A Fixed-Target Program at the LHC (AFTER@LHC): where do we stand ?

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

Part I

The scope of a fixed-target programme at the LHC

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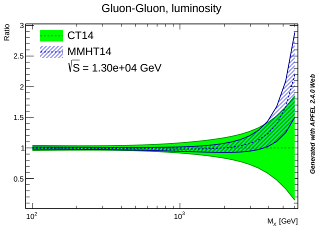

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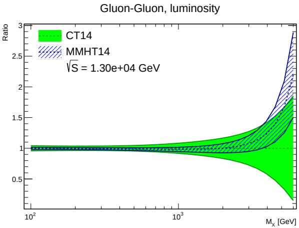

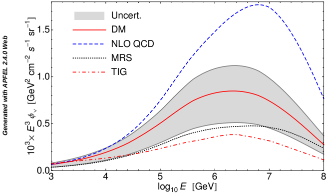

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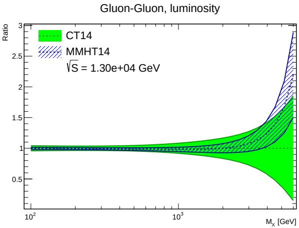

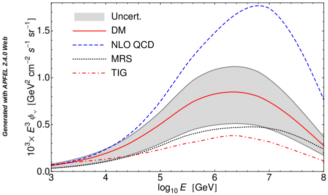

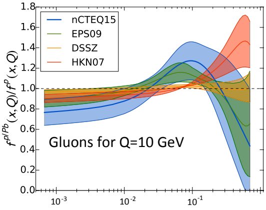

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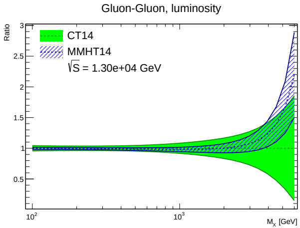
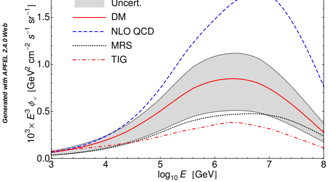
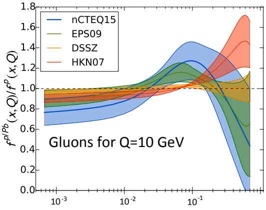
  where one gluon carries most of the proton momentum







3D mapping of the parton momentum

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$$\boxed{\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \mathcal{L}_g + \mathcal{L}_q}$$

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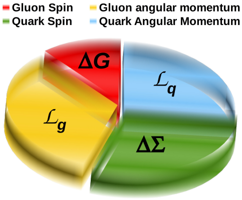

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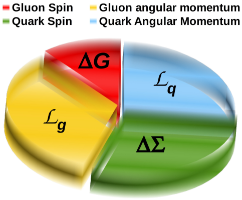

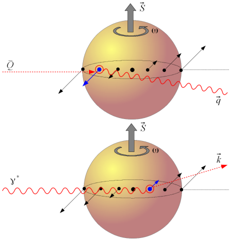

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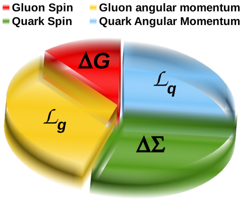
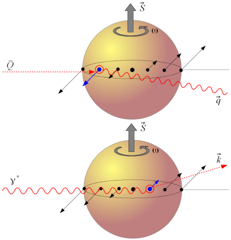
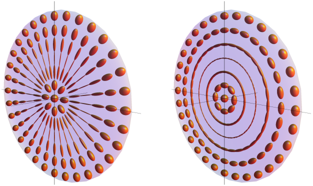
- Test of the QCD factorisation framework [beyond the DY A_N sign change]
- Determination of the linearly polarised gluons in unpolarised protons

[once measured, allows for spin physics without polarised proton, e.g. at the LHC]







Heavy-ion collisions from one colliding nucleus rest frame

Heavy-ion collisions towards large rapidities

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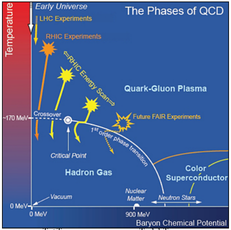
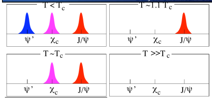
  [needed to calibrate the quarkonium thermometer (J/ψ, ψ', χ_c, Υ, D, $J/\psi \leftarrow b$ + pairs)]





