

# Status of Monte Carlo generators for energy scan and radiative return

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PHI 13  
PSI 13 PHIPSI13 - International Workshop on e+e-  
collisions from Phi to Psi 2013

# Outline of the talk

⇒ Motivation

⇒ Available generators

⇒ PHOKHARA and its recent upgrades

⇒ PHOKHARA event generator for scan

⇒ FSR for  $e^+e^- \rightarrow \bar{p}p\gamma$

⇒ Complete NLO corrections  
to  $e^+e^- \rightarrow \mu^+\mu^-\gamma$

⇒ Summary

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

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

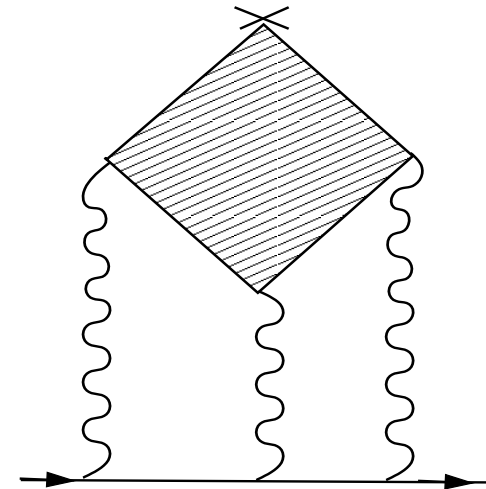
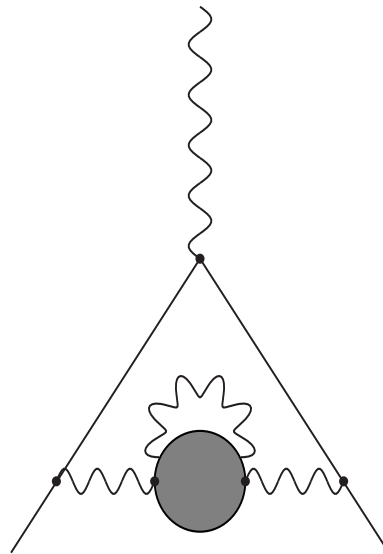
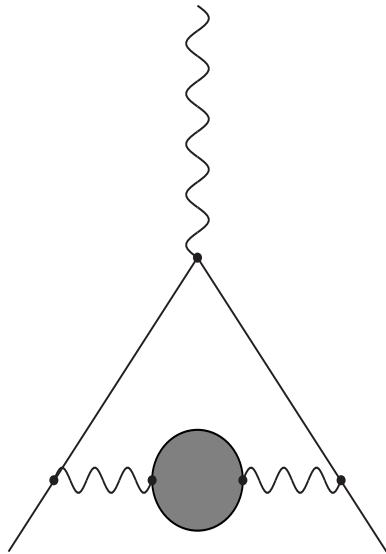
$$(g - 2)_\mu^{exp} = 11659208.9 \pm 5.4 \pm 3.3$$

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

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 $(g - 2)_\mu$



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

# The reason we need $R(s)$

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

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

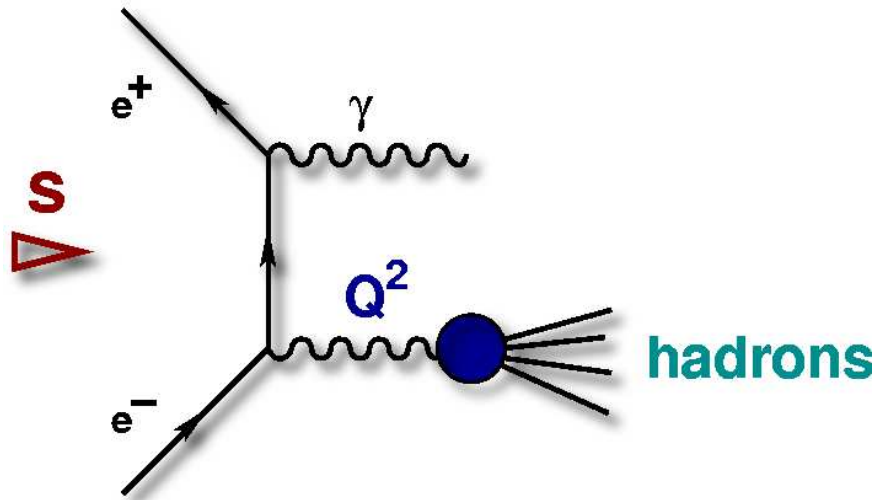
One has to measure :

$$\sigma(e^+e^- \rightarrow \text{hadrons})$$

# THE RADIATIVE RETURN METHOD

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

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



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

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

# MC generators needed

**EVA:**  $e^+e^- \rightarrow \pi^+\pi^-\gamma$

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

[Binner et al.]

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

- ISR at LO + Structure Function

[Czyż, Kühn, 2000]

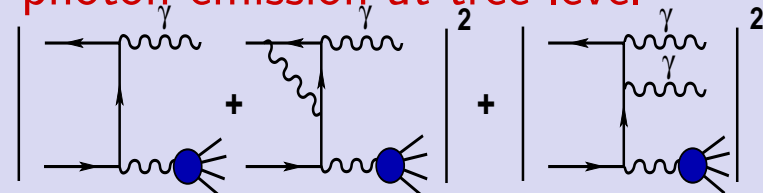
H.C., A. Grzelińska, M. Gunia,

J. H. Kühn, E. Nowak-Kubat,

G. Rodrigo, Sz. Tracz, A. Wapienik

**PHOKHARA 8.0:**  $\pi^+\pi^-$ ,  
 $\mu^+\mu^-$ ,  $4\pi$ ,  $\bar{N}N$ ,  $3\pi$ ,  $KK$ ,  
 $\Lambda(\rightarrow \dots)\bar{\Lambda}(\rightarrow \dots)$ ,  $J/\psi$ ,  $\psi(2S)$

- **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
- $e^+e^- \rightarrow hadrons$  (muons) ISR at NNLO
- Modular structure

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

# MC and FSR studies

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

- ISR at LO + Structure Function

[Czyż, Kühn]



$$e^+e^- \rightarrow \text{hadrons} + \gamma$$

- upgraded by BaBar - AfkQED not public
- PHOTOS [Barberio et al.] for FSR

$$\text{EVA: } e^+e^- \rightarrow \pi^+\pi^-\gamma$$

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

[Binner et al.]



$$e^+e^- \rightarrow \pi^{+,0}\pi^{-,0} + \gamma$$

- FASTERD: FSR studies

[Pancheri, Shekhovtsova, Venanzoni]



# MC for $e^+e^- \rightarrow \text{hadrons}(\text{muons})$

## KKMC

- ISR, YFS exponentiation, muons, 'hadrons'

[ S. Jadach, B. Ward and Z. Was]

Comp.Phys. Comm. 130 (2000) 260; Phys. Rev. D 63(2001)113009

## MCGPJ

- ISR, structure functions, muons,  $\pi^+\pi^-$ ,  $K^+K^-$ ,  $\bar{K}^0K^0$

[A. Arbuzov, G. Fedotov, F. Ignatov, E. Kuraev and A. Sibidanov]

JHEP10(1997)006; JHEP10(1997)001

JHEP08(2013)110.

