Precision proton-proton and proton-nucleus collision studies at A Fixed-Target ExpeRiment at the LHC (AFTER@LHC)

Jean-Philippe Lansberg
IPN Orsay, Université Paris-Sud

April 27, 2014 - May 2, 2014 – Warsaw – Poland

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), C. Lorcé (IPNO), R. Mikkelsen (Aarhus), A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino), U.I. Uggerhøj (Aarhus), R. Ulrich (KIT), Y. Zhang (Tsinghua)
Part I

Introduction
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 ($x_F \equiv \frac{p_z}{p_{z \text{max}}}$)
  - achieving **high luminosities** with dense targets,
  - varying the atomic mass of the **target** almost at will,
  - polarising the target.
Generalities

- *pp* or *pA* collisions with a 7 TeV *p* on a fixed target occur at a CM energy 
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]
A bit of kinematics with the 7 TeV proton beam

Generalities

- $pp$ or $pA$ collisions with a 7 TeV $p^+$ on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]
- 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
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: *boost*:
  \[ \gamma_{CM}^L = \frac{\sqrt{s}}{2m_p} \approx 60 \]
**Generalities**

- *pp* or *pA* collisions with a 7 TeV *p* on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), *i.e.* much larger

- Benefit of the fixed target mode: boost: \( \gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \approx 60 \)

- Consider a photon emitted at \( 90^\circ \) w.r.t. the z-axis (beam) in the CM:
  \( (p_{z,CM} = 0, E_{CM}^\gamma = p_T) \)
Generalities

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

\[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: boost: \( \gamma_{CM} = \frac{\sqrt{s}}{2m_p} \approx 60 \)

- Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM:

\[
\begin{pmatrix}
E_{Lab} \\
p_{z,Lab}
\end{pmatrix}
= \begin{pmatrix}
\gamma & \gamma \beta \\
\gamma \beta & \gamma
\end{pmatrix}
\begin{pmatrix}
p_T \\
0
\end{pmatrix}
\]

\( (p_{z,CM} = 0, E^\gamma_{CM} = p_T) \)
Generalities

- **pp** or **pA** collisions with a **7 TeV** **p⁺** on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: boost: \( \gamma_{CM} = \frac{\sqrt{s}}{2m_p} \approx 60 \)

  - Consider a photon emitted at **90°** w.r.t. the z-axis (beam) in the CM:
    \[
    \begin{pmatrix}
    E_{Lab} \\
    p_{z,Lab}
    \end{pmatrix} =
    \begin{pmatrix}
    \gamma & \gamma \beta \\
    \gamma \beta & \gamma
    \end{pmatrix}
    \begin{pmatrix}
    p_T \\
    0
    \end{pmatrix}
    \]
    \[ p_{z,Lab} \approx 60p_T ! \ [A \ 67 \text{ MeV } \gamma \text{ from a } \pi^0 \text{ at rest in the CM can easily be detected.}] \]
Generalities

- **pp** or **pA** collisions with a **7 TeV** **p**\(^+\) on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: **boost**: \( \gamma_{CM} = \frac{\sqrt{s}}{2m_p} \approx 60 \)

  - Consider a photon emitted at 90\(^{\circ}\) w.r.t. the z-axis (beam) in the CM:
    \[
    \begin{pmatrix}
    E_{Lab} \\
    p_{z,Lab}
    \end{pmatrix}
    =
    \begin{pmatrix}
    \gamma & \gamma \beta \\
    \gamma \beta & \gamma
    \end{pmatrix}
    \begin{pmatrix}
    p_T \\
    0
    \end{pmatrix}
    \]
    
    - \( p_{z,Lab} \approx 60p_T \) ! [A 67 MeV \( \gamma \) from a \( \pi^0 \) at rest in the CM can easily be detected.]

  - Angle in the Lab. frame: \( \tan \theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma \beta} \Rightarrow \theta \approx 1^{\circ} \).
    
    [Rapidity shift: \( \Delta y = \tanh^{-1} \beta \approx 4.8 \)]
A bit of kinematics with the 7 TeV proton beam

Generalities

- \( pp \) or \( pA \) collisions with a 7 TeV \( p^+ \) on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_NE_p} \simeq 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: boost: \( \gamma_{CM}^\text{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60 \)

- Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM:
  \[ \begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma \beta \\ \gamma \beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix} \]
  \( p_{z,Lab} \simeq 60p_T \) ! [A 67 MeV \( \gamma \) from a \( \pi^0 \) at rest in the CM can easily be detected.]

- Angle in the Lab. frame: \( \tan \theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma \beta} \Rightarrow \theta \simeq 1° \).
  [Rapidity shift: \( \Delta y = tanh^{-1}\beta \simeq 4.8 \)]

- The entire forward CM hemisphere (\( y_{CM} > 0 \)) within \( 0° \leq \theta_{Lab} \leq 1° \)
  \[ y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8 \]
**Generalities**

- **pp** or **pA collisions** with a 7 TeV **p** on a fixed target occur at a CM energy
  \[ \sqrt{s} = \sqrt{2m_N E_p} \approx 115 \text{ GeV} \]

- In a symmetric collider mode, \( \sqrt{s} = 2E_p \), i.e. much larger

- Benefit of the fixed target mode: **boost**:
  \[ \gamma_{CM} = \frac{\sqrt{s}}{2m_p} \approx 60 \]

  - Consider a photon emitted at 90\(^\circ\) w.r.t. the z-axis (beam) in the CM:
    \[
    \begin{pmatrix}
      E_{Lab} \\
      p_{z,Lab}
    \end{pmatrix} = \begin{pmatrix}
      \gamma & \gamma \beta \\
      \gamma \beta & \gamma
    \end{pmatrix} \begin{pmatrix}
      p_T \\
      0
    \end{pmatrix}
    \]
    \[ p_{z,Lab} \approx 60p_T \]
    [A 67 MeV \( \gamma \) from a \( \pi^0 \) at rest in the CM can easily be detected.]

  - Angle in the Lab. frame:
    \[ \tan \theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma \beta} \Rightarrow \theta \approx 1^\circ. \]
    [Rapidity shift: \( \Delta y = \tanh^{-1} \beta \approx 4.8 \)]

  - The entire forward CM hemisphere \( y_{CM} > 0 \) within \( 0^\circ \leq \theta_{CM} \leq 1^\circ \)
    \[ y_{CM} = 0 \Rightarrow y_{Lab} \approx 4.8 \]

  - **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 $x \rightarrow 1$ in the target
  - last, but not least, the beam pipe is in practice not a geometrical constrain at $\theta_{CM} \approx 180^\circ$
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 $\theta_{CM} \approx 180^\circ$

\[ x_1 \approx x_2 \]
The target-rapidity region: the uncharted territory

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 $\theta_{CM} \simeq 180^\circ$

\[
x_1 \simeq x_2
\]

\[
x_1 \ll x_2
\]

Hadron center-of-mass system

Target rest frame

$\sim 1^\circ$
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 $\theta_{CM} \approx 180^\circ$

**Hadron center-of-mass system**

\[ x_1 \approx x_2 \]

**Target rest frame**

\[ x_1 \ll x_2 \]

**backward physics = large-$x_2$ physics**
First systematic access to the target-rapidity region

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

\( x_F \rightarrow -1 \)

\( J/\psi \) suppression in \( pA \) collisions

- \( x_F \) 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
($x_F \rightarrow -1$)

- $x_F$ 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 $\Upsilon$, 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

(\(x_F \rightarrow -1\))

\(J/\psi\) 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
- PHENIX @ RHIC: \(-0.1 < x_F < 0.1\) [could be wider with \(\Upsilon\), 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

\( x_F \to -1 \)

\( J/\psi \) 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
- PHENIX @ RHIC: \(-0.1 < x_F < 0.1\) [could be wider with \( \Upsilon \), 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 \( y_{\text{cms}} \sim -2.5 \) \( \Rightarrow x_F \sim \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\text{cms}}) \sim -1 \)
The beam extraction

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

The beam extraction

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

The beam extraction

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


★ Illustration for collimation

A solid state primary collimator-scatterer

Bent-crystal as primary collimator
The beam extraction

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


★ Illustration for collimation

A solid state primary collimator-scatterer

Bent-crystal as primary collimator

★ 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!


