# Electroweak correction to parity violating ep scattering

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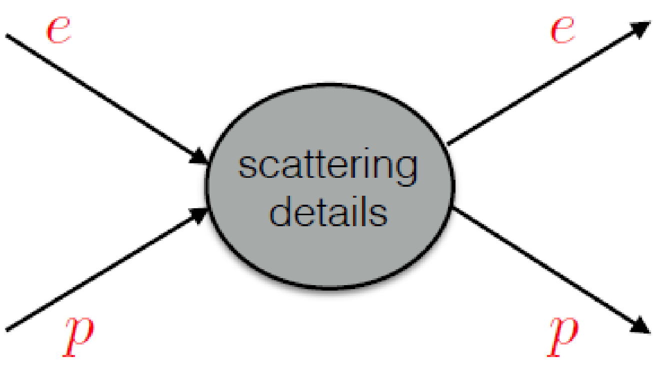
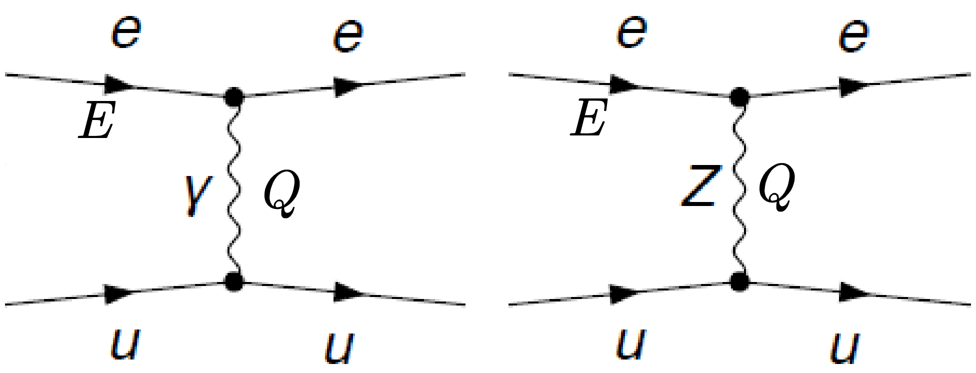
# Experimental Background

$$Q_w^p = 1 - 4\sin^2\theta_w \approx 0.07$$

An important standard model parameter

- Accidentally suppressed
- Sensitive to possible (SM, BSM) corrections




- PV ep scattering process
- Tree level diagram

Left-right hand asymmetry: $A^{PV} = \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L}$

Extract $Q_W^p$ through the ratio to tree level amplitude: $Q_W^p = \lim_{E \to 0} \lim_{Q^2 \to 0} \frac{A^{PV}}{A_0}$

