The LHCspin project

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In collaboration with:

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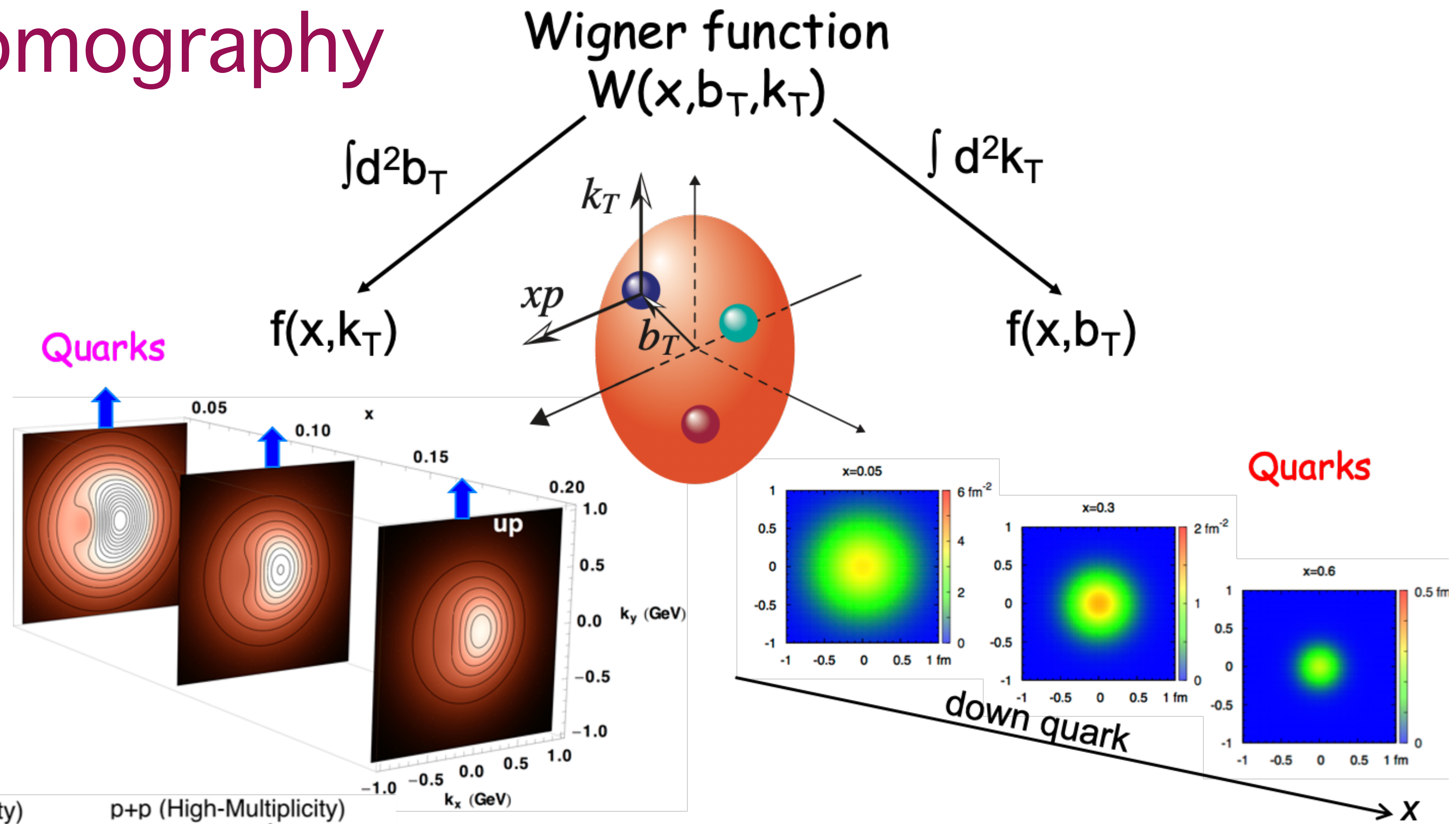
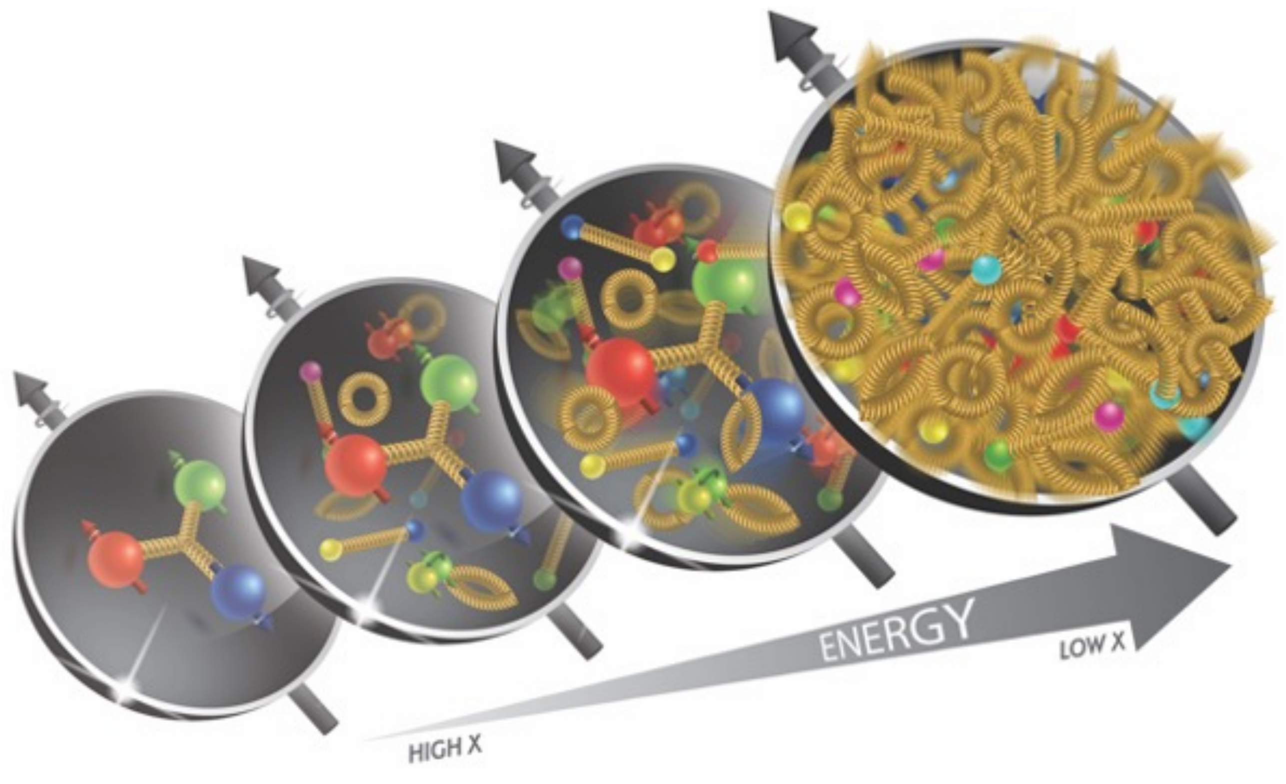
COMPASS-LHCspin-AMBER Joint Meeting, CERN 22/05/24

We have the opportunity to explore a wide range of new physics scenarios at LHC

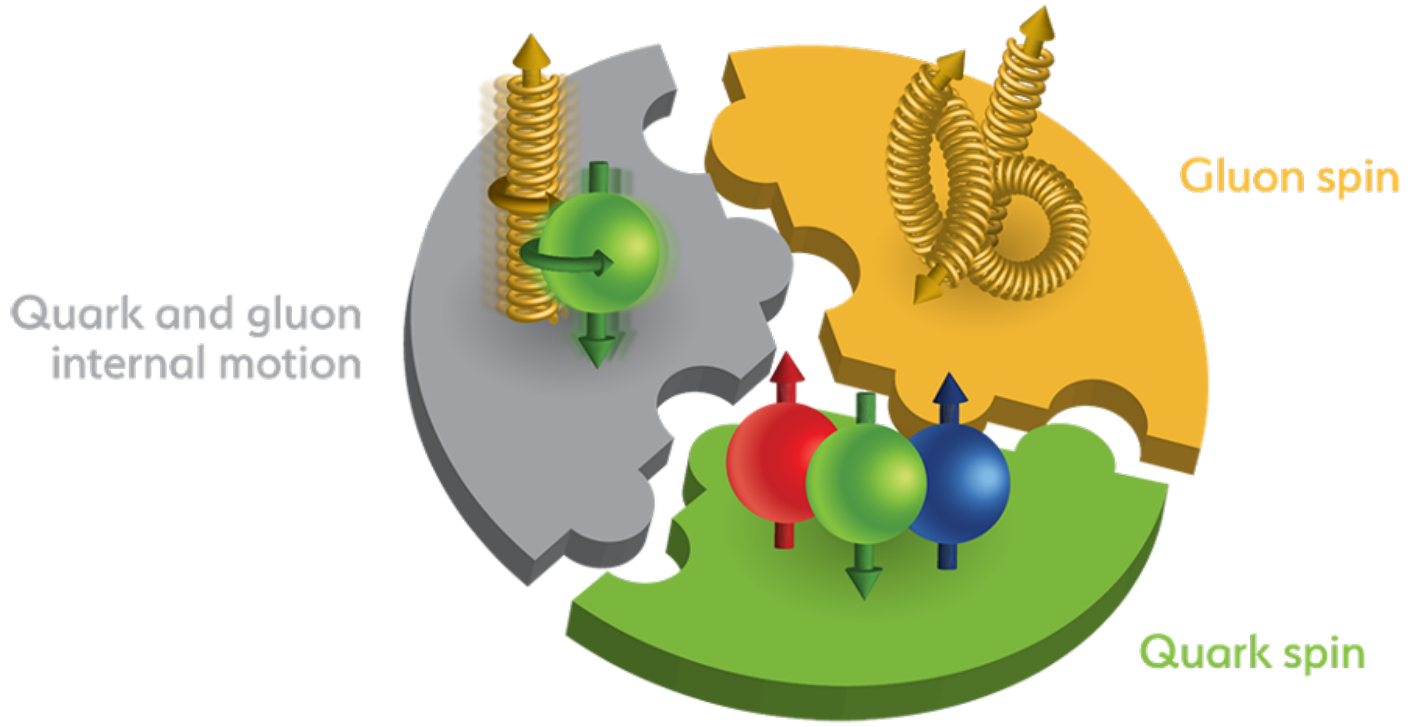
Hadron Tomography

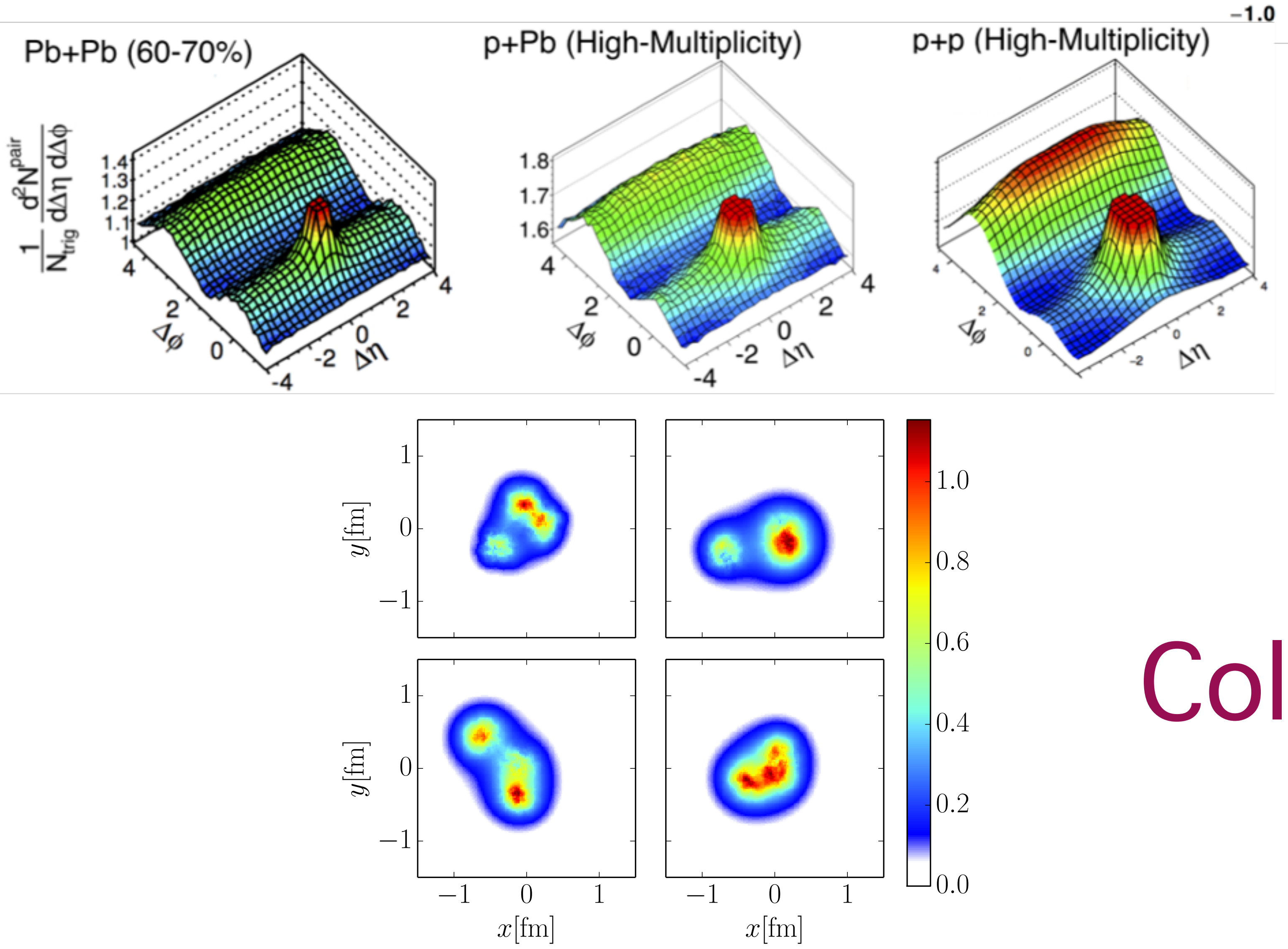


Hadron Structure



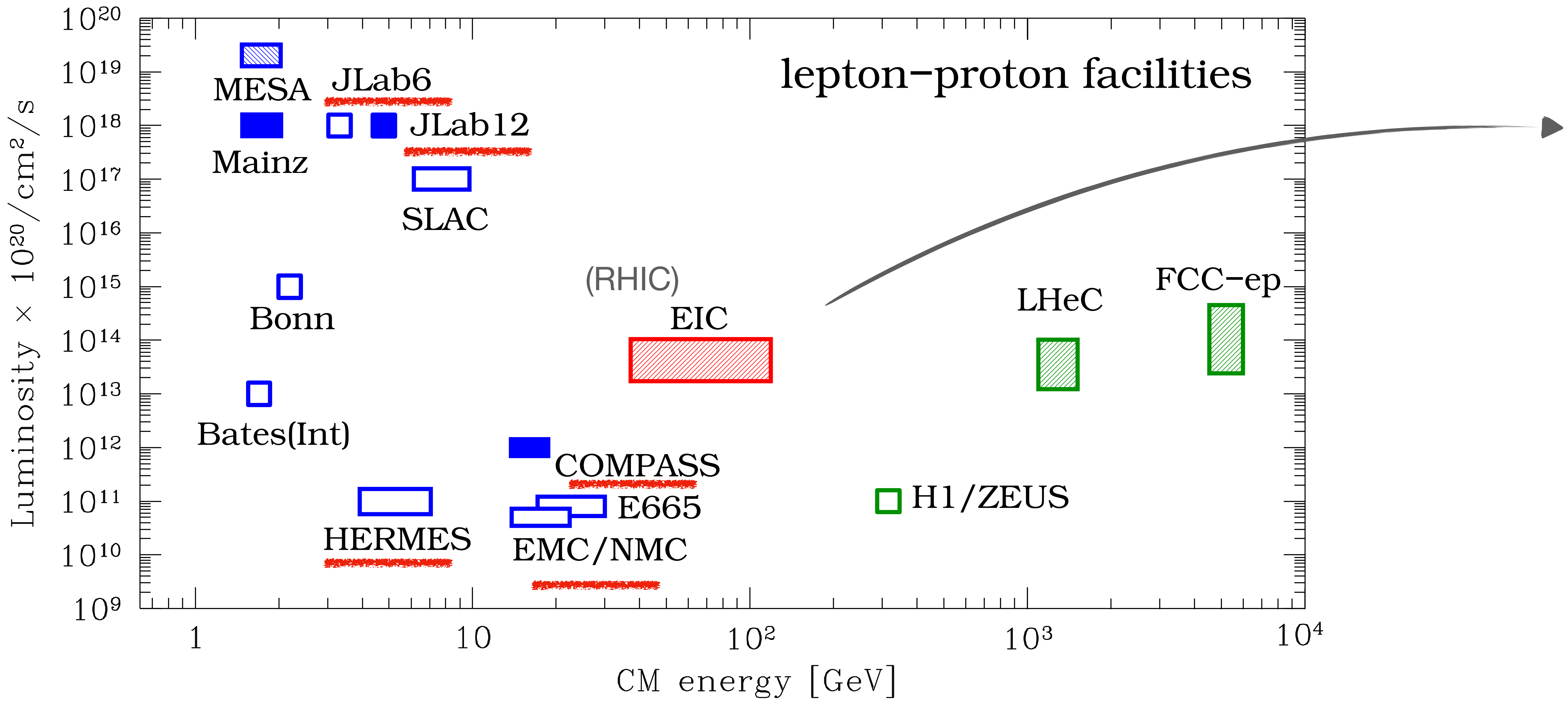
Spin structure

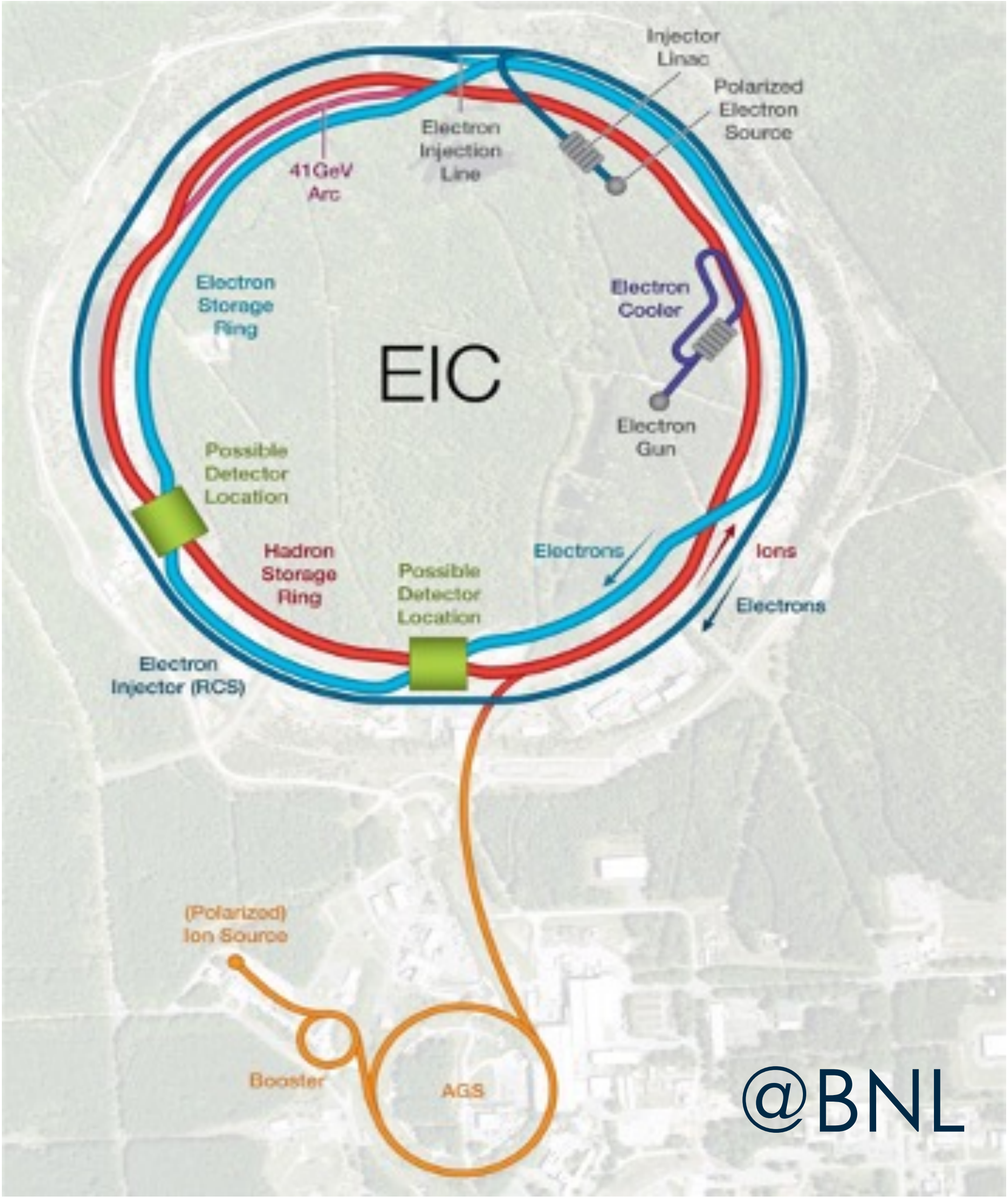




Collective phenomena

Huge efforts in the past/present … and future

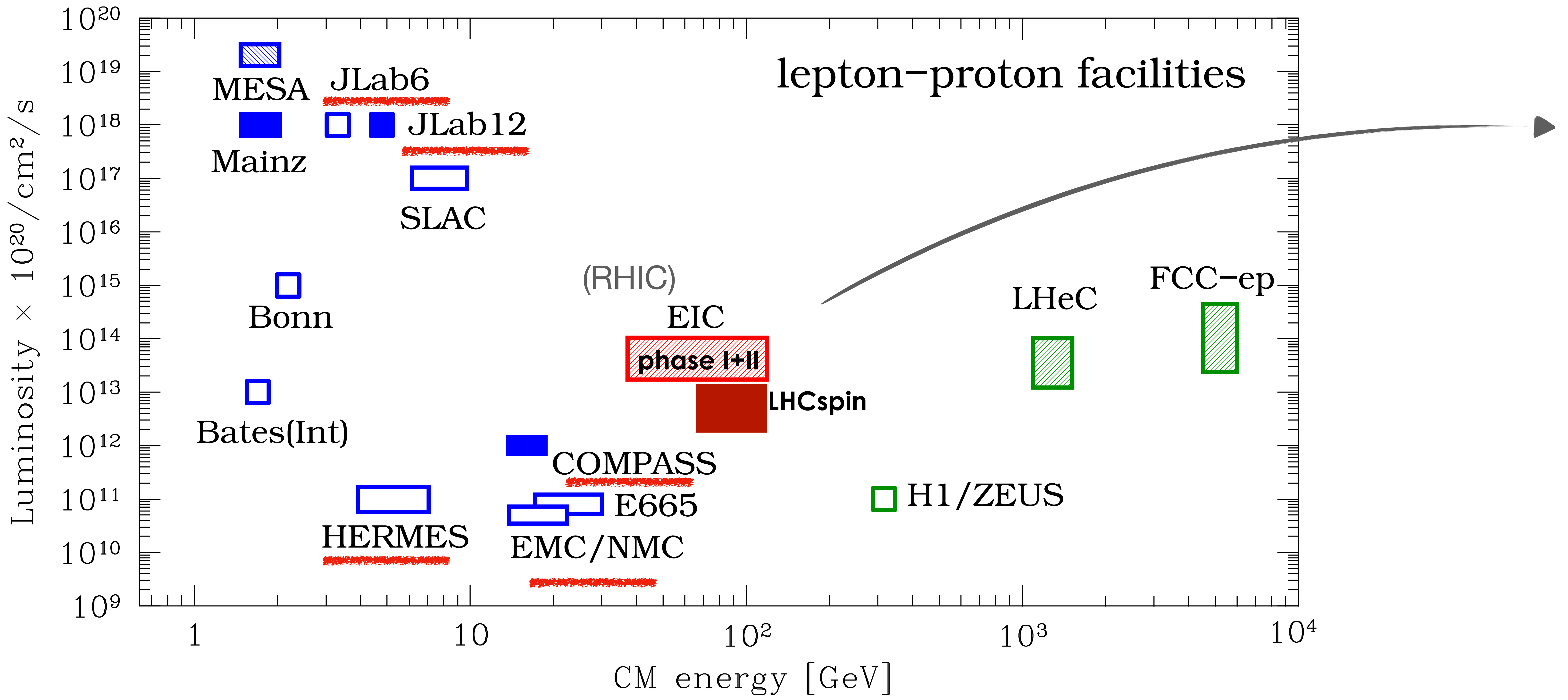


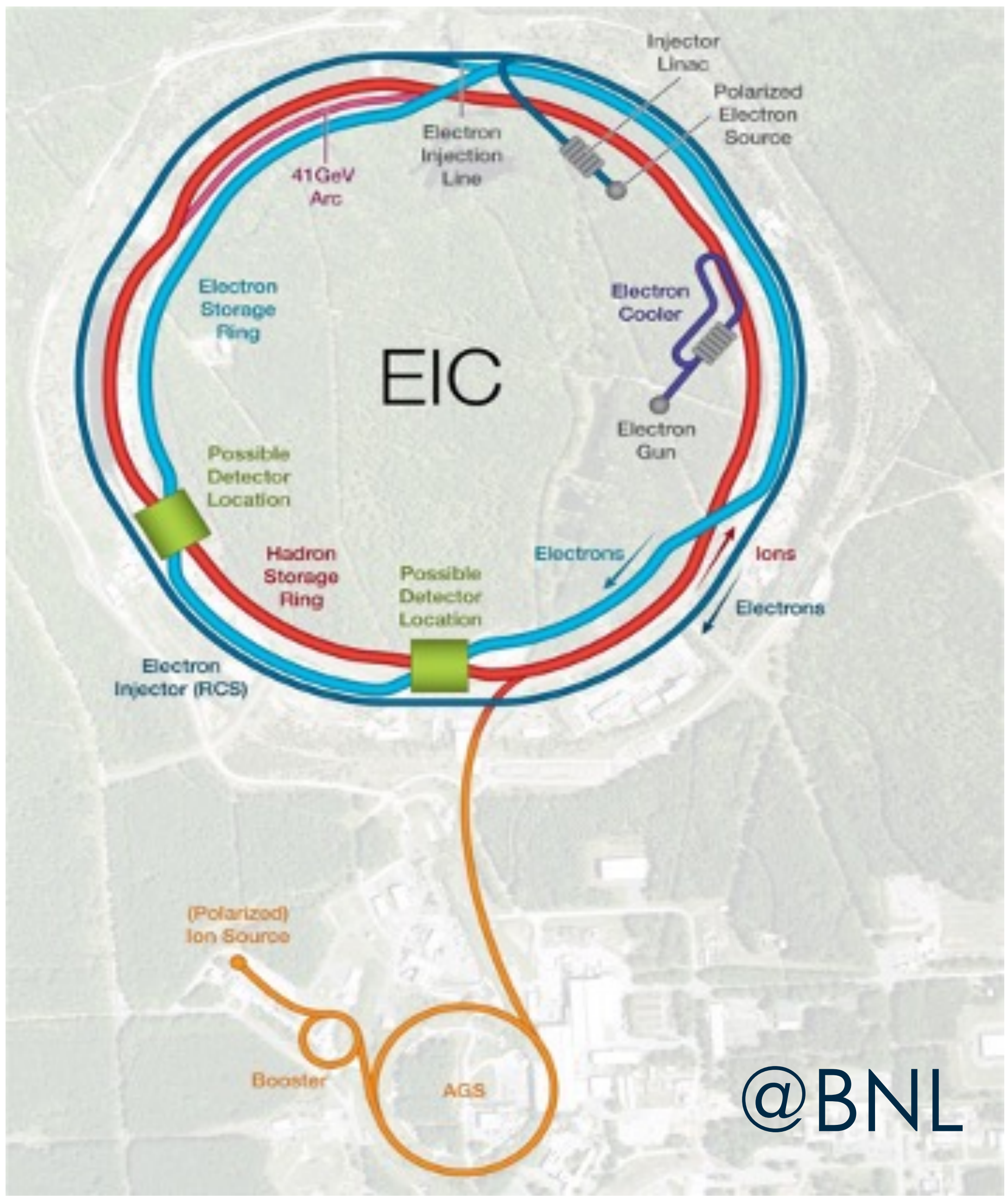


cost 3 B$

What about LHC?

Huge efforts in the past/present … and future

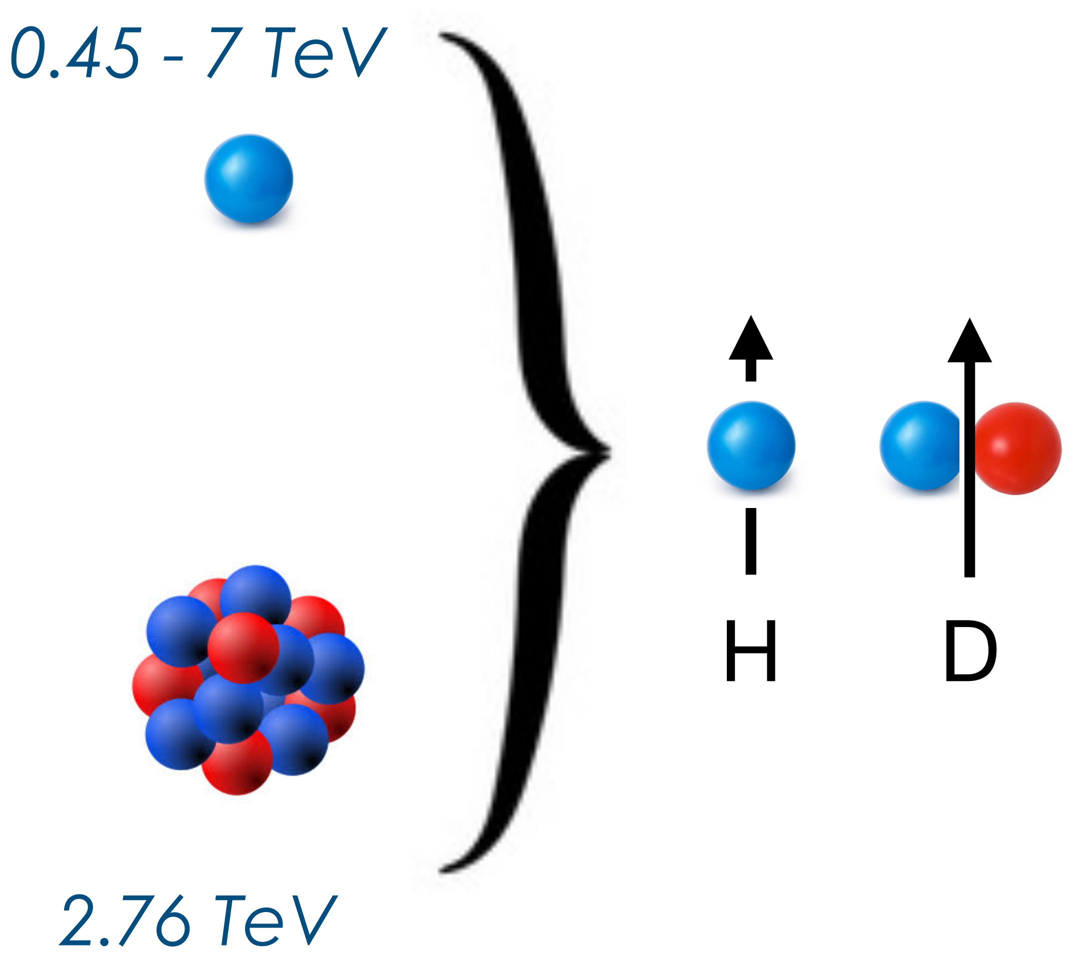




cost 3 B$

What about LHC?

