Fixed-Target Opportunities at the (HL)LHC

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Open Symposium - Update of the European Strategy for Particle Physics
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Part I

Introduction

Using the LHC beams in the fixed-target mode

Contributions to the ESPP update and other scientific sources

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Reviews, special issues

- S.J. Brodsky *et al.*: Phys.Rept. 522 (2013) 239
- AFTER@LHC Study Group Review: arXiv:1807.00603 [hep-ex]
- Adv. High En. Phys. Special issue

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Heavy-ion collisions towards large rapidities

- A complete set of heavy-flavour studies between SPS and RHIC energies
- Rapidity scan of the azimuthal asymmetries thanks to a broad rapidity reach
- Test the factorisation of cold nuclear effects from $p + A$ to $A + B$ collisions with Drell-Yan

Part II

Kinematics, Possible Implementations and Luminosities

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7 TeV proton beam on a fixed target

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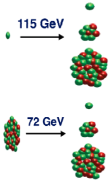

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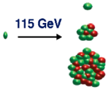

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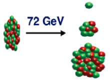

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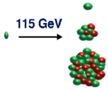

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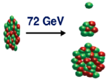

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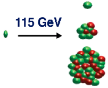

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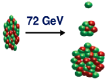

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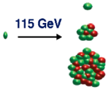

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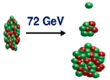

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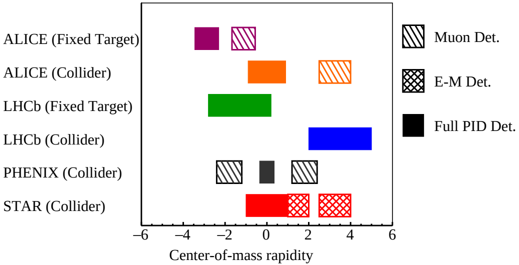

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→ The gas targets are the best polarised targets and satisfactory for heavy-ion studies

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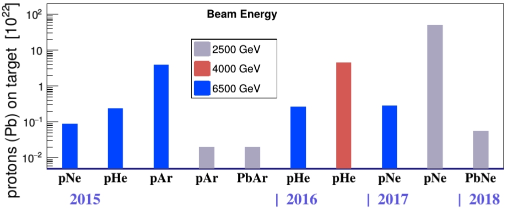

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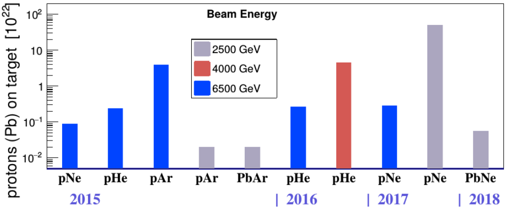

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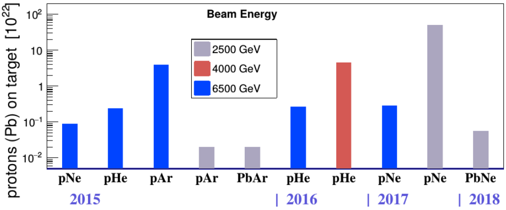

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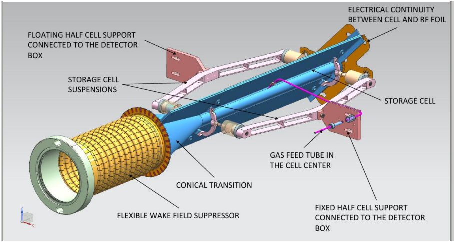

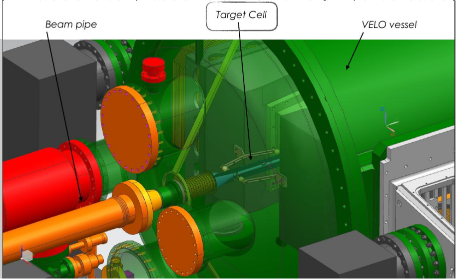

LHCb-PUB-2018-015 & CERN-PBC-Notes-2018-007

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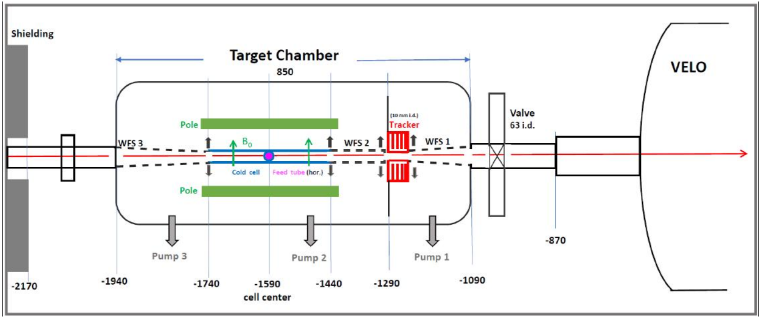

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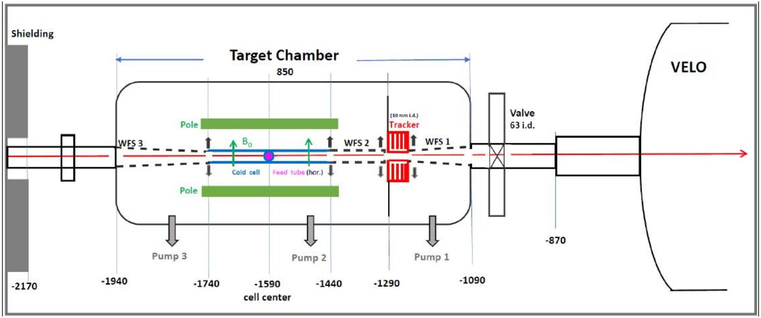