★ Illustration for collimation

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

★ 2 crystals to be installed in the LHC beampipe in 2014
Luminosities

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

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

\[ \mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times N_A)/A \]

[ $\ell$: target thickness (for instance 1cm)]
Expected proton flux $\Phi_{\text{beam}} = 5 \times 10^8 \ p^+\text{s}^{-1}$

**Instantaneous Luminosity:**

$$\mathcal{L} = \Phi_{\text{beam}} \times N_{\text{target}} = N_{\text{beam}} \times (\rho \times \ell \times N_A)/A$$

$[\ell$: target thickness (for instance 1cm)$]$

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

$[\text{the so-called LHC years}]$
Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8 \, p^+ s^{-1}$
- Instantaneous Luminosity:
  \[
  \mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times N_A)/A
  \]
  \[\text{[} \ell: \text{ target thickness (for instance 1cm)}\]
- Integrated luminosity: $\int dt \mathcal{L}$ over $10^7$ s for $p^+$ and $10^6$ for Pb
  \[\text{[the so-called LHC years]}\]

<table>
<thead>
<tr>
<th>Target</th>
<th>$\rho$ (g.cm$^{-3}$)</th>
<th>A</th>
<th>$\mathcal{L}$ ($\mu$b$^{-1}$s$^{-1}$)</th>
<th>$\int \mathcal{L}$ (pb$^{-1}$.yr$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol. H$_2$</td>
<td>0.09</td>
<td>1</td>
<td>26</td>
<td>260</td>
</tr>
<tr>
<td>Liq. H$_2$</td>
<td>0.07</td>
<td>1</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Liq. D$_2$</td>
<td>0.16</td>
<td>2</td>
<td>24</td>
<td>240</td>
</tr>
<tr>
<td>Be</td>
<td>1.85</td>
<td>9</td>
<td>62</td>
<td>620</td>
</tr>
<tr>
<td>Cu</td>
<td>8.96</td>
<td>64</td>
<td>42</td>
<td>420</td>
</tr>
<tr>
<td>W</td>
<td>19.1</td>
<td>185</td>
<td>31</td>
<td>310</td>
</tr>
<tr>
<td>Pb</td>
<td>11.35</td>
<td>207</td>
<td>16</td>
<td>160</td>
</tr>
</tbody>
</table>
Luminosities

- 1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)

This gives: $L_{H_2/D_2} \approx 20 \text{ fb}^{−1}$

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 Lumi for Pb runs in the backup slides (roughly 10 times that planned for the LHC)
Luminosities

- 1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)
- This gives: $\mathcal{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} \text{ y}^{-1}$
Luminosities

- 1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)
- This gives: $\mathcal{L}_{H_2/D_2} \simeq 20 \, \text{fb}^{-1} \, \text{y}^{-1}$
- Recycling the LHC beam loss, one gets a luminosity comparable to the LHC itself!

![Graph showing LHC 2012 RUN (4 TeV/beam) with data points for ATLAS, CMS, LHCb, and ALICE, indicating prelimary results.]

(J.P. Lansberg (IPNO, Paris-Sud U.) A Fixed-Target ExpeRiment at the LHC April 29, 2014 9 / 29)
Luminosities

- 1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, . . . )
- This gives: $\mathcal{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} \text{ y}^{-1}$
- 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
- Run14dAu 0.15 pb$^{-1}$ @ $\sqrt{s_{NN}} = 200$ GeV

\[ \text{LHC 2012 RUN (4 TeV/beam)} \]
\[ \text{Delivered integrated luminosity (fb$^{-1}$)} \]

- ATLAS 22.817 fb$^{-1}$
- CMS 22.637 fb$^{-1}$
- LHCb 2.115 fb$^{-1}$
- ALICE 9.099 pb$^{-1}$

(PRELIMINARY)

(generated 2012-12-02 18:23 including fill 3360)
Luminosities

- 1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)
- This gives: $\mathcal{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1}\text{y}^{-1}$
- Recycling the LHC beam loss, one gets a luminosity comparable to the LHC itself!

**PHENIX lumi in their decadal plan**
- Run14pp $12 \text{ pb}^{-1}$ @ $\sqrt{s_{NN}} = 200$ GeV
- Run14dAu $0.15 \text{ pb}^{-1}$ @ $\sqrt{s_{NN}} = 200$ GeV

**AFTER vs PHENIX@RHIC:**
- 3 orders of magnitude larger
1 meter-long liquid $H_2$ & $D_2$ targets can be used (see NA51, ...)

This gives: $\mathcal{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} \text{ y}^{-1}$

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
- Run14dAu 0.15 pb$^{-1}$ @ $\sqrt{s_{NN}} = 200$ GeV

AFTER vs PHENIX@RHIC:
- 3 orders of magnitude larger

Lumi for Pb runs in the backup slides
(roughly 10 times that planned for the LHC)
Part II

AFTER: flagship measurements
Key studies: gluons in the proton

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

  - Not easily accessible in DIS
  - Very large uncertainties
  - Accessible thanks to gluon sensitive probes, 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

  - Large-$x$ gluons: important for BSM searches at the LHC
Key studies: gluons in the proton

- **Gluon distribution** at mid, high and ultra-high $x_B$ in the proton
  - Not easily accessible in DIS
  - Very large uncertainties

![Gluon distribution graph](image-url)
Key studies: gluons in the proton

- **Gluon distribution** at mid, high and ultra-high $x_B$ in the proton
  - Not easily accessible in DIS
  - 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
  - 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
  - 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
  - Very large uncertainties

Accessible thanks gluon sensitive probes,

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

- **Isolated photon**

- **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
  - Very large uncertainties

Accessible thanks gluon sensitive probes,

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

- **Isolated photon**

- **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
  - Very large uncertainties

Accessible thanks gluon sensitive probes,

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

- **Isolated photon**

- **jets** ($P_T \in [20, 40]$ GeV)

**Large-$x$ gluons: important for BSM searches at the LHC**
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown

Gluon (μ = 100 GeV)

CT10 gluon uncertainty

x

10^{-3} 10^{-1} 10^{0}
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown
possible experimental probes
- heavy quarkonia
- isolated photons
- jets
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown possible experimental probes
- heavy quarkonia
- isolated photons
- jets

Pioneer measurement by E866
- using $\Upsilon \to Q^2 \approx 100 \text{ GeV}^2$
- outcome: $g_n(x) \approx g_p(x)$
Key studies: gluons in the neutron

Gluon PDF for the neutron unknown
possible experimental probes
- heavy quarkonia
- isolated photons
- jets

Pioneer measurement by E866
- using $\Upsilon \to Q^2 \simeq 100$ GeV$^2$
- outcome: $g_n(x) \simeq g_p(x)$

could be extended with AFTER
- using $J/\psi$, ..., $C = +1$ onia, ...
- wider $x$ range & lower $Q^2$
Gluon and heavy-quark distributions

Key studies: gluons in the neutron

Gluon PDF for the neutron unknown
possible experimental probes
- heavy quarkonia
- isolated photons
- jets

Pioneer measurement by E866
- using $\Upsilon \to Q^2 \sim 100$ GeV$^2$
- outcome: $g_n(x) \simeq g_p(x)$

could be extended with AFTER
- using $J/\psi$, ..., $C = +1$ onia, ...
- wider $x$ range & lower $Q^2$

<table>
<thead>
<tr>
<th>target</th>
<th>yearly lumi</th>
<th>$B \frac{dN_{J/\psi}}{dy}$</th>
<th>$B \frac{dN_{\Upsilon}}{dy}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m Liq. $H_2$</td>
<td>20 fb$^{-1}$</td>
<td>$4.0 \times 10^8$</td>
<td>$9.0 \times 10^5$</td>
</tr>
<tr>
<td>1m Liq. $D_2$</td>
<td>24 fb$^{-1}$</td>
<td>$9.6 \times 10^8$</td>
<td>$1.9 \times 10^6$</td>
</tr>
</tbody>
</table>
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

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
- Total open charm and beauty cross section (aim: down to $P_T \rightarrow 0$)

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
  - **Total open charm and beauty** cross section (aim: down to $P_T \to 0$)

requires

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
  - **Total open charm and beauty** cross section (aim: down to $P_T \to 0$) 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
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$) 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
  - Total open charm and beauty cross section (aim: down to $P_T \rightarrow 0$)
  
  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.)

DGLAP

BHPS

Sea-like
Key studies: heavy-quark content of the proton

- Heavy-quark distributions (at high $x_B$)
  - Pin down intrinsic charm, ... at last
  - Total open charm and beauty cross section
    (aim: down to $P_T \to 0$)
  - 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.)

```
gamma + c + X |y_\gamma| < 0.35, |y_Q| < 0.8 \sqrt{S} = 115 \text{ GeV}
```

T. Stavreva
Key studies: gluon contribution to the proton spin

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

  F. Yuan, PRD 78 (2008) 014024

  B & D meson production
  \(\gamma, \gamma\)-jet, \(\gamma-\gamma\)
  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 asymmetries** 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 ($J/\psi$, $\Upsilon$, $\chi_c$, ...)