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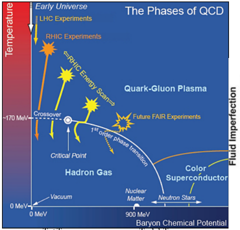

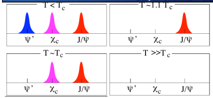

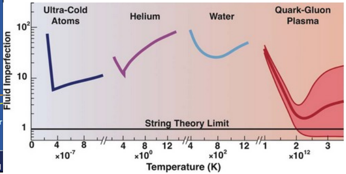

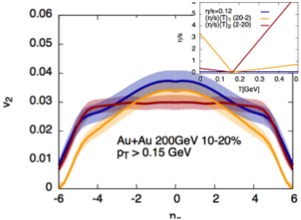

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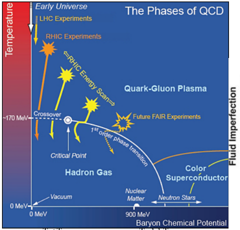

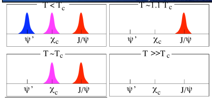

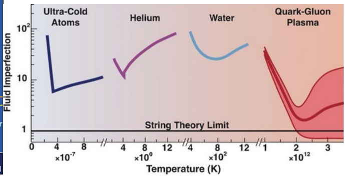

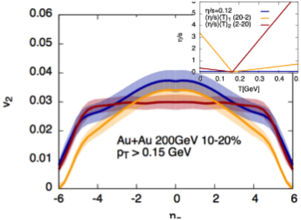

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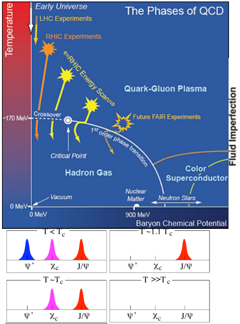
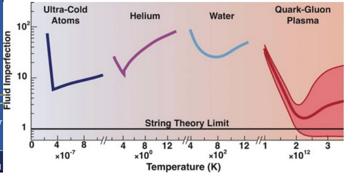
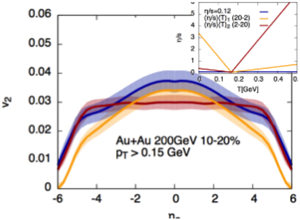
- Test the factorisation of cold nuclear effects from $p + A$ to $A + B$ collisions







Part II

Possible Implementations and Luminosities

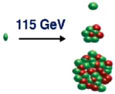
Fixed-target collisions at the LHC: main kinematical features

Fixed-target collisions at the LHC: main kinematical features

Energy range

7 TeV proton beam on a fixed target

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



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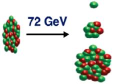

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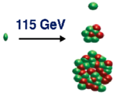

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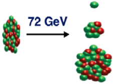

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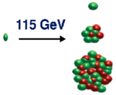

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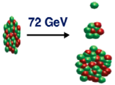

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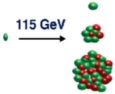

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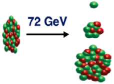

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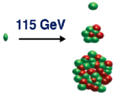

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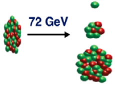

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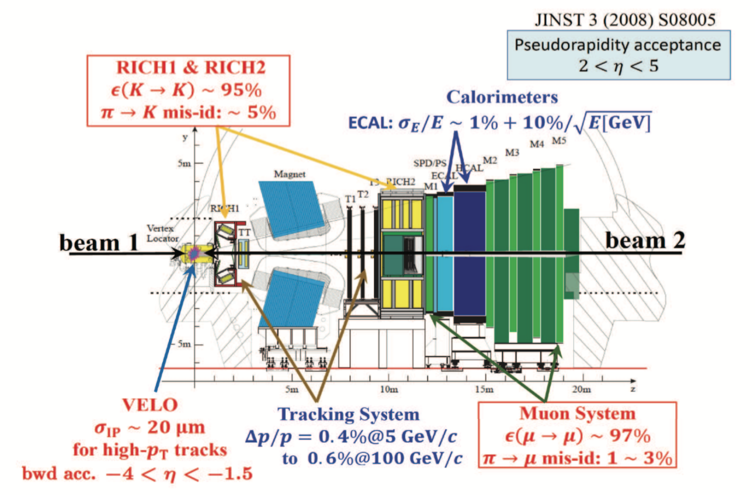
- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^{\uparrow}$ with large $x^{\uparrow}$]

