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

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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)

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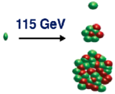
Boost: $\gamma = \sqrt{s}/(2m_N) \approx 60$	



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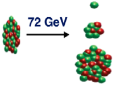

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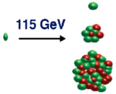

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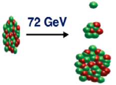

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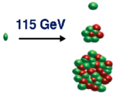

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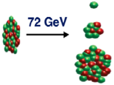

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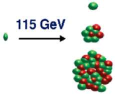

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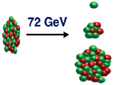

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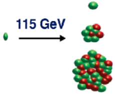

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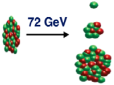

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- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^\uparrow$ with large $x^\uparrow$]

Possible implementations

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- 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)
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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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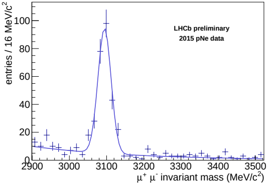

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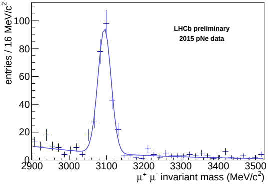

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The simulations showed in Part III are based on this set-up coupled to a LHCb like detector

Part II

Physics Motivation

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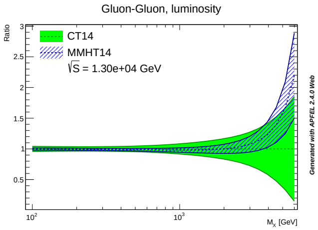

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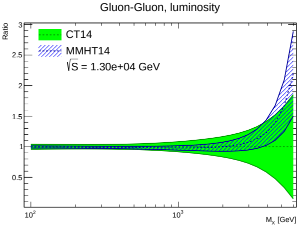

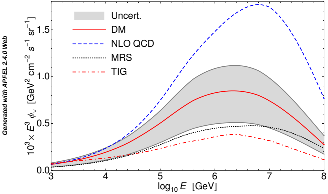

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- EMC effect is an open problem; studying a possible gluon EMC effect is essential
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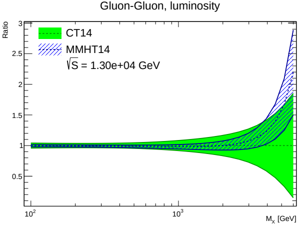

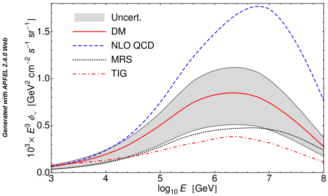

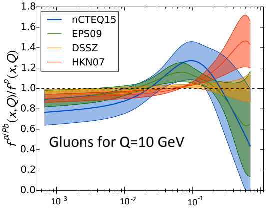

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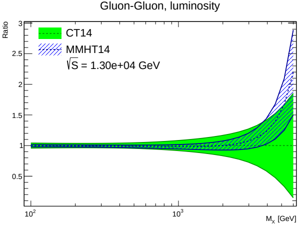
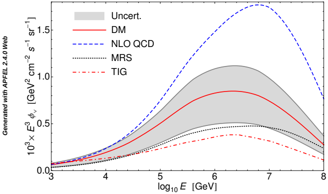
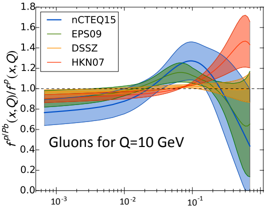
- Search and study rare proton fluctuations
  where one gluon carries most of the proton momentum







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3D mapping of the parton momentum

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- Possible missing contribution to the proton spin: Orbital Angular Momentum $\mathcal{L}_{g;q}$:

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

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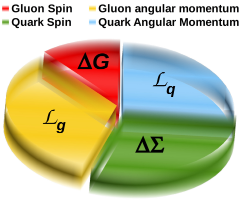

