The L⇅C spin project

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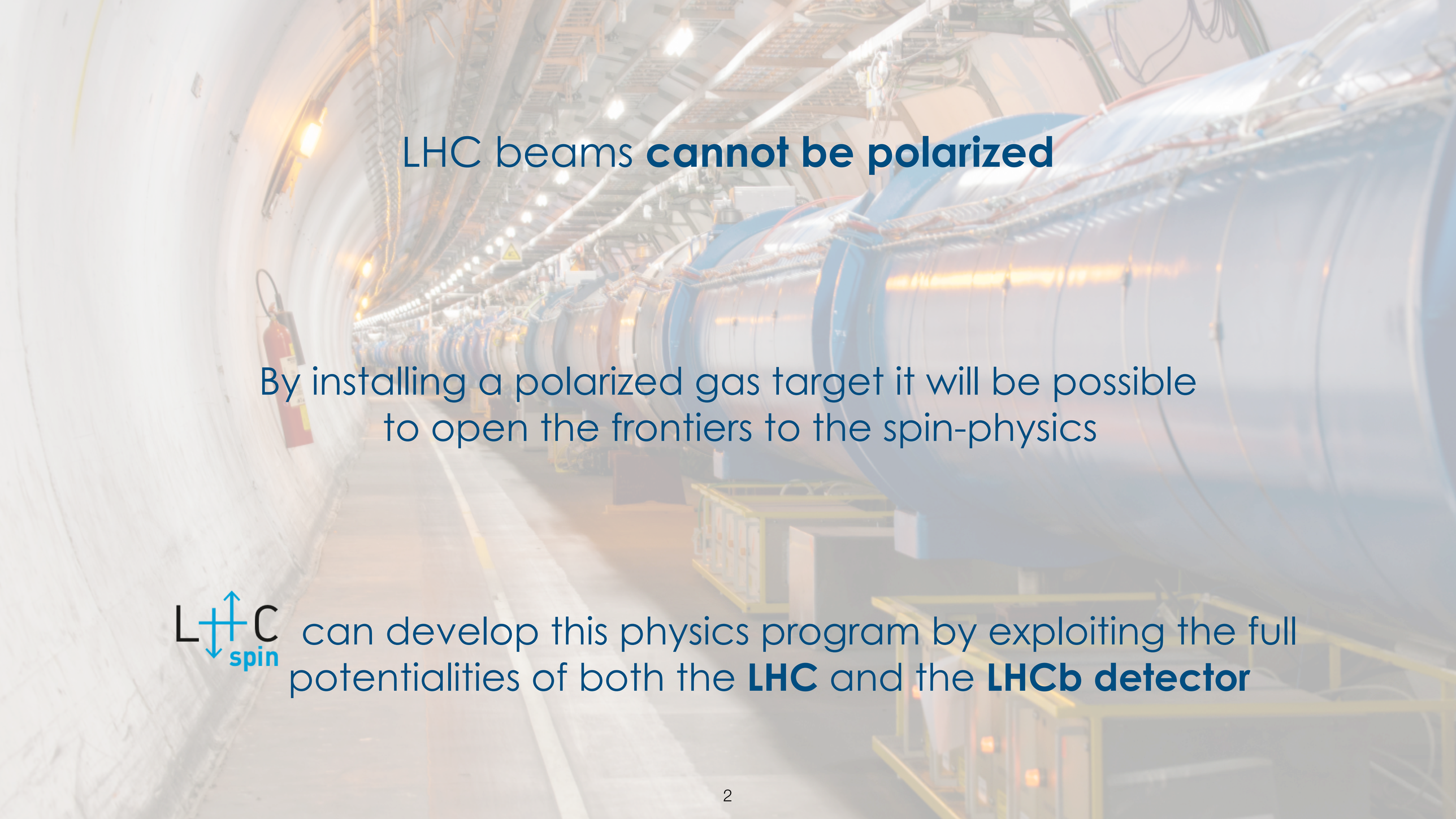
(1) CERN, (2) CNRS Saclay, (3) Duke University, (4) FZ Julich, (5) INFN Bari, (6) INFN Ferrara, (7) INFN Firenze, (8) INFN Frascati, (9) INFN Torino, (10) PSI Zurich, (11) TH Nuremberg, (12) University of Erlangen, (13) University of Ferrara, (14) University of Yamamata, (15) University of Yerevan

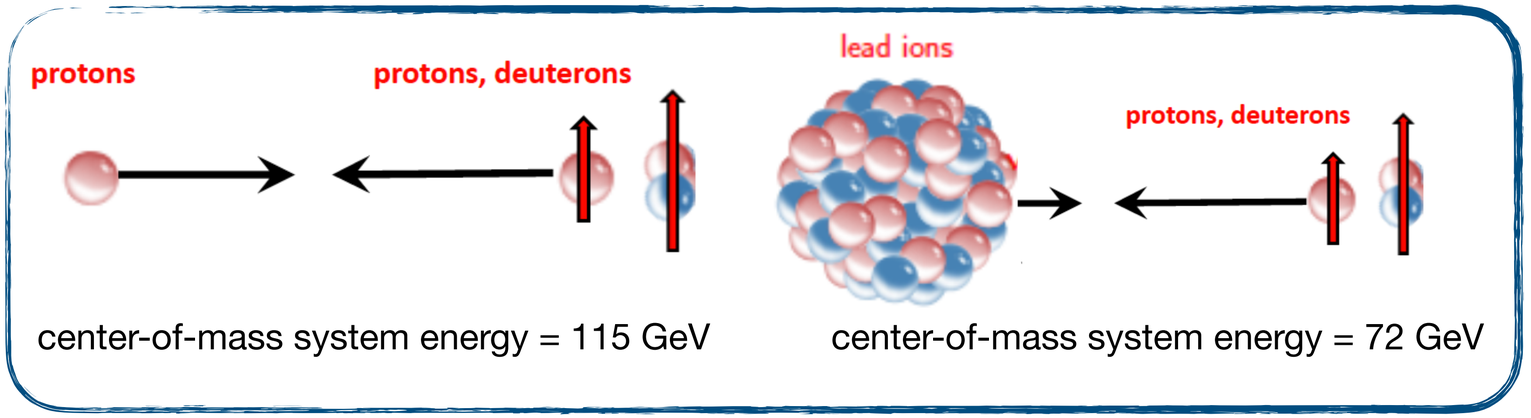


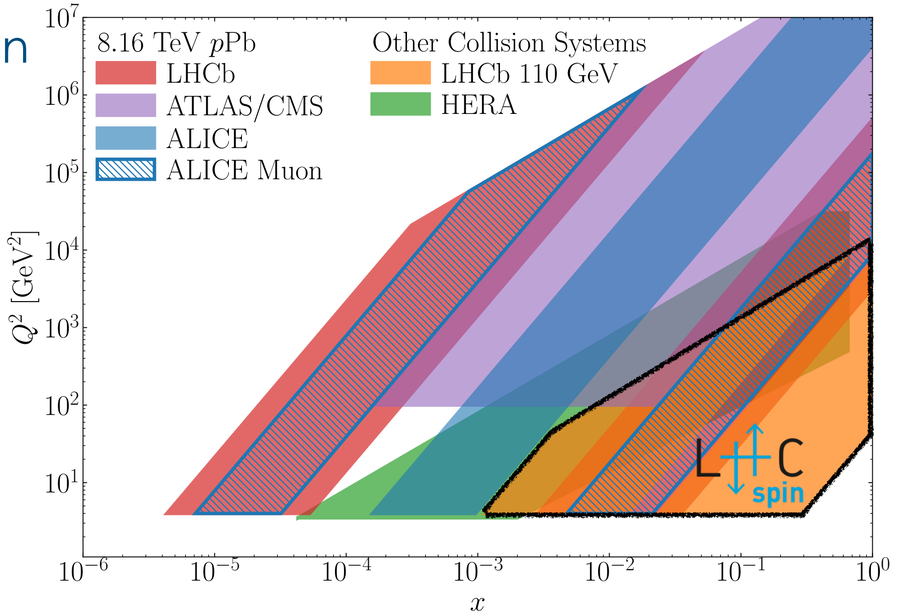
LHC beams **cannot be polarized**

By installing a polarized gas target it will be possible
to open the frontiers to the spin-physics

LHC spin can develop this physics program by exploiting the full potentialities of both the **LHC** and the **LHCb detector**

- Multi-dimensional nucleon structure in a poorly explored kinematic domain





- Make use of <u>new</u> probes (charmed and beauty mesons)

LHCb has been conceived and optimised for heavy-flavour physics

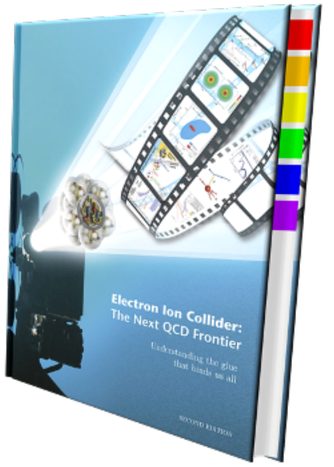
(η, η_c, $\eta_c(2S)$,$\chi_{c,b}$ = tri-gluon corr.), J/Ψ, Ψ', di–J/Ψ, Υ(1, 2, 3S), D, B-mesons, DY ($\mu^+\mu^-$) …

- Complement and extend present and future results (Compass, JLab, RHIC and, in particular, EIC)

US machine

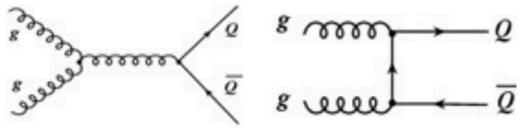
cost ~3 B$

time scale >>2035

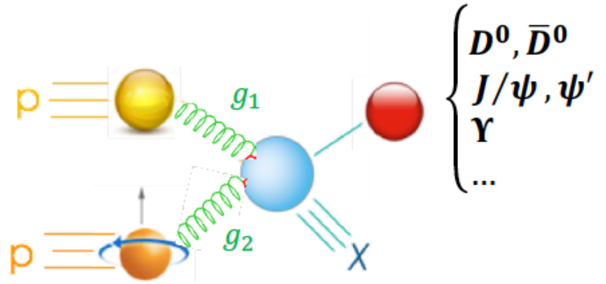


Gluon TMDs

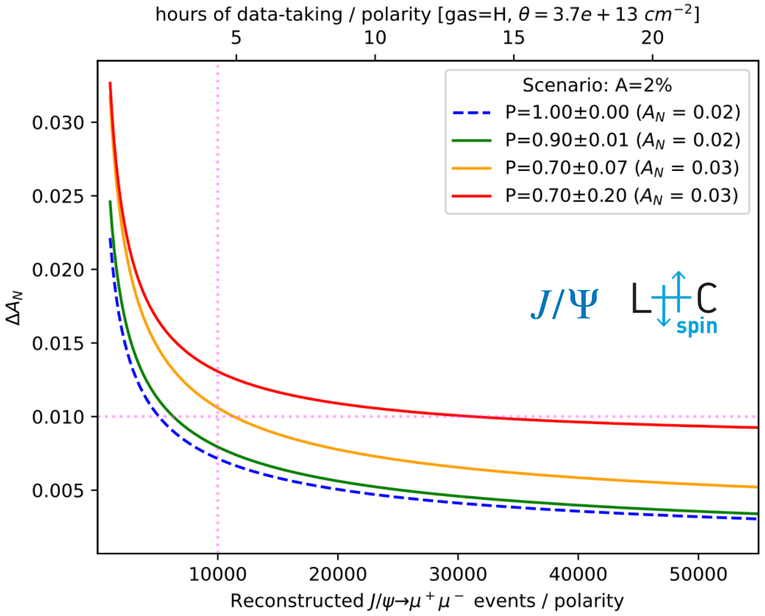
Completely unconstrained!

