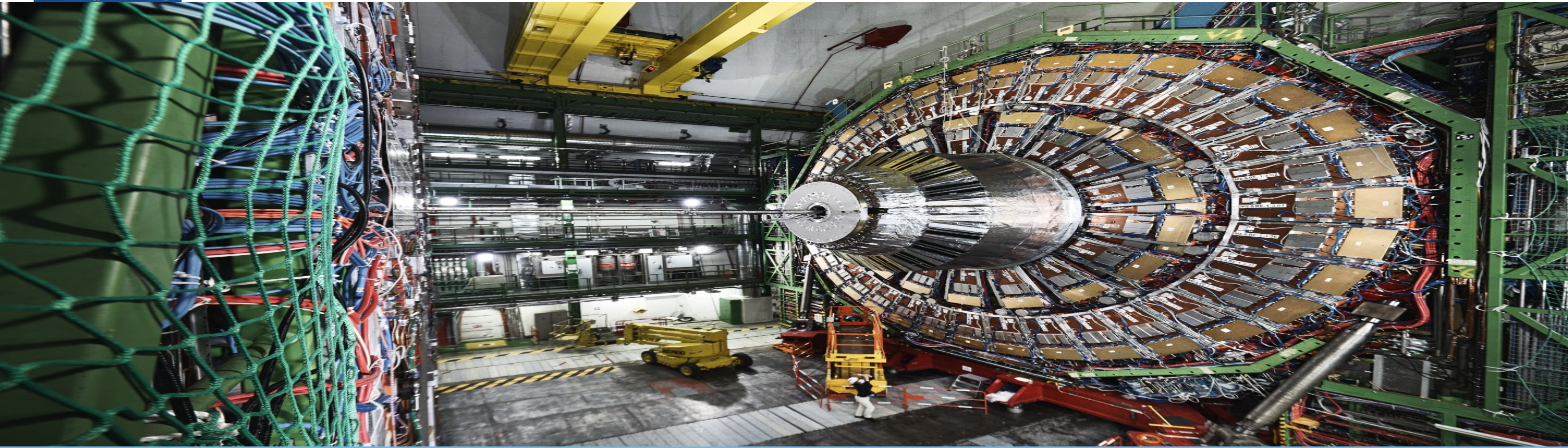


JRA2- Fixed Target Experiments at the LHC

Pasquale Di Nezza (INFN-LNF) Cynthia Hadjidakis (IJCLab *Orsay*)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

WP objectives:

- Investigation and implementation of fixed-target experiments with ALICE and LHCb detectors at high-luminosity
- Develop new theoretical ideas (rare events, large rapidities, ...)
- Quantify phenomenological opportunities with ALICE and LHCb in fixed-target modes
- Benchmark selected observables using realistic simulations

Fixed target collisions at the LHC represent a unique possibility for a laboratory for QCD and astroparticle in unexplored kinematic regions

Three tasks defined:

- Task 1: Feasibility studies in ALICE
- Task 2: Gas-target development in LHCb
- Task 3: Phenomenological and theoretical studies

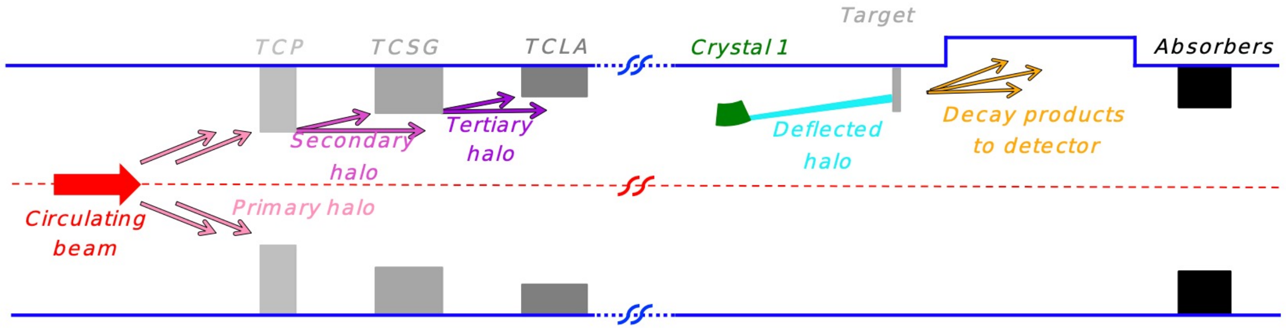
2021 (virtual) FTE@LHC workshop

https://indico.ijclab.in2p3.fr/event/7201

ALICE-FT progress

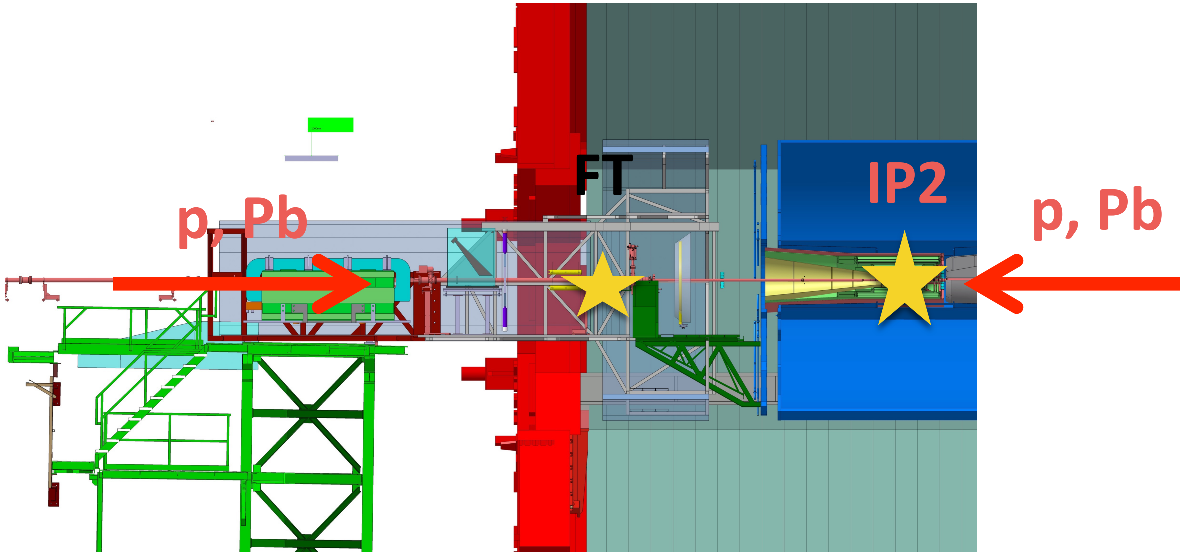
Proposed ALICE fixed-target programme *CERN-PBC-Note-2019*

- High-*x* physics (gluon, anti-quark and heavy quark)
- Proton and charm production: useful for cosmic ray physics
- Quark and gluon plasma studies (AA and small systems) between SPS and RHIC energy towards large rapidity



