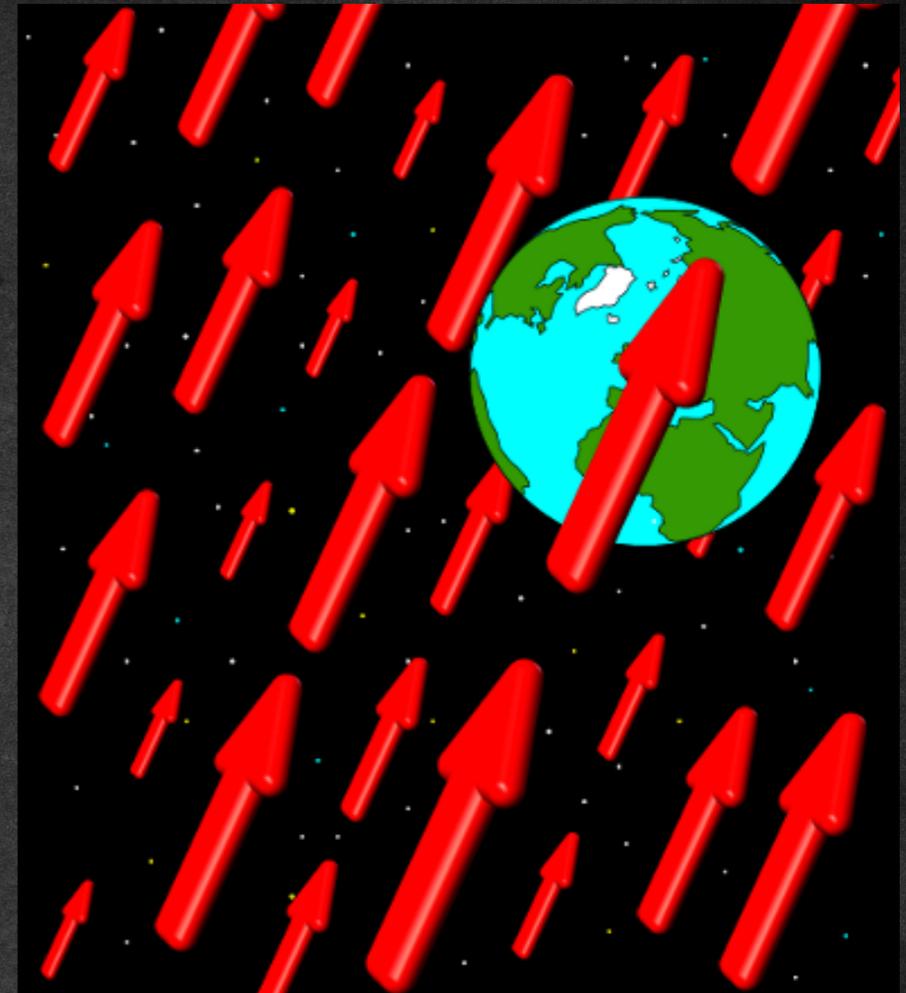


A suggestion for testing
Lorentz violation
in DIS with the
SoLID PVDIS setup



Nathaniel Sherrill

Leibniz University Hannover



Leibniz
Universität
Hannover

in collaboration with

Vladimir Khachatryan

Mississippi State University

Ye Tian

SoLID Collaboration

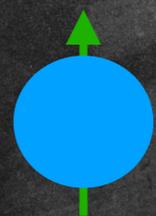
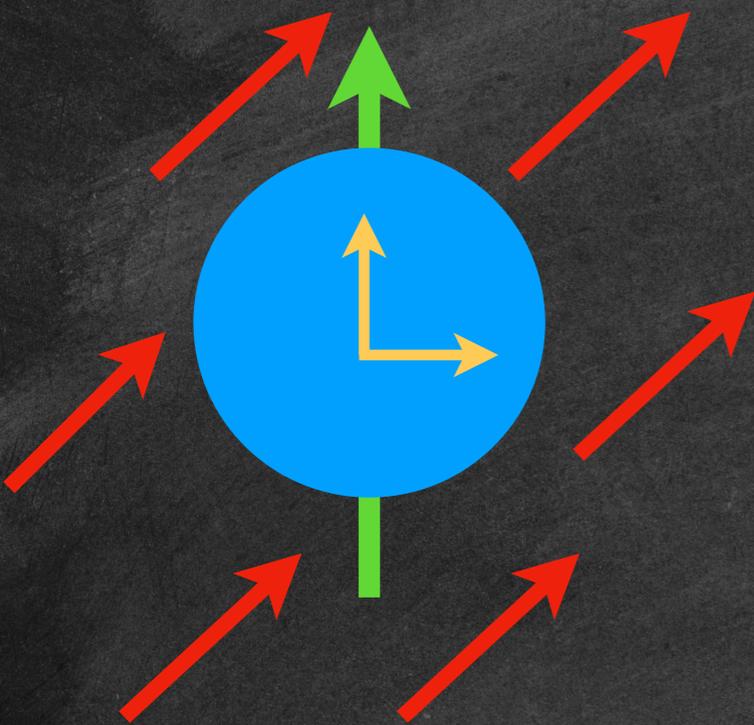


Outline

1. What is **Lorentz violation (LV)**?
2. Describing LV — **effective operators (SME)**
3. Testing **LV and CPT violation** in DIS
4. EIC predictions
5. ZEUS search
6. **Why SoLID? Unique opportunities with PVDIS**
7. **Summary and outlook**

What is Lorentz violation?

Can be visualized as a **background field**



= system/expt.



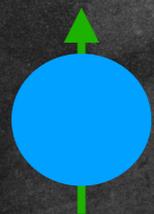
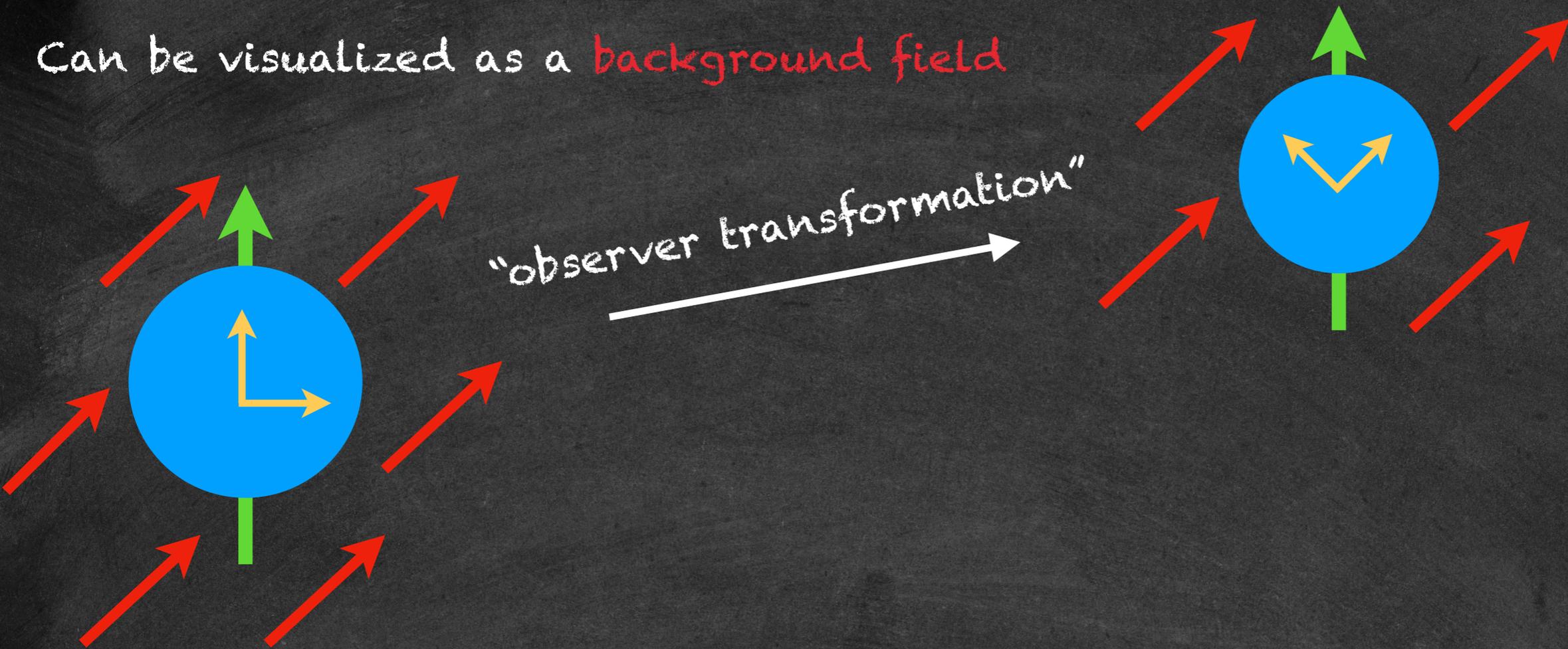
= lab coordinates



