AFTER@LHC: A fixed-target programme at the LHC for heavy-ion, hadron, spin and astroparticle physics

Barbara Trzeciak
(on behalf of the AFTER@LHC study group)
Faculty of Science, Utrecht University

XIIth Quark Confinement and
the Hadron Spectrum
September 3, 2016

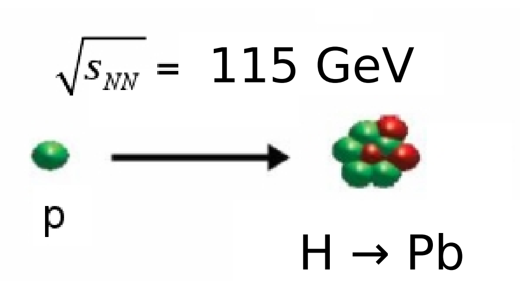
Advantages of a fixed target mode with TeV beams

- access to large Feynman $|x_F|$ thanks to the boost
- target versatility (easy to change)
- possibility to polarize target
  - ambitious spin physics program
- high luminosities with either dense targets or high intensity beams
- all this in a parasitic mode !

- With the LHC beams:

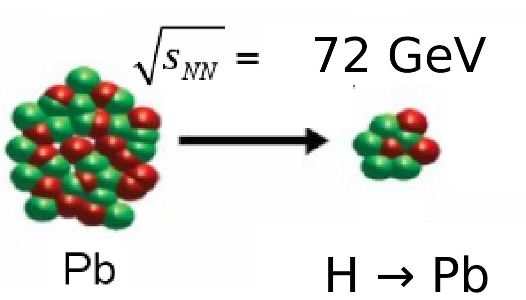
7 TeV proton beam on a fixed target

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

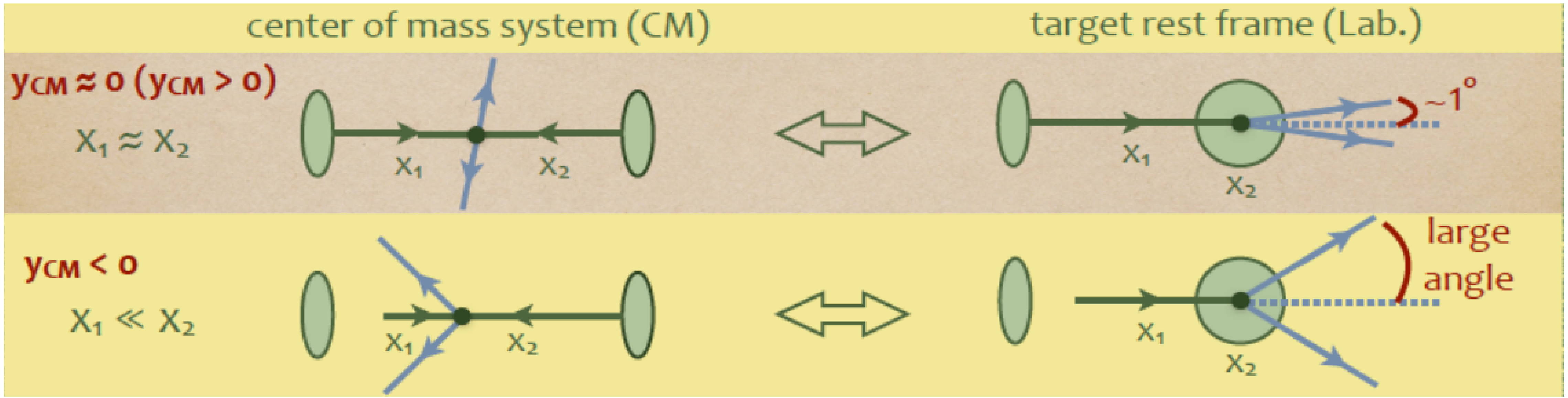


2.76 TeV Pb beam on a fixed target

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



Access to the large x



- Entire forward hemisphere – $y_{CM} > 0$ – within: $0° < \theta_{lab} < O(1°)$ - large occupancy – more challenging (only possible with an absorber - NA60)
- Backward region - $y_{CM} < 0$ – at large angles in the lab frame – low occupancy, no constrain from a beam pipe
  - backward physics fully accessible for the first time
  - access to partons with momentum fraction $x_2 \rightarrow 1$ in the target ($x_F \rightarrow -1$)
- AFTER@LHC focuses on the backward region

Possible implementations

- ✔ **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**
- ✔ **Beam line extracted with a bent crystal**
- ✔ **Beam "split" with a bent crystal**
  - 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

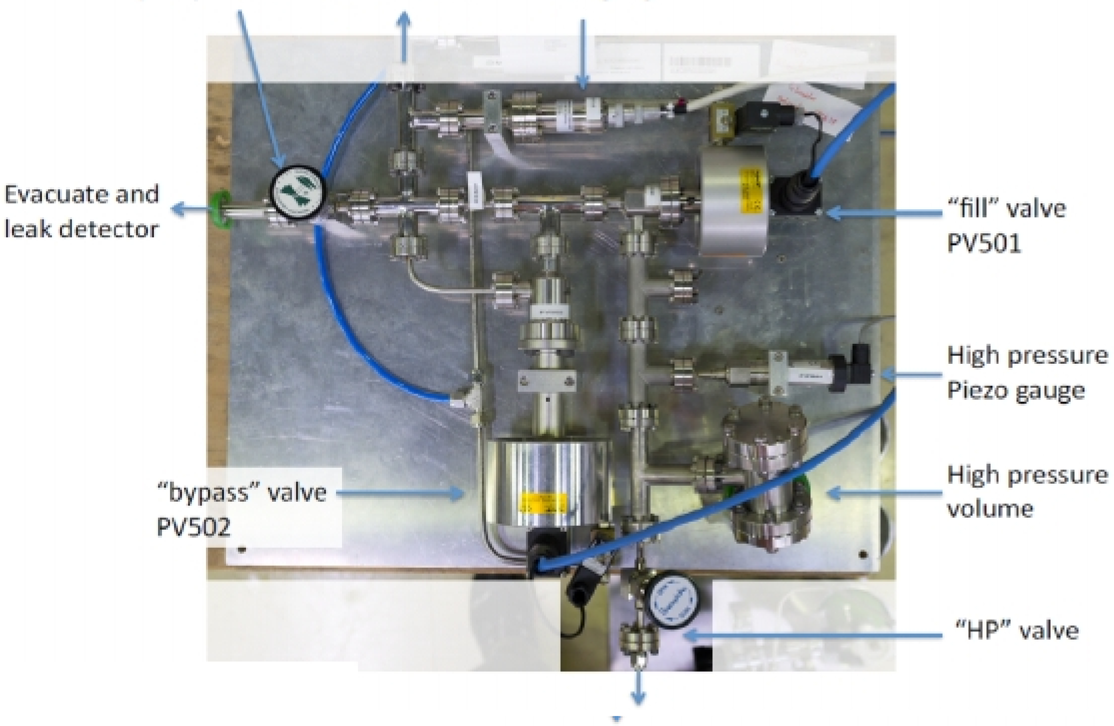
Dense targets

➔ **Expected integrated luminosities:**

✗ pp	✗ pA	✗ PbA
$\int \mathcal{L} \sim$ **10 fb^{-1}yr^{-1}**	$\int \mathcal{L} =$ **0.1 - 1 fb^{-1}yr^{-1}**	$\int \mathcal{L} =$ **1 - 50 nb^{-1}yr^{-1}**

SMOG@LHCb - a working example

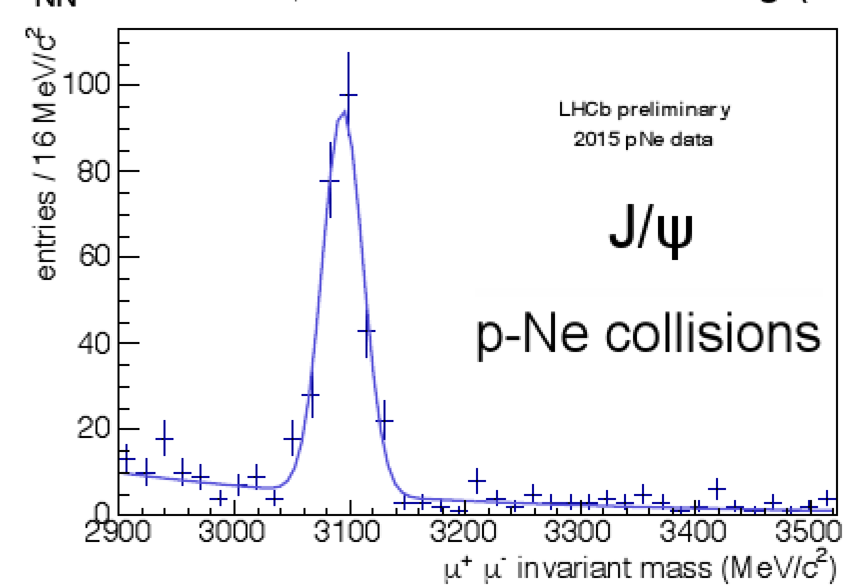
- ✓ *Direct gas injection motivated for precise luminosity determination*
- ✓ *No specific pumping system*



SMOG system

- ✓ Low density noble gas injected into VELO in LHCb
- ✓ Short pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012)
- ✓ Short PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013)
- ✓ He, Ne and Ar gas injected (2015) *LHCb-CONF-2012-034*
- ✓ pNe, pAr run at $\sqrt{s_{NN}}$ = 110 GeV (2015)
- ✓ 1.5 week of PbAr at $\sqrt{s_{NN}}$ = 69 GeV (2015)

$\sqrt{s_{NN}}$ = 110 GeV, about 12h of data taking (2015)



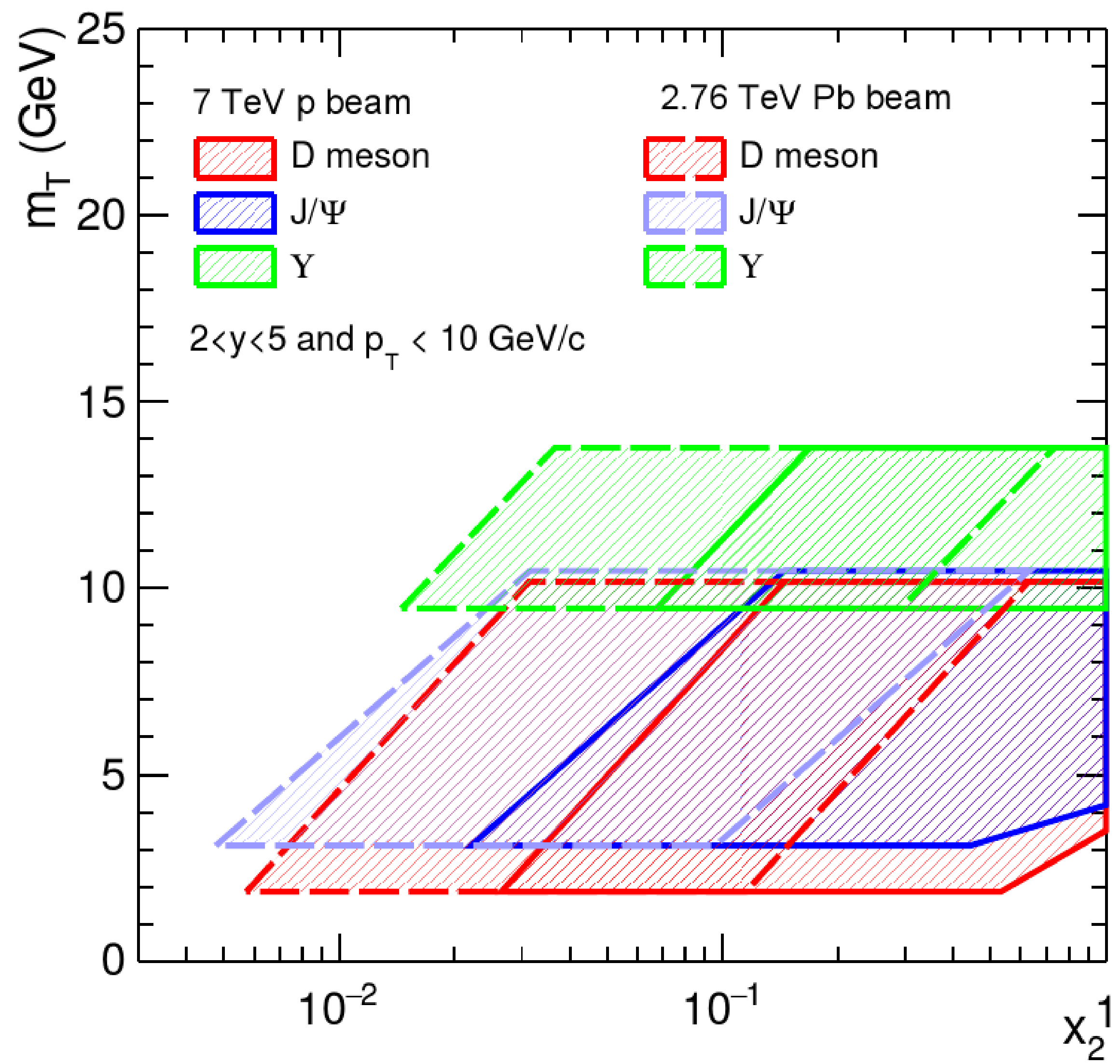
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- No decrease of LHC performances observed in test runs
- Fixed target collisions can be separated
  → no need for dedicated physics runs
- So far only noble gases (NEG filter)
- Target polarization is not possible with SMOG

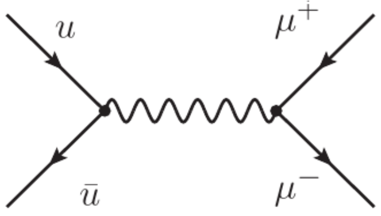
➔ However internal gas target can be polarized, like HERMES target

