Istituto Nazionale di Fisica Nucleare

The SMOG2 project

Pasquale Di Nezza

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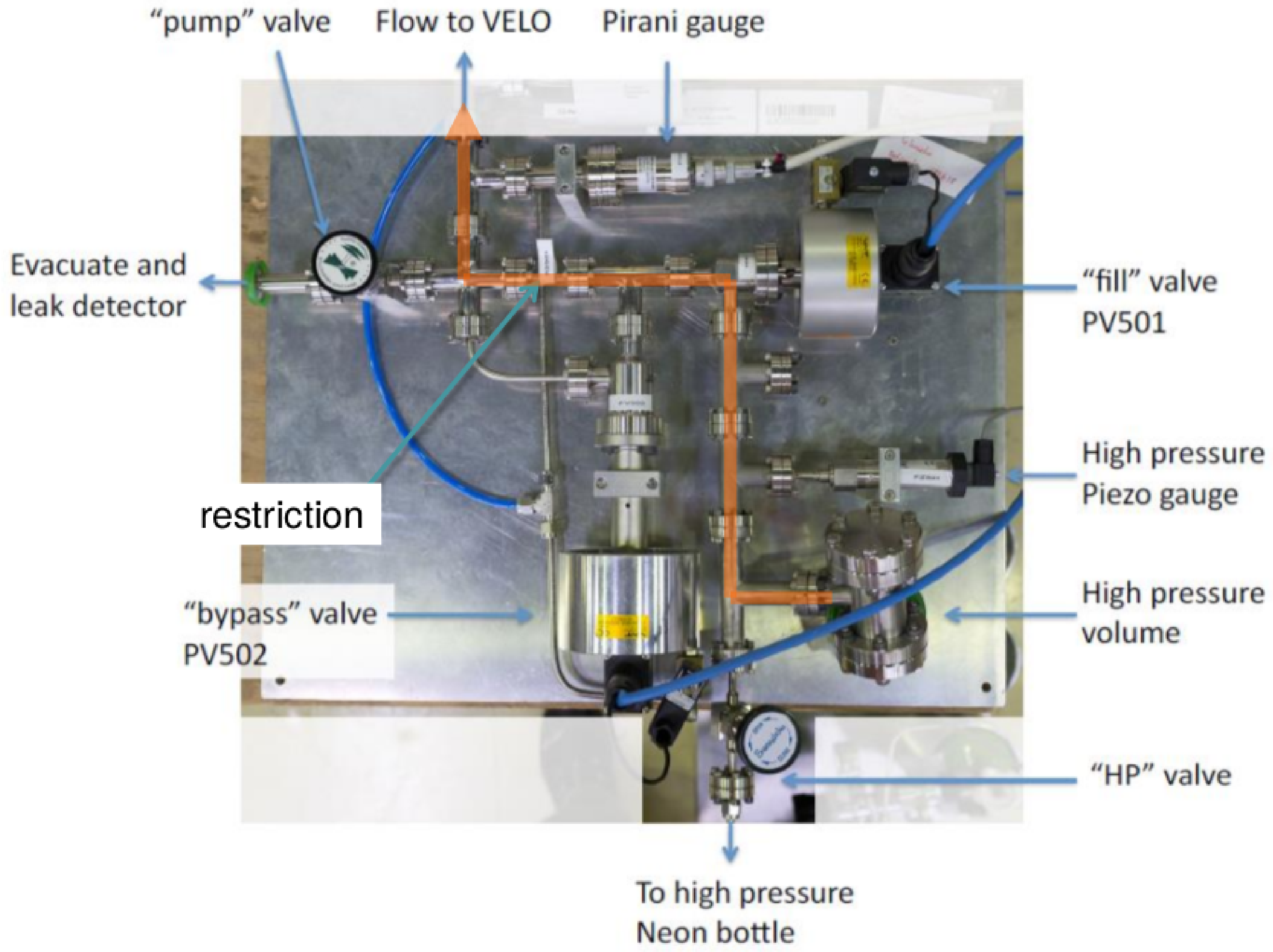
LHCb

In collaboration with: V.Carassiti, G.Ciullo, P.Lenisa, S.Mariani, L.Pappalardo, M.Santimaria, E.Steffens

SMOG, a successful idea and a pseudo-target

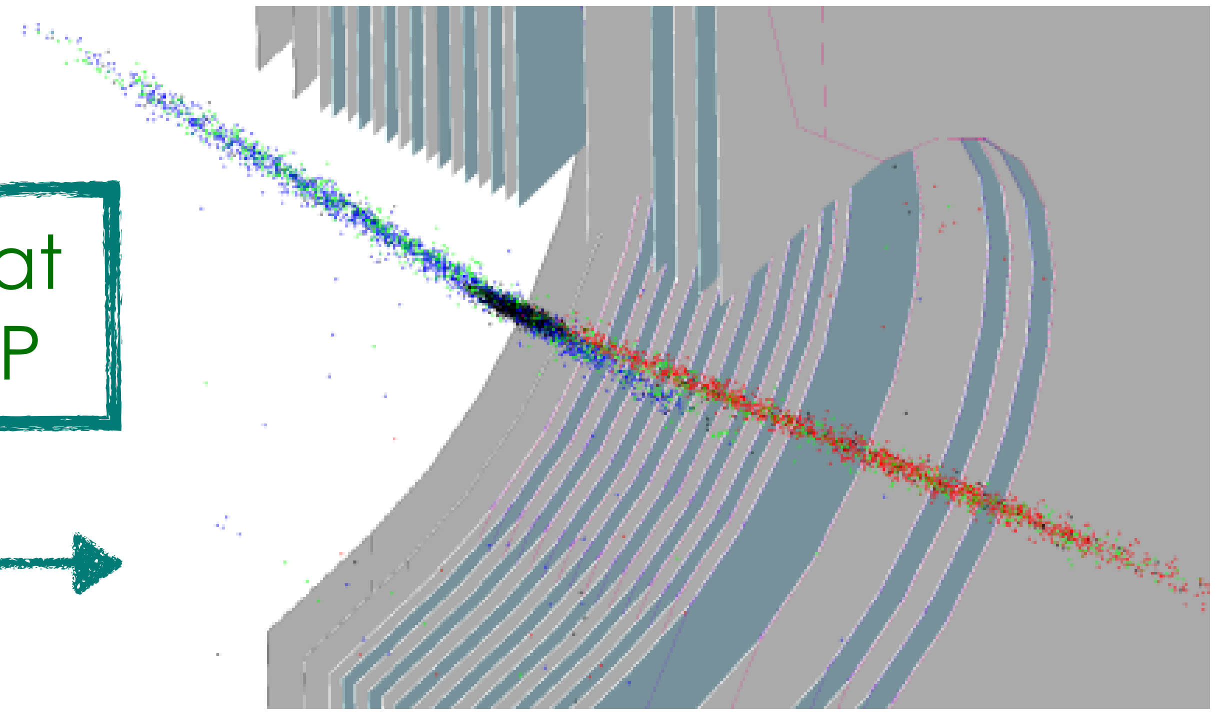
System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a "pseudo-target" producing interesting results



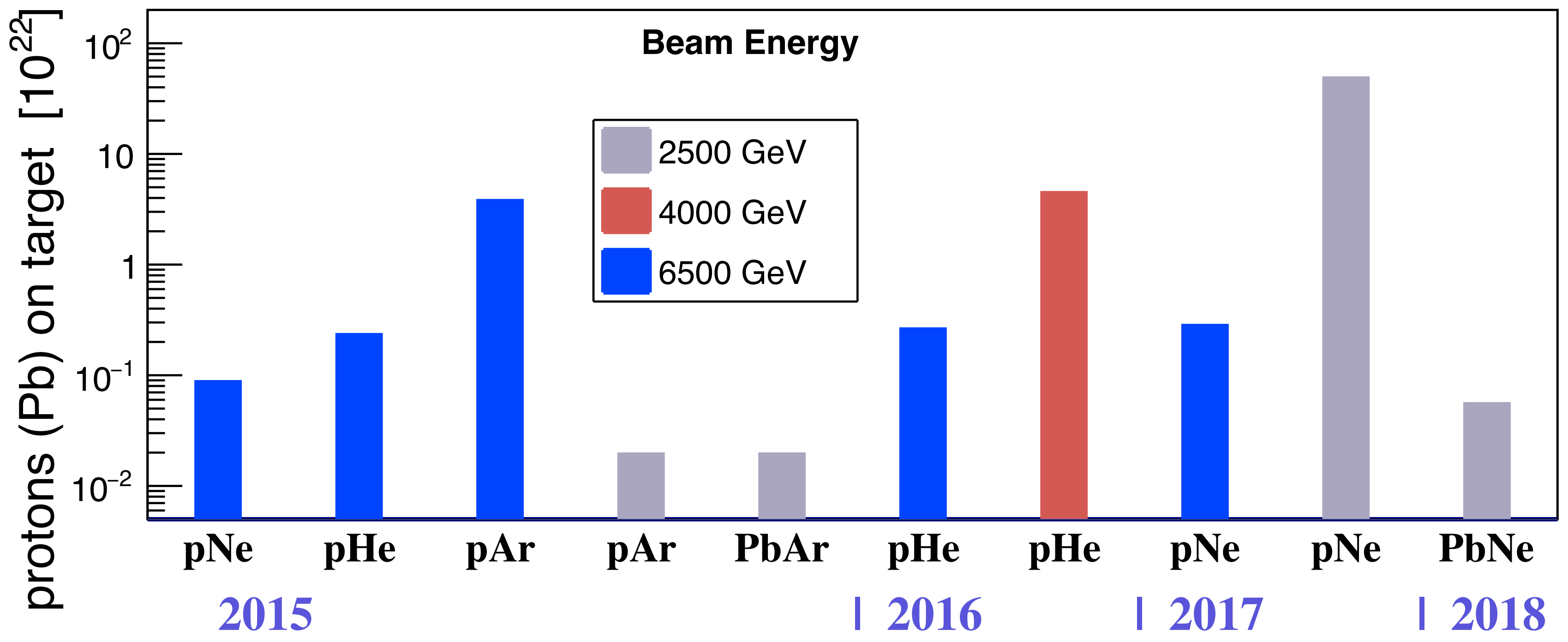
gas injection at the nominal IP

Gas pressure

10^{-7} to 10^{-6} mbar



Data taking SMOG 2015-2018



New methods developed

LHCb-PUB-20XX-YYY
May 27, 2021

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

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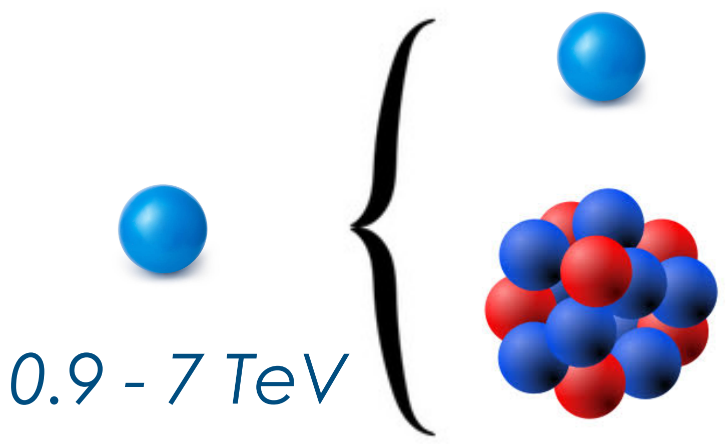
Several analysis are going on. Already published:

