AFTER@LHC, A Fixed Target ExpeRiment for hadron, heavy-ion and spin physics: status and short range plans

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STAR Regional meeting: Heavy quark production, jets and Correlations, 9-11th February, Prague, Czech Republic

OUTLINE

- What is AFTER@LHC and what for?
- Advantages of fixed target mode
- Some kinematics
- Various ways to collide LHC beams on fixed target
- LHC beam extraction using bent crystal
- Internal gas target technique
- Luminosity reached with a bent crystal
- Luminosity reached with an internal gas target
- Physics highlights of AFTER@LHC
- First simulations

WHAT IS AFTER@LHC AND WHAT FOR?

AFTER@LHC is a proposal for a multi-purpose fixed target experiment using the multi-TeV proton or heavy ion beams of the LHC, with 3 main objectives:

- **Advance our understanding of the large-x gluon, antiquark and heavy-quark content in the nucleon and nucleus**
  - → Large uncertainties on the PDF for $x \geq 0.5$
    - - Crucial to characterise possible Beyond-the-Standard Model discoveries
  - → Constrain the proton charm content
    - - Important for high energy neutrinos and cosmic ray physics
  - → EMC effect still an open problem; Search for possible gluon EMC effect
  - → Improve knowledge of nuclear pdf to understand the initial state of heavy-ion collisions
  - → Search for rare proton fluctuations where one gluon carries most of the proton momentum

- **Dynamics and spin of gluons inside (un)polarised nucleons**
  - → Possible missing contribution to the proton spin (e.g. angular momentum of partons)
  - → Test fundamental properties of QCD, such as factorization
  - → Study linearly polarised gluons in unpolarized protons

- **Heavy-ion collisions towards large rapidities**
  - → Explore the longitudinal expansion of QGP formation with new hard probes
  - → Test factorisation of cold nuclear matter effects from pA to A+B
  - → Origin of azimuthal asymmetries: hydrodynamical origin or initial state radiation?

ADVANTAGES OF FIXED-TARGET MODE

- **Several advantages of the fixed-target mode wrt to the collider mode**
  - Accessing **the high Feynman x_F** domain ($x_F = p_z/p_{zmax}$)
  - Achieving **high luminosities** thanks to dense targets
  - Easier **to change the target** type (≠ atomic mass)
  - Possibility to **polarize the target**

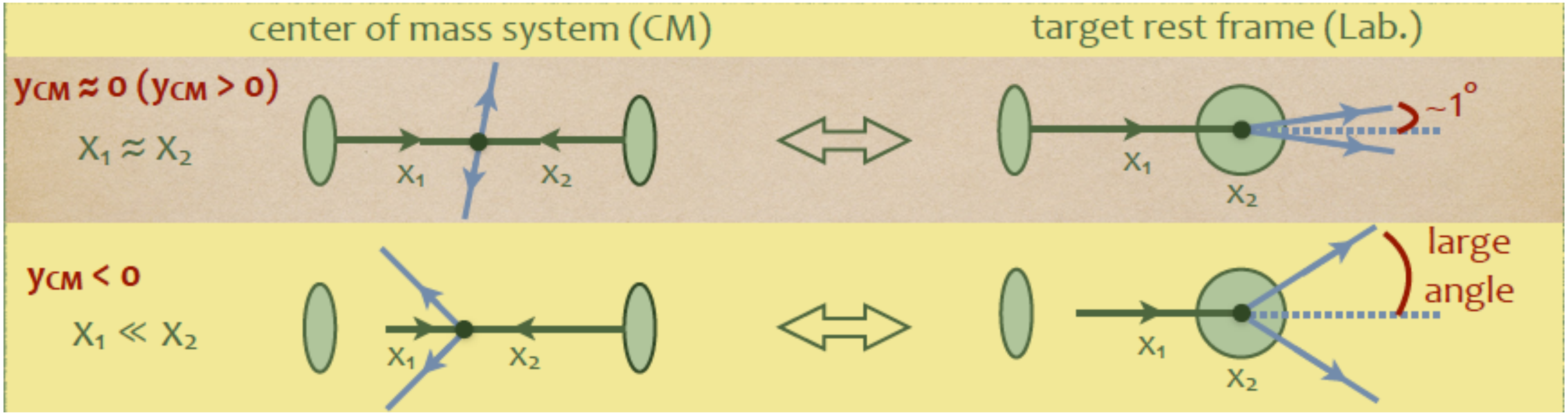
    → Open the possibility for a spin physics program!

- **<u>Without affecting the LHC performances</u>**
  - By recycling the beam losses (bent crystal in the halo of the LHC beam)
  - Or by using an internal gas target
- With an outstanding luminosity, yet without pile-up
- With modern detection techniques
- Virtually no limit on particle-species studies (except top quark)

AFTER@LHC would definitely be a unique experiment

SOME KINEMATICS

❑ **Provide a novel testing ground for QCD in the high x frontier: x = [0.3-1]**



- ❑ Entire CM forward hemisphere ($y_{CM} > 0$) within $0° < \theta_{lab} < 1°$ (small detector and high multiplicities → large occupancies)
- ❑ Backward physics ($y_{CM} < 0$) : larger angle in the laboratory frame (low occupancies, no constraint from beam pipe). Access to parton with momentum fraction $x_2 \to 1$ in the target

7 TeV proton beam on a fixed target

CMS energy:	$\sqrt{s} = \sqrt{2m_N E_p} \approx 115$ GeV	**Rapidity shift:** $y_{CM} = 0 \to y_{lab} = 4.8$
Boost:	$\gamma = \sqrt{s}/(2m_p) \approx 60$	

2.76 TeV Pb beam on a fixed target

CMS energy:	$\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} \approx 72$ GeV	**Rapidity shift:** $y_{CM} = 0 \to y_{lab} = 4.3$
Boost:	$\gamma \approx 40$	

VARIOUS WAYS TO COLLIDE LHC BEAMS ON FIXED TARGET

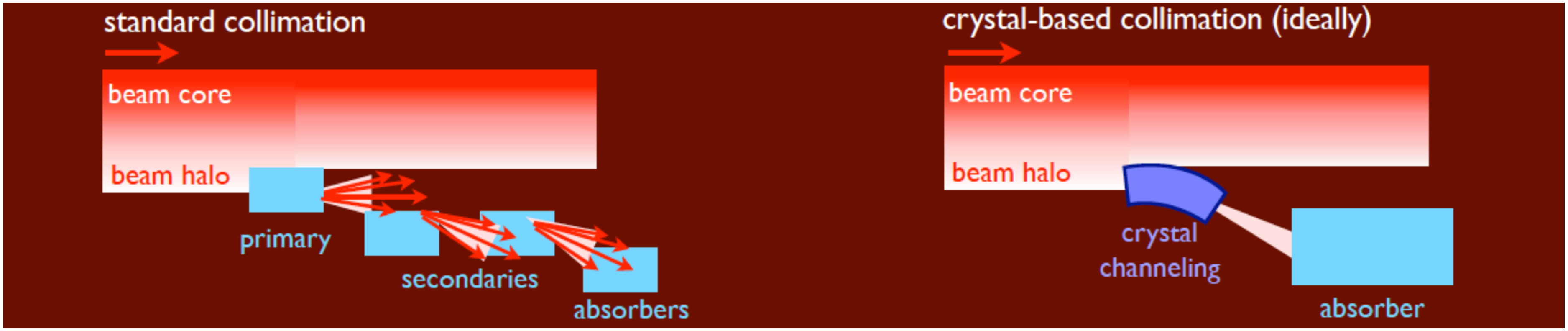
- ❑ **Beam line extracted with a bent crystal**
- ❑ **Beam «splitted» with a bent crystal**

Beam collimation at LHC using bent crystals is studied by the UA9 collaboration:
→ Amorphous collimator, inefficiency of 0.2% (3.5 TeV p beam)
→ Expected bent cristal inefficiency : 0.02%
UA9: test @SPS on the crystal with proton and ion beams
LUA9 (beam bending experiment at LHC using crystal): approved by LHCC
- 2 bent crystals installed in IR7 during LS1
- 2015/2016 first tests with beams
Proton beam extraction: Single or multi-pass extraction efficiency (50%)
LHC beam loss: 10^9 p/s **→ Expected extracted beam: 5 x 10^8 p/s**
Pb beam extraction: Succesfully tested @SPS, should also work @LHC
→ Expected extracted beam: 2 x 10^5 Pb/s

- ❑ **Internal wire target**
- ❑ **Internal gas target «à la» SMOG-LHCb**

Can be installed in one of the existing LHC experiment or in a new one
Currently tested by the LHCb collaboration via a luminosity monitor (SMOG)
Proton flux: **3.4 x 10^{18} p/s**
Pb flux: **3.6 x 10^{14} Pb/s**

