Status of MC generators for low energy e^+e^- scattering

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10th International Workshop on e^+e^- collisions from ϕ to ψ

Hefei, September 2015

Outline

- $\Rightarrow$ Monte Carlo generators for luminosity
- $\Rightarrow$ Monte Carlo generators for scan
- $\Rightarrow$ Monte Carlo generators for $\gamma - \gamma$
- $\Rightarrow$ Monte Carlo generators for radiative return
- $\Rightarrow$ Progress on PHOKHARA generator
- $\Rightarrow$ Radiative corrections
- $\Rightarrow$ Summary

MC for $e^+e^- \to e^+e^-$ -luminosity

BHWIDE

- **YFS exponentiation**

[S. Jadach, W. Placzek and B. Ward]

Phys.Lett. B390 (1997) 298-308

MCGPJ

- **ISR, structure functions, e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-, $\bar{K}^0K^0$**

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

Eur.Phys.J. C46 (2006) 689-703

BABAYAGA@NLO

- **parton showers, NLO,NNLO**

[G. Balossini, C. M. Carloni Calame, G. Montagna, O. Nicrosini and F. Piccinini]

Nucl. Phys. B758 (2006)

MC for $e^+e^- \to hadrons(muons)$

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, e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-, $\bar{K}^0K^0$

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

Eur.Phys.J. C46 (2006) 689-703

PHOKHARA 8.0

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

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

JHEP08(2013)110.

MC for $e^+e^- \rightarrow hadrons(muons)$

LUARLW

- adopted LUND model

[H. Hu, B. Anderson]

hep-ph/9910285

ZRC

- structure functions, narrow resonances

[D. Zhang, G. Rong, J.C. Chen]

Phys.Rev. D74 (2006) 054012

carlomat_3.0

- LO, CHPT, multi-hadronic states, ISR,FSR,automatic code generation

[K.Kolodziej]

CPC(2015)563.

MC for $\gamma^{(*)} - \gamma^{(*)}$

no name

- $e^+e^- \to e^+e^-\pi^0\pi^0$, **DAPHNE energy**

[F. Nguyen,F.Piccinini,A.D.Polosa]

Eur.Phys.J. C47 (2006) 65

TwoGam

- ??

[D.Coffman, V.Savinov]

CLEO

TREPS

- **equivalent photon approximation**

[S. Uehara]

KEK-REPORT-96-11, arXiv:1310.0157

MC for $\gamma^{(*)} - \gamma^{(*)}$

GALUGA

- $e^+e^- \to e^+e^-X$, LEP energy

[G.A.Schuler]

Comput.Phys.Commun. 108 (1998) 279

EKHARA

- exact matrix element at LO

[H.Czyz,S.Ivashyn,E.Nowak]

Comput.Phys.Commun. 182 (2011) 1338

GGRESRC

- approximated radiative correction

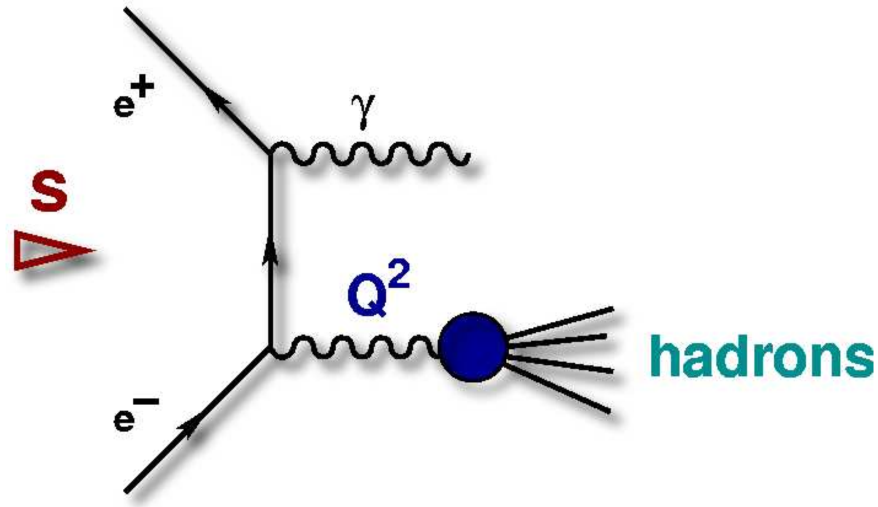
[Druzhinin, V. P. and Kardapoltsev, L. V. and Tayursky, V.A.]

Comput.Phys.Commun. 185 (2014) 236

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

MC generators needed

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]

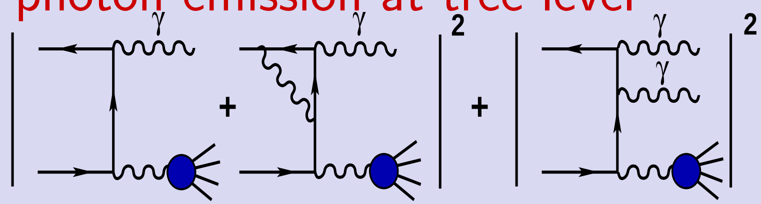
H.C., A. Grzelińska, M. Gunia,

J. H. Kühn, E. Nowak-Kubat,

G. Rodrigo, Sz. Tracz, A. Wapienik

PHOKHARA 9.1: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π, $\bar{N}N$, 3π, KK, $\Lambda(\to \cdots)\bar{\Lambda}(\to \cdots)$, $J/\psi, \psi(2S)$

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

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

MC for radiative return

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

- ISR at LO + Structure Function

[Czyż, Kühn]

→

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

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

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.]

→

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

- FASTERD: FSR studies

[Pancheri,Shekhovtsova,Venanzoni]

Modest progress on PHOKHARA

H.Czyz, J.H.Kuhn, Sz. Tracz, Phys.Rev. D90 (2014) 11, 114021

$\Rightarrow$ Nucleon form factors - new model

$\Rightarrow$ FSR corrections for $\bar{p}p$

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

$\Rightarrow$ χ_{c_1} and χ_{c_2} production in e^+e^-

Nucleon form factors - new model

$$F^p_{1,2} = F^s_{1,2} + F^v_{1,2} \qquad F^n_{1,2} = F^s_{1,2} - F^v_{1,2}$$

$$F^s_1 = \frac{1}{2}\frac{\sum_{n=0}^{N} c^1_n BW_{\omega_n}(s)}{\sum_{n=0}^{N} c^1_n},$$

$$F^v_1 = \frac{1}{2}\frac{\sum_{n=0}^{N} c^2_n BW_{\rho_n}(s)}{\sum_{n=0}^{N} c^2_n},$$

$$F^s_2 = -\frac{1}{2} b \frac{\sum_{n=0}^{N} c^3_n BW_{\omega_n}(s)}{\sum_{n=0}^{N} c^3_n},$$

$$F^v_2 = \frac{1}{2} a \frac{\sum_{n=0}^{N} c^N_n BW_{\rho_n}(s)}{\sum_{n=0}^{N} c^N_n},$$

