New measurements in fixed-target collisions at LHCb

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on behalf of the LHCb collaboration

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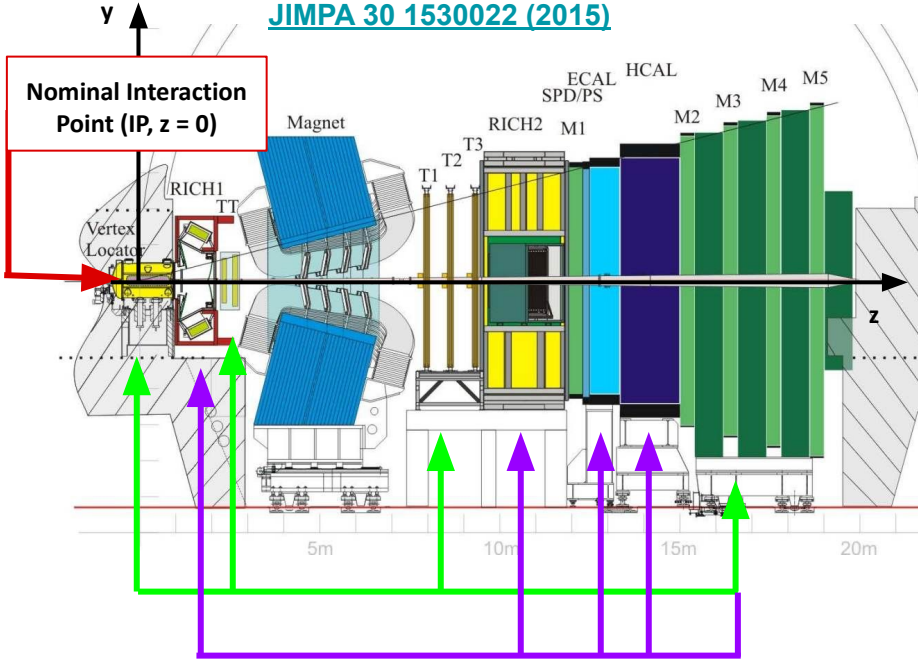
The LHCb experiment

- **Single-arm spectrometer** originally devoted to ***heavy flavour*** **physics,** now a **general purpose experiment** covering η ϵ [2, 5] (QCD, SM, **heavy ion and fixed-target**)

JINST 3 08005 (2008)
JIMPA 30 1530022 (2015)

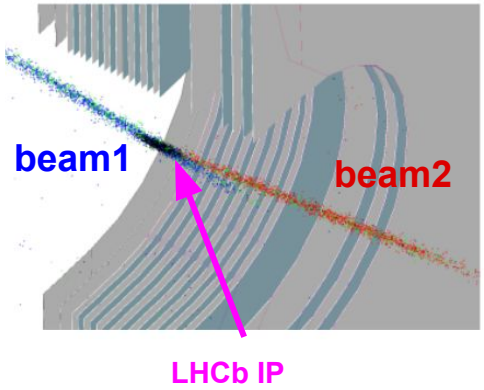


- **Complementary** wrt other LHC experiments
- Tracking system: **VErtex LOcator** + tracking stations and a dipole magnet
  - 0.5-1% *p* resolution for *p* < 300 GeV/c
  - 10-80 μm IP resolution
- Particle identification (PID): Two **Cherenkov detectors (RICH)** + calorimeters and muon
- **Flexible and versatile trigger**

JINST 8 04022 (2013)

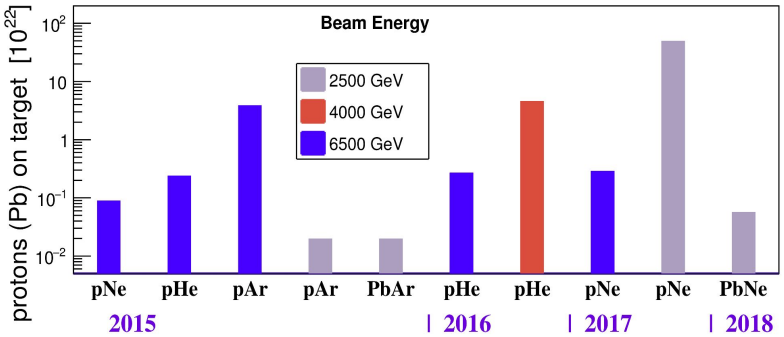
The SMOG system

JINST 9 (2014) 12005



- From 2011, LHCb **System for Measuring Overlap with Gas (SMOG)**
  - LHC beam collisions with the small quantity of injected gas (10^{-7} mbar) used to reconstruct the **beams transverse profiles**
- Forward detector + gas target = **highest-energy fixed-target ever!**

