Radiative corrections

in Monte Carlo generators Phokhara and Ekhara

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Outline

- $\Rightarrow$ PHOKHARA and EKHARA in brief
- $\Rightarrow$ Radiative corrections in PHOKHARA
- $\Rightarrow$ Radiative corrections in EKHARA
- $\Rightarrow$ Summary and near future developments

PHOKHARA MC generator

EVA: $e^+e^- \to \pi^+\pi^-\gamma$

- tagged photon ($\theta_\gamma > \theta_{cut}$)
- ISR at LO + Structure Function
- FSR: point-like pions

[Binner et al.]

$e^+e^- \to 4\pi + \gamma$

- ISR at LO + Structure Function

[Czyż, Kühn,2000]

F. Campanario, H.C., J. Gluza,

A. Grzelińska, M. Gunia, P. Kisza,

J. H. Kühn, E. Nowak-Kubat, T. Riemann,

G. Rodrigo, Sz. Tracz, A. Wapienik,

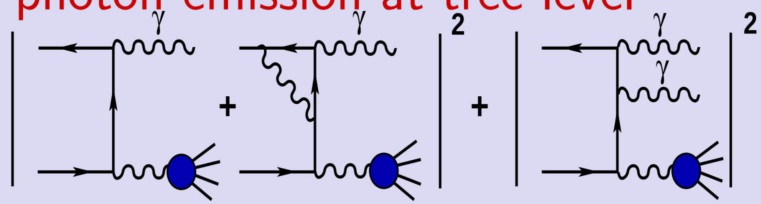
V. Yundin, D. Zhuridov

PHOKHARA 10.0: $\pi^+\pi^-, \mu^+\mu^-,$

4π, $\bar{N}N$, 3π, KK, $\Lambda\bar{\Lambda}$, $P\gamma$

$J/\psi, \psi(2S), \chi_{c_1}, \chi_{c_2}$

- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level



- FSR at NLO: $\pi^+\pi^-$, $\mu^+\mu^-$, K^+K^-, $\bar{p}p$
- tagged or untagged photons
- $e^+e^- \to hadrons$ $(muons)$ ISR at NNLO
- Modular structure

http://ific.uv.es/~rodrigo/phokhara/

EKHARA MC generator

1.0:
$e^+e^- \to \pi^+\pi^- e^+e^-$

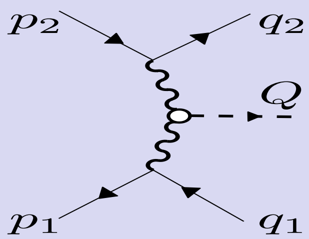
- background to $e^+e^- \to \pi^+\pi^-\gamma$
- Henryk Czyż, Elżbieta Nowak-Kubat, Phys. Lett. B 634, 493 (2006),

2.1: $e^+e^- \to \pi^0 e^+e^-$

- Henryk Czyż, Sergiy Ivashyn, Com.Phys.Commun. 182 (2011) 1338

+ A. Korchin, O. Shekhovtsova, P. Kisza

EKHARA 3.0: $\pi^+\pi^-$, π^0, η, η', χ_{c_i}, $\chi_{c_i} \to J/\psi(\to \mu^+\mu^-)\gamma$

