Prospectives for A Fixed-Target ExpeRiment using the LHC beams with unpolarized targets

AFTER @ LHC

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CERN, July 4th 2016

- Physics opportunities with a fixed target experiments using the LHC proton and ion beams
- Possible fixed-target modes with LHC beams and expected luminosities
- First simulations

Physics opportunities of A Fixed-Target ExpeRiment (AFTER) @LHC

- **Idea: use LHC beams on fixed target**
  - 7 TeV proton beam ($\sqrt{s}$ ~115 GeV)
    - p+H, p+A
    - $\gamma = \sqrt{s}/(2m_p) = 61.1$ and $y_{CMS} = 4.8$
  - 2.76 TeV Pb beam ($\sqrt{s_{NN}}$ ~72 GeV)
    - Pb+A, Pb+H
    - $\gamma = 38.3$ and $y_{CMS} = 4.3$

→ backward to mid-rapidity coverage in the center-of-mass using a « forward » (in the laboratory) detector!

- **High boost and luminosity give access to the QCD at backward rapidity and large *x* = [0.3-1]**
  - Nucleon partonic structure
  - Nuclear shadowing
  - Quark Gluon Plasma
  - Spin physics
  - W/Z production near threshold
  - …
- **Multi-purpose experiment**

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

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Physics Reports 522 (2013) 239

[hep-ph] 29 Feb 2012

Abstract

We outline the many physics opportunities offered by a multi-purpose fixed-target experiment using the proton and lead-ion beams of the LHC extracted by a bent crystal. In a proton run with the LHC 7-TeV beam, one can analyze *pp*, *pd* and *pA* collisions at center-of-mass energy $\sqrt{s_{NN}} \simeq 115$ GeV and even higher using the Fermi motion of the nucleons in a nuclear target. In a lead run with a 2.76 TeV-per-nucleon beam, $\sqrt{s_{NN}}$ is as high as 72 GeV. Bent crystals can be used to extract about 5×10^8 protons/sec; the integrated luminosity over a year reaches 0.5 fb^{-1} on a typical 1 cm-long target without nuclear species limitation. We emphasize that such an extraction mode does not alter the performance of the collider experiments at the LHC. By instrumenting the target-rapidity region, gluon and heavy-quark distributions of the proton and the neutron can be accessed at large x and even at x larger than unity in the nuclear case. Single diffractive physics and, for the first time, the large negative-x_F domain can be accessed. The nuclear target-species versatility provides a unique opportunity to study nuclear matter versus the features of the hot and dense matter formed in heavy-ion collisions, including the formation of the quark-gluon plasma, which can be studied in *PbA* collisions over the full range of target-rapidity domain with a large variety of nuclei. The polarization of hydrogen and nuclear targets allows an ambitious spin program, including measurements of the QCD lensing effects which underlie the Sivers single-spin asymmetry, the study of transversity distributions and possibly of polarized parton distributions. We also emphasize the potential offered by *pA* ultra-peripheral collisions where the nucleus target *A* is used as a coherent photon source, mimicking photoproduction processes in *ep* collisions. Finally, we note that *W* and *Z* bosons can be produced and detected in a fixed-target experiment and in their threshold domain for the first time, providing new ways to probe the partonic content of the proton and the nucleus.

Keywords: LHC beam, fixed-target experiment

Many more ideas for a fixed target experiment at LHC in a Special Issue in Advances in High Energy Physics:

Advances in High Energy Physics, Volume 2015 (2015)

- Heavy-ion physics
- Exclusive reactions
- Spin physics studies
- Hadron structure
- Feasibility study and technical ideas

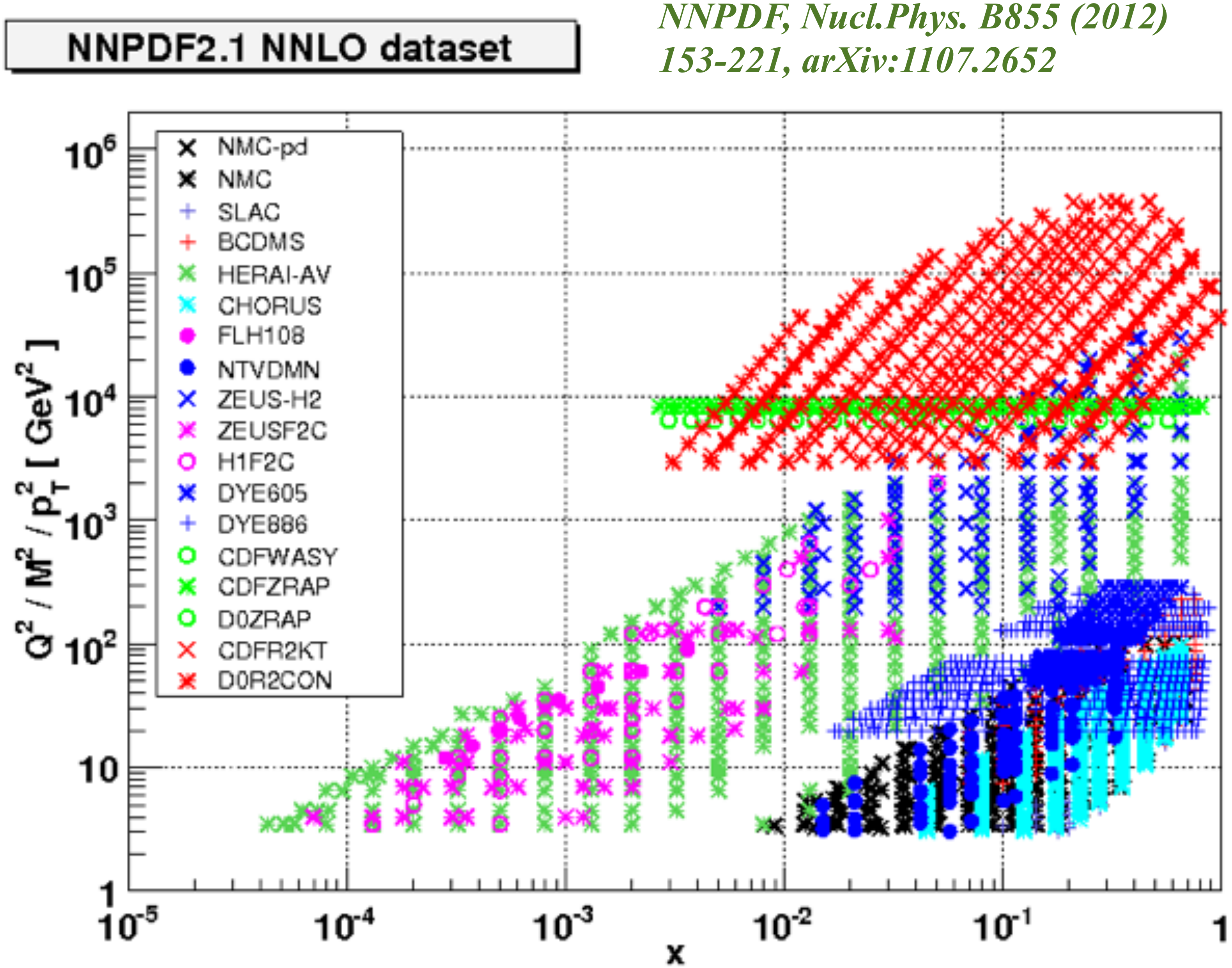
Proton structure: our current knowledge

Deep inelastic scattering (ep), Drell-Yan/Jet/Isolated photon/W/Z in hadronic collisions (pp): fixed-target or collider

High-*x* pdfs: few data available (DIS) and mostly sensitive to valence-quarks

Sea and gluon pdfs at large *x* extracted from DGLAP evolution equation → large uncertainty also for large scale

NNPDF, Nucl.Phys. B855 (2012) 153-221, arXiv:1107.2652



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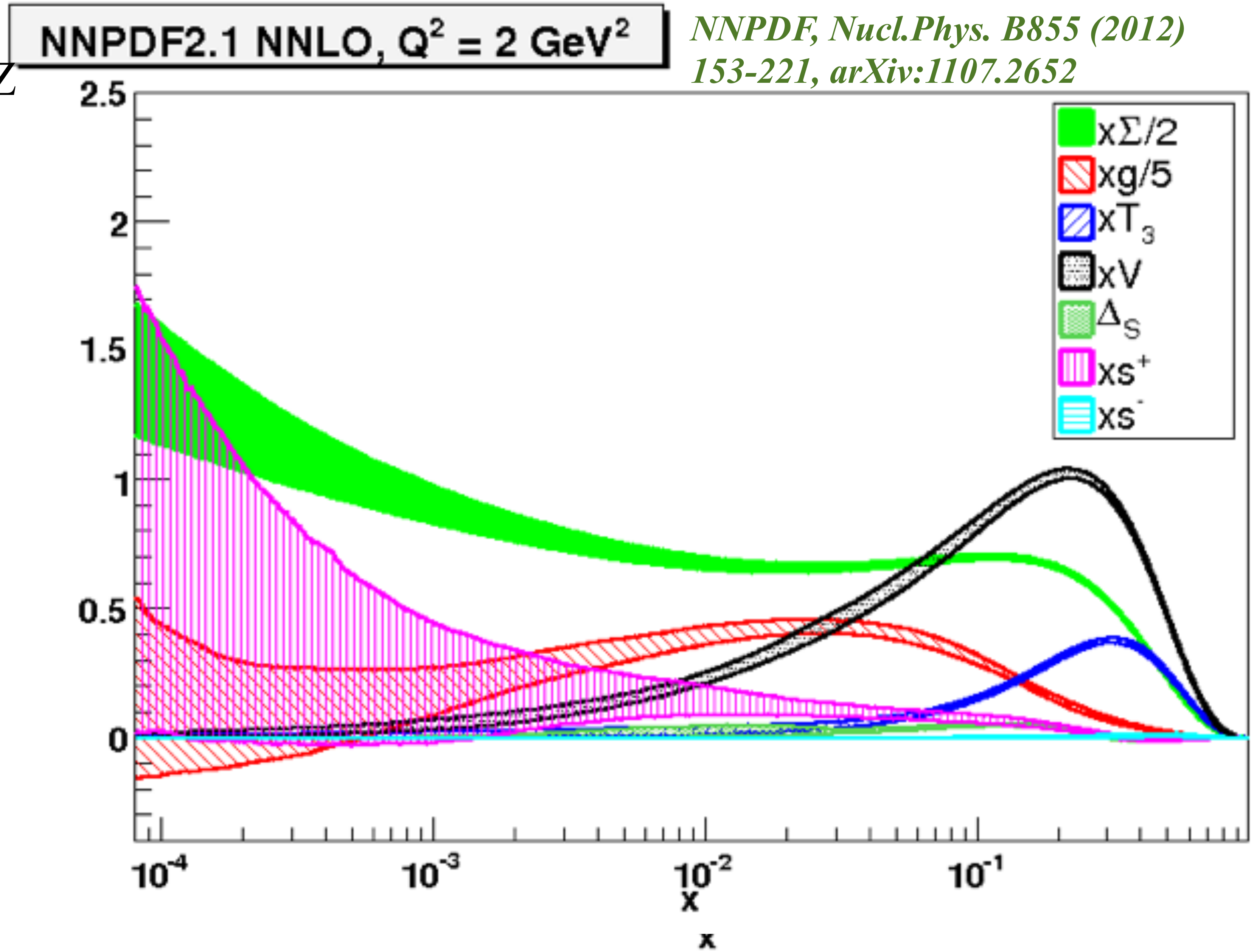

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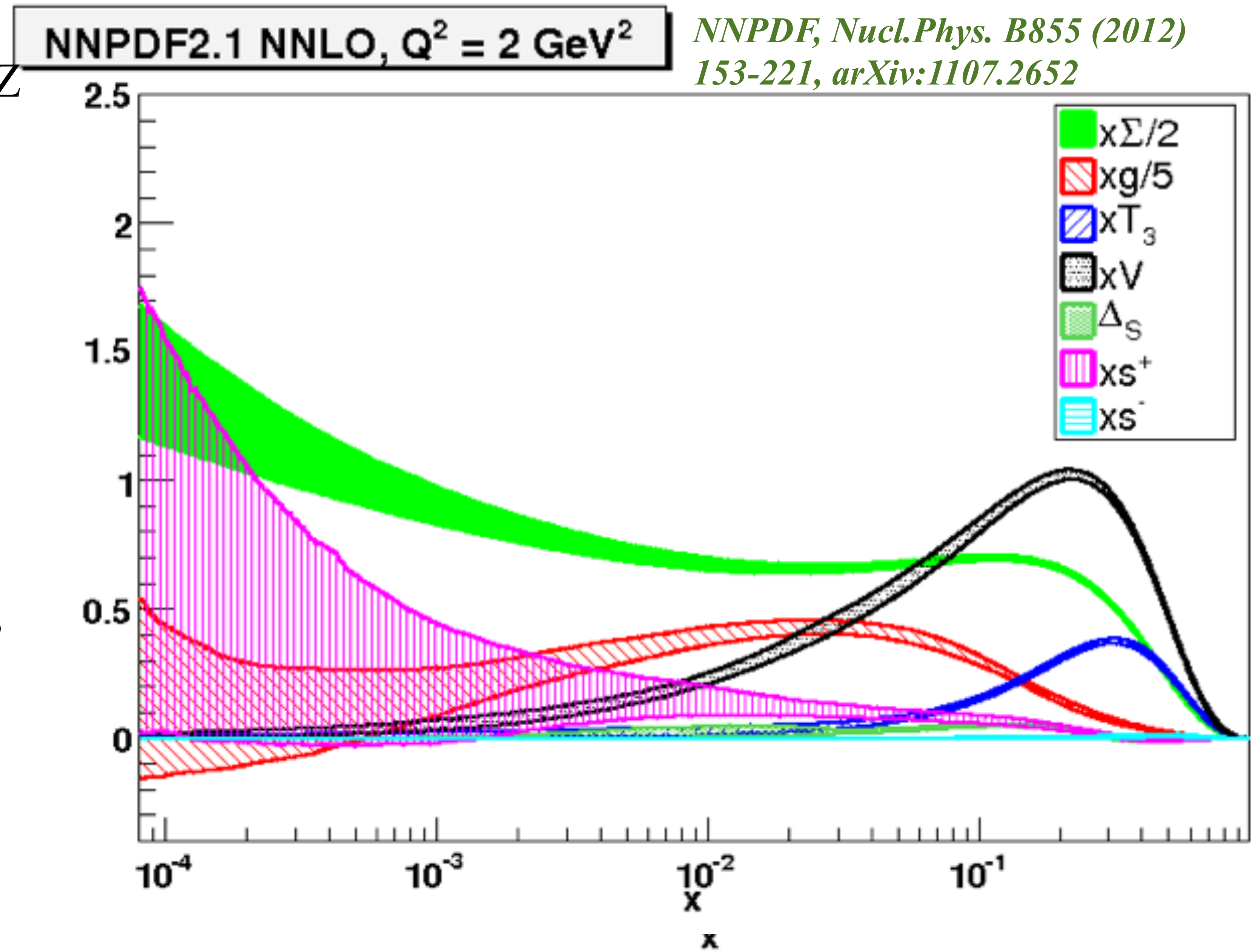
Sea and gluon pdfs at large *x* extracted from DGLAP evolution equation → large uncertainty also for large scale

What about *x* = 0.3 - 1 in proton, neutron and nuclear matter?

Search and study of rare proton fluctuations, where one gluons carries most of the proton momentum



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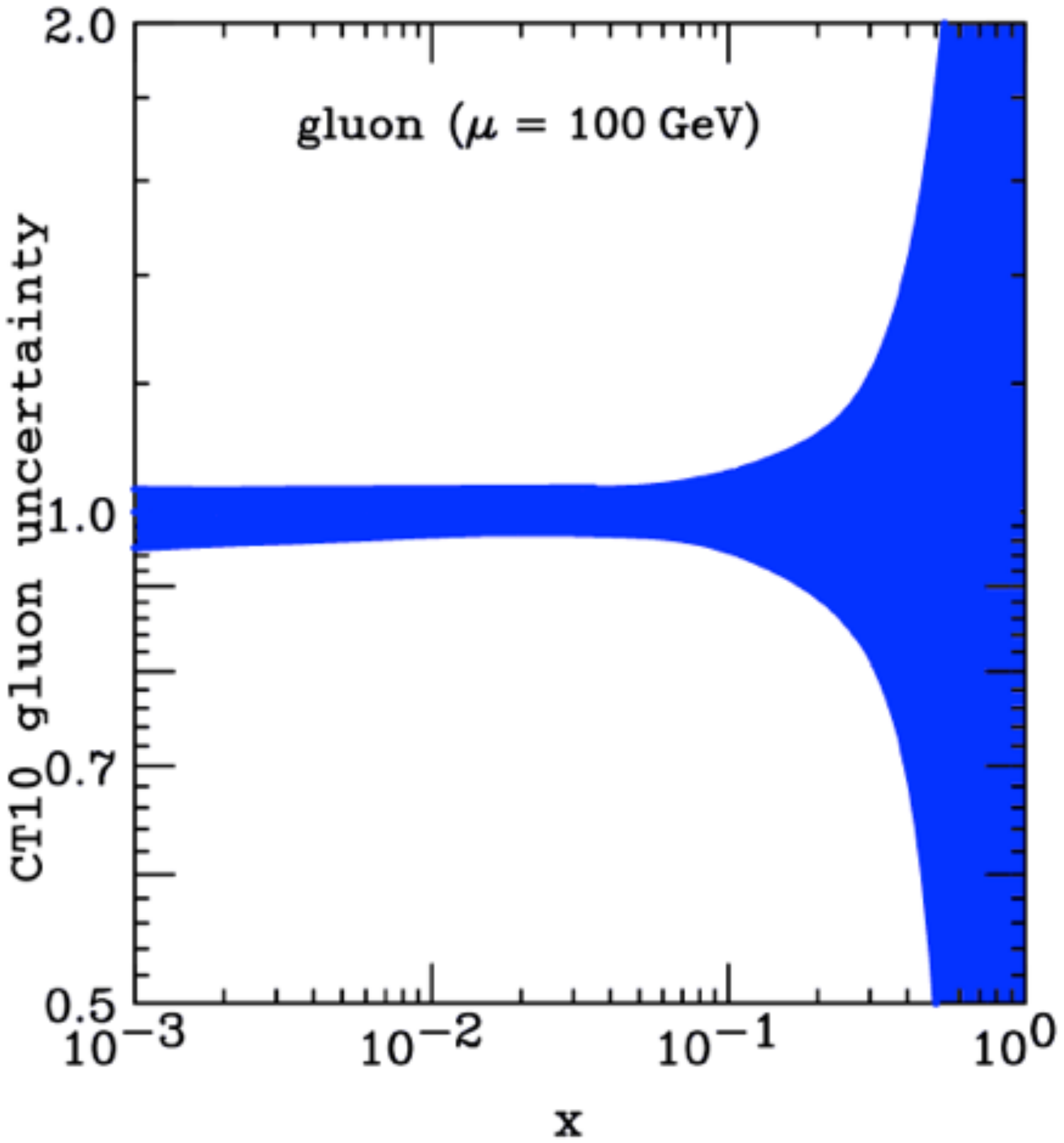
Gluon distribution in the nucleon at large x

Gluon distribution function in the proton: very large uncertainty at large x also at large Q



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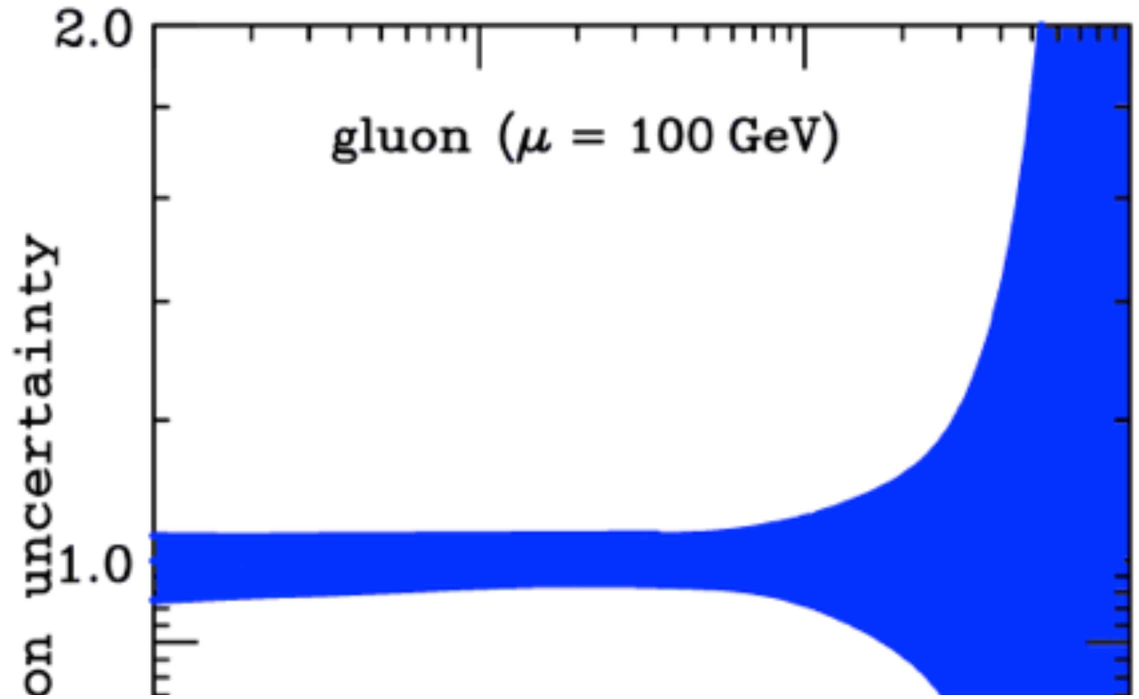
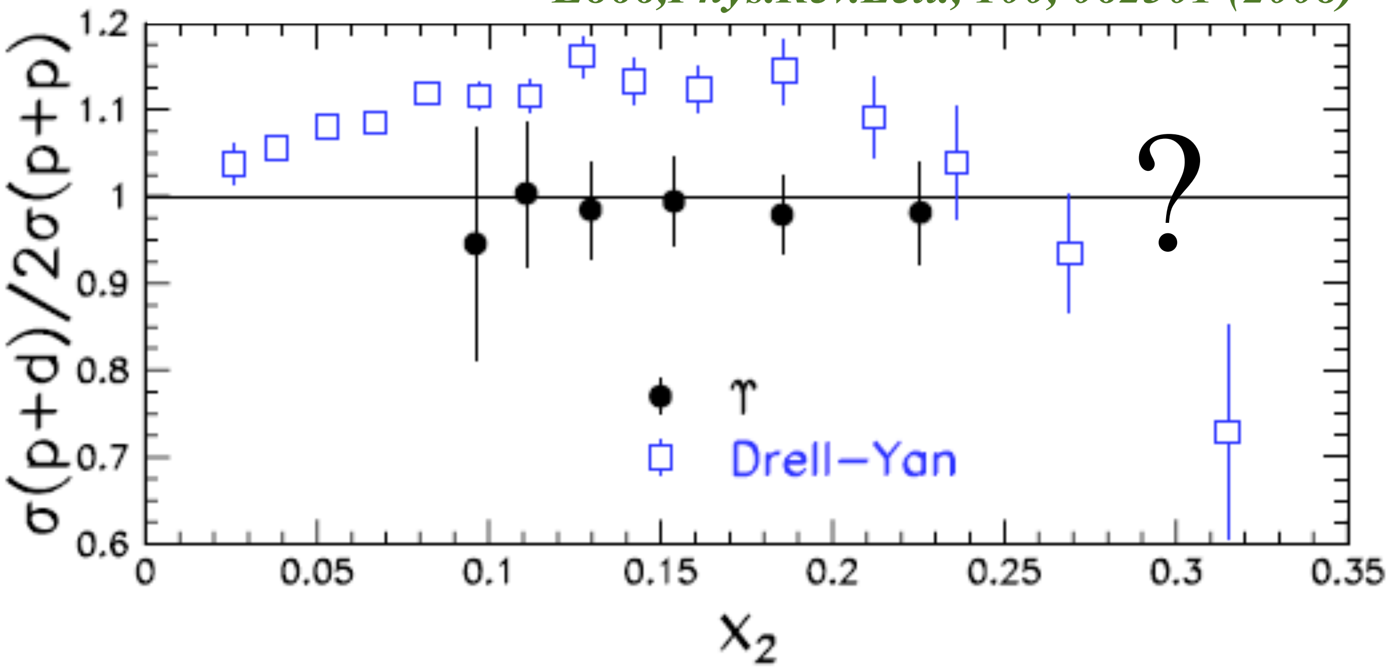
Gluon distribution function in the proton: very large uncertainty at large x also at large Q

