

Fresh Look at Tensor Polarized Deuterons at Nuclotron/NICA and HIAF

N.N. Nikolaev

L.D.Landau Institute of Theoretical Physics, Chernogolovka
N.N.Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna
Moscow Institute of Physics and Technology, Dolgoprudny

Natural Sci.Rev. 3 (2026) 200802

HEPD, PNPI, Gatchina

September 29, 2026

Supported by RSF grant 25-72-30005

Dedicated to the memory of

Igor M. Sitnik

(24.06.1941 – 29.07.2026)

an avid proponent of polarized deuterons
and
oscillating polarizations

Spin-1 deuterons are uniquely endowed with tensor polarization

Pioneering studies at LHEP, SATURNE, COSY

Open issues for Nuclotron/NICA and HIAF:

- LHEP, JINR tensor asymmetries → is the deuteron more than a pn bound state?
- First look at the gluon tensor structure function of the deuteron
- Two-spin asymmetries in the unexplored energy domain
- Unique facility to search for the millistrong CP-violation beyond the Standard Model with potential implications for the baryon asymmetry of the Universe via vector-tensor spin asymmetry in pd scattering
- Tensor polarizability driven spin dichroism and birefringence: spin comagnetometry and tensor polarimetry
- Search for the new quantum number of the deuteron: tensor polarizability
- Polarized deuterons as axion and EDM antennas

One needs **multiple switches** of vector and tensor **polarizations**

- **A new paradigm** of continuous rf driven flips of bunch polarizations and time-stamped horizontal (radial & longitudinal) polarization

Forerunners: I. Sitnik et al. (2002), JEDI Collab. (2012 and so forth)

Challenges:

- Long polarization lifetime
- Stabilization of rapid precessions of the horizontal polarization
- Frequent switching of the relative polarization of colliding bunches
- Extraction of horizontally (radially & longitudinally) polarized beams onto external targets

Doable at the expense of very modest new instrumentation at Nuclotron/NICA and HIAF

Paves the road to the first experimental program of full scale tensor polarization physics

EW Baryogenesis: Standard Model

Weak Scale Baryogenesis

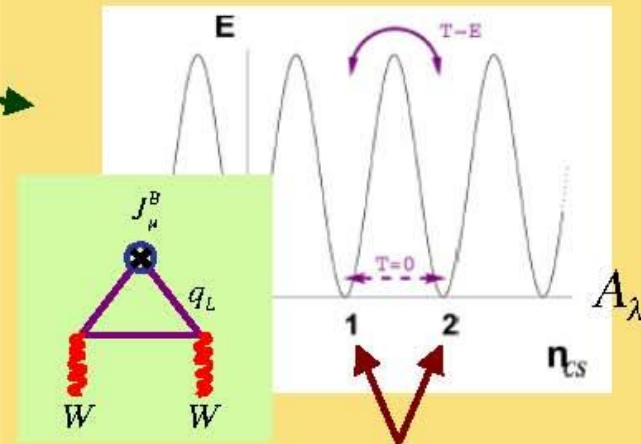
- *B violation*
- *C & CP violation*
- *Nonequilibrium dynamics*



Sakharov, 1967

*Kuzmin, Rubakov, Shaposhnikov
McLerran, ...*

Anomalous Processes



Different vacua: $\Delta(B+L) = \Delta N_{CS}$

Sphaleron Transitions

Much too feeble: the SM with CKM-mixing fails badly !

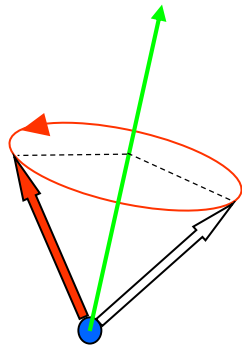
Proton spin lifetime in COSY: JEDI window to depolarization mechanism

C. Weidemann et al., Phys. Rev. ST Accelerators and Beams, 18, 020101 (2015)

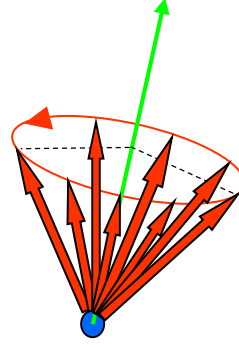
- 49.3 MeV protons in COSY
- **Without spin-flips** the vertical polarization lifetime $(2.7 \pm 0.5) \cdot 10^5$ s
- 99 spin flips during 300 s (0.15 Hz)
- RF flipping polarization lifetime 240 s.
- Polarization loss by **spin decoherence in the horizontal plane? Or is the spin-flip per se a culprit?**
- JEDI: **depolarization in the idle precession of the horizontal polarization.** Tune sextupole families to zero chromaticity → **spin coherence time up to 1500 s.** G. Guidoboni et al. Phys. Rev. Lett. 117, 054801 (2016)
- **Presume the technique will be applicable at NICA and HIAF**

Spin coherence

We usually don't worry about coherence of spins along the rotation axis $\hat{n}_{co}$



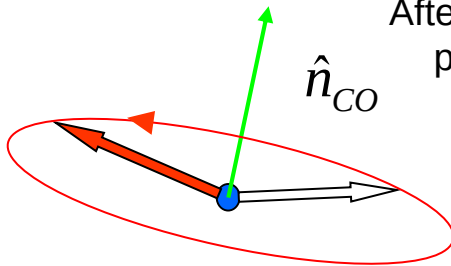
At injection all spin vectors aligned (coherent)



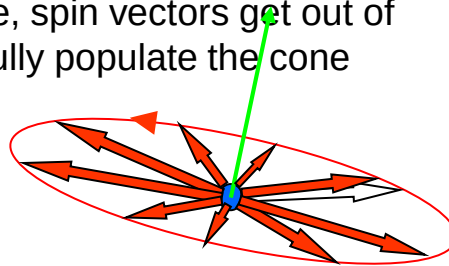
The vertical polarization is not affected!

Situation very different, when you deal with $\vec{S} \perp \hat{n}_{co}$

After some time, spin vectors get out of phase and fully populate the cone



At injection all spin vectors aligned



After some time, the spin vectors are all out of phase and in the horizontal plane

The horizontal spin-hedgehog: decohered polarization vanishes!

In an EDM machine with frozen spin, decoherence limits the observation time & sensitivity to EDM

Spin coherence time: $> 10^3$ s for the proton EDM measurement at 10^{-29} e cm level (srEDM, BNL)

NEW EXPERIMENT ON THE PRECISE COMPARISON OF THE ANOMALOUS MAGNETIC MOMENTS OF RELATIVISTIC ELECTRONS AND POSITRONS

I.B. Vasserman, P.V. Vorobev, E.S. Gluskin, P.M. Ivanov, G.Ya. Kezerashvili et al.

