Prospects for high-luminosity fixed-target physics at the LHC

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Outline

- Context and framework
- Advantages of the fixed target mode versus the collider mode
- Physics motivations for a high-luminosity fixed-target programme at the LHC
  - Explore the high-momentum fraction x frontier in nucleons and nuclei
  - Spin and 3D nucleon structure
  - Heavy ion physics at large rapidity
- Technological solutions and detector contraints
- A selection of physics projections for a high-luminosity fixed-target programme
- Conclusions

Context and framework

- First expressions of interest from individuals towards a fixed-target programme at the LHC started in ~ 2011 :
  - A. Kurepin et al., «Charmonium production in fixed-target experiments with SPS and LHC beams at CERN», M.B. Phys. Atom. Nuclei (2011) 74: 446
  - S. J. Brodsky et al., "Physics opportunities of a fixed target experiment using LHC beams", Phys. Rep. 522 (2013) 239-255

- Creation of a study group AFTER@LHC in 2013 with ~ 30 colleagues (theorists, members of experimental collaborations : ALICE, LHCb, STAR, COMPASS)

- First pilot runs (2012/2013) of fixed-target collisions in LHCb with the SMOG system allowing to inject noble gas inside the Vertex Locator (VELO) of LHCb

- Publication of a special issue on «Physics at a fixed-target experiment using the LHC beams» by AFTER@LHC members (Adv. High Energy Phys., Vol 2015)

- Review from the AFTER@LHC study group (2018) covering physics motivation, possible technical implementation, detector considerations (LHCb and ALICE), simulation/projections for several observables: arXiv: 807.00603

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

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arXiv:1807.00603v2 [hep-ex] 9 Nov 2018

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.

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[1] Editor
[2] Section editor

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Context and framework

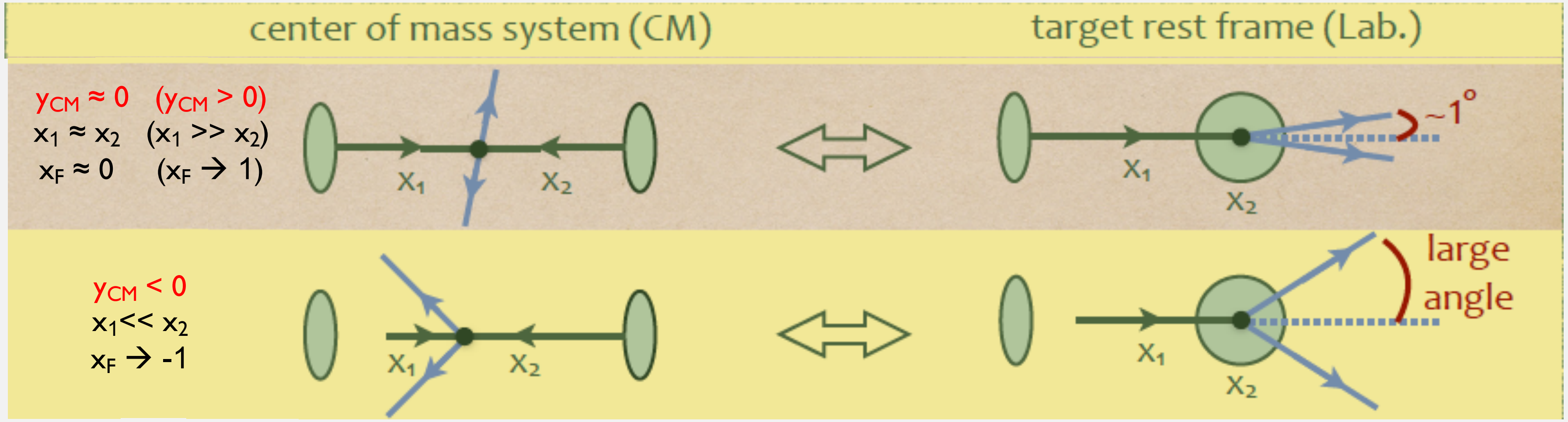
- The high-luminosity fixed-target projects are discussed within the Physics Beyond Collider (PBC) initiative from CERN since 2016

- Deliverable of the PBC also served as input to the next update of the European Strategy for Particle Physics
  - *Physics Beyond Collider: QCD Working Group Report (A. Dainese et al., arXiv:1901.04482)*
  - *Summary Report of Physics Beyond Colliders at CERN (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: 2019-001 (yet to appear)*

- 3 contributions in favor of a high-luminosity fixed-target programme submitted to ESPP :
  - *Physics opportunities for a fixed-target programme in the ALICE experiment (F. Gallucio et al., ID47) → 11 authors*
  - *Community support for a fixed-target programme for the LHC (J. D. Bjorken et al., ID66) → endorsed by 148 physicists*
  - *The LHCSpin project (C. Aidal et al., ID111) → 31 authors*

Advantages of the fixed-target mode versus the collider mode

- Several unique assets of the fixed-target mode w.r.t to the collider mode:
  - **Accessing the high Feynman-x_F domain** ($x_F = p_z/p_{zmax} = x_1 - x_2$)



→ Entire CM forward hemisphere ($y_{CM} > 0$) within $0° < \theta_{lab} < 1°$ (high multiplicities → large detector occupancy)

→ Backward physics ($y_{CM} < 0$) : larger angle in the laboratory frame (lower detector occupancy) : access to parton with momentum fraction $x_2 \rightarrow 1$ in the target (ie. $x_F \rightarrow -1$)

Advantages of the fixed target mode versus the collider mode

- **Target-species versatility :**
  - Change the target type in a reduced amount of time
  - Study the atomic-number dependence of nuclear effects
  - Isospin studies with deuteron and ^{3}He targets

- **Target polarisation (depending on the technology used) :**
  - The only way to make spin physics at the LHC complex
  - Access to single-spin asymmetries for several probes at large-x, where they are the largest
  - Polarised neutron studies with $^{3}\mathrm{He}^{\uparrow}$

- **Outstanding luminosities :**
  - Thanks to high target density and large LHC beam luminosity
  - Without affecting the LHC performances (parasitic mode with respect to the collider mode)

Advantages of the fixed target mode versus the collider mode

➢ **Probe a different energy range with the same accelerator :**

- Same $\sqrt{s_{NN}}$ for pH, pd, pA systems (115 GeV) → interesting for R_{pA} measurements
- Same $\sqrt{s_{NN}}$ for PbH, Pbd, PbA systems (72 GeV) → in between top SPS and RHIC energies

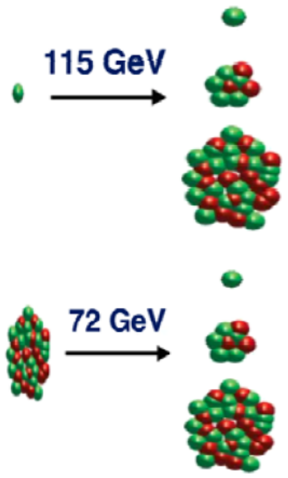
Energy range

7 TeV proton beam on a fixed target

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

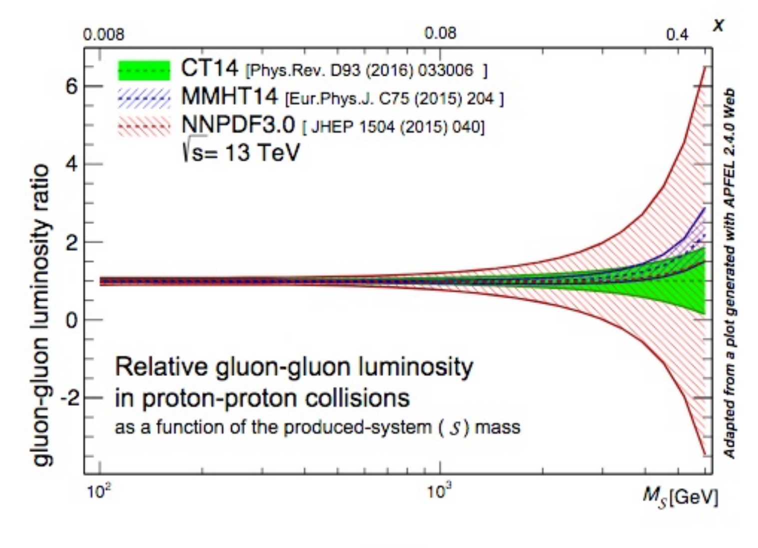
2.76 TeV Pb beam on a fixed target

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

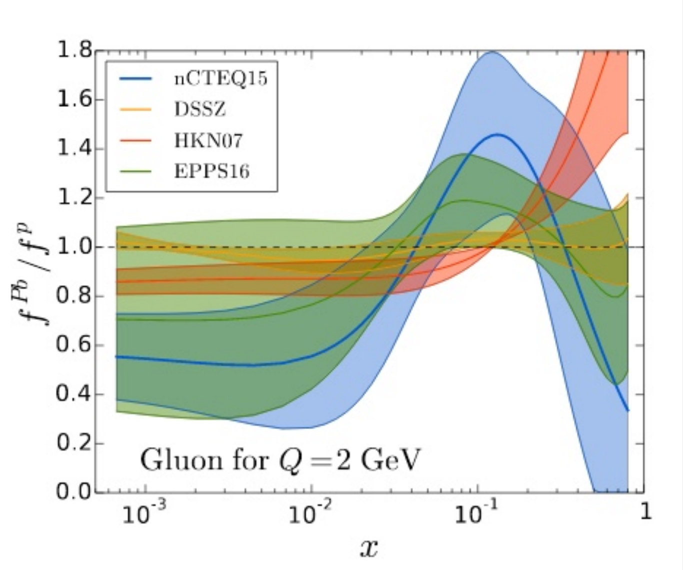


Physics motivations : Explore the high-momentum fraction x frontier in nucleons and nuclei

- **With an emphasis on the high-x gluon and heavy-quark content of the nucleon and nuclei**
  - Improve the knowledge of PDF for the gluon at large-x [also for strange, charm and bottom quark PDFs]
    - → Precise high-x PDFs crucial theoretical inputs for predictions of processes involving heavy new states in BSM
  - Study a possible non-perturbative source of c/b quarks in the proton carrying a relevant fraction of its momentum
    - → Connexion with CR physics : input to reduce the uncertainties on the prompt atmospheric neutrino flux
  - Study the origin of the nuclear EMC effect in nuclei (with gluon and sea quarks)



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



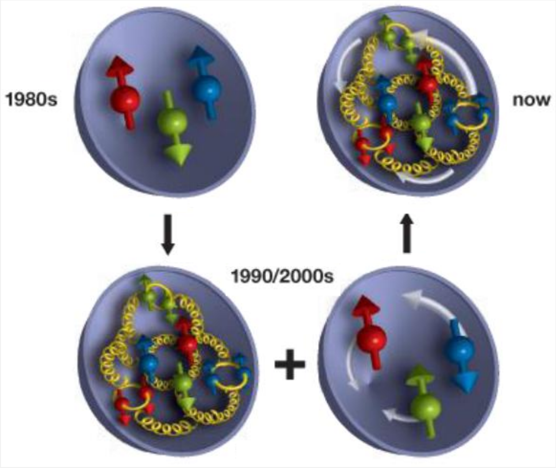
Gluon density in Pb nuclei

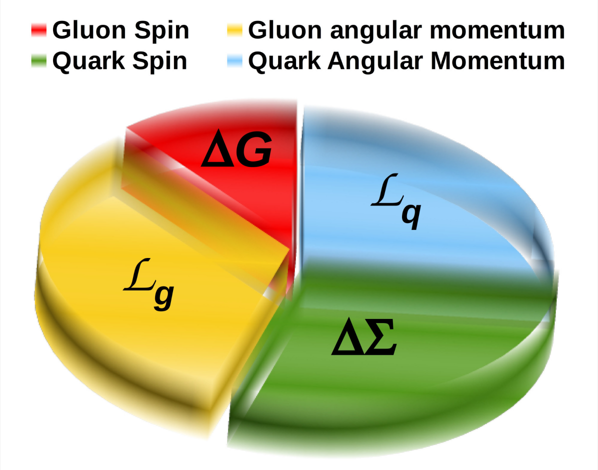
Physics motivations : Spin and 3D nucleon structure

❑ Advance our understanding of the dynamics and spin of quarks and gluons inside (un)polarised nucleons

- From the spin crisis to the spin puzzle
- For longitudinally polarised nucleon, with helicity +1/2:

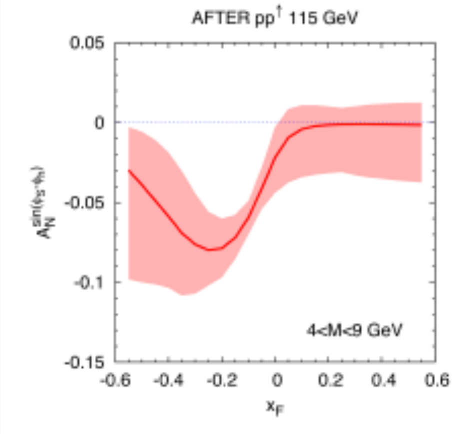
$$\frac{1}{2} = \underbrace{\frac{1}{2}\Delta\Sigma}_{\text{Spin of quarks and antiquarks}} + \underbrace{\Delta G}_{\text{Spin of gluons}} + \underbrace{\ell_g + \ell_q}_{\text{Orbital angular momentum of quarks and gluons}}$$





M. Anselmo, Feb. 2013(Courtesy U. d'Alessio)

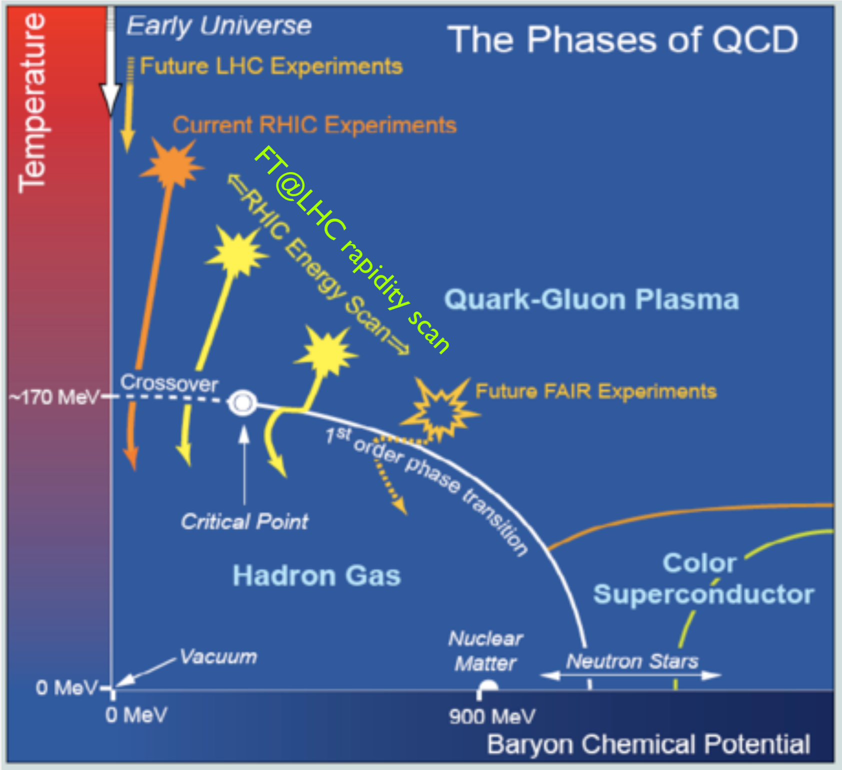
- First hint by COMPASS that $\ell_g \neq 0$
- Access information on the orbital motion of the partons inside bound hadrons via Single Spin Asymmetries (Sivers effect)
  - Sivers effects : correlation between the parton transverse momentum k_T and the proton spin
    - Gluon Sivers effect at large x_F with gluon sensitive probes
    - Quark Sivers effect at large x_F with Drell-Yan
- Test TMD factorization formalism → sign change of A_N between SIDIS and DY

