Status of the polarized gas target for the LHCspin project

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on behalf of LHCspin Collaboration

Yamagata University, Japan

SPIN2025 in 青島

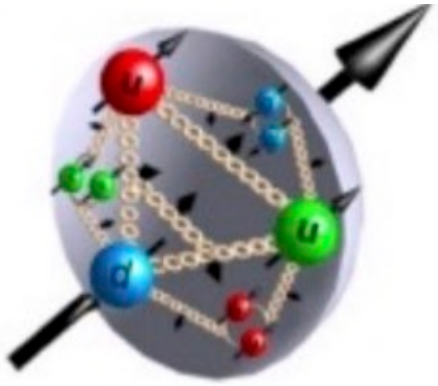
Please follow the talk

LHCspin project (by Rahul Shankar)
26/09/2025 11h30

Outline

- Physics motivation
  - Nucleon spin structure & TMD PDFs
- LHCb SMOG2 project with gas target
- Polarized gas target
  - Coating of target cell
  - Recombination of atoms
  - New polarimeter
- Timeline
  - Phase 1 at IR4
  - Phase 2 at IR8 (LHCb)
- Summary

Nucleon Spin Structure



Nucleon spin

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{z,q} + L_{z,g}$$

$\Delta\Sigma$: Quark spin
EMC、SMC、HERMES

ΔG : Gluon spin
COMPASS、PHENIX

$L_{z,q}$: Quark OAM
HERMES、COMPASS、
SeaQuest、PHENIX

$L_{z,g}$: Gluon OAM
COMPASS, PHENIX

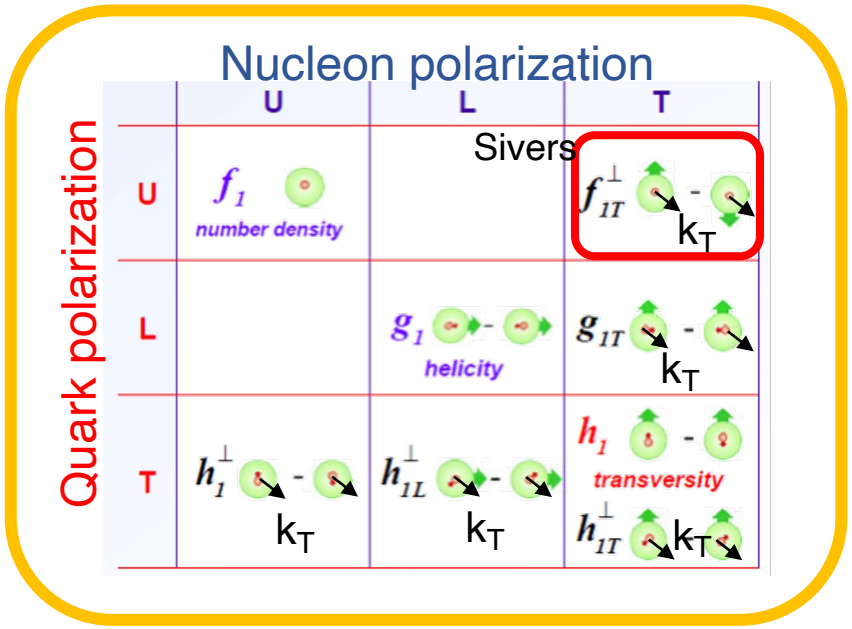
Precision measurements in 1990s
20-30 % by global analysis

Measurements in 2000s
It does not explain the nucleon spin.

TMD PDFs measurements since 2000s
Supporting OAM contribution

Just started. Precision measurements will be carried out.

Nucleon structure and TMD PDFs



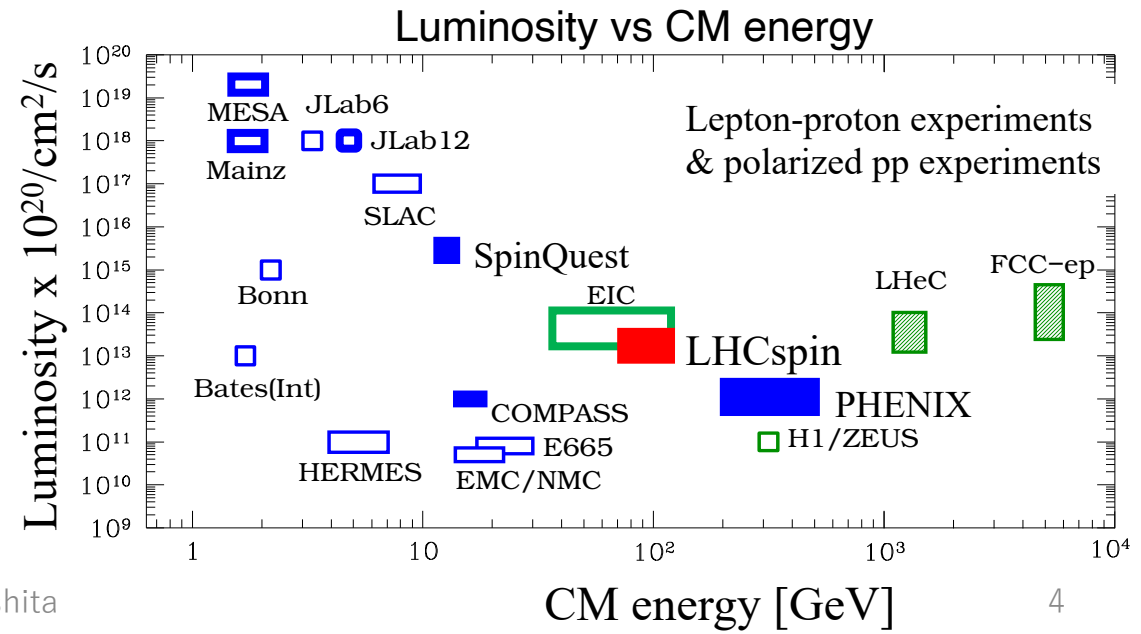
- **k_T** dependent 8 intrinsic Transverse Momentum Dependent Parton Distribution Functions (TMD PDFs) at LO

- Quark OAM
  Quark Sivers PDF $f_{1T}^{\perp}(x, k_T^2)$ 、
  Transversity PDF $h_1(x, k_T^2)$

- SIDIS and Drell-Yan process
  SIDIS : HERMES, COMPASS, Jlab, EIC
  DY : COMPASS, SpinQuest, RHIC, **LHCspin**

$$f_{1T}^{\perp}|_{DY} = -f_{1T}^{\perp}|_{SIDIS}$$

- Gluon TMDs at LHCspin
  Spin asymmetry of J/ψ production by gluon fusion
  $J/\psi \rightarrow \mu^+\mu^-$ channel : 1.3 x 10^7 events/week expected