LHCb acceptance for various colliding modes



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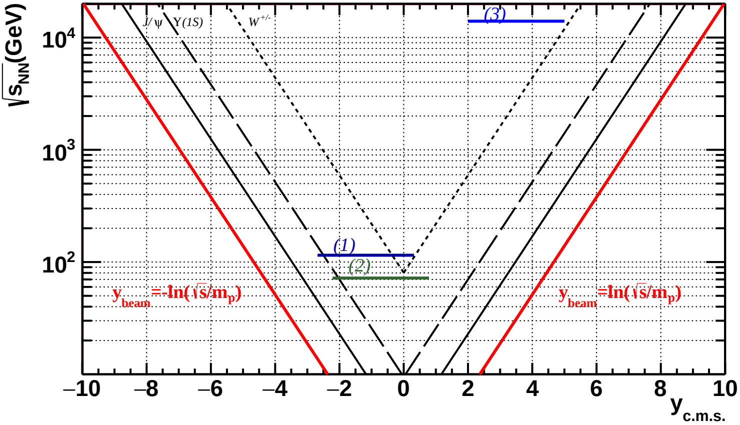

- (1) Fixed-target using p beam, E_p = 7 TeV
- (2) Fixed-target using Pb beam, E_{Pb} = 2.76 A.TeV
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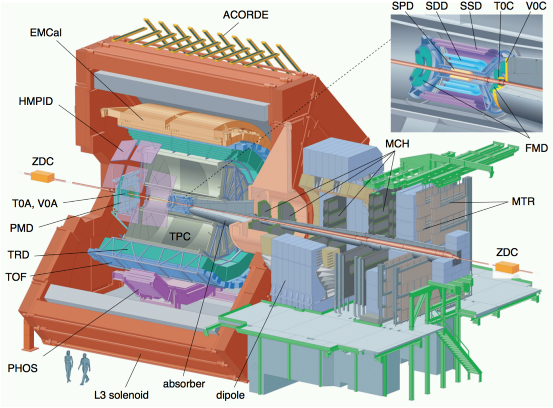
ALICE muon acceptance for various colliding modes



- Central barrel: $-0.9 < \eta < 0.9$
- Muon spectrometer acceptance: $2.5 < \eta < 4$

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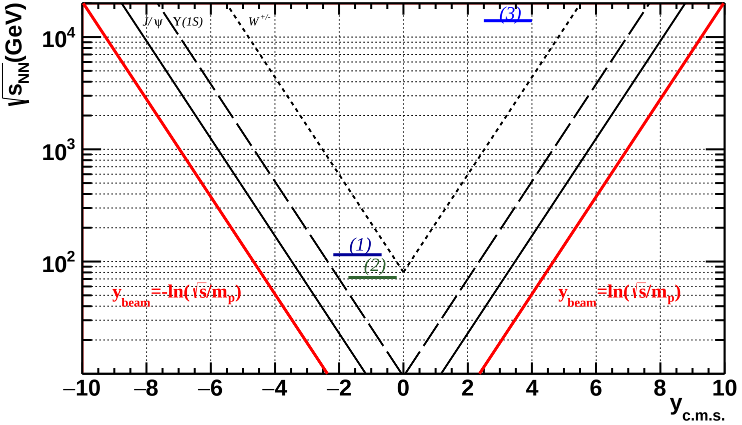

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- Internal gas target (with or without storage cell)
  - can be installed in one of the existing LHC caverns, and coupled to existing experiments
  - currently validated by the LHCb collaboration with SMOG **[See P. Robbe's talk on Wednesday at 3:10pm]**
  - uses the high LHC particle current: p flux: 3.4×10^{18} s^{-1} & Pb flux: 3.6×10^{14} s^{-1}
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- Internal wire/foil target [used by Hera-B on the 920 GeV HERA p beam and by STAR at RHIC]

