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

Search for T-odd mechanisms beyond the SM with a transversely polarized electron target?

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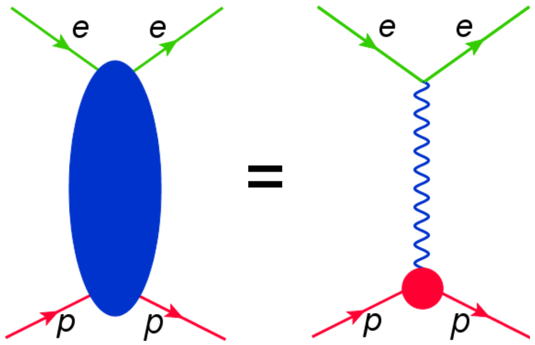
Content

- Puzzle in transverse spin asymmetry $A_{\perp}^{\vec{e}p}/A_{\perp}^{\vec{e}A}$
- New T-odd mechanisms search via $A_{\perp}^{p\vec{e}}$?
- Opportunities in China

A bit of history

Small coupling (1/137) $\Longrightarrow$ negligible higher order contributions



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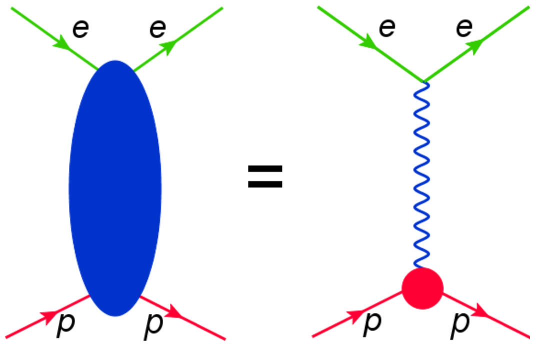
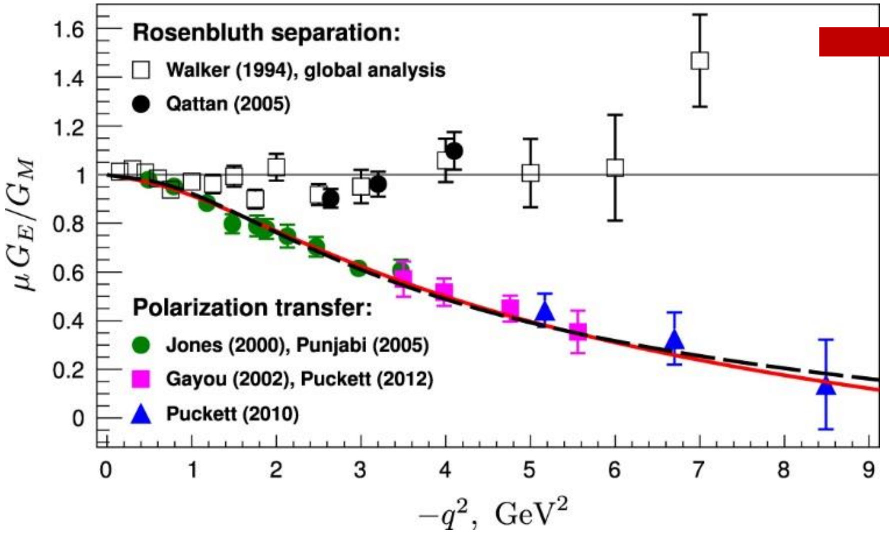


Two methods (both based on one-photon exchange) to study proton from factors

1. Rosenbluth separation 2. polarization transfer

yield different results



Proton form factor puzzle

A bit of history

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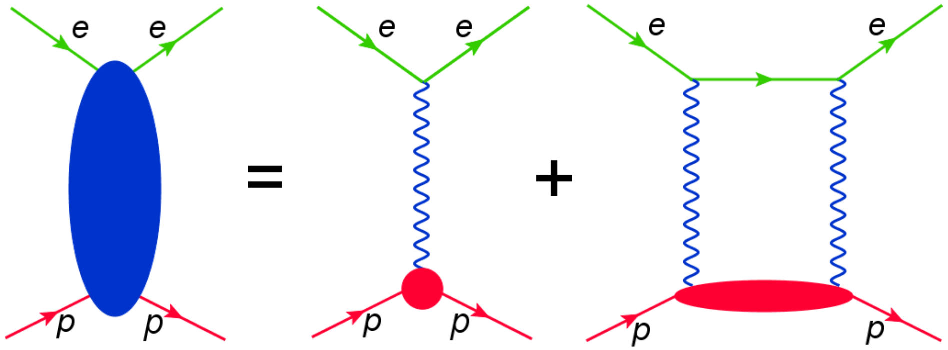

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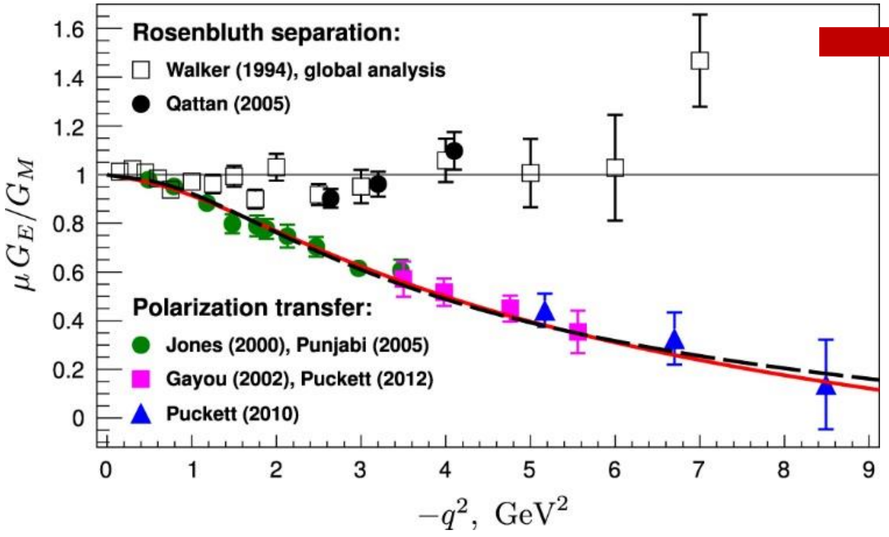
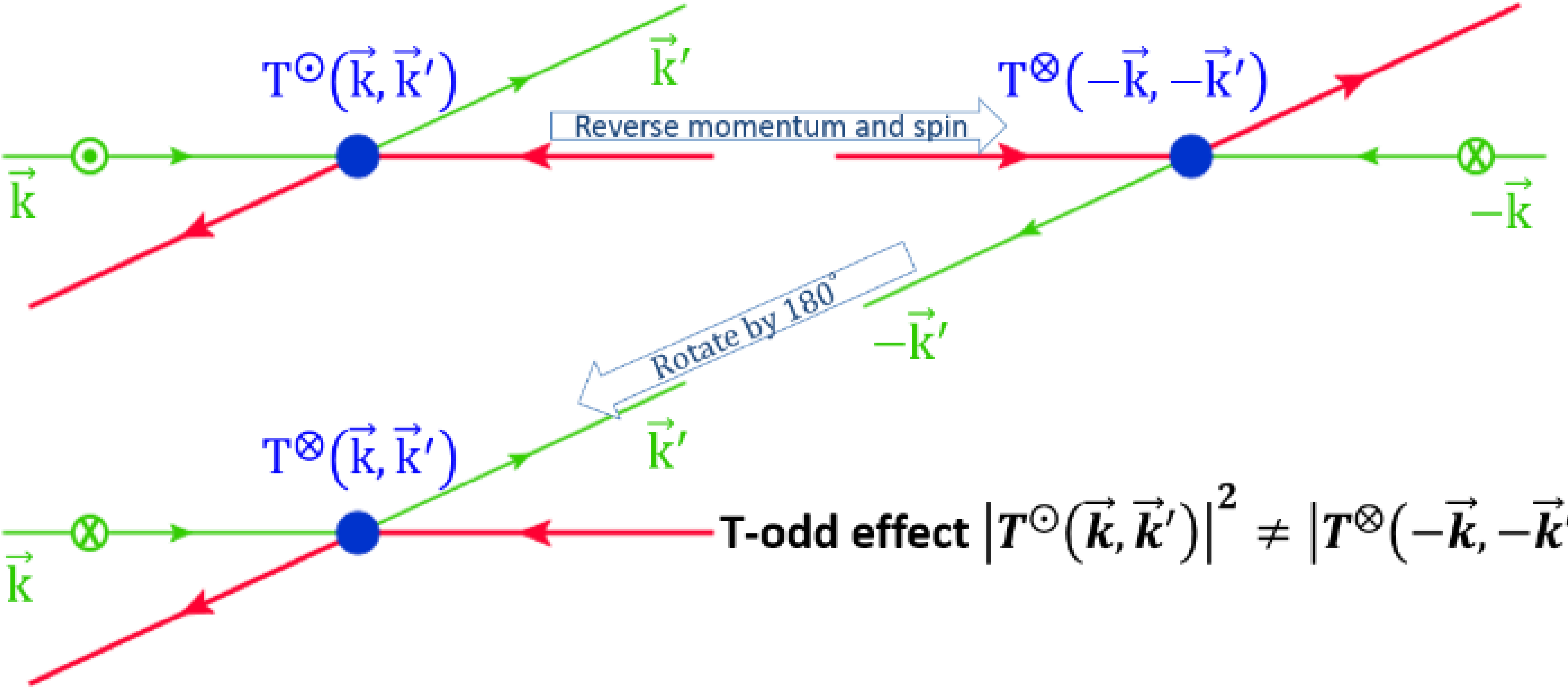