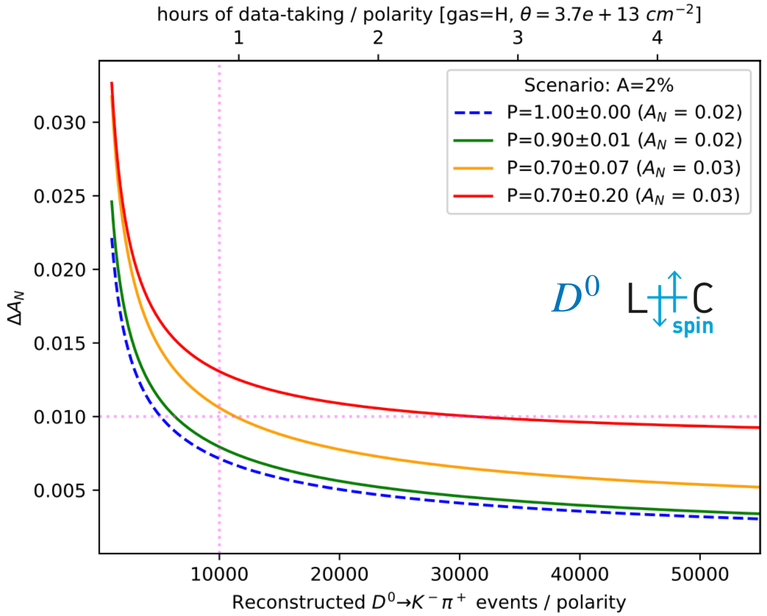


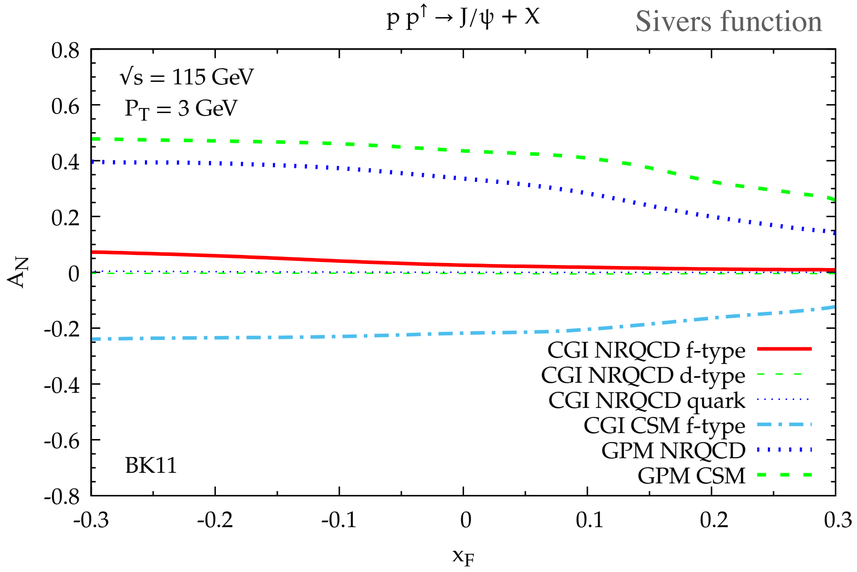
dominant process at LHC



- $pp^{\uparrow} \rightarrow Q\bar{Q}_{[HF]}X$ is the ideal observable to access gTMDs ($q_T(Q) \ll M_Q$)
- Deep insight into the nucleon gluon dynamics
- Sheds light on spin-orbit correlations
- Sensitive to the totally unknown gluon Orbital Angular Momentum



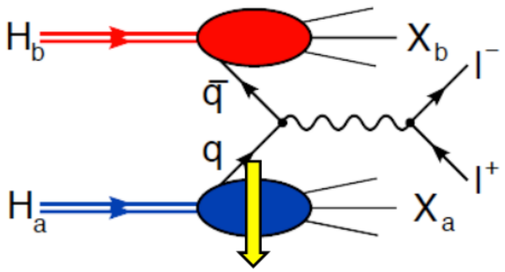




Phys. Rev. D 102, 094011 (2020)

Huge statistics of reconstructed particles

Quark TMDs



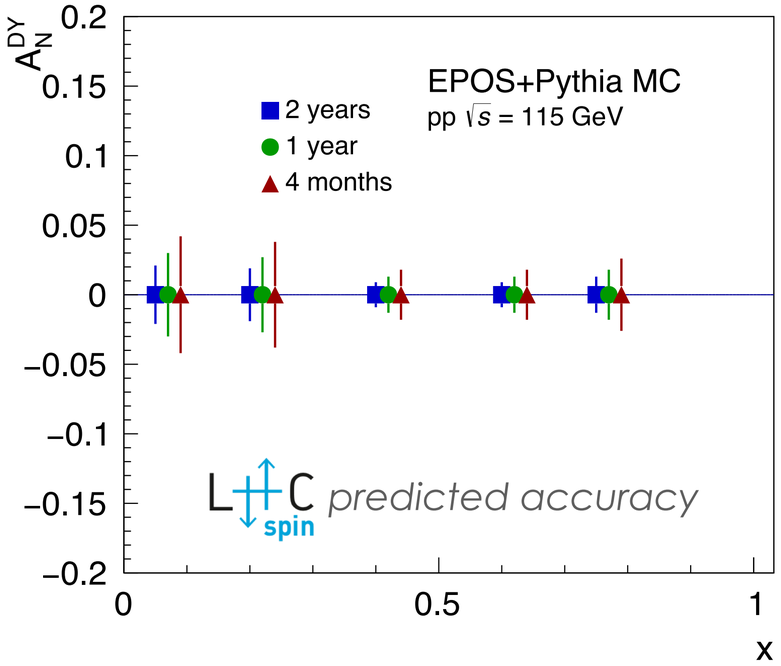
Golden Channel

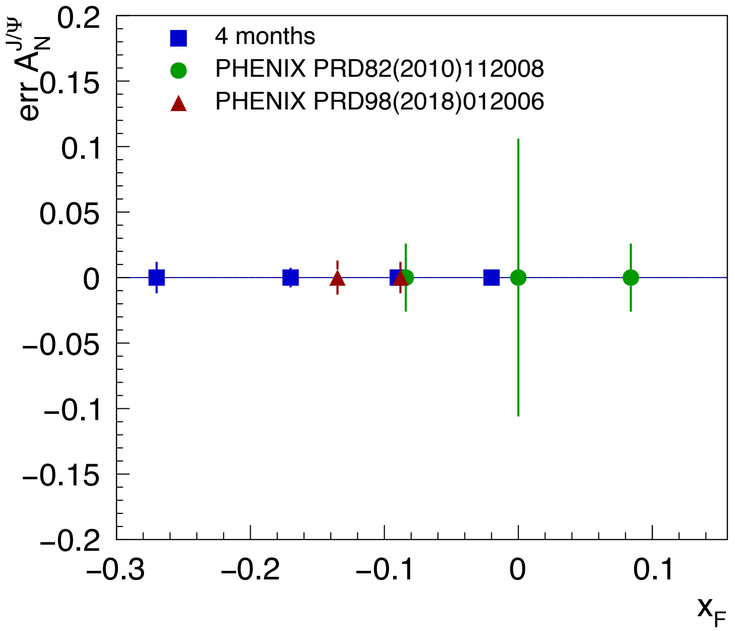
Transversely polarized Drell-Yan

hadron+hadron → lepton+lepton

We access Leading Order QCD fundamental functions

$$A_N^{DY} = \frac{1}{P}\frac{\sigma_{DY}^{\uparrow} - \sigma_{DY}^{\downarrow}}{\sigma_{DY}^{\uparrow} + \sigma_{DY}^{\downarrow}}$$





Comparison with RHIC results

Channel	Events / week	Total yield
$J/\psi \to \mu^+\mu^-$	6.3×10^5	7.6×10^7
$D^0 \to K^-\pi^+$	3.2×10^6	3.8×10^8
$\psi(2S) \to \mu^+\mu^-$	1.1×10^4	1.3×10^6
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (DPS)	4.2×10^{-1}	5.0×10^1
$J/\psi J/\psi \to \mu^+\mu^-\mu^+\mu^-$ (SPS)	1.2	1.5×10^2
Drell Yan ($5 < M_{\mu\mu} < 9$ GeV)	3.6×10^2	4.3×10^4
$\Upsilon \to \mu^+\mu^-$	2.7×10^2	3.3×10^4
$\Lambda_c^+ \to pK^-\pi^+$	6.3×10^4	7.6×10^6

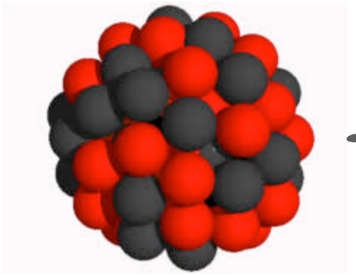
reconstructed particles

The **statistical precision achievable with LHCspin is remarkably high**, even for channels never measured before, indicating the potential for significant advancements in the field of research within a relatively short timeframe

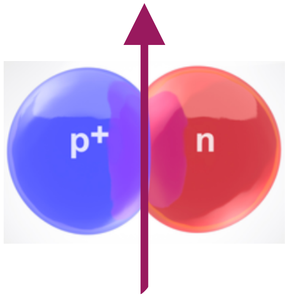
An experimental **statistical precision of 10%**, that LHCspin can easily reach, will improve the current theoretical knowledge by more than **an order of magnitude**

A new opportunity: spin physics in heavy-ion collisions

Never measured before
Unique possibility ❗

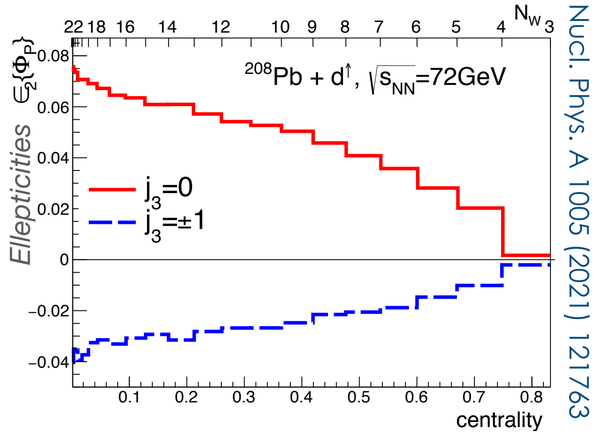


$\sqrt{s_{NN}} = 72\ GeV$



Deep insight into the dynamics of small systems:

a new probe for studying collectivity phenomena



Phys. Rev. Lett. 121 (2018) 202301
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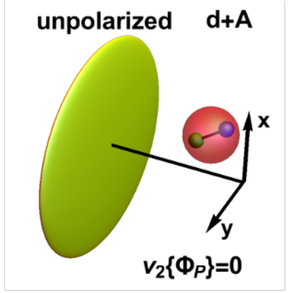
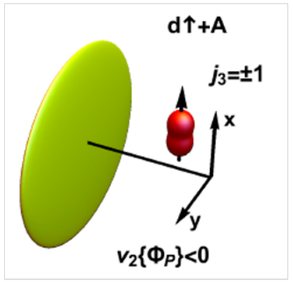
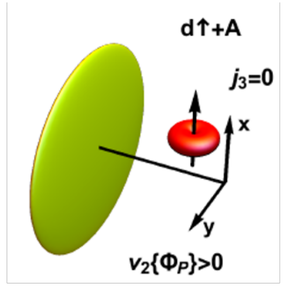


Unpol. deuterons: the **fireball is azimuthally symmetric** and $v_2 \approx 0$.



