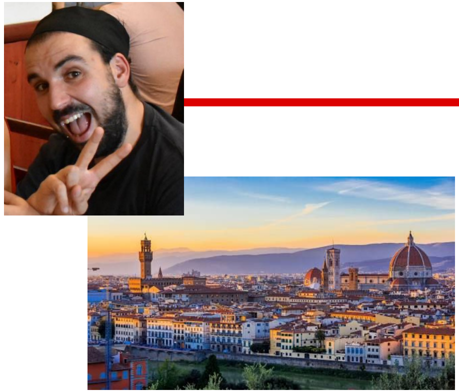
Fixed-target physics with the LHCb experiment at CERN

Saverio Mariani
Senior research fellow at CERN

Dortmund, 15.06.2023

Who am I



UNIVERSITÀ
DEGLI STUDI
FIRENZE

DOTTORATO DI RICERCA IN
Fisica e Astronomia

CICLO XXXIV

COORDINATORE Prof. Raffaello D'Alessandro

Fixed-target physics with the LHCb experiment at CERN

Settore Scientifico Disciplinare FIS/04

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Anni 2018/2021

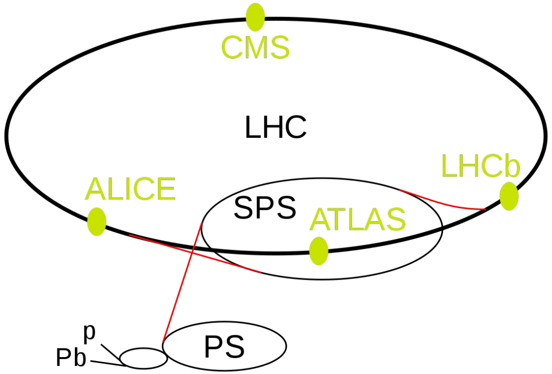
CERN-THESIS-2021-313
08/04/2022

- I was born in Florence and got there my Ph.D.
- I am now a **senior research fellow at CERN**

- I have been working on **fixed-target physics** at LHCb since 2019, mostly on three topics:
  - Antiproton production from anti-hyperon decays in *p*He (relevant for indirect DM searches)
  - Machine learning Particle IDentification calibration method for fixed-target data
  - Reconstruction/trigger sequence on upgraded fixed-target
- I am now convening the **"Ions and Fixed-target"** working group

- Will try to detail more these topics, but to give you all on overview of **LHCb unique fixed-target programme**

General overview (I)



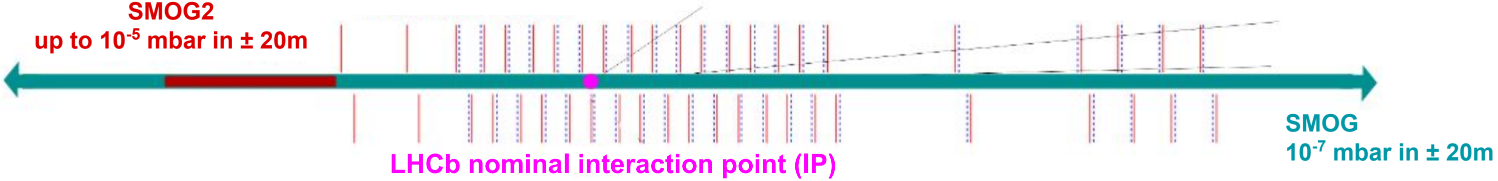
- **LHCb** is one of the experiments at the CERN LHC mostly studying proton and lead (*pp*, *p*Pb, PbPb) collisions

  and

  by injecting gases in LHC, **is also the only one acting as the highest-energy fixed-target beam-gas experiment ever**

LHCb- TDR-020, LHCb-PUB-2018-015

- The gas injection system, **SMOG,** was operated in 2011-2018 and is now upgraded to the **SMOG2 gas storage cell.** From 2022, **several gas species with x100 larger pressure** will be exploited



General overview (II)

- **SMOG/SMOG2 are unique laboratories for QCD studies at the LHC**, opening physics prospects unexpected and innovative at LHCb

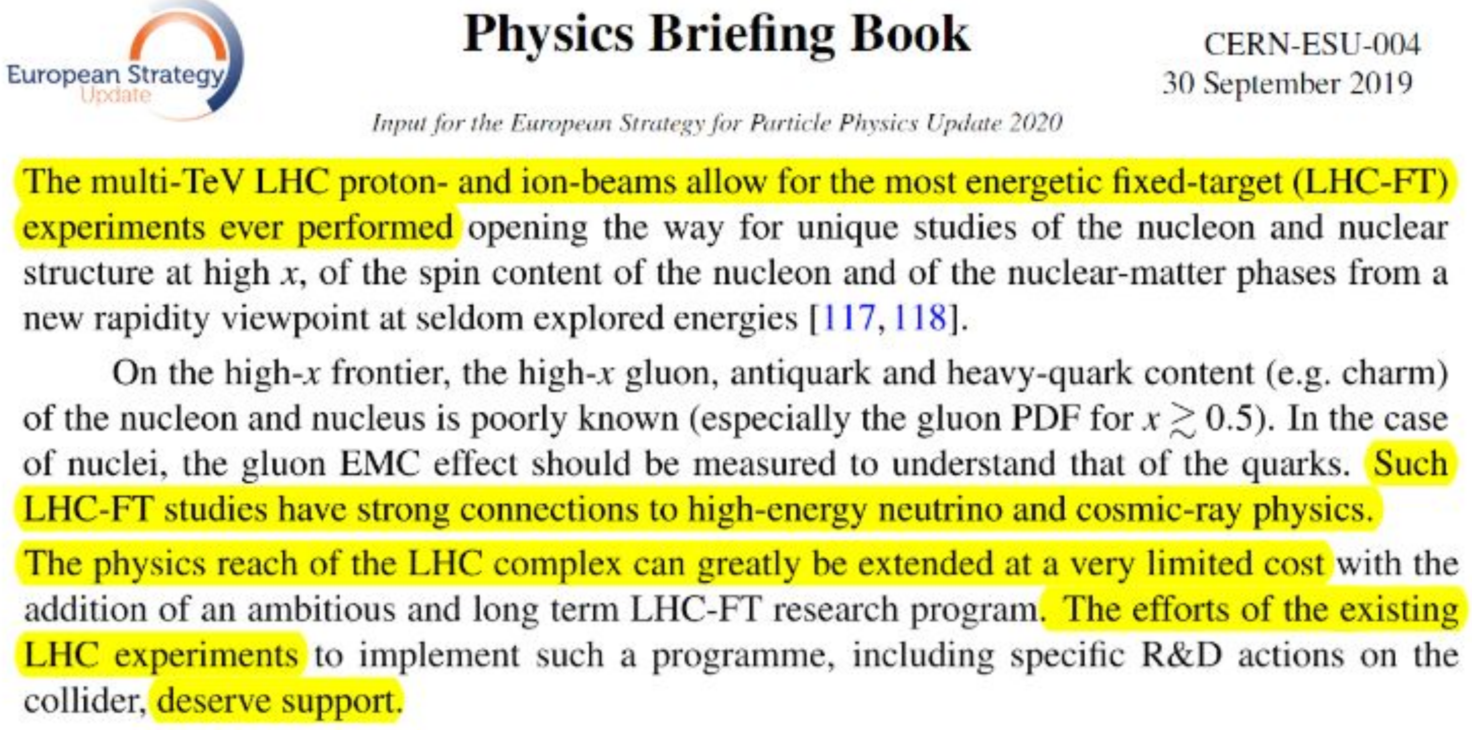
PRL 121 (2018)

- Already with 2016 data, $\sigma(p\mathrm{He} \to \bar{\mathrm{p}}_{\mathrm{prompt}}\mathrm{X})$ measurement gave birth to the **LHCb space mission,** with a rich programme of measurements that are **relevant for cosmic rays (CRs) physics** (antimatter production in the galaxy and DM indirect searches, neutrino studies, atmospheric CRs and muon puzzle…)
- At the same time, SMOG measurements are setting unique constraints on nucleon characterization, QGP phenomenology, cold nuclear matter effects …

- Today, of course, **a biased selection** of topics :)

General overview (III)

[Reference]



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.

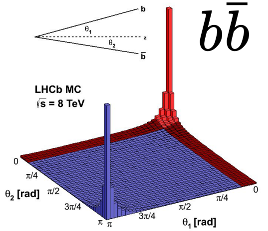
- Luckily, **we are not the only people thinking this way:)**

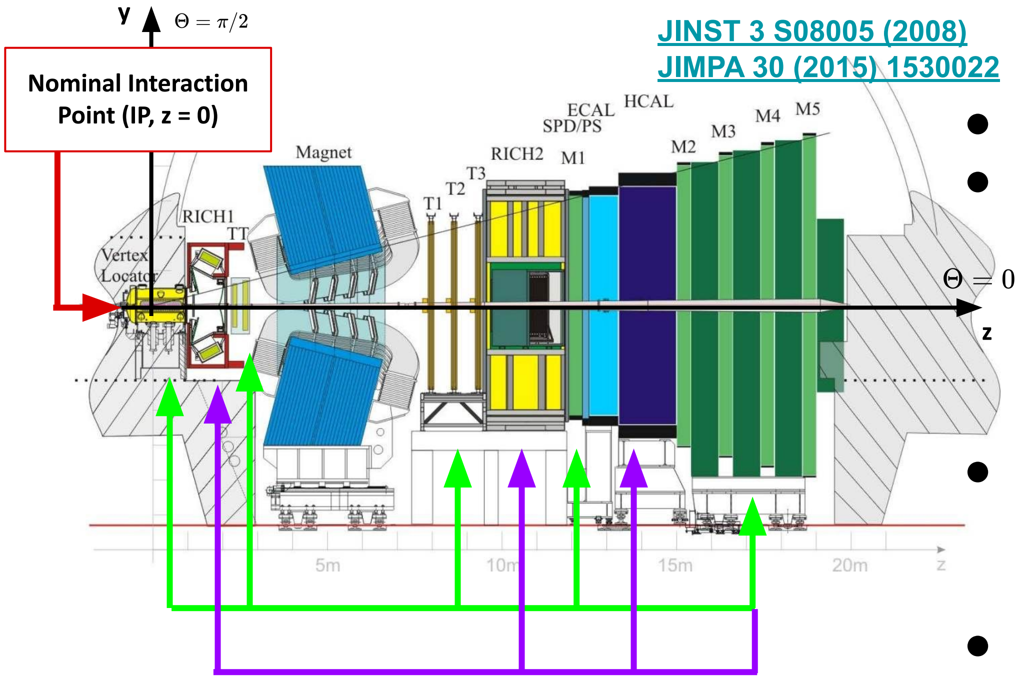
1

Introduction

The LHCb experiment, 2010-2018

- Originally designed for **heavy flavour physics**, the instrumented region covers $\Theta \in [10, 250]$ mrad to balance costs and acceptance of $b\bar{b}$ pairs



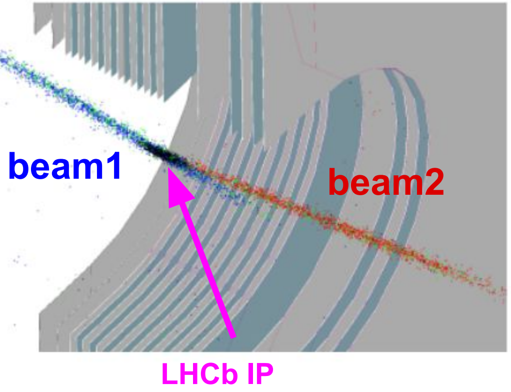


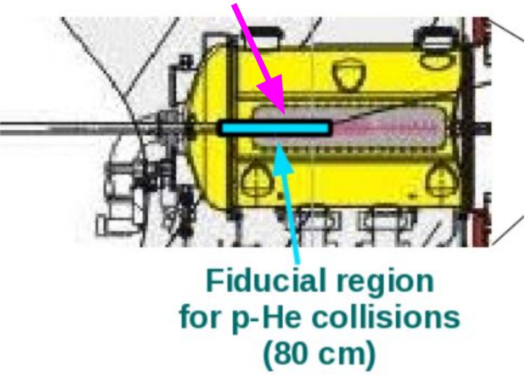
JINST 3 S08005 (2008)
JIMPA 30 (2015) 1530022

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

The gas injection system (SMOG)

JINST 9, (2014) P12005





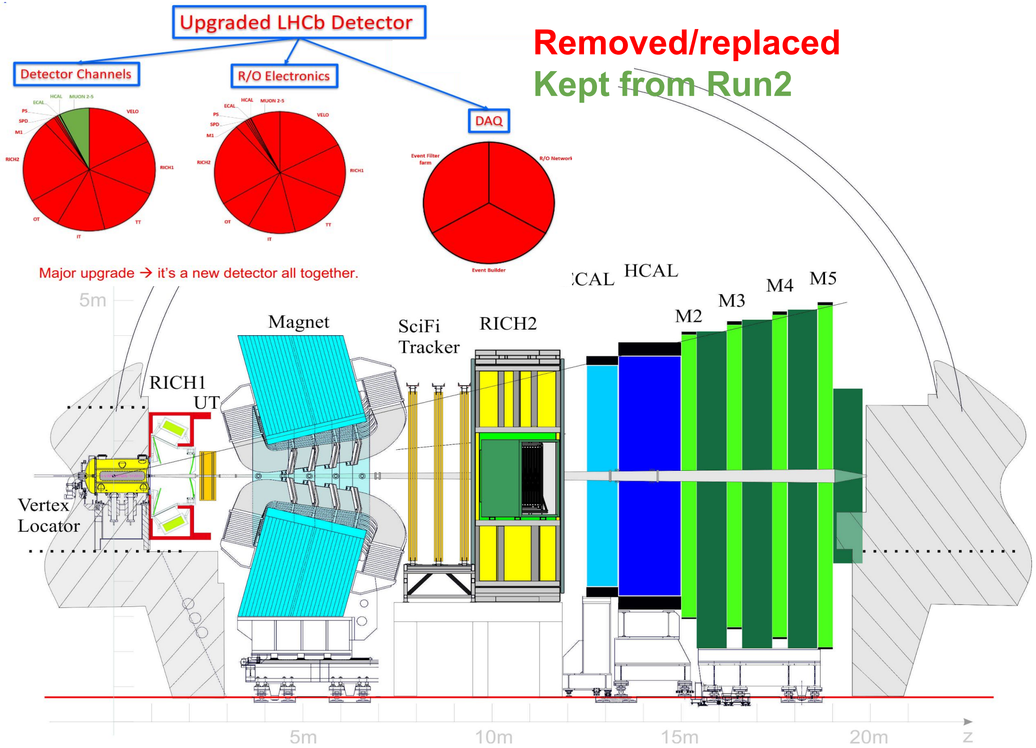
- Cross-section measurements require to precisely know the **luminosity** $\mathcal{L}$ of the LHC accelerator ($dN/dt = \mathcal{L} \cdot \sigma$)
- From 2011, also measured with the LHCb **System for Measuring Overlap with Gas (SMOG)**
  - Proton collisions with the small quantity of injected gas (10^{-7} mbar) used to reconstruct the **transverse profiles of the LHC beams**

- In proximity of the LHCb IP, **the proton-nucleus interaction can be fully reconstructed**!

- Forward detector + gas target = **highest-energy fixed-target ever!**

The LHCb experiment, now!

- Most detectors replaced. *De facto* **a brand new experiment at the LHC**



Removed/replaced

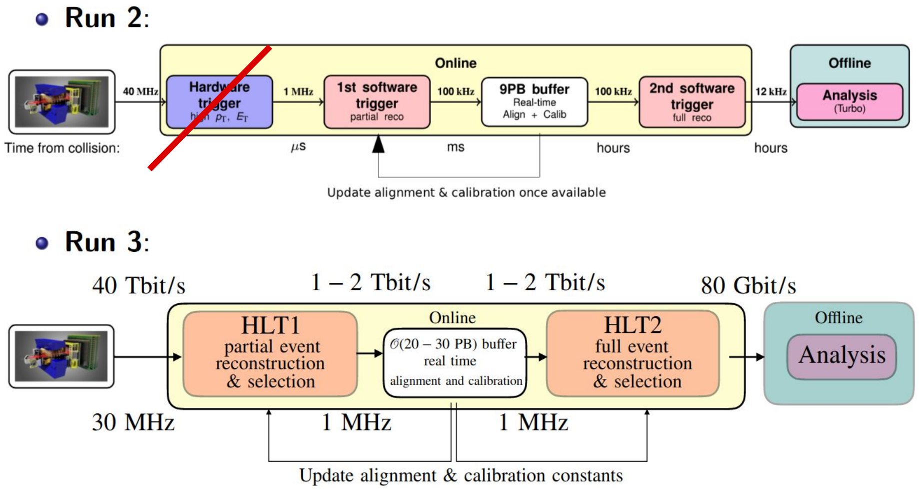
Kept from Run2

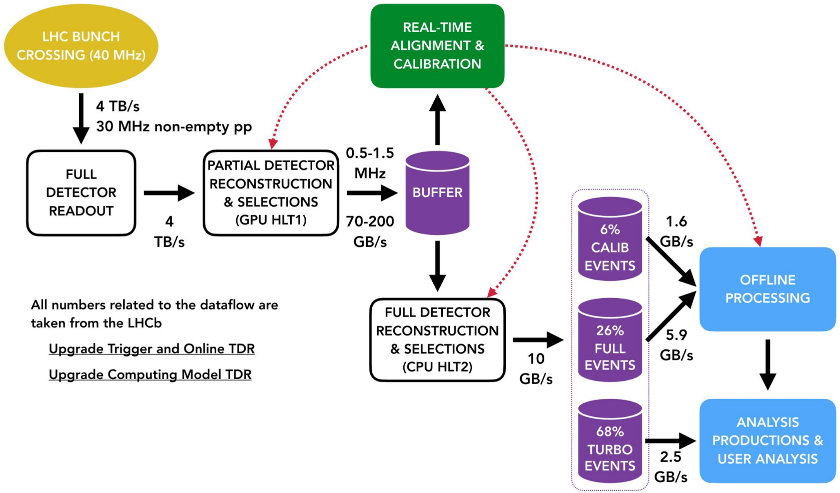
Major upgrade → it's a new detector all together.

The LHCb Upgrade data acquisition

- Hardware trigger removed. **Fully-software real-time detector read-out, calibration, alignment and event reconstruction and selection**
- **The first software trigger level will completely run on GPUs**, a novelty in large experiments

LHCb-TDR-017, LHCb-TDR-021, Comp Softw Big Sci 4, 7



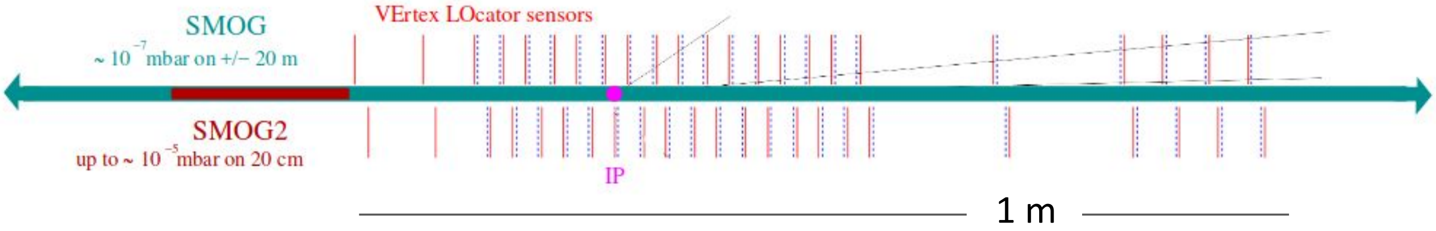


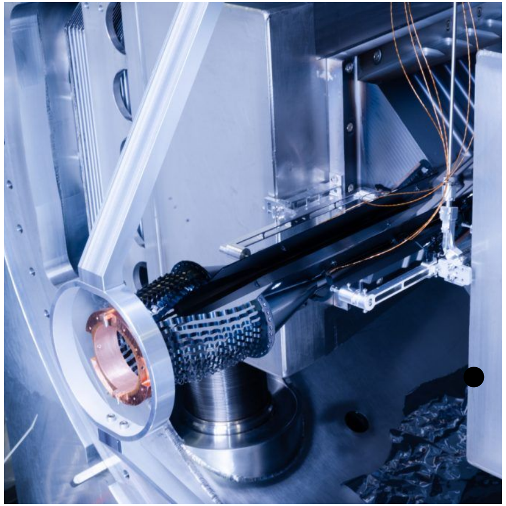
All numbers related to the dataflow are taken from the LHCb

Upgrade Trigger and Online TDR

Upgrade Computing Model TDR

The SMOG2 Upgrade - overview





- **SMOG2: confinement of the gas in a cell made up of two movable halves upstream of the LHCb IP** (z є [-541, -341] mm)
  - ○ Up to x100 gas **pressure wrt SMOG for the same gas flow**
  - ○ **Heavy noble (Kr, Xe) and non-noble gases (H_2, D_2, O_2, N_2 …)** can be injected → **extension of the physics programme**!

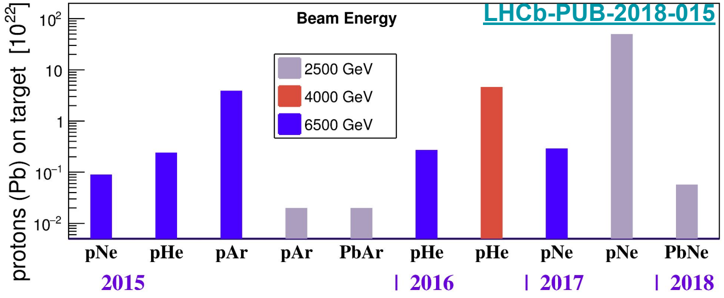
- **New Gas Feed System**
  - ○ Precise gas flow control → **direct luminosity measurement**
  - ○ More gas recipients → **full switch with no intervention**

2

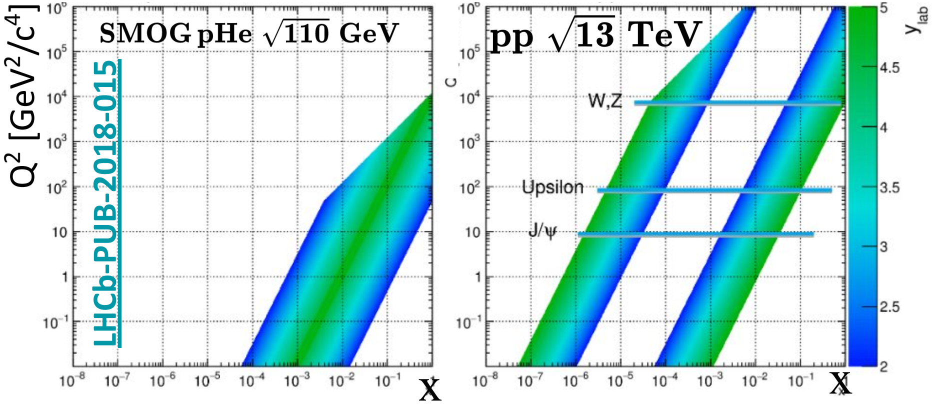
Measurement on Run2 data

SMOG kinematic coverage

- pA and PbA fixed-target samples **collected** (mostly) **during special runs in 2015-2018**



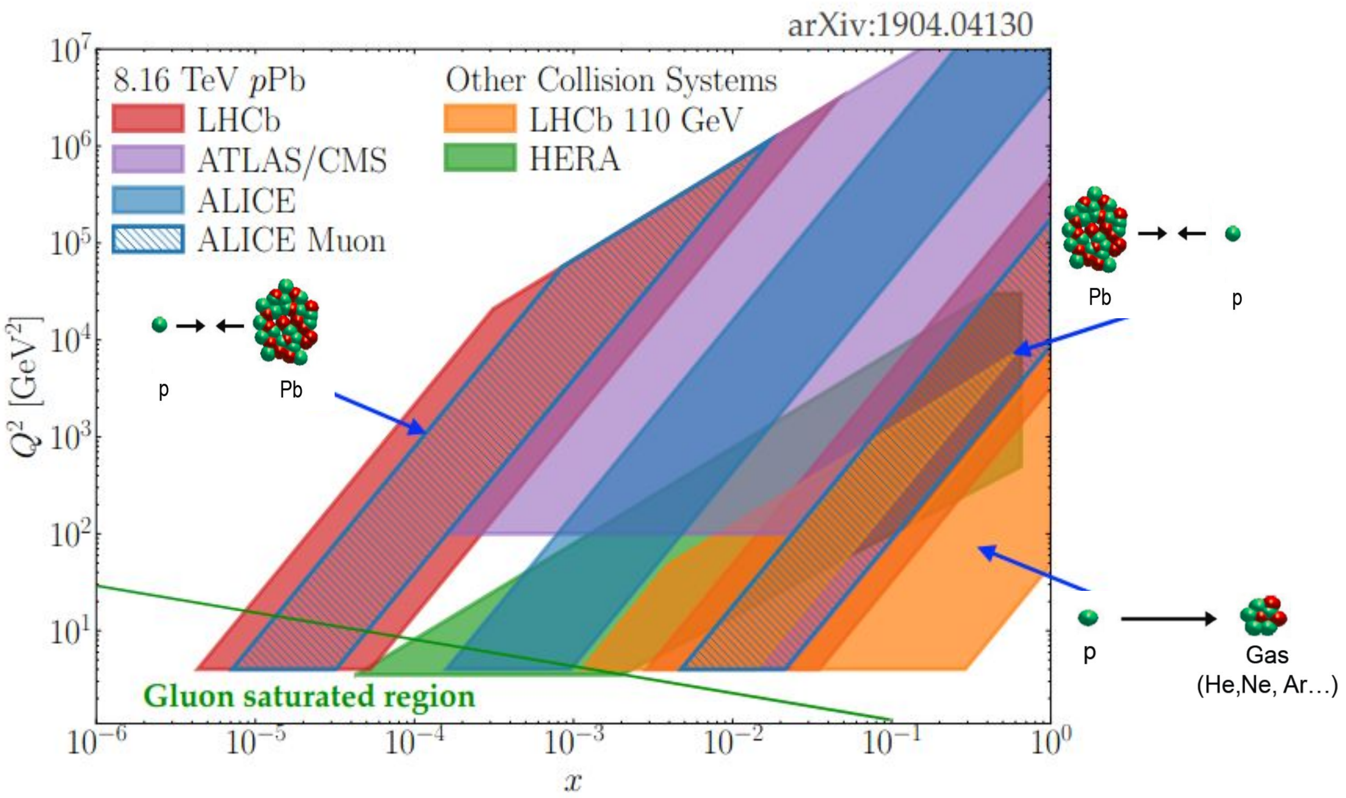
e.g. 6.5 TeV LHC protons on at-rest He correspond to a nucleon-nucleon centre-of-mass energy $\sqrt{s_{\mathrm{NN}}}$ =110 GeV



- **Intermediate energy** to SpS and LHC scales
- Many collision systems (Z dependence)
- **Access to the moderate Q^2 and large target Bjorken-x** (the nucleon momentum fraction carried by the colliding parton) region

→ **Unique experimental inputs**

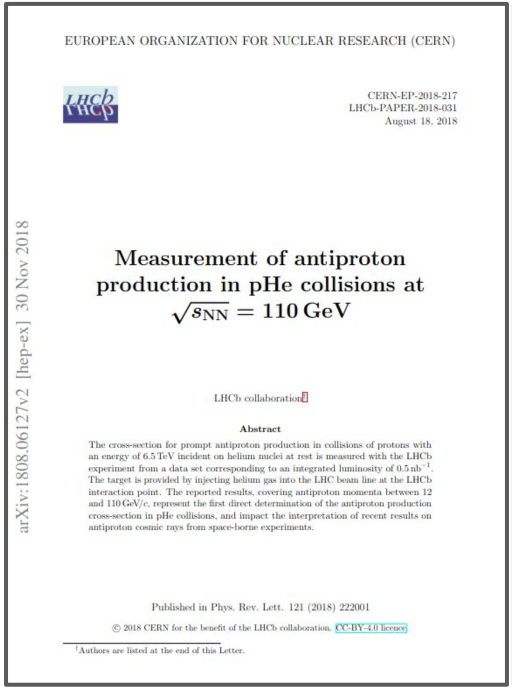
SMOG kinematic coverage (II)



… especially when compared to other experiments

2a

Physics case: antiproton production in the galaxy



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2018-217
LHCb-PAPER-2018-031
August 18, 2018

arXiv:1808.06127v2 [hep-ex] 30 Nov 2018

Measurement of antiproton production in pHe collisions at $\sqrt{s_{\mathrm{NN}}} = 110\,\mathrm{GeV}$

LHCb collaboration[†]

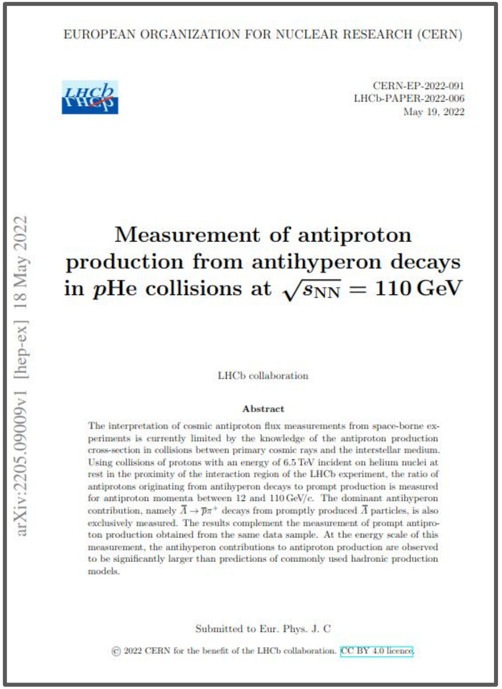
Abstract

The cross-section for prompt antiproton production in collisions of protons with an energy of 6.5 TeV incident on helium nuclei at rest is measured with the LHCb experiment from a data set corresponding to an integrated luminosity of $0.5\,\mathrm{nb}^{-1}$. The target is provided by injecting helium gas into the LHC beam line at the LHCb interaction point. The reported results, covering antiproton momenta between 12 and 110 GeV/c, represent the first direct determination of the antiproton production cross-section in pHe collisions, and impact the interpretation of recent results on antiproton cosmic rays from space-borne experiments.