Proton form factor puzzle

Two-photon exchange

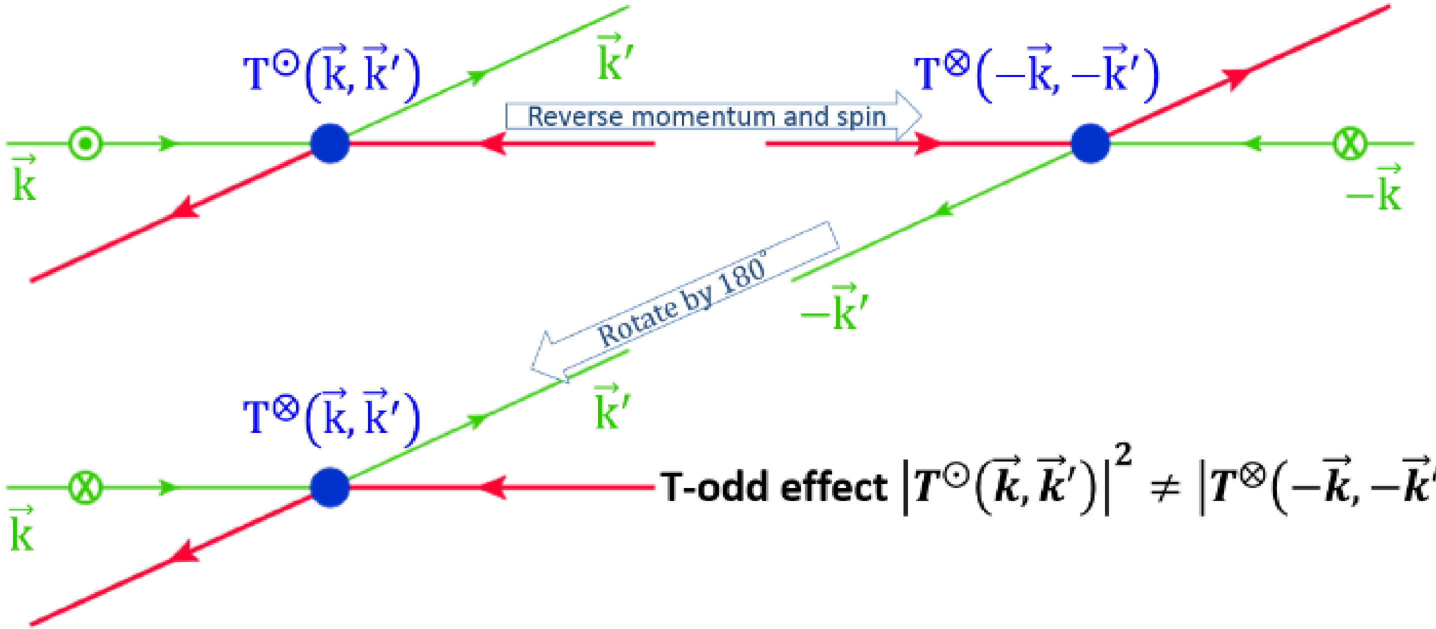
T-odd effects with transverse spin asymmetry

Transverse spin asymmetry arises from processes beyond one photon exchange



T-odd effect $\left|T^{\odot}(\vec{k}, \vec{k}')\right|^2 \neq \left|T^{\otimes}(-\vec{k}, -\vec{k}')\right|^2$

T-odd effects with transverse spin asymmetry



T-odd effect $|T^{\odot}(\vec{k},\vec{k}')|^2 \neq |T^{\otimes}(-\vec{k},-\vec{k}')|^2$

Azimuthal asymmetry

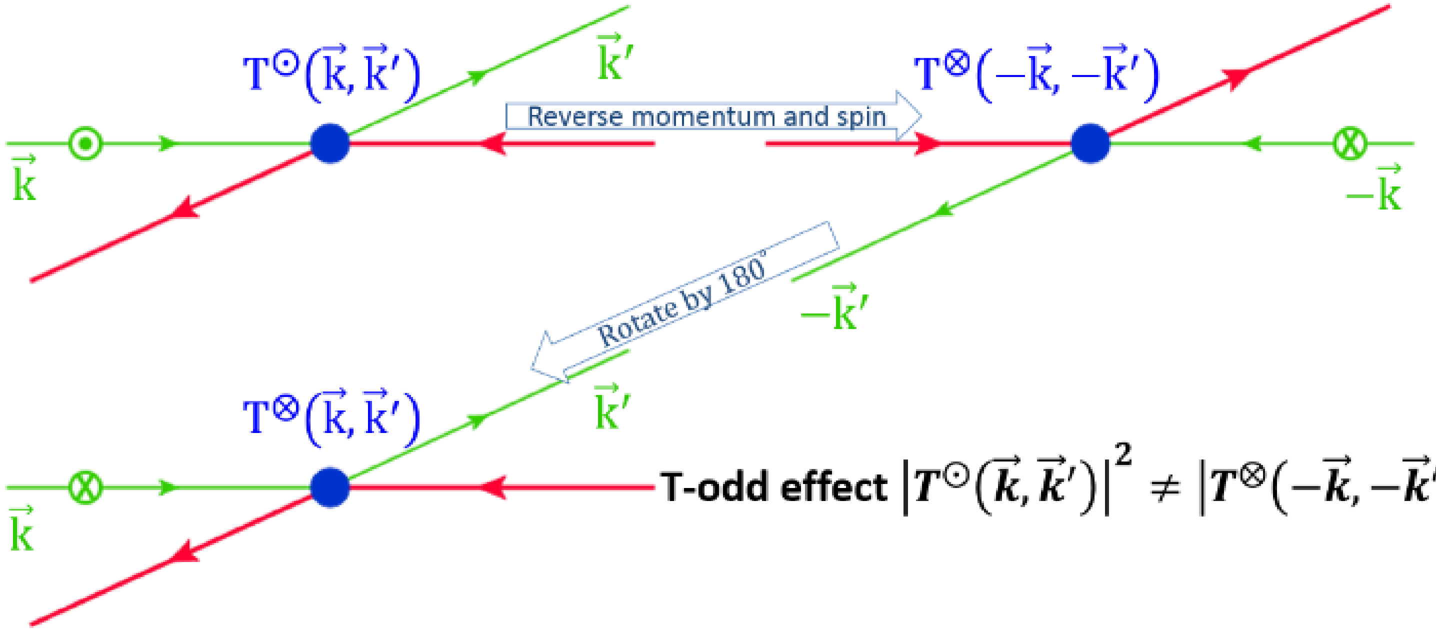
$$A_{exp} = \frac{\sigma^{\odot} - \sigma^{\otimes}}{\sigma^{\odot} + \sigma^{\otimes}} = A_{\perp}\frac{\vec{s}\cdot\vec{p}}{|\vec{s}||\vec{p}|} = -A_{\perp}\cos\varphi$$

$$A_{\perp} \propto \frac{Im(\mathcal{M}_{\gamma}^{*}\mathcal{M}_{2\gamma})}{|\mathcal{M}_{\gamma}|^2}$$

Nucl. Phys. B 35 (1971) 365.