F. Yuan, PRD 78 (2008) 014024
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 ($J/\psi$, $\Upsilon$, $\chi_c$, ...
- $B$ & $D$ meson production

F. Yuan, PRD 78 (2008) 014024
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 ($J/\psi$, $\Upsilon$, $\chi_c$, ...)
- $B$ & $D$ meson production
- $\gamma$, $\gamma$-jet, $\gamma - \gamma$

F. Yuan, PRD 78 (2008) 014024
J.W. Qiu, et al., PRL 107 (2011) 062001
Gluon contribution to 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 asymmetries using gluon sensitive probes
- Quarkonia ($J/\psi$, $\Upsilon$, $\chi_c$, …)
- $B$ & $D$ meson production
- $\gamma$, $\gamma$-jet, $\gamma - \gamma$

The target-rapidity region corresponds to high $x^\uparrow$ where the $k_T$-spin correlation is the largest

- F. Yuan, PRD 78 (2008) 014024
- 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 asymmetries using gluon sensitive probes
  - quarkonia ($J/\psi$, $\Upsilon$, $\chi_c$, …)
  - $B$ & $D$ meson production
  - $\gamma$, $\gamma$-jet, $\gamma - \gamma$

- 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

---

F. Yuan, PRD 78 (2008) 014024
J.W. Qiu, et al., PRL 107 (2011) 062001
Access to gluon Boer-Mulder functions
Gluon contribution to the proton spin

Access to gluon Boer-Mulder functions

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

PHYSICAL REVIEW D 86, 094007 (2012)
Access to gluon Boer-Mulder functions

- Low $P_T$ C-even quarkonium production is a good probe of the gluon Boer-Mulder functions
Access to gluon Boer-Mulder functions

- Low $P_T$ C-even quarkonium production is a good probe of the gluon Boer-Mulder functions.
Access to gluon Boer-Mulder functions

- Low $P_T$ $C$-even quarkonium production is a good probe of the gluon Boer-Mulder functions.

- Affect the low $P_T$ spectra:
  \[
  \frac{1}{\sigma} \frac{d\sigma(\eta_Q)}{dq_T^2} \propto 1 - R(q_T^2) \quad \text{and} \quad \frac{1}{\sigma} \frac{d\sigma(\chi_{0,Q})}{dq_T^2} \propto 1 + R(q_T^2)
  \]
  ($R$ involves the BM fcts)
Access to gluon Boer-Mulder functions

- Low $P_T$ $C$-even quarkonium production is a good probe of the gluon Boer-Mulder functions.

- Affect the low $P_T$ spectra:
  \[
  \frac{1}{\sigma} \frac{d\sigma(\eta_Q)}{dq_T^2} \propto 1 - R(q_T^2) \quad \text{and} \quad \frac{1}{\sigma} \frac{d\sigma(\chi_{0,Q})}{dq_T^2} \propto 1 + R(q_T^2)
  \]
  ($R$ involves the BM fcts)

- The boost is of great help to access low $P_T$ $P$-wave quarkonia.

Boer-Mulders effect: correlation between the parton $k_T$ and its spin (in an unpolarized nucleon)
Access to gluon Boer-Mulder functions

- Low $P_T$ $C$-even quarkonium production is a good probe of the gluon Boer-Mulder functions.

- Affect the low $P_T$ spectra:
  \[
  \frac{1}{\sigma} \frac{d\sigma(\eta_Q)}{dq_T^2} \propto 1 - R(q_T^2) \quad \text{and} \quad \frac{1}{\sigma} \frac{d\sigma(\chi_{0,Q})}{dq_T^2} \propto 1 + R(q_T^2)
  \]
  ($R$ involves the BM fcts)

- The boost is of great help to access low $P_T$ $P$-wave quarkonia.
SSA in Drell-Yan studies with AFTER@LHC

- Relevant parameters for the future proposed polarized DY experiments.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>particles</th>
<th>energy (GeV)</th>
<th>$\sqrt{s}$ (GeV)</th>
<th>$x_p^{\uparrow}$</th>
<th>$\mathcal{L}$ (nb$^{-1}$s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFTER</td>
<td>$p + p^{\uparrow}$</td>
<td>7000</td>
<td>115</td>
<td>$0.01 \div 0.9$</td>
<td>1</td>
</tr>
<tr>
<td>COMPASS</td>
<td>$\pi^\pm + p^{\uparrow}$</td>
<td>160</td>
<td>17.4</td>
<td>$0.2 \div 0.3$</td>
<td>2</td>
</tr>
<tr>
<td>COMPASS (low mass)</td>
<td>$\pi^\pm + p^{\uparrow}$</td>
<td>160</td>
<td>17.4</td>
<td>$\sim 0.05$</td>
<td>2</td>
</tr>
<tr>
<td>RHIC</td>
<td>$p^{\uparrow} + p$</td>
<td>collider</td>
<td>500</td>
<td>$0.05 \div 0.1$</td>
<td>0.2</td>
</tr>
<tr>
<td>J–PARC</td>
<td>$p^{\uparrow} + p$</td>
<td>50</td>
<td>10</td>
<td>$0.5 \div 0.9$</td>
<td>1000</td>
</tr>
<tr>
<td>PANDA (low mass)</td>
<td>$\bar{p} + p^{\uparrow}$</td>
<td>15</td>
<td>5.5</td>
<td>$0.2 \div 0.4$</td>
<td>0.2</td>
</tr>
<tr>
<td>PAX</td>
<td>$p^{\uparrow} + \bar{p}$</td>
<td>collider</td>
<td>14</td>
<td>$0.1 \div 0.9$</td>
<td>0.002</td>
</tr>
<tr>
<td>NICA</td>
<td>$p^{\uparrow} + p$</td>
<td>collider</td>
<td>20</td>
<td>$0.1 \div 0.8$</td>
<td>0.001</td>
</tr>
<tr>
<td>RHIC</td>
<td>$p^{\uparrow} + p$</td>
<td>collider</td>
<td>250</td>
<td>$0.2 \div 0.5$</td>
<td>2</td>
</tr>
<tr>
<td>Int.Target 1</td>
<td>$p^{\uparrow} + p$</td>
<td>250</td>
<td>22</td>
<td>$0.2 \div 0.5$</td>
<td>60</td>
</tr>
<tr>
<td>RHIC</td>
<td>$p^{\uparrow} + p$</td>
<td>250</td>
<td>22</td>
<td>$0.2 \div 0.5$</td>
<td>60</td>
</tr>
</tbody>
</table>

- For AFTER, the numbers correspond to a 50 cm polarized $H$ target.
- $\ell^{\uparrow} \ell^{-}$ angular distribution: separation Sivers vs. Boer-Mulders effects
SSA in Drell-Yan studies with AFTER@LHC

- Relevant parameters for the future proposed polarized DY experiments.

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

- ℓ⁺ℓ⁻ angular distribution: separation Sivers vs. Boer-Mulders effects

M. Anselmino, ECT*, Feb. 2013 (Courtesy U. d’Alessio)
pA studies: large-x gluon content of the nucleus
Gluons in nuclei

\textbf{pA studies: large-}\textit{x} gluon content of the nucleus

- Large-\textit{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 $\gamma$ data at RHIC
pA studies: large-\(x\) gluon content of the nucleus

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

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

- Large-x gluon nPDF: unknown
- Gluon EMC effect: unknown
- Hint from $\Upsilon$ 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:
Gluons in nuclei

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

- Large-x gluon nPDF: unknown
- Gluon EMC effect: unknown
- Hint from γ 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 $x \geq 0.1$
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \approx 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\text{lab}}^{\text{max}} \approx \gamma_{\text{lab}}^{\text{beam}} \times 30$ MeV ($1/R_{\text{Pb}} \approx 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_p E_{\gamma}}$ up to 20 GeV
  - No pile-up
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \sim 7000 \ (E_p = 7000 \ \text{GeV})$
  - $E_{\gamma,\text{lab}}^{\text{max}} \sim \gamma_{\text{lab}}^{\text{beam}} \times 30 \ \text{MeV} \ (1/R_{\text{Pb}} \sim 30 \ \text{MeV})$
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_p E_\gamma}$ up to 20 GeV
  - No pile-up

- Fracture functions
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \approx 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\text{lab}}^{\text{max}} \approx \gamma_{\text{lab}}^{\text{beam}} \times 30$ MeV ($1/R_{\text{Pb}} \approx 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_pE_\gamma}$ up to 20 GeV
  - No pile-up

- Fracture functions
  - via Drell-Yan pair production
  - + identified hadron

---

L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \sim 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\text{lab}}^{\text{max}} \sim \gamma_{\text{lab}}^{\text{beam}} \times 30$ MeV ($1/R_{Pb} \sim 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_p E_{\gamma}}$ up to 20 GeV
  - No pile-up

- Fracture functions
  - via Drell-Yan pair production
  - + identified hadron

- Privileged region for the identified hadron: either the projectile- or target-rapidity region

L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \sim 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\text{lab}}^{\text{max}} \sim \gamma_{\text{lab}}^{\text{beam}} \times 30$ MeV ($1/R_{Pb} \sim 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_p E_\gamma}$ up to 20 GeV
  - No pile-up