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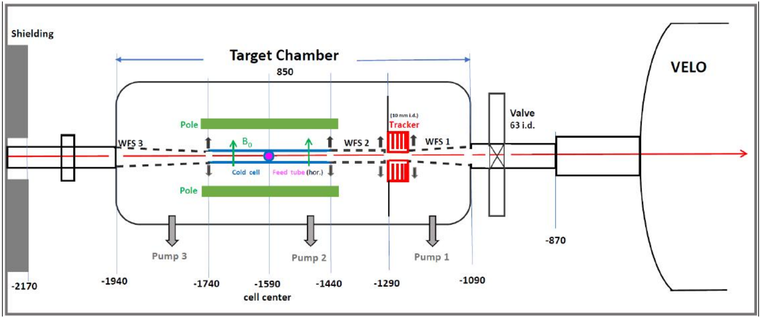

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- The target position is critical : acceptance toward large $x^\uparrow$ lost if too remote

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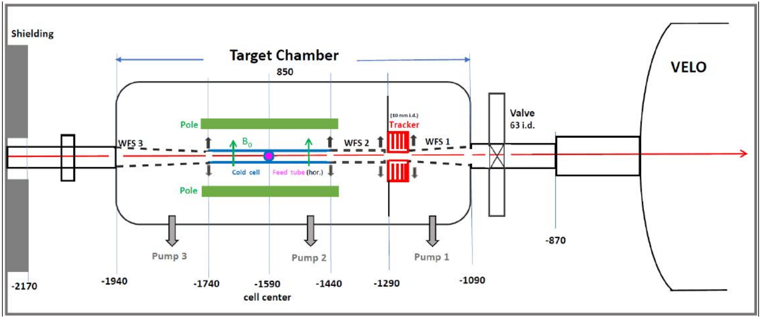

LHCSpin: injection of polarised gases

- R & D needed for the coating (depolarisation); goal :installation during LS3
- The target position is critical : acceptance toward large $x^\uparrow$ lost if too remote
- Gain of an additional tracker yet to be studied

SMOG 2: installation of an openable storage cell during LS2 [approved by LHCb]

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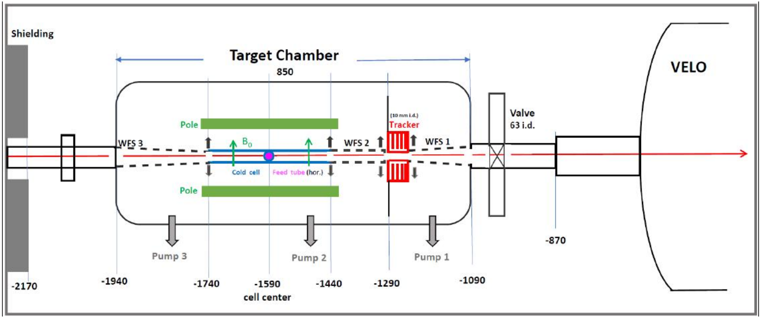

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- A similar solution w/o storage cell like the RHIC H-jet polarimeter is an alternative

Solutions within ALICE & reviewed by the PBC working group

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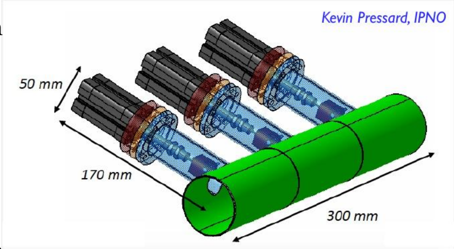

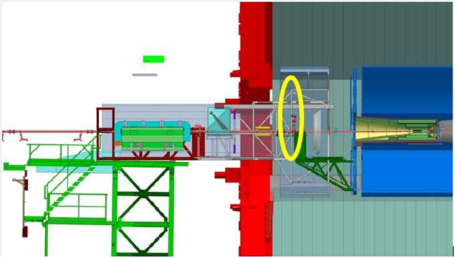

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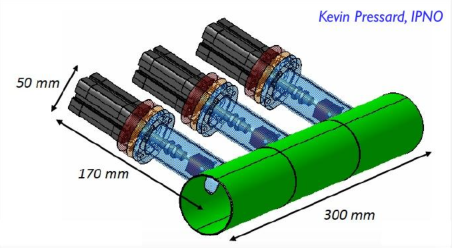

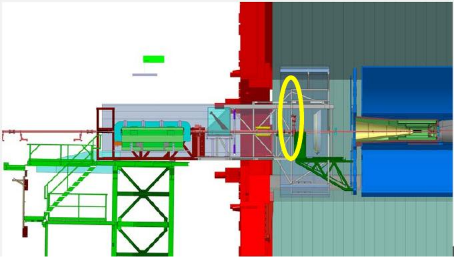

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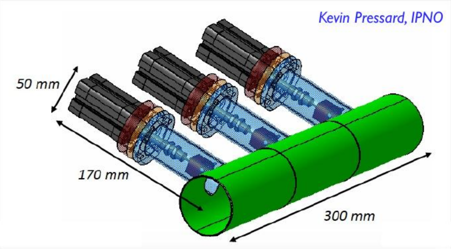

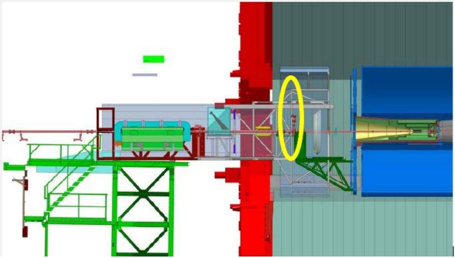

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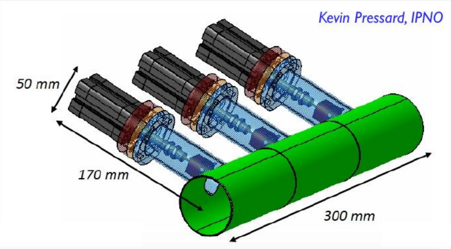

