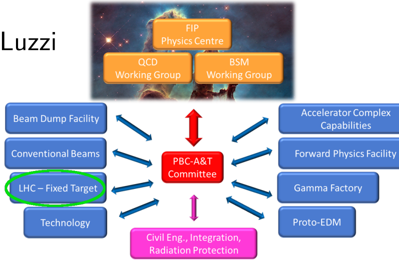
Fixed targets at the LHC: proposals and challenges

Massimiliano Ferro-Luzzi

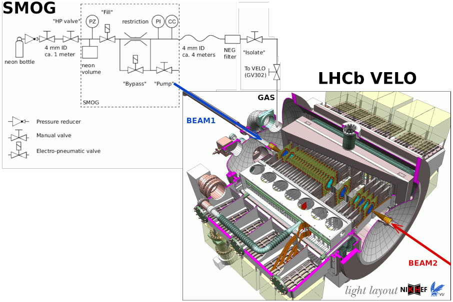


as co-convener of
PBC LHC-FixT WG
with Stefano Redaelli and
Cynthia Hadjidakis (scientific secretary)

thanks to all LHC-FixT WG participants

First LHC fixed-target physics runs (Run2)

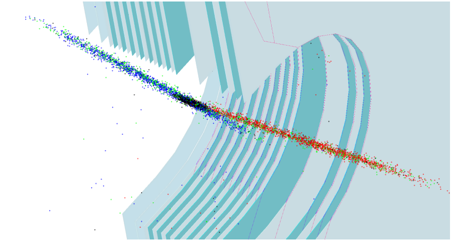
Once upon a time in the SMOG



⇒

Beam-gas vertices in LHCb VELO

empty, beam1, beam2, beam1-beam2 crossing types



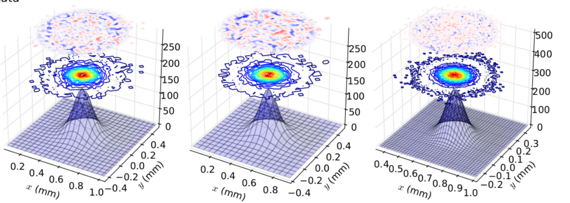
⇓

System to **M**easure the **O**verlap with **G**as

Was introduced to **determine the luminosity of LHC colliding beams**

Gas density not measured (not needed)

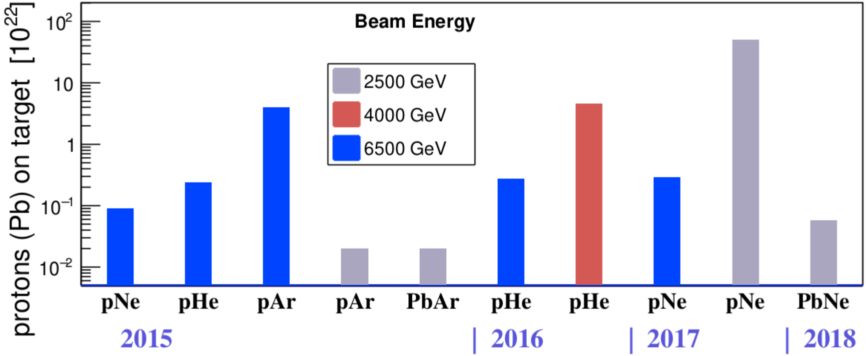
C. Barschel, CERN-THESIS-2013-301



First LHC fixed-target physics runs (Run2)

LHCb fixed target physics measurements with p-A and Pb-A (SMOG)
$\rightarrow$ Required a trick to measure the gas density! (i.e. luminosity)

first **neon**, then **helium**, finally **argon**

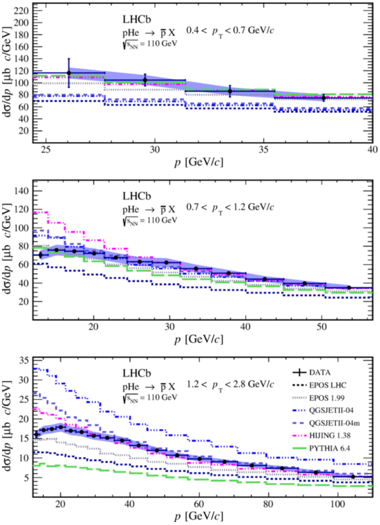


Very grossly, 10^{22} POTs $\approx$ 5 nb^{-1} (assuming 100 cm$\times 2 \cdot 10^{-7}$ mbar)

First LHC fixed-target physics results (Run2)

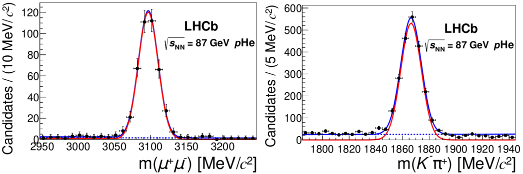
$\bar{p}$ from p-He

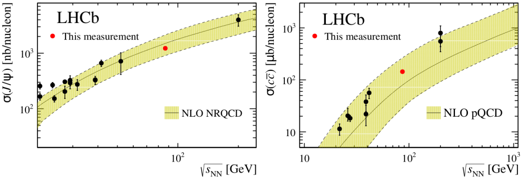
LHCb, PRL121, 222001(2018)



charm from p-He/Ar/Ne, Pb-Ne

LHCb, PRL122,132002(2019) & 123,239901(2019)



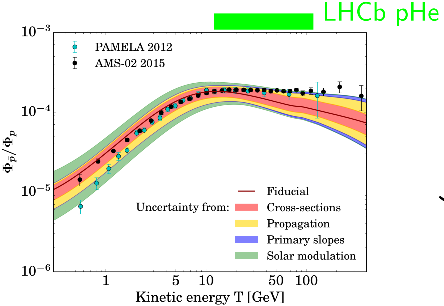


More recently:

- LHCb, arXiv:2205.09009, EPJC, submitted 18 May 2022
- LHCb, arXiv:2211.11652, EPJC, submitted 21 Nov 2022
- LHCb, arXiv:2211.11645, EPJC, submitted 21 Nov 2022
- LHCb, arXiv:2211.11633, EPJC, submitted 21 Nov 2022

AMS $\bar{p}/p$ and LHCb p-He$\rightarrow \bar{p}X$

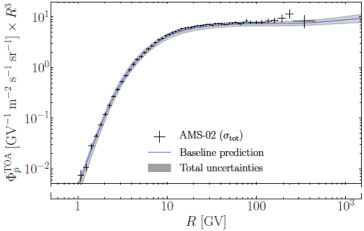
Giesen et al, JCAP09 (**2015**) 023



M.Korsmeier et al., Phys. Rev. D 97, 103019 (**2018**)

