Fixed target measurements in LHCb&ALICE

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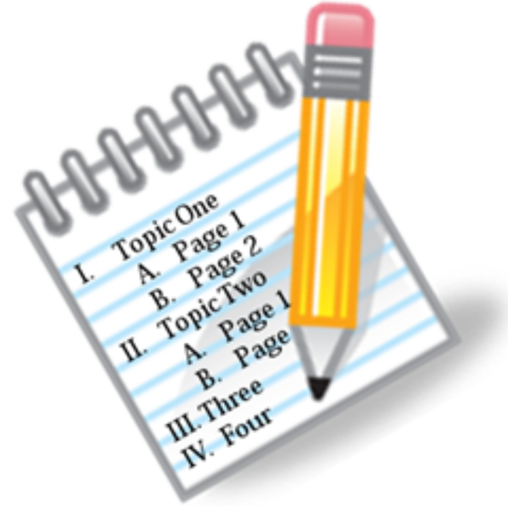
Outline

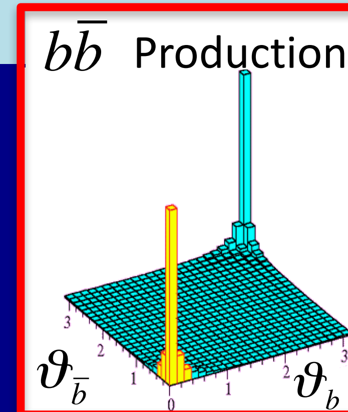
- LHCb and ALICE
  - Fixed target capabilities
- Physics interest
- LHCb results and prospects
- ALICE prospects & ideas
- Conclusions and outlook



LHCb Detector at the LHC

➡ Single arm spectrometer in the forward direction

- Designed for b-physics, becoming a General Purpose Detector
- Forward and backward coverage for asymmetric beams
- Precision in the forward not achievable by other experiments yet

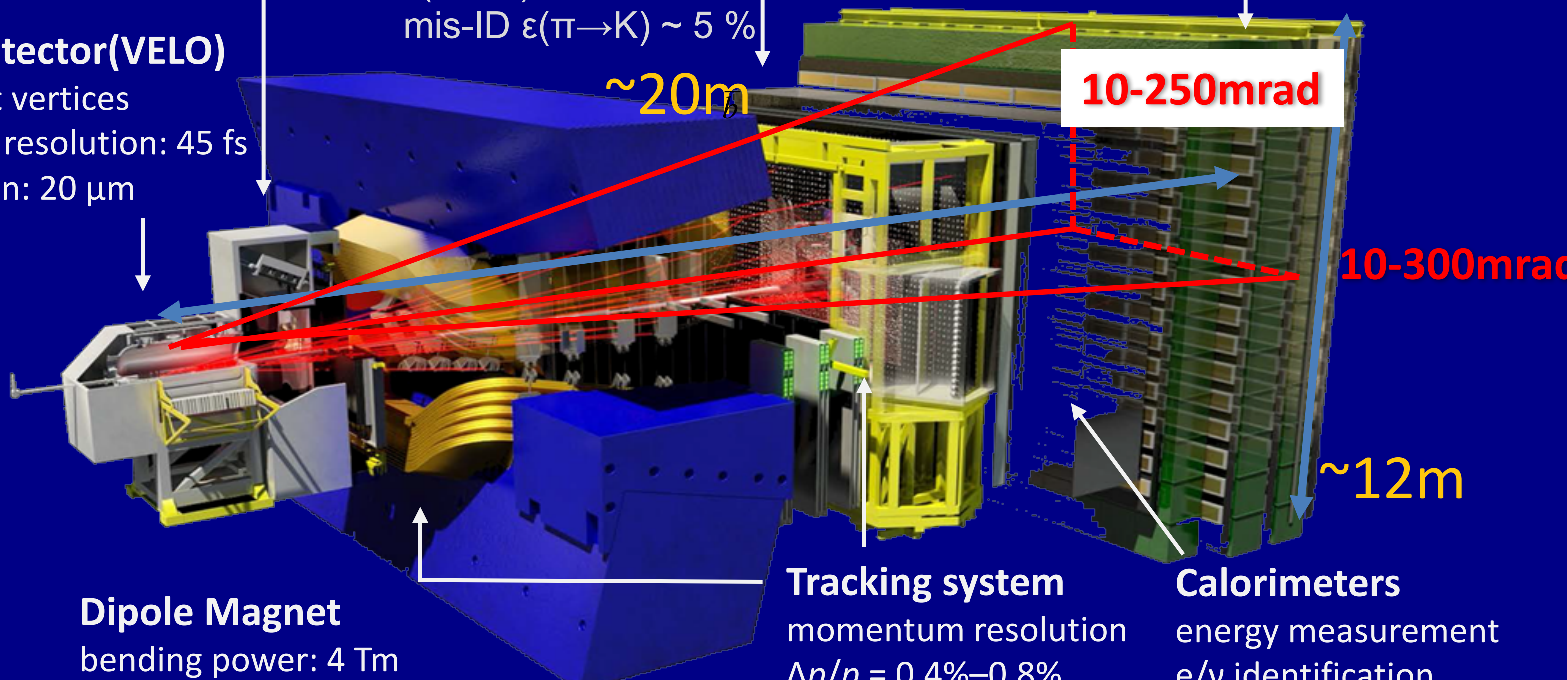


[JINST 3 (2008) S08005]
[IJMPA 30 (2015) 1530022]

RICH detectors
K/π/p separation
ε(K→K) ~ 95 %,
mis-ID ε(π→K) ~ 5 %

Muon system
μ identification ε(μ→μ) ~ 97 %,
mis-ID ε(π→μ) ~ 1-3 %

Vertex Detector(VELO)
reconstruct vertices
decay time resolution: 45 fs
IP resolution: 20 μm

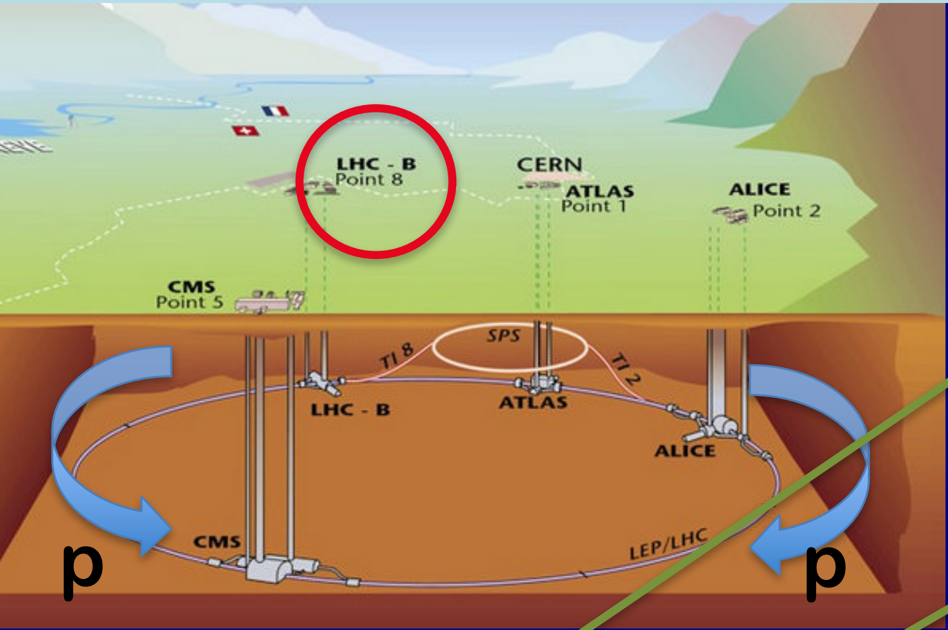


Dipole Magnet
bending power: 4 Tm

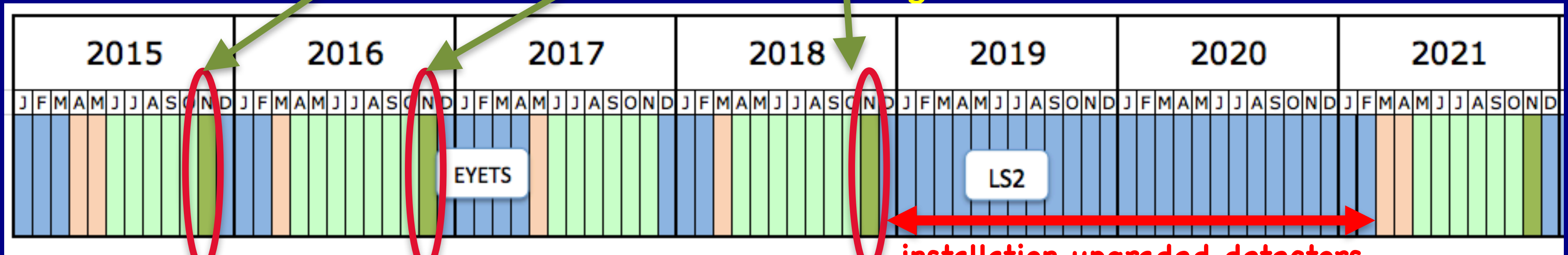
Tracking system
momentum resolution
$\Delta p/p$ = 0.4%–0.8%
(5 GeV/c – 100 GeV/c)

Calorimeters
energy measurement
e/γ identification
ΔE/E = 1 % ⊕10 %/√E (GeV)

