LHCb on a space mission:

fixed-target results and prospects for cosmic rays physics

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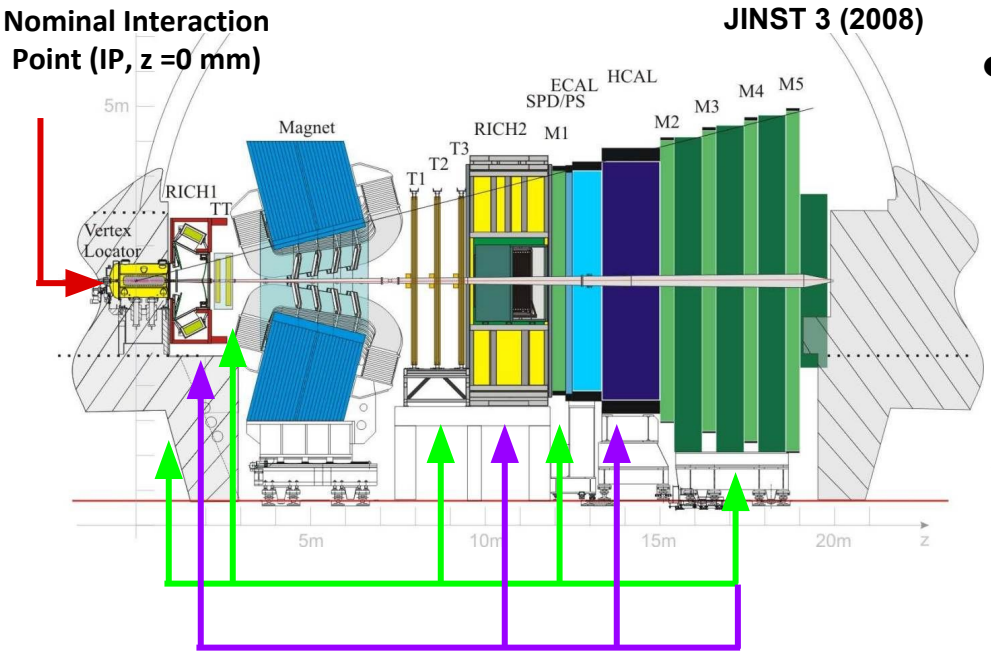
on behalf of the LHCb collaboration

The LHCb Experiment

The LHCb experiment

- Focusing on the **physics of heavy quarks**, the instrumented region covers the forward direction (θ in [10, 300] mrad wrt beam axis), where their production is maximum



- Same *onion-like* structure than general-purpose experiments made up of **tracking** and **particle identification** sub-detectors

- Now a **general-purpose** experiment in the forward direction (covering b and c physics, QCD, EW and Higgs, Heavy Ion and **fixed-target** physics) .

The SMOG system

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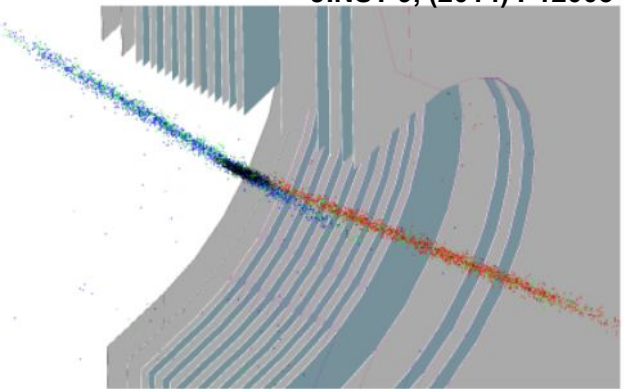
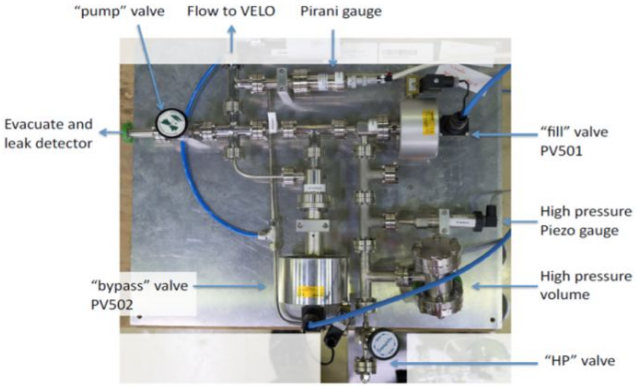