-Measurement of antiproton production in pHe collisions at $\sqrt{s_{NN}}$ =110 GeV
PRL 121 (2018), 222001
-First measurement of charm production in fixed-target configuration at the LHC
PRL 123, 239901

B.Audurier's talk on Monday 31.5
E.Franzoso's talk on Thursday 3.6
E.Niel's talk on Thursday 3.6

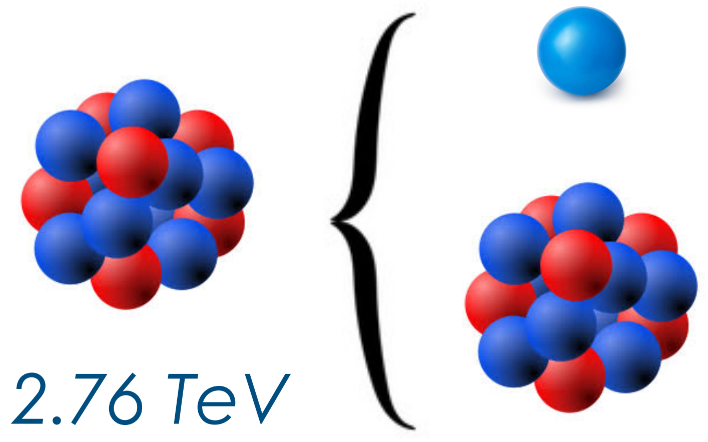
Kinematics on fixed target



pp or pA collisions: 7 TeV beam on fix target

$\sqrt{s} = \sqrt{2 m_N E_p} = 115\ GeV$

$-3.0 \leq y_{CMS} \leq 0 \ \rightarrow \ 2 \leq y_{lab} \leq 5$



AA collisions: 2.76 TeV beam on fix target

$\sqrt{s_{NN}} \simeq 72\ GeV$

$y_{CMS} = 0 \ \rightarrow \ y_{lab} = 4.3$

SMOG2 aims to significantly improve the performances of SMOG thanks to the use of a storage cell. This will allow to greatly expand the physics reach of SMOG paving the way to new and unique measurements

SMOG2 vs SMOG

- Increase of the luminosity by up to 2 orders of magnitude using the same gas load as SMOG
- Injection of $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$
- Multiple gas lines
- New Gas Feed System. Gas density (luminosity) measured with greatly improved precision (few %)
- Well defined interaction region upstream the nominal IP: strong background reduction, no mirror charges effect, possibility to use all the bunches —> pp and pgas simultaneous data taking

Typical SMOG2 areal densities for different gas species, compared with SMOG at the same flow rate

Gas species	He	Ne	Ar	Kr	Xe	H_2	D_2	N_2	O_2
SMOG2 areal density (10^{12} atoms/cm^2)	10	10	10	5	5	10	10	10	10
Intensity (10^{15} particles/s)	5.80	2.58	1.82	1.36	1.01	4.08	2.89	1.09	1.03
Flow rate (10^{-5} mbar · l/s)	21.4	9.6	6.8	4.68	3.75	15.02	10.07	4.05	3.83
SMOG areal density (10^{12} atoms/cm^2)	0.92	0.41	0.29	0.20	0.16	1.30	0.92	0.35	0.33
SMOG2/SMOG	10.9	24.4	34.5	25.0	31.3	7.7	10.9	28.6	30.3

Already used with SMOG

For the new gases simulations are going on in order to avoid embritilment of NEG (H_2,D_2) or condensation on machine elements (Kr, Xe)

Collision rates expected during Run3 wrt pp collisions

$$\frac{R_{H_2}}{R_{pp}} = \frac{\sigma_{pH_2}(115\ GeV) \cdot L_{SMOG2}}{\sigma_{pp}(14\ TeV) \cdot L_{pp}} \simeq 1.3\%,$$

$$\frac{R_{Ar}}{R_{pp}} = \frac{\sigma_{pAr}(115\ GeV) \cdot L_{SMOG2}}{\sigma_{pp}(14\ TeV) \cdot L_{pp}} \simeq 10.6\%.$$

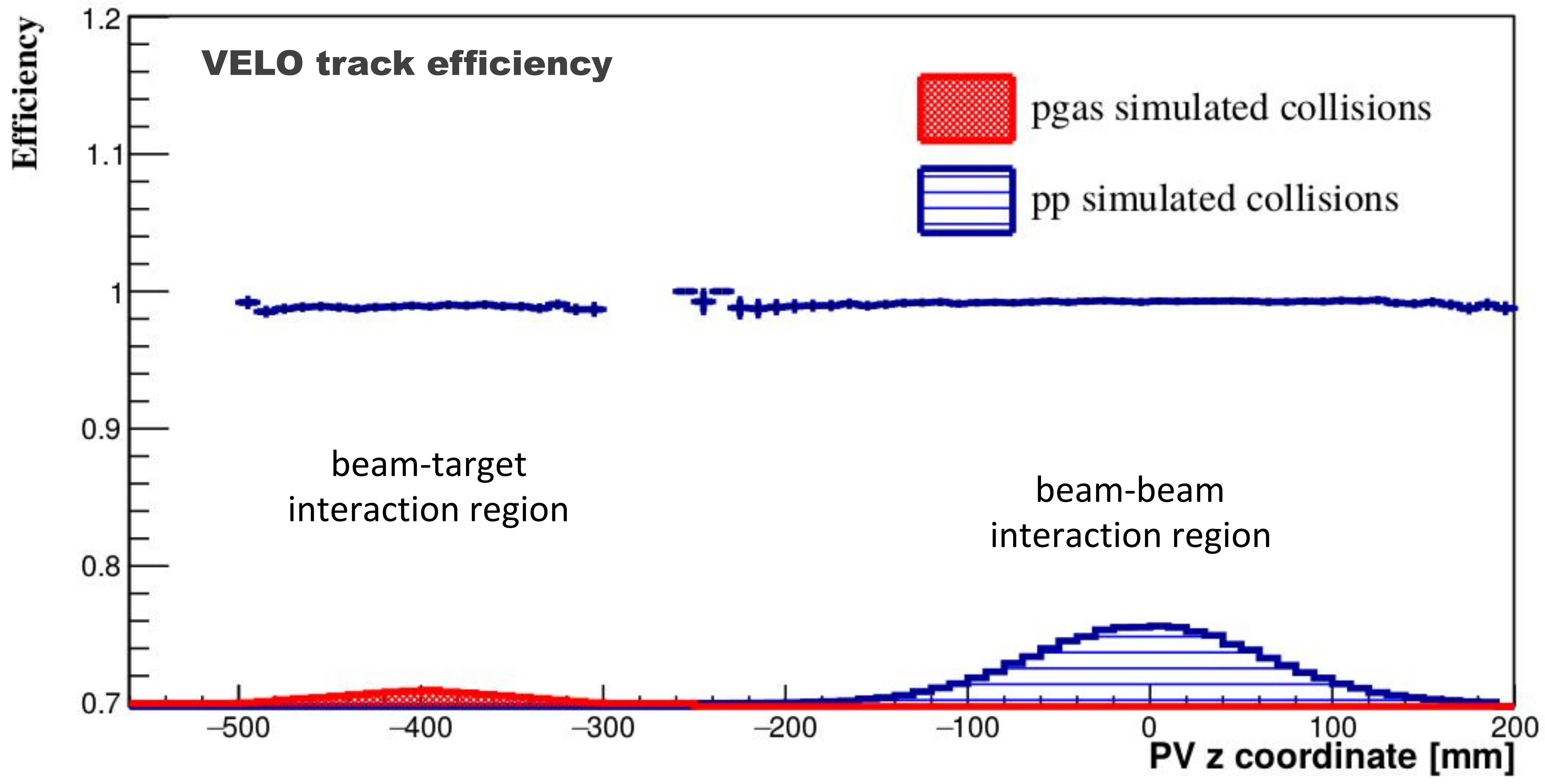
A factor 1/7 for the LHCb expected pp pileup has not been considered

Relative beam loss and beam life time reduction

Beam	Target Gas	σ_{loss} (barn)	τ_{loss} (days)	Relative loss in 10 h
p	H	0.05	2060	0.02 %
p	Ar	1.04	97	0.4 %
Pb	Ar	4.63	22	1.9 %

negligible impact of the target on the LHC beam

Simultaneous run for p-gas @ 115 GeV and pp @ 14 TeV



The two systems don't interfere each other and the reconstruction efficiencies stay unchanged

The DAQ data flow increases of 1-3% only

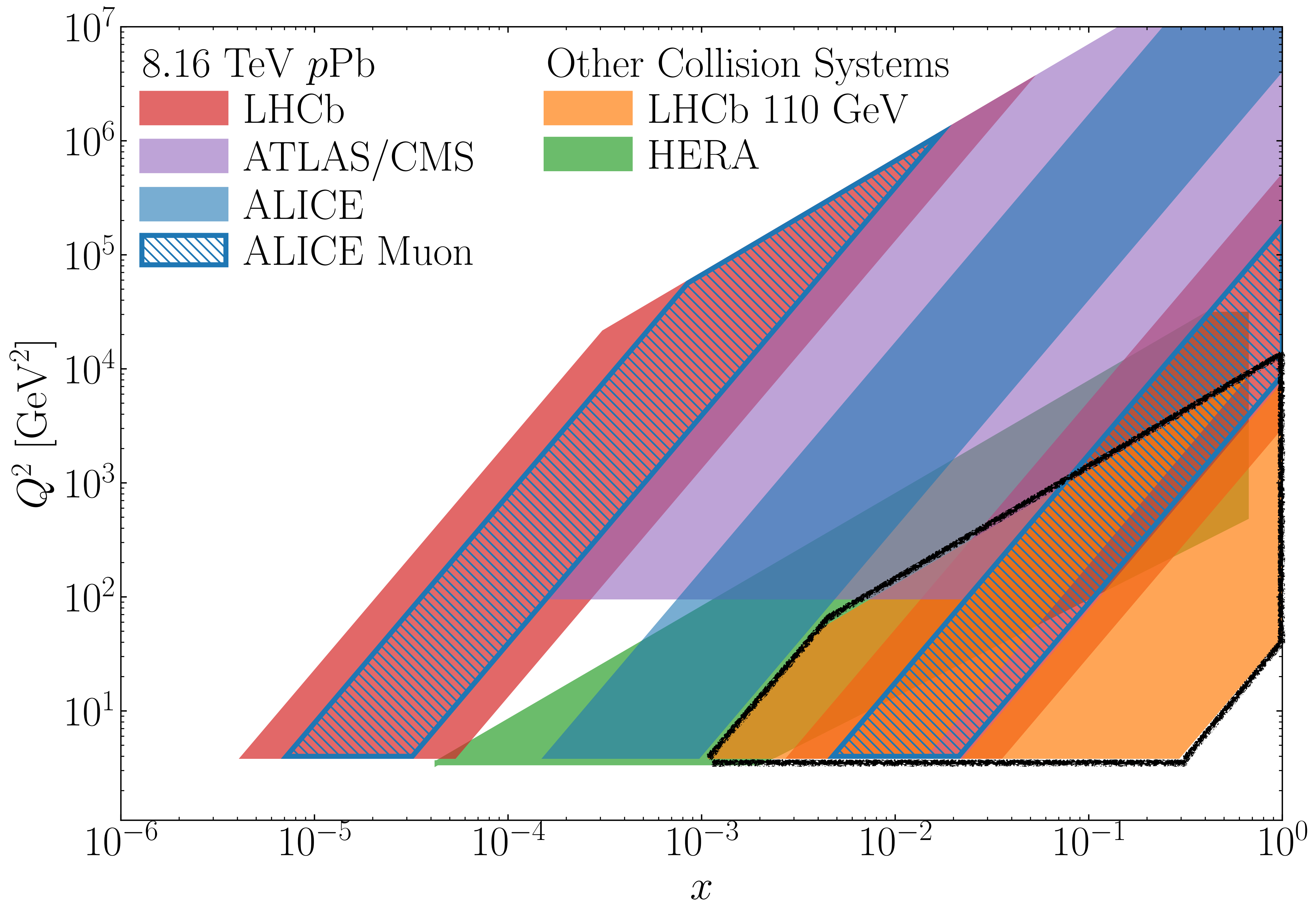
At the moment LHCb is the only experiment able to run both in collider and in fixed-target mode … simultaneously!

