



中国科学院
CHINESE ACADEMY OF SCIENCES



中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

Time-reversal Symmetry Test with Spin-rotating Polarized Target

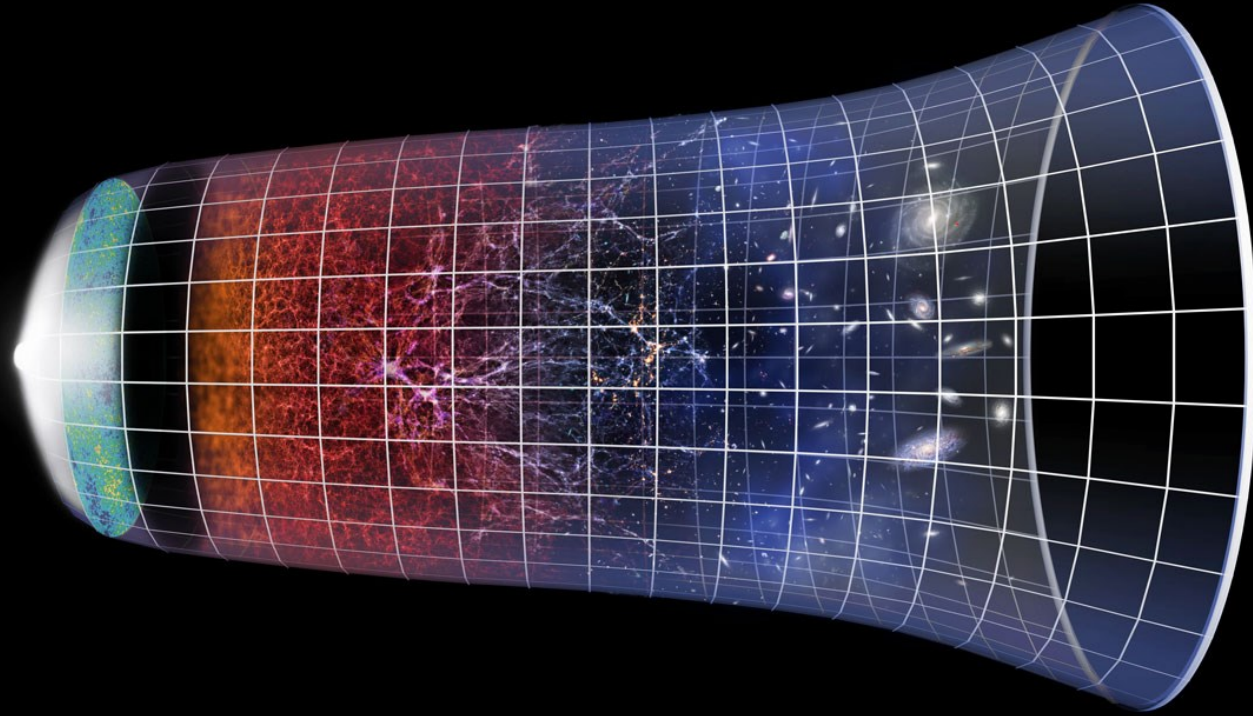
Boxing Gou (勾伯兴)
on behalf of the HIAF spin team

The 1st Conference on Strong-Interaction Spin Physics

- Time-reversal test in $\vec{p}\vec{d}$ scattering
- Efforts towards polarized beams/targets for HIAF
- Spin-rotating polarized target
(innovative technique for high-precision exp.)

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Why time-reversal asymmetry?



Big Bang → ~~CP~~ → Today

Excess of matter in the universe

Observation

$$\eta \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6.11 \pm 0.19) \times 10^{-10}$$

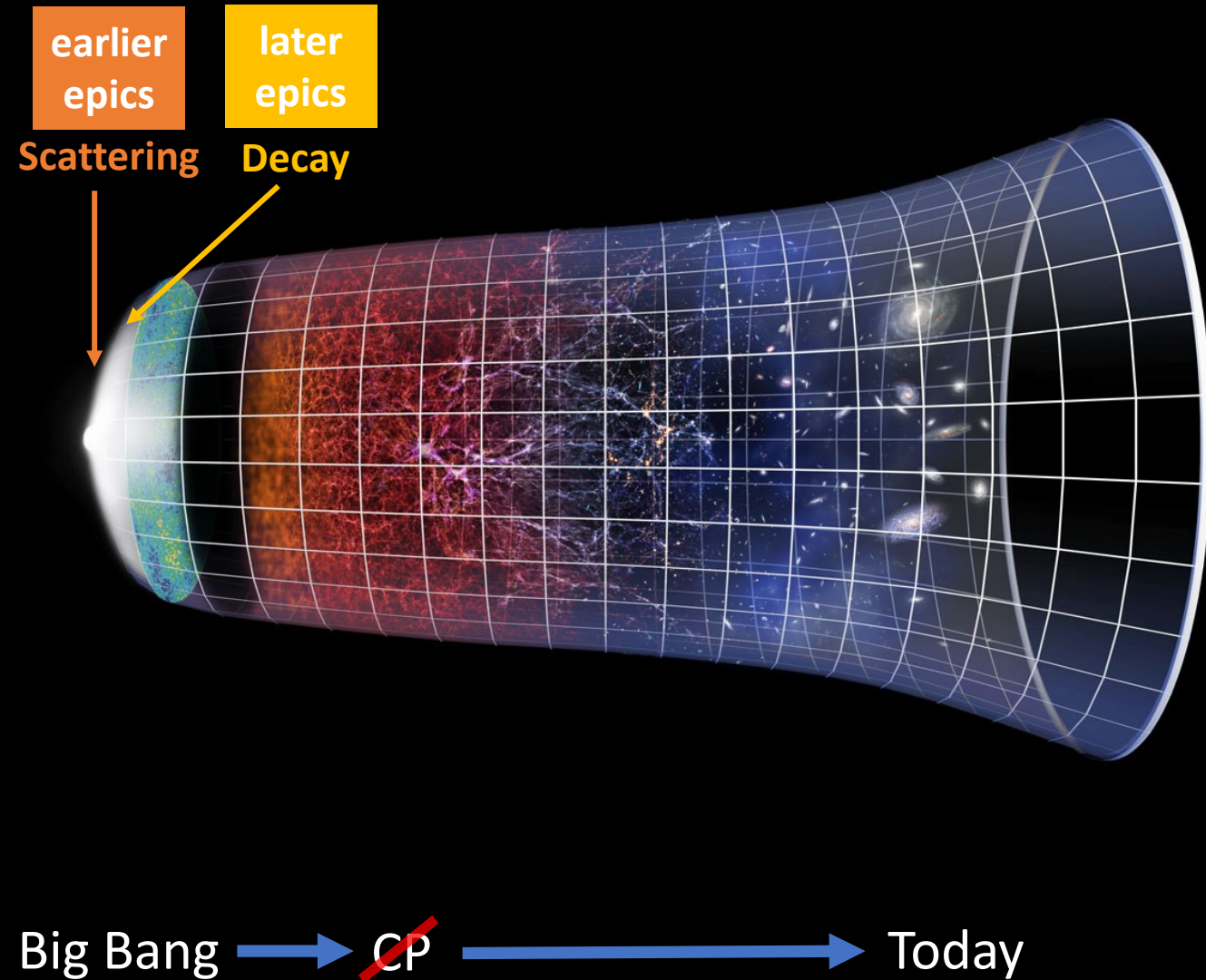
SM predication

$\sim 10^{-18}$

New sources of CP violation must exist



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Test time-reversal symmetry with $\vec{p}$ $\vec{d}$ scattering



What is time reversal?

