Monte Carlo generators for hadron physics: updates on PHOKHARA and EKHARA generators

H. CZYŻ, IF, UŚ, Katowice, Poland

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Outline

- ⇒ PHOKHARA and EKHARA in brief
- ⇒ Recent developments in PHOKHARA
  - ⇒ χ_{c_i} production- Sz. Tracz
  - ⇒ Missing radiative corrections:
    - ⇒ FSR modeling
    - ⇒ Pentaboxes
- ⇒ Recent developments in EKHARA
  - ⇒ χ_{c_i} production
- ⇒ Final remarks

Motivation: $(g-2)_\mu$

$$(g-2)_\mu^{SM} = 11659180.2 \pm 4.2(had) \pm 2.6(L-L) \pm 0.2$$

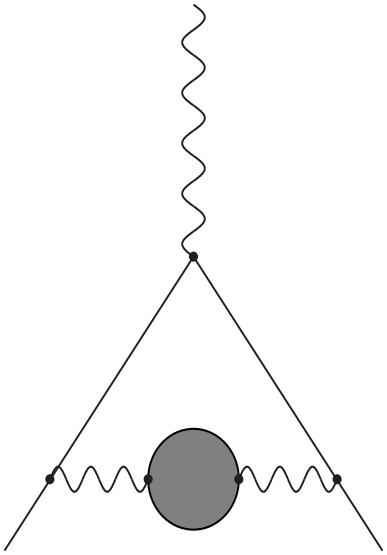
$$(g-2)_\mu^{exp} = 11659208.9 \pm 5.4 \pm 3.3$$

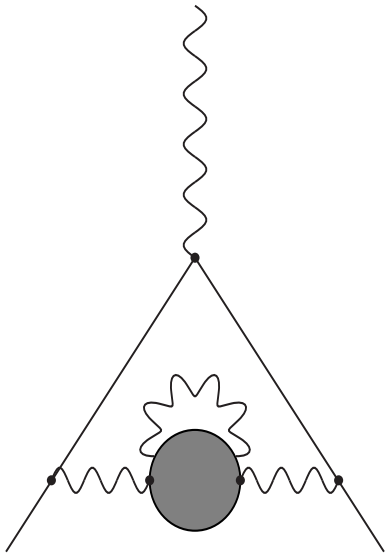
$$EXP - SM = 28.7 \pm 8.0$$

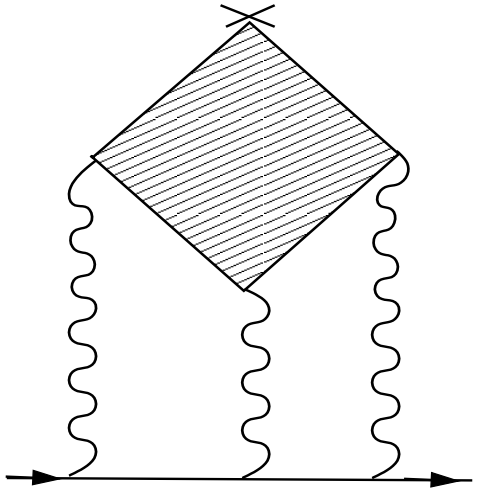
M. Davier, A. Hoecker, B. Malaescu, Z. Zhang, Eur. Phys. J. **C71** (2011) 1515.

Muon g-2 Collaboration (G.W. Bennett et al.), Phys. Rev. D 73, 072003 (2006) [hep-ex/0602035].

anatomy of $(g-2)_\mu$







$$a_\mu^{had} = a_\mu^{had,LO} + a_\mu^{had,HO} + a_\mu^{had,LBL}$$

The reason we need R(s)

$$a_\mu^{\mathrm{had,LO}} = \frac{\alpha^2}{3\pi^2} \int_{m_\pi^2}^{\infty} \frac{ds}{s}\, K(s)\, R(s)$$

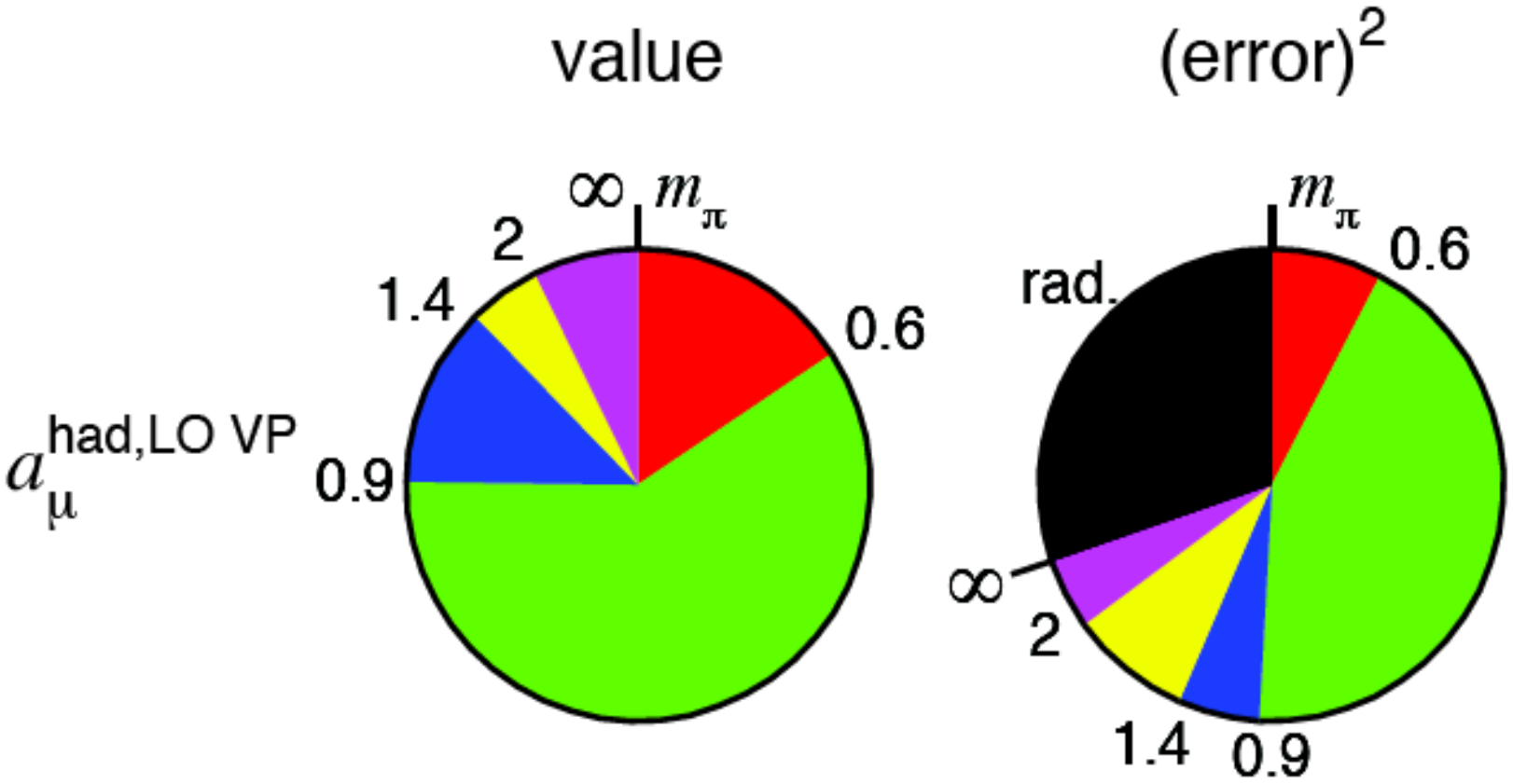
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma_{\mathrm{point}}}$$