Long list of potential physics measurements for Run3 not reported in this technical oriented talk

-Advance our understanding of the large-x gluon, antiquark and heavy quark content in nucleons and nuclei

-Advance our understanding of the dynamics and spin distributions of gluons inside unpolarised nucleons

-Study heavy-ion collisions between SPS and RHIC energies at large rapidities



With SMOG2 we access unique kinematic conditions at the poorly explored energy of √s ~ 115 GeV, mid-high rapidities, using also the LHCb capabilities to reconstruct rare probes with high efficiency

Reconstructed yield for ~1 yr of data taking during Run 3

	pAr
J/Ψ	28 M
D^0	280 M
Λ_c^+	3 M
$\Psi(2S)$	5 M
$\Upsilon(1S)$	24 k
$DY_{low\ mass}$	24 k

rule of thumb

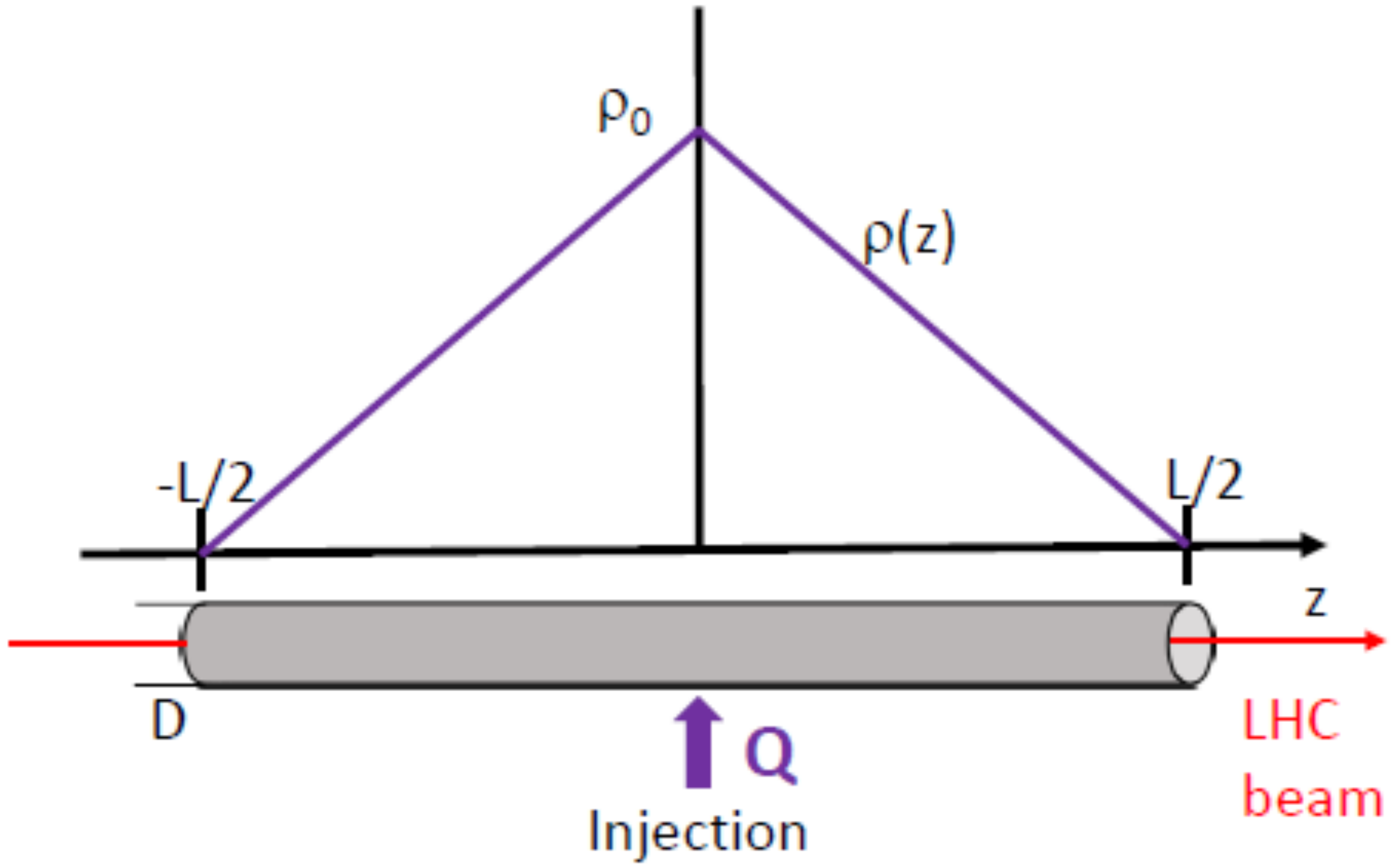
$$1\ pb^{-1} \simeq 24\ h\ \times\ 1000\ bunches\ \times 10^{13}\ cm^{-2}$$

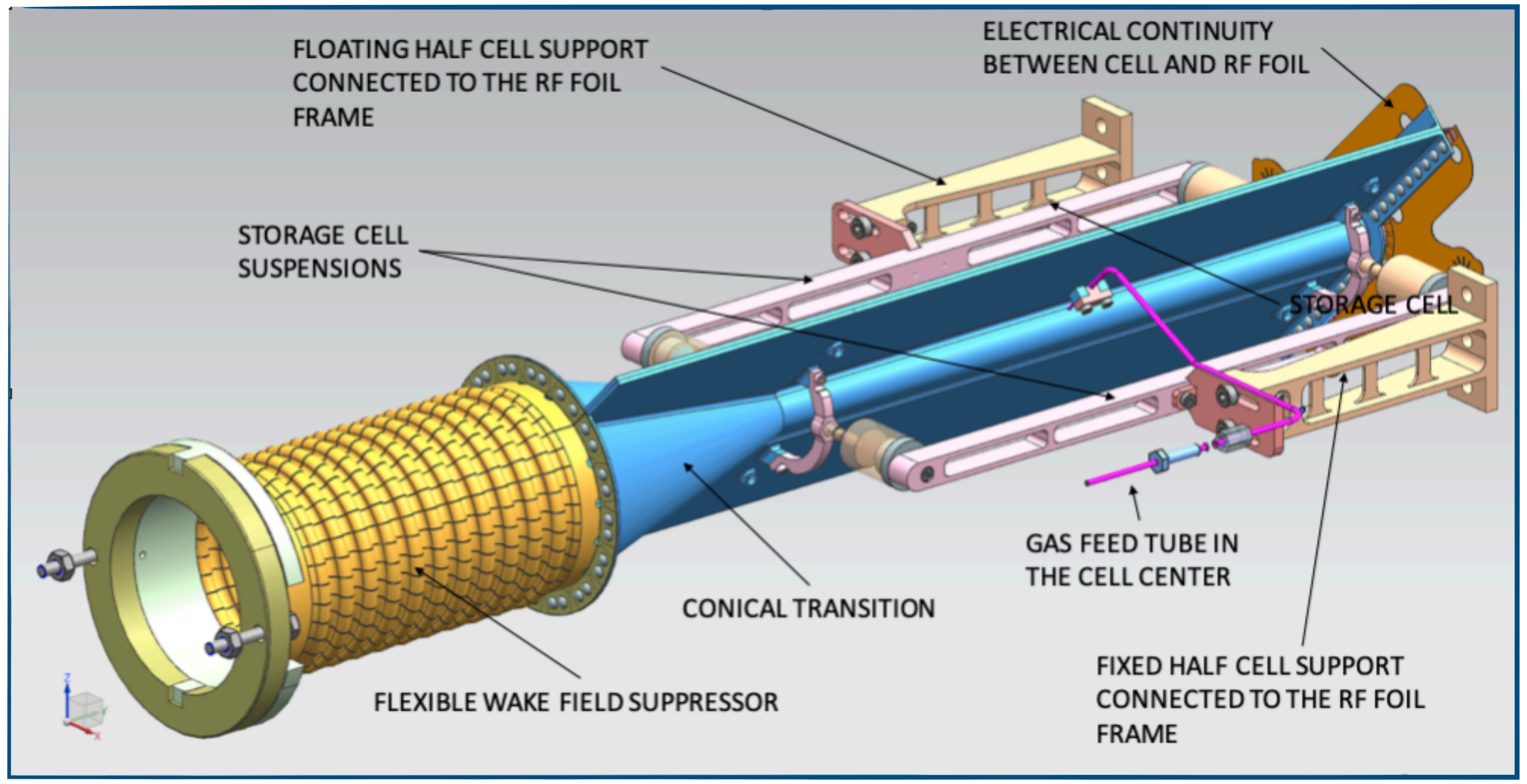
target density

This results as a laboratory for QCD

Storage cell concept

A Storage Cell consists of a tube (length L=200 mm, inner diameter D=10 mm).
Gas is injected at the tube center by means of a capillary from a gas-feed system as a directed flow

