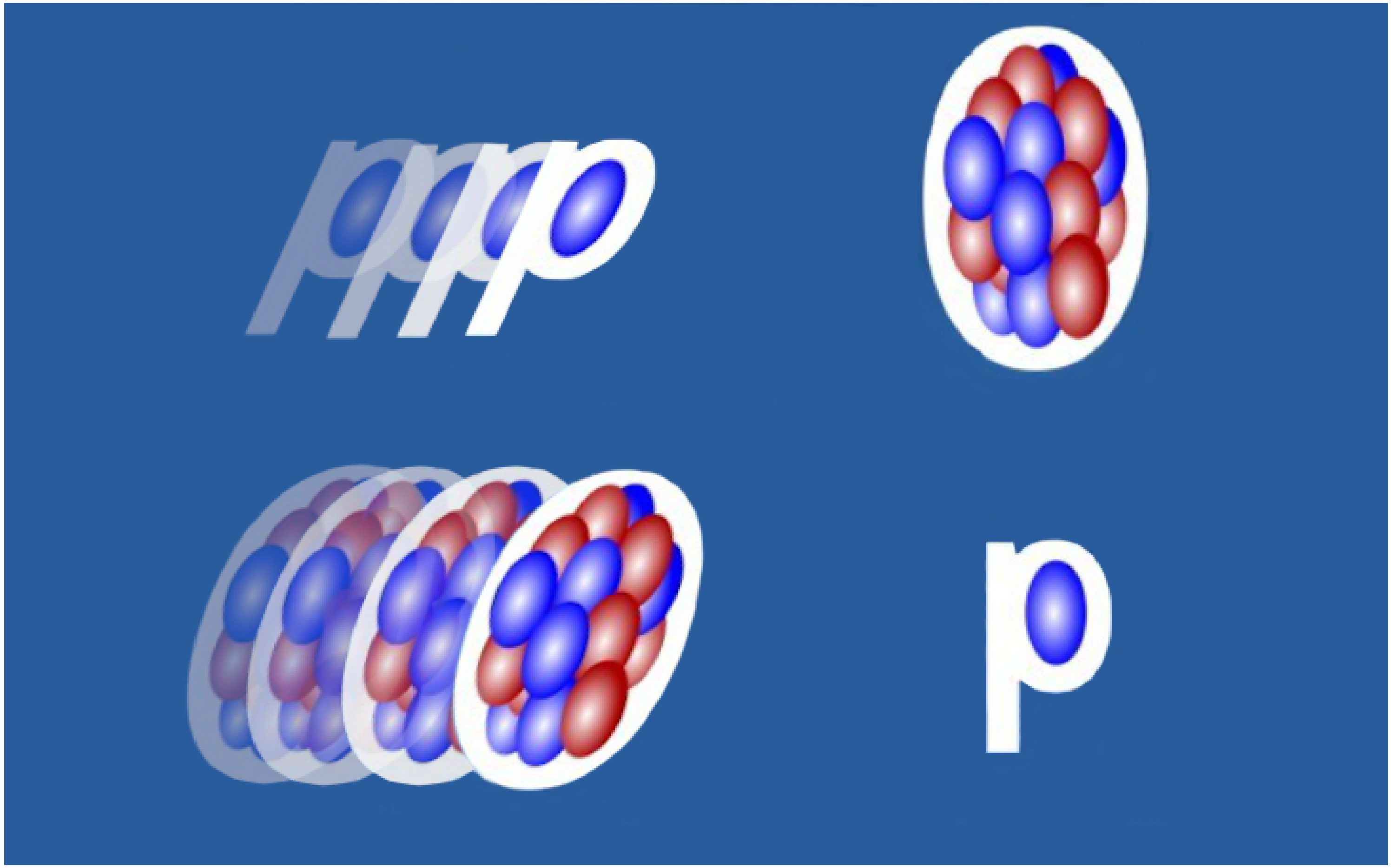
Oxygen beams and LHCb: prospects of collisions with fixed-targets



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

ppOrtunities at the LHC

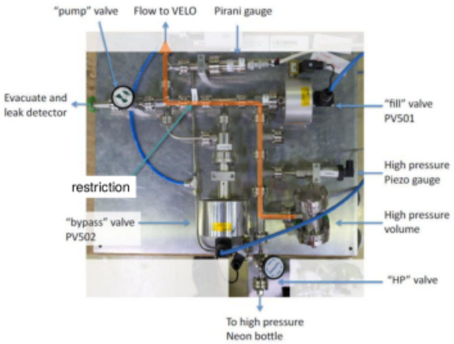
Feb 9, 2021

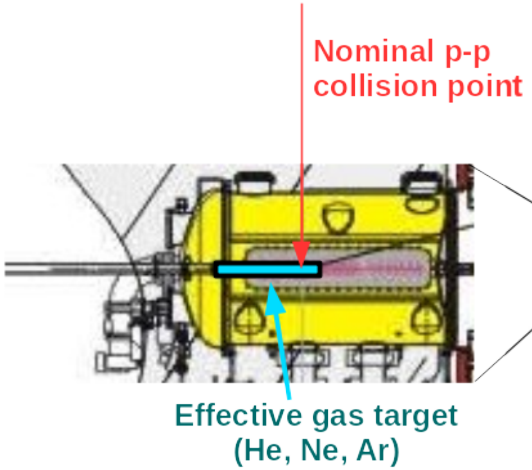
LHCb Fixed Target in Run 2 (2015 - 2017)

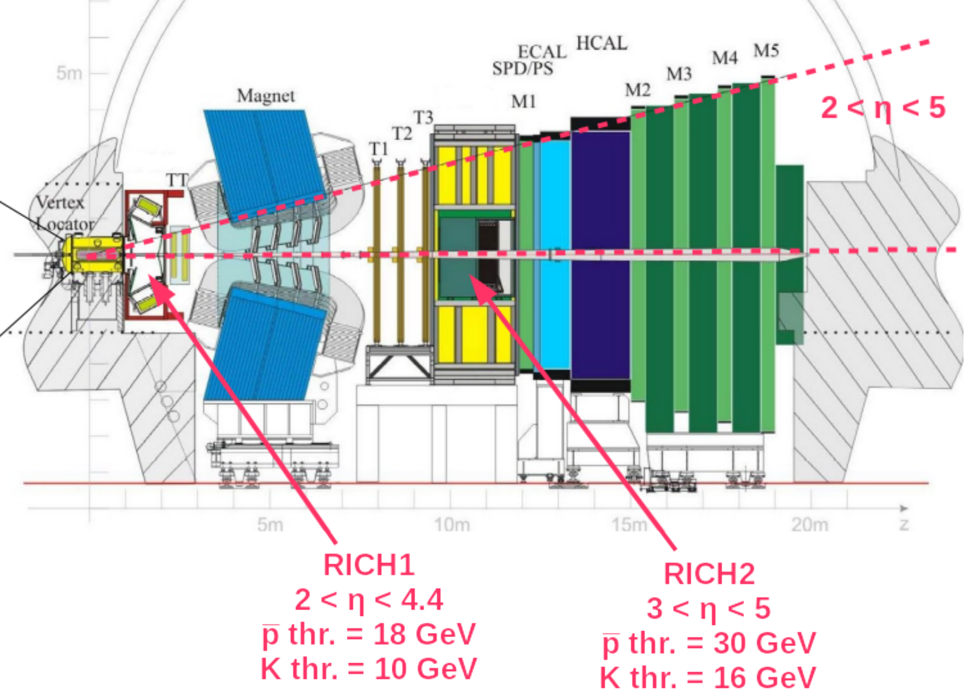
JINST 3, (2008) S08005

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

The System for Measuring Overlap with Gas (**SMOG**)

