LEPTONIC TENSOR APPROACH TO CALCULATE SCATTERING CROSS SECTIONS FOR DISTINGUISHABLE TARGET PARTICLES

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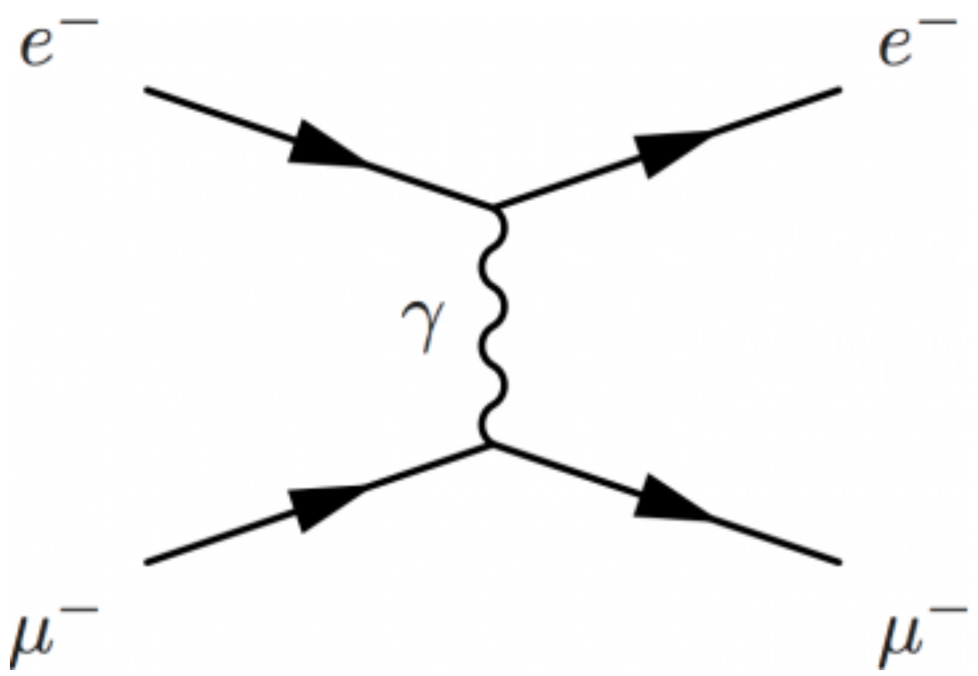
MOTIVATION

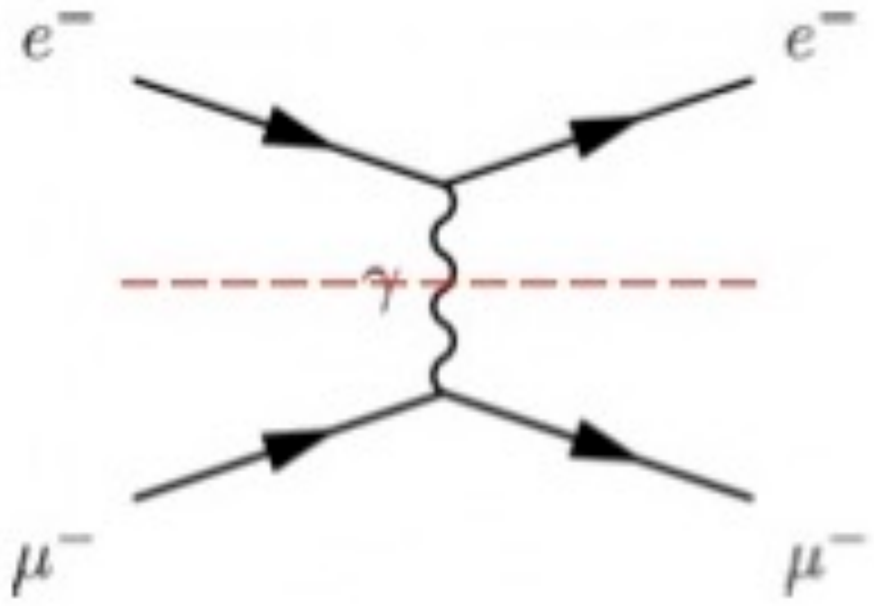
- Standard Model (SM) is the most precise theory in the human history and can make predictions that match experiments to one part in ten billion, **yet** it is supposed to be incomplete and cannot explain the mystery of dark matter, hierarchy problem, matter anti-matter asymmetry etc.
- For finding answers → Physics beyond the Standard Model
- We are doing precision physics → match the precision of SM theory with experiments by calculating the higher order terms.

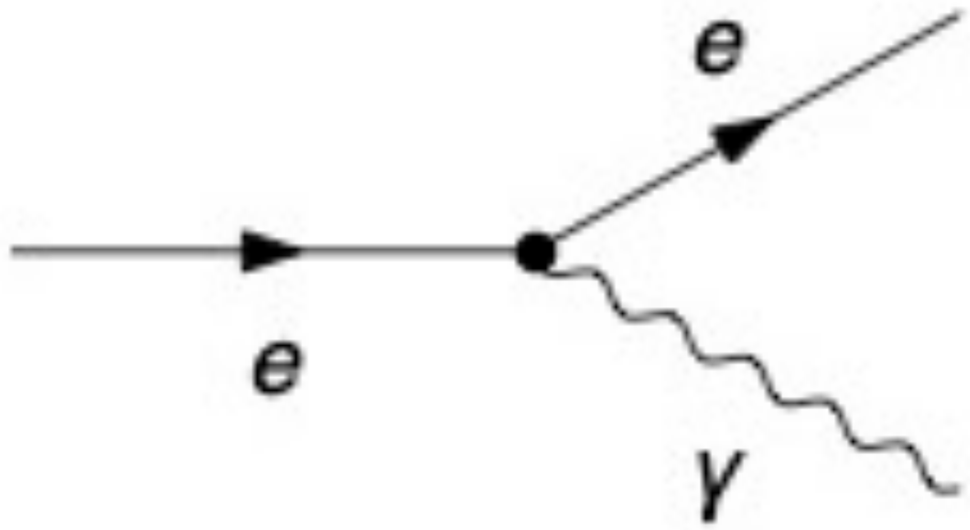
- We are checking the Standard Model precision by studying the full electroweak ($e^-\mu^-$, e^-p) differential scattering cross section using NLO and quadratic level (NNLO) **Covariant/ leptonic tensor approach.**