## PHOKHARA 8.0

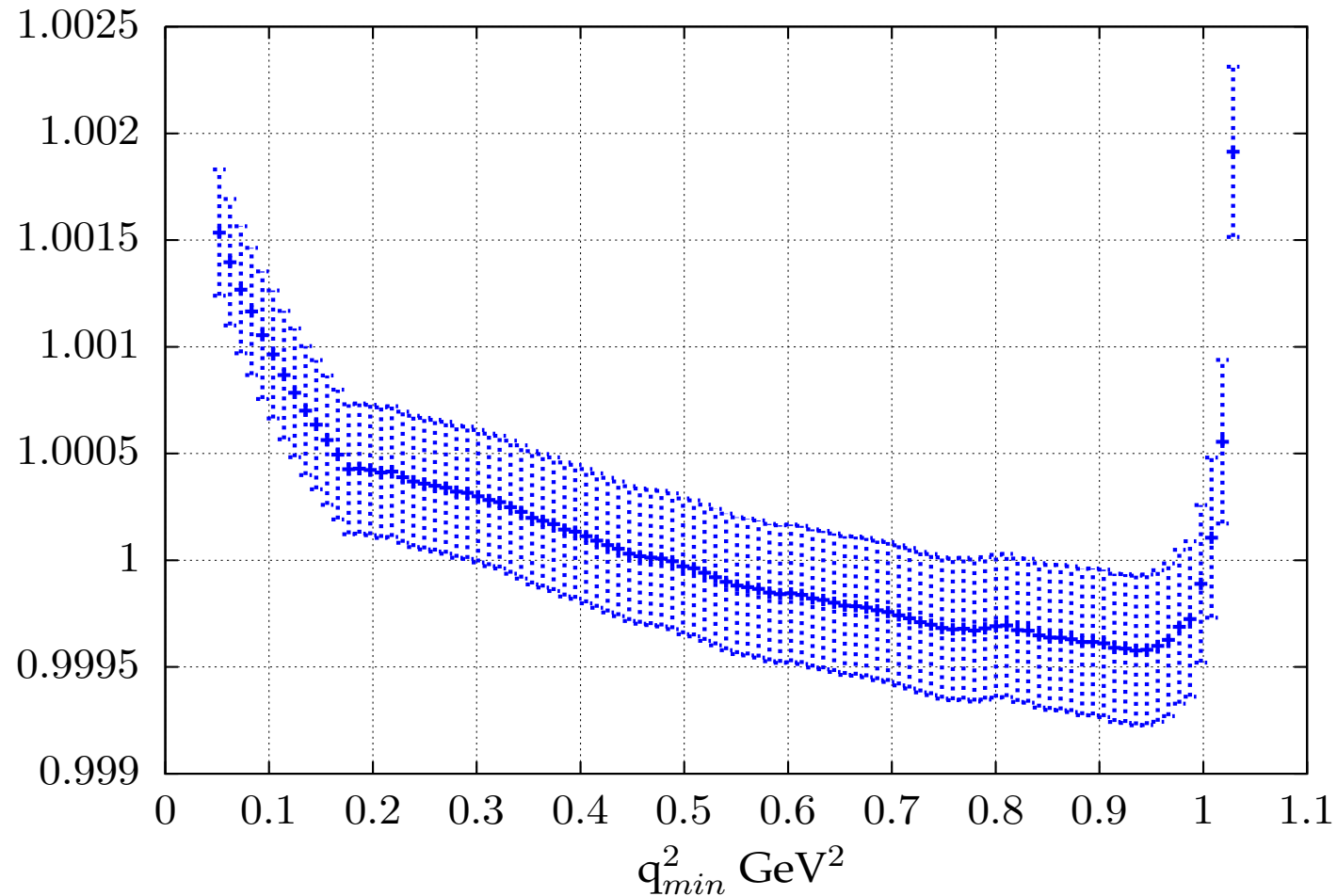
- ISR, fixed order (NNLO), muons, hadrons

[H.Czyz, M. Gunia, J.H. Kuhn]

# PHOKHARA 8.0 vs. KKMC 4.13

$\frac{PHOKHARA}{KKMC}$

$\sqrt{s} = 1.01942 \text{ GeV}$



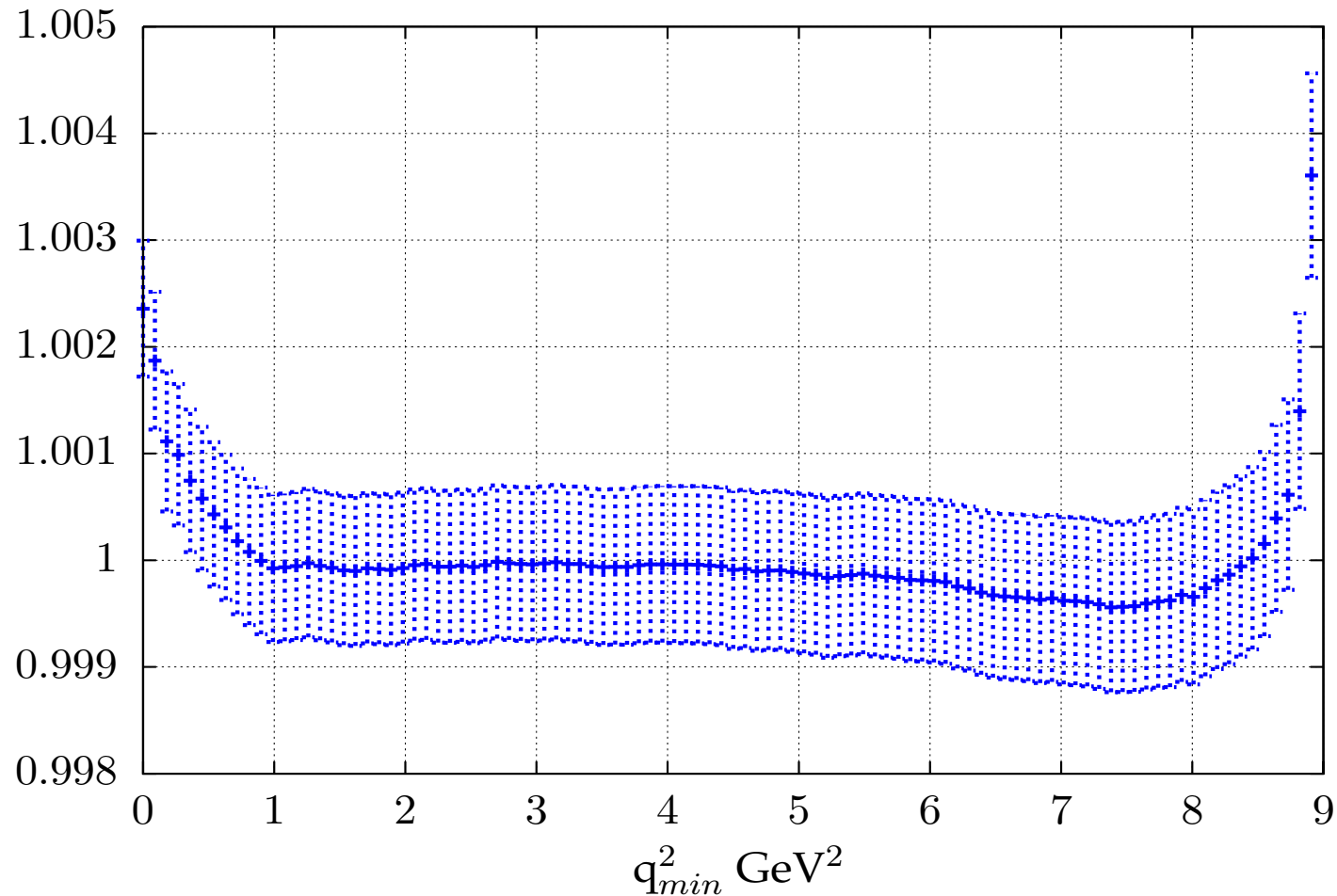
H. Czyz, M. Gunia and J.H. Kuhn, JHEP08(2013)110.