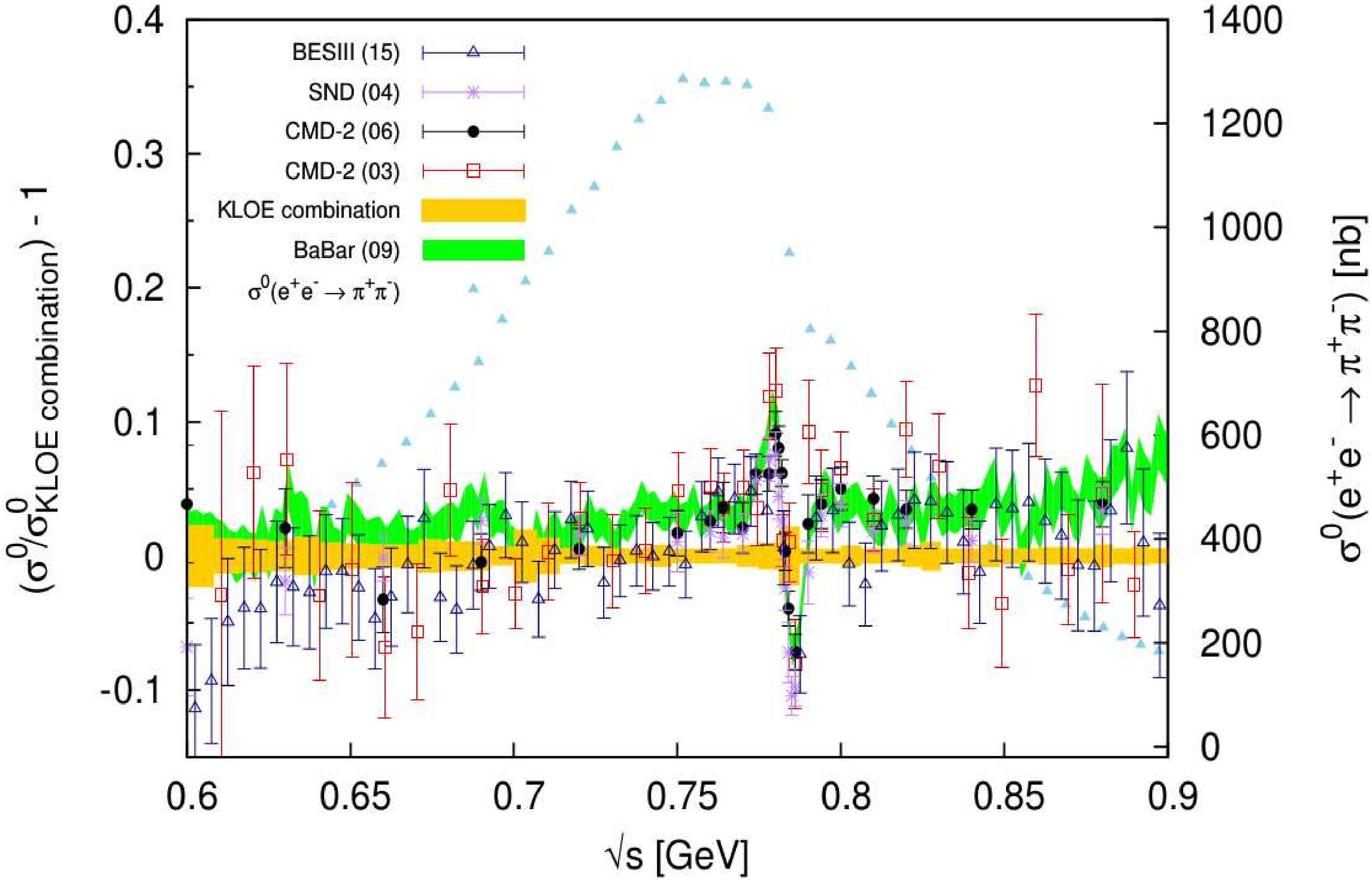


- Modular structure
- Radiative corrections included for P

`http://prac.us.edu.pl/~ ekhara/`

HC, P. Kisza, Comput.Phys.Commun. 234 (2019) 245

NLO $e^+e^- \to \pi^+\pi^-\gamma$ -motivation



KLOE: JHEP 1803 (2018) 173

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

The team:

F. Campanario, G. Rodrigo, Sz. Tracz (Valencia)

H.C., J. Gluza, (Katowice)

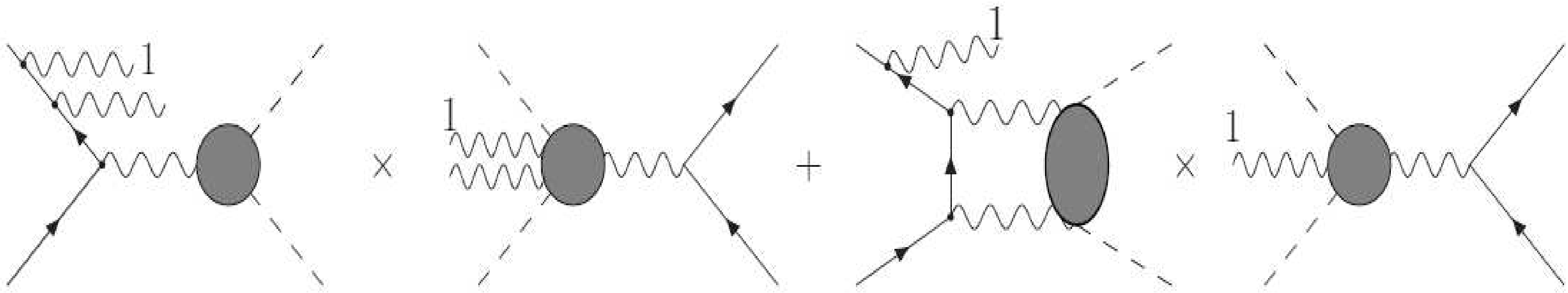
T. Jeliński, D. Zhuridov (left physics)

Status - finished: arXiv:1903.10197

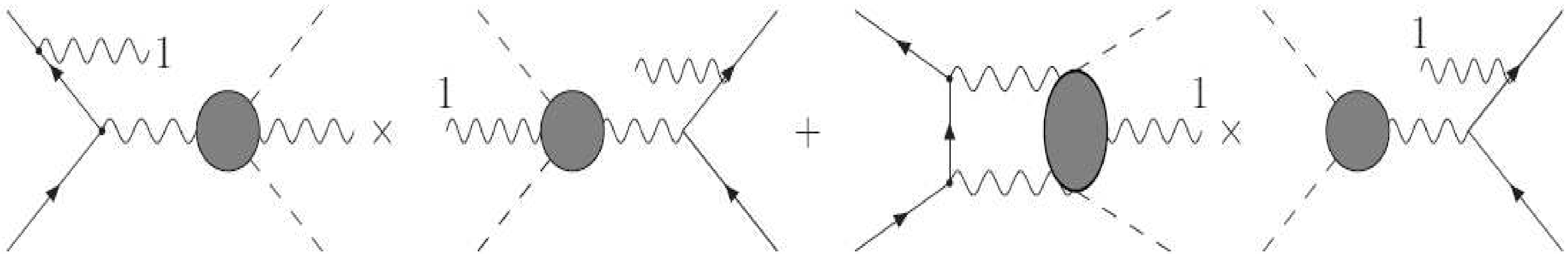
$\Rightarrow$ sQED + form factors:
FSR at NLO and pentaboxes ready and fully tested

