Introduction to AFTER@LHC: generalities & physics highlights

Jean-Philippe Lansberg
IPN Orsay, CNRS/IN2P3, Université Paris-Sud

AFTER@LHC week
CERN, November 17-21, 2014

thanks to M. Anselmino (Torino), R. Arnaldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPNO), J.P. Didelez (IPNO), E.G. Ferreiro (USC), F. Fleuret (LLR), B. Genolini (IPNO), Y. Gao (Tsinghua), C. Hadjidakis (IPNO), I. Hrvinacova (IPNO), C. Lorcé (SLAC), L. Massacrier (LAL), R. Mikkelsen(Aarhus), A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino), B. Trzeciak (Prague U.), U.I. Uggerhøj (Aarhus), R. Ulrich (KIT), Y. Zhang (Tsinghua)+ W. den Dunnen, C. Pisano, M.Schlegel

Part I

Why a new fixed-target experiment for High-Energy Physics now ?

Decisive advantages of Fixed-target experiments

- Fixed-target experiments offer specific **advantages** that are still nowadays **difficult to challenge by collider experiments**

Decisive advantages of Fixed-target experiments

- Fixed-target experiments offer specific **advantages** that are still nowadays **difficult to challenge by collider experiments**
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv \frac{p_z}{p_{z\,\mathrm{max}}}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.

Decisive advantages of Fixed-target experiments

- Fixed-target experiments offer specific **advantages** that are still nowadays **difficult to challenge by collider experiments**
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv \frac{p_z}{p_{z\,\mathrm{max}}}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.
- which are essential assets to study
  - rare proton fluctuations at large x
  - vector boson production near threshold and other rare processes
  - nuclear dependence in heavy-ion collisions
  - observables involving gluons and the proton spin

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on July 14, 2006

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on July 14, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*
pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,
the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

The European strategy for particle physics

Updated by the CERN council at the special Session held in Brussels on May 30, 2013

k. A variety of research lines at the boundary between particle and nuclear physics require dedicated experiments. *The CERN Laboratory should maintain its capability to perform unique experiments. CERN should continue to work with NuPECC on topics of mutual interest.*

pg 22. of the Strategy Update Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity, yet without pile-up
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

AFTER@LHC would definitely be a **unique** experiment

Part II

A fixed-target experiment using the LHC beam(s): AFTER@LHC

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
$$\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

[Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector $\equiv$ large acceptance

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector $\equiv$ large acceptance

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
- Rather soft particles in the CM are in principle be detectable
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector $\equiv$ large acceptance
- Bad thing: high multiplicity $\Rightarrow$ absorber $\Rightarrow$ physics limitation

Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**

Backward physics ?

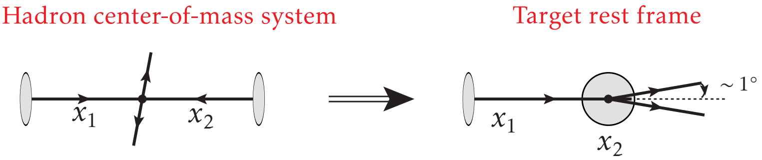
- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  · reduced multiplicities at large(r) angles
  · **access to partons with momentum fraction $x \to 1$ in the target**
  · last, but not least, the beam pipe is in practice
  not a geometrical constrain at $\theta_{CM} \simeq 180°$

Backward physics ?

- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  - · reduced multiplicities at large(r) angles
  - · **access to partons with momentum fraction $x \to 1$ in the target**
  - · last, but not least, the beam pipe is in practice

    not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$

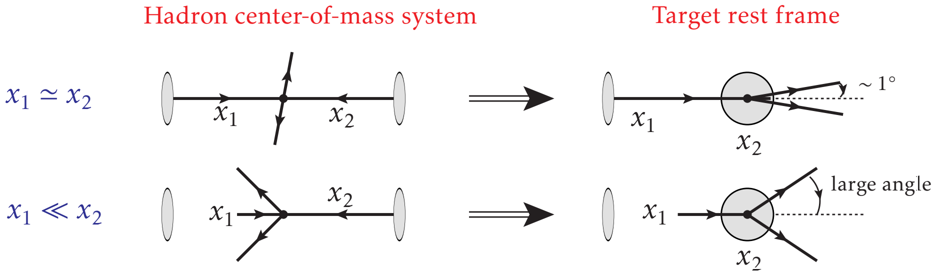
$x_1 \simeq x_2$



Backward physics ?

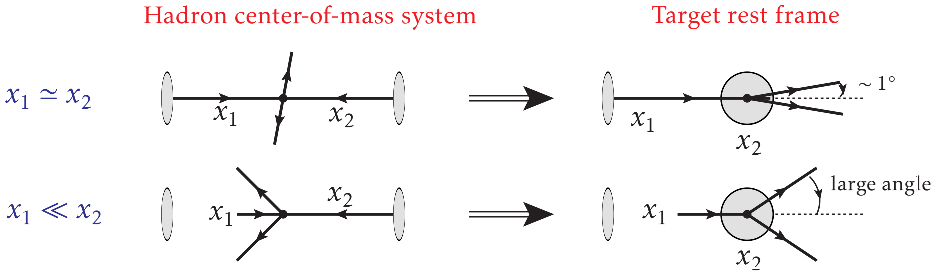
- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  - · reduced multiplicities at large(r) angles
  - · **access to partons with momentum fraction $x \to 1$ in the target**
  - · last, but not least, the beam pipe is in practice

    not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$



Backward physics ?

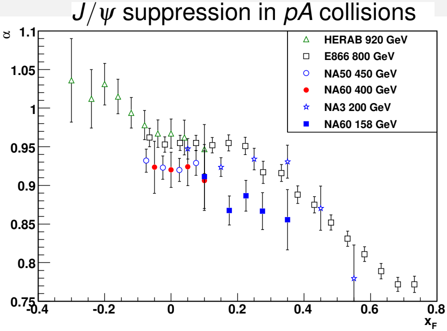
- Let's adopt a novel strategy and look at **larger angles**
- Advantages:
  · reduced multiplicities at large(r) angles
  · **access to partons with momentum fraction $x \to 1$ in the target**
  · last, but not least, the beam pipe is in practice
  not a geometrical constrain at $\theta_{CM} \simeq 180^\circ$



backward physics = large-x_2 physics

First systematic access to the target-rapidity region ($x_F \to -1$)

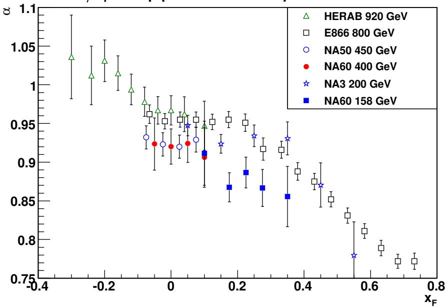
First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1

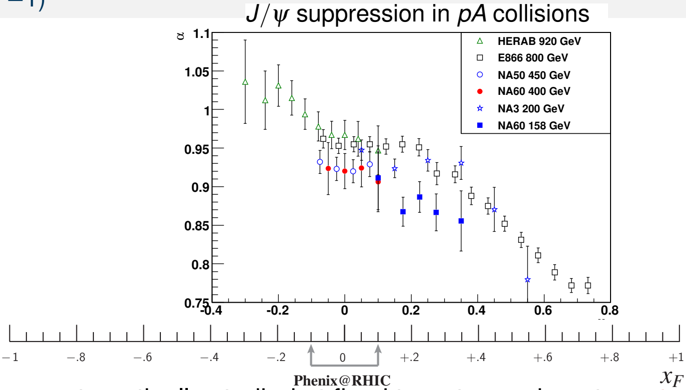
First systematic access to the target-rapidity region ($x_F \to -1$)

J/ψ suppression in pA collisions



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3

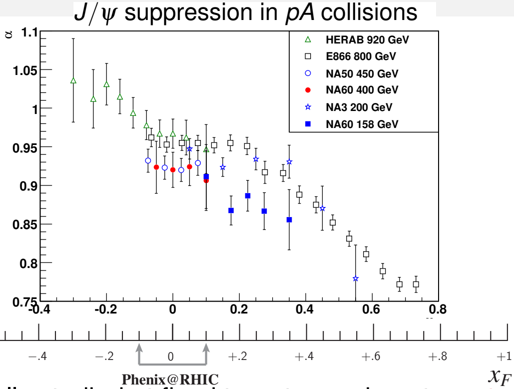
First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

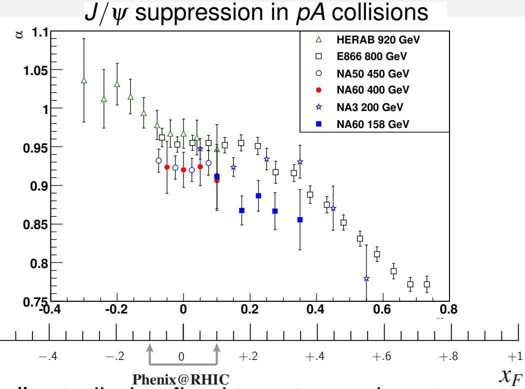
First systematic access to the target-rapidity region ($x_F \to -1$)

?



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$
- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

See Barbara's talk

The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

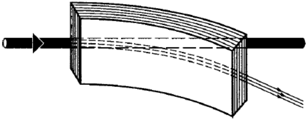
E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131

The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”

without any decrease in performance of the LHC !

