AFTER@LHCb

Projecting AFTER@LHC onto the reality

Jean-Philippe Lansberg
IPN Orsay, CNRS/IN2P3, Univ. Paris-Sud, Université Paris-Saclay

"LHCb Ion and Fixed Target physics" workshop, CERN, January 9-10, 2017

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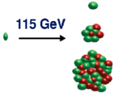
Boost: $\gamma = \sqrt{s}/(2m_N) \approx 60$	



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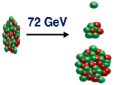

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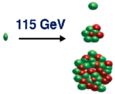

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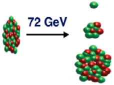

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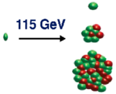

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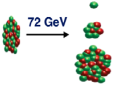

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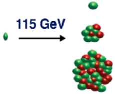

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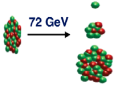

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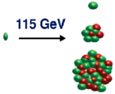

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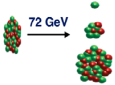

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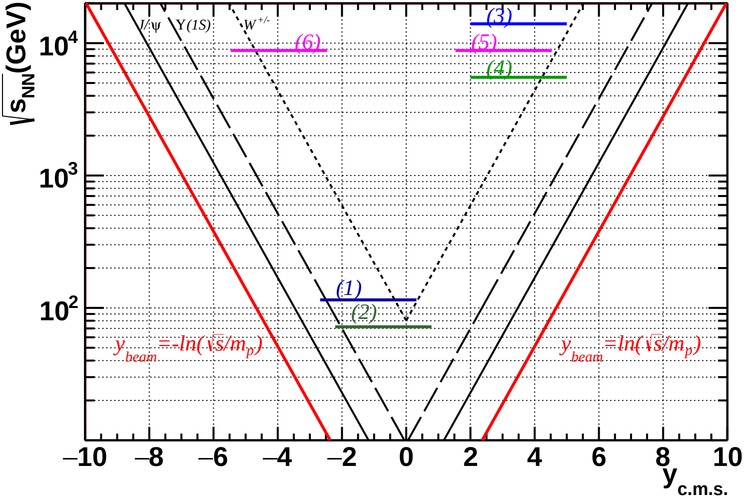
- Allows for backward physics up to high x_{target} ($\equiv x_2$) [uncharted for proton-nucleus; most relevant for p-p$^\uparrow$ with large $x^\uparrow$]

LHCb acceptance as a function of the colliding modes



At lower energies, LHCb has a wider relative physical acceptance !

Possible implementations

Nota: In most of the cases, the luminosity is limited by the detector or by the *parasiticity*

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: 3.4×10^{18} s^{-1} & lead flux: 3.6×10^{14} s^{-1}

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- Beam line extracted by a bent crystal [see S. Radaelli's talk at the PBC workshop]
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  - provides a new facility with 7 TeV proton beam
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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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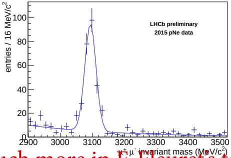

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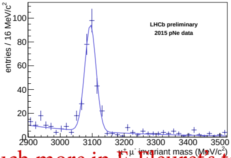

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The simulations showed in Part III are based on this set-up coupled to a LHCb like detector

[Much more in E.Steffens' talk]

Part II

Physics Motivation

High-x frontier

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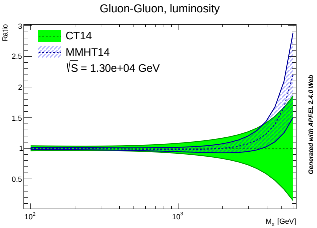

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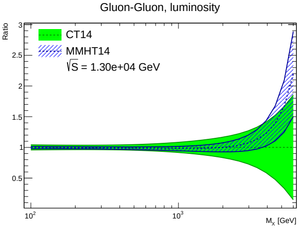