- Flip momentum and spin for all particles
- Exchange initial and final states

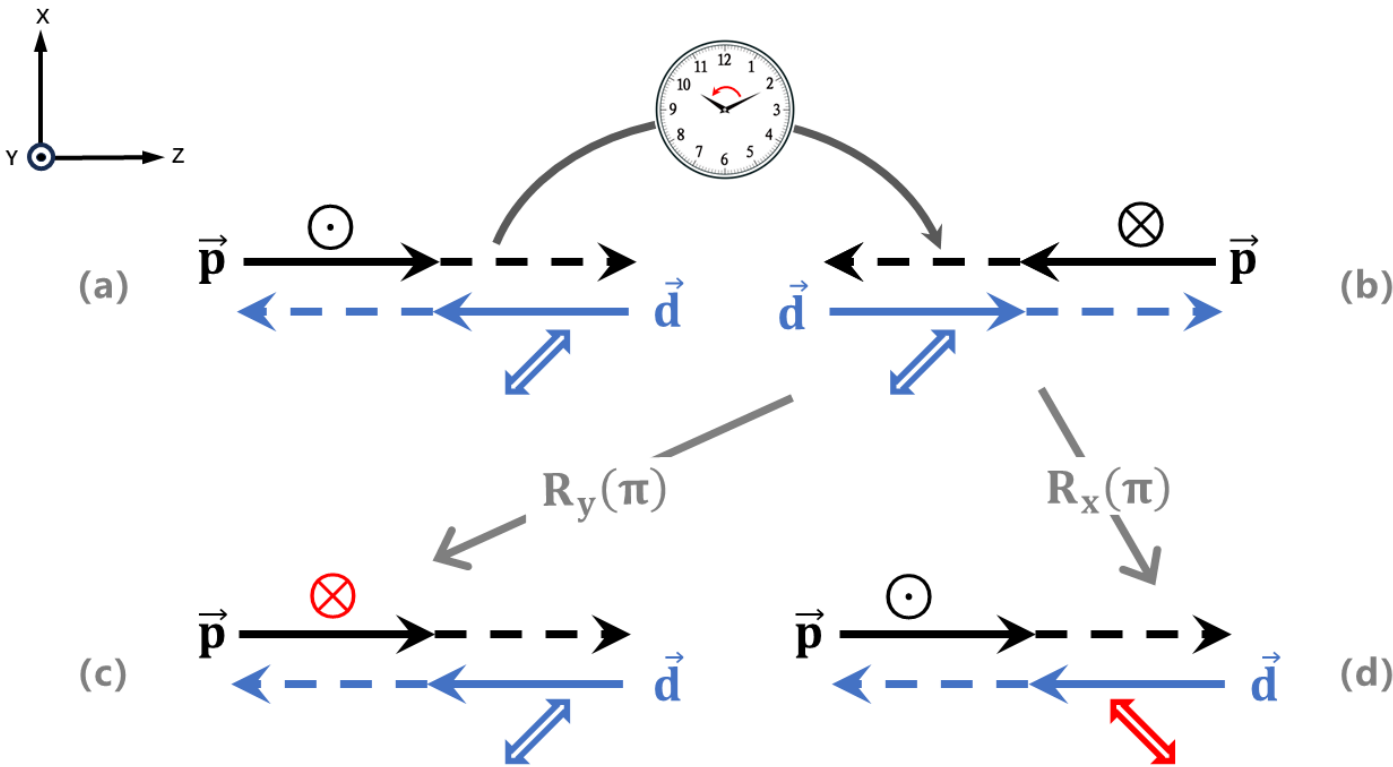
Test time-reversal symmetry with $\vec{p}$ $\vec{d}$ scattering

Parity conserving (unlike EDM)
Time-reversal violating



What is time reversal?

- Flip momentum and spin for all particles
- Exchange initial and final states
- Equivalent to spin flip (at forward scattering/ $\theta = 0^\circ$)
- Optical theorem

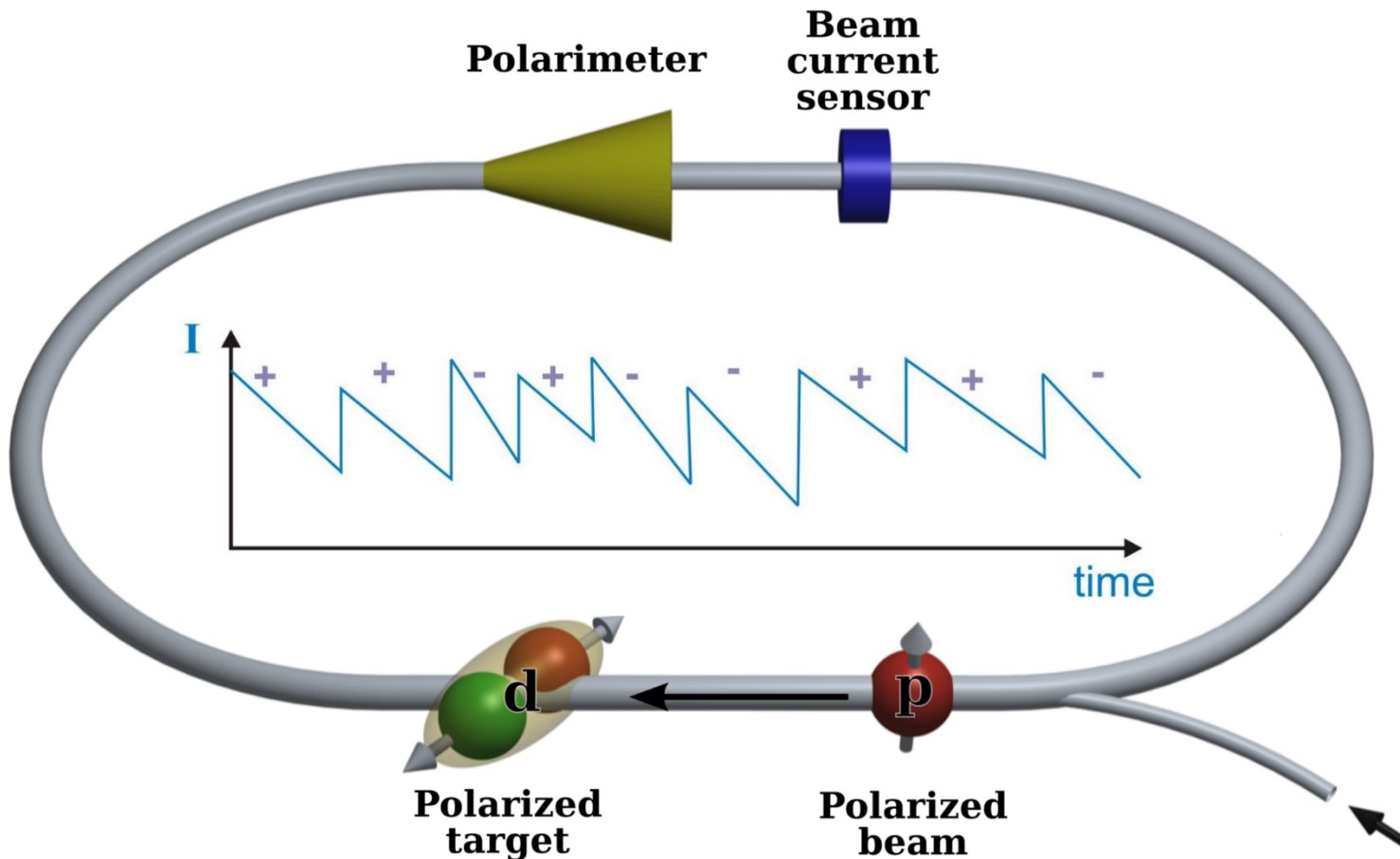


$$\frac{4\pi}{k} \text{Im } F^{el}(0^\circ) = \sigma_{total}$$

$$\sigma_{total}^{\uparrow} = \bar{\sigma}_{total}(1 + P_Y \cdot P_{XZ} \cdot A_{Y,XZ})$$

$$\sigma_{total}^{\downarrow} = \bar{\sigma}_{total}(1 - P_Y \cdot P_{XZ} \cdot A_{Y,XZ})$$

What do we need



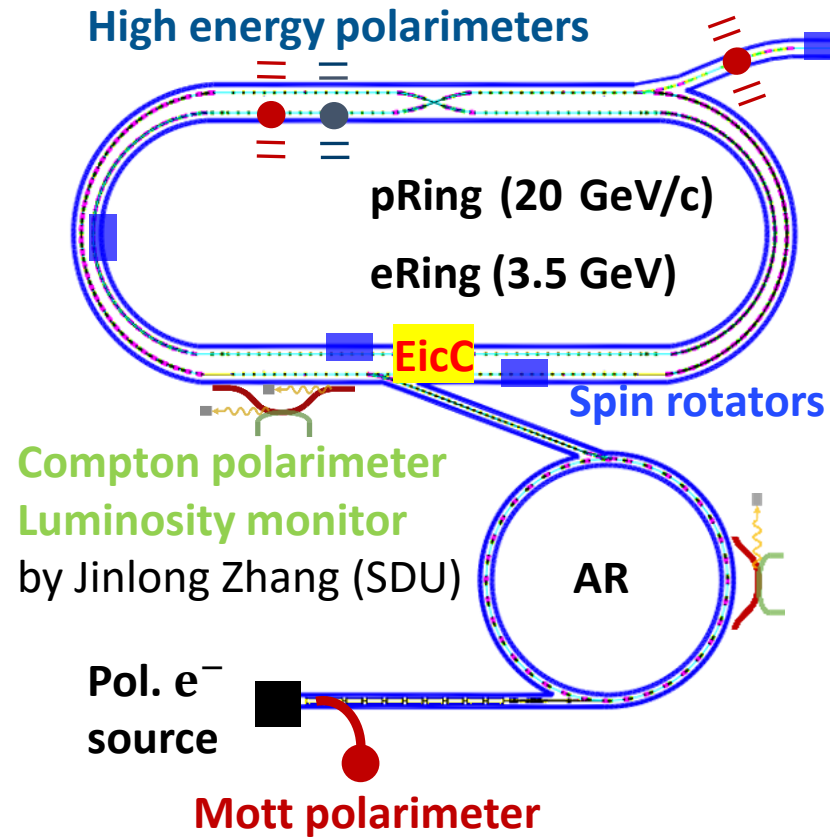
plot adopted from PAX and TRIC publications

$$\sigma_{total}^{\uparrow\downarrow} = \bar{\sigma}_{total} (1 \pm P_Y \cdot P_{XZ} \cdot A_{Y,XZ})$$

- polarized proton $\rightarrow P_Y$
- polarized deuteron $\rightarrow P_{XZ}$
- beam current monitor $\rightarrow \sigma_{total}^{\uparrow\downarrow}$

- Time-reversal test in $\vec{p}\vec{d}$ scattering
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(innovative technique for high-precision exp.)