$j_3 = \pm 1$ → **prolate fireball** stretched along the pol. axis, corresponds to $v_2 < 0$



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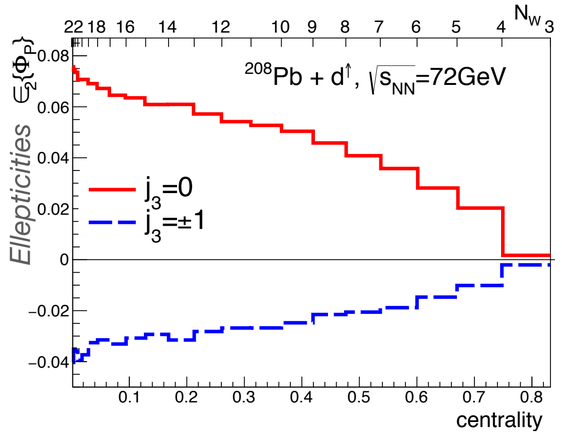

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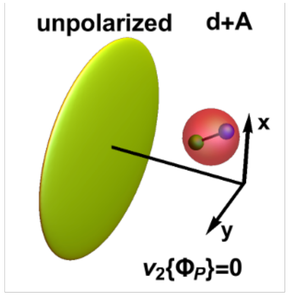

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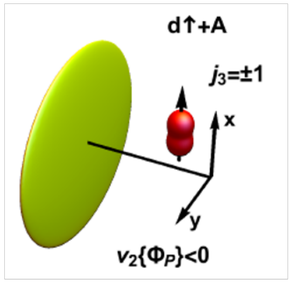

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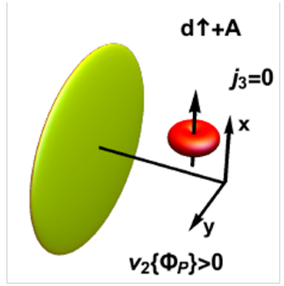

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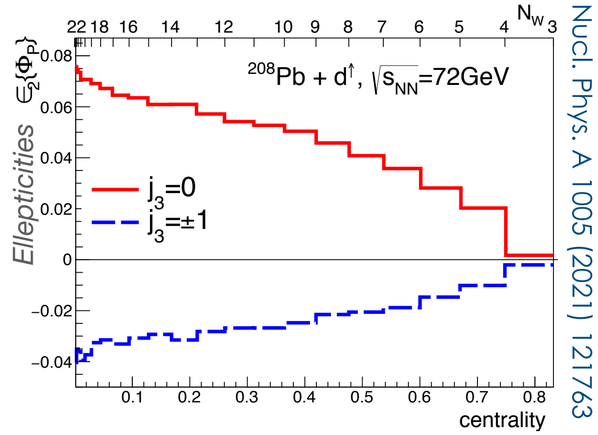

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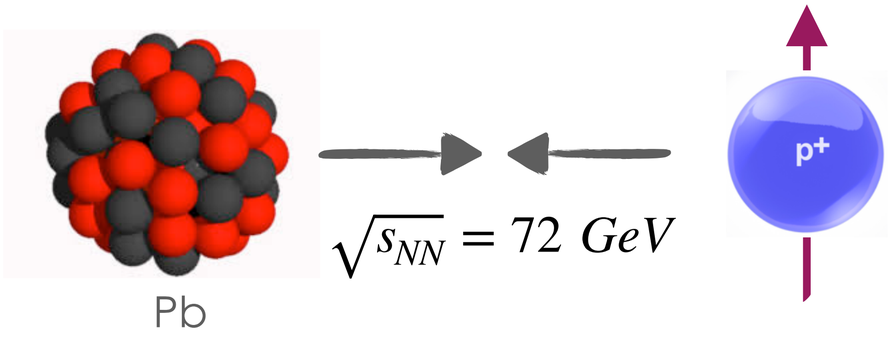
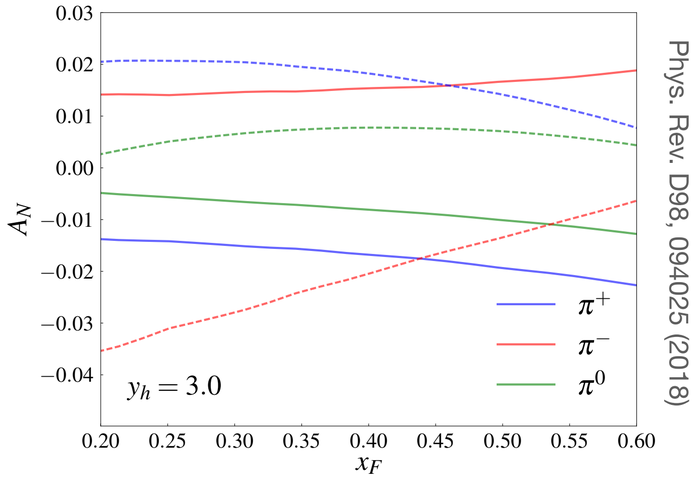
Single spin asymmetries in ultra-peripheral $p^{\uparrow}A \rightarrow hAX$ collisions

to access the twist-three contributions of the fragmentation functions





Phys. Rev. D98, 094025 (2018)

The kinematic region and the required precision well fit the LHCspin potentialities

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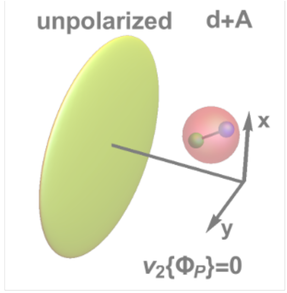
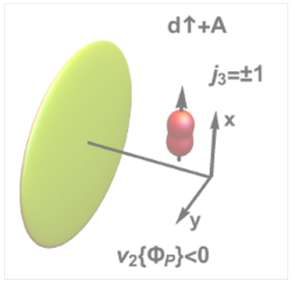
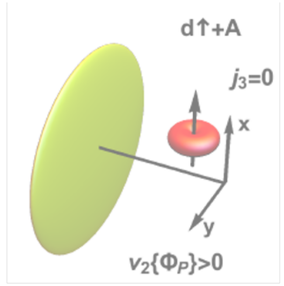
Never measured before
Unique possibility !







Unpol. deuterons: the
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sy

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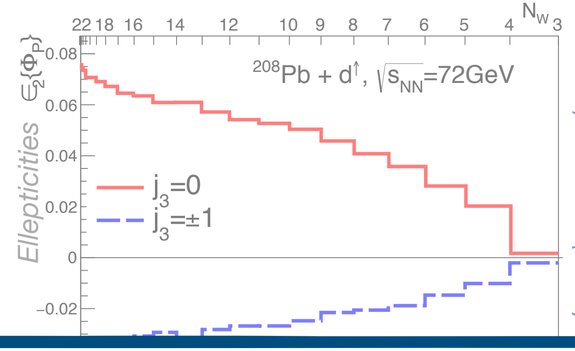


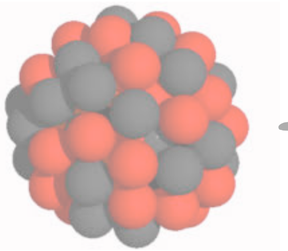
Nucl. Phys. A 1005 (2021)

Phys. Rev. Lett. 121 (2018) 202301

There are 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

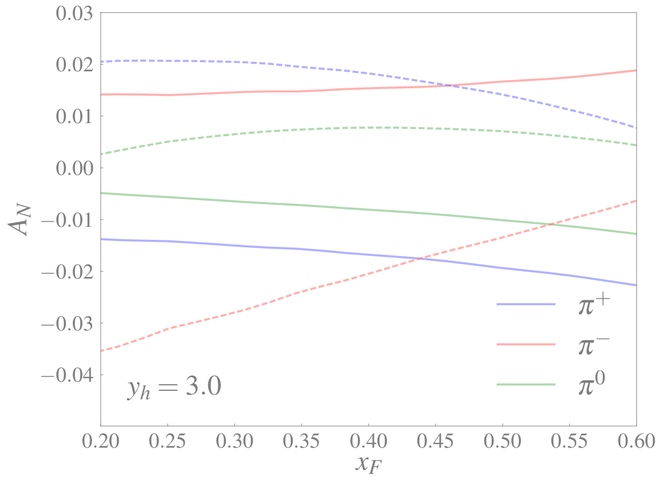


Pb

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

p+

to access the twist-three contributions of the fragmentation functions

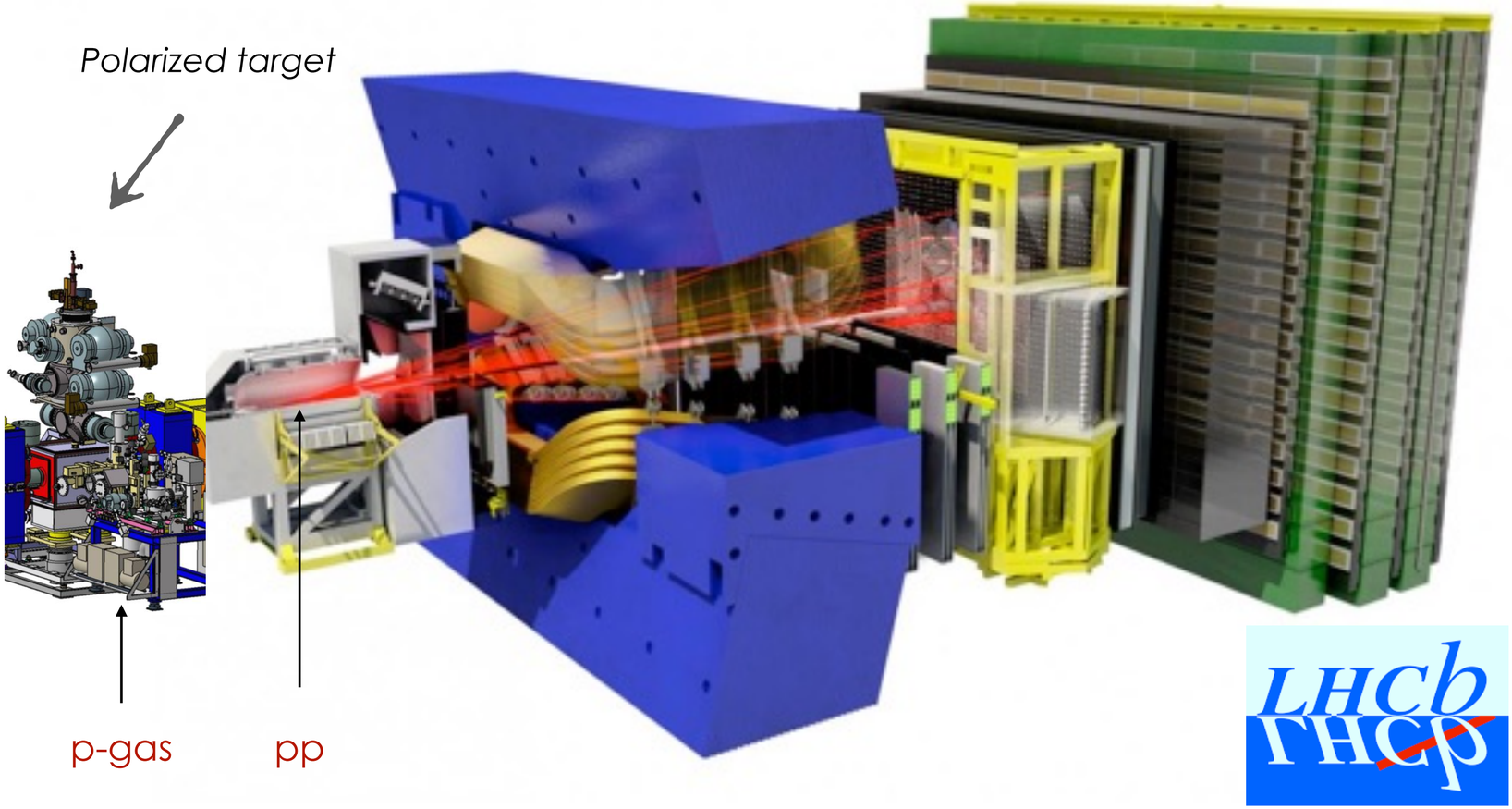


Phys. Rev. D98, 094025 (2018)

The kinematic region and the required precision well fit the LHCspin potentialities