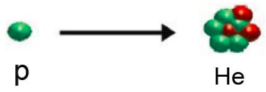
LHCb-PUB-2018-015



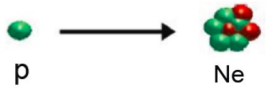
- Sveral pA and PbA fixed-target samples collected
- **Unique energy scale**: $\sqrt{s_{\mathrm{NN}}} \in [68.5, 110]$ GeV
- **Access to the high-x and intermediate Q^2** kinematic region, mostly unexplored by previous experiments

→ **Unique experimental inputs** to models

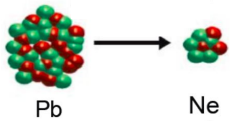
Today's menu

$\sqrt{s_{\mathrm{NN}}} = 110\,\mathrm{GeV}$ 

LHCb-PAPER-2022-006: Detached antiprotons in *p*He
arXiv:2205.09009

$\sqrt{s_{\mathrm{NN}}} = 68.5\,\mathrm{GeV}$ 

LHCb-PAPER-2022-014: Charmonium production in *p*Ne
(In preparation)

$\sqrt{s_{\mathrm{NN}}} = 68.5\,\mathrm{GeV}$ 

LHCb-PAPER-2022-011: J/ ψ production in PbNe
(In preparation)
(first result for this collision system!)

Hot of the press results from the **commissioning of the upgraded system**

… and other results already **in the pipeline**…

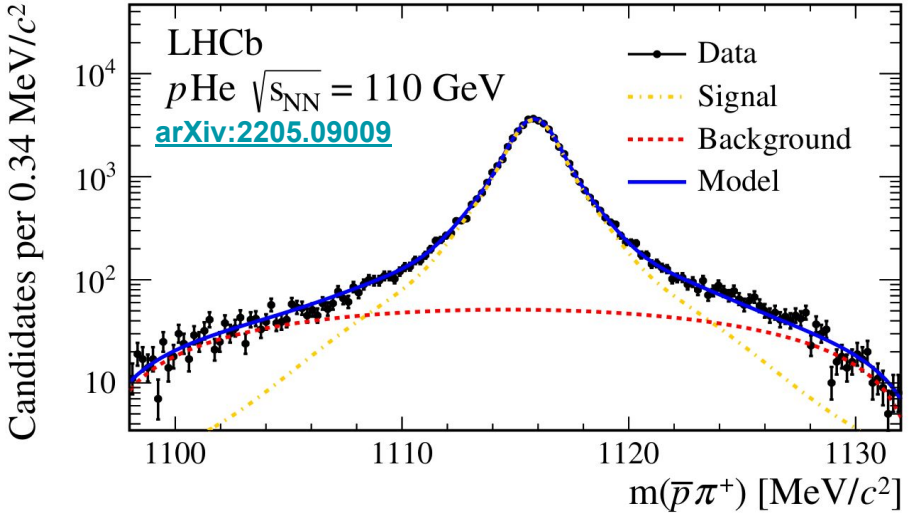
Antiprotons from antihyperon in *p*He (I)

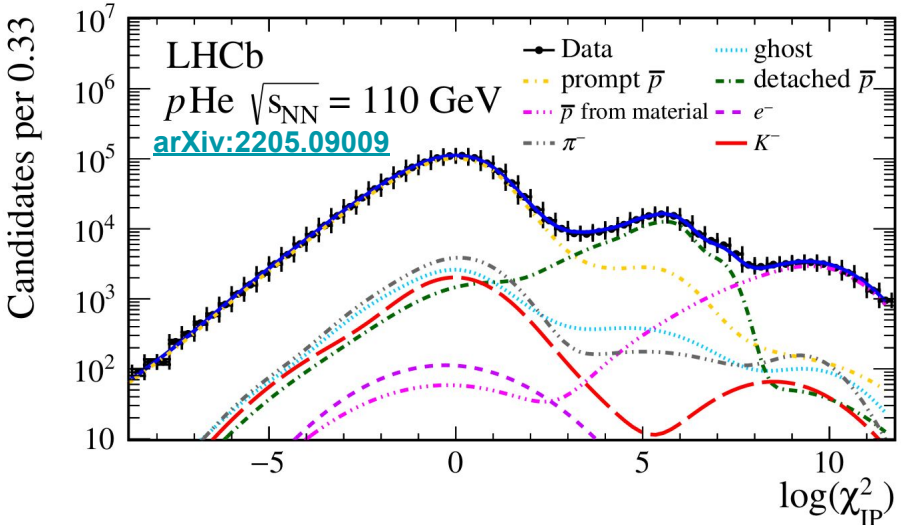
- Interpretation of $\bar{p}$ flux in CRs (indirect DM searches) limited by models of its **production in CRs collisions with the interstellar medium** (H, He)
- Addressing **antihyperon decays**, after a first result for prompt production on the same data