Nucleon form factors - new model

G. P. Lepage and S. J. Brodsky, Phys.Rev. D22, 2157(1980).

$$F_1 \sim \frac{1}{(Q^2)^2}, \quad F_2 \sim \frac{1}{(Q^2)^3},$$

$$BW_i(Q^2) = \frac{m_i^2}{m_i^2 - Q^2 - i m_i \Gamma_i \theta(Q^2)}.$$

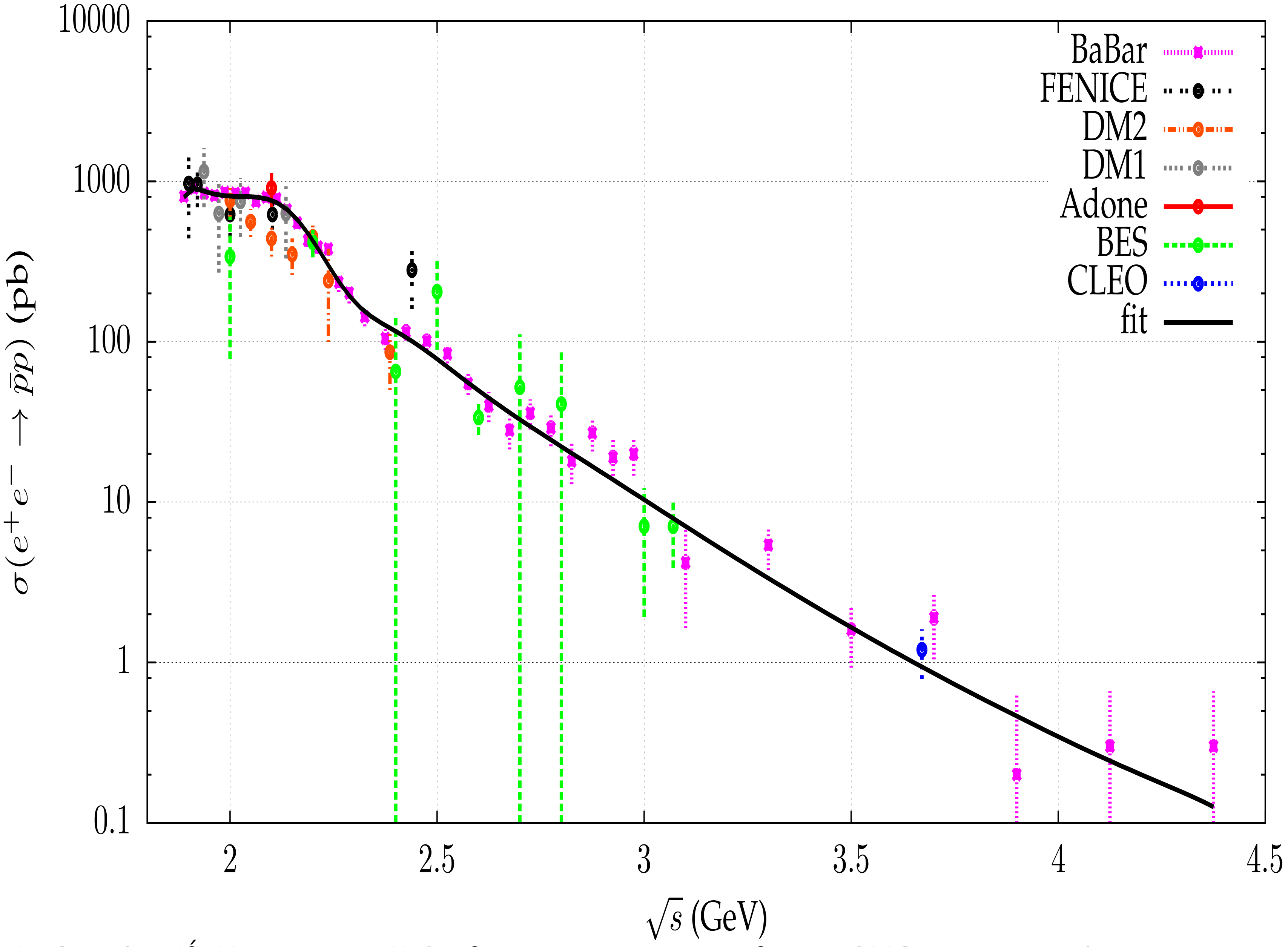
$$c_i^j = c_i^{jR} + i c_i^{jI} \theta(Q^2)$$

Phys.Rev. D90 (2014) 11, 114021 fit, N=4

Experiment	nep	χ^2	Experiment	nep	χ^2
BaBar cs [12]	38	30	BaBar r [12]	6	0.6
$PS170_1$ cs [16]	8	109	PS170 r [16]	5	16
$PS170_2$ cs [17]	4	4	$PS170_3$ cs [18]	4	52
$E760_1$ cs [19]	3	0.5	$E835_1$ cs [20]	5	1
$E835_2$ cs [21]	2	0.03	DM2 cs [22, 23]	7	26
BES cs [24]	8	10	CLEO cs [25]	1	0.4
FENICE cs [26]	5	5	DM1 cs [27]	4	0.7
JLab 05 r [28]	10	16	JLab 02 r [29]	4	1
JLab 01 r [30]	13	10	JLab 10 r [31]	3	6
MAMI 01 r [32]	3	2	JLab 03 r [33]	3	6
BLAST 08 r [34]	4	6	FENICE cs [26]	4	0.6
			SLAC cs [35]	32	27

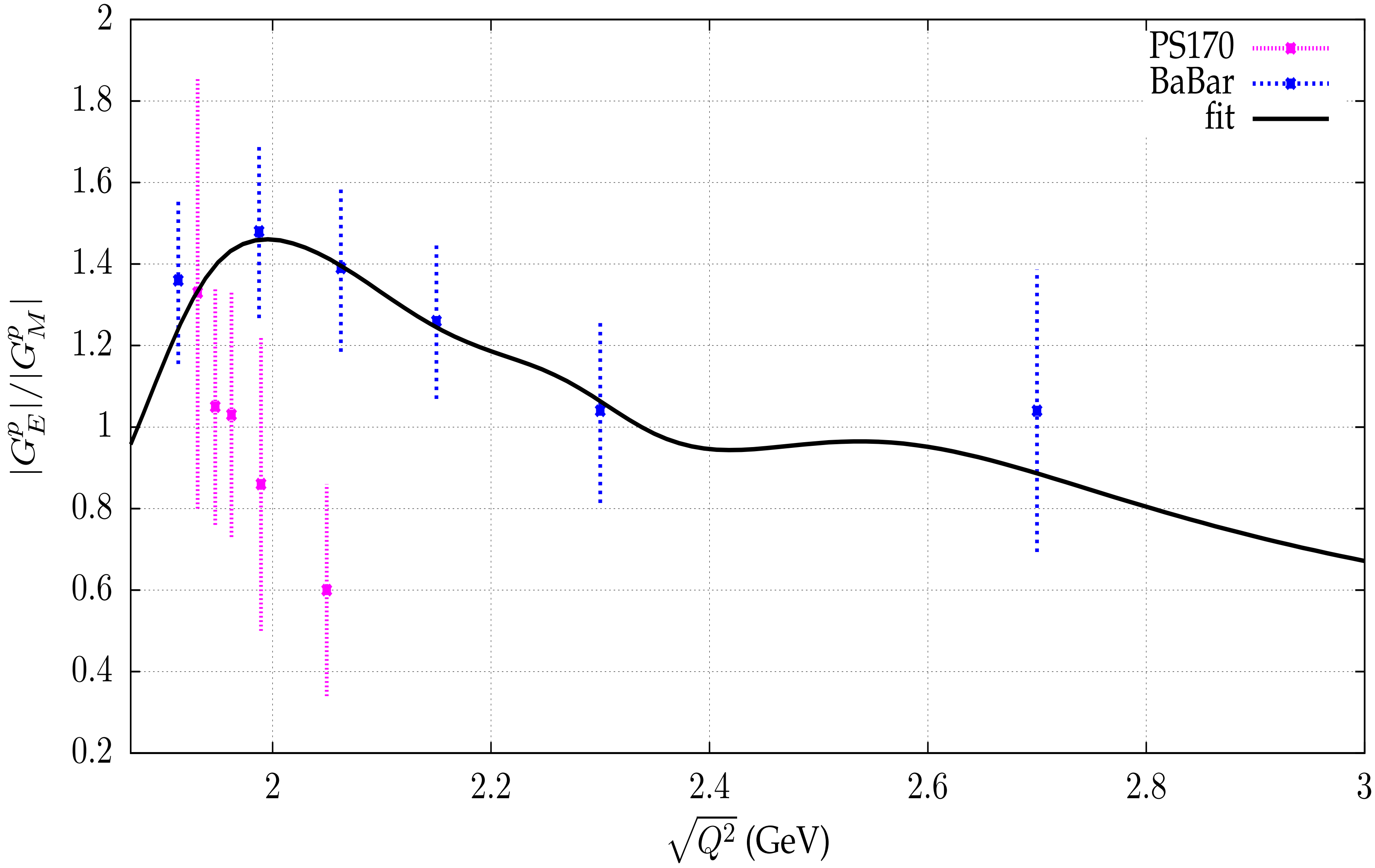
$\chi^2 = 124$ for 150 data points and fitted 20 parameters