One has to measure :

$$\sigma(e^+e^- \to hadrons)$$

$a_\mu^{had\ LO}$

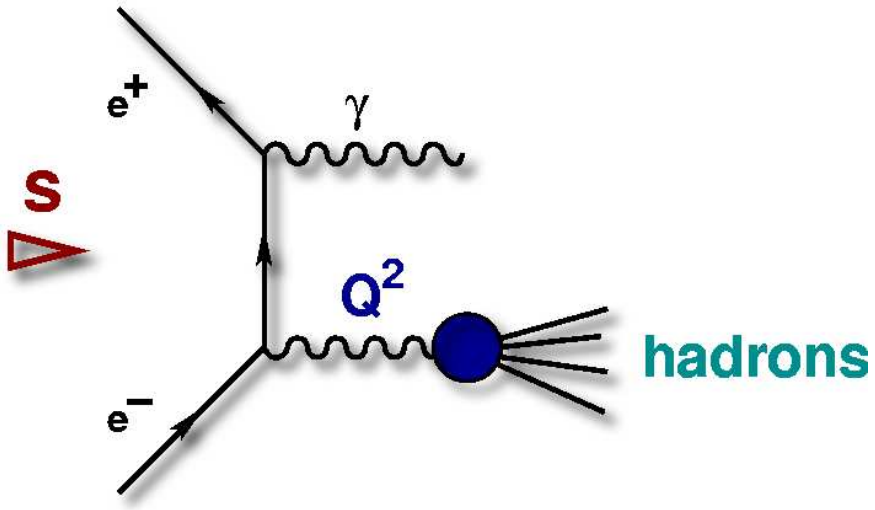
Hagiwara et al. J.Phys. G38 (2011) 085003



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,

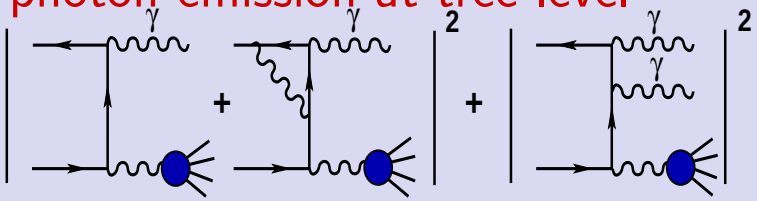
E. Nowak-Kubat, T. Riemann,

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

V. Yundin, D. Zhuridov

PHOKHARA 9.2: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π, $\bar{N}N$, 3π, KK,$\Lambda\bar{\Lambda}$ $J/\psi, \psi(2S)$, χ_{c_1}, χ_{c_2}

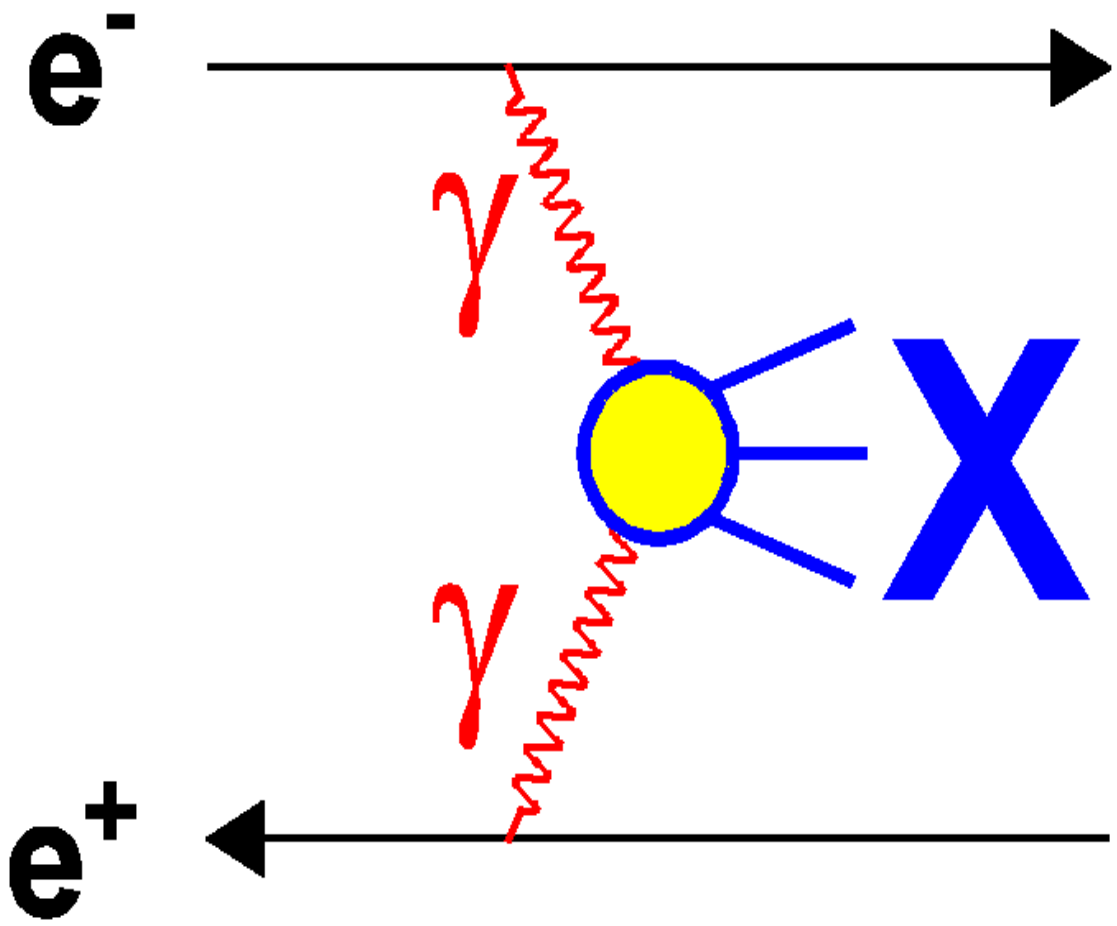
- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level



