Updates from the AFTER@LHC study group

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AFTER@LHC Study group: http://after.in2p3.fr/after/index.php/Current_author_list

Part I

Possible Implementations and Luminosities

Possible implementations

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- Internal gas target
  - 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)
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- Beam line extracted by a bent crystal
  - crystals successfully tested at the LHC for proton and lead beam collimation
  - provides a new facility with 7 TeV proton beam but requires civil engineering
  - the LHC beam halo is recycled on dense target
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- The gas target is the best for polarised target and satisfactory for heavy-ion studies

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The polarised H-jet polarimeter at RHIC-BNL

Zelenski et al. NIM A 536 (2005) 248

- Used to measure the proton beam polarisation at RHIC
- 9 vacuum chambers: 9 stages of differential pumping
- Polarised gas: free atomic beam source (ABS) crossing the RHIC beam: H, D and ^{3}He possible
- Holding field in the target vacuum chamber
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- Polarised inlet $H^{\uparrow}$ flux: 1.3×10^{17} H/s
- Areal density $\theta_{H^{\uparrow}} = 1.2 \times 10^{12}$ atoms/cm^2 [7 – 15× SMOG but much longer data taking]
- Higher flux can be obtained for $^{3}He^{\uparrow}$ (×100) and H_2 (× 1000)
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Luminosity

- Using nominal LHC bunch number [2808 bunches for proton and 592 for lead] and for 1 LHC year [10^7 s proton beam and 10^6 s lead beam]
- $\mathcal{L}_{pH^\uparrow} = 4.5 \times 10^{30}$ cm^{-2} s^{-1} [$t = 10^7$ s: $\mathcal{L}_{pH^\uparrow} = 45$ pb^{-1}]
- $\mathcal{L}_{pH_2} = 10^{33} - 10^{34}$ cm^{-2} s^{-1} [$t = 10^7$ s : $\mathcal{L}_{pH_2} = 10 - 100$ fb^{-1}]

Part II

An updated selection of projected performances

What is not covered

- Azimuthal anisotropies [Heavy-Ion, Spin]
- Photon related observables [High-x, Spin, Heavy-Ion]
- W boson [High-x, Spin]
- Antiproton and related x-section measurements for astroparticle MC tuning [High-x]
- C-even quarkonia [High-x, Spin, Heavy-Ion]
- Associated production [Spin, Heavy-Ion]

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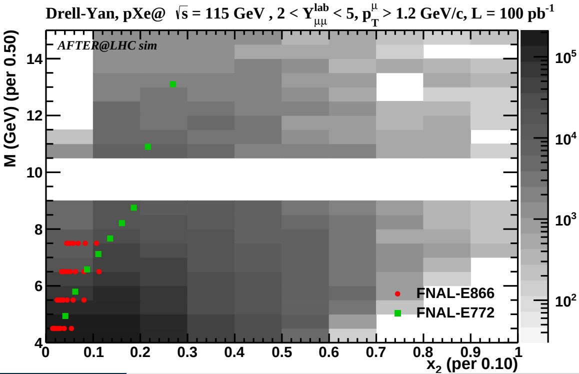

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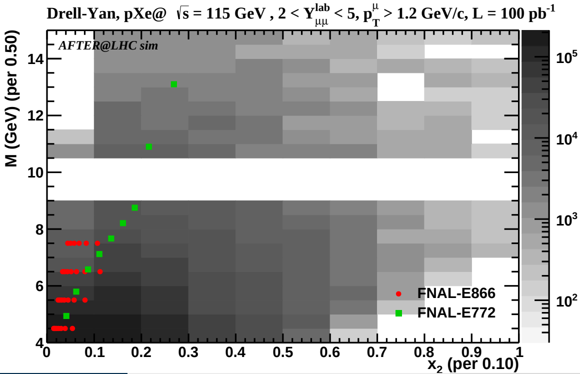

