The Phokhara and Ekhara event generators

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Mainz, June 2017

Outline

$\Rightarrow$ Motivation

$\Rightarrow$ PHOKHARA and EKHARA in brief

$\Rightarrow$ Recent developments in PHOKHARA and EKHARA

$\Rightarrow$ χ_{c_1} and χ_{c_2} production

Outline

- ⇒ Work in progress: PHOKHARA
  - ⇒ $e^+e^- \to P\gamma(\gamma)$
  - ⇒ ISR NNLO
- ⇒ Work in progress: EKHARA
  - ⇒ New $P - \gamma^* - \gamma^*$ form factors
  - ⇒ Radiative corrections
- ⇒ Concluding remarks

The reason we need R(s)

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

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

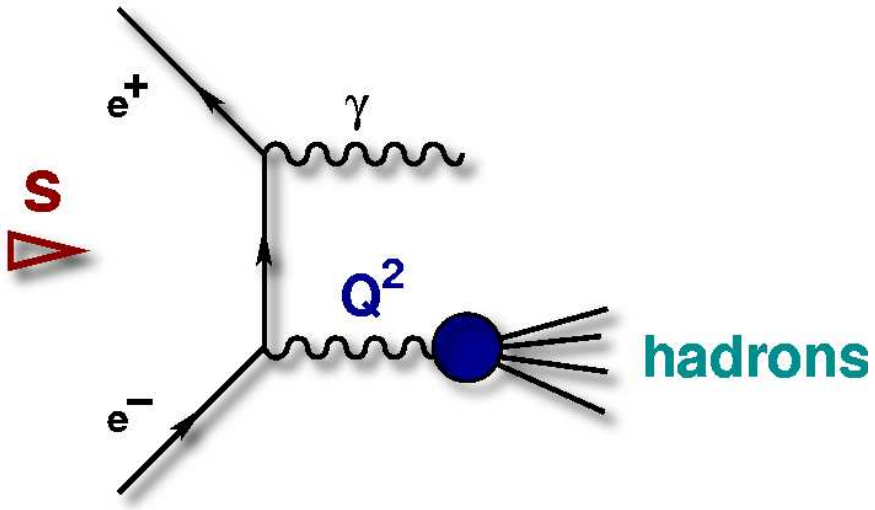
One has to measure :

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

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,

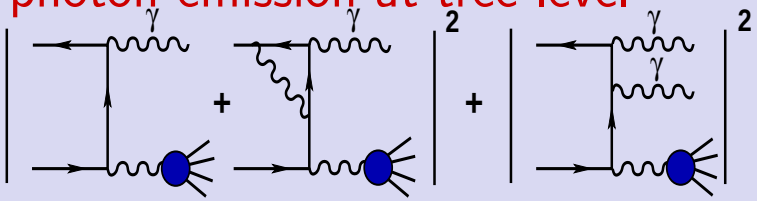
E. Nowak-Kubat, T. Riemann,

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}

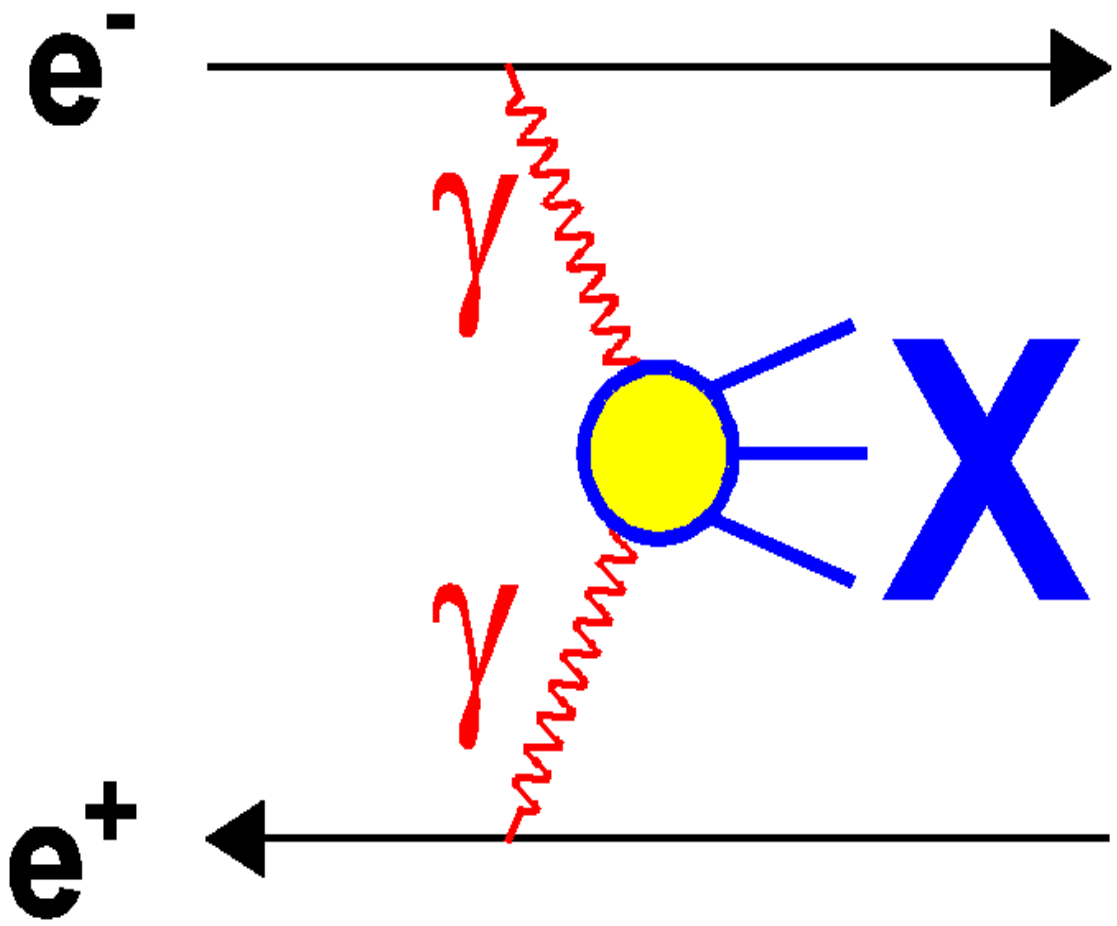
- **ISR at NLO:** virtual corrections to one photon events and two photon emission at tree level



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

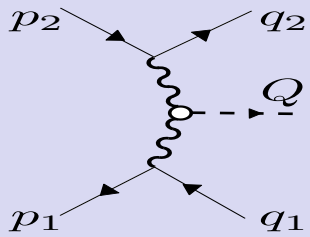
- background to $e^+e^- \to \pi^+\pi^-\gamma$
- Henryk Czyż, Elżbieta Nowak-Kubat, Phys. Lett. B 634, 493 (2006),

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

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

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

EKHARA 2.2: $\pi^+\pi^-$, π^0, η, η', χ_{c_i}, $\chi_{c_i} \to J/\psi(\to \mu^+\mu^-)\gamma$