The cosmic-ray flux of antiprotons is measured with high precision by the space-borne particle spectrometers AMS-02. Its interpretation requires a correct description of the dominant production process for antiprotons in our Galaxy, namely, the interaction of cosmic-ray proton and helium with the interstellar medium. In light of new cross section measurements by the NA61 experiment of $p+p\rightarrow\bar{p}+X$ and the first ever measurement of $p+\mathrm{He}\rightarrow\bar{p}+X$ by the LHCb experiment, we update the parametrization of proton-proton and proton-nucleon cross sections. We find that the LHCb pHe data constrain a shape for the cross section at high energies and show for the first time how well the rescaling from the pp channel applies to a helium target. By using pp, pHe and pC data we estimate the uncertainty on the Lorentz invariant cross section for $p+\mathrm{He}\rightarrow\bar{p}+X$. We use these new cross sections to compute the source term for all the production channels, considering also nuclei heavier than He both in cosmic rays and the interstellar medium. The uncertainties on the total source term are up to $\pm 20\%$ and slightly increase below antiproton energies of 5 GeV. This uncertainty is dominated by the $p+p\rightarrow\bar{p}+X$ cross section, which translates

M.Boudaud et al., Phys. Rev. Res. 2, 023022 (**2020**)

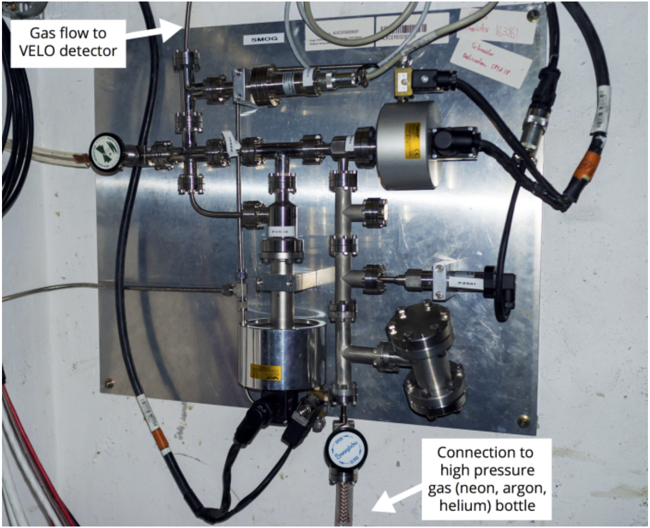


Significant shrinking of uncertainty for the predicted secondary antiproton flux from the use of LHCb and NA61 (pp) new data (plus other improvements)

Other studies still suggest a possible excess from dark matter annihilation

First LHC fixed-target physics runs (Run2)

SMOG $\sim \mathcal{O}(50 \text{ kCHF})$

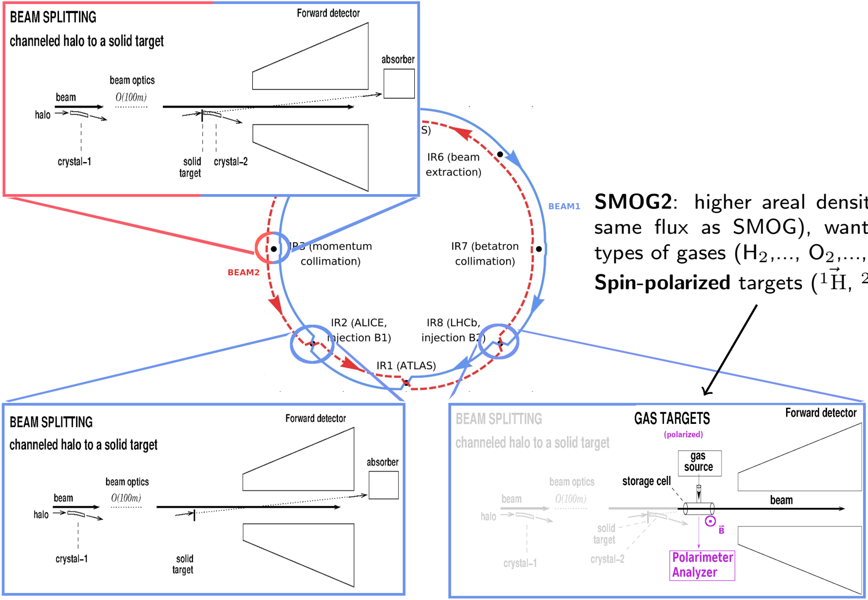


Encouraged by exciting results, from crystal channeling tests and from SMOG, and by the adequacy of LHCb / ALICE for fixed target experiments...

NEW PROPOSALS FOR MORE PHYSICS

Run3, Run4: time to do more

Current geography of (proposed) LHC FixT



SMOG2: higher areal density (at same flux as SMOG), want new types of gases (H_2,..., O_2,..., Xe)

Spin-polarized targets ($^1\vec{\mathrm{H}}$, $^2\vec{\mathrm{H}}$)

Run3, Run4: time to do more

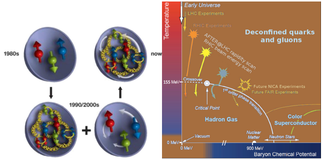
Gaseous targets (IP8):

- **SMOG2**: higher areal density (at same flux), want new types of gases (H_2,..., O_2,..., Xe)
- **Spin-polarized** targets ($^1\vec{\mathrm{H}}$, $^2\vec{\mathrm{H}}$)

Solid targets:

- **Solid wire** targets in the LHC ? (à la Hera-B)
- **One-crystal** setup (IP2): halo deflection onto a solid off-axis target (W, C ... ?)
- **Two-Crystal** setup (IP8/IR3): halo deflection onto a solid off-axis target (W) and precess channeled baryons

physics



figs from Hadjidakis et al. PhysRep911(2021)1

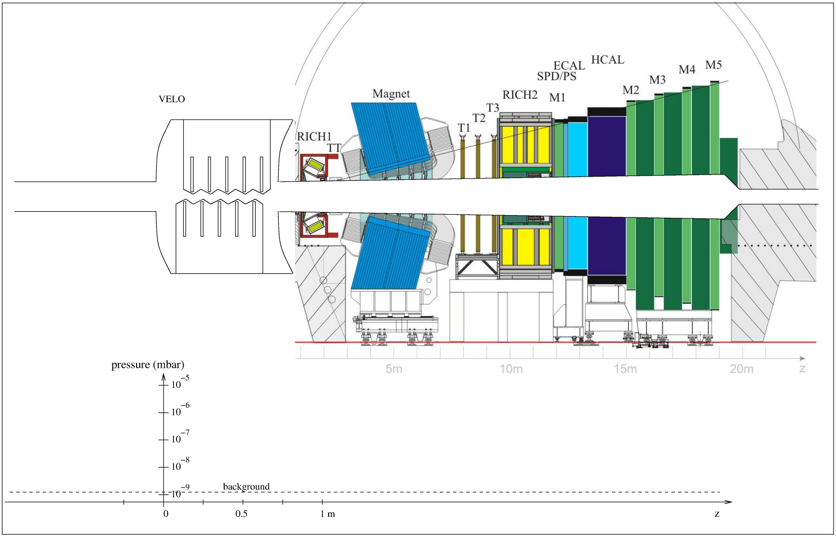
hadron structure, QGP, data for phenomenology (colliders, cosmic rays), ...