- **Target spin asymmetry in $e\overrightarrow{N} \to eN$: $A_{\perp} \sim \alpha \sim 10^{-2}$**
  - HallA@JLab
- **Beam spin asymmetry in $\vec{e}N \to eN$: $A_{\perp} \sim \alpha \cdot \frac{m_e}{E} \sim 10^{-5} - 10^{-6}$**
  - SAMPLE@MIT-Bates
  - HAPPEX, G0, Q_{weak} @JLab
  - A4@MAMI

T-odd effects with transverse spin asymmetry



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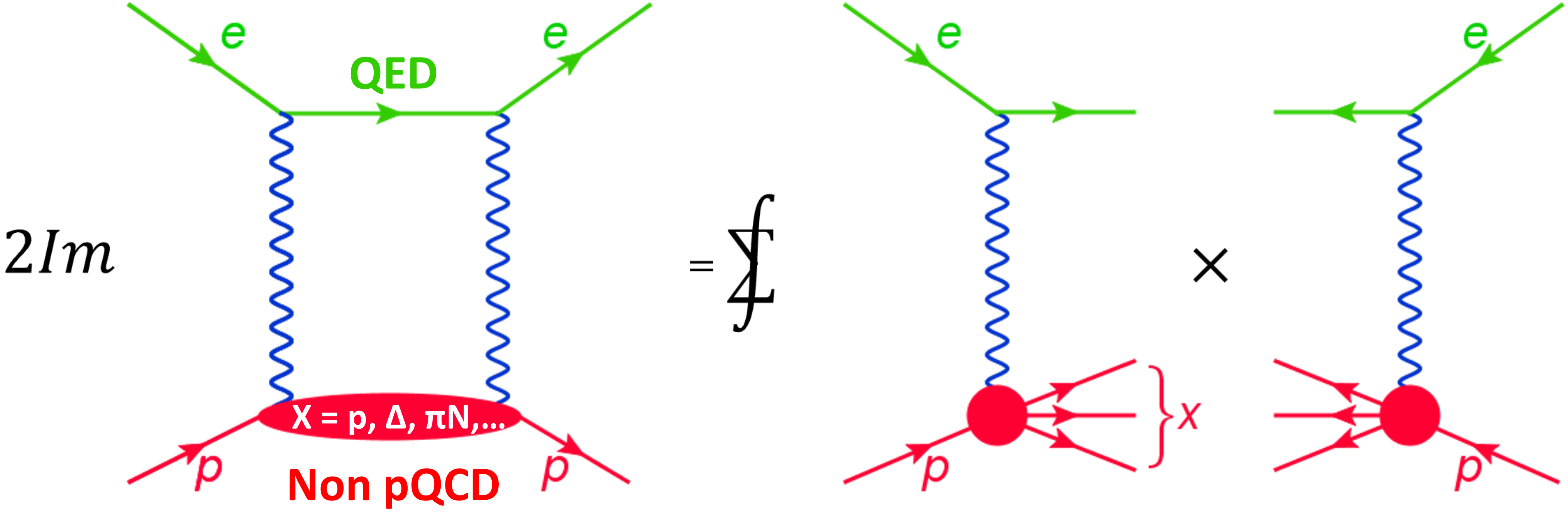
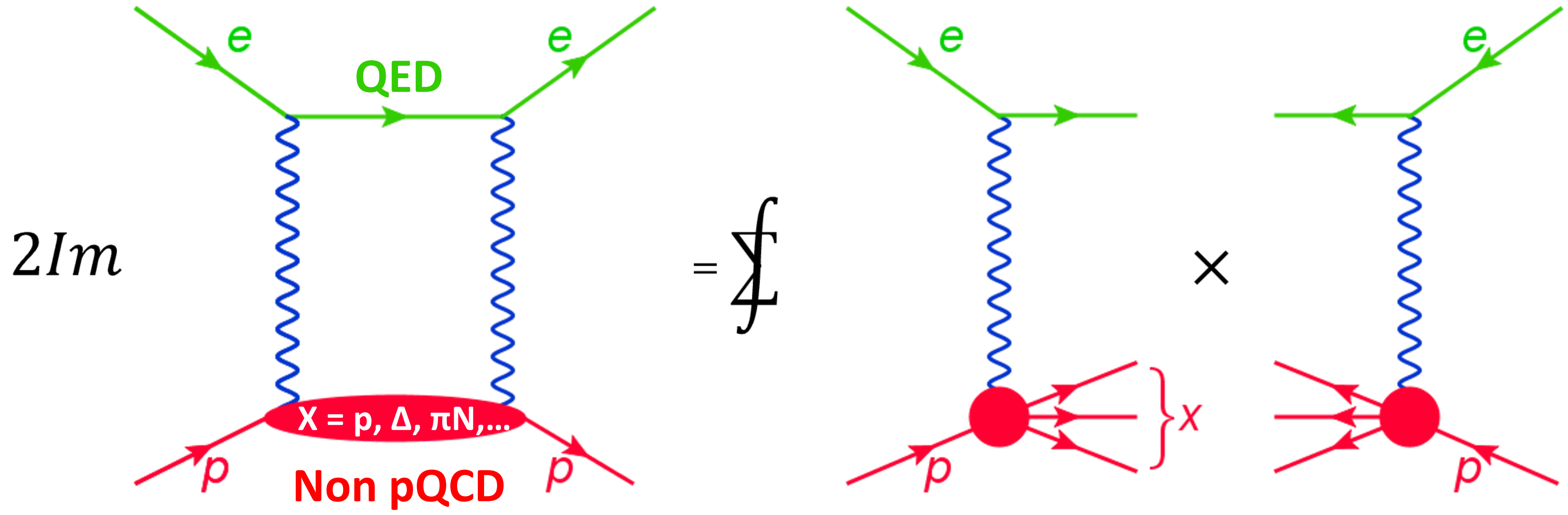
Relativistic effect

TPE amplitudes



TPE amplitudes



Calculation 1

by B. Pasquini and M. Vanderhaeghen

Phy. Rev. C 70, 045206(2004)

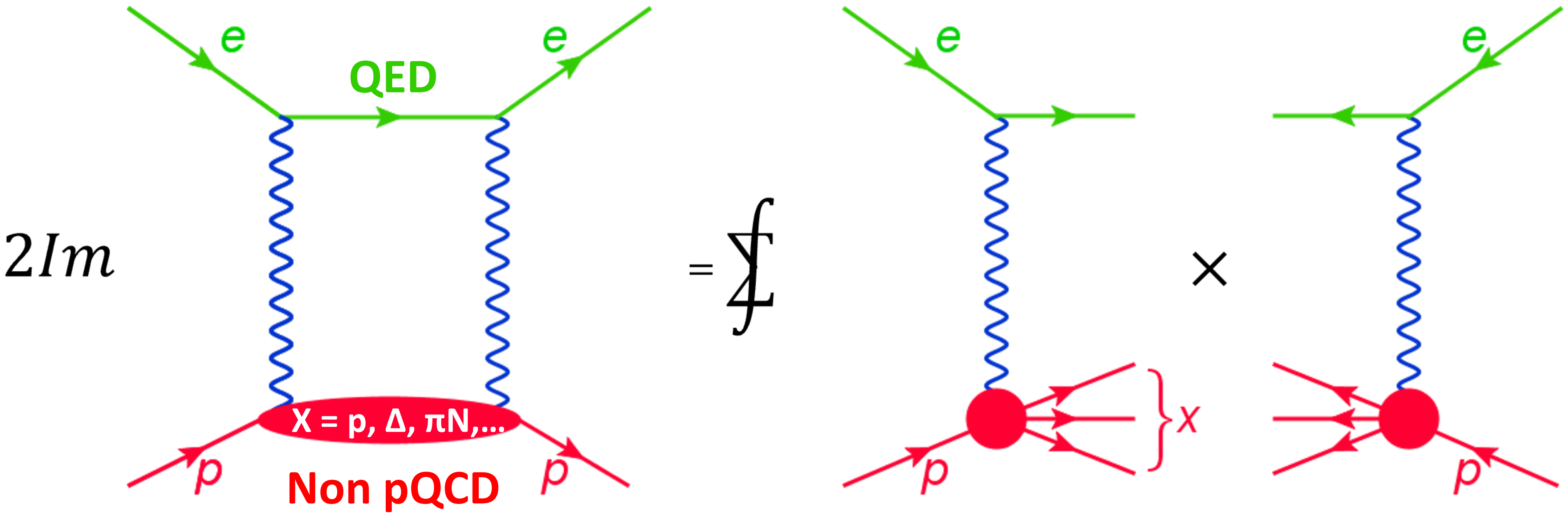
Ground proton state

G_E and G_M as input

All πN intermediate states (both resonant and nonresonant)

$\gamma N \rightarrow \pi N$ amplitudes from MAID 2007

TPE amplitudes



Calculation 2

by J. Ahmed, P. G. Blunden, and W. Melnitchouk

Phy. Rev. C 108, 055202(2023)