Unknown for the neutron



E866,Phys.Rev.Lett., 100, 062301 (2008)



Gluon distribution in the nucleon at large *x*

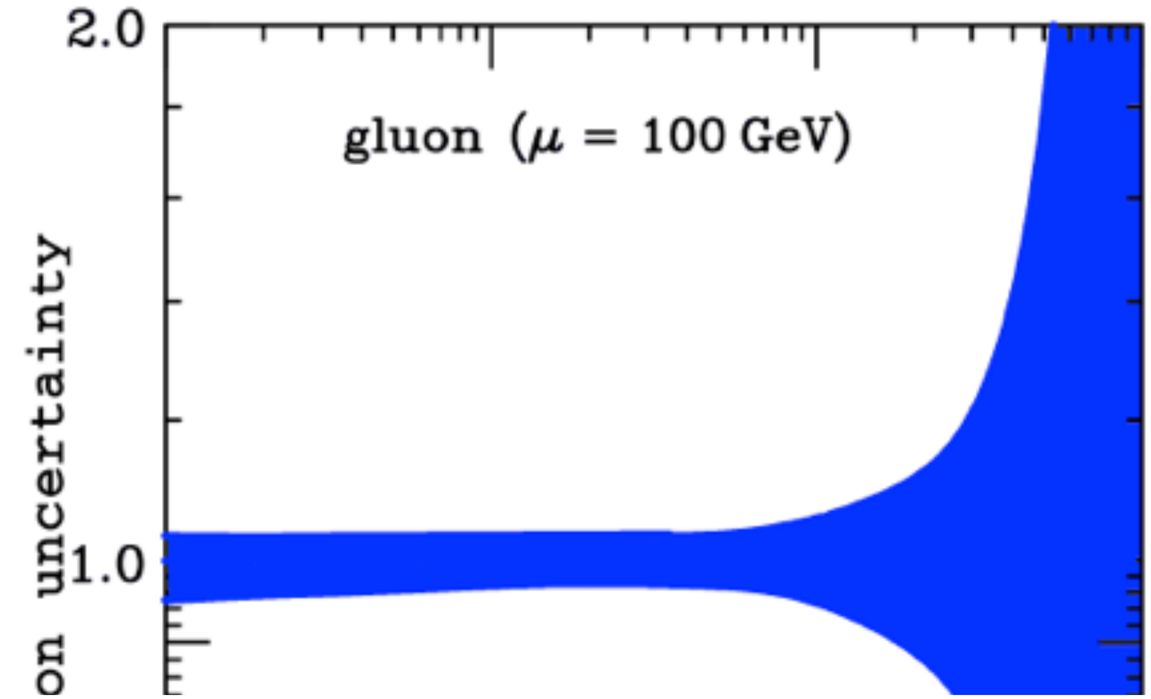
Gluon distribution function in the proton: very large uncertainty at large *x* also at large Q

Unknown for the neutron

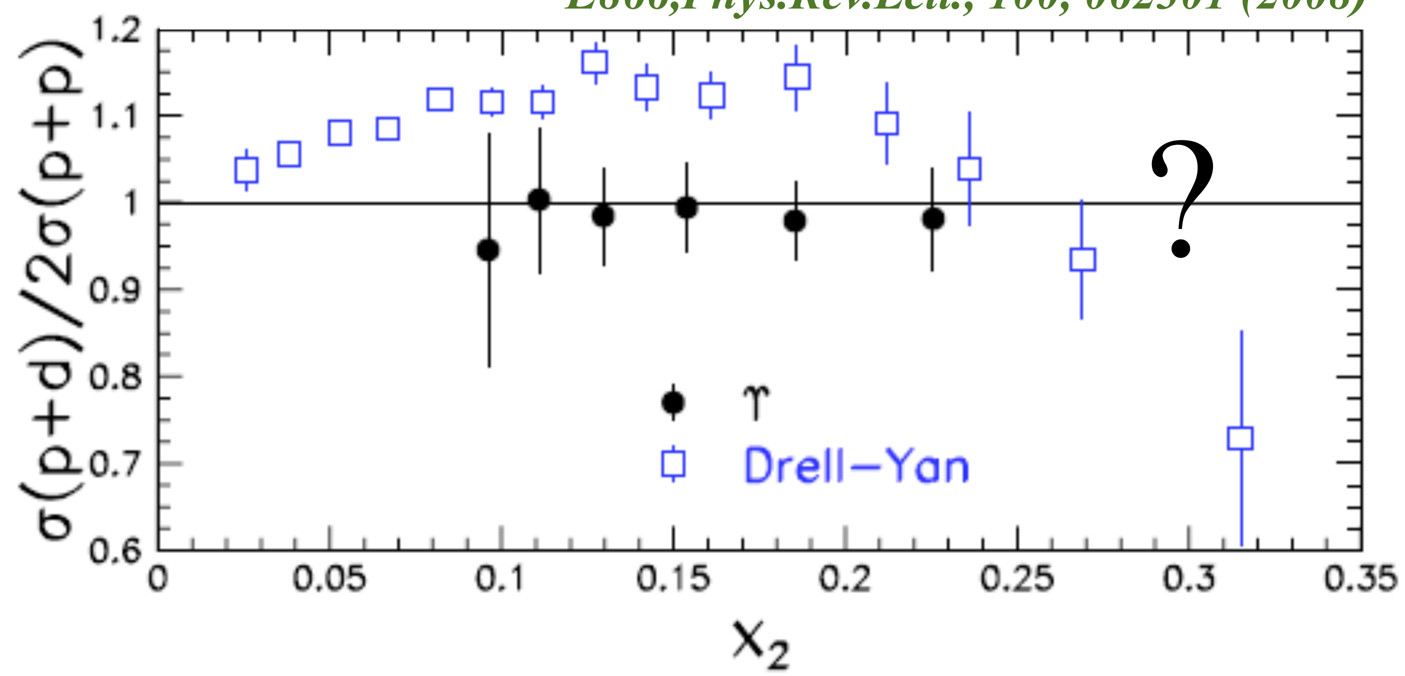
- **Experimental probes @ AFTER**
  - Quarkonia
  - Isolated photons
  - High p_T jets ($p_T > 20$ GeV/c)

  → to access target $x_g = 0.3$ - 1 (>1 Fermi motion in nucleus)

- **Target versatility**
  - Hydrogen
  - Deuteron (neutron)



E866,Phys.Rev.Lett., 100, 062301 (2008)



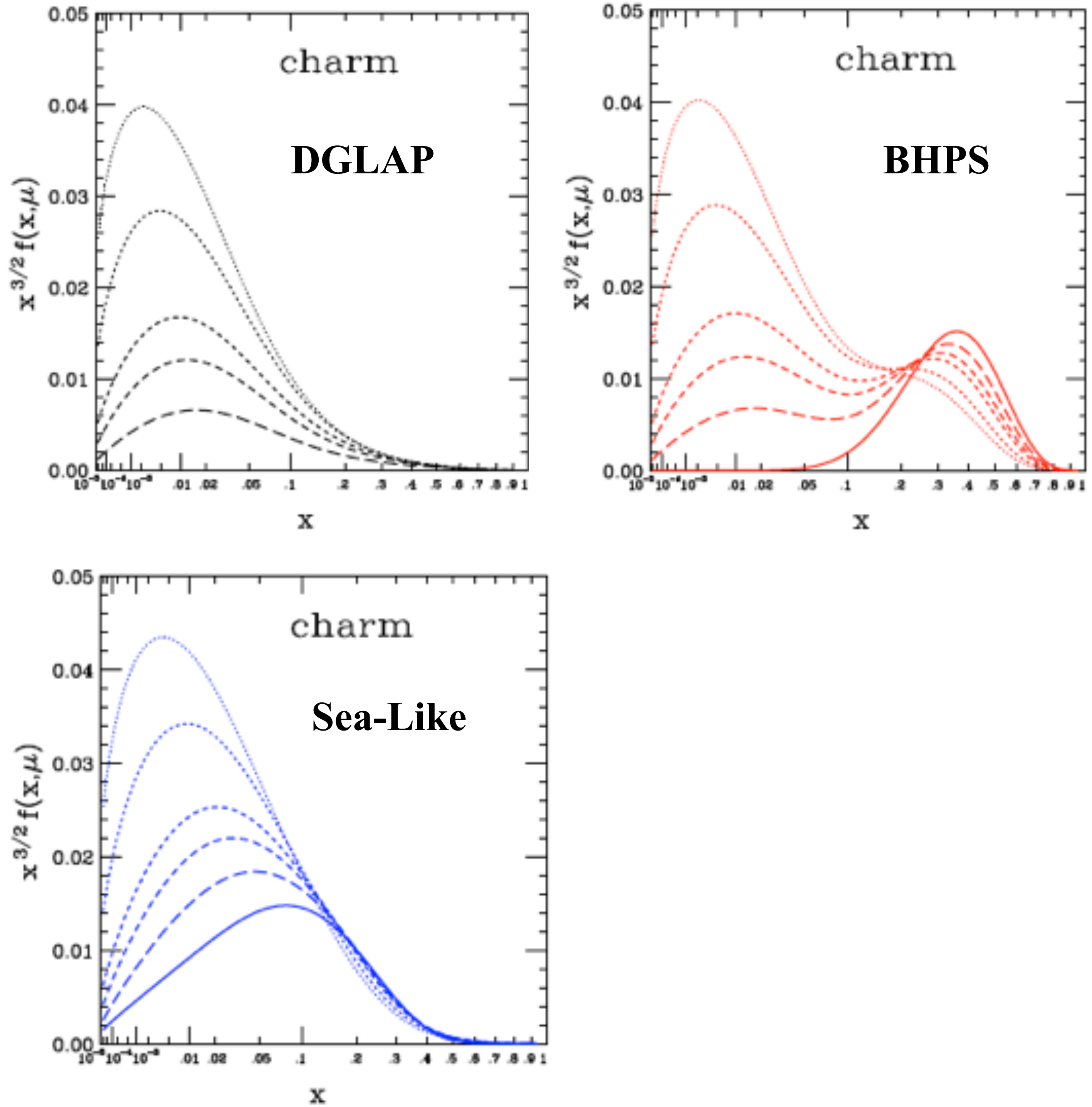
Heavy-quark distribution at large x

Intrinsic charm motivated by non perturbative models of hadron structure

All different charm pdfs (DGLAP or intrinsic charm) in agreement with DIS data

Proton charm content important to high-energy neutrino and cosmic-ray physics

Pumplin et al. Phys.Rev. D75 (2007)



Heavy-quark distribution at large *x*

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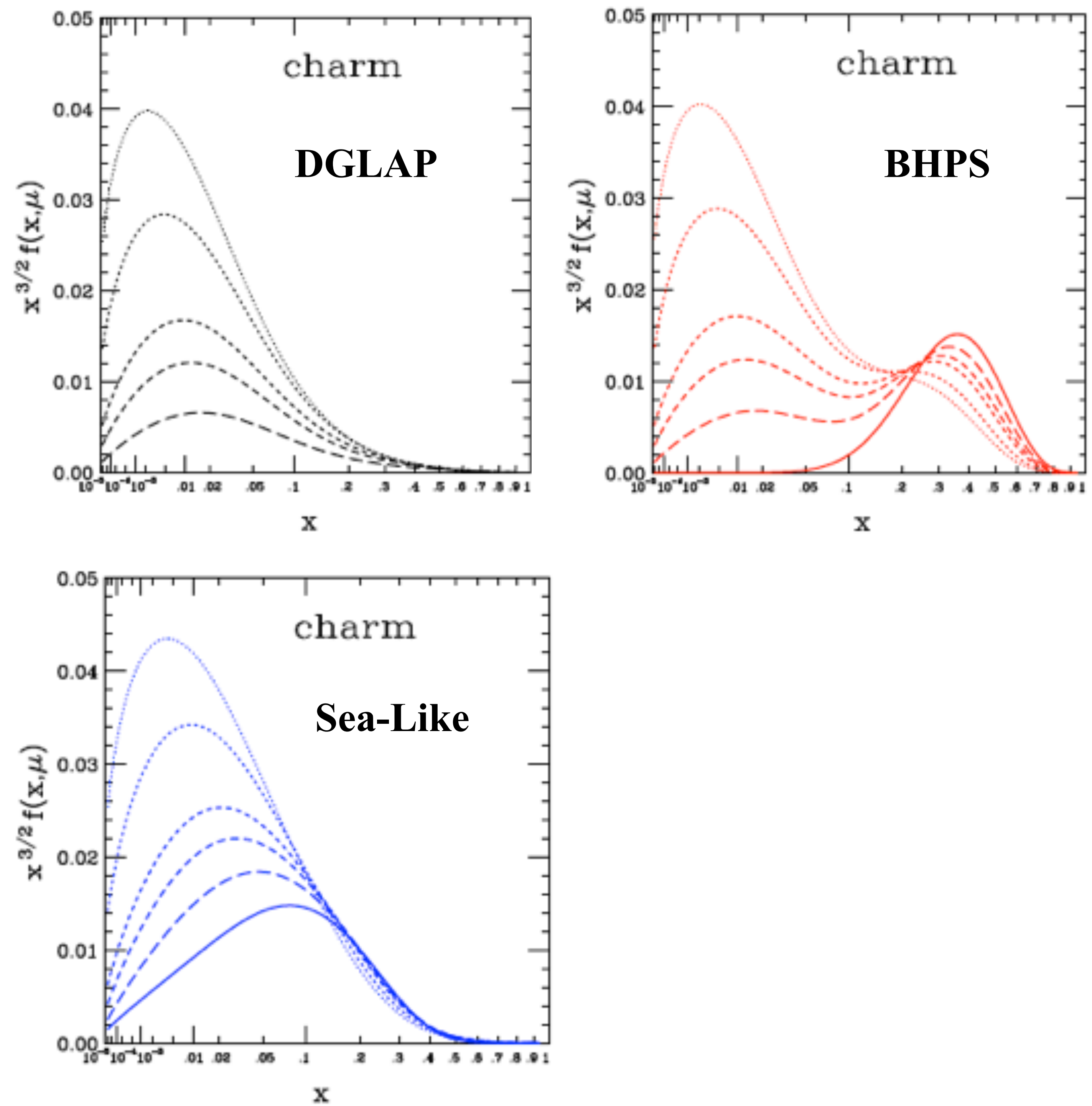
Proton charm content important to high-energy neutrino and cosmic-ray physics

- **Experimental probes @ AFTER**
  - Open charm (D meson or displaced-vertex lepton)
  - Open beauty

Pumplin et al. Phys.Rev. D75 (2007)



Gluon distribution in nucleus at large x

From low x to large x: shadowing, anti-shadowing, EMC effect, Fermi motion

Large uncertainty of nuclei for gluon at large x → AFTER@LHC complementary to EIC, LHeC

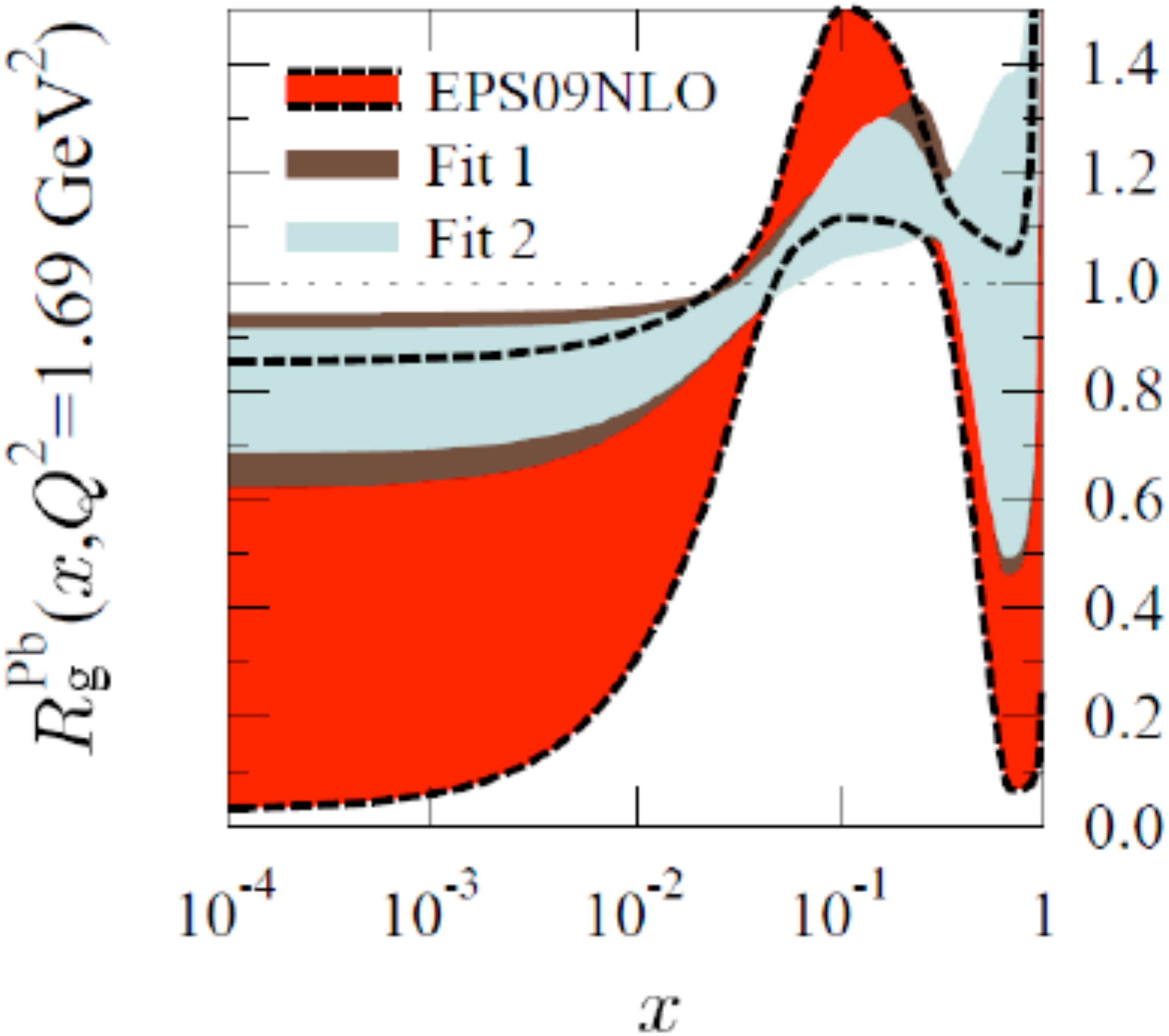
EMC effect is an open problem; unknown for gluon

Relevance of nuclear PDF to understand initial state of heavy-ion collisions

- **Experimental probes @ AFTER**
  - Quarkonia
  - Isolated photons
  - High p_T jets (p_T > 20 GeV/c)
    → to access target x_g = 0.3 - 1 (>1 Fermi motion in nucleus)

- **Target versatility**
  - Probing the A-dependence of shadowing and nuclear matter effects

LHeC CDR J. Phys. G 39 (2012) 075001



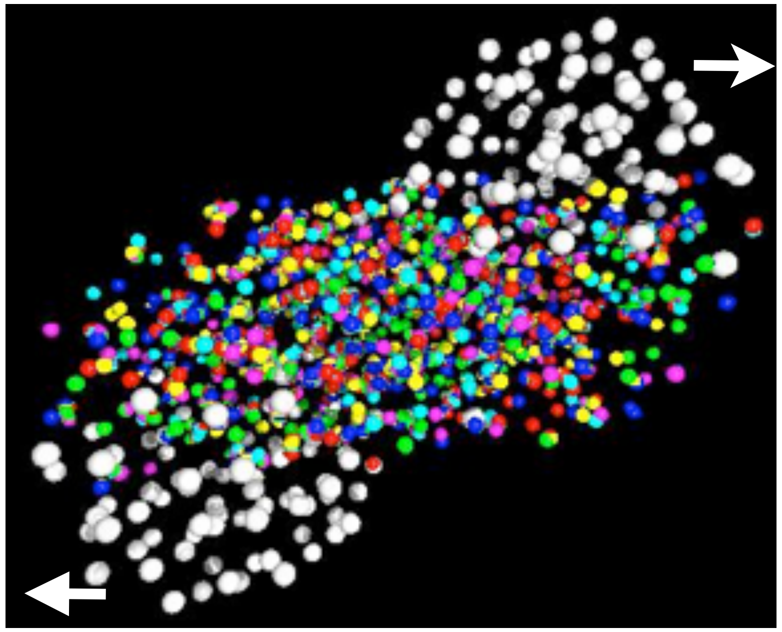
Quark Gluon Plasma

In nucleus-nucleus collisions at ultra-relativistic energies → Quark Gluon Plasma (QGP) formation