LHC BEAM EXTRACTION USING A BENT CRYSTAL

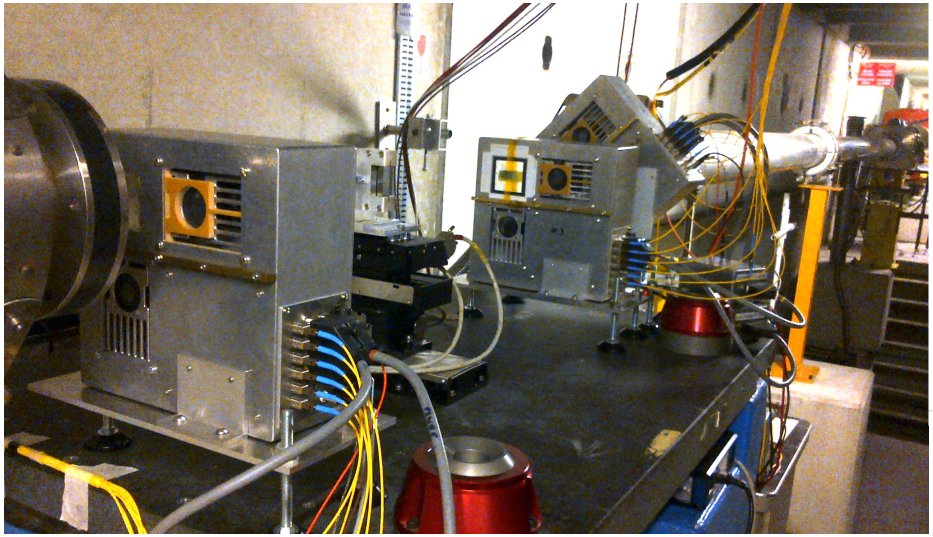


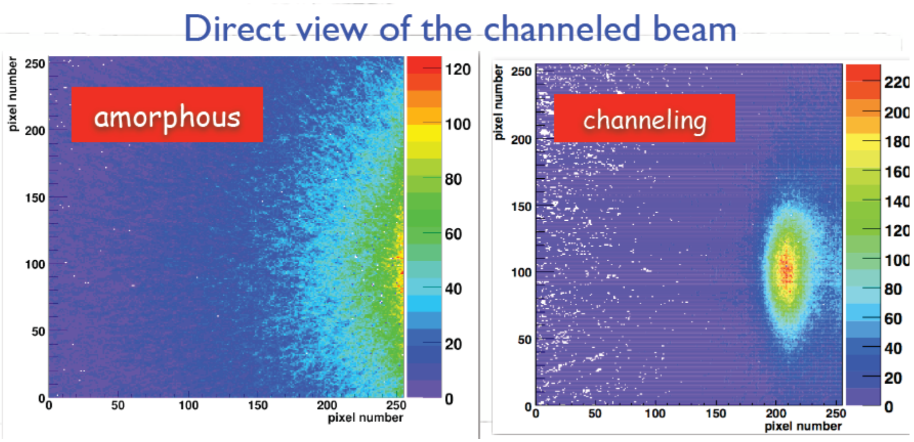
Standard collimation today

Crystal-based collimation
- UA9 (@SPS)
- LUA9 (@LHC)

To beam extraction
- CRYSBEAM (@SPS then LHC)
- AFTER@LHC

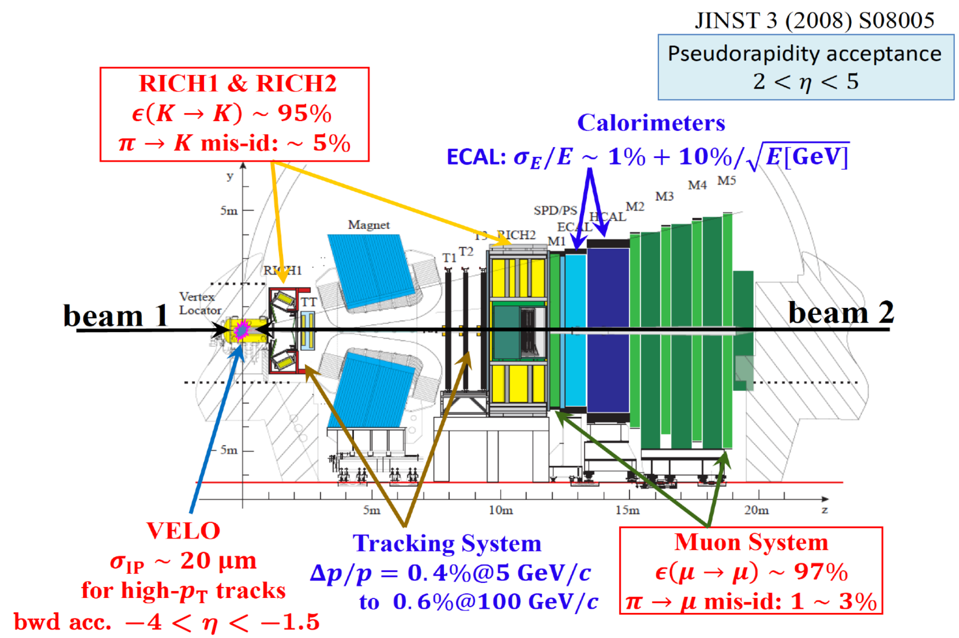
H8 beam line (UA9 experiment @ SPS), 15/10/2014



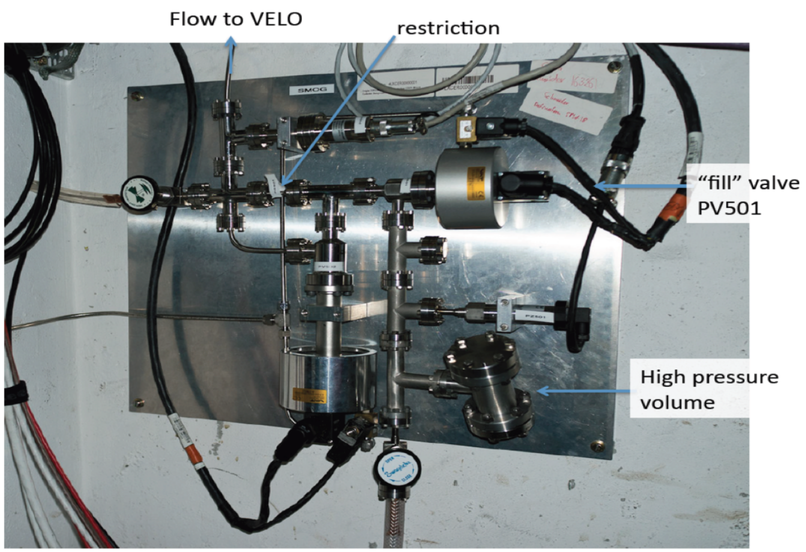


S. Montesano, W. Scandale, Joint LUA9-AFTER meeting, Nov. 2013

INTERNAL GAS TARGET TECHNIQUE



SMOG: System for Measuring Overlap with Gas



➜ injection of Ne-gas into VELO

- ❑ Low density Ne-gas injected into LHCb Vertex Locator
- ❑ Short pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV in 2012 *LHCb-CONF-2012-034*
- ❑ Short PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV in 2013
- ❑ Noble gases favored
- ❑ No polarization of the target possible with the current SMOG system
  - → but could be done with another system, using for e.g. atomic beam source or optical pumping to polarize the target

SMOG tested only during few hours in a row during data taking
- → no decrease of LHC performances observed
- → more studies needed over extended periods of time

LUMINOSITIES IN pH, pA @ $\sqrt{S_{NN}}$ = 115 GeV WITH BENT CRYSTAL

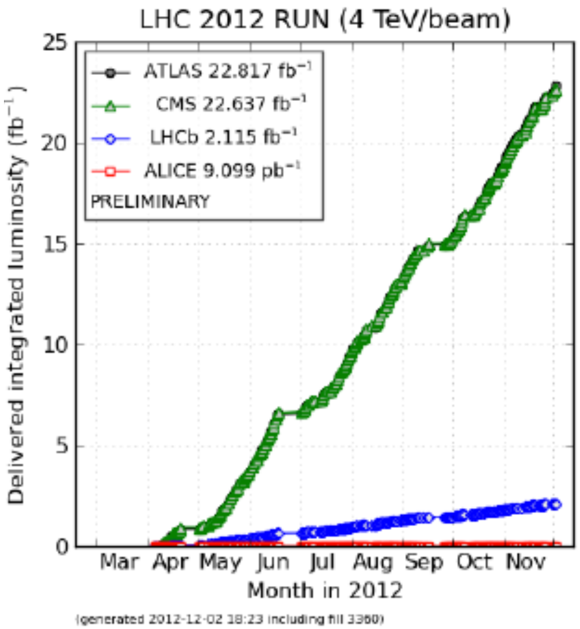
Instantaneous luminosity: $L = \phi_{beam} \times N_{target} = \phi_{beam} \times (\rho \times \ell \times N_A)/A$

With ℓ target thickness, $\phi_{beam} = 5 \times 10^8 p^+ s^{-1}$ (1/2 of the beam loss)

Integrated luminosity: assuming 10^7s of p beam (LHC year)

In pH and pA (115 GeV/c)

Target	ρ (g.cm^{-3})	A	L (μb^{-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



Luminosity comparable to the LHC itself (with 1m long H_2 (D_2) target)
3 orders of magnitude larger than PHENIX@RHIC
typical luminosities (RHIC decadal plan): pp@200GeV: 12pb^{-1}; dAu@200GeV: 0.15pb^{-1}

LUMINOSITIES IN PbA @ $\sqrt{S_{NN}}$ = 72 GeV WITH BENT CRYSTAL

Instantaneous luminosity: $L = \phi_{\text{beam}} \times N_{\text{target}} = \phi_{\text{beam}} \times (\rho \times \ell \times N_A)/A$

With ℓ target thickness, $\phi_{beam} = 2\times10^5\,\text{Pb}\,s^{-1}$ (1/2 of the beam loss)

Integrated luminosity: assuming 10^6s of Pb beam (LHC year)

In PbA (72 GeV/c)

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

Typical luminosity (PHENIX decadal plan) :
AuAu@200GeV ~ 3 nb^{-1} (0.13 nb^{-1} @62 GeV)
Nominal LHC lumi for PbPb 0.5 nb^{-1}

LUMINOSITIES IN pA and PbA WITH INTERNAL GAS TARGET

Instantaneous luminosity: $L = \phi_{\mathrm{beam}} \times N_{\mathrm{target}} = \phi_{\mathrm{beam}} \times (\rho \times \ell \times N_A) / A$

With $\phi_{p^+} = 3.2 \times 10^{14} p^+ \times 11000\,\mathrm{Hz} = 3.5 \times 10^{18} p^+ s^{-1}$
With $\phi_{\mathrm{Pb}} = 4.2 \times 10^{10}\,\mathrm{Pb} \times 11000\,\mathrm{Hz} = 4.6 \times 10^{14}\,\mathrm{Pb}\, s^{-1}$
Usable gas zone ℓ up to 100 cm

Target density: $\rho = \frac{A \times \mathrm{P}}{22400}\ \mathrm{bar}^{-1} g\ \mathrm{cm}^{-3}$ (1mol of perfect gas occupies 22400 cm^3 at 273K and 1 bar)

Instantaneous luminosity is therefore: $L = \phi_{\mathrm{beam}} \times N_{\mathrm{target}} = \phi_{\mathrm{beam}} \times (\frac{\mathrm{P}}{22400} \times \ell \times N_A)$

Calculation assuming **P = 10^{-9} bar** (~7 times larger than SMOG 2012 [unofficial])

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
Pb	Perfect gas	100	10^{-9}	0.001	0.001

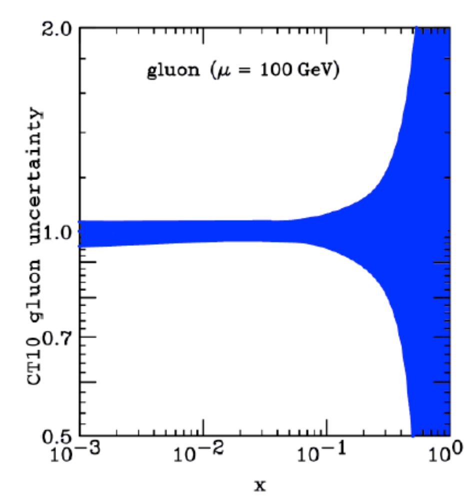
Provided that the runs can last as long, similar integrated luminosities in **pA** as with the bent crystal case
In **pp**, to be competitive with bent crystal ($\int L$ ~ 10 fb^{-1}y^{-1}), one needs **P = 10^{-7} bar**!

