Photoproduction prospects at a fixed target experiment at the LHC (AFTER@LHC)

Laure Massacrier,

Institut de Physique Nucléaire d'Orsay

CNRS/IN2P3

Current members for the study group of the AFTER@LHC project
http://after.in2p3.fr/after/index.php/Current_author_list
M. Anselmino (Torino), R. Arnaldi (Torino), S. J. Brodsky (SLAC), V. Chambert (IPN), C. Da Silva (Los Alamos), J.P. Didelez (IPN), M. G. Echevarria (Barcelona), E. G. Ferreiro (USC), F. Fleuret (LLR), Y. Gao (Tsinghua), B. Genolini (IPN), C. Hadjidakis (IPN), I. Hrivnacova (IPN), D. Kikola (Warsaw University), A. Klein (Los Alamos), U. Kramer (Karlsruhe), A. Kurepin (Moscow), A. Kusina (LPSC), J. P. Lansberg (IPN), L. Massacrier (IPN), I. Lehmann (Darmstadt), C. Lorcé (IPN), R. Mikkelsen (Aarhus), A. Nass (Julich), C. Pisano (Pavia), C. Quintans (Lisbon), F. Rathmann (Julich), I. Schienbein (LPSC), M. Schlegel (Tubingen), E. Scomparin (Torino), J. Seixas (Lisbon), H. S. Shao (CERN), A. Signori (Nikhef), E. Steffens (Erlangen), N. Topilskaya (Moscow), B. Trzeciak (CTU), U. I. Uggerhøj (Aarhus), R. Ulrich (Karlsruhe), A. Uras (IPNL), Z. Yang (Tsinghua)

Nucleon and resonance structure with hard exclusive processes, Orsay, France
29-31th May 2017

OUTLINE

- What is AFTER@LHC ?
- Main kinematical features
- General Physics Motivations
- Possible technical implementations at the LHC and projected luminosities
- Prospects for photoproduction studies with AFTER@LHC
- A selection of projected performances

WHAT IS AFTER@LHC ?

AFTER@LHC is a proposal for a multi-purpose fixed target experiment using the multi-TeV proton or heavy ion beams of the LHC, with 3 main physic objectives:

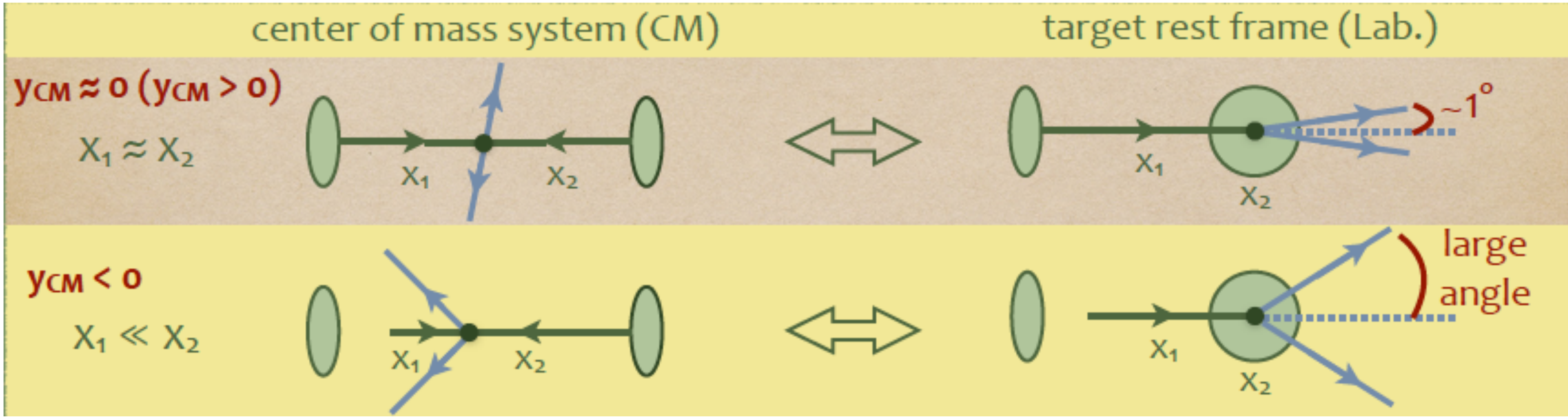
- ❑ Advance our understanding of the **large-x gluon, antiquark and heavy-quark content in the nucleon and nucleus**
- ❑ Advance our understanding of the **dynamics and spin of gluons inside (un)polarised nucleons**
- ❑ Study **heavy-ion collisions** between SPS and RHIC energies towards large rapidities

Several advantages of the fixed-target mode wrt to the collider mode:

- Accessing **the high Feynman x_F** domain ($x_F = p_z/p_{zmax}$)
- Achieving **high luminosities** thanks to dense targets
- Easier **to change the target** type (≠ atomic mass)
- Possibility to **polarize the target**

➡ All this can be realised at CERN in a parasitic mode with the most energetic beam ever (without affecting LHC performances → recycling beam losses / internal gas target)

MAIN KINEMATICAL FEATURES

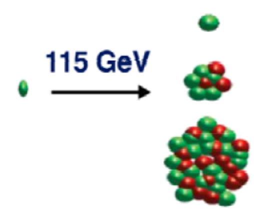


- Entire CM forward hemisphere ($y_{CM} > 0$) within $0° < \theta_{lab} < 1°$
  (high multiplicities → large occupancies)
- Backward physics ($y_{CM} < 0$) : larger angle in the laboratory frame (lower occupancies)
  Access to parton with momentum fraction $x_2 \to 1$ in the target

Energy range

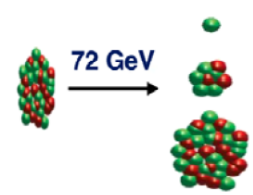
7 TeV proton beam on a fixed target

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



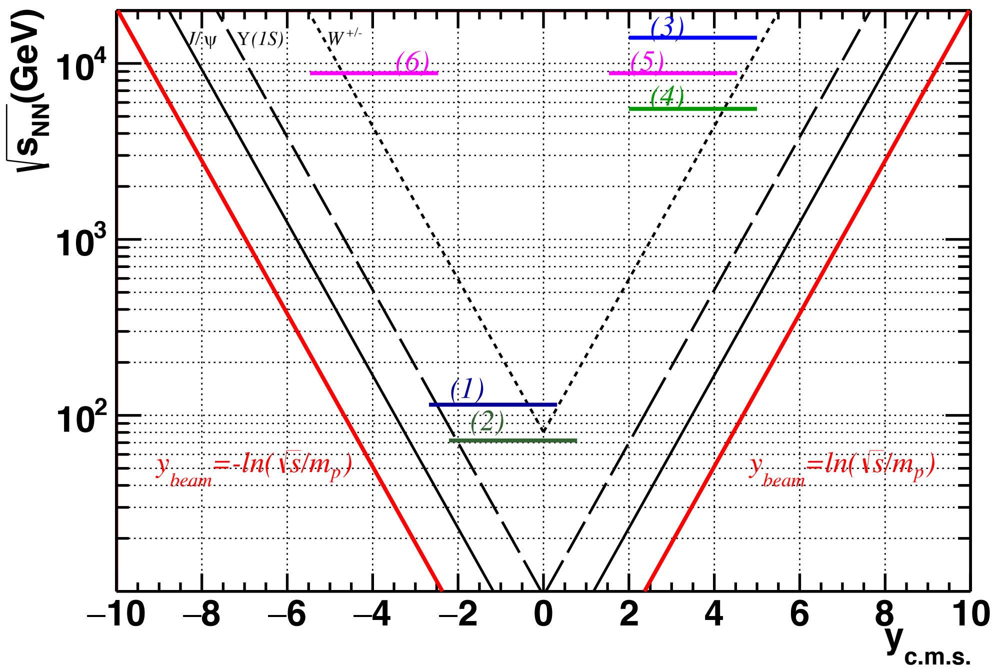
2.76 TeV Pb beam on a fixed target

c.m.s. energy: $\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} \approx 72\,\text{GeV}$	**Rapidity shift:** $y_{c.m.s.} = 0 \to y_{lab} = 4.3$
Boost: $\gamma \approx 40$	



MAIN KINEMATICAL FEATURES

- LHCb and ALICE muon arm become backward detectors in fixed target mode
- Half of the backward region covered for most of the probe → $-1 < x_F < 0$
- ALICE central barrel very backward detector



Example of acceptance for an LHCb-like detector : $2 < \eta_{lab} < 5$

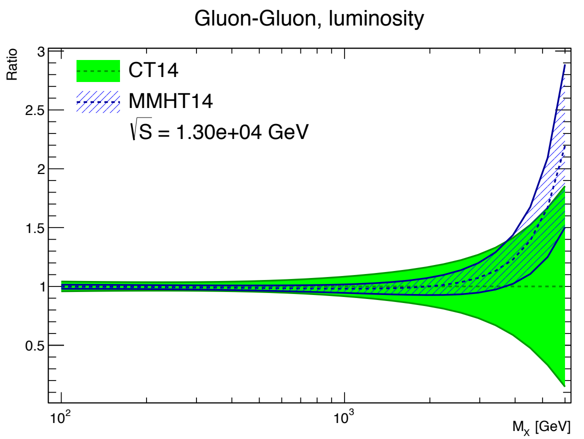
(1) pA collisions in fixed target mode, $\sqrt{s_{NN}}$ = 115 GeV
(2) PbA collisions in fixed target mode, $\sqrt{s_{NN}}$ = 72 GeV

(3) pp collisions in collider mode, $\sqrt{s}$ = 14 TeV
(4) PbPb collisions in collider mode, $\sqrt{s_{NN}}$ = 5.5 TeV
(5) pPb collisions in collider mode, $\sqrt{s_{NN}}$ = 8.8 TeV
(6) Pbp collisions in collider mode, $\sqrt{s_{NN}}$ = 8.8 TeV

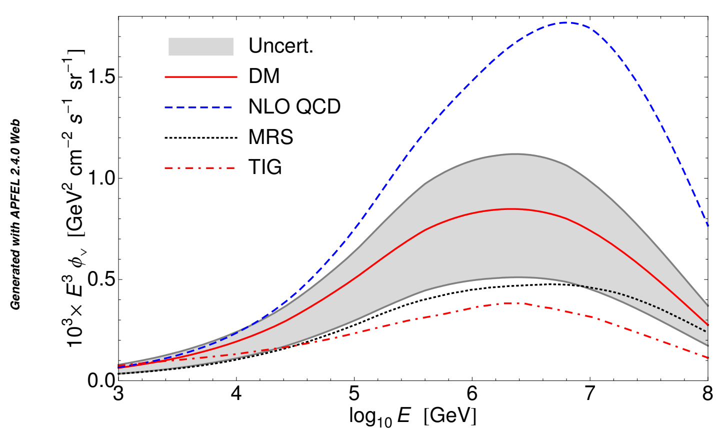
PHYSICS MOTIVATIONS: HIGH-x FRONTIER

❑ Advance our understanding of the high-x gluon, antiquark and heavy-quark content in the nucleon and nucleus

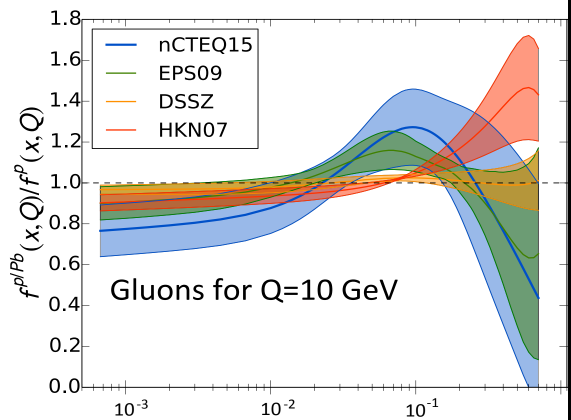
- Very large uncertainties for x ≥ 0.5
  [could be crucial to characterise possible BSM discoveries]
- Proton charm content important for high-energy neutrino and cosmic ray physics
- EMC effect is an open problem; studying a possible gluon EMC effect is essential
- Relevance of nuclear PDF to understand the initial state of heavy-ion collisions
- Search and study rare proton fluctuations
  where one gluon carries most of the proton momentum



Uncertainty on the gluon-gluon luminosity at √s = 13 TeV



Energy spectrum of neutrino flux



Gluon density in Pb nuclei

PHYSICS MOTIVATIONS: 3D MAPPING OF THE PARTON MOMENTUM

- Advance our understanding of the dynamics and spin of quarks and gluons inside polarised and unpolarised nucleons

  - Possible missing contribution to the proton spin: Orbital Angular Momentum (OAM)

→ For longitudinally polarised nucleon, with helicity +1/2: $\ell_{g,q}$

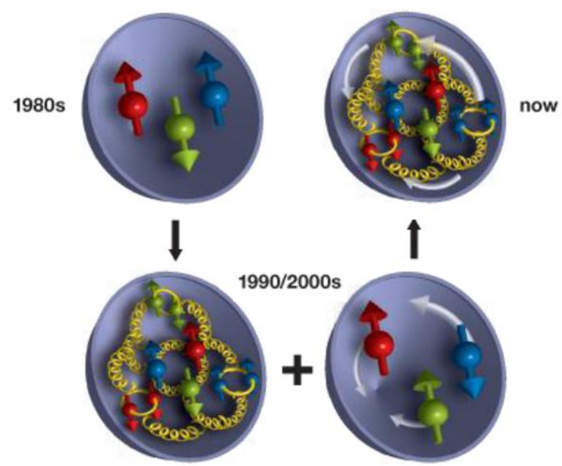
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \ell_g + \ell_q$$

