Status of the SMOG2 system at LHCb

Saverio Mariani
CERN
On behalf of the SMOG team, but with the contributions of many

Outline

- Introduction to the SMOG2 project
- SMOG2 commissioning and first results
- Plans and prospects for the 2023 data-taking

STRONG 2020 workshop, 06/01/2023

LHCb Upgrade in a nutshell (I)

- In view of the LHC Run3, most electronics/optics/DAQ channel and the entire tracking system **have been replaced or removed**

Removed/replaced
Kept from Run2
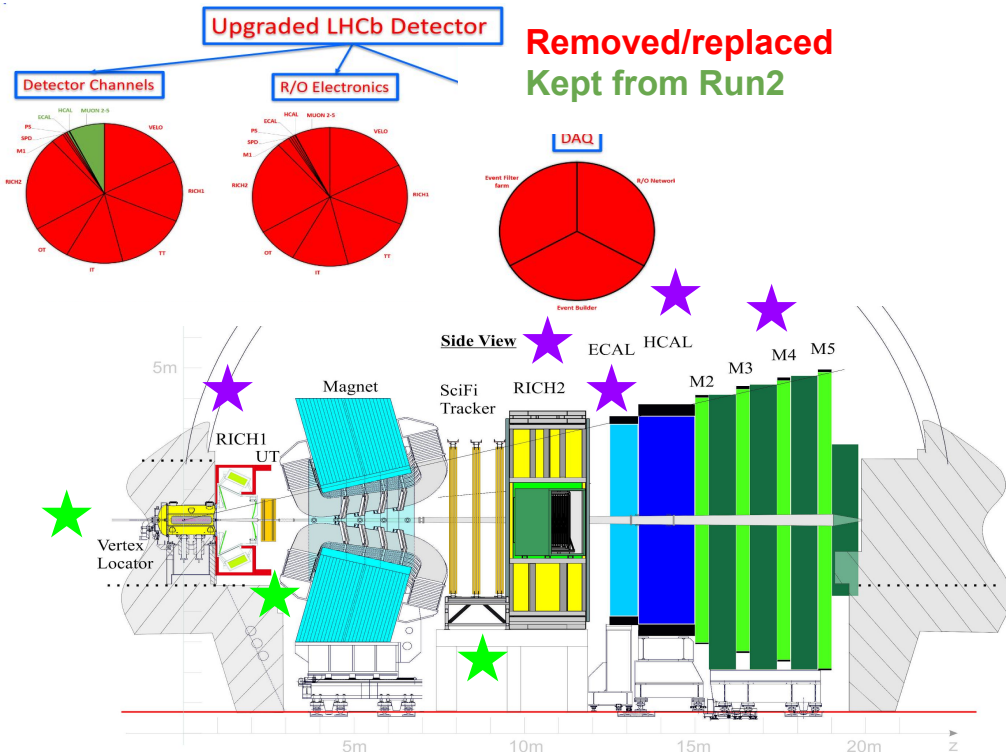
- *De facto*, a new experiment is running at the LHC:
  - ⭐ Tracking system with **pixel VELO detector + UT** silicon tracking station + scintillating fibers (**SciFi**) tracker
  - ⭐ PID from two **RICH detectors + calorimeters + Muon** stations
- 2022 is a commissioning year…
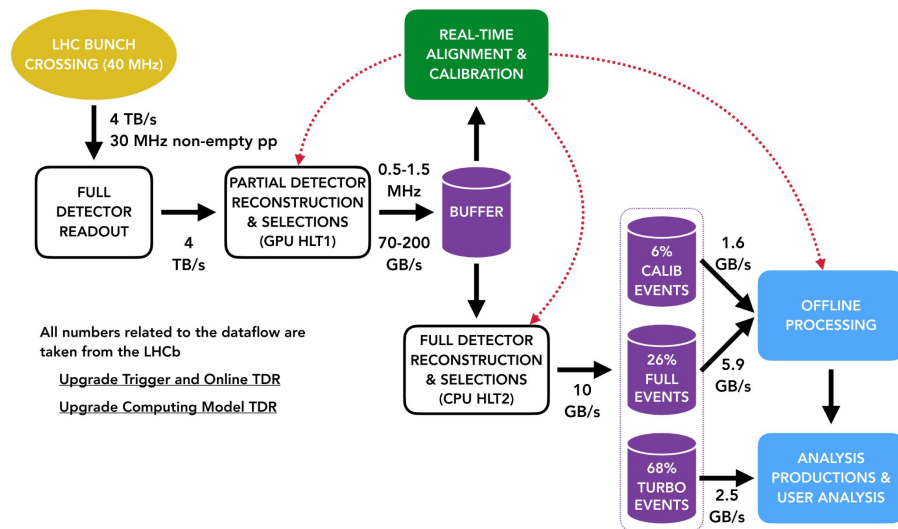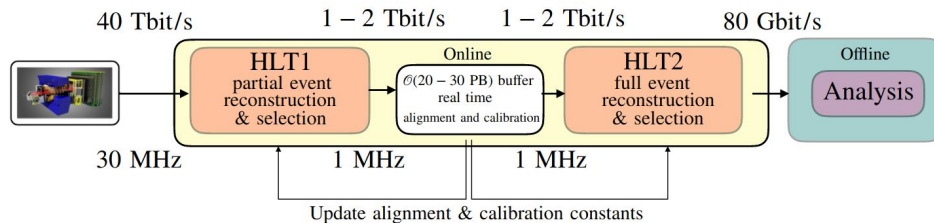
LHCb Upgrade in a nutshell (II)

