A Fixed-Target Programme at the LHC

J.P. Lansberg

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Rencontre QGP France, Etretat, July 4, 2018

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

Part I

The AFTER@LHC programme

The Genesis

Physics Reports 522 (2013) 239–255

Contents lists available at SciVerse ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

ELSEVIER

Physics opportunities of a fixed-target experiment using LHC beams

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- September 2016: PBC kickoff, …
- Finally the EoI, which became a review to motivate a full FT LHC program, is out !

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The AFTER@LHC programme

A Fixed-Target Programme at the LHC: Physics Case and Projected Performances for Heavy-Ion, Hadron, Spin and Astroparticle Studies

C. Hadjidakis[a,1], D. Kikoła[b,1], J.P. Lansberg[a,1,*], L. Massacrier[a,1], M.G. Echevarria[c,2], A. Kusina[d,2], I. Schienbein[e,2], J. Seixas[f,g,2], H.S. Shao[h,2], A. Signori[i,2], B. Trzeciak[j,2], S.J. Brodsky[k], G. Cavoto[l], C. Da Silva[m], F. Donato[n], E.G. Ferreiro[o,p], I. Hřivnáčová[a], A. Klein[m], A. Kurepin[q], C. Lorcé[r], F. Lyonnet[s], Y. Makdisi[t], S. Porteboeuf[u], C. Quintans[g], A. Rakotozafindrabe[v], P. Robbe[w], W. Scandale[x], N. Topilskaya[q], A. Uras[y], J. Wagner[z], N. Yamanaka[a], Z. Yang[aa], A. Zelenski[t]

Abstract

We review the context, the motivations and the expected performances of a comprehensive and ambitious fixed-target program using the multi-TeV proton and ion LHC beams. We also provide a detailed account of the different possible technical implementations ranging from an internal wire target to a full dedicated beam line extracted with a bent crystal. The possibilities offered by the use of the ALICE and LHCb detectors in the fixed-target mode are also reviewed.

To be submitted to Physics Reports

The AFTER@LHC HIC programme

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Possible implementations

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- Internal gas target (with or without storage cell)
  - can be installed in one of the existing LHC caverns, and coupled to existing experiments
  - currently validated by the LHCb collaboration with SMOG [their luminosity monitor used as a gas target]
  - uses the high LHC particle current: p flux: 3.4×10^{18} s^{-1} & Pb flux: 3.6×10^{14} s^{-1}
  - Hermes storage cell proposed in LHCb (R&D needed for coating and polarisation performance)
  - A system like the polarised H-jet polarimeter at RHIC-BNL (no storage cell) may also be used

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- Bent crystal option: beam line vs split
  - crystals successfully tested at the LHC for proton and lead beam collimation **[UA9 collaboration]**
  - the LHC beam halo is recycled on dense target: proton flux: 5×10^{8} s^{-1} & lead flux: 2×10^{5} s^{-1}

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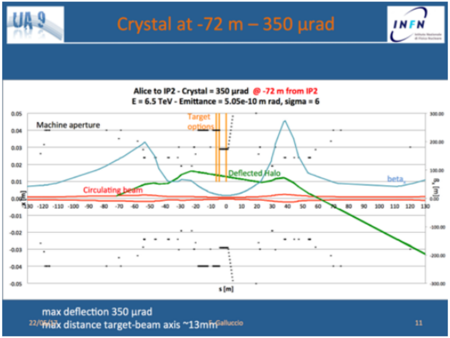
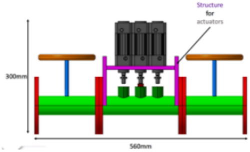
pp	pA	PbA
$\mathcal{O}(0.1-10\ \text{fb}^{-1}\text{yr}^{-1})$	$\mathcal{O}(0.1-1\ \text{fb}^{-1}\text{yr}^{-1})$	$\mathcal{O}(1-50\ \text{nb}^{-1}\text{yr}^{-1})$

Solid targets

Conceptual design work for a crystal beam-splitting scenario with in-beam solid targets in ALICE started by the proponents.
Compatibility with ALICE collider programme to be studied in detail.



Sketch of the internal solid target



- movable target with pumping system
- 2 valves on each side
- possibility to have several target types

- First study of single-crystal experiment at IP2 by F. Galluccio and W. Scandale
- Integration of a movable internal solid target with ALICE under study by K. Pressard

My suggestion: push in ALICE for a small modification **during the coming shutdown** of the beampipe to allow for tests [planned in LHCb] → urgent !!!

