Fixed Target opportunities at the (HL-)LHC (v0.2)

J.P. Lansberg

IPN Orsay – Paris-Sud U./Paris Saclay U. –CNRS/IN2P3

Depuis 80 ans, nos connaissances
bâtissent de nouveaux mondes

Using the LHC beams in the fixed-target mode

Contributions to the ESPP update and other scientific sources

3 Contributions to submitted in December [overall signed by 200+ physicists]

- *Physics opportunities for a fixed-target programme in the ALICE experiment* by F. Galluccio *et al.*: ID 47
- *Community Support for A Fixed-Target Programme for the LHC* by J.D. Bjorken *et al.*: ID 67
- *The LHCSpin Project* by C. Aidala *et al.*: ID 111

Physics Beyond Colliders documents

- *Physics Beyond Colliders: QCD Working Group Report* by the PBC QCD Working Group (A. Dainese *et al.*) : arXiv:1901.04482
- *Summary Report of Physics Beyond Colliders at CERN* by R. Alemany *et al.*: arXiv:1902.00260
- CERN-PBC-Notes: e.g. 2019-003,2019-002,2019-001,2018-008,2018-007,2018-003,2018-001
- Summary by the PBC LHC FT Working Group: yet to appear

Reviews

- Phys. Rept 2012
- AFTER@LHC Review 2019

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High-x gluon, antiquark and heavy-quark content in the nucleon & nucleus

- Very large gluon PDF uncertainties for $x \gtrsim 0.5$.
- Gluon EMC effect to understand the quark EMC effect
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Dynamics and spin of gluons and quarks inside (un)polarised nucleons

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

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

- Test of the QCD factorisation framework
- Determination of the linearly polarised gluons in unpolarised protons

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Heavy-ion collisions towards large rapidities

- A complete set of heavy-flavour studies between SPS and RHIC energies
- Test the formation of 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 I

Possible Implementations and Luminosities

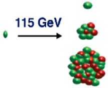
Fixed-target collisions at the LHC: main kinematical features

Fixed-target collisions at the LHC: main kinematical features

Energy range

7 TeV proton beam on a fixed target

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



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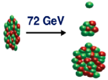

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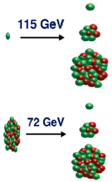

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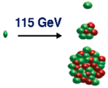

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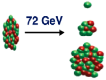

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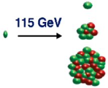

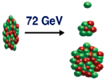

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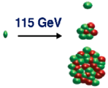

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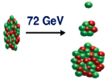

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- Allows for backward physics up to high x_2 [uncharted for proton-nucleus coll.; most relevant for $pp^{\uparrow}$ with large $x^{\uparrow}$]

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→ The beam line option is currently a little too ambitious (this could change with FCC)
→ The gas targets are the best polarised targets and satisfactory for heavy-ion studies

Solutions within ALICE & reviewed by the PBC working group

Material mainly from *Physics opportunities for a fixed-target programme in the ALICE experiment* by F. Galluccio *et al.*: ID 47

Solutions within LHCb & reviewed by the PBC working group

Material on SMOG2 and LHCSpin from *The SMOG2 Project* CERN-PBC-Notes-2018-007 and *The LHCSpin Project* by C. Aidala *et al.*: ID 111

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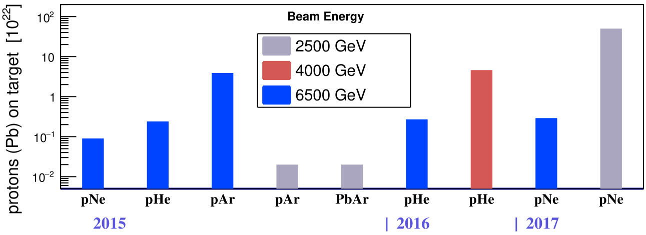

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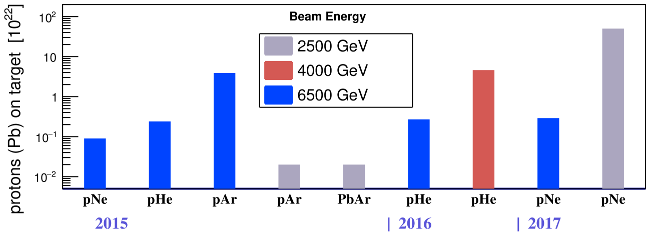

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- Plan to install a storage cell [SMOG2] to increase the target local density
- Different options discussed for future LHCb upgrades: No decision taken yet
- However decision for the installation of a vacuum valve during LS2.