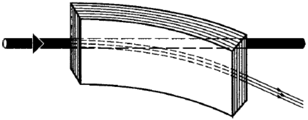
E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



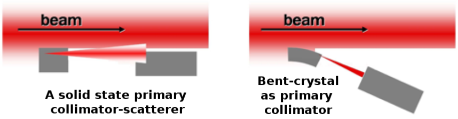
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field” **without any decrease in performance of the LHC !**

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



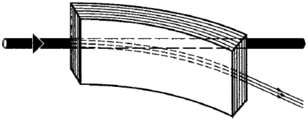
★ Illustration for collimation



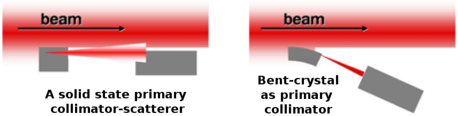
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



★ Illustration for collimation

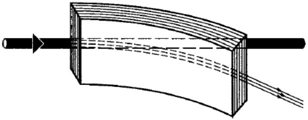


★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC

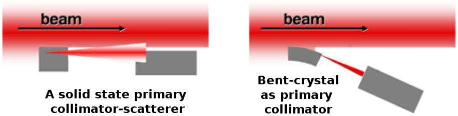
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



★ Illustration for collimation



★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC

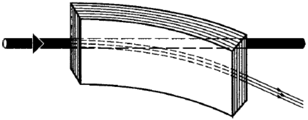
★ 2 crystals and 2 goniometers already installed in the LHC beampipe
See Simone’s talk

The beam extraction

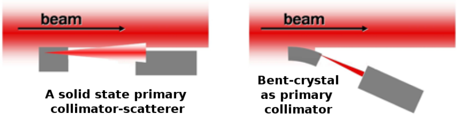
★ The LHC beam may be extracted using "Strong crystalline field"

without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



★ Illustration for collimation



★ Tests will be performed on the LHC beam:

LUA9 proposal approved by the LHCC

★ 2 crystals and 2 goniometers already installed in the LHC beampipe

See Simone's talk

★ CRYSBEAM: ERC funded project to extract the LHC beams with a bent crystal

See Luca's talk

Luminosities with proton beams

- Expected proton flux $\Phi_{beam} = 5 \times 10^8 \; p^+ s^{-1}$

Luminosities with proton beams

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

Luminosities with proton beams

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Luminosities with proton beams

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

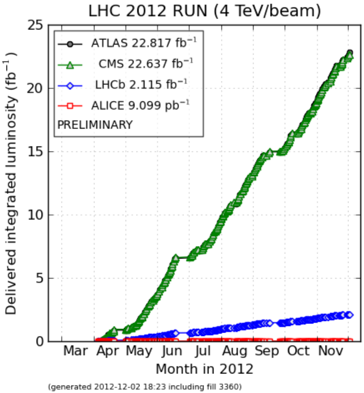
Target	ρ (g.cm^{-3})	A	$\mathscr{L}$ (μb^{-1}.s^{-1})	$\int \mathscr{L}$ (fb^{-1}.yr^{-1})
1m Liq. H_2	0.07	1	2000	20
1m Liq. D_2	0.16	2	2400	24
1cm Be	1.85	9	62	.62
1cm Cu	8.96	64	42	.42
1cm W	19.1	185	31	.31
1cm Pb	11.35	207	16	.16

Luminosities with proton beams II

- For *pp* and *pd* collisions : $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$

Luminosities with proton beams II

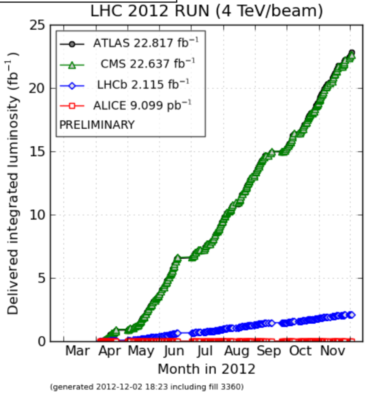
- For *pp* and *pd* collisions : $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$



Luminosities with proton beams II

- For *pp* and *pd* collisions : $\mathscr{L}_{H_2/D_2} \simeq 20\ \mathrm{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

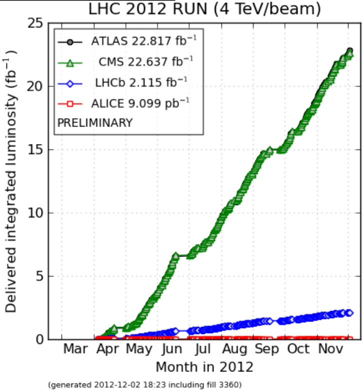


Luminosities with proton beams II

- For *pp* and *pd* collisions : $\mathscr{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  - Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  - Run14*d*Au 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV

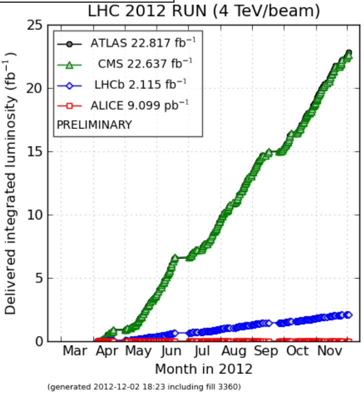


Luminosities with proton beams II

- For *pp* and *pd* collisions : $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  · Run14*d*Au 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
- AFTER vs PHENIX@RHIC:
  3 orders of magnitude larger



Luminosities with lead beams

- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

$$\Phi_{beam} = 2 \times 10^5 \text{ Pb s}^{-1}, \quad \ell = 1 \text{ cm (target thickness)}$$

- Integrated luminosity $\int dt \mathscr{L} = \mathscr{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
1m Liq. H_2	0.07	1	**800**
1m Liq. D_2	0.16	2	**1000**
1cm Be	1.85	9	**25**
1cm Cu	8.96	64	**17**
1cm W	19.1	185	**13**
1cm Pb	11.35	207	**7**

- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

Part III

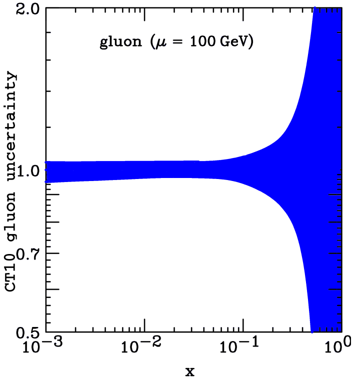
AFTER@LHC: my (biased) selection of key measurements

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton

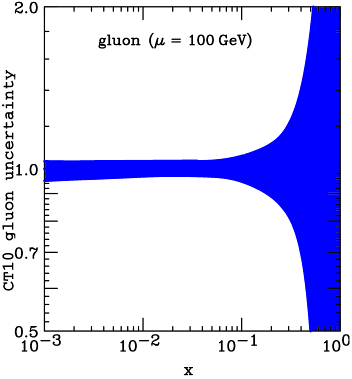
Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties



Key studies: gluons in the proton

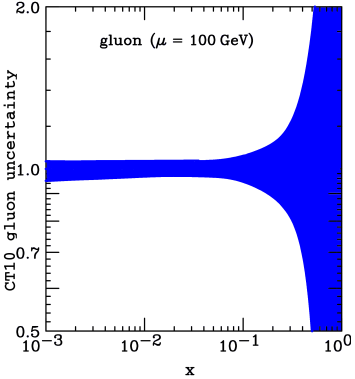
- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties



Accessible thanks gluon sensitive probes,

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties

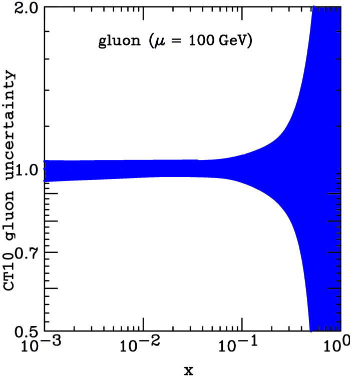


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties

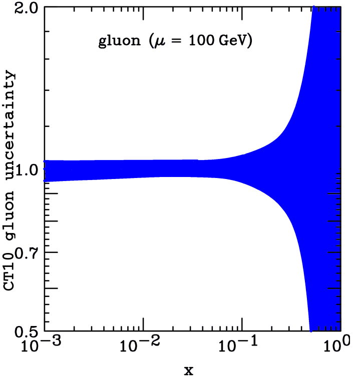


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties

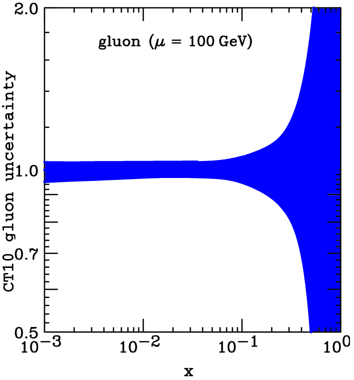


Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311
- jets ($P_T \in [20, 40]$ GeV)

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties



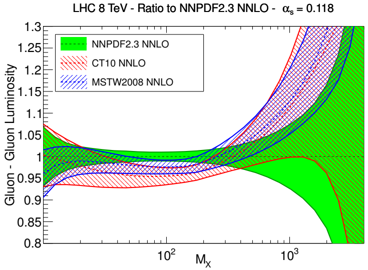
Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311
- jets ($P_T \in [20, 40]$ GeV)

Multiple probes needed to **check factorisation**

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - translates into very large uncertainties



Accessible thanks gluon sensitive probes,

- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
  see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311
- jets ($P_T \in [20, 40]$ GeV)