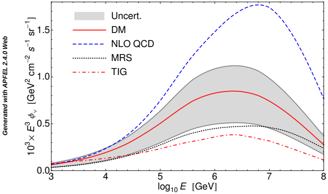

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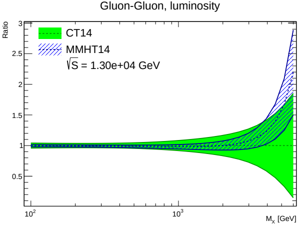

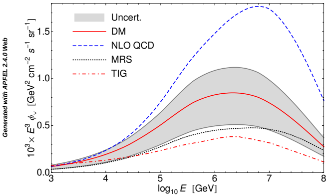

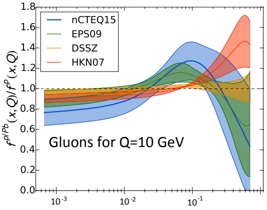

Best to take data at large x and small scale, than at large scale: advantange of low E; provided HT are under control

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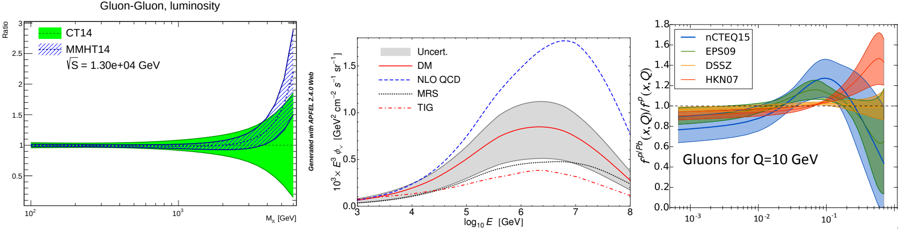
- Search and study rare proton fluctuations

  where one gluon carries most of the proton momentum



Best to take data at large x and small scale, than at large scale: advantange of low E; provided HT are under control

3D mapping of the parton momentum

Advance our understanding of the dynamics and spin of gluons and quarks inside (un)polarised nucleons

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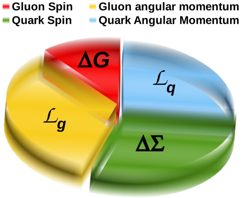

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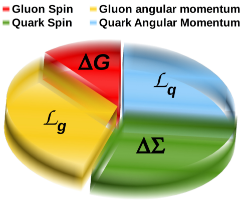

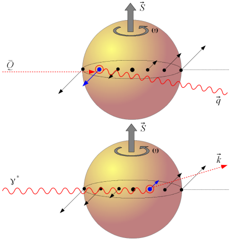

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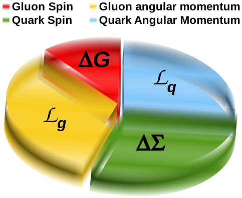
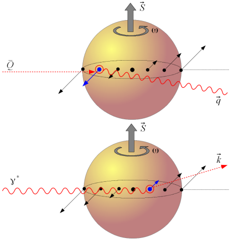
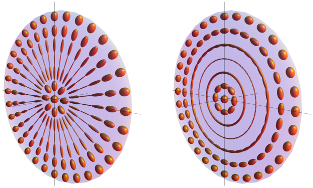
- Determination of the linearly polarised gluons in unpolarised protons

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







Heavy-ion collisions towards large rapidities

heavy-ion collisions from one colliding nucleus rest frame

Heavy-ion collisions towards large rapidities

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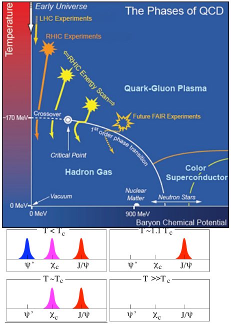

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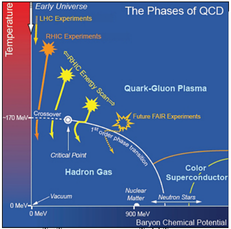

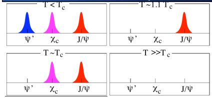

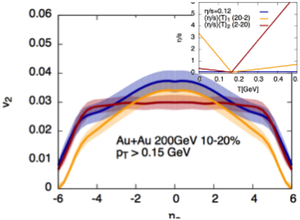

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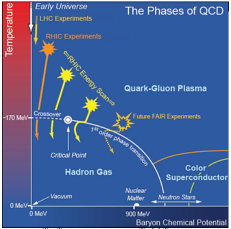