PHYSICS HIGHLIGHTS FOR AFTER@LHC

p-p and p-A @ $\sqrt{s_{NN}}$ = 115 GeV

Nucleon partonic structure

- ❑ Gluon PDF in the proton → large uncertainty at large x. DIS not ideal
- ❑ $g_n(x) = g_p(x)$?
- ❑ Experimental probes: quarkonia, isolated photons, high p_T jets
- ❑ Multiple probes essential to check factorization



Heavy quark distribution at large x in the proton

- ❑ Pin down Intrinsic charm
- ❑ Experimental probes: open heavy flavors

Spin Physics

Gluon Sivers effect

Linearly polarized gluons: $h_1^{\perp g}$

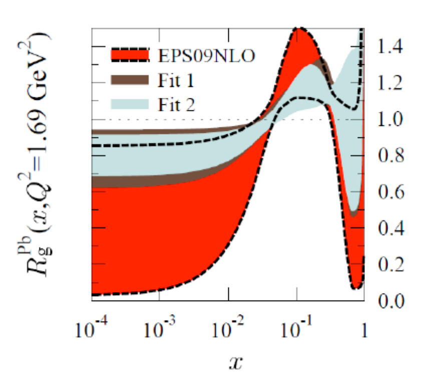
STSA in HF and DY studies

W and Z bosons production near threshold

p-A @ $\sqrt{s_{NN}}$ = 115 GeV and Pb-A @ $\sqrt{s_{NN}}$ = 72 GeV

Gluon distribution in nucleus at large x

- ❑ Large uncertainty at high x
- ❑ EIC, LHeC experiments do not help much



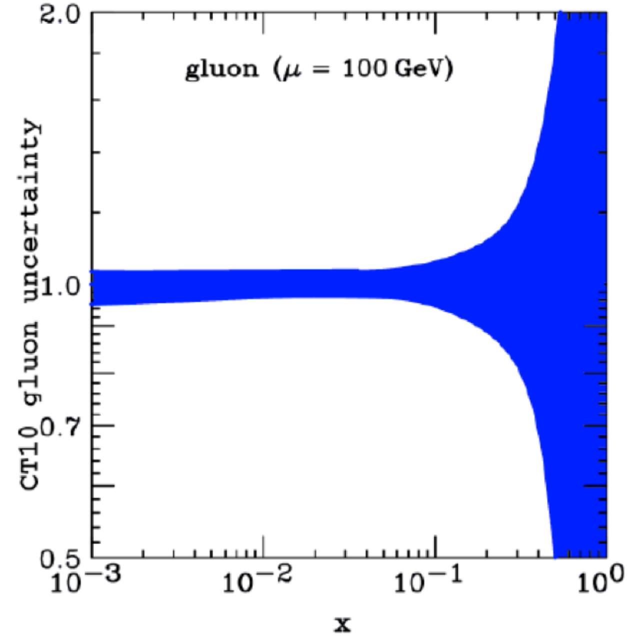
Quark Gluon Plasma

- ❑ ϒ sequential suppression
- ❑ Quarkonium excited state suppression
- ❑ Jet-HF quenching
- ❑ Direct photons

Ultra-peripheral collisions

NUCLEON PARTONIC STRUCTURE: GLUONS IN THE PROTON

- ❑ Study gluon distributions at mid and high x_B in the proton
  - Not easily accessible in DIS
  - Translates into very large uncertainties

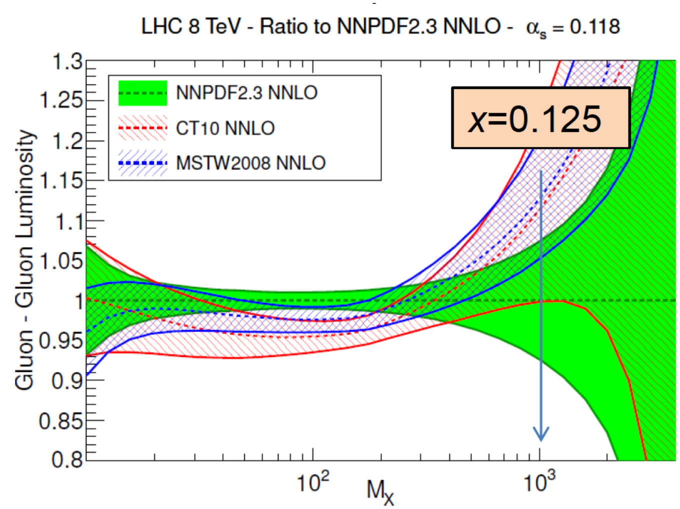


- ❑ Accessible via gluon sensitive probes:
- Quarkonia

  D. Diakonov et al., JHEP 1302 (2013) 069
- Isolated photons

  D. d'Enterria, R. Rojo, Nucl. Phys. B860 (2012) 311
- Jets ($20 \leq p_T \leq 40$ GeV/c)

- ❑ Gluon distribution unknown for the neutron



Multiple probes needed to check factorisation

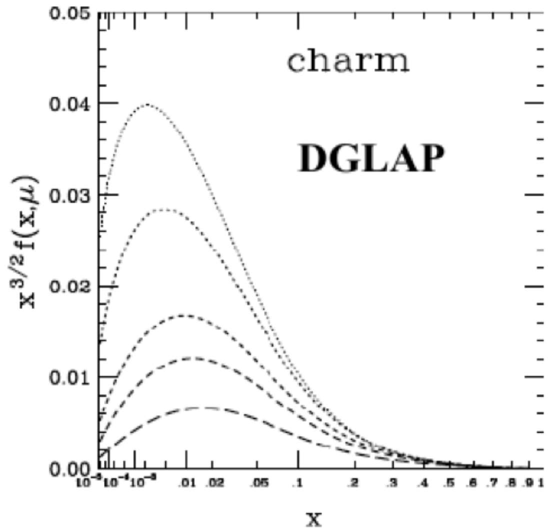
Large-x gluons: important to characterise some possible BSM findings at the LHC

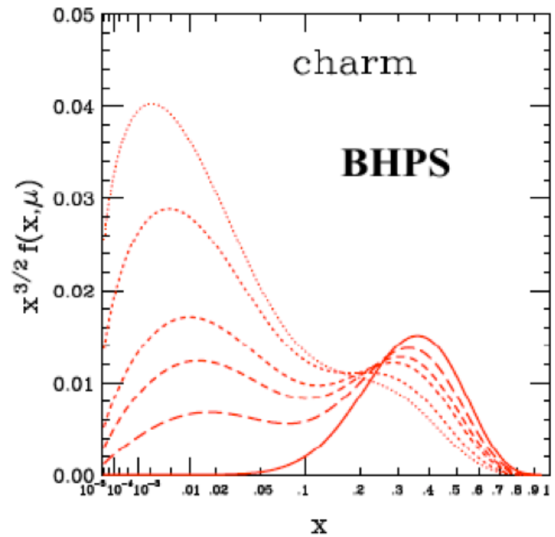
HEAVY QUARK CONTENT OF THE PROTON

❑ Pin down intrinsic charm

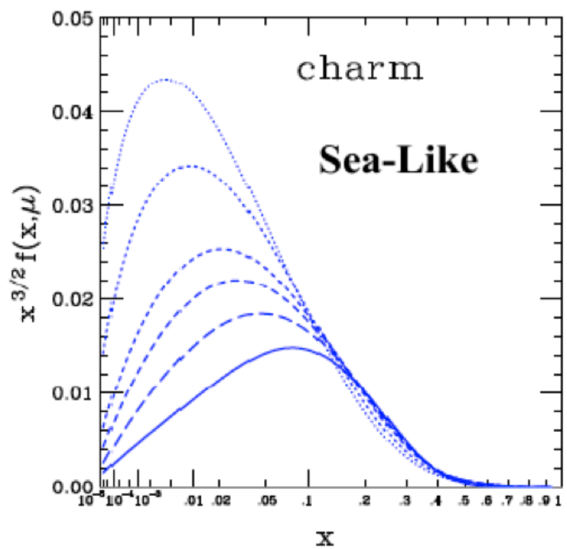
- ❑ Intrinsic charm is a rigorous property of QCD
- ❑ Different charm pdfs (DGLAP or models with intrinsic charm) are in agreement with DIS data
- ❑ Important for high energy neutrino and cosmic ray physics
- ❑ Requirement

- Several complementary measurements
- Good coverage in the target-rapidity region
- High luminosity to reach large x_B





CTEQ6.5C with intrinsic charm



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

(Gluon) Sivers effects with a transversely polarized target

Gluon Sivers effect: correlation between the gluon transverse momentum k_T and the proton spin

- **The target rapidity region ($x_F < 0$) corresponds to high $x^{\uparrow}$ ($x_F \rightarrow -1$) where the k_T - spin correlation is the largest**
- Transverse single spin asymmetries studied using **gluon sensitives probes:**
  - quarkonia (J/ψ, Υ, χ_c) *F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)*
  - B & D mesons production
  - γ, γ-jet, γ-γ also J/ψ-γ *A. Bacchetta et al., PRL 99 (2007) 212002* *J. W. Qiu et al., PRL 107 (2011) 062001*
- High precision data and high luminosities needed to study Single Transverse Spin Asymmetries