The LHC beams cannot be polarised. The only possibility to have polarised collisions is through a polarised fixed-target



pp collisions: 0.45 - 7 TeV beam on fix target

$$\sqrt{s} = \sqrt{2m_N E_p} \simeq 41 - 115\ GeV$$

$$y_{CMS} = 0 \ \rightarrow \ y_{lab} = 4.8$$

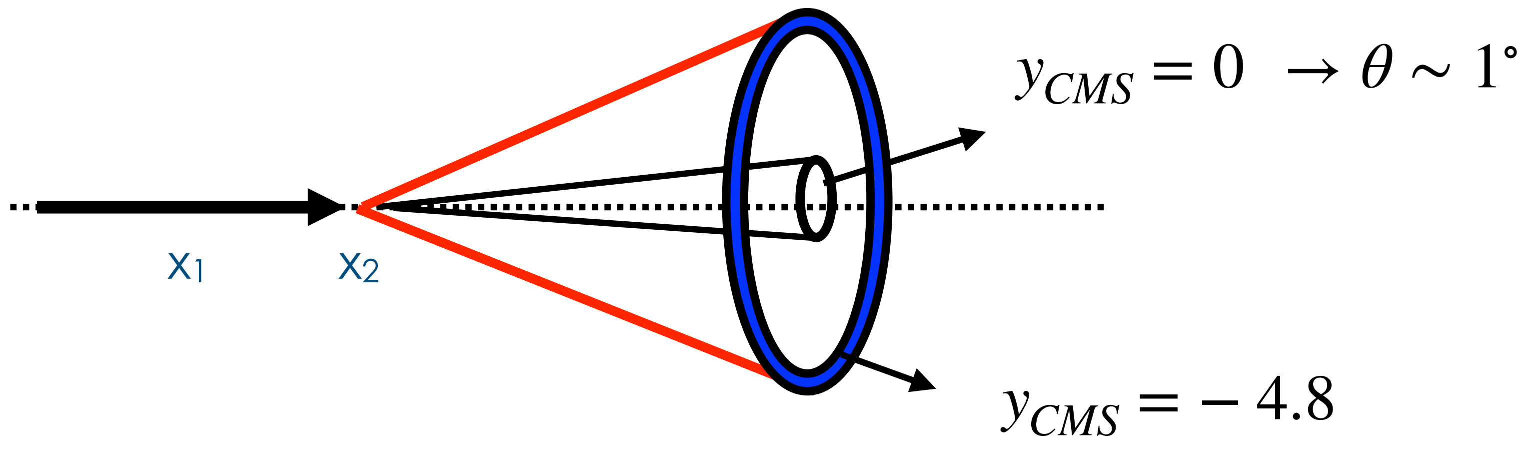
Ap collisions: 2.76 TeV beam on fix target

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

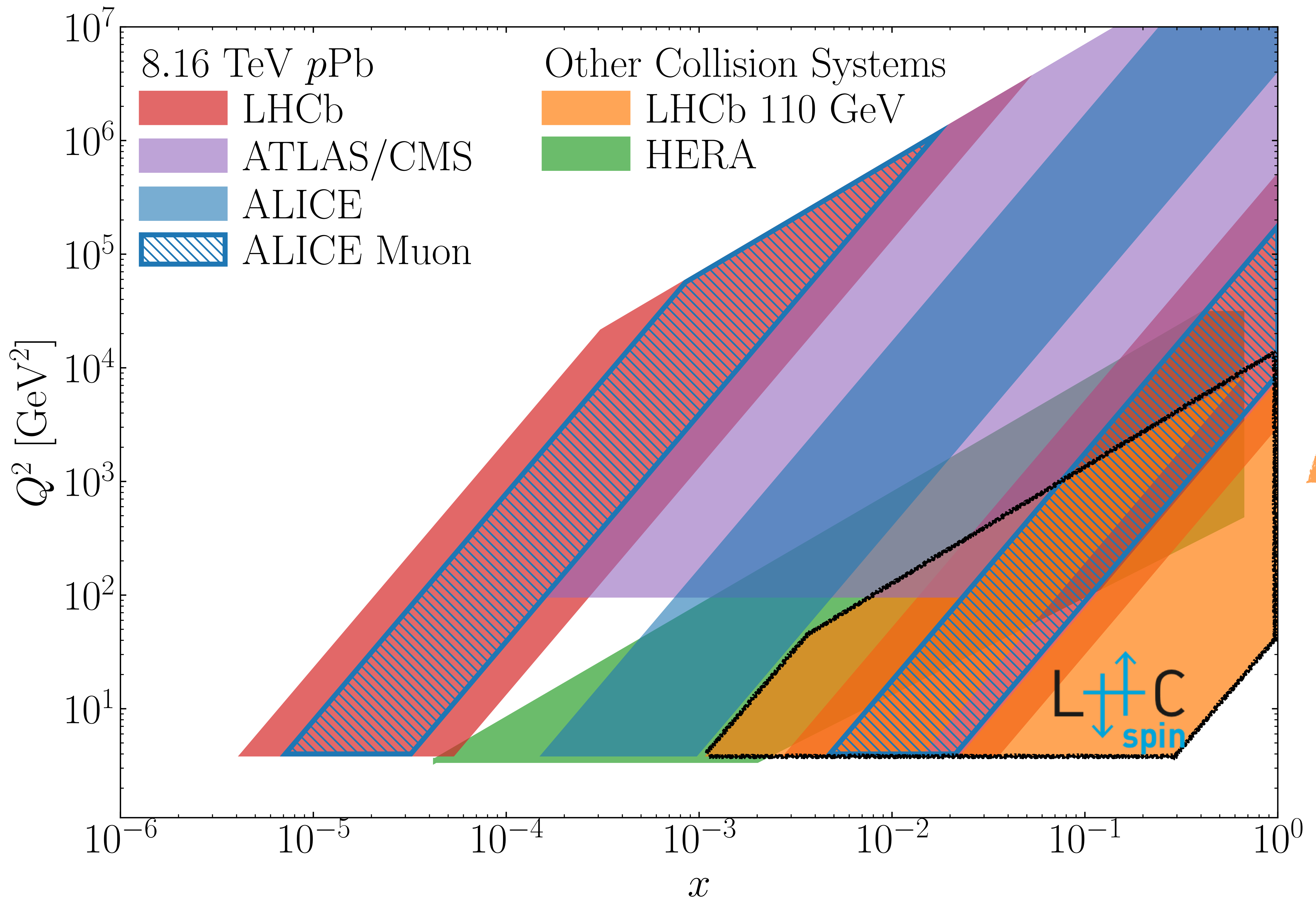
$$y_{CMS} = 0 \ \rightarrow \ y_{lab} = 4.3$$

1: beam; 2: target

Large CM boost, large x_2 values (x_F<0) and small x_1



$$\gamma = \frac{\sqrt{s_{NN}}}{2m_p} \simeq 60$$



Broad and poorly explored kinematic range

The LHCb detector

- LHCb is a general-purpose forward spectrometer, fully instrumented in $2 < \eta < 5$, and optimised for c and b hadron detection
- Excellent momentum resolution with VELO + tracking stations:

$$\sigma_p/p = 0.5 - 1.0\,\% \;(p \in [2{,}200]\ \mathrm{GeV})$$

- Particle identification with RICH+CALO+MUON

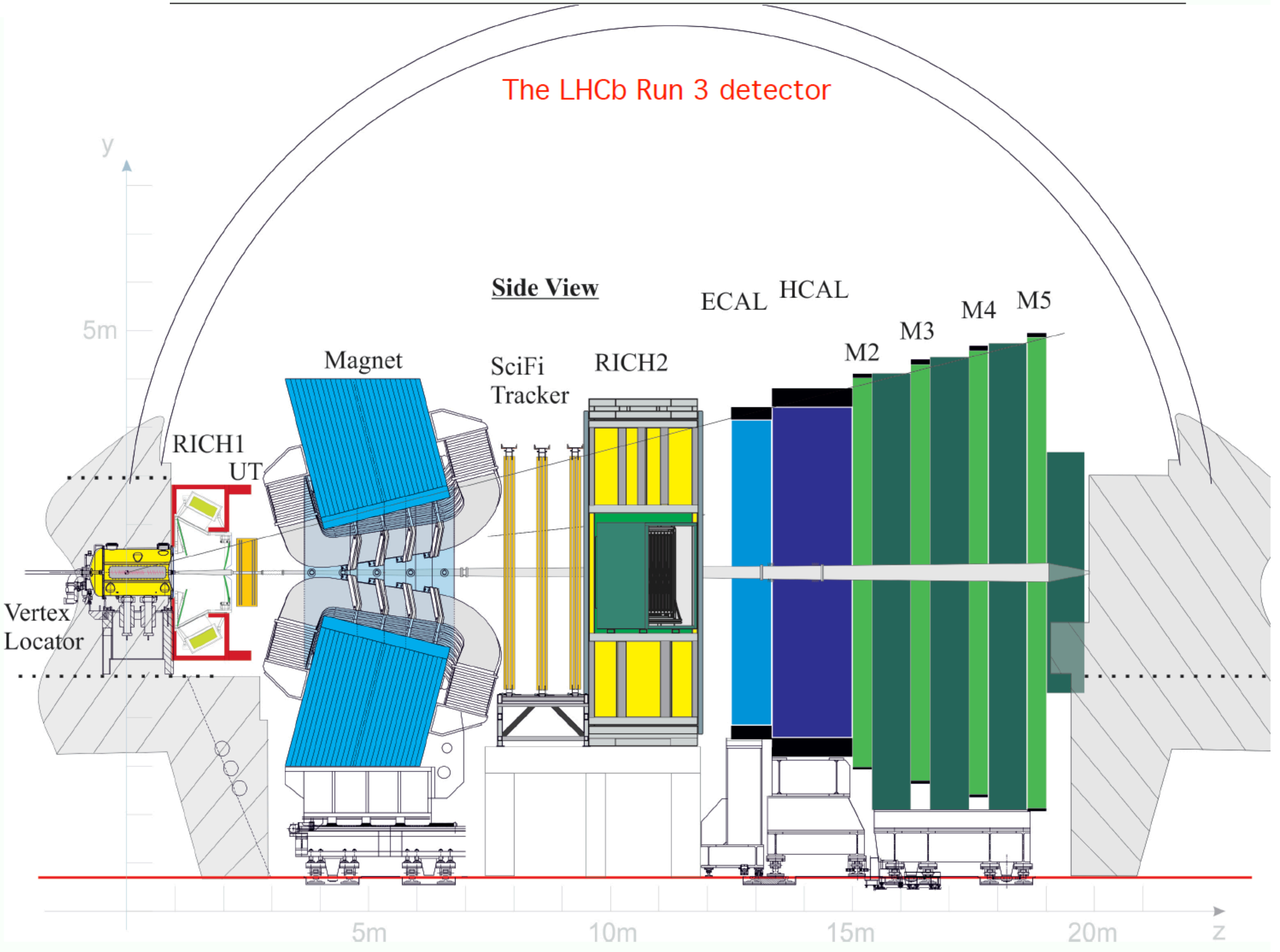
$\epsilon_\mu \sim 98\,\%$ with $\epsilon_{\pi \to \mu} \lesssim 1\,\%$

- Low momentum muon trigger:

$$p_{T_\mu} > 1.75\ \mathrm{GeV}\ (2018)$$

will be reduced thanks to the new fully-software trigger

- Major detector upgrades performed during LS2 for the Run 3 (5x luminosity)



[JINST 3 (2008) S08005]

[IJMP A 30, 1530022 (2015)]

[Comput Softw Big Sci 6, 1 (2022)]

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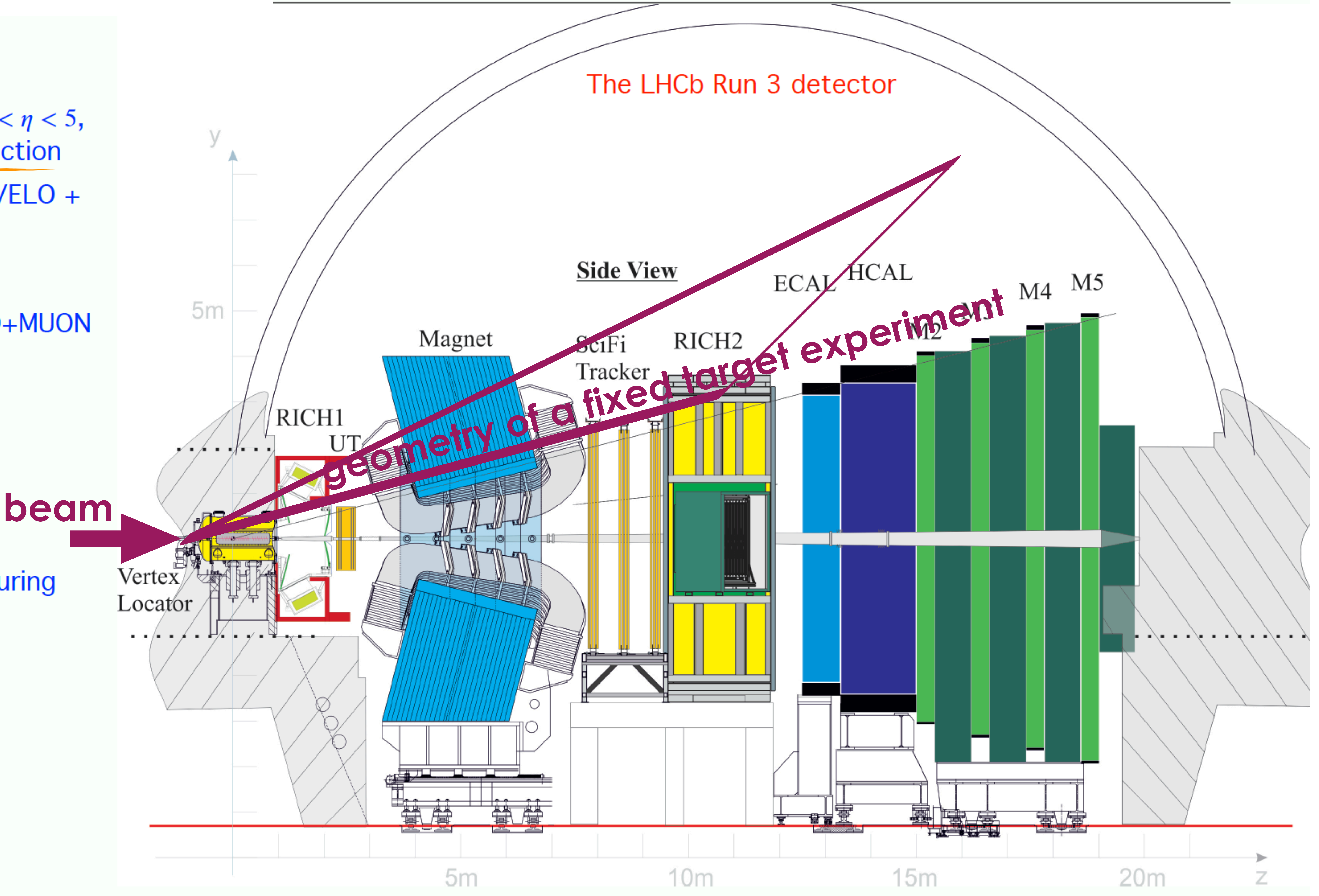


[JINST 3 (2008) S08005]

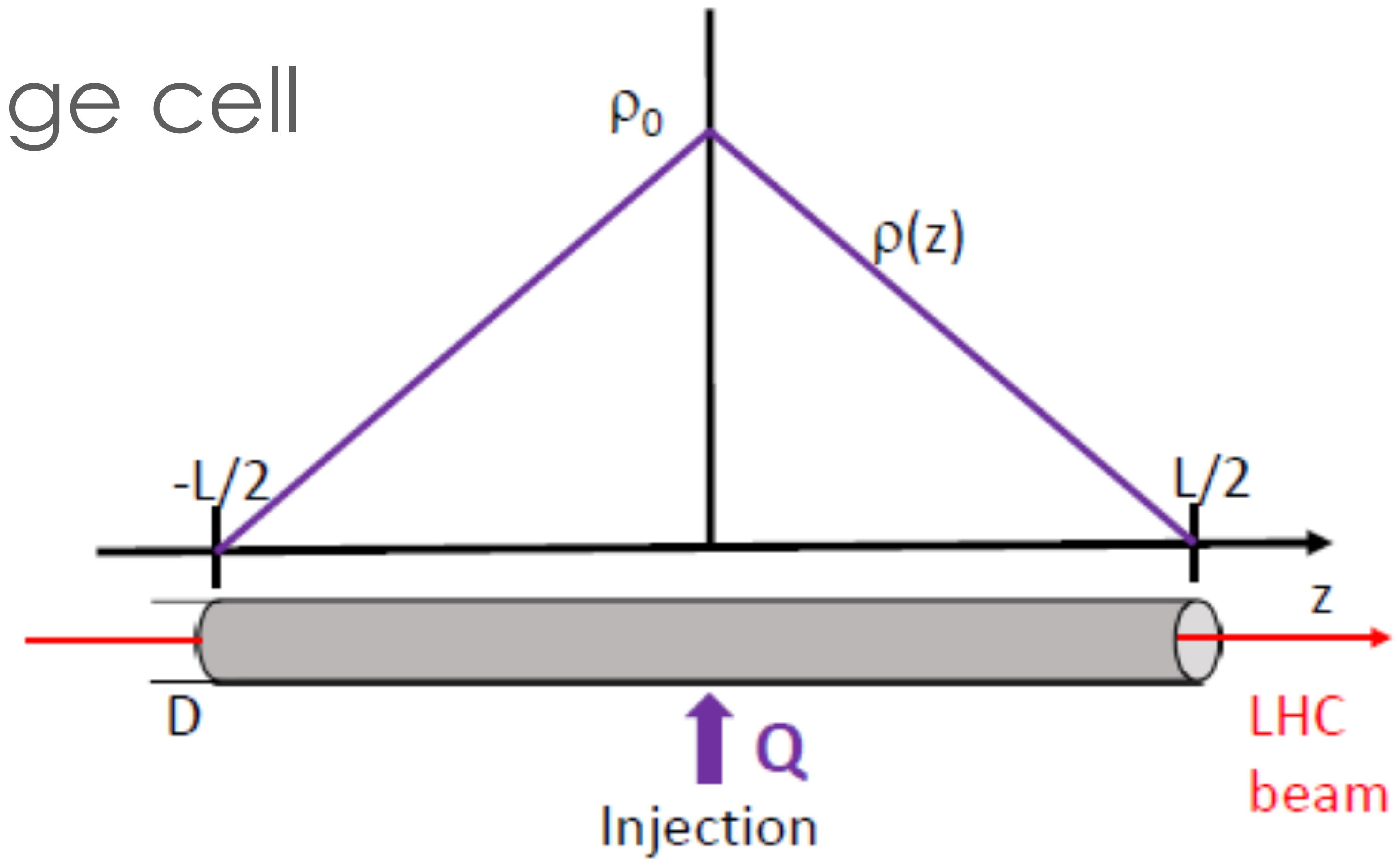
[IJMP A 30, 1530022 (2015)]

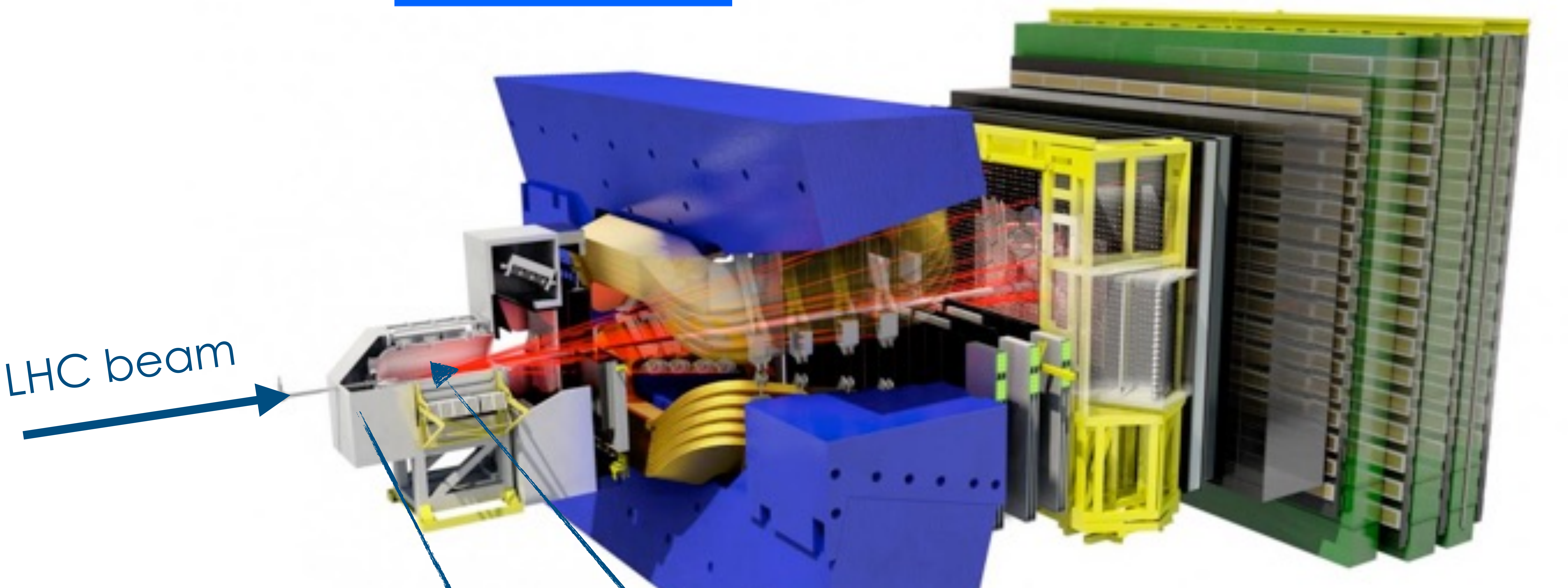
[Comput Softw Big Sci 6, 1 (2022)]

SMOG2 an unpolarized target at LHCb

JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

Storage cell

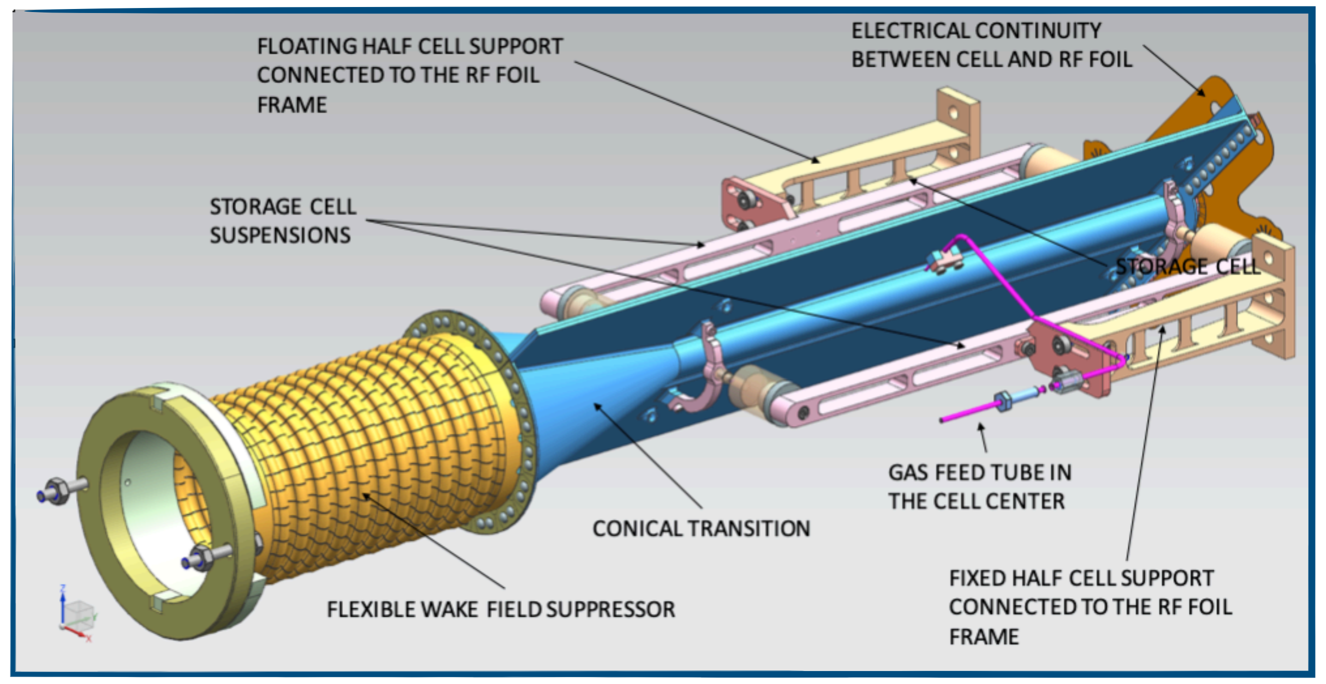


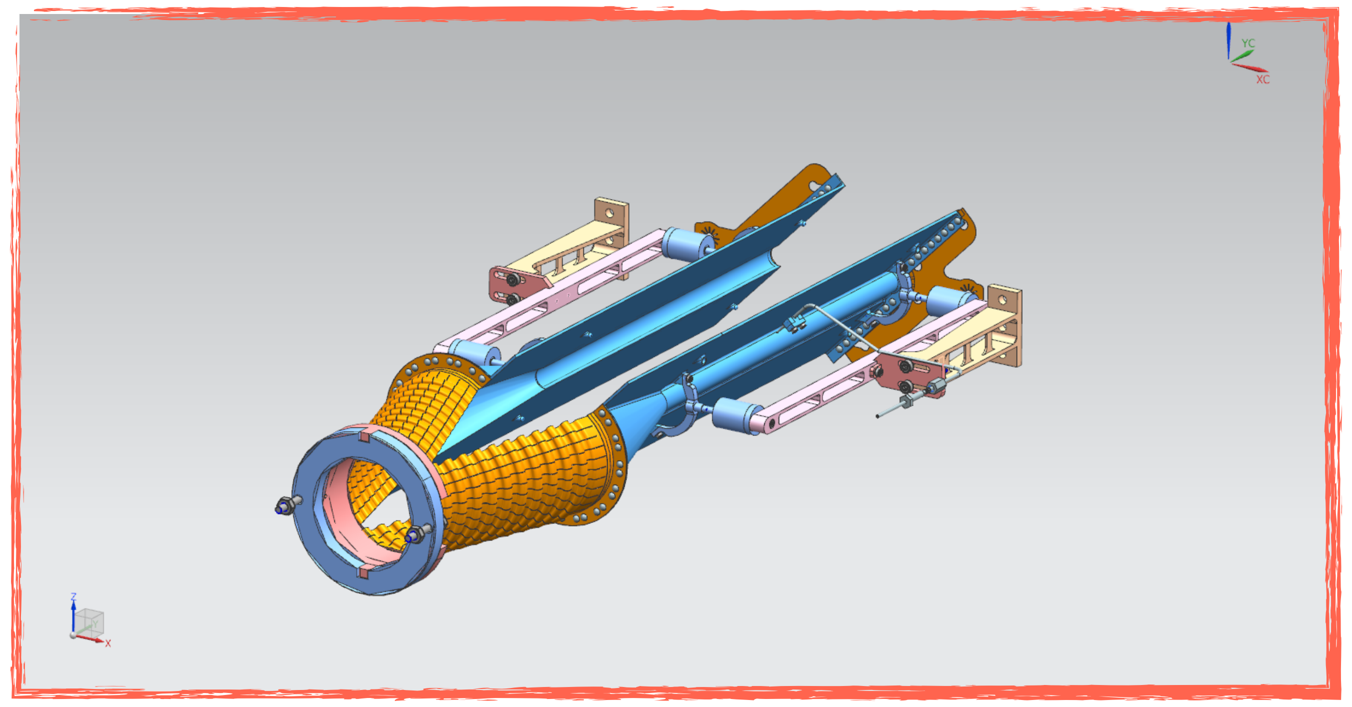


Forward acceptance: $2 < \eta < 5$

Tracking system momentum resolution
$\Delta p/p$ = 0.5%–1.0% (5 GeV/c – 100 GeV/c)

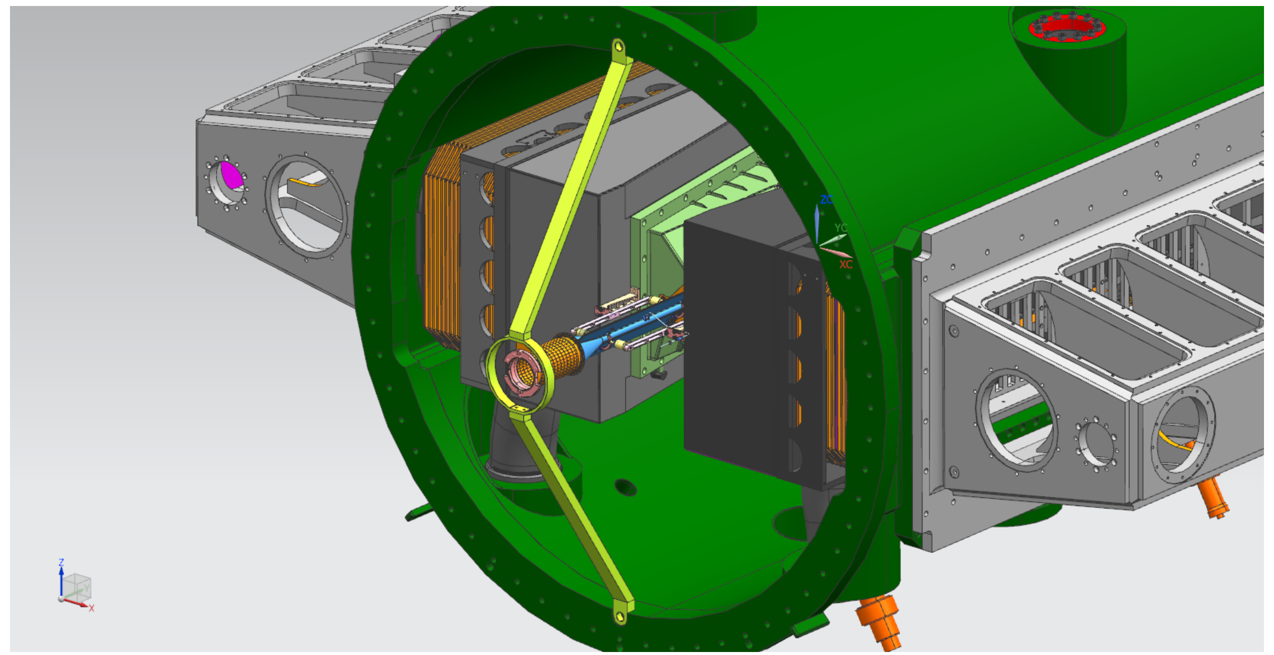
Openable cell





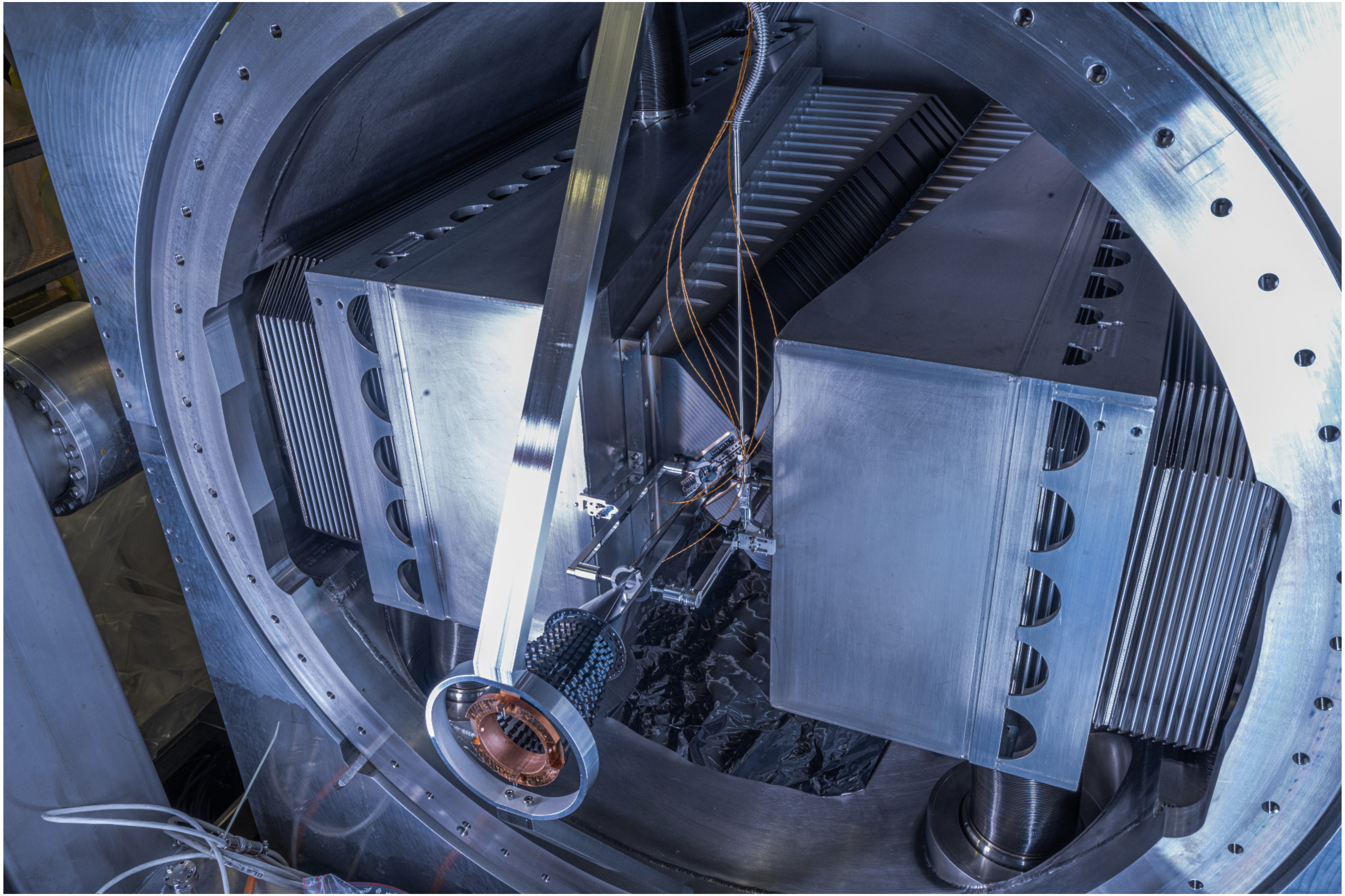
5 mm radius x 200 mm length

beam-beam collisions



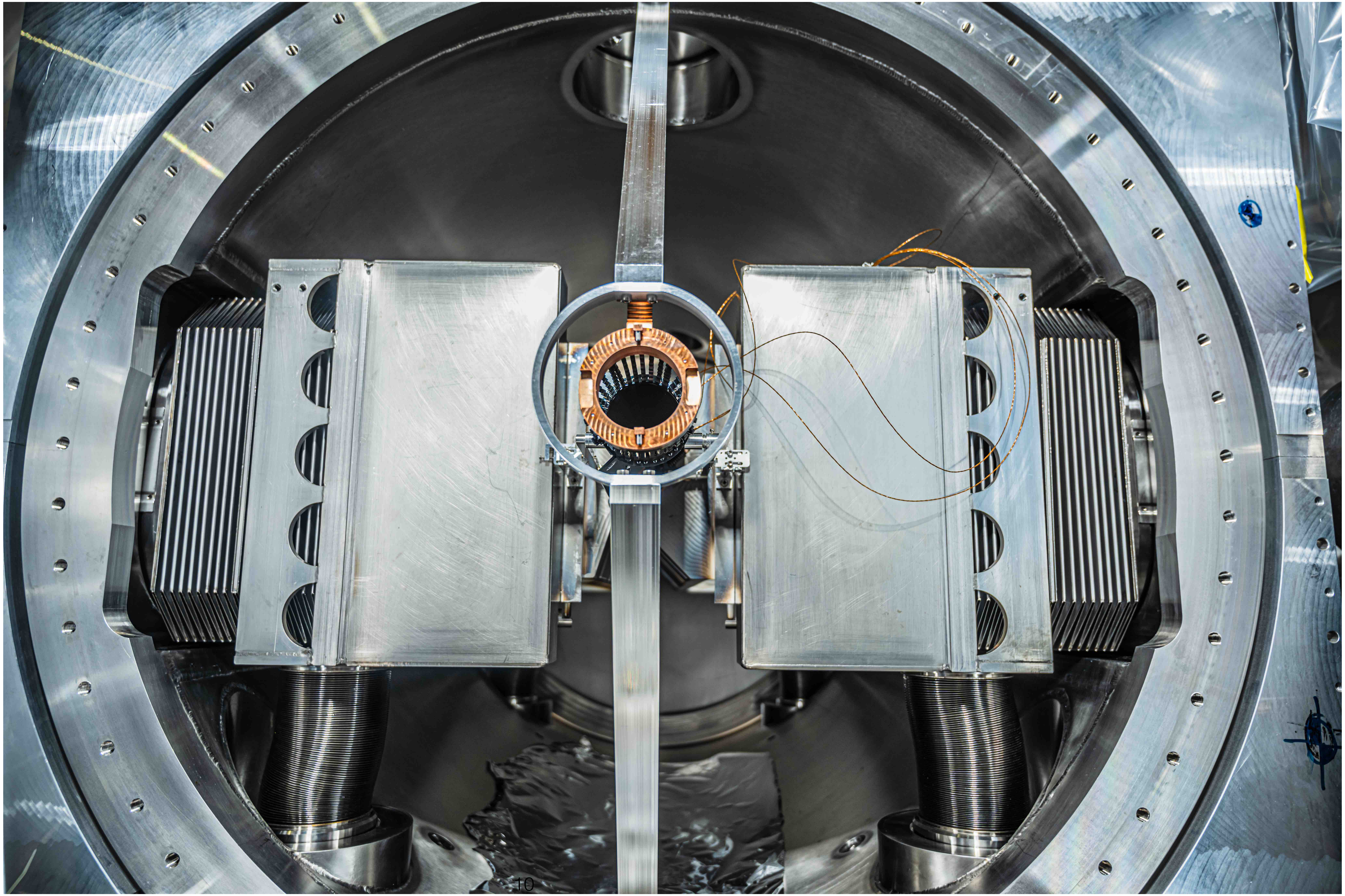
beam-gas collisions

SMOG2



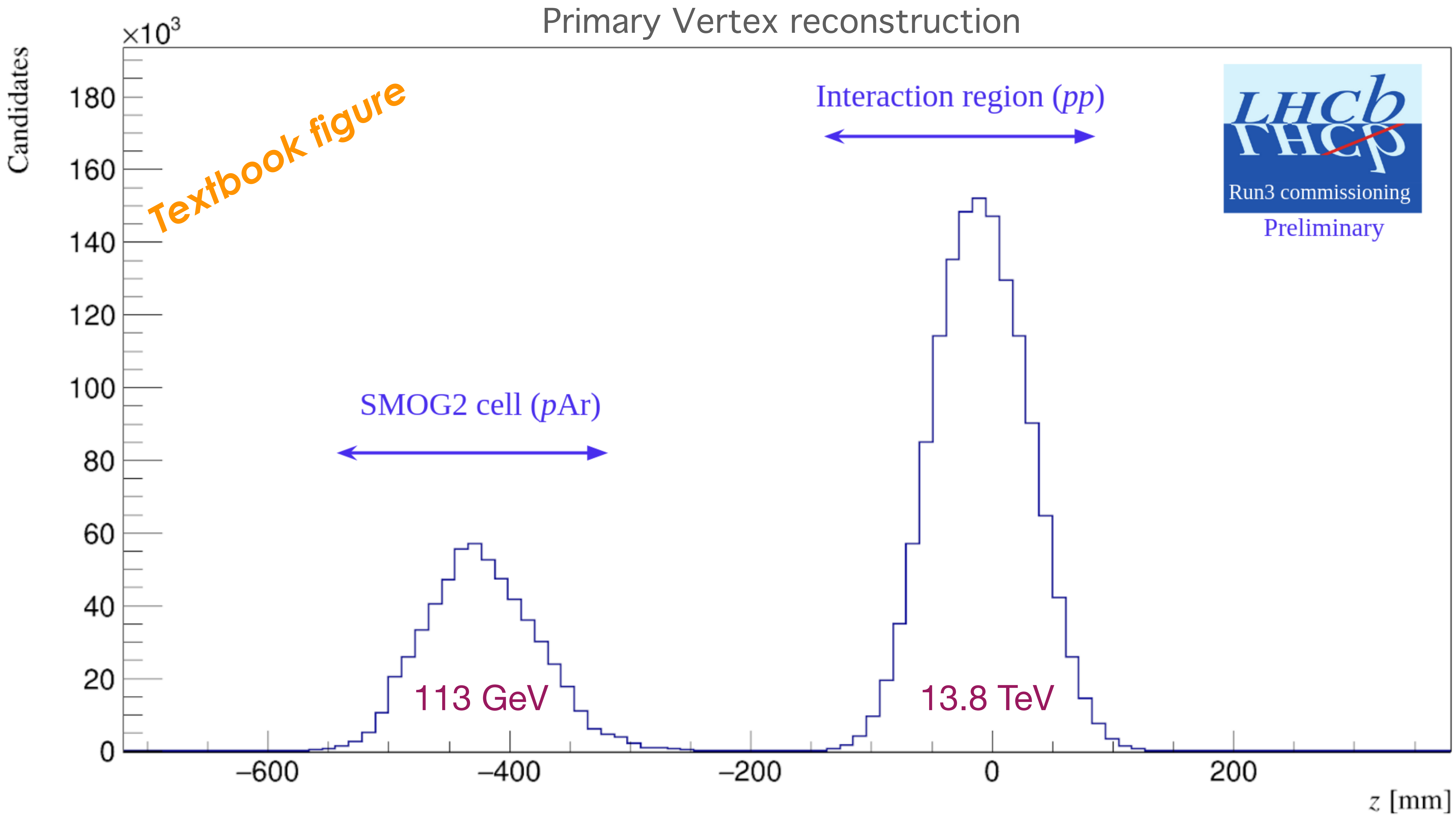
It is the only system present in the LHC primary vacuum

