STRONG-2020 ANNUAL MEETING (2022)

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

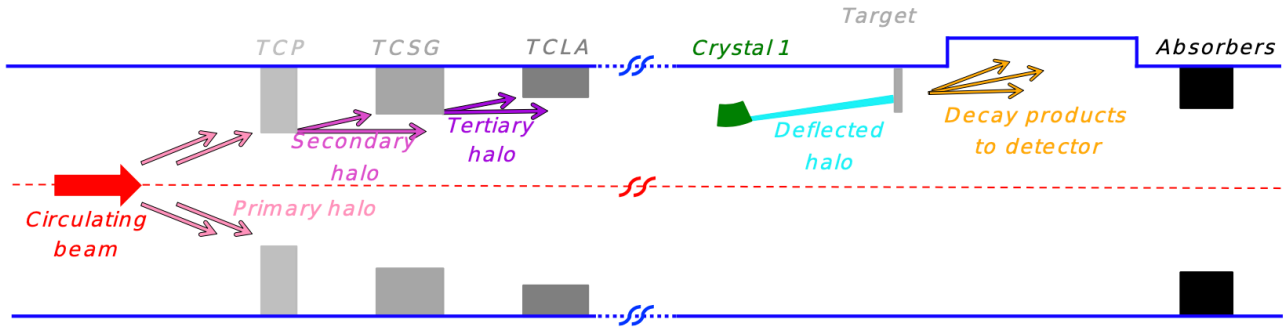
ALICE-FT

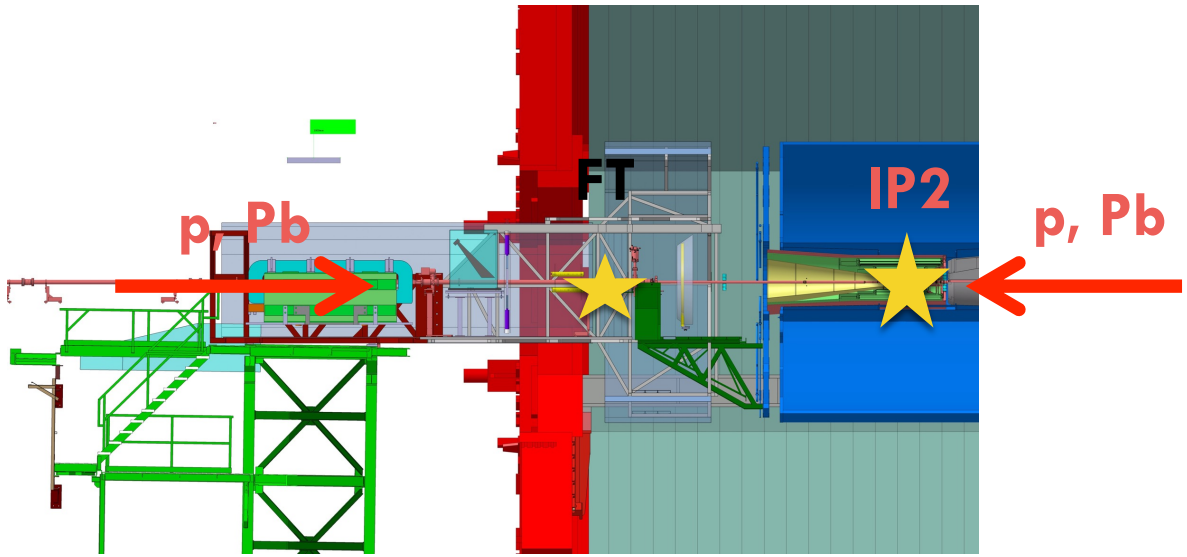
Proposed ALICE fixed-target programme ***CERN-PBC-Note-2019***

- 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)

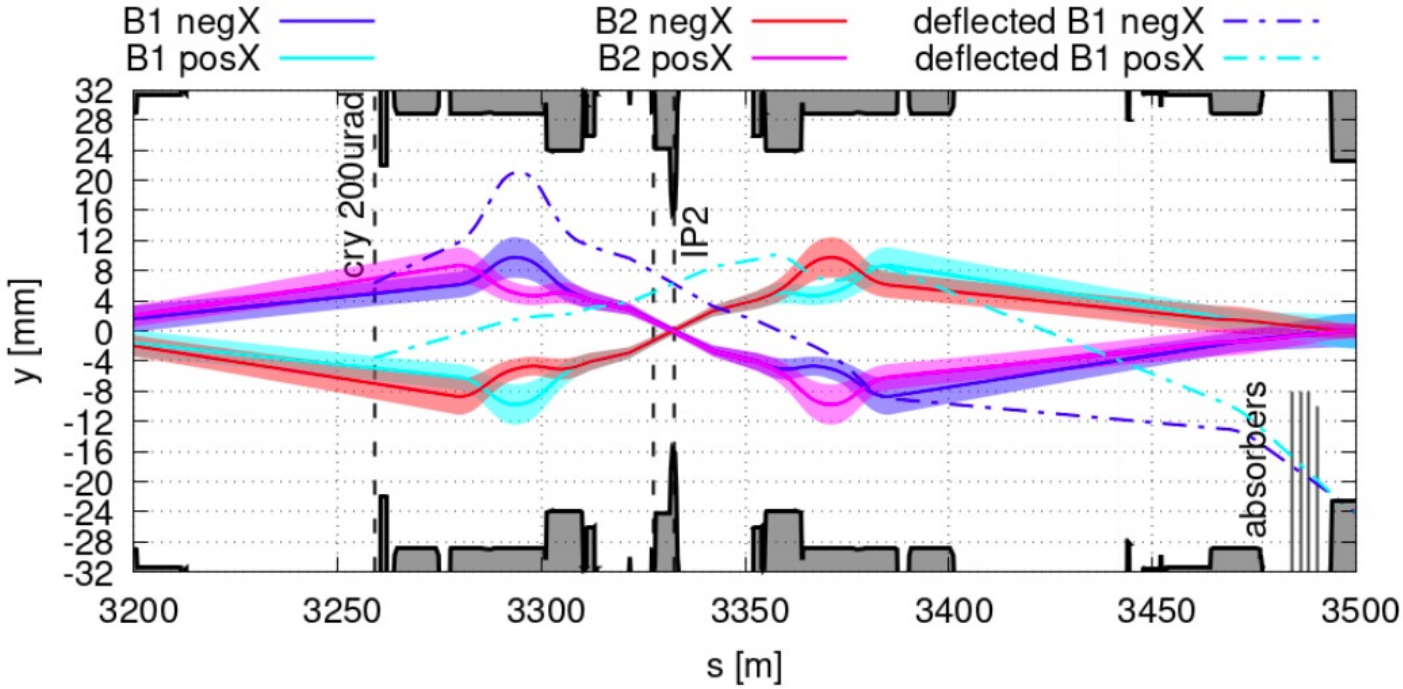




CRYSTAL LAYOUT

Crystal collimation study

- Positions of crystal updated in a location with more space around the beam pipe at z = 3259 m
- Proton beam studies performed: Proton on Target (PoT) ~ 10^6 p/s expected in Run 4 as a minimum limit in parasitic mode, equivalent to (assuming one year of data taking and target length of 1 cm)
  - L = 1.1/pb in pC
  - L = 0.6/pb in pTi and pW
- Deflected halo nicely collimated, more than 4 mm away from the main beam at target position
- Ongoing studies to:
  - Increase PoT
  - Optimize absorber location and number
- Lead beam studies about to start
- Estimations rely on simulations: experimental verification and identification of operation challenges needed in a dedicated test-stand, possibly to be deployed at IR3



FTE@LHC 2022 workshop

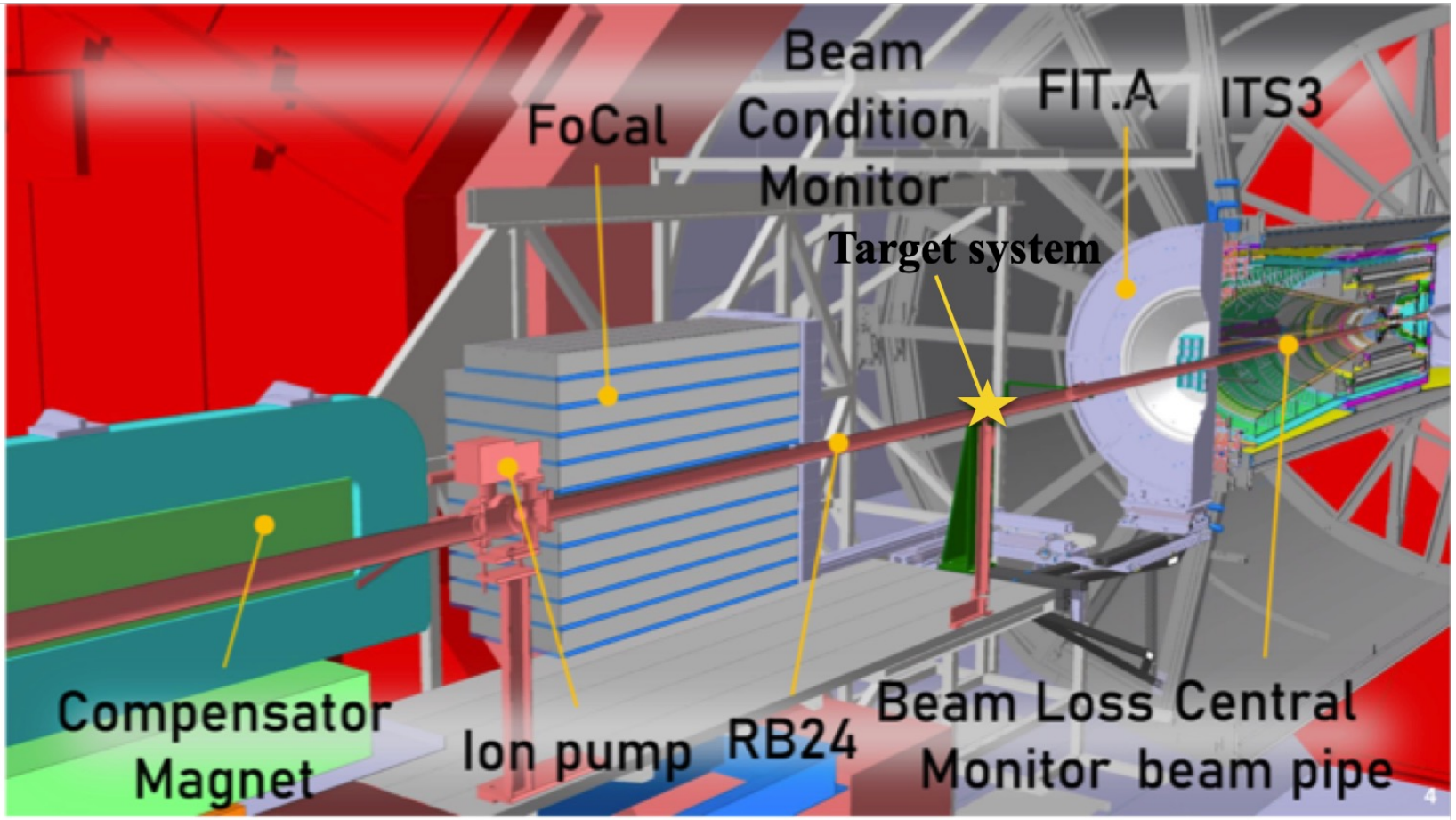
M. Patecki

TARGET SYSTEM

Target integration and design:

- Implementation as closer to IP2 as possible preferable for the physics case but no space between z ~ -4.7 m and IP2 (FIT and ITS displacement)
- ITS support frame imposes the target to be in the longitudinal plane
- Vacuum valve size reduced wrt to previous design to fit into the ITS support structure (not shown) when ITS in open position

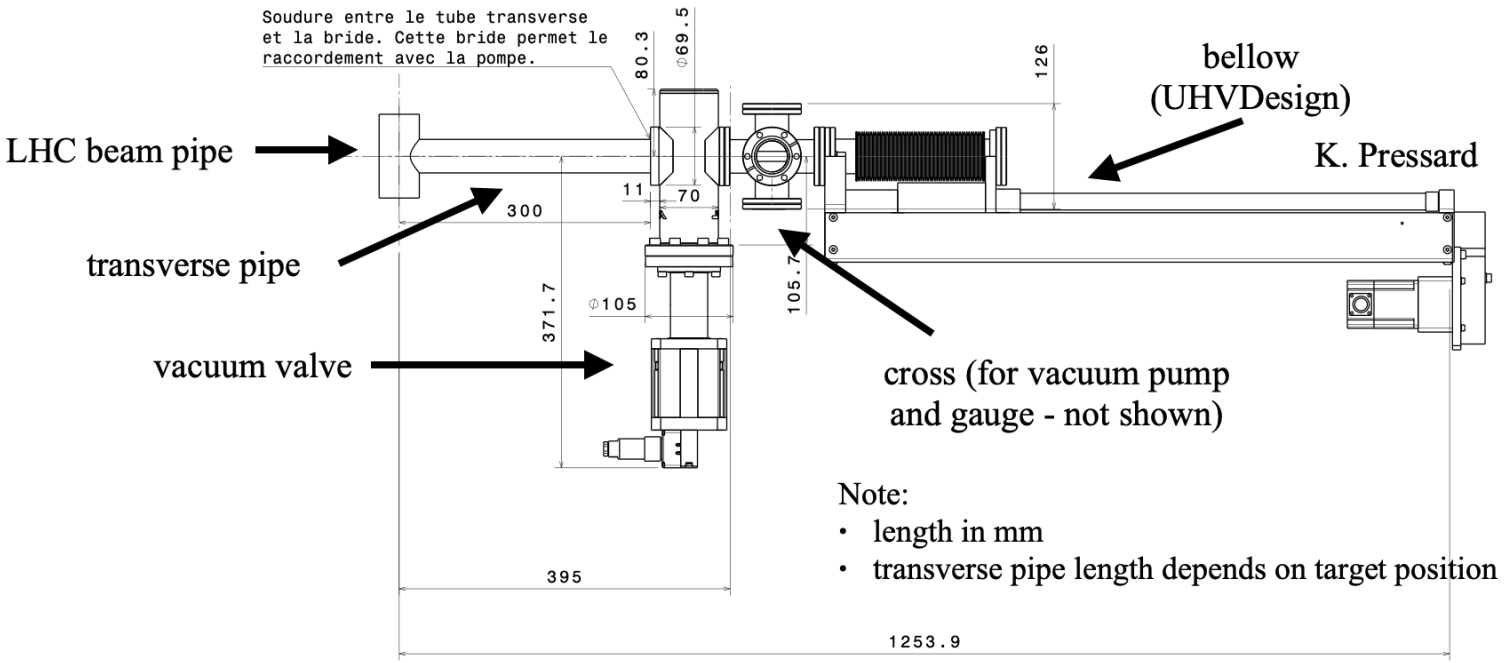
Run 4 view



TARGET SYSTEM

Target integration and design:

- Implementation as closer to IP2 as possible preferable for the physics case but no space between z ~ -4.7 m and IP2 (FIT and ITS displacement)
- ITS support frame imposes the target to be in the longitudinal plane
- Vacuum valve size reduced wrt to previous design to fit into the ITS support structure (not shown) when ITS in open position
- Vacuum equipment ongoing (need vacuum studies: pressure profile in the beam pipe, …)

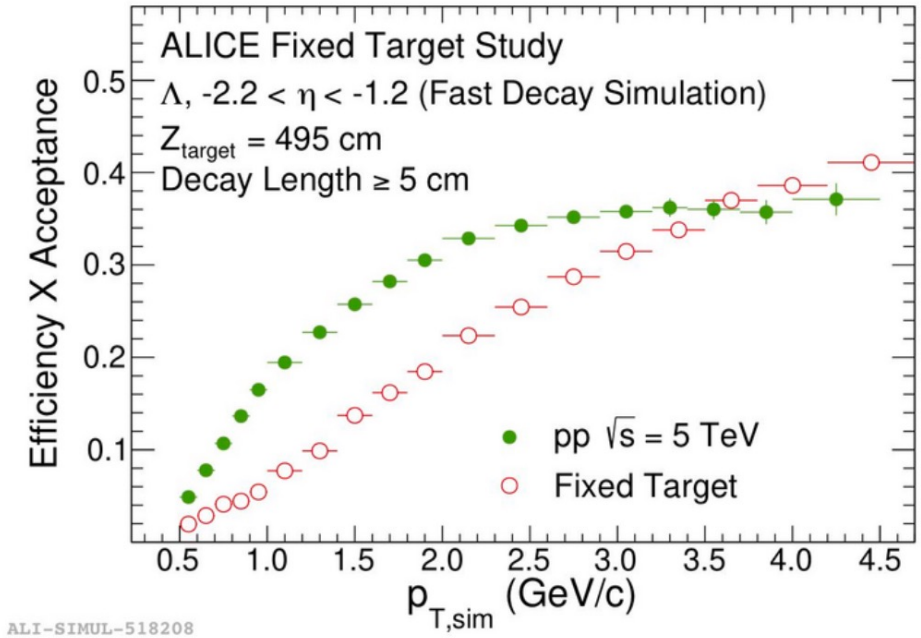


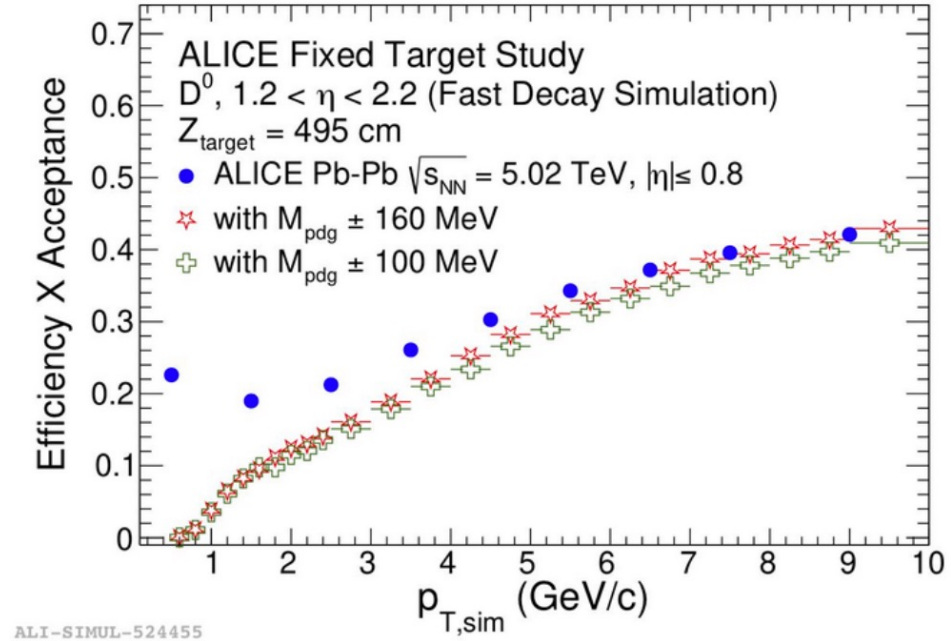
PERFORMANCE STUDIES

Full simulations and physics performances:

- Run 3 setting simulations
- Tracking and vertexing with ALICE TPC
- Good tracking acceptance x efficiency and resolution obtained for charged tracks (see last strong-2020 report)

- Fast decay simulations in p+W at $\sqrt{s_{NN}}$ = 115 GeV using as input the obtained acceptance x efficiency and resolution
- Λ as a probe for strangeness content of nucleon/nuclei (selection on decay length > 5 cm and p+π invariant mass)
- D^0 as a probe for gluon/intrinsic charm content of nucleon/nuclei (selection on K+π invariant mass)
- Efficiency lower than in collider mode but sufficient to for D^0 and Λ production studies without additional vertex detector
- Signal/Background studies ongoing