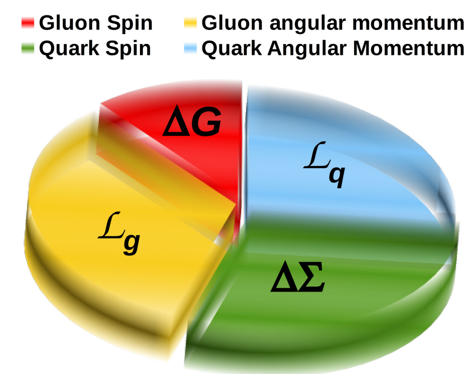
Spin of quarks /antiquarks ($\frac{1}{2}\Delta\Sigma$)

Spin of gluons (ΔG)

Orbital angular momentum of quarks and gluons ($\ell_g + \ell_q$)

- First hint by COMPASS that $\ell_g \neq 0$
- Access information on the orbital motion of the partons inside bound hadrons via Single Spin Asymmetries (Sivers effect)
- Test TMD factorization formalism → sign change of A_N between SIDIS and DY
- Determination of linearly polarised gluons in unpolarised protons (Boer Mulders effect)

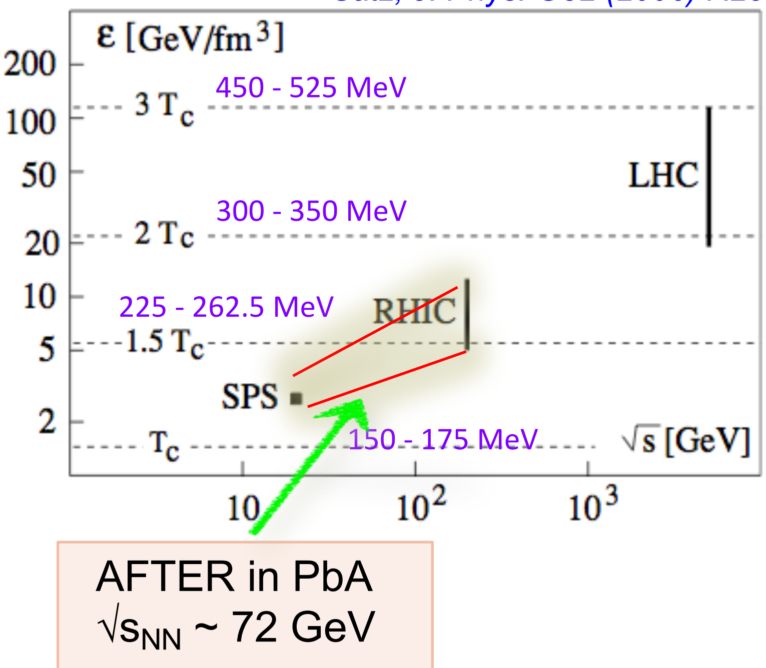




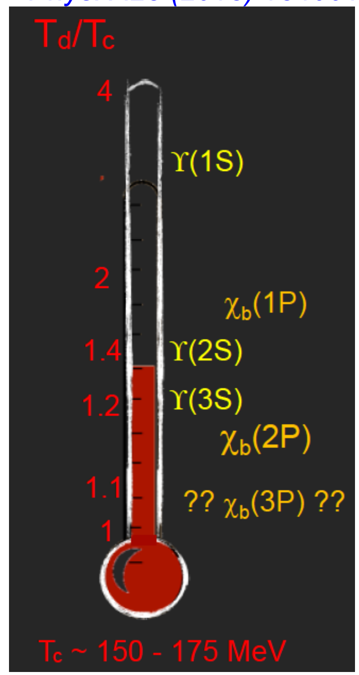
PHYSICS MOTIVATIONS: HEAVY ION COLLISIONS TOWARD LARGE RAPIDITIES

❑ QGP studies between SPS and RHIC energies (with eg. quarkonia)

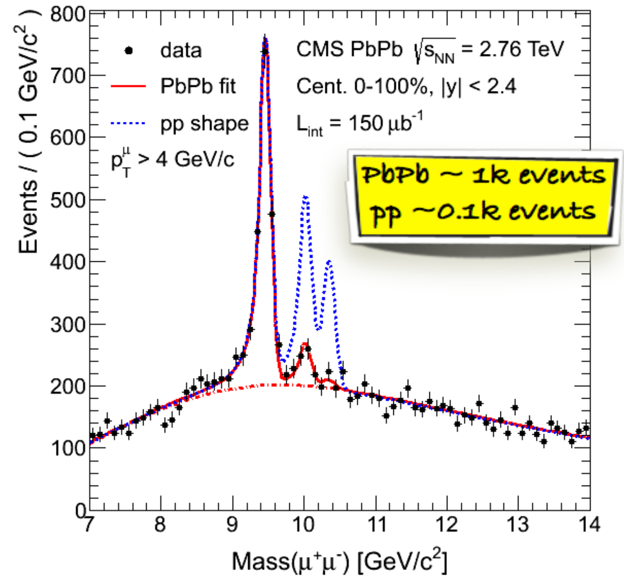
Satz, J. Phys. G32 (2006) R25



Mocsy et al, Int. J. Mod. Phys. A28 (2013) 1340012



Dissociation temperature from lattice QCD (+hydro)



Phys. Rev. Lett. 109 (2012) 222301

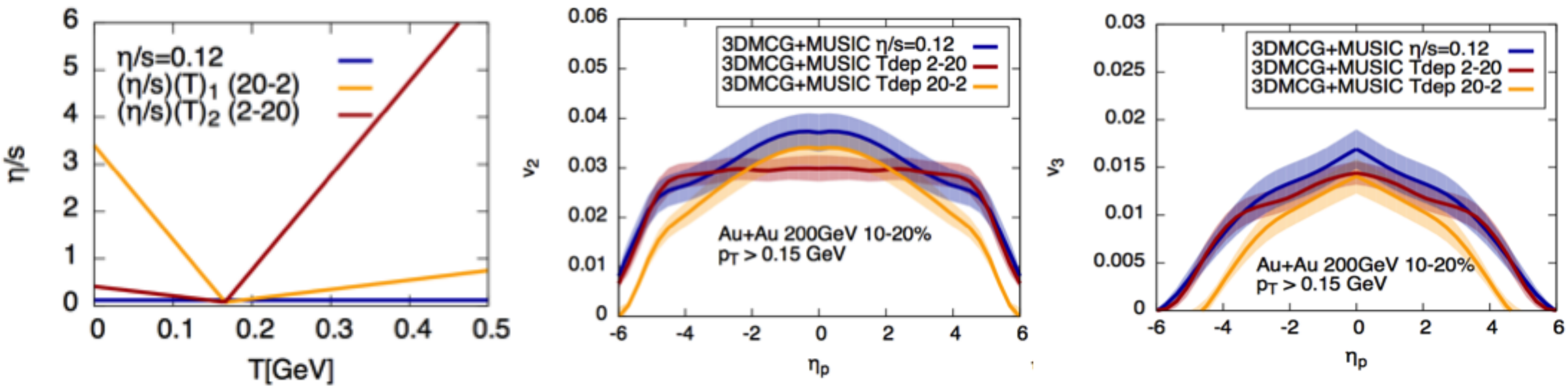
- A complete set of heavy-flavour studies between SPS and RHIC energies
  → Calibration of the quarkonium thermometer

- At AFTER@LHC energy, Υ(3S) and Υ(2S) are expected to melt
- Enough statistics to perform the same study as CMS at low energy

PHYSICS MOTIVATIONS: HEAVY ION COLLISIONS TOWARD LARGE RAPIDITIES

- ❑ Test the formation of azimuthal asymmetries: hydrodynamics vs initial-state radiation
- ❑ Explore the longitudinal expansion of QGP formation

→ Particle yields and v_N measured at large rapidities powerful tool to measure the medium shear viscosity and temperature



- ❑ Test the factorization of Cold Nuclear Matter effects

- Use probe insensitive to Quark Gluon Plasma formation: Drell Yan
- Measure Drell Yan in pA and pB to predict A+B and compare with measurement
- Cannot be done at an EIC

POSSIBLE TECHNICAL IMPLEMENTATIONS AT THE LHC

- Two main possibilities: **- Internal Target + already existing detector**
  - New beam line + new detector

- Various possible implementations:

  - Internal **Gas** target:
    - Can be installed in already existing LHC cavern coupled to existing experiment
    - Currently validated by the LHCb collaboration with the SMOG system
    - Caveat: AFTER is not necessarily SMOG! (higher pressure, polarisation…)
      → Several possibilities: gas jet, storage cell gas target
    - Benefit from the full p and Pb fluxes: 3.4×10^{18} p/s, 3.6×10^{14} Pb/s

  - Internal **Wire/Foil** target (in the beam halo):
    - Used by Hera-B on the 920 GeV p beam and by STAR at RHIC

  - **Beam line** extracted via **bent crystal**:
    - Most ambitious solution (civil engineering, new beam line, new experiment)
    - LHC beam halo is recycled:
      - Proton flux: 5×10^{8} p/s, Lead flux: 2×10^{5} Pb/s

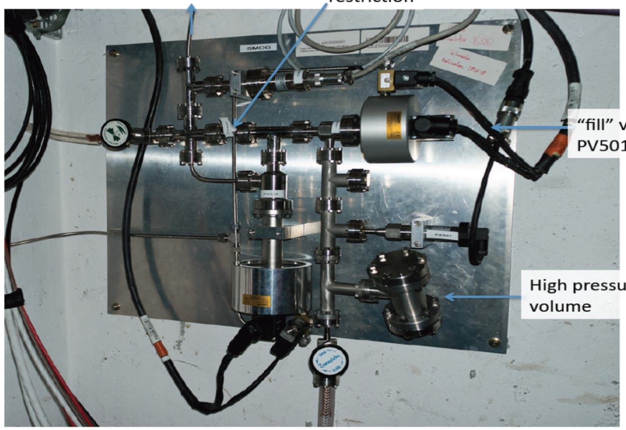
  - **Beam splitted** via **bent crystal** (in fact another « internal target » solution):
    - Intermediate option which reduces civil engineering (re-use existing detector)
    - Particles deflected onto a solid target
    - Need to absorb the secondary beam

→ Similar luminosities can be reached with an internal gas target or a crystal based solution

INTERNAL GAS TARGET (SMOG LHCb)

- Currently validated by the LHCb Collaboration with the SMOG system
- Low density noble gas injected (He, Ne, Ar so far) into LHCb Vertex Locator
- Benefit from the full LHCb beam without decrease of the beam lifetime:
  - Due to limited gas pressure (1.5 x 10^{-7} mbar)
- Limited running time, no polarization of the target, only noble gases

SMOG: System for Measuring Overlap with Gas



Beam	Target Gas	Pressure [mbar]	Gas Length ℓ [cm]	θ_{target} [cm^{-2}]	$\mathcal{L}$ * [cm^{-2}s^{-1}]	$\sigma_{MB}^{Beam-Target}$ (barn)	beam fraction used over a fill
p	{He, Ne, Ar, Kr, Xe}	$1.5 \cdot 10^{-7}$	40	$1.6 \cdot 10^{11}$	$5.8 \cdot 10^{29}$	{0.15, 0.4,0.6,1.0,1.3}	<< ‰
Pb	{He, Ne, Ar, Kr, Xe}	$1.5 \cdot 10^{-7}$	40	$1.6 \cdot 10^{11}$	$7.4 \cdot 10^{25}$	{2.5, 3.7, 4.5, 5.5, 6.2}	<< ‰

* Assuming all the bunches are non colliding (maxima) [nb = 2808 (p), 592 (Pb)]
Current SMOG ~ 10% of the total number of bunches are non colliding
Gas length can be up to 80cm

Typical integrated luminosity:
- p-Ar collisions at $\sqrt{s_{NN}}$ = 115 GeV, ~ 17h of data taking, -20 cm < Z < 20 cm
- L_{int} ~ 3.75 nb^{-1}

INTERNAL GAS TARGET (GAS JET OPTION)

- Polarised H-jet polarimeter (used at RHIC)
  - Used to measure the proton beam polarisation at RHIC
  - 9 vacuum chambers → 9 stages of differential pumping
  - Gas target: polarised free atomic beam source (ABS) cooled down to 80K crossing the RHIC beam

- Target Areal density
  - Polarised inlet Hydrogen flux: 1.3×10^{17} H/s
  - Higher flux can be obtained for ^{3}He
  - $\theta_{target} = 1.2 \times 10^{12}$ atoms/cm^2
    → ~ 7.5 x SMOG

- Instantaneous luminosity
  - $\mathscr{L}_{pH} = 4.5 \times 10^{30}$ cm^{-2} s^{-1} (full LHC flux)

- Integrated luminosity over one LHC year
  - $\mathscr{L}_{int}$ (pH) = 45 pb^{-1}