Ground proton state

G_E and G_M as input

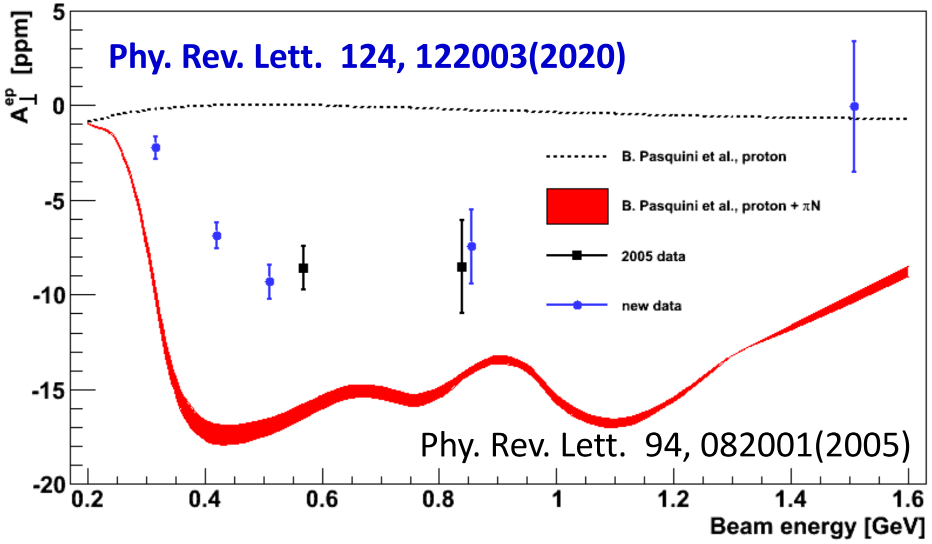
Resonant states of spin-parity $1/2^{\pm}$ and $3/2^{\pm}$ ($W \leq 1.8$ GeV)

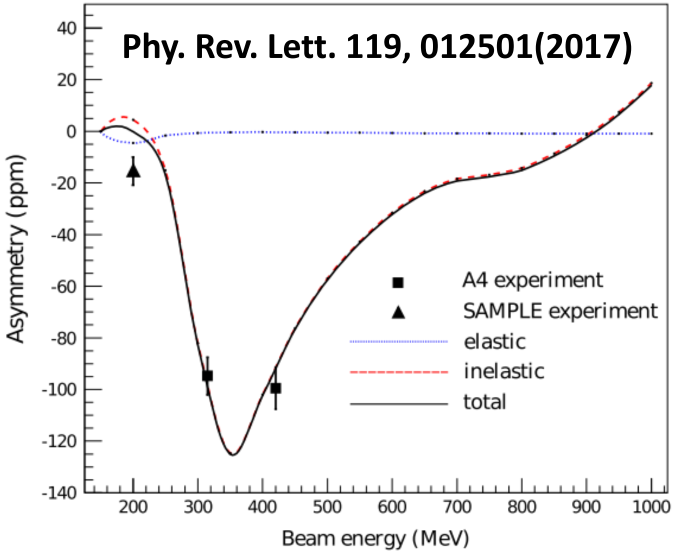
$\gamma N \rightarrow X$ amplitudes from the latest CLAS exclusive meson production

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

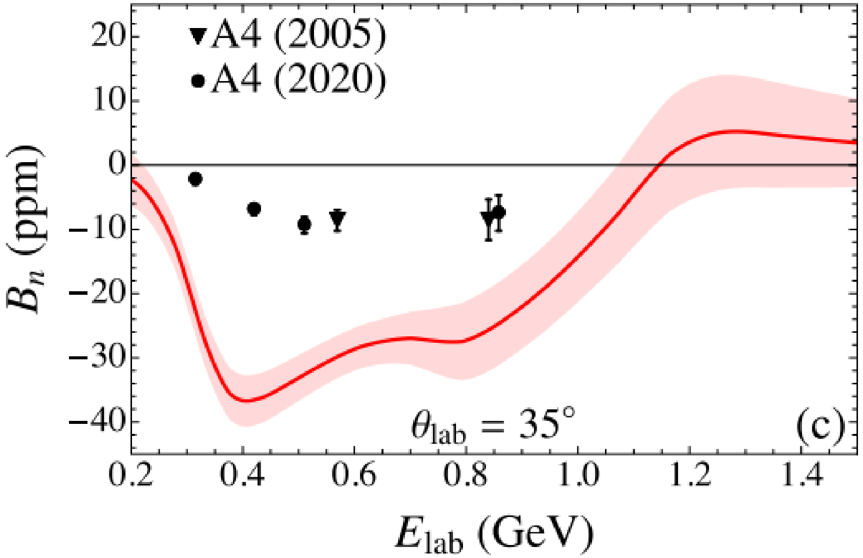
Surprising discrepancies between theoretical and exp. data of different laboratories

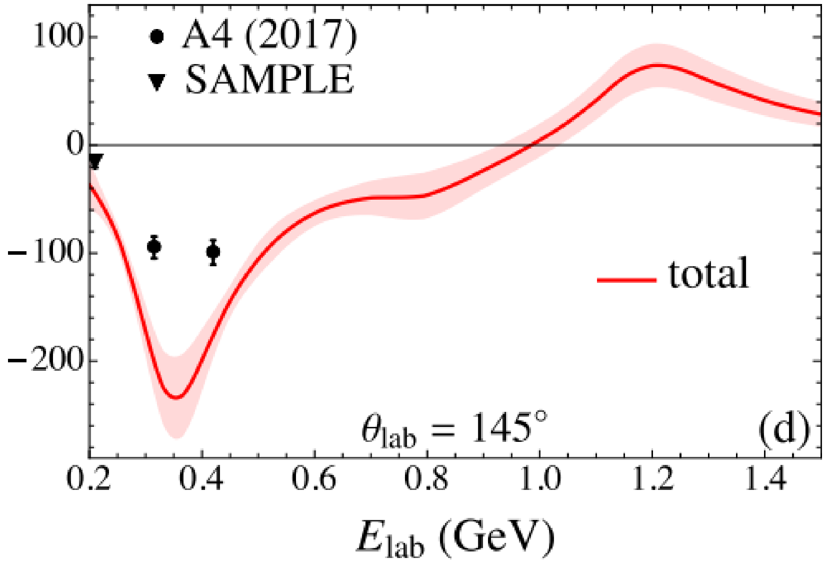
Calculation 1





Calculation 2





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

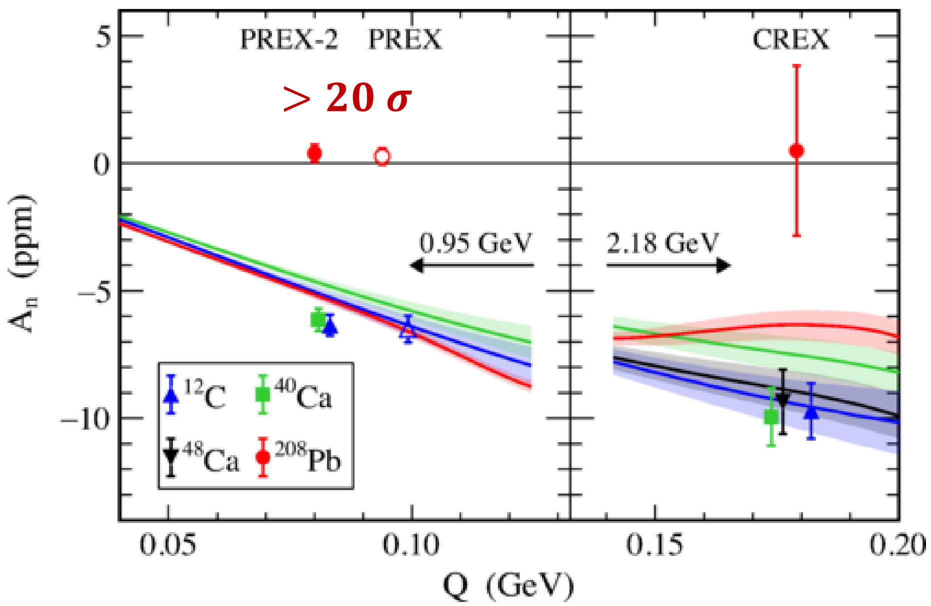
Not only $\vec{e}p$, but also $\vec{e}A$

Optical Theorem: $\sigma_{tot} = \frac{4\pi}{k} Im(0)$

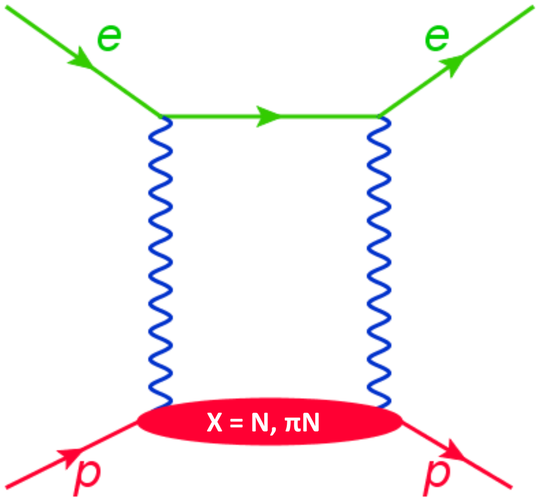
Phy. Rev. C 103, 064316(2021) by
O. Koshchii, M. Gorchtein, X. Roca-Maza, and H. Spiesberger