+ baryon MDM/EDM, very fwd charm production

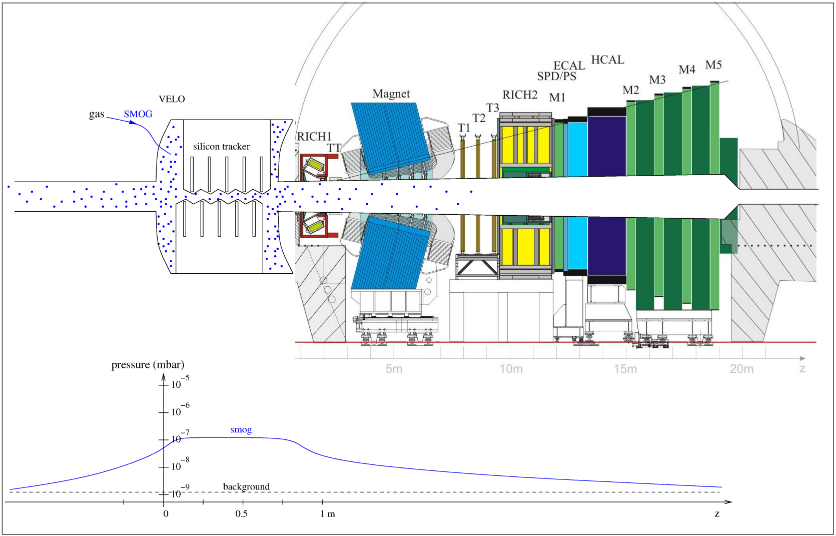
UNPOLARIZED GAS TARGETS

a.k.a. SMOG2

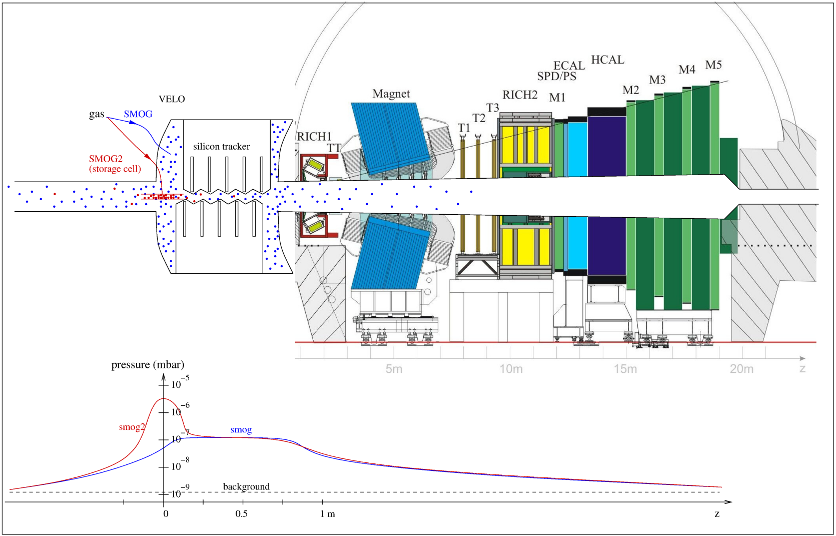
Unpolarized gas targets at IP8



Unpolarized gas targets at IP8



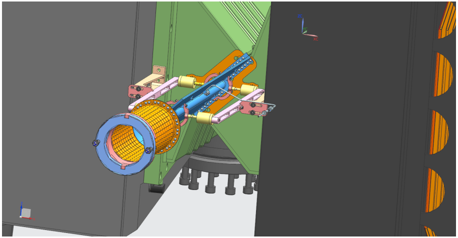
Unpolarized gas targets at IP8

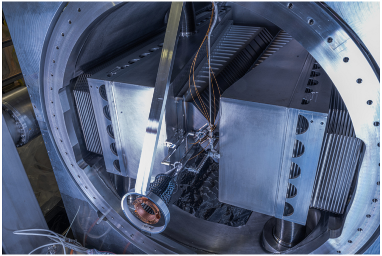


Unpolarized gas targets at IP8

as a result of much work & cooperation (impedance, aperture, SEY/vac)...
SMOG2 Storage Cell successfully attached to LHCb VELO at IP8 (summer 2020)

