Advancing the precision of proton-proton and proton-nucleus collision studies with A Fixed-Target ExpeRiment at the LHC (AFTER@LHC)

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On behalf of the AFTER@LHC Study group: http://after.in2p3.fr/after/index.php/Current_author_list

Part I

Assets, Kinematics, Possible Implementations and Luminosities

The fixed-target mode with TeV beams: why and what for ?

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- achieving high luminosities,
- varying the atomic mass of the target almost at will,
- polarising the target.

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All this can be realised at CERN in a parasitic mode with the most energetic beams ever !

Nota: all (past) colliders with $E_p \geq 100$ GeV have had a fixed-target program (Tevatron, HERA, SPS, RHIC)

Fixed-target collisions at the LHC: main kinematical features

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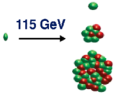
7 TeV proton beam on a fixed target

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



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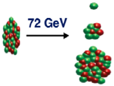

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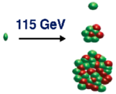

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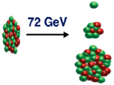

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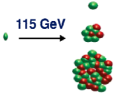

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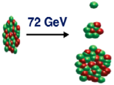

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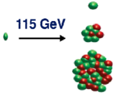

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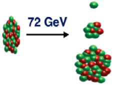

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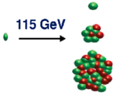

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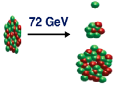

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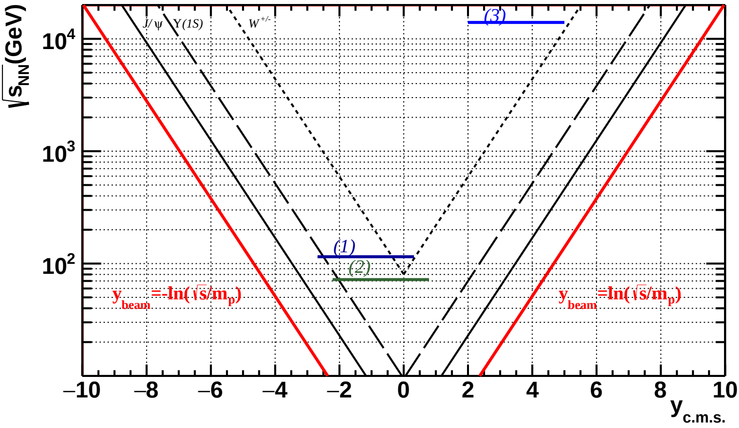
- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^\uparrow$ with large $x^\uparrow$]

LHCb acceptance for various colliding modes



- (1) Fixed-target using p beam, E_p = 7 TeV
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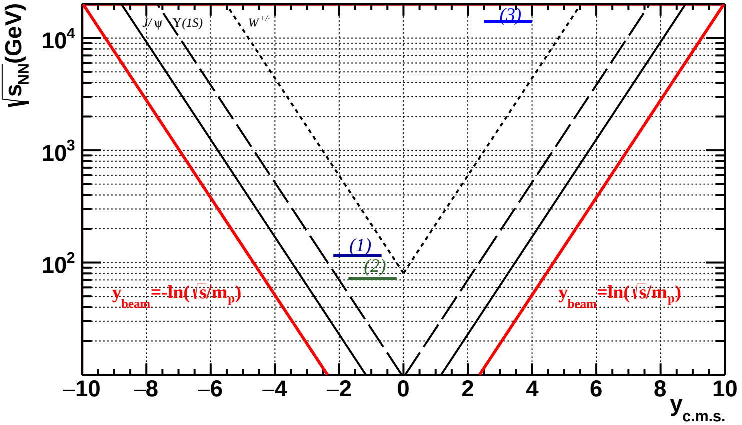
ALICE muon acceptance for various colliding modes



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Possible implementations

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Possible implementations

- Internal gas target (see next slide)
  - can be installed in one of the existing LHC caverns, and coupled to existing experiments
  - currently validated by the LHCb collaboration via a luminosity monitor (SMOG)
  - bears on the high LHC particle current
    - proton flux: $3.4 \times 10^{18}\ s^{-1}$ & lead flux: $3.6 \times 10^{14}\ s^{-1}$

