Radiative corrections

H. CZYŻ, IF, UŚ, Katowice, Poland

First Workshop of the (g-2)$_\mu$ Theory Initiative
June 2017

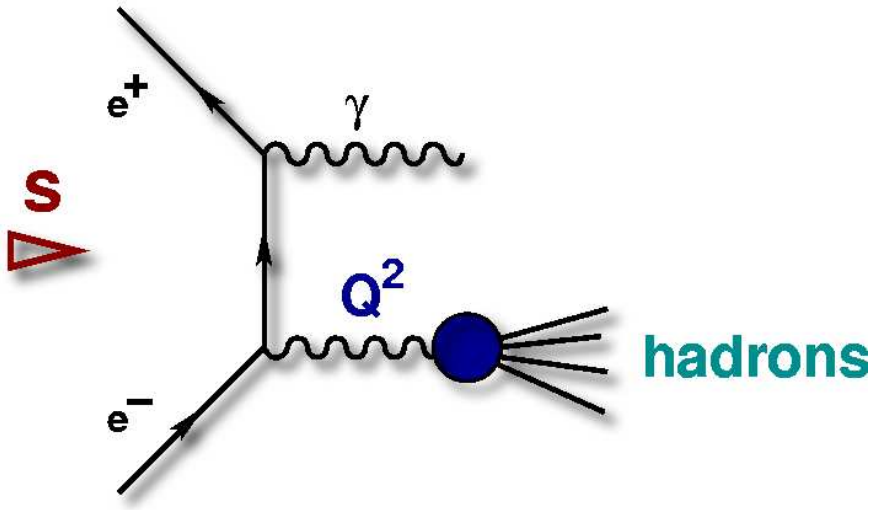
Outline

- ⇒ PHOKHARA in brief
- ⇒ Missing radiative corrections:
  - ⇒ FSR modeling
  - ⇒ Pentaboxes
  - ⇒ ISR NNLO
- ⇒ Recent developments in PHOKHARA
- ⇒ Final remarks

THE RADIATIVE RETURN METHOD

$$d\sigma(e^+e^- \to \text{hadrons} + \gamma(ISR)) =$$

$$H(Q^2, \theta_\gamma)\; d\sigma(e^+e^- \to \text{hadrons})(s = Q^2)$$



- measurement of $R(s)$ over the full range of energies, from threshold up to $\sqrt{s}$
- large luminosities of factories compensate α/π from photon radiation
- radiative corrections essential (NLO,...)

High precision measurement of the hadronic cross-section at meson-factories

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, J. H. Kühn,

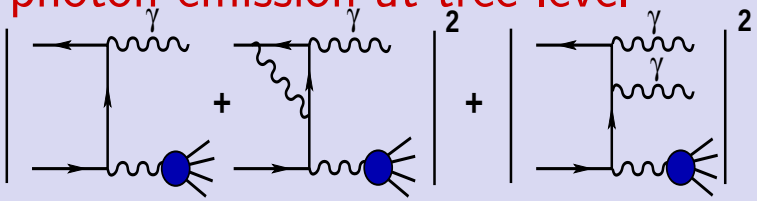
E. Nowak-Kubat, T. Riemann,

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

V. Yundin, D. Zhuridov

PHOKHARA 9.2: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π, $\bar{N}N$, 3π, KK,$\Lambda\bar{\Lambda}$ $J/\psi, \psi(2S), \chi_{c1}, \chi_{c2}$

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

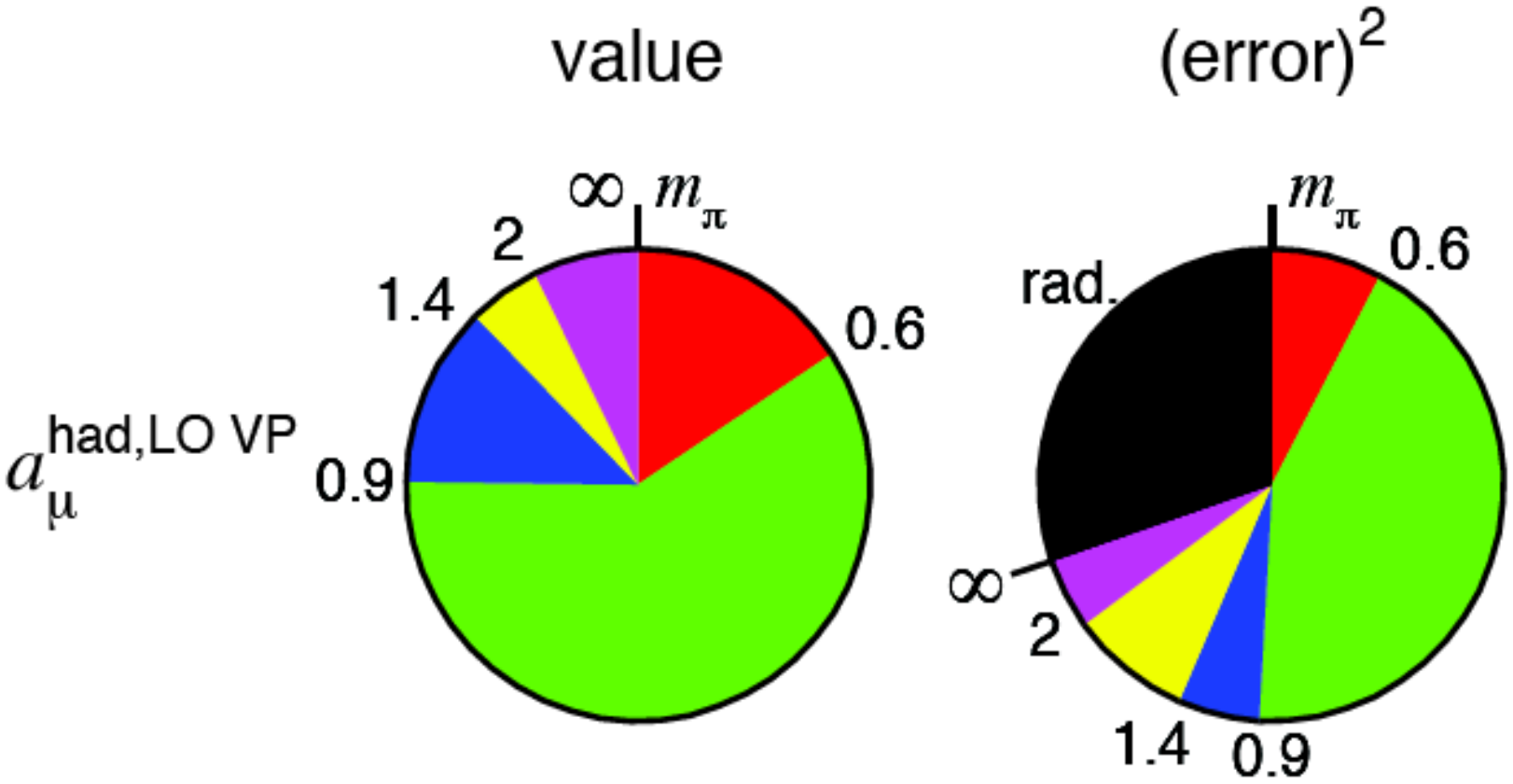


- FSR at NLO:$\pi^+\pi^-$, $\mu^+\mu^-$,K^+K^-, $\bar{p}p$
- tagged or untagged photons
- $e^+e^- \to hadrons\ (muons)$ ISR at NNLO
- Modular structure