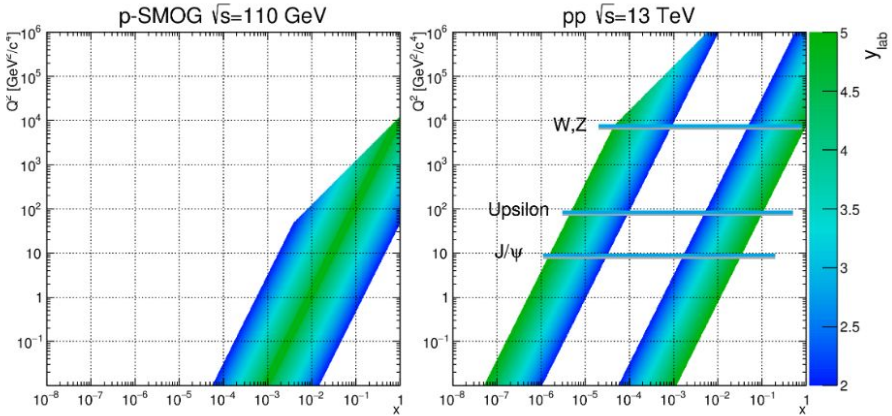


- The gas injection system **SMOG (System for Measuring Overlap with Gas)** was originally conceived to complement the LHC luminosity measurements with the VdM scans with the reconstruction of the transverse beam profiles via the proton-gas interactions.

- For the injection, the nearest pumps to the IP are switched off and the **gas is free to flow** in ± 20 m.
- **Limitation of the maximum injected pressure** around 10^{-7} mbar and of the injectable gases to **only some noble gases** to keep the beam contamination low

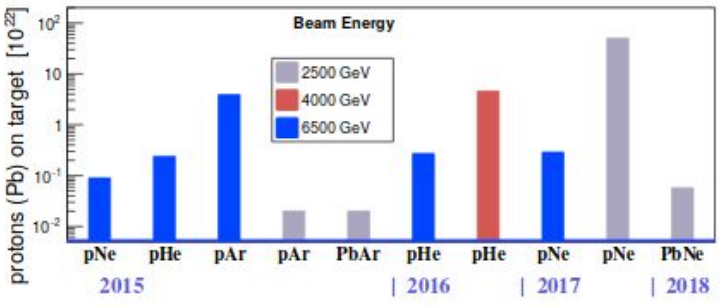
Physics with the SMOG system

- A gaseous target and a forward detector geometry are well suited to fixed-target physics!



LHCb-PUB-2018-015

- The accessible kinematic region is unique:
  - Beam energies of [0.9, 7] TeV on at-rest nuclei correspond to a CM per-nucleon energy of $\sqrt{s_{NN}} \in [41, 115]\, GeV$, **intermediate between fixed-target *SpS* and LHC scales**
  - Large Bjorken-x target values can be studied at lower energy than *pp*

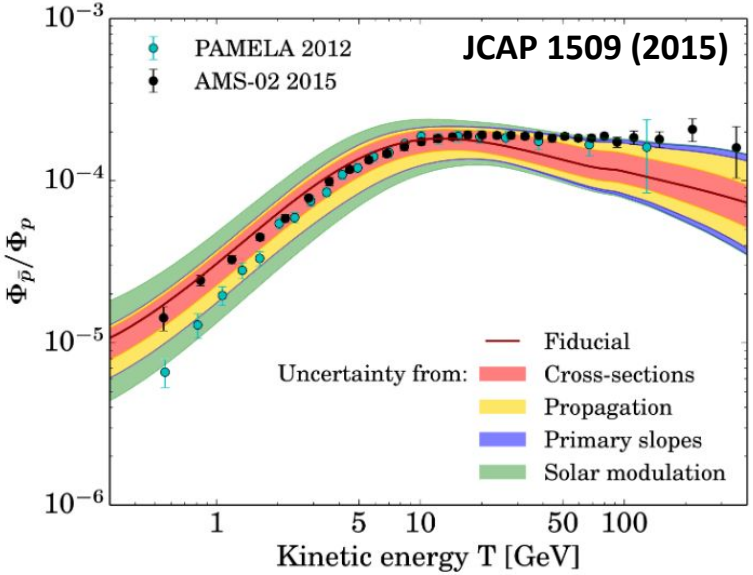


- **Wide variety** of samples collected in Run2
- I will cover today only the measurements of Cosmic Rays interest, but **many others are in progress**