- Hardware trigger removed. Full detector read-out, calibration and alignment and event reconstruction and selection **in real time and only via software**
- **First trigger level completely running on GPUs**, a novelty in large experiments

LHCb-TDR-017, LHCb-TDR-021, Comp Softw Big Sci 4, 7
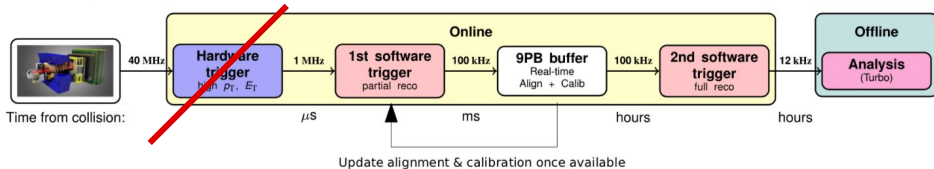
# Past and present fixed-target LHCb

- Since 2015, LHCb has collected beam-gas data as **the highest-energy fixed-target experiment ever** by injecting inject noble gases in the LHC beam-pipe through SMOG
- Gas was free to spread in ±20 m from the nominal IP, which limited
  - **the pressure and species of injectable gases** (He, Ar, Ne with $O(10^{-7})$ mbar)
  - the possibility to **simultaneously acquire data with *pp*** for all LHC bunches
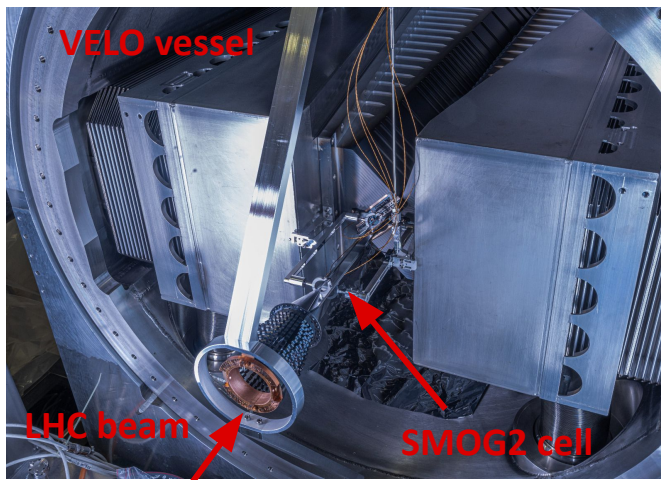
- Installed a **gas storage cell in z ∈ [-541, -341] mm**
  - Up to **x100 areal density** for the same flow as in Run2
  - **Non-noble gases** allowed (H_2, D_2, N_2, O_2) + Kr, Xe
  - **Simultaneous data-taking** with beam-beam
- A new **gas feed system** with 4 recipients with more precise control of the gas flow (measurable)
  - Address **dominant uncertainty due to luminosity**

Just few examples of the SMOG2 physics prospects
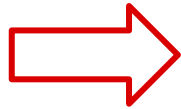
➡️ **A unique laboratory for QCD studies at the LHC!**

	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
$\psi(2S)$ yield	150	400k
$\Upsilon(1S)$ yield	4	15k
Low-mass ($5 < M_{\mu\mu} < 9$ GeV/c^2) Drell-Yan yield	5	20k

- Pending an exact definition of the data-taking strategy, but **the increase in statistics is striking!**

- 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: $\bar{\text{p}}$ **production processes with H$_2$, D$_2$, He,** probes for the study of the atmospheric showers with N$_2$, O$_2$; **nuclei production**?

SMOG2 cell and GFS
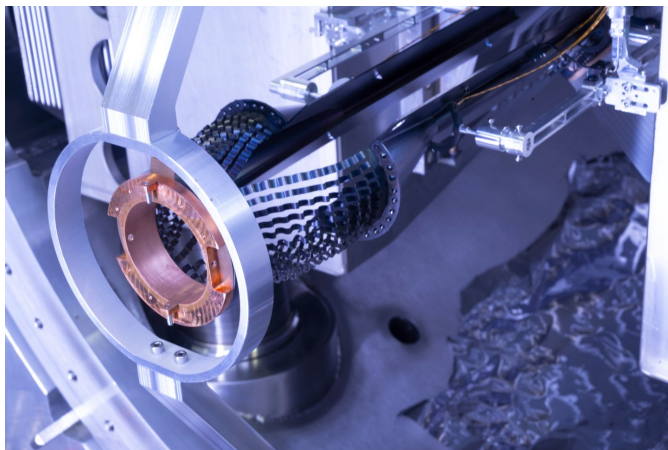
- VELO aperture is lower wrt required one in non-stable beam → **VELO opens up outside data-taking** [TDR]
- To cope with it, **the cell is also made up of two halves**, with one side with a spring to ensure enough flexibility

| Offset to nominal		
dXphys [mm]	dYphys [mm]	dZphys [mm]
-0.25	0.14	0.11
-0.19	-0.14	0.11