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[14]	⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆⋆⋆
Parasiticity[15]	⋆⋆⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆⋆⋆
Integrated luminosity[16]	⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆⋆⋆
Absolute luminosity determination[17]	⋆	⋆⋆	⋆⋆	⋆	⋆⋆	⋆⋆⋆
Target versality[18]	⋆⋆	⋆⋆	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆⋆
Target polarisation[19]	-	⋆⋆	⋆⋆	-	- / ⋆[20]	⋆
Use of existing experiment[21]	⋆⋆	⋆	⋆	⋆	⋆	-
Civil engineering or R&D [22]	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆
Cost	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆
Implementation time	⋆⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆⋆	⋆
High x[23]	⋆	⋆⋆	⋆⋆⋆	⋆	⋆/ ⋆⋆	⋆⋆⋆
Spin Physics[24]	-	⋆⋆⋆	⋆⋆⋆	-	- / ⋆⋆	⋆⋆⋆
Heavy-Ion[25]	⋆	⋆⋆	⋆⋆	⋆/ ⋆⋆	⋆⋆	⋆⋆⋆

Table 8: Qualitative comparison of the various technological solutions.

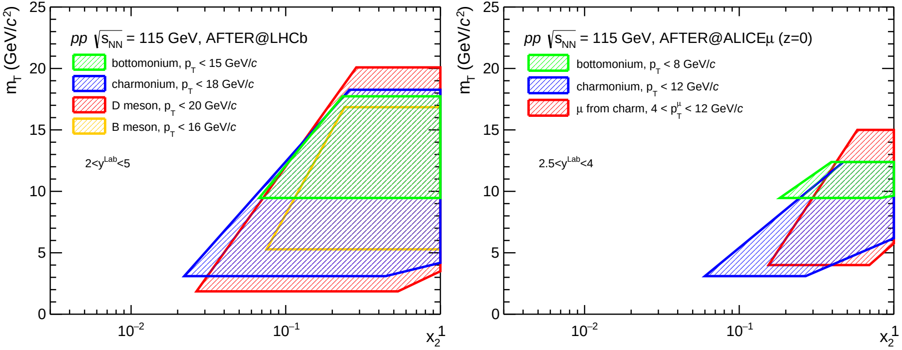
Luminosity comparison

Target			Beam					
			p			Pb		
			$\mathcal{L}$ [$cm^{-2}s^{-1}$]	Δt [s]	$\int\mathcal{L}$ [nb^{-1}]	$\mathcal{L}$ [$cm^{-2}s^{-1}$]	Δt [s]	$\int\mathcal{L}$ [nb^{-1}]
Internal gas target	SMOG	He, Ne, Ar	5.8×10^{29}	2.5×10^{5}	145	7.4×10^{25}	10^{6}	0.074
	Gas-Jet	$H^{\uparrow}$	4.3×10^{30}	10^{7}	4.3×10^{4}	5.6×10^{26}	10^{6}	0.56
		H_2	3.6 x (10^{33} -10^{34})	10^{7}	3.6 x (10^{7} -10^{8})	4.66 x (10^{29} -10^{30})	10^{6}	466-4660
		$D^{\uparrow}$	4.3×10^{30}	10^{7}	4.3×10^{4}	5.6×10^{26}	10^{6}	0.56
		$^3He^{\uparrow}$	3.6×10^{32}	10^{7}	3.6×10^{6}	4.66×10^{28}	10^{6}	47
	Storage Cell	$H^{\uparrow}$	0.92×10^{33}	10^{7}	9.2×10^{6}	1.18×10^{29}	10^{6}	118
		H_2	5.8×10^{33}	10^{7}	5.8×10^{7}	7.5×10^{29}	10^{6}	750
		$D^{\uparrow}$	1.1×10^{33}	10^{7}	1.1×10^{7}	1.4×10^{29}	10^{6}	140
		$^3He^{\uparrow}$	3.7×10^{33}	10^{7}	3.7×10^{7}	4.7×10^{29}	10^{6}	474
		Xe	2.34×10^{32}	10^{7}	2.34×10^{6}	3.0×10^{28}	10^{6}	30
Internal solid target with beam halo	Wire Target (0.5 mm)	C	2.8×10^{30}	10^{7}	2.8×10^{4}	5.6×10^{26}	10^{6}	0.56
		Ti	1.4×10^{30}	10^{7}	1.4×10^{4}	2.8×10^{26}	10^{6}	0.28
		W	1.6×10^{30}	10^{7}	1.6×10^{4}	3.1×10^{26}	10^{6}	0.31
Beam splitting	E1039	$NH_3^{\uparrow}$	7.2×10^{31}	10^{7}	7.2×10^{5}	1.4×10^{28}	10^{6}	14
		$ND_3^{\uparrow}$	7.2×10^{31}	10^{7}	7.2×10^{5}	1.4×10^{28}	10^{6}	14
	Unpolarised solid target (5 mm)	C	2.8×10^{31}	10^{7}	2.8×10^{5}	5.6×10^{27}	10^{6}	5.6
		Ti	1.4×10^{31}	10^{7}	1.4×10^{5}	2.8×10^{27}	10^{6}	2.8
		W	1.6×10^{31}	10^{7}	1.6×10^{5}	3.1×10^{27}	10^{6}	3.1
Beam extraction	E1039	$NH_3^{\uparrow}$	7.2×10^{31}	10^{7}	7.2×10^{5}	1.4×10^{28}	10^{6}	14
		$ND_3^{\uparrow}$	7.2×10^{31}	10^{7}	7.2×10^{5}	1.4×10^{28}	10^{6}	14
	COMPASS	$NH_3^{\uparrow}$	1.0×10^{33}	10^{7}	1.0×10^{7}	2.0×10^{29}	10^{6}	200
		butanol $^{\uparrow}$	2.7×10^{32}	10^{7}	2.7×10^{6}	5.3×10^{28}	10^{6}	53