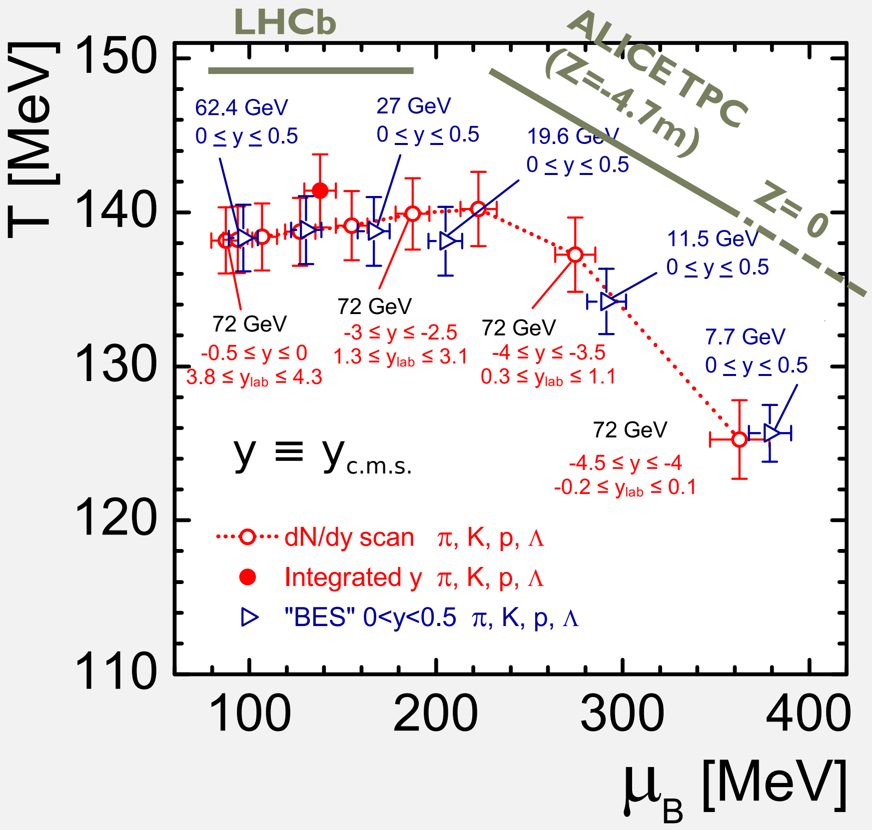


Physics motivations : heavy-ion physics at large rapidity

❑ **Advance the understanding of hadronic matter properties under extreme conditions (QGP) and explore the phase diagramme of nuclear matter thanks to a rapidity scan down to the target rapidity**

- Systematic studies of the medium properties with three experimental degrees of freedom : rapidity scan, different colliding systems, centrality dependence
- Rapidity scan at 72 GeV with FT@LHC can complement the RHIC beam energy scan from 62.4 GeV down to 7.7 GeV (at y_{cms} ~ 0)
- A novel way to search for the QCD critical point and probe the nature of the phase transition to confined partons



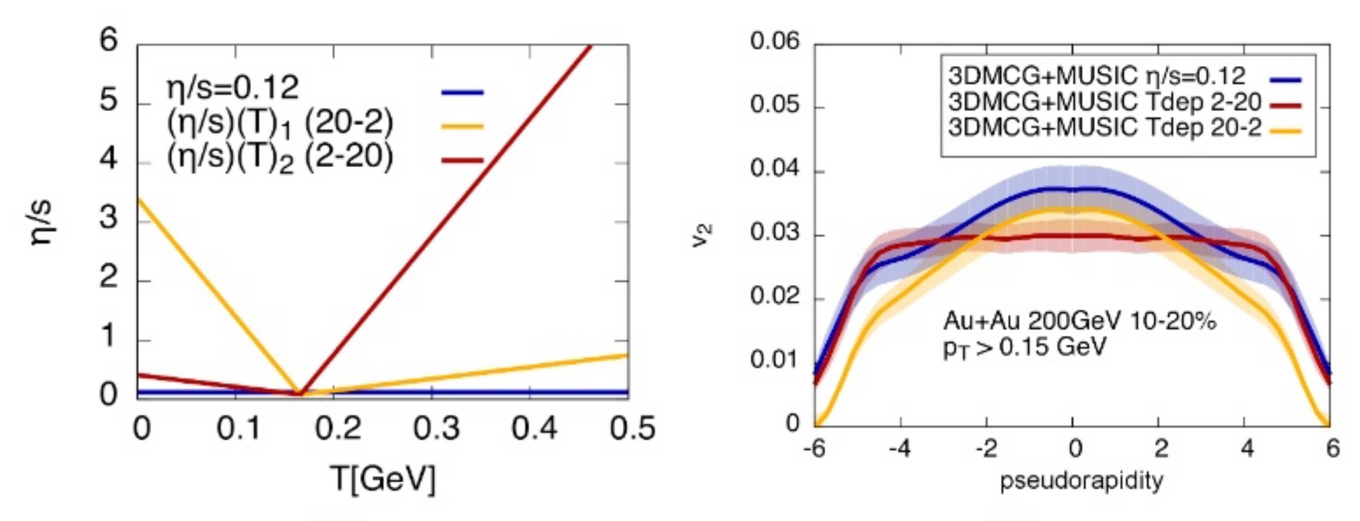


V. Begun, D. Kikola, V. Vovchenko, D. Wielanek, PRC 98 (2018) 034905

Physics motivations : heavy-ion physics at large rapidity

- **Advance our understanding of QGP macroscopic properties by probing the temperature dependence of the shear viscosity to entropy density ratio (η/s) of the created matter**

  - Thanks to particle yields and flow (v_N) coefficients
  - Compare to hydrodanymic models which include the medium longitudinal expansion (ie. not only the transverse dynamics of the QGP at mid-y)
  - Clarification of collective effects between SPS and LHC energies



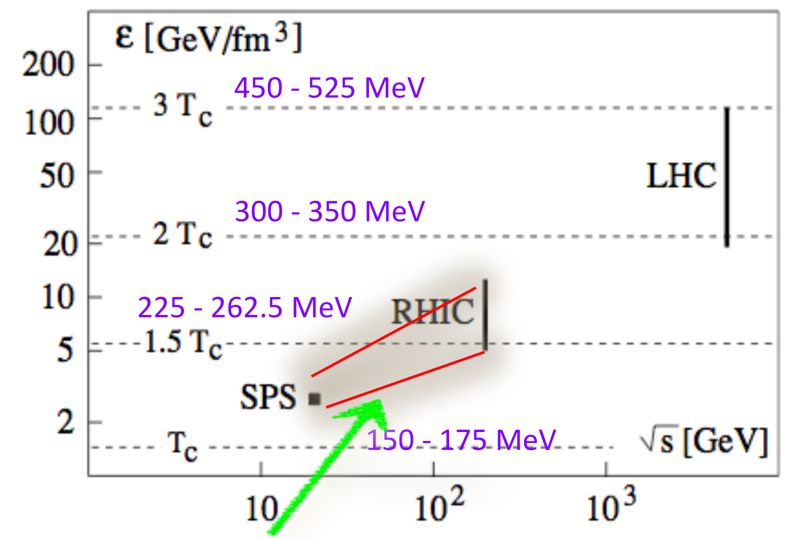
(a) (b)

- **Test the factorization of Cold Nuclear Matter effects with the Drell-Yan process**
  - Probe insensitive to Quark gluon Plasma formation, better accessible w.r.t to collider mode due to lower background
  - Cannot be done at an EIC

Physics motivations : heavy-ion physics at large rapidity

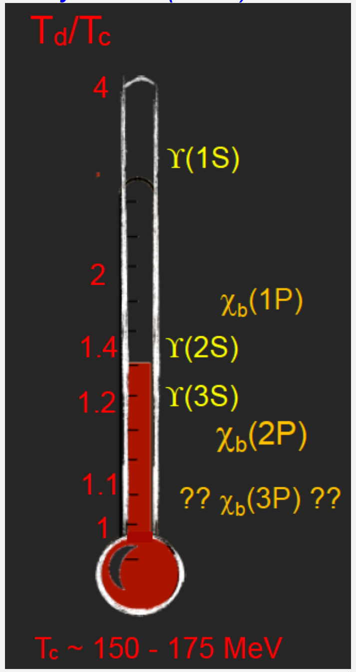
- **Search for the phase transition by looking at $\Upsilon(nS)$ suppression as a function of rapidity and system size**
- In PbA collisions at $\sqrt{s_{NN}}$ ~ 72 GeV, $\Upsilon(3S)$ and $\Upsilon(2S)$ are expected to be suppressed : calibration of the QGP thermometer in AA collisions
- Clarify the charmonium suppression pattern between top SPS and RHIC energies (no recombination, high statistics for hard probes)
- Probe large gluon x_2 in the target, in particular with $\Upsilon(1S)$ → constrain gluon anti-shadowing and EMC effects in pA

Satz, J. Phys. G32 (2006) R25

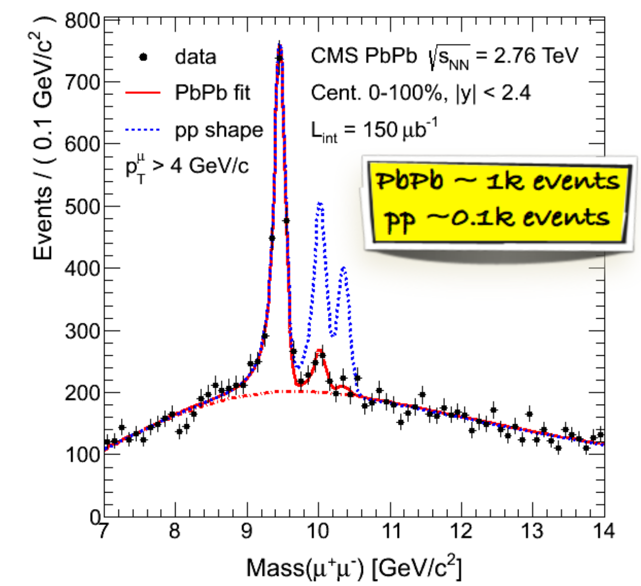


PbA fixed-target
$\sqrt{s_{NN}}$ ~ 72 GeV

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



Dissociation temperature from lattice QCD (+hydro)

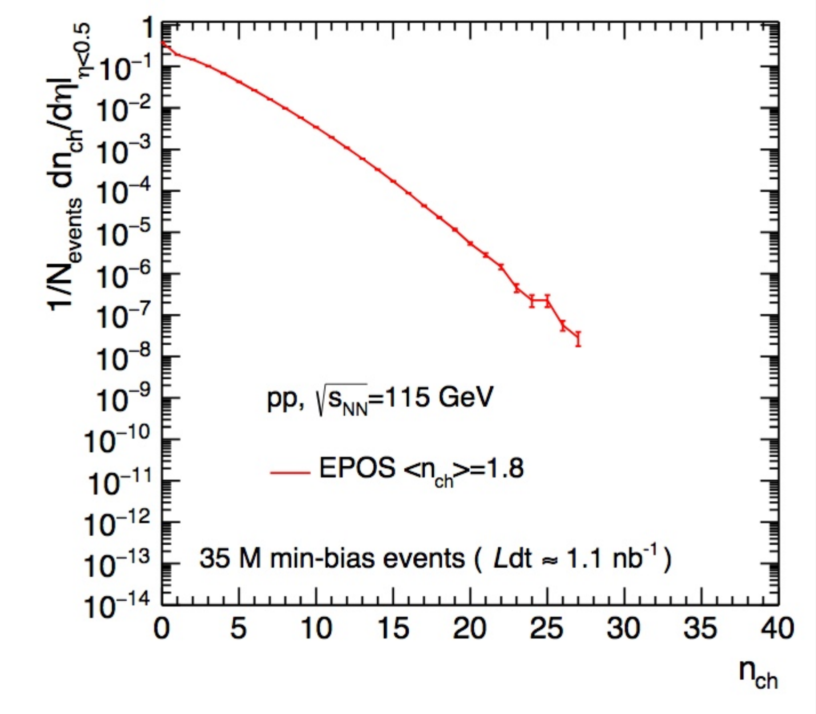


Phys. Rev. Lett. 109 (2012) 222301

Physics motivations : heavy-ion physics at large rapidity

- **Study of the heavy-quark energy loss and their interaction with the surrounding nuclear matter**
  - Produced in hard scattering at early stages of collision, loose energy while crossing the hot and dense medium
  - Distinguish between collisional and radiative energy loss mechanisms with high precision D^0 yield versus p_T and rapidity
  - R_{AA} and v_2 of B and D mesons → transport properties of the QGP, degree of thermalization
  - Baseline for quarkonium suppression studies

- **Search for a collective dynamics of partons in small systems at low energy**
  - Benefit from luminosity larger than at RHIC by several orders of magnitude (differential studies of J/ψ, D versus multiplicity, also v_2)
  - Can probe rare events with ~15 times the average multiplicity



Possible technical implementations of a fixed target setup

- Various ways of making fixed target collisions at the LHC with an **existing detector (focus on ALICE/LHCb)** :

  - **Internal Gas target :**
    - Already in use at the LHC with the SMOG system inside LHCb
      → already providing interesting physics results although the gas density is limited
    - Other technologies exist: storage cell inspired by HERMES experiment at HERA, gas-jet (RHIC polarimeter)
    - Benefit from the full p and Pb fluxes: 3.4×10^{18} p/s, 3.6×10^{14} Pb/s

  - **Internal Wire/Foil target (directly in the beam halo) :**
    - Used by HERA-B on the 920 GeV p beam and by STAR at RHIC
    - Recycling the beam halo onto a solid target

  - **Beam splitted via bent crystal coupled to a solid target :**
    - LHC beam halo is recycled :
      → Proton flux considered for the projections: ~ 5×10^{8} p/s*, Lead flux : ~ 2×10^{5} Pb/s*
    - Halo particles deflected by a bent crystal onto a solid target inside an experiment
    - Need to absorb the particles not interacting with the target

→ Luminosities with internal gas target or crystal-based solutions are not very different

* See caveats in slide 20

The landscape of the proposals in ALICE/LHCb beyond Run 3

LHC(b)SPIN?

EDM/MDM with bent crystal?

