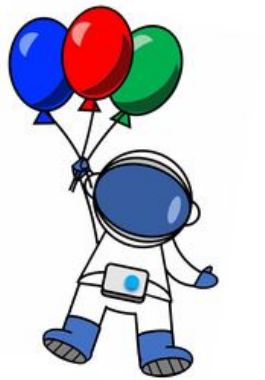
Commissioning and first collisions with the LHCb SMOG2 system



Saverio Mariani
CERN
On behalf of the LHCb collaboration

Quark Matter 2023, 06/09/2023

Introduction

- Since 2015, **LHCb has been pioneering fixed-target physics at LHC,** at the **highest energy ever reached in fixed-target mode**
- With SMOG and its upgrade SMOG2, collected several *p*A and PbA samples, constraining theoretical models in a **poorly explored kinematic region**

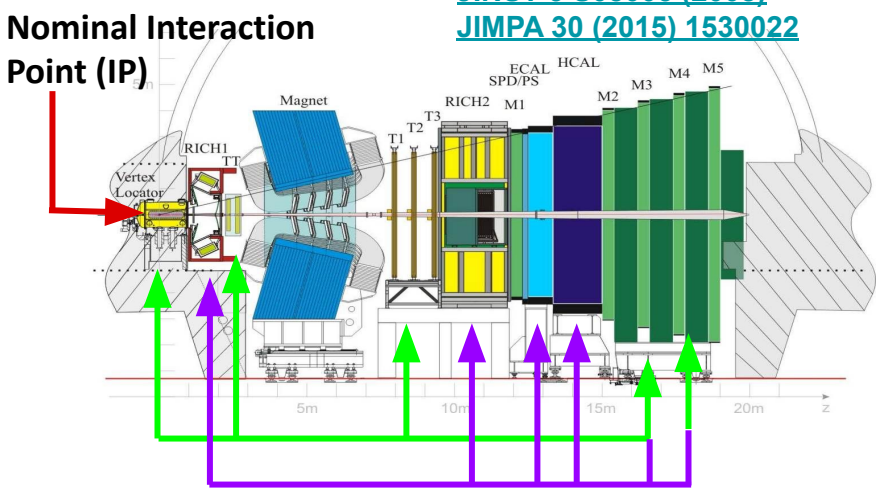
- Back to last edition in 2022, **expected results from simulation studies** discussed

- SMOG2 is now in action and **proof of principle validation accomplished**

Run1-2 LHCb and its upgrade

- **A single-arm spectrometer working as a general purpose experiment** for η ϵ [2, 5]

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



- Excellent **tracking** and **particle identification** in a **complementary η** wrt other experiments
- Flexible and versatile trigger system

JINST 8 04022 (2013)

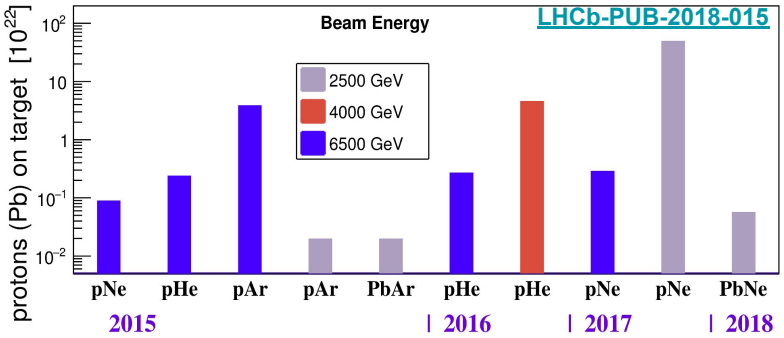
- Major upgrade in 2018-2022: LHCb-DP-2022-002
  - **Tracking system fully replaced** + all electronics/DAQ channels
  - **Hardware trigger removed**: now full detector read-out, calibration, alignment and event reconstruction and selection in software (including full HLT1 on GPUs)

