PHOKHARA 2008

a report

on the status of the program

H. CZYŻ, IF, UŚ, Katowice, BEIJING 2008

in collaboration with

A. Grzelińska, J. H. Kühn, E. Nowak-Kubat,

G. Rodrigo and A. Wapienik

The outline of the talk

The radiative return: a primer

- motivation
- theoretical basis
- radiative return: a tool in hadronic physics
- FSR: problems and how to deal with them
- $\pi\pi / \mu\mu$

PHOKHARA and its tests

The implemented hadronic currents

Plans

The reason we need R(s)

$$a_\mu^{\mathrm{had,LO}} = \frac{\alpha^2}{3\pi^2} \int_{4m_\pi^2}^{\infty} \frac{ds}{s} \, K(s) \, R(s)$$

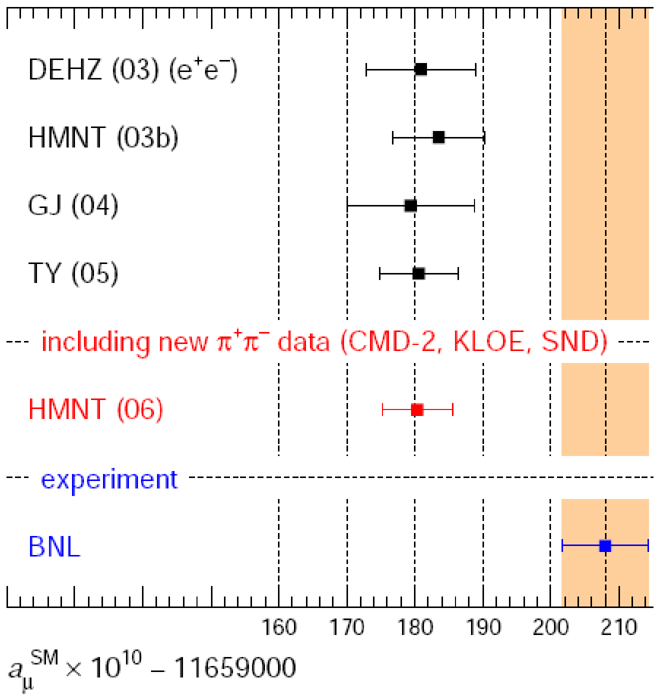
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma_{\mathrm{point}}}$$

One has to measure :

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

a_μ, T. Teubner, Liverpool

$a_\mu^{\rm SM}$ compared to BNL world av.



DEHZ 06: 180.5 ± 5.6 $[3.3\,\sigma]$

Jegerlehner 06: 179.3 ± 6.8 $[3.2\,\sigma]$

Recent changes

TH: Update of QED, up to 5–loop, new α:

was: $(116\ 584\ 719.35 \pm 1.43) \cdot 10^{-11}$

$\longrightarrow$ is now: $(116\ 584\ 718.09 \pm 0.16) \cdot 10^{-11}$

TH: Improved LO hadr. (from e^+e^-):

Now, with new CMD-2, SND, KLOE:

$(6924 \pm 64) \cdot 10^{-11} \longrightarrow (6894 \pm 46) \cdot 10^{-11}$

EXP: BNL's '01 μ^- data [PRL92(2004)161802]:

$a_{\mu^-} = 11\ 659\ 214(8)(3) \times 10^{-10}\ (0.7ppm)$

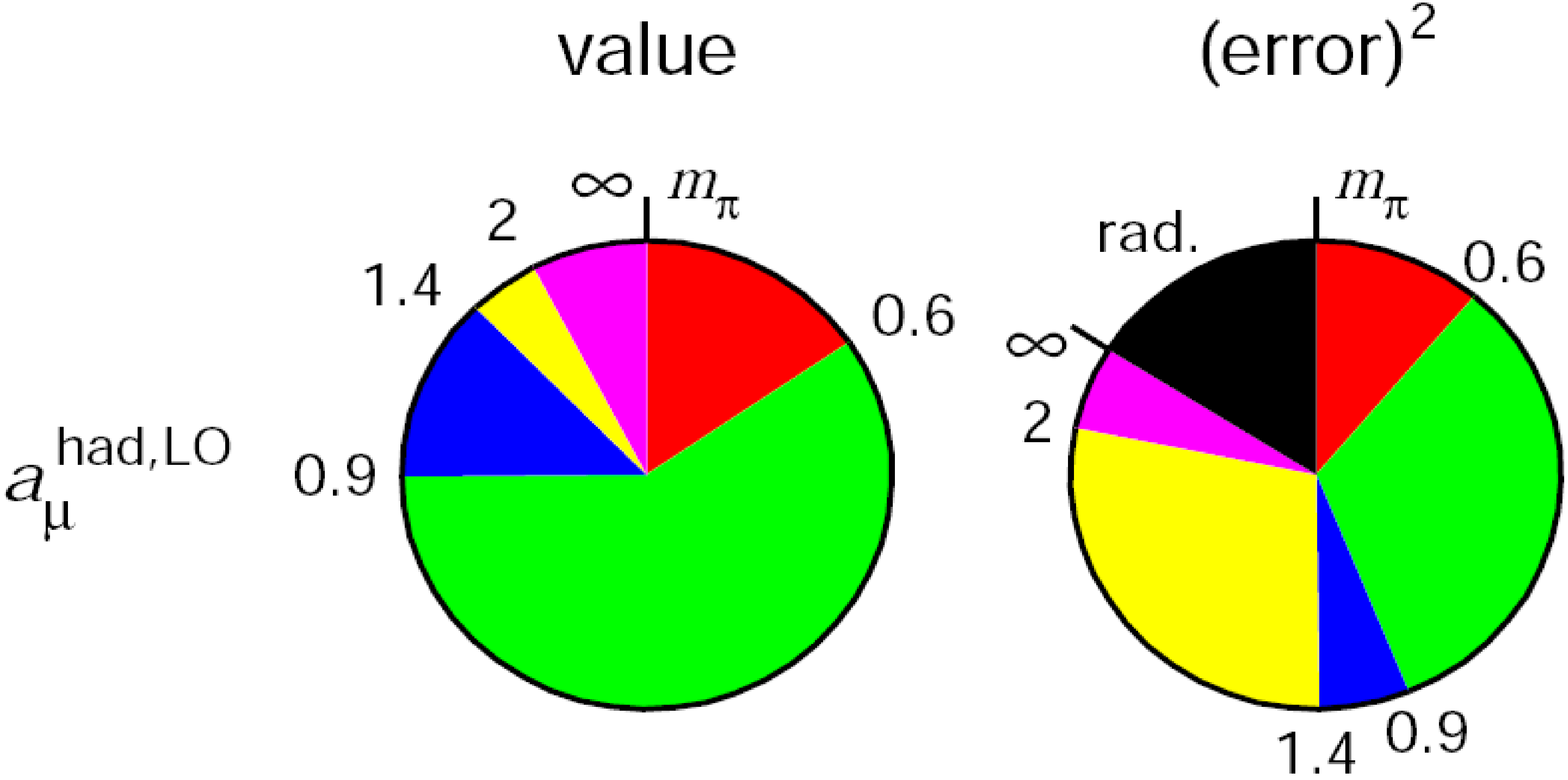
$\longrightarrow a_\mu = 116\ 592\ 080(63) \times 10^{-11}\ (0.5ppm)$

▶ With this input HMNT get:

$a_\mu^{\rm EXP} - a_\mu^{\rm TH} = (27.6 \pm 8.1) \cdot 10^{-10}$, $\sim \mathbf{3.4\sigma}$

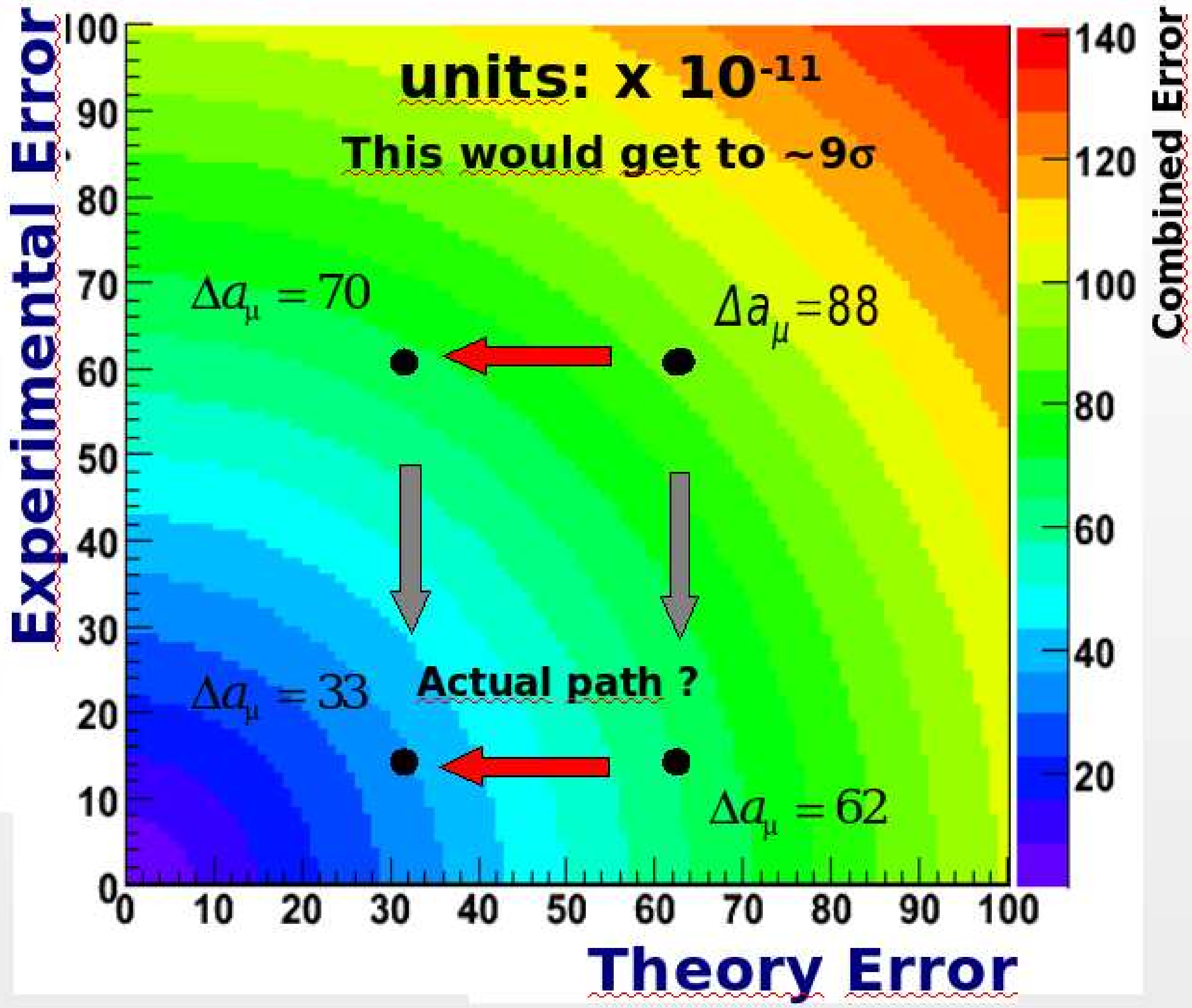
.. Discrepancy increased .. still not fully conclusive .. constrain SUSY ..

a_μ, T. Teubner, Liverpool



a_μ, D. Hertzog, Univ. Of Illinois

Δa_μ improvement requires both experimental and theoretical progress



a_μ, J. Prades, Granada

Conclusions and Prospects

At present, large N_c results agree within 1 σ ✓

$$a_\mu^{\rm lbl} = (11.0 \pm 4.0) \times 10^{-10}$$

More work needed to have the hadronic light-by-light contribution to muon $g-2$ with reduced uncertainty •

Goal: To have under control model dependences •

a_μ, BaBar preliminary

Conclusions

- BaBar analysis of ππ and μμ ISR processes completed
- Precision goal has been achieved: 0.6% in ρ region (0.6-0.9 GeV)
- Absolute μμ cross section agrees with NLO QED within 1.2%
- Preliminary results available for ππ in the range 0.5-3 GeV
- Structures observed in pion form factor at large masses