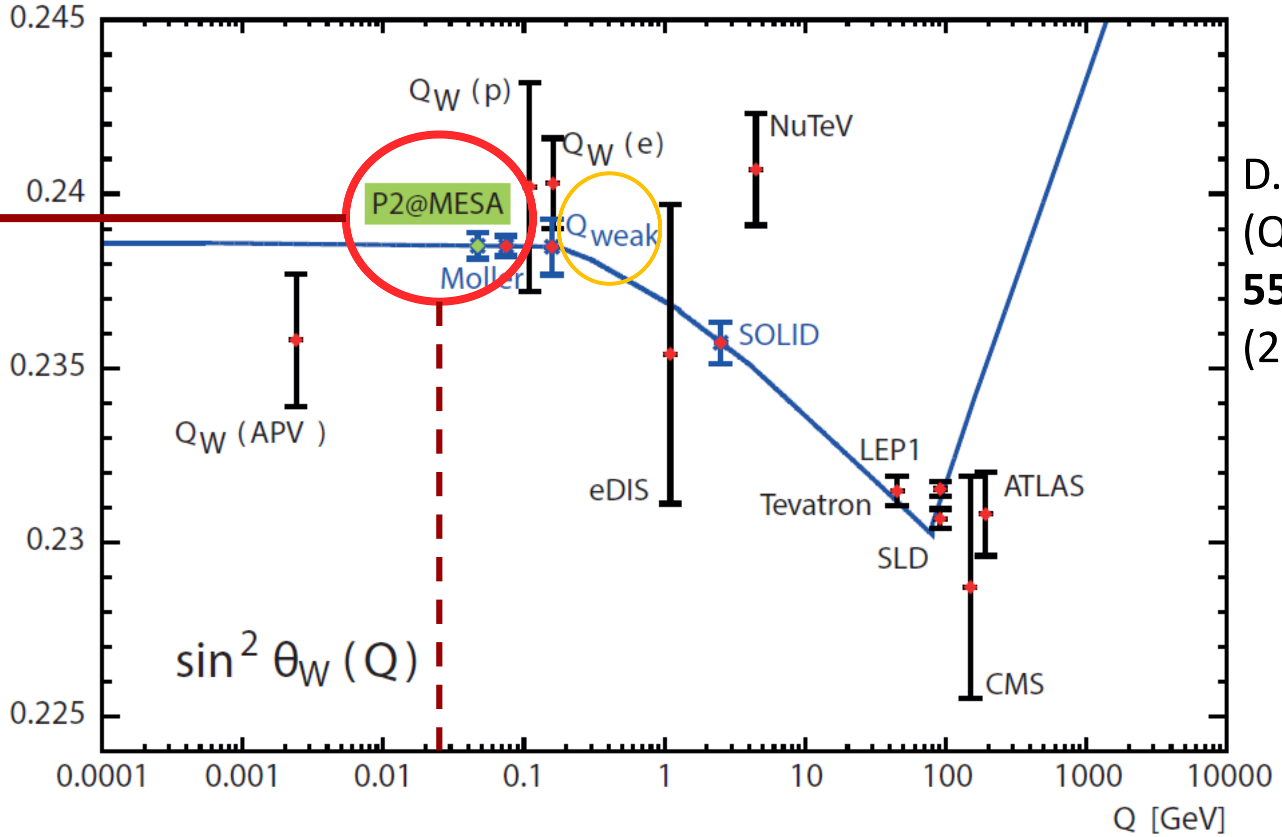
# Experimental Background

Ongoing P2 experiment at Mainz[1] is targeting at precise measurement of $Q_W^p$

[1]D.Becker *et al* , *EPJA* , **54**, 208 (2018)

Electron energy $E < 155 MeV$

**Low energies !**




D. Androic et al. (Qweak), *Nature* **557**, 207–211 (2018).

Low momentum transfer $Q^2 < 0.0045 GeV^2$

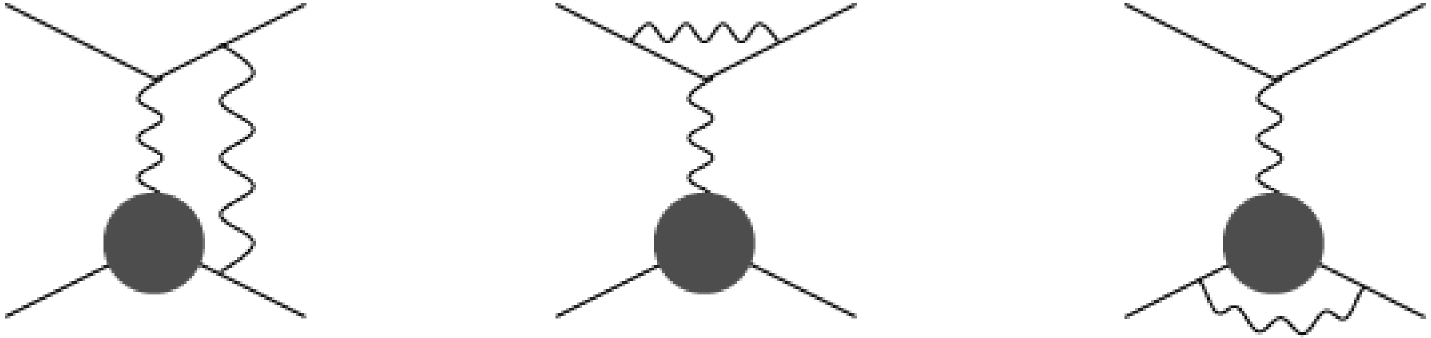
**Near forward scattering !**

# Theoretical Background

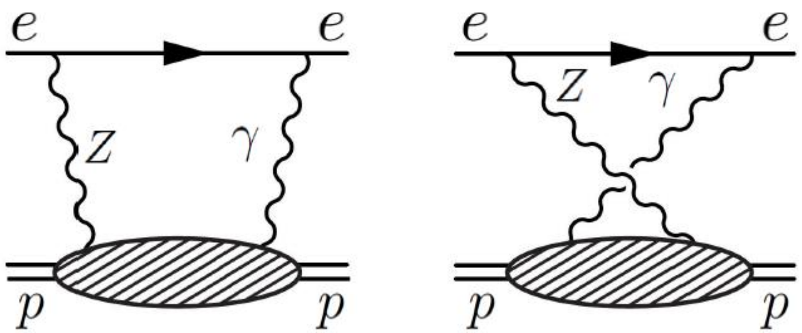
- To compare the theory with experiment, one has to include electroweak corrections[1]

[1]J. Erler, A. Kurylov, and M. J. Ramsey-Musolf, *PRD*, **68**, 016006

- Up to one-loop level electroweak correction, there're three kinds of non-trival diagrams



WW box, $\gamma Z$ box, ZZ box    leptonic vertex correction    hadronic vertex correction