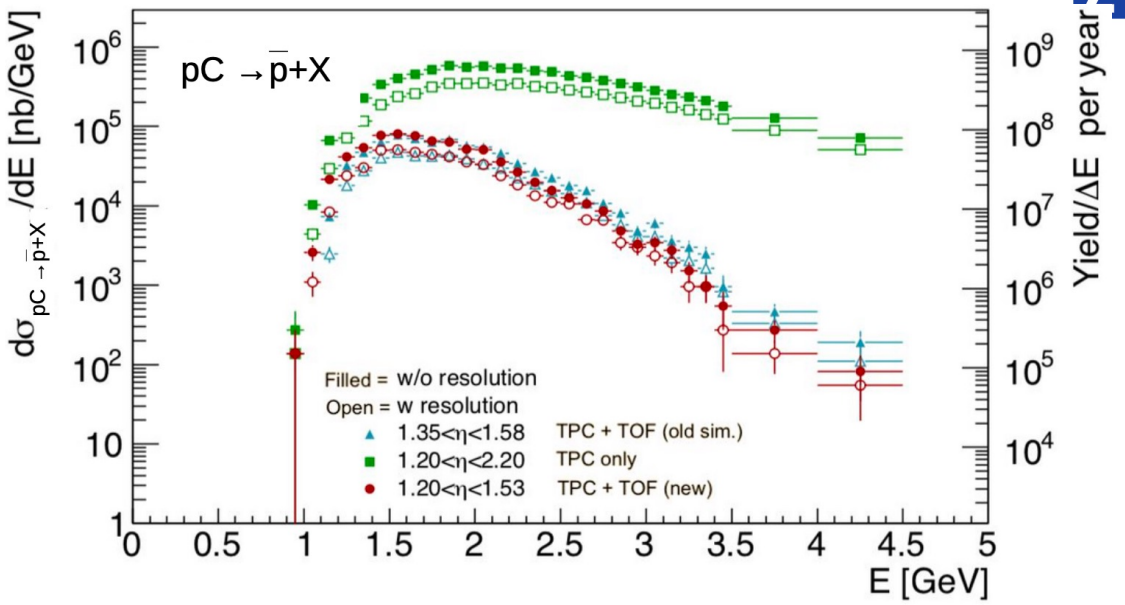


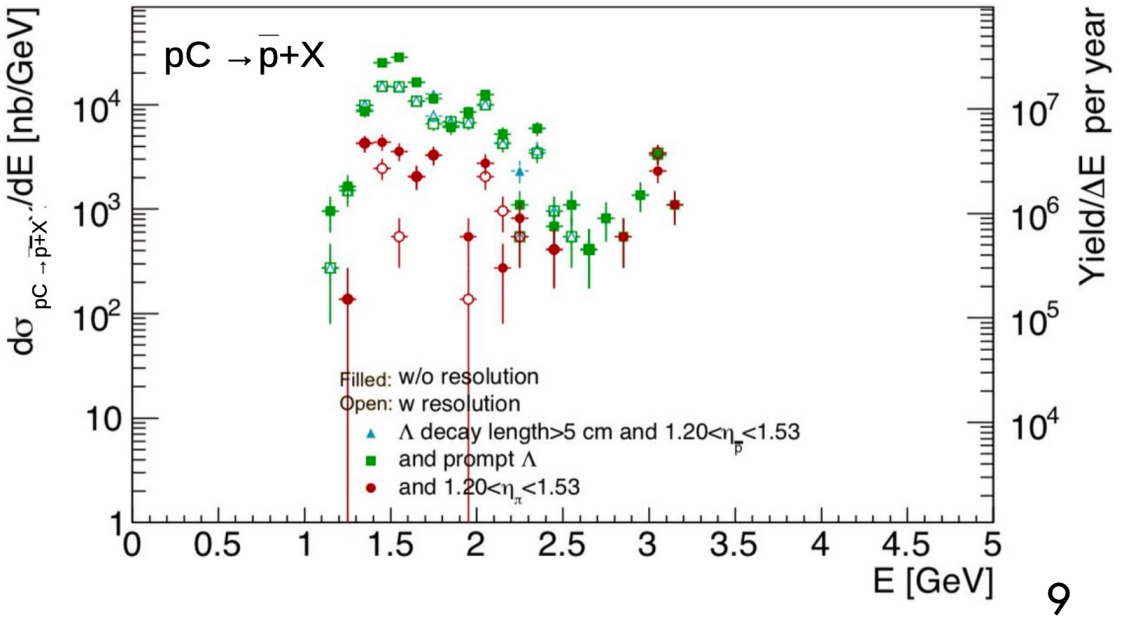


PERFORMANCE STUDIES

Full simulations and physics performances:

- Antiproton important input for theoretical calculations of secondary cosmic antiproton spectrum:
  - p+C (target) → antiproton of low E: inverse kinematic process of C+H (target) → antiproton of large E
- Large yield expected in the TPC and TOF
- Antiproton feed-down could be as well measured by measuring anti-Λ (Anti-Λ → antiproton + π)
- Estimation of the PID performance with TPC and TOF ongoing





FTE@LHC 2022 workshop

C. Van Hulse

ALICE-FT

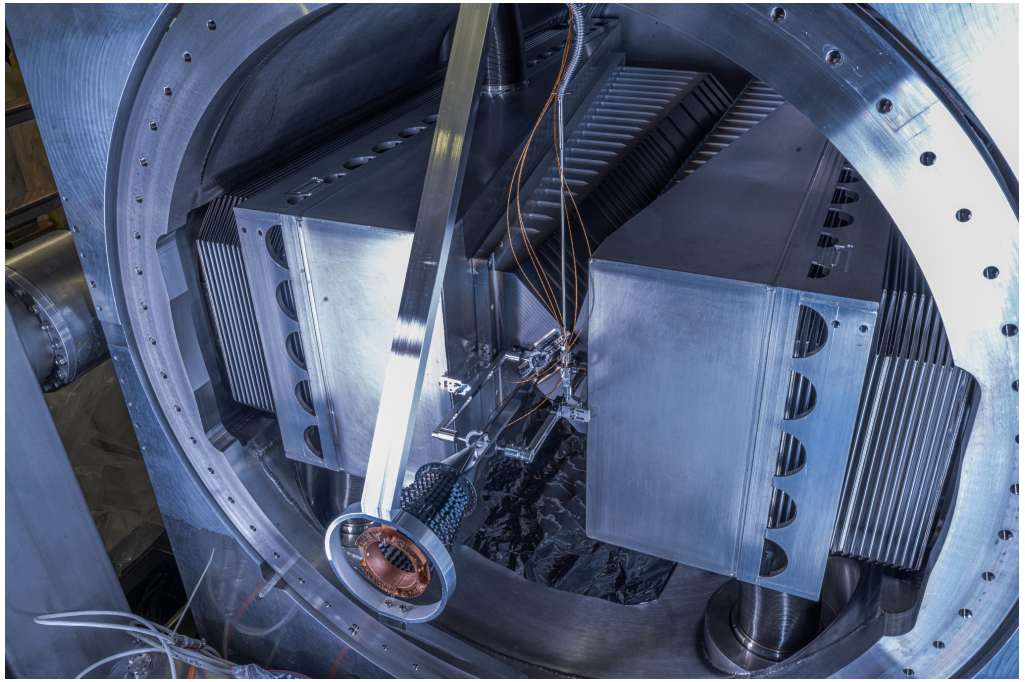
Recent publications:

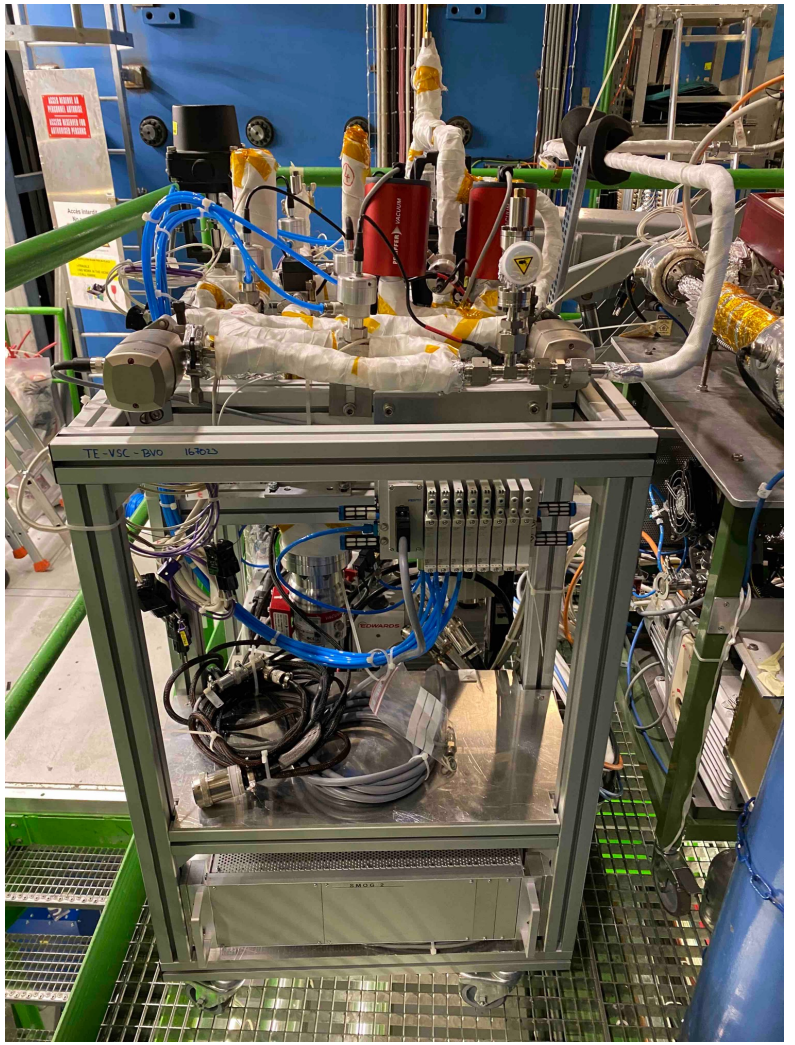
- M. Patecki et al., "Status of Layout Studies for Fixed-Target Experiments in Alice Based on Crystal-Assisted Halo Splitting » JACoW HB2021 (2022) 146 proceedings