S. Jadach, Acta Phys. Polonica B36 (2005) 2387.

# PHOKHARA 8.0 vs. KKMC 4.13

$\frac{PHOKHARA}{KKMC}$

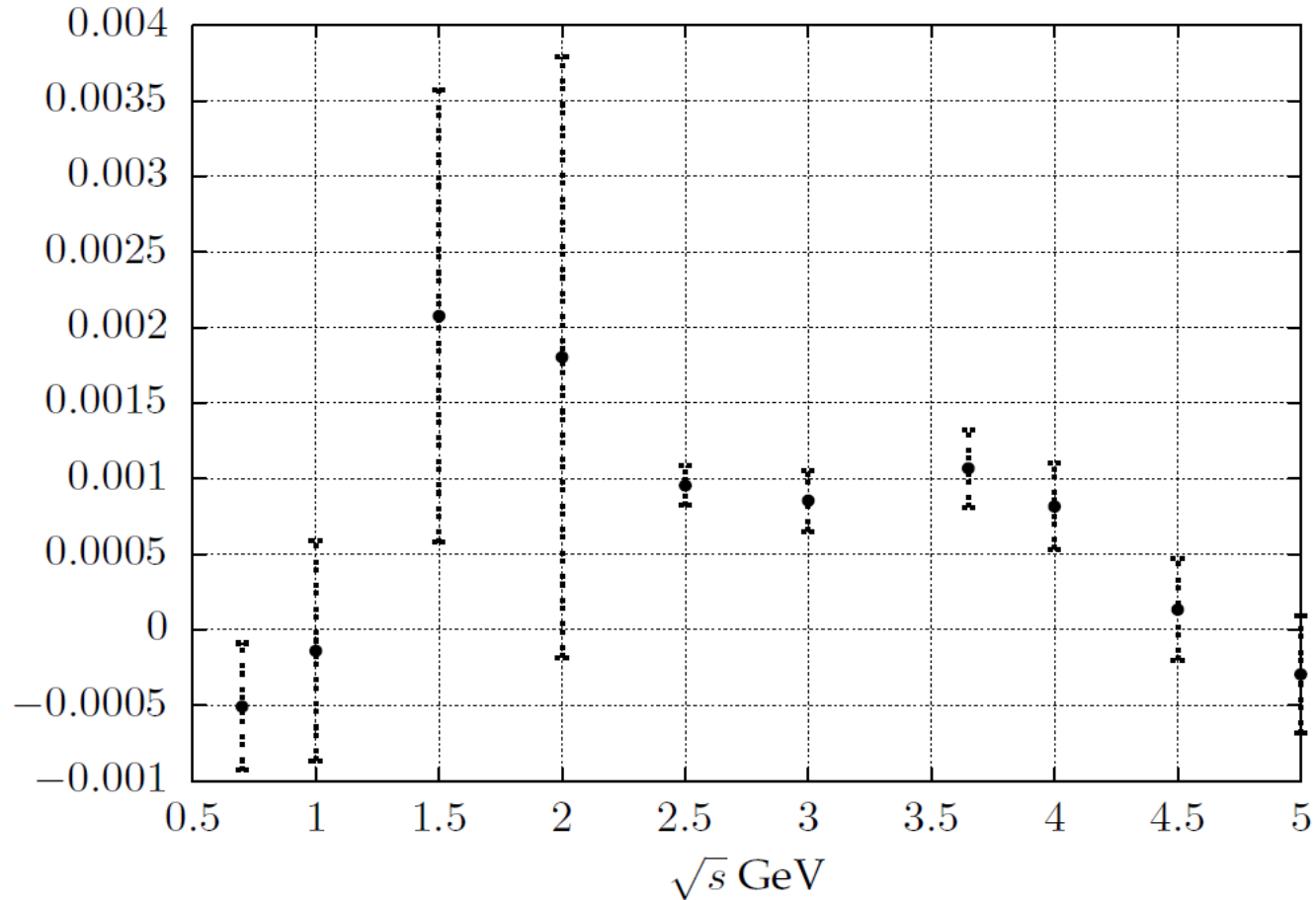
$\sqrt{s} = 3 \text{ GeV}$



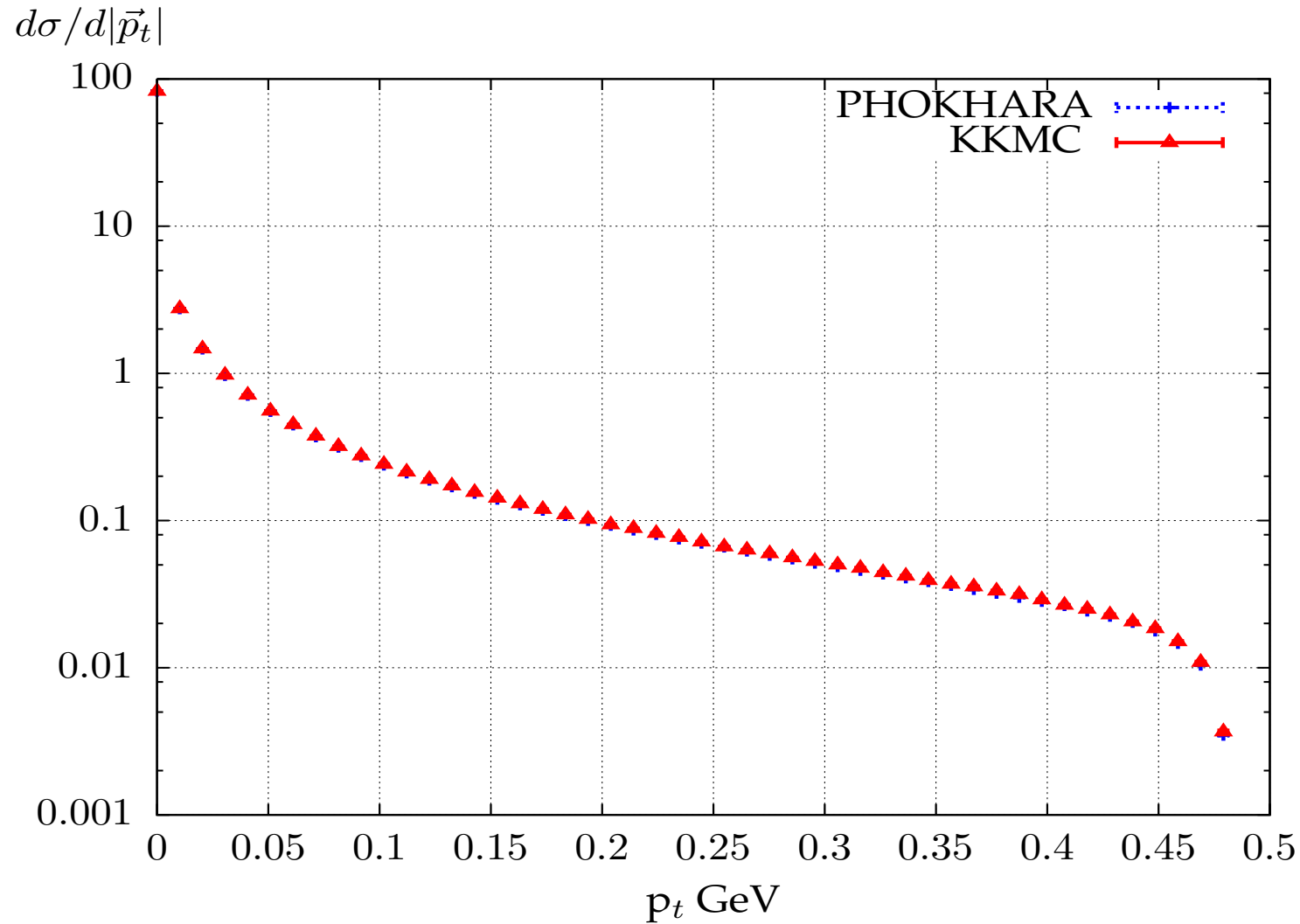