The hardware system

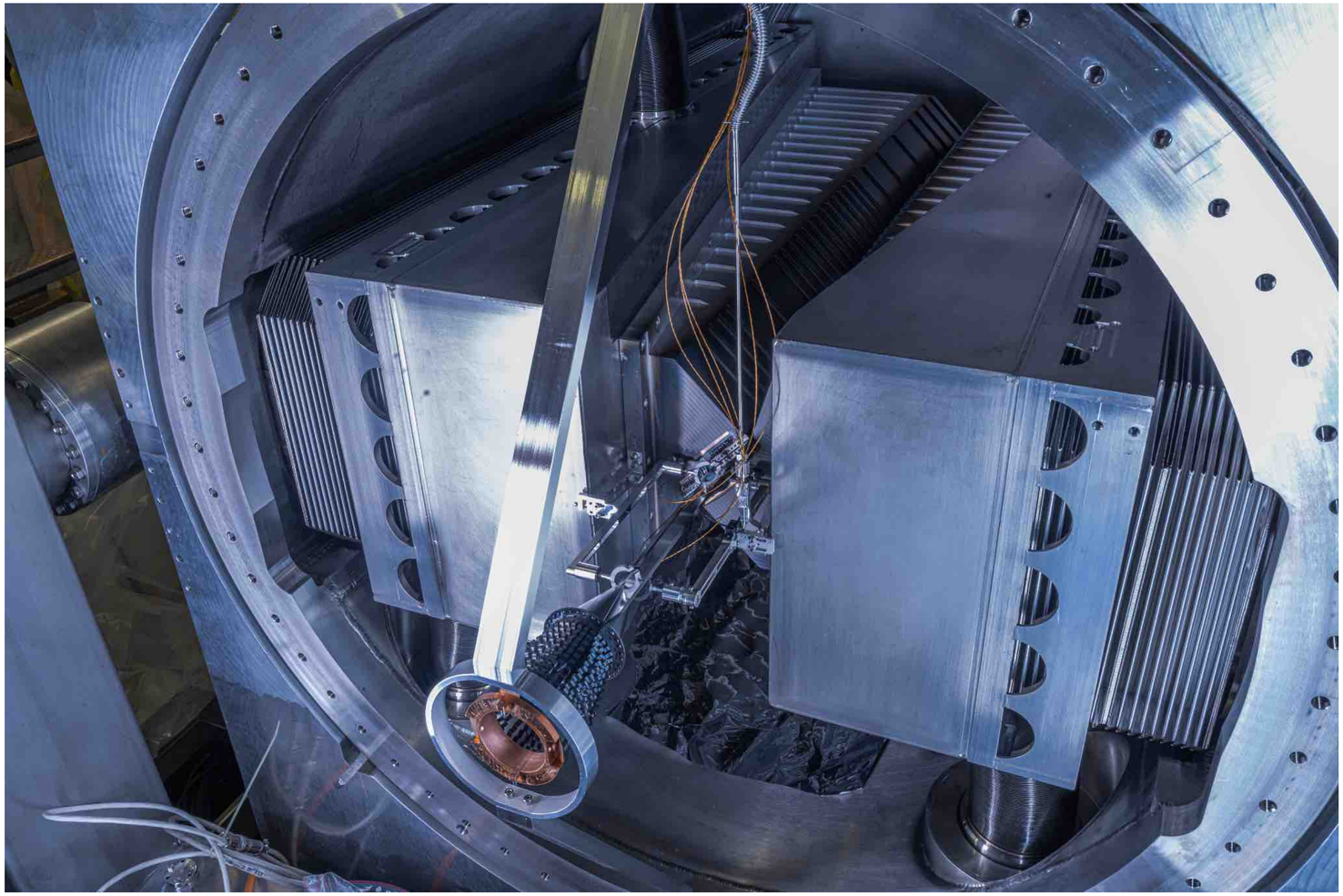
Successful technology based on HERA and COSY experiments



However, the project requires a new polarized target that complies with all the requirements of the LHC

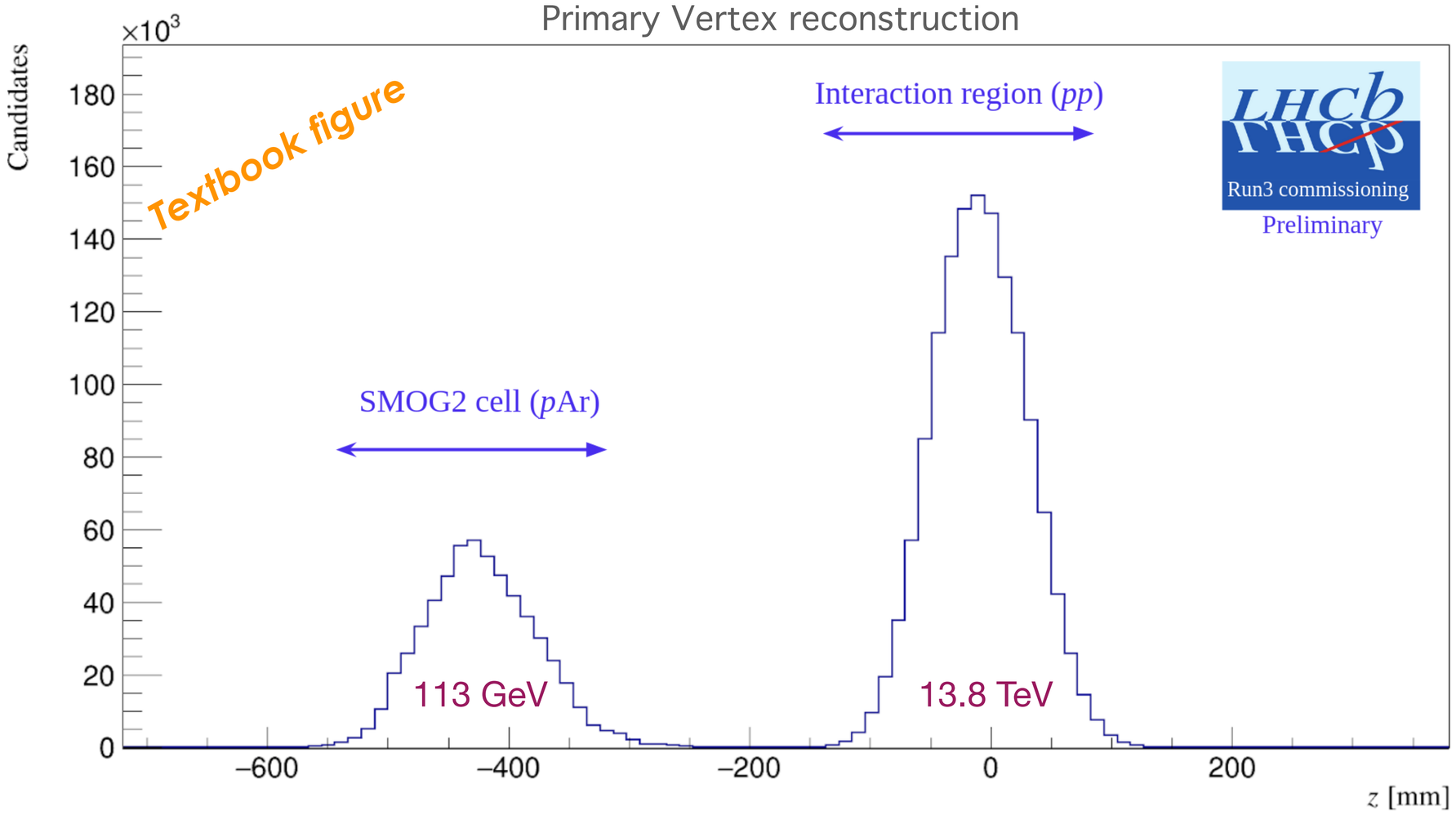
would start from a unique result that has been just achieved

SMOG2 the first and unique unpolarised gas target with storage cell at LHC/LHCb



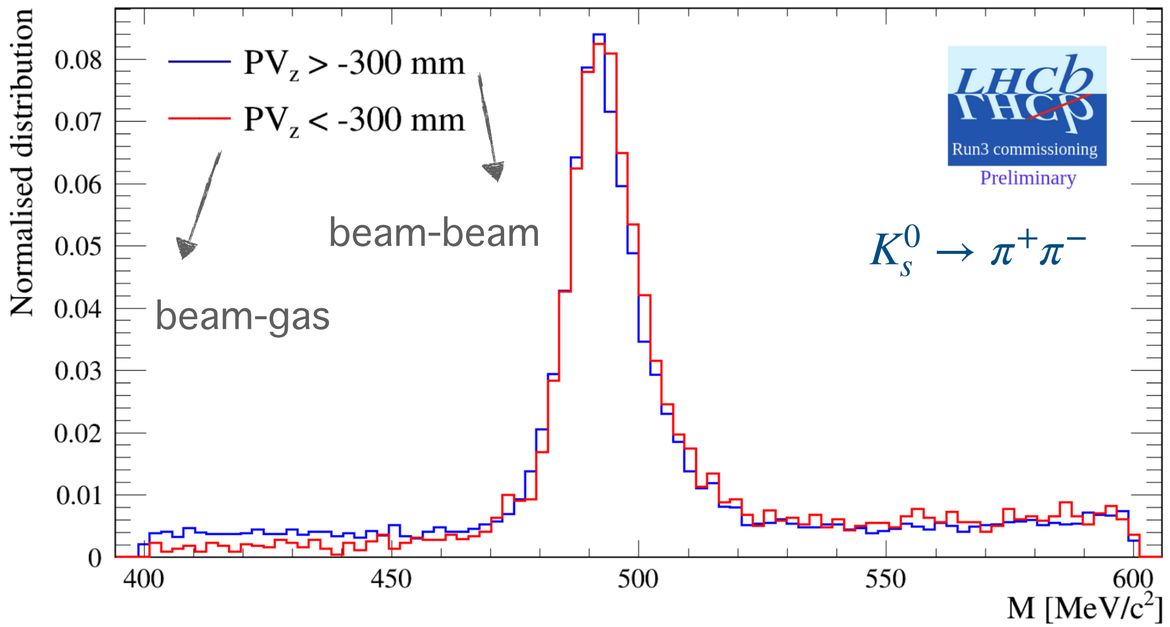
The existence of this storage cell is a unique playground for the LHCspin R&D

SMOG2



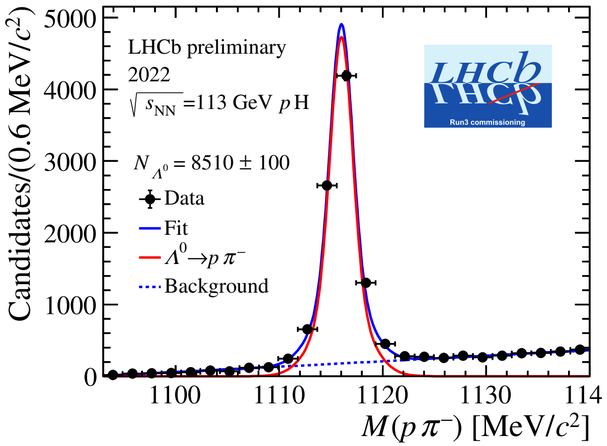
Two well separated and independent Interaction Points working simultaneously

SMOG2

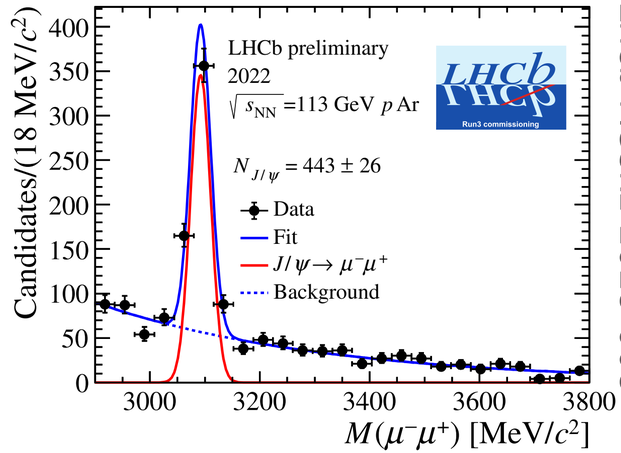


LHCb-FIGURE-2023-001

$pH \to \Lambda^0\ X$



$pAr \to J/\Psi\ X$



LHCb-FIGURE-2023-008

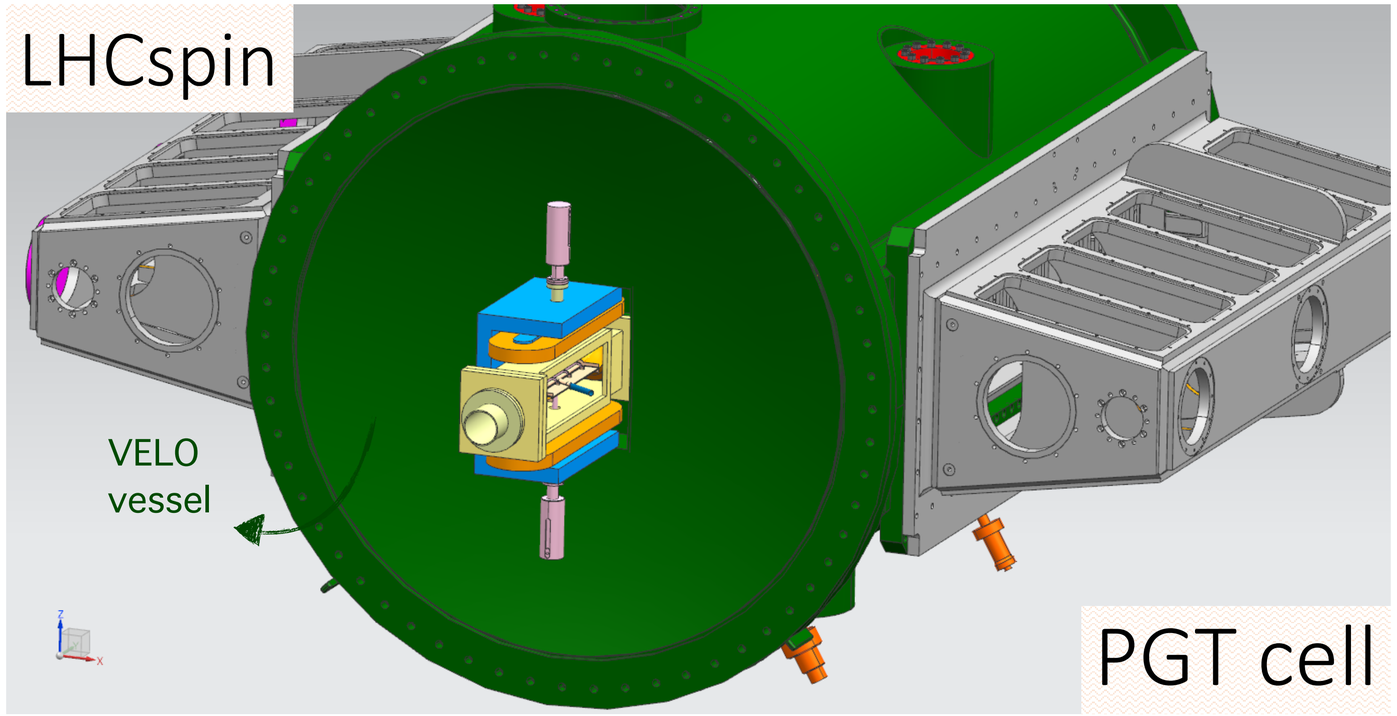
excellent results in ~20 minutes of data taking, albeit low gas pressure and preliminary sub-detector performance