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- Similar luminosities with an internal gas target or a crystal-based solution

pp	pA	PbA
$\mathcal{O}(10\ \text{fb}^{-1}\text{yr}^{-1})$	$\mathcal{O}(0.1-1\ \text{fb}^{-1}\text{yr}^{-1})$	$\mathcal{O}(1-50\ \text{nb}^{-1}\text{yr}^{-1})$

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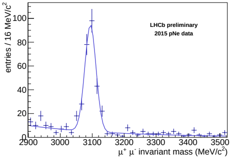

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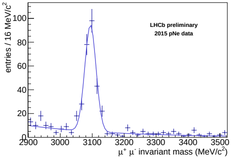

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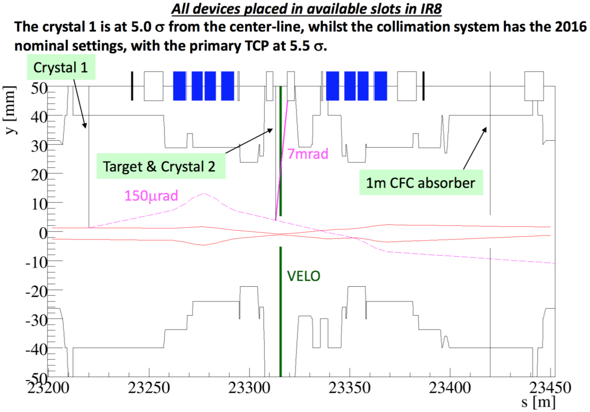
The simulations showed in Part II are based on this set-up coupled to a LHCb like detector

Beam splitting option

Proposed at the *Physics Beyond Collider workshop Sept.2016* (S.Redaelli, W.Scandale)



- Crystal located ~ 100 m downstream the target to deflect the beam halo
- Solid target close to the nominal interaction point
- Absorber 100 m upstream for the non-interacting beam halo

Part II

A selection of projected performances

What is not covered by lack of time

- Heavy-ion physics case
- Azimuthal asymmetries [Spin]
- Photon related observables [High-x, Spin]
- W boson [High-x, Spin]
- Antiproton and related x-section measurements for astroparticle MC tuning [High-x]
- C-even quarkonia [High-x, Spin]
- Associated production (beyond double J/ψ) [Spin]

Drell-Yan

D. Kikola *et al.*. **arXiv:1702.01546 [hep-ex]**

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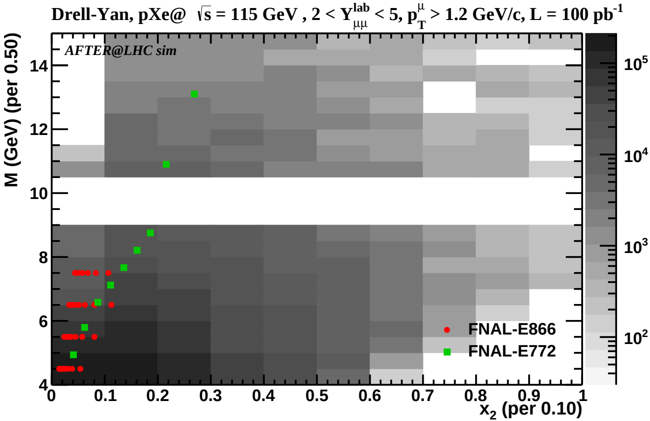

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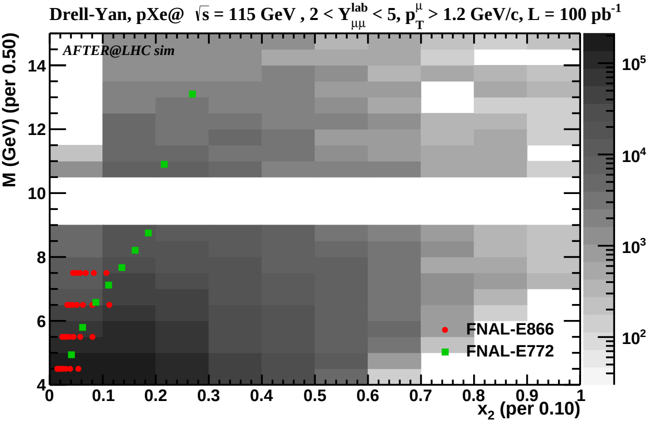