PREX, PREXII, CREX @ JLab
Phy. Rev. Lett. 109, 192501(2012), Phy. Rev. Lett. 128, 142501(2022)

E_{beam} (GeV)	Target	$\langle\theta_{lab}\rangle$ (deg)	$\langle Q^2\rangle$ (GeV^2)	$\langle\cos\phi\rangle$
0.95	^{12}C	4.87	0.0066	0.967
0.95	^{40}Ca	4.81	0.0065	0.964
0.95	^{208}Pb	4.69	0.0062	0.966
2.18	^{12}C	4.77	0.033	0.969
2.18	^{40}Ca	4.55	0.030	0.970
2.18	^{48}Ca	4.53	0.030	0.970
2.18	^{208}Pb	4.60	0.031	0.969

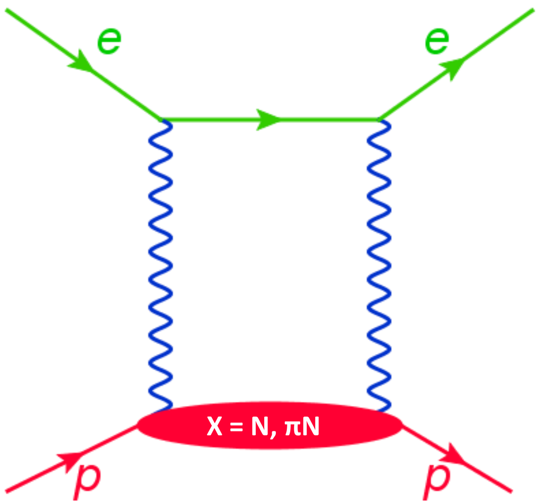


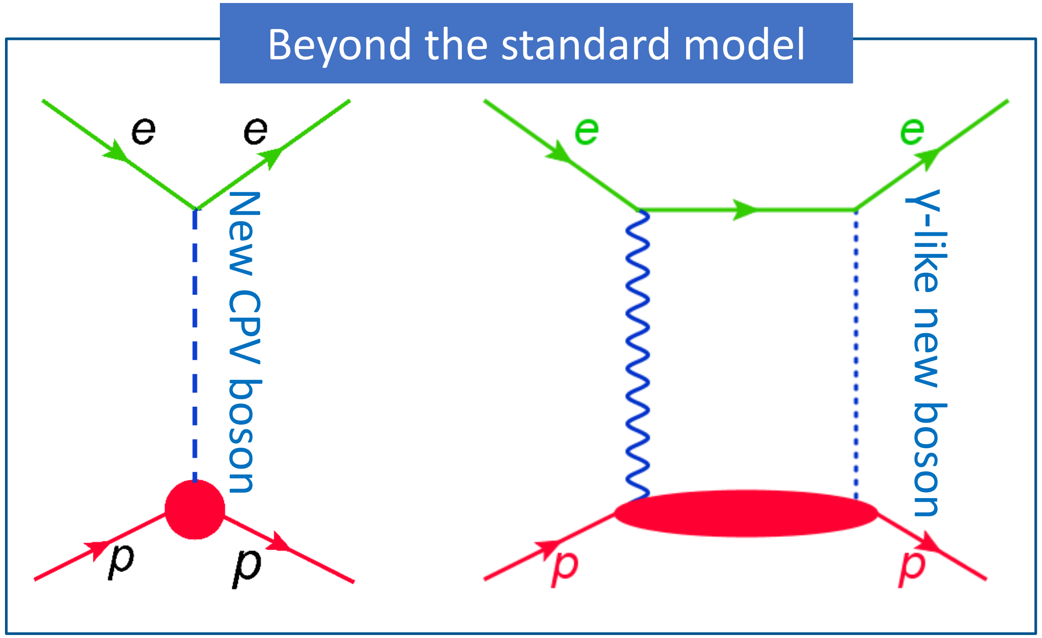
How to understand the surprise



- More intermedite state?
- MAID database and CLAS data need improvement?

How to understand the surprise





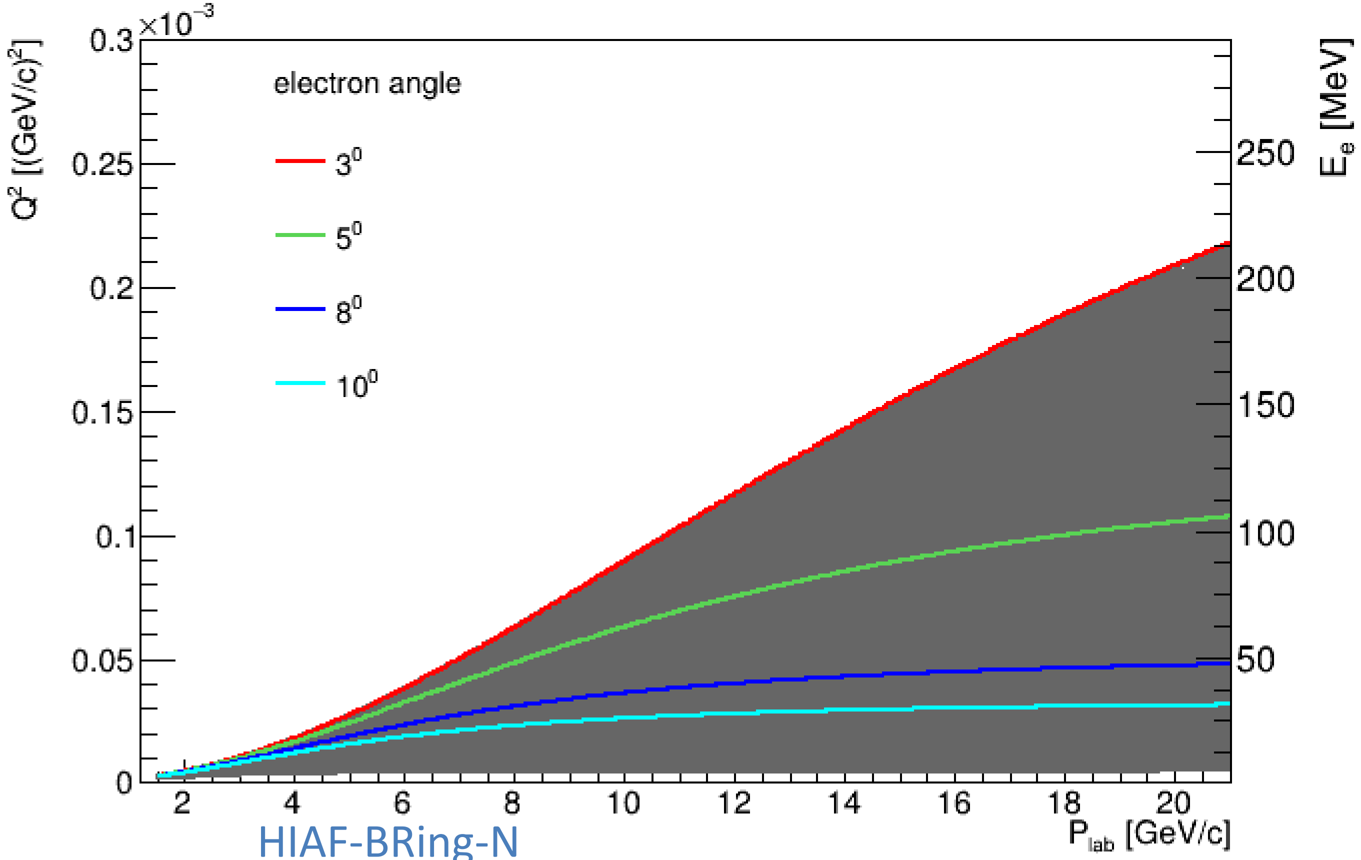
- More intermedite state?
- MAID database and CLAS data need improvement?
- **New unknown boson?**