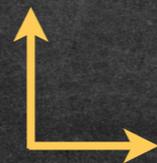
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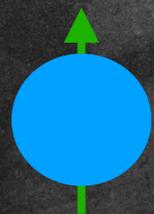
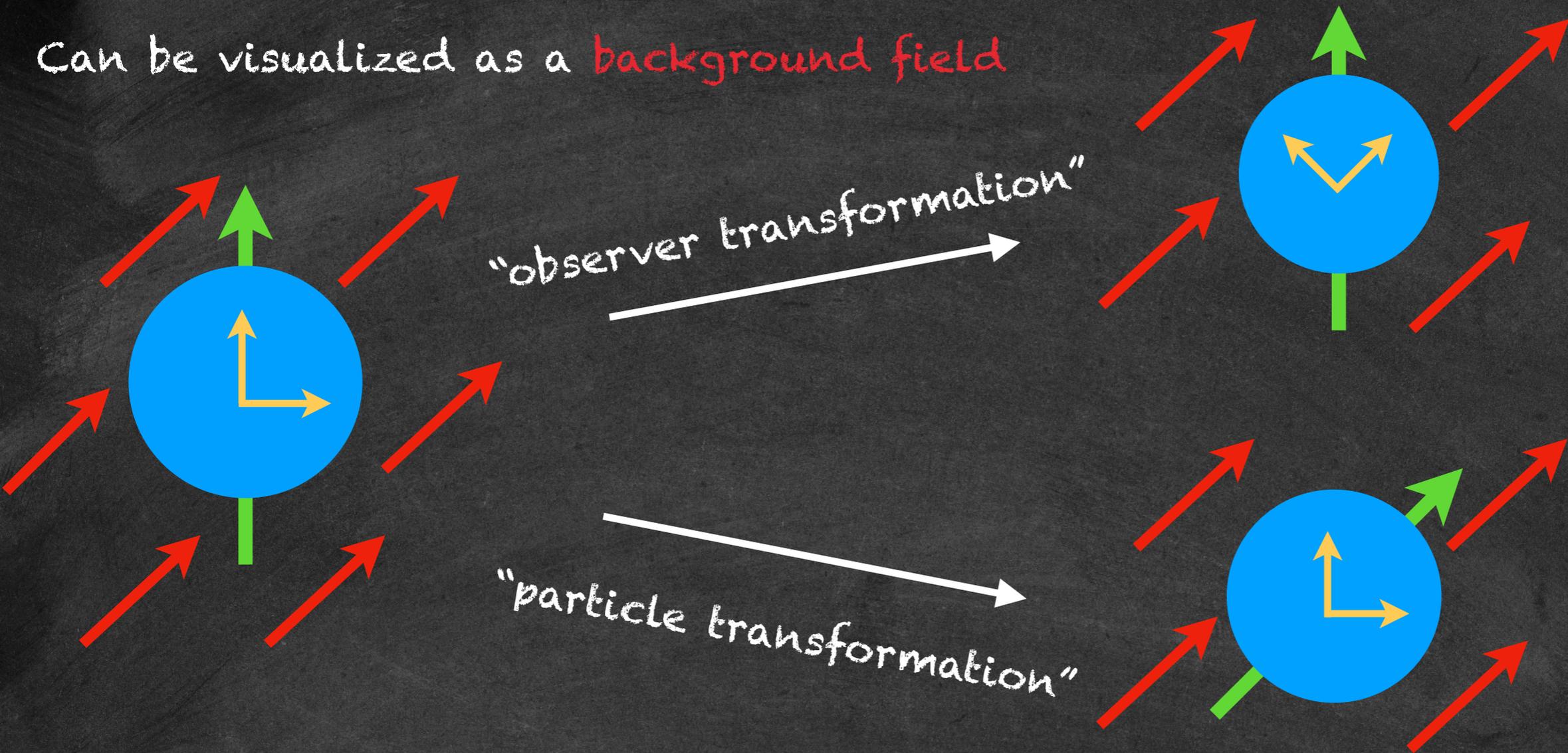
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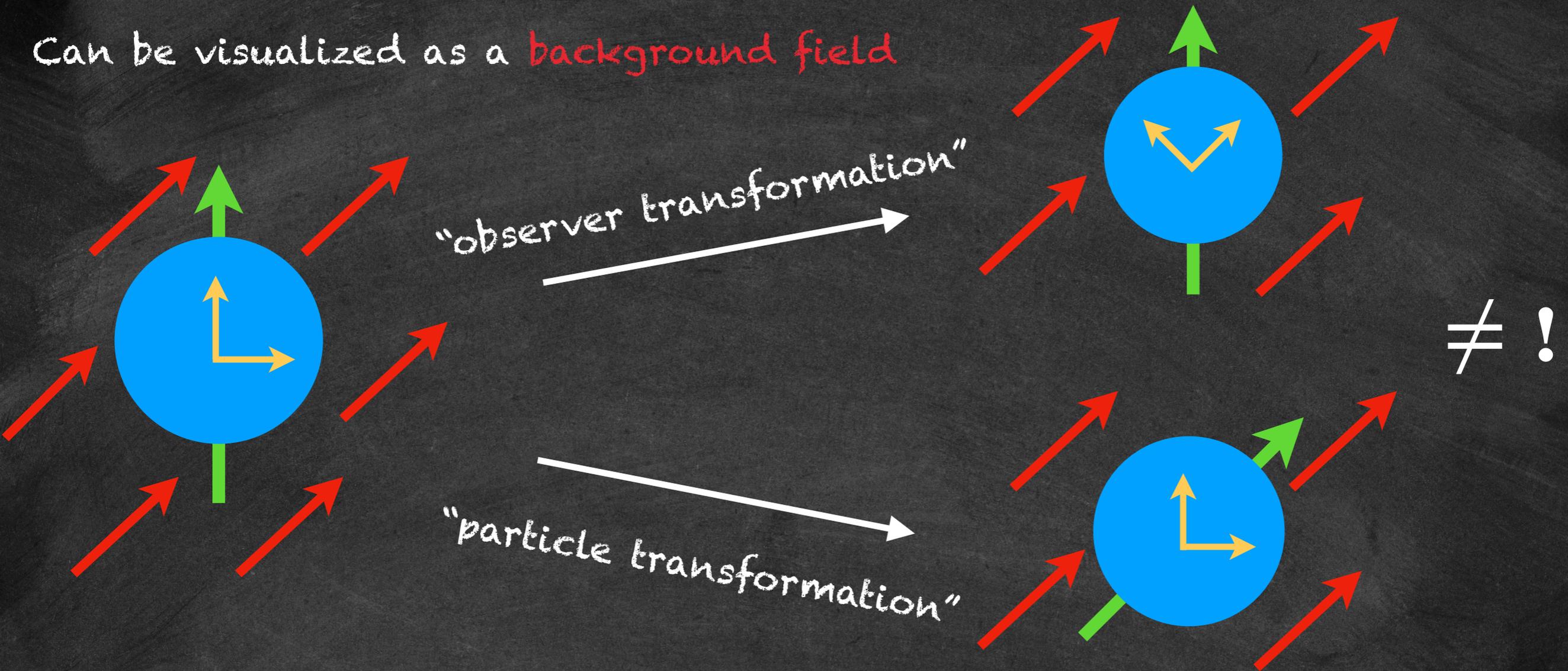
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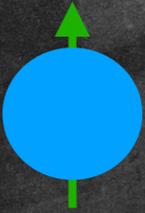