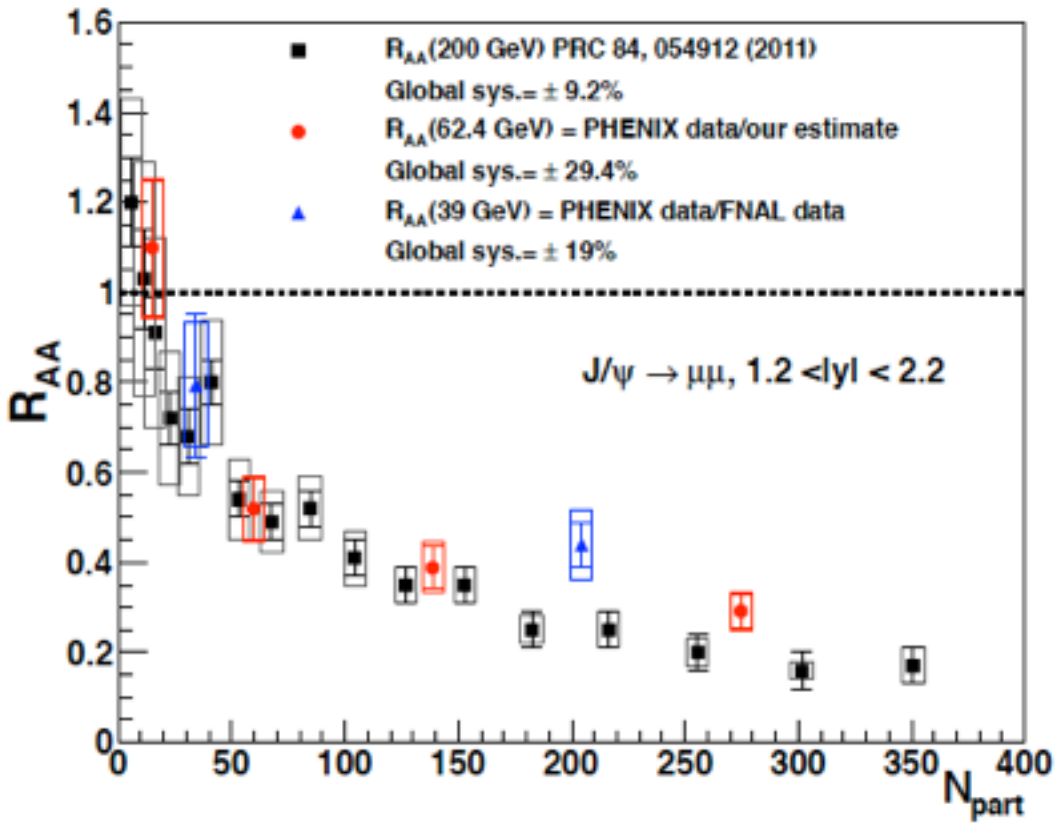
Heavy-ion collisions from mid- to large rapidities: explore the longitudinal expansion of QGP formation with soft and hard probes

Test the factorisation of cold nuclear effect from p+A to A+B collisions

Suppression of particles at RHIC for $\sqrt{s_{NN}}$ = 39, 62, 200 GeV (π^0, J/ψ, ...) but low statistics for $\sqrt{s_{NN}}$ < 200 GeV and scarse / no pp and pA reference



PHENIX, Phys.Rev. C86 (2012) 064901



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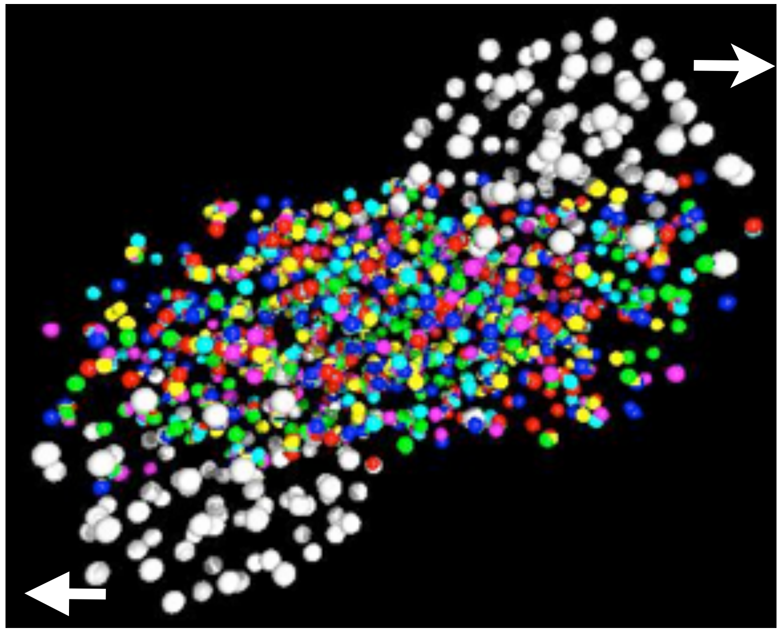
Suppression of particles at RHIC for $\sqrt{s_{NN}}$ = 39, 62, 200 GeV (π^0, J/ψ, ...) but low statistics for $\sqrt{s_{NN}}$ < 200 GeV and scarse / no pp and pA reference

- **Experimental probes @ AFTER $\sqrt{s_{NN}}$ = 72 GeV**
  - Charged identified particles vs rapidity (yields and azimuthal asymmetries)
  - Charmonia vs open charm, bottomonia vs open bottom
  - Jets
  - Drell-Yan
  - Low mass lepton pairs, direct photons, …

- **Target versatility**
  - In PbA, different nuclei: A-dependent studies
  - In pA, precise estimate of Cold Nuclear effects



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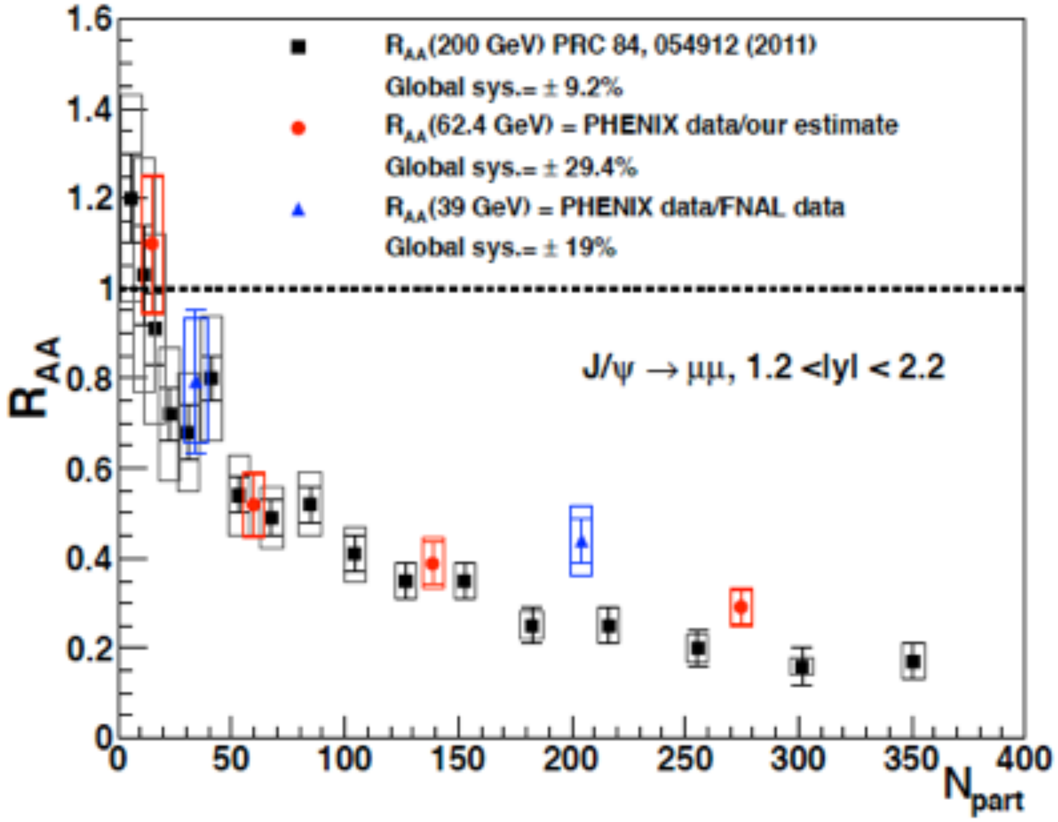
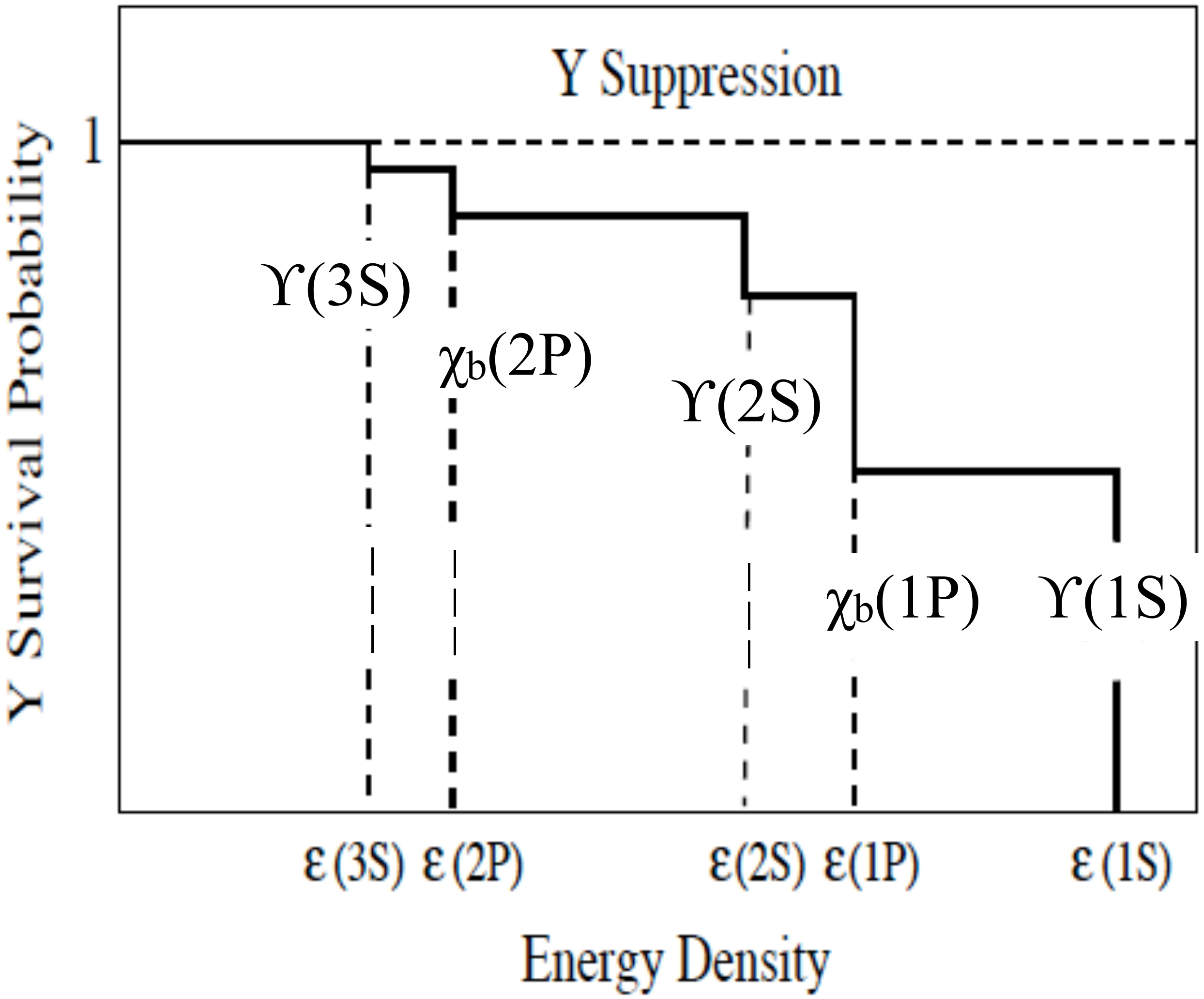
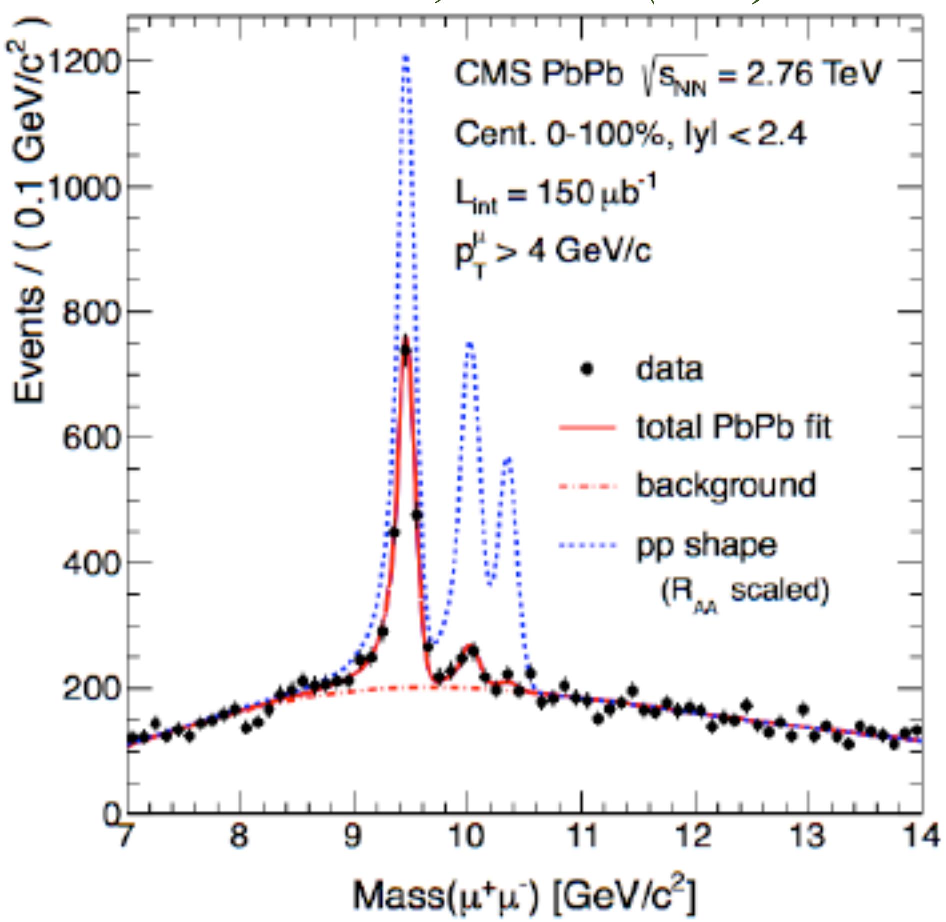


ϒ sequential melting in QGP

Satz J.Phys.G32 (2006) R25



CMS, PRL 109 (2012) 222301



- **Bottomonium family @ AFTER $\sqrt{s_{NN}}$ = 72 GeV**
- Detection of the three ϒ states separately (good resolution and high luminosity needed) to probe the bottomonium sequential suppression

ϒ sequential melting in QGP

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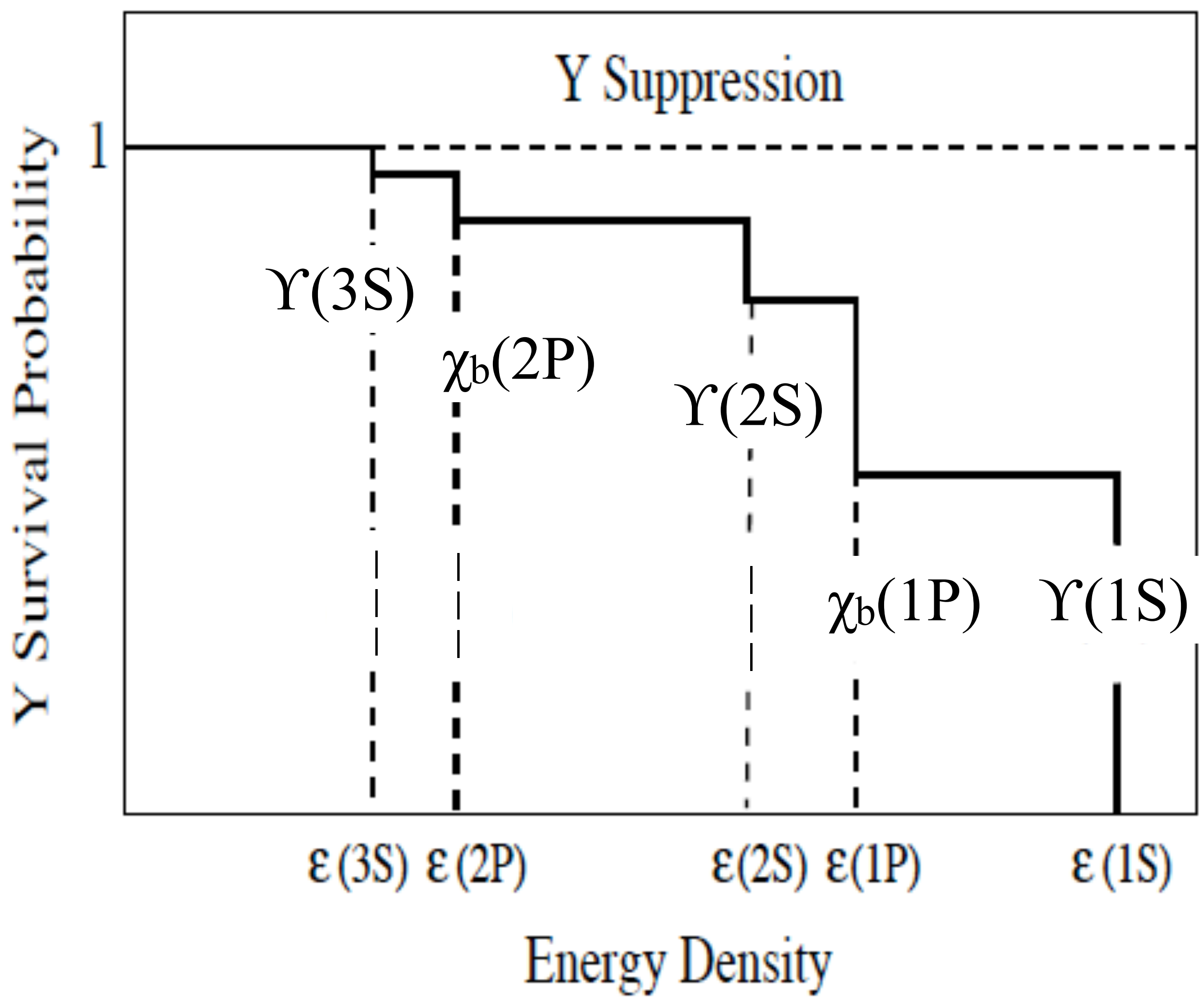
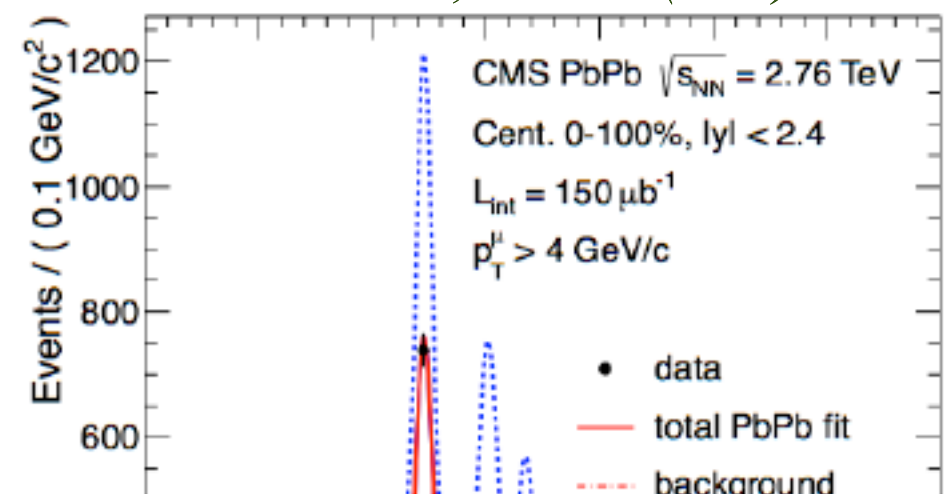
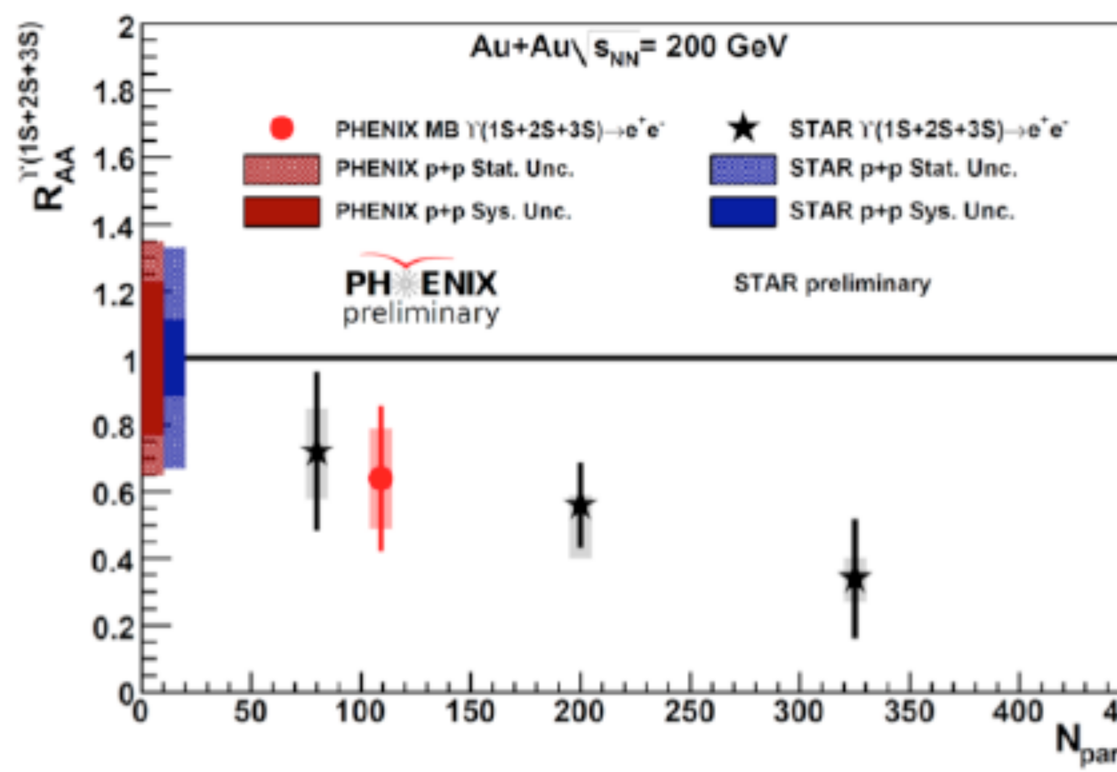