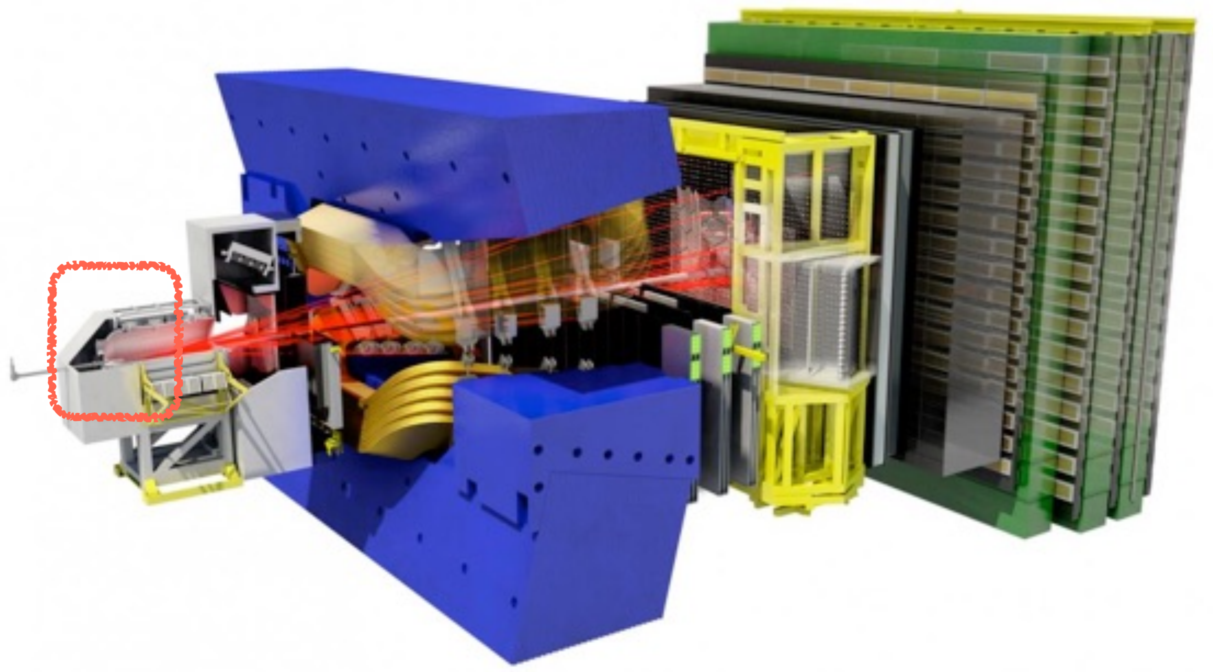


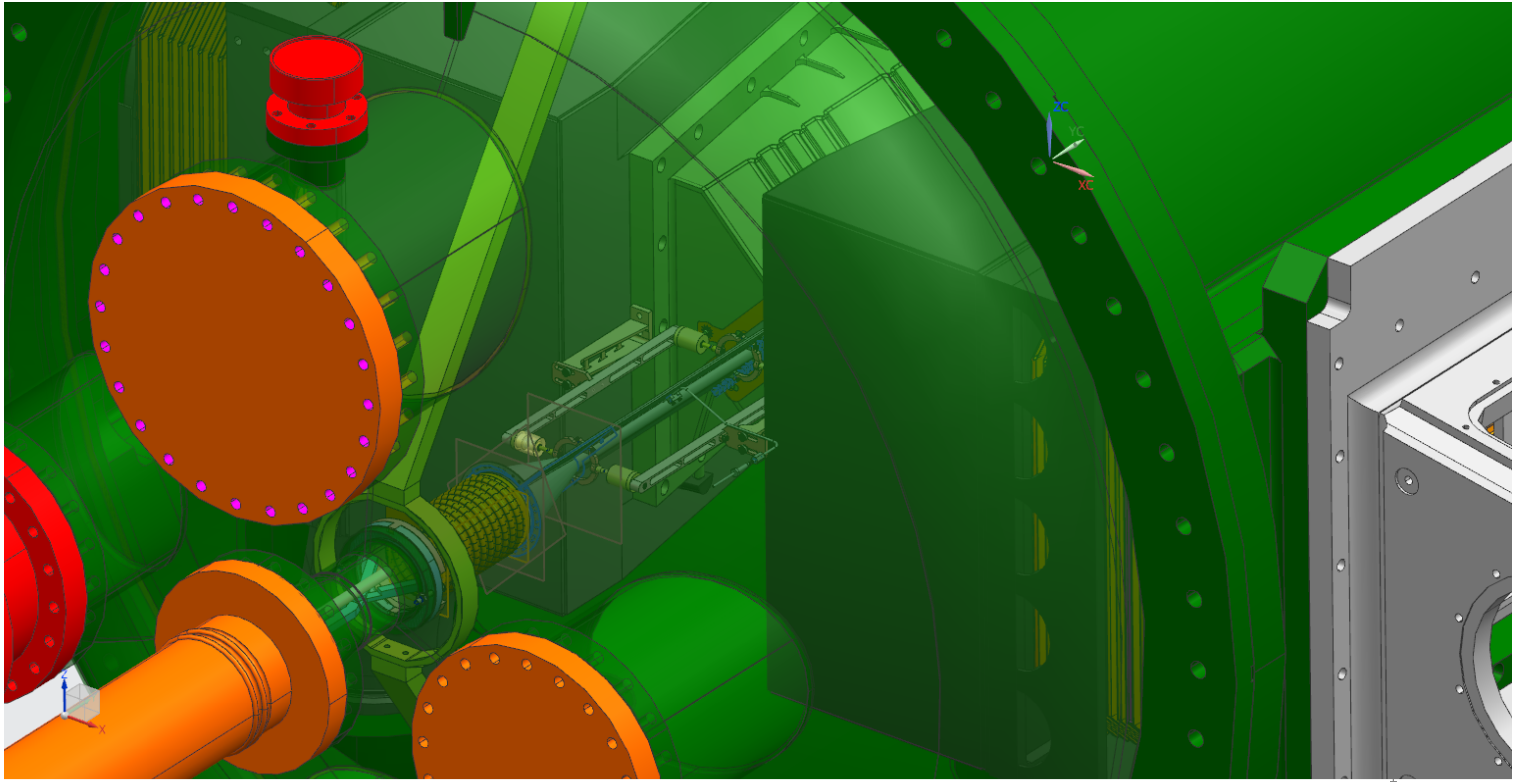


- Compared with a free beam, the gas atoms are confined by the tube thus forming a target of higher areal density atoms/cm². The 'compression factor' can be as high as 100x depending on the geometry of the storage cell and gas type.
- The density (luminosity) increases with increasing L and decreasing D

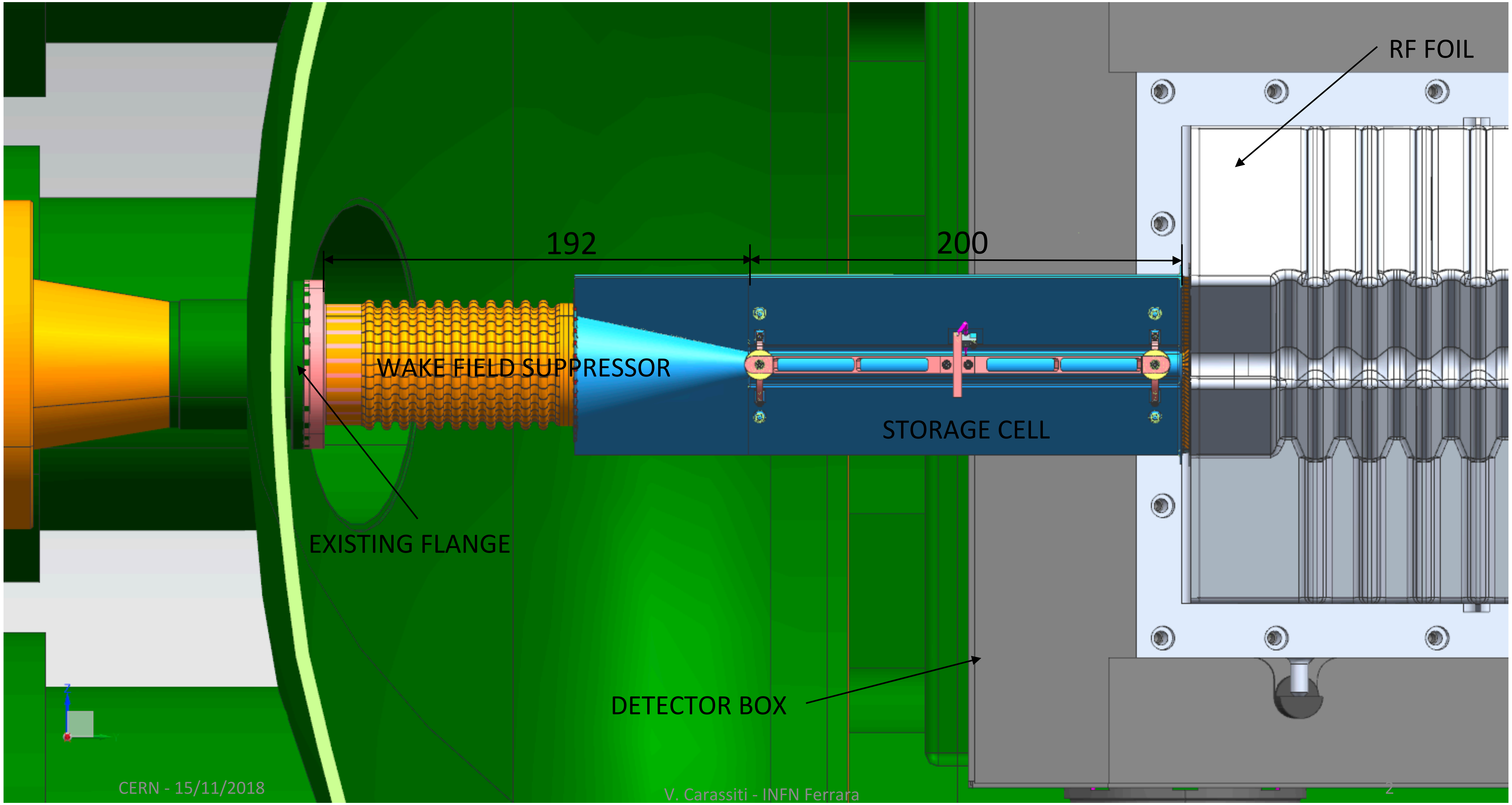
$$\rho_0 = \frac{I}{C_{tot}} \qquad C(\mathrm{l/s}) = 3.81\sqrt{T/M}\,\frac{D^3}{L + 1.33\,D}$$