LHC and LHCb



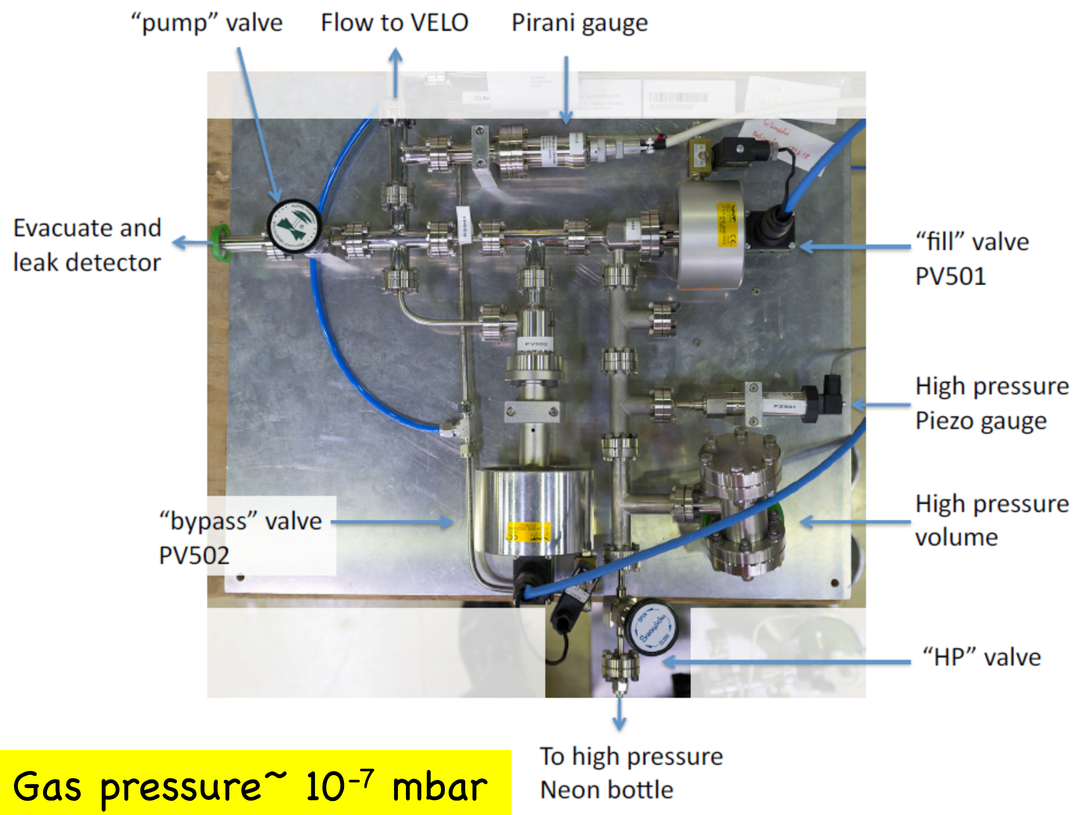
- pp collider : 2010-2017:
  - ➡ @ $\sqrt{s}$ = 2.76, 5, 7, 8, 13 TeV
  - ➡ L = 40 pb^{-1} – 3.1 fb^{-1} – 6 fb^{-1}
- ➡ PbPb collisions at $\sqrt{s}$=5TeV successfully collected at LHCb for the first time in 2015; next run end 2018
- ➡ In 2013 also collected 1.6 nb^{-1} of pPb data at $\sqrt{s_{NN}}$=5 TeV;
- ➡ pPb run at end 2016, @ $\sqrt{s}$ =5 and 8.16 TeV, ~34 nb^{-1};
- ➡ LHCb also able to collect data in "fixed target" mode (SMOG)



Luminosity uncertainty 3.5-5%
(J. Instrum. 7 (2012) P01010)
=> reach 2% in pp

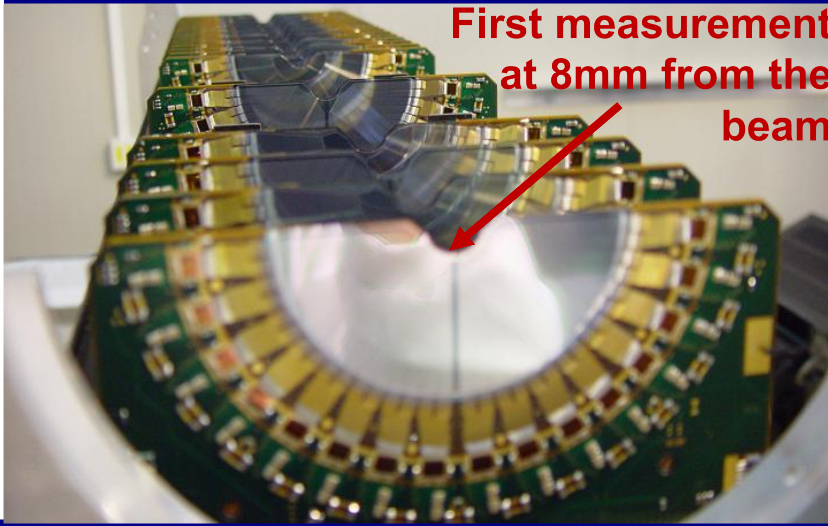
The SMOG System

SMOG : System for Measuring the Overlap with Gas



Gas pressure~ 10^{-7} mbar

- Injection of noble gas into interaction region
- Very simple robust system
- Used for a precise luminosity determination

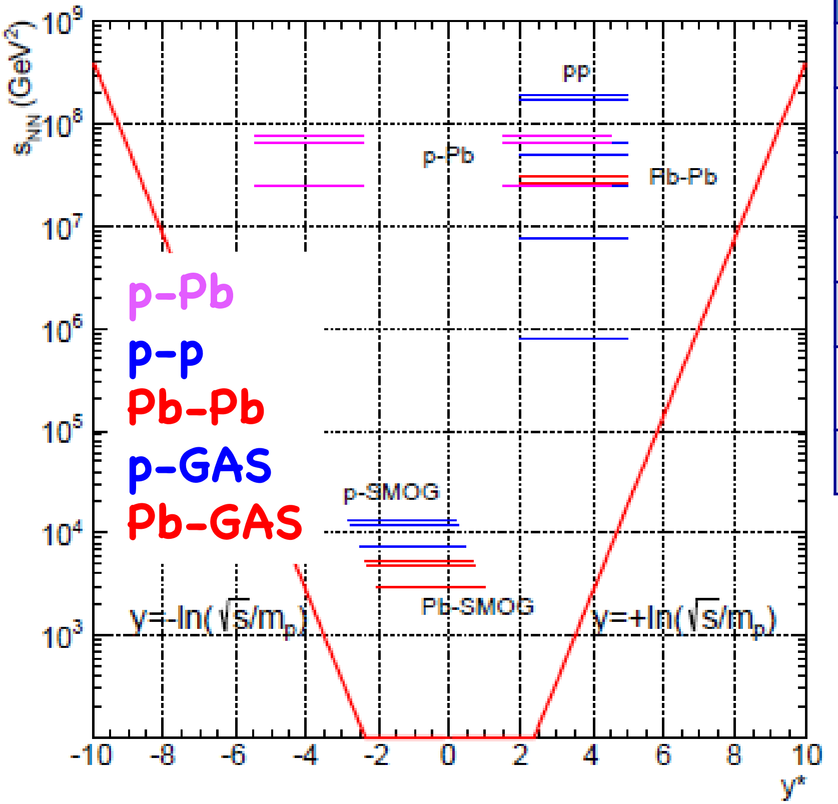


SMOG can be used for fixed target physics:

- Precise vertexing allows to separate beam-beam and beam-gas contributions
- With a run of few hours can collect samples large enough for analysis

Phase Space Coverage and Running Modes

➡ Kinematic acceptance & (existing/future) beam-target combinations



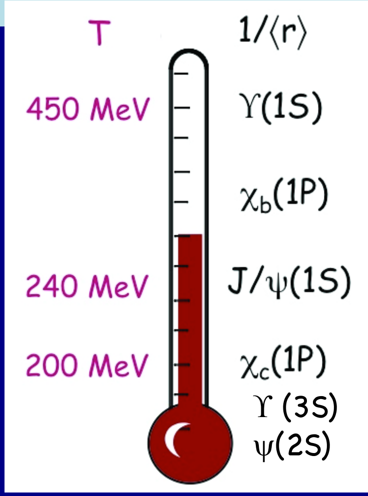
E_{beam}(p)	pp	p-GAS	p-Pb/Pb-p	Pb-GAS	Pb-Pb
450 GeV	0.90 TeV				
1.38 TeV	2.76 TeV				
2.5 TeV	5 TeV	69 GeV			
3.5 TeV	7 TeV				
4.0 TeV	8 TeV	87 GeV	5 TeV	54 GeV	
6.5 TeV	13 TeV	110 GeV	8.2 TeV	69 GeV	5.1 TeV
7.0 TeV	14 TeV	115 GeV	8.8 TeV	72 GeV	5.5 TeV

p/Pb-GAS operation so far:

Collisions	√s (GeV)	Length	# p on target	Year
pHe	87	84 h	4.6×10^{22}	2016
pHe	110	18 h	3×10^{21}	2016
pNe	110	12 h	1×10^{21}	2015
pHe	110	8 h	2×10^{21}	2015
pAr	110	17 h	4×10^{22}	2015
PbAr	69	100 h	2×10^{20}	2015
pNe (pilot run)	87	30 m		2012
PbNe(pilot run)	54	30 m		2013

➡ y*: rapidity in nucleon-nucleon centre-of-mass system, with forward direction (positive values) in direction of the proton/beam

LHCb Physics Programme



➡ Heavy Flavours (HF) and Quarkonia

- Probe colour screening and measurement of the QGP temperature through sequential melting of states
- Sensitive to cold and hot nuclear matter effects

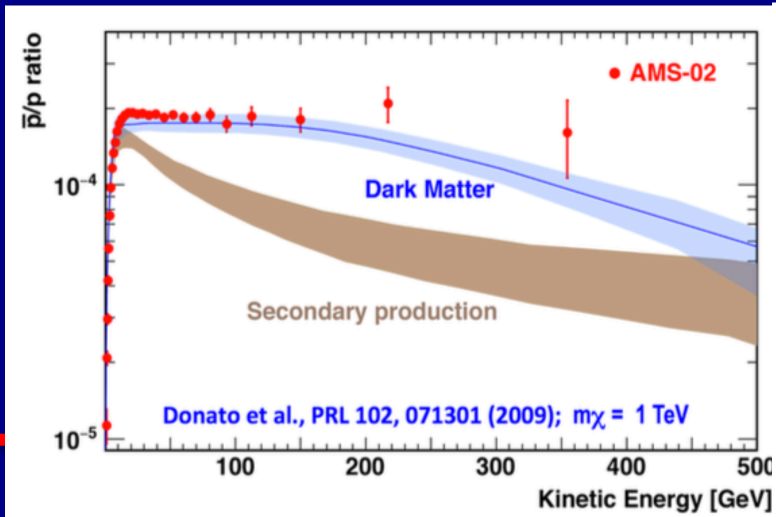
➡ Soft QCD and Electroweak physics

- Nucleon structure (low and high x), collective effects,

ultra-peripheral collisions, central exclusive production, diffractive processeS

➡ Cosmic ray physics

- LHCb can prove AMS-02 results by testing secondary antiproton production in pHe interactions using SMOG