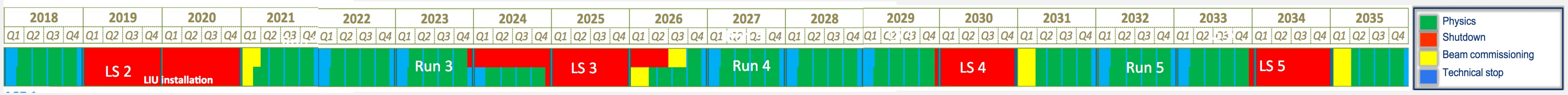
SMOG2

?

LHCb Upgrade (Phase 1)

LHCb Upgrade (Phase 2)

LHC injectors



ALICE Upgrade

new ITS3?

« All-silicon » new detector?

ALICE-FT with solid target?

Luminosity projections (SMOG2, LHCSpin)

CERN-PBC-Notes-2018-007

SMOG2 (up to ~ 100 x SMOG)

Reaction	DAQ time	Non coll. bunches	Lumi (nb^{-1})	Decays	SMOG yields	Scale factor	SMOG2 proj. yields
pAr	18 h	684	~ 2	$D^0 \to K^-\pi^+$	6450	62	400 k
				$D^+ \to K^-\pi^+\pi^+$	975		60 k
				$D_s^+ \to K^-K^+\pi^+$	131		8 k
				$D^{*+} \to D^0\pi^+$	2300		140 k
				$\Lambda_c^+ \to pK^-\pi^+$	50		3 k
				$J/\psi^+ \to \mu^+\mu^-$	500		30 k
				$\psi' \to \mu^+\mu^-$	20		1.2 k
pHe	84 h	648	7.6	$J/\psi^+ \to \mu^+\mu^-$	500	19.6	10 k
				$\psi' \to \mu^+\mu^-$	20		0.4 k

LHCSpin

Projections for Run4 → $L_{int} \sim 5\ fb^{-1}$ for pH↑ collisions ($\Phi \sim 3.8 \times 10^8$ p/s, $L_{inst} \sim 4.7 \times 10^{32}\ cm^{-2}.s^{-1}$, $t \sim 10^7$ s)

Maximum achievable luminosities with the LHCb detector*

Target			LHCb: proton beam ($\sqrt{s_{NN}}$ = 115 GeV) $\mathcal{L}$ [$cm^{-2}\ s^{-1}$]	σ_{inel}	Inel rate kHz	$\int \mathcal{L}$	Pb beam ($\sqrt{s_{NN}}$ = 72 GeV) $\mathcal{L}$ [$cm^{-2}\ s^{-1}$]	σ_{inel}	Inel rate kHz	$\int \mathcal{L}$
Internal gas target	Gas-Jet	H↑	4.3×10^{30}	39 mb	168	43 pb^{-1}	5.6×10^{26}	1.8 b	1	0.56 nb^{-1}
		H_2	1.0×10^{33}	39 mb	40000	10 fb^{-1}	1.18×10^{29}	1.8 b	212	118 nb^{-1}
		D↑	4.3×10^{30}	72 mb	309	43 pb^{-1}	5.6×10^{26}	2.2 b	1.2	0.56 nb^{-1}
		^{3}He↑	3.4×10^{32}	117 mb	40000	3.4 fb^{-1}	4.7×10^{28}	2.5 b	118	47 nb^{-1}
		Xe	3.1×10^{31}	1.3 b	40000	0.31 fb^{-1}	2.3×10^{28}	6.2 b	186	23 nb^{-1}
	Storage Cell	H↑	0.92×10^{33}	39 mb	35880	9.2 fb^{-1}	1.18×10^{29}	1.8 b	212	118 nb^{-1}
		H_2	1.0×10^{33}	39 mb	40000	10 fb^{-1}	1.18×10^{29}	1.8 b	212	118 nb^{-1}
		D↑	5.6×10^{32}	72 mb	40000	5.6 fb^{-1}	8.82×10^{28}	2.2 b	194	88 nb^{-1}
		^{3}He↑	1.3×10^{33}	117 mb	40000	13 fb^{-1}	8.25×10^{28}	2.5 b	206	83 nb^{-1}
		Xe	3.1×10^{31}	1.3 b	40000	0.31 fb^{-1}	3.0×10^{28}	6.2 b	186	30 nb^{-1}

* Assuming LHCb runs the full year in parallel in fixed target and collider mode. The storage cell is considered to be 1m long.
Maximum readout rate considered (40MHz in pp and 5MHz in AA). In PbA collisions, the rate is also limited by the beam lifetime (no more than 15% of the Pb beam flux used)

Toward a fixed-target setup for ALICE* : bent crystal + solid target

- Advantages of the bent crystal solution with respect to an internal solid target intercepting directly the beam halo:
  - Minimise impedance issue
  - Target system can be compact since the positionning of the target doesn't require to be controlled at the micron level
  - Better knowledge of the luminosity and control of the particle flux sent onto the target

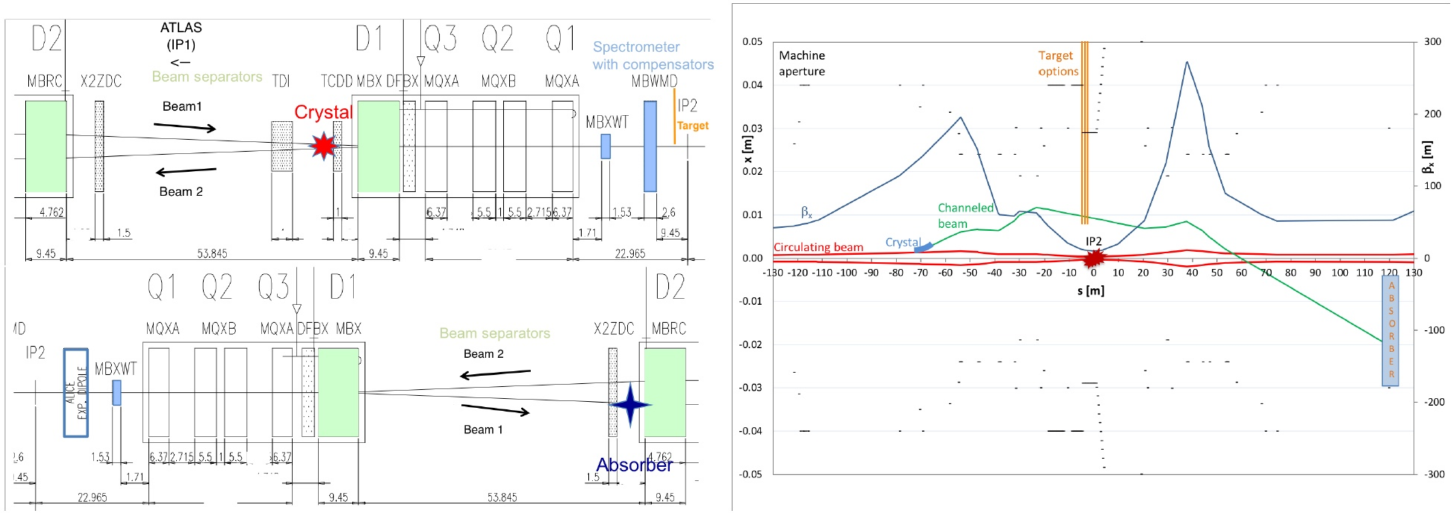
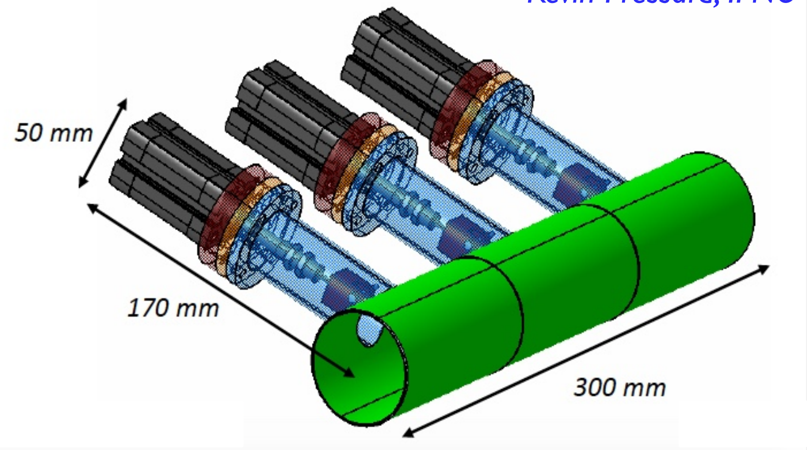


Figure 1: Left: A possible layout for an internal fixed-target experiment at the LHC: a bent crystal is used to deflect the beam halo onto an internal solid target. Right: Particle trajectories for an internal fixed-target experiment: a bent crystal splits and deflects the halo (green) from the circulating beam (red), and sends it on an internal target (orange) placed in front of the ALICE detectors; the non-interacting channeled particles are caught by an absorber downstream; a safe distance is maintained between the channeled beam (green) and the machine aperture (black).

Simulation of the deflected beam at ALICE IP, F. Galluccio, UA9

Kevin Pressard, IPNO

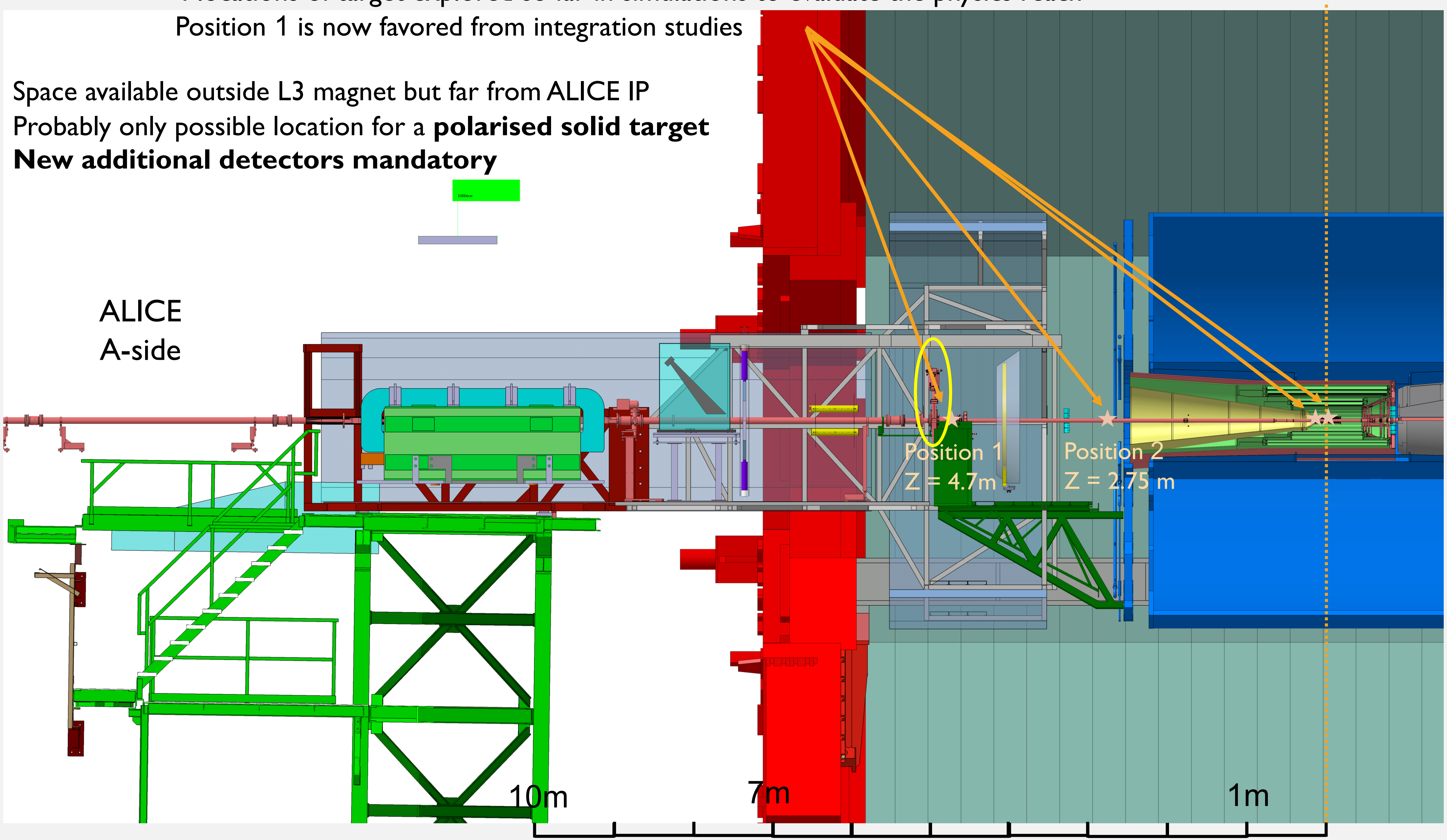


* Possibility to use a (polarised) gas target also considered (Varsaw group)

Exploring possible target locations in ALICE

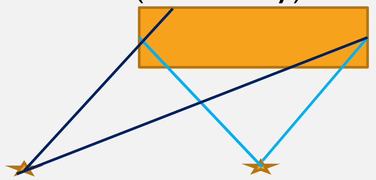
4 locations of target explored so far in simulations to evaluate the physics reach
Position 1 is now favored from integration studies

Space available outside L3 magnet but far from ALICE IP
Probably only possible location for a **polarised solid target**
New additional detectors mandatory