Projection studies

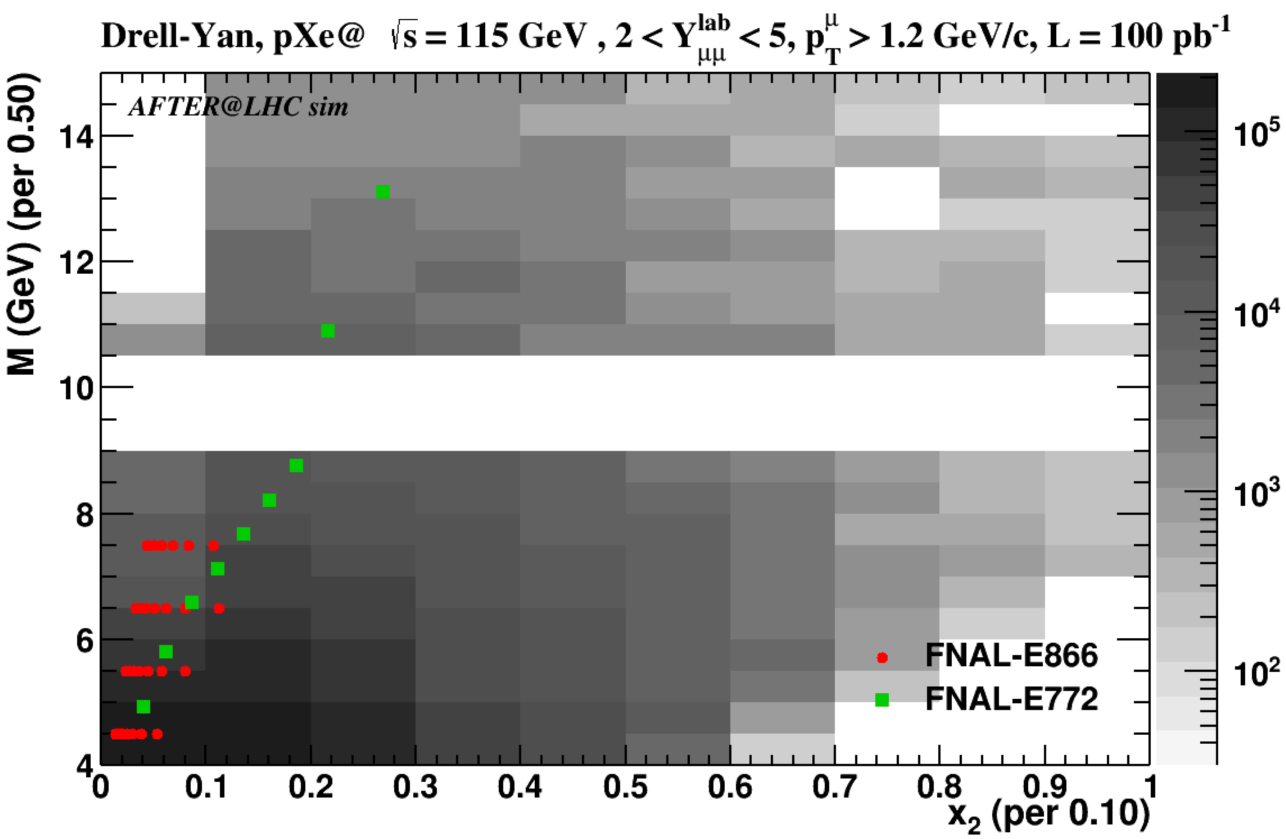
- **Includes:**
  - **Drell-Yan**
  - **J/psi, Upsilon**
  - **Open Heavy Flavour**
- **Not covered here:**
  - **Azimuthal anisotropies**
  - **Photons**
  - **$W^{+/-}$ boson**
  - **Other quarkonia**
  - **HF pairs**
  - **UPC**

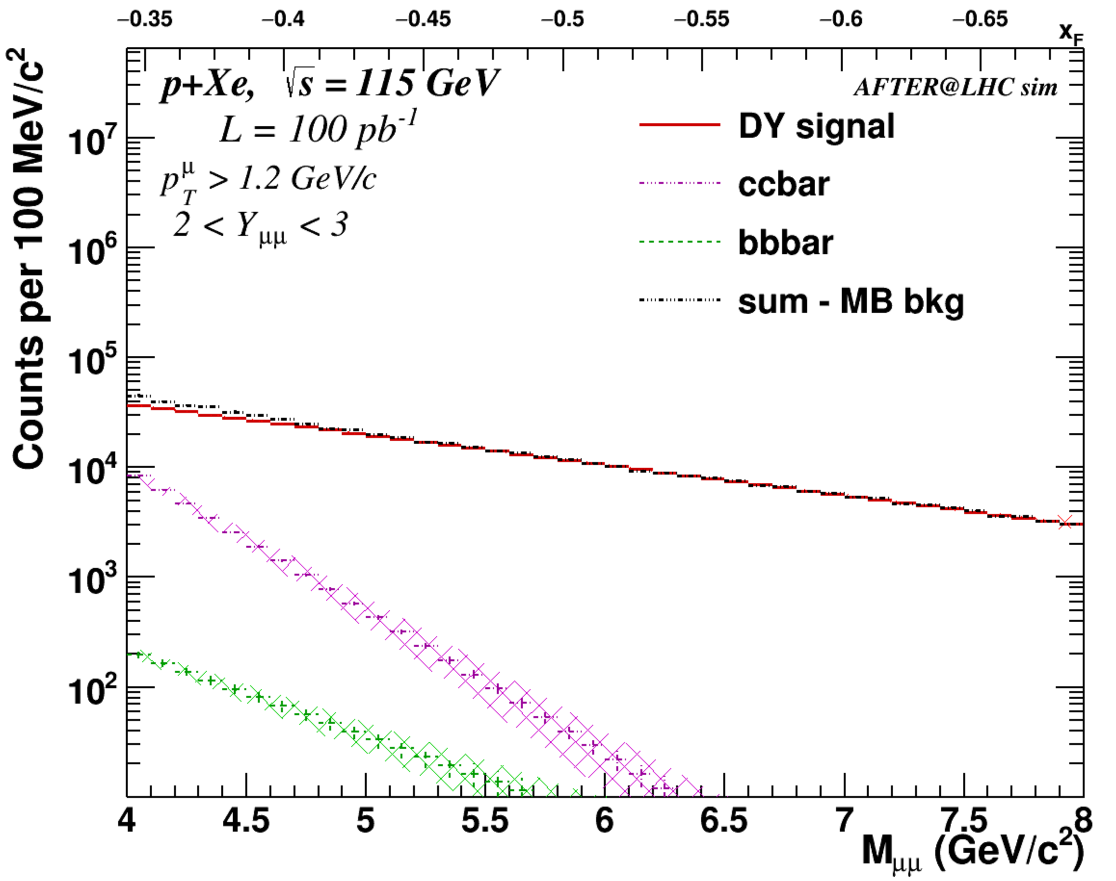


Drell-Yan simulations with full background



p+Xe 115 GeV



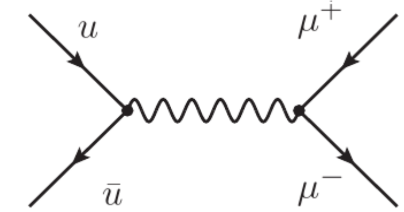


- High Drell-Yan yields for pp, pXe, pPb
- Unique coverage towards large x in pA

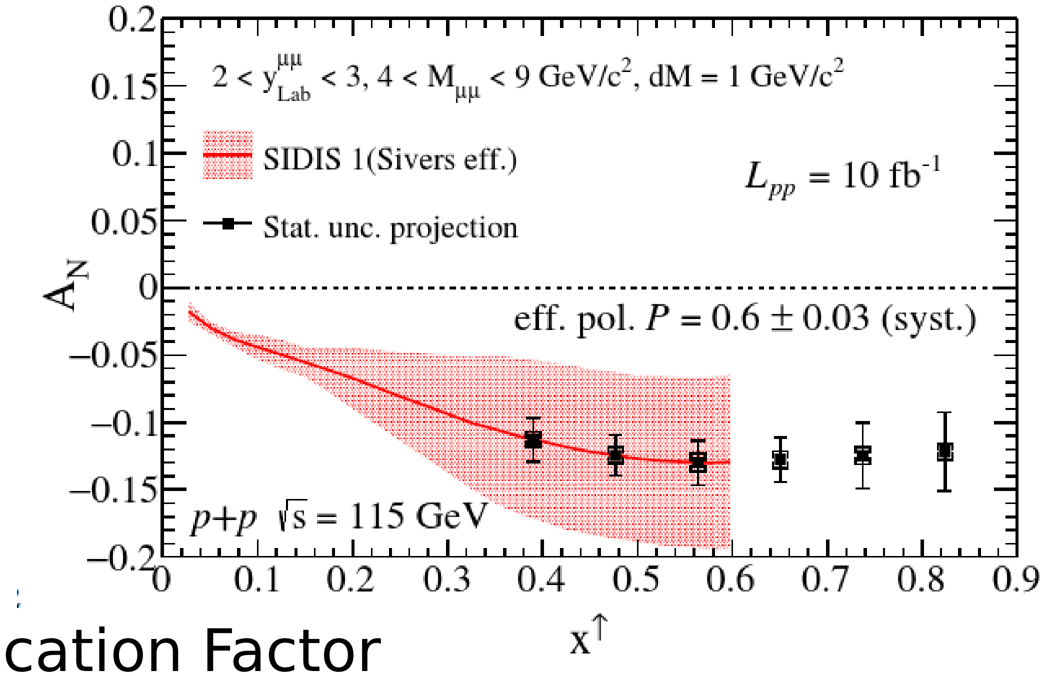
- No nuclear effects assumed
- Combinatorial background subtracted with the like-sign method

- At backward rapidities quark-induced processes are favoured → background gets smaller
- Charm and beauty background can be reduced (secondary vertex cut), however interesting on their own

Drell-Yan projections



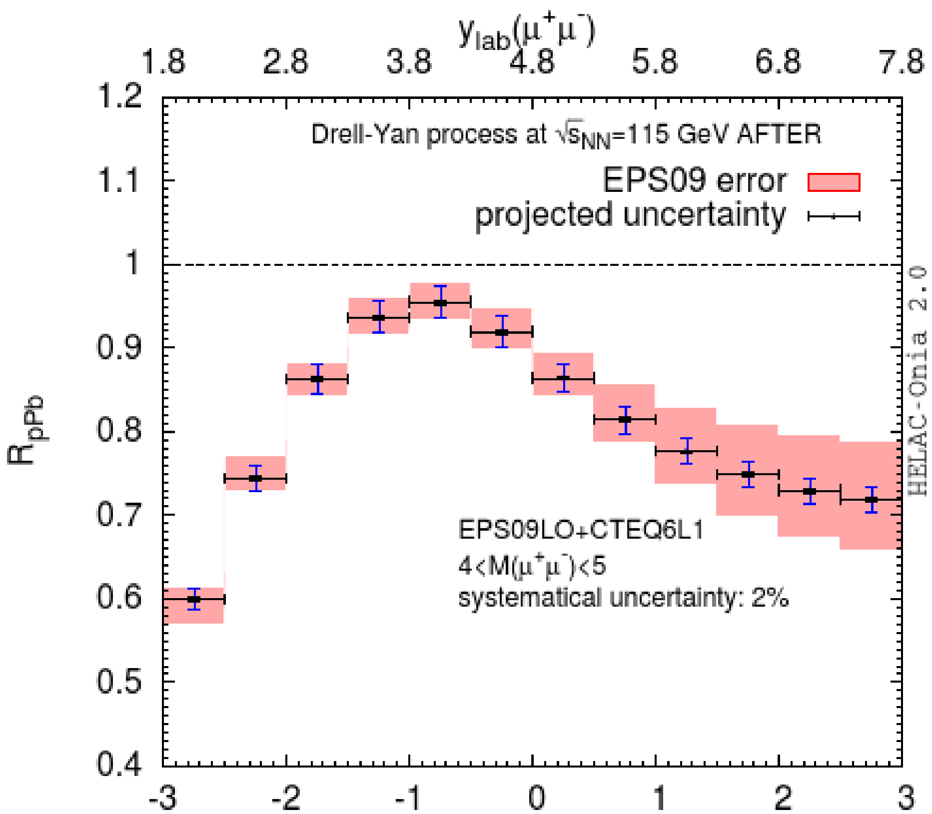
Single spin asymmetry → <u>Quark Sivers effect</u>

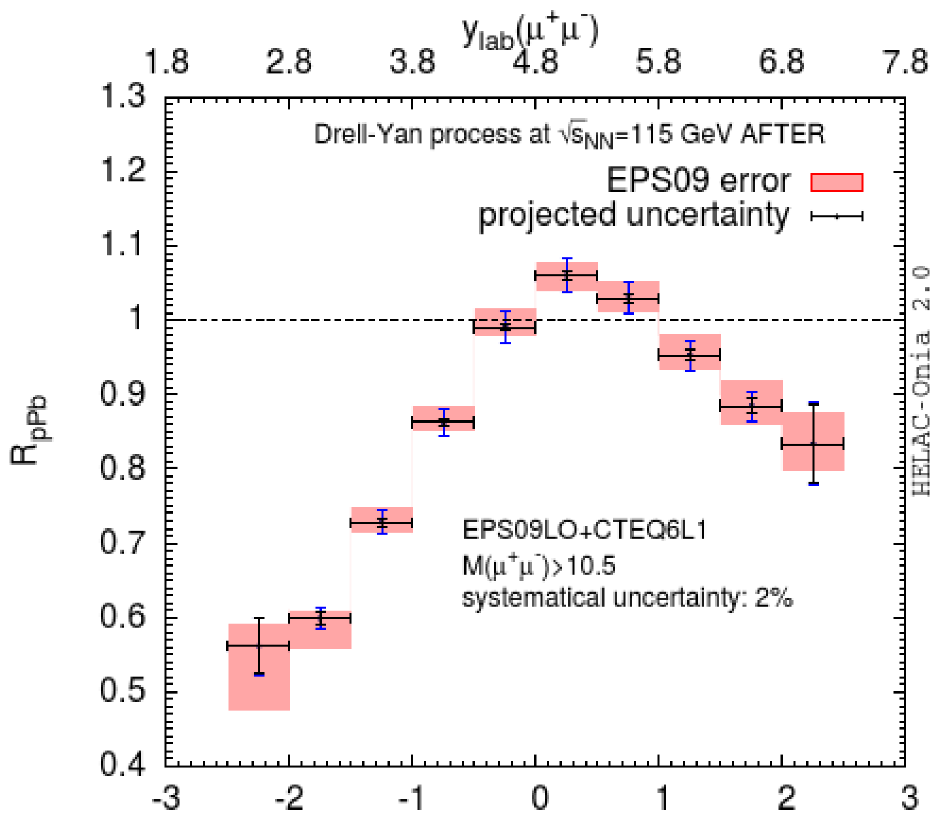


➔ Precise measurements of A_N^{DY} at high x

p+p 115 GeV

Nuclear Modification Factor



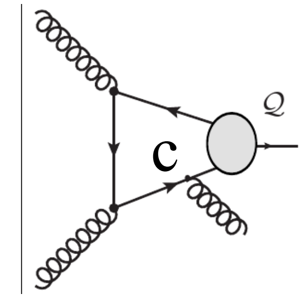


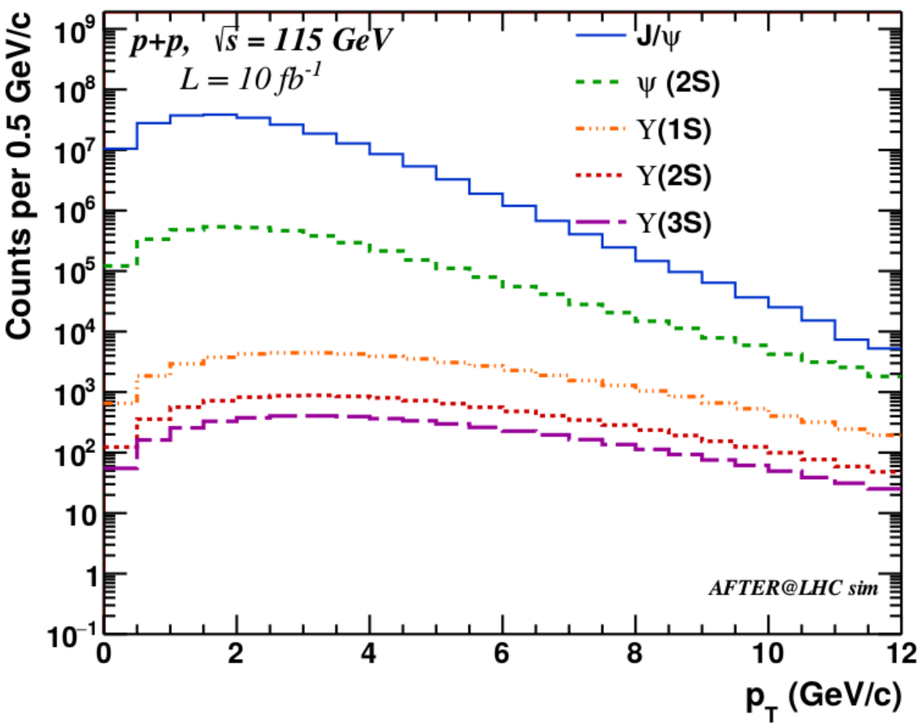
$y_{CMS}(\mu^+\mu^-)$ Systematic uncertainties in blue $y_{CMS}(\mu^+\mu^-)$