Part II

Some FoM for Heavy-Ion Studies

Kinematical coverage



ALICE could cover $\eta \sim 1-2$ for quarkonium into dileptons with one muon in the muon arm and another in the central barrel

[done for UPCs in the collider mode]

NB: The coverage depends on the target position

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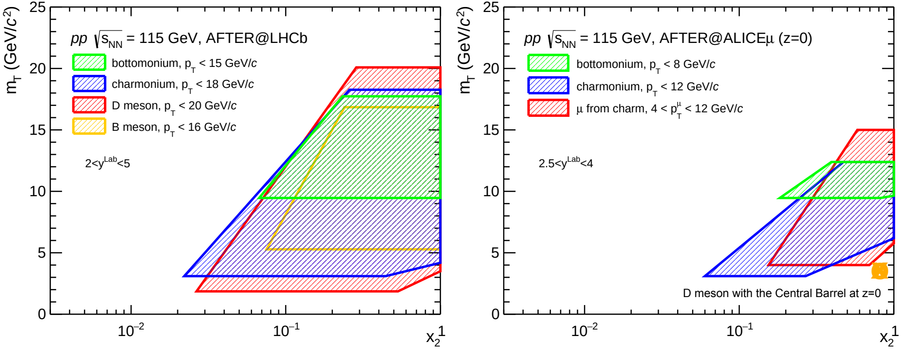

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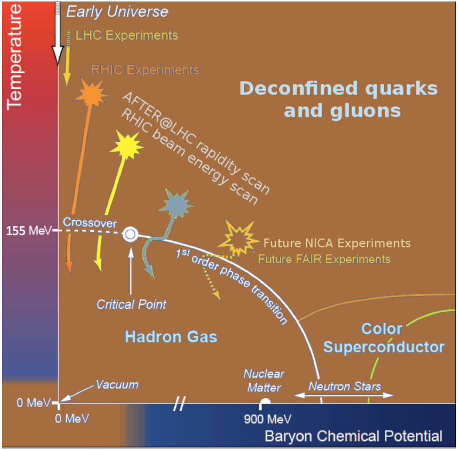
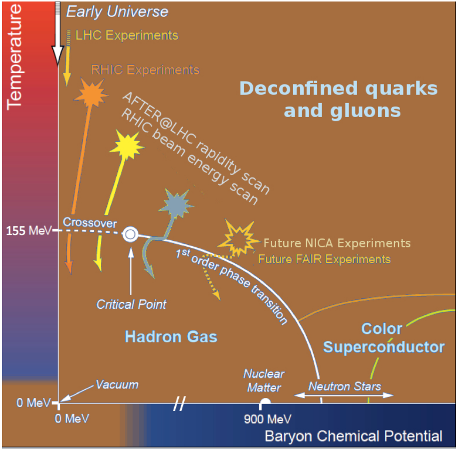
Heavy ions: rapidity scan & quarkonium precision studies