CMS, PRL 109 (2012) 222301



RHIC, QM 2012



- **Bottomonium family @ AFTER $\sqrt{s_{NN}}$ = 72 GeV**
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Possible fixed-target modes with LHC beams and luminosities

Possible fixed-target modes with LHC beams

Advances in High Energy Physics, Volume 2015 (2015)

- **Beam line extracted with a bent crystal**
- **Beam "split" with a bent crystal**
  - beam collimation at LHC using bent crystals is studied by the UA9 collaboration
  - UA9 test @SPS of the crystal with proton and ion beams
  - LUA9 (beam bending experiment at LHC using crystal)
  - 2 bent crystals installed in IR7 during LS1, 2015/2016 tests with beams
  - proton beam extraction: single or multi-pass extraction efficiency, 50%
  - expected extracted p beam: 5×10^8 p/s (LHC beam loss: $\sim 10^9$ p/s)
  - expected extracted Pb beam: 2×10^5 Pb/s

→ Dense targets

- **Internal gas target similar to SMOG at LHCb / inspired by HERMES at HERA**
  - can be installed in one of the existing LHC cavens or in a new one
  - currently tested by the LHCb collaboration via a luminosity monitor (SMOG)
  - proton flux: 3.4×10^{18} p/s
  - Pb flux: 3.6×10^{14} Pb/s

→ High Intensity beams

- **Internal wire target**

Luminosities in p+H and p+A at $\sqrt{s_{NN}} = 115$ GeV

Extracted beam

Target	ρ (g.cm^{-3})	A	L ($\mu b^{-1}.s^{-1}$)	$\int L$ ($pb^{-1}.yr^{-1}$)
Liq H_2 (1m)	0.07	1	2000	20000
Liq D_2 (1m)	0.16	2	2400	24000
Be (1cm)	1.85	9	62	620
Cu (1cm)	8.96	64	42	420
W (1cm)	19.1	185	31	310
Pb (1cm)	11.35	207	16	160

Internal gas target

Beam	Target	Usable gas zone (cm)	Pressure (Bar)	L ($\mu b^{-1}.s^{-1}$)	$\int L$ ($pb^{-1}.yr^{-1}$)
p	Perfect gas	100	10^{-9}	10	100

10^{-6} mbar = 3 x SMOG pressure

Yearly integrated lumosities = 10^7 s corresponding to 9 months of LHC running:

p+p: $\mathscr{L} = 20$ fb^{-1}

p+p: $\mathscr{L} = 10$ fb^{-1} if P = 10^{-4} mbar

→ Large luminosities comparable to LHC, 3 order of magnitude larger than RHIC

Luminosities in Pb+H and Pb+A at $\sqrt{s_{NN}} = 72$ GeV

Extracted beam

Target	ρ ($g.cm^{-3}$)	A	L ($\mu b^{-1}.s^{-1}$)	$\int L$ ($pb^{-1}.yr^{-1}$)
Liq H_2 (1m)	0.07	1	0.8	0.8
Liq D_2 (1m)	0.16	2	1	1
Be (1cm)	1.85	9	0.025	0.025
Cu (1cm)	8.96	64	0.017	0.017
W (1cm)	19.1	185	0.013	0.013
Pb (1cm)	11.35	207	0.007	0.007

Internal gas target

Beam	Target	Usable gas zone (cm)	Pressure (Bar)	L ($\mu b^{-1}.s^{-1}$)	$\int L$ ($pb^{-1}.yr^{-1}$)
Pb	Perfect gas	100	10^{-9}	0.001	0.001

10^{-6} mbar = 3 x SMOG pressure

Yearly integrated lumosities = 10^6 s corresponding to 1 month of LHC running:

Pb+Pb: $\mathscr{L} = 7$ nb^{-1}

Pb+A: $\mathscr{L} = 1$ nb^{-1} if P = 10^{-6} mbar

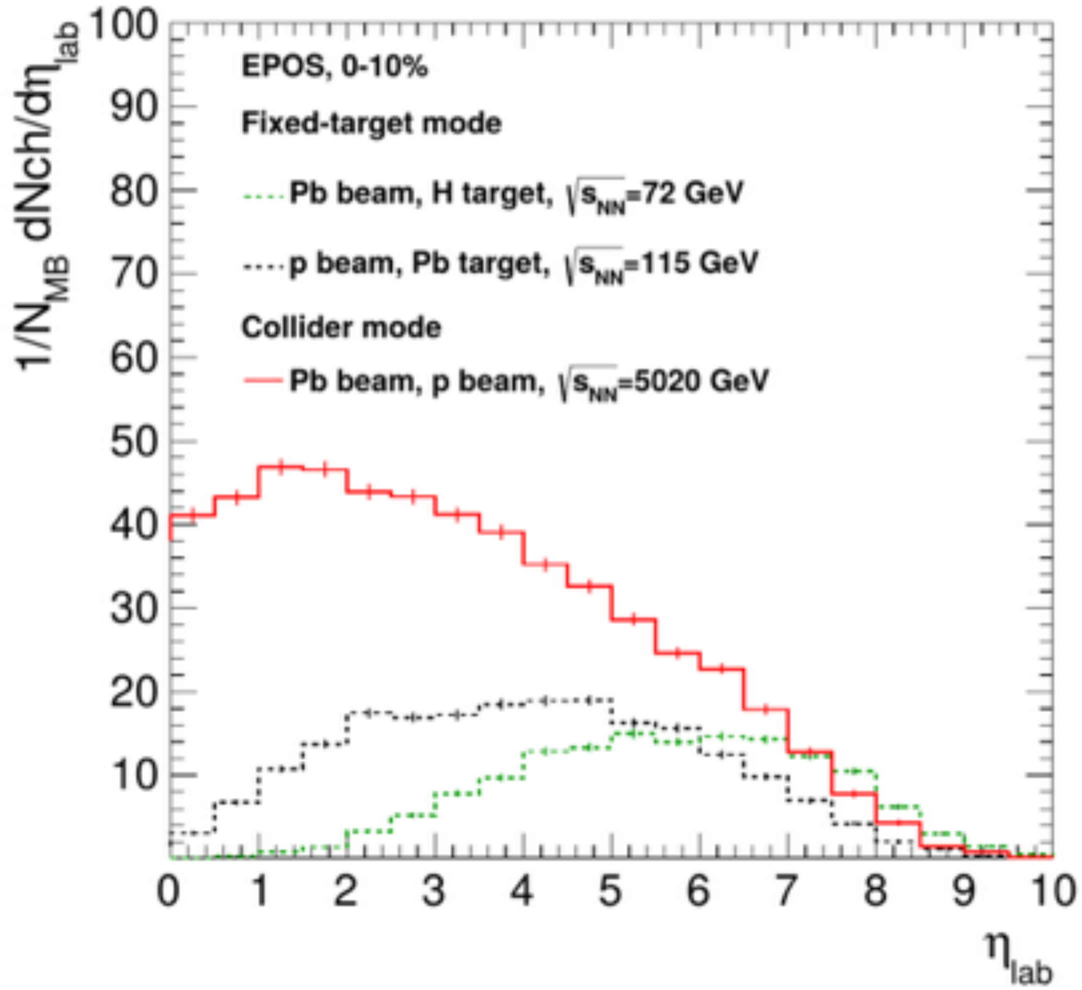
→ Large luminosities comparable to LHC

Feasibility studies: few items

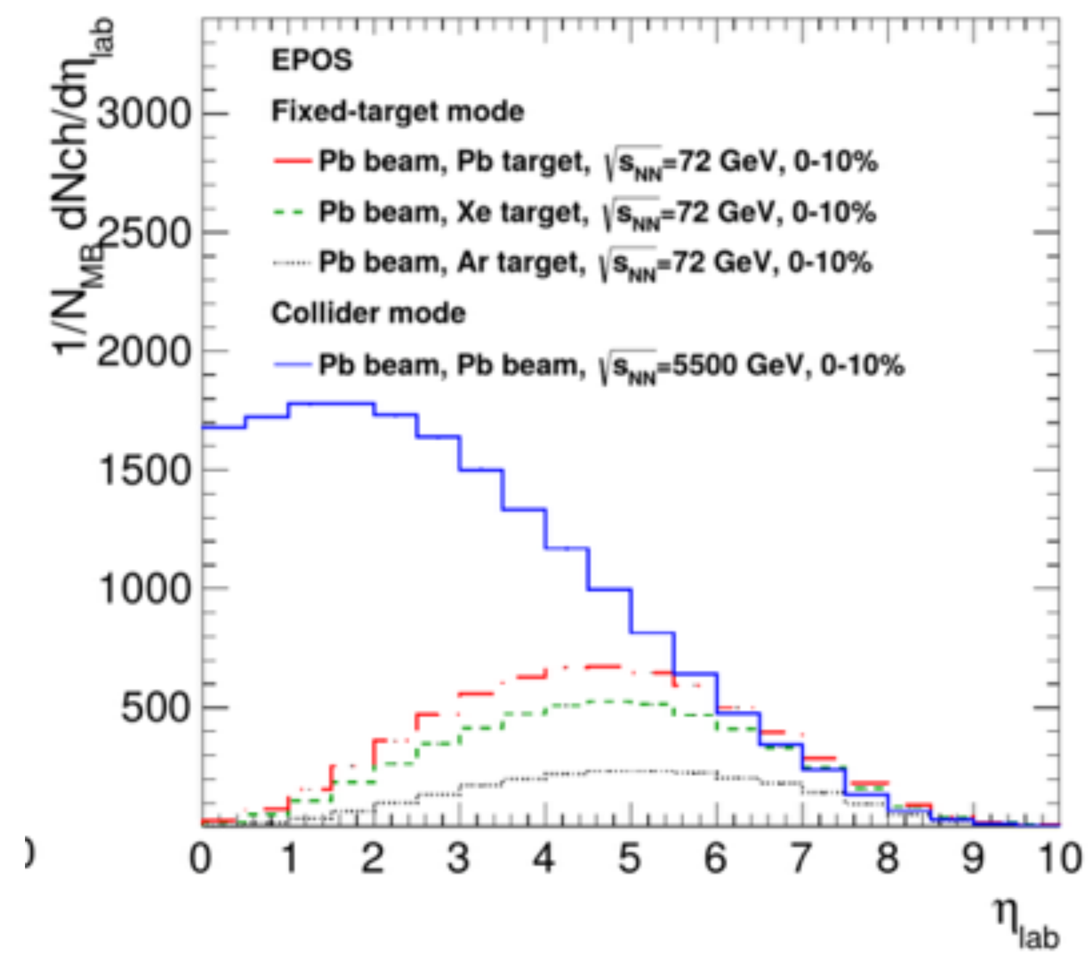
See more in Advances in High Energy Physics, Volume 2015 (2015)

Charged particle multiplicities

p+A



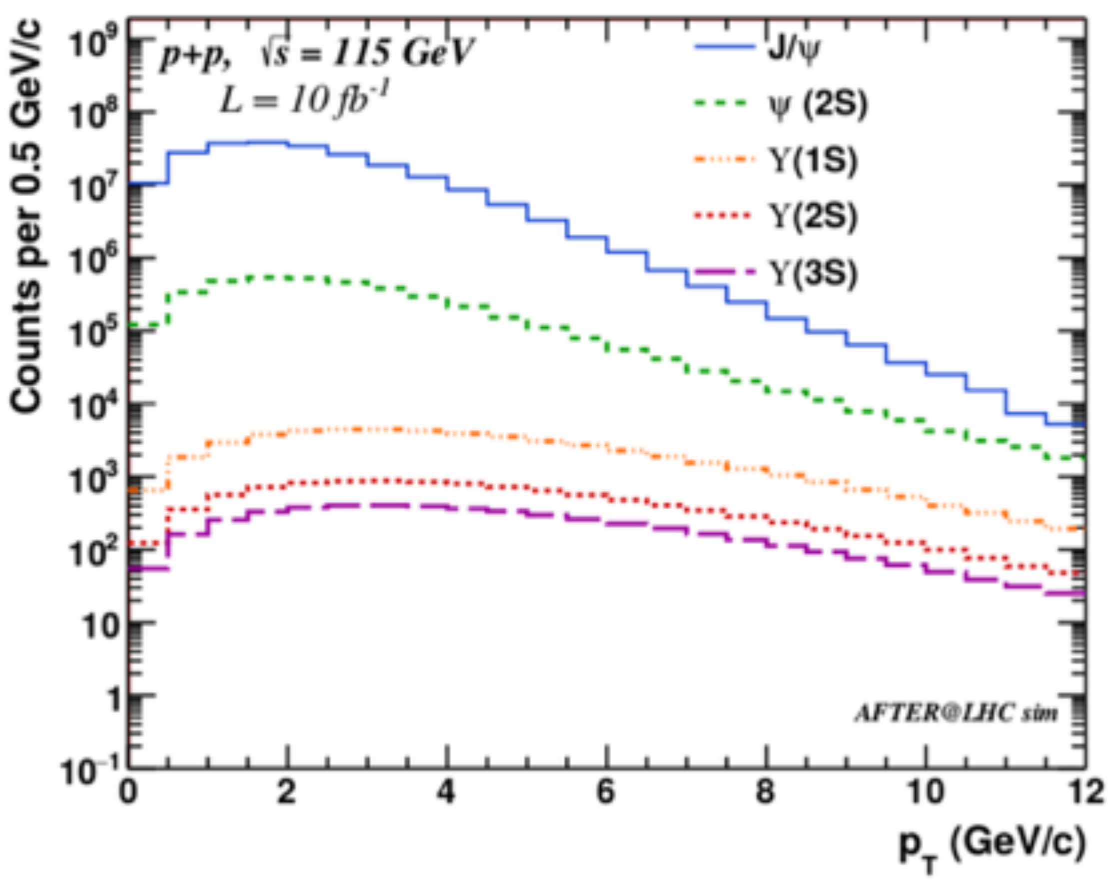
Pb+A

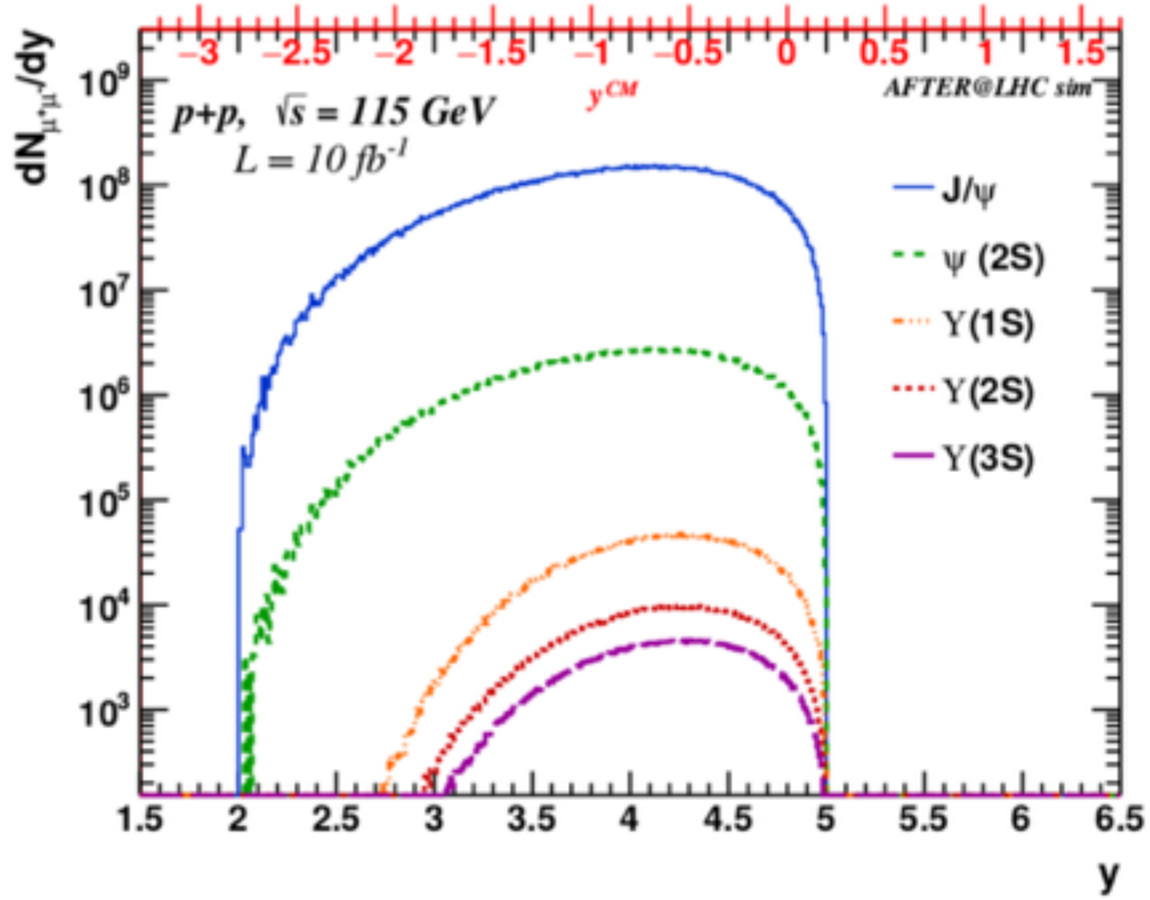


- Charge particle multiplicities, for all possible fixed target modes: p+Pb@115 GeV, Pb+H@72GeV, Pb+Pb@72 GeV
- Multiplicities smaller than the ones reached in the collider modes
- A detector with the LHCb capabilities is expected to be able to reconstruct all event centralities up to Pb-Ar

Quarkonium yields in p+p@115 GeV

Fast simulation with LHCb-like reconstruction parameters





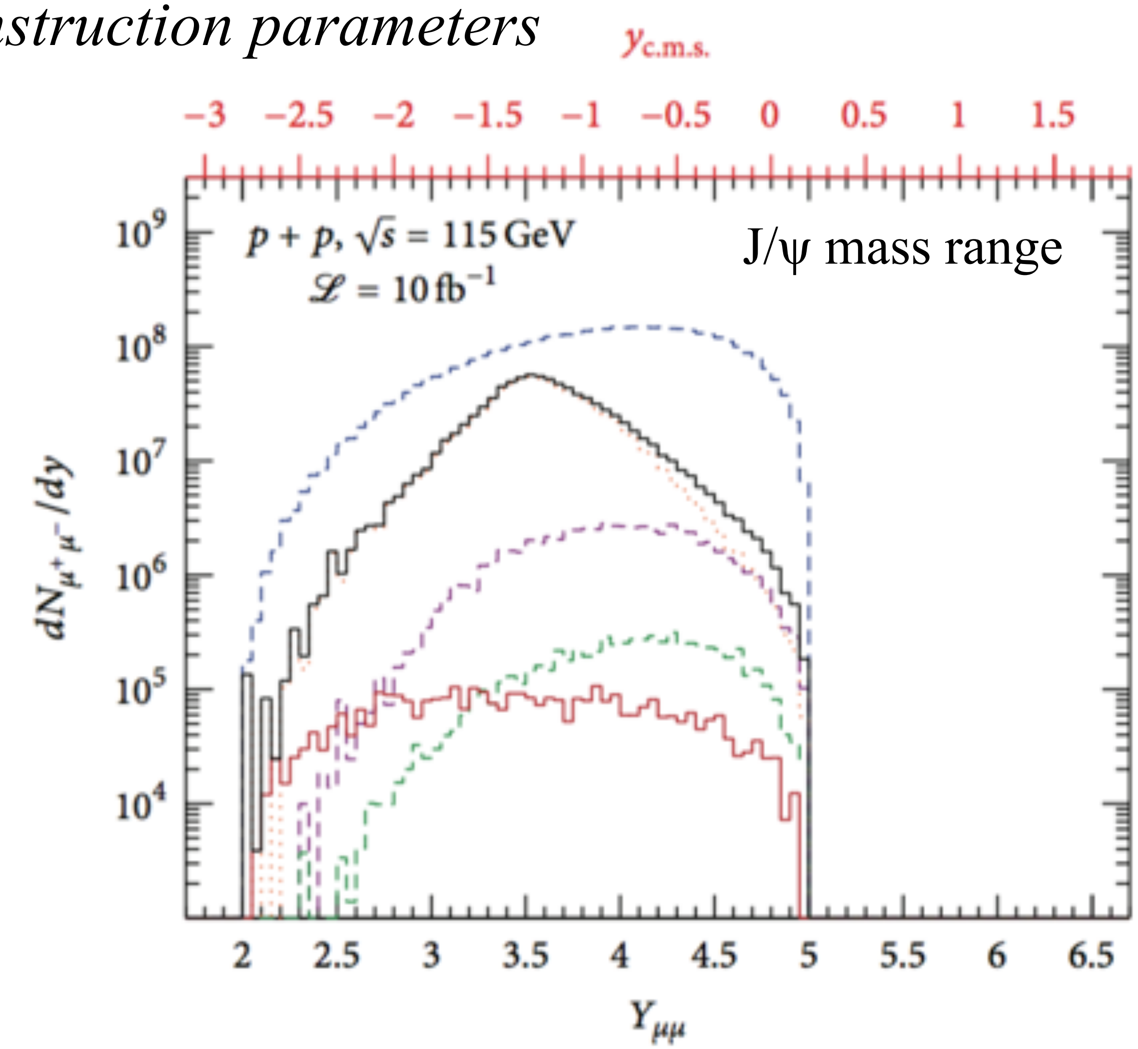
– Large statistics ($\mathscr{L}$ = 10 fb^{-1}) allow to reach in pp