ALICE fixed-target solution under study

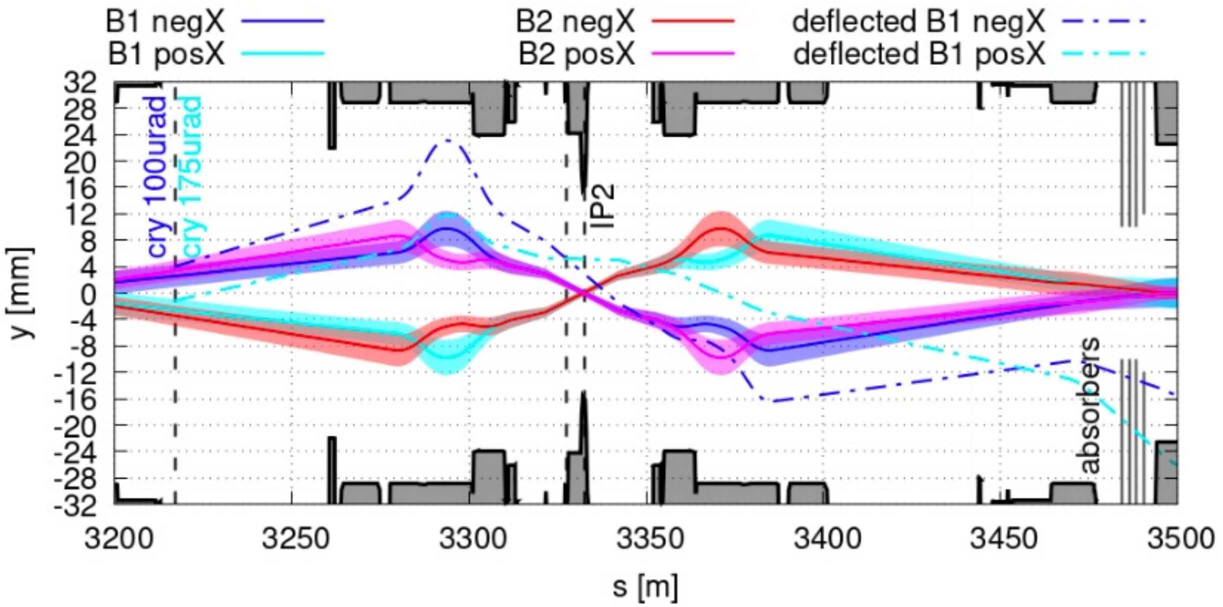
- Beam halo deflected with a bent crystal
- Couple to a solid target in front of ALICE detectors (~5 m from the nominal Interaction Point)
- Absorbers downstream to absorb the non-interacting particles
- Aim: installation in LS3 (2025-2027)



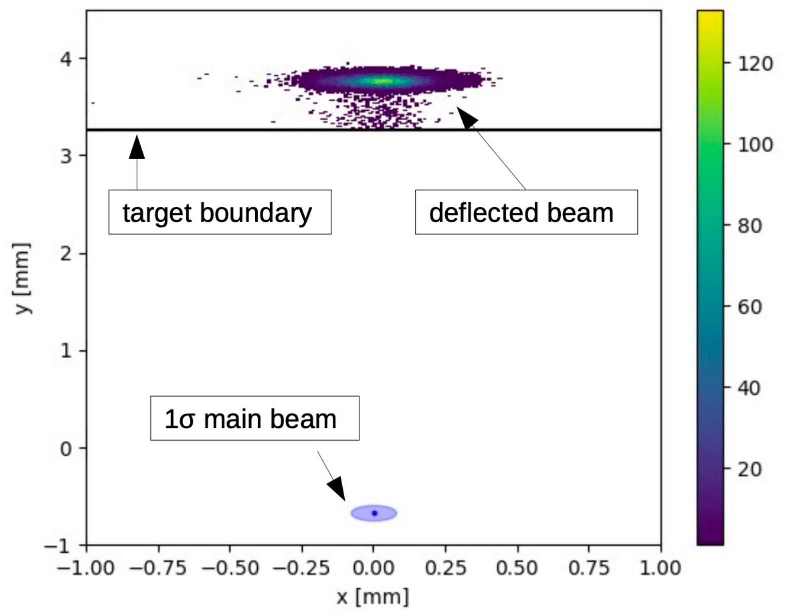
ALICE-FT progress

Crystal collimation study

- Proton beam studies performed: ~10^6 p/s expected in Run 4
    - Equivalent to L = 1.1/pb in pC and L = 0.6/pb in pW for one year of data taking and target length of 1 cm
- Deflected halo nicely collimated, 4 mm away from the main beam at target position
- Positions of crystal and absorbers defined
- Crystal unity integration study started
- Lead beam studies to be done



HB2021 conference
M. Patecki

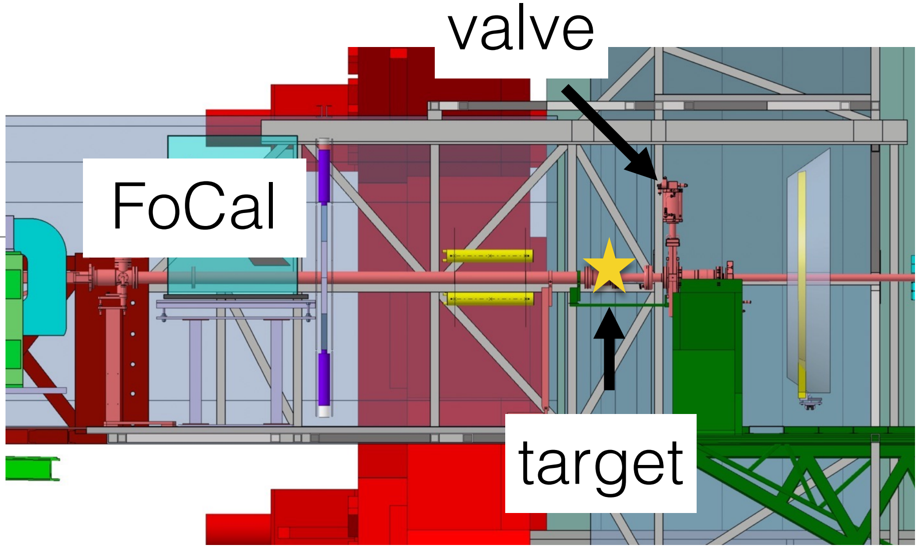


FTE@LHC 2021 workshop

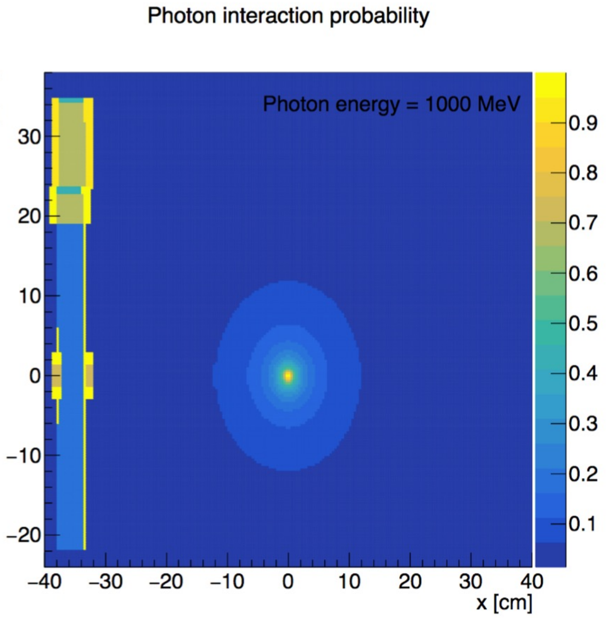
ALICE-FT progress

Target system and integration constraints

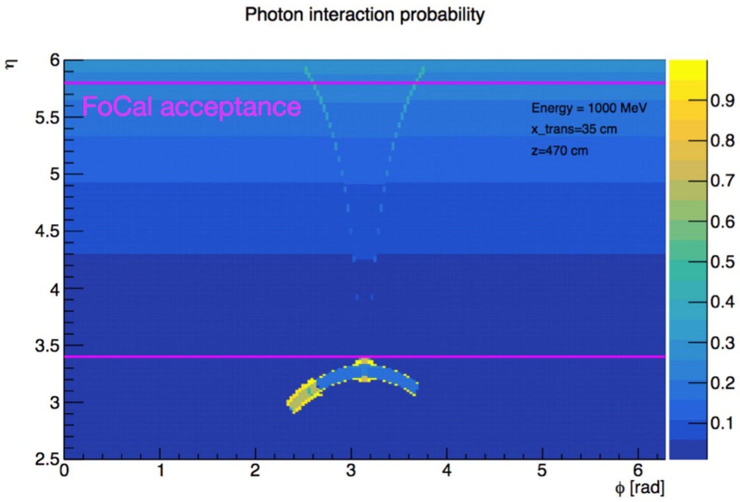
- Possible position:
  - z = 4.8 m due to possible displacement of the ITS during winter shutdown
  - z = 3.5 m investigating to maximize the backward coverage of the TPC
- Avoid shadow to FoCal detector (LoI to LHCC June 2020)
  - Vacuum valve placed ~35 cm away from the beam pipe to reduce the material budget in front of FoCal
  - Full simulations performed with Be or Al transverse pipe → neglected effects on photon or π^0 deposited energy in FoCal