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

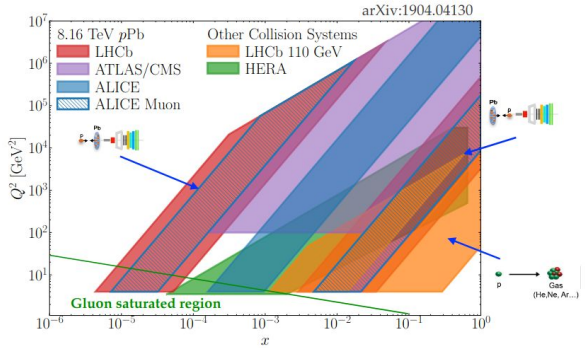
Fixed-target physics @ LHCb

- LHCb with a **gas injection system (SMOG) since 2011**, initially for LHC lumi measurements

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



- Several *p*A and PbA samples collected (A = He, Ne, Ar) with **intermediate energy between SPS and RHIC/LHC energies** ($\sqrt{s_{\mathrm{NN}}} \in [68.5, 110]\,\mathrm{GeV}$)



- **High-*x* and intermediate Q^2 region**, poorly explored by previous experiments, now accessible
- Many results published with Run2 samples, addressing CNM, QGP probes, astrophysics…

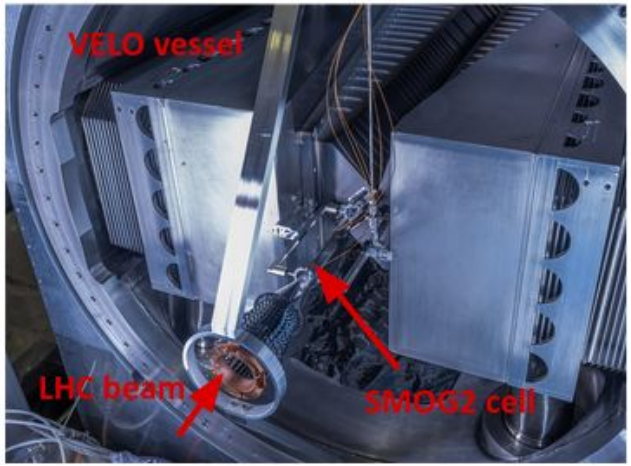
PRL (2019) 132002
EPJ C83 (2023) 541
EPJ C83 (2023) 625
EPJ C83 (2023) 658

PRL 121 222001 (2018)
EPJC 83, 543 (2023)

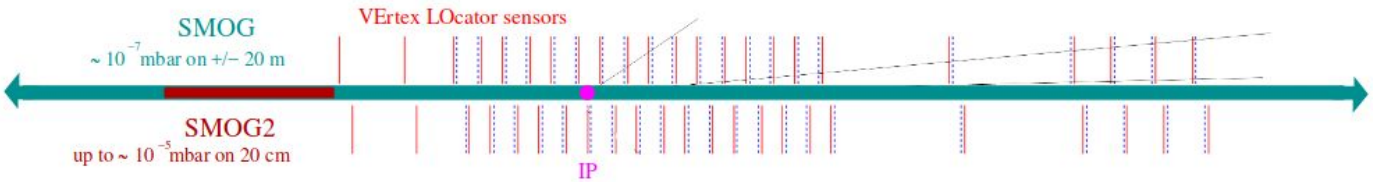
More in the talk by Kara Mattioli on 05/09!

The SMOG2 system

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



- **SMOG2: gas confinement in a cell upstream of the LHCb IP** ($z \in [-541, -341]$ mm), installed in 2020
  - Cell **made up of two halves**, to be opened and closed together with the VELO
  - Up to x100 **density 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 ⟶ **fast gas replacement**



Foreseen physics opportunities with SMOG2

- The **wider choice of gases, the increase in injected pressure** and the simultaneous beam-beam and beam-gas data-taking open new possibilities