- Comparison with results from earlier experiments
  - discrepancy with CMD-2 and SND mostly below ρ
  - large disagreement with KLOE
  - better agreement with τ results, especially Belle
- Contribution to a_μ from BaBar agrees better with τ results
- Deviation between BNL measurement and theory prediction significantly reduced using BaBar ππ data

$$a_\mu[\mathrm{exp}] - a_\mu[\mathrm{SM}] = (27.5 \pm 8.4) \times 10^{-10} \Rightarrow (14.0 \pm 8.4) \times 10^{-10}$$

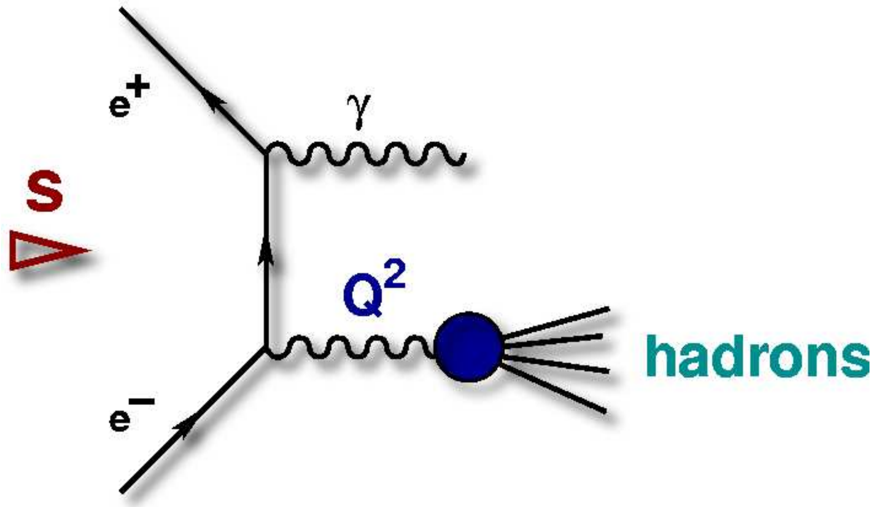
- Wait for final results and contributions of multi-hadronic modes

M.Davier BaBar pi pi Tau08 22-25/9/2008 31

THE RADIATIVE RETURN METHOD

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

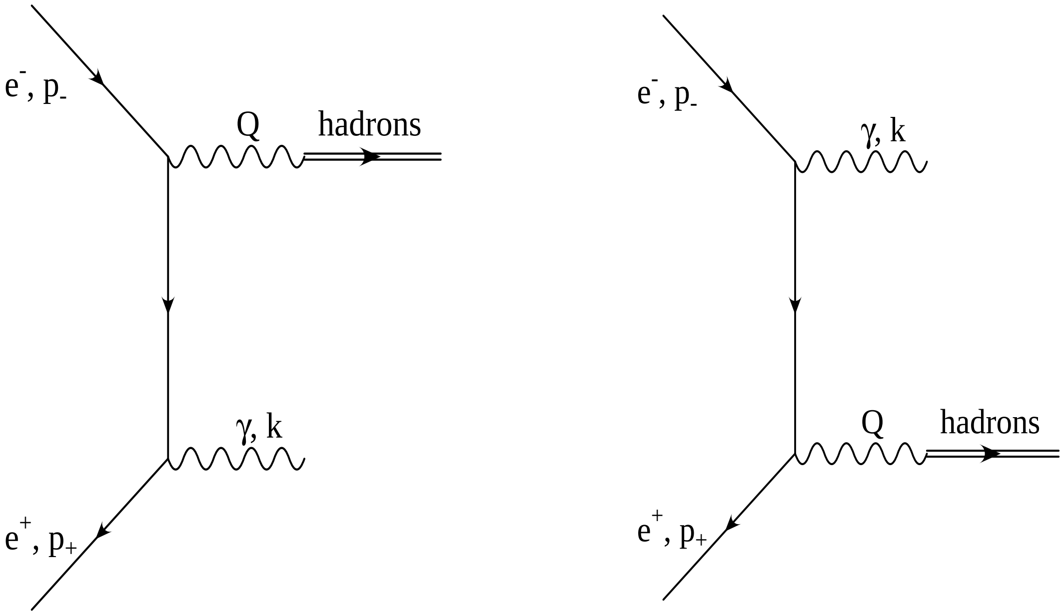
$$H(Q^2, \theta_\gamma)\; d\sigma(e^+e^- \to \text{hadrons})(s = Q^2)$$



- 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

BASIC IDEA - more details



$$\mathcal{M} \sim \bar{v}\,(p_+)\left[\gamma^\nu \frac{1}{\not p_- - \not k - m}\not\epsilon^*(k) + \not\epsilon^*(k)\,\frac{1}{\not k - \not p_+ - m}\gamma^\nu\right] u(p_-)$$

$$\frac{1}{Q^2}\,J_\nu^{em}\,.$$

BASIC IDEA - more details

$$\mathcal{M} \sim \bar{v}\,(p_+) \left[\gamma^\nu \frac{1}{\not p_- - \not k - m} \not\epsilon^*(k) + \not\epsilon^*(k)\, \frac{1}{\not k - \not p_+ - m} \gamma^\nu \right] u(p_-)$$

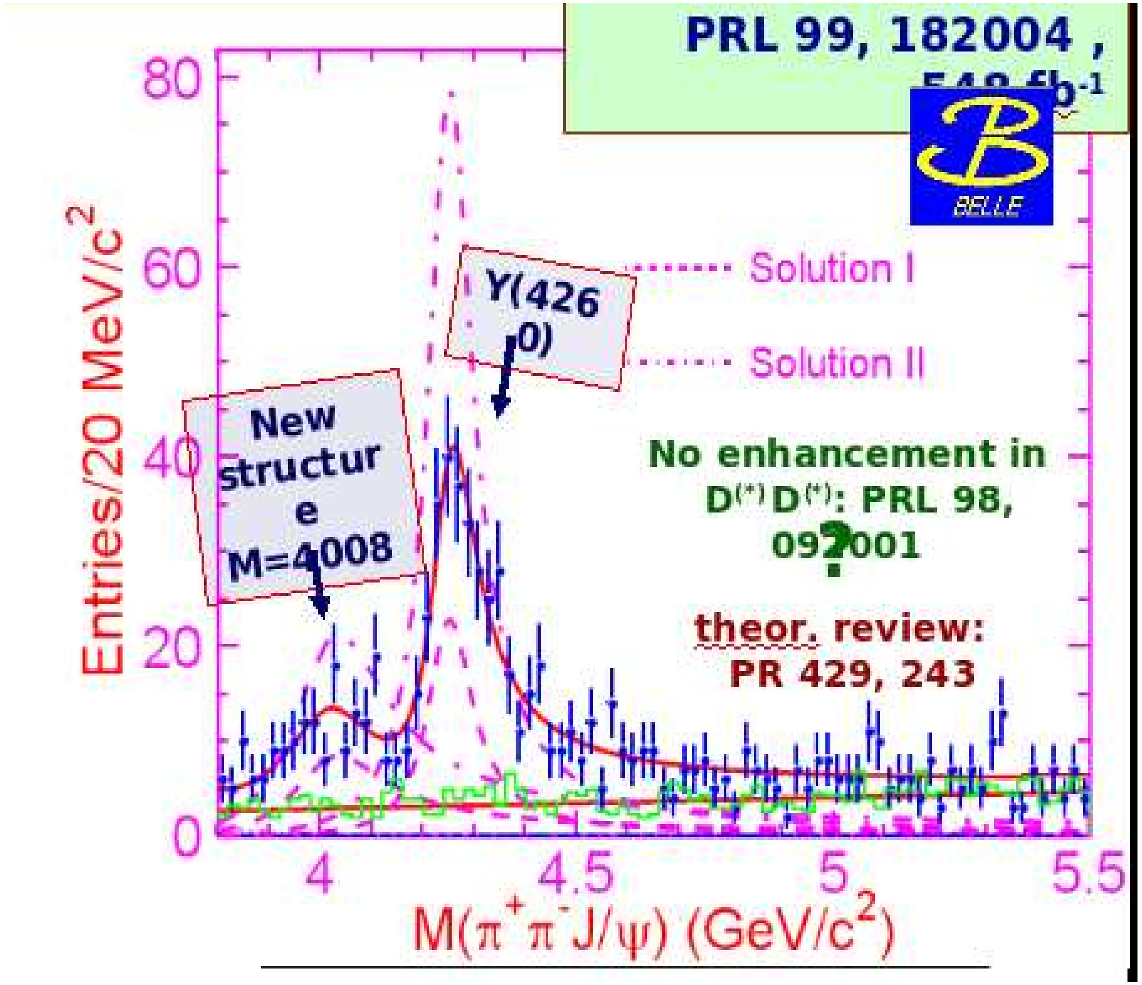
$$\frac{1}{Q^2}\, J_\nu^{em}\,.$$

$$\int J_\mu^{em} (J_\nu^{em})^* \quad d\bar{\Phi}_n(Q; q_1, \ldots, q_n) =$$

$$\frac{1}{6\pi}\Big(Q_\mu Q_\nu - g_{\mu\nu} Q^2\Big)\; R(Q^2)$$

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

Radiative return: a tool in hadronic physics



From EVA to PHOKHARA

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.]

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

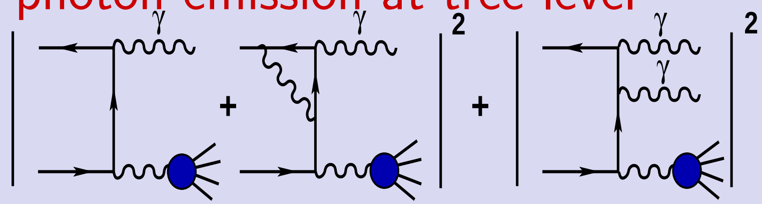
- ISR at LO + Structure Function

[Czyż, Kühn,2000]

H.C., A. Grzelińska, J. H. Kühn, E. Nowak-Kubat, G. Rodrigo, A. Wapienik

PHOKHARA 6.0: $\pi^+\pi^-$, $\mu^+\mu^-$, 4π, $\bar{N}N$, 3π, KK, $\Lambda(\to\cdots)\bar{\Lambda}(\to\cdots)$

- **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^-
- tagged or untagged photons
- Modular structure

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

Differential luminosity:

$$\frac{d\sigma}{dQ^2}\left(e^+e^- \to \gamma \ + \ had(Q^2)\right) = \sigma\left(e^+e^- \to had(Q^2)\right)$$

$$\times \frac{\alpha}{\pi s}\left\{ \begin{array}{c} \frac{s^2+Q^4}{s(s-Q^2)}\left(\log(s/m_e^2) - 1\right) \\ \frac{s^2+Q^4}{s(s-Q^2)}\log\left(\frac{1+\cos\theta_{min}}{1-\cos\theta_{min}}\right) - \frac{s-Q^2}{s}\cos\theta_{min} \end{array} \right\}$$

$$\frac{dL}{dQ^2}\left(Q^2, s\right) = \frac{\alpha}{\pi s}\left\{\cdots\right\} L(at\ s)$$

Differential luminosity

$$\theta_{min} = 20^\circ,\ L(s) = 20\ \mathrm{fb}^{-1},\ \Delta Q^2 = 0.1 GeV^2$$

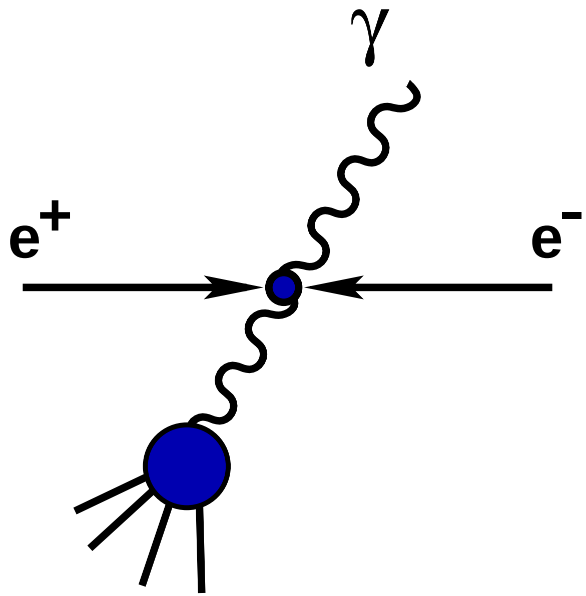
$$\frac{dL}{dQ^2}\left(Q^2, s\right)\Delta Q^2 \quad [pb^{-1}]$$

	$\sqrt{s}\ [GeV]$			
$\sqrt{Q^2}\ [GeV]$		0.7	1	2
	2	3.7	4.9	-
	3	1.4	1.6	3.6
	3.77	0.88	0.94	1.5