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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}; $\mathcal{L}_{\text{PbXe}}$: 8 nb^{-1}
With beam splitting and solid target: $\mathcal{L}_{p\text{W}}$: 6 pb^{-1} ; $\mathcal{L}_{\text{PbW}}$: 3 nb^{-1}

Part II

Examples of Physics Studies

Drell-Yan

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

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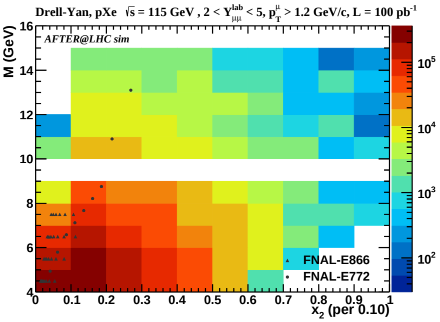

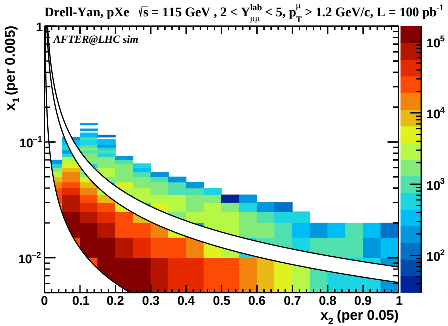

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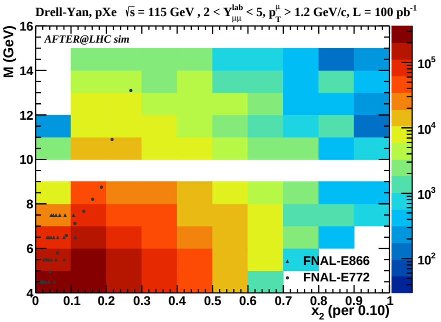

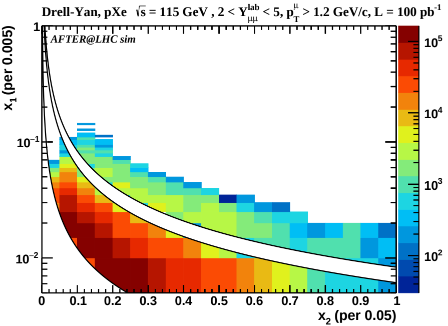

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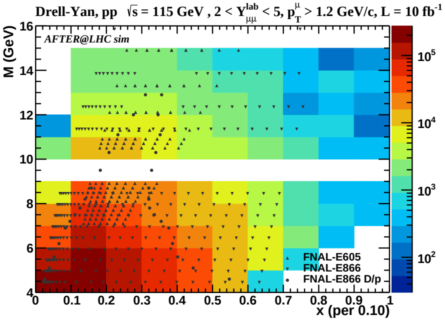

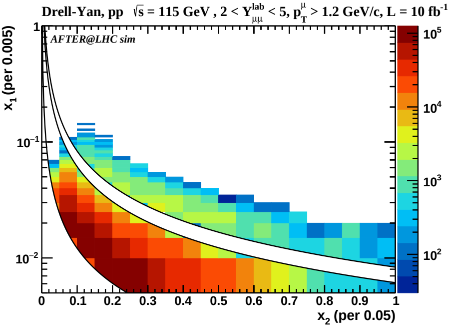

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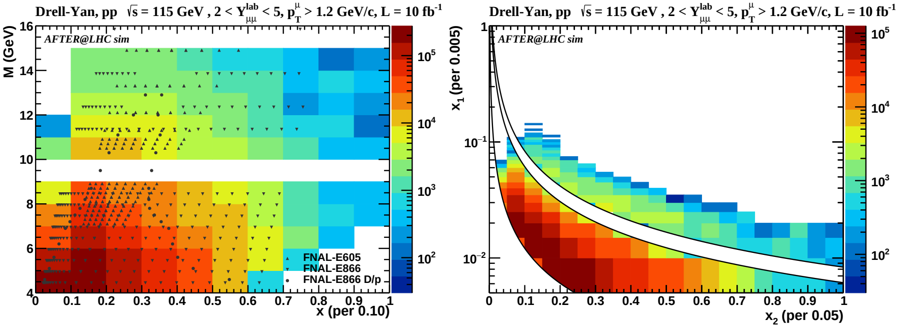

