Spin Physics at HIAF

Boxing Gou
on behalf of the HIAF spin team

Huizhou • March 30 - April 3, 2026
2nd Workshop on Polarized Beams and Targets (PBT2026)

Content

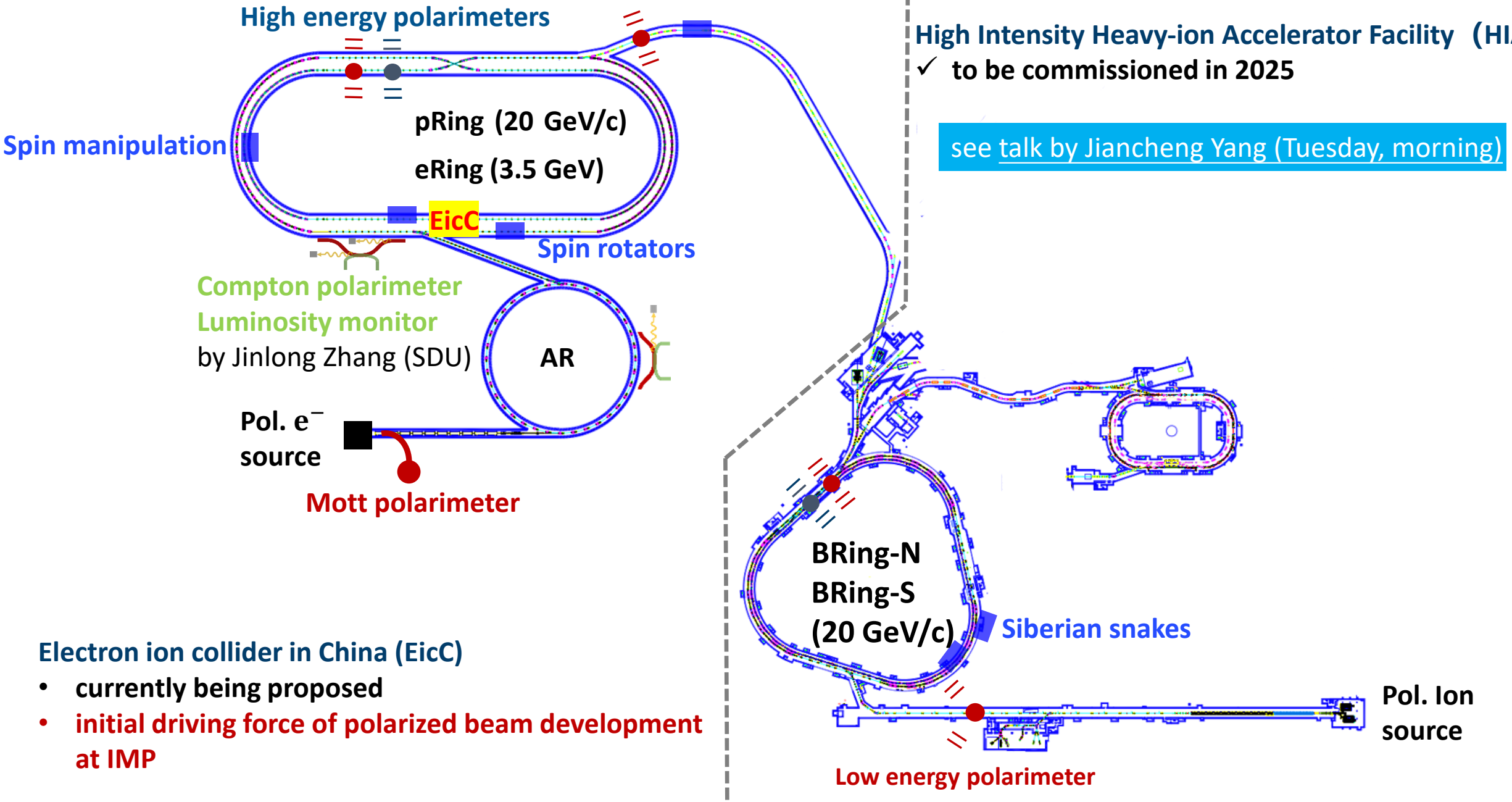
- Efforts towards polarized beams/targets for HIAF
  - Polarized ion sources
  - Acceleration of polarized beams
  - Beam polarimetry and polarized targets

- Spin physics at HIAF in the near future
  - Atomic, nuclear and hadron physics
  - New boson search
  - Test of time-reversal symmetry
  - Spin-rotating polarized target

Final-state polarization measurements not covered

see talk by Yutie Liang (Wednesday, morning)

HIAF-EicC



High Intensity Heavy-ion Accelerator Facility （HIAF）

✓ **to be commissioned in 2025**

see talk by Jiancheng Yang (Tuesday, morning)

Electron ion collider in China (EicC)

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

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Efforts towards polarized beams/targets at HIAF

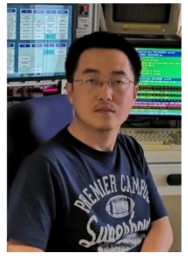
- A team for **polarized ion source**, **polarized beam acceleration** and **polarized target**
- International collaborations


team leader


pol. 3He


engineering
vacuum


pol. H/D source


polarimeter
pol. H target


pol. ion source
pol. H target

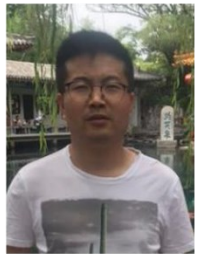

magnet

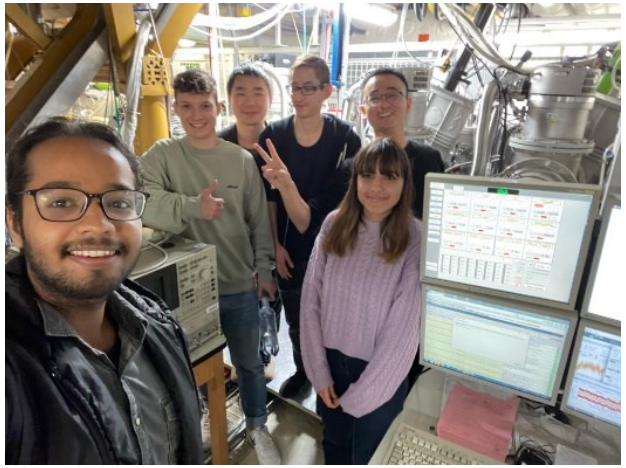

beam diagnostic


polarimeter
pol. H target

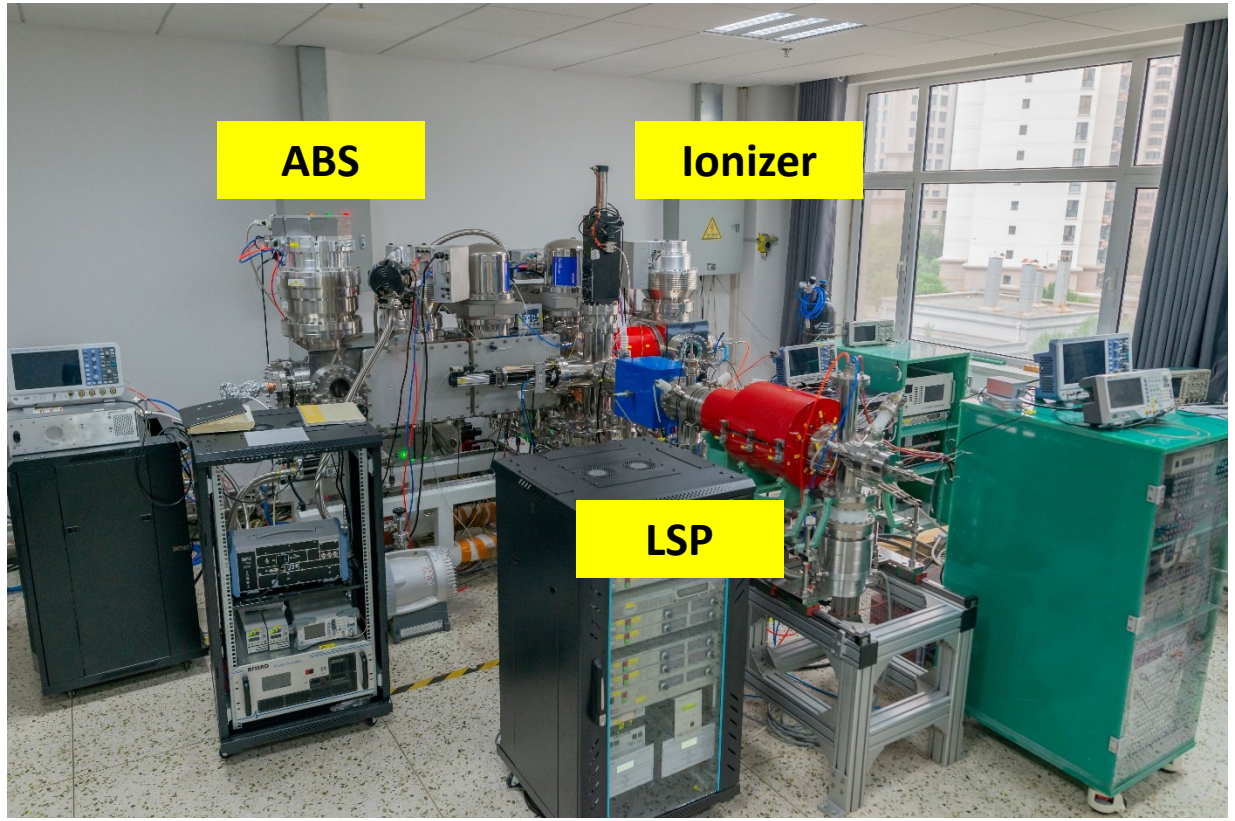

pol. beam acc.
spin manipulation


ionizer
Lamb-Shift
polarimeter


control system



Efforts towards polarized beams/targets at HIAF



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

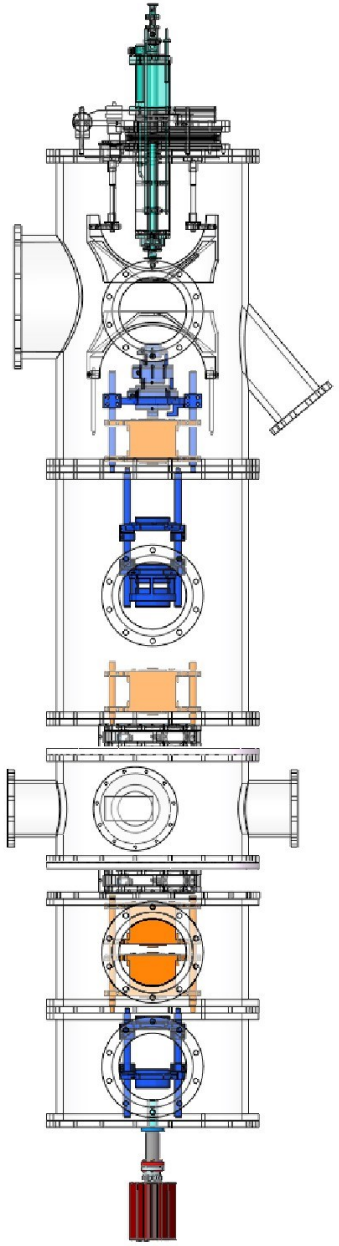
- **Intensity: > 1 mA**
- **Polarization: > 80%**
- **Repetition frequency: 2-5 Hz**
- **Pulse width: > 100 us**

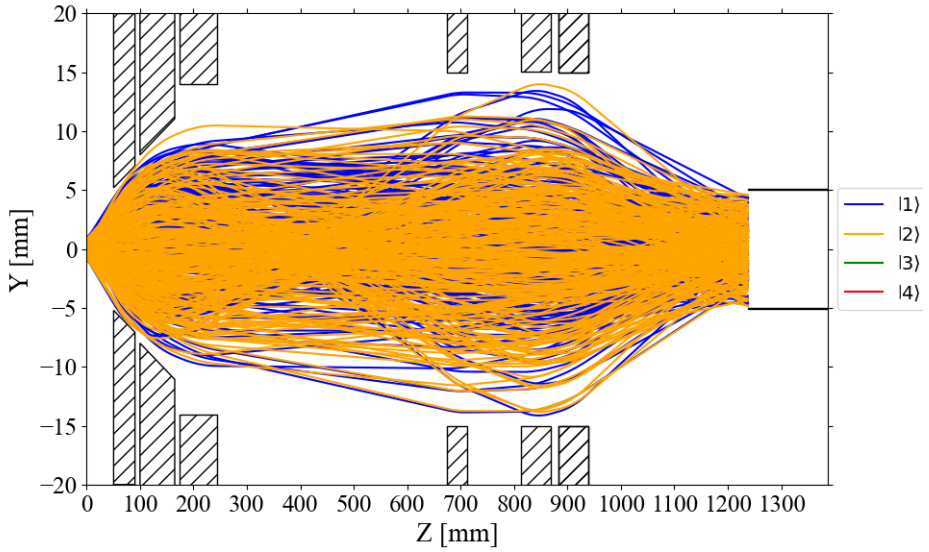
see talk by Yaojie Zhai (Wednesday, morning)