➔ **Statistics smaller than nPDF uncertainties**

p+Pb 115 GeV

Quarkonium simulations with full background

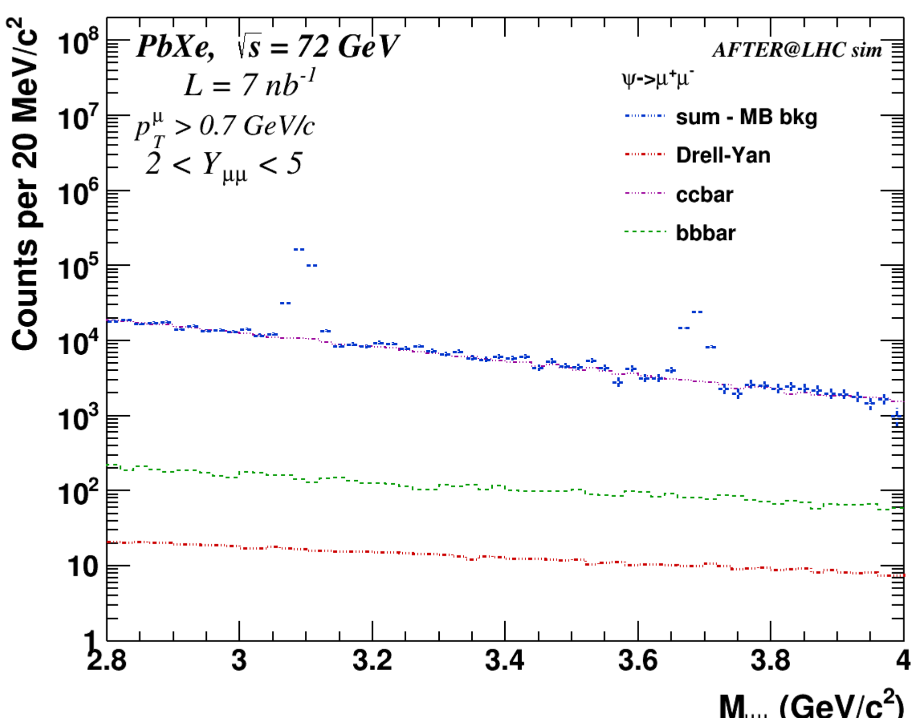


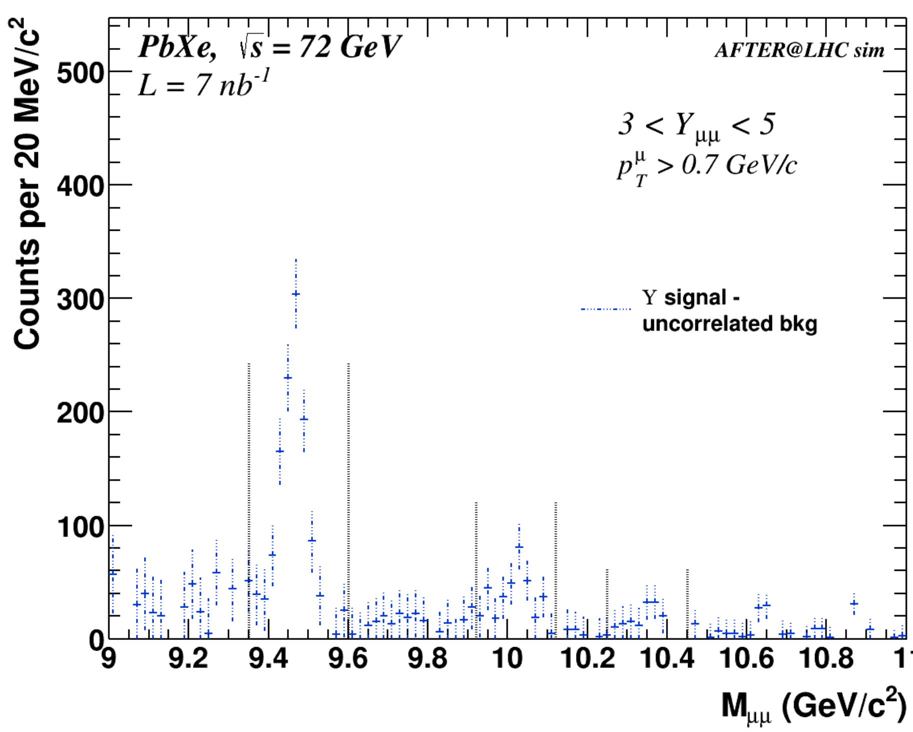


- High yields of quarkonia
  - J/ψ and ψ(2S) signals can be studies up to ~ 15 GeV/c, ϒ(nS) up to ~ 10 GeV/c
  - Down to 0 GeV/c
  - Similar p_T reach expected for pA

- J/ψ / ψ(2S): 2 < y < 5
- ϒ(nS) is ~ 2.5-3 < y < 5

p+p 115 GeV



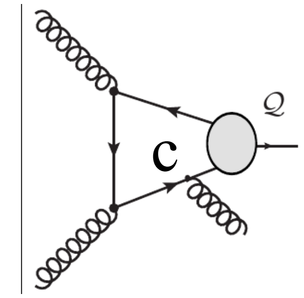


- **Good separation of different Upsilon states**

Pb+Xe 72 GeV

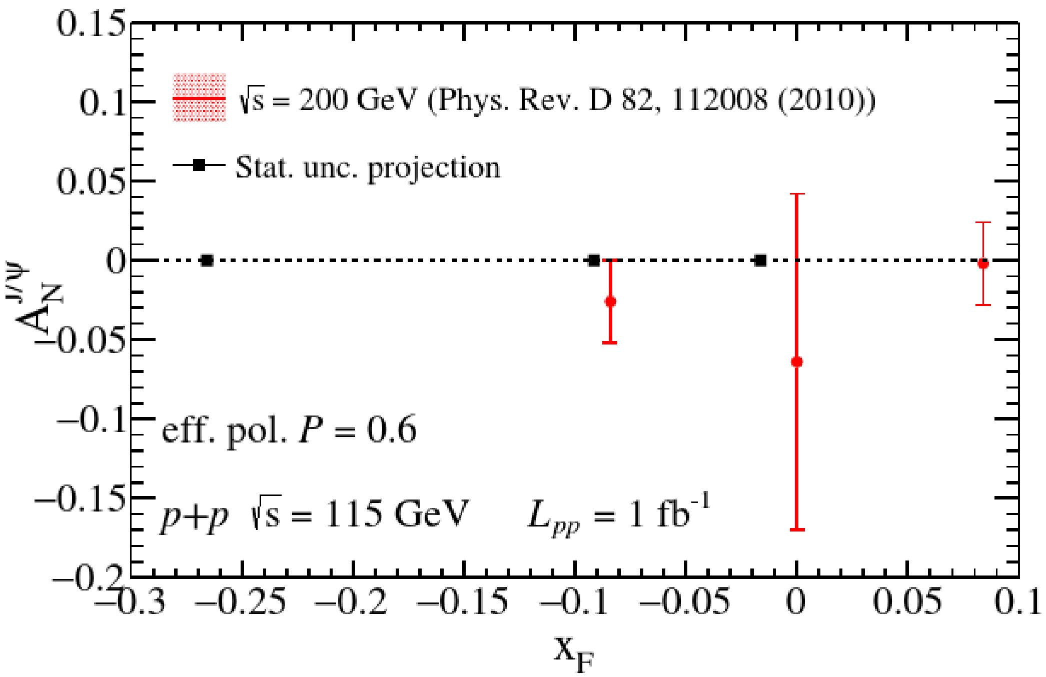
- No nuclear effects assumed
- Combinatorial background subtracted with the like-sign method

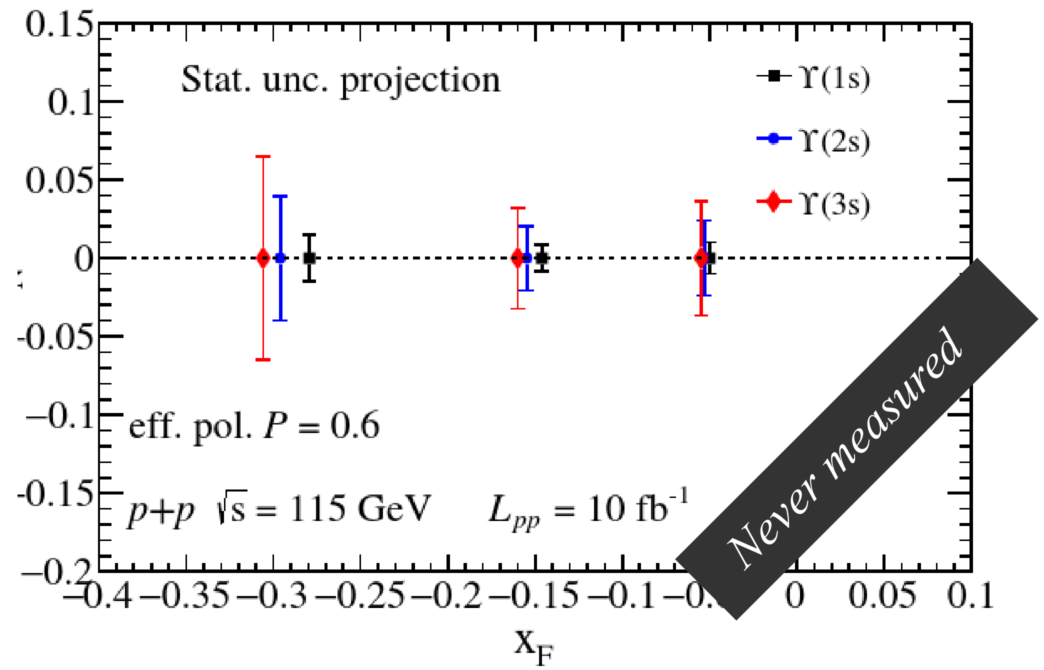
Quarkonium projections



Single spin asymmetry → <u>Gluon Sivers effect (hint from COMPASS, see G.Mallot's talk)</u>