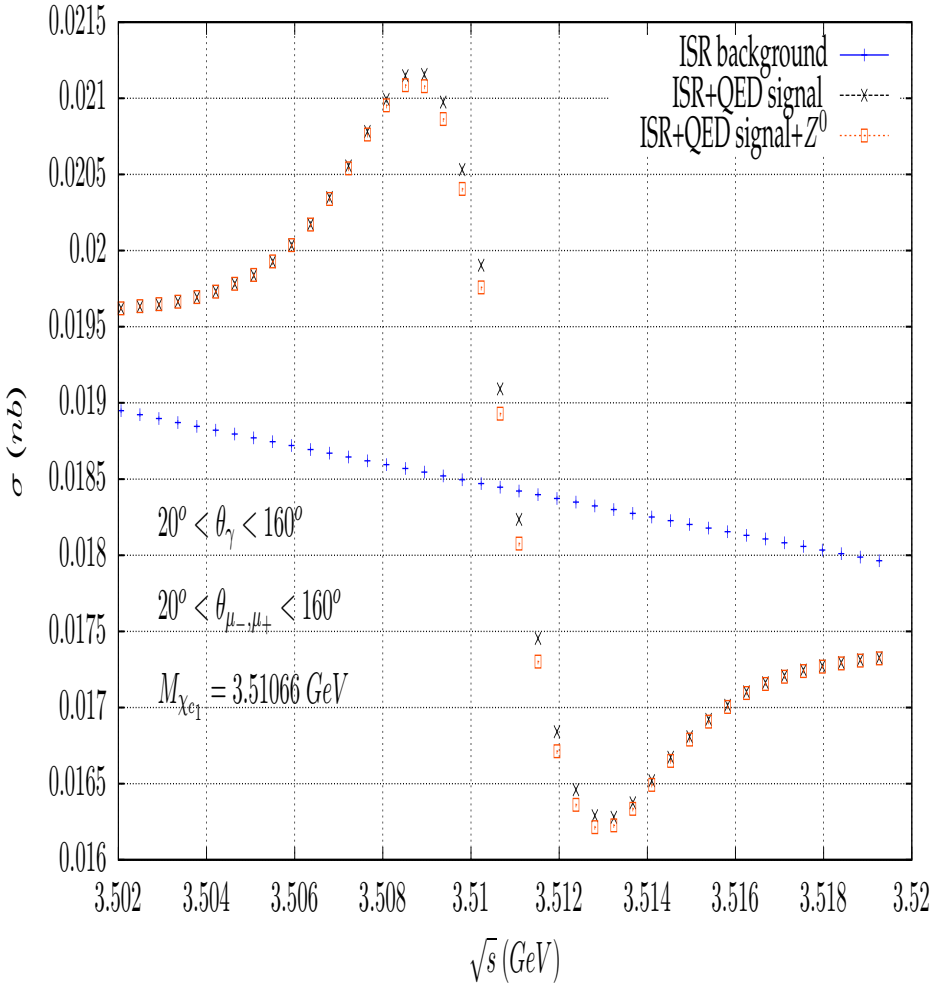
- Modular structure
- radiative correction to be included soon