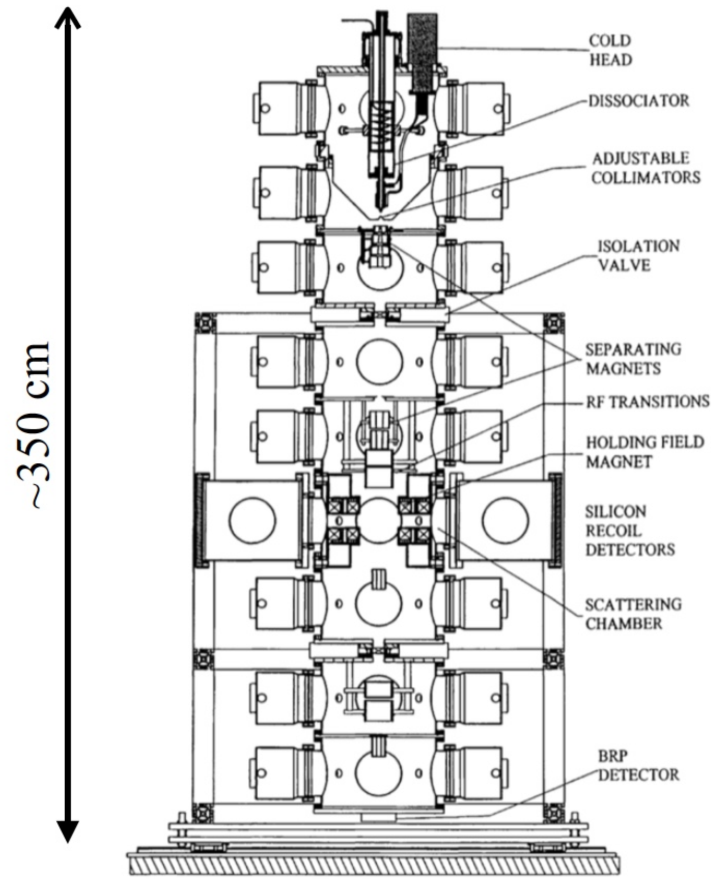
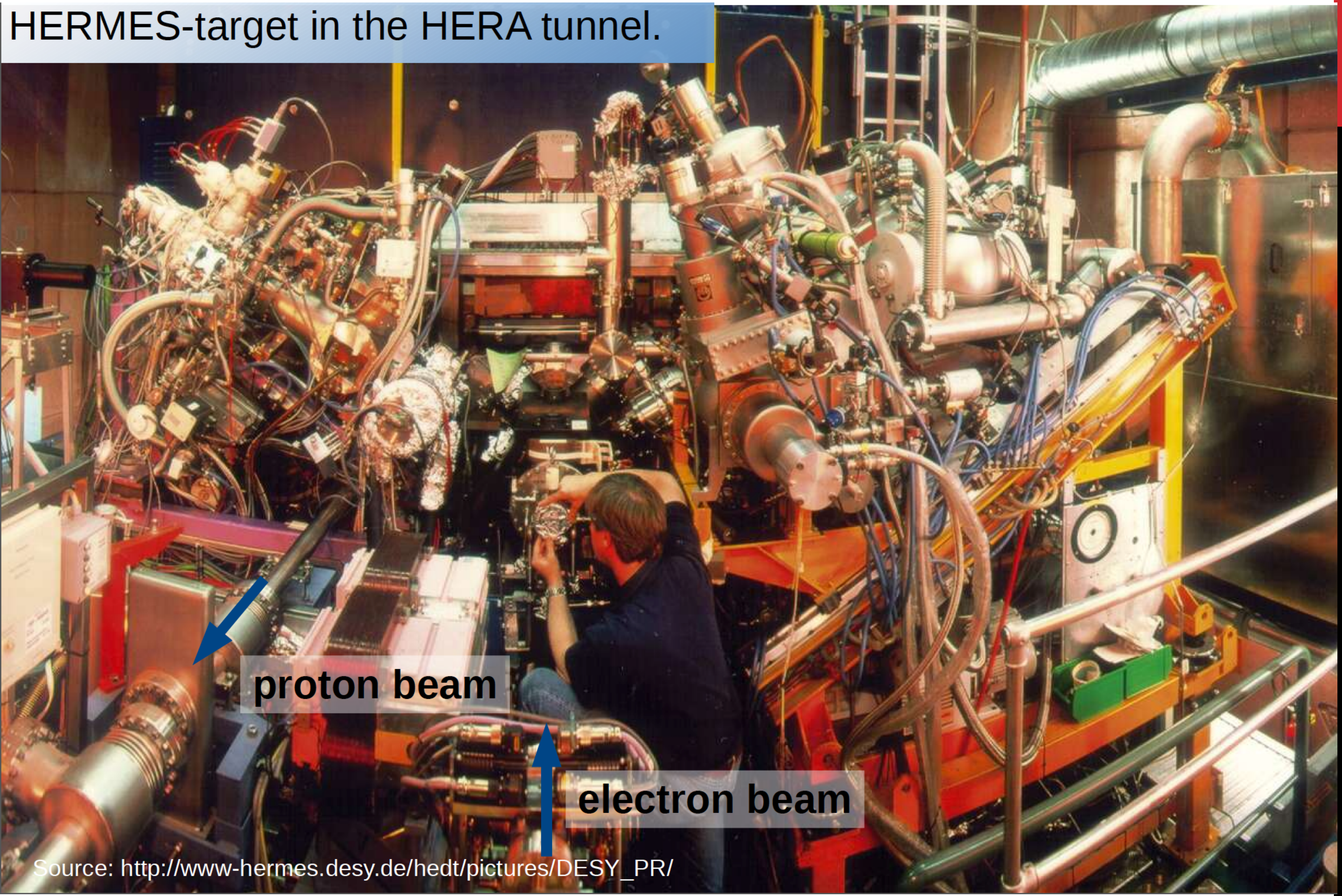


Fig. 1. H-jet polarimeter general layout.

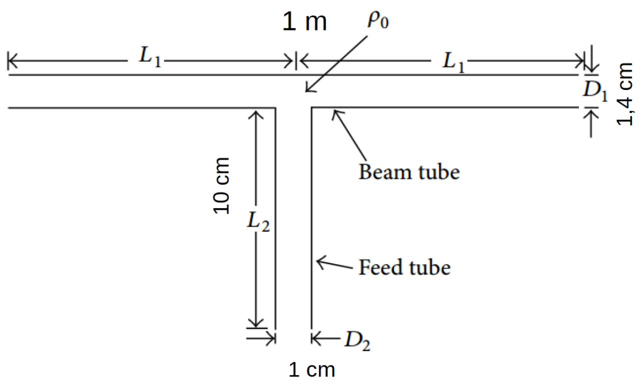
Zelenski et al. NIM A 536 (2005) 248

INTERNAL GAS TARGET (HERMES TARGET LIKE OPTION)



INTERNAL GAS TARGET (HERMES TARGET LIKE OPTION)

- Openable storage cell:
  - Beam tube: 1000 mm length
  - 14 mm radius (50 mm open position)
- Benefit from higher pressure in the target cell
- Dedicated pumping system [turbo molecular pumps]
- Polarised H, D, ^{3}He can be injected (P ~80%)
- Unpolarised heavy gas can also be injected



Adv. High Energy Phys. 2015 (2015) 463141

E. Steffens, PoS (PSTP2015) 019

Beam	Target Gas	inlet flux [s^{-1}]	θ_{target} [cm^{-2}]	$\mathcal{L}$ [$cm^{-2}s^{-1}$]	$\sigma_{MB}^{Beam-Target}$	beam fraction used over a fill
p	$H^{\uparrow}$	$6.5 \cdot 10^{16}$	$2.5 \cdot 10^{14}$	$0.92 \cdot 10^{33}$	39 mb	0.4%
p	$D^{\uparrow}$	$5.2 \cdot 10^{16}$	$2.9 \cdot 10^{14}$	$1.1 \cdot 10^{33}$	71 mb	0.9 %
p	$^3He^{\uparrow}$	$1.0 \cdot 10^{16}$	$6.8 \cdot 10^{13}$	$0.25 \cdot 10^{33}$	96 mb	0.3 %
p	H_2	$2.8 \cdot 10^{17}$	$1.6 \cdot 10^{15}$	$5.8 \cdot 10^{33}$	39 mb	2.5%
p	{Ne, Ar, Kr, Xe}	$1.3 \cdot 10^{15}$	$6.44 \cdot 10^{13}$	$2.34 \cdot 10^{32}$	{0.4,0.6,1.0,1.3} b	{1.0,1.6,2.6,3.4} %
Pb	$H^{\uparrow}$	$6.5 \cdot 10^{16}$	$2.54 \cdot 10^{14}$	$1.18 \cdot 10^{29}$	1.8 b	9.3%
Pb	Xe	$1.3 \cdot 10^{15}$	$6.44 \cdot 10^{13}$	$3 \cdot 10^{28}$	6.2 b	8.1%

→ x 200 free gas-jet!

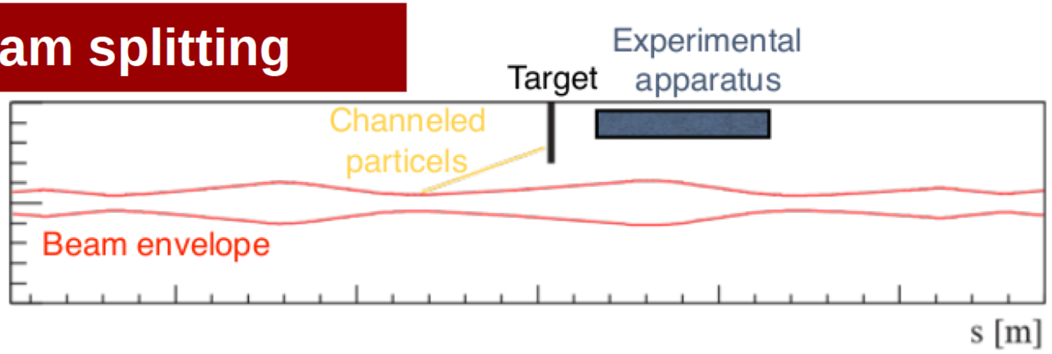
→ Gas pressure limited by beam lifetime

Typical integrated luminosity over a year:

- p-H collisions at $\sqrt{s_{NN}}$ = 115 GeV → L_{int} ~ 10 fb^{-1}
- Pb-H collisions at $\sqrt{s_{NN}}$ = 72 GeV → L_{int} ~ 100 nb^{-1}

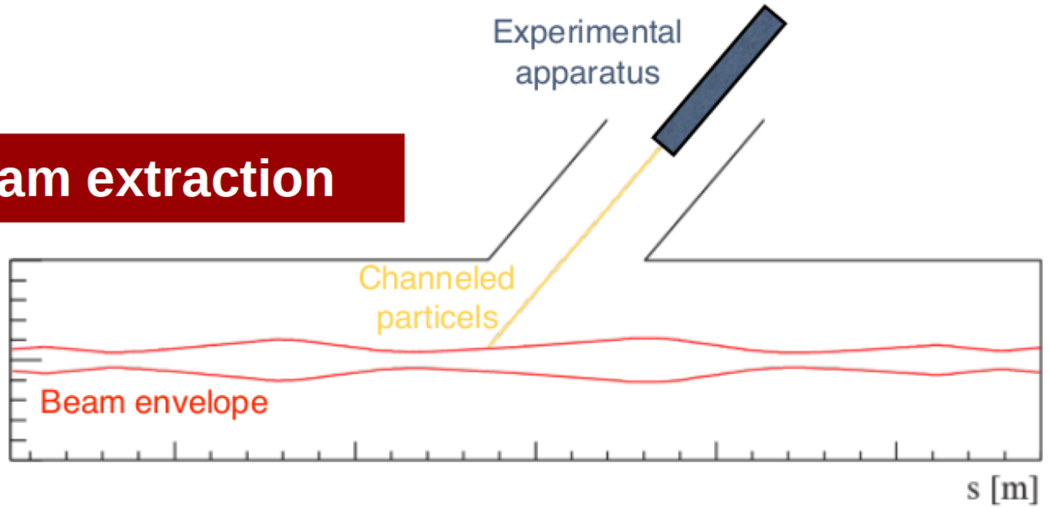
BEAM EXTRACTION OR BEAM SPLITTING USING BENT CRYSTALS

Beam splitting



S. Redaelli, Physics Beyond Colliders, CERN, 06/09/2016

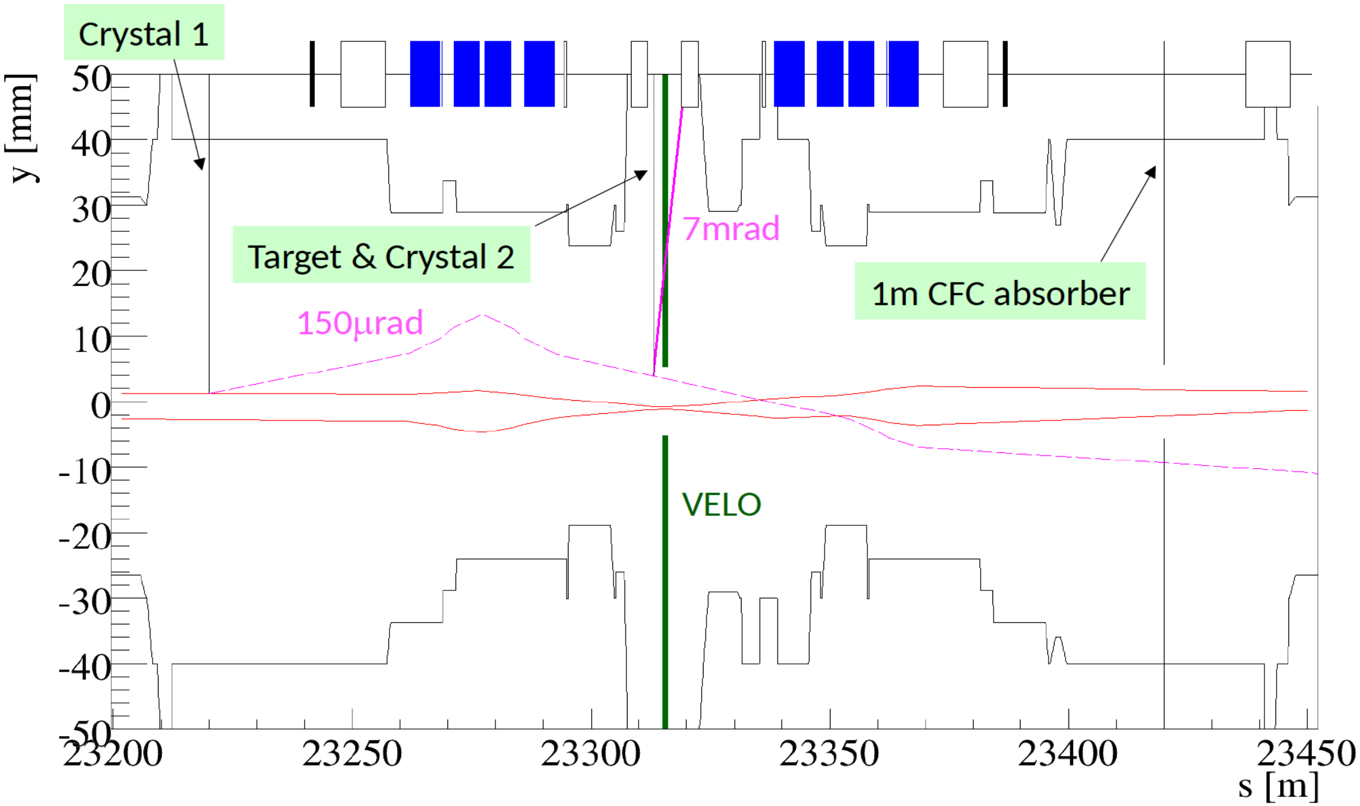
Beam extraction



- ❑ Bent crystals studied for collimation purposes: deflect the beam halo to reduce beam losses
- ❑ Beam extraction solution: civil engineering required, new facility with 7 TeV proton beam
- ❑ Beam splitting: intermediate option
  - Less civil engineering
  - Similar fluxes as for beam extraction
  - Compatible with an existing experiment