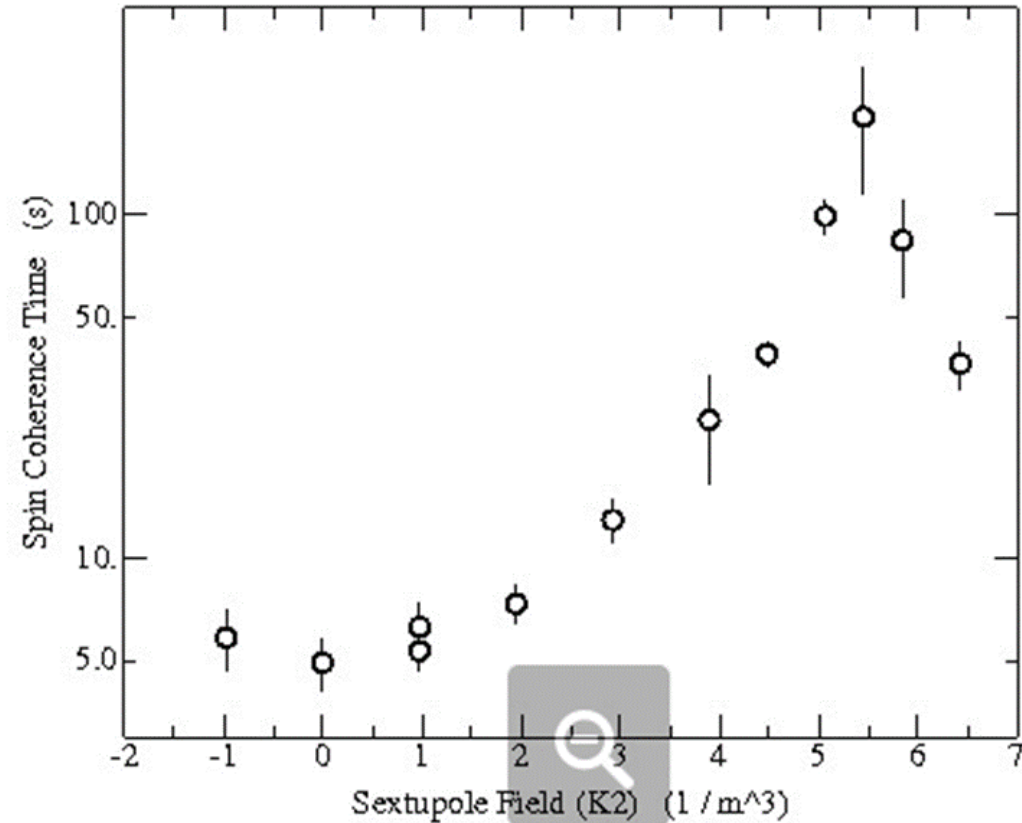
Phys.Lett.B 187 (1987) 172-174

A comparison of the anomalous magnetic moments of the electron and positron has been performed using the resonance depolarization method for the VEPP-2M storage ring beams. It has been shown that the difference between the anomalous magnetic moments of the electron and positron does not exceed 1.2×10^{-7} with 95% confidence level, in agreement with the *CPT*-theorem and the principle of relativistic invariance.

N. B. Achieved spin coherence time 0.5 s

A key to this record result --- suppression of decoherence by sextupole families

*Courtesy of Ed Stephenson:
Preliminary data from 2012 run at COSY*

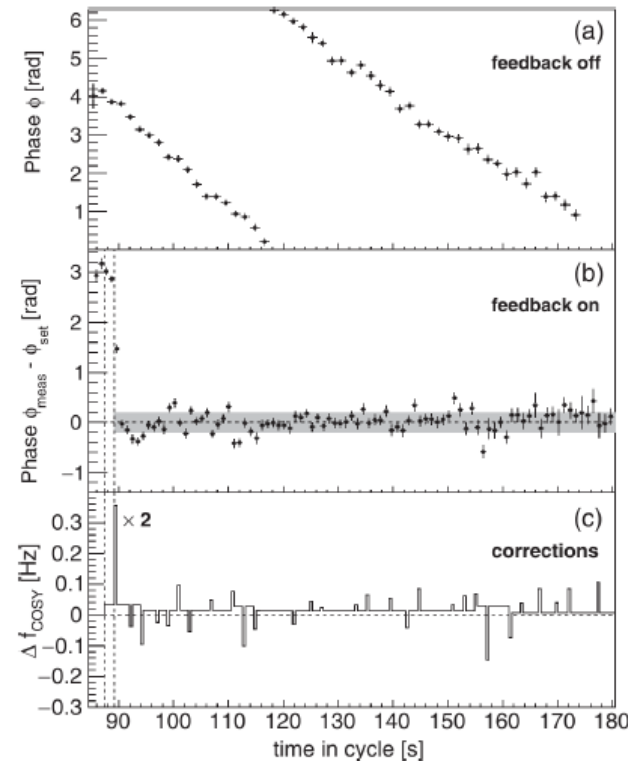
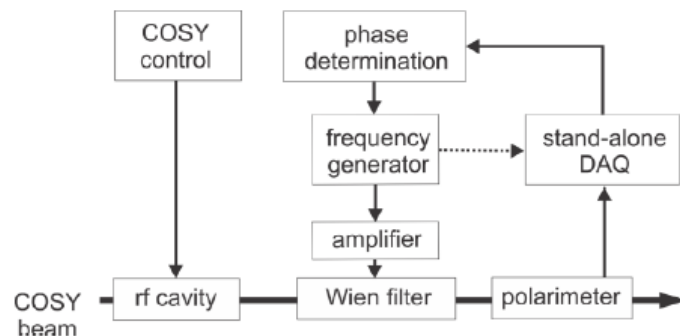


First ever convincing proof of a control of the spin decoherence in a hadronic storage ring

Phase locking spin precession in machine to device RF

Feedback system maintains

1. resonance frequency, and
2. phase between spin precession and device RF (solenoid or Wien filter)



Major achievement : Error of phase-lock $\sigma_{\phi} = 0.21$ rad [18].

A unique case of self-comagnetometry in idle precession vs. standard two-species comagnetometry

Spin envelopes in spin flip (y=vertical, x=radial, z= tangential, flipper axis)

- Idle precession: $\vec{S}(n) = \mathbf{R}_s(n\theta_s)\vec{p}(n)$
 $\theta_s = 2\pi\nu_s \quad \nu_s = 2\pi G\gamma,$

