ALICE Fixed-Target
Recent progress and status

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PBC WG meeting, 5-6 November 2019, CERN

Recent news

❑ Contribution submitted in Dec. 2018 to European Particle Physics Strategy Update 2018-2020
CERN-PBC-Notes-2019-004 : http://cds.cern.ch/record/2671944/files/PDF%20document%20submitted%20to%20ESPP%20strategy%20update.pdf?version=1

❑ Informal meeting in presence of ALICE technical coordination with LHC vacuum and impedance experts (Mar. 2019)
https://indico.cern.ch/event/801807/

❑ Project discussed during ALICE technical board (Mar. 2019): https://indico.cern.ch/event/750575/

❑ Organisation of regular monthly ALICE fixed target meeting since Sept. 2019: https://indico.cern.ch/category/11595/

❑ Workshop on Fixed-Target Physics at the LHC (7-8th Mov. 2019) / KickOff of the STRONG2020 european joint research activities related to fixed-target projects: https://indico.cern.ch/event/853688/

❑ Working on the preparation of a calendar for the project

Physics motivations for a fixed-target setup in ALICE

❑ Three main physics goals identified (see arXiv:1807.00603):

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

✓ Structure of nucleon and nuclei at large-x poorly known

✓ Study possible gluon EMC effect in nuclei

✓ Existence of possible non-perturbative source of c/b quarks in the proton : useful for HE neutrino and CR physics

➢ Advance our understanding of the dynamics and spin of gluons inside polarised nucleons (with a polarised target)

✓ Limited understanding of nucleon spin structure

✓ Test TMD factorization formalism

➢ Study heavy-ion collisions between SPS and RHIC energies towards large rapidities

✓ Explore the longitudinal expansion of QGP formation

✓ Study collectivity in small systems with new probes thanks to high luminosity (heavy quarks)

✓ Test factorization of CNM effects with Drell-Yan

Fixed-Target implementation in ALICE

❑ **Beam splitted thanks to a bent crystal + a solid target inside ALICE :**
  ➢ Halo particles deflected by a bent crystal (~70m upstream ALICE) sent onto an internal solid target in the ALICE cavern
  ➢ Particles not interacting with the target need to be absorbed

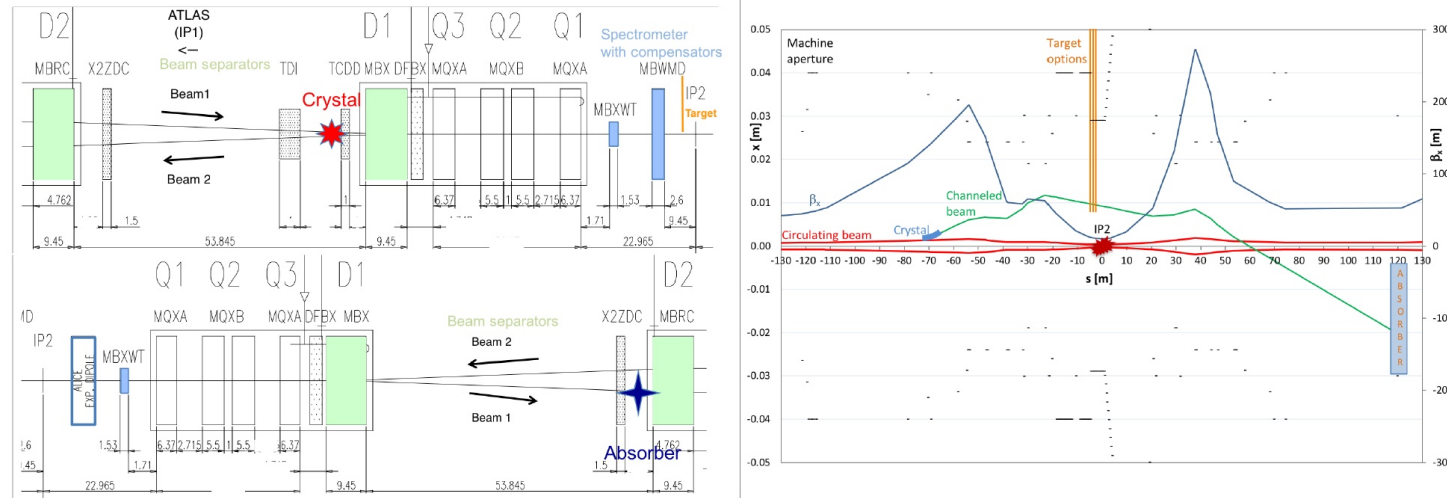❑ Possibility to use a (polarised) gas target also considered (Varsaw group, STRONG2020)

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, W. Scandale UA9

Target setup and integration constraints

❑ Target System :
  ➢ Size : 5 mm diameter, 0.2mm to 5mm thickness
  ➢ Target holder : interface between target and motion system (also heat drain)
  ➢ Pneumatic motion system (electromagnetic compatibility)
  ➢ Electro-valve distribution away from setup

❑ 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 further impedance studies)

➡ Easiest location for installing the target is before the already
   existing valve at Z ~ - 4.8m on the ALICE A-side

❑ Output of discussion at the ALICE technical board:
  ➢ Manpower needed for vacuum and impedance work
  ➢ Discussion needed with FOCAL (both projects target LS3 and similar
    location, solution to be found for the valve)
  ➢ Encourage to pursue the studies on bent crystal (layout, deflected beam
    intensities) and ALICE TPC tracking performances for displaced verteces

Kevin Pressard, IPNO

50 mm
170 mm
300 mm
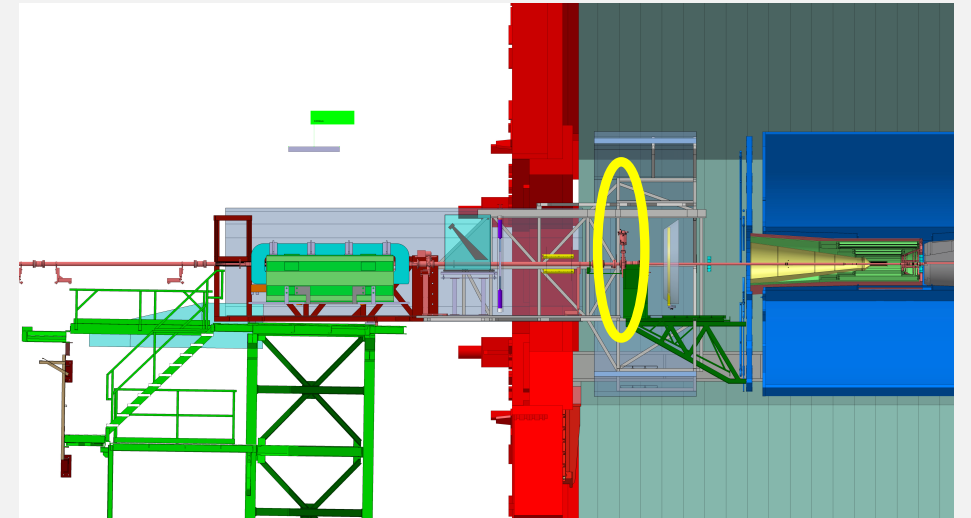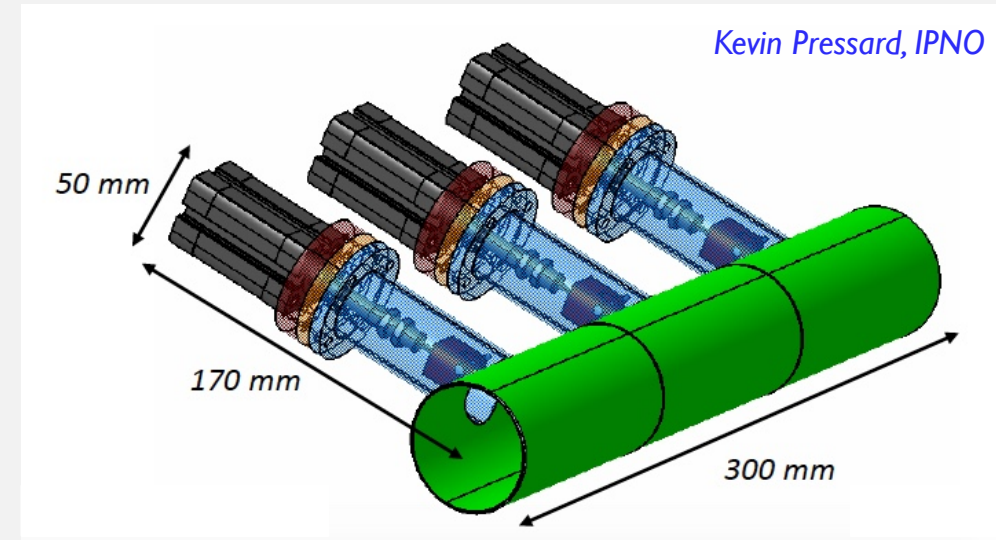
Favored position from integration studies