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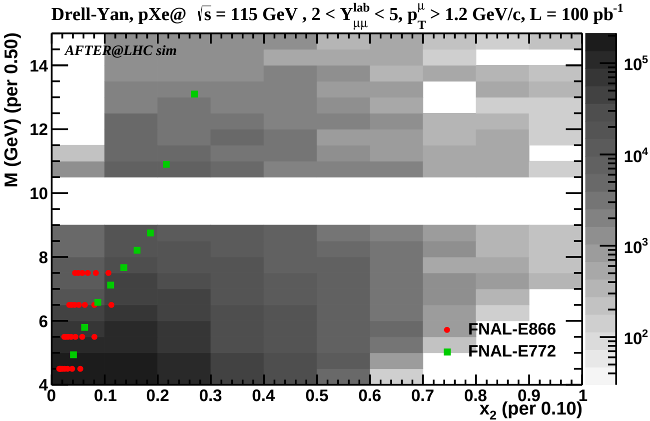

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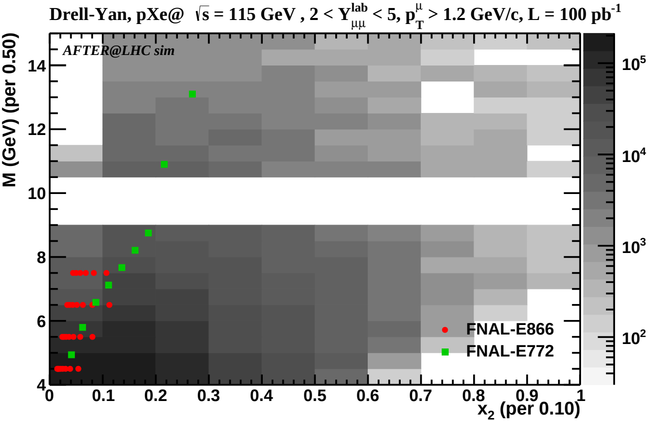
- Extremely large yields up to $x_2 \to 1$ [plot made for *p*Xe with a Hermes like target]
- No existing measurements at RHIC



Drell-Yan performances for spin analyses [LHCb-like detector]

D. Kikola *et al.*. **arXiv:1702.01546 [hep-ex]**

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Experiment	particles	beam energy (GeV)	$\sqrt{s}$ (GeV)	$x^{\uparrow}$	$\mathcal{L}$ (cm^{-2}s^{-1})	$\mathcal{P}_{\rm eff}$	$\mathcal{F}$ (cm^{-2}s^{-1})
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AFTER@LHCb	$p+{}^3\mathrm{He}^{\uparrow}$	7000	115	$0.05 \div 0.95$	$2.5 \cdot 10^{32}$	23%	$1.4 \cdot 10^{31}$
AFTER@ALICE$_{\mu}$	$p+p^{\uparrow}$	7000	115	$0.1 \div 0.3$	$2.5 \cdot 10^{31}$	80%	$1.6 \cdot 10^{31}$
COMPASS (CERN)	$\pi^{-}+p^{\uparrow}$	190	19	$0.05 \div 0.55$	$2 \cdot 10^{33}$	18%	$6.5 \cdot 10^{31}$
PHENIX/STAR (RHIC)	$p^{\uparrow}+p^{\uparrow}$	collider	510	$0.05 \div 0.1$	$2 \cdot 10^{32}$	50%	$5.0 \cdot 10^{31}$
E1039 (FNAL)	$p+p^{\uparrow}$	120	15	$0.1 \div 0.45$	$4 \cdot 10^{35}$	15%	$9.0 \cdot 10^{33}$
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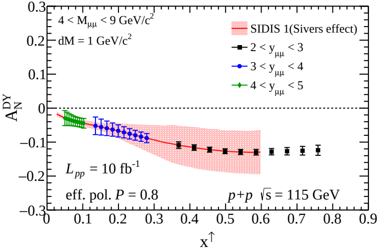

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- With a $^3He^\uparrow$ target, access to the quark Sivers effect in the neutron via DY: unique !