LHCb-PUB-2018-015

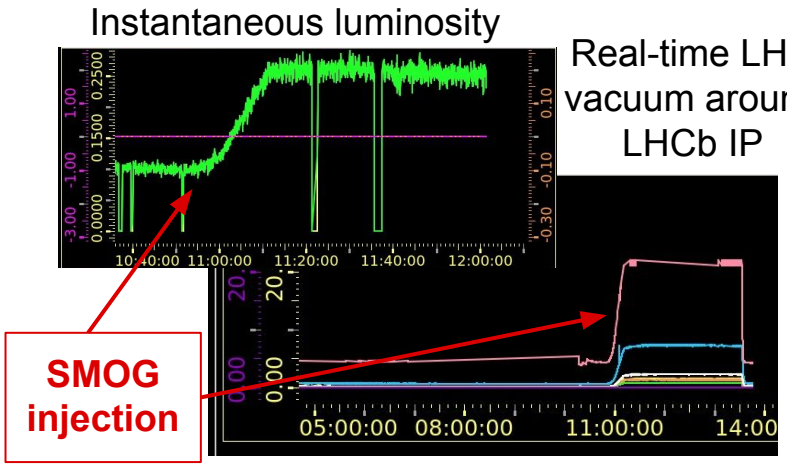
	SMOG largest sample p–Ne@68 GeV	SMOG2 example p–Ar@115 GeV
Integrated luminosity	~ 100 nb^{-1}	100 pb^{-1}
syst. error on J/ψ x-sec.	6–7%	2–3 %
J/ψ yield	15k	35M
D^0 yield	100k	350M
Λ_c yield	1k	3.5M
ψ(2S) yield	150	400k
Υ(1S) yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9$ GeV/c^2) Drell-Yan yield	5	20k

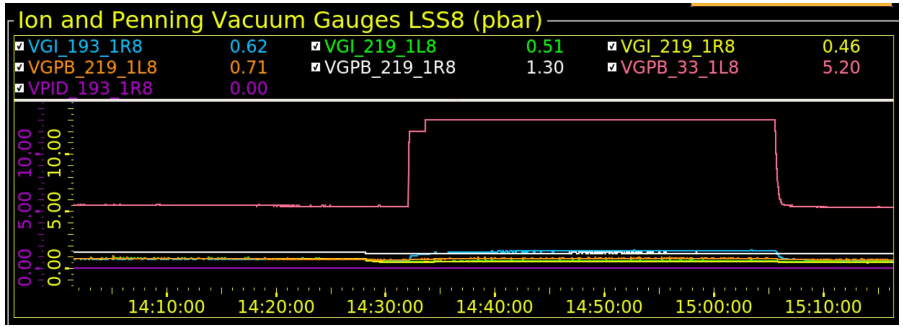
- Precision studies of **charm sequential suppression**, bottomonia, low-mass DY

- 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: antimatter production in the galaxy **with H_2, D_2, He; atmospheric showers with N_2, O_2**

A unique laboratory for many and diverse QCD studies at the LHC!