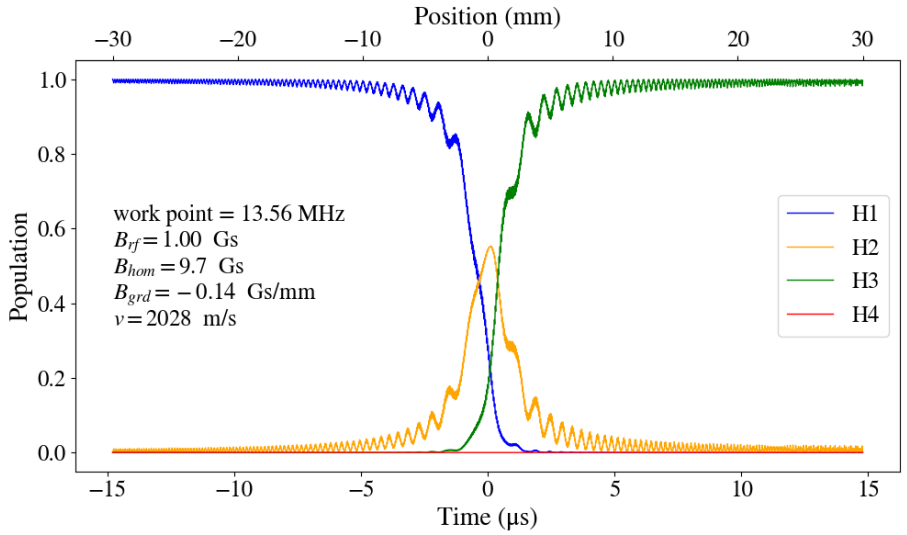
Polarized beam acceleration at HIAF investigated by Minxiang Li et al.

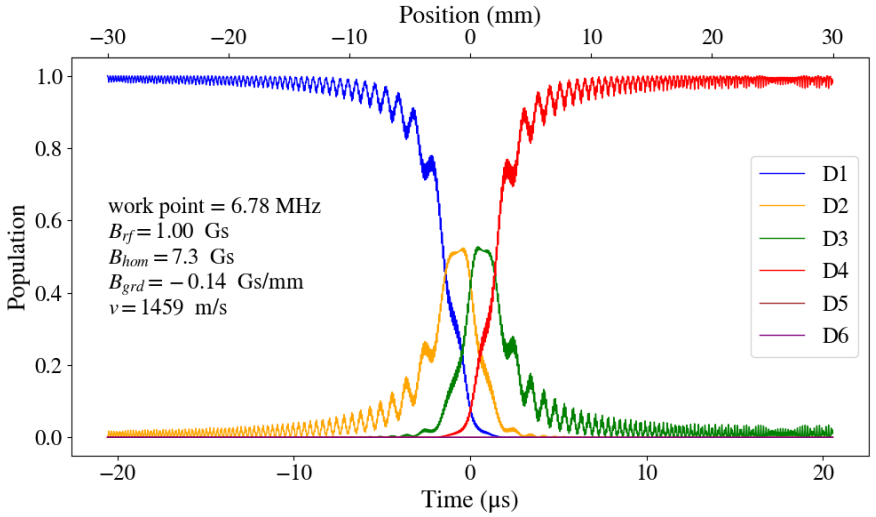
- constant field solenoid Siberian snake: NIMA 1031, 166405 (2022)
- tensor-polarized deuteron beam: Phys. Rev. Accel. Beams 28, 094002

PIT design in progress









PIT design in progress

- ✓ Preliminary mechanical design
- ✓ Atomic tracking in sextuple magnet
- ✓ Zeeman transition in RF units

see poster by Xiaorong Lv

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Spin physics at HIAF

- A kick-off workshop (PBT2024)
- Productive discussions about spin physics at HIAF
- Nice physics identified

JÜLICH Forschungszentrum

GSI

HI JENA Helmholtz-Institut Jena

SNS 中国散裂中子源

TECHNISCHE UNIVERSITÄT DARMSTADT

JGU JOHANNES GUTENBERG UNIVERSITÄT MAINZ

hhu Heinrich Heine Universität Düsseldorf

ITMO UNIVERSITY

SHANDONG UNIVERSITY 1901

TSINGHUA UNIVERSITY 1911

Spin physics at HIAF

- **A kick-off workshop (PBT2024)**
- **Productive discussions about spin physics at HIAF**

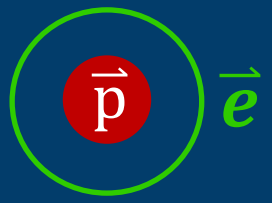
The 2nd Workshop on Polarized Beam and Polarized Target – Physics and Application (PBT2026)

- **PBT2026**
  - **new ideas**
  - **innovative techniques**
  - **more exciting physics**

Spin physics at HIAF

Highlights

- Polarized gas target will be used as both proton target and electron target



- Spin degree of freedom in atomic/nuclear physics
- Beyond SM physics

① pol. e target — **unpol. beams (A, p)**

$Z^{Q+} + \vec{e} \rightarrow Z^{(Q-1)+} + \hbar\omega$	pol. electron capture (atomic physics)
$p\vec{e} \rightarrow pe$	proton EM radii, new boson search (BSM boson)

② pol. p target — **unpol. heavy ion beams (C, Ca, Au, …)**

$A\vec{p} \rightarrow Ap$	→ many body structure nuclear physics

③ heavy target — **pol. d beams**

$\vec{d}A \rightarrow Anp$	EOS → nuclear physics

④ pol. p target — **pol. p beams**

$p\vec{p} \rightarrow pp$ $\vec{p}\vec{p} \rightarrow pp$	A_N, A_{NN} → NN spin dynamics glueball in t channel hadron physics

⑤ pol. d target — **pol. p beams**

$\vec{p}\vec{d} \rightarrow pd$	test of time reversal symmetry (T symmetry)

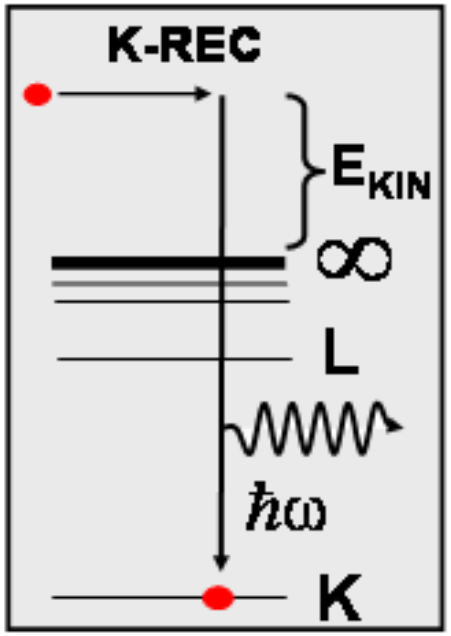
Polarized e^- capture

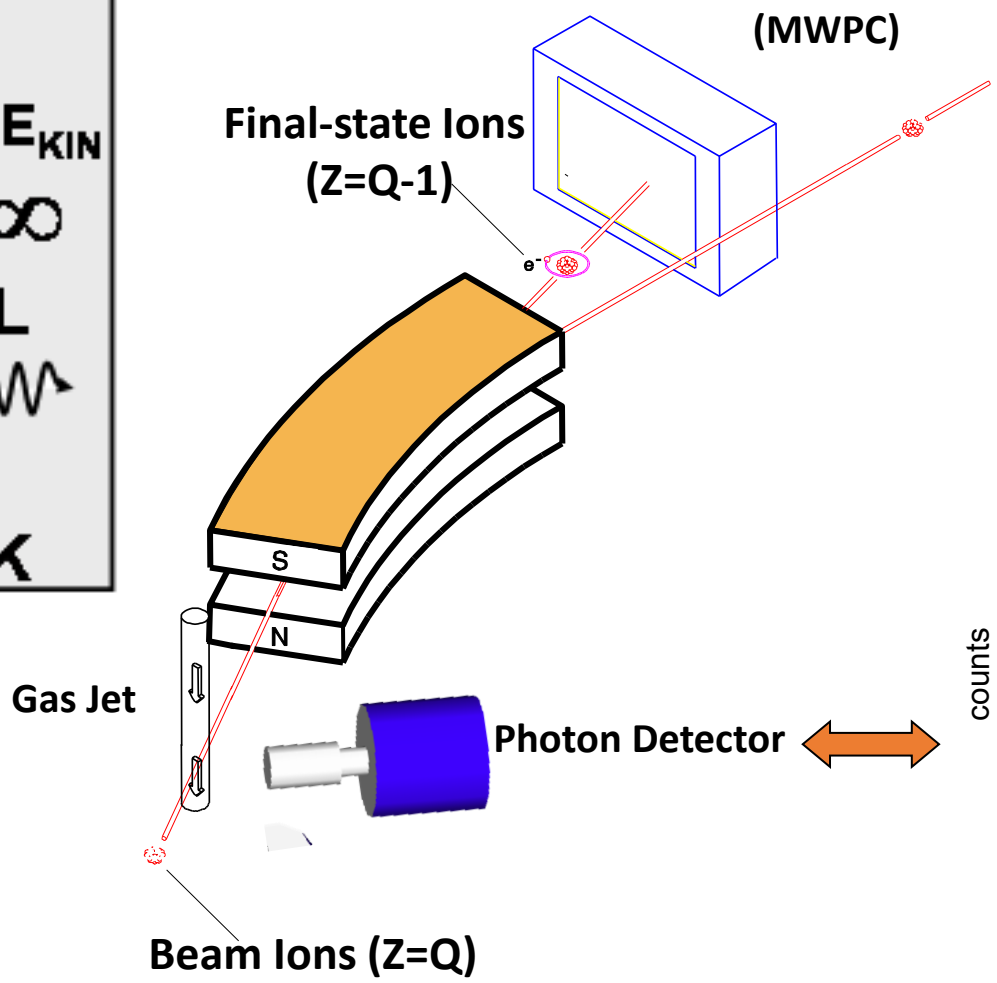
see talk by Thomas Stöhlker (Thursday, morning)

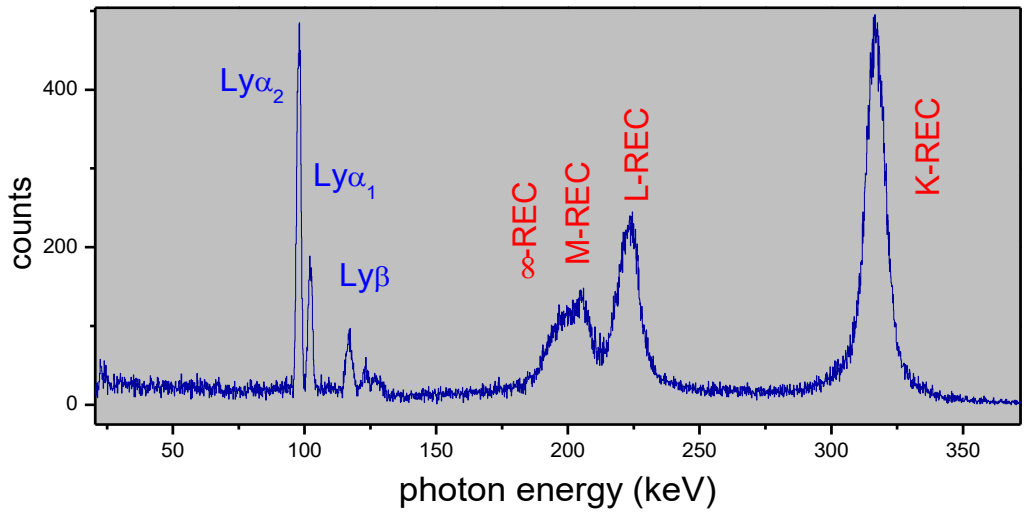
REC with pol. e target

- Radiative electron capture (REC): $Z^{Q+} + e^- \rightarrow Z^{(Q-1)+} + \hbar\omega + \cdots$

courtesy of Prof. Thomas Stöhlker and Dr. Anna Mayorova

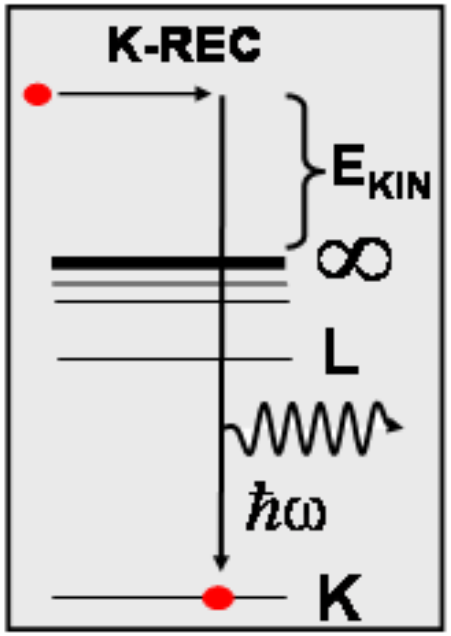






REC with pol. e target

- Radiative electron capture (REC): $Z^{Q+} + e^- \rightarrow Z^{(Q-1)+} + \hbar\omega + \cdots$
- **Sensitive to ion and electron spin states**



