AFTER@LHC, A Fixed Target ExpeRiment for hadron, heavy-ion and spin physics

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OUTLINE

- What is AFTER@LHC ?
- Main kinematical features
- Physics Motivations
- Possible technical implementations at the 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

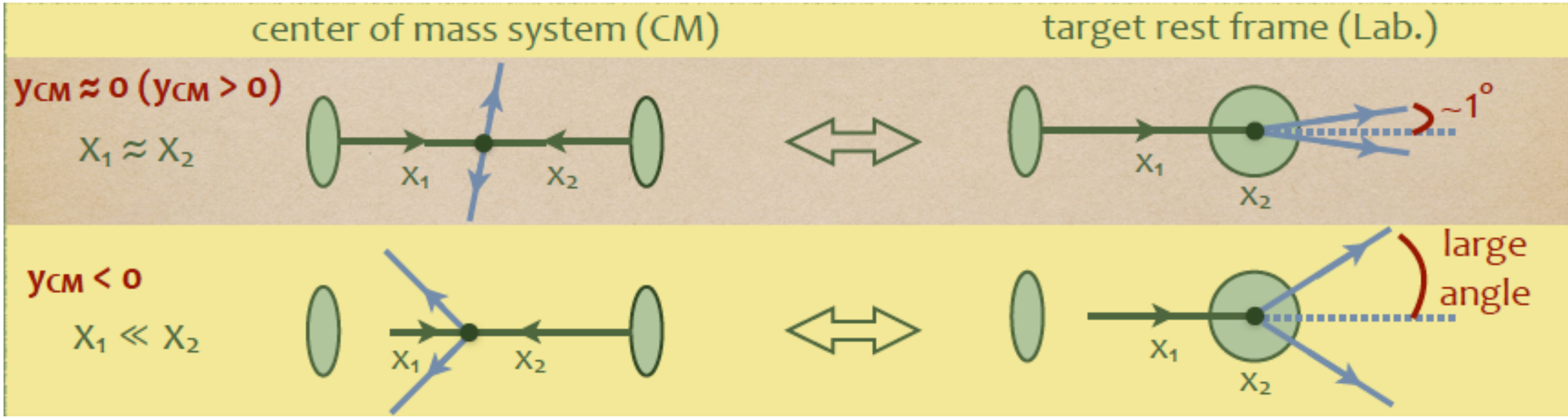
Several advantages of the fixed-target mode wrt to the collider mode:

- 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)

Nota: all (past) colliders with Ep ≥ 100 GeV have had a fixed target program (Tevatron, HERA, SPS, RHIC)

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→ 1 in the target

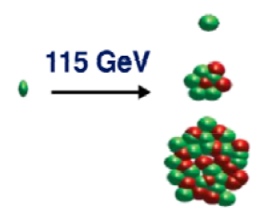
Energy range

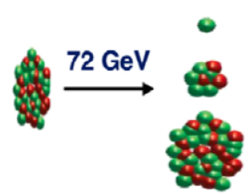
7 TeV proton beam on a fixed target

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

2.76 TeV Pb beam on a fixed target

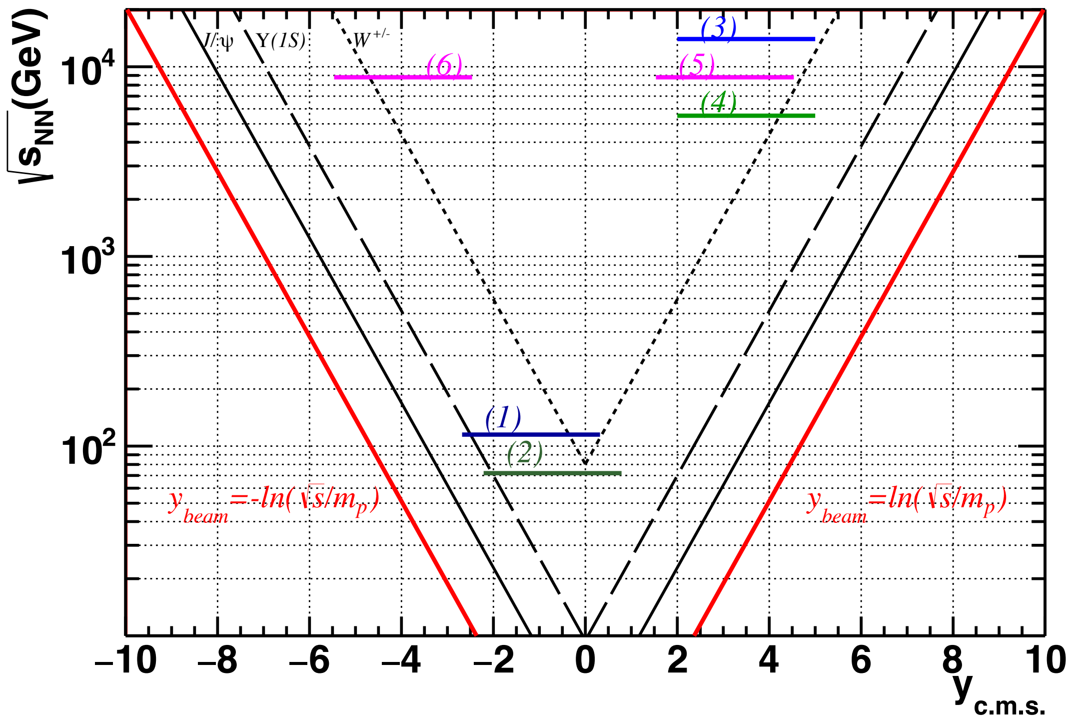
c.m.s. energy:	$\sqrt{s_{NN}} = \sqrt{2m_N E_{Pb}} \approx 72\,\text{GeV}$	**Rapidity shift:** $y_{c.m.s.} = 0 \rightarrow y_{lab} = 4.3$
Boost:	$\gamma \approx 40$	





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 → $-1 < x_F < 0$



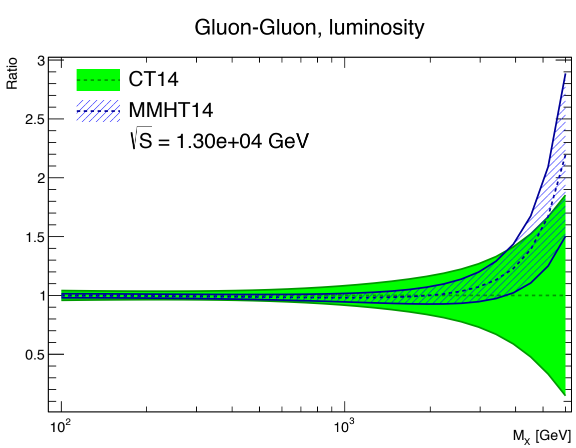
Acceptance for an LHCb-like detector : $2 < \eta < 5$

(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

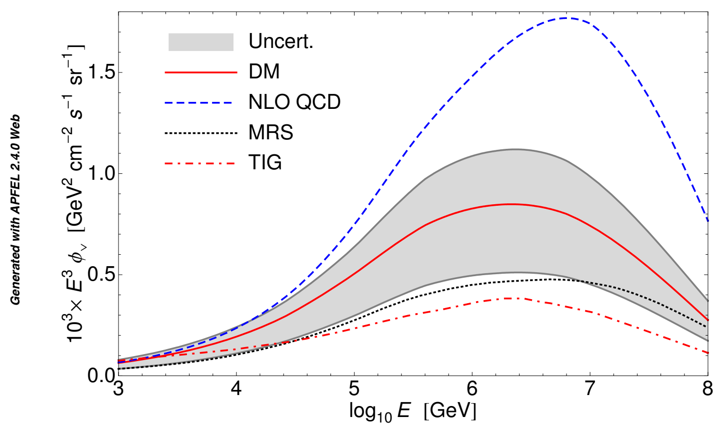
PHYSICS MOTIVATIONS: HIGH-x FRONTIER

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

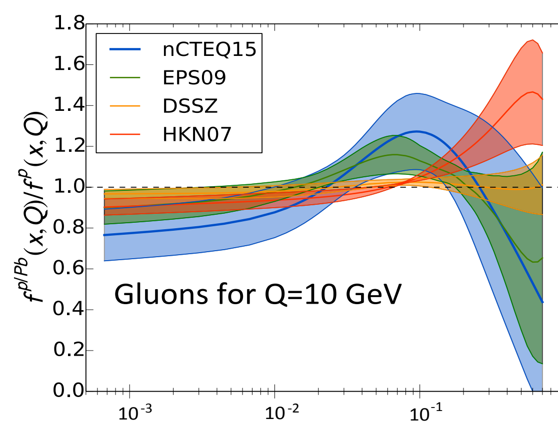
    - Very large uncertainties for x ≥ 0.5
      [could be crucial to characterise possible BSM discoveries]
    - Proton charm content important for high-energy neutrino and cosmic ray physics
    - EMC effect is an open problem; studying a possible gluon EMC effect is essential
    - Relevance of nuclear 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

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

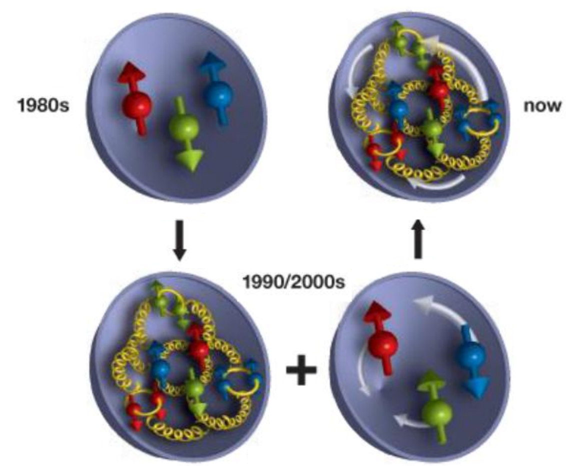
$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \underbrace{\ell_g + \ell_q}$$

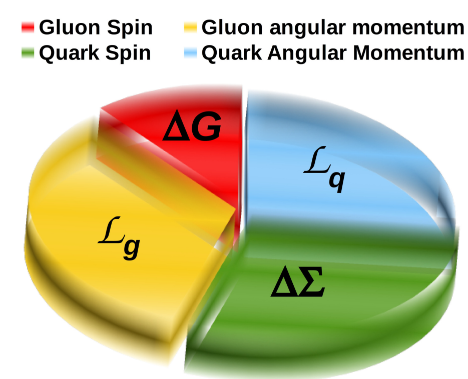
Spin of quarks /antiquarks

Spin of gluons

Orbital angular momentum of quarks and gluons

- 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)