HIAF-EicC

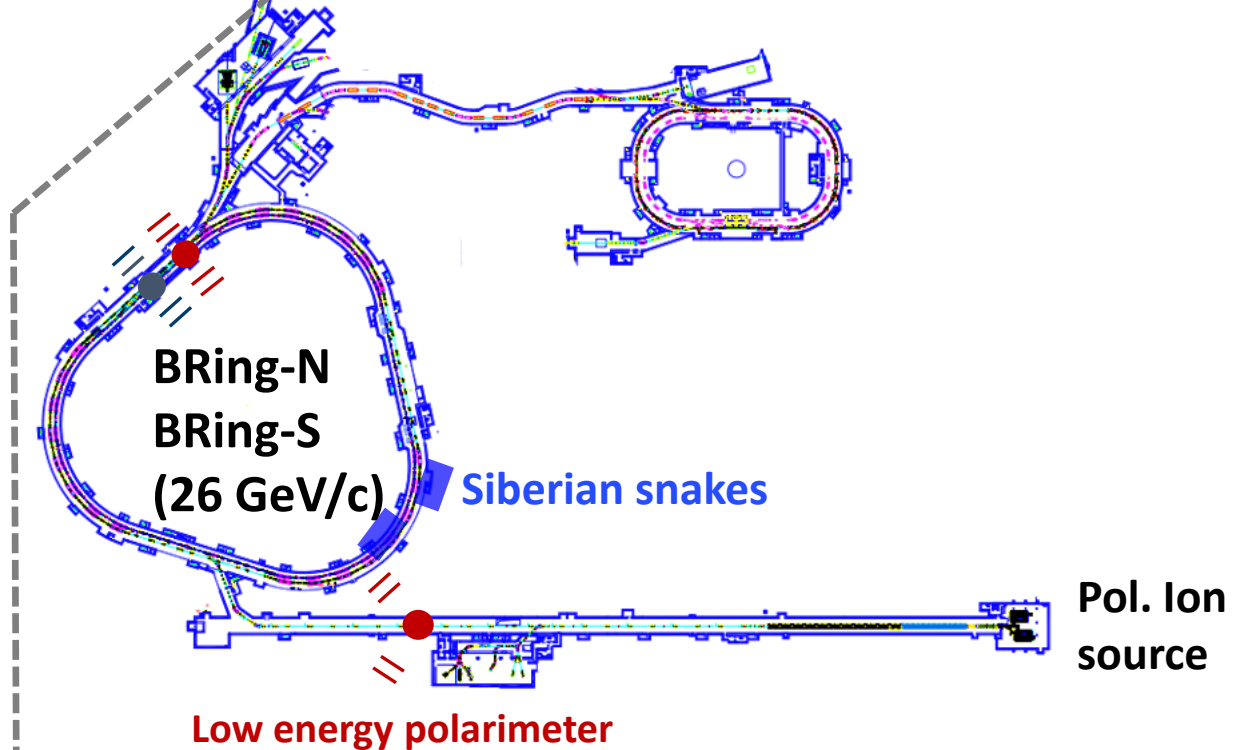


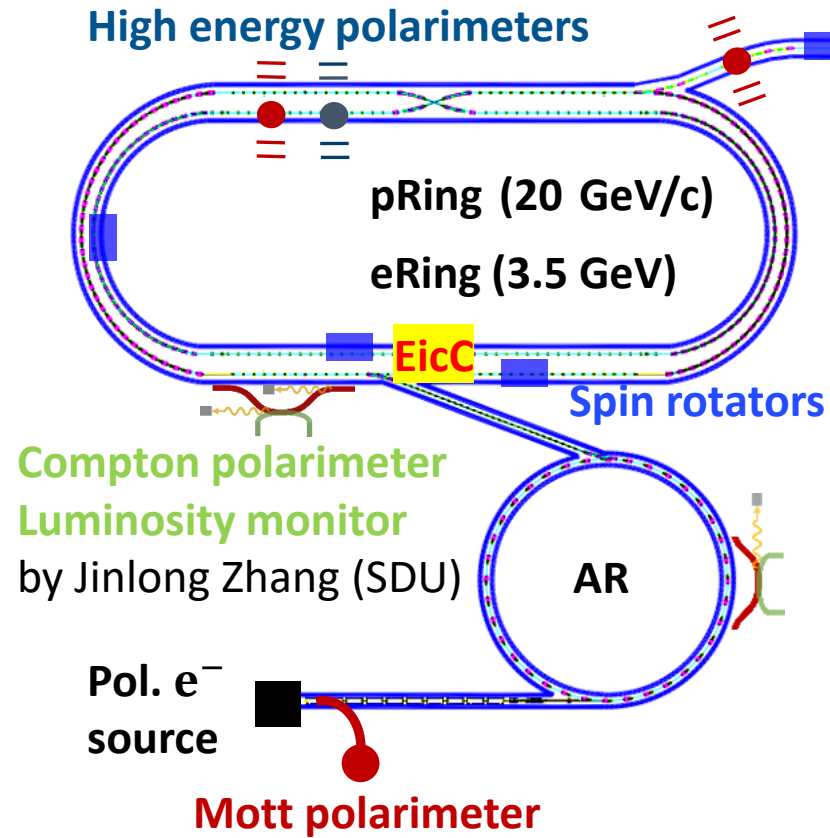
Electron ion collider in China (EicC)

- currently being proposed
- **initial driving force of polarized beam development at IMP**

Other talks at this conference

- [HIAF overview](#) (Lijun Mao, Monday)
- [Pol. Beam at HIAF](#) (Liangting Sun, Monday)
- [Final-state polarization](#) (Yutie Liang, Wednesday)



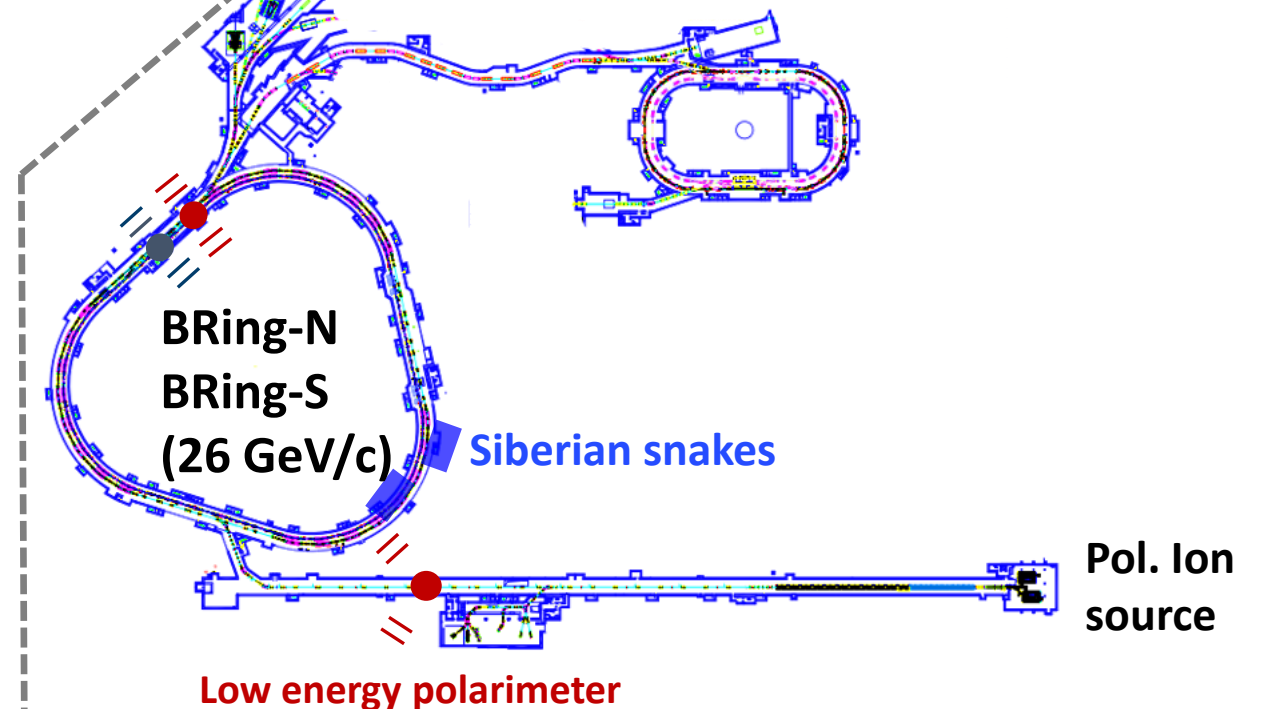


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➤ Spin Physics at HIAF

The 2nd Workshop on Polarized Beam and Target - Physics and Applications (PBT2026)