- **Aligned to nominal position** within 250 µm

- **Gas injected through a capillary** from the cell centre

- **Gas feed system (GFS)** calibrated at 10^{-4} for gas purity and 10^{-2} for the flux
- **Temperature measured with 5 probes** with a 0.2 C accuracy

- **Both cell and GFS installed before the start of the LHC Run3!**

Preparation for simultaneous data-taking

- **The SMOG2 displacement** wrt the beam-beam interaction region and the **small increase** in detector multiplicity support **a simultaneous beam-beam + beam-gas data acquisition**
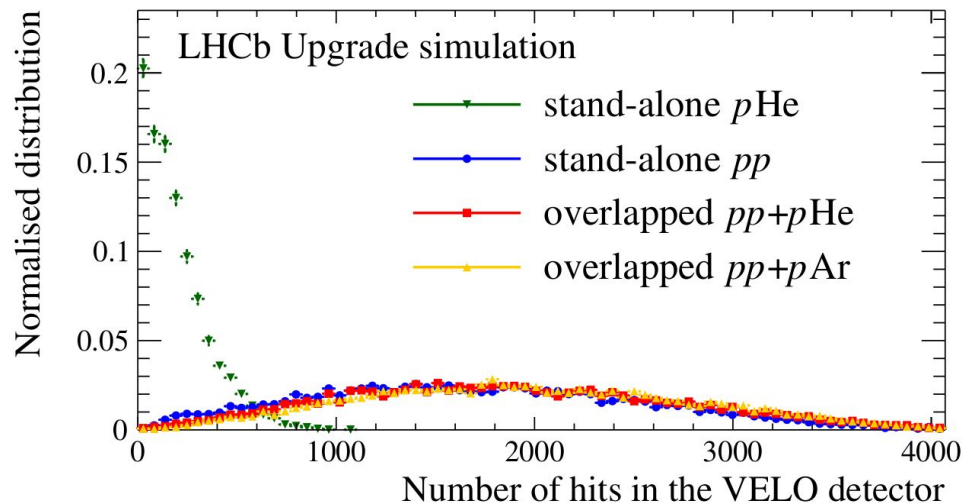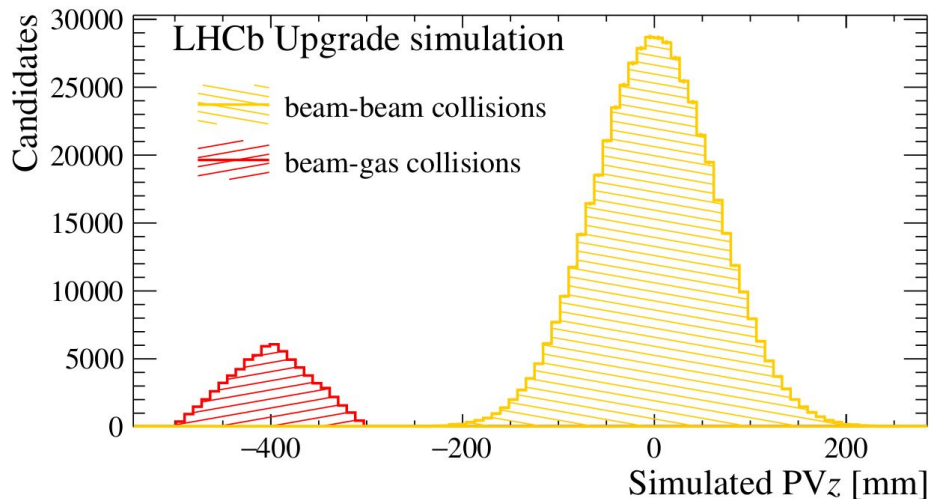

- Intense activity on software event reconstruction before start of LHC Run3, aiming to **demonstrate the reconstruction of beam-gas events is efficient** **Ref**
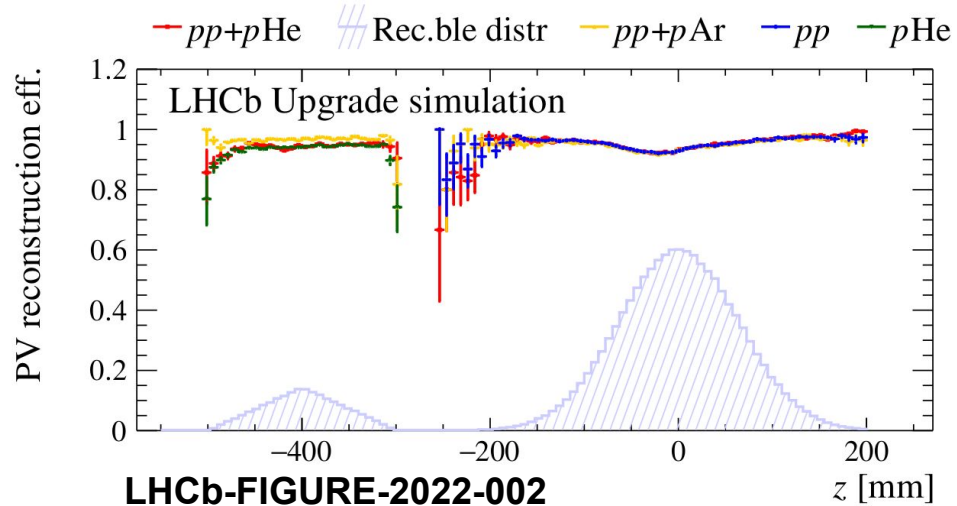
Preparation for simultaneous data-taking (II)