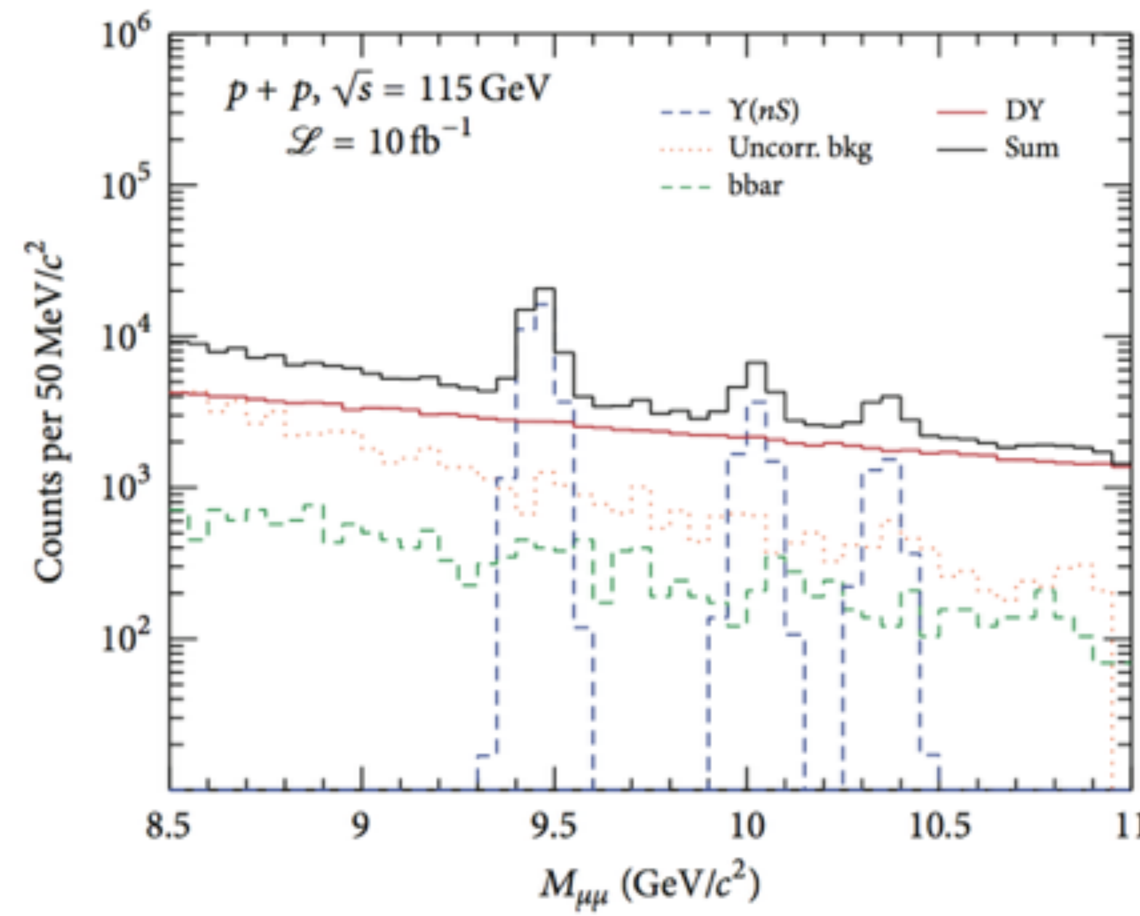
- J/ψ, ψ(2S): $2 < y_{lab} < 5$ and $0 < p_T < 15$ GeV/c
- Υ(nS): $2.5\text{-}3 < y_{lab} < 5$ and $0 < p_T < 10$ GeV/c

– Similar kinematic ranges expected in p+A

Drell-Yan and open HF in p+p@115 GeV

Fast simulation with LHCb-like reconstruction parameters



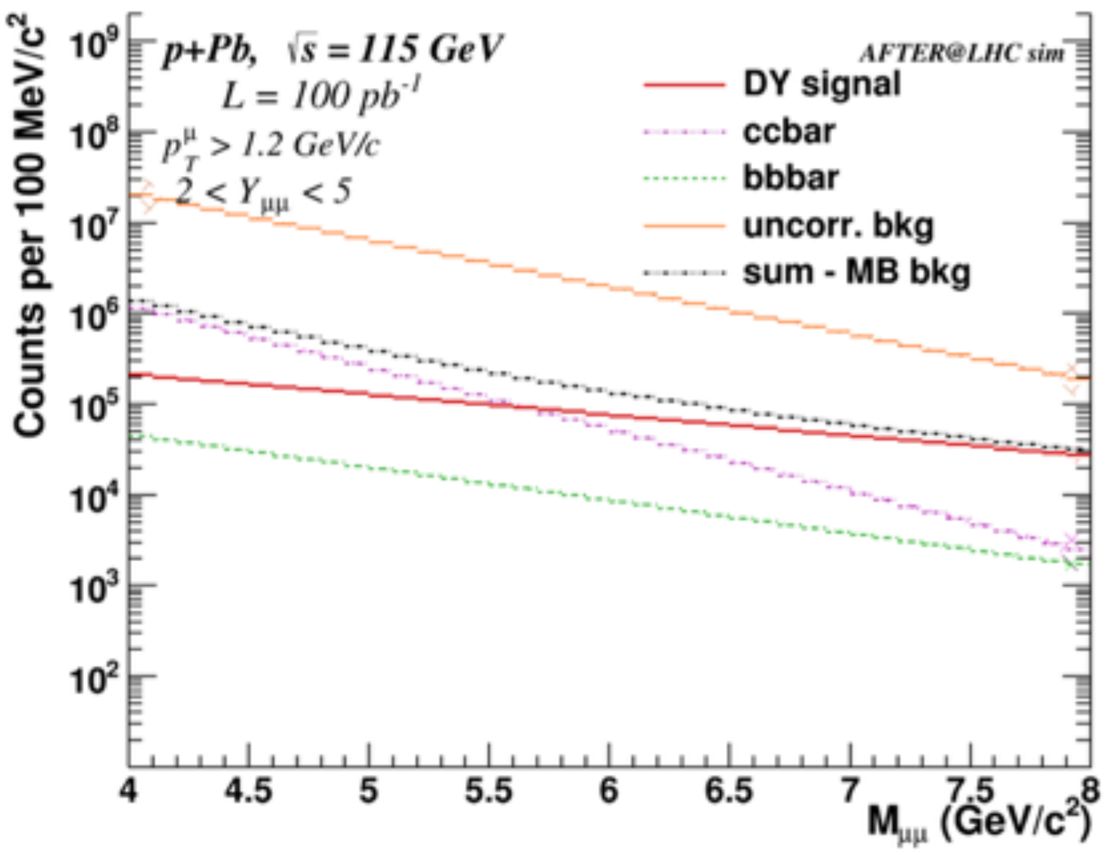


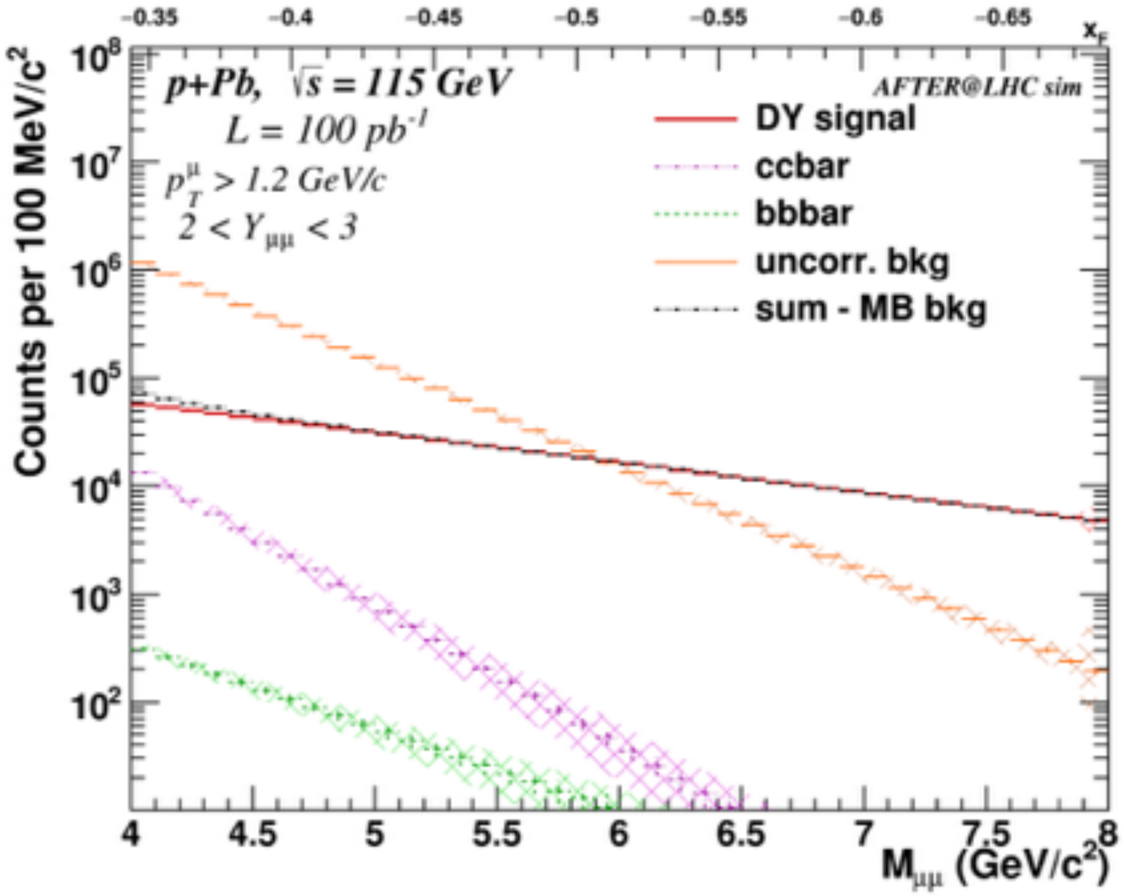
– At backward rapidities quark-induced processes are favoured → DY relative contribution gets higher

– Charm and beauty can be studied using dimuon and secondary vertex

Drell-Yan and open HF in p+Pb@115 GeV

Fast simulation with LHCb-like reconstruction parameters

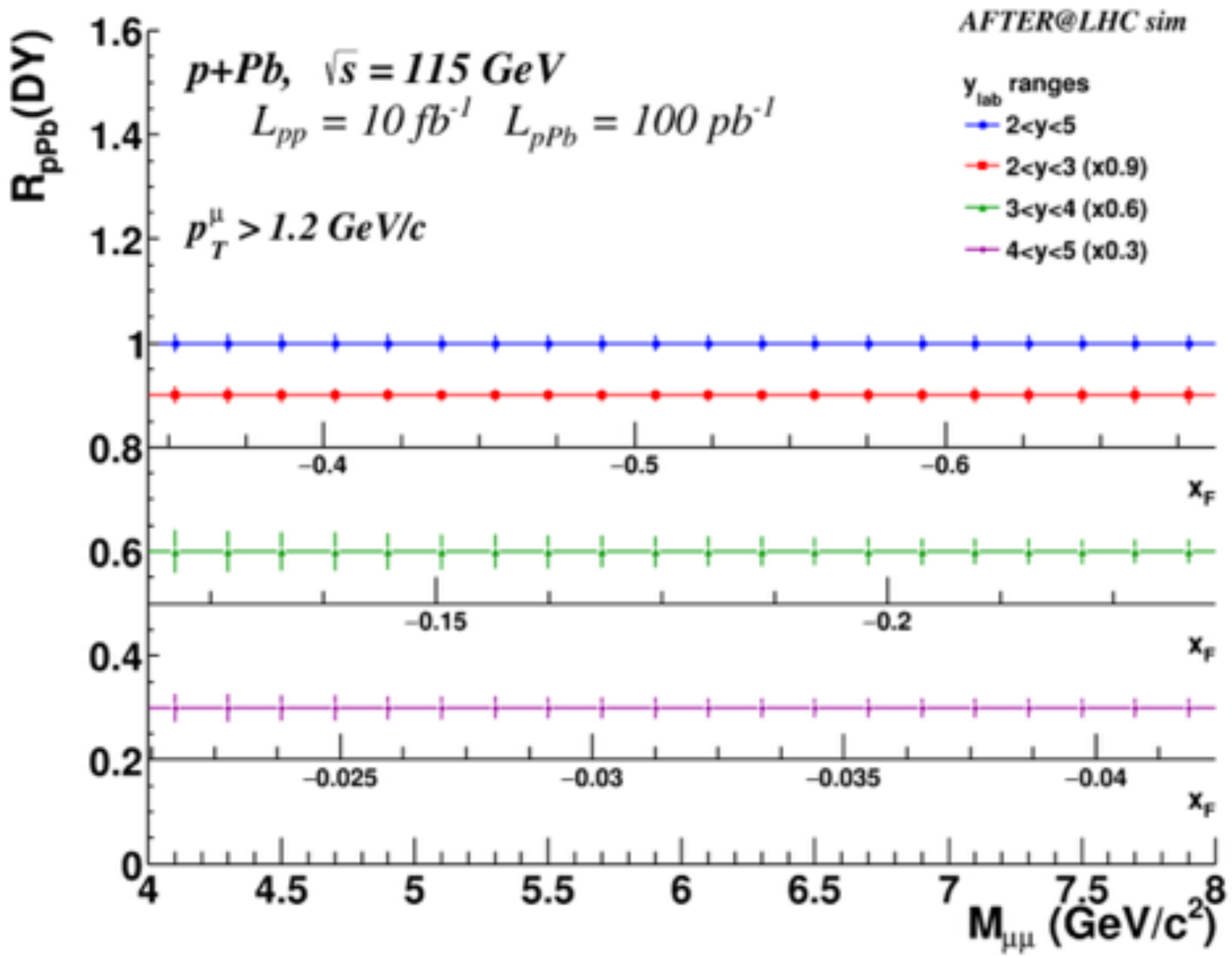




– No nuclear effects assumed

Drell-Yan R_{pPb} from p+p and p+Pb@115 GeV

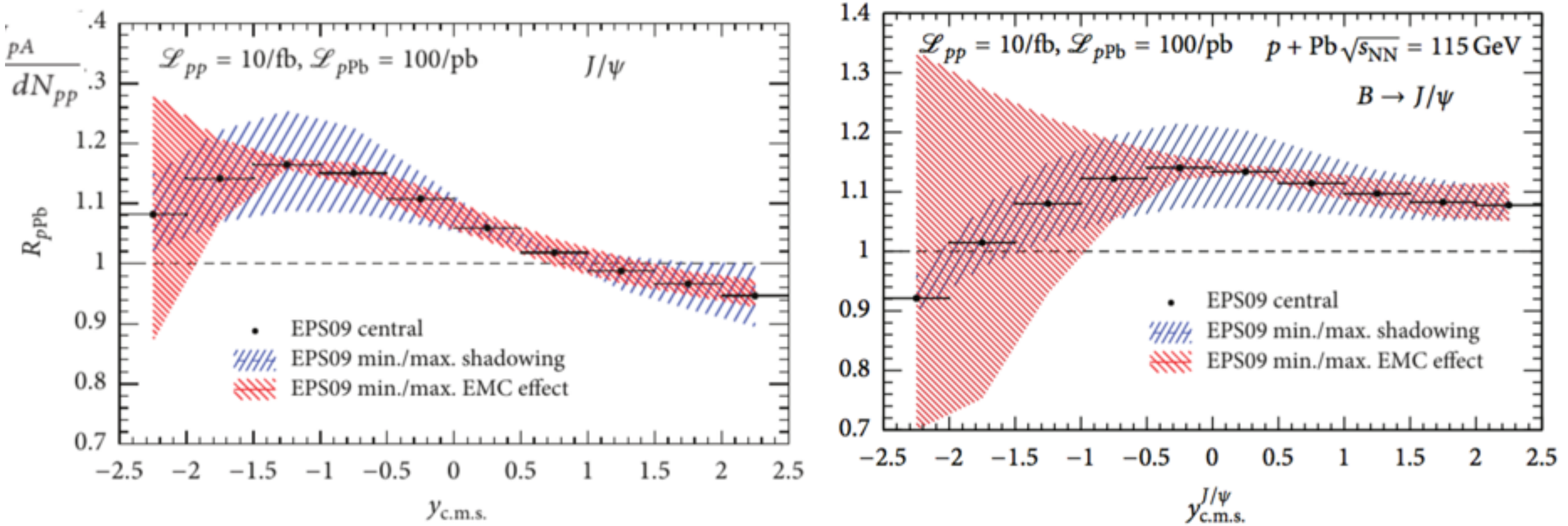
Fast simulation with LHCb-like reconstruction parameters



– No nuclear effects assumed
– Drell-Yan uncertainties: statistical and from background subtraction (using like-sign background subtraction method)
– Broad range in rapidity → broad range in x_F

J/ψ R_{pPb} from p+p and p+Pb@115 GeV

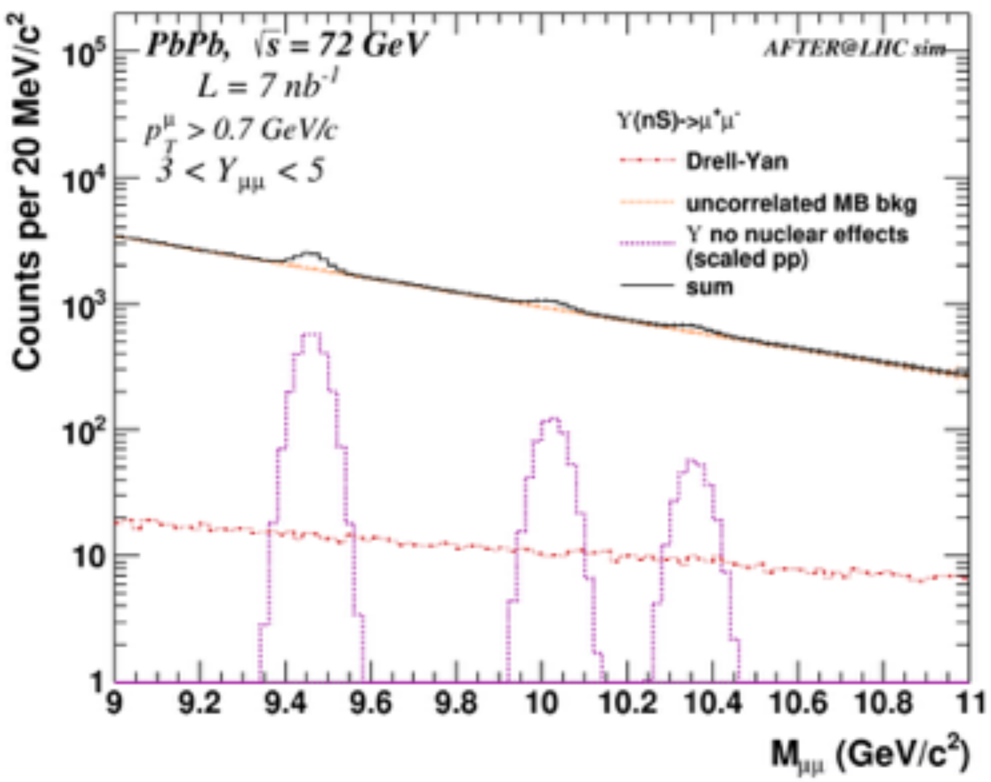
Fast simulation with LHCb-like reconstruction parameters

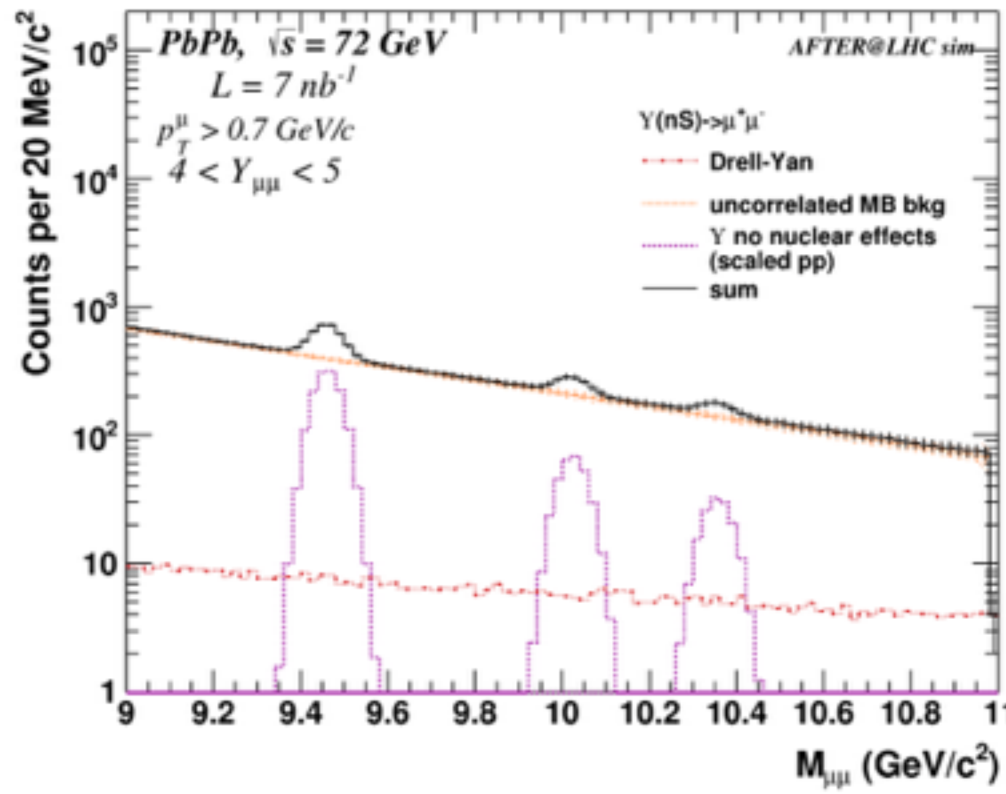


– Statistical uncertainties from the signal yield only
– Combination of J/ψ, ψ(2S), ϒ(nS) and open HF production in a broad rapidity range allows to study anti-shadowing and EMC effect

Υ(nS) in Pb+Pb@72 GeV

Fast simulation with LHCb-like reconstruction parameters





- Signal and background (dominated by uncorrelated one)
- Large statistics (here: $\mathscr{L}$ = 7 nb^{-1} and A=Pb) allow to reach a broad rapidity range $3 < y_{lab} < 5$
- Υ(nS) can be studied in Pb+A@72 GeV
- Larger Υ(nS) significance at $y_{lab} \sim 5$ (corresponding to ycms ~ 0.7)