Excellent statistical precision





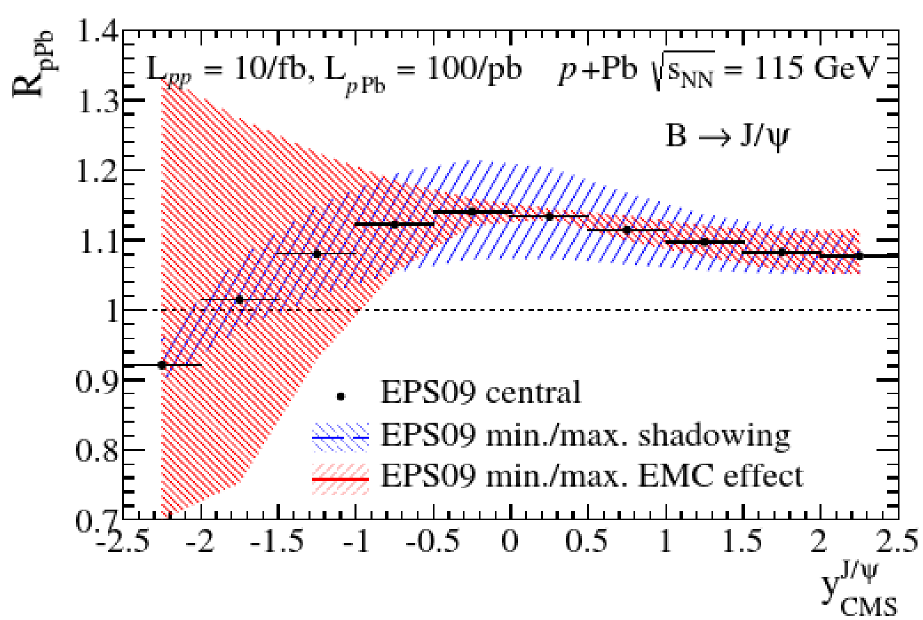
p+p 115 GeV

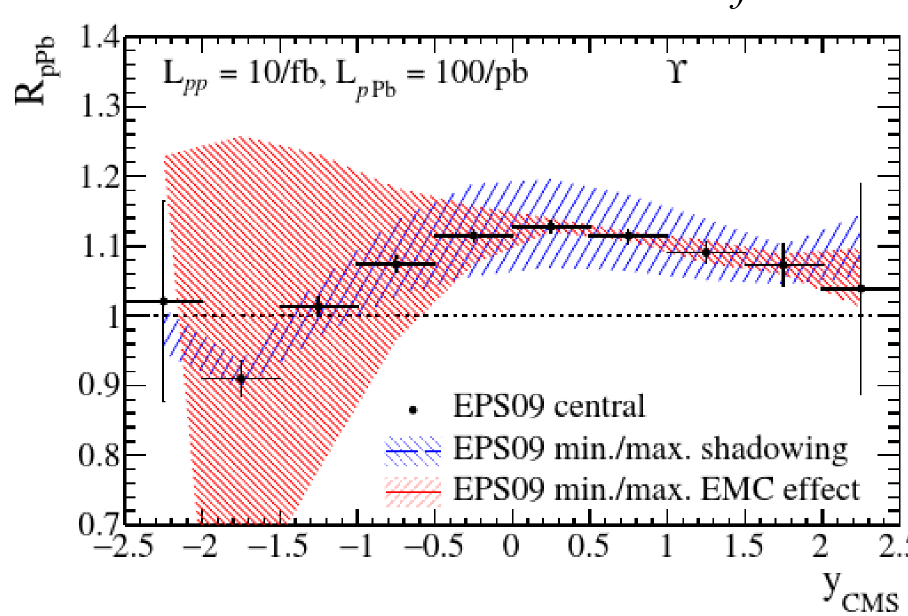
Nuclear Modification Factor

→ pin down <u>the gluon EMC and antishadowing effect</u>

statistical uncertainties from the signal yield only

Excellent statistical precision

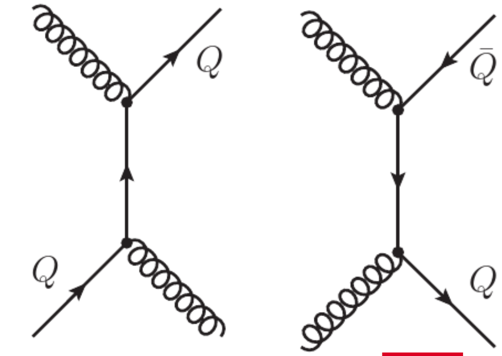


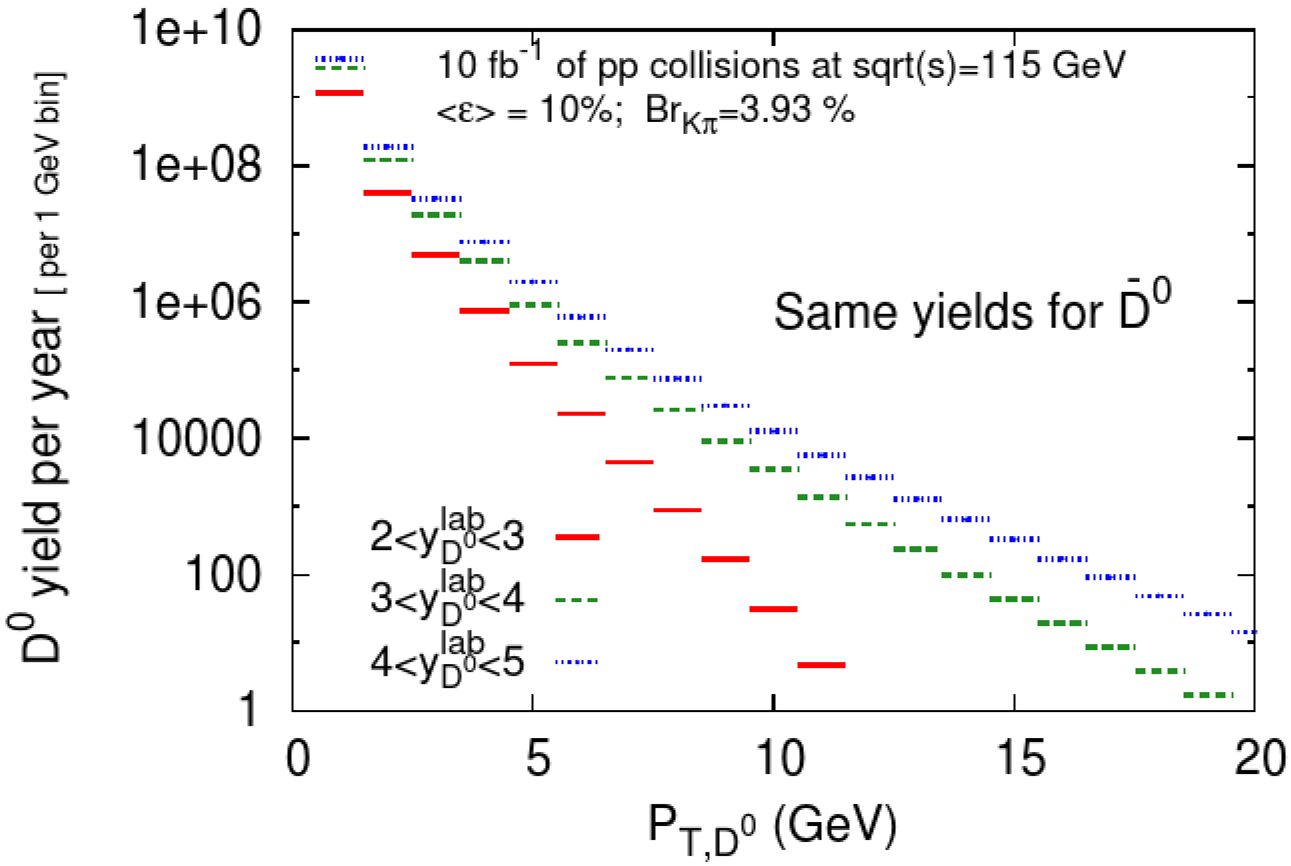


p+Pb 115 GeV

Open Heavy Flavour simulations

$D^0 \rightarrow K^- \pi^-$





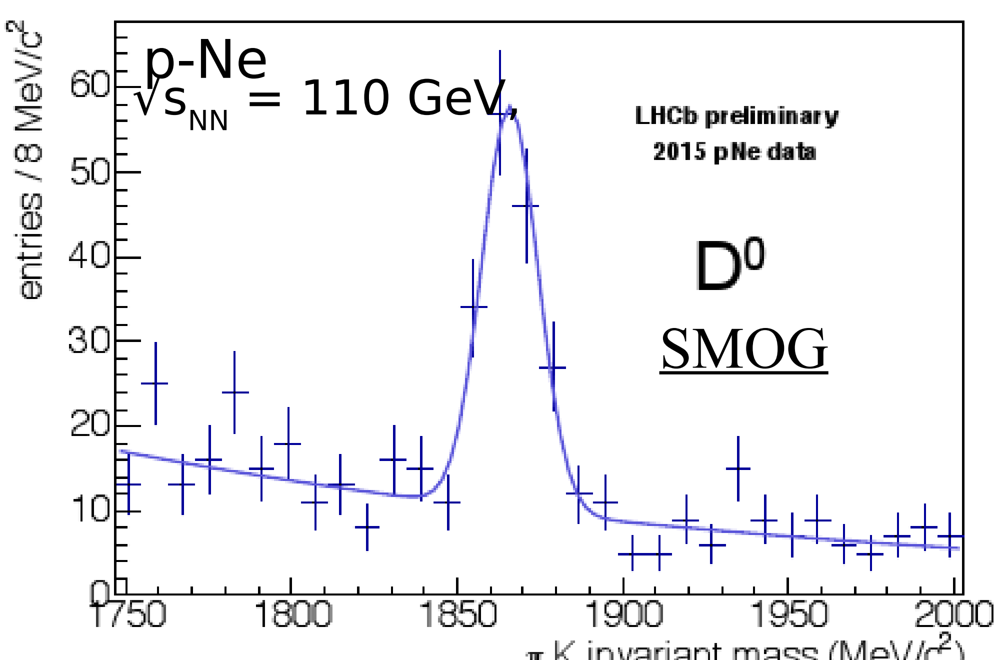
Huge expected yields

→ Charm can easily be measured down to 0 p_T

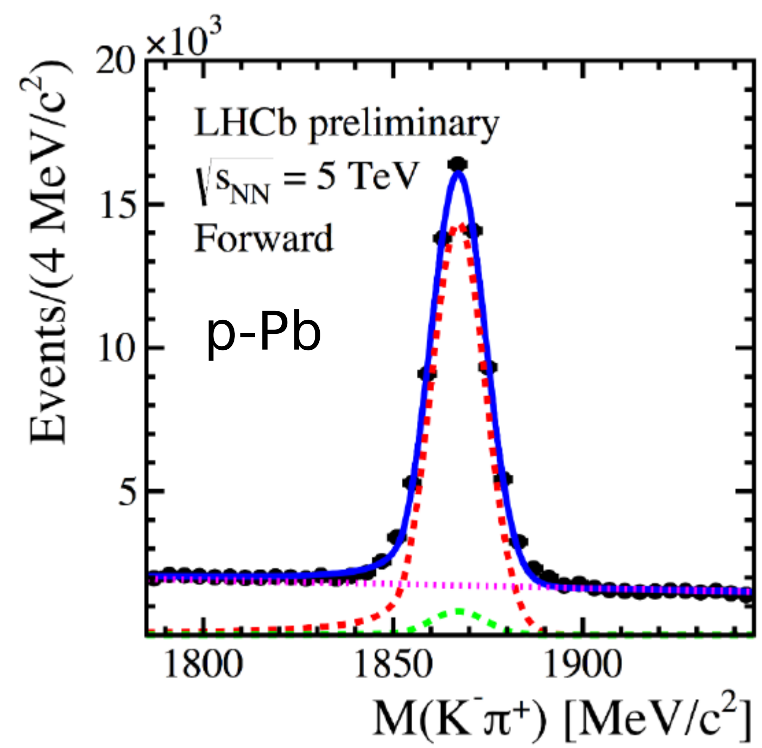
→ Charm-anticharm asymmetry accessible

p+p 115 GeV

→ LHCb measurements – very low background



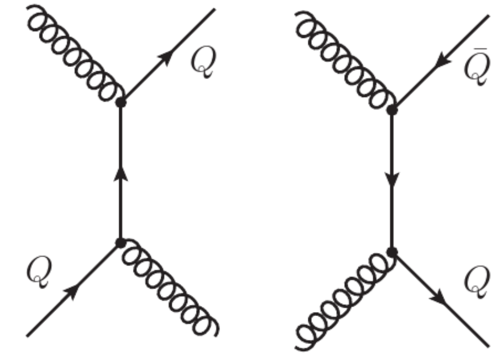
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015



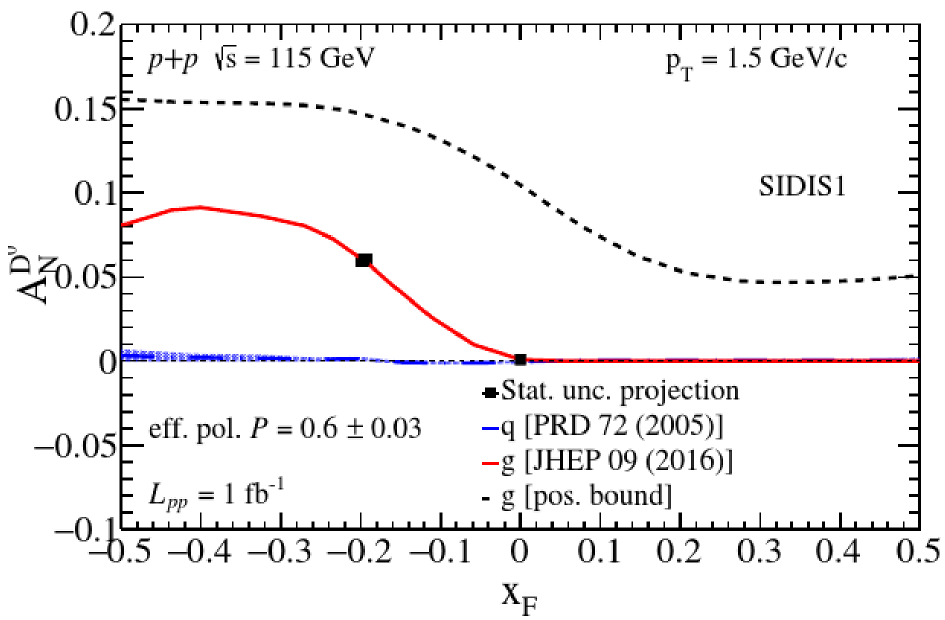
LHCb

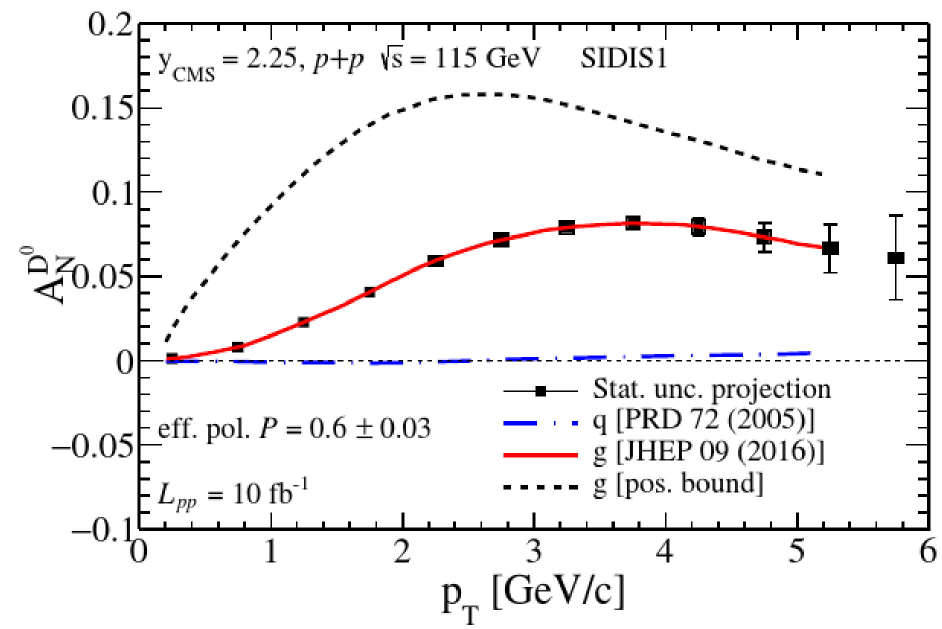
Open Heavy Flavour projections

$D^0 \rightarrow K^- \pi^-$



Single spin asymmetry → <u>Gluon Sivers effect and quark-gluon correlations</u>

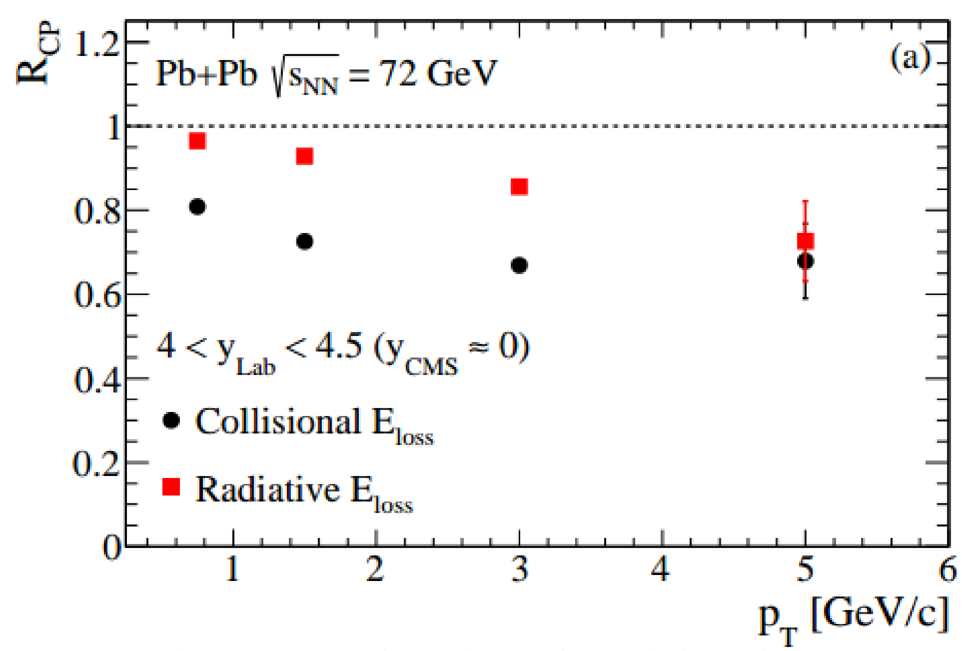


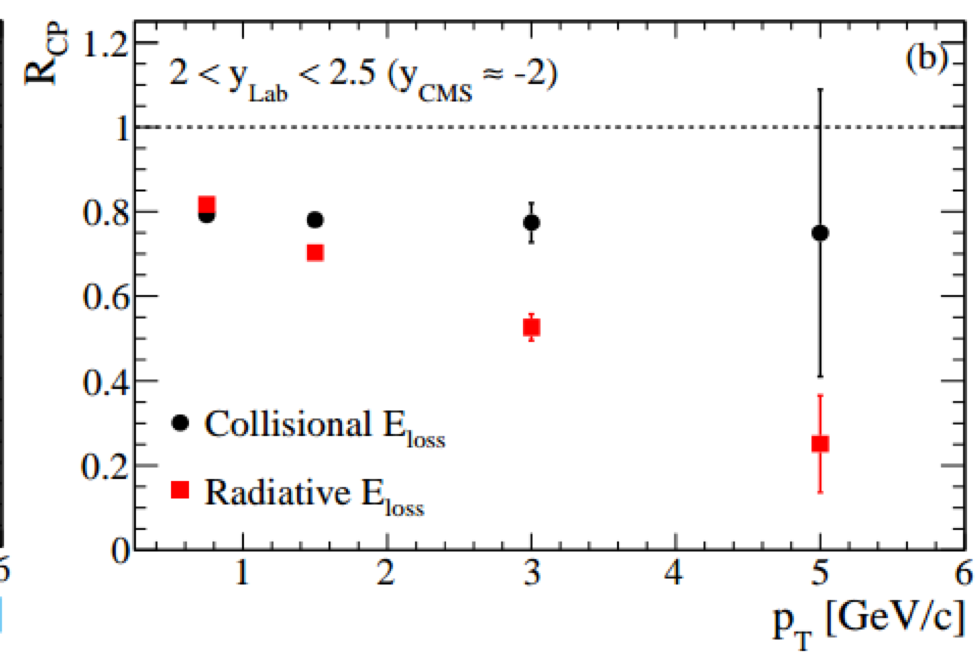


Excellent statistical precision

p+p 115 GeV

Nuclear Modification Factor vs y and p_T → <u>insight into charm E_{loss}</u>





Excellent statistical precision

Pb+Pb 72 GeV

statistical uncertainties from the signal yield only

WHAT IS AFTER@LHC AND WHAT FOR?