SMOG2



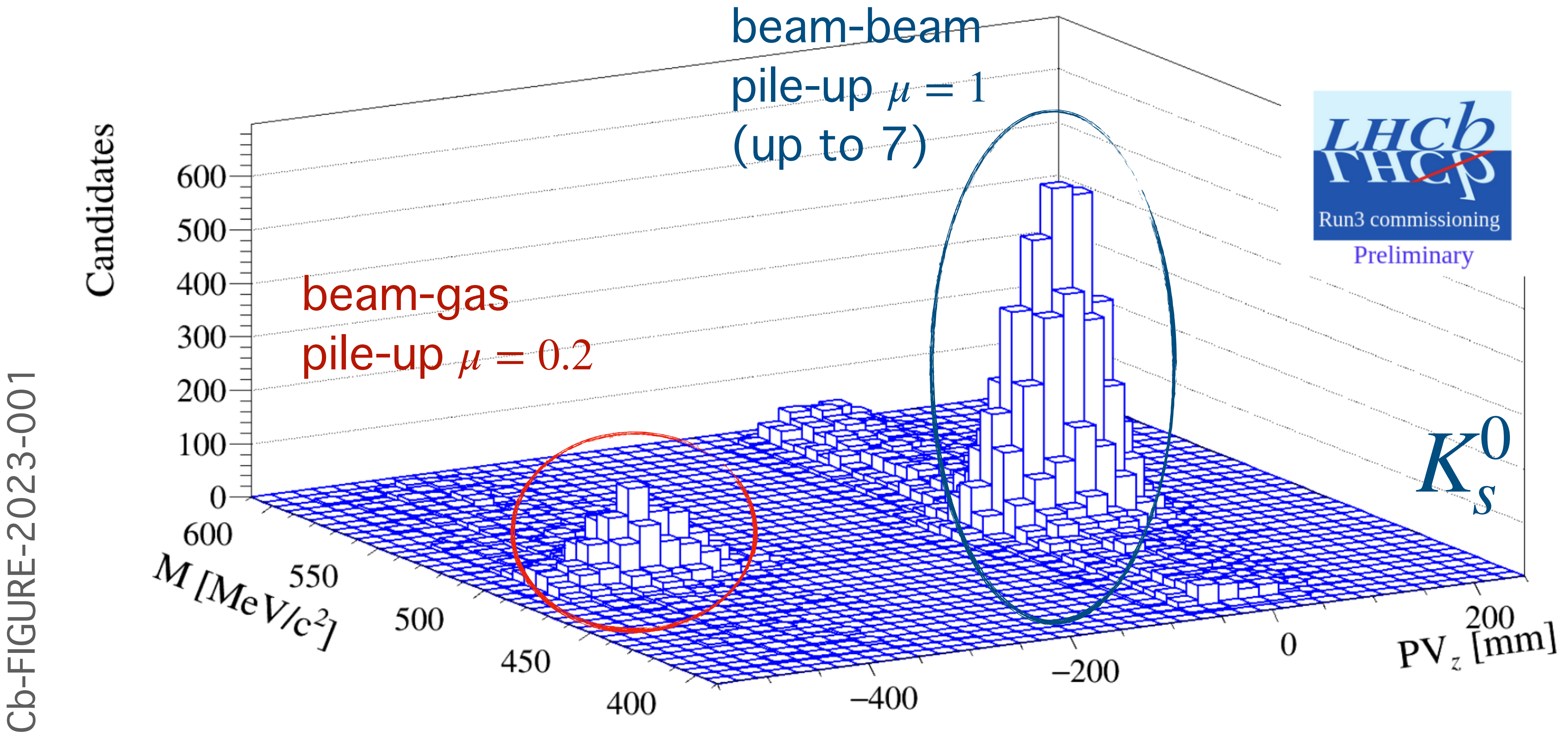
It is the only system present in the LHC primary vacuum

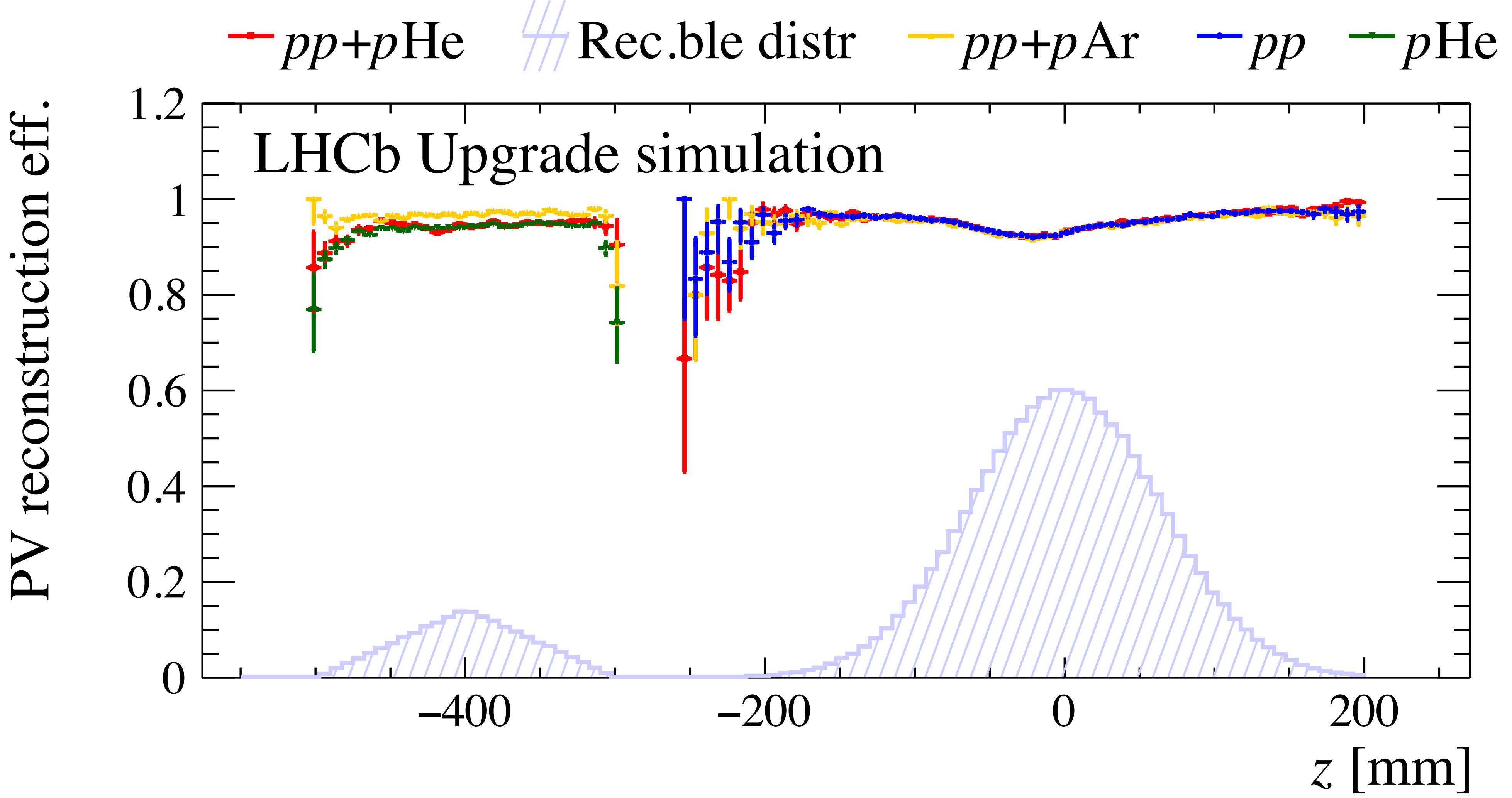
SMOG2 ... wow-factor!

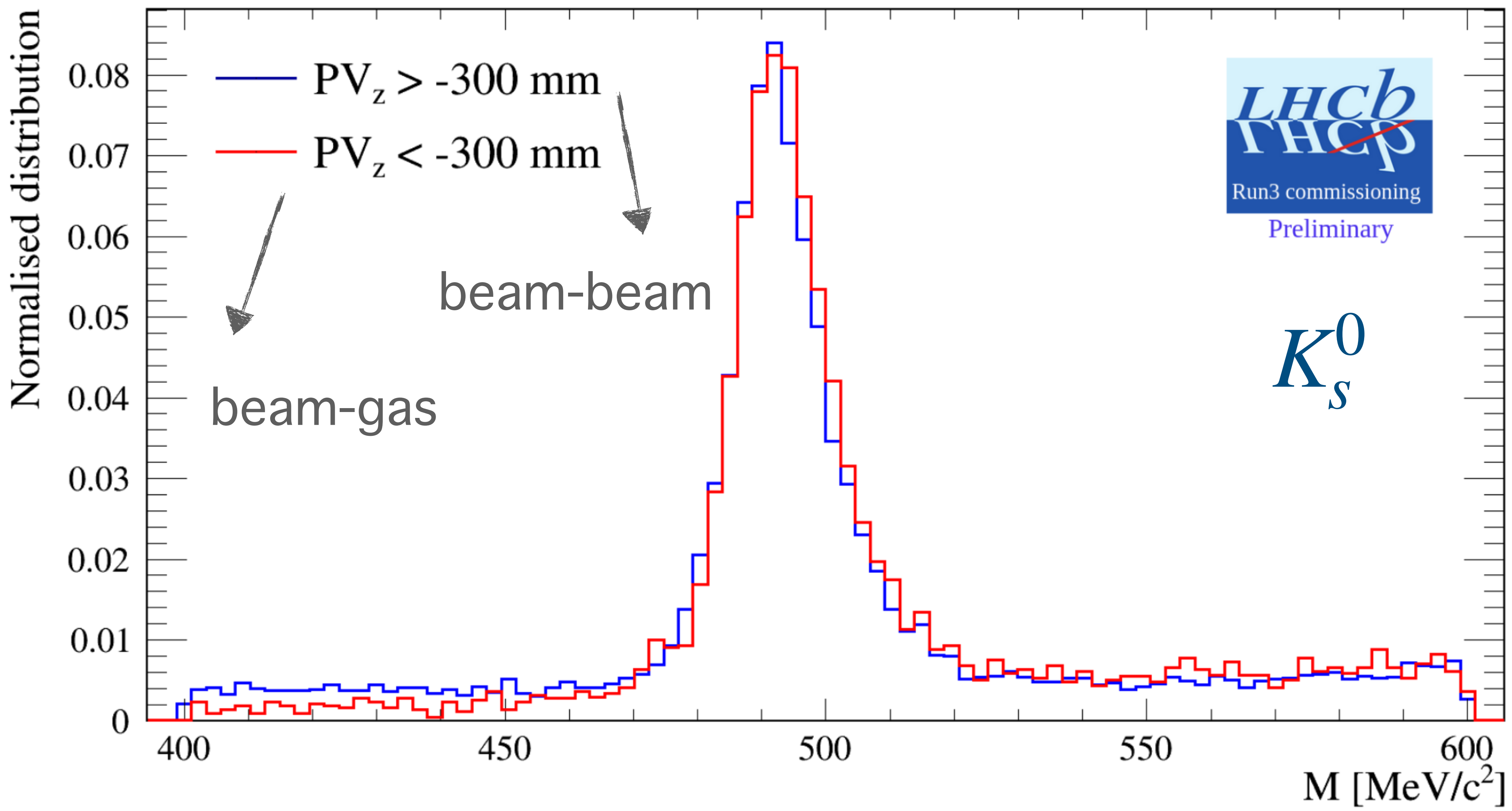


Two well separated and independent Interaction Points working simultaneously

SMOG2 … wow-factor!



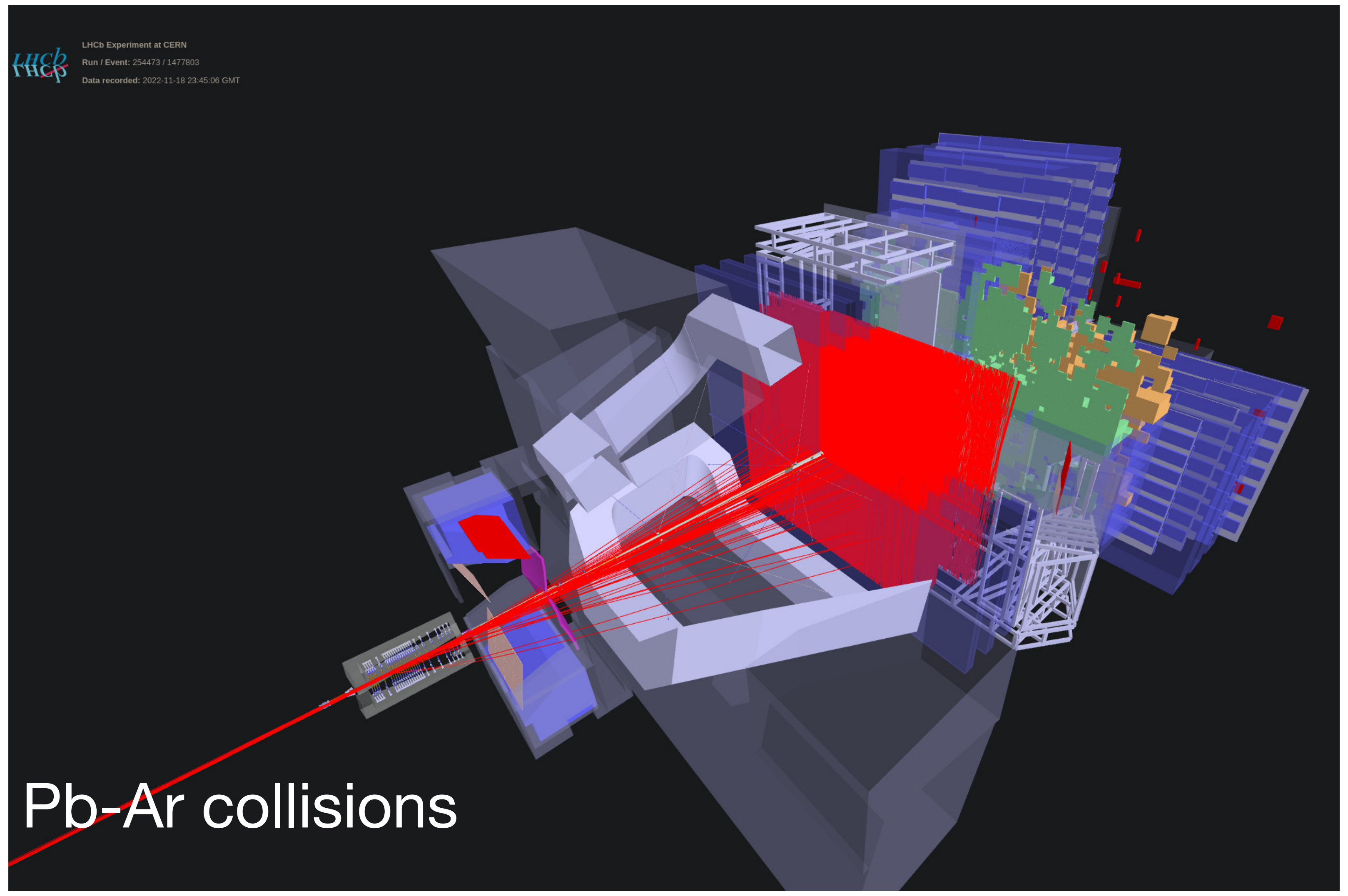


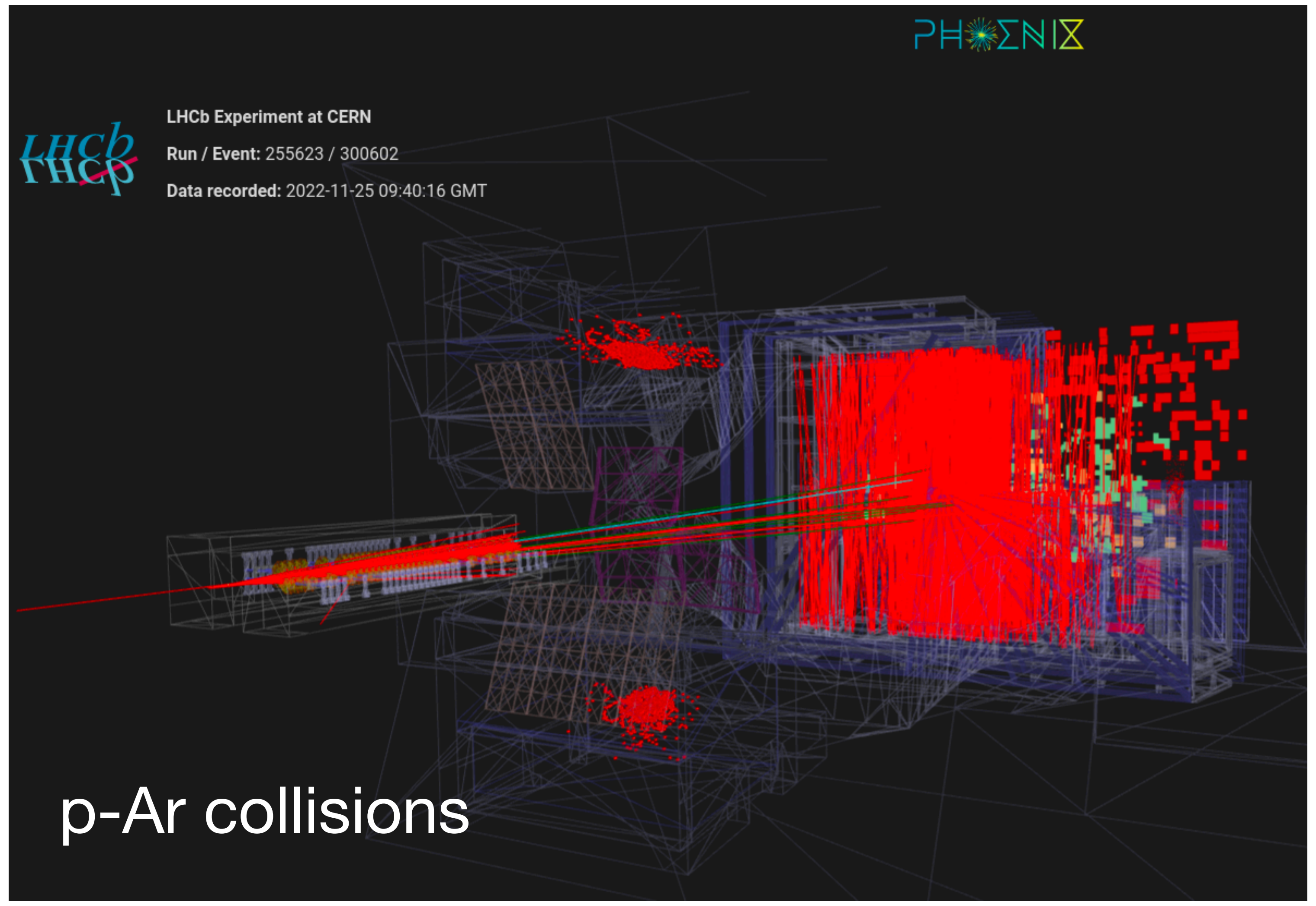


- beam-beam and beam-gas interactions are well detached
- same resolution for beam-gas and beam-beam collisions

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

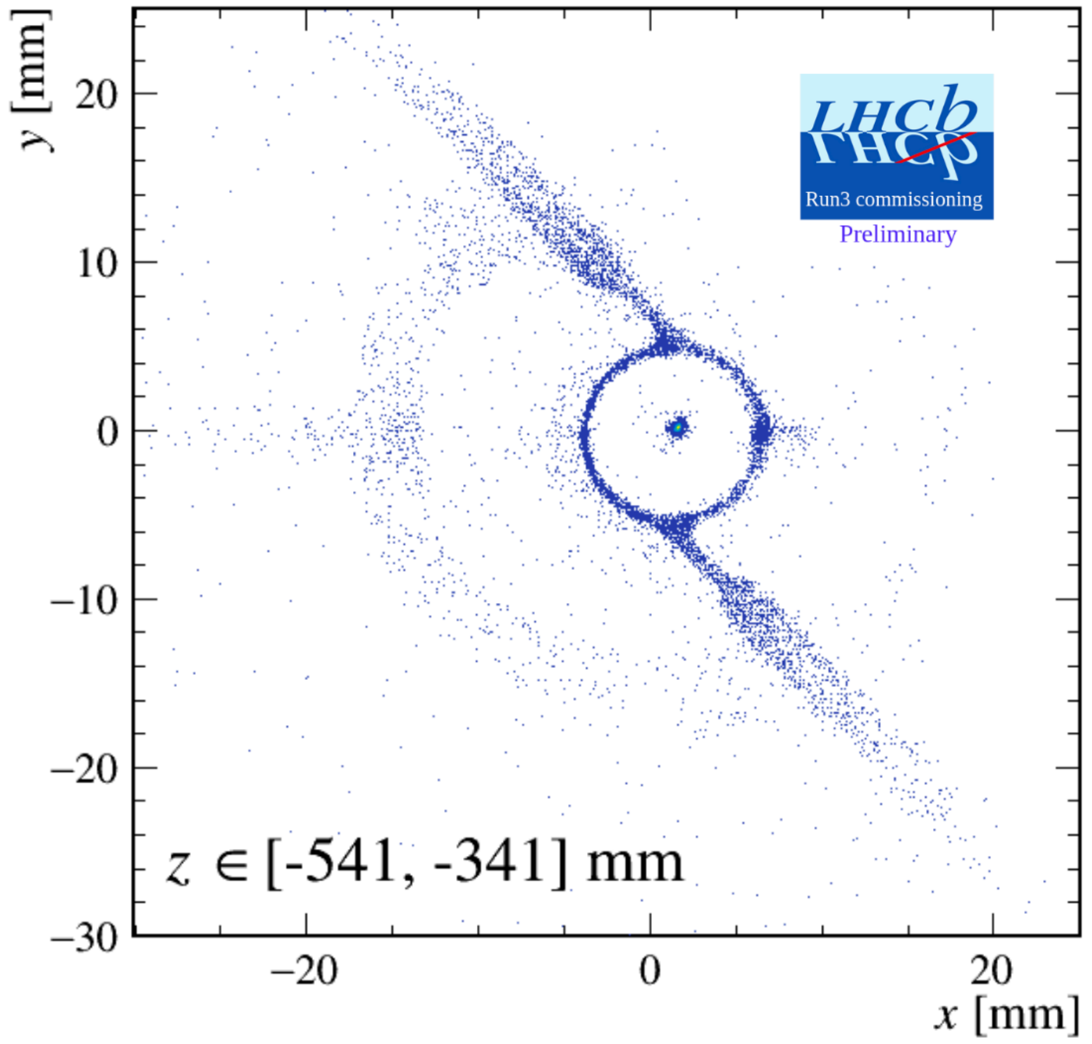
SMOG2 *early data*



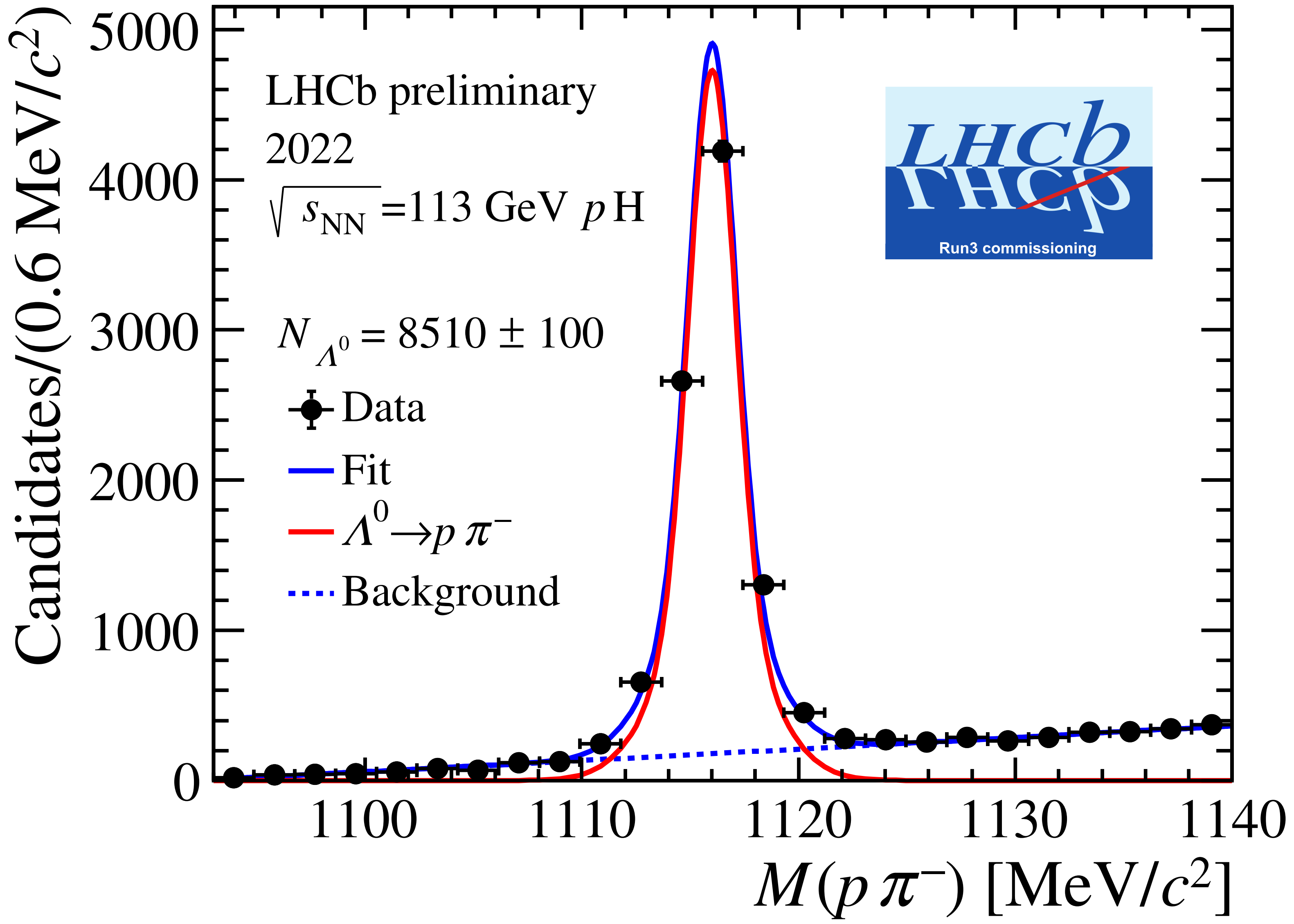


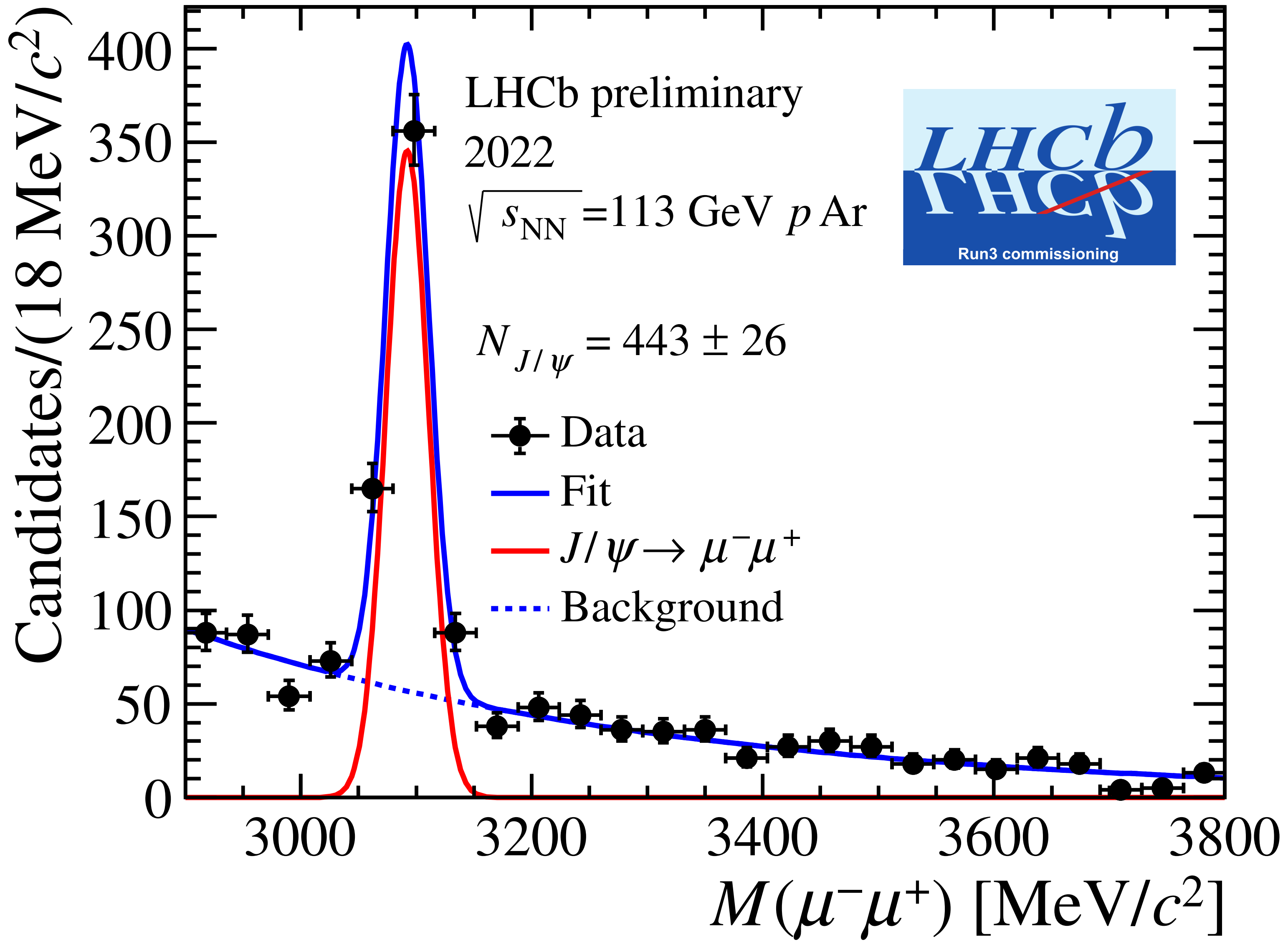
tomography of the cell from residual gas & secondary interactions