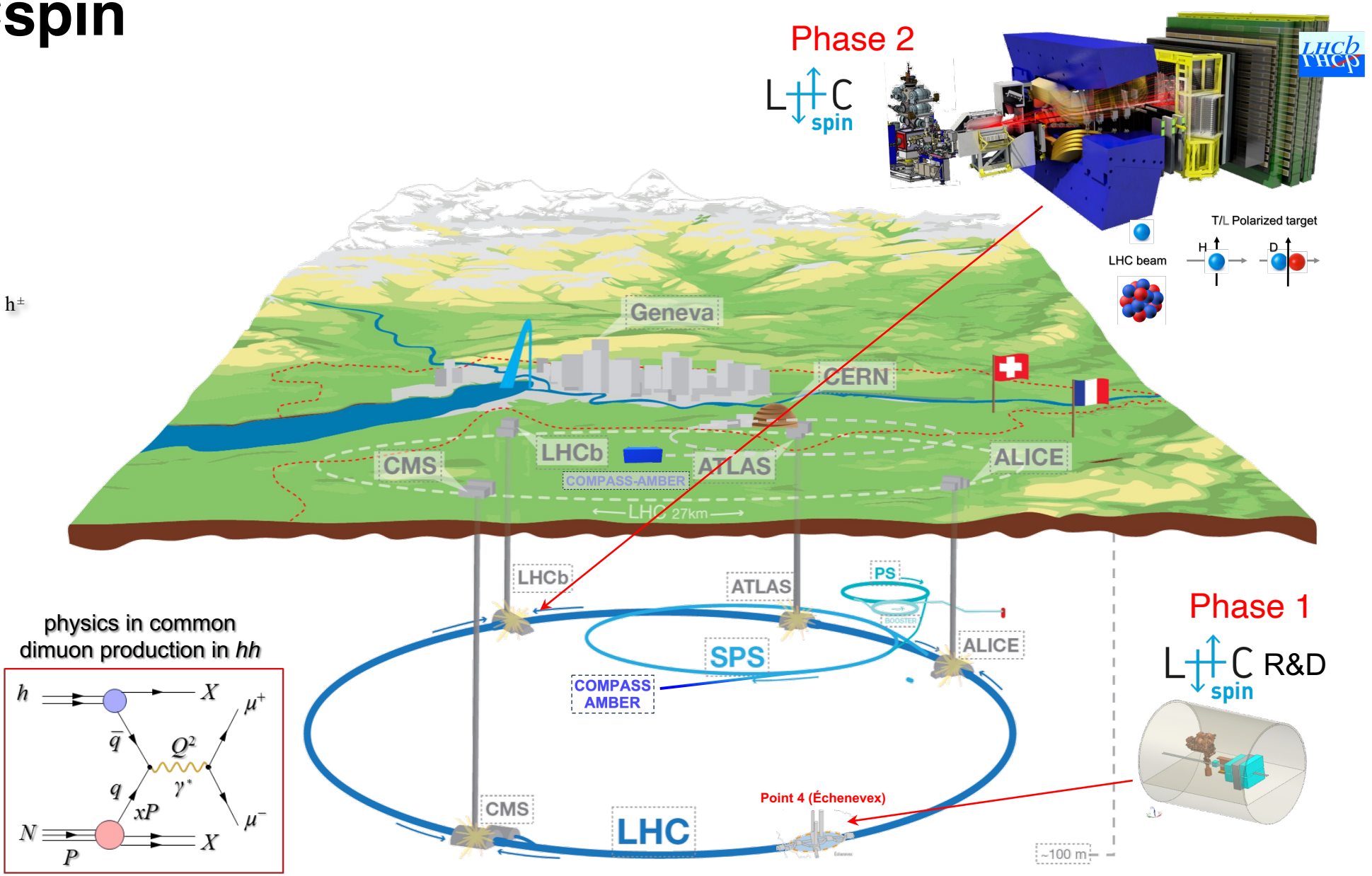
CERN & LHCspin

LHCspin

Armenia, China, Czechia, France, Germany, Italy, Japan, Mexico, Poland, Portugal, Spain, Switzerland, USA, CERN

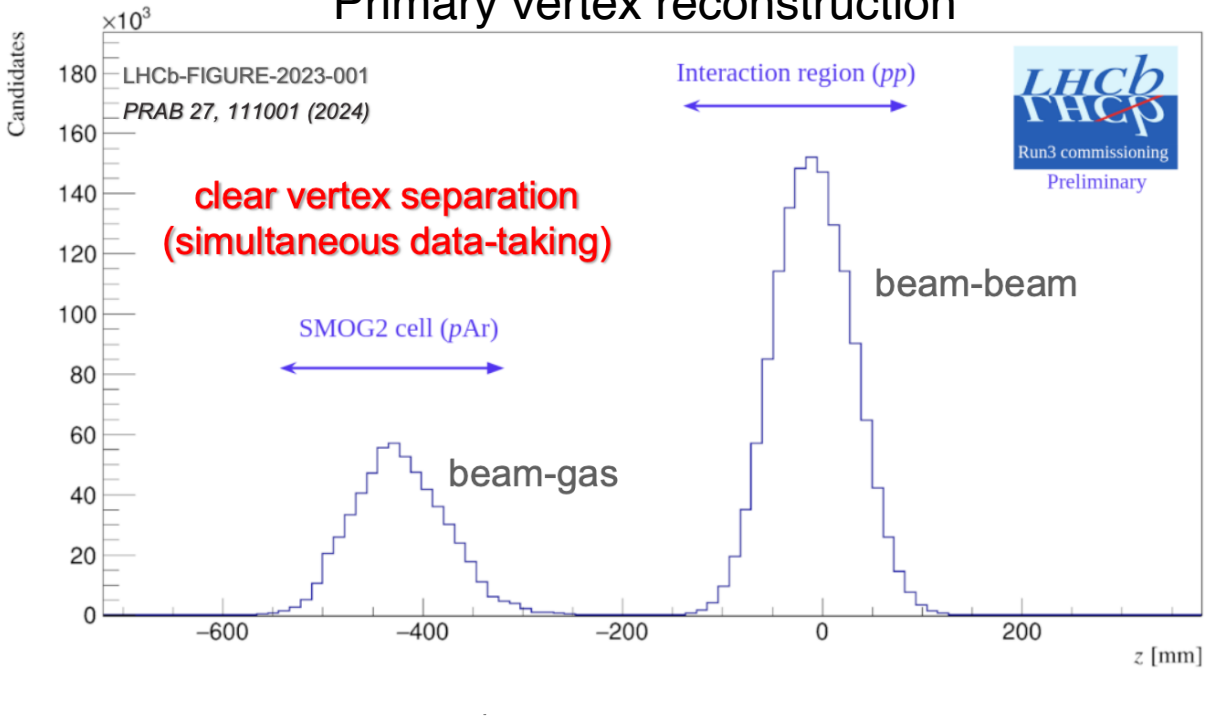
The LHCspin project" (arXiv:2111.04515)
"LHCspin: a Polarized Gas Target for LHC" (arXiv:2504.16034)