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

ALICE
A-side

position
Z ~ 4.8m
A side

IP
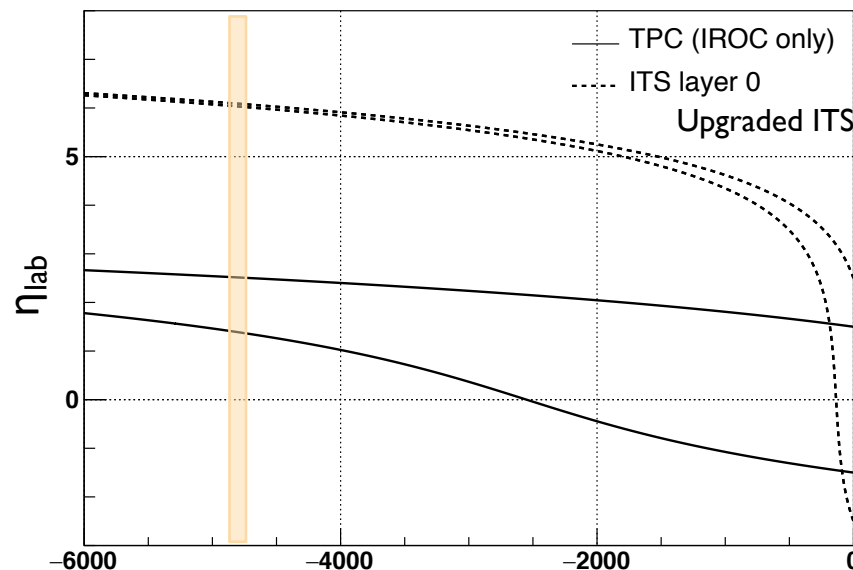
10m

7m

1m

6
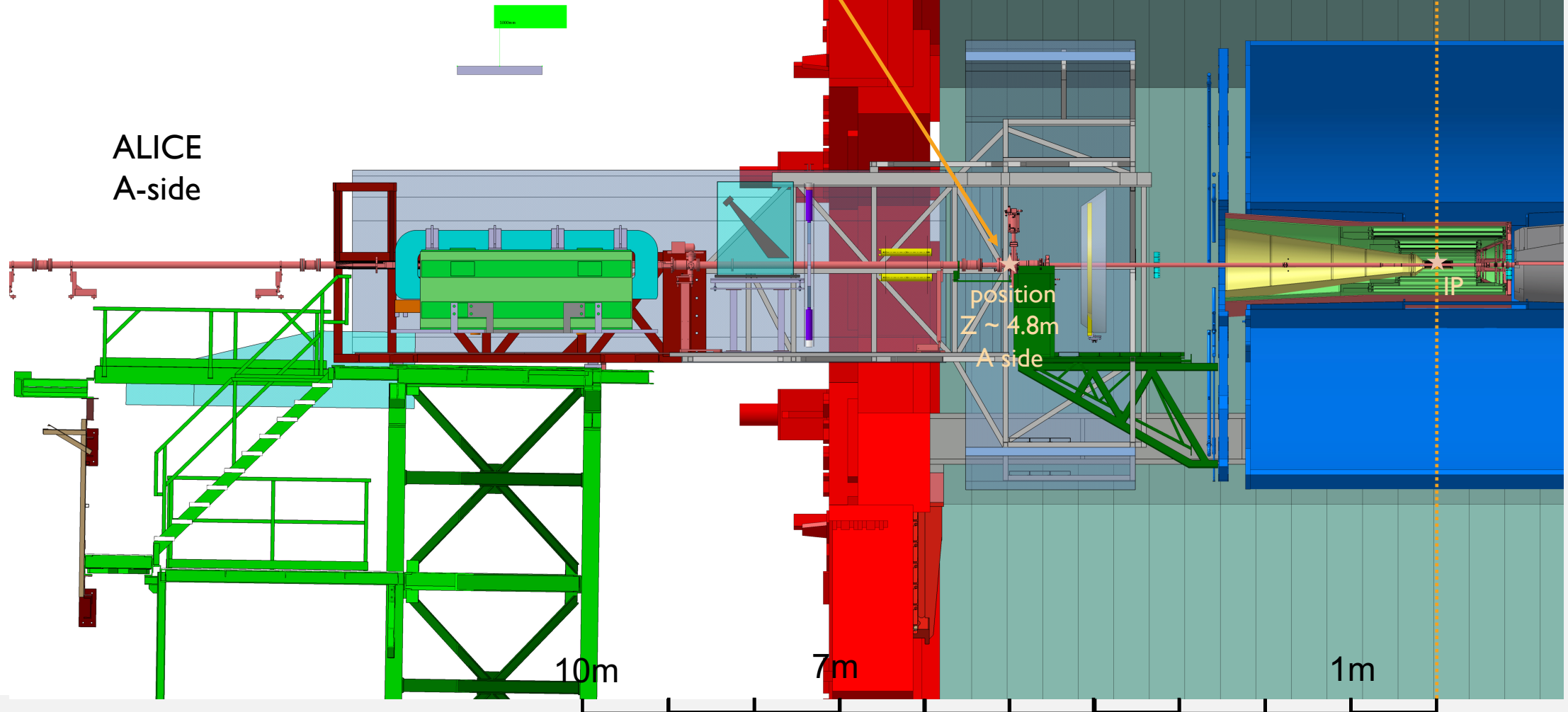
ALICE detector acceptance vs z_{target}