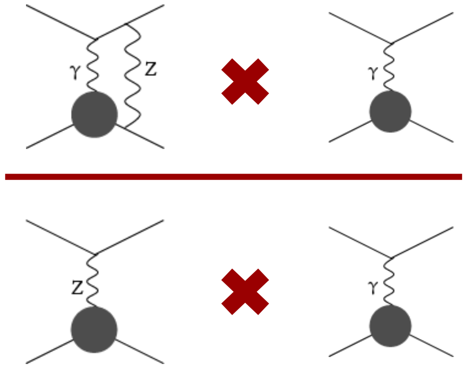



- Nonperturbative nature
- Dominate hadronic uncertainty

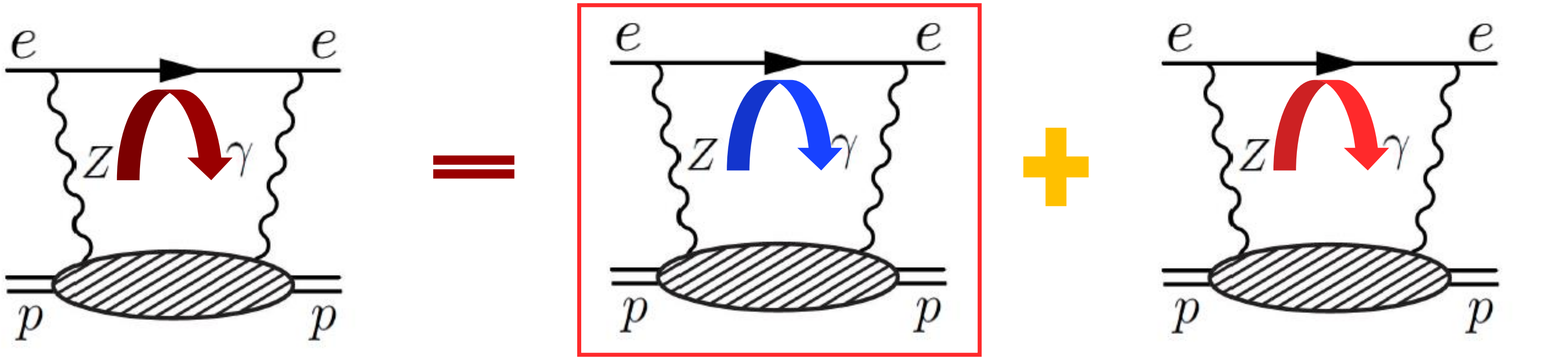
# Lattice methodology of $\Box_{\gamma Z}(E)$

- We'd like to calculate the $\gamma Z$ box term $\Box_{\gamma Z}(E)$ in the near forward limit, and low electron energy scale: $E < 155MeV$

- The definition of box term is $\Box_{\gamma Z}(E) =$



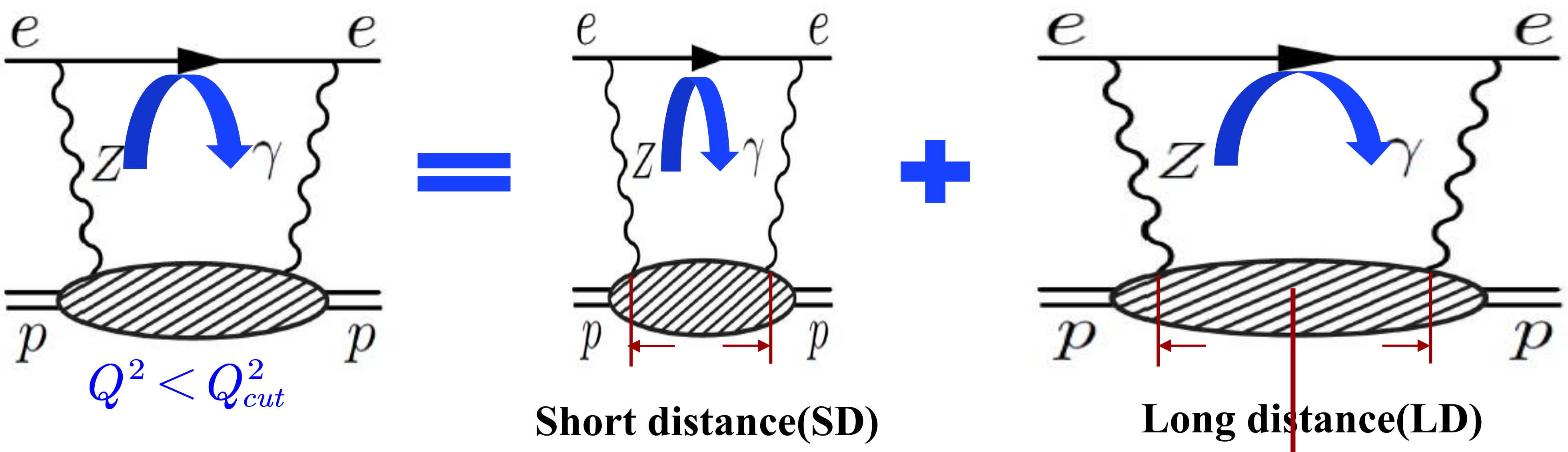

- To evaluate the $\Box_{\gamma Z}(E)$ loop integral, we adopt the following procedure:




$Q^2 < Q^2_{cut}$ (lattice QCD) $Q^2 > Q^2_{cut}$ (pQCD)

# Lattice methodology of $\Box_{\gamma Z}(E)$

- Secondly, we split the contribution into SD and LD part, according to the time separation between two currents.