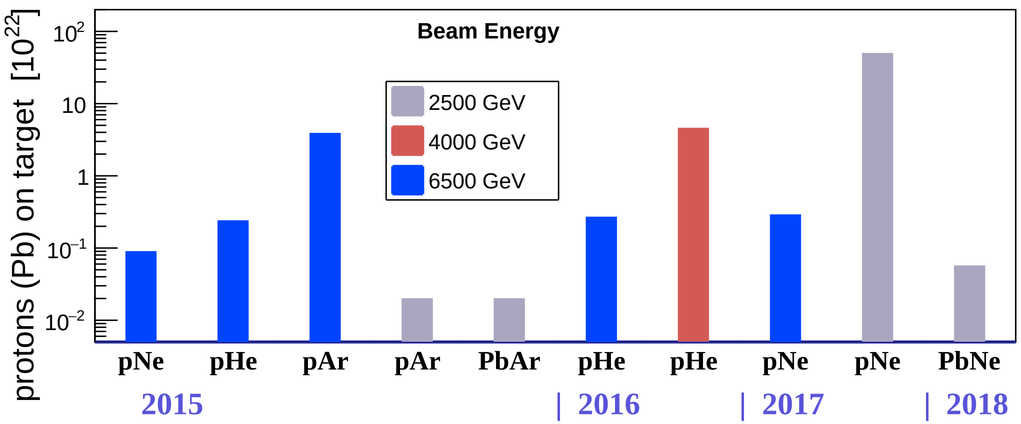






"Fixed-target like" geometry of LHCb is very well suited to study collisions of LHC beams on gas targets, obtained by injecting light noble gas (He, Ne, Ar) in the LHC beam pipe around the detector.

Unique fixed-target experiment using LHC beams! $\sqrt{s_{\mathrm{NN}}} \sim 100$ GeV



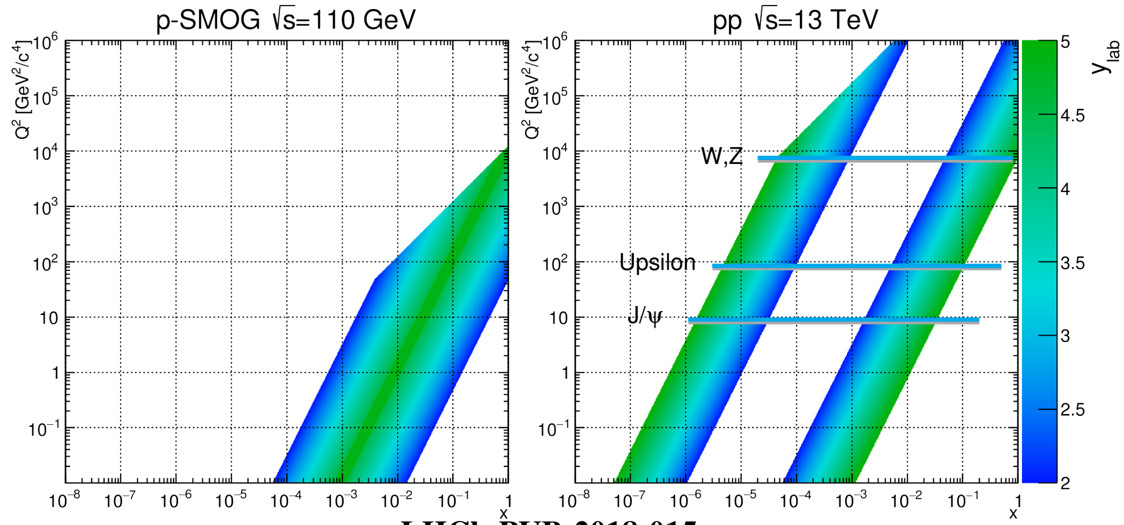
Dedicated runs of limited duration with gas target pressure of order 10^{-7} mbar

➡ $\mathcal{L} \sim \mathcal{O}(10^{29}\mathrm{cm}^{-2}\mathrm{s}^{-1})$
data samples of 1-100 nb^{-1} collected so far

Fixed target physics opportunities

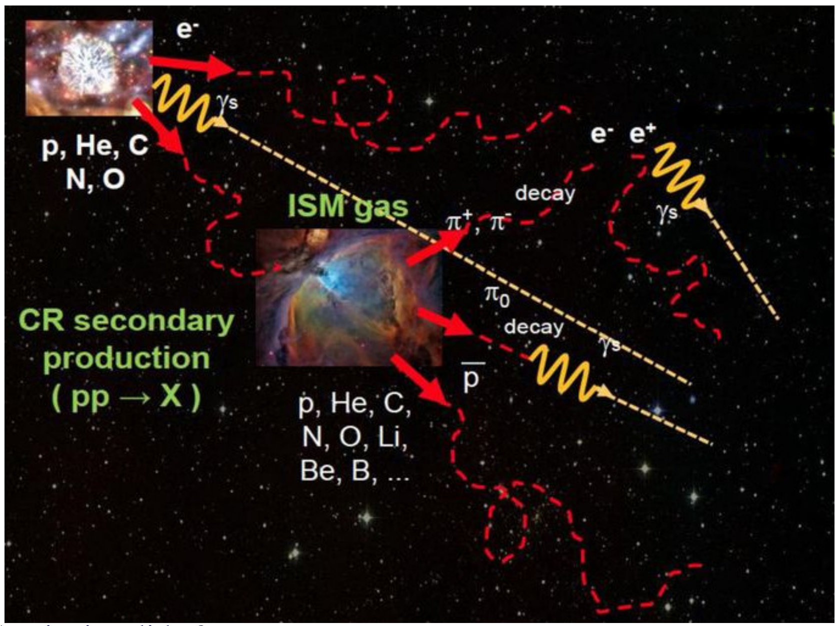
Nuclear physics

- accessing **large** x region in the target, not accessible in collider mode, with **different collision systems**
  ➡ study nuclear PDFs at large x
- large **charm production** cross-section
  ➡ QGP probe at $\sqrt{s_{\mathrm{NN}}} \sim$ **100 GeV**, investigate **intrinsic charm**