Phys.Rev. Lett.117 (2016) 091103

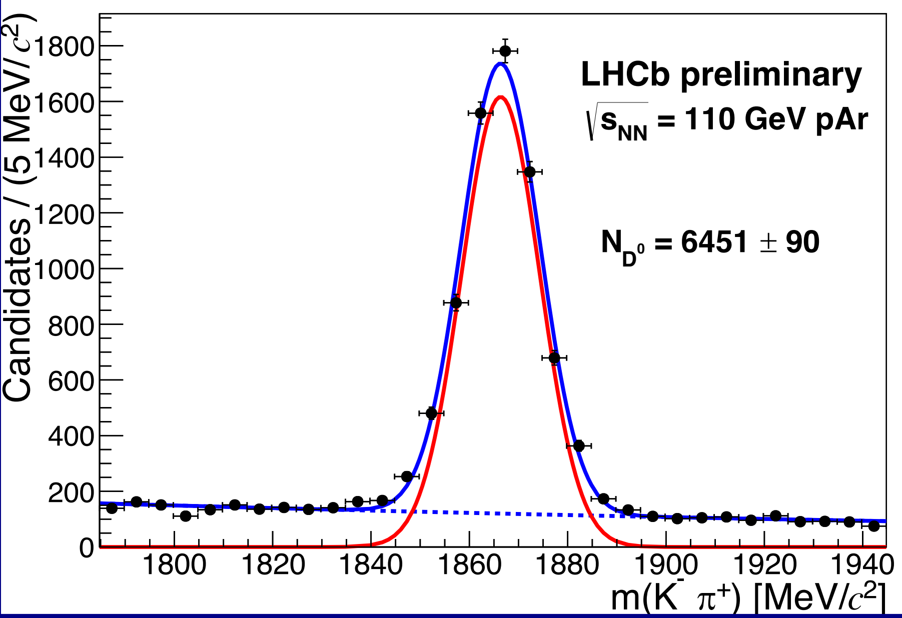
Running in fixed target mode NOW

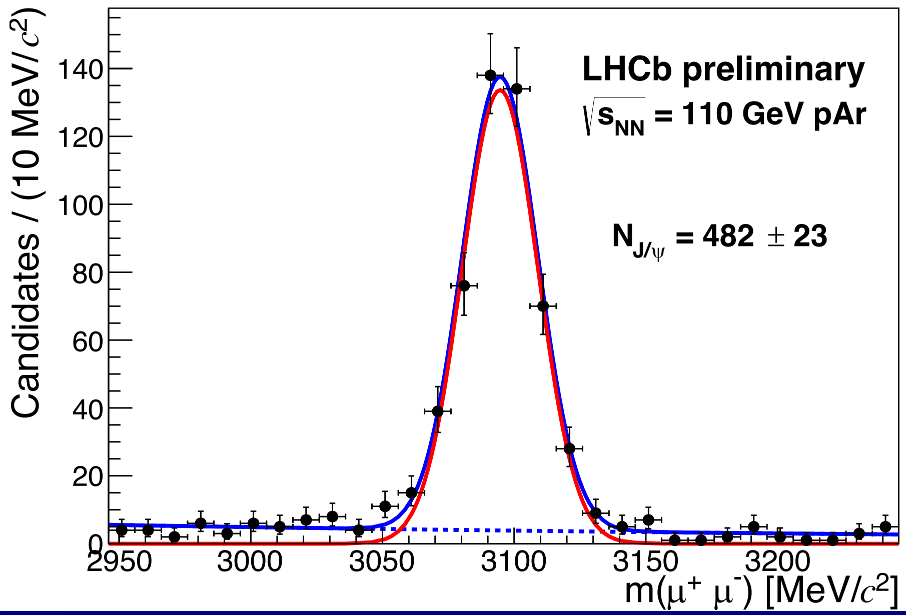
J/ψ and D^0 production in pAr collisions

LHCb-CONF-2017-001

- First result in fixed target mode !
- √s=110 GeV, never explored before and unique at LHCb
- p-A collisions main tool to evaluate Cold Nuclear Matter effects

Very clear D^0 and J/ψ signals





J/ψ and D^0 production in pAr collisions

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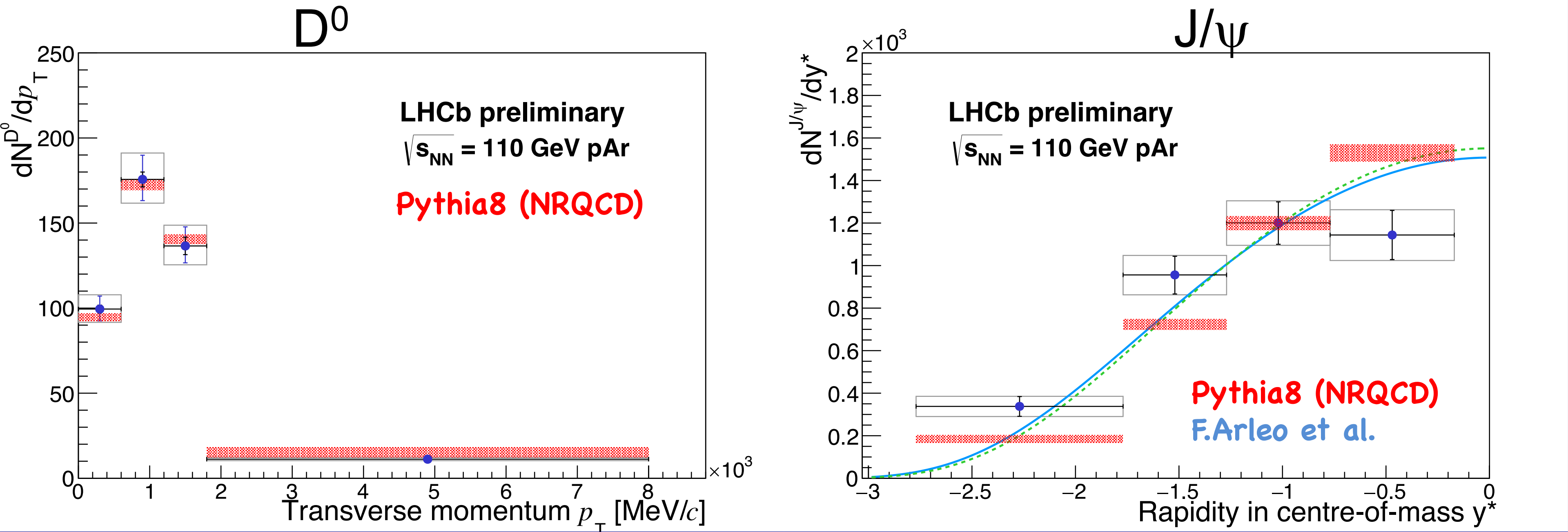
➡ Data in agreement with NRQCD predictions



➡ Compatible with Pythia8 results using CT09MCS/NRQCD and predictions from F.Arleo et al. [JHEP(2013) 20113:122,JHEP(2013) 2013:155]

J/ψ and D^0 production in pAr collisions

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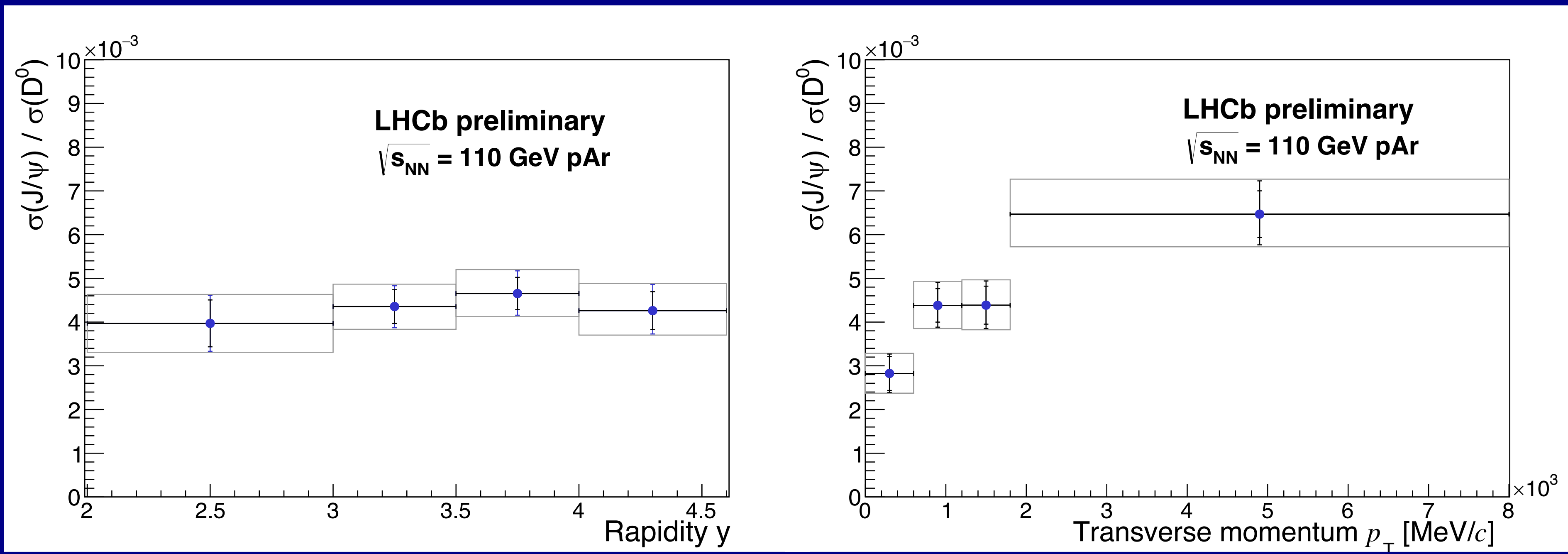
- Measure the ratio

$$\left(\frac{\sigma(J/\psi)}{\sigma(D^0)} = \frac{Y(J/\psi)}{\mathcal{L}} \times \frac{\mathcal{L}}{Y(D^0)}\right)$$



- No dependence on y, increase with momentum
- Result being finalised for publication

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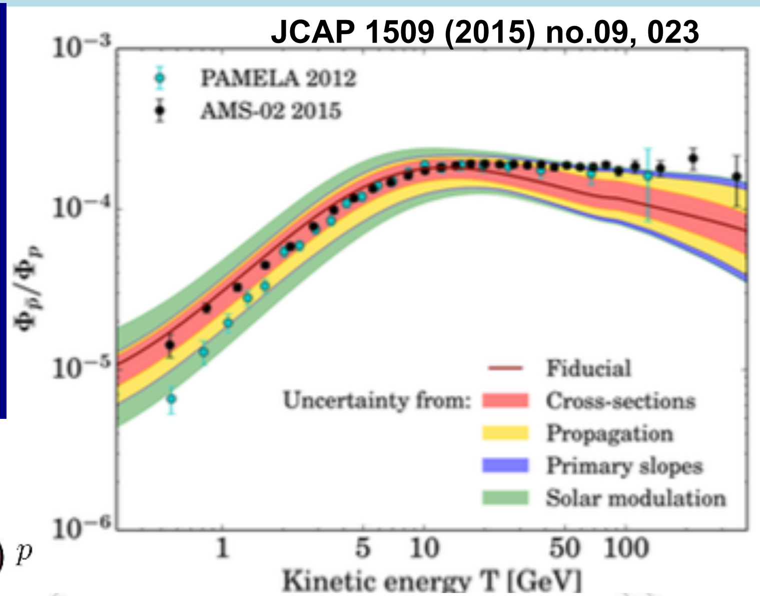
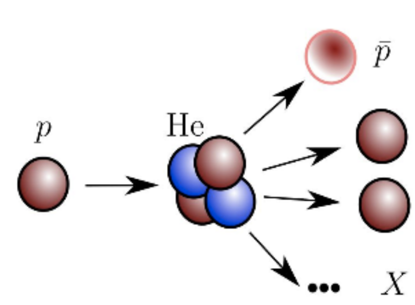
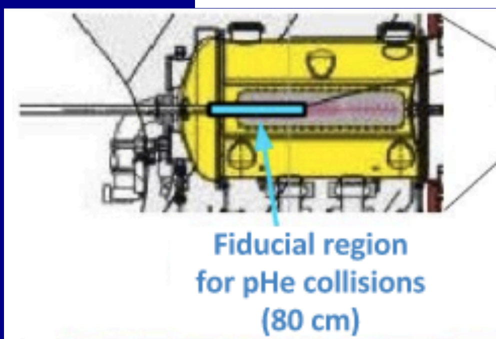
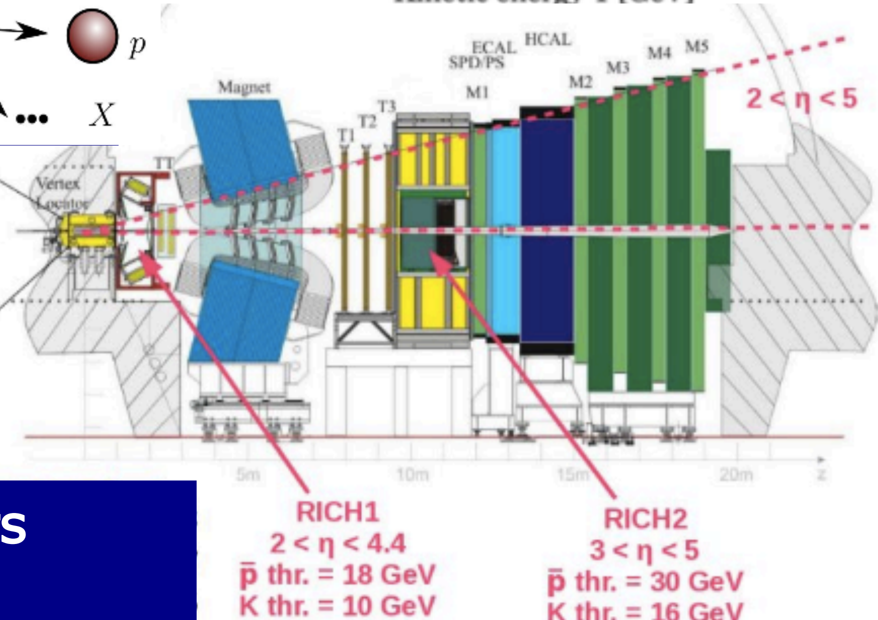
$\bar{p}$ production in pHe collisions