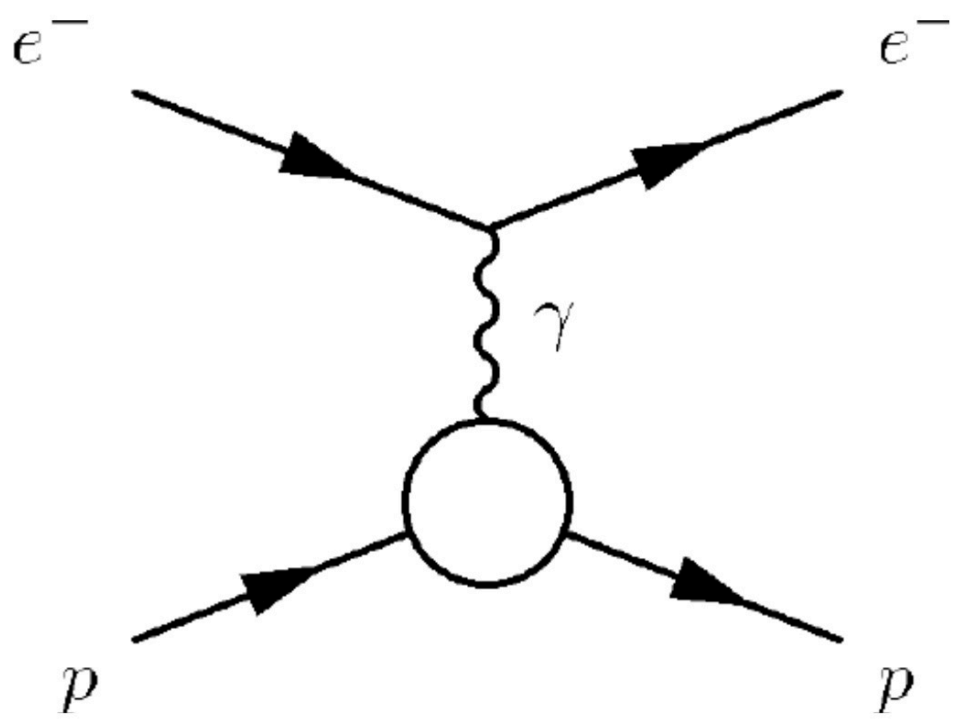
- The more higher orders we include, the more precise results could be obtained. Any discrepancy between the results of our theoretical calculations and experimentally measured values may enable us to search for the physics beyond the Standard Model.

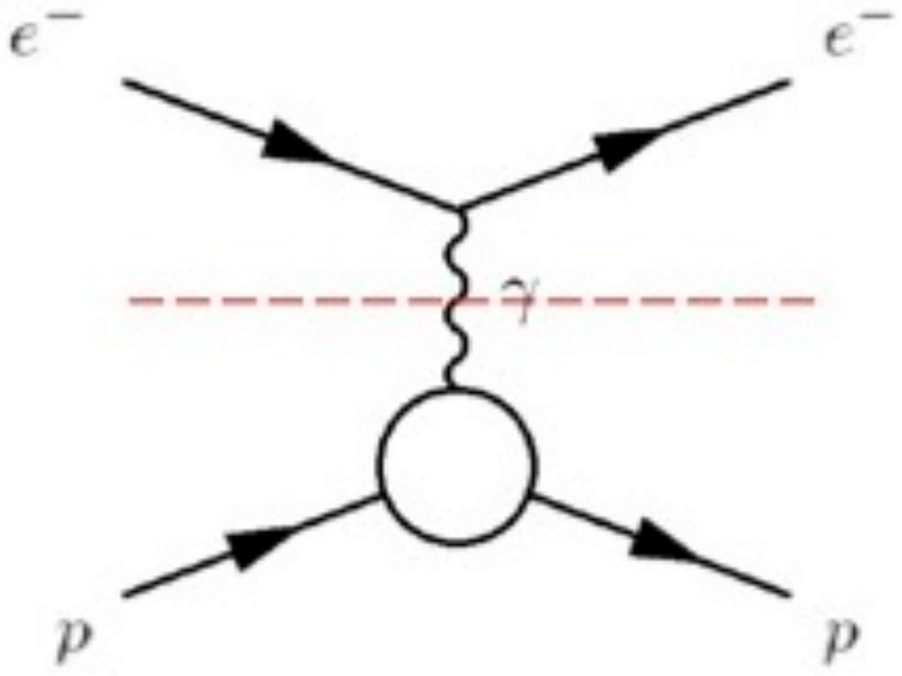
WHAT IS A COVARIANT APPROACH?

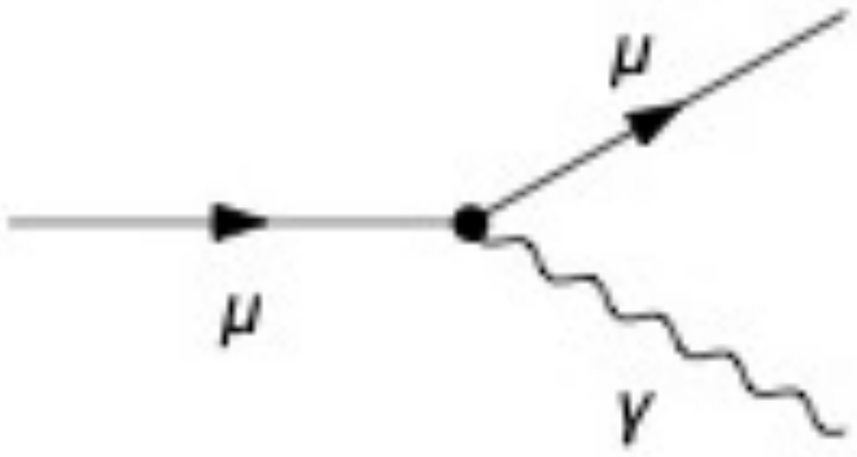












- The differential cross section of general lepton-lepton/hadron scattering can be obtained by: $d\sigma \sim L^{\mu\nu}L_{\mu\nu}$ or $d\sigma \sim L^{\mu\nu}W_{\mu\nu}$

- where $W_{\mu\nu}$ is the hadronic tensor and can be obtained using general covariant form [2]