- On simulation, **two milestone goals achieved in 2020-2022**:   **Ref**
  - **Same reconstruction performance** for beam-beam and beam-gas collisions
  - By injecting gas on top of the *pp* collisions, **no performance change observed**

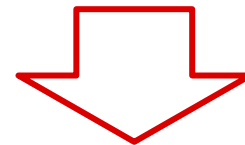**Charged particle reconstruction efficiency**
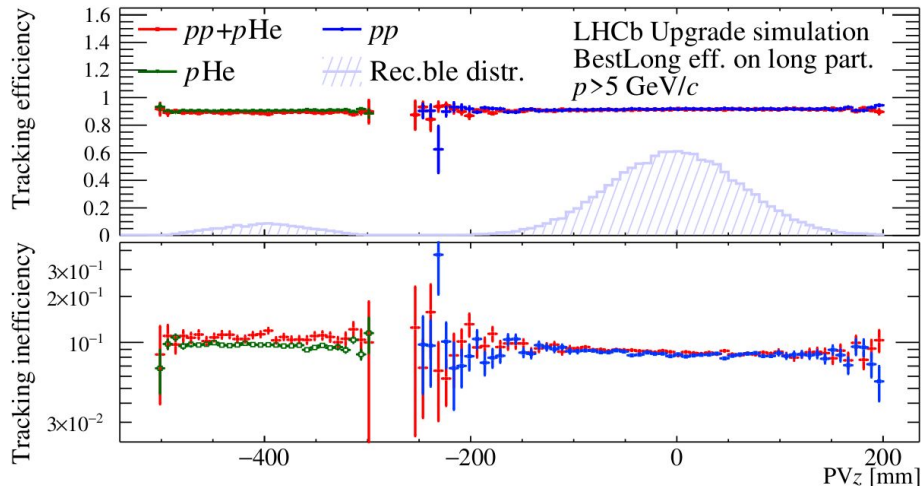
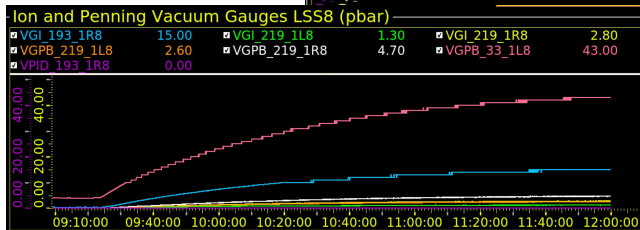**Collision reconstruction efficiency**
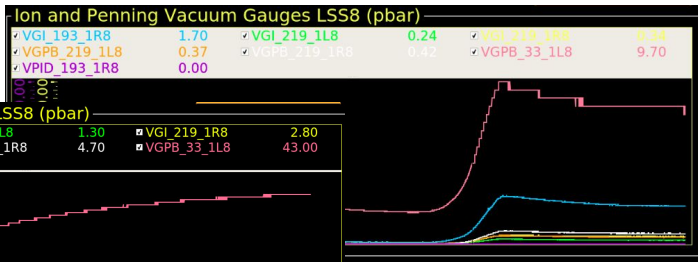

LHCb-FIGURE-2022-002
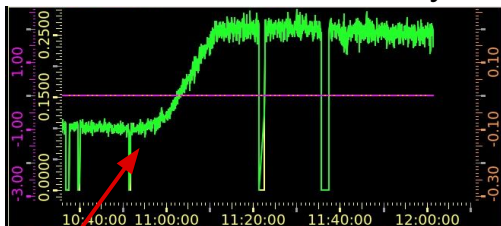
Time to talk about real data?

Gas feed system commissioning (I)

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

Instantaneous luminosity

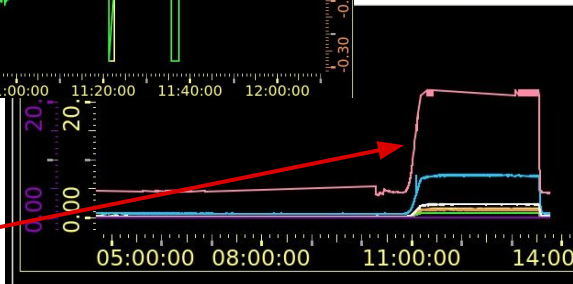Real-time pressure

SMOG injection

- With the low-intensity beams LHC delivered during summer, SMOG2 clearly contributed to **increase the detector activity** and to **speed-up the overall experiment commissioning**