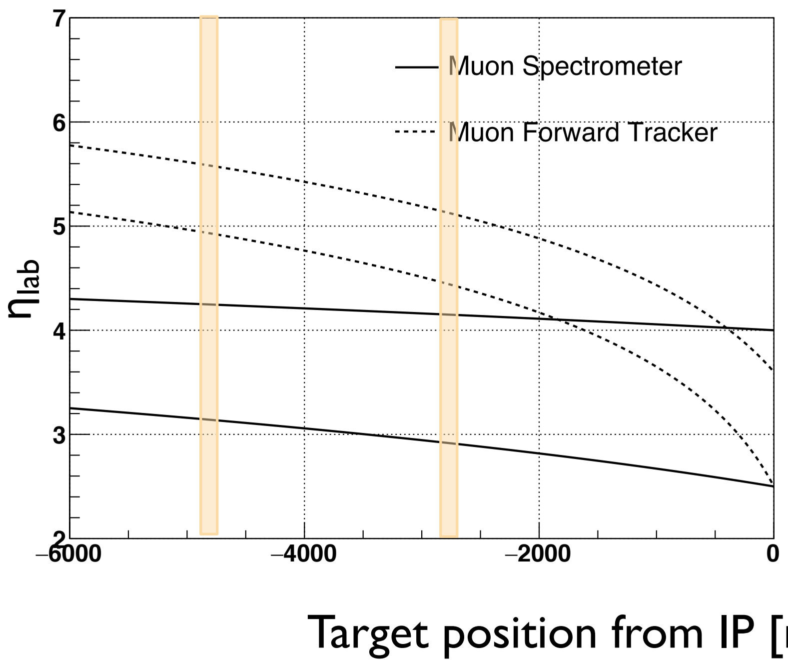
ALICE detector acceptance vs z_{target}

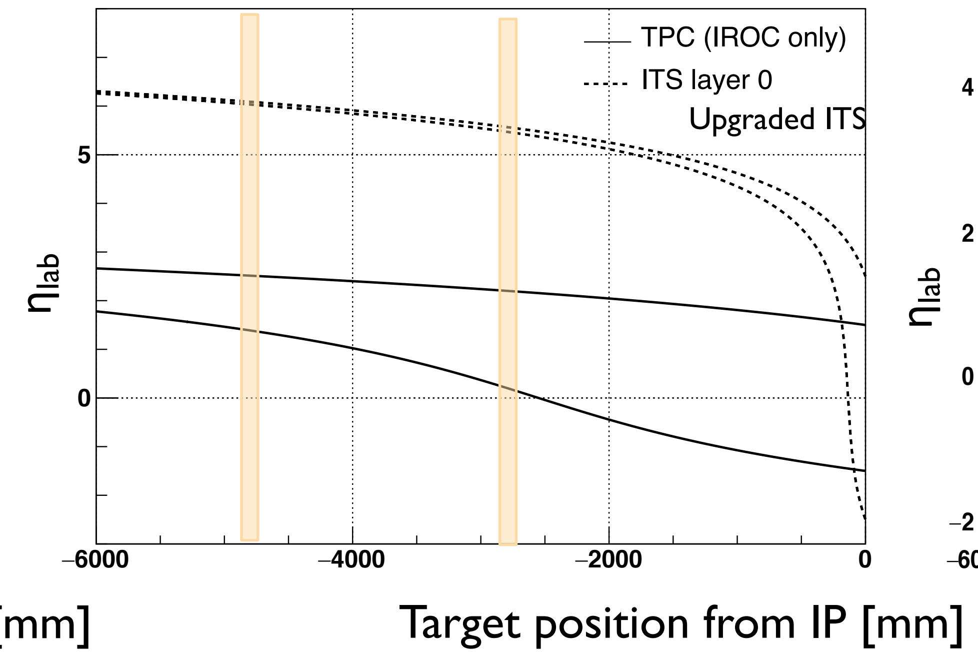
- Considering Z direction negative on A side and forward pseudo-rapidity in the lab defined positively

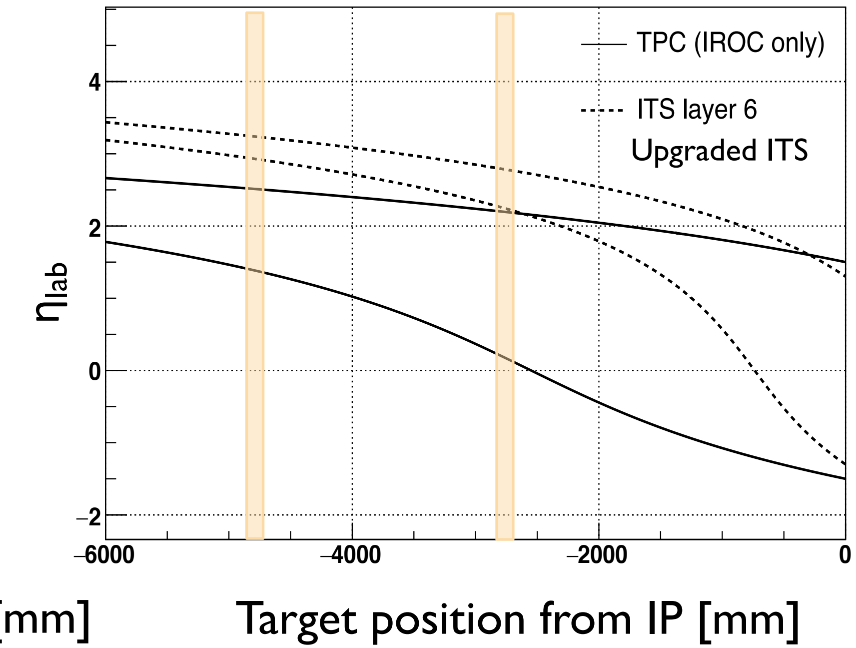


Position 1 Position2

Caveat: Simple geometrical considerations







If target at Z << 0, new vertex detector (and probably other detectors) needed

The tracking performances of the TPC and the effect of material budget for large negative Z have still to be studied

At large Z << 0, no acceptance shared anymore between MFT and muon spectrometer

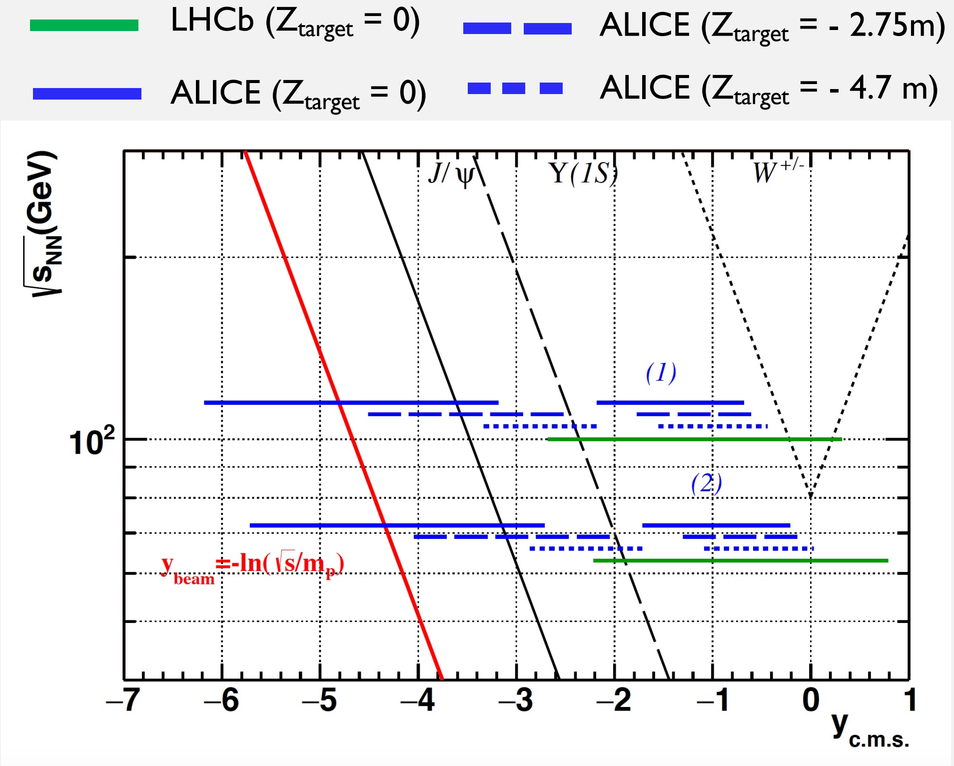
Achievable luminosities considering ALICE detector rate limitations*

Target		ALICE proton beam ($\sqrt{s_{NN}}$= 115 GeV) $\mathcal{L}$ [$cm^{-2}\ s^{-1}$]	Inel. rate [kHz]	$\int\mathcal{L}$	ALICE Pb beam ($\sqrt{s_{NN}}$= 72 GeV) $\mathcal{L}$ [$cm^{-2}\ s^{-1}$]	Inel. rate [kHz]	$\int\mathcal{L}$
Internal gas target (gas-jet option)	$H^{\uparrow}$	4.3×10^{30}	168	43 pb^{-1}	5.6×10^{26}	1	0.56 nb^{-1}
	H_2	2.6×10^{31}	1000	0.26 fb^{-1}	2.8×10^{28}	50	28 nb^{-1}
	$D^{\uparrow}$	4.3×10^{30}	309	43 pb^{-1}	5.6×10^{26}	1.2	0.56 nb^{-1}
	$^3He^{\uparrow}$	8.5×10^{30}	1000	85 pb^{-1}	2.0×10^{28}	50	20 nb^{-1}
	Xe	7.7×10^{29}	1000	7.7 pb^{-1}	8.1×10^{27}	50	8.1 nb^{-1}
Beam splitting	C	3.7×10^{30}	1000	37 pb^{-1}	5.6×10^{27}	18	5.6 nb^{-1}
	Ti	1.4×10^{30}	1000	14 pb^{-1}	2.8×10^{27}	13	2.8 nb^{-1}
	W	5.9×10^{29}	1000	5.9 pb^{-1}	3.1×10^{27}	21	3.1 nb^{-1}

Table 1: Summary table of the achievable integrated luminosities with the ALICE detector accounting for the data-taking-rate capabilities in the collider mode. The solid target lengths are 658 μm (5 mm) for C, 515 μm (5 mm) for Ti, 184 μm (5 mm) for W, with the proton (lead) beam respectively.

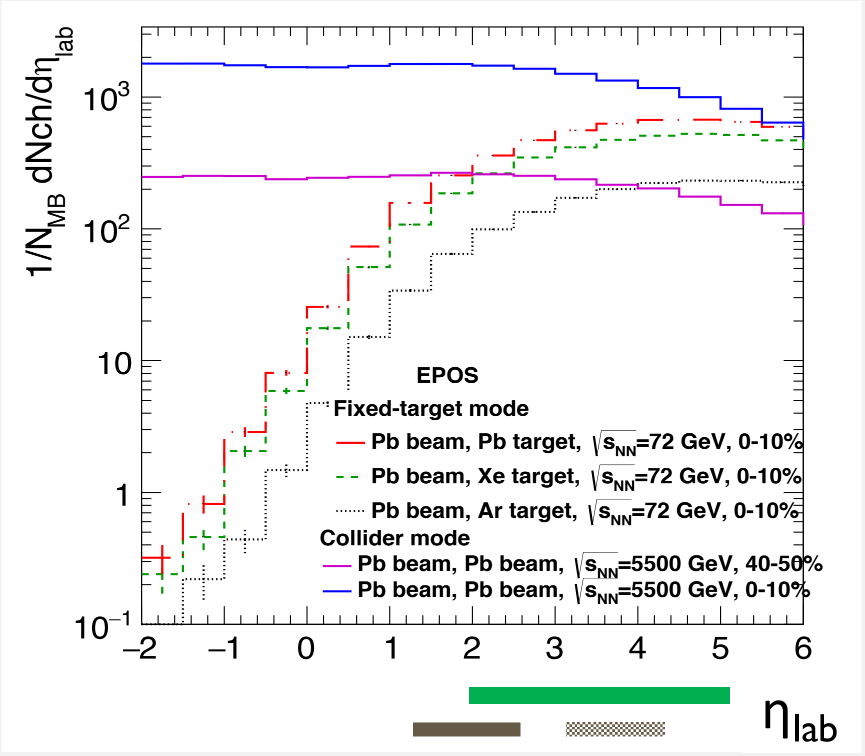
* Assuming ALICE runs the full year in fixed target mode
Proton flux considered : ~ 5 x 10^8 p/s, Lead flux : ~ 2 x 10^5 Pb/s → could be lower by 2 order of magnitude from recent studies, but can be compensated by increasing the target thickness. Extraction of Pb beam with bent crystal needs further studies.
Maximum readout rate considered 1MHz in pp/pA collisions and below 50kHz in PbA

Detector considerations : ALICE versus LHCb



(1) pp/pA fixed target collisions

(2) PbA fixed target collisions



ALICE TPC IROC only (Z_{target} = - 4.7m)
ALICE muon arm (Z_{target} = - 4.7 m)

- ❑ ALICE : Access to most central fixed-target AA collisions still unique with good tracking performances (until LHCb upgrade Phase II (?)). Could potentially devote a significant proton beam time to fixed-target physics, unique very backward coverage with the central barrel

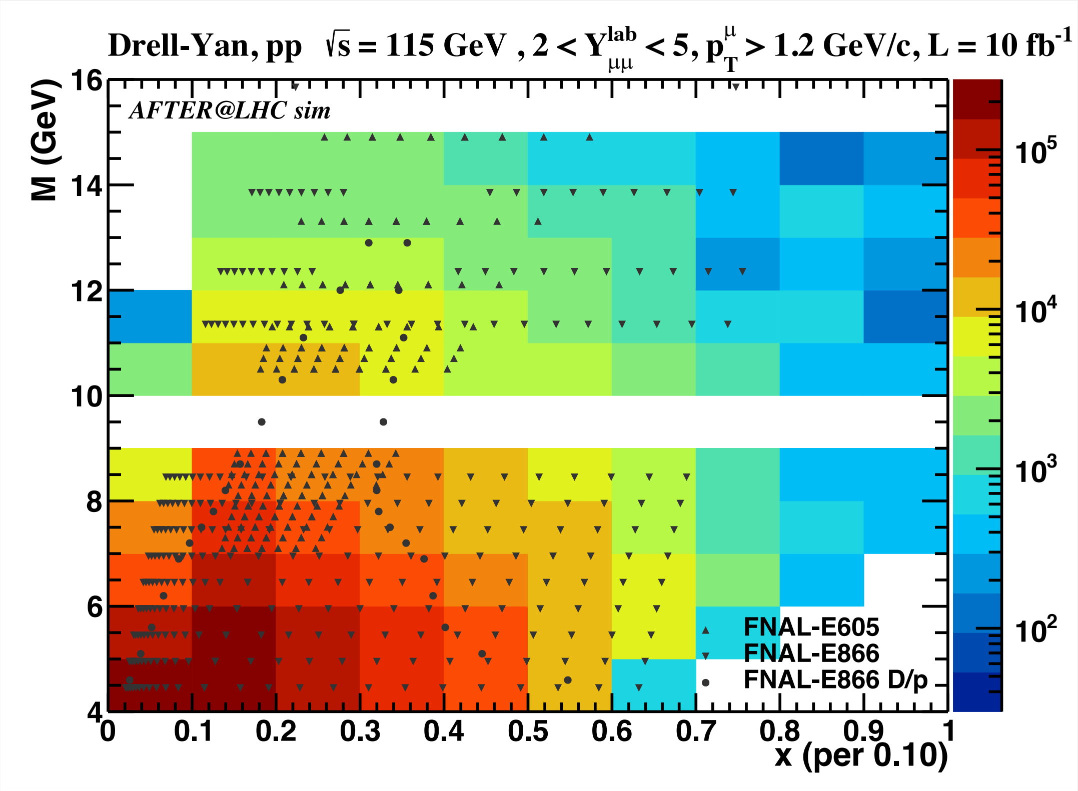
- ❑ LHCb : The only detector fully equipped in the forward region (PID, calorimeter) with already excellent M, p_T resolutions in pA collisions

A selection of physics projections for a high-luminosity fixed-target programme at the LHC