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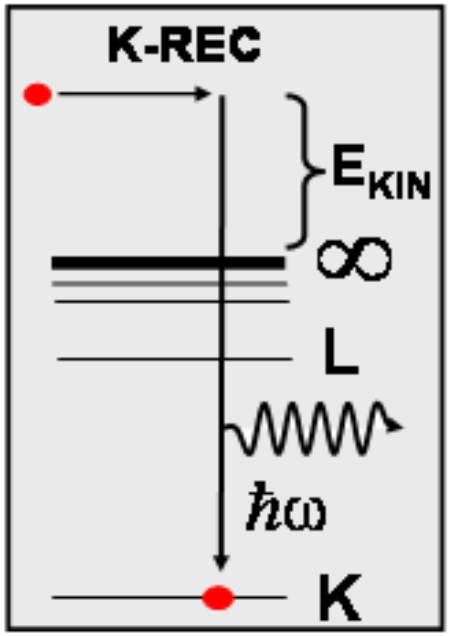
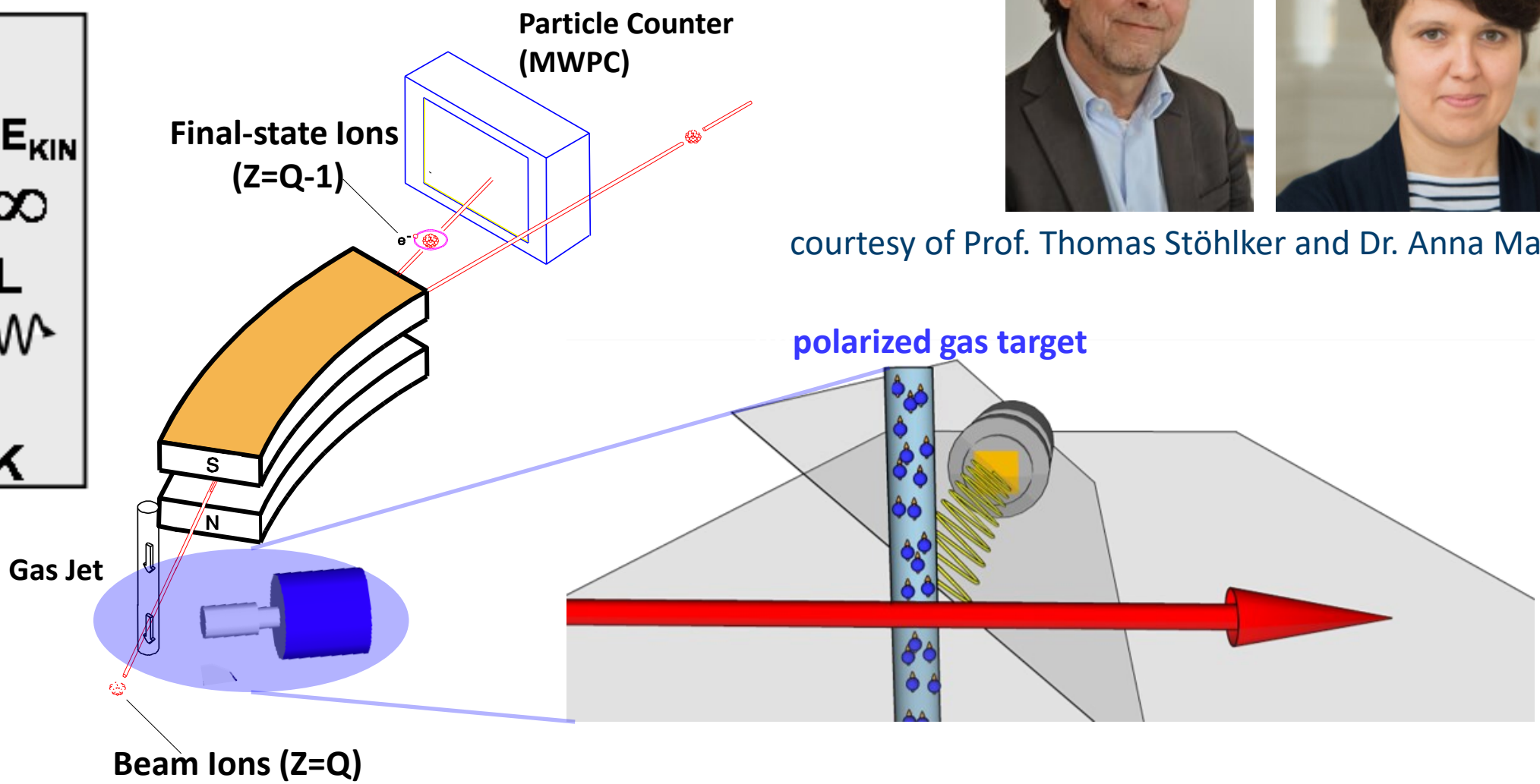
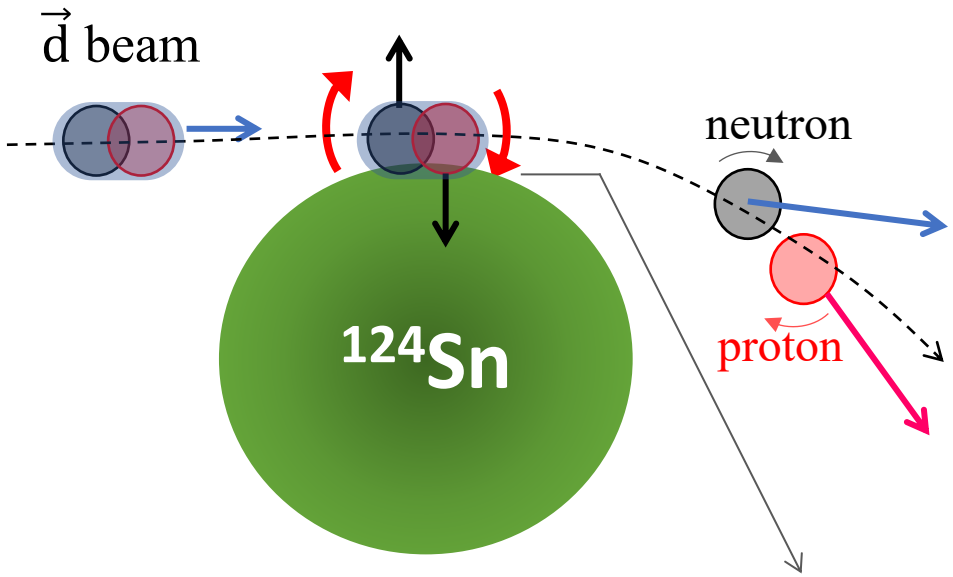




courtesy of Prof. Thomas Stöhlker and Dr. Anna Mayorova

EoS and isovector force

EoS study with pol. d beam



Due to the difference of nuclear forces neutron and proton experiences, **extra rotation** occurs !

Isovector force

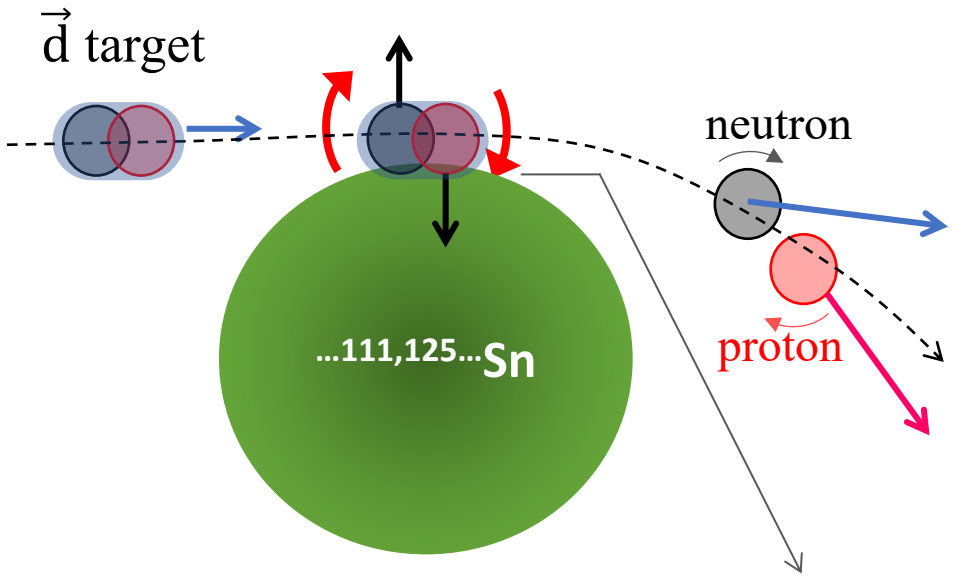
- $F_v \propto \delta^2 \frac{\mathrm{d}E_{\mathrm{sym}}}{\mathrm{d}\rho}\frac{\mathrm{d}\rho}{\mathrm{d}r}$ $\left(\delta = \frac{\rho_{\mathrm{n}}-\rho_{\mathrm{p}}}{\rho}\right)$
- Attractive to p, repulsive to n
- Comparable with Coulomb force

courtesy of Prof. Zhigang Xiao

PRL 115, 212501 (2015); **PRC 101**, 024603 (2020)

- Coulomb force: leads to *Coulomb polarization* (Oppenheimer et al., 1935)
- Isovector force: leads to *isovector reorientation* **(IVR)**

EoS study with pol. d beam



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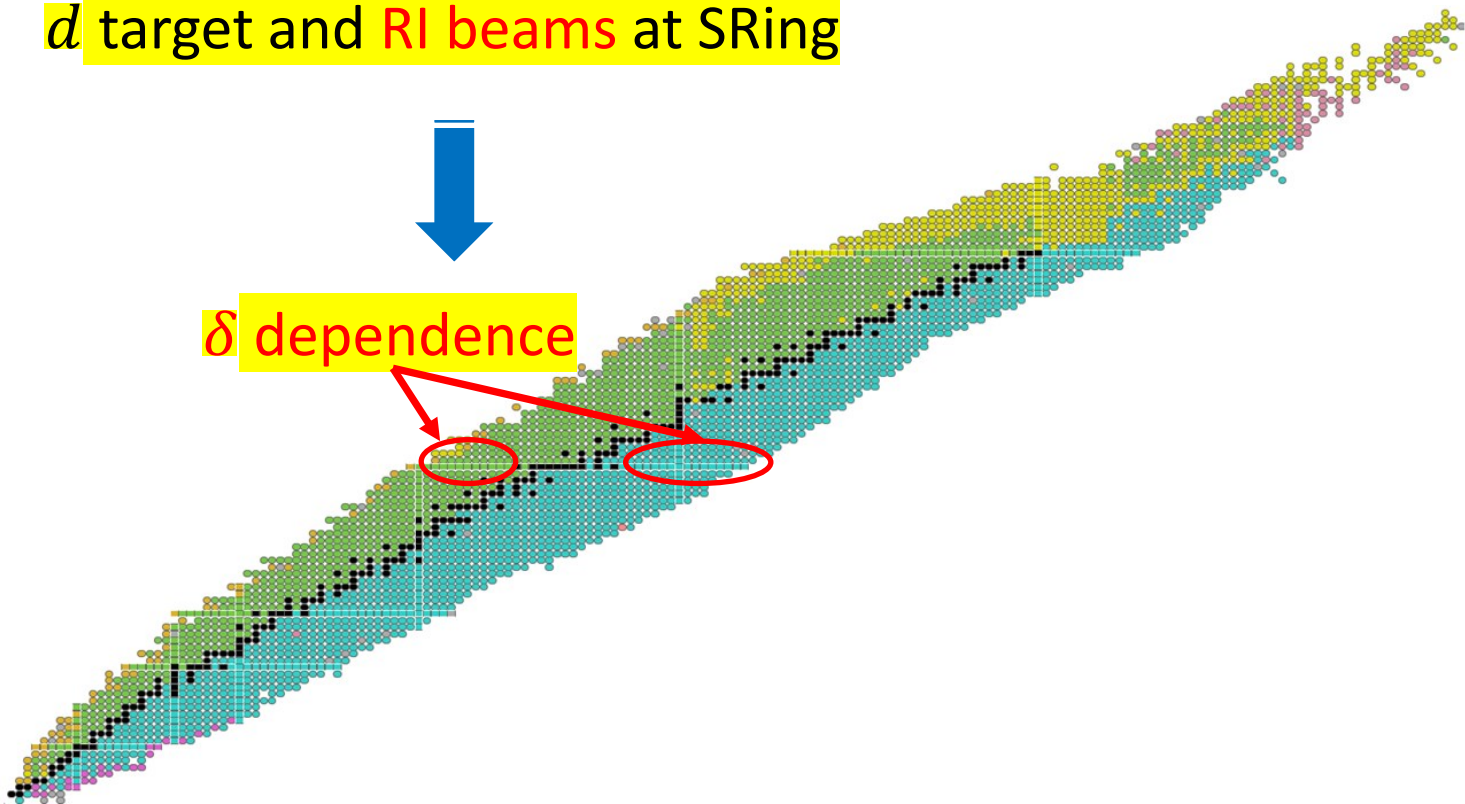
$\vec{d}$ target and RI beams at SRing