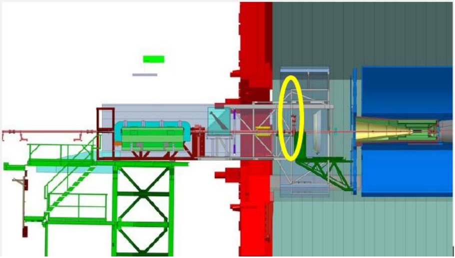

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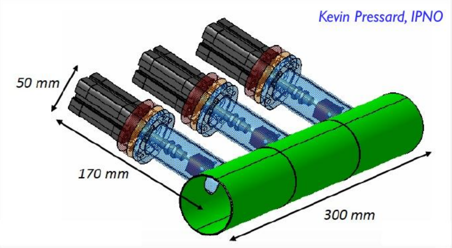

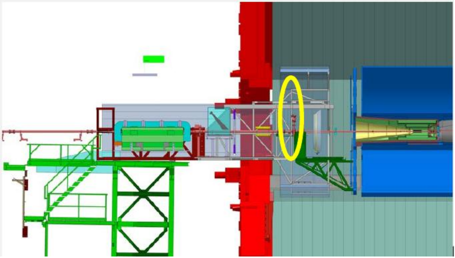

Luminosity comparison [w detector constraints]

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LHCb 'possible'

Assumption: Rates only constrained by the DAQ (40 MHz for *pp* coll.)
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LHCb 'SMOG2' baseline for Run3

Assumption: Storage cell installed, very parasitic mode
$\mathcal{L}_{p\ \mathrm{beam}}$: 150 pb^{-1} on H, 10 pb^{-1} on D or 45 pb^{-1} on Ar; $\mathcal{L}_{\mathrm{Pb\ beam}}$: 5 nb^{-1} on Ar

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ALICE 'possible' from Run4*

Assumption: Readout rate: 50 kHz in PbPb coll. and possibly up to 1 MHz in *pp* and *p*A coll.
With internal gas target: $\mathcal{L}_{pH_2/H^\uparrow}$: 250 pb^{-1}; $\mathcal{L}_{\mathrm{PbXe}}$: 8 nb^{-1}
With beam splitting and solid target: $\mathcal{L}_{p\mathrm{W}}$: 0.6 ÷ 6 pb^{-1} ; $\mathcal{L}_{\mathrm{PbW}}$: 3 nb^{-1}

Part III

Examples of Physics Studies

Drell-Yan

C. Hadjidakis ***et al.*****, 1807.00603**

Drell-Yan

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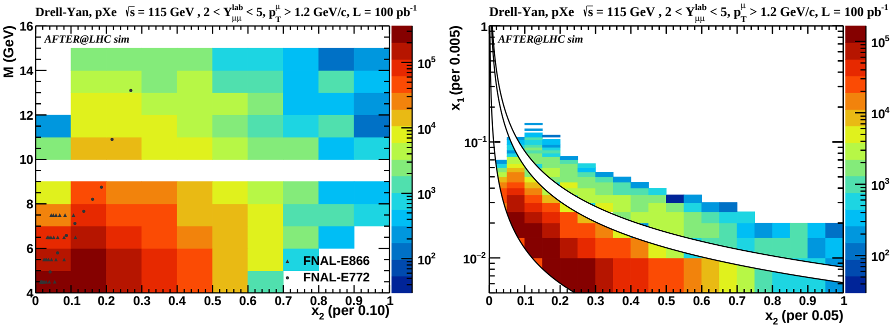
- Unique acceptance (with a LHCb-like detector) compared to existing DY *pA* data used for nuclear PDF fit (E866 & E772 @ Fermilab).



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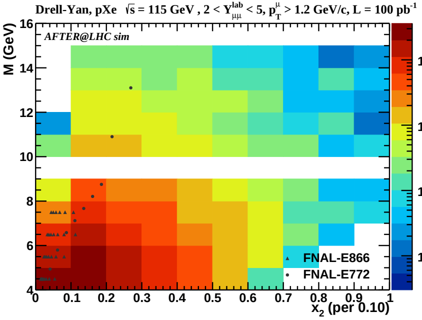

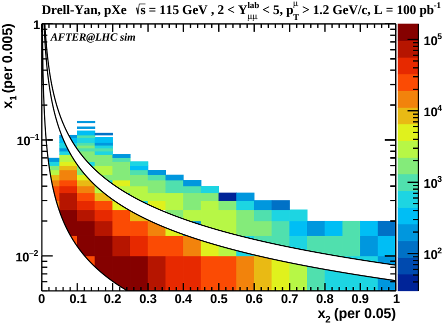

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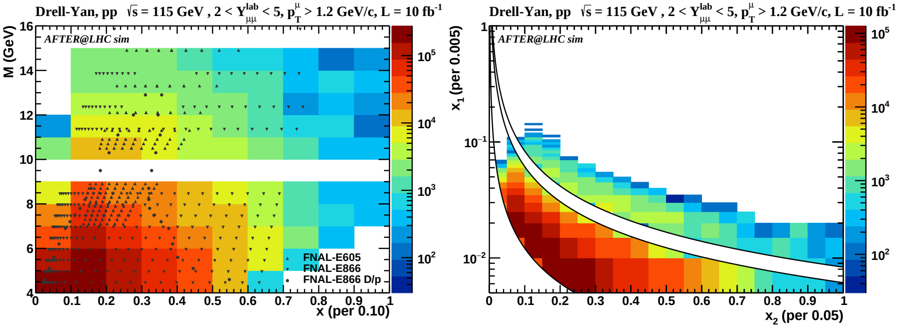

