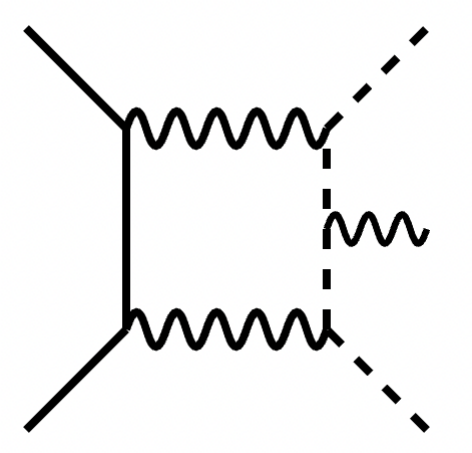
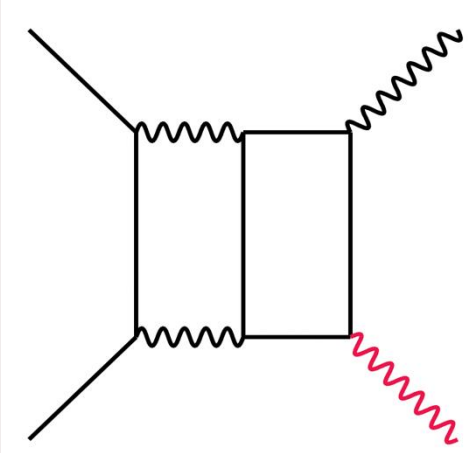
SCATTERING AMPLITUDES RELEVANT FOR MUON PHYSICS





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OVERVIEW

For various processes, I am computing the scattering amplitudes via tensor decomposition.

Then I perform analysis on the resulting form factors.

The processes I have been working on are:

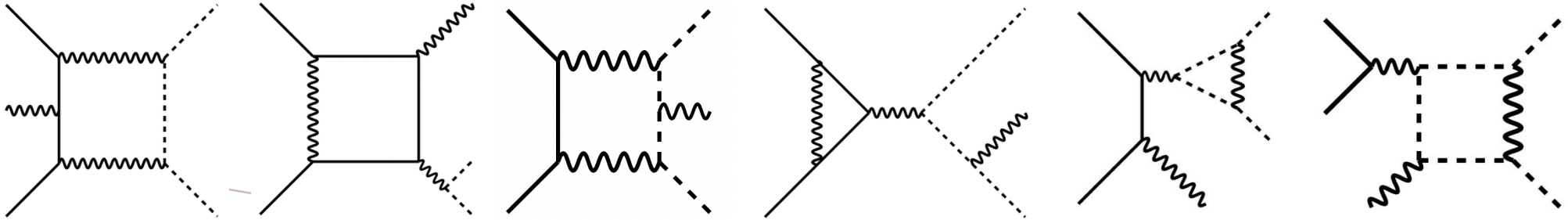
- $e^+e^- \to \pi^+\pi^-\gamma$ (at 1L)
- $e^+e^- \to \pi^+\pi^-$ and $e^+e^- \to \mu^+\mu^-$ (at 1L)
- $e^+e^- \to \gamma\gamma^*$ (at 2L)
- $e^+e^- \to \mu^+\mu^-$ and $e^+e^- \to \gamma\gamma$ in a fully massless model (at 3L)

$e^+e^- \rightarrow \pi^+\pi^-\gamma$

Aim: To obtain the Form Factors (via Tensor decomposition) at NLO and therefore polarized amplitudes and interference up to higher orders in the dimensional regulator. This will allow us to understand the IR structure at NNLO.

Progress:

- All Form Factors computed.
- All gauge invariant groups well understood.
- Numerical checks have been performed against GoSam3.0 (up to the finite part) and we find agreement.
- We now need to optimize the implementation of differential equations to give fast numerical evaluation then we have everything to complete our paper.



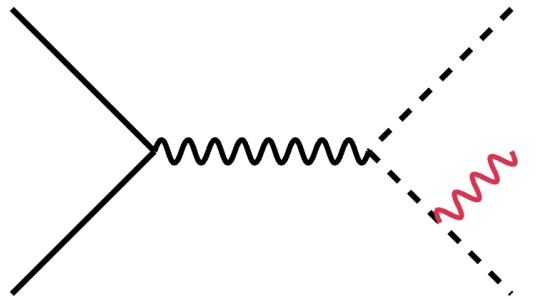
$ISR\ q_e^3 q_\pi^2$ $ISR\ q_e^4 q_\pi^1$ $FSR\ q_e^2 q_\pi^3$ $FSR\ q_e^3 q_\pi^2$ $ISR\ q_e^2 q_\pi^3$ $FSR\ q_e^1 q_\pi^4$

$e^+e^- \to \pi^+\pi^- / e^+e^- \to \mu^+\mu^-$

Aim: To obtain predictions for the soft photon effects at NLO for these processes as well as $e^+e^- \to \pi^+\pi^-\gamma$.