DAΦNE versus B and c -factories:

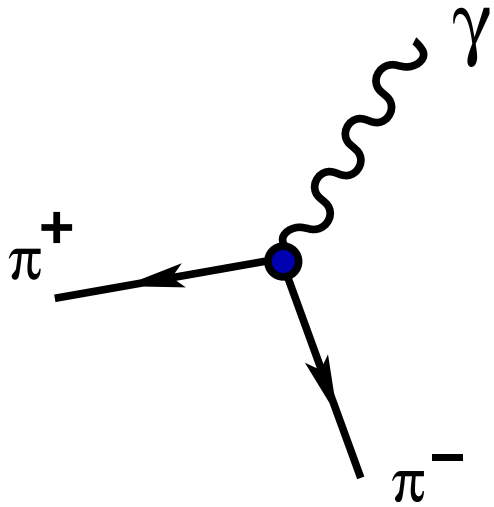
configurations in the cms - frame

10(4) GeV



very hard photon: clear kinematic separation between photon and hadrons

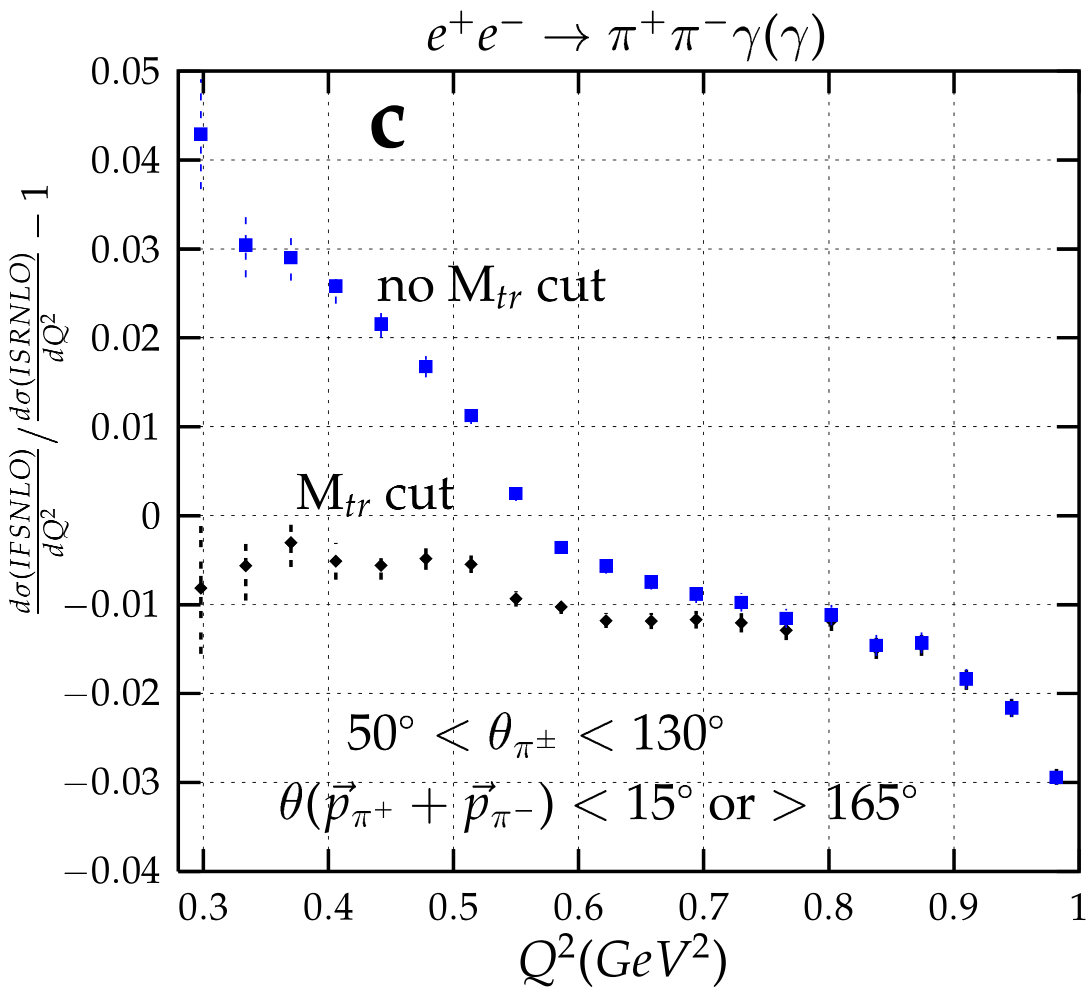
1(4) GeV



no natural kinematic separation

➪ cuts to control FSR versus ISR

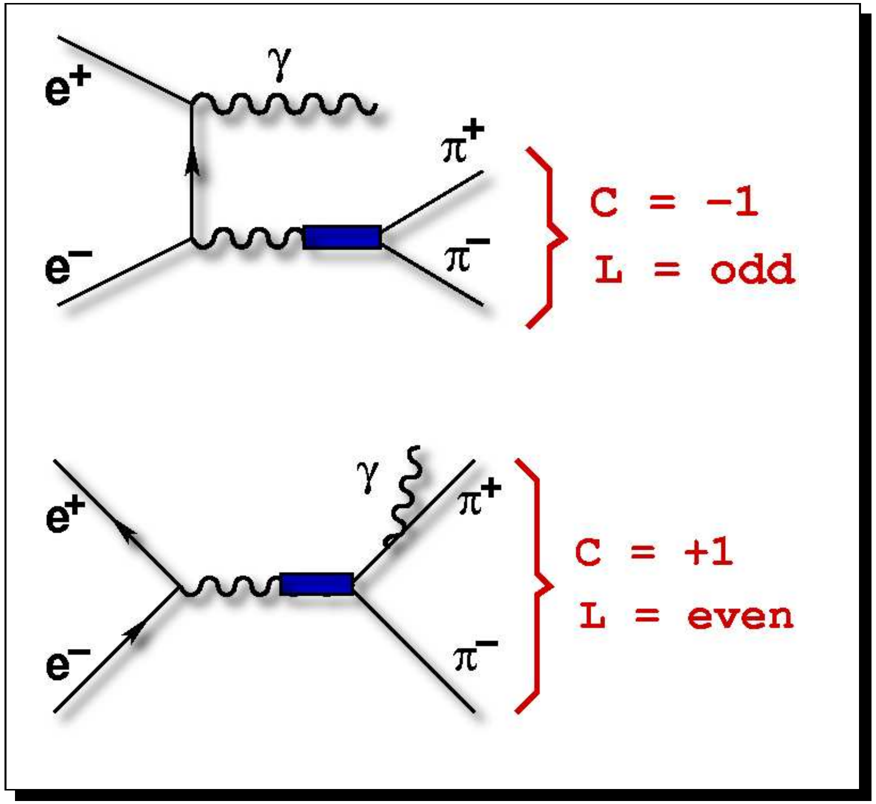
Solution I: kill FSR



KLOE: small angle analysis

Solution II: test of a FSR model

interference:

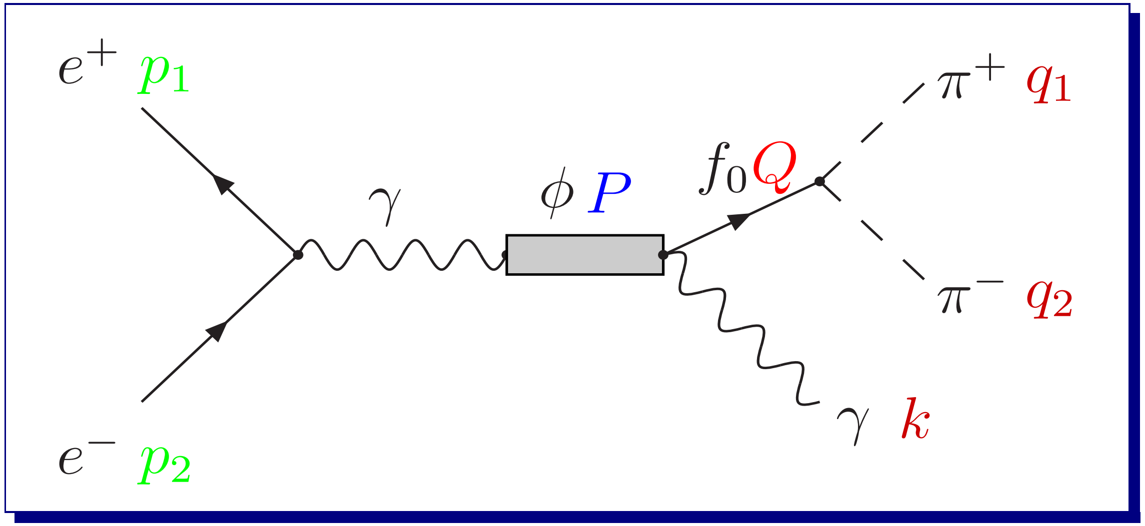


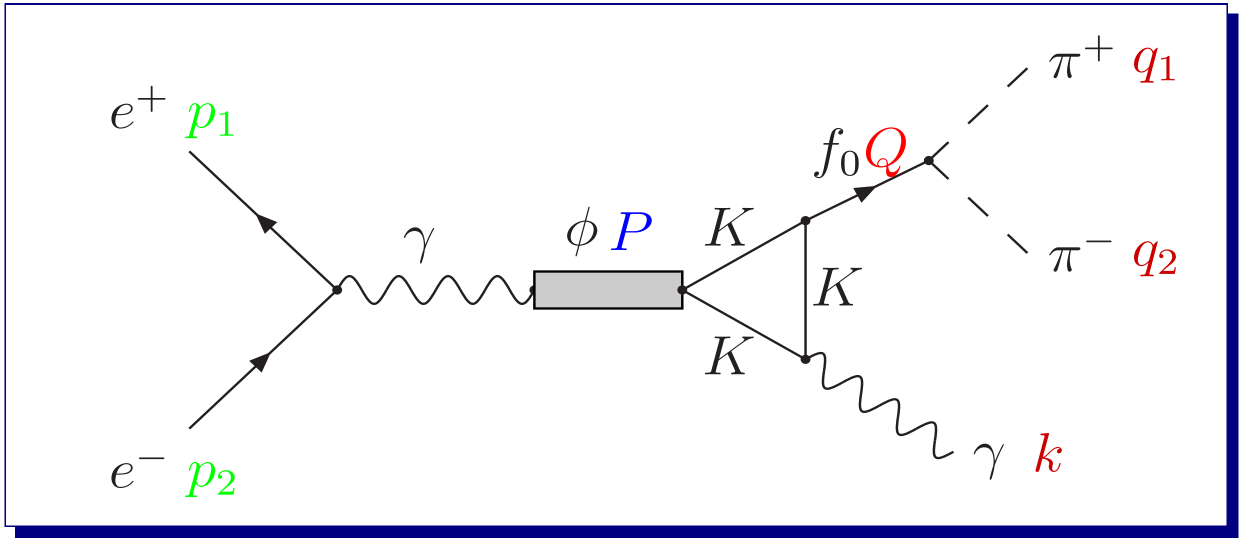
- interference odd under $\pi^+ \leftrightarrow \pi^-$
- asymmetric differential distribution: $\int$ interf. $= 0$

$$A(\theta) = \frac{N^{\pi^+}(\theta) - N^{\pi^-}(\theta)}{N^{\pi^+}(\theta) + N^{\pi^-}(\theta)}$$

FSR at KLOE, additional contributions:

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





Charge asymmetries

⇒ forward-backward asymmetry defined for π^+

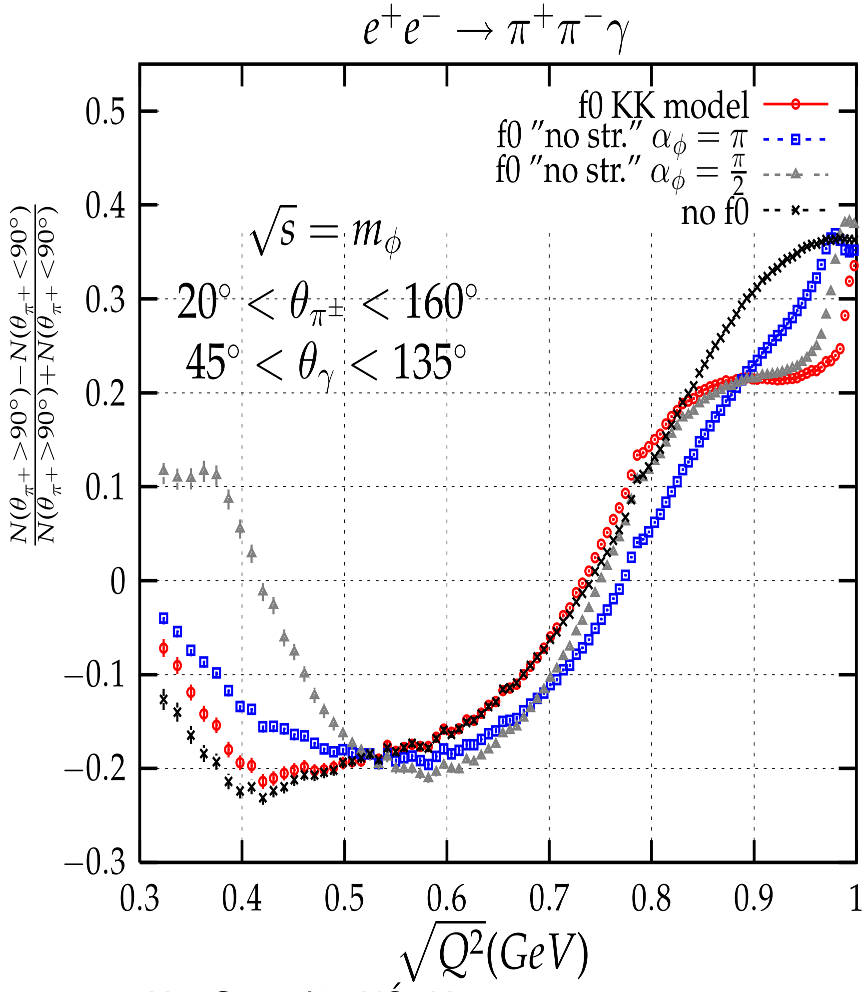
$$\mathcal{A}_{FB}(Q^2) = \frac{N(\theta_{\pi^+}>90^\circ)-N(\theta_{\pi^+}<90^\circ)}{N(\theta_{\pi^+}>90^\circ)+N(\theta_{\pi^+}<90^\circ)}(Q^2)$$

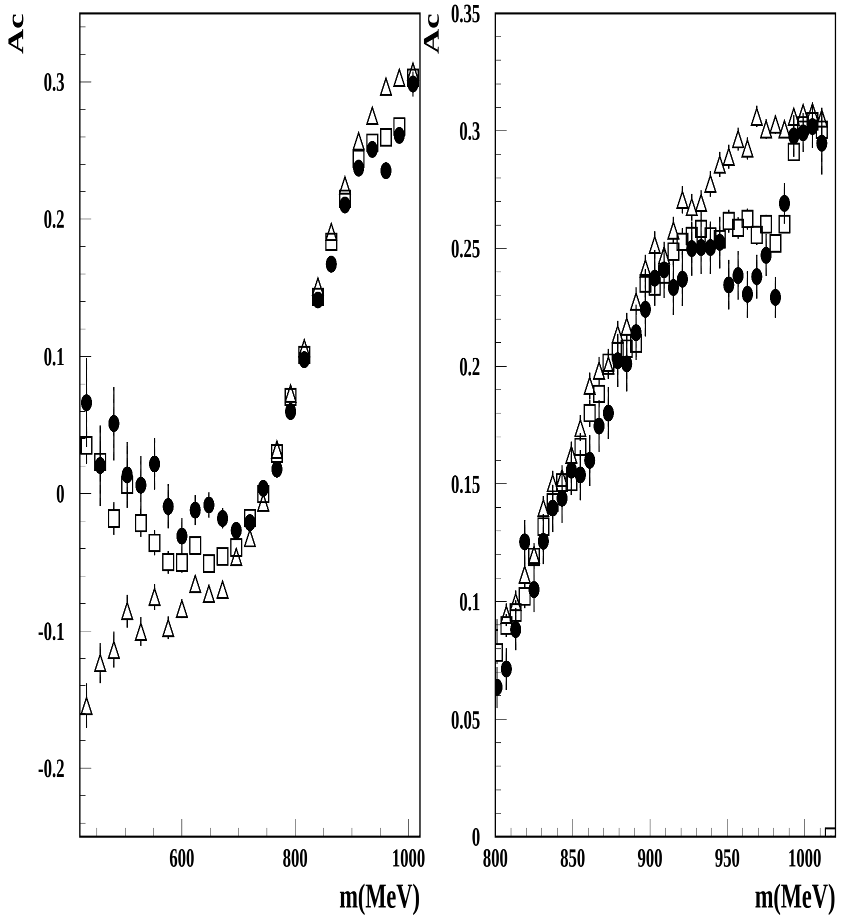
⇒ charge asymmetry

$$\mathcal{A}_C(\theta_\pi) = \frac{N(\pi^+)-N(\pi^-)}{N(\pi^+)+N(\pi^-)}(\theta_\pi)$$

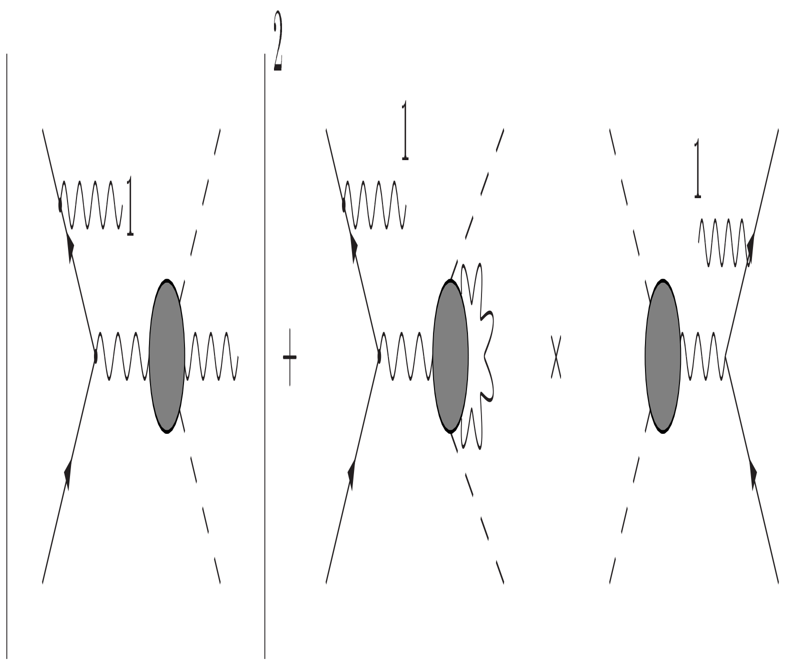
Test of a FSR model

H. Czyż, A. Grzelińska and J. H. Kühn, Phys.Lett.B611:116,2005
KLOE Collaboration: Phys.Lett.B634:148,2006

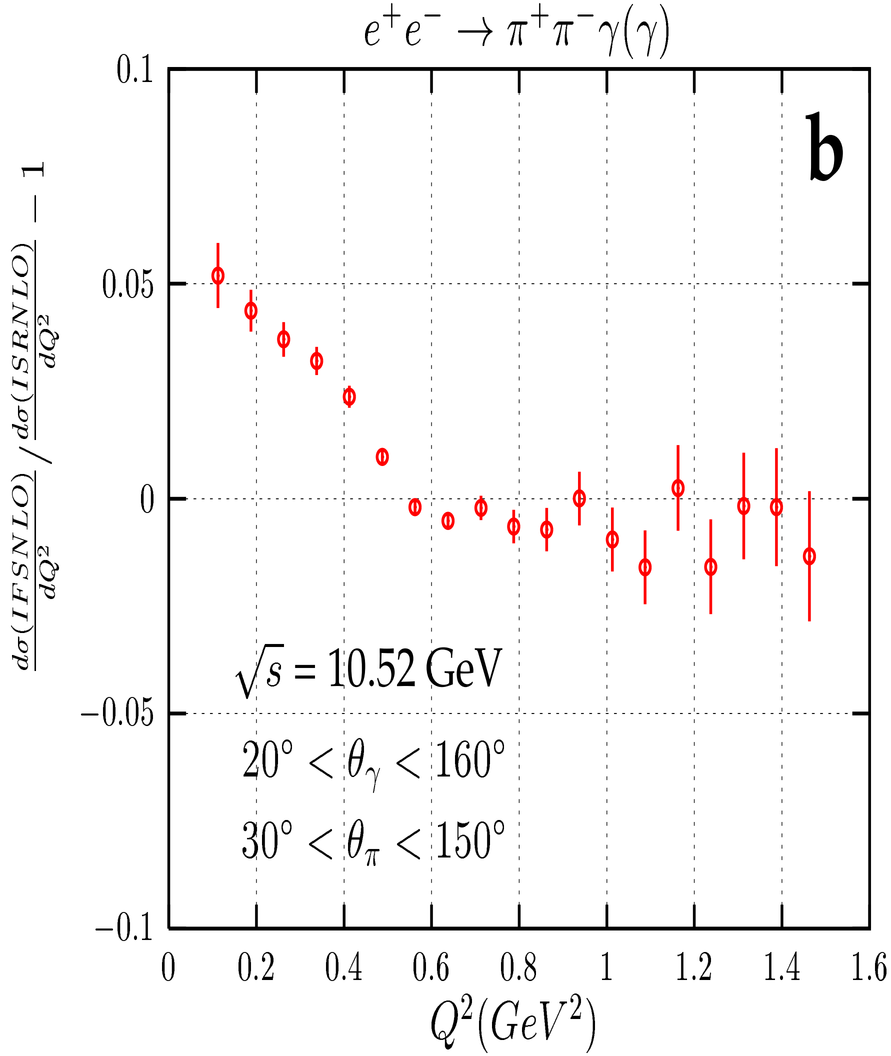




FSR at NLO



2
1
1
1
+
×



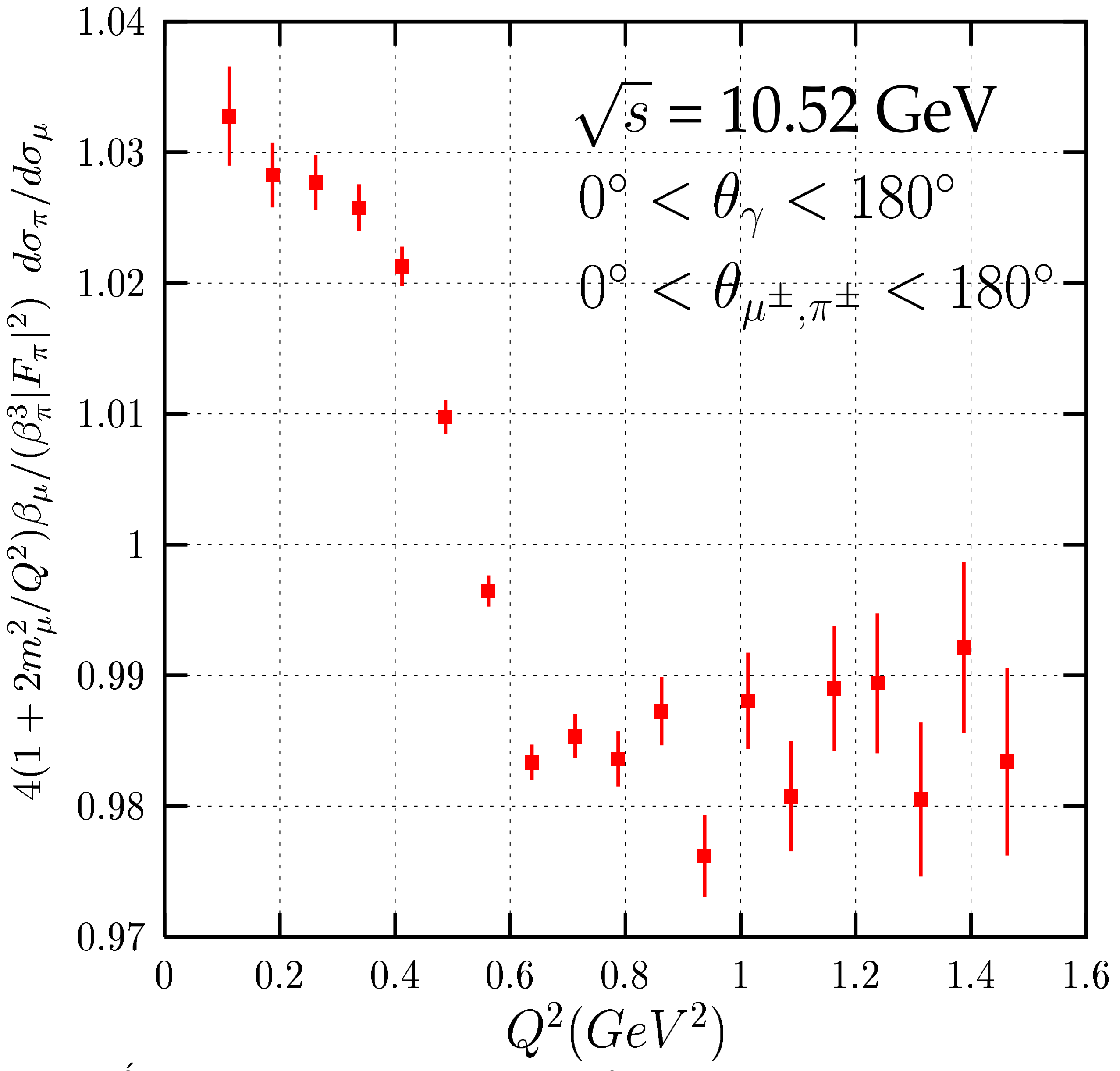
$e^+e^- \to \pi^+\pi^-\gamma(\gamma)$
b
$\frac{d\sigma(IFSNLO)}{dQ^2} / \frac{d\sigma(ISRNLO)}{dQ^2} - 1$
$\sqrt{s}$ = 10.52 GeV
$20° < \theta_\gamma < 160°$
$30° < \theta_\pi < 150°$
0.1
0.05
0
−0.05
−0.1
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
$Q^2(GeV^2)$