$\Rightarrow$ Phokhara10.0
http://ific.uv.es/$\sim$ rodrigo/phokhara/

TPE(PB) for pions

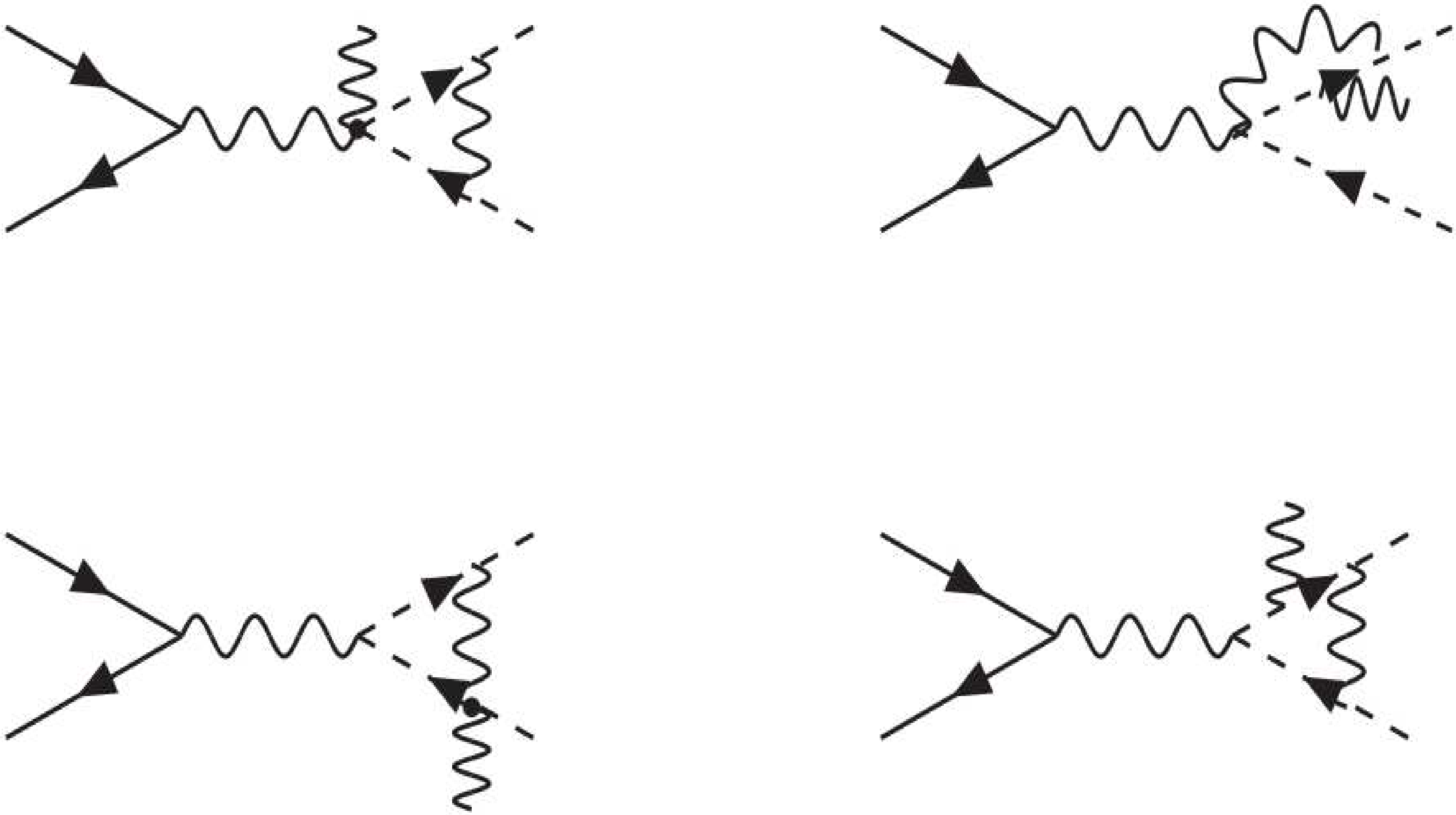


(E)



ETC.

FSR for pions



ETC.