- Fracture functions
  - via Drell-Yan pair production
    - + identified hadron

privileged region for the identified hadron: either the projectile- or target-rapidity region

the fixed-target mode is ideal for such studies

L. Trentadue, G. Veneziano, PLB 323 (1994) 201
F. Ceccopieri, L. Trentadue, PLB 668 (2008) 319
More with AFTER: photoproduction and “beyond” DY

- $\gamma + p$ interaction via ultra-peripheral collisions
  - $\gamma_{\text{lab}}^{\text{beam}} \approx 7000$ ($E_p = 7000$ GeV)
  - $E_{\gamma,\text{lab}}^{\text{max}} \approx \gamma_{\text{lab}}^{\text{beam}} \times 30$ MeV ($1/R_{\text{Pb}} \approx 30$ MeV)
  - $\sqrt{s_{\gamma p}} = \sqrt{2m_p E_{\gamma}}$ up to 20 GeV
  - No pile-up

- Fracture functions
  - via Drell-Yan pair production
  - + identified hadron

- privileged region for the identified hadron: either the projectile- or target-rapidity region

- the fixed-target mode is ideal for such studies
- good prospects for fracture-function studies with AFTER


Fixed Target @ LHC

Non perturbative regime

EMC effect
Nuclear fermi motion

DGLAP
BFKL
saturation

log (x^{-1})

x \rightarrow 1

log (Q^2)

log (x-1)

\log (Q^2)

Non perturbative regime

Dilute system

saturation

BK-JIMWLK

x \rightarrow 1
Dilute system

BK-JIMWLK
saturation

Fixed Target @ LHC

Non perturbative regime

$Q^2 = Q^2_s(x)$

$log (x-1)$

$log (Q^2)$

Nuclear fermi motion

EMC effect

$x \to 1$

$x \to \infty$

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target ExpeRiment at the LHC

April 29, 2014 19 / 29
log \left( x^{-1} \right) \uparrow

\begin{align*}
DGLAP & \quad \text{Non perturbative regime} \\
BFKL & \\
DGLAP & \quad \text{Dilute system} \\
Q^2 = Q^2_s(x) & \quad \text{BK-JIMWLK} \\
\log (x-1) & \\
\log (Q^2) & \\
\end{align*}

\begin{align*}
\text{Fixed Target @ LHC} & \\
\text{Quarkonia} & \\
\text{EMC effect} & \\
\text{Nuclear fermi motion} & \\
\text{Drell-Yan} & \\
\end{align*}
Overall

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target ExpeRiment at the LHC

April 29, 2014 19 / 29
Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky, F. Fleuret, C. Hadjidakos, J.P. Lansberg

1. Introduction
2. Key numbers and features
3. Nucleon partonic structure
   3.1. Drell-Yan
   3.2. Gluons in the proton at large $x$
      3.2.1. Quarkonia
      3.2.2. Jets
      3.2.3. Direct/isolated photons
   3.3. Gluons in the deuteron and in the neutron
   3.4. Charm and bottom in the proton
      3.4.1. Open-charm production
      3.4.2. $J/\psi + D$ meson production
      3.4.3. Heavy-quark plus photon production
4. Spin physics
   4.1. Transverse SSA and DY
   4.2. Quarkonium and heavy-quark transverse SSA
   4.3. Transverse SSA and photon
   4.4. Spin asymmetries with a final state polarization
5. Nuclear matter
   5.1. Quark nPDF: Drell-Yan in pA and PbP
   5.2. Gluon nPDF
      5.2.1. Isolated photons and photon–jet correlations
      5.2.2. Precision quarkonium and heavy-flavour studies
   5.3. Color filtering, energy loss, Sudakov suppression and hadron break-up in the nucleus
6. Deconfinement in heavy-ion collisions
   6.1. Quarkonium studies
   6.2. Jet quenching
   6.3. Direct photon
   6.4. Deconfinement and the target rest frame
   6.5. Nuclear-matter baseline
7. W and Z boson production in pp, pd and pA collisions
   7.1. First measurements in pA
   7.2. W/Z production in pp and pd
8. Exclusive, semi-exclusive and backward reactions
   8.1. Ultra-peripheral collisions
   8.2. Hard diffractive reactions
   8.3. Heavy-hadron (diffractive) production at $x_F \approx -1$
   8.4. Very backward physics
   8.5. Direct hadron production
9. Further potentials of a high-energy fixed-target set-up...
   9.1. $D$ and $B$ physics
   9.2. Secondary beams
   9.3. Forward studies in relation with cosmic shower
Conclusions
Acknowledgments
References
Part III

First simulations
First simulation: is the boost an issue?

LHCb has successfully carried out pPb and PbPb analyses at 5 TeV. See e.g. M. Adinolfi's talk, WG2, Thursday at 8H50.

We have compared the number-of-track distribution as a function of $\eta$ measured in the collider mode by LHCb ($\sqrt{s} = 5$ TeV) vs. that expected in fixed target mode ($\sqrt{s} = 115$ TeV) using a LHCb-like detector (simulation with HIJING).

Despite the boost, the number of tracks in the LHCb acceptance (forward $\eta$) is lower in the fixed mode than in the collider mode. Very encouraging indication that the boost is not an issue, but really an asset.
First simulation: is the boost an issue?

- LHCb has successfully carried out $p$Pb and Pb$p$ analyses at 5 TeV

  See e.g. M. Adinolfi’s talk, WG2, Thursday at 8H50
First simulation: is the boost an issue?

- LHCb has successfully carried out $p$Pb and Pb$p$ analyses at 5 TeV. See e.g. M. Adinolfi’s talk, WG2, Thursday at 8H50.

- We have compared the number-of-track distribution as function of $\eta$ measured in the collider mode by LHCb ($\sqrt{s} = 5$ TeV) vs. that expected in fixed target mode ($\sqrt{s} = 115$ TeV) using a LHCb-like detector (simulation with HIJING).
First simulation: is the boost an issue?

- LHCb has successfully carried out $p\text{Pb}$ and $\text{Pb}p$ analyses at 5 TeV
  
  See e.g. M. Adinolfi’s talk, WG2, Thursday at 8H50

- We have compared the number-of-track distribution as function of $\eta$ measured in the collider mode by LHCb ($\sqrt{s} = 5$ TeV) vs. that expected in fixed target mode ($\sqrt{s} = 115$ TeV) using a LHCb-like detector (simulation with HIJING)

- Despite the boost, the number of tracks in the LHCb acceptance [forward $\eta$] is lower in the fixed mode than in the collider mode
First simulation: is the boost an issue?

- LHCb has successfully carried out $p$Pb and Pb$p$ analyses at 5 TeV

  See e.g. M. Adinolfi’s talk, WG2, Thursday at 8H50

- We have compared the number-of-track distribution as function of $\eta$ measured in the collider mode by LHCb ($\sqrt{s} = 5$ TeV) vs. that expected in fixed target mode ($\sqrt{s} = 115$ TeV) using a LHCb-like detector (simulation with HIJING)

  ![](image.png)

- Despite the boost, the number of tracks in the LHCb acceptance [ forward $\eta$] is lower in the fixed mode than in the collider mode

- Very encouraging indication that the boost is not issue, but really an asset
Some quarkonium and decay-product distributions at 115 GeV in the backward hemisphere \((y_{\text{Lab}} < 4.8)\)

**Pythia 6.4.21**: \(p(7 \text{ TeV}) + p \rightarrow J/\psi (\text{isub}=86)\) 
\[ J/\Psi \rightarrow \mu^+\mu^- \]

\(\mu\) from \(J/\psi\) for \(1.3 < y_{\text{lab}} < 5.3\)
\(P_T \sim 1.7\) GeV
\(P_L \sim 62\) GeV

**Longitudinal muon momentum**
\(1.3 < y_{\text{lab}} < 3.3\)
\(p_L(\text{max}) \sim 16\) (50) GeV
\(3.3 < y_{\text{lab}} < 4.3\)
\(p_L(\text{max}) \sim 45\) (150) GeV
\(4.3 < y_{\text{lab}} < 5.3\)
\(p_L(\text{max}) \sim 120\) (300) GeV
First look at some backgrounds

Effect of pion decay cuts on combinatorial background of 500k J/ψ events

\[ L = 25 \text{pb}^{-1} \]

- \( 2 < \eta < 5 \)
- \( 2 < \eta_{\pi} < 4.5 \)

- \( p_T^\mu > 1.8 \text{ GeV/c} \)
- \( p_T^{\mu_1} > 0.56 \text{ GeV/c} \)
- \( p_T^{\mu_2} > 0.48 \text{ GeV/c} \)

Counts per 50 MeV/c² in thousands

Minimum bias background

- \( 2 < \eta < 5 \)
- \( \pi \) decay before 15 m

A few hours of data taking with 1 m H2 target

PYTHIA v. 8.183, process: Charmonium:gg2Q\bar{Q}bar[3S1(1)]g at \( \sqrt{s} = 115 \text{GeV} \)
First look at some backgrounds

Minimum bias background

A few hours of data taking with 1 m H2 target
PYTHIA v. 8.183, process: Charmonium:gg2QQbar[3Si[1]]g at $\sqrt{s} = 115\text{GeV}$

60000 $\chi_c$ events

Additional cuts can be added (vertex, etc.)
Accessing the large $x$ glue with quarkonia:

PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

Statistical relative uncertainty
Large statistics allow to access very backward region

Gluon uncertainty from MSTWPDF
- only for the gluon content of the target
- assuming $x_g = M_{J/\Psi} / \sqrt{s} e^{-y_{CM}}$

$J/\Psi$
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

$\Rightarrow$ Backward measurements allow to access large $x$ gluon pdf

$Y$: larger $x_g$ for same $y_{CM}$
$y_{CM} \sim 0 \rightarrow x_g = 0.08$
$y_{CM} \sim -2.4 \rightarrow x_g = 1$

Assuming that we understand the quarkonium-production mechanisms
Part IV

Conclusion and outlooks
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.