$\pi\pi$ / $\mu\mu$ ratio

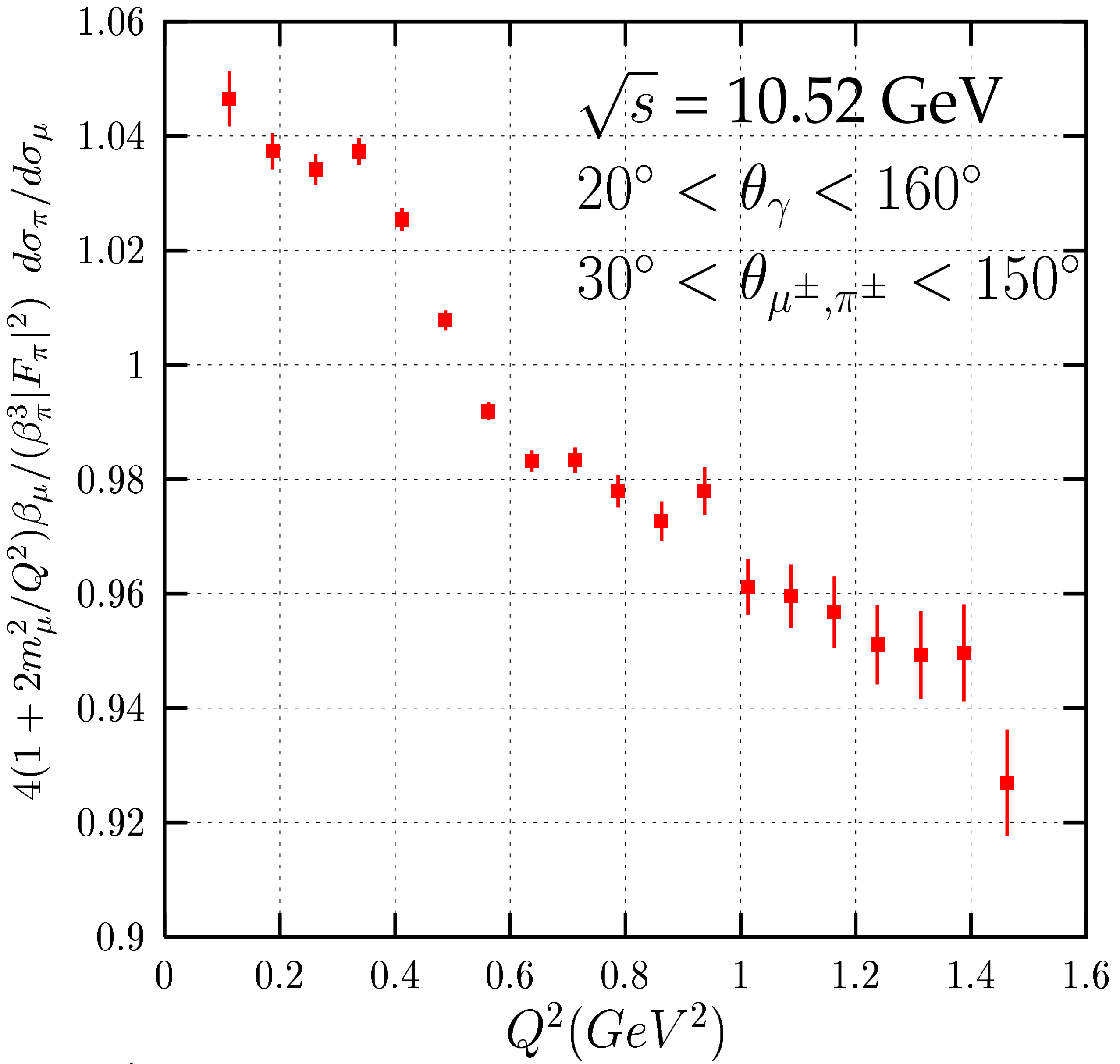
H. C., A. Grzelinska, J. H. Kuhn and G. Rodrigo
Eur.Phys.J.C39:411-420,2005.

$$\mathcal{R}(Q^2) = \frac{4(1+\frac{2m_\mu^2}{Q^2})\beta_\mu}{\beta_\pi^3|F_\pi(Q^2)|^2}\frac{\frac{d\sigma_\pi}{dQ^2}}{\frac{d\sigma_\mu}{dQ^2}} \ ,$$

$\pi\pi$ / $\mu\mu$ ratio: FSRNLO



$\pi\pi$ / $\mu\mu$ ratio: FSRNLO



From EVA to ...

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

- 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]

PHOKHARA tests

$\Rightarrow$ matrix elements tests

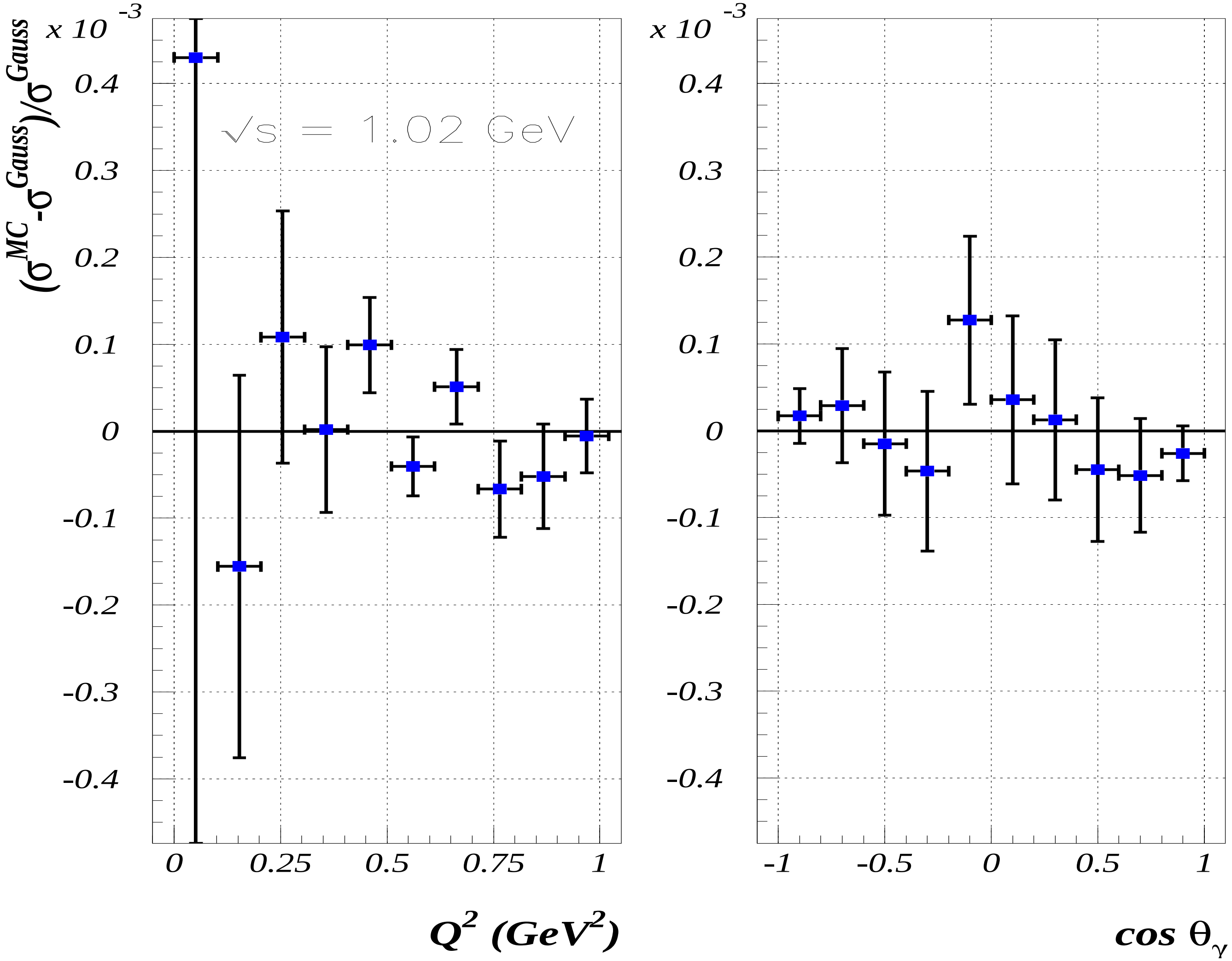
$\Rightarrow$ generation tests

$\Rightarrow$ KKMC comparison + ...