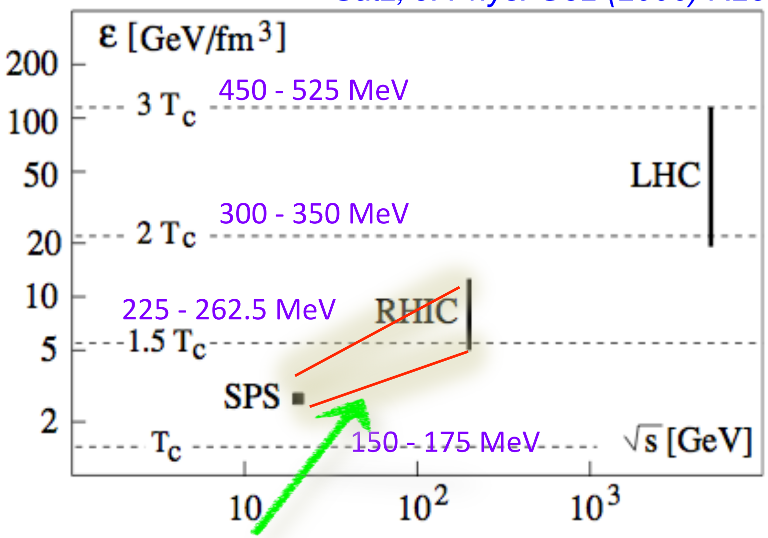




PHYSICS MOTIVATIONS: HEAVY ION COLLISIONS TOWARD LARGE RAPIDITIES

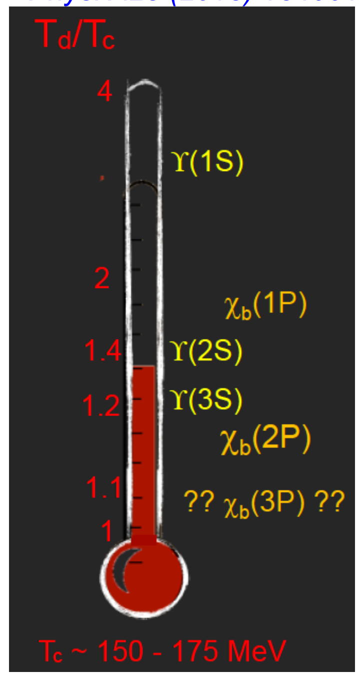
❑ QGP studies between SPS and RHIC energies (with eg. quarkonia)

Satz, J. Phys. G32 (2006) R25

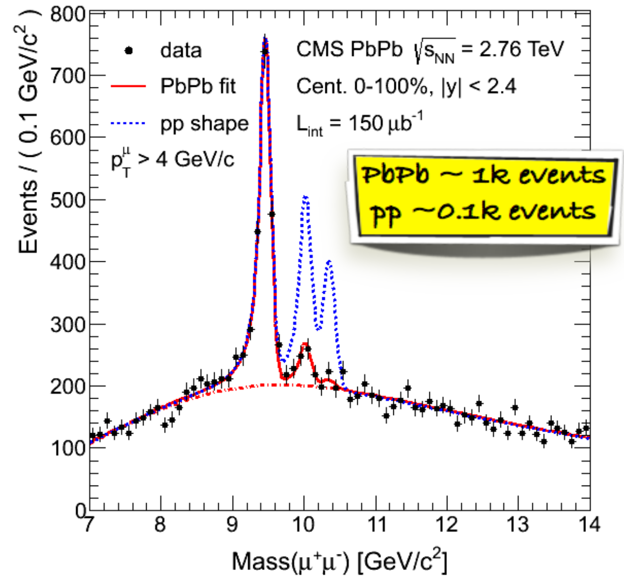


AFTER in PbA
$\sqrt{s_{NN}}$ ~ 72 GeV

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

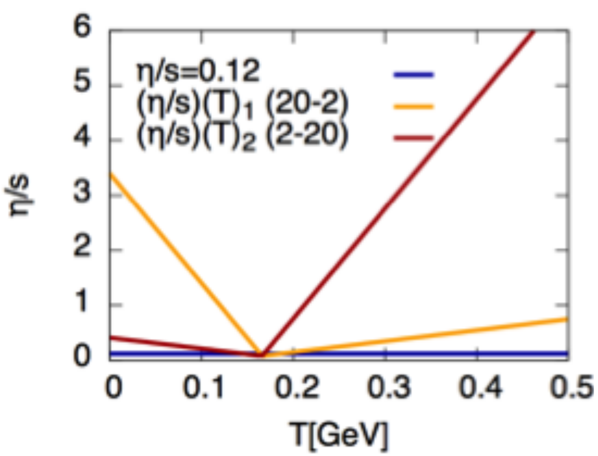
  → Calibration of the quarkonium thermometer

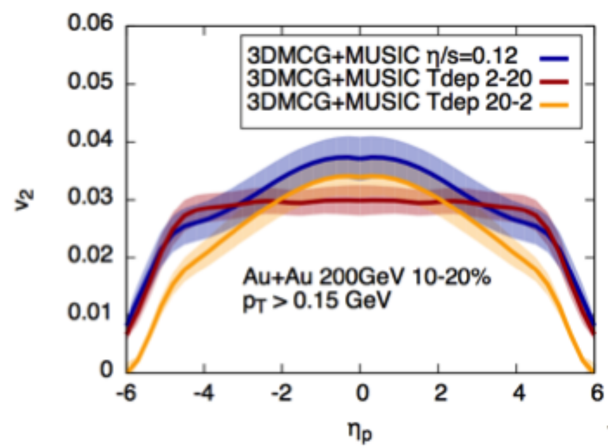
- At AFTER@LHC energy, Υ(3S) and Υ(2S) are expected to melt
- Enough statistics to perform the same study as CMS at low energy

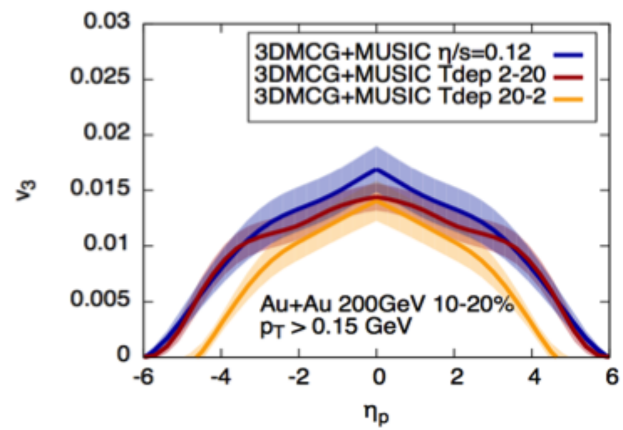
PHYSICS MOTIVATIONS: HEAVY ION COLLISIONS TOWARD LARGE RAPIDITIES

- ❑ 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! (high pressure, polarisation…)
    - Benefit from the full p and Pb fluxes: 3.4×10^{18} p/s, 3.6×10^{14} Pb/s

  - Internal **Wire** target:
    - 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 « internat target » solution):
    - Intermediate option which reduces civil engineering (re use exsisting 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:

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

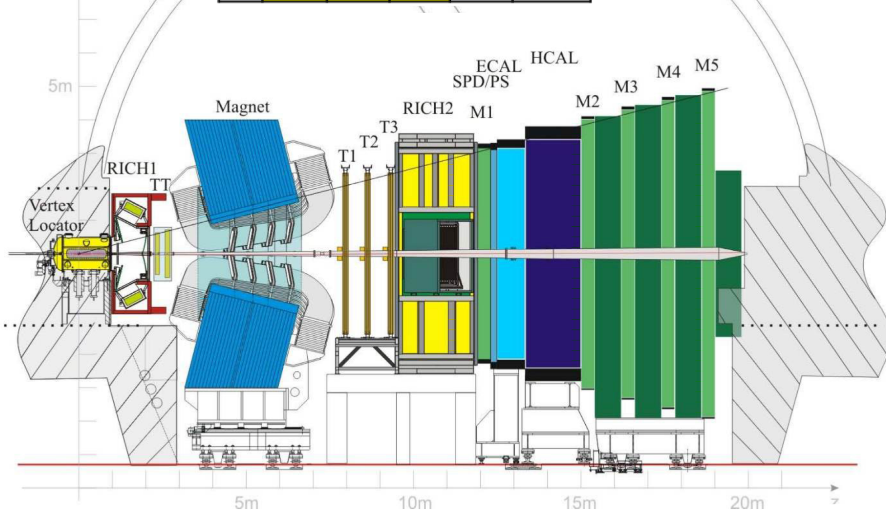
INTERNAL GAS TARGET (SMOG LHCb)

- Currently validated by the LHCb Collaboration with the SMOG system (originally a luminosity monitor)
- Low density noble gas injected into LHCb Vertex Locator, into the beam vacuum
- Benefit from the full LHCb beam without decrease of the beam lifetime

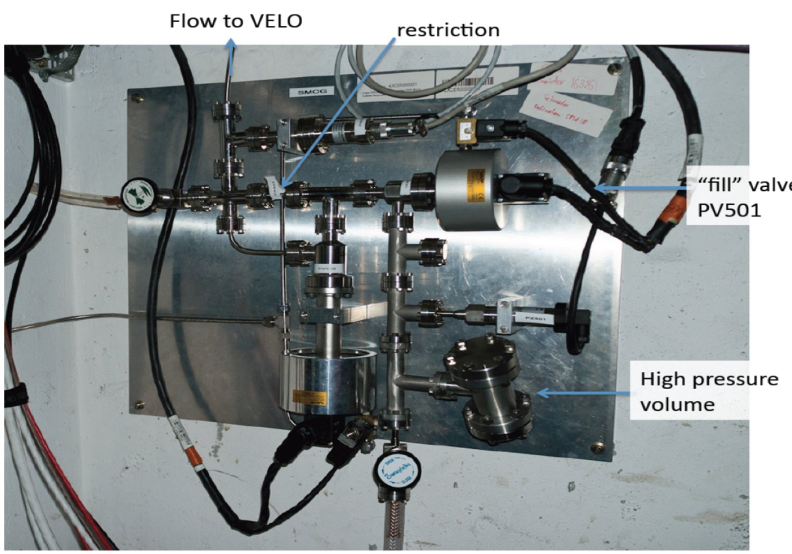
Preferred target Gas

	He	Ne	Ar	Kr	Xe
A	4	20	40	84	131

$2 < \eta < 5$



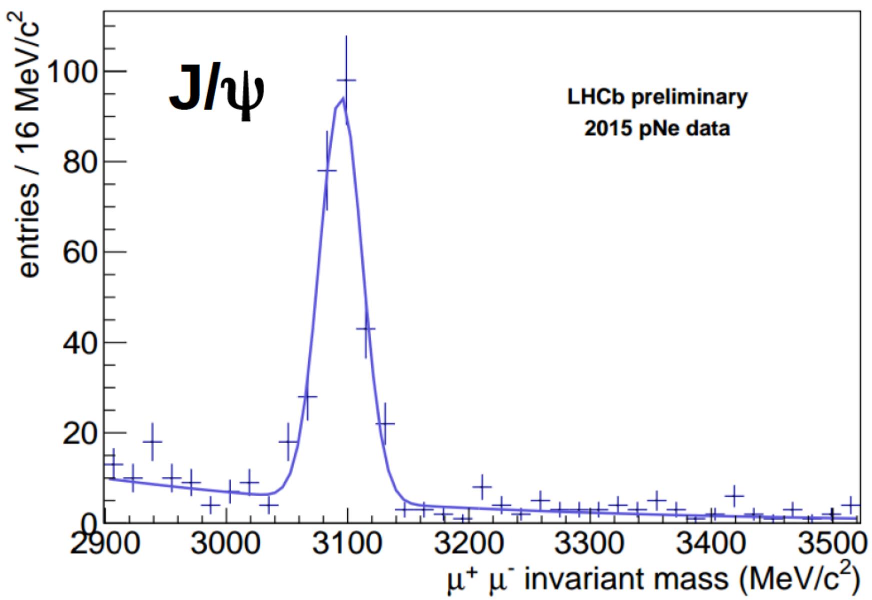
SMOG: System for Measuring Overlap with Gas