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

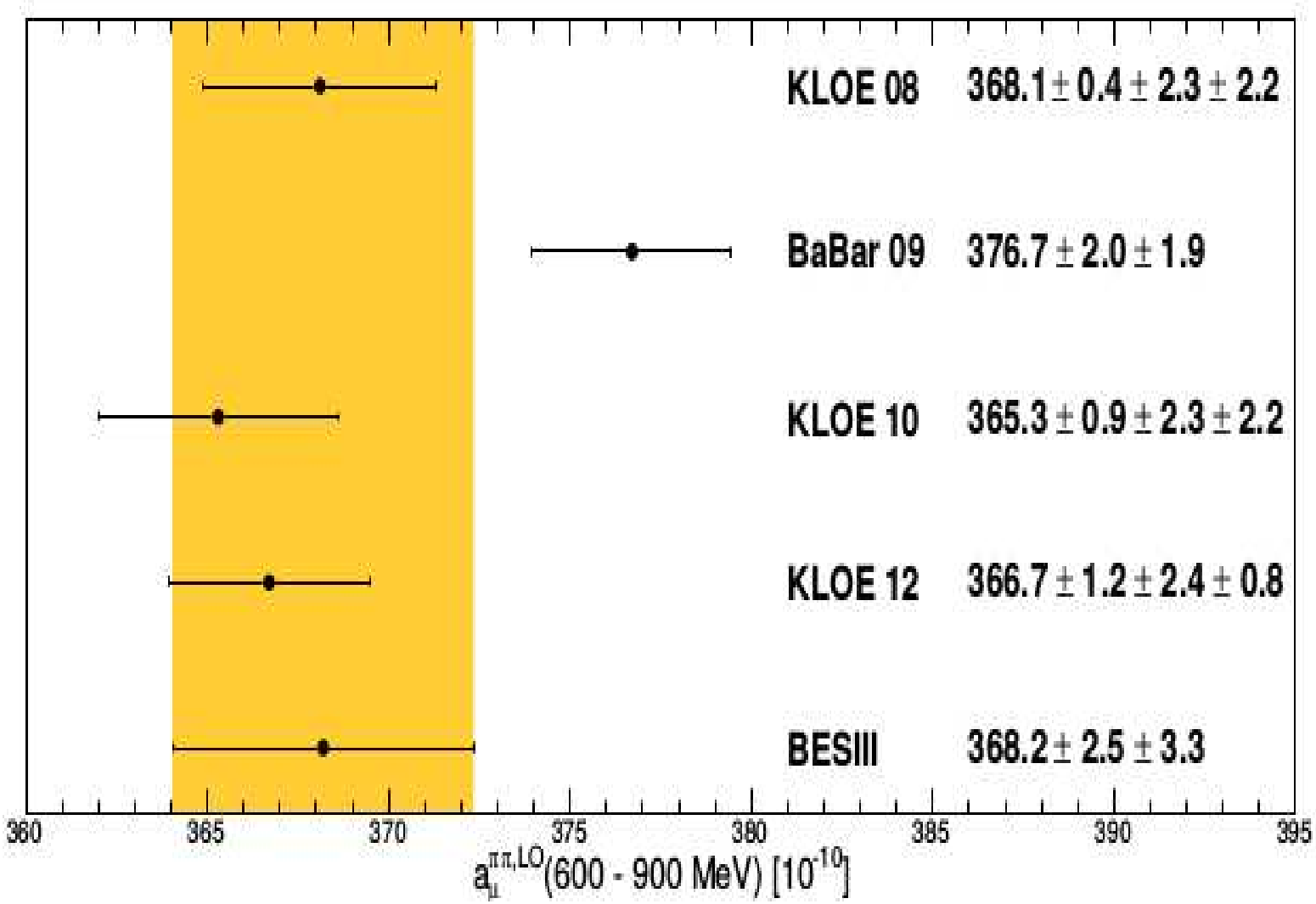
$a_\mu^{had\ LO}$

Hagiwara et al. J.Phys. G38 (2011) 085003



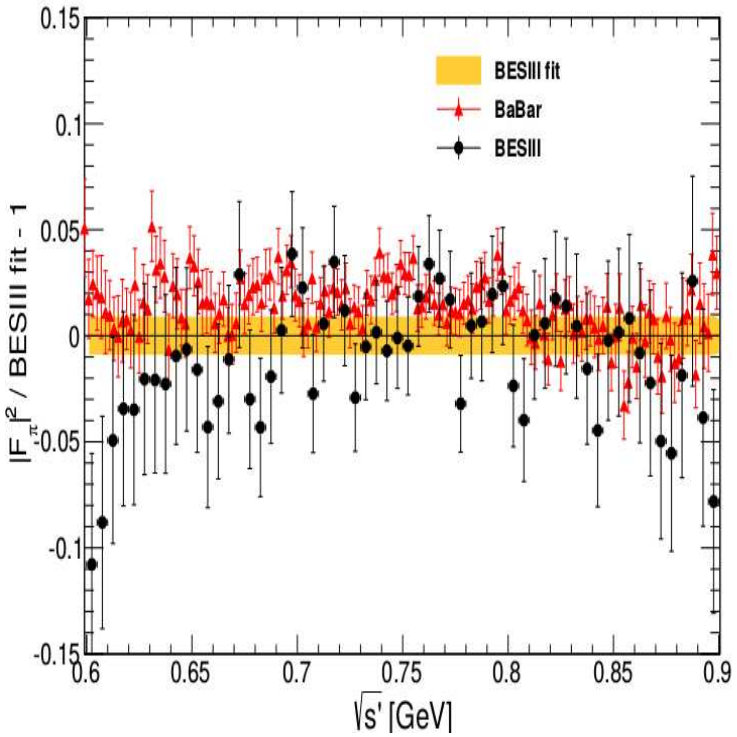
BESIII new results

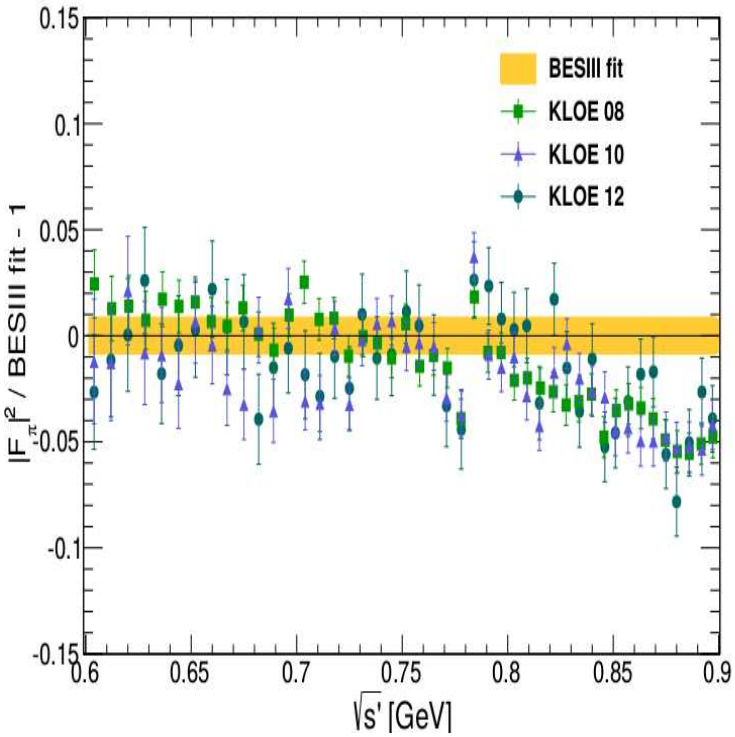
Phys.Lett. B753 (2016) 629



BESIII new results

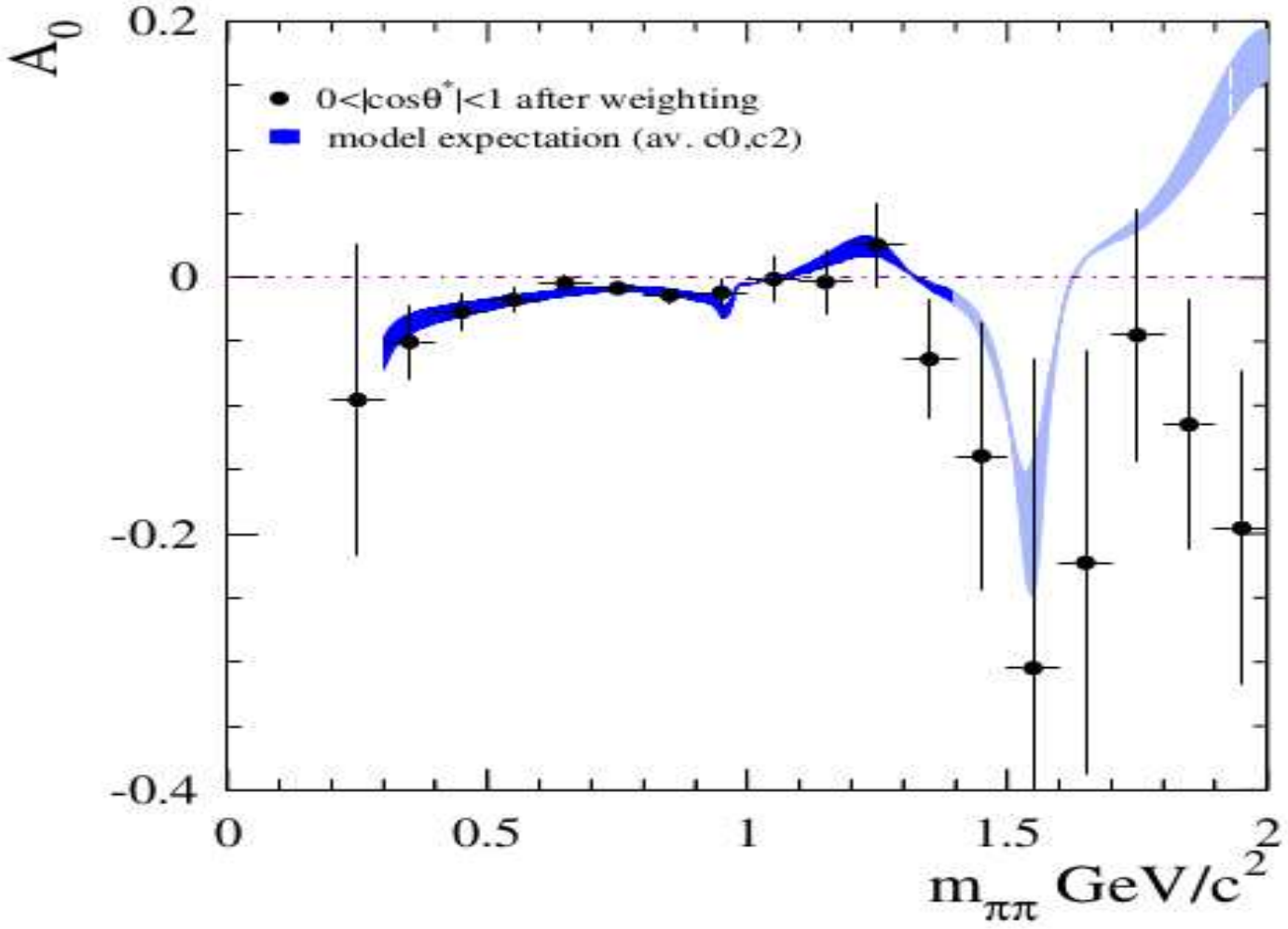
Phys.Lett. B753 (2016) 629