δ dependence



New boson search

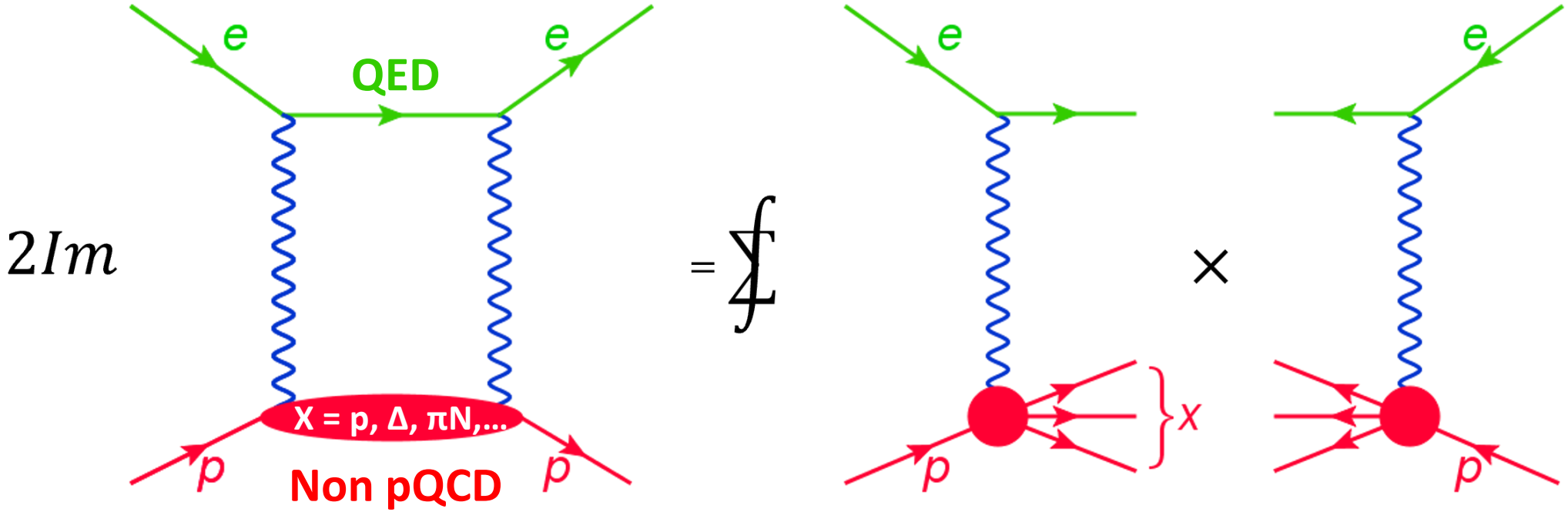
T-odd effects with transverse spin asymmetry

- transverse single spin asymmetry ($A_\perp$) is a T-odd observable

- arises from two-photon exchange in electron elastic scattering

$$A_\perp \propto \frac{Im\left(\mathcal{M}_\gamma^* \mathcal{M}_{2\gamma}\right)}{\left|\mathcal{M}_\gamma\right|^2} \sim \alpha_{EM} \sim 10^{-2}$$

Nucl. Phys. B 35 (1971) 365.



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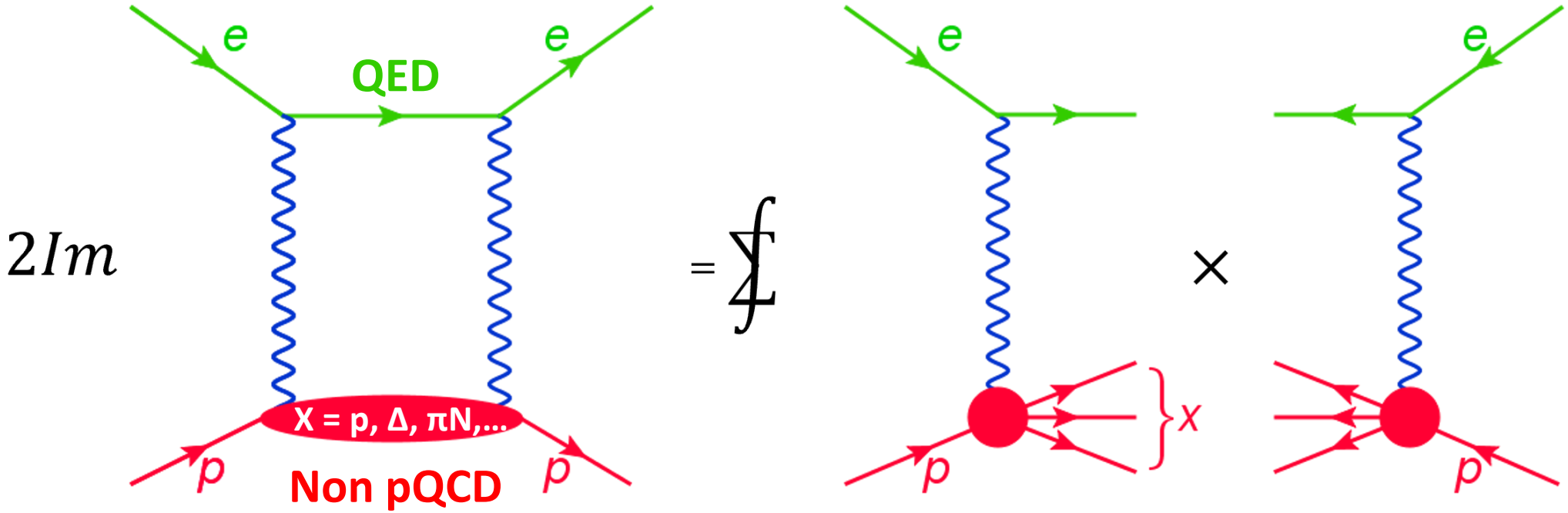
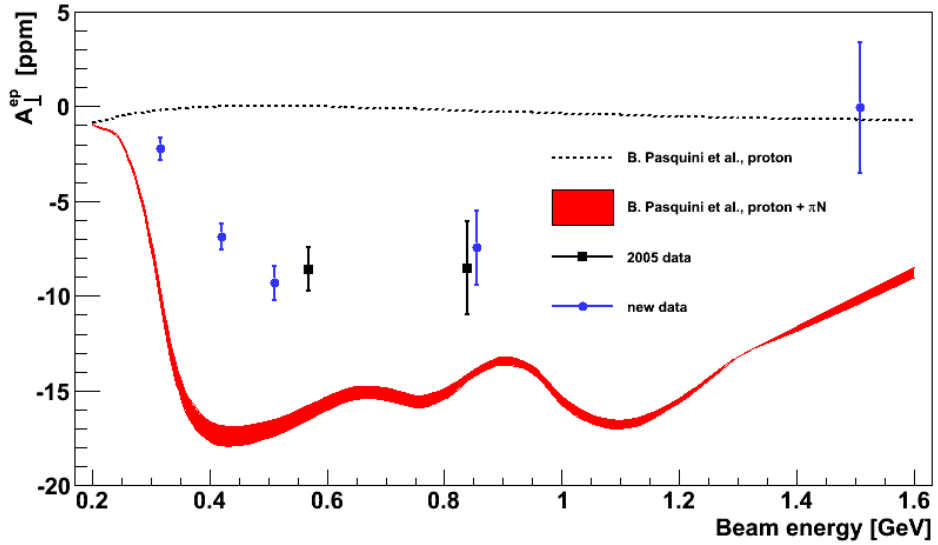
Nucl. Phys. B 35 (1971) 365.

Relativistic suppression ($1/\gamma$) for transversely pol. beam → 10^{-6}



Exp. data vs calculation ($A_{\perp}^{\vec{e}p}$)

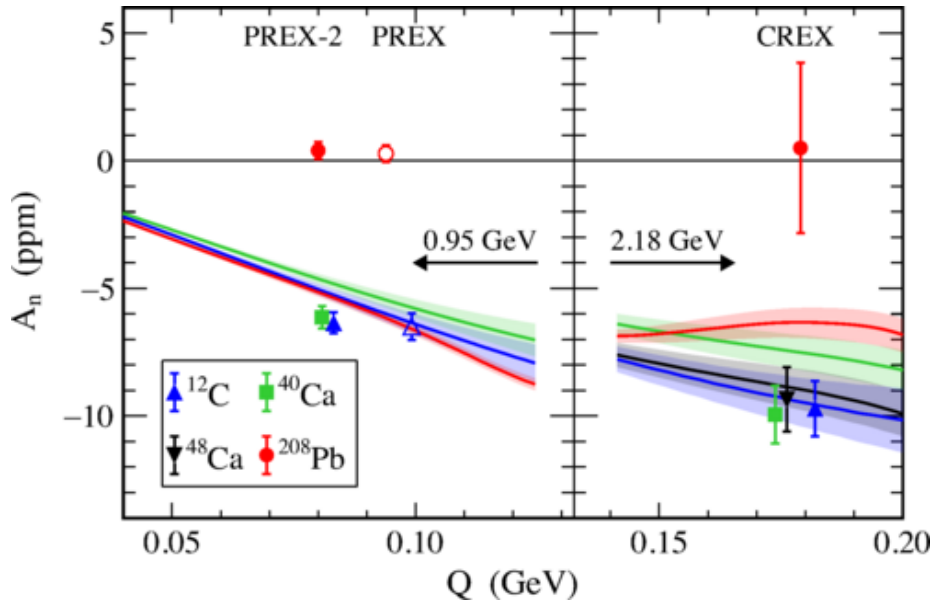
- surprising discrepancies between theory and exp. data
- observed at different laboratories
- not only in $\vec{e}p$, but also in $\vec{e}A$



A4 @ MAMI

Phy. Rev. Lett. 124, 122003 (2020)

Phy. Rev. Lett. 94, 082001 (2005)