before and after coating with amorphous carbon



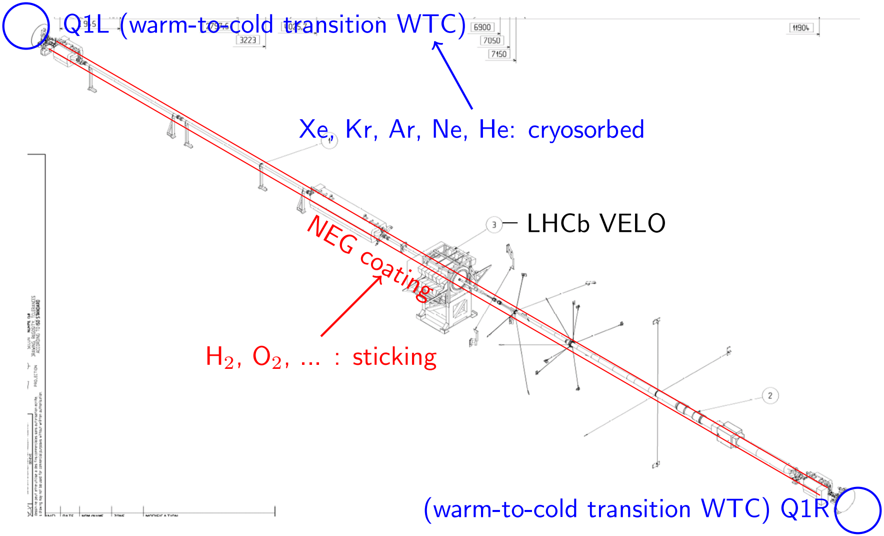


2022: gas-feed system & VELO+SC closing commissioned successfully

LOOKING FORWARD TO EXPLOITATION OF THIS NEW DEVICE IN 2023!
SEE TALK BY SAVERIO MARIANI

Unpolarized gas targets at IP8

Challenges: coatings, SEY

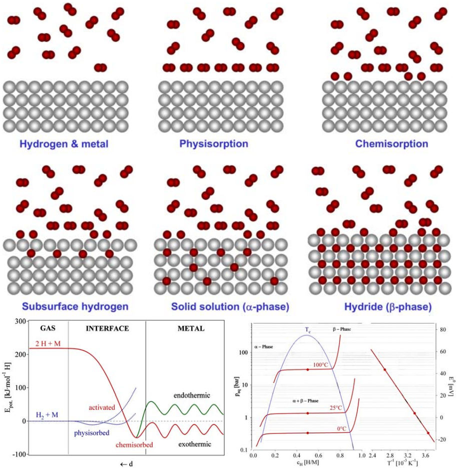


Unpolarized gas targets at IP8

The case of hydrogen (H_2 or D_2):

figs. from A. Züttel, Mitig Adapt Strat Glob Change 12 (2007) 343

- molecular hydrogen on the surface of TiZrV (LHC low-T° NEG): sticks and dissociates or is re-emitted
- atomic hydrogen diffuses in the bulk of TiZrV ($\sim 1\ \mu$m thick)
- results in a pressure equilibrium between hydrogen in the bulk and hydrogen in the gas volume
- an excess of hydrogen in the bulk may result in embrittlement (and peel off) of the NEG
  - R&D needed to quantify this in SMOG2@LHC conditions
  - Most exposed NEG is on the VELO RF foil, 3.5 mm from the beam axis



What gas flux results in what presssure equilibrium at the VELO RF foil ?
Possible mitigation ?

Unpolarized gas targets at IP8

The case of oxygen (O_2):

- molecular oxygen is pumped on the surface of TiZrV (LHC low-T° NEG)
- sticking coefficient depends on available pumping sites
- continuous gas flow will saturate progressively the NEG surfaces, from the SC vicinity to farther away
- results in less pumping speed for getterable gases ('ok' for LHCb)
- but also in an increase of the SEY ?
  $\rightarrow$ to be quantified!
  (data available ?)

quotes from P. Chiggiato, P. Costa Pinto, Thin Solid Films 515 (2006) 382

3.5. Performance deterioration: ageing of Ti–Zr–V films

In many applications, vacuum chambers are frequently exposed to air and, as a consequence, Ti–Zr–V coatings undergo several venting–activation cycles. Since the film thickness is typically about 1 μm and the maximum quantity of oxygen that can be dissolved in the film is limited, a deterioration of the film performances is expected [11]. The

The experimental results can be interpreted by using both thermodynamic and kinetic considerations. Each cycle dissolves into the film an identical quantity of oxygen; hence the maximum possible number of cycles is reached when the oxygen solubility limit is attained. If an oxygen solubility limit similar to that of the elements of the fourth group is considered, full saturation after about 100 cycles is expected for each μm of film thickness [47]. However, heating at temperatures lower than 250 °C does not allow a uniform oxygen concentration to be reached in the film and, as a consequence, oxygen atoms are settled in the film to form a concentration profile with the maximum close to the surface, which finally leads to accelerated performance degradation. These conclusions are not peculiar to films but rather they apply to NEG materials of any nature.

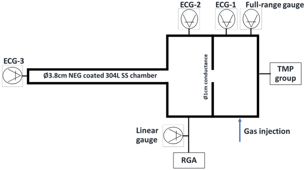
Possible mitigation:

- re-activation ? (beam pipe bake-out, heavy operation)
- limited number of re-activations ?

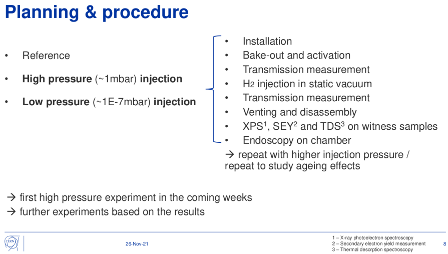
Unpolarized gas targets at IP8

Activities started to study hydrogen/oxygen effects on NEG

David Parragh (TE-VSC)



- Characterization at high H_2 pressure injection
- Characterization and ageing test at low H_2 pressure injection
- Simulations on the complete LHCb vacuum system
- H_2 saturation and replenishing time measurements
- Accumulation measurements to measure CH_4 outgassing



Planning & procedure

- Reference
- **High pressure** (~1mbar) **injection**
- **Low pressure** (~1E-7mbar) **injection**

- Installation
- Bake-out and activation
- Transmission measurement
- H_2 injection in static vacuum
- Transmission measurement
- Venting and disassembly
- XPS[1], SEY[2] and TDS[3] on witness samples
- Endoscopy on chamber

→ repeat with higher injection pressure / repeat to study ageing effects

→ first high pressure experiment in the coming weeks
→ further experiments based on the results

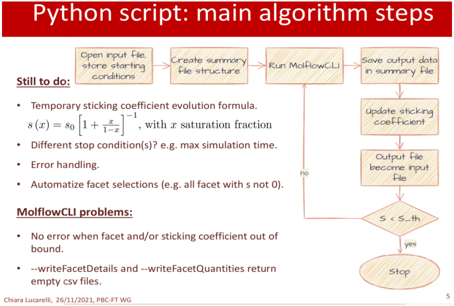
26-Nov-21

1 – X-ray photoelectron spectroscopy
2 – Secondary electron yield measurement
3 – Thermal desorption spectroscopy

8

Chiara Lucarelli (Univ. Firenze)

- Understand and quantify limitations to the gas flux injection
- Detailed molecular flow simulations needed (Molflow)
- local model of SC+RF & complete IP8 region model (Q1-Q1)
- adapt MolflowCLI to update surface properties (e.g. sticking coefficient) during simulation



Python script: main algorithm steps

Still to do:

- Temporary sticking coefficient evolution formula. $s(x) = s_0 \left[1 + \frac{x}{1-x}\right]^{-1}$, with x saturation fraction
- Different stop condition(s)? e.g. max simulation time.
- Error handling.
- Automatize facet selections (e.g. all facet with s not 0).

MolflowCLI problems:

- No error when facet and/or sticking coefficient out of bound.
- --writeFacetDetails and --writeFacetQuantities return empty csv files.