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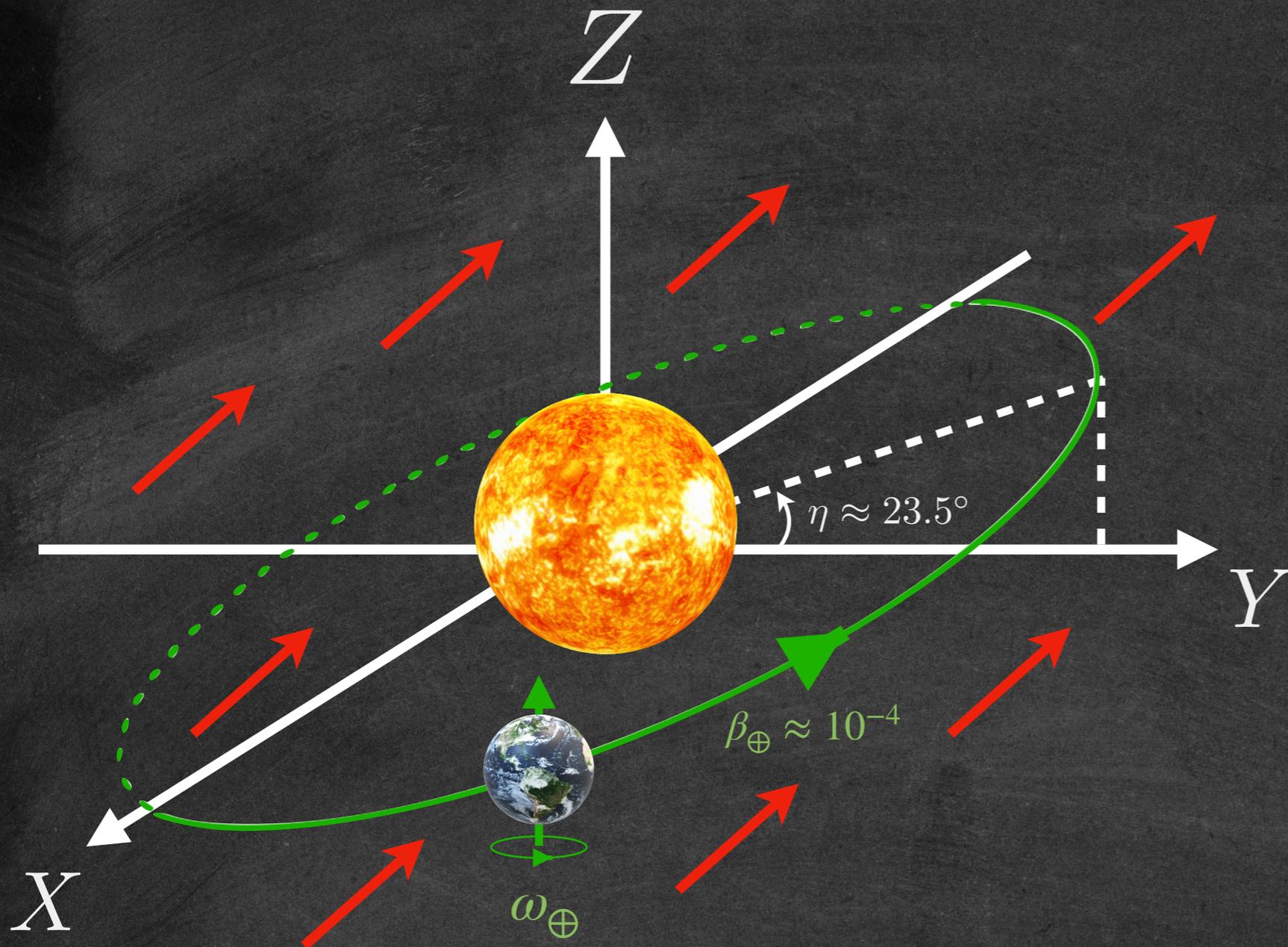
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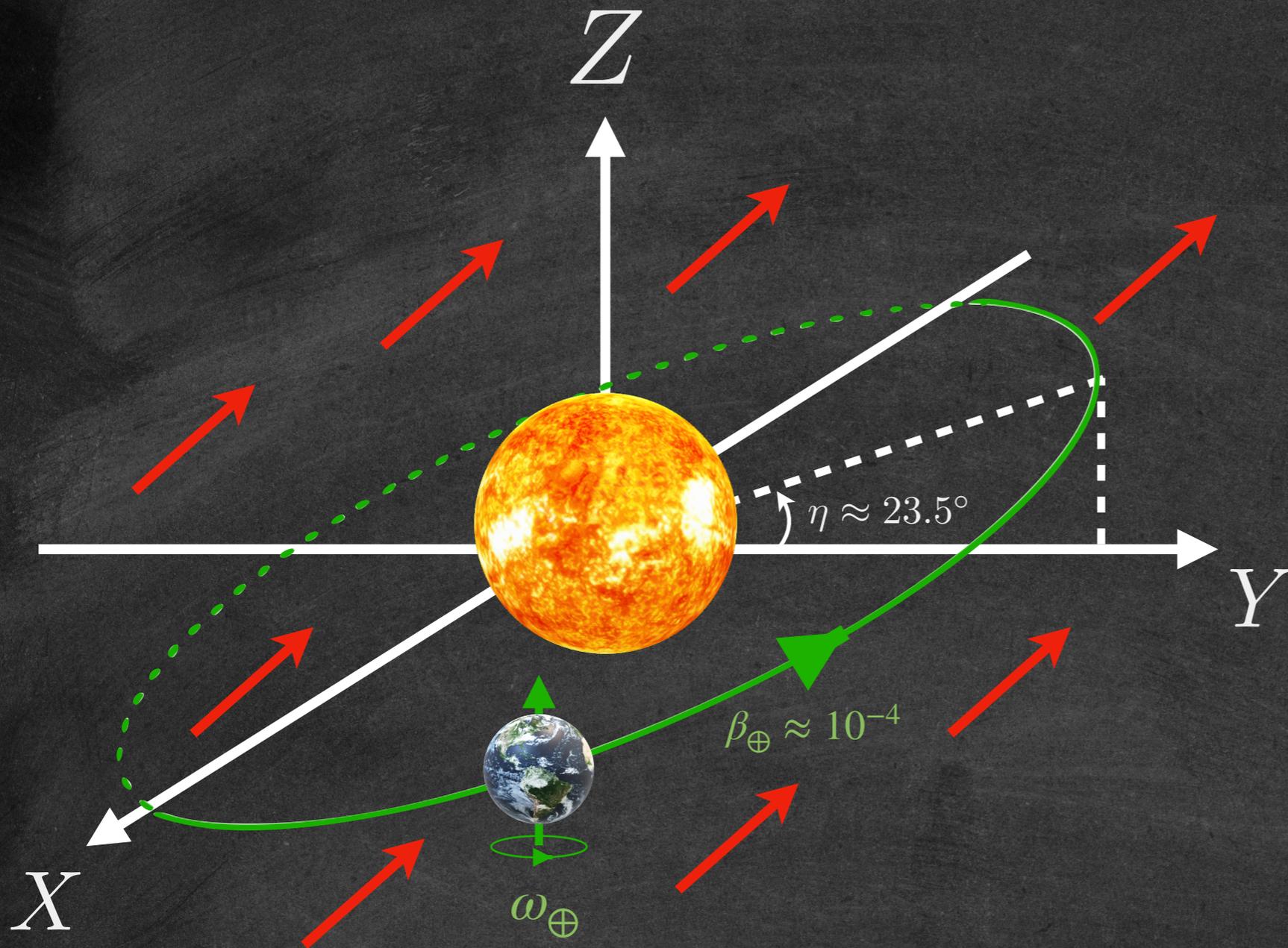


 = system/expt.  = lab coordinates  = \vec{b}

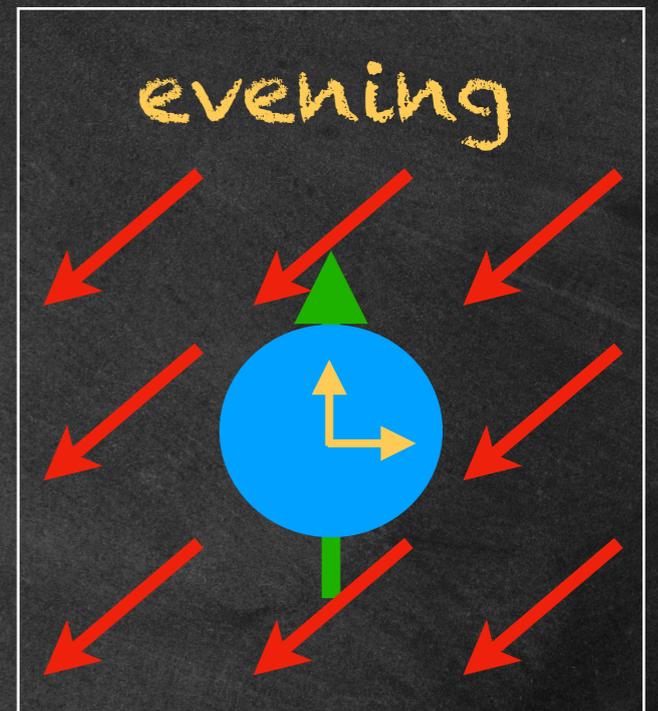
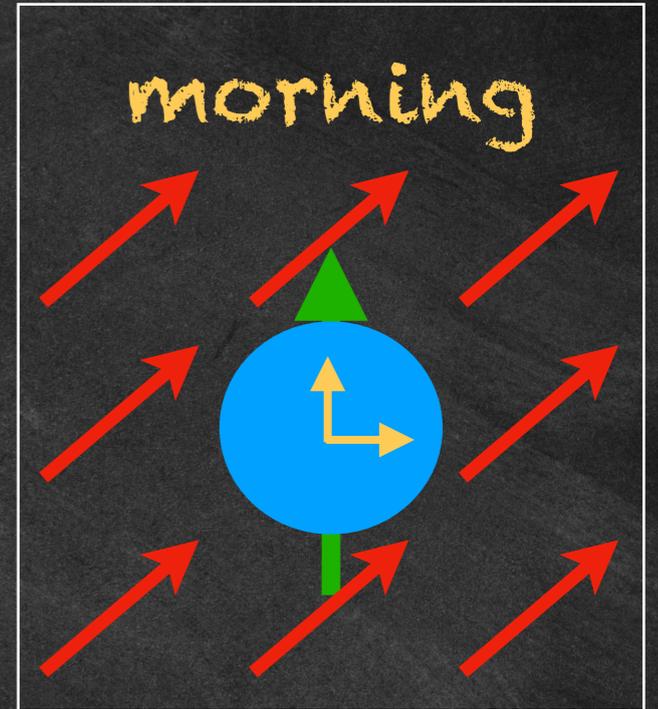
LV induces time-dependent effects