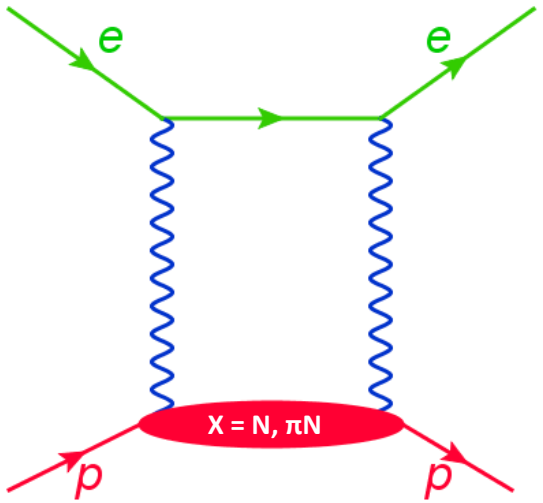


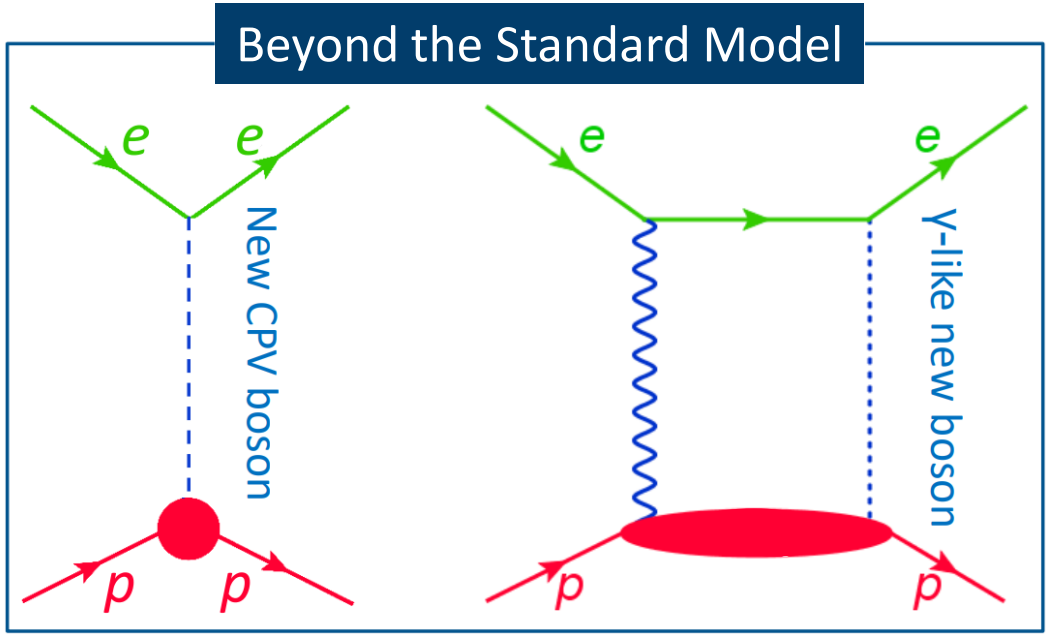
PREX, PREXII, CREX @ JLab

Phy. Rev. Lett. 109, 192501(2012)

Phy. Rev. Lett. 128, 142501(2022)

How to understand the surprise





- More intermedite state?
- MAID database and CLAS data need improvement?
- **New unknown boson?**

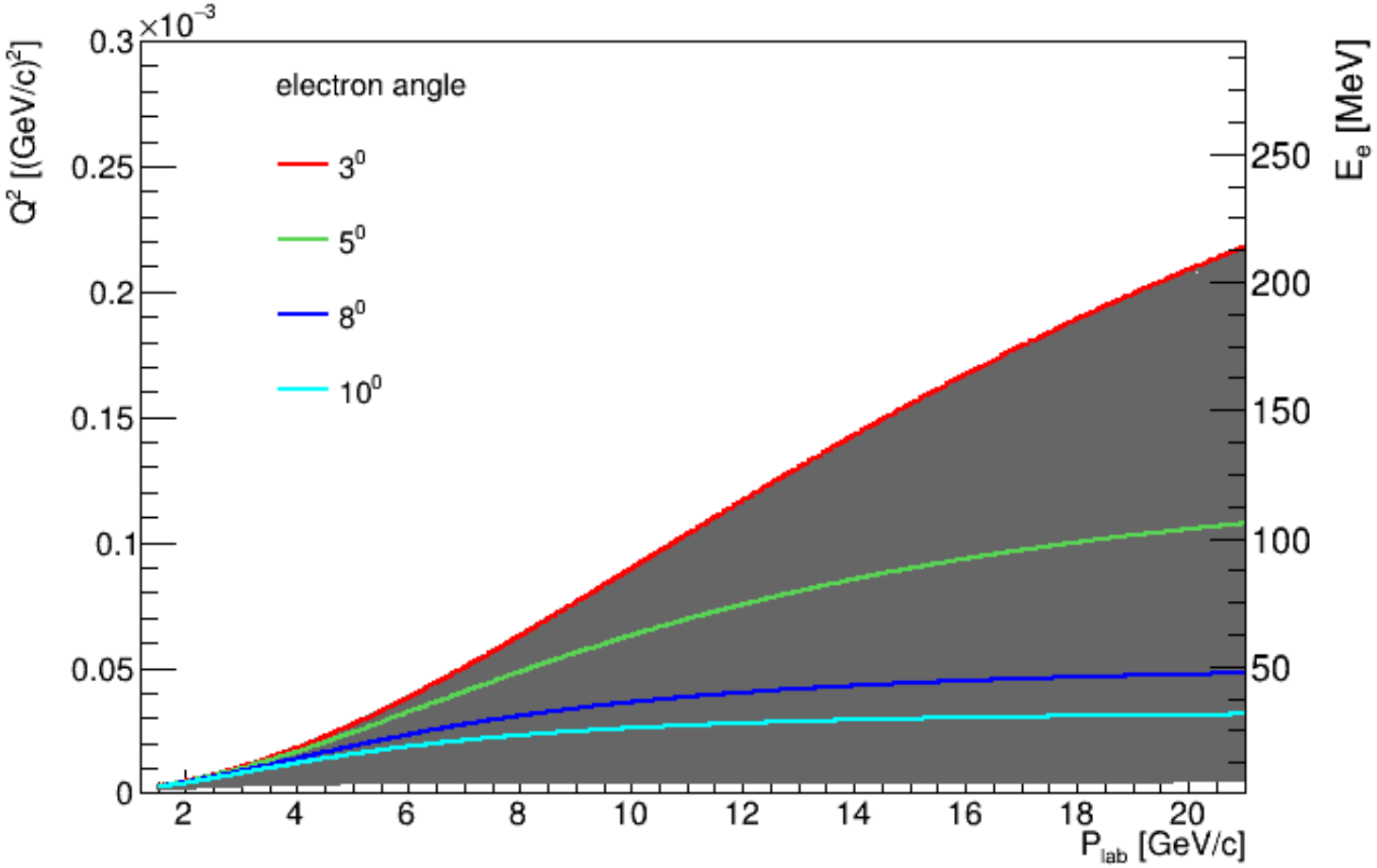
➢ Hard to test new-physics hypothesis in $\vec{e}\mathrm{p} \rightarrow \mathrm{ep}$

- Possible intermediates: X = N, πN … → **Non-pQCD uncertainty**
- Lorentz effect with transverse $\vec{e}$ beam → $A_{\perp} \propto \frac{m_e}{E} \sim 10^{-6}$ **(tiny signal)**

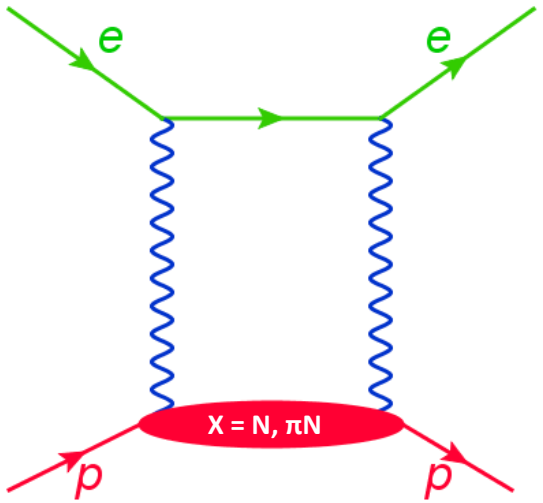
New idea: $p\vec{e} \rightarrow pe$?

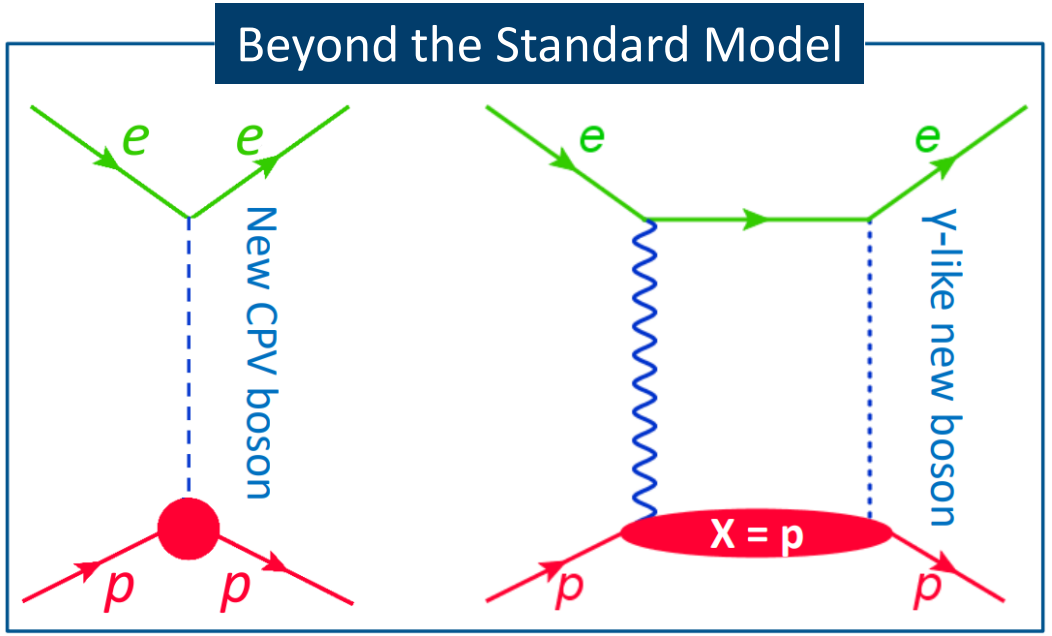
With proton beam and electron target, ultra low $Q_2\left(< 1 \times 10^{-5}\right)$ accessed in pe scattering

Reminder: Q_2 in ep scattering ($10^{-2} \sim 10^{-1}$)



Transverse spin asymmetry: $p\vec{e}$ vs $\vec{e}p$





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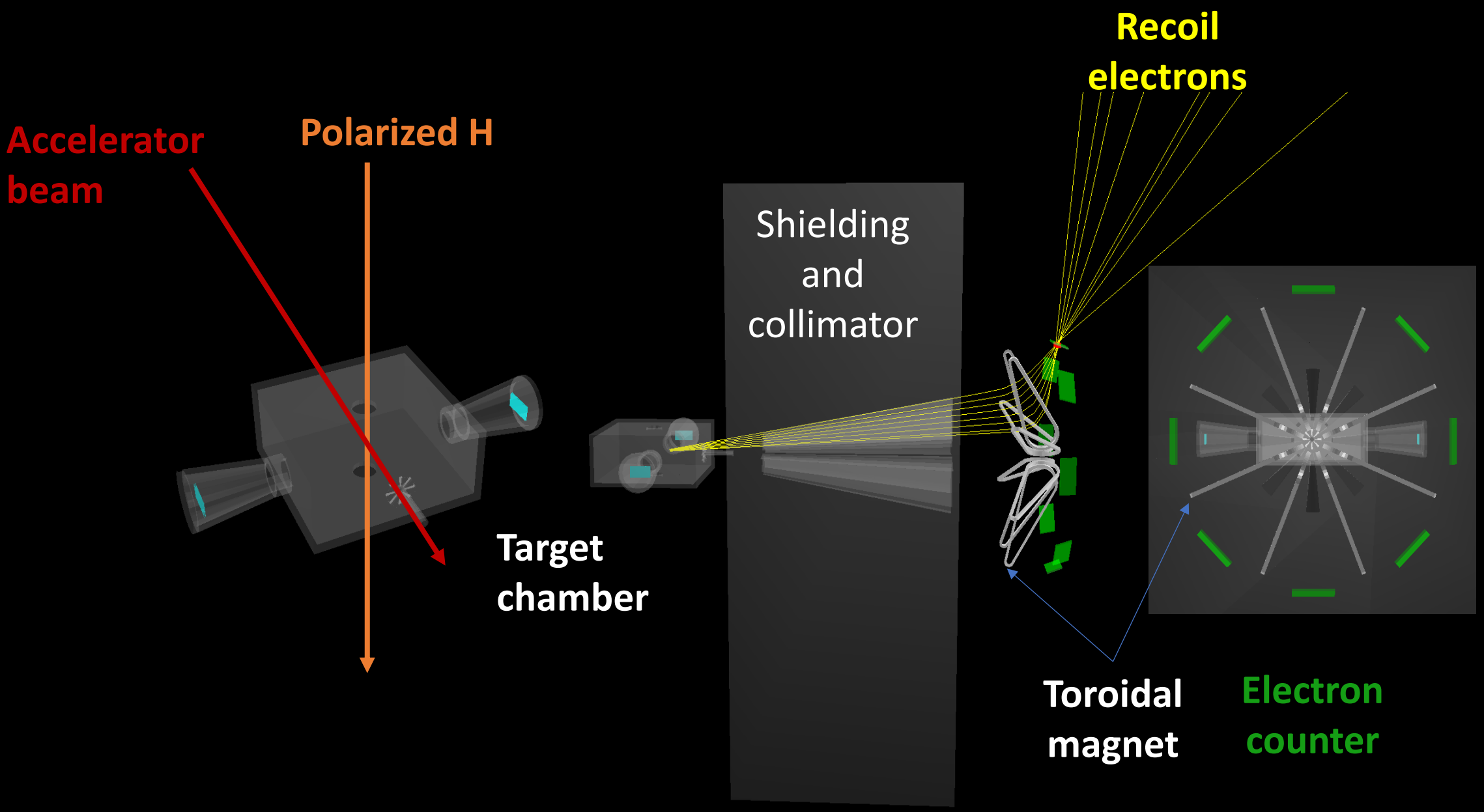
➢ In $p\vec{e} \rightarrow pe$ (very-low $\mathbf{Q_2}$)
- X = N → $A_\perp$ calculated with **G_E and G_M (no theoretical uncertainty)**
- No Lorentz effect → $A_\perp$ increases by 3 orders