S. Jadach, B. F. L. Ward and Z. Wąs, CPC 130:260,2000.

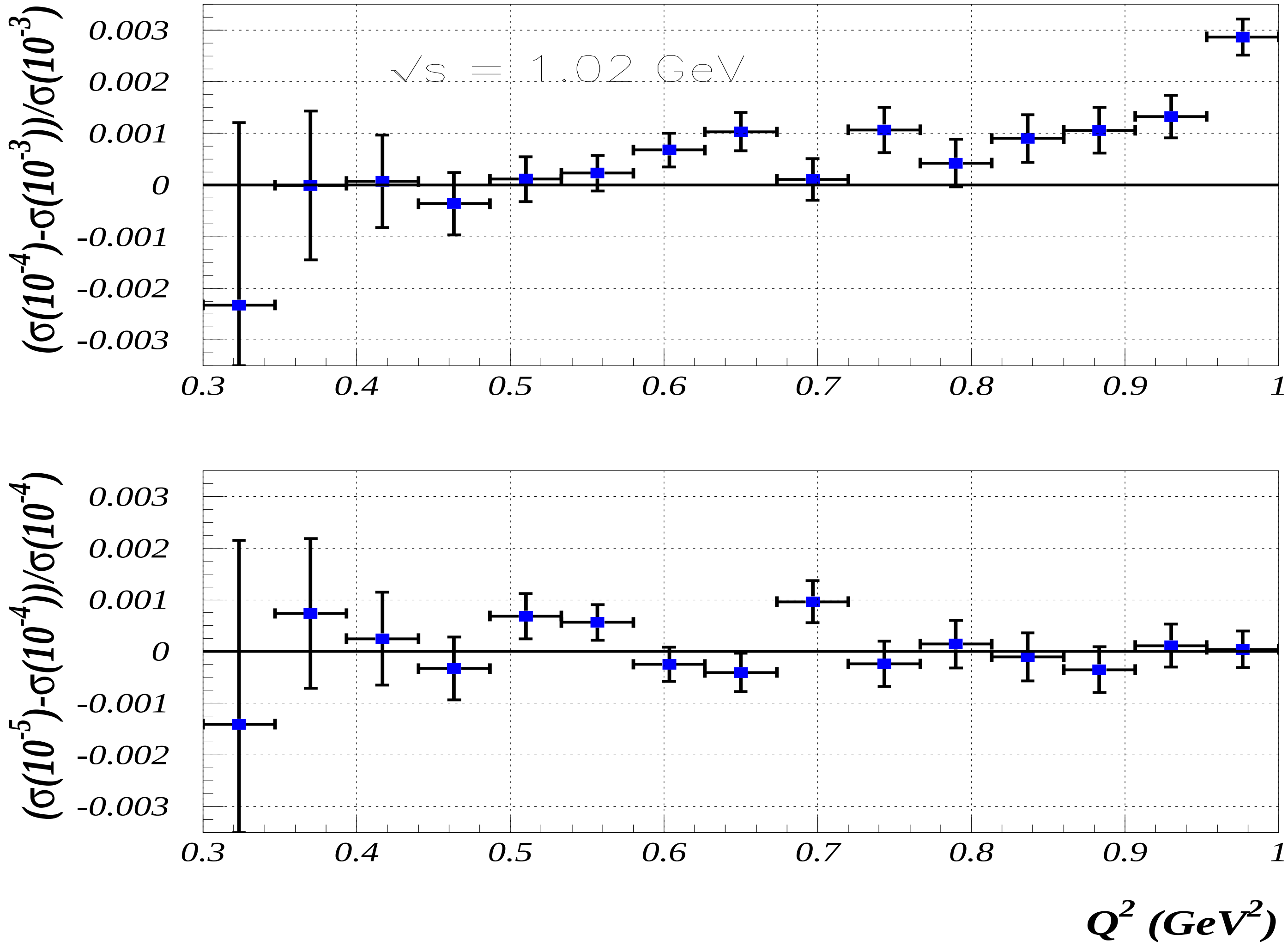
PHOKHARA generation tests

G. Rodrigo, H.C., J.H. Kühn and M. Szopa,EPJ C24:71,2002



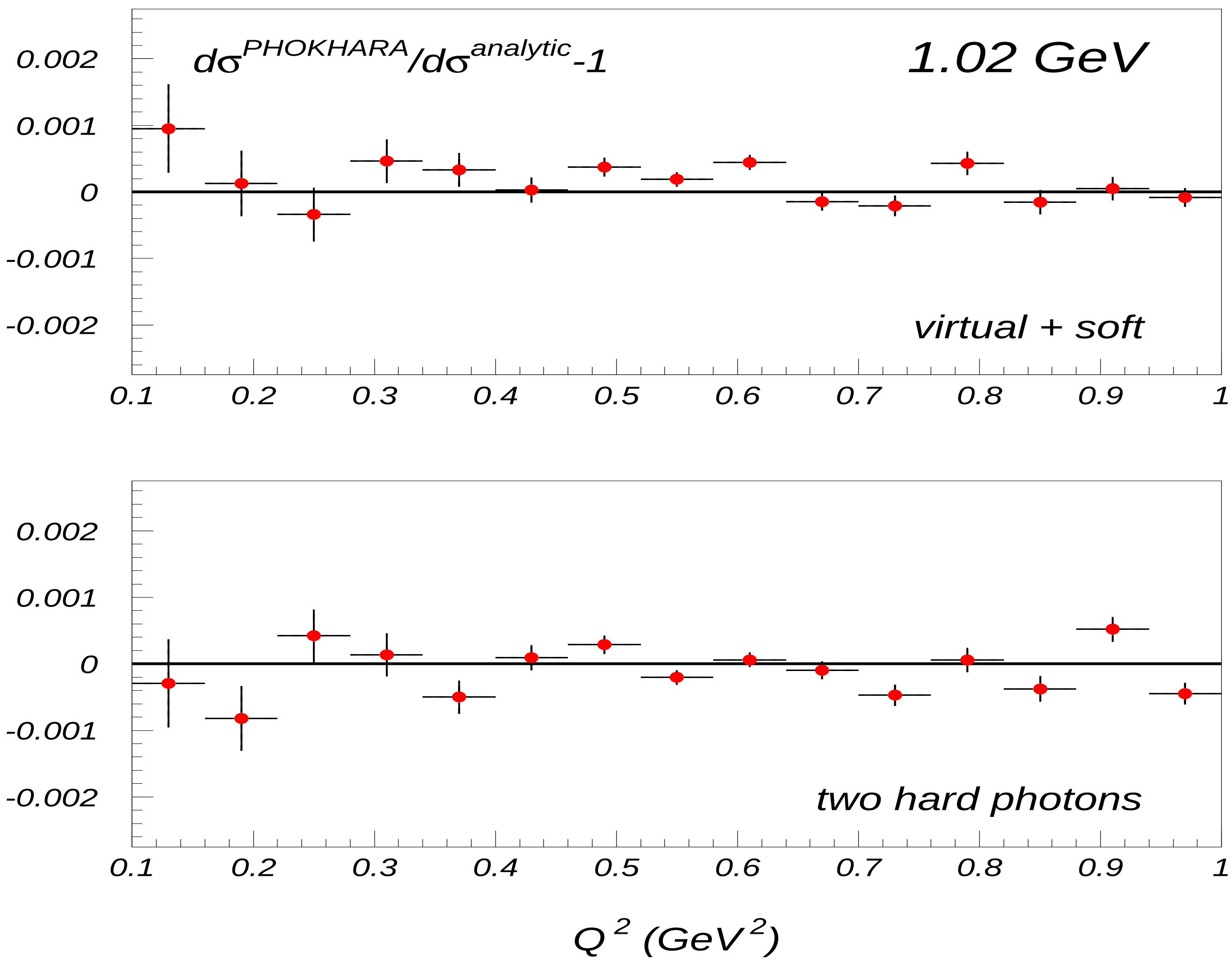
PHOKHARA generation tests

G. Rodrigo, H.C., J.H. Kühn and M. Szopa, EPJ.C24:71,2002.



PHOKHARA generation tests

H.C., A. Grzelińska, J.H. Kühn and G. Rodrigo, EPJ.C27:563,2003



KKMC

S. Jadach, B. F. L. Ward and Z. Wąs

- YFS exponentation
- high accuracy only for muon pairs
- can we hope for: upgrades ???

S.Jadach: KKMC- Pisa 2003

Summary

- We found very good agreement of KKMC and PHOKHARA to within 0.2% for μ-pair final states for pure ISR
- Discrepancy of order 1-2% between KKMC and PHOKHARA or even larger at low mass, was found for π-pair final state.
- This is due to use of the inferior EEX matrix element in KKMC instead of CEEX.
- NB. We know how to upgrade ISR in KKMC to CEEX level for any hadronic final state...

Dubna - Novosibirsk papers 2003

A. B. Arbuzov, E. Bartos (Bratislava),
V. V. Bytev, E. A. Kuraev, Z. K. Silagadze

- muon and pion pairs

- analytic formulae based on RG - SF

- Comparisons with PHOKHARA planned
  first results in January 2009 ??

MCGPJ

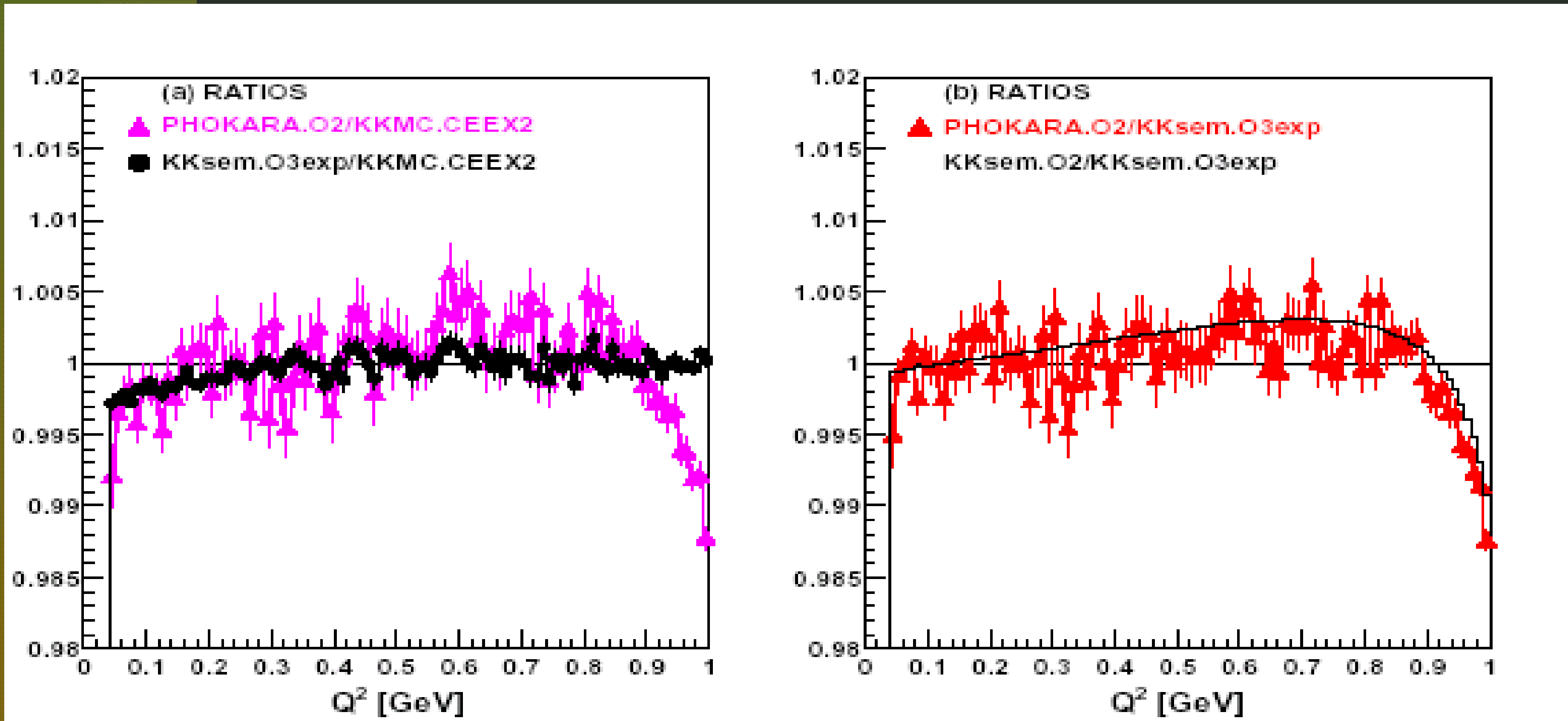
A. B. Arbuzov, G. V. Fedotovich, E. A. Kuraev, F. V. Ignatov, and A. L. Sibidanov,

EPJ.C46:689,2006.

- Comparisons with PHOKHARA planned
  first results in January 2009 ??

S.Jadach: KKMC

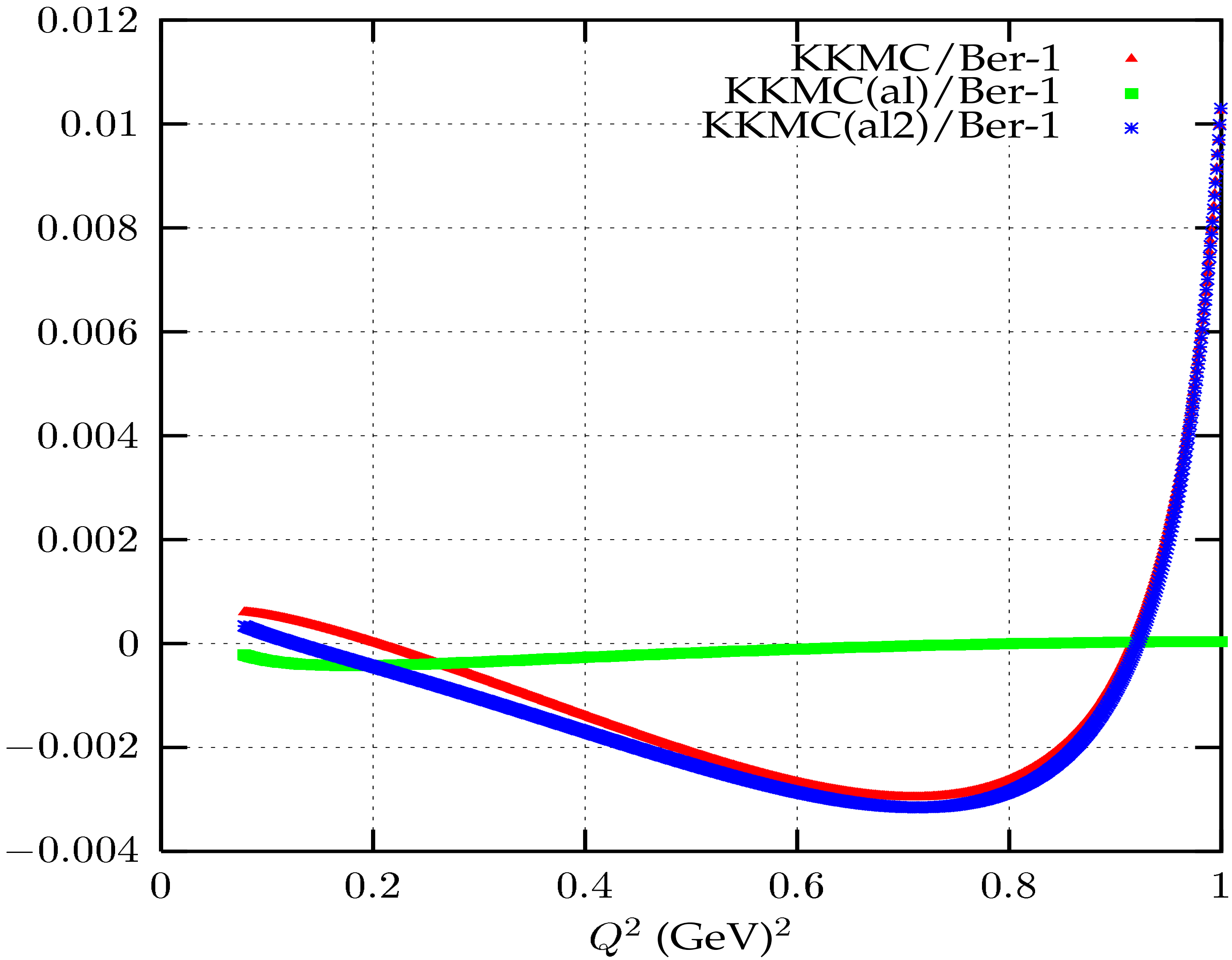
PHOKHARA included in the game, μ-pairs again