SMOG2 system commissioning

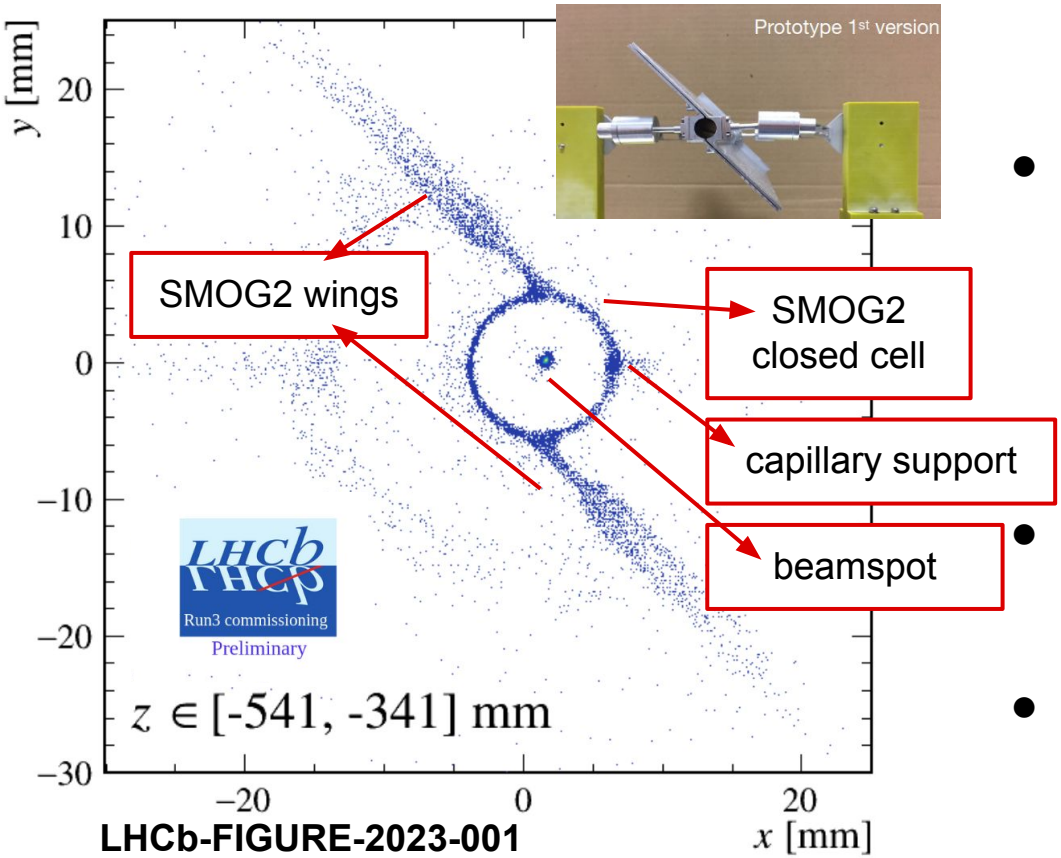




- In June 2022, with 450 GeV beams, first injections **through the open SMOG2 cell**, allowing CERN vacuum experts to **set the injection procedure**
  - **01/11:** First injection in the closed cell
  - **Very stable operations,** with injected Ar with a pressure 6.5 times lower wrt Run2, already **achieved a x5.5 higher inst. luminosity**!
  - In 11/2022, injected He, Ne, Ar and, **for the first time ever**, H_2