- Example: precision quarkonium studies taking advantage of high luminosity (reach in $y$, $P_T$, small BR channels).

- Target versatility (nuclear effects, strongly limited at colliders).

- Modern detection techniques (e.g. $\gamma$ detection with high multiplicity).

- This would likely prepare the ground for $g(x, Q^2)$ extraction.

- A wealth of possible measurements: DY, Open $b/c$, jet correlation, UPC... (not mentioning secondary beams).

- LHC long shutdown (LS2 ? in 2018) needed to install the extraction system.

- Very good complementarity with electron-ion programs.
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.
- Example: precision quarkonium studies taking advantage of...
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. Example: precision quarkonium studies taking advantage of:

- high luminosity (reach in $y$, $P_T$, small BR channels)
- target versatility (nuclear effects, strongly limited at colliders)
- modern detection techniques (e.g. $\gamma$ detection with high multiplicity)
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.

Example: precision quarkonium studies taking advantage of:
- high luminosity (reach in $y$, $P_T$, small BR channels)
- target versatility (nuclear effects, strongly limited at colliders)
- modern detection techniques (e.g. $\gamma$ detection with high multiplicity)

This would likely prepare the ground for $g(x, Q^2)$ extraction.
Conclusion

- Both $p$ and $Pb$ LHC beams can be extracted without disturbing the other experiments.
- Extracting a few per cent of the beam → $5 \times 10^8$ protons per sec.
- This allows for high luminosity $pp$, $pA$ and $PbA$ collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV.
- **Example**: precision quarkonium studies taking advantage of:
  - high luminosity (reach in $y$, $P_T$, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. $\gamma$ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction.
- A wealth of possible measurements:
  - $DY$, Open $b/c$, jet correlation, UPC... (not mentioning secondary beams)
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.

**Example:** precision quarkonium studies taking advantage of:
- high luminosity (reach in $y$, $P_T$, small BR channels)
- target versatility (nuclear effects, strongly limited at colliders)
- modern detection techniques (e.g. $\gamma$ detection with high multiplicity)

This would likely prepare the ground for $g(x, Q^2)$ extraction.

A wealth of possible measurements:
- $DY$, Open $b/c$, jet correlation, UPC... (not mentioning secondary beams)

LHC long shutdown (LS2 ? in 2018) needed to install the extraction system.
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.

- **Example**: precision quarkonium studies taking advantage of:
  - high luminosity (reach in \( y, P_T \), small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. \( \gamma \) detection with high multiplicity)

- This would likely prepare the ground for \( g(x, Q^2) \) extraction.

- A wealth of possible measurements:
  - \( DY, Open \ b/c, jet \) correlation, \( UPC \)... (not mentioning secondary beams)

- LHC long shutdown (LS2 ? in 2018) needed to install the extraction system.

- Very good complementarity with electron-ion programs.
Outlooks

- First physics paper *Physics Reports 522 (2013) 239*
Outlooks

- First physics paper *Physics Reports 522 (2013) 239*
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013* slides at [http://indico.in2p3.fr/event/AFTER@ECTstar](http://indico.in2p3.fr/event/AFTER@ECTstar)

We are looking for more partners to:
- Do first simulations (we are starting fast simulations)
- Think about possible designs
- Think about the optimal detector technologies
- Enlarge the physics case (cosmic rays, flavour physics, ...)

Outlooks

- First physics paper *Physics Reports 522* (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014 http://indico.in2p3.fr/event/AFTER@LesHouches
- and 3-day workshop in Orsay with LUA9 on November 18-20, 2013 http://indico.in2p3.fr/event/LUA9-AFTER-1113

We are looking for more partners to
do first simulations (we are starting fast simulations)
think about possible designs
think about the optimal detector technologies
enlarge the physics case (cosmic rays, flavour physics, ...)

Outlooks

- First physics paper *Physics Reports* 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at [http://indico.in2p3.fr/event/AFTER@ECTstar](http://indico.in2p3.fr/event/AFTER@ECTstar)
- Workshop in *Les Houches* on 12-17 January 2014 [http://indico.in2p3.fr/event/AFTER@LesHouches](http://indico.in2p3.fr/event/AFTER@LesHouches)
- 3-day workshop in Orsay with LUA9 on November 18-20, 2013 [http://indico.in2p3.fr/event/LUA9-AFTER-1113](http://indico.in2p3.fr/event/LUA9-AFTER-1113)
- We are looking for more partners to

---

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target ExpeRiment at the LHC

April 29, 2014

28 / 29
Outlooks

- First physics paper *Physics Reports 522 (2013) 239*
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013* slides at [http://indico.in2p3.fr/event/AFTER@ECTstar](http://indico.in2p3.fr/event/AFTER@ECTstar)
- Workshop in Les Houches on 12-17 January 2014 [http://indico.in2p3.fr/event/AFTER@LesHouches](http://indico.in2p3.fr/event/AFTER@LesHouches) and 3-day workshop in Orsay with LUA9 on November 18-20, 2013 [http://indico.in2p3.fr/event/LUA9-AFTER-1113](http://indico.in2p3.fr/event/LUA9-AFTER-1113)
- We are looking for more partners to do first simulations (we are starting fast simulations)
Outlooks

- First physics paper *Physics Reports* 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at [http://indico.in2p3.fr/event/AFTER@ECTstar](http://indico.in2p3.fr/event/AFTER@ECTstar)
- Workshop in Les Houches on 12-17 January 2014
  [http://indico.in2p3.fr/event/AFTER@LesHouches](http://indico.in2p3.fr/event/AFTER@LesHouches)
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013
- We are looking for more partners to
  - do first simulations (we are starting fast simulations)
  - think about possible designs
Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at http://indico.in2p3.fr/event/AFTER@ECTstar
- Workshop in Les Houches on 12-17 January 2014 http://indico.in2p3.fr/event/AFTER@LesHouches
  and 3-day workshop in Orsay with LUA9 on November 18-20, 2013 http://indico.in2p3.fr/event/LUA9-AFTER-1113
- We are looking for more partners to
  - do first simulations (we are starting fast simulations)
  - think about possible designs
  - think about the optimal detector technologies
  - enlarge the physics case
    (cosmic rays, flavour physics, ...)
Outlooks

- First physics paper *Physics Reports 522* (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at [http://indico.in2p3.fr/event/AFTER@ECTstar](http://indico.in2p3.fr/event/AFTER@ECTstar)
- Workshop in Les Houches on 12-17 January 2014 [http://indico.in2p3.fr/event/AFTER@LesHouches](http://indico.in2p3.fr/event/AFTER@LesHouches)
- and 3-day workshop in Orsay with LUA9 on November 18-20, 2013 [http://indico.in2p3.fr/event/LUA9-AFTER-1113](http://indico.in2p3.fr/event/LUA9-AFTER-1113)

We are looking for more partners to
  - do first simulations (we are starting fast simulations)
  - think about possible designs
  - think about the optimal detector technologies
  - enlarge the physics case
    (cosmic rays, flavour physics, ...)

Further readings

- **Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC**  

- **Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams.**  

- **Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)**  

- **Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER**  

- **Ultra-relativistic heavy-ion physics with AFTER@LHC**  

- **Spin physics at A Fixed-Target ExpeRiment at the LHC (AFTER@LHC)**  

- **Physics Opportunities of a Fixed-Target Experiment using the LHC Beams**  
Part V

Backup slides
The beam extraction

- Inter-crystalline fields are huge

Ge (110), 450 GeV protons

Deflection efficiency vs. deflection angle [mrad]

2000 T!
The beam extraction

- Inter-crystalline fields are huge

- The channeling efficiency is high for a deflection of a few mrad
The beam extraction

- Inter-crystalline fields are huge

- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss \(10^9 p^+ s^{-1}\)
The beam extraction

- Inter-crystalline fields are huge

- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss \(10^9 p^+ s^{-1}\)
- Simple and robust way to extract the most energetic beam ever:
Beam extraction @ LHC

... there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.