Efforts towards polarized beams/targets at HIAF

- A team for **polarized ion source**, **polarized beam acceleration** and **polarized target**
- International collaborations



team leader



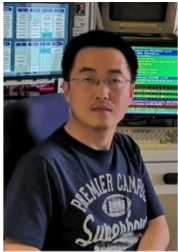
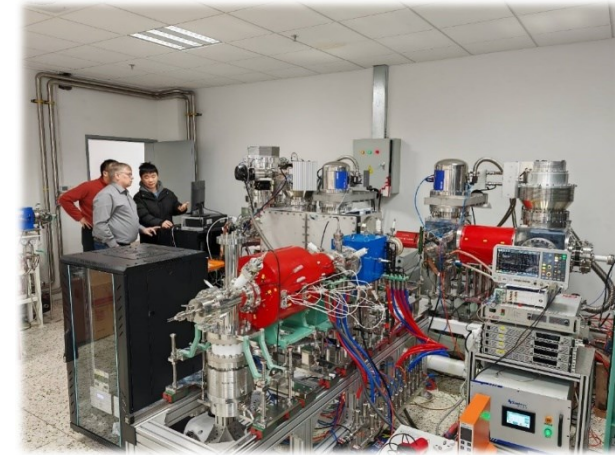
pol. ^3He



engineering
vacuum



pol. H/D source



polarimeter
pol. H/D target



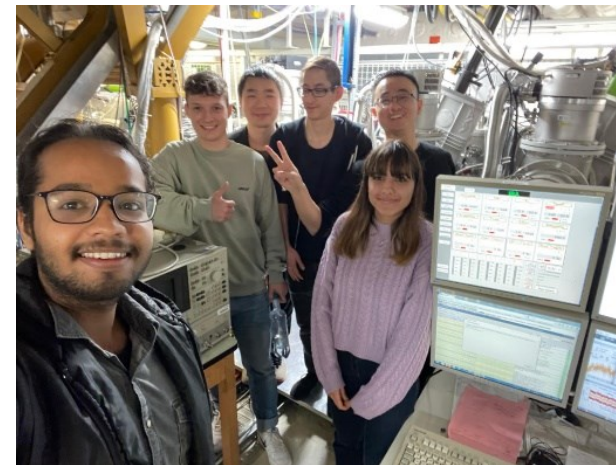
pol. ion source
pol. H/D target



magnet



beam diagnostic



polarimeter
pol. H/D target



pol. beam acc.
spin manipulation



ionizer
Lamb-Shift
polarimeter



control system
pol. atomic beam

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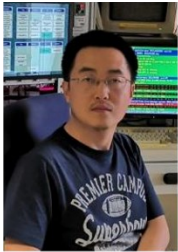
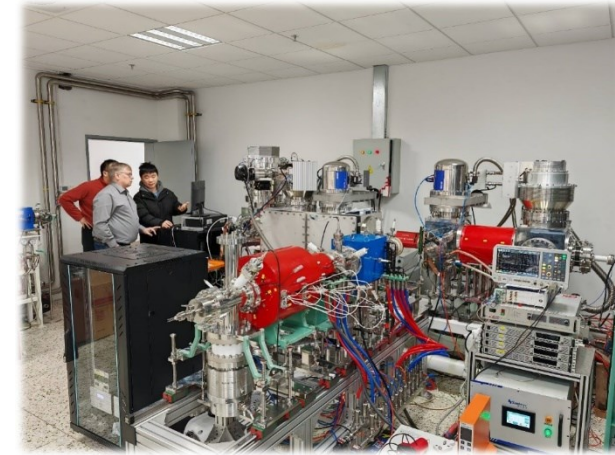
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polarimeter
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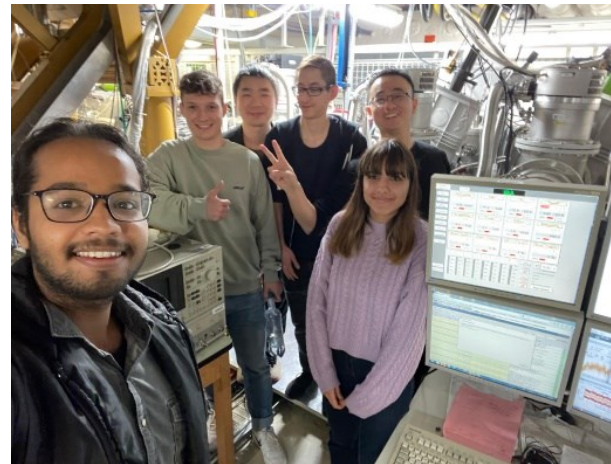
pol. ion source
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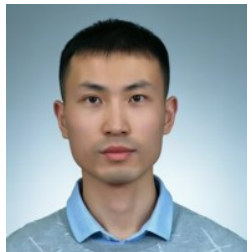
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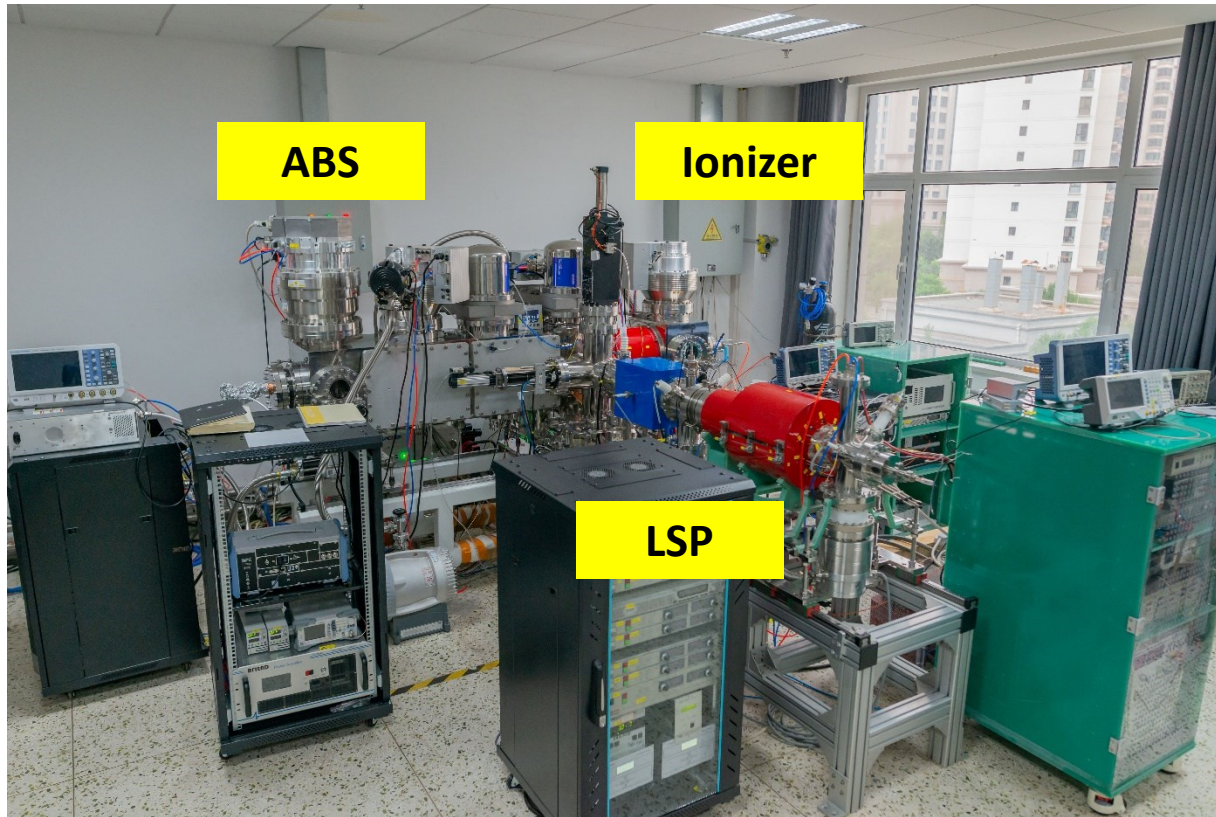


ionizer
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control system
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Efforts towards polarized beams/targets at HIAF