# PHOKHARA 8.0 vs. MCGPJ

$$\frac{\sigma_{PHOKHARA} - \sigma_{MCGPJ}}{\sigma_{PHOKHARA}}$$

Muons: MCGPJ vs. PHOKHARA



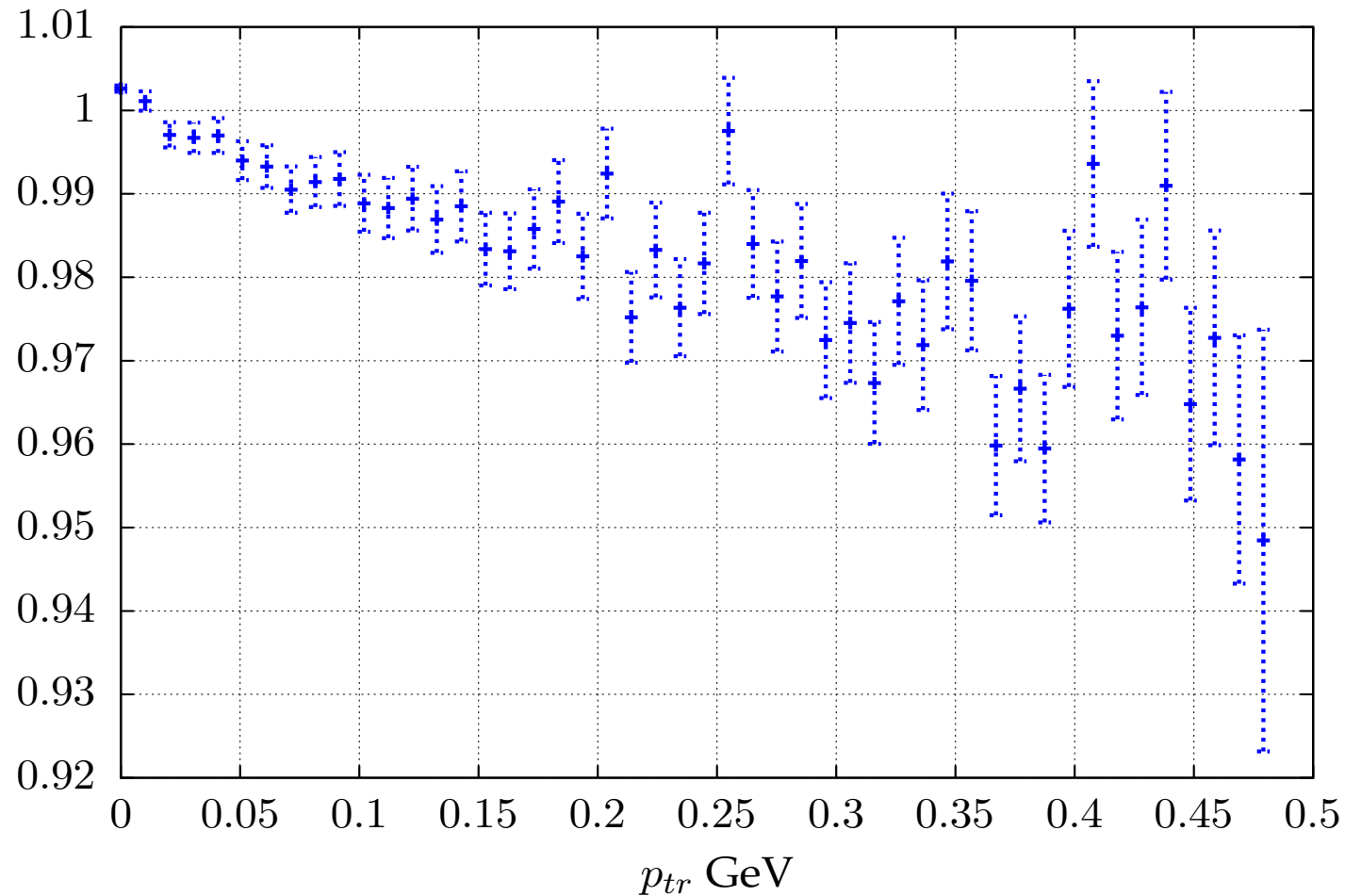
# PHOKHARA 8.0 vs. KKMC 4.13



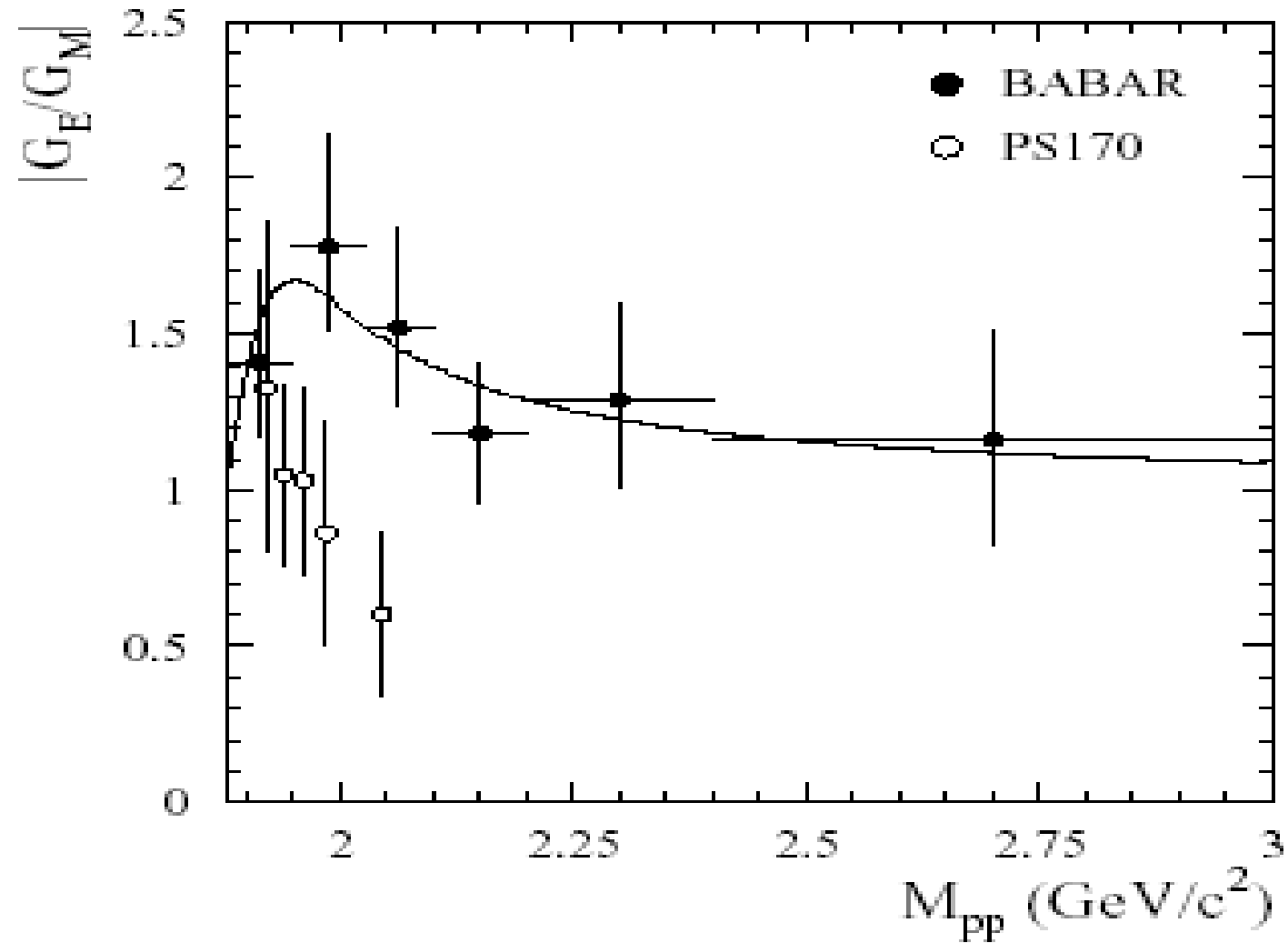