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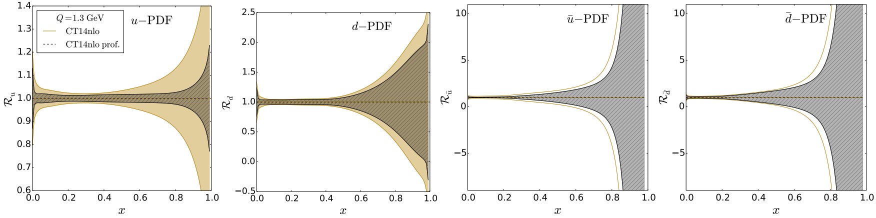

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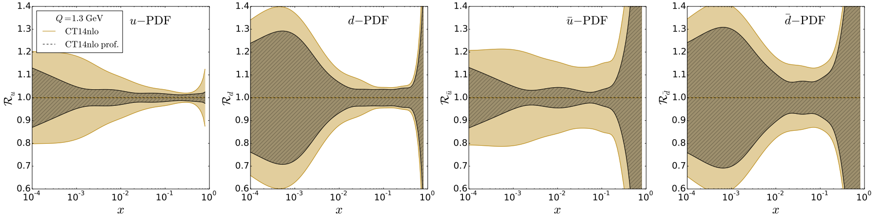

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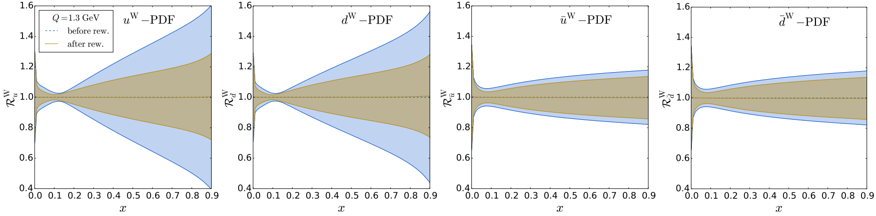
*p*W case



Drell-Yan

C. Hadjidakis *et al.*, 1807.00603

- Unique acceptance (with a LHCb-like detector) compared to existing DY pA data used for nuclear PDF fit (E866 & E772 @ Fermilab).
- Extremely large yields up to $x_2 \to 1$ [plot made for pXe with a Hermes like target]
- Same acceptance for pp collisions
- A single measurement (in pp coll.) at RHIC, just released
- Decrease of the proton PDF uncertainties : FoM using Bayesian reweighting
- 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]

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

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Experiment	colliding systems	beam energy [GeV]	$\sqrt{s}$ [GeV]	$x^\uparrow$	$\mathcal{L}$ [cm^{-2}s^{-1}]	$\mathcal{P}_{\rm eff}$	$\mathcal{F} / \sum_i A_i$ [cm^{-2}s^{-1}]
AFTER@LHCb	$p\mathrm{H}^\uparrow$	7000	115	$0.05 \div 0.95$	1×10^{33}	80%	6.4×10^{32}
AFTER@LHCb	$p^3\mathrm{He}^\uparrow$	7000	115	$0.05 \div 0.95$	2.5×10^{32}	23%	1.4×10^{31}
AFTER@ALICE$_\mu$	$p\mathrm{H}^\uparrow$	7000	115	$0.1 \div 0.3$	2.5×10^{31}	80%	1.6×10^{31}
COMPASS (CERN)	$\pi^-\mathrm{NH}_3^\uparrow$	190	19	$0.05 \div 0.55$	2×10^{33}	14%	4.0×10^{31}
PHENIX/STAR (RHIC)	$p^\uparrow p^\uparrow$	collider	510	$0.05 \div 0.1$	2×10^{32}	50%	5.0×10^{31}
E1039 (FNAL)	$p\mathrm{NH}_3^\uparrow$	120	15	$0.1 \div 0.45$	4×10^{35}	15%	9.0×10^{33}
E1027 (FNAL)	$p^\uparrow\mathrm{H}_2$	120	15	$0.35 \div 0.9$	2×10^{35}	60%	7.2×10^{34}
NICA (JINR)	$p^\uparrow p$	collider	26	$0.1 \div 0.8$	1×10^{32}	70%	4.9×10^{31}
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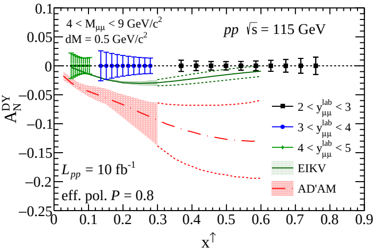