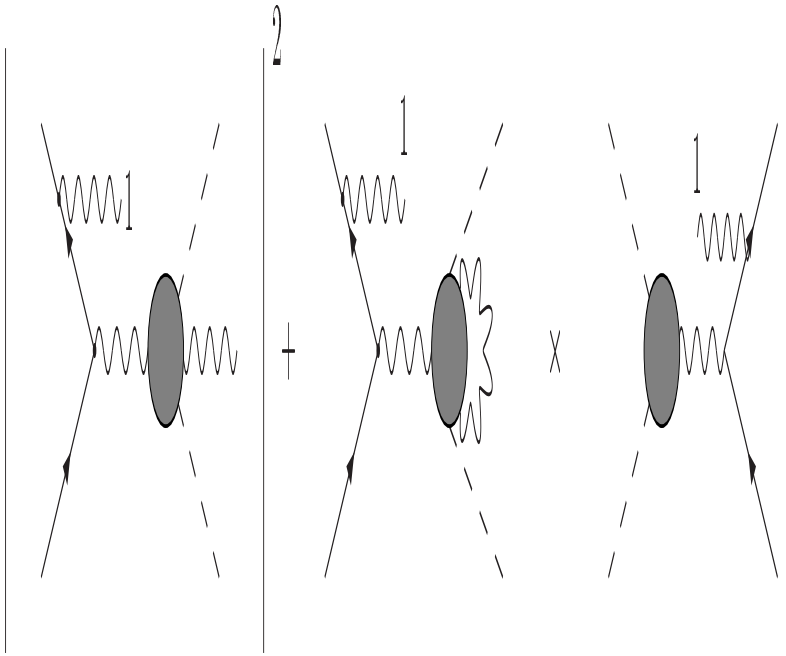


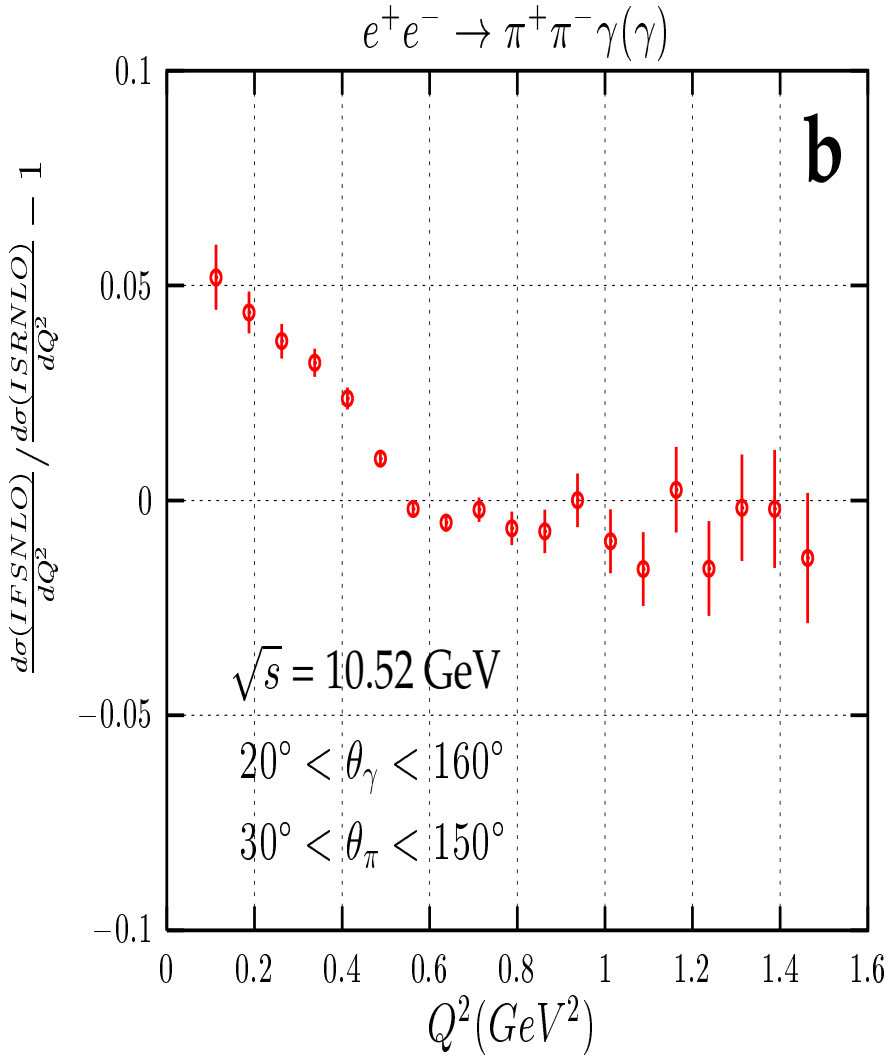
Charge asymmetries, pions

BaBar vs. AfkQed, Phys.Rev. D92 (2015) 7, 072015



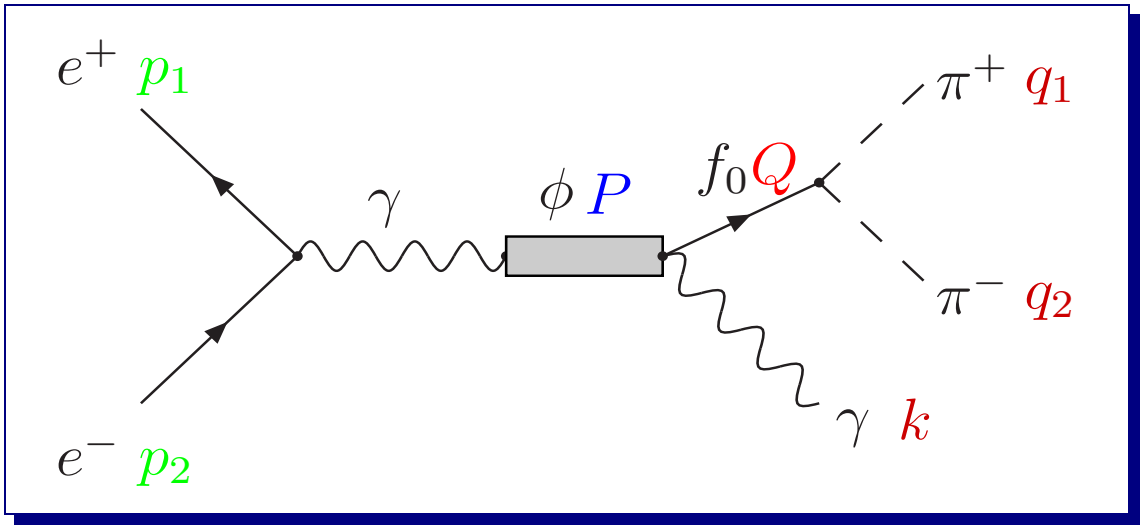
FSR at NLO, PHOKHARA

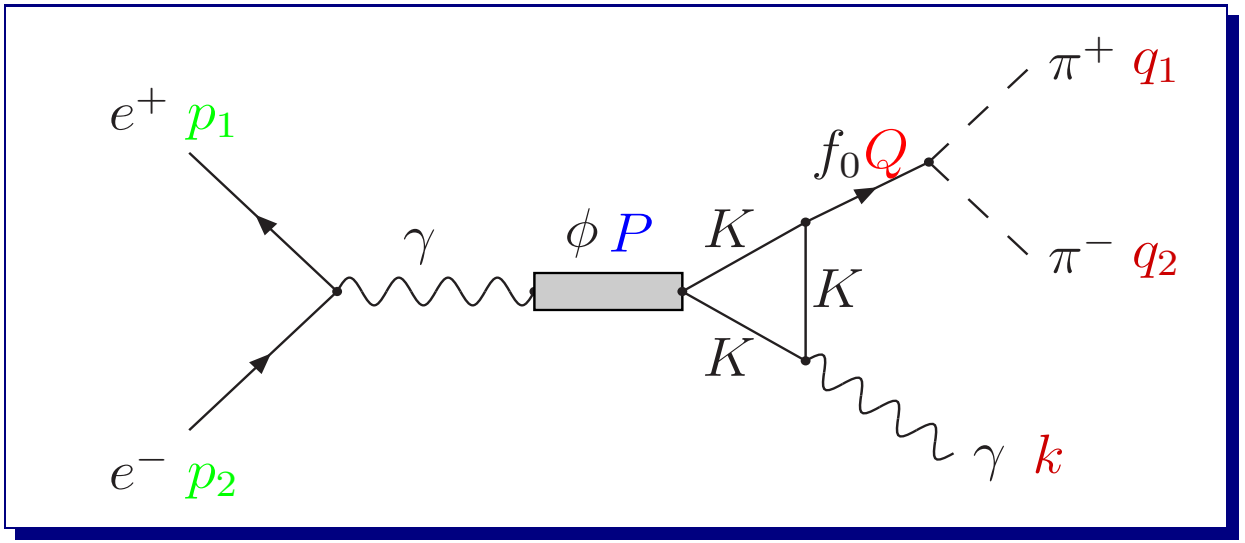




FSR at KLOE, additional contributions:

$$e^+e^- \to \phi^* \to (f_0(980)_{f_0} + f_0(600)_{\sigma})\gamma \to \pi\pi\gamma$$