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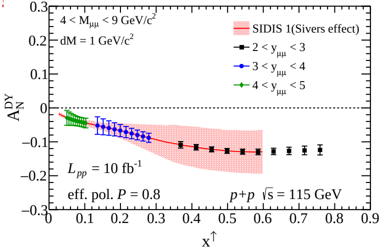

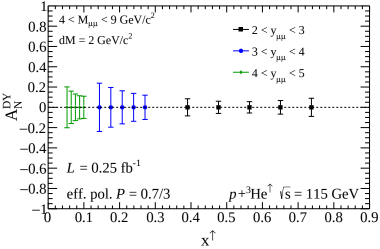

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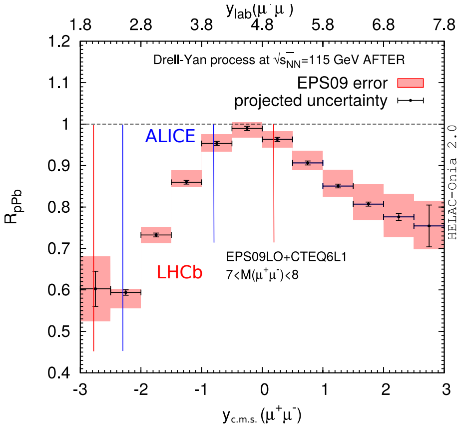
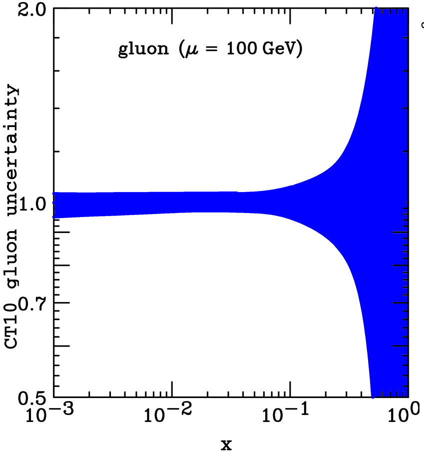
- Stat. uncertainties smaller than nPDF: discrimating power

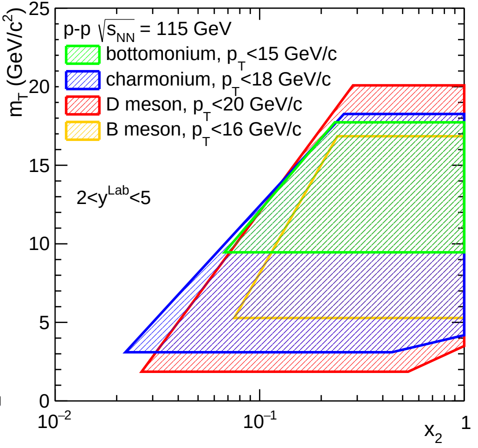
[**only 1 bin out of 5 shown**; global syst. : *pp* vs *pA* lumi.]



[$\mathcal{L}_{pp}$ = 10 fb^{-1}; $\mathcal{L}_{p\mathrm{Pb}}$ = 100 pb^{-1}]

Open/Closed heavy flavour: kinematical coverage





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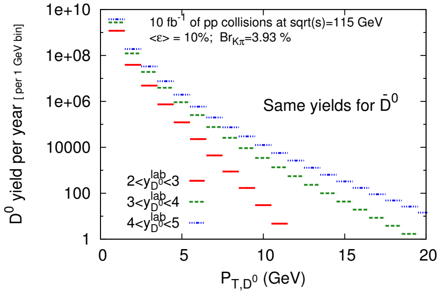

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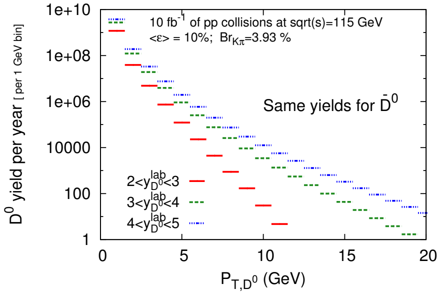