The LHCb space mission

Antiprotons in Cosmic Rays back to 2015

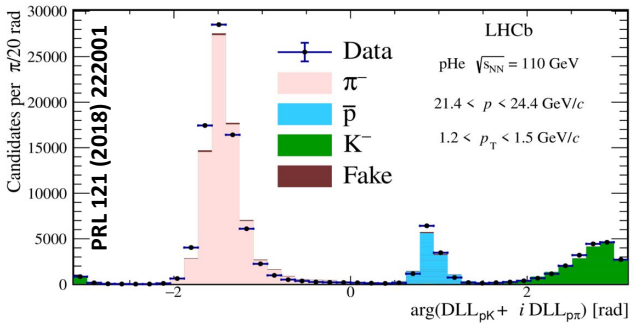
- **Antimatter measurement in Cosmic Rays** (CRs) is a promising experimental strategy for indirect Dark Matter annihilation or decay process searches.
- Space experiments, like PAMELA and AMS-02, have measured the **positron and antiproton fluxes in CRs (and are collecting light anti-nuclei data)**.



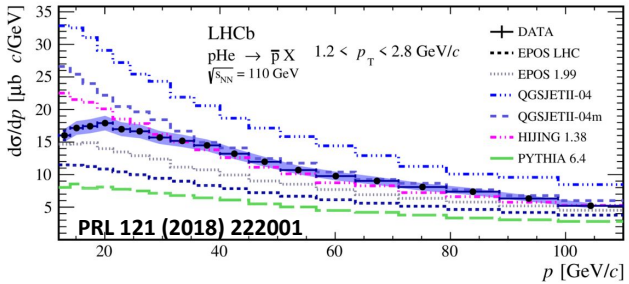
- In 2015, AMS-02 confirmed a hint for an **excess of high-energy antiprotons** wrt the expected production in CRs - Interstellar Medium (mainly *H* and *He*) collisions.
- Interpretation of the results limited by the poor knowledge of hadronic production cross-sections:
  - Poor data for $\sigma(pp \to \bar{p}X)$
  - **No data at all** for $\sigma(pHe \to \bar{p}X)$

Prompt antiproton production in pHe measurement

- 2016 *pHe* SMOG sample allowed to measure **for the first time** $\sigma(\mathbf{pHe} \to \bar{\mathbf{p}}\mathbf{X})$
- All **promptly produced** negatively-charged particles are selected and counted in kinematic bins within the fiducial region p ϵ [12, 110] GeV/c; p_T ϵ [0.4, 4] GeV/c; PV_z ϵ [-700, 100] mm

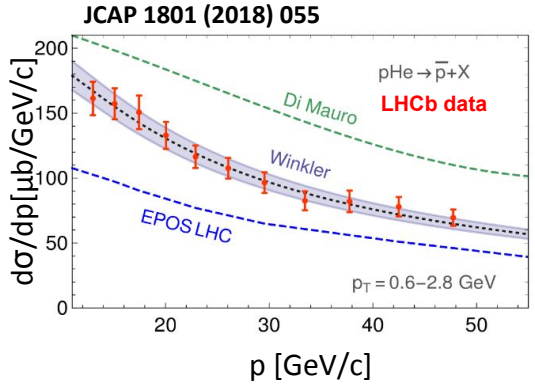


- Antiprotons are distinguished **fitting the particle identification variables** with simulated or calibration templates and leaving abundances as free parameters
- Can PID performance for SMOG analyses **be improved?**



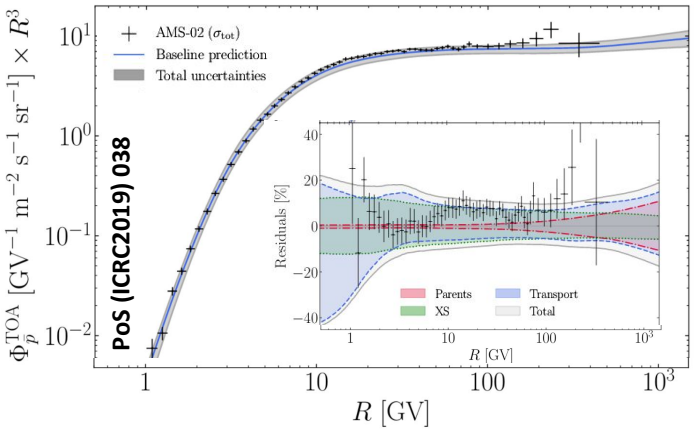
- Because of the **lack of precise gauges for the gas pressure**, the luminosity is indirectly obtained measuring **the LHC protons and He electrons elastic scattering** with a 6% relative uncertainty, the dominant contribution
- Results **uncertainty lower than the models spread**