IVR[1]
Exponentially suppressed finite volume effects

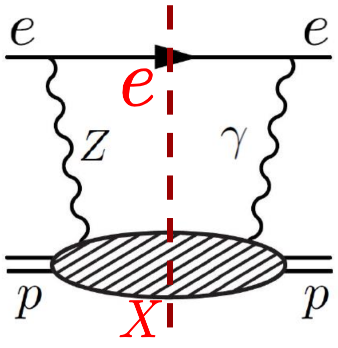
Proton state
(ground state)

[1]X. Feng, L. Jin, *PRD*.**100**.094509

# Lattice methodology of $\Box_{\gamma Z}(E)$

- There's a special phenomenon in the IVR for this work[1]: [1]X. Tuo, X. Feng, *arXiv*:2407.16930

$\gamma Z$ box's case:

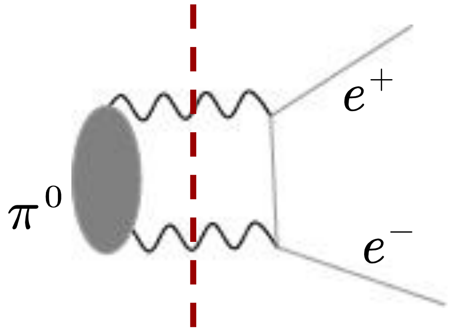



**On shell intermediate states** $eX$

***Multi-hadron states!***

$X = N,\ N\pi,\ N\pi\pi\ldots$

$\pi^0 \to e^+e^-$ case[2]:




**On shell intermediate states** $2\gamma$

[2]N. Christ, X. Feng, L. Jin, C. Tu, and Y. Zhao, *Phys. Rev. Lett.* **130**, 191901 (2023)

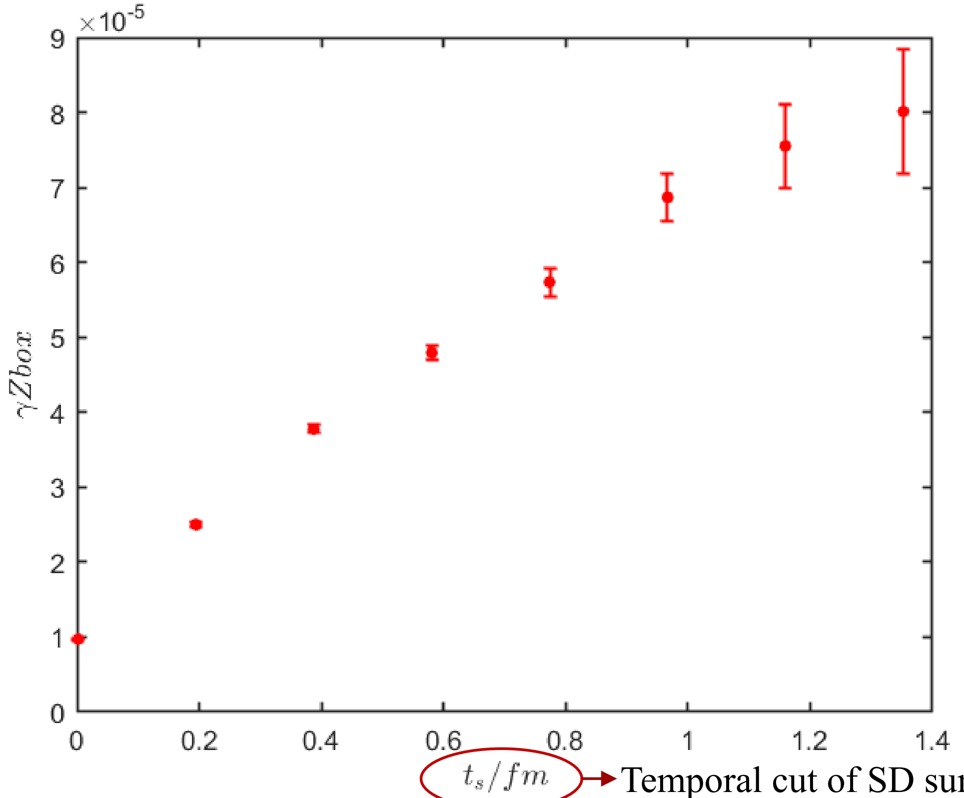
When electron's energy $E > 0$:

- Possibly $E_{eX} < E_{init}$
- Unphysical exponentially growing $eX$ contribution
- Removing the unphysical $eX$ contribution by IVR