FSR vs. TPE - few remarks

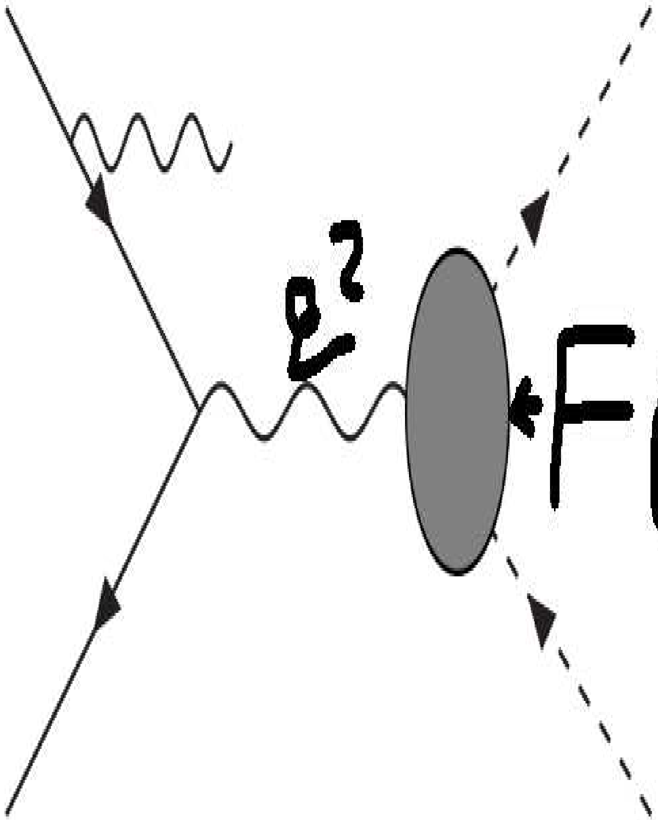
$\Rightarrow$ TPE

UV finite, IR infinite

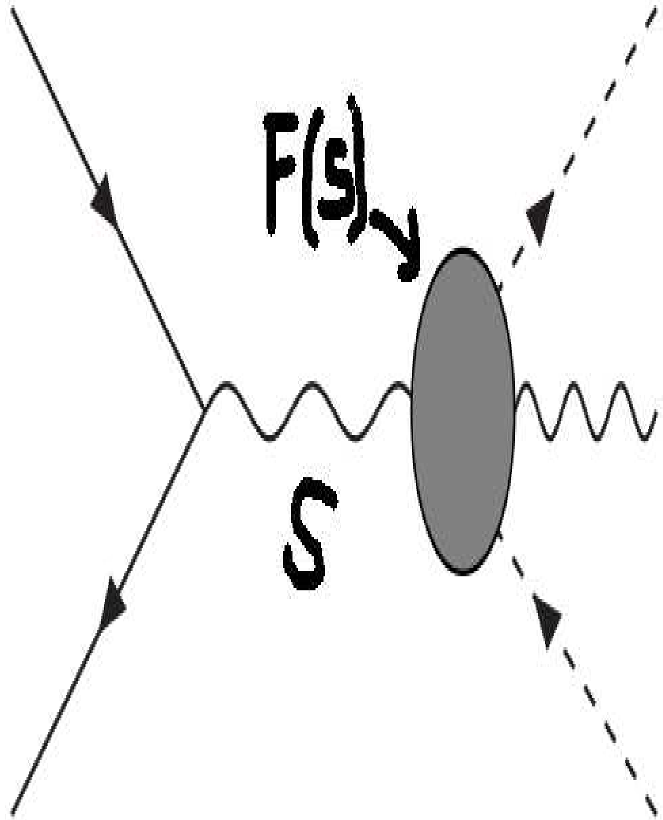
$\Rightarrow$ FSR

UV and IR infinite
on-mass-shell renormalization scheme was used

Model assumptions

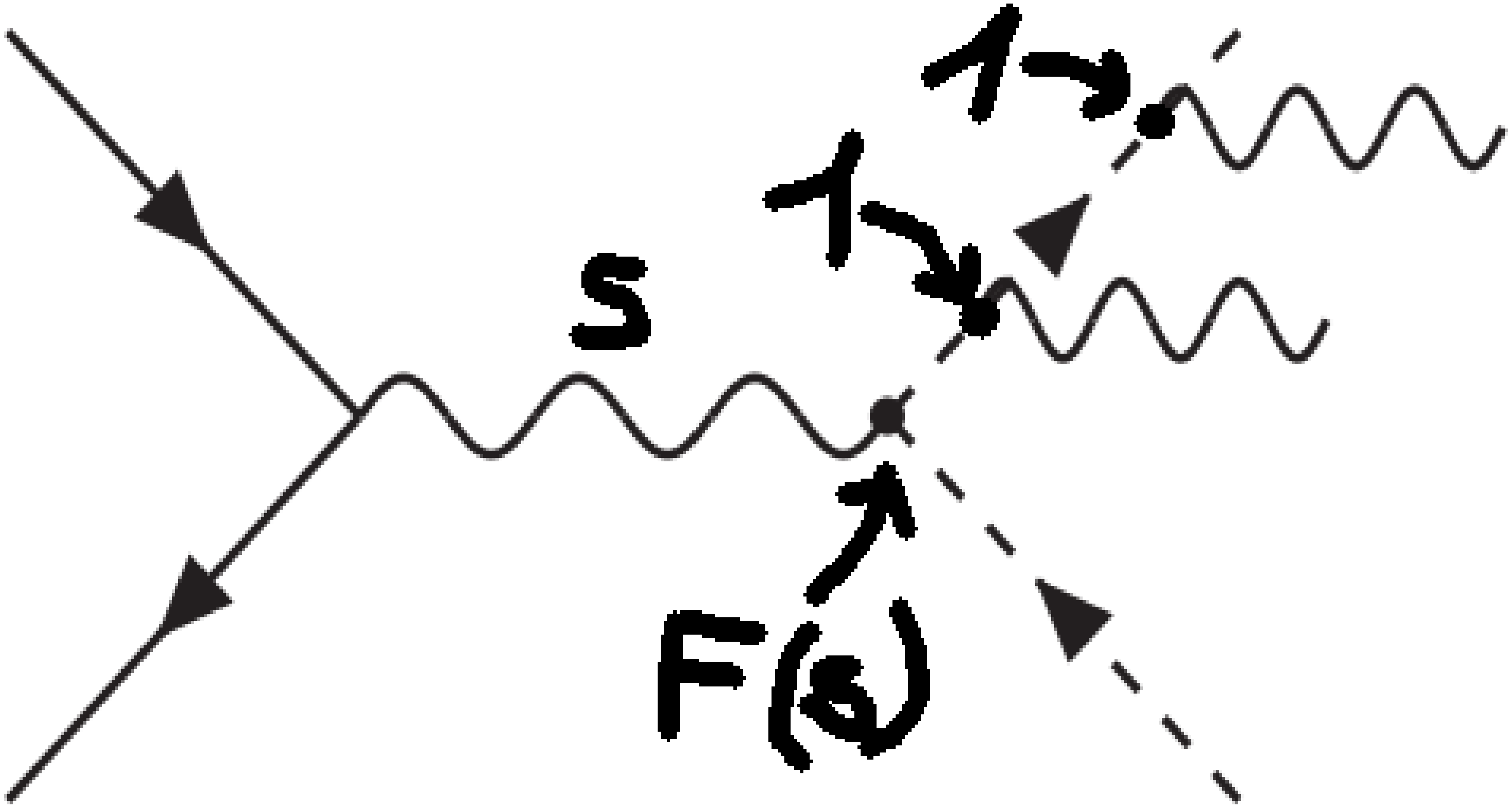


a)

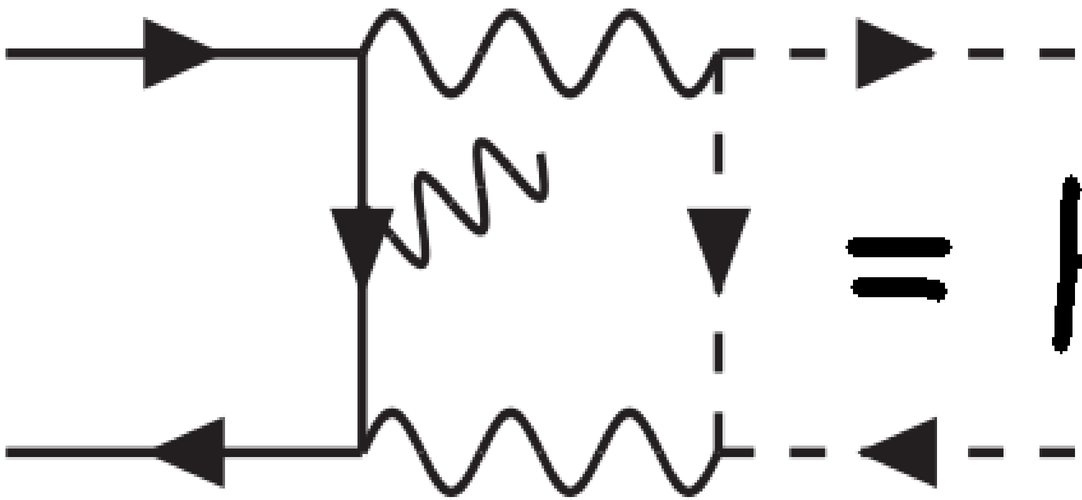


b)