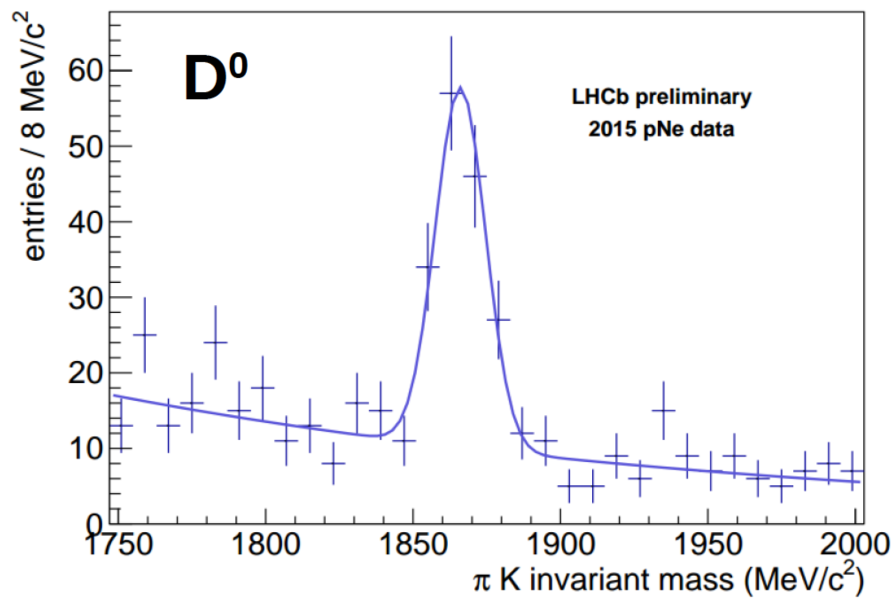


- Limited gas pressure ($P \sim 1.5 \times 10^{-7}$ mbar), limited running time, no polarization of the target, only noble gases

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)

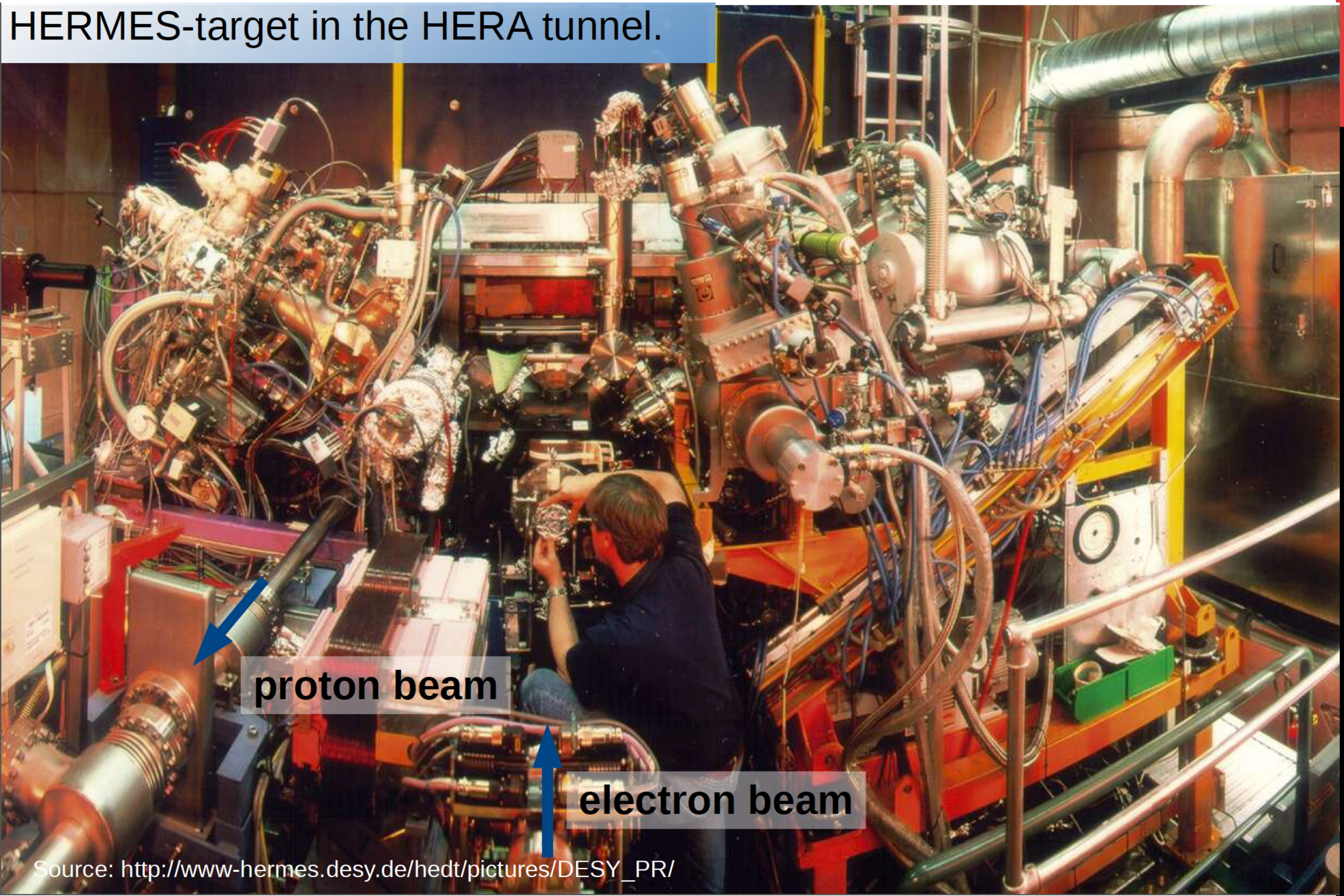




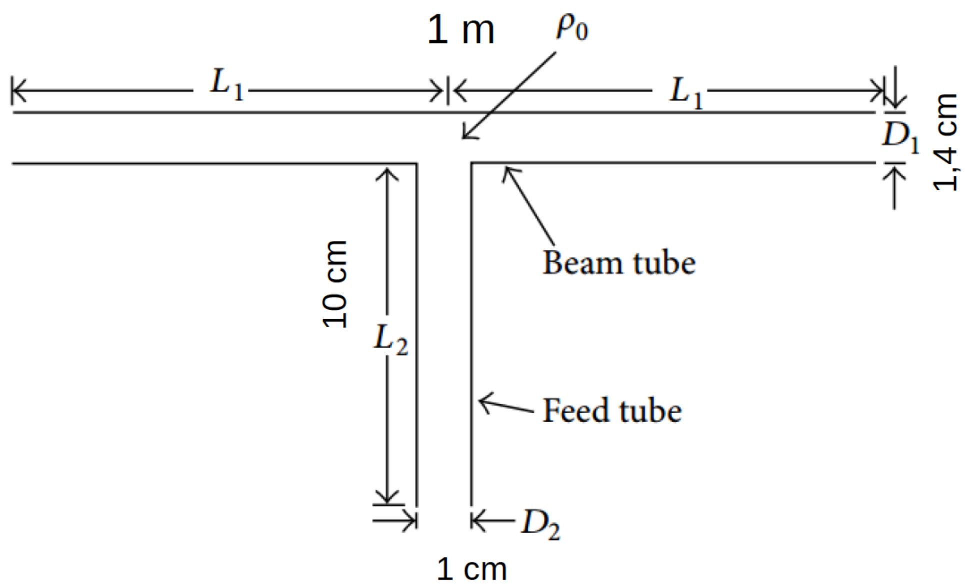
https://twiki.cern.ch/twiki/bin/view/LHCb/LHCbPlots2015

- Good resolution, high signal over background ratio

INTERNAL GAS TARGET (HERMES TARGET LIKE OPTION)



INTERNAL GAS TARGET (HERMES TARGET LIKE OPTION)



Adv. High Energy Phys. 2015 (2015) 463141

E. Steffens, PoS (PSTP2015) 019

- Benefit from higher pressure in the target cell
- Dedicated pumping system [turbo molecular pumps]
- Polarised Hydrogen, Deuteron , ^{3}He can be injected (P ~80%)
- Unpolarised heavy gas can also be injected

QUALITATION COMPARISON OF INTERNAL GAS TARGET SOLUTIONS

SMOG(-like) system

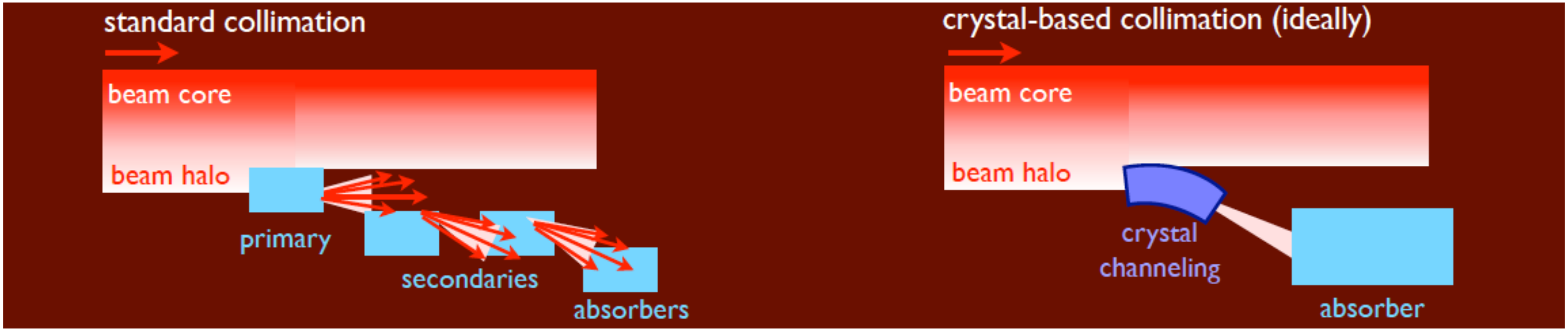
- SMOG: System for Measuring Overlap with Gas
- Designed for precise luminosity determination
- Noble gas directly injected in the VELO
- ✓ p(He,Ne,Ar), Pb(Ne,Ar) tested : completely parasitic [up to one week, so far]
- ✓ New pressure monitoring to be installed
- ✓ Could be coupled to ALICE: ideal demonstrator
- ✗ No specific pumping system: limit in the gas inject [pressure and duration]
- ✗ No possibility to use polarised gases
- ✗ Gas flows in the beampipe; pressure profile not optimised
- ✗ Kr and Xe maybe only at end of a run

HERMES(-like) system

- Injection of gas in an open-end storage cell
- Used e.g. at DESY for 10 years
- ✓ Dedicated pumping system [turbo-molecular pumps]
- ✓ Pressure in the cell significantly higher [diameter ≤ 2cm in the closed position]
- ✓ Polarised H and D can be injected ballistically with high polarisation
- ✓ Polarised ^{3}He or unpolarised heavy gas (Kr, Xe) can also be injected
- ✗ Not compatible with an injection inside ALICE; only upstream
- ✗ May need complementary vertexing capabilities