❑ Considering Z direction negative on A side and forward pseudo-rapidity in the lab defined positively
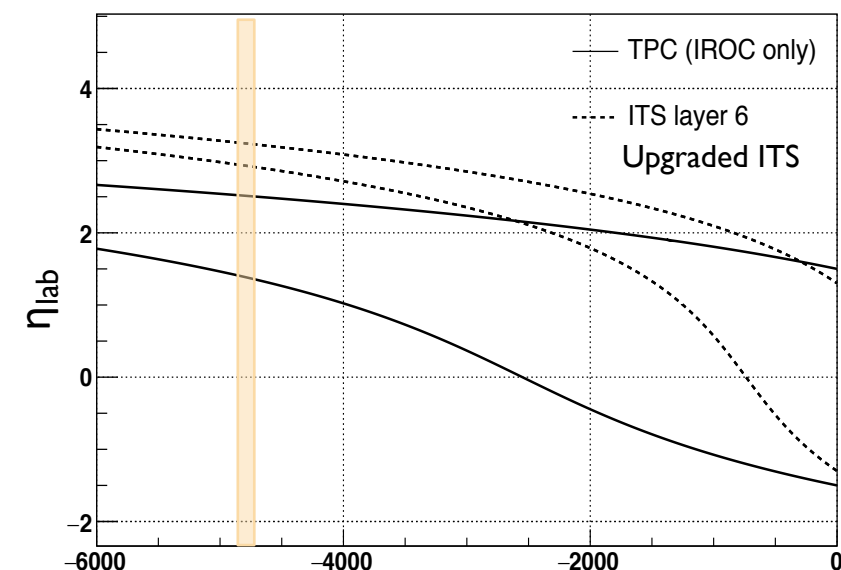❑ Based on simple geometrical considerations

possible target location
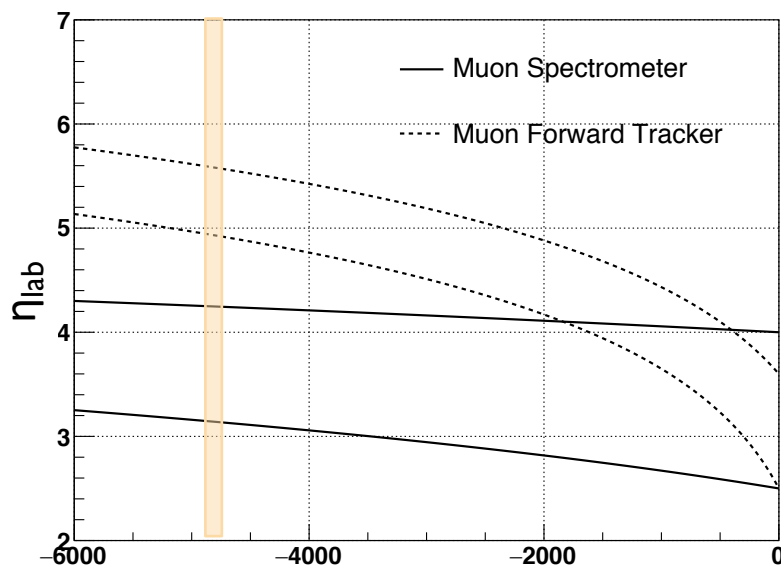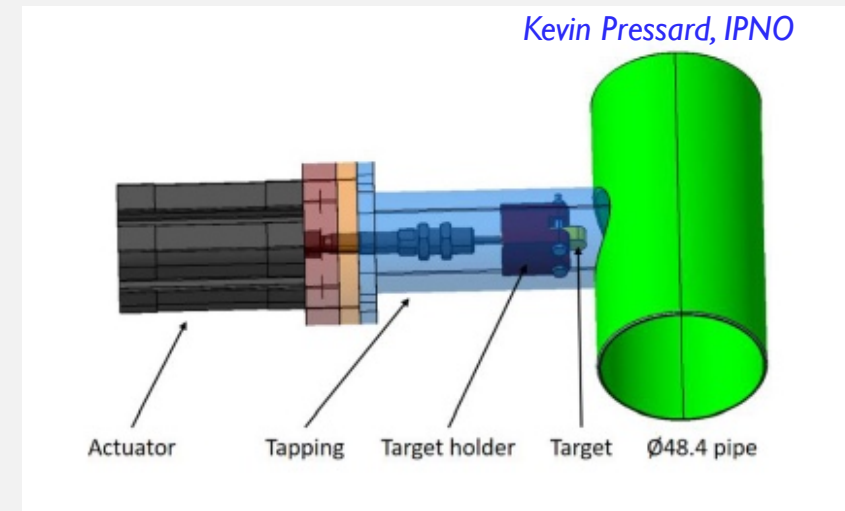
possible target location

possible target location

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

Target requirements

❑ 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 8 mm from the beam axis, parking position out of the beam pipe

Kevin Pressard, IPNO

Actuator   Tapping   Target holder   Target   Ø48.4 pipe

ALICE

Target			proton beam ($\sqrt{s_{NN}}$ = 115 GeV)				Pb beam ($\sqrt{s_{NN}}$ = 72 GeV)			
			$\mathcal{L}$	σ_{inel}	Inel rate	$\int\mathcal{L}$	$\mathcal{L}$	σ_{inel}	Inel rate	$\int\mathcal{L}$
			[cm^{-2} s^{-1}]		[kHz]		[cm^{-2} s^{-1}]		[kHz]	
Internal gas target	Gas-Jet	H$^\uparrow$	4.3×10^{30}	39 mb	168	43 pb^{-1}	5.6×10^{26}	1.8 b	1	0.56 nb^{-1}
		H$_2$	2.6×10^{31}	39 mb	1000	0.26 fb^{-1}	2.8×10^{28}	1.8 b	50	28 nb^{-1}
		D$^\uparrow$	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$^\uparrow$	8.5×10^{30}	117 mb	1000	85 pb^{-1}	2.0×10^{28}	2.5 b	50	20 nb^{-1}
		Xe	7.7×10^{29}	1.3 b	1000	7.7 pb^{-1}	8.1×10^{27}	6.2 b	50	8.1 nb^{-1}
Beam splitting	Unpolarised solid target	C (658 μm)	3.7×10^{30}	271 mb	1000	37 pb^{-1}	–	–	–	–
		C (5 mm)	–	–	–	–	5.6×10^{27}	3.3 b	18	5.6 nb^{-1}
		Ti (515 μm)	1.4×10^{30}	694 mb	1000	14 pb^{-1}	–	–	–	–
		Ti (5 mm)	–	–	–	–	2.8×10^{27}	4.7 b	13	2.8 nb^{-1}
		W (184 μm)	5.9×10^{29}	1.7 b	1000	5.9 pb^{-1}	–	–	-	–
		W (5 mm)	–	–	–	–	3.1×10^{27}	6.9 b	21	3.1 nb^{-1}

Assumptions:

	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

❑ ALICE runs the full year in fixed target mode
❑ Maximum readout rate considered 1MHz in pp/pA collisions and 50kHz in PbA
→ higher rate could be envisoned in fixed-target mode depending on detector occupancy (factor ~2 Pb/Xe, factor ~10 pH)

Proton flux to be (re)considered from recent studies: 10^6 p/s (could potentially be increased to 10^7 p/s)   CERN-PBC-REPORT-2019-001
Decrease of the flux can be compensated by increasing the target thickness
      eg: pC ($\Phi = 10^6$ p/s, length = 1cm, L$_{int}$ = 1.1pb^{-1})
Extraction of Pb beam with bent crystal needs further studies (crystal location (primary/secondary/tertiary halo), composition in terms of species of the channelled ion beam…)
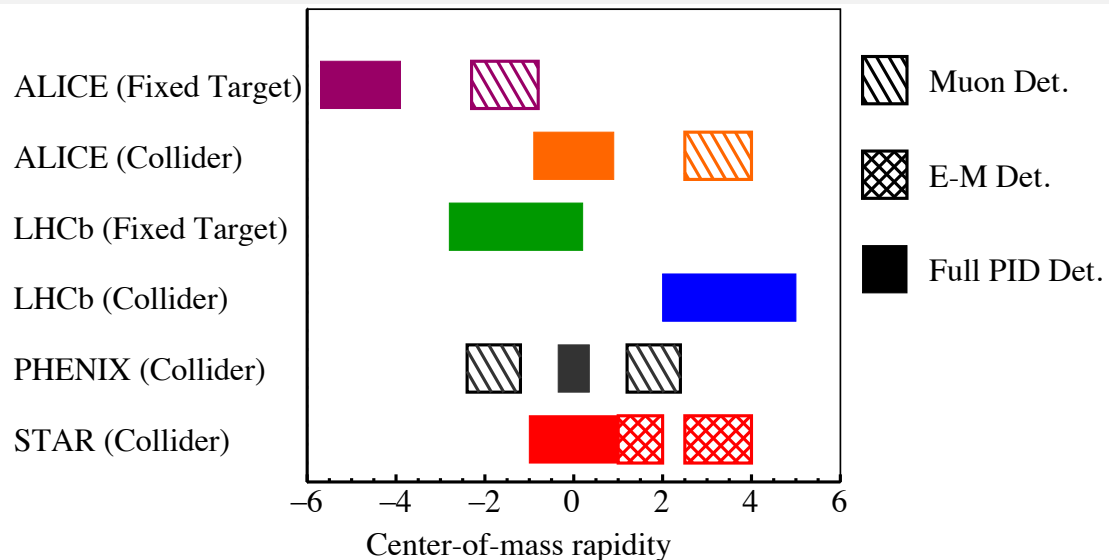
Phys. Lett. B703 (2011) 547–551 (UA9 studies with Pb beam)