- 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/

Photon-photon interactions



EKHARA MC generator

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

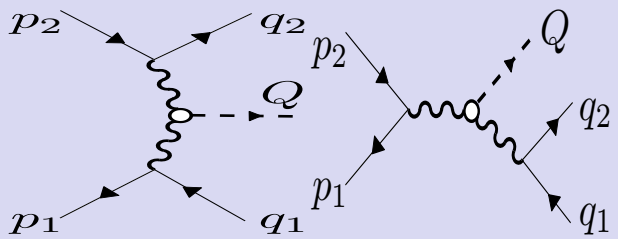
- background to $e^+e^- \to \pi^+\pi^-\gamma$
- Henryk Czyż, Elżbieta Nowak-Kubat, Phys. Lett. B 634, 493 (2006),

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

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

\+ A. Korchin, O. Shekhovtsova; Phys.Rev. D85 (2012) 094010

EKHARA 2.1: $\pi^+\pi^-$, π^0, η, η'

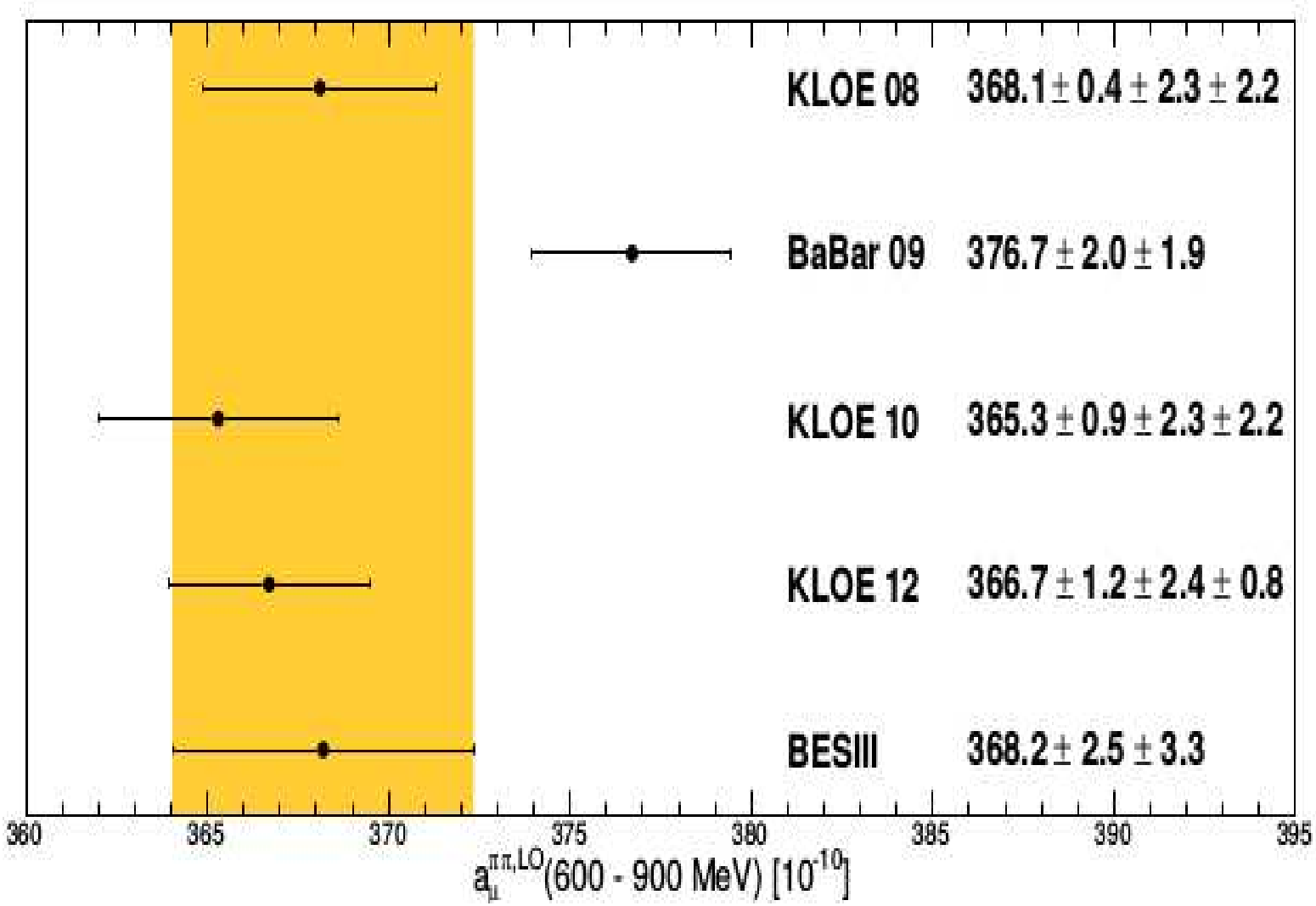


- Modular structure
- radiative correction to be included soon

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