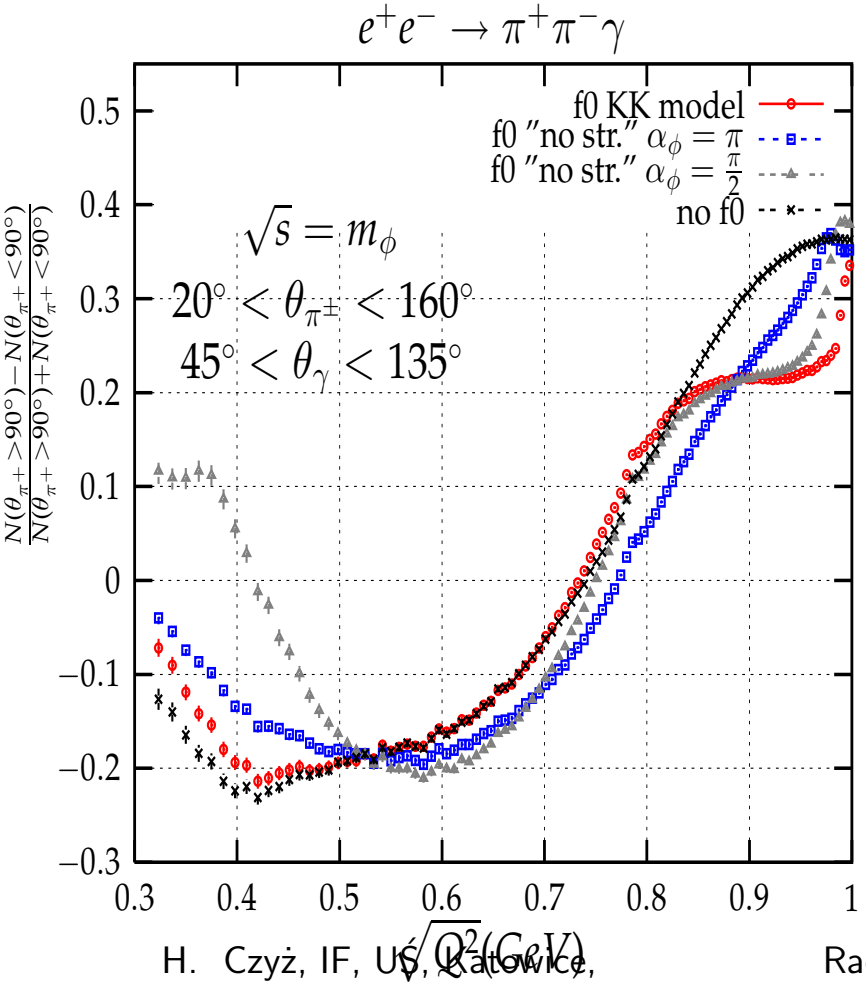


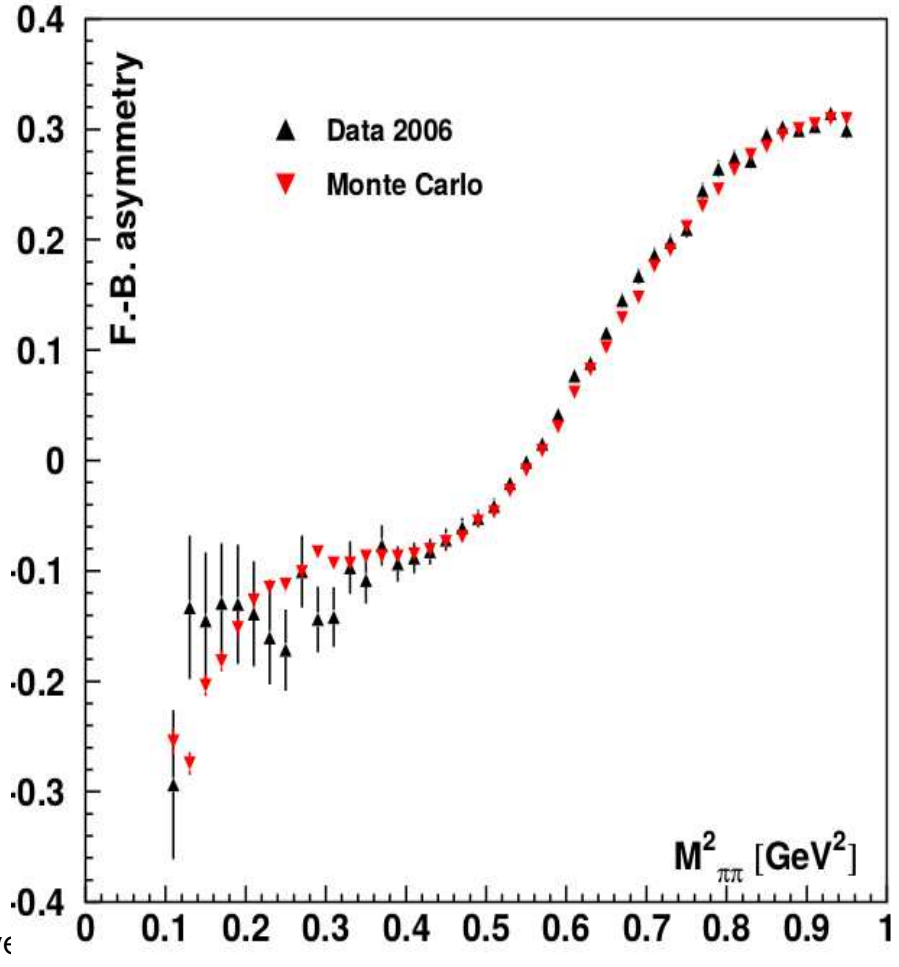
FSR at NLO

H. Czyż, A. Grzelińska and J. H. Kühn, Phys.Lett. B611 (2005) 116

KLOE Collaboration: Phys.Lett. B634 (2006) 148

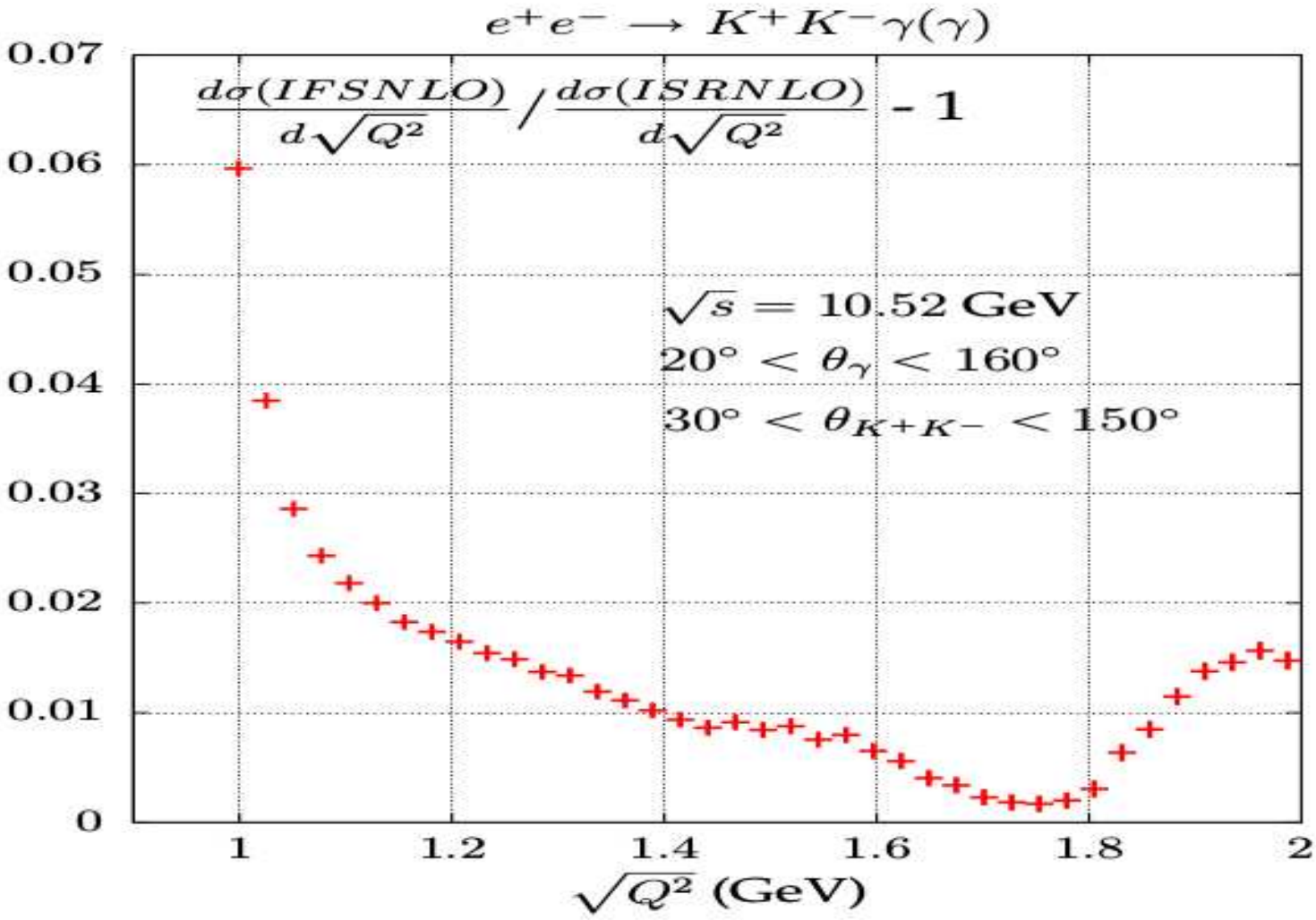
and RMCWG Eur.Phys.J. C66 (2010) 585





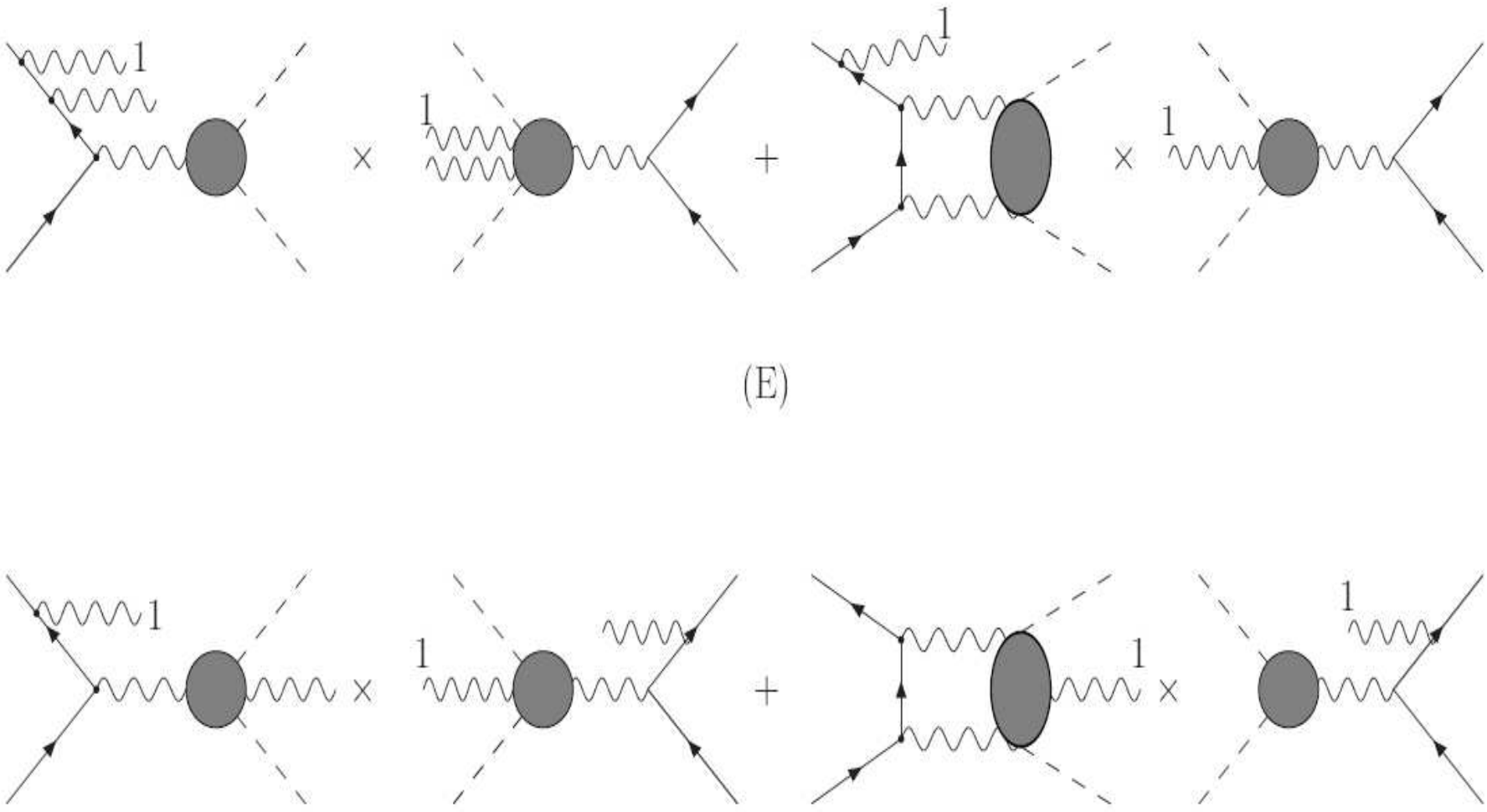
FSR at NLO for K^+K^-

H. Czyż, A. Grzelińska and J. H. Kühn, Phys.Rev. D81 (2010) 094014



PENTABOXES

For muons only, for pions in progress