- ➡ Measurement triggered by astrophysics community
  - AMS02[PRL117(2016)091103] and Pamela[Nature 458 (2009) 607-609] measured excess in $\bar{p}$ flux
  - Large uncertainties from $\bar{p}$ production in interstellar matter (H,He)
    - Possible with SMOG (He)
    - Acceptance :
      - ✓ $12 < p < 110$ GeV/c
      - ✓ $p_T > 0.4$ GeV/c









- ➡ Profit from high precision detectors

$\bar{p}$ production in pHe collisions

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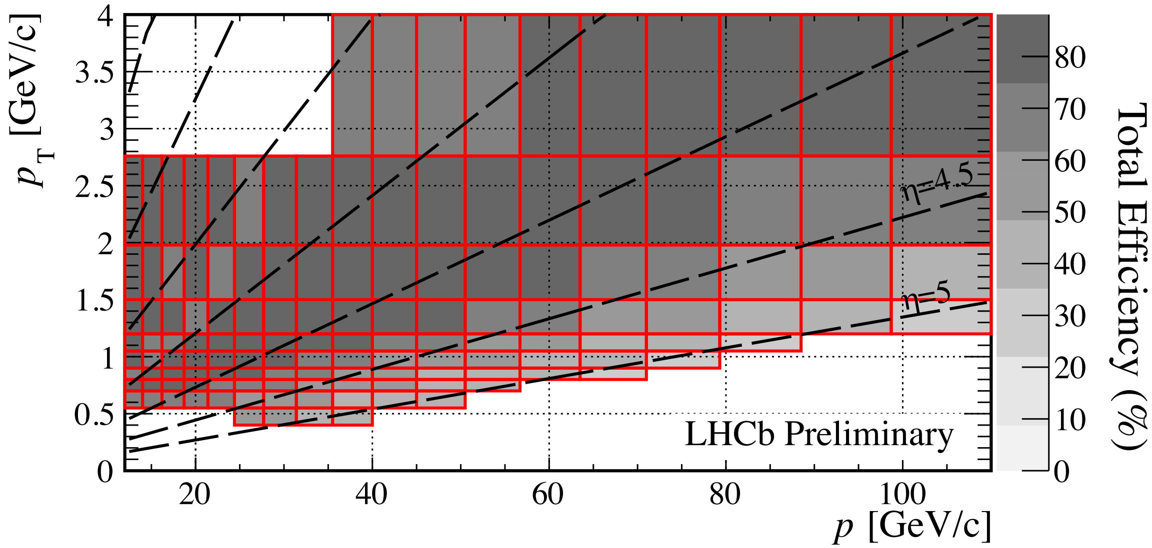
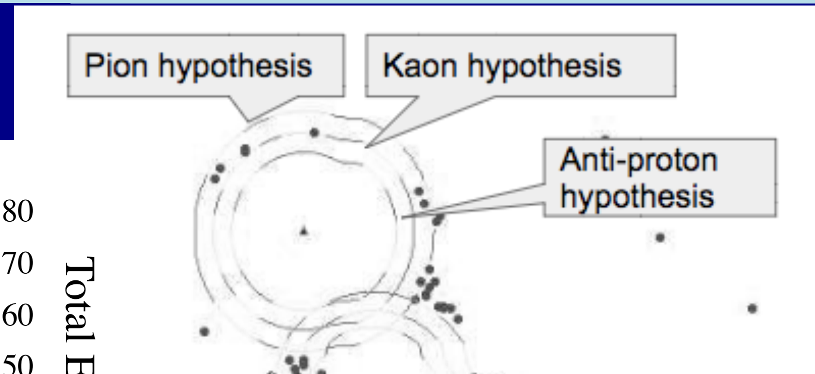
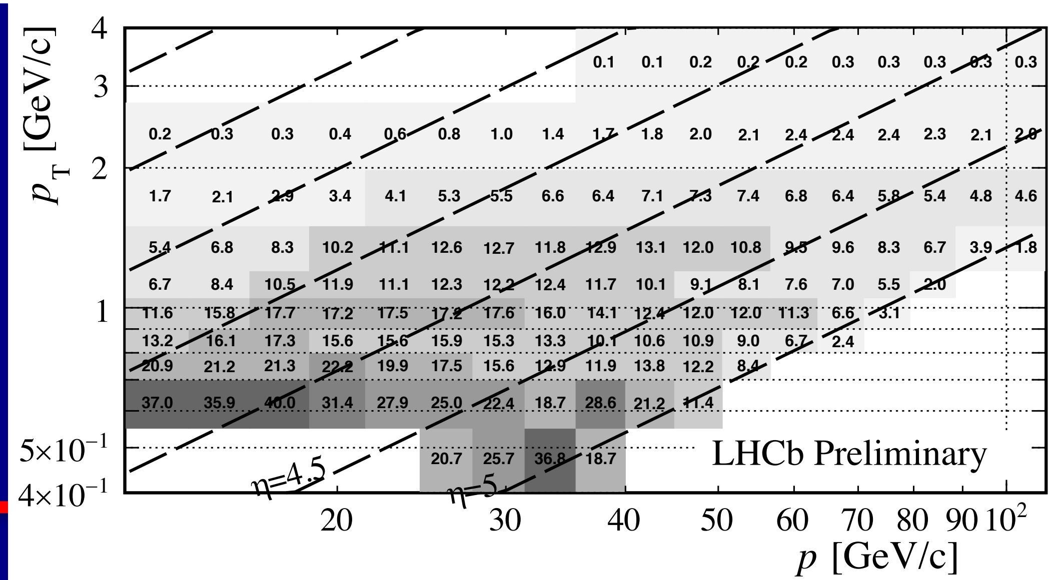
- Antiprotons identified with Cerenkhov radiation detectors (RICH);





- Number of $\bar{p}$ reconstructed in acceptance (x10^{-3})
- Luminosity estimated using elastic *pe* scattering as normalisation channel