A polarized H^+/D^+ source already built at IMP

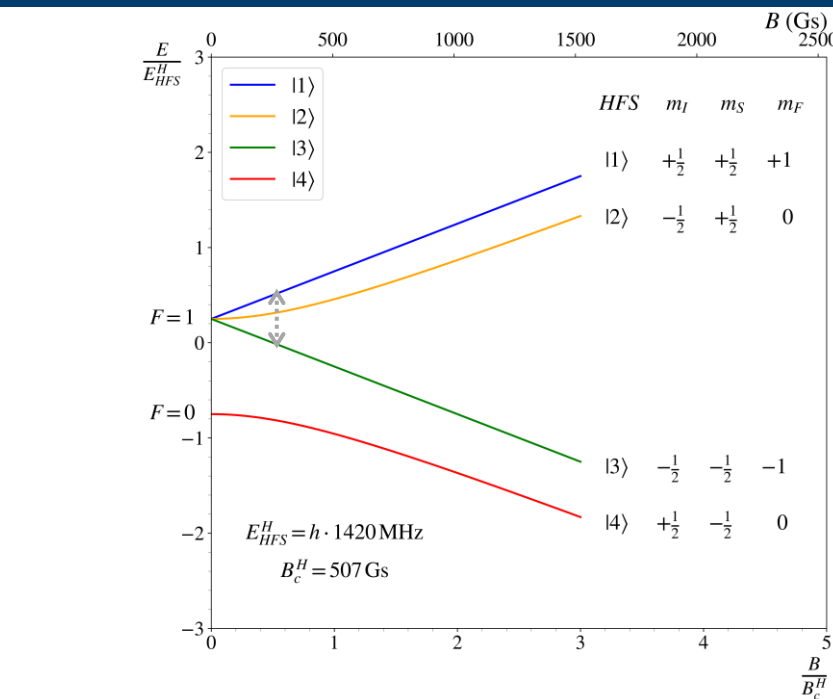
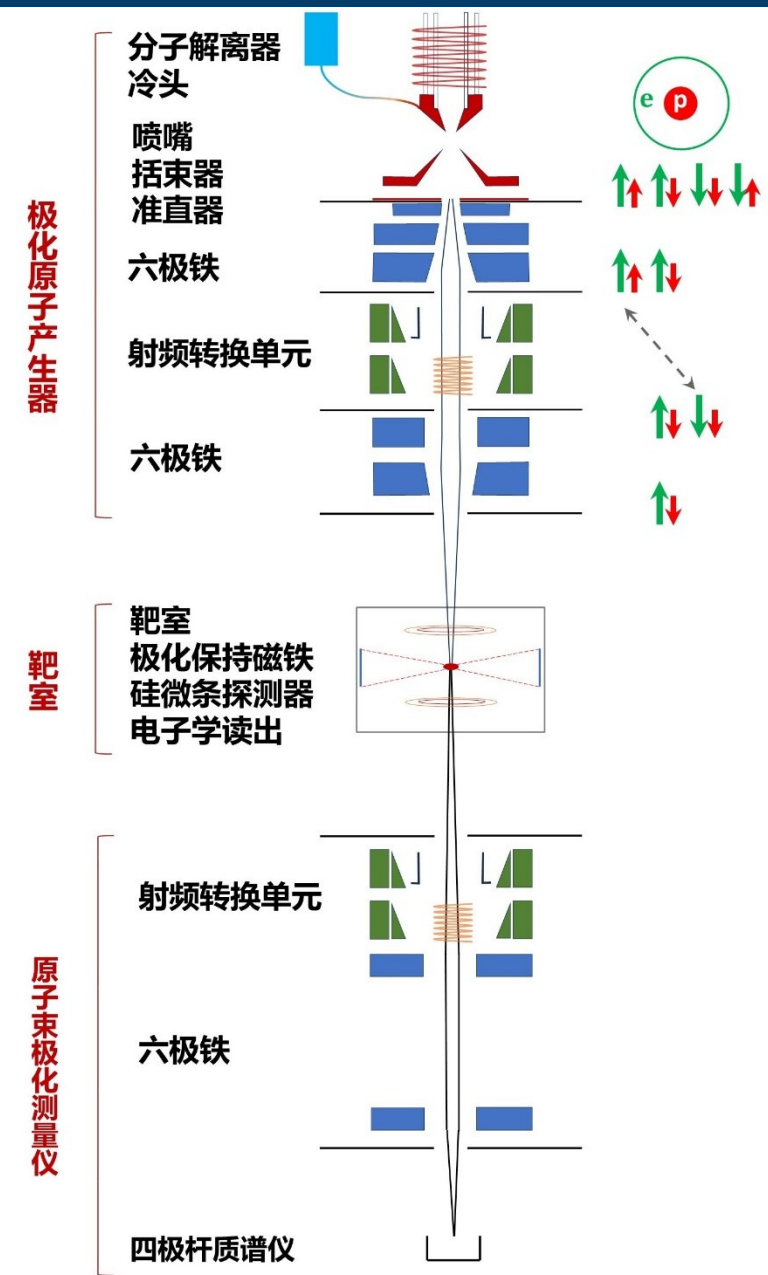
- **Intensity: > 1 mA**
- **Polarization: $> 80\%$**
- **Repetition frequency: 2-5 Hz**
- **Pulse width: > 100 us**

see [talk by Liangting Sun](#) (Monday, morning)

Polarized beam acceleration at HIAF investigated by Minxiang Li et al.

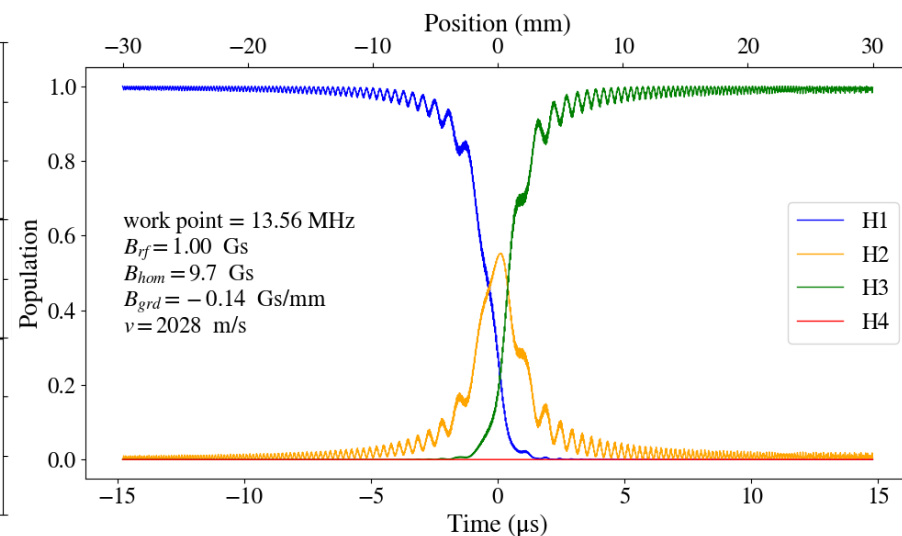
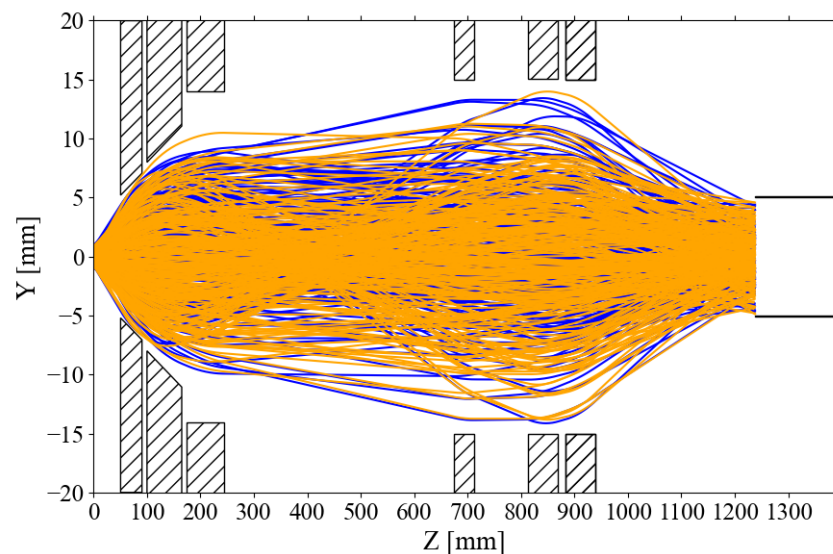
- constant field solenoid Siberian snake: [NIMA 1031, 166405 \(2022\)](#)
- tensor-polarized deuteron beam: [Phys. Rev. Accel. Beams 28, 094002](#)