2D



3D





LHCb-FIGURE-2023-008

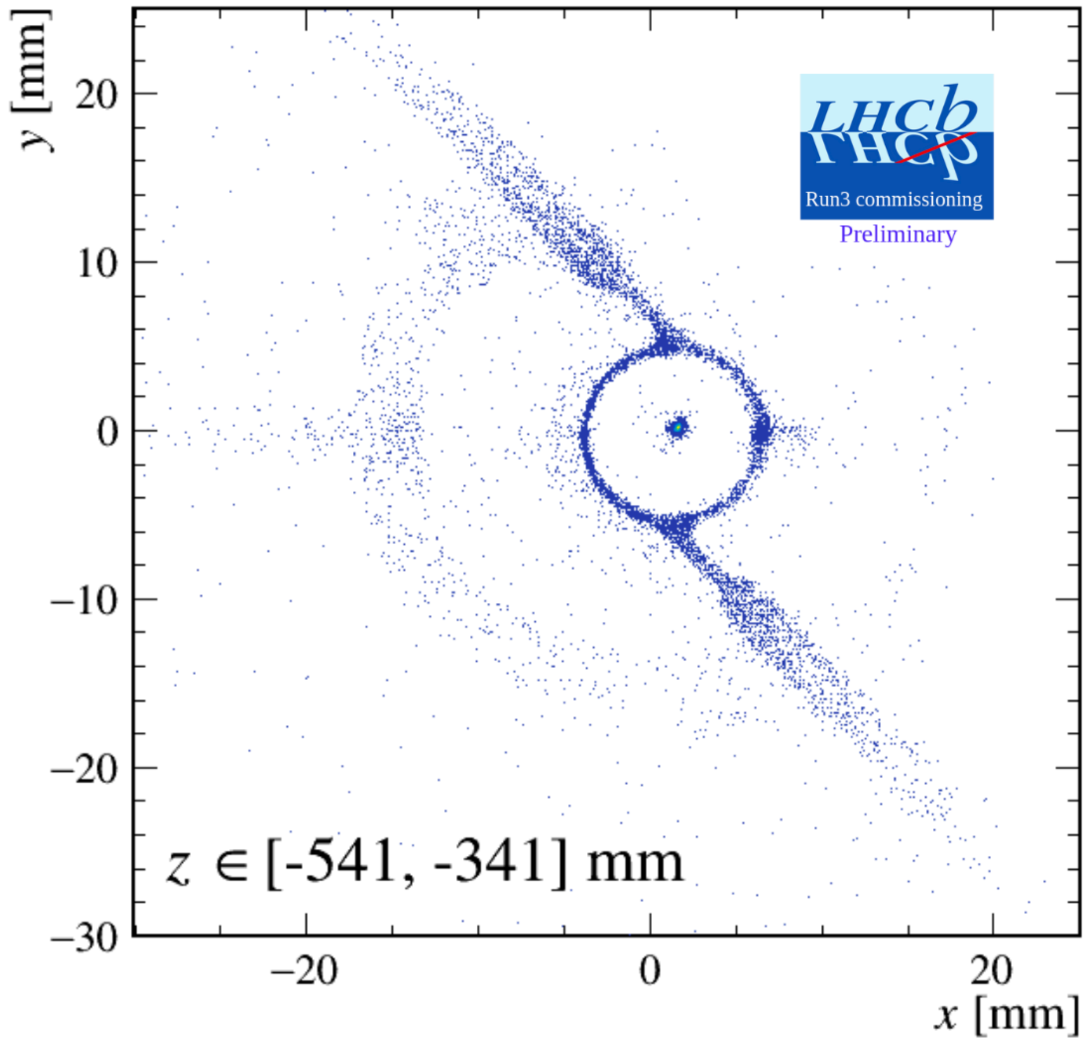
excellent results in 18 minutes of data taking, albeit low gas pressure & preliminary sub-detector performance as we were commissioning them

LHCb-FIGURE-2023-001

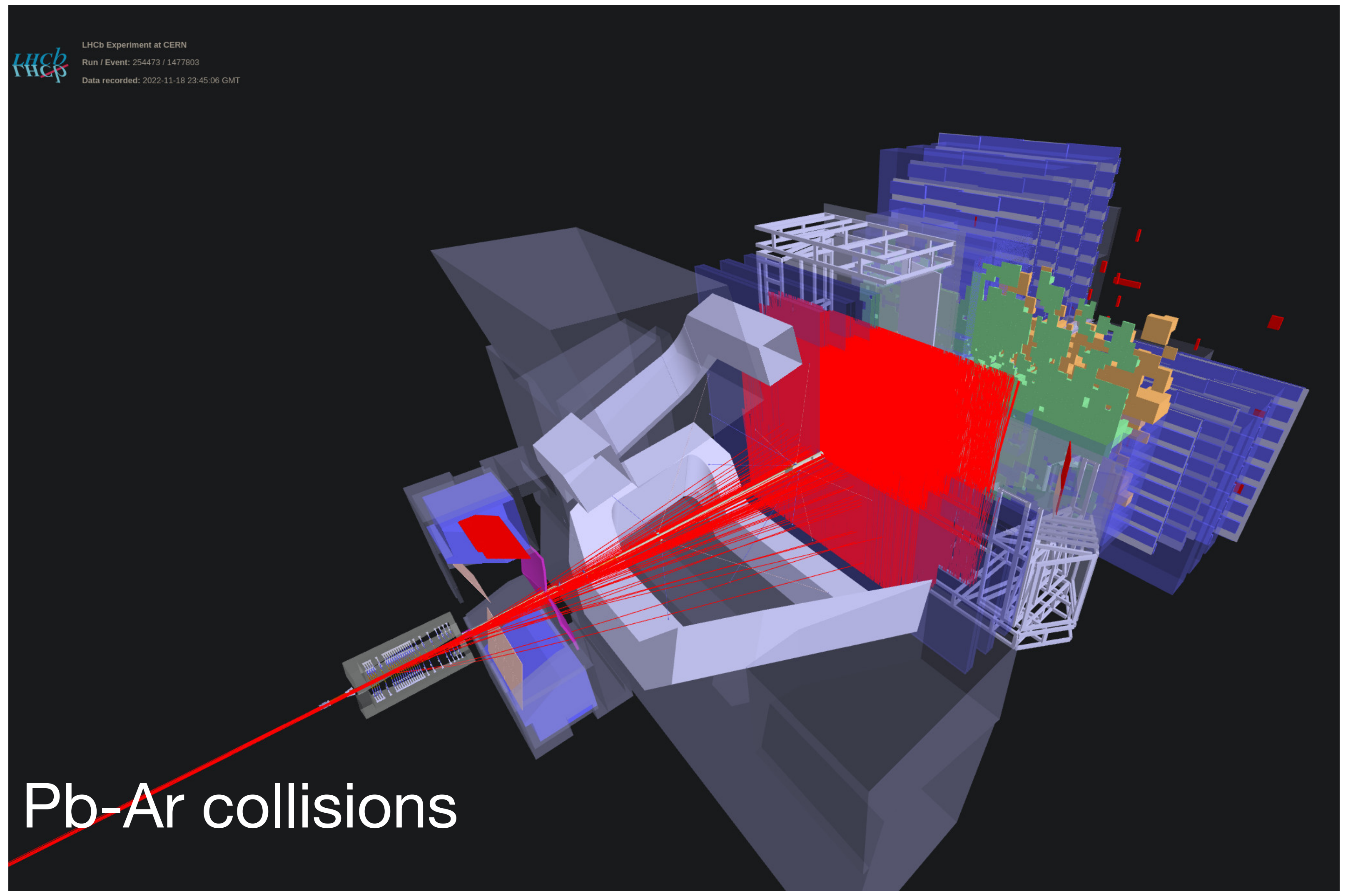
SMOG2 early data

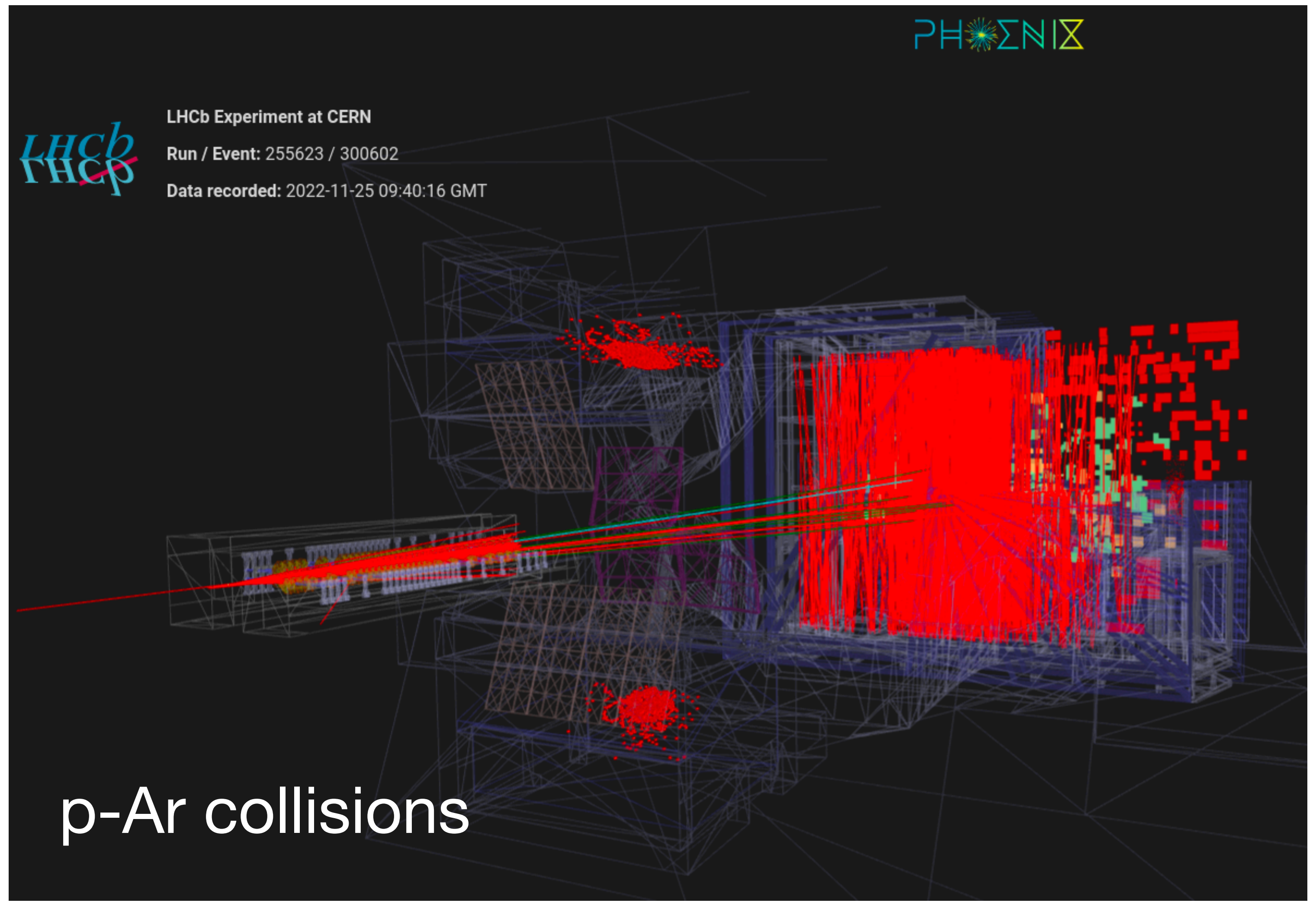
tomography of the cell from residual gas & secondary interactions

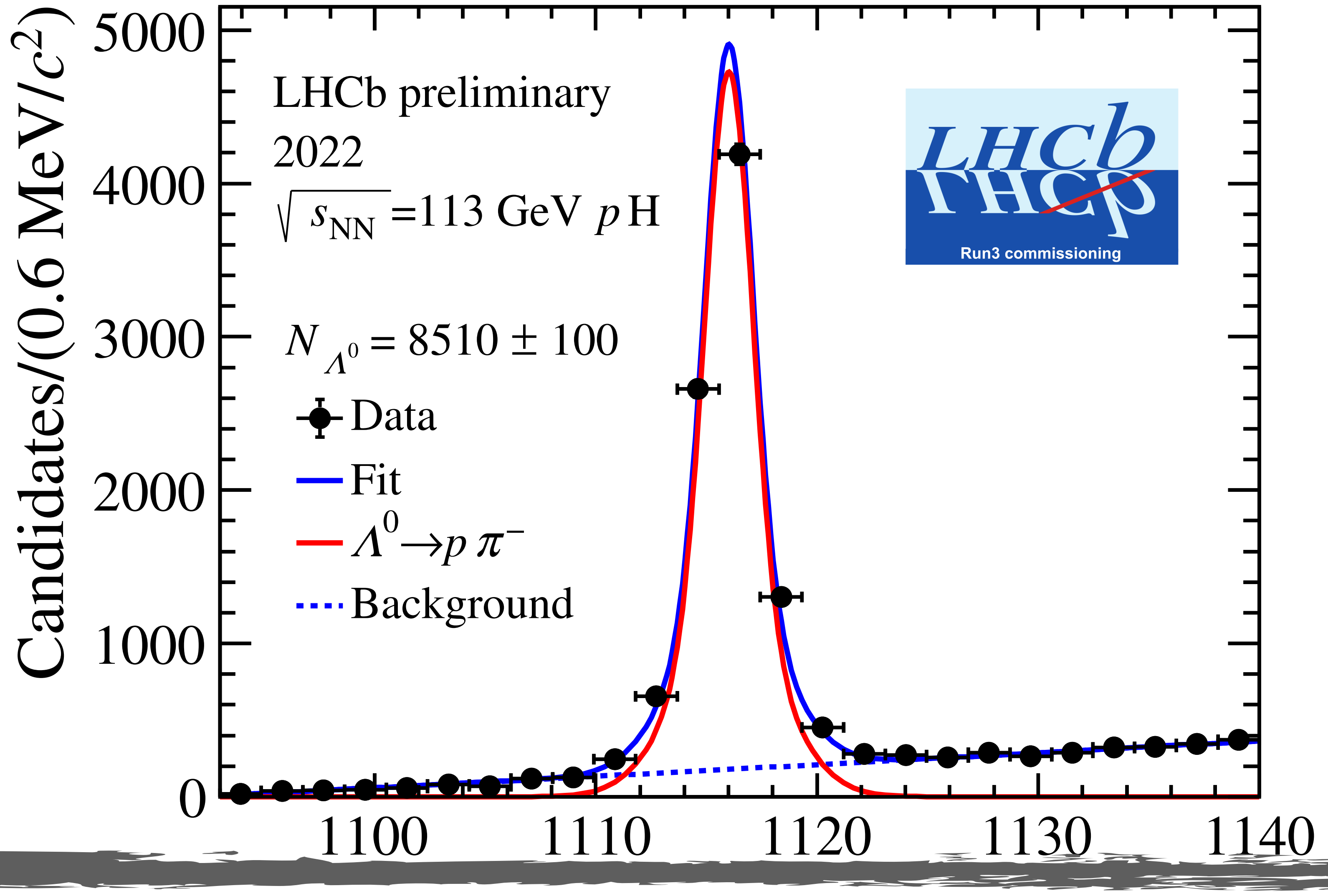
2D

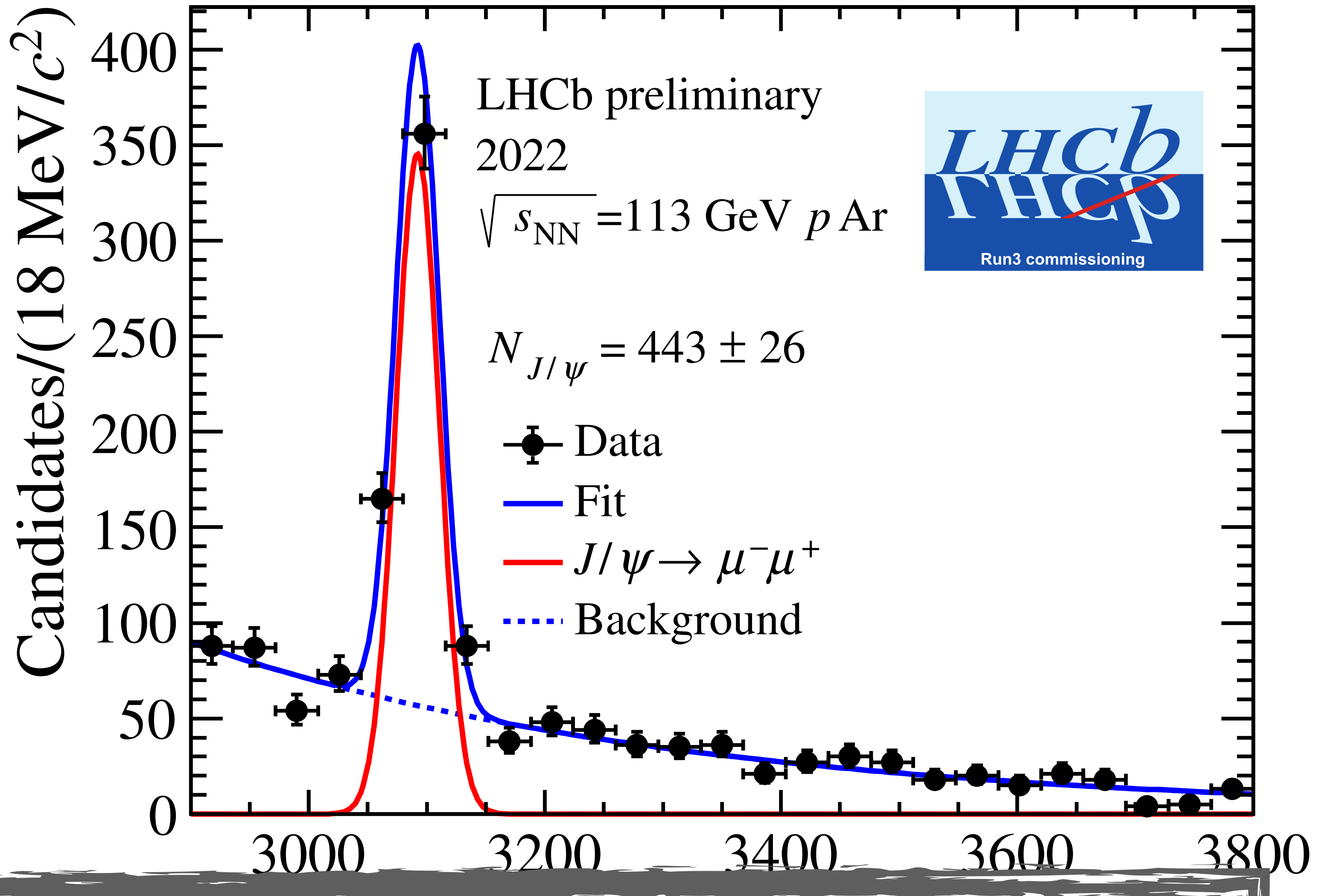


3D









LHCb-FIGURE-2023-008

Thumb rule: in 2023, LHCb reconstructs ~100 J/Ψ particles per minute (after background subtraction) from SMOG2 collisions

The physics goals of LHC spin

- Multi-dimensional nucleon structure in a poorly explored kinematic domain
- Measure experimental observables sensitive to both **quarks and gluons TMDs**
- **Make use of new probes (charmed and beauty mesons)**
- Complement present and future SIDIS results
- Test non-trivial process dependence of quarks and (especially) gluons TMDs
- Measure exclusive processes to access GPDs

Talk of Luciano Pappalardo at 2 pm

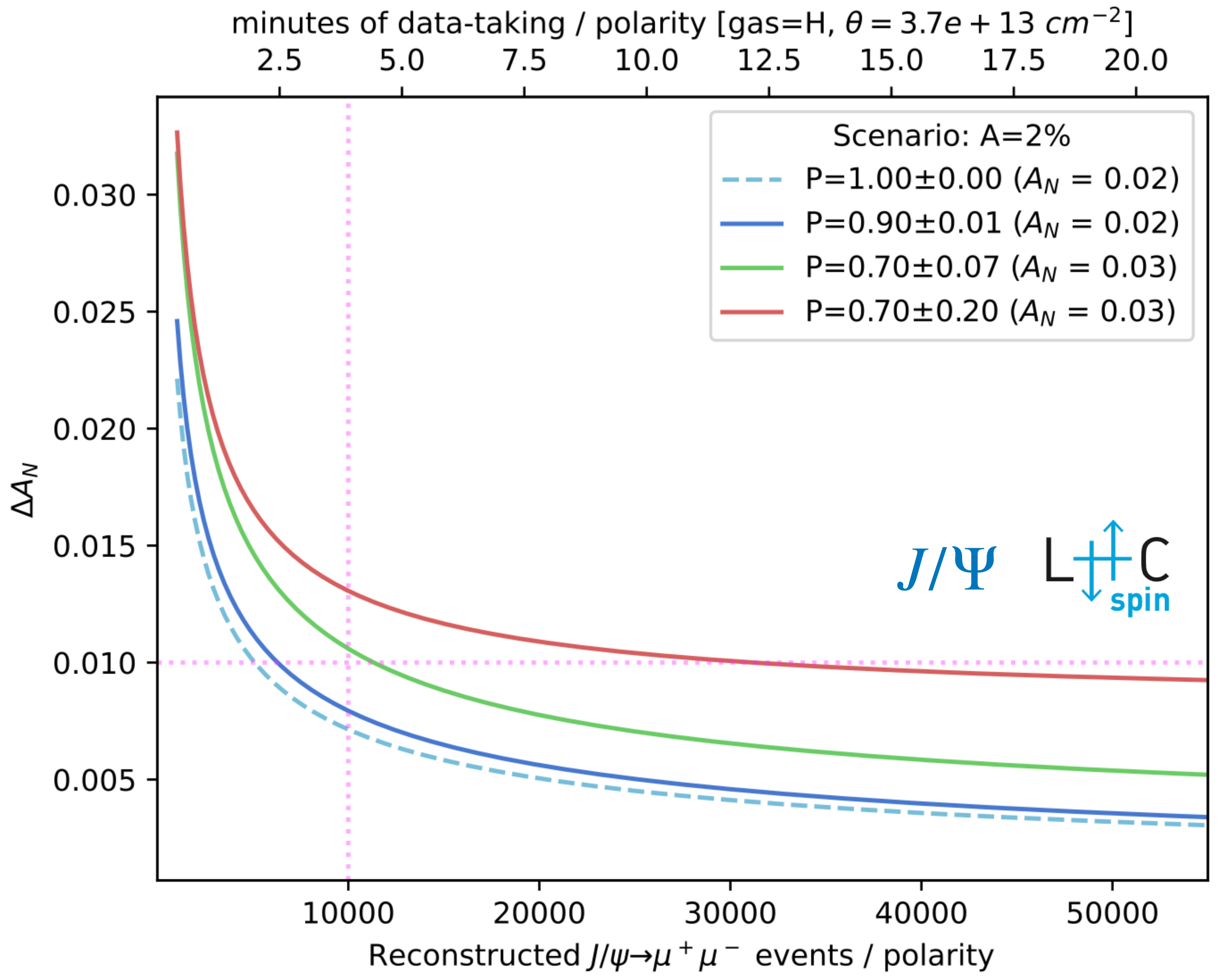
LHCspin event rates

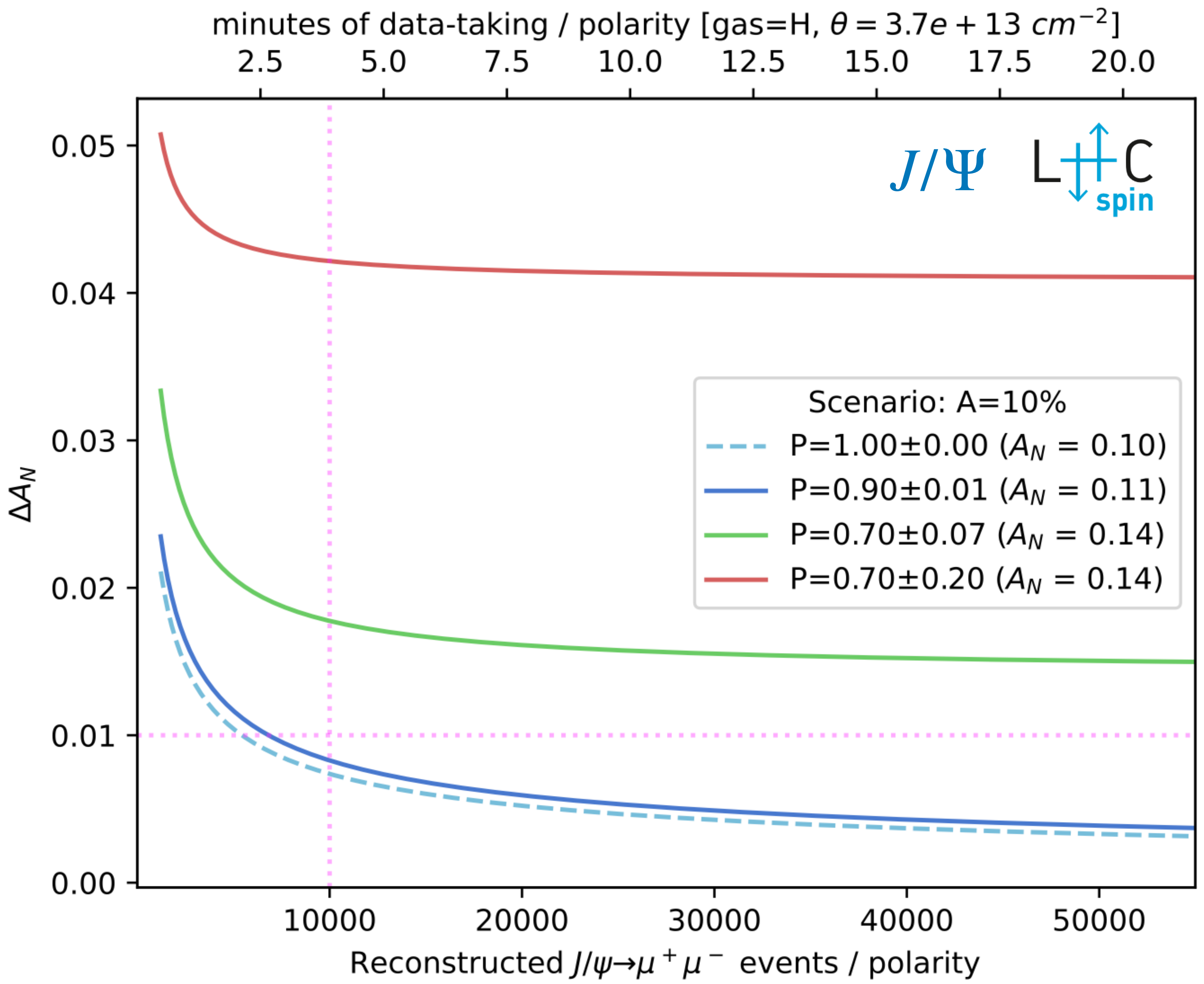
Channel	Events / week	Total yield
$J/\psi \to \mu^+\mu^-$	1.3×10^7 !!	1.5×10^9
$D^0 \to K^-\pi^+$	6.5×10^7	7.8×10^9
$\psi(2S) \to \mu^+\mu^-$	2.3×10^5	2.8×10^7
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (DPS)	8.5	1.0×10^3
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (SPS)	2.5×10^1	3.1×10^3
Drell Yan ($5 < M_{\mu\mu} < 9$ GeV)	7.4×10^3	8.8×10^5
$\Upsilon \to \mu^+\mu^-$	5.6×10^3	6.7×10^5
$\Lambda_c^+ \to pK^-\pi^+$	1.3×10^6	1.5×10^8

Statistics further enhanced by a factor 3-5 in LHCb upgrade II

Precise *spin asymmetry* on $J/\Psi \to \mu^+\mu^-$ and $D^0 \to K^-\pi^+$ for $pH^\uparrow$ collisions in just few weeks