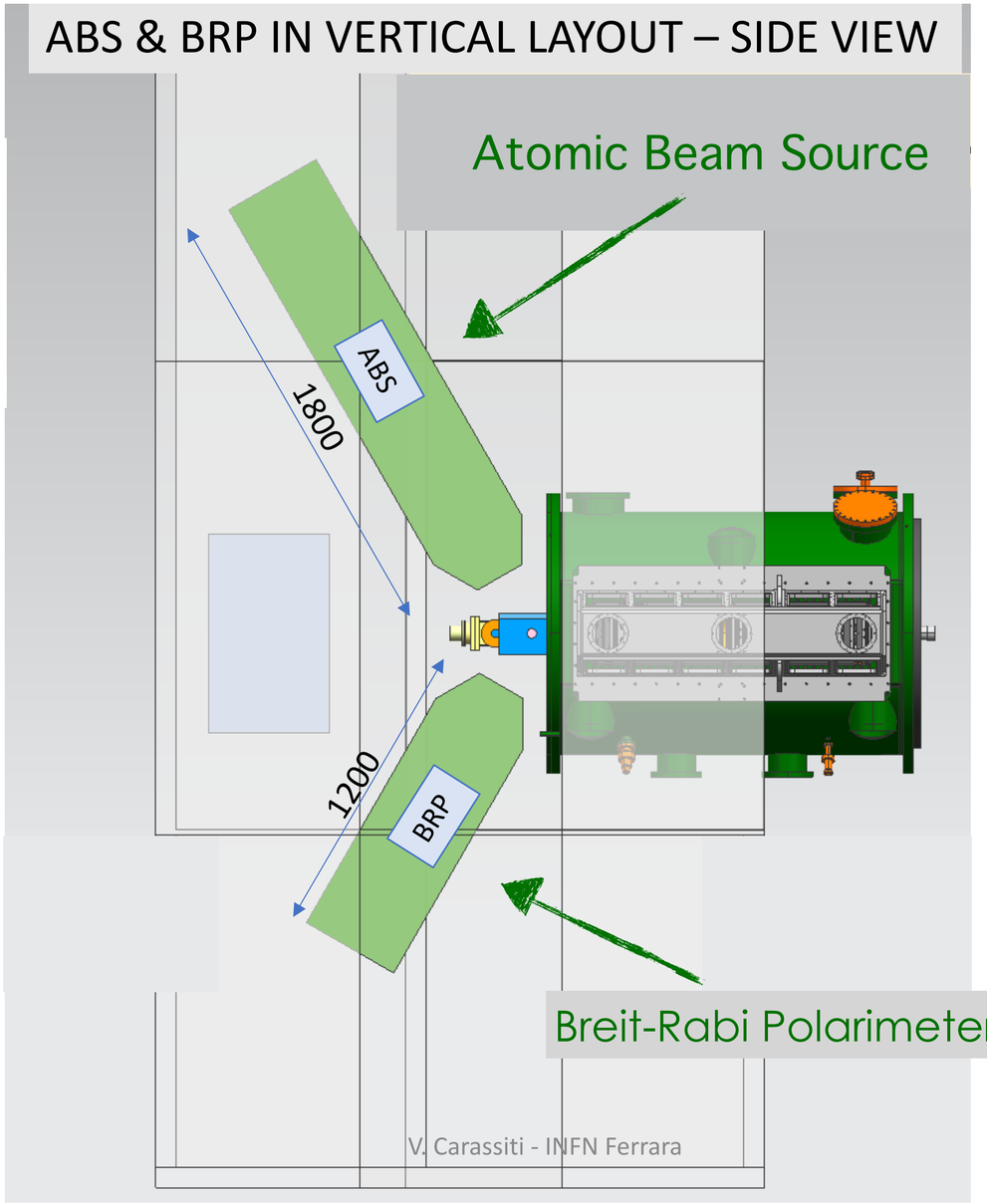
- same resolution for beam-gas and beam-beam collisions
- small impact in the LHCb data reconstruction and processing sequence

LHC and LHCb can effectively operate in collider and fixed-target mode simultaneously, collecting large statistics

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





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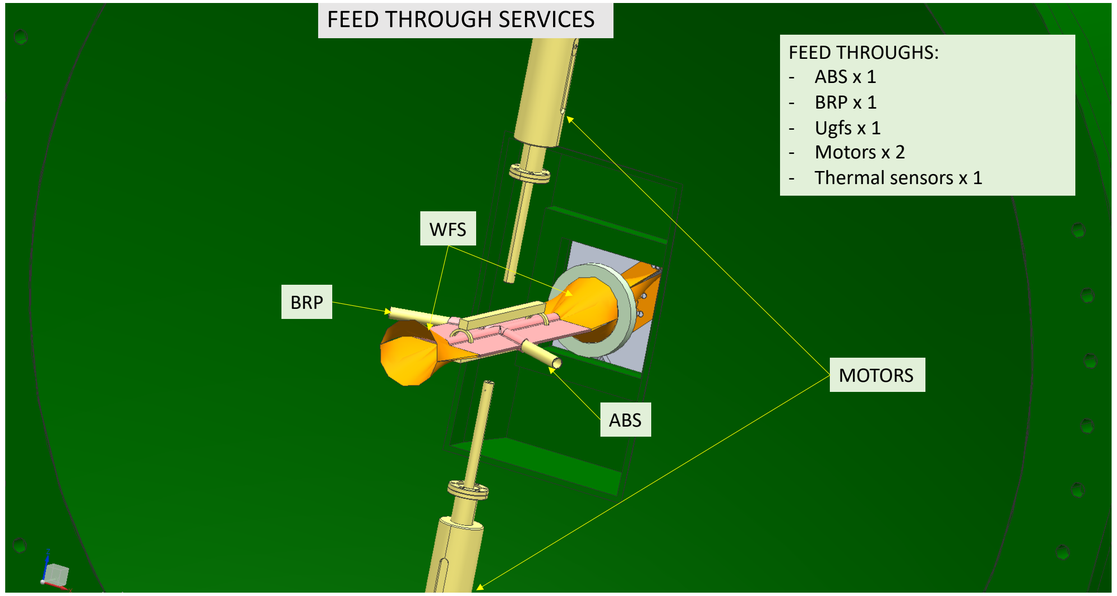
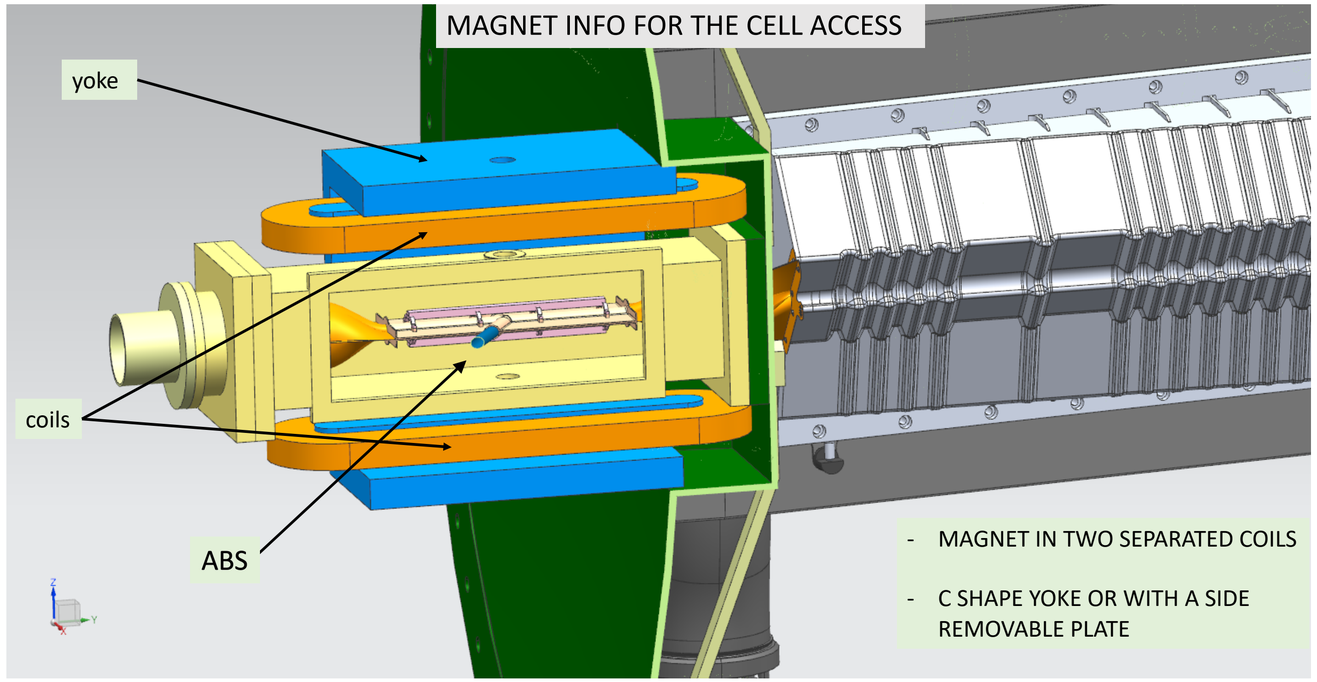
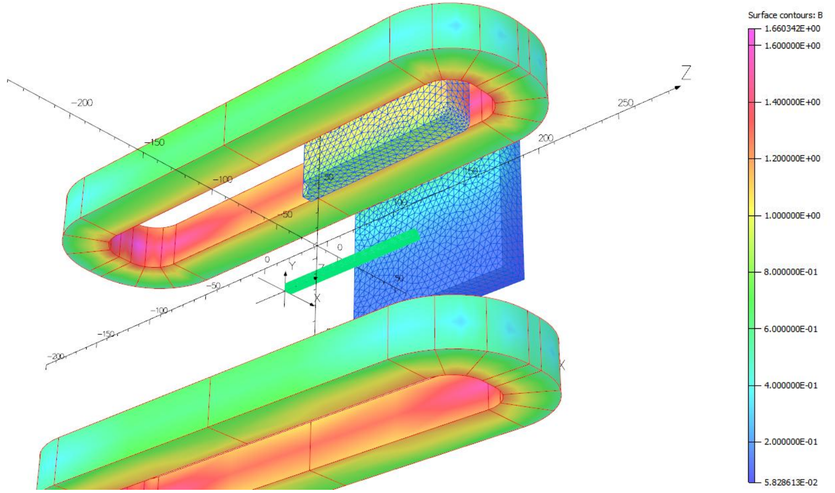


Transverse polarisation



- Compact dipole magnet → static transverse field
- Superconductive coils + iron yoke configuration fits the space constraints
- $B = 300\ \mathrm{mT}$ with polarity inversion, $\Delta B/B \simeq 10\,\%$, suitable to avoid beam-induced depolarisation