... The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of \( \sim 7\sigma \) to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

... ions with the same momentum per charge as protons are deflected in a crystal with similar efficiencies.

Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj

Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, Aarhus C DK-8000, Denmark

Received 9 September 2004; received in revised form 6 January 2005
Available online 24 February 2005

If the crystal is positioned at the kicking section, the whole dump system can be used for slow extraction of parts of the beam halo, the particles that are anyway lost subsequently at collimators.
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)
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)
- 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: $10^9 \, p^+s^{-1}$
- 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 $3.10^5 \, \text{km.s}^{-1}/27 \, \text{km} \approx 11 \, \text{kHz}$
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)  
- 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 $3.10^5 \, \text{km.s}^{-1}/27 \, \text{km} \approx 11 \, \text{kHz}$
- Extracted “mini” bunches:
  - the crystal sees $2808 \times 11000 \, \text{s}^{-1} \approx 3.10^7 \, \text{bunches s}^{-1}$
  - one extracts $5.10^8 / 3.10^7 \approx 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,  
    no pile-up !

Extraction over a 10h fill:

$$5 \times 10^8 \, p^+ \times 3600 \, \text{s h}^{-1} \times 10 \, \text{h} = 1.8 \times 10^{13} \, p^+$$

This means $1.8 \times 10^{13} / 3.2 \times 10^{14} \approx 5.6\%$ of the $p^+$ in the beam

These protons are lost anyway !

Similar figures for the Pb-beam extraction
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)  
- 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 $3.10^5 \text{ km} \cdot \text{s}^{-1}/27 \text{ km} \simeq 11 \text{ kHz}$

Extracted “mini” bunches:
- the crystal sees $2808 \times 11000 \text{ s}^{-1} \simeq 3.10^7 \text{ bunches s}^{-1}$
- 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%,

Extraction over a 10h fill:
- $5 \times 10^8 p^+ \times 3600 \text{ s h}^{-1} \times 10 \text{ h} = 1.8 \times 10^{13} p^+ \text{ fill}^{-1}$
- 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)  
- 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 $3.10^5 \ km.s^{-1}/27 \ km \approx 11 \ kHz$
- Extracted “mini” bunches:
  - the crystal sees $2808 \times 11000 \ s^{-1} \approx 3.10^7$ bunches $s^{-1}$
  - one extracts $5.10^8/3.10^7 \approx 15p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%,
- 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 $1.8 \times 10^{13}/3.2 \times 10^{14} \approx 5.6\%$ of the $p^+$ in the beam
  - These protons are lost anyway!

- similar figures for the Pb-beam extraction

no pile-up!
The beam extraction: news

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

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

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

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

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

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
Luminosities

- Instantaneous Luminosity:
  \[ L = \Phi_{\text{beam}} \times N_{\text{target}} = N_{\text{beam}} \times (\rho \times \ell \times N_A)/A \]
  \[ \Phi_{\text{beam}} = 2 \times 10^5 \text{ Pb s}^{-1}, \quad \ell = 1 \text{ cm (target thickness)} \]

- Integrated luminosity \( \int dtL = L \times 10^6 \text{ s for Pb} \)

- Expected luminosities with \( 2 \times 10^5 \text{ Pb s}^{-1} \) extracted (1cm-long target)

<table>
<thead>
<tr>
<th>Target</th>
<th>( \rho ) (g.cm(^{-3}))</th>
<th>A</th>
<th>( L ) (mb(^{-1}).s(^{-1})) = ( \int L ) (nb(^{-1}).yr(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol. ( \text{H}_2 )</td>
<td>0.09</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Liq. ( \text{H}_2 )</td>
<td>0.07</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Liq. ( \text{D}_2 )</td>
<td>0.16</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Be</td>
<td>1.85</td>
<td>9</td>
<td>25</td>
</tr>
<tr>
<td>Cu</td>
<td>8.96</td>
<td>64</td>
<td>17</td>
</tr>
<tr>
<td>W</td>
<td>19.1</td>
<td>185</td>
<td>13</td>
</tr>
<tr>
<td>Pb</td>
<td>11.35</td>
<td>207</td>
<td>7</td>
</tr>
</tbody>
</table>

- Planned lumi for PHENIX Run15AuAu 2.8 nb\(^{-1}\) (0.13 nb\(^{-1}\) at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb\(^{-1}\)
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 $5 \times 10^{12}$ protons every 14.4 s, one year irradiation, $2.4 \times 10^{20}$ 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 ($3 \times 10^{13}$ 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

---

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

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

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

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

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

![Graph showing measured J/ψ production yields normalized 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 systems.]

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 systems.
The lead-ion beam

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

![Graph showing evidence for deconfinement of quarks and gluons measured in Pb-Pb collisions at the CERN-SPS](image.png)
AFTER, among other things, a quarkonium observatory in $pp$

Interpolating the world data set:

<table>
<thead>
<tr>
<th>Target</th>
<th>$\int L \ (fb^{-1}.yr^{-1})$</th>
<th>$N(J/\Psi) \ yr^{-1}$</th>
<th>$N(\Upsilon) \ yr^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. $H_2$</td>
<td>20</td>
<td>$4.0 \times 10^8$</td>
<td>$8.0 \times 10^5$</td>
</tr>
<tr>
<td>1 m Liq. $D_2$</td>
<td>24</td>
<td>$9.6 \times 10^8$</td>
<td>$1.9 \times 10^6$</td>
</tr>
<tr>
<td>LHC pp 14 Tev</td>
<td>0.05 (ALICE) 2 LHCb</td>
<td>$3.6 \times 10^7$</td>
<td>$1.8 \times 10^5$</td>
</tr>
<tr>
<td>(low pT)</td>
<td></td>
<td>$1.4 \times 10^9$</td>
<td>$7.2 \times 10^6$</td>
</tr>
<tr>
<td>RHIC pp 200GeV</td>
<td>$1.2 \times 10^{-2}$</td>
<td>$4.8 \times 10^5$</td>
<td>$1.2 \times 10^3$</td>
</tr>
</tbody>
</table>
AFTER, among other things, a quarkonium observatory in $pp$

Interpolating the world data set:

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

1000 times higher than at RHIC; comparable to ALICE/LHCb at the LHC
AFTER, among other things, a quarkonium observatory in \textit{pp}

Interpolating the world data set:

<table>
<thead>
<tr>
<th>Target</th>
<th>(\int L\ (\text{fb}^{-1} \cdot \text{yr}^{-1}))</th>
<th>(N(J/\Psi) \text{ yr}^{-1})</th>
<th>(N(\Upsilon) \text{ yr}^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. (H_2)</td>
<td>20</td>
<td>(4.0 \times 10^8)</td>
<td>(8.0 \times 10^5)</td>
</tr>
<tr>
<td>1 m Liq. (D_2)</td>
<td>24</td>
<td>(9.6 \times 10^8)</td>
<td>(1.9 \times 10^6)</td>
</tr>
<tr>
<td>LHC pp 14 Tev (low pT)</td>
<td>0.05 (ALICE) 2 LHCb</td>
<td>(3.6 \times 10^7)</td>
<td>(1.8 \times 10^5)</td>
</tr>
<tr>
<td>RHIC pp 200 GeV</td>
<td>1.2 \times 10^{-2}</td>
<td>(4.8 \times 10^5)</td>
<td>(1.2 \times 10^3)</td>
</tr>
</tbody>
</table>

- 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:

<table>
<thead>
<tr>
<th>Target</th>
<th>$\int \mathcal{L} \ (fb^{-1}.yr^{-1})$</th>
<th>$N(J/\Psi) \ yr^{-1}$</th>
<th>$N(\Upsilon) \ yr^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. $H_2$</td>
<td>20</td>
<td>$4.0 \times 10^8$</td>
<td>$8.0 \times 10^5$</td>
</tr>
<tr>
<td>1 m Liq. $D_2$</td>
<td>24</td>
<td>$9.6 \times 10^8$</td>
<td>$1.9 \times 10^6$</td>
</tr>
<tr>
<td>LHC pp 14 TeV (low pT)</td>
<td>0.05 (ALICE)</td>
<td>$3.6 \times 10^7$</td>
<td>$1.8 \times 10^5$</td>
</tr>
<tr>
<td></td>
<td>2 LHCb</td>
<td>$1.4 \times 10^9$</td>
<td>$7.2 \times 10^6$</td>
</tr>
<tr>
<td>RHIC pp 200GeV</td>
<td>$1.2 \times 10^{-2}$</td>
<td>$4.8 \times 10^5$</td>
<td>$1.2 \times 10^3$</td>
</tr>
</tbody>
</table>

- 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:

<table>
<thead>
<tr>
<th>Target</th>
<th>$\int L \ (fb^{-1}.yr^{-1})$</th>
<th>$N(J/\Psi) \ yr^{-1} = ALB\sigma_{\Psi}$</th>
<th>$N(\Upsilon) \ yr^{-1} = ALB\sigma_{\Upsilon}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. $H_2$</td>
<td>20</td>
<td>$4.0 \times 10^8$</td>
<td>$8.0 \times 10^5$</td>
</tr>
<tr>
<td>1 m Liq. $D_2$</td>
<td>24</td>
<td>$9.6 \times 10^8$</td>
<td>$1.9 \times 10^6$</td>
</tr>
<tr>
<td>LHC pp 14 Tev (low pT)</td>
<td>0.05 (ALICE) 2 LHCb</td>
<td>$3.6 \times 10^7$</td>
<td>$1.8 \times 10^5$</td>
</tr>
<tr>
<td>RHIC pp 200GeV</td>
<td>$1.2 \times 10^{-2}$</td>
<td>$4.8 \times 10^5$</td>
<td>$1.2 \times 10^3$</td>
</tr>
</tbody>
</table>

- 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
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.