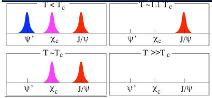

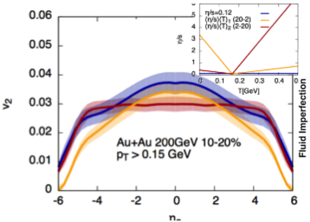

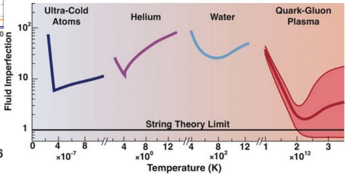

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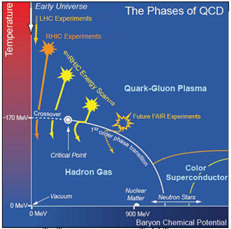
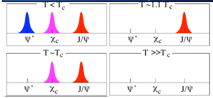
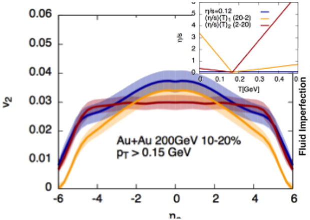
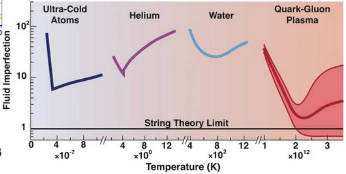
- Test the factorisation of cold nuclear effects from $p + A$ to $A + B$ collisions









Part 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]

Drell-Yan simulation

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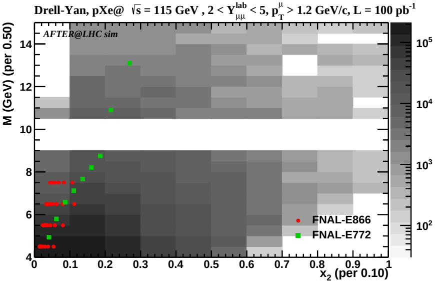

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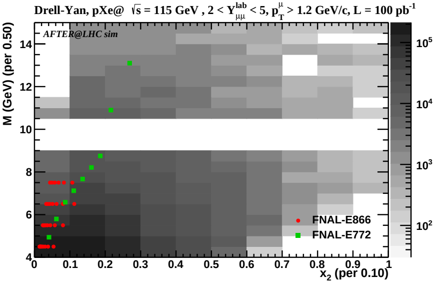

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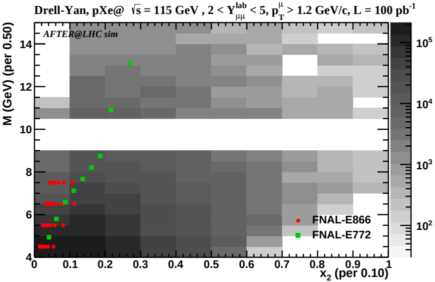

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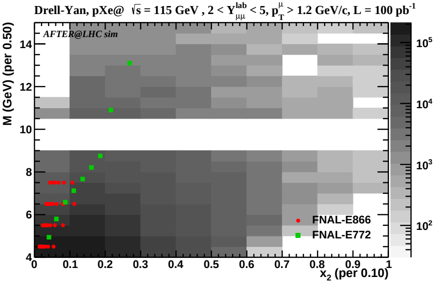

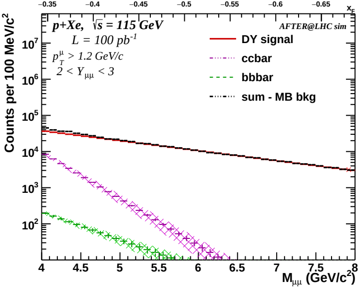

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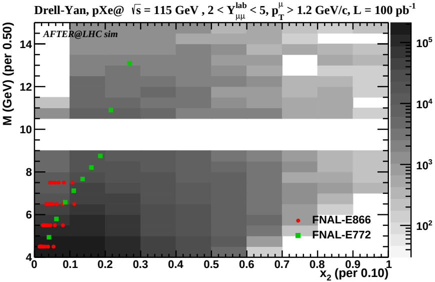