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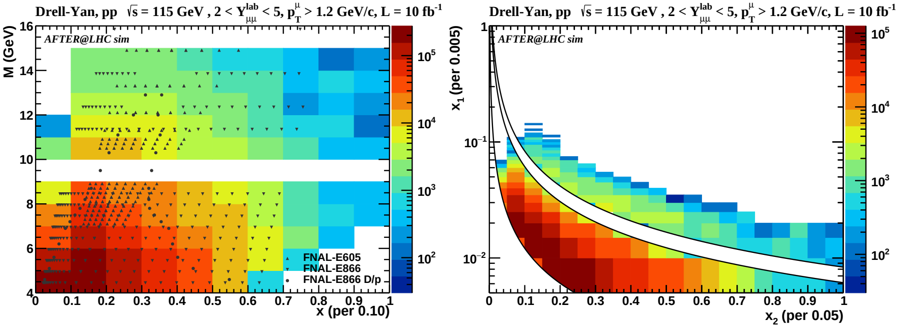

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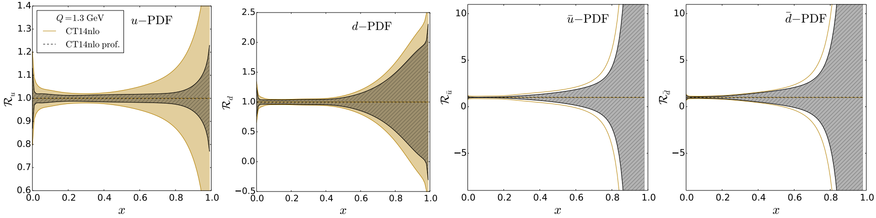
pp case



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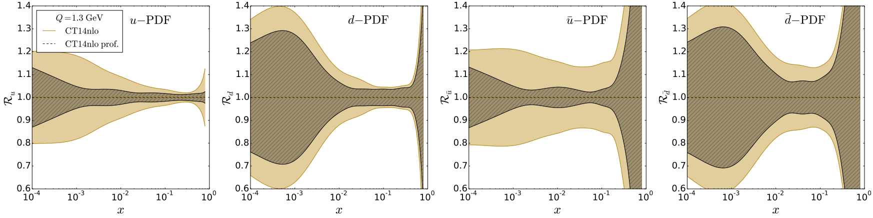

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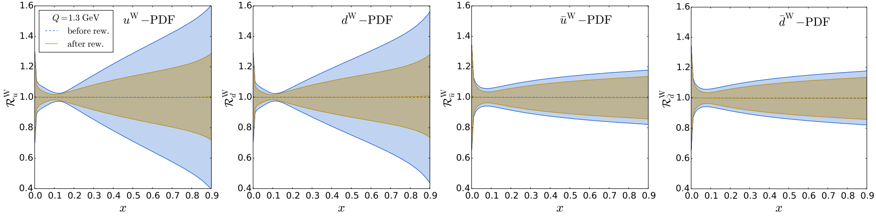
- as well as the nuclear PDF uncertainties

pW case



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- as well as the nuclear PDF uncertainties
- On-going theory study for $W^{\pm}$ production accounting for threshold resummation

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

C. Hadjidakis *et al.*, **1807.00603; D. Kikola** *et al.* **Few Body Syst. 58 (2017) 139**

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

- DY pair production on a transversely polarised target
- Check the sign change in A_N DY vs SIDIS: **hot topic in spin physics !**

C. Hadji

Experiment	colliding systems	beam energy [GeV]	$\sqrt{s}$ [GeV]	$x^{\uparrow}$	$\mathcal{L}$ [cm^{-2}s^{-1}]	$\mathcal{P}_{\text{eff}}$	$\mathcal{F}/\sum_i A_i$ [cm^{-2}s^{-1}]
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PHENIX/STAR (RHIC)	$p^{\uparrow}p^{\uparrow}$	collider	510	$0.05 \div 0.1$	2×10^{32}	50%	5.0×10^{31}
E1039 (FNAL)	$pNH_3^{\uparrow}$	120	15	$0.1 \div 0.45$	4×10^{35}	15%	9.0×10^{33}
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NICA (JINR)	$p^{\uparrow}p$	collider	26	$0.1 \div 0.8$	1×10^{32}	70%	4.9×10^{31}
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C. Hadji

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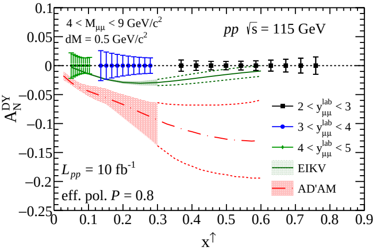

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- **$^3He^\uparrow$ target → quark Sivers effect in the neutron via DY: unique !**

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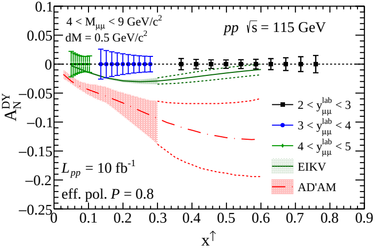
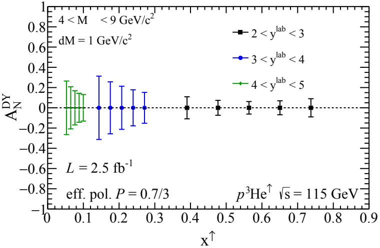
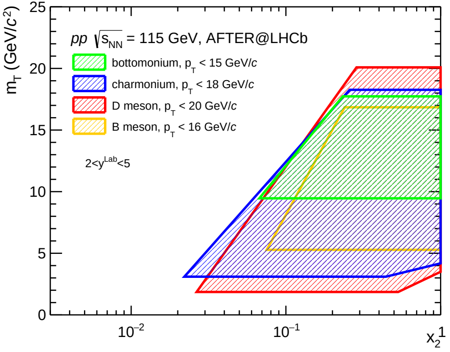
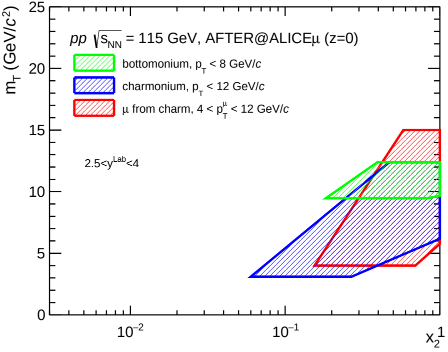