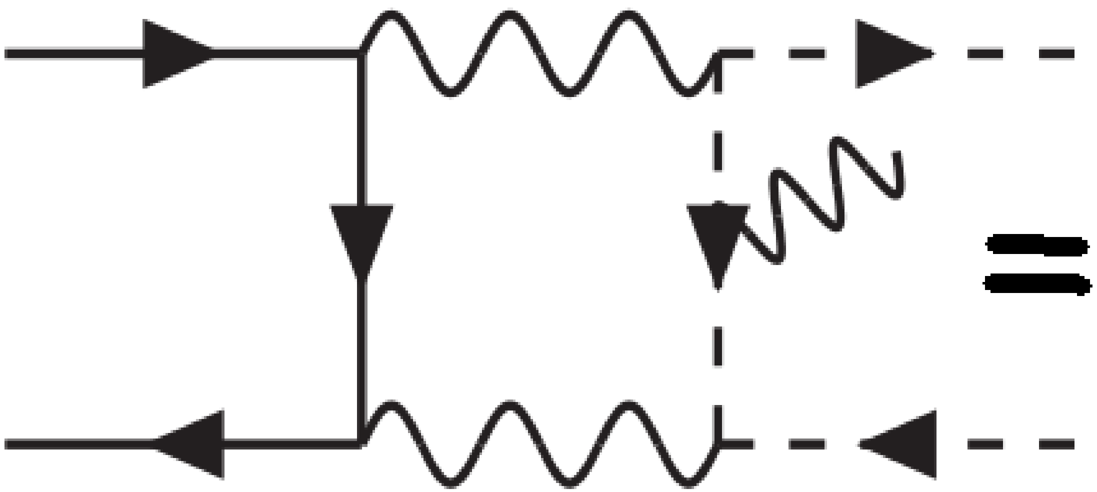
Model assumptions



Model assumptions



$= F(q^2) \cdot$ sQED



$= F(s) \cdot$ sQED

Complete NLO for pions - tests

⇒ two independent codes for the new hard part

⇒ the virtual corrections implementation:

the tensor reduction and the amplitude (trace) in quadruple(TPV) double(FSR) precision

A. Denner et al. Nucl. Phys. B 734 (2006) 62, T. Binoth et al., JHEP 0510 (2005) 015

F. Campanario, JHEP 1110 (2011) 070

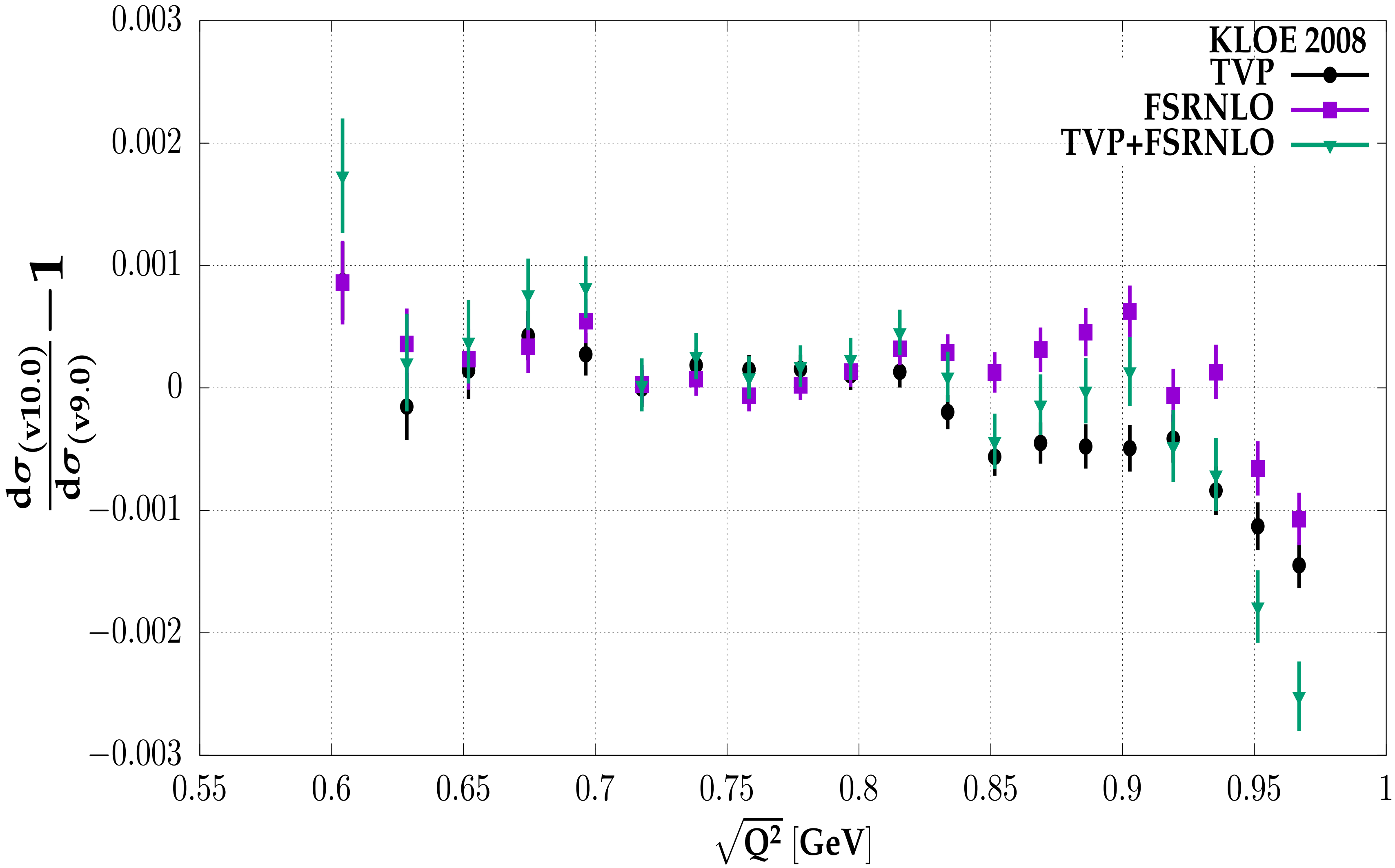
with scalar integrals in double precision (QCDLOOP)