Result impact on theoretical models



- Result received by theoretical community and contributing to:
  - **Constrain the σ extrapolation** from a *H* to a *He* target.
  - **Constrain the σ evolution with energy**

JCAP 1801 (2018) 055
PRD97 (2018) 103019



- Significance for an exotic contribution to the antiproton flux significantly reduced

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PRD 99, 103014

- Uncertainty on the hadronic production cross-sections **still a limiting factor**
- Other cross-section measurements will help the comprehension of data more sensible to exotic contributions (like for light nuclei)

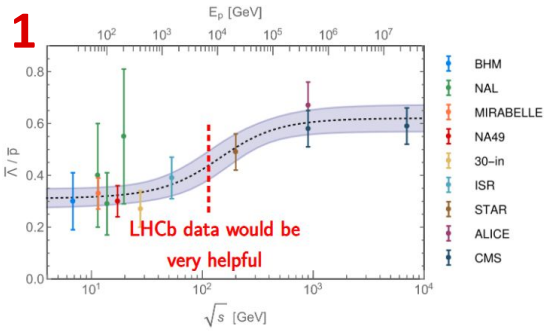
Program extensions

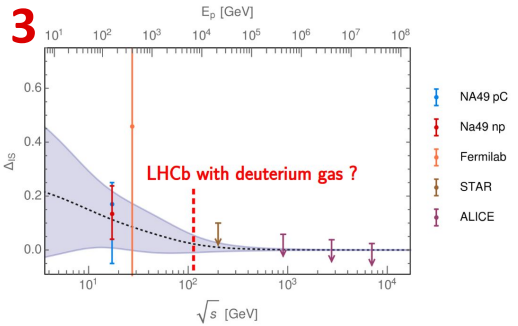
- Efforts ongoing to mitigate the program dominant experimental limiting factors:
  - Lack of a direct luminosity measurement → **Solved with SMOG2**
  - Poor PID performance → **Calibration with larger pNe sample employing machine learning tools under development** (uncovered today, technical paper in preparation)
- **Measurement of prompt antiprotons will be repeated** with the available sample with 4 TeV beam energy and with SMOG2 at lower energies, possibly even the LHC injection one.
- **LHCb can successfully address** the other results required to the model improvement

- LHCb SMOG wishlist:

1) $p\,He \rightarrow \bar{\Lambda}, \bar{\Sigma}$ from existing run — **Ongoing with 6.5 and 4 TeV samples**
2) $p\,p\,(H_2) \rightarrow \bar{p}$ to test scaling violation in forward hemisphere — **Possible with SMOG2**
3) $p\,d \rightarrow \bar{p}$ to test isospin effects — **Possible with SMOG2**
4) $p\,p,\ p\,He \rightarrow \bar{d}, \bar{He}$ to determine coalescence momentum — **Ongoing feasibility studies**
5) $p\,p,\ p\,He \rightarrow \pi,\ K$ to model positron source term — **Ongoing**

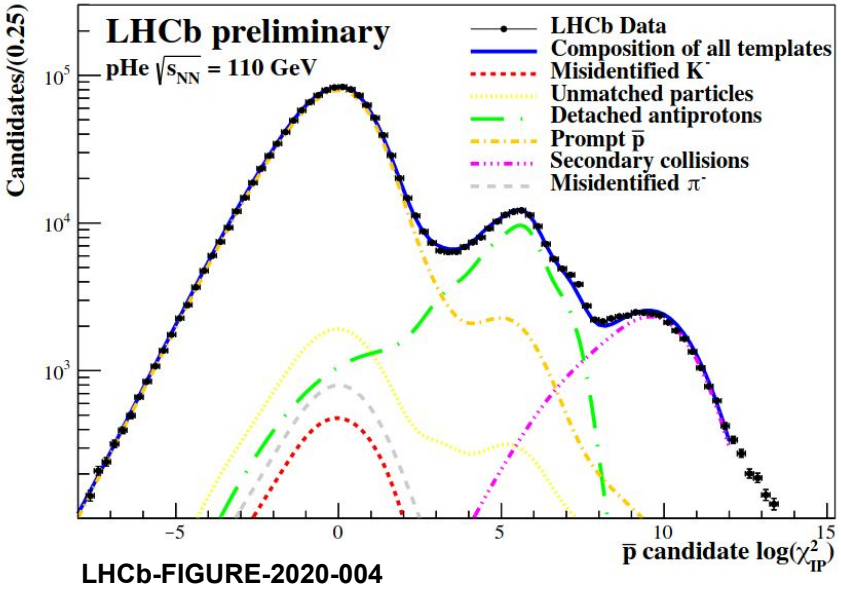
Martin Winkler at 2nd LHCb Heavy Ion workshop