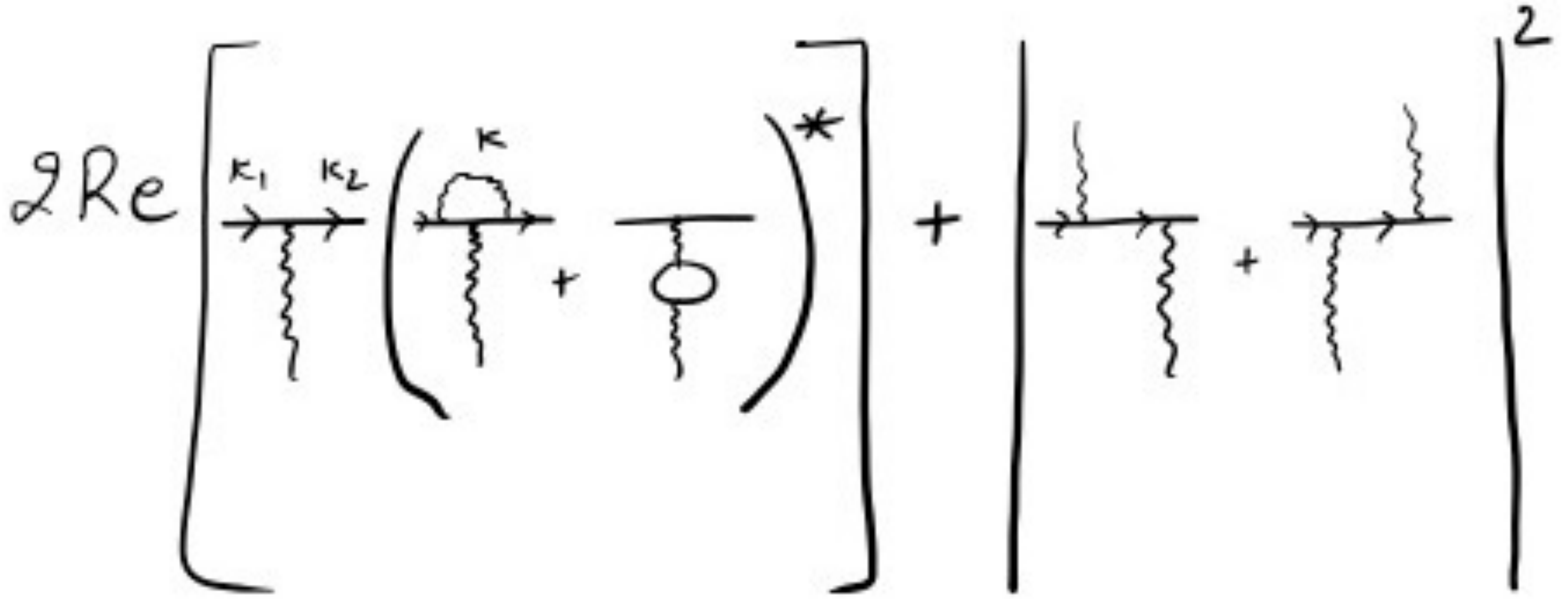
$$W_{\mu\nu} = -\tilde{g}_{\mu\nu}H_1 + \tilde{p}_\mu\tilde{p}_\nu H_2 + \tilde{p}_{\mu h}\tilde{p}_{\nu h}H_3 + (\tilde{p}_\mu\tilde{p}_{\nu h} + \tilde{p}_{\mu h}\tilde{p}_\nu)H_4 + (\tilde{p}_{\mu h}\tilde{p}_\nu - \tilde{p}_\mu\tilde{p}_{\nu h})H_5$$

Where H_1, H_2, H_3, H_4 and H_5 are hadronic structure functions and can be obtained by experiments. The tilde for an arbitrary 4-vector a_μ denotes the substitution: $\tilde{a}_\mu = a_\mu - \frac{aq}{q^2}q_\mu$ for gauge invariance.

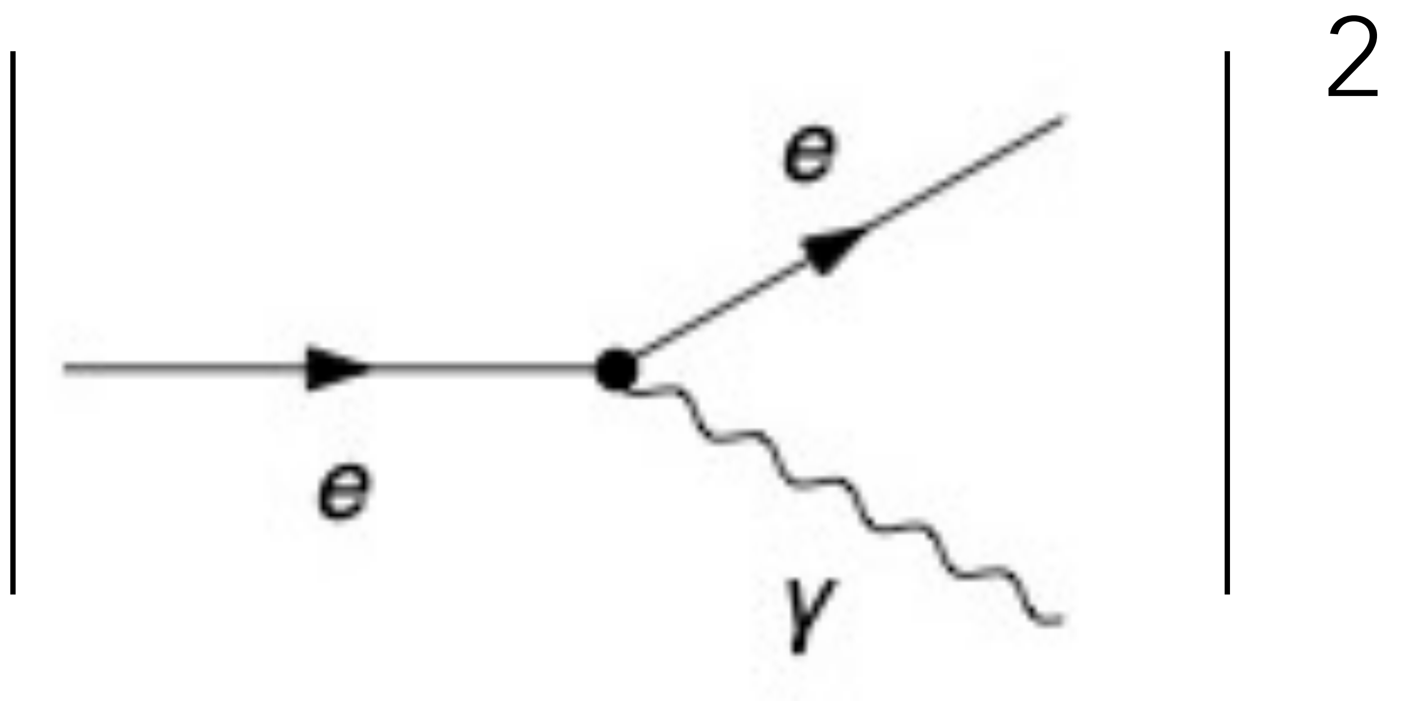
QED LEPTONIC TENSOR AND INTRODUCTION TO COVARIANT APPROACH

- First introduced by Bardin and Shumeiko in 1976 [1] to extract the infrared divergence from the lowest order bremsstrahlung cross section.