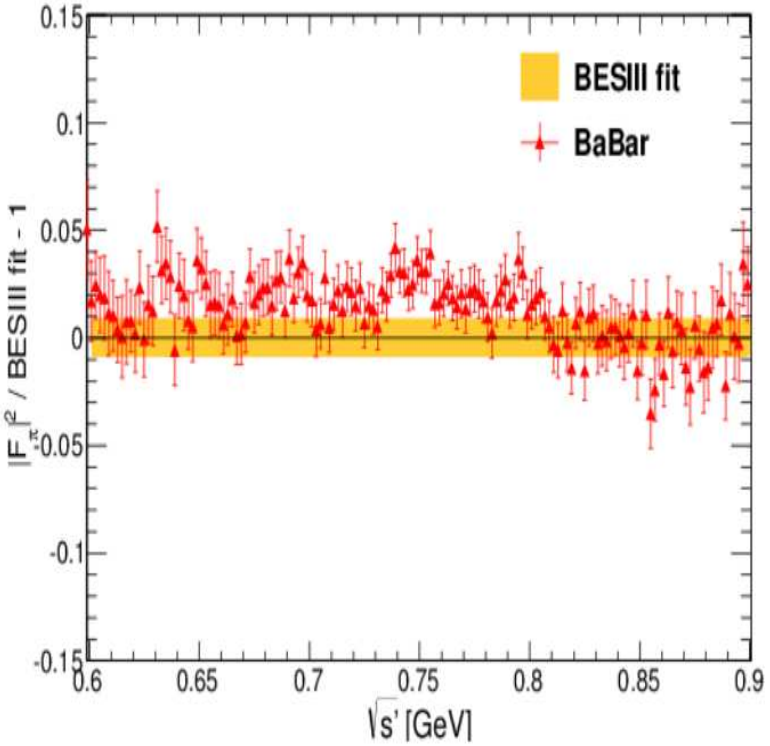
BESIII new results

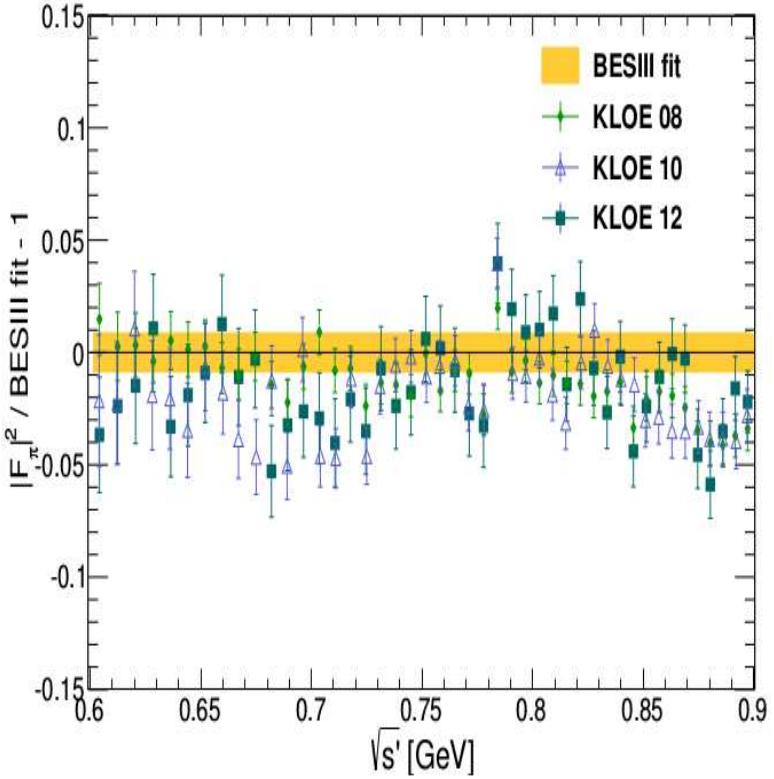
Phys.Lett. B753 (2016) 629



BESIII new results

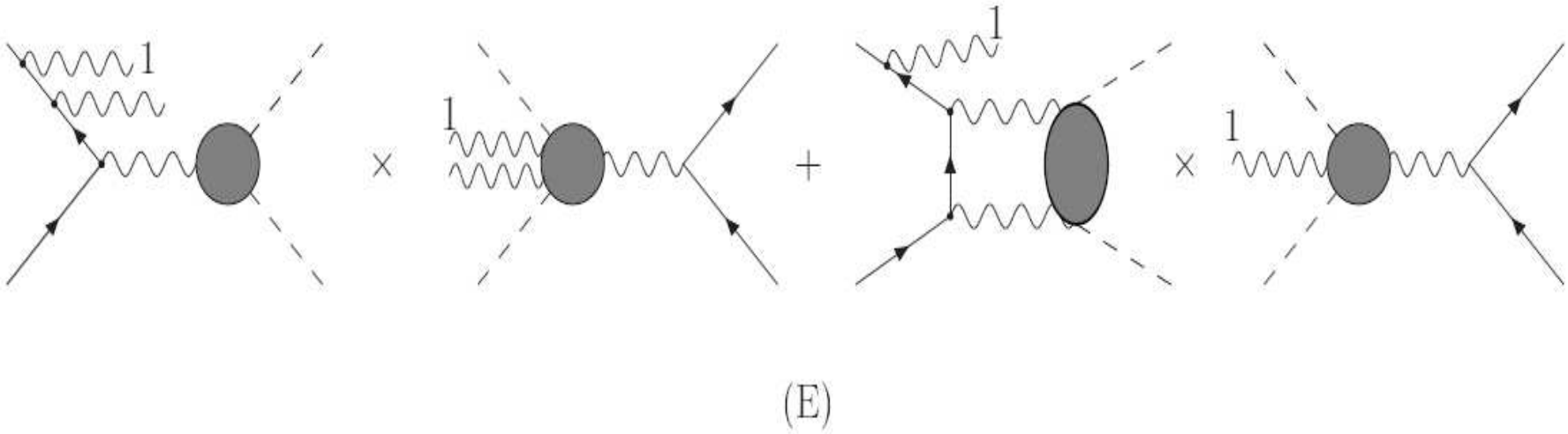
Phys.Lett. B753 (2016) 629





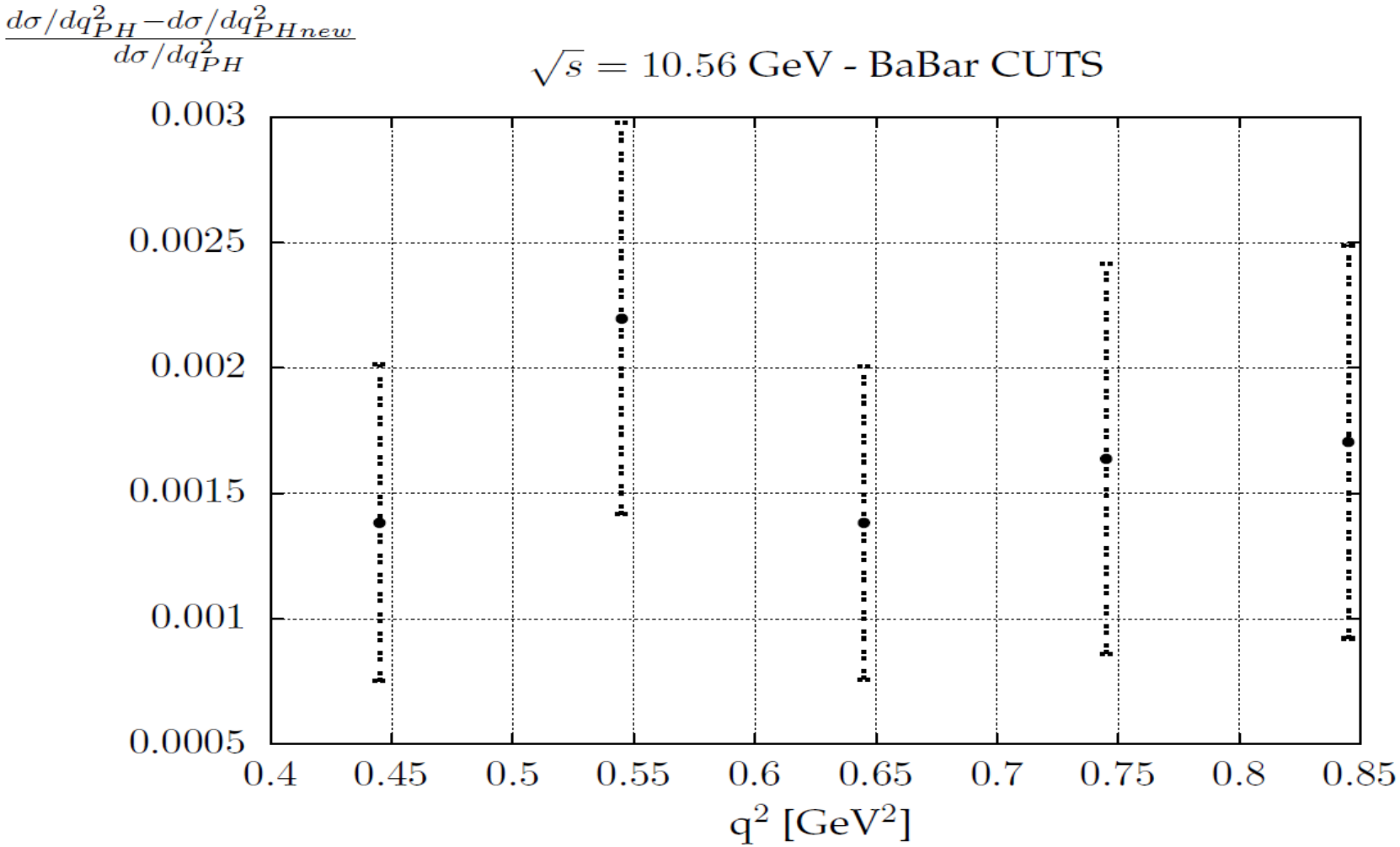
PENTABOXES

For muons only, for pions in progress



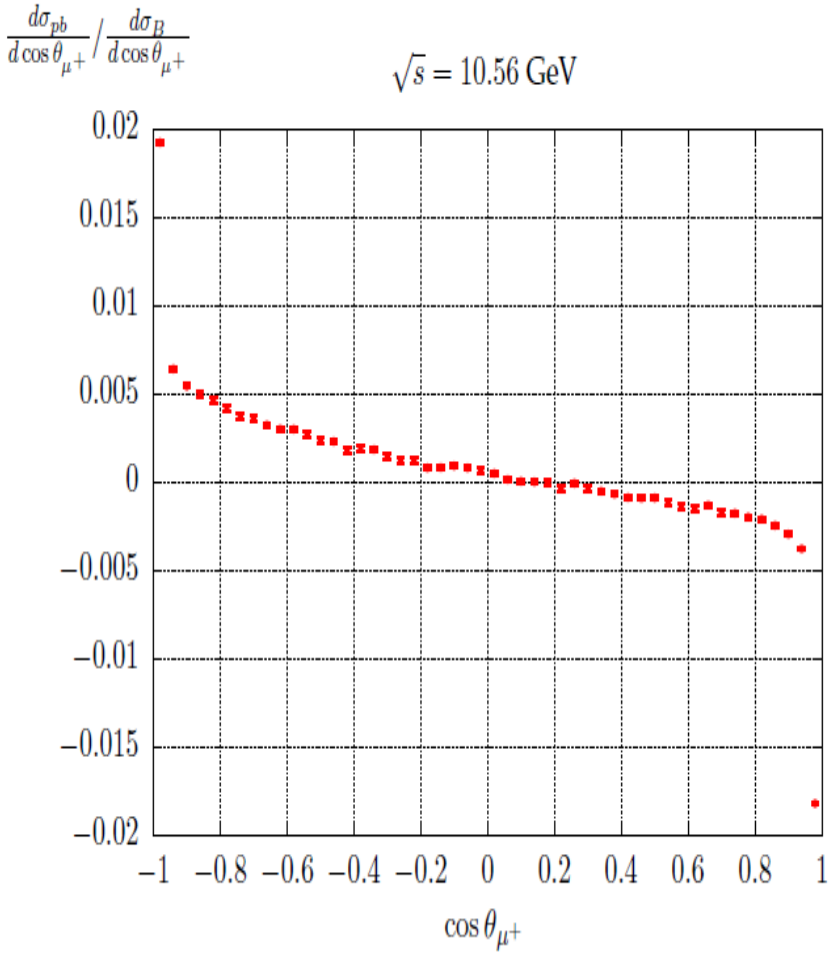
(E)