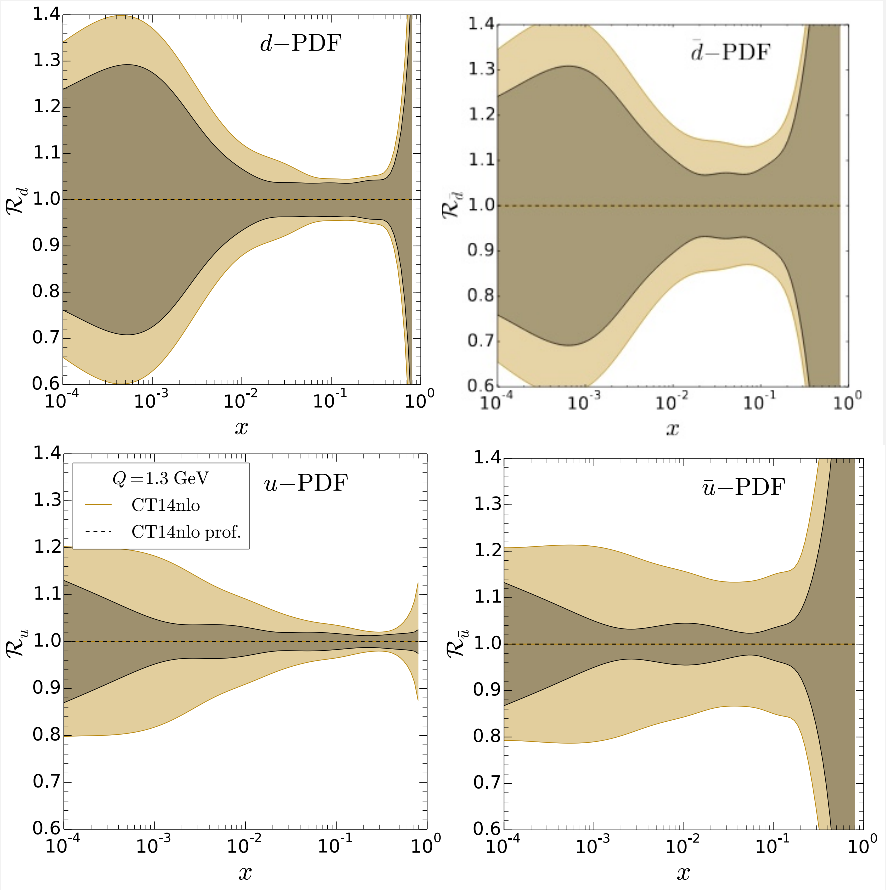
Most of the material from the AFTER review : https://arxiv.org/abs/1807.00603, and ESPP document ID47 :
See also these dedicated papers on simulations from the AFTER@LHC study group:
Adv.High Energy Phys. 2015 (2015) 986348
Few Body Syst. 58 (2017) no.4, 139
Few Body Syst. 58 (2017) no.5, 148
Phys.Lett. B793 (2019) 33-40

Drell-Yan process to probe the nucleon structure at large-x

- ❑ LHCb-like detector, pp collisions
- ❑ Extension of the measurement to larger x_2 w.r.t existing Fermilab data (suffering from limited statistical precision at kinematic boundaries)



- ❑ Impact on quark PDFs evaluated with Bayesian reweighting



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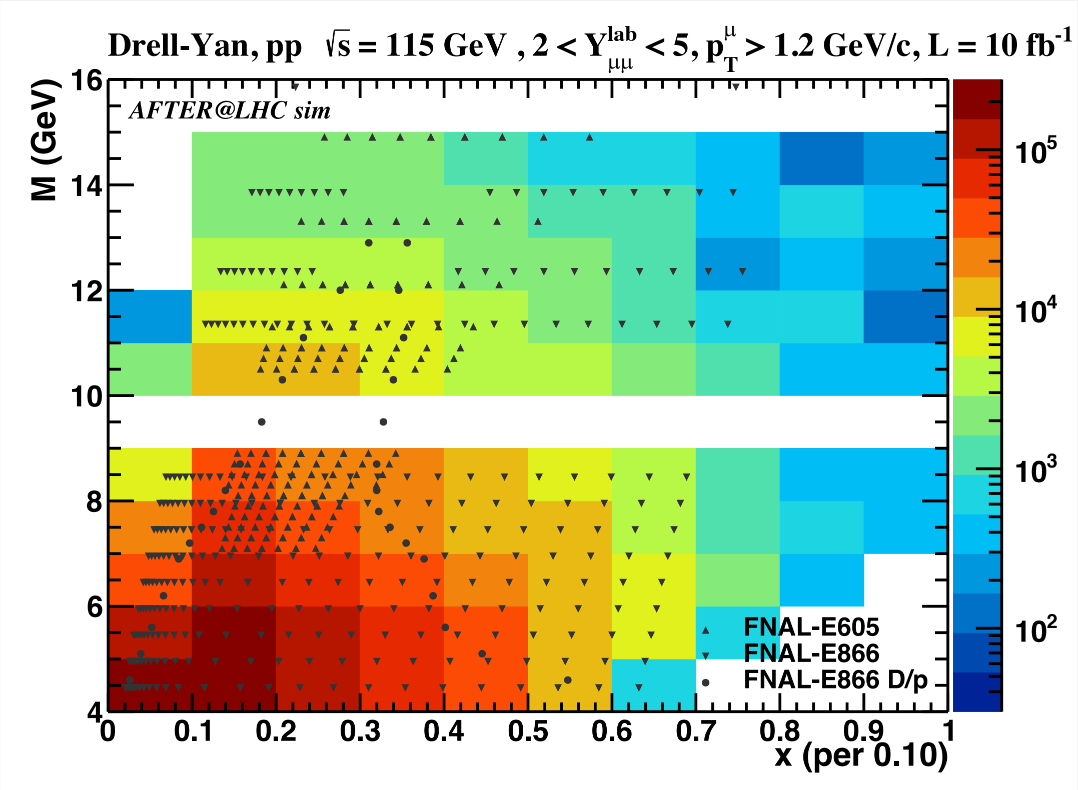
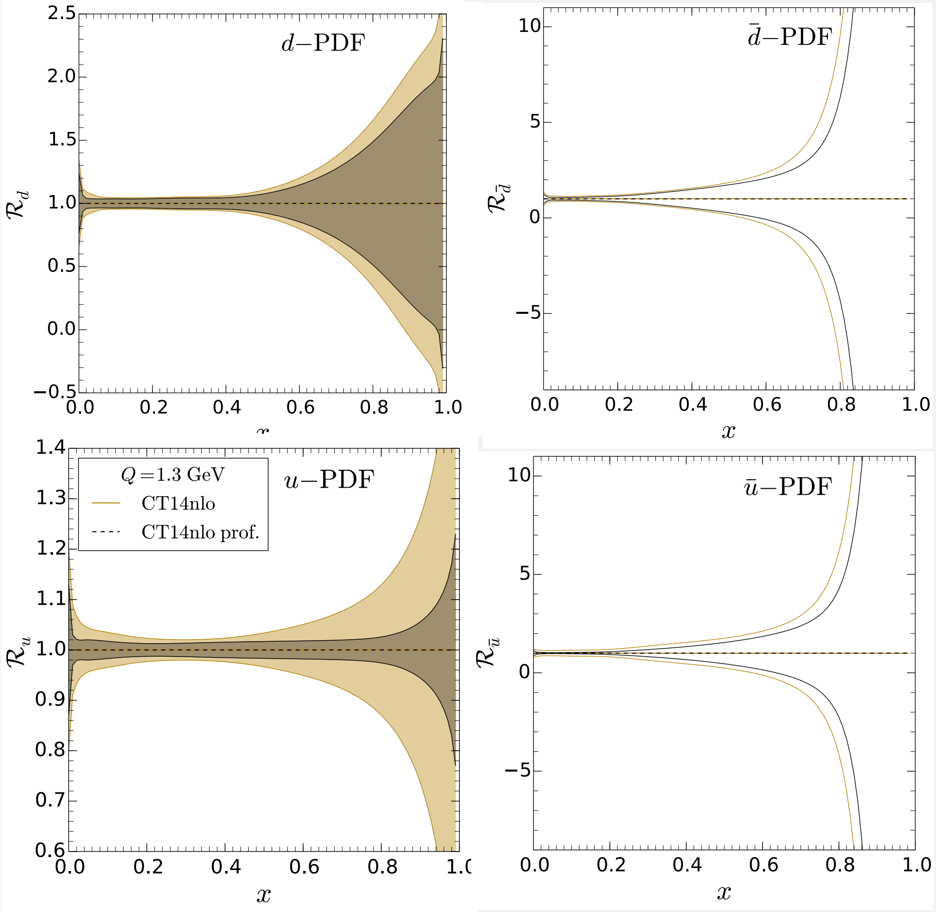
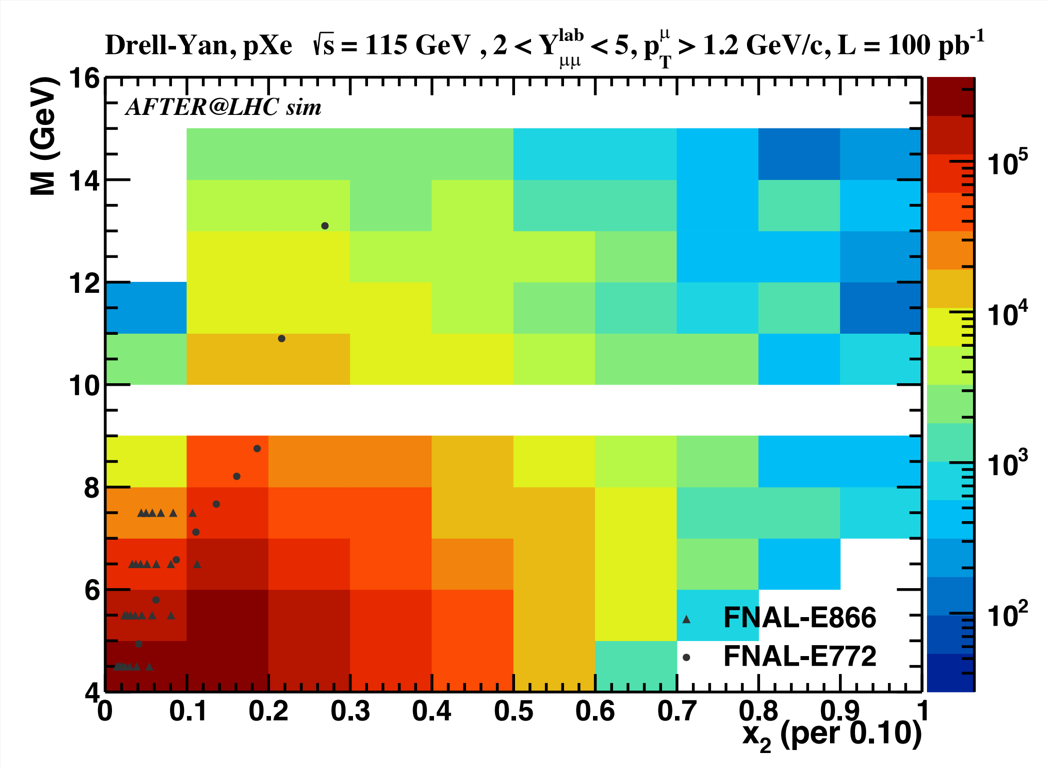


- Impact on quark PDFs evaluated with Bayesian reweighting
- Knowledge of valence quarks distribution considerably improved for x > 0.4 (esp. for u quark)

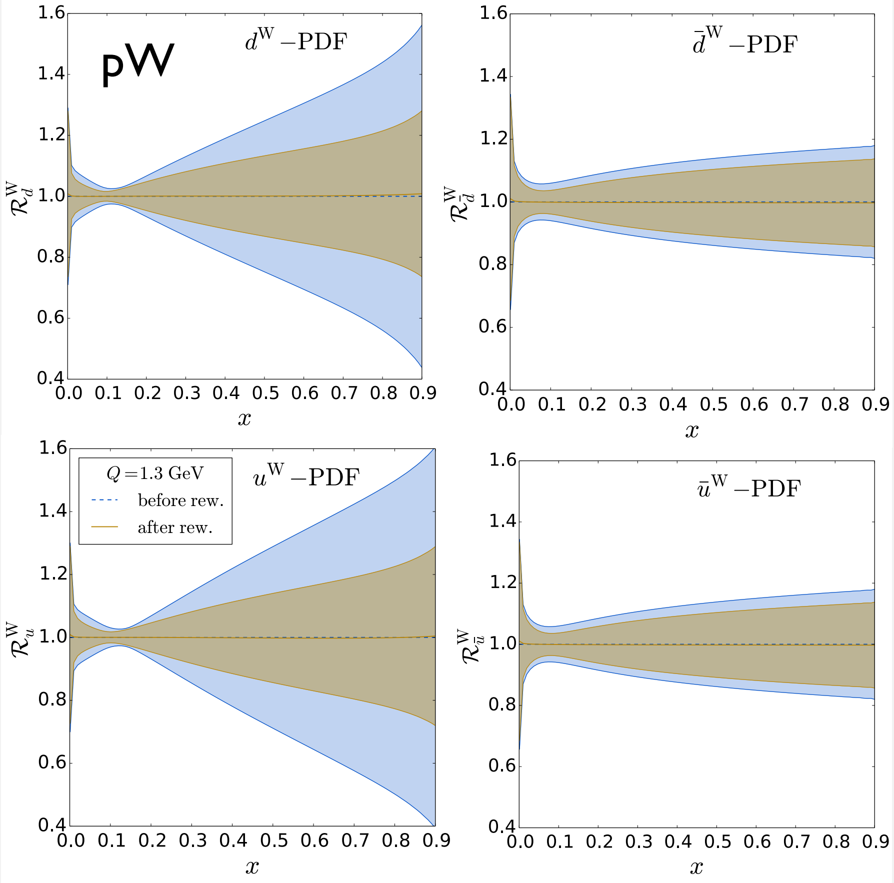


Drell-Yan process to probe the nuclear structure at large-x

- ❑ LHCb-like detector, pXe collisions
- ❑ Unique acceptance compared to existing DY pA data (E866 & E772 @Fermilab)
- ❑ Same coverage in pp and pA
- ❑ Large yields up to $x_2 \rightarrow 1$

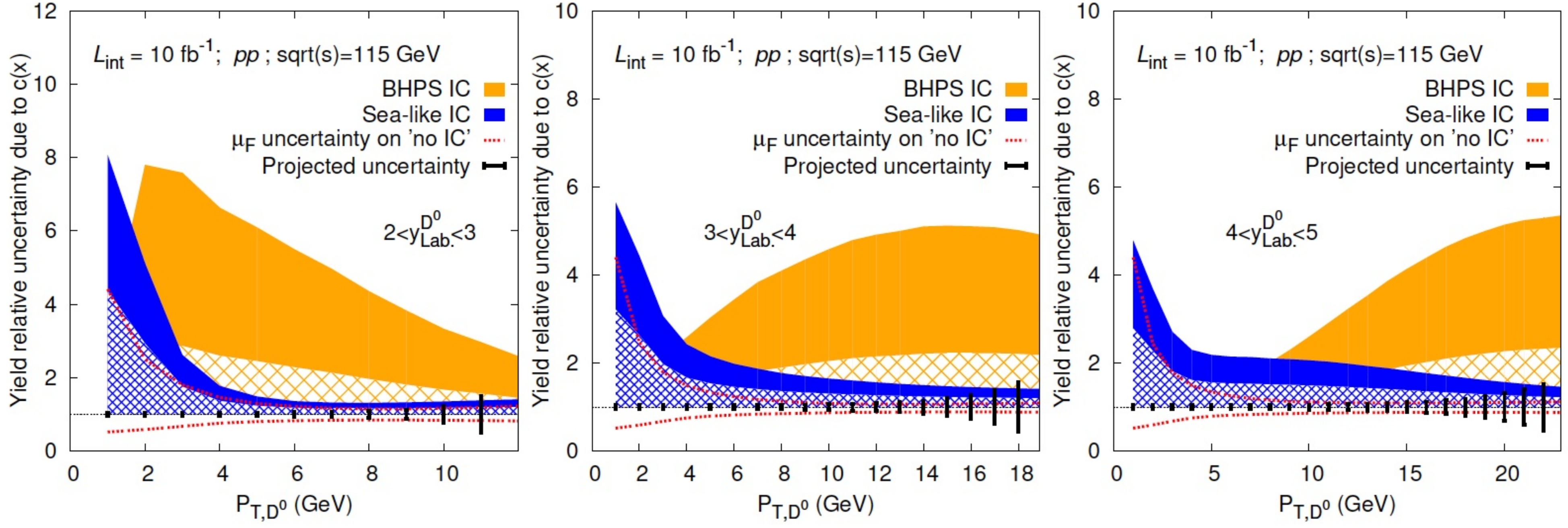


- ❑ Decrease of the nuclear PDF uncertainties
- ❑ Significant impact for u and d quark nPDFs at large x