Chiara Lucarelli, 26/11/2021, PBC-FT WG 5

SEE TALK BY DAVID MATE PARRAGH

Unpolarized gas targets at IP8

The case of heavy noble gases Xe, Kr, (Ar):

- not pumped by NEG!
- part of the noble gas flows from VELO vacuum vessel into beam pipe
- at ± 20 m from IP8, gas reaches transition (WTC) from room to cryogenic temperature ($\mathcal{O}(10\ \mathrm{K})$ in the quadrupole Q1)
- noble gas is cryosorbed on the cold surfaces
- due to its high SEY, cryosorbed layer can provoke beam instabilities

  $\rightarrow$ more specific data needed

What gas flux results in what coverage at the WTCs ?

Possible mitigation:

- For Ne or Ar, a cryo/vacuum operation (local partial warm-up) may be used to force the cryosorbed gas to “migrate” towards the cold bore (behind the beam screen). It seems impossible to apply this method to Kr and Xe due to their thermodynamic properties.
- longer term: upgrade/adapt pumping scheme L/R of IP8 ?

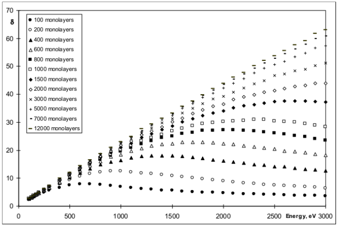


Fig. 14. “Secondary electron yield - incident energy” plane for neon.

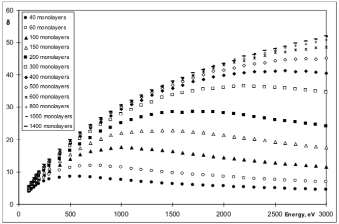


Fig. 20. “Secondary electron yield - incident energy” plane for xenon.

NB: data taken at 4.2 K

plots from
Y. Bozhko et al., arXiv:1302.2334 [physics.acc-ph]

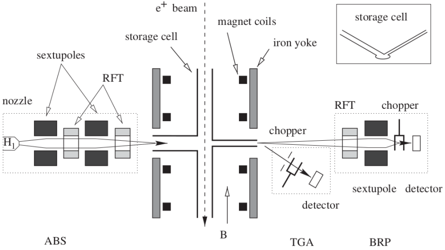
POLARIZED GAS TARGETS

a.k.a. LHCSpin

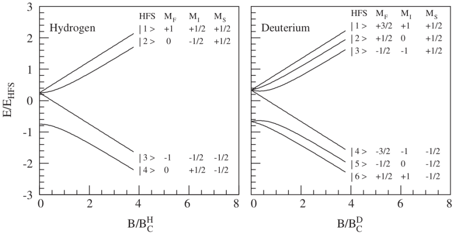
Polarized gas targets at IP8

From A. Airapetian et al., NIM A540 (2005) 68

Sketch of HERMES pol. H/D target



Hyperfine levels of atomic H and D



$$B_C^{H/D} = 50.7 \ / \ 11.7 \text{ mT}$$

Nuclear polarization of the target in the storage cell:

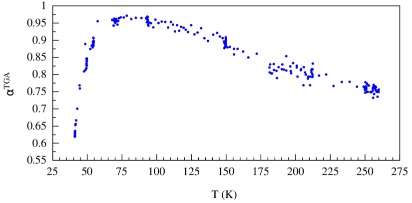
$$P = \underbrace{\alpha_0\, \alpha_r P_a}_{\text{atoms}} + \underbrace{\alpha_0\,(1-\alpha_r)\,\beta\, P_a}_{\text{molecules}}$$

α_0 = injected dissociation fraction

α_r = non-recombined fraction

$\beta = P_m / P_a$

$P_{a,m}$ = avg nucl. pol. of molec./atoms

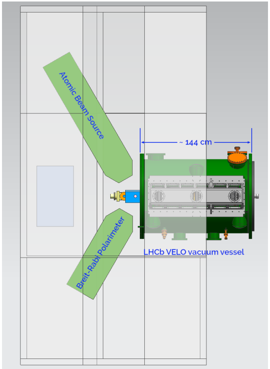


atomic fraction sampled from SC

Polarized gas targets at IP8

HERMES setup at DESY / Hera
(picture from Pasquale Di Nezza)

Top view sketch at IP8 / LHCb
(V. Carassiti, Ferrara)

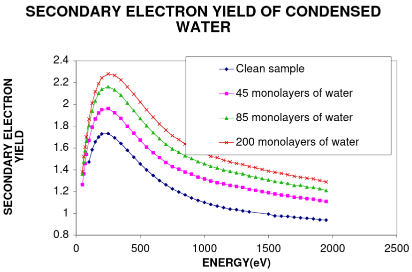


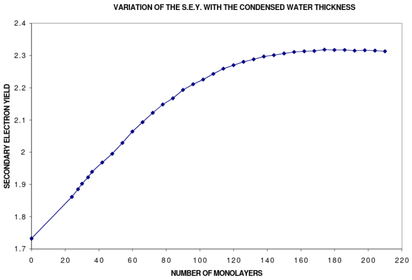
Main challenges: (my bias)

- demonstrate a suitable SC coating. (Cooling needed ? was $\sim$ 80 K at HERMES)
- ABS/BRP compactness / interfacing to VELO system

HERMES used a thin layer of ice (H_2O) on a (Drifilm-coated) Al storage cell surface in order to prevent recombination and nuclear depolarization

Applicable to LHC ?
- Drifilm not
- H_2O not so obvious... R&D needed!





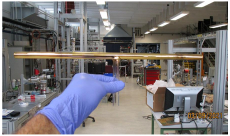
From Baglin et al., Proceedings of EPAC 2000, Vienna, Austria

Polarized gas targets at IP8

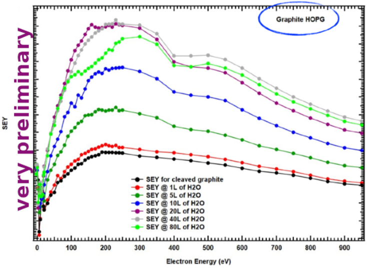
R&D effort to identify suitable coating for $\vec{\mathrm{H}}$

- amorphous carbon has excellent SEY
- very robust, "ages well", ...
- effect of impurities: hydrogen is bad, nitrogen is good
- does it preserve H nuclear polarization ?
- can one apply/control a few H_2O monolayers ?
- started R&D FZJ, LNF, Ferrara, CERN/TE-VSC