# PHOKHARA 8.0 vs. KKMC 4.13

$\frac{PHOKHARA}{KKMC}$

$\sqrt{s} = 1.01942 \text{ GeV}$

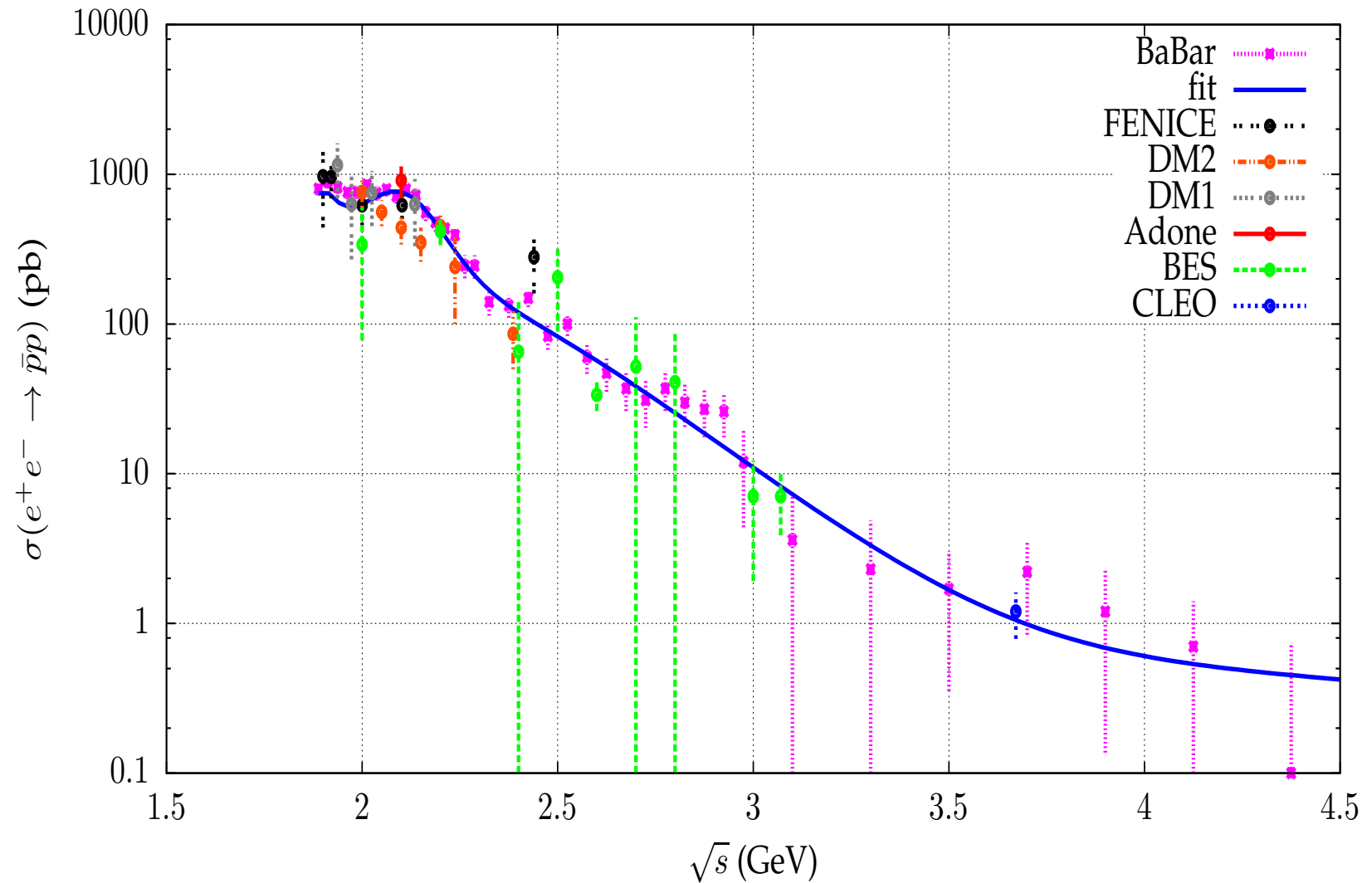


# nucleon FF



**BaBar: Phys.Rev.D73:012005,2006.**

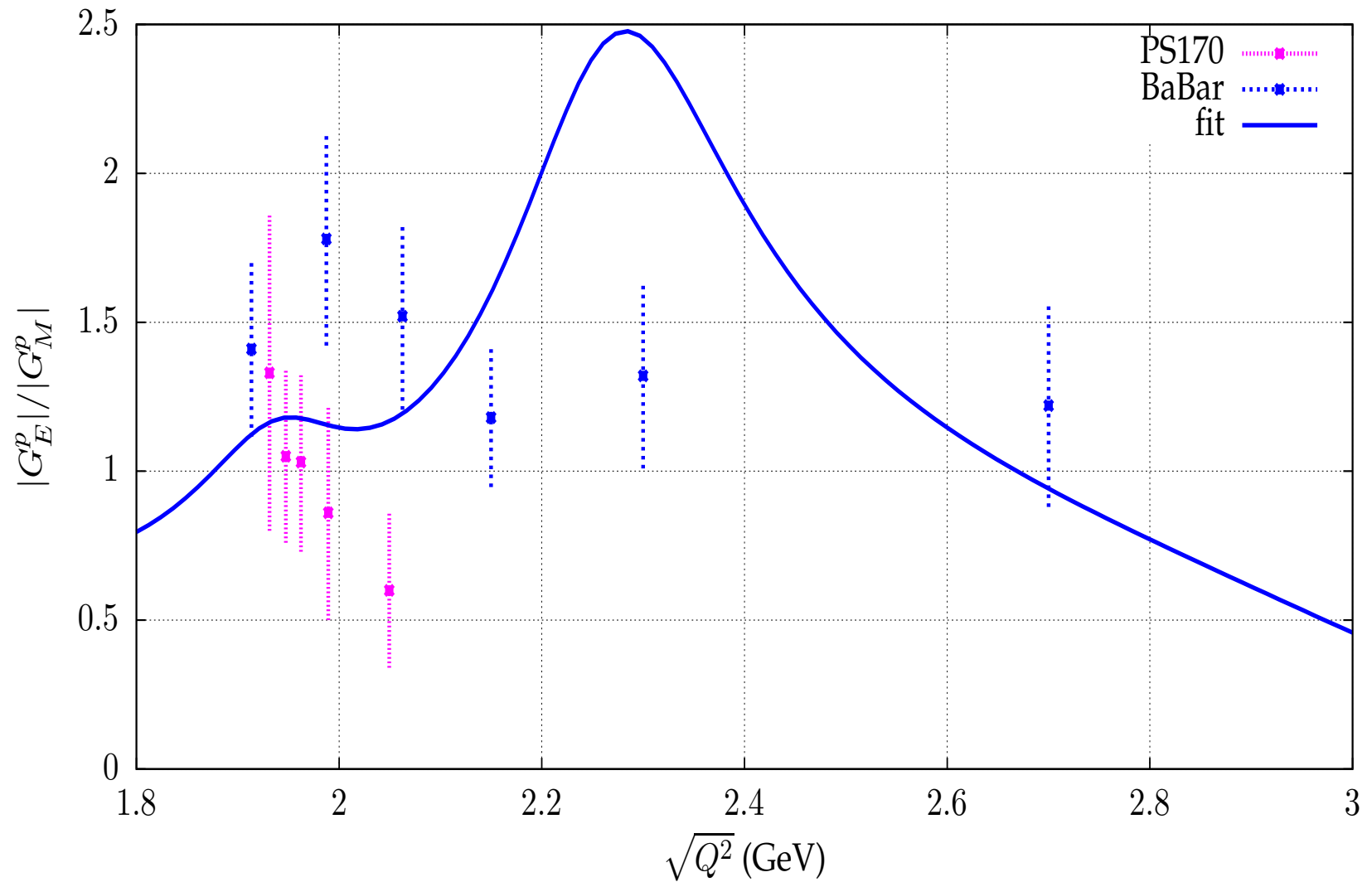