SPIN OF QUARKS INSIDE POLARIZED NUCLEONS

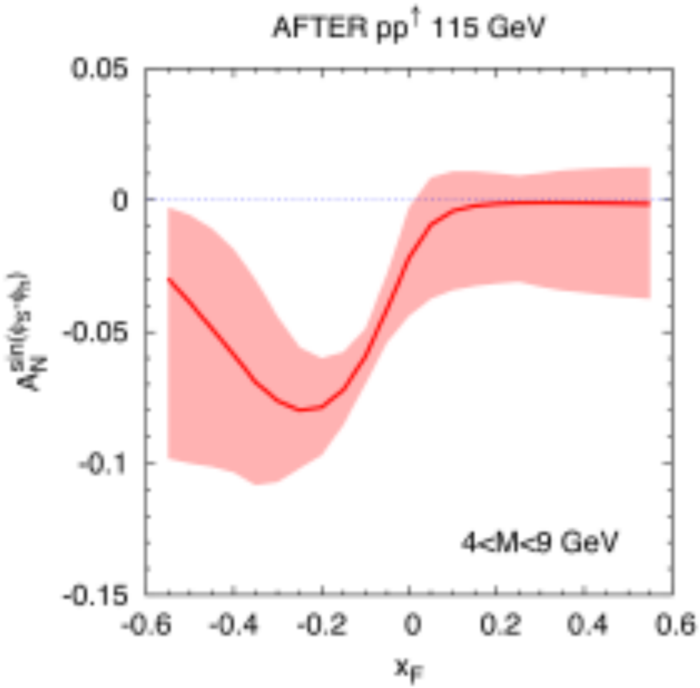
(Quark) Sivers effects with a transversely polarized target

- Can be probed with the Drell-Yan process

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

Relevant parameters for the future proposed polarized DY experiments

S. J. Brodsky et al., Phys. Rep. 522 (2013) 239
V. Barone et al., Prog. Part. Nucl. Phys. 65 (2010) 267



Prediction for AFTER

M. Anselmino, ECT*, Feb. 2013
(Courtesy U. D'Alesio)

Asymmetry up to 10% predicted in DY for the target rapidity region ($x_F < 0$)

SPIN OF GLUONS INSIDE (UN)POLARIZED NUCLEONS

Access to the distribution of linearly polarized gluons ($h_1^{\perp g}$)

« Boers-Mulder » effect: correlation between the parton k_T and its spin
For gluons, it is encoded in $h_1^{\perp g}$

- Low-p_T C-even quarkonium production is a good probe of the gluon TMDs.
- The low-p_T spectra of scalar and pseudo-scalar quarkonium (χ_{c0}, χ_{b0}, η_c, η_b) are affected differently by the linearly polarized gluons in unpolarized nucleons

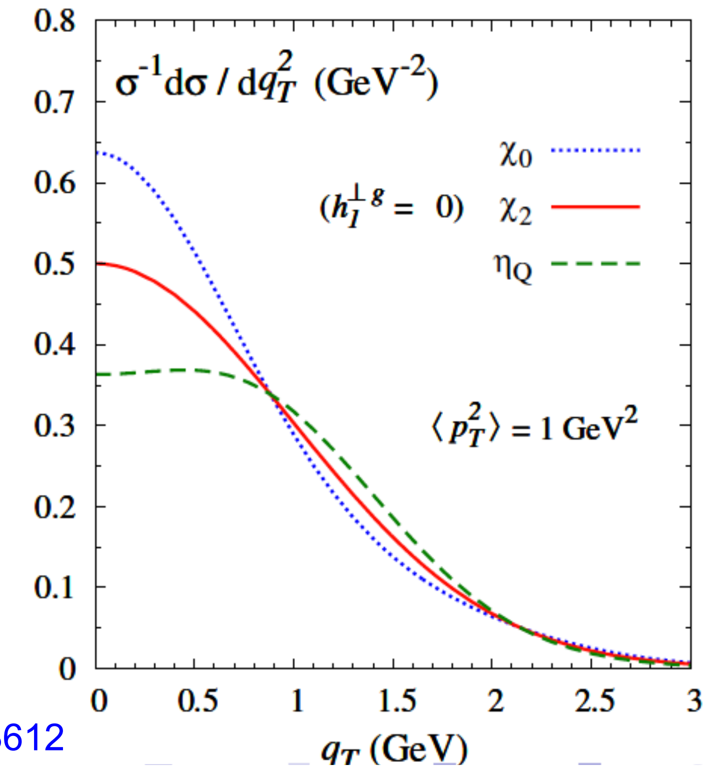
$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \;\&\; \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

R involves $h_1^{\perp g}$

→ Boost: better access to low-p_T C-even quarkonia

→ Still challenging experimentally (first study of η_c in collider by LHCb for p_T > 6 GeV/c) arXiv:1409.3612

→ If possible somewhere, it is at AFTER@LHC



Boer, Pisano, PRD 86 (2012) 094007

- Back-to-back J/ψ + γ is also a good probe of gluon TMDs

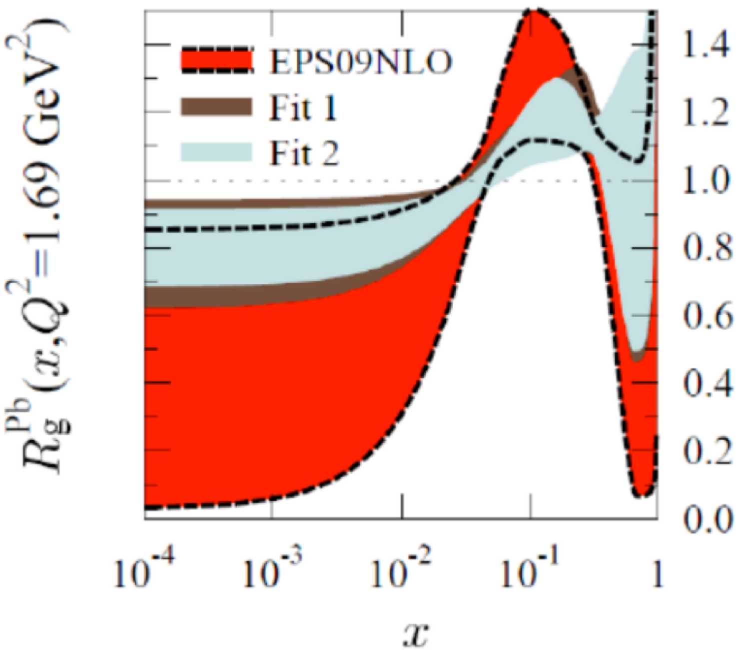
Den dunnen et al., PRL 112 (2014) 212001, J. P. Lansberg, Transversity 2014

pA STUDIES

❑ GLUON DISTRIBUTION IN NUCLEUS AT LARGE X

- ❑ Large-x gluon nPDF unknown
- ❑ EIC and LHeC focused on low x (and not before 2028?)
- ❑ Look for possible gluon EMC effect
- ❑ Use gluon sensitive probes: quarkonia, isolated photons, high x_T jets

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



❑ TEST FACTORISATION OF COLD NUCLEAR MATTER EFFECTS

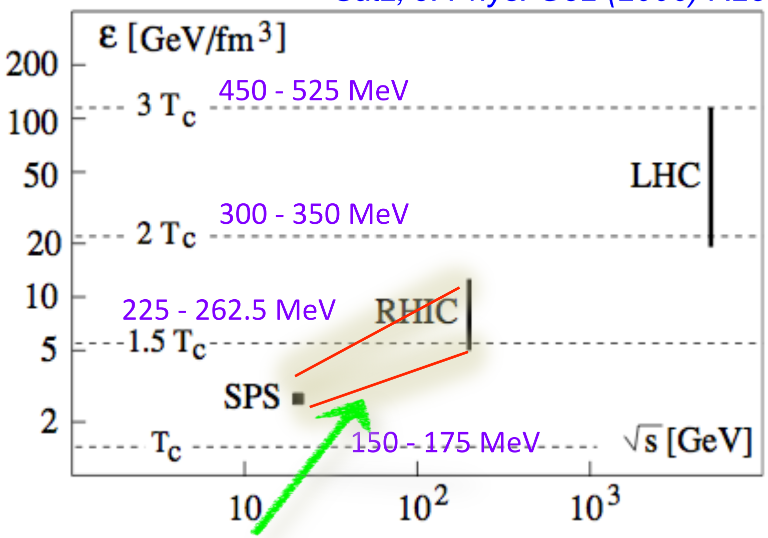
- ❑ Can one predict the cold nuclear effects in A+B collisions from p+A data?
- ❑ Use probe insensitive to quark gluon plasma formation: **Drell Yan**
- ❑ Measure Drell Yan in pA and pB to predict A+B and compare with measurement
- ❑ Cannot be done at an EIC

HEAVY ION COLLISIONS TOWARDS LARGE RAPIDITIES

From the viewpoint of one of the colliding nuclei ⏎

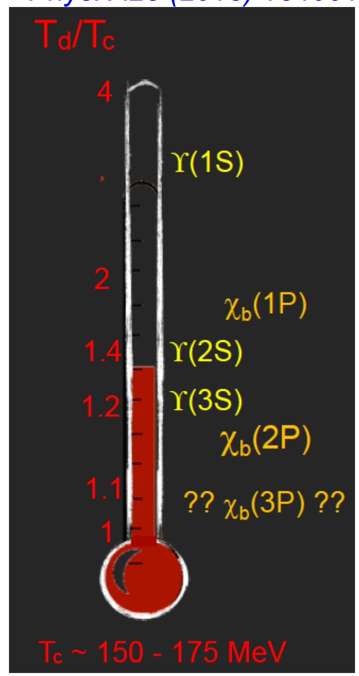
❑ QUARK GLUON PLASMA STUDIES

Satz, J. Phys. G32 (2006) R25

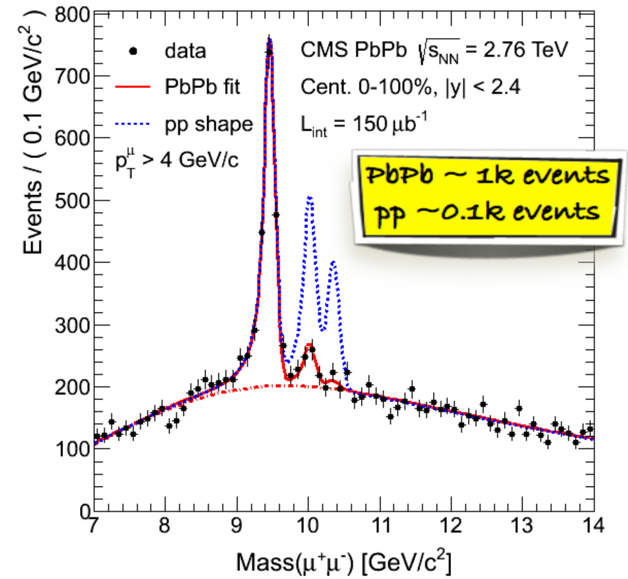


AFTER in PbA
$\sqrt{s_{NN}}$ ~ 72 GeV

Mocsy et al, Int. J. Mod. Phys. A28 (2013) 1340012



Dissociation temperature from lattice QCD (+hydro)