PRL 121 (2018) 222001

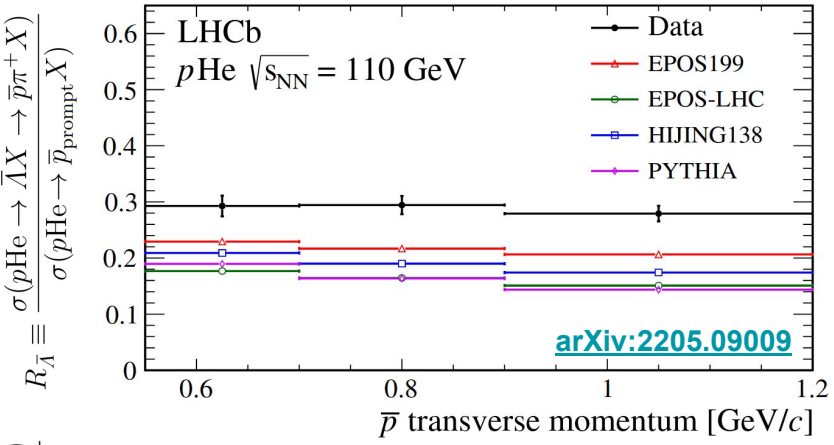
$$R_{\bar{\Lambda}} \equiv \frac{\sigma(p\mathrm{He} \to \bar{\Lambda} X \to \bar{p}\pi^+ X)}{\sigma(p\mathrm{He} \to \bar{p}_{\mathrm{prompt}} X)}$$ **(this paper)** **(PRL 121 (2018) 222001)**

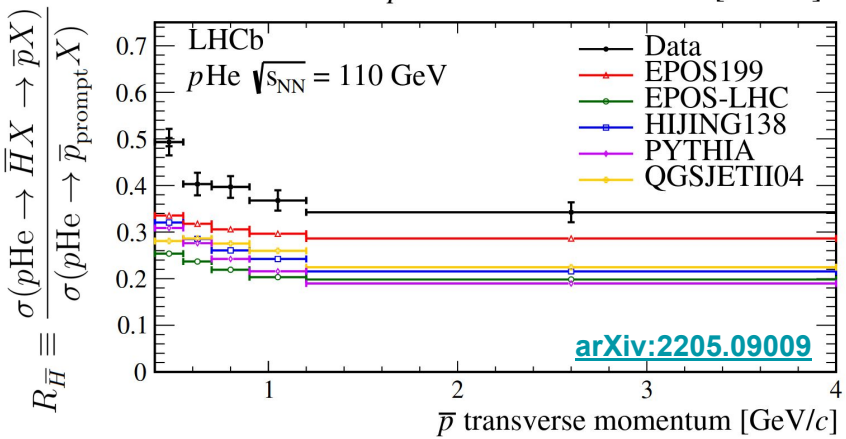
$$R_{\bar{H}} \equiv \frac{\sigma(p\mathrm{He} \to \bar{H} X \to \bar{p} X)}{\sigma(p\mathrm{He} \to \bar{p}_{\mathrm{prompt}} X)} \qquad \bar{H} = \bar{\Lambda}, \bar{\Sigma}, \bar{\Xi}, \bar{\Omega}$$