Huge statistics

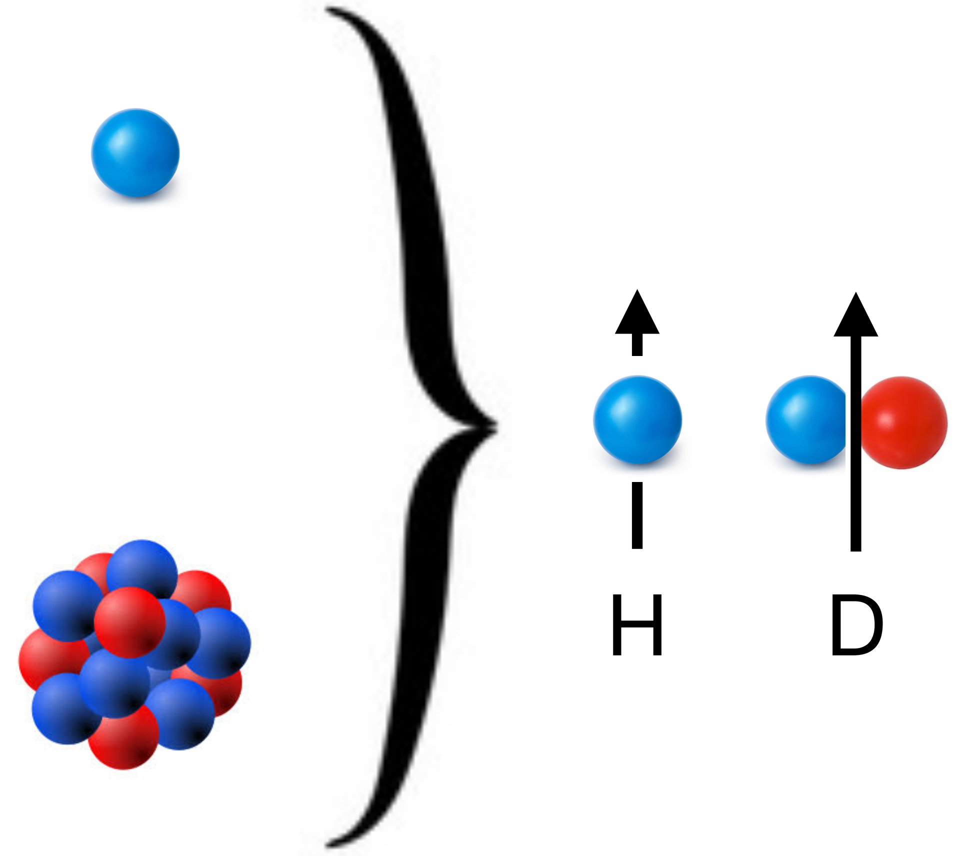


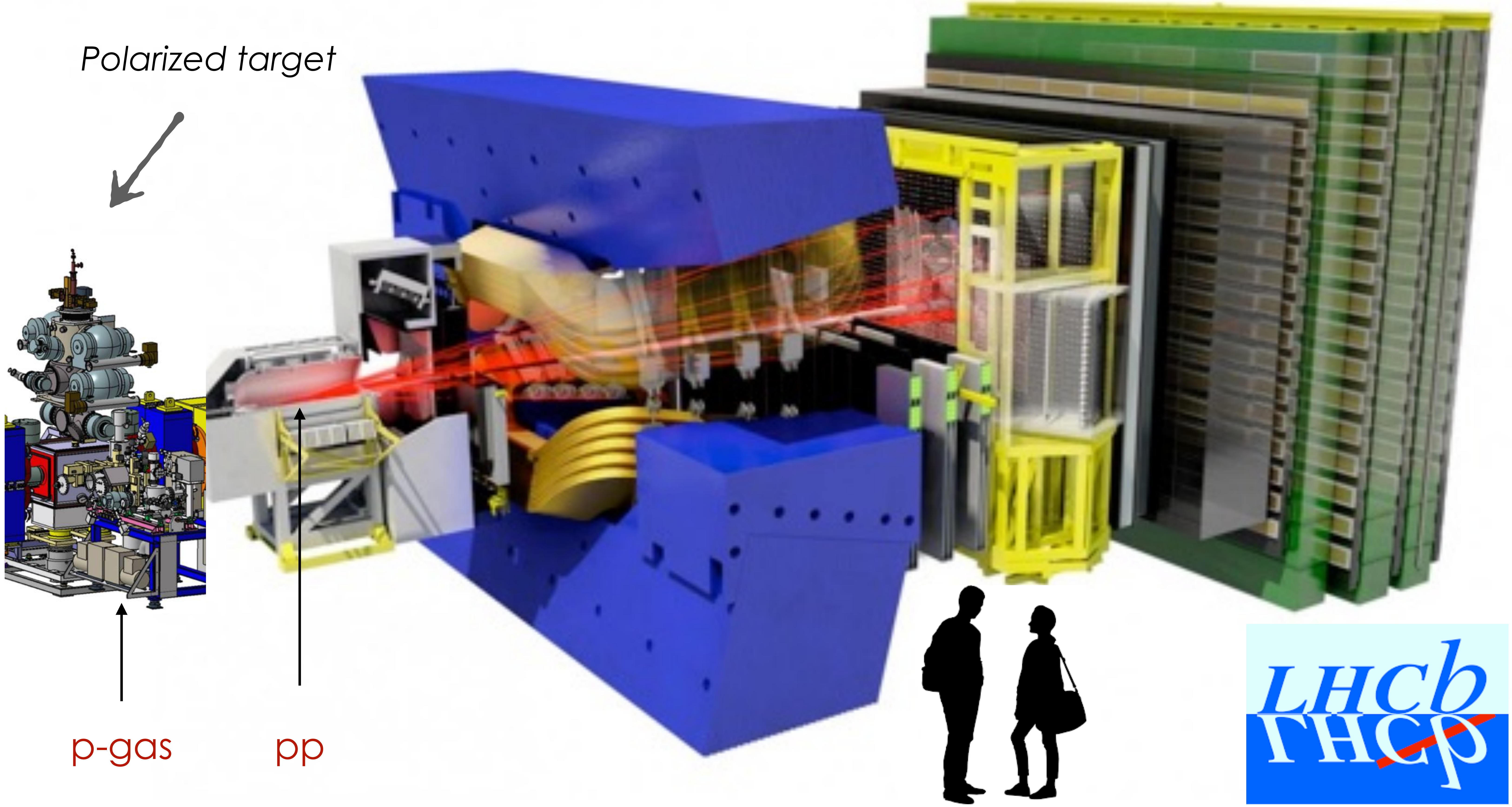


reconstructed particles

Talk of Marco Santimaria at 2.40 pm

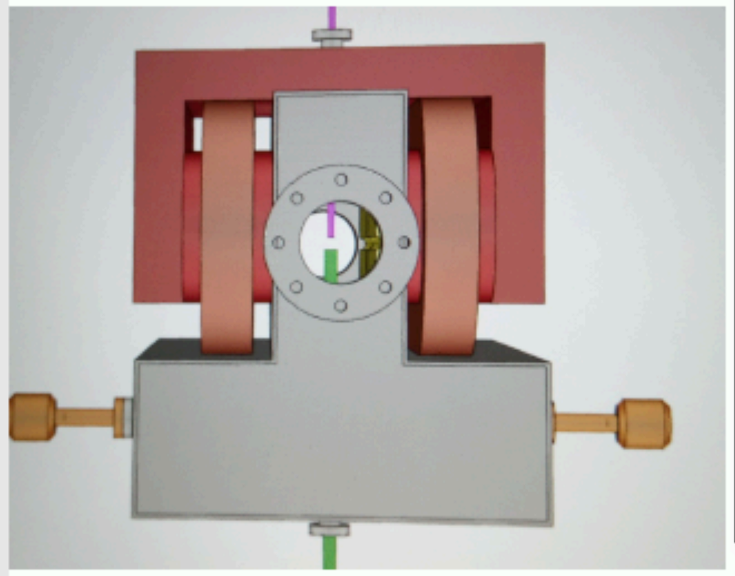
LHCspin a polarized target at LHCb

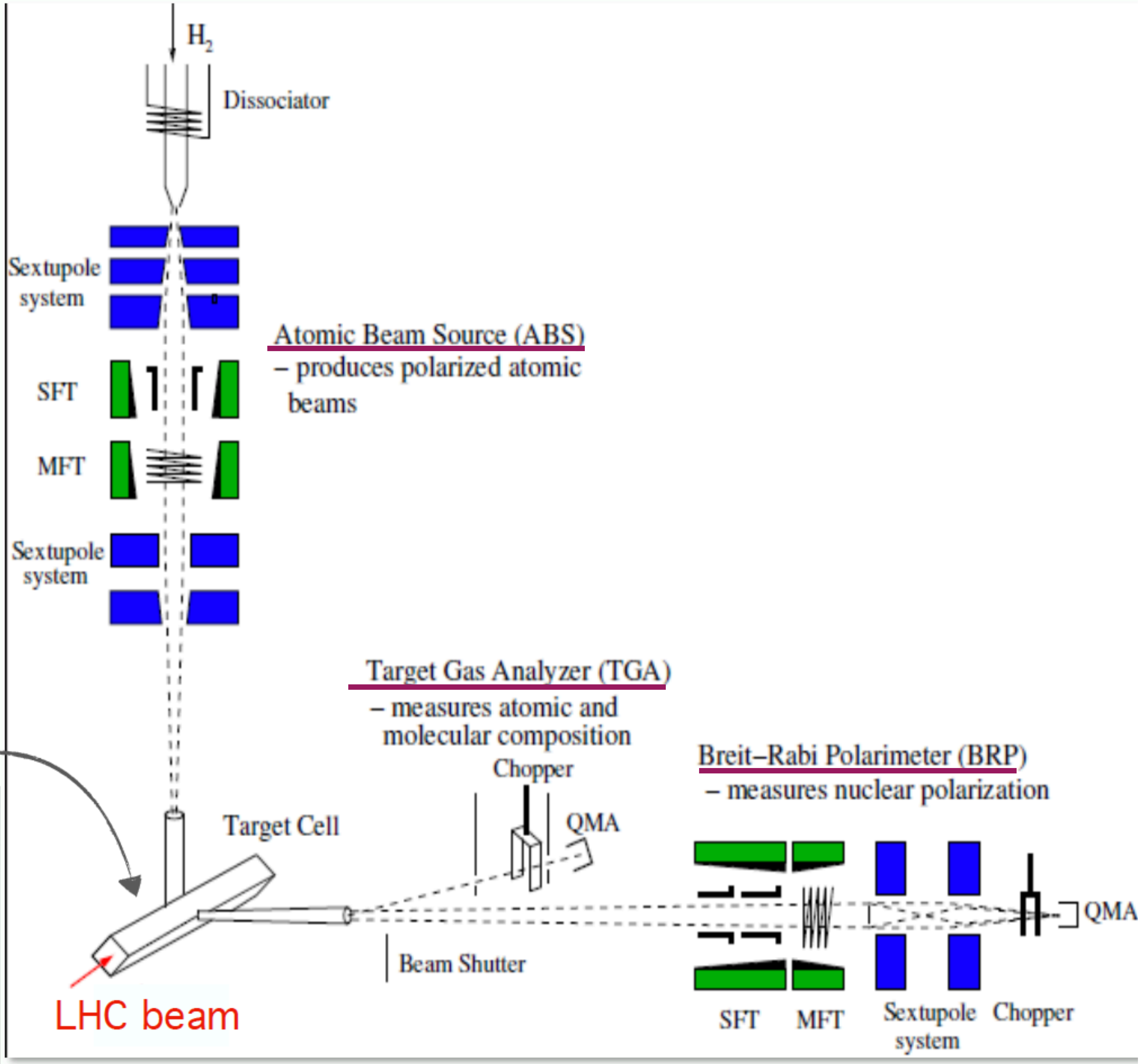




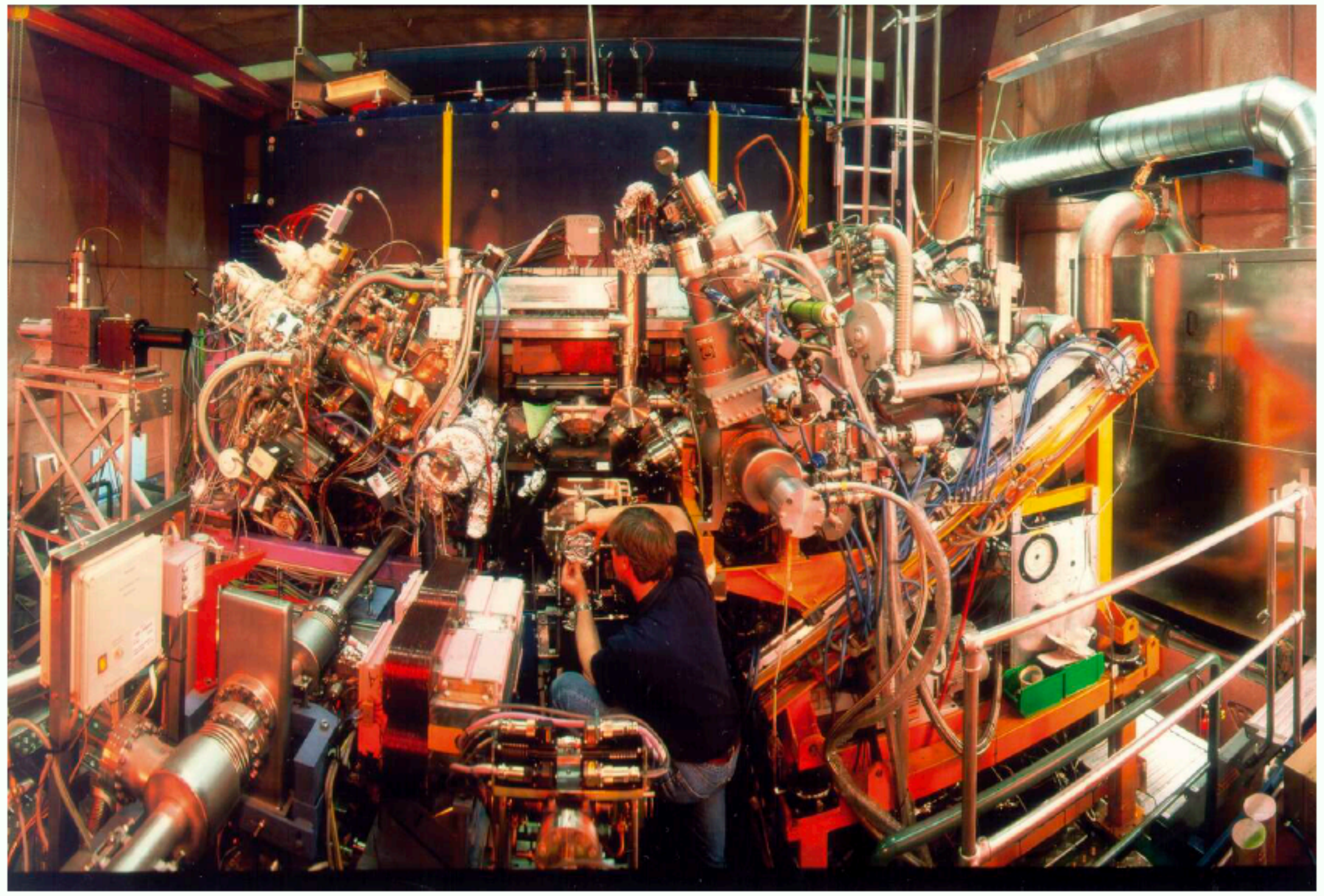
Successful technology based on
HERA and COSY experiments

LHCspin experimental setup





- Start from the well established HERMES setup @ DESY…
- … to create the next generation of fixed target polarisation techniques!



[NIMA 540 (2005) 68-101]

LHCspin experimental setup

Target density (H) = 3.7×10^{13} cm^{-2}
LHC beam (Run5) = 6.8×10^{18} p s^{-1}

L_{pH} = 2.5×10^{32} cm^{-2} s^{-1}

Negligible impact on the beam lifetime, $\tau^{p-H}_{beam-gas} \sim 2000$ days to be compared with the typical 10h of the LHC beam lifetime

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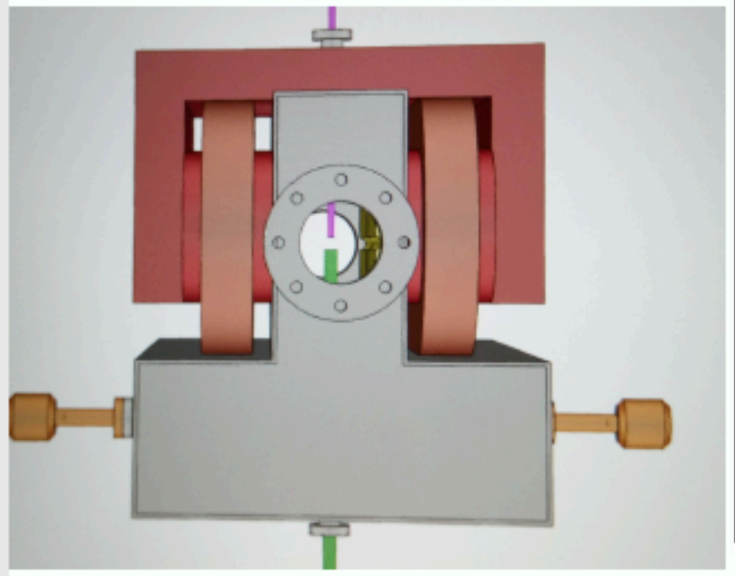
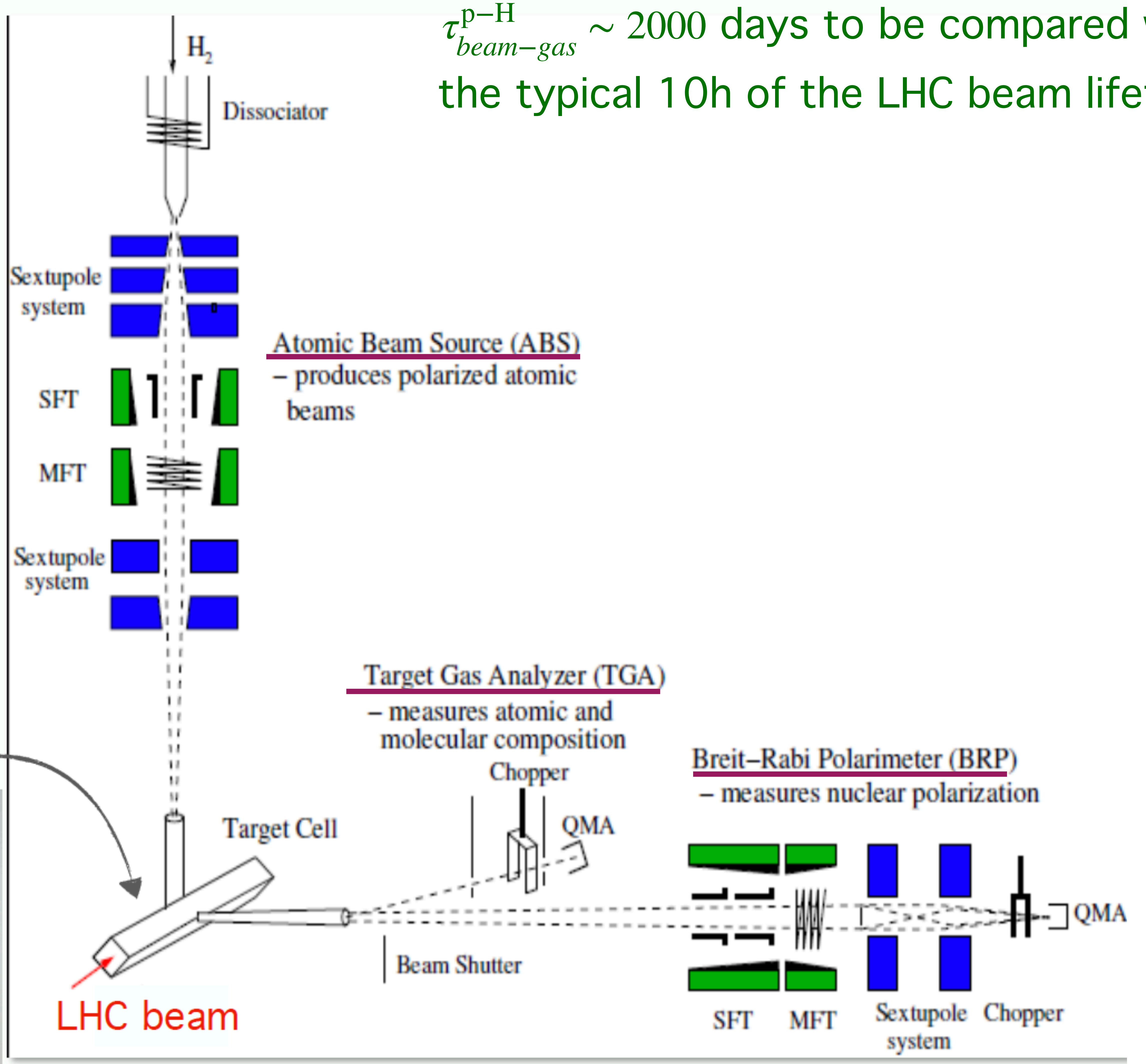
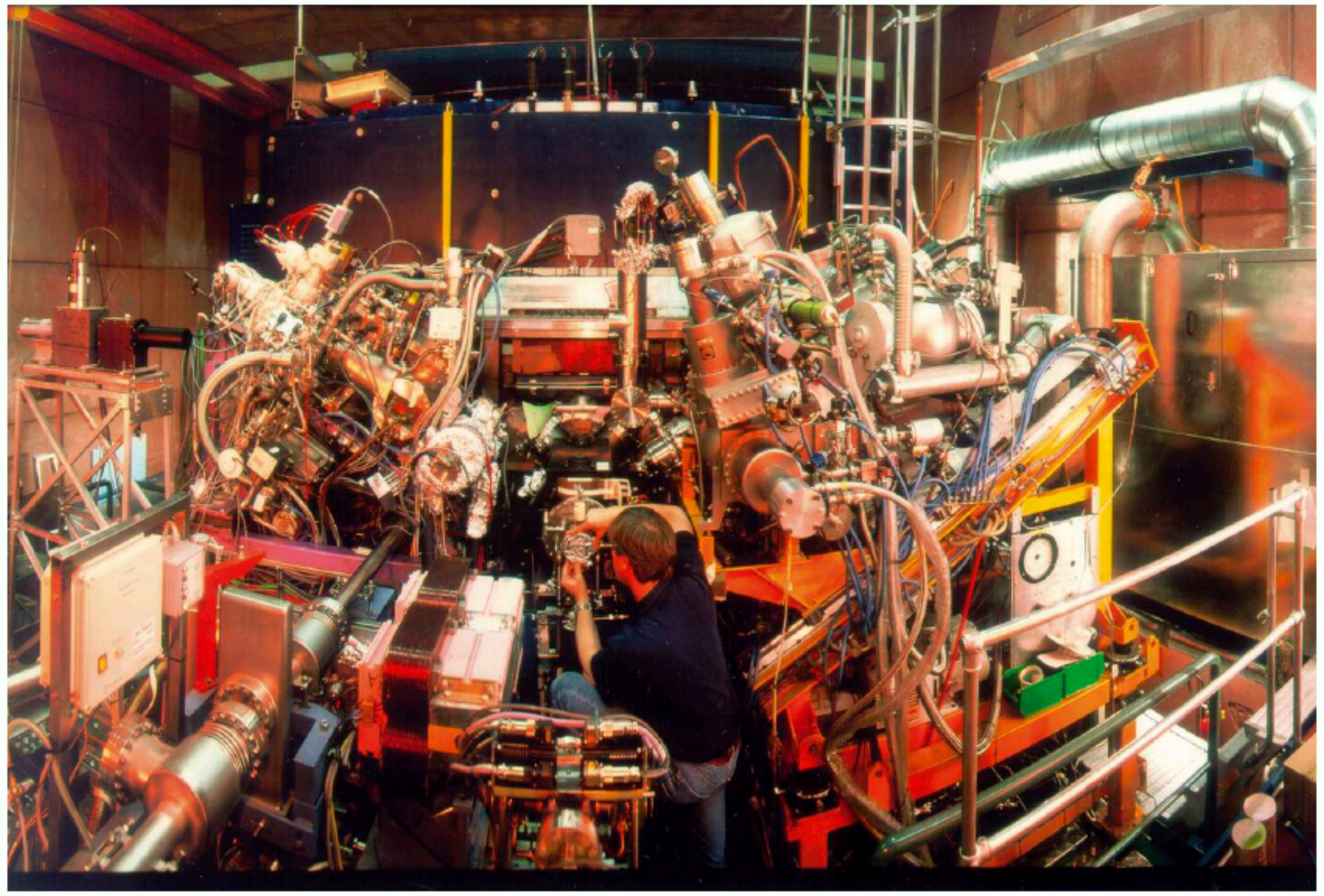
- … to create the next generation of fixed target polarisation techniques!





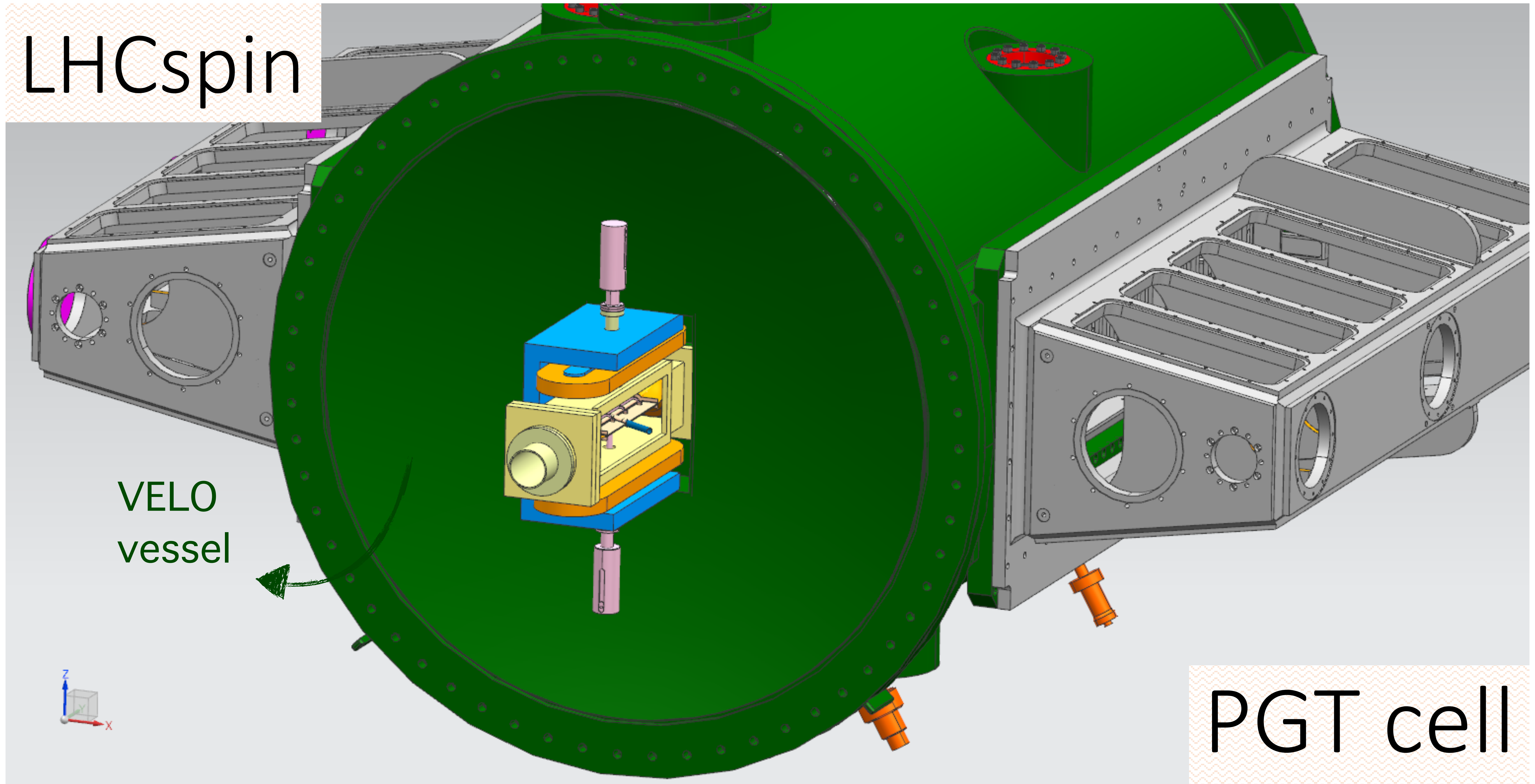


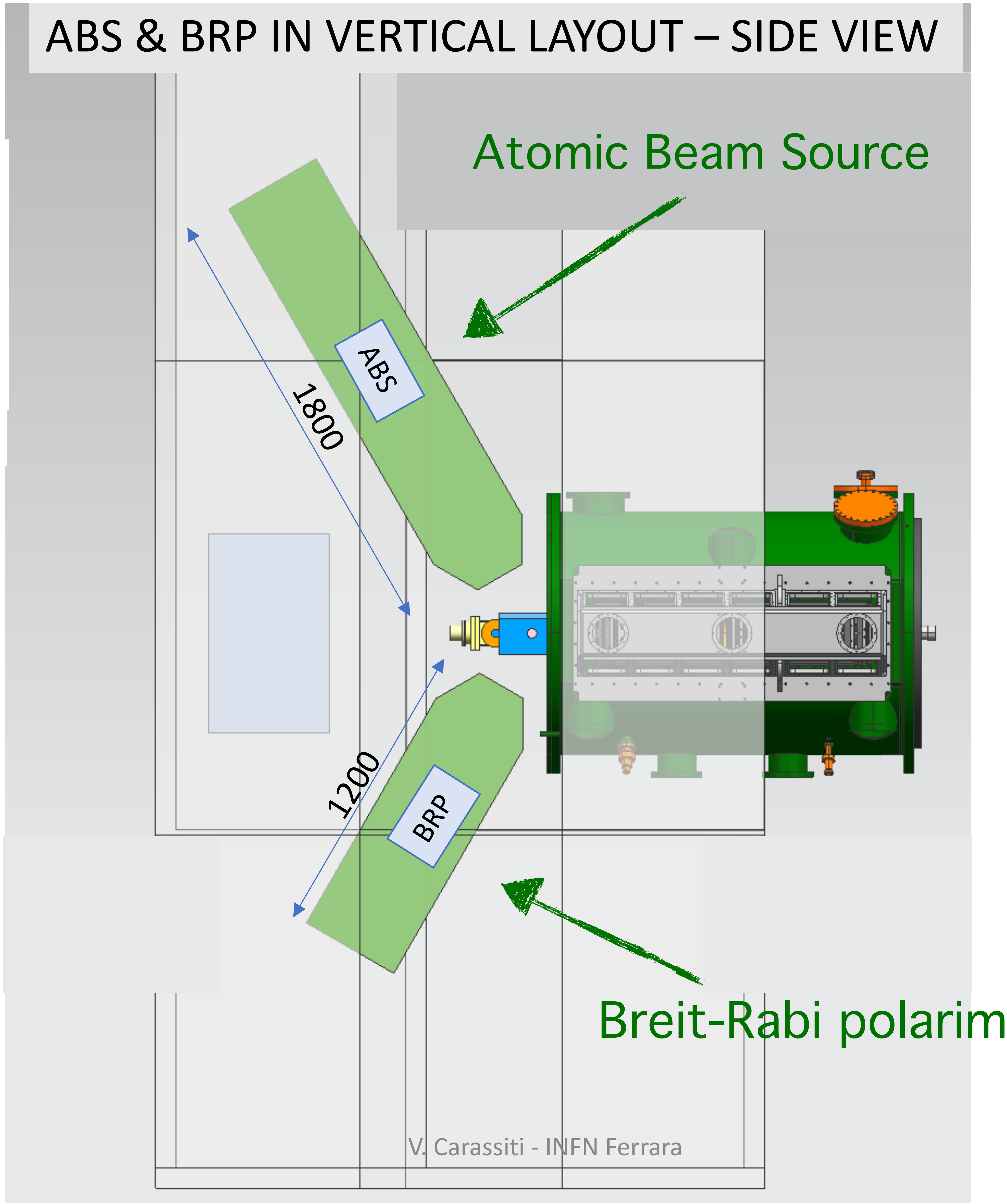
[NIMA 540 (2005) 68-101]

PGT implementation into LHCb

- Cylindrical target cell with SMOG2 dimensions: $L = 20$ cm and $D = 1$ cm

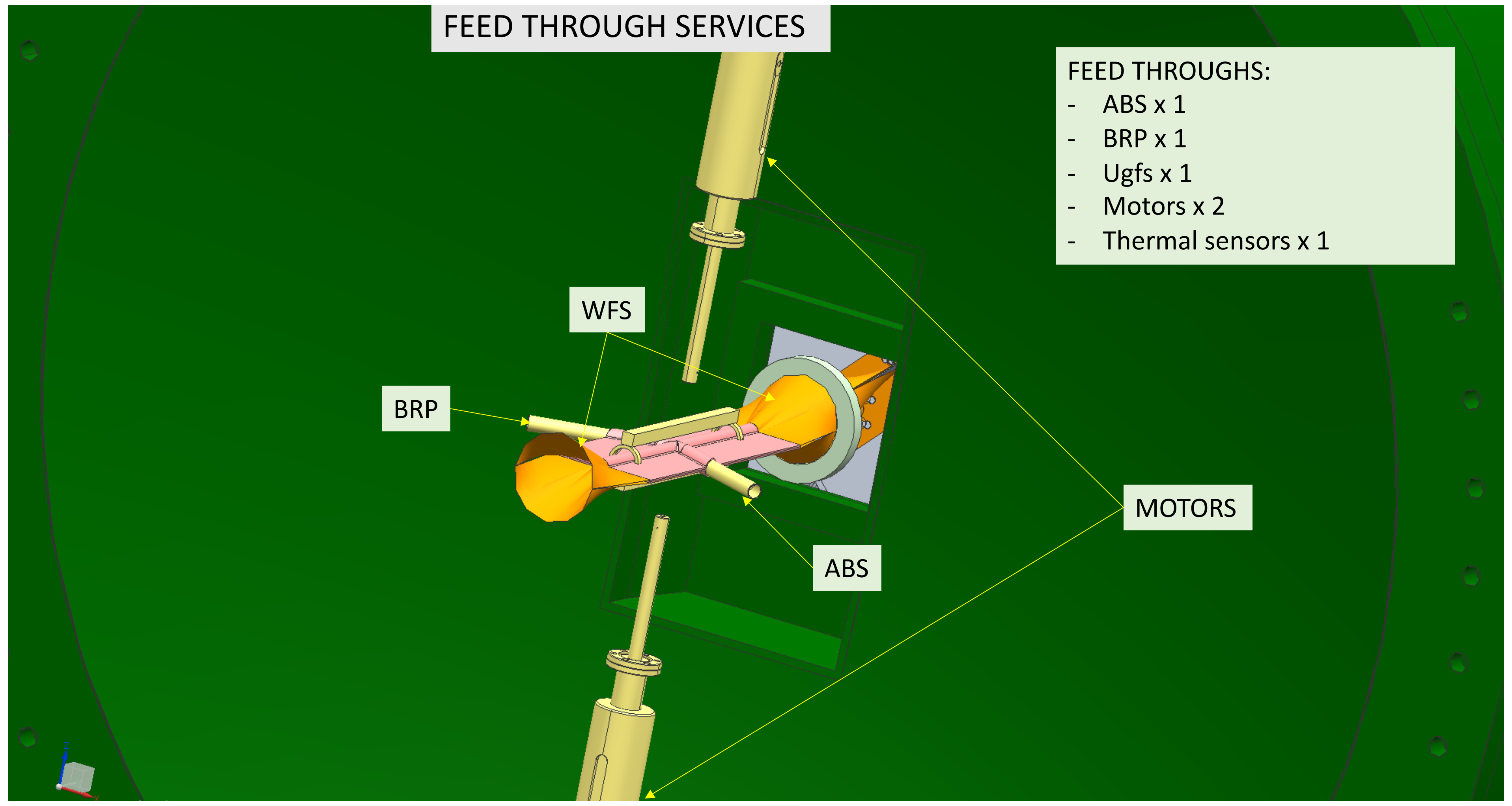
- Full LHCb simulations show broader kinematic acceptance & higher efficiency in the same position of the SMOG2 cell



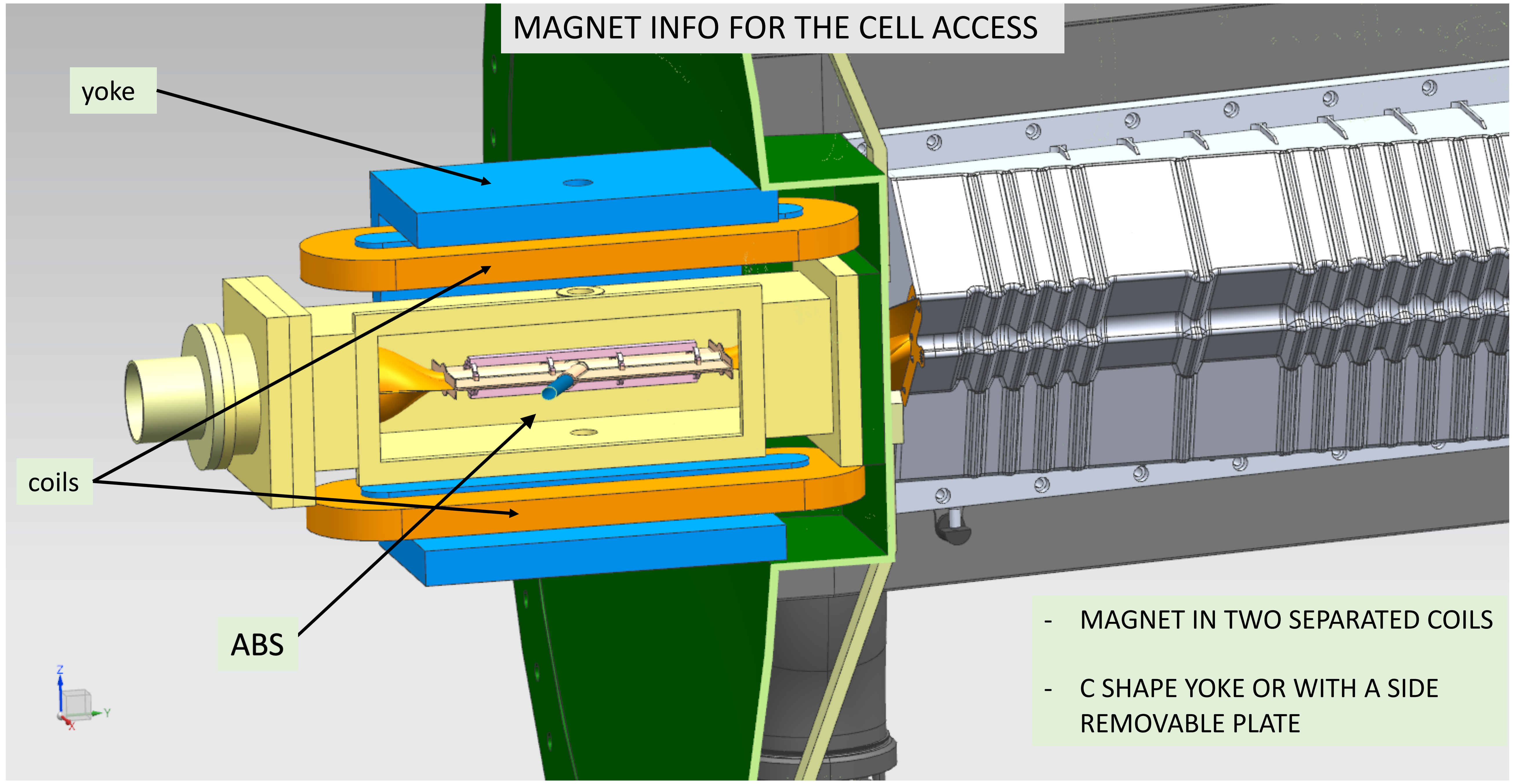


PGT implementation into LHCb

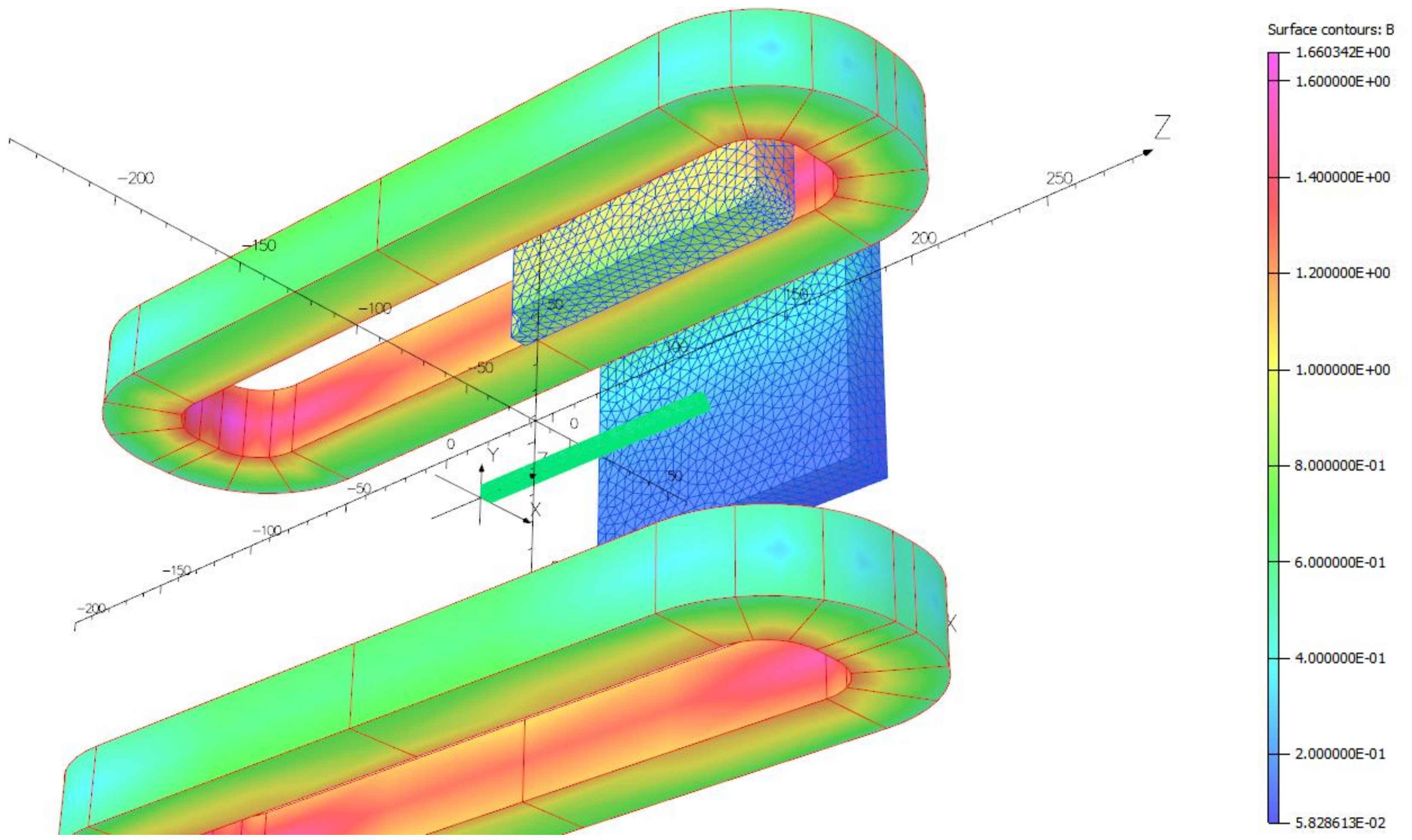
- Inject polarized gas via ABS and unpolarized gas via UGFS