# Lattice methodology of $\square_{\gamma Z}(E)$

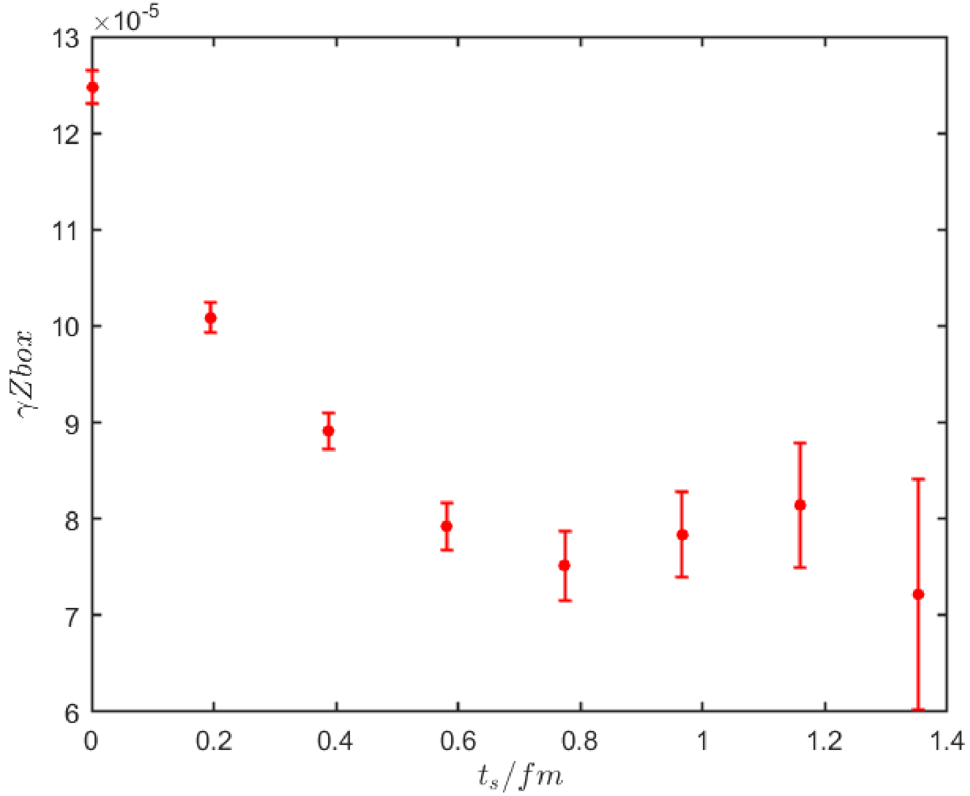


- Only remove exponentially growing $ep$ contribution ($X = p$) → No onshell $N\pi$ states → $E < 150MeV$




Temporal cut of SD summation

$E = 150MeV$ **Before IVR**




$E = 150MeV$ **After IVR**

# Lattice methodology of $\Box_{\gamma Z}(E)$

- Thirdly, we utilize substitution method[1] to control large statistical error when $Q^2 \approx 0$.
- lattice zero momentum contribution → accurate well known quantity

$$\int d^3\vec{x}\ \epsilon_{\mu\nu\alpha 0} x_\alpha H^{\gamma Z}_{\mu\nu}(\vec{x},t) \xrightarrow{t \gg 0} \frac{3}{2} g_A \mu_p$$

[1]P.X. Ma et al., *PRL*. 132 (2024) **19**, 191901

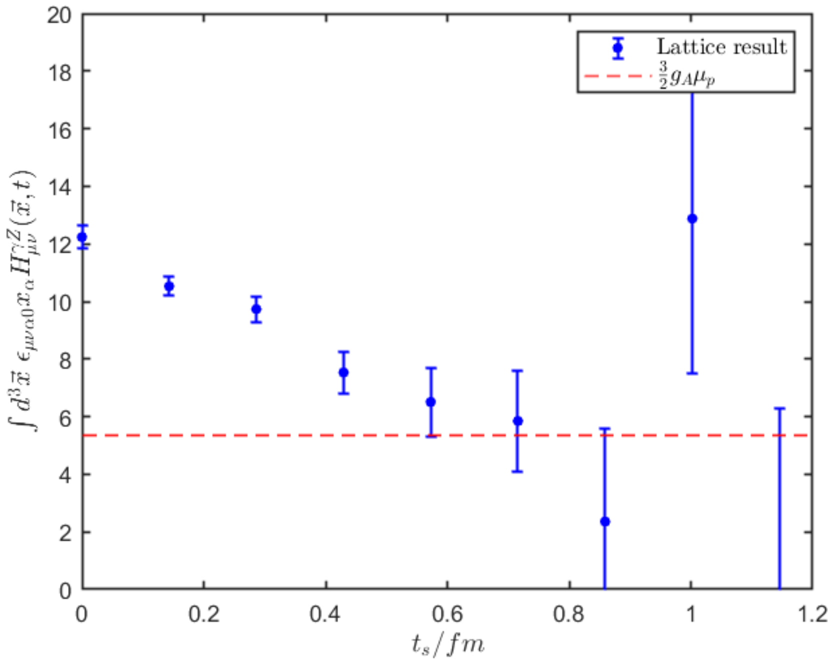
VVCS matrix element

$$H^{\gamma Z}_{\mu\nu}(\vec{x},t) = \langle p | T[J^{em}_\mu(x) J^Z_\nu(0)] | p \rangle$$

