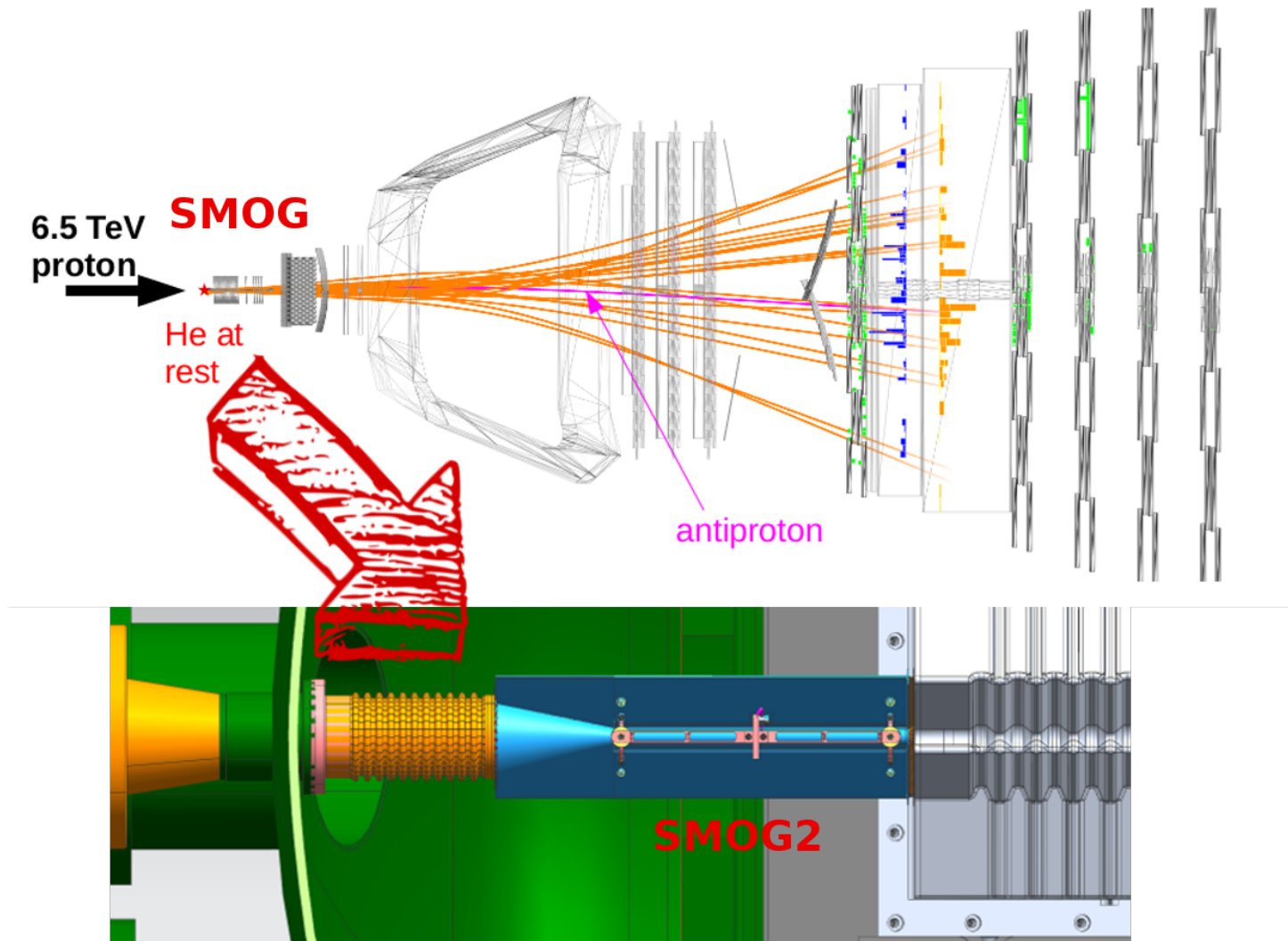


LHCb as a fixed-target experiment



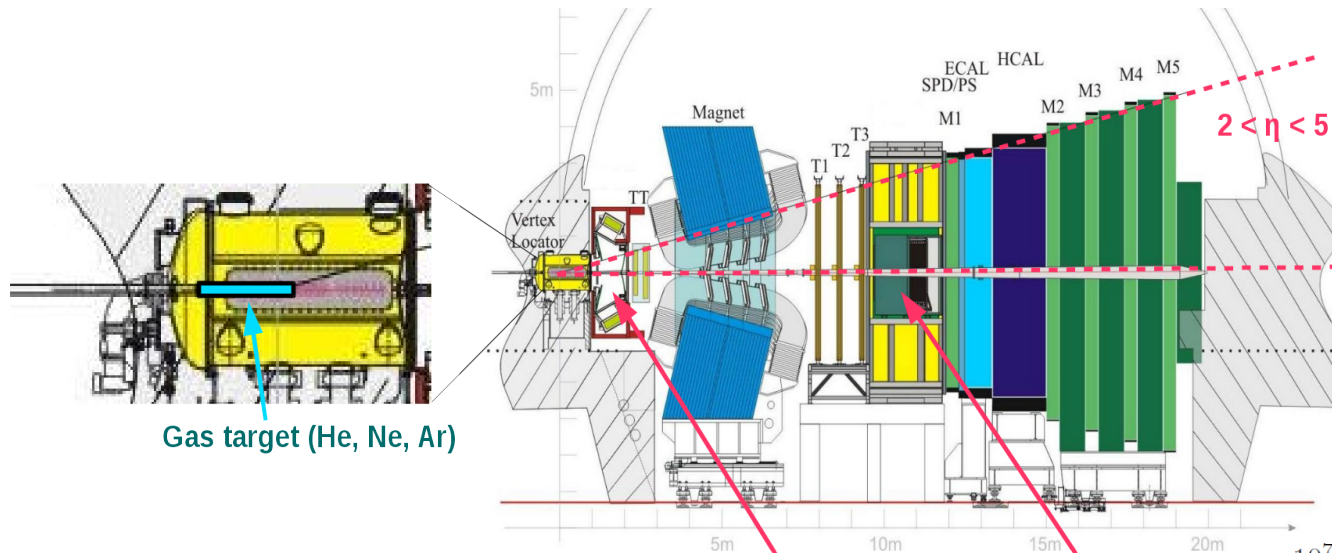
Giacomo Graziani (INFN Firenze)
on behalf of the LHCb Collaboration

Physics Beyond Colliders General Meeting
Nov 05, 2019



Reminder on LHCb Fixed Target