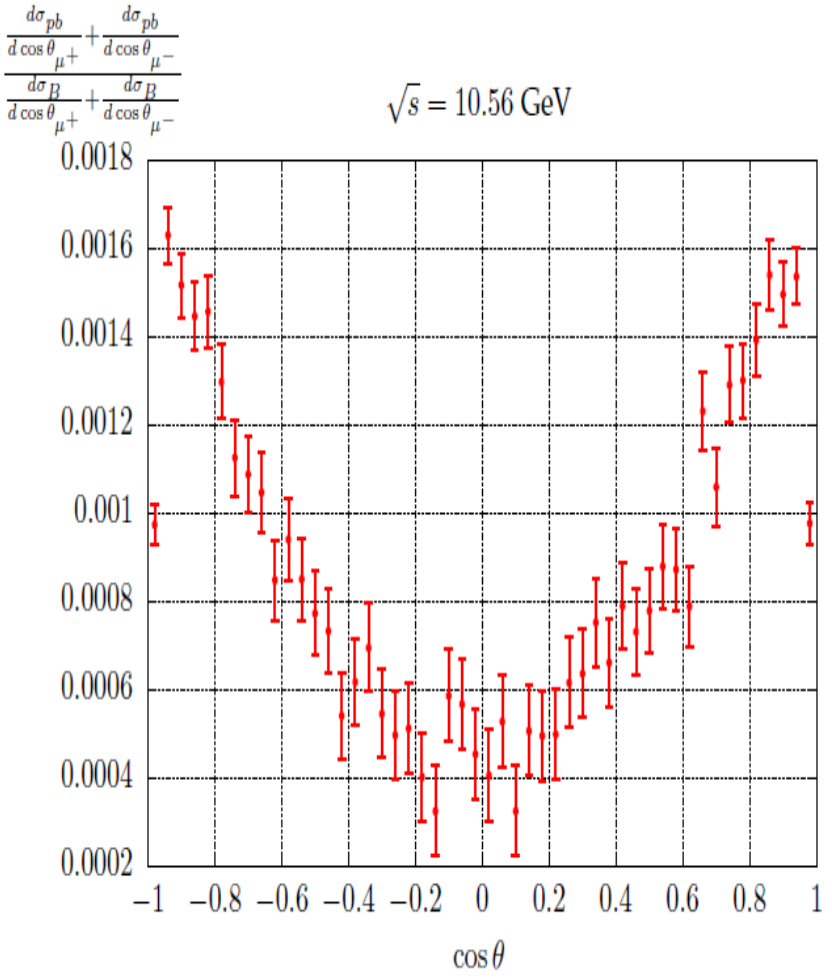
Size of the new corrections



JHEP 1402 (2014) 114

Size of the pentaboxes





JHEP 1402 (2014) 114

PENTABOXES-pions

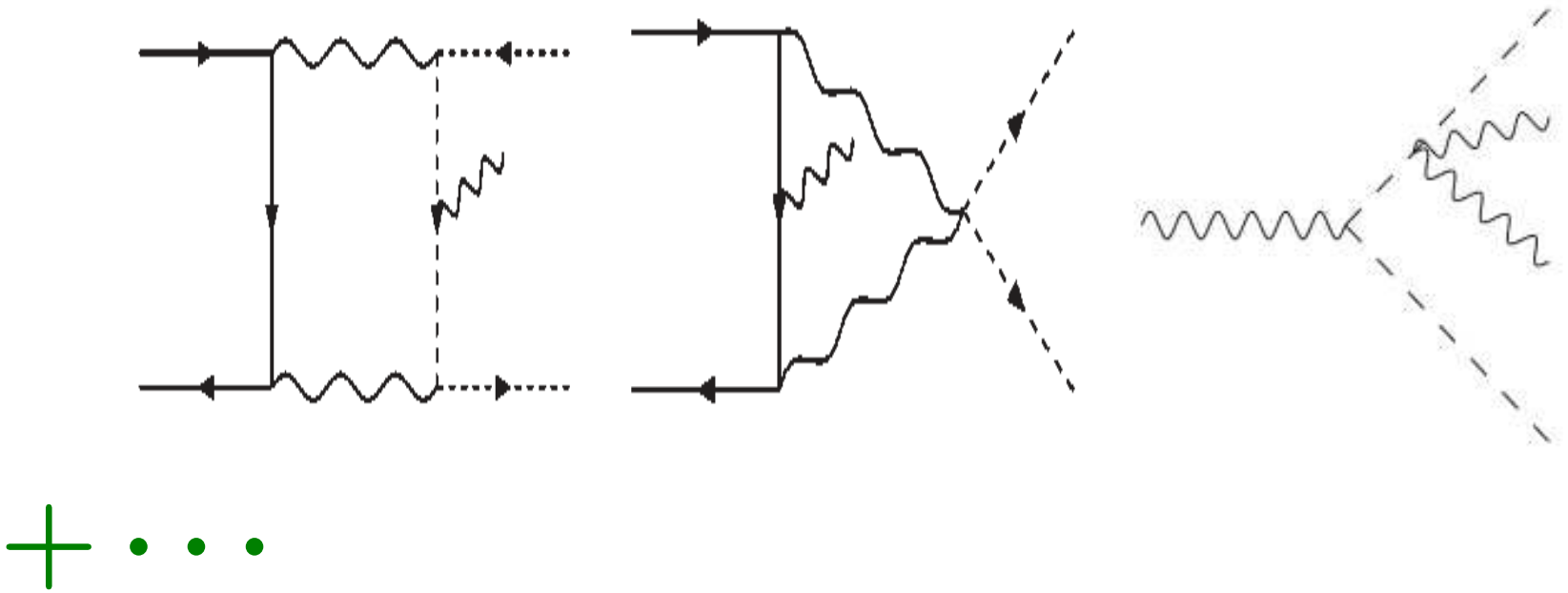
The team:

F. Campanario, (Karlsruhe)

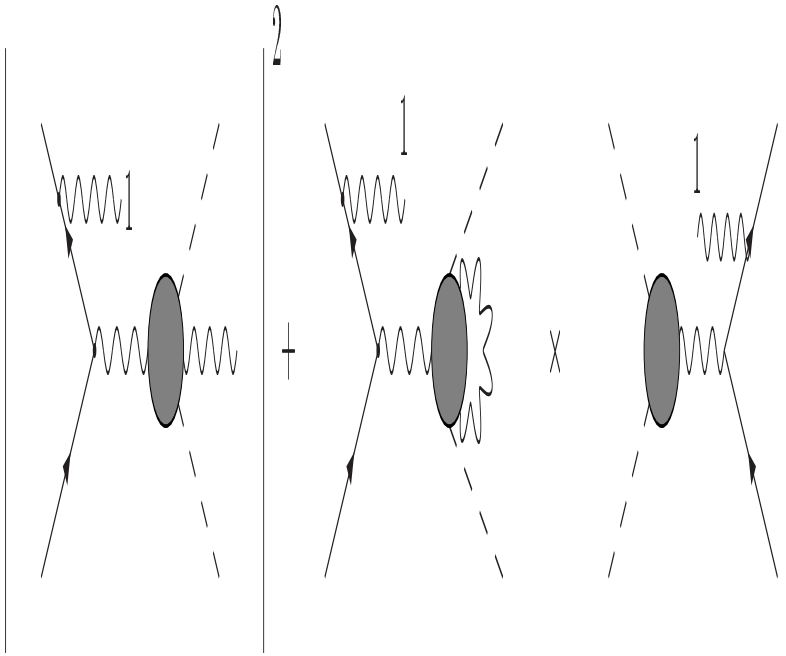
H.C., J. Gluza, T. Jeliński, Sz. Tracz, D. Zhuridov (Katowice)