# Fits



HC, J.H. Kuhn, Sz. Tracz, in preparation

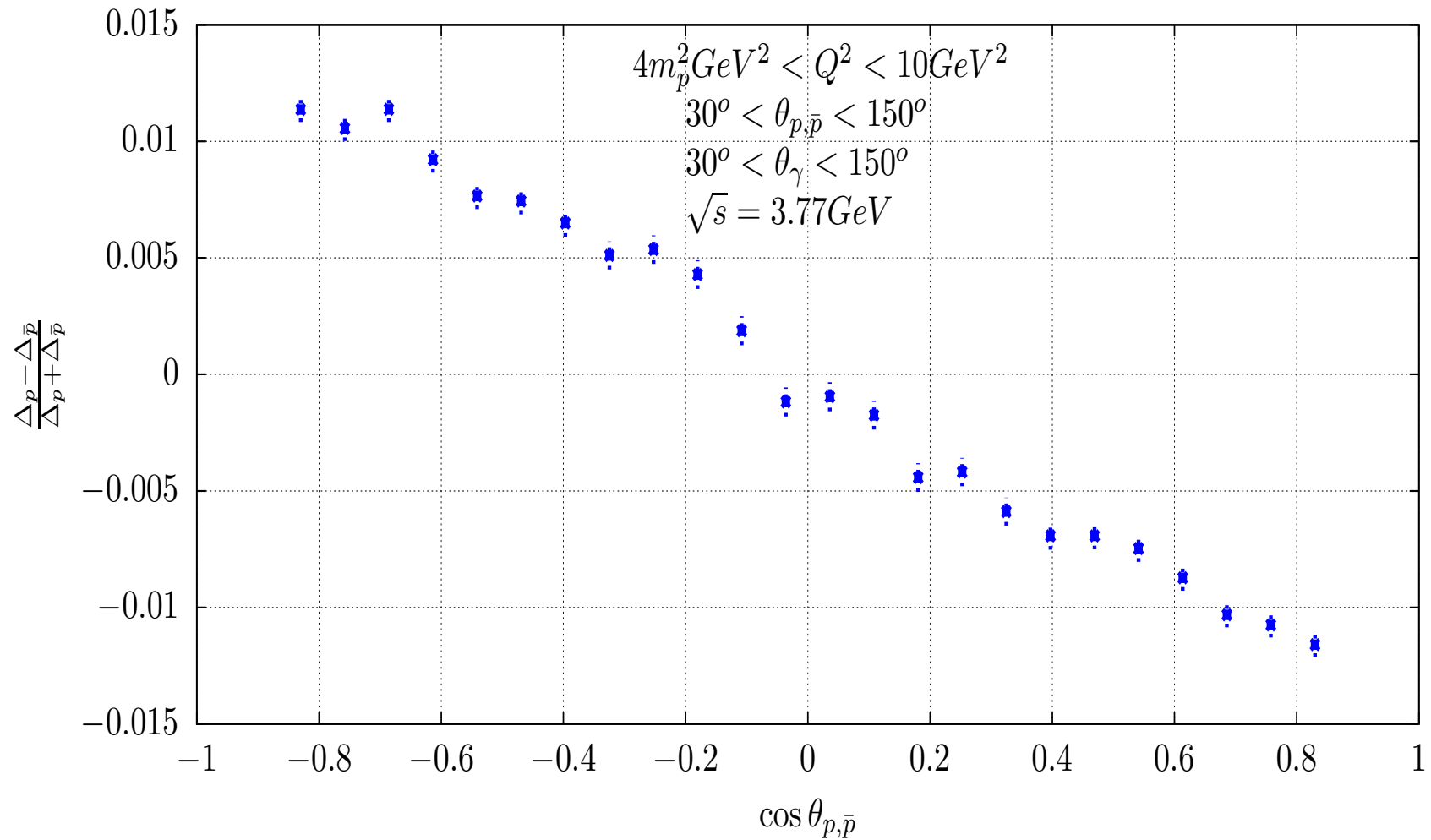


# Fits



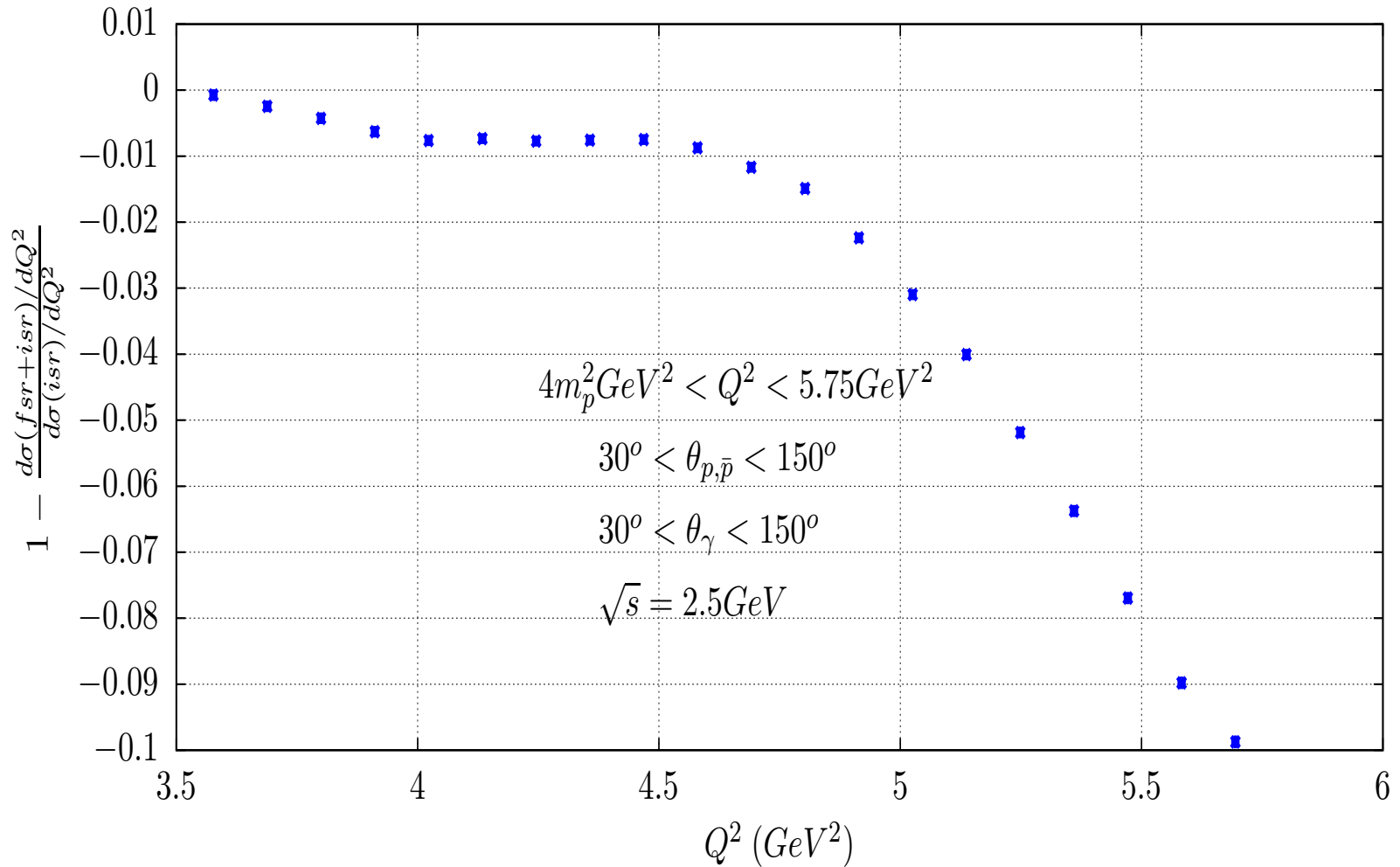
# FSR

$e + e^- \rightarrow p\bar{p}\gamma$  LO



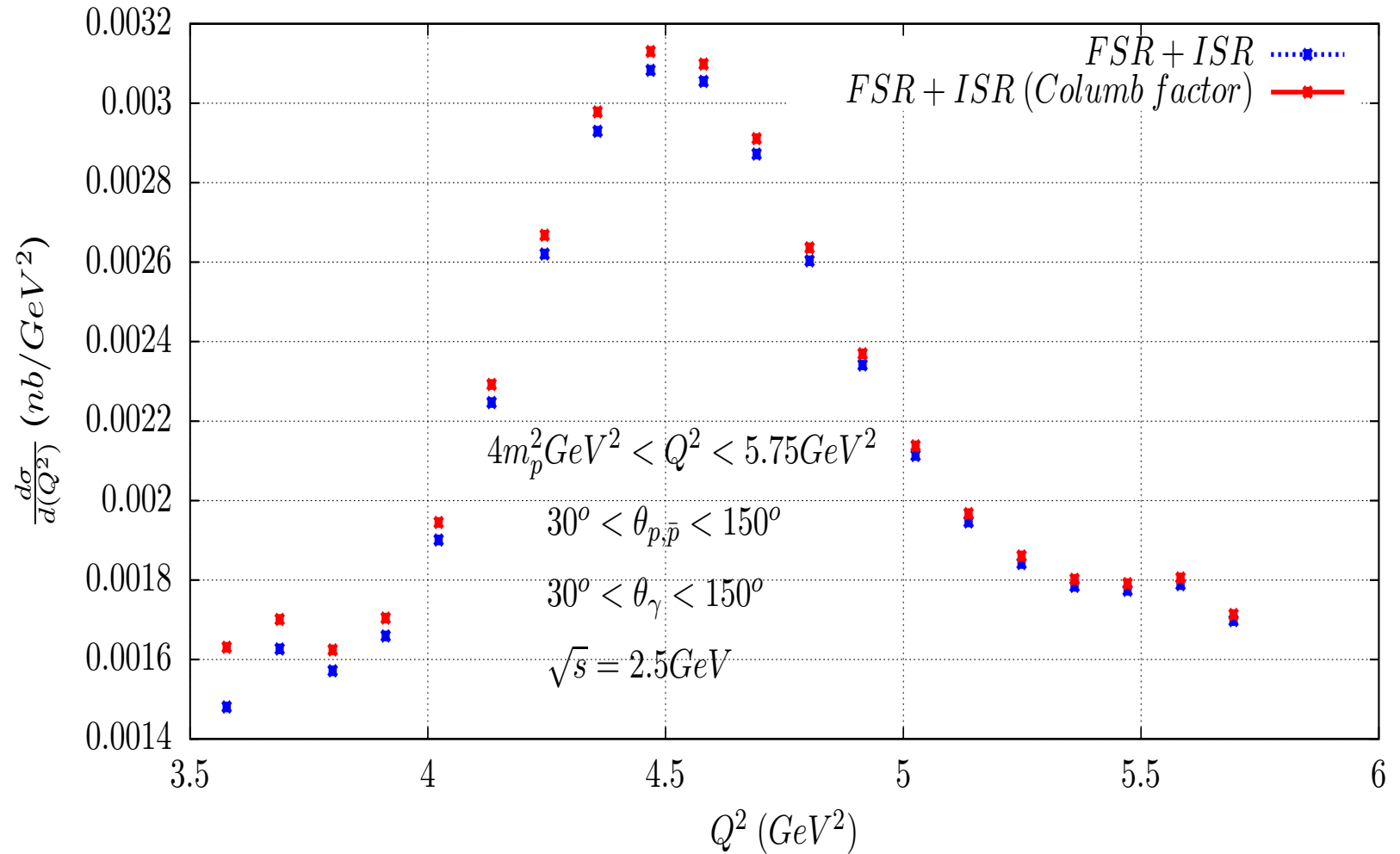