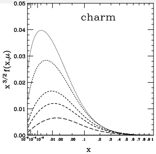
Large-x gluons: important for BSM searches at the LHC

Key studies: heavy-quark content of the proton

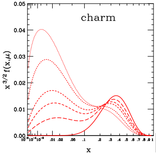
- Heavy-quark distributions (at high x_B)

Key studies: heavy-quark content of the proton

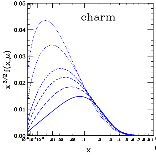
- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last



DGLAP



BHPS

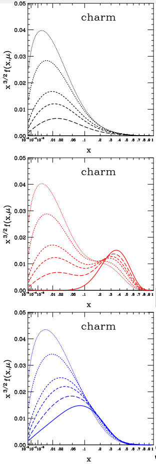


Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies **F.Maltoni,..., JHEP 1207 (2012) 022**



DGLAP

BHPS

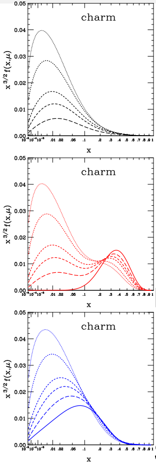
Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies **F.Maltoni,..., JHEP 1207 (2012) 022**

requires



DGLAP

BHPS

Sea-like

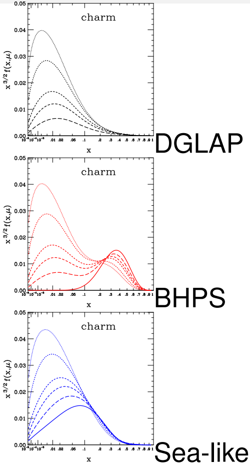
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies **F.Maltoni,..., JHEP 1207 (2012) 022**

requires

  - several complementary measurements



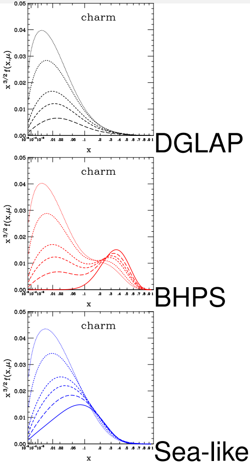
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies **F.Maltoni,..., JHEP 1207 (2012) 022**

requires

  - several complementary measurements
  - good coverage in the target-rapidity region



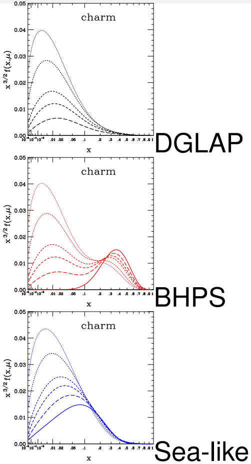
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies **F.Maltoni,..., JHEP 1207 (2012) 022**

requires

  - several complementary measurements
  - good coverage in the target-rapidity region
  - high luminosity to reach large x_B

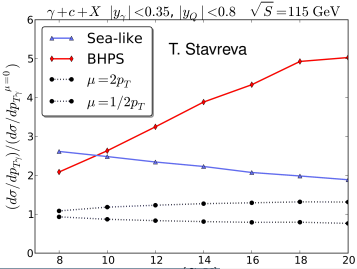


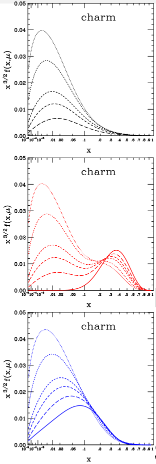
3 sets from CTEQ6c (Pumplin *et al.*)

Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)
  - Pin down intrinsic charm, ... at last
  - $c(x)$ & $b(x)$ & the 5-flavour scheme at large x for BSM studies F.Maltoni,..., JHEP 1207 (2012) 022

  requires
  - several complementary measurements
  - good coverage in the target-rapidity region
  - high luminosity to reach large x_B





DGLAP

BHPS

Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

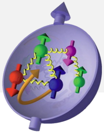
Key studies: gluon contribution to the proton spin

- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin

Key studies: gluon contribution to the proton spin

- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes

Key studies: gluon contribution to the proton spin



- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...)

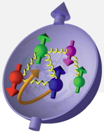
F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)

Key studies: gluon contribution to the proton spin

- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...)

    F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)
  - *B* & *D* meson production

Key studies: gluon contribution to the proton spin



- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...)

F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)

  - *B* & *D* meson production
  - γ, γ-jet, $\gamma - \gamma$

A. Bacchetta, ***et al.*****, PRL 99 (2007) 212002**
J.W. Qiu, ***et al.*****, PRL 107 (2011) 062001**

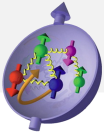
Key studies: gluon contribution to the proton spin

- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...)

    F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)
  - B & D meson production
  - γ, γ-jet, $\gamma-\gamma$

    A. Bacchetta, *et al.*, PRL 99 (2007) 212002
    J.W. Qiu, *et al.*, PRL 107 (2011) 062001
- the target-rapidity region corresponds to high $x^{\uparrow}$ where the k_T-spin correlation is the largest

Key studies: gluon contribution to the proton spin



- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...)

    F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)
  - *B* & *D* meson production
  - γ, γ-jet, $\gamma - \gamma$

    A. Bacchetta, ***et al.*****, PRL 99 (2007) 212002**
    J.W. Qiu, ***et al.*****, PRL 107 (2011) 062001**
- the target-rapidity region corresponds to high $x^{\uparrow}$
  where the k_T-spin correlation is the largest
- In general, one can carry out an extensive spin-physics program

Distribution of linearly polarised gluons in unpolarised protons

Distribution of linearly polarised gluons in unpolarised protons

PHYSICAL REVIEW D **86**, 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*

Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano†

Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

Distribution of linearly polarised gluons in unpolarised protons

PHYSICAL REVIEW D **86,** 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*
Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano†
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$

Distribution of linearly polarised gluons in unpolarised protons

PHYSICAL REVIEW D **86,** 094007 (2012)

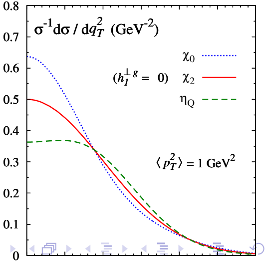
Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*
Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands
Cristian Pisano†
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$
- Affect the low P_T spectra:

$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \;\&\; \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

(R involves $f_1^g(x, k_T, \mu)$ and $h_1^{\perp g}(x, k_T, \mu)$)



Distribution of linearly polarised gluons in unpolarised protons

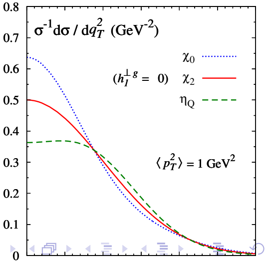
PHYSICAL REVIEW D **86**, 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*
Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano†
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$
- Affect the low P_T spectra:
  $$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \ \& \ \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$
  (R involves $f_1^g(x, k_T, \mu)$ and $h_1^{\perp g}(x, k_T, \mu)$)
- The boost is of great help to access low P_T P-wave quarkonia



Distribution of linearly polarised gluons in unpolarised protons

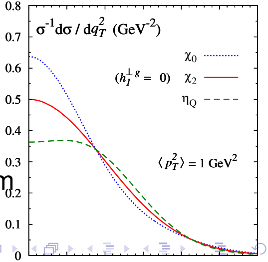
PHYSICAL REVIEW D **86**, 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*
Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano†
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$
- Affect the low P_T spectra:
  $\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2)$ & $\frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$
  (R involves $f_1^g(x,k_T,\mu)$ and $h_1^{\perp g}(x,k_T,\mu)$)
- The boost is of great help to access low P_T P-wave quarkonia
- $h_1^{\perp g}$ is connected to the Higgs transverse-momentum distribution **D. Boer,** ***et al.*** **PRL 108 (2012) 032002**



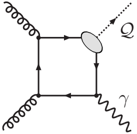
Access to $h_1^{\perp g}$: II

Access to $h_1^{\perp g}$: II

PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]*Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France*
[3]*Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands*

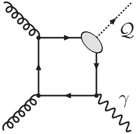


Access to $h_1^{\perp g}$: II

PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]*Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France*
[3]*Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands*



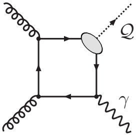
- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon + \gamma$ associated production at the LHC. Also true at AFTER@LHC !