LHCb-PUB-2018-015

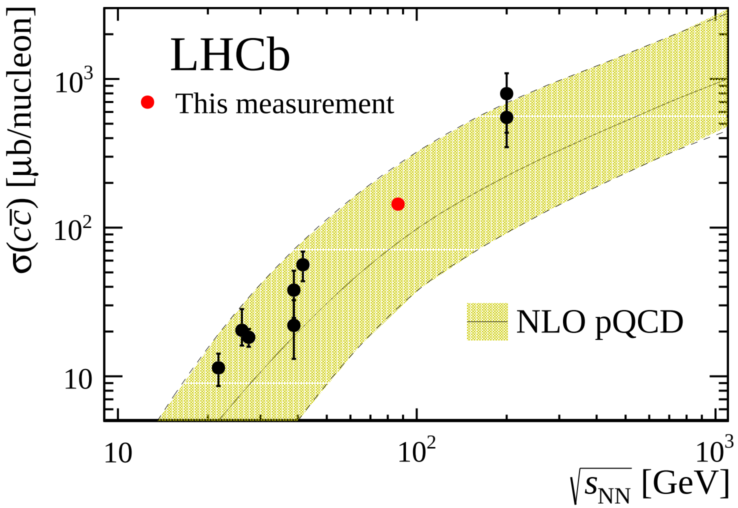
Astroparticle physics



- p**He collisions** reproduce **cosmic ray interactions in the interstellar medium** at the energy scale $\sqrt{s_{\mathrm{NN}}} \sim 100$ GeV, relevant for current experiments in space, notably for antimatter production
- p**Ne collisions** (O, N targets in the future) can provide useful input to models of atmospheric showers
- charm PDF at large x important to understand background to **neutrino astronomy** from UHE atmospheric showers

Charm production in fixed-target data

PRL 122 (2019) 132002



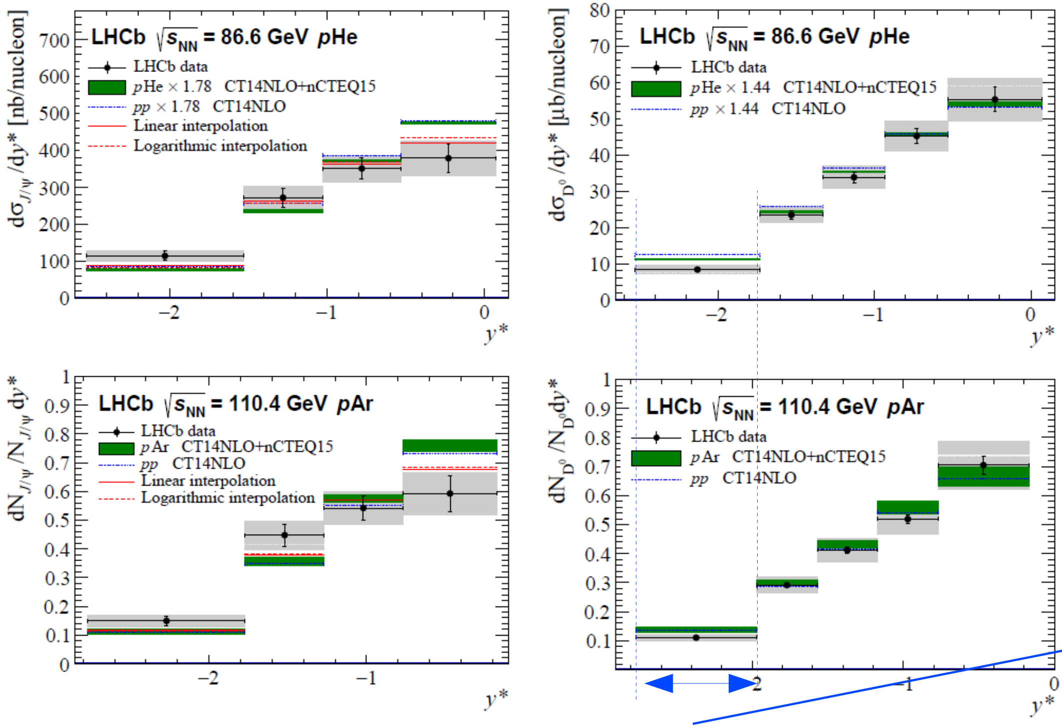
- First charm samples from pHe @86 GeV ($7.6 \pm 0.5\ \mathrm{nb}^{-1}$) and pAr @110 GeV (few nb^{-1})
- First determination of $c\bar{c}$ cross-section at this scale
- Rapidity distributions in backward region compatible with predictions without Intrinsic Charm in both pHe and pAr samples ➡ no evidence for large IC effects
- Results still limited by statistics