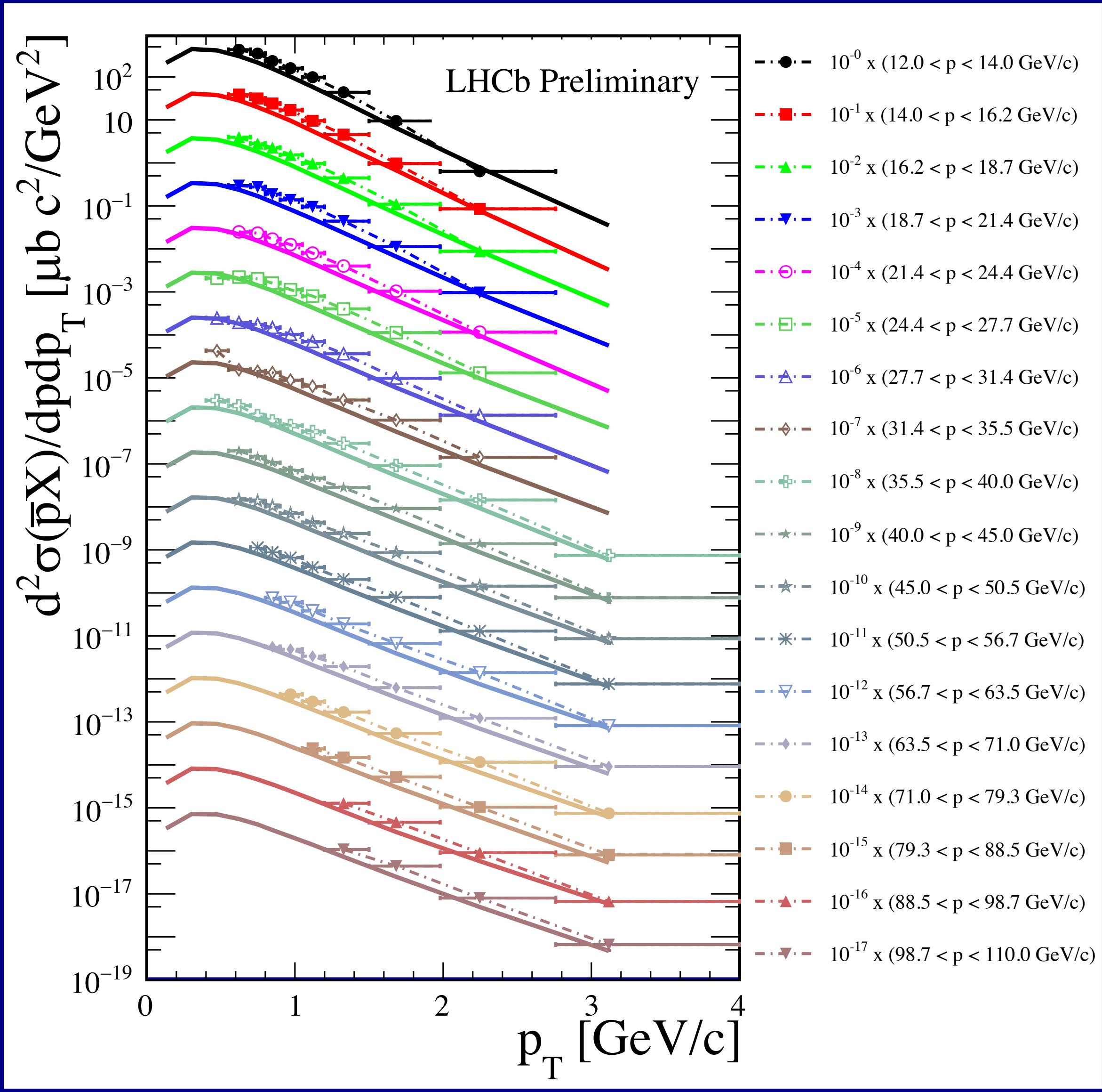
  => σ_{pe} well known



$\bar{p}$ production in pHe collisions

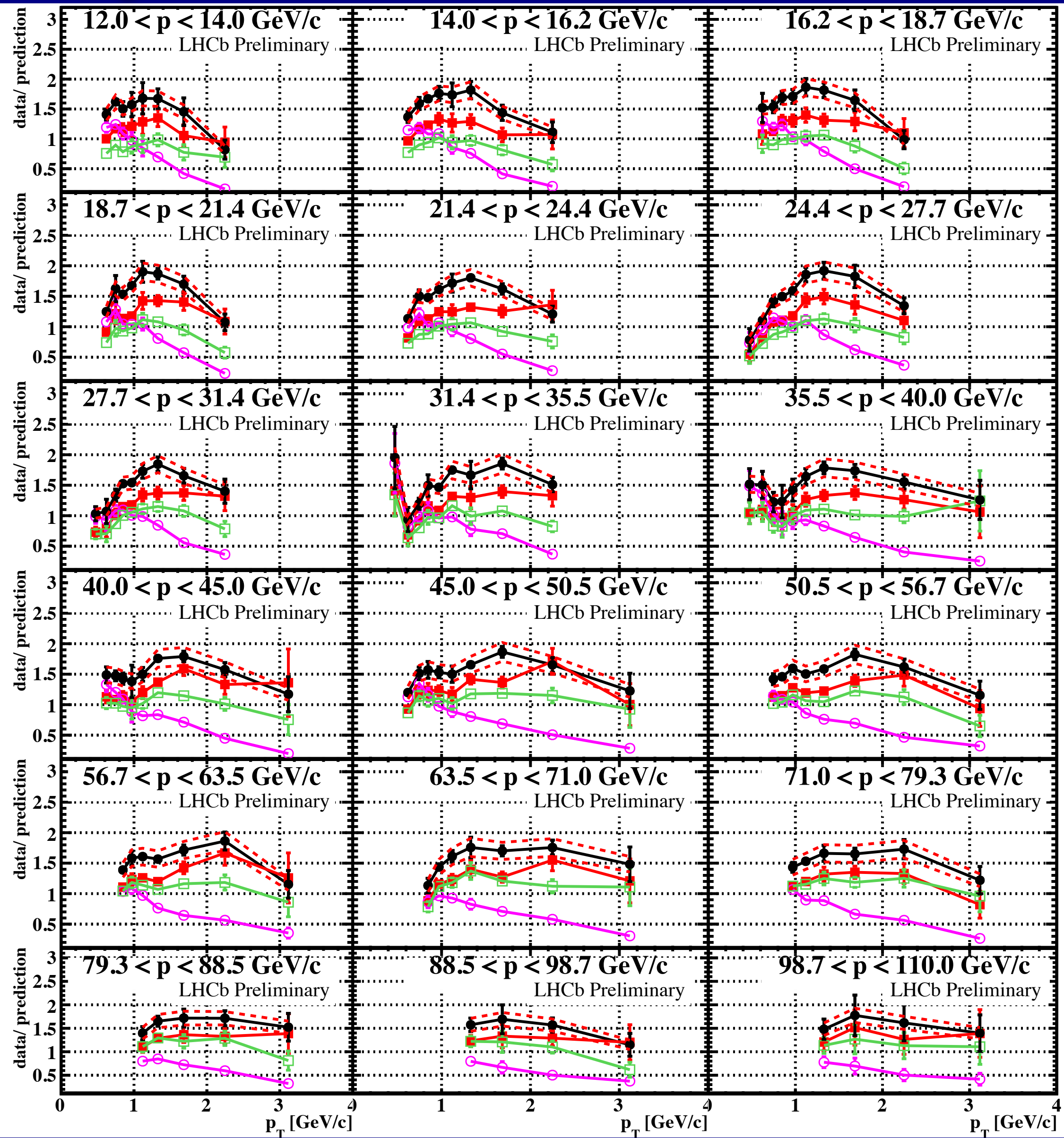
- Measurement of prompt antiproton production cross section in 18 p_T bins compared with the predictions from EPOS LHC
- σ^{LHCb}_{inel} =(140±10) mb
- EPOS : 118 mb

[Nucl. Phys. Proc. Suppl.196 (2009) 102, arXiv:0905.1198]



$\bar{p}$ production in pHe collisions

- Measurement of prompt antiproton production cross section in 18 p_T bins
- Data compared to different models
  - black EPOS LHC[1],
  - red EPOS 1.99[2],
  - green HIJING 1.38[3],
  - violet QGSJETII-04[4].
- Result being finalised for publications
- Next step to analyse larger sample @ 4 TeV

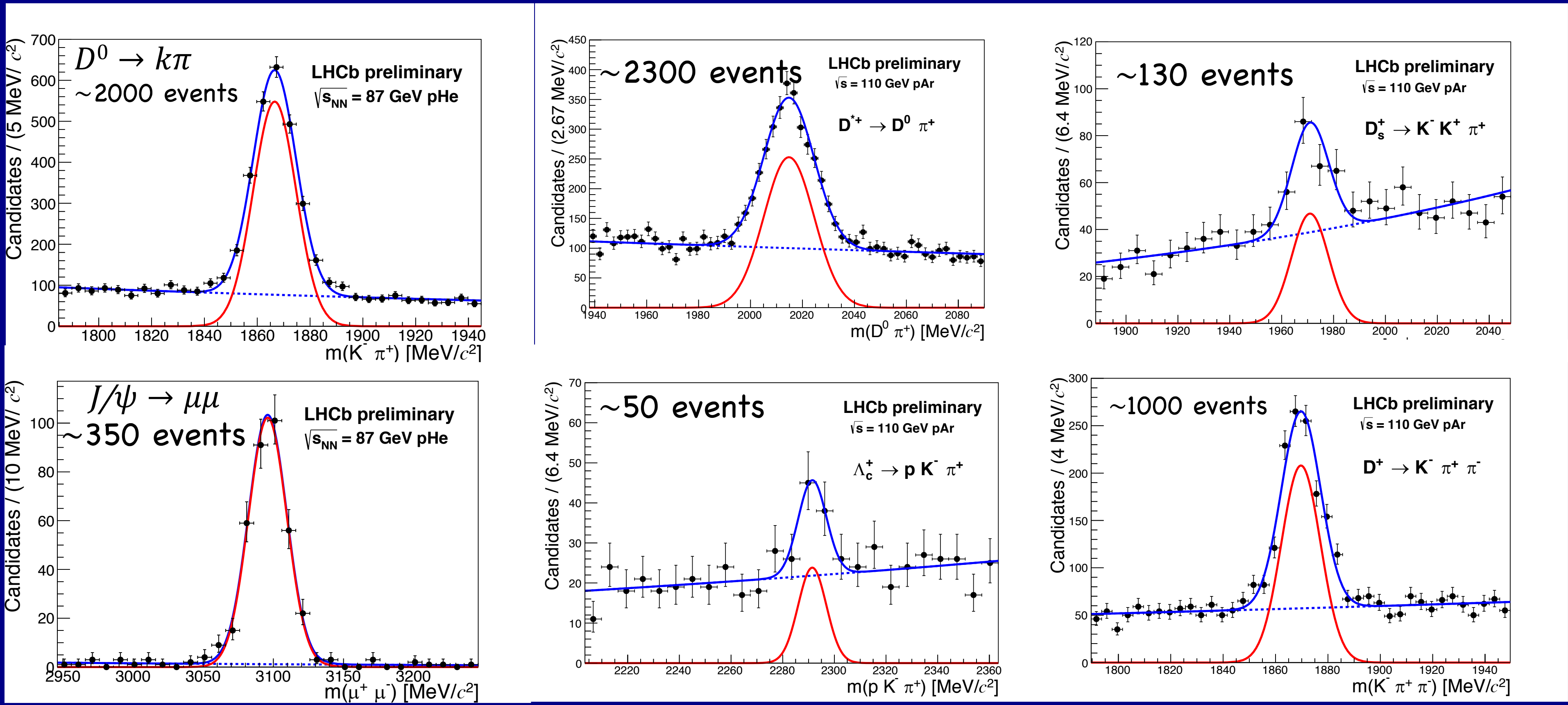


[1,2] [Nucl. Phys. Proc. Suppl.196 (2009) 102, arXiv:0905.1198]
[3] Comput. PhysCommun. 83 (1994) 307, arXiv:nucl-th/9502021
[4] Phys. Rev.D83 (2011) 014018, arXiv:1010.1869

More results ahead…

LHCb-CONF-2017-001

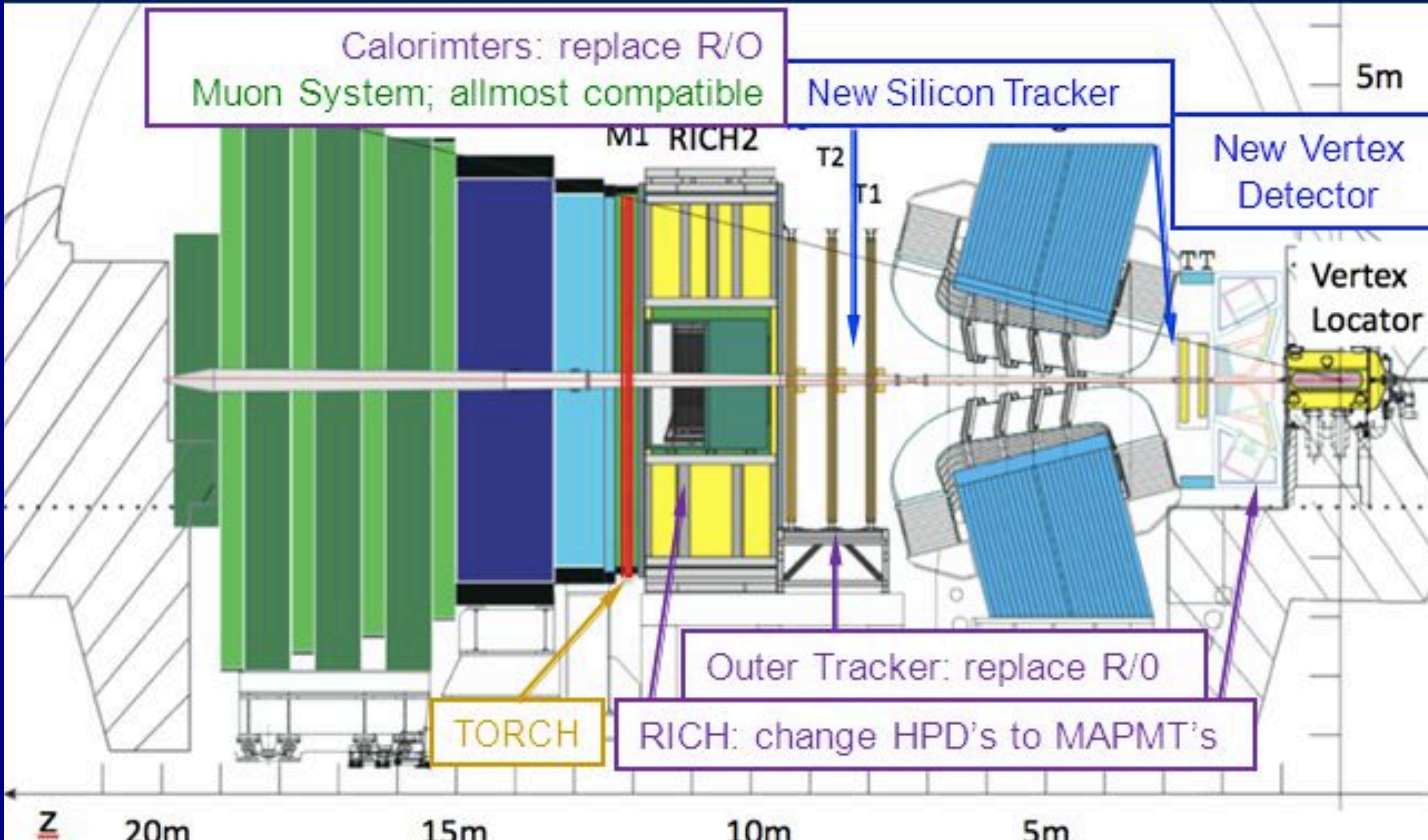
➡ More signals to be analysed in pAr and pHe data