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

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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
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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 : $\mathcal{L}_{pH_2} > 10$ fb^{-1}]

Part III

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]

Drell-Yan

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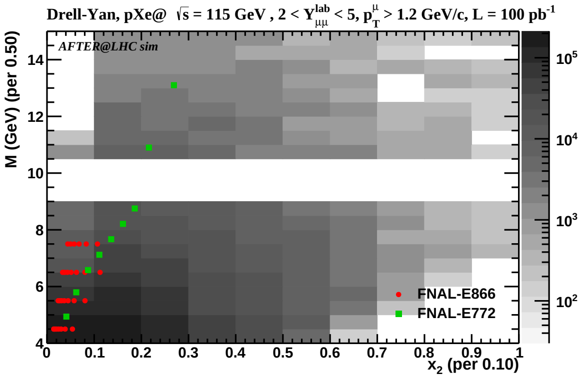

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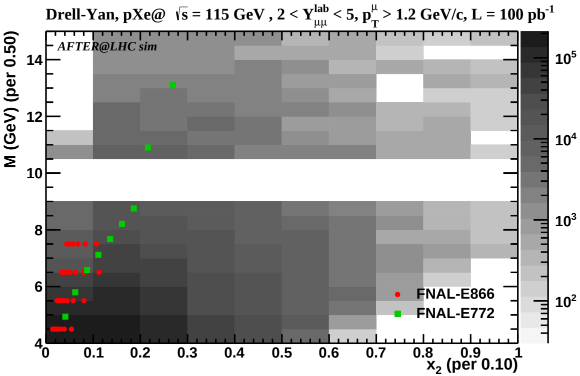

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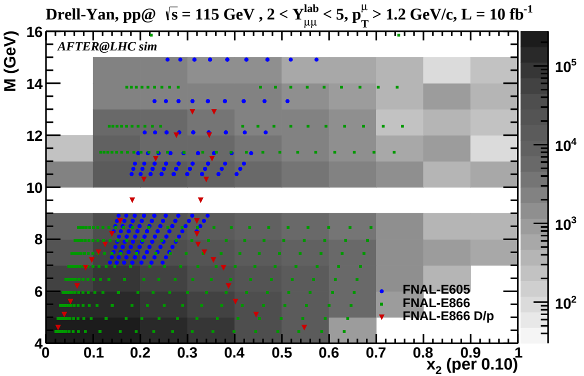

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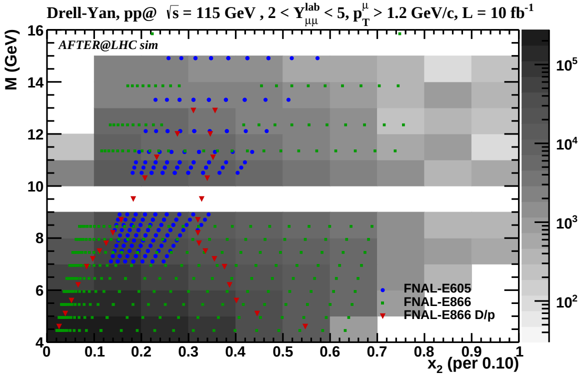

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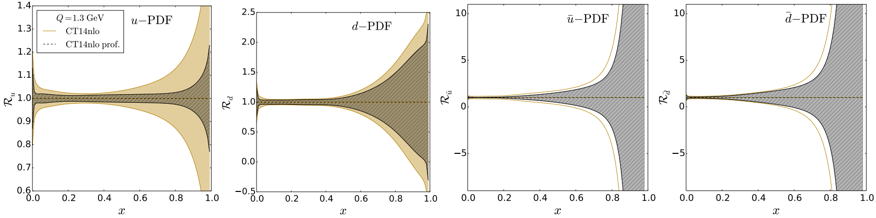