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

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

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

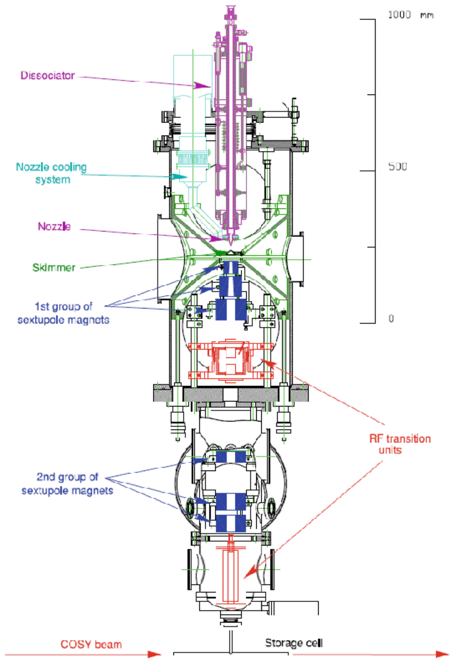
With proton beam and electron target at HIAF/EicC-pRing, ultra low $Q_2 (< 2 \times 10^{-4})$ can be accessed in pe scattering

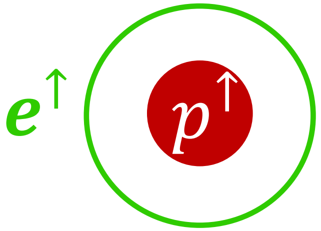


HIAF-BRing-N

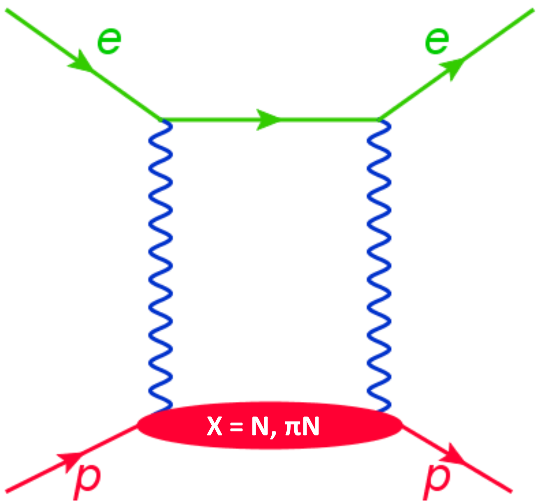
BRing-S, EicC-pRing

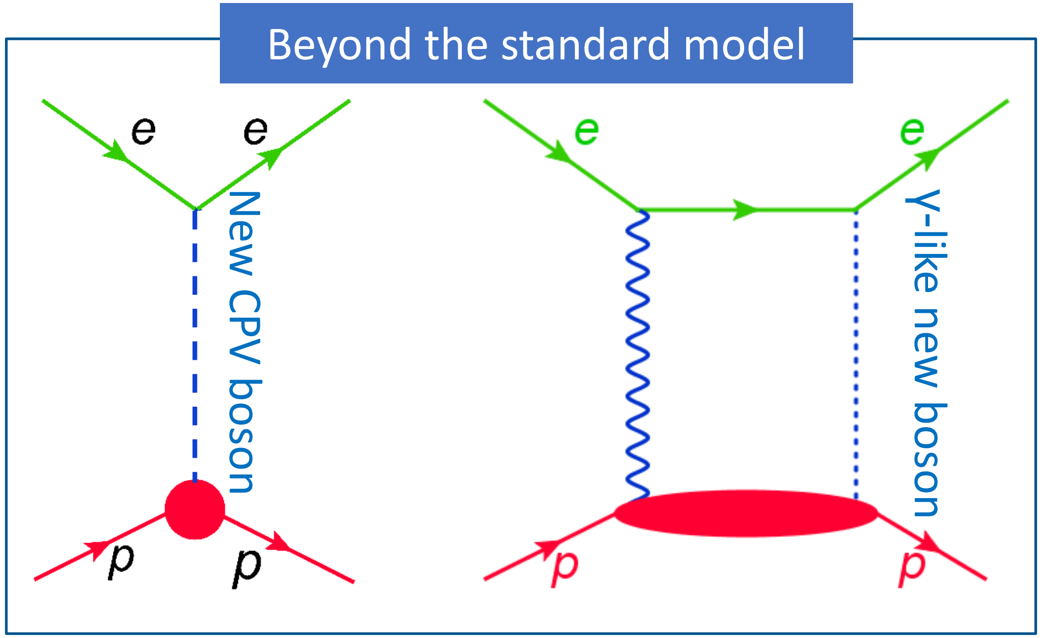
Polarized hydrogen target is a polarized electron target!!!





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





- **New unknown boson?**

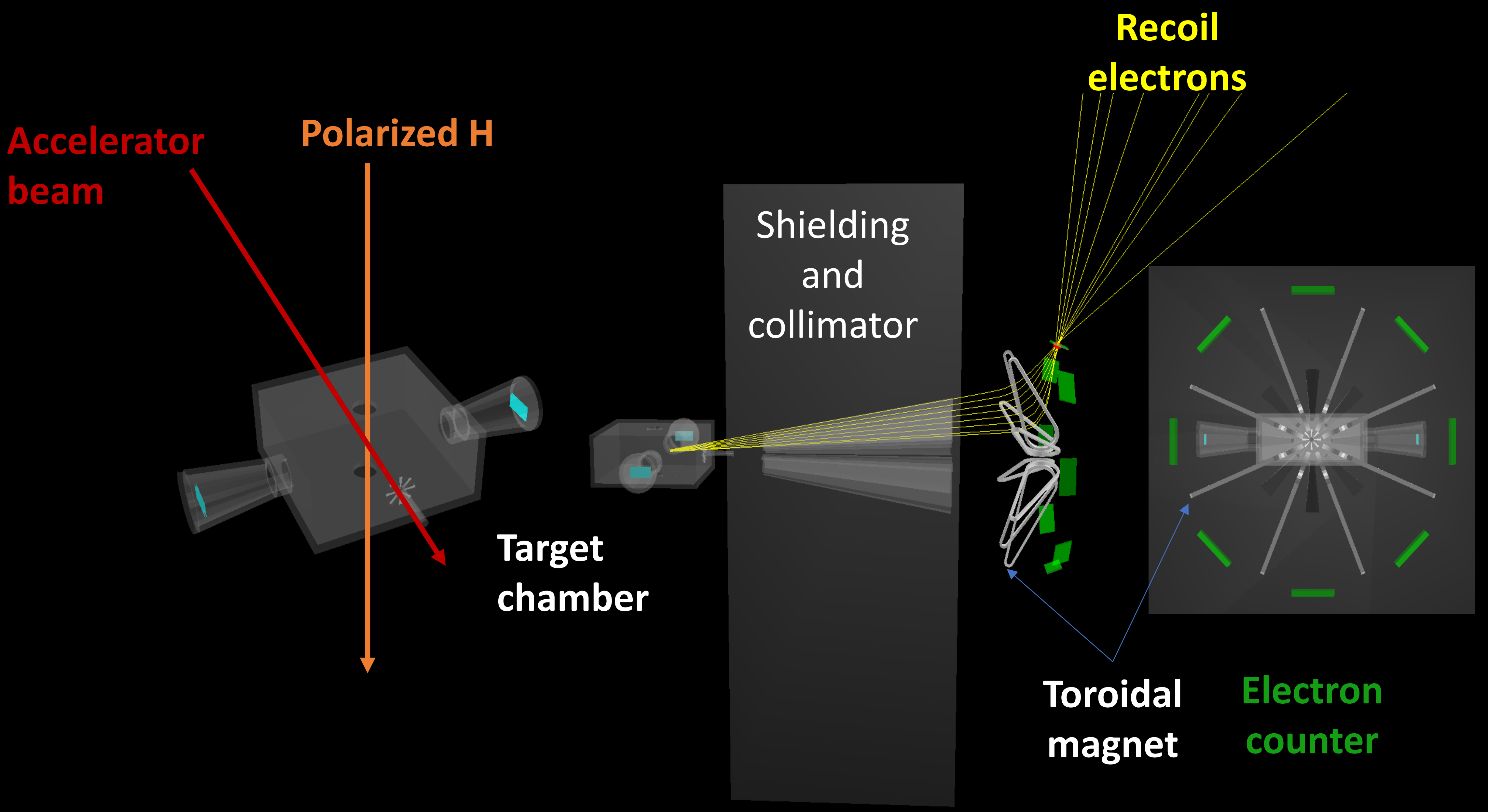
➢ In $\vec{e}\mathrm{p} \to \mathrm{ep}$

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

➢ In $\mathrm{p}\vec{\mathrm{e}} \to \mathrm{pe}$ (very-low $\mathbf{Q_2}$)