Open-HF at large-x to study intrinsic charm in the proton

- LHCb-like detector, pp colisions

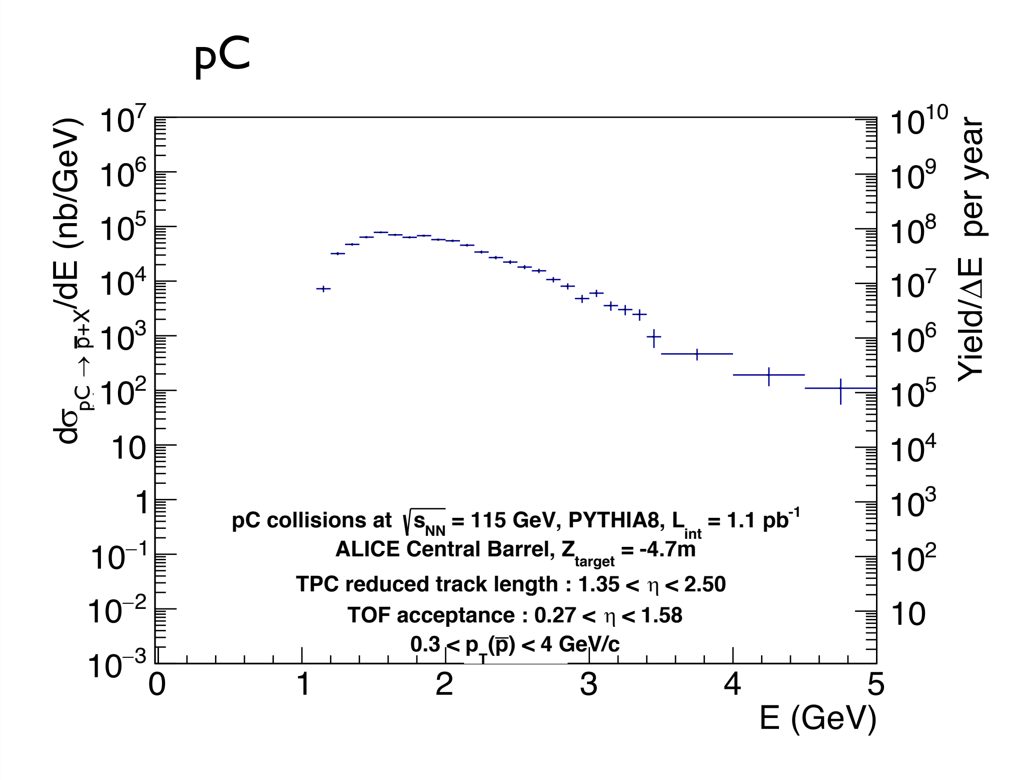


(a) $2 < y_{Lab} < 3$ (b) $3 < y_{Lab} < 4$ (c) $4 < y_{Lab} < 5$

Experimental precision in this p_T/y range should provide strong constraints on intrinsic charm model

Antiproton production for CR physics

- Antiproton production in pH, pHe collisions : important input for astrophysics (Dark Matter searches)
- Constrain models for secondary antiproton production in interstellar medium and be able to confirm excess in data (AMS)
  - **p/^{4}He/^{12}C/^{14}N/^{16}O/… (cosmic ray) + H (at rest) → antiproton of large E**
  - Equivalent to: **p (7 TeV beam) + p/^{4}He/^{12}C/^{14}N/^{16}O/… (at rest) → antiproton of small E**
  - Complementary measurement with respect to LHCb



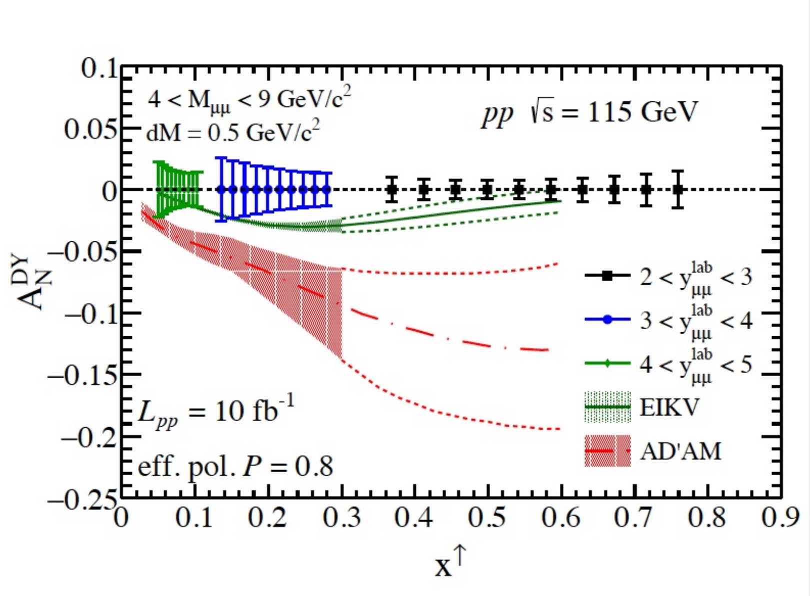
- Minimum bias pp collisions scaled to pC
- "ALICE-like" detector performances (central barrel)
- Z_{target} = - 4.7m

ALICE CB is accessing the very low energy domain for antiproton production

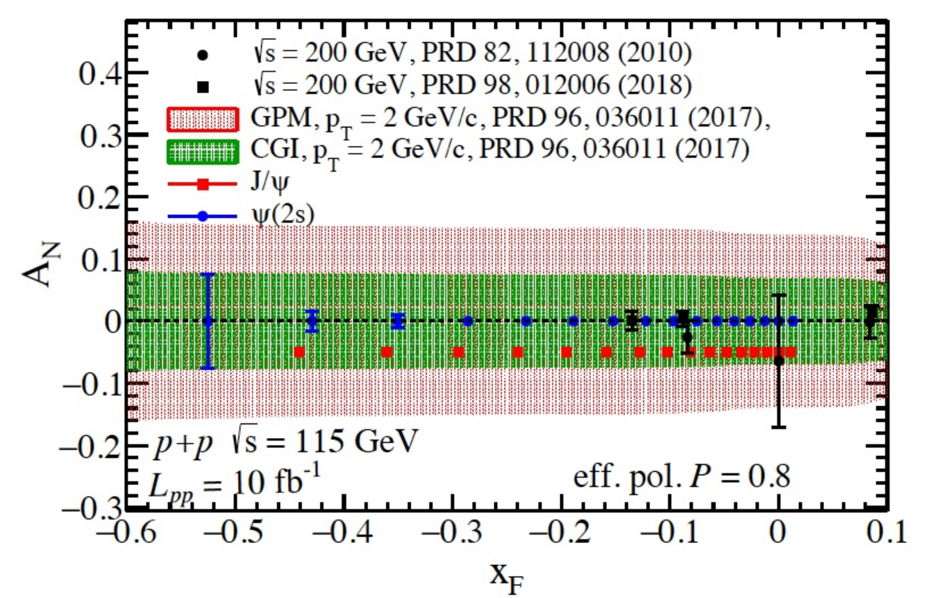
Spin and 3D nucleon structure

$$A_N = \frac{1}{\mathcal{P}_{\text{eff}}} \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

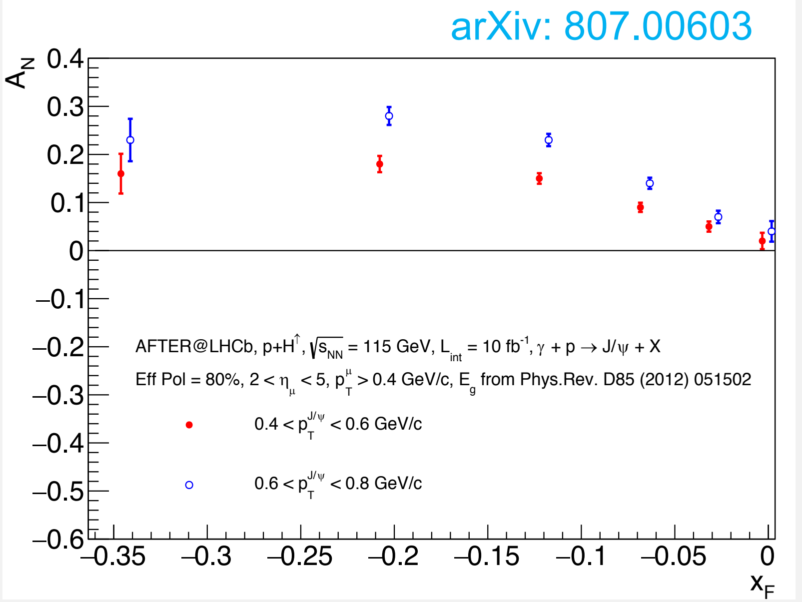
Drell-Yan STSA to probe the quark Sivers effect



Quarkonia STSA to probe the gluon Sivers effect



Photoproduced J/ψ to probe the gluon GPD Eg

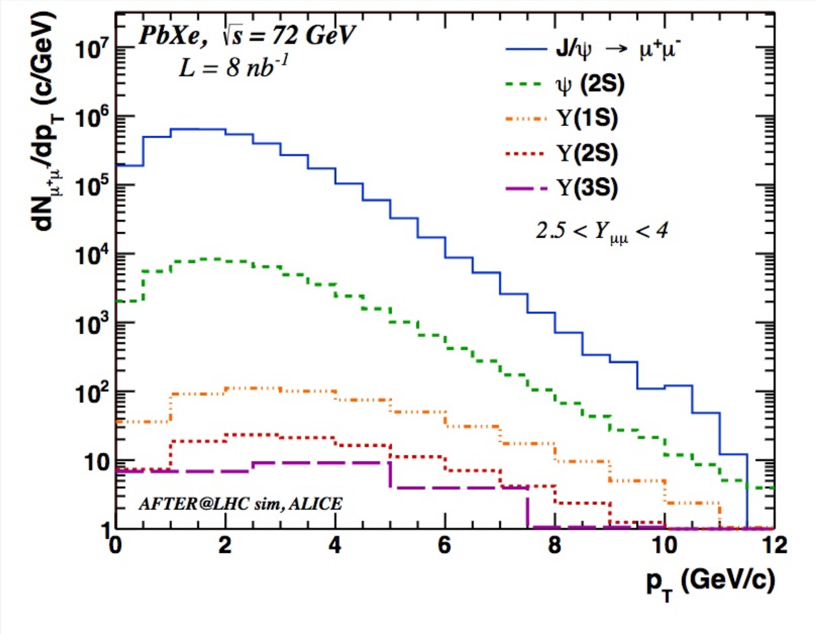


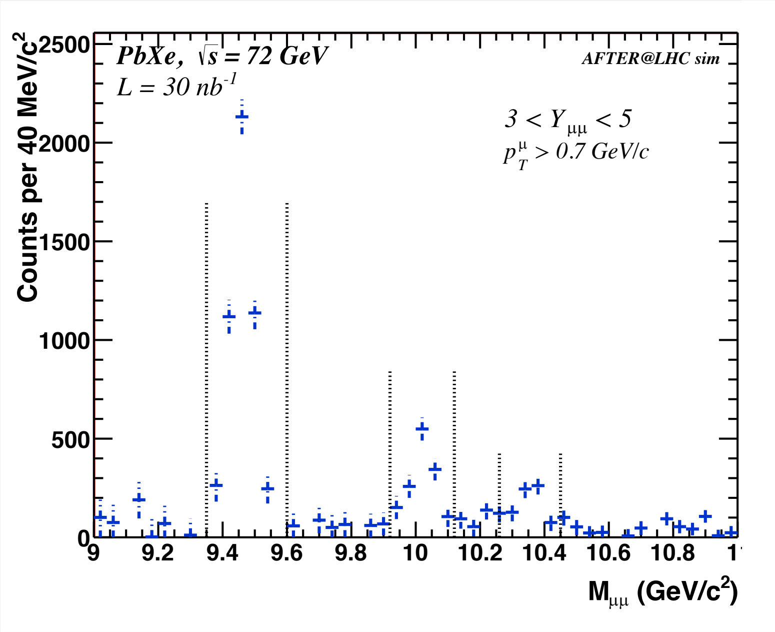
- "LHCb-like" detector, pp collisions, polarised H target (P ~ 80%)

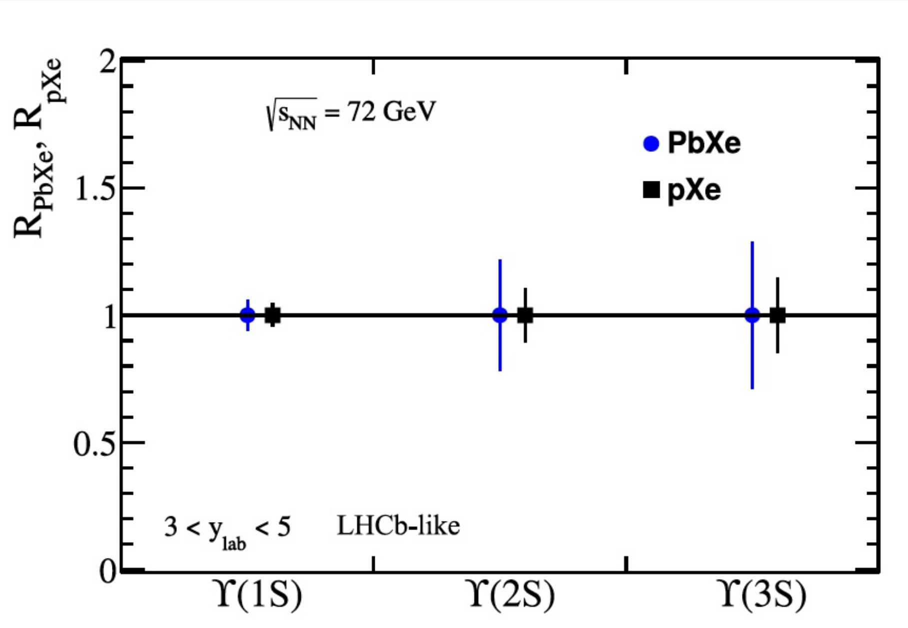
Quarkonium as a probe of the QGP in heavy ion collisions