Published in Phys. Rev. Lett. 121 (2018) 222001

[†] Authors are listed at the end of this Letter.

PRL 121 222001 (2018)



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2022-091
LHCb-PAPER-2022-006
May 19, 2022

arXiv:2205.09009v1 [hep-ex] 18 May 2022

Measurement of antiproton production from antihyperon decays in pHe collisions at $\sqrt{s_{\mathrm{NN}}} = 110\,\mathrm{GeV}$

LHCb collaboration

Abstract

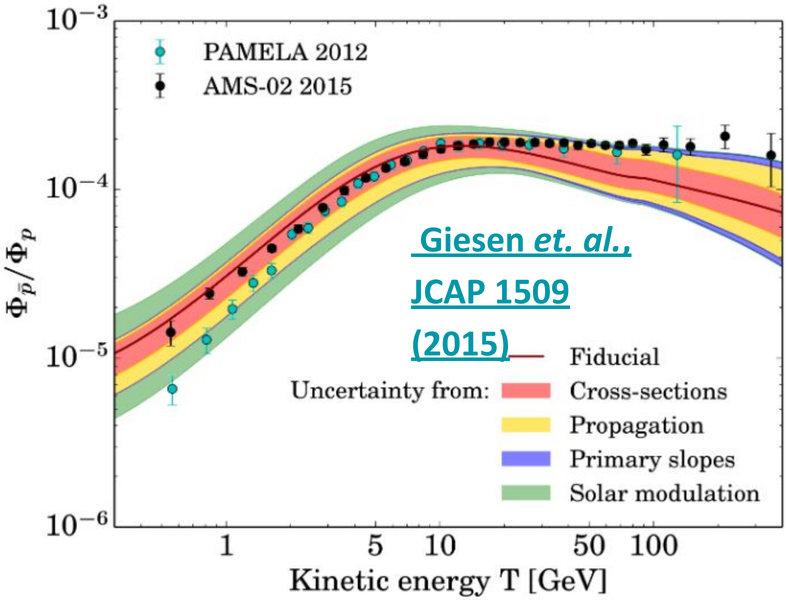
The interpretation of cosmic antiproton flux measurements from space-borne experiments is currently limited by the knowledge of the antiproton production cross-section in collisions between primary cosmic rays and the interstellar medium. Using collisions of protons with an energy of 6.5 TeV incident on helium nuclei at rest in the proximity of the interaction region of the LHCb experiment, the ratio of antiprotons originating from antihyperon decays to prompt production is measured for antiproton momenta between 12 and 110 GeV/c. The dominant antihyperon contribution, namely $\overline{\Lambda} \to \overline{p}\pi^{+}$ decays from promptly produced $\overline{\Lambda}$ particles, is also exclusively measured. The results complement the measurement of prompt antiproton production obtained from the same data sample. At the energy scale of this measurement, the antihyperon contributions to antiproton production are observed to be significantly larger than predictions of commonly used hadronic production models.

Submitted to Eur. Phys. J. C

EPJC-22-05-151

Brief motivation

- Antiprotons in space can (could) be produced with two mechanisms:
    - **Cosmic rays - Interstellar Medium** (mostly H, He) collisions (secondary production)
    - Exotic sources, maybe **Dark Matter annihilation** in proton-antiproton?

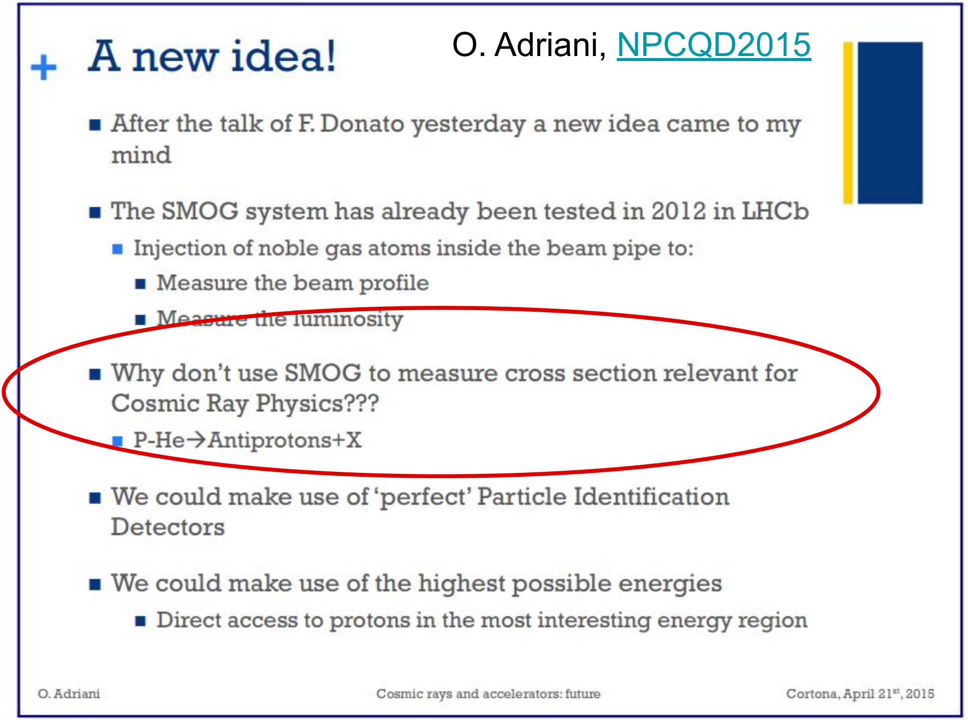


Giesen *et. al.*, JCAP 1509 (2015)

- In 2015, AMS-02 data compared to secondary only production gave **hint of an excess → DM?**
- **Inconclusive interpretation** because of the large uncertainties affecting the fiducial prediction:
    - Primary CRs energy spectrum
    - CRs propagation up to detection
    - Antiproton production cross-sections
    - Solar modulation effect

Experimental inputs for the cross-section estimation

- 2015 prediction only relied on few data for $\sigma(pp \to \bar{p}X)$ and **no data at all for the channels involving helium** (estimated from *pp* or *p*C data)



O. Adriani, NPCQD2015

+ A new idea!

- After the talk of F. Donato yesterday a new idea came to my mind
- The SMOG system has already been tested in 2012 in LHCb
  - Injection of noble gas atoms inside the beam pipe to:
    - Measure the beam profile
    - Measure the luminosity
- Why don't use SMOG to measure cross section relevant for Cosmic Ray Physics???
  - P-He→Antiprotons+X
- We could make use of 'perfect' Particle Identification Detectors
- We could make use of the highest possible energies
  - Direct access to protons in the most interesting energy region

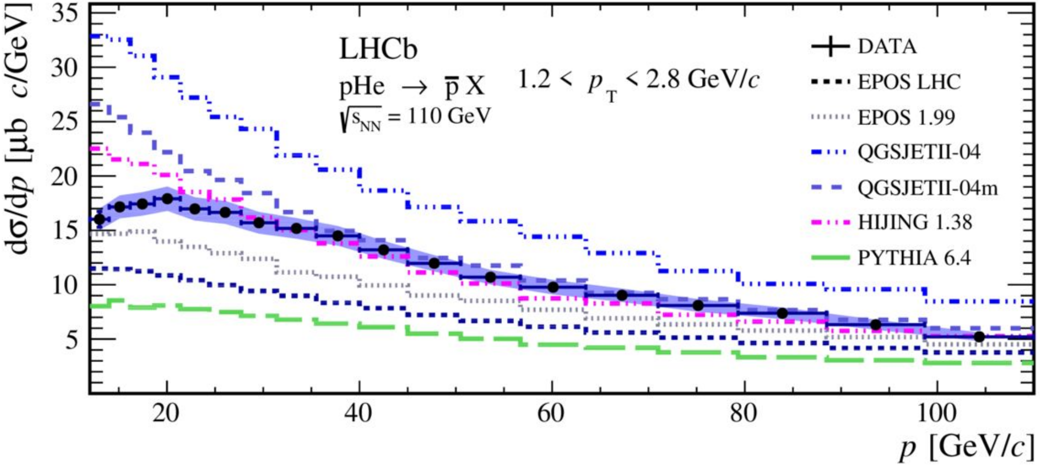
O. Adriani Cosmic rays and accelerators: future Cortona, April 21st, 2015

- Why not to exploit **the LHCb SMOG system to measure for the first time** the antiproton production in *p*He collisions?

Prompt antiproton production in *p*He (I)

PRL 121 222001 (2018)

- **First measurement ever** of $\sigma(p\text{He} \rightarrow \bar{\text{p}}_{\text{prompt}}\text{X})$ at $\sqrt{s_{\text{NN}}} = 110$ GeV with 2016 *p*He data
- Only particles **produced promptly at the *p*He vertex** are selected within the fiducial region *p* ϵ [12, 110] GeV/c; $p_{\text{T}} = \sqrt{\text{p}_{\text{x}}^2 + \text{p}_{\text{y}}^2}$ ϵ [0.4, 4] GeV/c



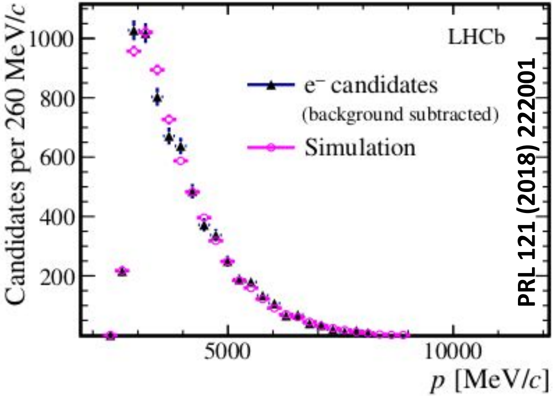
- Result uncertainties are **lower wrt to the spread of theoretical models**

Prompt antiproton production in *p*He (II)

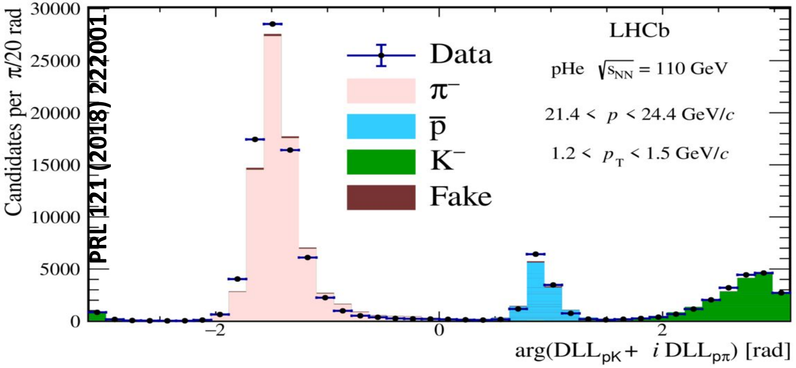
PRL 121 222001 (2018)

- Dominant uncertainties for this analysis are:

1. **Beam-gas luminosity measurement:** being SMOG not equipped with precise enough gauges for the gas pressure, proton-electron elastic scattering used
    a. 6% uncertainty, due to low-p *e* reconstruction



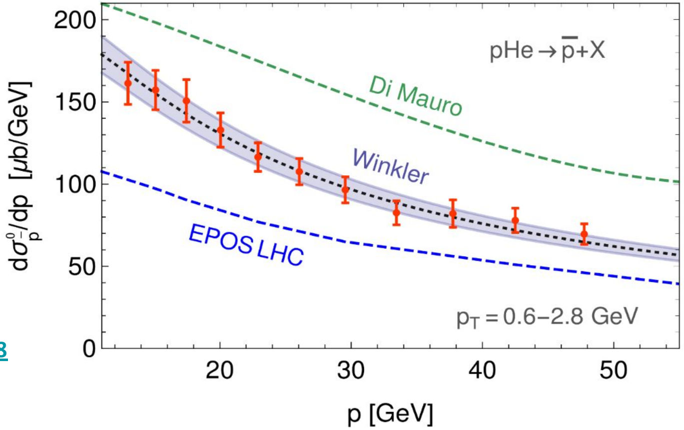
2. **PID performance:** antiprotons are counted via a template fit to selected prompt particles
    a. Poor PID calibration statistics ⇒ poor quality in describing data
    b. Impossible to use pp calibration because of scarce phase-space overlap with *p*He



Impact on the theoretical models

- **LHCb data** firstly constrain the σ extrapolation **from H to He at high energies** A. Reinert et. al., JCAP 1801 (2018) 055 M. Korsmeier et. al., PRD97 (2018) 103019
- With LHCb (+ NA61 + theoretical improvements) room for exotic contribution **drastically reduced**
- **Uncertainty still dominated by cross-section**, in particular because of: A. Cuoco et. al., PRD 99, 103014 M. Boudaud et. al., PoS (ICRC2019) 038

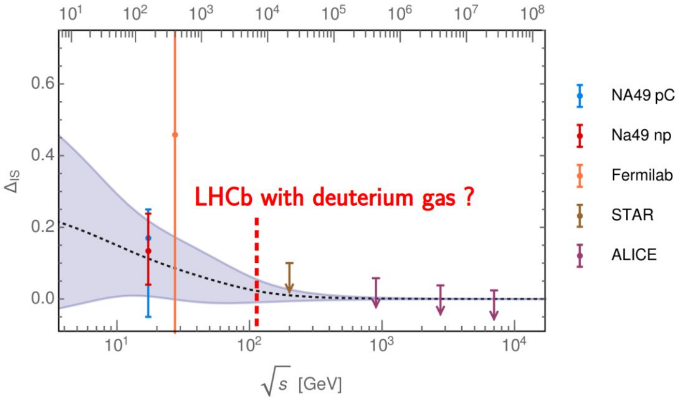
$$\sigma_{inv} = \sigma^0_{inv}(2 + \Delta_{IS} + 2\Delta_{\bar{\Lambda}})$$



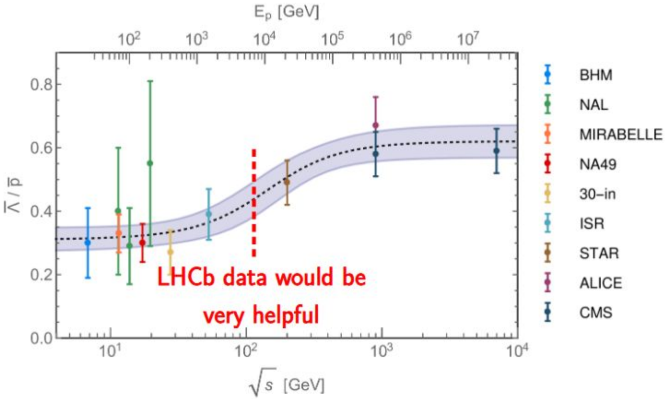
Isospin asymmetry in antineutron-to-antiproton?

Antiproton production from anti-hyperon decays

Martin Winkler



LHCb with deuterium gas ?



LHCb data would be very helpful

Measurement of detached antiproton production in *p*He

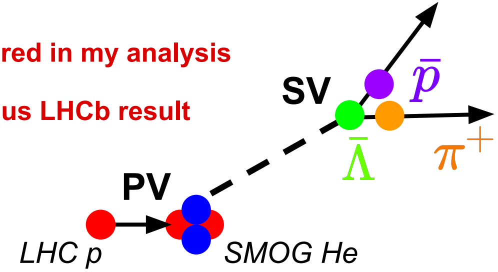
- Second LHCb result covering with two approaches $\bar{p}$ **from anti-hyperon decays** (detached)

$$\bar{\Lambda}^0_{\text{prompt}} \to \bar{p}\pi^+ \qquad \bar{\Sigma}^- \to \bar{p}\pi^0 \qquad \bar{\Xi}^+ \to \bar{\Lambda}\pi^+ \qquad \bar{\Xi}^0 \to \bar{\Lambda}\pi^0 \qquad \bar{\Omega}^+ \to \bar{\Lambda}K^+$$

- **Exclusive approach**: $R_{\bar{\Lambda}} = \dfrac{\sigma(p\text{He} \to (\bar{\Lambda}_{\text{prompt}} \to \bar{p}\pi^+)X)}{\sigma(p\text{He} \to \bar{p}_{\text{prompt}}\, X)}$

  → **measured in my analysis**

  → **previous LHCb result**

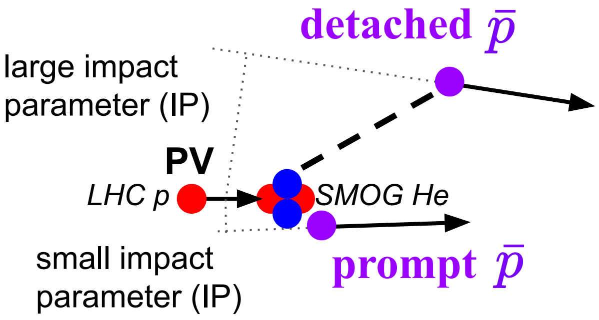


  - ➔ Focused on the **dominant detached component**
  - ➔ **Not using PID** information

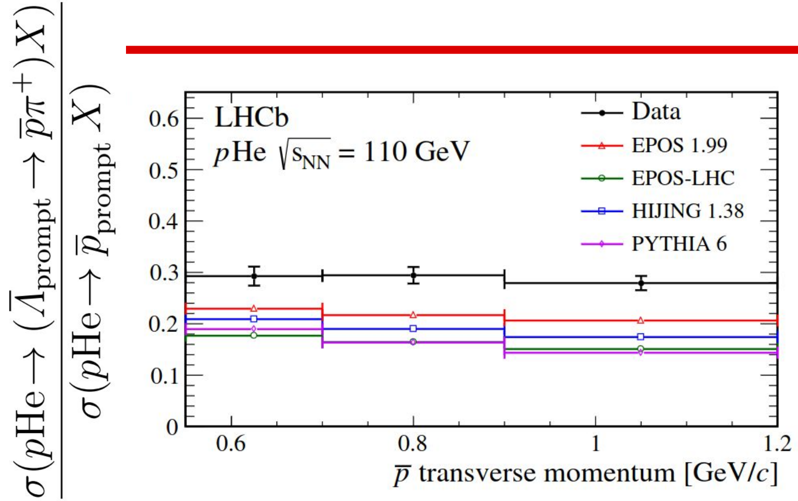
- **Inclusive approach**: $R_{\bar{H}} \equiv \dfrac{\sigma(p\text{He} \to \bar{H}X \to \bar{p}X)}{\sigma(p\text{He} \to \bar{p}_{\text{prompt}}X)}$

$$\bar{H} = \bar{\Lambda}, \bar{\Sigma}, \bar{\Xi}, \bar{\Omega}$$

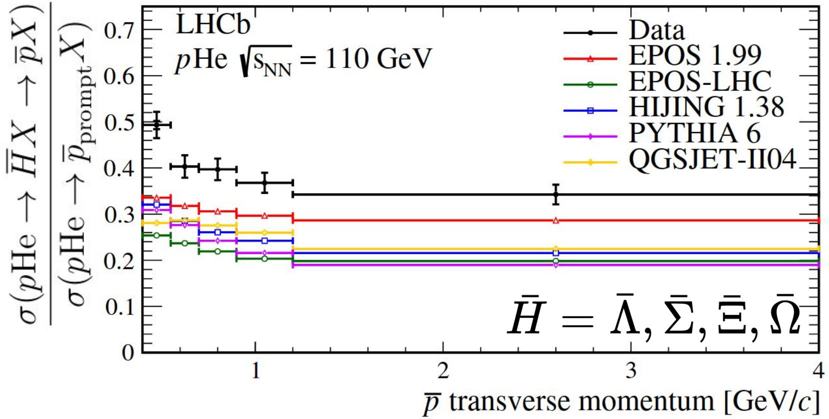
  - ➔ Focused on all **detached components**
  - ➔ **Selecting antiproton with PID** information and distinguishing between prompt and detached via the **excellent VELO IP resolution**

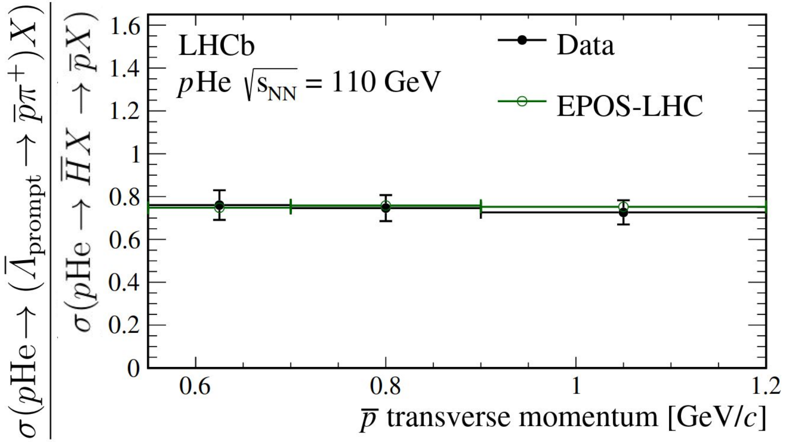


Results



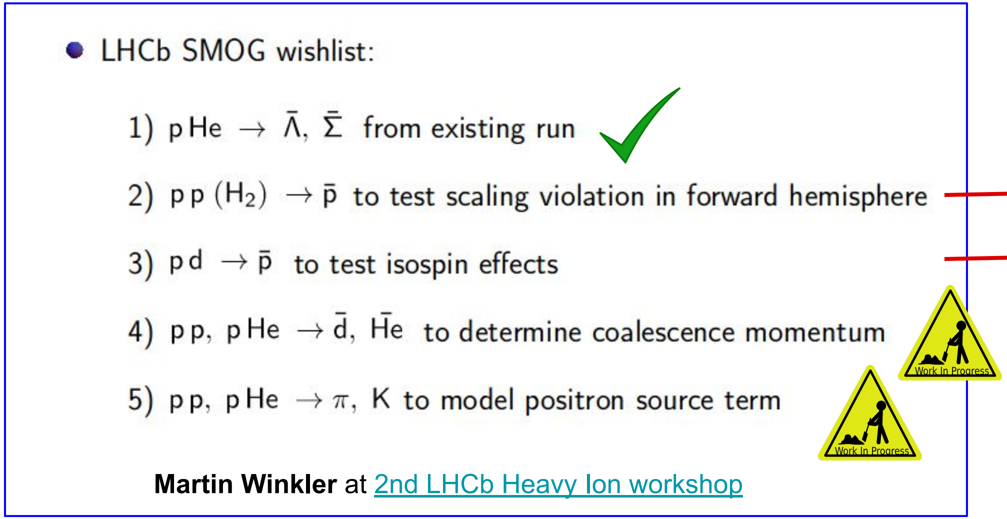
- **Larger contribution measured wrt all most widely used theoretical models**
- Results mutually cross-checked since ratio found to be **consistent with EPOS-LHC prediction** (more reliable being only depending on hadronization)





Prospects for this physics case

- Our data are resulting to be very important for theoreticians of the field



- LHCb SMOG wishlist:

1) $\mathrm{p\,He} \to \bar{\Lambda}, \bar{\Sigma}$ from existing run ✓

2) $\mathrm{p\,p\,(H_2)} \to \bar{\mathrm{p}}$ to test scaling violation in forward hemisphere

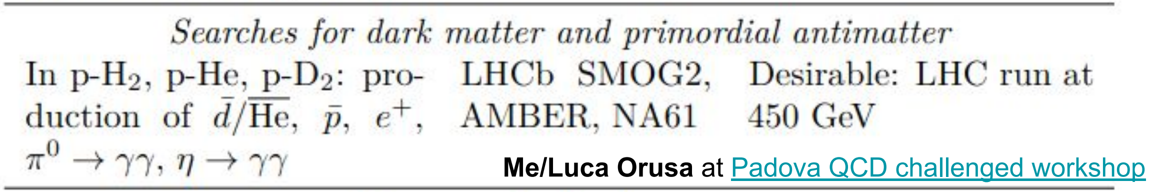
3) $\mathrm{p\,d} \to \bar{\mathrm{p}}$ to test isospin effects

4) $\mathrm{p\,p,\ p\,He} \to \bar{\mathrm{d}}, \overline{\mathrm{He}}$ to determine coalescence momentum

5) $\mathrm{p\,p,\ p\,He} \to \pi, \mathrm{K}$ to model positron source term

Martin Winkler at 2nd LHCb Heavy Ion workshop

SMOG2

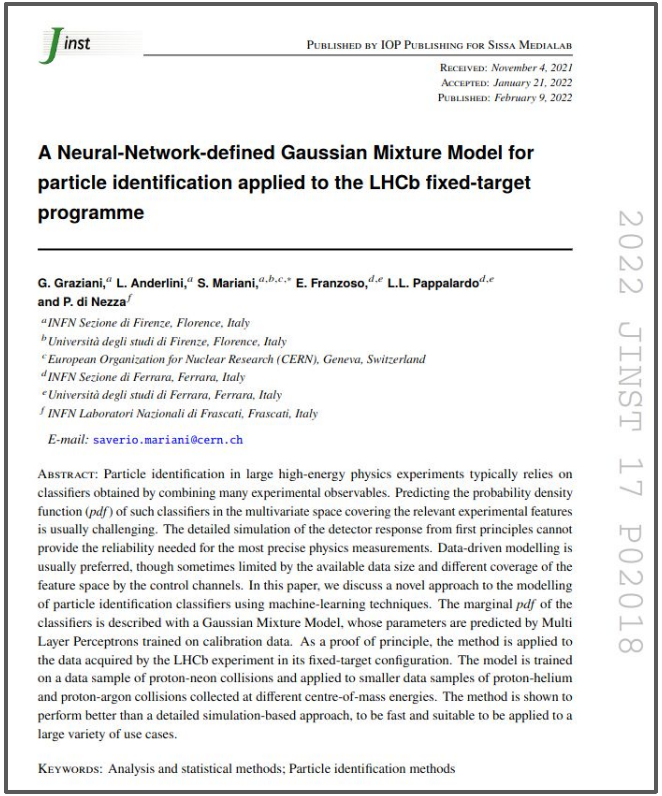


Searches for dark matter and primordial antimatter

In p-H_2, p-He, p-D_2: production of $\bar{d}/\overline{\mathrm{He}}$, $\bar{p}$, e^+, $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$	LHCb SMOG2, AMBER, NA61	Desirable: LHC run at 450 GeV

Me/Luca Orusa at Padova QCD challenged workshop

2b



JINST

Published by IOP Publishing for Sissa Medialab

Received: *November 4, 2021*
Accepted: *January 21, 2022*
Published: *February 9, 2022*

A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme

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Abstract: Particle identification in large high-energy physics experiments typically relies on classifiers obtained by combining many experimental observables. Predicting the probability density function (*pdf*) of such classifiers in the multivariate space covering the relevant experimental features is usually challenging. The detailed simulation of the detector response from first principles cannot provide the reliability needed for the most precise physics measurements. Data-driven modelling is usually preferred, though sometimes limited by the available data size and different coverage of the feature space by the control channels. In this paper, we discuss a novel approach to the modelling of particle identification classifiers using machine-learning techniques. The marginal *pdf* of the classifiers is described with a Gaussian Mixture Model, whose parameters are predicted by Multi Layer Perceptrons trained on calibration data. As a proof of principle, the method is applied to the data acquired by the LHCb experiment in its fixed-target configuration. The model is trained on a data sample of proton-neon collisions and applied to smaller data samples of proton-helium and proton-argon collisions collected at different centre-of-mass energies. The method is shown to perform better than a detailed simulation-based approach, to be fast and suitable to be applied to a large variety of use cases.