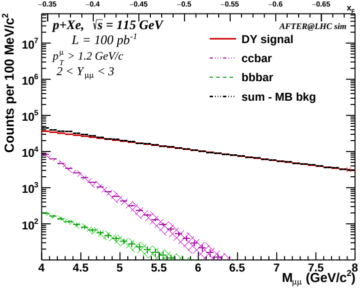

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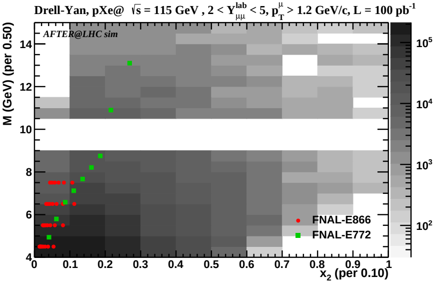

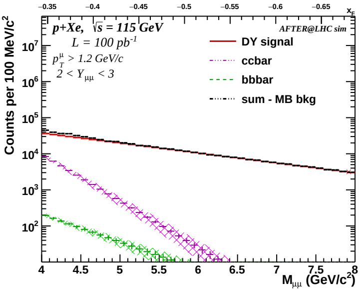

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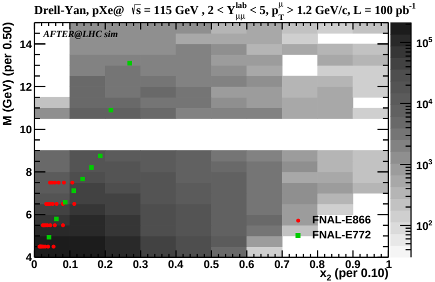

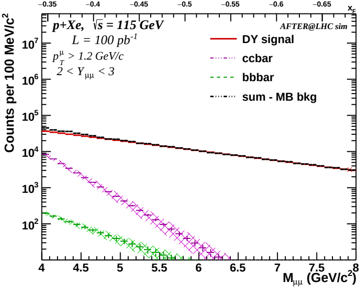

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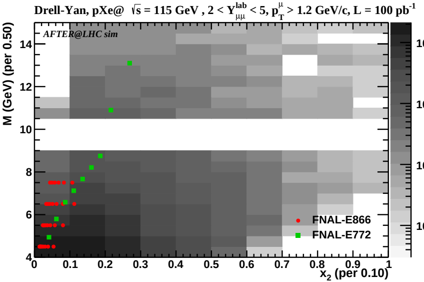

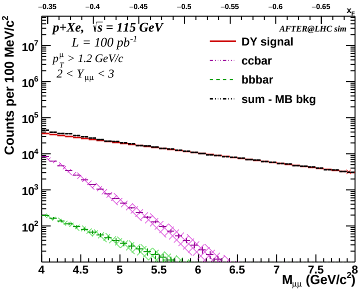

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➟ Relevant parameters for existing and proposed polarized DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
V. Barone, F. Bradamante, A. Martin, Prog. Part. Nucl. Phys. 65 (2010) 267.

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathcal{L}$ (nb^{-1}s^{-1})
AFTER	$p+p^\uparrow$	7000	115	$0.01 \div 0.9$	1
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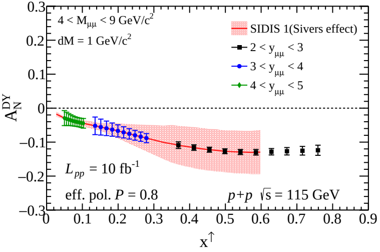

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- With a highly polarised gas target, from an exploration phase to a consolidation phase
- With a $^3He^\uparrow$ target, access to the quark Sivers effect in the neutron via DY: unique !

