WP3: processes with hadrons

Summary of WorkStop / ThinkStart discussions

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5th Workstop / Thinkstart: RC and MC tools for Strong 2020

University of Zurich[UZH]

PAUL SCHERRER INSTITUT

PSI

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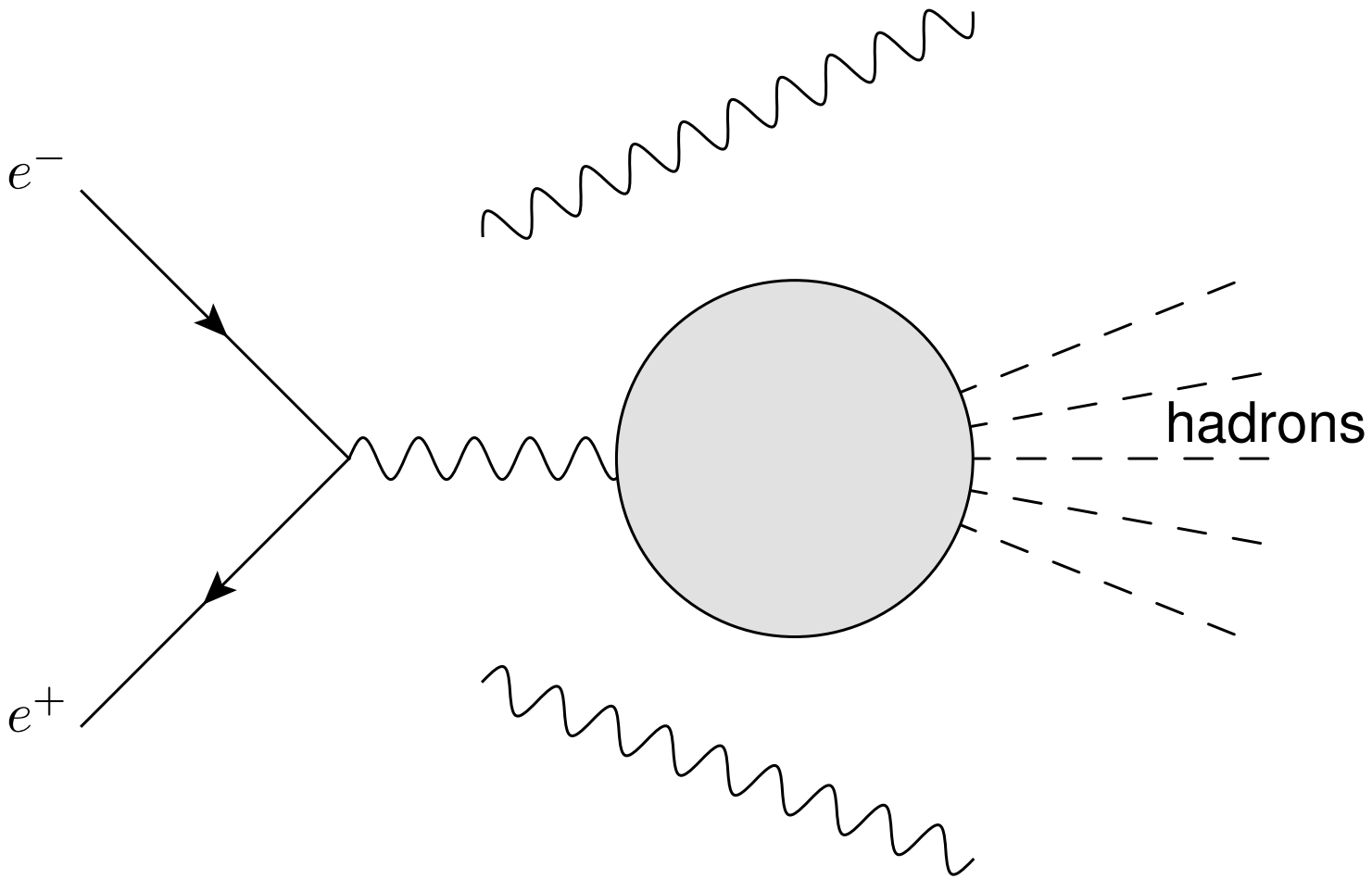
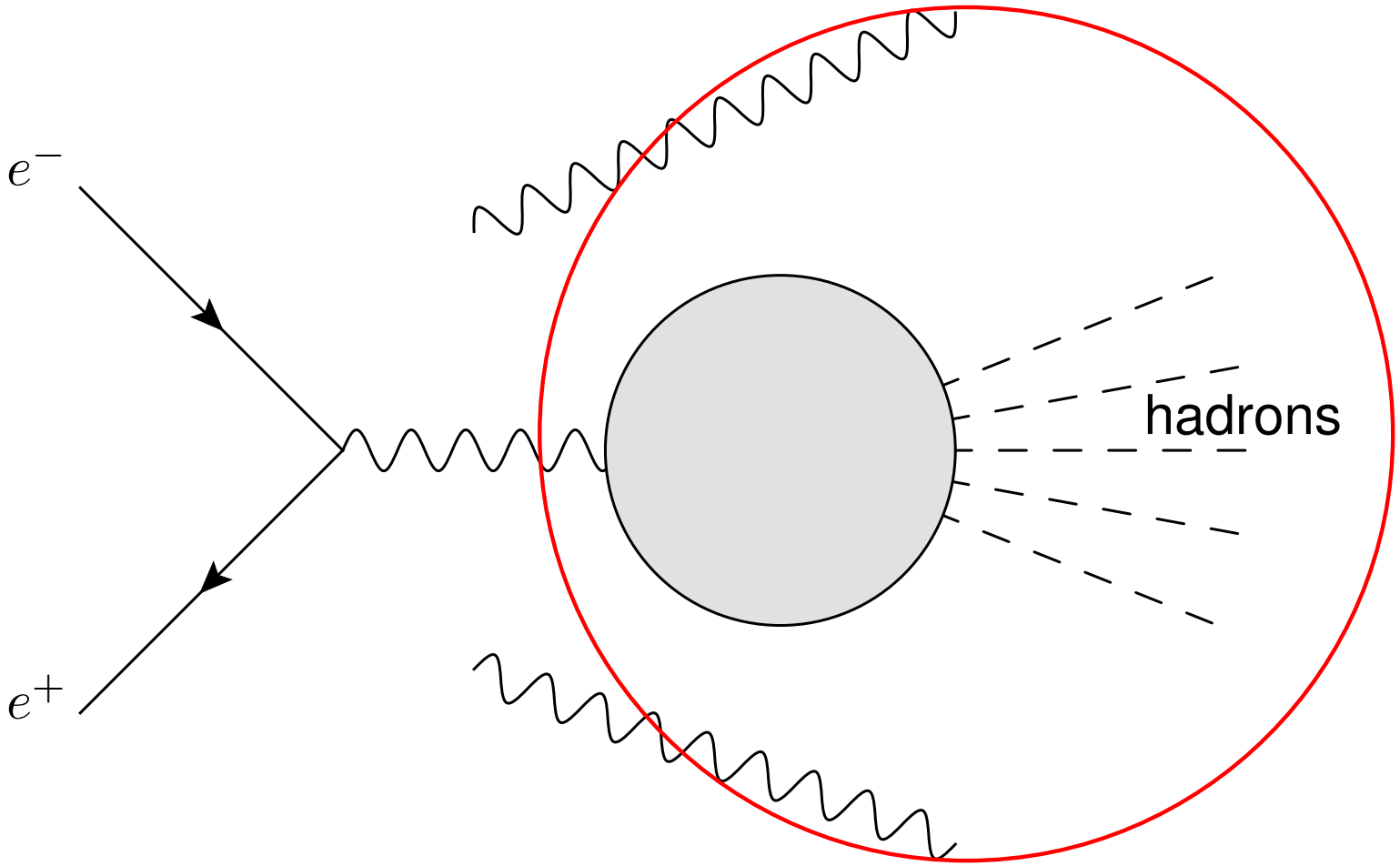
Outline