BEAM SPLITTING USING BENT CRYSTALS

- First setup proposed by W. Scandale et al. to measure the magnetic moment of Λ_c and other charm charged baryons at LHC energies
- First crystal, located at 5σ from the beam line, upstream of LHCb → deflection of 150 μrad
- Target in the pipe to intercept the deflected beam
- Second crystal channels part of the baryons in the LHCb detector to measure spin orientation
- Additional absorber intercepts the halo particles non interacting with the target
- Parasitic operation allowed according to loss map simulations



First setup compatible with the LHCb detector

BEAM EXTRACTION OR BEAM SPLITTING USING BENT CRYSTALS

- Bent crystals can be used to deflect the beam on either an unpolarised or polarised solid target (E1039 or COMPASS like targets)

- Considerations for 5mm-thick targets compatible both with beam splitting or beam extraction options

LHC beam	Target species	Density ρ [g cm^{-3}]	M [g mol^{-1}]	Thickness [mm]	θ_{Target} [cm^{-2}]	beam flux [s^{-1}]	$\mathcal{L}$ [cm^{-2}s^{-1}]
p	Solid H	0.088	1	5	$2.6 \cdot 10^{22}$	5×10^8	$1.3 \cdot 10^{31}$
p	C	2.25	12	5	$5.6 \cdot 10^{22}$	5×10^8	$2.8 \cdot 10^{31}$
p	Ti	4.43	48	5	$2.8 \cdot 10^{22}$	5×10^8	$1.4 \cdot 10^{31}$
p	W	19.25	184	5	$3.1 \cdot 10^{22}$	5×10^8	$1.6 \cdot 10^{31}$
Pb	Solid H	0.088	1	5	$2.6 \cdot 10^{22}$	10^5	$2.6 \cdot 10^{27}$
Pb	C	2.25	12	5	$5.6 \cdot 10^{22}$	10^5	$5.6 \cdot 10^{27}$
Pb	Ti	4.43	48	5	$2.8 \cdot 10^{22}$	10^5	$2.8 \cdot 10^{27}$
Pb	W	19.25	184	5	$3.1 \cdot 10^{22}$	10^5	$3.1 \cdot 10^{27}$

Typical integrated luminosity over a year:

- p-H collisions at $\sqrt{s_{NN}}$ = 115 GeV → L_{int} ~ 0.1 fb^{-1}. (÷100 internal gas target)
- Pb-H collisions at $\sqrt{s_{NN}}$ = 72 GeV → L_{int} ~ 3 nb^{-1} (÷30 internal gas target)

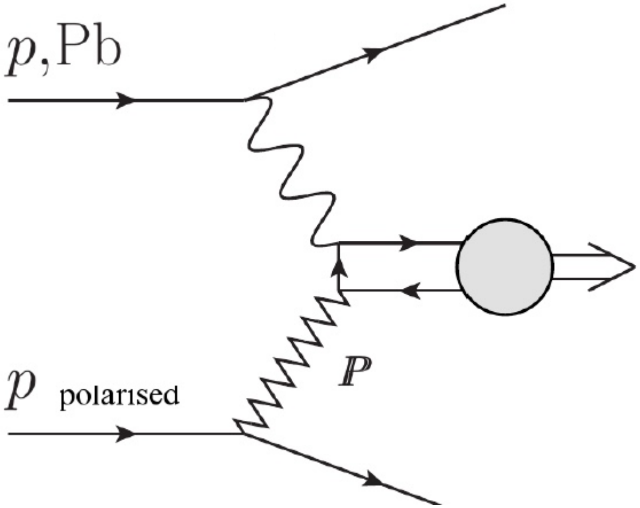
- Similar luminosities as the internal gas target case at reach by increasing the target lenght

- Note that the beam splitting option combined with an internal target is similar as putting a wire in the beam halo (but with a better control on the flux sent to the wire, ie better for luminosity determination). Beam splitting option can be use parasitically to collider events while it is not clear for wire/foil put in the halo

PROSPECTS FOR PHOTOPRODUCTION STUDIES WITH AFTER@LHC

J.P. Lansberg, L. Massacrier, L. Szymanowski, J. Wagner

- $\gamma_{lab}^{p\ beam} \sim 7450\ (E_p = 7000\ GeV)$
- $\gamma_{lab}^{Pb\ beam} \sim 2940\ (E_p = 2760\ GeV)$
- $E_\gamma^{max} \sim \gamma_{lab}^{beam}$ x 30 MeV
- $W_{\gamma p} \sim [5, 100]$ for y_{lab} ~ [0,9]
- Single Transverse Spin Asymmetry measurement $A_N^{\gamma p^\uparrow \to J/\Psi p}$ → access to the GPD E_g and the gluon Orbital Angular Momentum
- Access to pentaquark at very backward rapidity?



Simulations with STARLIGHT generator

Phys. Rev. C60 (1999) 014903, arXiv:hep-ph/9902259 [hep-ph]

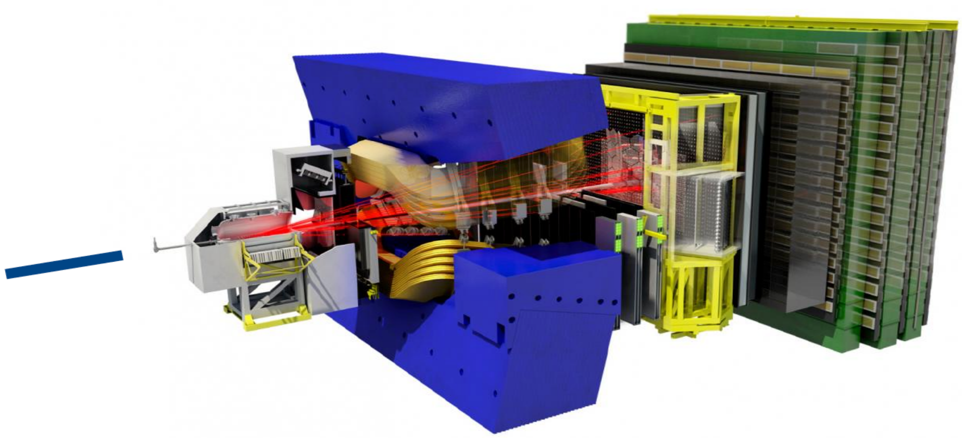
1. Proton-Hydrogen collisions in fixed target mode ($\sqrt{s_{NN}}$ = 115 GeV) for AFTER@LHC;
2. Lead-Hydrogen collisions in fixed target mode ($\sqrt{s_{NN}}$ = 72 GeV) for AFTER@LHC;

	Case 1	Case 2
Photon-emitter	proton	Lead
$\sigma_{J/\psi}^{tot}$ (pb)	1.18×10^3	276.77×10^3
$\sigma_{J/\psi\to l^+l^-}$ (pb)	70.10	16.50×10^3

Sum of 2 contributions, both protons are photon emitters

A SELECTION OF PROJECTED PERFOMANCES

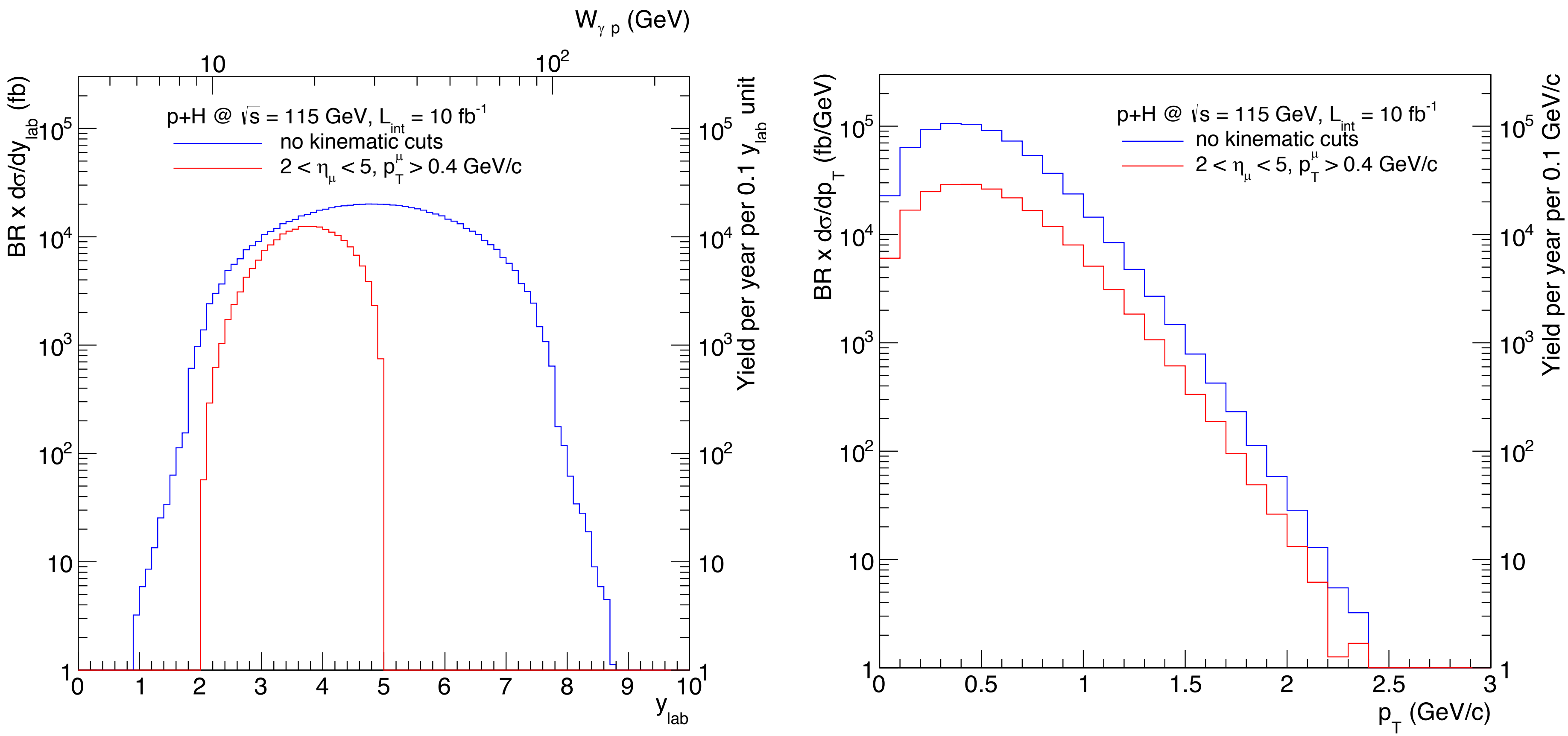
- With a HERMES-type polarized target (Pol ~ 60%) coupled to a LHCb like detector
- LHCb acceptance: $2 < \eta_{\mu} < 5$
- $p_T^{\mu} > 0.4$ GeV/c
- Integrated luminosity over a year:
  - p-H collisions at $\sqrt{s_{NN}} = 115$ GeV → $L_{int} = 10$ fb^{-1}
  - Pb-H collisions at $\sqrt{s_{NN}} = 72$ GeV → $L_{int} = 100$ nb^{-1}



HERMES-type polarized target + LHCb – like acceptance and performance

A SELECTION OF PROJECTED PERFOMANCES

- J/ψ photoproduction in p-H↑ collisions at $\sqrt{s_{NN}}$ = 115 GeV (dimuon channel)