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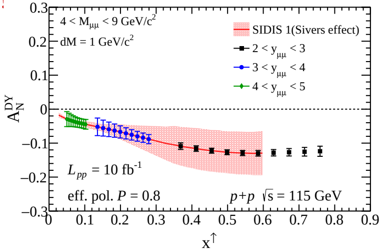

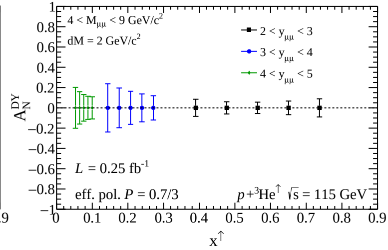

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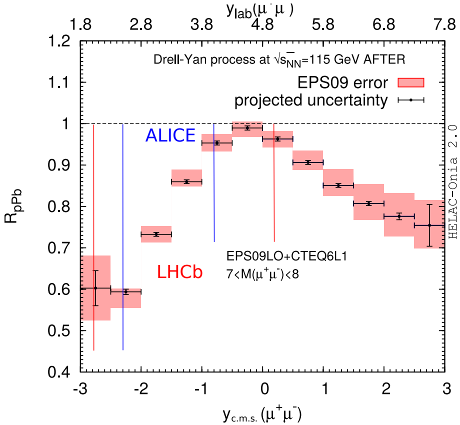
- Stat. uncertainties smaller than nPDF: discrimating power

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



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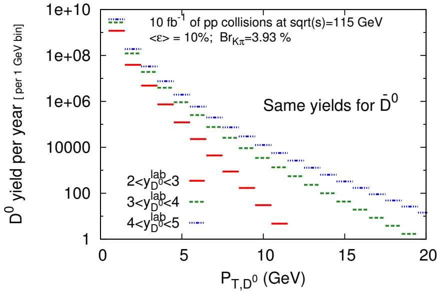

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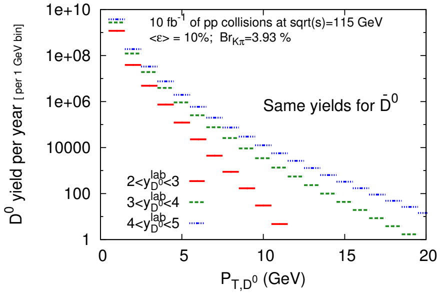
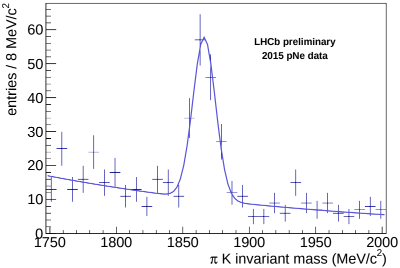
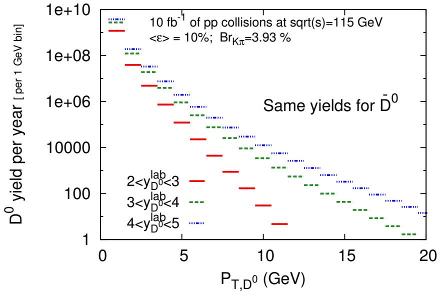
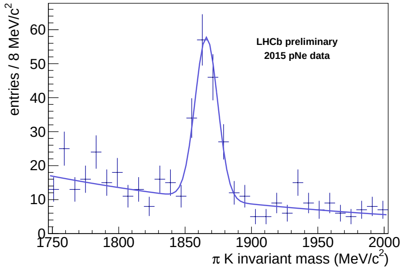




Open heavy flavour: charm

- Extremely good prospects to measure charm
  - down to zero p_T [total x-section]
  - over a wide rapidity coverage [$x_F \to -1$]
  - with extremely high statistical precision in *pp*, *pA* and *AA* collisions
- With a LHCb-like detector, the background is well under control [see below]
- Looking at $D \to K\pi$ gives direct acces to charm – anticharm asymmetries





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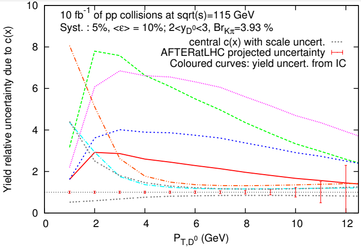

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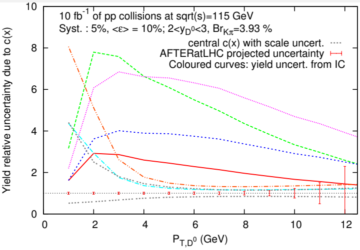