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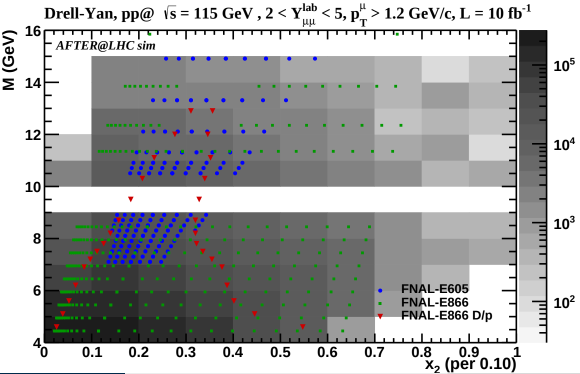

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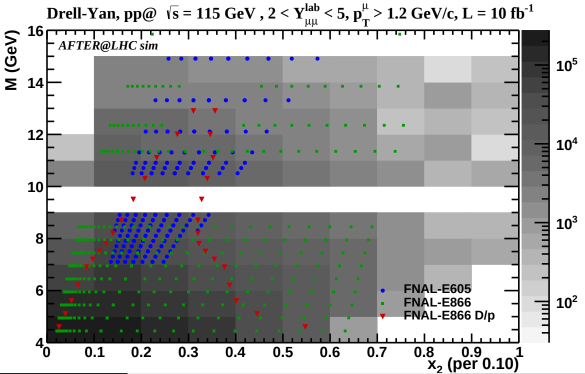

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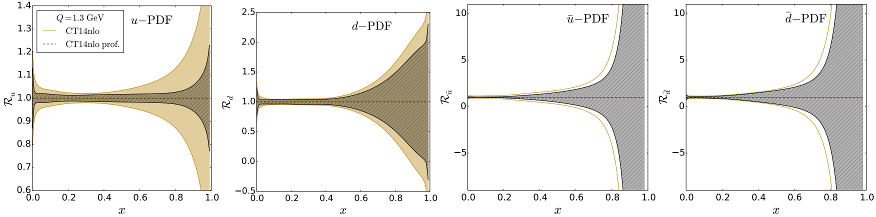

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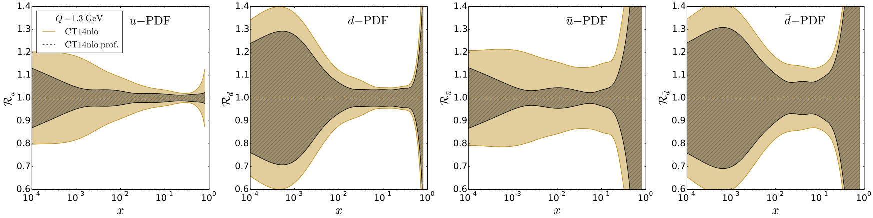

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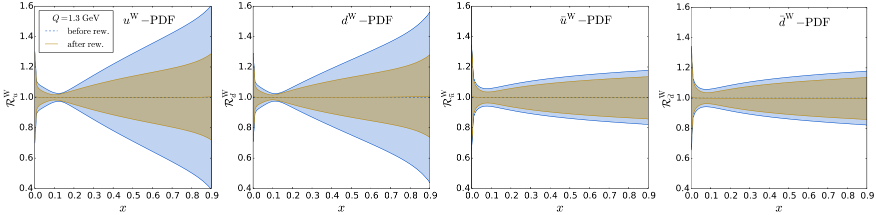
pW case



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- On-going theory study for $W^{\pm}$ production accounting for threshold resummation

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

D. Kikola *et al.* **Few Body Syst. 58 (2017) 139**

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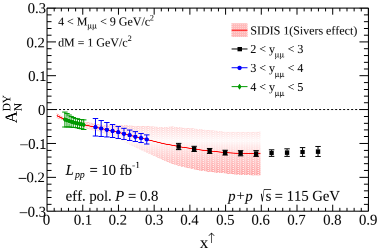

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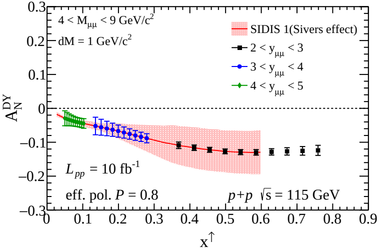