Access to $h_1^{\perp g}$: II

PRL 112, 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

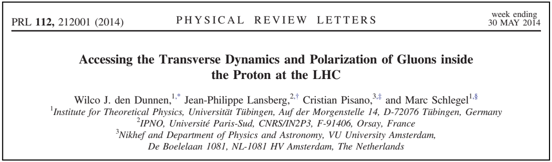
Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]*Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France*
[3]*Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands*



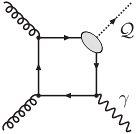
- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon + \gamma$ associated production at the LHC. Also true at AFTER@LHC !
- Smaller yield (14 TeV $\rightarrow$ 115 GeV) compensated by an access to lower P_T

Access to $h_1^{\perp g}$: II

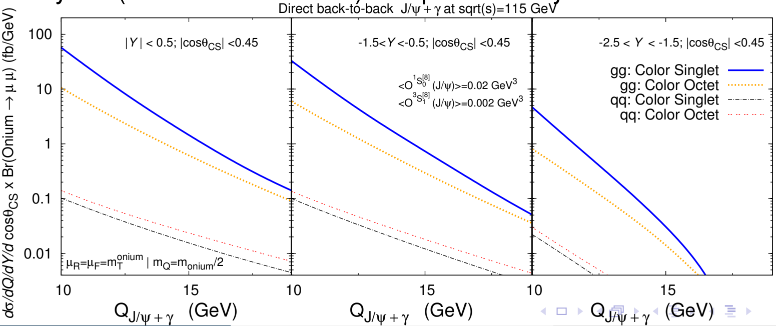

PRL 112, 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]*Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France*
[3]*Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands*



- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon+\gamma$ associated production at the LHC. Also true at AFTER@LHC !
- Smaller yield (14 TeV $\to$ 115 GeV) compensated by an access to lower P_T

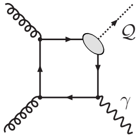


Access to $h_1^{\perp g}$: II

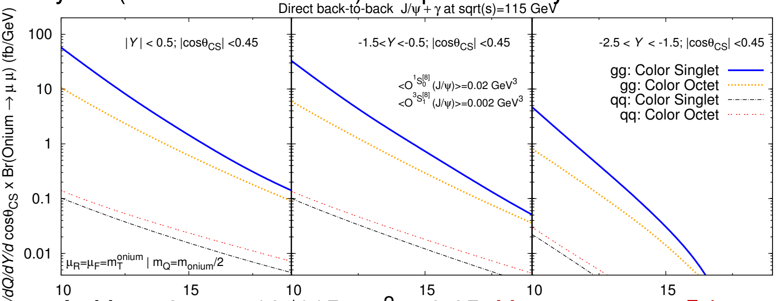
PRL 112, 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany
[2]IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France
[3]Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands



- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon + \gamma$ associated production at the LHC. Also true at AFTER@LHC !
- Smaller yield (14 TeV $\to$ 115 GeV) compensated by an access to lower P_T



At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g - g > q - \bar{q}$!

SSA in Drell-Yan studies with AFTER@LHC

➡ Relevant parameters for the future proposed polarized DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
V. Barone, F. Bradamante, A. Martin, Prog. Part. Nucl. Phys. 65 (2010) 267.

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathscr{L}$ ($nb^{-1}s^{-1}$)
AFTER	$p+p^\uparrow$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
RHIC	$p^\uparrow + p$	collider	500	$0.05 \div 0.1$	0.2
J–PARC	$p^\uparrow + p$	50	10	$0.5 \div 0.9$	1000
PANDA (low mass)	$\bar{p} + p^\uparrow$	15	5.5	$0.2 \div 0.4$	0.2
PAX	$p^\uparrow + \bar{p}$	collider	14	$0.1 \div 0.9$	0.002
NICA	$p^\uparrow + p$	collider	20	$0.1 \div 0.8$	0.001
RHIC Int.Target 1	$p^\uparrow + p$	250	22	$0.2 \div 0.5$	2
RHIC Int.Target 2	$p^\uparrow + p$	250	22	$0.2 \div 0.5$	60
P1027	$p^\uparrow + p$	120	15	$0.35 \div 0.85$	400-1000
P1039	$p + p^\uparrow$	120	15	$0.1 \div 0.3$	400-1000

➡ For AFTER, the numbers correspond to a 50 cm polarized *H* target.

➡ $\ell^+\ell^-$ angular distribution: separation Sivers vs. Boer-Mulders effects

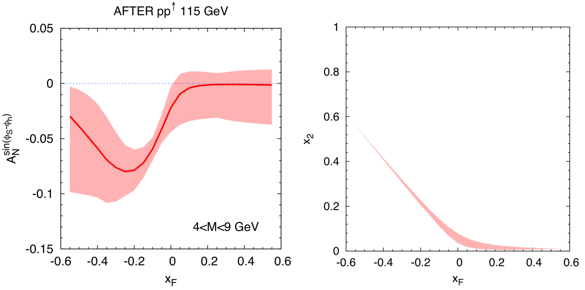
SSA in Drell-Yan studies with AFTER@LHC

➠ Relevant para … ts.

267.

Expe
AFT
COI
COI (low
RHI
J–P/
PAN (low
PAX
NIC/
RHI Int.T
RHI Int.T
P10
P10

expected Sivers asymmetry in D-Y@AFTER, sign change, no TMD evolution



M. Anselmino, ECT*, Feb. 2013 (Courtesy U. d'Alessio)

➠ For AFTER, the numbers correspond to a 50 cm polarized H target.

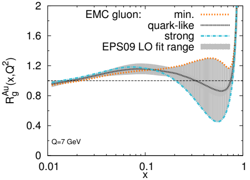
➠ $\ell^+\ell^-$ angular distribution: separation Sivers vs. Boer-Mulders effects

pA studies: large-*x* gluon content of the nucleus

pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown

- **Gluon EMC effect: unknown**

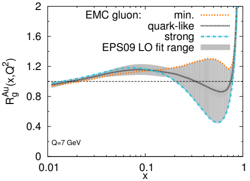


pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown

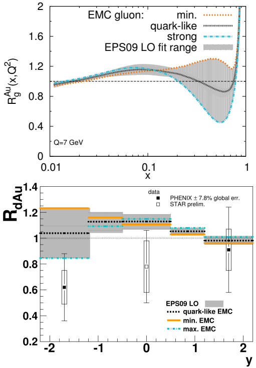
- **Gluon EMC effect: unknown**

- Hint from Υ data at RHIC



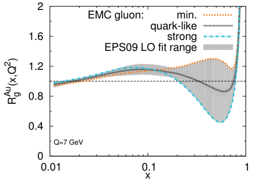
pA studies: large-*x* gluon content of the nucleus

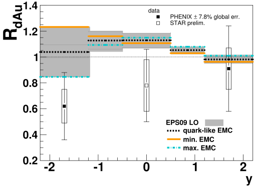
- Large-*x* gluon nPDF: unknown
- **Gluon EMC effect: unknown**
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC (now 3 points from STAR):

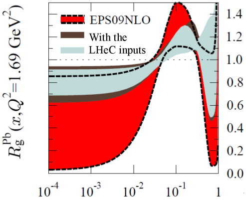


pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown
- **Gluon EMC effect: unknown**
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC (now 3 points from STAR):
- DIS contribution expected for low *x* mainly projected contribution of LHeC:

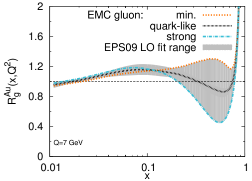


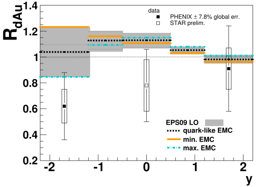


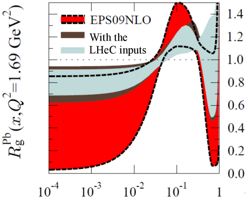


pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown
- **Gluon EMC effect: unknown**
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics
  after 10 years of RHIC (now 3 points from STAR):
- DIS contribution expected for low *x* mainly
  projected contribution of LHeC:
- AFTER allows for extensive studies of
  gluon sensitive probes in *pA*
- Unique potential for gluons at $x > 0.1$







Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

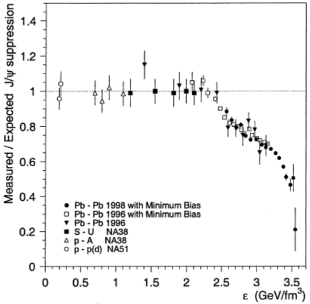


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

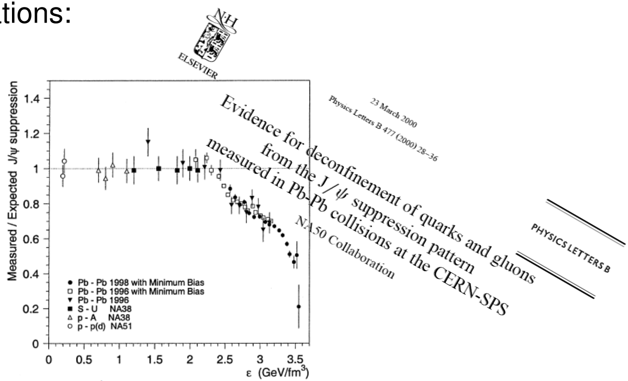


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, Pb*A* collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations: quarkonium sequential melting

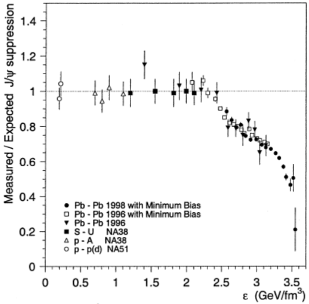
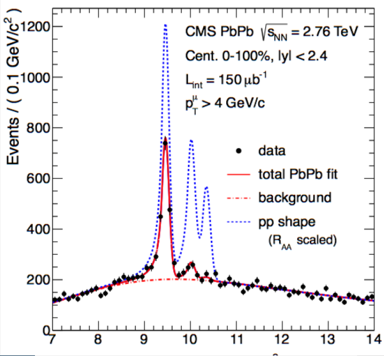


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations: quarkonium sequential melting
- Enough stat to perform the same study as CMS at low energy



More details in

Physics Reports 522 (2013) 239–255

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky[a], F. Fleuret[b], C. Hadjidakis[c], J.P. Lansberg[c,*]

[a] SLAC National Accelerator Laboratory, Stanford University, Menlo Park, CA 94025, USA

[b] Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France

[c] IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France

Contents

Part IV

Special Issue in Advances in High-Energy Physics & Workshop at CERN

Advances in High Energy Physics

Special Issue on
Physics at a Fixed-Target Experiment Using the LHC Beams

CALL FOR PAPERS

Fixed-target experiments (FTE) have brought essential contributions to particle and nuclear physics. They have led to particle discoveries (Ω, J/ψ, γ,...) and evidence for the novel dynamics of quarks and gluons in heavy-ion collisions. In accessing high x_F and in offering options for (un-) polarised proton and nuclear targets, they have also led to the observation of surprising QCD phenomena. They offer specific advantages compared to collider experiments: access to high x_F, high luminosities, target versatility, and polarisation.