J/ψ

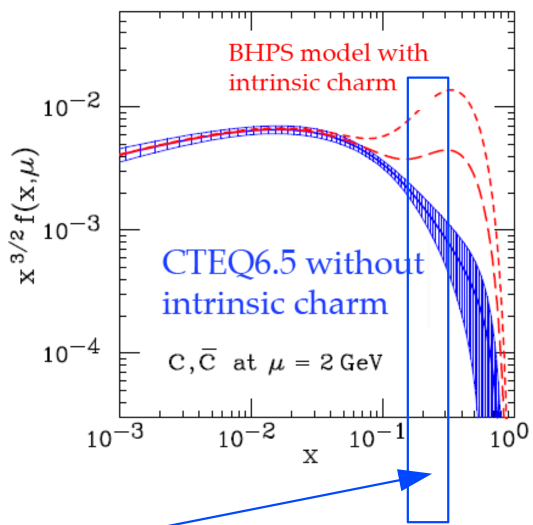
D^0

pHe

pAr



Pumplin, Lai, Tung, PRD75 054029



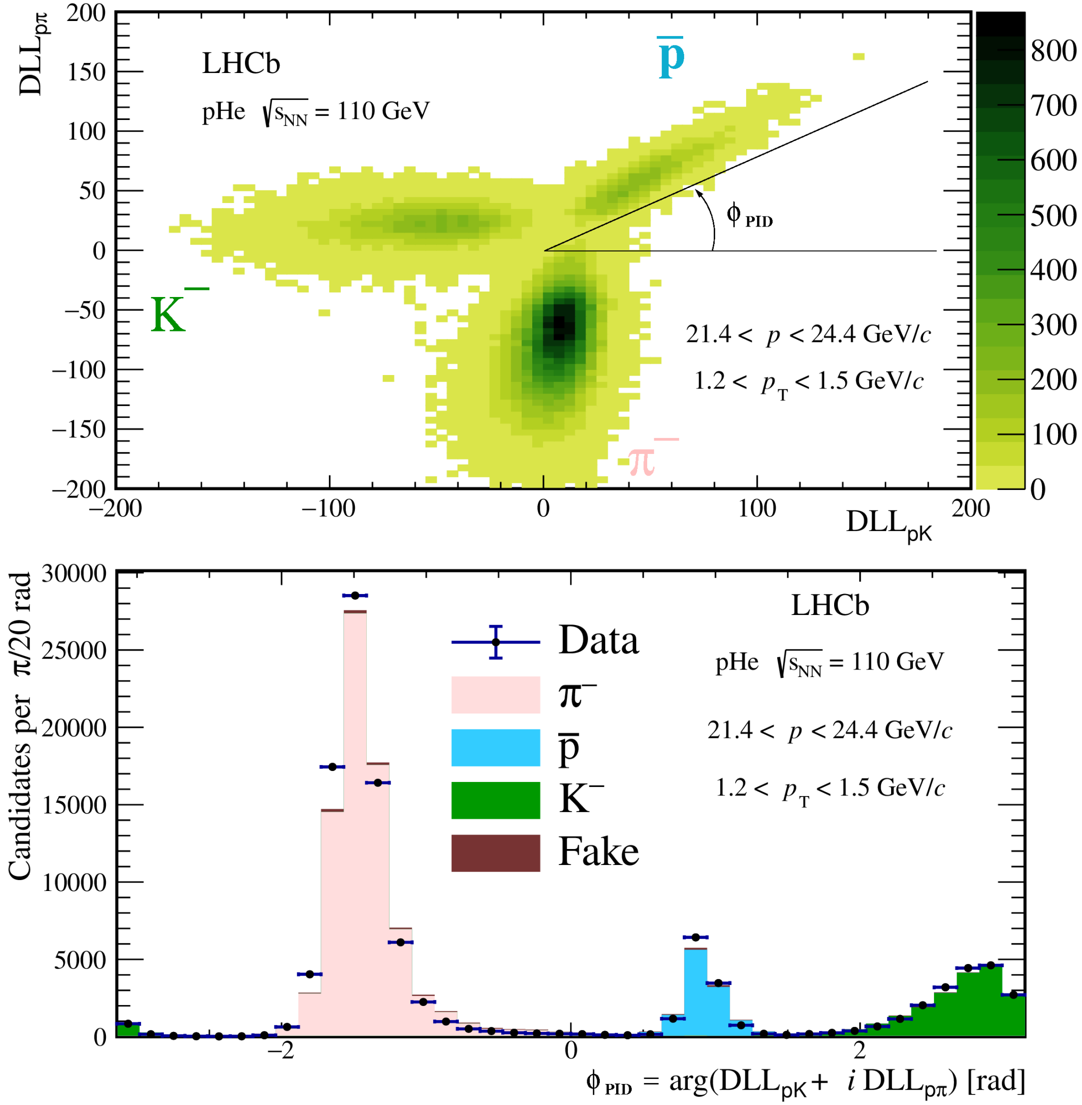
Antiprotons from pHe collisions

PRL 121 (2018), 222001

- First measurement of $p\text{He} \rightarrow \bar{p}X$ cross-section, the process accounts for $\sim 40\%$ of secondary cosmic $\bar{p}$
- Proton energy 6.5 TeV ➡ $\sqrt{s_{\rm NN}} = 110$ GeV
  Combined with pp data at lower energies, data constrain amount of scaling violation
- Exploiting **excellent particle identification** (PID) capabilities in LHCb to count antiprotons in $(p, p_{\rm T})$ bins within the kinematic range

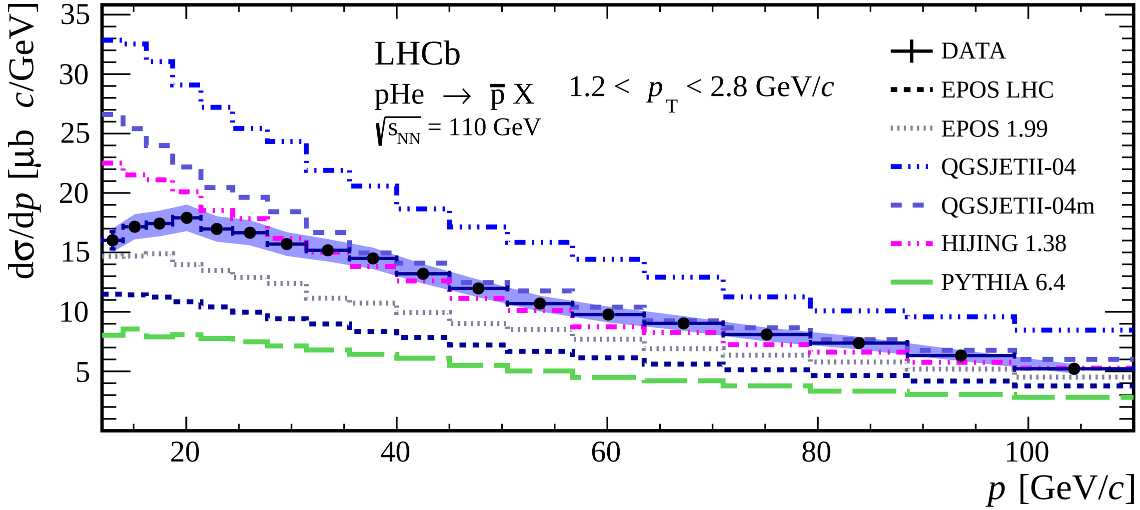
  $$12 < p < 110\,\text{GeV}/c, \quad p_{\rm T} > 0.4\,\text{GeV}/c$$

  (good match with PAMELA/AMS-02 capabilities)
- Exploiting excellent vertexing capabilities to distinguish **prompt** production and **anti-hyperon** component