LHCb as a fixed target experiment, thanks to the SMOG internal gas target



JINST 3, (2008) S08005

Int.J.Mod.Phys.A30 (2015) 1530022

Gas target (He, Ne, Ar)

RICH1
 $2 < \eta < 4.4$
 \bar{p} thr. = 18 GeV
 K thr. = 10 GeV

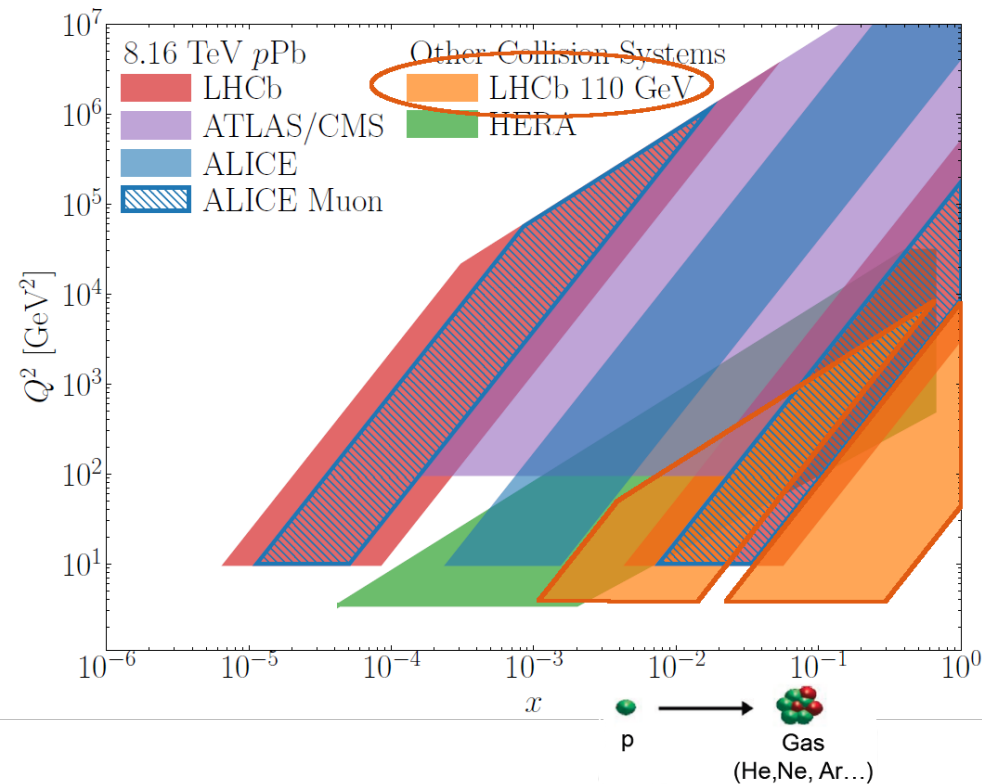
RICH2
 $3 < \eta < 5$
 \bar{p} thr. = 30 GeV
 K thr. = 16 GeV