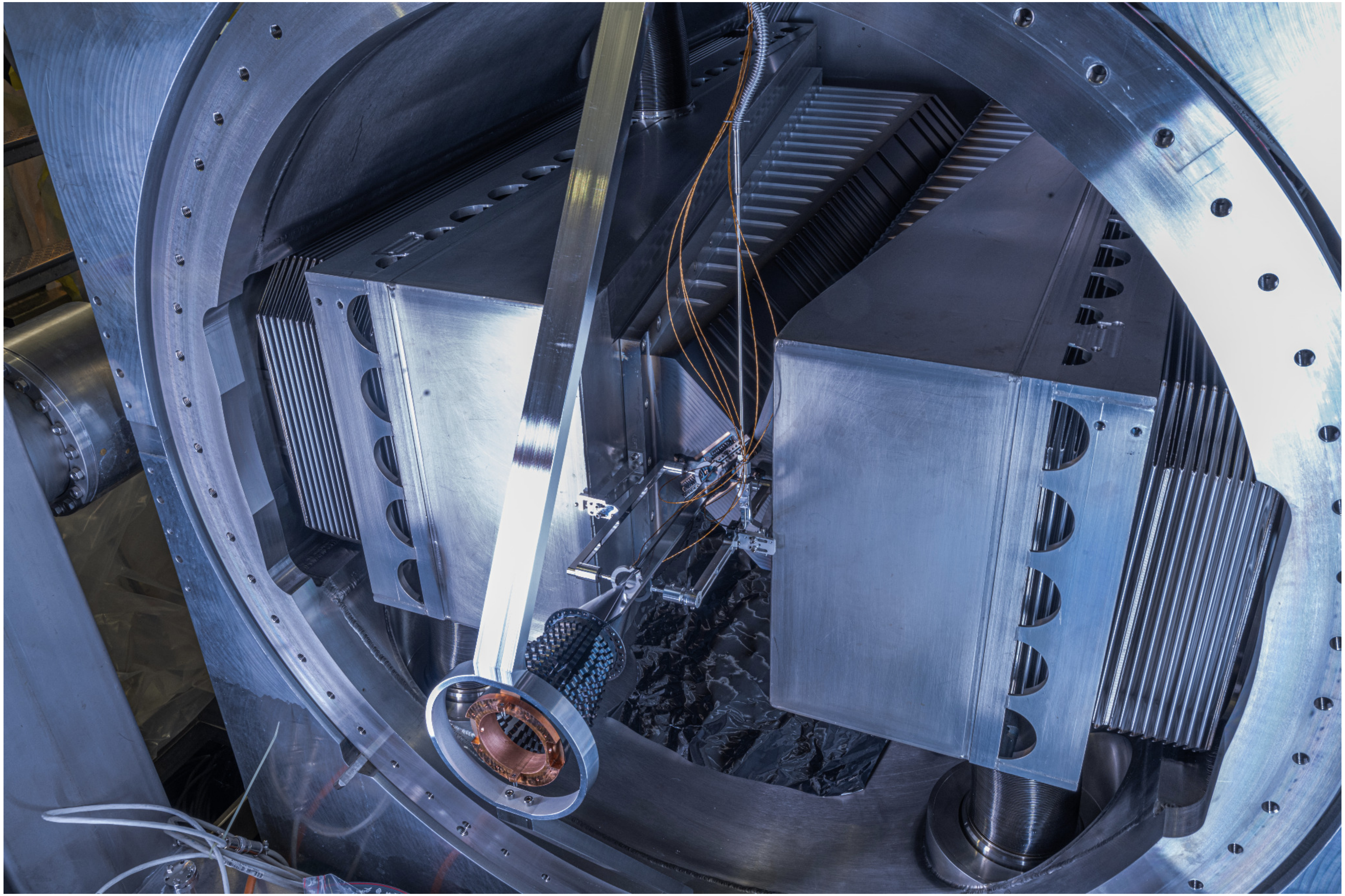
- The atoms diffuse outwards via the openings in MolFlow mode by performing many wall collisions



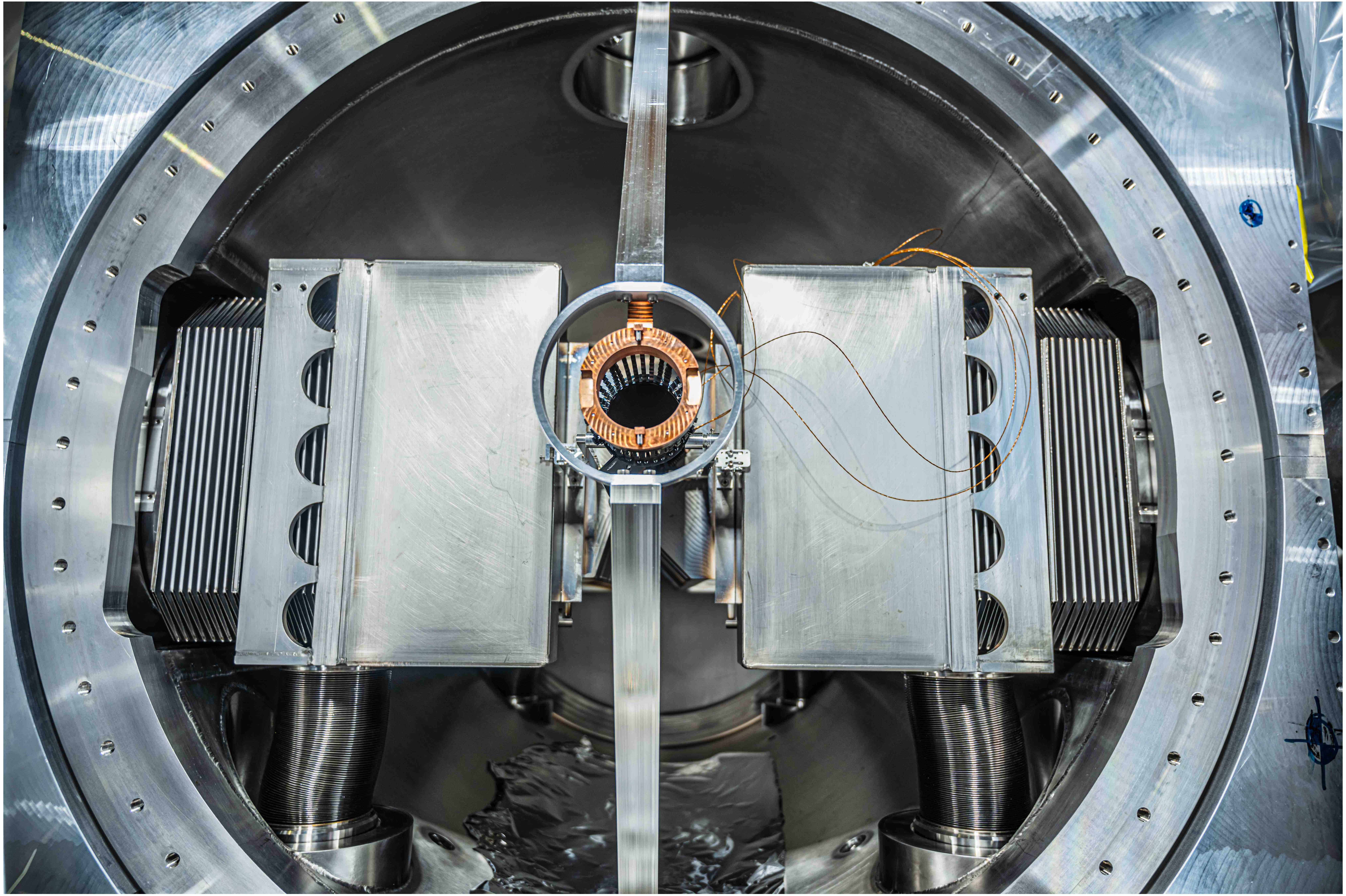


LHC beam

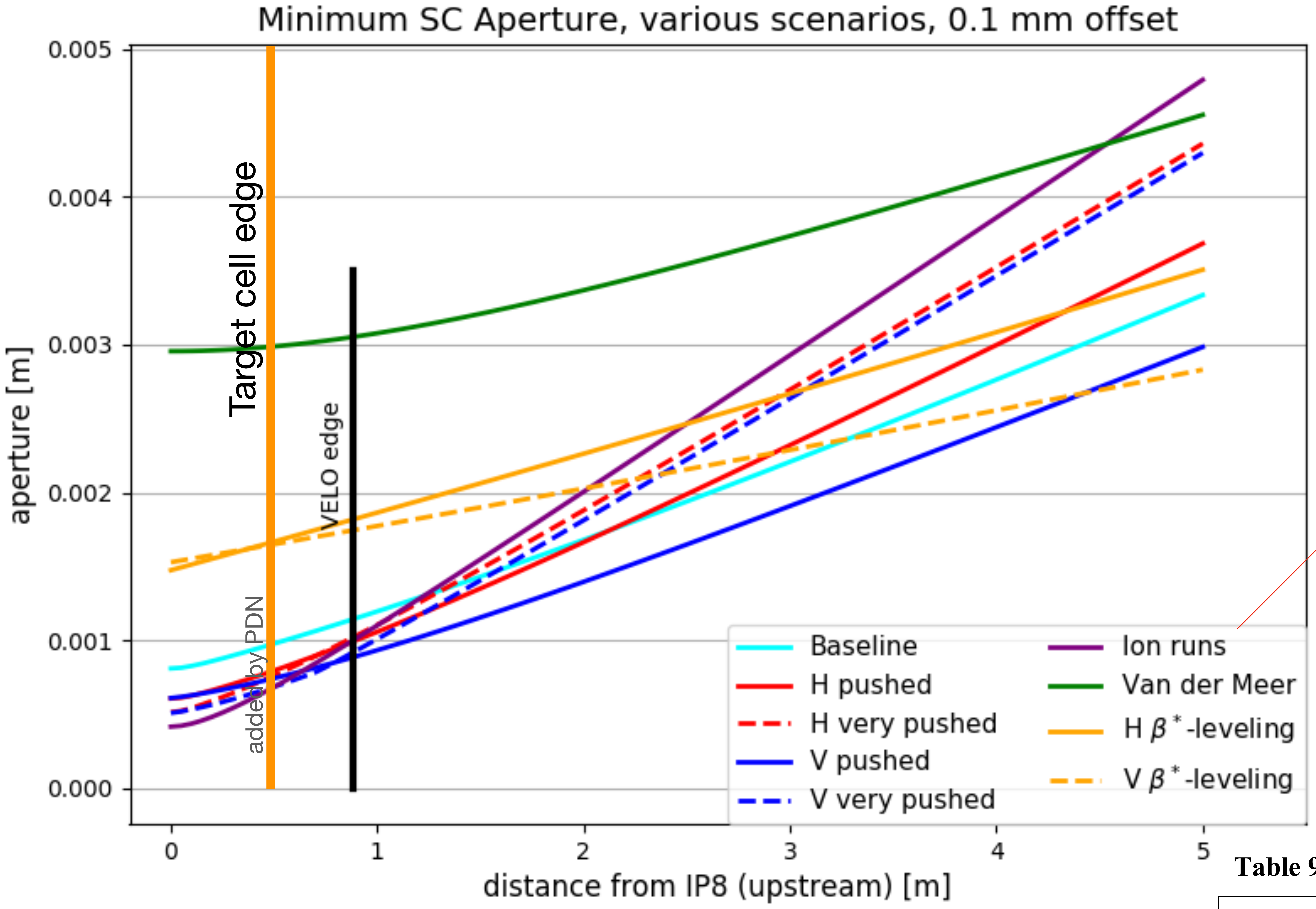

RF FOIL
192
200
WAKE FIELD SUPPRESSOR
STORAGE CELL
EXISTING FLANGE
DETECTOR BOX
CERN - 15/11/2018
V. Carassiti - INFN Ferrara