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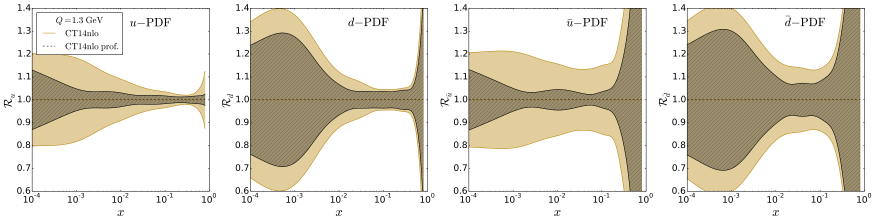

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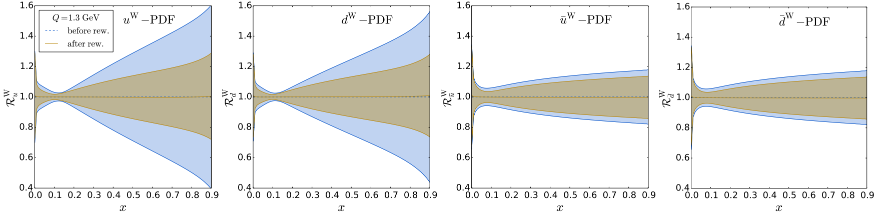

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- On-going theory study for $W^{\pm}$ production accounting for threshold resummation

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

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

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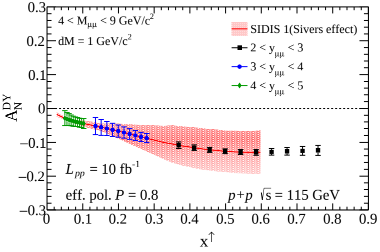

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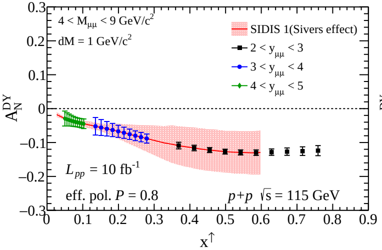

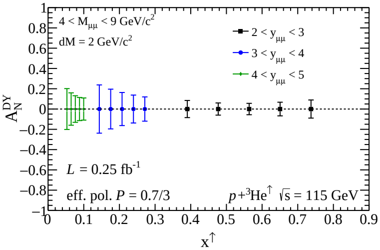

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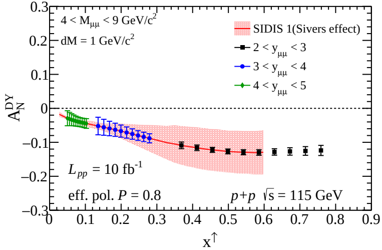
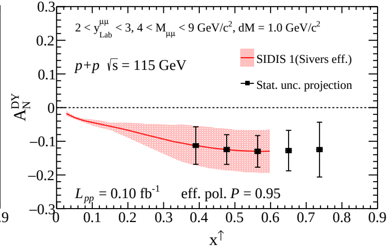
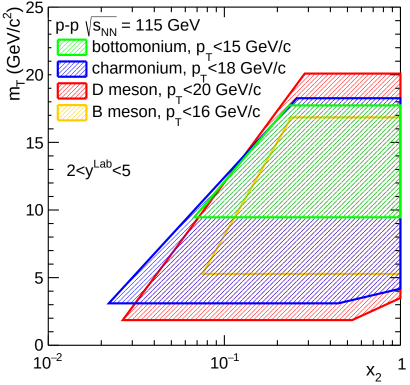
PHENIX/STAR (RHIC)	$p^\uparrow + p^\uparrow$	collider	510	$0.05 \div 0.1$	$2 \cdot 10^{32}$	50%	$5.0 \cdot 10^{31}$
E1039 (FNAL)	$p+p^\uparrow$	120	15	$0.1 \div 0.45$	$4 \cdot 10^{35}$	15%	$9.0 \cdot 10^{33}$
E1027 (FNAL)	$p^\uparrow + p$	120	15	$0.35 \div 0.9$	$2 \cdot 10^{35}$	60%	$7.2 \cdot 10^{34}$
NICA (JINR)	$p^\uparrow + p$	collider	26	$0.1 \div 0.8$	$1 \cdot 10^{32}$	70%	$4.9 \cdot 10^{31}$
fsPHENIX (RHIC)	$p^\uparrow + p^\uparrow$	collider	200	$0.1 \div 0.5$	$8 \cdot 10^{31}$	60%	$2.9 \cdot 10^{31}$
fsPHENIX (RHIC)	$p^\uparrow + p^\uparrow$	collider	510	$0.05 \div 0.6$	$6 \cdot 10^{32}$	50%	$1.5 \cdot 10^{32}$
PANDA (GSI)	$\bar{p} + p^\uparrow$	15	5.5	$0.2 \div 0.4$	$2 \cdot 10^{32}$	20%	$8.0 \cdot 10^{30}$