BEAM EXTRACTION OR BEAM SPLITTING USING BENT CRYSTALS

- Solution studied for beam collimation purposes

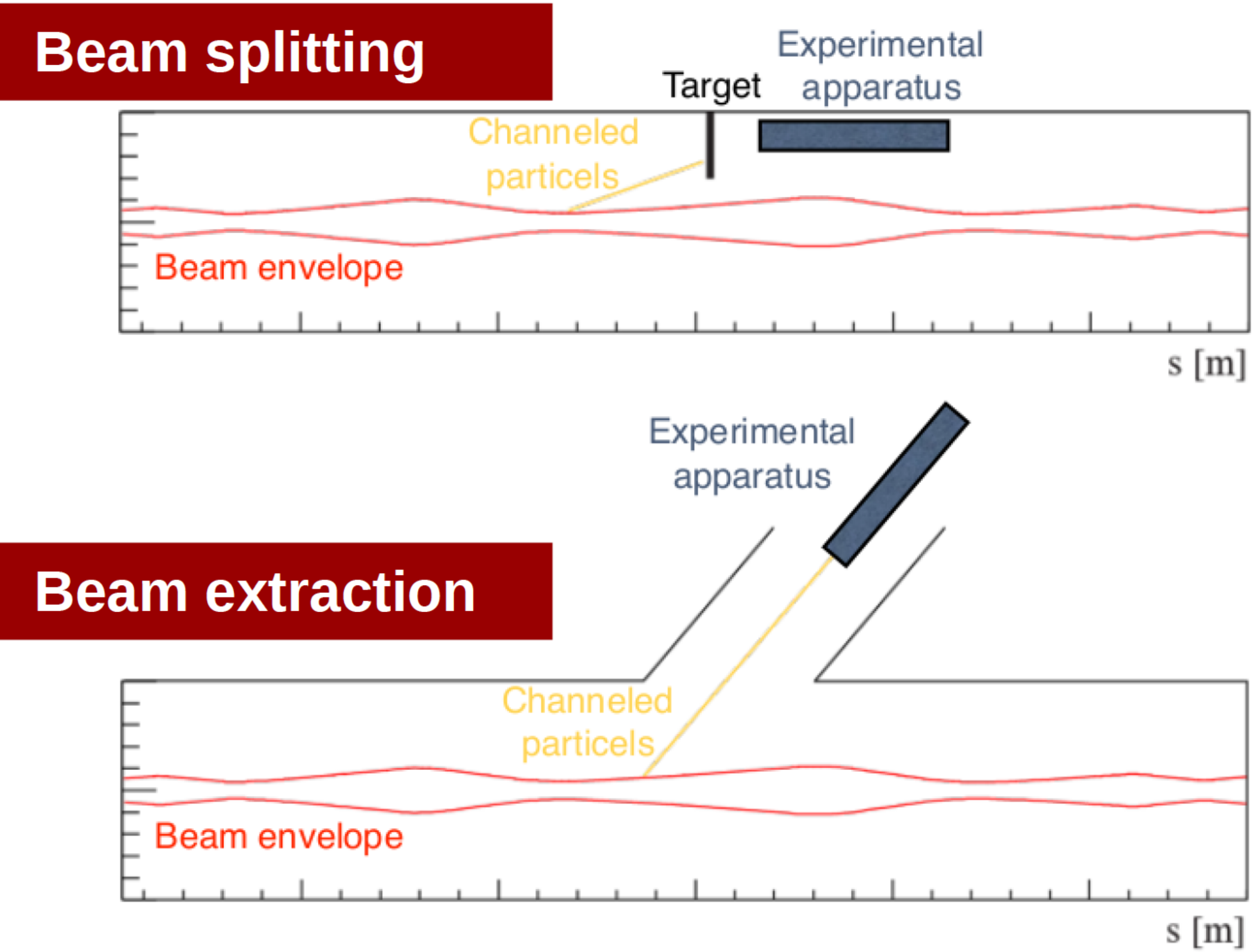


Standard collimation today → Crystal-based collimation
- UA9 (@SPS)
- LUA9 (@LHC)

→ To beam extraction
- CRYSBEAM (@SPS then LHC)
- AFTER@LHC

- Deflecting the beam halo at about 7σ distance to the beam
- Reduces the LHC beam loss

BEAM EXTRACTION OR BEAM SPLITTING USING BENT CRYSTALS

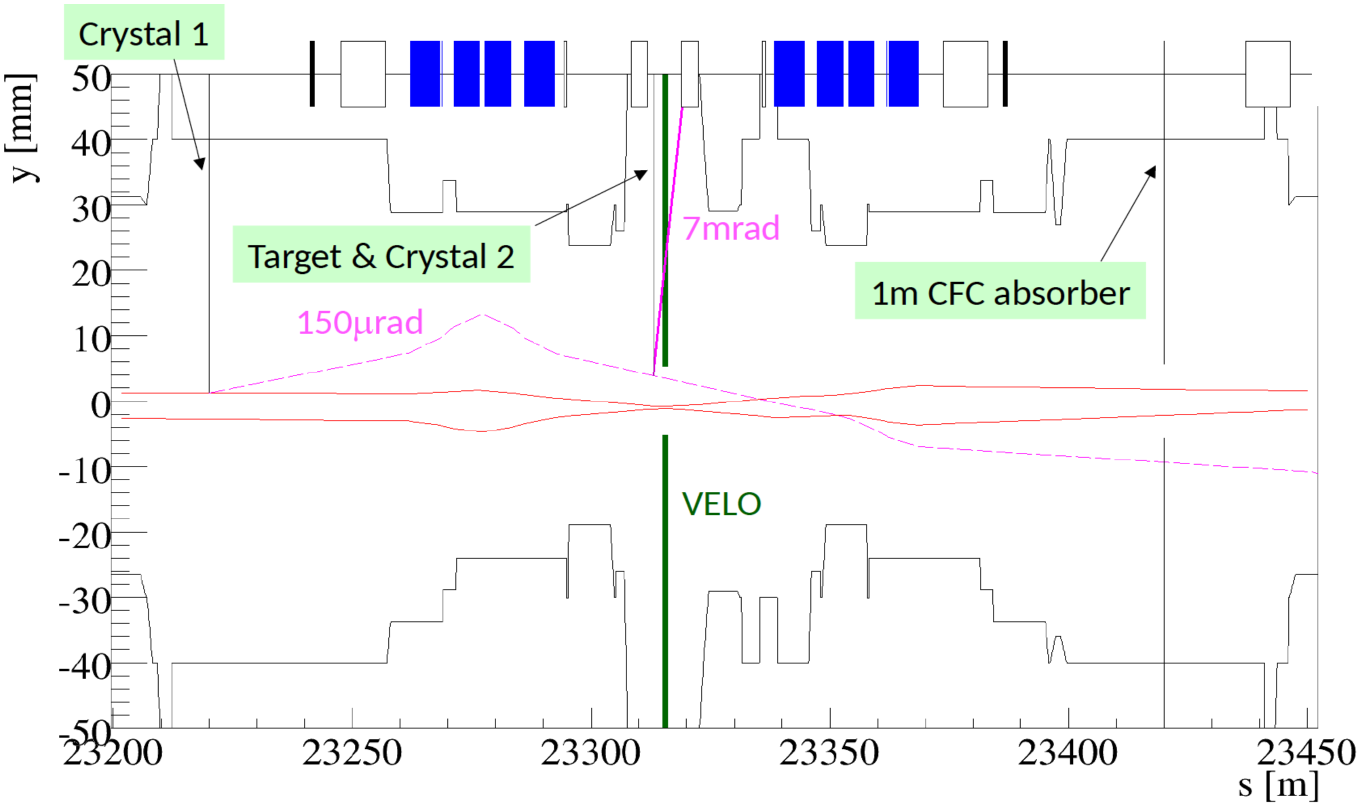


S. Redaelli, Physics Beyond Colliders, CERN, 06/09/2016

- ❑ Beam extraction: civil engineering required, new facility with 7 TeV proton beam
- ❑ Beam splitting: intermediate option
  - Less civil engineering
  - Similar fluxes as for beam extraction
  - Might be use with 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



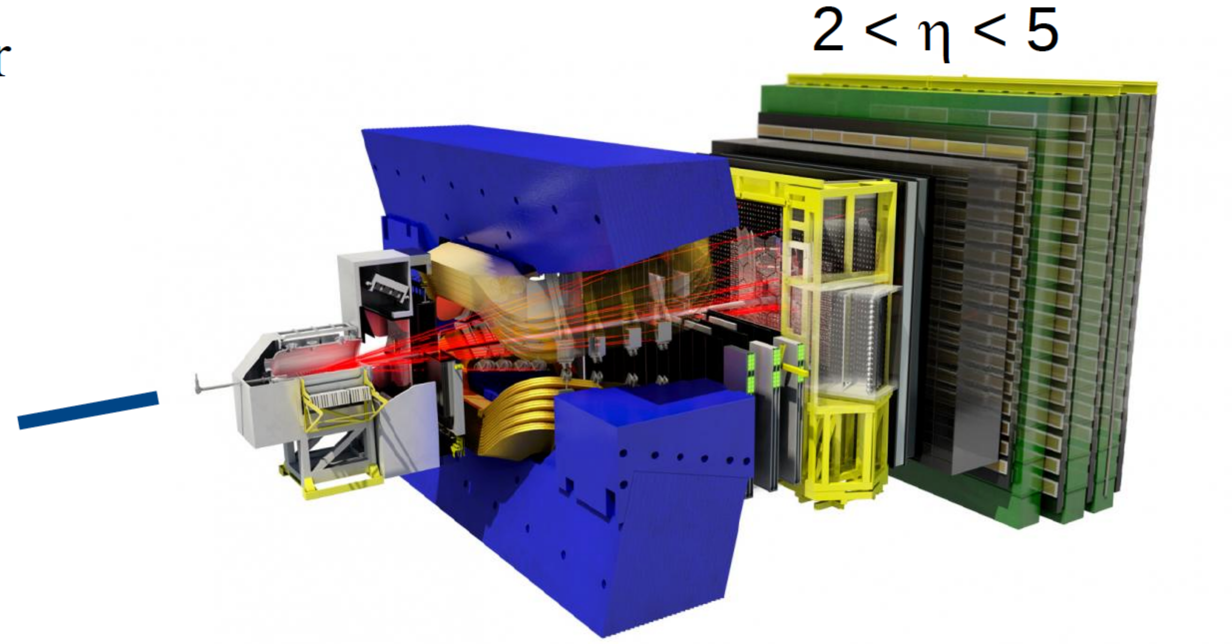
First setup compatible with the LHCb detector

A SELECTION OF PROJECTED PERFOMANCES

Assumptions:

$\int \mathscr{L} = 10\ \mathrm{fb}^{-1}$ /year

$P = 60\%$

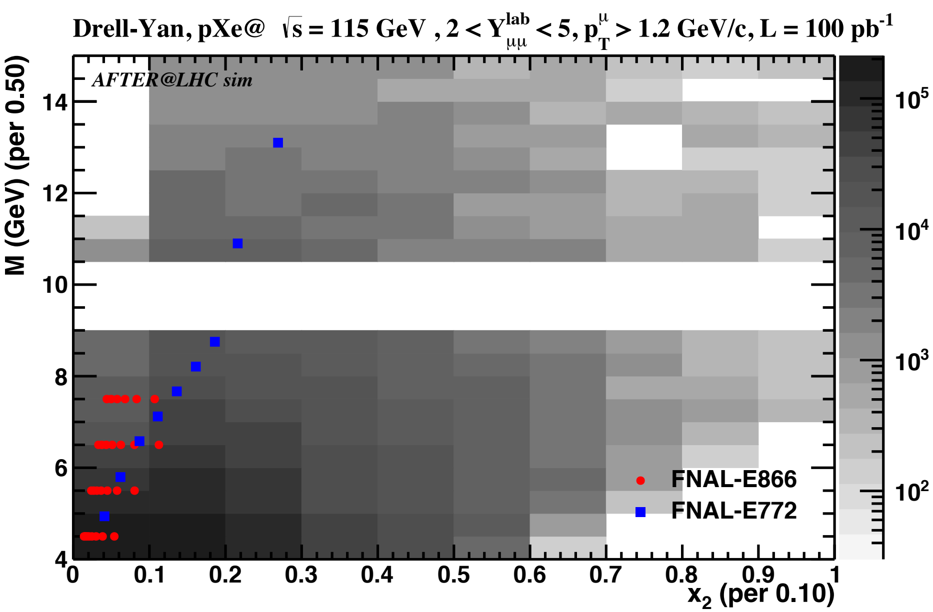


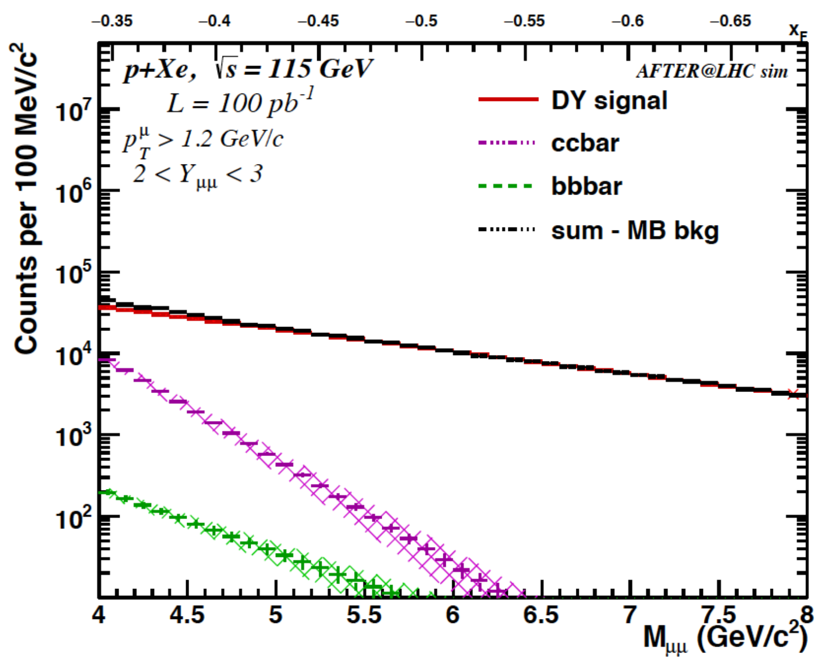
HERMES-type polarized target + LHCb – like acceptance and performance

microvertexing, particle ID, μ ID, electromagnetic and hadonic cal.

DRELL-YAN SIMULATIONS

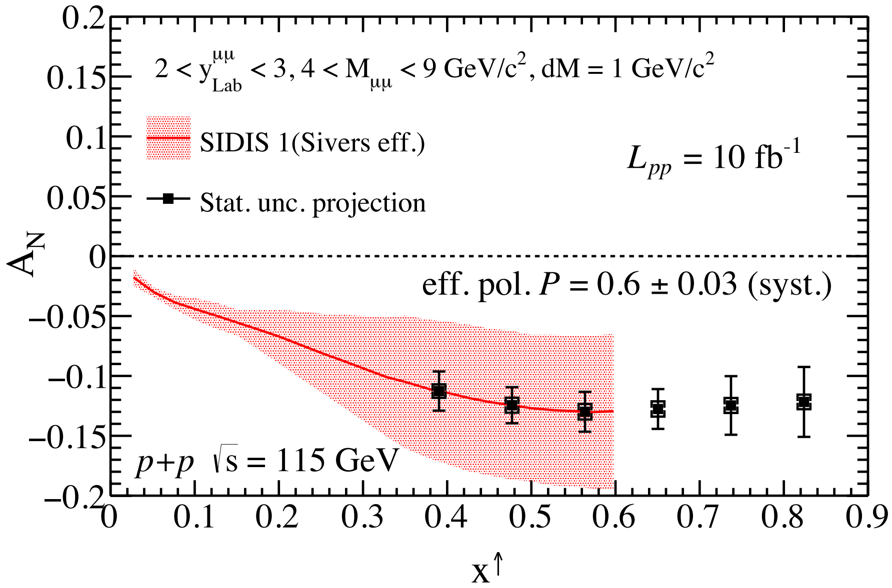
- Unique acceptance (with LHCb-like detector) compared to existing DY pA data (E866 & E772 @ Fermilab) used for nPDF fit. Same acceptance for pp collisions.
- Extremely large yields up to $x_2 \rightarrow 1$ (pXe simulations with LHCb like detector)
- No existing measurements at RHIC
- Assume combinatorial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



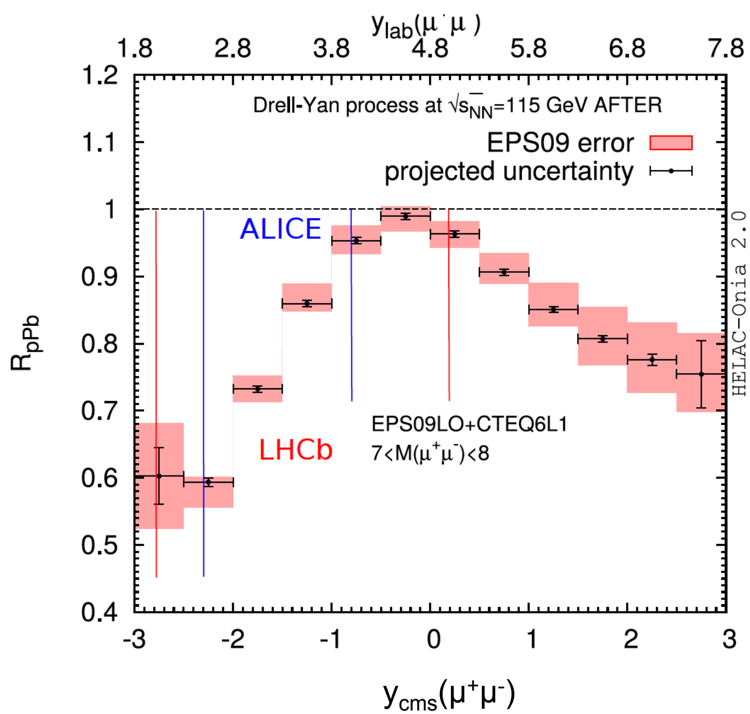


DRELL-YAN SIMULATIONS

- 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



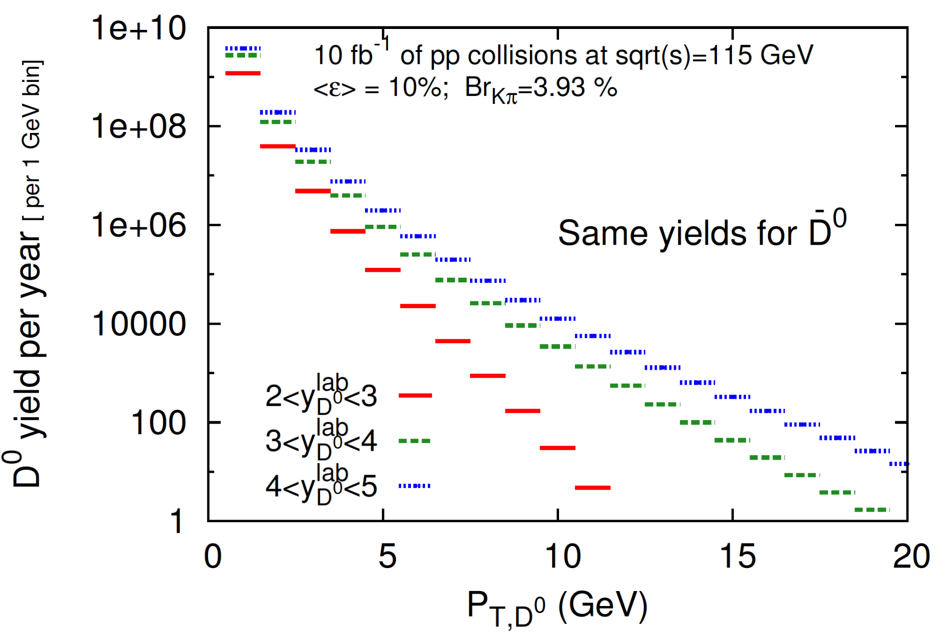
- Novel constraints on the quark nPDF with DY in pA collisions
- Statistical uncertainty smaller than nPDF uncertainties: discriminating power
- With the muon spectrometer of ALICE and its absorber, opportunity to study DY in PbA collisions

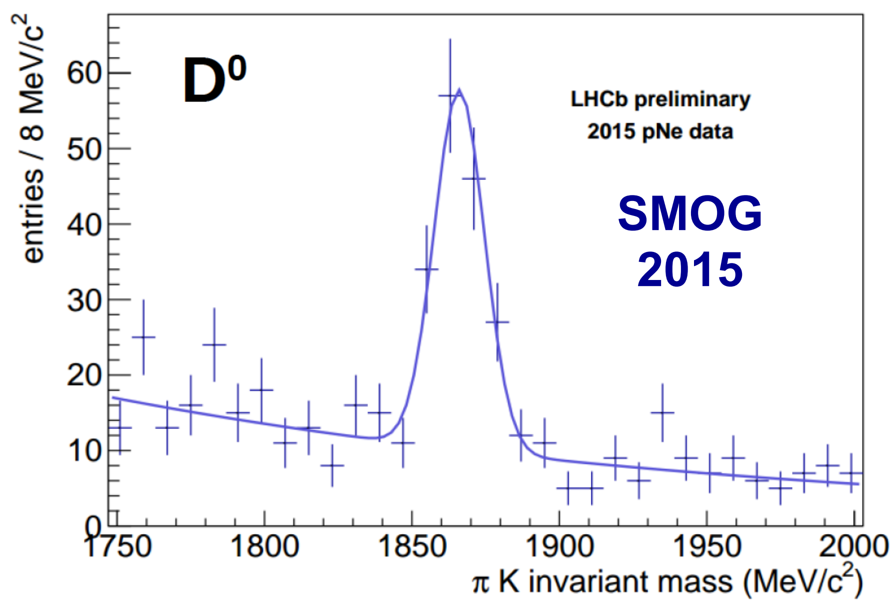


OPEN CHARM SIMULATIONS

- 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

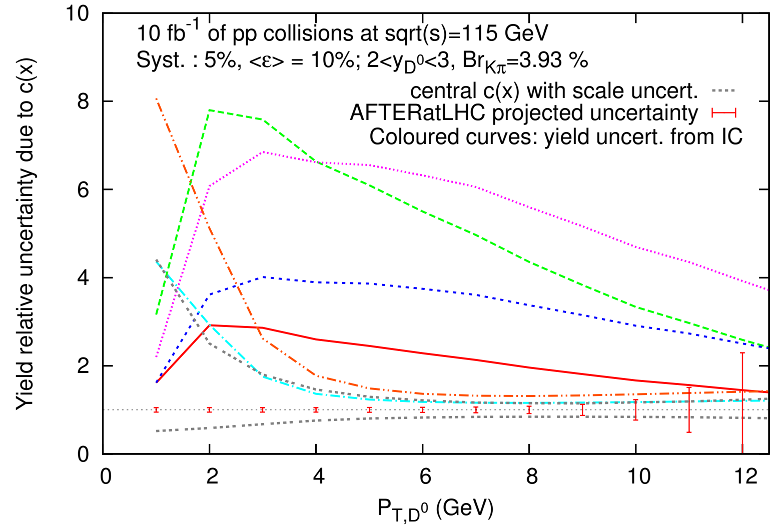
- With a LHCb-like detector , the background is well under control
- Looking at D→ Kπ gives direct access to charm-anticharm asymmetries