LHC beam pipe and transverse pipe=0.8 mm thick Be



z=470 cm from IP



C. Van Hulse
FTE@LHC 2021 workshop

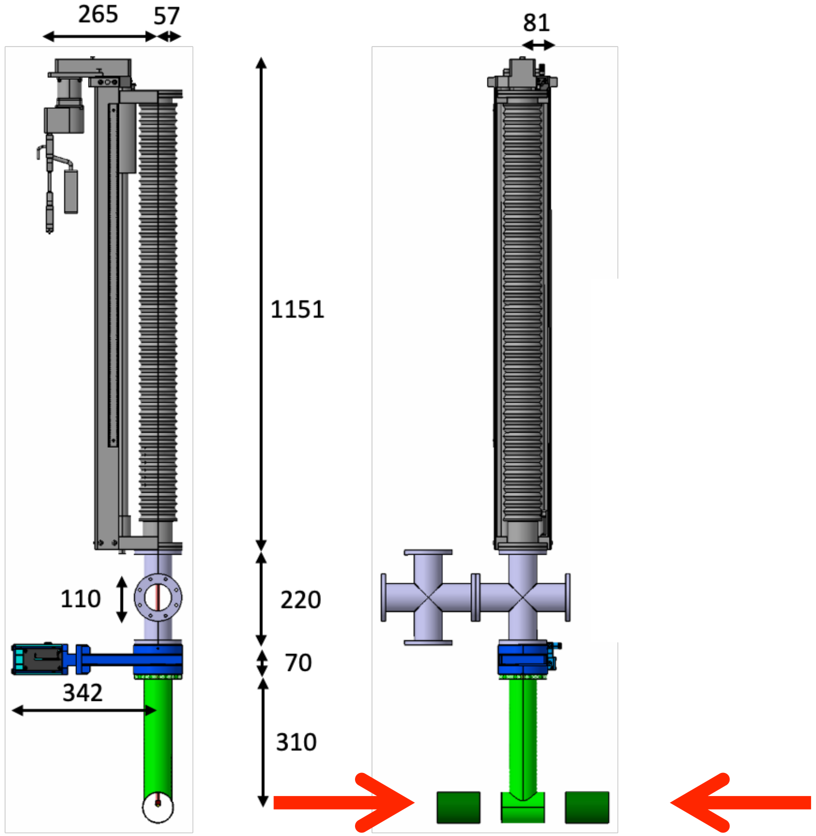
ALICE-FT progress

Target system

- Retractable target with linear motion
- Few mm radius target with varying length from 0.1 to 10 mm
- 30 cm Al transverse pipe to avoid shadow to FoCal detector
- Valve along the transverse pipe to isolate the target system for retracted target
- Target actuator in a vacuum chamber that moves thanks a step motor that compresses a bellow
- Target system conceptual design report delivered (delivery D20.1)
- Integration study in the ALICE mini-frame under study

One valve solution: everything remains in the cavern. Every vacuum-related job must be performed in the cavern.
Pumps and a baking system are switched on before opening the valve.

Moving speed: 10 mm/s.
Accuracy: 10 µm.



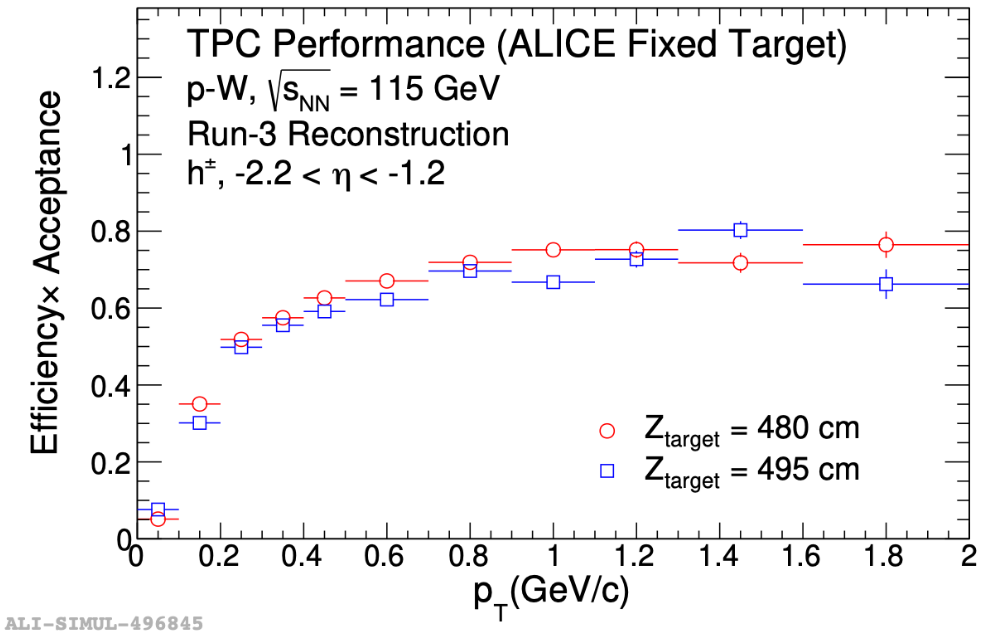
K. Pressard
FTE@LHC 2021 workshop

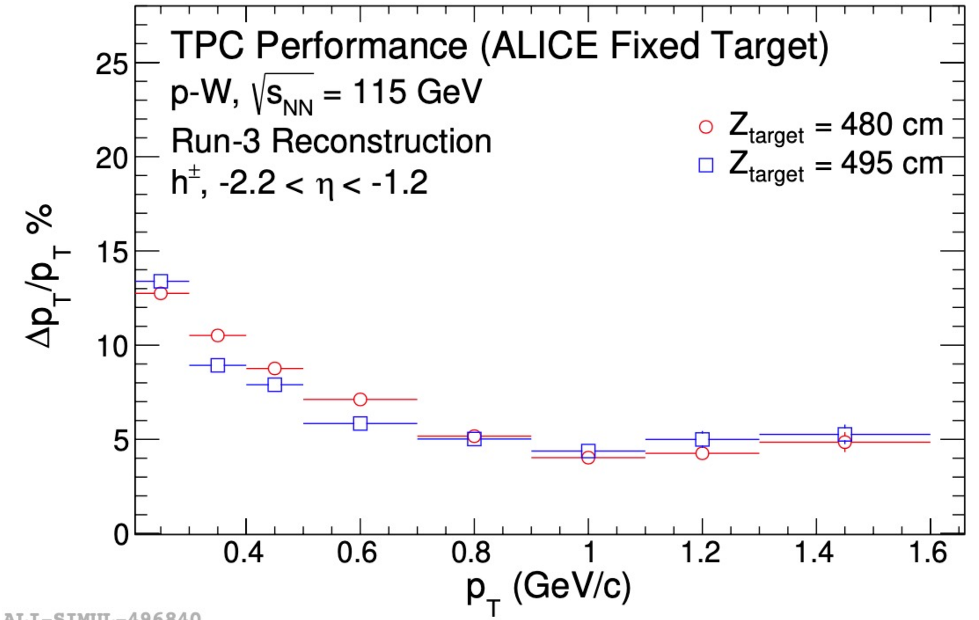
ALICE-FT progress

Full simulation and tracking efficiency

- Run 3 setting simulations
- Tracking and vertexing with ALICE TPC
- Tracking algorithm improved for large angle particles in the TPC
- Good tracking efficiency x acceptance obtained
- Fixed-target event tag needed for reconstruction in parallel mode (fixed-target and collider modes)
- Code for full simulations (for fixed-target mode only) ready, report ongoing (delivery D20.3)