Coating issues

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

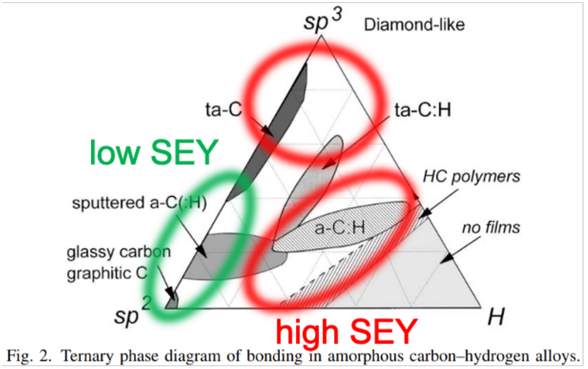
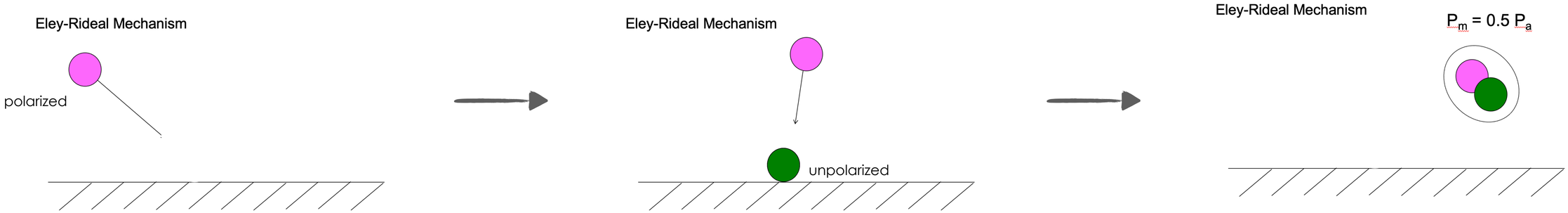


Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

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



Coating issues

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

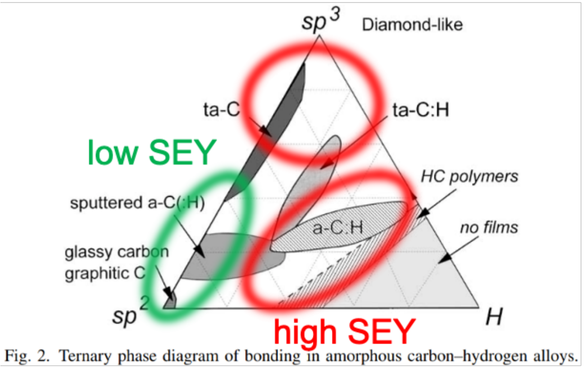
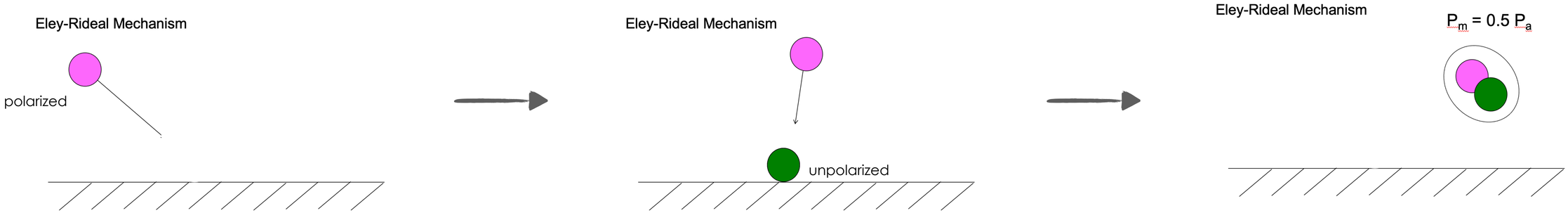


Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

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



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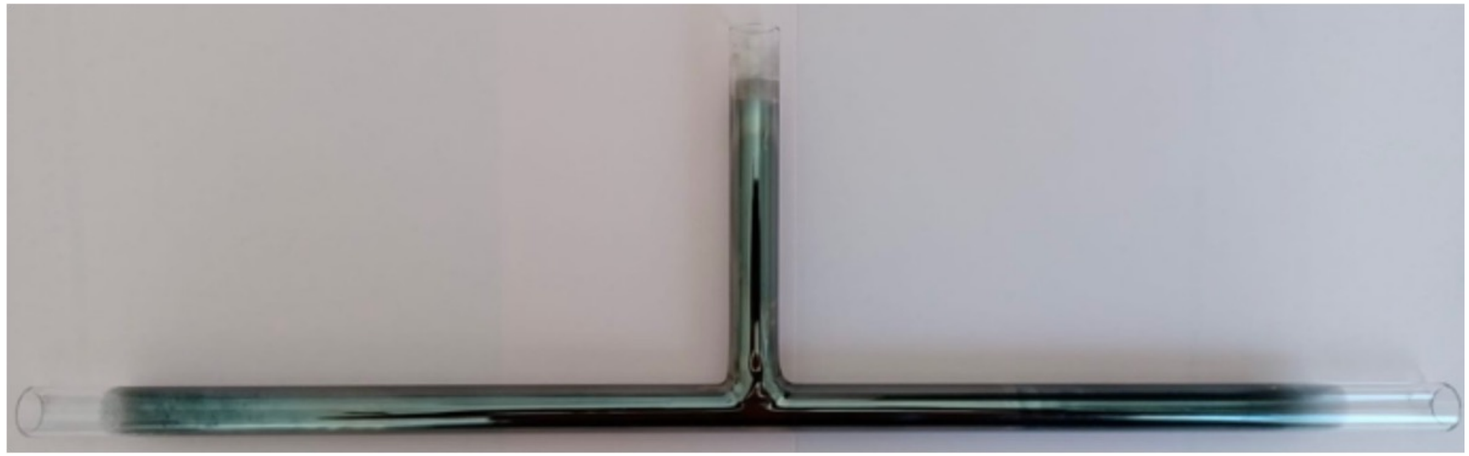
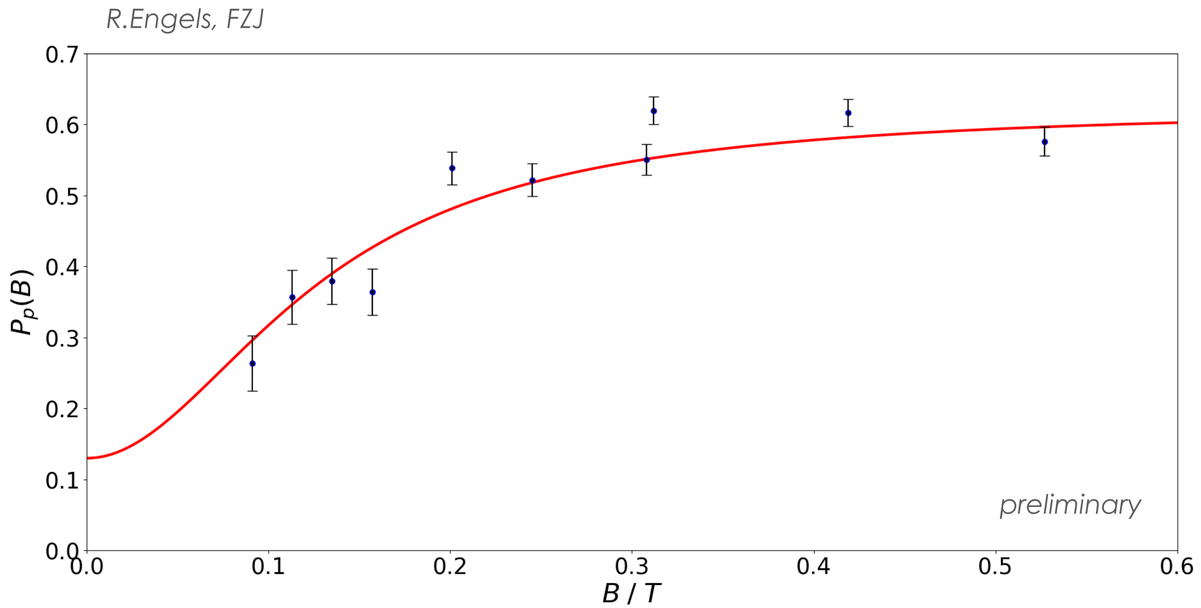
A test was performed at FZ-Julich on a quartz storage cell coated at CERN with amorphous carbon, just like the SMOG2 storage cell



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

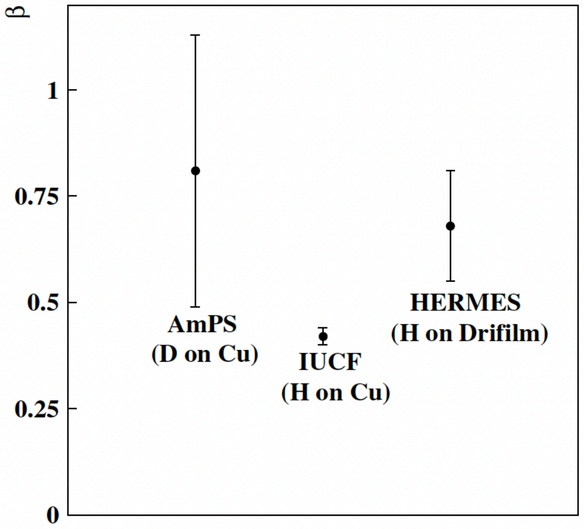
Coating issues

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



Proton vector polarization for different magnetic fields
- aC coating -

Nuclear polarization of hydrogen molecules recombined on Cu from D-atoms (left) and H-atoms (center), and from H-atoms on a non-metallic surface (right)



HERMES Coll
Eur. Phys. J. D 29, 21–26 (2004)
DOI: 10.1140/epjd/e2004-00023-5

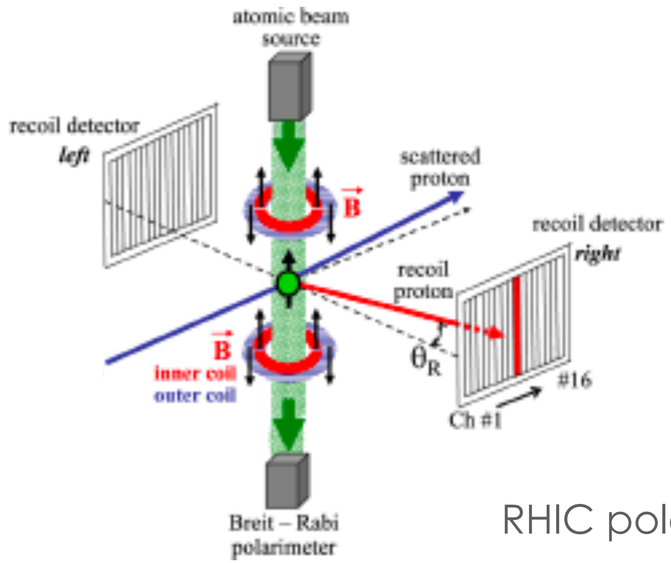
Initial atomic polarisation $P_a = 0.90$
Recombination rate *95.8 - 100 %*

LHCspin can develop a new storage cell using polarized molecules →

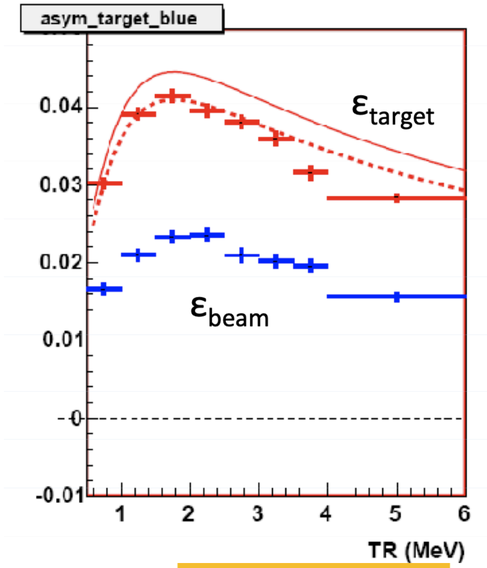
- high density target
- but an absolute polarimeter is needed