# FSR

$e + e^- \rightarrow p\bar{p}\gamma$  NLO



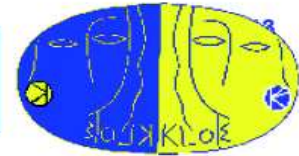
# FSR

$e + e^- \rightarrow p\bar{p}\gamma$  NLO

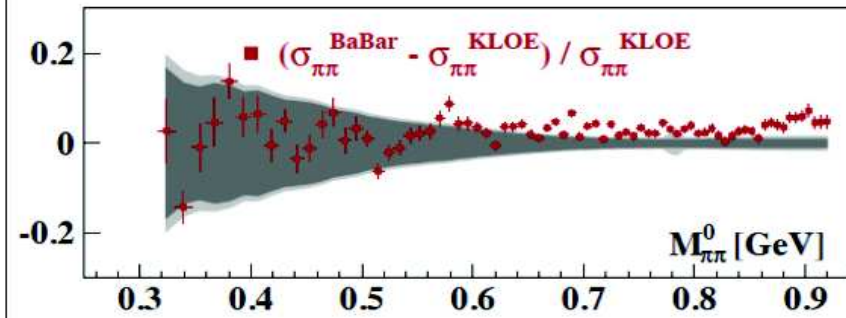
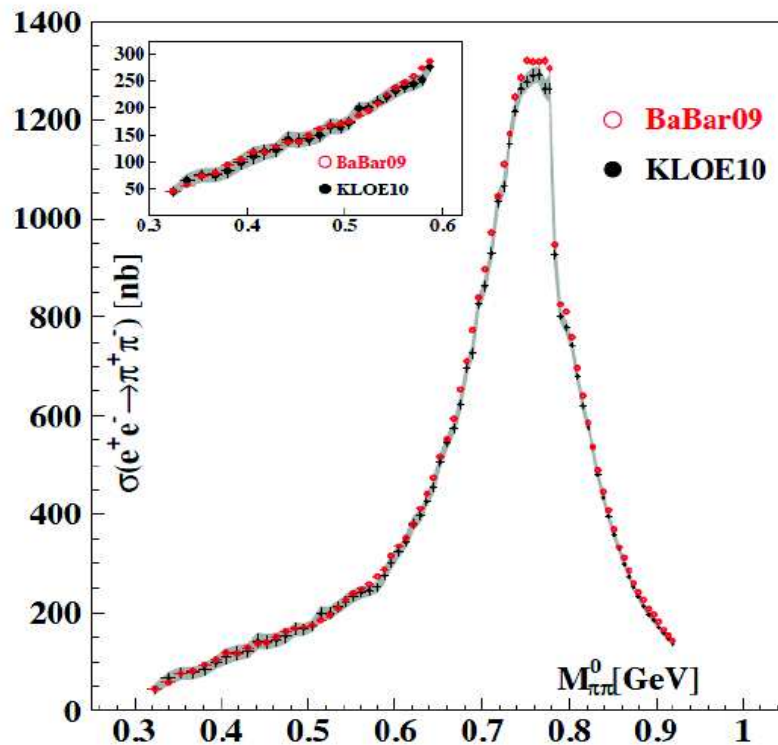