PHOKHARA agrees to within 0.3% with KKMC and KKsem.

Discrepancy at high Q^2 reflects lack of exponentiation in PHOKHARA

PHOKHARA vs. KKMC cnd.



KKMC vs. PHOKHARA - ISR virt. corr.

C. Glosser, S. Jadach, B. F. L. Ward and S. A. Yost
Phys. Lett. B **605** (2005) 123;
Phys. Rev. D **73** (2006) 073001

- a precison $\mathbf{1.5 \cdot 10^{-5}}$

- not direct tests

PHOKHARA: ISR tests summary

$\Rightarrow$ technical precision: few $\times 10^{-4}$

$\Rightarrow$ 'physical' precision: 0.5%

$\Rightarrow$ plans: accuracy $\sim$ 0.2%

FF separation at B-factories

H.C., J. H. Kühn, E. Nowak and G. Rodrigo, Eur.Phys.J.C35(2004)527

Electromagnetic current describing production of baryon-antibaryon pair

$$J_\mu = -ie\cdot\bar{u}(q_2)\left(F_1^N(Q^2)\gamma_\mu - \frac{F_2^N(Q^2)}{4m_N}\left[\gamma_\mu, \not{Q}\,\right]\right)v(q_1)\ ,$$

$$G_M^N = F_1^N + F_2^N\ , \qquad G_E^N = F_1^N + \tau F_2^N\ ,$$

$\tau = Q^2/4m_N^2$, $Q = q_1 + q_2$

FF separation at B-factories

H.C., J. H. Kühn, E. Nowak and G. Rodrigo, Eur.Phys.J.C35(2004)527

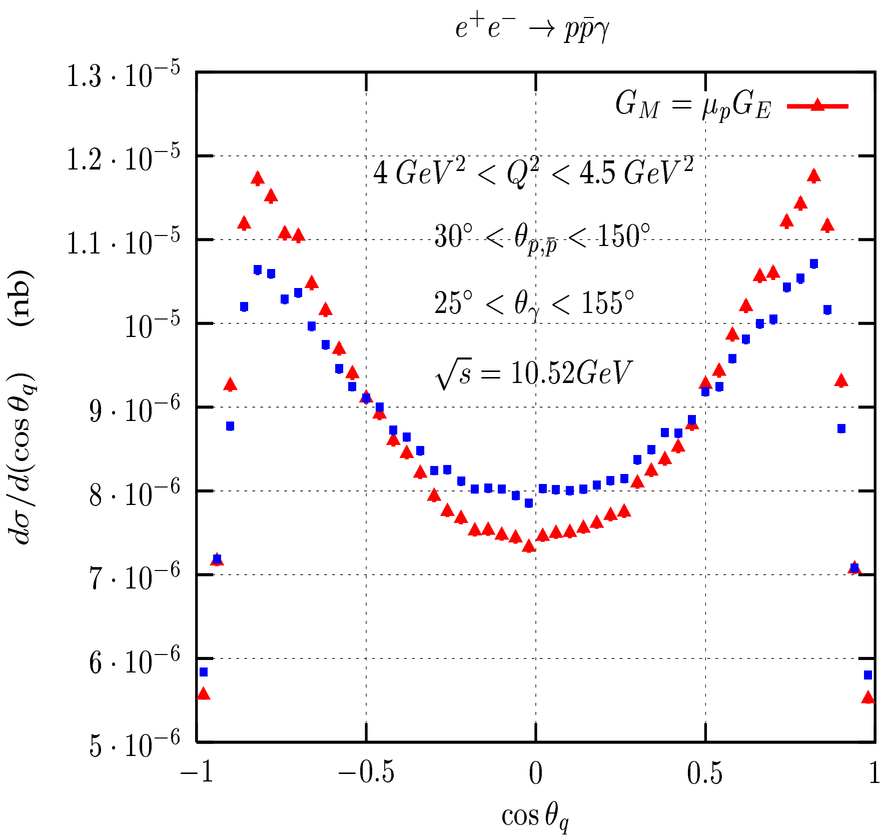
AT LO ISR : $e^+ + e^- \to \bar{N} + N + \gamma.$

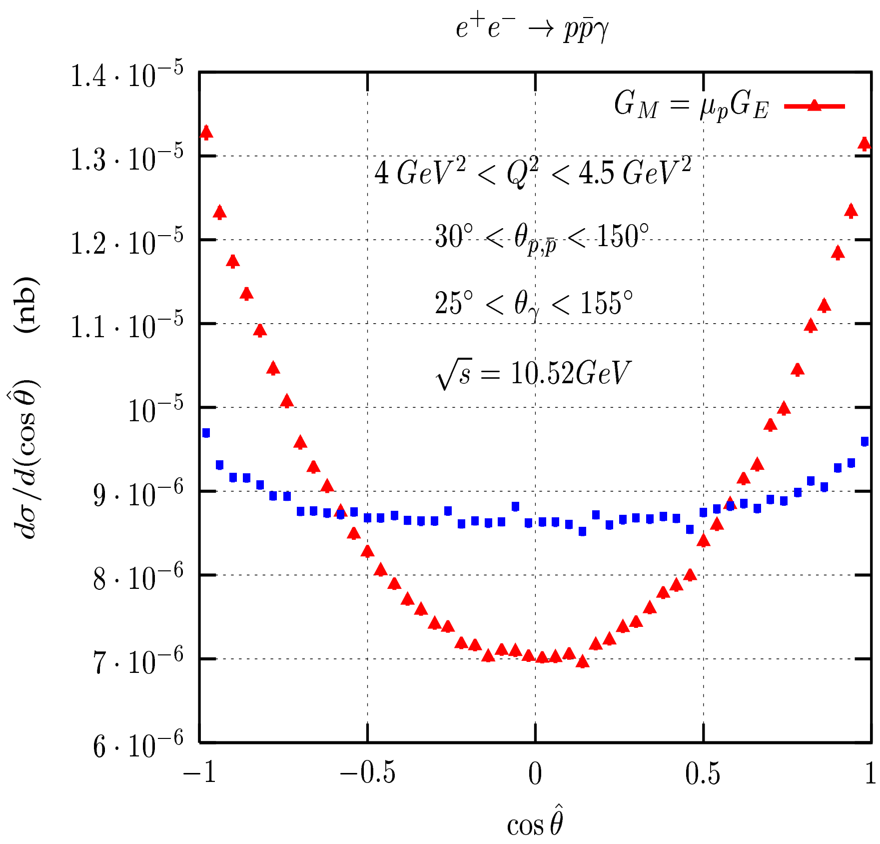
$$d\sigma = \frac{1}{2s} L_{\mu\nu} H^{\mu\nu} dLips(p_1 + p_2; q_1, q_2, k)$$

$$H_{\mu\nu} = 2|G_M^N|^2 (Q_\mu Q_\nu - g_{\mu\nu} Q^2) - \frac{8\tau}{\tau - 1} \left(|G_M^N|^2 - \frac{1}{\tau} |G_E^N|^2 \right) q_\mu q_\nu$$

FF separation at B-factories

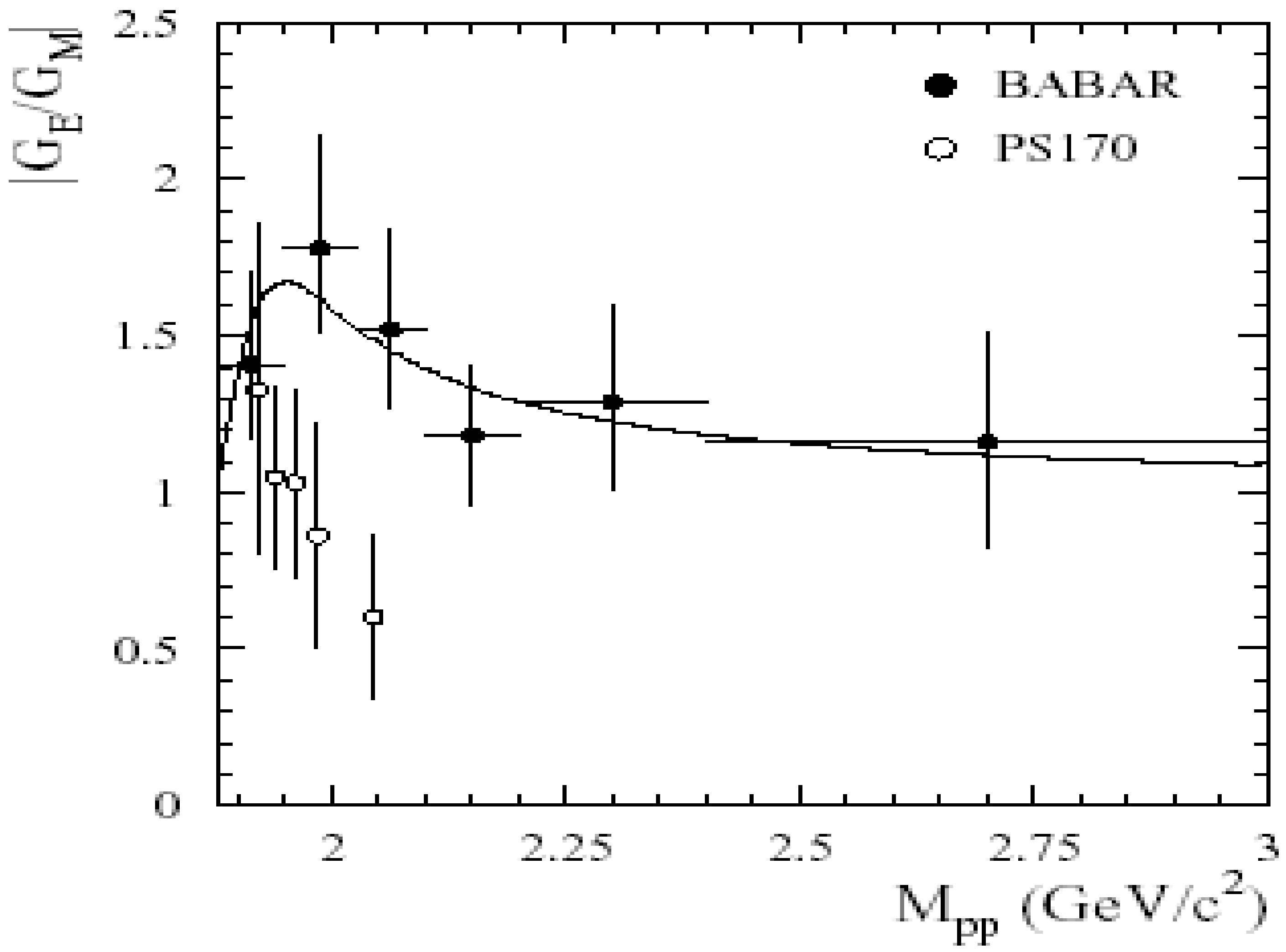
H.C., J. H. Kühn, E. Nowak and G. Rodrigo, Eur.Phys.J.C35(2004)527