Detection system



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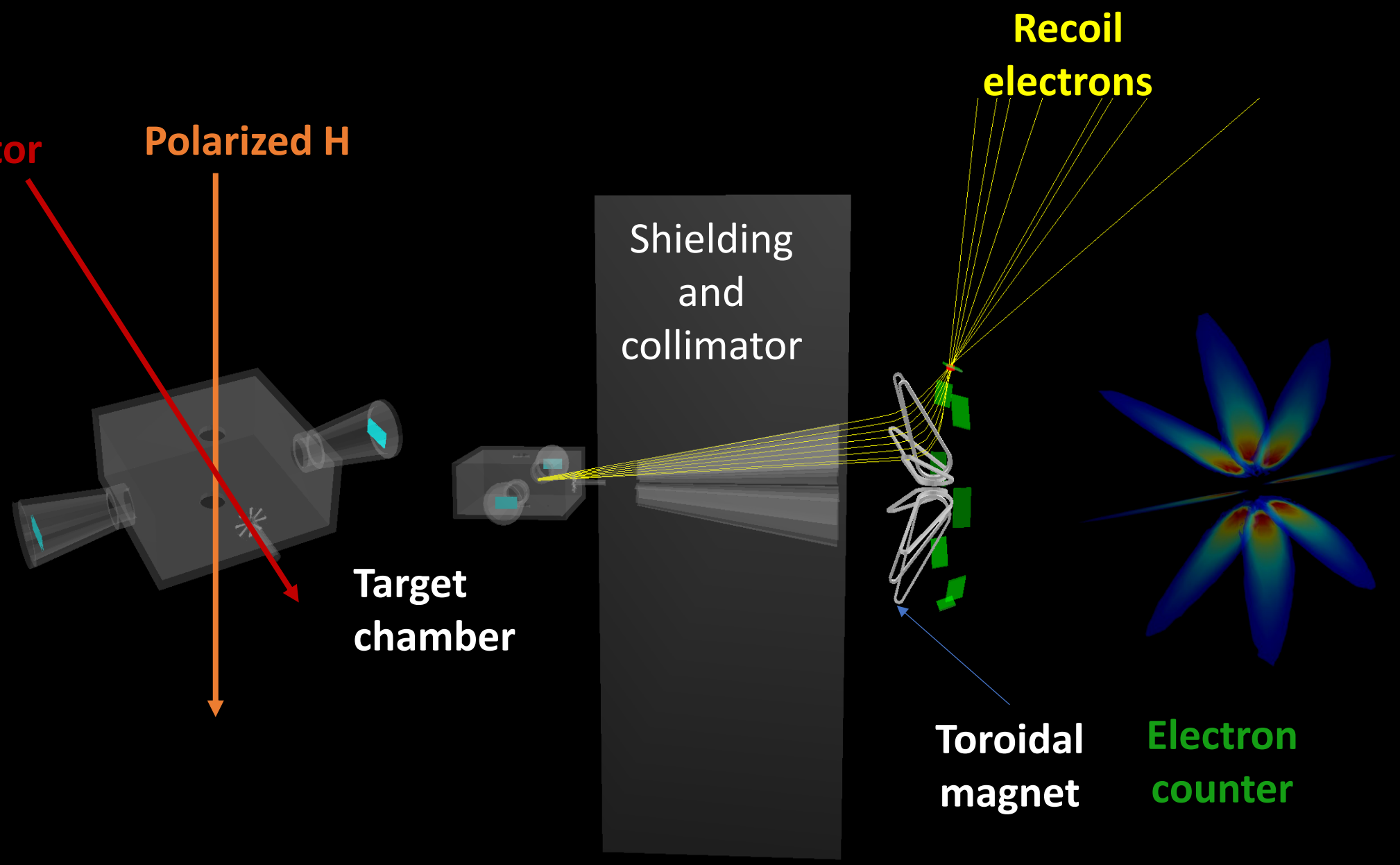
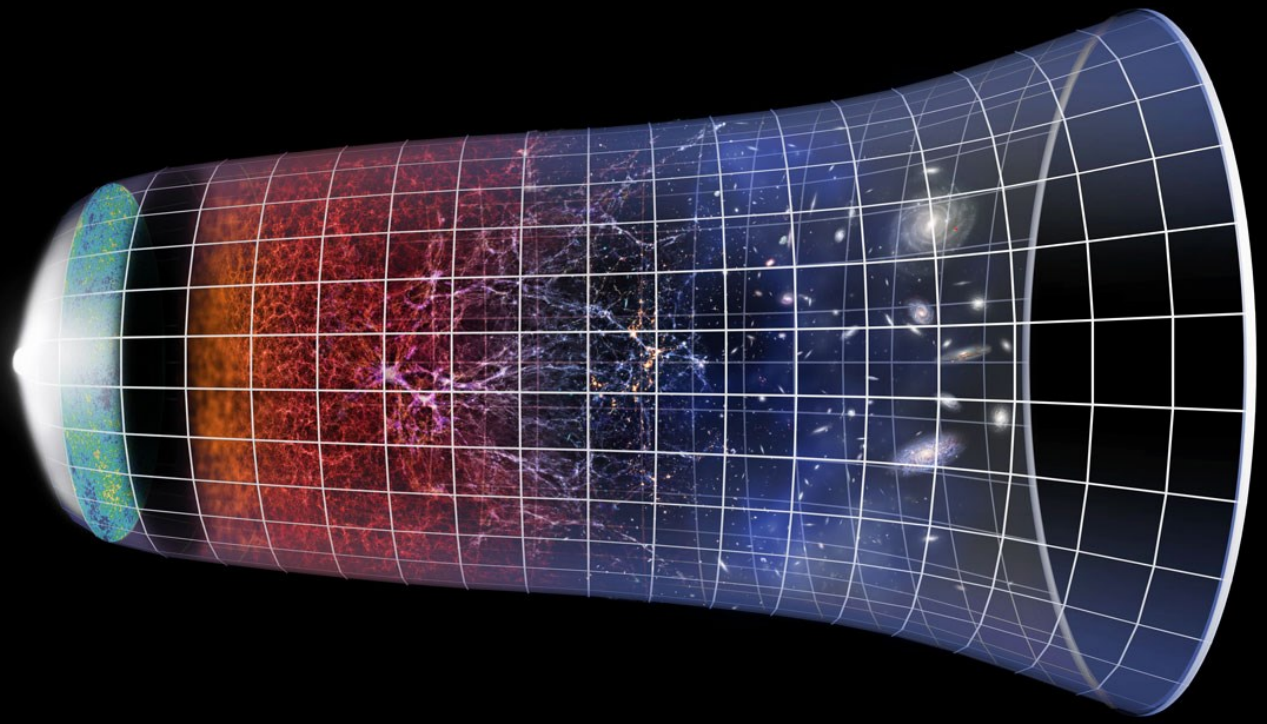


Test of time-reversal symmetry

Why time-reversal asymmetry?



Big Bang → ~~CP~~ → Today

Excess of mater in the universe

Observation

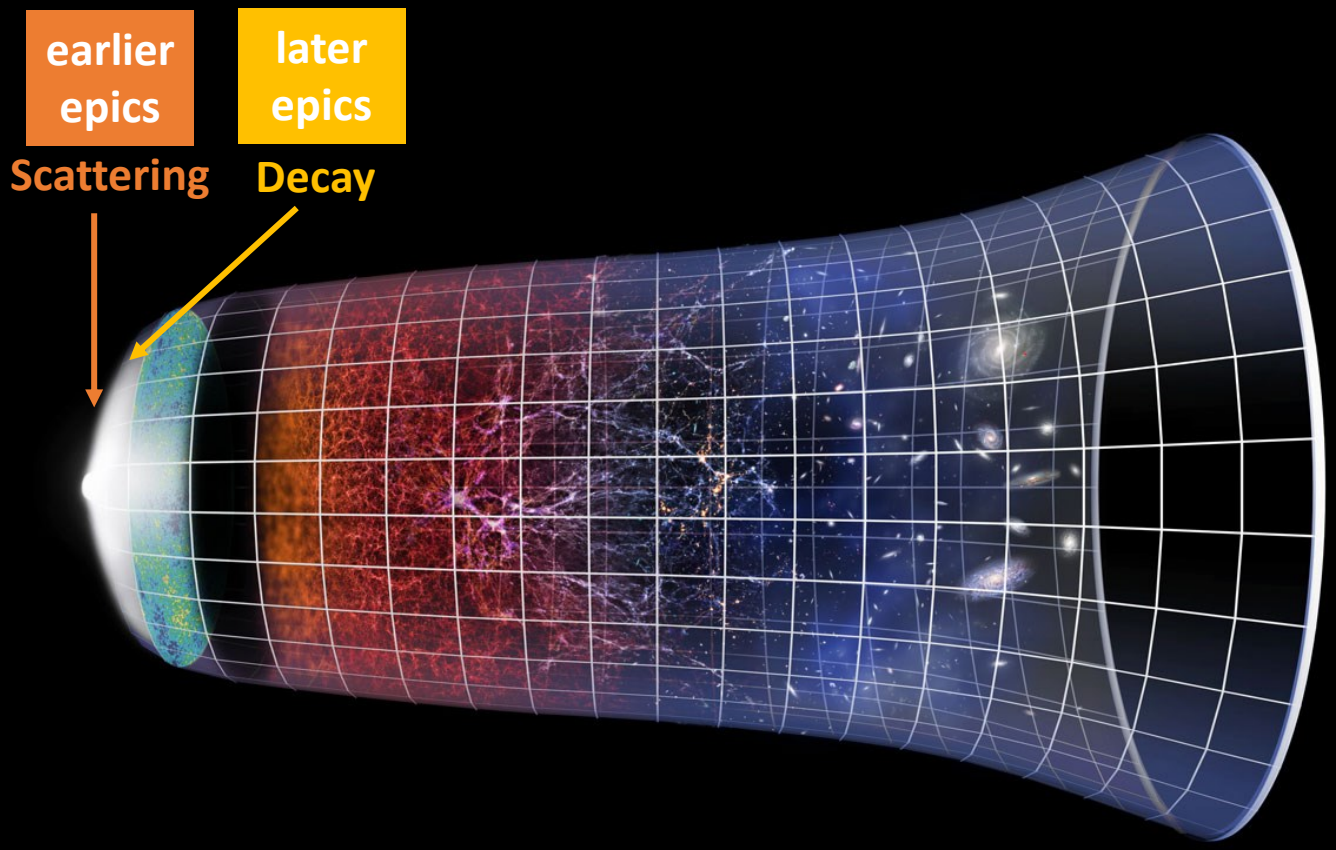
$$\eta \equiv \frac{n_B - n_{\bar{B}}}{n_\gamma} = (6.11 \pm 0.19) \times 10^{-10}$$

SM predication $\sim 10^{-18}$

New sources of CP violation must exist

CP ⟷ T (CPT)

Why time-reversal asymmetry?