- pA collisions at unique energy scale

$$\sqrt{s_{NN}} \sim 100 \text{ GeV}$$

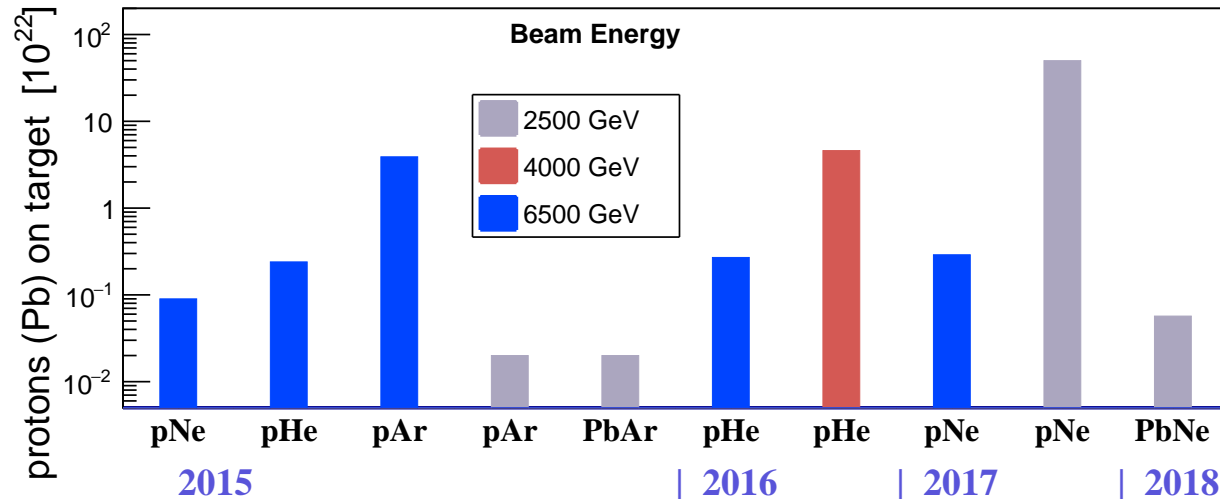
- Unique coverage for (n)PDF at large x
- Exploiting LHCb specific features
 - forward geometry
 - extreme vertexing performance + complete particle identification : ideal for heavy flavours

- Possible targets (so far): He, Ne, Ar



SMOG data samples

Final summary of fixed-target samples acquired with SMOG in Run 2



$$\int \mathcal{L} dt \sim 5 \text{ nb}^{-1} \times \frac{pot}{10^{22}} \\ \times \frac{p_{gas}}{2 \times 10^{-7} \text{ mbar}} \times \text{Exp_Efficiency}$$

Largest sample (pNe 2017)
 $\sim 100 \text{ nb}^{-1}$

Main physics goals:

- charm production to investigate nuclear effects and (n)PDF at large x ;
- studies of hadron production in novel kinematic regime and collision systems (notably **proton - Helium**), bringing crucial inputs to cosmic ray physics.

First two physics results published during the last year:

antiprotons in pHe, PRL 121 (2018), 222001

charm production in pHe and pAr, PRL 122 (2019) 132002

Physics Goals for LHC Run 3/4

Physics Briefing Book

Input for the European Strategy for Particle Physics Update 2020

The multi-TeV LHC proton- and ion-beams allow for the most energetic fixed-target (LHC-FT) experiments ever performed opening the way for unique studies of the nucleon and nuclear structure at high x , of the spin content of the nucleon and of the nuclear-matter phases from a new rapidity viewpoint at seldom explored energies [117, 118].

...