Data vs. fit



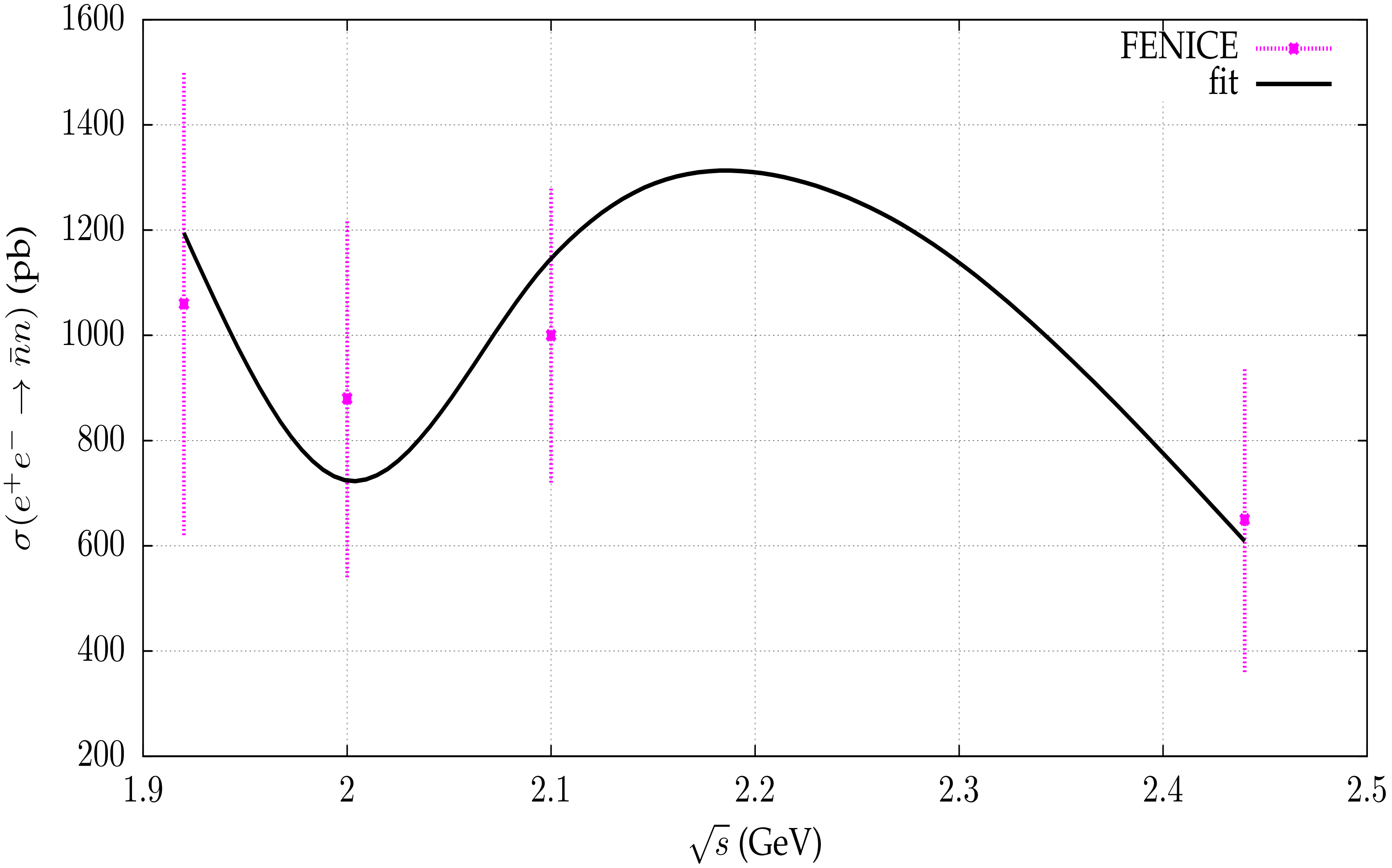
10000
1000
100
10
1
0.1
2
2.5
3
3.5
4
4.5
$\sigma(e^+e^- \to \bar{p}p)$ (pb)
$\sqrt{s}$ (GeV)
BaBar
FENICE
DM2
DM1
Adone
BES
CLEO
fit

Data vs. fit



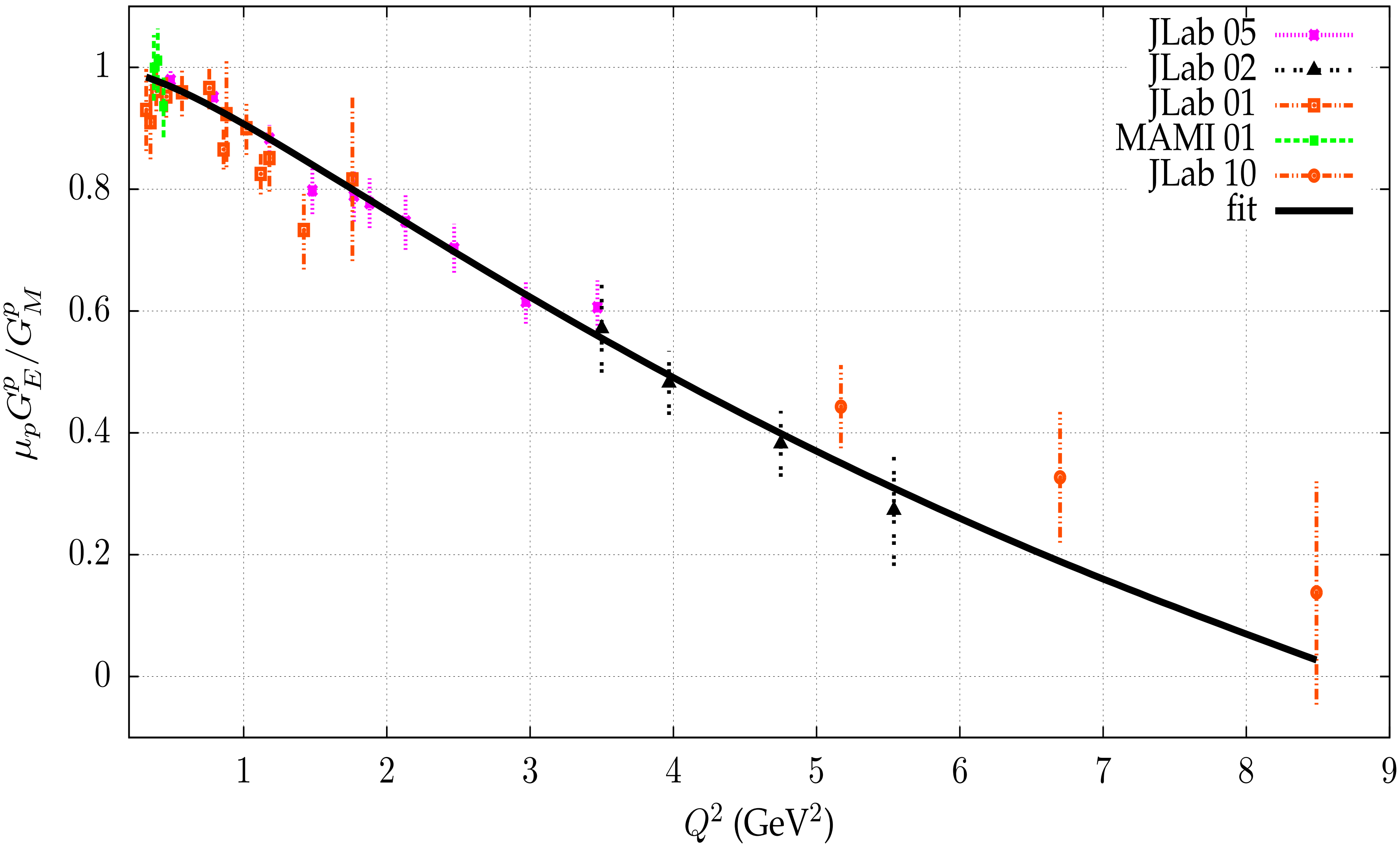
PS170
BaBar
fit
$|G_E^p|/|G_M^p|$
$\sqrt{Q^2}$ (GeV)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
2
2.2
2.4
2.6
2.8
3