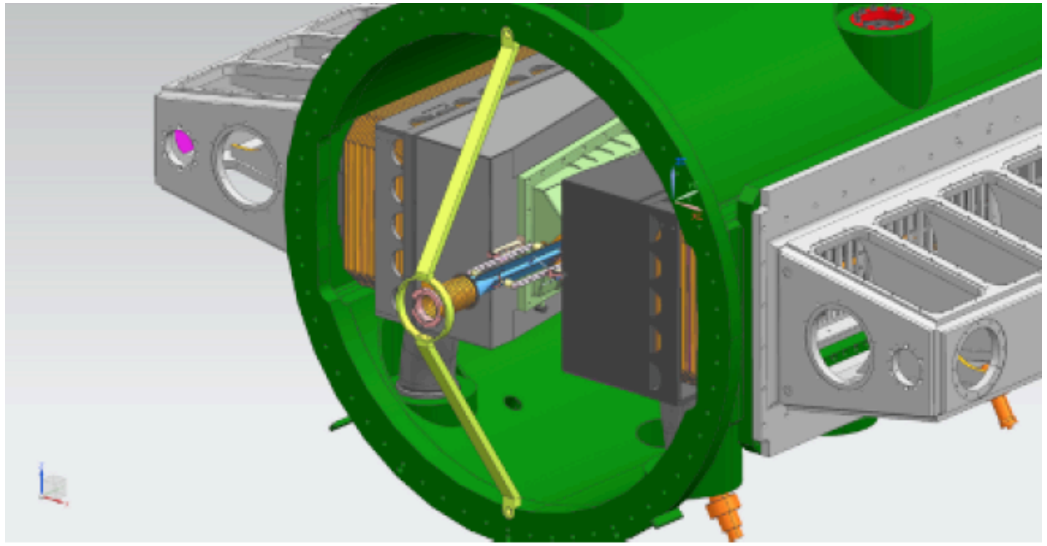
R. Haque

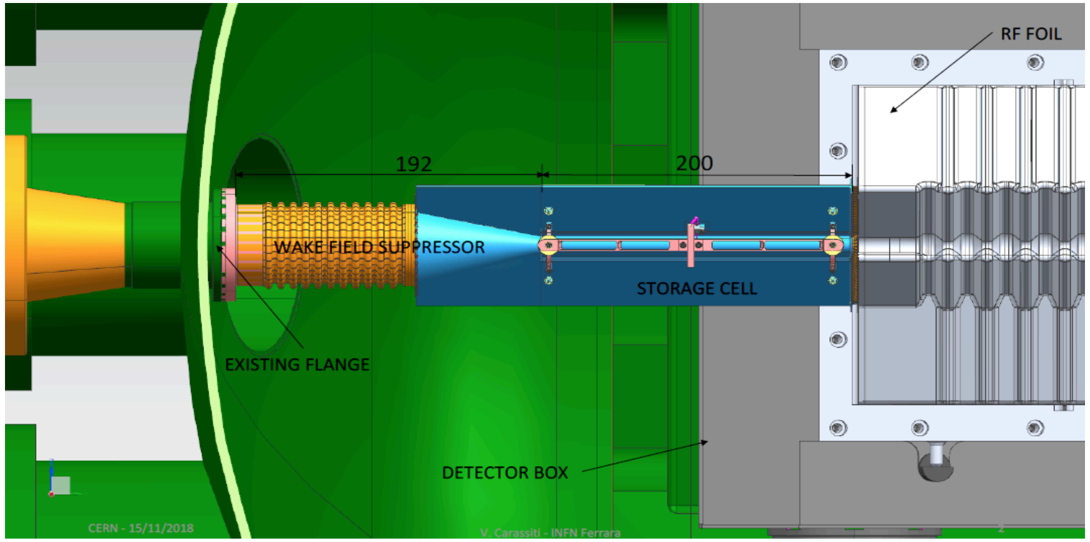


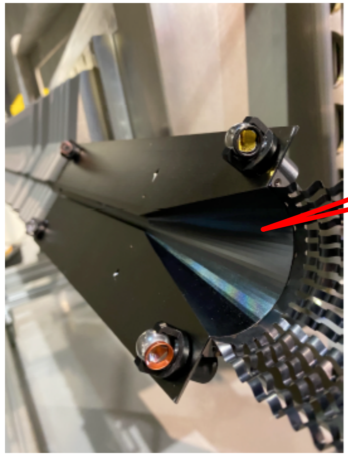


SMOG2: the fixed target @ LHCb

CERN-LHCC-2019-005
LHCB-TDR-020





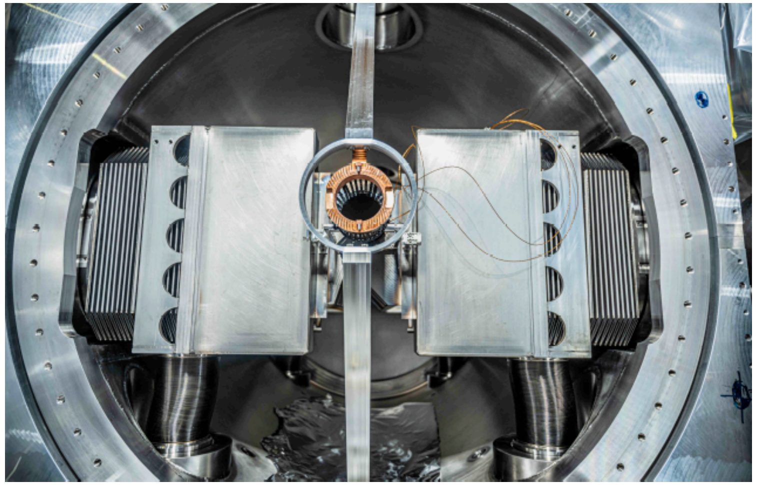


Cell coated (in/out) with Ti+aC

pre-installation and pre-alignement in clean room (Feb '20)

SMOG2: the fixed target @ LHCb

CERN-LHCC-2019-005
LHCB-TDR-020



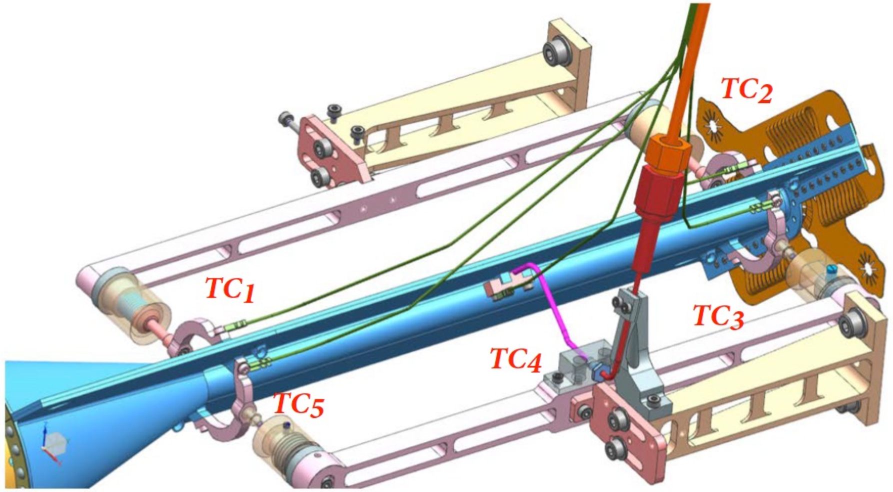
- ➢ Temperature is a key parameter for precise measurement of the target density (→ Lumi)
- ➢ 5 Temperature probes installed on cell walls and acquisition system installed on the balcony at P8, now in operation.