By cylindrical magnetron sputtering
Length = 400 mm; ID =10 mm



cell aC coating test, send sample to FZJ

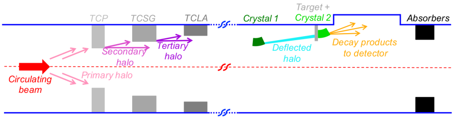


from M. Santimaria/LNF

PBC-FT WG 26.11.2021

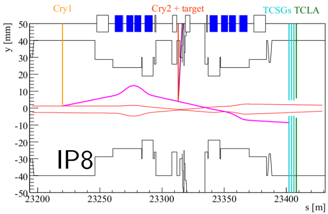
BENT CRYSTALS

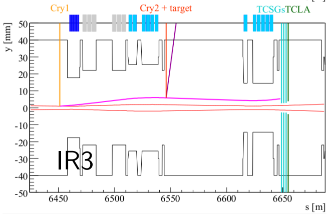
Bent crystals: LHC layouts IP2, IP8, IR3

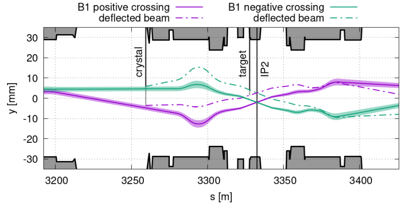


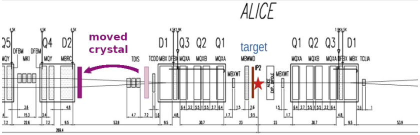
LHC tracing simulations performed, machine layouts defined and optimized, work still ongoing!

thanks to D. Mirarchi, A. Fomin, P. Hermes, M. Patecki, K. Dewhurst





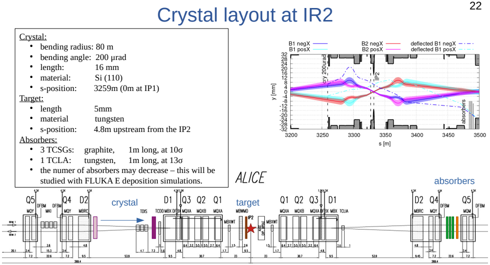




1-Crystal Setup at IP2

(see talk by Marcin Patecki)

- Found best phase advance between primary collimator and crystal
- crucial for reaching high performance
- phase adv adjustable using minor, local modification of optics; needed every time optics changes



PBC note in preparation (M. Patecki et al)

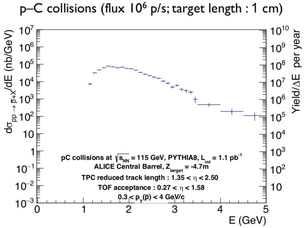
- s-location 3259m is only one where crystal can serve both crossing scenarios; good space availability for crystal installation
- flux $\sim 7.6 \cdot 10^{6}$ PoT/s (assuming 2018 beam conditions)
- ALICE can handle $\sim 10^{7}$ PoT/s.
- estimations rely on complex multi-turn tracking simulations; experimental verification and identification of operational challenges is desirable

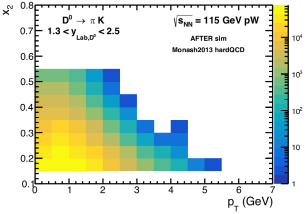
1-Crystal Setup at IP2

(excerpts from L. Massacrier at PBC 2021-12-02)

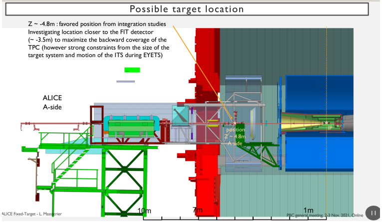
Physics case and feasability under study in ALICE, some highlights:

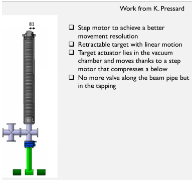
- $p - \mathrm{C} \rightarrow \bar{p}X$: very low $E(\bar{p}) \Leftrightarrow$ reverse kinematics of cosmic $\mathrm{C} - p$
- Gluon nPDFs from low energy D^0 (TPC), reach high x! (Cold Nuclear Matter effect)
- … (more to come)





Actions started with Cern teams:





- target, mech. (SY-STI)
- controls (BE-CEM)
- vacuum (TE-VSC)
- layout optimiz. (BE-ABP)

2-Crystal setup

Measurement of MDM/EDM with bent crystals in LHC

fig. from Botella et al., EPJC (2017) 77:828

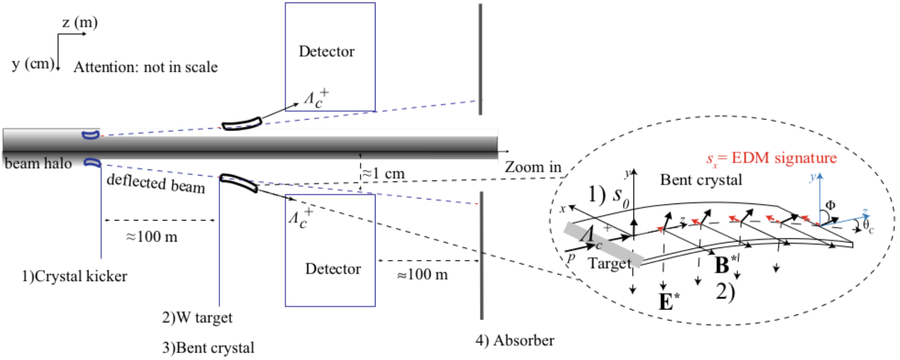


Fig. 7 Conceptual layout of the fixed-target setup shown in side view with down- and up-bending crystals. The zoom in shows the spin precession in the down-bending crystal for channeled Λ_c^+ baryons

MDM LHC 2-crystal expt proposed by Burmistrov et al., CERN-SPSC-2016-030

(see also Fomin et al., JHEP08 (2017) 120), see talks by W. Scandale & A. Stocchi in PBC Annual Workshop 2016

EDM addition proposed by Botella et al., EPJC (2017) 77:181

(see also Bagli et al., EPJC (2017) 77:828 and (2020) 80:680, Aiola et al., PRD 103, 072003), see talk by F. Martinez Vidal in PBC Annual Workshop 2017

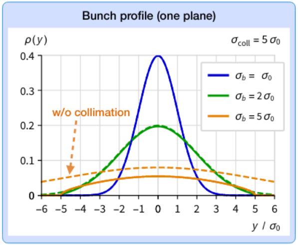
2-Crystal setup

Challenge: PoT/s

- Originally hoped for few 10^8 PoT/s
- LHC studies showed that at least 10^6 PoT/s was possible
- Efforts deployed to "recover" factors
  - Ways to resonantly excite some bunches to increase halo at crystal-1
    - $\times 3$ at cost of 1.2% of $\mathcal{L}$(CMS, ATLAS)
  - Amplitude analysis, add decay modes, optimize target length
    - stat. uncertainty scales with $\sqrt{\mathrm{PoT}}$
    - Showed: $\sim 1.4 \cdot 10^{13}$ p on $W_{2\mathrm{cm}}$+Si can reach sensitivity of $\delta_{\mathrm{EDM}} = 5 \cdot 10^{-16}$ $e\,\mathrm{cm}$ and $\delta_{\mathrm{MDM}} = 3 \cdot 10^{-2}$ μ_N

      with some assumptions on the unknowns, like production, initial polarization, channeling eff at 1 TeV
  - Improve channeling efficiency (next slide)

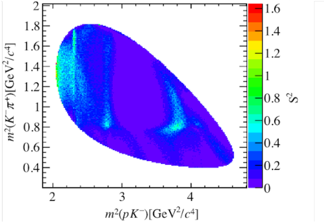
Work still ongoing!