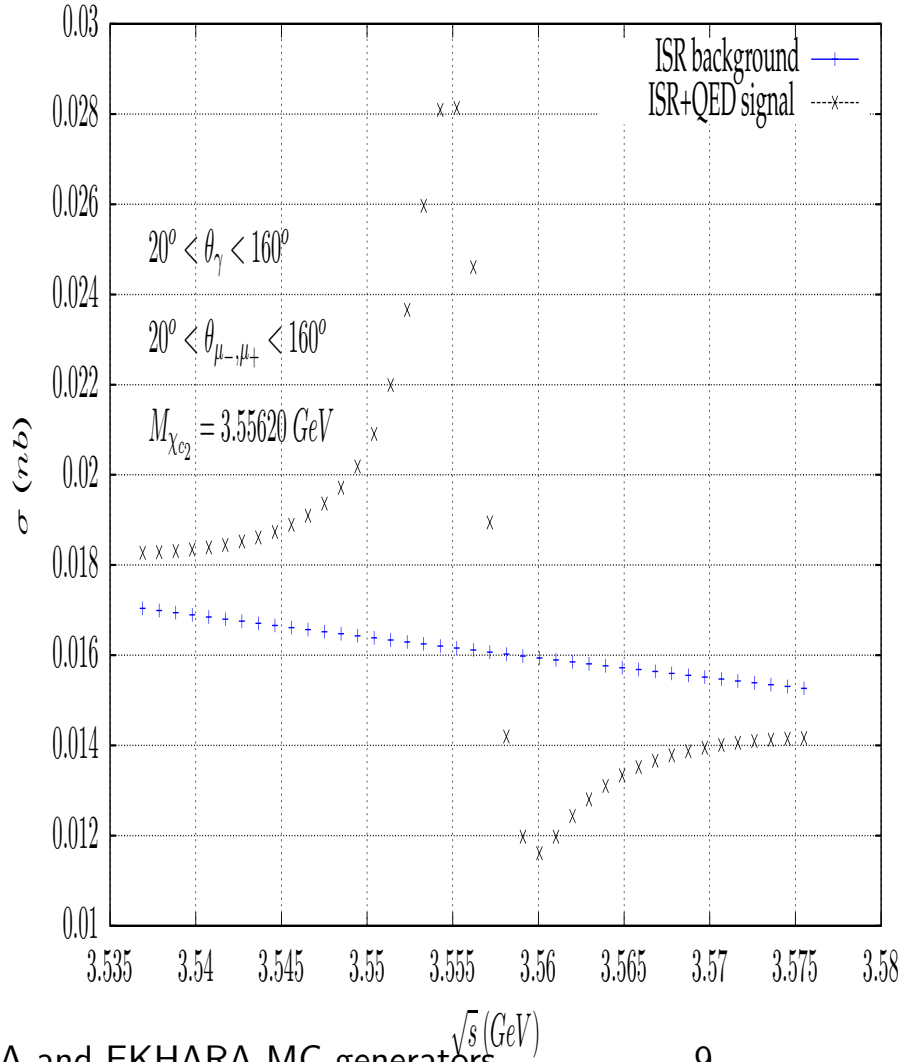
http://prac.us.edu.pl/~ ekhara/

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

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

$e^+e^- \to \mu^+\mu^-\gamma$: talk by J. H. Kühn ; 26.06



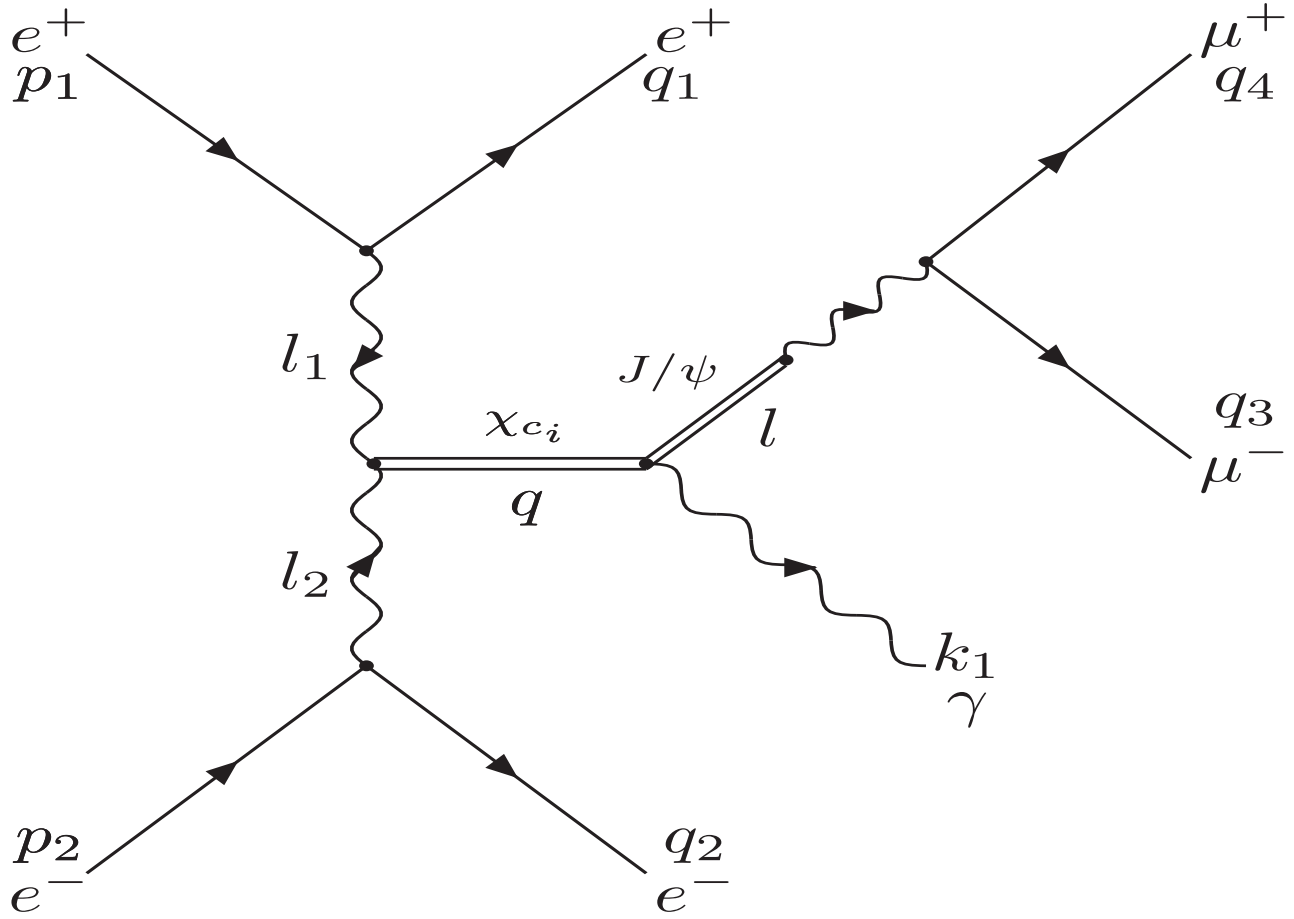


χ_{ci} production at e^+e^- colliders.

H. Czyż, P. Kisza, Phys.Lett. B771 (2017) 487

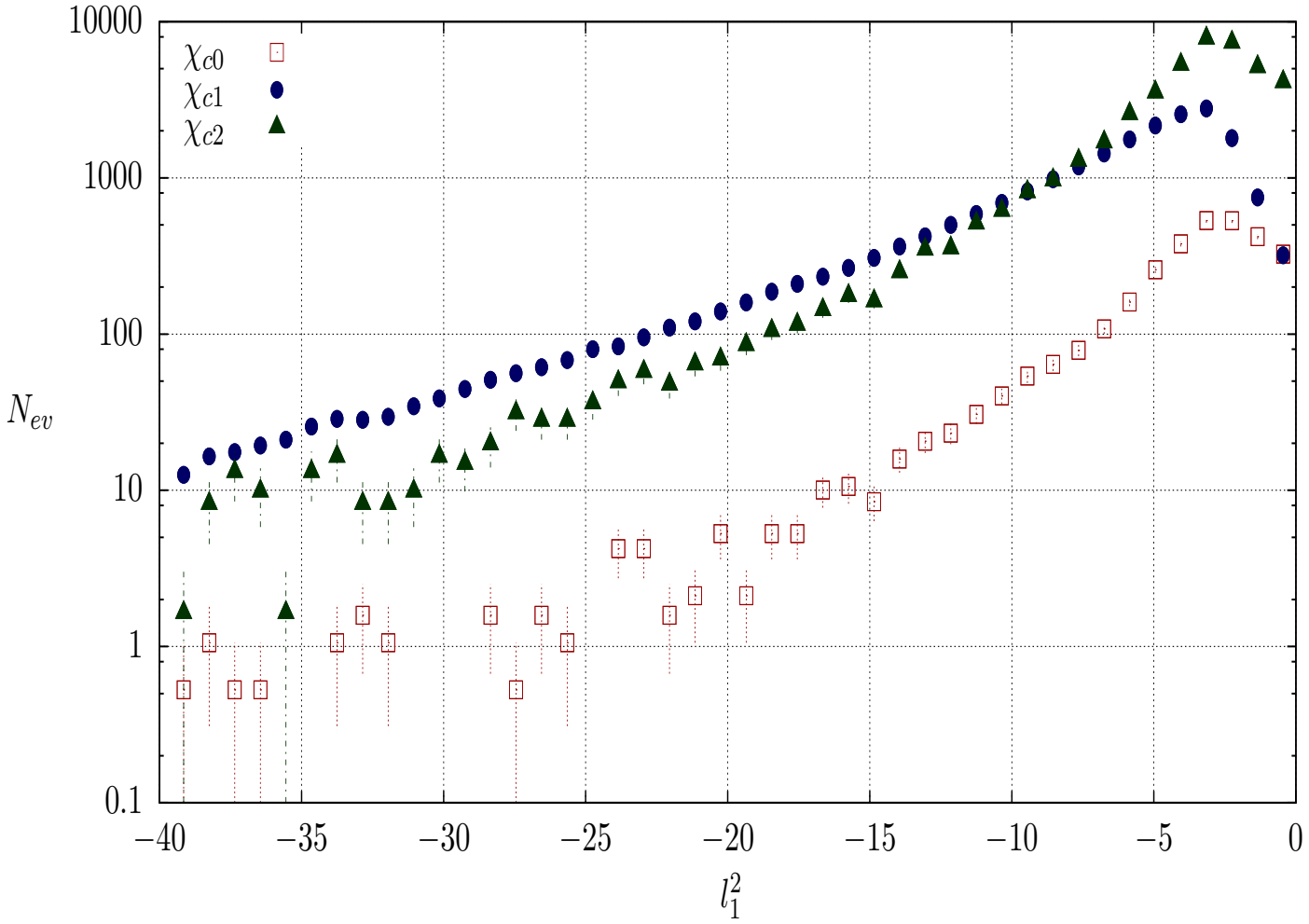
$e^+e^- \to e^+e^-\chi_{ci}\ (\to J/\psi(\to \mu^+\mu^-)\gamma)$:

P. Kisza: poster session and RadioMonteCarLow satelite meeting



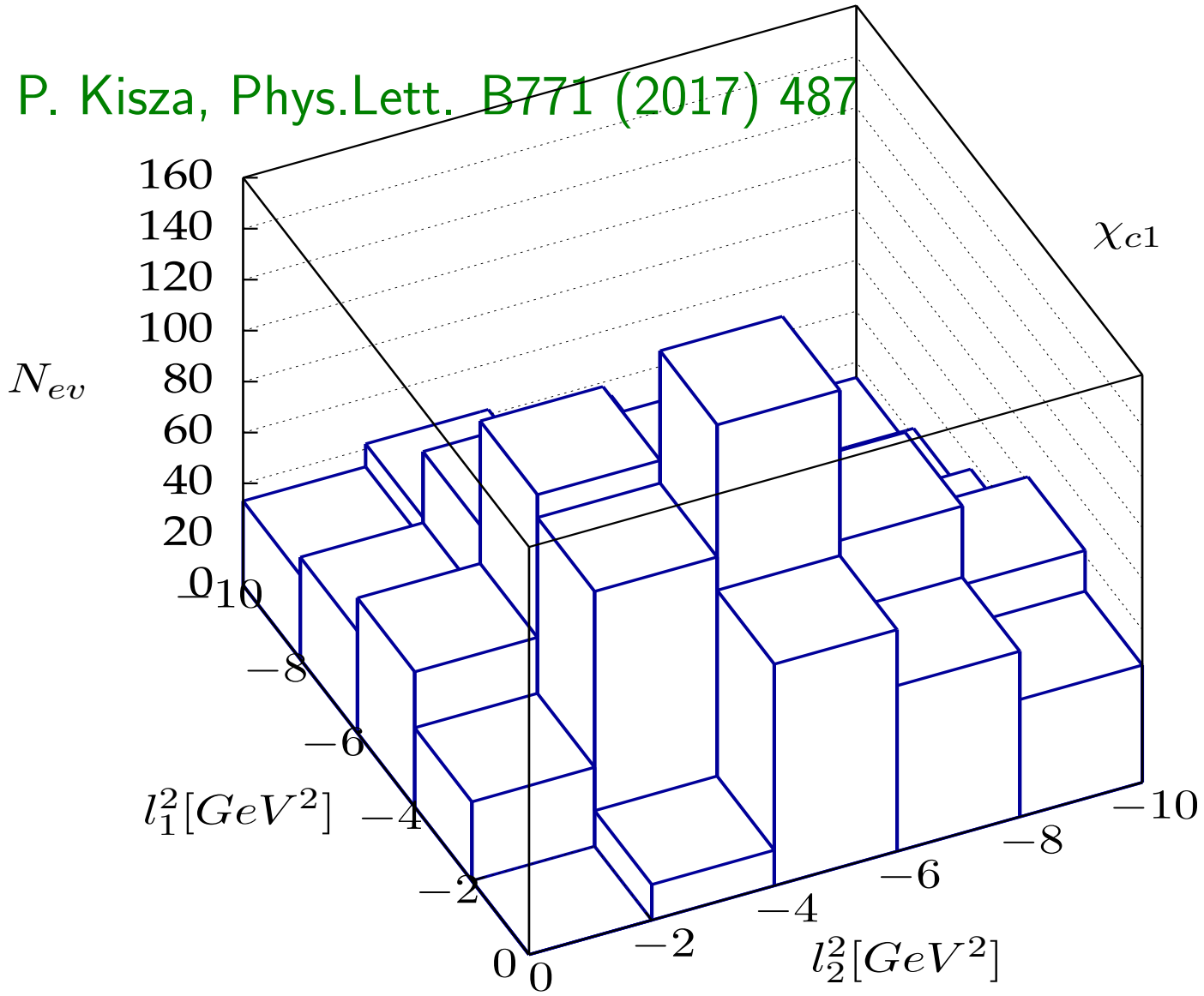
BELLE II event rates

H. Czyż, P. Kisza, Phys.Lett. B771 (2017) 487



BELLE II event rates

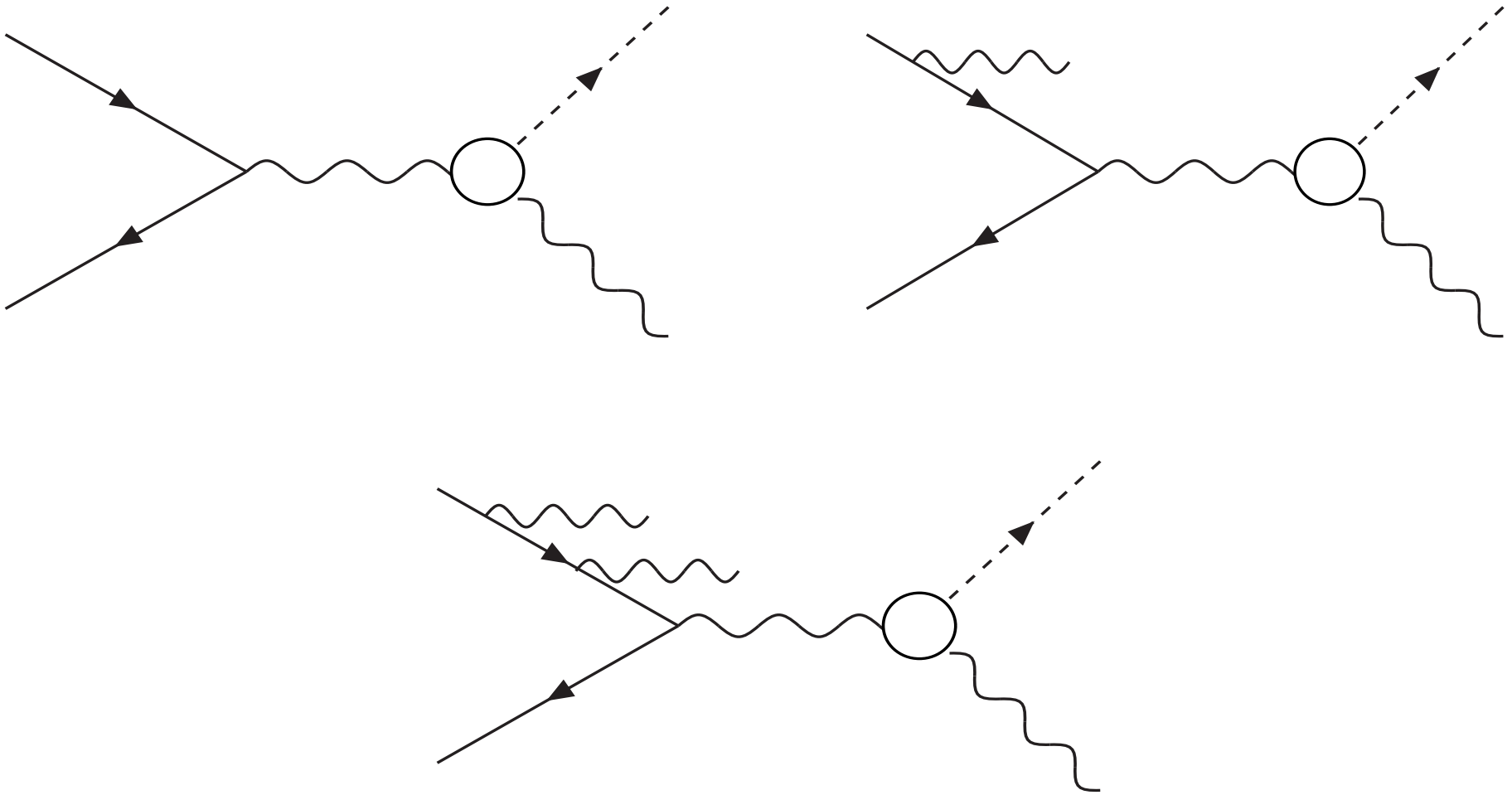
H. Czyż, P. Kisza, Phys.Lett. B771 (2017) 487



Work in progress: $e^+e^- \to P\gamma(\gamma)$

H. Czyż, P.Kisza, Sz. Tracz, in preparation

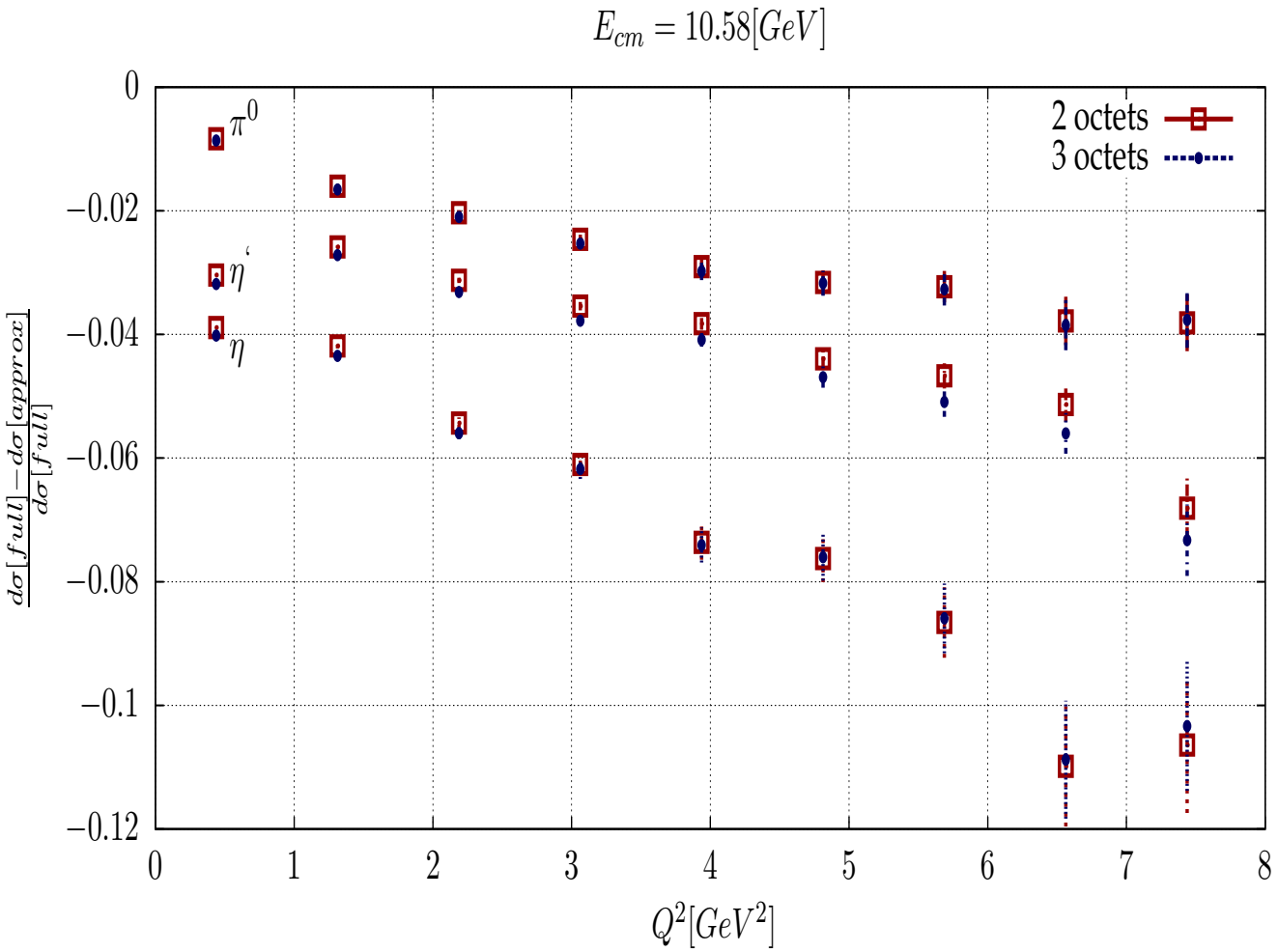
Sz. Tracz: poster session and RadioMonteCarLow satelite meeting