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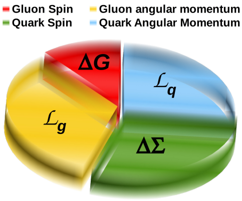

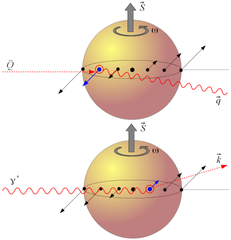

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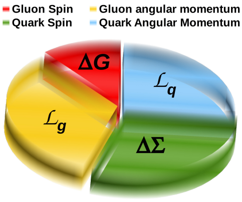
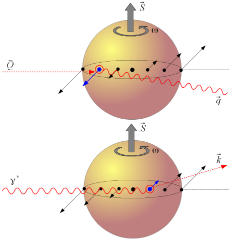
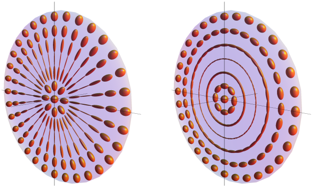
[once measured, allows for spin physics without polarised proton, e.g. at the LHC]







heavy-ion collisions from one colliding nucleus rest frame

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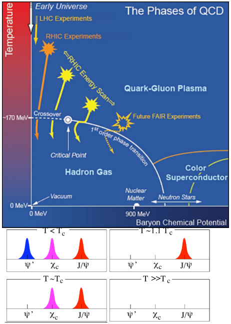

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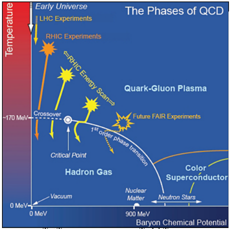

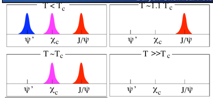

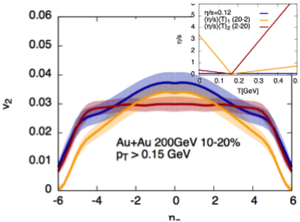

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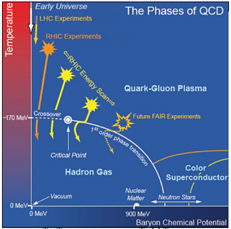

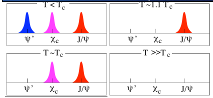

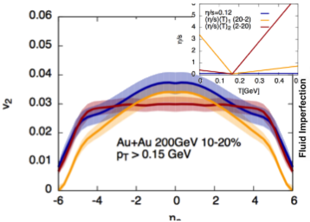

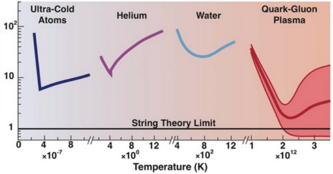

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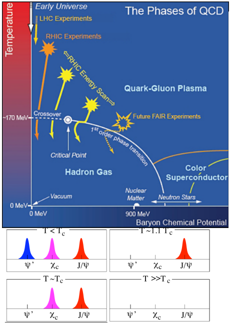

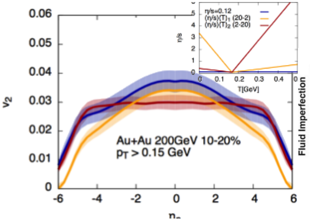

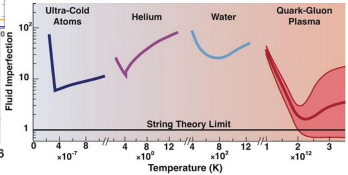

Part III

A selection of projected performances

What is not covered by lack of time

- 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]
- Ultra-peripheral collisions [Spin, High-x]

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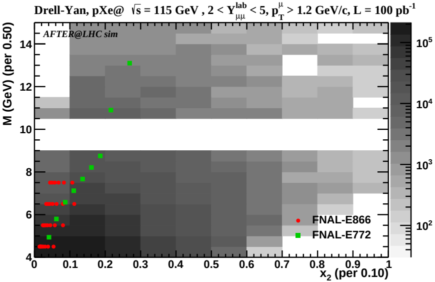