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- $^3He^\uparrow$ target → quark Sivers effect in the neutron via DY: unique !

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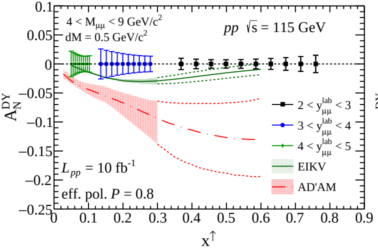
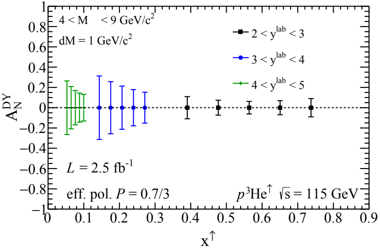
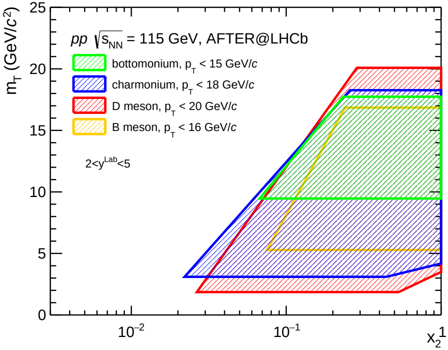
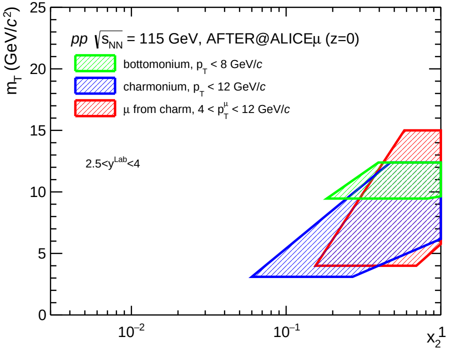




Kinematical coverage for heavy flavours





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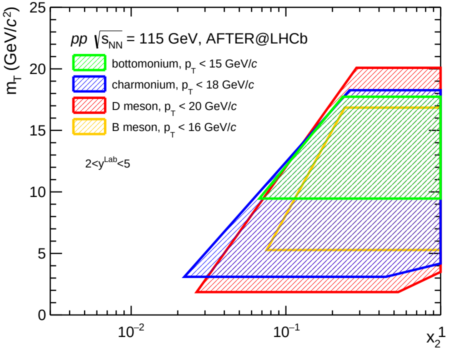

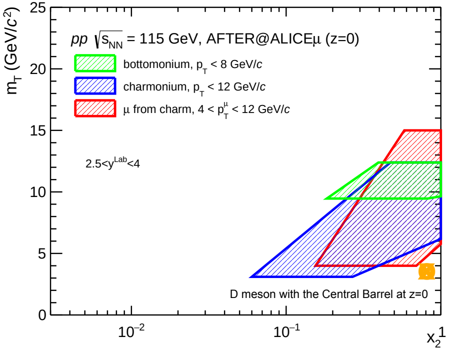

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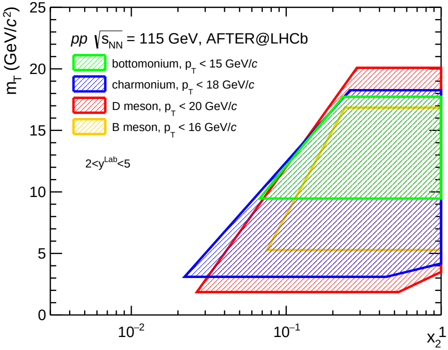