Conclusion

- Fixed target experiment using LHC proton and lead beams extracted from a bent crystal offers many physics opportunities such as QCD in the high-x frontier and an extensive heavy-ion program

- High luminosity can be achieved and fixed-target mode allows target versatility: hydrogen, deuteron and various nucleus targets

- First fast simulations published and more ongoing

References

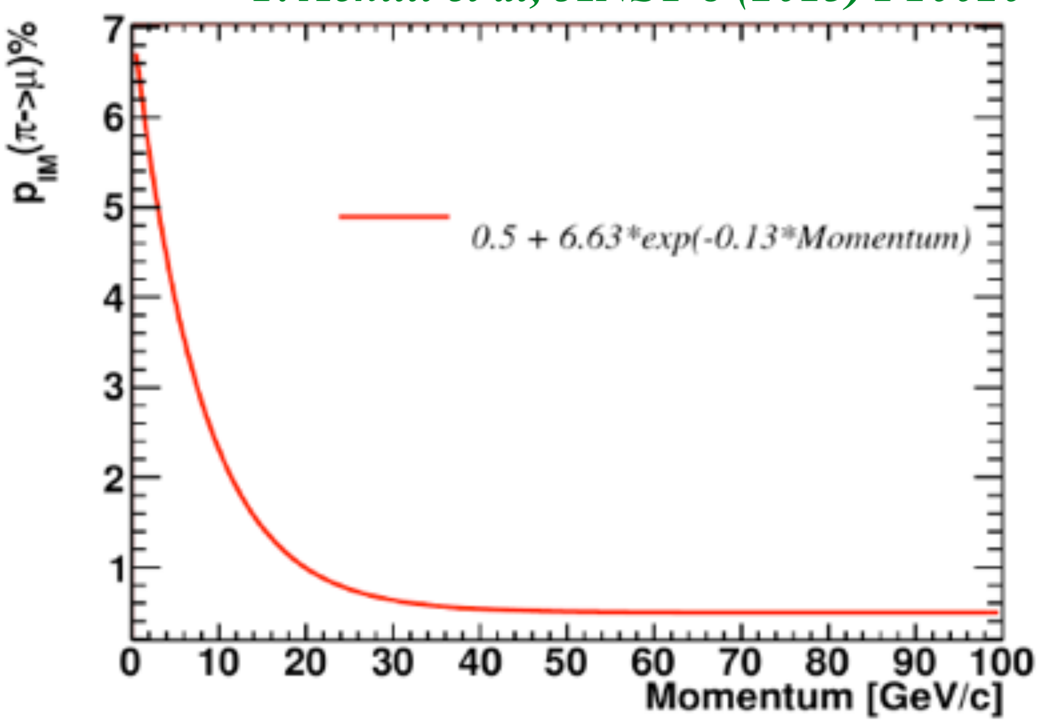
AFTER @ LHC

http://after.in2p3.fr

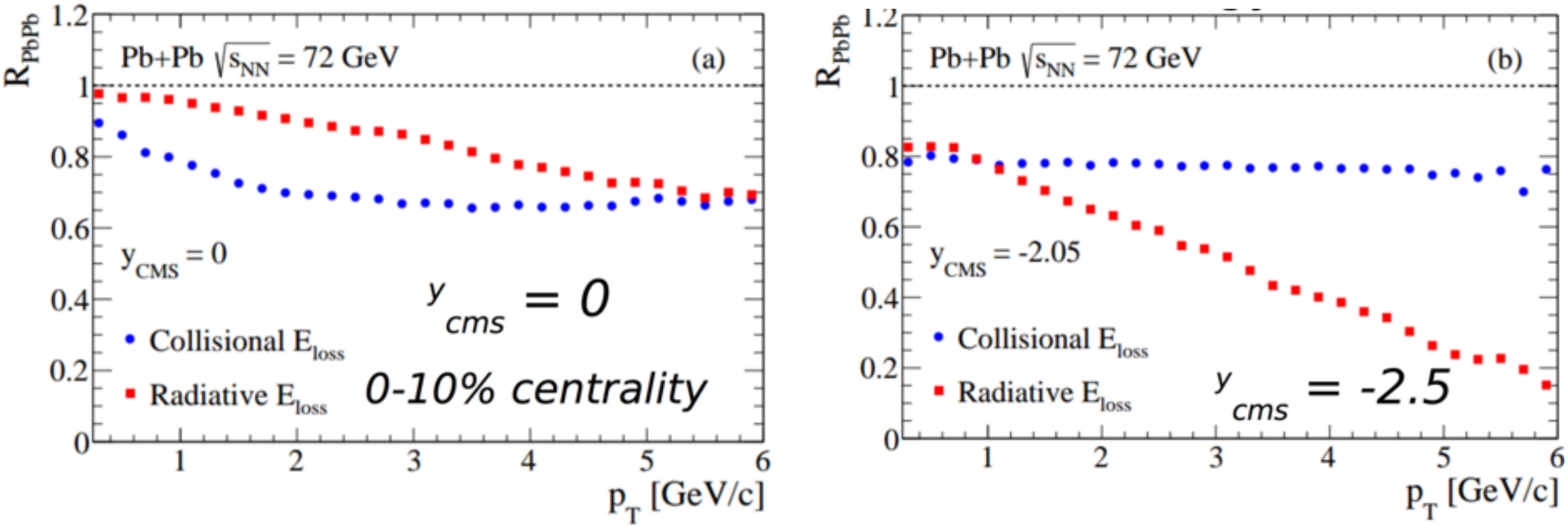
Simulation inputs for quarkonia, open HF and Drell-Yan

– Inputs:
  - HELAC-Onia: quarkonium, ccbar, bbar, Drell-Yan
  - PYTHIA8: minimum bias uncorrelated background ($\pi \leftarrow \mu$)
  - Hadronization, initial/final-state radiation and resonance decay with PYTHIA
– Fast simulation with LHCb-like reconstruction parameters
  - Momentum resolution: $\delta p/p \sim 0.5\%$
  - Muon identification efficiency ~ 98%
  - $2 < \eta_\mu < 5$
  - $p_{T,\mu} > 0.7$ GeV/c
  - Misidentification probability $\mathscr{P}_{\pi\rightarrow\mu}$ and $\mathscr{P}_{K\rightarrow\mu}$
– Fast simulations for
  - pp@115 GeV
  - p+Pb@115 GeV
  - Pb+Pb@115 GeV

F. Achilli et al, JINST 8 (2013) P10020

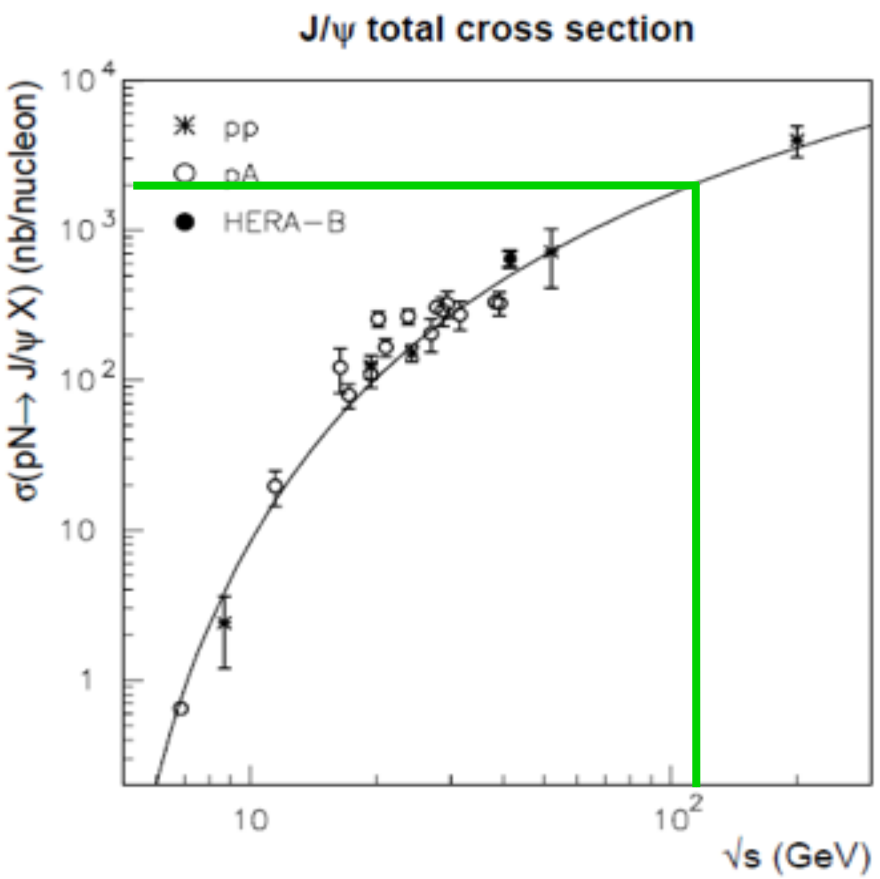


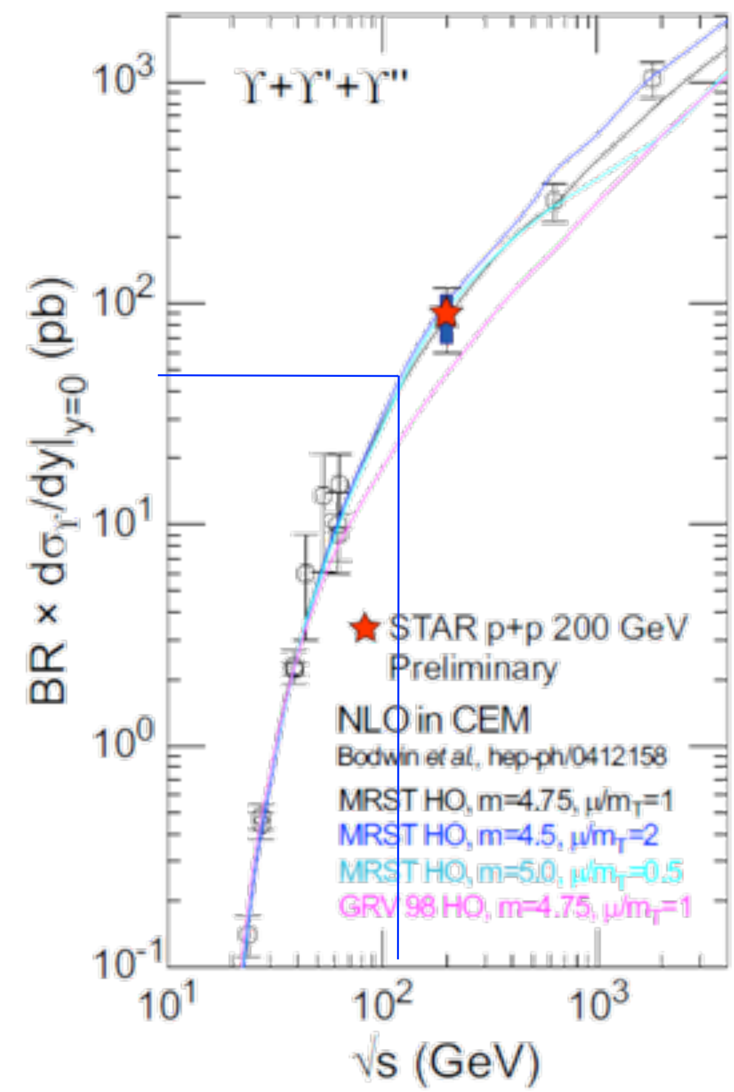
D^0 R_{AA} from Pb+Pb@72 GeV



– Statistical uncertainties from the signal yield only
– R_{AA} and R_{CP} (not shown) in a broad rapidity and p_T range gives insight to charm E_{loss}

Quarkonium cross-sections at AFTER energy





Inclusive pp cross-sections

$B_{ll}\, d\sigma/dy|_{y=0}$ @ 115 GeV

J/ψ = 20 nb

Y = 40 pb

Inclusive pp cross-sections

$B_{ll}\, d\sigma/dy|_{y=0}$ @ 72 GeV

J/ψ = 10 nb

Y = 15 pb

Quarkonium yields in pH and pA @ 115 GeV

In pp
⇒ RHIC @ 200 GeV x 100 with 10 cm thick H target
⇒ Comparable to LHCb if 1m H target
⇒ Detailed studies of quarkonium production (p_T, y, polarization, different quarkonium states, ...)

In pA
⇒ RHIC @ 200 GeV x 100 with 1 cm Pb target
⇒ Detailed studies of cold nuclear matter effect in pA (p_T, y, A, ...)

Geometrical Acceptance
Simulations using ALICE as a fixed target experiment at LHC quotes a Geometrical Acceptance of 8% for J/ψ (4 π) → $\mu^+\mu^-$ (2.5< y < 4) using the Forward Muon Spectrometer @ 115 GeV

Kurepin et al. Phys.Atom.Nucl. 74 (2011)

Target	$\int dt \mathcal{L}$	$\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$	$\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$
10 cm solid H	2.6	$5.2\ 10^7$	$1.0\ 10^5$
10 cm liquid H	2	$4.0\ 10^7$	$8.0\ 10^4$
10 cm liquid D	2.4	$9.6\ 10^7$	$1.9\ 10^5$
1 cm Be	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1 cm Cu	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1 cm W	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1 cm Pb	0.16	$6.7\ 10^8$	$1.3\ 10^6$
pp low P_T LHC (14 TeV)	0.05	$3.6\ 10^7$	$1.8\ 10^5$
	2	$1.4\ 10^9$	$7.2\ 10^6$
pPb LHC (8.8 TeV)	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
pp RHIC (200 GeV)	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$
dAu RHIC (200 GeV)	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
dAu RHIC (62 GeV)	$3.8\ 10^{-6}$	$1.2\ 10^4$	$1.8\ 10^1$

Luminosity per year in fb^{-1}

Quarkonium yields in PbA @ 72 GeV

PbA

⇒ Same statistics than RHIC @ 200 GeV and LHC and 2 orders of magnitude larger than RHIC @ 62 GeV

⇒ Detailed studies possible for quarkonium states (ψ', χ_c, A-dependence, ...)

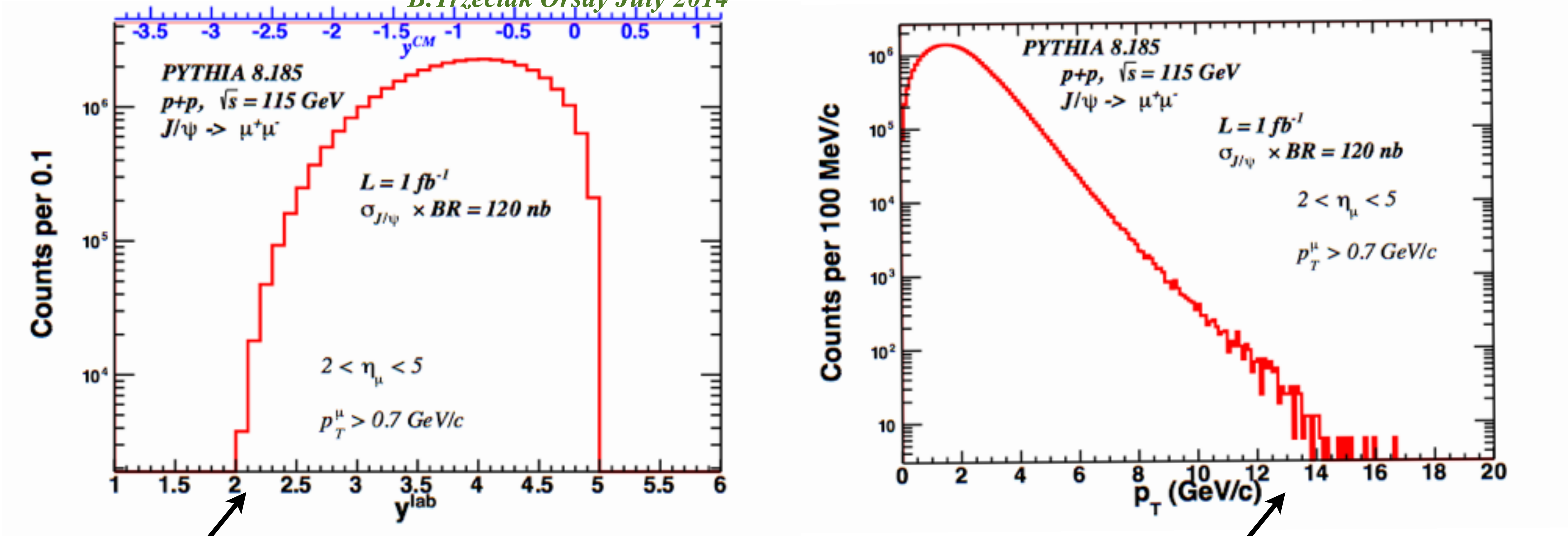
Target	$\int dt\mathcal{L}$	$\mathcal{B}_{\ell\ell}\frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$	$\mathcal{B}_{\ell\ell}\frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$
10 cm solid H	110	4.3 10^5	8.9 10^2
10 cm liquid H	83	3.4 10^5	6.9 10^2
10 cm liquid D	100	8.0 10^5	1.6 10^3
1 cm Be	25	9.1 10^5	1.9 10^3
1 cm Cu	17	4.3 10^6	0.9 10^3
1 cm W	13	9.7 10^6	1.9 10^4
1 cm Pb	7	5.7 10^6	1.1 10^4
*d*Au RHIC (200 GeV)	150	2.4 10^6	5.9 10^3
*d*Au RHIC (62 GeV)	3.8	1.2 10^4	1.8 10^1
AuAu RHIC (200 GeV)	2.8	4.4 10^6	1.1 10^4
AuAu RHIC (62 GeV)	0.13	4.0 10^4	6.1 10^1
*p*Pb LHC (8.8 TeV)	100	1.0 10^7	7.5 10^4
PbPb LHC (5.5 TeV)	0.5	7.3 10^6	3.6 10^4

Luminosity per year in fb^{-1}

J/ψ in pp @ $\sqrt{s}$=115 GeV

For 1 m of H target and two weeks of data taking

B.Trzeciak Orsay July 2014



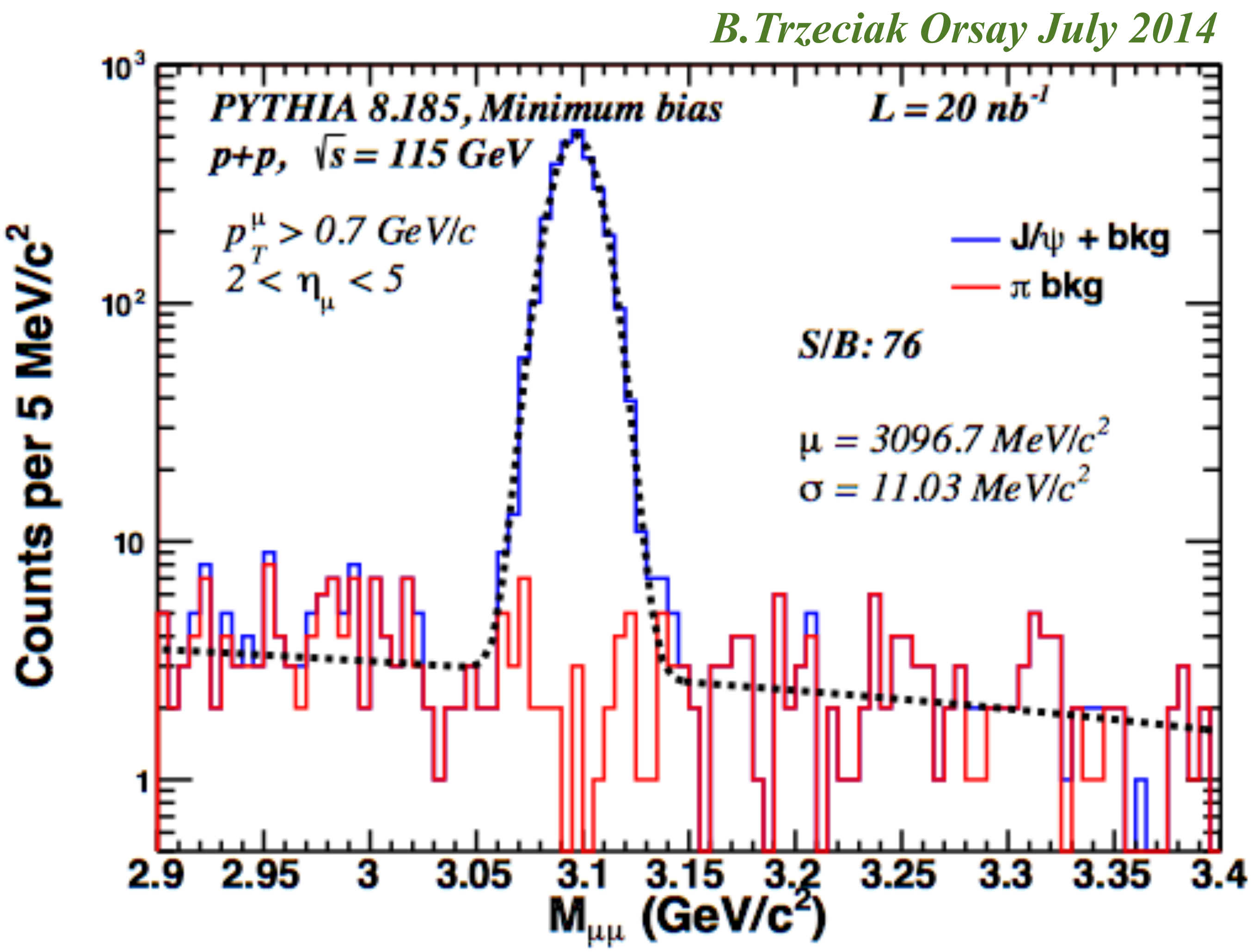
Large statistics allow to reach

- low y_{lab}: $2 < y_{lab} < 5 \Rightarrow -2.8 < y_{cms} < 0.2 \Rightarrow 0.03 < x_{target} < 0.4$ (considering a $gg \rightarrow J/\psi$ mechanism)
- large p_T

To reach larger x_{target}, one can study larger mass particles (e.g. Υ(1S)) or increase detection acceptance to lower y_{lab}