Gas feed system commissioning (II)
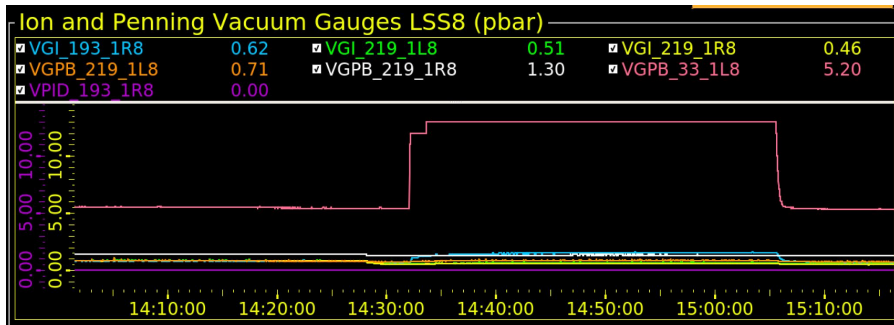
Ion and Penning Vacuum Gauges LSS8 (pbar)

☑ VGI_193_1R8	0.62	☑ VGI_219_1L8	0.51	☑ VGI_219_1R8	0.46
☑ VGPB_219_1L8	0.71	☑ VGPB_219_1R8	1.30	☑ VGPB_33_1L8	5.20
☑ VPID_193_1R8	0.00				

14:10:00   14:20:00   14:30:00   14:40:00   14:50:00   15:00:00   15:10:00

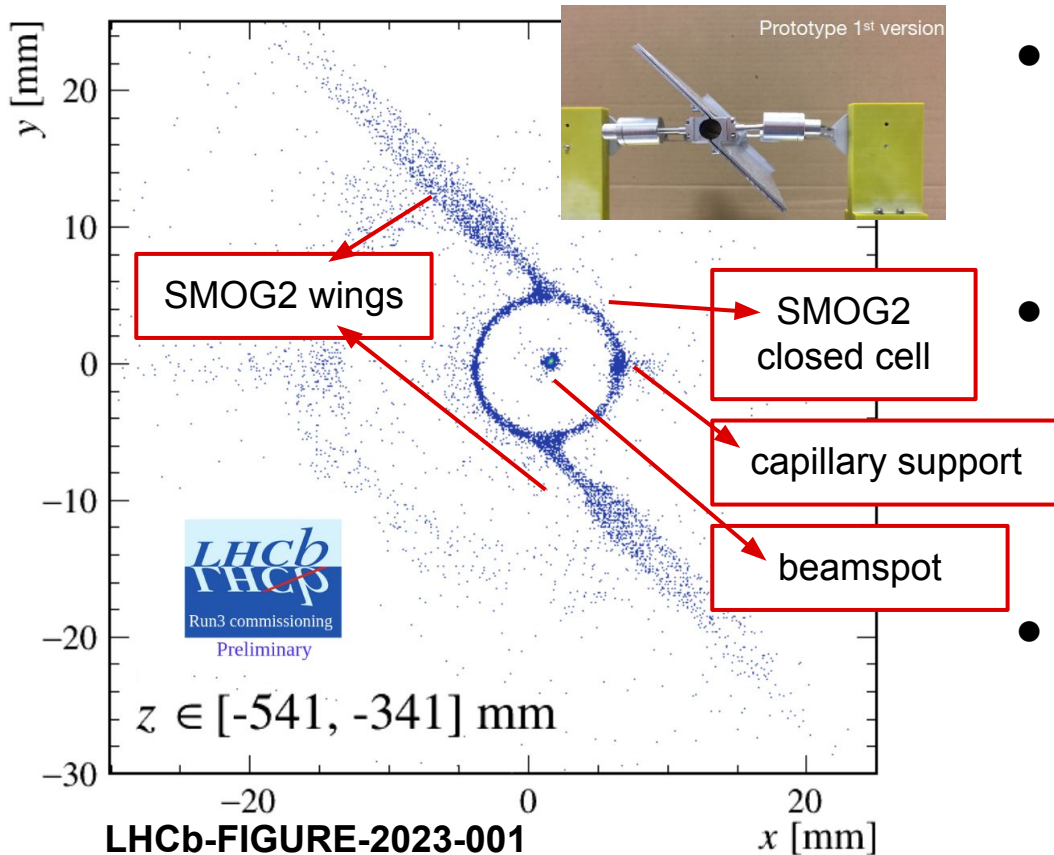- **01/11:** First injection in the closed cell

- **Very stable** pressure plateau and very fast vacuum recovery thanks to the **preparatory work** by the vacuum team!

- By injecting Ar with a pressure 6.5 times lower wrt Run2, already **achieved a 5.5 higher instantaneous luminosity**!

- Before the end of the 2022 data-taking:
  - Injected He, Ne, Ar and, **for the first time ever**, H_2
  - Injected gases at **different pressures** both in the VELO vessel and with closed cell

- **GFS fully and successfully commissioned,** vacuum experts agreed in giving LHCb the **complete control of the system** for 2023 data-taking!