Overview

Processes with hadrons



Processes with hadrons



Hadronic vacuum polarization in muon $g-2$

importance of different channels: $\rightarrow$ White Paper (2020)

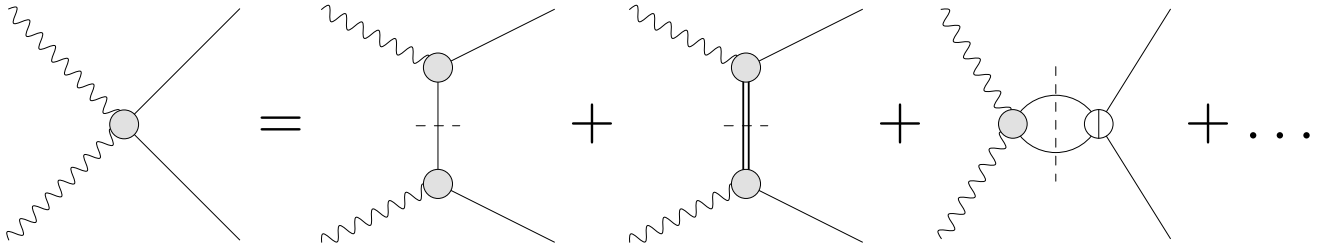
- 2π: 73% of total HVP
- 3π: 7% of total HVP
- $2K$: 5% of total HVP
- $> 1.8\,\text{GeV}$ (without $\bar{c}c$): 7% of total HVP

How to calculate radiative corrections in the context of non-perturbative strong interaction?

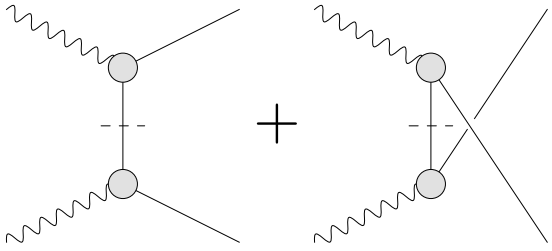
- lattice QCD: limited access to timelike region
- chiral perturbation theory (χPT): limited to energies $\ll 4\pi F_\pi \sim 1$ GeV, poorly known LECs
- models: no systematic error estimate; e.g., sQED $\subset$ χPT, resonance chiral theory, ...
- **dispersion relations**, based on unitarity/analyticity: truncation of infinite sum in unitarity relation
- for pions, FsQED may appear in dispersion relations as (leading) pole term (process dependent statement)

Dispersion relations: example $\gamma^*\gamma^* \to \pi^+\pi^-$

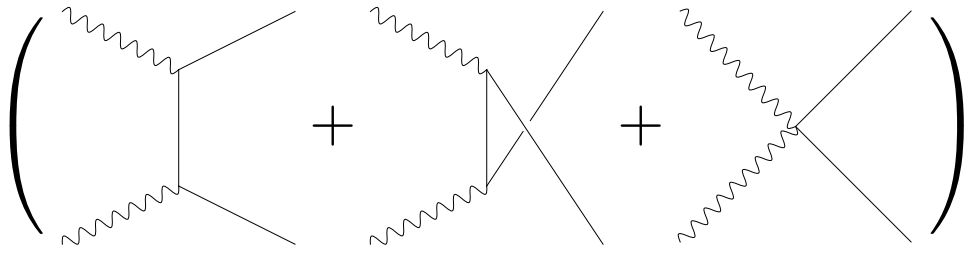
→ Colangelo, Hoferichter, Procura, Stoffer (2015), Hoferichter, Stoffer (2019)