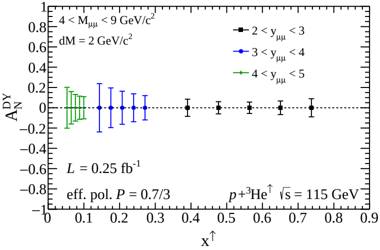

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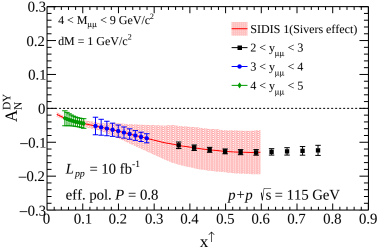
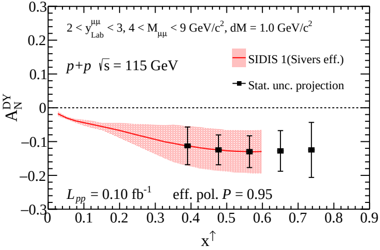
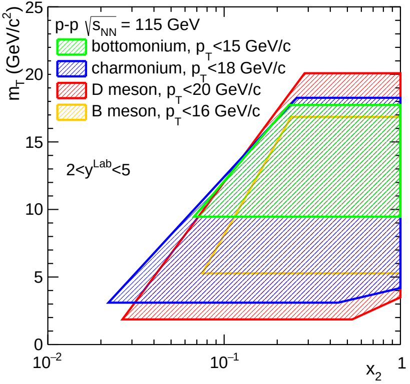
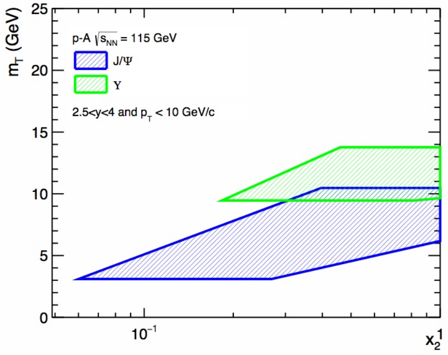




NEW: preliminary FoM with H-jet (1 year)

Heavy-flavour studies : kinematical ranges





- Left: for LHCb based on 10 fb^{-1} of data
- Right : for ALICE based on a P_T cut (to be improved with 0.25 fb^{-1} of data)

Open charm projections

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- Longstanding debate in the QCD community: pertubative vs. non-perturbative origin
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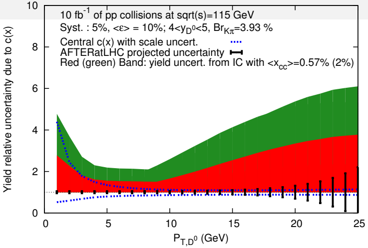

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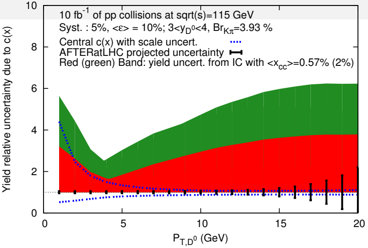

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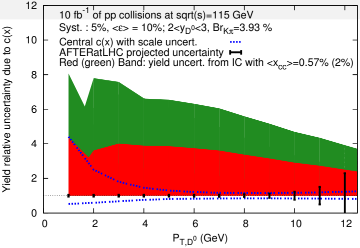

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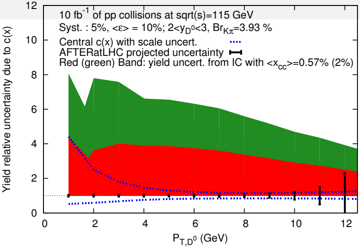