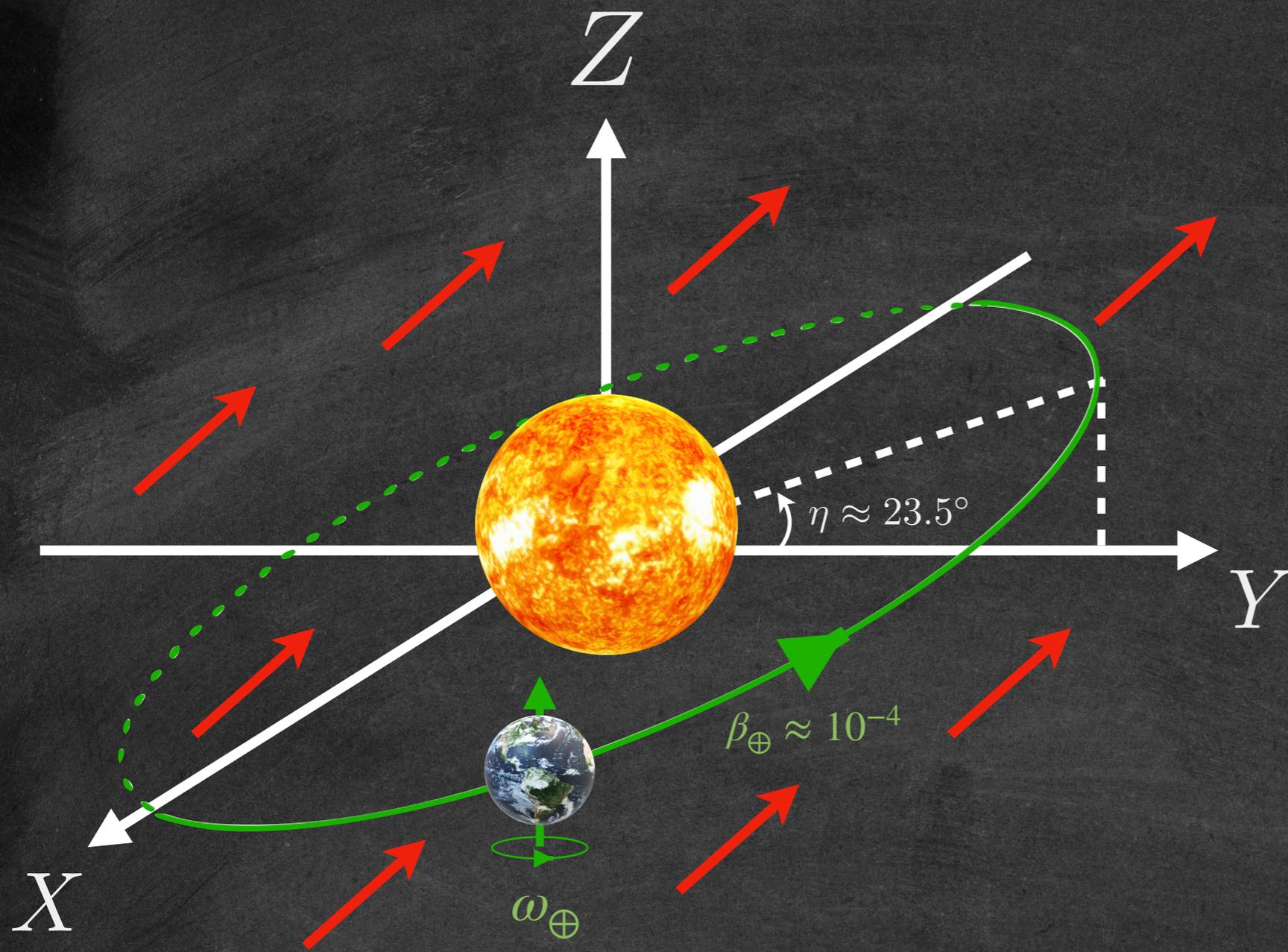
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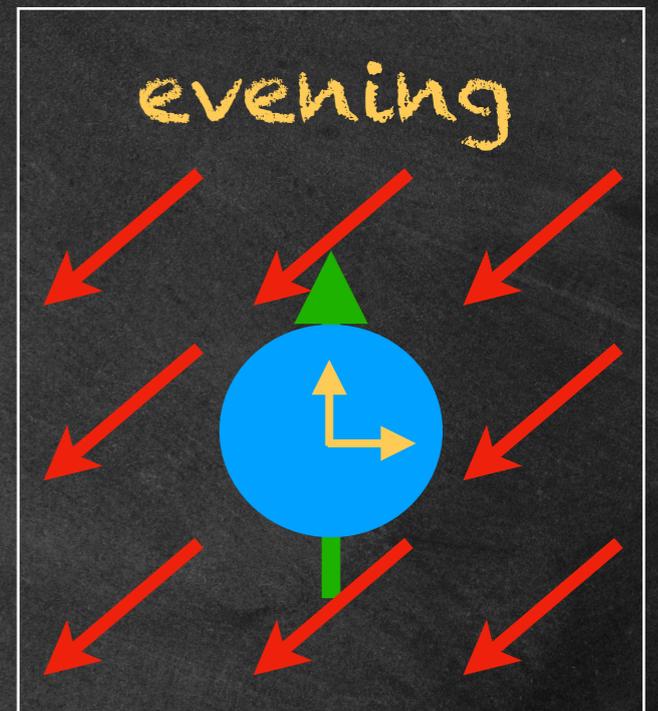
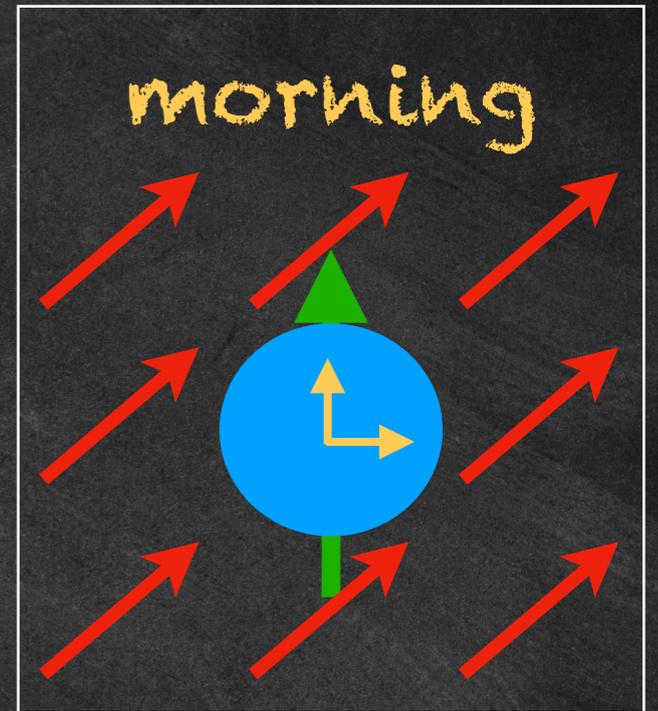
lab frame



LV induces time-dependent effects



lab frame



Observables depend on laboratory parameters

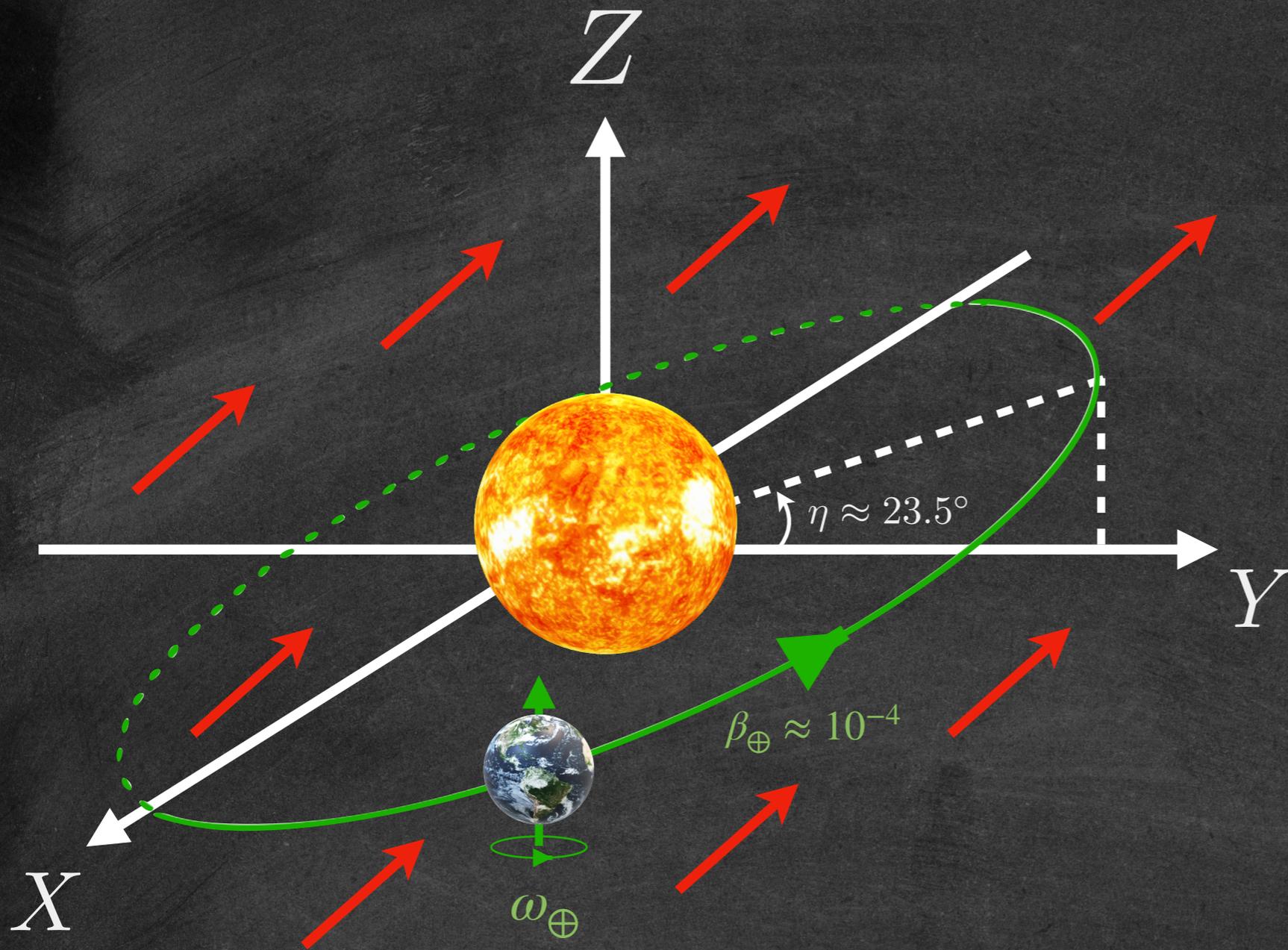
$$\mathcal{O} = \mathcal{O}(\chi, \psi, \omega_\oplus T_\oplus)$$

T_\oplus = measurement time

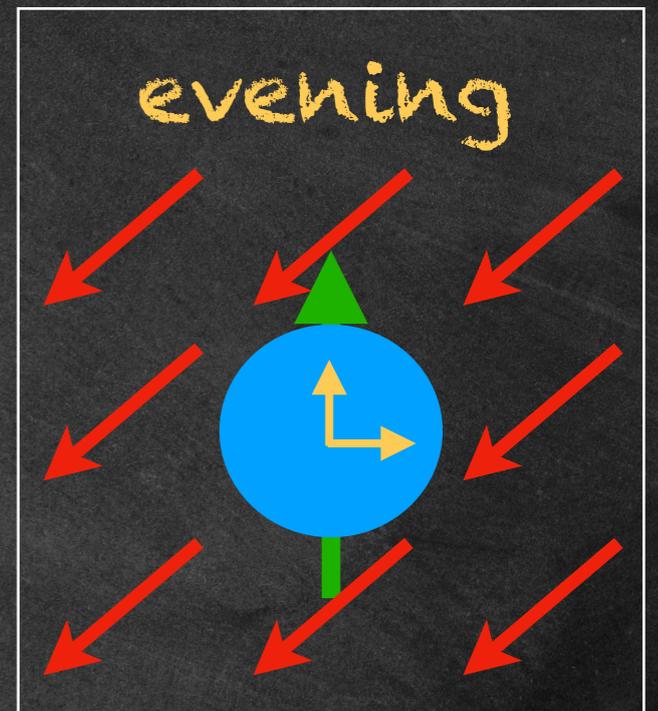
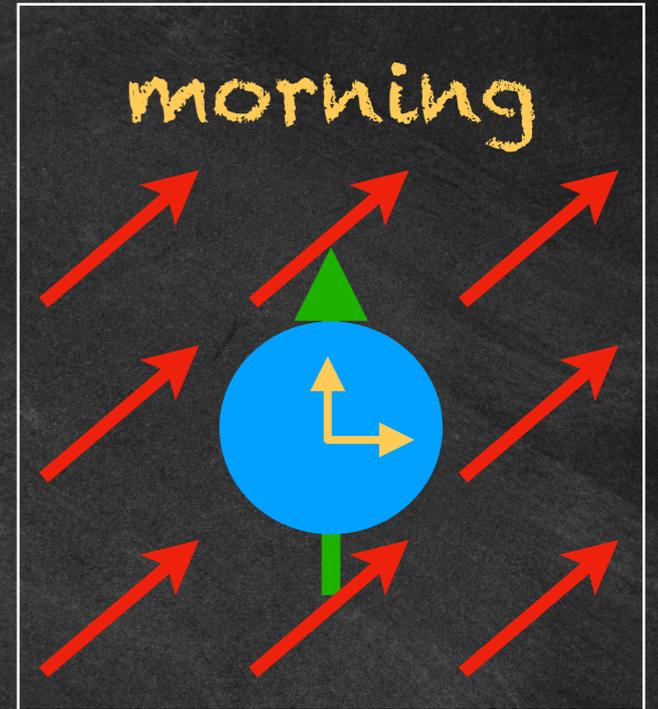
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LV induces time-dependent effects



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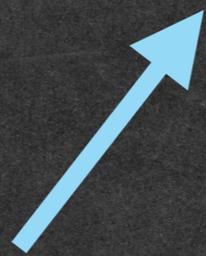
(record event times!)