Reconstructing beam-gas collision: the cell

Prototype 1st version

SMOG2 wings

SMOG2 closed cell

capillary support

beamspot

LHCb Run3 commissioning Preliminary

$z \in [-541, -341]$ mm

LHCb-FIGURE-2023-001

- Waiting for 2023, analysis of the data collected so far has already started…

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

- Remarkable level of details describing in real-time the **SMOG2 cell position** and the **experiment material budget**

Reconstructing beam-gas collision: particles in the VELO

- **Particles reconstructed in the VELO** from pp and pAr collisions
- **Highly efficient separation** between the two components as in simulation observed
- While pp collisions are central (same number of forward and backward particles), particles from **pAr fixed-target collisions** only have positive η values
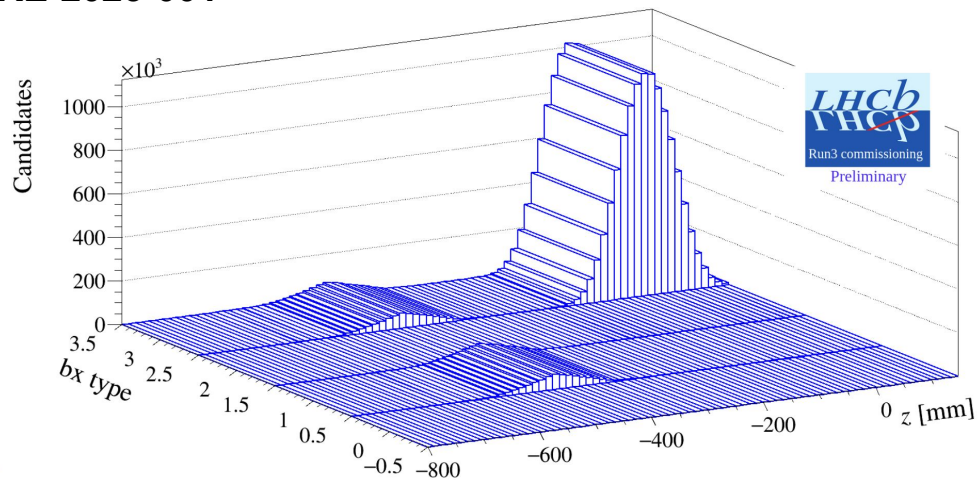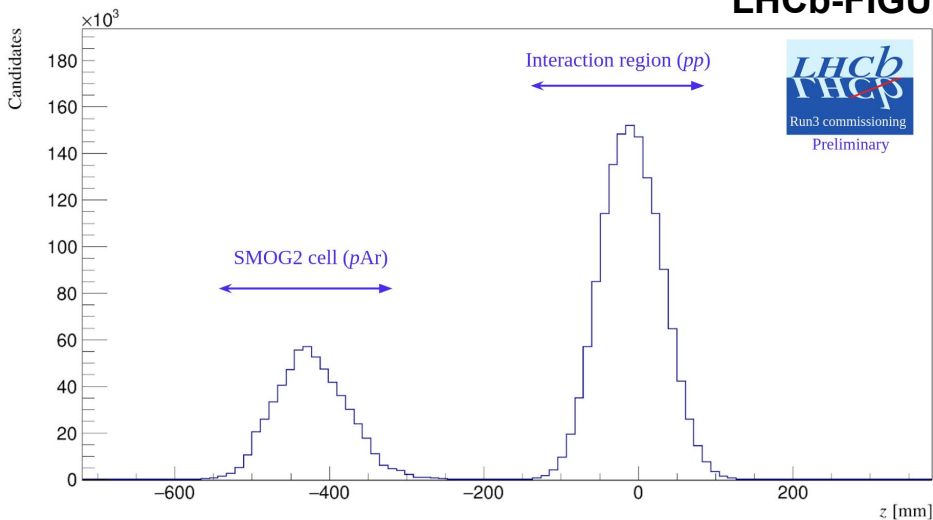
LHCb-FIGURE-2023-001

POCA = position of closest approach
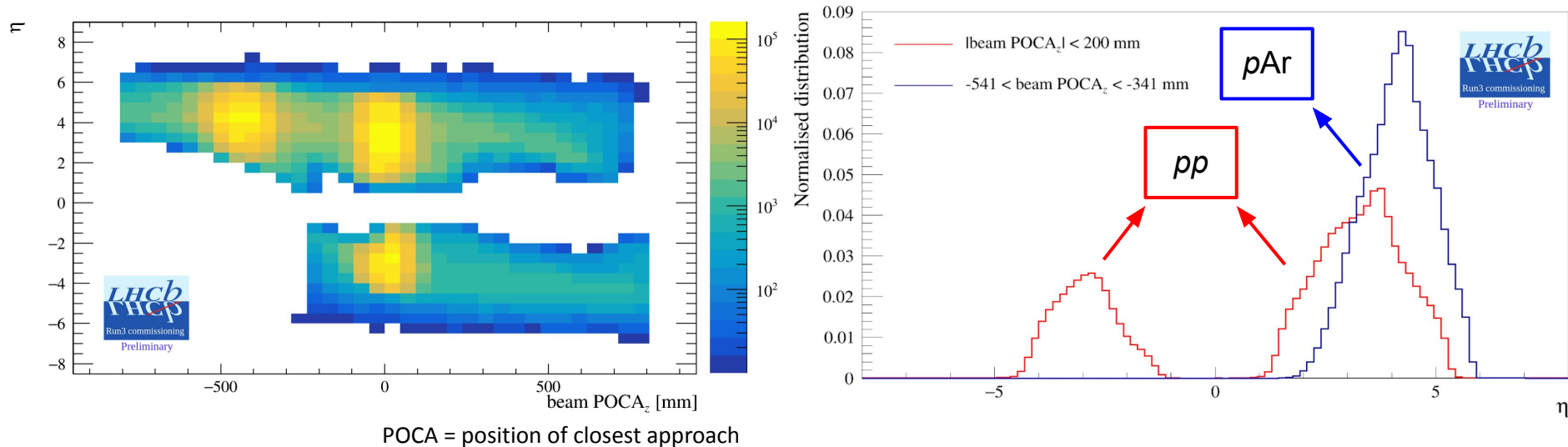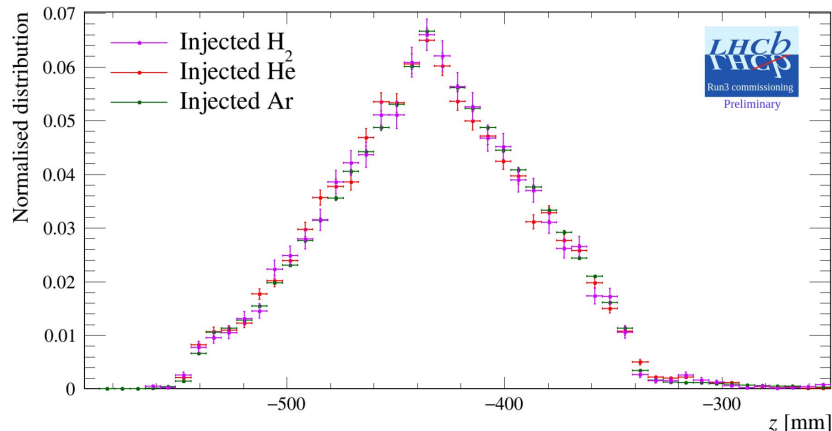
Reconstructing beam-gas collision: PVs (I)