- Recently used by Afanasev et al. [2] to calculate QED radiative corrections in processes of exclusive Pion electroproduction.

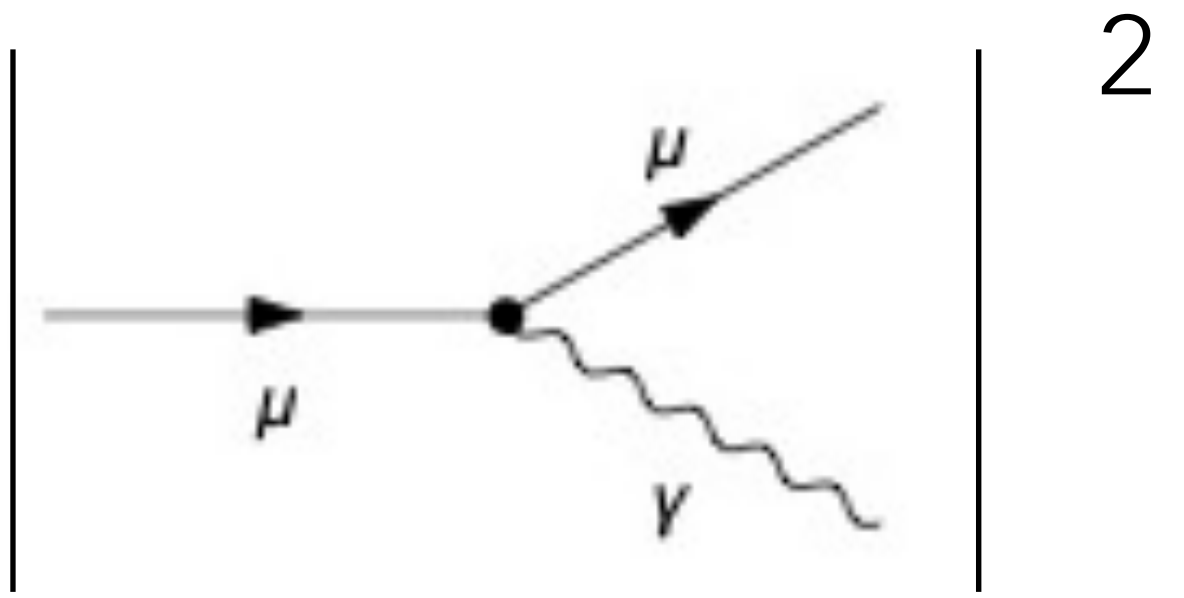


TREE LEVEL LEPTONIC TENSOR (α-ORDER)



- For tree level upper part of the diagram (say $e^-\mu^-$ scattering), one can easily calculate leptonic tensor which is:

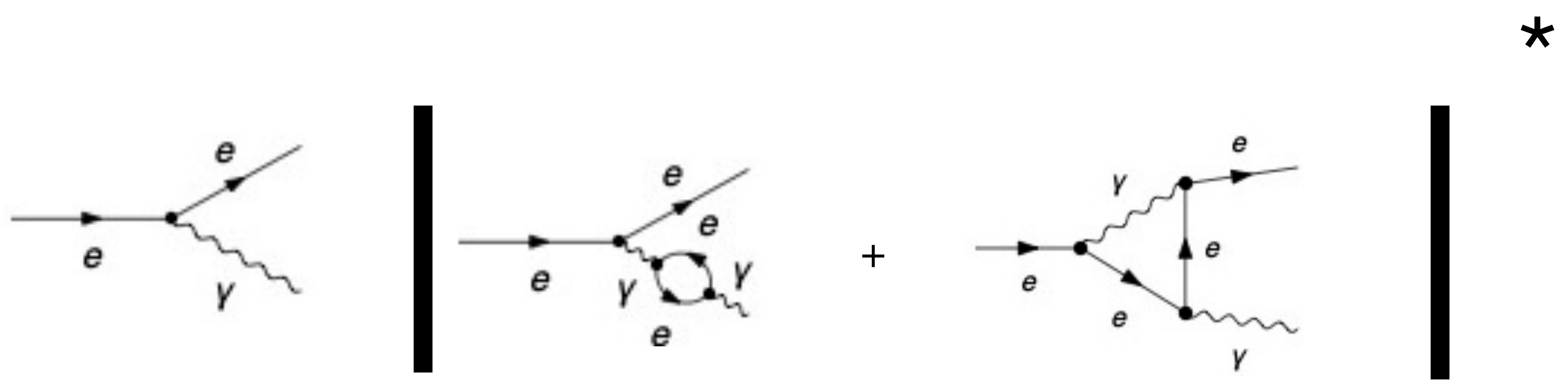
$$L^0_{\mu\nu} = \frac{2\pi\alpha(Tg_{\mu\nu} + 2(k_{2\mu}k_{1\nu} + k_{1\mu}k_{2\nu}))}{T}$$



Where T is the momentum transfer and k_1, k_2 are incoming and outgoing e^- momenta.