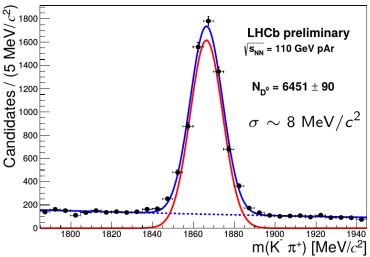

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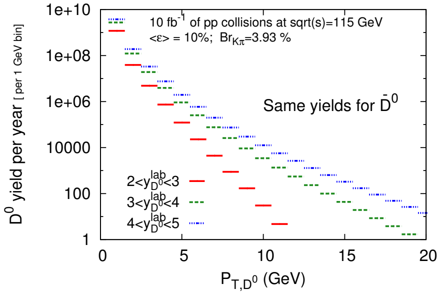

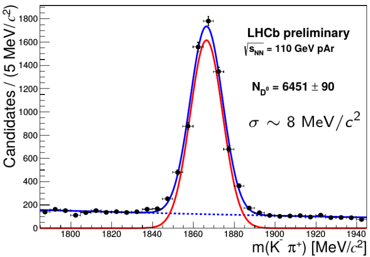

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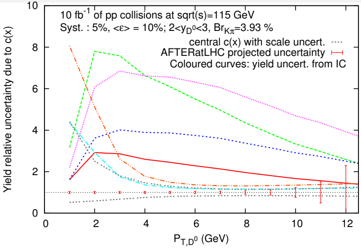

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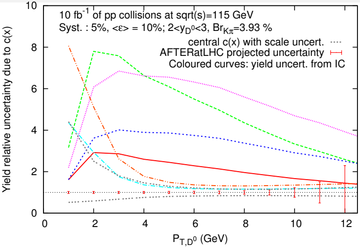

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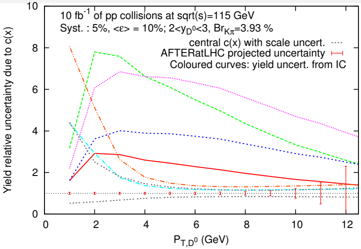

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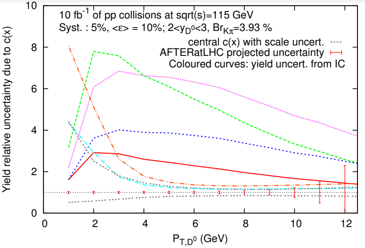

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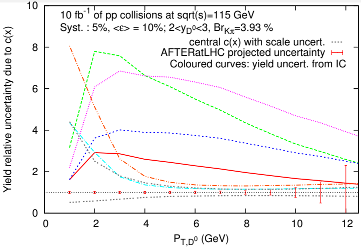

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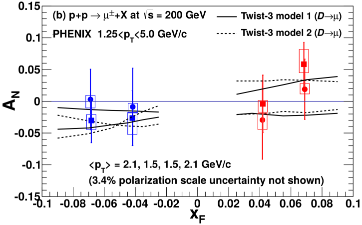

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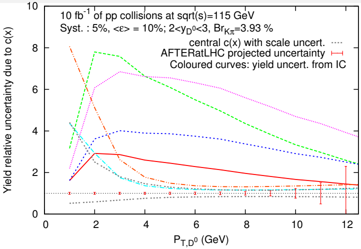

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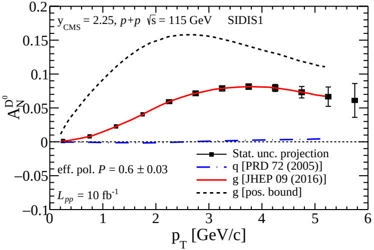

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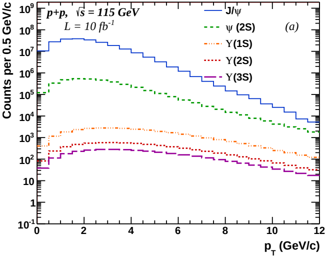

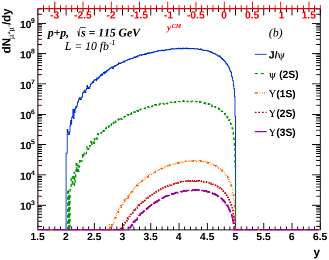

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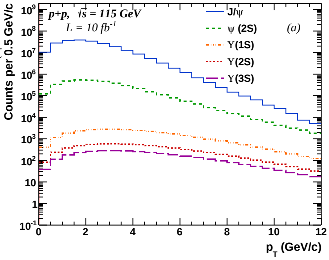