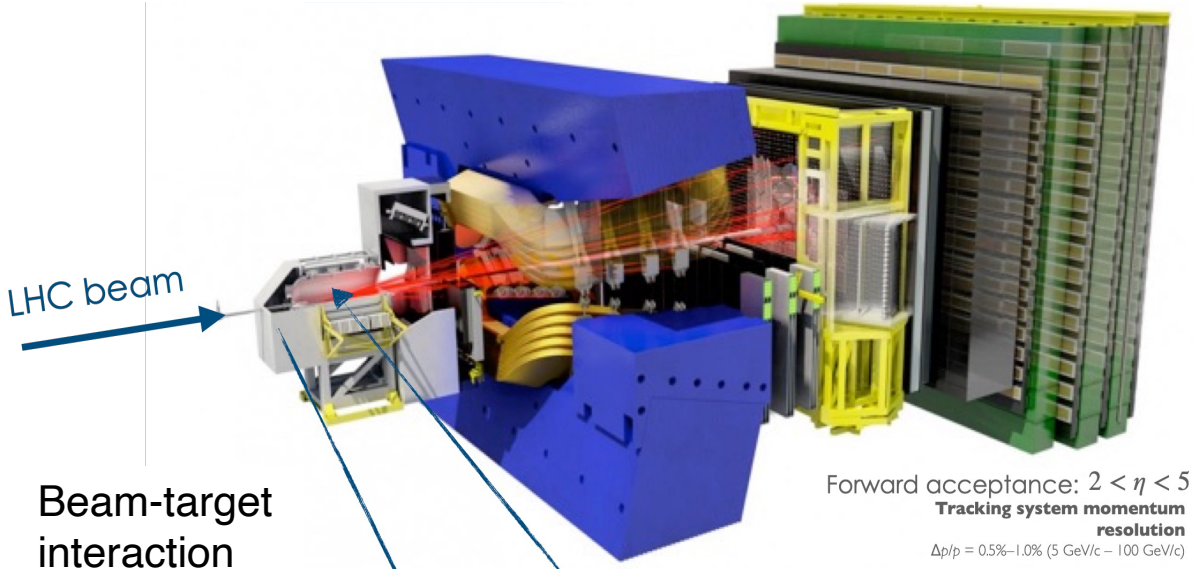
submitted in 04/2025



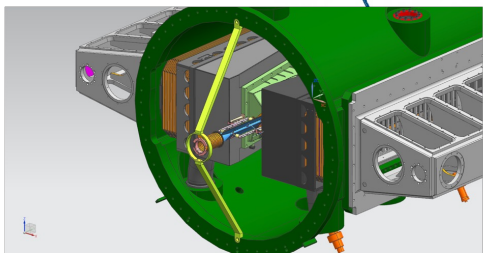
SMOG2 project at LHCb with gas target

Primary vertex reconstruction

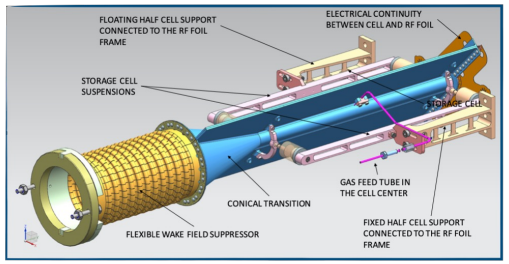




Beam-target interaction



Beam-Beam collision point



20cm long target cell

Injection gas : H_2, D_2, N_2, O_2, He, Ne, Ar, Kr, Xe

- Flux : 1% accuracy
- Luminosity : 1.5% accuracy
- PDF, gluon PDF, Antiproton production cross section

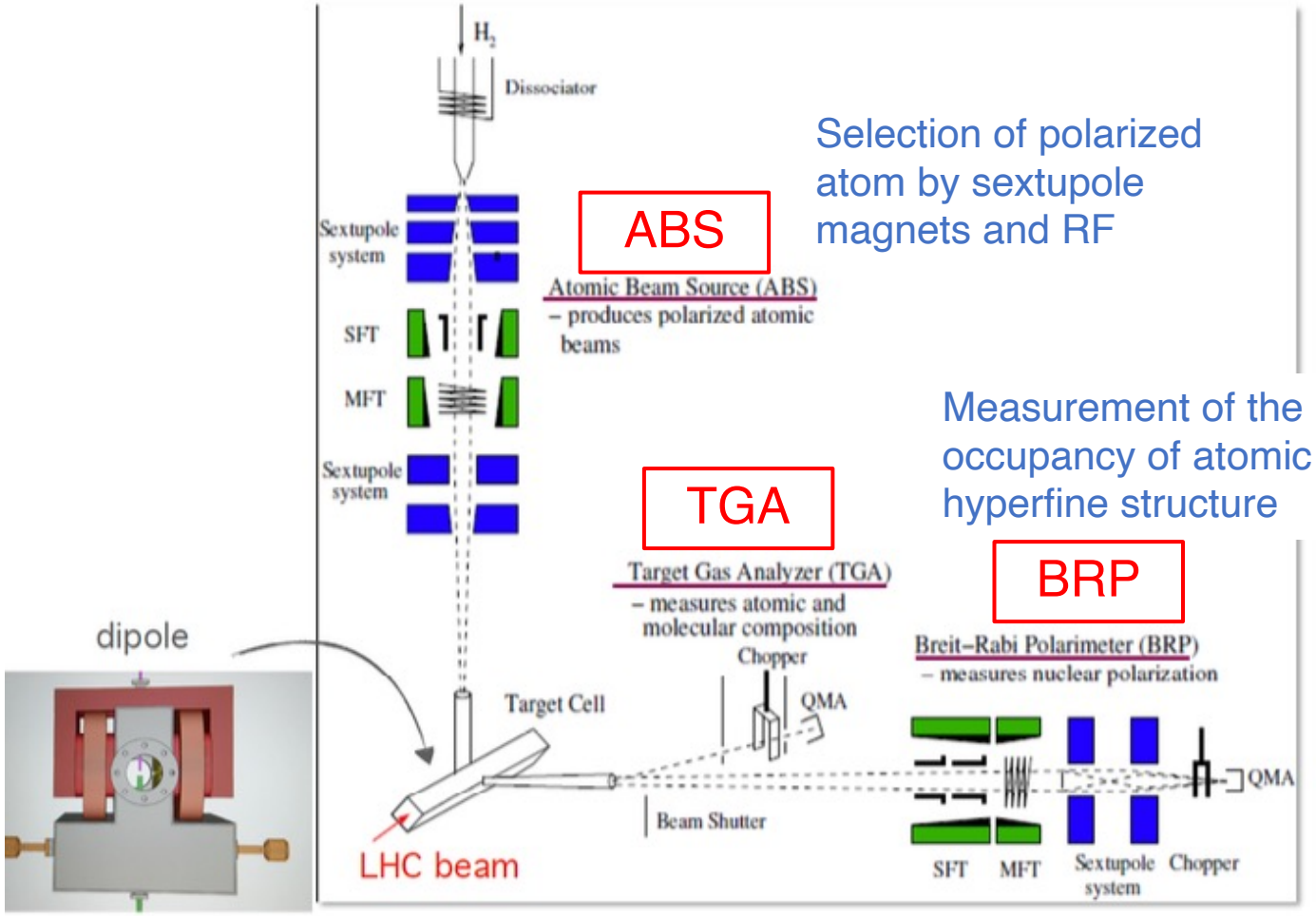
To be replaced by **polarized** gas target