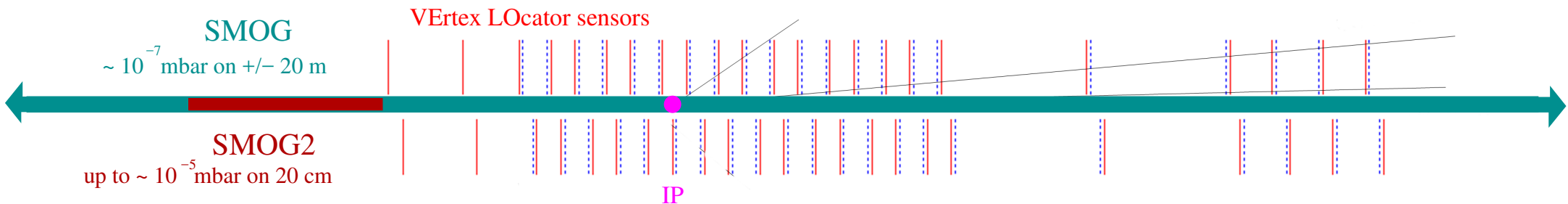
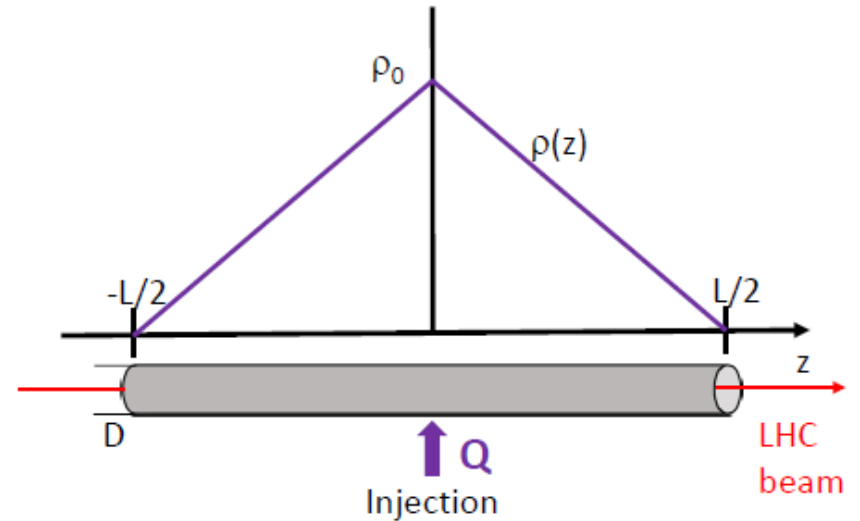
The physics reach of the LHC complex can greatly be extended at a very limited cost with the addition of an ambitious and long term LHC-FT research program. The efforts of the existing LHC experiments to implement such a programme, including specific R&D actions on the collider, deserve support.

- **Increase data size:** better accuracy, access rarer states (including $b\bar{b}$, DY)
➔ strong impact on PDFs at large x , QGP studies in PbA
- **Extend target choice:**
 - **Hydrogen and Deuterium** would provide pp reference measurements, studies of GPDs/TMDs (through unpolarized observables), more \bar{p} production for CR in space (production in pp and isospin violation)
 - **Nitrogen/Oxygen** for atmospheric CR
 - **Heavier** gas (Kr, Xe?). Upgraded LHCb detector (from Run 3) will allow better reconstruction of central event