Keywords: Analysis and statistical methods; Particle identification methods

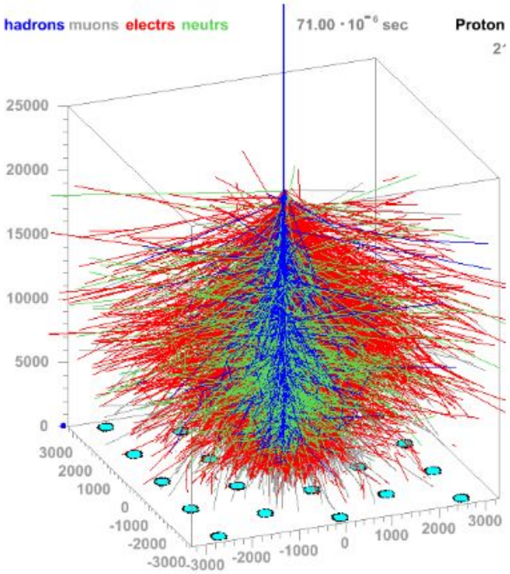
2022 JINST 17 P02018

JINST 17 (2022) P02018

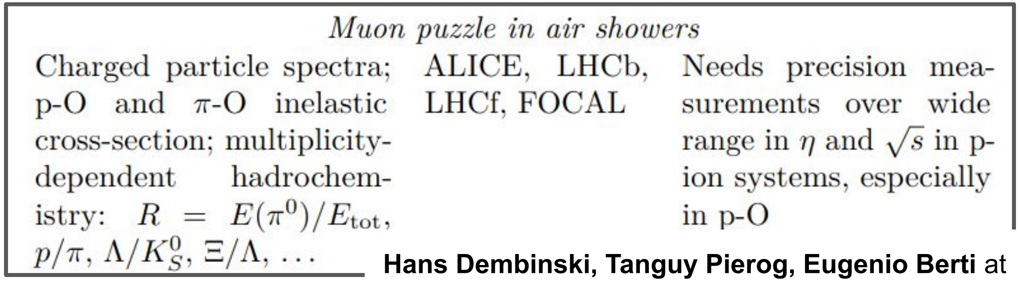
Physics case: prompt light particle production

Brief motivation

- Understanding the bulk of particle production, dominated by non-perturbative effects, is crucial to **model the underlying event at particle colliders**
- Models largely based on tuning on available data → SMOG/SMOG2 can provide crucial inputs, **filling the energy gap between SPS and LHC/RHIC**



- Also, understanding of ground-based measurements of ultra-high-energy cosmic rays are currently limited by **uncertainties in hadron production models**
- **Muon puzzle**: Significant deficit in muon production with respect to model [Astrophys.Space Sci. 367 (2022) 3, 27]

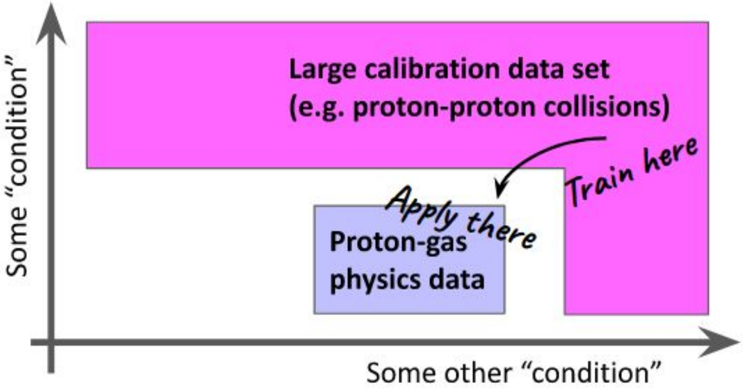


Muon puzzle in air showers		
Charged particle spectra; p-O and π-O inelastic cross-section; multiplicity-dependent hadrochemistry: $R = E(\pi^0)/E_{\mathrm{tot}}$, p/π, Λ/K^0_S, Ξ/Λ, ...	ALICE, LHCb, LHCf, FOCAL	Needs precision measurements over wide range in η and $\sqrt{s}$ in p-ion systems, especially in p-O

Hans Dembinski, Tanguy Pierog, Eugenio Berti at [Padova QCD challenged workshop]

Machine-learning PID (I)

- Non-public results on this yet, but measurements of different ratios ongoing for *p*He/*p*Ar/*p*Ne; pNe/PbNe on the available data
- Covering here the main challenge: **how to improve PID calibration** for fixed-target data?



- **Problem:** the simulation cannot be fully trusted, but we can **calibrate on decays** selected with no PID info and then apply to the signal of interest
- **How robust is the extrapolation**, provided that **the calibration and application phase-spaces differ**?

- For fixed-target, calibrating on $\Lambda \to p\pi\,(\bar{\Lambda} \to \bar{p}\pi)$, $K_s \to \pi\pi$ and $\phi(1020) \to KK$ decays reconstructed and selected in 2017 pNe data (the highest-statistics SMOG sample)

Machine-learning PID (II)

- At LHCb, classifiers are built with the RICH detector responses as $\mathrm{DLL}_{h1,h2} = log\left(\frac{\text{h1 likelihood}}{\text{h2 likelihood}}\right)$
- For each calibration decay, the ($\mathrm{DLL}_{p,\pi}$ - $\mathrm{DLL}_{p,K}$) distribution is modelled with **a sum of N_g multinormal distributions**:

PID classifiers

particle index

Number of Gaussians (user-defined)

Features affecting the RICH

$$\underline{x}_p \sim \sum_{j=1}^{N_{g,p}} \alpha_{j,p}(\underline{\theta}) \frac{\exp(-\frac{1}{2}(\underline{x}_p - \underline{\mu}_{j,p}(\underline{\theta}))^T \, \Sigma_{j,p}^{-1}(\underline{\theta}) \, (\underline{x}_p - \underline{\mu}_{j,p}(\underline{\theta})))}{2\pi\sqrt{\det(\Sigma_{j,p}(\underline{\theta}))}} \qquad \Sigma = \begin{bmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix}$$

  - For each Gaussian, all parameters are a function variables (θ) describing the particle produced in the collision (its kinematic, the reconstruction quality, the overall event occupancy..).
  - Such a relation is expressed through **neural-networks** fed with θ

⇨ $\underline{x}_p(\theta)$ **relation is the relation we need to be learned**

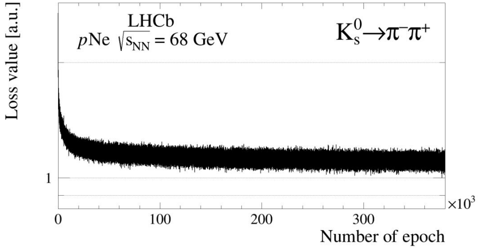
Machine-learning PID (II)

- Training loss is the **opposite of the likelihood** on *p*Ne calibration events

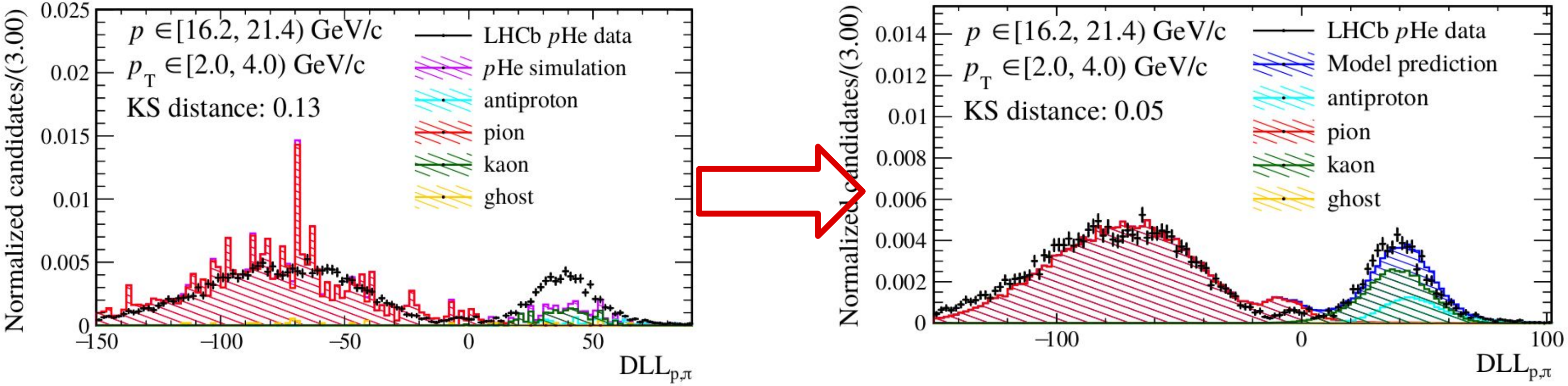
calibration events

$$\mathcal{L} = -\sum_{i=1}^{n_p} w_i \log\left[\sum_{j=1}^{N_{g,p}} \alpha_{j,p}(\underline{\theta}_i)\mathcal{G}(\underline{x}_i, \mu_{j,p}(\underline{\theta}_i), \sigma_{j,p}(\underline{\theta}_i))\right]$$

bkg subtraction weights (if any)



- By applying to *p*He data templates from **the simulation** (left) and from **machine-learning calibration trained on *p*Ne** data (right), the improvement is by-eye



2c

Physics case: Charm production

[PRL 122, 132002 (2019)](#)

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2018-266
03 October 2018

First measurement of charm production in fixed-target configuration at the LHC

LHCb collaboration[†]

Abstract

The first measurement of heavy-flavour production by the LHCb experiment in its fixed-target mode is presented. The production of J/ψ and D^0 mesons is studied with beams of protons of different energies colliding with gaseous targets of helium and argon with nucleon-nucleon centre-of-mass energies of $\sqrt{s_{\rm NN}} = 86.6$ and 110.4 GeV, respectively. The J/ψ and D^0 production cross-sections in pHe collisions in the rapidity range [2, 4.6] are found to be $\sigma_{J/\psi} = 652 \pm 33\,(\rm stat) \pm 42\,(\rm syst)$ nb/nucleon and $\sigma_{D^0} = 80.8 \pm 2.4\,(\rm stat) \pm 6.3\,(\rm syst)$ μb/nucleon, where the first uncertainty is statistical and the second is systematic. No evidence for a substantial intrinsic charm content of the nucleon is observed in the large Bjorken-x region.

Submitted to Phys. Rev. Lett.

[†] Authors are listed at the end of this paper.

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arXiv:2211.11645

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2022-216
LHCb-PAPER-2022-014
November 21, 2022

arXiv:2211.11645v1 [hep-ex] 21 Nov 2022

Charmonium production in pNe collisions at $\sqrt{s_{\rm NN}} = 68.5$ GeV

LHCb collaboration

Abstract

The measurement of charmonium states produced in proton-neon (pNe) collisions by
the LHCb experiment in its fixed-target configuration is presented. The production
of J/ψ and $\psi(2S)$ mesons is studied with a beam of 2.5 TeV protons colliding on
gaseous neon targets at rest, corresponding to a nucleon-nucleon centre-of-mass
energy $\sqrt{s_{\rm NN}} = 68.5$ GeV. The data sample corresponds to an integrated luminosity
of 21.7 ± 1.4 nb^{-1}. The J/ψ and $\psi(2S)$ hadrons are reconstructed i
states. The J/ψ production cross-section per target nucleon in the ce
rapidity range $y^* \in [-2.29, 0]$ is found to be $506 \pm 8 \pm 25$ nb/nucleon. T
J/ψ relative production rate is found to be $(1.67 \pm 0.27 \pm 0.10)\%$ in goo
with other measurements involving beam and target nuclei of similar

Submitted to Eur. Phys. J. C

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arXiv:2211.11633

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-EP-2022-217
LHCb-PAPER-2022-015
November 21, 2022

arXiv:2211.11633v1 [hep-ex] 21 Nov 2022

Open charm production and asymmetry in pNe collisions at $\sqrt{s_{\rm NN}} = 68.5$ GeV

LHCb collaboration

Abstract

A measurement of D^0 meson production by the LHCb experiment in its fixed-target configuration is presented. The production of D^0 mesons is studied with a beam of 2.5 TeV protons colliding on a gaseous neon target at rest, corresponding to a nucleon-nucleon centre-of-mass energy of $\sqrt{s_{\rm NN}} = 68.5$ GeV. The D^0 and $\overline{D}^0$ production cross-section in pNe collisions in the centre-of-mass rapidity range $y^* \in [-2.29, 0]$ is found to be $\sigma_{D^0}^{y^* \in [-2.29, 0]} = 48.2 \pm 0.3 \pm 4.5$ μb/nucleon where the first uncertainty is statistical and the second is systematic. The $D^0 - \overline{D}^0$ production asymmetry is also evaluated and suggests a negative trend at large negative y^*. The considered models do not account precisely for all the features observed in the LHCb data, but theoretical predictions including 1% intrinsic charm and 10% recombination contributions better describe the data than the other models considered.

Submitted to Eur. Phys. J. C.

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arXiv:2211.11652v2 [hep-ex]

J/ψ and D^0 production in $\sqrt{s_{\rm NN}} = 68.5$ GeV PbNe collisions

LHCb collaboration

Abstract

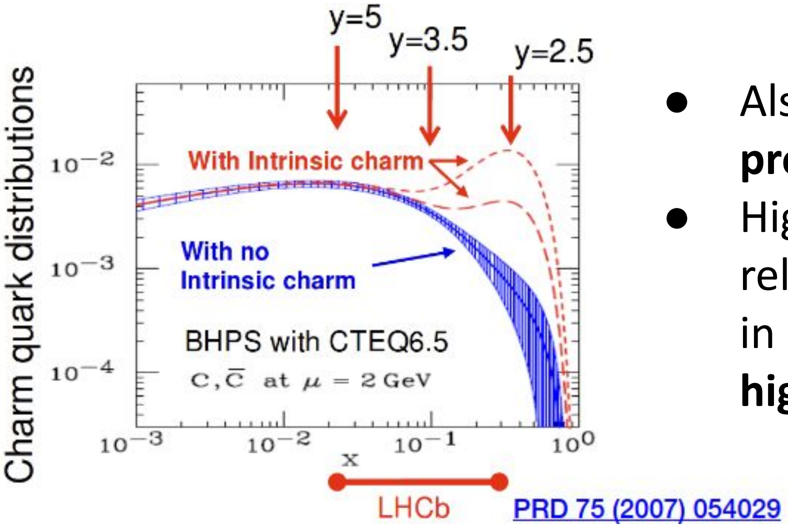
The first measurement of J/ψ and D^0 production in PbNe collisions by the LHCb experiment in its fixed-target configuration is reported. The production of J/ψ and D^0 mesons is studied with a beam of lead ions with an energy of 2.5 TeV per nucleon colliding on gaseous neon targets at rest, corresponding to a nucleon-nucleon centre-of-mass energy of $\sqrt{s_{\rm NN}} = 68.5$ GeV. The $J/\psi\,/D^0$ production cross-section ratio is studied as a function of rapidity, transverse momentum and collision centrality. These data are compared with measurements from pNe collisions at the same energy. No anomalous J/ψ suppression that could indicate the formation of a deconfined medium is observed.

Submitted to Eur. Phys. J. C

arXiv:2211.11652

Brief motivation

- Heavy quark production is only produced in early stage of QGP ⇒ powerful tool to characterise **transition from hadronic matter to QGP**
- To disentangle QGP effects (sequential suppression) from other hadronic effects (saturation, initial and final state…) measurements in different systems are needed



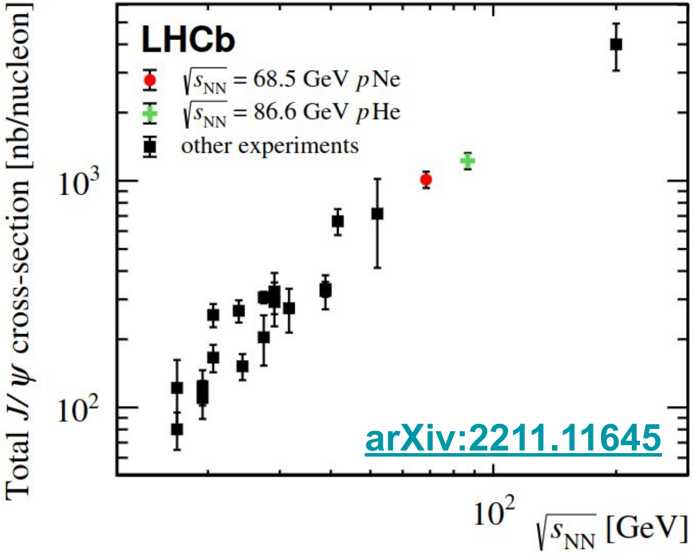
PRD 75 (2007) 054029

- Also, by accessing high-x region in the target, possible **proton intrinsic charm** contribution can be constrained
- High-x measurements of charm production very relevant for CRs too, being decays of charmed hadrons in atmospheric showers the main background in **high-energy neutrino fluxes** observation

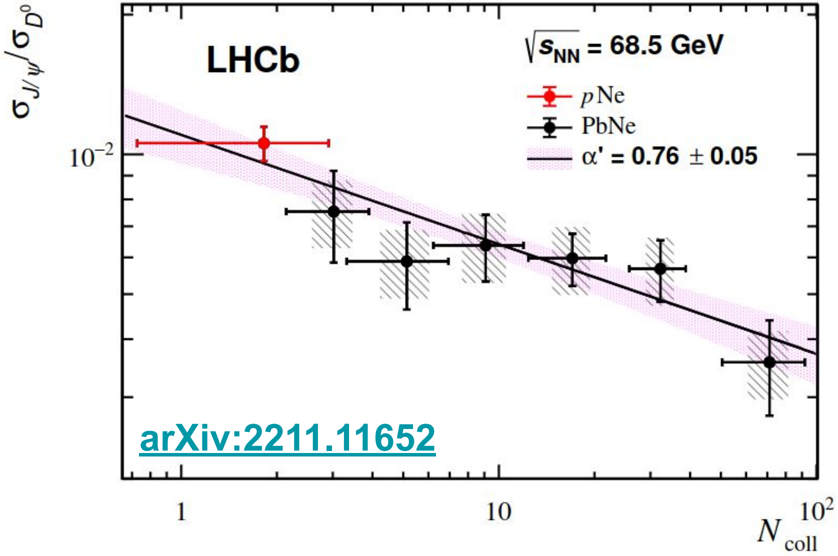
Measurements on Run2 data

Ref

- Measured open charm (D0) and charmonia states (J/ψ and ψ(2s)) in *p*He, *p*Ar, *p*Ne



arXiv:2211.11645



arXiv:2211.11652

- SMOG allows to **fill an energy gap**
- **No anomalous J/ψ suppression** seen

3

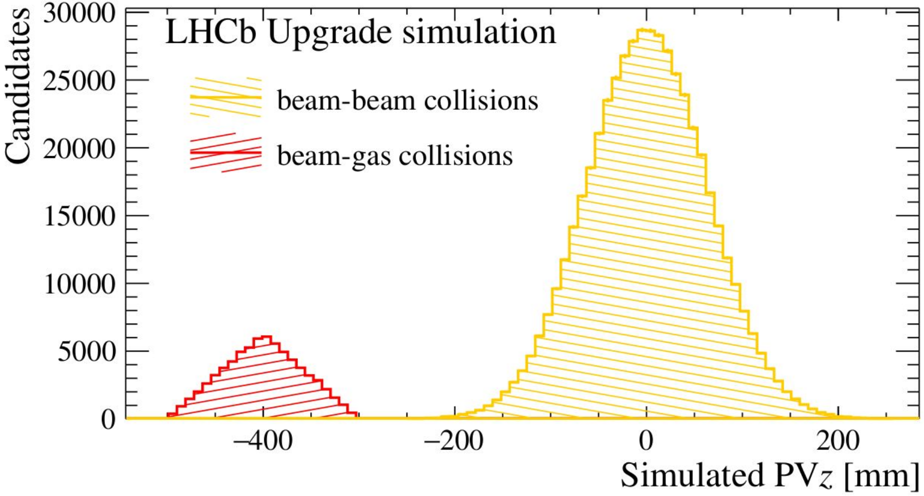
SMOG2 commissioning and physics prospects

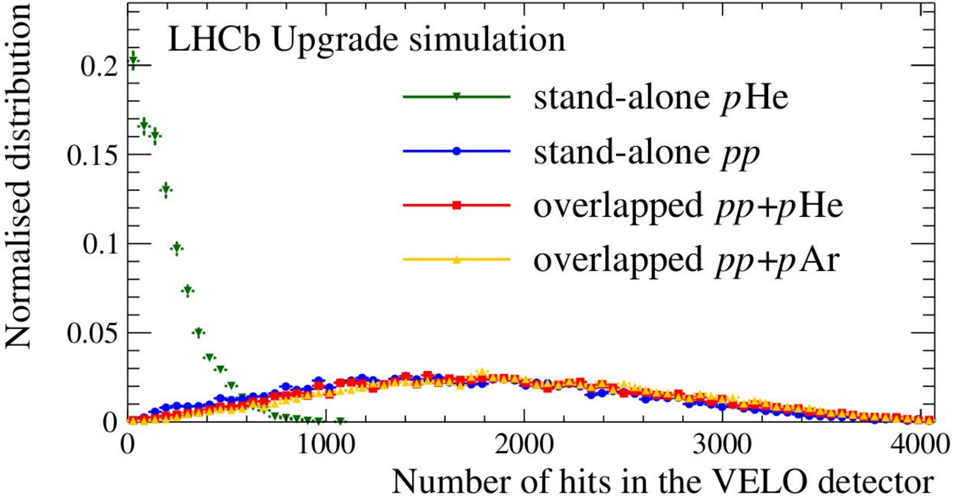
Data-taking with SMOG2

LHCb-FIGURE-2022-002

- **The beam-beam and beam-gas interactions separation** and the **expected small increase in detector multiplicity** support a possible simultaneous data-taking

⇨ **LHCb could be at the same time collider and fixed-target experiment**

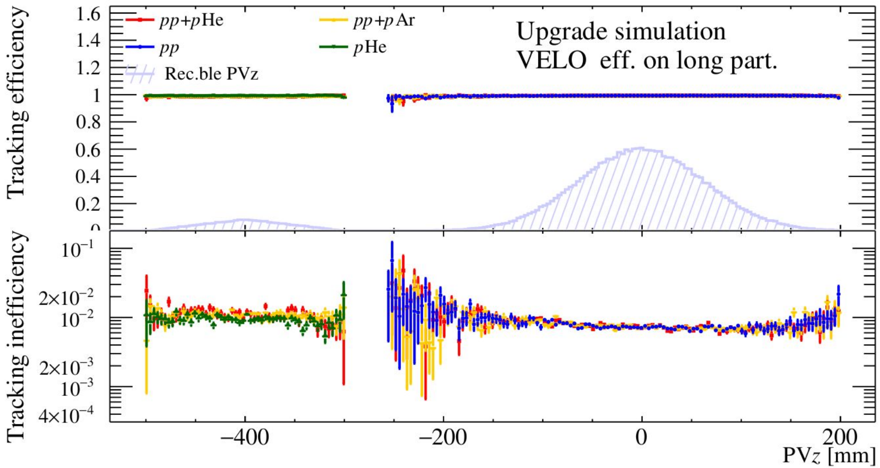


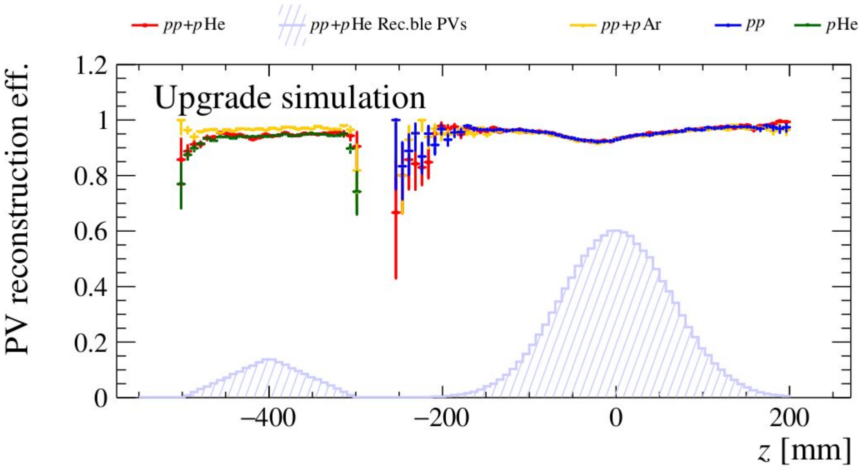


- I have been (am) responsible to prove **the feasibility of this strategy**, *i.e.* that the beam-gas event reconstruction is **efficient** and that there is **no interference** between the two systems