GFS fully and successfully commissioned

Visualise SMOG2 in real-time

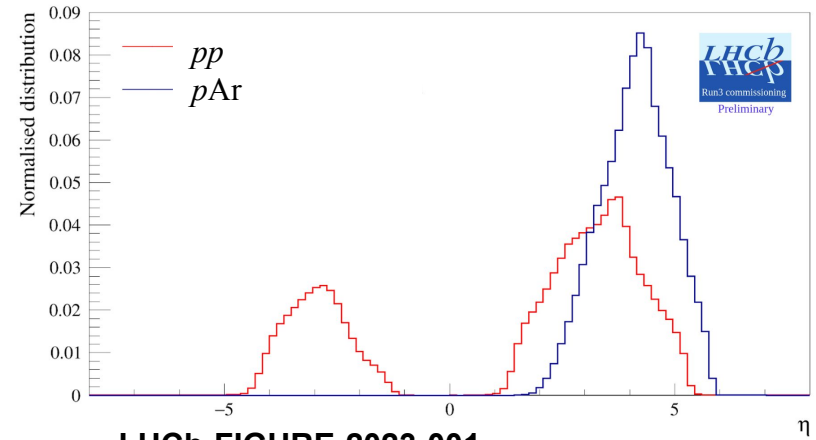


LHCb-FIGURE-2023-001

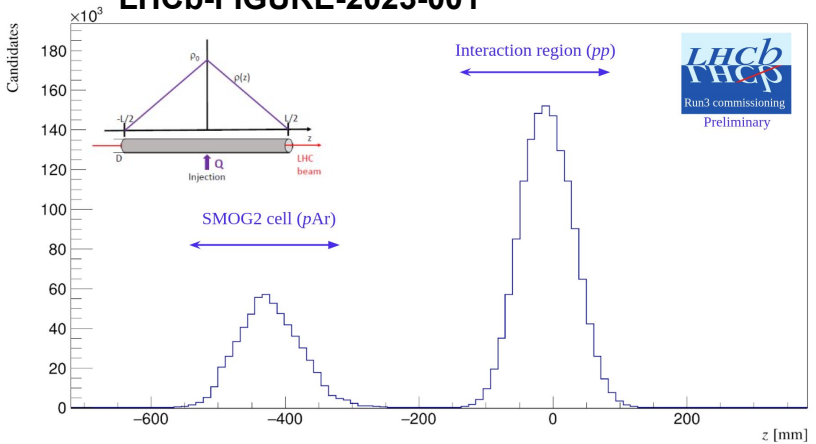
- **SMOG2 cell radiography**, as obtained from material interaction vertices reconstructed in real-time

- Remarkable level of details describing the **SMOG2 cell position** and its **material distribution**
- Alignment achieved during installation cross-checked on data

Reconstructing 2022 early-data (I)



LHCb-FIGURE-2023-001



- Early data collected in 2022 also used to **validate reconstruction algorithms** and have a first performance assessment

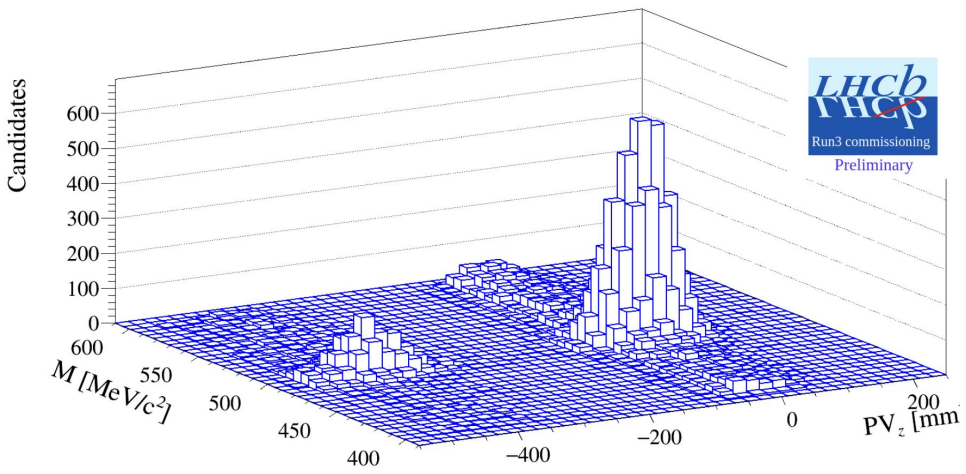
- Tracks reconstructed in the VELO show central geometry for *pp*, forward-only for *p*Ar collisions in SMOG2
- Despite different collision geometry, **two clearly distinct primary vertex distributions**

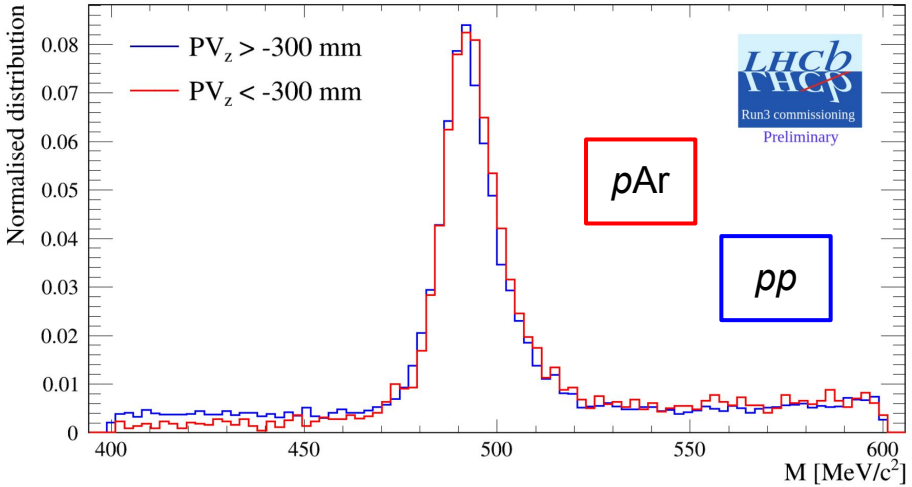
- **LHCb working simultaneously as collider and fixed-target experiment @ two different energies**