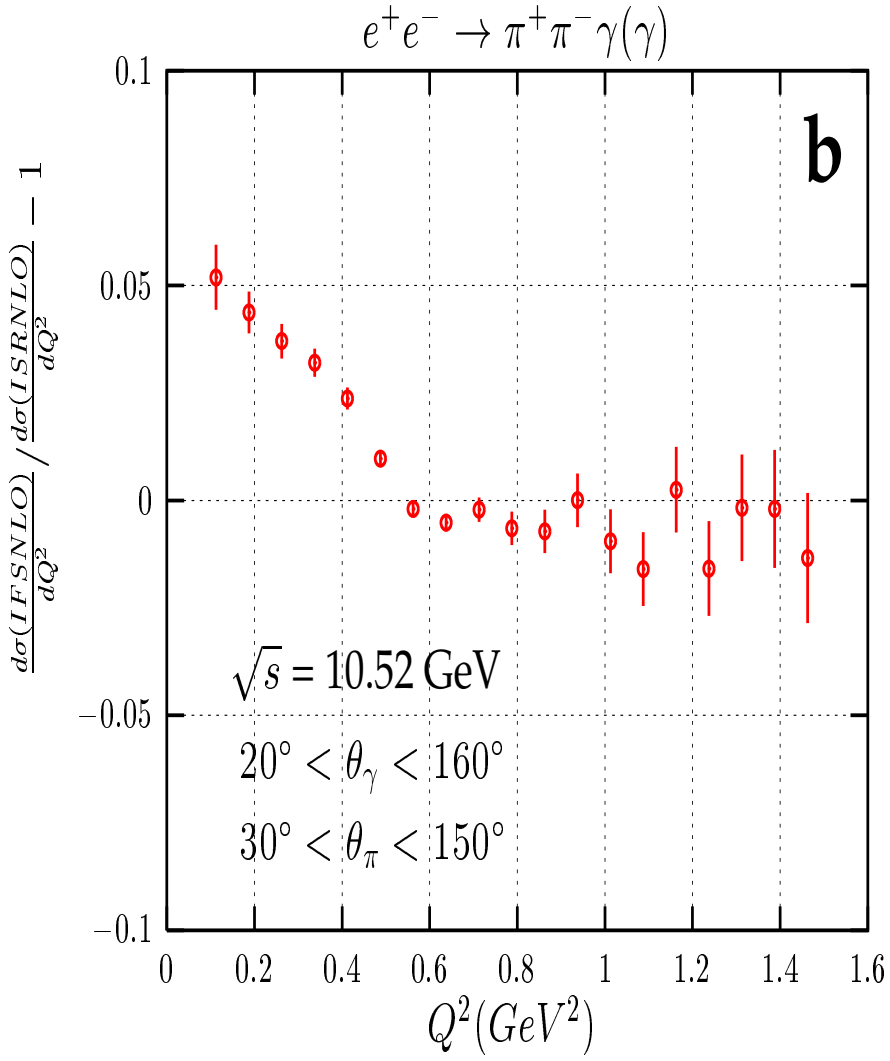
T. Riemann (DESY, Zeuthen)

The task:



FSR at NLO, PHOKHARA





PENTABOXES-pions

Preliminary results for ISR pentaboxes (sQED):