HERMES Polarized target system at DESY

Nucl.Instrum.Meth.A540:68-101,2005

Target density (H) = 7 x 10^{13} cm^{-2}
LHC beam (Run4) = 6.8 x 10^{18} p s^{-1}

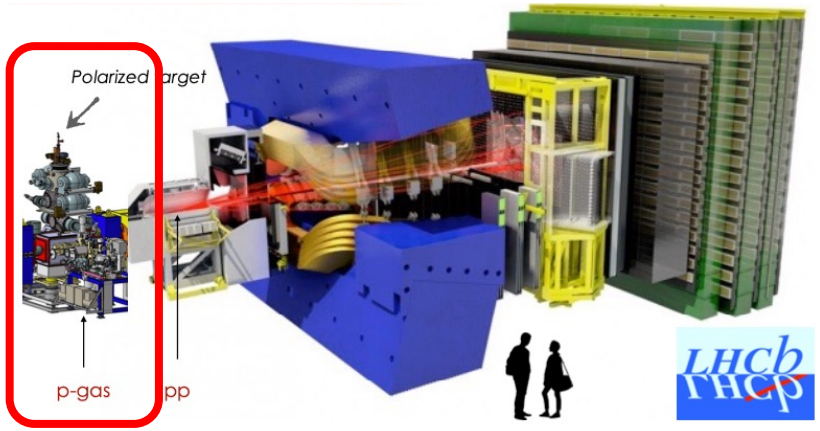
L_{pH} = 8 x 10^{32} cm^{-2} s^{-2}



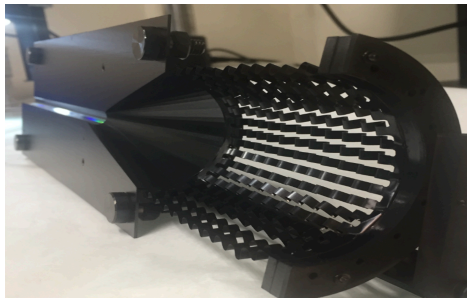
HERMES SYSTEM

Polarized gas target R&D

HERMES system
- Storage cell
- Polarization 90%
- H atom production: 6.5 x 10^{16} /s



Polarized gas target



- **Coating for storage cell**

Different from the vacuum system, Si, F, H2O cannot be used at LHC

- HERMES target: Hydrophobic silicon-based polymer (Drifilm) coating with 100K water-ice layer
- LHCspin: Amorphous carbon (SMOG2)

→ Secondary Electron Yield (SEY) considered below 1.4

Non-crystalline form :a mix of graphite and diamond-like crystals

→ It fixes the LHC beam stability issues.

→ Atomic recombination

The coating may facilitate the recombination.

→ It preserves the target polarization.

→ BRP can not measure the recombined molecular polarization.

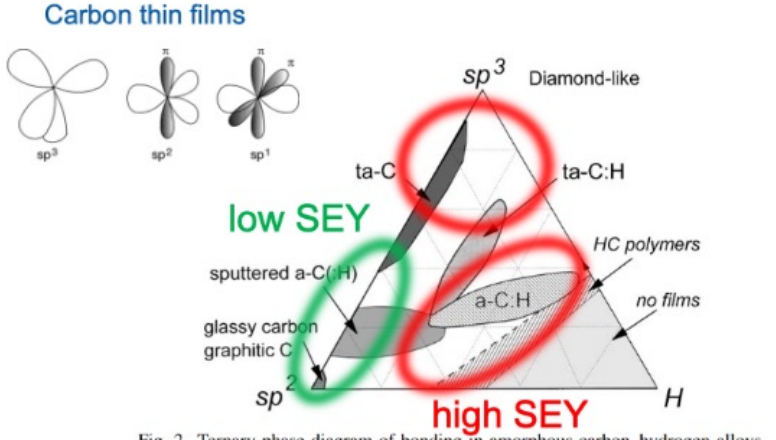
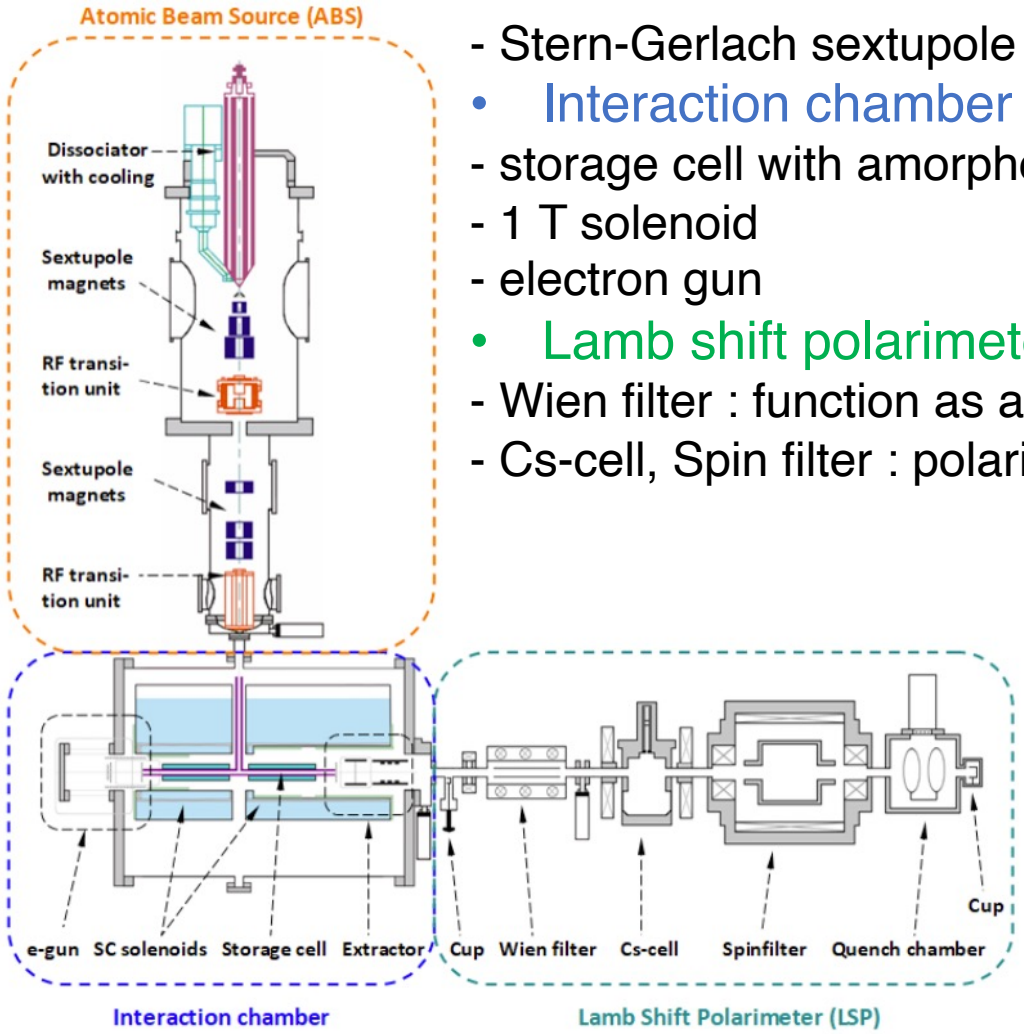


Fig. 2. Ternary phase diagram of bonding in amorphous carbon–hydrogen alloys.