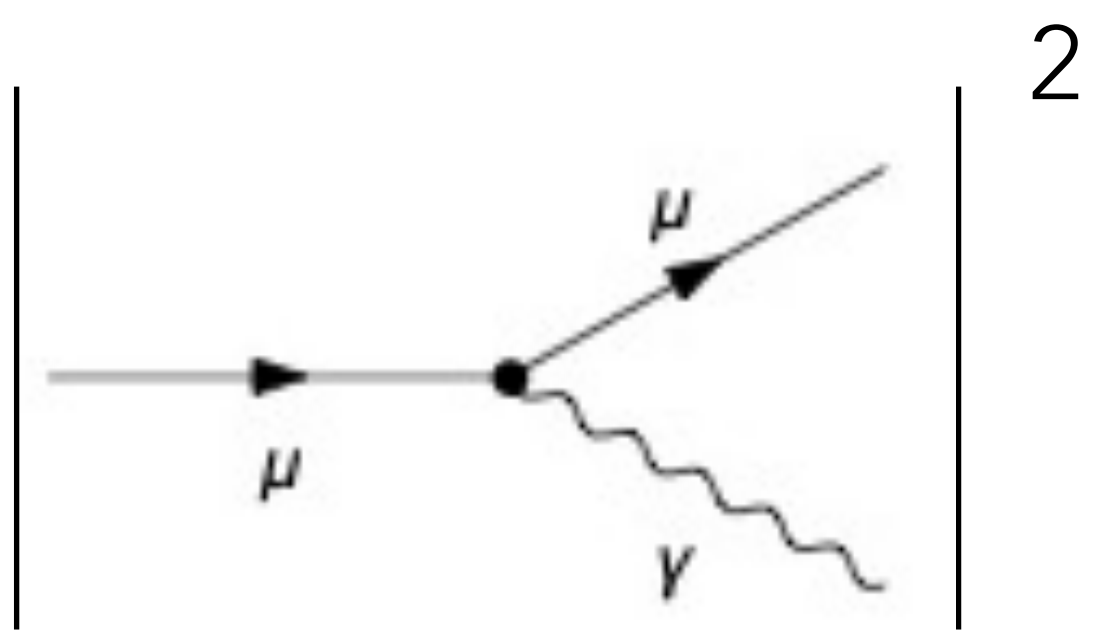
NEXT TO THE LEADING ORDER (NLO) QED LEPTONIC TENSOR (α^2-ORDER)

- The NLO leptonic tensor can be obtained by multiplying tree level upper diagram with the sum of one-loop level SE and triangular diagrams.



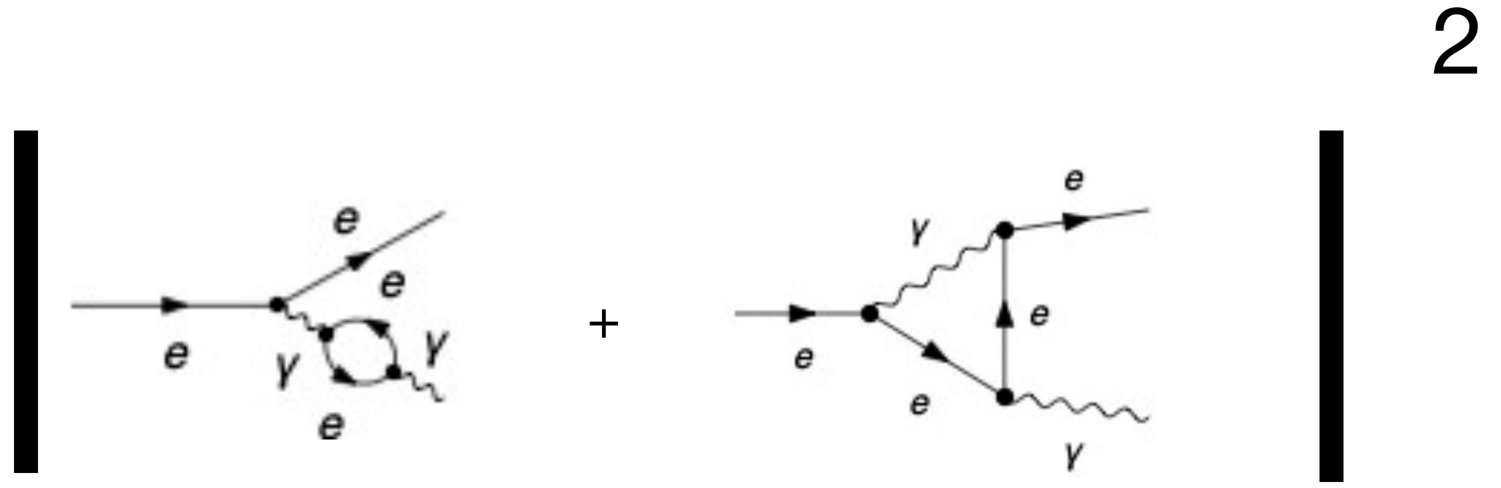
$$L_{\mu\nu}^{NLO} = (l_1)g_{\mu\nu} + (l_2)k_{1\mu}k_{2\nu} + (l_3)k_{1\mu}k_{1\nu} + (l_4)k_{2\mu}k_{2\nu}$$

Where l_1, l_2, l_3 and l_4 are tensor structure functions which depends on the momentum transfer T and written in terms of Pa-Ve functions. We used LoopTools Mathematica package to calculate them.

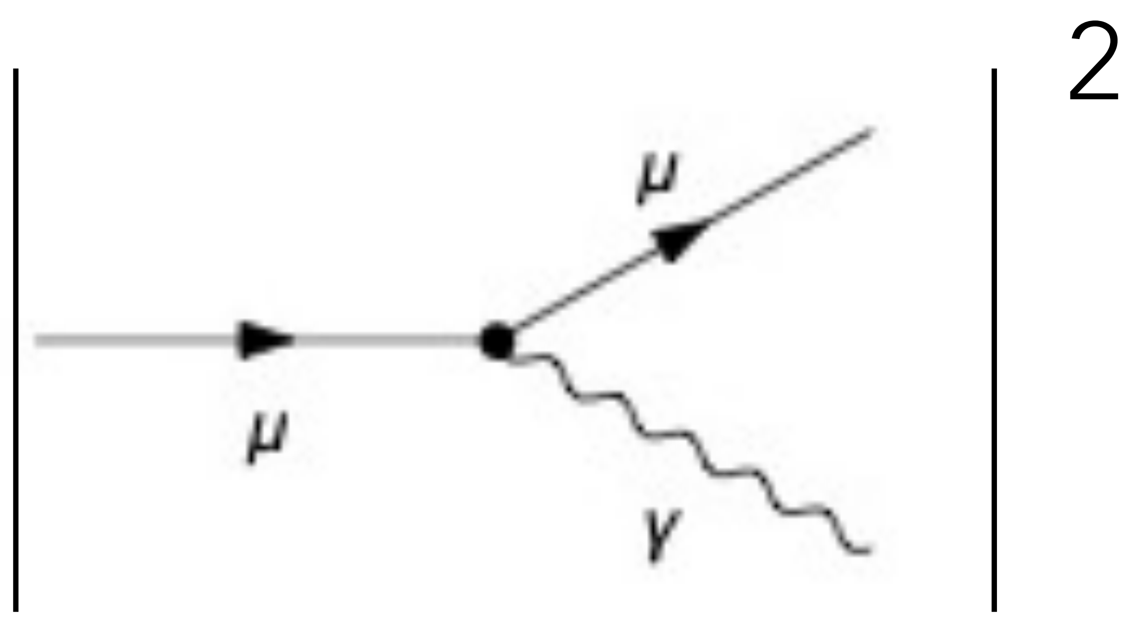


NEW RESULTS: QUADRATIC LEPTONIC TENSOR (α^3-ORDER)