Structure-function analysis and $\psi$, 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 $\mu N$ and $eN$ 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 $x$. $\psi$ 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 $\sigma_W$ and $\sigma_Z$ 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

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

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 $pA$

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

In principle, one can get **300 times more $J/\psi$**—not counting the likely wider $\gamma$ coverage—than at RHIC, allowing for
AFTER: also a quarkonium observatory in $pA$

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

- In principle, one can get 300 times more $J/\psi$ –not counting the likely wider $\gamma$ coverage– than at RHIC, allowing for
  - $\chi_c$ measurement in $pA$ via $J/\psi + \gamma$ (extending Hera-B studies)
AFTER: also a quarkonium observatory in pA

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

- In principle, one can get **300 times more $J/\psi$** – not counting the likely wider $y$ coverage – than at RHIC, allowing for
  - $\chi_c$ 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 \( pA \)

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

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

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

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

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target ExpeRiment at the LHC

April 29, 2014 40 / 29
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**

---

J.P. Lansberg (IPNO, Paris-Sud U.)

A Fixed-Target ExpeRiment at the LHC

April 29, 2014
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
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise \textit{pp} and \textit{pA} baselines (yields, \( A \) & \( y \) dependences)
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise $pp$ and $pA$ baselines (yields, $A$ & $y$ dependences)
- Modern technologies to look for quarkonium excited states
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise $pp$ and $pA$ baselines (yields, $A$ & $y$ dependences)
- Modern technologies to look for quarkonium excited states

HERA-B PRD 79 (2009) 012001, and ref. therein
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise $pp$ and $pA$ baselines (yields, $A$ & $y$ dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination

HERA-B PRD 79 (2009) 012001, and ref. therein
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise $pp$ and $pA$ baselines (yields, $A$ & $y$ dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination
- Open heavy-flavour measurement down to $P_T = 0$ thanks to the boost.

HERA-B PRD 79 (2009) 012001, and ref. therein
Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise $pp$ and $pA$ baselines (yields, $A$ & $y$ dependences)
- Modern technologies to look for quarkonium excited states
- Energy between SPS and RHIC: QGP should be formed w/o $c\bar{c}$ recombination
- Open heavy-flavour measurement down to $P_T = 0$ thanks to the boost.
- Real hope of being able to look at the quarkonium sequential suppression

HERA-B PRD 79 (2009) 012001, and ref. therein
AFTER: also an heavy-flavour observatory in $PbA$

- Luminosities and yields with the extracted 2.76 TeV Pb beam
  \[ \sqrt{s_{NN}} = 72 \text{ GeV} \]

<table>
<thead>
<tr>
<th>Target</th>
<th>A.B</th>
<th>$\int L$ (nb$^{-1}$·yr$^{-1}$)</th>
<th>$N(J/\Psi)$ yr$^{-1}$ = $AB\int L B\sigma_{\Psi}$</th>
<th>$N(\Upsilon)$ yr$^{-1}$ = $AB\int L B\sigma_{\Upsilon}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. H$_2$</td>
<td>207.1</td>
<td>800</td>
<td>3.4 $10^6$</td>
<td>6.9 $10^3$</td>
</tr>
<tr>
<td>1 cm Be</td>
<td>207.9</td>
<td>25</td>
<td>9.1 $10^5$</td>
<td>1.9 $10^3$</td>
</tr>
<tr>
<td>1 cm Cu</td>
<td>207.64</td>
<td>17</td>
<td>4.3 $10^6$</td>
<td>0.9 $10^3$</td>
</tr>
<tr>
<td>1 cm W</td>
<td>207.185</td>
<td>13</td>
<td>9.7 $10^6$</td>
<td>1.9 $10^4$</td>
</tr>
<tr>
<td>1 cm Pb</td>
<td>207.207</td>
<td>7</td>
<td>5.7 $10^6$</td>
<td>1.1 $10^4$</td>
</tr>
<tr>
<td>LHC PbPb 5.5 TeV</td>
<td>207.207</td>
<td>0.5</td>
<td>7.3 $10^6$</td>
<td>3.6 $10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 200GeV</td>
<td>198.198</td>
<td>2.8</td>
<td>4.4 $10^6$</td>
<td>1.1 $10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 62GeV</td>
<td>198.198</td>
<td>0.13</td>
<td>4.0 $10^4$</td>
<td>61</td>
</tr>
</tbody>
</table>

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 \( \text{PbA} \)

- Luminosities and yields with the extracted 2.76 TeV Pb beam

\( \sqrt{s_{NN}} = 72 \text{ GeV} \)

<table>
<thead>
<tr>
<th>Target</th>
<th>( A.B )</th>
<th>( \int \mathcal{L} ) (nb(^{-1}).yr(^{-1}))</th>
<th>( N(J/\Psi) ) yr(^{-1}) ( = \frac{ABL_B\sigma_\Psi}{N(\Upsilon)} ) yr(^{-1})</th>
<th>( N(\Upsilon) ) yr(^{-1}) ( = \frac{ABL_B\sigma_\Upsilon}{N(\Upsilon)} ) yr(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. ( \text{H}_2 )</td>
<td>207.1</td>
<td>800</td>
<td>( 3.4 \times 10^6 )</td>
<td>( 6.9 \times 10^3 )</td>
</tr>
<tr>
<td>1 cm Be</td>
<td>207.9</td>
<td>25</td>
<td>( 9.1 \times 10^5 )</td>
<td>( 1.9 \times 10^3 )</td>
</tr>
<tr>
<td>1 cm Cu</td>
<td>207.64</td>
<td>17</td>
<td>( 4.3 \times 10^6 )</td>
<td>( 0.9 \times 10^3 )</td>
</tr>
<tr>
<td>1 cm W</td>
<td>207.185</td>
<td>13</td>
<td>( 9.7 \times 10^6 )</td>
<td>( 1.9 \times 10^4 )</td>
</tr>
<tr>
<td>1 cm Pb</td>
<td>207.207</td>
<td>7</td>
<td>( 5.7 \times 10^6 )</td>
<td>( 1.1 \times 10^4 )</td>
</tr>
<tr>
<td>LHC ( \text{PbPb} 5.5 \text{ TeV} )</td>
<td>207.207</td>
<td>0.5</td>
<td>( 7.3 \times 10^6 )</td>
<td>( 3.6 \times 10^4 )</td>
</tr>
<tr>
<td>RHIC ( \text{AuAu} 200\text{GeV} )</td>
<td>198.198</td>
<td>2.8</td>
<td>( 4.4 \times 10^6 )</td>
<td>( 1.1 \times 10^4 )</td>
</tr>
<tr>
<td>RHIC ( \text{AuAu} 62\text{GeV} )</td>
<td>198.198</td>
<td>0.13</td>
<td>( 4.0 \times 10^4 )</td>
<td>( 61 )</td>
</tr>
</tbody>
</table>

- 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)