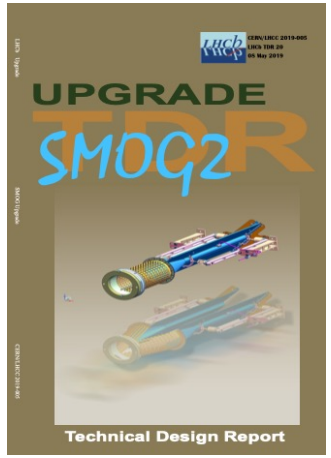
Recent internal notes:

- “Performance study of the ALICE TPC for future fixed-target collisions”, R. Haque et al., ALICE internal note, 2022

SMOG2: THE FIXED TARGET @ LHCB







Openable cell, aligned with the excellent precision of 0.25 mm (2 mm of remaining aperture)
It is the only system present in the LHC primary vacuum

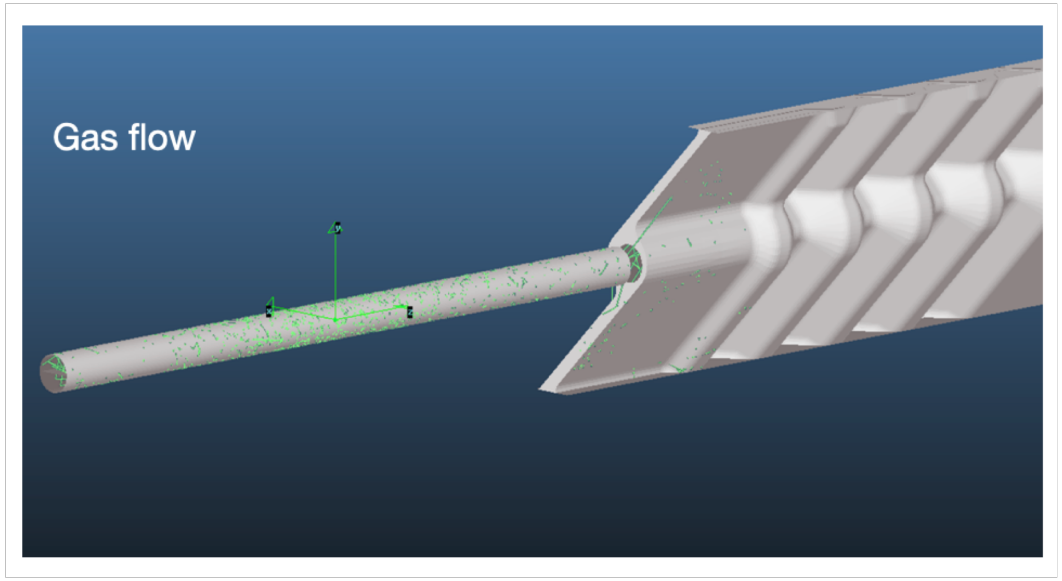
x

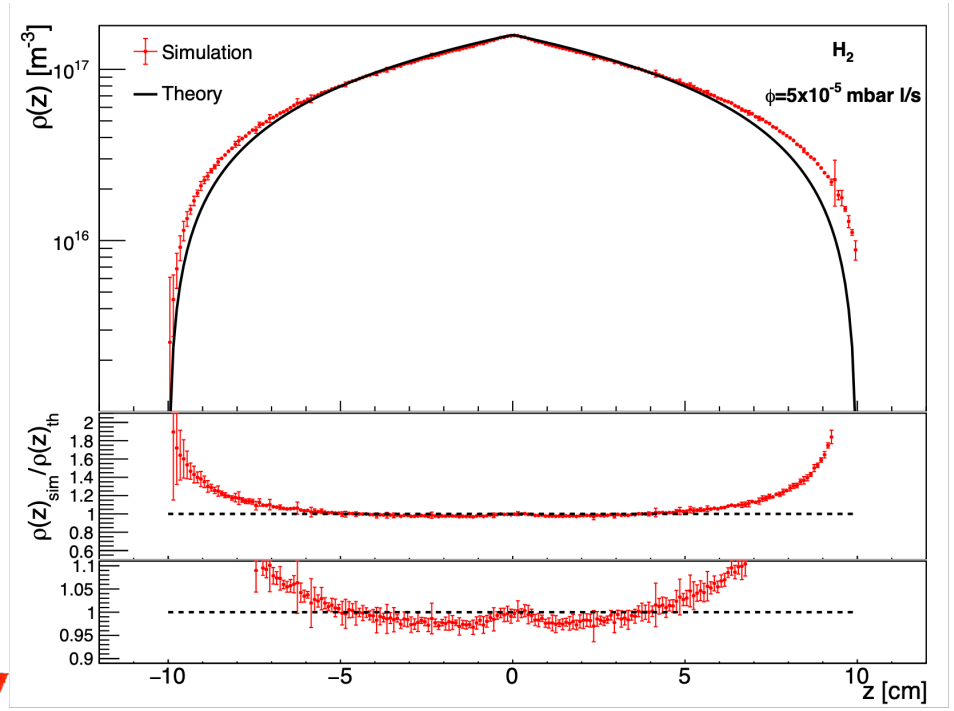
- The system is completely installed (storage cell + GFS + triggers + reconstruction)
- Negligible impact on the beam lifetime ($\tau^{p-H_2}_{beam-gas}$~2000 days, $\tau^{Pb-Ar}_{beam-gas}$~500 h)
- Injectable gases (3+1 reservoirs): He, Ne, Ar … H_2, D_2, N_2, O_2, Kr, Xe
- Flux known with 1% precision, measured relative contamination 10^{-4}

Deliverable D20.4 - OK

GAS DENSITY: LUMINOSITY AND SYSTEMATICS

- The analytical density profile is compared with a Molflow simulation of the actual cell + VELO RF box





- Some deviations (presence of VELO) are observed from the expected triangular profile $\rho(z)$ with the real geometry
- However, the correcting factor for the integrated θ is only $\sim 2\,\%$ (for all the gas species and for the range $\phi = (2-10)\times 10^{-5}\ 1*\mathrm{mbar/s}$)

$$\theta^{real}(M,T,\Phi) = 0.015\,[\tfrac{s}{cm^2}]\,\Phi\,[\tfrac{part}{s}]\,\sqrt{\frac{M}{T\,[K]}}$$

SMOG2: temperature calibration and luminosity measurement

June 10, 2022

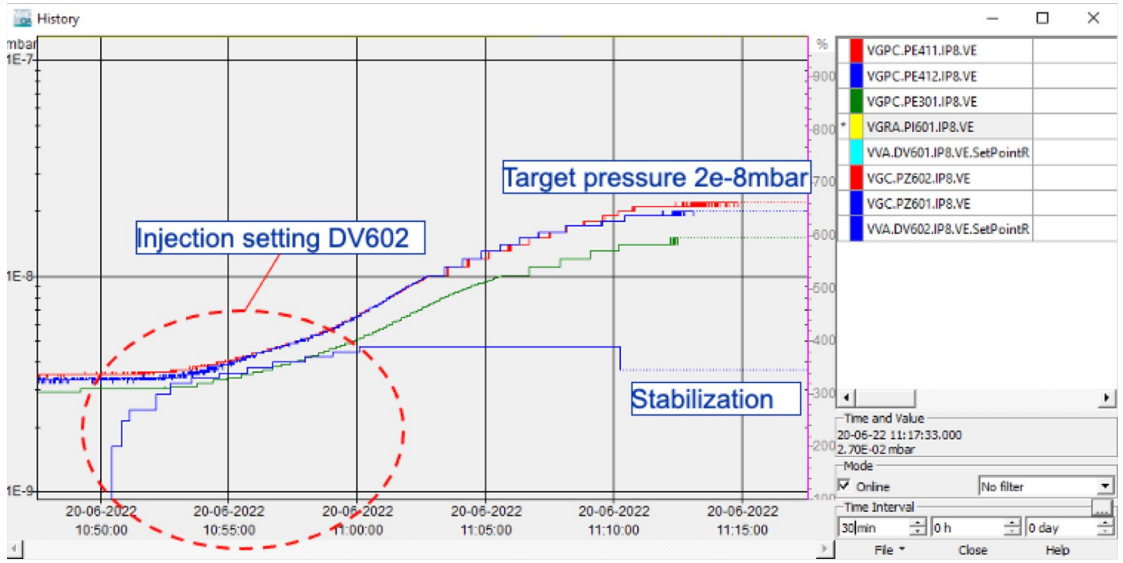
C. De Angelis[1] V. Carassiti[2], G. Ciullo[1,2], P. Di Nezza[3], P. Lenisa[1,2], C. Lucarelli[4], L. L. Pappalardo[1,2], M. Santimaria[3], E. Steffens[5] and G. Tagliente[6]