Reconstructing 2022 early-data (II)

- Reconstruction of composite particles out of the first software trigger level compared between beam-beam and beam-gas
  - **The mass resolution for Ks produced in *pp* and *p*Ar collisions is the same!**

LHCb-FIGURE-2023-001

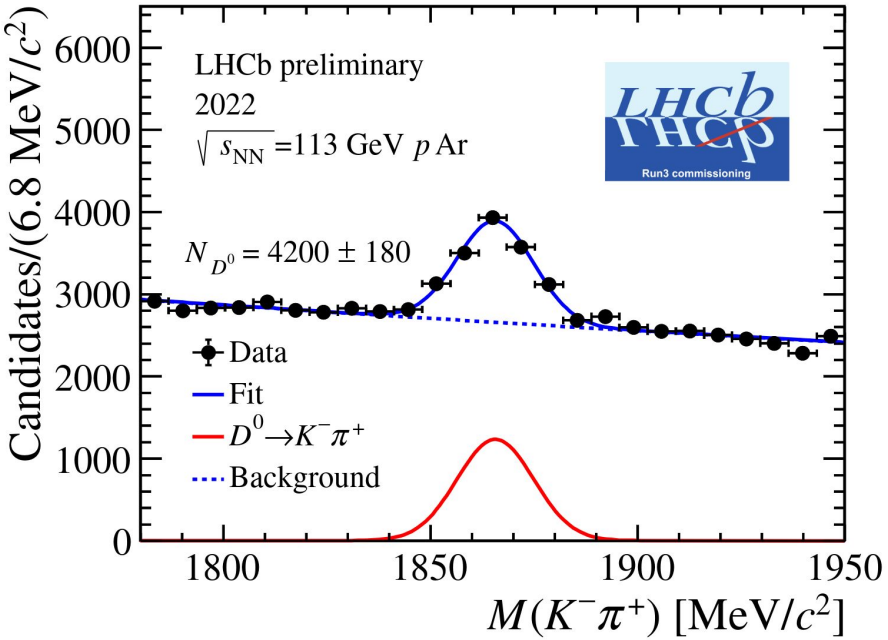


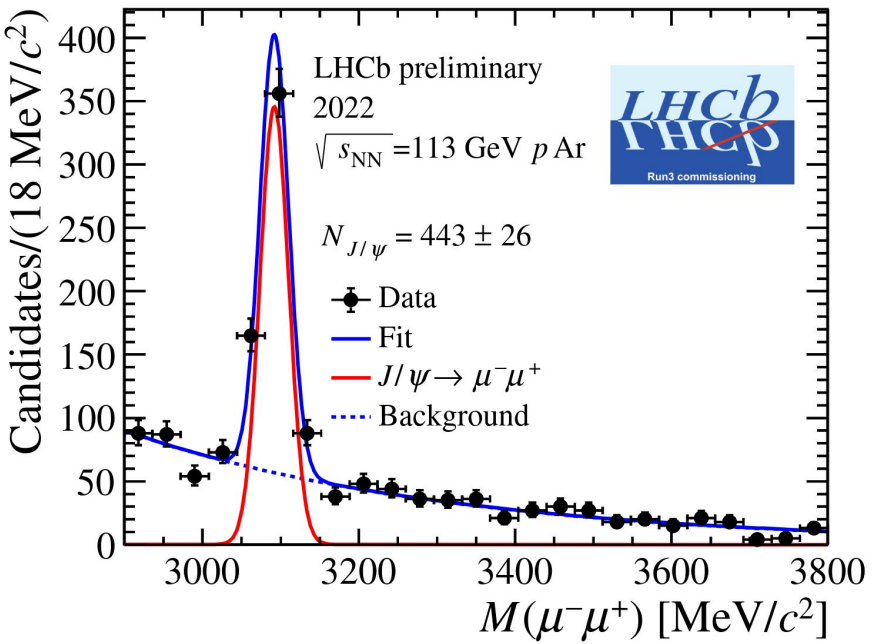


- **Very promising in view of precision physics with Run3 data**

Reconstructing 2022 early-data (III)