Data vs. fit



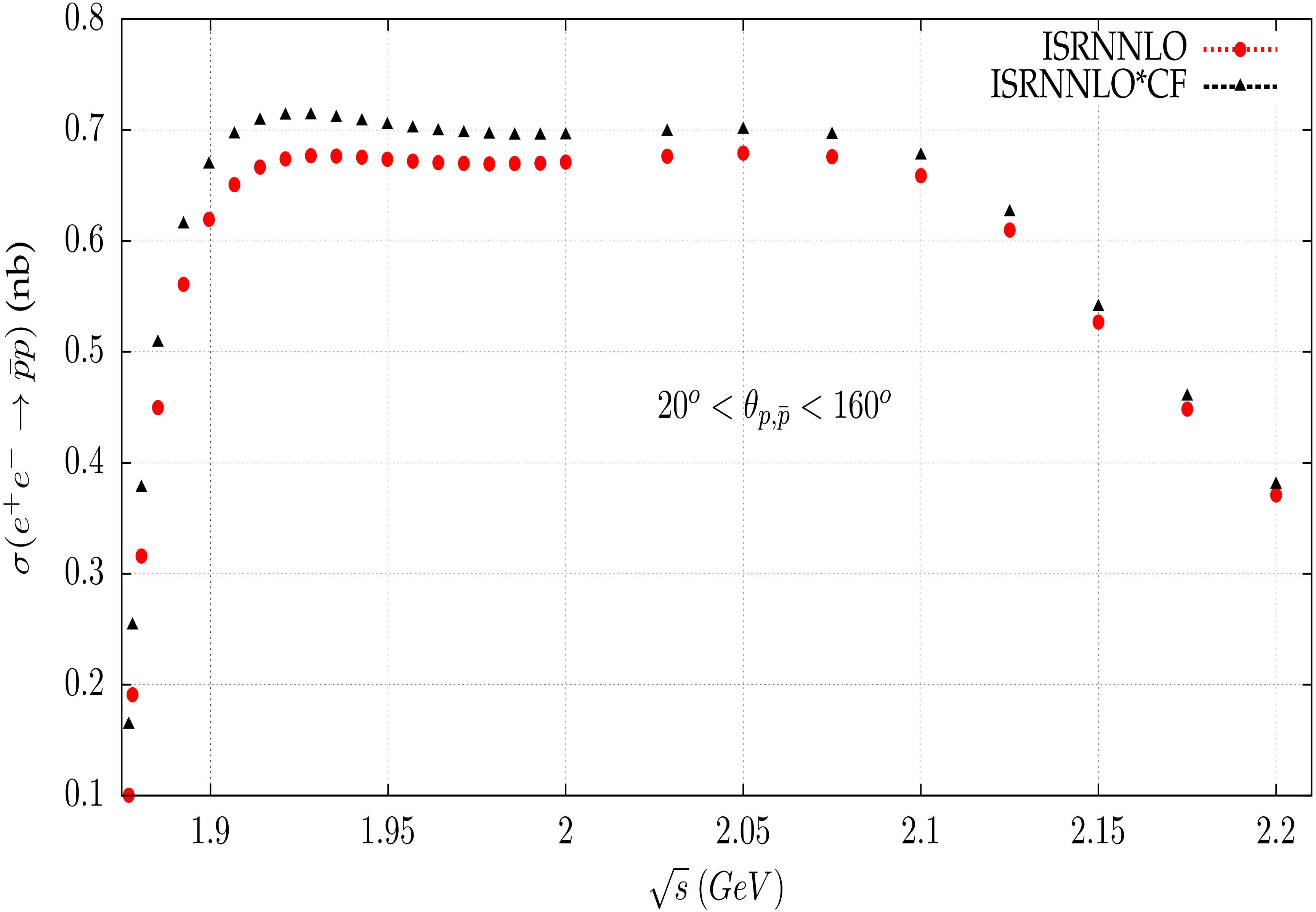
FENICE
fit
1600
1400
1200
1000
800
600
400
200
1.9
2
2.1
2.2
2.3
2.4
2.5
$\sigma(e^+e^- \to \bar{n}n)$ (pb)
$\sqrt{s}$ (GeV)

Data vs. fit



JLab 05
JLab 02
JLab 01
MAMI 01
JLab 10
fit
$\mu_p G_E^p / G_M^p$
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
6
7
8
9
Q^2 (GeV^2)