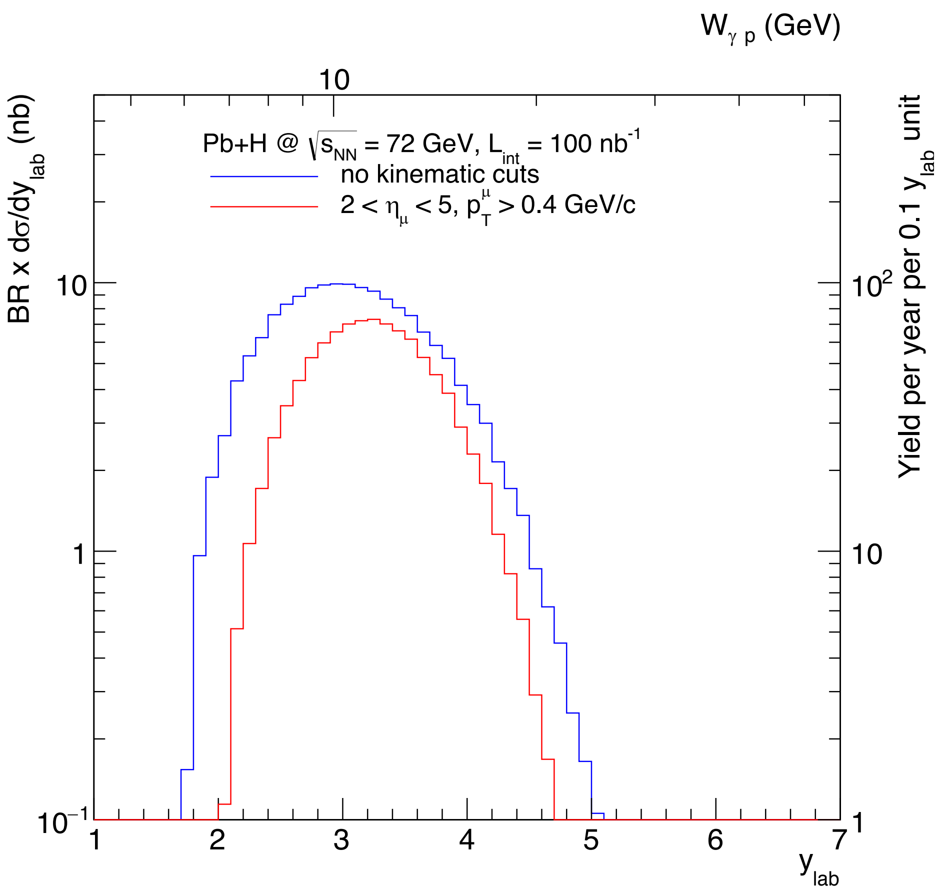
$$\sigma_{J/\psi\to\mu^+\mu^-}\left(2 < \eta^\mu < 5, p_T^\mu > 0.4 \text{ GeV/c}\right) = 20.64 \text{ pb}$$

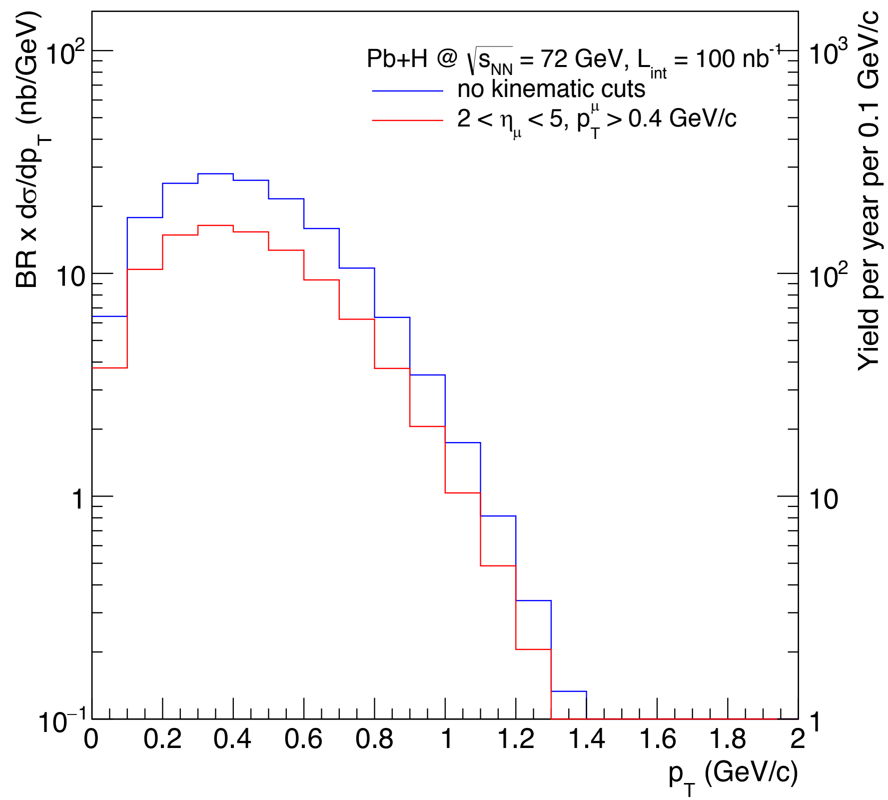
→ 200000 photoproduced J/ψ emitted in the LHCb acceptance (each p can emit the photon)

→ ~ x20 number of photoproduced J/ψ to be recorded at RHIC for 2017 Run in pp collisions at √s = 500 GeV (L_{int} ~ 400 pb^{-1}) arXiv:1602.03922 [nucl-ex]

PHOTOPRODUCTION PROSPECTS

- J/ψ photoproduction in Pb-H↑ collisions at $\sqrt{s_{NN}}$ = 72 GeV (dimuon channel)





$\sigma_{J/\psi\rightarrow\mu^+\mu^-}\left(2 < \eta^{\mu} < 5, p_T^{\mu} > 0.4\ \text{GeV/c}\right) = 9.81 \times 10^3$ pb

→ 1000 photoproduced J/ψ emitted in the LHCb acceptance (Pb photon emitter)

→ ~ ÷13 number of photoproduced J/ψ to be recorded at RHIC for 2023 Run in Aup collisions at $\sqrt{s_{NN}}$ = 200 GeV (L_{int} ~ 1.75 pb^{-1}) arXiv:1602.03922 [nucl-ex]

FIRST LOOK AT PROJECTED PERFOMANCES FOR ALICE

- With a Bent crystal coupled to an internal wire located at 135mm upstream of the ALICE interaction point (A side)

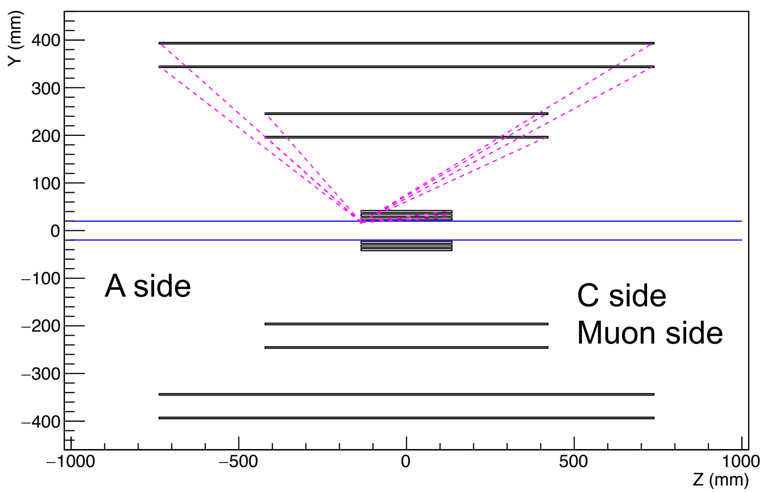
- ALICE TPC acceptance with a fixed target located at 135mm (A side):
  - $0.79 < \eta_e < 0.86$*

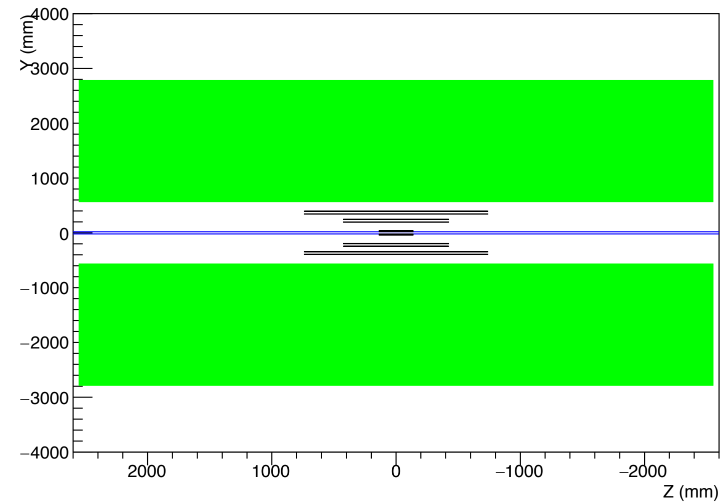
  * basic geometrical consideration
  forward direction define with positive pseudo-rapidity (opposite ALICE convention)

- $p_T^e > 0.4$ GeV/c

- Upgraded ITS and TPC (maximum rate of 1MHz for pp collisions assumed)

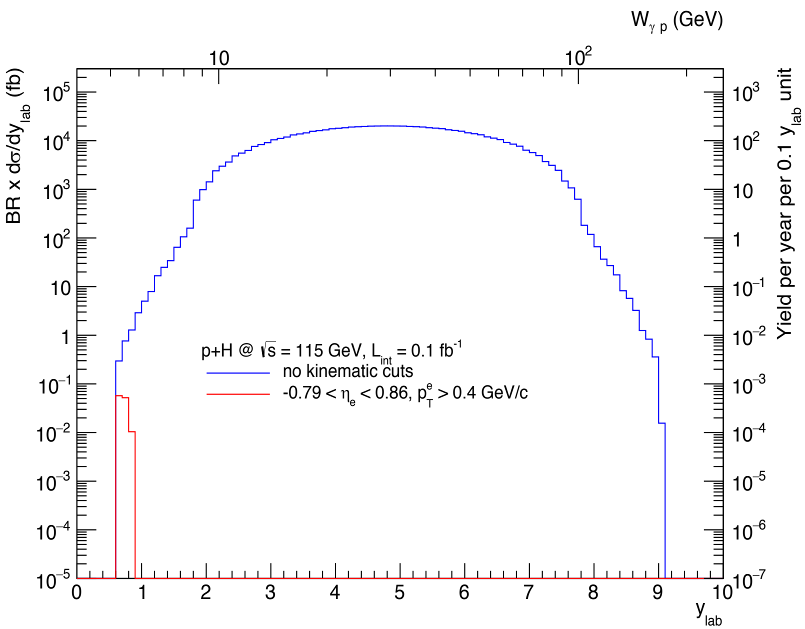
- Integrated luminosity over a year:
  p-H collisions at $\sqrt{s_{NN}} = 115$ GeV
  → $L_{int} = 0.1\ fb^{-1}$ (limited by target lenght)





FIRST LOOK AT PROJECTED PERFOMANCES FOR ALICE

❑ J/ψ photoproduction in p-H collisions at $\sqrt{s_{NN}}$ = 115 GeV (dielectron channel)



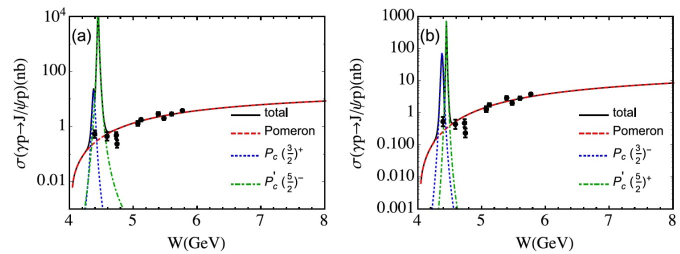


FIG. 3 (color online). The total cross section of $\gamma p \rightarrow J/\psi p$ in terms of the c.m. energy. The red dashed, blue dotted, green dot-dashed and black solid curves are the contributions from Pomeron, P_c with spin 3/2, P_c with spin 5/2 and the coherent sum of all. (a) shows $(3/2^+, 5/2^-)$ combination. (b) shows $(3/2^-, 5/2^+)$ combination. The coupling constants [Eq. (21)] between $J/\psi p$ and the two P_c states are extracted by assuming $J/\psi p$ saturates all their total widths. The experimental data are from Refs. [24–26].

Photoproduction of hidden charm pentaquark states P_c^+ (4380) and P_c^+ (4450), PHYSICAL REVIEW D 92, 034022 (2015)
S/B ratios ~ 10^3 – 10^4 depending on the state and coupling

→ ~ 0.001 photoproduced J/ψ emitted per year in the ALICE TPC acceptance
→ Could expect to produce ~ 1-10 pentaquark per year in the ALICE very backward acceptance

CONCLUSIONS

- Three main physics motivations for a fixed target program at the LHC:

  → Without interfering with other experiments

  - The high x frontier: new probes of the confinement and connections with astroparticles
  - The nucleon spin and the transverse dynamics of the partons
  - The approach to the deconfinement phase transition:

  → New energy, new rapidity domain and new probes

- Two ways towards fixed target collisions with the LHC beams:

  - An internal gas target inspired from SMOG@LHCb/HERMES/H-jet@RHIC,…
  - A slow extraction with a bent crystal

- AFTER@LHC can access GPD Eg and gluon OAM via the A_N measurement of photoproduced J/ψ using a polarised H target

  → J/ψ photoproduction in p-H↑ collisions at $\sqrt{s_{NN}}$ = 115 GeV (dimuon channel)
    - 200000 photoproduced J/ψ expected in the LHCb acceptance

  → J/ψ photoproduction in Pb-H↑ collisions at $\sqrt{s_{NN}}$ = 72 GeV (dimuon channel)
    - 1000 photoproduced J/ψ expected in the LHCb acceptance

  → Working on the projected statistical uncertainties on A_N measurement

- An expression of interest to be submitted to the LHCC is beeing written
- AFTER Webpage: http://after.in2p3.fr