Phys. Rev. Lett. 109 (2012) 222301

- ❑ At AFTER@LHC energy, ϒ(3S) and ϒ(2S) are expected to melt (QGP thermometer)
- ❑ Enough stat to perform the same study as CMS at low energy

❑ UNDERSTAND FORMATION OF AZIMUTHAL ASYMMETRIES

- ❑ Hydro versus initial state radiations

PHYSICS HIGHLIGHTS FOR AFTER@LHC

- More details in Physics Reports 522 (2013) 239

Physics Reports 522 (2013) 239–255

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ELSEVIER

Physics opportunities of a fixed-target experiment using LHC beams

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Contents

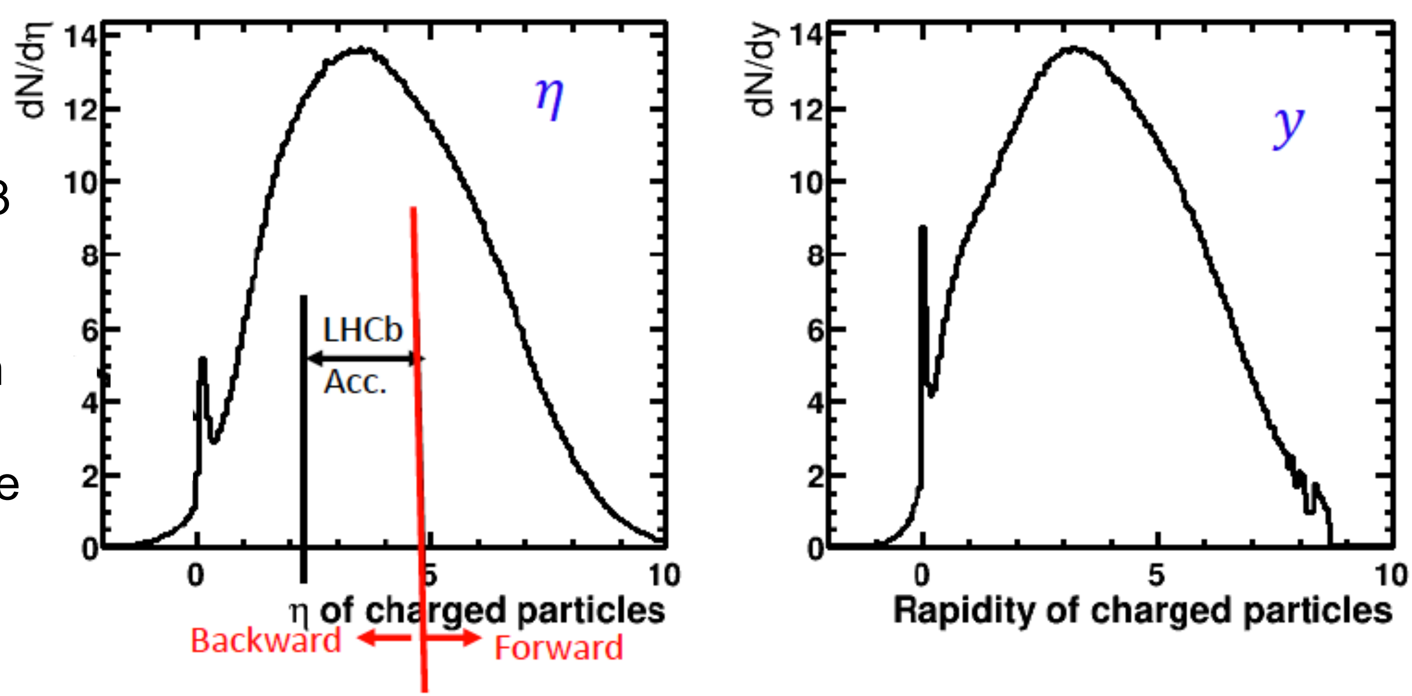
Simulations of a 7 TeV proton beam on a Pb target ($\sqrt{s_{NN}}$ = 115 GeV)

- **Full LHCb simulation and standard reconstruction**
- Study the resolution at vertex, the occupancy in the pixels…
- Compare multiplicities in AFTER with LHCb pA run

- Simulations with HIJING version 1.383bs.2
- 10 000 events generated, no pile-up

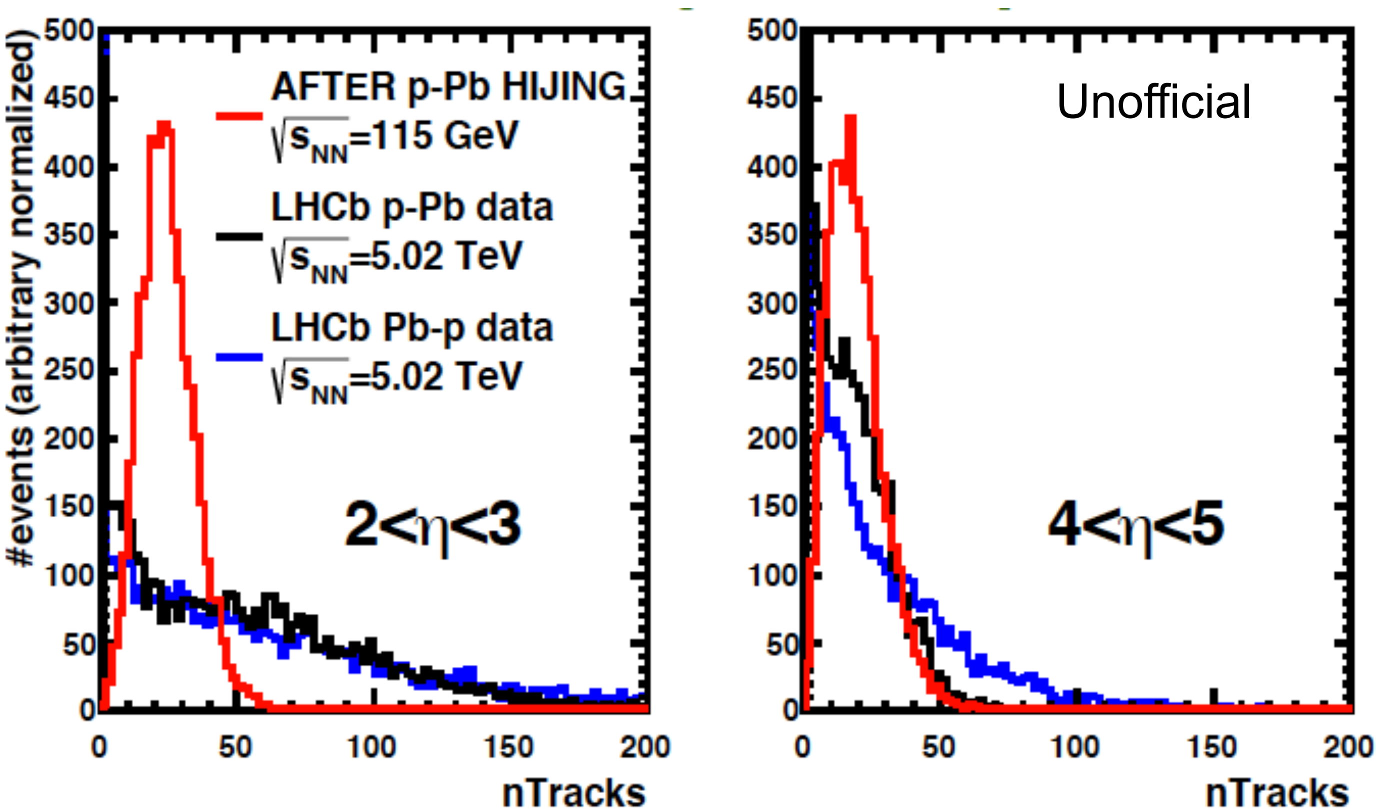
Z. Yang, AFTER workshop les Houches, January 2014

dN/dη ~ 13
Generated charged particles in LHCb acceptance



Simulations of a 7 TeV proton beam on a Pb target ($\sqrt{s_{NN}}$ = 115 GeV)

Z. Yang, AFTER workshop les Houches, January 2014



- ❑ Probability for high track multiplicity in AFTER (pPb @ 115 GeV) is lower than the one measured by LHCb (pPb/Pbp @ 5.02 TeV)

- ❑ No problem for a LHCb-like detector to cope with the multiplicity of pPb collisions at $\sqrt{s_{NN}}$ = 115 GeV in 2 < η <5

QUARKONIUM CASE

Expected quarkonium yields

In pH and pA (115 GeV)

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

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

In PbA (72 GeV)

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

pp : 1000 times more statistics than at RHIC ($\sqrt{s}$ = 200 GeV) and comparable statistics to LHCb with a 1m H_2 target
pA: 100 times more statistics than at RHIC (dAu $\sqrt{s}$ = 200 GeV) with a 1cm Pb target

PbA: similar statistics as at RHIC (Au-Au $\sqrt{s_{NN}}$ = 200 GeV) and 2 orders of magnitude larger than at RHIC (Au-Au $\sqrt{s_{NN}}$ = 62 GeV) with a 1cm thick Pb target