Antiproton from anti-hyperon measurement

- Antiproton contribution from $\bar{\Lambda}^0 \to \bar{p}\pi^+$ and $\bar{\Sigma}^- \to \bar{p}\pi^0$ decays affected by large uncertainties
- All antiprotons produced in *pHe* collisions are reconstructed, selected and distinguished between prompt and produced in strange decays (**detached**) according to the χ^2_{IP} wrt the PV, the χ^2 difference for the PV fit considering or ignoring the track.

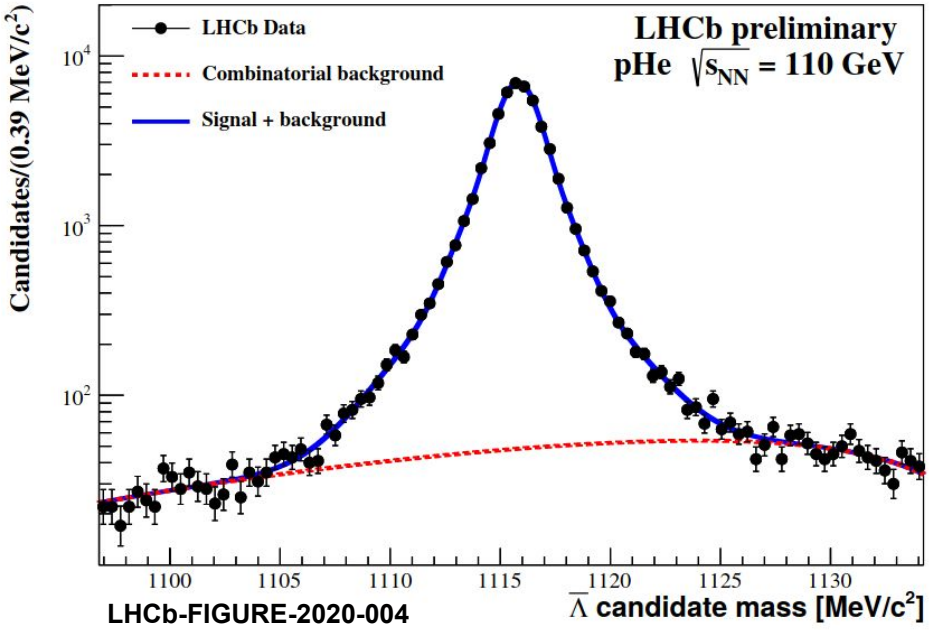


LHCb-FIGURE-2020-004

- Data χ^2_{IP} distribution shows **three distinct peaks**, corresponding to prompt, detached antiprotons and secondary collisions
- A fit with simulated templates composition **measures the raw detached-to-prompt $\bar{p}$ ratio**
- This approach measures all antiprotons from strange decays (needed for the CRs models), but strongly relies on simulation and **needs to be independently cross-checked**

Antiproton from anti-hyperon measurement (II)

- **Measurement of the $\bar{\Lambda} \to \bar{p}\pi^+$ cross-section in *pHe* collisions** is an interesting production study itself, but also can confirm the detached antiprotons dominant contribution