Deliverable D20.4 - OK

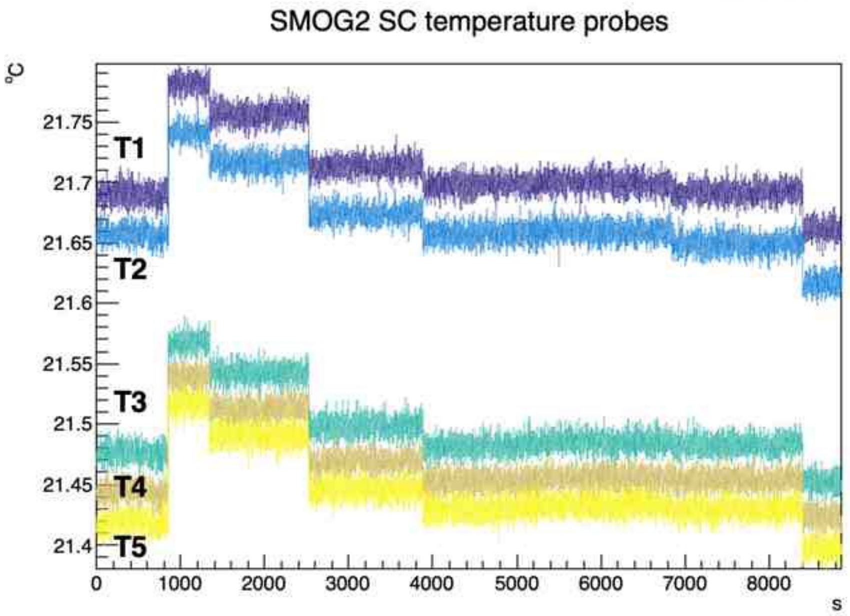
First feedback from LHC test beam

LHC test beam 2021

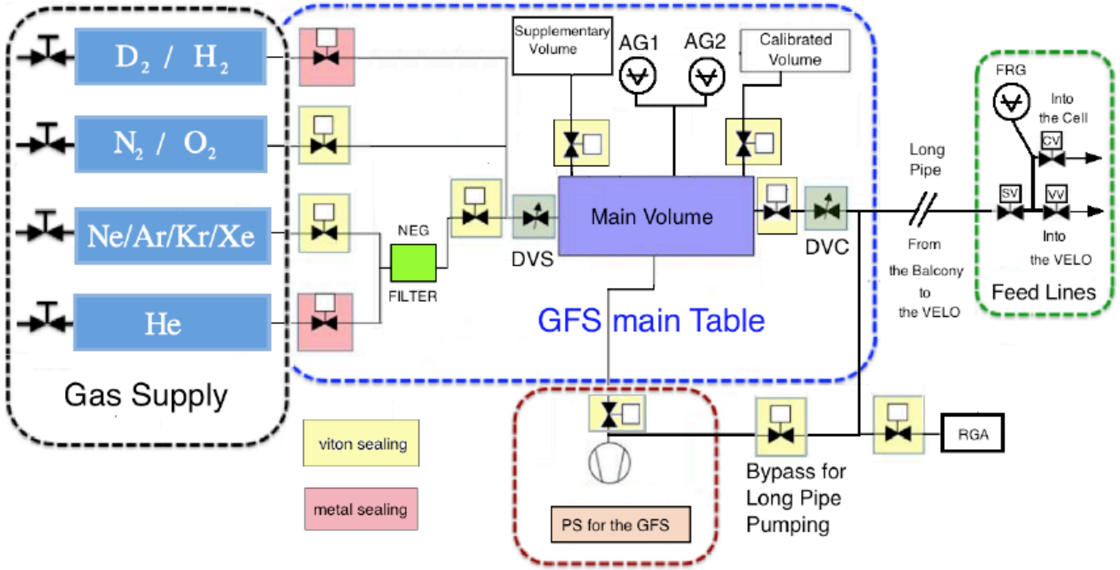
- The beams went through the storage cell
- The system was completely transparent to the beams, as expected
- Temperatures stable and independent on the beam status

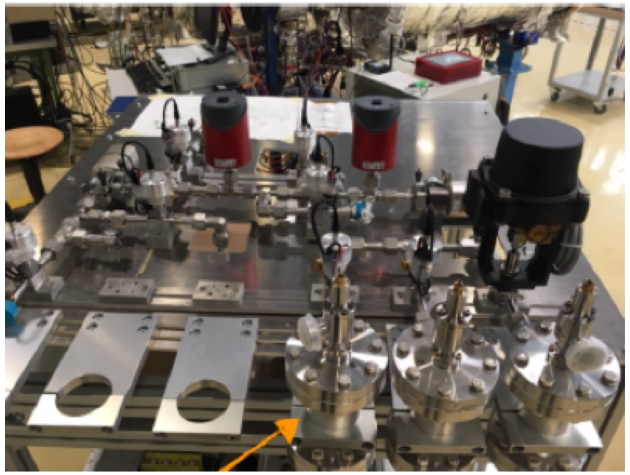


- The calibration is applied offline
- Very high sensibility and accuracy
  → fundamental for a precise luminosity determination
- The "steps" are due to different data taking periods and are real changes in the vessel temperature (max 0.1 C)



SMOG2: Gas Feed System





- 3+1 (H/D) gas lines. The H/D line without NEG (non-evaporable-getter) cartridge
- Pipe to storage cell already installed in balcony at P8
- System is ~ 80% ready (**full installation by end of ’21/beginning of ’22**)
- Need calibrations
- Need to merge control parameters and outputs into LHCb Slow Control system

SMOG2: Software and Triggers

Milestone MS35 - OK

SMOG2 software developments:

Goal: Define reconstruction/trigger strategies for SMOG2 such to optimize efficiencies and minimize the timing costs while not affecting performances for stand-alone pp data-taking.

Caveat: SMOG2 events reconstruction is quite challenging due to

- large displacement of vertices wrt nominal IP
- collisions topology characterized by low multiplicity and forward direction

Deliverables:

- Dedicated reconstruction algorithms for tracks and PV
- Dedicated trigger lines

➢ SMOG2 physics program extremely diverse but mostly requires simple trigger lines.

➢ Need to ensure suppression of pp contamination

Already implemented SMOG2 trigger lines:

✓ **Minimum Bias** (relevant for hadro-production + eff studies):

✓ **DimuonHighMass** (relevant for Charm, DY, CEP)

✓ **DiTrack** (relevant for charm and CEP)

✓ **SingleTrack** (generic)