(E)

The team

F. Campanario, (Valencia)

H.C., J. Gluza, T. Jeliński, Sz. Tracz, D. Zhuridov (Katowice)

T. Riemann (DESY, Zeuthen)

Status

$\Rightarrow$ sQED + form factors:
two independent codes ready

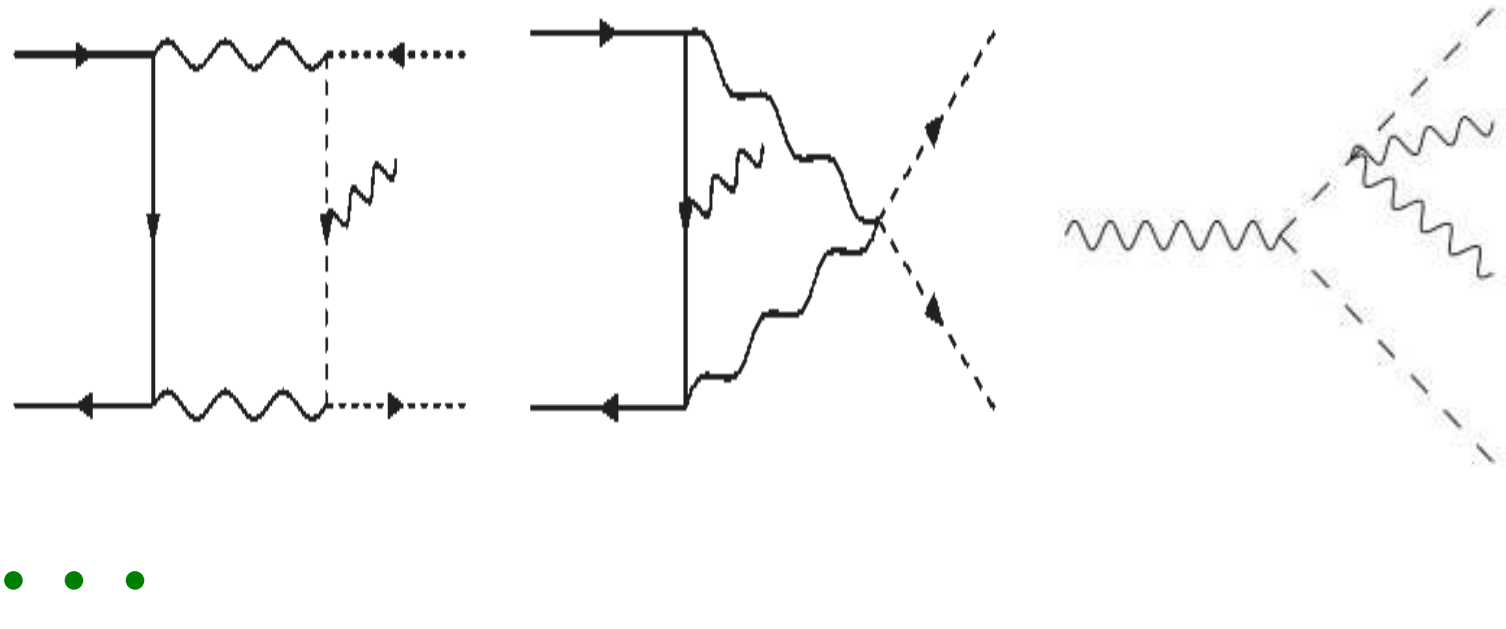
$\Rightarrow$ sQED + form factors: going on tests

$\Rightarrow$ the code(s) partly tested

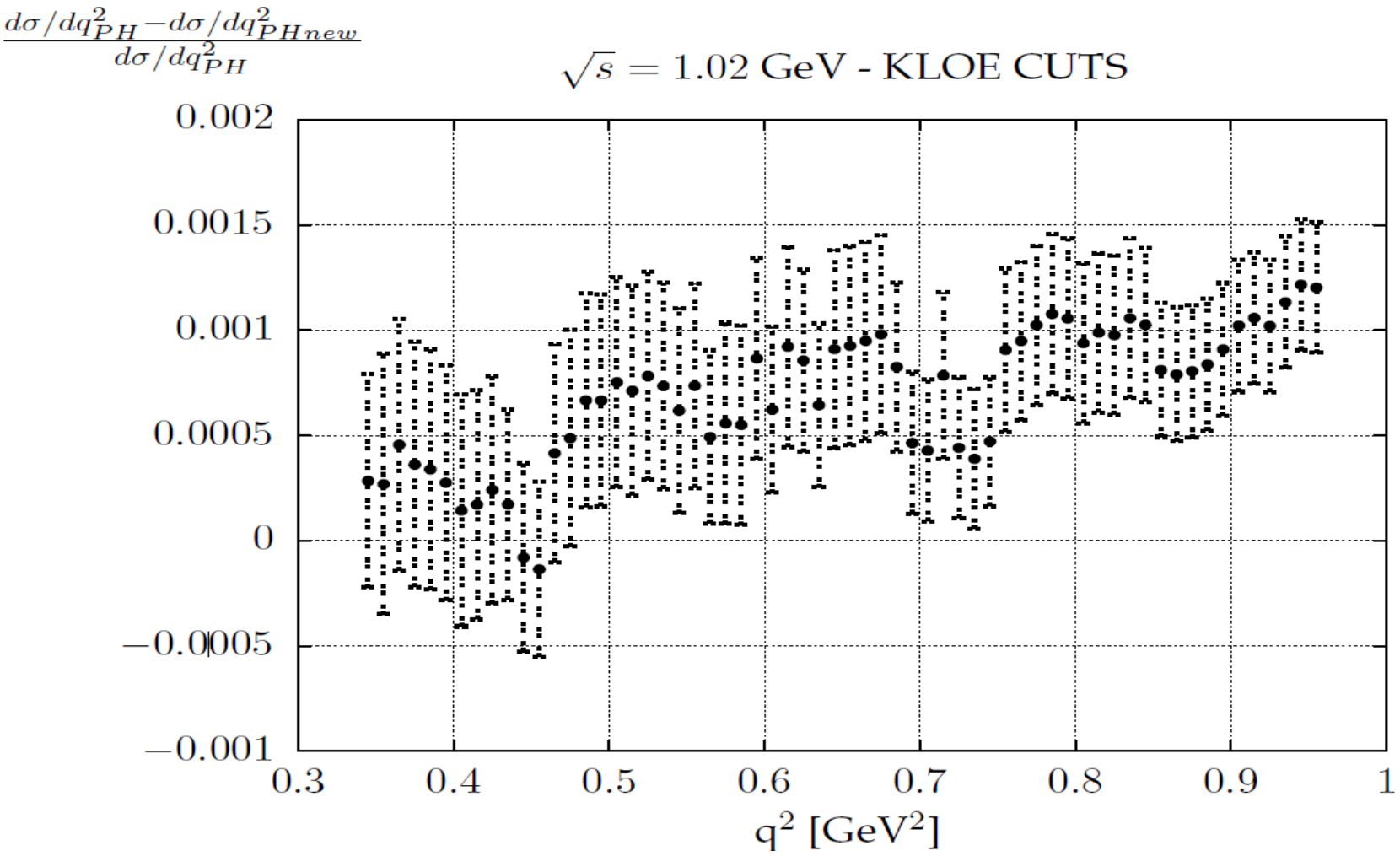
$\Rightarrow$ hoping to finish this year

PENTABOXES-pions

The task:

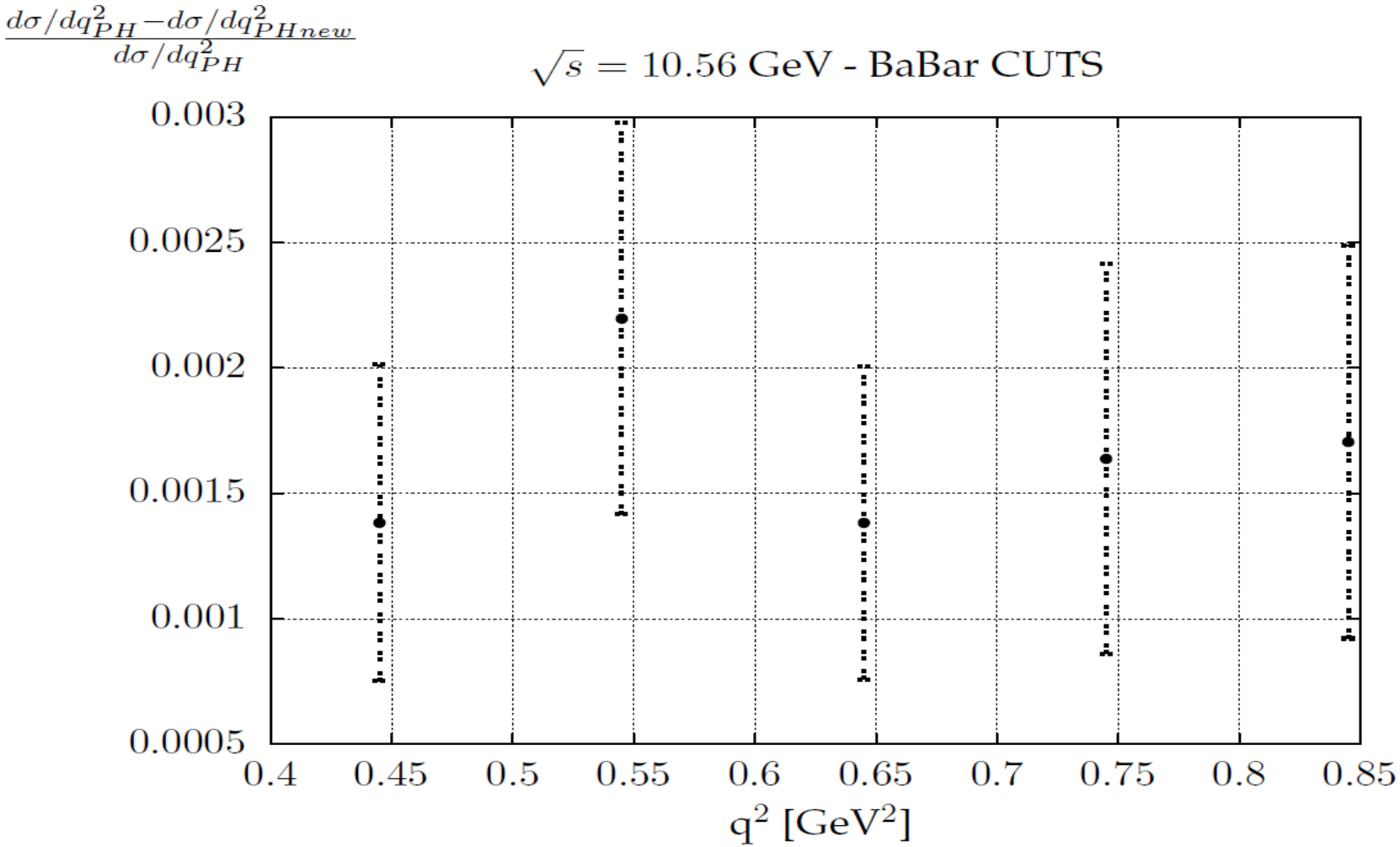


Size of the new corrections



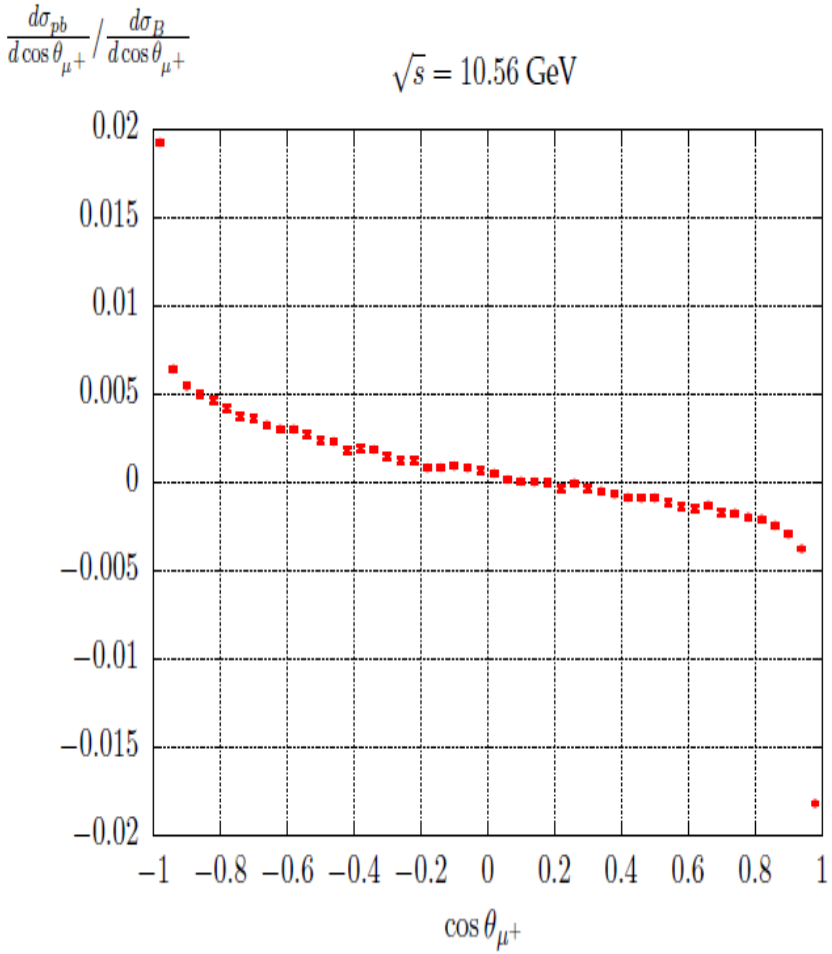
JHEP 1402 (2014) 114

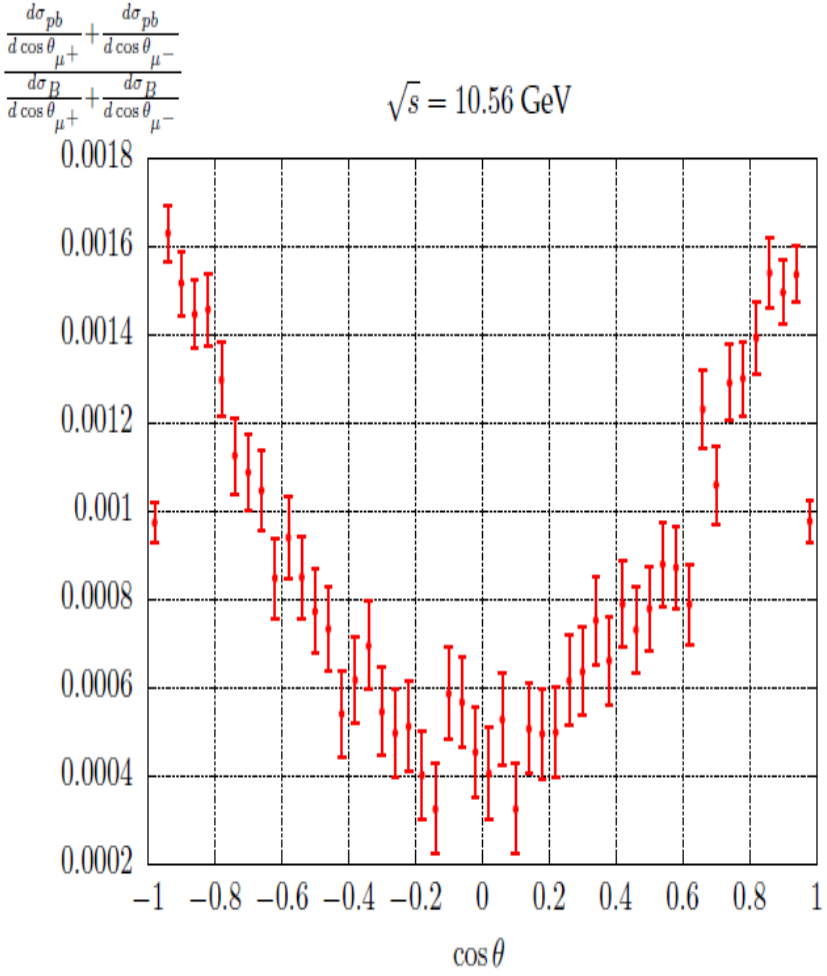
Size of the new corrections



JHEP 1402 (2014) 114

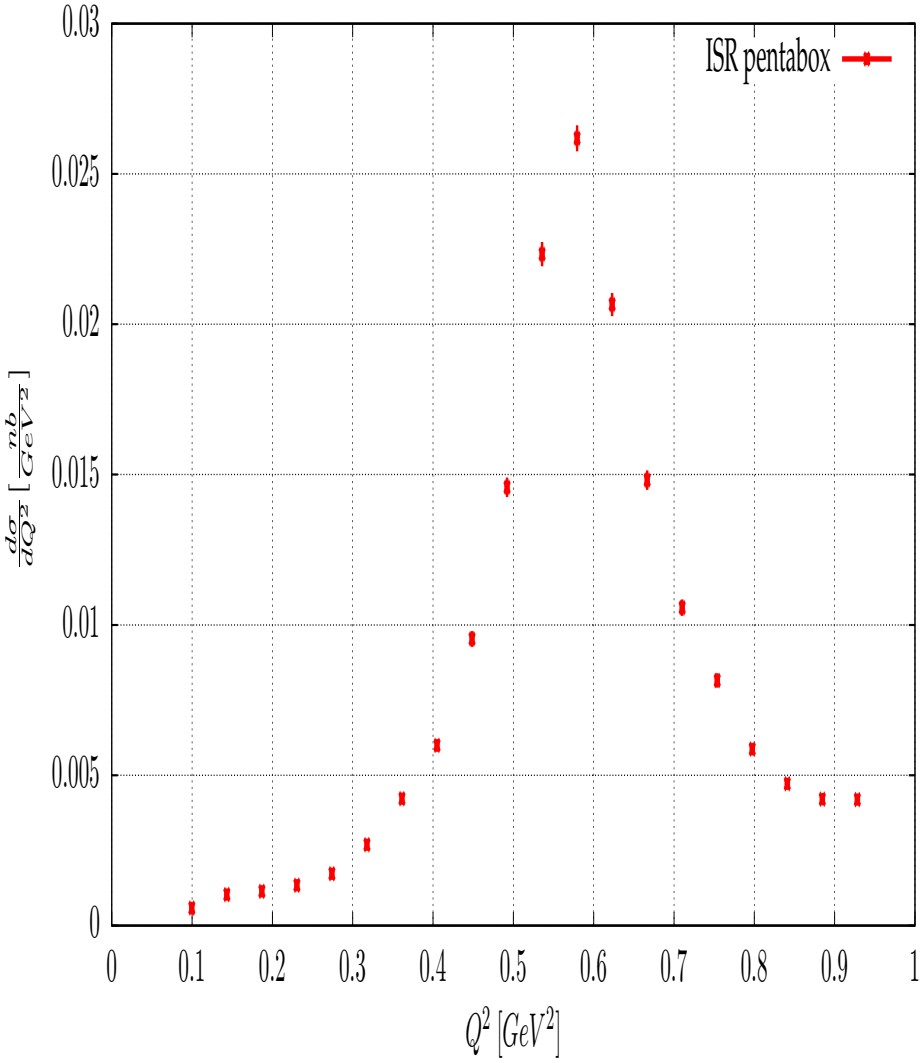
Size of the pentaboxes

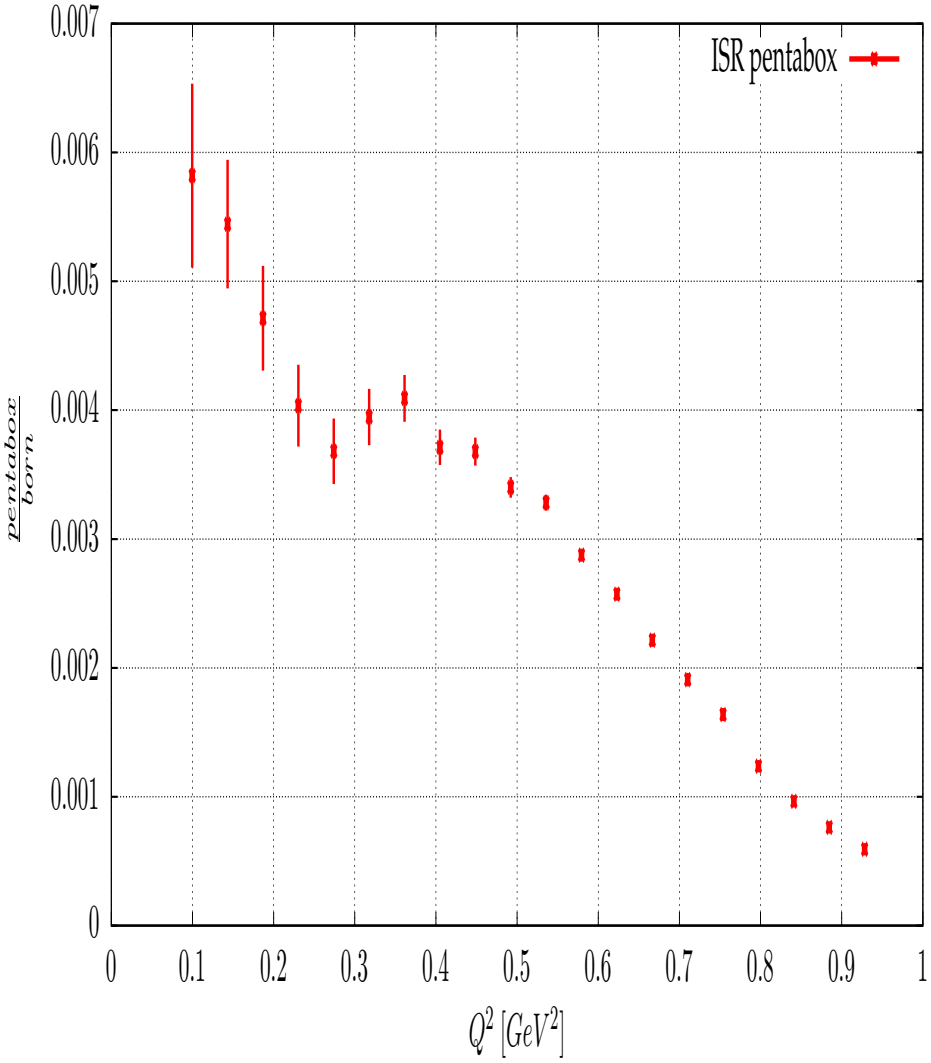




JHEP 1402 (2014) 114

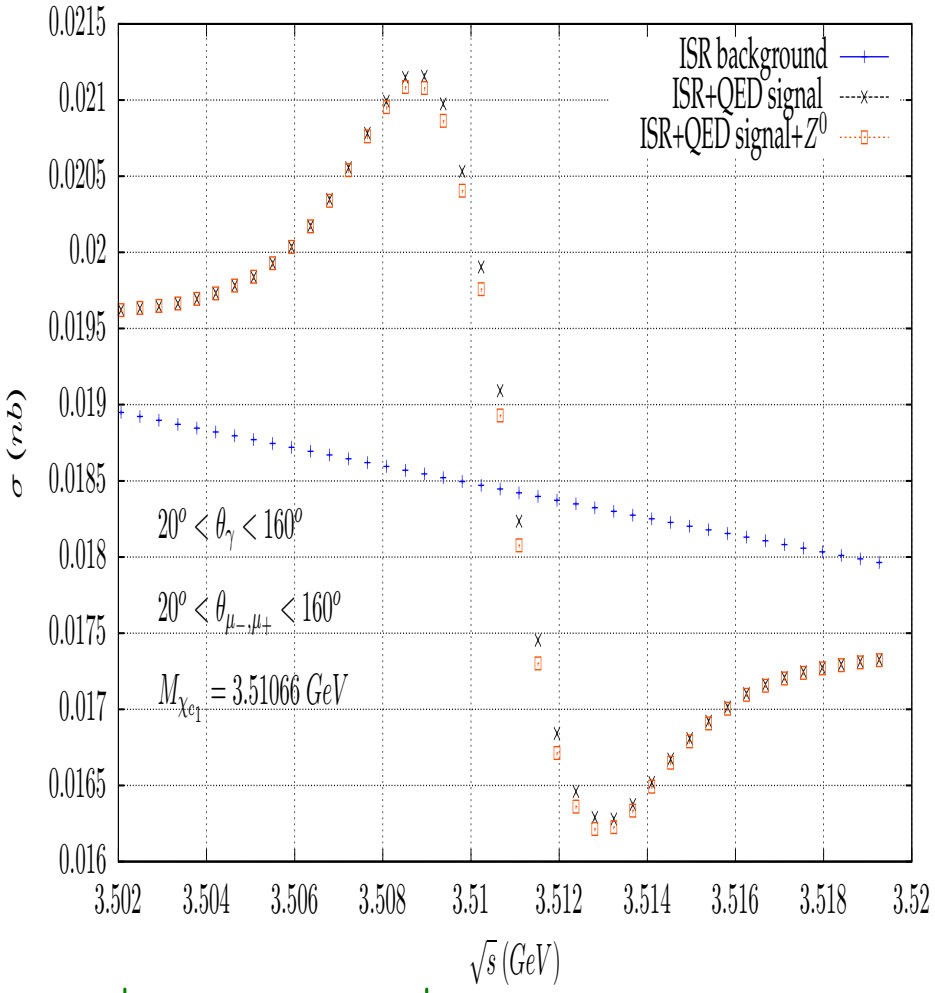