AFTER@LHC is a proposal for a multi-purpose fixed target experiment using the multi-TeV proton and heavy ion beams of the LHC

- ✔ Advance our understanding of the **large-x gluon, antiquark** and **heavy-quark** content in the **nucleon** and **nucleus**
  - PDF at large x relevant for BSM searches at the LHC
  - Proton charm content important to high-energy neutrino and cosmic-ray physics
  - EMC effect is an open problem; studying a possible gluon EMC effect is essential
  - Relevance of nuclear PDF to understand initial state of heavy-ion collisions
- ✔ **Dynamics and spin of gluons inside (un)polarised nucleons**
  - Possible missing contribution to the proton spin: Orbital Angular Momentum
  - Precision measurement of the quark Sivers effect
  - Test of the QCD factorisation framework
  - Determination of linearly polarised gluons in unpolarised protons
- ✔ **Heavy-ion collisions from mid- to large rapidities**
  - Explore the longitudinal expansion of QGP thanks to a wide rapidity coverage
  - Test the factorisation of cold nuclear effect from p+A to A+B collisions
  - Test azimuthal asymmetries: hydro vs. initial-state radiation
- ✔ **Implementation with internal gas target or bent crystal**
  - Gas target implementation compatible with ALICE or LHCb

BACKUP

Ideas in favour of AFTER@LHC

Future Reading

Heavy-Ion Physics

- *Gluon shadowing effects on J/ψ and Υ production in p+Pb collisions at $\sqrt{s_{NN}}$ = 115 GeV and Pb+p collisions at $\sqrt{s_{NN}}$ = 72 GeV at AFTER@LHC* by R. Vogt. Adv.Hi.En.Phys. (2015) ID:492302.
- *Prospects for open heavy flavor measurements in heavy-ion and p+A collisions in a fixed-target experiment at the LHC* by D. Kikola. Adv.Hi.En.Phys. (2015) ID:783134
- *Quarkonium suppression from coherent energy loss in fixed-target experiments using LHC beams* by F. Arleo, S.Peigné. [arXiv:1504.07428 [hep-ph]]. Adv.Hi.En.Phys. (2015) ID:961951
- *Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams* by K. Zhou, Z. Chen, P. Zhuang. arXiv:1507.05413 [nucl-th].
- *Lepton-pair production in ultraperipheral collisions at AFTER@LHC*
  By J.P. Lansberg, L. Szymanowski, J. Wagner. arXiv:1504.02733 [hep-ph]. To appear in JHEP
- *Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams.* By J.P. Lansberg, S.J. Brodsky, F. Fleuret, C. Hadjidakis. [arXiv:1204.5793 [hep-ph]]. Few Body Syst. 53 (2012) 11.

Future Reading

Spin physics

- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment*
  by K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. [arXiv:1502.04021 [hep-ph]. Adv.Hi.En.Phys. (2015) ID:257934.
- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment in a TMD factorisation scheme*
  by M. Anselmino, U. D'Alesio, and S. Melis. [arXiv:1504.03791 [hep-ph]]. Adv.Hi.En.Phys. (2015) ID:475040.
- *The gluon Sivers distribution: status and future prospects*
  by D. Boer, C. Lorcé, C. Pisano, and J. Zhou. [arXiv:1504.04332 [hep-ph]]. Adv.Hi.En.Phys. (2015) ID:371396
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)*
  By T. Liu, B.Q. Ma. [arXiv:1203.5579 [hep-ph]]. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER*
  By D. Boer, C. Pisano. [arXiv:1208.3642 [hep-ph]]. Phys.Rev. D86 (2012) 094007.

Future Reading

Hadron structure

- *Double-quarkonium production at a fixed-target experiment at the LHC (AFTER@LHC).*
  by J.P. Lansberg, H.S. Shao. [arXiv:1504.06531 [hep-ph]]. To appear in Nucl. Phys. B
- *Next-To-Leading Order Differential Cross-Sections for Jpsi, psi(2S) and Upsilon Production in Proton-Proton Collisions at a Fixed-Target Experiment using the LHC Beams (AFTER@LHC)*
  by Y. Feng, and J.X. Wang. Adv.Hi.En.Phys. (2015) ID:726393, in press.
- *η_c production in photon-induced interactions at a fixed target experiment at LHC as a probe of the odderon*
  By V.P. Goncalves, W.K. Sauter. arXiv:1503.05112 [hep-ph].Phys.Rev. D91 (2015) 9, 094014.
- *A review of the intrinsic heavy quark content of the nucleon*
  by S. J. Brodsky, A. Kusina, F. Lyonnet, I. Schienbein, H. Spiesberger, and R. Vogt. Adv.Hi.En.Phys. (2015) ID:231547, in press.
- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. [arXiv:1401.6269 [hep-ph]]. Phys.Rev. D89 (2014) 074020.

Future Reading

Feasibility study and technical ideas

- *Feasibility studies for quarkonium production at a fixed-target experiment using the LHC proton and lead beams (AFTER@LHC)* by L. Massacrier, B. Trzeciak, F. Fleuret, C. Hadjidakis, D. Kikola, J.P.Lansberg, and H.S. Shao arXiv:1504.05145 [hep-ex]. Adv.Hi.En.Phys. (2015) ID:986348
- *A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions* by C. Barschel, P. Lenisa, A. Nass, and E. Steffens. Adv.Hi.En.Phys. (2015) ID:463141
- *Quarkonium production and proposal of the new experiments on fixed target at LHC* by N.S. Topilskaya, and A.B. Kurepin. Adv.Hi.En.Phys. (2015) ID:760840

Generalities

- *Physics Opportunities of a Fixed-Target Experiment using the LHC Beams*
  By S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg. [arXiv:1202.6585 [hep-ph]]. Phys.Rept. 522 (2013) 239.

http://www.hindawi.com/journals/ahep/si/354953/

Hindawi Publishing Corporation

Advances in High Energy Physics

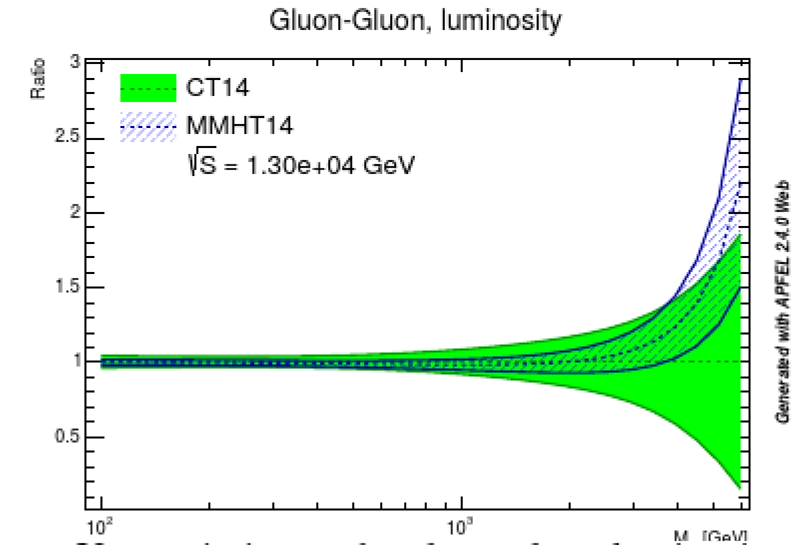
Impact Factor 2.203

Physics at a Fixed-Target Experiment Using the LHC Beams

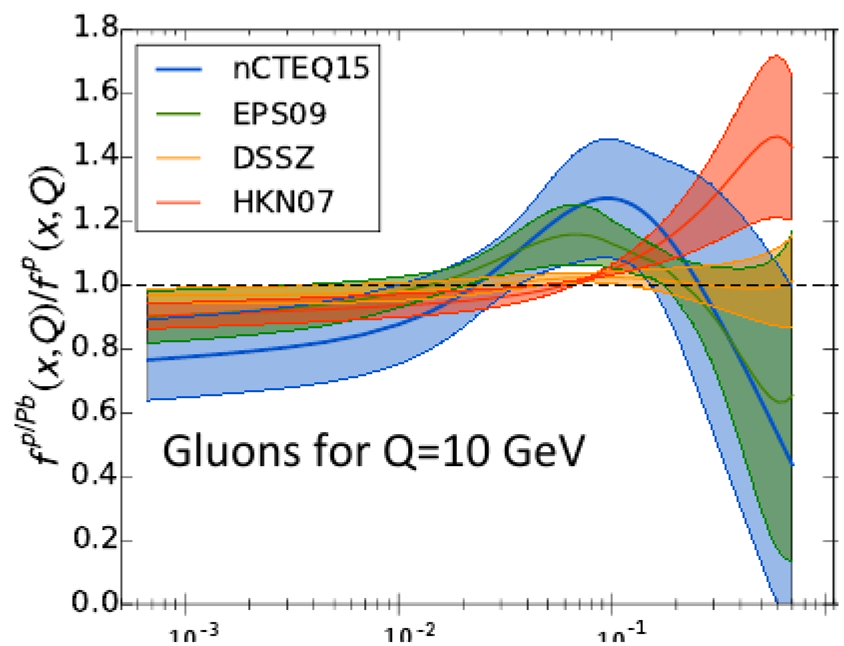
Guest Editors: Jean-Philippe Lansberg, Gianluca Cavoto, Cynthia Hadjidakis, Jibo He, Cédric Lorcé, and Barbara Trzeciak

Physics Highlights: AFTER@LHC

- ➔ **Large x frontier**
- ✓ **Nucleon partonic structure**
  - Gluon pdf in the proton – large uncertainties at high x
  - $g_p(x) = g_n(x)$?
- ✓ **Heavy-quark distribution at large x in the proton**
- ✓ **Nuclear structure – gluon distribution**
  - Complementary to EIC, LHeC
  - Large uncertainty in nuclei at large x, unknown gluon EMC effect
  - Relevance of nuclear PDF to understand the initial state of heavy-ion collisions
  - Search and study rare proton fluctuations where one gluon carries most of the proton momentum



Uncertainties on the gluon-gluon luminosity at $\sqrt{s}$ = 13 TeV



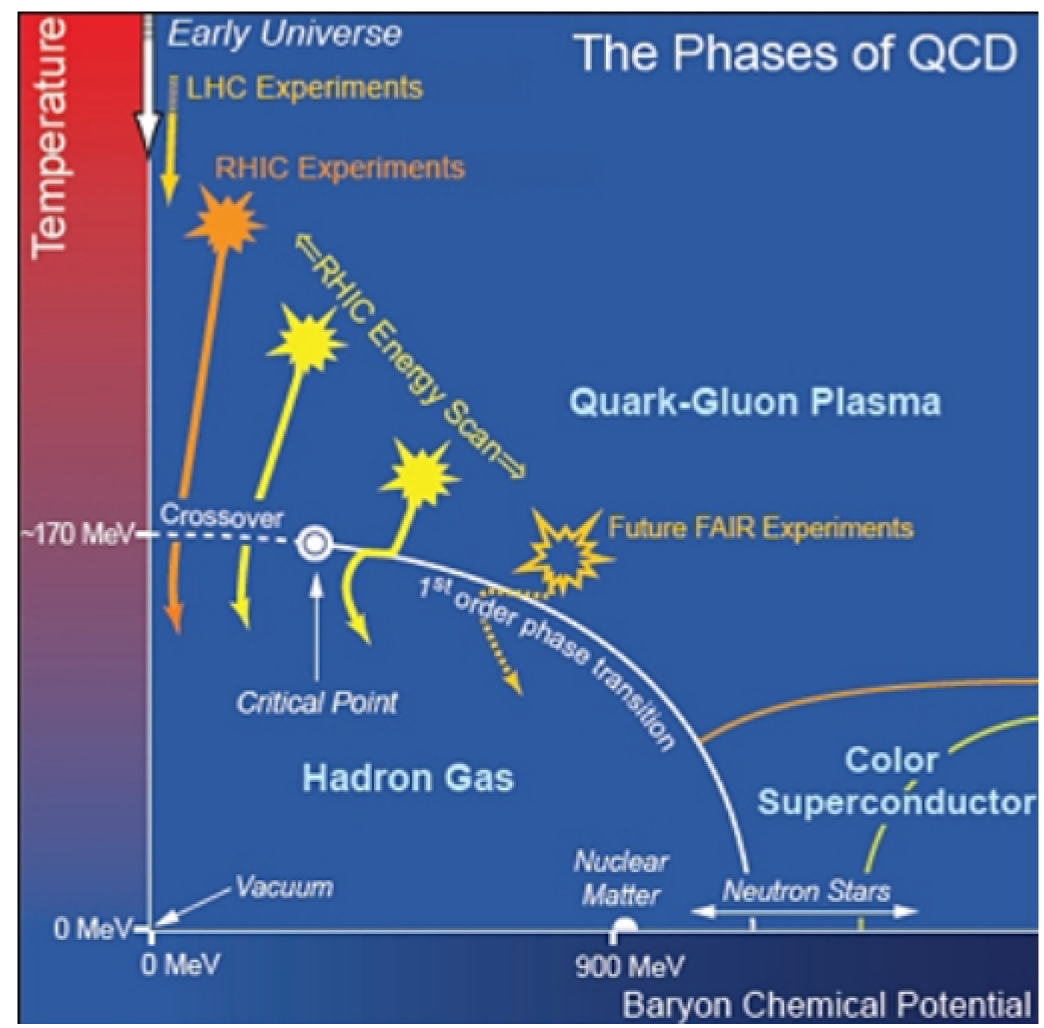
lack of knowledge in the gluon densities in nuclei for $x > 0.1$

- ➔ **Spin physics**
  - Test of the QCD factorisation framework
  - Linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$, “Boers-Mulder” effect
  - Sivers effect
  - Single Spin Asymmetry in DY and HF studies

Physics Highlights: AFTER@LHC

- **Heavy-Ion collisions from mid to large rapidities**

  - **Precise estimation of Cold Nuclear Matter effect from pA and AB – test of the factorization**
    - In PbA, different nuclei, A-dependent studies
  - **Quark-Gluon Plasma studies in heavy-ion collisions**
  - **Longitudinal expansion of QGP formation**
    - Quarkonia, HF jets quenching, low mass lepton pairs, direct photons
  - **Test the formation of azimuthal asymmetries: hydrodynamics vs initial-state radiation**