- The quadratic leptonic tensor can be obtained by squaring the sum of one-loop level SE and triangular diagrams. Tensor form is the same as that of NLO and is given by:

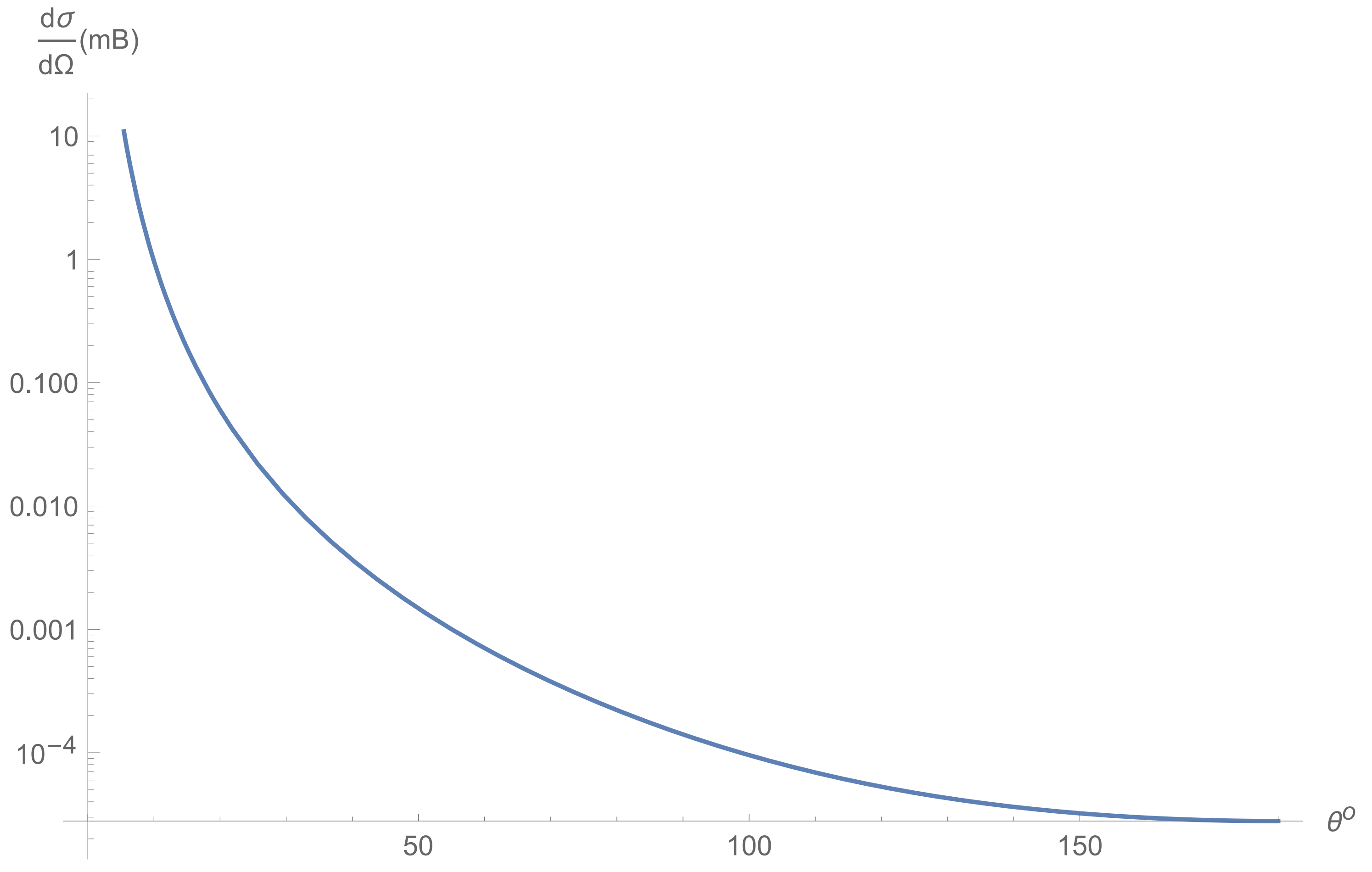


$$L_{\mu\nu}^{Quadratic} = (l_1)g_{\mu\nu} + (l_2)k_{1\mu}k_{2\nu} + (l_3)k_{1\mu}k_{1\nu} + (l_4)k_{2\mu}k_{2\nu}$$