pole term = FsQED

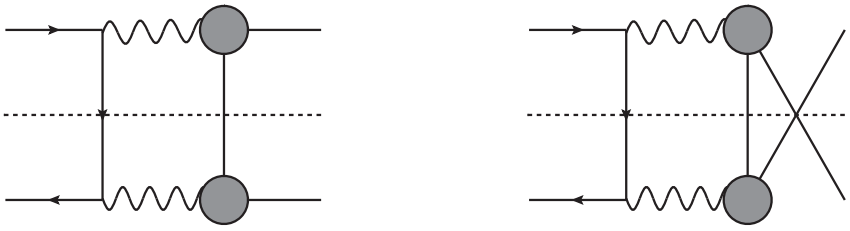


$$= \quad F_\pi^V(q_1^2)F_\pi^V(q_2^2) \times$$

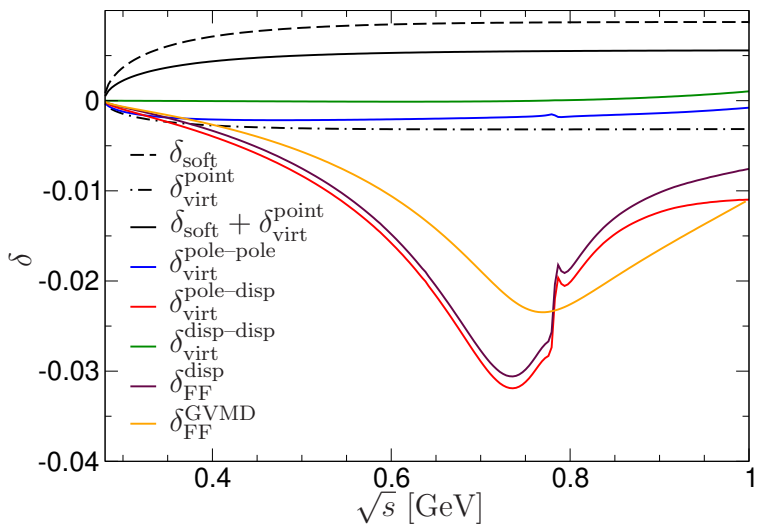


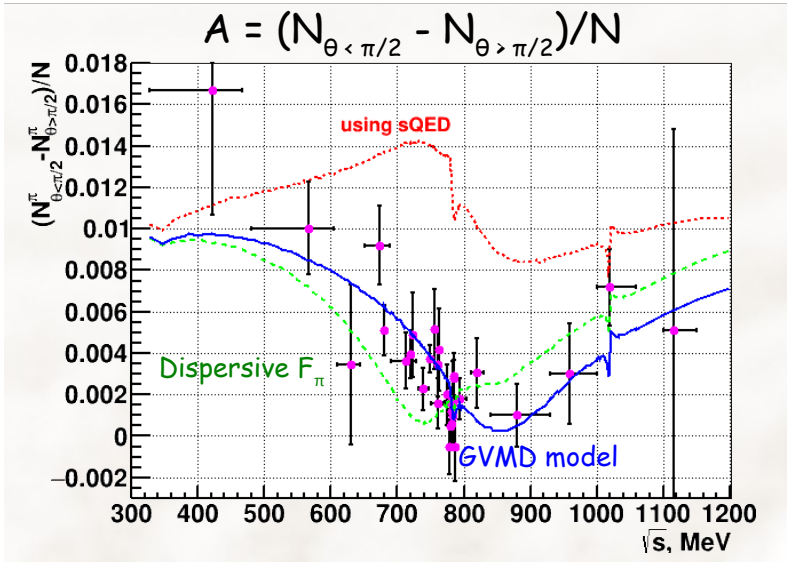
Overview

Forward-backward asymmetry



→ talk by G. Colangelo



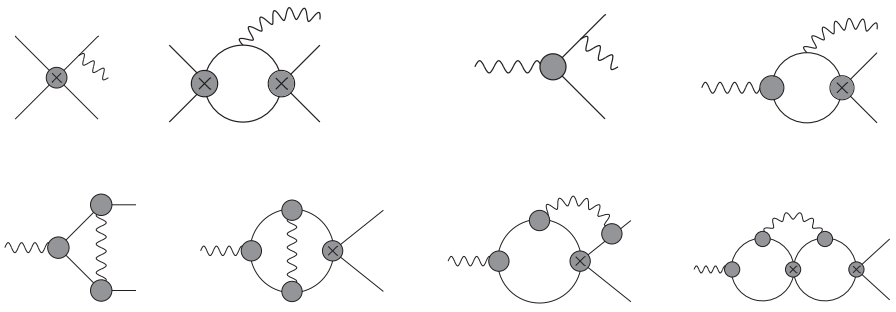


→ Colangelo, Hoferichter, Monnard, Ruiz de Elvira (2022)