LHCb Note

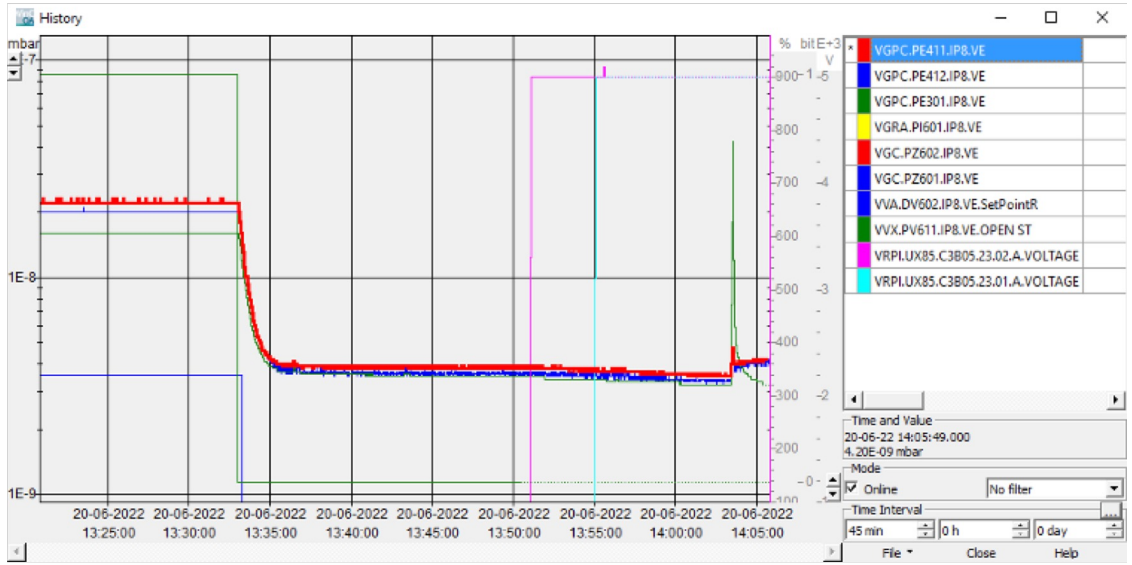
Systematic uncertainty 1.5%

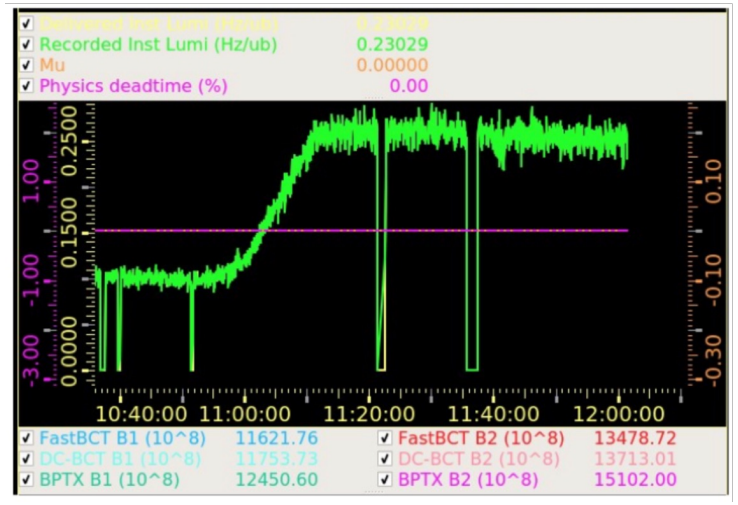
SMOG2 GAS INJECTION AT LHC RUN3 STARTED IN JUNE 2022

Pressure increase into the primary vacuum



Vacuum recovery after the gas injection stop in <20'





Luminosity increase seen by the LHCb luminometer (Plume)

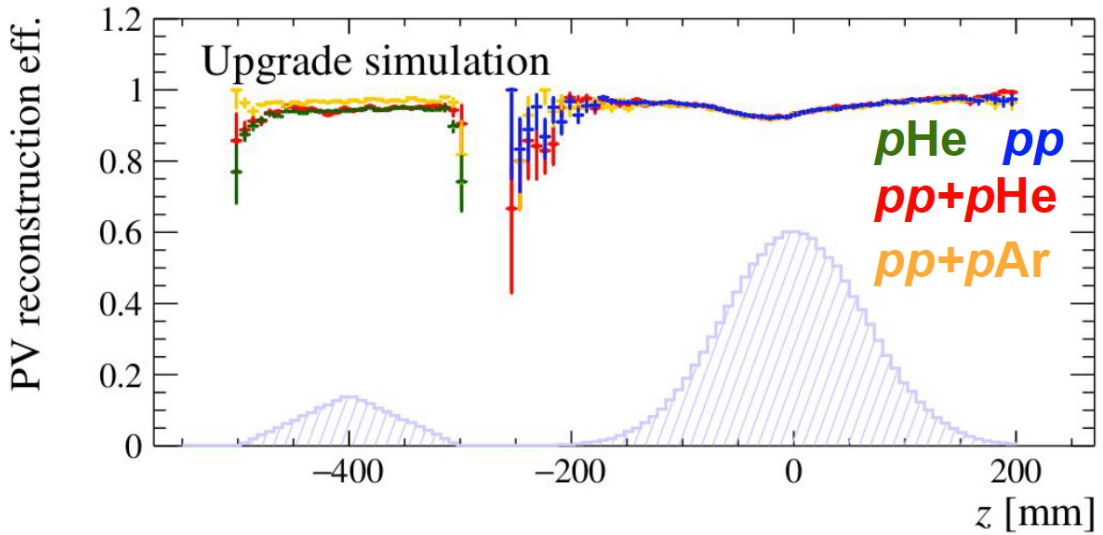
Extremely useful also for the LHCb commissioning

LHC official statement

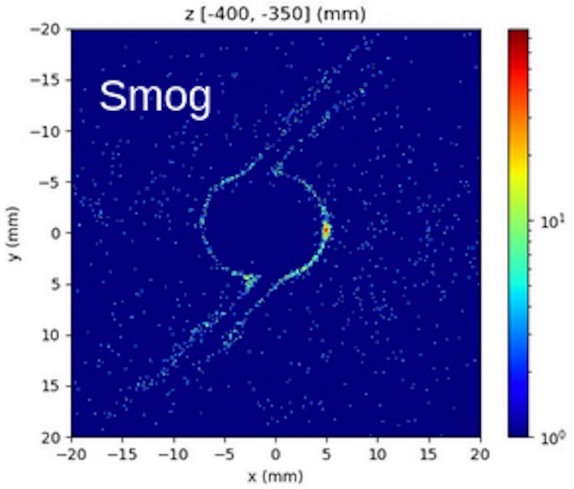
No negative feedback when there is gas injection. Green light to inject when needed

SMOG2: SOFTWARE AND TRIGGERS

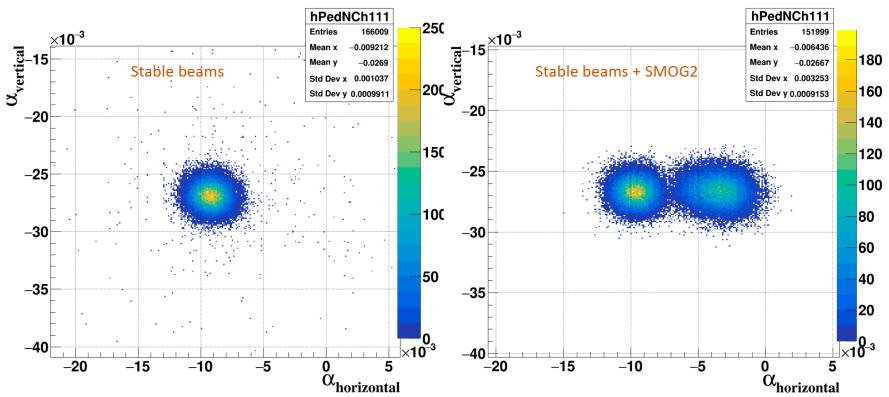
- ✓ Reconstruction and HLT1 trigger: studies on simulation
- ✓ HLT2
- ✓ Central production
- ○ Validate data: stand alone beam-gas and simultaneous beam-beam and beam-gas data acquisition