The LHC 7 TeV protons on targets release a c.m.s. energy close to 115 GeV (72 GeV with Pb), in a range never explored so far, significantly higher than that at SPS and not far from RHIC. The production of quarkonia, DY, heavy flavours, jets, and γ in *pA* collisions can be studied with statistics previously unheard of and in the backward region, $x_F < 0$, which is uncharted. High precision QCD measurements can also obviously be carried out in *pp* and *pd* collisions with H_2 and D_2 targets. With the 50 TeV protons of the future circular collider (FCC), the c.m.s. energy could reach 300 GeV for original studies of W and Z boson, and perhaps H^0, production in *pp* and *pA* collisions.

With the LHC Pb beam, one can study the quark-gluon plasma (QGP) from the viewpoint of the nucleus rest frame after its formation. Thanks to modern technologies, studies of, for instance, direct γ and quarkonium *P*-waves production in heavy-ion collisions can be envisioned.

Polarising the target allows one to study single-spin correlations including the Sivers effect, hence, the correlation between the parton k_T and the nucleon spin.

We intend to publish a special issue on the physics at such a FTE using the LHC or FCC beams. The editors welcome original research articles and review articles from both theorists and experimentalists.

Potential topics include, but are not limited to:

- Heavy-quark and gluon content at large x
- TMDs and single-spin asymmetries
- Heavy-flavour studies in *pA* and *AA* collisions at FTEs
- W, Z, and H^0 production near threshold
- Target polarisation
- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

Lead Guest Editor
Jean-Philippe Lansberg, Université Paris-Sud, Orsay, France
lansberg@in2p3.fr

Guest Editors
Gianluca Cavoto, Istituto Nazionale Di Fisica Nucleare, Roma, Italy
gianluca.cavoto@roma1.infn.it

Cynthia Hadjidakis, Université Paris-Sud, Orsay, France
cynthia@ipno.in2p3.fr

Jibo He, CERN, Geneva, Switzerland
jibo.he@cern.ch

Cédric Lorcé, Université de Liège, Liège, Belgium
c.lorce@ulg.ac.be

Barbara Trzeciak, Czech Technical University, Prague, Czech Republic
trzecbar@fjfi.cvut.cz

Manuscript Due
Friday, 20 March 2015

First Round of Reviews
Friday, 12 June 2015

Publication Date
Friday, 7 August 2015

Impact Factor: 2.7 (like Nucl. Phys. A, JPhysG), Open Access

Advances in High Energy Physics

Hindawi

Special Issue on
Physics at a Fixed-Target E
Beams

CALL FOR

Fixed-target experiments (FTE) have brought essential contributions to pa
nuclear physics. They have led to particle discoveries (Ω, J/ψ, ϒ,...) and
for the novel dynamics of quarks and gluons in heavy-ion collisions. In
high x_F and in offering options for (un-) polarised proton and nuclear tar
have also led to the observation of surprising QCD phenomena. They offe
advantages compared to collider experiments: access to high x_F, high lum
target versatility, and polarisation.

The LHC 7 TeV protons on targets release a c.m.s. energy close to 115 GeV
with Pb), in a range never explored so far, significantly higher than that at
not far from RHIC. The production of quarkonia, DY, heavy flavours, jets
pA collisions can be studied with statistics previously unheard of and in the l
region, $x_F < 0$, which is uncharted. High precision QCD measurements
obviously be carried out in *pp* and *pd* collisions with H_2 and D_2 targets.
50 TeV protons of the future circular collider (FCC), the c.m.s. energy co
300 GeV for original studies of W and Z boson, and perhaps H^0, product
and *pA* collisions.

With the LHC Pb beam, one can study the quark-gluon plasma (QGP) from the viewpoint of the nucleus rest frame after its formation. Thanks to modern technologies, studies of, for instance, direct γ and quarkonium *P*-waves production in heavy-ion collisions can be envisioned.

Polarising the target allows one to study single-spin correlations including the Sivers effect, hence, the correlation between the parton k_T and the nucleon spin.

We intend to publish a special issue on the physics at such a FTE using the LHC or FCC beams. The editors welcome original research articles and review articles from both theorists and experimentalists.

Potential topics include, but are not limited to:

- Heavy-quark and gluon content at large x
- TMDs and single-spin asymmetries
- Heavy-flavour studies in *pA* and *AA* collisions at FTEs
- W, Z, and H^0 production near threshold
- Target polarisation
- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

Cédric Lorcé, Université de Liège, Liège, Belgium
c.lorce@ulg.ac.be

Barbara Trzeciak, Czech Technical University, Prague, Czech Republic
trzecbar@fjfi.cvut.cz

Manuscript Due
Friday, 20 March 2015

First Round of Reviews
Friday, 12 June 2015

Publication Date
Friday, 7 August 2015

- Heavy-quark and gluon content at large x
- TMDs and single-spin asymmetries
- Heavy-flavour studies in *pA* and *AA* collisions at FTEs
- W, Z, and H^0 production near threshold
- Target polarisation
- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

Impact Factor: 2.7 (like Nucl. Phys. A, JPhysG), Open Access

Advances in High Energy Physics

Hindawi

Special Issue on
Physics at a Fixed-Target E
Beams

CALL FOR

Fixed-target experiments (FTE) have brought essential contributions to pa
nuclear physics. They have led to particle discoveries (Ω, J/ψ, γ,...) and
for the novel dynamics of quarks and gluons in heavy-ion collisions. In
high x_F and in offering options for (un-) polarised proton and nuclear tar
have also led to the observation of surprising QCD phenomena. They offe
advantages compared to collider experiments: access to high x_F, high lum
target versatility, and polarisation.

The LHC 7 TeV protons on targets release a c.m.s. energy close to 115 GeV
with Pb), in a range never explored so far, significantly higher than that at
not far from RHIC. The production of quarkonia, DY, heavy flavours, jets
pA collisions can be studied with statistics previously unheard of and in the l
region, $x_F < 0$, which is uncharted. High precision QCD measurements
obviously be carried out in *pp* and *pd* collisions with H_2 and D_2 targets.
50 TeV protons of the future circular collider (FCC), the c.m.s. energy co
300 GeV for original studies of W and Z boson, and perhaps H^0, product
and *pA* collisions.

With the LHC Pb beam, one can study the quark-gluon plasma (QGP) from the viewpoint of the nucleus rest frame after its formation. Thanks to modern technologies, studies of, for instance, direct γ and quarkonium *P*-waves production in heavy-ion collisions can be envisioned.

Polarising the target allows one to study single-spin correlations including the Sivers effect, hence, the correlation between the parton k_T and the nucleon spin.

We intend to publish a special issue on the physics at such a FTE using the LHC or FCC beams. The editors welcome original research articles and review articles from both theorists and experimentalists.

Potential topics include, but are not limited to:

- Heavy-quark and gluon content at large *x*
- TMDs and single-spin asymmetries
- Heavy-flavour studies in *pA* and *AA* collisions at FTEs
- W, Z, and H^0 production near threshold
- Target polarisation
- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

- Heavy-quark and gluon content at large *x*
- TMDs and single-spin asymmetries
- Heavy-flavour studies in *pA* and *AA* collisions at FTEs
- W, Z, and H^0 production near threshold
- Target polarisation
- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

Cédric Lorcé, Université de Liège, Liège, Belgium
c.lorce@ulg.ac.be

Barbara Trzeciak, Czech Technical University, Prague, Czech Republic
trzecbar@fjfi.cvut.cz

Manuscript Due
Friday, 20 March 2015

First Round of Reviews
Friday, 12 June 2015

Publication Date
Friday, 7 August 2015

Manuscript Due
Friday, 20 March 2015

First Round of Reviews
Friday, 12 June 2015

Publication Date
Friday, 7 August 2015

Impact Factor: 2.7 (like Nucl. Phys. A, JPhysG), Open Access

Part V

Conclusion and outlooks

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised *pp* collisions $\rightarrow$ access to gluon $h_1^{\perp g}$

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5\times10^{8}$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised *pp* collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised *pp* collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible
- Large potential for heavy-ion physics

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow$ 5×10^8 protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
    - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
    - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
    - SSA for DY also possible
- Large potential for heavy-ion physics
    - excellent baseline with precise proton-nucleus studies

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible
- Large potential for heavy-ion physics
  - excellent baseline with precise proton-nucleus studies
  - uncharted kinematical region (nucleus rapidity region)

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible
- Large potential for heavy-ion physics
  - excellent baseline with precise proton-nucleus studies
  - uncharted kinematical region (nucleus rapidity region)
  - high-potential with excited-state quarkonium studies