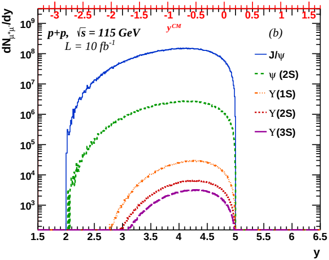

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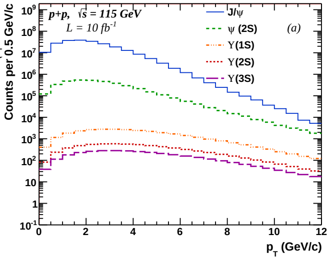

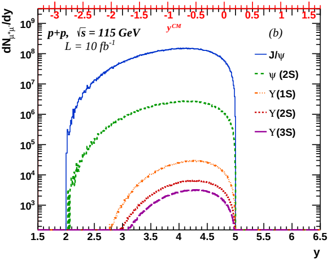

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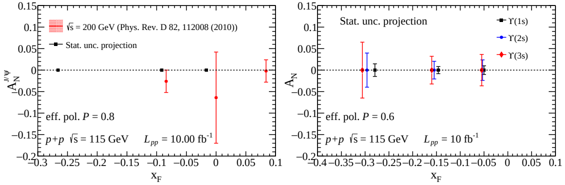

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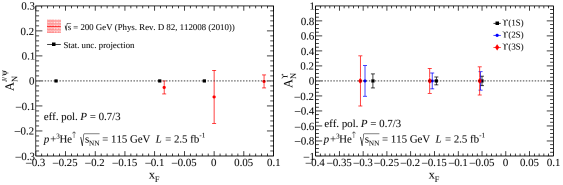

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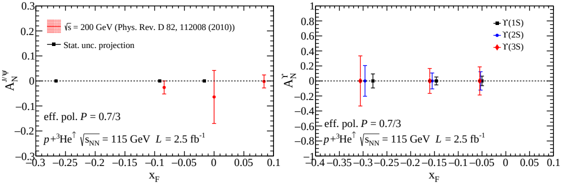

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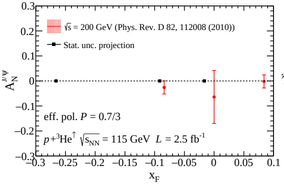

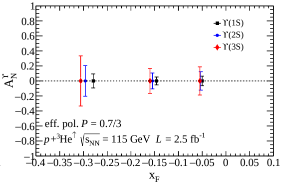

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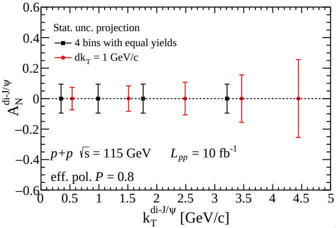

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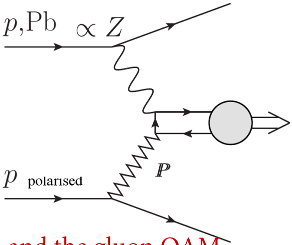

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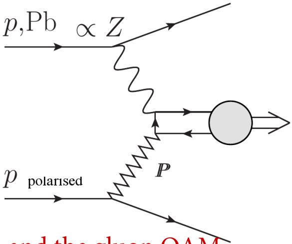

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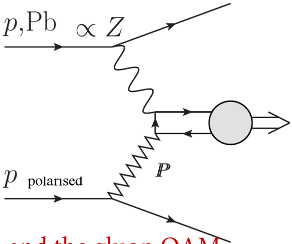

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- In parallel, we pursuit our effort to finalise the Expression of Interest

  → **Inputs are still welcome until June**

Part III

Backup slides

Further quarkonium projections

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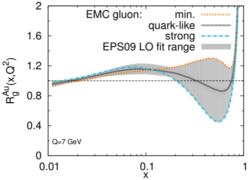

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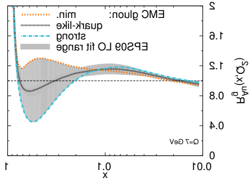

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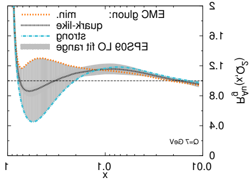