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

Recombination & polarization studies at FZJ

NIMA 1068(2024) 169707



- Atomic Beam Source (ABS)

- Stern-Gerlach sextupole magnets & microwaves

- Interaction chamber

- storage cell with amorphous coating with 100 K
- 1 T solenoid
- electron gun

- Lamb shift polarimeter (LSP)

- Wien filter : function as a mass spectrometer
- Cs-cell, Spin filter : polarization measurement

Recombination & polarization studies at FZJ

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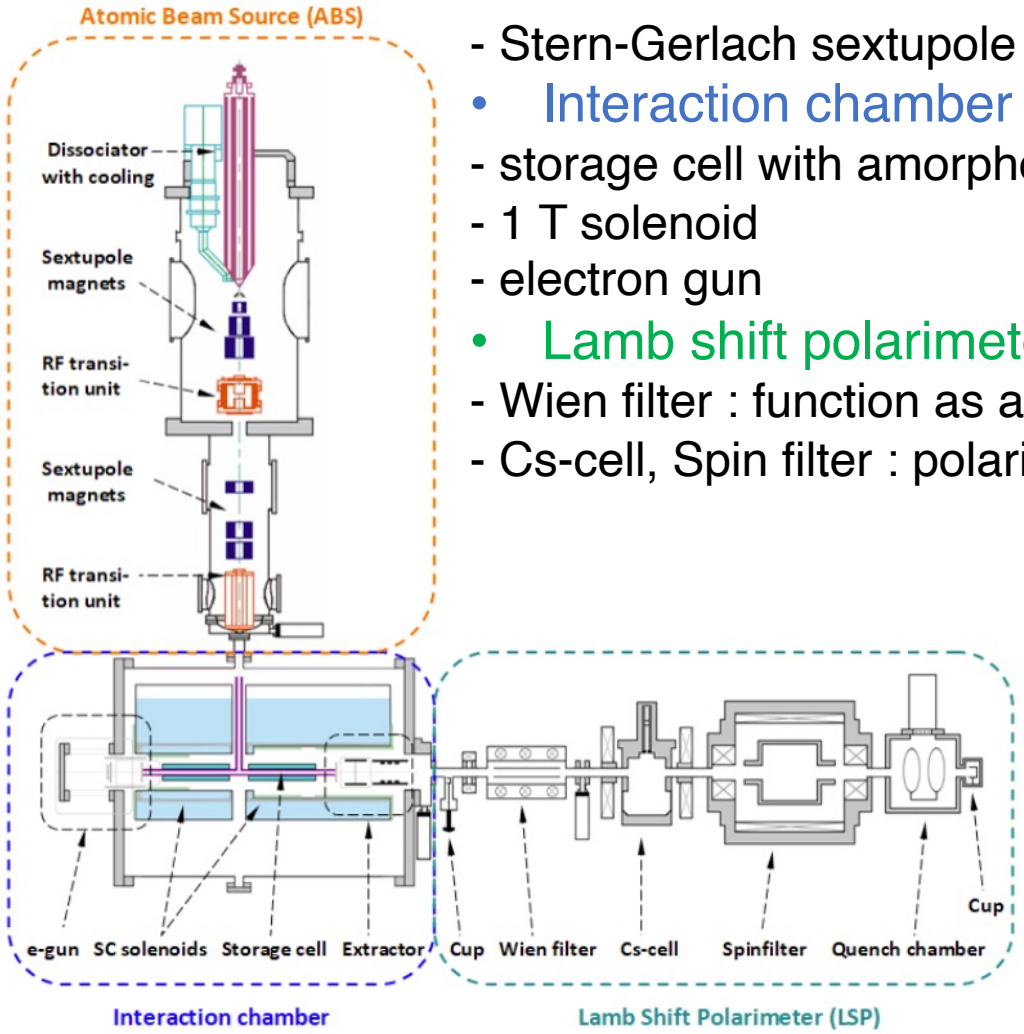

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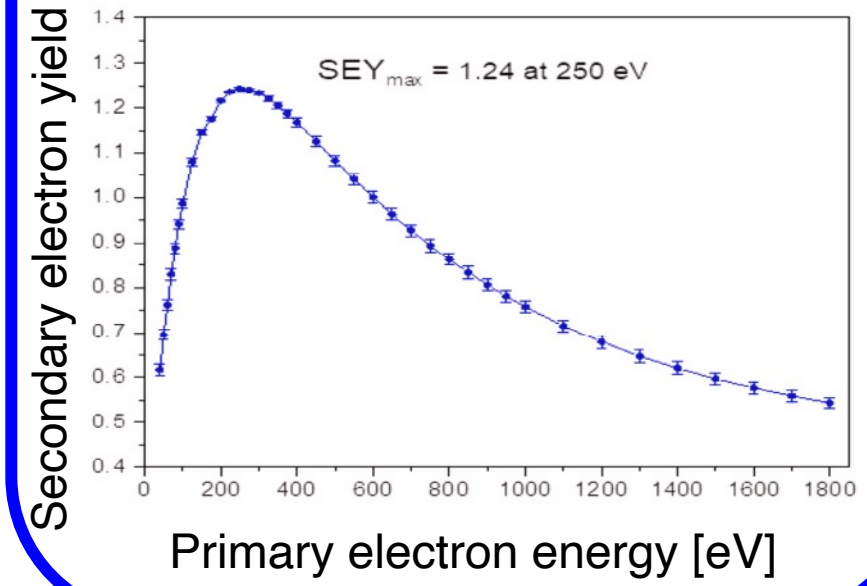
→ **Maximum SEY : 1.24**