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible
- Large potential for heavy-ion physics
  - excellent baseline with precise proton-nucleus studies
  - uncharted kinematical region (nucleus rapidity region)
  - high-potential with excited-state quarkonium studies
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- Large potential for spin physics
  - in unpolarised pp collisions $\rightarrow$ access to gluon $h_1^{\perp g}$
  - SSA for a number of HF systems $\rightarrow$ access to gluon Sivers fct
  - SSA for DY also possible
- Large potential for heavy-ion physics
  - excellent baseline with precise proton-nucleus studies
  - uncharted kinematical region (nucleus rapidity region)
  - high-potential with excited-state quarkonium studies
- A wealth of possible measurements: DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)
- LHC long shutdown (LS2 ? LS3 ?) needed to install the extraction system

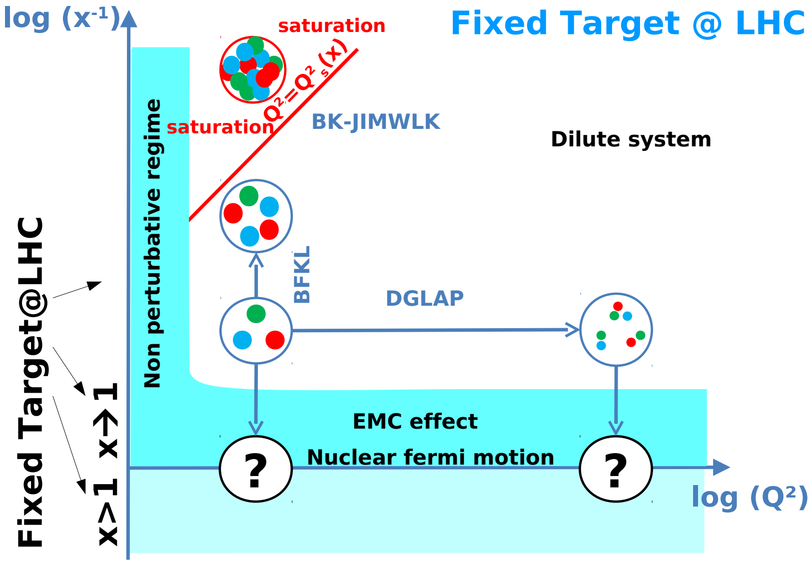
Part VI

Backup slides

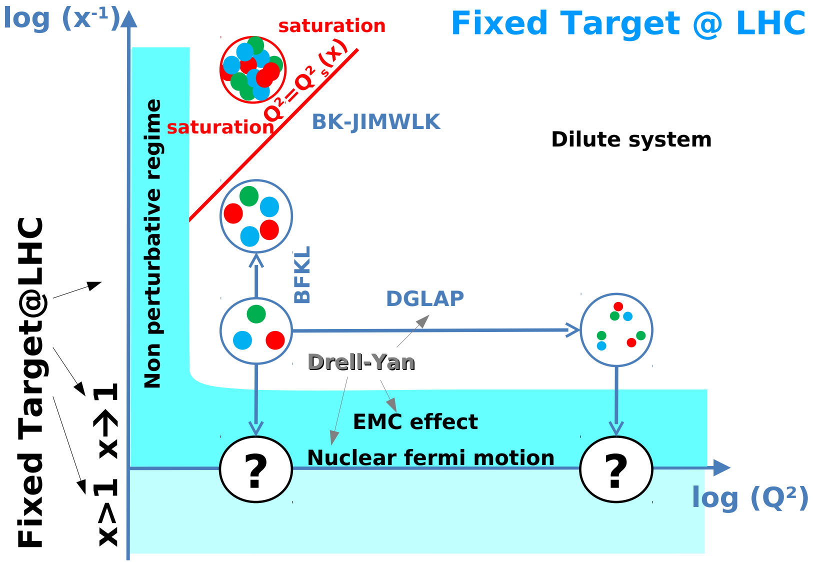
Further readings

- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. [arXiv:1401.6269 [hep-ph]]. Phys.Rev. D89 (2014) 074020.
- *Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams.*
  By J.P. Lansberg, S.J. Brodsky, F. Fleuret, C. Hadjidakis. [arXiv:1204.5793 [hep-ph]]. Few Body Syst. 53 (2012) 11.
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)*
  By T. Liu, B.Q. Ma. [arXiv:1203.5579 [hep-ph]]. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER*
  By D. Boer, C. Pisano. [arXiv:1208.3642 [hep-ph]]. Phys.Rev. D86 (2012) 094007.
- *Ultra-relativistic heavy-ion physics with AFTER@LHC*
  By A. Rakotozafindrabe, *et al.* . [arXiv:1211.1294 [nucl-ex]]. Nucl.Phys. A904-905 (2013) 957c.
- *Spin physics at A Fixed-Target ExpeRiment at the LHC (AFTER@LHC)*
  By A. Rakotozafindrabe, *et al.* .[arXiv:1301.5739 [hep-ex]]. Phys.Part.Nucl. 45 (2014) 336.
- *Physics Opportunities of a Fixed-Target Experiment using the LHC Beams*
  By S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg. [arXiv:1202.6585 [hep-ph]]. Phys.Rept. 522 (2013) 239.

Overall

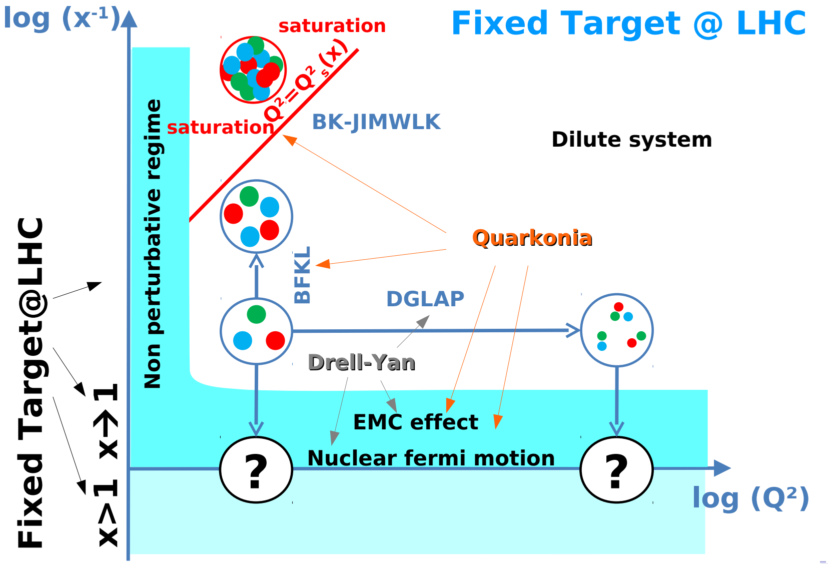

log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
BFKL
DGLAP
x→1
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall

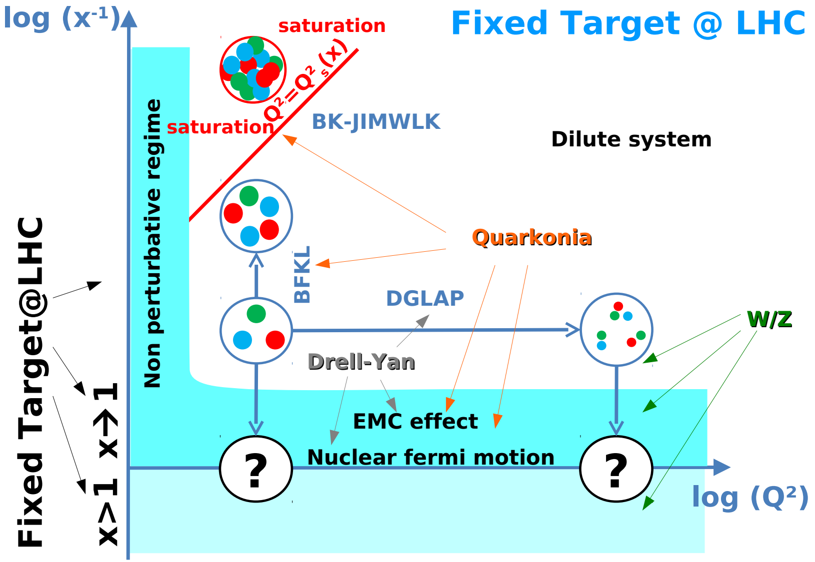


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
x>1 x→1
BFKL
DGLAP
Drell-Yan
EMC effect
Nuclear fermi motion
?
?
log (Q²)

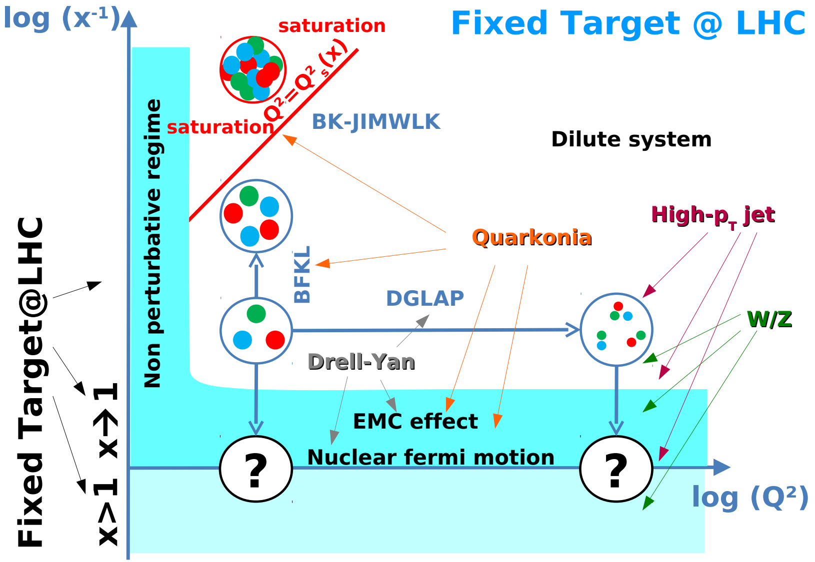
Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
DGLAP
Fixed Target@LHC
Drell-Yan
x→1
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
DGLAP
Fixed Target@LHC
W/Z
Drell-Yan
x>1 x→1
EMC effect
?
Nuclear fermi motion
?
log (Q²)