→ Ignatov, Lee (2022), talk by F. Ignatov

Dispersive approach to isospin corrections in $\pi\pi$ scattering and F_π^V → talk by G. Colangelo

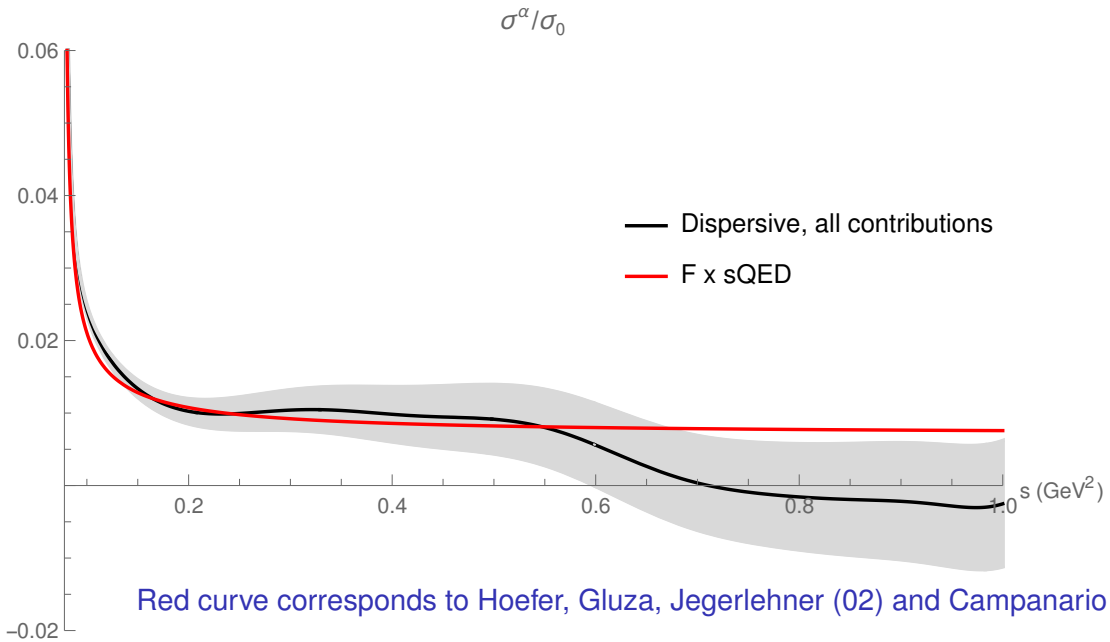
→ G. Colangelo, M. Cottini, J. Monnard, J. Ruiz de Elvira, work in progress



- pion-mass difference in Roy equations
- photonic corrections (real + virtual) to $\pi\pi$ scattering and pion vector form factor

Dispersive approach to isospin corrections in $\pi\pi$ scattering and F_π^V → talk by G. Colangelo

→ G. Colangelo, M. Cottini, J. Monnard, J. Ruiz de Elvira, work in progress



Red curve corresponds to Hoefer, Gluza, Jegerlehner (02) and Campanario et al. (19)

→ J. Monnard, PhD thesis (2021)

Overview

Dispersive approach to radiative corrections to $\gamma^* \to 3\pi$

$\to$ talk by B. Kubis

$\to$ M. Hoferichter, B.-L. Hoid, B. Kubis, D. Schuh, work in progress

- second-largest channel after $\pi\pi$
- odd intrinsic parity: not part of sQED
- correction factor $1 + \frac{\alpha}{\pi}\eta_{2\pi}(s)$ applied to 2π subsystem in **Khuri–Treiman** representation
- 3π correction factor defined via

$$\frac{\sigma_{3\pi(\gamma)}(q^2)}{\sigma^0_{3\pi}(q^2)} =: 1 + \frac{\alpha}{\pi}\eta_{3\pi}(q^2)$$