Kinematical coverage for heavy flavours





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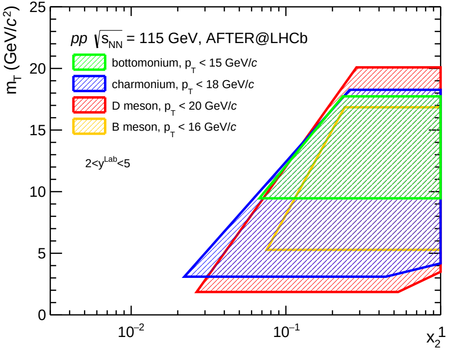

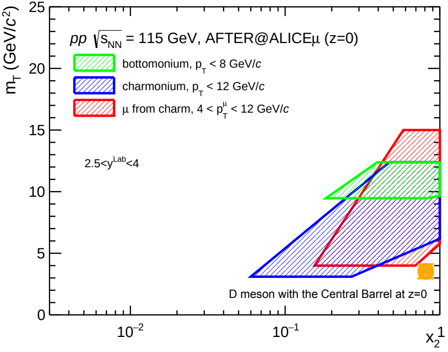

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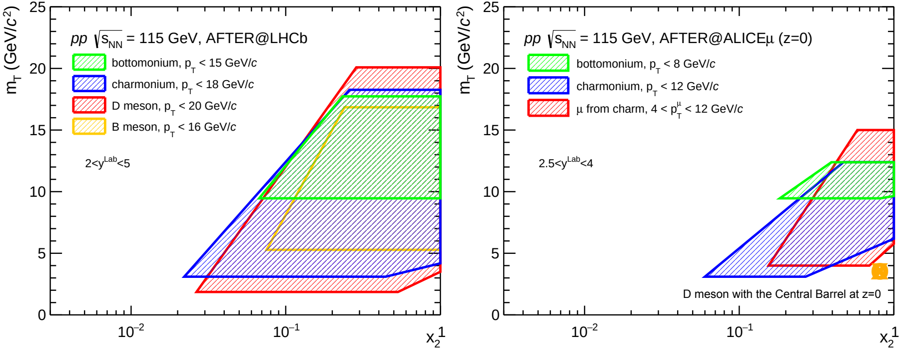

- ALICE could extend its coverage with $\eta_{\rm Lab} \sim 1-2$ for quarkonia into dileptons with one muon in the muon arm and another in the central barrel

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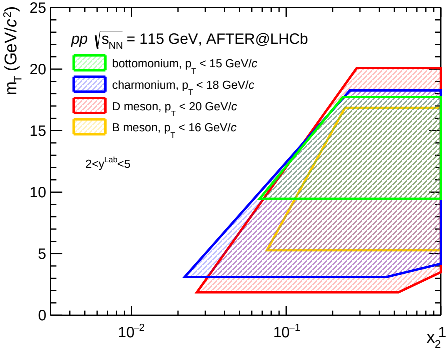

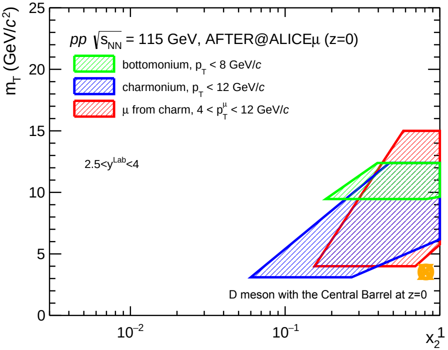

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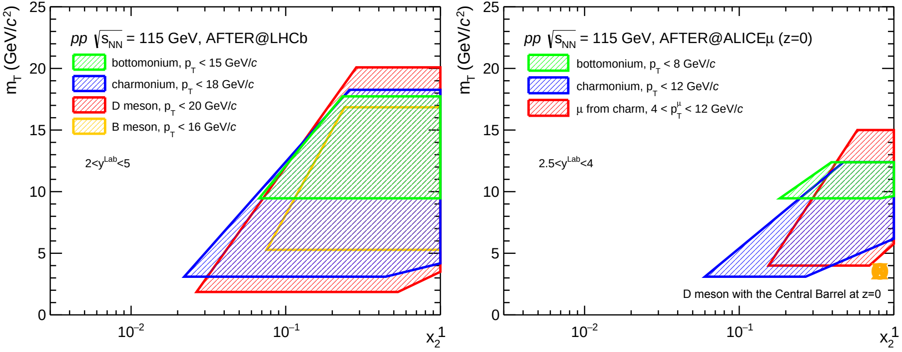

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- Access towards large x crucial : EMC effect, spin and UHE neutrinos

Quarkonium Projections for spin asymmetries

C. Hadjidakis *et al.*, **1807.00603; D. Kikola** *et al.* **Few Body Syst. 58 (2017)**

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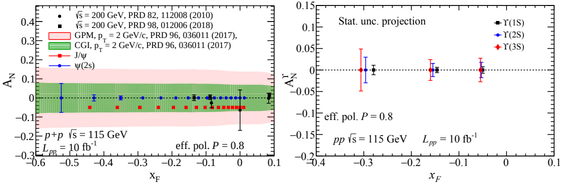

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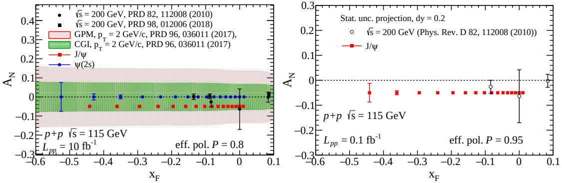