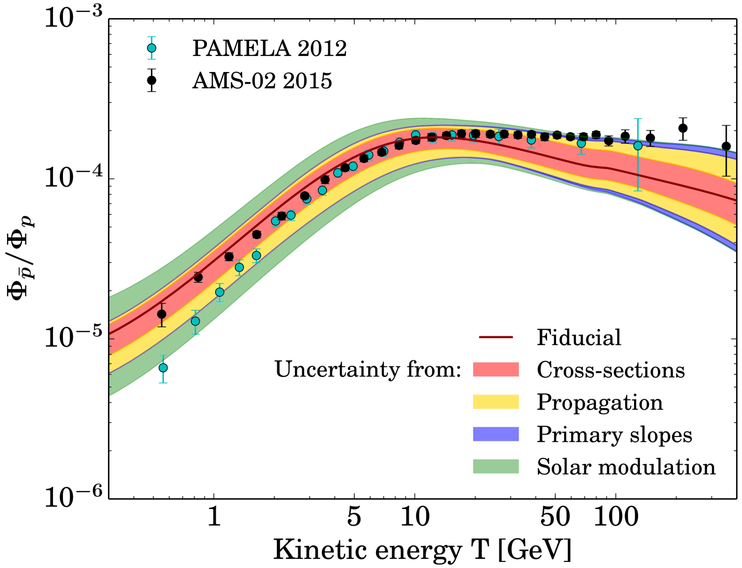
pHe antiproton result

PRL 121 (2018), 222001

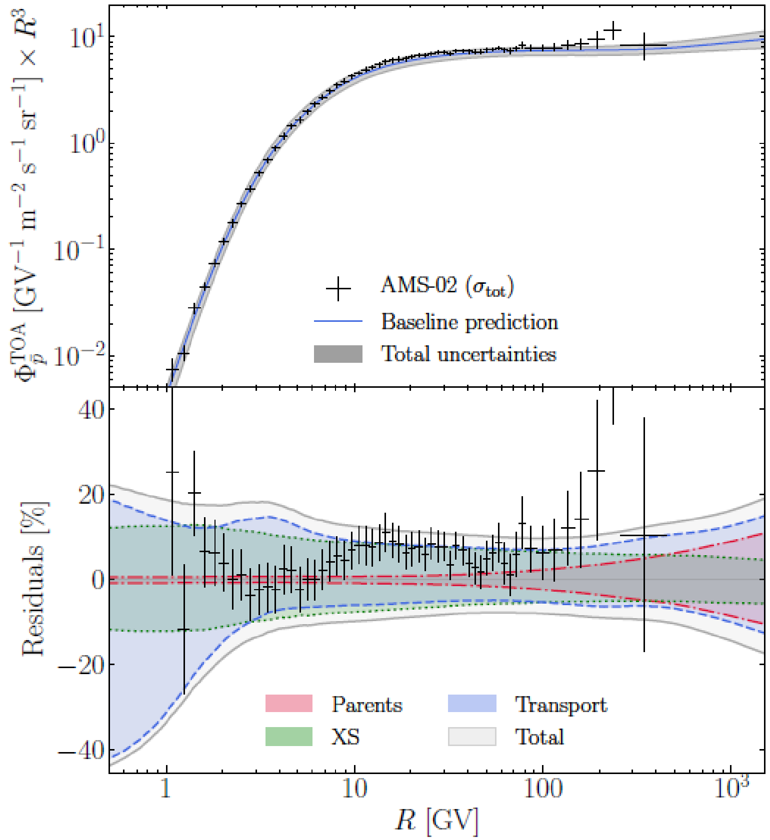


- Result for prompt $\bar{p}$ production
- Accuracy better than 10 %, lower than spread among models

2015 Giesen et al., JCAP 1509, 023



2019 Boudad et al., arXiv:1906.07119



- Significant shrinking of uncertainty for the predicted secondary antiproton flux from the use of LHCb and NA61 (pp) new data (plus other improvements)

The case for LHC Fixed Target

Concluding slide from C. Vallée (convener of the PBC forum) at EPS 2019 (ECFA session)

CERN Physics Beyond Colliders

THE MAIN PBC MESSAGES TO THE EPPSU

FOR CERN PROJECTS

LHC Fixed-Target opens a worldwide unique domain to both SF and QGP measurements

Requires support for full exploitation of its potential on the LHC lifetime

from ESPP Update 2020

European Strategy Update

Physics Briefing Book

CERN-ESU-004
30 September 2019

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].

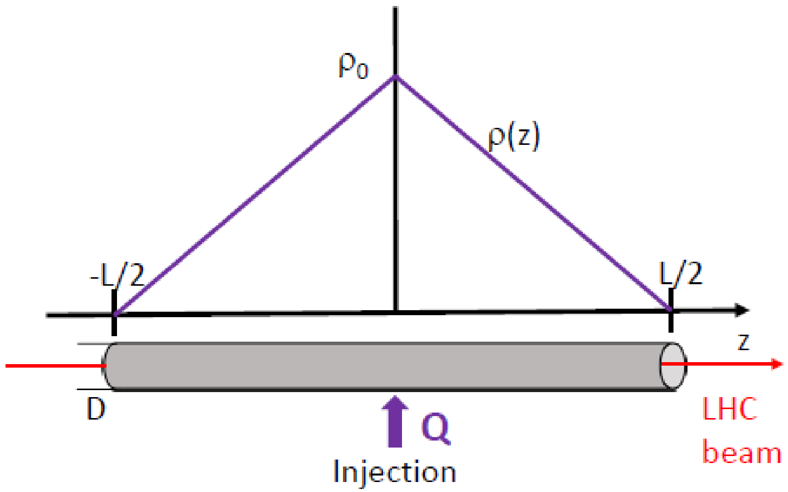
On the high-x frontier, the high-x gluon, antiquark and heavy-quark content (e.g. charm) of the nucleon and nucleus is poorly known (especially the gluon PDF for $x \gtrsim 0.5$). In the case of nuclei, the gluon EMC effect should be measured to understand that of the quarks. Such LHC-FT studies have strong connections to high-energy neutrino and cosmic-ray physics.

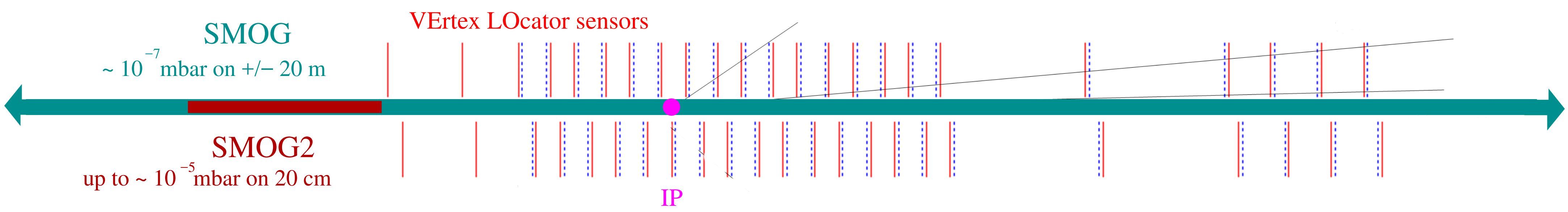
The physics reach of the LHC complex can greatly be extended at a very limited cost with the addition of an ambitious and long term LHC-FT research program. The efforts of the existing LHC experiments to implement such a programme, including specific R&D actions on the collider, deserve support.