The upgraded target idea

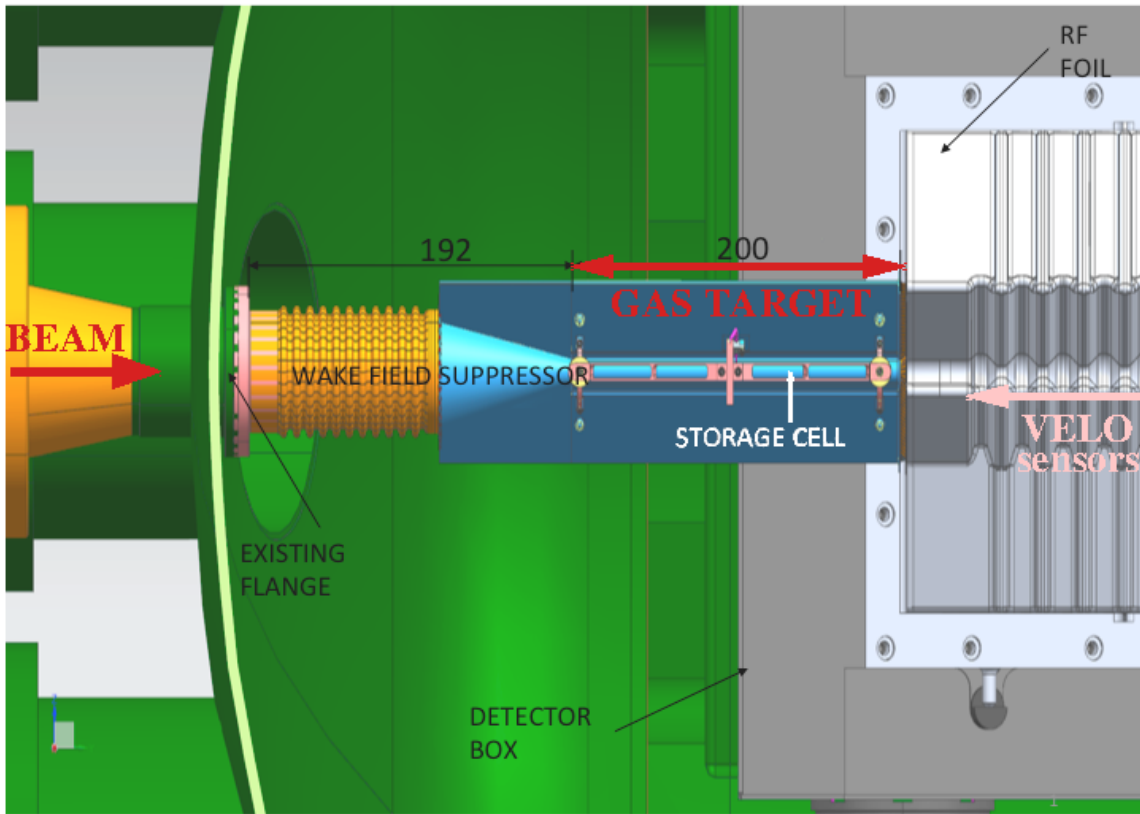
Implementation: the **SMOG2** target upgrade

- contain gas in 20 cm long storage cell
➔ up to x100 increase of target density for same gas flow;



- lower contamination of beam line ➔ more gas species possible;
- better control over injected gas density (better accuracy on absolute cross sections).

The SMOG2 gas target



- 20-cm long storage cell, 5 mm radius around the beam, just upstream the LHCb Vertex LOcator
- Made of two retractable halves as the rest of VELO
- Up to x100 higher gas density with same gas flow of current SMOG
- Gas feed system measures the gas density with $\sim 2\%$ accuracy

- Approved by LHCC
CERN-LHCC-2019-0051
- Technical design finalized: ready for installation with the VELO box. Current schedule:

Nov 2019	Coating
Dec 2019	Pre-installation (surface lab) and alignment
Jan 2020	Installation in the pit



Possible gas flow limitations

- Up to the same gas flow used with SMOG, it will be possible to inject the light noble gases:

Gas	Increase in luminosity SMOG2/SMOG
He	10.9
Ne	24.4
Ar	34.5

- Maximum allowed gas flow for the “new” species still to be determined:
 - for H₂ and D₂, possible limitations from embrittlement and, as for other getterable gases, from the integrity of the NEG coating in the vicinity of IP8;
 - heavy noble gases Kr and Xe which will be cryosorbed at the warm-to-cold transitions of the triplet quadrupoles and cause an increase of the local secondary electron yield.