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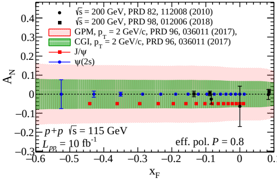

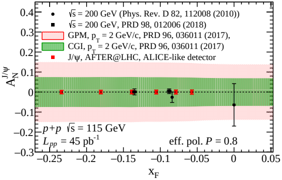

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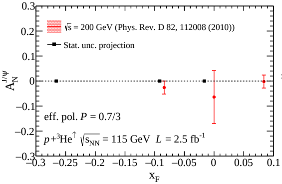

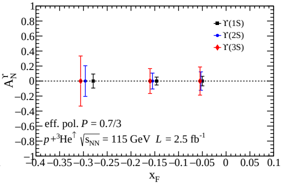

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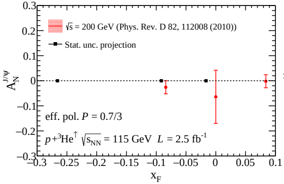

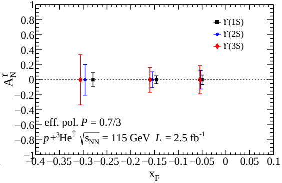

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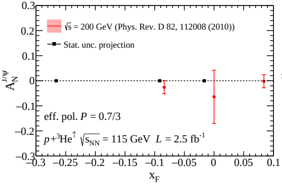

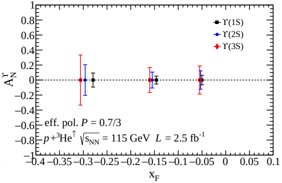

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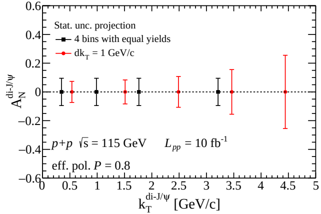
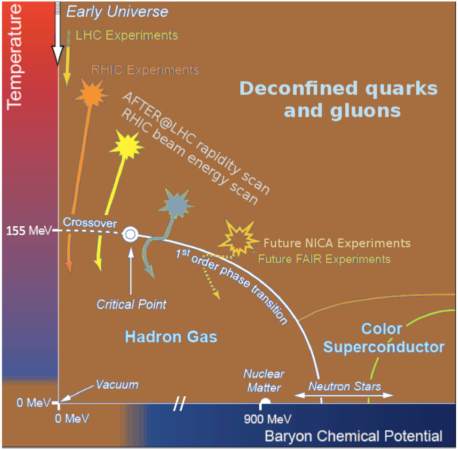
- Di-J/ψ allow one to study the k_T dependence of the gluon Sivers function for the very first time !



Heavy ions: rapidity scan & heavy-flavour precision studies



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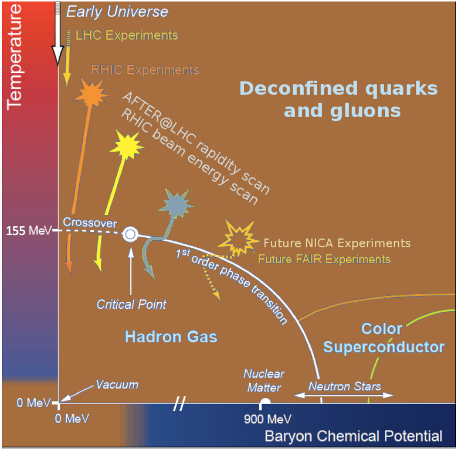

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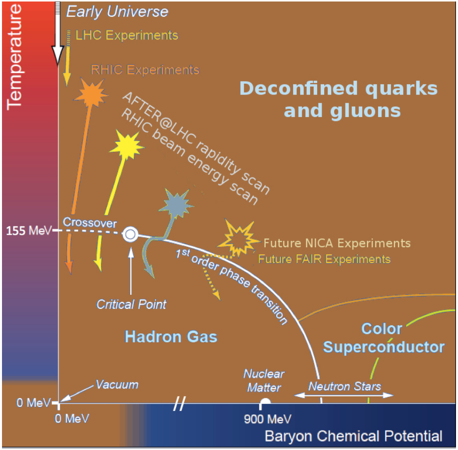

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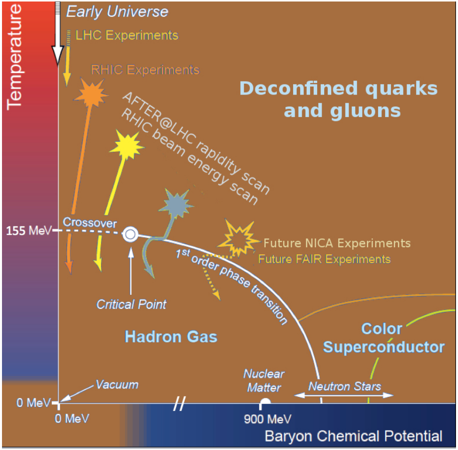

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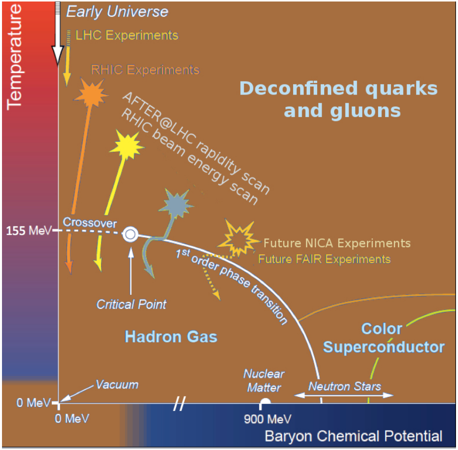
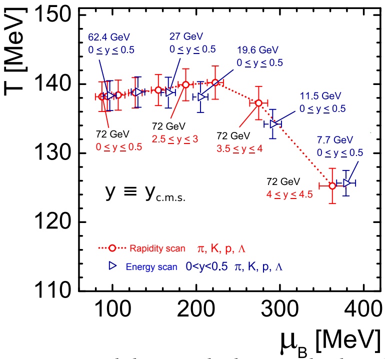