Luminosities in pH and pA at 115 GeV

Instantaneous luminosity:

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

l is a target thickness

Extracted beam

Target	ρ (g.cm^{-3})	A	L (μb^{-1}.s^{-1})	∫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 (μb^{-1}.s^{-1})	∫L (pb^{-1}.yr^{-1})
p	Perfect gas	100	10^{-9}	10	100

With pressure of 10^{-6} mbar - 3 times SMOG – one gets 100 pb^{-1} yr^{-1}

→ target storage cell that can be **polarised**

$P = 10^{-4}$ mbar

Advances in High Energy Physics, Volume 2015 (2015), Article ID 463141

Luminosities in pH and pA at 115 GeV

Instantaneous luminosity:

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

l is a target thickness

Extracted beam

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

Internal gas target

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

With pressure of 10^{-6} mbar - 3 times SMOG – one gets 100 pb^{-1} yr^{-1}

→ target storage cell that can be **polarised**

P = 10^{-4} mbar

Advances in High Energy Physics, Volume 2015 (2015), Article ID 463141

Integrated luminosities with 10^7 s (LHC year – 9 months of running)

For 1m long H_2 target

$$\int\mathcal{L} = 20\ \text{fb}^{-1}\text{yr}^{-1}$$

$$\int\mathcal{L} = 10\ \text{fb}^{-1}\text{yr}^{-1}$$ for P = 10^{-4} mbar

Large luminosities comparable to LHC, 3 orders of magnitude larger that at RHIC

Similar integrated luminosities in **pA** in the target storage cell case as with the extracted beam option

Luminosities in PbH and PbA at 72 GeV

Instantaneous luminosity:

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

l is a target thickness

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

$P = 10^{-6}$ *mbar*

→ target storage cell that can be **polarised**

Integrated luminosities with 10^6 s (Pb LHC year – 1 months of running)

For 1m long H_2 target

$$\int \mathcal{L} = 0.8\ pb^{-1}yr^{-1}$$

For 1cm long Pb target

$$\int \mathcal{L} = 7\ nb^{-1}yr^{-1}$$

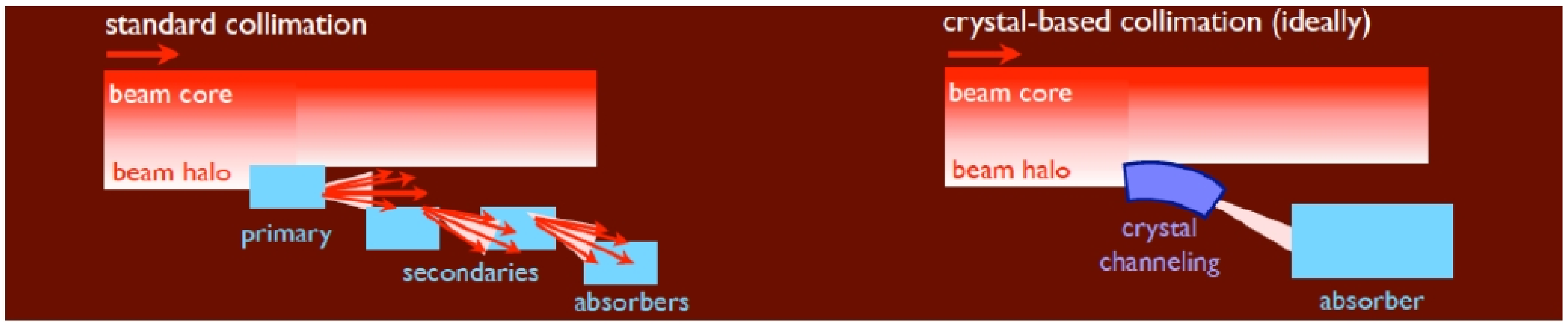
$$\int \mathcal{L} = 0.001\ pb^{-1}yr^{-1}$$

$P = 10^{-6}$ *mbar*

Nominal LHC collider luminosity for PbPb: 0.5 nb^{-1}

Beam extraction using bent crystal

✓ **Motivated for collimation purposes**



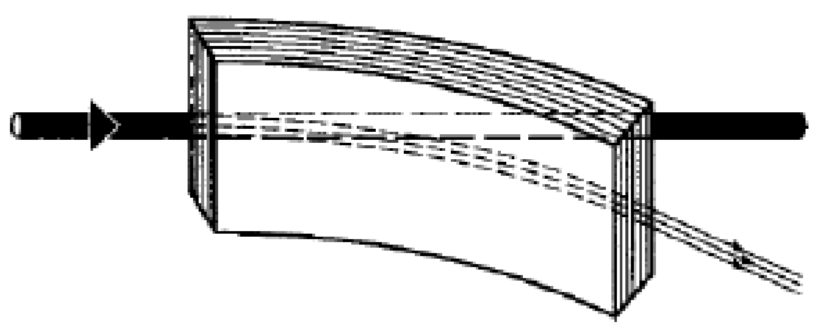
Standard collimation today → Crystal-based collimation
- UA9 (@SPS)
- LUA9 (@LHC)

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

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

✓ The LHC beam extraction with "strong crystalline filed"

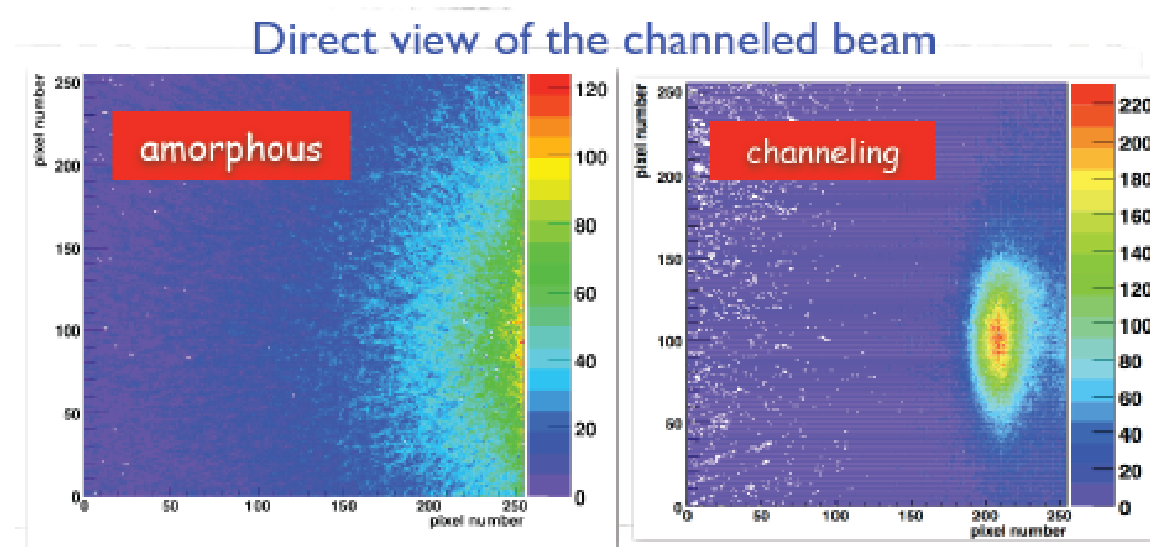
E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