$e^+e^- \to e^+e^-\pi_0$

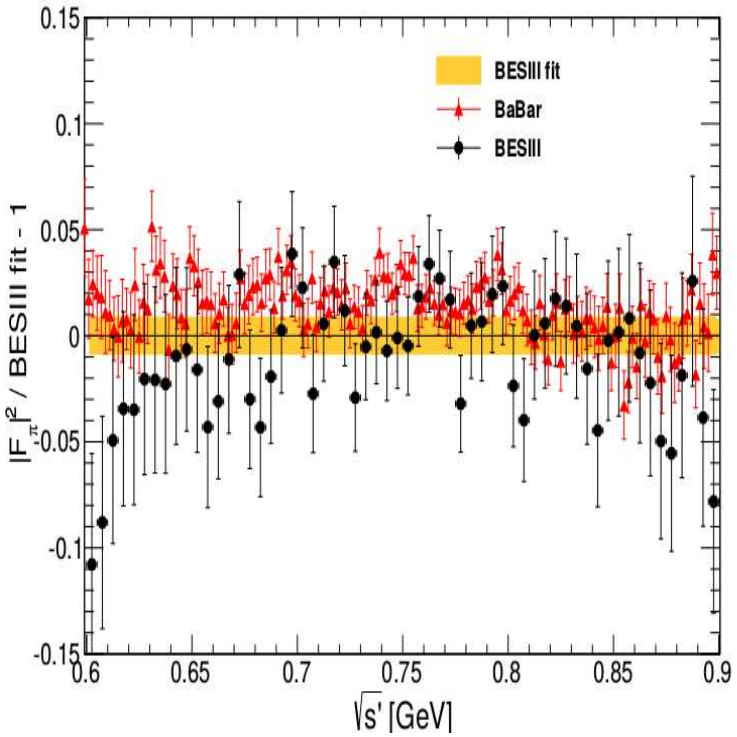
H. Czyż, P.Kisza, Sz. Tracz, in preparation

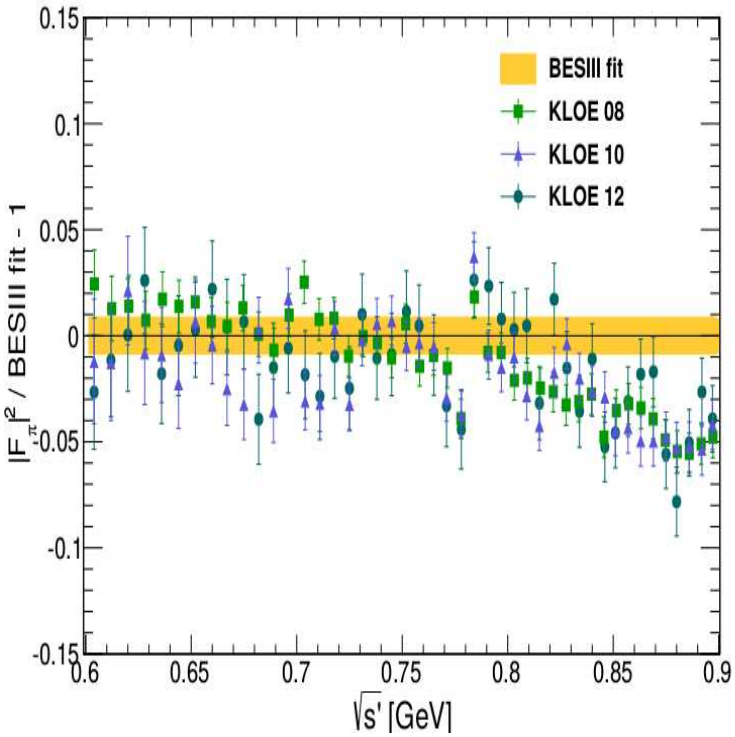
Sz. Tracz: poster session and RadioMonteCarLow satelite meeting