Polarized H/D gas target

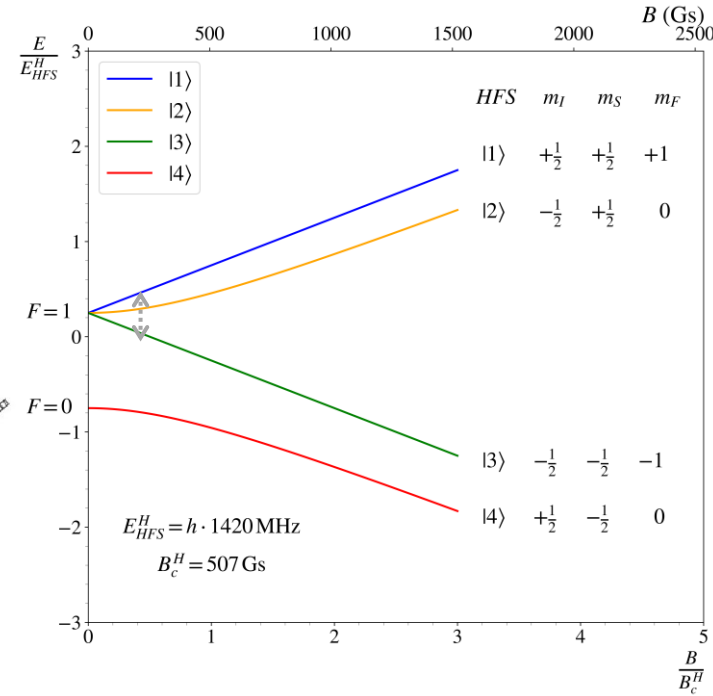
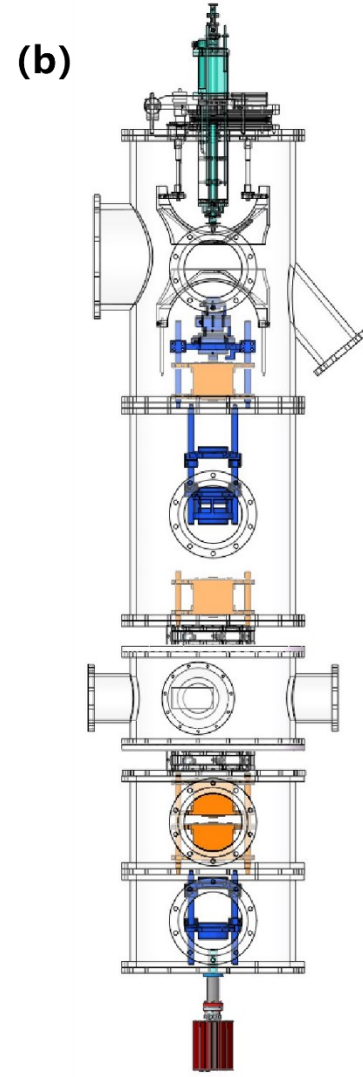
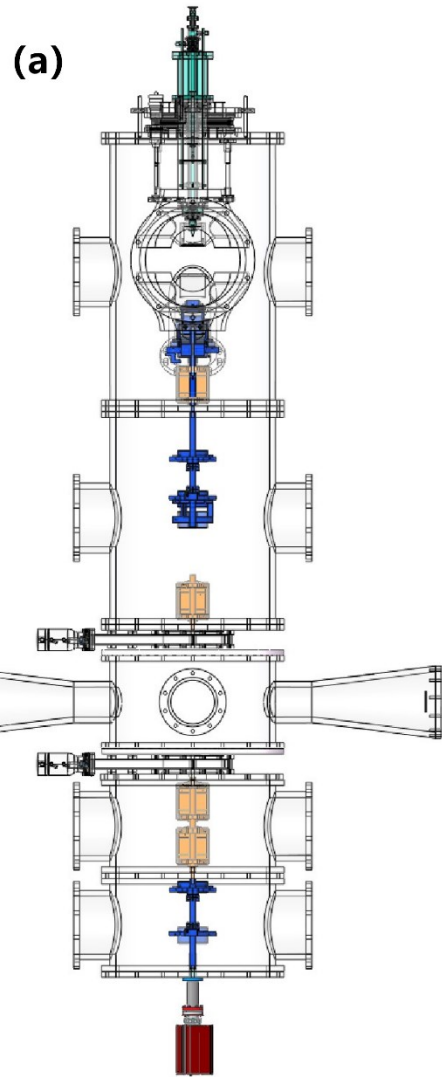


PIT principle

- Dissociator: $\text{H}_2 \rightarrow \text{H}$
- Sextuple mag: spin filter
- RF transition unit: spin flip
- Produce both $\vec{H}$ and $\vec{D}$ jet



Polarized H/D gas target

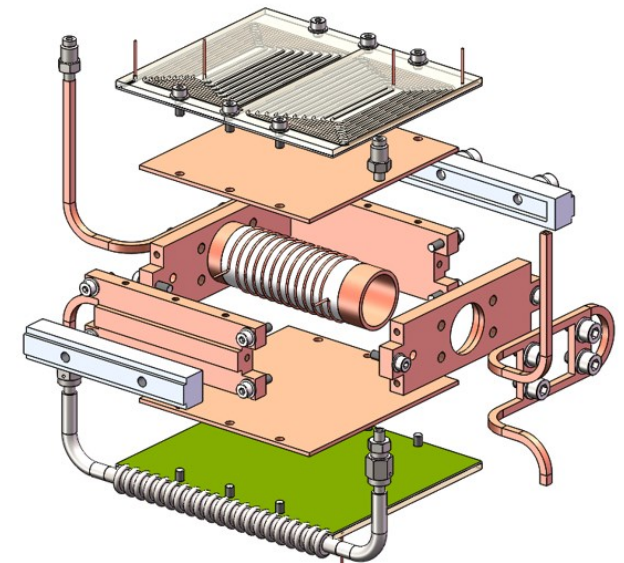
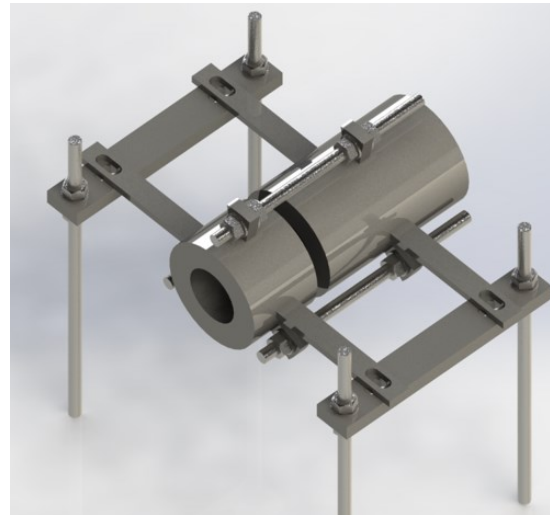


PIT at IMP

✓ Design ready

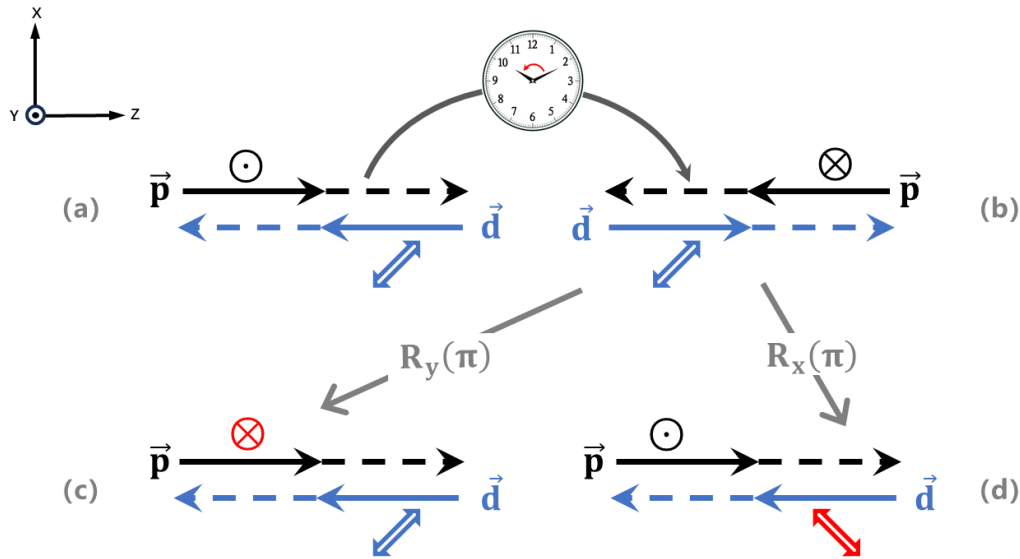
✓ Funded by CAS ☺

□ Construction in progress ...