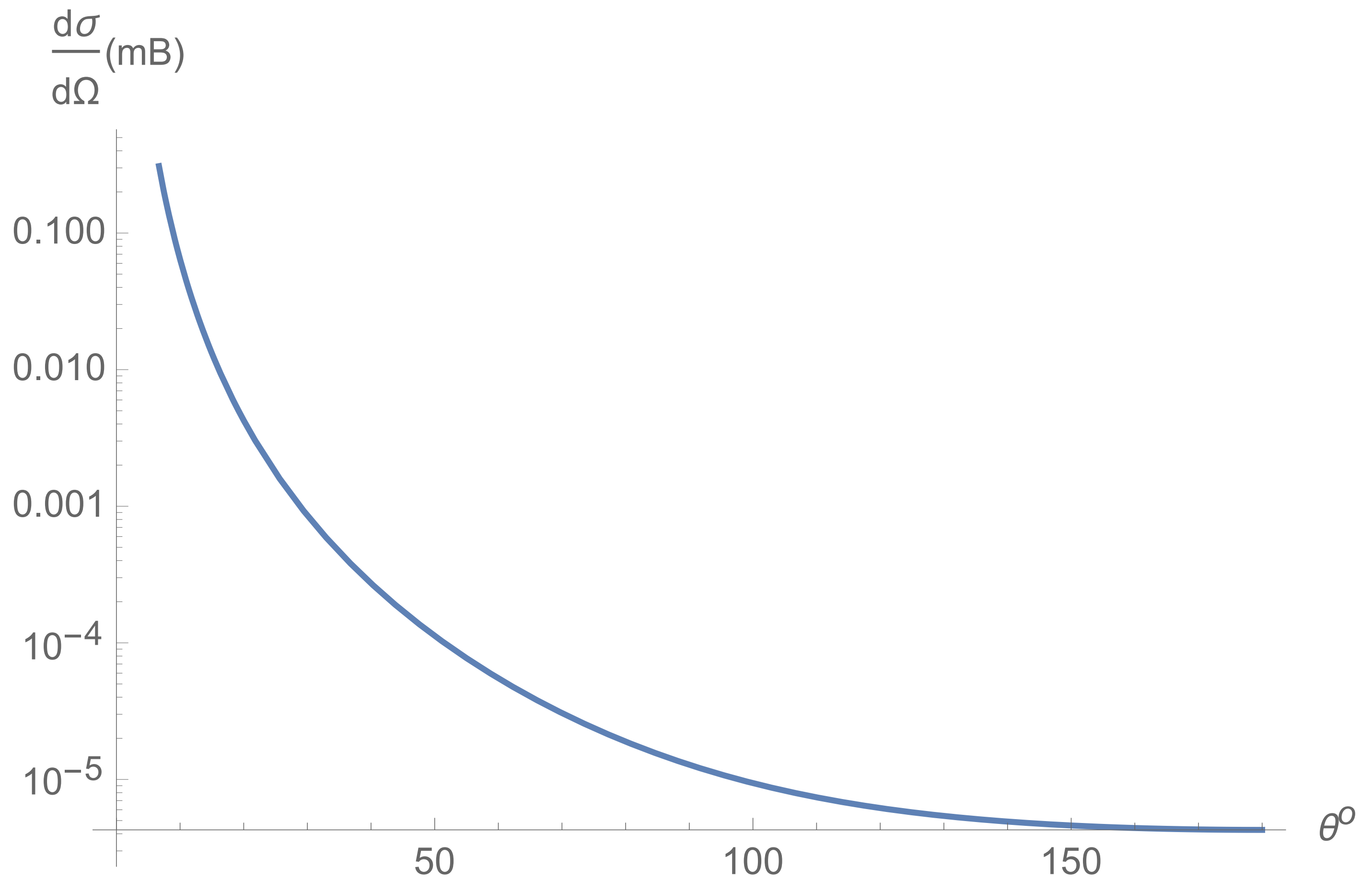


However, l_1, l_2, l_3 and l_4 tensor structure function's values are different from NLO structure functions.

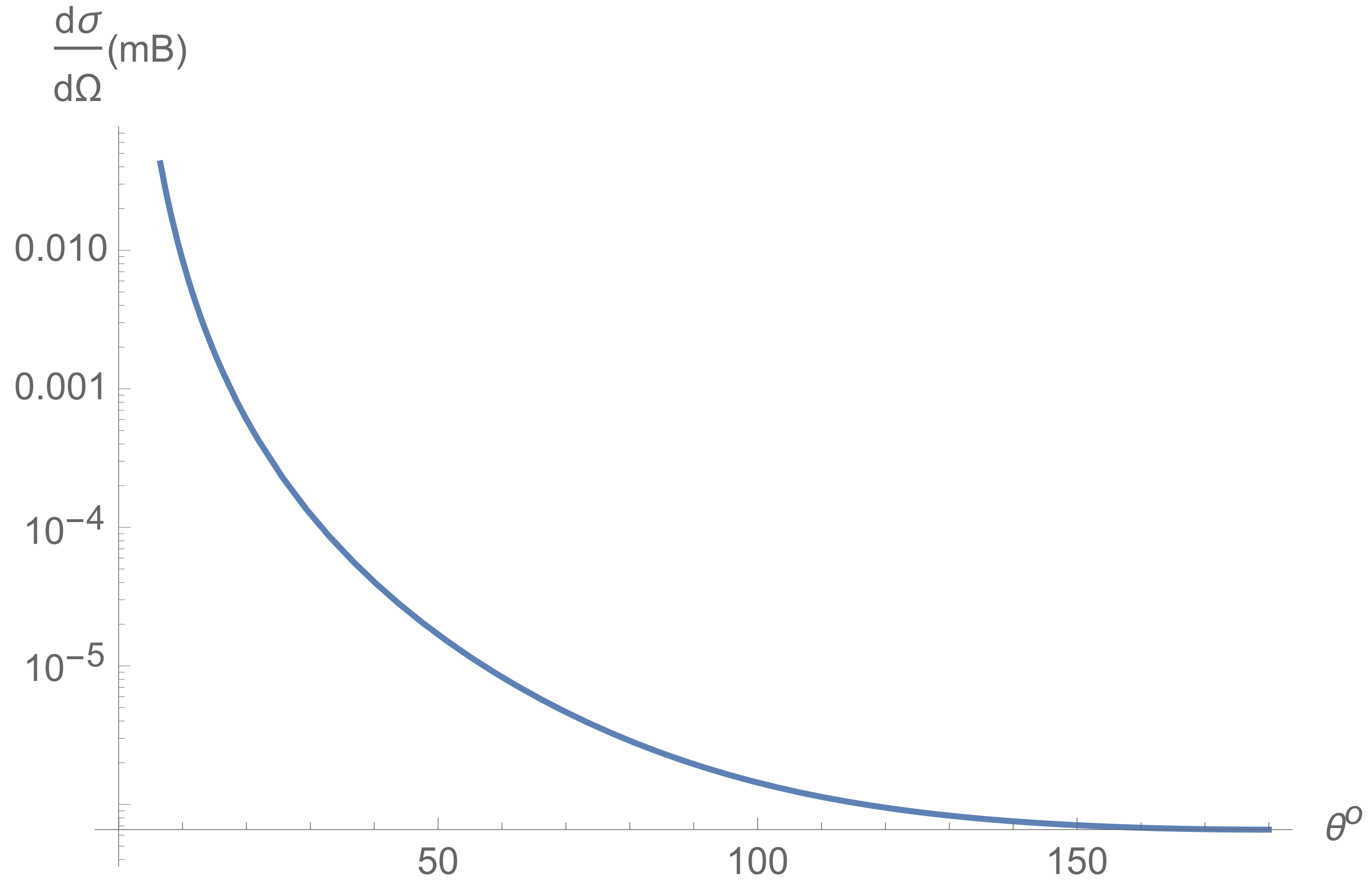
Graphs for Tree level, NLO and Quadratic level Differential ($e^-\mu^-$) Scattering Cross Sections versus Scattering angle θ