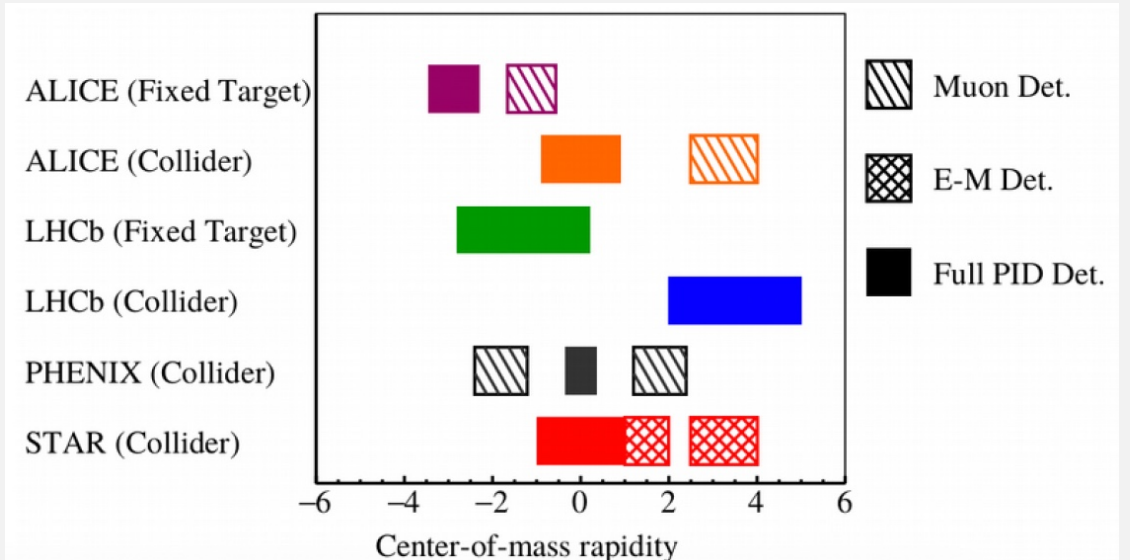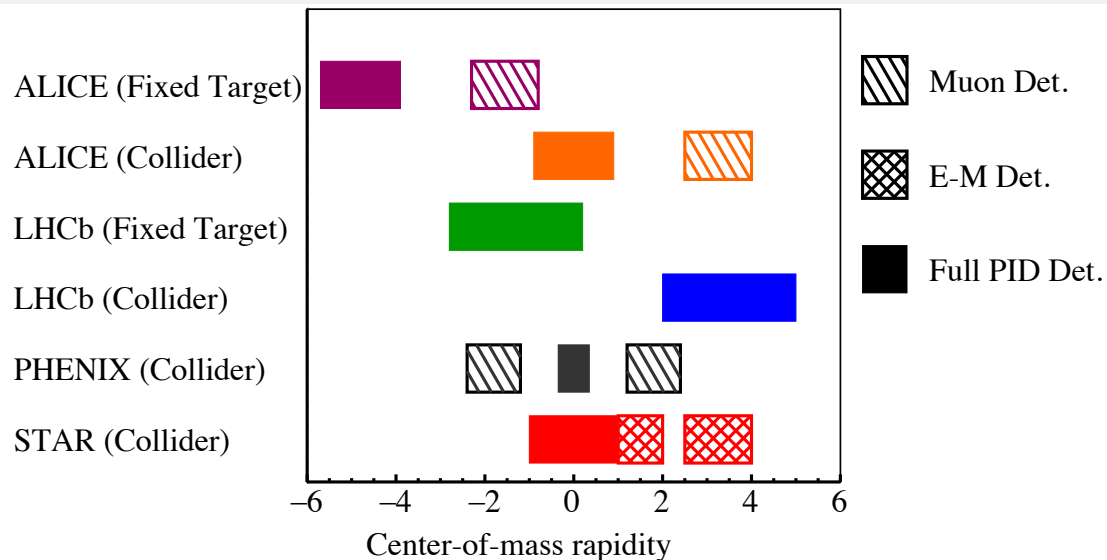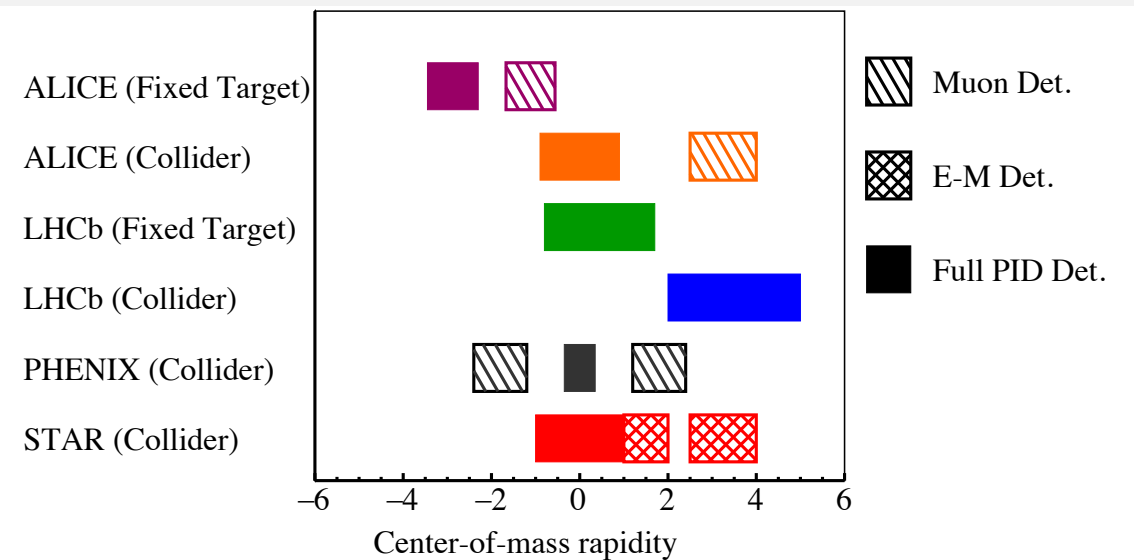# Main strengths of the ALICE detector in fixed-target mode

❑ **Large rapidity coverage**

➢ ALICE muon arm (+ future MFT) access the mid- to backward- rapidity region ($y_{c.m.s}<0$)
  - ✓ Quarkonium detection down to zero p_T
  - ✓ Rejection of background from π and K decays thanks to the absorber : asset for Drell-Yan studies at low energy

➢ ALICE central barrel probes very backward region (unique wrt to LHCb)
  - ✓ Excellent PID capabilities, particle detection and identification down to low p_T
 - ✓ Caveat: For Z_{target} << 0, ALICE central barrel coverage shifts toward mid-rapidity

ALICE Z_{target} = 0 cm

ALICE Z_{target} = -4.7 m

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ALICE Z_{target} = -4.7 m, LHCb Z_{target} = -1.5m