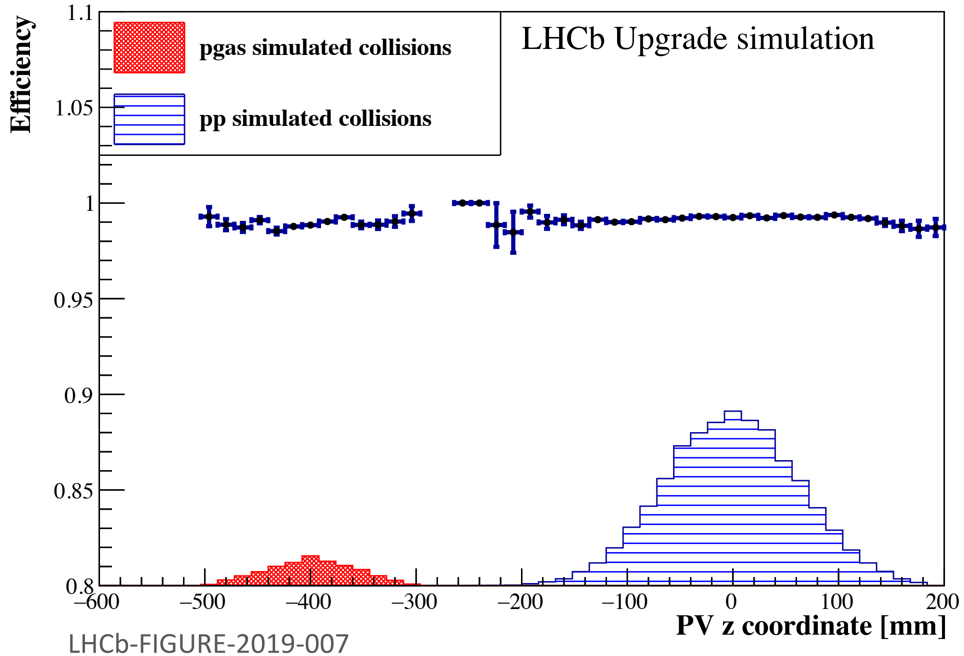
Line name	Run2 implementation	
Minimum bias lines		
Hlt1BEMicroBiasVelo	>=1 Velo tr	✓
Hlt1BEMicroBiasLowMultVelo	2016 : 1< Velo tr < 10 & Back 2017 : 1< Velo tr < 7.5 & Velo bkwd tr < 3 & Tr ($3.5 < \eta < 7$) > 0	
Single hadron lines		
Hlt1SMOGSingleTrack	2016 : $p_T > 800\,MeV/c \;\&\; p > 3GeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ 2017 : $p_T > 1\,GeV/c \;\&\; \mathrm{tr}GhostProb < 0.2$	✓
Muon lines		
Hlt1SMOGDiMuonHighMass	isMuon & $p > 3GeV/c \;\&\; p_T > 500MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 3$ $\mathrm{M}(\mu^+,\mu^-) > 2.5\,GeV \;\&\; q_1 \cdot q_2 == -1$	✓
Two body lines		
Hlt1SMOGGeneric	$p > 3GeV/c \;\&\; p_T > 400\,MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 800\,MeV$ $M > 0\,MeV/c^2$ vtx $\chi_{ndf} < 25$	✓
Hlt1SMOGKpi	$p > 3GeV/c \;\&\; p_T > 400MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 400\,MeV \;\&\; \vert AM - PDGM(D^0)\vert < 250\,MeV/c^2$ vtx $\chi_{ndf} < 25 \;\&\; \vert M - PDGM(D^0)\vert < 150\,MeV/c^2$	✓
Hlt1SMOGppbar	$p > 3GeV/c \;\&\; p_T > 400MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 400\,MeV \;\&\; \vert AM - PDGM(\eta_c(1S))\vert < 300\,MeV/c^2$ vtx $\chi_{ndf} < 25 \;\&\; \vert M - PDGM(\eta_c(1S))\vert < 150\,MeV/c^2$	✓
Three body lines		
Hlt1SMOGKKpi	$p > 3GeV/c \;\&\; p_T > 400MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 400\,MeV \;\&\; \vert AM - PDGM(D_s^+)\vert < 250\,MeV/c^2$ $\vert M - PDGM(D_s^+)\vert < 150\,MeV/c^2 \&$ vtx $\chi_{ndf} < 25$	
Hlt1SMOGKpipi	$p > 3GeV/c \;\&\; p_T > 400MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 400\,MeV \;\&\; \vert AM - PDGM(D^+)\vert < 250\,MeV/c^2$ $\vert M - PDGM(D^+)\vert < 150\,MeV/c^2 \&$ vtx $\chi_{ndf} < 25$	
Hlt1SMOGpKpi	$p > 3GeV/c \;\&\; p_T > 400MeV/c \;\&\; \mathrm{tr}\chi_{dof} < 4$ $doca < 1.0\,mm \;\&\; max_{ch}(p_T) > 400\,MeV \;\&\; \vert AM - PDGM(\Lambda_c^+)\vert < 250\,MeV/c^2$ $\vert M - PDGM(\Lambda_c^+)\vert < 150\,MeV/c^2 \&$ vtx $\chi_{ndf} < 25$	

Next goals:

- complete the HLT1 menu above
- decide the HLT2 strategy

SMOG2: track reconstruction

Velo tracking efficiency vs. z of the primary vertex

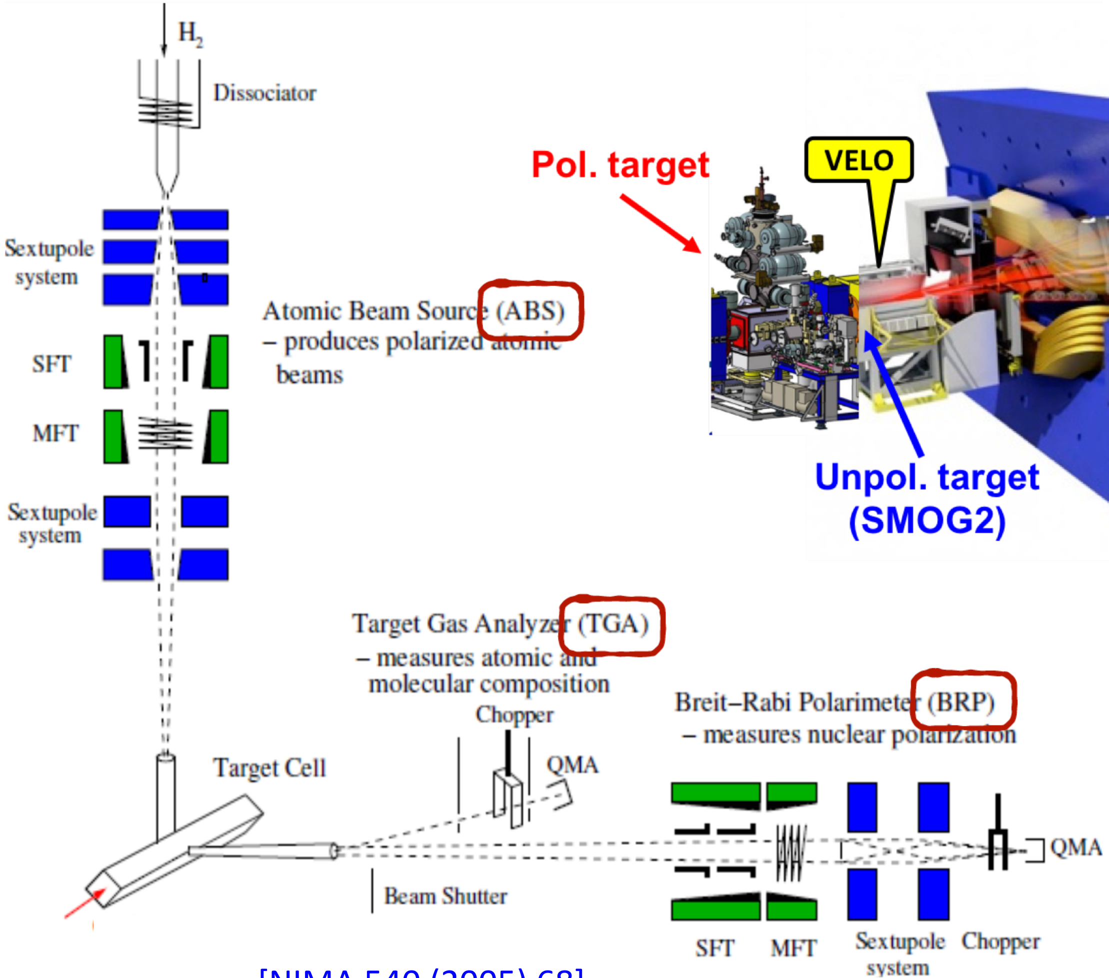


LHCb-FIGURE-2019-007

- **SMOG2 and pp interaction regions very well separated**
- pp and pgas performance (full tracking efficiency, vertex reconstr. efficiency) are compatible overall the entire z range

- **SMOG2 reconstruction efficiencies are not worsened by simultaneous pp collisions and vice-versa.** Results do not depend on gas species (same for He and Ar)
- As expected, vertex resolution gets worse towards negative z due to increasing distance from the VELO
- Event processing: Gas presence in the cell only provides few % decrease wrt standard pp throughput rate (can be tuned with gas pressure)