- PVs are reconstructed around z = -441 and z = 0 mm: **LHCb is the only experiment at the LHC operating simultaneously with two interaction points**
- Beam-gas collisions are **reconstructed in both beam-empty** (bx type = 1) **and beam-beam** (bx type = 3) **LHC bunch-crossings**
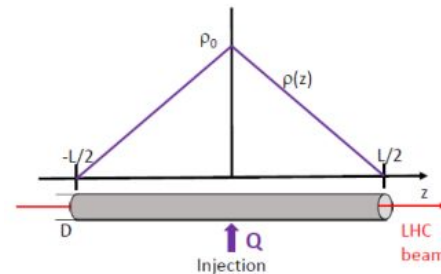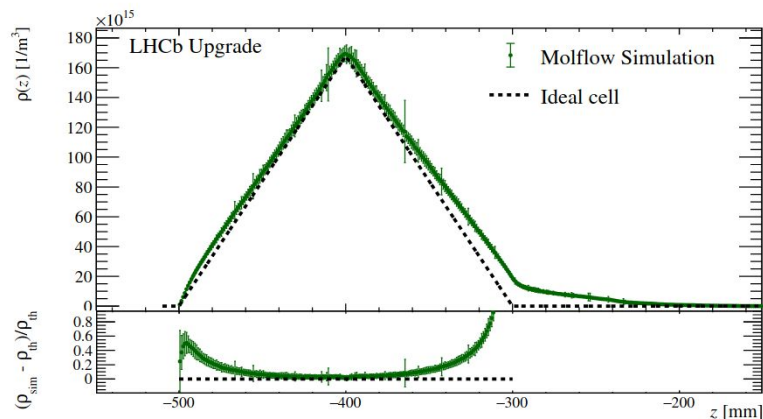
LHCb-FIGURE-2023-001

Reconstructing beam-gas collision: PVs (II)

- Being the gas injected at the cell centre, beam-gas vertices follow a z **triangular profile**
- The **PVz profile does not depend on the gas** species, as expected from Molflow simulations
- **Full validation** of the simulated profiles with detailed efficiency estimations ongoing

Reconstructing beam-gas collision: composite particles

- Composite particles produced in beam-gas collisions can be reconstructed!
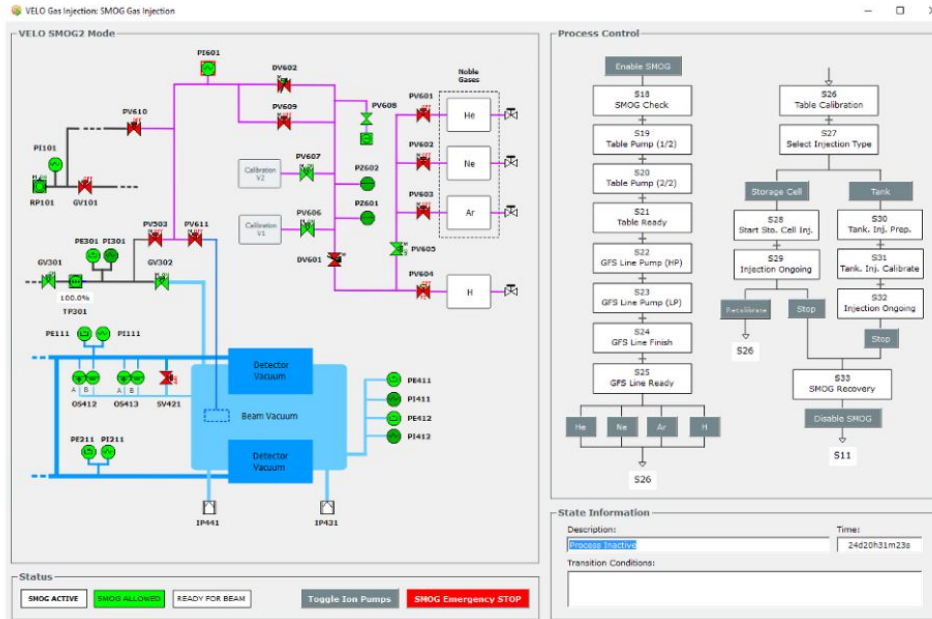- **The mass resolution for Ks produced in *pp* and *p*Ar collisions is the same!**