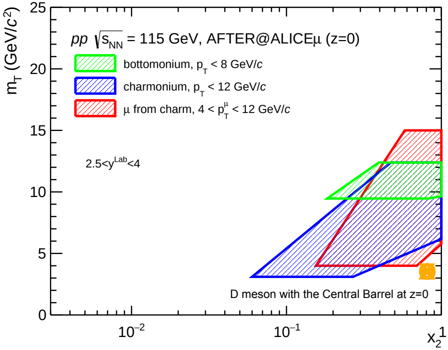

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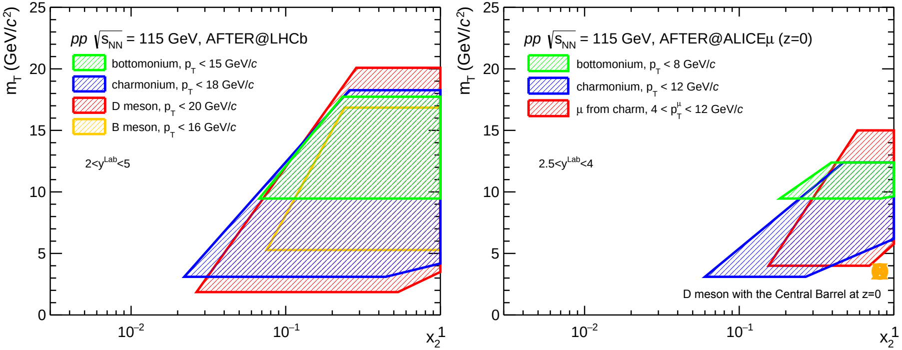

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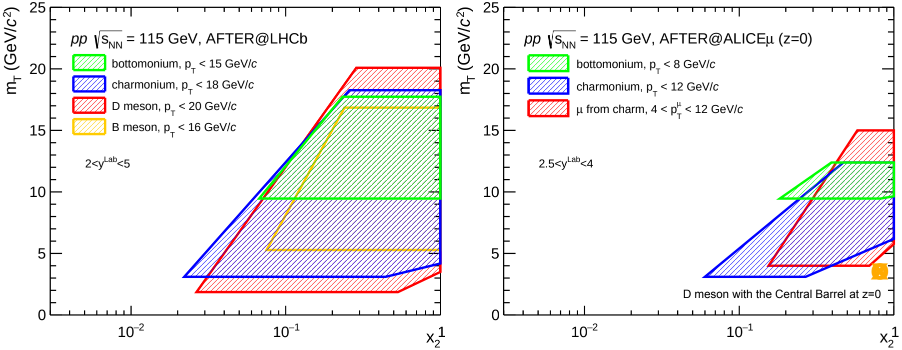

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- Access towards large x crucial : EMC effect, spin and UHE neutrinos

Quarkonium Projections

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

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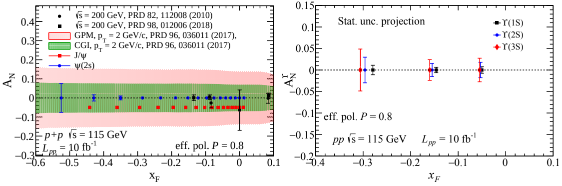

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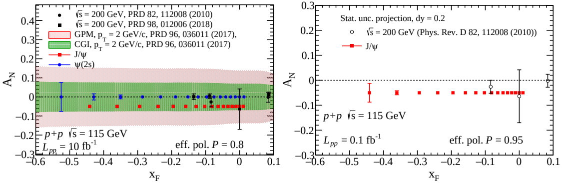

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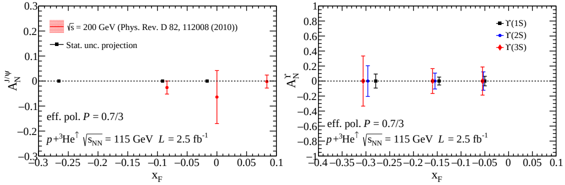