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T symmetry test: status and challenges



Proposed since early 1990s

H. E. Conzett. Null tests of time-reversal invariance. Phys. Rev. C 48, 423 (1993)

<https://tric-experiment.hiskp.uni-bonn.de/>

<https://www.fz-juelich.de/en/ikp/ikp-2/research/previous-list/tric>

P. Lenisa et al. EPJ Tech. Instr. (2019) 6

Challenges

✓ **Signal asymmetry ($A_{y,xz}$)**

■ **Instrumental background asymmetry:** nonperfect beam/target parameters ($\Delta E, \Delta X, \Delta X', \Delta I \dots$)

■ **Physical background asymmetry:** residual vector polarization of deuteron ($P_y \rightarrow A_{y,y}$)

New idea: spin modulation

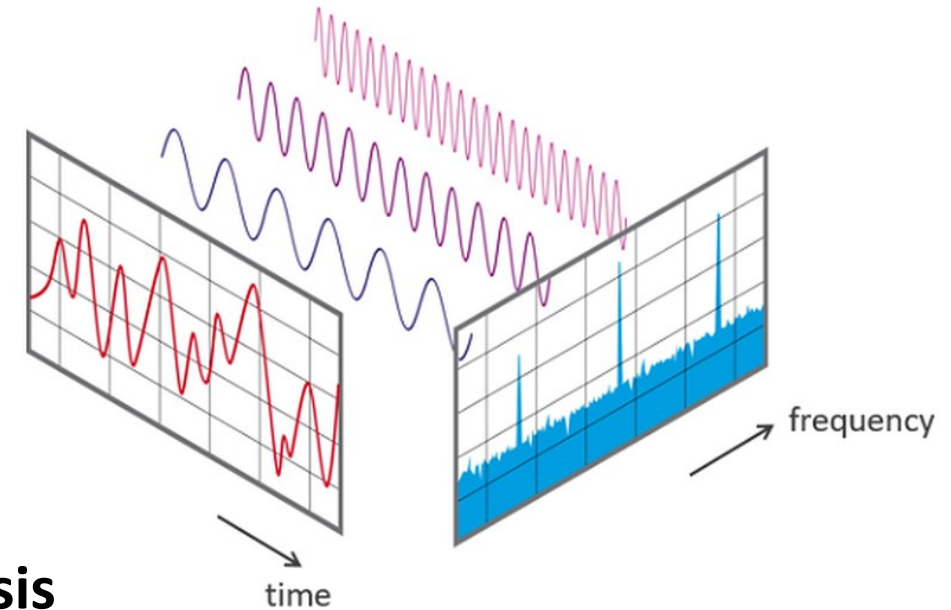
New approach to search for parity-even and parity-odd time-reversal violation beyond the Standard Model in a storage ring

N.N. Nikolaev, F. Rathmann , A.J. Silenko, Yu.N. Uzikov

Phys. Lett. B 811, 135983 (2020)

Main idea

- Conceived in the JEDI collaboration
- **Beam polarization rotates** with an RF solenoid
- Experimental asymmetry oscillates
- False asymmetry easily separated via **Fourier analysis**



New idea: spin modulation

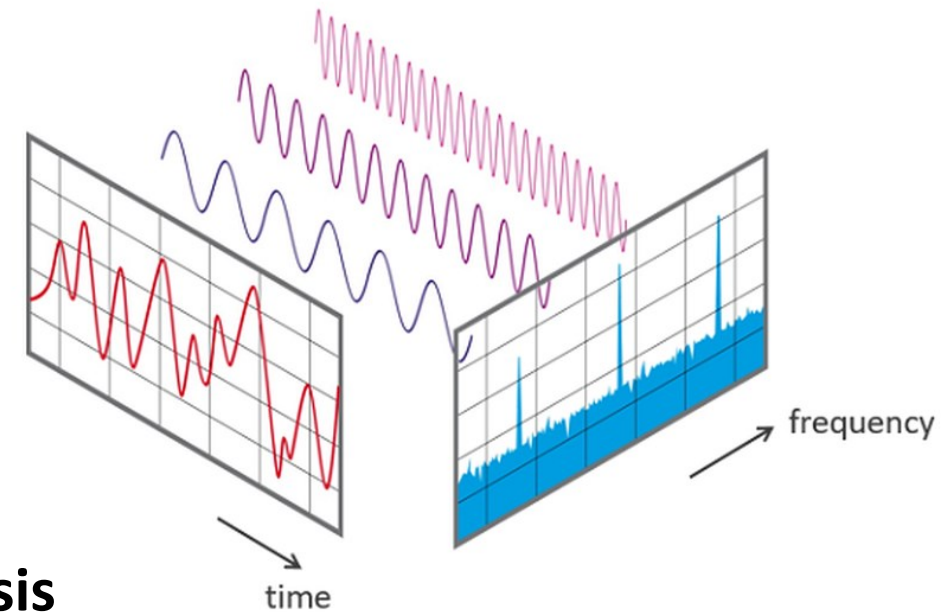
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Spin-rotating polarized target?

Spin-rotating polarized target

- Atoms polarized in pol. H/D gas target
- Electron spin aligned with the holding field at interaction point
- Proton/deuteron spin attached to electron spin (HF not too strong)
- Up to now, only static holding fields are used: transverse, longitudinal or superposed
- **How to make a rotating field?**
 - Triple coils driven by 3-phase rf current (proposed at SPIN2025)
 - Static dipole $\vec{B}$ superposed by perpendicular RF $\vec{B}$
 - proposed for NICA
 - private communication with N.N. Nikolaev

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To my great delight, just days after being inspired by their fantastic paper, I was introduced to Prof. Nikolaev, who had been trying to contact the HIAF-SPIN team, when we surprisingly found out that we had similar ideas!!!



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ITP/CAS - Landau ITP
Joint Online Colloquium

Fundamental Symmetries in Storage Ring Experiments

N. N. Nikolaev

L. D. Landau Institute for
Theoretical Physics
Russian Academy of Sciences



Abstract

Principal aim of this talk is to draw attention of Chinese high energy community to exciting physics Beyond Standard Model (BSM) offered by spin experiments in storage rings (SR). SR based searches for the electric dipole moment of charged particles have a potential of uncovering an origin of the BSM CP-violation badly needed to explain the observed baryogenesis in Universe. I will briefly comment on classic results of JEDY@COSY and ongoing activity of CPEDM@CERN, srEDM@BNL and SPRINT@NICA (JINR) collaborations in this direction. My major focus will be on the spin in SRs as a broadband antenna of axions and axionlike particles. A beauty of SRs is a relativistic enhancement by a factor 1000 of a pseudomagnetic field induced by the axion halo of our Galaxy. I comment on new ideas on search for the SM parity violation based on the JEDI experience with precessing horizontal polarization. Next I move to a so far little explored BSM C-odd and T-odd millistrong interaction postulated in 1965 by Okun, Lee, Wolfenstein, Prentky and Veltman as a source of CP violation. Here precessing polarization would allow systematics-free extraction of the T-violation in pd scattering. As a cherry on cake, I will comment on a unique discovery potential of precessing polarization targets and share my excitement that a remarkably close idea is being pursued by Dr. Boxing Gou of the Institute of Modern Physics, Lanzhou.