Tuning of the reconstruction algorithms

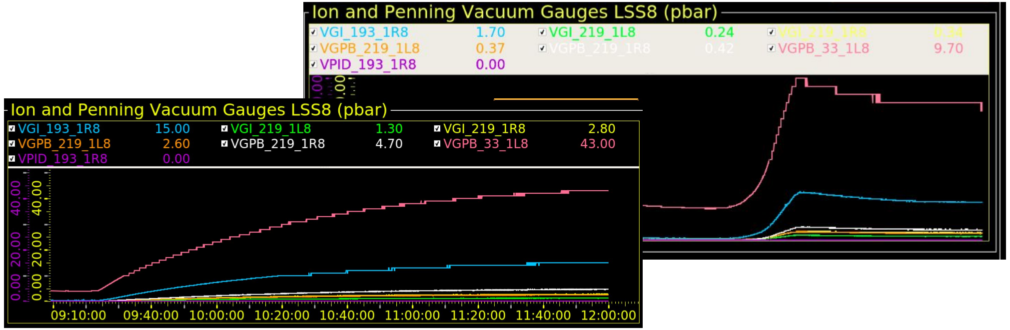
- With the default implementation of the track and vertex reconstruction algorithms, **beam-gas particles are reconstructed with a poorer performance wrt beam-beam**





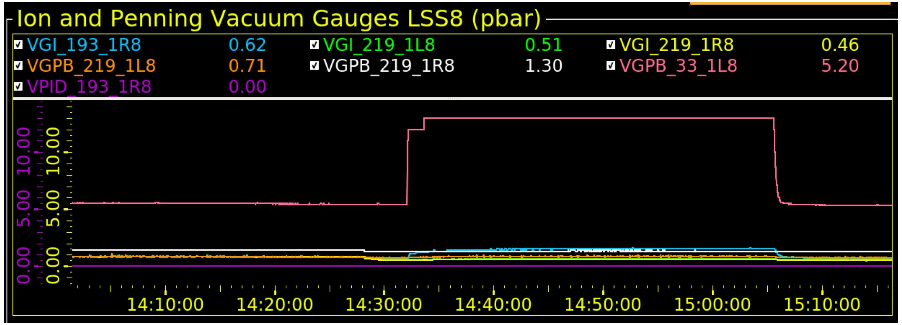
- **Same reconstruction efficiency** for ***pp*** and **pHe** despite the different event topology
- By comparing the *pp* efficiency for ***pp***, ***pp*+*p*He** and ***pp*+*p*Ar**, **there is no efficiency loss for beam-beam when injecting the gas**

Commissioning of the system in 2022 (I)



- First injections **through the open SMOG2 cell** in June 2022, allowing vacuum experts to **set the injection procedure**

- At November, reached a remarkable stability and injected He, Ne, Ar and H2 (for the first time) at different pressures

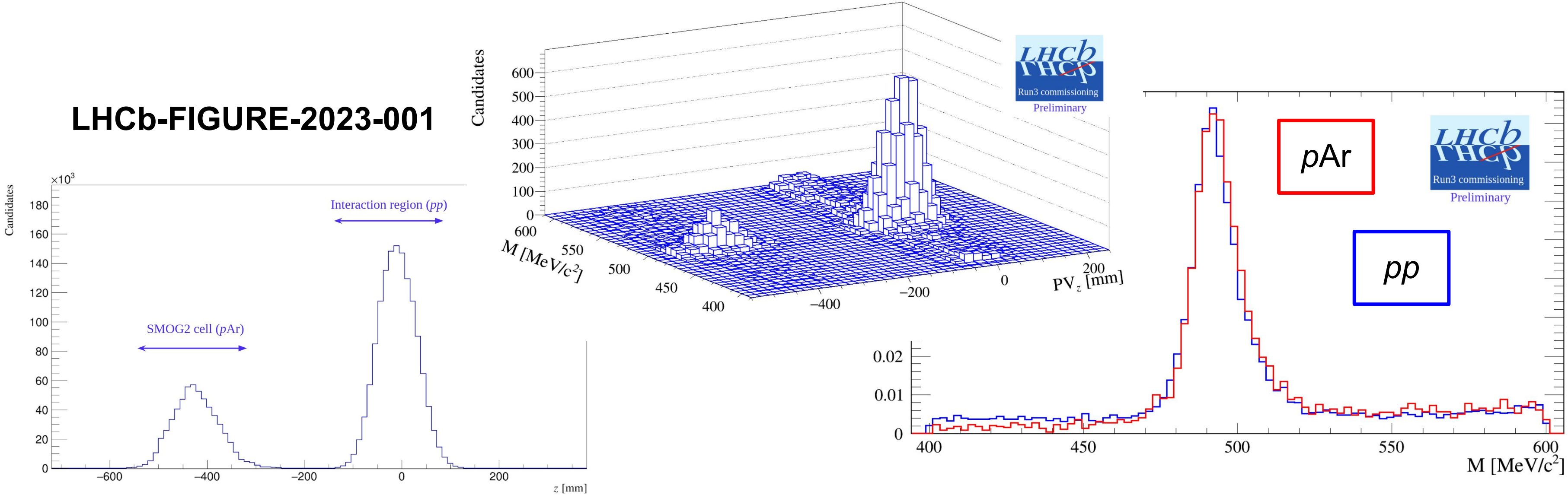


- **SMOG2 completely commissioned and ready to take data in 2023**

First performance studies on 2022 LHC data (I)

- **LHCb is the only experiment at LHC operating simultaneously with two interaction points**
- Ks reconstructed from both interaction points, with **similar mass resolution**

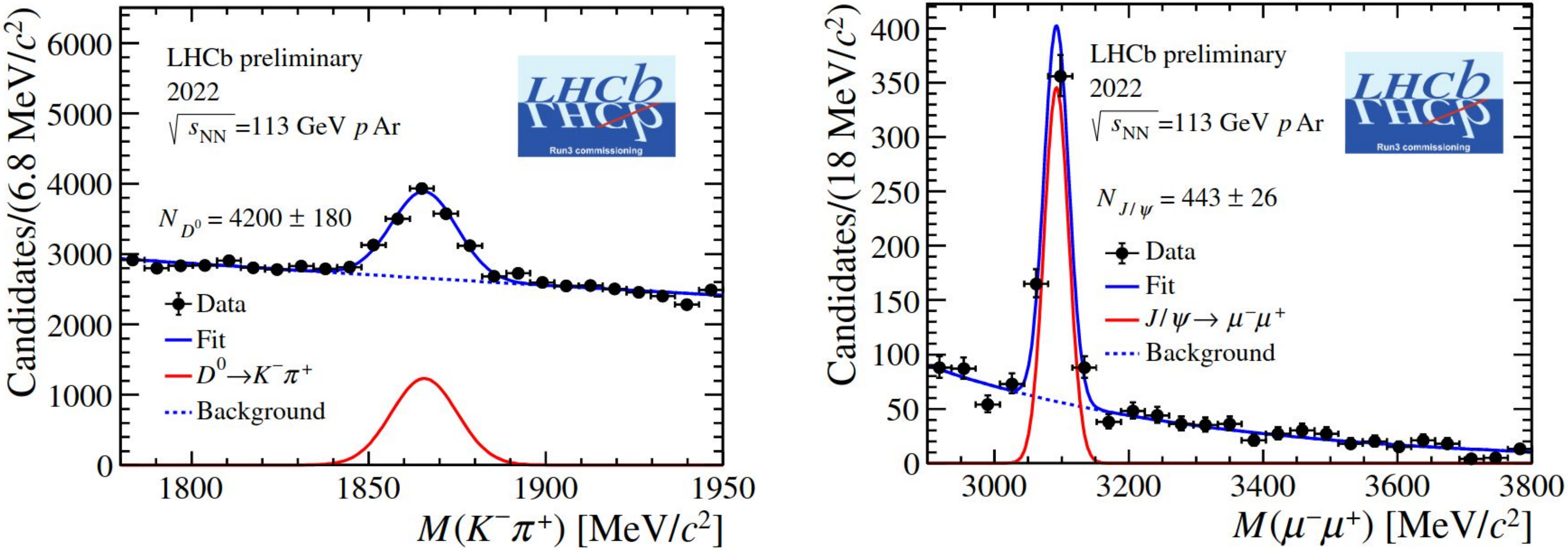
LHCb-FIGURE-2023-001



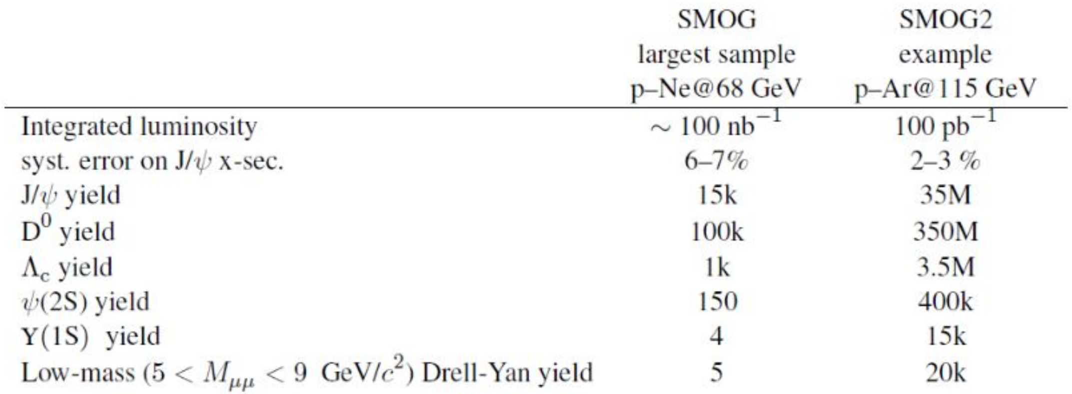
First performance studies on 2022 LHC data (II)

- Charm hadrons also reconstructed, proving the full chain to work correctly
  - Worth to notice, the analysed data **correspond to 18 minutes**

LHCb-FIGURE-2023-008



Physics prospects with SMOG2



	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 ($5 < M_{\mu\mu} < 9\ \text{GeV}/c^2$) Drell-Yan yield	5	20k

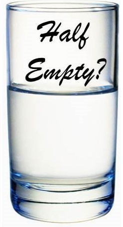
- The larger samples, the wider injectable gas choice and the direct lumi measurement will further **widen the LHCb-SMOG accessible physics scenario**

- Sequential suppression of **charm and bottom states, study of low-mass Drell-Yan**
- Detailed study of the high-*x* **parton PDFs and probes for TMDs**
- High-statistics ultra-peripheral ρ, ω, charmonia and bottomonia states with **high-Z targets**
- Extension of the programme of cosmic rays interest: **$\bar{p}$ production processes with H_2, D_2, He,** probes for the study of the atmospheric showers with N_2, O_2; **nuclei production**?
- Can't enter in details here, but please have a look to **LHCb-PUB-2018-015**

Reality sometimes hits hard

- On 10th January 2023 a **failure of the LHC vacuum system** of the VELO happened, leading to a plastic deformation of the RF foils (aluminium foils separating the machine from the detector vacua)

- VELO detectors and motion system seems not to be affected by the incident
- Tracking efficiency, hit resolution still as the design ones



- RF foils replacement could only be possible in 2023/2024 YETS
- VELO (and alas, SMOG2 cell) will have to be partially closed, **significantly impacting the physics programme this year**

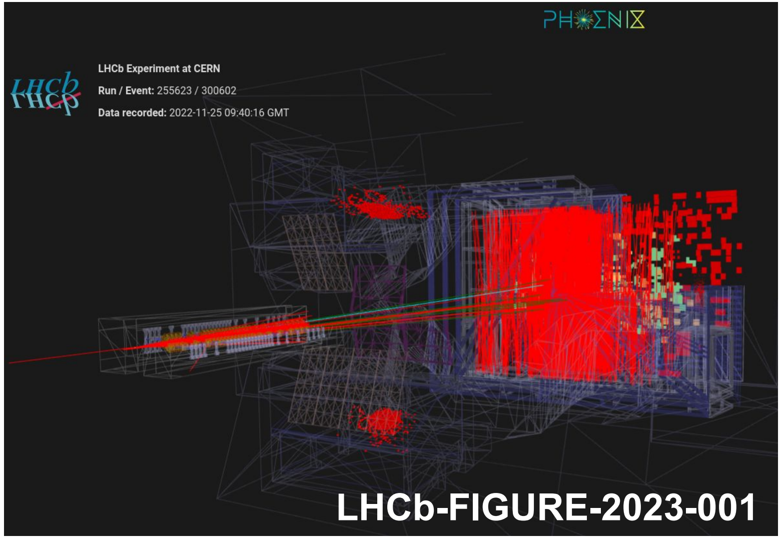
Still, 2023 can be relevant for fixed-target physics and lots of possibilities remain

4

Conclusions

Conclusions

- Since 2015, LHCb is acting as the **highest energy fixed-target experiment ever** by injecting in the LHC accelerator **small quantities of noble gases** (He, Ne and Ar in 2015-2018)
- **Fixed-target programme now being upgraded** to increase the gas pressure x100, inject more and fastly switch gases (also H_2, D_2, O_2, N_2…) and measure the luminosity



LHCb-FIGURE-2023-001

- With available and future data, exciting opportunities for measurements covering **different fields of interest** in poorly constrained kinematic region
- **A unique and a highly complementary to existing and future facilities system for QCD studies**

Thanks for your attention!

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BACKUP

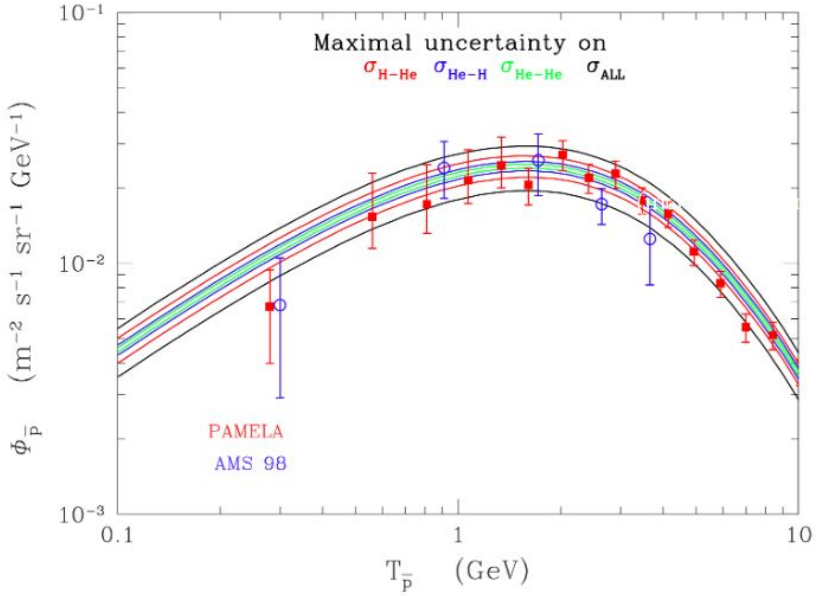
1

Motivation, experimental setup and previous result

Uncertainties on the antiproton flux from **nuclear cross sections**

(Donato+ ApJ 2001, PRL 2009)

nPQCD

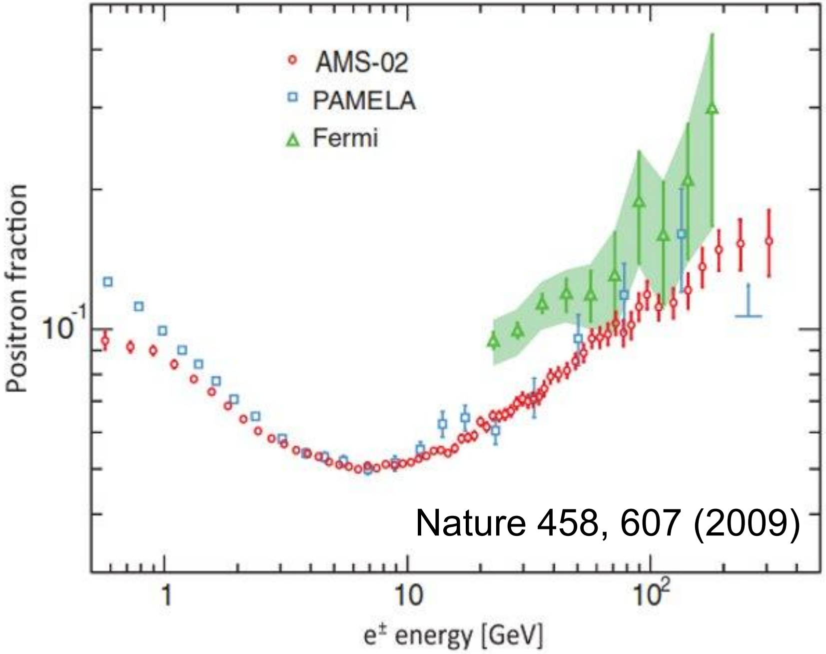


- pp: Tan& Ng
- H-He, He-H, He-He: DTUNUC MC
- Functional form for the cross section derived from other reactions, given **NO DATA!!**

Maximal uncertainty from p-He cross sections: 20-25%!

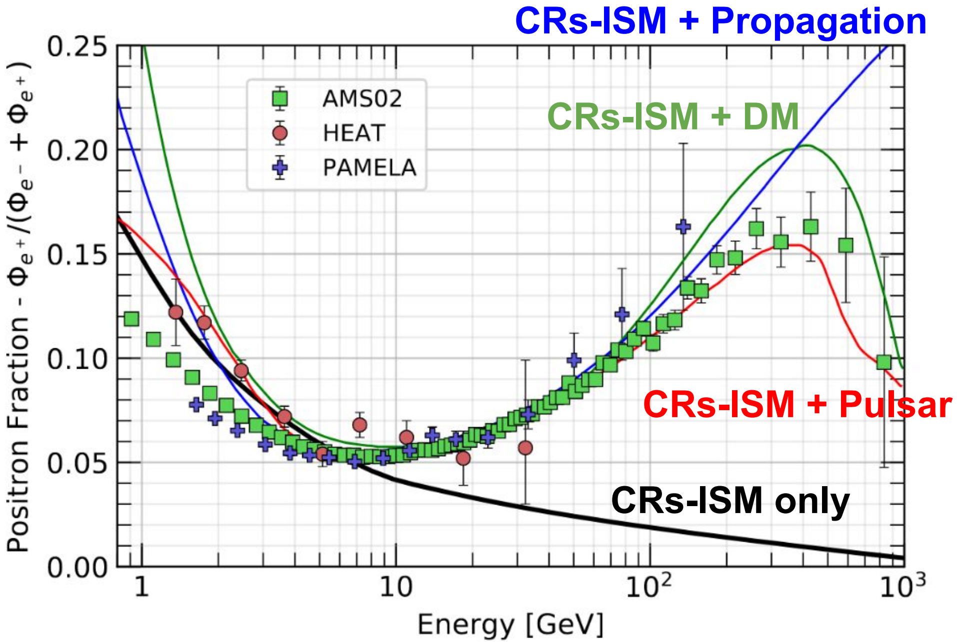
Data from AMS-02 on cosmic antiprotons are at ~ 10% accuracy

Positron excess

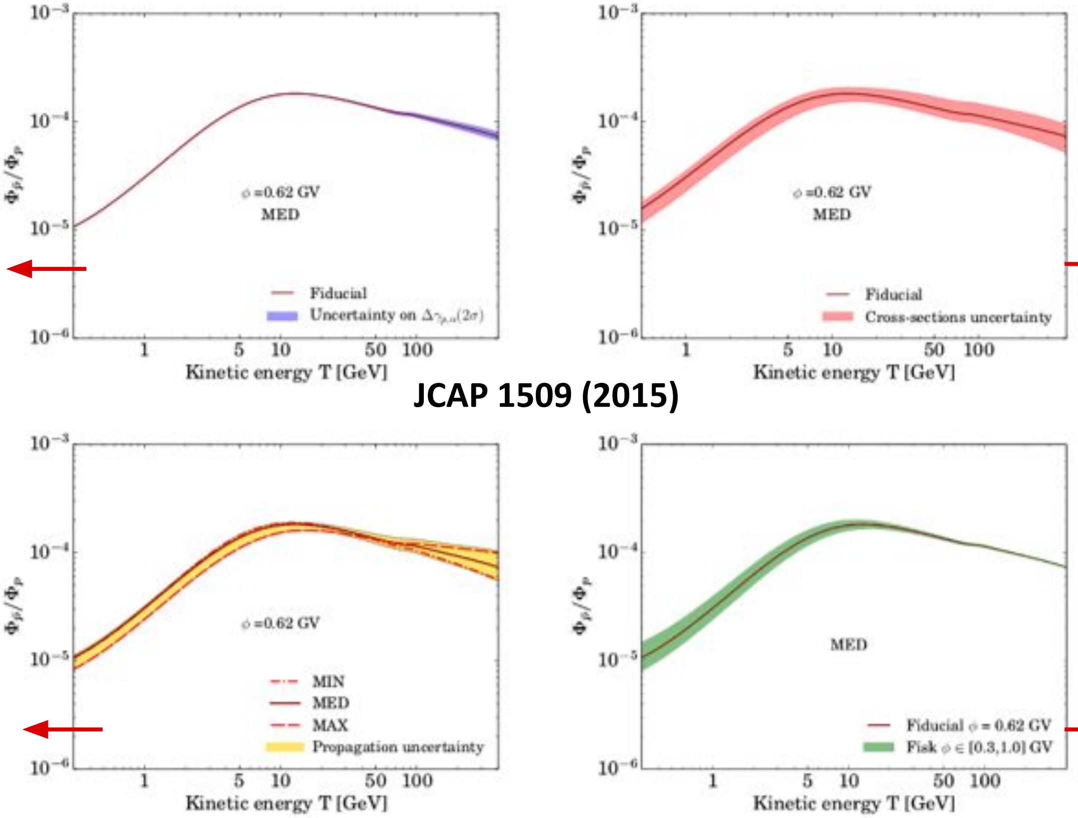


Nature 458, 607 (2009)

- **Why is the positron fraction increasing?**



Uncertainties on 2015 fiducial prediction



JCAP 1509 (2015)

Primary fluxes

Antiproton production cross-section

Propagation

Solar modulation

CRs state equation

PRD97 (2018) 103019

CR density

Local production rate

Spatial diffusion

Momentum diffusion

Radiative processes

$$\frac{\partial \psi_i(\vec{r},p,t)}{\partial t} = q_i(\vec{r},p,t) + \vec{\nabla}\cdot(D_{xx}\vec{\nabla}\psi_i) + \frac{\partial}{\partial p}\left[p^2 D_{pp}\frac{\partial}{\partial p}\left(\frac{\psi_i}{p^2}\right)\right] - \frac{\partial}{\partial p}(\dot{p}\psi_i)$$

$$-\vec{\nabla}\cdot(\vec{v}_c\psi_i) + \frac{\partial}{\partial p}\left[\frac{p}{3}(\vec{\nabla}\cdot\vec{v}_c)\psi_i\right] - \frac{\psi_i}{\tau_{i,\,frag}} - \frac{\psi_i}{\tau_{i,\,decay}}$$

Convection (galactic winds)

Fragmentation

Decay

CR isotropy

ISM density

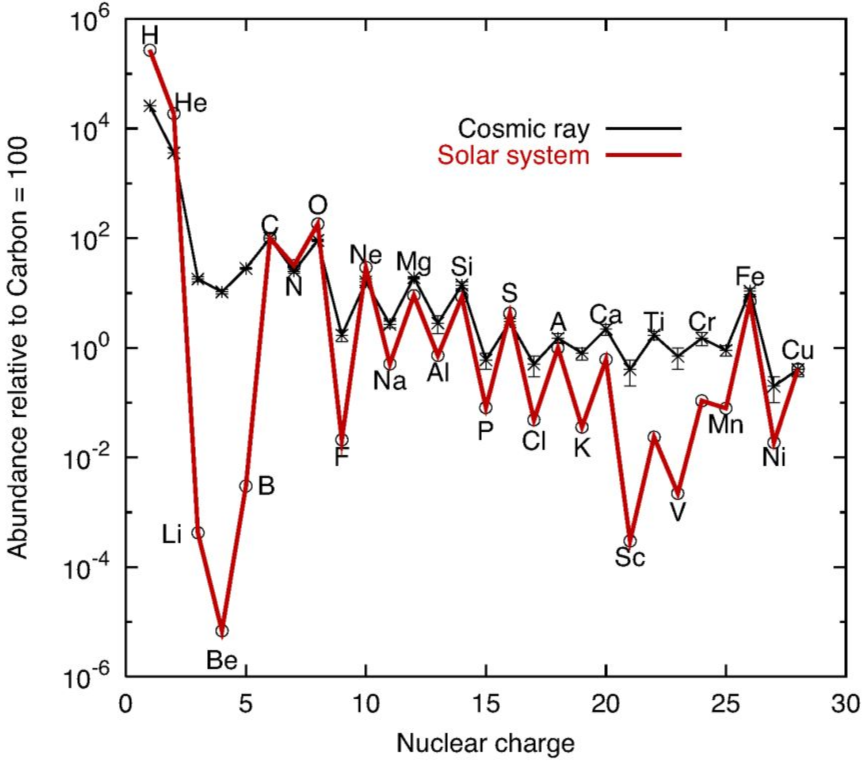
- For purely **secondary antiprotons**: $$q_i(T_{\bar{p}}) = \sum_j \int_{T_{th}}^{\infty} dT_i\, 4\pi n^j_{ISM}\psi_i(T_i)\frac{d\sigma_{ij}}{dT_{\bar{p}}}(T_i, T_{\bar{p}}),$$