Heavy ions: rapidity scan & quarkonium precision studies

- Energy domain between SPS and RHIC



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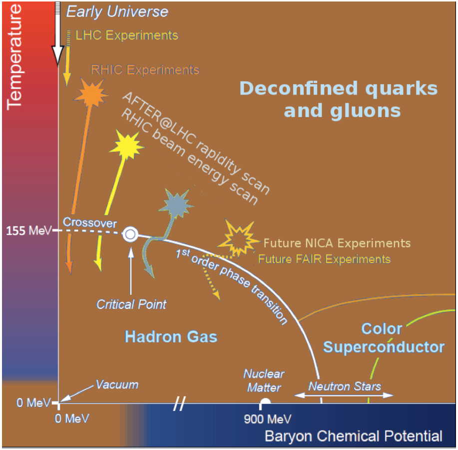

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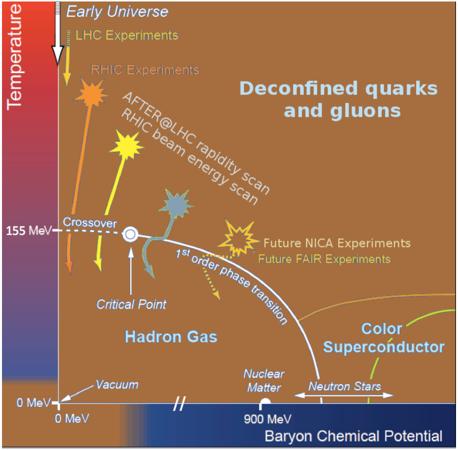

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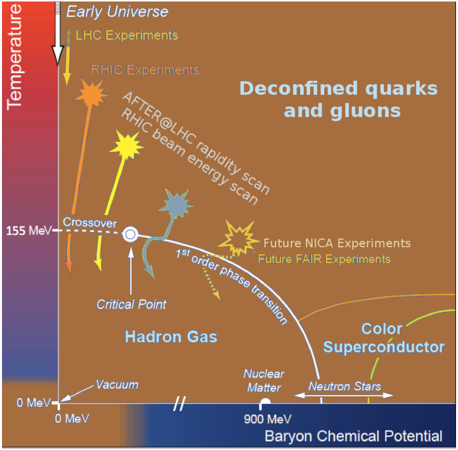

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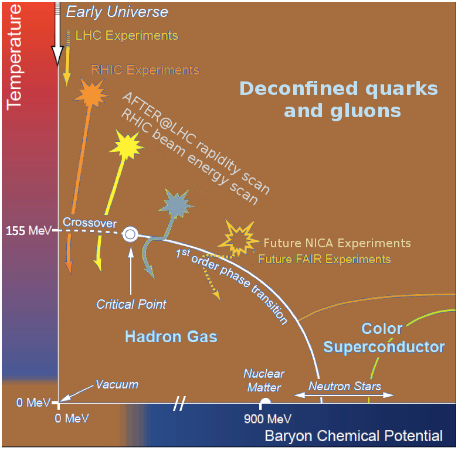
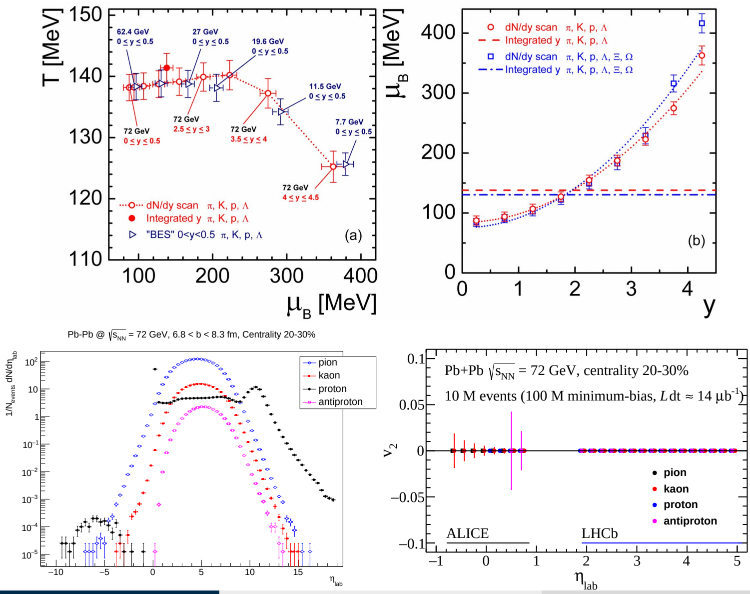


Even with 1 billion J/ψ's, the *direct* J/ψ yield will remain unprecise by 30 % !