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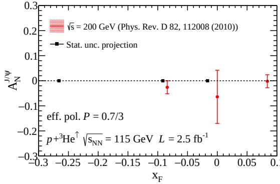

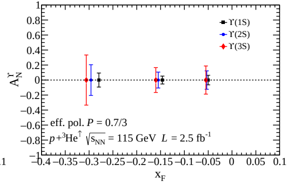

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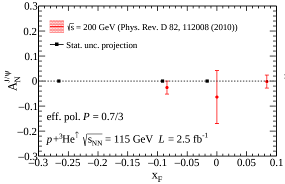

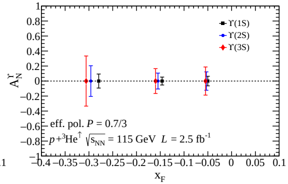

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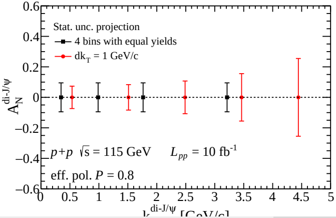
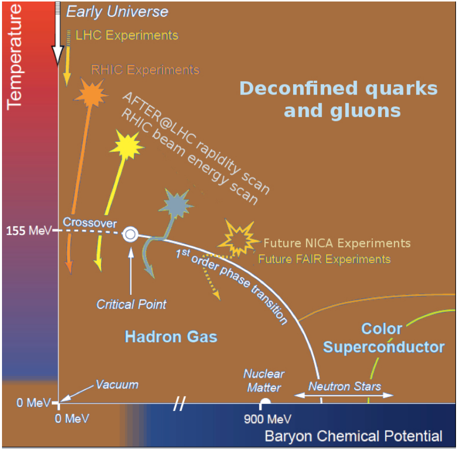
- Di-J/ψ allow one to study the k_T dependence of the gluon Sivers function for the very first time !



Heavy ions: rapidity scan & quarkonium precision studies



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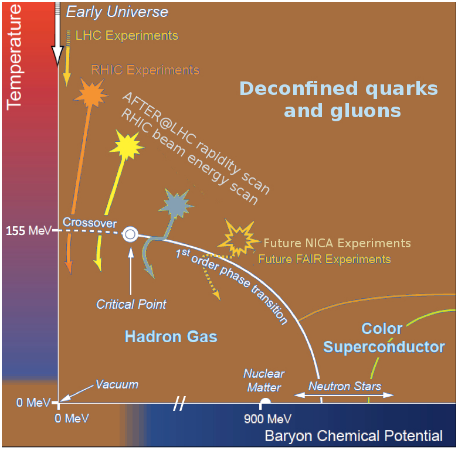

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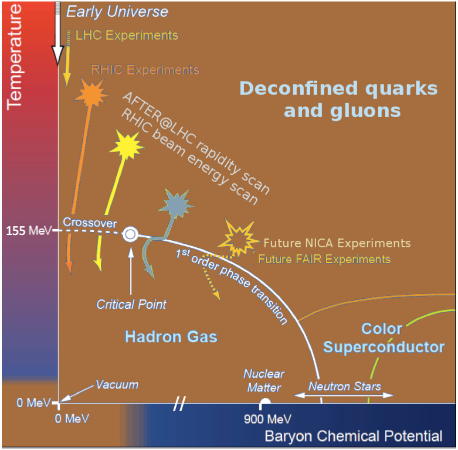

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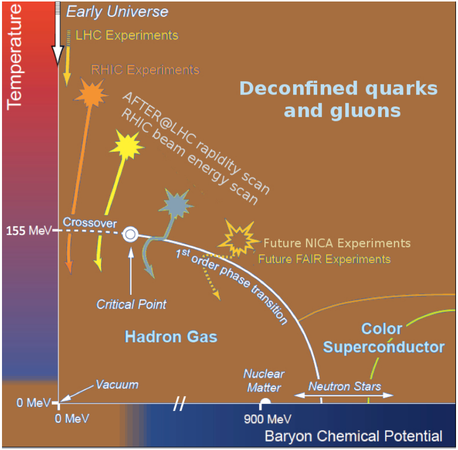