# $e^+e^- \rightarrow \mu^+\mu^-\gamma$ - a motivation

## Comparison of results: KLOE10 vs BaBar



BaBar results compared to KLOE10: Fractional difference



band: KLOE10 error

*Agreement within errors below  
0.6 GeV; BaBar higher by 2-3%  
above*

$e^+e^- \rightarrow \mu^+\mu^-\gamma$  complete NLO

## PHOKHARA 9.0

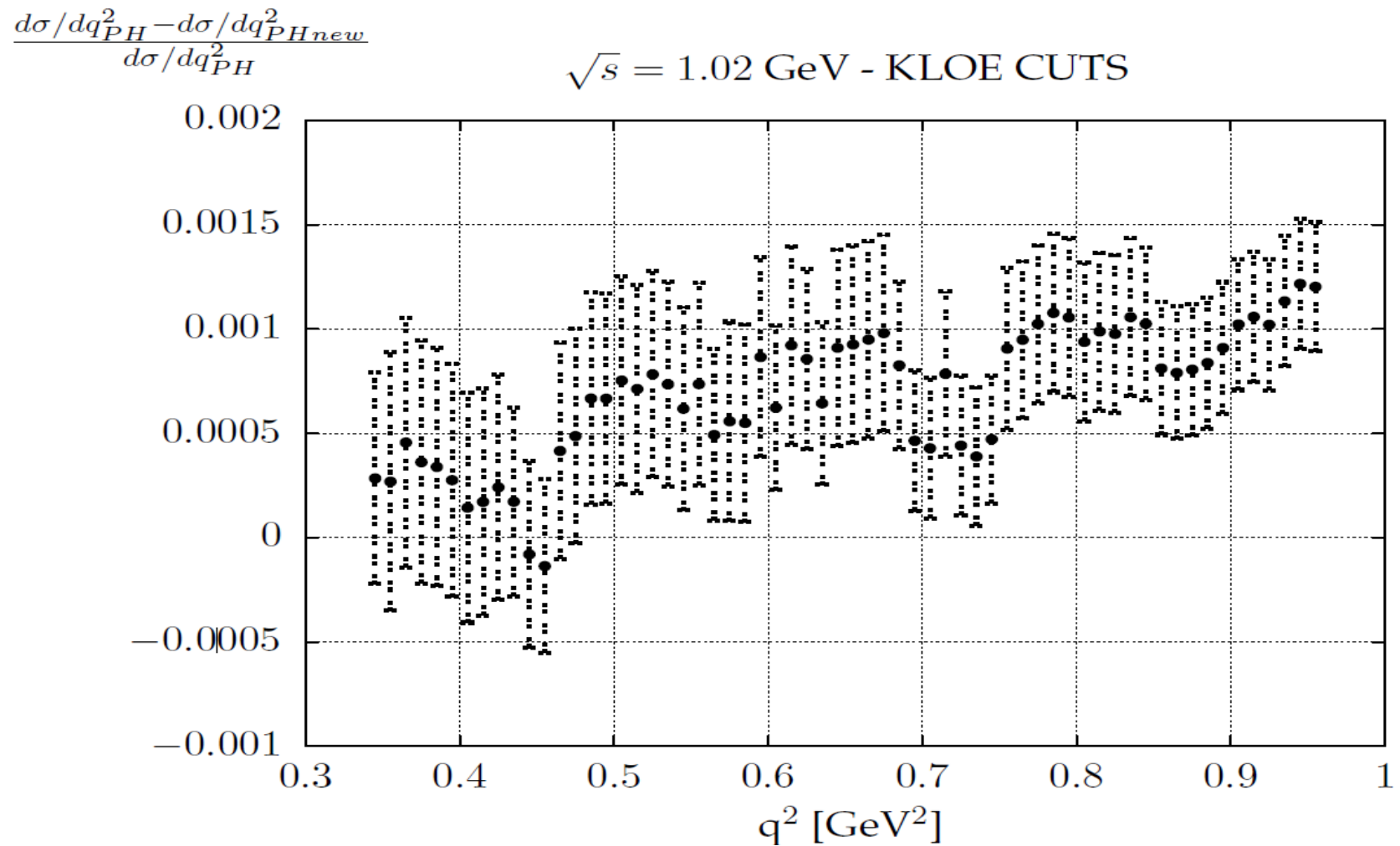
F. Campanario, H. Czyz, J. Gluza, M. Gunia, T. Riemann,  
G. Rodrigo, V. Yundin

⇒ two independent codes  
for each new part

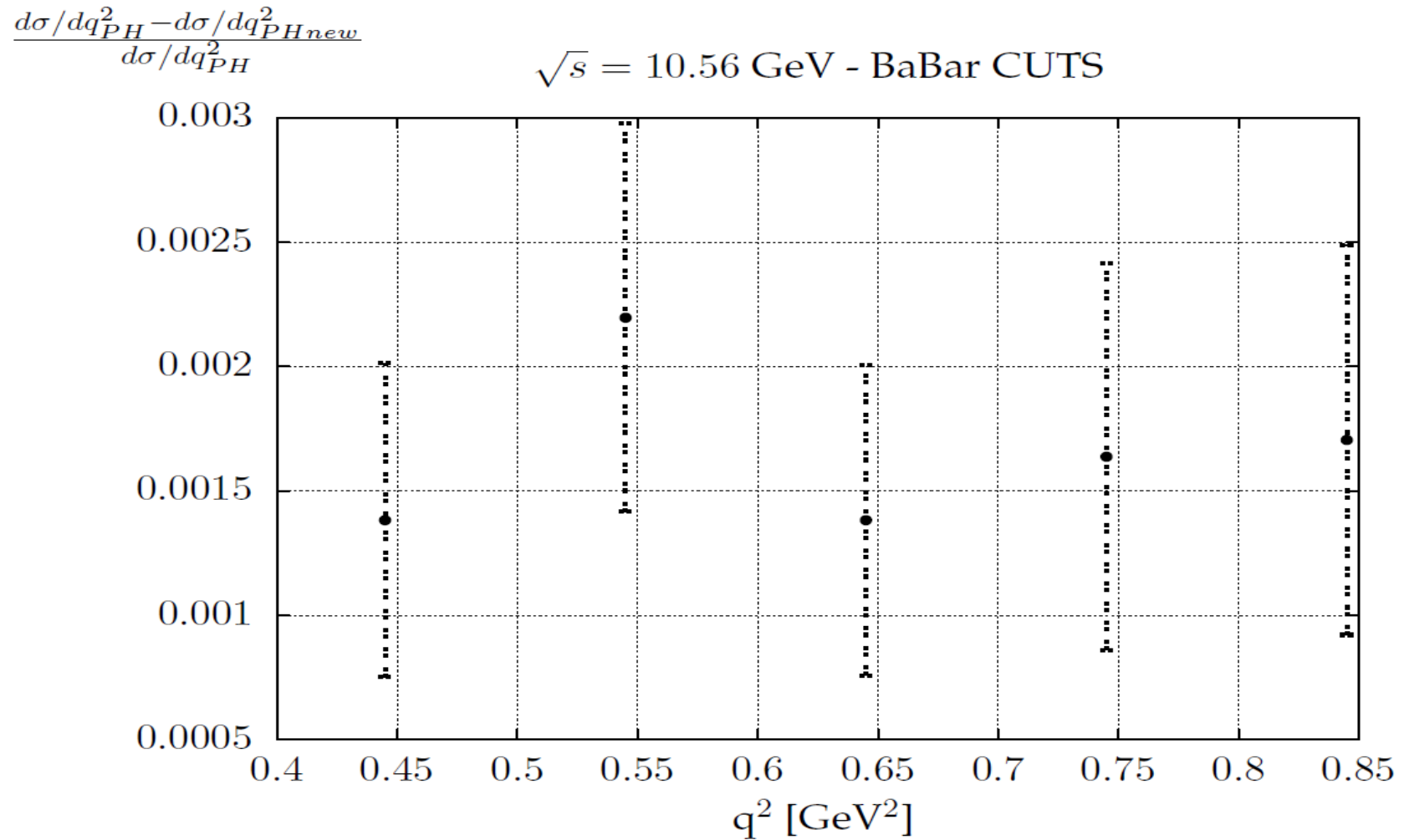
⇒ tests finished

⇒ paper in preparation

# Size of the new corrections



# Size of the new corrections





# Summary

- ⇒ We keep working:
- ⇒ **PHOKHARA** for the scan mode
- ⇒ Comparisons with the existing codes
- ⇒ Further comparisons hopefully will be done as a MonteCarLow WG activity
- ⇒ FSR for  $e^+e^- \rightarrow \bar{p}p\gamma$
- ⇒ Complete NLO for  $e^+e^- \rightarrow \mu^+\mu^-\gamma$