A. Fomin PBC FT WG 2021-10-28

$$\rho(y, \sigma_b) = \frac{1}{\sqrt{2\pi}\sigma_b} \exp\left(-\frac{y^2}{2\,\sigma_b^2}\right) \mathrm{Erf}\sqrt{\frac{\frac{\varepsilon_{\mathrm{coll}}}{\varepsilon_0} - \frac{y^2}{\sigma_0^2}}{2\,\sigma_b^2/\sigma_0^2}}$$

S. AIOLA *et al.* PHYS. REV. D **103,** 072003 (2021)



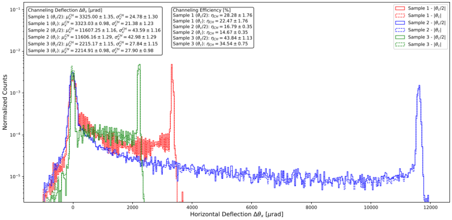
thanks A. Merli, D. Marangotto, J. Ruiz Vidal

2-Crystal setup

Challenge: (long, large angle) crystal channeling efficiency at $\mathcal{O}(1\ \mathrm{TeV})$ is not measured. Only model prediction available.

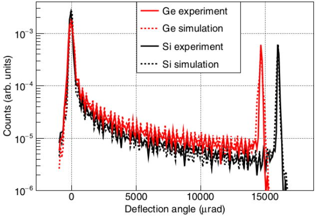
A lot has been done!   Here results from North Area, 180 GeV π^+

R. Rossi et al 2021 JINST 16 P05017   setup



Si, length 8/8/2.5 cm, bending angle 3/12/2.5 mrad

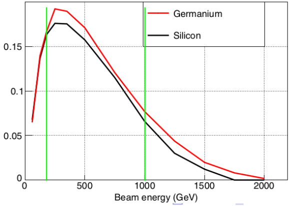
Aiola et al, PRD103, 072003(2021)



Si/Ge, length 5/3.5 cm, bending angle 16/15 mrad

$\rightarrow$ efficiencies of $\mathcal{O}(10-20\%)$ at 0.18 TeV for "long, large angle" crystals established

What about 1 TeV ?



2-Crystal setup

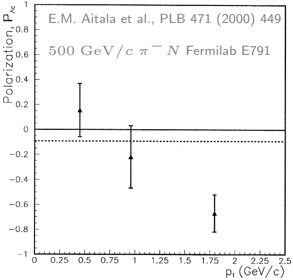
More challenges

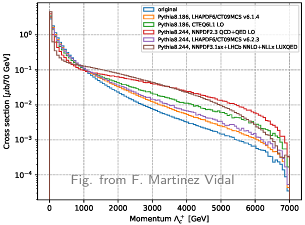
What is the Λ_c^+ initial degree of polarization ?

What is the Λ_c^+ production cross-section and spectrum near 0 degrees ?

- Large differences in hard part of the spectrum, explains some discrepancies between crystal setup simulations
- Large uncertainties of PDFs at very small x, LO vs NLO vs NNL approximations, besides production (matrix elements) and fragmentation
- Ongoing discussion with theorists
- Unique experimental setup for studies of charm production in the very forward region
- etc

This is interesting physics in its own right!





Proof-of-principle setup at IR3

Summing up (for the two-crystal proposal) round 2021

- LHCb expressed strong interest in the MDM/EDM experiments. However, in light of LHCb Upgrade 1 installation / schedule and given the complexity / challenging nature of the proposed 2-crystal experiment, encourages the proponents to make first a proof-of-principle experiment in IR3
- Agreed to set up a proof-of-principle experiment in IR3 $\rightarrow$ "Phase 0"
- Now in the process of defining this P-o-P experiment , then, if succesful
- Phase 1: setup to perform first physics measurements (Λ_c^+ MDM/EDM, $\mathcal{O}(10^{13}$ POT), charm physics ?)
- Phase 2: setup to perform full blown physics measurements (ultimate reach for MDM/EDM)

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Advantages of IR3 over IP8:

1. single-beam vacuum pipe
2. collimation region
   ('robust' region, no LHC experiment, detector can be designed ad hoc, may come closer to primary collimator position ? more PoT ?)
3. parasitic operational scenario, no bkg to host experiment
4. no lower limit on bending angle linked to LHCb acceptance (more ch. eff.)
5. no interference/competition from other usptream devices of LHCb

Disadvantage: build a new detector (a jump in cost)

Main goals:

- test control/management and channeling of secondary halo (never done in LHC, only simulation available)
- measure channeling efficiency of long crystal at 1-2 TeV in LHC (e.g. with double channeling)
- demonstrate design compatible with high intensity
- test PoT rate capability, bunch excitation, identify challenges of two-crystal scheme in LHC
- measure background environment with a track/vertexing detector

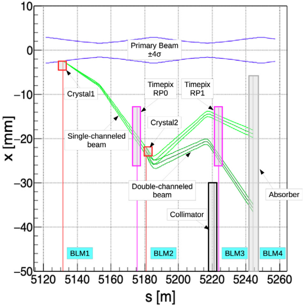
Proof-of-principle setup at IR3

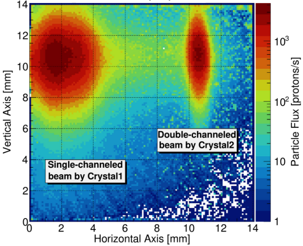
Double channeling demonstration

- Using SPS, 270 GeV p on 301/197 μrad bending crystal 1/2 of 4/6 mm length
- Demonstrated/developed operational method for the double-crystal scenario
- Double channeling clearly seen
- Measured values of beam trajectories, profiles and channeling efficiency agree with Monte-Carlo simulation

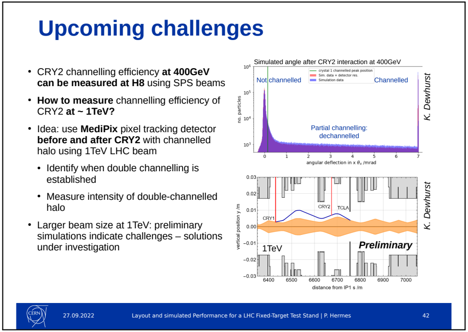
Next step: repeat this in the LHC with $p \sim O(1\ \text{TeV})$ and a long crystal-2

W. Scandale et al. NIMA 1015 (2021) 165747



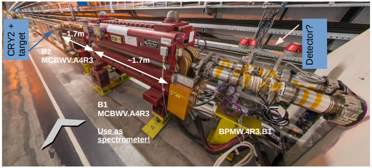


More info at recent Workshop here.