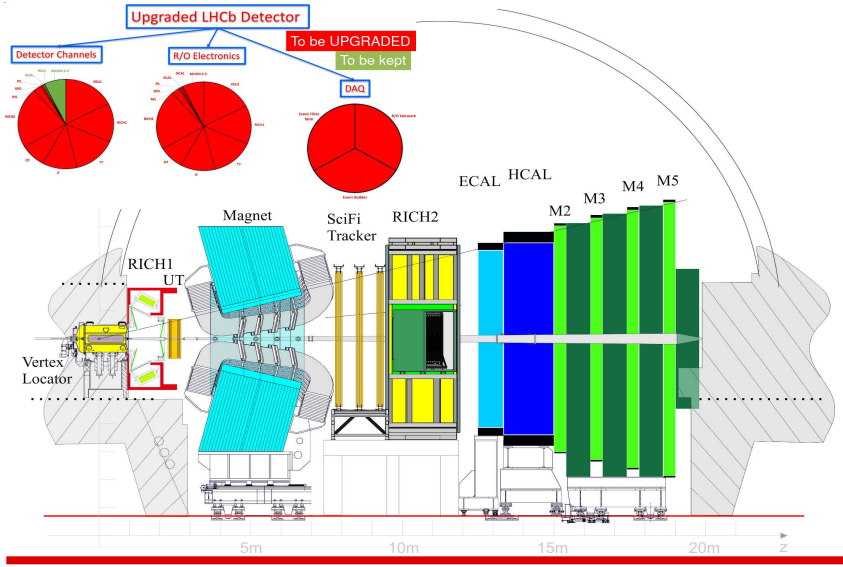


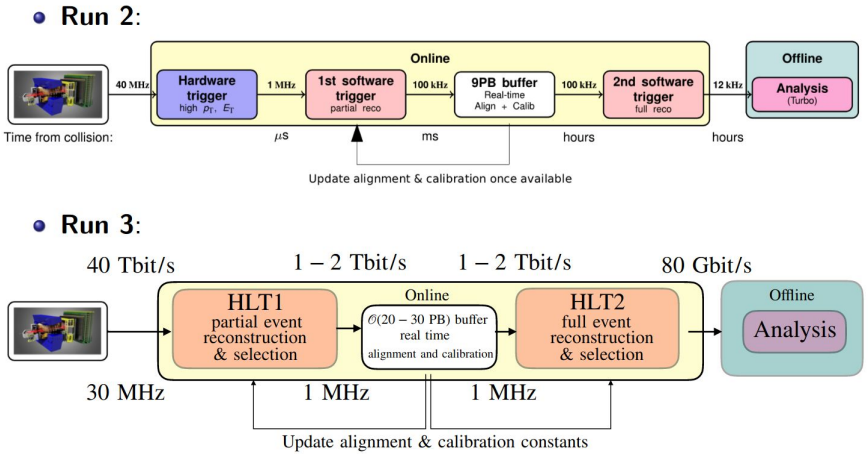
- Measurement **in advanced status** with signal selection, efficiencies evaluation and studies for the systematic uncertainties ongoing
- Ratio between the results and the available prompt cross-section measurement will be compared to the previous approach

The SMOG2 upgrade

The LHCb Upgrade - overview

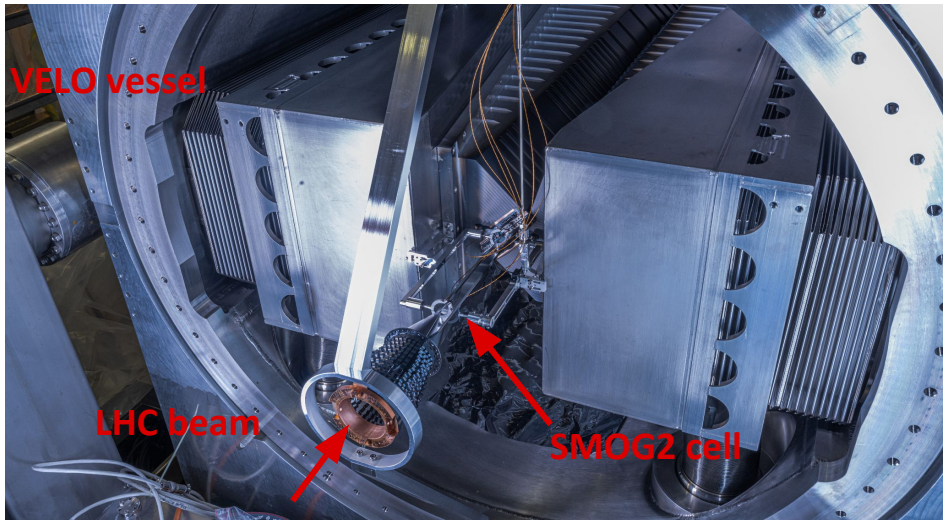
- LHCb is currently facing **a major upgrade**, *de facto* **a brand-new experiment**
- The hardware trigger level will be removed and the **full detector read-out, calibration and alignment and event selection will be in real time**
- **The first software trigger level will completely run on GPUs**, a novelty in large experiments