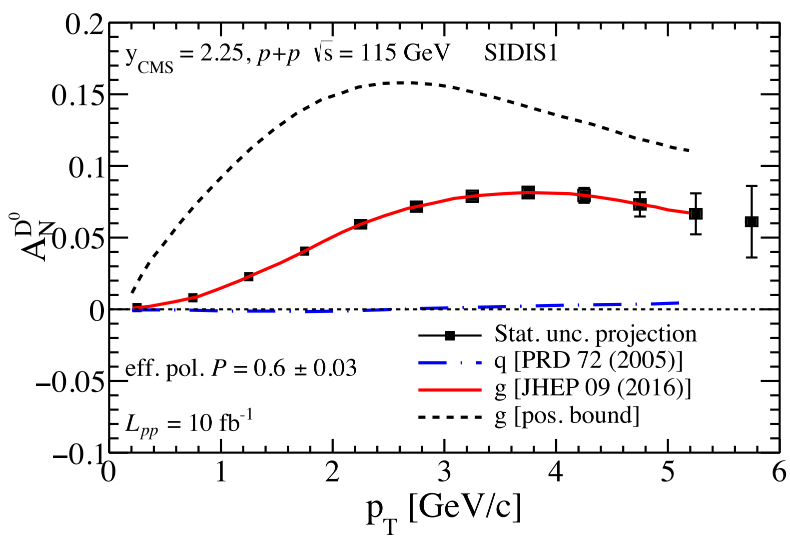


OPEN CHARM SIMULATIONS

- 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



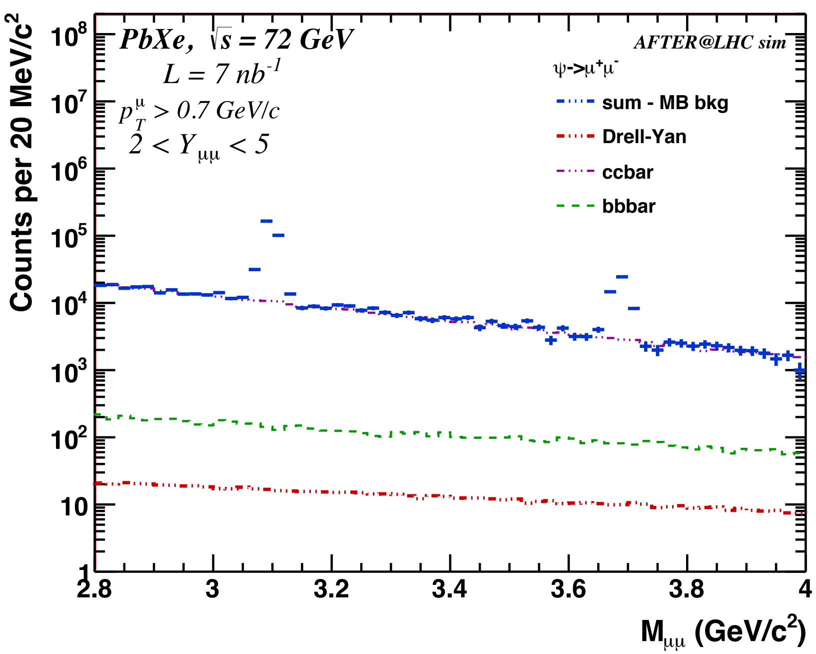
- D^0 can also be collected with a transversaly polarised target → never measured
- Both open and hidden charm → Gives access to tri-gluon correlation and the gluon Sivers effects → related to ℓ_g
- Statistical precision at percent level
- Interesting to measure charm and anticharm separately

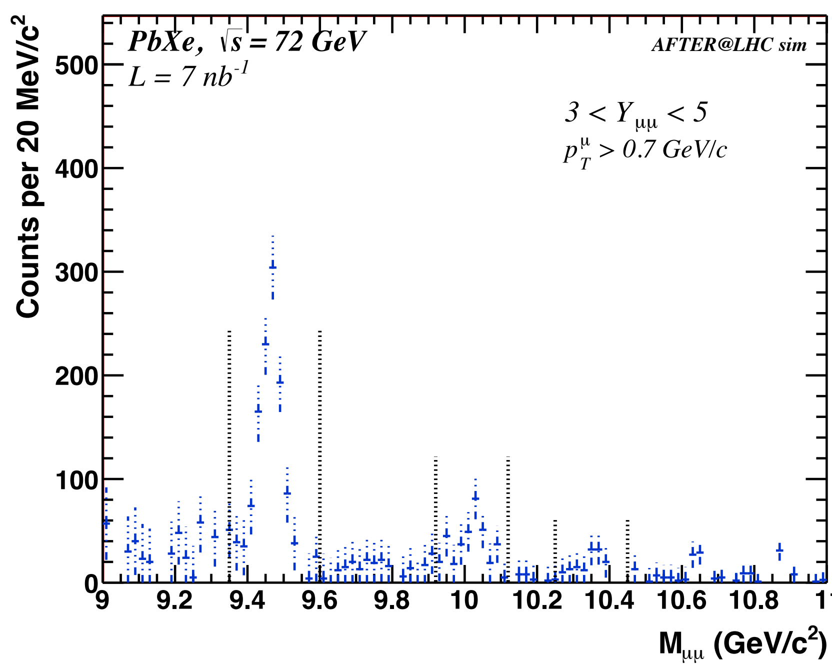


- As for AA collisions, nuclear modification factors vs p_T, y, centrality as well as azimuthal anisotropies (v_2) can also be measured

QUARKONIA SIMULATIONS

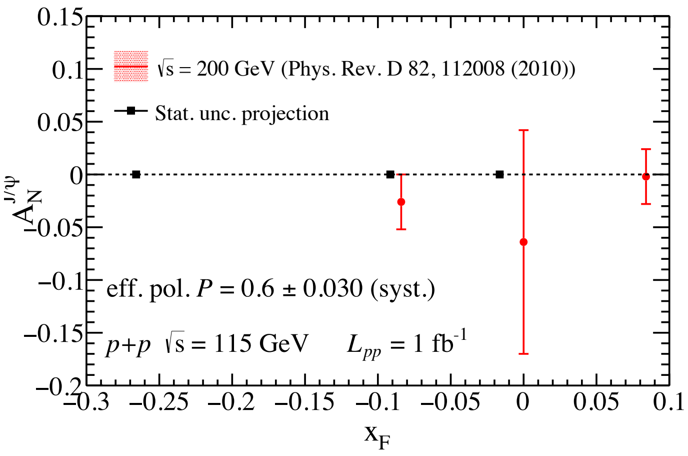
- Aim is to measure a complete set of heavy-flavours to use them as tools (TMD, PDF, nPDF, QGP effects)
- Wide rapidity coverage, p_T up to ~ 15 GeV and down to 0 GeV
- Unique opportunity to access $\chi_{c,b}$, η_c + associated production
- Full background simulations show very good prospects for all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

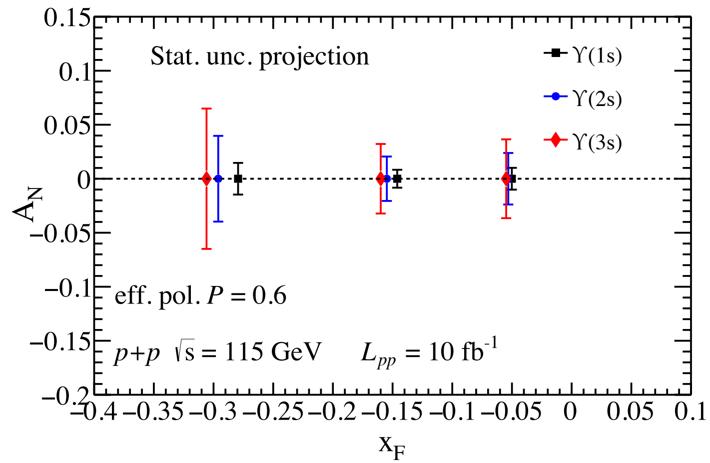




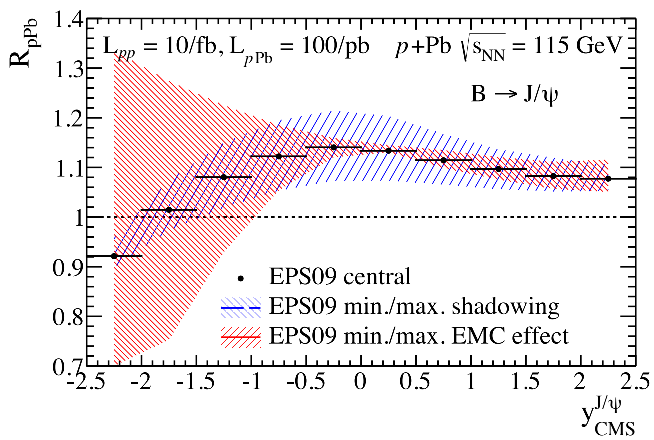
QUARKONIA SIMULATIONS

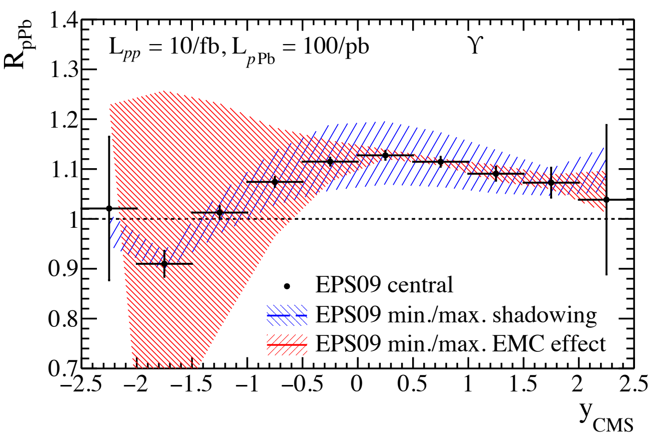
- ❑ A_N for all quarkonia can be measured → so far on J/ψ by PHENIX with large uncertainties
- ❑ Completely new perspectives to study the gluon Sivers effect