The FUTURE

LHCb Upgraded : 2018-19 (in LS2)

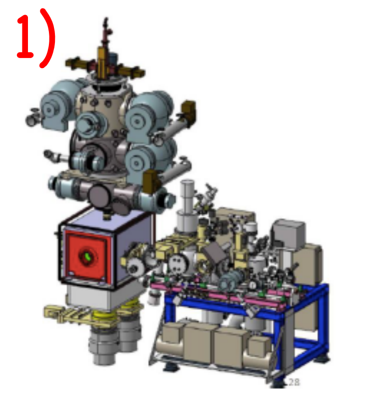
➡ Aims to collect > 50 fb^{-1}, ~ $5fb^{-1}/y$, $\sqrt{s}$=14 TeV, L=10^{33} $cm^{-2}s^{-1}$

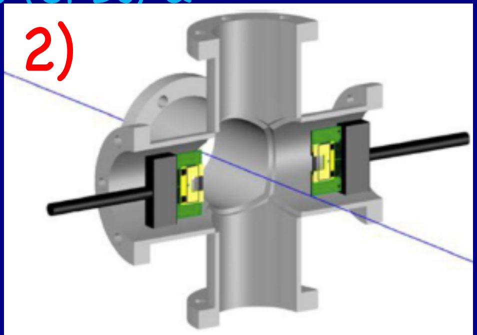


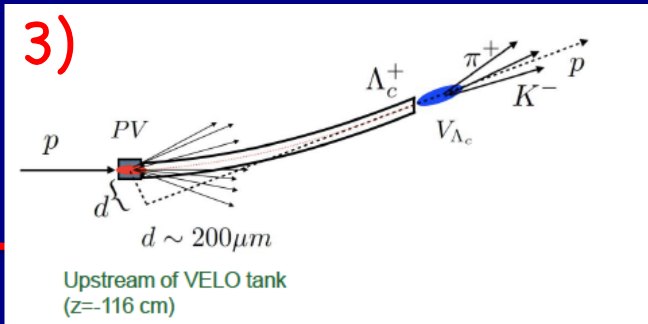
Fixed target future @ LHCb

DISCLAIMER: All of these still in discussion state, nothing approved yet !!

- At the time of LS2 : SMOG2
  - unpolarised gas target cell
- After LS3 : several options under study
  1) Polarised gas target (a' la` HERMES):
     - upstream of VELO vacuum tank. Storage cell could contain polarised H_2 or D (+ other unpolarised gases)=> many spin-dependent observables & provide input for generalised parton distributions (GPDs) & transverse-momentum distributions (TMDs).
  2) Wires as (solid) targets (a' la` HERA-b):
     - Install wire target in halo of beam in region upstream of VELO vacuum tank => Nuclear modFac & onia production
  3) Bending crystals to extract part of the beam
     - Particles extracted from halo with one crystal and sent to a tungsten target, and subsequent bending crystal, in which baryons will precess if they have a non-zero EDM/MDM => Λc EDM/MDM
  4) …other options ?



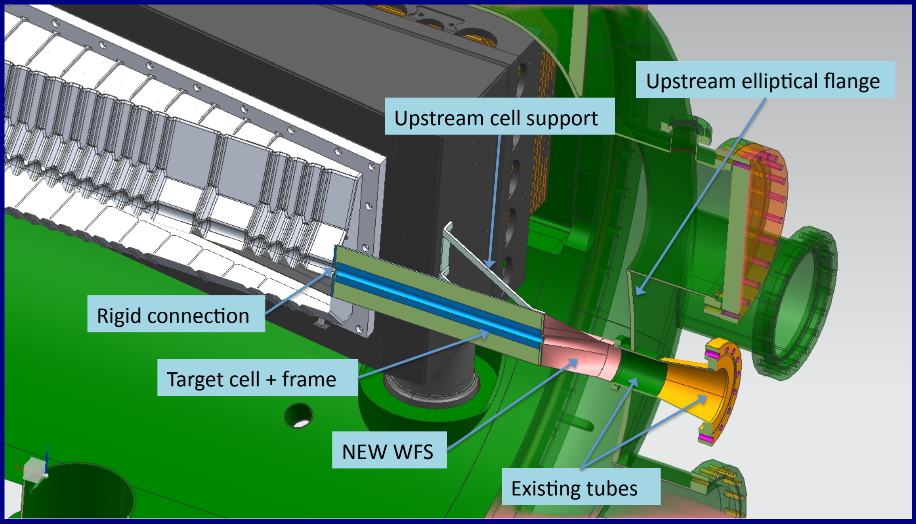


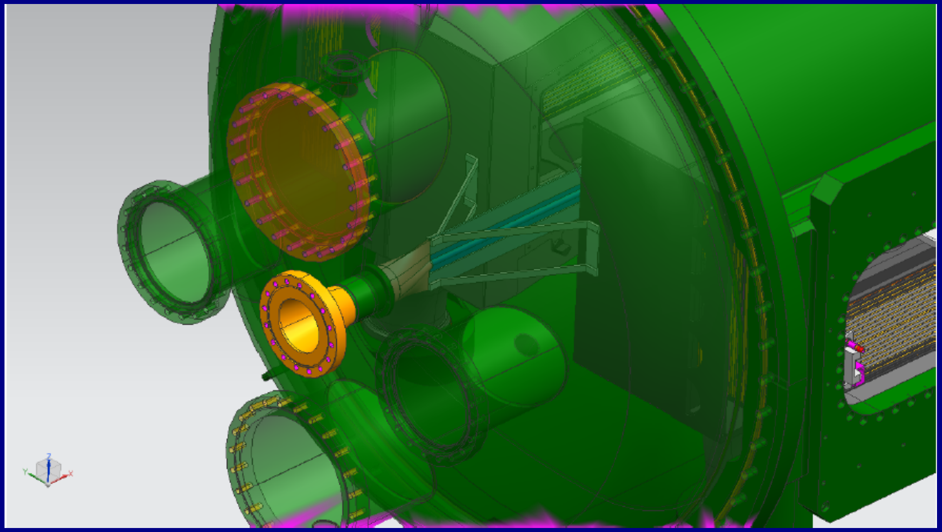


SMOG2

Pasquale Di Nezza

- In SMOG The gas eventually diffuses along the full length (20 m) of the LHCb beam pipe section.
- SMOG2 will have a storage cell (length L=20 cm, diameter=1 cm) which, with respect to SMOG, will be able to increase the areal density by about two orders of magnitude, keeping the same vacuum level in the LHC beam pipe. With SMOG2 it will be possible to inject H_2 (first pp data at $\sqrt{s}$=115 GeV), D_2, $^{3,4}He$, Ne and all the noble gasses up to Xe





SMOG2

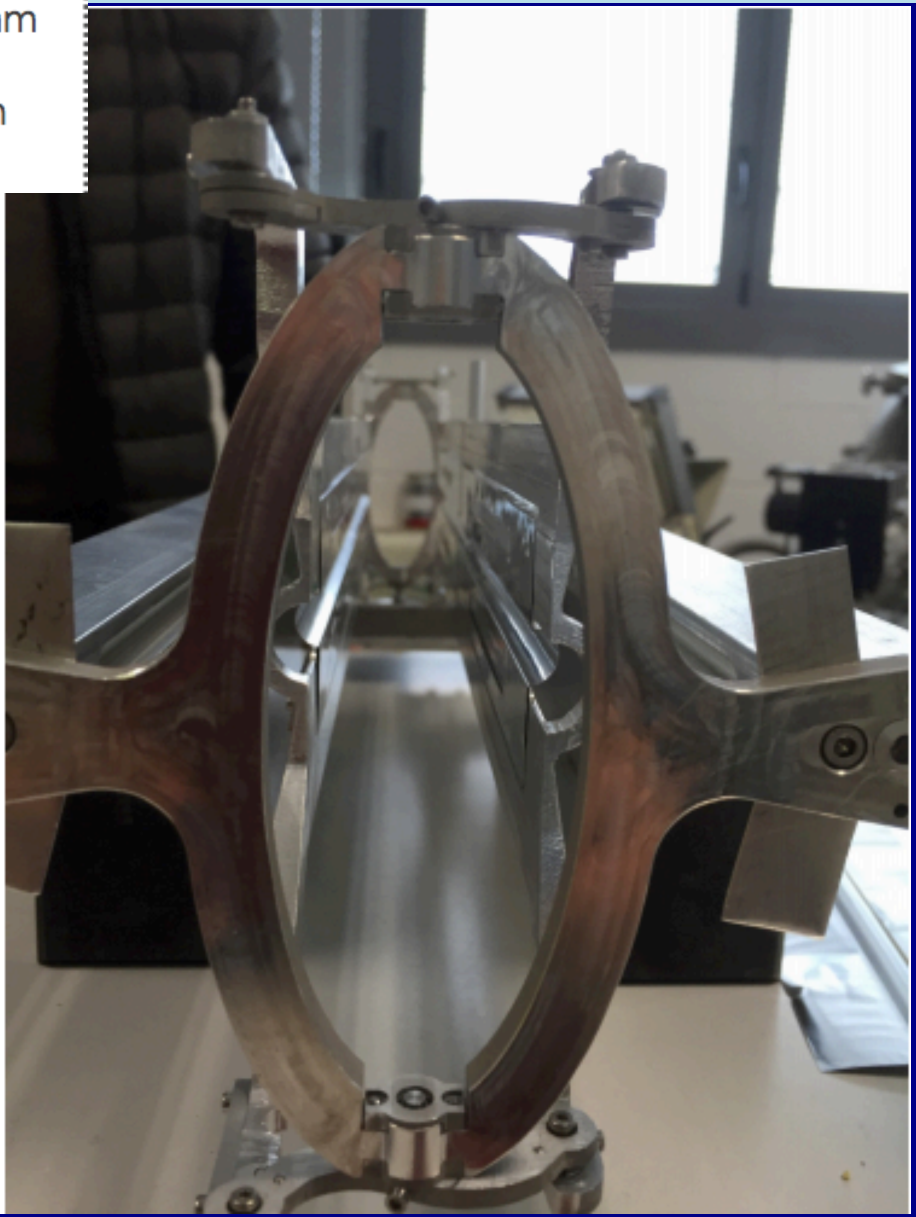
Pasquale Di Nezza

1σ-radius at IP (full energy): < 0.02 mm

- Negligible compared with the cell radius (~ 5 mm)