Overall

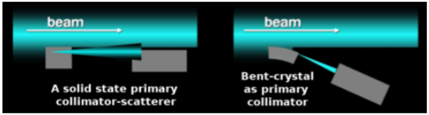

log (x-1)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
High-p_T jet
Quarkonia
BFKL
DGLAP
W/Z
Fixed Target@LHC
Drell-Yan
x>1 x→1
EMC effect
Nuclear fermi motion
?
?
log (Q2)

The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS



Prototype crystal collimation system at SPS :

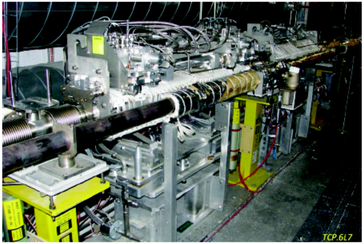
- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS



LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

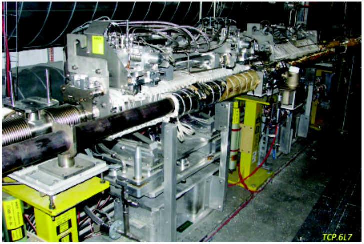
The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS

2010 - 2012



LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

Towards an installation in the LHC : propose and install during LS1 a min. number of devices

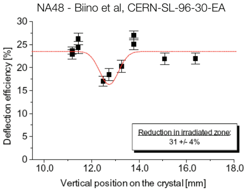
- 2 crystals

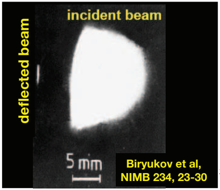
Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

Simone Montesano - February 11th, 2013 - Physics at AFTER using the LHC beams

Crystal resistance to irradiation

- **IHEP U-70** (Biryukov et al, NIMB 234, 23-30):
  - 70 GeV protons, 50 ms spills of **10^{14} protons every 9.6 s**, several minutes irradiation
  - equivalent to 2 nominal LHC bunches for 500 turns every 10 s
  - 5 mm silicon crystal, **channeling efficiency unchanged**
- **SPS North Area - NA48** (Biino et al, CERN-SL-96-30-EA):
  - 450 GeV protons, 2.4 s spill of 5 x 10^{12} protons every 14.4 s, one year irradiation, **2.4 x 10^{20} protons/cm^2** in total,
  - equivalent to several year of operation for a primary collimator in LHC
  - 10 x 50 x 0.9 mm^3 silicon crystal, 0.8 x 0.3 mm^2 area irradiated, **channeling efficiency reduced by 30%**.
- **HRMT16-UA9CRY** (HiRadMat facility, November 2012):
  - 440 GeV protons, up to 288 bunches **in 7.2 μs**, 1.1 x 10^{11} protons per bunch (**3 x 10^{13} protons** in total)
  - energy deposition comparable to an asynchronous beam dump in LHC
  - 3 mm long silicon crystal, **no damage to the crystal after accurate visual inspection**, more tests planned to assess possible crystal lattice damage
    - **accurate FLUKA simulation of energy deposition** and residual dose





30

S. Montesano (CERN - EN/STI) @ ECT* Trento workshop, Physics at AFTER using the LHC beams (Feb. 2013)

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ \mathrm{s}^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s$^{-1}/27$ km $\simeq 11$ kHz

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+\mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+\mathrm{s}^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees $2808 \times 11000\ \mathrm{s}^{-1} \simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

pile-up is not an issue

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ \mathrm{s}^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees $2808 \times 11000\ \mathrm{s}^{-1} \simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15 p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

pile-up is not an issue

- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600\ \mathrm{s\ h}^{-1} \times 10\ \mathrm{h} = 1.8 \times 10^{13} p^+\ \mathrm{fill}^{-1}$
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq$ 5.6% of the p^+ in the beam

These protons are lost anyway !

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq$ 15p^+ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,

pile-up is not an issue

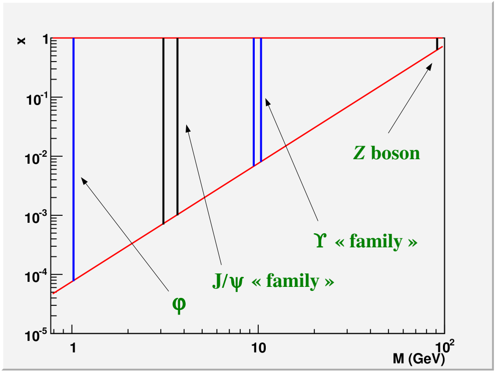
- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h^{-1} $\times$ 10 h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq$ 5.6% of the p^+ in the beam

These protons are lost anyway !

- similar figures for the Pb-beam extraction

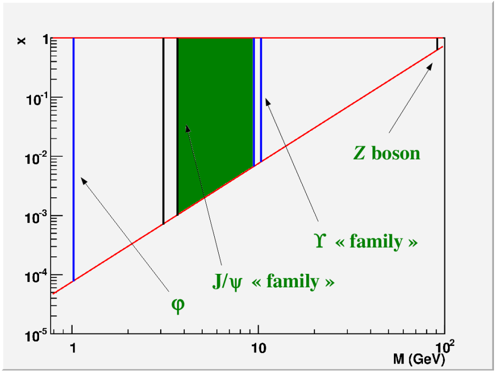
AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$



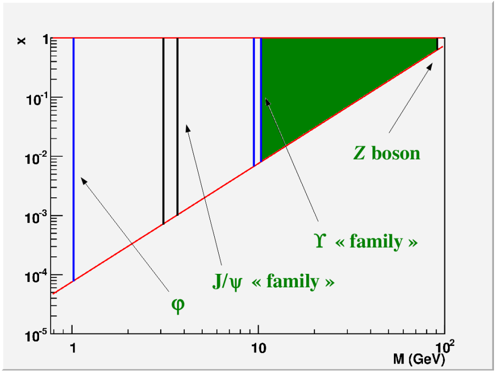
AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - → Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - → Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$
  - → Above $c\bar{c}$: $x \in [10^{-3}, 1]$
  - → Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



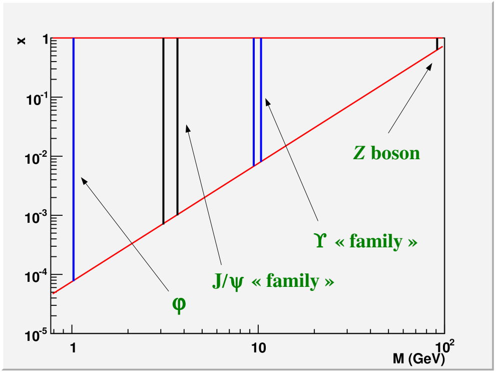
AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$

Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$
"backward" region

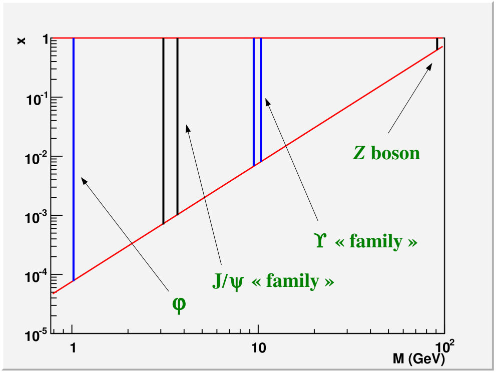


AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$



Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$
"backward" region

→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")
- at small(est) x: forward (need to stop the (extracted) beam)

AFTER@LHC: A dilepton observatory ?

➟ Region in x probed by dilepton production as function of $M_{\ell\ell}$

→ Above $c\bar{c}$: $x \in [10^{-3}, 1]$

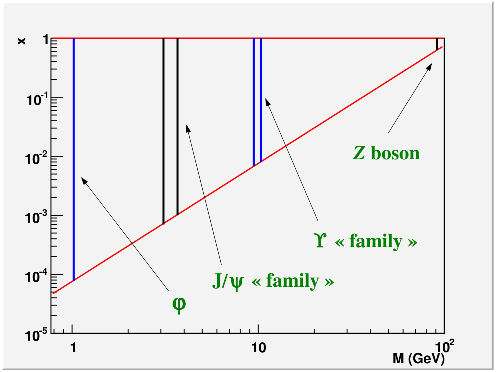
→ Above $b\bar{b}$: $x \in [9 \times 10^{-3}, 1]$

Note: $x_{target} (\equiv x_2) > x_{projectile} (\equiv x_1)$
"backward" region

→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)



➟ To do: to look at the rates to see how competitive this will be

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1} = A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	$N(\Upsilon)\ yr^{-1} = A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} =$A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(ϒ) yr^{-1} =$A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region
- Probe of the (very) large *x* in the target

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
    - in photo/lepto production (DIS)
    - but also *pp* collisions in *gg*-fusion process
    - mainly because of the presence of a natural “hard” scale: m_Q
    - and the good detectability of a dimuon pair

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
    - in photo/lepto production (DIS)
    - but also *pp* collisions in *gg*-fusion process
    - mainly because of the presence of a natural "hard" scale: m_Q
    - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\rightarrow$ quarkonium not used anymore in global fits