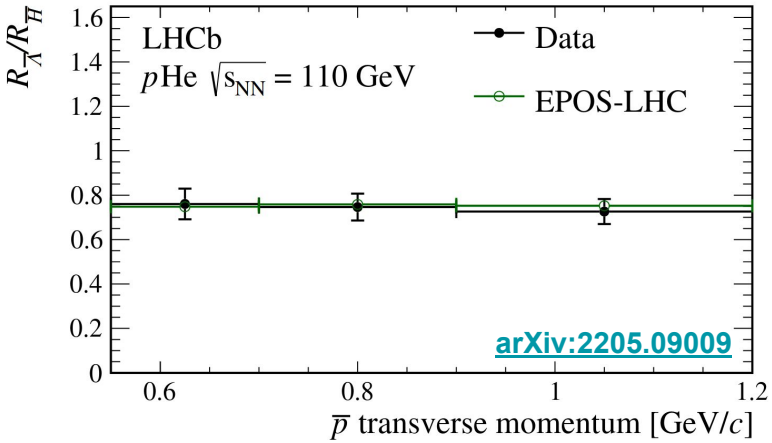
Antiprotons from antihyperon in *p*He (II)





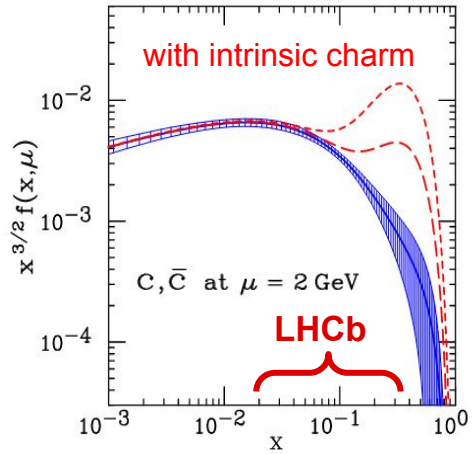
- Models **largely underestimate the anti-hyperon contributions** to the total $\bar{p}$ yield
- **Mutual consistency** between the two approaches proved by the agreement of their ratio with EPOS-LHC (**predicted more reliably**)

Becattini et al, EPJC 66, 377–386 (2010)

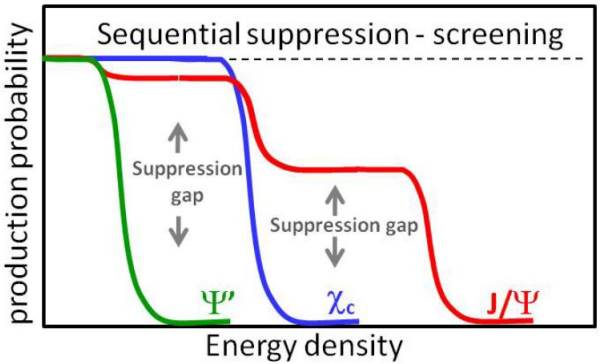


Charm in *p*Ne/PbNe

LHCb-PAPER-2022-014, in preparation



Pumplin et al. Phys Rev D75 054029

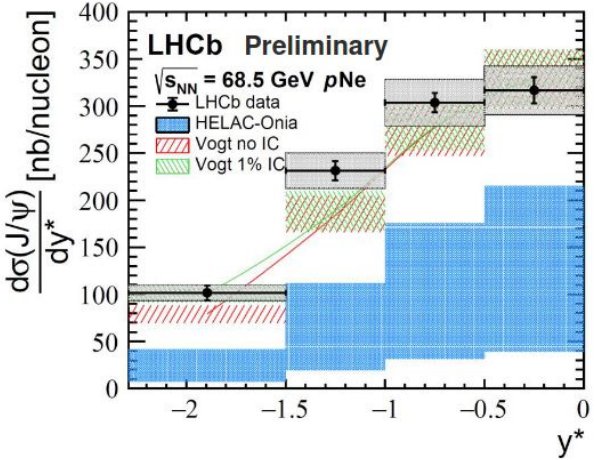


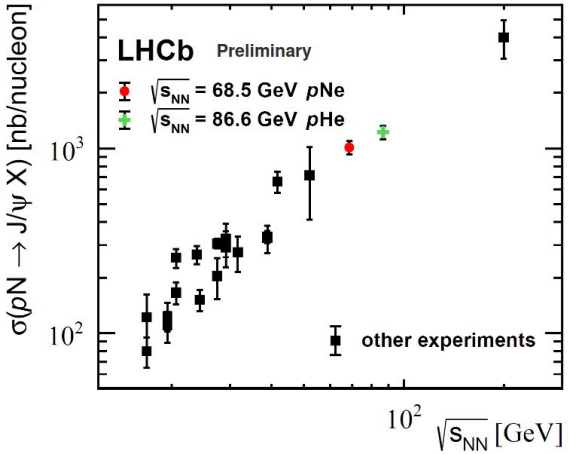
- Charmonia production is an excellent probe for **Cold Nuclear Matter effects** (PDF nuclear modification, nuclear absorption, multiple scatterings…)
- LHCb fixed-target acceptance sensitive to a **possible nucleon intrinsic charm content**
- Heavy charmonia states also probe the color screening mechanism in QGP **via the sequential suppression**