The gas target upgrade

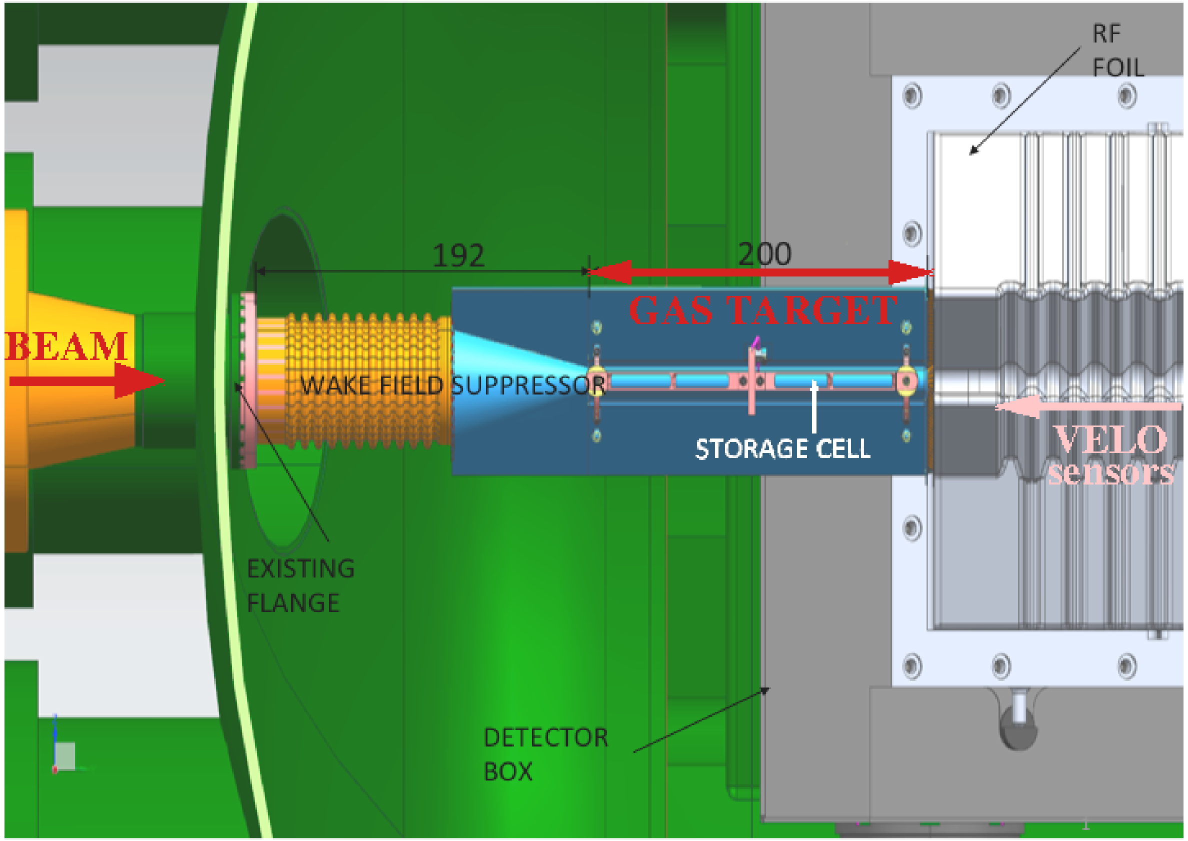
- Major LHCb detector upgrade for the LHC Run 3, including upgraded VErtex LOcator (microstrip $\rightarrow$ pixel)
- The new VELO integrates a new fixed target device SMOG2, based on a storage cell:
  - increase instantaneous luminosity
  - possibly inject other gases, as H, D, N, **O**, Kr, Xe
  - precise control of the gas density (improved accuracy on luminosity determination)
  - spatial separation between beam-gas and beam-beam collision regions

    ➡ easier **simultaneous data-taking**





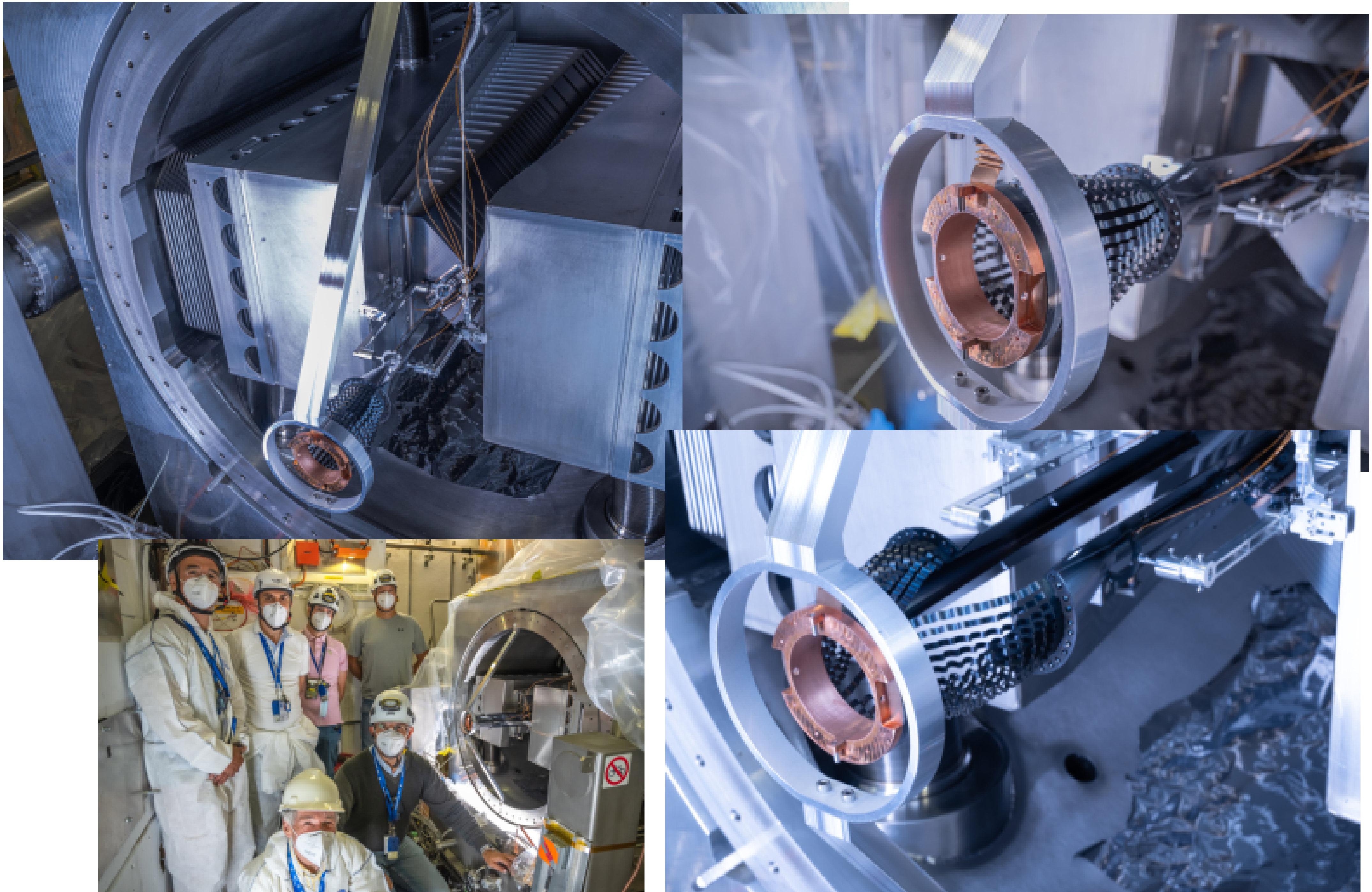
The SMOG2 gas target



- 20-cm long storage cell, 5 mm radius around the beam, just upstream the LHCb VErtex LOcator
- Made of two rectractable halves as the rest of VELO
- Up to x100 higher gas density with same gas flow of current SMOG
- Gas density measured with $\sim 2\%$ accuracy via Gas Feed System
- Fast switch between gas species