SMOG2: towards the polarised target



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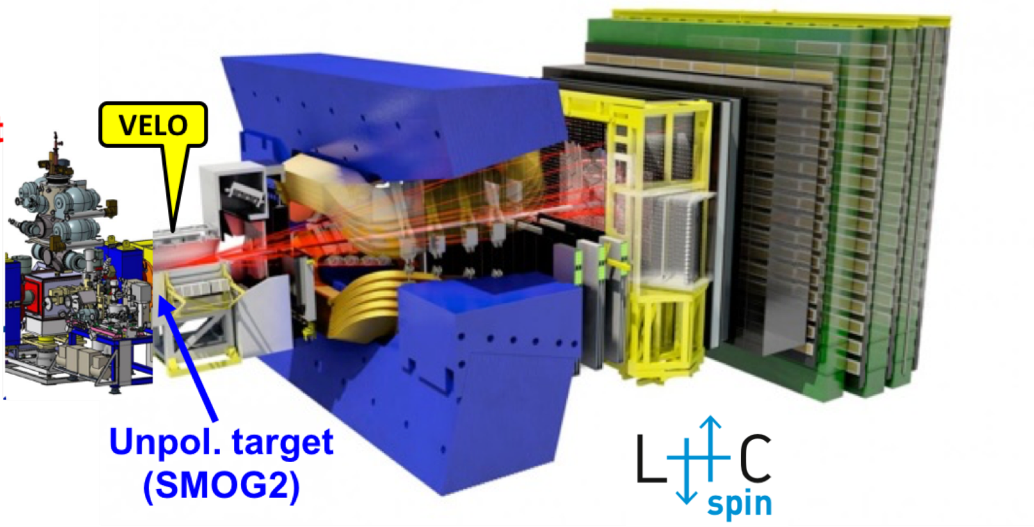


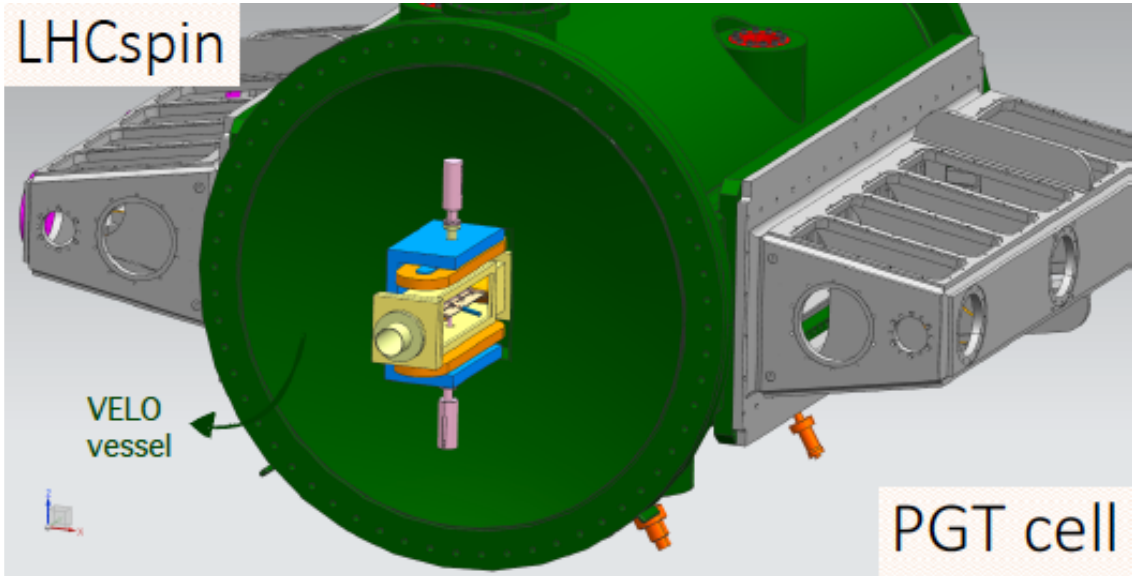
PGT
- $I_0 = 6.5 \cdot 10^{16} s^{-1}$
- C_{tot} = 17.4 l/s (20 cm cell)
- $\boldsymbol{\theta}$**= 3.7 ·10^{13}/cm^2**

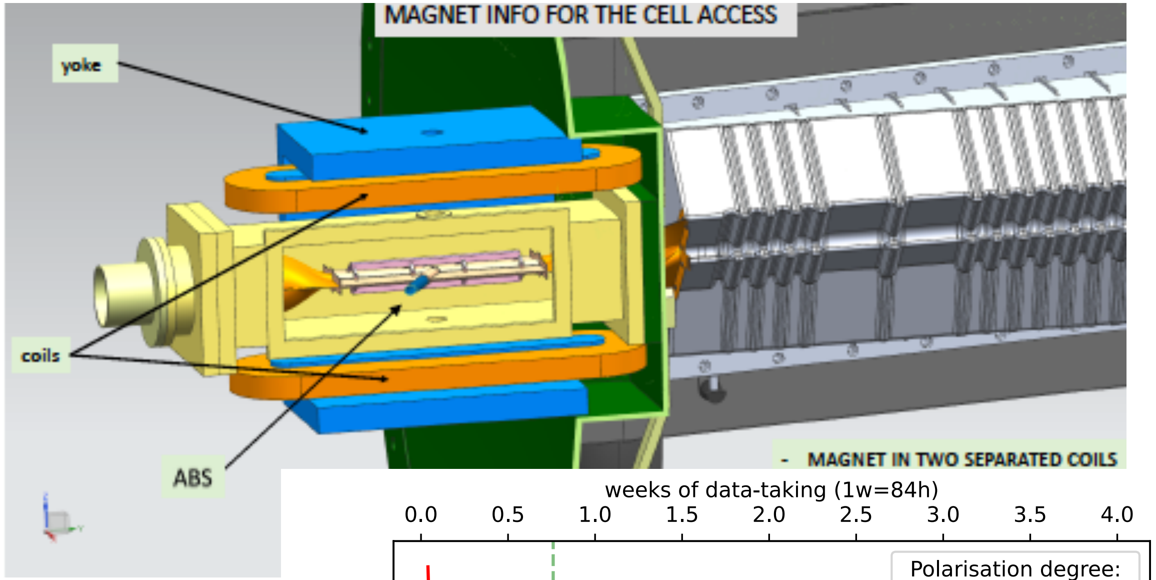
Beam
- $2.2 \cdot 10^{11}$ p/bunch
- 2760 bunches
- $\boldsymbol{I_{beam} = 6.8 \cdot 10^{18}\ p/s}$

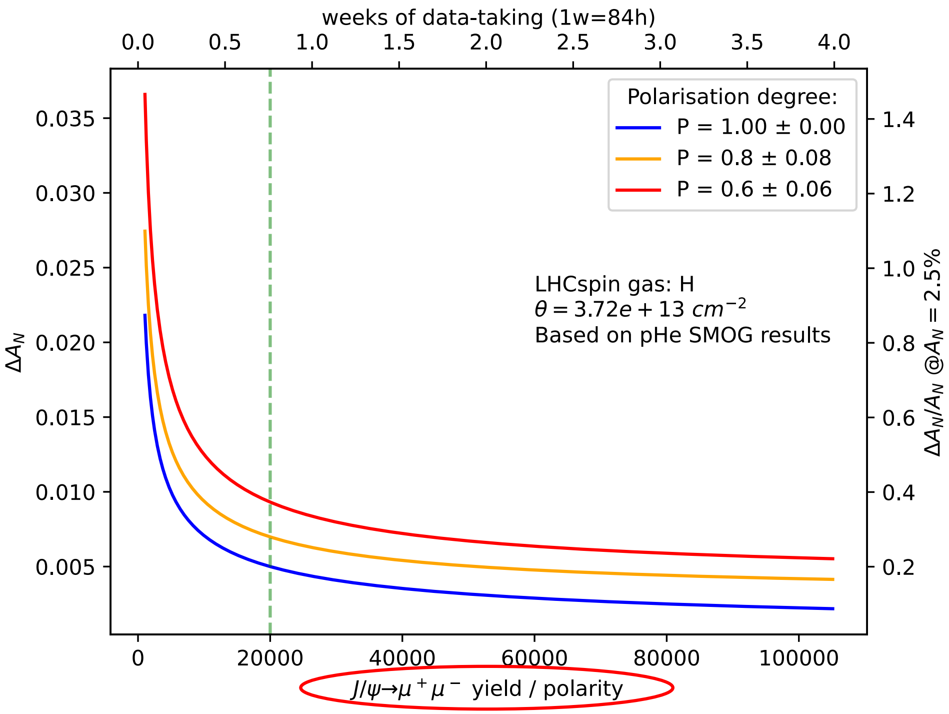
$$\boldsymbol{L_{pH}(T_{cell} = 300\ K) = 2.5 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}}$$

$$\boldsymbol{L_{pH}(T_{cell} = 100\ K) = 4.4 \cdot 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}}$$