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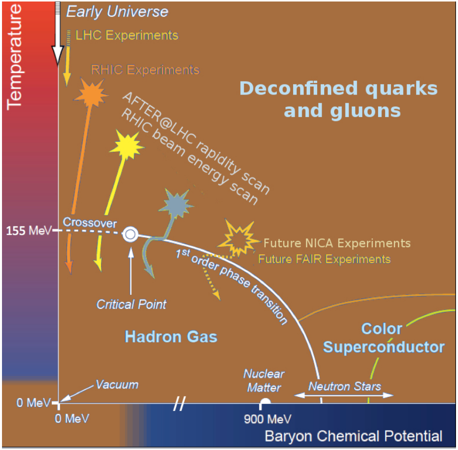

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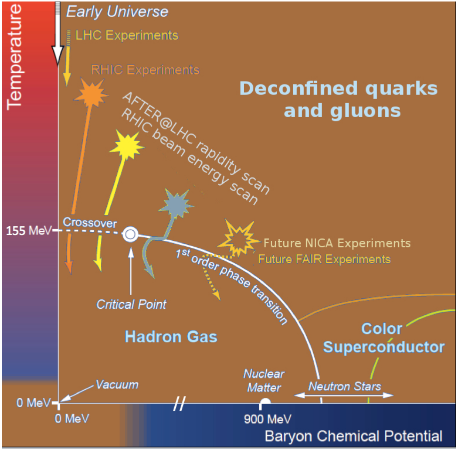

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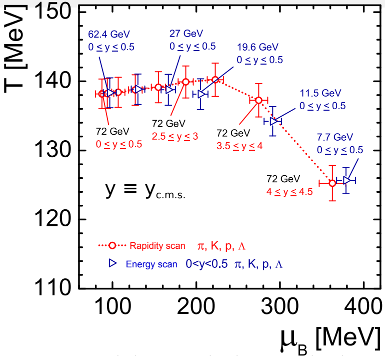
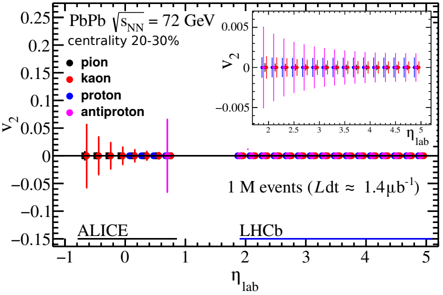


V. Begun, D. Kikola, V. Vovchenko, D. Wielanek, PRC 98 (2018)



Quarkonium Projections: heavy-ion collisions

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

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

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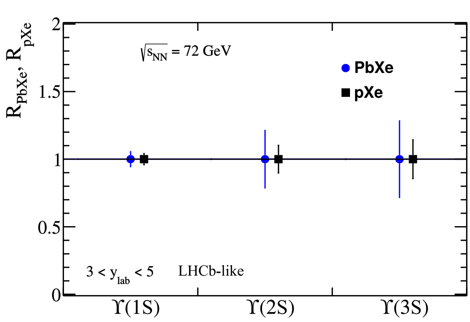

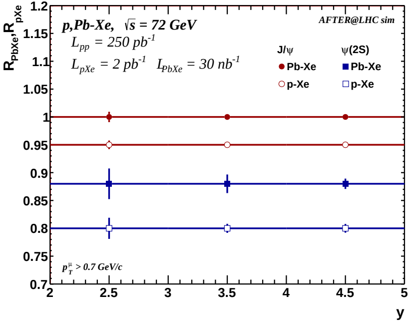

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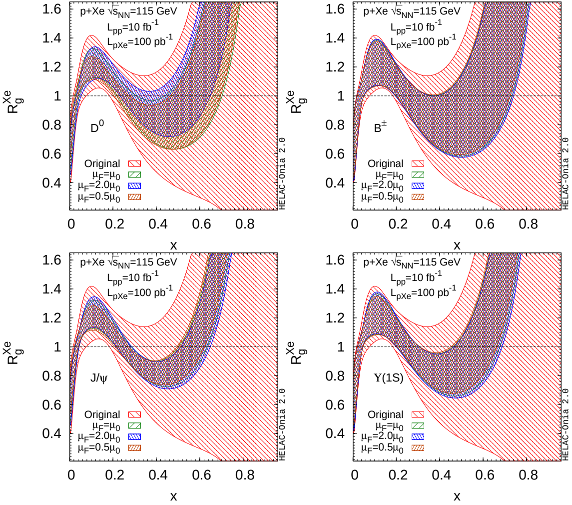