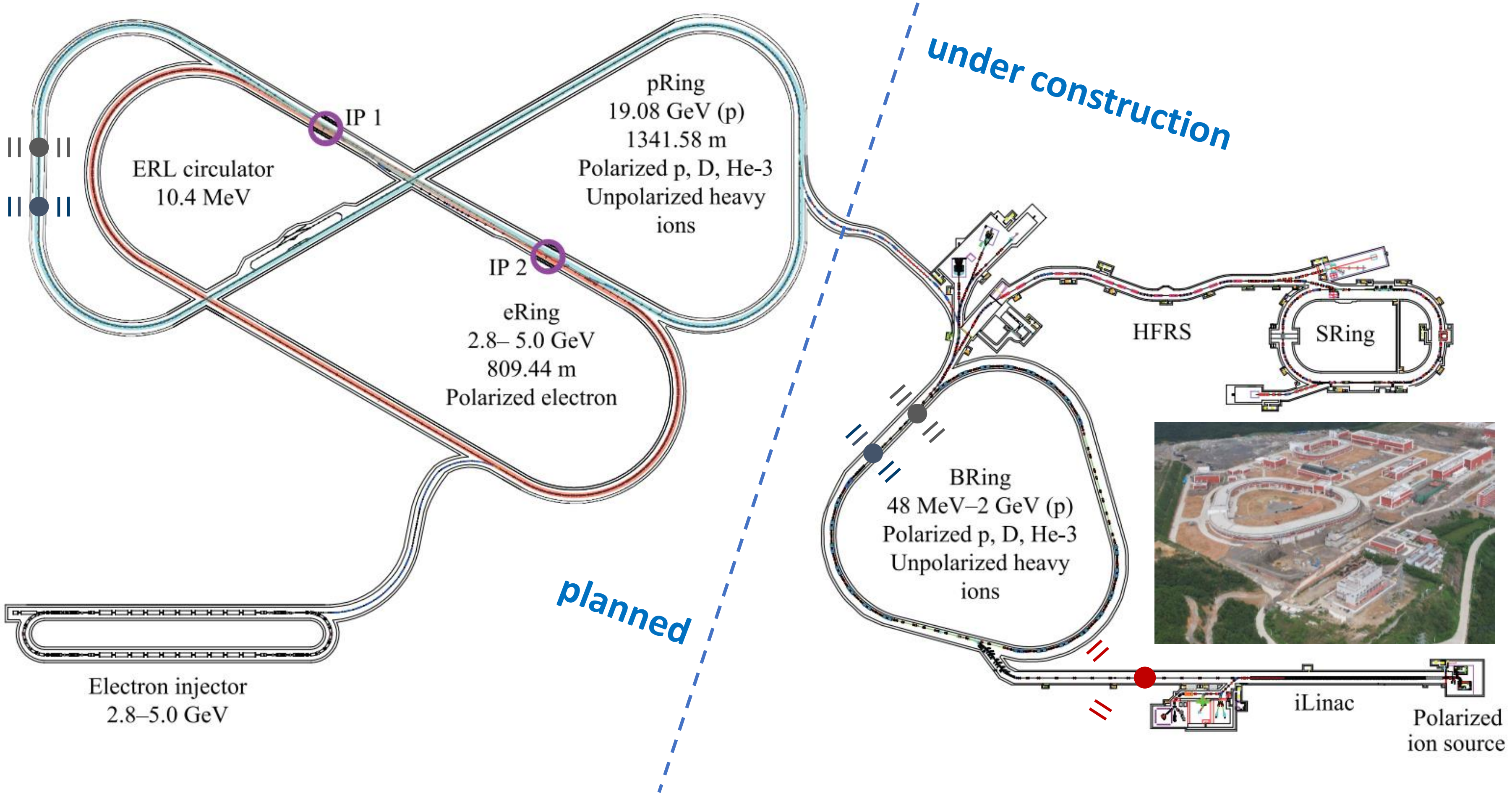
- X = N → $A_\perp$ calculated with **G_E and G_M (no theoretical uncertainty)**
- No Lorentz effect → $A_\perp$ increases by 3 orders

Detection system



Opportunities at HIAF and pRing

- HIAF is under construction
- EicC is being proposed
- **National Key R&D Program** received from MOST for polarized ion source and **polarized hydrogen target → pol. e^- target**



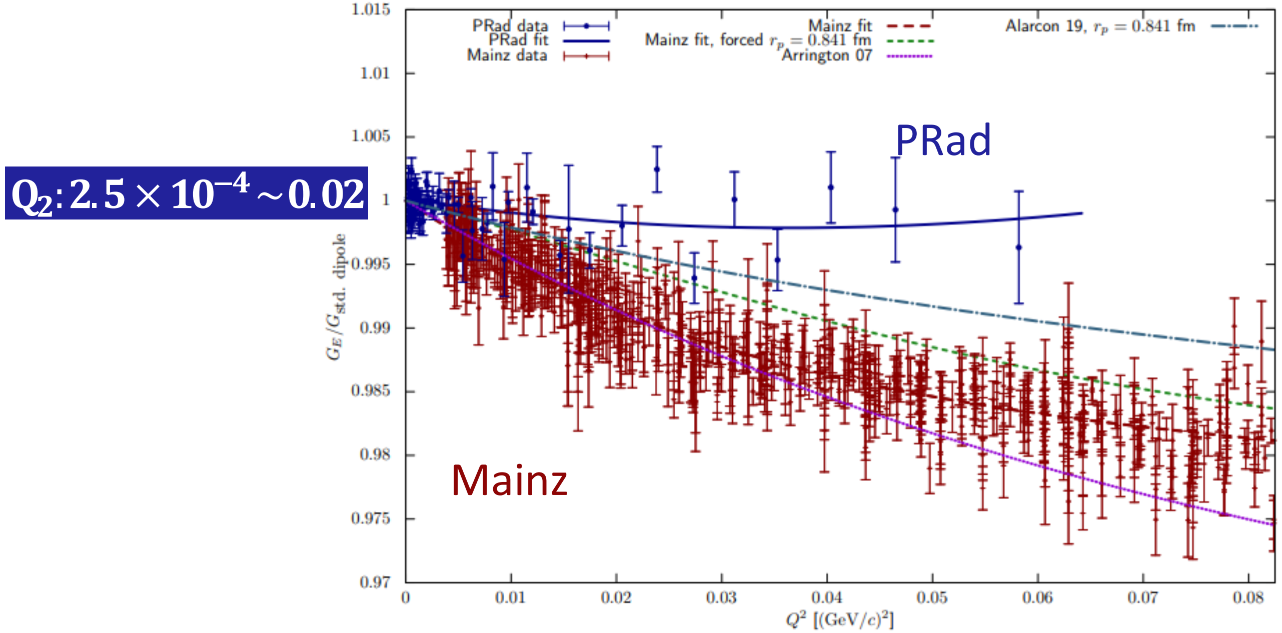
Summary

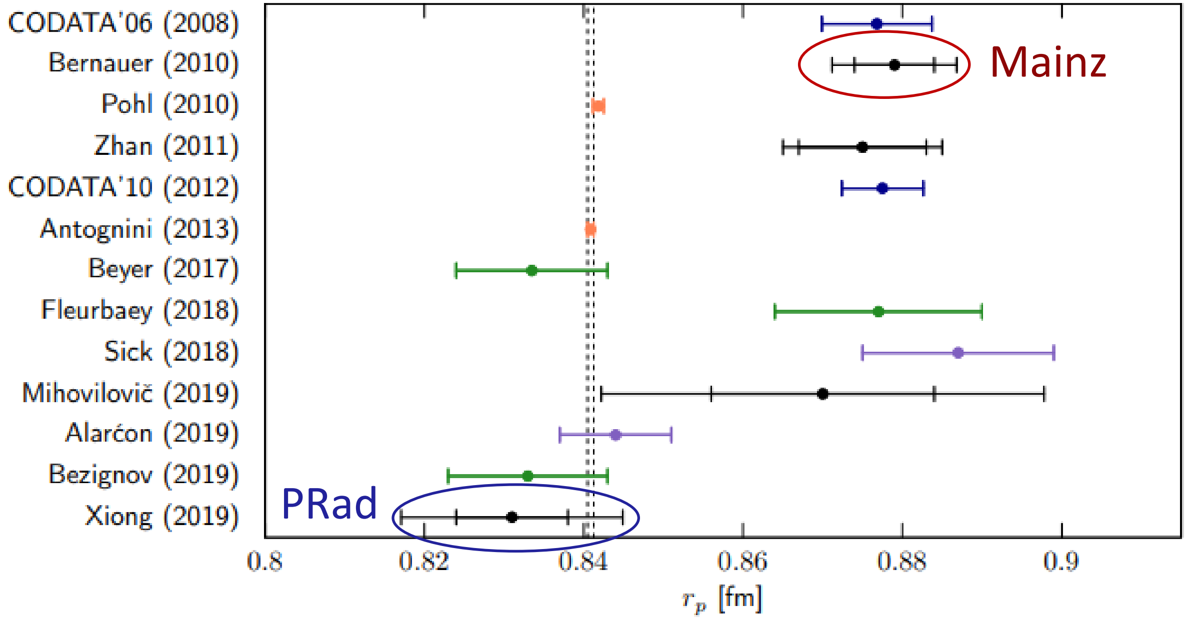
- Surprising theory-experiment discrepancies in both $A_{\perp}^{\vec{e}p}$ and $A_{\perp}^{\vec{e}A}$
- New approach to search new T-odd mechanisms via $A_{\perp}^{p\vec{e}}$ with polarized electron target
- Opportunities at proton machines (HIAF and EicC-pRing)
- Collaborations are more than welcome

Thanks for your attention !