Size of the new corrections - pions

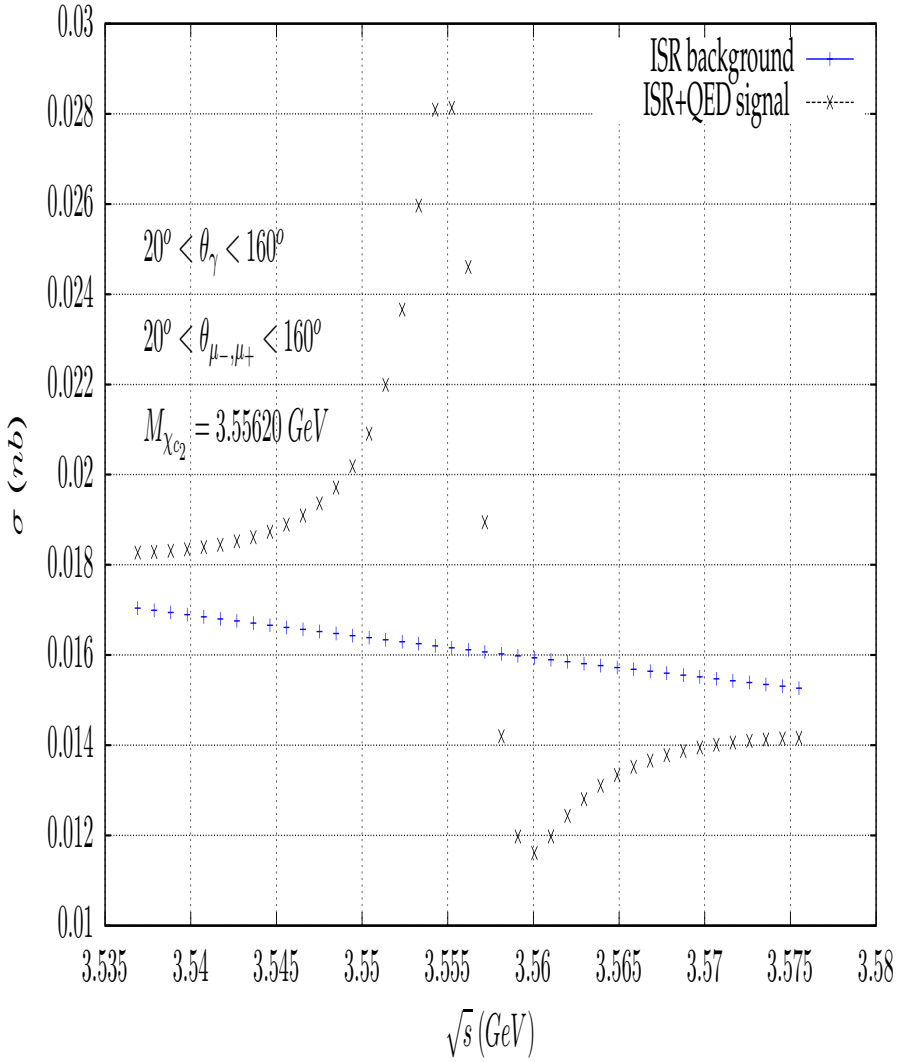




χ_{c1} and χ_{c2} production at e^+e^- colliders.

H. Czyż, J. H. Kühn, Sz. Tracz, Phys. Rev. D94 (2016), 034033

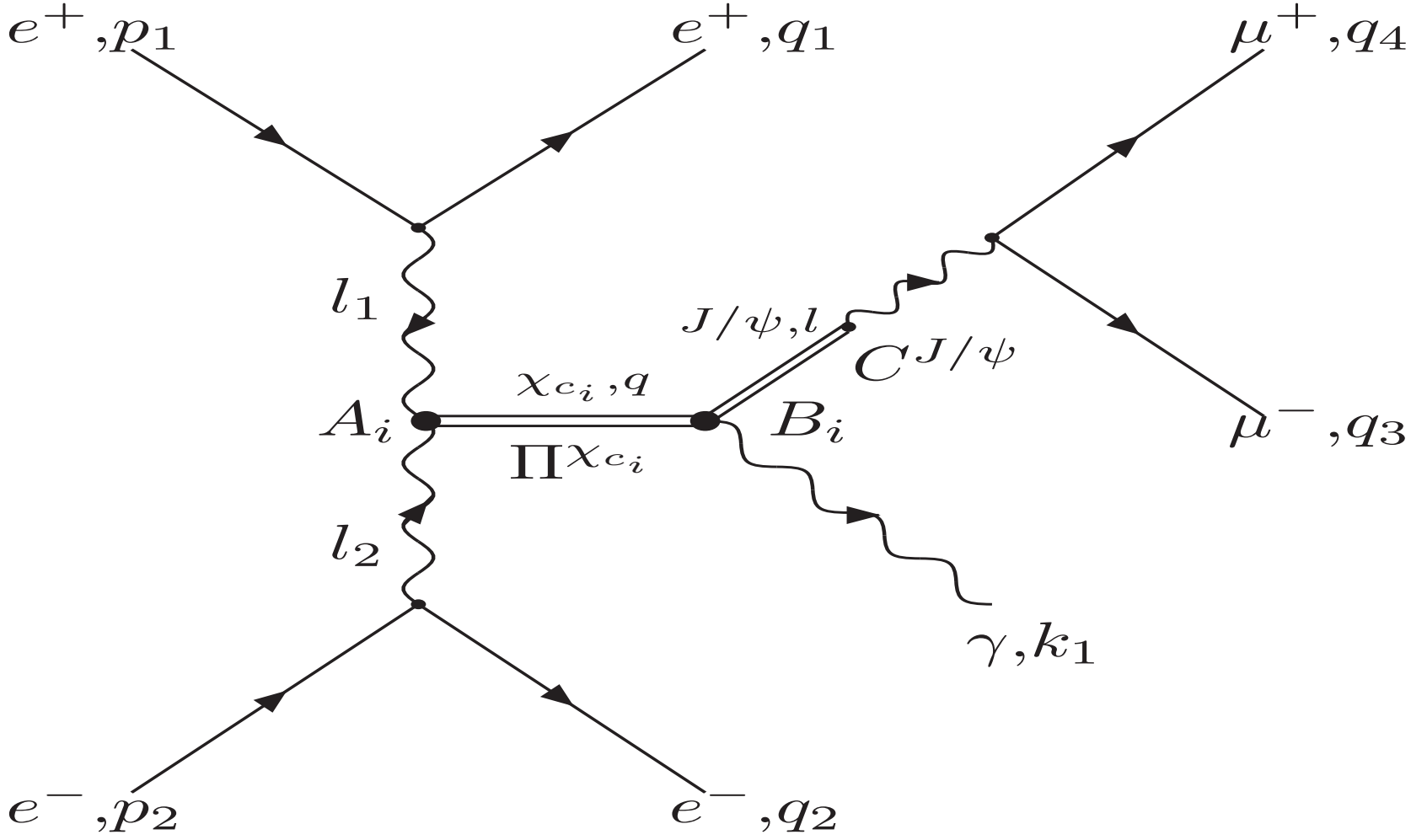




$e^+e^- \to \mu^+\mu^-\gamma$

χ_{ci} in $\gamma^* - \gamma^*$: EKHARA

HC, Patrycja Kisza PLB(to be published)



χ_{ci} in $\gamma^* - \gamma^*$: EKHARA