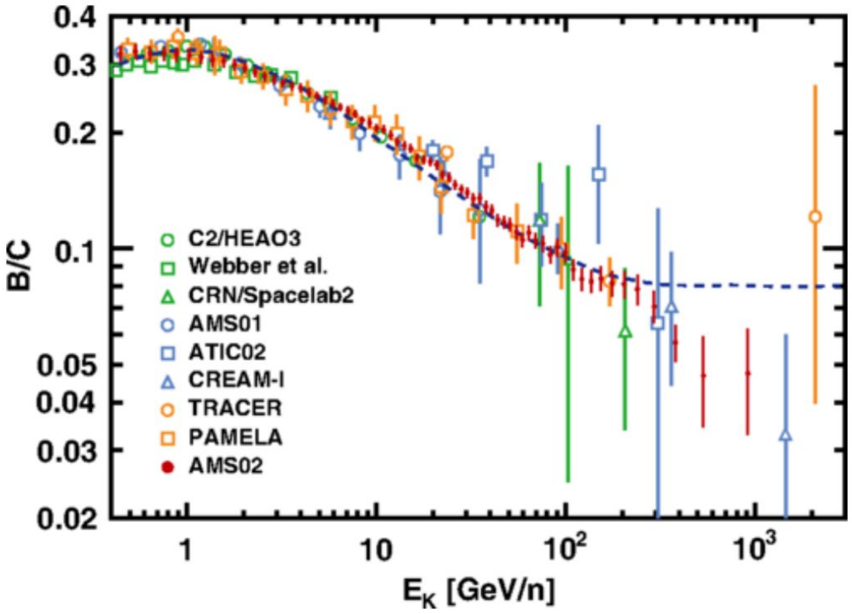
i = incoming CR species

j = ISM element

production threshold

Boron-to-Carbon ratio

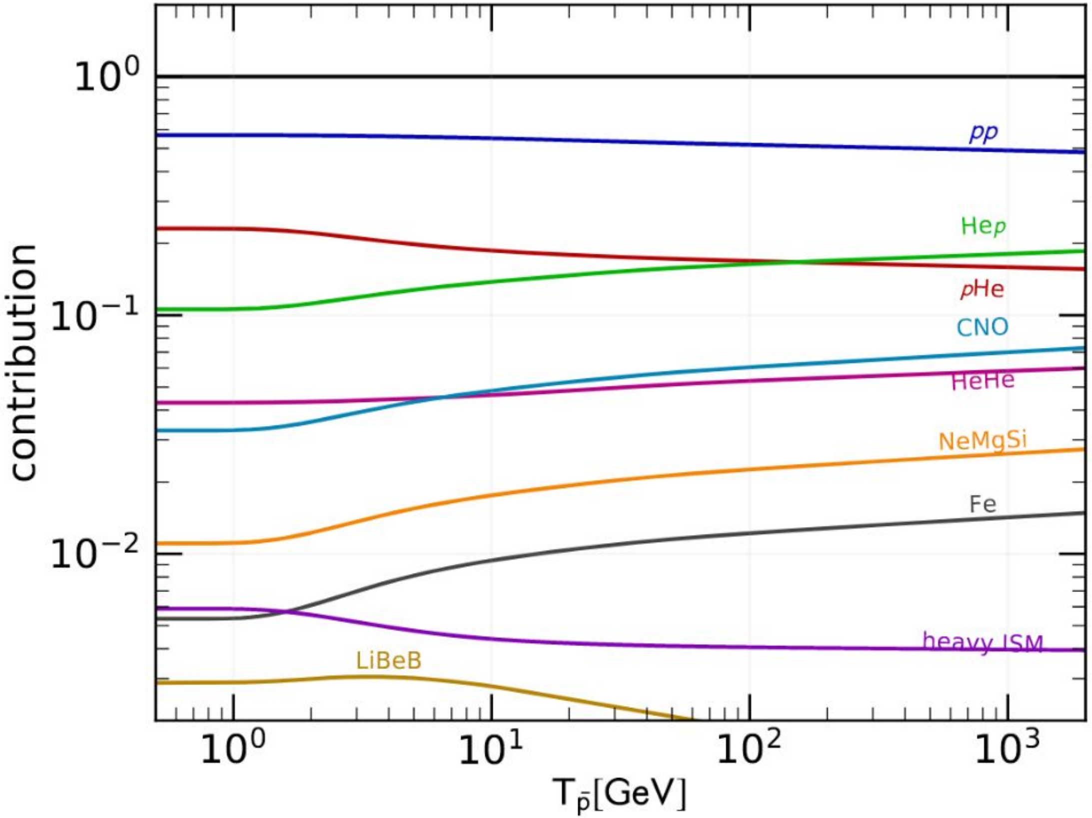




- **Secondary-to-primary** ratio used to constrain **CRs propagation**

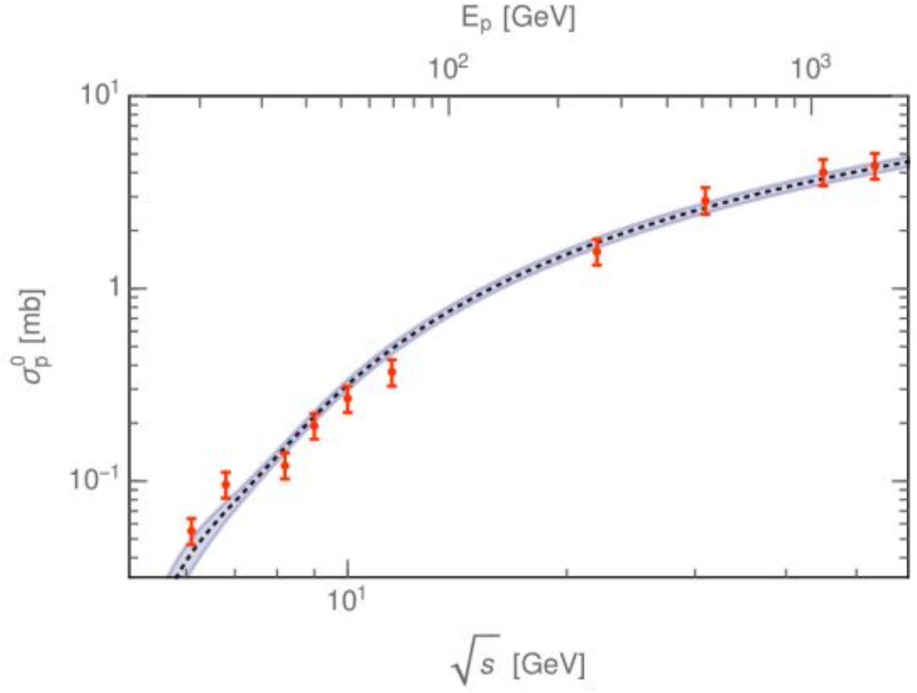
Antiproton production contributions

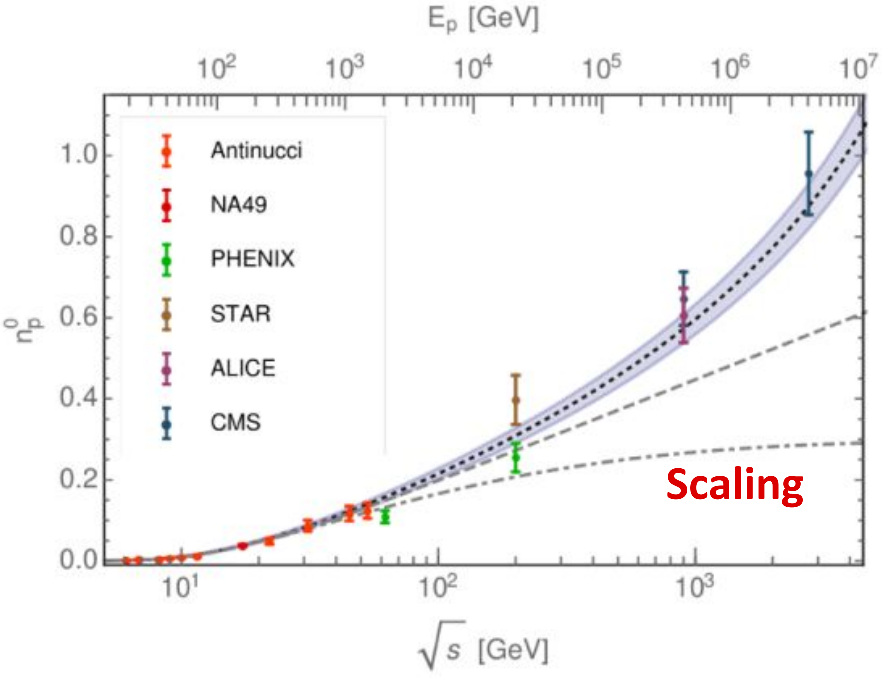
PRD97 (2018) 103019



Feynman scaling violation

$$\sigma_{inv}(\sqrt{s_{\rm NN}}, p_{\rm T}, x_R) \quad \rightarrow \quad \sigma_{inv}(p_{\rm T}, x_R) \propto (1-x_R)^{7.76} exp\left[-\frac{\sqrt{p_{\rm T}^2+m^2}}{0.168}\right]$$





Luminosity

Collider mode

$$\mathcal{L} \simeq 2c \cdot cos^2\alpha \cdot n_b N_1 N_2 \nu_{rev} \int \rho_1(x,y,z,t)\rho_2(x,y,z,t)\, dxdydzdt \equiv n_b N_1 N_2 \nu_{rev} \cdot \Omega$$

$$\mathcal{L} \simeq n_b \nu_{rev} \frac{N_1 N_2}{4\pi\sigma_x\sigma_y}$$

Fixed-target mode

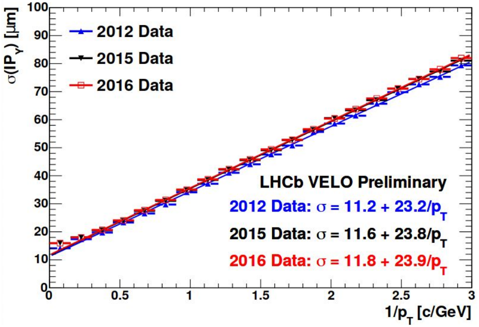
$$\int \mathcal{L}\, dt \sim 5\,\mathrm{nb}^{-1} \times \frac{pot}{10^{22}} \times \frac{p_{gas}}{2 \cdot 10^{-7}\,\mathrm{mbar}} \times \frac{\Delta z}{1\,\mathrm{m}}.$$

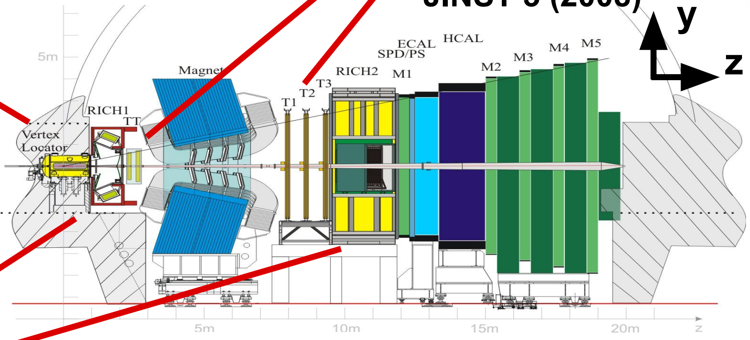
$$\mathcal{L} = \nu_{rev} \cdot n_b \cdot N_1 \cdot \sigma_t = \nu_{rev} \cdot n_b \cdot N_1 \cdot \frac{p_{gas}\Delta z}{K_B T}$$

The LHCb detector

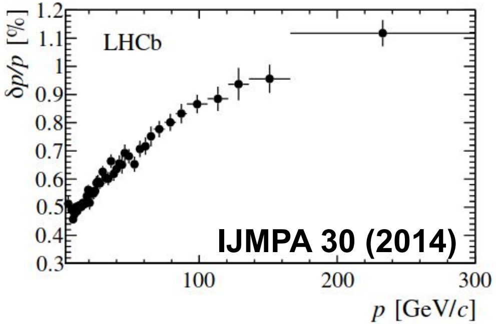
- **VELO**: excellent **vertices and IP resolutions**. Made of **two opening halves** to increase the sensors distance from the beam (7 mm for data-taking) during machine operation

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

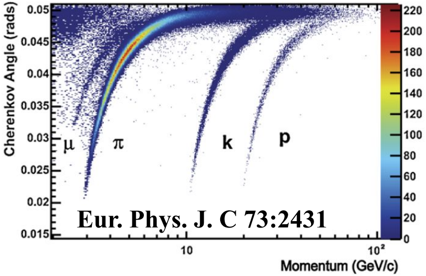




JINST 3 (2008)



IJMPA 30 (2014)

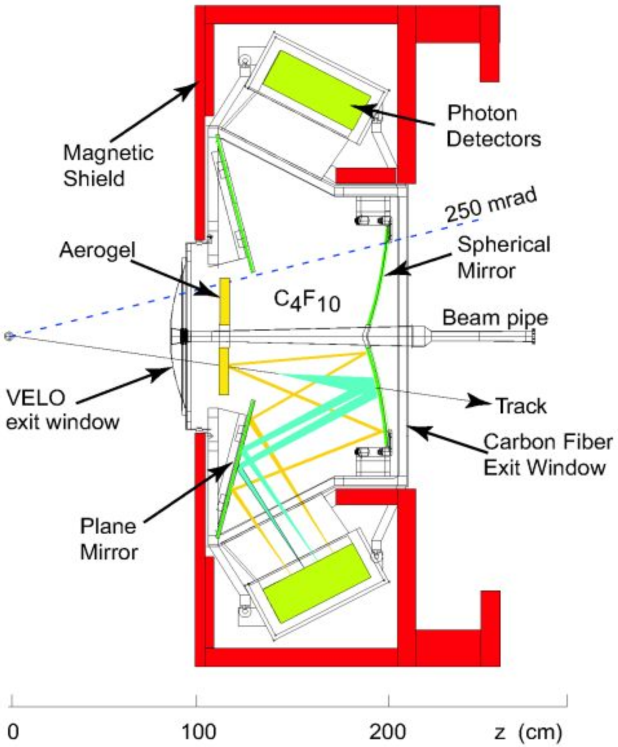


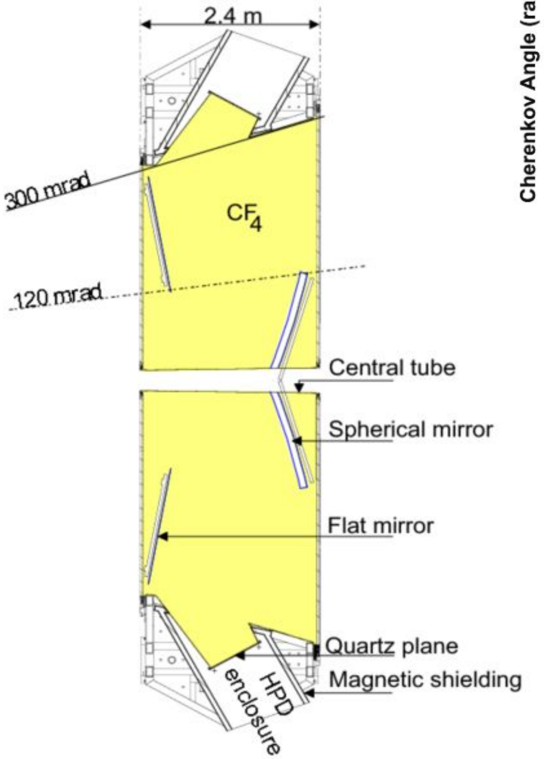
Eur. Phys. J. C 73:2431

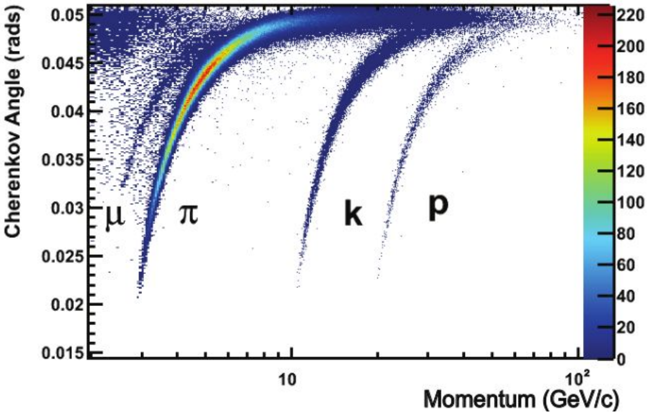
- **RICH**: excellent **separation** among kaons, pions and protons

- Flexible and versatile **trigger system**.

The RICH system







$$cos\theta_c = \frac{1}{n\beta} = \frac{1}{n}\sqrt{1 + \left(\frac{mc^2}{pc}\right)^2}.$$

$$\mathrm{DLL}_{h1,h2} = log\left(\frac{\text{h1 likelihood}}{\text{h2 likelihood}}\right)$$

Phase-space coverage (II)

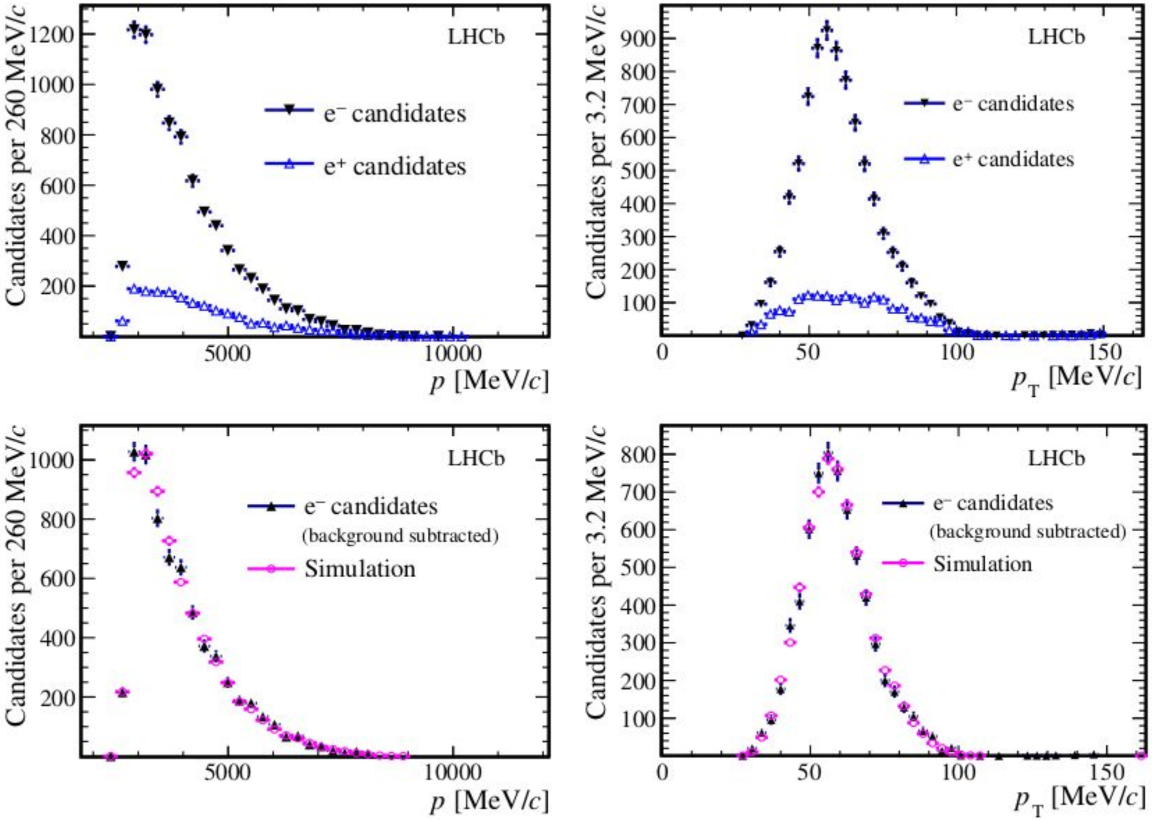
$$\sqrt{s_{NN}} = \sqrt{2E_N M_N c^2} \in [29, 115]\,\mathrm{GeV}$$

$$y_{CM} \sim arcsinh(\sqrt{E_N/2M_N\,c^2}) \in [3.8, 4.8]$$

$$\eta \in [2,5] \qquad \Rightarrow \qquad y^* \in [-2.8, 0.2]$$

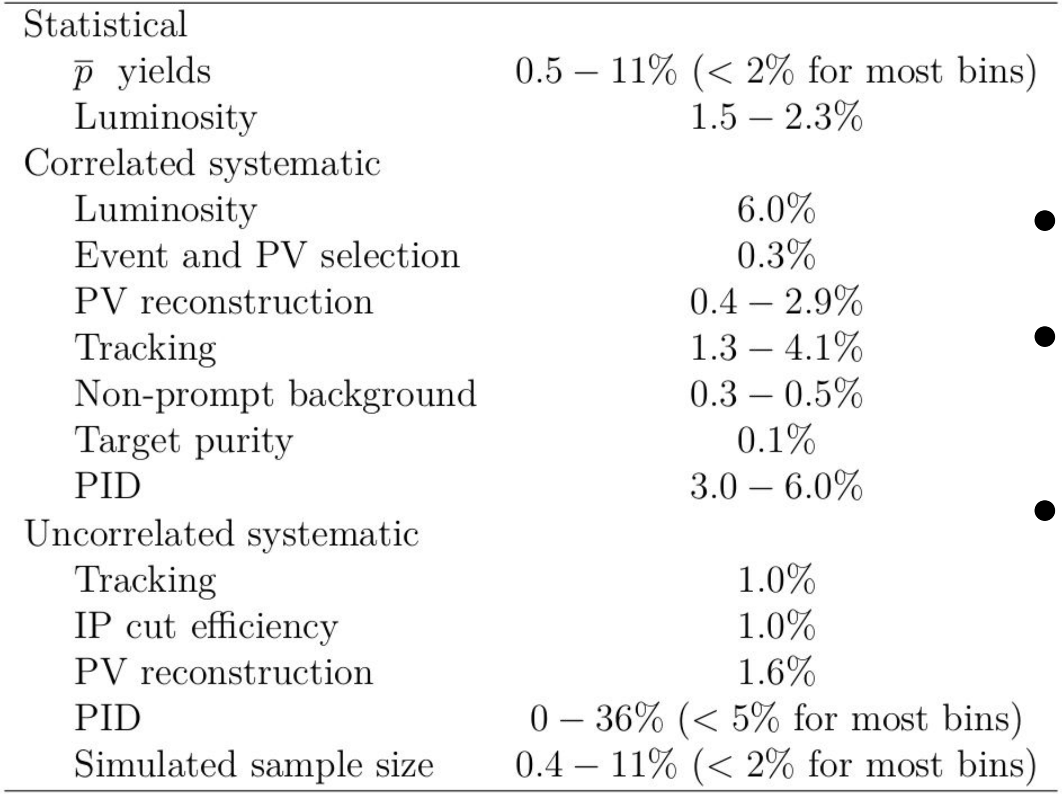
$$x_F \simeq \frac{2}{\sqrt{s_{NN}}}\sqrt{(Mc^2)^2 + (p_{\mathrm{T}}c)^2} \cdot sinh(y^*) \simeq x_1 - x_2$$

*p*He luminosity measurement



$$\int \mathcal{L}\,dt = \frac{(1-f_{bkg})\cdot N_e}{Z_{He}\cdot\sigma_{pe}\cdot\varepsilon}$$

Prompt antiproton systematics



Statistical	
$\bar{p}$ yields	$0.5 - 11\%$ ($< 2\%$ for most bins)
Luminosity	$1.5 - 2.3\%$
Correlated systematic	
Luminosity	6.0%
Event and PV selection	0.3%
PV reconstruction	$0.4 - 2.9\%$
Tracking	$1.3 - 4.1\%$
Non-prompt background	$0.3 - 0.5\%$
Target purity	0.1%
PID	$3.0 - 6.0\%$
Uncorrelated systematic	
Tracking	1.0%
IP cut efficiency	1.0%
PV reconstruction	1.6%
PID	$0 - 36\%$ ($< 5\%$ for most bins)
Simulated sample size	$0.4 - 11\%$ ($< 2\%$ for most bins)

PRL 121 (2018) 222001

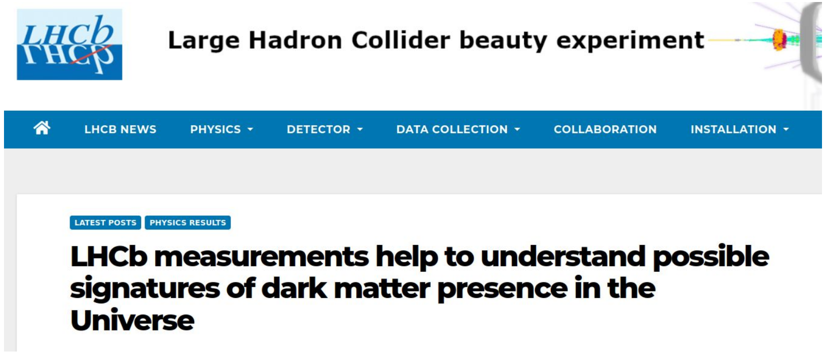
- Uncertainty below **10%** in most kinematic interval
- Dominant contribution from **luminosity** measurement: motivation for SMOG2 upgrade
- Sub-dominant PID contribution: started activity to improve performance with **machine learning techniques**.

2a

My Ph.D.

Antiproton production from antihyperon decays

LHCb-PAPER-2022-006 (~ready to be submitted)



Large Hadron Collider beauty experiment

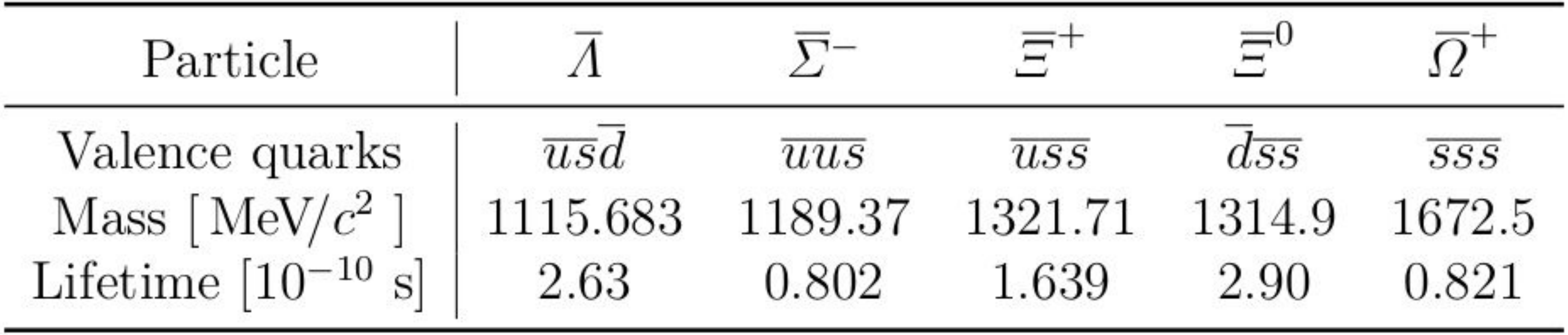
LHCb measurements help to understand possible signatures of dark matter presence in the Universe

LHCb reveals secret of antimatter creation in cosmic collisions

The finding may help determine whether or not any antimatter seen by experiments in space originates from dark matter

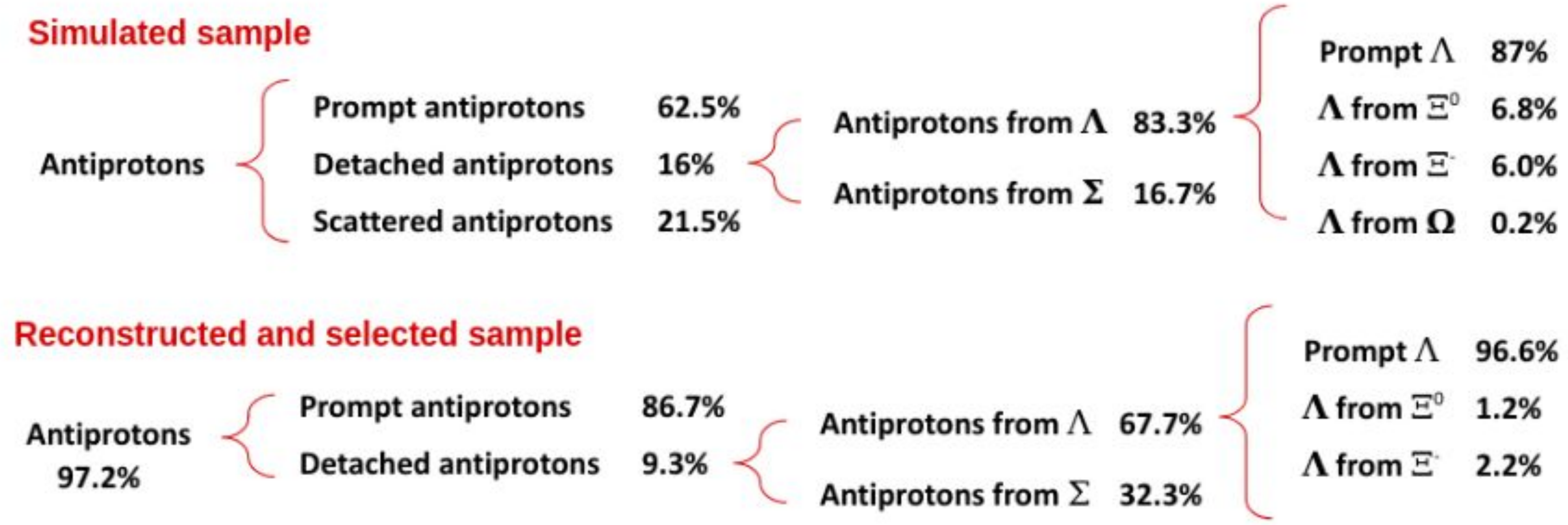
7 APRIL, 2022

Antihyperon characteristics



Particle	$\overline{\Lambda}$	$\overline{\Sigma}^-$	$\overline{\Xi}^+$	$\overline{\Xi}^0$	$\overline{\Omega}^+$
Valence quarks	$\overline{us}\overline{d}$	$\overline{uus}$	$\overline{uss}$	$\overline{d}\overline{ss}$	$\overline{sss}$
Mass [MeV/c^2]	1115.683	1189.37	1321.71	1314.9	1672.5
Lifetime [10^{-10} s]	2.63	0.802	1.639	2.90	0.821