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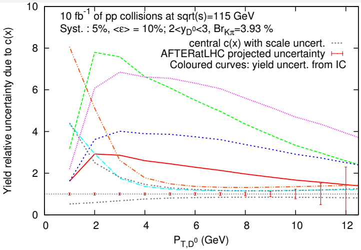

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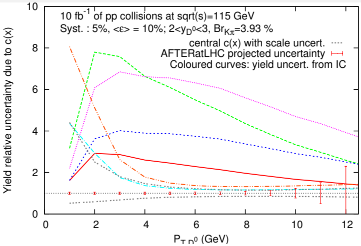

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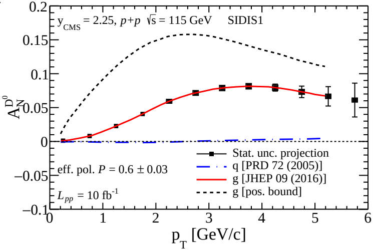

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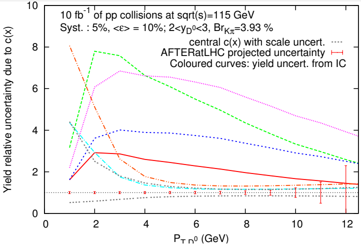

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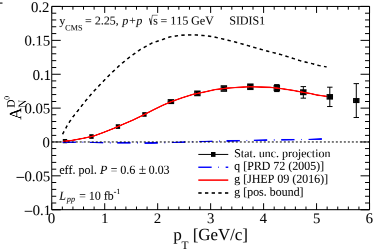

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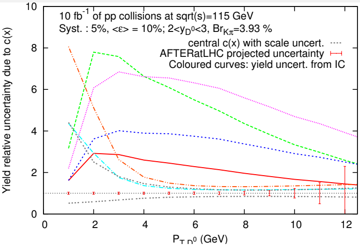

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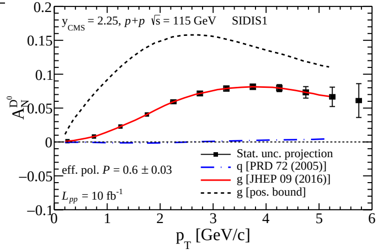

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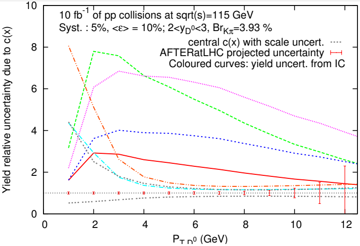

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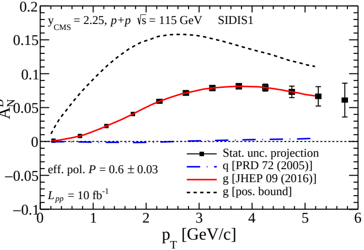

As for AA collisions, nuclear modification factors vs p_T, y, centrality as well as azimuthal anisotropies (v_2) can be of course measured [no time to cover them]

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- Design LHC lead-beam energy: 2.76 TeV per nucleon

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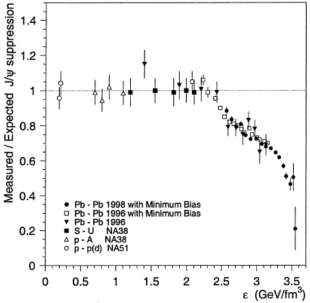

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ELSEVIER
23 March 2000
Physics Letters B 477 (2000) 28–36
PHYSICS LETTERS B

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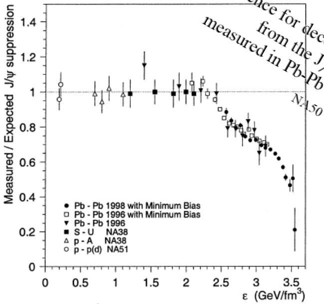
NA50 Collaboration