PRL 123 239901 (2019)

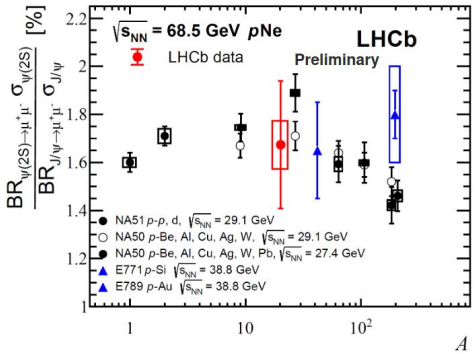
- LHCb-SMOG **unique energy scale measurements**: J/ψ and D^0 production in *p*He (110 GeV) and *p*Ar (68 GeV) in 2019, new result with the ***p*Ne SMOG highest-statistic sample** (68.5 GeV)

Charmonia in *p*Ne





- **Good agreement** with prediction without and with 1% IC, **underpredicted by HELAC-ONIA**
- Full phase-space result **agrees with previous experiments**

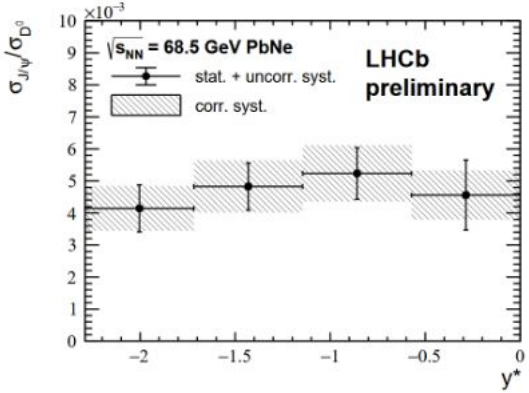


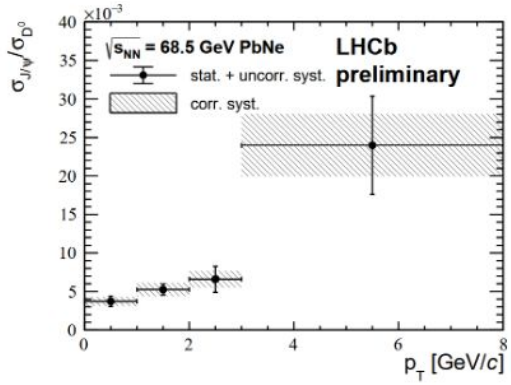
- ψ(2s)/ψ ratio result compatible with previous measurements, but **analysis is statistically limited**