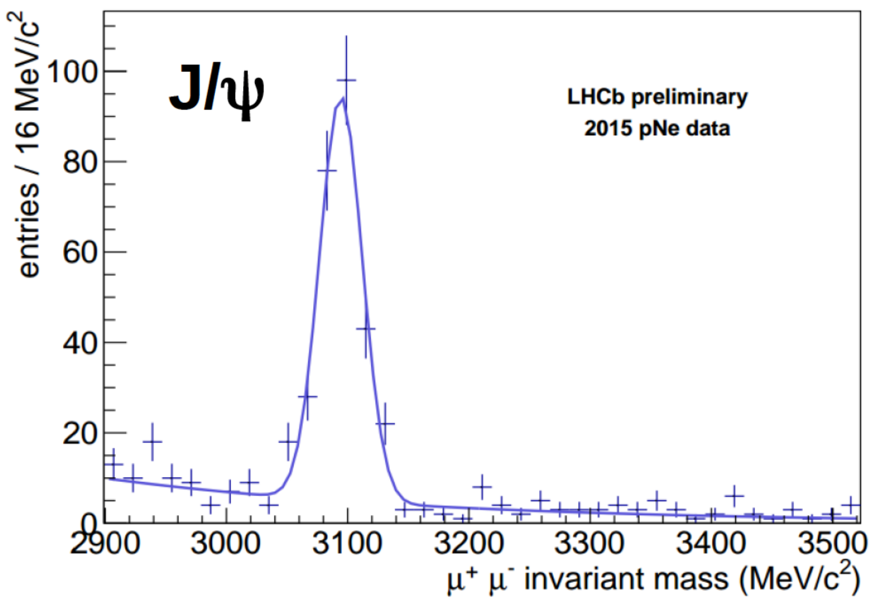
BACKUP

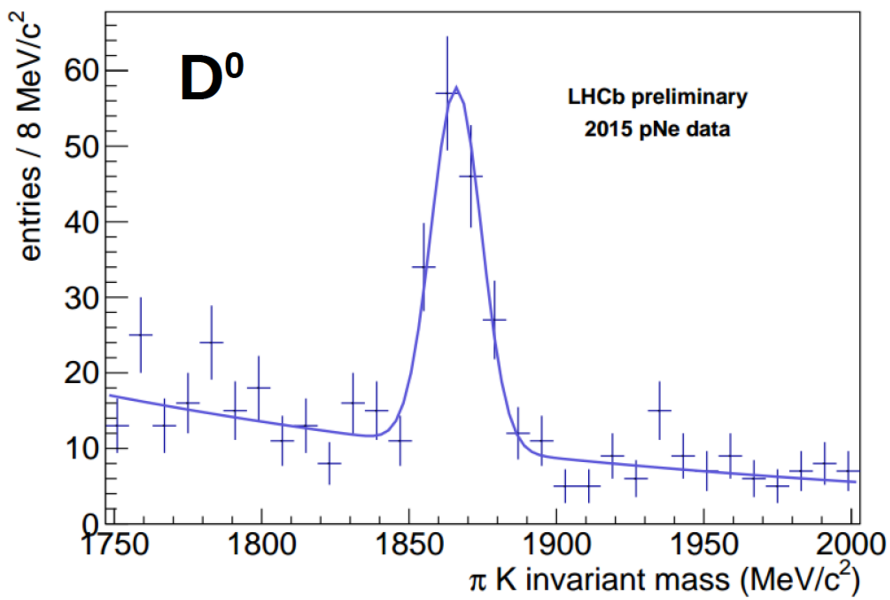
RELEVANT LHC PARAMETERS

	proton beam	lead beam
Number of bunches in the LHC	2808	592
Number of particles per bunch	1.15×10^{11}	7×10^{7}
LHC Revolution frequency [Hz]	11245	
Particle flux in the LHC [s^{-1}]	3.63×10^{18}	4.66×10^{14}
LHC yearly running time [s]	10^{7}	10^{6}
Nominal energy of the beam [TeV]	7	2.76
Fill duration considered [h]	10	5
Usable particle flux in the halo (when relevant) [s^{-1}]	5×10^{8}	10^{5}

INTERNAL GAS TARGET (SMOG LHCb)

- Sucessfull pA and PbA data taking
- Heavy flavour signals from pNe data taking period at $\sqrt{s_{NN}}$ = 110 GeV (~12h)



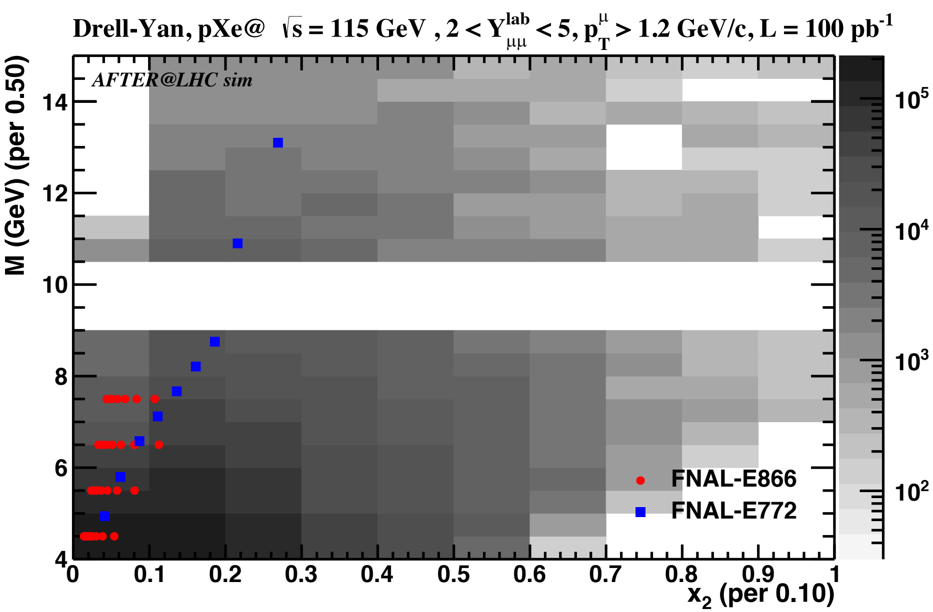


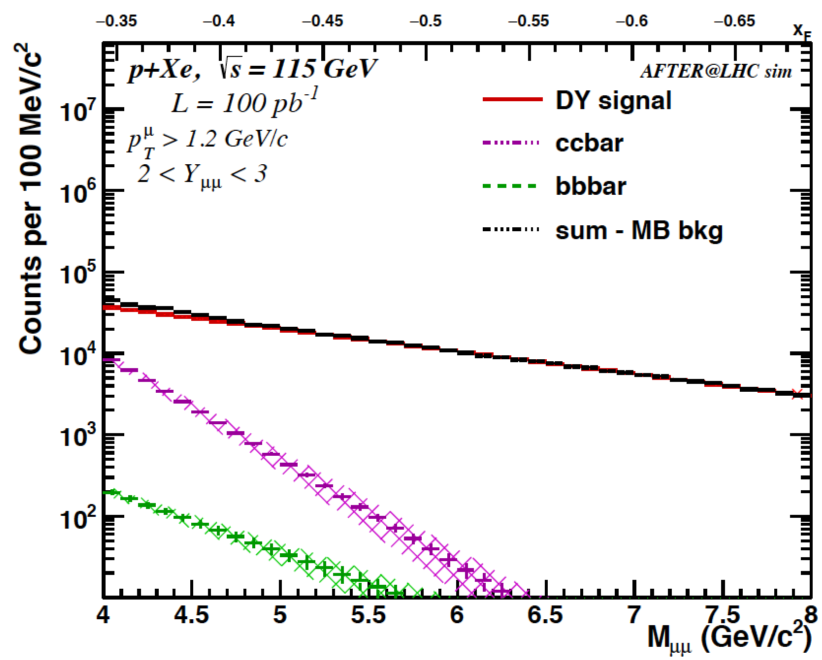
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- Good resolution, high signal over background ratio

DRELL-YAN SIMULATIONS

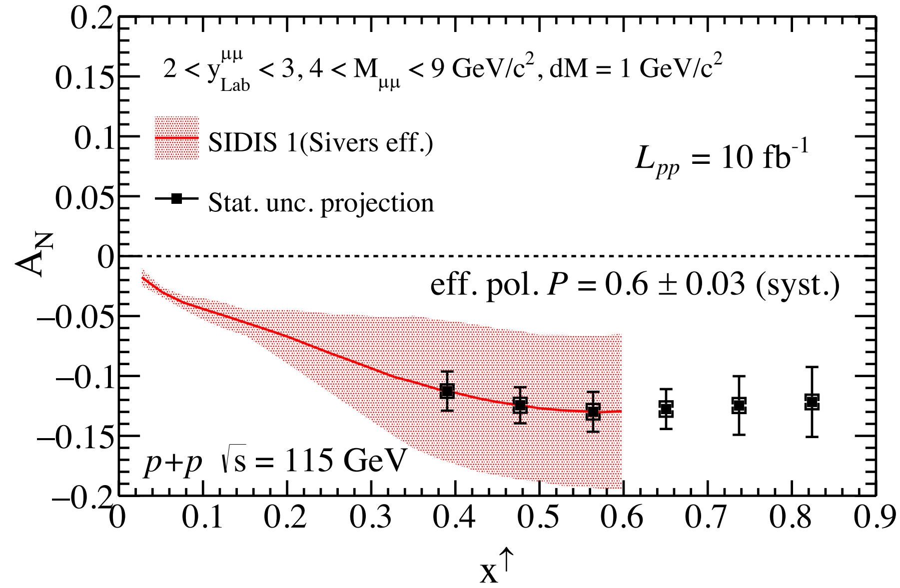
- Unique acceptance (with LHCb-like detector) compared to existing DY pA data (E866 & E772 @ Fermilab) used for nPDF fit. Same acceptance for pp collisions.
- Extremely large yields up to $x_2 \rightarrow 1$ (pXe simulations with LHCb like detector)
- No existing measurements at RHIC
- Assume combinatorial background subtraction via Like Sign or Event Mixing techniques



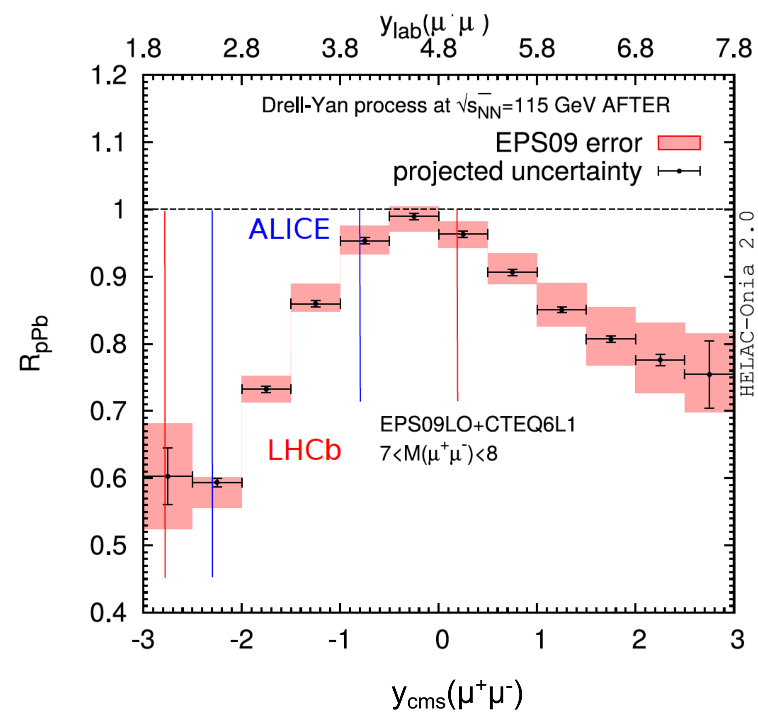


DRELL-YAN SIMULATIONS

- DY pair production on a transversaly polarised target: aim of several experiment (COMPASS, E1039, STAR)
- Check sign change in A_N DY vs SIDIS: hot topic in spin physics!
- With a highly polarised gas target, one simply goes from an exploration phase to a consolidation phase



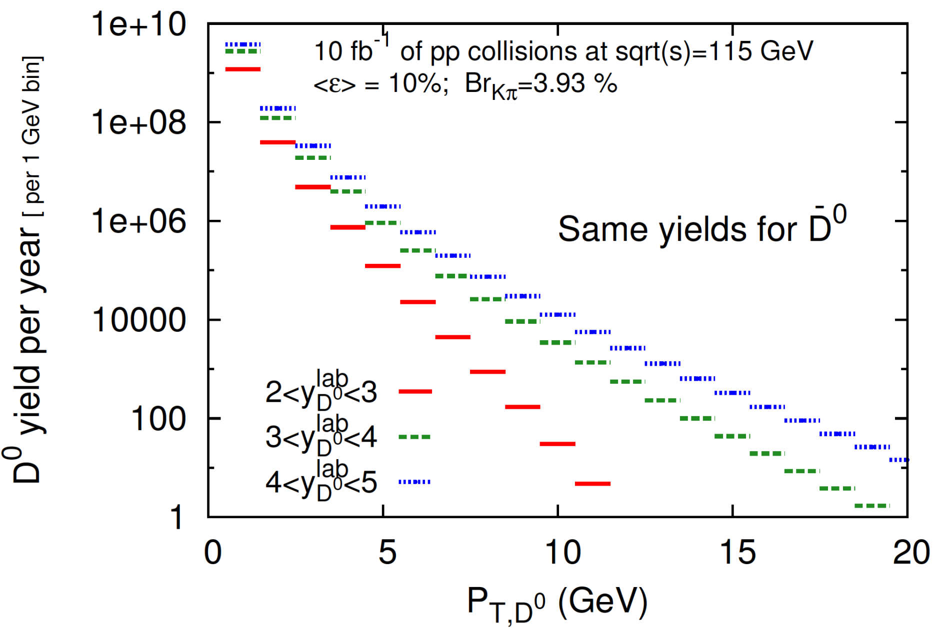
- Novel constraints on the quark nPDF with DY in pA collisions
- Statistical uncertainty smaller than nPDF uncertainties: discriminating power
- With the muon spectrometer of ALICE and its absorber, opportunity to study DY in PbA collisions