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production:
Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\rightarrow$ quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1}$ = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	**0.62**	**$1.1\ 10^8$**	**$2.2\ 10^5$**
1cm Cu	64	**0.42**	**$5.3\ 10^8$**	**$1.1\ 10^6$**
1cm W	185	**0.31**	**$1.1\ 10^9$**	**$2.3\ 10^6$**
1cm Pb	207	**0.16**	**$6.7\ 10^8$**	**$1.3\ 10^6$**
LHC pPb 8.8 TeV	207	**10^{-4}**	**$1.0\ 10^7$**	**$7.5\ 10^4$**
RHIC dAu 200GeV	198	**$1.5\ 10^{-4}$**	**$2.4\ 10^6$**	**$5.9\ 10^3$**
RHIC dAu 62GeV	198	**$3.8\ 10^{-6}$**	**$1.2\ 10^4$**	**18**

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	0.62	$1.1\ 10^{8}$	$2.2\ 10^{5}$
1cm Cu	64	0.42	$5.3\ 10^{8}$	$1.1\ 10^{6}$
1cm W	185	0.31	$1.1\ 10^{9}$	$2.3\ 10^{6}$
1cm Pb	207	0.16	$6.7\ 10^{8}$	$1.3\ 10^{6}$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^{7}$	$7.5\ 10^{4}$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^{6}$	$5.9\ 10^{3}$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^{4}$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	0.62	1.1 10^{8}	2.2 10^{5}
1cm Cu	64	0.42	5.3 10^{8}	1.1 10^{6}
1cm W	185	0.31	1.1 10^{9}	2.3 10^{6}
1cm Pb	207	0.16	6.7 10^{8}	1.3 10^{6}
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^{7}	7.5 10^{4}
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^{6}	5.9 10^{3}
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^{4}	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, y or P_T

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*
  - not to mention ratio with **open charm, Drell-Yan,** etc ...

What for ?

- The target versatility of a fixed-target experiment is undisputable

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)
- One should be careful with factorization breaking effects:

This calls for multiple measurements to (in)validate factorization

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(ϒ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	**800**	**3.4 10^6**	**6.9 10^3**
1cm Be	207.9	**25**	**9.1 10^5**	**1.9 10^3**
1cm Cu	207.64	**17**	**4.3 10^6**	**0.9 10^3**
1cm W	207.185	**13**	**9.7 10^6**	**1.9 10^4**
1cm Pb	207.207	**7**	**5.7 10^6**	**1.1 10^4**
LHC PbPb 5.5 TeV	207.207	**0.5**	**7.3 10^6**	**3.6 10^4**
RHIC AuAu 200GeV	198.198	**2.8**	**4.4 10^6**	**1.1 10^4**
RHIC AuAu 62GeV	198.198	**0.13**	**4.0 10^4**	**61**

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1} = AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	$N(\Upsilon)\ yr^{-1} = AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	800	$3.4\ 10^6$	$6.9\ 10^3$
1cm Be	207.9	25	$9.1\ 10^5$	$1.9\ 10^3$
1cm Cu	207.64	17	$4.3\ 10^6$	$0.9\ 10^3$
1cm W	207.185	13	$9.7\ 10^6$	$1.9\ 10^4$
1cm Pb	207.207	7	$5.7\ 10^6$	$1.1\ 10^4$
LHC PbPb 5.5 TeV	207.207	0.5	$7.3\ 10^6$	$3.6\ 10^4$
RHIC AuAu 200GeV	198.198	2.8	$4.4\ 10^6$	$1.1\ 10^4$
RHIC AuAu 62GeV	198.198	0.13	$4.0\ 10^4$	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(ϒ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	**800**	**3.4 10^6**	**6.9 10^3**
1cm Be	207.9	**25**	**9.1 10^5**	**1.9 10^3**
1cm Cu	207.64	**17**	**4.3 10^6**	**0.9 10^3**
1cm W	207.185	**13**	**9.7 10^6**	**1.9 10^4**
1cm Pb	207.207	**7**	**5.7 10^6**	**1.1 10^4**
LHC PbPb 5.5 TeV	207.207	**0.5**	**7.3 10^6**	**3.6 10^4**
RHIC AuAu 200GeV	198.198	**2.8**	**4.4 10^6**	**1.1 10^4**
RHIC AuAu 62GeV	198.198	**0.13**	**4.0 10^4**	**61**

- Yields similar to those of RHIC at 200 GeV,
  100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

The same picture also holds for open heavy flavour

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

... not well understood

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

  ... not well understood

- the difficulty to observe directly the excited states

  which would melt before the ground states

  - χ_c never studied in AA collisions
  - $\psi(2S)$ not yet studied in AA collisions at RHIC

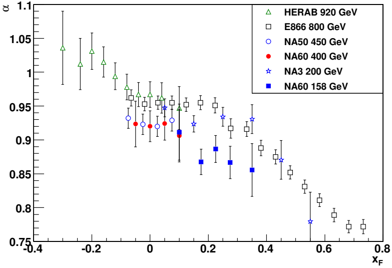
What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and
  ... not well understood
- the difficulty to observe directly the excited states
  which would melt before the ground states
  - χ_c never studied in AA collisions
  - $\psi(2S)$ not yet studied in AA collisions at RHIC
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence ...

SPS and Hera-B

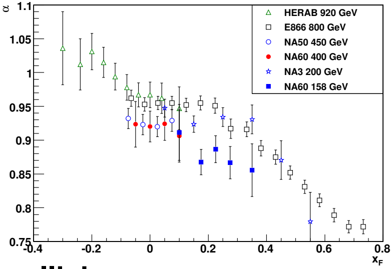
– J/ψ **data in** pA **collisions**



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

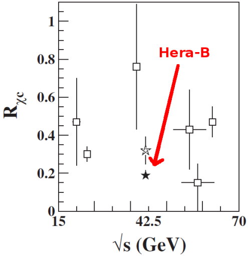
SPS and Hera-B

– J/ψ **data in** pA **collisions**



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

– χ_c **data in** pA **collisions**



HERA-B PRD 79 (2009) 012001, and ref. therein

LHB

Our idea is not completely new

Nuclear Instruments and Methods in Physics Research A 333 (1993) 125–135
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

LHB, a fixed target experiment at LHC to measure CP violation in B mesons

Flavio Costantini

University of Pisa and INFN, Italy

A fixed target experiment at LHC to measure CP violation in B mesons is presented. A description of the proposed apparatus is given together with its sensitivity on the CP violation asymmetry measurement for the two benchmark decay channels $B^0 \rightarrow J/\psi + K_s^0$, $B^0 \rightarrow \pi^+\pi^-$. The possibility of obtaining an extracted LHC beam hinges on channeling in a bent silicon crystal. Recent results on beam extraction efficiencies measured at CERN SPS based on this technique are presented.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\overline{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} cm^{-2}s^{-1} luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} cm^{-2}s^{-1} luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions
- After a year, one simply moves the crystal by less than one mm ...

Further key studies ?

(Multiply) heavy baryons:

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathscr{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathscr{B}(b \to \Lambda_b) \times \mathscr{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
    $(\mathscr{B}(J/\psi \to \mu\mu) = 6\%)$

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathcal{B}(b \to \Lambda_b) \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
    $(\mathcal{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathscr{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathscr{B}(b \to \Lambda_b) \times \mathscr{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathscr{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathcal{B}(b \to \Lambda_b) \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathcal{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)
  - Ξ_{cc}, ..., cross sections in the central region are being calculated with the MC generator GENXICC

C.H. Chang, J.X. Wang, X.G. Wu. Comput.Phys.Commun. 177 (2007) 467

Further key studies ?

(Multiply) heavy baryons:

- $\Lambda_b \to \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
  - $\mathcal{N}(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
  - $\mathcal{B}(b \to \Lambda_b) \times \mathcal{B}(\Lambda_b \to J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$ $(\mathcal{B}(J/\psi \to \mu\mu) = 6\%)$
  - 15 000 $\Lambda_b \to J/\psi\Lambda \to \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement **see e.g. LHCb arXiv:1302.5578 [hep-ex]**
- discovery potential ? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)
  - Ξ_{cc}, ..., cross sections in the central region are being calculated with the MC generator GENXICC

    C.H. Chang, J.X. Wang, X.G. Wu. Comput.Phys.Commun. 177 (2007) 467
  - they should also be calculated for $x_F \to -1$

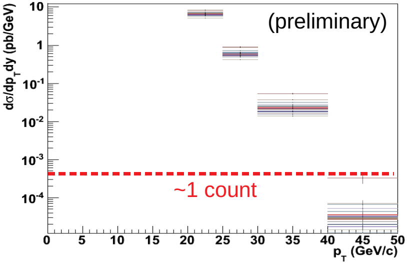
    where IQ could dominate

Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

- p-p photon kinematics at fixed-target LHC (central rapidities):
  To access x > 0.3 one needs isolated-γ at: $p_T = x_T\sqrt{s}/2 > 20$ GeV/c
- JETPHOX NLO pQCD calculations:

  p-p at √s=115 GeV
  |y|<0.5, p_T>20 GeV/c
  Isolation: R=0.4, E_T^{had}<5 GeV

  $\mathcal{L}$(10 cm H_2-target) ~ $2 \bullet 10^3$ pb^{-1}/year



PDF: CT10 52 eigenval. (90% CL)
Scales: $\mu_i = p_T$
FF = BFG-II
x-section uncertainties(*) of ±150%

(*) (68%CL)/(90% CL) ~ 1.65