Detailed simulations are required, work has started

Data-taking scenario

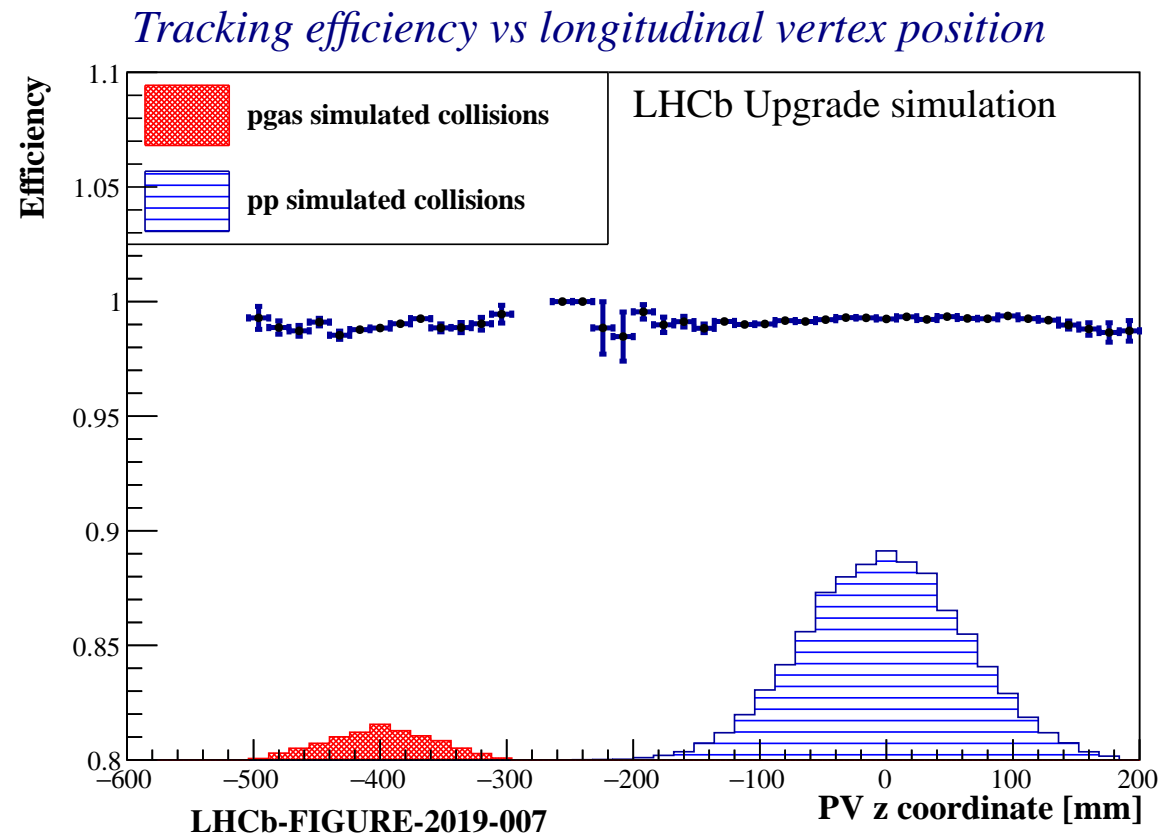
- Fixed-target data-taking should not affect the core LHCb p - p program
- In Run 3 LHCb will adopt an extremely challenging online reconstruction strategy:
 - full detector readout at 40 MHz
 - real time reconstruction and selection on bunch crossings at ~ 30 MHz with average 5 p - p collisions
- Three possible strategies:
 1. **Dedicated Runs**
 - ✓ simpler trigger implementation (decouple p - p and FT physics)
 - ✗ very limited running time
 2. **Simultaneous Runs, FT physics only with beam1 non-colliding bunches**
 - ✓ simpler trigger implementation (decouple p - p and FT physics)
 - ✗ exploit only ~ 10 - 20 % of bunches
 - ✗ (small) FT background on p - p physics
 3. **Simultaneous Runs, FT physics with **all** bunches**
 - ✓ maximise physics output for given gas flow
 - ✗ merge FT physics and core LHCb physics requirements for online rec. and trigger
 - ✗ (small) FT background on p - p physics, and vice-versa

Real time reconstruction of fixed-target events

Work ongoing to realize the third scenario:

- fit FT physics in the CPU budget and trigger data bandwidth
- study additional backgrounds from FT events on p - p physics, and vice-versa

- Promising performance has been reached, no show-stopper identified so far



Possible scenario for Run3

Given these caveats, an **optimistic**, still realistic, scenario for the fixed-target samples to be collected during the 3 years of Run3 is the following:

System	$\sqrt{s_{NN}}$ (GeV)	< pressure > (mbar)	\mathcal{L} ($cm^{-2}s^{-1}$)	Rate (MHz)	Time (s)	$\int \mathcal{L}$ (pb^{-1})
pH_2	115	$4 \cdot 10^{-5}$	$6 \cdot 10^{31}$	4.6	$2.5 \cdot 10^6$	150
pD_2	115	$2 \cdot 10^{-5}$	$3 \cdot 10^{31}$	4.3	$0.3 \cdot 10^6$	9
pAr	115	$1.2 \cdot 10^{-5}$	$1.8 \cdot 10^{31}$	11	$2.5 \cdot 10^6$	45
pKr	115	$0.8 \cdot 10^{-5}$	$1.2 \cdot 10^{31}$	12	$2.5 \cdot 10^6$	30
pXe	115	$0.6 \cdot 10^{-5}$	$0.9 \cdot 10^{31}$	12	$2.5 \cdot 10^6$	22
pHe	115	$2 \cdot 10^{-5}$	$3 \cdot 10^{31}$	3.5	$3.3 \cdot 10^3$	0.1
pNe	115	$2 \cdot 10^{-5}$	$3 \cdot 10^{31}$	12	$3.3 \cdot 10^3$	0.1
pN_2	115	$1 \cdot 10^{-5}$	$1.5 \cdot 10^{31}$	9.0	$3.3 \cdot 10^3$	0.1
pO_2	115	$1 \cdot 10^{-5}$	$1.5 \cdot 10^{31}$	10	$3.3 \cdot 10^3$	0.1
PbAr	72	$8 \cdot 10^{-5}$	$1 \cdot 10^{29}$	0.3	$6 \cdot 10^5$	0.060
PbH ₂	72	$8 \cdot 10^{-5}$	$1 \cdot 10^{29}$	0.2	$1 \cdot 10^5$	0.010
pAr	72	$1.2 \cdot 10^{-5}$	$1.8 \cdot 10^{31}$	11	$3 \cdot 10^5$	5