Detailed study of quarkonium production and nuclear effects

Detailed study of quarkonium states

FAST SIMULATIONS FOR QUARKONIA (pp $\sqrt{s}$ = 115 GeV) USING LHCb RECONSTRUCTION PARAMETERS

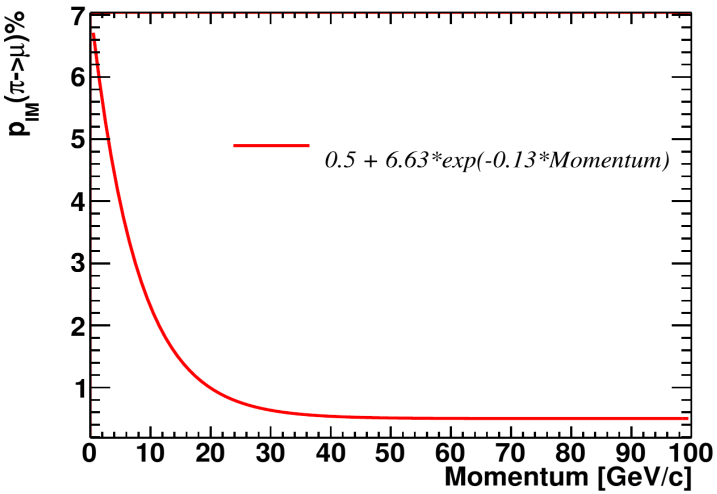
- Simulations with Pythia 8.185
- LHCb detector is NOT simulated but LHCb reconstruction parameters are introduced in the fast simulation (resolution, analysis cuts, efficiencies…)

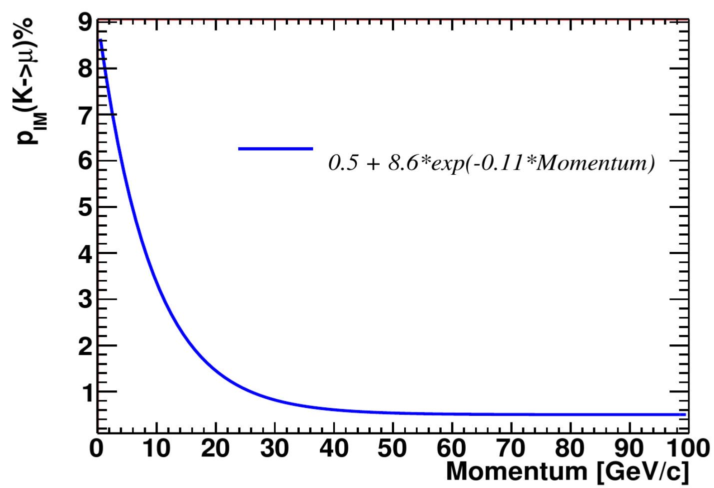
Requirements
Momentum resolution : $\Delta p/p = 0.5\%$
Muon identification efficiency: 98%

Cuts at the single muon level
$2 < \eta_{\mu} < 5$
$p_T^{\mu} > 0.7$ GeV/c

Muon misidentification
If π and K decay before the calorimeters (12m), they are rejected by the tracking
Otherwise a misidentification probability is applied

Performance of the muon identification at LHCb,
F. Achilli et al, arXiv:1306.0249

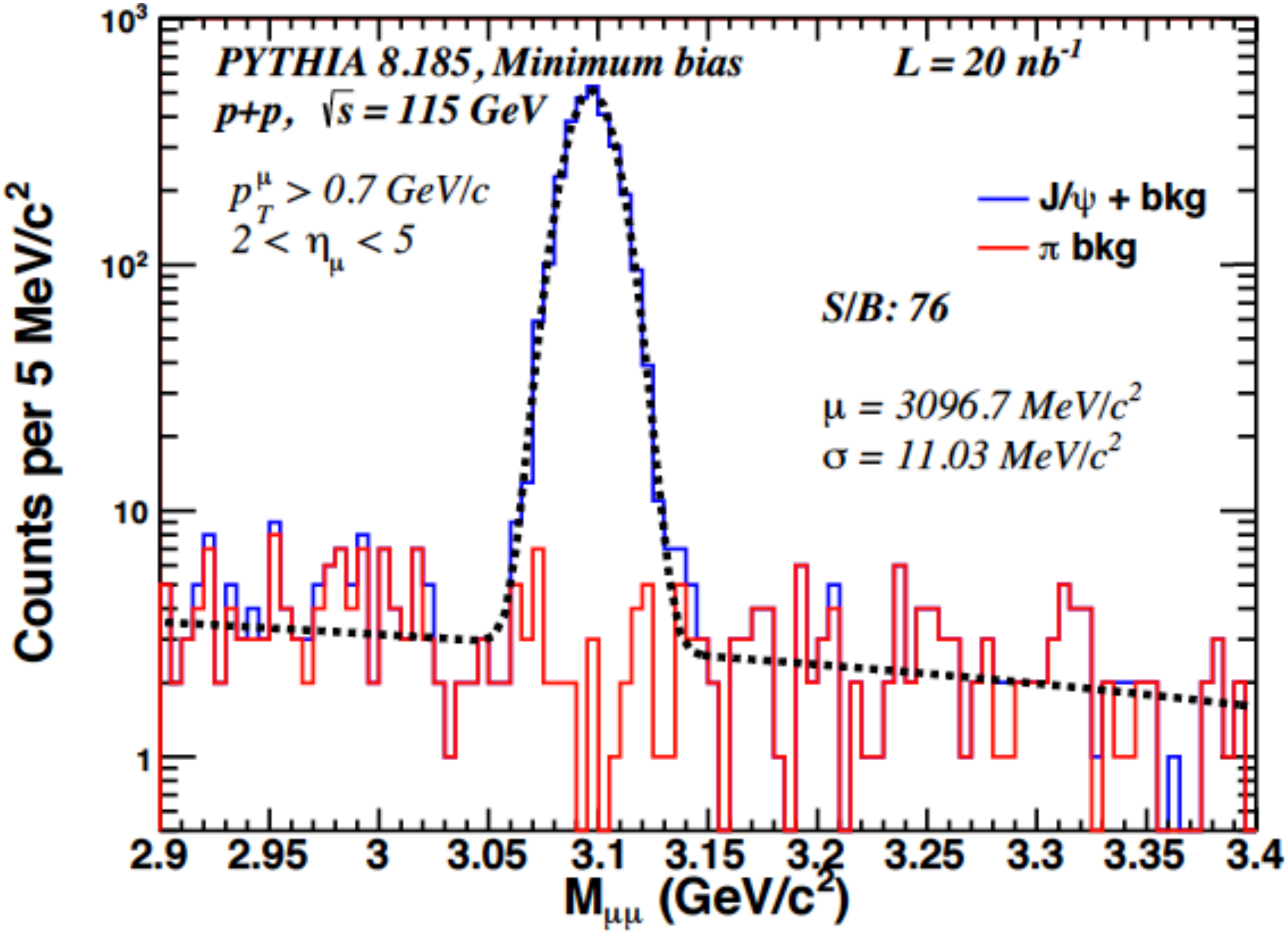




J/Ψ → $\mu^+\mu^-$ IN MINIMUM BIAS pp COLLISIONS @ 115 GeV

- For 1m of H target and 10 seconds of data taking!

B. Trzeciak, July 2014, Orsay



Misidentified pions is the dominant source of background

J/Ψ →μ⁺μ⁻ IN MINIMUM BIAS pp COLLISIONS @ 115 GEV (BINS IN RAPIDITY)

- ❑ For 1m of H target and 1.5 minute of data taking

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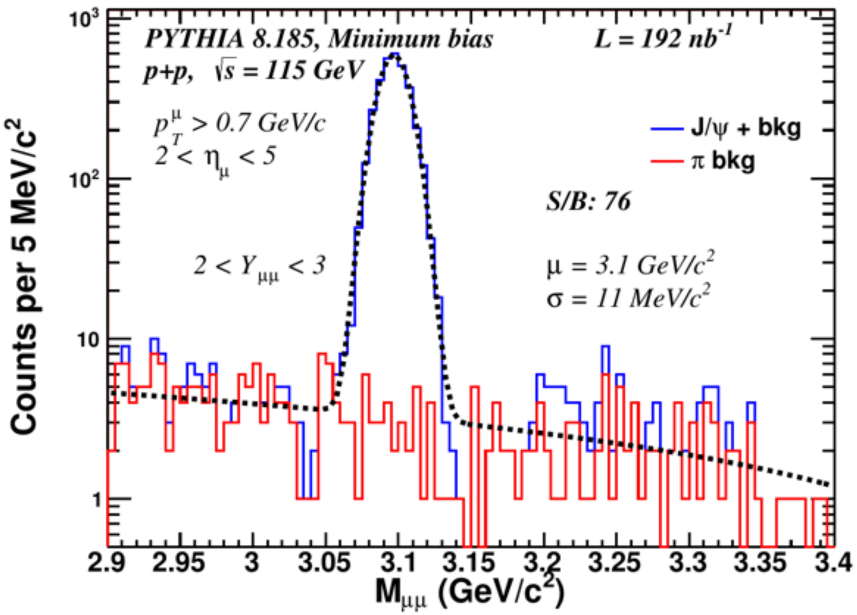
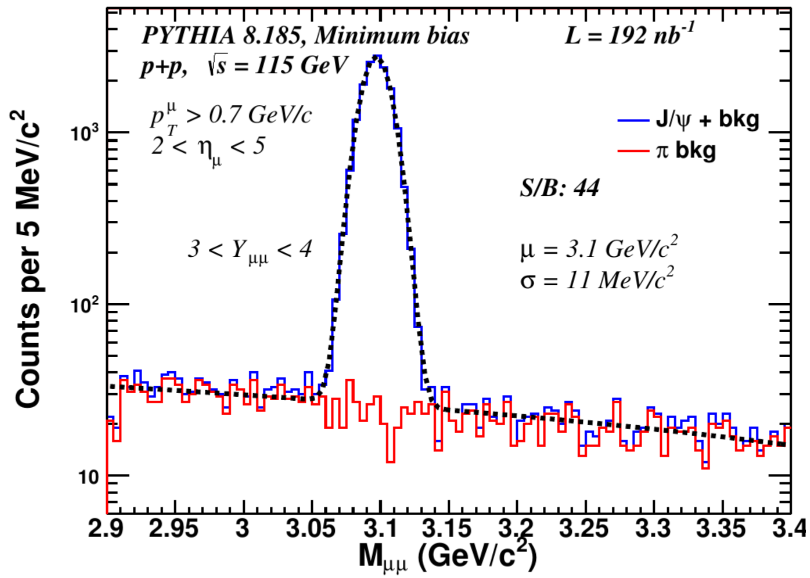
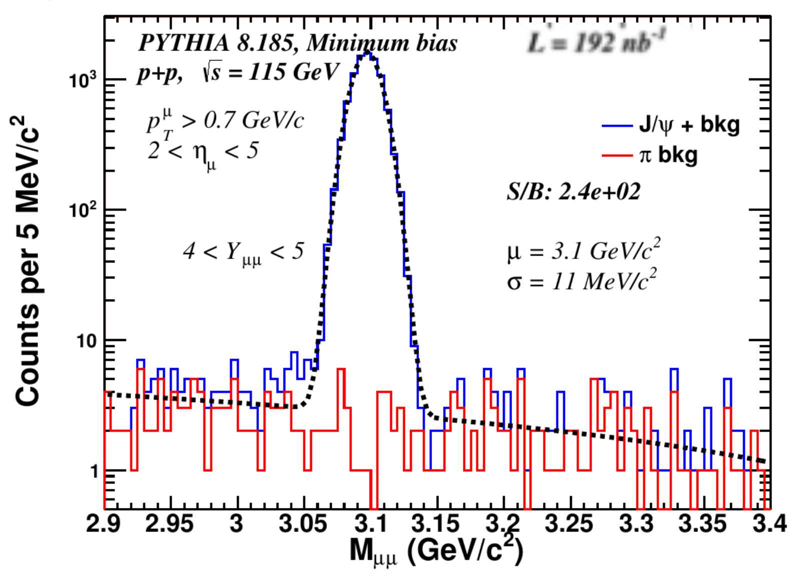