D. Kikola *et al.*. Few Body Syst. 58 (2017) 139

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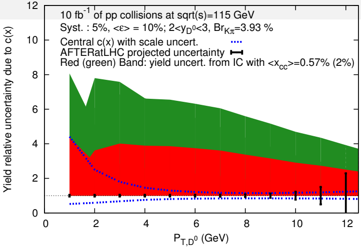

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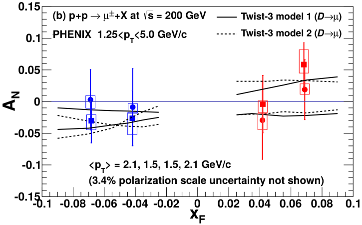

[Beware of the unconventional definition of x_F at RHIC which does not correspond to $x_1 - x_2$ in the fixed target mode]

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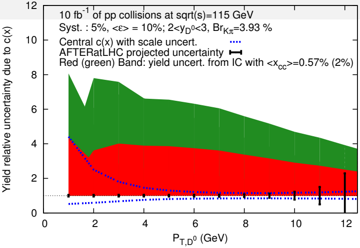

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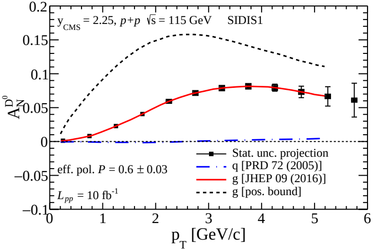

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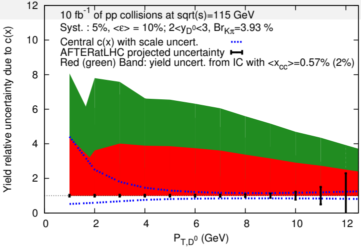

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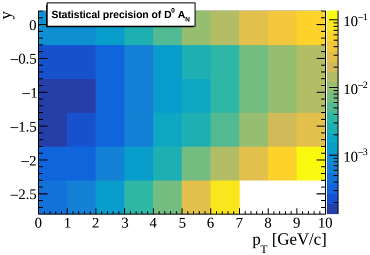

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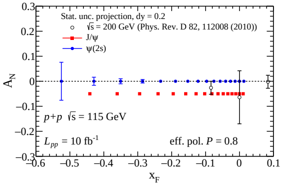

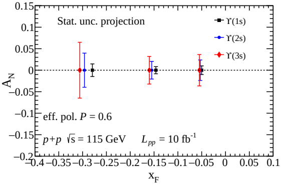

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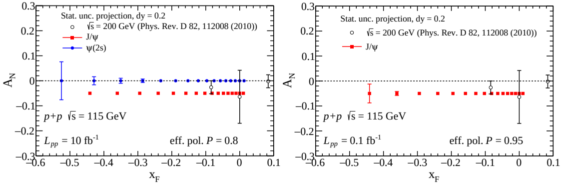

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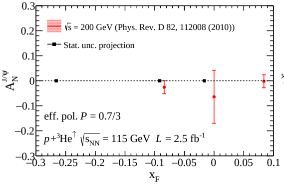

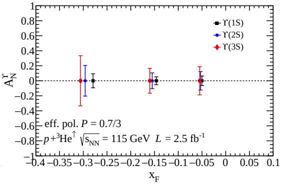

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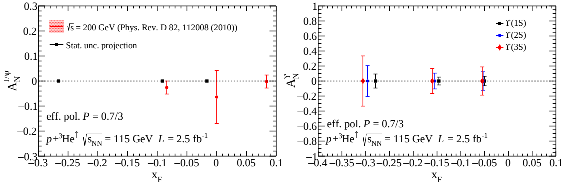

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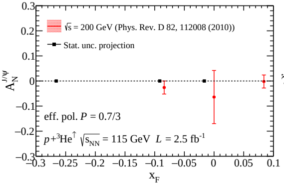
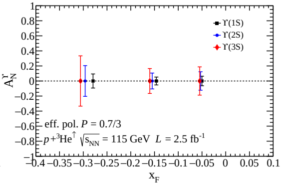
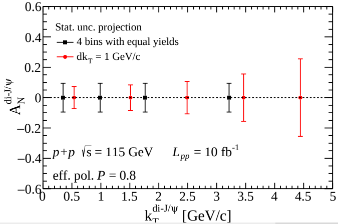




- Completely new perspectives to study the gluon Sivers effect [and beyond $\rightarrow \mathcal{L}_g$]
- Di-J/ψ allow one to study the k_T dependence of the gluon Sivers function for the very first time !