Safety radius at injection (450 GeV for p): > 25 mm

- "Openable" cell required



ALICE Detector at the LHC

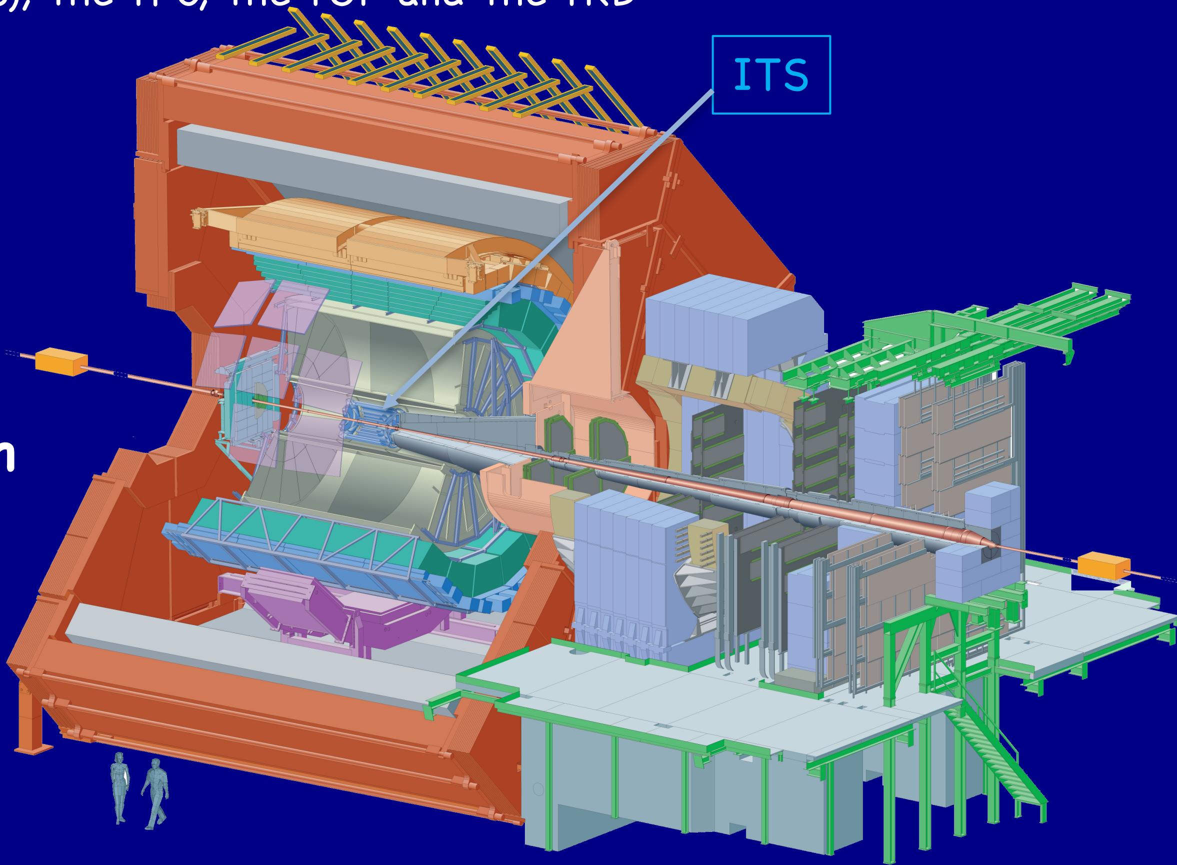
Antonio Uras

The ALICE detector consists of a central barrel part, which measures hadrons, electrons, and photons, and a forward muon spectrometer

- The central barrel : $|\eta| < 0.9$
- Main detectors for tracking and PID:
  - Internal Tracking System (ITS), the TPC, the TOF and the TRD

- **The muon spectrometer $2.5 < \eta < 4$, similar to LHCb**

- **Will be upgraded in the LHC LS2 with the addition of the dedicated internal tracker MFT**



Fixed target in ALICE ?

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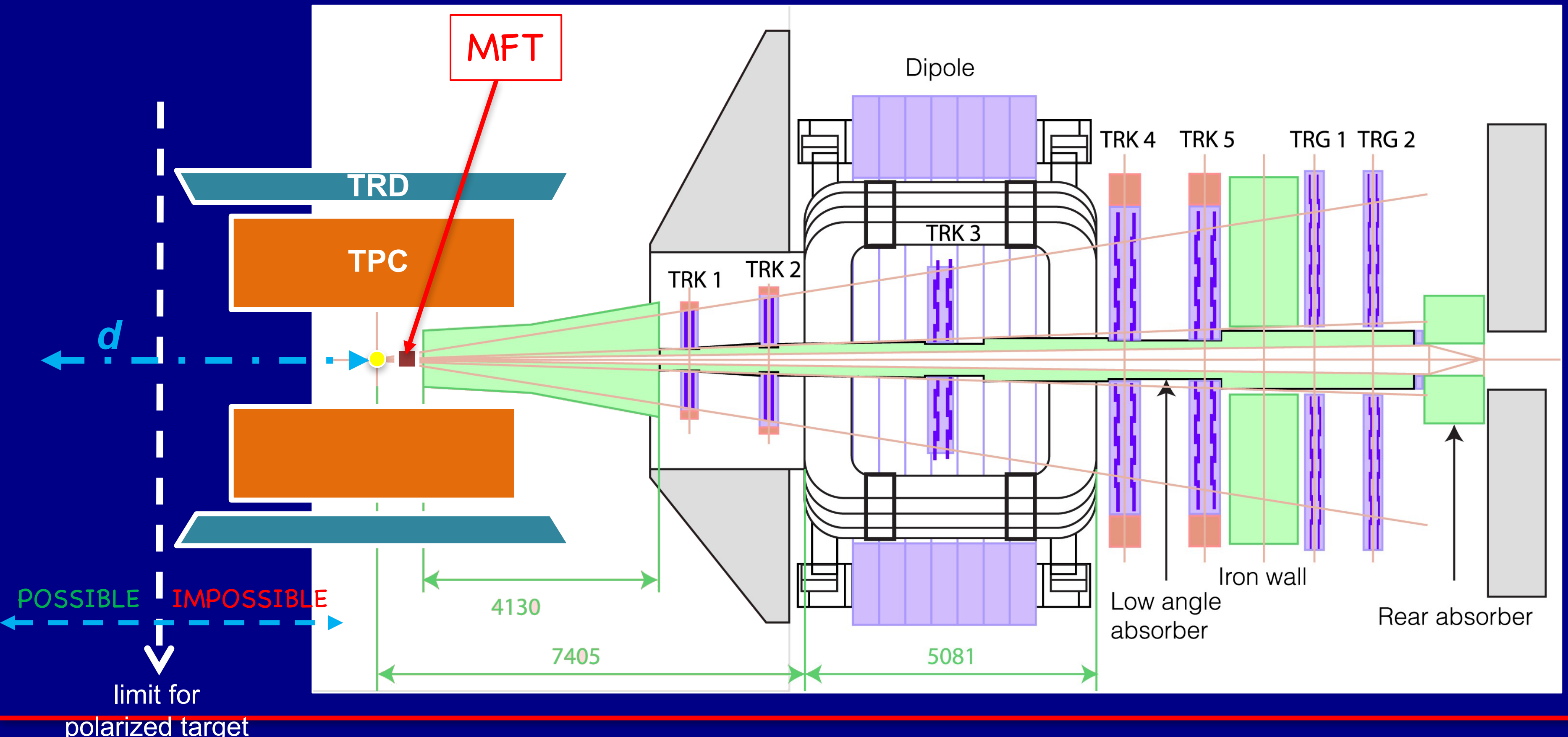
- The minimum distance from IP for the installation of a polarized gas target (implying a sizable volume due to the dedicated magnetic field) corresponds to the end of the TPC+TRD volumes. The maximum distance is imposed by the position of the door of the L3 magnet (not shown in the figure) and the dimensions of its central hole (particles should not traverse the doors before reaching the tracking detectors)



Possible fixed target implementations

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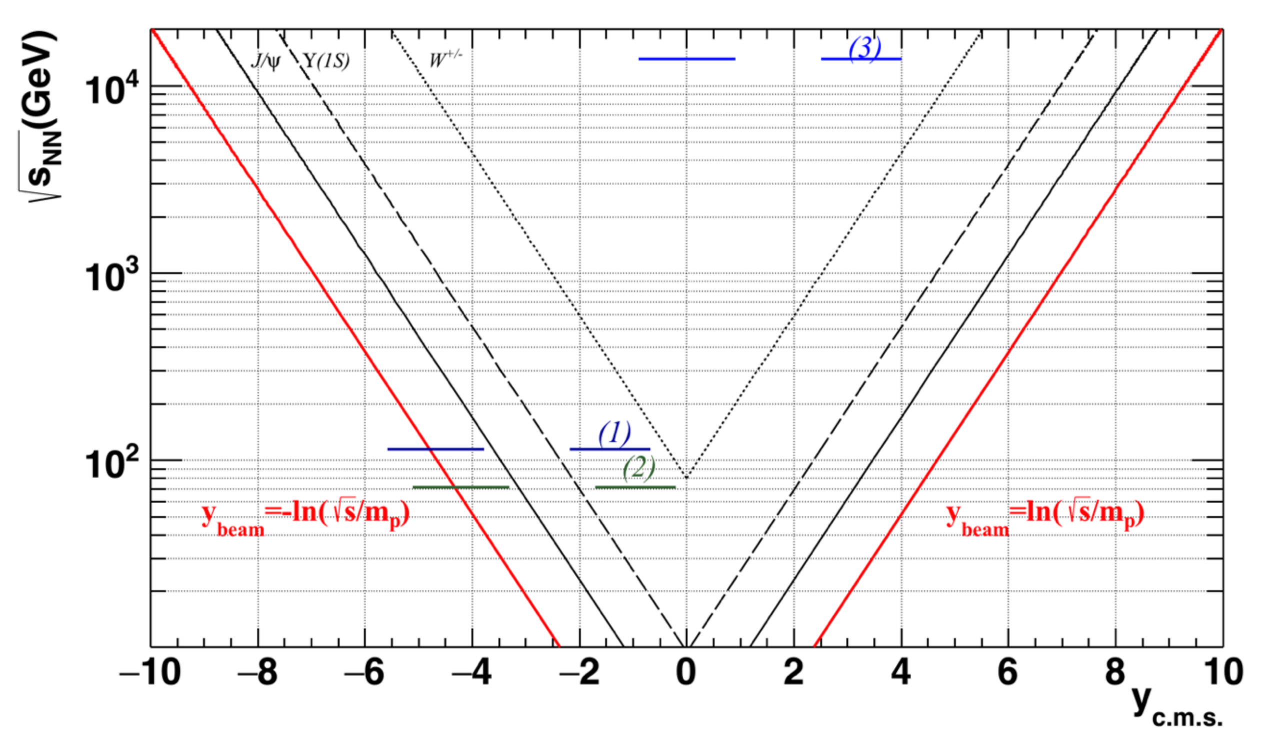
- **Internal gas target similar to SMOG at LHCb - inspired by HERMES at HERA**
  - Full LHC proton flux: 3.4×10^{18} p/s and Pb flux: 3.6×10^{14} Pb/s on internal gas target
  - Currently used by the LHCb collaboration via the luminosity monitor (SMOG) at low gas density
    - High intensity beam on gas target
- **Internal wire/foil target**
  - Beam halo is recycled directly on internal solid targets (HERA-B, STAR)
- **Beam "split" with a bent crystal**
  - Beam halo is deflected by a bent crystal on a solid target internal to the beam pipe
  - Expected proton flux approx. 5×10^{8} p/s (LHC beam loss: approx. 10^{9} p/s), Pb flux approx. 2×10^{5} Pb/s
    - Beam halo on dense target