Dispersive approach to radiative corrections to $\gamma^* \to 3\pi$

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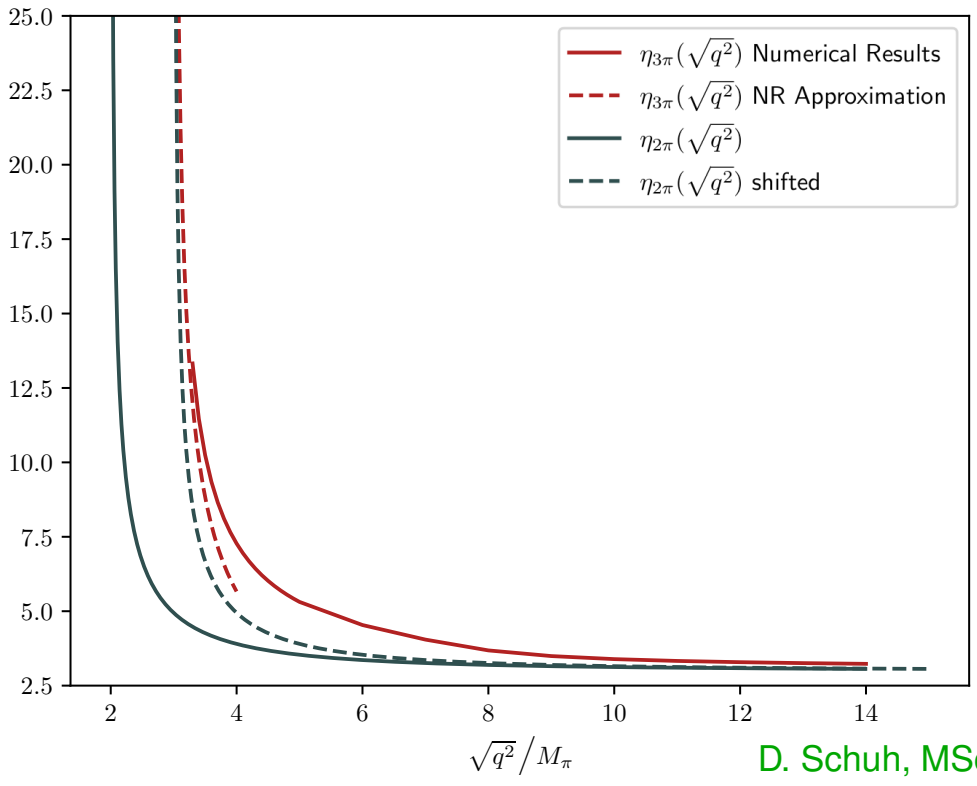


D. Schuh, MSc thesis 2023

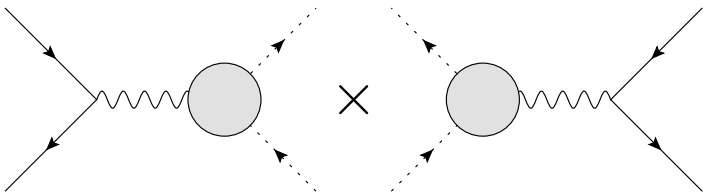
Overview

Comparison of MCs → talks by H. Czyż and F. Ignatov

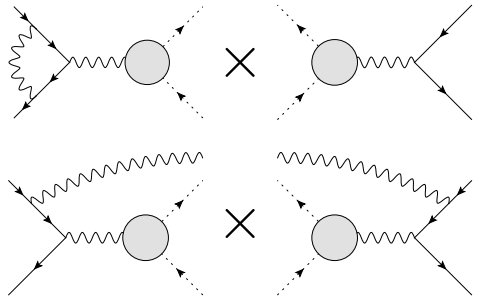
- ISR experiments: PHOKHARA
  - FSR from pointlike pions
  - boxes, pentagons with vector form factor *outside* loop integral
- direct scan experiments: MCGPJ
  - FSR from pointlike pions
  - box diagrams for asymmetry with vector form factor inside loop