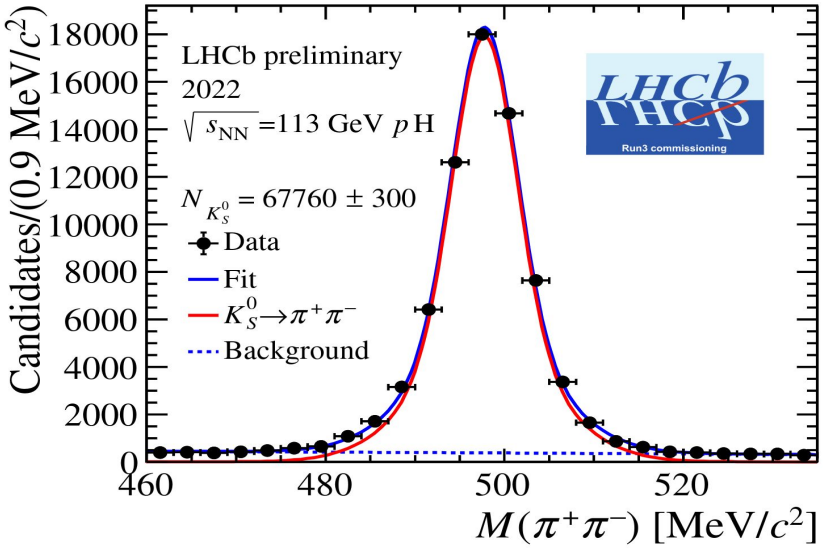
- Full data-processing chain validated with **reconstruction of charm states**
  - Plots obtained with <u>18 minutes</u> of *pp* + *p*Ar data-taking

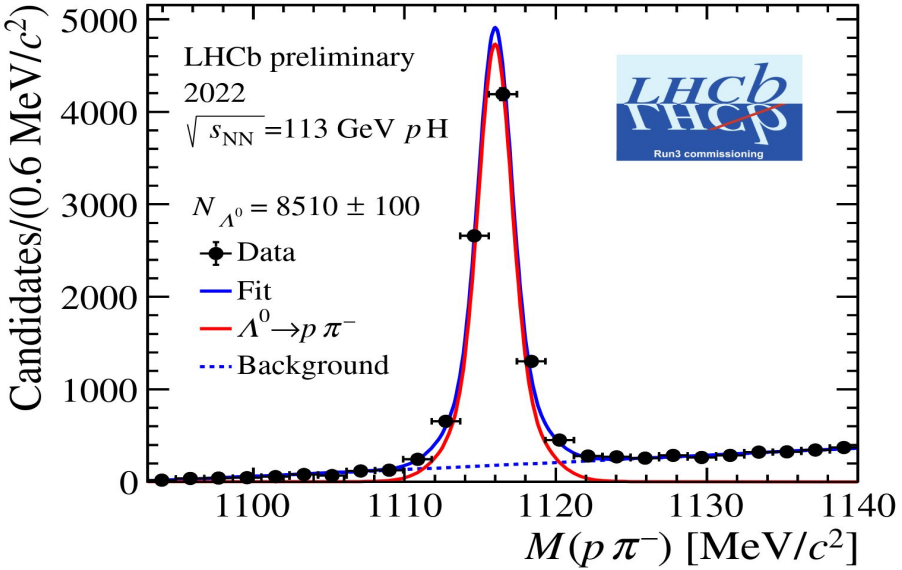




Reconstructing 2022 early-data (IV)