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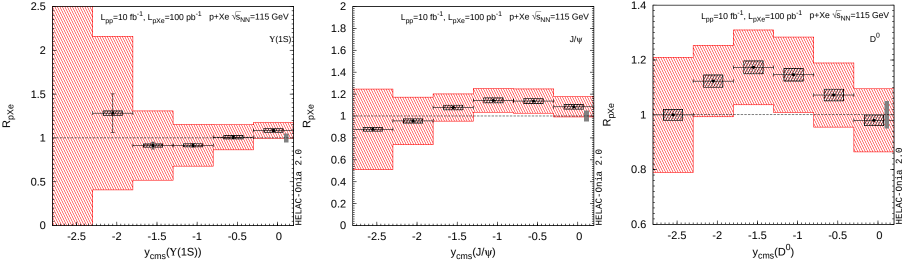
nCTEQ uncertainties vs. projected statistical uncertainties



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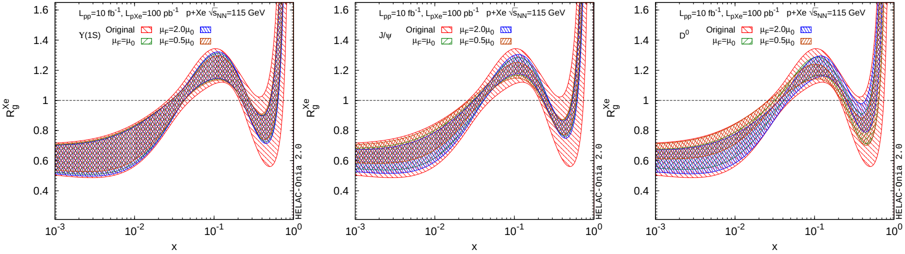
nCTEQ reweighting uncertainties: main uncertainties is the scale



Clear decrease of the nPDF uncertainty in the EMC region:

uncharted for gluons ! [current uncertainty : result of pure extrapolation]

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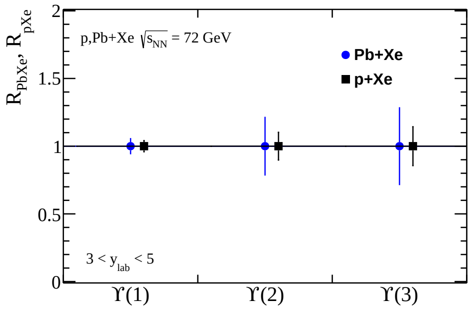
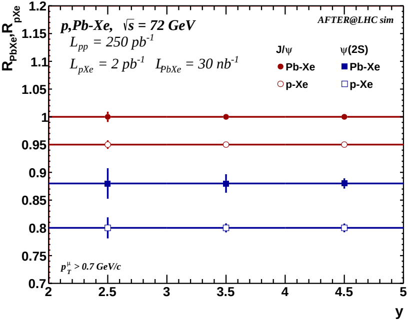
- Statistical-uncertainty projections (accounting for background subtraction)





[No nuclear modifications assumed, $\mathcal{L}_{PbXe} = 30\ nb^{-1}$]

Ultra-Peripheral Collisions in the FT mode and J/ψ production

JPL, L. Massacrier, L. Szymanowski, J. Wagner, arXiv:1709.09044 & in progress

	pH ($\sqrt{s_{NN}} = 115$ GeV)	PbH ($\sqrt{s_{NN}} = 72$ GeV)
Photon-emitter	proton	Lead
$\sigma^{tot}_{J/\psi}$ (pb)	1.18×10^3	276.77×10^3
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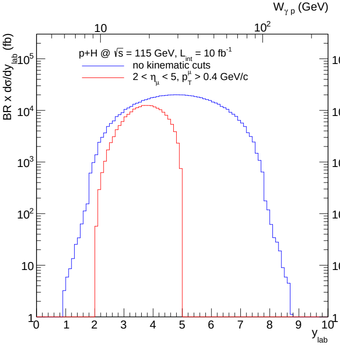