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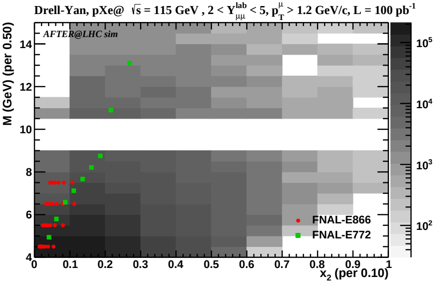

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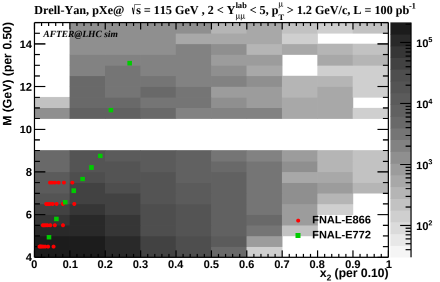

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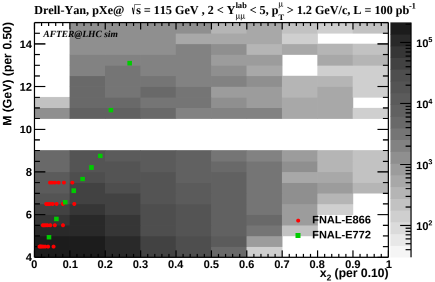

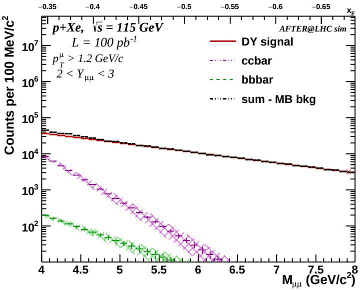

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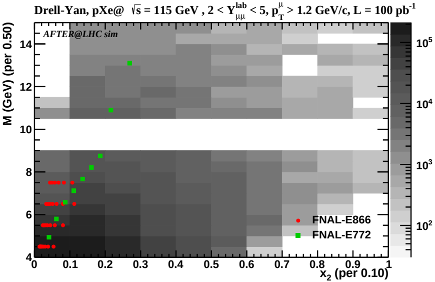

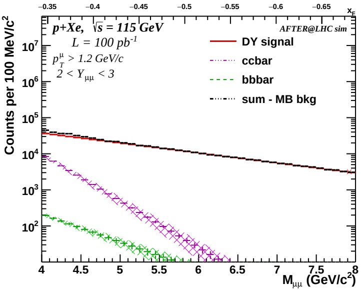

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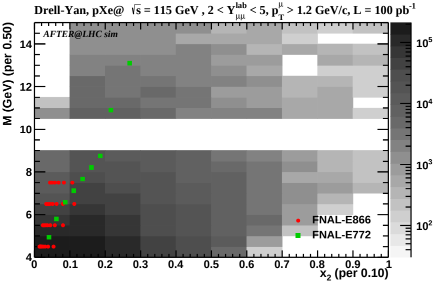

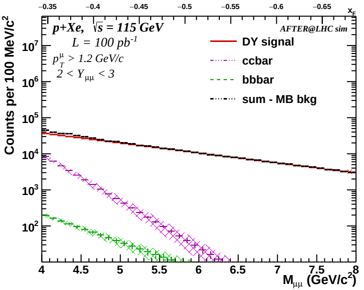

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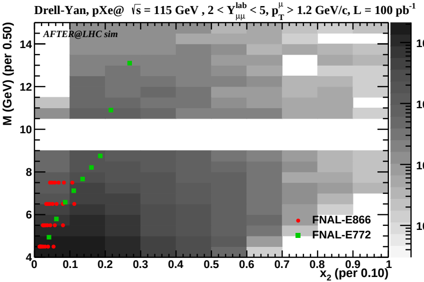