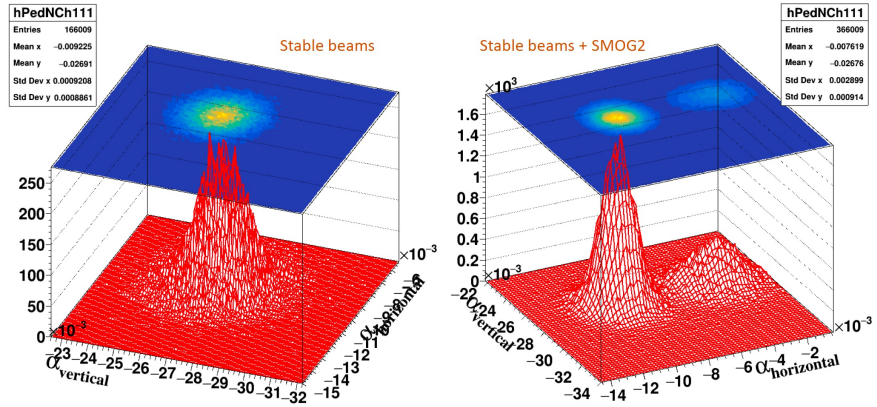


It is possible to run in parallel beam-gas and beam-beam



Material budget tomography

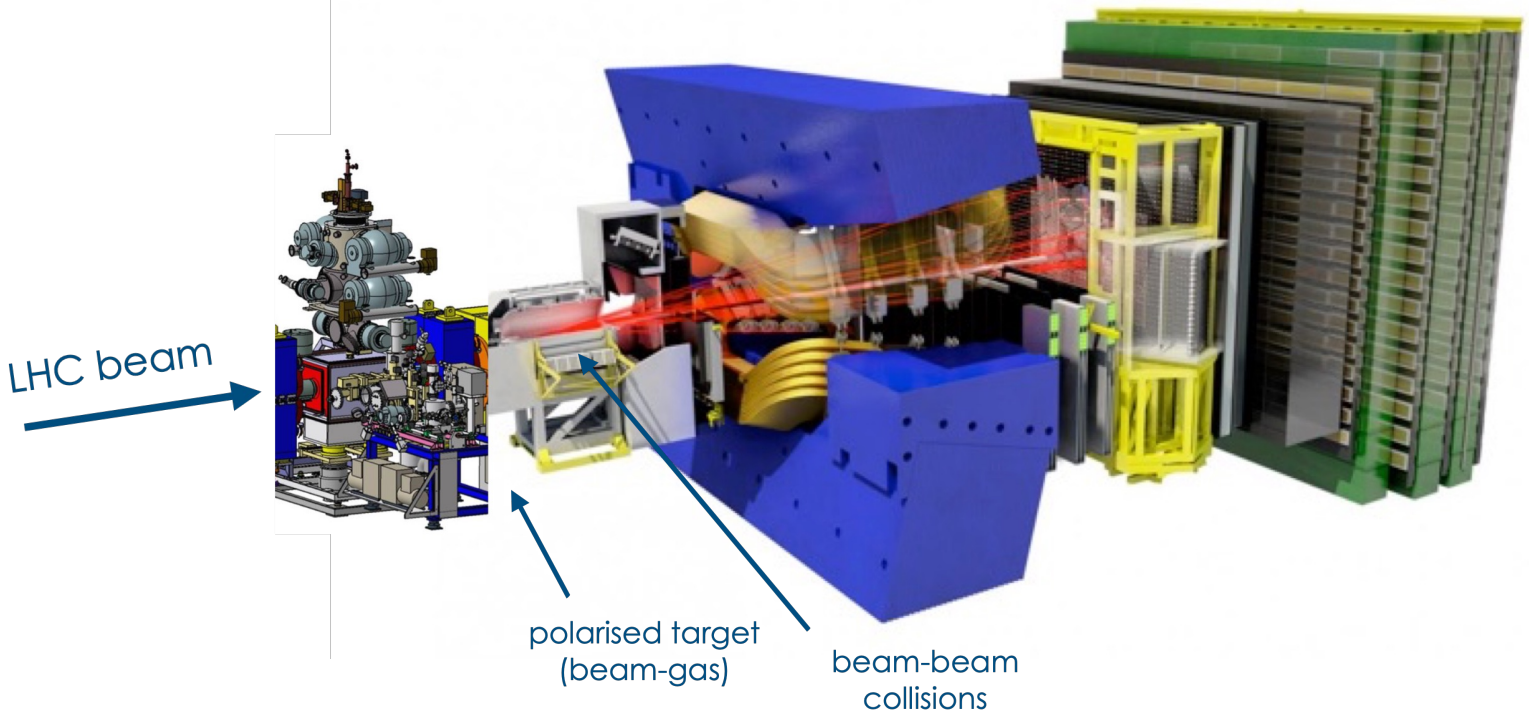


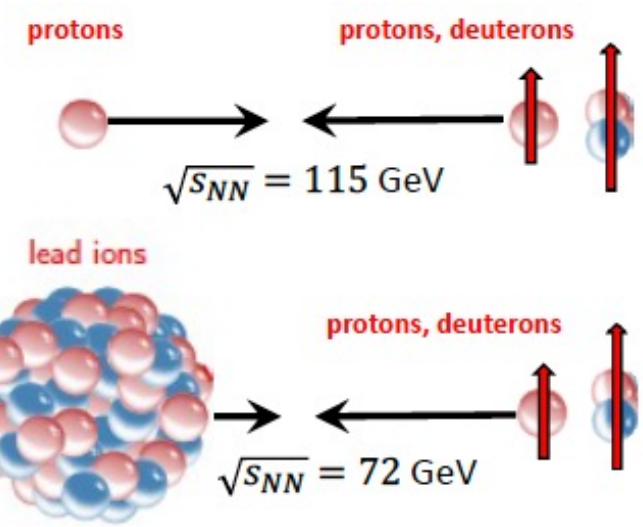


Preliminary primary vertex reconstruction

SMOG2: TOWARDS THE POLARISED TARGET

The LHC beams cannot be polarised

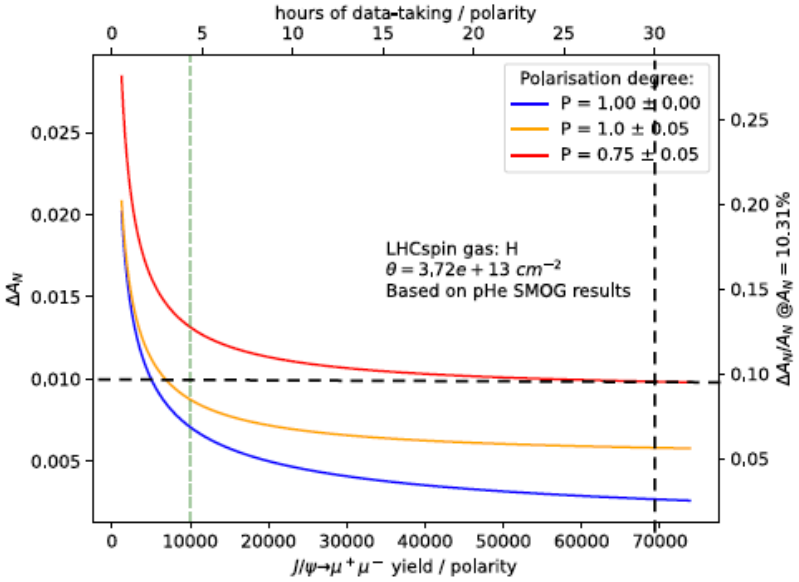




- ✓ Unique project accessing kineatic regions poorly explored
- ✓ Making use of rare probes
- ✓ Polarised HI interactions
- ✓ Complementary to the EIC and other pol. experiments

A LITTLE LOOK INTO SOFTWARE AND HARDWARE R&D

Huge statistics

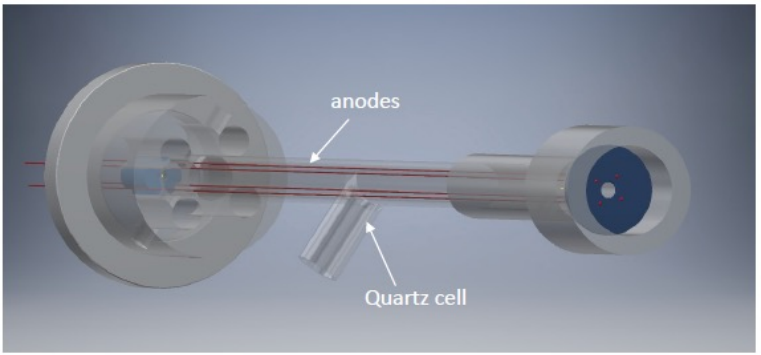


Expected yields for Run4 (Run4+Run5):

Channel	Events / week	Total events
$J/\psi \to \mu^+\mu^-$	194k (434k)	23M (75M)
$\psi(2S) \to \mu^+\mu^-$	3.5k (7.7k)	414k (1.3M)
$D^0 \to K^-\pi^+$	976k (2.2M)	117M (380M)
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$	77 (170)	930 (3000)
Drell Yan ($5 < M_{\mu\mu} < 9$ GeV)	110 (250)	13k (43k)
$\Upsilon \to \mu^+\mu^-$	83 (187)	10k (32k)
$\Lambda_c^+ \to pK^-\pi^+$	19k (43k)	2.3M (7.5M)

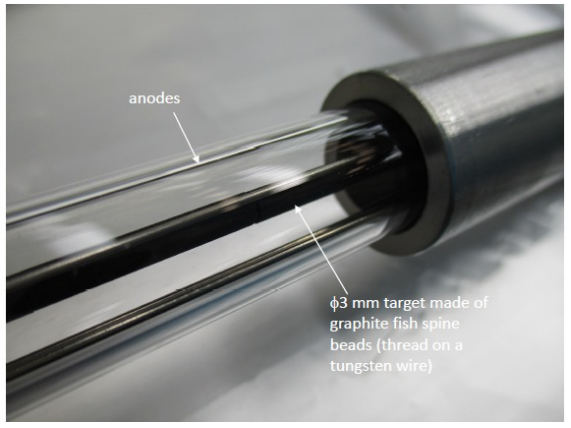
assumptions:

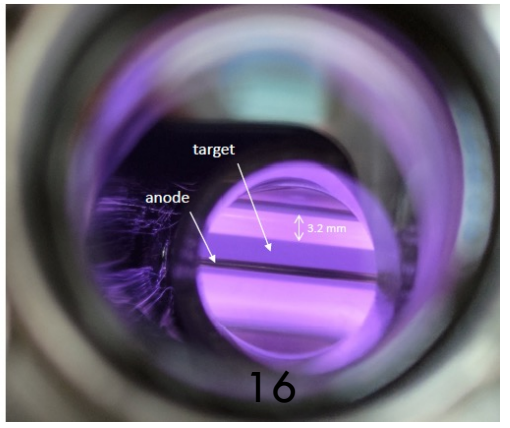
- 120 weeks/RUN
- 84h/week
- $Stat(Run5) \sim \sqrt{5}\, Stat(Run4)$