Biography

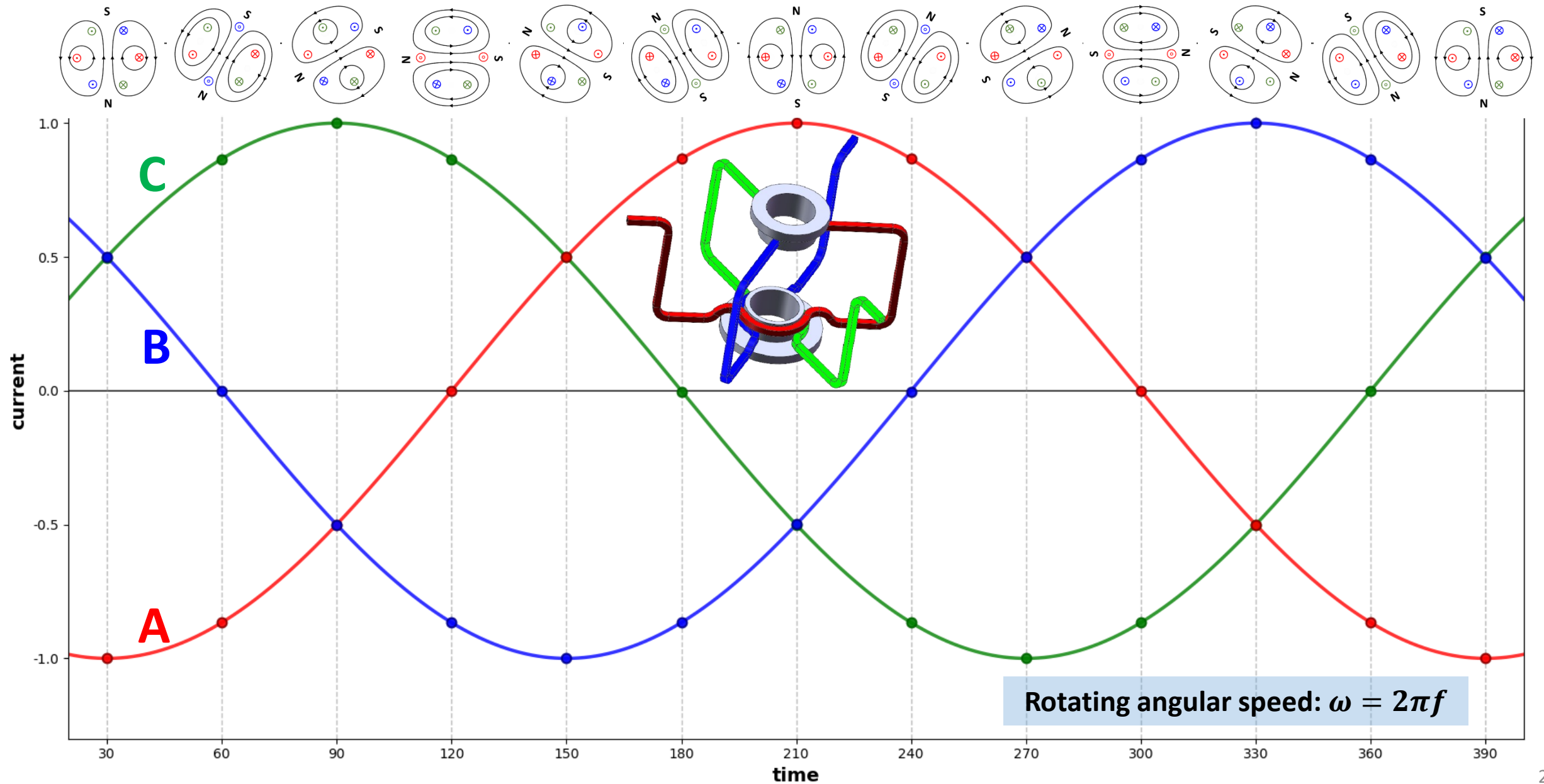
Nikolai Nikolaevich Nikolaev, born 20.05.1947, Mari El Republic, Russia. Moscow Institute of Physics and Technology (1964-1970), with honors. PhD student (1970-1973) at MIPT, supervisor Lev Borisovich Okun. Since 1973 at the Landau Institute for Theoretical Physics. Other positions: Research fellow at the Theory Division, CERN (1978-1979); Visiting professor at the University of Torino, Italy (1990-1991); Senior researcher, Institut f. Kernphysik, Forschungszentrum Juelich, Germany (1993-2012). Major Research interests: electroweak interactions, formation length in nuclear interactions, pre-QCD parton model, antishadowing phenomenon, QCD formalism for DIS on nuclear targets; QCD theory of color transparency and diffractive DIS; spin filtering in storage rings; quantum collective betatron oscillations; general relativity effects for spins in storage rings; spin dynamics in precision searches for the EDM and axionlike particles in storage ring experiments. H-index 45, 8600+ citations, sample publications:

- N. N. Nikolaev, B. G. Zakharov, Color transparency and scaling properties of nuclear shadowing in deep inelastic scattering, DOI: 10.1007/BF01483577, Z.Phys.C 49 (1991), 607-618.
- S. N. Vergeles, N. N. Nikolaev, Yu. N. Obukhov, A. Ya. Silenko, O. V. Teryaev. General relativity effects in precision spin experimental tests of fundamental symmetries, Usp.Fiz.Nauk 193 (2023) 2, 113-154, DOI: 10.3367/UFNr.2021.09.039074, 10.3367/UFNr.2021.09.039074
- N. N. Nikolaev et al. (JEDI Collaboration), Spin decoherence and off-resonance behavior of radio-frequency-driven spin rotations in storage rings, Phys.Rev.Accel.Beams 27 (2024) 11, 111002, DOI: 10.1103/PhysRevAccelBeams.27.111002

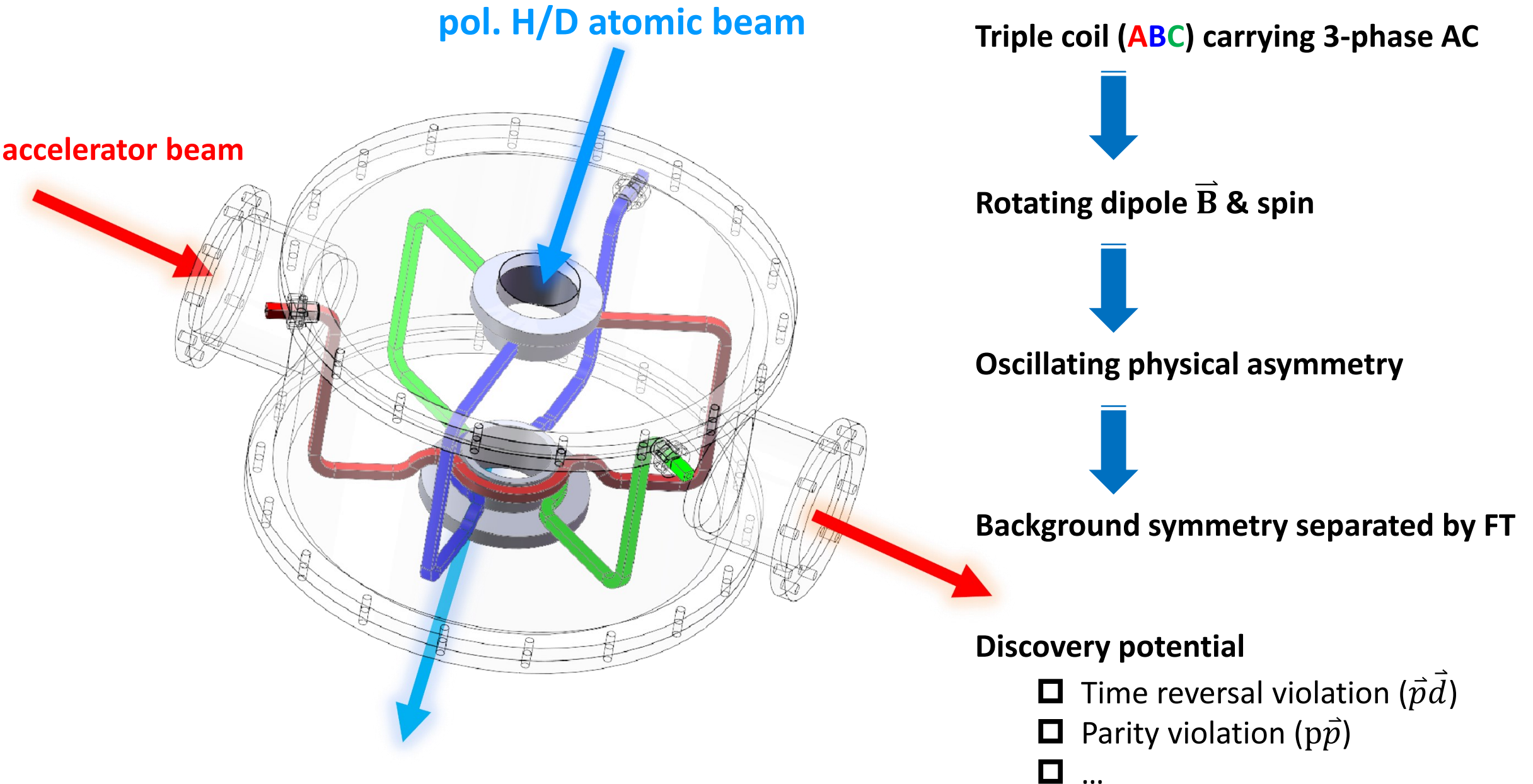
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 - B. Gou et al., **Spin physics at HIAF**, in: Proc. of 26th International Symposium on Spin Physics — PoS(SPIN2025), Tsingtao, China, 2025.
 - B. Gou, V. P. Ladygin, N. N. Nikolaev, F. Rathmann, A. J. Silenko, Yu. N. Uzikov, **Fresh Look at Polarized Deuterons at the Nuclotron/NICA & HIAF and Beyond**, Natural Sci. Rev. 3200802 (2026)

Rotating magnetic field



Spin-rotating polarized target



Summary

- Time-reversal symmetry test in $\vec{p}\vec{d}$ scattering
- Polarized beam/target at HIAF
 - Polarized ion source (built)
 - Polarized beam acceleration (investigated)
 - Polarized target (funded)
- Spin-rotating polarized target (great discovery potential)
- Spin physics at HIAF – great physics & a necessary step toward EicC
 - Instrument (Siberian Snakes ...)
 - Expertise and team

Thank you!