<table>
<thead>
<tr>
<th>Target</th>
<th>A.B</th>
<th>$\int L$ (nb$^{-1}$.yr$^{-1}$)</th>
<th>N($J/\Psi$) yr$^{-1}$ = AB$LB\sigma_{\Psi}$</th>
<th>N($\Upsilon$) yr$^{-1}$ = AB$LB\sigma_{\Upsilon}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. H$_2$</td>
<td>207.1</td>
<td>800</td>
<td>$3.4 \times 10^6$</td>
<td>$6.9 \times 10^3$</td>
</tr>
<tr>
<td>1 cm Be</td>
<td>207.9</td>
<td>25</td>
<td>$9.1 \times 10^5$</td>
<td>$1.9 \times 10^3$</td>
</tr>
<tr>
<td>1 cm Cu</td>
<td>207.64</td>
<td>17</td>
<td>$4.3 \times 10^6$</td>
<td>$0.9 \times 10^3$</td>
</tr>
<tr>
<td>1 cm W</td>
<td>207.185</td>
<td>13</td>
<td>$9.7 \times 10^6$</td>
<td>$1.9 \times 10^4$</td>
</tr>
<tr>
<td>1 cm Pb</td>
<td>207.207</td>
<td>7</td>
<td>$5.7 \times 10^6$</td>
<td>$1.1 \times 10^4$</td>
</tr>
<tr>
<td>LHC PbPb 5.5 TeV</td>
<td>207.207</td>
<td>0.5</td>
<td>$7.3 \times 10^6$</td>
<td>$3.6 \times 10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 200GeV</td>
<td>198.198</td>
<td>2.8</td>
<td>$4.4 \times 10^6$</td>
<td>$1.1 \times 10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 62GeV</td>
<td>198.198</td>
<td>0.13</td>
<td>$4.0 \times 10^4$</td>
<td>61</td>
</tr>
</tbody>
</table>

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)

<table>
<thead>
<tr>
<th>Target</th>
<th>A.B</th>
<th>$\int L$ (nb$^{-1}.yr^{-1}$)</th>
<th>ABLB$\sigma_{\Psi}$</th>
<th>ABLB$\sigma_{\Upsilon}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m Liq. H$_2$</td>
<td>207.1</td>
<td>800</td>
<td>$3.4 \times 10^6$</td>
<td>$6.9 \times 10^3$</td>
</tr>
<tr>
<td>1cm Be</td>
<td>207.9</td>
<td>25</td>
<td>$9.1 \times 10^5$</td>
<td>$1.9 \times 10^3$</td>
</tr>
<tr>
<td>1cm Cu</td>
<td>207.64</td>
<td>17</td>
<td>$4.3 \times 10^6$</td>
<td>$0.9 \times 10^3$</td>
</tr>
<tr>
<td>1cm W</td>
<td>207.185</td>
<td>13</td>
<td>$9.7 \times 10^6$</td>
<td>$1.9 \times 10^4$</td>
</tr>
<tr>
<td>1cm Pb</td>
<td>207.207</td>
<td>7</td>
<td>$5.7 \times 10^6$</td>
<td>$1.1 \times 10^4$</td>
</tr>
<tr>
<td>LHC PbPb 5.5 TeV</td>
<td>207.207</td>
<td>0.5</td>
<td>$7.3 \times 10^6$</td>
<td>$3.6 \times 10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 200GeV</td>
<td>198.198</td>
<td>2.8</td>
<td>$4.4 \times 10^6$</td>
<td>$1.1 \times 10^4$</td>
</tr>
<tr>
<td>RHIC AuAu 62GeV</td>
<td>198.198</td>
<td>0.13</td>
<td>$4.0 \times 10^4$</td>
<td>61</td>
</tr>
</tbody>
</table>

- 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 $J/\psi$ sequential suppression seems to be hindered by
- the Cold Nuclear Matter effects: non trivial and
  ... not well understood
What for?

Observation of $J/\psi$ 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
  - $\chi_c$ never studied in AA collisions
  - $\psi(2S)$ not yet studied in AA collisions at RHIC
Observation of $J/\psi$ 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
  - $\chi_c$ 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

– $J/\psi$ data in $pA$ collisions

SPS and Hera-B

– $J/\psi$ data in $pA$ collisions

![Graph showing $J/\psi$ data in $pA$ collisions with points for different energies and collaborations.]


– $\chi_c$ data in $pA$ collisions

![Graph showing $\chi_c$ data with points for different energies and collaborations.]

HERA-B PRD 79 (2009) 012001, and ref. therein
Our idea is not completely new

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 \(B^0 \rightarrow J/\psi + K^0\), \(B^0 \rightarrow \pi^+ \pi^-\). 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 $10^{10}$ $B\bar{B}$ 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].
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].

- $B$-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].

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

- **B-factories**: 1 ab$^{-1}$ means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb$^{-1}$ means $\approx 2 \times 10^{11} B\bar{B}$ 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.
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].

- $B$-factories: 1 ab$^{-1}$ means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb$^{-1}$ means $\approx 2 \times 10^{11} B\bar{B}$ 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 $\approx 6\%$ per $10^{20}$ particles/cm$^2$
- $10^{20}$ particles/cm$^2$ : one year of operation for realistic conditions
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].

- $B$-factories: $1$ ab$^{-1}$ means $10^9 B\bar{B}$ pairs
- For LHCb, typically $1$ fb$^{-1}$ means $\approx 2 \times 10^{11} B\bar{B}$ 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 $\approx 6\%$ 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:

- $\Lambda_b \rightarrow \Lambda J/\psi$
(Multiply) heavy baryons:

- $\Lambda_b \rightarrow \Lambda J/\psi$
- $d\sigma(b)/dy|_{y=0} \gtrsim 100 \text{ nb}$
Further key studies?

(Multiply) heavy baryons:

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

- $\Xi_{cc}$, $\Omega^{++}$, $\Xi_{ccc}$, ... cross sections in the central region are being calculated with the MC generator GENXICC


They should also be calculated for $xF \rightarrow u^-$ where IQ could dominate.
Further key studies?

(Multiply) heavy baryons:

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

(Multiply) heavy baryons:

- $\Lambda_b \rightarrow \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
- $N(b)/\text{year} \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
- $\mathcal{B}(b \rightarrow \Lambda_b) \times \mathcal{B}(\Lambda_b \rightarrow J/\psi\Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
  ($\mathcal{B}(J/\psi \rightarrow \mu\mu) = 6\%$)
- 15 000 $\Lambda_b \rightarrow J/\psi\Lambda \rightarrow \mu^+\mu^-\Lambda$ events: enough to perform a polarisation measurement

see e.g. LHCb arXiv:1302.5578 [hep-ex]
Further key studies?

(Multiply) heavy baryons:

- $\Lambda_b \rightarrow \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100$ nb
- $N(b)/year \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
- $\mathcal{B}(b \rightarrow \Lambda_b) \times \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
  - ($\mathcal{B}(J/\psi \rightarrow \mu \mu) = 6\%$)
- $15\,000$ $\Lambda_b \rightarrow J/\psi \Lambda \rightarrow \mu^+ \mu^- \Lambda$ events: enough to perform a polarisation measurement

- discovery potential? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)

see e.g. LHCb arXiv:1302.5578 [hep-ex]
Further key studies?

(Multiply) heavy baryons:

- $\Lambda_b \rightarrow \Lambda J/\psi$
  - $d\sigma(b)/dy|_{y=0} \gtrsim 100 \text{ nb}$
- $N(b)/\text{year} \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$
- $B(b \rightarrow \Lambda_b) \times B(\Lambda_b \rightarrow J/\psi \Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
  - $(B(J/\psi \rightarrow \mu \mu) = 6\%)$
- $15,000 \Lambda_b \rightarrow J/\psi \Lambda \rightarrow \mu^+ \mu^- \Lambda$ events: enough to perform a polarisation measurement

- discovery potential? ($\Xi_{cc}, \Omega^{++}(ccc), ...$)
- $\Xi_{cc}$, ..., cross sections in the central region are being calculated with the MC generator GENXICC

Further key studies?

(Multiply) heavy baryons:

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

- $N(b)/\text{year} \simeq 2 \times 100 \times 10^6 \times 20 = 4 \times 10^9$

- $\mathcal{B}(b \rightarrow \Lambda_b) \times \mathcal{B}(\Lambda_b \rightarrow J/\psi \Lambda) = 5.8 \pm 0.8 \times 10^{-5}$
  - $(\mathcal{B}(J/\psi \rightarrow \mu \mu) = 6\%)$

- 15 000 $\Lambda_b \rightarrow J/\psi \Lambda \rightarrow \mu^+ \mu^- \Lambda$ events: enough to perform a polarisation measurement

- discovery potential? ($\Xi_{cc}, \Omega^{++}(ccc)$, ...)
  - $\Xi_{cc}$, ..., cross sections in the central region are being calculated with the MC generator GENXICC

- they should also be calculated for $x_F \rightarrow -1$
  - where IQ could dominate

see e.g. LHCb arXiv:1302.5578 [hep-ex]
**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 $\sqrt{s}=115$ GeV
    $|y|<0.5$, $p_T > 20$ GeV/c
  - Isolation: $R=0.4$, $E_T^{\text{had}} < 5$ GeV
  - $\mathcal{L}$ (10 cm $H_2$-target) $\sim 2 \cdot 10^3$ pb$^{-1}$/year

**PDF: CT10 52 eigenval. (90% CL)**

- Scales: $\mu_T = p_T$
- FF = BFG-II
- x-section **uncertainties**$^{(*)}$ of ±150%

$^{(*)}$ (68%CL)/(90% CL) $\sim 1.65$