29

MCBWV.A4R3 as a spectrometer



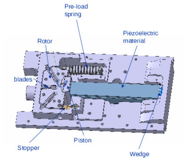
https://edms.cern.ch/panoramas/viewer?fov=90.00&id=36409858&lat=-27.06&lon=241.01

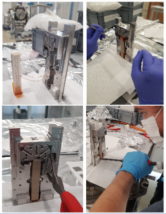
- To be checked: available space at BPM position → enough for detector?

There is a continuous effort on LHC machine simulations.
A concrete location has been identified in IR3 and studied.
Checking suitability at all desired energies (450 GeV, 1 TeV, 6.8 TeV).

Proof-of-principle setup at IR3

Design to requirement
Rotation actuator





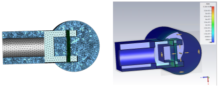
SY Accelerator Systems STI 7

Toward a new generation of bended crystal devices
Impedance and power loss of "ideal" devices

Ions runs with crystal in operating position : up to 10W

HL protons runs : up to 900W with crystal retracted

Quartullo, Danilo et al. "Electromagnetic characterization of the crystal primary collimators for the HL-LHC." *Nuclear Instruments & Methods in Physics Research Section A-accelerators Spectrometers Detectors and Associated Equipment* 1010 (2021): 165465.



Courtesy of Chiara Antuono, BE/ABP

IR7 type crystal in operating position for HL protons runs: up to 9W

IR3 long crystal in operating position for HL protons runs: up to 570W

SY Accelerator Systems STI 16

Geometry

- Simulation is configured by `xml` files
- Geometry (according to Elisabetta Spadaro Norella):
  - Target: W, 2 cm long
  - Crystal2: Si, 7 cm long, 7 mrad
  - Beam pipe: Cu OFE, elliptical form
  - MCBW Magnet: Fe, at 1 m from crystal
    - B=1.1 T, L=1.7 m
    - Bore: $R_B(x, y) = (2.6, 7.2)$ cm
  - Tracker stations: 2 blocks of 4 trackers before and after magnet
    - Si, 300 µm thick, 15 × 15 cm^2
    - Tracker block length=40 cm
  - (Transition radiation detector (TRD))

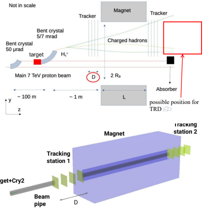


Fig. 2 Upper: A schematic picture of IR3 test; Lower: Geometry in simulation

Channeling process

by Chiara Maccani

- Example in Geant4 has been reproduced in DD4hep
  - Crystal characteristics:
    - Dimension: 1.0 mm × 70.0 mm × 1.94 mm
    - Bending radius: 38.416 m
  - Gun:
    - 400 GeV protons
    - 100 events

Channeling works correctly in DD4hep

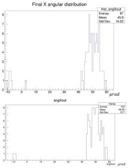


Fig. 5 The distribution of escaping angles. The upper picture is simulated by DD4hep and the lower is from Geant4

13

Run3, Run4: time to do more

Gaseous targets (IP8): | aim for

- **SMOG2**: higher areal density (at same flux), want new types of gases (H_2,..., O_2,..., Xe) — **Run3**
- **Spin-polarized** targets ($^1\vec{\mathrm{H}}$, $^2\vec{\mathrm{H}}$) — Run4

Solid targets:

- **Solid wire** targets in the LHC ? (à la Hera-B) — ?
- **One-crystal** setup (IP2): halo deflection onto a solid off-axis target (W, C ... ?)
- **Two-Crystal** setup (IP8/IR3): halo deflection onto a solid off-axis target (W) and precess channeled baryons

} **Run3** (proof-of-princ) Run4 (physics)

Out of the Briefing Book (ESU 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 [121, 122].

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 dynamics and spin of gluons and quarks inside (un)polarised nucleons is also very poorly known; possible missing contributions are expected to come from their orbital angular momentum. The LHC-FT mode enables to test the QCD factorisation framework and to measure TMD distributions, such as that of the linearly polarised gluons in unpolarised protons or the correlation between the proton spin and the gluon transverse momentum.

For heavy-ion studies, the proposed fixed-target experiments with LHCb and ALICE enable the exploration of new energy regimes between SPS and RHIC energies, across a wide rapidity domain to scan azimuthal asymmetries, and the use of new physics probes (e.g. excited quarkonia, Drell-Yan pairs) to test the factorisation of nuclear effects. In addition, double crystal LHC-FT experiments give access to studies beyond QCD, such as MDM and EDM of heavy baryons.

There are two proposed ways towards LHC-FT collisions [ID67]: a slow extraction with a bent crystal, or internal gas target inspired by SMOG@LHCb, HERMES, H-Jet, and others. 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.

Outlook

Unpolarized gas targets:

- ongoing, SMOG storage cell + gas feed system installed and commissioned,
- hydrogen studies show that it can be safely used (start humbly)
- working on luminosity determination (T°, real conductances, ...)

Polarized gas targets:

- R&D on storage cell coating ongoing
- backup without SC considered

Crystal channeling:

- TWOCRYST taking form (proof-of-principle at IR3, with 2 crystals)
- Design efforts ongoing, for P.o.P. and for final experiments in IP2, IR3/IP8.

Read more about this at recent PBC Annual workshop

Thanks for your attention

A rich and exctiting programme ahead!

Thanks to all proponents for stimulating ideas and to our CERN accelerator sector groups for the continued support:

- BE-ABP (collimation/optics layouts, impedance, e-cloud effects...)
- TE-VSC (dynamic vacuum effects, surface studies, ...)
- BE-CEM, SY-STI (mechatronics, design, integration, ...)

... and more will be involved in the future.