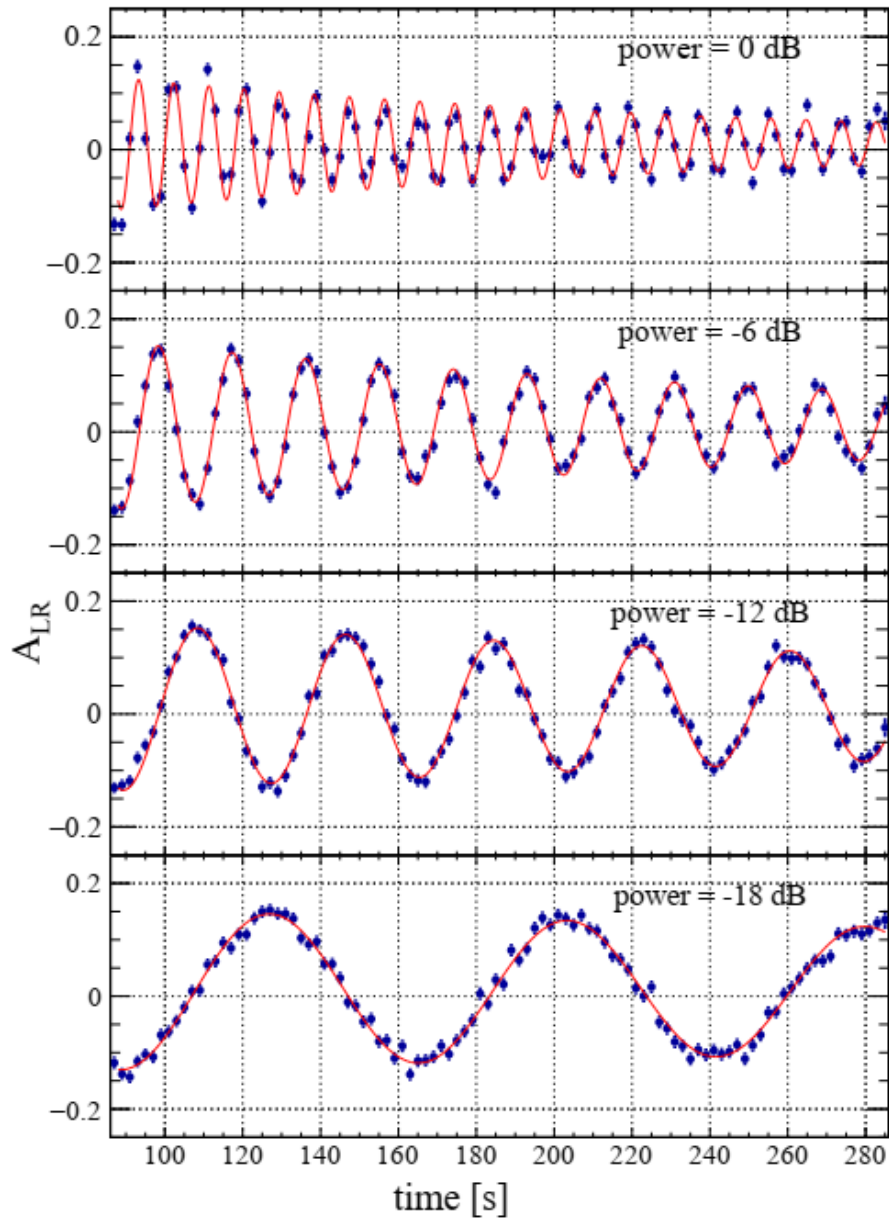
$$\mathbf{R}_s(\theta_s) = \begin{pmatrix} \cos \theta_s & 0 & \sin \theta_s \\ 0 & 1 & 0 \\ -\sin \theta_s & 0 & \cos \theta_s \end{pmatrix}$$

- Envelope with solenoid spin flipper

$$\vec{p}(n) = \mathbf{E}(x)\vec{p}(0) \quad \mathbf{E}(x) = \begin{pmatrix} \cos x & \sin x & 0 \\ -\sin x & \cos x & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\begin{aligned} S_y(n) &= S_y(0) \cos x, \\ S_x(n) &= S_y(0) \cos \theta \sin x, \\ S_z(n) &= -S_y(0) \sin \theta \sin x, \end{aligned}$$

- Oscillating helicity $\rightarrow$ SM P-violation I.Koop et al. PEPAN 52, 549(2021)
- Double helicity pp, dd at NICA $\rightarrow$ gluon helicity SF
- Different imperfection fields in two rings may detune spin precessions $\rightarrow$ synchronize spin
- precessions by **static Wien filters to fine tune spin precession frequencies**
- Periodical switch of one of the helicities by $\pm \pi$ bumps of the spin precession phase by a static Wien filter



Spin decoherence: Spin-off from the JEDI axion search

S.Karant et al., Phys. Rev. X 13, 031004 (2023)

- Polarization damping stronger for higher spin-flip frequency & larger spin-flip phase $x=2\pi f_{sf} t$
- First evidence for a **prominent** synchrotron oscillation driven depolarization: theory in

N. Nikolaev et al. PRAB 27 (2024) 111002.

- Average over ensemble $\rightarrow$ Non-exponential attenuation and nonlinear spin-flip phase walk

$$D(x) = \frac{1}{\sqrt{1 + Q_{sy}^2 x^2}}$$

$$Q_{sy} = \frac{1}{2}(K + G\gamma)^2 \sigma_{sy}^2$$

$$\phi(x) = \arctan(Q_{sy} x).$$

$\sigma_{sy} \ll 1$ is the rms angular length of a bunch

- JEDI data analysis is in progress

Tensor polarization of deuterons

- $\mathbf{T}_{mn} = \frac{1}{2}(S_m S_n + S_n S_m - \frac{2}{3}\delta_{mn}\vec{S}^2)$ 5 independent elements --- 5 dimensions ?
- Spin-1 dumbbell deuteron: S and D waves $\rightarrow$ electric quadrupole moment, entirely negligible effect in the magnetic storage rings
- Weak tensor polarizability. Never measured experimentally. Baryshevsky (2008)
- Tensor envelope evolution is entirely driven by that of the vector polarization
Silenko 2015, Nikolaev, Rathmann, Silenko, Uzikov (2020)

$$\mathbf{t}(n) = \mathbf{R}_s^{-1}(n\theta_s)\mathbf{T}(n)\mathbf{R}_s(n\theta_s)$$

$$\mathbf{t}(n) = \mathbf{E}(x)\mathbf{t}(0)\mathbf{E}^T(x)$$

- only 3x3 matrices, no need to solve secular equation in 5D

Evolution of tensor polarization: a reference particle

$$\frac{1}{2}(t_{xx}(n) - t_{yy}(n)) =$$

$$= \frac{1}{2}(t_{xx}(0) - t_{yy}(0)) \cos 2x + t_{xy}(0) \sin 2x ,$$

$$t_{xy}(n) = -\frac{1}{2}(t_{xx}(0) - t_{yy}(0)) \sin 2x + t_{xy}(0) \cos 2x$$

Vector in vertical XY plane,
rotates with double spin-flip
frequency

$$t_{xz}(n) = t_{xz}(0) \cos x + t_{yz}(0) \sin x ,$$

$$t_{yz}(n) = -t_{xz}(0) \sin x + t_{yz}(0) \cos x ,$$

$$t_{zz}(n) = t_{zz}(0) ,$$

Vector in vertical XY plane,
rotates with the spin-flip
frequency

Unique Fourier signatures!

We found eigenfunctions without ever troubling with a secular equation for 5x5 matrix

Where is millistrong parity-even T-violation?

$$\begin{aligned}
 \sigma_{tot} = & \sigma_0 \\
 & + \sigma_{tt}((\vec{P}^d \cdot \vec{P}^p) - (\vec{P}^d \cdot \vec{k})(\vec{P}^p \cdot \vec{k})) \\
 & + \sigma_{zz}(\vec{P}^d \cdot \vec{k})(\vec{P}^p \cdot \vec{k}) \\
 & + \sigma^T T_{ab} k_a k_b \\
 & + \sigma_{PV}^p(\vec{P}^p \cdot \vec{k}) \\
 & + \sigma_{PV}^d(\vec{P}^d \cdot \vec{k}) \\
 & + \sigma_{PV}^T(\vec{P}^p \cdot \vec{k}) T_{ab} k_a k_b \\
 & + \sigma_{TVPV}(\vec{k} \cdot [\vec{P}^p \times \vec{P}^d]) \\
 & + \sigma_{TVPC} k_a T_{ab} \epsilon_{bcd} P_c^p k_d,
 \end{aligned}$$

TVPC

$$k_a T_{ab} \epsilon_{bcd} P_c^p k_d = T_{xz} P_y^p - T_{yz} P_x^p.$$

Flavor conserving T- and C-violating millistrong interaction is a source of CP violation beyond the SM.