Main strengths of the ALICE detector in fixed-target mode
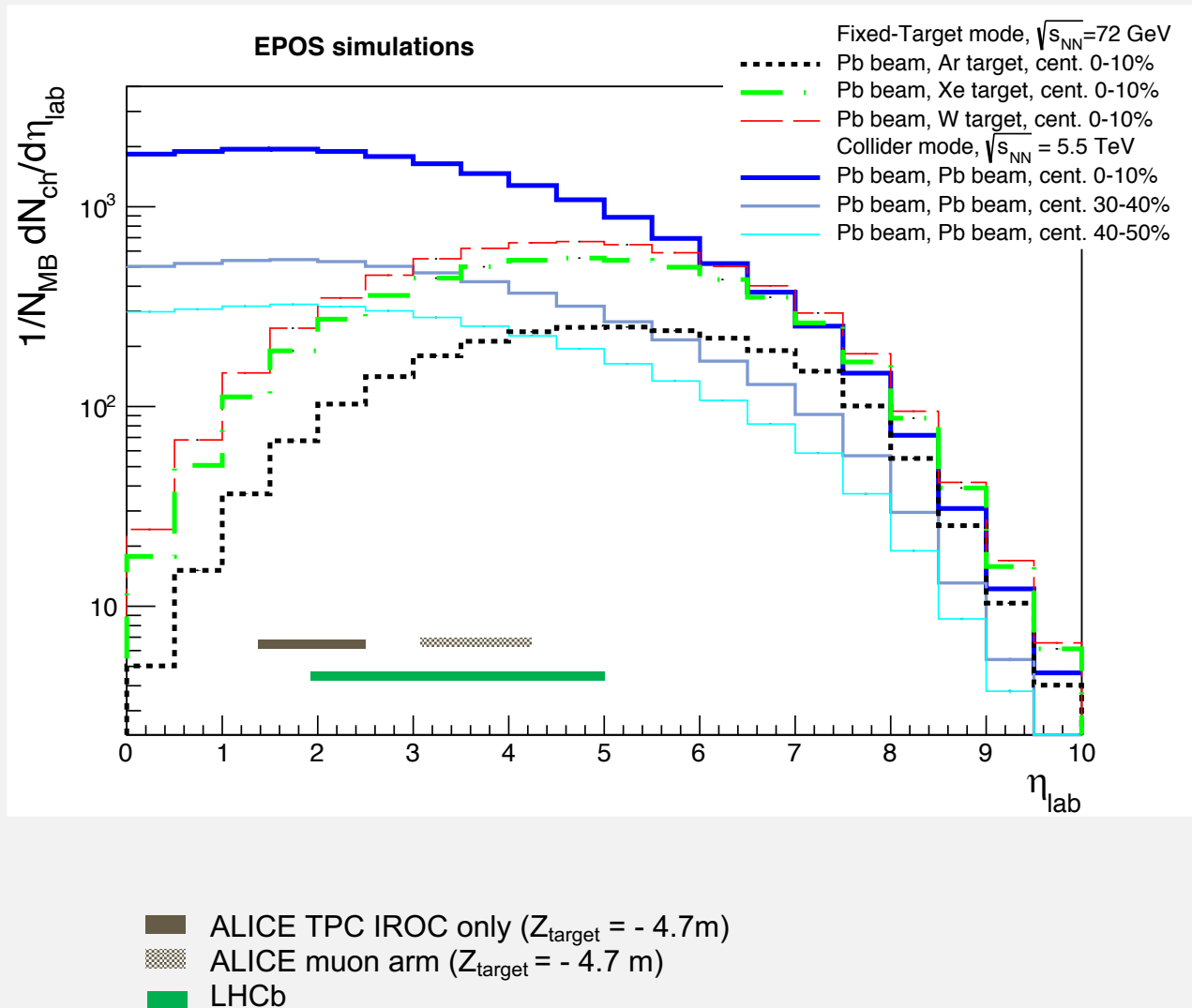

- ❑ ALICE can operate with good performance in a high multiplicity environment

- ❑ Multiplicities in AA collisions in fixed target mode always smaller than the multiplicity in Pb-Pb collisions (centrality 0-10%) in collider mode at $\sqrt{s_{NN}} \sim 5.5$ TeV, in the ALICE acceptance

- ❑ Multiplicities in most central fixed target Pb-Xe / Pb-W collisions above multiplicity in Pb-Pb collider events for y > 2 (centrality 40-50%) , y > 3.5 (centrality 30-40%)

- ❑ Access to most central fixed target AA collisions should be possible with ALICE (if reasonable interaction rate)

- ❑ ALICE could potentially devote significant time to a fixed-target programme
  - → Collection of large integrated luminosities
  - → Investigation of several target types

A selection of physics projections for ALICE Fixed-Target

❑ Updates with reduced luminosity
❑ Updates for Z_{target} = - 4.7 m
❑ Simulations for PbW/PbXe instead of PbPb

High-x physics: Drell-Yan to probe the nucleon structure

❑ DY measurement can constraint the valence and light sea quark PDFs at large-x

❑ Measurement of DY pairs in the ALICE central barrel would allow measurement up to $x_2 \rightarrow 1$ for intermediate mass Drell-Yan pairs
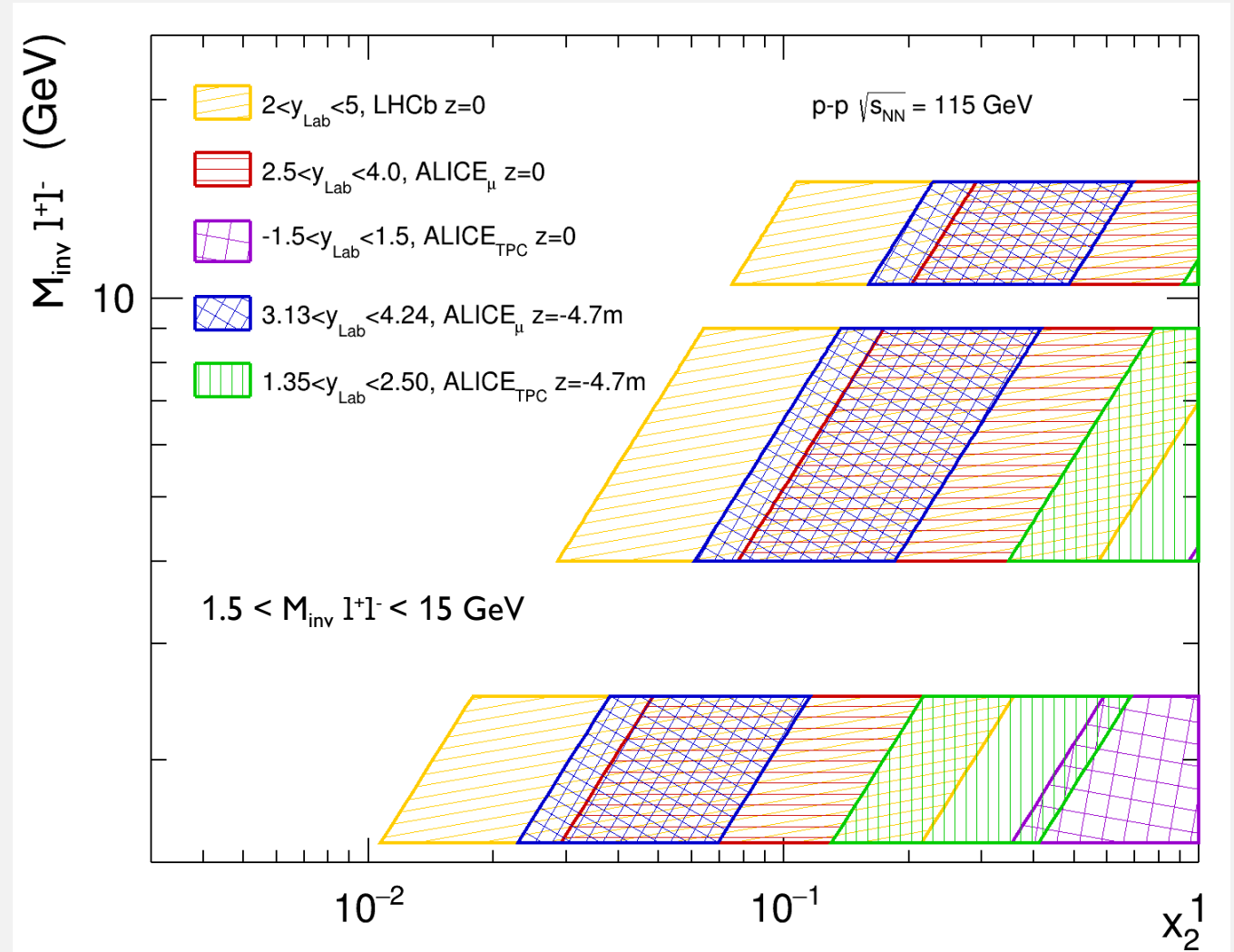
Antiproton production for CR physics