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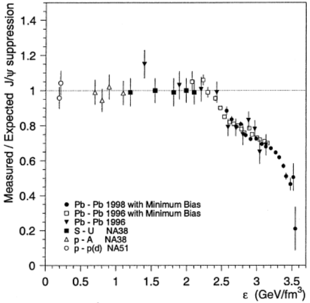

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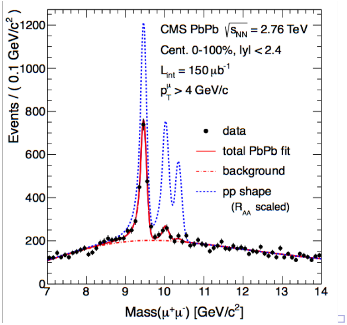

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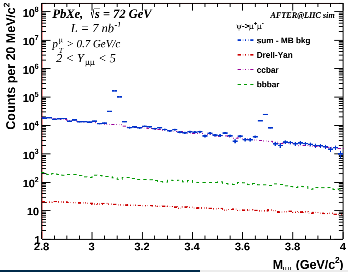

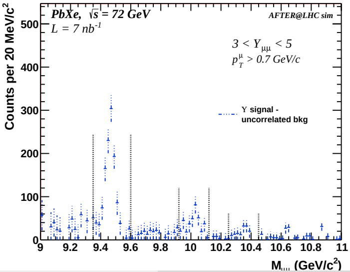

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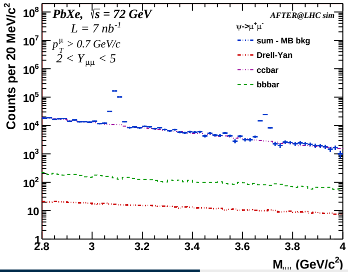

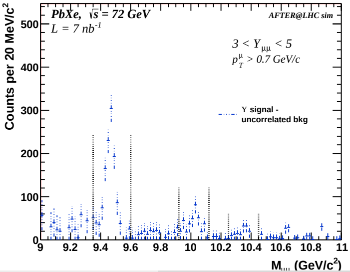

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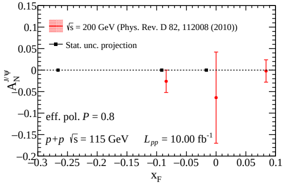

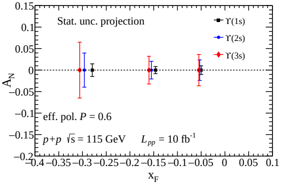

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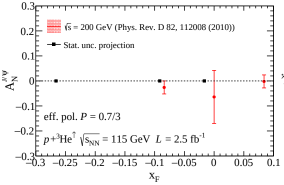

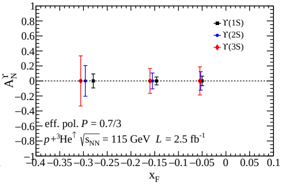

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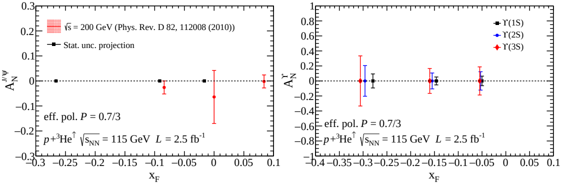

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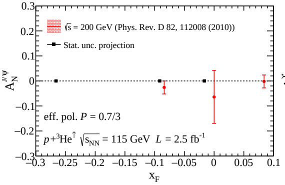

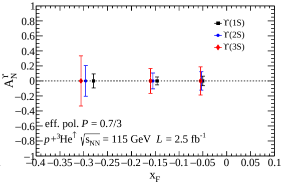

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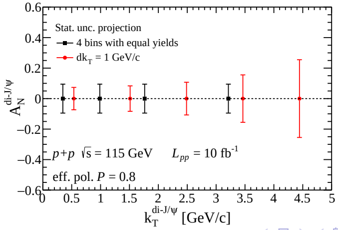
- Di-J/ψ allow one to study the k_T dependence of the gluon Sivers function for the very first time !