Axial charge

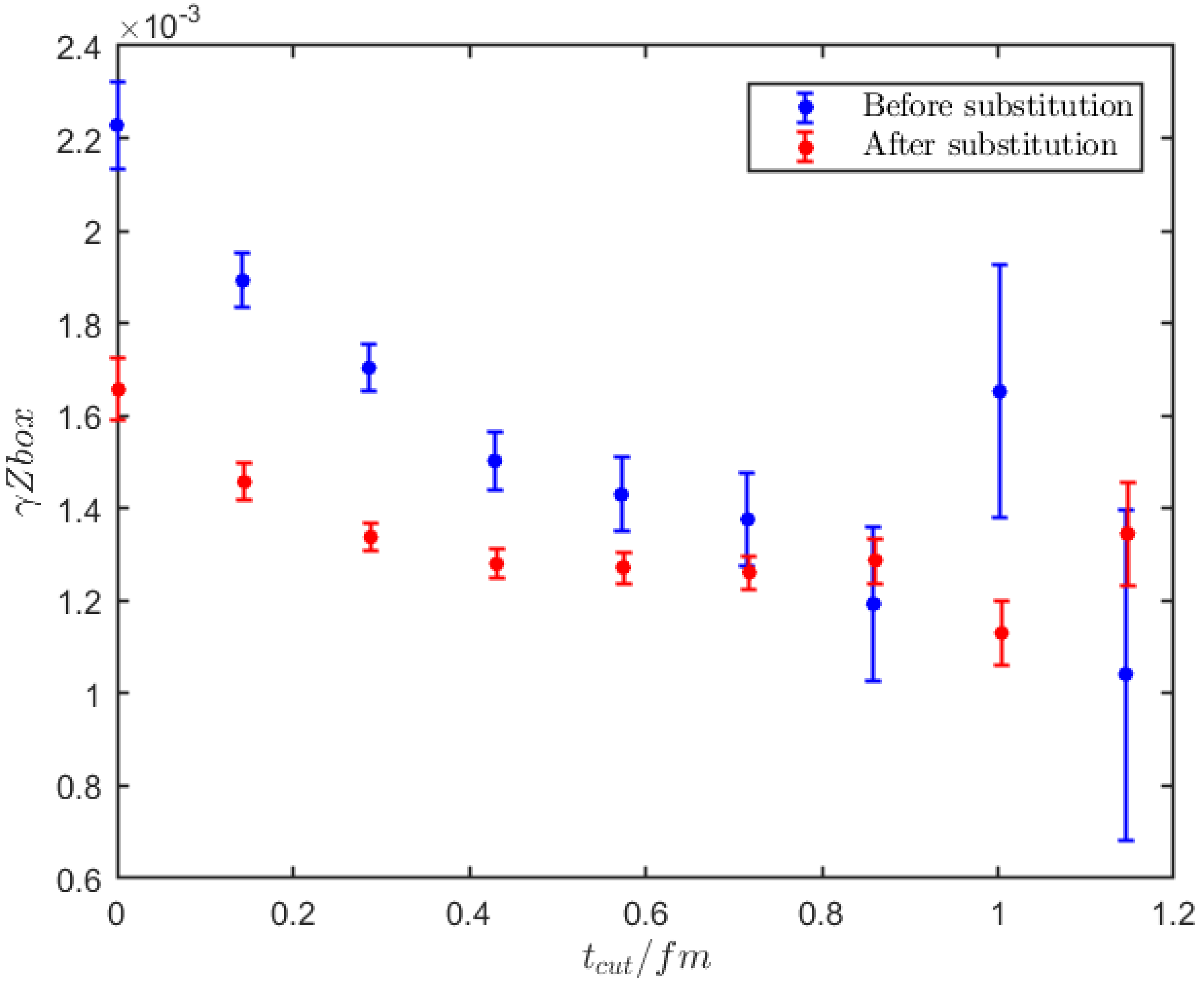
Proton magnetic moment

Numerical check of the equation:



# Lattice methodology of $\square_{\gamma Z}(E)$

- .Using substitution method to improve the signal of $\square_{\gamma Z}(E)$




- Electron energy $E = 0MeV$
- Clearer plateau
- Smaller statistical error

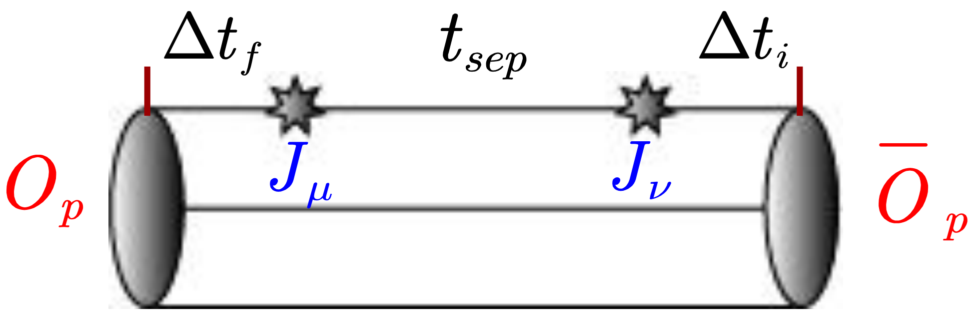
# Preliminary numerical results

- We use two DWF ensembles with physical pion mass[1].

| Ensemble | $m_\pi$ [MeV] | $L/a$ | $T/a$ | $a^{-1}$ [GeV] | $N_{\rm conf}$ |
|---|---|---|---|---|---|
| 24D | 142.6(3) | 24 | 64 | 1.023(2) | 207 |
| 32Dfine | 143.6(9) | 32 | 64 | 1.378(5) | 69 |