May it help to resolve a mystery of baryon asymmetry in the Universe? It remains an entirely unexplored option.

Depolarization from averaging over ensemble

- Spin tune $\nu_{\text{sf}}(\xi) = \nu_{\text{sf}} J_0(2\xi \sqrt{Q_{\text{sy}}})$
- Spin-flip phase $x \rightarrow x(Q_{\text{sy}}\xi) = J_0(2\xi \sqrt{Q_{\text{sy}}})x \approx (1 - Q_{\text{sy}}\xi^2)x$
- Synchrotron amplitude distribution $F(\xi) = 2\xi \exp(-\xi^2)$

$$\frac{1}{2}(t_{\text{xx}}(n) - t_{\text{yy}}(n)) = D(2x) \left[\left(\frac{1}{2}(t_{\text{xx}}(0) - t_{\text{yy}}(0)) \cos(2x - \phi(2x)) + t_{\text{xy}}(0) \sin(2x - \phi(2x)) \right) \right],$$

$$t_{\text{xy}} = D(2x) \left[\frac{1}{2}(t_{\text{xx}}(0) - t_{\text{yy}}(0)) \sin(2x - \phi(2x)) + t_{\text{xy}}(0) \cos(2x - \phi(2)x) \right],$$

$$t_{\text{xz}}(n) = D(x) [t_{\text{xz}}(0) \cos(x - \phi(x)) + t_{\text{yz}}(0) \sin(x - \phi(x))],$$

$$t_{\text{yz}}(n) = D(x) [-t_{\text{xz}}(0) \sin(x - \phi(x)) + t_{\text{yz}}(0) \cos(x - \phi(x))],$$

$$t_{\text{zz}}(n) = t_{\text{zz}}(0),$$

Boundary condition for stored polarization

$$\langle \vec{S} \rangle = S_y \vec{e}_y, \quad \langle S_{x,z}(0) \rangle = 0,$$

$$\langle T_{yx}(0) \rangle = \langle T_{yz}(0) \rangle = \langle T_{xz}(0) \rangle = 0, \quad \langle T_{xx}(0) \rangle = \langle T_{zz}(0) \rangle = -\frac{1}{2} \langle T_{yy}(0) \rangle.$$

Flipping & depolarizing and spectator components of $\mathbf{T}$

$$\frac{1}{2}[T_{xx}(n) - T_{zz}(n)] = \frac{3}{8} \langle T_{yy}(0) \rangle \cos(2\theta_s n) - \frac{3}{8} \langle T_{yy}(0) \rangle \underline{Q(2x) \cos(2x - \phi(2x))} \cos(2\theta_s n)$$

$$T_{xz}(n) = -\frac{3}{8} \langle T_{yy}(0) \rangle \sin(2\theta_s n) + \frac{3}{8} \langle T_{yy}(0) \rangle \underline{Q(2x) \cos(2x - \phi(2x))} \sin(2\theta_s n),$$

$$T_{xy}(n) = \frac{3}{4} \langle T_{yy}(0) \rangle \underline{Q(2x) \sin(2x - \phi(2x))} \cos(\theta_s n),$$

$$T_{zy}(n) = -\frac{3}{4} \langle T_{yy}(0) \rangle \underline{Q(2x) \sin(2x - \phi(2x))} \sin(\theta_s n),$$

$$\frac{1}{2}T_{yy}(n) = -\frac{1}{2}[T_{xx}(n) + T_{zz}(n)] = \frac{1}{8} \langle T_{yy}(0) \rangle + \frac{3}{8} \langle T_{yy}(0) \rangle \underline{Q(2x) \cos(2x - \phi(2x))},$$

Fresh look at the tensor polarimetry

- CNI polarimetry is indispensable (consumes a tiny fraction of the beam interactions)
- Take advantage of the Glauber eclipse effect driven dichroism complement the CNI polarimeter by large FOM forward counters to detect inelastic interaction

$$\sigma_{\text{tot}} = \sigma_0(1 + A_{zz}T_{zz}).$$

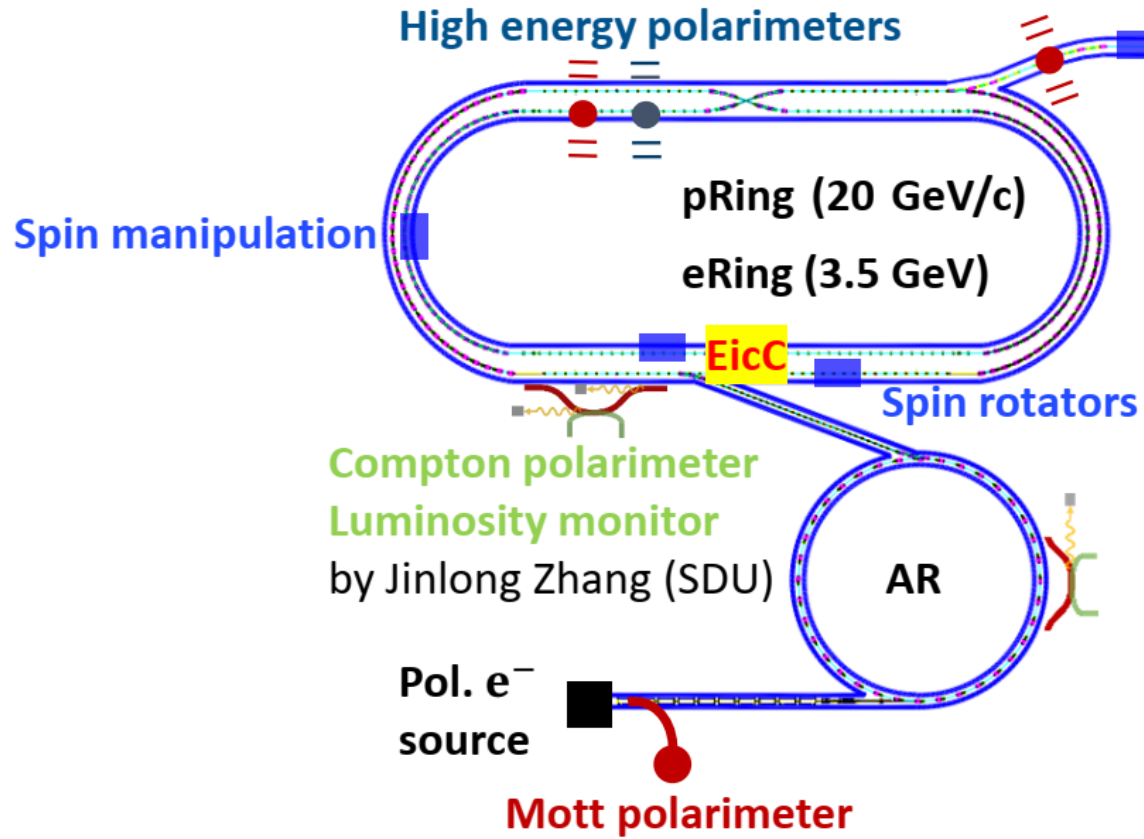
- Analyzing power $A_{zz} \sim 0.3\%$
- Fourier extraction of the tensor asymmetry

$$T_{zz}(n) = \frac{1}{2} \langle T_{yy}(0) \rangle \left\{ -1 + \frac{3}{2} \sin^2(\theta) [1 + Q(2x) \cos(2x - \phi(2x))] \right\}$$