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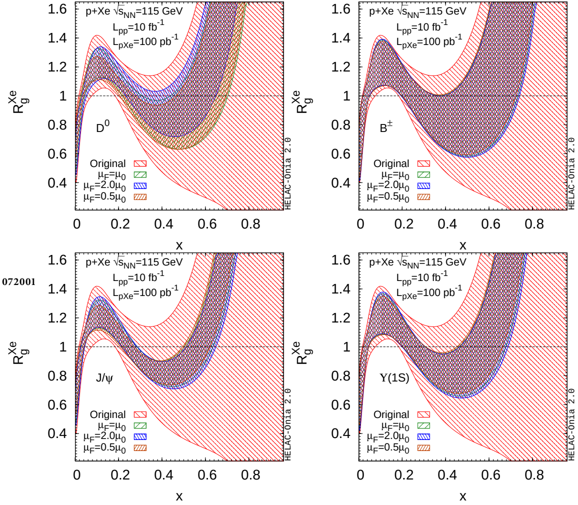
PROSA Coll. Eur.Phys.J. C75 (2015) 396; R. Gauld, J. Rojo PRL 118 (2017) 072001



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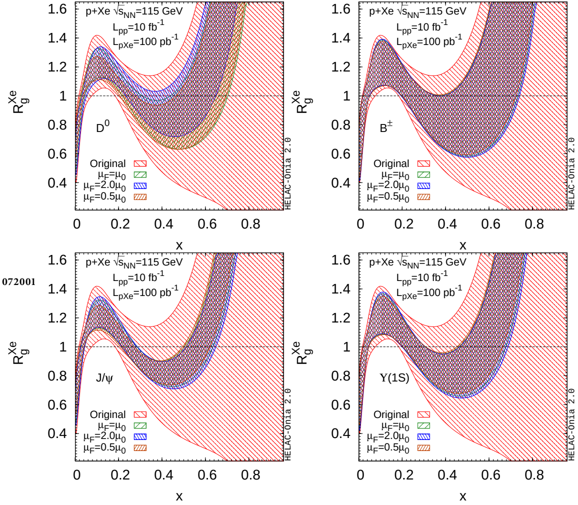
↳ Contrary to nPDF studies bearing on nuclear modification factors, one needs ways to reduce the systematical theory uncertainties



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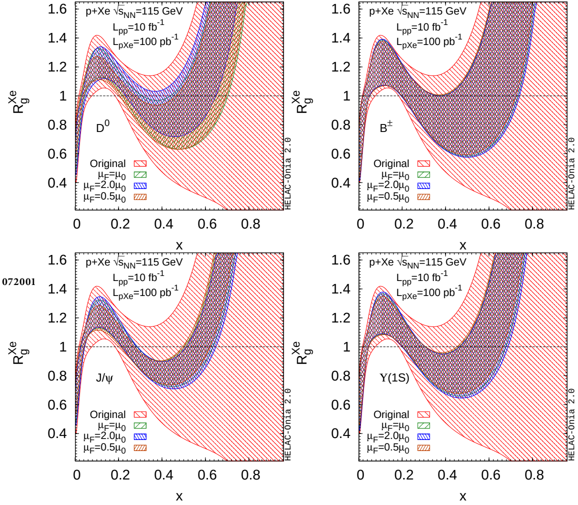
PROSA Coll. Eur.Phys.J. C75 (2015) 396; R. Gauld, J. Rojo PRL 118 (2017) 072001

↳ Contrary to nPDF studies bearing on nuclear modification factors, one needs ways to reduce the systematical theory uncertainties



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

Part III

Conclusion and recommandations

Conclusions and recommandations

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

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- Three main themes push for a fixed-target program at the LHC

- The high x frontier: new probes of the confinement
  and connections with astroparticles

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- R2
- R3, ...

Part IV

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	★	★★★	★★★	★★	★★	★★★★

Further readings

Heavy-Ion Physics

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- *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.
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- *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.

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Spin physics

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- *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.
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- *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
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Generalities

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