[1]T. Blum et al. (RBC, UKQCD), *PRD*, **93**, 074505

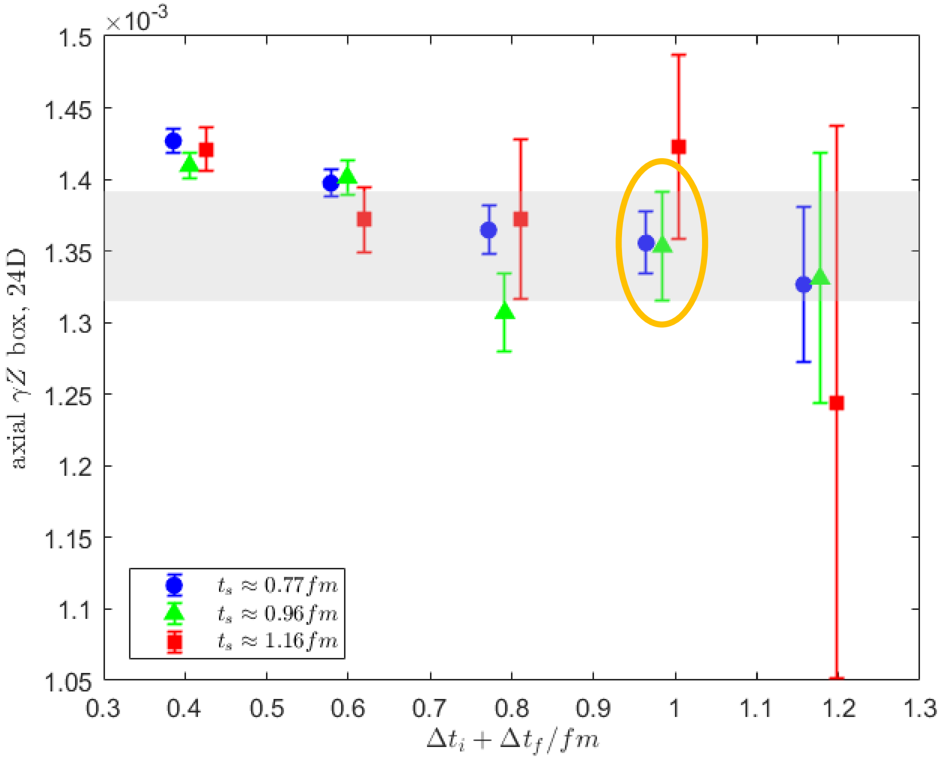
- To calculate the VVCS matrix element, we calculate the 4pt function (take one topology as an example):



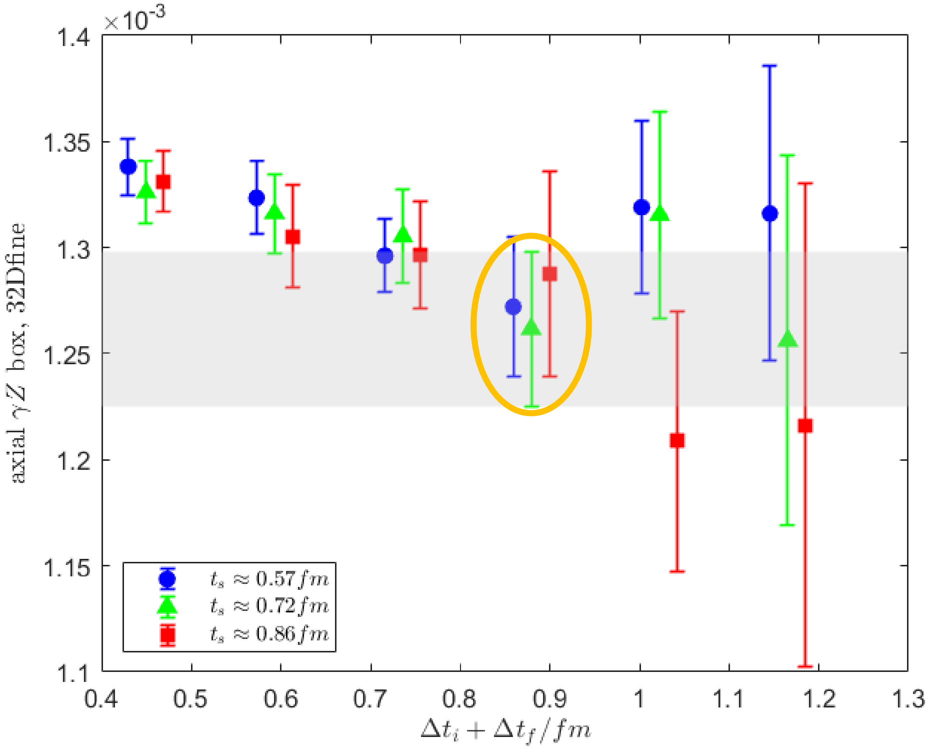
# Preliminary numerical results



- Result using: ( $t_{sep} < t_s$ SD + $t_{sep} > t_s$ LD contribution) (IVR)
- Show the dependence of $t_s$ and $\Delta t_i + \Delta t_f$ → Small excited states' contamination effects ?