Rapidity scan



Quarkonium Projections: heavy-ion collisions

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

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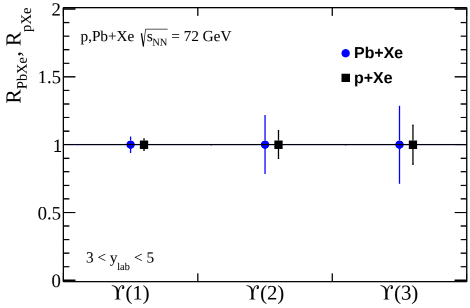
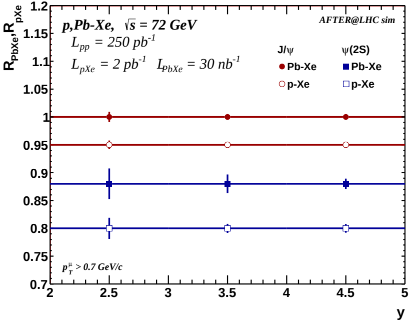
- Statistical-uncertainty projections (accounting for background subtraction)

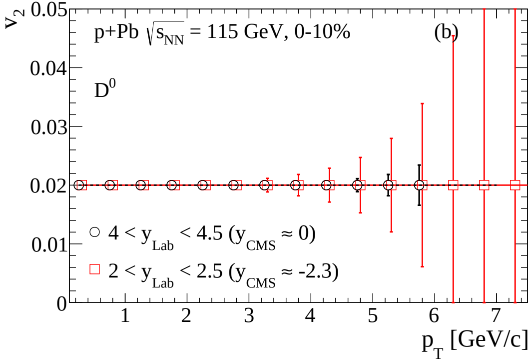




Part III

Some FoM for Cold Nuclear Matter Studies

First look at small systems or new look at Cold Nuclear Matter effects



For *pp* collisions, multiplicity studies will be done soon !

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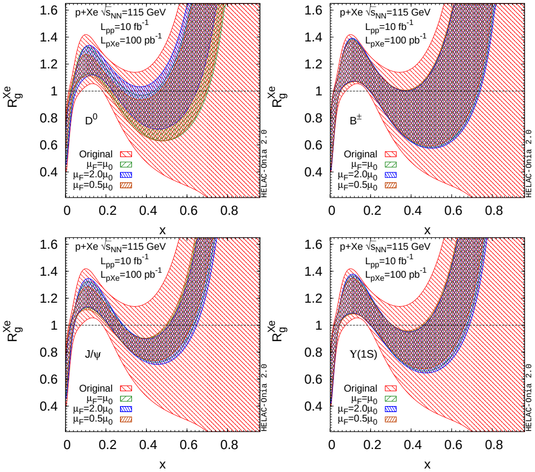

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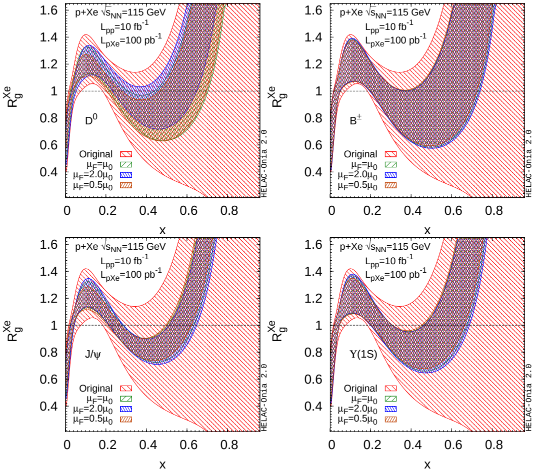