→ **Motivation to upgrade our fixed-target programme!**

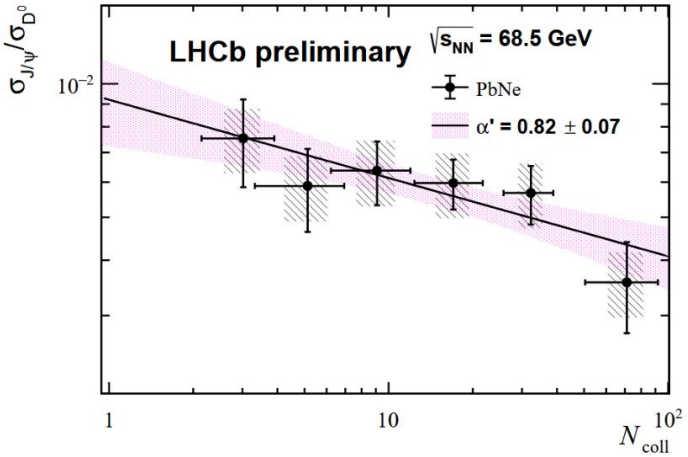
Charm in PbNe

LHCb-PAPER-2022-011, in preparation





- Observation of J/ψ and D^0 production in PbNe, **unique possibility at LHC**

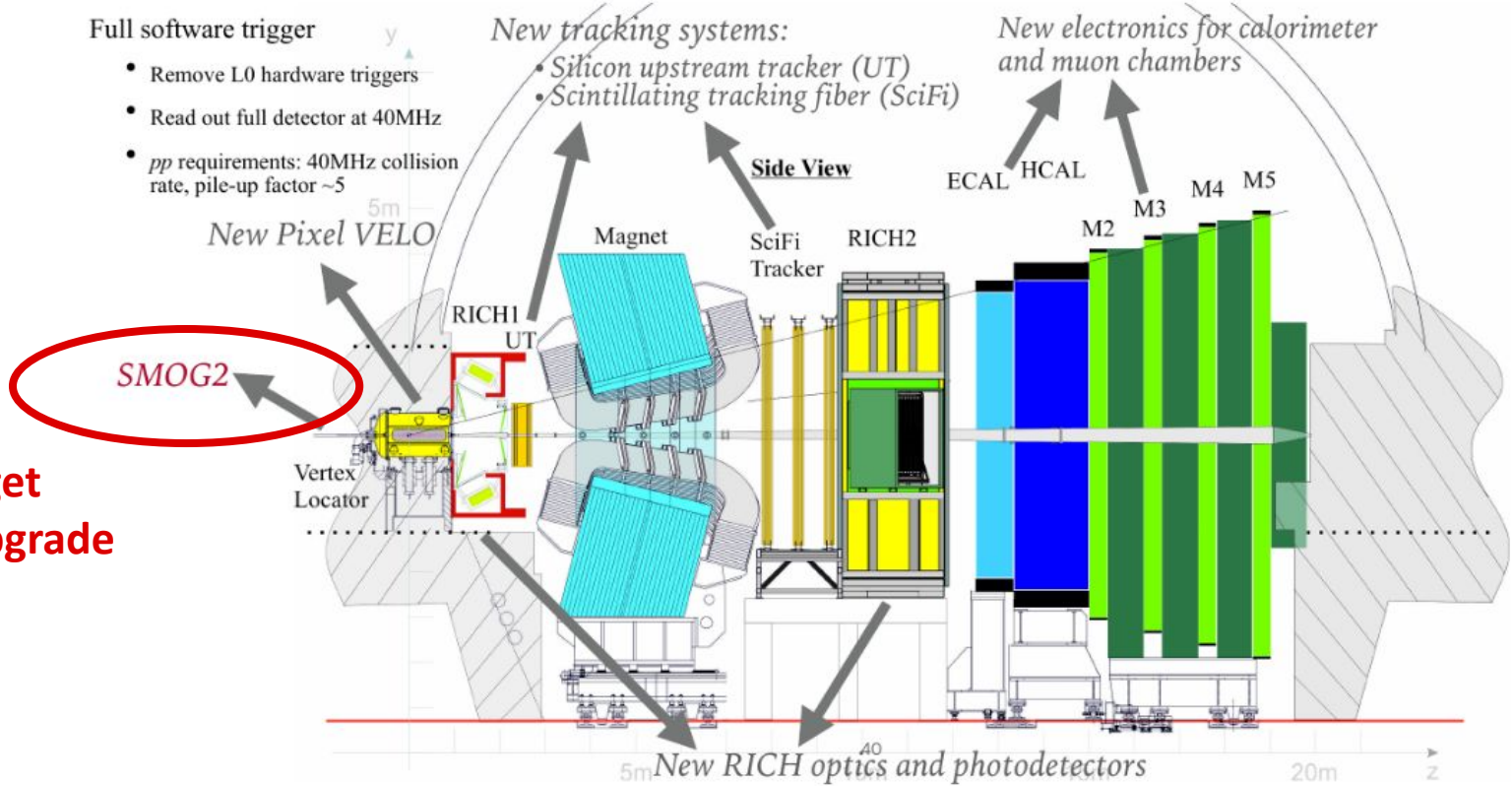


- N_{coll} obtained from **Glauber model** applied to ECAL energy deposits [JINST 17 05009 (2022)]

PLB410 (1997) 337

- α' **in agreement with previous NA50 pA** result
- **No evidence for anomalous J/ψ suppression** (expected from QGP formation)