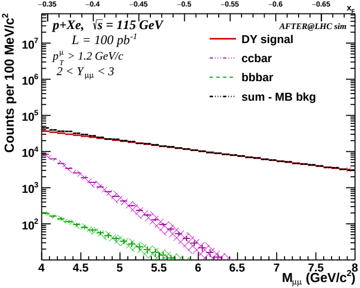

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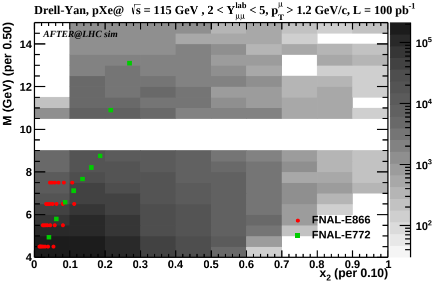

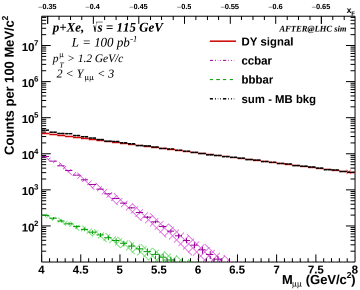

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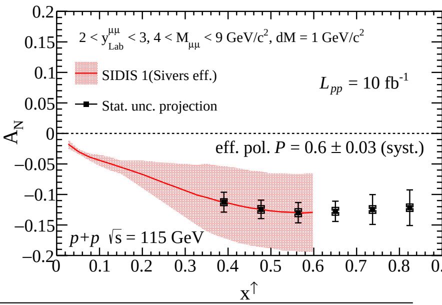

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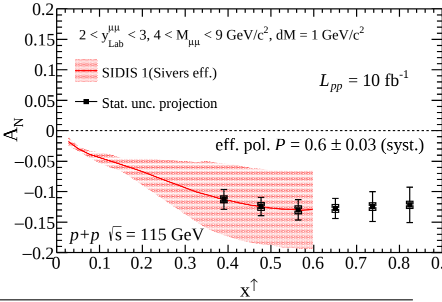

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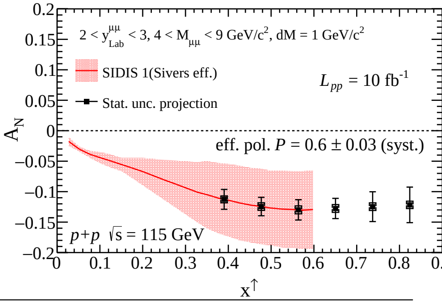

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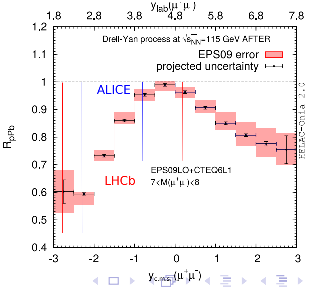

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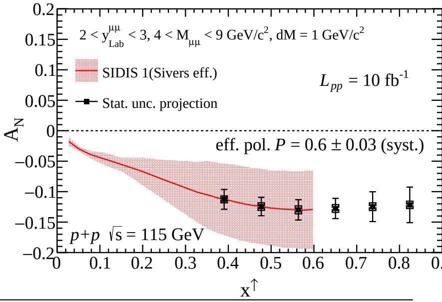

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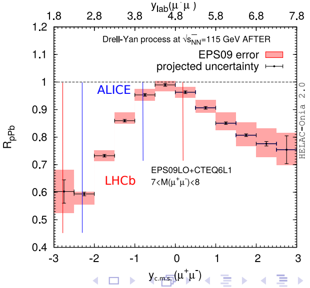
  [Only done once at SPS; no effect seen]