Transverse polarization



- Compact dipole magnet → static transverse field
- Superconductive coils + iron yoke configuration fits the space constraints
- $B = 300$ mT with polarity inversion, $\Delta B/B \simeq 10\,\%$, suitable to avoid beam-induced depolarization [PoS (SPIN2018)]



Possibility to switch to a solenoid and provide longitudinal polarization

Role of the storage cell coating

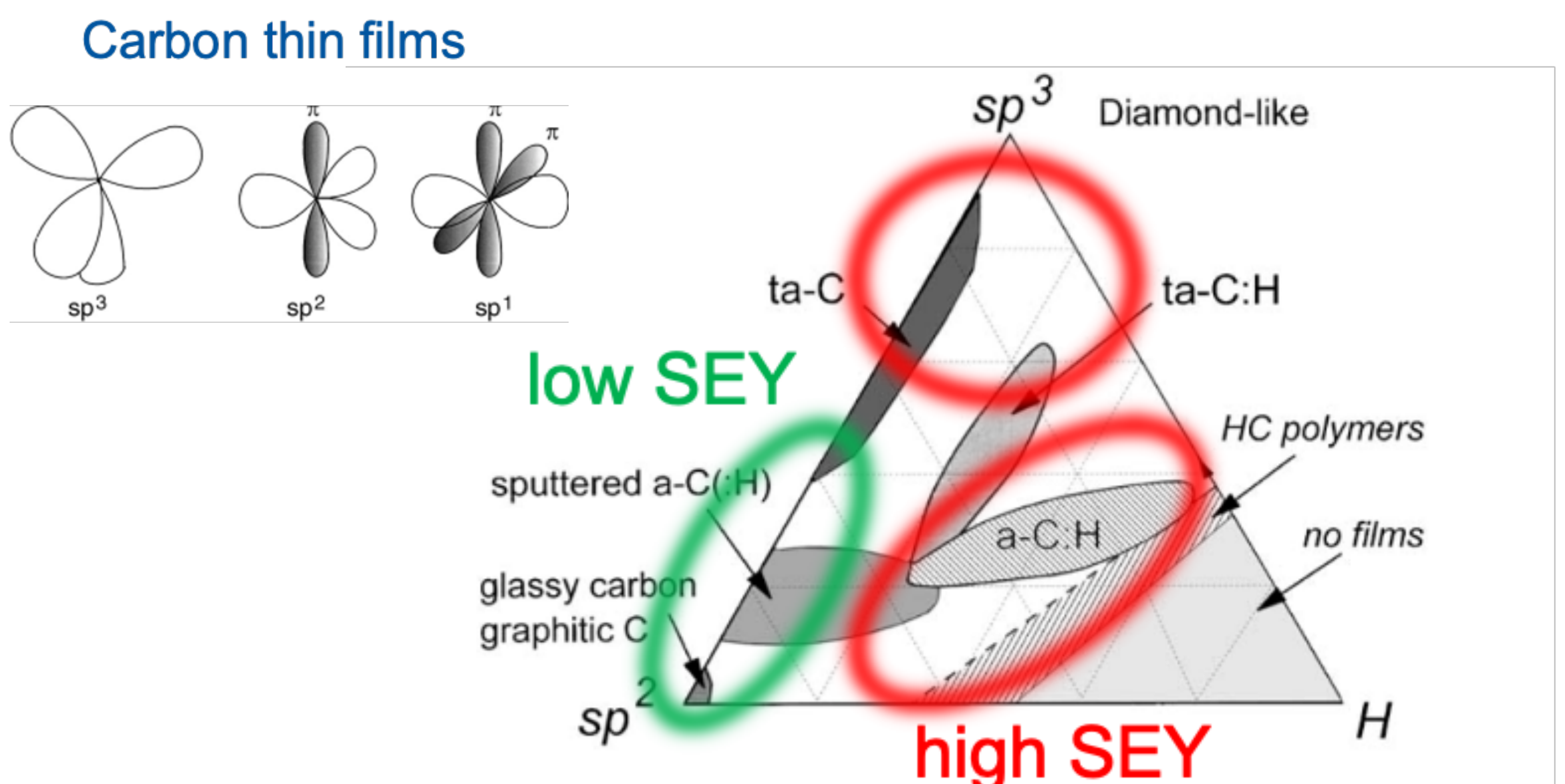
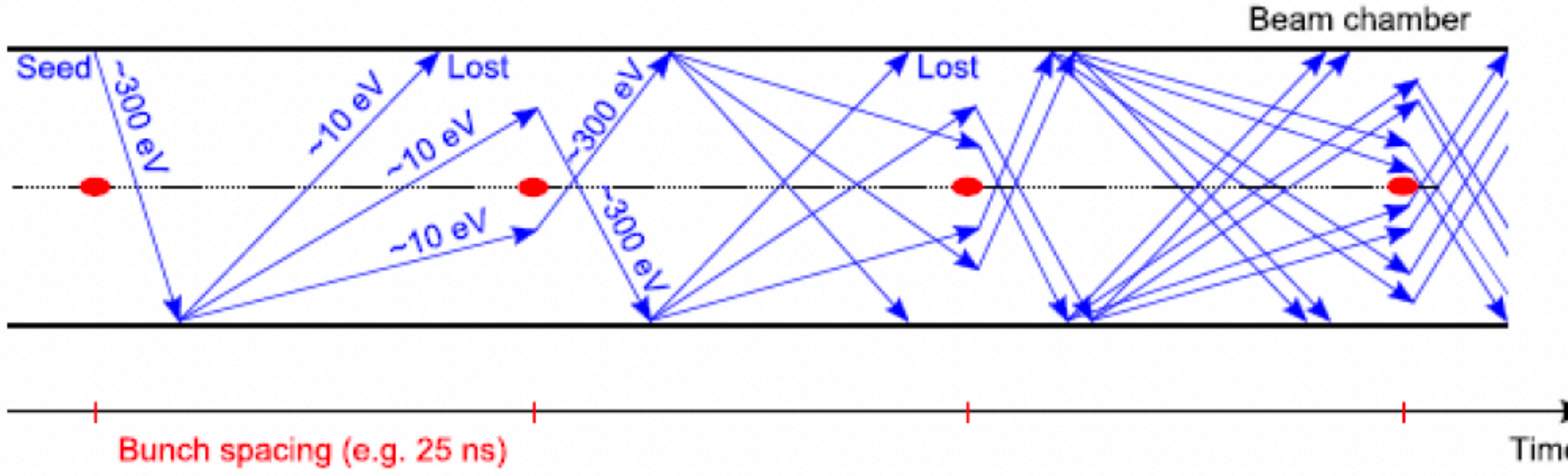


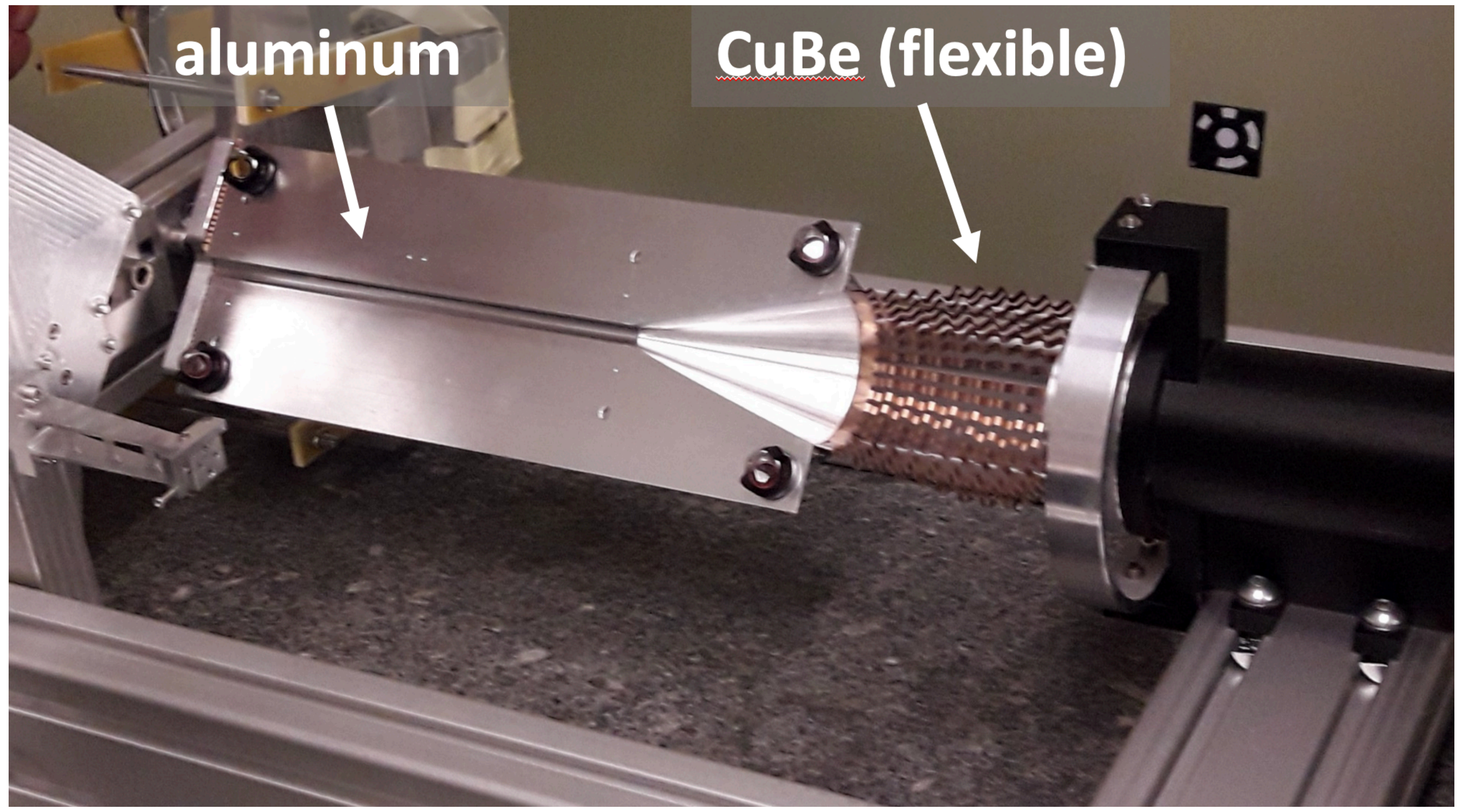
Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

J. Robertson / Materials Science and Engineering R 37 (2002) 129–281

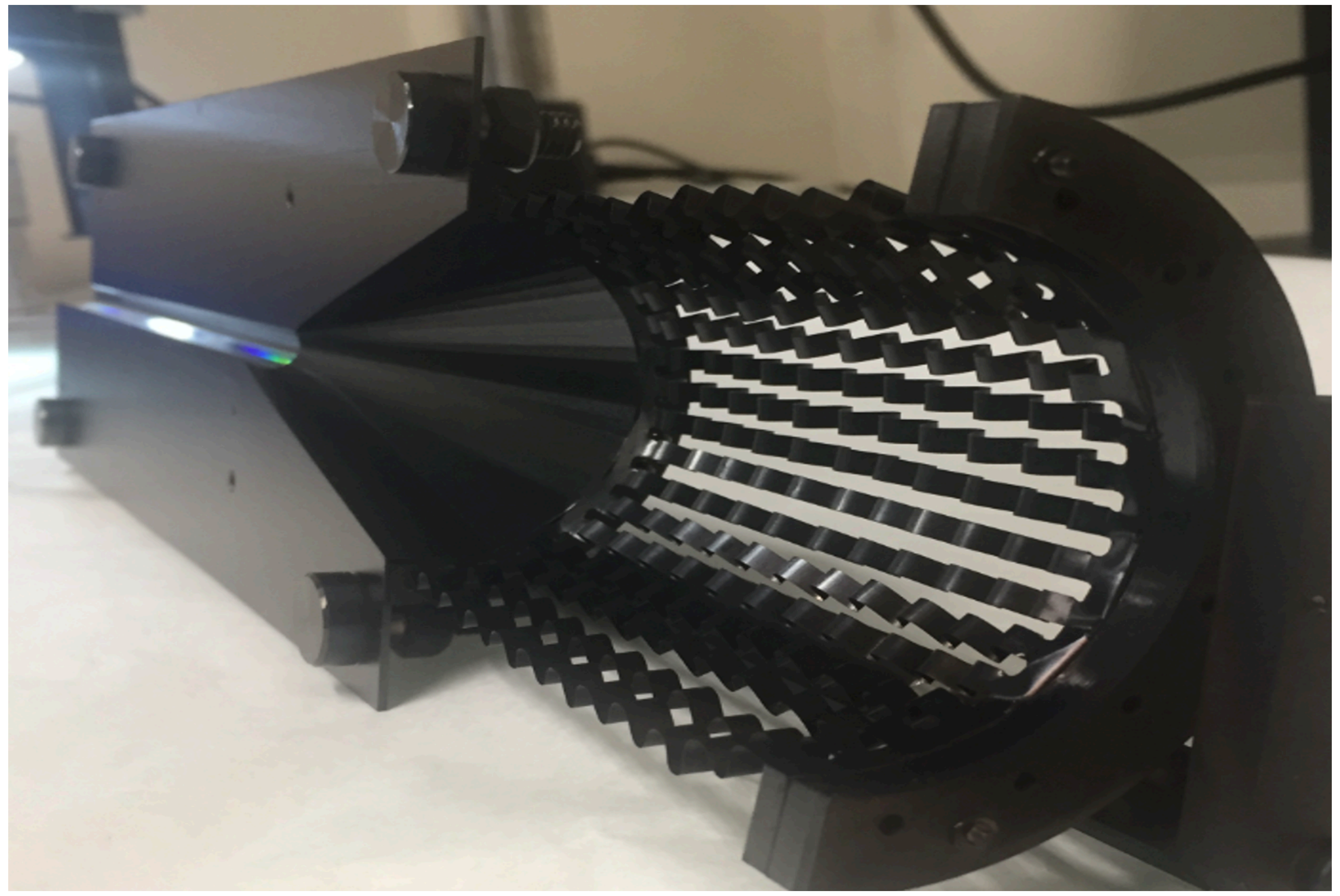


The material of the cell walls must have a low Secondary Electron Yield (e-cloud)

SMOG2 non coated cell

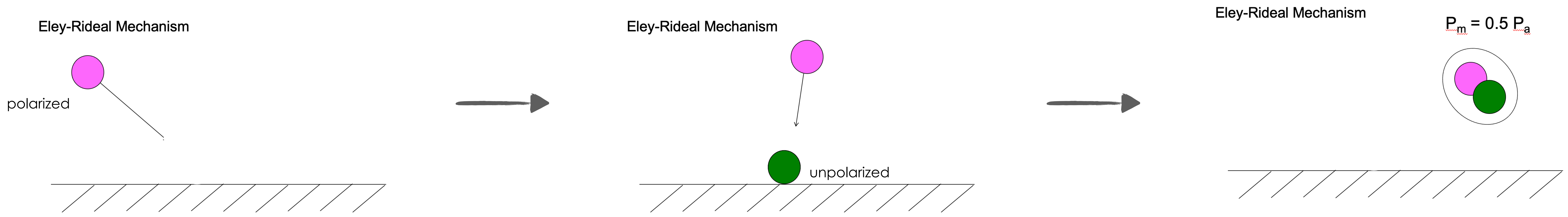


SMOG2 amorphous Carbon coated cell



Coating issues

Amorphous carbon is a very effective coating for maintaining low SEY, as demonstrated by SMOG2. However, what about atomic recombination?



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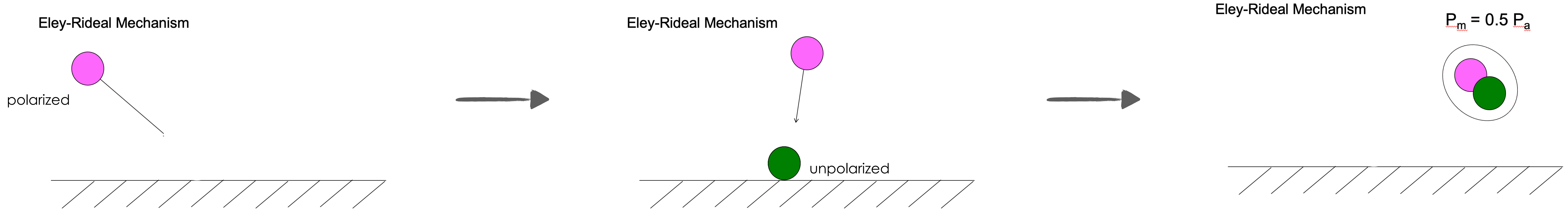

In previous experiments at HERA and COSY, Dryfilm (silicon) or Teflon (fluoride) coating, combined with ice layers, kept the SEY low and prevented recombination

This is not possible at LHC: no fluoride, no silicon materials allowed

Coating issues

Let’s try to change the paradigm and exploit the recombination effects.
This can happen if:

1) the recombination process is “fast enough” to recombine two polarized atoms
2) the recombination into molecules is very high

Coating issues

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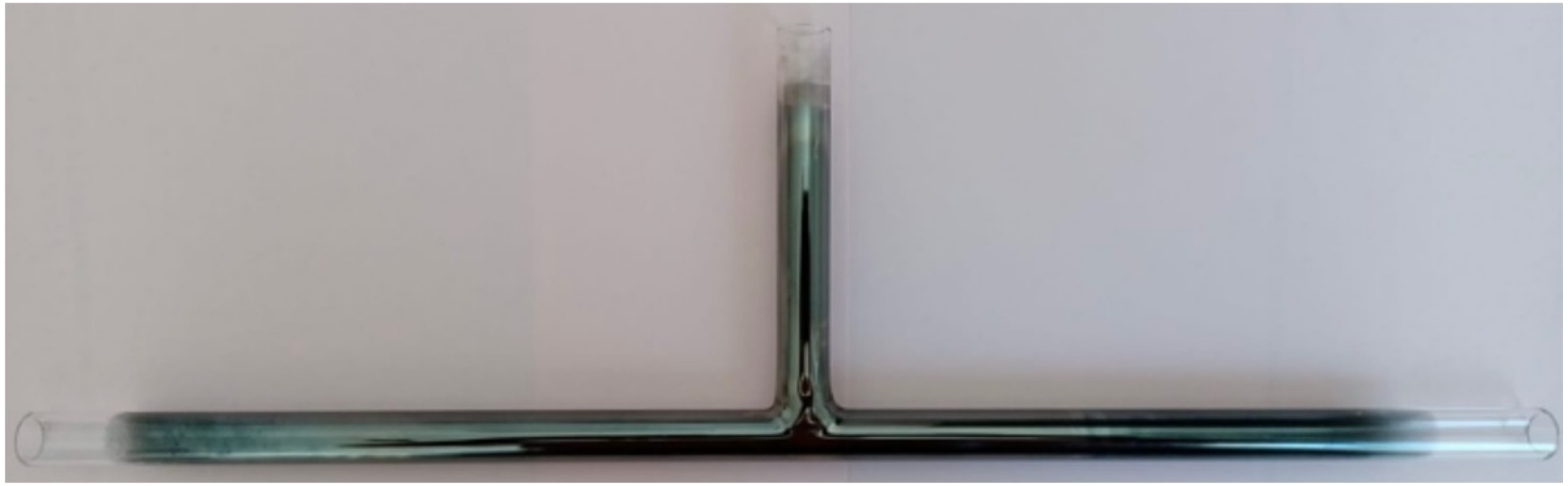
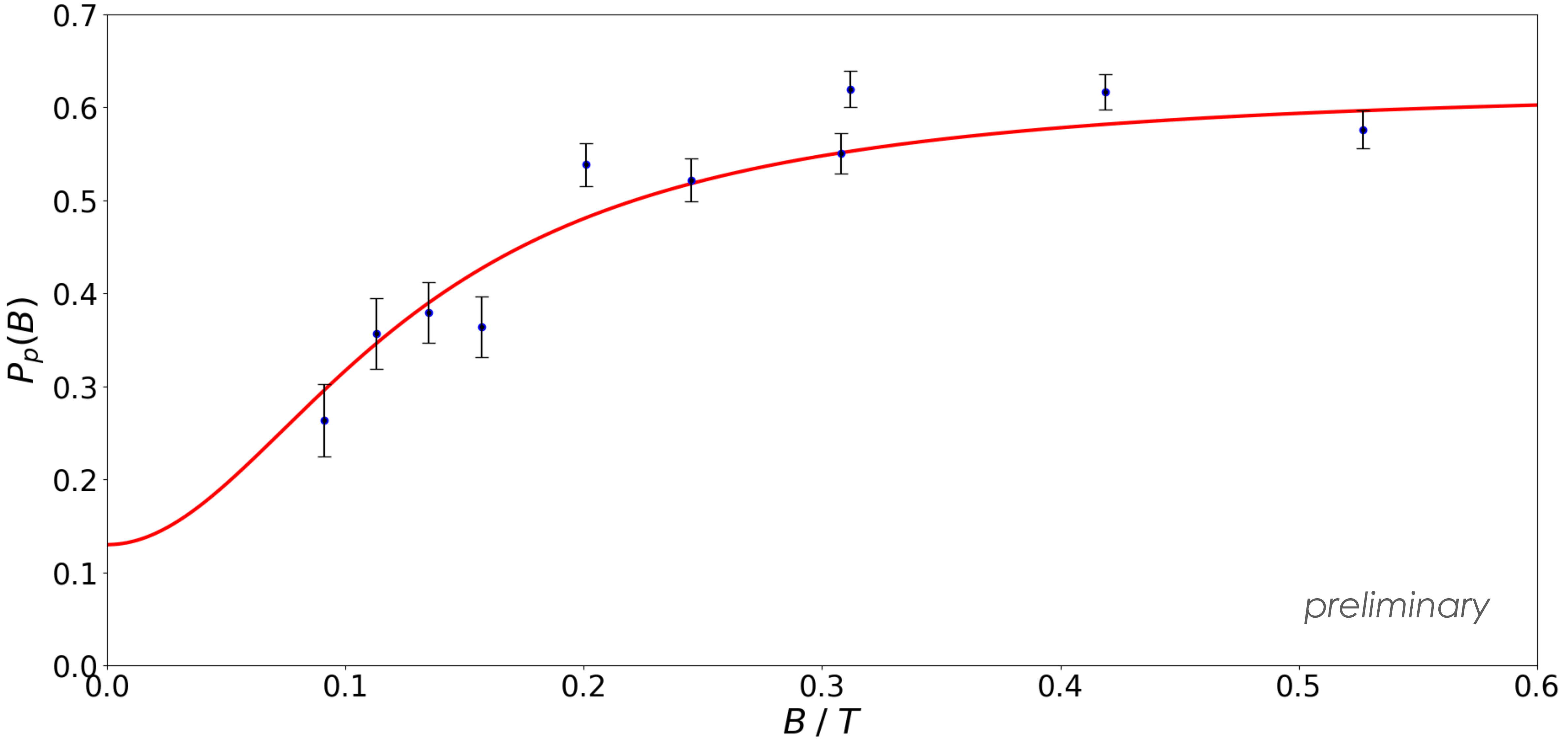
A test was performed at FZ-Julich on a quartz storage cell coated at CERN with amorphous carbon, just like the SMOG2 storage cell



Acknowledgement for the coating process: Yorick DELAUP, Bernard HENRIST, Pedro COSTA PINTO - CERN TE-VSC

Coating issues

PoS PSTP2022 (2023) 036
PRL 124, 113003 (2020)
PRL 115, 113007 (2015)



Proton vector polarization for different magnetic fields
- aC coating -

Initial atomic polarisation $P_a = 0.90$
Recombination rate *95.8 - 100 %*

We can develop a new storage cell using polarized molecules →

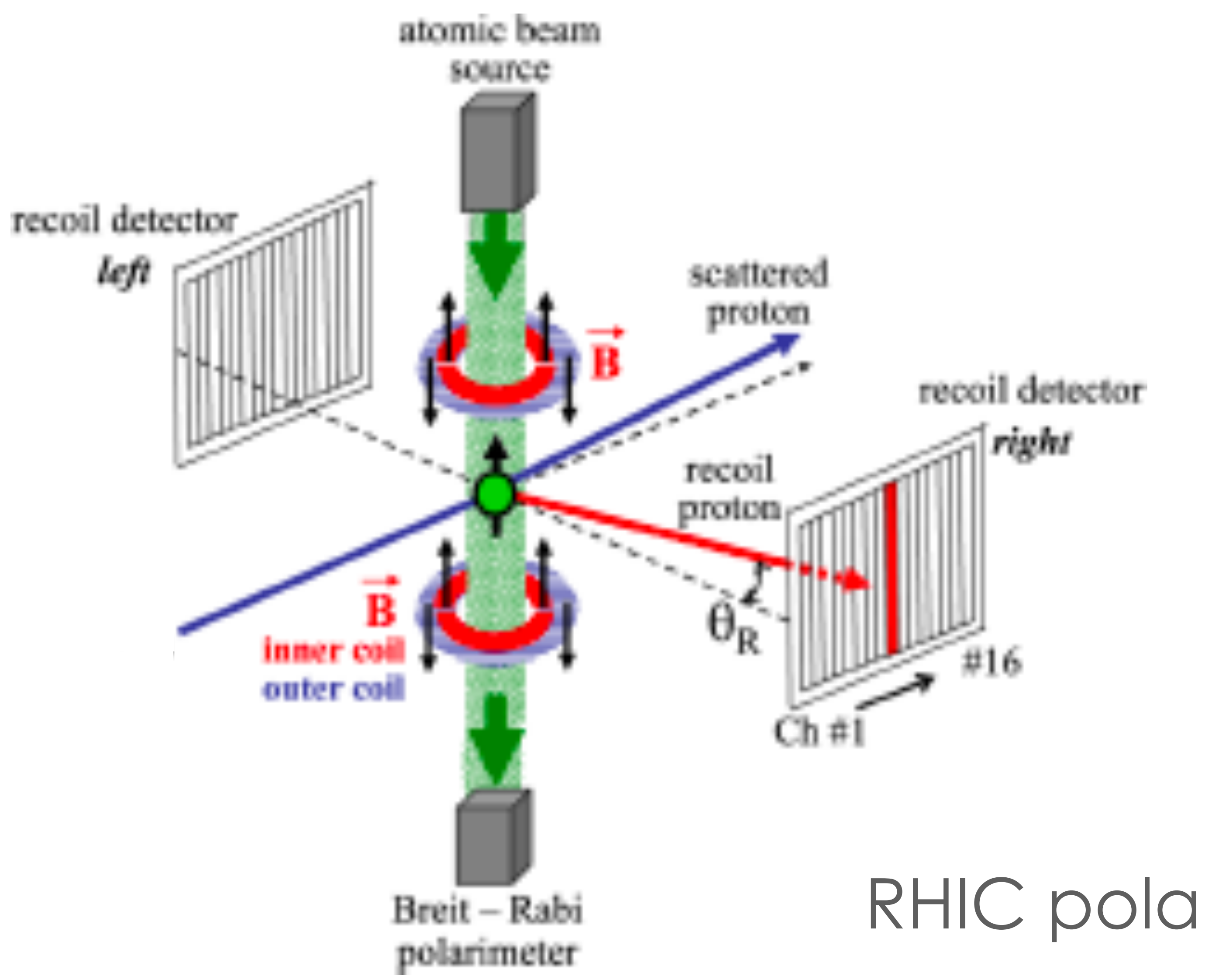
- high density target
- but an <u>absolute polarimeter</u> is needed

Development of an absolute polarimeter

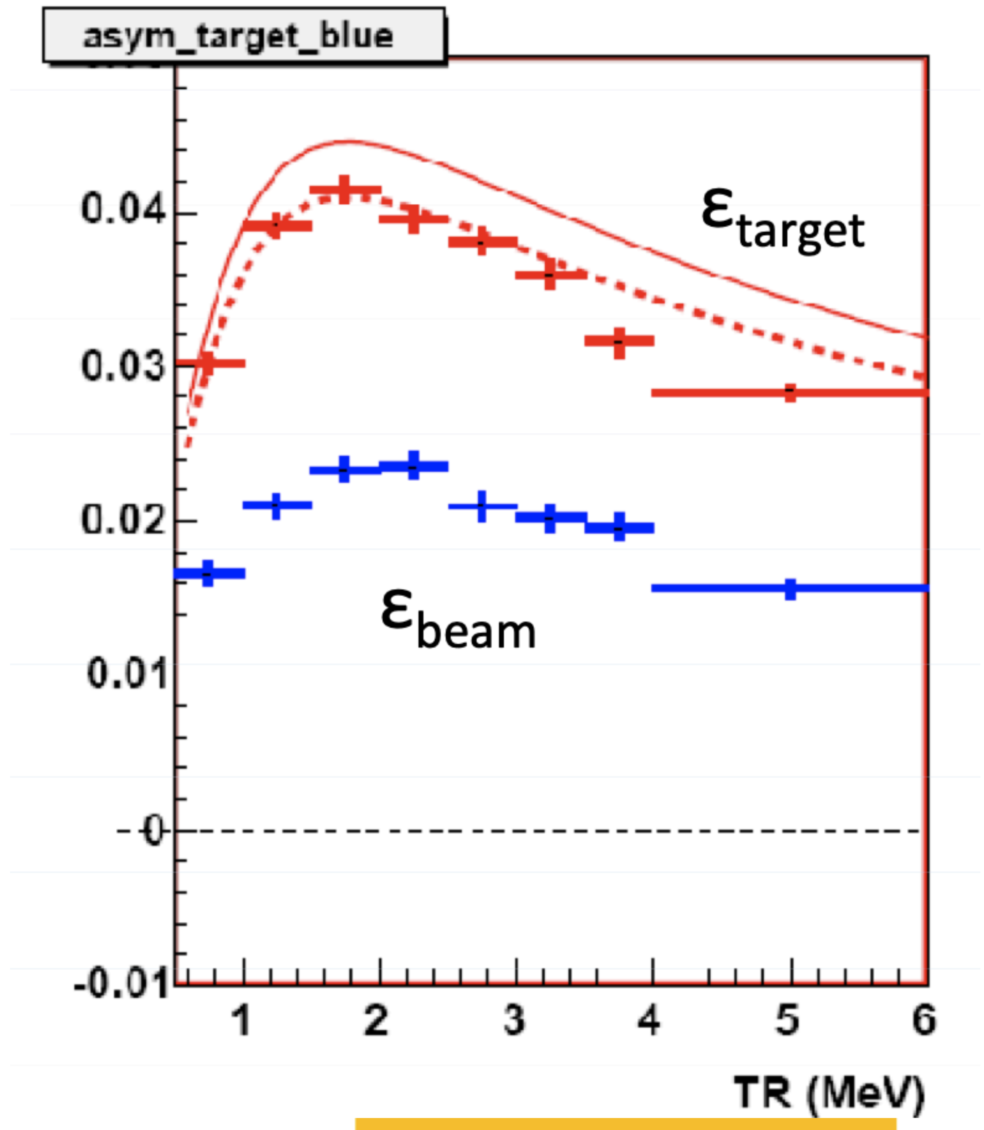
Based on the Coulomb Nuclear Interference (CNI)