- ❑ 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





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

- An expression of interest to be submitted to the LHCC is beeing written

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

BACKUP

(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

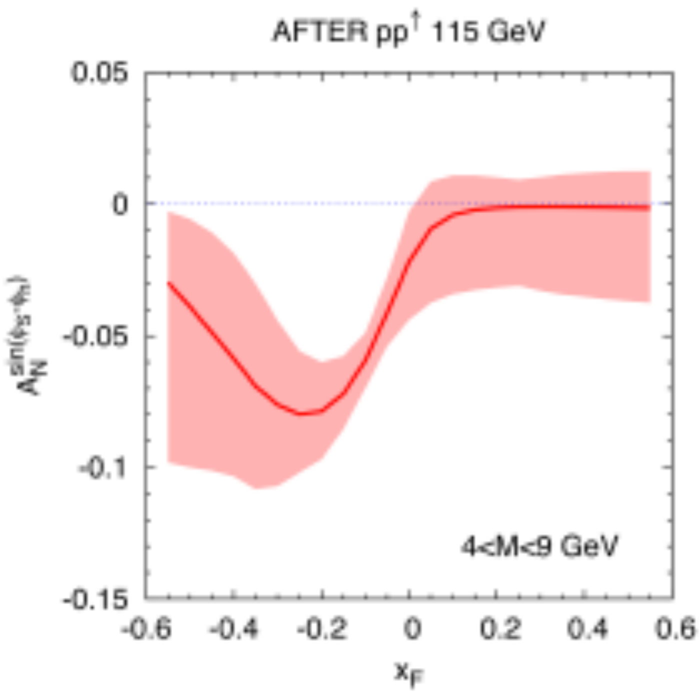
(Quark) Sivers effects with a transversely polarized target

- ❑ Can be probed with the Drell-Yan process

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^{\uparrow}$	$\mathscr{L}$ ($\mathrm{nb}^{-1}\mathrm{s}^{-1}$)
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

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



Prediction for AFTER

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

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 $h_1^{\perp g}$

- ❑ 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

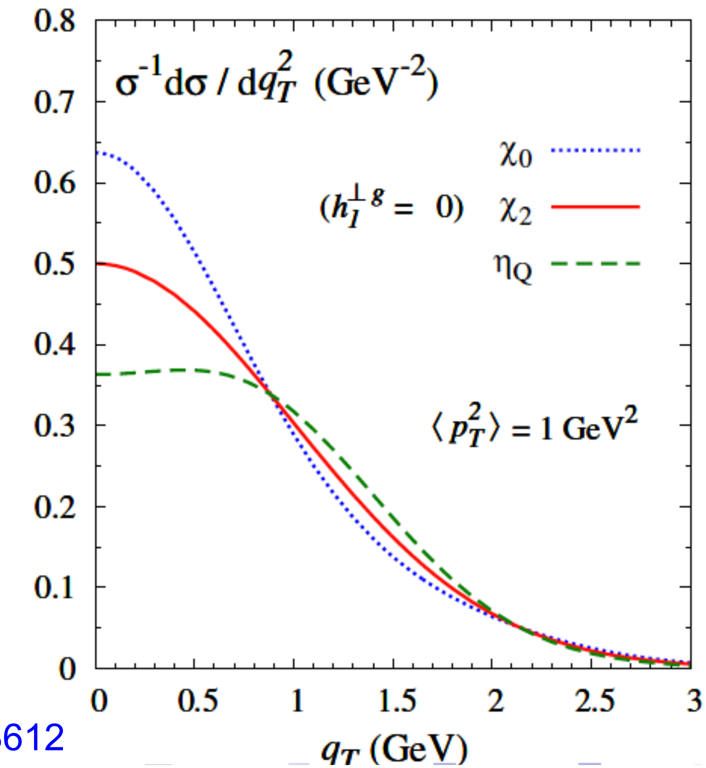
$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \ \& \ \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

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

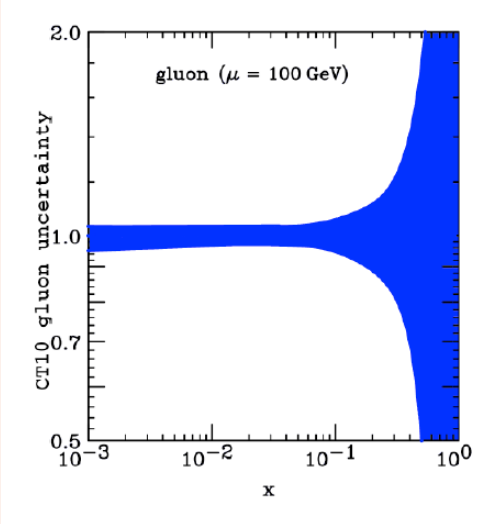
Den dunnen et al., PRL 112 (2014) 212001, J. P. Lansberg, Transversity 2014

PHYSICS HIGHLIGHTS FOR AFTER@LHC

p-p and p-A @ $\sqrt{s_{NN}}$ = 115 GeV

Nucleon partonic structure

- ❑ Gluon PDF in the proton → large uncertainty at large x. DIS not ideal
- ❑ $g_n(x) = g_p(x)$?
- ❑ Experimental probes: quarkonia, isolated photons, high p_T jets
- ❑ Multiple probes essential to check factorization



Heavy quark distribution at large x in the proton

- ❑ Pin down Intrinsic charm
- ❑ Experimental probes: open heavy flavors

Spin Physics

Gluon Sivers effect

Linearly polarized gluons: $h_1^{\perp g}$

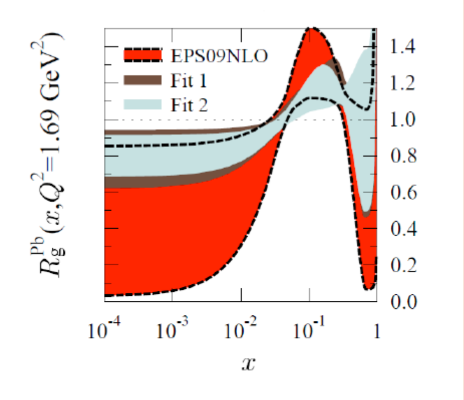
STSA in HF and DY studies

W and Z bosons production near threshold

p-A @ $\sqrt{s_{NN}}$ = 115 GeV and Pb-A @ $\sqrt{s_{NN}}$ = 72 GeV

Gluon distribution in nucleus at large x

- ❑ Large uncertainty at high x
- ❑ EIC, LHeC experiments do not help much



Quark Gluon Plasma

- ❑ ϒ sequential suppression
- ❑ Quarkonium excited state suppression
- ❑ Jet-HF quenching
- ❑ Direct photons

Ultra-peripheral collisions

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

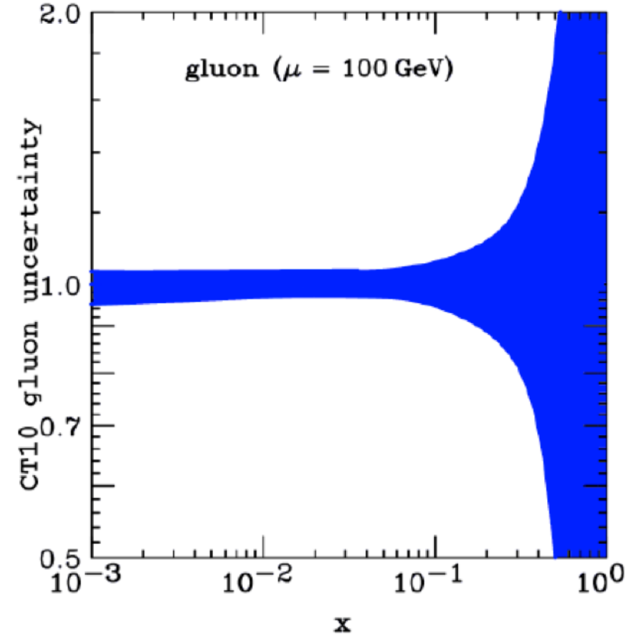
  D. Diakonov et al., JHEP 1302 (2013) 069
- Isolated photons

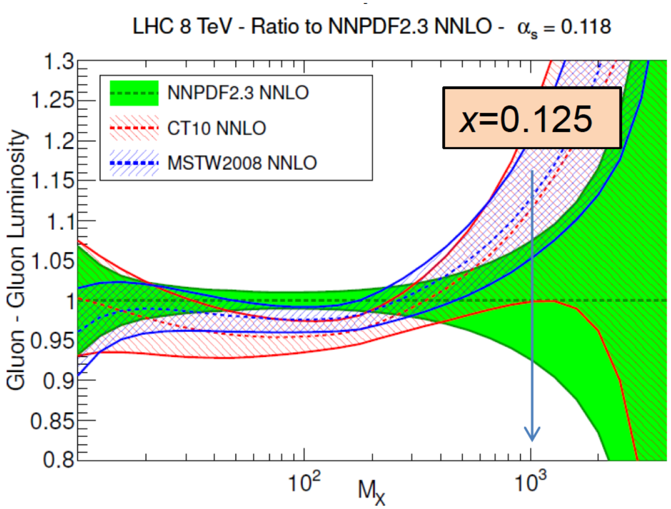
  D. d'Enterria, R. Rojo, Nucl. Phys. B860 (2012) 311
- Jets ($20 \leq p_T \leq 40$ GeV/c)

- ❑ 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

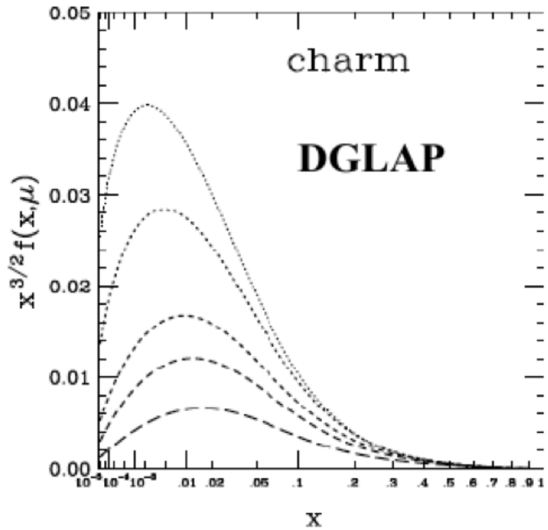
- ❑ Intrinsic charm is a rigorous property of QCD

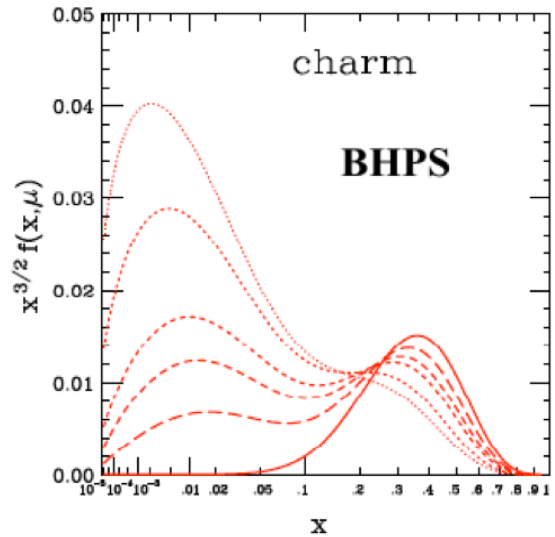
- ❑ Different charm pdfs (DGLAP or models with intrinsic charm) are in agreement with DIS data