- TDR approved by LHCC in 2019
  CERN-LHCC-2019-005l
- Installed in the LHCb cavern on august 2020

SMOG2 installation



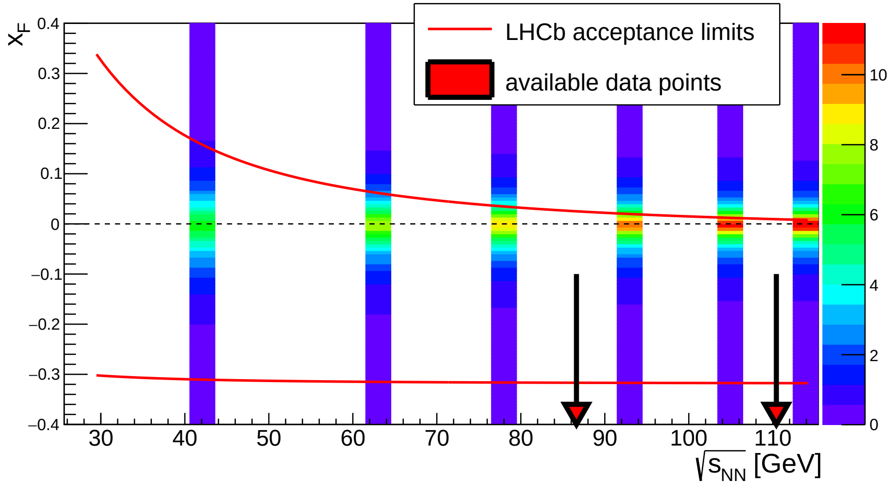
Prospects with SMOG2

LHCB-PUB-2018-015
arXiv:1812.06772

- Aiming at data samples up to 100 pb^{-1}
- Precision charm production measurements, access b states, Drell-Yan, ...
- H and D targets to provide reference and study **3D structure functions**

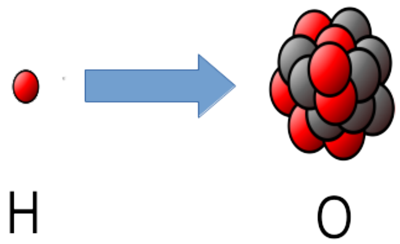
	SMOG largest sample p–Ne@68 GeV	SMOG2 example p–Ar@115 GeV
Integrated luminosity	$\sim 100\ \mathrm{nb}^{-1}$	$100\ \mathrm{pb}^{-1}$
syst. error on J/ψ x-sec.	6–7%	2–3 %
J/ψ yield	15k	35M
D^0 yield	100k	350M
Λ_c yield	1k	3.5M
ψ(2S) yield	150	400k
Υ(1S) yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9\ \mathrm{GeV}/c^2$) Drell-Yan yield	5	20k

- Possibility to complete the cosmic $\overline{p}$ study:
  H target to also measure $pp \to \overline{p}X$ and ratios with pHe
  D target to test isospin violation (relevant for antineutron production)
  Data at lower energy to measure evolution with energy (scaling violations) and access forward region (Feynman-$x > 0$)

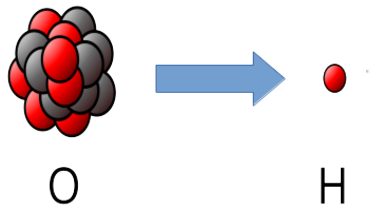


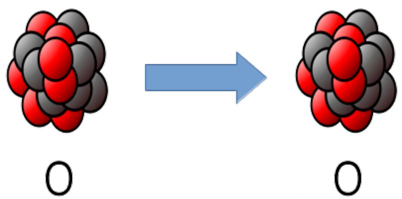
Feynman-x distribution for $\overline{p}$ vs $\sqrt{s_{NN}}$ and accessible region to LHCb

…and Oxygen!



Oxygen target Data with proton beams on Oxygen targets (and N, Ne, Ar, …) can be used to test and tune hadron production models at the energy scale up to $\sqrt{s_{\mathrm{NN}}} = 115\ \mathrm{GeV}$ for rapidities up to 5 in the oxygen rest frame



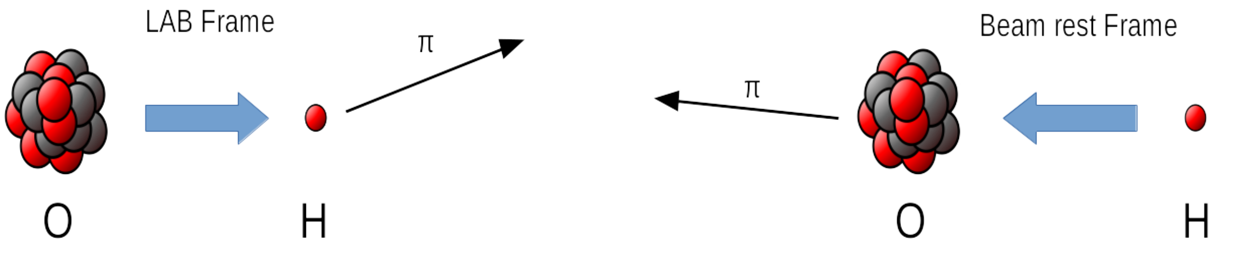


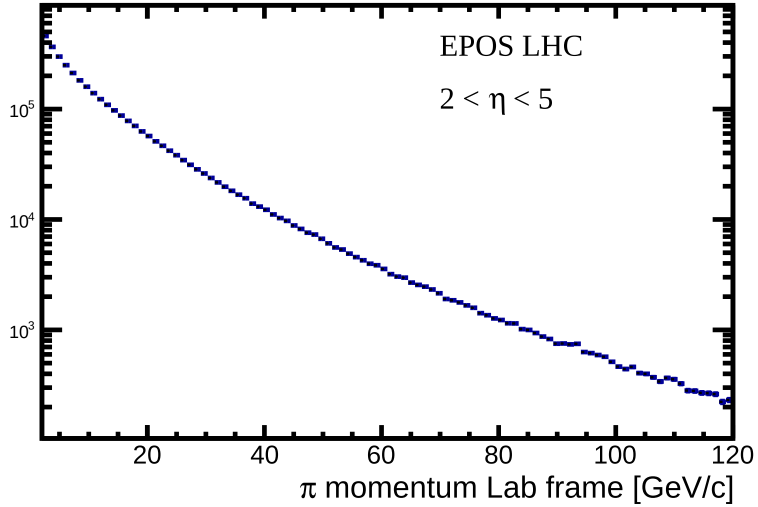
Oxygen beam The possibility to have O projectiles in LHC beam 1 (certainly during OO collisions) opens very interesting opportunities:

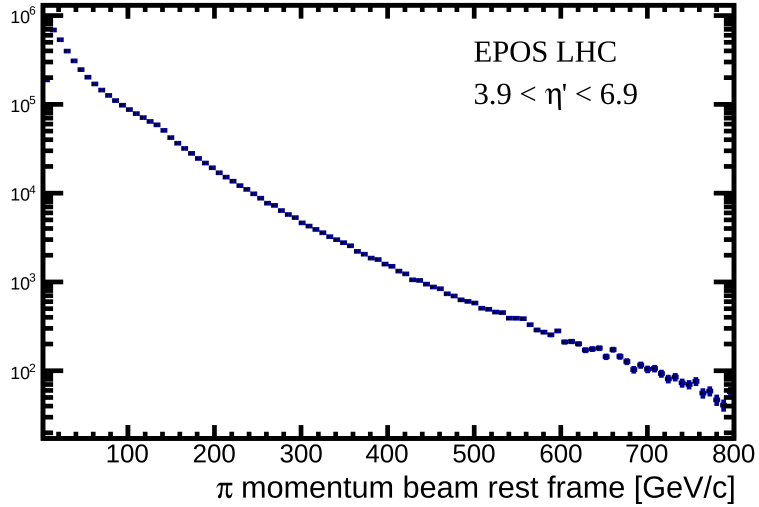
- Oxygen on proton: access very forward rapidities in O rest frame
- Oxygen on Oxygen: low energy reference for beam-beam collisions

Oxygen on Hydrogen

Assuming a beam of Z × 7 TeV, we get $\sqrt{s_{\mathrm{NN}}} = 81$ GeV
LHCb rapidity ($2 < \eta < 5$) corresponds to $3.9 < \eta' < 6.9$ in projectile rest frame !
➡ measurement of **identified** light particles up to very forward rapidities

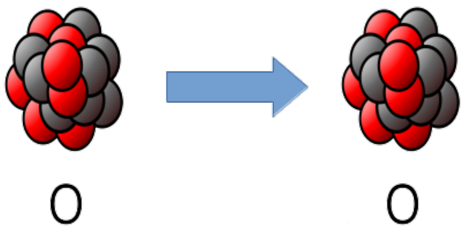






Expected luminosity: $\mathcal{L}_{Op} \sim 7 \times 10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
(assuming a beam of 3×10^{10} ions, average H_2 target pressure 2×10^{-5} mbar)
➡ target integrated lumi of $0.5\,\mathrm{nb}^{-1}$ (about 150M collisions needed for light particle production studies) require **20 hours of data taking**

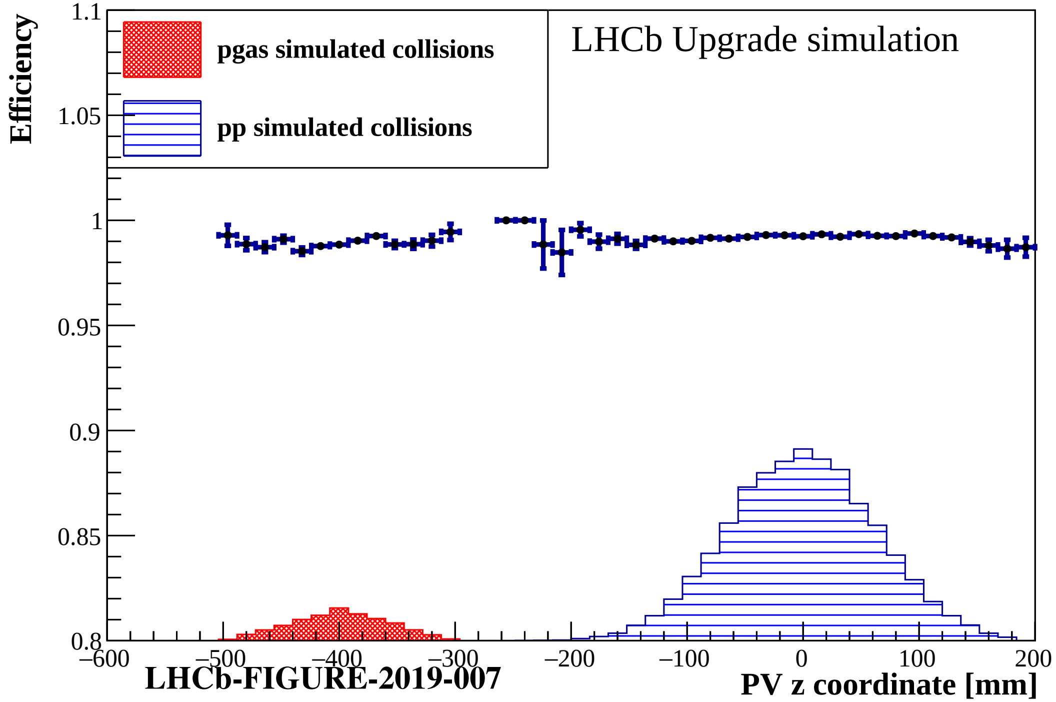
Oxygen on Oxygen



With Oxygen beam and target, we get OO collisions at $\sqrt{s_{\rm NN}} = 81$ GeV and mid rapidities ($-2.5 < \eta_{cms} < 0.5$)
➡ useful low-energy reference for beam-beam OO collisions.
Same luminosity of Op case, data sample of $\mathcal{O}(1)$ nb^{-1} can be collected in a few days

To maximise physics output, we aim at acquiring beam-gas events simultaneously with beam-beam events, using all bunches in the LHC beam
➡ include beam-gas events in the extremely challenging online software reconstruction and selection foreseen for the LHCb upgrade (up to 30 MHz collisions with 5 visible pp interaction per bunch crossing, event rate will be much smaller in OO)

Tracking efficiency vs longitudinal vertex position



Conclusions

- LHCb opened the way to the use of LHC beams in fixed-target configuration
- Physics case is strongly supported by CERN and EPSS Update
- Program developed through very fruitful exchange with Nuclear and Astroparticle physics communities
- The possibility of Oxygen beams provides intriguing opportunities
- Looking forward to these new possibilities in the **near future**!