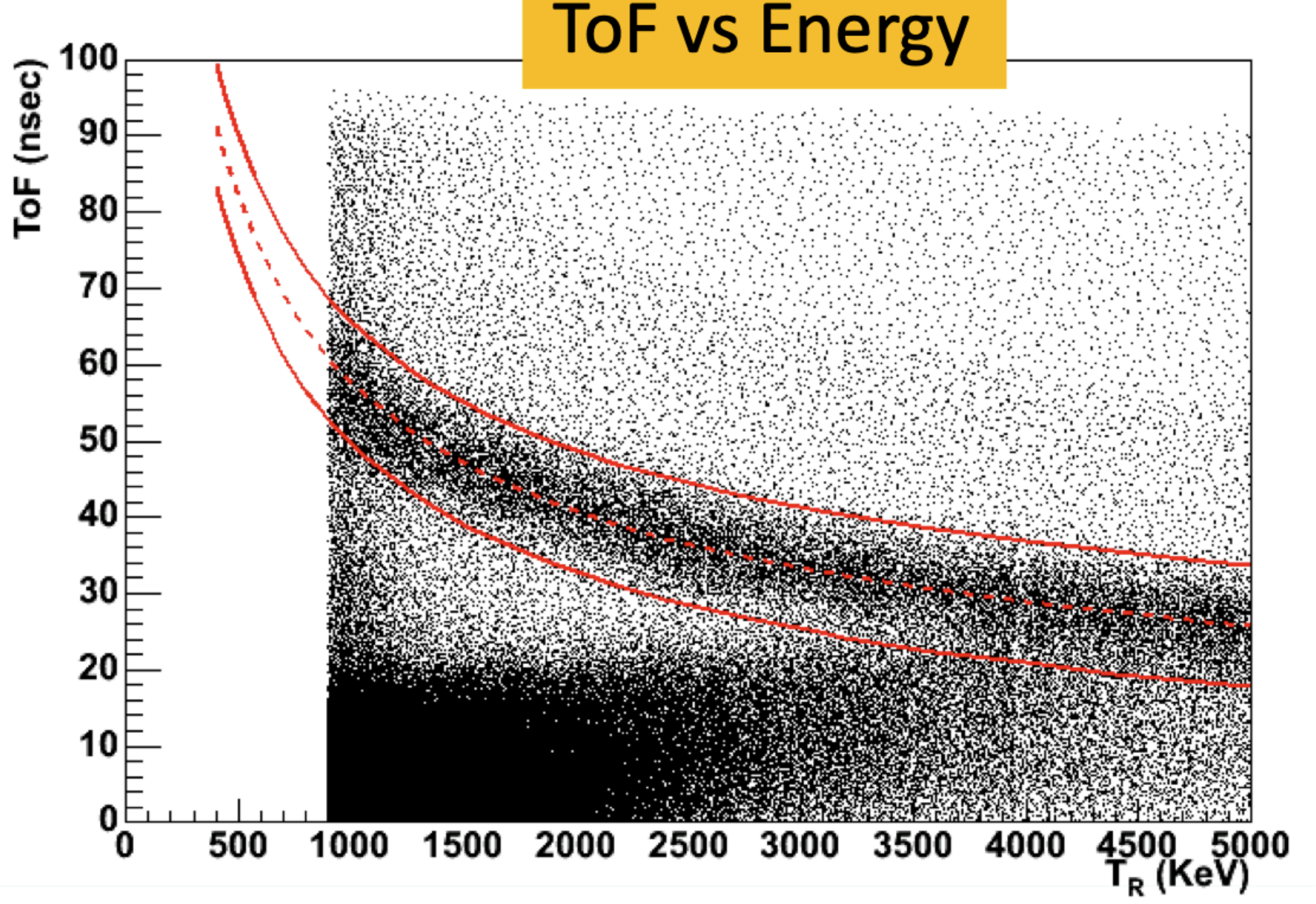
Nuclear Inst. and Methods in Physics Research, A 976 (2020) 164261

JPS Conf. Proc. 37, 021103 (2022)



RHIC polarimeter





To validate the theoretical predictions of the analyzing power at 7 TeV, in addition to evaluating detection efficiency and background, the absolute polarimeter must be installed in coincidence with the standard Breit-Rabi Polarimeter along the beamline

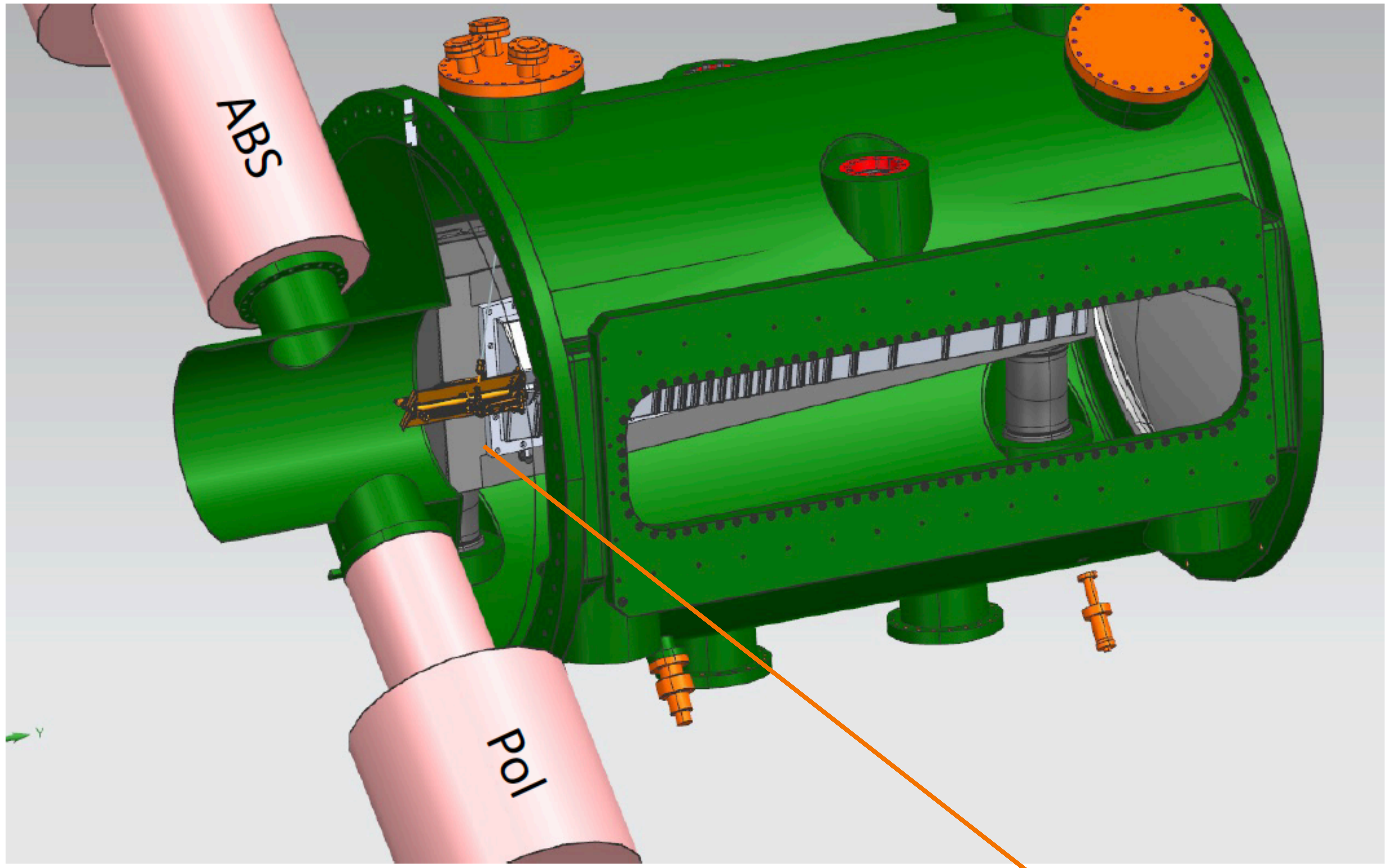
The backup: the jet target

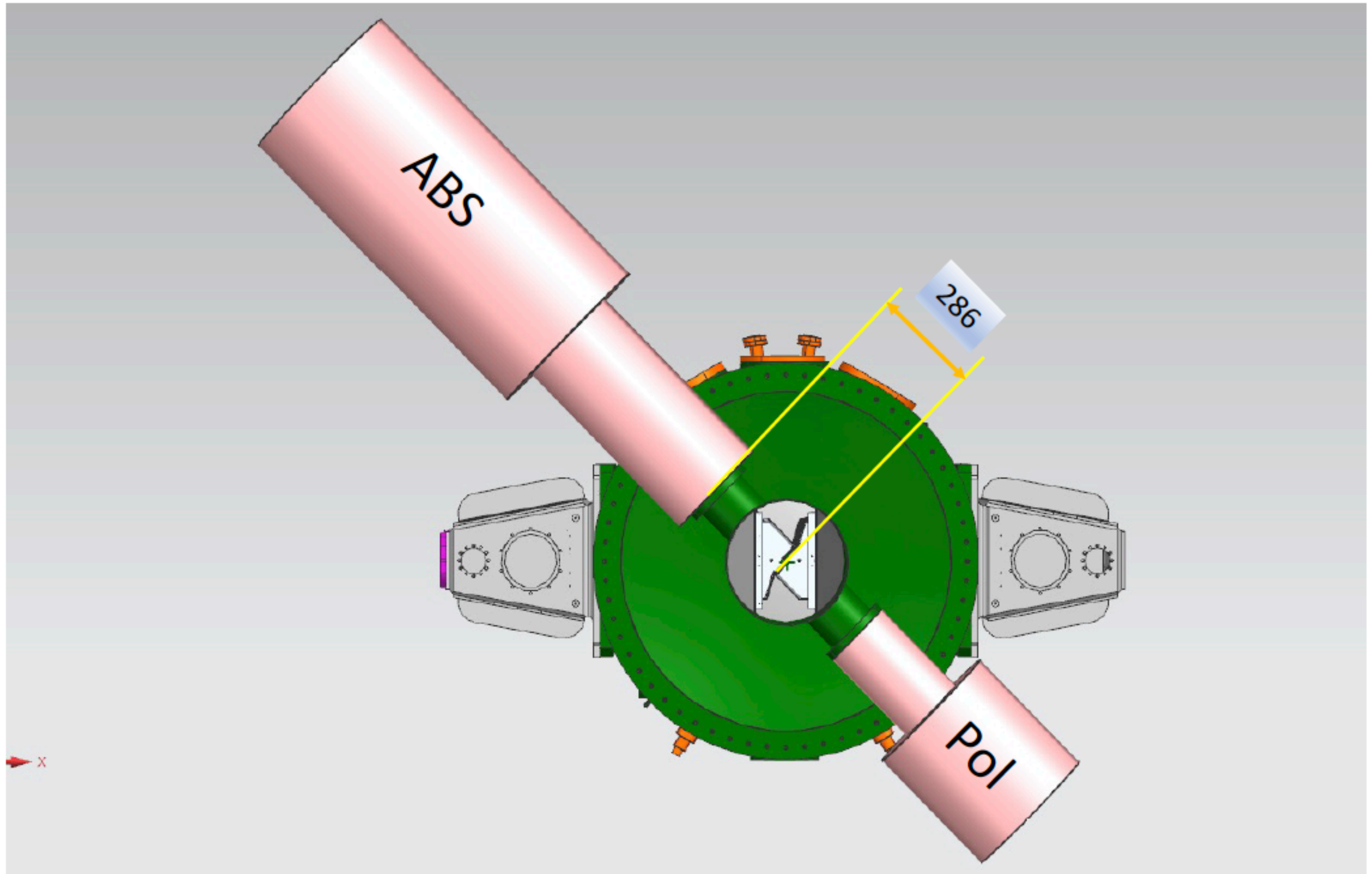
Alternative solution with **jet target** also under evaluation:

- lower density ($\sim 10^{12}$ atoms$/cm^2$)
- higher polarization (up to 90%)
- lower systematics in P measurement (virtually close to 0)

Pro
-no recombination
-high polarisation
-very small systematics on the polarisation measurements

Contra
-x40 less luminosity than the cell solution
(tolerable for the standard channels, relevant for the rare probes)





In this case the small dipole becomes a simple small Helmholtz coil that has basically no impact on the LHCb current or future setup

The plan is to develop the project in 2 phases:

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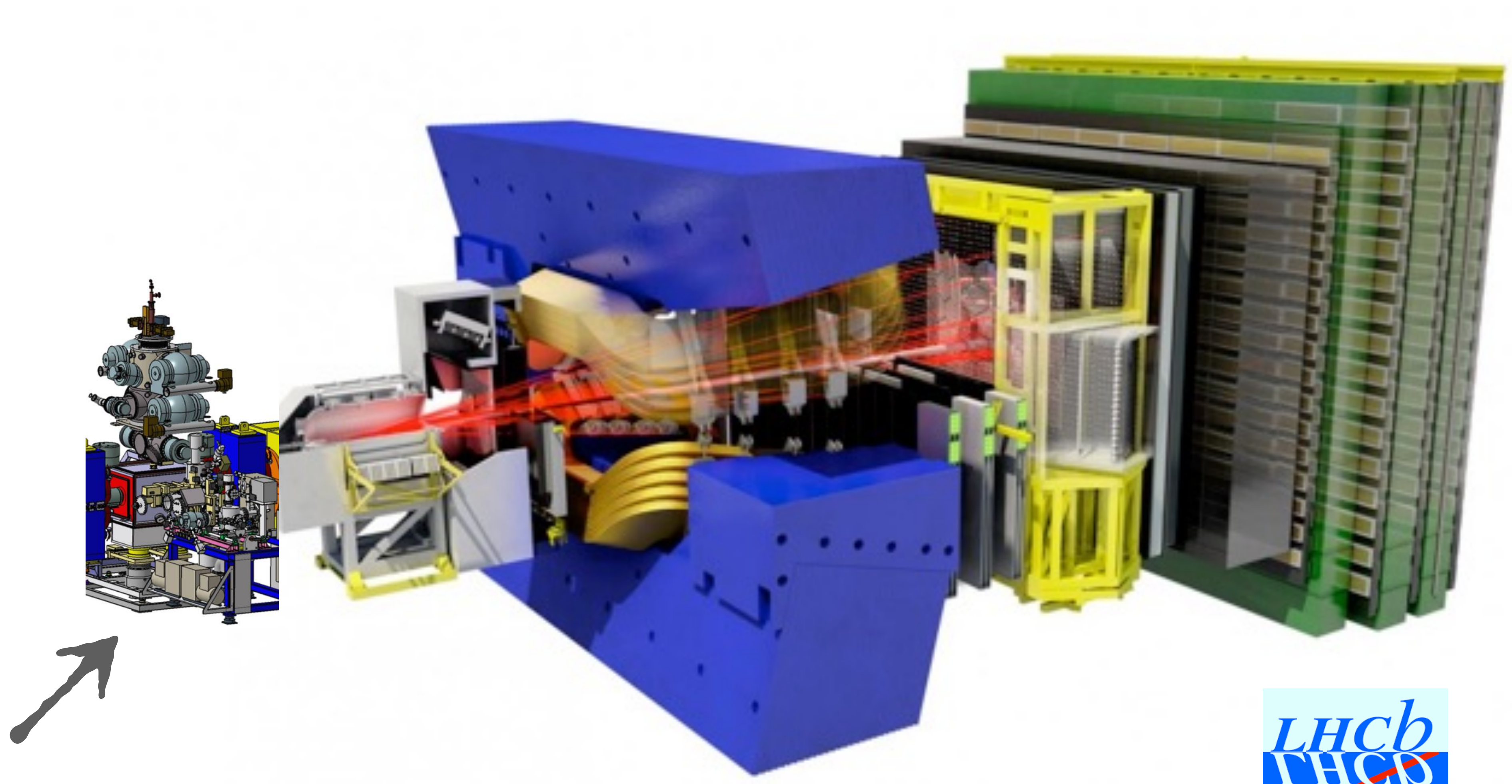
2

Install the PGT in LHCb for the Run5 and exploit all the enormous potentialities due to the LHCb (upgrade II) spectrometer: c-, b-quark reconstruction, rare probes, RTA, …



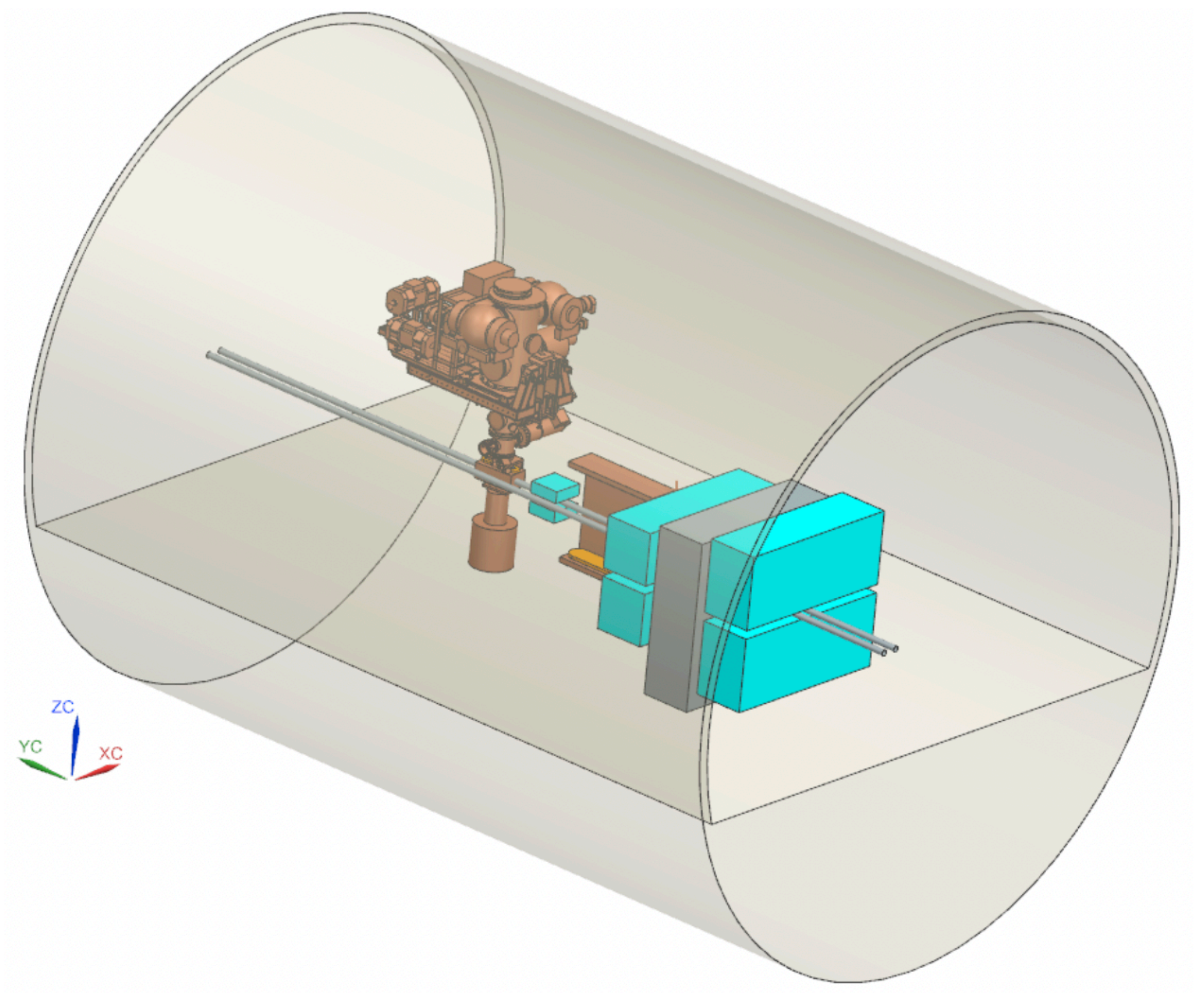
Polarized target

The plan is to develop the project in 2 phases:

1

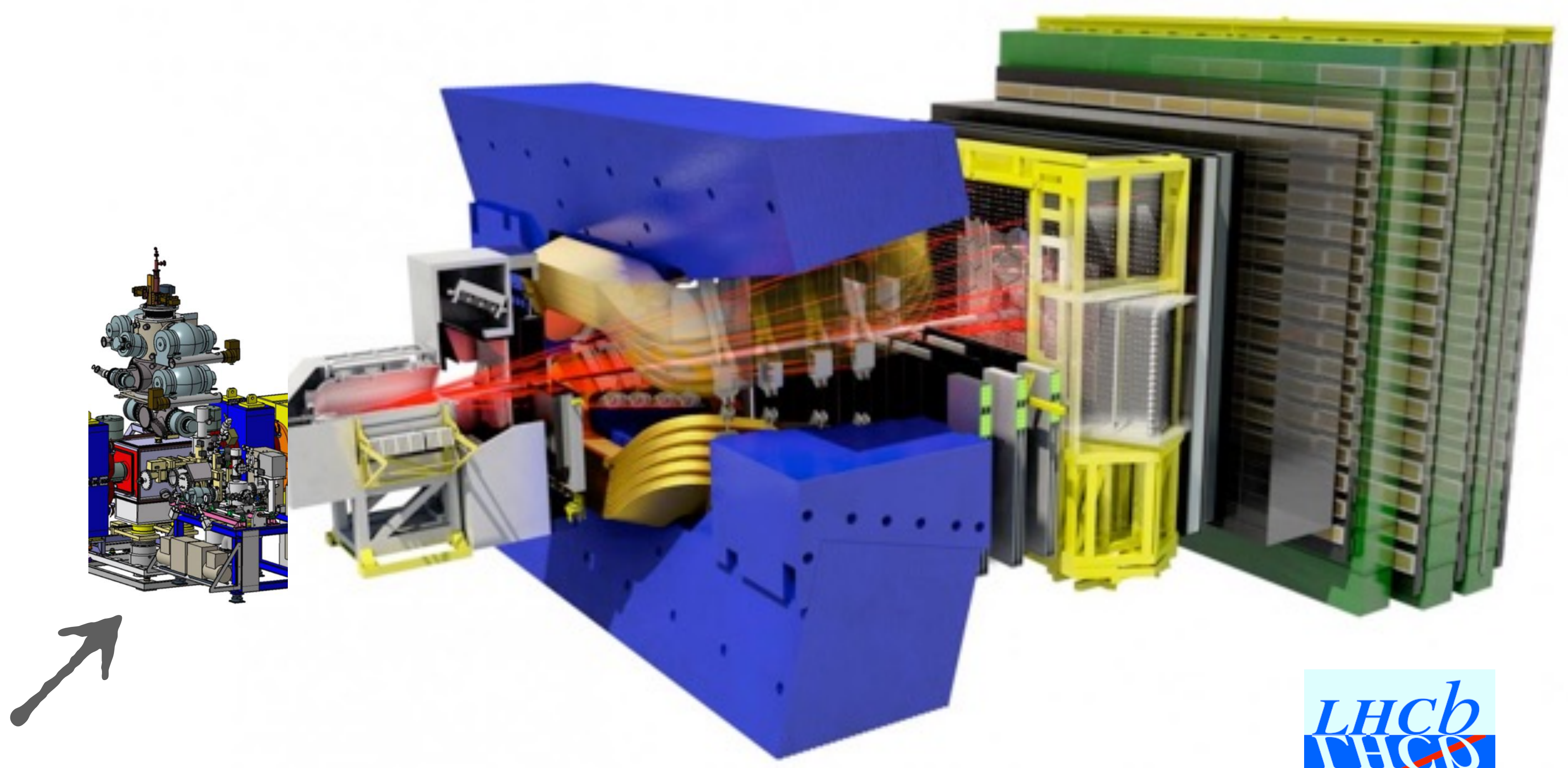
Develop a compact - LHCb independent - apparatus capable of:

- conducting R&D to have a “plug & play” PGT for Run5
- perform physics measurements never accessed before
- perform measurements connected to LHC
- etc…



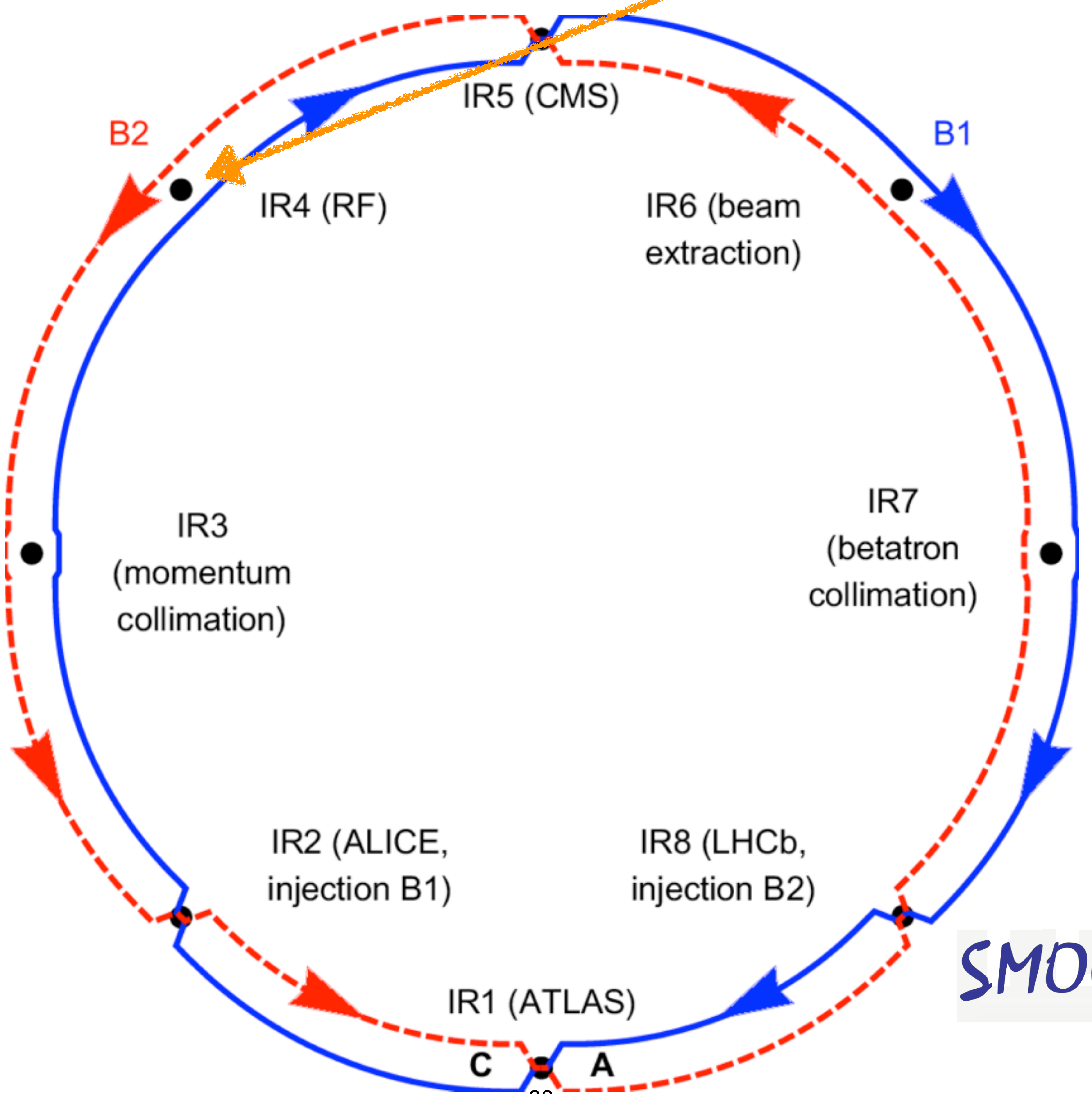
2

Install the PGT in LHCb for the Run5 and exploit all the enormous potentialities due to the LHCb (upgrade II) spectrometer: c-, b-quark reconstruction, rare probes, RTA, …



Polarized target

The LHC Interaction Regions



Other possibilities:
-IR3
-IR8 just before or after LHCb (beyond the wall)

The LHC Interaction Region 4

BGV

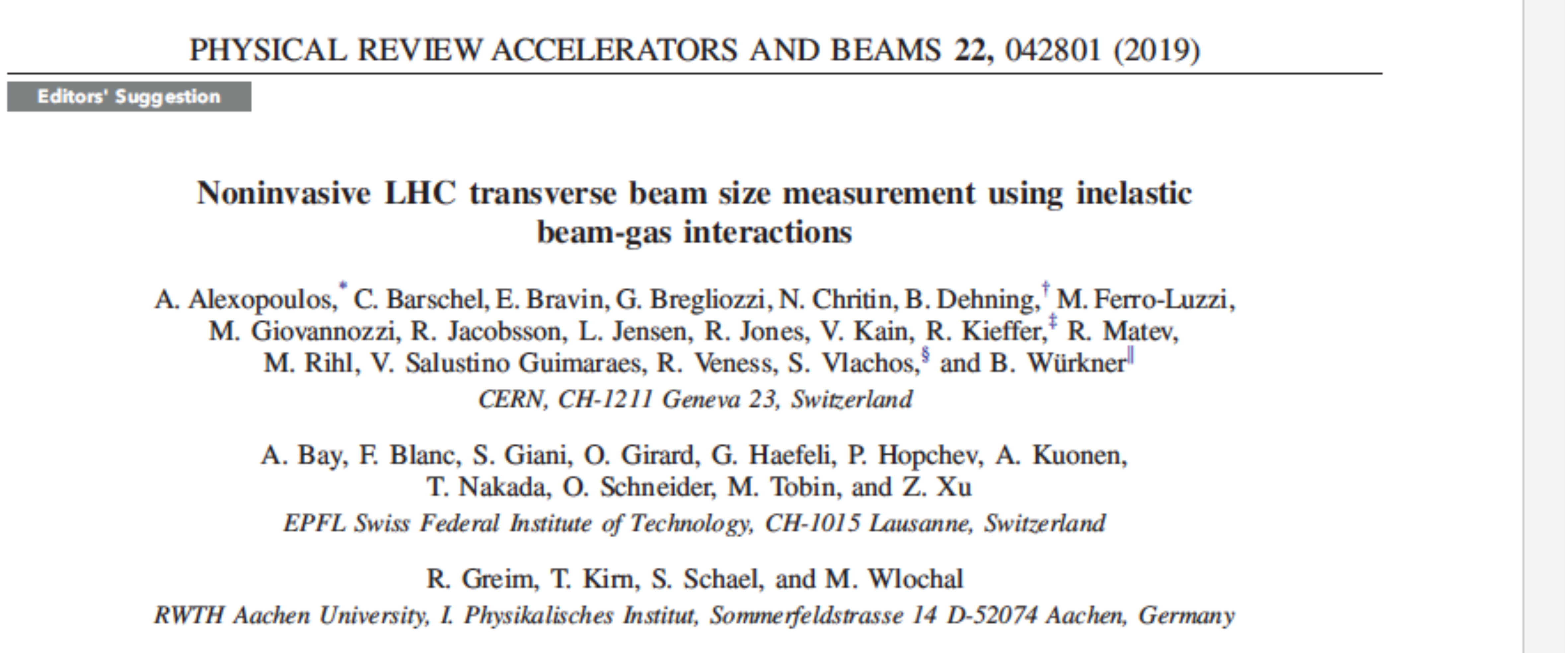

HiLumi
HL-LHC PROJECT

Beam Gas Vertex instrument
Potential integration of a gas jet as target

Robert Kieffer
rkieffer@cern.ch

BGC Collaboration Meeting at the Cockcroft Institute June 2019

https://indico.cern.ch/event/817655/contributions/3442649/attachments/1861615/3059737/2019_06_BGV_GasJetTarget.pdf


PHYSICAL REVIEW ACCELERATORS AND BEAMS **22**, 042801 (2019)

Editors' Suggestion

Noninvasive LHC transverse beam size measurement using inelastic beam-gas interactions

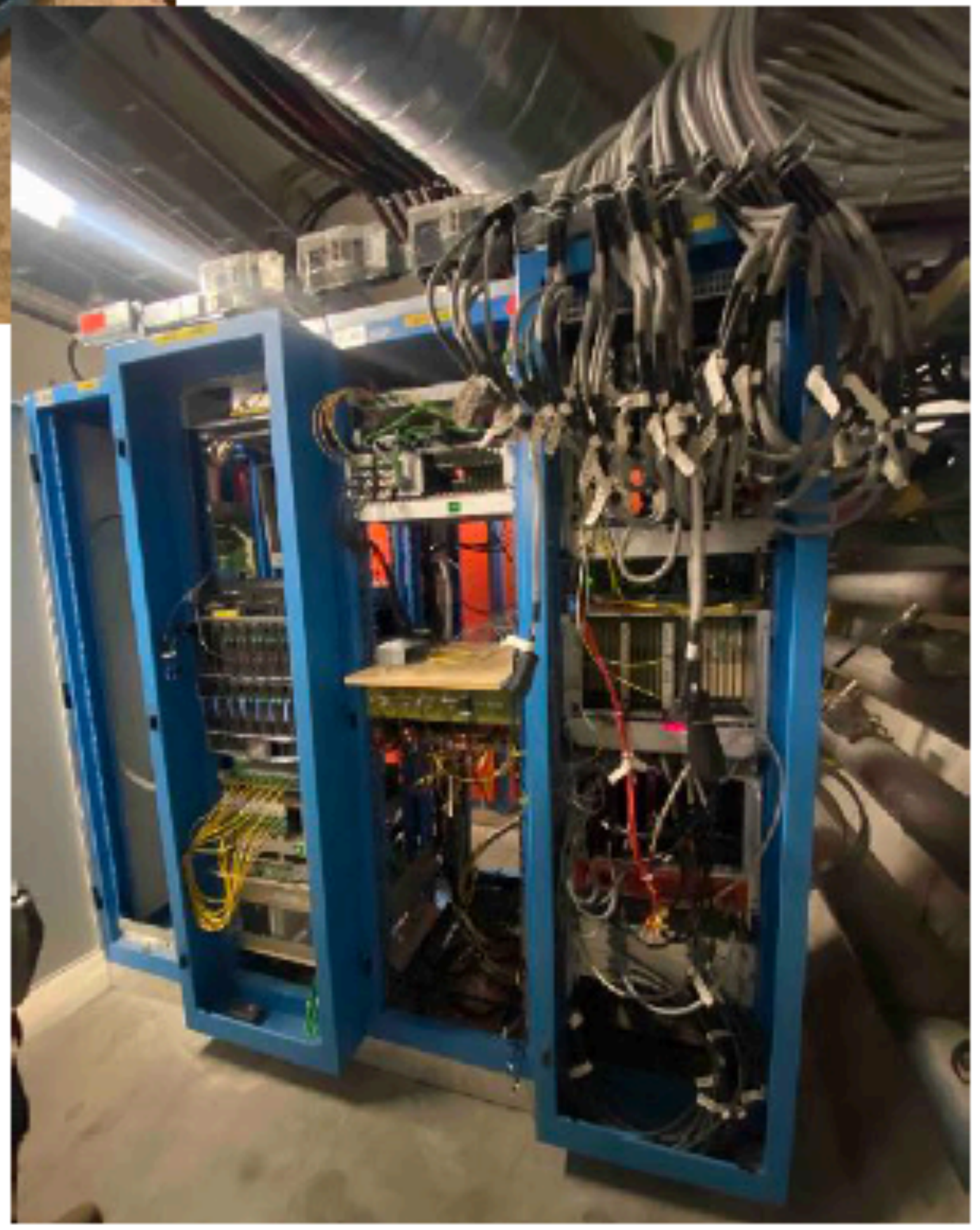
A. Alexopoulos,* C. Barschel, E. Bravin, G. Bregliozzi, N. Chritin, B. Dehning,† M. Ferro-Luzzi, M. Giovannozzi, R. Jacobsson, L. Jensen, R. Jones, V. Kain, R. Kieffer,‡ R. Matev, M. Rihl, V. Salustino Guimaraes, R. Veness, S. Vlachos,§ and B. Würkner‖
CERN, CH-1211 Geneva 23, Switzerland