Effective theory description

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LV extension of SM

[D. Colladay, V. A. Kostelecky,
PRD 55, 6760 \(1997\);
PRD 58, 116002 \(1998\)](#)

$$\text{SME} = \text{SM} + \text{LV}$$

Testing **LV** — deep inelastic scattering (DIS)

Potential LV effects on *quarks* are difficult to access

QCD confinement

Large momentum transfer Q^2

- * asymptotic freedom
- * hadronic factorization
- * perturbative predictions

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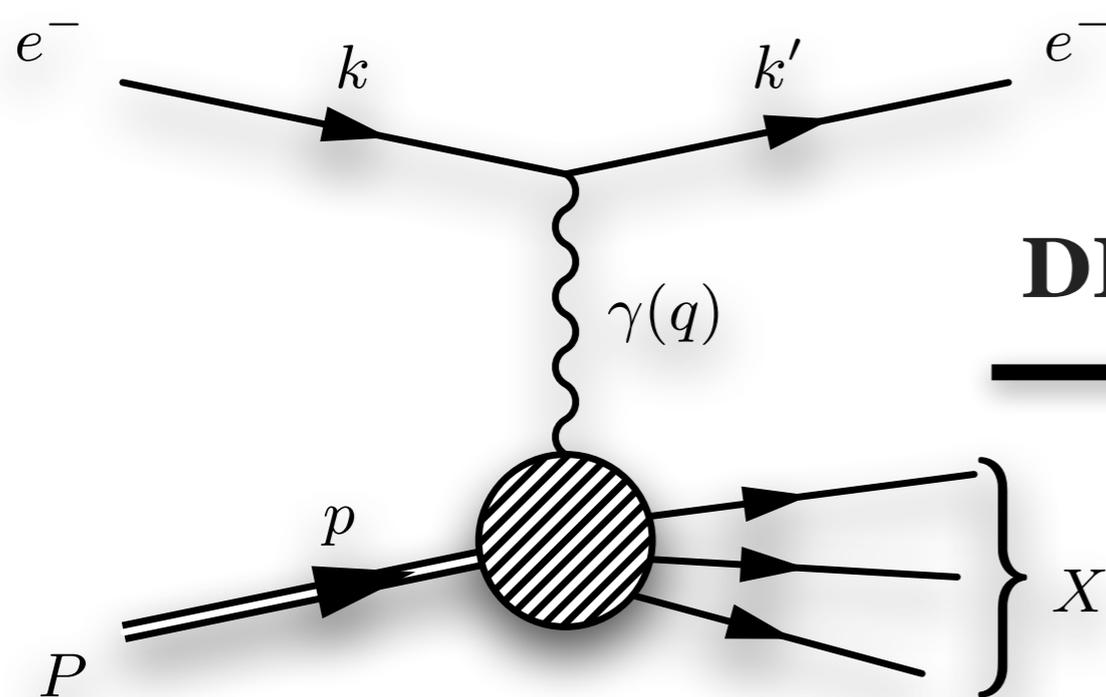
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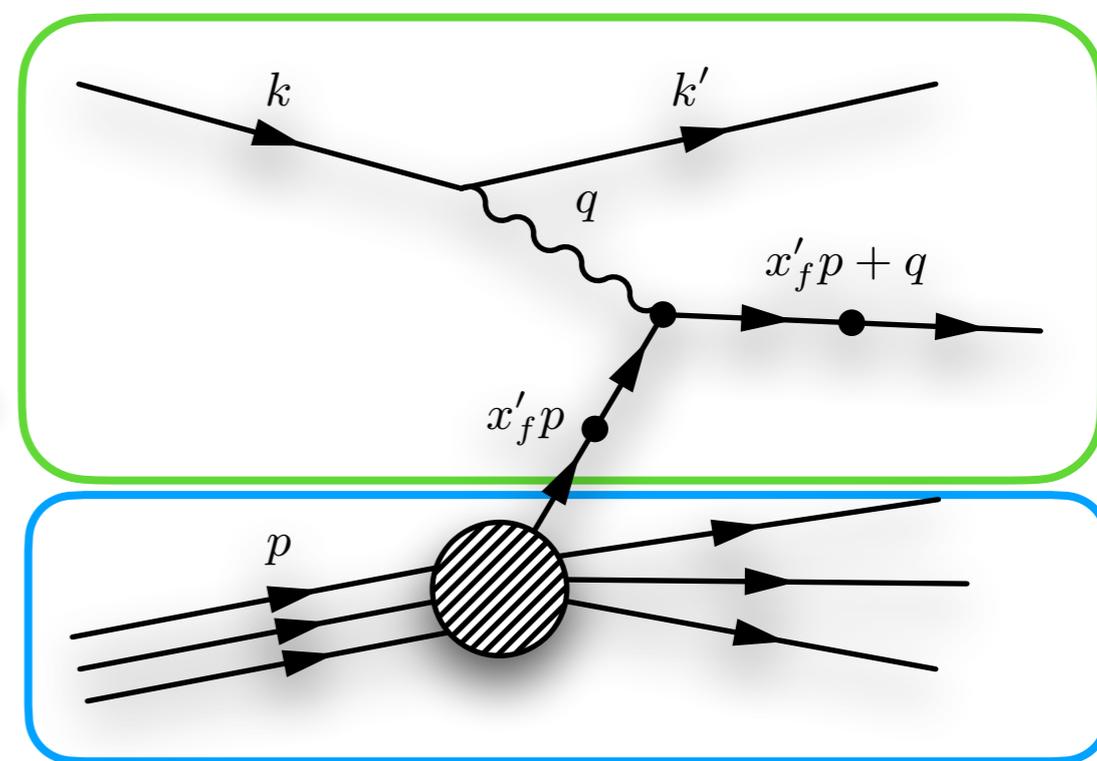
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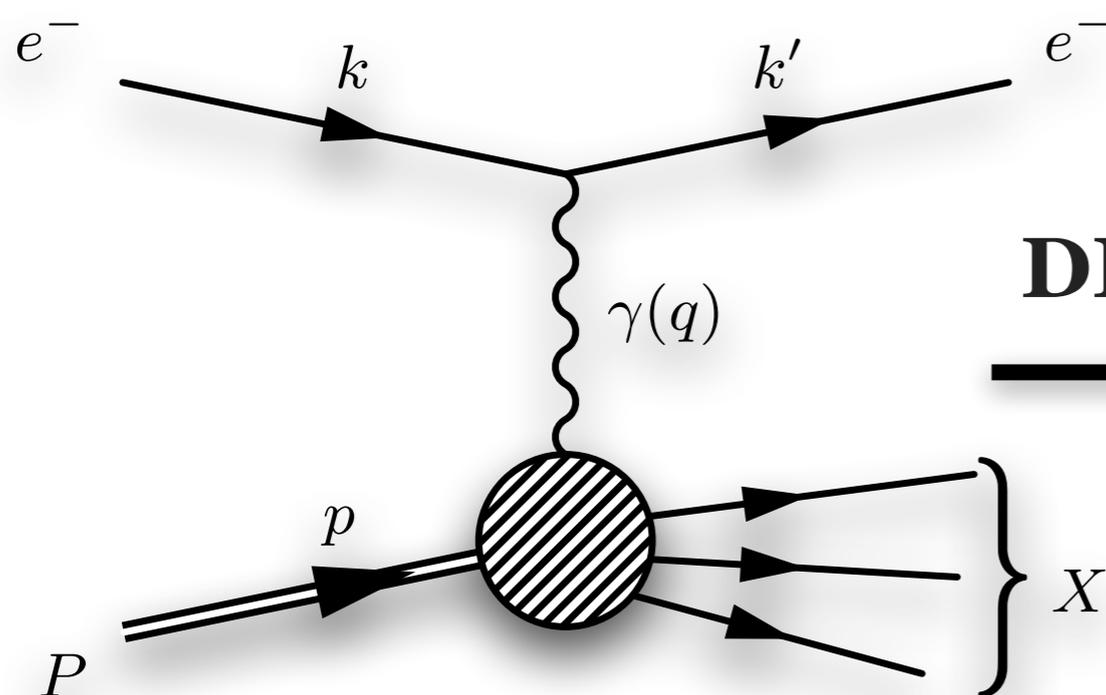
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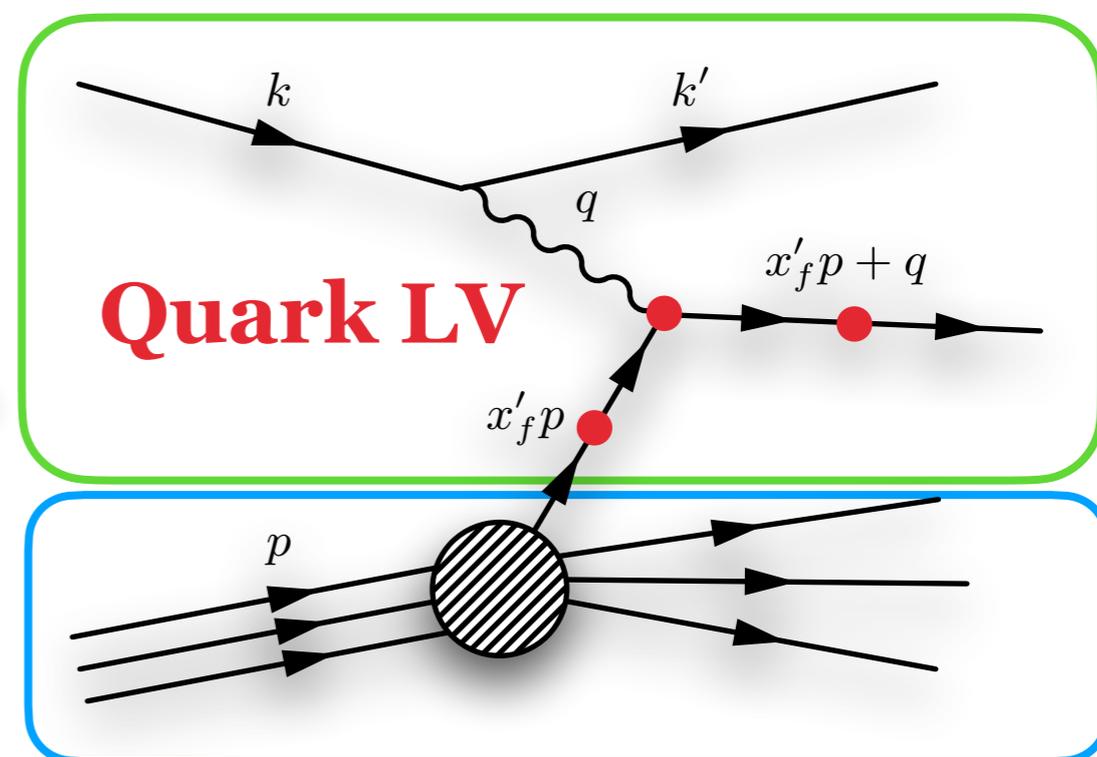
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Class of quark-level effects