Development of an absolute polarimeter

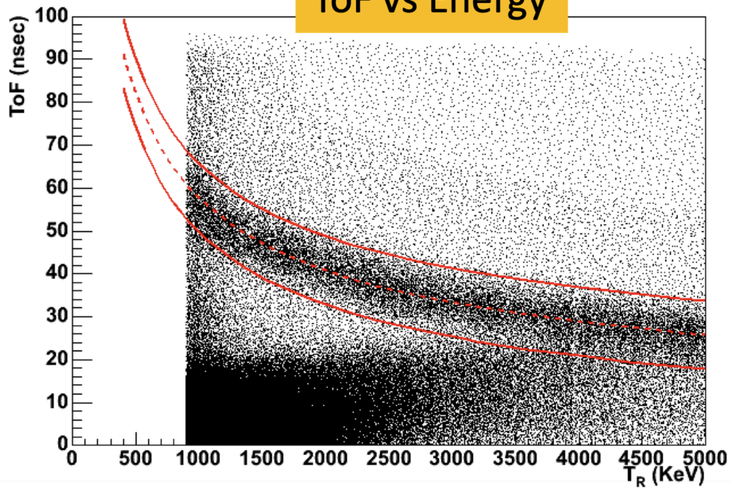
Based on the Coulomb Nuclear Interference (CNI)



RHIC polarimeter



ToF vs Energy



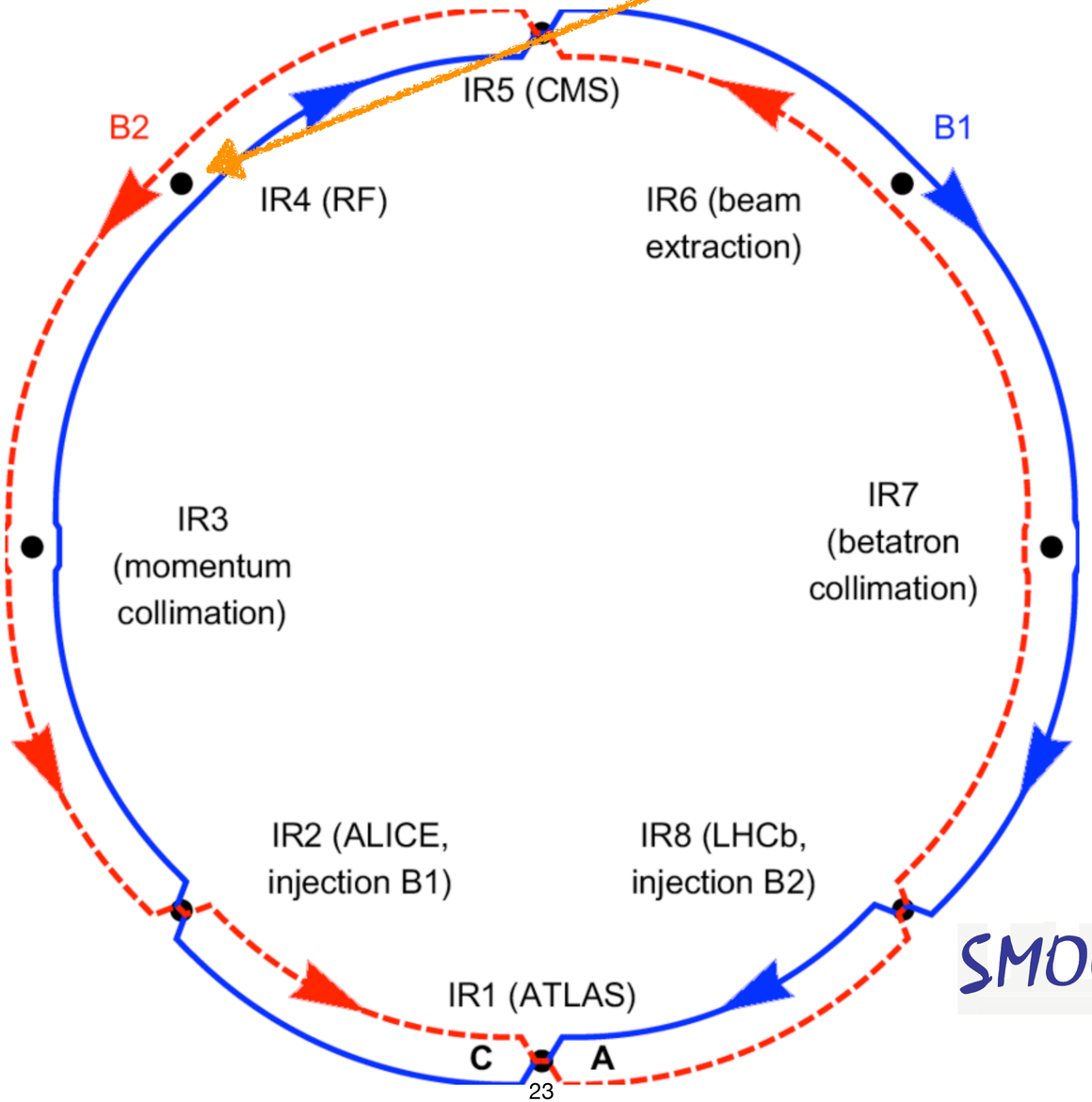
To validate the theoretical predictions of the analyzing power at 7 TeV, in addition to evaluating detection efficiency and background, the absolute polarimeter must be installed in coincidence with the standard Breit-Rabi Polarimeter along the beamline

Here a new idea/proposal comes …

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

JPS Conf. Proc. 37, 021103 (2022)

The LHC Interaction Regions



The LHC Interaction Region 4

HiLumi HL-LHC PROJECT

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

Robert Kieffer
rkieffer@cern.ch

CERN **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)

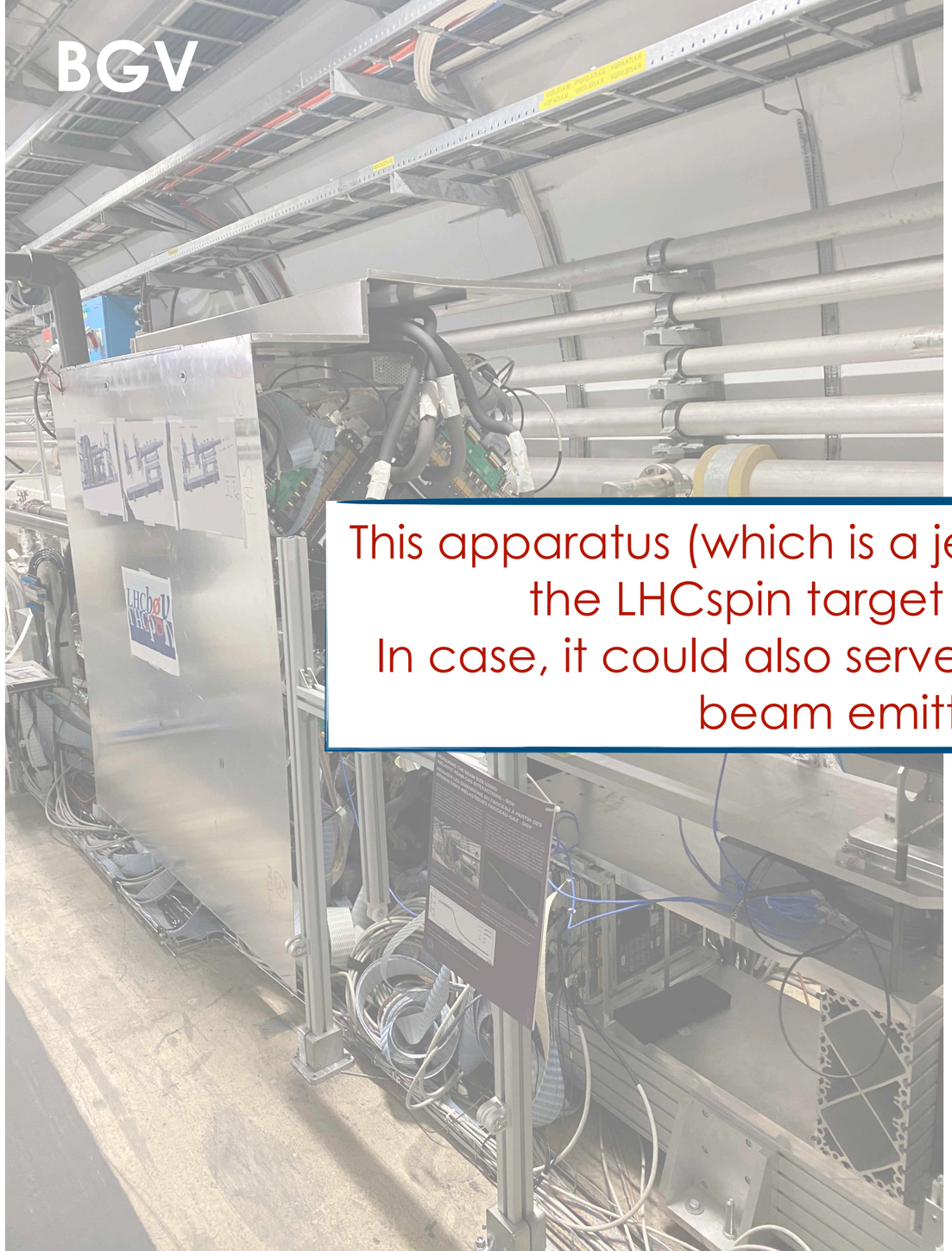
Editors' Suggestion

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



HiLumi
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rget.pdf

This apparatus (which is a jet target itself) could be replaced by the LHCspin target and its absolute polarimeter.
In case, it could also serve as a beam gas vertex detector for beam emittance measurements

1 (2019)