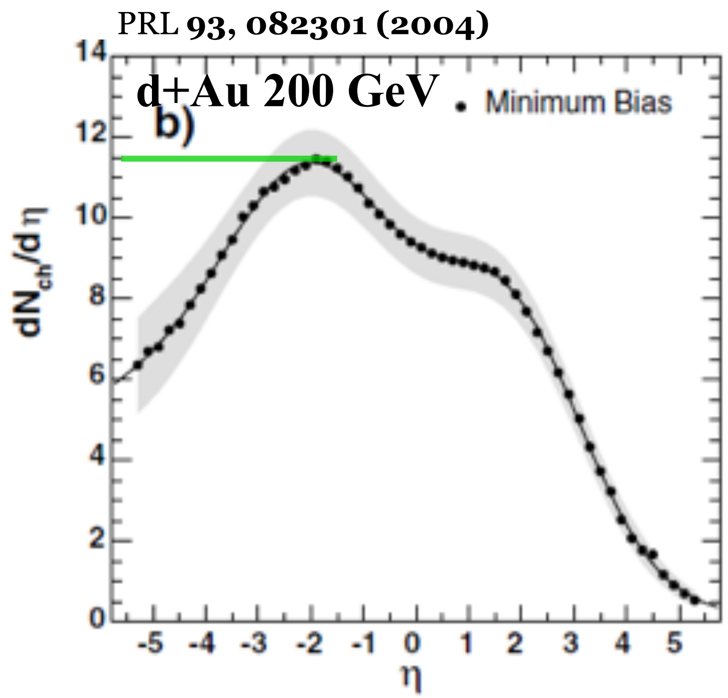
S/B for J/ψ in pp @ √s=115 GeV

For 1 m of H target and few tens of seconds of data taking

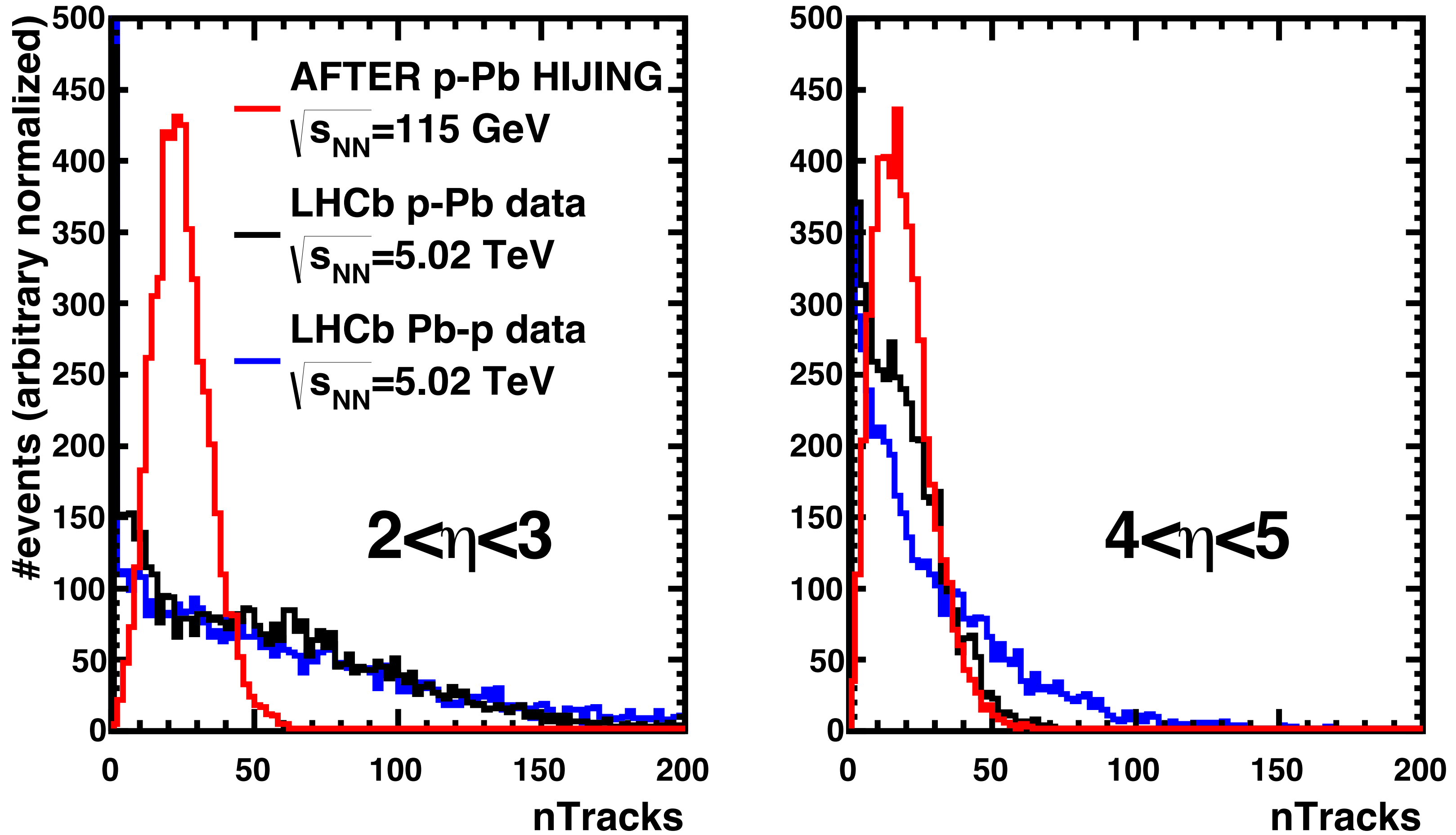


→ Background mostly from misidentified π

Track multiplicity in pPb @ $\sqrt{s_{NN}} = 115$ GeV



Z.Yang AFTER Workshop LesHouches 2014



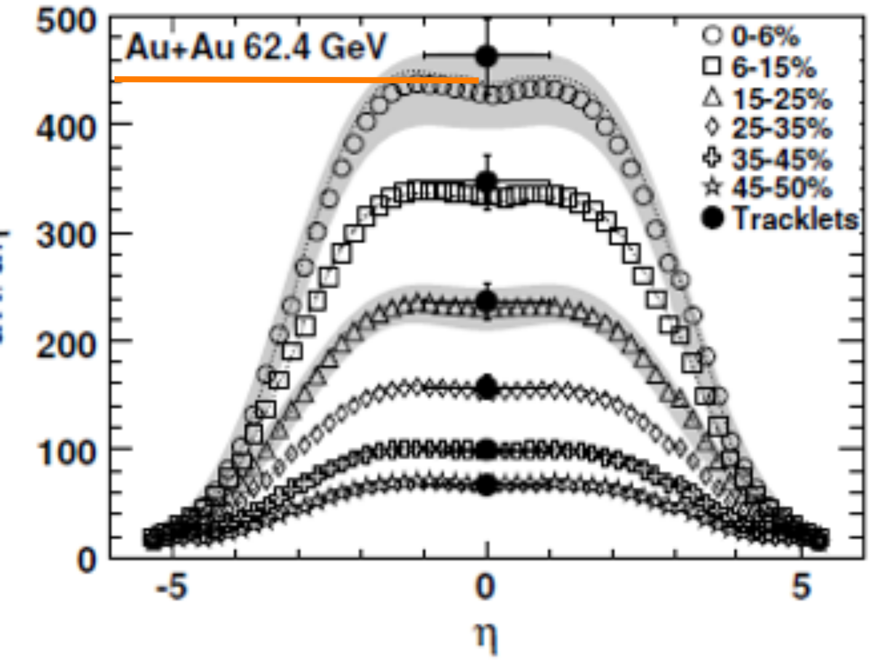
- Full LHCb simulation and standard reconstruction
- MonteCarlo: HIJING MB with proton beam and Pb target at $\sqrt{s_{NN}} = 115$ GeV

  ⇒ track multiplicity in AFTER lower than the one measured by LHCb in Pb-p collisions at $\sqrt{s_{NN}} = 5$ TeV

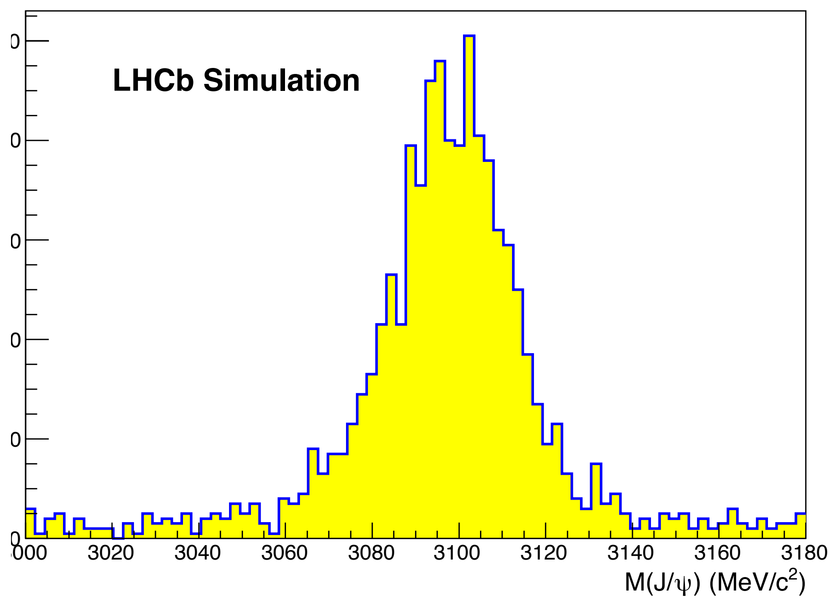
  ⇒ LHCb detector setup can cope with the multiplicity of pPb at $\sqrt{s_{NN}} = 115$ GeV in $2 < \eta < 5$

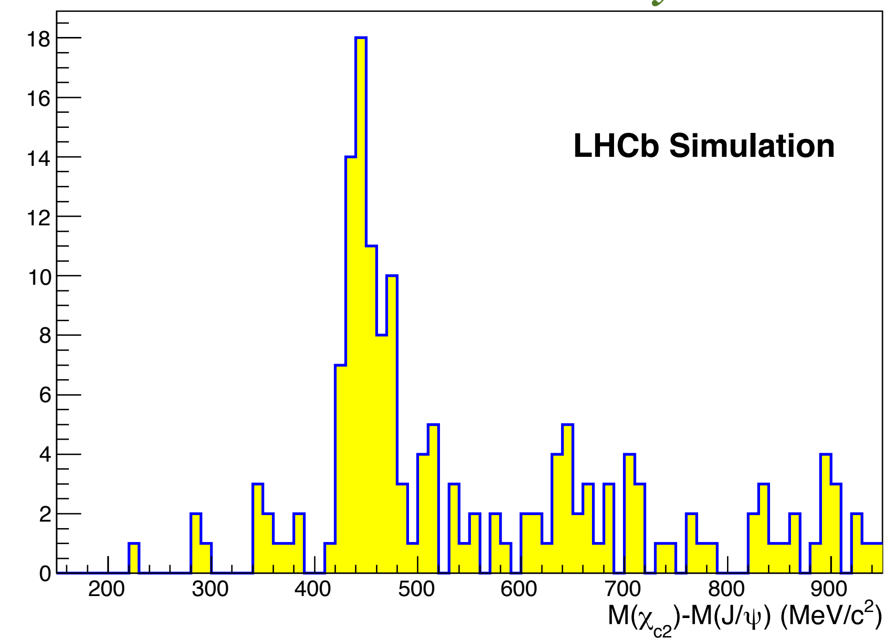
J/ψ and χ_c in PbAr @ $\sqrt{s_{NN}}$ = 72 GeV

PRC 74, 021901(R) (2006)



P. Robbe Orsay June 2014





- Full simulation and standard reconstruction with LHCb detector
- MonteCarlo: enriched signal in EPOS
- χ_c reconstructed in $\chi_c \rightarrow J/\psi\ \gamma$
- Total efficiency (J/ψ) ~ 20% and total efficiency (χ_c) ~ 1.5%
- In most central events, tracking may need refinement

Quarkonium distributions in pp @ $\sqrt{s}$=115 GeV

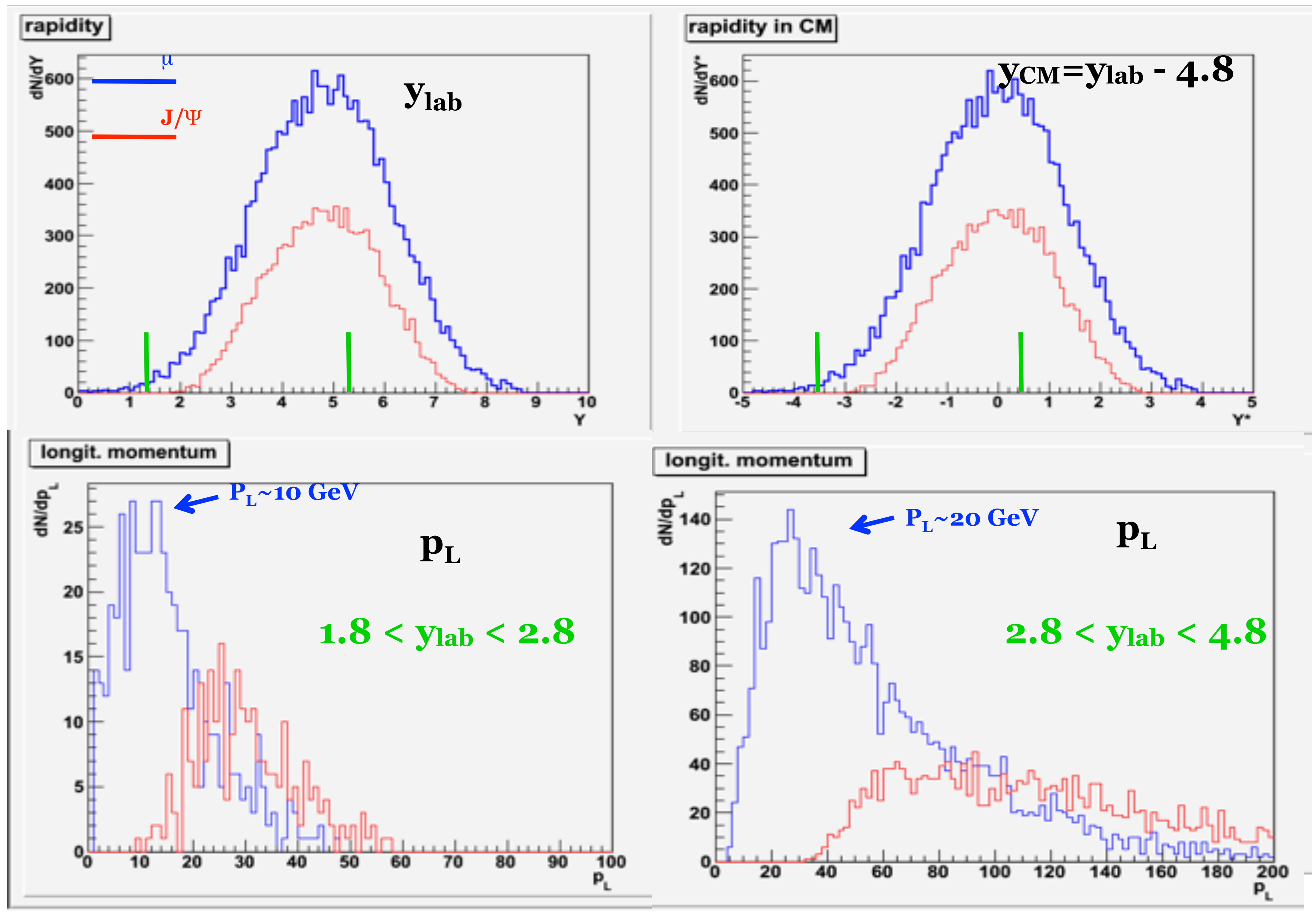
Pythia 6.4.21: p (7 TeV) + p $\rightarrow$ J/ψ (isub=86)

J/$\Psi \rightarrow \mu^+\mu^-$

μ from J/ψ for $1.3 < y_{lab} < 5.3$

$P_T \sim$ 1.7 GeV/c

$P_L \sim$ 62 GeV/c



Longitudinal muon momentum

$1.3 < y_{lab} < 3.3$

p_L (max) ~ 16 (50) GeV/c

$3.3 < y_{lab} < 4.3$

p_L (max)~ 45 (150) GeV/c

$4.3 < y_{lab} < 5.3$

p_L (max)~ 120 (300) GeV/c

Accessing the large x gluon pdf

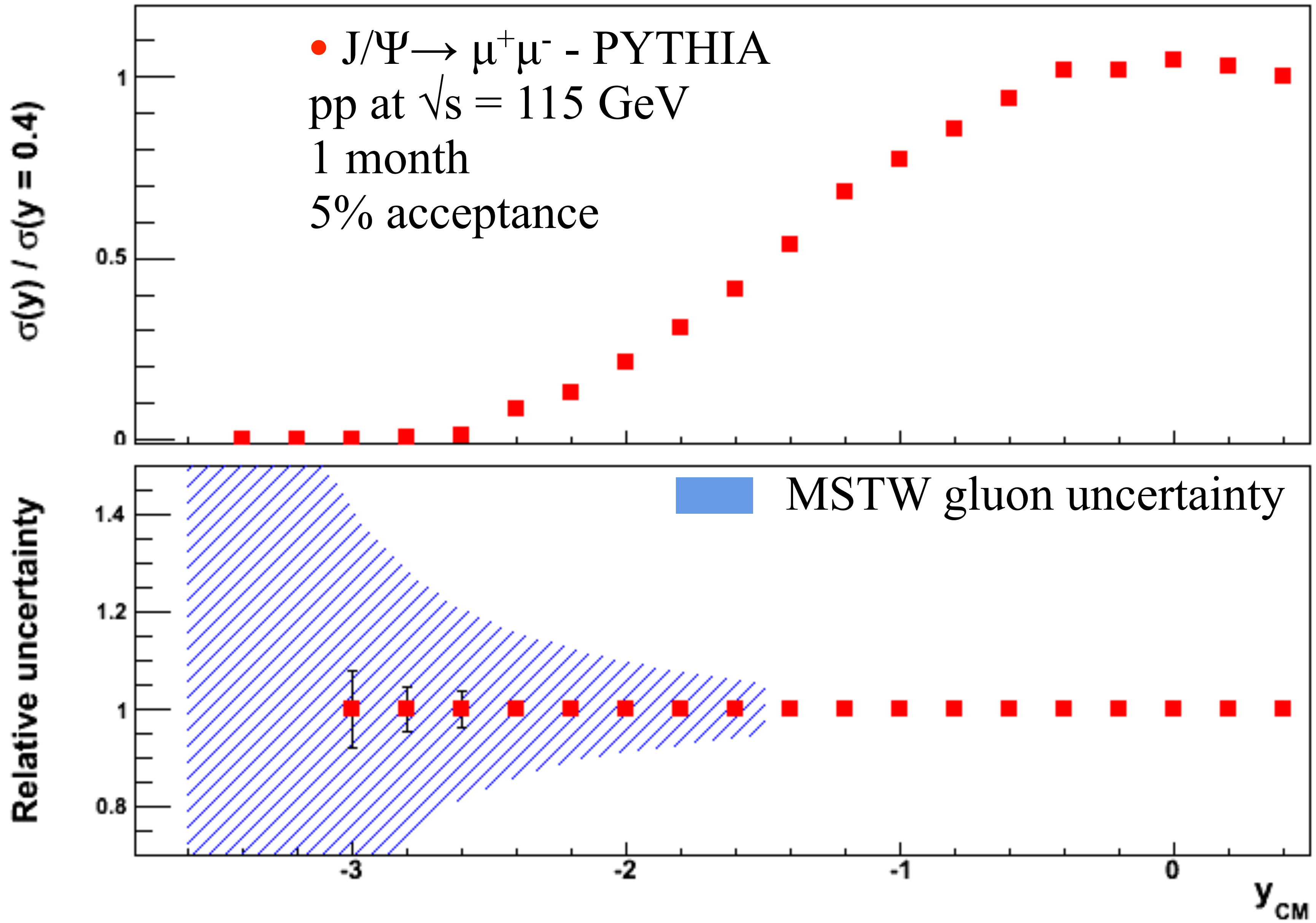
PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

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

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



⇒ Backward rapidity measurements allow to access large x gluon pdf

Simulations needed !