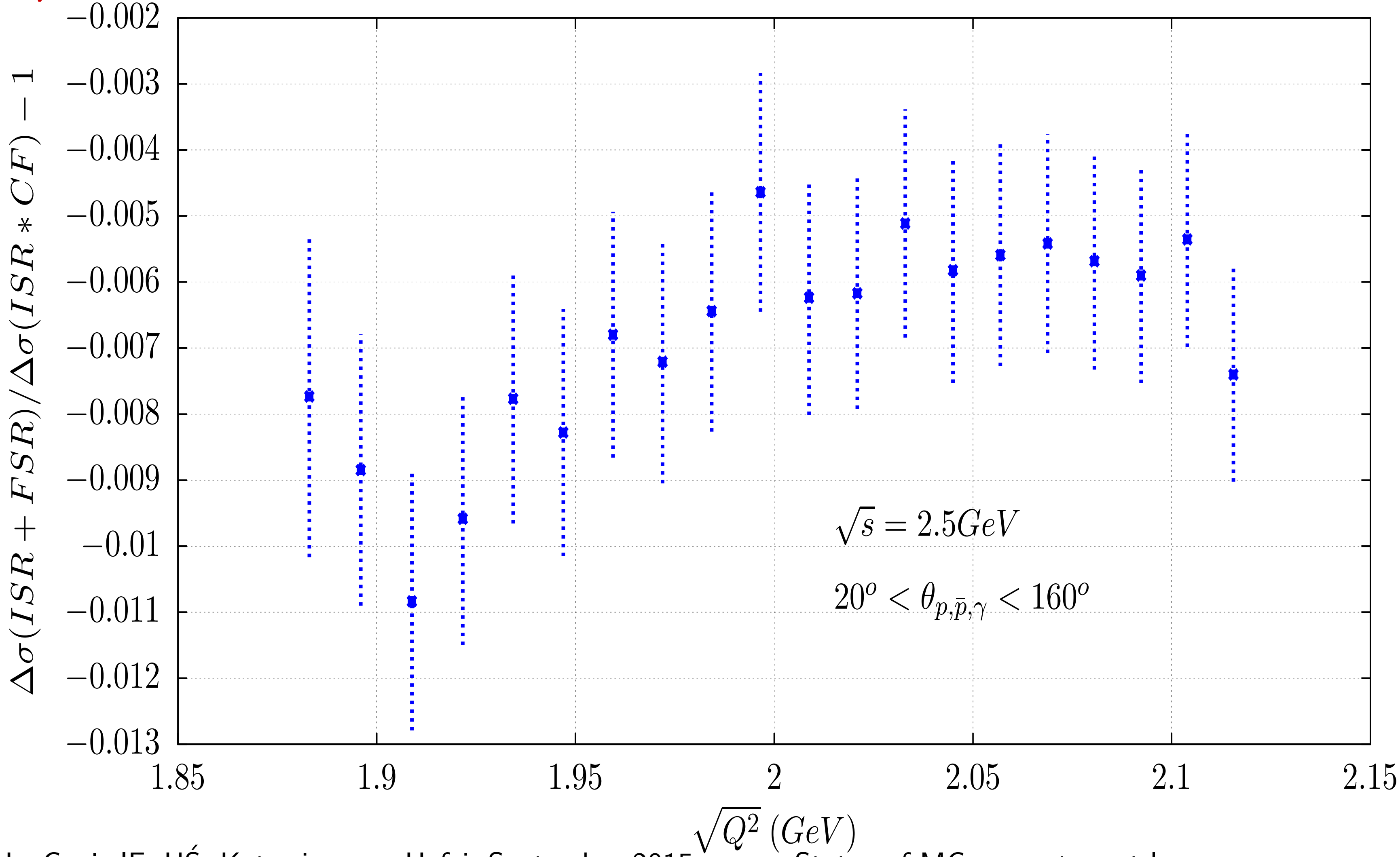
Radiative corrections



FSR modelling - few remarks

⇒ typical corrections - beyond CF are small

⇒ and not under control



FSR modelling - problems

$\Rightarrow$ 2 form factors for on shell particles

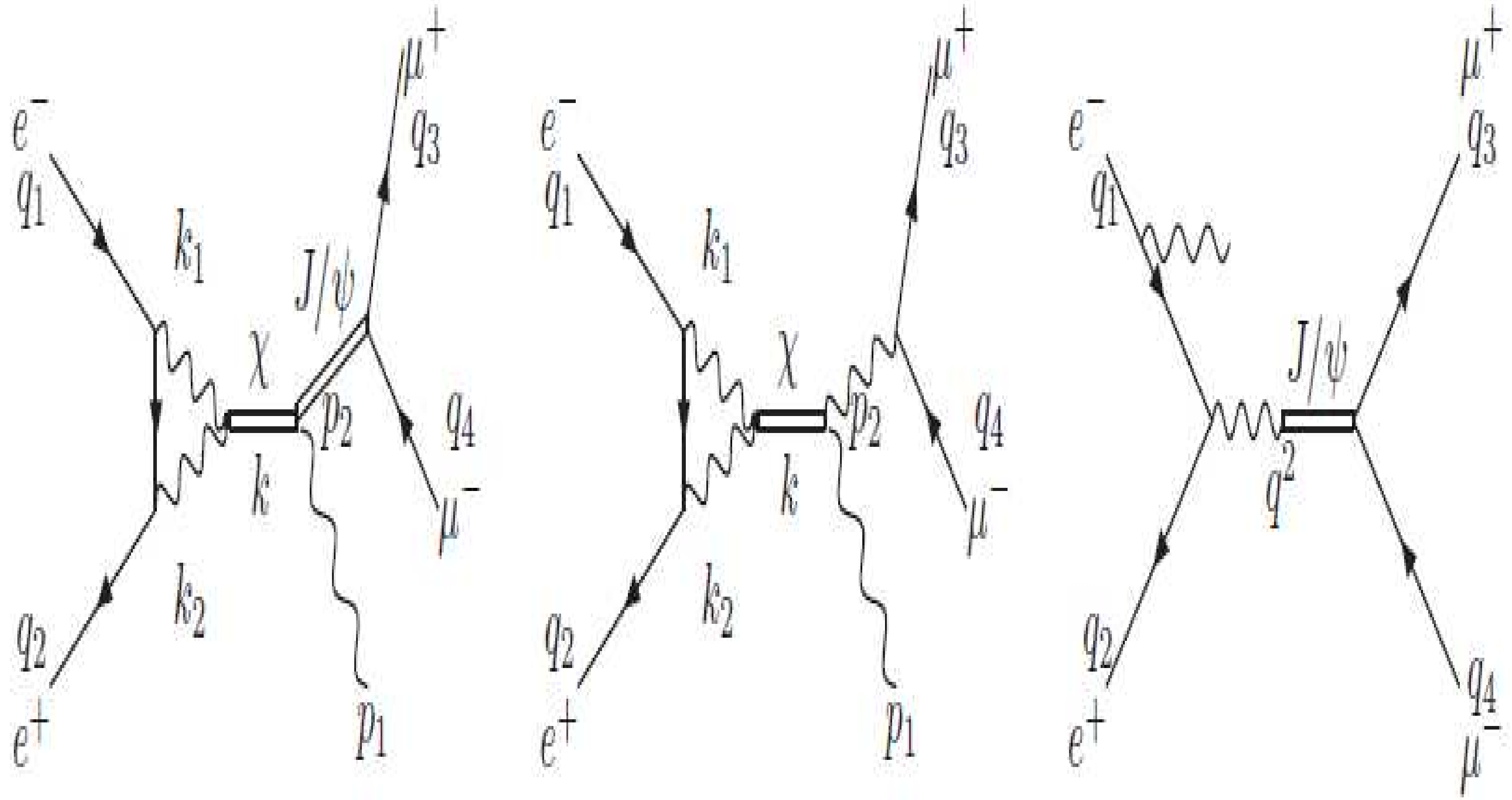
$\Rightarrow$ modelling of transition form factors necessary