❑ Antiproton production in pH, pA 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
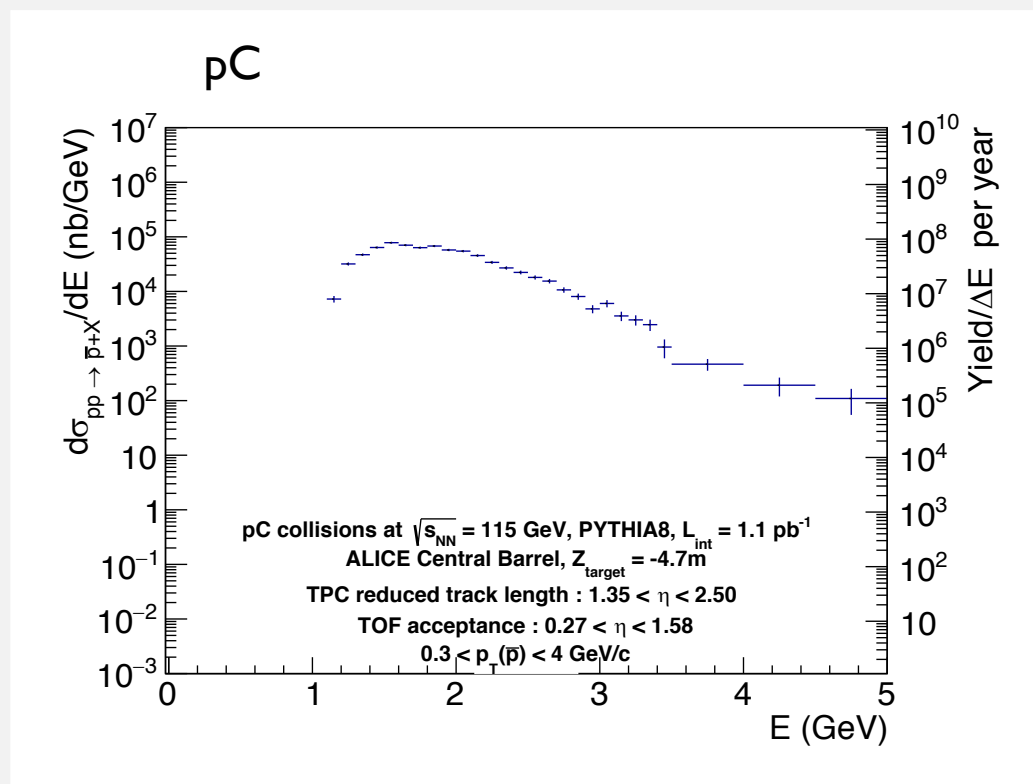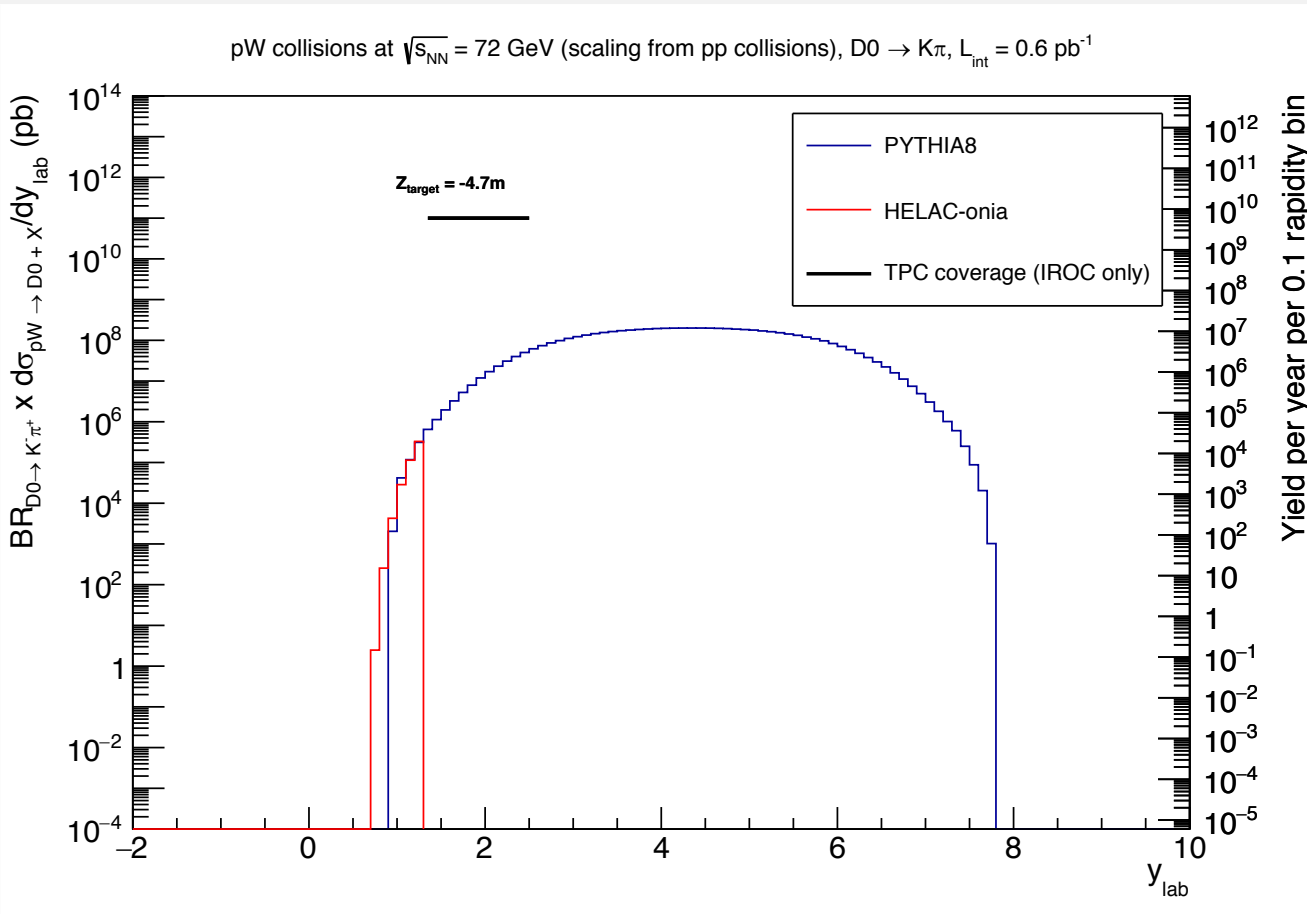