Overview

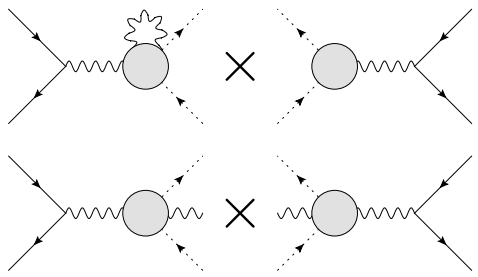
Direct scan experiments: LO



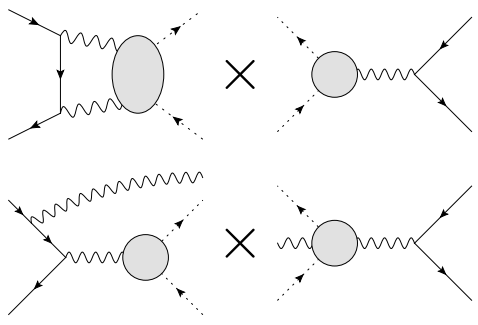
Direct scan experiments: NLO



pure QED



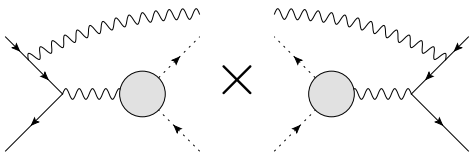
included in generators in terms of sQED
dispersive approach by Colangelo et al.



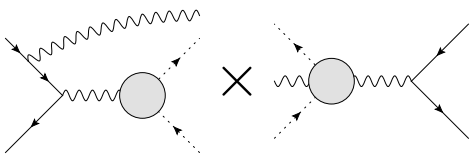
contributes only to asymmetry;

only pole terms:
$\longrightarrow$ Ignatov, Lee (2022)
$\longrightarrow$ Colangelo, Hoferichter, Monnard, Ruiz de Elvira (2022)