Expected yields for some benchmark modes

	SMOG released result pHe@87 GeV	SMOG largest sample pNe@69 GeV	SMOG2 example pAr@115 GeV
Integrated luminosity	7.6 nb ⁻¹	~ 100 nb ⁻¹	~ 45 pb ⁻¹
syst. error on J/ψ x-sec.	7%	6 - 7%	2 - 3 %
J/ψ yield	400	15k	15M
D^0 yield	2000	100k	150M
Λ_c^+ yield	20	1k	1.5M
$\psi(2S)$ yield	negl.	150	150k
$\Upsilon(1S)$ yield	negl.	4	7k
Low-mass (5 – 9 GeV) Drell-Yan	negl.	5	9k

Notes:

- list is far from being exhaustive;
- extrapolations are crude estimates, just to provide figures of merit;

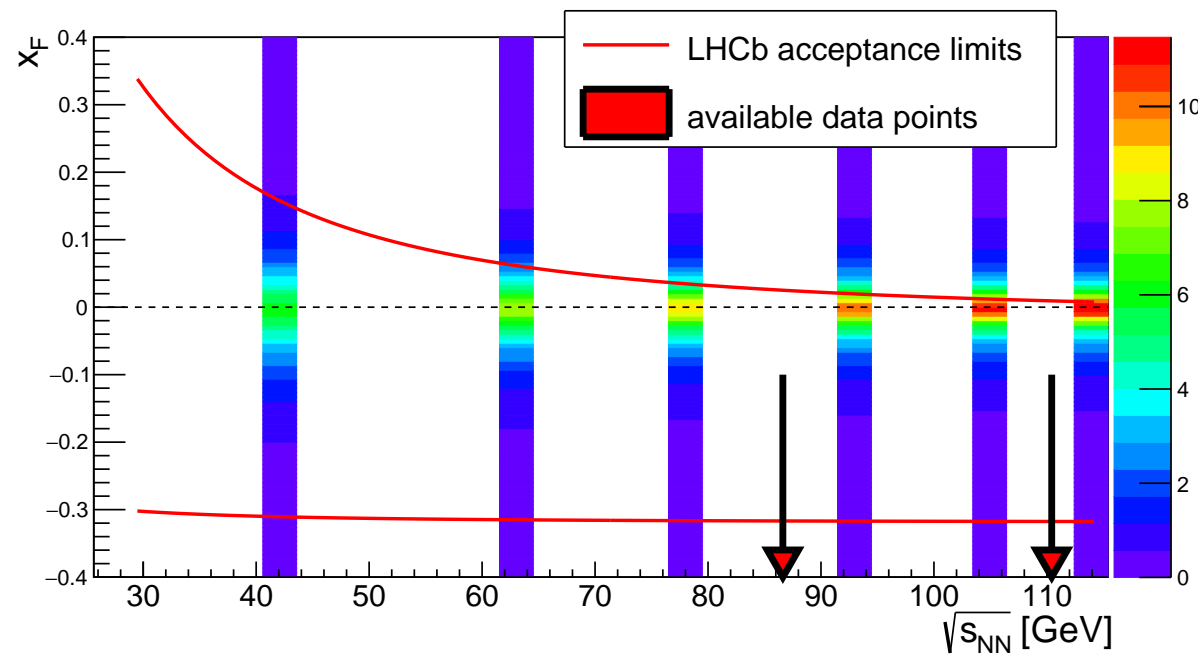
More detailed discussion in the PBC deliverable LHCb-PUB-2018-015

Low energy runs for “cosmic” antiprotons

Special request:

Data at lower energy to measure evolution with energy (scaling violations) of $p - \text{He} \rightarrow \bar{p}X$ cross-section and access forward region (Feynman- $x > 0$).

This measurements with He, H and D targets would make the cross-section uncertainty negligible in the interpretation of the AMS-02 antiproton results.