SEY spectrum of amorphous coating



Recombination & polarization studies at FZJ

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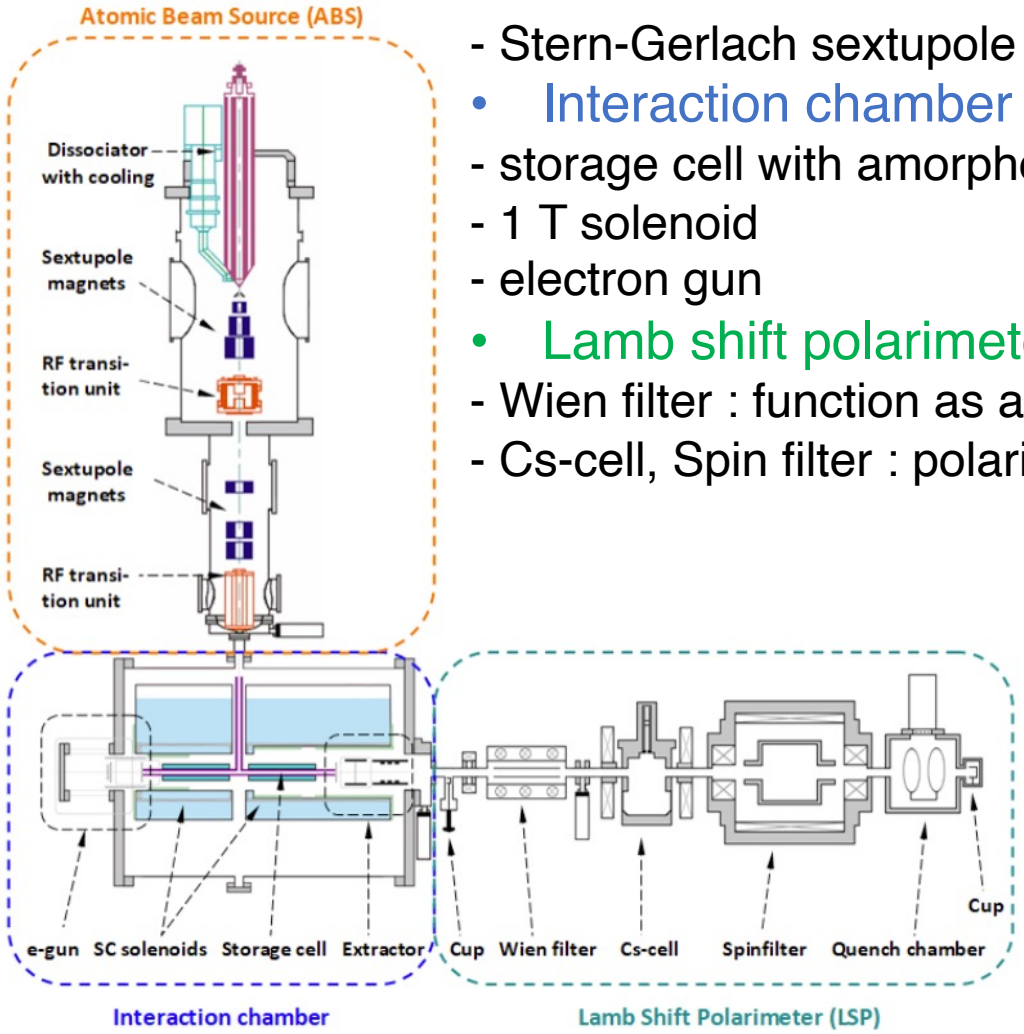

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- storage cell with amorphous coating with 100 K
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- Wien filter : function as a mass spectrometer → Recombination : 93%
- Cs-cell, Spin filter : polarization measurement

Recombination & polarization studies at FZJ

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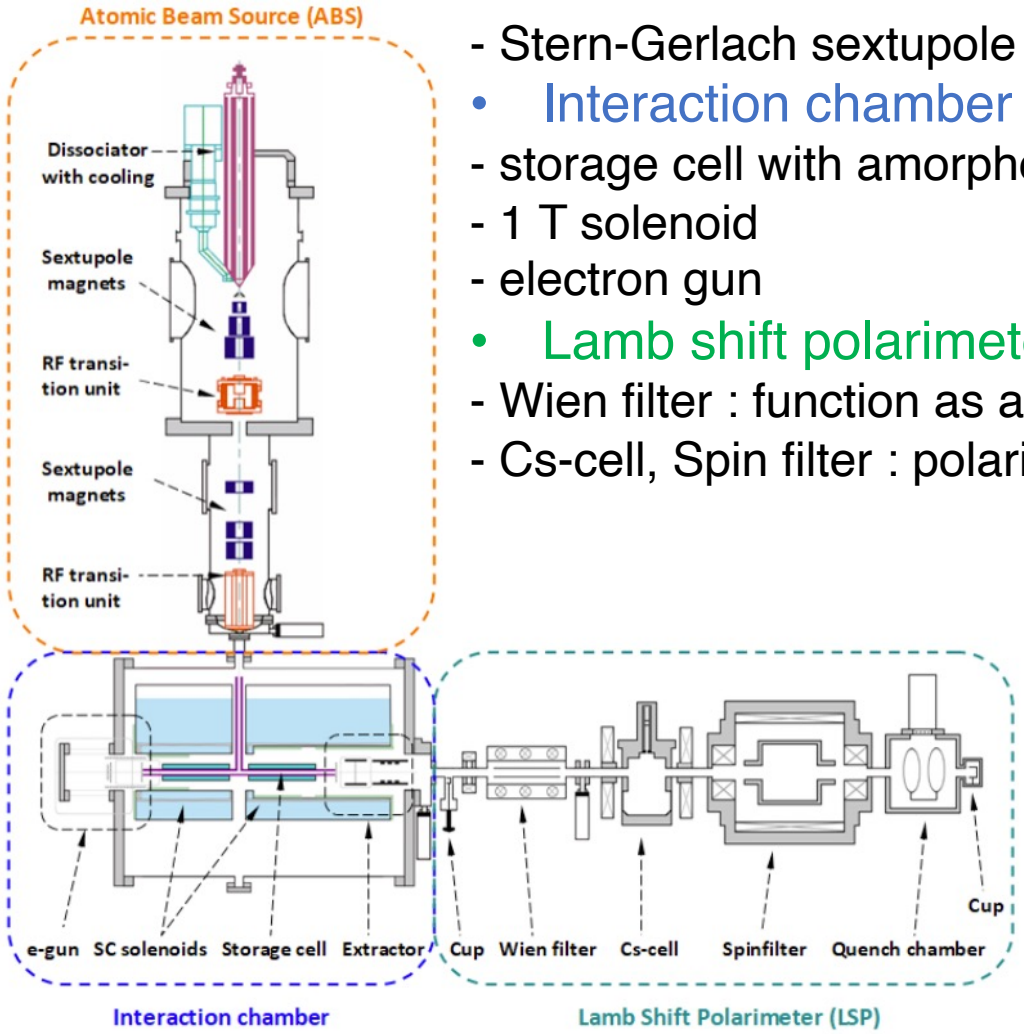

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- Stern-Gerlach sextupole magnets & microwaves