➡ Similar luminosities can be obtained with internal solid/high-density gas targets

ALICE Acceptance

Antonio Uras

- **ALICE acceptance at z_{target} = 0**
  - With the muon spectrometer, on can access mid- to backward-rapidity region (y_{CM} < 0)
  - With mid-rapidity detectors, on can probe very backward-rapidity region (end of phase space)



(1) fixed-target mode with 7 TeV p beam

(2) fixed-target mode with 2.76 TeV Pb beam

(3) collider mode with 7 TeV p beams

Geometrical acceptance boundaries

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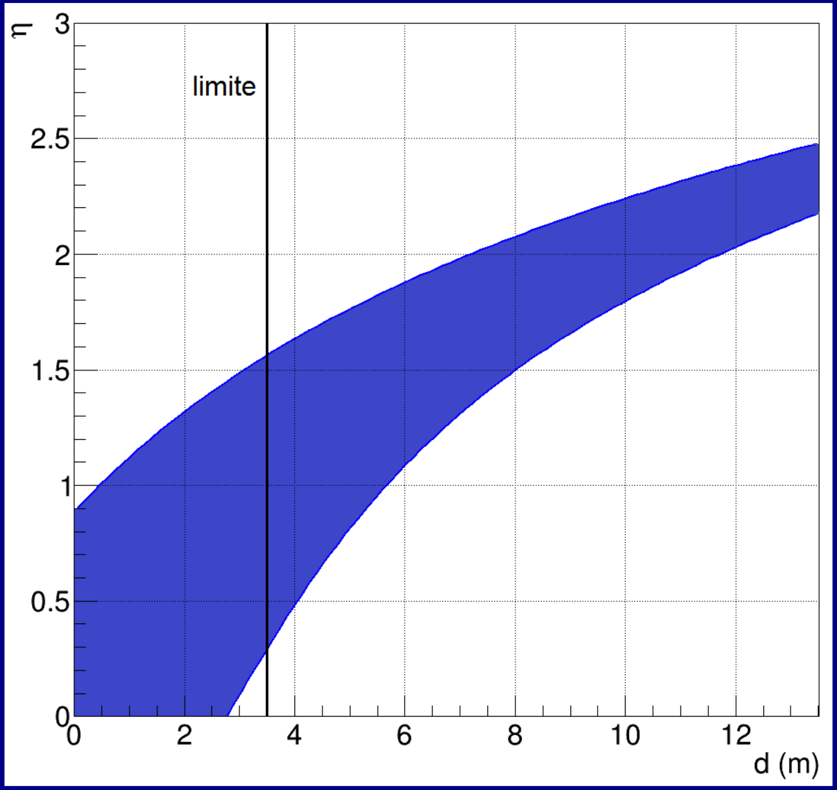
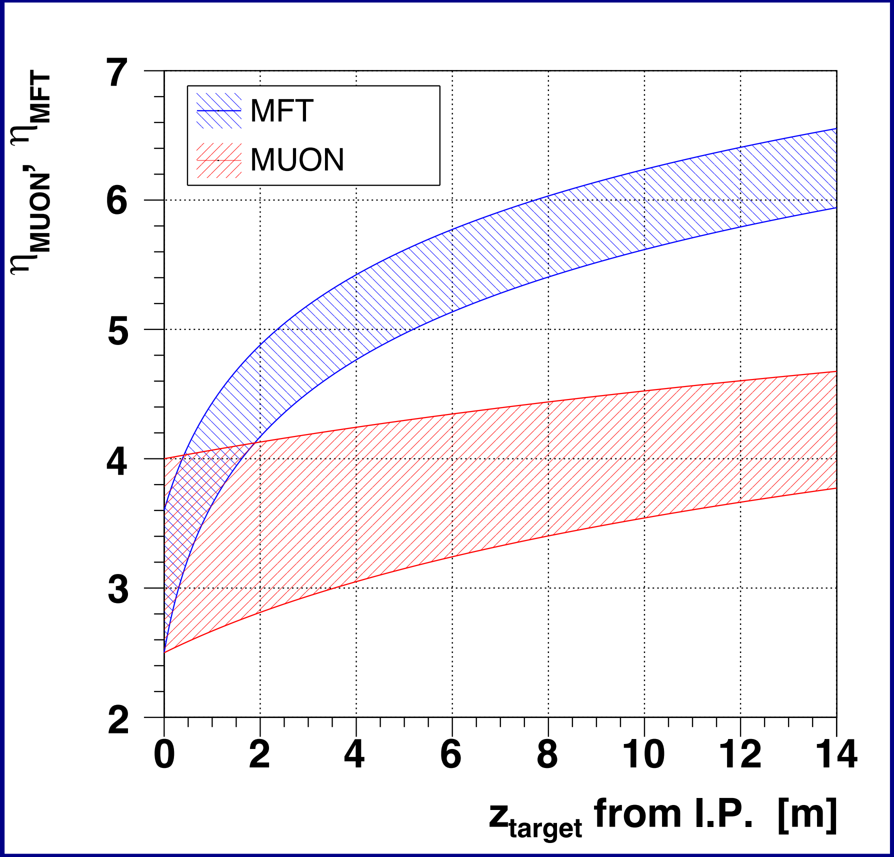
- The **TPC+TRD system** (no ITS) stays in the backward hemisphere, moving to mid-rapidity as d increases



- **MUON spectrometer and MFT can only be combined if collisions happen close to the nominal interaction point of ALICE**



Both the central barrel and the Muon Spectrometer detectors would need new internal tracker systems if the fixed target is installed far from the nominal I.P.

Electrons produced at the entrance of the TPC

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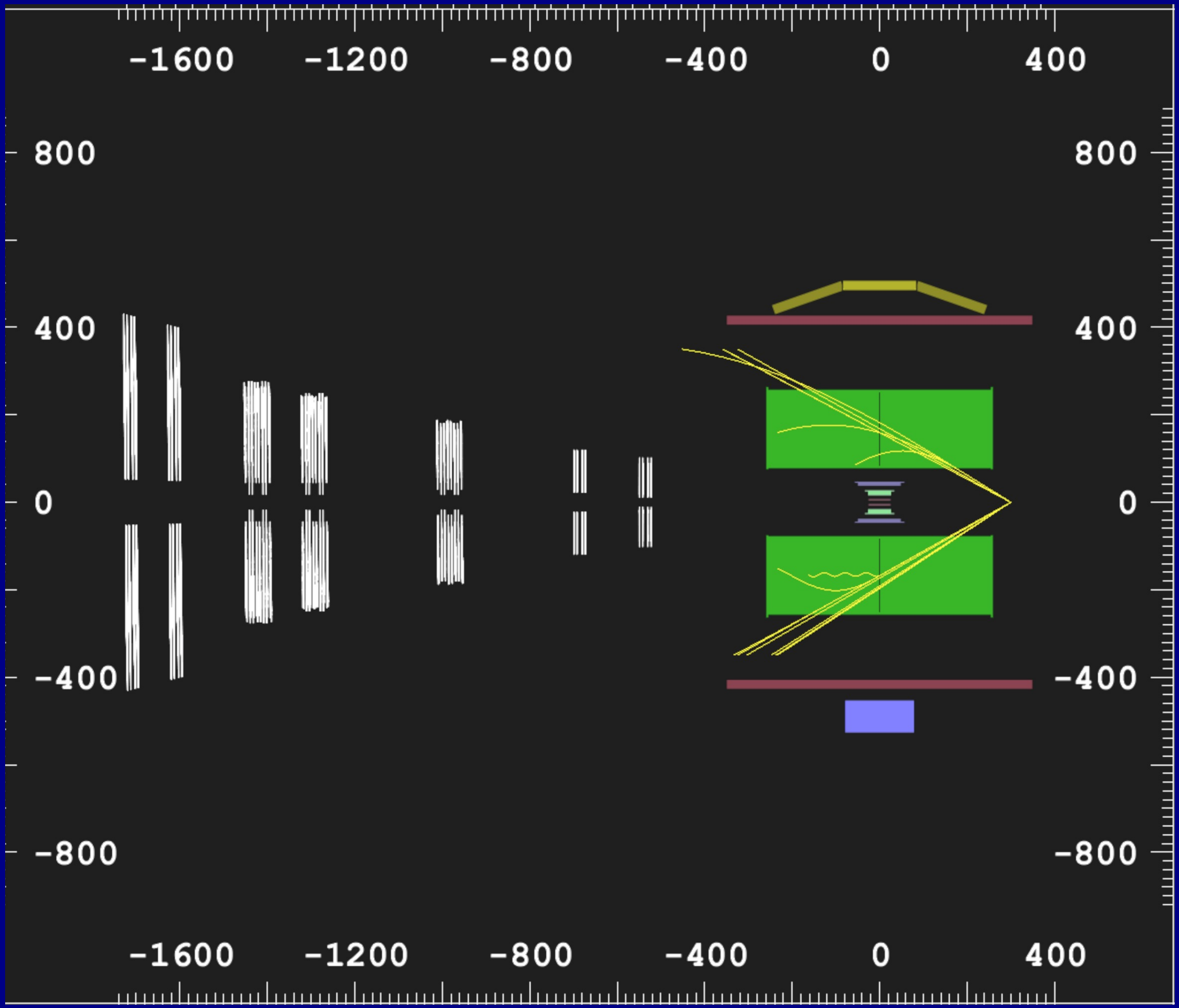

Summary and Conclusions

- LHCb and ALICE both running very well

- LHCb is in the unique position to do also fixed target physics
  - Exploiting the SMOG system with different noble gases
    - pAr, pHe results released !
    - Bridge the gap from SPS to LHC physics by a single experiment
    - Samples of order 1-10/nb are being analysed, more data to be collected within Run2
  - more options being studied to improve the fixed target setups in and after the upgrade (polarised targets, bended crystals, …)

- ALICE also exploring fixed target program for LS2 and beyond
  - Rich potential on paper ! Worth to explore hardware possibilities

- Interesting results ahead, stay tuned !