❑ Minimum bias pp collisions scaled to pC

❑ "ALICE-like" detector performances (central barrel)

❑ Z_{target} = - 4.7m

❑ Reduced yearly luminosity (L_{int} = 1.1pb^{-1}) :

➢ proton flux deflected by bent crystal : **10^6 p/s**

➢ Target length : 1 cm

➡ ALICE CB is accessing the very low energy domain
for antiproton production
Large yearly yields expected

High-x and HI physics : Open heavy flavours

❑ Study large-x gluon nPDFs [assuming modification of nPDF is the dominant Cold Nuclear Matter effect, also need pH reference]

Phys.Rev.Lett. 121 (2018) no.5, 052004

❑ Search for collective dynamics of partons in small systems at low energy with heavy flavour (v_2 of D mesons)

pW collisions at $\sqrt{s_{NN}}$ = 72 GeV (scaling from pp collisions), D0 → Kπ, L_{int} = 0.6 pb^{-1}

❑ Hard $c\bar{c}$ pair production in pp collisions scaled to pW

❑ "ALICE-like" detector performances (central barrel)

❑ Z_{target} = - 4.7m coverage in black

❑ Reduced yearly luminosity (L_{int} = 0.6 pb^{-1}) :

➤ proton flux deflected by bent crystal : **10^6 p/s**

➤ Target length : 1 cm

➡ ALICE CB is accessing the very backward domain for D meson production → sensitivity to large-x gluon nPDFs Large yields for Z_{target} = -4.7 m to allow for v_2 measurements

# HI physics : rapidity scan to search for the QCD critical point

❑ **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 $y_{cms} \sim 0$)

➢ A novel way to search for the QCD critical point and probe the nature of the phase transition to confined partons
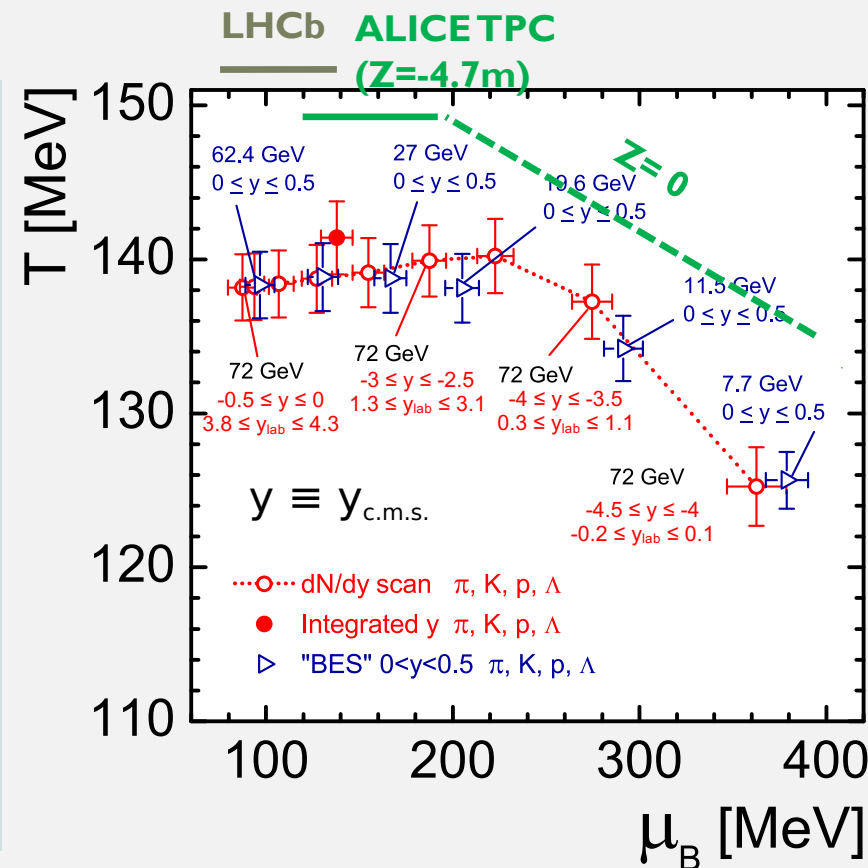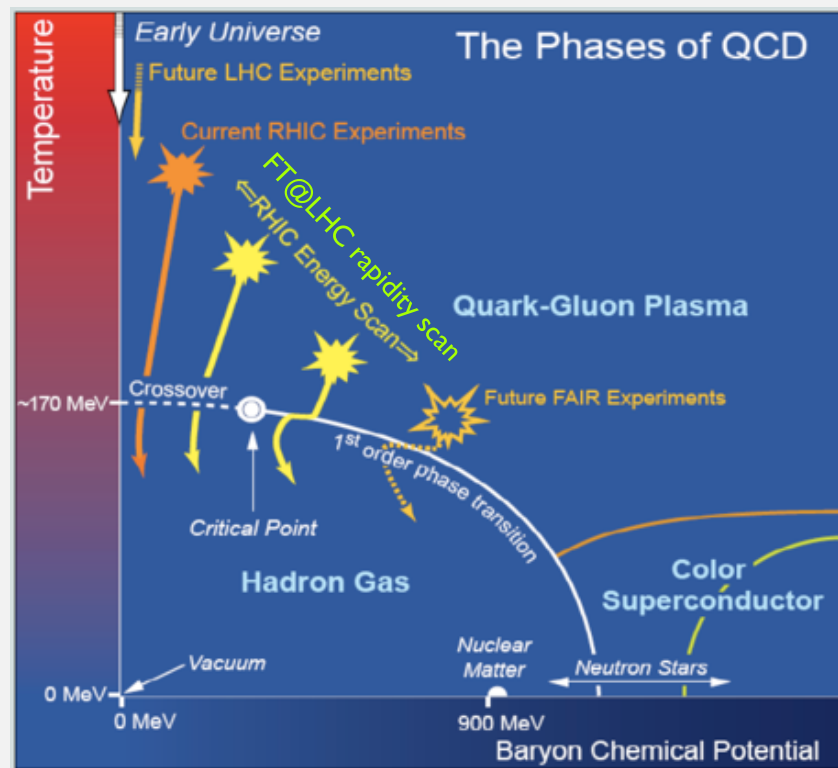
V. Begun, D. Kikola, V. Vovchenko, D. Wielanek, PRC 98 (2018) 034905
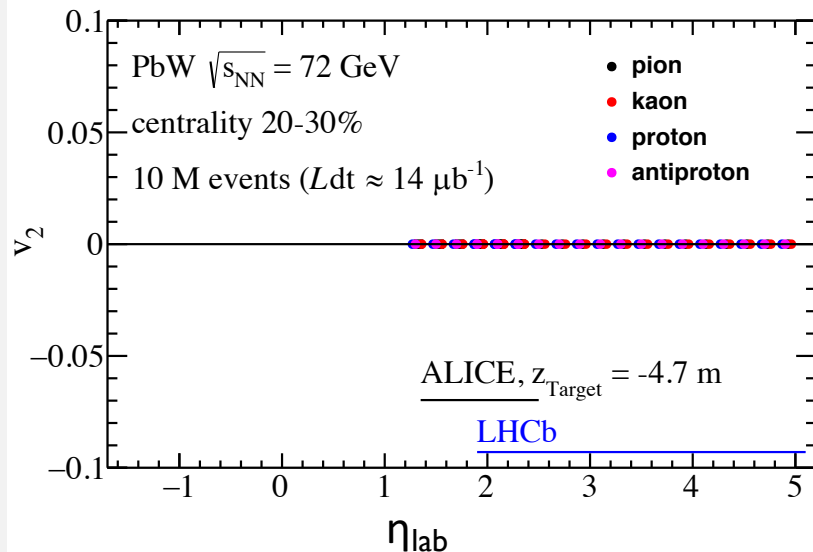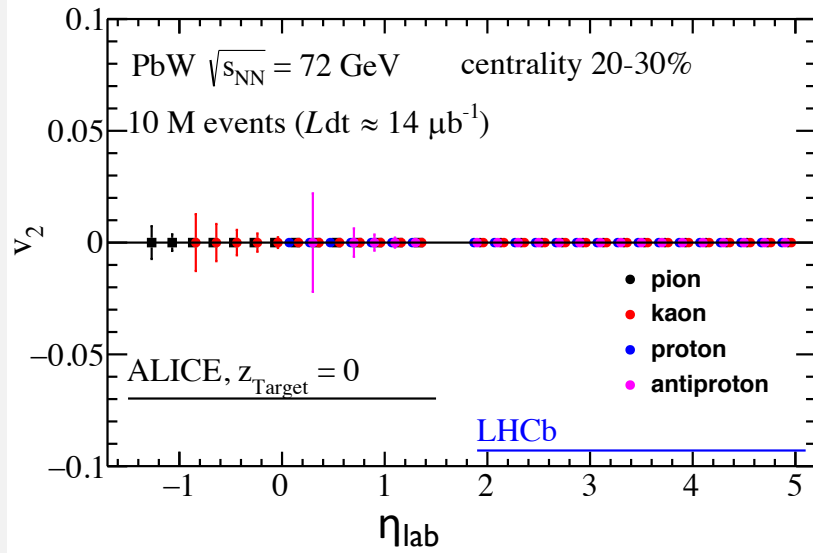
❑ **Advance our understanding of QGP macroscopic properties by probing the temperature dependence of the shear viscosity to entropy density ratio (η/s) of the created matter**