SMOG2: towards the polarised target







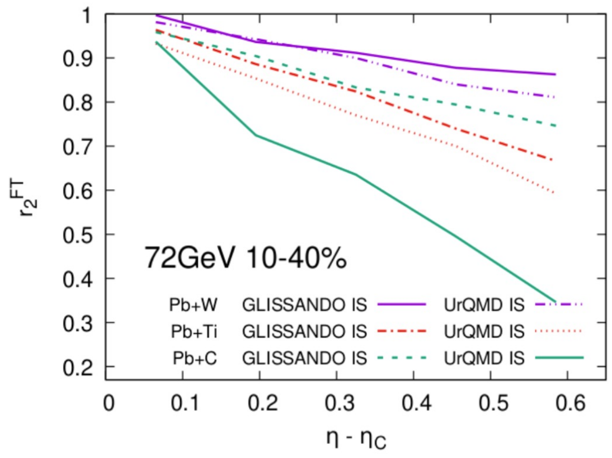
- Polarised target cell in SMOG2 position
- Compact dipole magnet for static transverse field of 300 mT
- Required relatively high field uniformity ΔB/B ~10%
- Superconductive coils + iron yoke fits the geometrical constraints

Pheno progress

Longitudinal flow decorrelation in AA in ALICE

- Study the longitudinal dynamics of heavy-ion collisions
- Provide information on the initial stages of the collision
- Strong decorrelation, increasing with decreasing system size
- Can be used to discriminate between initial state models

Jakub Cimerman et al., Phys.Rev.C 104 (2021) 1, 1



➔ **r_n definition**

- Fixed-target with two acceptance windows

$$r_n^{\mathrm{FT}}(\eta-\eta_C)=\frac{\langle q_n(-\eta+2\eta_C)q_n^*(\eta_{\mathrm{ref}})\rangle}{\langle q_n(\eta)q_n^*(\eta_{\mathrm{ref}})\rangle}$$

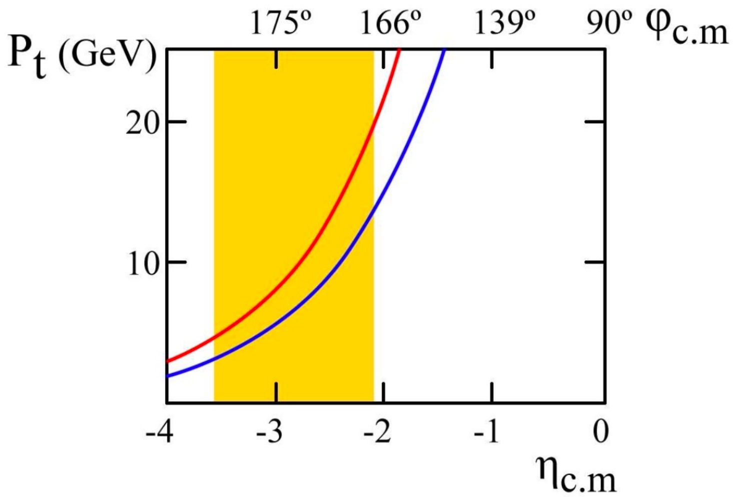
- TPC: $-2.9 < \eta < -1.6$
- Muon det: $-1.0 < \eta_{\mathrm{ref}} < -0.5$
- Decorrelation around the center of the pseudo-rapidity bin:

$$\eta_C = -2.25$$

B. Trzeciak
FTE@LHC 2021 workshop

Antiproton subthreshold production in pA collisions in ALICE

- Measure subthreshold antiproton production in a kinematically forbidden region (above the blue line): possible with the TPC
- Linked to superheavy particle search at LHC in heavy-ion collisions



A. Kurepin
FTE@LHC 2021 workshop

Pheno progress

Identified particles in pA in a fixed-target mode with the LHCb setup

- Measurement of the nuclear modification factor of identified particles both in collider and fixed-target mode in LHCb and phenomenological related calculations
  - Sara Sellam: identification of charged particles for LHCb in fixed and collider mode
  - Elena Ferreiro: probing different shadowing models for the FT energies and checking the impact of comovers at those energies for different nuclei

Cross sections studies of quarkonium processes at LHC in a fixed target mode:

- Postdoc to be started at NCBJ soon on χ_c at NLO in pp

Workshop

- CERN workshop 31 May – 4 June 2021: The four groups "QCD at short distances" of the "GDR QCD", "Fixed target experiments at LHC", "3DPartons" and "NLOAccess" of STRONG-2020
- Next meeting at CERN: spring 2022

Physics Beyond Colliders

LHC fixed target experiments
CERN Yellow Reports: Monographs CERN-2020-004

Manpower

Generally, delay in hiring postdocs due to Covid

1. Feasibility studies in ALICE
    - Md Rihan Haque in WUT since April 2020 (2 year postdoc)
    - Charlotte Van Hulse in IJCLab: September 2020 – 31/1/2022

2. Gas-target development in LHCb
    - Barbara Passalacqua at Ferrara (PhD co-funding)
    - Marco Santimaria at LNF from November 2020 (2 year INFN postdoc)

3. Phenomenological and theoretical studies
    - Sara Sellam in USC since September 2020 (PhD co-funding)
    - Maxim Nefedov in NCBJ : 1/12/2021 - 1/12/2022

Conclusions

Plan: schematic achievements

1 Work performed

ALICE: i) a conceptual design of a fixed-target system was proposed, that takes into account the target system material budget and its impact on the FoCal detector; its integration into the ALICE mini-frame is ongoing; ii) the tracking algorithm of the ALICE TPC has been improved for fixed target events with a large displaced vertex and full simulations were obtained with Run 3 settings. Good acceptance x tracking efficiencies are obtained. Full simulations for selected processes (D0 and anti-proton) are ongoing towards a LoI in ALICE in 2022.

LHCb: **i)** The storage cell has been installed and tested in the latest LHC beam test. Everything works as expected. **ii)** Codes for implementing the storage cell into the LHCb simulation and DAQ, including triggers, have been written and included into the experiment's software chain. **iii)** A new geometrical setup has been developed for the polarised target. **iv)** MC simulations for the PGT are ongoing and are very promising.

Phenomenology: i) the study at USC includes the measurement of the nuclear modification factor of identified particles both in collider and fixed-target mode and phenomenological related calculations. These measurements will be used to characterize the initial states of the collision and determine the different physical phenomena involved. ii) at NCBJ, quarkonium hadroproduction cross sections will be studied at NLO starting with the χ_c production.

Conclusions

Plan: schematic achievements

2 List of the Deliverables and Milestones achieved

- conceptual design report of a fixed-target system in the ALICE experiment was delivered, internal to strong-2020 collaboration (delivery D20.1)

- code for full simulation in ALICE ready (milestone MS34)

- internal report: Installation of the unpolarised gas target into LHCb (delivery 20.4)

-code for full simulation in LHCb ready (milestone MS35)

3 Progress beyond the state of the art, expected results until the end of the project and potential impact

Develop, for the first time, a full program for fixed-targets physics at the LHC