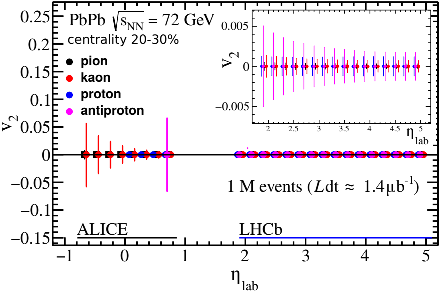
Rapidity scan

Illustration of the ALICE-LHCb complementarity



V. Begun, D. Kikola, V. Vovchenko, D. Wielanek, PRC 98 (2018)

C. Hadjidakis *et al.*, 1807.00603



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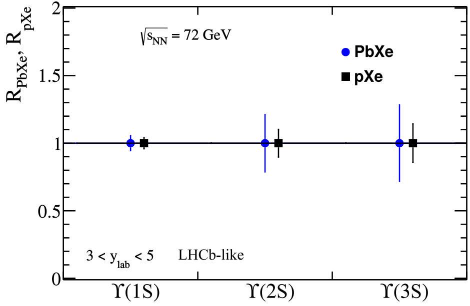

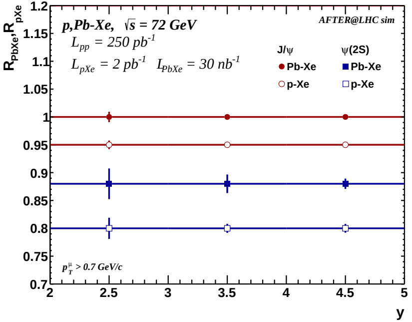

Gluons at the high-x frontier using precision heavy-flavour-production data

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- Extremely promising first projections using Bayesian reweighting
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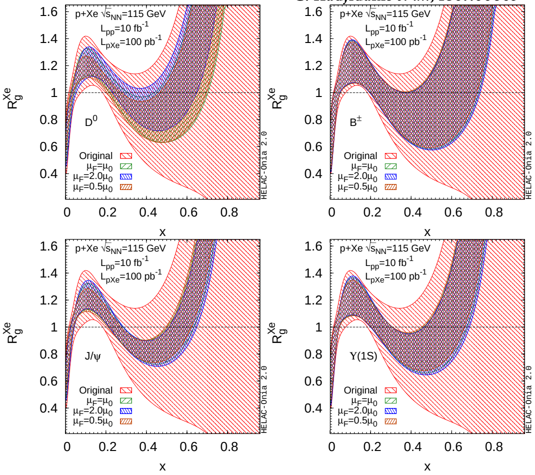

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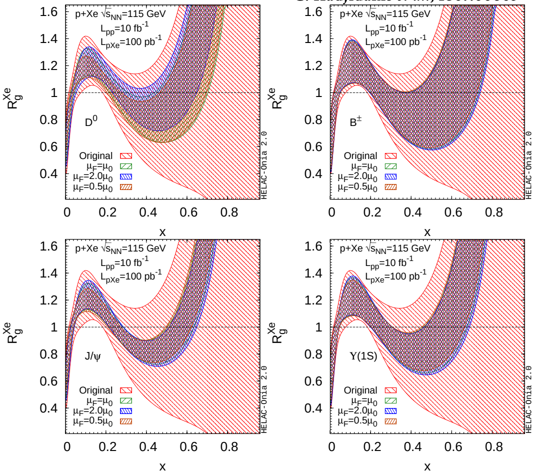

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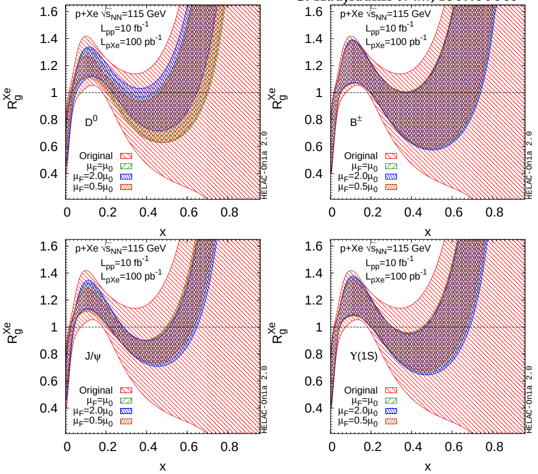

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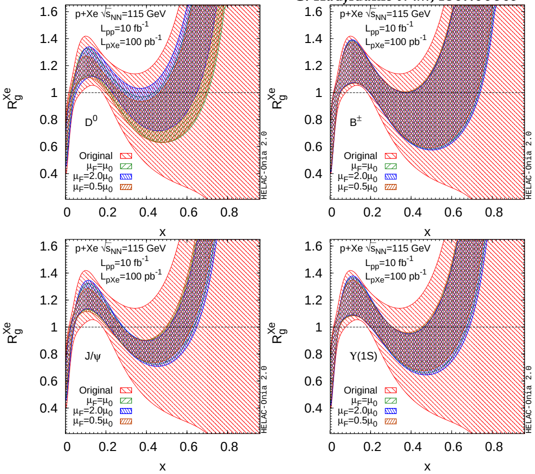