- **Tensor comagnetrometry:**
- Fourier analysis of the tensor polarimeter $\rightarrow$ spin precession frequency
- Basis of synchronization of spin precessions in two rings by static Wien filters

Prospects of the Fourier analyzed flipping and oscillating deuteron polarization at Nuclotron/NICA

- Spin flip frequency 0.02 Hz $\rightarrow$ 144 flips for 1 h fill
- NICA bunch length ~ 60 cm $\rightarrow \sigma_{sy}=0.0012$, $\sim$ 100 times smaller than at COSY!
O. Kozlov et al. PEPAN 53, 1021 (2022)
- RF solenoid run at side band $K=0$: $Q_{sy} = 7e-7$
- 1 h fill: $Q_{sy} \times \sim 0.001 \rightarrow$ synchrotron oscillation effects were substantial at COSY but are expected to be entirely negligible at NICA away of spin resonances
- Still shorter bunches are anticipated at HIAF



Electron ion collider in China (EicC)

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

High Intensity Heavy-ion Accelerator Facility (HIAF) ✓ to be commissioned in 2025

Zhou et al. AAPPS Bulletin (2022) 32:35
<https://doi.org/10.1007/s43673-022-00064-1>

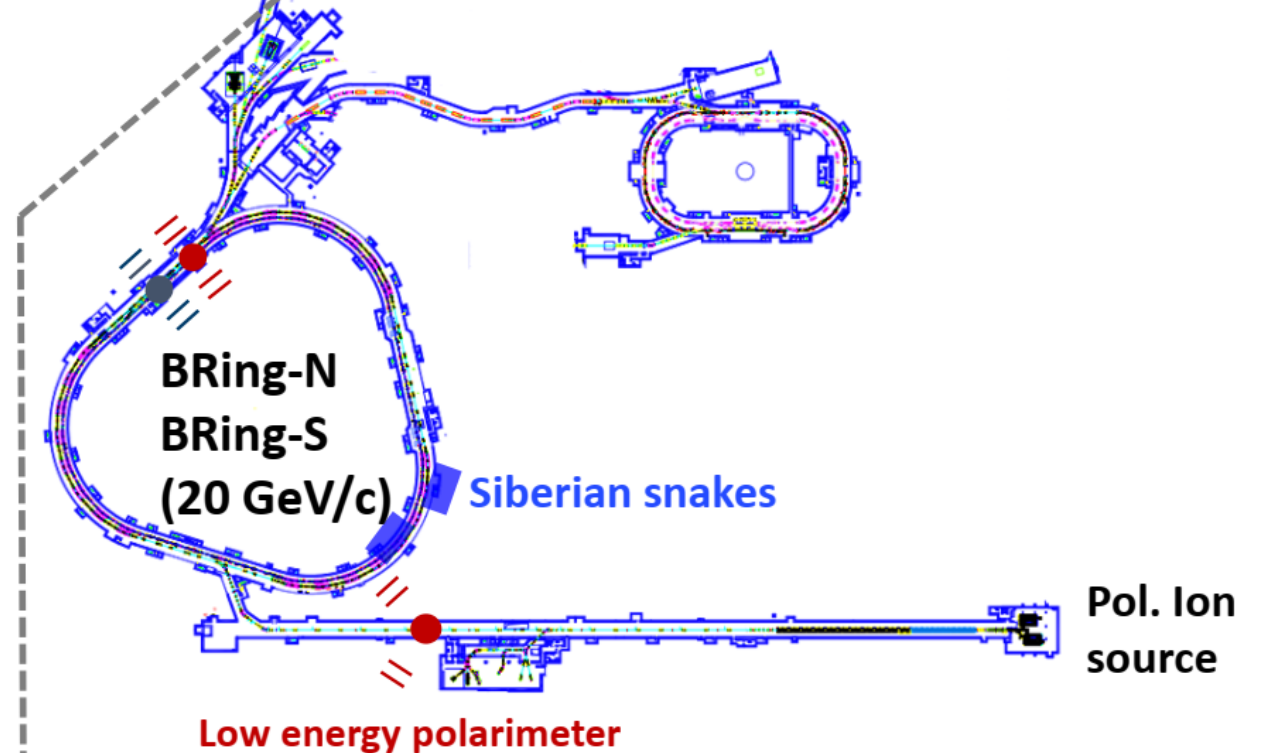
AAPPS Bulletin

REVIEW ARTICLE

Open Access

Status of the high-intensity heavy-ion accelerator facility in China

Xiaohong Zhou*, Jiancheng Yang and the HIAF project team



Spin physics at HIAF

- Nice spin physics at HIAF with polarized target and (un)polarized beams
- Polarized gas target will be used as both **proton target** and **electron target**



- Ideas and collaborations are more than welcome!

① pol. e target

unpol. beams (A, p)

$$Z^{Q+} + \vec{e} \rightarrow Z^{(Q-1)+} + \hbar\omega$$

$$p\vec{e} \rightarrow pe$$

pol. electron capture (atomic physics)
proton EM radii, new boson search

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

Conclusions

New instrumentation per Nuclotron and NICA rings:

- RF solenoid spin-flippers
- Reasonably large FOM detectors to count inelastic events for the comagnetometry purposes
- Static Wien filters for synchronization of polarizations of colliding bunches: CW ring as a comagnetometer for ACW ring
- The same static Wien filters for switching the relative polarization of colliding bunches
- A feedback from vertical polarization to synchronize the spin-flip phases of colliding bunches

The oscillating polarization regime is feasible at NICA

Georg Christoph Lichtenberg (1742-1799)



“Man muß etwas Neues machen, um etwas Neues zu sehen.”

**“You have to make (create) something new,
if you want to see something new”**

Из всех видов деспотизма самый страшный — деспотизм верования и системы.
Большинство людей - рабы моды и нелепых обычаев.

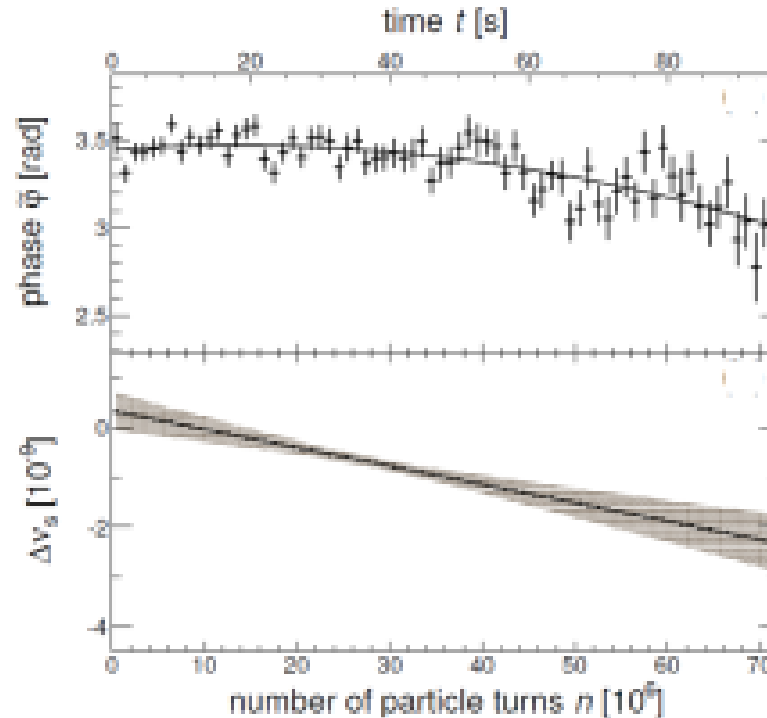
Thank you for your patience!