Installation completed in August 2020



Minimum aperture: all scenarios



Laser alignment during installation

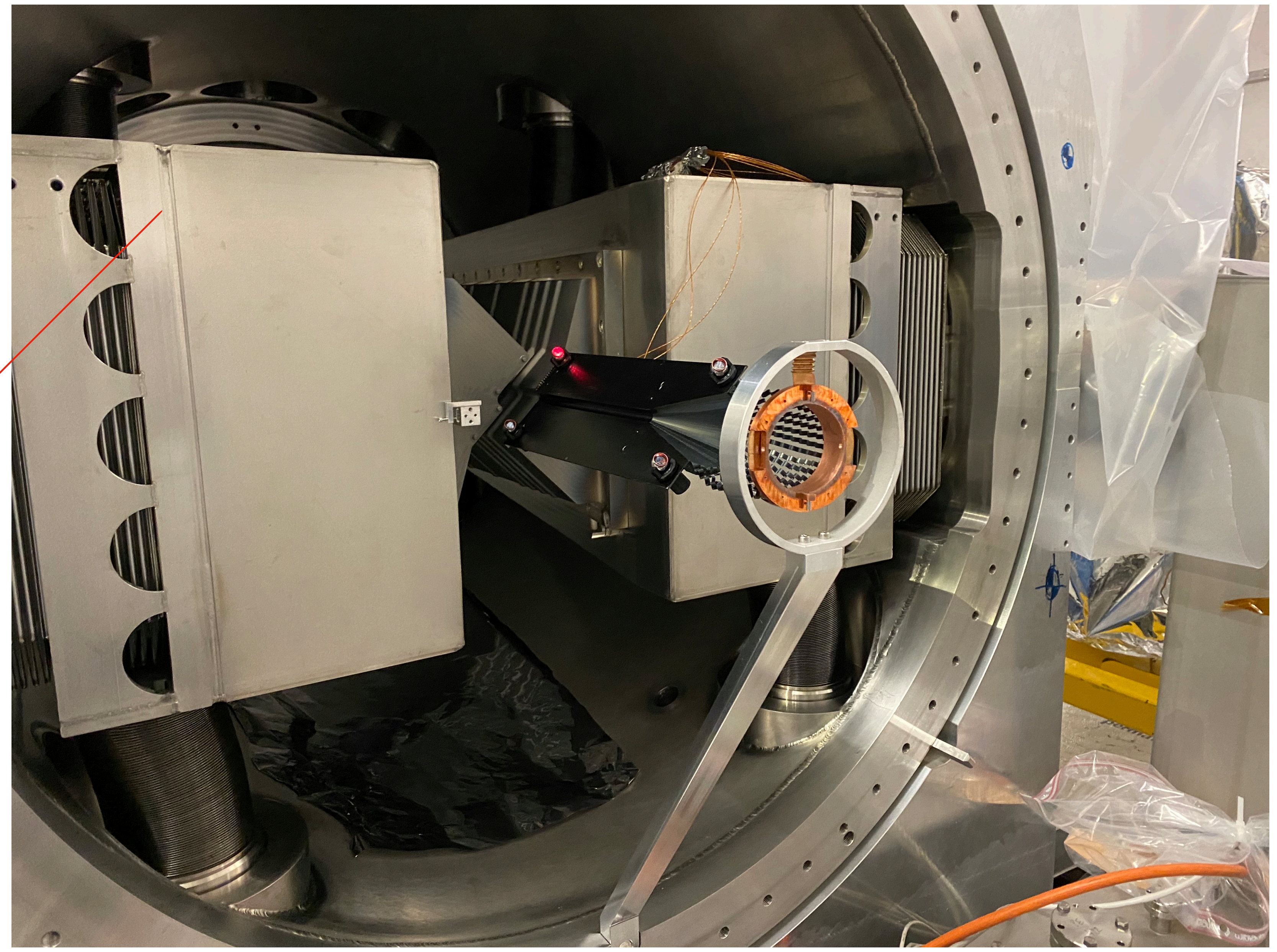


Table 9: Final position of the SMOG2 and its offset to the nominal position

Position of SMOG2				Offset to nominal		
Name	**Xphys [m]**	**Yphys [m]**	**Zphys [m]**	**dXphys [mm]**	**dYphys [mm]**	**dZphys [mm]**
S_E	-0.00142	-0.00017	-0.61739	-0.25	0.14	0.11
S_S	-0.00136	-0.00040	-0.33739	-0.19	-0.14	0.11
S_ROLL	-0.00082	0.99983	-0.61658			

R_{cell} = 5 mm —> clearance of 2 mm

Very good alignment reached

Due to the variable traverse size of the LHC beam, the storage cell must be openable:

-open (R=30 mm) during the beam injection and tuning phase

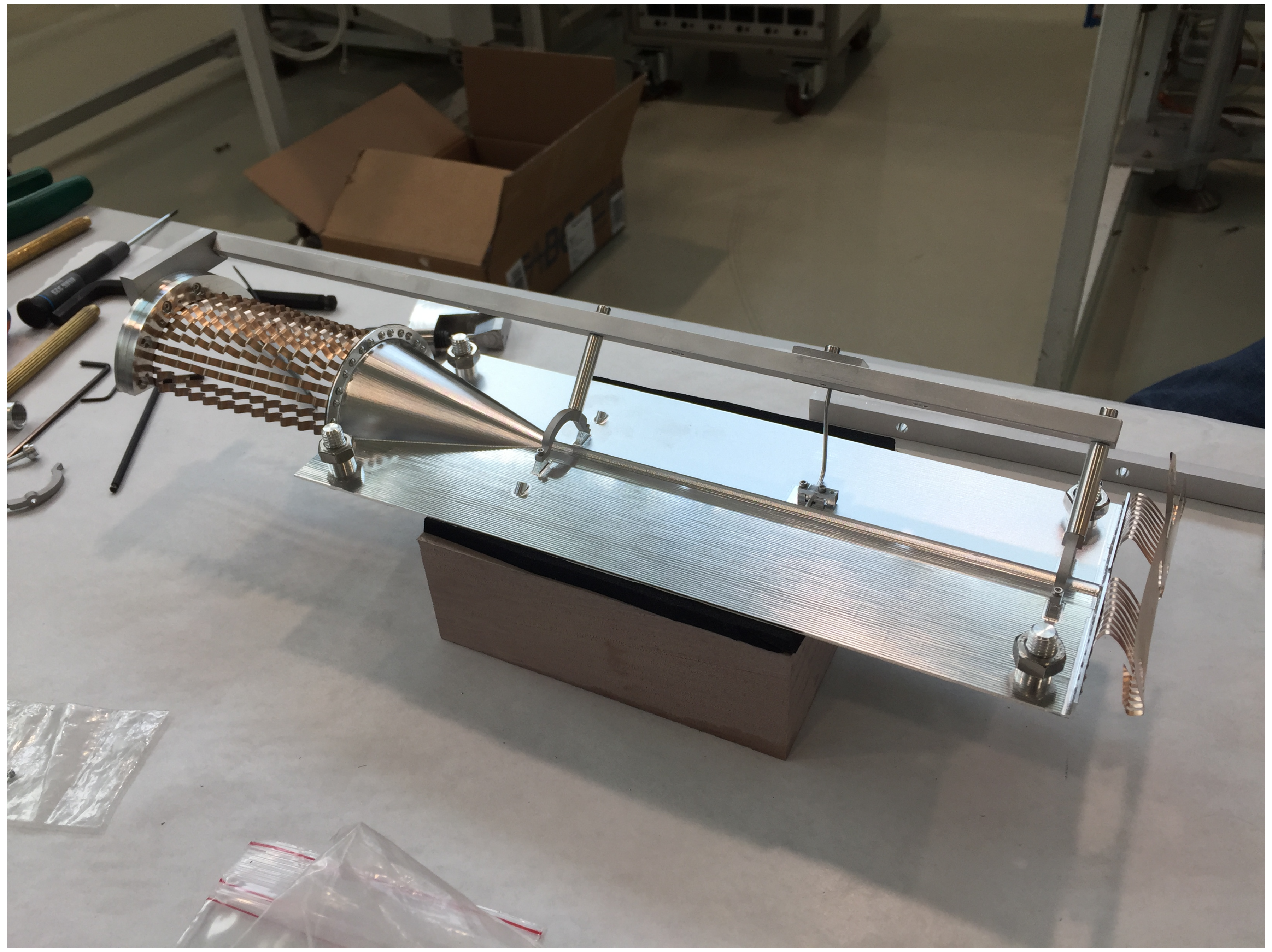
-close (R=5 mm) during lumi run

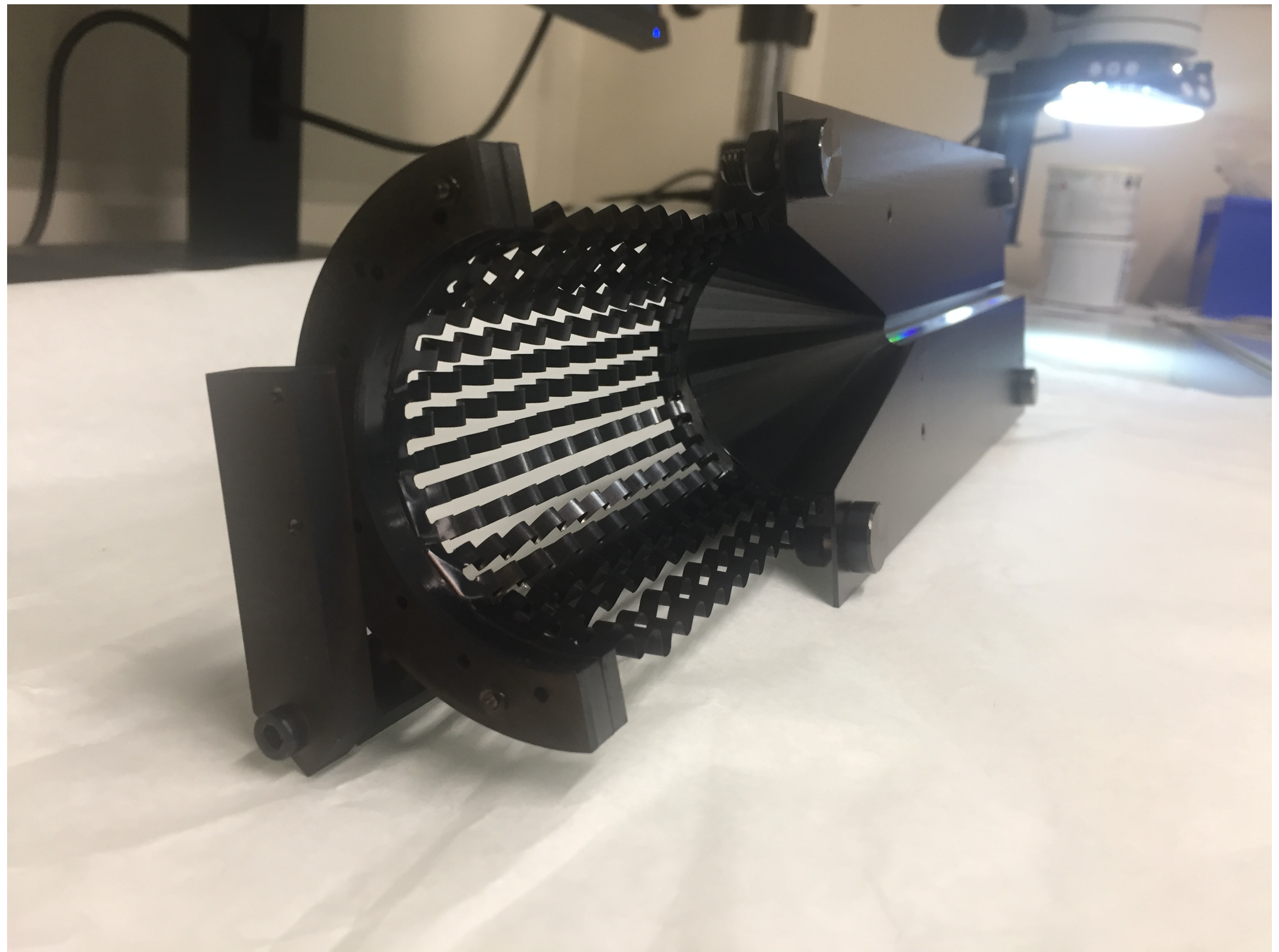
10 times faster than normal

Secondary Electron Yield

Electron cloud effects are observed in accelerators with positive particles. Slow electrons produced by various ionization processes are trapped near the beam producing secondary electrons (SEY), which may lead to beam instabilities.