*Feynman- x distribution for \bar{p} vs $\sqrt{s_{NN}}$
and accessible region to LHCb*

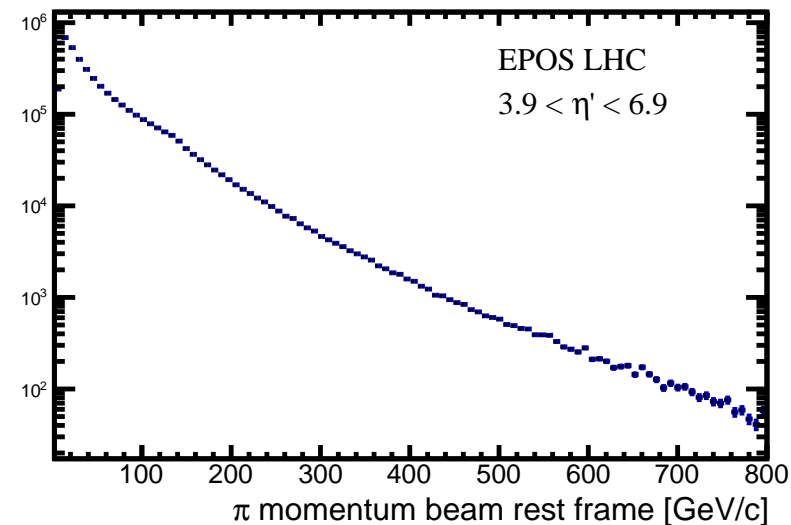
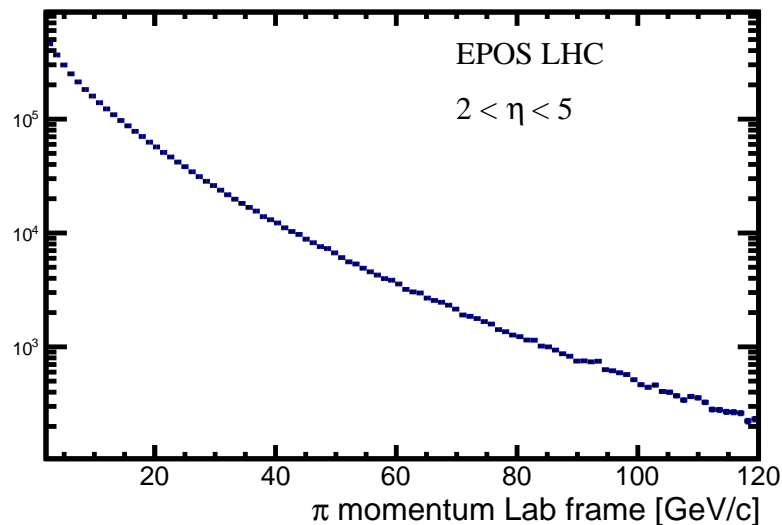
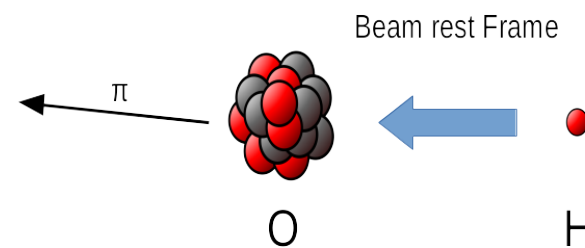
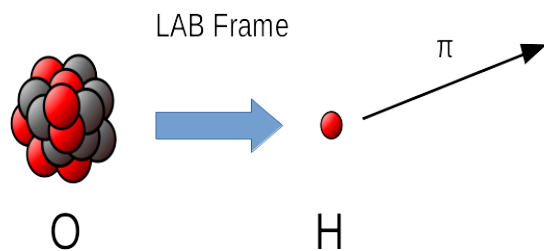
The Oxygen run

A special run with Oxygen beam is foreseen already in Run 3.

This will provide proton-Oxygen collisions at the maximum available energy

➔ key input to modeling of extensive atmospheric showers

- LHCb can measure production of charged particles in p -O beam-beam collisions at the highest rapidities at LHC
- in addition, using SMOG2 with an H target (with Oxygen in beam 1) would give access to very forward tracks in the projectile rest frame



Conclusions

- LHCb demonstrated the potential for fixed target physics at the LHC using internal gas targets in existing detectors
- First two physics results on PRL, more to come from Run 2 samples
- **SMOG2 upgrade approved by LHCC** and being installed
 - ➔ great possibilities for a substantial increase of data size and choice of target gas species wrt the current SMOG program already from Run3
- The LHCspin group is working on a polarized target proposal allowing for a further upgrade for Run4/Run5, see next talk