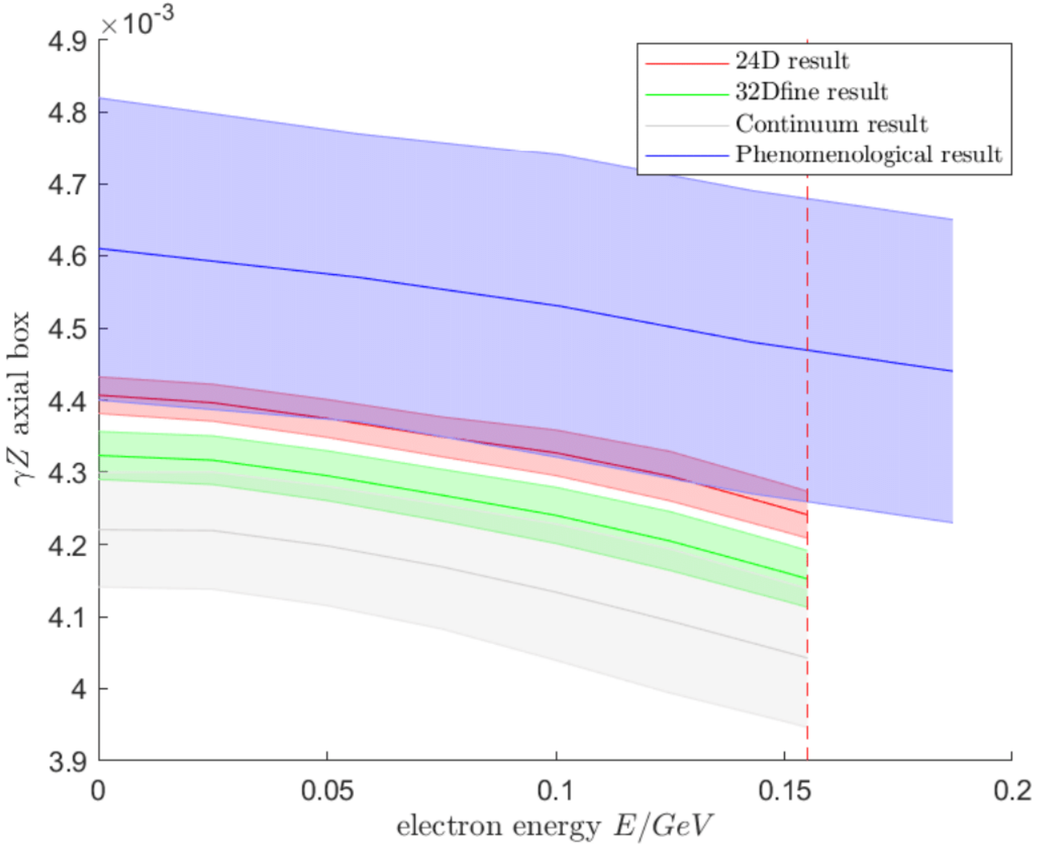

24D ensemble

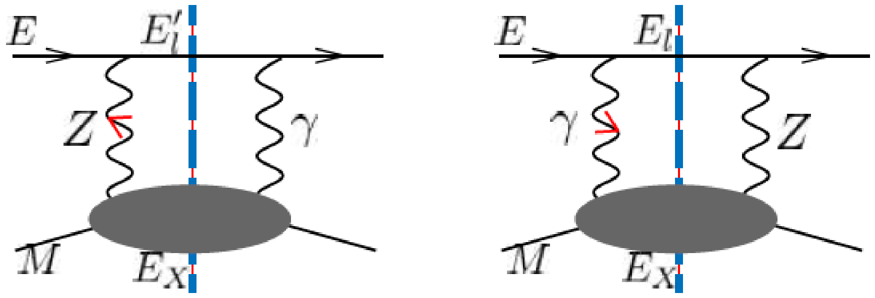



32Dfine ensemble

# Preliminary numerical results

- Result of $\Box_{\gamma Z}(E)$ with $E = 0 \sim 155MeV$, along with phenomenological result[1]




The energy limit E<155MeV is constraint by possible exponential growing $N\pi$ states

[1]J. Erler, M. Gorchtein, O. Koshchii, C.-Y. Seng, and H. Spiesberger, *Phys. Rev. D* **100**, 053007

# Possible future prospect



- The restriction of leptonic energy may be loosed, by removing more low-lying excited states, such as nucleon-pion states, to work out this contribution ,we need to calculate following matrix element in little group:

$$\langle p|J|\pi N\rangle$$

- And we also have to carefully analyze the finite volume error when nucleon pion is an interacting two particle intermediate state1.

[1]X. Tuo, X. Feng, *arXiv*:2407.16930, Talk: LT3, 15:15, 2th August

- Only axial $\gamma Z$ box is calculated in this work. However, vector box $\gamma Z$ also has a considerable contribution, and could also been evaluated in principle. But one has to deal with a IR divergence, which is absent in axial contribution.

Thank you for listening!