LHCb-FIGURE-2023-001
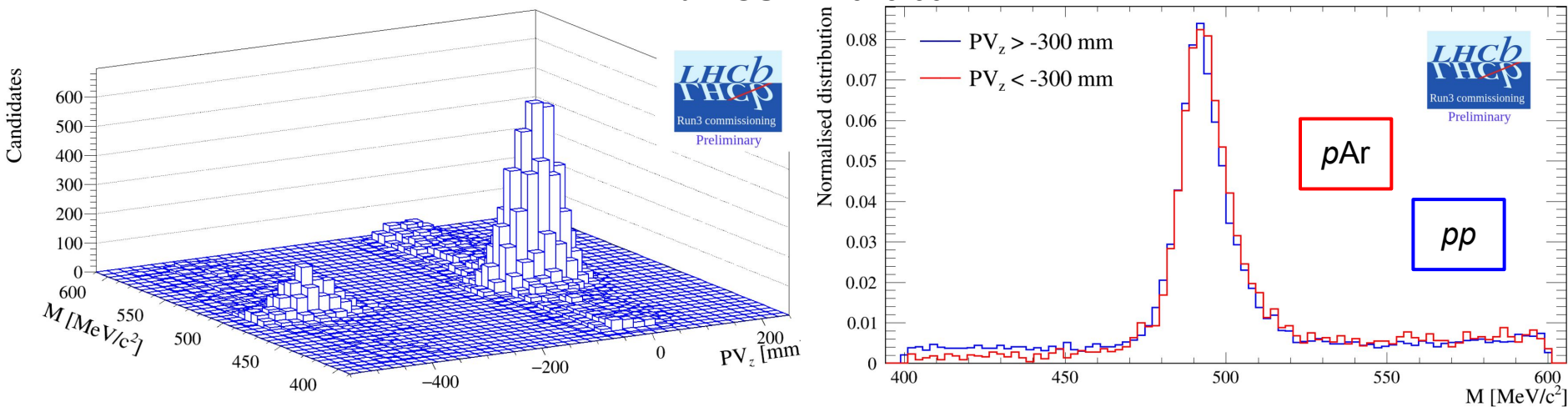
- **Exciting physics results will come with the 2023 data-taking!**

Plans for 2023 data-taking

- **Define a data-taking strategy**, i.e. which gases and how long will be injected, to be discussed within the LHCb collaboration

- **Activate the gas feed system control panel**, adding some safety protections to interface it with the detector
- **Complete the studies on the software reconstruction performance and the trigger selection algorithms implementation**

Conclusions

- **SMOG2 works** ⇒ green light from the vacuum group to get the **full control of the injections Gas Feed System is fully** calibrated and commissioned:
  - **Injected He, Ne, Ar and, for the first time ever, H_2**
  - Line pressurisation, gas stability and pump configuration **procedures defined**

LHCb-FIGURE-2023-001
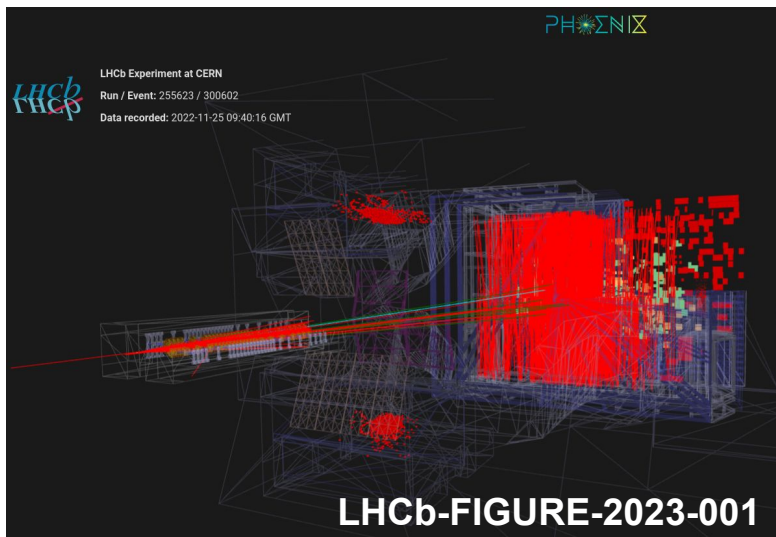
- First performance of the real-time reconstruction shown today: **beam-gas particles and collisions can be efficiently reconstructed!**
- Looking forward to 2023, **aiming to full-physics data-taking and many new results**

Thanks for the attention!

saverio.mariani@cern.ch