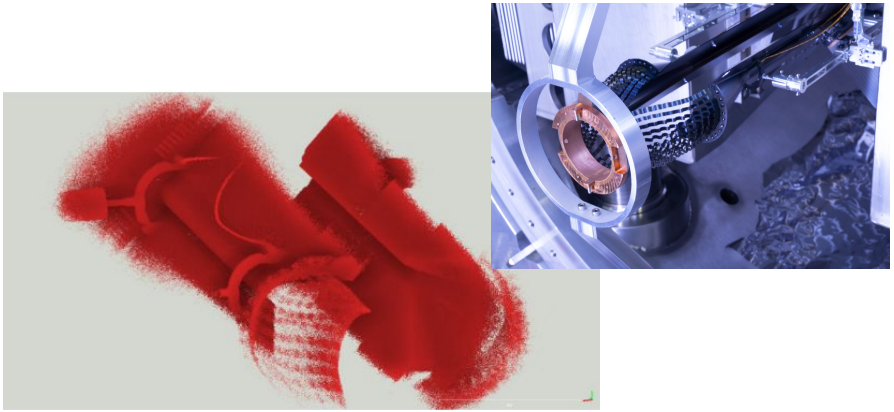
- **Hydrogen injected in LHC for the first time** to collect simultaneous *pp* collisions at two energy scales with LHCb
- High statistics already obtained in a **20 minutes data acquisition,** will serve as a reference to other fixed-target data samples (R_{AA})

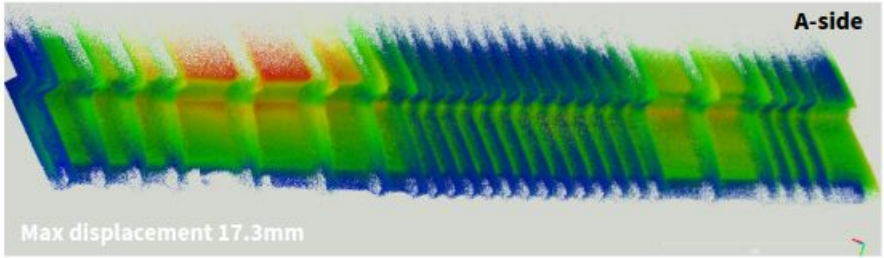




What about 2023?

- A 150-250 µm aluminium foil separates LHC and VELO vacua, shielding the electronics
- Due to the failure of the LHC vacuum system controlling the VELO, an overpressure **induced a deformation on these foil,** which will have to be replaced during 23-24 YETS
- **VELO sensors and SMOG2 cell not damaged** by the incident, but <u>VELO to stay open in 2023</u>





- Also thanks to the gas injected via SMOG, secondary vertices used to describe as a tomography the foil and the detector material ⇒ **incredible level of precision reached**
- SMOG2 cell closes with the VELO ⇒ **need to have a bit more of patience to see it in action**

Conclusions (I)

European Strategy Update

Physics Briefing Book

[ref]

CERN-ESU-004
30 September 2019

Input for the European Strategy for Particle Physics Update 2020

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

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

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

- The community acknowledges the unique possibilities of fixed-target physics at LHC, **widely expanding the facility physics reach**
- R&D projects also ongoing (**officially supported yet not approved** by LHCb)

L⇅C spin

- Bring a **polarized gas target** for the first time at LHC(b) [arXiv:1901.08002]

SELDOM

- Superthin fixed **solid-state target** [ref]
- EDM/MDM measurements via **channelling in bending crystals** [publications]

Conclusions (II)

- Since 2015, **LHCb is pioneering fixed-target physics at LHC,** with a wide variety of measurements on the *p*He, *p*Ar, *p*Ne, PbNe data samples collected in 2015-2018
- Major upgrade to SMOG2 in 2018-2022, allowing **more gases to be injected** (Kr, Xe, H_2, D_2, N_2, O_2…) with **up to x100 areal density** for the same gas flow as Run2
- Gas Feed System commissioned in 2022 ⇒ **SMOG2 validated**
  - Injection procedure set for He, Ne, Ar and, **for the first time ever, H_2**
  - **Particles and collision vertices** efficiently reconstructed
  - **Physics signals** (Λ, K_s, J/ψ, D^0…) well visible even with O(20 mins) data
- **Exciting opportunities ahead** with the current system and with possible future upgrades

Thanks for your attention!

Follow up? saverio.mariani@cern.ch