$\Rightarrow$ it has to be addressed together with $ep \to ep$

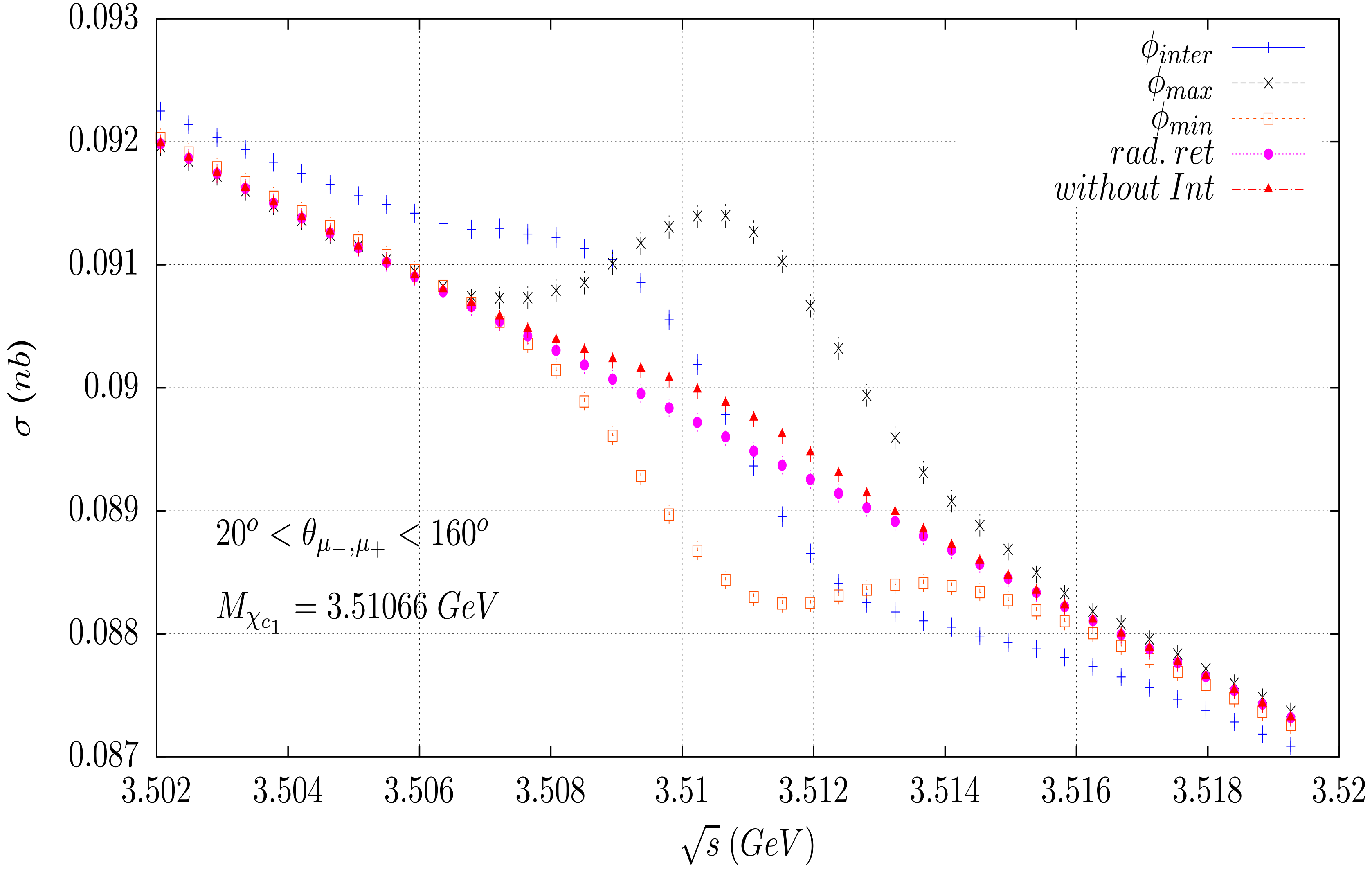
Conclusions

for pragmatic reasons further FSR modelling postponed till $\cdots$

χ_c production in e^+e^-

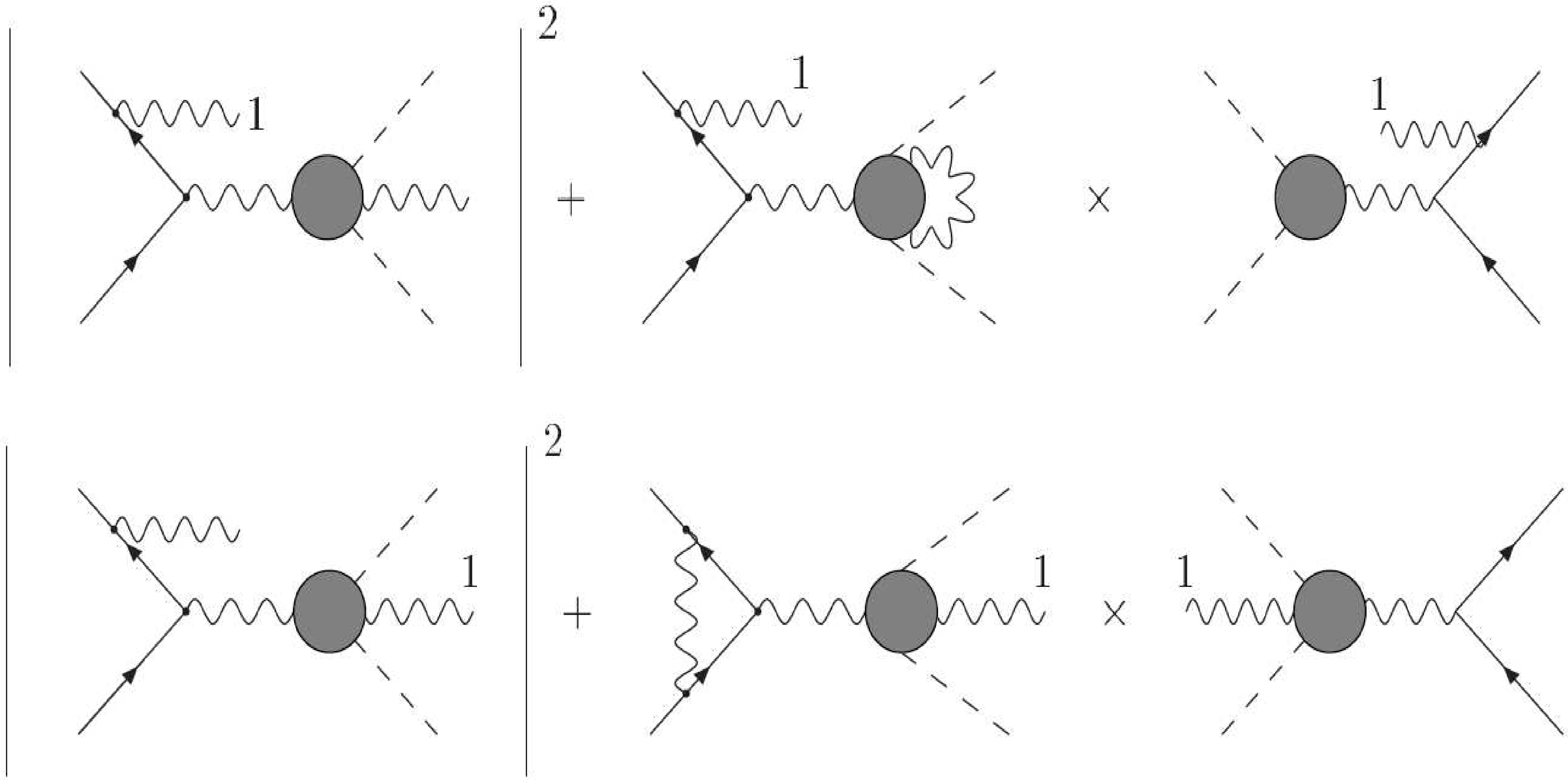


χ_c production in e^+e^-



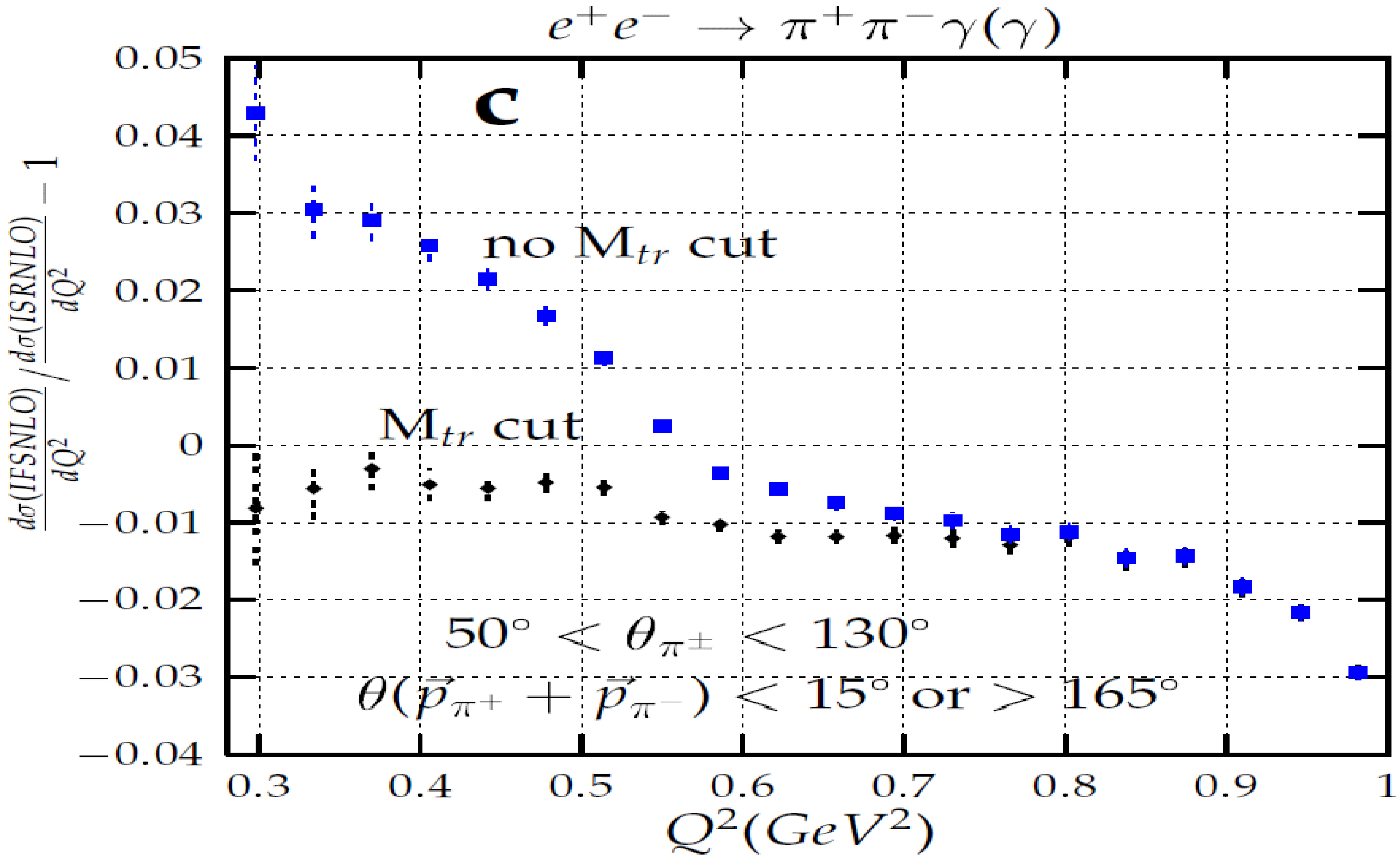
NLO-IFS

Included for muons and pions



NLO-ISR-FSR