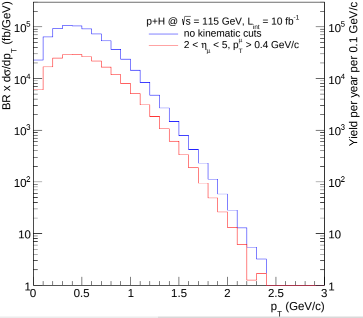

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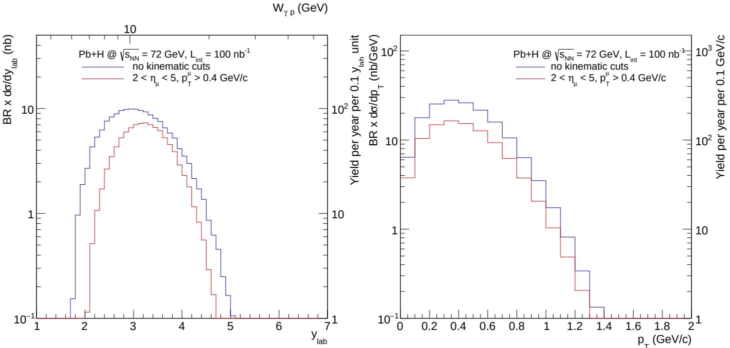

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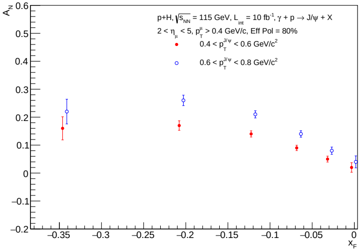

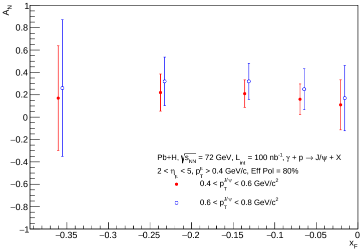

$A_N^{\gamma p^\uparrow \to J/\psi p} \propto \sqrt{t_0 - t} Im(\mathcal{E}_g^* \mathcal{H}_g) \to$ access to the GPD E_g and the gluon OAM

Part III

Conclusion

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- In synergy with & under the advice of the PBC, we now prepare a document on the fixed-target physics at the LHC

Conclusions

- THREE MAIN THEMES PUSH FOR A FIXED-TARGET PROGRAM AT THE LHC

  S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg. Phys.Rept. 522 (2013) 239

  - The high x frontier: new probes of the confinement
    and connections with astroparticles
  - The nucleon spin and the transverse dynamics of the partons
  - The approach to the deconfinement phase transition:
    new energy, new rapidity domain and new probes
- 2 WAYS TOWARDS FIXED-TARGET COLLISIONS WITH THE LHC BEAMS
  - A slow extraction with a bent crystal
  - An internal gas target inspired from SMOG@LHCb/Hermes/H-Jet, ...
- Based on fast simulations, the AFTER@LHC study group has made FoMs for LHCb and ALICE in the FT mode which clearly support a full physics program
- In synergy with & under the advice of the PBC, we now prepare a document on the fixed-target physics at the LHC
- However, even for FoMs based on fast simulations, we will need to imagine a coherent data-taking plan (pH, pA, PbA, PbH) given allocatable bandwidths, ...

Part IV

Backup slides

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 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

- *Feasibility Studies for Single Transverse-Spin Asymmetry Measurements at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC)* by Daniel Kikola et al. [arXiv:1702.01546 [hep-ex]]. Few Body Syst. 58 (2017) 139.
- *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]] Few Body Syst. 58 (2017) 148
- *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

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.