✓ LUA9 test in the LHC complex

Deflecting the beam halo at 7σ distance to the beam

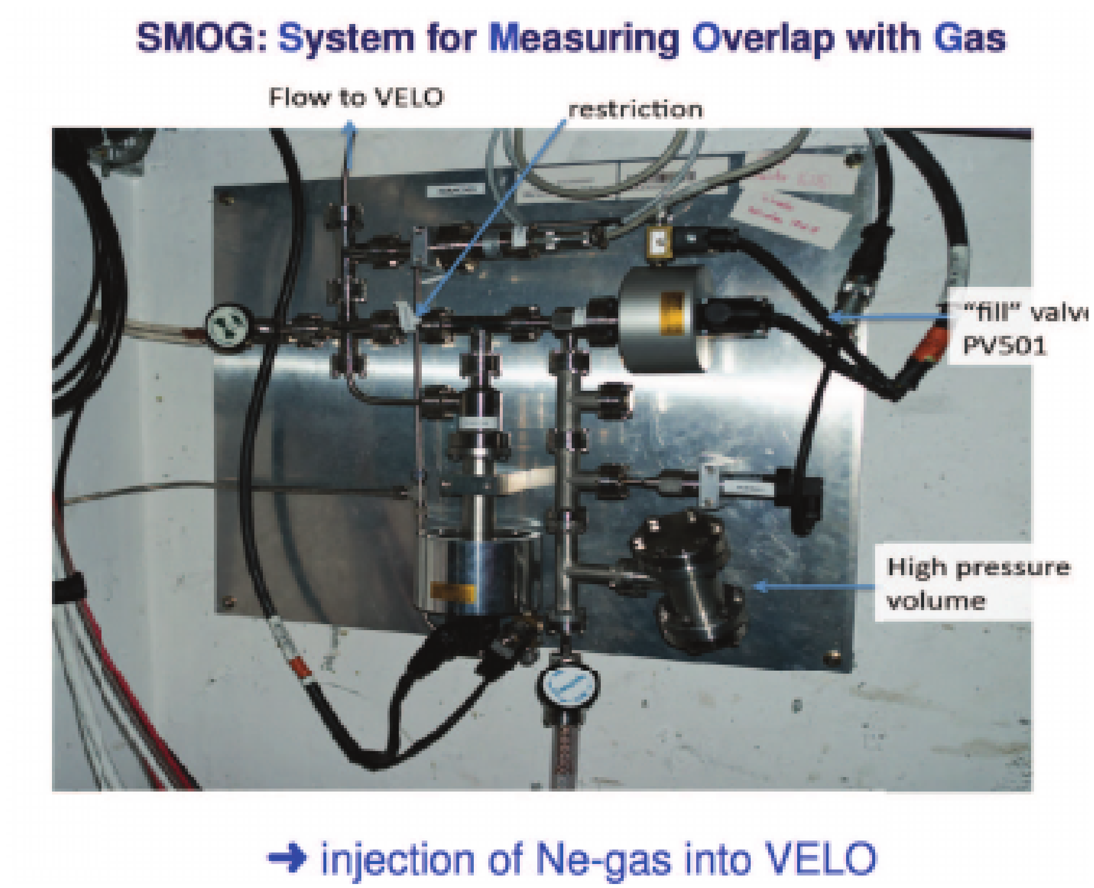
Reduce the LHC beam loss



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

Internal gas target, *SMOG@LHC*

✓ **Motivated for precise luminosity determination**

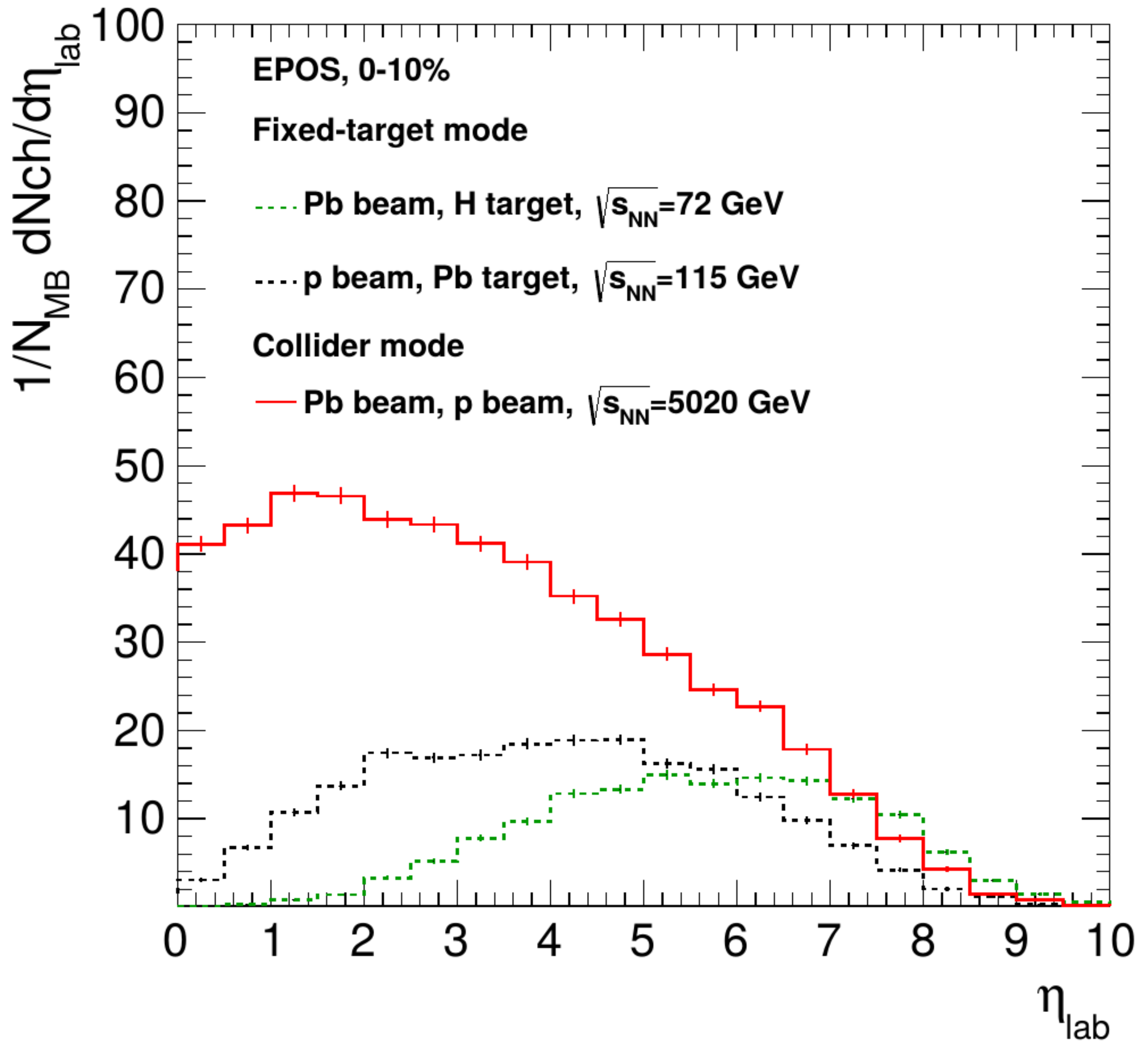


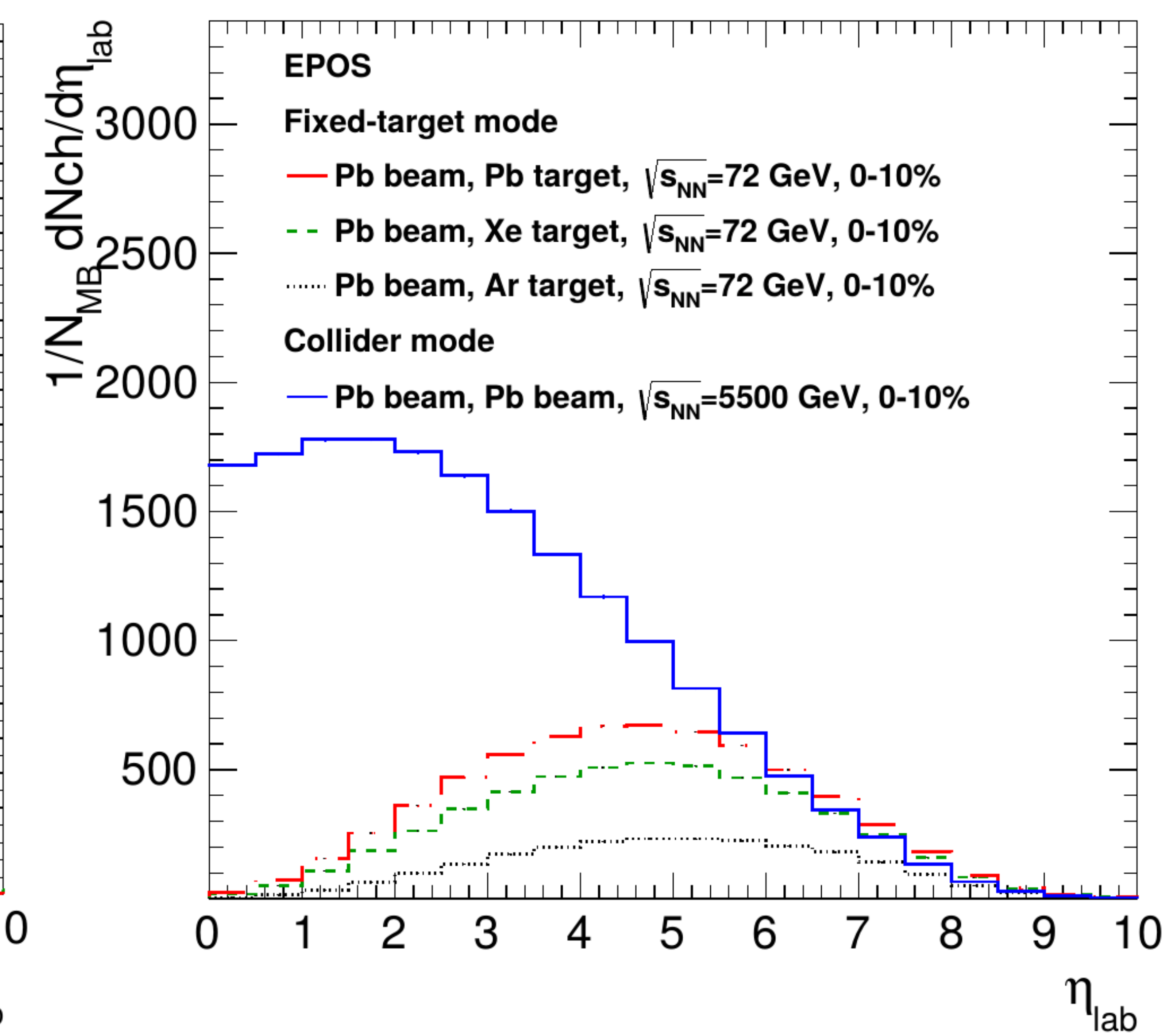
- ✓ Low density noble gas injected into VELO in LHCb
- ✓ Short pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012)
- ✓ Short PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013) *LHCb-CONF-2012-034*
- ✓ He, Ne and Ar gas injected (2015)
- ✓ pNe, pAr run at $\sqrt{s_{NN}}$ = 110 GeV (end of August 2015)
- ✓ 1.5 week of PbAr at $\sqrt{s_{NN}}$ = 69 GeV (2015)

- ✗ So far only noble gases
- ✗ No decrease of LHC performances observed in test runs
- ✗ Target polarization is not possible with SMOG
- ✗ <u>However internal gas target can be polarized</u>, like HERMES target

Charge particle multiplicities in a fixed target mode

Advances in High Energy Physics, Volume 2015 (2015), Article ID 986348





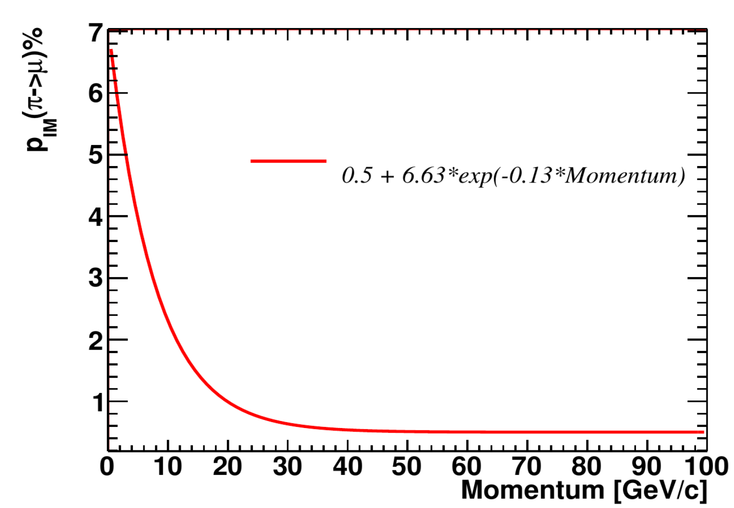
- ✓ Charge particle multiplicities, for all possible fixed target modes, p+Pb, Pb+H, Pb+Pb, are smaller than the ones reached in the collider modes. A detector with the LHCb capabilities is able to reconstruct all event centralities up to Pb-Ar.

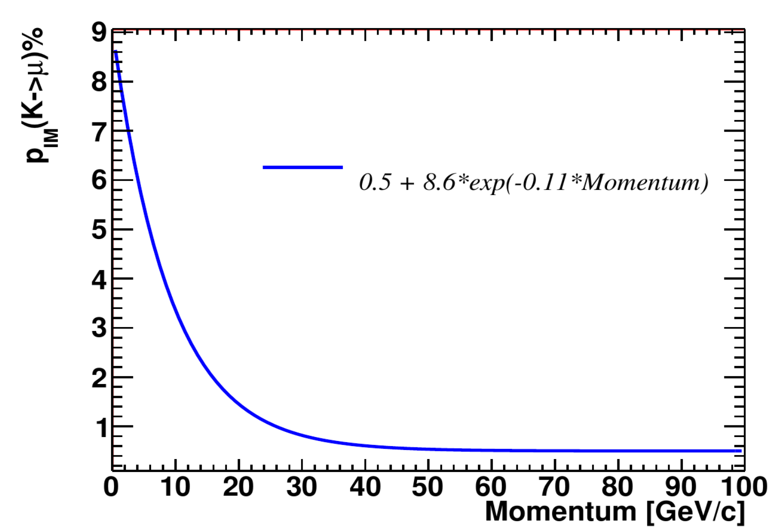
First simulations of quarkonia and Drell-Yan

Advances in High Energy Physics, Volume 2015 (2015), Article ID 986348

- ✓ *Input for quarkonium signals: HELAC-Onia*
- ✓ *Estimation of different dimuon background sources:*
  - ➔ Drell-Yan – HELAC-Onia
  - ➔ cc, bb – HELAC-Onia
  - ➔ Uncorrelated background – min bias PYTHIA 8
- ✓ Outputs from HELAC-Onia were processed with Pythia to perform the hadronization, initial/final radiations, and resonance decays
- ✗ Separate simulations to have under control p_T and y input distributions and normalization of different sources

- ✓ PYTHIA 8.185, fast simulations with LHCb-like reconstruction parameters
  - ✗ *Single μ cuts:*
    - ➔ $2 < \eta_\mu < 5$
    - ➔ Minimum $p_T^\mu > 0.7$ GeV/c
  - ✗ *Requirements:*
    - ➔ momentum resolution: $\Delta p/p = 0.5\%$
    - ➔ μ identification efficiency: 98%
    - ➔ *μ misidentification (with π or K) for the uncorrelated background*



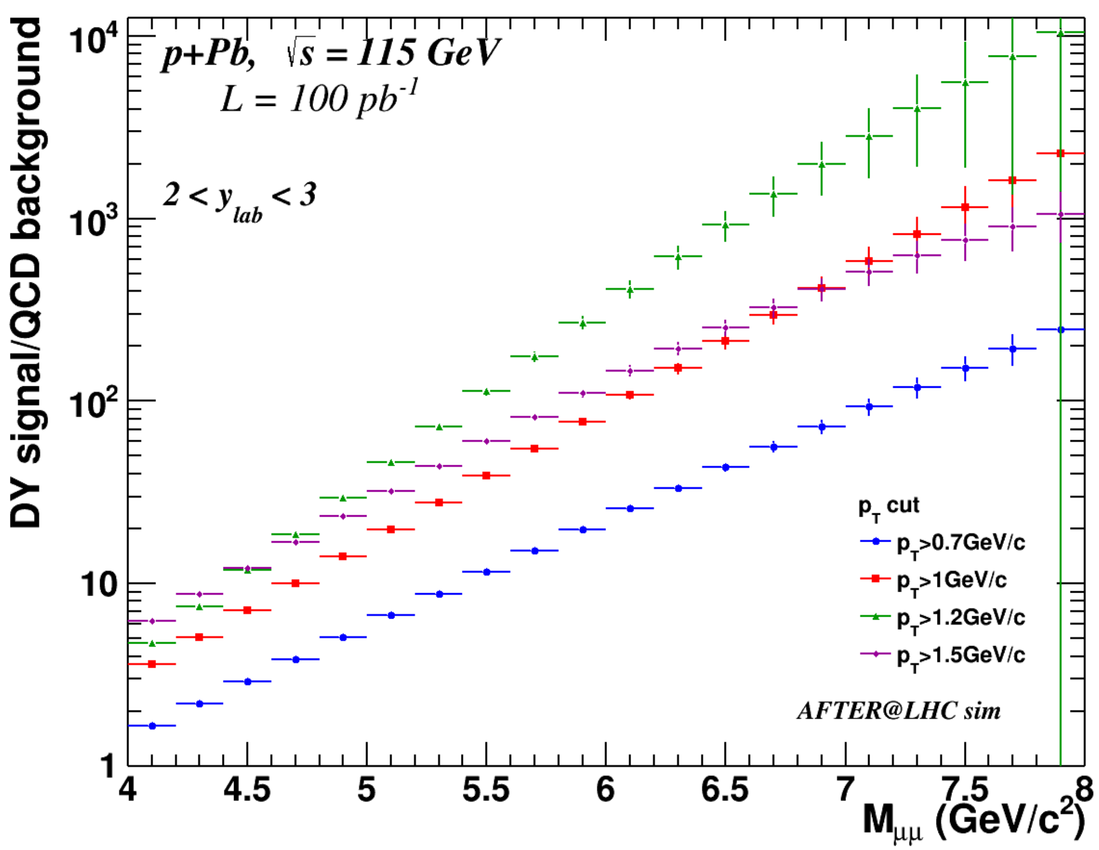


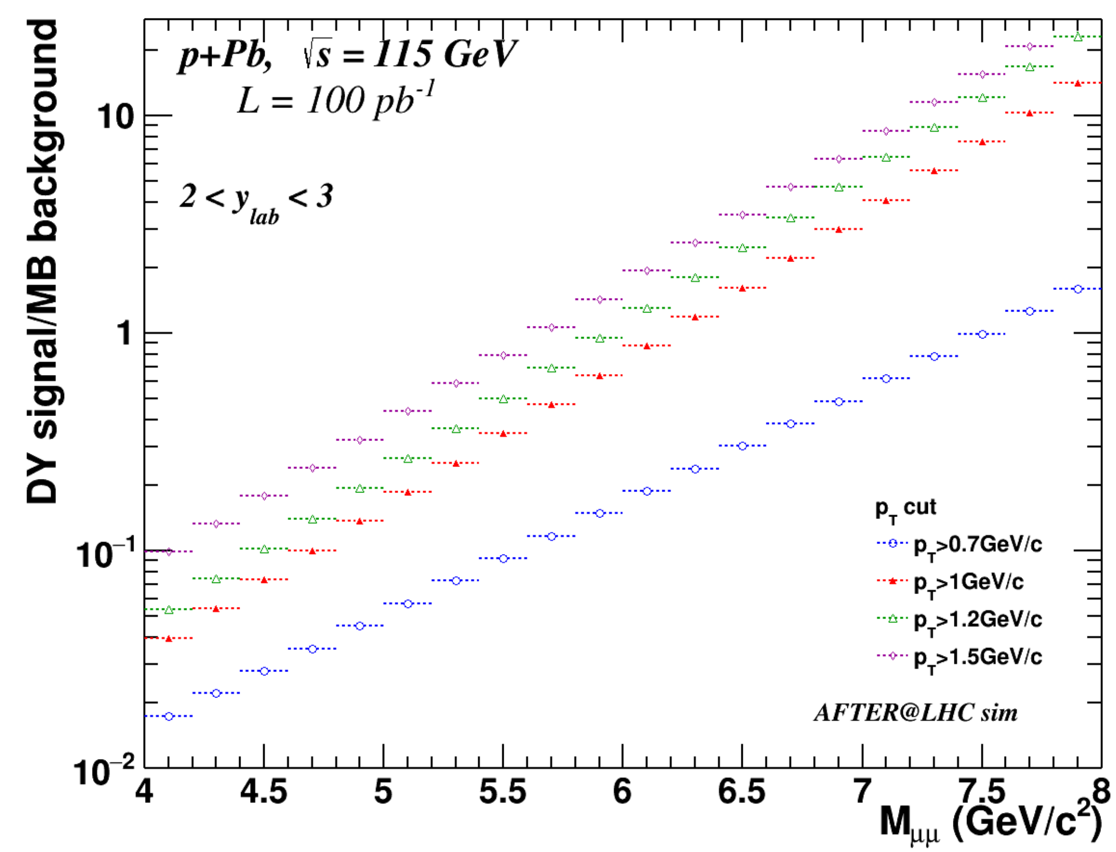
F. Achilli et al, JINST 8 (2013) P10020
arXiv:1306.0249

Drell-Yan simulations with full background - signal / background

p+Pb 115 GeV

- Backward rapidity: $2 < y < 3$
- Different single μ p_T cuts
  - QCD background: ccbar + bbbar background
  - MB background: uncorrelated background



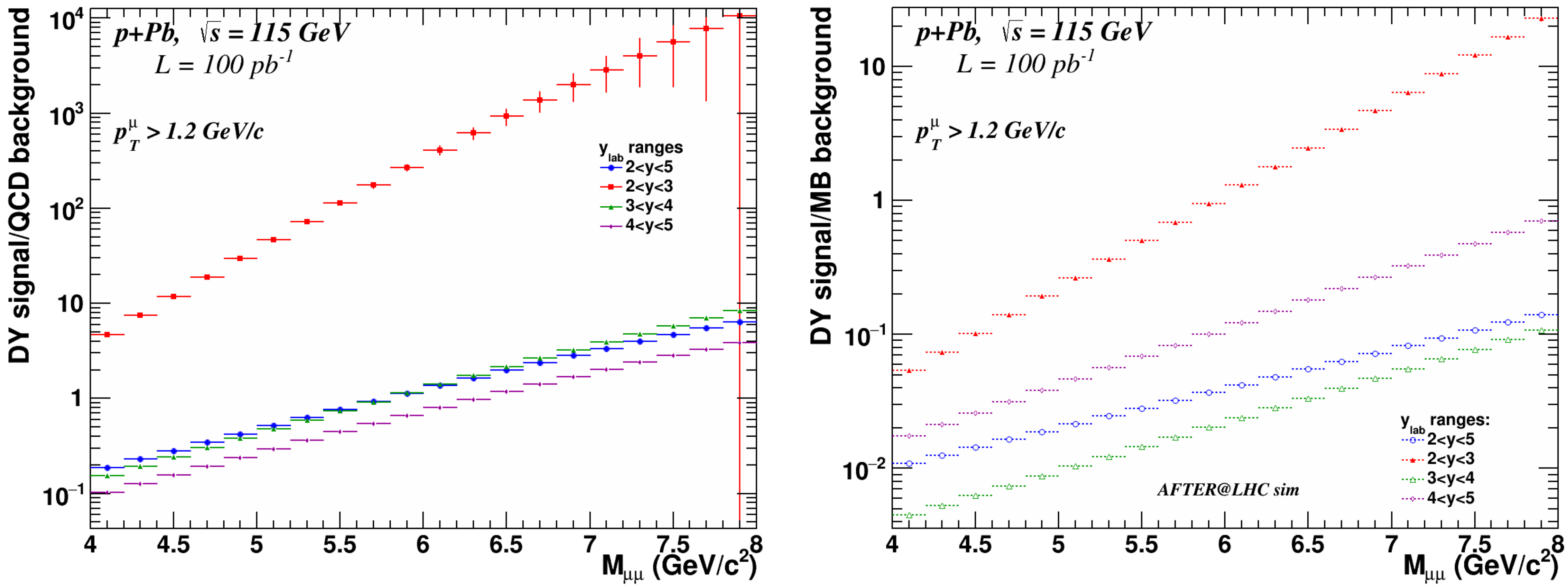


- Raising single μ p_T cut from default 0.7 GeV/c improves signal / background

Drell-Yan simulations with full background - signal / background

p+Pb 115 GeV

- Different rapidity ranges, single μ p_T > 1.2 GeV/c
  - QCD background: ccbar + bbbar background
  - MB background: uncorrelated background