BESIII new results

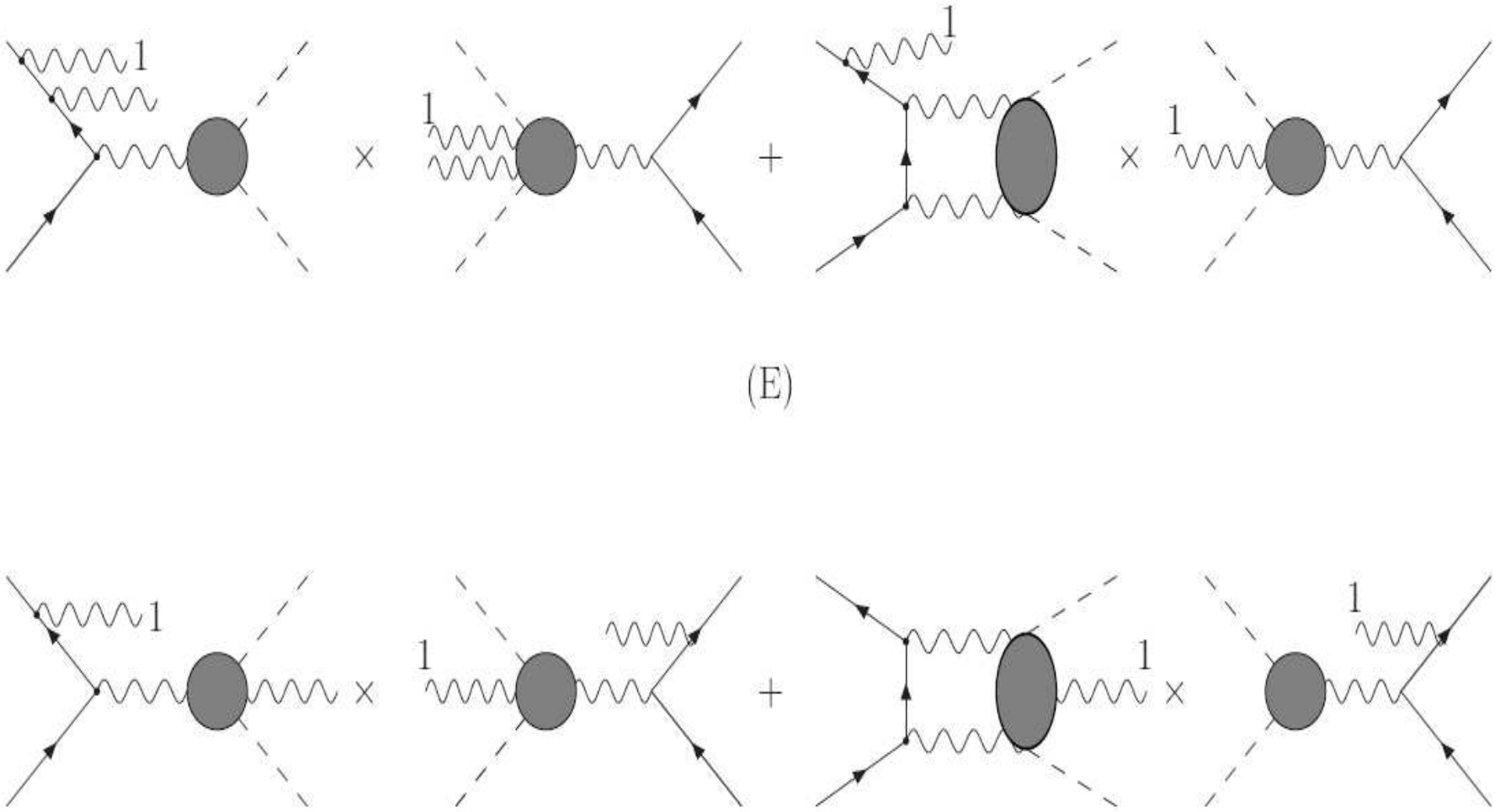
Phys.Lett. B753 (2016) 629





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

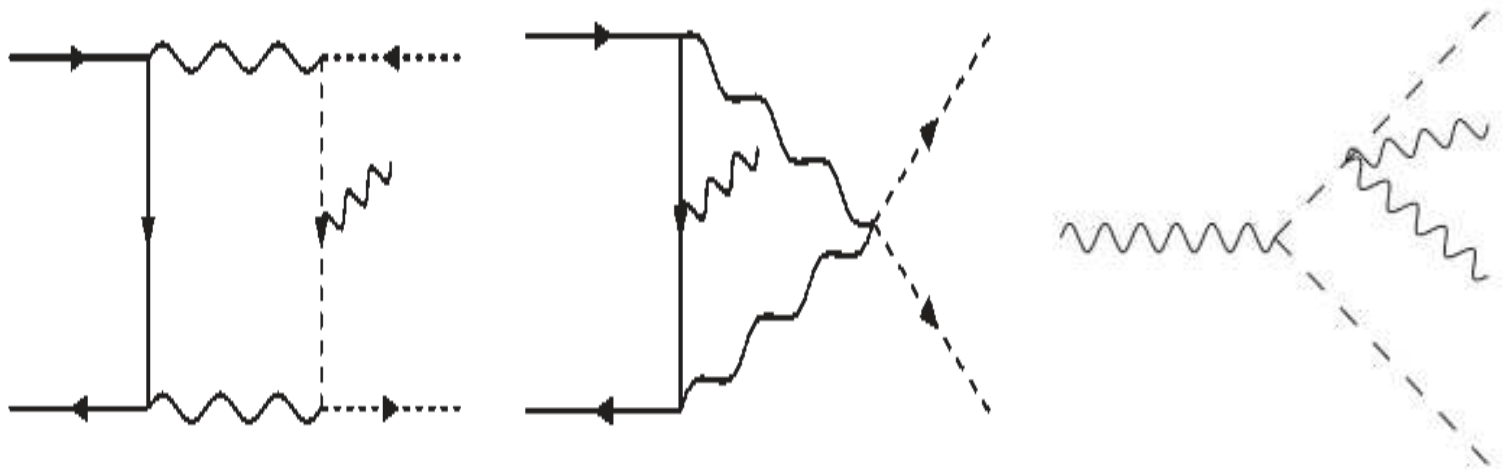
$\Rightarrow$ the code(s) partly tested

$\Rightarrow$ hoping to finish this year

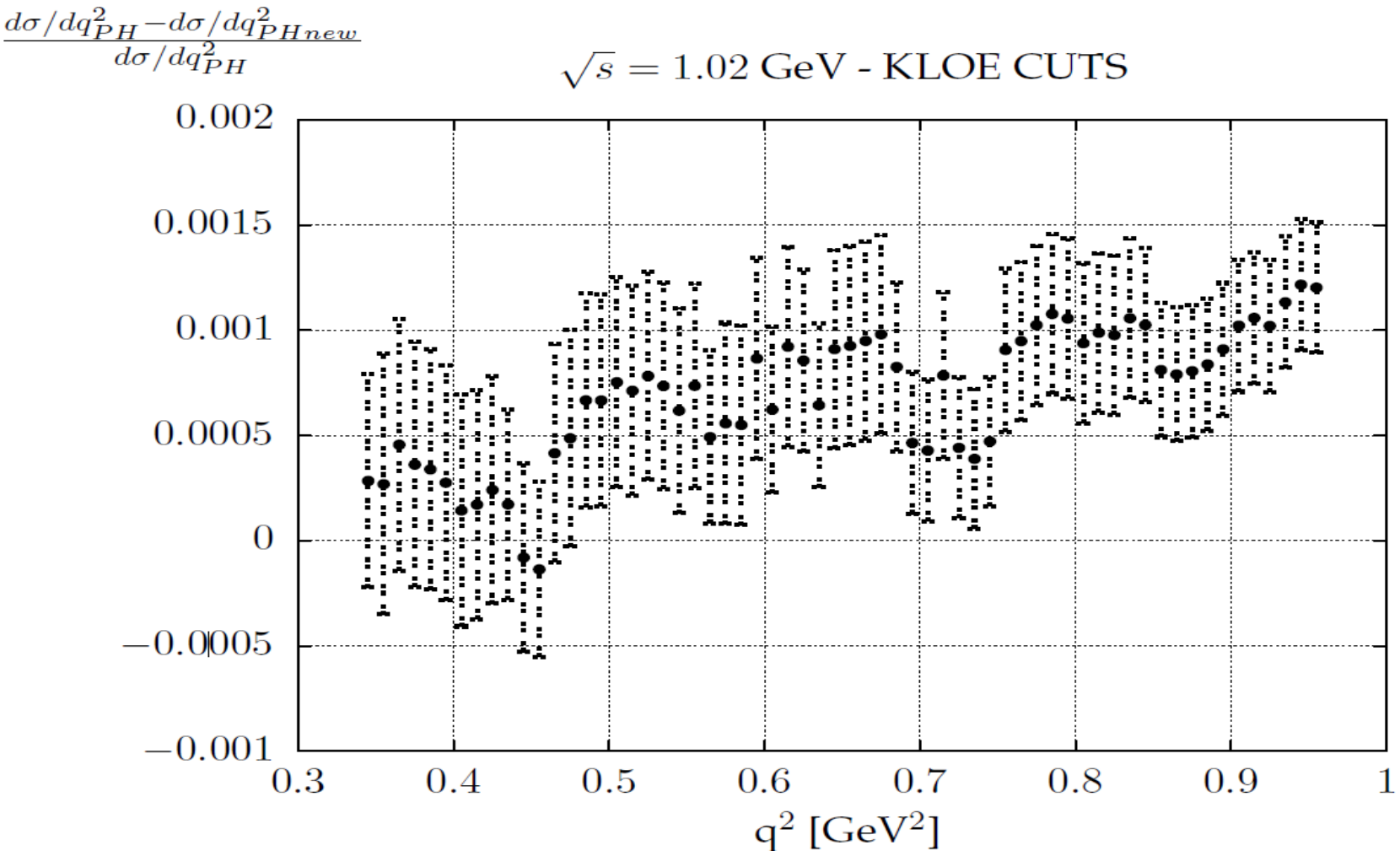
PENTABOXES-pions

The task:

D. Zhuridov: poster session and RadioMonteCarLow satelite meeting

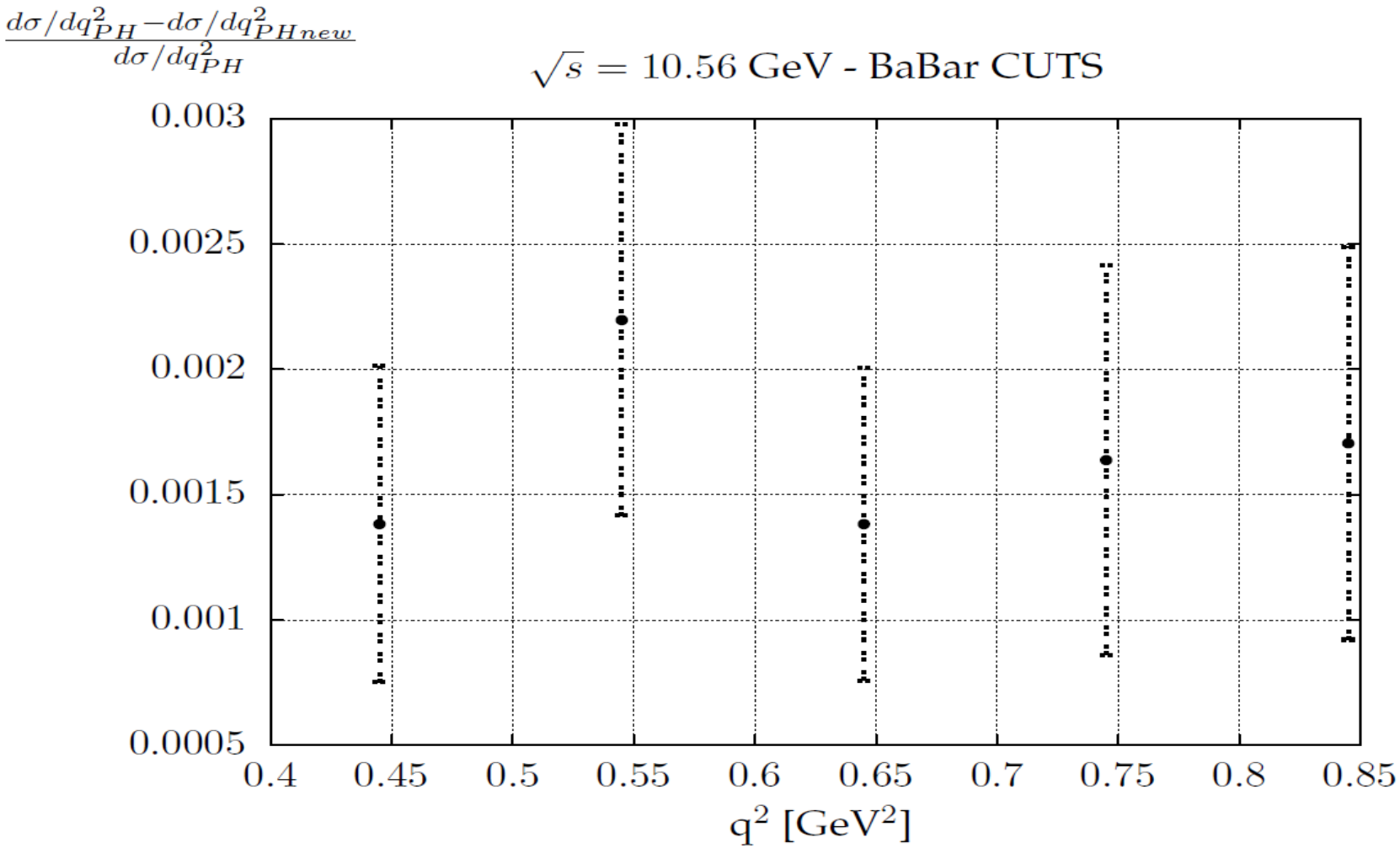


Size of the new corrections



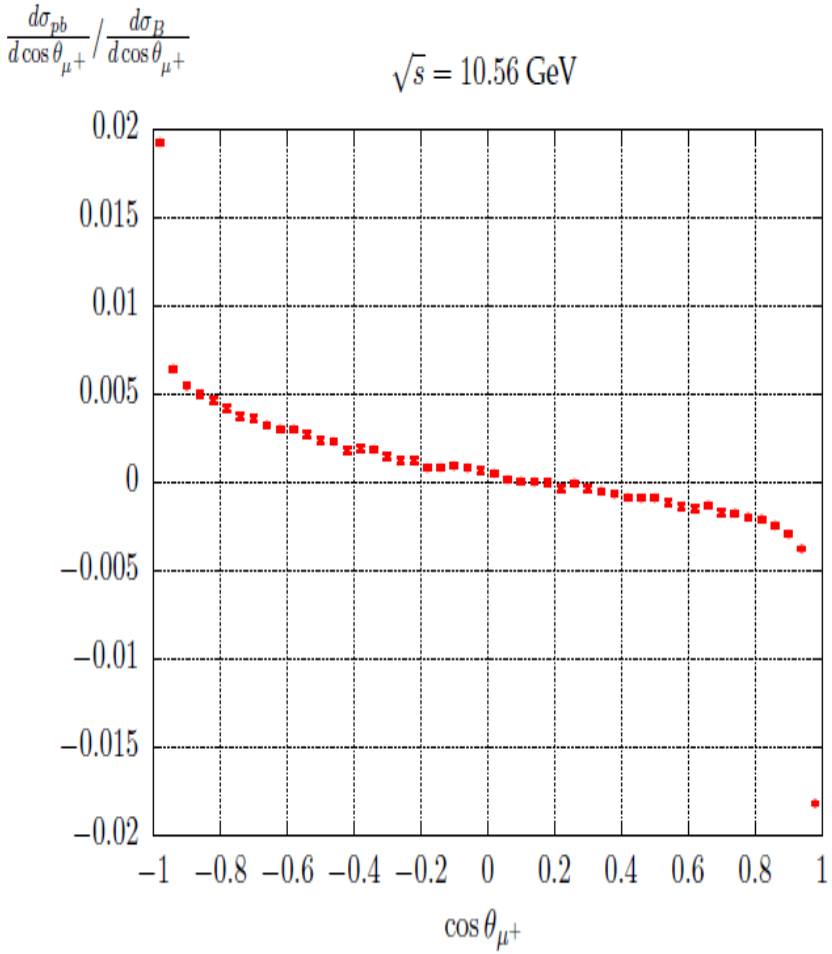
JHEP 1402 (2014) 114

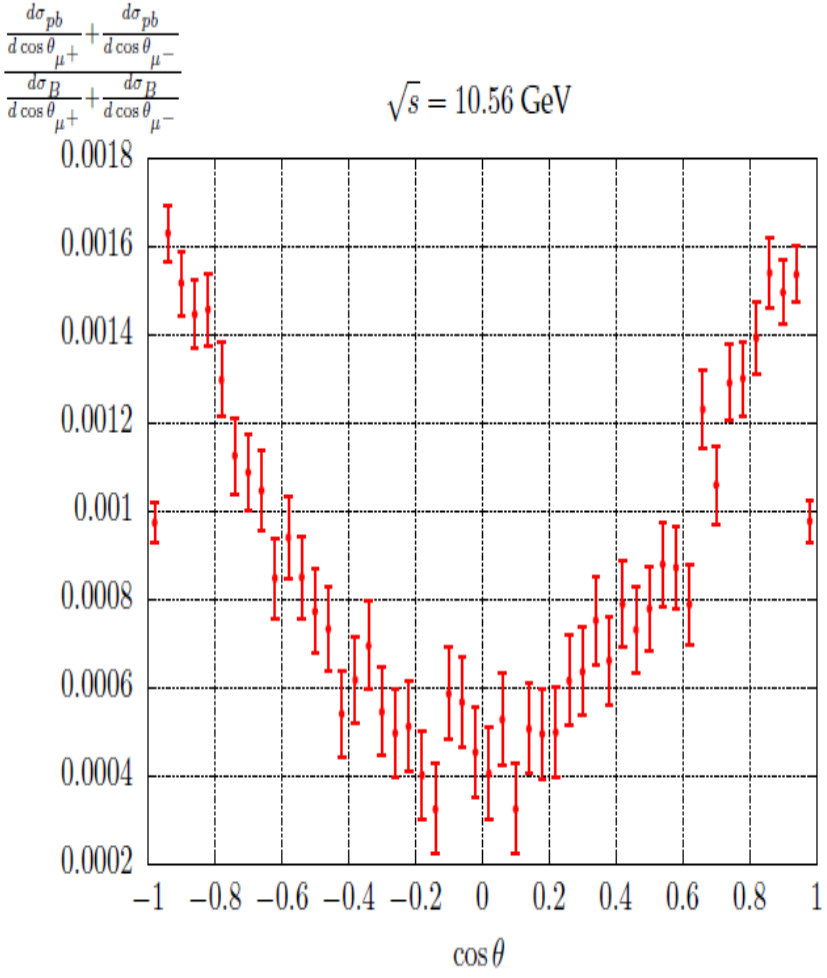
Size of the new corrections



JHEP 1402 (2014) 114