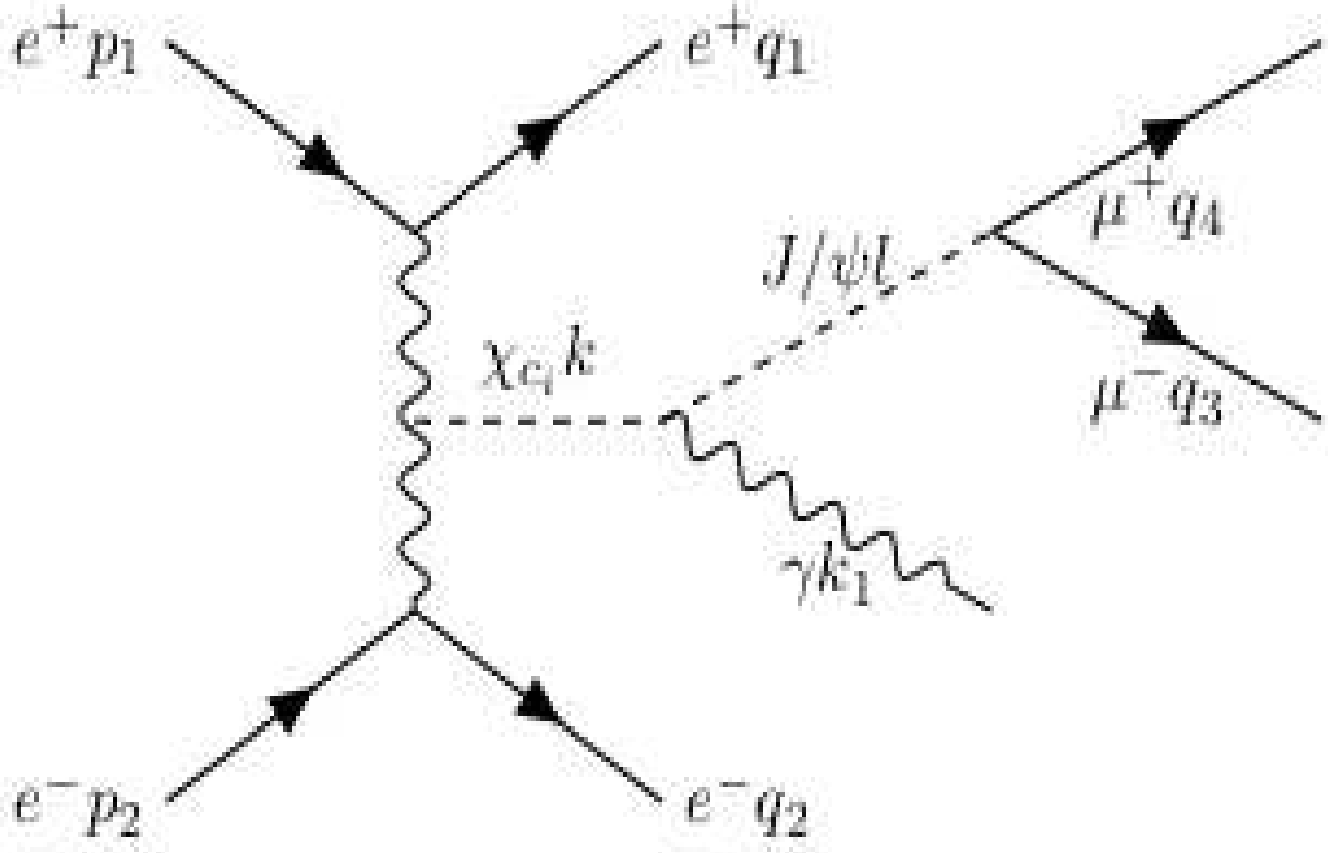
E= 1.02 GeV; penta/Born = 0.0018

KLOE -tag; penta/Born = 0.0018

E= 10.56 GeV; penta/Born =0.00072

BaBar; penta/Born =0.00073

χ_c in EKHARA



H.C., P.Kisza, in preparation

χ_c in EKHARA

BELLE2: $e^+e^- \to e^+e^-\chi_{c_i}$

χ_c	Number of events (Luminosity $= 50ab^{-1}$)
0	140641955
1	4303389
2	141529595

H.C., P.Kisza, in preparation

χ_c in EKHARA

BELLE2: $e^+e^- \to e^+e^-\chi_{c_i} \to J/\psi(\to \mu^+\mu^-)\gamma$

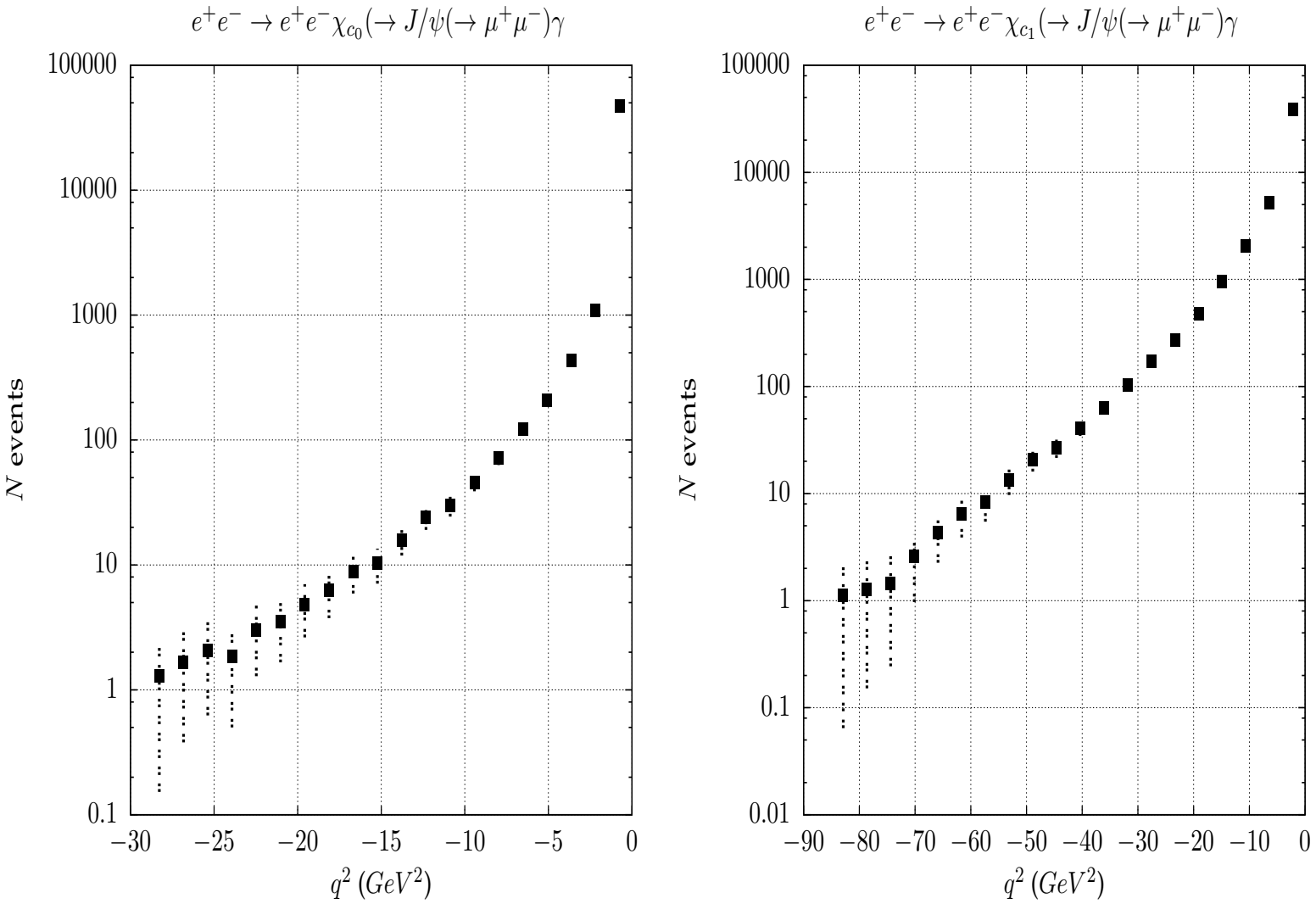
$20^\circ < \theta_\gamma, \theta_\mu < 160^\circ$

$M - 10\Gamma < inv.\ mass < M + 10\Gamma$

χ_c	Number of events (Luminosity $= 50 ab^{-1}$)
0	49583
1	48494

H.C., P.Kisza, in preparation

χ_c in EKHARA



H.C., P.Kisza, in preparation

Concluding remarks

- slow but continuous progress observed

  in quest for precision in low energy hadronic physics

- serious challenges in the forthcoming years

  radiative corrections, form factors modelling ...

- promising perspectives of new measurements

  at BELLE2, BES-III, VEPP2000, KLOE2,