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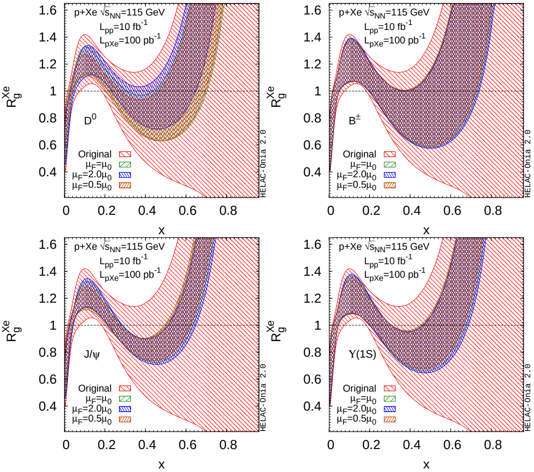
- Contrary to nPDF studies bearing on nuclear modification factors, one needs ways to reduce the systematical theory uncertainties



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

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

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

	pH	PbH
Photon-emitter	proton	Lead
$\sigma^{tot}_{J/\psi}$ (pb)	1.18×10^3	276.77×10^3
$\sigma_{J/\psi\to l^+l^-}$ (pb)	70.10	16.50×10^3
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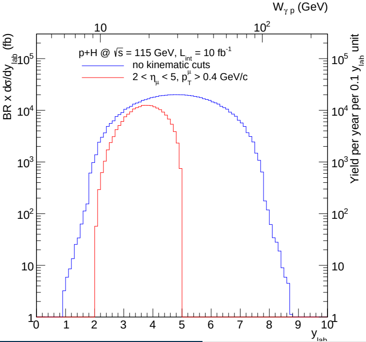

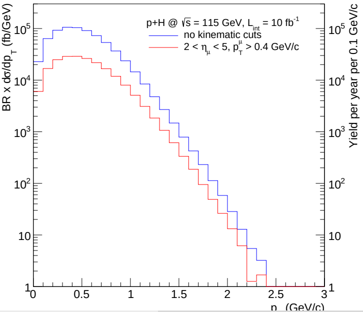

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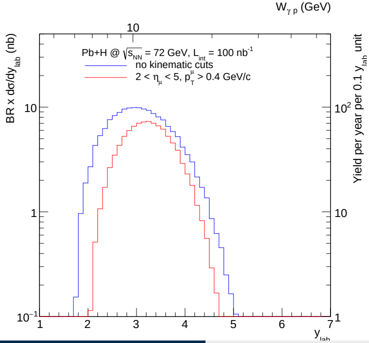

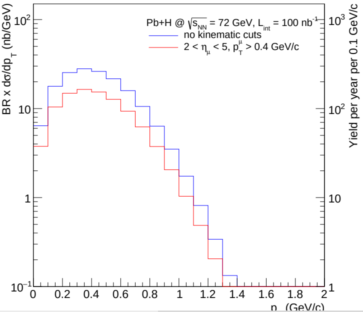

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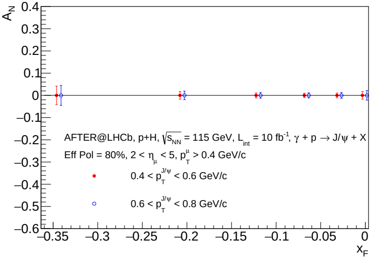

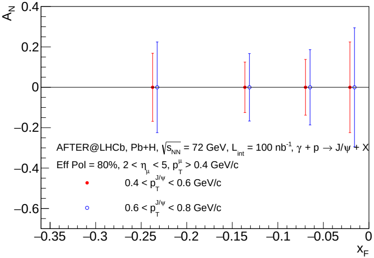

$A_N^{\gamma p^\uparrow \to J/\psi p} \propto \sqrt{t_0 - t} Im(\mathcal{E}_g^* \mathcal{H}_g) \to$ access to the GPD E_g and the gluon OAM

Part IV

Conclusion

Conclusions

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- Our review is now out and will feed in the European Strategy via the Physics Beyond Collider WG