Supplementary slides

Precise time-stamping of events,

- allows us to monitor phase of measured asymmetry with (assumed) fixed spin tune ν_s in a 100 s cycle:

$$\begin{aligned}\nu_s(n) &= \nu_s^{\text{fix}} + \frac{1}{2\pi} \frac{d\phi}{dn} \\ &= \nu_s^{\text{fix}} + \Delta\nu_s(n)\end{aligned}\quad (9)$$



Origin of frequency walk:
hysteresis in magnets?
unstable temperature?

COSY was not designed
as even 10^{-6} ring

Experimental technique allows for:

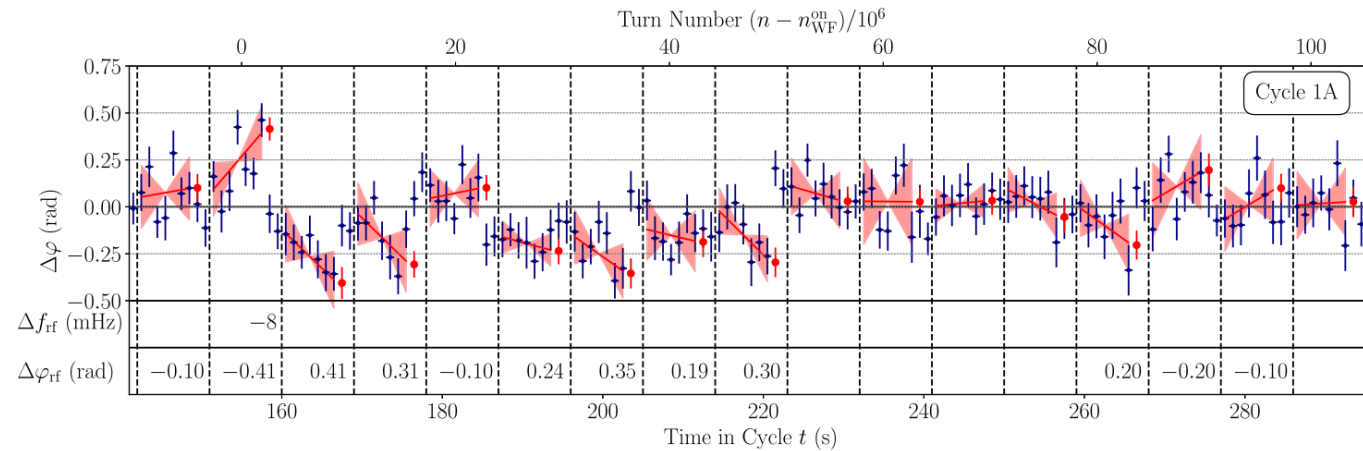
- Spin tune ν_s determined to $\approx 10^{-8}$ in 2 s time interval.
- In a 100 s cycle at $t \approx 38$ s, interpolated spin tune amounts to $|\nu_s| = (16097540628.3 \pm 9.7) \times 10^{-11}$, i.e., $\Delta\nu_s/\nu_s \approx 10^{-10}$.
- $\Rightarrow$ new precision tool to study systematic effects in a storage ring.

Excellent example of
Ramsay's theorem
in action

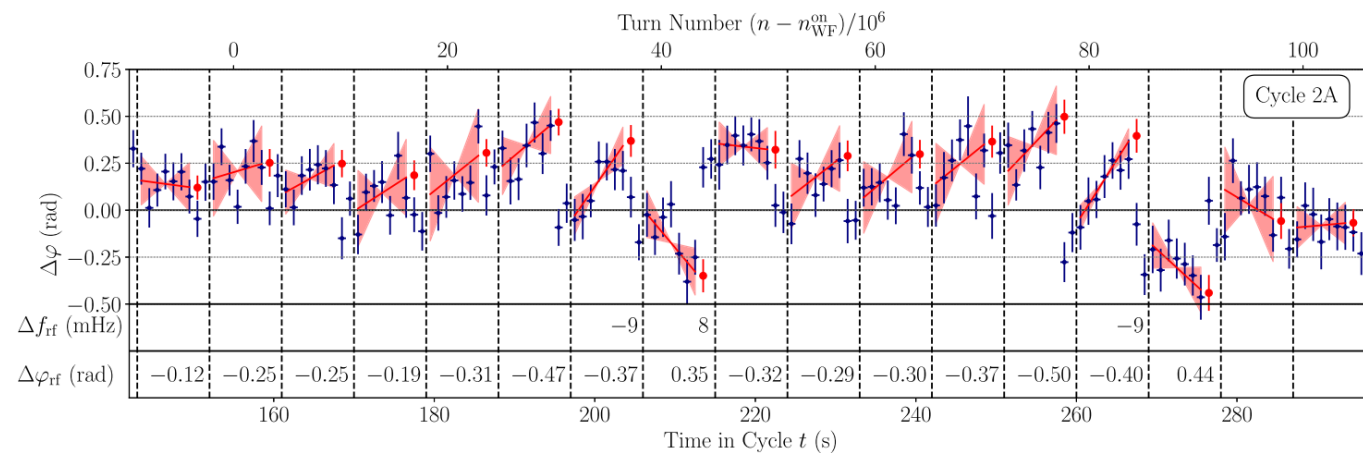
JEDI @ COSY: example of corrections for the spin precession phase walk

V. HEJNY *et al.*

PHYS. REV. ACCEL. BEAMS **28**, 062801 (2025)