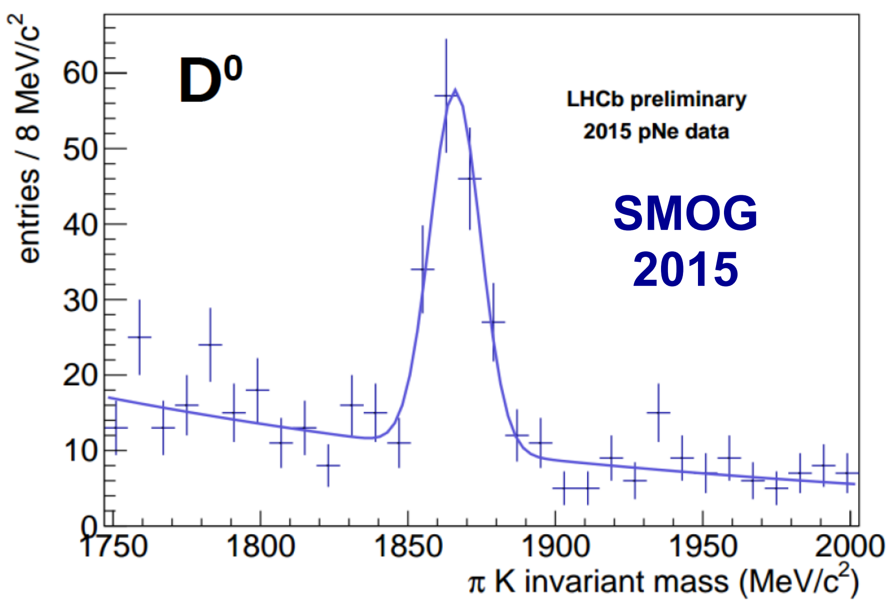


OPEN CHARM SIMULATIONS

- Extremely good prospects to measure charm:
  - down to zero p_T → total x-section
  - over a wide rapidity coverage → x_F → -1
  - with extremely high statistical precision in pp, pA and AA collisions

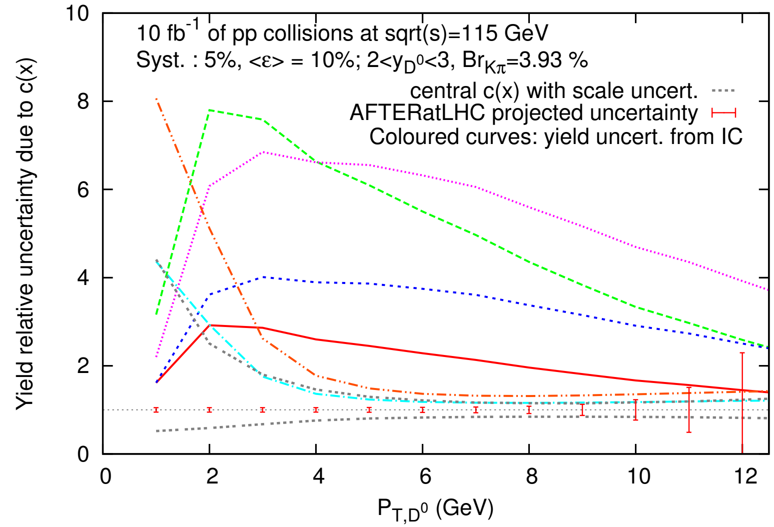
- With a LHCb-like detector , the background is well under control
- Looking at D→ Kπ gives direct access to charm-anticharm asymmetries



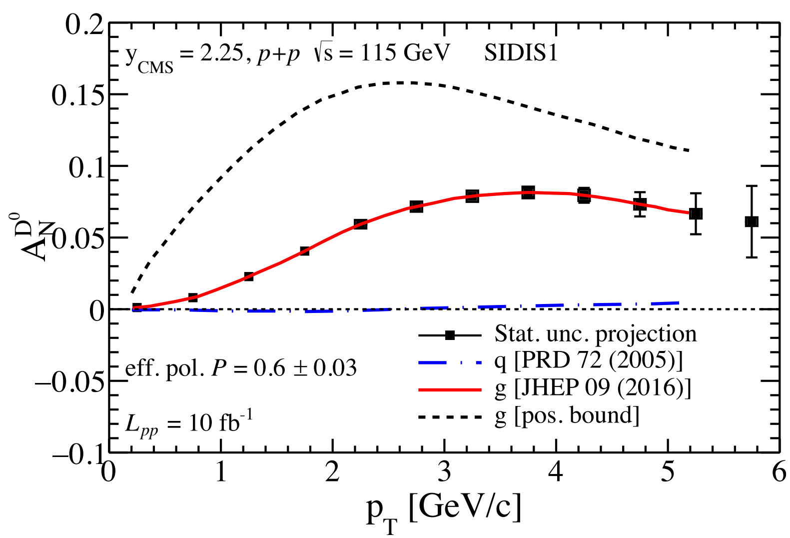


OPEN CHARM SIMULATIONS

- Huge data sample over wide kinematical coverage gives unique handle on charm content in the proton at high x
- Relevant for cosmic neutrinos: constrained by lack of inputs



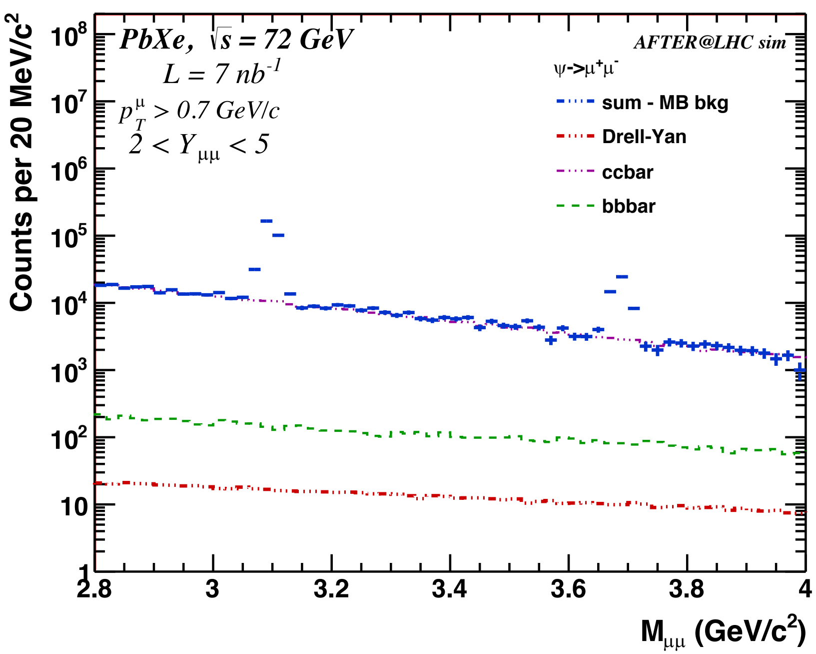
- D^0 can also be collected with a transversaly polarised target → never measured
- Both open and hidden charm → Gives access to tri-gluon correlation and the gluon Sivers effects → related to ℓ_g
- Statistical precision at percent level
- Interesting to measure charm and anticharm separately

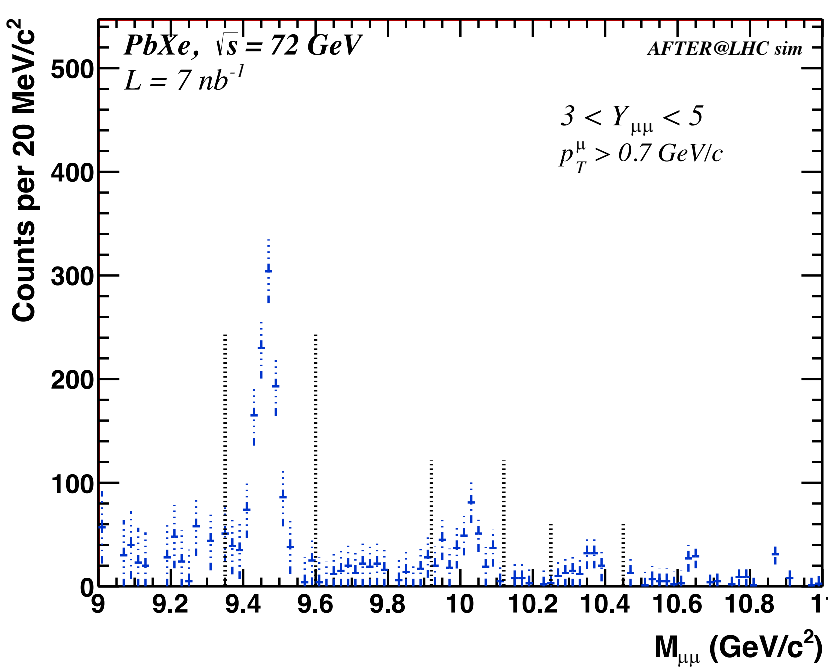


- As for AA collisions, nuclear modification factors vs p_T, y, centrality as well as azimuthal anisotropies (v_2) can also be measured

QUARKONIA SIMULATIONS

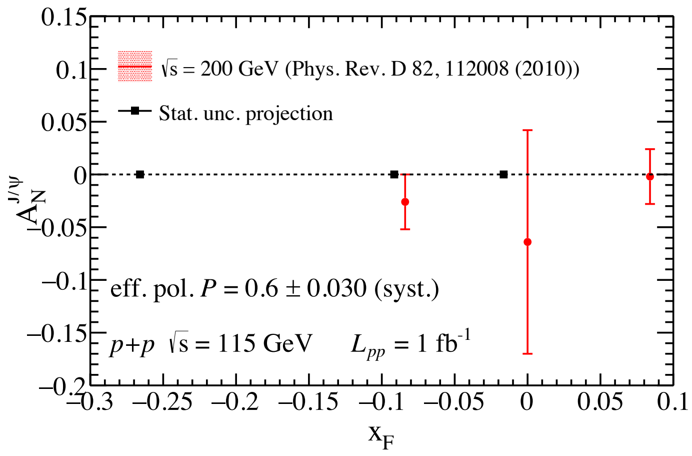
- Aim is to measure a complete set of heavy-flavours to use them as tools (TMD, PDF, nPDF, QGP effects)
- Wide rapidity coverage, p_T up to ~ 15 GeV and down to 0 GeV
- Unique opportunity to access $\chi_{c,b}$, η_c + associated production
- Full background simulations show very good prospects for all systems (worst scenario PbA shown below)
- In PbA collisions, one can repeat the Υ(ns) CMS analysis in a new energy domain

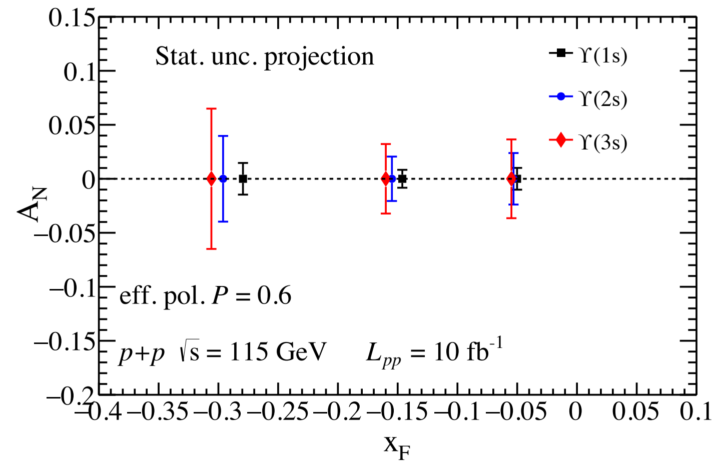




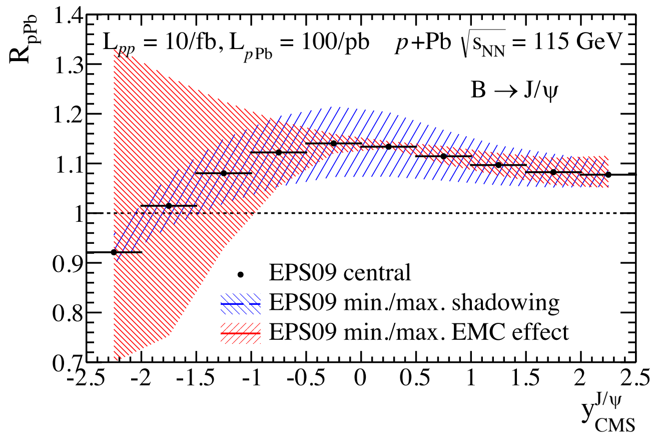
QUARKONIA SIMULATIONS

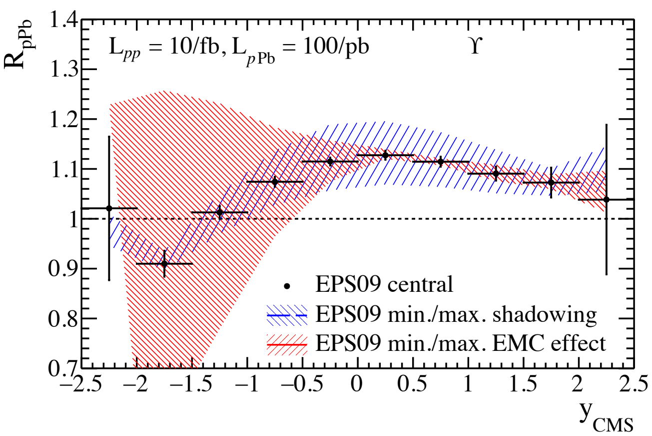
- A_N for all quarkonia can be measured → so far on J/ψ by PHENIX with large uncertainties
- Completely new perspectives to study the gluon Sivers effect