Rapidity boost in a fixed target mode

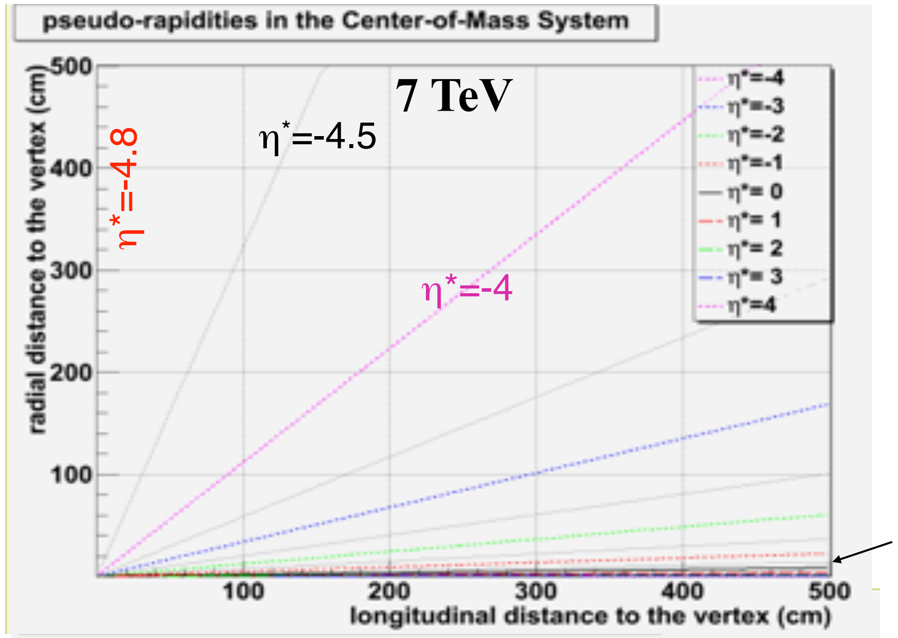
- **Very high boost:**
  - With 7 TeV beam
    $\gamma = \sqrt{s}/(2m_p) = 61.1$ and $y_{CMS} = 4.8$
  - With 2.76 TeV beam
    $\gamma = 38.3$ and $y_{CMS} = 4.3$

- $\eta_{CM} = \eta_{lab} - y_{CMS}$
  forward region: $\eta_{CM}>0$
  backward region: $\eta_{CM}<0$

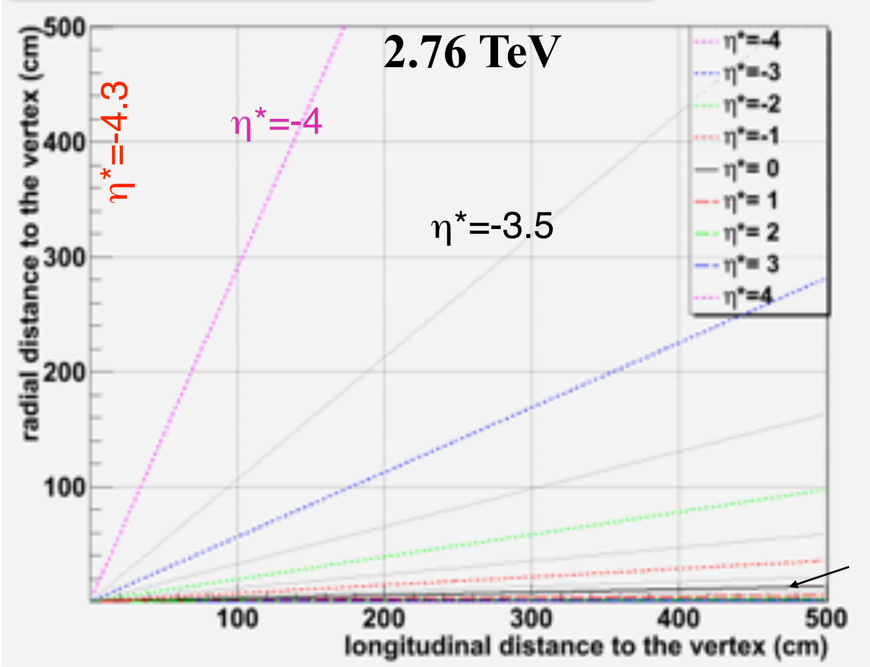
- $\eta = -\ln \tan \theta/2$
  $\rightarrow \theta\ (y_{CM}=0) \sim 0.9°$ (16 mrad)
  - $y_{lab}(J/\Psi) \sim 4.8 \rightarrow x_2(J/\Psi) = 0.03$
  - $y_{lab}(\Upsilon) \sim 4.8 \rightarrow x_2(\Upsilon) = 0.08$

- **Taking $x_2 = M/\sqrt{s}\ e^{-y_{CM}}$**
  - $x_2(J/\Psi) = 1 \rightarrow y_{lab}(J/\Psi) \sim 1.2$
  - $x_2(\Upsilon) = 1 \rightarrow y_{lab}(\Upsilon) \sim 2.4$

- **Very well placed to access backward physics**

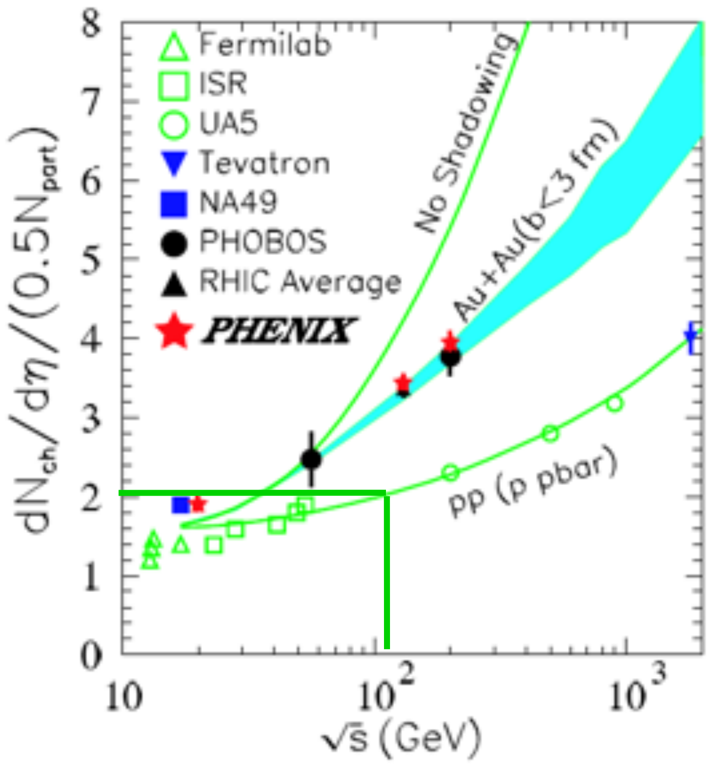


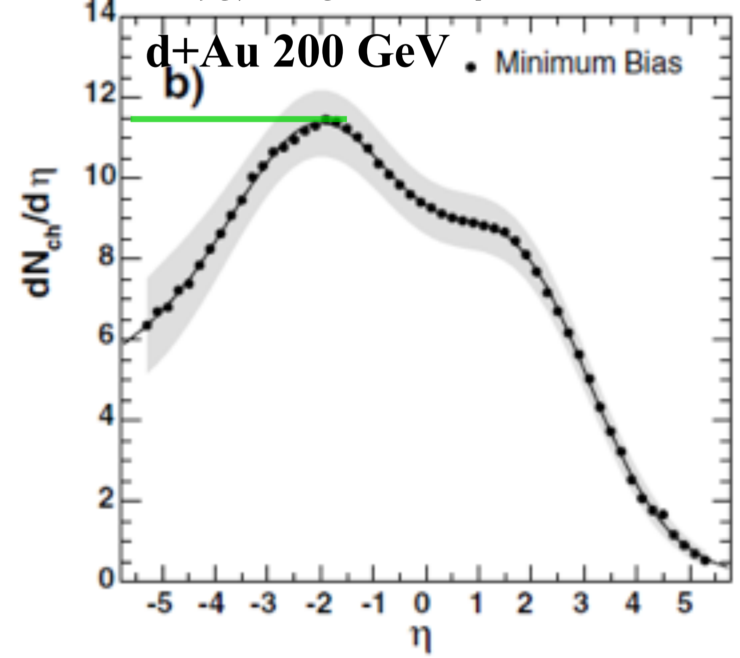
y_{CMS}= 4.8

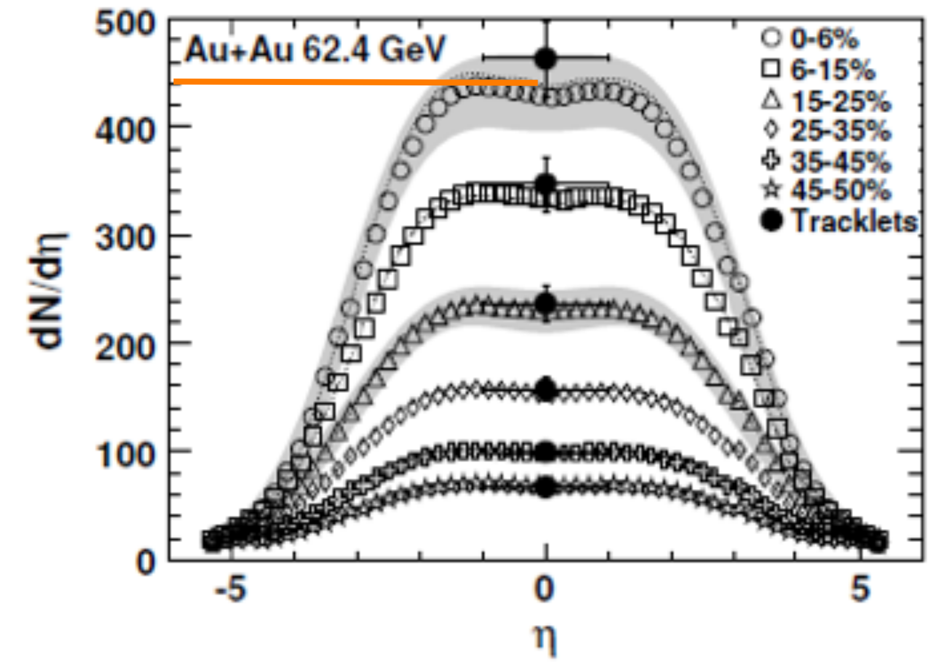


y_{CMS}= 4.3

Multiplicity







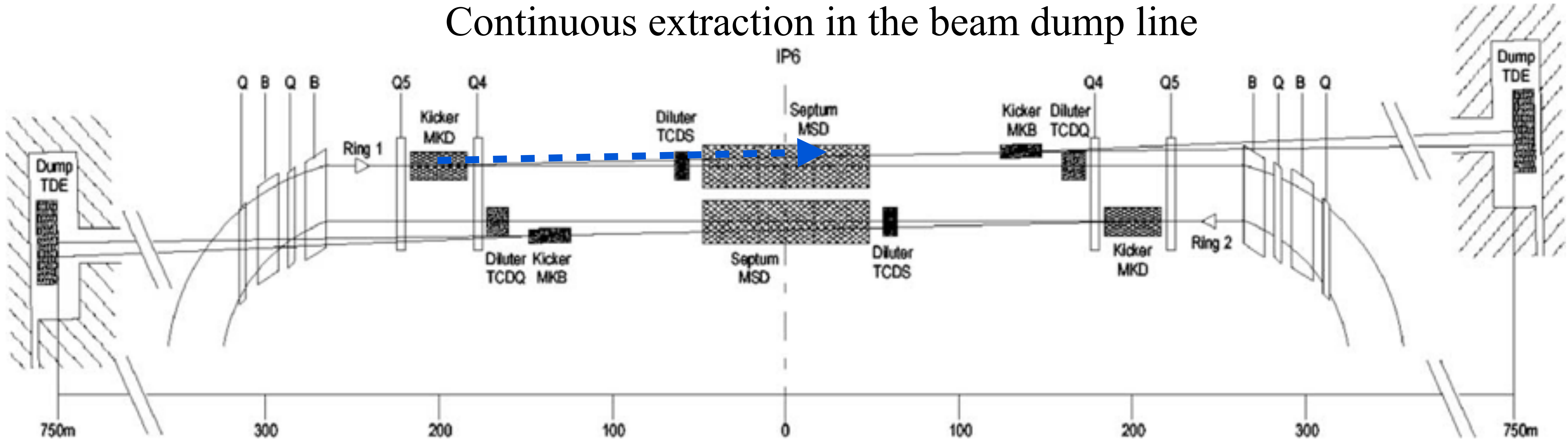
Charged particles per unit of rapidity: (x 1.5 = charged+neutral)

p+p @ 115 GeV ~ 2 **d+Au @ 200 GeV : max ~11** **Au+Au @ 62.4 GeV : max ~ 450**

A possibility for proton and lead beam extraction at the LHC

E. Uggerhoj and U.I Uggerhoj NIMB 234 (2005) 34

Continuous extraction in the beam dump line



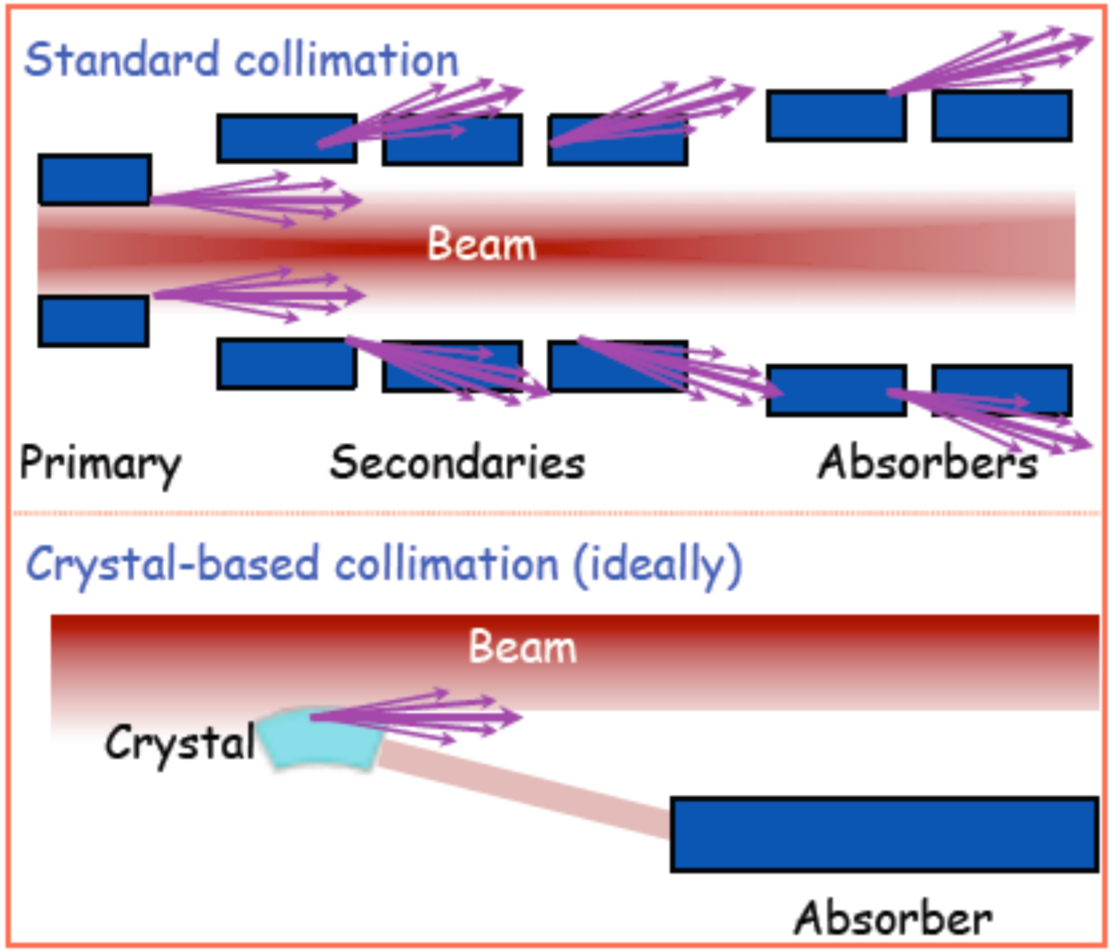
- Proposal for the insertion of a bent crystal in the LHC beam
  - Bent, single crystal of Si or Ge - 17cm long crystal
  - MKD kicker section at ~200 m from IP6
  - Deflection angle = 0.257 mrad (~7 T.m equivalent magnet)
  - Distance of 7 σ to the beam to intercept and deflect the beam halo
  - No loss in the LHC beam
  - Bent crystal acts as a beam collimator

- Proton beam extraction
  - Single- or multi pass extraction efficiency of 50%
    - $N_{\text{beam loss LHC}} \sim 10^9$ p/s $\rightarrow N_{\text{extracted beam}} = 5\ 10^8$ p/s
  - Extremely small emittance: beam size in the extraction direction) 950 m after the extraction ~ 0.3 mm

- Ion beam extraction
  - Ions extraction tested at SPS, is expected to be also possible at LHC but needs more study
  - May require bent diamonds (highly resistant to radiations)

P. Ballin et al, NIMB 267 (2009) 2952

Bent crystal as primary collimator at the LHC



W. Scandale et al., JINST 6 T10002 (2011)

- Beam collimation @ LHC: amorphous collimator: inefficiency @ 3.5 TeV proton beam = 0.2% → expected bent crystal inefficiency = 0.02%
- LHC Committee approved beam bending experiments using crystals at the LHC (LUA9 Collaboration)
- Tests at SPS on proton and ion beams for a LHC setup
- Long Shutdown 1: 2 bent crystals installed in IR7
- 2015-2016: first tests with beam

Luminosities in pH and pA @ $\sqrt{s_{NN}}$=115 GeV

- **Intensity: $N_{beam} = 5.10^8$ protons.s^{-1}**
  - Beam: 2808 bunches of 1.15×10^{11} p = 3.2×10^{14} p
  - Bunch: Each bunch passes IP at the rate: ~11 kHz
  - Instantaneous extraction: IP sees 2808 x 11000~3.10^7 bunches passing every second → extract ~16 protons in each bunch at each pass
  - Integrated extraction: Over a 10h run: extract ~5.6% of the protons stored in the beam

- **Instantaneous Luminosity**

  $L = N_{beam} \times N_{Target} = N_{beam} \times (\rho \times e \times N_A)/A$

  - N_{beam}=5 x 10^8 p^+/s
  - **e** (target thickness) = 1 cm

- **Integrated luminosity**
  - 9 months running/year
  - 1 year ~ 10^7 s

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ (μb^{-1} s^{-1})	$\int\mathcal{L}$ (pb^{-1} yr^{-1})
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	0.16	2	24	240
Be	1.85	9	62	620
Cu	8.96	64	42	420
W	19.1	185	31	310
Pb	11.35	207	16	160

⇒ Large luminosity in pH(A) ranging from 0.1 and 0.6 fb^{-1} for a 1 cm thick target

⇒ Larger luminosity with 50 cm or 1 m H2 or D2 target

Luminosities in PbA @ $\sqrt{s_{NN}}$=72 GeV

- **Intensity: N_{beam} = 2.10^5 Pb.s^{-1}**
  - Beam: 592 bunches of 7x10^7 ions = 4.1x10^{10} ions
  - Bunch: Each bunch passes IP at the rate ~ 11 kHz
  - Instantaneous extraction: IP sees 592 x 11000~6.5.10^6 bunches passing every second → extract ~0.03 ions in each bunch at each pass
  - Integrated extraction: Over a 10h run: extract ~15% of the ions stored in the beam

- **Instantaneous Luminosity**

  $L = \mathbf{N_{beam}} \times \mathbf{N_{Target}} = \mathbf{N_{beam}} \times (\rho \times \mathbf{e} \times \mathbf{N_A})/\mathbf{A}$

  - $\mathbf{N_{beam}}$=2 x 10^5 Pb/s
  - **e** (target thickness) = 1 cm

- **Integrated luminosity**
  - 1 months running/year
  - 1 year ~ 10^6 s

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ (mb^{-1} s^{-1})	$\int\mathcal{L}$ (nb^{-1} yr^{-1})
solid H	0.088	1	11	11
liquid H	0.068	1	8	8
liquid D	0.16	2	10	10
Be	1.85	9	25	25
Cu	8.96	64	17	17
W	19.1	185	13	13
Pb	11.35	207	7	7

⇒ AFTER provides a good luminosity to study QGP related measurements

Polarizing the hydrogen target

- **Instantaneous Luminosity**

  $L = \mathbf{N_{beam}} \times \mathbf{N_{Target}} = \mathbf{N_{beam}} \times (\rho \times \mathbf{e} \times \mathbf{N_A})/\mathbf{A}$

  - $\mathbf{N_{beam}} = 5 \times 10^8\ p^+/s$
  - **e** (target thickness) = 50 cm

$x_p^\uparrow$ range corresponds to Drell-Yan measurements

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

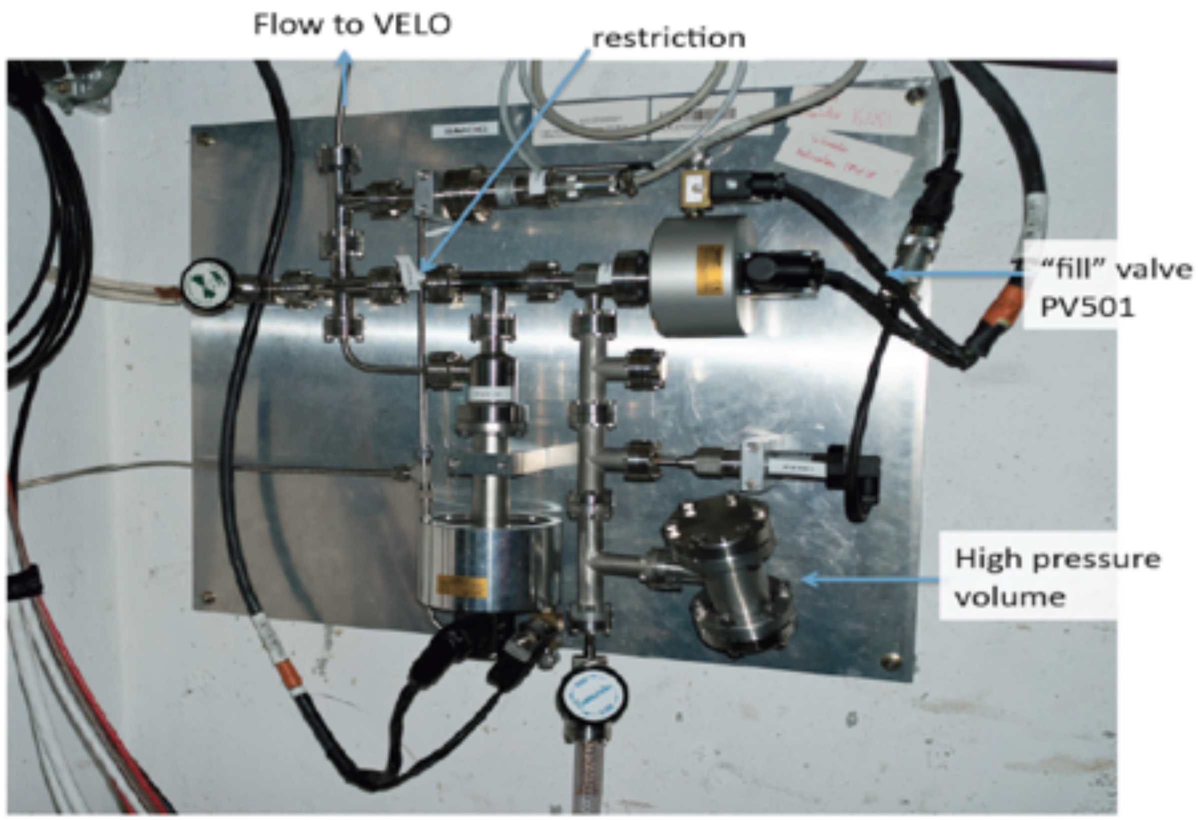
$\Rightarrow$ AFTER provides a good luminosity to study target spin related measurements

$\Rightarrow$ Complementary x_p range with other spin physics experiments

Internal gas target: SMOG @ LHCb

Internal gas target: SMOG @ LHCb

SMOG: System for Measuring Overlap with Gas



➜ injection of Ne-gas into VELO

- Only noble gas possible
- Gas jet target (target polarisation) strongly defavored
- Short data-taking p-Ne in 2012 and Pb-Ne in 2013 with low density gas target

2012 run p-Ne at $\sqrt{s}$ = 87 GeV
δt = 9600 s

LHCb-CONF-2012-034

2013 run Pb-Ne at $\sqrt{s}$ = 54 GeV
δt = 2400 s

M.Schmelling AFTER Workshop LesHouches 2014