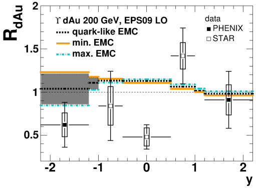

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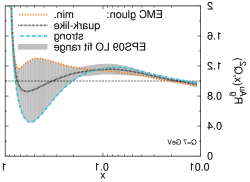

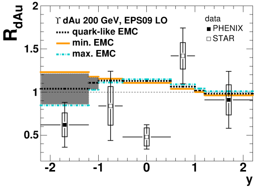

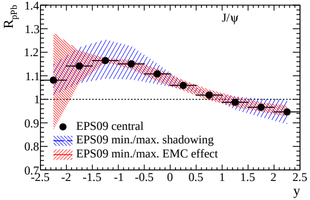

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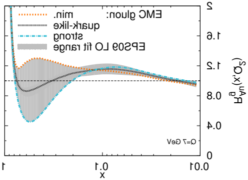

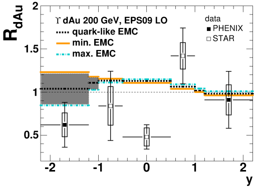

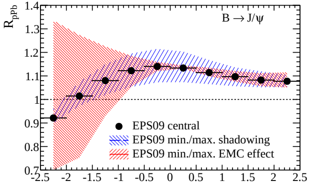

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L. Massacrieret al., Adv.Hi.En.Phys. (2015) 986348

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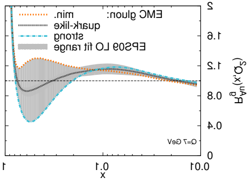

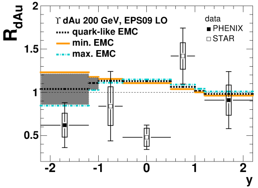

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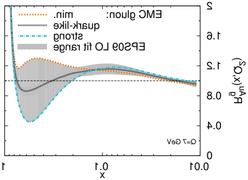

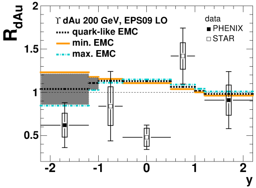

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- High stat. → quarkonium polarisation in pA and AA collisions

[→ production/suppression mechanisms]

Further readings

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) 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) 783134
- *Quarkonium suppression from coherent energy loss in fixed-target experiments using LHC beams* by F. Arleo, S.Peigne. [arXiv:1504.07428 [hep-ph]]. Adv.Hi.En.Phys. (2015) 961951
- *Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams* by K. Zhou, Z. Chen, P. Zhuang. Adv.High Energy Phys. 2015 (2015) 439689
- *Lepton-pair production in ultraperipheral collisions at AFTER@LHC*
  By J.P. Lansberg, L. Szymanowski, J. Wagner. JHEP 1509 (2015) 087
- *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.

Further readings

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) 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) 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) 371396
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)* By T. Liu, B.Q. Ma. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER* By D. Boer, C. Pisano. Phys.Rev. D86 (2012) 094007.

Further readings

Hadron structure

- *Double quarkonium production at high Feynman-x*
  by S. Koshkarev and S. Groote, Nucl. Phys. B **915** (2017) 384
- *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]]. Nucl.Phys. B900 (2015) 273-294
- *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) 726393.
- *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) 231547.
- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. Phys.Rev. D89 (2014) 074020.

Further readings

Feasibility study and technical ideas

- *Heavy-ion Physics at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC): Feasibility Studies for Quarkonium and Drell-Yan Production*
  by B. Trzeciak *et al.*. arXiv:1703.03726 [nucl-ex]
- *Feasibility Studies for Single Transverse-Spin Asymmetry Measurements at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC)*
  by D. Kikola *et al.*. arXiv:1702.01546 [hep-ex]
- *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) 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) 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) 760840

Fast simulation using LHCb reconstruction parameters

Projection for a LHCb-like detector

L. Massacrier, B. Trzeciak, *et al.*, Adv.Hi.En.Phys. (2015) 986348

- Simulations with Pythia 8.185
- the 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
- Muon misidentification:
  - If π and K decay before the calorimeters (12m), they are rejected by the tracking
  - otherwise a misidentification probability is applied following: F. Achilli et al, arXiv:1306.0249