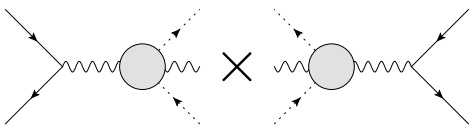
ISR experiments: LO



pure QED

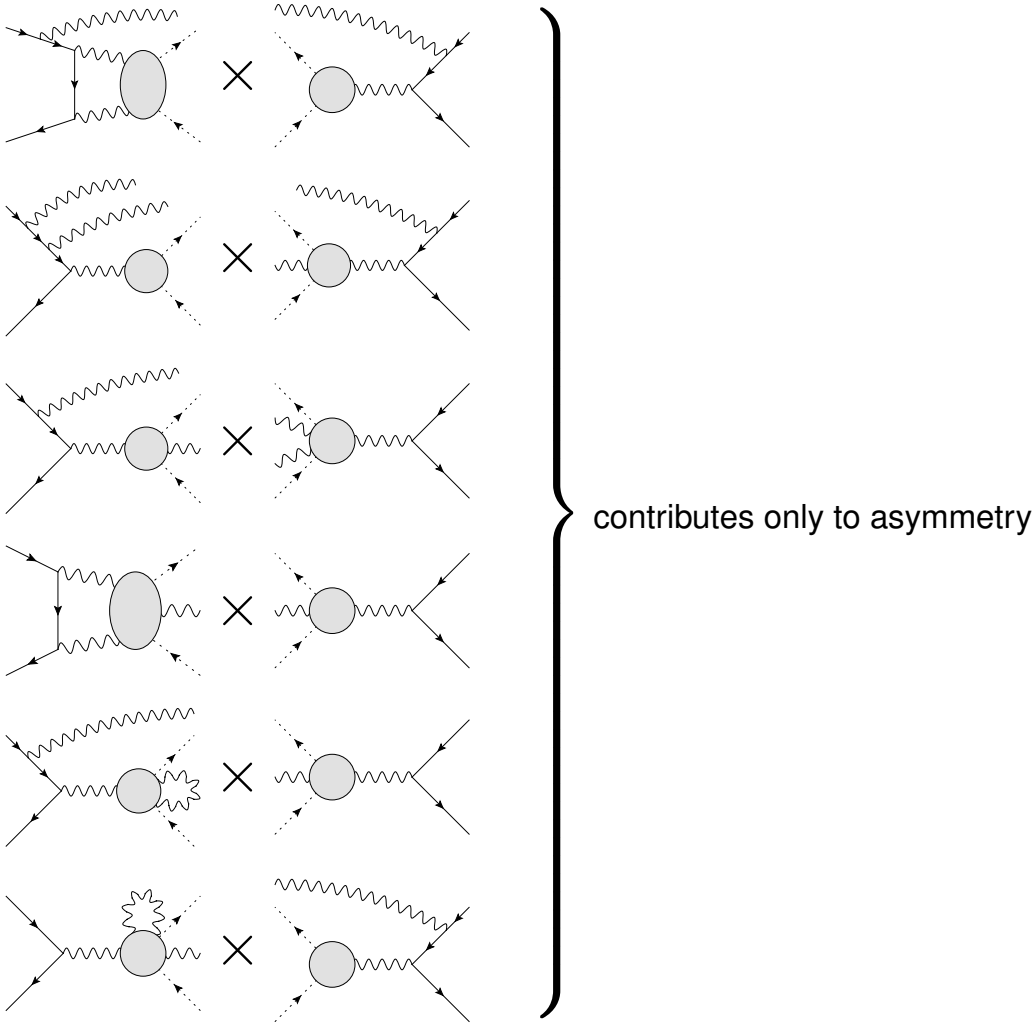


contributing only to charge asymmetry



suppressed by cuts?
PHOKHARA: sQED + resonance approximations
dispersive approach by Colangelo et al.

ISR experiments: NLO (omitting pure QED corrections to LO)



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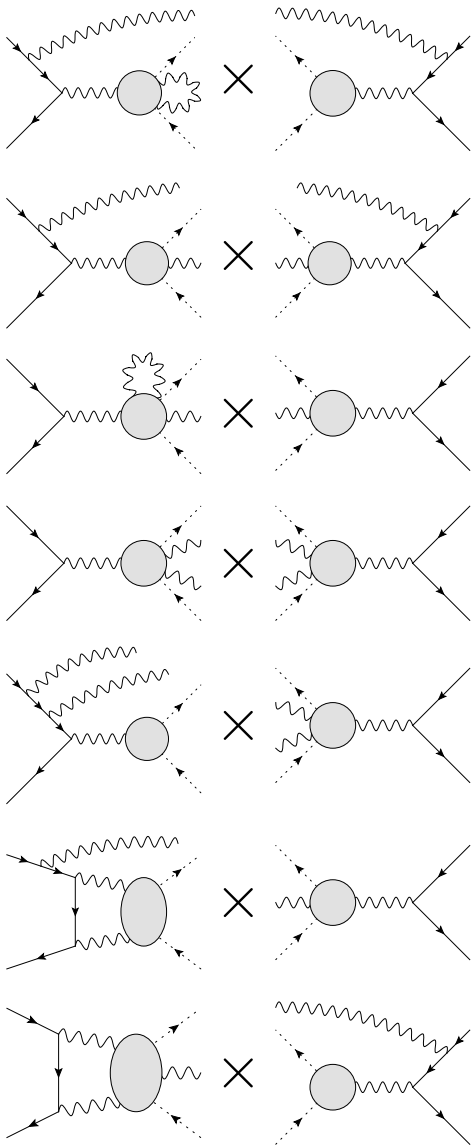

PHOKHARA: sQED + resonance approximations
dispersive approach by Colangelo et al.

contained in PHOKHARA
pure FSR: sufficiently suppressed by experimental cuts?

???
PHOKHARA: sQED, multiplied by form factors *outside* loop
ISR–FSR interference
potential red flag identified during WorkStop

Overview

Summary and outlook

- on hadronic side: require improvements in **structure-dependent** NLO effects
- recent progress on contributions to asymmetry, ongoing work on 2π and 3π channels
- NNLO probably science fiction; not clear that NNLO on hadronic side in some approximation (sQED) should be of any relevance