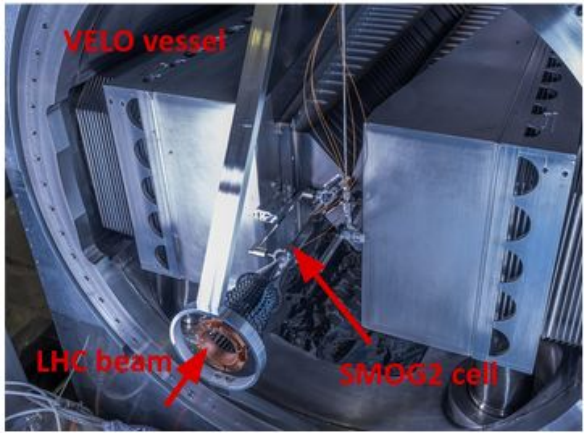
The LHCb upgrade



Fixed-target system upgrade

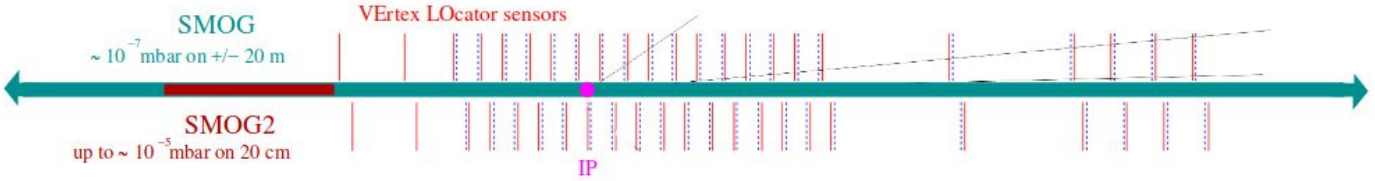
SMOG2 in a nutshell

LHCb-TDR-020



- **SMOG2: gas confinement in a cell upstream of the LHCb IP** ($z \in [-500, -300]$ mm)
  - Up to x100 **pressure wrt SMOG for the same gas flow**
  - **Simultaneous beam-beam beam-gas data-taking**
  - **Heavy noble (Kr, Xe) and non-noble gases (H_2, D_2, O_2, N_2 …)** can be injected
- **New Gas Feed System**
  - Precise flow control → **direct lumi measurement**
  - More gas recipients → **switch with no intervention**

⇨ **A unique laboratory for QCD @ LHC!**



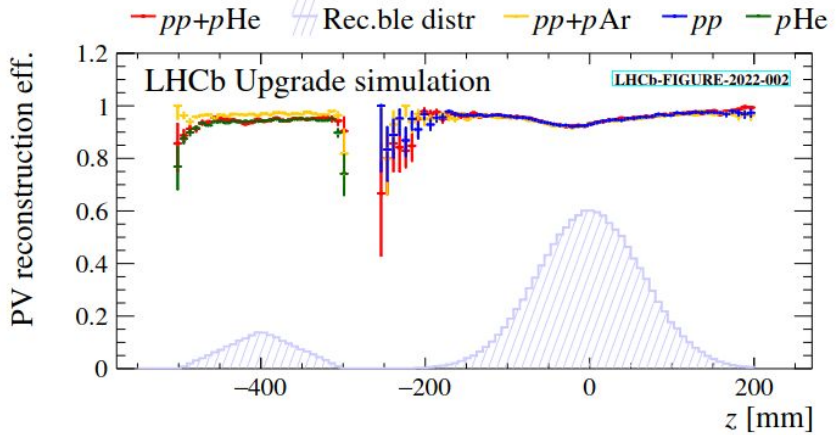
SMOG2 physics opportunities

LHCb-PUB-2018-015

	SMOG largest sample p–Ne@68 GeV	SMOG2 example p–Ar@115 GeV
Integrated luminosity	$\sim 100\ \text{nb}^{-1}$	$100\ \text{pb}^{-1}$
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
$\psi(2S)$ yield	150	400k
$\Upsilon(1S)$ yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9$ GeV/c^2) Drell-Yan yield	5	20k

- **Charmonia spectra** in different collision systems**, b and low-mass Drell Yan states**
- Extension of the cosmic-rays programme
- **High-x parton PDFs, nucleon structure**