The SMOG2 Upgrade

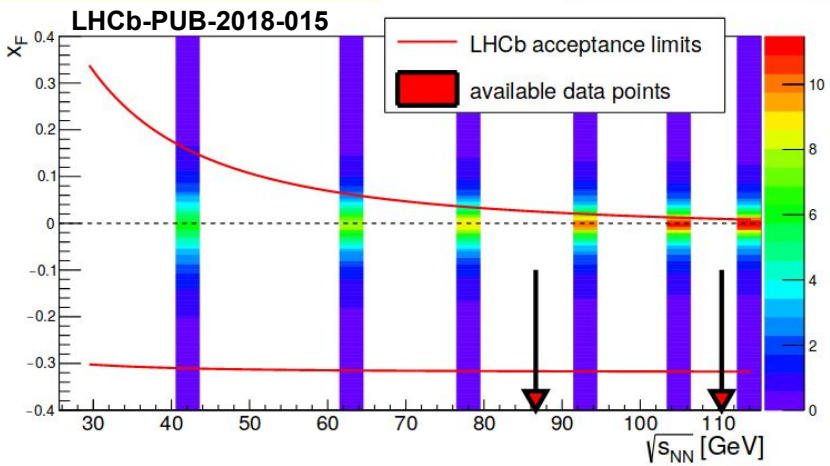
- From Run3 **the gas will be confined** in a cell covering z ϵ [-500, -300] mm, allowing to **inject a x100 gas pressure** with the same SMOG flow and to **also inject non-noble gases** (H_2 , D_2...)
- **A new Gas Feed System with 4 gas bottles** allows a fast gas replacement (to evaluate ratios) and to measure the *pgas* luminosity, mitigating the dominant experimental uncertainty



- The project, proposed, developed and installed by Ferrara, Florence and Frascati INFN units together with CERN expert, **mostly speaks italian**

Physics opportunities with SMOG2

- SMOG2 expected increase in collected statistics and wider gas choice opens a rich physics program of heavy ion (sequential suppression, Drell-Yan, photoproduction) and QCD (detailed studies of the quark and gluon pdfs) interest (LHCb-PUB-2018-015)
- For the completion of the LHCb space mission:



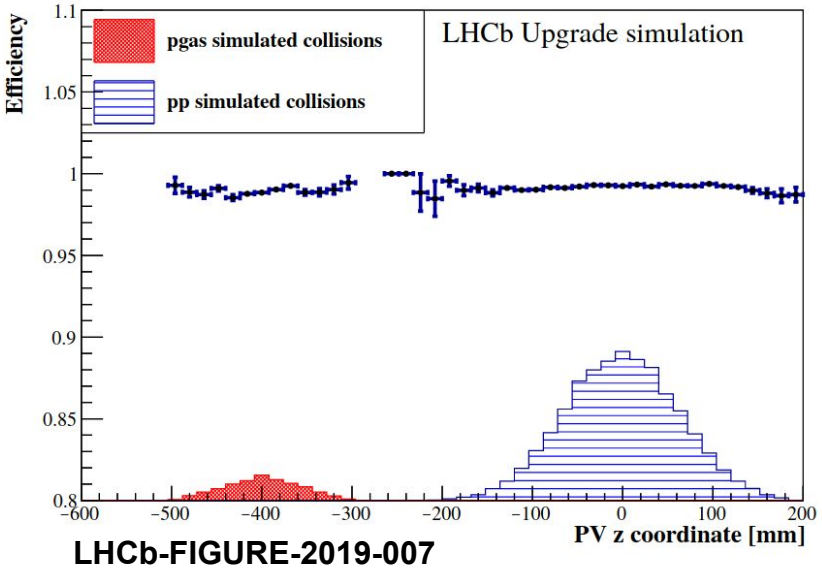
- Widening of the covered CM energy range
- Measuring the *H*/*He* antiproton production ratio most systematics will cancel, improving the result precision
- With deuterium and hydrogen, the *D*/*H* ratio will constrain the antiproton production in antineutron decays (**isospin violation**?)
- Possible to study anti-nuclei production?

Preparation to SMOG2 data-taking in Run3

- The collected statistics could profit from a **simultaneous pp-SMOG2 data-taking**:
  - SMOG2 collisions caused by the LHC beam crossing the cell and confined within the cell, displaced wrt *pp* luminous region
  - SMOG2 expected rate of collision, gas and pressure dependent, is of 0.3 collisions per-bunch and typical detector occupancy is much lower wrt *pp*

- To investigate its feasibility, ongoing studies are aimed at:
  - Testing and tuning the Run3 reconstruction algorithms **asking efficient reconstruction for SMOG2 events**, whose characteristics largely differ from *pp* (lower tracks radial aperture, higher tracks pseudorapidity, lower PVs multiplicities…)
  - **Checking that the *pp* performance is not degraded** when adding the gas
  - **Evaluating the timing requirements** for SMOG2 data reconstruction and selection, which need to cope with the strict constraints posed by the hardware trigger removal