EPOS-LHC relative antihyperon abundances



Simulated sample

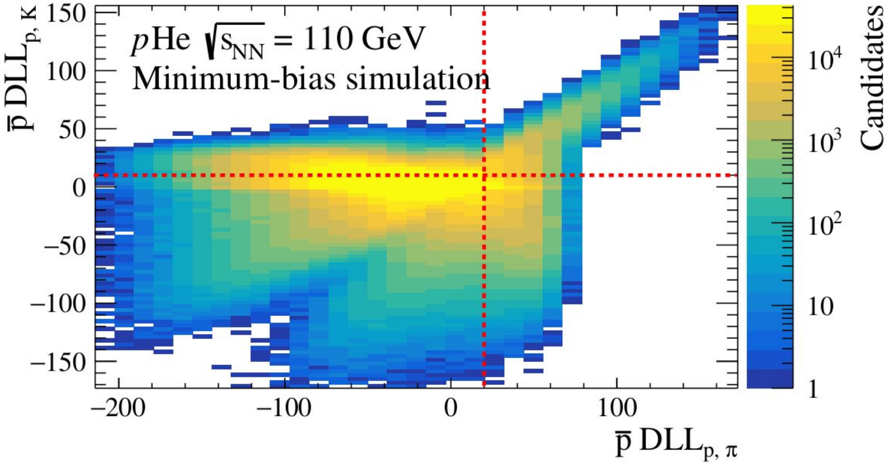
- Antiprotons
  - Prompt antiprotons 62.5%
  - Detached antiprotons 16%
    - Antiprotons from Λ 83.3%
      - Prompt Λ 87%
      - Λ from Ξ^0 6.8%
      - Λ from Ξ^- 6.0%
      - Λ from Ω 0.2%
    - Antiprotons from Σ 16.7%
  - Scattered antiprotons 21.5%

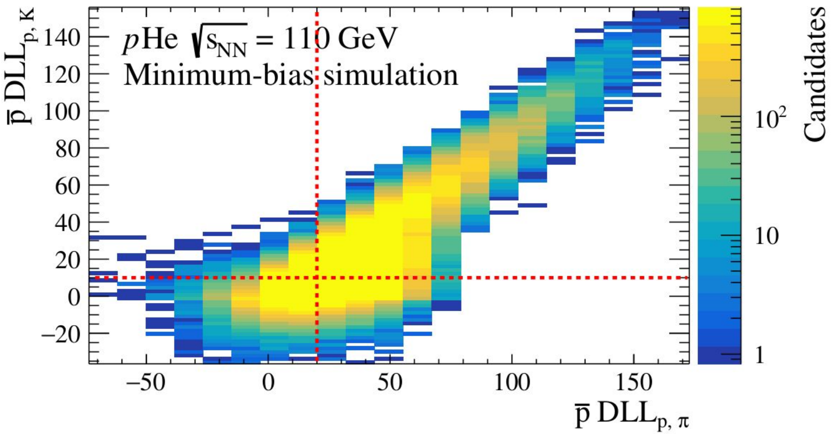
Reconstructed and selected sample

- Antiprotons 97.2%
  - Prompt antiprotons 86.7%
  - Detached antiprotons 9.3%
    - Antiprotons from Λ 67.7%
      - Prompt Λ 96.6%
      - Λ from Ξ^0 1.2%
      - Λ from Ξ^- 2.2%
    - Antiprotons from Σ 32.3%

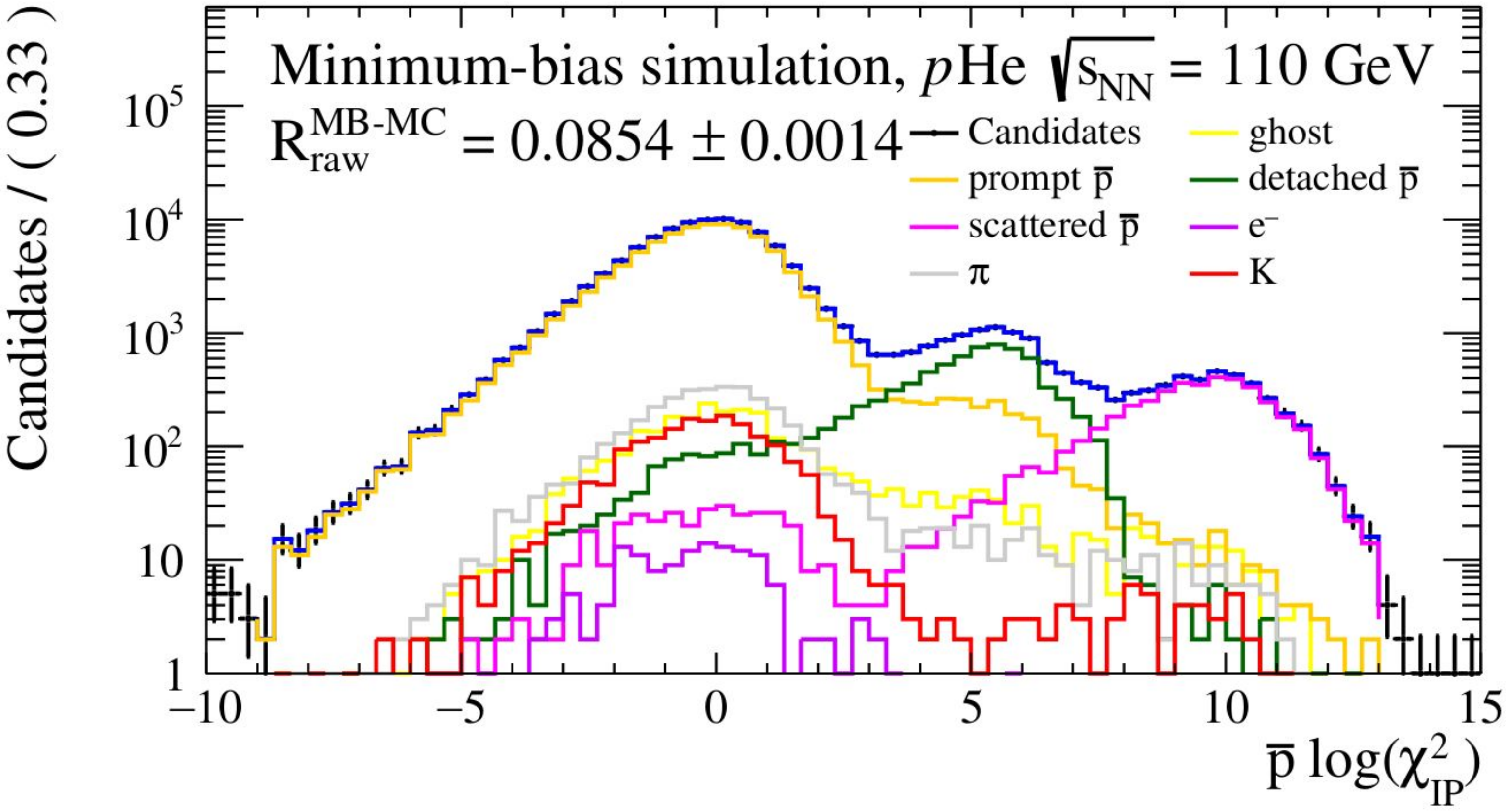
Inclusive: antiproton selection

Event	$N_{SPD} > 0,\ N_{VELO} > 0,\ N_{\mathrm{trk}}(\eta < 0) < 5$
PV	$z \in [-700, 100]\,\mathrm{mm}$ $\sqrt{[(x\text{-}(0.81\,\mathrm{mm}\text{-}z \cdot 490))^2 + (y\text{-}(\text{-}0.22\,\mathrm{mm}\text{-}z \cdot 45))^2]} < 0.4\,\mathrm{mm}$
$\overline{p}$	$\chi^2/\mathrm{ndf} < 4,\ GhostProb < 0.15$ $p \in [12, 100]\ \mathrm{GeV}/c,\ p_{\mathrm{T}} \in [0.4, 4]\ \mathrm{GeV}/c,\ \eta < 5$ $\mathrm{DLL}_{p,\pi} > 20,\ \mathrm{DLL}_{p,K} > 10$

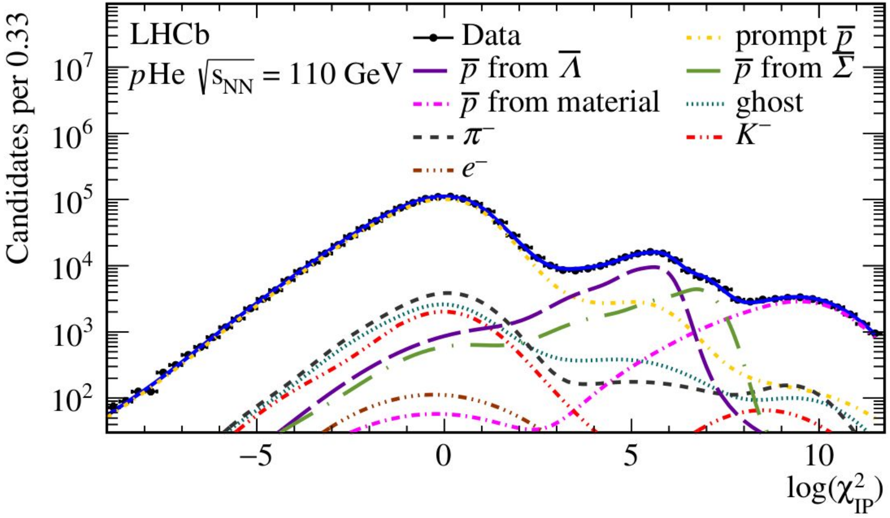


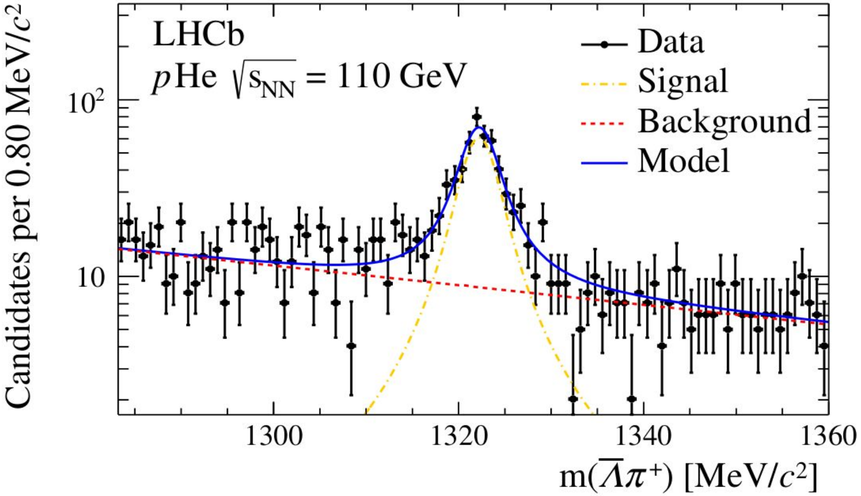


Inclusive: fit to simulation



Inclusive: syst on antihyperon abundance





Inclusive: systematics

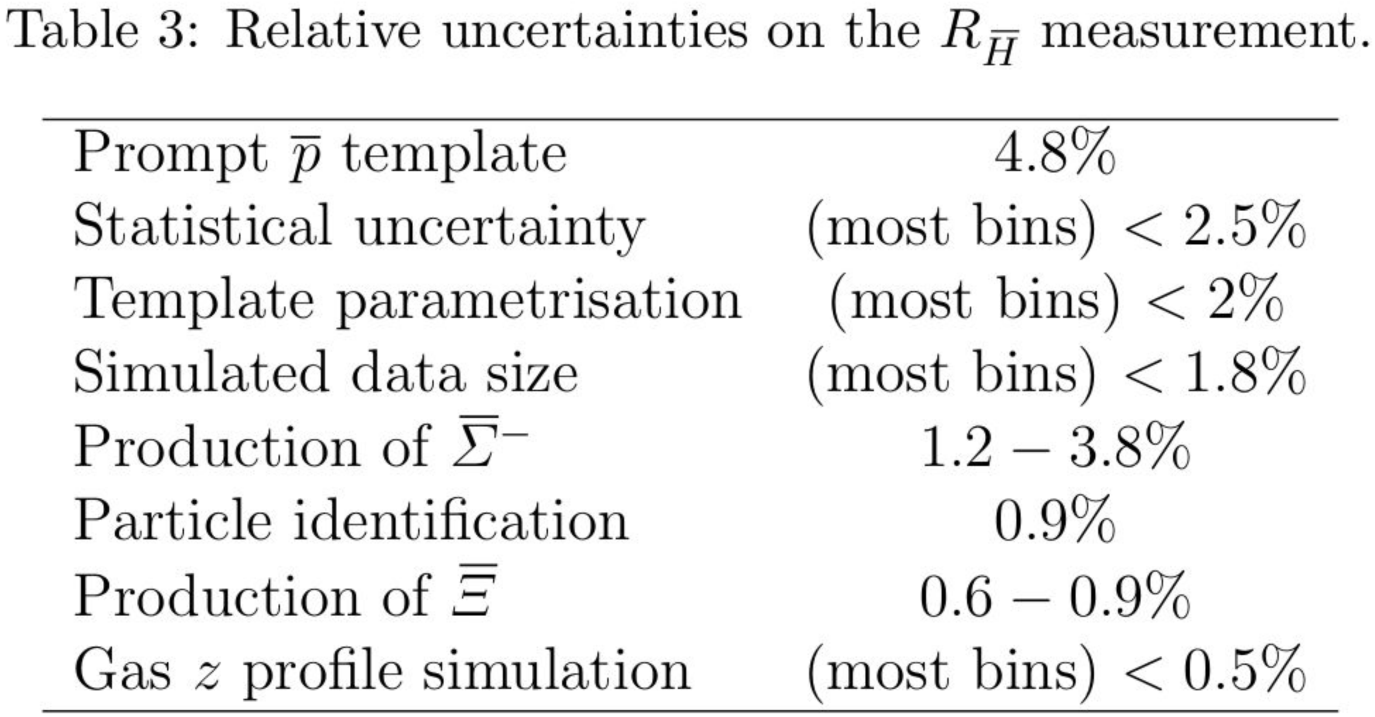


Table 3: Relative uncertainties on the $R_{\overline{H}}$ measurement.

Prompt $\overline{p}$ template	4.8%
Statistical uncertainty	(most bins) $<$ 2.5%
Template parametrisation	(most bins) $<$ 2%
Simulated data size	(most bins) $<$ 1.8%
Production of $\overline{\Sigma}^-$	$1.2 - 3.8$%
Particle identification	0.9%
Production of $\overline{\Xi}$	$0.6 - 0.9$%
Gas z profile simulation	(most bins) $<$ 0.5%

Exclusive: systematics

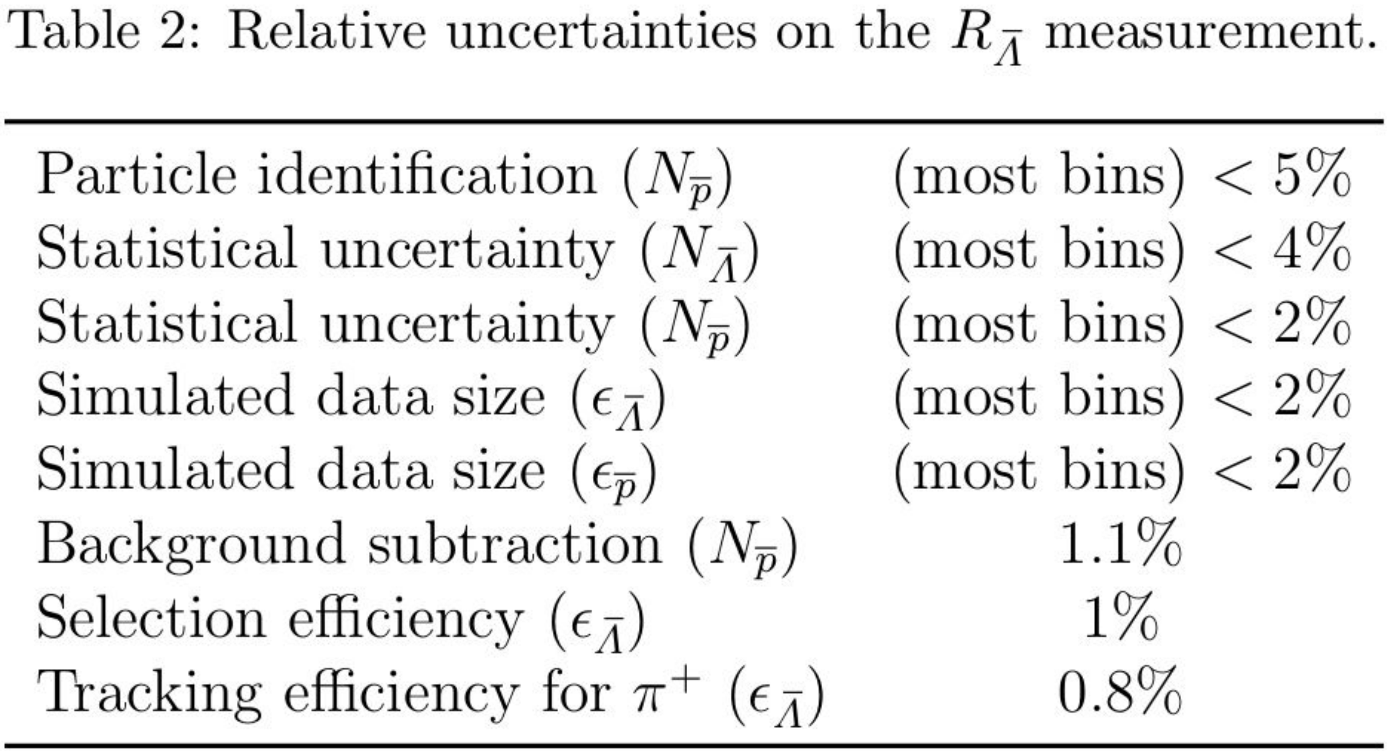


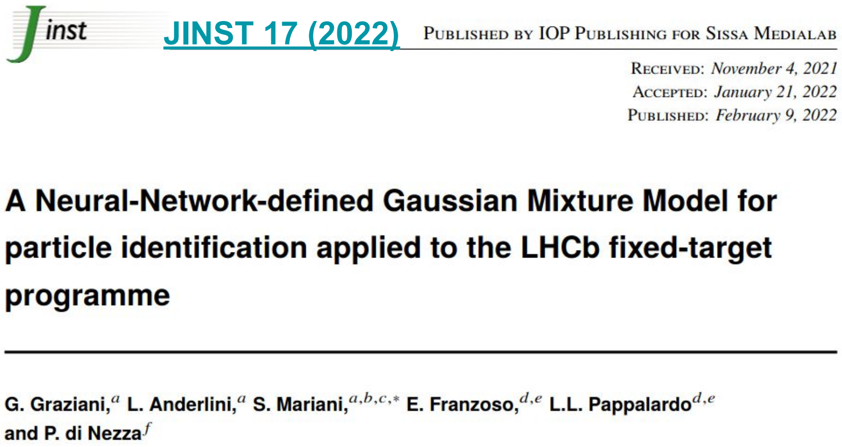
Table 2: Relative uncertainties on the $R_{\overline{\Lambda}}$ measurement.

Particle identification ($N_{\overline{p}}$)	(most bins) $< 5\%$
Statistical uncertainty ($N_{\overline{\Lambda}}$)	(most bins) $< 4\%$
Statistical uncertainty ($N_{\overline{p}}$)	(most bins) $< 2\%$
Simulated data size ($\epsilon_{\overline{\Lambda}}$)	(most bins) $< 2\%$
Simulated data size ($\epsilon_{\overline{p}}$)	(most bins) $< 2\%$
Background subtraction ($N_{\overline{p}}$)	1.1%
Selection efficiency ($\epsilon_{\overline{\Lambda}}$)	1%
Tracking efficiency for π^+ ($\epsilon_{\overline{\Lambda}}$)	0.8%

2b

My Ph.D.

Fixed-target PID with machine learning techniques



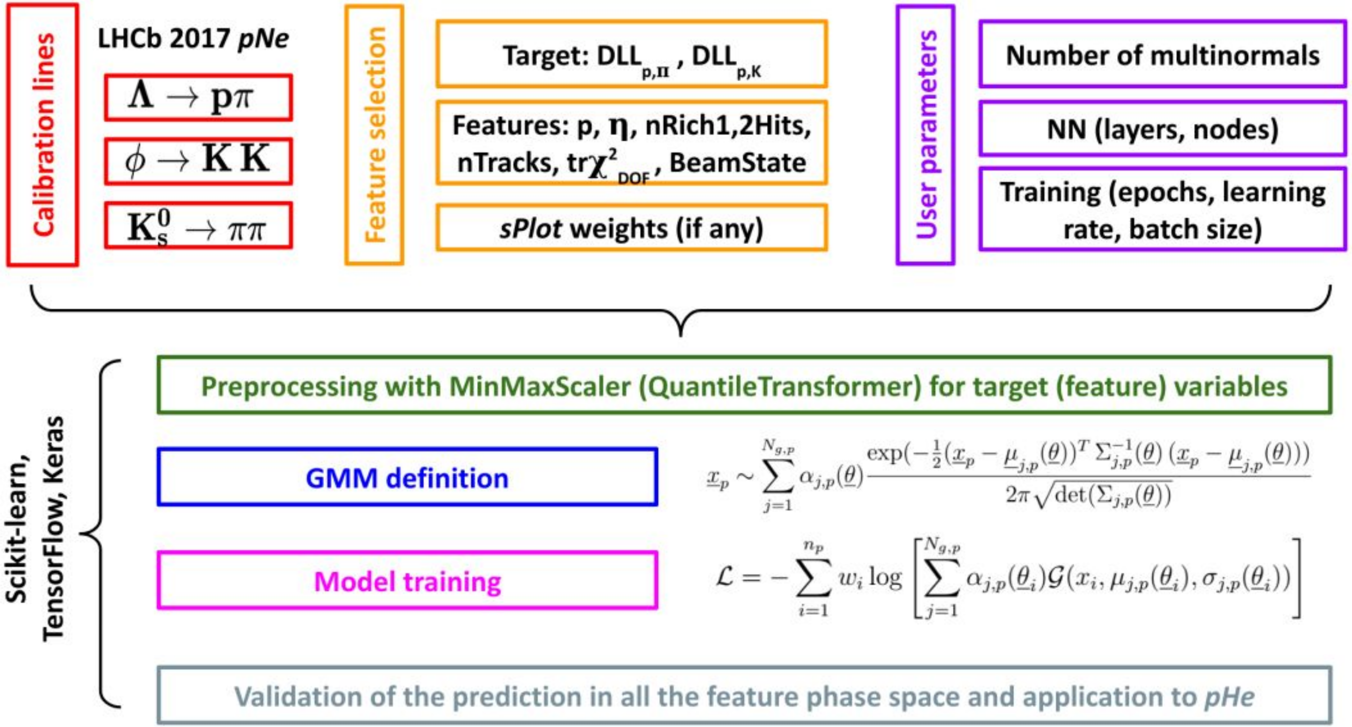
JINST 17 (2022) PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *November 4, 2021*
ACCEPTED: *January 21, 2022*
PUBLISHED: *February 9, 2022*

A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme

G. Graziani,[a] L. Anderlini,[a] S. Mariani,[a,b,c,*] E. Franzoso,[d,e] L.L. Pappalardo[d,e]
and P. di Nezza[f]

PID4SMOG



Calibration lines

LHCb 2017 *pNe*

$\Lambda \to p\pi$

$\phi \to K\,K$

$K^0_s \to \pi\pi$

Feature selection

Target: $DLL_{p,\pi}$, $DLL_{p,K}$

Features: p, η, nRich1,2Hits, nTracks, trχ^2_{DOF}, BeamState

sPlot weights (if any)

User parameters

Number of multinormals

NN (layers, nodes)

Training (epochs, learning rate, batch size)

Scikit-learn, TensorFlow, Keras

Preprocessing with MinMaxScaler (QuantileTransformer) for target (feature) variables

GMM definition

$$\underline{x}_p \sim \sum_{j=1}^{N_{g,p}} \alpha_{j,p}(\underline{\theta}) \frac{\exp(-\frac{1}{2}(\underline{x}_p - \underline{\mu}_{j,p}(\underline{\theta}))^T \Sigma_{j,p}^{-1}(\underline{\theta})\,(\underline{x}_p - \underline{\mu}_{j,p}(\underline{\theta})))}{2\pi\sqrt{\det(\Sigma_{j,p}(\underline{\theta}))}}$$

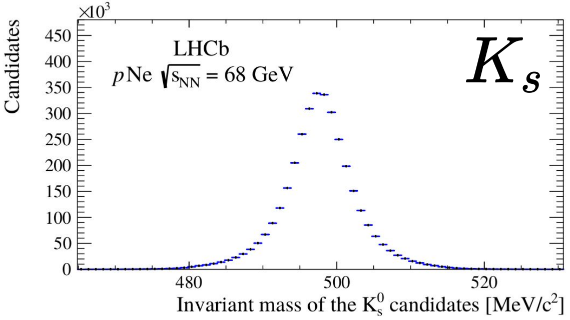
Model training

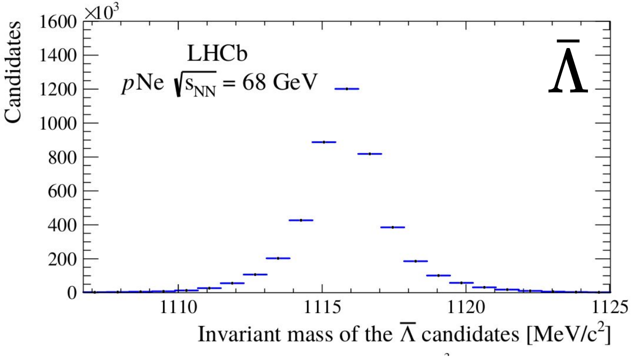
$$\mathcal{L} = -\sum_{i=1}^{n_p} w_i \log\left[\sum_{j=1}^{N_{g,p}} \alpha_{j,p}(\underline{\theta}_i)\mathcal{G}(x_i, \mu_{j,p}(\underline{\theta}_i), \sigma_{j,p}(\underline{\theta}_i))\right]$$