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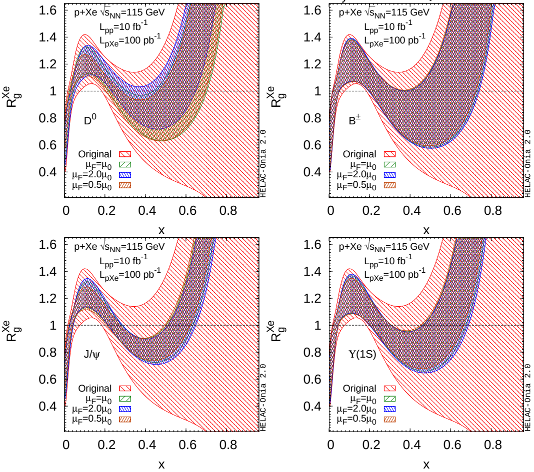

Reward: unique constraints on gluon (n)PDFs at high x and low scales

Part IV

Conclusions and recommandation

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The physics reach of the LHC complex can greatly be extended at a very limited cost with the adjunction of an ambitious and long term research program using the LHC beams in the fixed-target mode. *The CERN laboratory should support the efforts of the existing LHC experiments to implement such a program, including specific R&D actions on the LHC.*

Part V

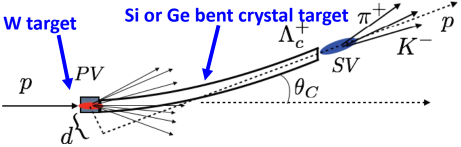
Backup slides

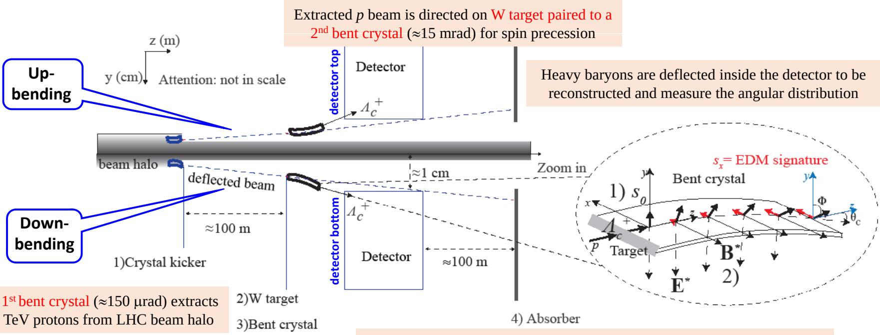
Qualitative comparison

Characteristics	Internal gas target: SMOG	Internal gas target: Gas Jet	Internal gas target: Storage Cell	Internal solid target with beam halo	Beam splitting	Beam extraction
Run duration	★	★★	★★	★	★★	★★★
Parasiticity	★★	★★	★★	★	★★	★★★
Integrated luminosity	★	★★★	★★★	★	★★	★★★
Absolute luminosity determination	★	★★	★★	★	★★	★★★
Target versatility	★	★★	★★	★	★★	★★★
(Effective) target polarisation	-	★★★	★★	-	- / ★	★
Use of existing experiment	★★★	★★	★	★★	★★	-
Civil engineering or R&D	★★★★	★★★	★★	★★	★★	★
Cost	★★★	★★	★★	★★★	★★	★
Implementation time	★★★	★★	★★	★★★	★★	★
High *x*	★	★★★	★★★★	★	★★	★★★★
Spin Physics	-	★★★	★★★	-	- / ★★	★★★
Heavy-Ion	★	★★★	★★★	★★	★★	★★★★

Bent crystals proposal

- **Magnetic** (MDM) and **electric** (EDM) **dipole moments** of short-lived particles, i.e. **charm**, **beauty** baryons, τ lepton, have never been measured
- A tool for SM and BSM physics
- Exploit the high electric field between Si or Ge crystallographic planes to induce spin precession





Non-interacting protons, non-channeling particles and most secondary interactions outside acceptance, to be absorbed downstream the detector

Bent crystals proposal

Ongoing activities:

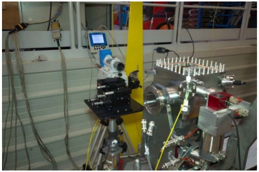
LHC Collimation: layout, simulations, beam extraction, collimators, absorbers

SELDOM project & **LHCb** experiment: exp. techniques, physics program, preparatory measurements, R&D on long bent crystals

UA9 experiment: bent crystals, channeling, layout, LHC beam extraction, double-crystal scheme studies at SPS, physics studies

Si crystal (8 cm, 16 mrad) tested on beam at SPS (October 2018, courtesy of A. Mazzolari, INFN-Ferrara)

LHC goniometer used for LHC beam extraction test (courtesy of UA9)



Phys. Lett. B 758 (2016) 129

Aiming for:

- **1st phase** installation at IR8 (LHCb) in YETS Run3:

  Up to $\sim 10^{15}$ PoT (5 mm W target) Eur. Phys. J. C 77 (2017) 828, JHEP 1708 (2017)

  e.g. for Λ_c^+, MDM $\sim 10^{-3}\,\mu_N$ and EDM $\sim 10^{-17}\,e$ cm

- **2nd phase** (high lumi) in dedicated experiment (e.g. IR7 or IR3, longer term)

  e.g. for τ lepton, $\sim 10^{17}$ PoT for $g-2 \sim 10^{-3}$ (SM) and EDM$\sim 10^{-17}\,e$ cm

JHEP 1903 (2019) 156
arXiv:1810.06699 (2018)

Further readings

Heavy-Ion Physics

- *Estimation of the freeze-out parameters reachable in the AFTER@LHC project* by V. Begun, D. Kikola, V. Vovchenko, D. Wielanek, Phys. Rev. C 98 (2018)
- *Rapidity scan in heavy ion collisions at $\sqrt{s_{NN}}$ = 72 GeV using a viscous hydro + cascade model* by I. Karpenko: arXiv:1805.11998 [nucl-th]
- *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

- *Exclusive vector meson photoproduction in fixed - target collisions at the LHC* by V.P. Goncalves, M.M. Jaime. Eur.Phys.J. C78 (2018) no.9, 693
- *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.