⇒ Tests performed:

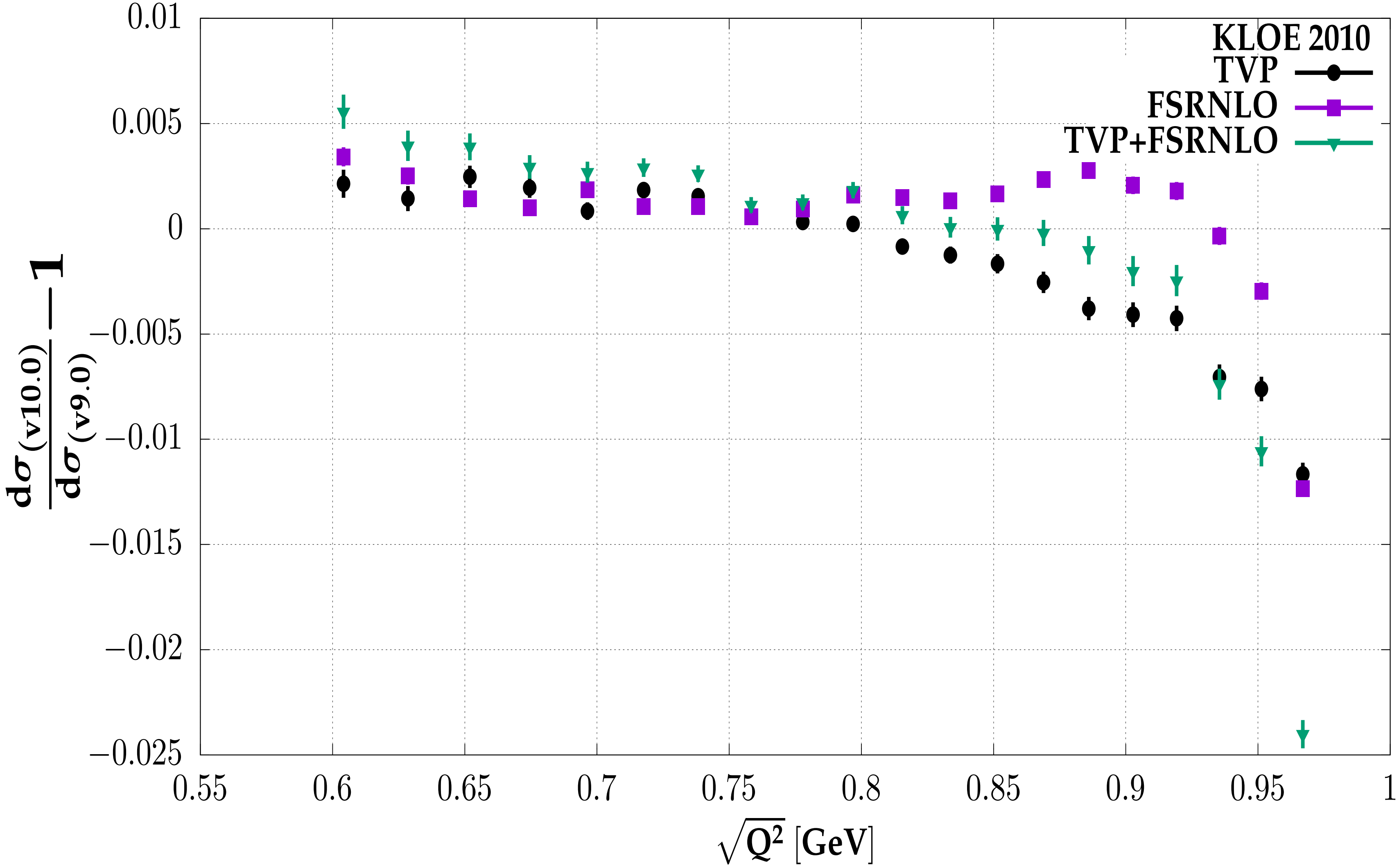
Comparison with LOOPTOOLS full quadruple precision within Mathematica; accuracy: $\mathbf{10^{-5}}$