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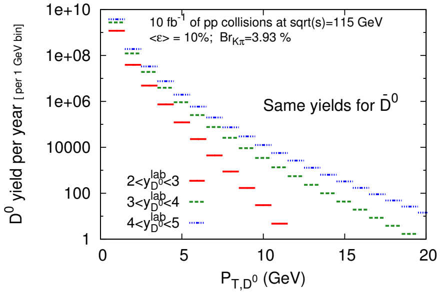

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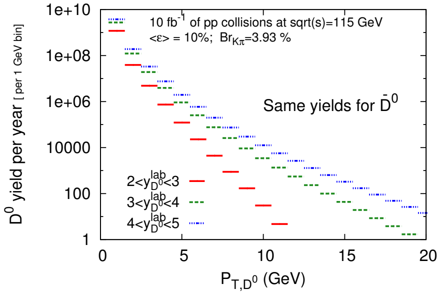

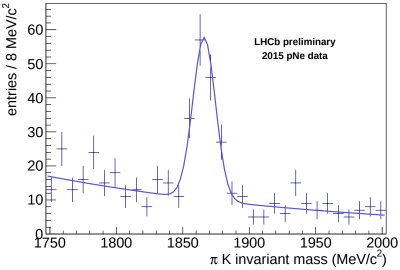

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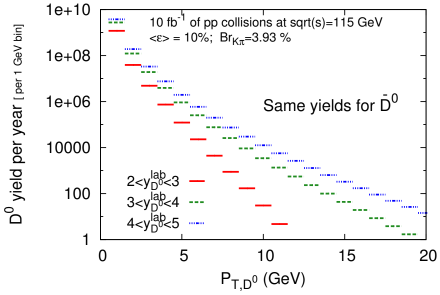

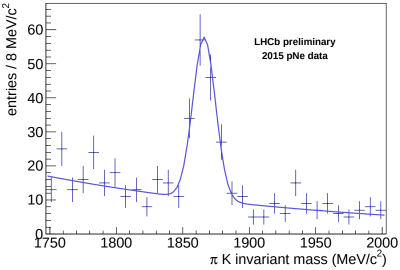

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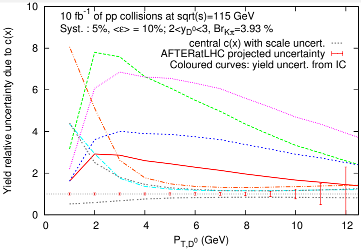

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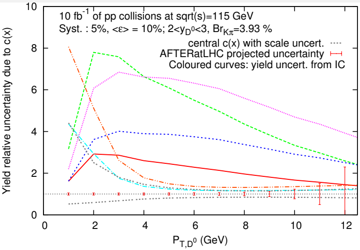

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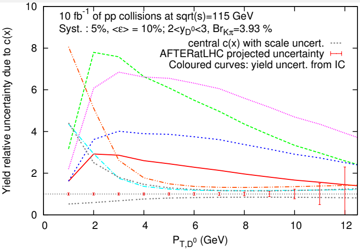

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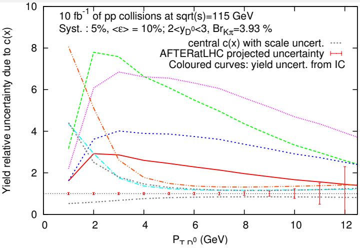

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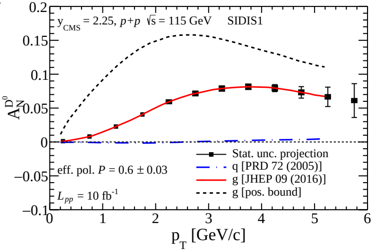
- Gives access to the tri-gluon correlation and the gluon Sivers effect [related to $\mathcal{L}_g$]



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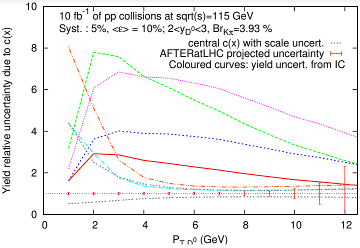