- At backward rapidities quark-induced processes are favoured → background gets smaller

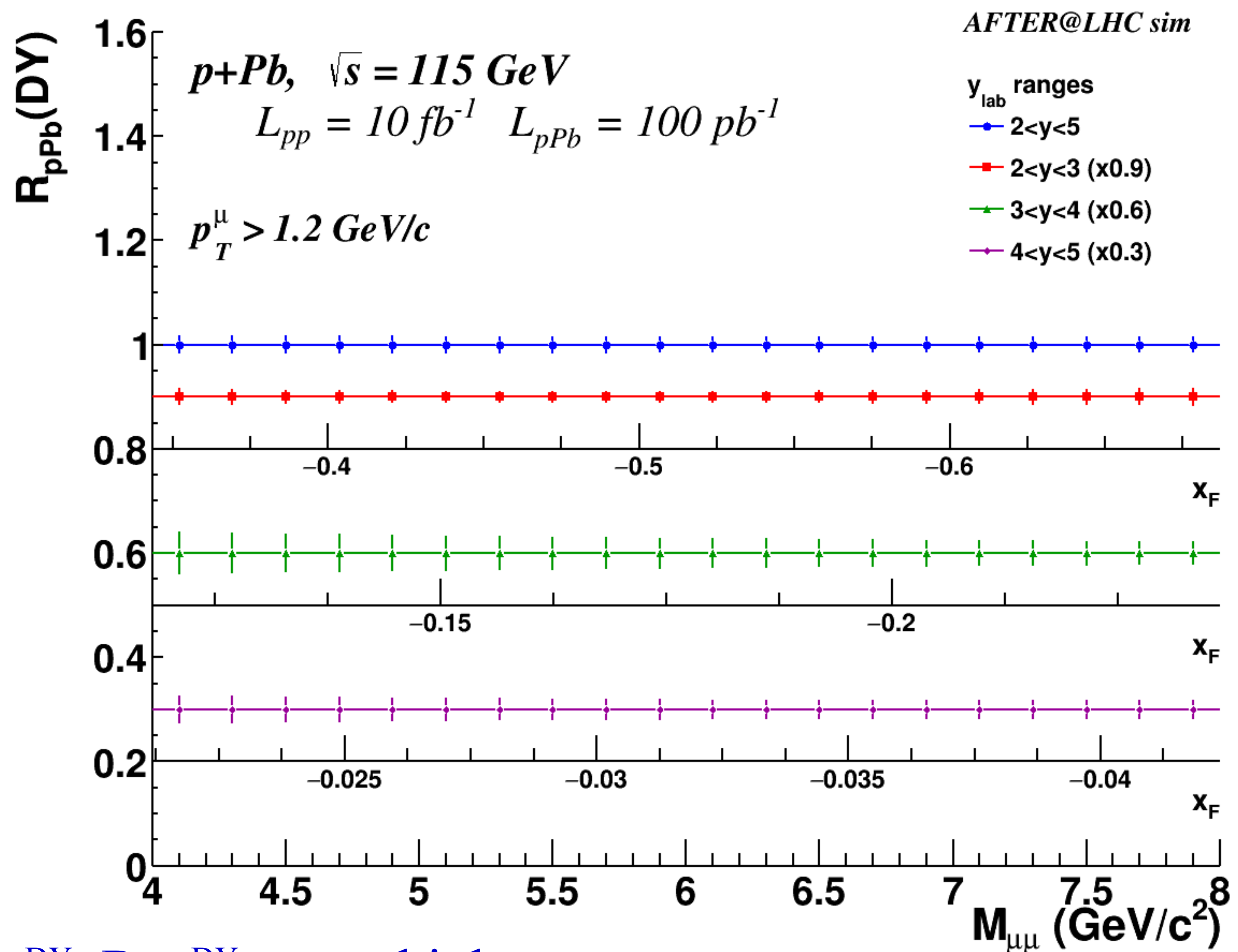
Drell-Yan simulations with full background - R_{pXe}

p+Xe 115 GeV

- Statistical precision on R_{pPb} vs di-μ invariant mass – x_F in different rapidity ranges
- Combinatorial background uncertainties taken into account assuming like-sign background subtraction
- No nuclear effects assumed

$\int L_{pp}$ = 10 fb^{-1}

$\int L_{pXe}$ = 100 pb^{-1}

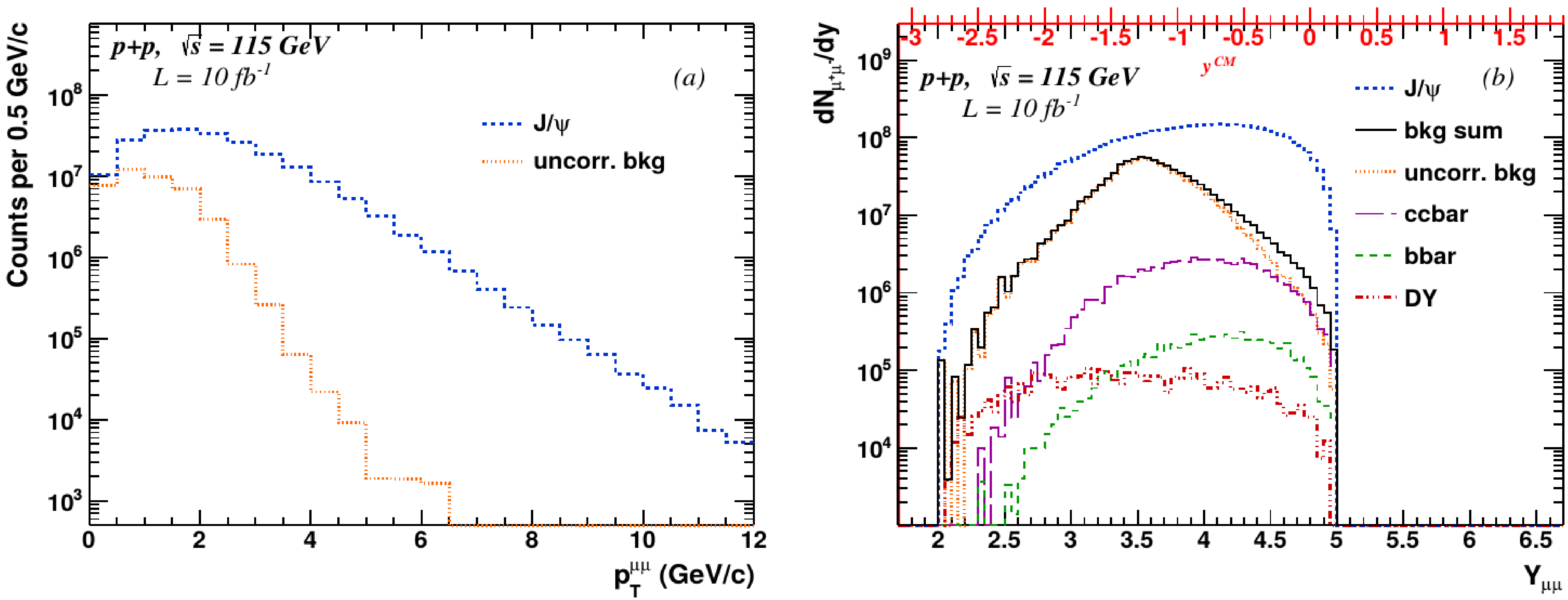


- Precise measurements of R_{pXe}^{DY}, R_{pPb}^{DY} up to high x_F - **nPDF constraints**

J/ψ signal simulation with full background

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

$\int L = 10\ fb^{-1}$



→ p_T and rapidity distributions for the J/ψ and different backgrounds differ.

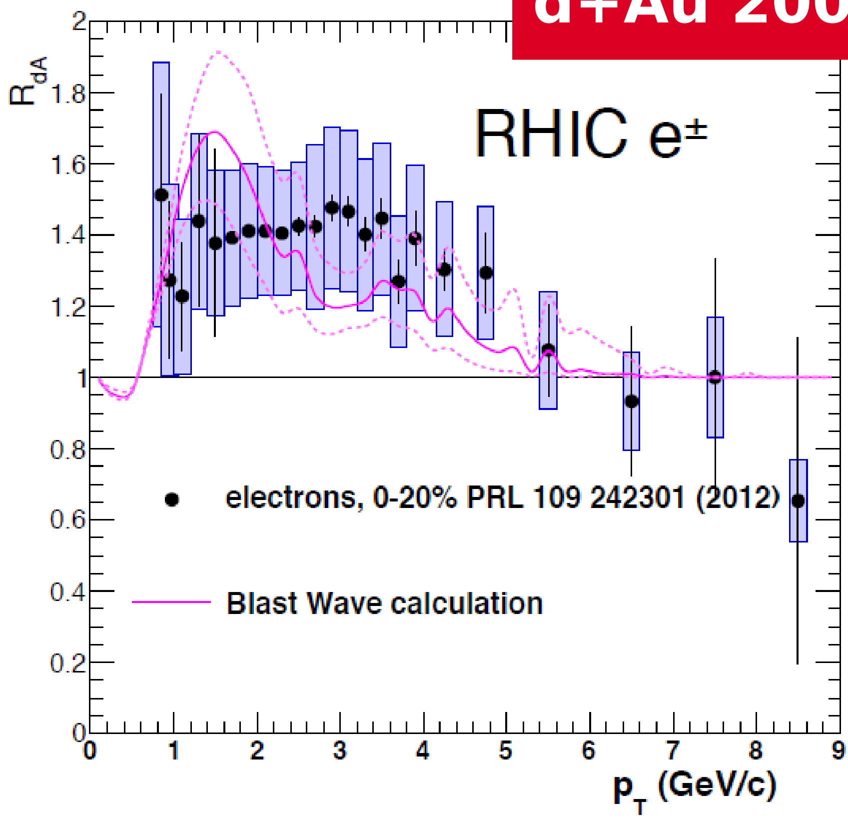
→ In more backward or forward rapidity regions, the signal to background ratio increases

Open Heavy Flavour in pA collisions

$D^0 \rightarrow K^- \pi^-$

- Heavy quarks in pA

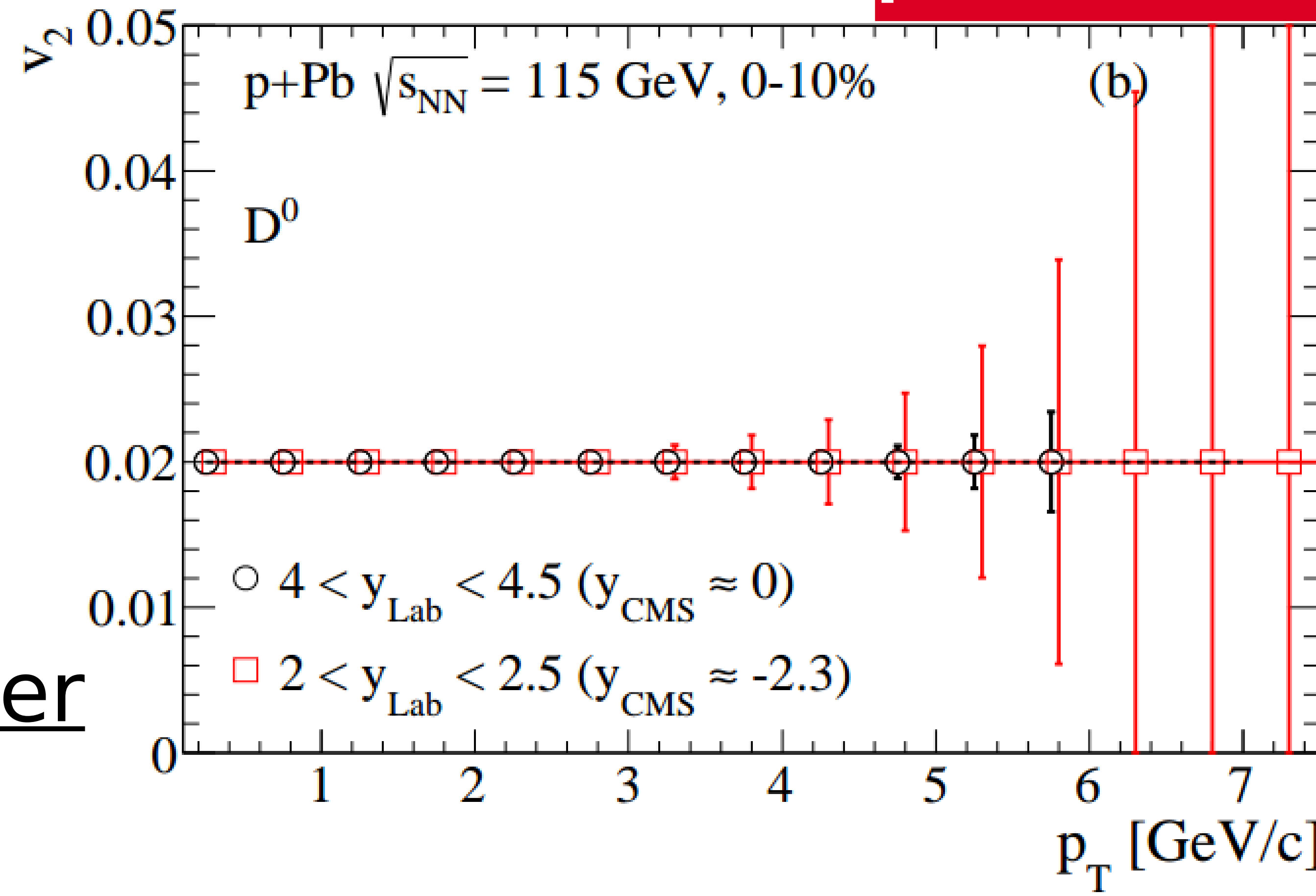
d+Au 200 GeV



Cronin effect ?
Collective effects (radial flow)?

„Possible evidence for radial flow of heavy mesons in d+Au collisions" Phys. Lett. B731 51-56 (2014)

p+A 115 GeV



<u>AFTER → definitive answer</u>