How big are the corrections

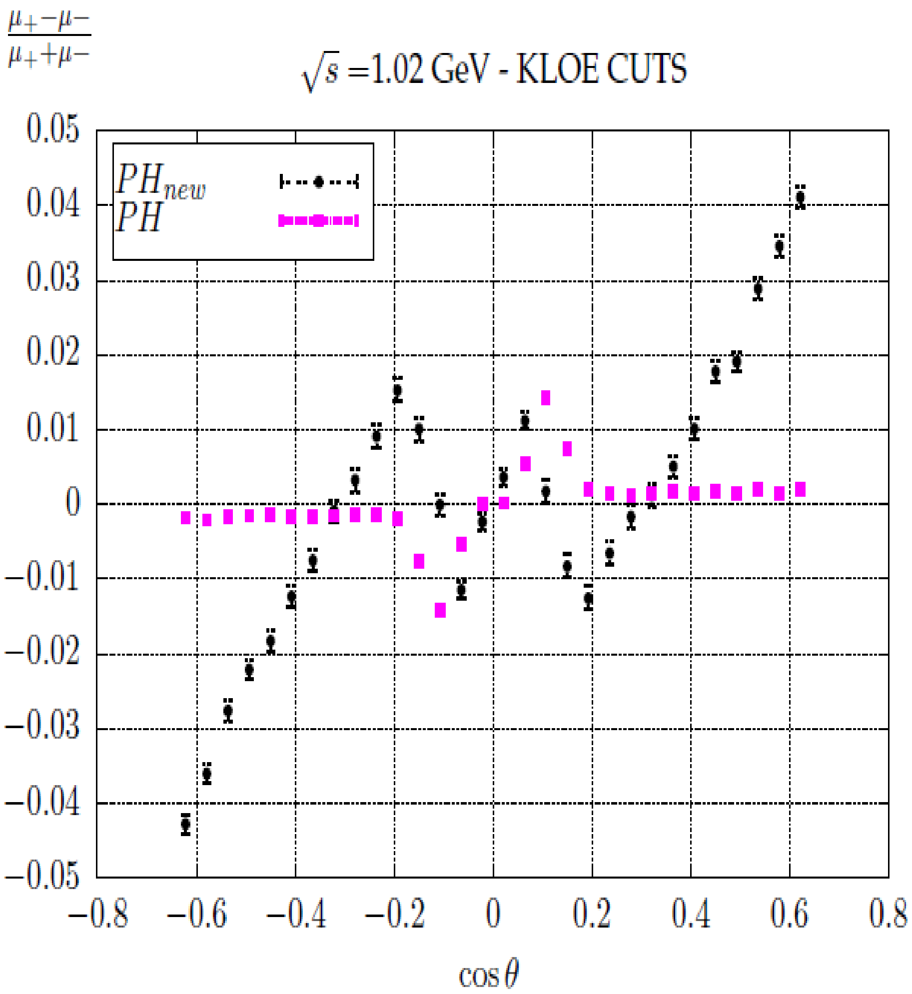


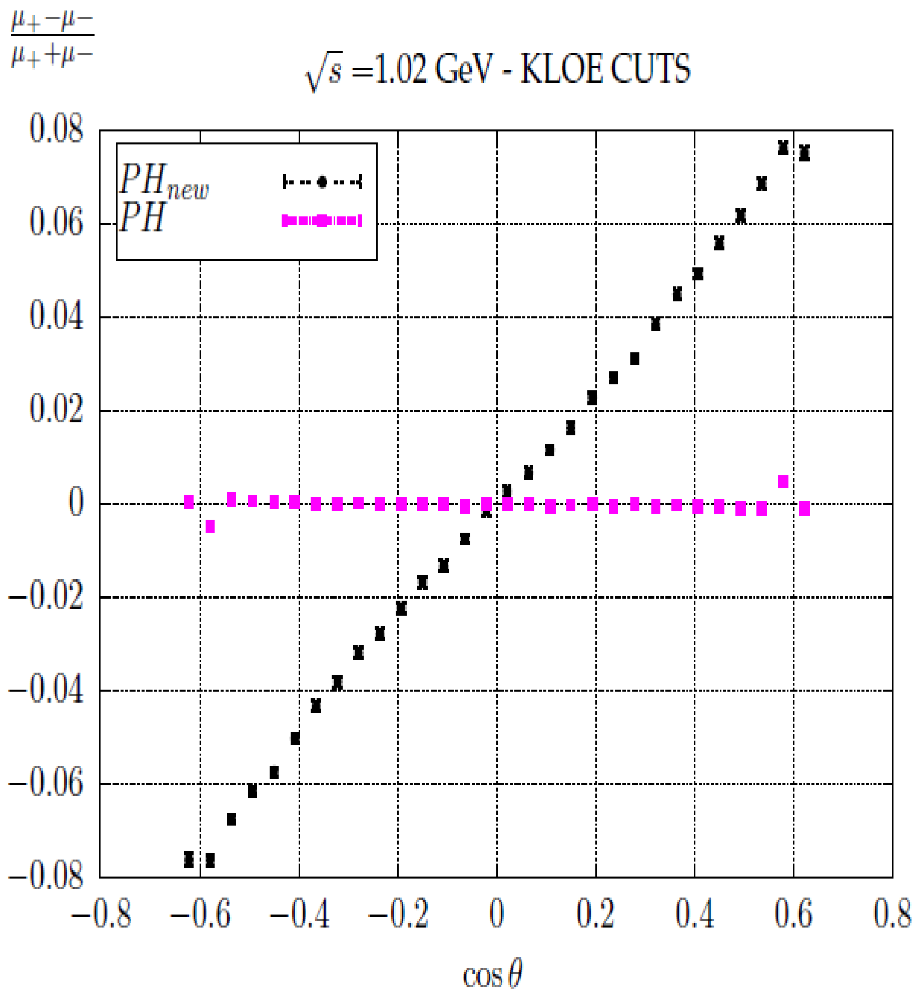
NLO-ISR vs. SF

Structure functions to be used carefully

	$\sqrt{s}$ =1.02 GeV	4 GeV	10.6 GeV
Born	2.1361 (4)	0.12979 (3)	0.011350 (3)
SF	2.0192 (4)	0.12439 (5)	0.010526 (3)
NLO (1)	2.0332 (5)	0.12526 (5)	0.010565 (4)
NLO (2)	2.4126 (7)	0.14891 (9)	0.012158 (9)