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

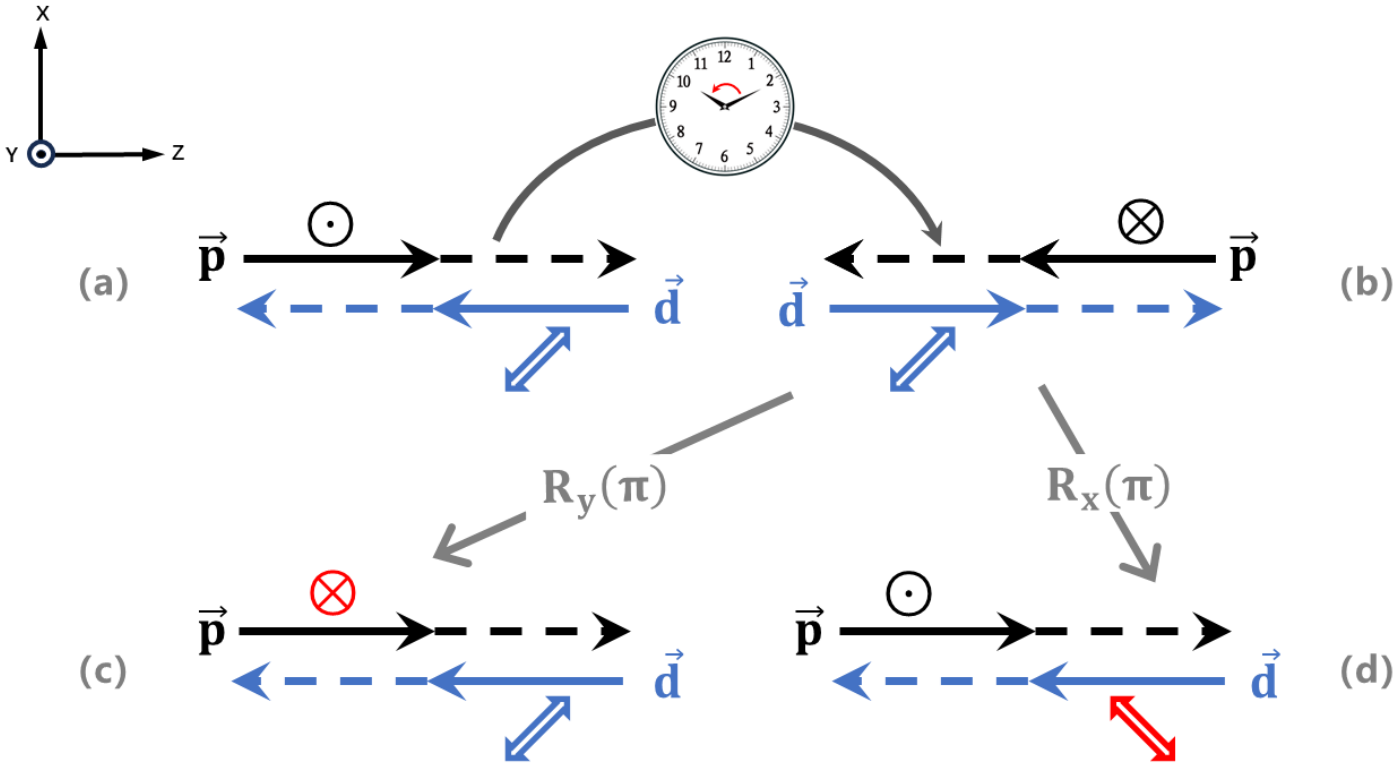
What is time reversal?

- 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?

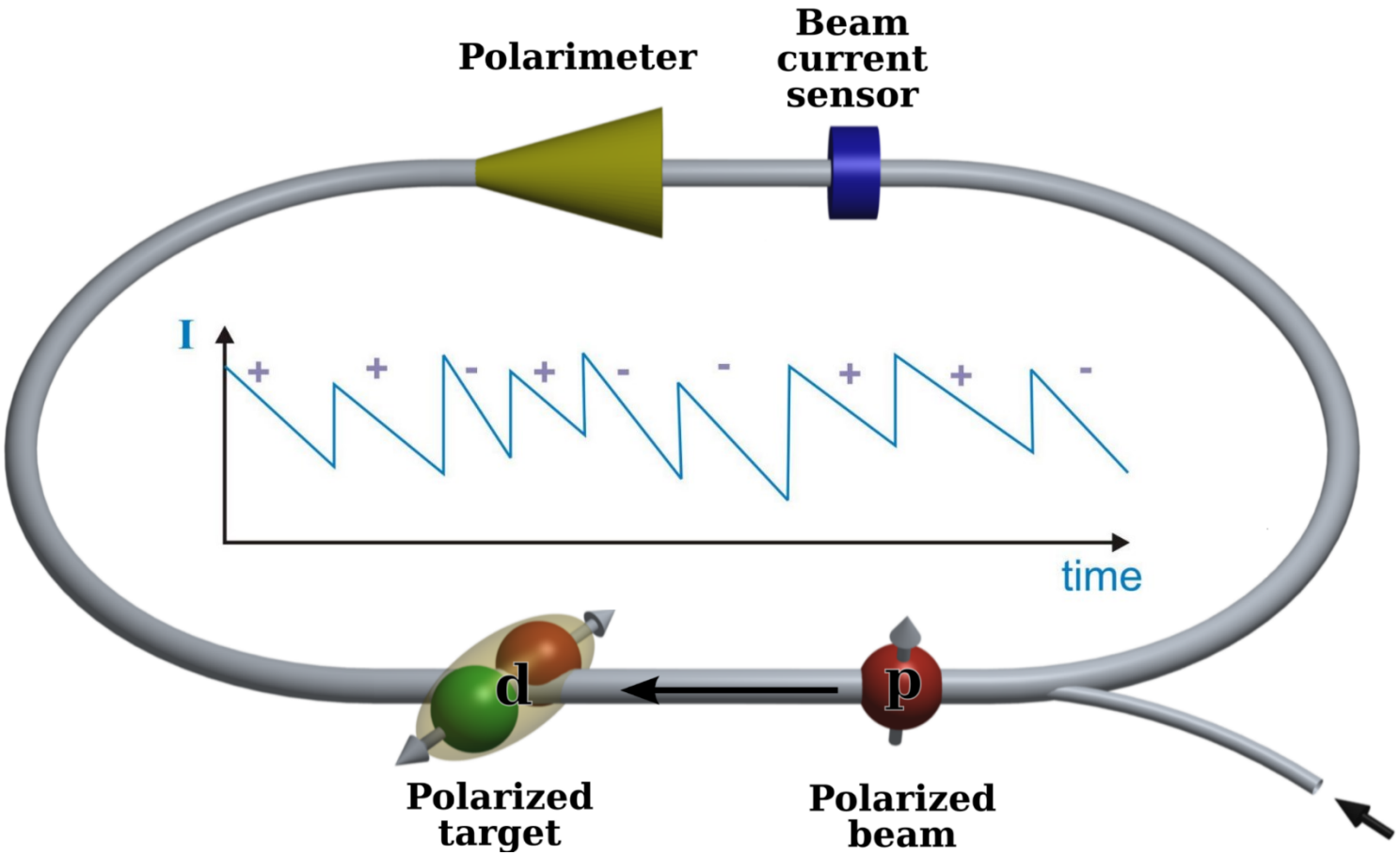
- Flip momentum and spin for all particles
- Exchange initial and final states
- Equivalent to spin flip (at forward scattering/$\theta = 0^\circ$)
- Optical theorem

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

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

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

What do we need

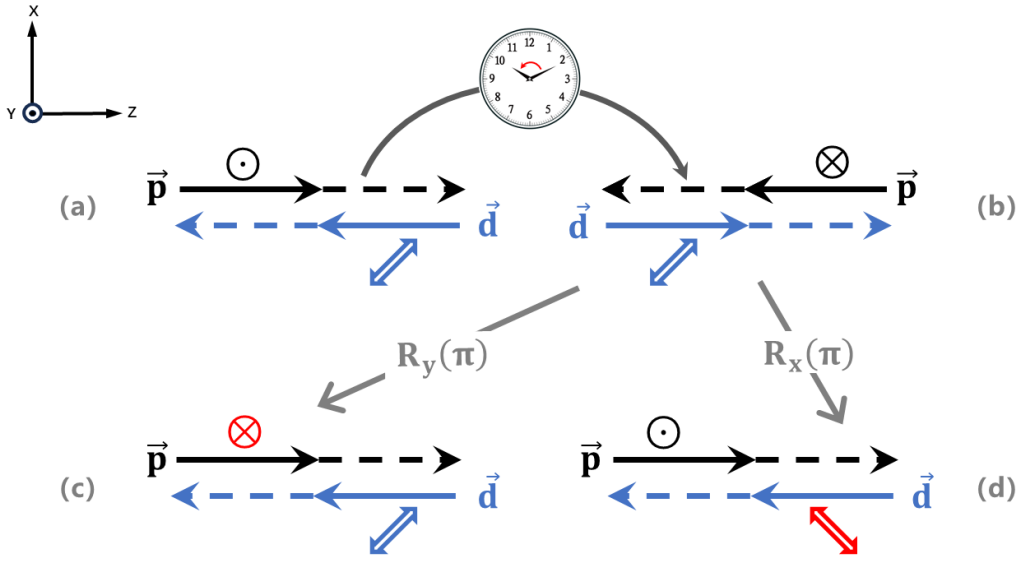


plot adopted from PAX and TRIC publications

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

- polarized proton -> P_Y
- polarized deuteron -> P_{XZ}
- beam current monitor -> $\sigma^{\uparrow\downarrow}_{total}$

Test of time-reversal symmetry



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 ($\Delta E, \Delta X, \Delta X', \Delta I$ …)
- Physical background asymmetry: residual vector polarization of deuteron ($P_y \rightarrow A_{y,y}$)

Test of time-reversal symmetry

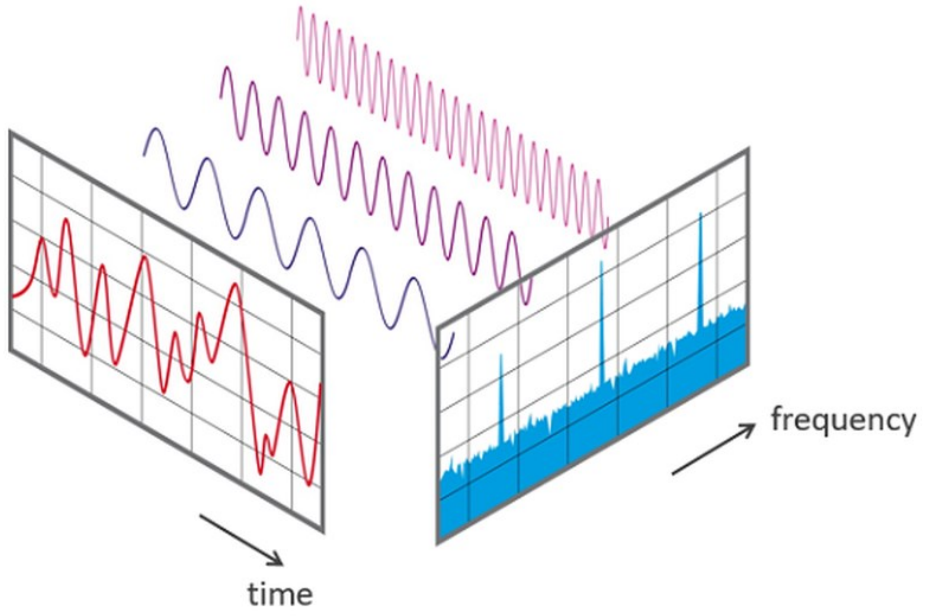
New approach to search for parity-even and parity-odd time-reversal violation beyond the Standard Model in a storage ring

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 analy**



Test of time-reversal symmetry

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)

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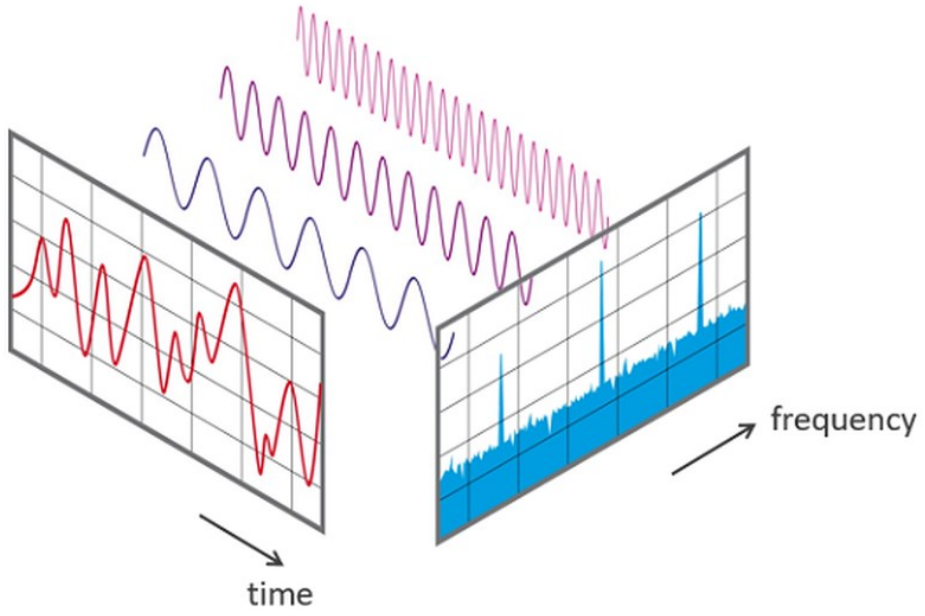

Spin-rotating polarized target?