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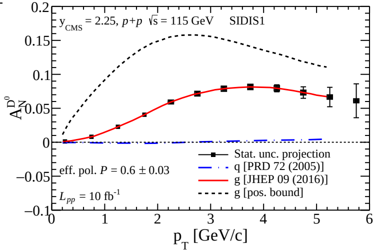

Open charm projections

- This huge data sample over a wide kinematical coverage gives a unique handle on the charm content in the proton at high x
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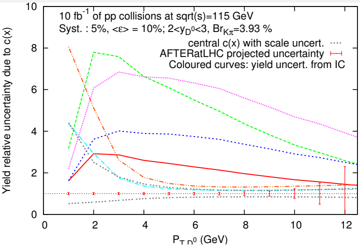

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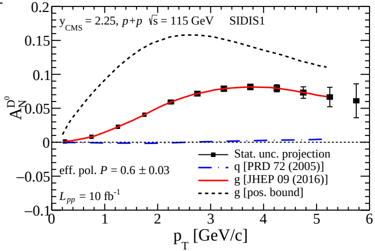

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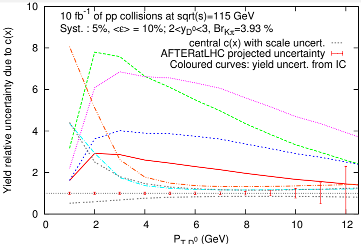

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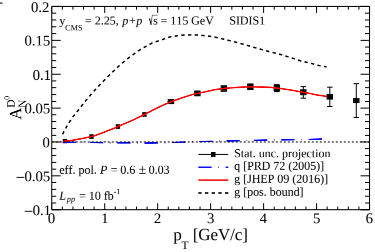

As for *AA* collisions, nuclear modification factors vs p_T, y, centrality as well as azimuthal anisotropies (v_2) can be of course measured [no time to cover them]

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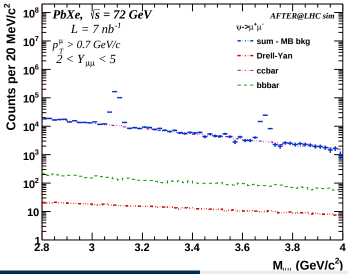

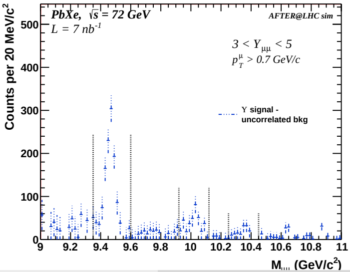

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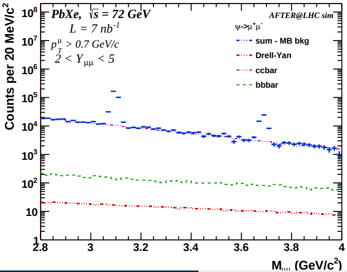

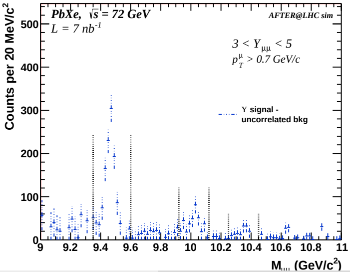

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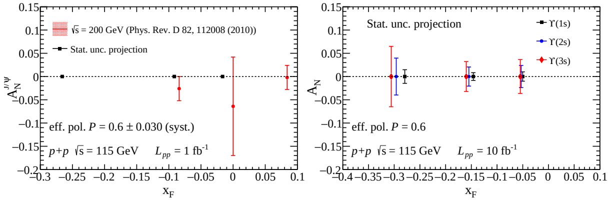

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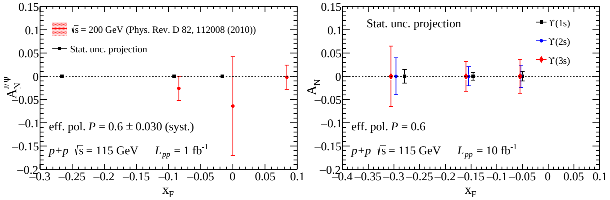