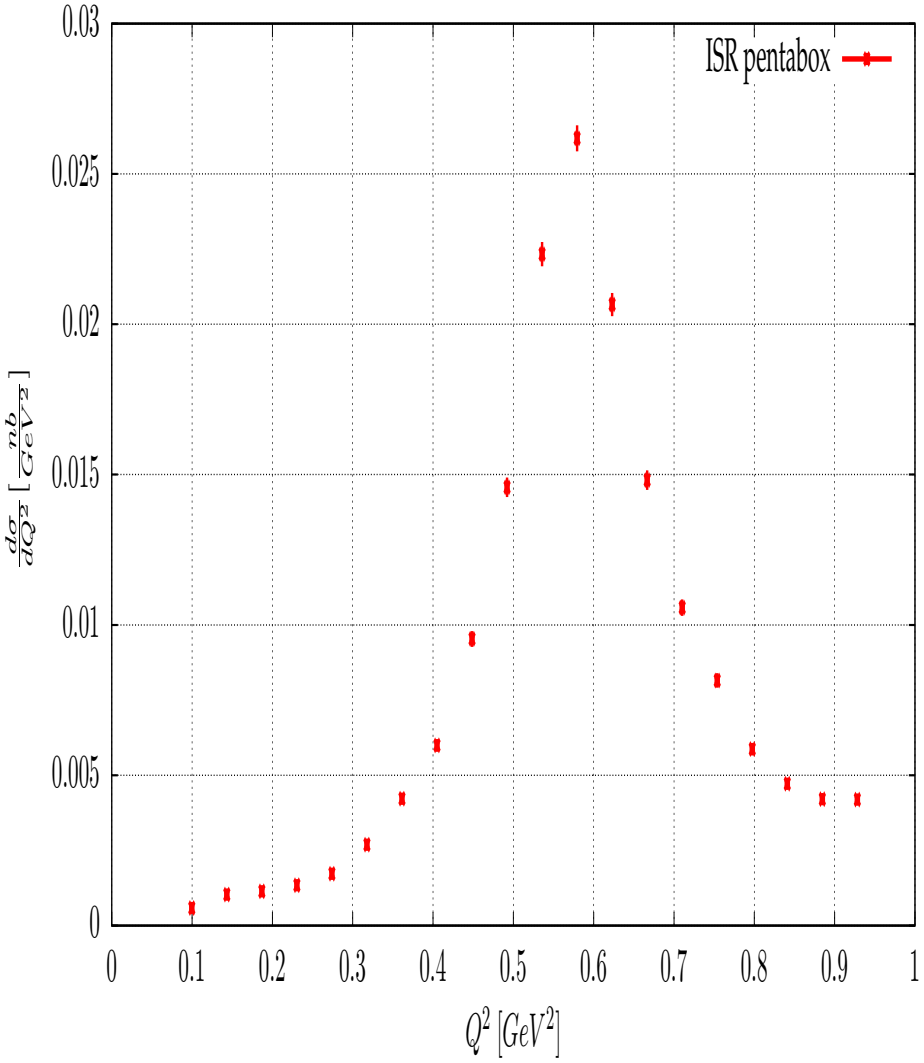
Size of the pentaboxes

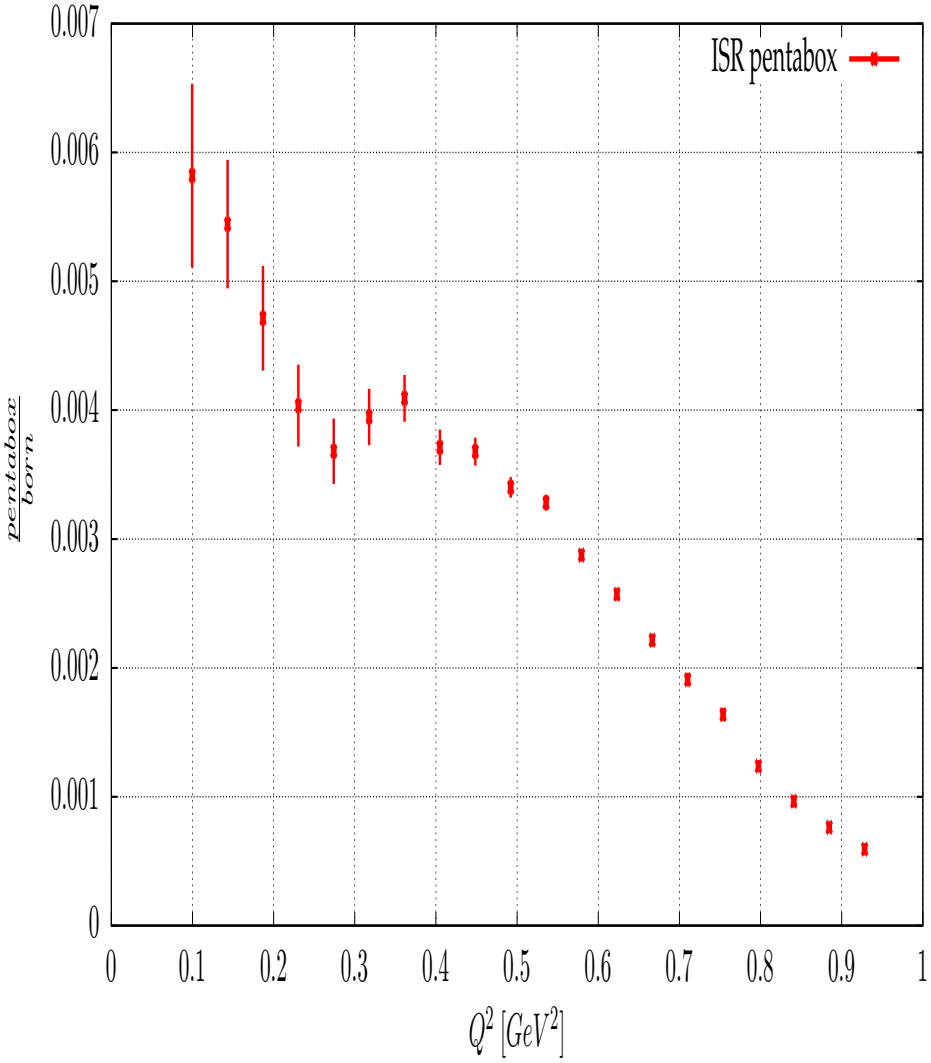




JHEP 1402 (2014) 114

Size of the new corrections - pions





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%

$\Rightarrow$ This year: radiative corrections in EKHARA