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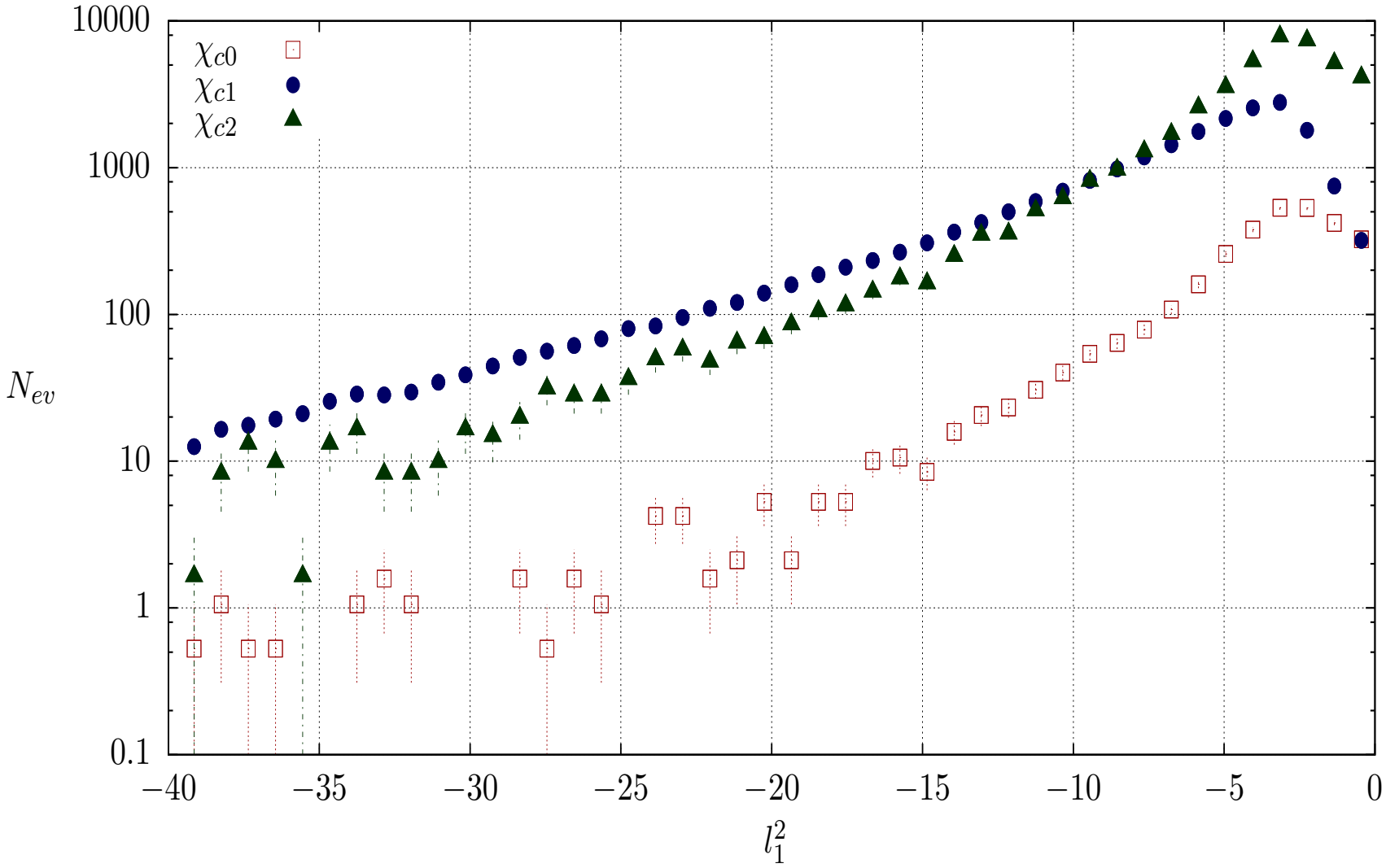

ISR NNLO

$\Rightarrow$ The goal:

Accuracy of the radiator function: $\mathbf{0.5\% \rightarrow 0.1 - 0.2\%}$

$\Rightarrow$ Time scale: 1.5 years

Concluding remarks

$\Rightarrow$ Slow progress,
but hoping to be of help

$\Rightarrow$ In about 2 years the accuracy of PHOKHARA should be at 0.1-0.2%