Tree level $\frac{d\sigma}{d\Omega}$



NLO level $\frac{d\sigma}{d\Omega}$



NNLO level $\frac{d\sigma}{d\Omega}$

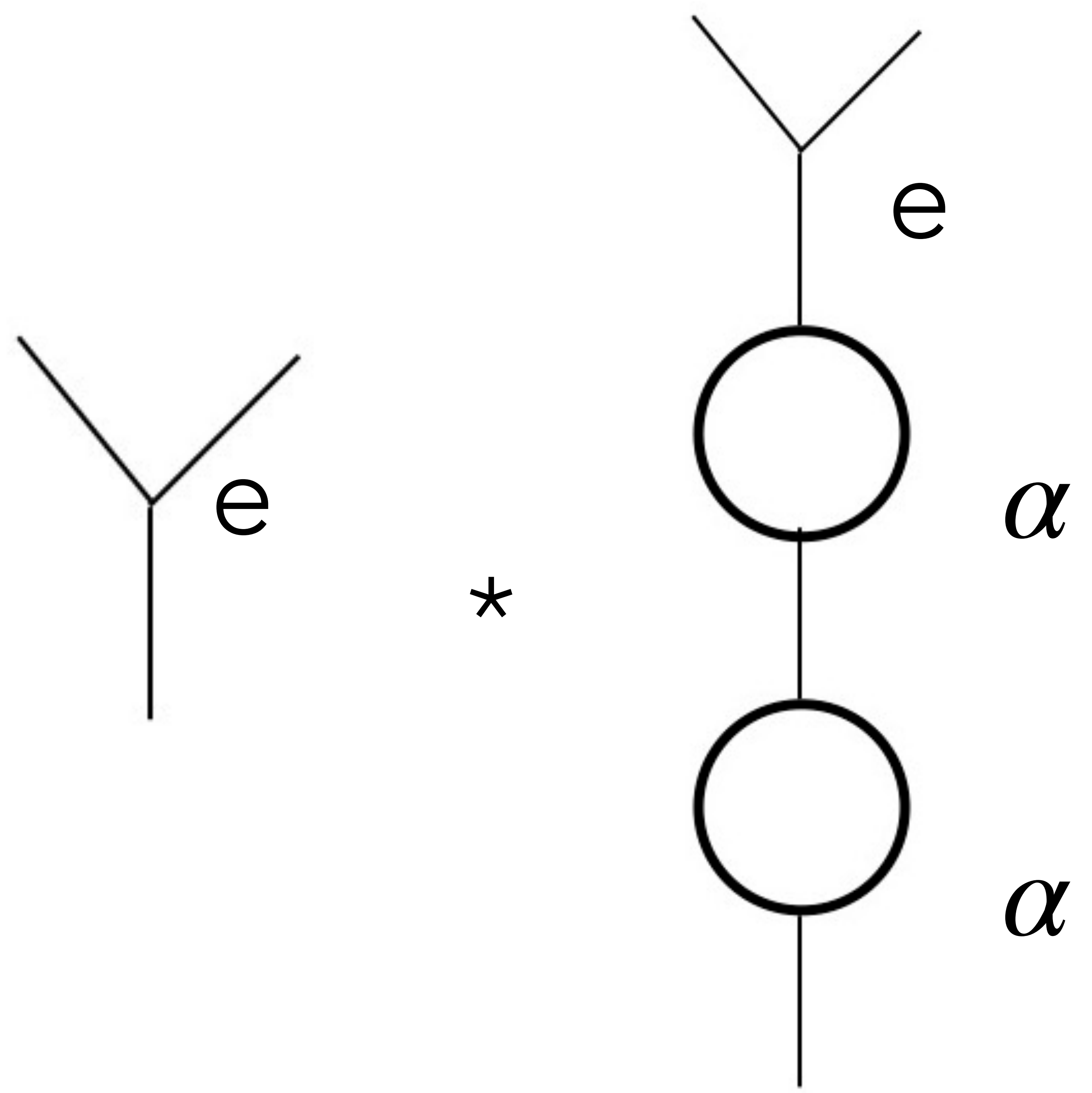
$$\delta^{(1)} = \frac{2\Re[M_0 M_1^\dagger]}{|M_0|^2} \sim 15\%$$

$$\delta^{(2)} = \frac{|M_1|^2}{|M_0|^2} \sim 1.14\%$$

ADVANTAGES OF USING COVARIANT APPROACH

- This is a general approach and can be used to calculate any scattering process with a distinguishable target.

- We can get the NNLO effects without going to the two loop level calculations. For example our **Quadratic leptonic tensor** is of the order of α^3 which is usually obtained by considering two loop level Feynman diagram.



where $e^2 = \alpha$

OUR NEXT GOAL:

- We have produced **new results** for the QED quadratic leptonic tensor which were not calculated previously. These results are correct as we move towards higher orders of perturbation theory the values of observables become smaller and smaller as we can clearly see from the graphs.

- $e^-\mu^-$ scattering is our toy model. Next we would like to calculate the ep scattering using hadronic tensor to compare our theoretical results with actual experimentally measured values.

- We are planning to calculate full electroweak leptonic tensor by calculating NLO and quadratic tensor structure functions as we did in case of QED.

- Once we get these results it's a good check to test the precision of the Standard Model up to NNLO level.

REFERENCES

[1] D. Yu. Bardin and N.M. Shumeiko, “On an Exact calculation of the Lowest-Order Electromagnetic Correction to the Point Particle Elastic Scattering”, Nuclear Physics **B127** (1977)

[2] A. Afanasev, I. Akushevich, V. Burkert and K. Joo, “QED Radiative Corrections in Processes of Exclusive Pion Electroproduction”, arXiv:hep-ph/0208183**v1** (20 Aug 2002)

[3] M. Gorchtein, Phys. Rev. C **73**, 055201 (2006)

Thank you for listening :)

QUESTIONS!!