Back up

Physics with $p\vec{e} \to pe$ – proton radius puzzle



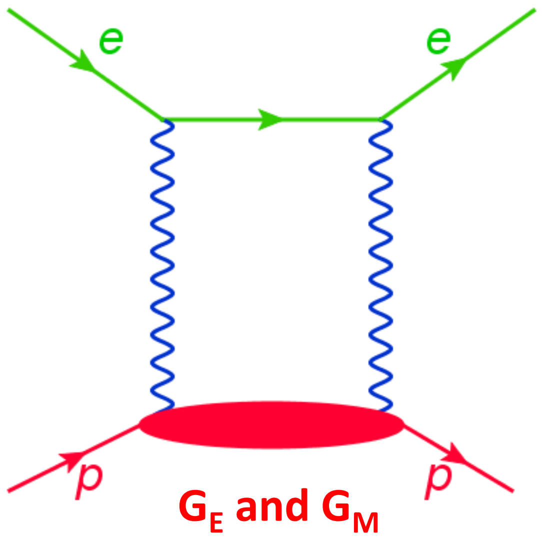


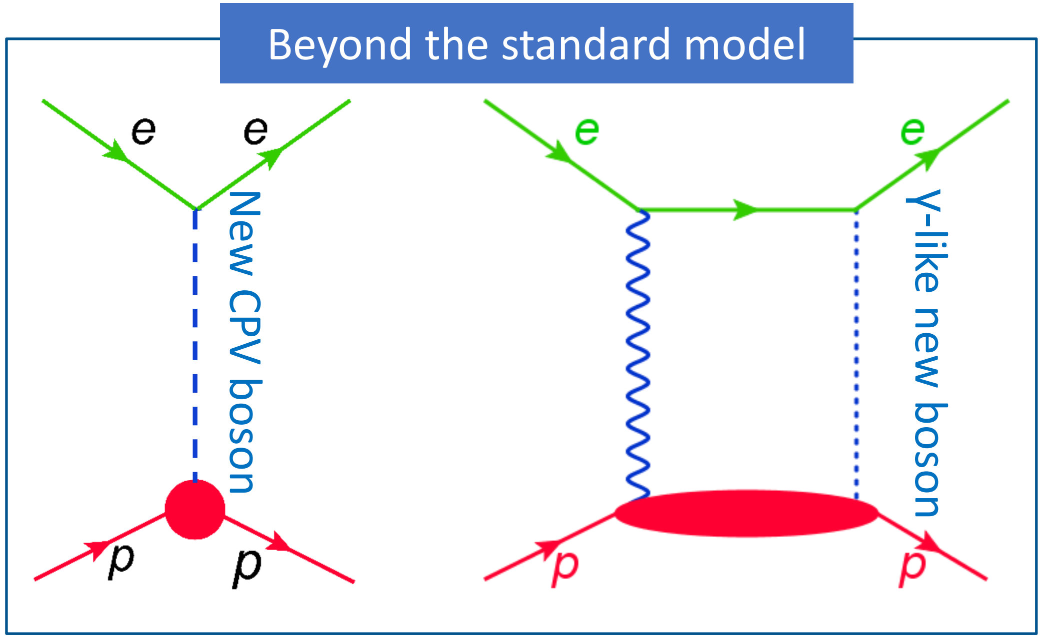
- Proton electromatic form factors (G_E, G_M) measured in ep elastic scattering
- Proton charge radius (r_p) extracted from G_E

$$r_p = -6 \frac{dG_E}{dQ^2}\bigg|_{Q^2 \to 0}$$

- **r_p (G_E) from PRad is different from previous measurements**

Physics with $p\vec{e} \rightarrow pe$ – proton radius puzzle





- ➢ $A_\perp$ only sensitive to **G_E and G_M** → **New approach to study proton EM radius**
- ➢ Possible to distinguished PRad and Mainz measurements
- ➢ **New physics** if $A_\perp$ differs significantly from the SM calculation

Physics with $p\vec{e} \to pe$ – proton radius puzzle

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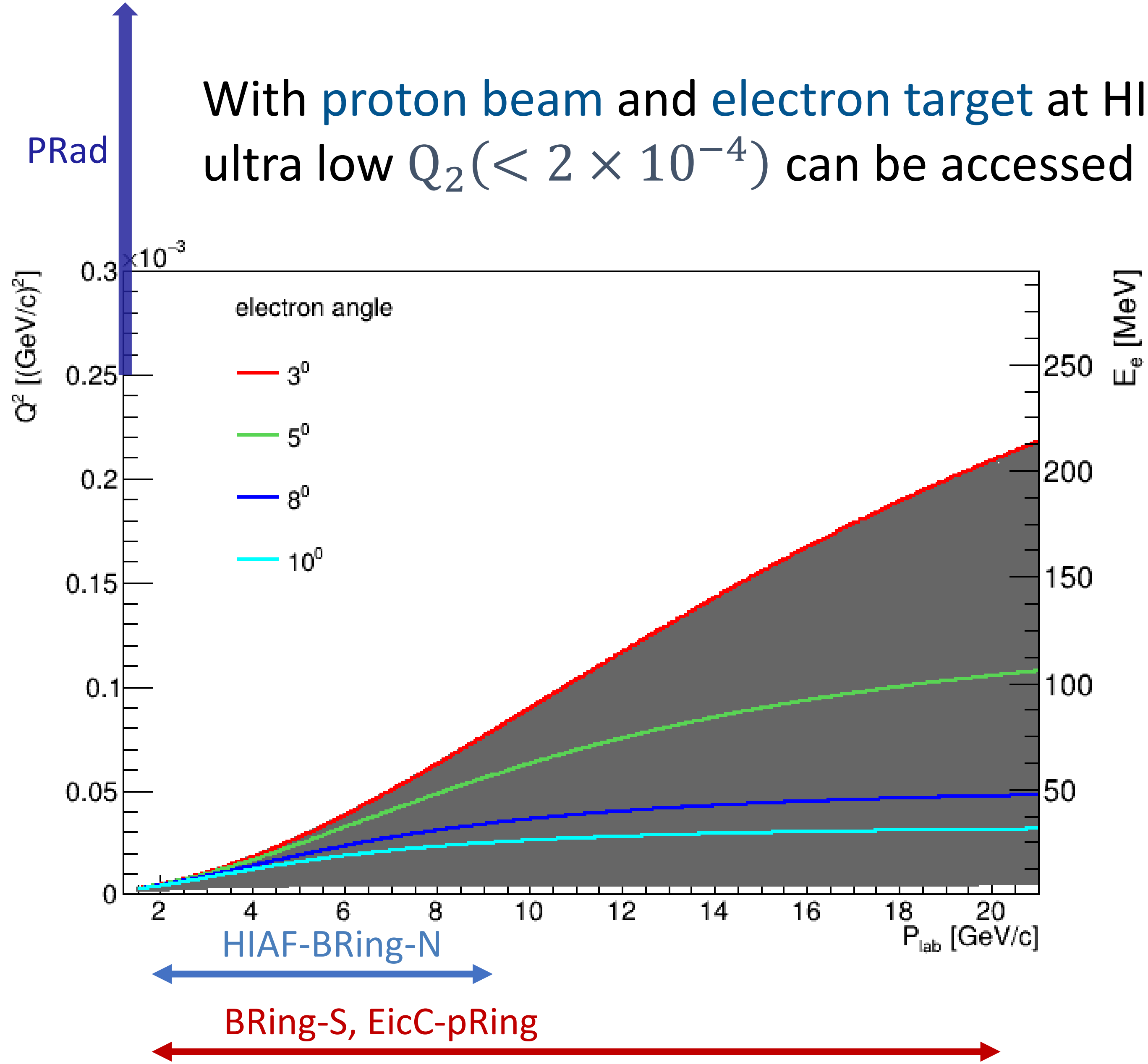

Exp. data vs calculation ($A_{\perp}^{\vec{e}p}$)