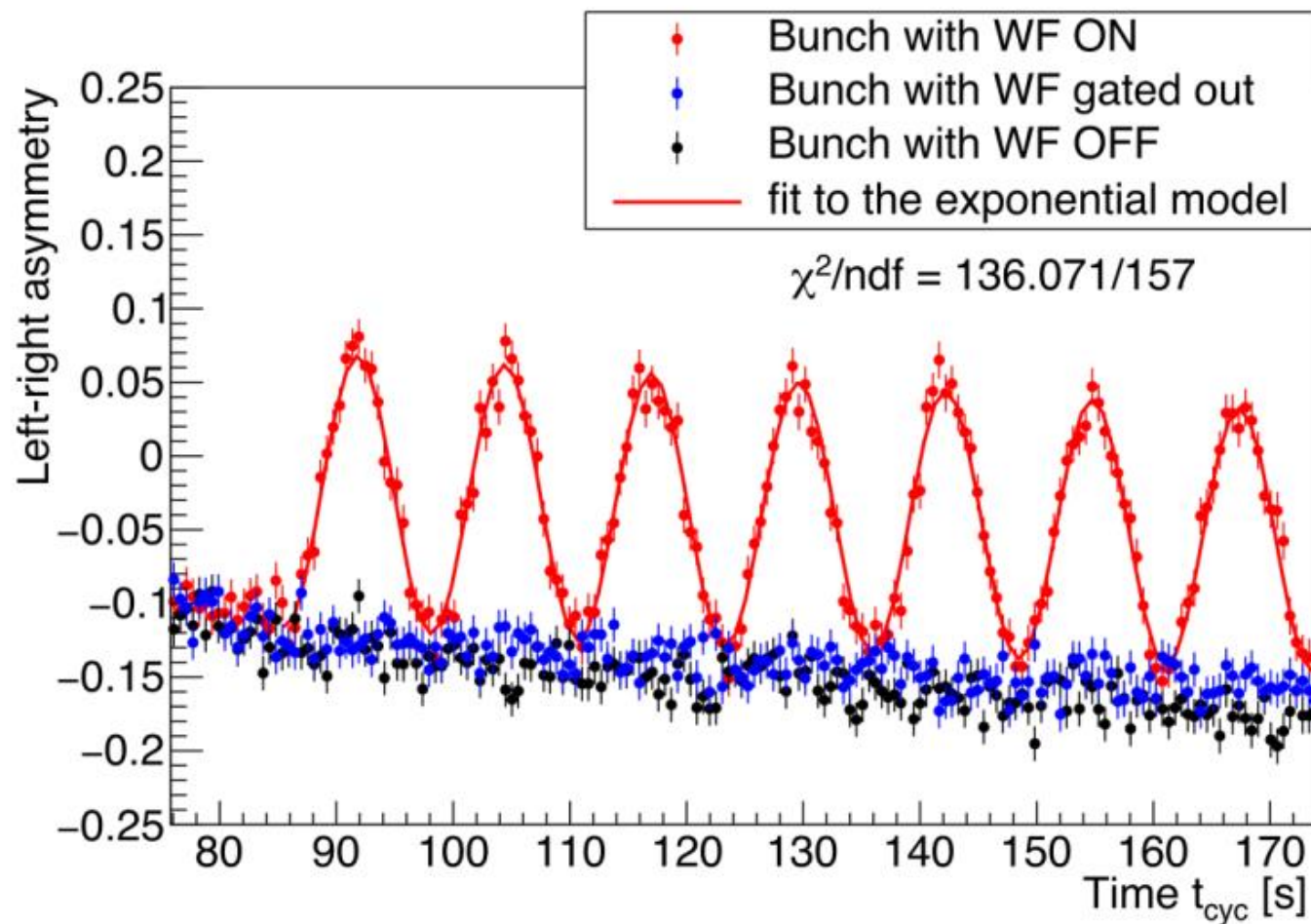


$$\sigma_\phi = 0.2 \text{ rad}$$



Comagnetometry for continuous spin flips to maintain the spin resonance: monitor the in-plane precession of gated out pilot bunch

JEDI, J. Slim et al. *Phys.Rev.Res.* 7 (2025) 2, 023257



Fast switches with
switch time of < 10 ns

$$f_{\text{SF}} = 0.07944 \pm 0.00010 \text{ Hz}$$

1 h SF phase walk ~ 2 rad

Synchronize SF phases of
colliding bunches by the
flipper field strength

CP and the observed Baryon Asymmetry in Universe

Carina Nebula: Largest-seen star-birth regions in the galaxy

	$(n_B - n_{\bar{B}})/n_\gamma$	
Observed	$(6.11 \pm 0.19) \times 10^{-10}$	WMAP+COBE (2003)
SM exp.	$\sim 10^{-18}$	

Why this strange number? Why not zero?

Mystery of missing antimatter addresses the puzzle of our existence

Sakharov's fundamental criterions

- Baryon number nonconservation
- CP violation
- Nonequilibrium expansion at baryon number generation

All present in the SM, but it is short of strength

Electric dipole moments (EDMs)

For particles with EDM $\vec{d}$ and MDM $\vec{\mu} (\propto \vec{s})$,

- non-relativistic Hamiltonian:

$$H = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E}$$

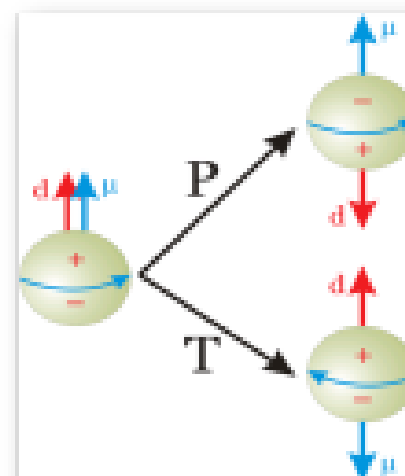
- **Energy of magnetic dipole** invariant under P and T :

$$-\vec{\mu} \cdot \vec{B} \xrightarrow{P \text{ or } T} -\vec{\mu} \cdot \vec{B}$$

No other direction than spin $\Rightarrow \vec{d}$ parallel to $\vec{\mu}$ ($\vec{s}$).

- **Energy of electric dipole** $H = -\vec{d} \cdot \vec{E}$, includes term

$$\vec{s} \cdot \vec{E} \xrightarrow{P \text{ or } T} -\vec{s} \cdot \vec{E}, \quad (1)$$



EDMs violate both P and T symmetry

- EDMs possibly constitute the missing cornerstone to explain surplus of matter over antimatter in the Universe.
 - Non-vanishing EDMs would add 4th quantum number to fundamental particles (besides m , q , and s).

Naive estimate of scale of nucleon EDM

From Khriplovich & Lamoreux [4] and Nikolaev [5]:

- CP and P conserving magnetic moment $\approx$ nuclear magneton μ_N .

$$\mu_N = \frac{e}{2m_p} \sim 10^{-14} \text{ e cm.}$$

- A non-zero EDM requires:

- ▶ P violation: price to pay is $\approx 10^{-7}$, and
- ▶ CP violation (from K decays): price to pay is $\sim 10^{-3}$.

- In summary:

$$|d_N| \sim 10^{-7} \times 10^{-3} \times \mu_N \sim 10^{-24} \text{ e cm}$$

- In Standard model (without θ_{QCD} term):

$$|d_N| \sim 10^{-7} \times 10^{-24} \text{ e cm} \sim 10^{-31} \text{ e cm}$$

Region to search for Beyond Standard Model (BSM) physics

- from nucleon EDMs with $\theta_{\text{QCD}} = 0$:

$$10^{-24} \text{ e cm} > |d_N| > 10^{-31} \text{ e cm}$$

(Okun, 1965)