⇒ Soft divergences tests

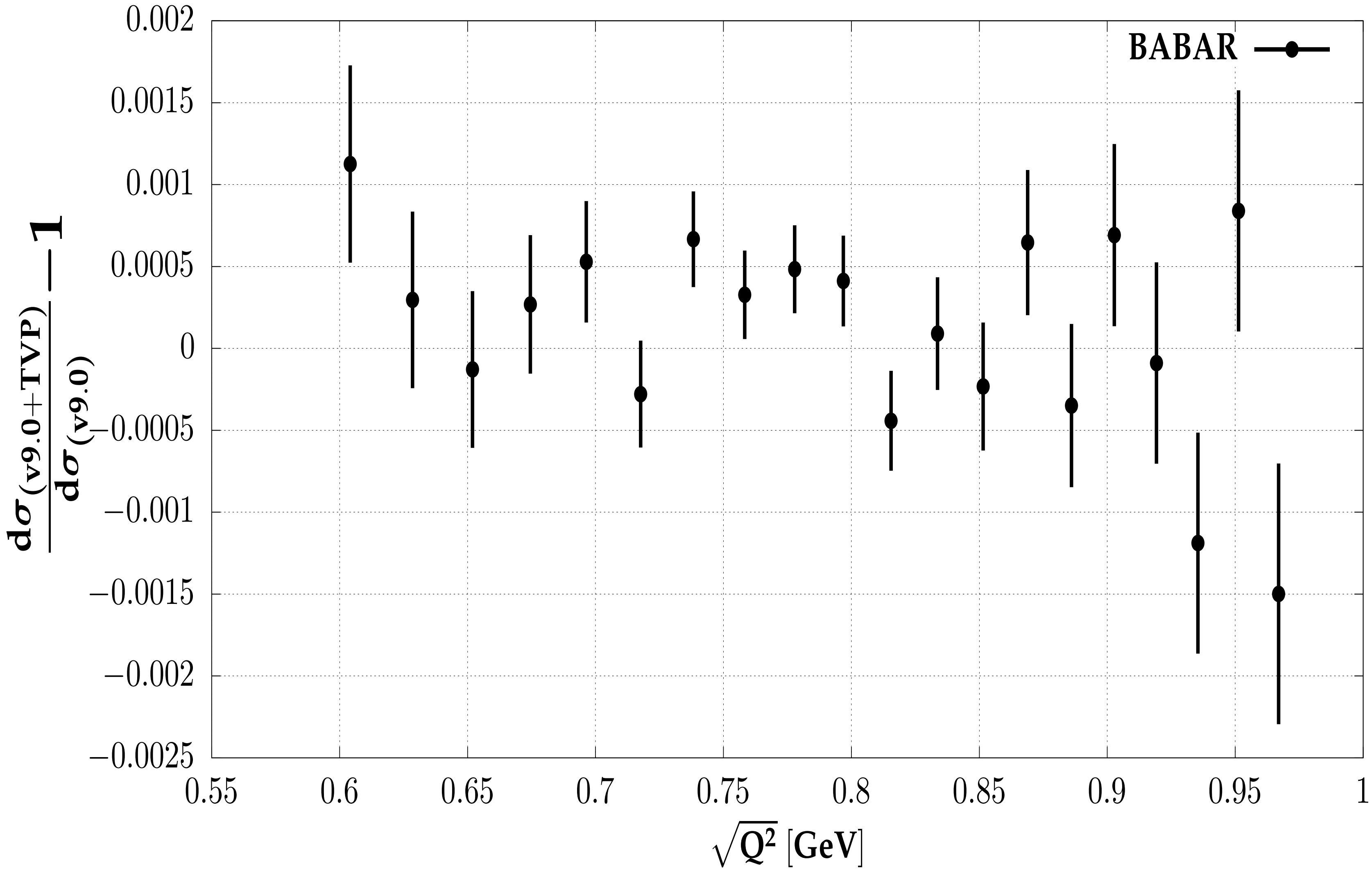
Complete NLO: KLOE-small



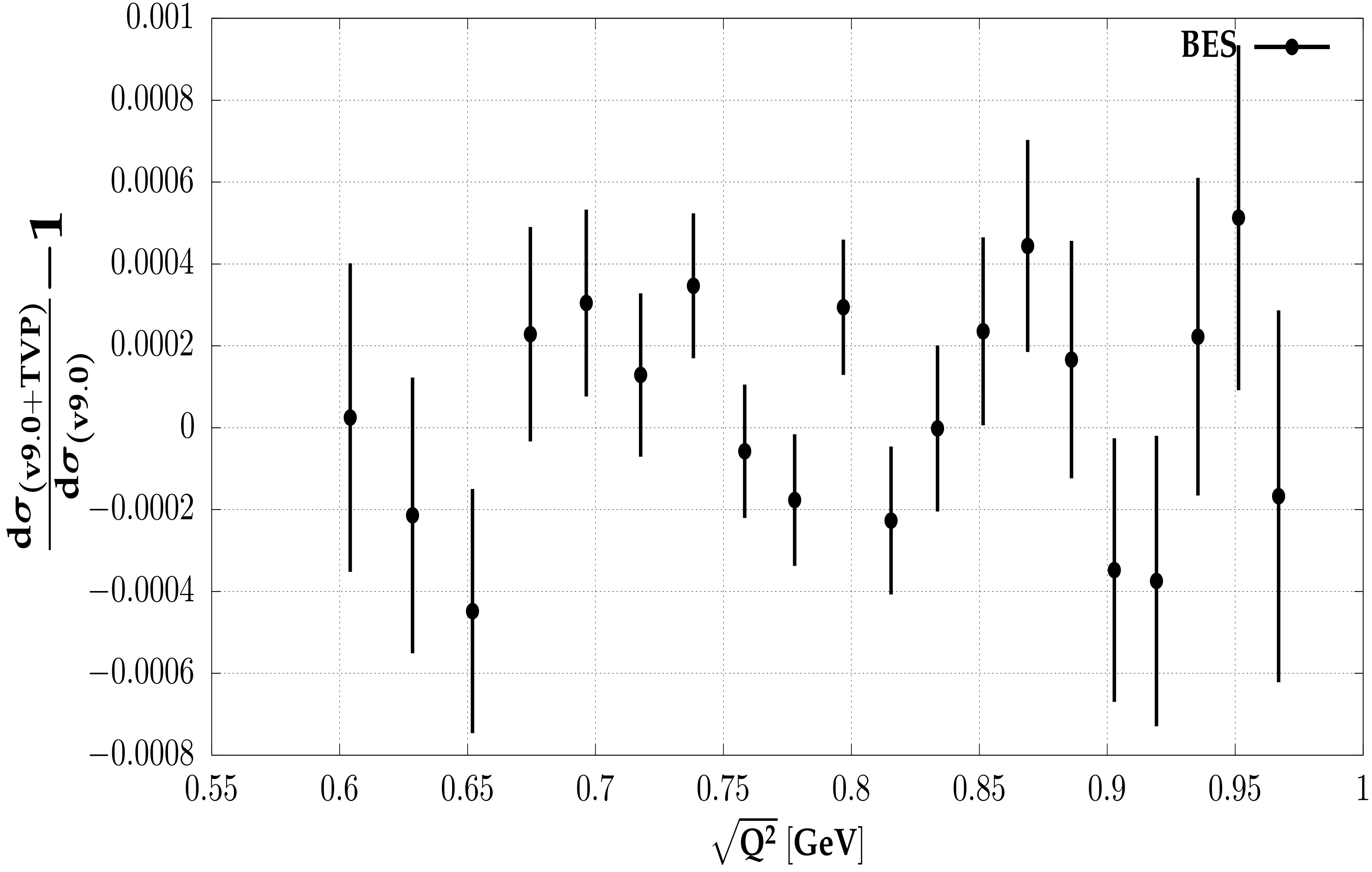
Complete NLO: KLOE-large



Complete NLO: BaBar



Complete NLO: BES



Conclusions

$\Rightarrow$ arXiv:1903.10197(tbp in PRD) and JHEP 1402 (2014) 114

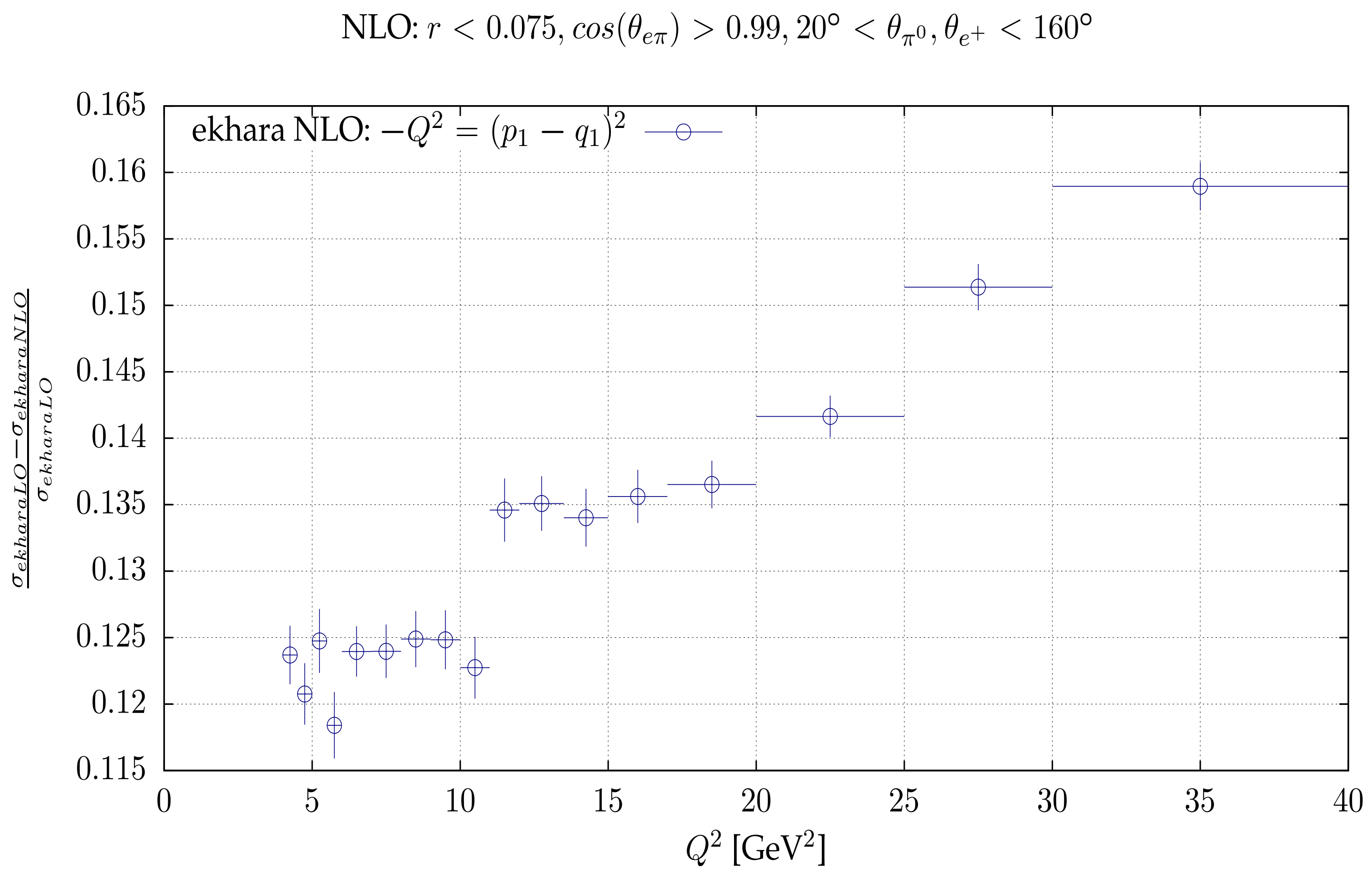
show that missing NLO radiative corrections

cannot be the source of the discrepancies between

the different extractions of the pion form factor

performed by BaBar, BES and KLOE

EKHARA: NLO for experimental cuts



$$e^+e^- \to e^+e^-\pi^0$$

HC, P. Kisza, Comput.Phys.Commun. 234 (2019) 245

Near future developments

$\Rightarrow$ PHOKHARA: NNLO at LL

$\Rightarrow$ EKHARA,$e^+e^- \to e^+e^-\pi^+\pi^-$

(HC, I.Danilkin, Y.Guo, M.Vanderhaeghen):

$\Rightarrow$ New phase space generation algorithm

$\Rightarrow$ Rescattering amplitudes

$\Rightarrow$ $\pi^0\pi^0$ and $\pi^0\eta$ modes