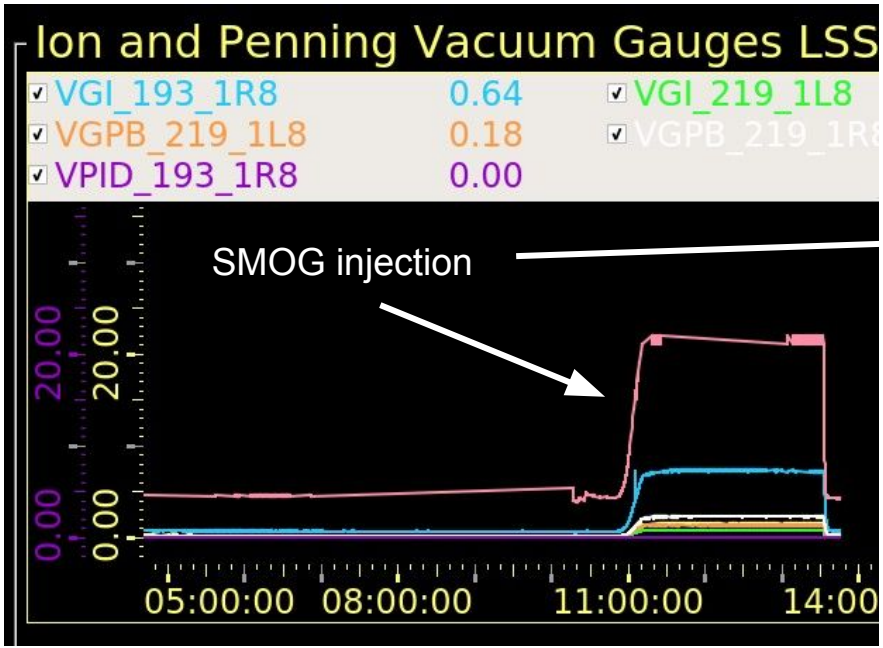
LHCb-FIGURE-2022-002



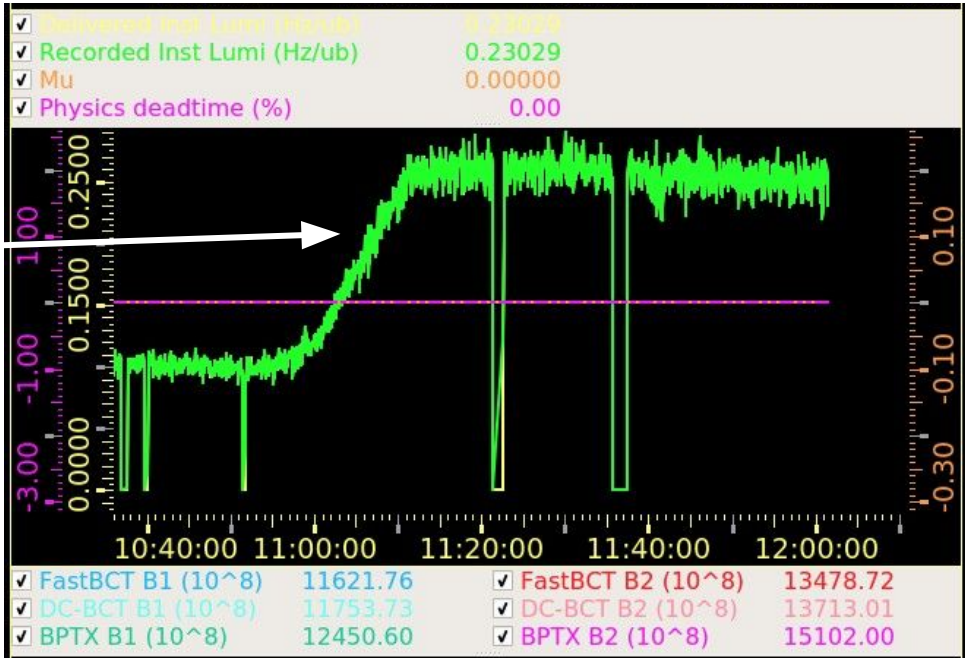
- Activity on reconstruction software demonstrates **same performance on beam-beam and beam-gas and no interference**

Hot of the press…

- Gas (Ne) injection in LHC restarted to **ease the early commissioning of the detector**



Pressure as recorded around the LHCb IP



LHCb instantaneous luminosity

Conclusions (I)

[Ref]

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.

Conclusions (II)

LHCb-PUB-2018-015

- Since 2015, LHCb is acting as the **highest energy ever fixed-target experiment** by injecting in the LHC accelerator **small quantities of noble gases**
- **Performed measurements in different collision systems** and for many fields of interest:
  - **Detached-to-prompt antiproton production in *p*He**, showing a large underestimation of all theoretical models for the antihyperon decay contributions
  - **Charm production in *p*Ne and PbNe,** giving useful insights to the charm production mechanisms
- **The ongoing upgrade of the fixed-target programme,** with the increase of the gas target areal density and the injectable gas species, will improve the accuracy and will extend all of these measurements… **stay tuned!**

Thanks for your attention!

Want to follow up? saverio.mariani@cern.ch