PSI(2020): ultracold neutrons

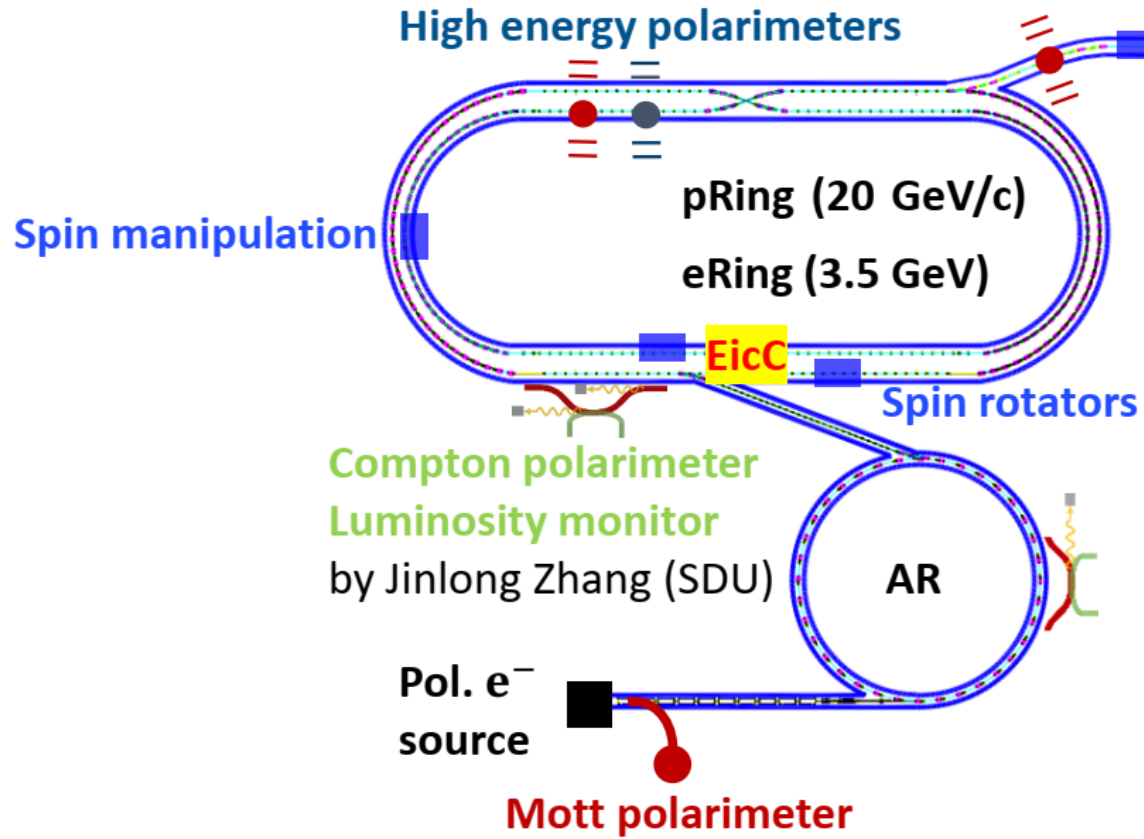
$d_n < 1.8 \times 10^{-26} \text{ e cm}$ --- about ultimate limit with neutrons, possible improvements by at most factor 10

Don't ask too much from dimensional estimates:

SM: Shabalin, 1978
Extra suppression by QCD coupling at electroweak scale

$$d_n \sim 10^{-34} \text{ e cm}$$

Confirmed by later studies



Electron ion collider in China (EicC)

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

High Intensity Heavy-ion Accelerator Facility (HIAF) ✓ to be commissioned in 2025

Zhou et al. AAPPS Bulletin (2022) 32:35
<https://doi.org/10.1007/s43673-022-00064-1>

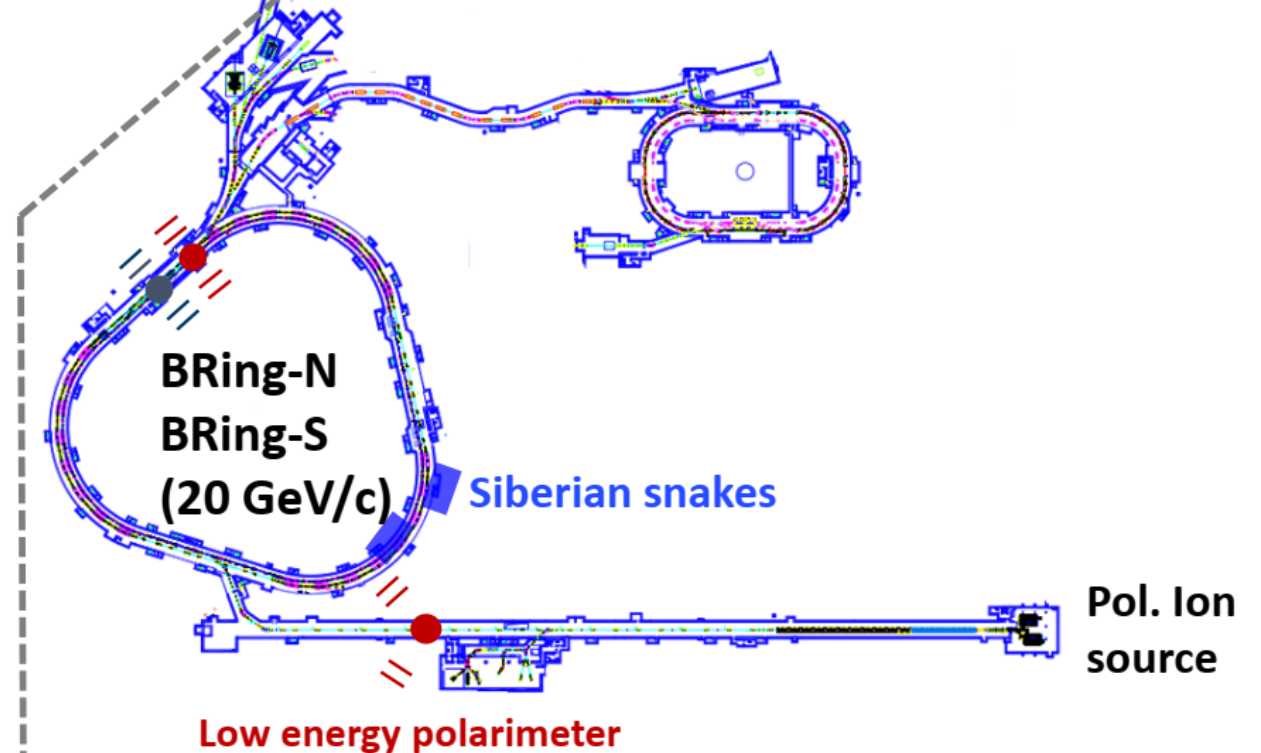
AAPPS Bulletin

REVIEW ARTICLE

Open Access

Status of the high-intensity heavy-ion accelerator facility in China

Xiaohong Zhou*, Jiancheng Yang and the HIAF project team



Spin physics at HIAF

- Nice spin physics at HIAF with polarized target and (un)polarized beams
- Polarized gas target will be used as both **proton target** and **electron target**



- Ideas and collaborations are more than welcome!

① pol. e target

unpol. beams (A, p)

$$Z^{Q+} + \vec{e} \rightarrow Z^{(Q-1)+} + \hbar\omega$$

$$p\vec{e} \rightarrow pe$$

pol. electron capture (atomic physics)
proton EM radii, new boson search

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

Testing SM by Parity Violation (PV)

- The observable: PV beam helicity dependence of the total X-section and elastic scattering
- New approach: single turn extraction of horizontal polarized beam onto external target--- time-tag control of the extracted horizontal beam helicity
- A challenge to experimentalists: the expected asymmetries are few 10^{-8} to 10^{-7} --- counting events is entirely hopeless, measure beam current upstream and downstream thick nuclear target instead
- I.A. Koop, A.I. Milstein, N.N. Nikolaev, A.S. Popov, S.G. Salnikov, P.Yu. Shatunov, Yu.M. Shatunov, *Tests of Fundamental Discrete Symmetries at the NICA Facility: Addendum to the Spin Physics Programme*, Physics of Particles and Nuclei, 52(4), 549-554 (2021); Physics of Particles and Nuclei, 52(6), 1044-1119 (2021)
- Polarimetry requirements: < 1 GeV/c deuterons are favored
- High energy: B.G. Zakharov, *Sov. J. Nucl. Phys.* Sov. J. Nucl. Phys., 42 (3), 479-482 (1985)]