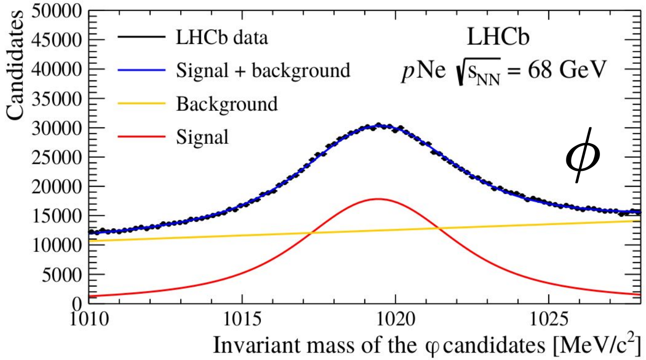
Validation of the prediction in all the feature phase space and application to *pHe*

Calibration decays and relevant features

- The $\Lambda \to p\pi\,(\bar{\Lambda} \to \bar{p}\pi)$, $K_s \to \pi\pi$ and $\phi(1020) \to KK$ decays are reconstructed and selected in the **SMOG largest-statistics sample (2017 *p*Ne)**





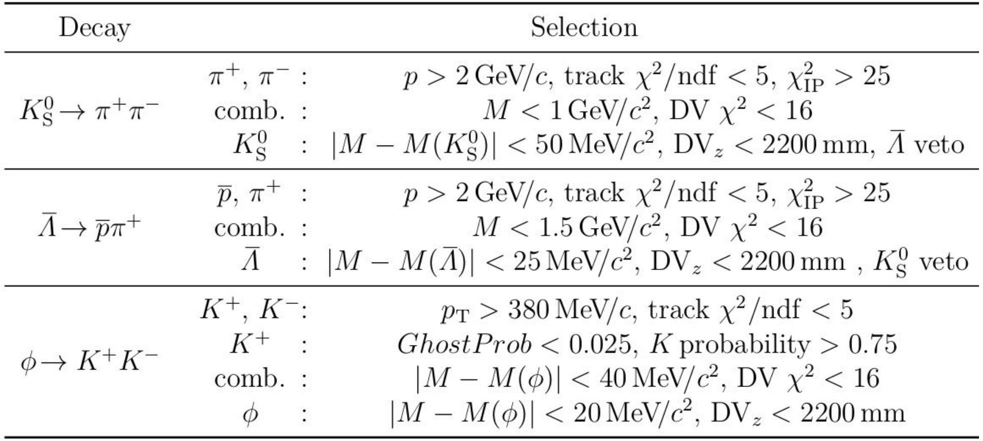


Variable	Variable	Variable
$\boldsymbol{p}$	p_z	$\boldsymbol{\eta}$
p_{T}	**yz slope**	**track ndf**
xz slope	**nTracks**	**$\mathrm{N}_{\mathrm{RICH2}}$ hits**
N_{SPD} hits	**$\mathrm{N}_{\mathrm{RICH1}}$ hits**	**track χ^2/ndf**

- Particle kinematics, detector occupancy, event geometry, track reconstruction quality confirmed to be the most relevant features (see backup)

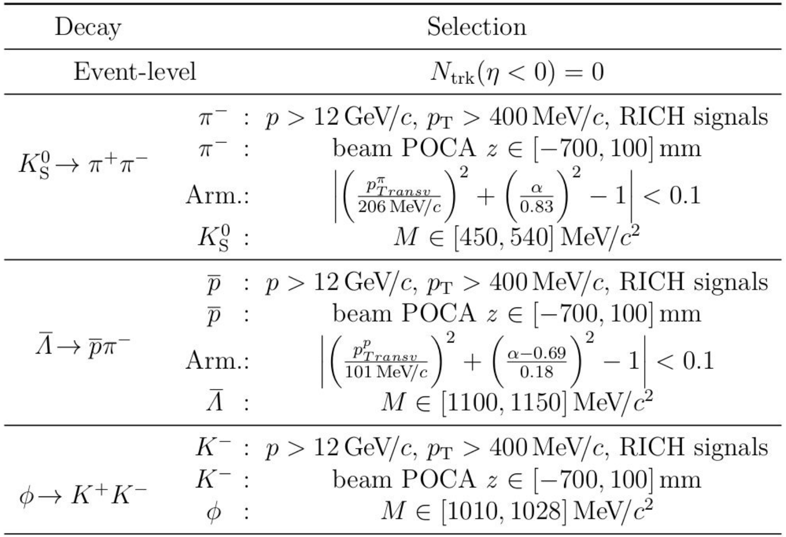
PID4SMOG: calibration decays selection

Table III.1.1: PID calibration channels first selection stage in the 2017 pNe data.



Decay		Selection
$K^0_\mathrm{S} \to \pi^+\pi^-$	π^+, π^- :	$p > 2\,\mathrm{GeV}/c$, track $\chi^2/\mathrm{ndf} < 5$, $\chi^2_\mathrm{IP} > 25$
	comb. :	$M < 1\,\mathrm{GeV}/c^2$, DV $\chi^2 < 16$
	K^0_S :	$\lvert M - M(K^0_\mathrm{S})\rvert < 50\,\mathrm{MeV}/c^2$, $\mathrm{DV}_z < 2200\,\mathrm{mm}$, $\bar{\mathit{\Lambda}}$ veto
$\bar{\mathit{\Lambda}} \to \bar{p}\pi^+$	$\bar{p}$, π^+ :	$p > 2\,\mathrm{GeV}/c$, track $\chi^2/\mathrm{ndf} < 5$, $\chi^2_\mathrm{IP} > 25$
	comb. :	$M < 1.5\,\mathrm{GeV}/c^2$, DV $\chi^2 < 16$
	$\bar{\mathit{\Lambda}}$:	$\lvert M - M(\bar{\mathit{\Lambda}})\rvert < 25\,\mathrm{MeV}/c^2$, $\mathrm{DV}_z < 2200\,\mathrm{mm}$, K^0_S veto
$\phi \to K^+K^-$	K^+, K^-:	$p_\mathrm{T} > 380\,\mathrm{MeV}/c$, track $\chi^2/\mathrm{ndf} < 5$
	K^+ :	$GhostProb < 0.025$, K probability > 0.75
	comb. :	$\lvert M - M(\phi)\rvert < 40\,\mathrm{MeV}/c^2$, DV $\chi^2 < 16$
	ϕ :	$\lvert M - M(\phi)\rvert < 20\,\mathrm{MeV}/c^2$, $\mathrm{DV}_z < 2200\,\mathrm{mm}$

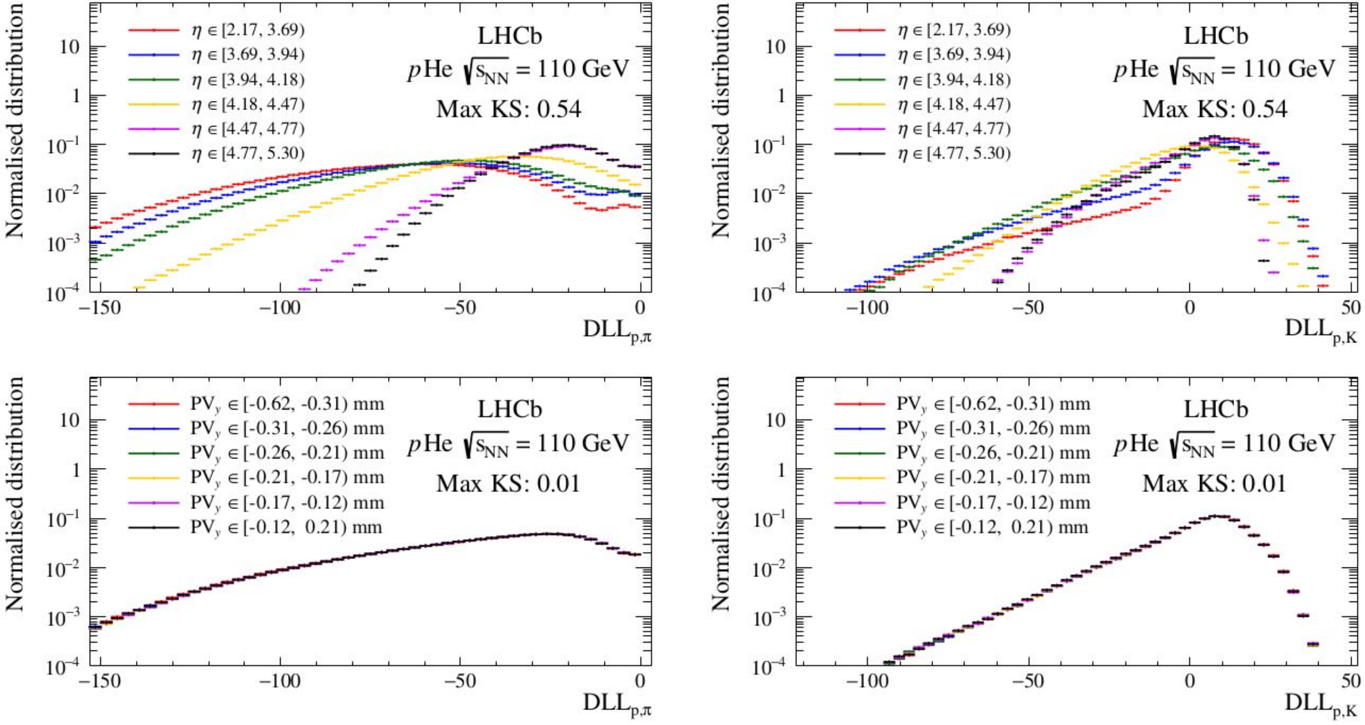
Table III.1.2: PID calibration channels second selection stage in the 2017 pNe data.



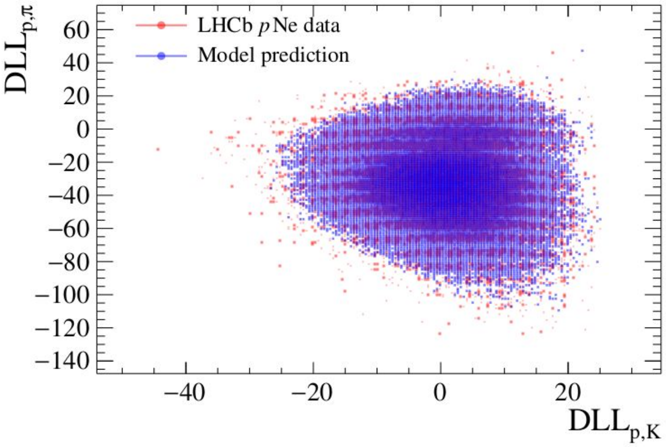
Decay		Selection
Event-level		$N_\mathrm{trk}(\eta < 0) = 0$
$K^0_\mathrm{S} \to \pi^+\pi^-$	π^- :	$p > 12\,\mathrm{GeV}/c$, $p_\mathrm{T} > 400\,\mathrm{MeV}/c$, RICH signals
	π^- :	beam POCA $z \in [-700, 100]\,\mathrm{mm}$
	Arm.:	$\left\lvert\left(\frac{p^{\pi}_{Transv}}{206\,\mathrm{MeV}/c}\right)^2 + \left(\frac{\alpha}{0.83}\right)^2 - 1\right\rvert < 0.1$
	K^0_S :	$M \in [450, 540]\,\mathrm{MeV}/c^2$
$\bar{\mathit{\Lambda}} \to \bar{p}\pi^-$	$\bar{p}$:	$p > 12\,\mathrm{GeV}/c$, $p_\mathrm{T} > 400\,\mathrm{MeV}/c$, RICH signals
	$\bar{p}$:	beam POCA $z \in [-700, 100]\,\mathrm{mm}$
	Arm.:	$\left\lvert\left(\frac{p^{p}_{Transv}}{101\,\mathrm{MeV}/c}\right)^2 + \left(\frac{\alpha-0.69}{0.18}\right)^2 - 1\right\rvert < 0.1$
	$\bar{\mathit{\Lambda}}$:	$M \in [1100, 1150]\,\mathrm{MeV}/c^2$
$\phi \to K^+K^-$	K^- :	$p > 12\,\mathrm{GeV}/c$, $p_\mathrm{T} > 400\,\mathrm{MeV}/c$, RICH signals
	K^- :	beam POCA $z \in [-700, 100]\,\mathrm{mm}$
	ϕ :	$M \in [1010, 1028]\,\mathrm{MeV}/c^2$

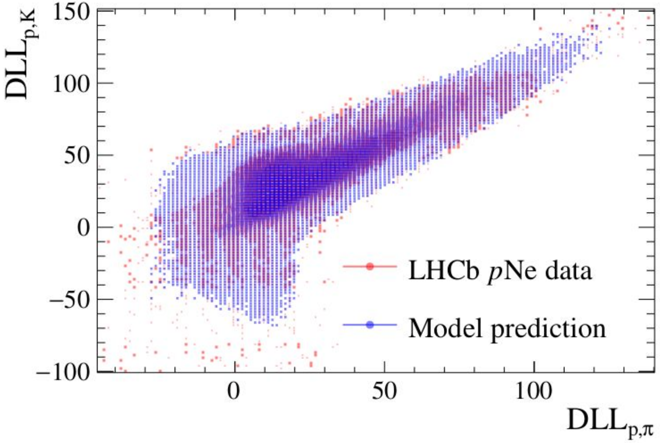
PID4SMOG: feature selection

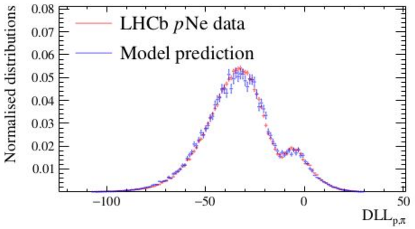
Variable	Max KS	Variable	Max KS	Variable	Max KS
$\boldsymbol{p}$	0.64	p_z	0.64	$\boldsymbol{\eta}$	0.54
p_{T}	0.51	$\boldsymbol{yz}$ **slope**	0.38	**track ndf**	0.34
$\boldsymbol{xz}$ **slope**	0.34	**nTracks**	0.34	$\mathbf{N_{RICH2}}$ **hits**	0.33
N_{SPD} hits	0.32	$\mathbf{N_{RICH1}}$ **hits**	0.28	**track** $\boldsymbol{\chi^2}$**/ndf**	0.26