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- storage cell with amorphous coating with 100 K
- 1 T solenoid
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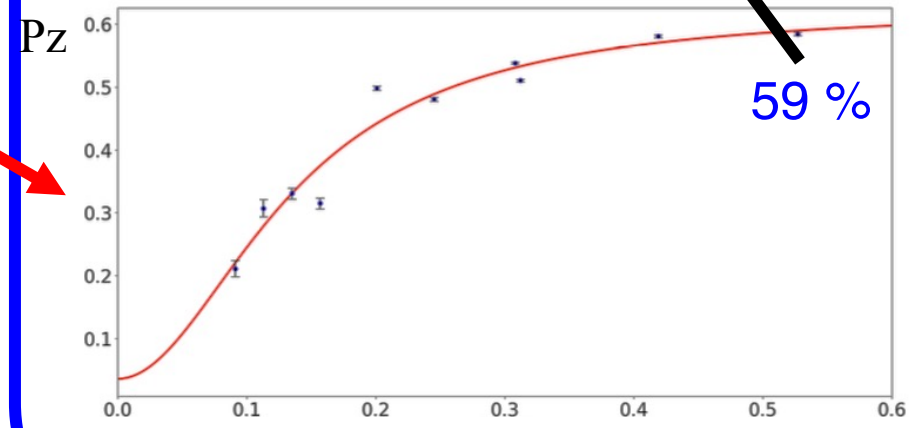
- Lamb shift polarimeter (LSP)

- Wien filter : function as a mass spectrometer
- Cs-cell, Spin filter : polarization measurement

80 % : initial polarization

74 % of the atomic polarization preserved

Polarization after recombination

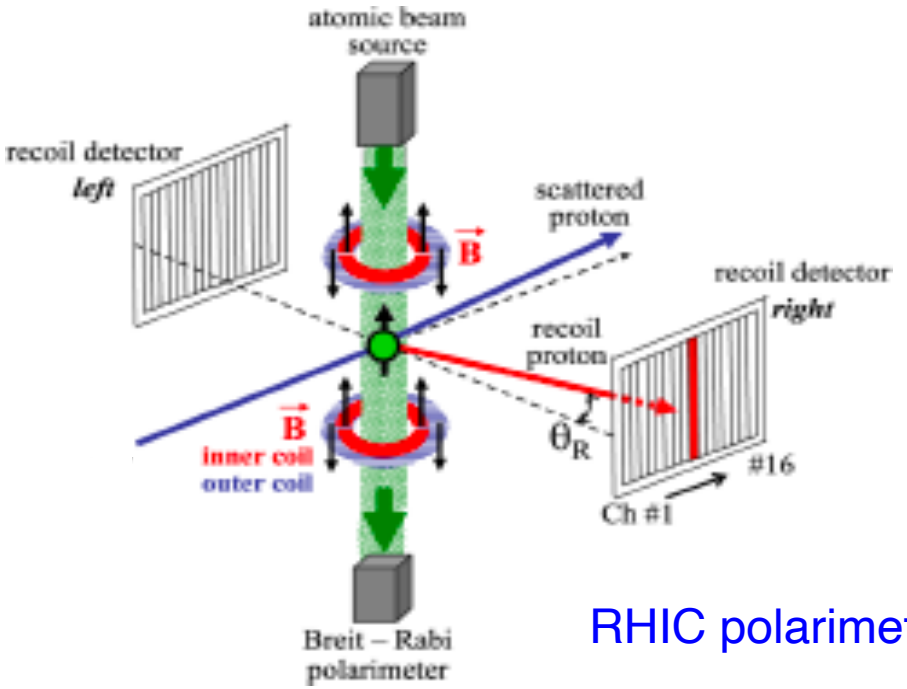


59 %

New absolute polarimeter

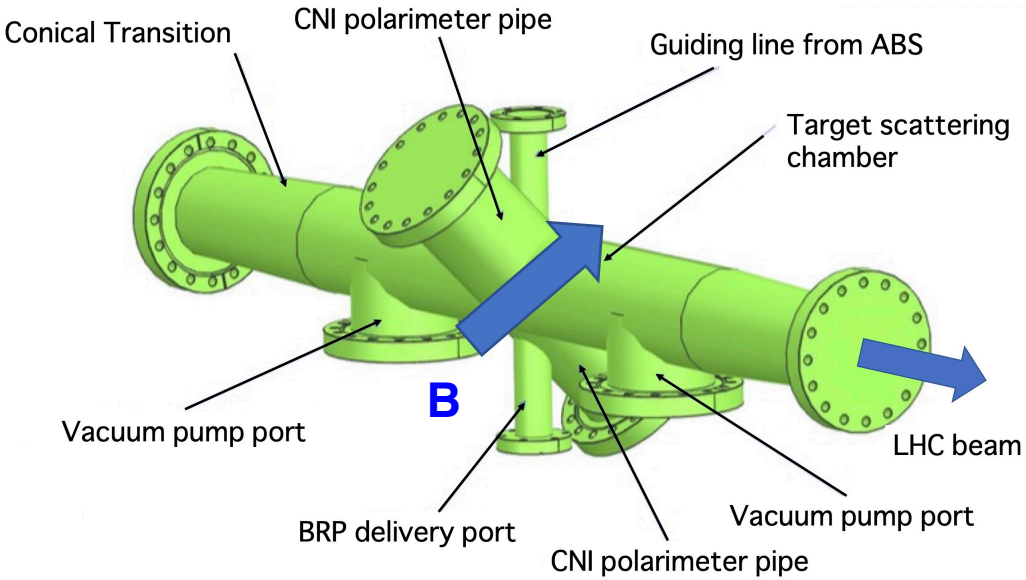
Elastic scattering of pp at $|t|\sim10^{-3}\ GeV^2$
base on Coulomb-Nuclear Interference (CNI)

- Polarized jet target for phase 1 at IR4
- Scattering chamber
- Holding coil : about 300 mT
- Recoil detector : silicon strip

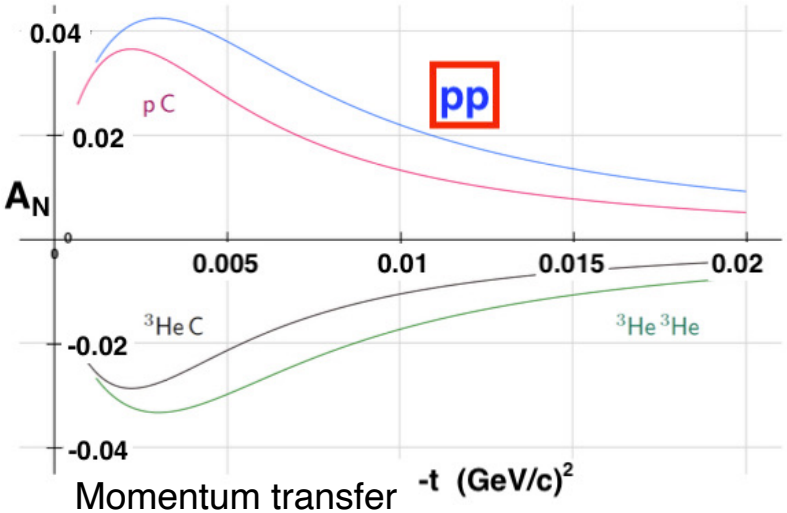


RHIC polarimeter

Scattering chamber



Theoretical estimation of the analyzing power



Present status of the gas target system

HERMES target system
- in Ferrara
- refurbishment

Timeline

LHC	IR4	LHCb	Pol. target
LS3 (2027 - 2030)	Installation of the apparatus		Development
Run4 (2030 - 2033)	Data taking		Target test & Polarimeter test
LS4 (2033 - 2035)	Upgrade of the apparatus	Installation of the apparatus	Improvement & installation
Run5 (2035 -)	Data taking	Data taking	Operations at IR4 and LHCb

Run4 @IR4 (phase 1)

Small spectrometer with PT

- PT, magnet, trackers
- 1% momentum resolution expected
- Feasibility test

Run5 @IR4 (phase 2)

New inclusive physics measurement

- Use the apparatus for Run4
- Upgrade spectrometer
- Further discussion

Run5 @LHCb (phase 2)

Downsizing of the PT system is also considered.