Progress:

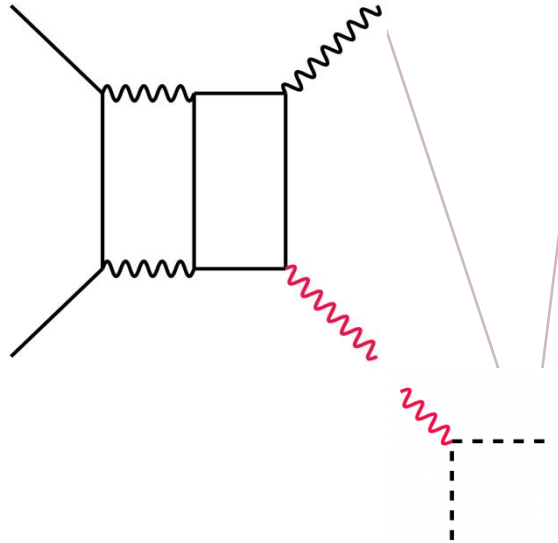
- Plenty of Numerical checks have been completed against Jérémy's Fortran implementation and GoSam3.0.
- Full agreement at LO and IR Structure agrees at NLO.
- UV renormalization being implemented then we should have full predictions for NLO resummation for $e^+e^- \to \pi^+\pi^-$ / $e^+e^- \to \mu^+\mu^-$.
- We are also working on optimizing our expressions for use in Monte Carlo generators.



With the much appreciated support of Mattia Pozzoli

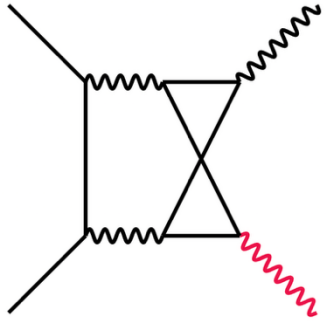
$e^+e^- \rightarrow \gamma\gamma^*$

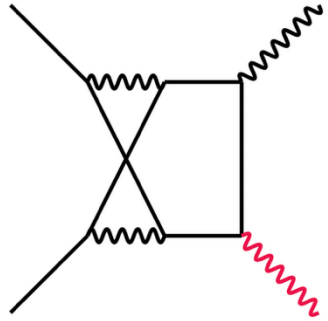
Aim: To obtain expressions that can be numerically evaluated quickly for $e^+e^- \rightarrow \gamma\gamma^*$ at 2L. We can learn a lot about ISR at NNLO from this process.



Progress:

- Form Factors for all contributing diagrams computed.
- We are currently computing the differential equations for the integral families that appear within this calculation.
- All Planar families have been computed, the non-planar families are in progress.
- Numerical evaluations of the amplitude are in progress. Currently using AMFlow (slower approach) but will be using a fast numerical integrator when we have the differential equations for all families.





$e^+e^- \to \mu^+\mu^- / e^+e^- \to \gamma\gamma$ *AT 3L*

Aim: To obtain the finite remainders for the helicity (polarised) amplitudes of four QED processes at 3L in a massless model

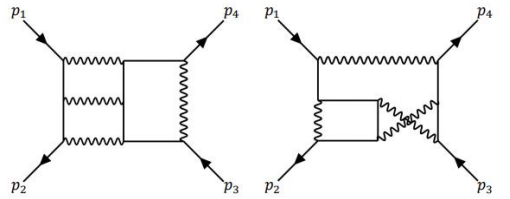


Figure 1. Representative three-loop diagrams of four-fermion scattering in QED, with outgoing external momenta p_i: solid lines represent leptons, and wavy lines, photons.

Progress:

- The calculation three four-lepton scatterings have been completed and a paper has been submitted to arXiv (2602.10807). This paper has also been submitted to PLB and is currently under review.
- Compton scattering well under way. Currently undergoing IBP reduction, which is the bottleneck of the calculation. We have a good strategy in place, so we don't foresee any complications.

$$e^+e^- \to \mu^+\mu^-$$

$$e^+\mu^- \to \mu^+e^-$$

$$e^+e^- \to e^+e^-$$

$$e^+e^- \to \gamma\gamma$$

CONCLUSIONS

- All form factors for the processes we are working on have been computed
- Optimization of the expressions is ongoing, but there have been positive steps towards this.
- $e^+e^- \rightarrow \pi^+\pi^-\gamma$ at NLO to higher orders in the dimensional regulator is very close to completion and a paper should be coming in the near future.
- Significant progress has been made in the 3L massless QED calculations with the Compton scattering entering the finals stages.
- Obtaining the differential equations and numerical evaluations of $e^+e^- \rightarrow \gamma\gamma^*$ is going well with focus going into non-planar families.

Please ask any questions you may have! ☺