- ❑ Important for high energy neutrino and cosmic ray physics

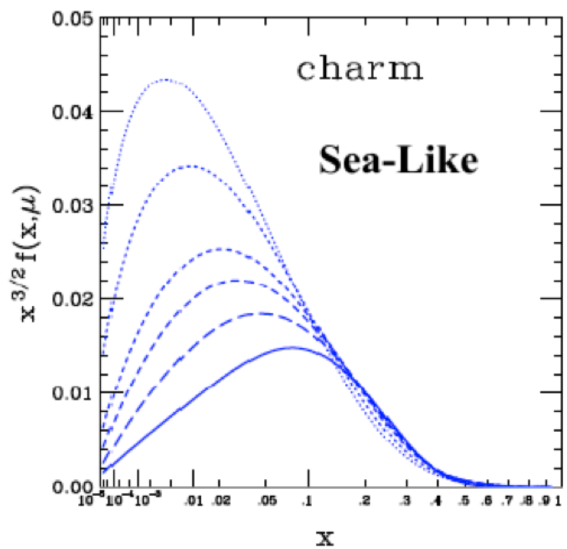
- ❑ Requirement

  - 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)

Luminosities in p+p and p+A at 115 GeV

Instantaneous luminosity:

$$\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

l is a target thickness

Extracted beam

Target	ρ (g.cm^{-3})	A	L (μb^{-1}.s^{-1})	$\int$L (pb^{-1}.yr^{-1})
Liq H_2 (1m)	0.07	1	2000	20000
Liq D_2 (1m)	0.16	2	2400	24000
Be (1cm)	1.85	9	62	620
Cu (1cm)	8.96	64	42	420
W (1cm)	19.1	185	31	310
Pb (1cm)	11.35	207	16	160

Internal gas target

Beam	Target	Usable gas zone (cm)	Pressure (Bar)	L (μb^{-1}.s^{-1})	$\int$L (pb^{-1}.yr^{-1})
p	Perfect gas	100	10^{-9}	10	100

With pressure of 10^{-6} mbar - 3 times SMOG – one gets 100 pb^{-1} yr^{-1}

→ target storage cell that can be **polarised**

P = 10^{-4} mbar

Advances in High Energy Physics, Volume 2015 (2015), Article ID 463141

Integrated luminosities with 10^7 s (LHC year – 9 months of running)

For 1m long H_2 target

$$\int\mathcal{L} = 20\ \mathrm{fb^{-1}yr^{-1}}$$

$$\int\mathcal{L} = 10\ \mathrm{fb^{-1}yr^{-1}}$$ for P = 10^{-4} mbar

Large luminosities comparable to LHC, 3 orders of magnitude larger that at RHIC

Similar integrated luminosities in **pA** in the target storage cell case as with the extracted beam option

Luminosities in A+A at 72 GeV

Instantaneous luminosity:

$$\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$$

l is a target thickness

Extracted beam

Target	ρ (g.cm^{-3})	A	L (μb^{-1}.s^{-1})	∫L (pb^{-1}.yr^{-1})
Liq H_2 (1m)	0.07	1	0.8	0.8
Liq D_2 (1m)	0.16	2	1	1
Be (1cm)	1.85	9	0.025	0.025
Cu (1cm)	8.96	64	0.017	0.017
W (1cm)	19.1	185	0.013	0.013
Pb (1cm)	11.35	207	0.007	0.007

Internal gas target

Beam	Target	Usable gas zone (cm)	Pressure (Bar)	L (μb^{-1}.s^{-1})	∫L (pb^{-1}.yr^{-1})
Pb	Perfect gas	100	10^{-9}	0.001	0.001

$P = 10^{-6}$ *mbar*

→ target storage cell that can be **polarised**

Integrated luminosities with 10^6 s (Pb LHC year – 1 months of running)

For 1m long H_2 target

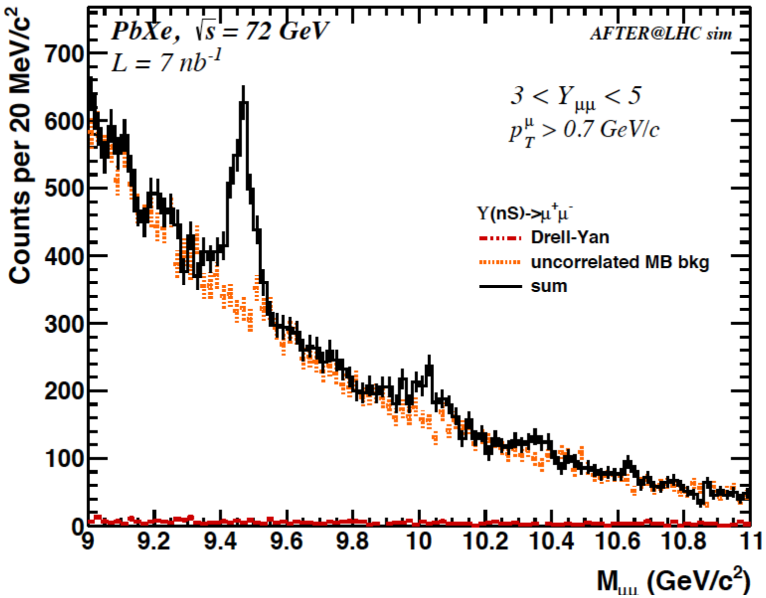
$$\int\mathcal{L} = 0.8\ \mathrm{pb}^{-1}\mathrm{yr}^{-1}$$

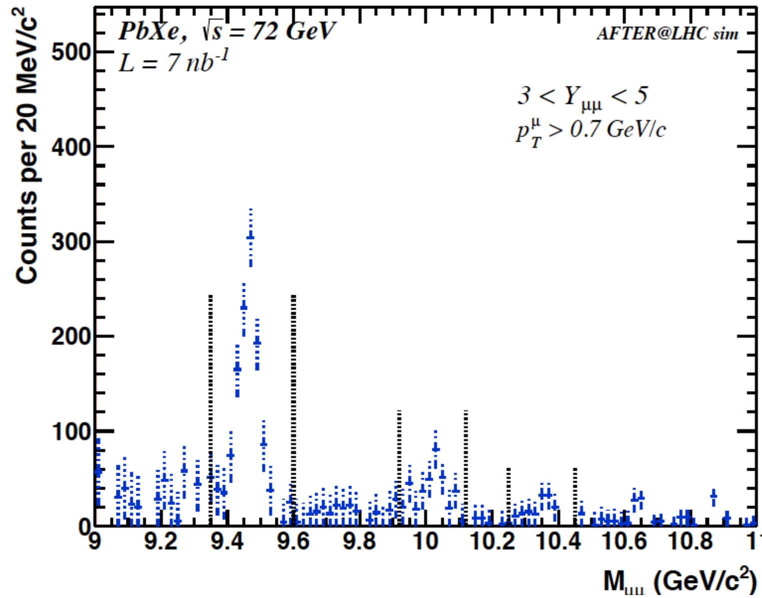
For 1cm long Pb target

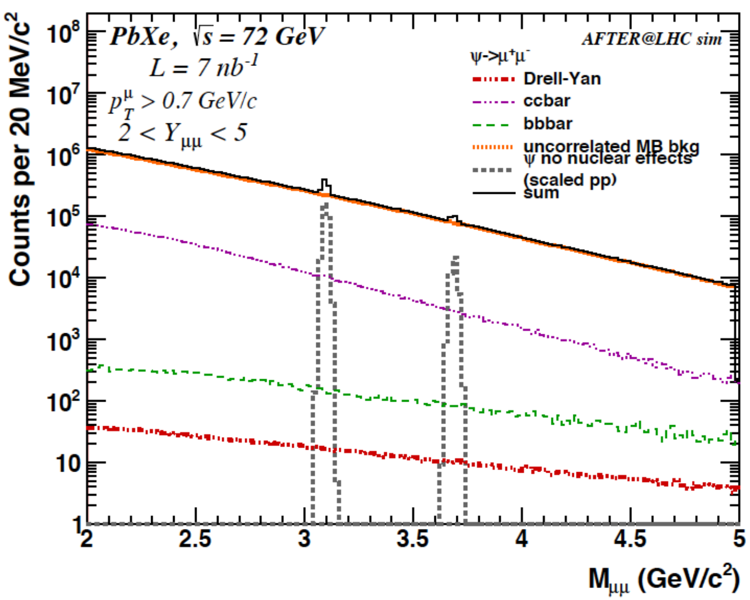
$$\int\mathcal{L} = 7\ \mathrm{nb}^{-1}\mathrm{yr}^{-1}$$

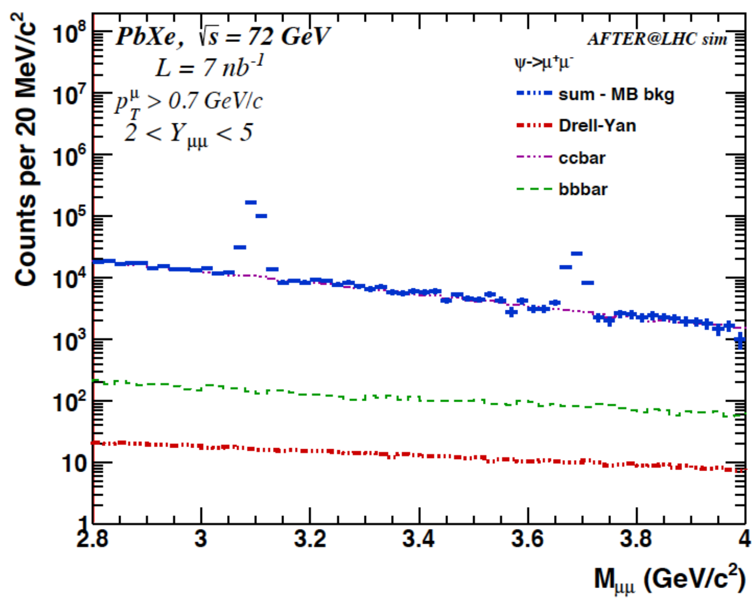
$$\int\mathcal{L} = 0.001\ \mathrm{pb}^{-1}\mathrm{yr}^{-1} \qquad P = 10^{-6}\ \mathit{mbar}$$

Nominal LHC collider luminosity for PbPb: 0.5 nb^{-1}


PbXe, √s = 72 GeV
AFTER@LHC sim
L = 7 nb⁻¹
3 < Y_μμ < 5
p_T^μ > 0.7 GeV/c
Y(nS)->μ⁺μ⁻
Drell-Yan
uncorrelated MB bkg
sum
Counts per 20 MeV/c²
M_μμ (GeV/c²)


PbXe, √s = 72 GeV
AFTER@LHC sim
L = 7 nb⁻¹
3 < Y_μμ < 5
p_T^μ > 0.7 GeV/c
Counts per 20 MeV/c²
M_μμ (GeV/c²)


PbXe, √s = 72 GeV
AFTER@LHC sim
L = 7 nb⁻¹
p_T^μ > 0.7 GeV/c
2 < Y_μμ < 5
ψ->μ⁺μ⁻
Drell-Yan
ccbar
bbbar
uncorrelated MB bkg
ψ no nuclear effects
(scaled pp)
sum
Counts per 20 MeV/c²
M_μμ (GeV/c²)


PbXe, √s = 72 GeV
AFTER@LHC sim
L = 7 nb⁻¹
p_T^μ > 0.7 GeV/c
2 < Y_μμ < 5
ψ->μ⁺μ⁻
sum - MB bkg
Drell-Yan
ccbar
bbbar
Counts per 20 MeV/c²
M_μμ (GeV/c²)