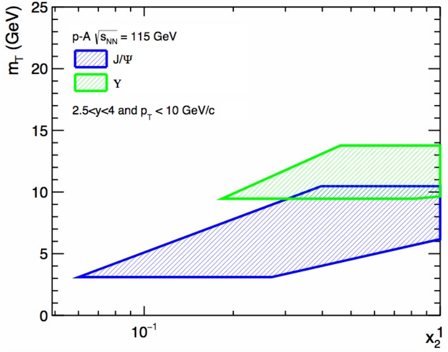




NEW: preliminary FoM with H-jet (1 year)

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} and HF μ))

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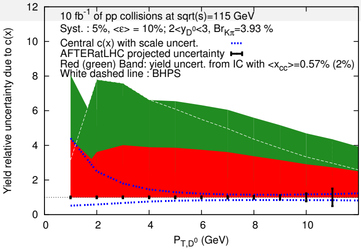

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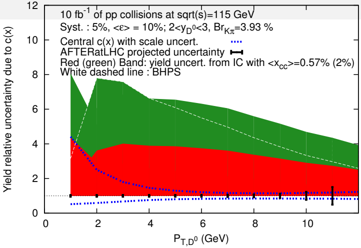

D. Kikola *et al.*. Few Body Syst. 58 (2017) 139

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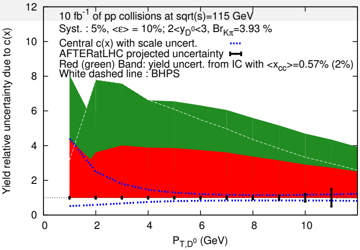

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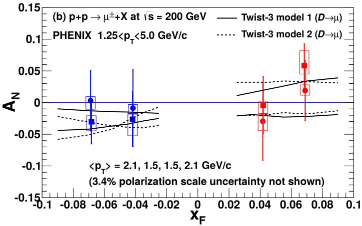

[Beware of the unconventional definition of x_F at RHIC which does not correspond to $x_1 - x_2$ in the fixed target mode]

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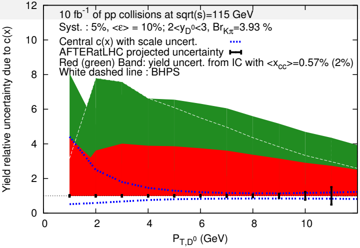

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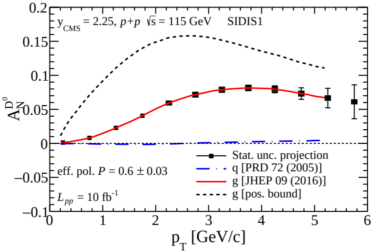

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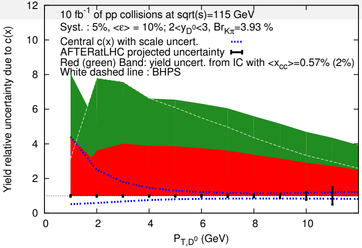

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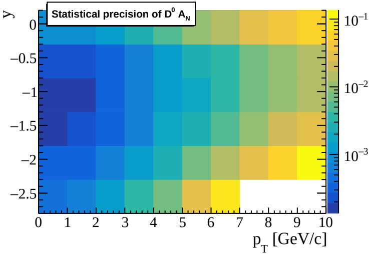

Quarkonium Projections: spin

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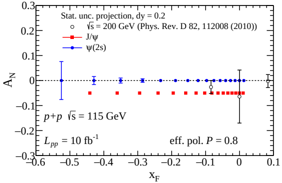