- Limited space of LHCb spectrometer
- Additional equipment (polarimeter)
- Should be solved in LS4

Summary & outlook

- **LHCspin project with polarized target at LHC**
  - innovative and unique project conceived to bring polarized physics
- **The SMOG2 fixed target at LHCb performed in parallel with beam-beam collision.**
- **Amorphous carbon coating considered**
  - tested at FZJ
    -- polarization preserved after recombination
    -- further investigations (coating, temperature)
- **New absolute polarimeter**
  - preparation ongoing
    -- Geant simulation
    -- design of the vacuum chamber
  - commissioning at IR4
- **Kick-off meeting**
  - Nov. 20-21 at Ferrara in Italy
- **Post-doc position available in Frascati(LNF)/Ferrara, Italy**
  - Please contact : Pasquale.DiNezza@lnf.infn.it

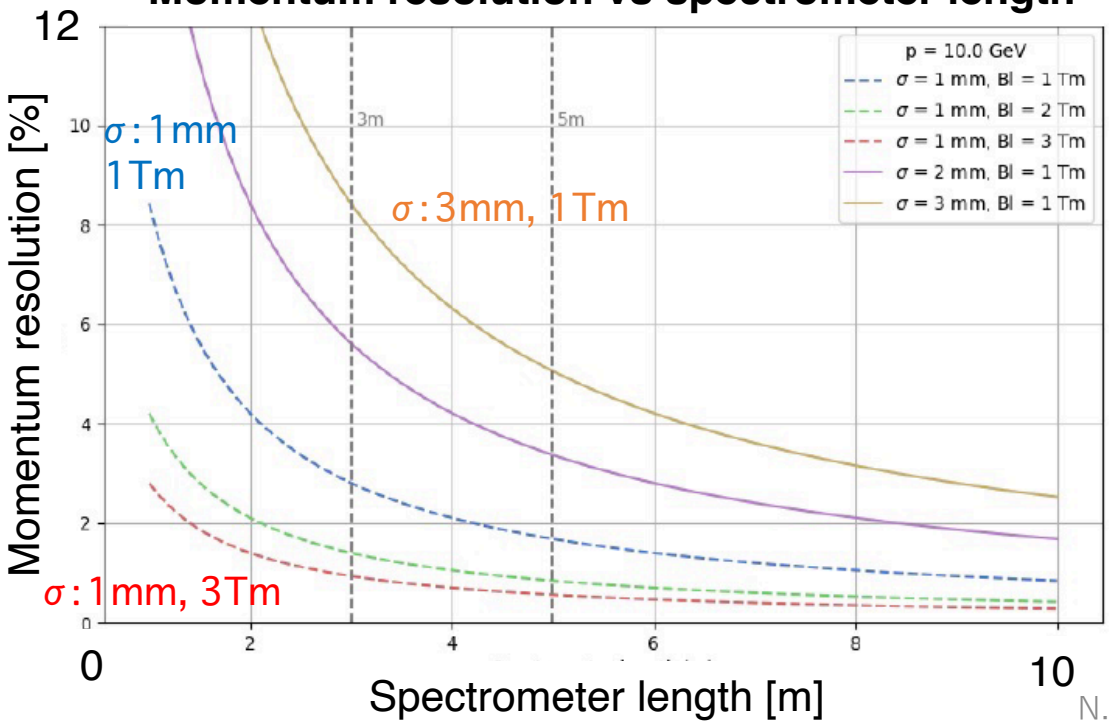
Back up

Phase1at IR4 (2030 – 2033)

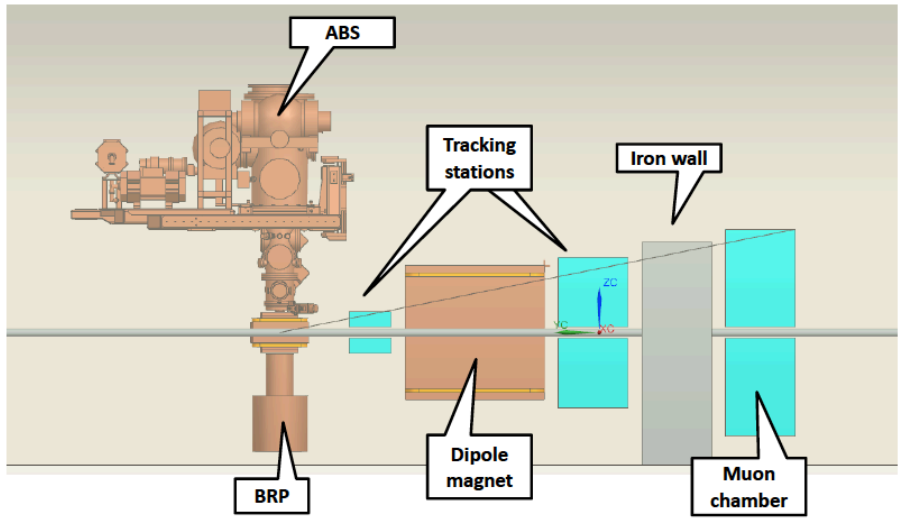
IR4 : Limited space (different from LHCb)

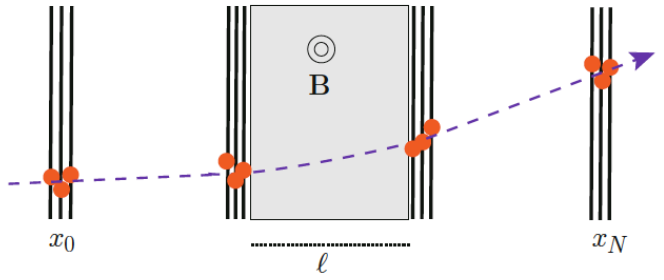
- Feasibility check for Phase2
- Single-spin asymmetry with J/psi production
- Polarimeter commissioning
- PT, Spectrometer magnet, trackers + α

Momentum resolution vs spectrometer length



Spectrometer setup at IR4





$$\frac{\delta p}{p} = \frac{8\sigma}{\sqrt{N+1}} \frac{1}{0.3z \cdot Bl \cdot L} p$$

$\frac{\delta P}{P}$ ~ 1% expected
with a several meter long spectrometer