NLO-asymmetries

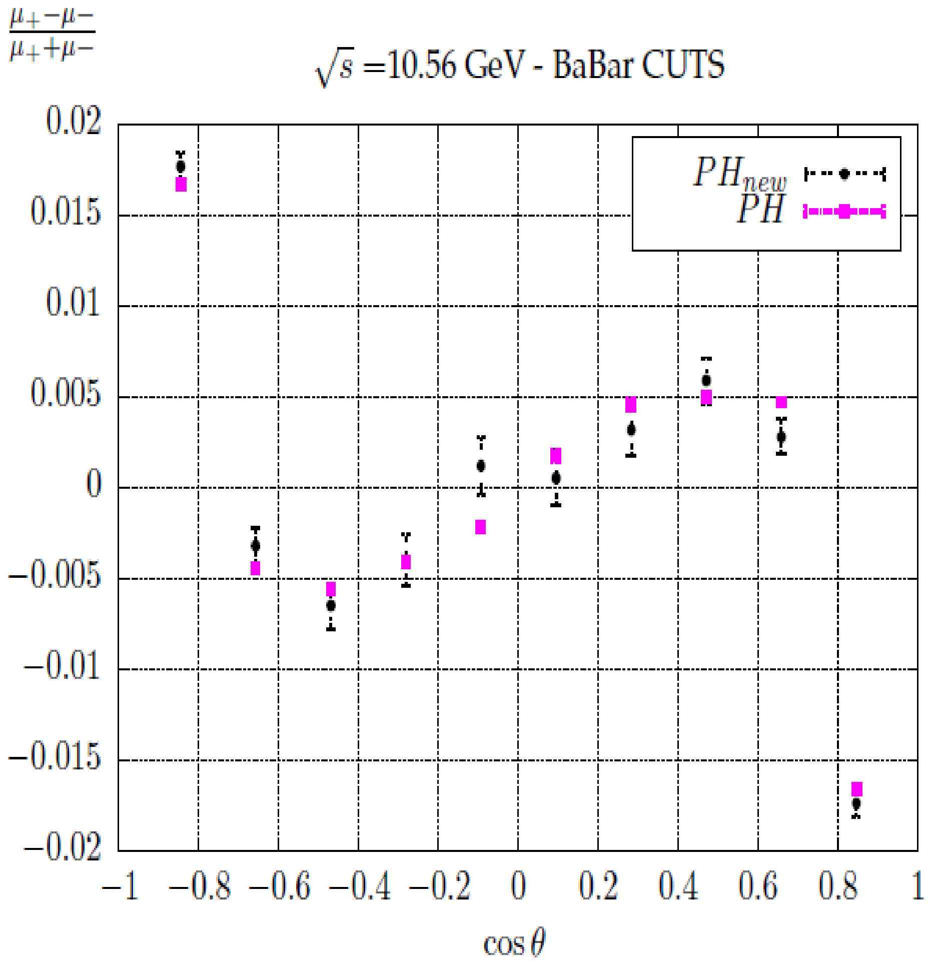


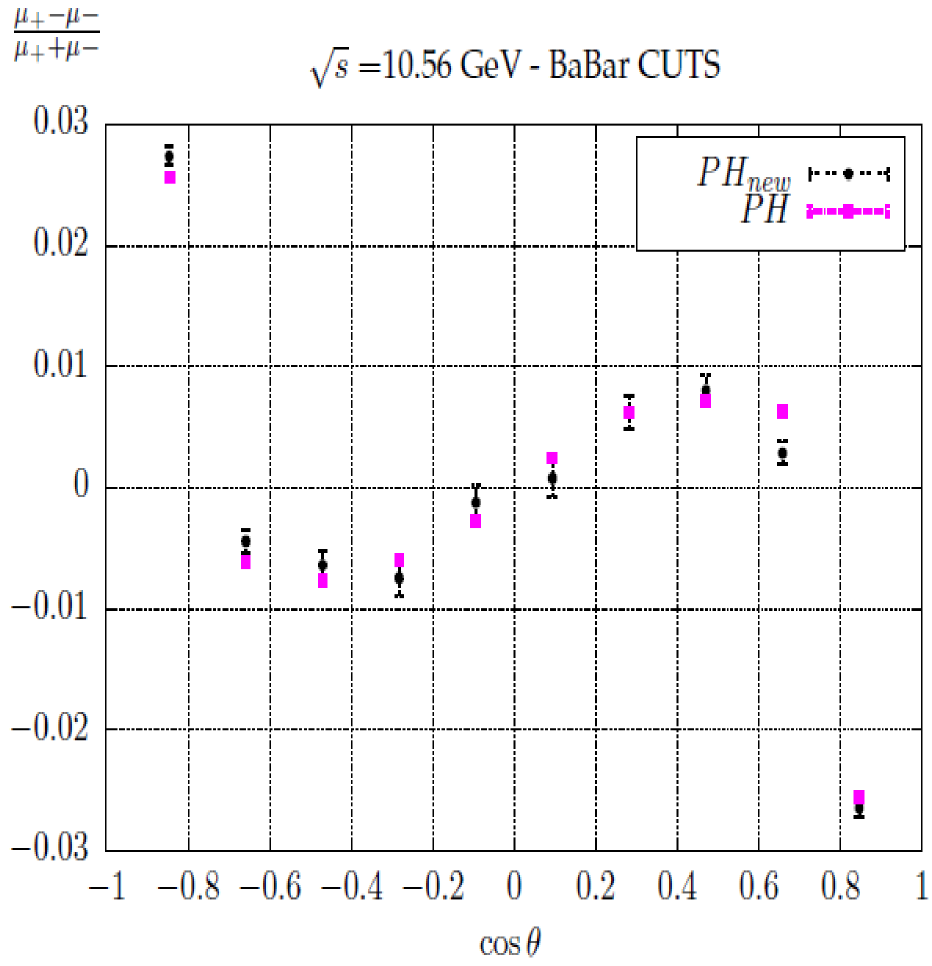


Campanario, F. and Czyż, H. and Gluza, J. and Gunia, M. and Riemann, T. and Rodrigo, G. and Yundin, V.

JHEP 1402 (2014) 114

NLO-asymmetries





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

JHEP 1402 (2014) 114

To be done in PHOKHARA

$\Rightarrow$ PH: get the complete NLO for pions

in progress

$\Rightarrow$ PH: improve efficiency in muon mode

$\Rightarrow$ PH: add NNLO corrections for ISR

Conclusions

IN PROGRESS ...

$\Rightarrow$ critical mass of number of people working on Monte Carlo and radiative corrections not reached

$\Rightarrow$ ... but we keep working