Preliminary results for tracking efficiency



LHCb-FIGURE-2019-007

- **Clear distinction** between SMOG2 and *pp*
- **Similar performance for *pp* and SMOG2** obtained for tracks and vertex reconstruction
- By comparing simulated samples with only *pp* and with *pp*+SMOG2 collisions, **no *pp* efficiency degradation** observed
- By comparing samples with *pp+pHe* and *pp+pAr*, **no relevant differences observed**
- **Processing bandwidth decreases by few percents** when adding the gas to *pp*

- Results are preliminary, but **no showstopper observed so far**
- **LHCb could be the first detector at the LHC running in parallel in collider and fixed-target mode!**

Conclusions

Conclusions

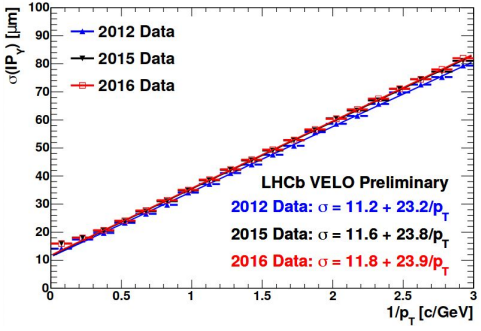
- Employing its detector geometry and excellent performance and the gas injection in the LHC accelerator, the LHCb experiment is developing a **pioneering fixed-target program** in parallel to the core flavour-physics analyses
- The LHCb-SMOG **first measurement of the antiproton production in *pHe*** is contributing to improve the **cosmic rays propagation modelling** in the **Dark Matter indirect searches**
- The extension of the cosmic call to LHCb is ongoing **measuring the antiproton production in anti-hyperon decays** and mitigating the experimental limitations
- The installation of a confinement cell for the gas will allow to **increase the gas pressure by a factor 100 and to widen the choice of gases** that can be injected
- Preliminary results for the preparation to Run3 data acquisition indicate that **LHCb could be the first LHC detector running in collider and fixed-target mode at the same time!**

Thanks for your attention!

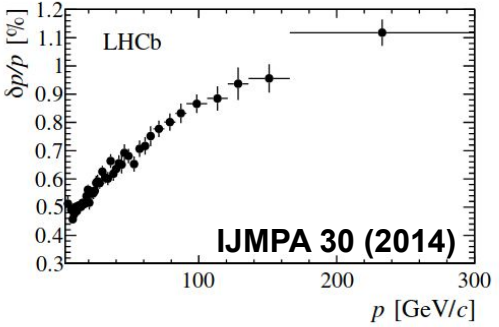
Further questions? saverio.mariani@cern.ch

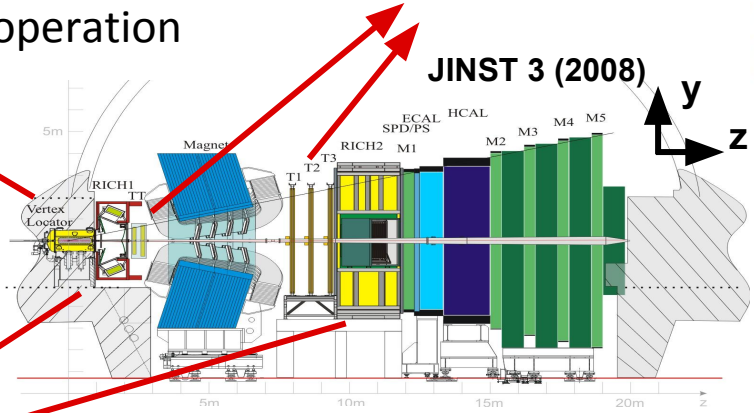
The LHCb detector (II)

- **VELO**: excellent **vertices and IP resolutions**. Made of **two opening halves** to increase the sensors distance from the beam (7 mm for data-taking) during machine operation

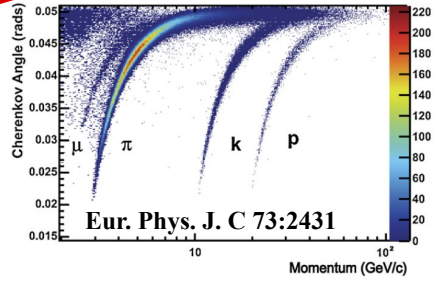


- **Tracking system**: momentum resolution **between 0.5 and 1.1%.**





- **RICH**: excellent **separation** among kaons, pions and protons with a momentum.



- Flexible and versatile **trigger system**.