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

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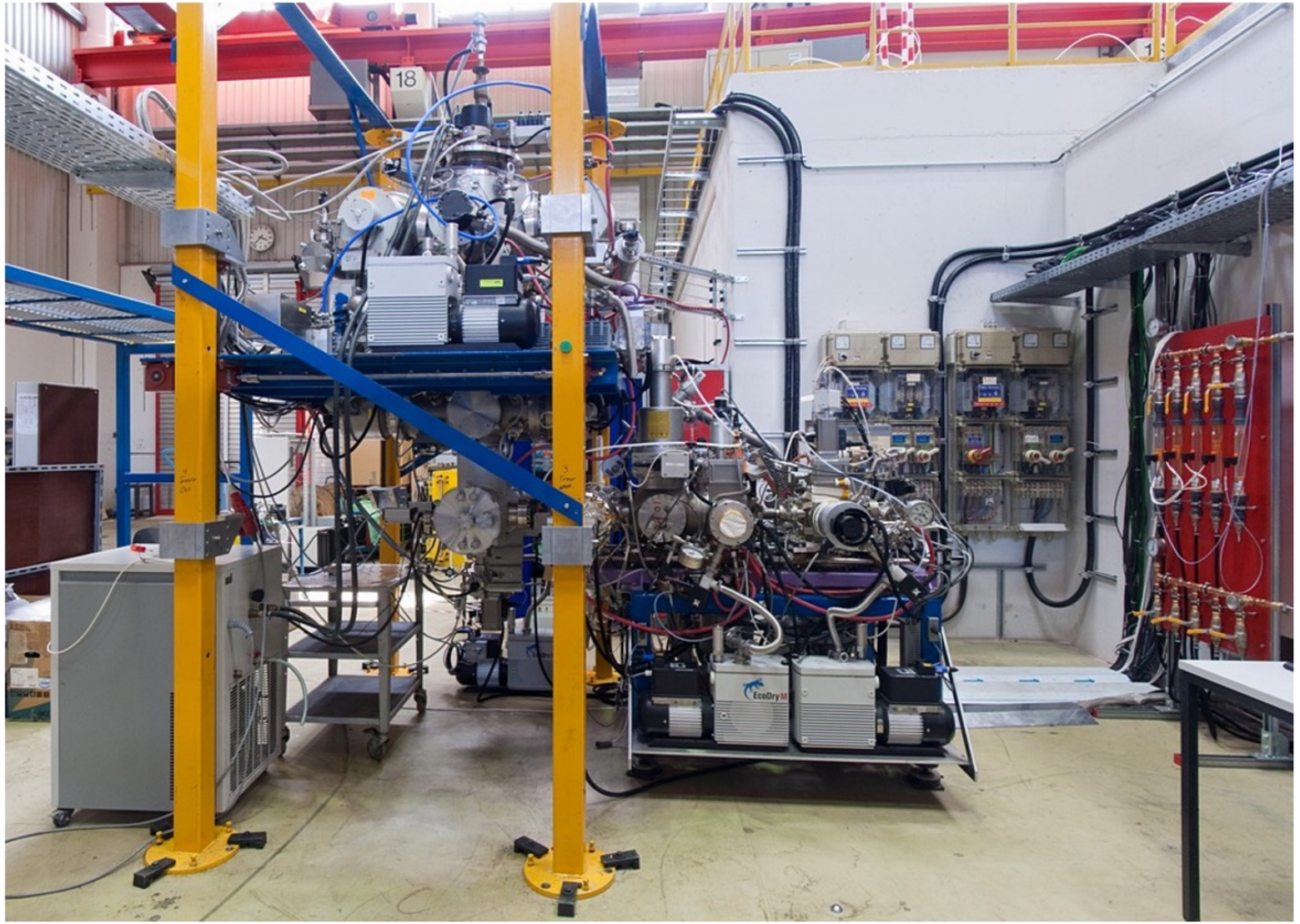
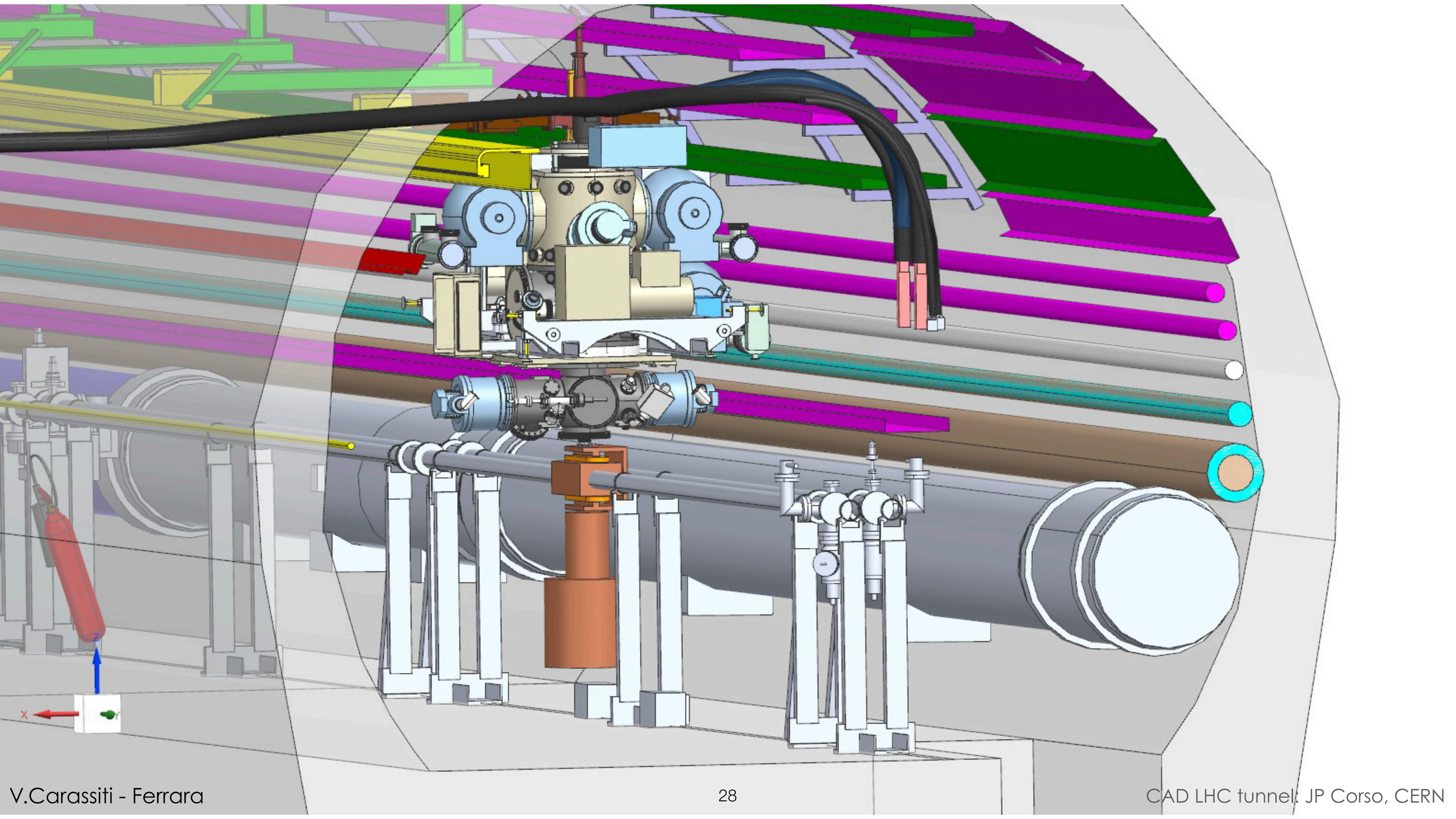
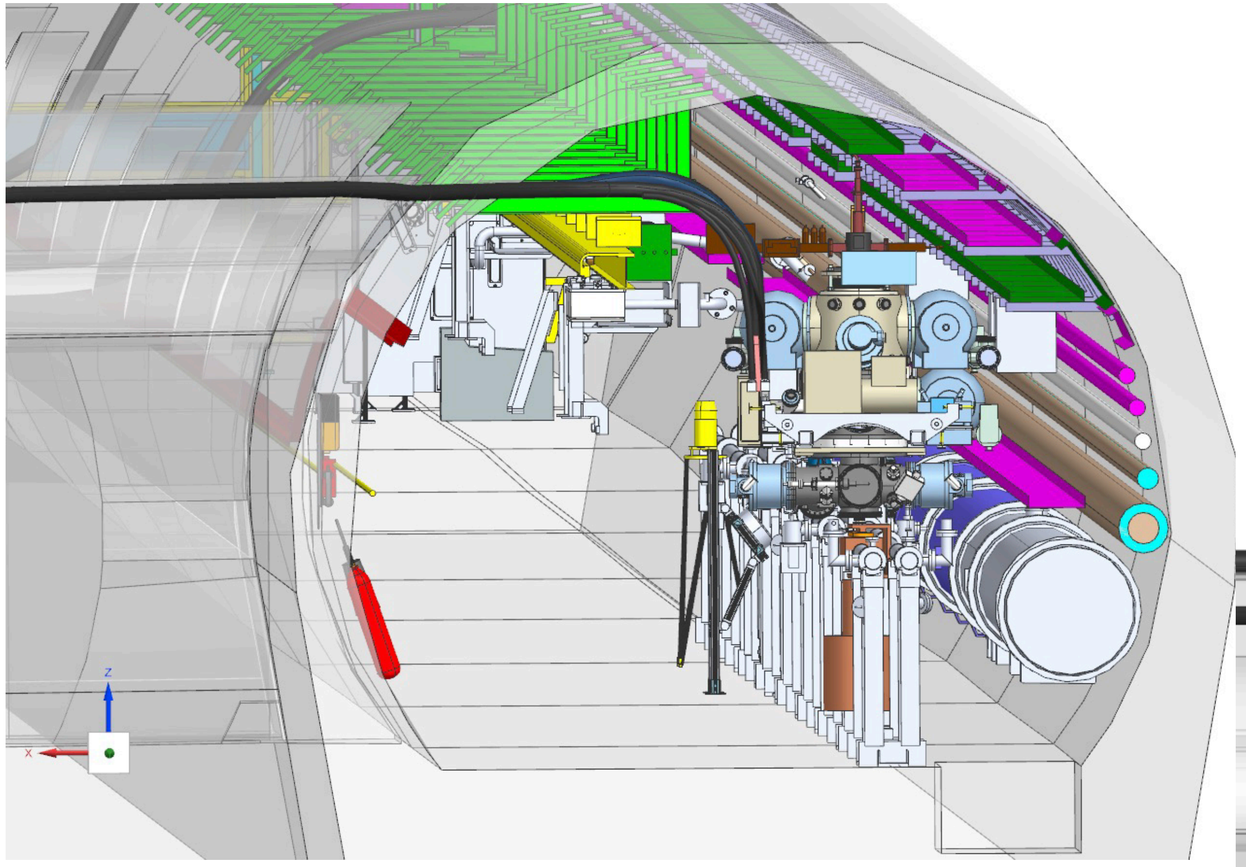
The existing target in Julich to be used for the R&D activities





CAD LHC tunnel: JP Corso, CERN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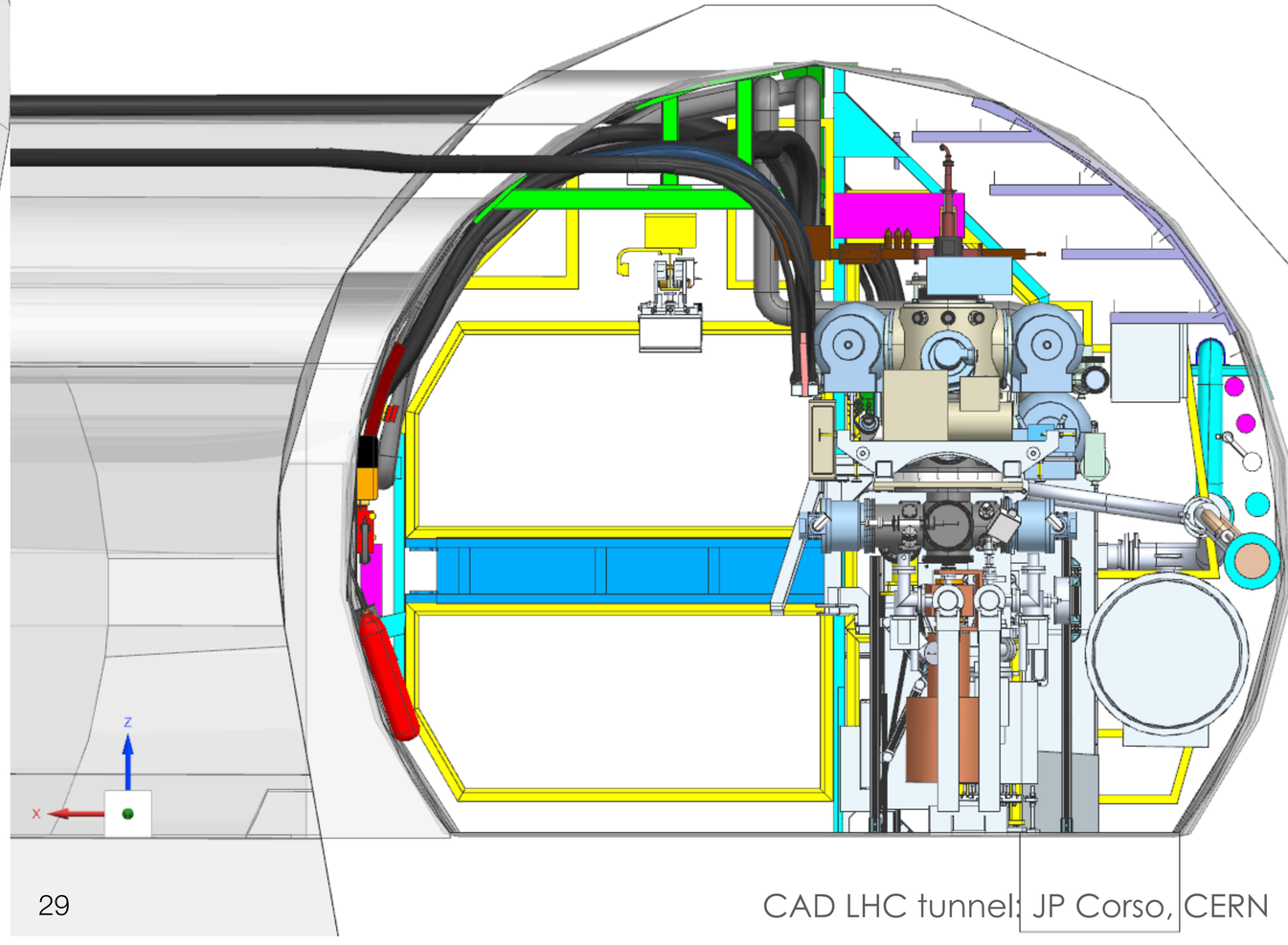
Z
X

Conclusions

- LHCspin is a groundbreaking project conceived to bring polarized physics at the LHC exploiting its potential, along with LHCb, one of the most advanced detectors

- It is extremely ambitious in terms of both physics reach and technical complexity

- The installation of the Polarized Gas Target at the IR4 could be used to adapt an absolute polarimeter for a Polarised Molecular Target, study and fulfill all the LHC requirements to be ready for the installation in LHCb

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LHCspin represents a unique opportunity within a realistic timeframe and budget