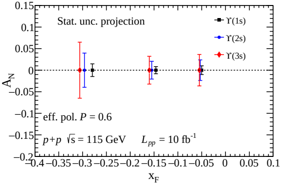

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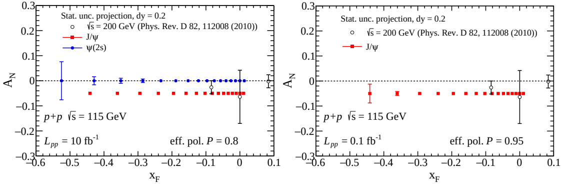

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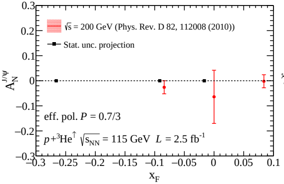

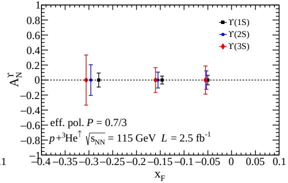

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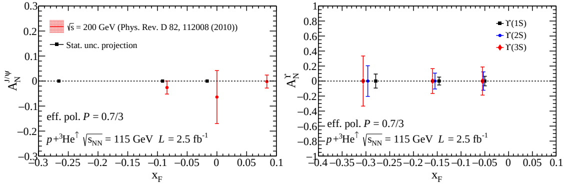

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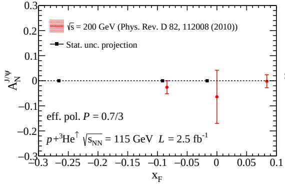
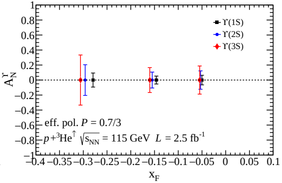
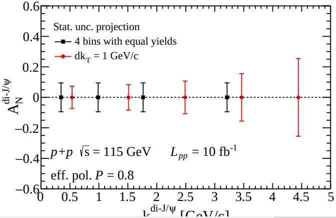




- Completely new perspectives to study the gluon Sivers effect [and beyond → $\mathcal{L}_g$]
- Di-J/ψ allow one to study the k_T dependence of the gluon Sivers function for the very first time !



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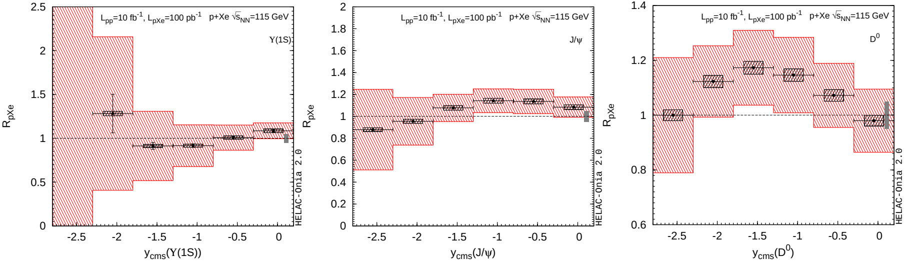
nCTEQ uncertainties vs. projected statistical uncertainties

A. Kusina, J.P. Lansberg, I. Schienbein, H.S. Shao, 1712.07024; See A. Kusina's talk tomorrow at 11:30am for the LHC case



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nCTEQ reweighting uncertainties: main uncertainties is the scale

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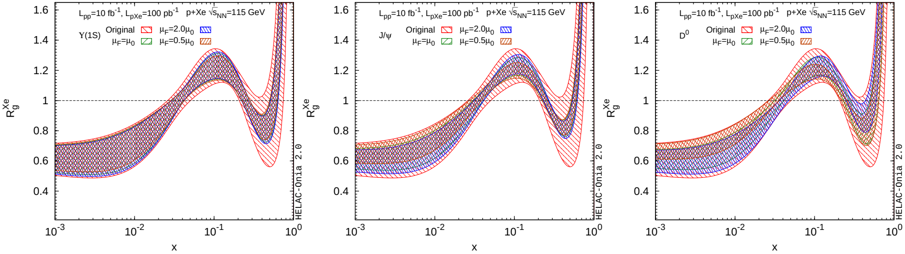