$$\mathcal{L}_q \supset \frac{1}{2} \bar{q} \left(\gamma^\mu i D_\mu + \widehat{Q} \right) q$$

Theory literature

- 1) [V. A. Kostelecký, E. Lunghi, A. R. Vieira, PLB 769, 272 \(2017\)](#)
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- 4) [E. Lunghi, NS, A. Szczepaniak, A. R. Vieira, JHEP 04, 228 \(2021\)](#)
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$$\begin{aligned} \frac{1}{2} \bar{q} \widehat{\mathcal{Q}} q \supset & -a^\mu \bar{q} \gamma_\mu q - b^\mu \bar{q} \gamma_5 \gamma_\mu q + \dots & \text{CPT odd} \\ & + c^{\mu\nu} \bar{q} \gamma_\mu iD_\nu q + d^{\mu\nu} \bar{q} \gamma_5 \gamma_\mu iD_\nu q + \dots & \text{CPT even} \\ & - a^{(5)\mu\alpha\beta} \bar{q} \gamma_\mu iD_{(\alpha} iD_{\beta)} q + \dots & \text{CPT odd} \\ & + \dots & \vdots \end{aligned}$$

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Predictions (hadronic cross sections)

ZEUS (HERA), ATLAS & CMS (LHC), EIC (Brookhaven)

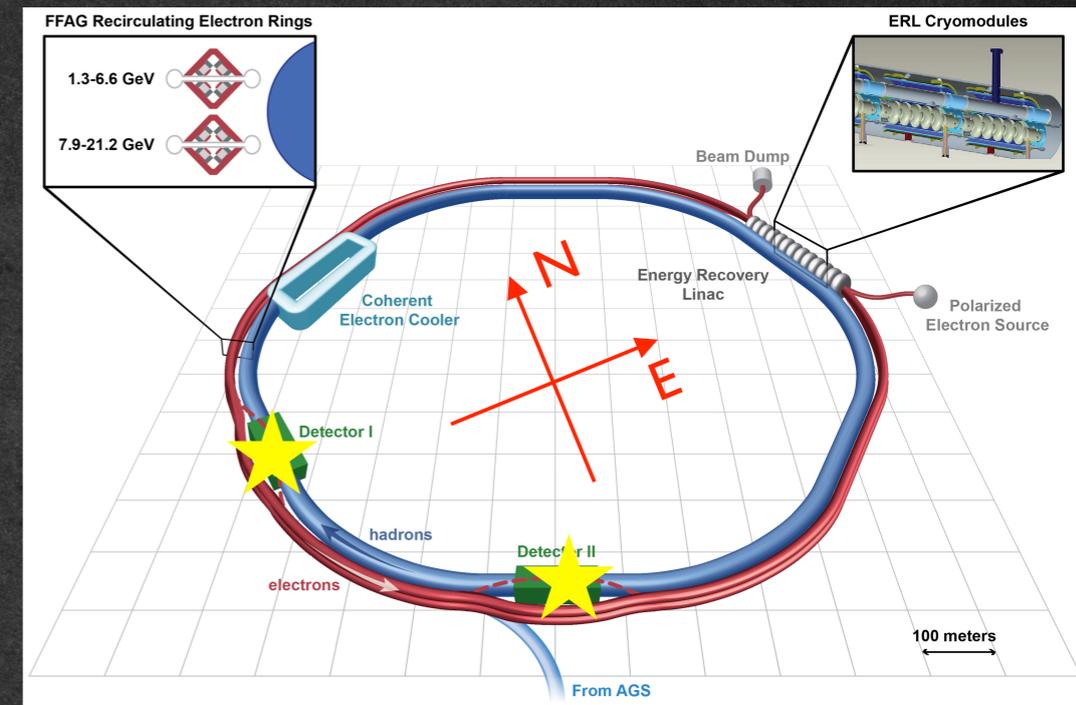
EIC predictions

[E. Lunghi, NS, PRD 98, 115018 \(2018\)](#)

Observable = unpolarized cross section

- * focus on $c_q^{\alpha\beta}$ coefficients
- * sidereal oscillations free SM background
- * investigated sensitivity to EIC phase space

$$\sigma \approx \sigma_{\text{SM}} [1 + c_q^{\alpha\beta} f_{\alpha\beta}(x, Q^2, T_{\oplus})]$$



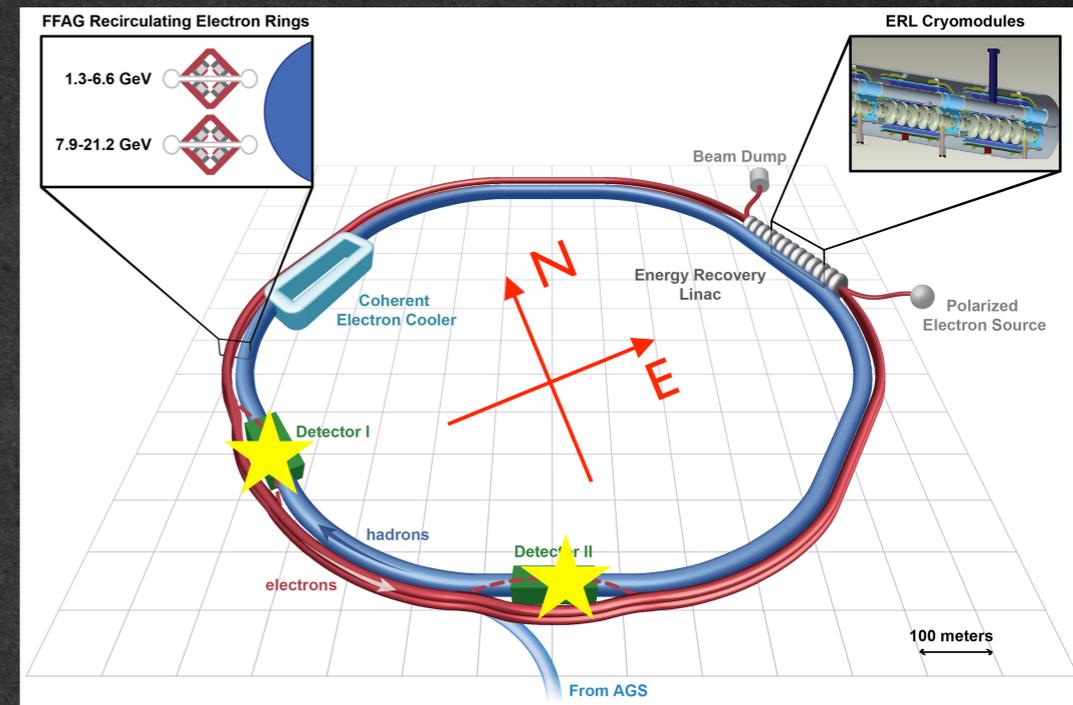
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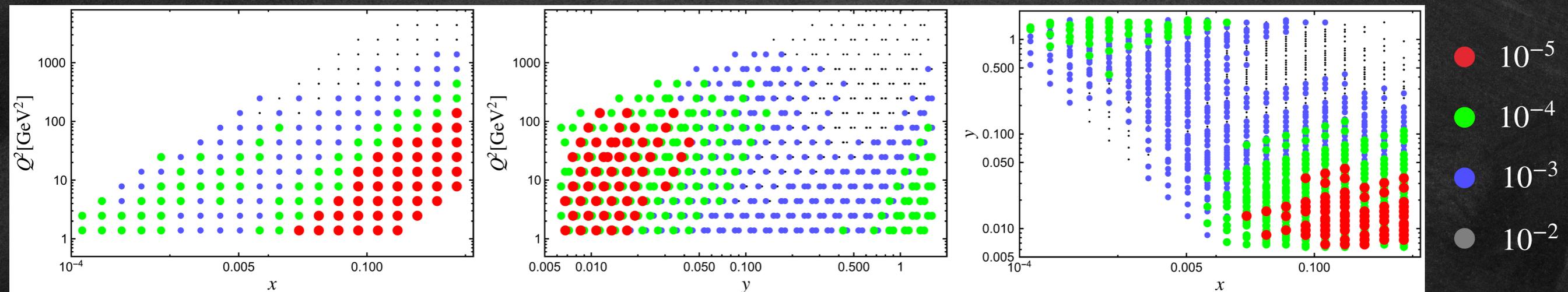
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Example: distribution of best constraints for c_u^{TX}