A. Bay, F. Blanc, S. Giani, O. Girard, G. Haefeli, P. Hopchev, A. Kuonen, T. Nakada, O. Schneider, M. Tobin, and Z. Xu
EPFL Swiss Federal Institute of Technology, CH-1015 Lausanne, Switzerland

R. Greim, T. Kirn, S. Schael, and M. Wlochal
RWTH Aachen University, I. Physikalisches Institut, Sommerfeldstrasse 14 D-52074 Aachen, Germany

This apparatus is not used and could be replaced by LHCspin

Cables are available, as well as the rail for transporting the apparatus



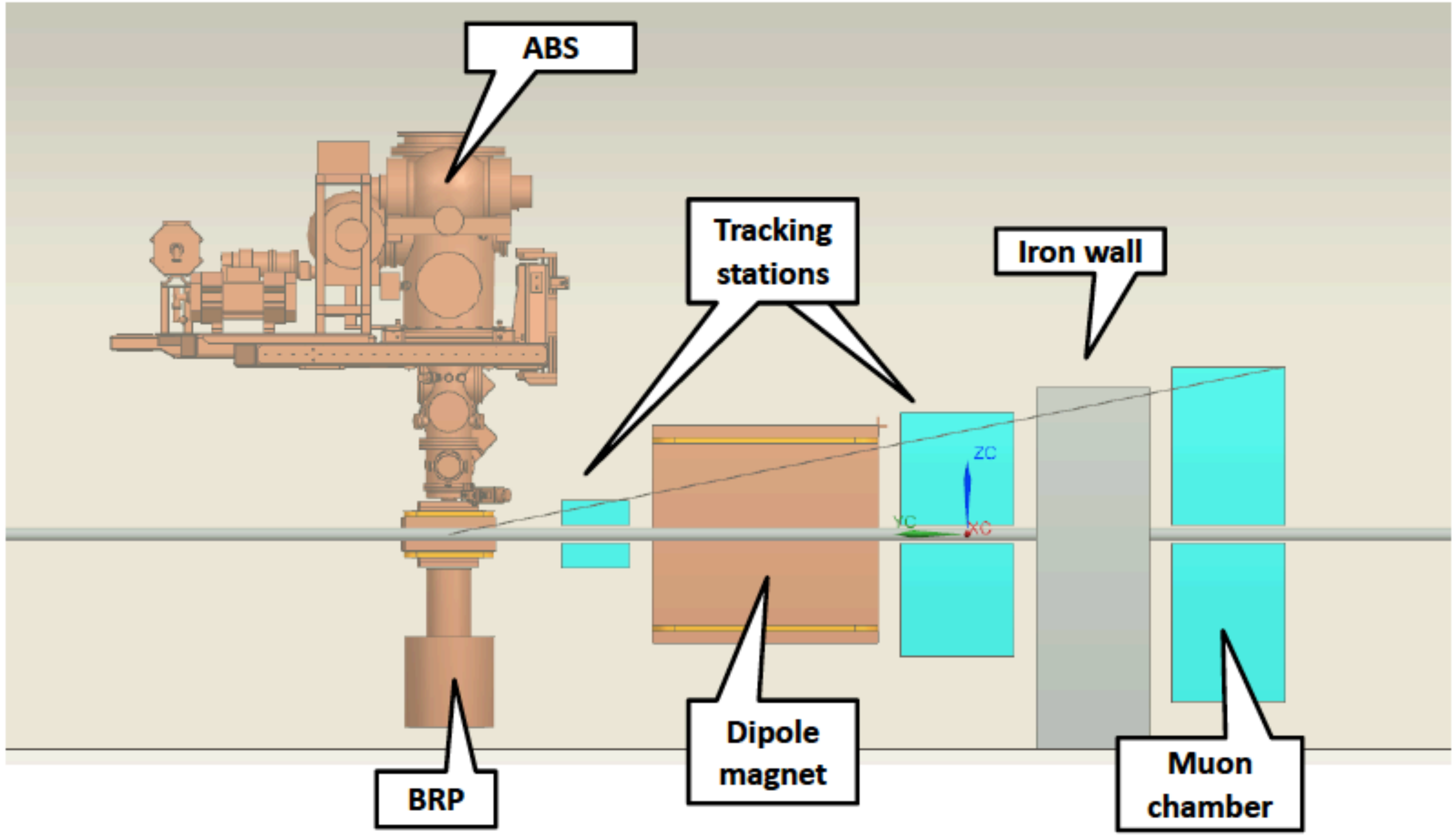
There are racks available

Detector concept at the IR4

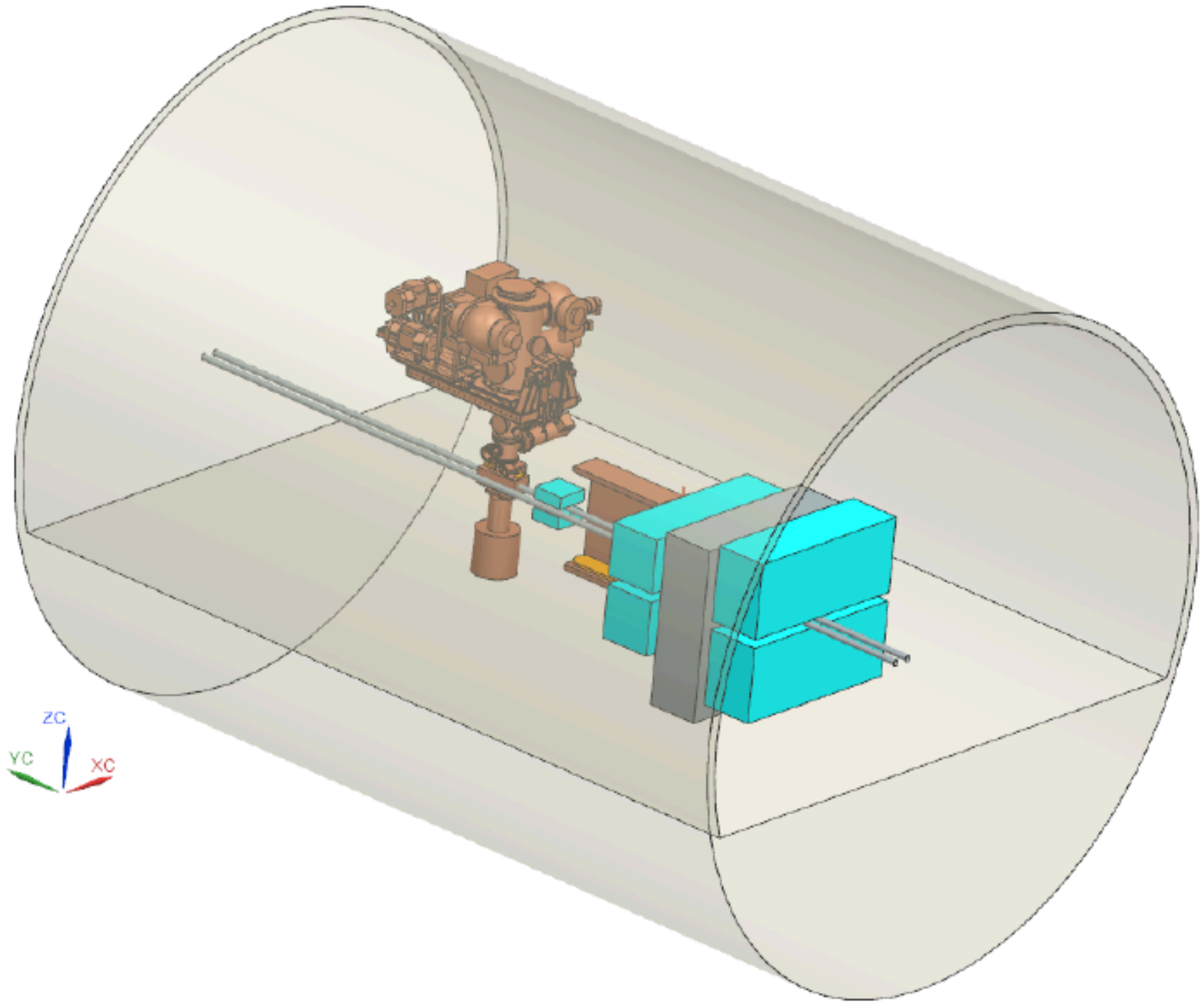
Goals:
- proof of principle of the future (large-scale) experiment with LHCb.
- measurement of single-spin asymmetries in inclusive hadron production in $pH^{\uparrow}$ and $PbH^{\uparrow}$ (see next slides)

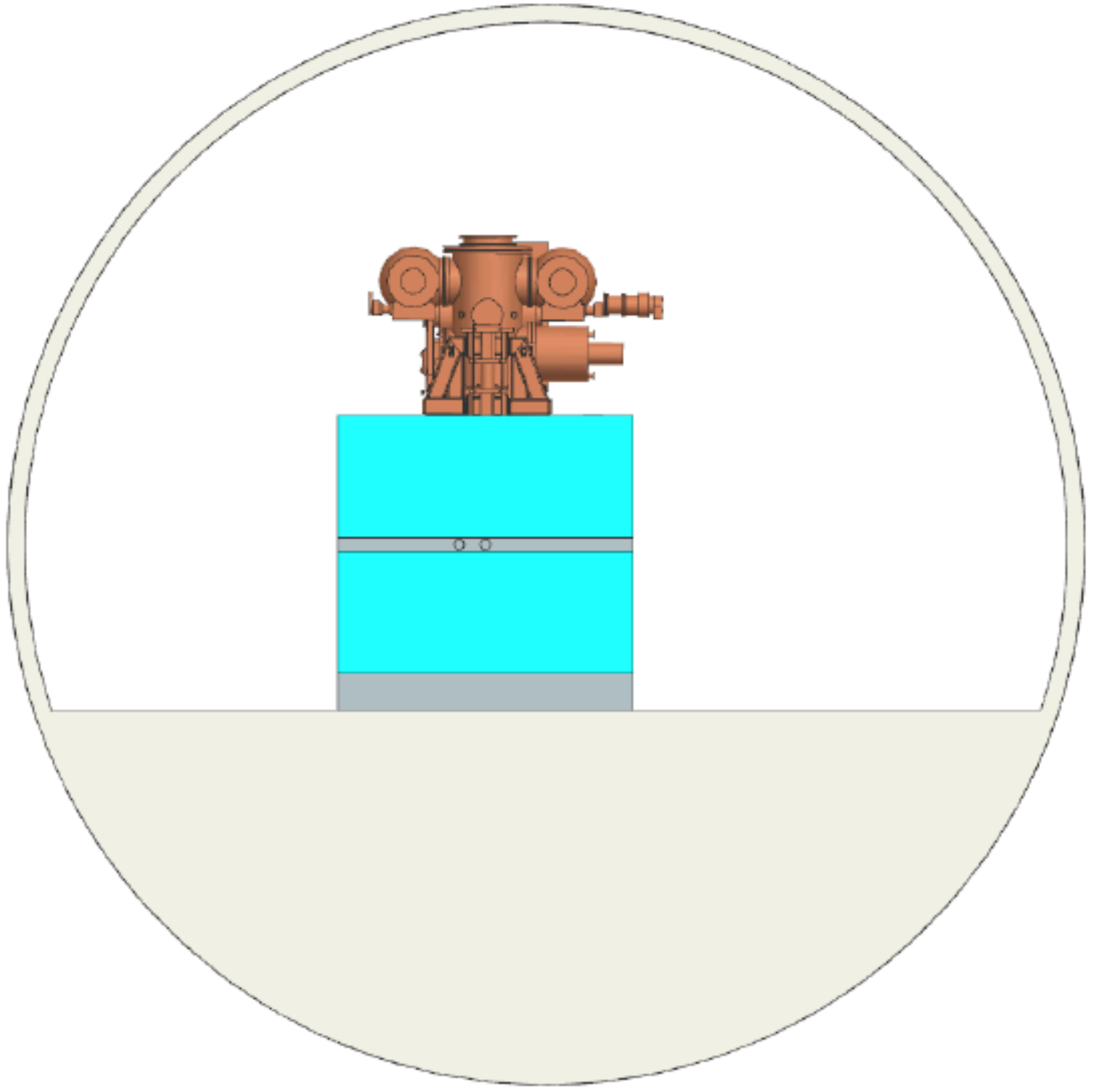
Apparatus:
- jet-target (but could be done also with storage cell)
- full (minimal) spectrometer: dipole magnet, tracking stations, muon system
- simple PID detectors (Calo, RICH)?

Needed expertise (apart from pol. target):
- dipole magnet
- tracking detectors (Si strip, SciFi, drift chambers?)
- muon chambers (MWPC?)
- electronics
- DAQ
- slow control
- tracking/reconstruction algorithms
- ...

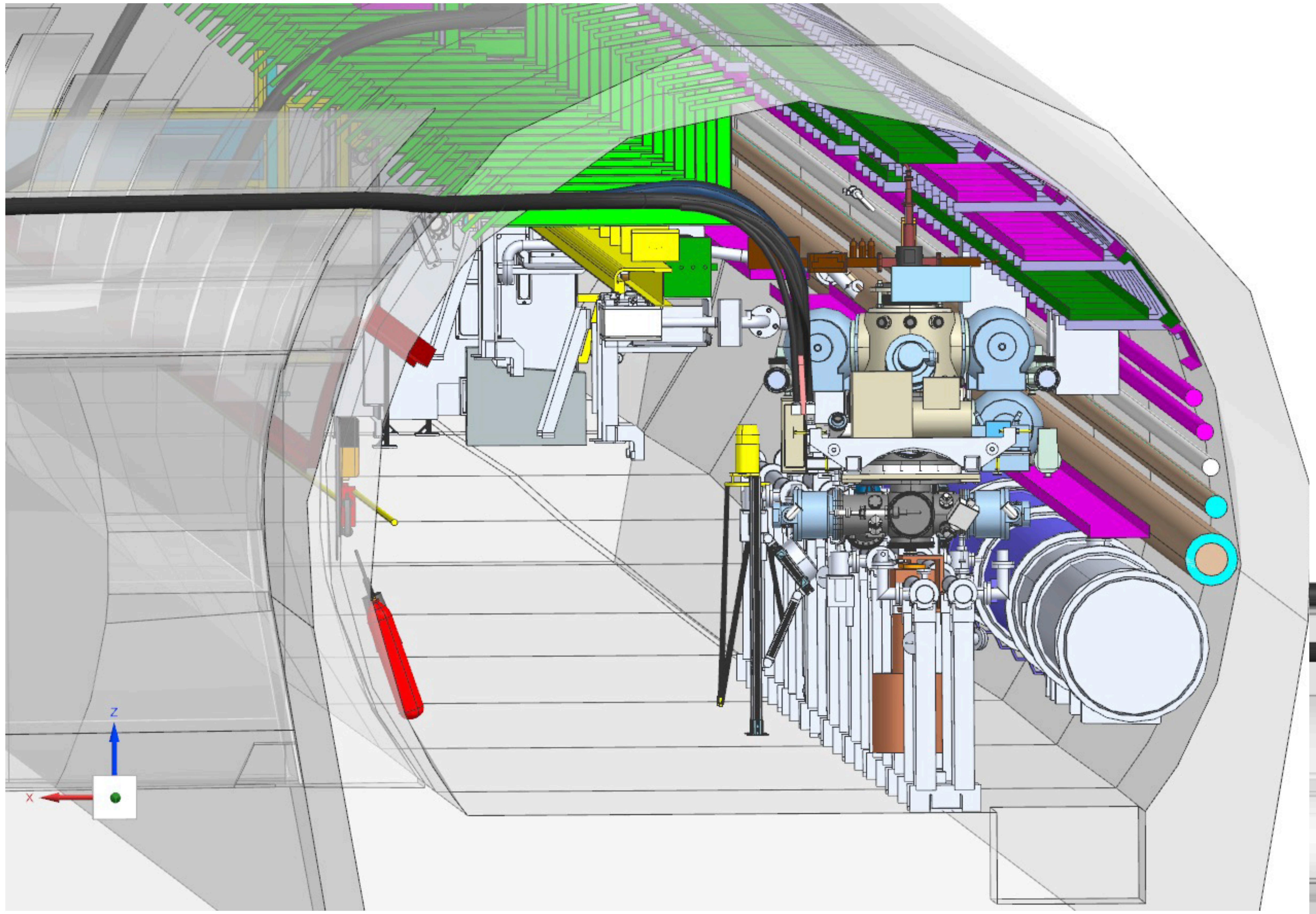


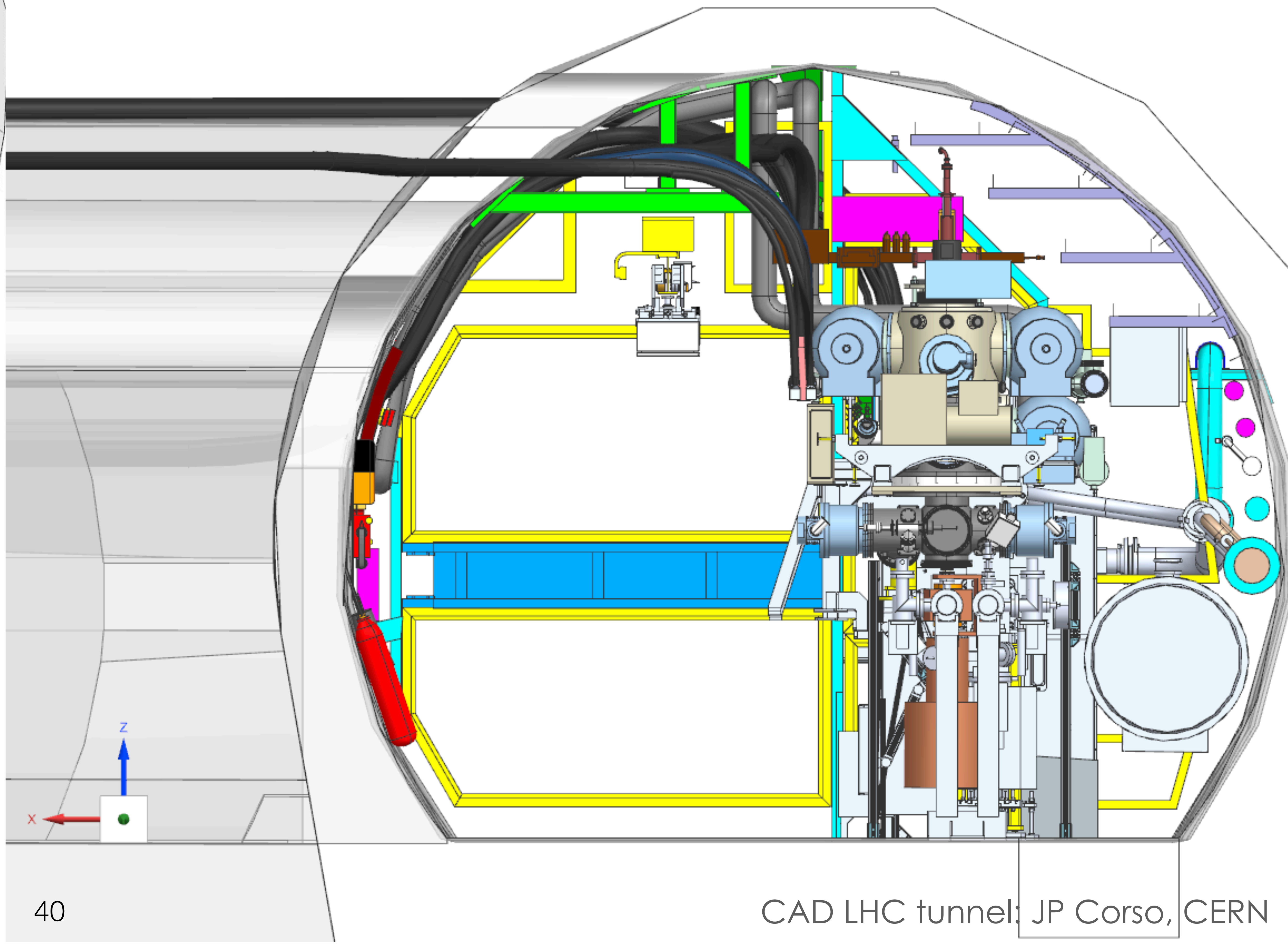
Detector concept at the IR4





CAD LHC tunnel: JP Corso, CERN

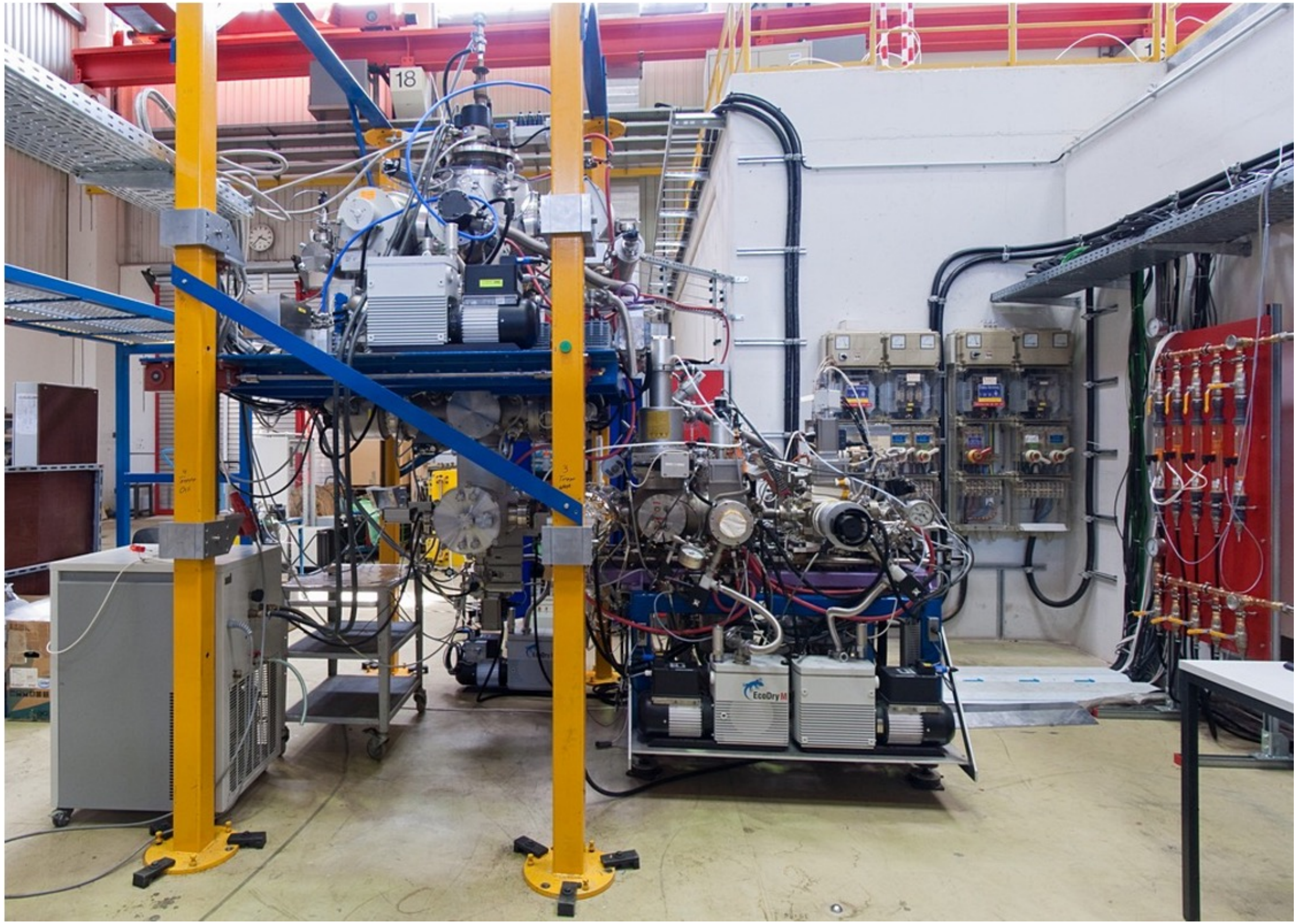




-It is a bit tight, but we don’t currently see any showstoppers in the available space

CAD LHC tunnel: JP Corso, CERN

The existing target ready to be used for the R&D



The R&D work is proceeding well

lhcspin@lists.lnf.infn.it

There already several WPs working on different subjects
The idea is to present an EoI to the LHCC in the next few months

Polarized ABS
- Alexander Nass
- Davide Reggiani
- Erhard Steffens
- Giuseppe Ciullo
- Giuseppe Tagliente
- Massi Ferro Luzzi
- Paolo Lenisa
- Pasquale Di Nezza
- Norbert Koch
- Ralf Engels
- Tarek El Kordy

BRP
- Davide Reggiani
- Erhard Steffens
- Giuseppe Ciullo
- Giuseppe Tagliente
- Paolo Lenisa
- Pasquale Di Nezza
- Ralf Engels
- Tarek El Kordy

Absolute pol.
- Erhard Steffens
- Giuseppe Ciullo
- Giuseppe Tagliente
- Luciano Pappalardo
- Paolo Lenisa
- Pasquale Di Nezza
- Ralf Engels
- Tarek El Kordy

BGV integr.
- Giuseppe Ciullo
- Massi Ferro Luzzi
- Pasquale Di Nezza
- Saverio Mariani

Spectrometer
- Aram Movsisyan
- Bakur Parsamyan
- Chiara Oppedisano
- Erika De Lucia
- Giuseppe Tagliente
- Luciano Pappalardo
- Marcello Rotondo
- Marco Mirazita
- Marco Santimaria
- Massi Ferro Luzzi
- Norihito Doshita
- Pasquale Di Nezza
- Saverio Mariani
- Takahiro Iwata
- Vito Carassiti

Physics channels
- Aram Kotzinian
- Aram Movsisyan
- Bakur Parsamyan
- Chiara Oppedisano
- Cynthia Hadjidakis
- Luciano Pappalardo
- Marco Mirazita
- Marco Santimaria
- Norihito Doshita
- Pasquale Di Nezza
- Takahiro Iwata

DB repository
- Chiara Lucarelli
- Pasquale Di Nezza
- Saverio Mariani

Dissemination
- Chiara Oppedisano
- Pasquale Di Nezza
- Susanna Bertelli

Very valuable note: all this developed at CERN, along LHC, in an international contest, by a small group of colleagues

Cost

Jet target solution

Total cost - 400 kE

Storage Cell solution (including the absolute polarimeter)

Total cost - 600 kE

Then we have to add the spectrometer part

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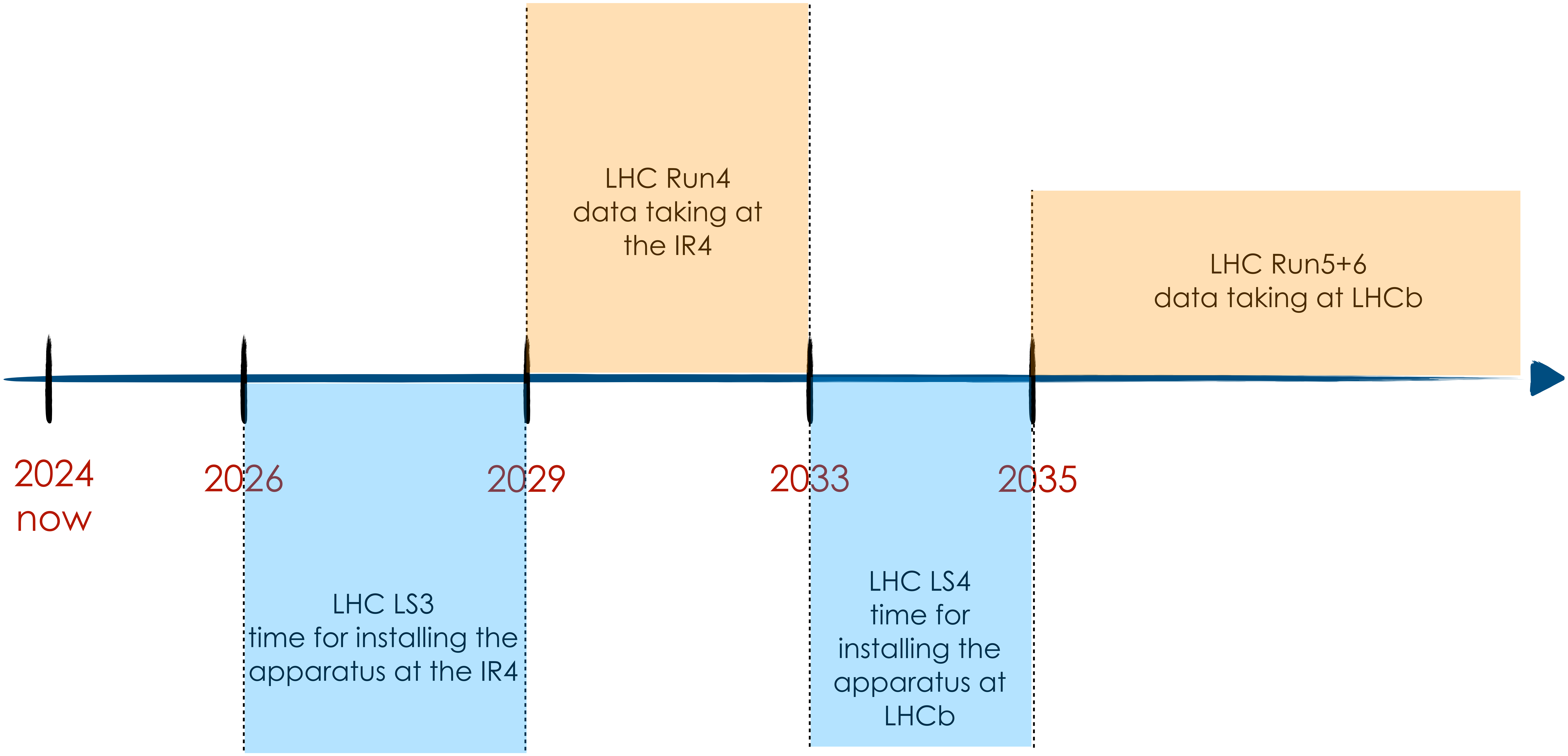
Storage Cell solution (including the absolute polarimeter)

Total cost - 600 kE

Then we have to add the spectrometer part

LHCb will include the polarized target in the official upgrade plan. I believe that, even though the IR4 proposal is independent, having the LHCb upgrade stamp adds value. At a certain point, LHCb will ask to become a "technical associate". This request does not imply any special obligation (no fee, no duties, no LHCb authorship), it is simply an expression of interests

Timetable



LHC Run4
data taking at
the IR4
LHC Run5+6
data taking at LHCb
2024
now
2026
2029
2033
2035
LHC LS3
time for installing the
apparatus at the IR4
LHC LS4
time for
installing the
apparatus at
LHCb

International framework and feedback

Several experiments dedicated to spin physics, but with many limitations:
very low energy, no rare probes, no ion beam, … ➡ LHCspin is unique in this respect

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Several experiments dedicated to spin physics, but with many limitations:
very low energy, no rare probes, no ion beam, … → LHCspin is unique in this respect

LHCspin is complementary to EIC

[D. Boer: arXiv:1611.06089] unpolarized gluon TMD

	DIS	DY	SIDIS	$pA \to \gamma\, \text{jet}\, X$	$e\,p \to e'\, Q\,\overline{Q}\, X$ $e\,p \to e'\, j_1\, j_2\, X$	$pp \to \eta_{c,b}\, X$ $pp \to H\, X$	$pp \to J/\psi\, \gamma\, X$ $pp \to \Upsilon\, \gamma\, X$
$f_1^{g\,[+,+]}$ (WW)	×	×	×	×	√	√	√
$f_1^{g\,[+,-]}$ (DP)	√	√	√	√	×	×	×

linearly polarized gluon TMD

	$pp \to \gamma\,\gamma\, X$	$pA \to \gamma^*\, \text{jet}\, X$	$e\,p \to e'\, Q\,\overline{Q}\, X$ $e\,p \to e'\, j_1\, j_2\, X$	$pp \to \eta_{c,b}\, X$ $pp \to H\, X$	$pp \to J/\psi\, \gamma\, X$ $pp \to \Upsilon\, \gamma\, X$
$h_1^{\perp\, g\,[+,+]}$ (WW)	√	×	√	√	√
$h_1^{\perp\, g\,[+,-]}$ (DP)	×	√	×	×	×

TMDs (Sivers) [D. Boer: arXiv:1611.06089, D. Boer et al. HEPJ 08 2016 001]

	DY	SIDIS	$p^\uparrow A \to h\, X$	$p^\uparrow A \to \gamma^{(*)}\, \text{jet}\, X$	$p^\uparrow p \to \gamma\,\gamma\, X$ $p^\uparrow p \to J/\psi\, \gamma\, X$ $p^\uparrow p \to J/\psi\, J/\psi\, X$	$e\,p^\uparrow \to e'\, Q\,\overline{Q}\, X$ $e\,p^\uparrow \to e'\, j_1\, j_2\, X$
$f_{1T}^{\perp\, g\,[+,+]}$ (WW)	×	×	×	×	√	√
$f_{1T}^{\perp\, g\,[+,-]}$ (DP)	√	√	√	√	×	×

$f_{1T}^{\perp g[+,+]}$ (Weizsacker-Williams type or "**f-type**") → antisymmetric colour structures

$f_{1T}^{\perp g[+,-]}$ (Dipole s type or "**d-type**") → symmetric colour structures

Can be measured at the Electron Ion-Collider (EIC)

Can be measured at LHCspin

"Ambitious and long term LHC-Fixed Target research program. The efforts of the existing LHC experiments to implement such a programme, including specific R&D actions on the collider, deserve support" (European Strategy for Particle Physics)

"This would be unique and highly complementary to existing and future measurements in lepton-proton collisions, because the asymmetries in question have a process dependence between pp and lp that is predicted by theory" (CERN Physics Beyond Collider)

Recognised relevance

Conclusions

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It will pave the way for another new frontier for LHC