- "ALICE-like" detector (muon arm), Ztarget = 0, PbXe collisions

- "LHCb-like" detector performances, PbXe/pXe collisions





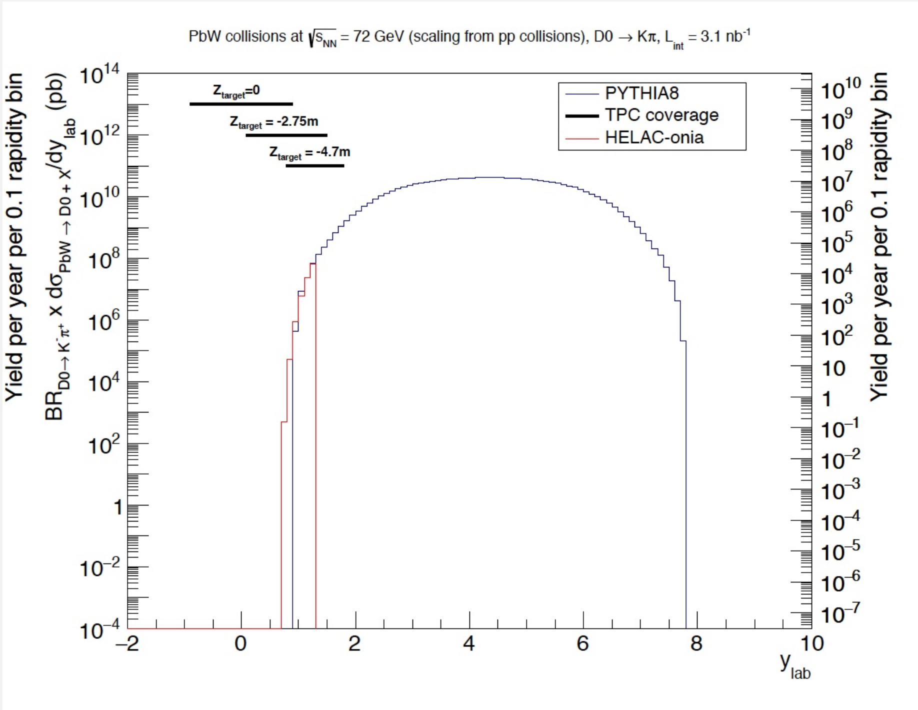


After uncorrelated background subtraction (LS pairs)

Large yields for charmonium production both in ALICE/LHCb in PbXe. Access to most central collisions guarantied in ALICE. Upsilon(nS) studies more accessible in LHCb thanks to larger yields.
~ 450 Υ(3S) in one data taking year. Statistical accuracy of ~7% on Υ(1S) R_{AA}

Open-HF to study heavy quark energy loss in medium

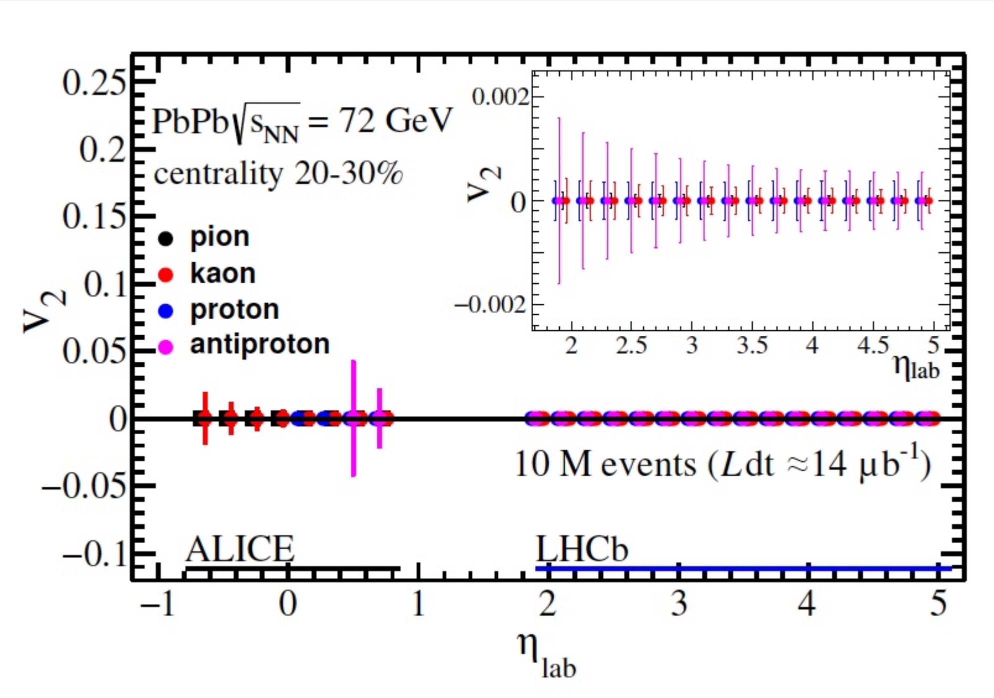
- pp scaled to PbW, « ALICE-like » detector



→ Unique access to D meson end of phase space with ALICE CB

Particle flow coefficient to constrain T dependence of η/s

- Pb-Pb, « ALICE-like and LHCB-like » detectors
- Identified charged particles in wide-rapidity range down to phase space limit
- Percent level statistical accuracy for the v_2 measurement



→ Complementary coverage between ALICE and LHCb

Conclusion

- **Three main physics goals identified to motivate a high-luminosity fixed-target programme at the LHC**
  - High momentum fraction x frontier in nucleon and nuclei
  - Spin and 3D nucleon structure
  - Heavy ion collisions at large rapidities

- **Two main ways to perform fixed-target collisions with the LHC beams**
  - A slow extraction with a bent crystal coupled to a solid target
  - An internal gas target inspired from SMOG@LHCb/Hermes/H-jet

- **Fast simulation work has been performed to provide figures of merit for LHCb and ALICE for a selection of observables (Drell-Yan, Open-HF, quarkonia, charged and identified particles) to motivate a high-luminosity fixed-target programme at the LHC**

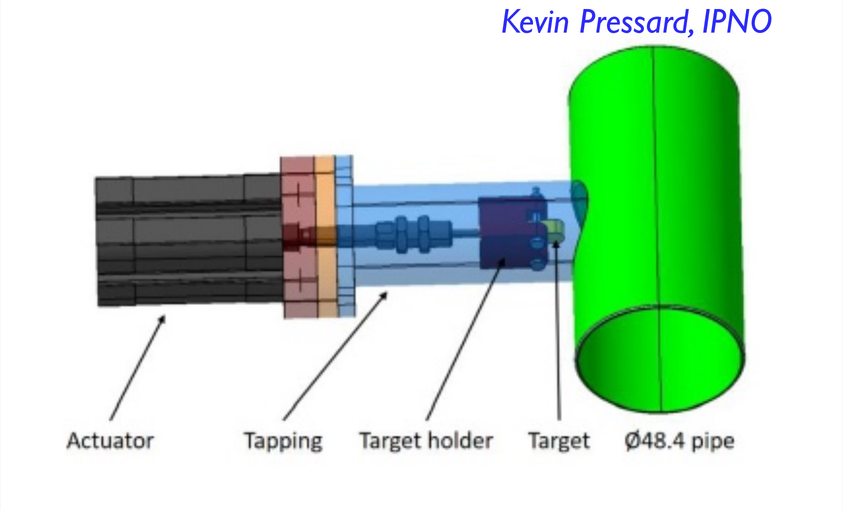
- **3 ESPP contributions submitted in December related to fixed target physics at the LHC**

The physics reach of the LHC complex can greatly be extended at a very limited cost with the adjunction of an ambitious and long term research program using the LHC beam in the fixed target mode

BACKUP

Target requirements for ALICE

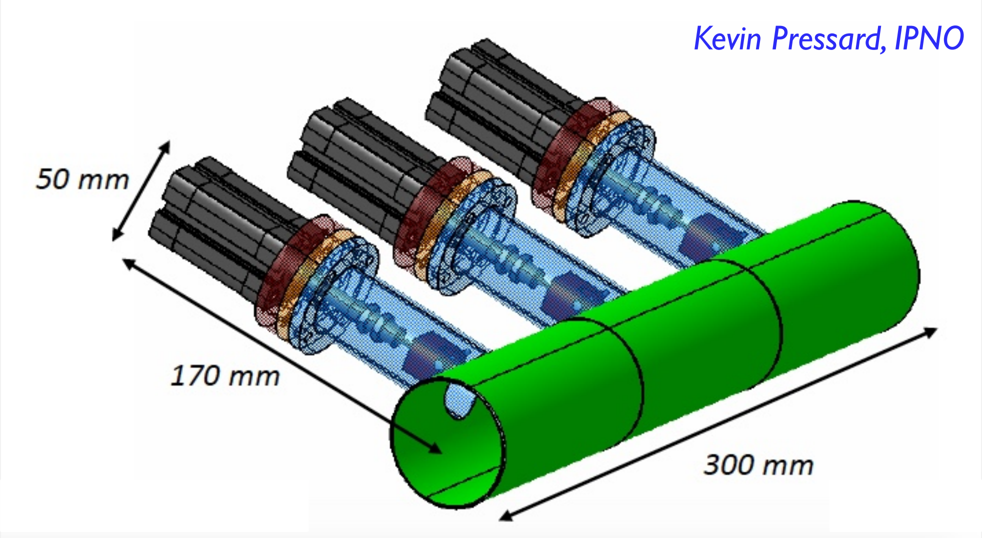
- ❑ Some target requirements to conduct the full heavy-ion programme foreseen:
  - ➢ Have a reference system, ie. a target with lowest possible atomic number (ideally pH):
    - Solid H probably not compatible with LHC vacuum
    - Lighter target that could be envisonned is probably Beryllium (Z = 4)
  - ➢ Have good target versatily : take data with different target species / be able to change frequently the target
  - ➢ Have target with large atomic numbers
    - W might be possible if cooled
    - Pb probably not usable because of too low melting temperature
  - ➢ Other possible target species: Ca, C, Os, Ir, Ti, Ni, Cu
- ❑ Target holder and other elements : stainless steel
- ❑ Retractable target : active position at 8mm from the beam axis, parking position out of the beam pipe

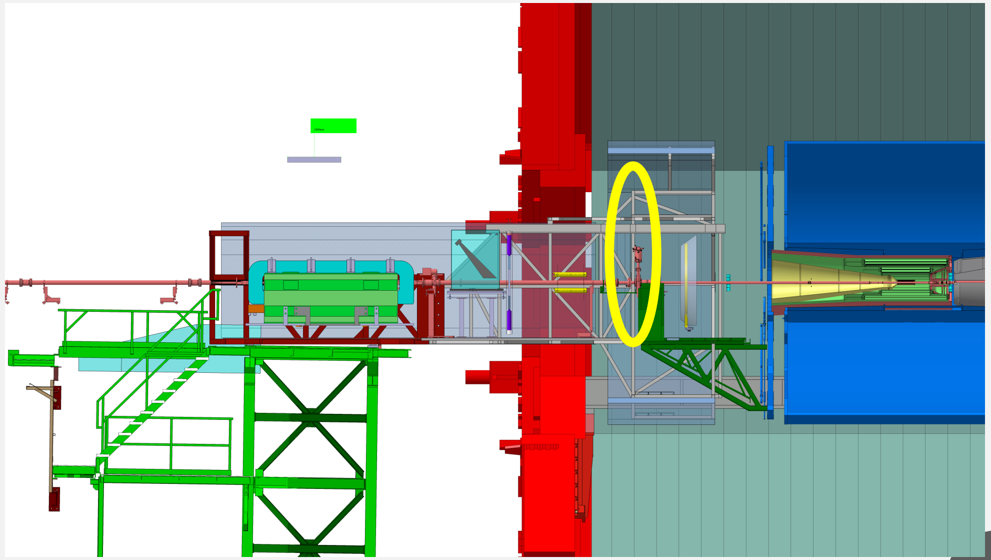


Target setup design and integration constraints (ALICE)

- Target Size :
  - 5 mm diameter
  - 0.2mm to 5mm thickness depending on the material and if p/Pb beam
- Target holder makes the interface between the target and the motion system (also heat drain)
- Pneumatic motion system (electro-magnetic compatibility)
- Electro-valve distribution away from the setup itself
  → minimum shadow for existing detectors
- Integration constraints :
  - Need to isolate the pipe region where the target will be located
  - Avoid shadow to existing detector
  - Take into account ITS removal constraints during winter shutdown
  - Need pumping system because of outgassing and bake-out device
  - RF shielding probably needed (need impedance studies)

➡ Easiest location for installing the target is before the already existing valve (~ - 4.8m)





The ALICE detector after LS2 (RUN3)

- ❑ New Silicon Tracker
  - ➢ First layer closer to IP
  - ➢ Beam pipe with reduced radius (~ 2cm)
- ❑ A Muon Forward Tracker
- ❑ TPC readout via GEM
- ❑ Continous readout (50 kHz in Pb-Pb)

ALICE LoI, J. Phys. G 41 (2014) 087001

SMOG data taking

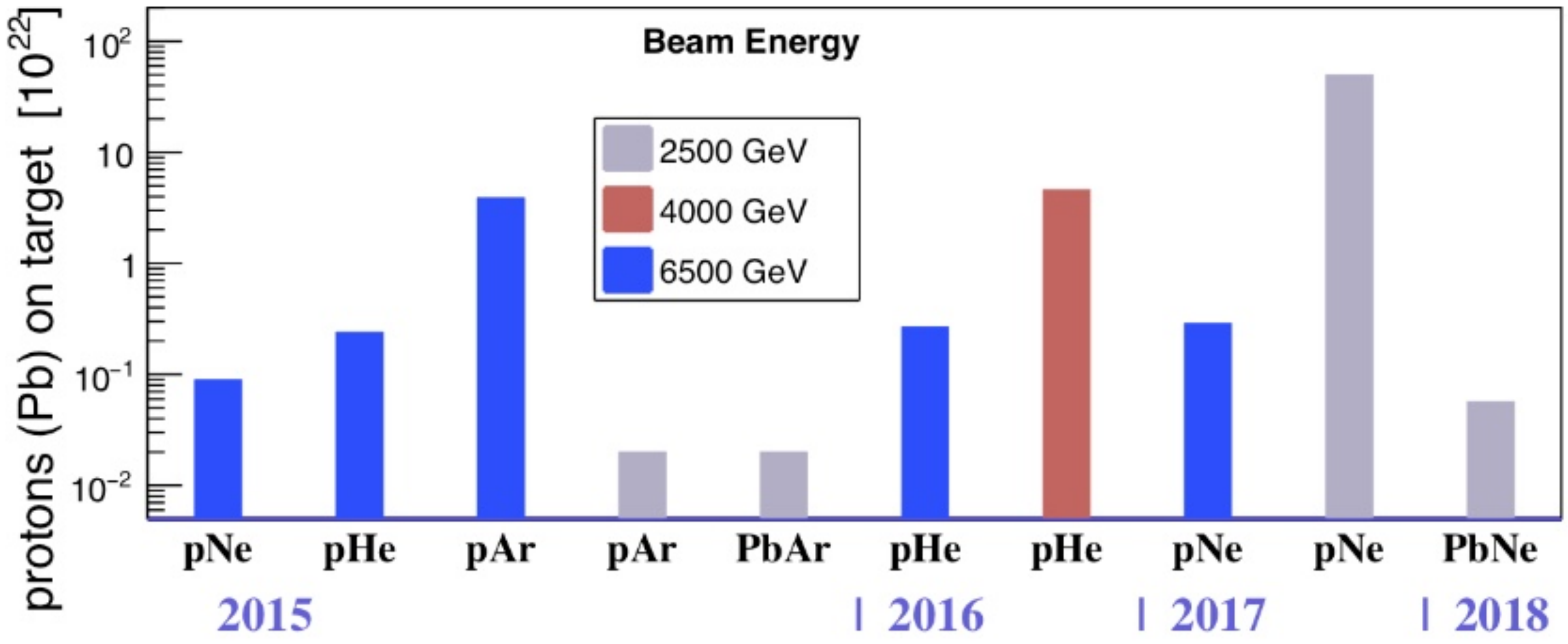


Figure 1: Dedicated SMOG runs collected since 2015. Beam-gas collisions have been recorded using different gas types (He, Ar, Ne) and beam energies.