Fruitful collaboration: Frascati-Ferrara-CERN-Julich

Target polarisation studies

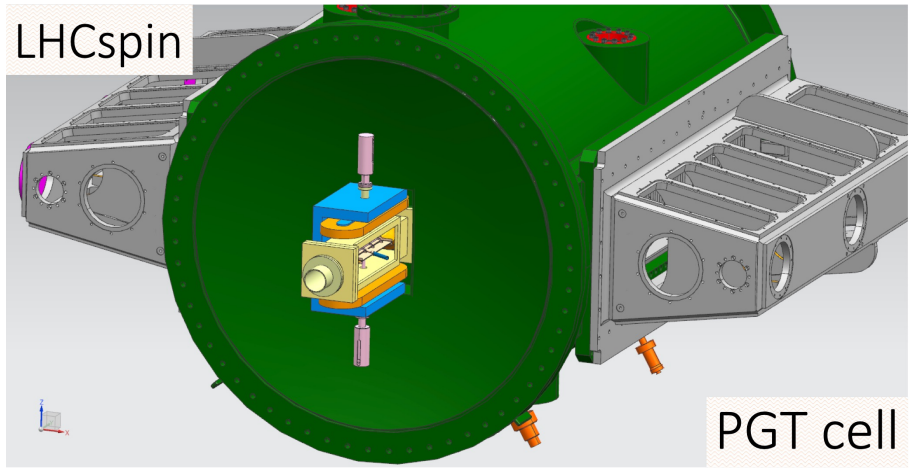


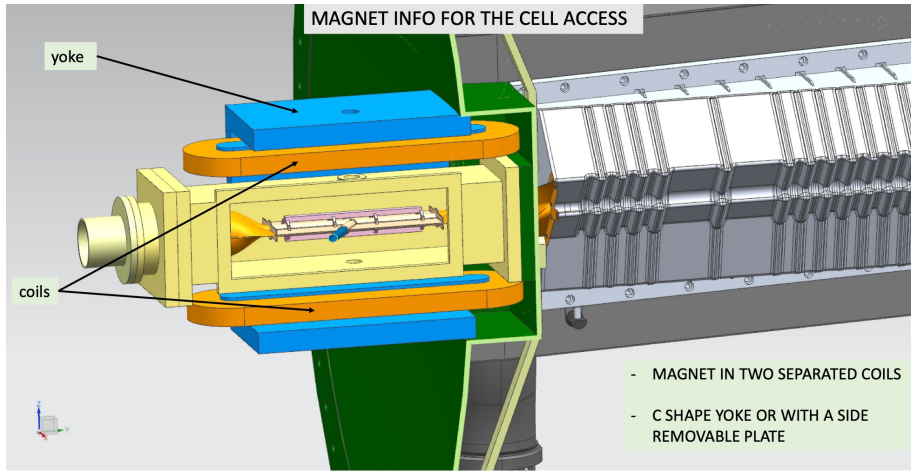


Deliverable OK

2 OPTIONS ON THE TABLE

Storage Cell

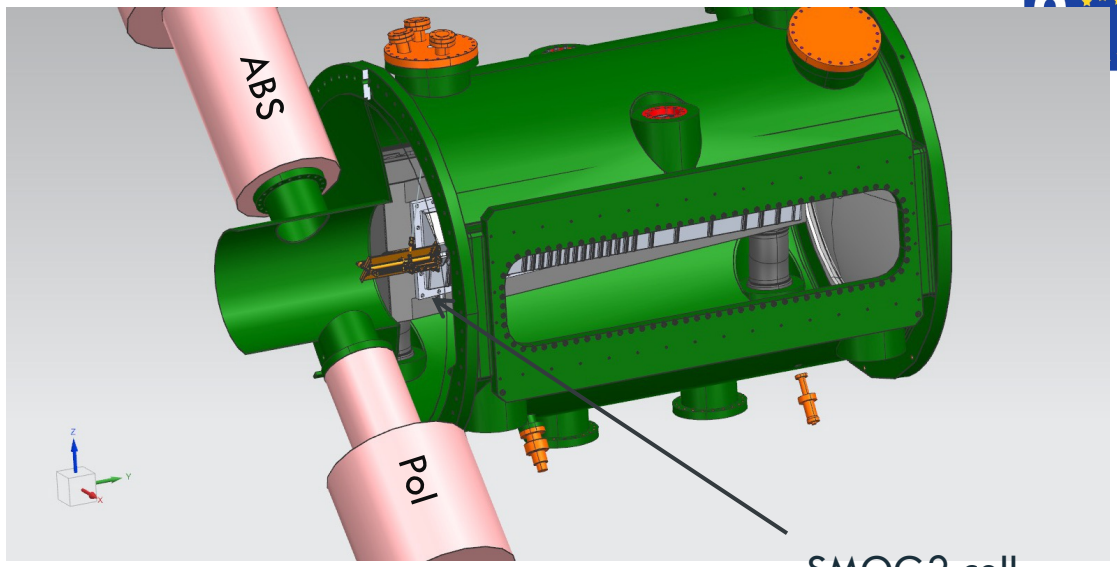


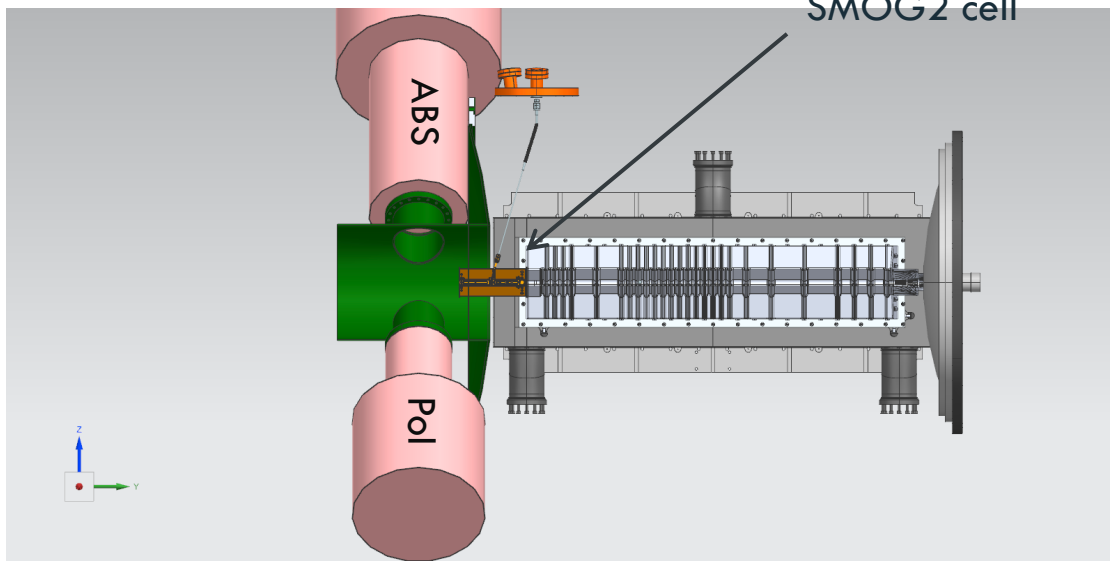


High luminosity

High atomic recombination, lower polarisation

Jet Target





Lower luminosity

No atomic recombination, high polarisation

Deliverable OK

PHENOMENOLOGY

Recent progresses (next slides):

- p_T integrated quarkonium production via matching of NLO and High-Energy Factorization
- Comover interaction model

Recent publications:

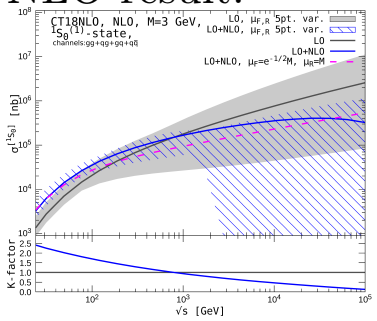
- B. Trzeciak et al., “Heavy-flavour studies with a high-luminosity fixed-target experiment at the LHC”, PoS HardProbes2020 (2021) 190
- A. Kurepin et al., “Antiproton production with a fixed target and search for superheavy particles at the LHC”, JMP13(2022)1093
- M. Nefedov et al., "Matching next-to-leading-order and high-energy-resummed calculations of heavy-quarkonium-hadroproduction cross sections" JHEP05(2022)083

p_T-integrated quarkonium cross sections via matching of NLO and High-Energy Factorisation (M.Nefedov, NCBJ Warsaw)

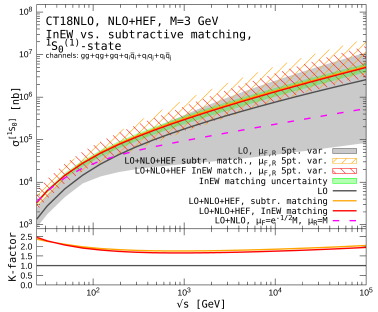
The matching with HEF resummation of logarithms of **partonic** center of mass energy resolves the instability problem of NLO calculation at high $\sqrt{s_{pp}}$ and $\sqrt{s_{\gamma p}}$, and provides *uniformly accurate predictions over wide range of energies, including the LHC fixed-target energy range (69-115 GeV).*

η_c-hadroproduction [JHEP 05 (2022) 083]:

NLO result:

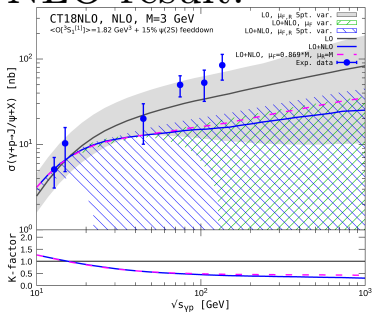


Matched NLO+HEF result:

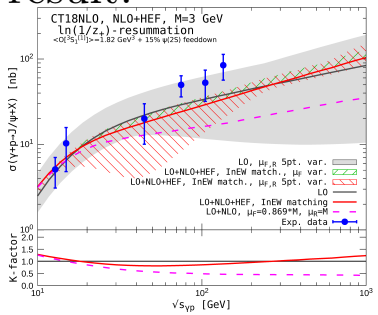


J/ψ-photoproduction [paper in prep.]:

NLO result:



Matched NLO+HEF result:



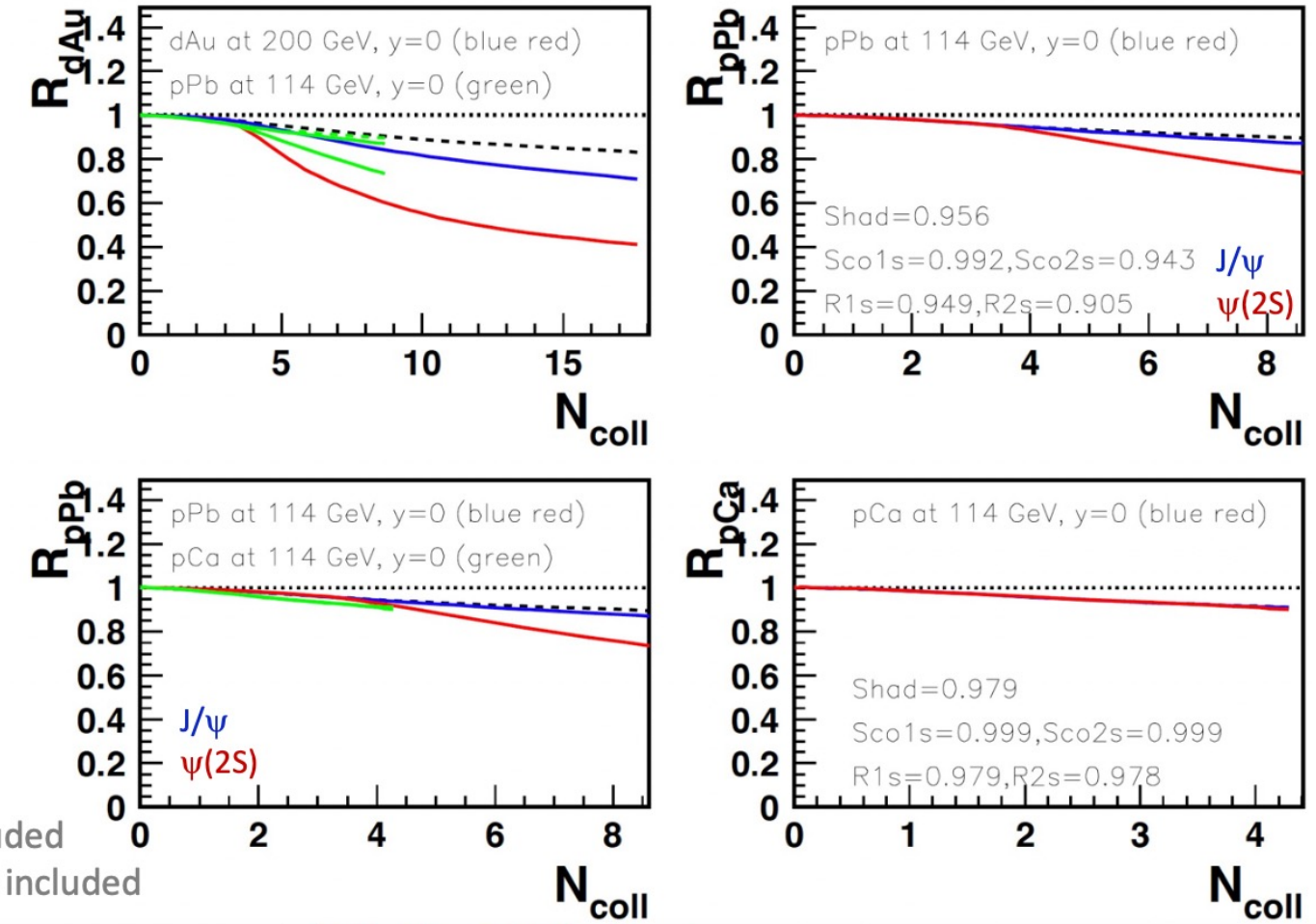
- The NLO calculation for J/ψ photoproduction is reproduced using dipole-subtraction method
- Calculation of rapidity-differential production cross section is in progress
- Calculations of $\chi_{c0,2}$ production cross sections are in progress