- In pA collisions, constrain the gluon antishadowing and EMC effects
- pD collisions → $g_n(x) = g_p(x)$?
- Access η_c production in pA collisions for the first time
- High statistics → quarkonium polarisation in pA/AA collisions





(Gluon) Sivers effects with a transversely polarized target

Gluon Sivers effect: correlation between the gluon transverse momentum k_T and the proton spin

- **The target rapidity region ($x_F < 0$) corresponds to high $x^{\uparrow}$ ($x_F \rightarrow -1$) where the k_T - spin correlation is the largest**

- Transverse single spin asymmetries studied using **gluon sensitives probes:**
  - quarkonia (J/ψ, ϒ, χ_c) *F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013)*

  - B & D mesons production
  - γ, γ-jet, γ-γ also J/ψ-γ *A. Bacchetta et al., PRL 99 (2007) 212002*
  J. W. Qiu et al., PRL 107 (2011) 062001

- High precision data and high luminosities needed to study Single Transverse Spin Asymmetries

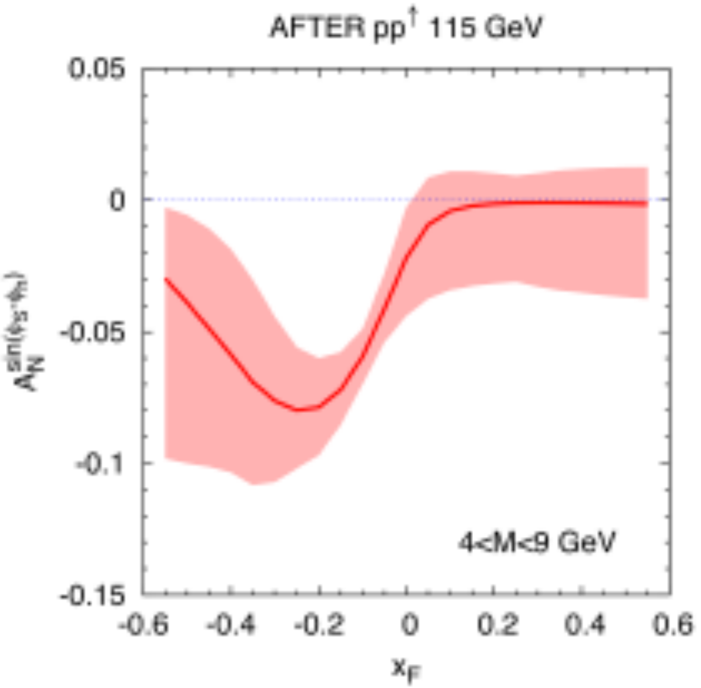
SPIN OF QUARKS INSIDE POLARIZED NUCLEONS

(Quark) Sivers effects with a transversely polarized target

- Can be probed with the Drell-Yan process

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^{\uparrow}$	$\mathscr{L}$ ($nb^{-1}s^{-1}$)
AFTER	$p+p^{\uparrow}$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^{\pm}+p^{\uparrow}$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^{\pm}+p^{\uparrow}$	160	17.4	~ 0.05	2
RHIC	$p^{\uparrow}+p$	collider	500	$0.05 \div 0.1$	0.2
J–PARC	$p^{\uparrow}+p$	50	10	$0.5 \div 0.9$	1000
PANDA (low mass)	$\bar{p}+p^{\uparrow}$	15	5.5	$0.2 \div 0.4$	0.2
PAX	$p^{\uparrow}+\bar{p}$	collider	14	$0.1 \div 0.9$	0.002
NICA	$p^{\uparrow}+p$	collider	20	$0.1 \div 0.8$	0.001
RHIC Int.Target 1	$p^{\uparrow}+p$	250	22	$0.2 \div 0.5$	2
RHIC Int.Target 2	$p^{\uparrow}+p$	250	22	$0.2 \div 0.5$	60
P1027	$p^{\uparrow}+p$	120	15	$0.35 \div 0.85$	400-1000
P1039	$p+p^{\uparrow}$	120	15	$0.1 \div 0.3$	400-1000

Relevant parameters for the future proposed polarized DY experiments



Prediction for AFTER

M. Anselmino, ECT*, Feb. 2013
(Courtesy U. D'Alesio)

S. J. Brodsky et al., Phys. Rep. 522 (2013) 239
V. Barone et al., Prog. Part. Nucl. Phys. 65 (2010) 267

Asymmetry up to 10% predicted in DY for the target rapidity region ($x_F < 0$)

SPIN OF GLUONS INSIDE (UN)POLARIZED NUCLEONS

Access to the distribution of linearly polarized gluons ($h_1^{\perp g}$)

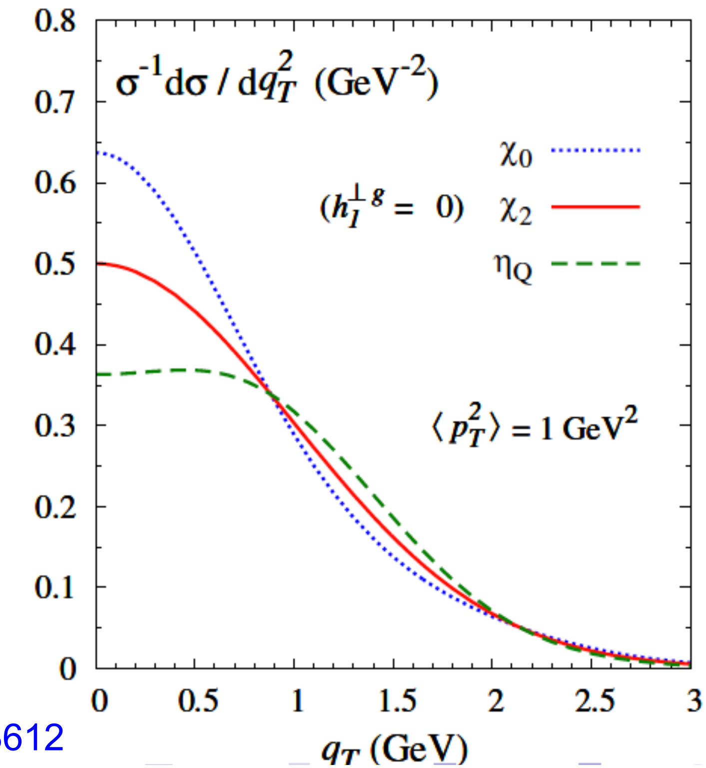
« Boers-Mulder » effect: correlation between the parton k_T and its spin
For gluons, it is encoded in $h_1^{\perp g}$

- The low-p_T C-even quarkonium production is a good probe of the gluon TMDs.
- The low-p_T spectra of scalar and pseudo-scalar quarkonium (χ_{c0}, χ_{b0}, η_c, η_b) are affected differently by the linearly polarized gluons in unpolarized nucleons

$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \text{ \& } \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

R involves $h_1^{\perp g}$

→ Boost: better access to low-p_T C-even quarkonia
→ Still challenging experimentally (first study of η_c in collider by LHCb for p_T > 6 GeV/c) arXiv:1409.3612
→ If possible somewhere, it is at AFTER@LHC



Boer, Pisano, PRD 86 (2012) 094007

- Back-to-back J/ψ + γ is also a good probe of gluon TMDs

Den dunnen et al., PRL 112 (2014) 212001, J. P. Lansberg, Transversity 2014

NUCLEON PARTONIC STRUCTURE: GLUONS IN THE PROTON

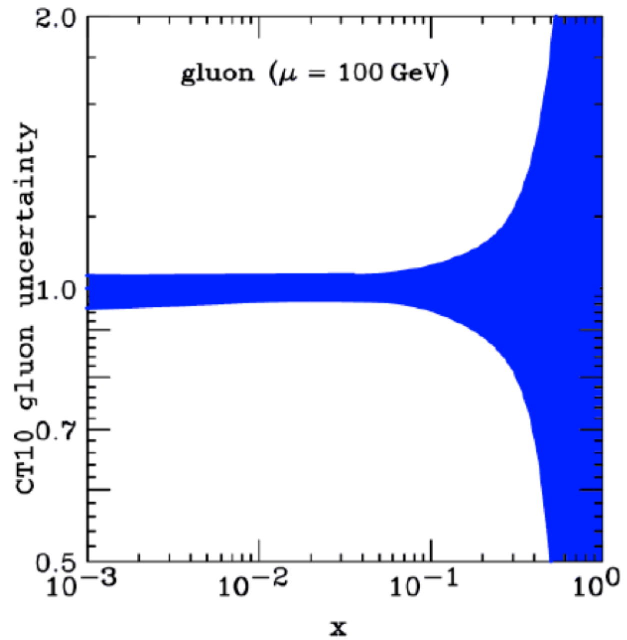
- ❑ Study gluon distributions at mid and high x_B in the proton
  - Not easily accessible in DIS
  - Translates into very large uncertainties

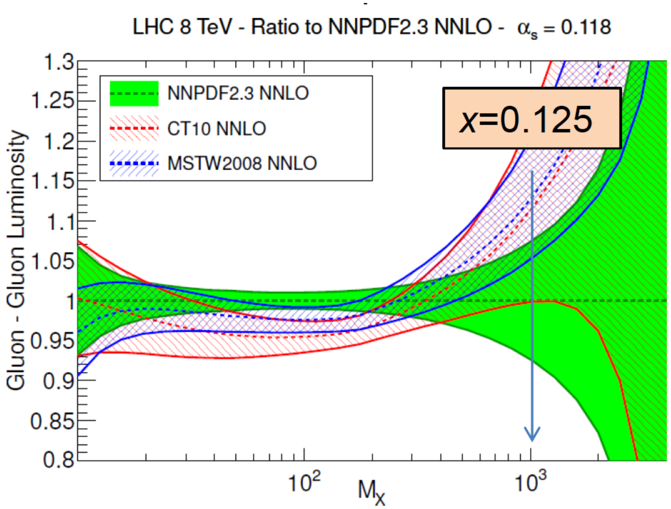
- ❑ Accessible via gluon sensitive probes:
  - Quarkonia
    D. Diakonov et al., JHEP 1302 (2013) 069
  - Isolated photons
    D. d'Enterria, R. Rojo, Nucl. Phys. B860 (2012) 311
  - Jets ($20 \le p_T \le 40$ GeV/c)

- ❑ Gluon distribution unknown for the neutron

Multiple probes needed to check factorisation

Large-x gluons: important to characterise some possible BSM findings at the LHC





HEAVY QUARK CONTENT OF THE PROTON

- **Pin down intrinsic charm**

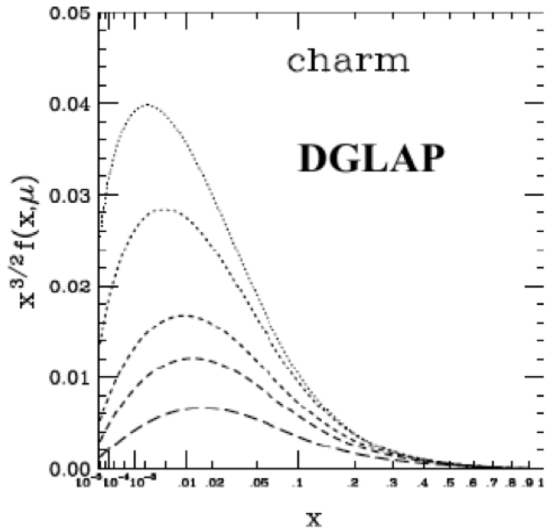
- Intrinsic charm is a rigorous property of QCD

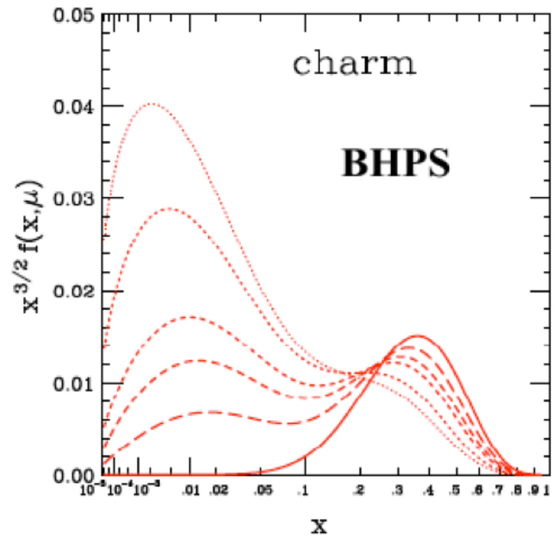
- Different charm pdfs (DGLAP or models with intrinsic charm) are in agreement with DIS data

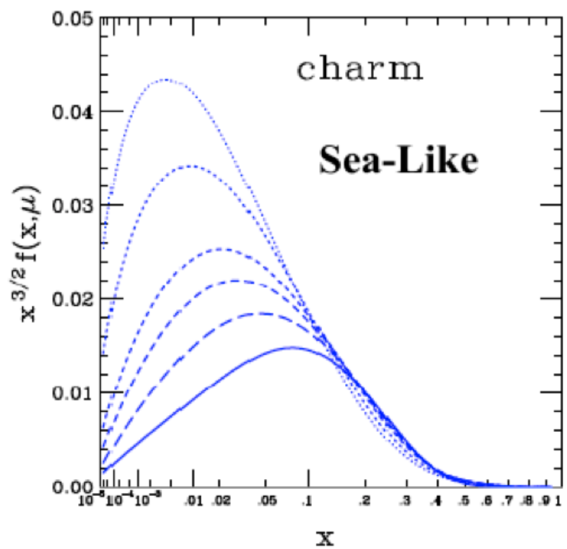
- Important for high energy neutrino and cosmic ray physics

- Requirement

  - Several complementary measurements
  - Good coverage in the target-rapidity region
  - High luminosity to reach large x_B







CTEQ6.5C with intrinsic charm

Pumplin et al. Phys.Rev. D75 (2007)