The fixed-target setup of LHCb

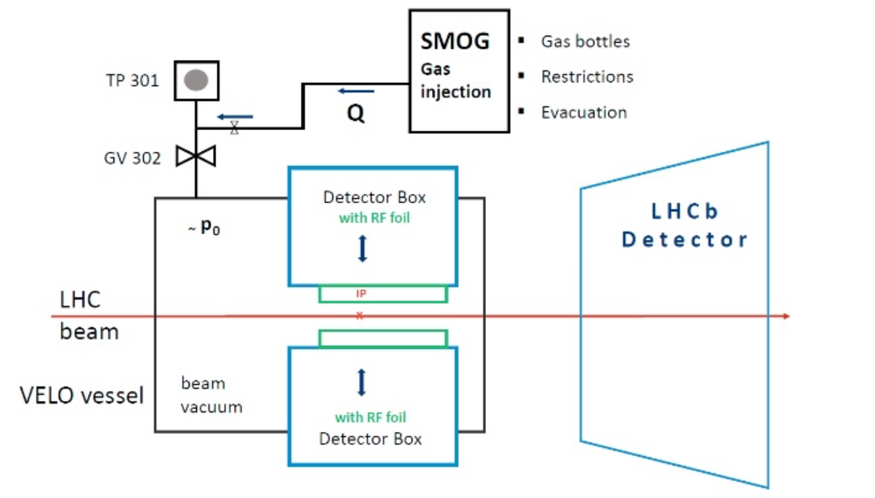


Figure 5: Principle of the SMOG system, consisting of a gas feed system (Fig. 2) injecting into a pump (TP 301). With valve GV 302 open, the VELO vessel is filled with gas at low density, determined by the injected flow rate.

- ❑ Low density noble gas injected (He, Ne, Ar so far) into LHCb Vertex Locator with pressure P ~ 1.5 x 10^{-7} mbar
- ❑ Benefit from the full LHCb beam without decrease of the beam lifetime
- ❑ Limited luminosities (density, running time,..)
- ❑ No polarization of the target, only noble gases, no heavy nuclei and no pH baseline

➡ Physics reach still limited by the statistics (~ few hundreds of J/Ψ and D^0, PRL 122 (2019) 132002)
Maximum luminosity collected so far : **L_{int} ~ 100 nb^{-1} (pNe @68 GeV)**

New projects under investigation in LHCb

- **SMOG2 (approved) : addition of an unpolarised storage cell target**
  - 20 cm long attached to the VELO
  - Injection of unpolarised gas via capillary
  - Boost local gas density with same gas flow

Gas species	He	Ne	Ar	Kr	Xe	H_2	D_2	N_2	O_2
$\theta_{SMOG2}/\theta_{SMOG})$	10.9	24.4	34.5	25.0	31.3	7.7	10.9	28.6	30.3

→ And probably up to a factor x 100 SMOG with an increased gas flow

  - Extended target choice : H_2, D_2
  - Better control over injected gas density (i.e over luminosity)
  - Projections for SMOG2:

Reaction	DAQ time	Non coll. bunches	Lumi (nb^{-1})	Decays	SMOG yields	Scale factor	SMOG2 proj. yields
pAr	18 h	684	~ 2	$D^0 \to K^-\pi^+$	6450	62	400 k
				$D^+ \to K^-\pi^+\pi^+$	975		60 k
				$D_s^+ \to K^-K^+\pi^+$	131		8 k
				$D^{*+} \to D^0\pi^+$	2300		140 k
				$\Lambda_c^+ \to pK^-\pi^+$	50		3 k
				$J/\psi^+ \to \mu^+\mu^-$	500		30 k
				$\psi' \to \mu^+\mu^-$	20		1.2 k
pHe	84 h	648	7.6	$J/\psi^+ \to \mu^+\mu^-$	500	19.6	10 k
				$\psi' \to \mu^+\mu^-$	20		0.4 k

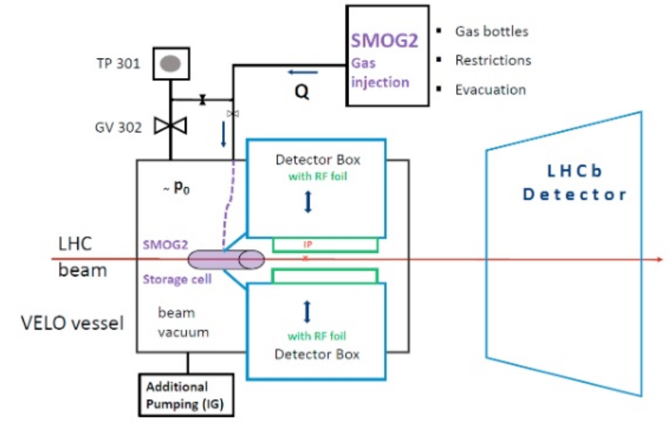
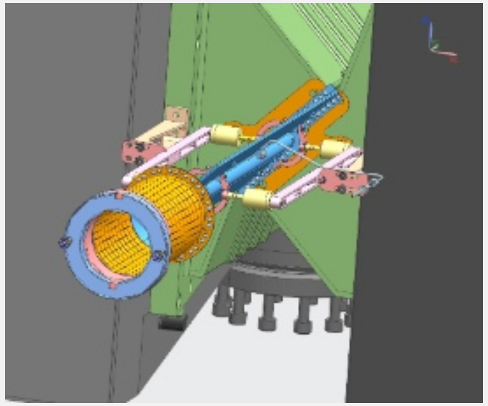
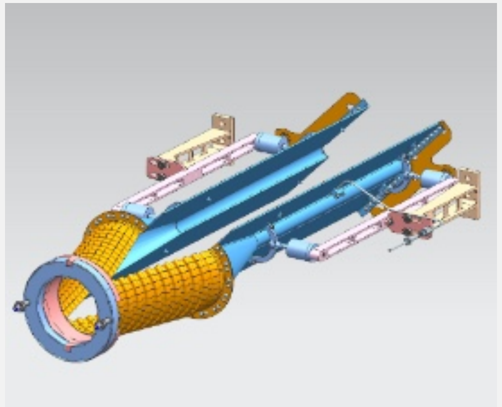


Figure 7: Sketch of the SMOG2 system. The gas is injected via capillary at the center of the storage cell.

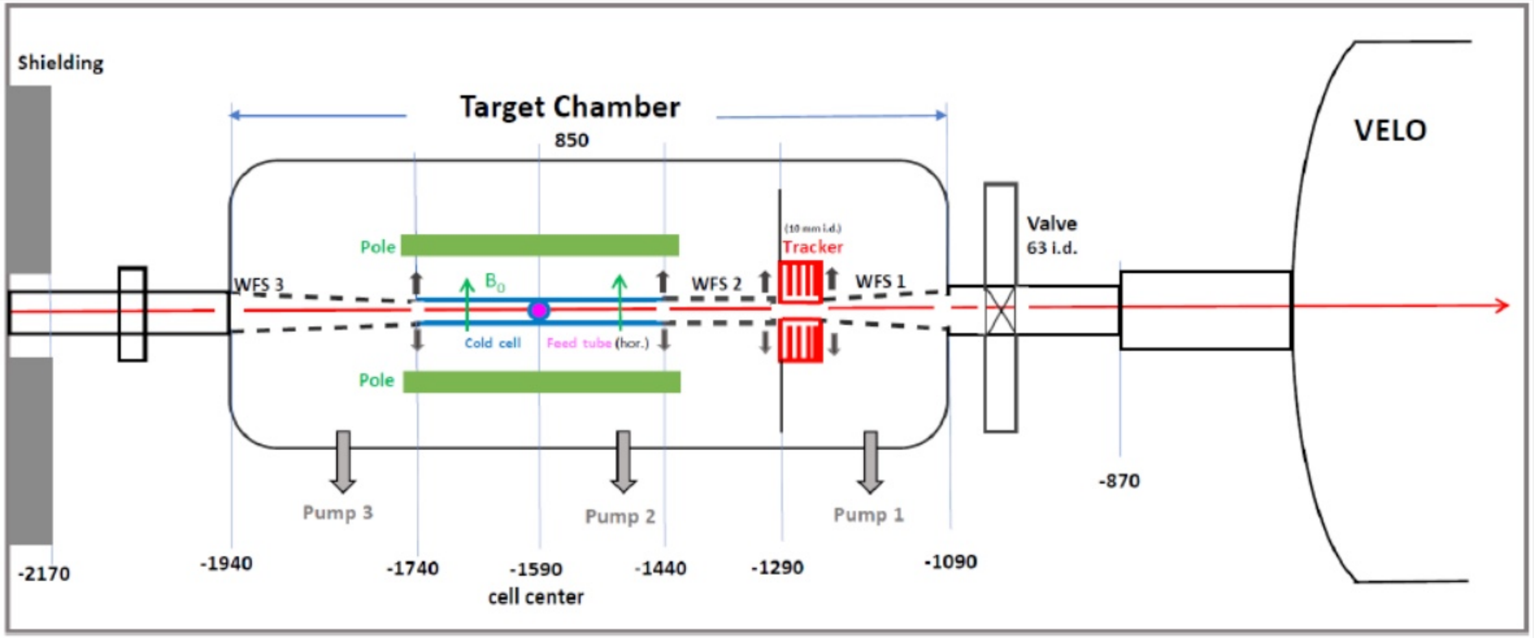




CERN-PBC-Notes-2018-007

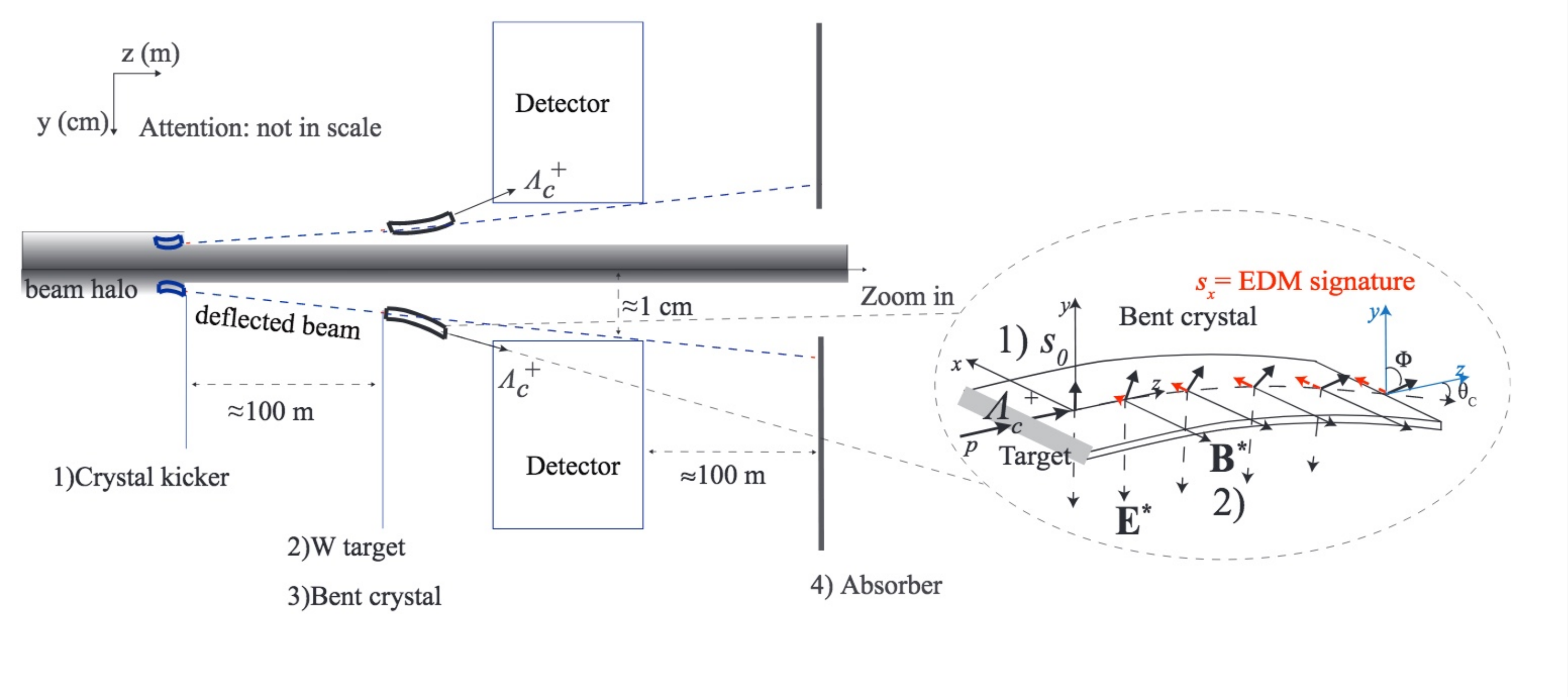
New projects under investigation in LHCb

- **LHCSpin (currently not approved) : polarised storage cell target for spin physics in front of LHCb**
  - Setup with : Atomic beam source, target chamber, diagnostic system and additional tracking detector
  - Integration constraints: target chamber located at least 1m upstream of the LHCb IP → consequences on the « large-x » reach
  - Projections for Run4 → L_{int} ~ 5 fb^{-1} for pH↑ collisions (Φ ~ 3.8 x 10^8 p/s, L_{inst} ~ 4.7 x 10^{32} cm^{-2}.s^{-1}, t~10^7 s)
  - R&D needed for the coating (depolarisation)



New projects under investigation in LHCb

- **Beam splitting with double crystal setup for the measurement of EDM/MDM of charmed baryon (currently not approved)**
  - Intense magnetic field between crystal atomic planes induces spin precession during the lifetime of the particle
  - Measurement of MDM of heavy baryons never performed due to their short lifetime
    → test of QCD calculations, improve current understanding of internal structure of hadrons
  - Measurement of EDM of heavy and strange baryons powerful to probe physics beyond the standard model



Open-HF and quarkonia to constrain high-x nuclear gluon distributions

- LHCb-like detector, pXe collisions
- Extremely promising first projections using Bayesian reweighting
- Assume that other nuclear effects are under control : different observables are thus needed
- Unique constraints on gluon nPDFs at high-x and low scales