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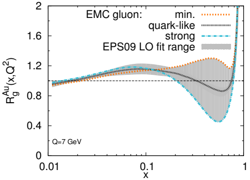

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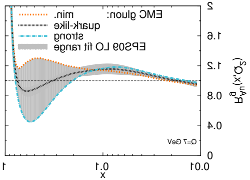

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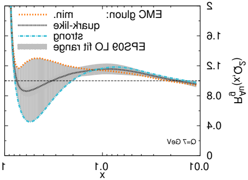

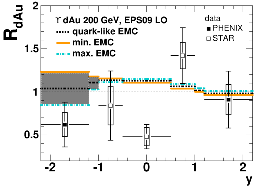

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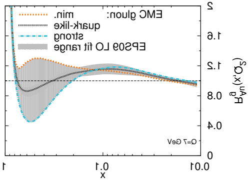

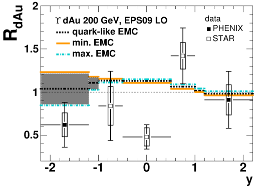

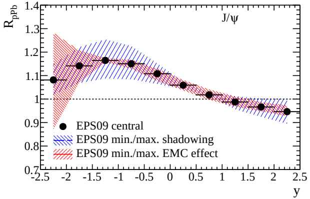

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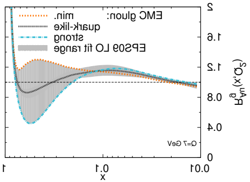

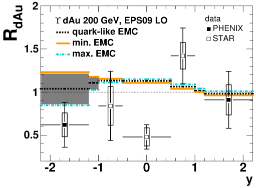

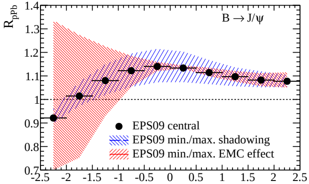

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L. Massacrier*et al.*, Adv.Hi.En.Phys. (2015) 986348

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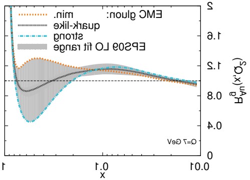

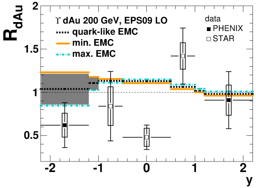

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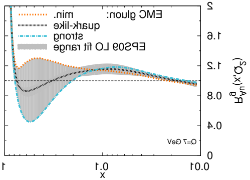

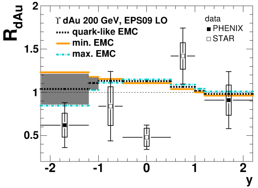

L. Massacrier *et al.*, Adv.Hi.En.Phys. (2015) 986348

- One could access η_c production in pA collisions for the first time
- High stat. → quarkonium polarisation in pA and AA collisions

[→ production/suppression mechanisms]

UPC in the fixed target mode and J/ψ production

JPL, L. Massacrier, L. Szymanowski, J. Wagner

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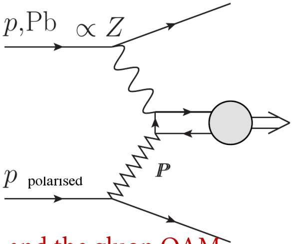

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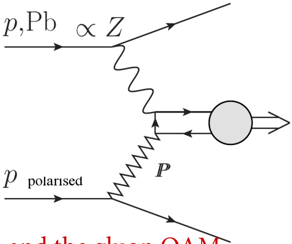

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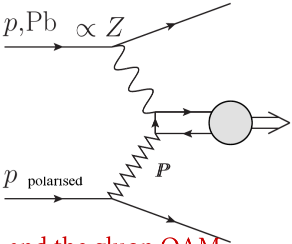

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  - 340 000 dimuon events with the p beam [each p can emit; possible $\mathbb{OP}$ contributions]

Part IV

Conclusion and outlooks

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  [without interfering with the other experiments]

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- Webpage: http://after.in2p3.fr

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[Slightly anticipating C. Vallée's talk]

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- Ideal framework to work together towards the best option for AFTER@LHC(b)
- In parallel, we pursuit our effort to finalise the Expression of Interest

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 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