Spin-rotating 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 in this talk)
  - Static dipole $\vec{B}$ superposed by perpendicular RF $\vec{B}$
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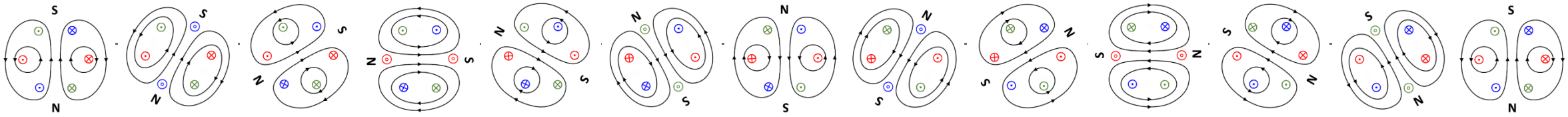
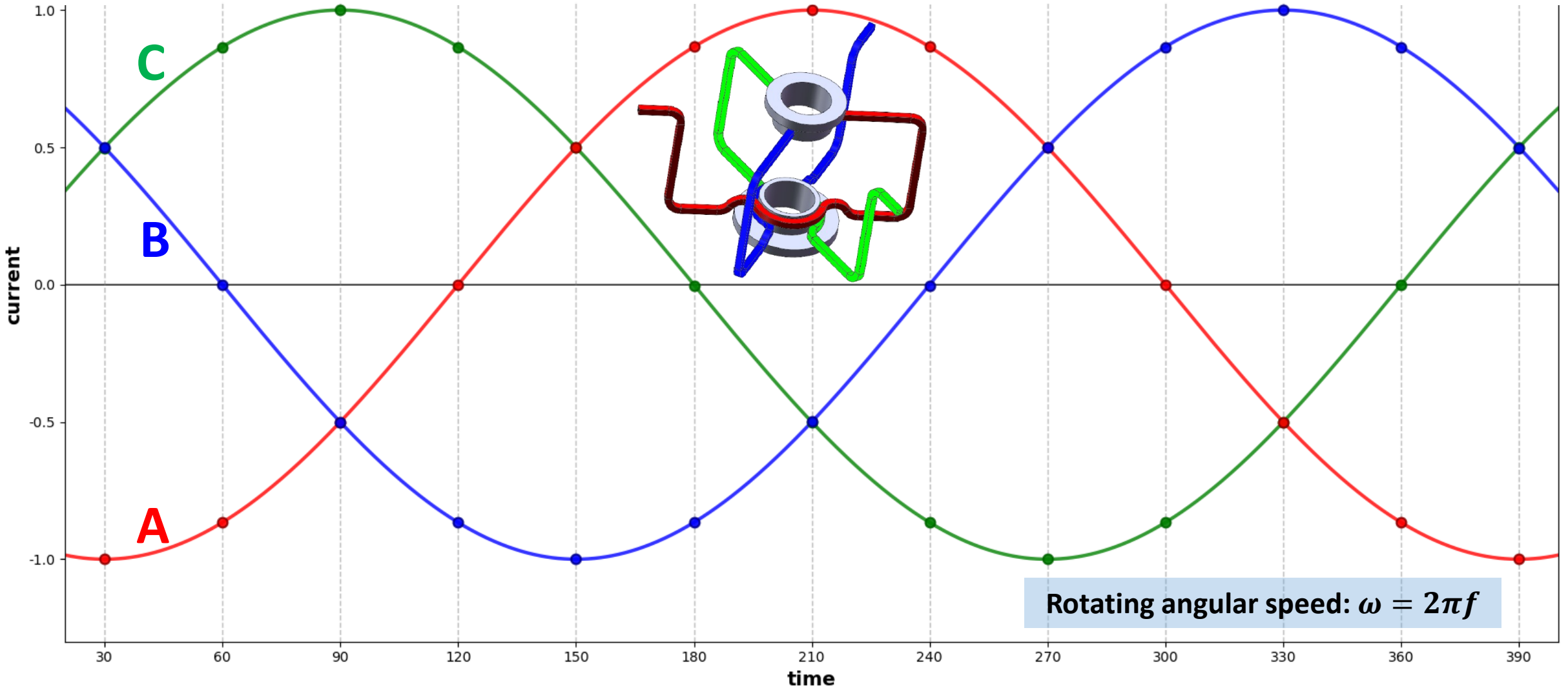
It was really joyful that Prof. Nikolaev who was trying to contact HIAF-SPIN team, was introduced to me just a few days after I was inspired by their fantastic paper, when we surprisingly found out that we had similar ideas!!!

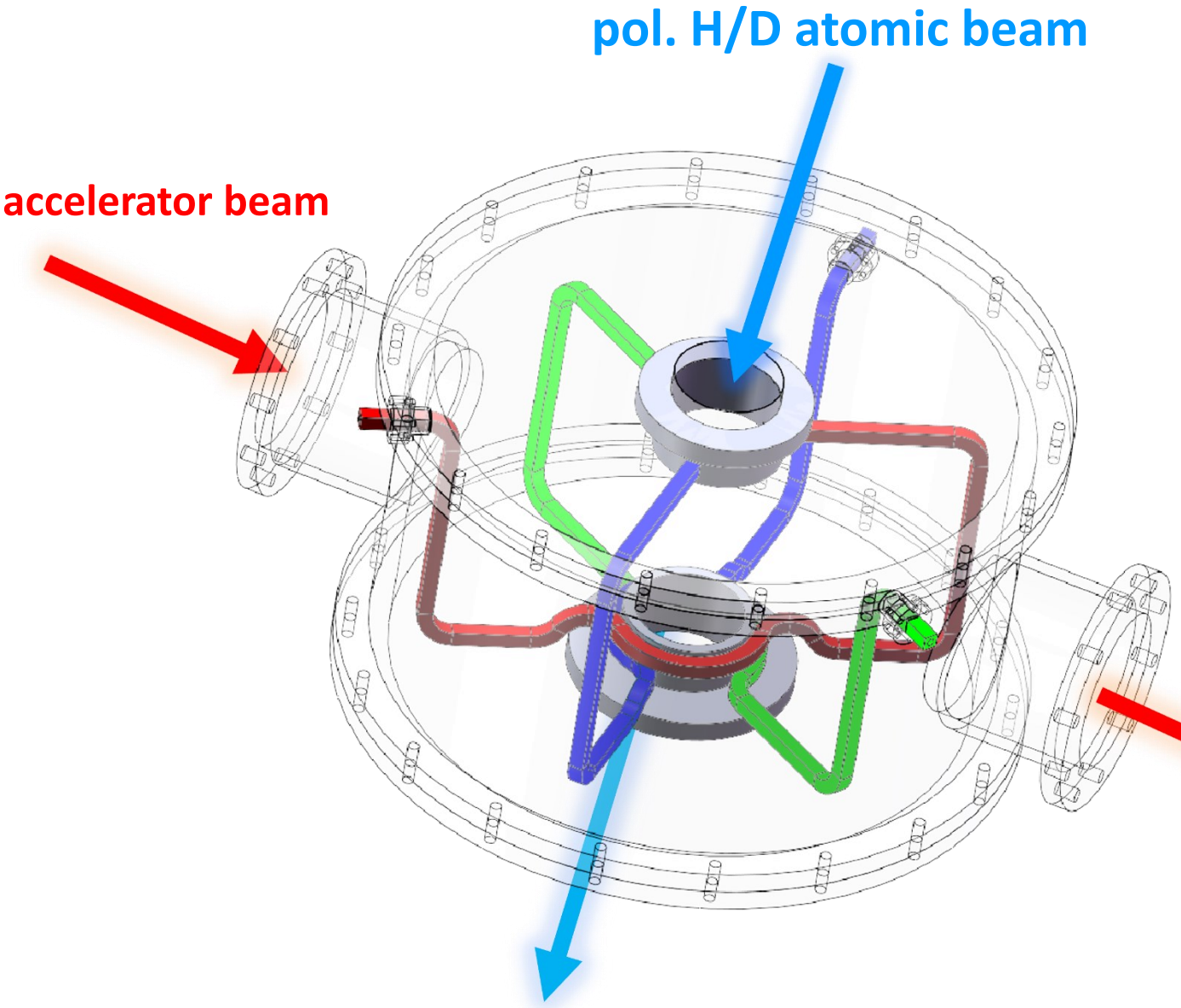
Rotating magnetic field





Rotating angular speed: $\omega = 2\pi f$

Spin-rotating polarized target



Triple coil (ABC) carrying 3-phase AC

↓

Rotating dipole $\vec{B}$ & spin

↓

Oscillating physical asymmetry

↓

Background symmetry separated by FT

Discovery potential

- Time reversal violation ($\vec{p}\vec{d}$)
- Parity violation ($p\vec{p}$)
- …

Roadmap

Roadmap

target	beam	physics and observables
$\vec{e}$	charged ion beam	spin dependence of REC $Z^{Q+} + \vec{e} \rightarrow Z^{(Q-1)+} + \hbar\omega$
	p	$A_\perp$ in $p\vec{e} \rightarrow pe$ proton EM radii, new boson search
$\vec{p}$	p, d, A $\vec{p}$, $\vec{d}$	A_N, A_{NN} in $p\vec{p}$, $A\vec{p}$, $\vec{p}\vec{p}$, $\vec{n}\vec{p}$ ... NN interaction, NA spin dynamics
heavy-ion target (A)	$\vec{d}$	isovector force induced $\vec{d}$ rotation in $\vec{d}A \rightarrow pnA$ symmetry energy in EOS
$\vec{d}$	radioactive beams (A)	
	$\vec{p}$	$A_{y,xz}(0)$ in $\vec{p}\vec{d} \rightarrow pd$ time-reversal symmetry test

Atomic physics

New boson search

bread-and-butter physics

Nuclear physics

Fundamental symmetry

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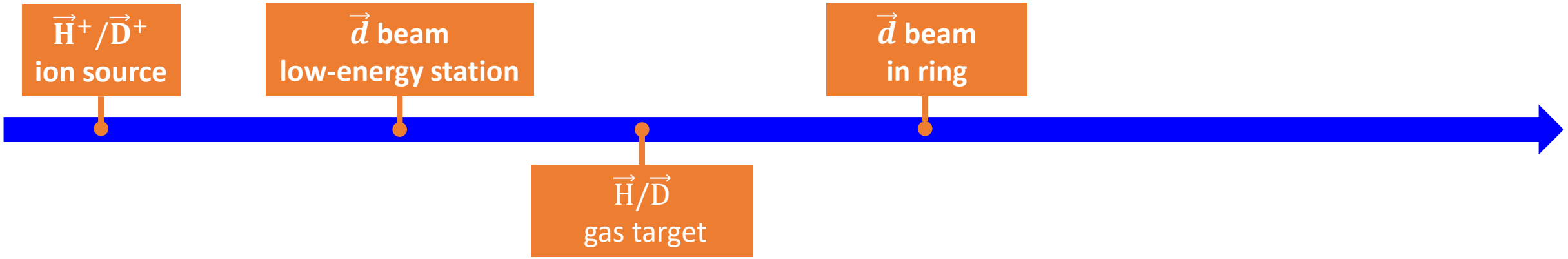

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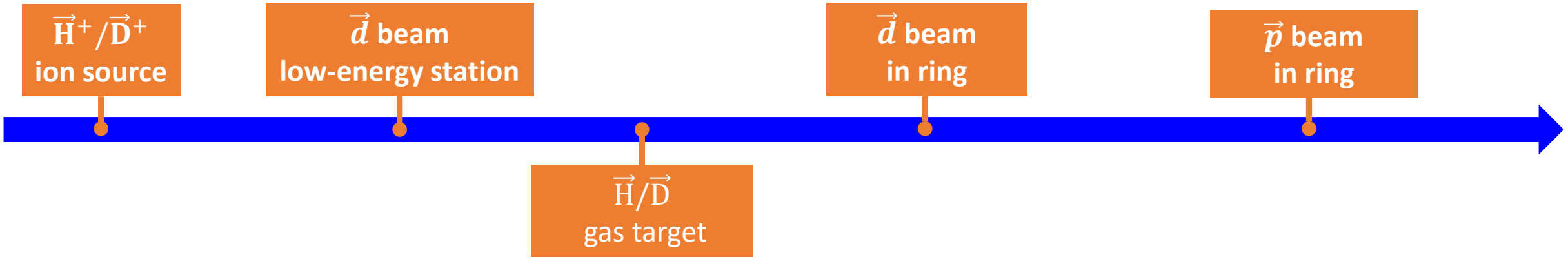

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Summary

- Tools for spin physics at HIAF being developed
- Physics with polarized beam/target at HIAF
  - Atomic, nuclear and hadron physics
  - New physics search with $p\vec{e}$
  - Test of time-reversal invariance with $\vec{p}\vec{d}$
  - Spin-rotating polarized target

Thank you!

Great Physics is yet to come!