For this reason, surfaces exposed to the LHC beams need to have a low enough SEY —> coating





All the surfaces have been coated with Amorphous Carbon

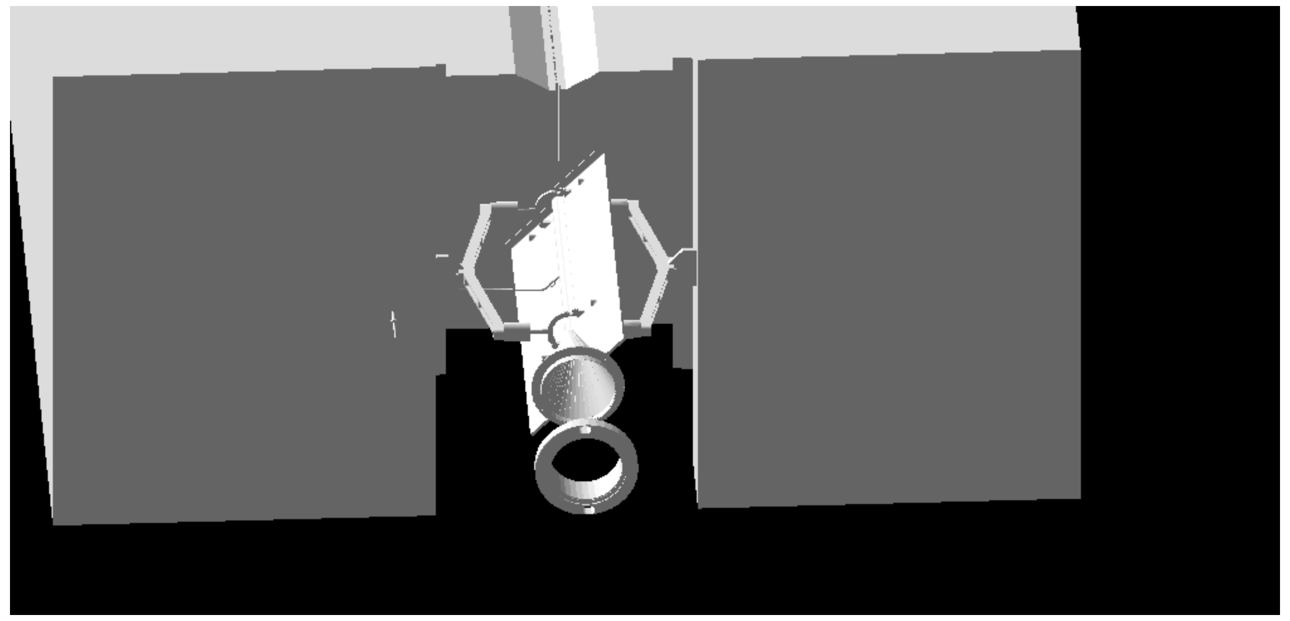
Machine Induced background … in the LHCb spectrometer

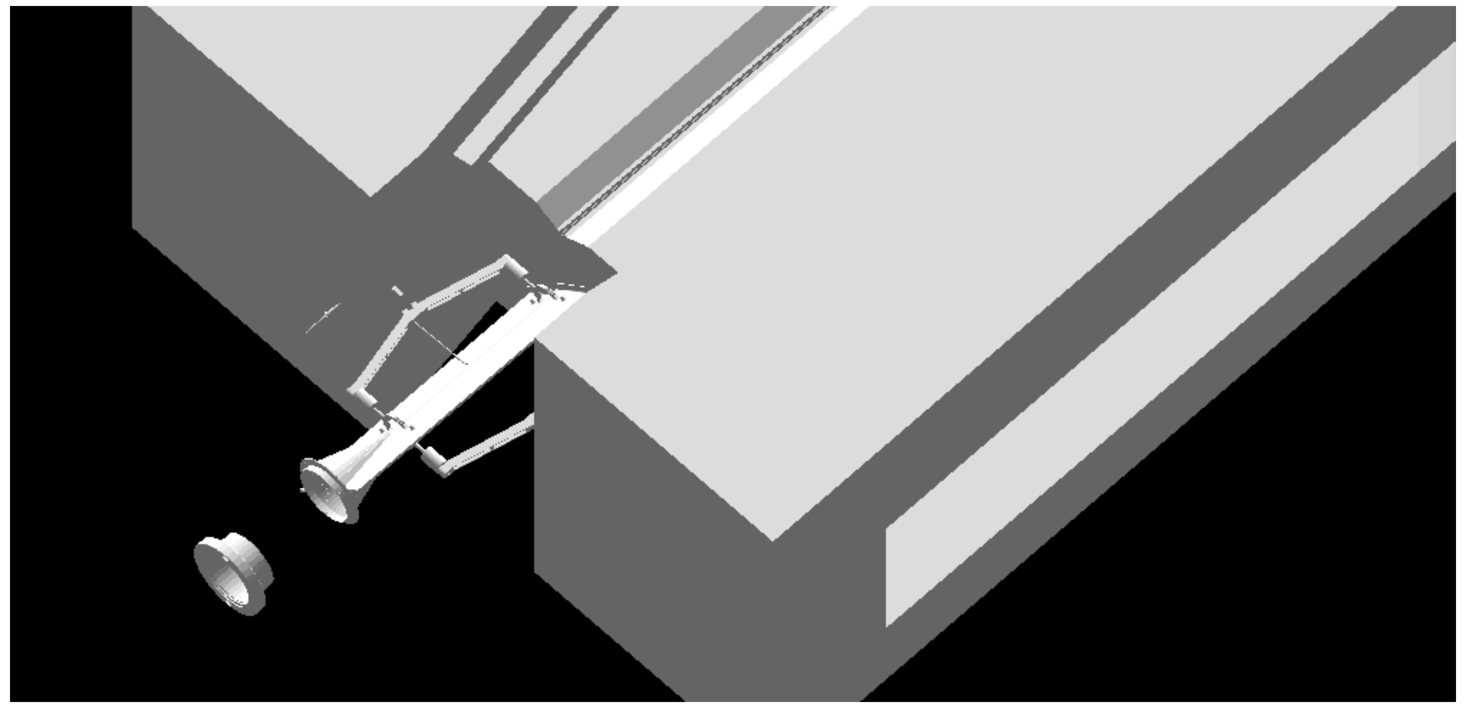
The installation of the gas target in the upstream section of the LHCb spectrometer adds material budget that can, in principle, increase the background seen by the sub-detectors

This has been carefully calculated checking the:

-**Beam-gas interactions in Long Straight Section (LSS)** leading up to the experiment
-**Interactions with the Tertiary Collimators (TCT)** located upstream on both sides of the beam pipe.

Simulations in GEANT





Config.	Average VELO clusters per event MIB-TCT (μ=0.0238)	MIB-LSS (μ=0.0019)	pp	pp + μ MIB	$\Delta^{MIB-TCT}$	$\Delta^{MIB-LSS}$	$\Delta^{pp+\mu MIB}$
no target	75	481	443	446	–	–	–
target	87	506	442	445	+16.0 %	+5.2 %	0

- This is un upper limit because the pileup has not been considered
- Adding the SMOG2 material budget in front of the LHCb detector does not change the number of VELO clusters per event in the pp collisions
- When the MIB is properly scaled and embedded into the pp collisions, **the effect of SMOG2 is completely negligible**

Luminosity measurements

f_{rev}: beam revolution frequency
$N_{p/b}$: number of particles per bunch
N_b: number of bunches
ρ_0 : target density at the cell center
Φ: gas flow
θ : areal density
C= total conductance
D: cell diameter
L: cell length
T: temperature
M: molecular mass

$$L_{ist} = \theta \, N_p \, f_{rev}$$

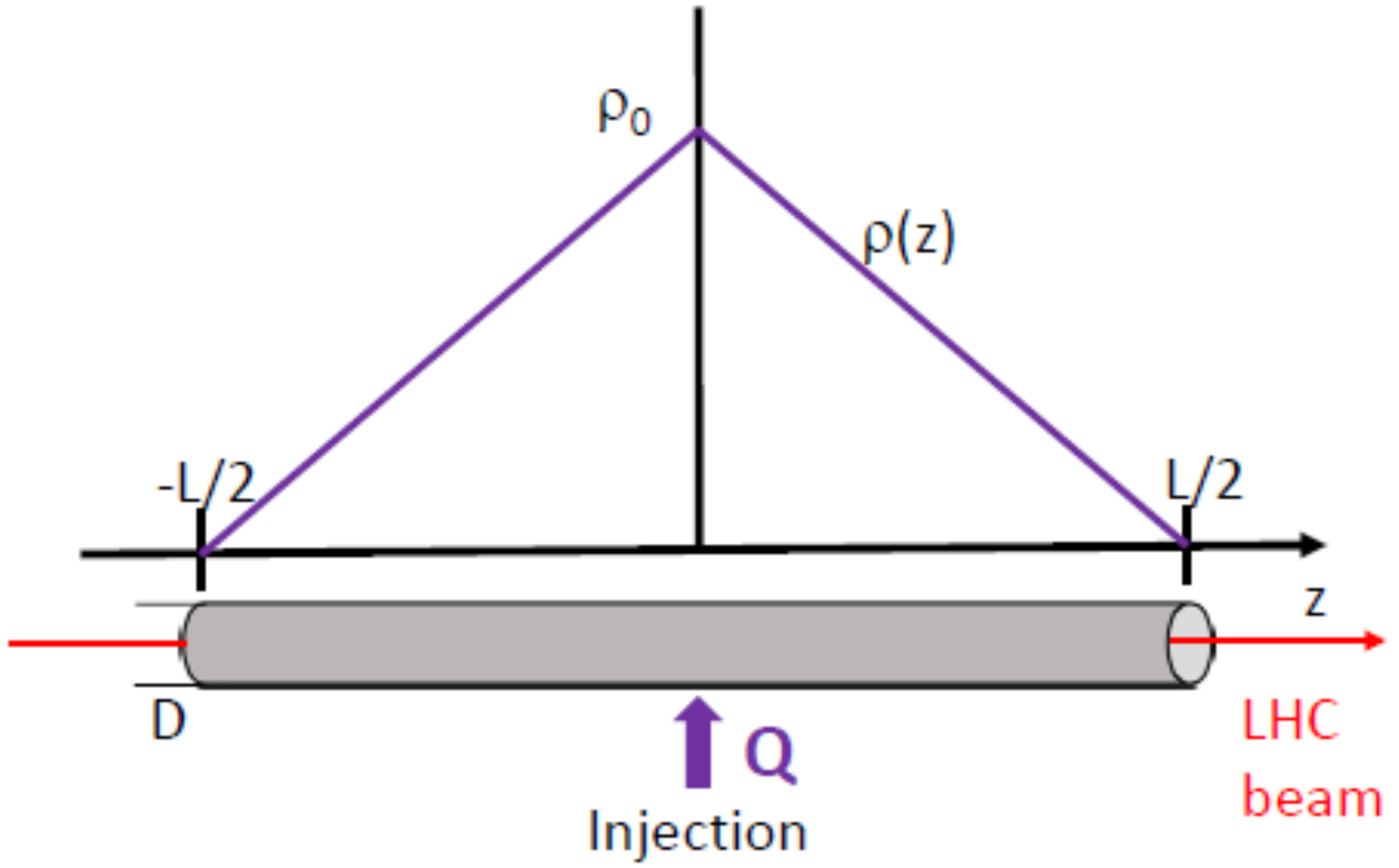
areal density

number of particles

$$N_{p/b} \cdot N_b$$

$$\rho_0 \frac{L}{2} = \frac{\Phi}{C} \frac{L}{2}$$

$$C = 3.81 \sqrt{\frac{T}{M}} \frac{D}{L + \frac{4}{3} D}$$



flux injected

Gas Feed System

geometry

Storage Cell

areal density

Molecular Dynamics
Temperature
Leakage
Sticking Factor

Instantaneous measurements

Luminosity measurements

Contributions to systematic uncertainty:

Molecular Dynamics (Molflow): 0.5 %

Temperature: ΔT <0.1 K —> negligible

Leakage: wings ensure a negligible conductance along the cell edges —> negligible

Sticking Factor: 1.4% (pessimistic estimation)

Geometry: real geometry measured by CMM —> negligible

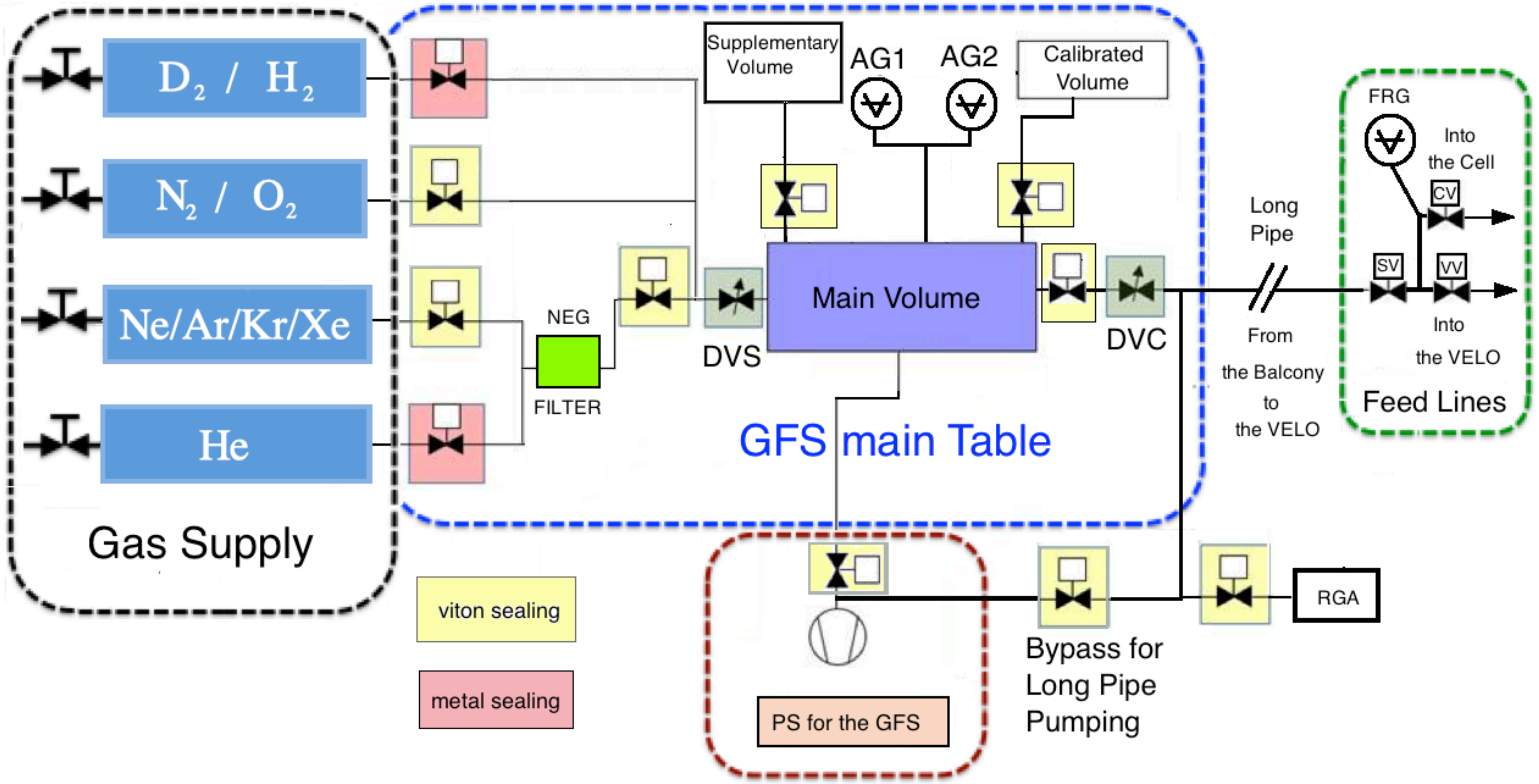
GFS: <1% (to be confirmed after the calibration of the whole system)

Preliminary

Total expected uncertainty on luminosity ~2%
(slightly dependent on the gas: worse for H_2 than for Xe)

Comparison with the method used with SMOG (ep elastic scattering) is possible offline

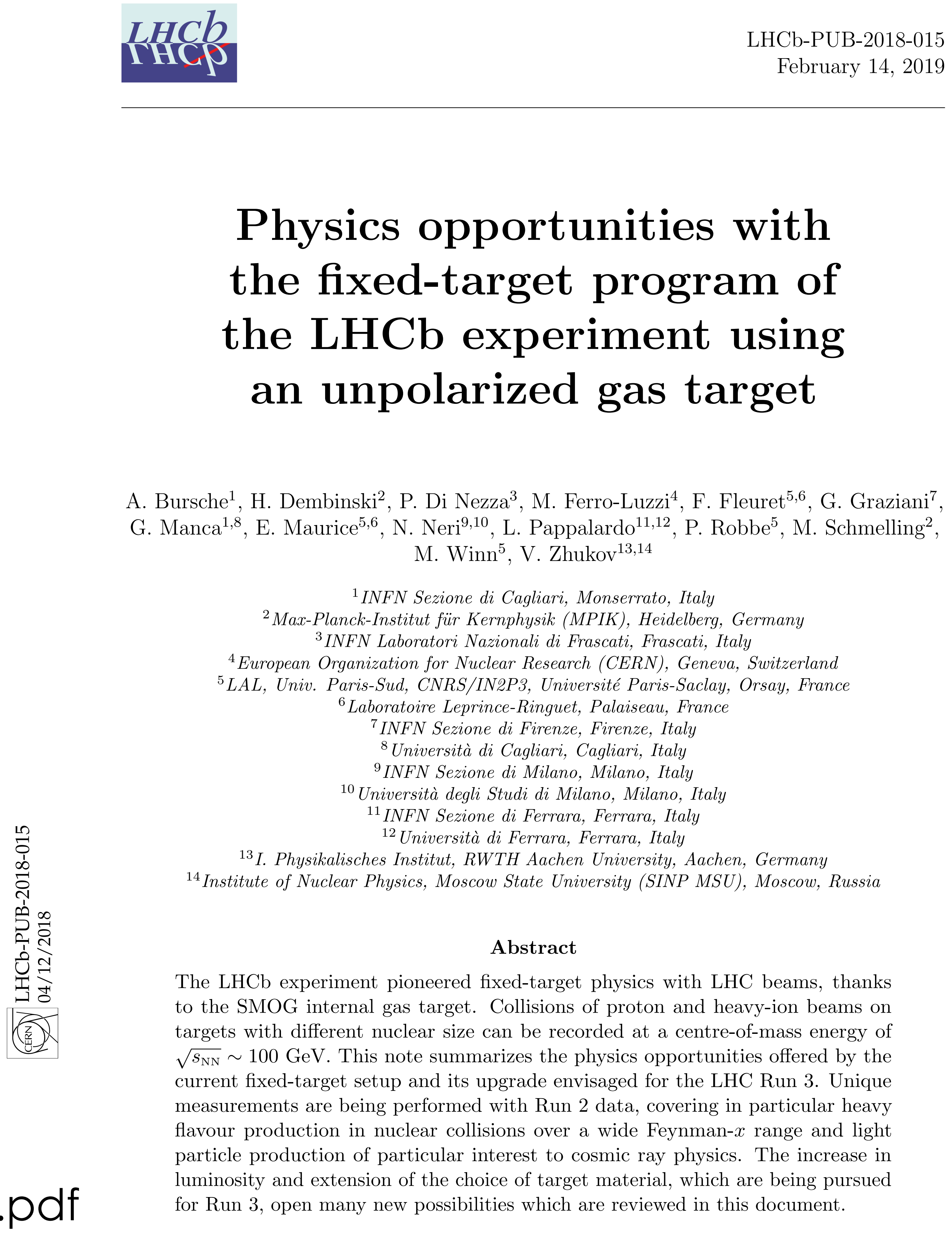
Gas feed system



3+1 gas lines/reservoirs

It will be installed in 2022, before the end of the LS2

https://cds.cern.ch/record/2673690/files/LHCB-TDR-020.pdf


LHCb-PUB-2018-015
February 14, 2019

LHCb-PUB-2018-015
04/12/2018

Physics opportunities with the fixed-target program of the LHCb experiment using an unpolarized gas target

A. Bursche[1], H. Dembinski[2], P. Di Nezza[3], M. Ferro-Luzzi[4], F. Fleuret[5,6], G. Graziani[7], G. Manca[1,8], E. Maurice[5,6], N. Neri[9,10], L. Pappalardo[11,12], P. Robbe[5], M. Schmelling[2], M. Winn[5], V. Zhukov[13,14]

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Abstract

The LHCb experiment pioneered fixed-target physics with LHC beams, thanks to the SMOG internal gas target. Collisions of proton and heavy-ion beams on targets with different nuclear size can be recorded at a centre-of-mass energy of $\sqrt{s_{NN}} \sim 100$ GeV. This note summarizes the physics opportunities offered by the current fixed-target setup and its upgrade envisaged for the LHC Run 3. Unique measurements are being performed with Run 2 data, covering in particular heavy flavour production in nuclear collisions over a wide Feynman-x range and light particle production of particular interest to cosmic ray physics. The increase in luminosity and extension of the choice of target material, which are being pursued for Run 3, open many new possibilities which are reviewed in this document.

https://cds.cern.ch/record/2653780?ln=en

The SMOG2 unpolarized gas target is not only a very interesting project itself, but provides an ideal test-bench for the R&D for its upgrade —> the polarized target

LHC spin

Marco Santimaria's talk
Wednesday 2.6

Conclusions

- The SMOG2 project is unique, not only in the LHC panorama
- The R&D and validation process have been complex but all the relevant aspects, wrt LHC and LHCb, have been studied in details
- The SMOG2 storage cell has been installed and is ready for the LHC Run 3
- The GFS is in its final phase (calibration and installation)

Fixed target collisions at LHCb offer a unique opportunity for *a laboratory for QCD and astroparticle* in unexplored kinematic regions