➢ 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

❑ Pb-W collisions (centrality 20-30%)

❑ « ALICE-like » and « LHCB-like » detectors

❑ Update with Z_{target} = -4.7m for ALICE

❑ 100M MB events (few hours of data-taking)

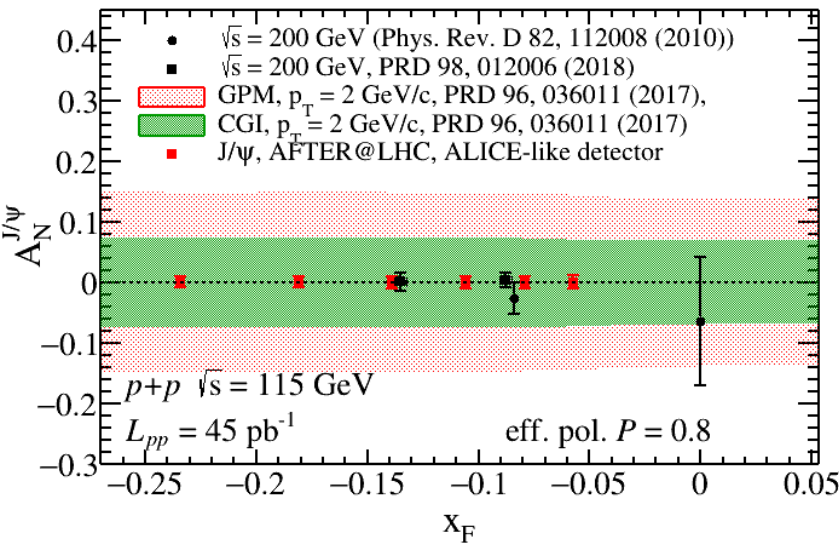❑ Percent level statistical accuracy for the v_2 measurement

➡ Study of identified particles in wide rapidity range
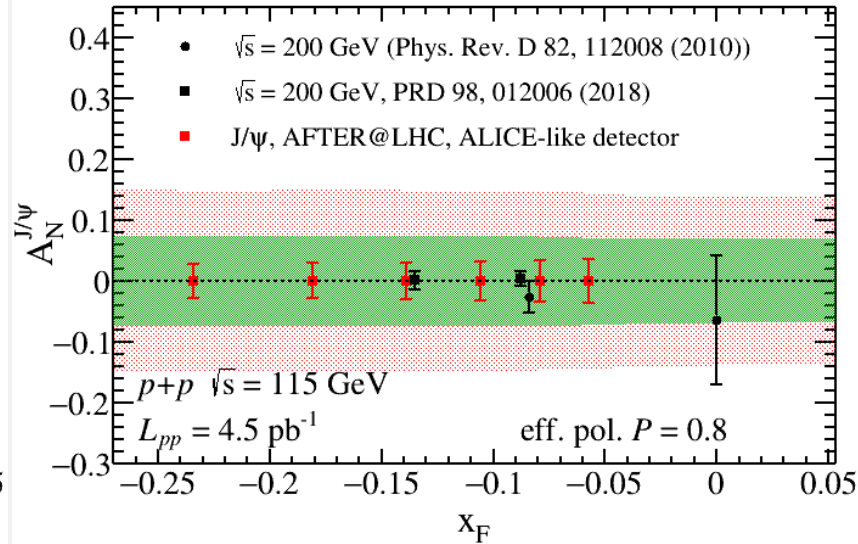Complementary coverage between ALICE and LHCb

Spin physics : J/ψ A_N with **polarised target**

❑ **Probe the gluon Sivers effect over a broad Feynman-x range with gluon sensitive probe (charmonia)**
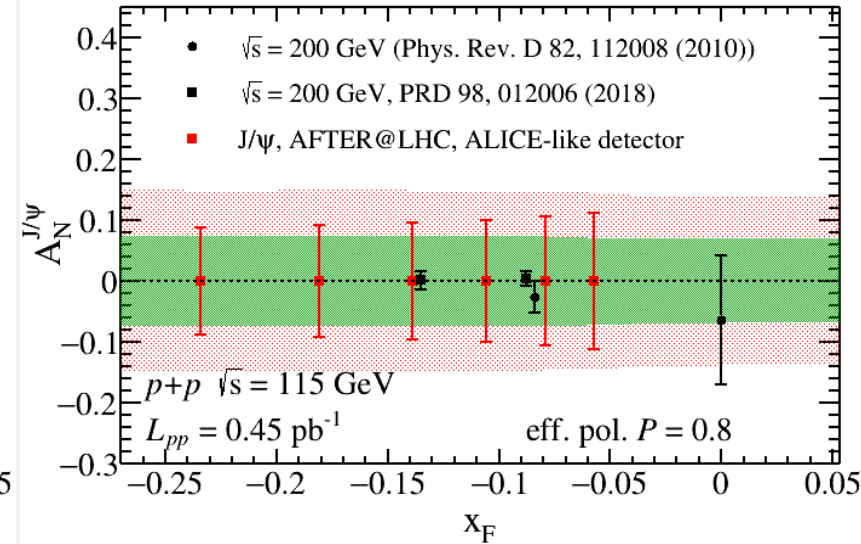
Full luminosity	Reduced luminosity factor 10	Reduced luminosity factor 100

❑ pH collisions (target polarization P = 0.8)

❑ "ALICE-like" detector performances (muon arm)

❑ Z_{target} = 0 (caveat not updated to Z < -4.8m)

❑ Reduced yearly luminosity by factor 10 and 100

Conclusion

❑ **Three main physics goals identified to motivate a 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

❑ **Integration studies of a target setup pursued in ALICE**

  ➢ Technology currently studied : a slow extraction with a bent crystal coupled to a solid target

  ➢ Possible target location identified

❑ **Fast simulation work has been performed to provide figures of merit for ALICE for a selection of observables (Drell-Yan, Open-HF, quarkonia, antiproton, identified particles)**

❑ **Next steps**

  ➢ Impedance and vacuum studies in collaboration with LHC experts

  ➢ Test of the crystal + target system at SPS in Collaboration with UA9

  ➢ Simulation of the TPC performances for displaced verteces