Part V

Backup slides

Further readings

Heavy-Ion Physics

- *Gluon shadowing effects on J/ψ and Υ production in p+Pb collisions at $\sqrt{s_{NN}}$ = 115 GeV and Pb+p collisions at $\sqrt{s_{NN}}$ = 72 GeV at AFTER@LHC* by R. Vogt. Adv.Hi.En.Phys. (2015) 492302.
- *Prospects for open heavy flavor measurements in heavy-ion and p+A collisions in a fixed-target experiment at the LHC* by D. Kikola. Adv.Hi.En.Phys. (2015) 783134
- *Quarkonium suppression from coherent energy loss in fixed-target experiments using LHC beams* by F. Arleo, S.Peigne. [arXiv:1504.07428 [hep-ph]]. Adv.Hi.En.Phys. (2015) 961951
- *Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams* by K. Zhou, Z. Chen, P. Zhuang. Adv.High Energy Phys. 2015 (2015) 439689
- *Lepton-pair production in ultraperipheral collisions at AFTER@LHC*
  By J.P. Lansberg, L. Szymanowski, J. Wagner. JHEP 1509 (2015) 087
- *Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams.* By J.P. Lansberg, S.J. Brodsky, F. Fleuret, C. Hadjidakis. [arXiv:1204.5793 [hep-ph]]. Few Body Syst. 53 (2012) 11.

Further readings

Spin physics

- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment* by K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. [arXiv:1502.04021 [hep-ph]. Adv.Hi.En.Phys. (2015) 257934.
- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment in a TMD factorisation scheme* by M. Anselmino, U. D'Alesio, and S. Melis. [arXiv:1504.03791 [hep-ph]]. Adv.Hi.En.Phys. (2015) 475040.
- *The gluon Sivers distribution: status and future prospects* by D. Boer, C. Lorcé, C. Pisano, and J. Zhou. [arXiv:1504.04332 [hep-ph]]. Adv.Hi.En.Phys. (2015) 371396
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)* By T. Liu, B.Q. Ma. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER* By D. Boer, C. Pisano. Phys.Rev. D86 (2012) 094007.

Further readings

Hadron structure

- *Double-quarkonium production at a fixed-target experiment at the LHC (AFTER@LHC).*
  by J.P. Lansberg, H.S. Shao. [arXiv:1504.06531 [hep-ph]]. Nucl.Phys. B900 (2015) 273-294
- *Next-To-Leading Order Differential Cross-Sections for Jpsi, psi(2S) and Upsilon Production in Proton-Proton Collisions at a Fixed-Target Experiment using the LHC Beams (AFTER@LHC)*
  by Y. Feng, and J.X. Wang. Adv.Hi.En.Phys. (2015) 726393.
- *η_c production in photon-induced interactions at a fixed target experiment at LHC as a probe of the odderon*
  By V.P. Goncalves, W.K. Sauter. arXiv:1503.05112 [hep-ph].Phys.Rev. D91 (2015) 9, 094014.
- *A review of the intrinsic heavy quark content of the nucleon*
  by S. J. Brodsky, A. Kusina, F. Lyonnet, I. Schienbein, H. Spiesberger, and R. Vogt. Adv.Hi.En.Phys. (2015) 231547.
- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. Phys.Rev. D89 (2014) 074020.

Further readings

Feasibility study and technical ideas

- *Feasibility Studies for Single Transverse-Spin Asymmetry Measurements at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC)* by Daniel Kikola et al. [arXiv:1702.01546 [hep-ex]]. Few Body Syst. 58 (2017) 139.
- *Heavy-ion Physics at a Fixed-Target Experiment Using the LHC Proton and Lead Beams (AFTER@LHC): Feasibility Studies for Quarkonium and Drell-Yan Production* by B. Trzeciak et al. [arXiv:1703.03726 [nucl-ex]] Few Body Syst. 58 (2017) 148
- *Feasibility studies for quarkonium production at a fixed-target experiment using the LHC proton and lead beams (AFTER@LHC)* by L. Massacrier, B. Trzeciak, F. Fleuret, C. Hadjidakis, D. Kikola, J.P.Lansberg, and H.S. Shao arXiv:1504.05145 [hep-ex]. Adv.Hi.En.Phys. (2015) 986348
- *A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions* by C. Barschel, P. Lenisa, A. Nass, and E. Steffens. Adv.Hi.En.Phys. (2015) 463141
- *Quarkonium production and proposal of the new experiments on fixed target at LHC* by N.S. Topilskaya, and A.B. Kurepin. Adv.Hi.En.Phys. (2015) 760840

Generalities

- *Physics Opportunities of a Fixed-Target Experiment using the LHC Beams*
By S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg. [arXiv:1202.6585 [hep-ph]]. Phys.Rept. 522 (2013) 239.