11 / 5

Final effects: Comover interaction model

Results from the CIM at fixed-target LHC energies

- At mid rapidities, the effect on charmonium excited vs ground state can be measurable for p-Pb collisions

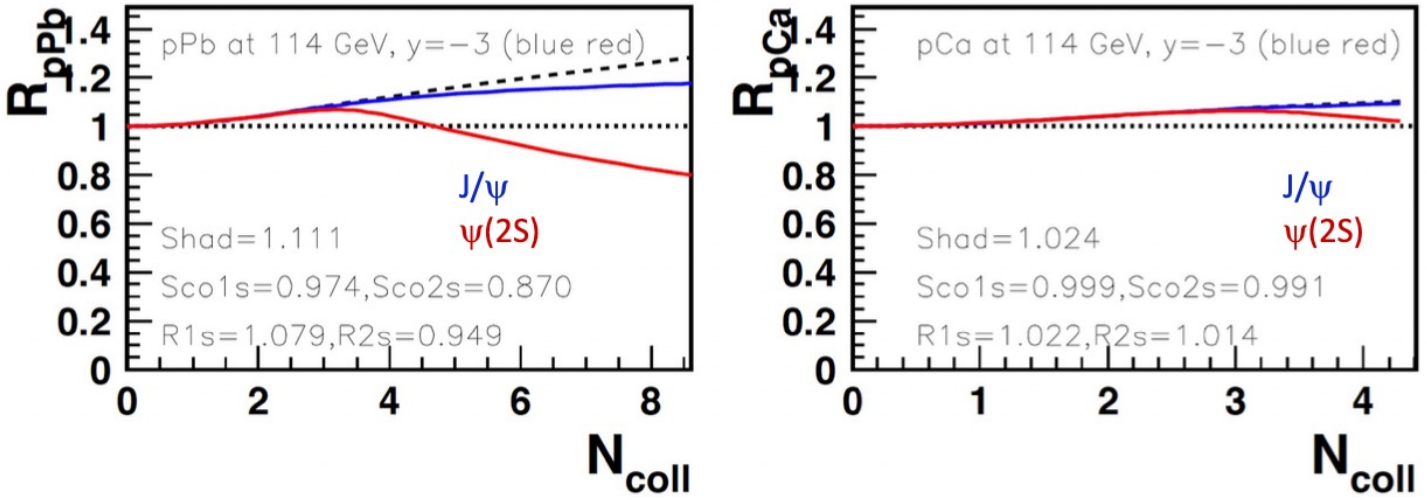


nPDF modification included
Nuclear absorption not included

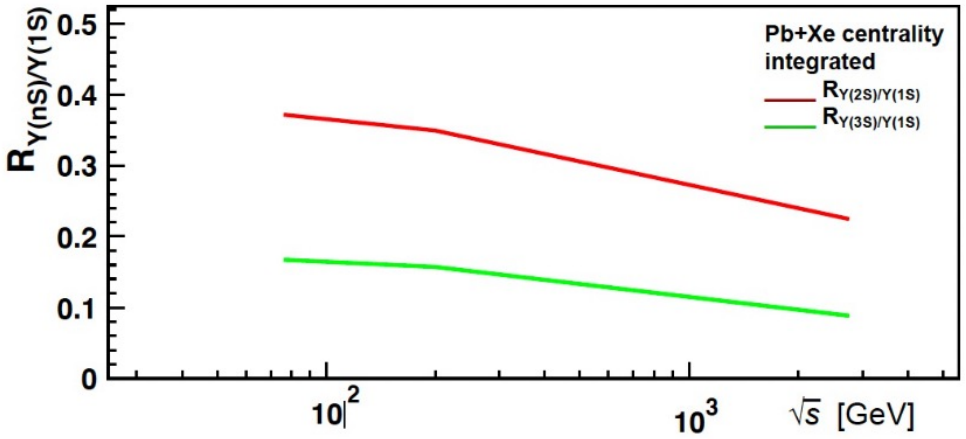
Final effects: Comover interaction model

Results from the CIM at fixed-target LHC energies

- At backward rapidities, the effect on charmonium excited vs ground state will be stronger and might be measurable for lighter nuclei

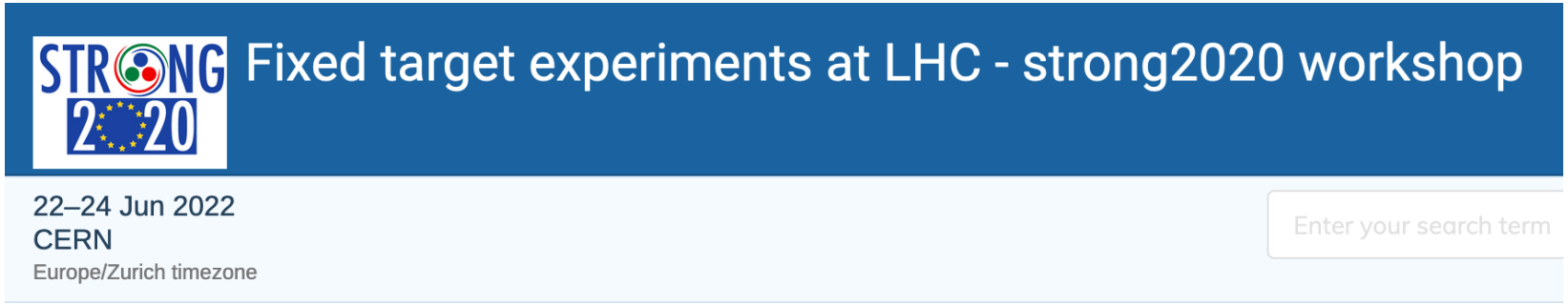


- It can be particularly relevant for upsilon production



nPDF modification included
Nuclear absorption not included

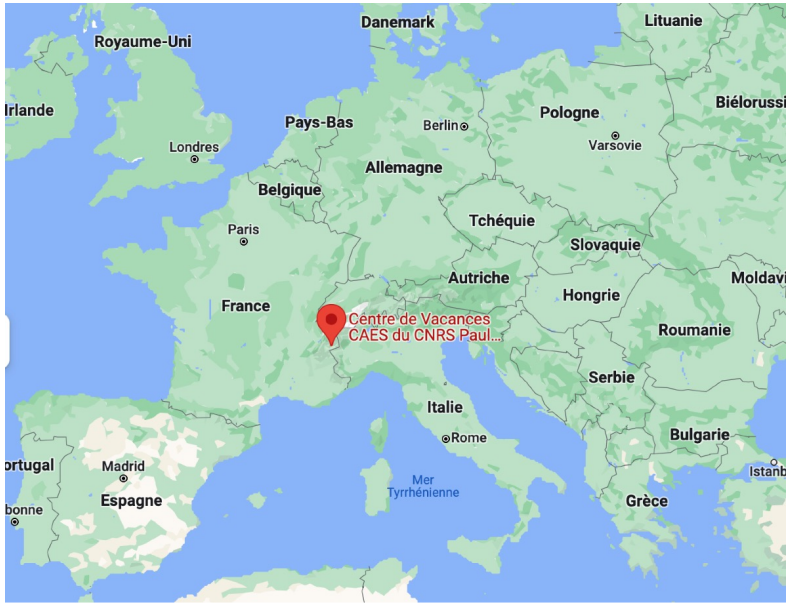
WORKSHOPS



24 talks, time for interesing discussions, a lot of useful feedback

FTE@LHC Workshop January 2023

Satellite workshop (January 5-7 2023) before
Quarkonia as Tools 2023 (January 8-14 2023)
Centre Paul Langevin, Aussois, France



CONCLUSIONS

ALICE: a conceptual design of a fixed-target system, its integration along LHC and into the ALICE mini-frame, and reconstruction algorithms have been studied and will be summarised in a LoI for the ALICE Collaboration. The specific kinematic range allows one to probe the high-x frontier of nuclear structure.

LHCb: the storage cell system has been installed and commissioned. LHC gave the green light to inject gas. The data acquisition and reconstruction chain has been implemented and ready to take data. The Polarised Gas Target R&D continues: two engineer drawings are currently under study, while physics channels simulations show unique potentialities.

Phenomenology: recent progress about the p_T integrated quarkonium production via matching of NLO and High-Energy Factorization. Interesting results about *comover interaction model* for different collision systems and probes

Milestones reached
Everything on track

Budget fully used, few money for traveling still available

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