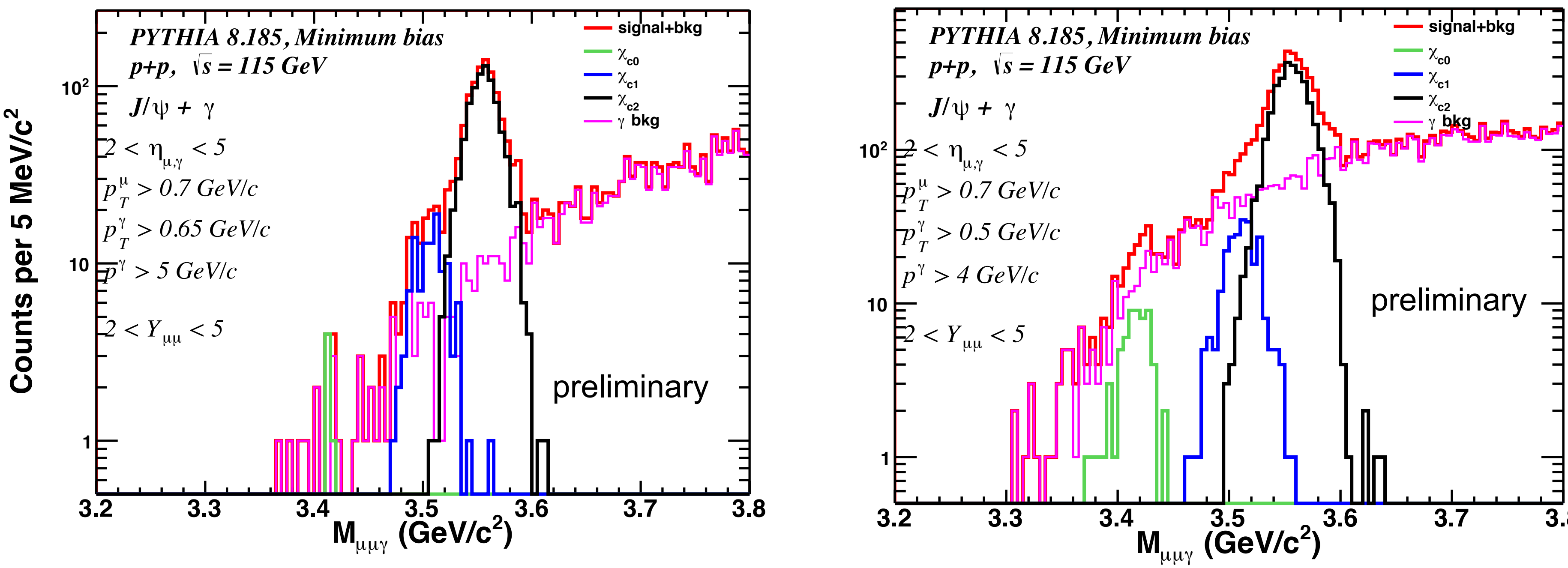




$\chi_c \rightarrow \mu^+\mu^-\gamma$ IN MINIMUM BIAS pp COLLISIONS @ 115 GEV

- Preliminary studies of the χ_c also started
- L_{int} = 192 nb^{-1}, **for 1m of H target and 1.5 minute of data taking**

B. Trzeciak, July 2014, Orsay



- Hope to be able to reach p_T of the χ_c down to 0
- χ_{c1} and χ_{c2} separation

SUMMARY

- ❑ AFTER@LHC provides a novel testing ground for QCD in the high x frontier
- ❑ High luminosities are achievable in pp, pA @ 115 GeV and PbA @ 72 GeV using dense targets and without affecting the LHC beam
- ❑ Large potential for spin physics, heavy ion physics, and improvement of the understanding of the large-x gluon, antiquark and heavy-quark content in the nucleon and nucleus
- ❑ First fast simulations with LHCb like setup are promising

- ❑ What's next :
  - Special issue in Advances in High Energy Physics (submission deadline in March 2015)
    Everybody is welcome to contribute
  - Expression of interest expected in 2015

- ❑ The AFTER web page : after.in2p3.fr

Hindawi

Advances in High Energy Physics

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

CALL FOR PAPERS

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

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

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

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

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

Potential topics include, but are not limited to:

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

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Manuscript Due
Friday, 20 March 2015

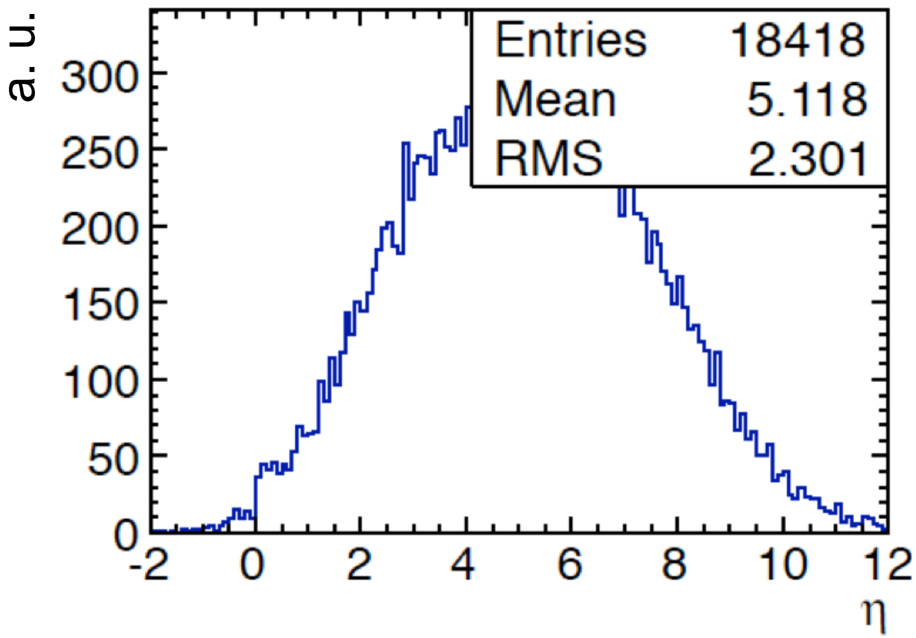
First Round of Reviews
Friday, 12 June 2015