Clear decrease of the nPDF uncertainty in the EMC region:

Quarkonium Projections: heavy-ion collisions

B.Trzeciak *et al.***Few-Body Syst (2017) 58:148**

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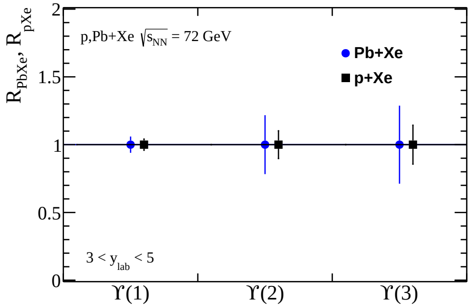

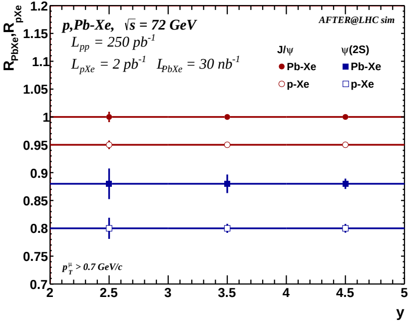

Ultra-Peripheral Collisions in the FT mode and J/ψ production

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

	pH	PbH
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$\sigma_{J/\psi}^{tot}$ (pb)	1.18×10^3	276.77×10^3
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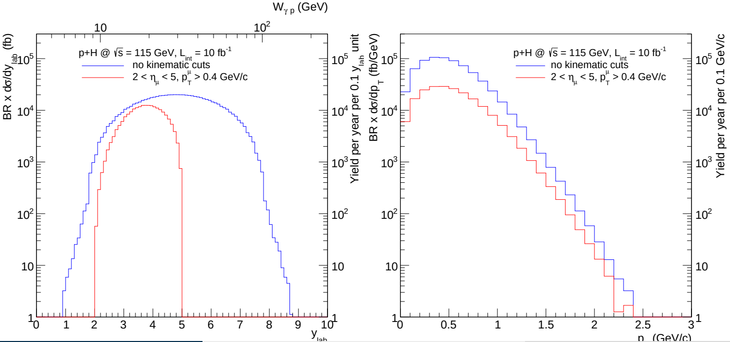

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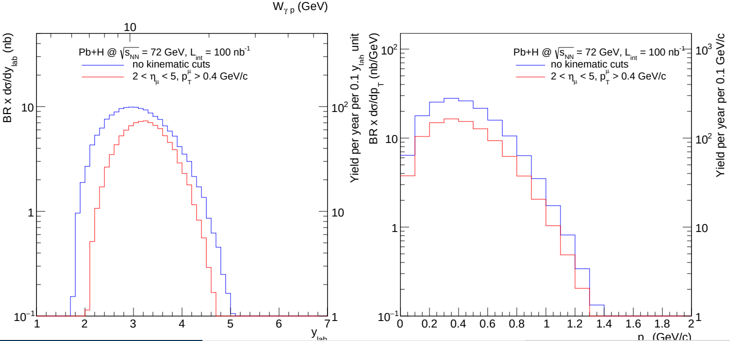

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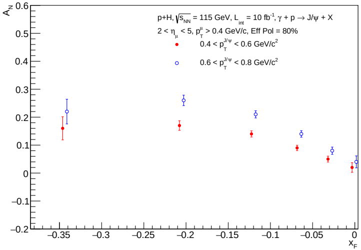

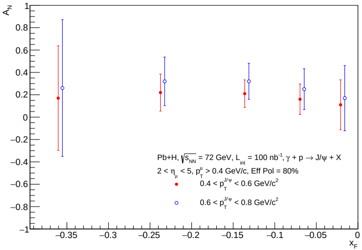

$A_N^{\gamma p^\uparrow \to J/\psi p} \propto \sqrt{t_0 - t} Im(\mathcal{E}_g^* \mathcal{H}_g) \to$ access to the GPD E_g and the gluon OAM

Part IV

Conclusion

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

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- 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

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  - 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 conveners of the CERN Physics Beyond Collider working group [`pbc.web.cern.ch`], we now prepare a document on the fixed-target physics at the LHC

Part V

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.