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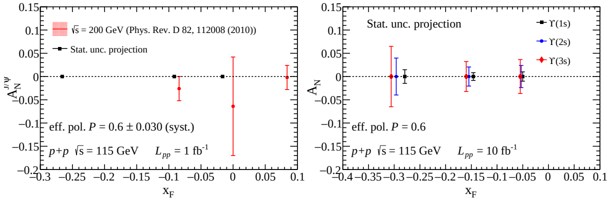

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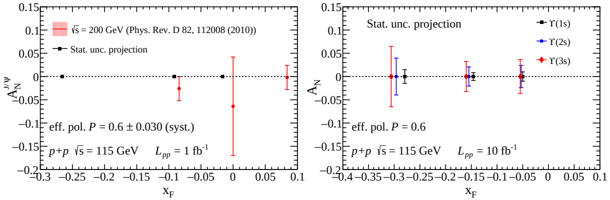

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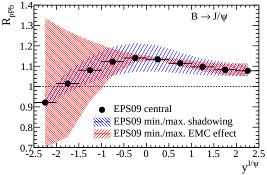

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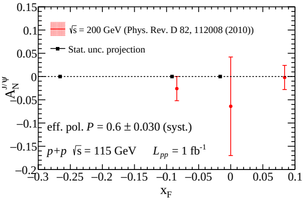

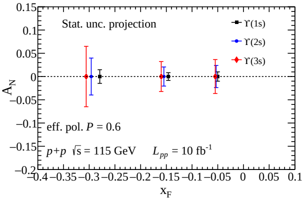

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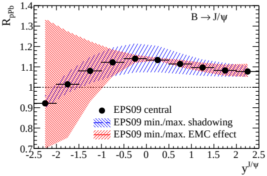

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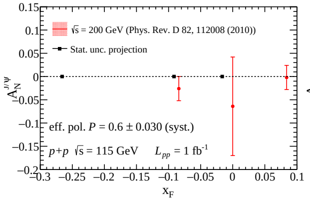

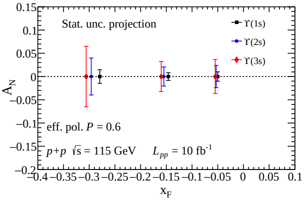

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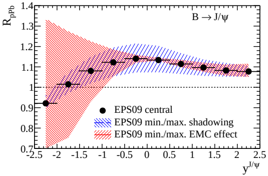

Part IV

Conclusion and outlooks

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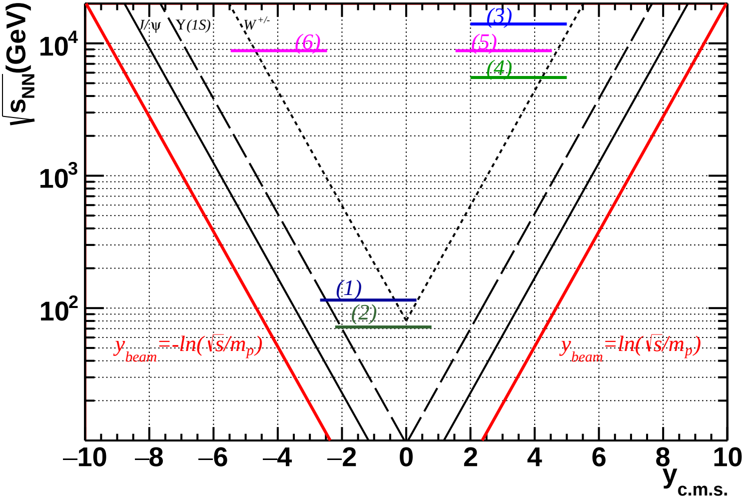
Part V

Backup slides

LHCb acceptance as a function of the colliding modes



Nota: similar for the ALICE spectrometer

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 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