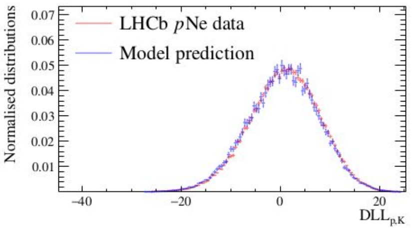


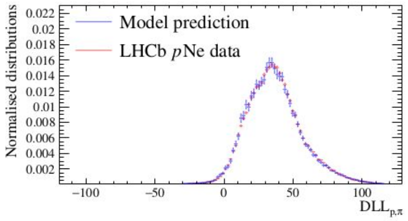
PID4SMOG: model validation

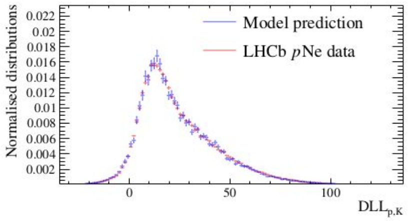




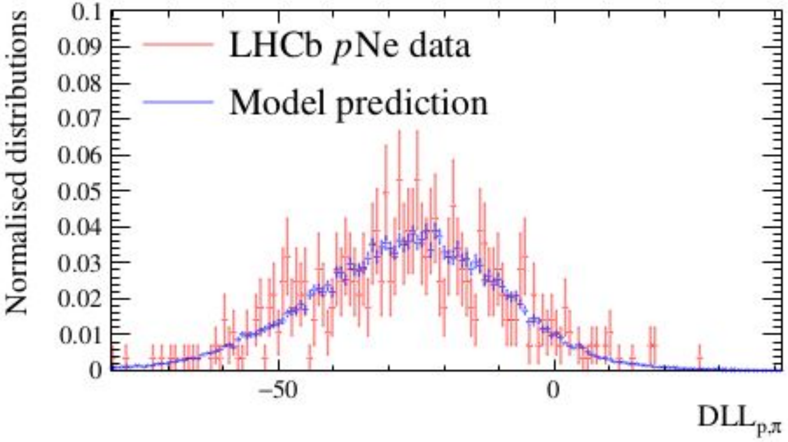


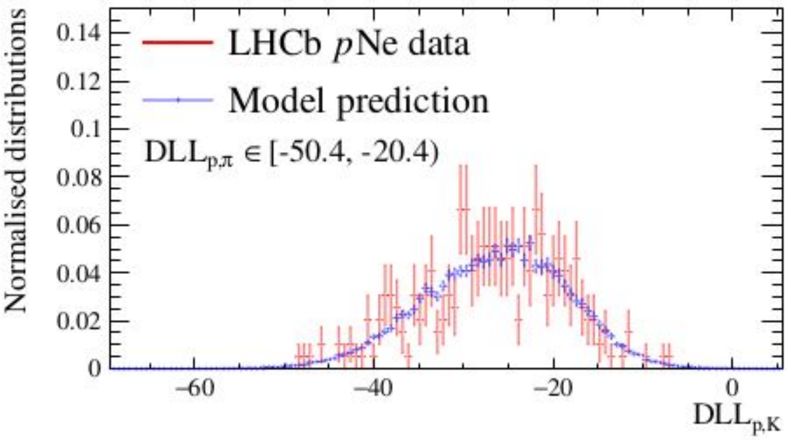




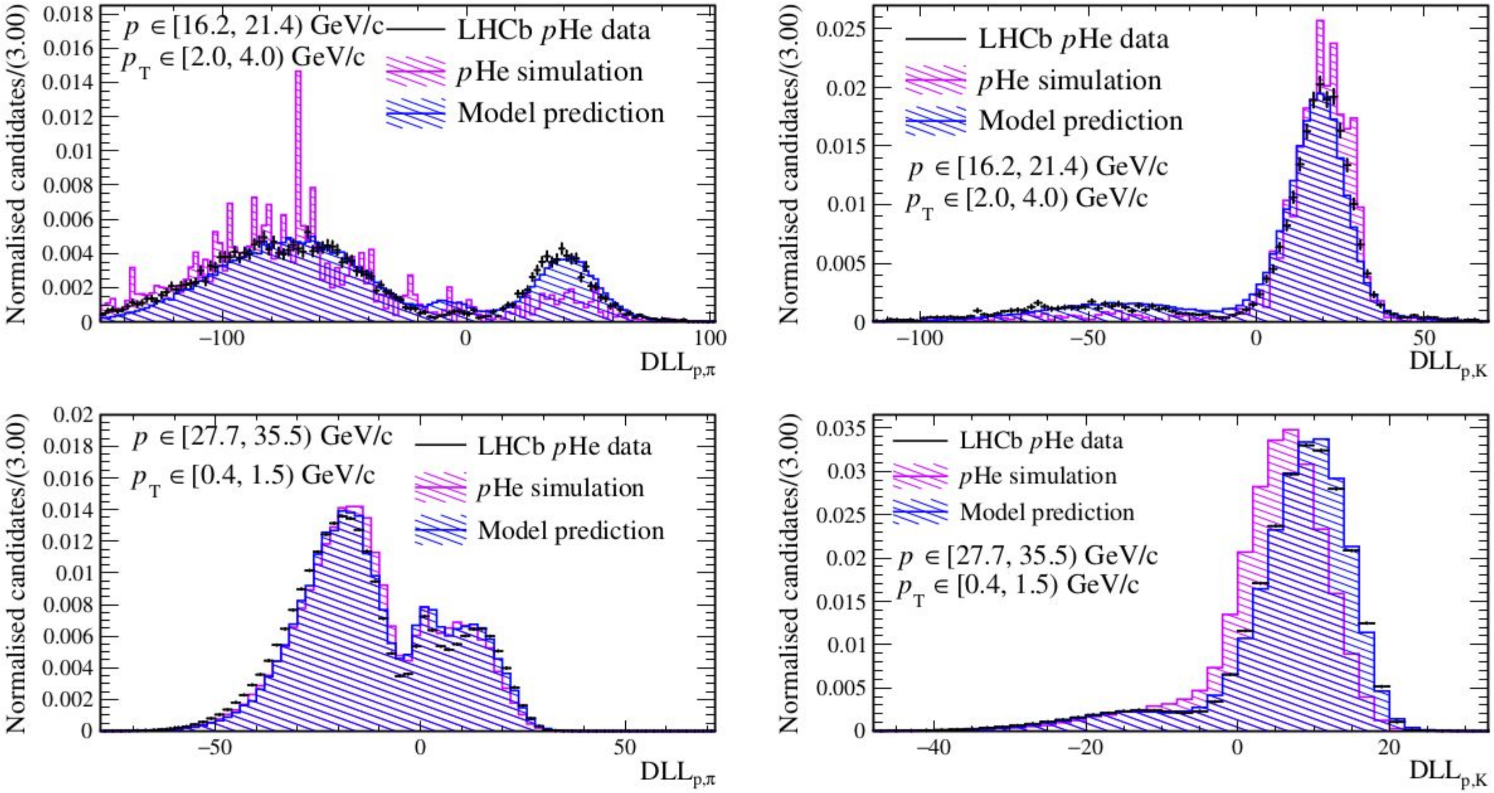


PID4SMOG: model validation

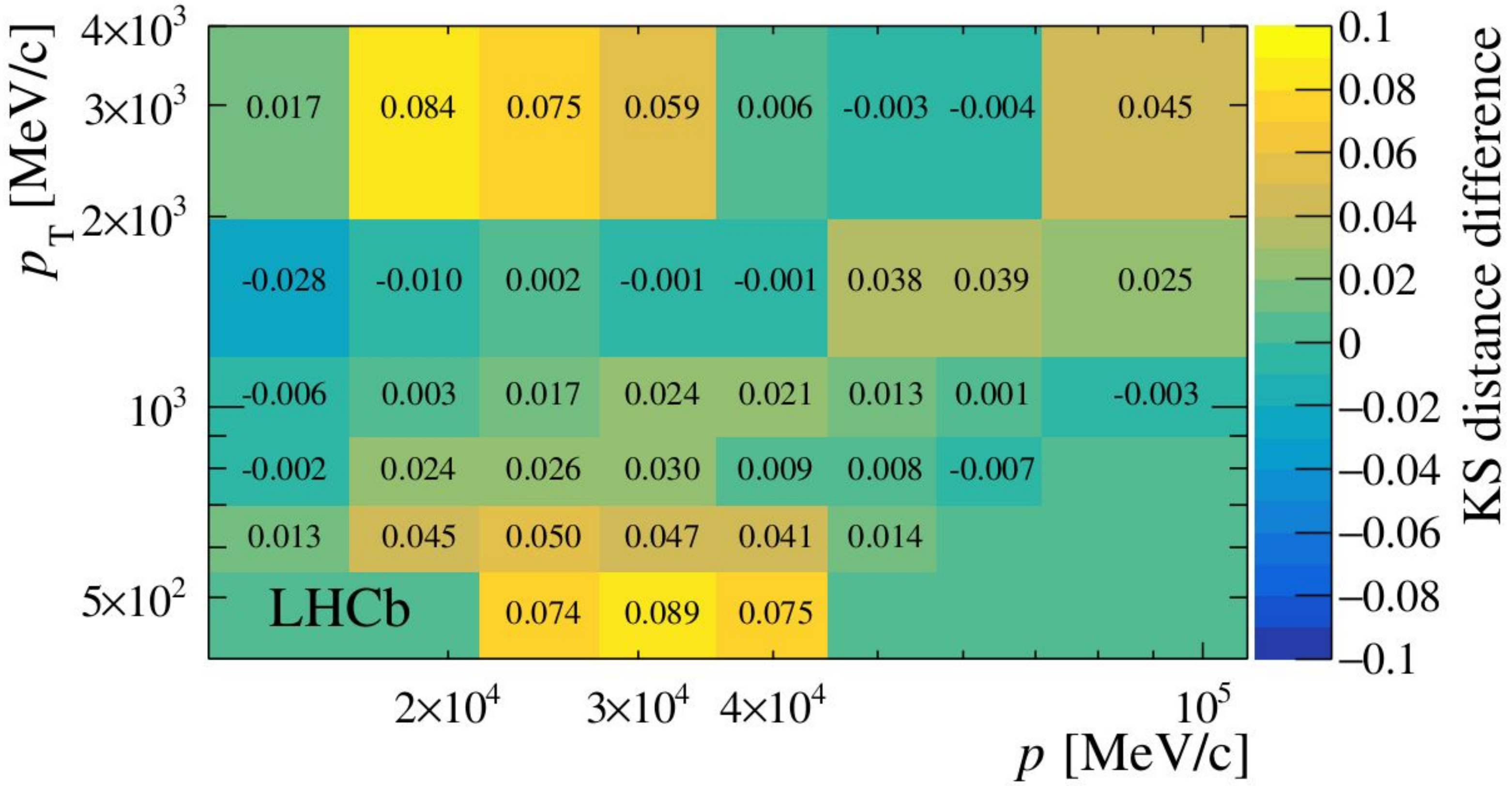




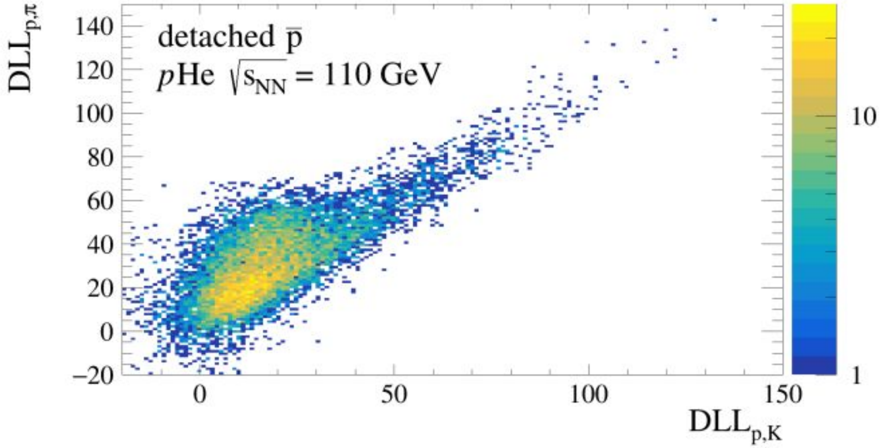
PID4SMOG: model validation

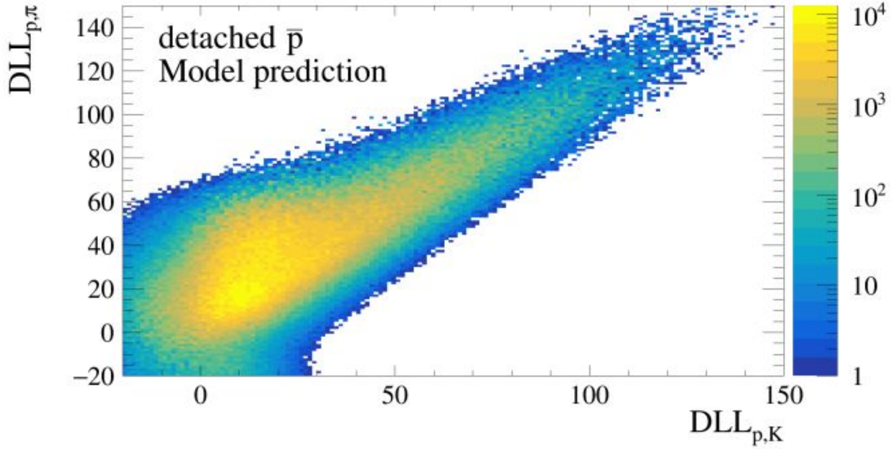


PID4SMOG: KS difference

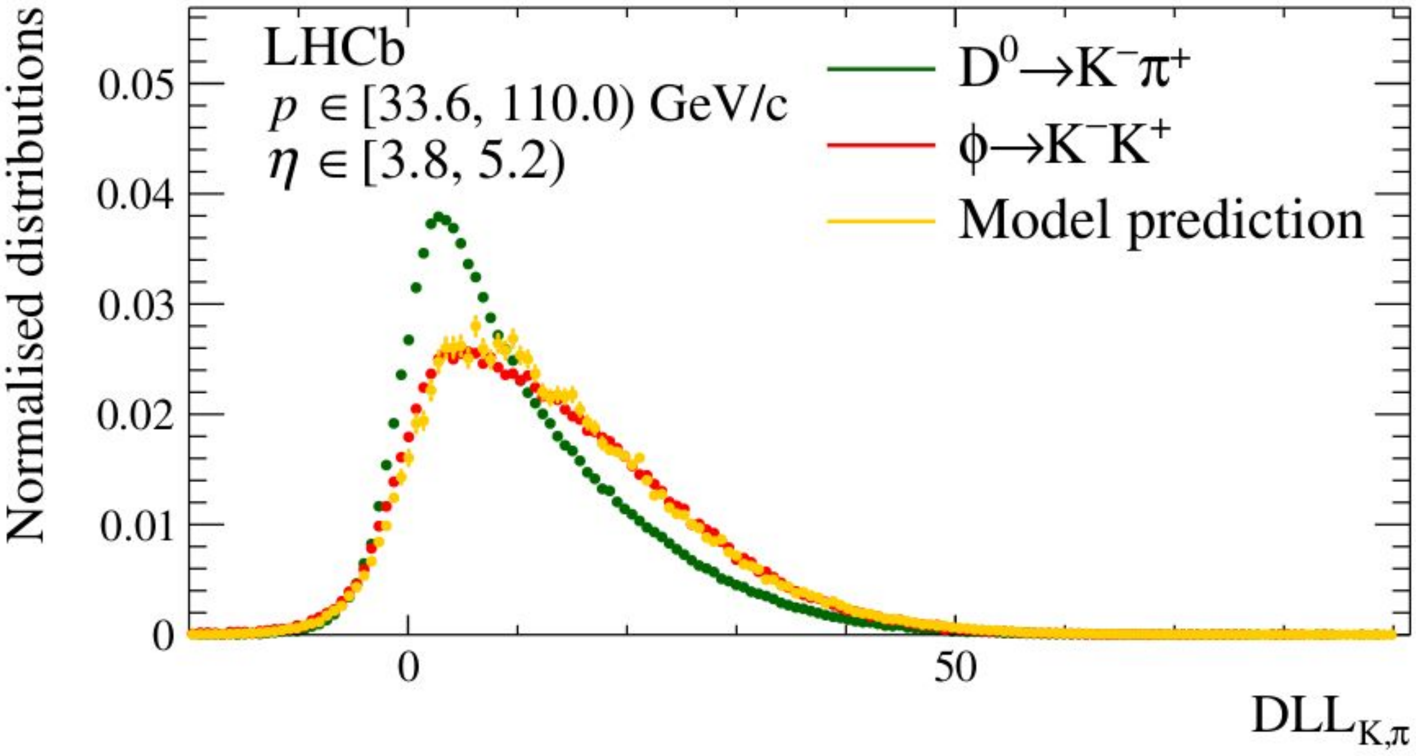


PID4SMOG: Detached antiprotons





PID4SMOG: Application to *pp*



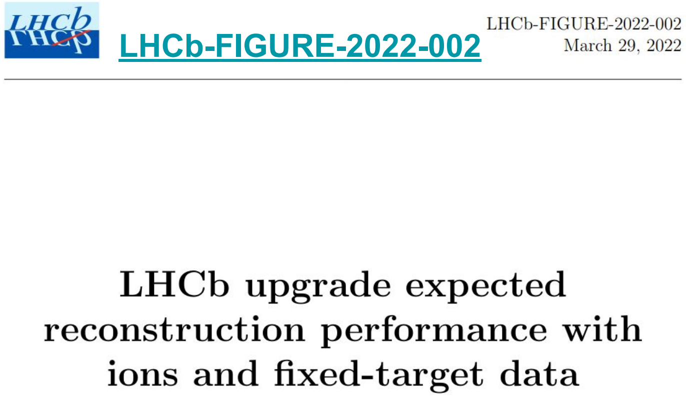
3

My Ph.D.

Upgrade of the SMOG system

LHCb- TDR-020
LHCb-PUB-2018-015

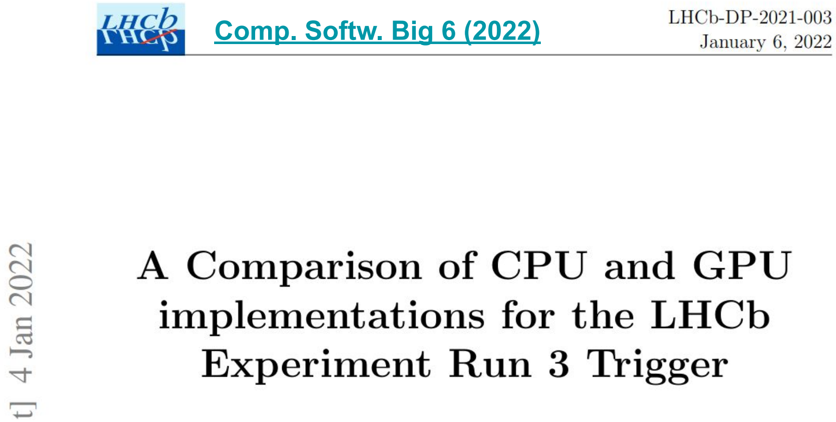
PoS(EPS-HEP2021) 396



LHCb-FIGURE-2022-002

LHCb-FIGURE-2022-002
March 29, 2022

LHCb upgrade expected reconstruction performance with ions and fixed-target data



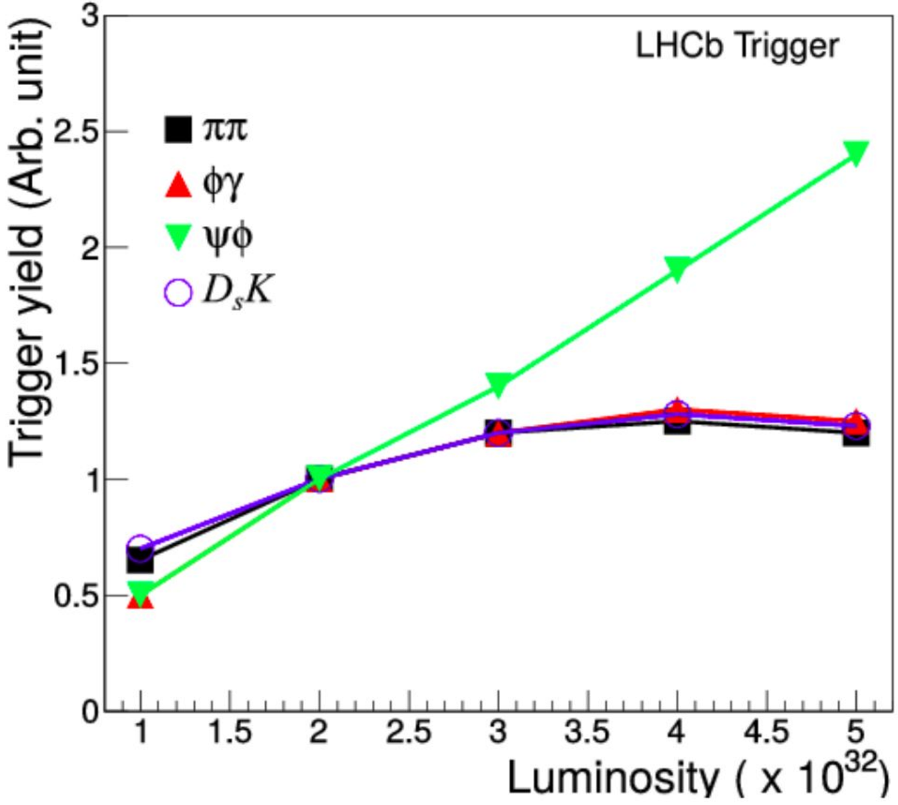
Comp. Softw. Big 6 (2022)

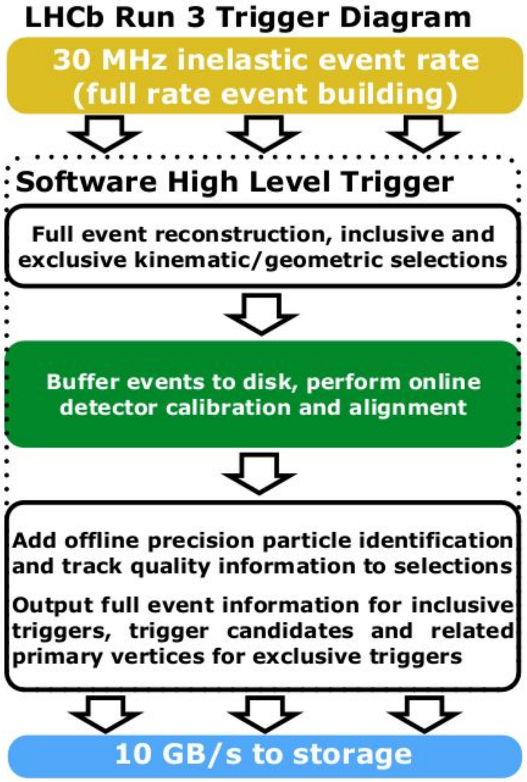
LHCb-DP-2021-003
January 6, 2022

t] 4 Jan 2022

A Comparison of CPU and GPU implementations for the LHCb Experiment Run 3 Trigger

LHCb Upgrade trigger





LHCb Run 3 Trigger Diagram

30 MHz inelastic event rate (full rate event building)

Software High Level Trigger

Full event reconstruction, inclusive and exclusive kinematic/geometric selections

Buffer events to disk, perform online detector calibration and alignment

Add offline precision particle identification and track quality information to selections

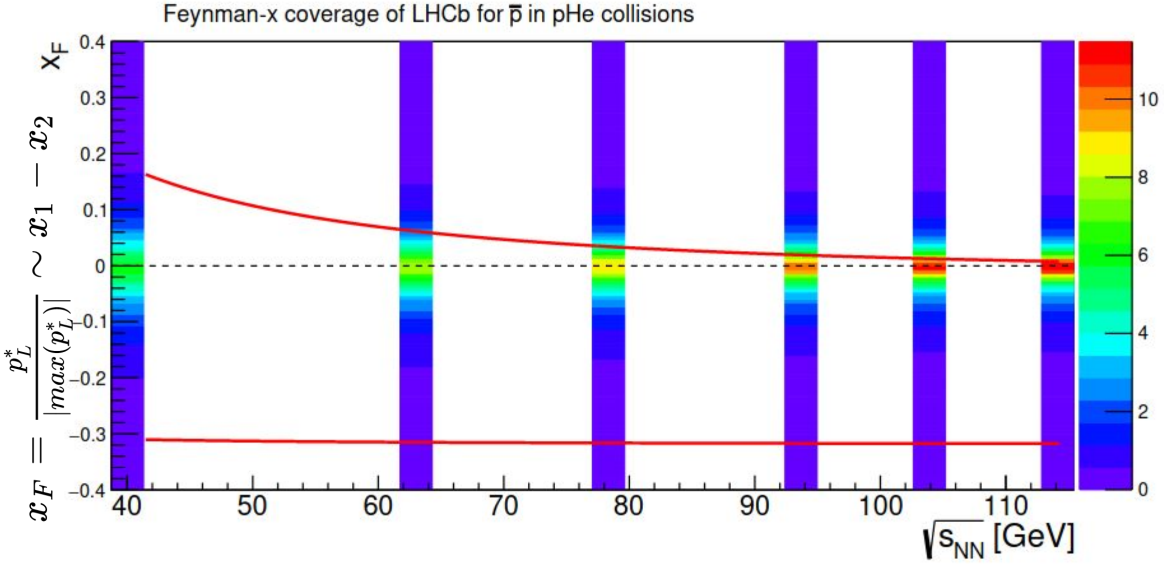
Output full event information for inclusive triggers, trigger candidates and related primary vertices for exclusive triggers

10 GB/s to storage

Physics opportunities with SMOG2 for CRs

- For the LHCb space mission completion:

LHCb-PUB-2018-015



- Lowering of the CM energy range, accessing **positive Feynman x values**
- Result precision improvement with the *H/He* production ratio,where most systematics cancels
- Constraint of the **antiproton production in antineutron decays** with the *D/H* ratio (**isospin violation**?)
- Possible to study **anti-nuclei production**?

Prospects for DY measurements with SMOG2

LHCb-PUB-2018-015

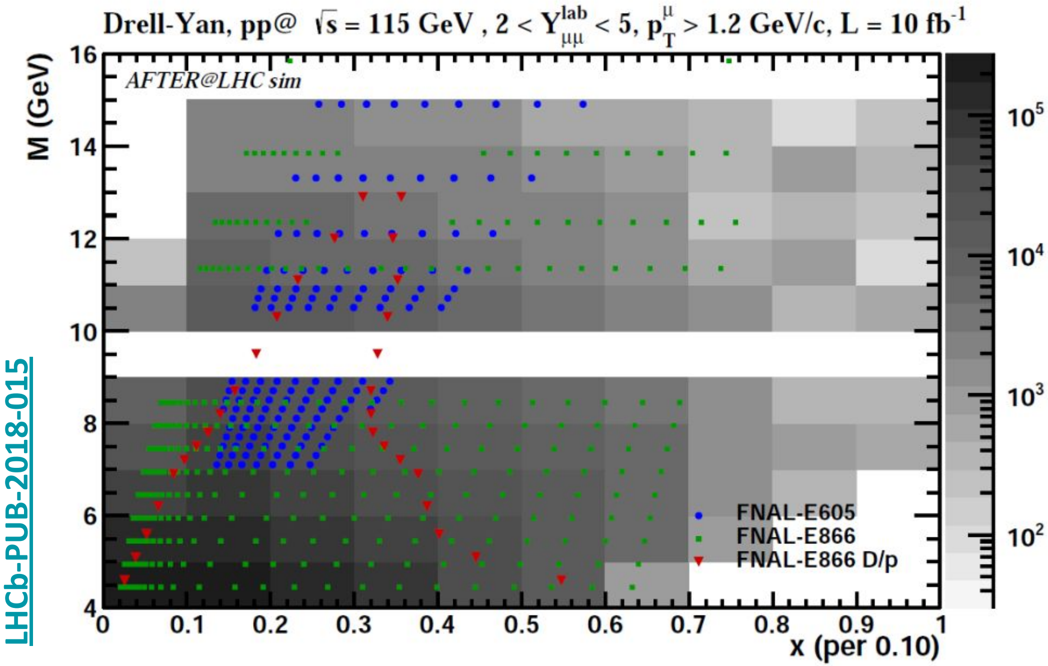
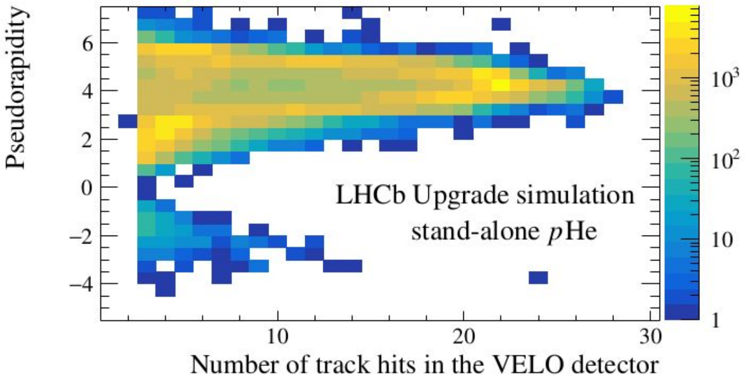
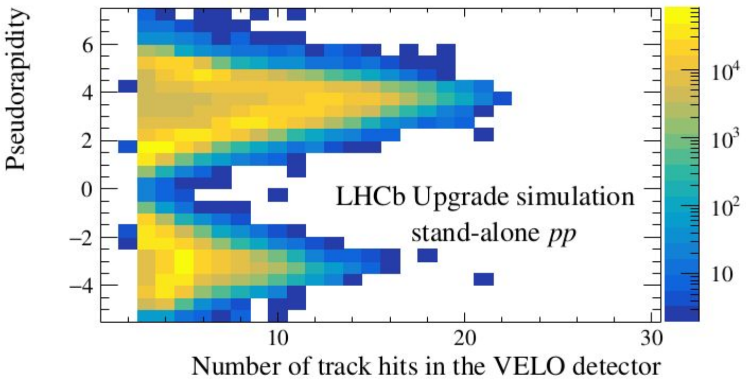
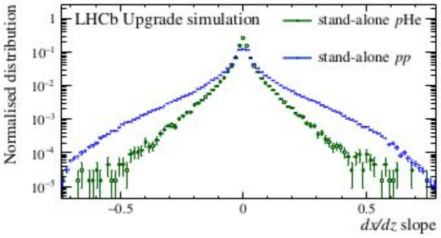


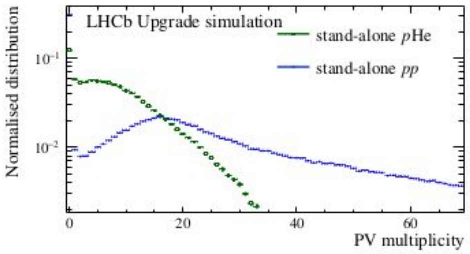
Figure 10: Comparison of the kinematic reach for DY muon-pair production between fixed-target LHCb (gray histogram) and existing data used in current global PDF fits (coloured points). The histogram represents the number of events for 10 fb^{-1} of pp collisions. Estimation performed by the AFTER collaboration [3].

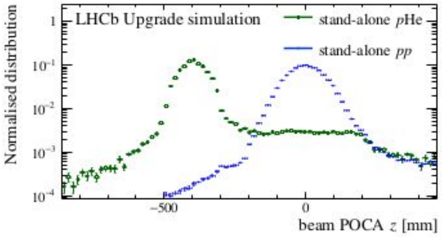
Event topology differences

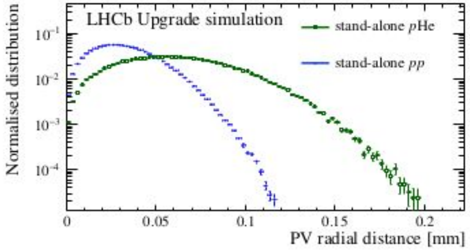






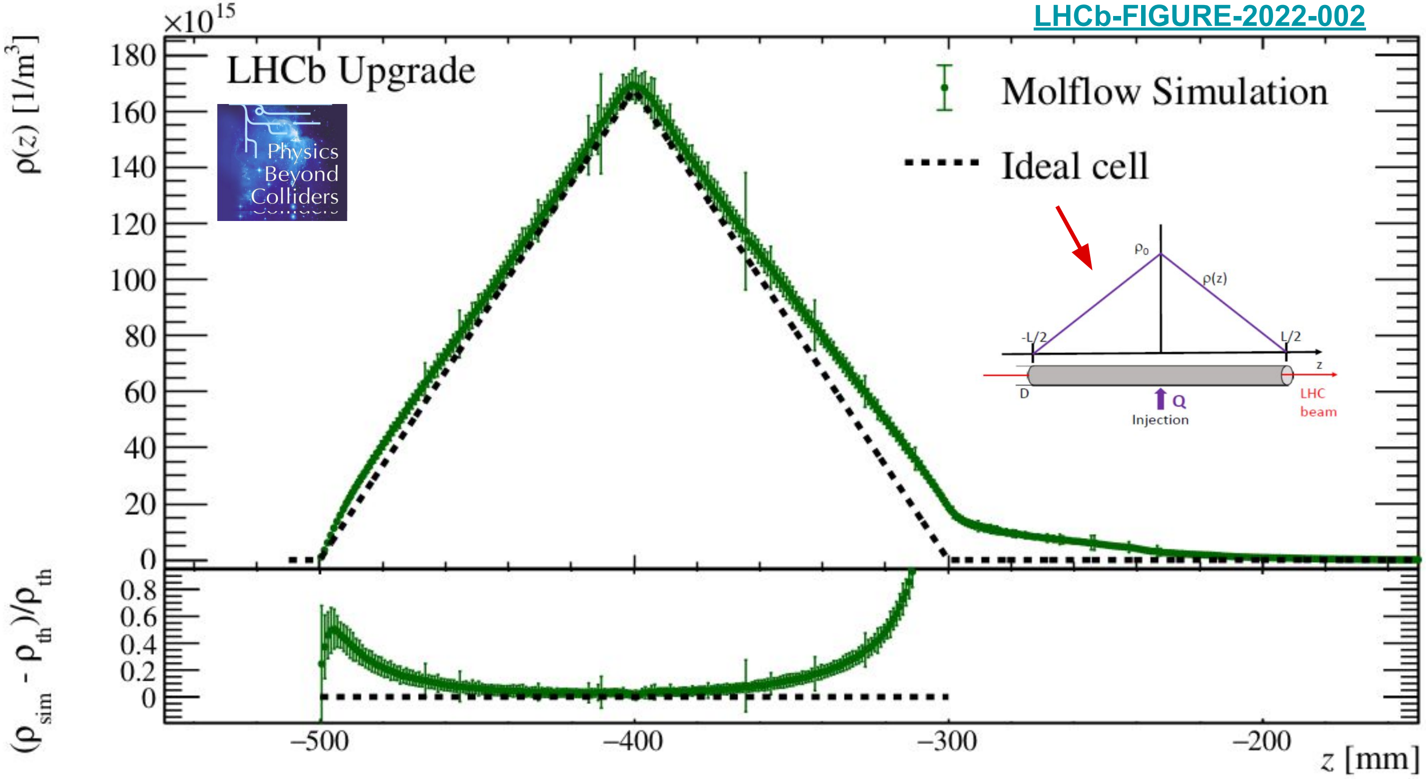




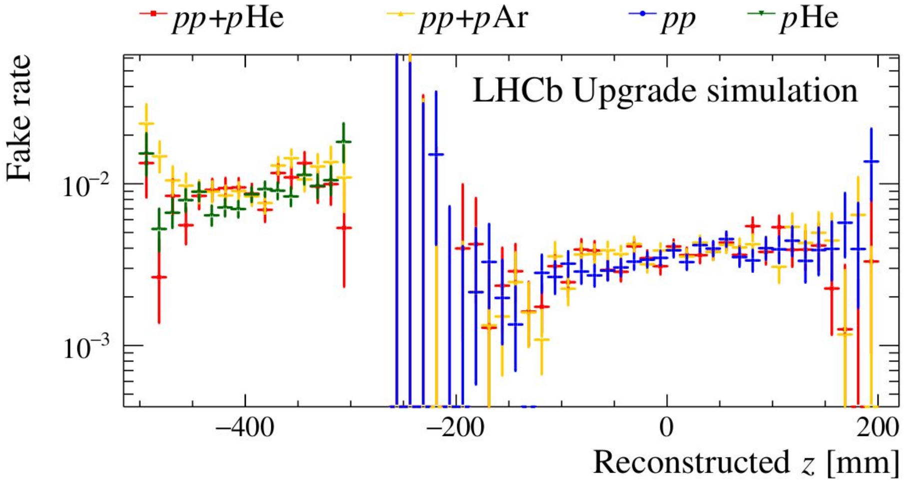


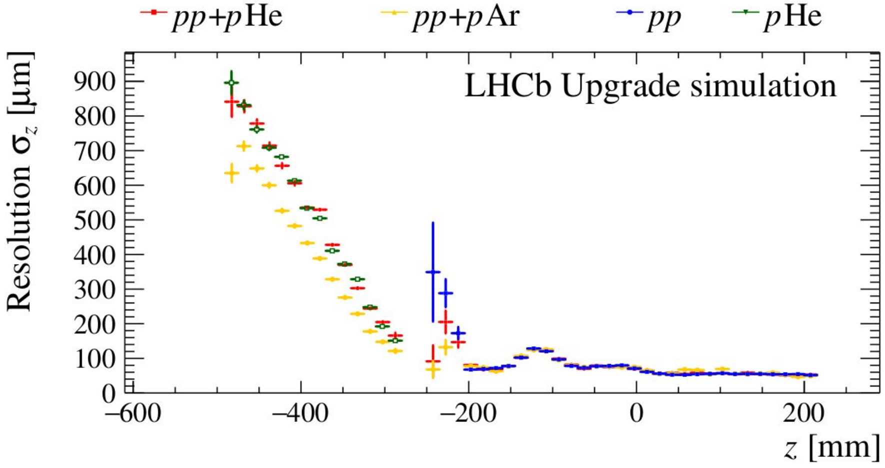
Validation of the ideal cell model

LHCb-FIGURE-2022-002

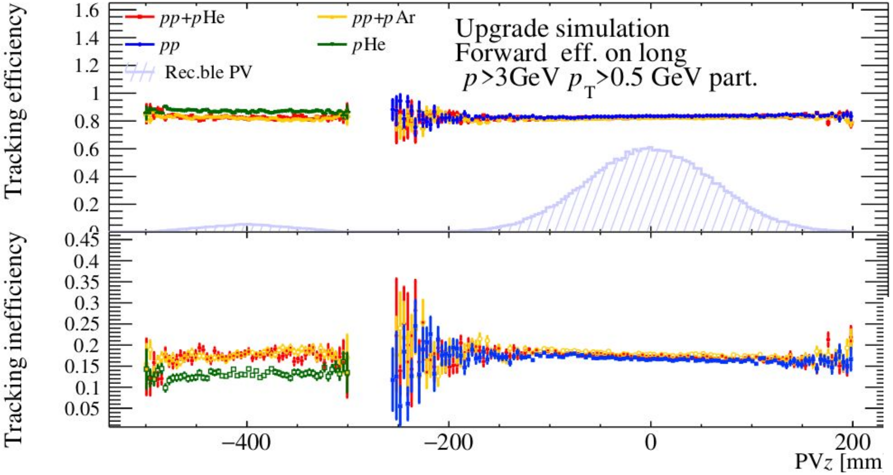


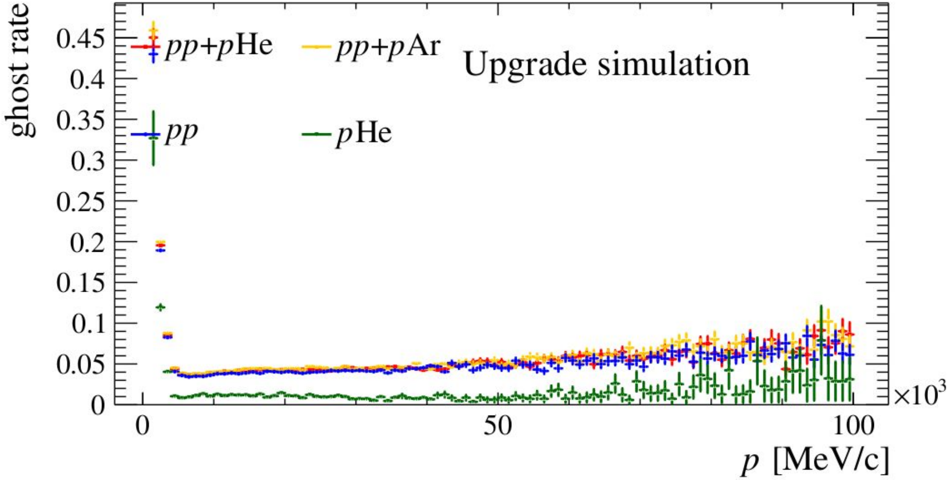
PV resolution





Forward tracking





Offline-quality tracking