- * **In general: most sensitivity** at low-moderate Q^2 , low *or* high Bjorken x
- * \simeq 1-2 orders of magnitude more sensitive than early HERA estimates

ZEUS search

[I. Abt et al. \(ZEUS Collaboration\), PRD 107, 092008 \(2023\)](#)

- * 5 years of DIS data (2003-2007)
- * 372 pb^{-1} , 45 million NC DIS events
- * $E_p = 920 \text{ GeV}$, $E_e = 27.5 \text{ GeV}$, $\sqrt{s} = 318 \text{ GeV}$
- * $x \in [8 \times 10^{-5}, 1]$, $Q^2 \in [5, 8800] \text{ GeV}^2$



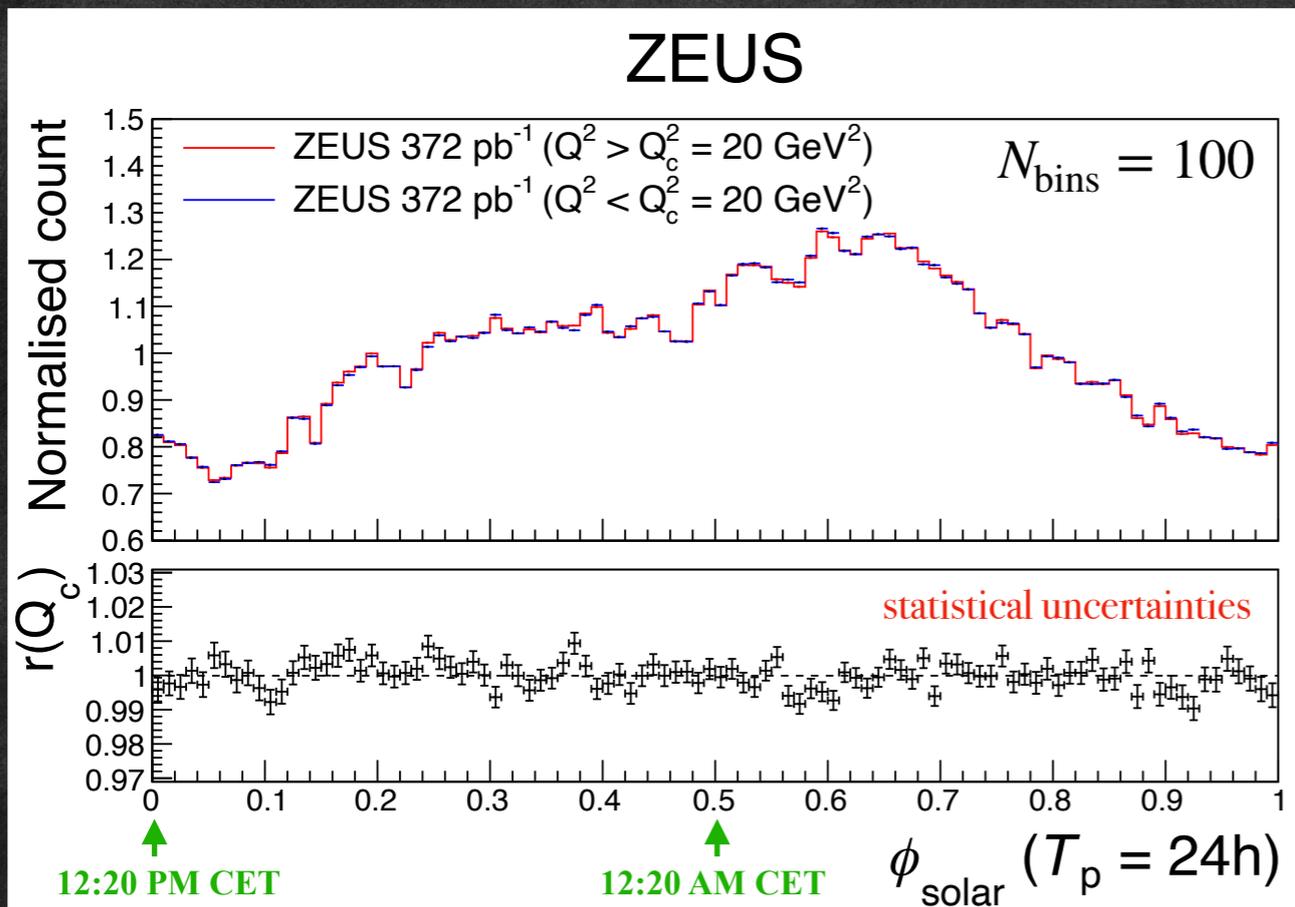
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Large daily variation observed in instantaneous luminosity



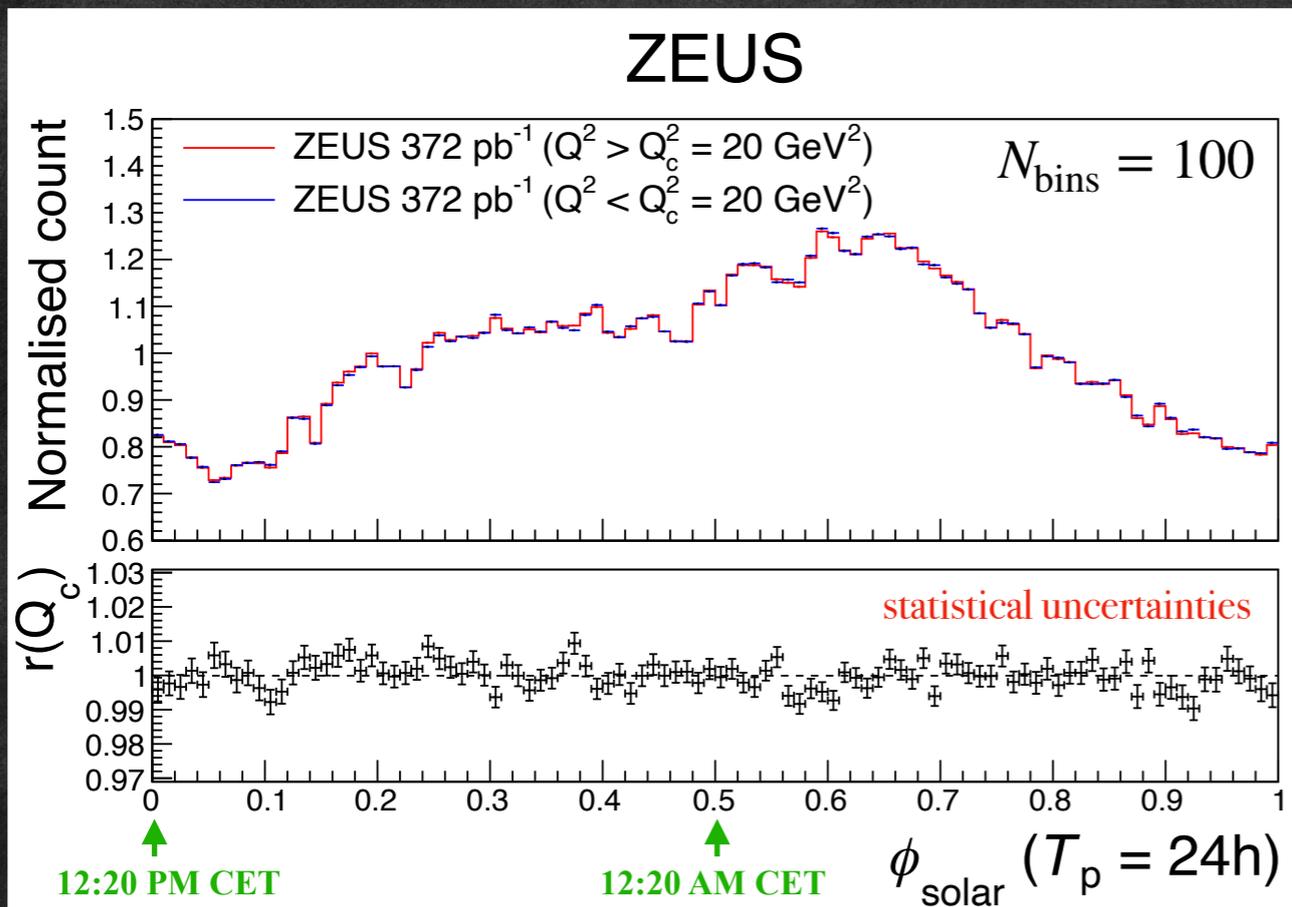
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Large daily variation observed in instantaneous luminosity



\Rightarrow constructed lumi-insensitive double ratio $r(\text{PS}_1, \text{PS}_2)$