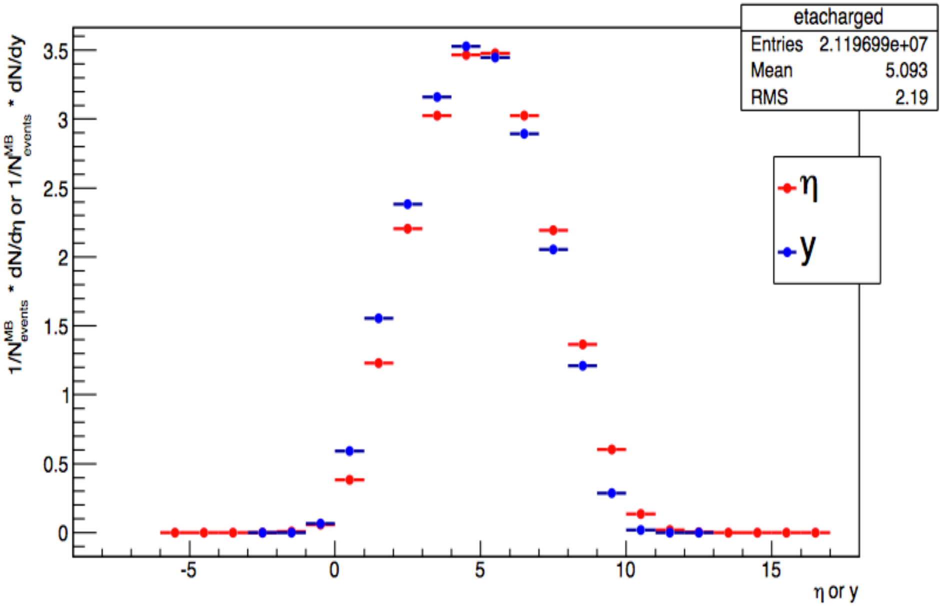
Publication Date
Friday, 7 August 2015

BACK UP

NUMBER OF CHARGED PARTICLES IN MB pp @ √S = 115 GEV

AFTER workshop les Houches, January 2014
AFTER simulation group





EPOS 1.6.5
Number of generated events: 1000

$dN_{ch}/d\eta\,|_{\eta = 0} \sim 3$

PYTHIA 8.170
Number of generated events: 10^6

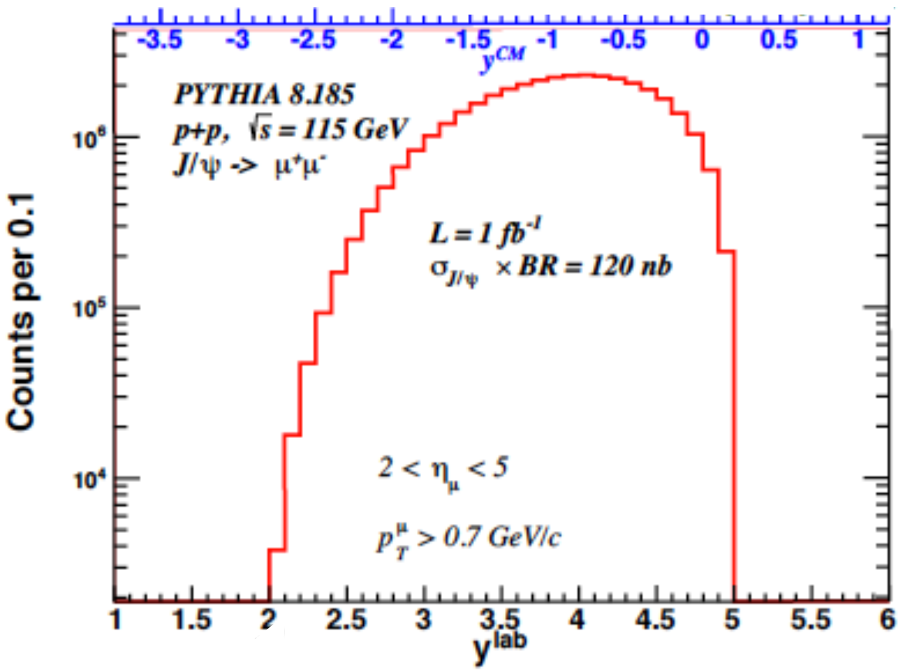
$dN_{ch}/d\eta\,|_{\eta = 0} \sim 3.5$

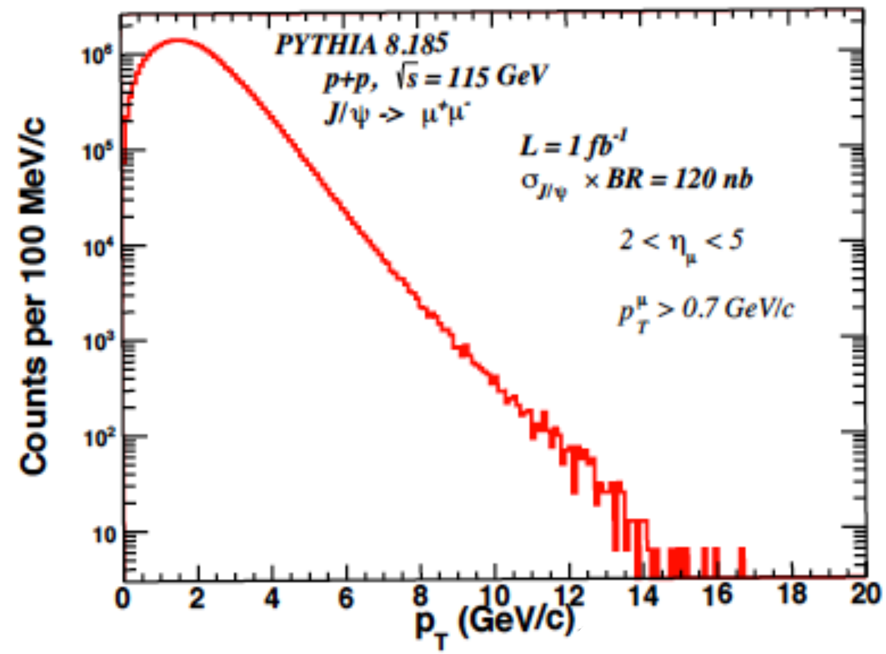
Rapidity shift: $\Delta y = \tan^{-1}\beta \approx 4.8$
$y_{CM} = 0 \rightarrow y_{lab} \approx 4.8$

J/Ψ →μ⁺μ⁻ IN MB pp @ 115 GEV (Y_{LAB} AND P_T REACH)

- For 1m of H target and 2 weeks of data taking

B. Trzeciak, July 2014, Orsay





Large statistics allow one:

- To reach large p_T
- Large y_{lab} acceptance $2 < y_{lab} < 5$

ACCESSING THE LARGE x GLUON PDF

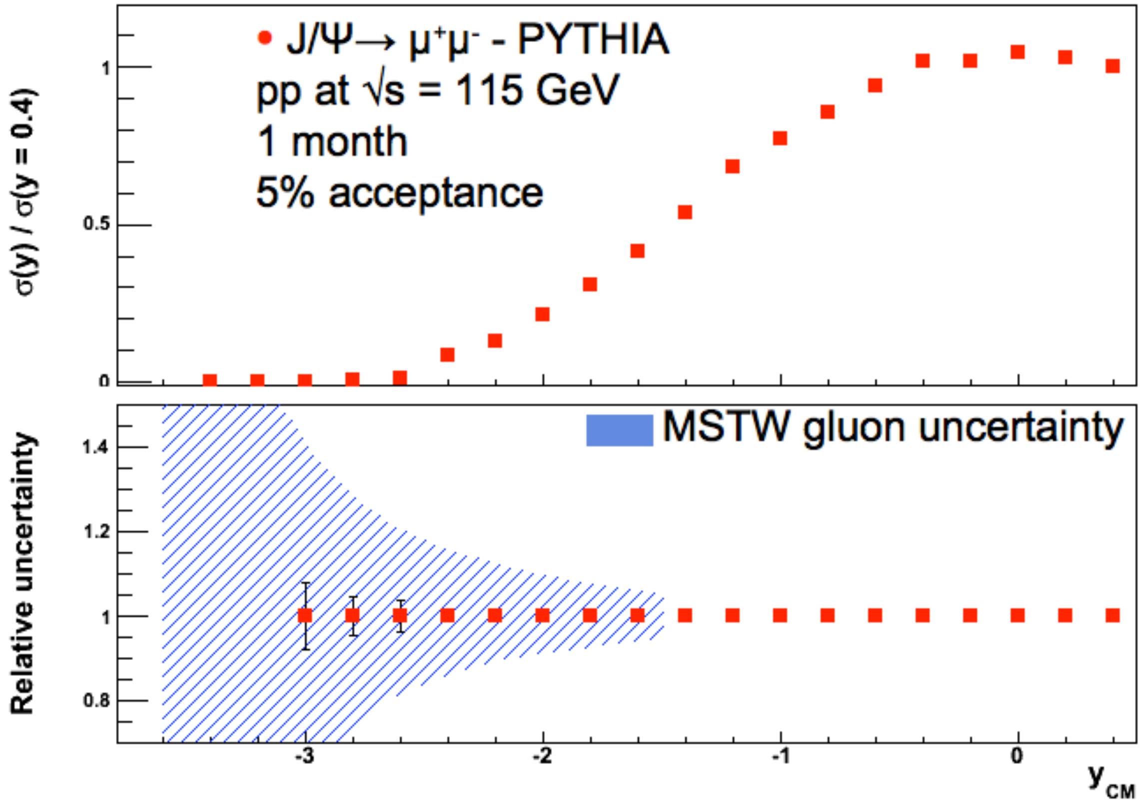
PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

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

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

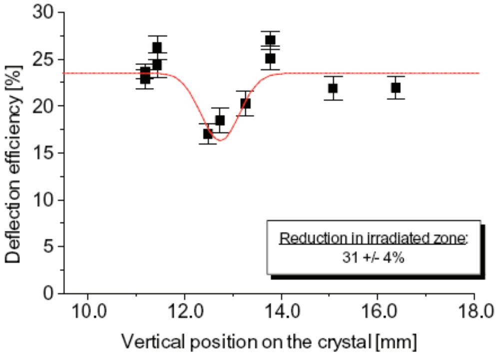


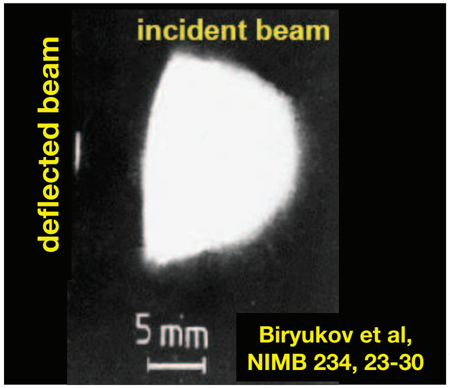
⇒ Backward measurements allow to access large x gluon pdf

Crystal resistance to irradiation

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

NA48 - Biino et al, CERN-SL-96-30-EA





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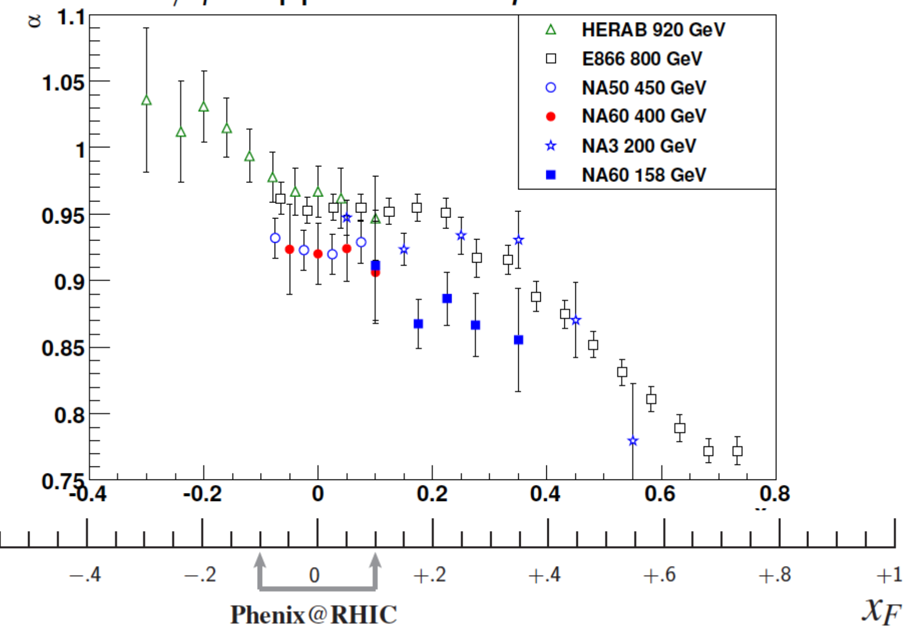
First systematic access to the target-rapidity region

($x_F \to -1$)

?

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
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$