No sidereal signals observed within uncertainties

Placed constraints on 42 coefficients for **LV/CPTV**

$$|c_q^{\mu\nu}| \sim 10^{-4} \quad q = u, d, s$$

$$|a_q^{(5)\alpha\mu\nu}| \sim 10^{-6} \text{ GeV}^{-1} \quad q = u, d$$

SoLID Experiment + BSM physics

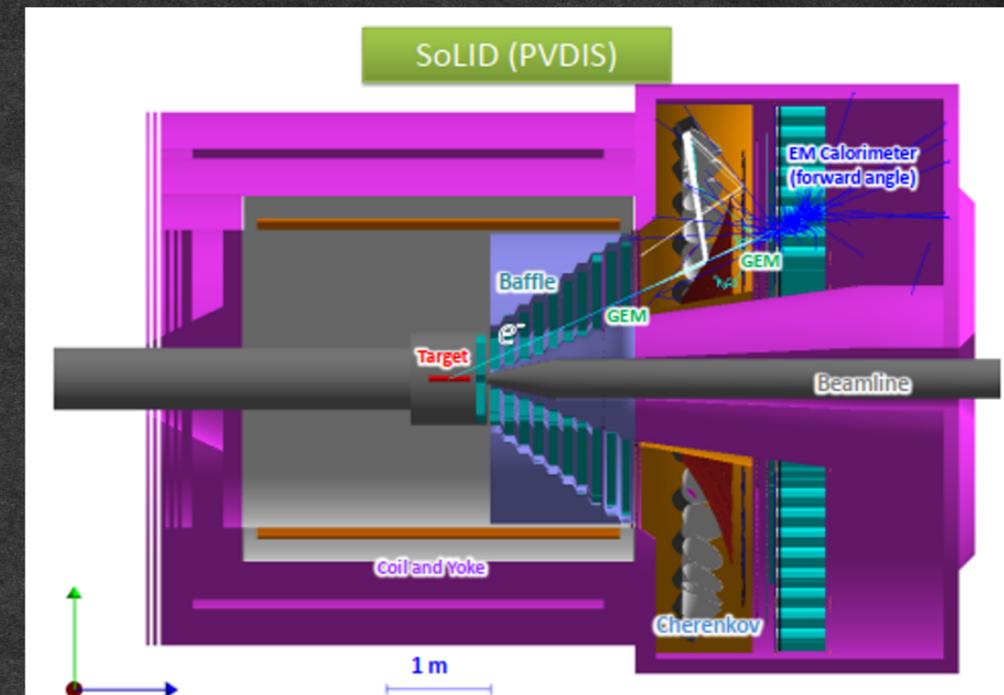
Fixed-target experiment with polarized e^- beam

Large acceptance + luminosity = **high statistics**

⇒ **precision physics**

Large Acceptance
Full azimuthal ϕ coverage

High Luminosity
 $10^{37-39} / \text{cm}^2/\text{s}$
[>100x CLAS12] [>1000x EIC]



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Parity-violating DIS (PVDIS) program

$$A_{PV} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

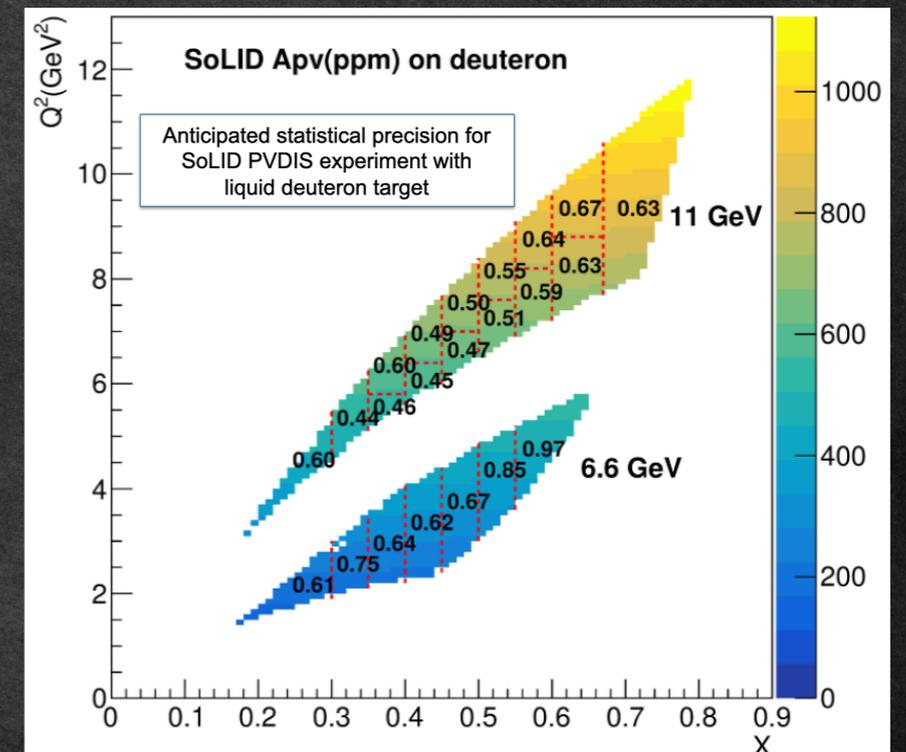
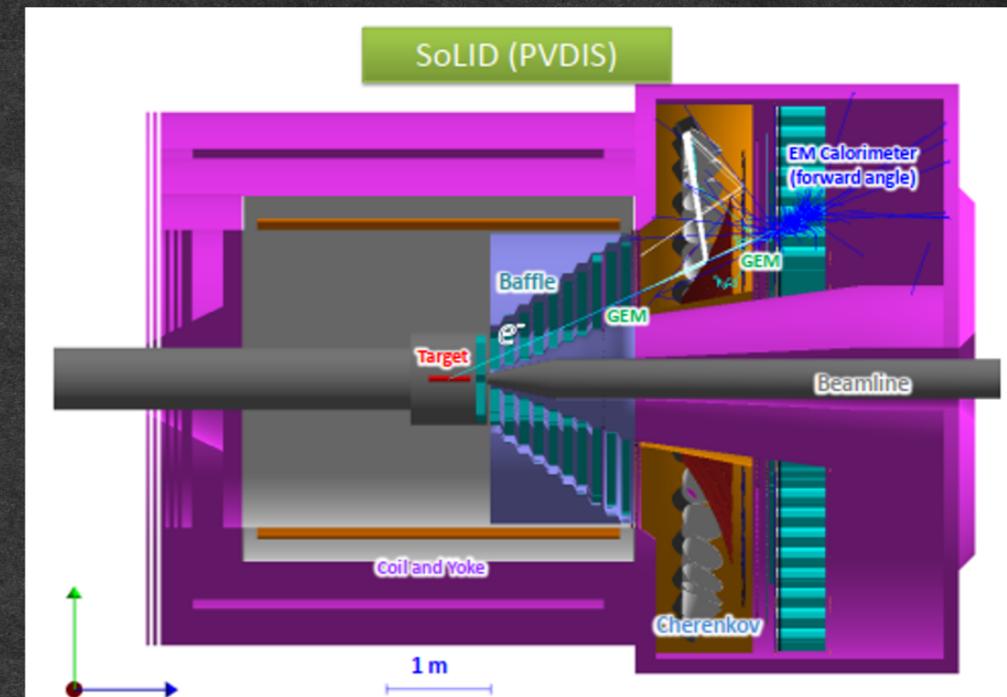
10x improvement over JLab 6 GeV expected

- * determination of EW parameters, e.g. θ_W
- * searches for dark Z bosons/heavy photons, which effectively shift EW vertices

other interesting possibilities?

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Full azimuthal ϕ coverage

High Luminosity
 $10^{37-39} / \text{cm}^2/\text{s}$
[>100x CLAS12] [>1000x EIC]



SoLID for **LV** and **CPTV**?

Can SoLID exceed/complement LV searches at EIC/HERA/LHC?

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Main advantage: *near-term* polarized observables

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* *ongoing* ATLAS Drell-Yan search *also* sensitive, but to fewer coefficients (and sometimes less sensitivity) than in DIS

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2. **probe of high Bjorken x** \Rightarrow optimal for **CPT** tests

* (hopefully) operating years before EIC, while *complementing* low- x region

* high SoLID lumi ($\gtrsim 10^3 L_{\text{EIC}}$) \Rightarrow advantage in statistics

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3. new tests of the gauge sector

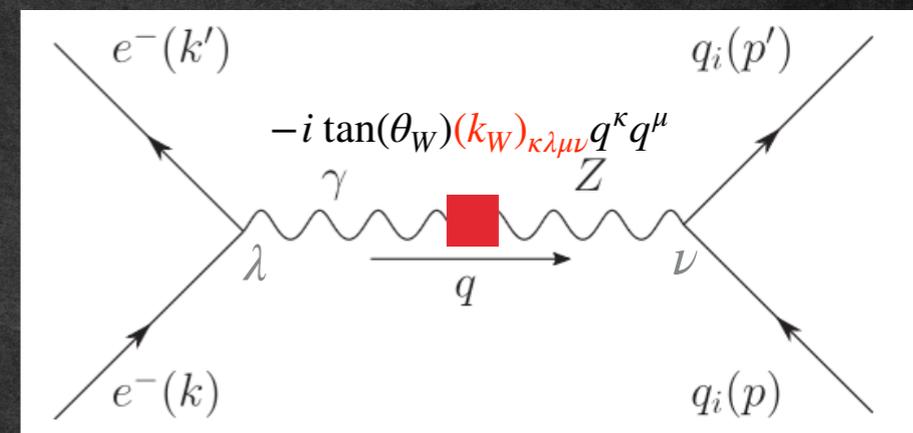
* LV modifies Z^0 exchange, γZ^0 interference

* many coefficients untested

* PV asymmetry binned in time
 \Rightarrow novel sidereal analysis!

$$A_{\text{PV}} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

[A. Michel, M. Sher, PRD 100, 095011 \(2019\)](#)



Note an important quote from JLab PAC 50 report in 2022:

“PAC 37 recommended that the experiment should begin with 169 PAC days out of the 338 PAC days requested in the original proposal. At the present PAC, the collaboration asked for the full amount of 338 PAC days to be allocated. To justify such a change, the committee would need to be presented with sufficient detail, such as projections for the physics reach with 338 versus 169 PAC days. A revision of the beam time allocation may be discussed by a future PAC when the experiment comes closer to its running period.”

- * A new run-group proposal (with projections with 169 and 338 days) added to the main PVDIS experiment E12-10-007 may be helpful in this regard, enriching physics scope and output
- * Let us assume that a proposal on measurements of Lorentz violation in DIS with SoLID can be actually made as a run-group proposal to the PVDIS setup by also using requested beam times

Summary and outlook

Basic concepts surrounding **LV/CPTV** introduced

Discussed predictions for DIS at EIC and HERA

ZEUS analysis serves as baseline for future searches

SoLID can provide unprecedented precision at JLab kinematics, while being complementary to the EIC

After comments from the Collaboration, we may prepare a LOI for this PAC: already working on this!

Backup

ZEUS search

I. Abt et al. (ZEUS Collaboration), PRD 107, 092008 (2023)