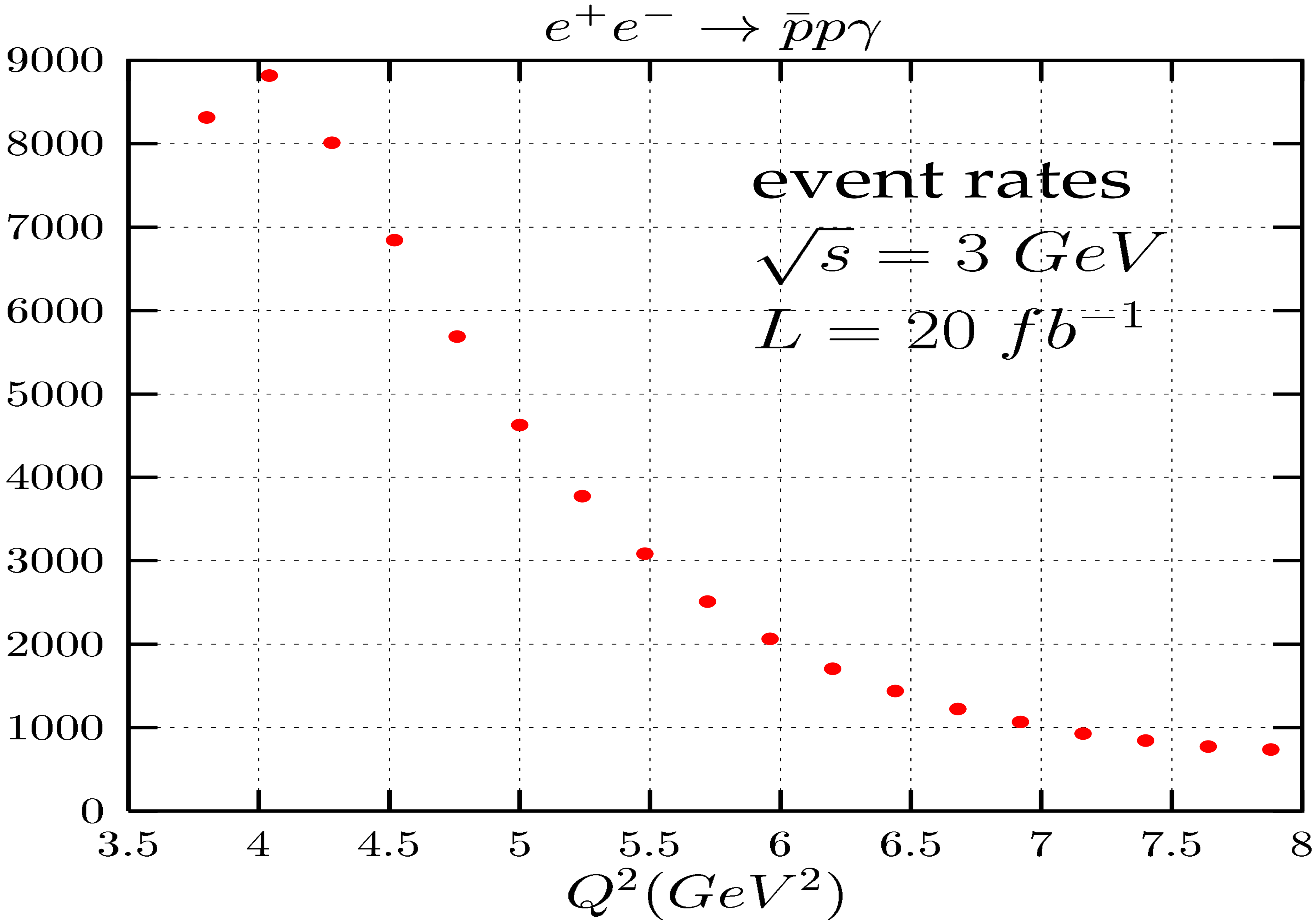
about 2000 events per 100 fb^{-1}

nucleon FF



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

nucleon FF at $\sqrt{s} = 3$ GeV



Λ formfactors

$$e^+e^- \to \Lambda(q_2,S_2)\bar{\Lambda}(q_1,S_1)$$

$$e^+e^- \to \Lambda(q_2,S_2)\bar{\Lambda}(q_1,S_1)\gamma_{ISR}$$

$$J_\mu = -ie \cdot \bar{u}(q_2,S_2)$$

$$\left(F_1^\Lambda(Q^2)\gamma_\mu - \frac{F_2^\Lambda(Q^2)}{4m_\Lambda}[\gamma_\mu, \not{Q}] \right) \; v(q_1,S_1)$$

The polarized cross section

$$d\sigma(e^+e^- \to \bar{\Lambda}\Lambda) \;=\; \frac{1}{2s}\, L^0_{\mu\nu}\, H^{\mu\nu} d\Phi_2(p_1+p_2; q_1, q_2)$$

$$L^0_{\mu\nu}\, H^{\mu\nu} =$$

$$4\pi^2\alpha^2 \Bigg\{ |G_M|^2 \left(1+\cos^2\theta_{\bar{\Lambda}}\right) + \frac{1}{\tau}|G_E|^2 \sin^2\theta_{\bar{\Lambda}}$$

$$+\;\; Im(G_M G_E^*)/\sqrt{\tau}\;\, \sin(2\theta_{\bar{\Lambda}})\;\, \left(S^y_{\Lambda} + S^y_{\bar{\Lambda}}\right)$$

$$-\;\; Re(G_M G_E^*)/\sqrt{\tau}\;\;\, \sin(2\theta_{\bar{\Lambda}})\, \left(S^z_{\Lambda} S^x_{\bar{\Lambda}} + S^z_{\bar{\Lambda}} S^x_{\Lambda}\right)$$

$$+ \left(\frac{1}{\tau}|G_E|^2 + |G_M|^2\right) \sin^2\theta_{\bar{\Lambda}}\;\; S^x_{\bar{\Lambda}} S^x_{\Lambda}$$

$$+ \left(\frac{1}{\tau}|G_E|^2 - |G_M|^2\right) \sin^2\theta_{\bar{\Lambda}}\;\; S^y_{\bar{\Lambda}} S^y_{\Lambda}$$

$$- \left(\frac{1}{\tau}|G_E|^2 \sin^2\theta_{\bar{\Lambda}} - |G_M|^2 \left(1+\cos^2\theta_{\bar{\Lambda}}\right)\right)\;\; S^z_{\bar{\Lambda}} S^z_{\Lambda} \Bigg\}$$

$$Im(G_M G_E^*)/\sqrt{\tau}\ \sin(2\theta_{\bar\Lambda})\ \left(S_\Lambda^y + S_{\bar\Lambda}^y\right)$$

and

$$Re(G_M G_E^*)/\sqrt{\tau}\ \ \sin(2\theta_{\bar\Lambda})\left(S_\Lambda^z S_{\bar\Lambda}^x + S_{\bar\Lambda}^z S_\Lambda^x\right)$$

$$G_M = |G_M|\ e^{i\phi_M}$$

$$G_E = |G_E|\ e^{i\phi_E}$$

$$Re(G_M G_E^*) = |G_M|\ |G_E| \cos(\phi_M - \phi_E)$$

$$Im(G_M G_E^*) = |G_M|\ |G_E| \sin(\phi_M - \phi_E)$$

$$\boxed{\phi_M - \phi_E = \Delta\phi}$$

- relative phase between electric and magnetic form factors

The subsequent two body decays of Λs

The measurement of the subsequent two body decays:

$$\Lambda \to \pi^- p \quad \text{and} \quad \bar{\Lambda} \to \pi^+ \bar{p}$$

allow for a spin analysis of the decaying Λs.

The decay distribution: $$R_\Lambda = 1 - \alpha_\Lambda \, \bar{S}_\Lambda \cdot \bar{n}_{\pi^-}$$

The spin vector is replaced by:

$$\bar{S}_\Lambda \to -\alpha_\Lambda \bar{n}_{\pi^-} \;\text{ and }\; \bar{S}_{\bar{\Lambda}} \to -\alpha_{\bar{\Lambda}} \bar{n}_{\pi^+}$$

$$e^+e^- \to \bar{\Lambda}(\to \pi^+\bar{p})\Lambda(\to \pi^-p)$$

using the narrow width approximation

$$d\sigma\left(e^+e^- \to \bar{\Lambda}(\to \pi^+\bar{p})\Lambda(\to \pi^-p)\right) =$$

$$d\sigma\left(e^+e^- \to \bar{\Lambda}\Lambda\right)\left(S_{\Lambda,\bar{\Lambda}} \to \mp\alpha_\Lambda n_{\pi^\mp}\right)$$

$$\times\ d\bar{\Phi}_2(q_1; p_{\pi^+}, p_{\bar{p}})d\bar{\Phi}_2(q_2; p_{\pi^-}, p_p)$$

$$\times\ \mathrm{Br}(\bar{\Lambda} \to \pi^+\bar{p})\mathrm{Br}(\Lambda \to \pi^-p)$$

$n_{\pi^+}(n_{\pi^-}) = (0, \bar{n}_{\pi^+})\ ((0, \bar{n}_{\pi^-}))$ in the $\bar{\Lambda}$ (Λ) rest frame

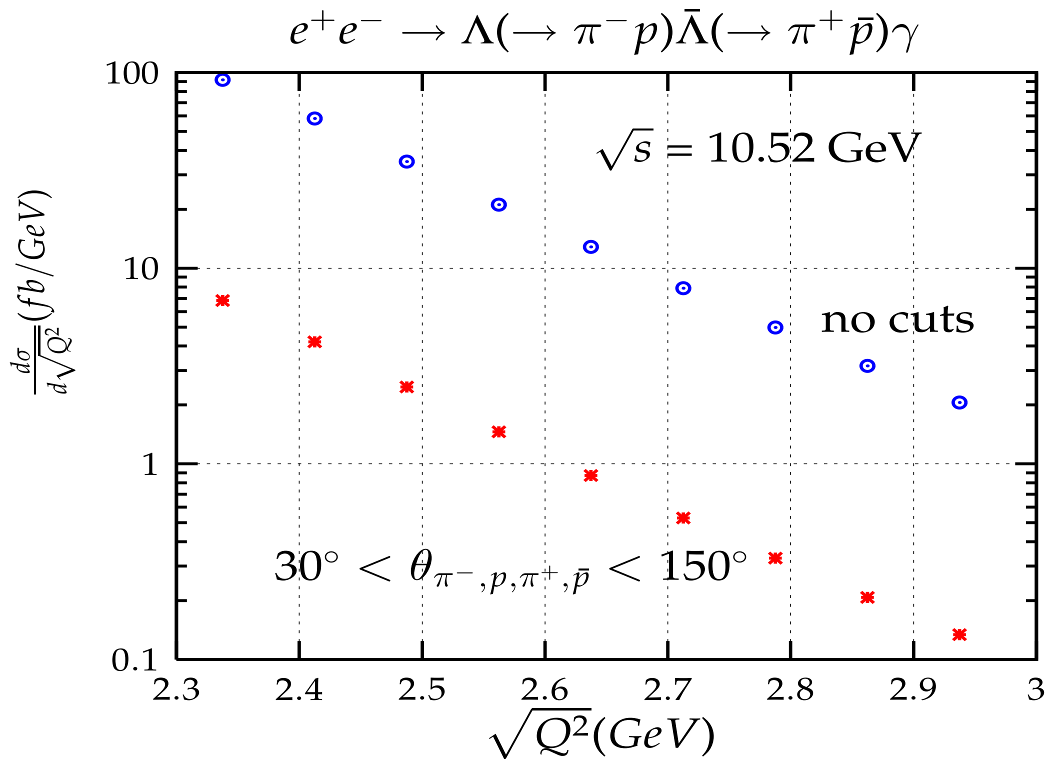
The cross section with ISR photon emision

$$
\begin{aligned}
L^{ij}H_{ij} \simeq \frac{(4\pi\alpha)^3}{4Q^2y_1y_2}\left(1+\cos^2\theta_\gamma\right)\Bigg\{ & |G_M|^2\left(1+\cos^2\theta_{\bar\Lambda}\right) \\
& +\frac{1}{\tau}|G_E|^2\sin^2\theta_{\bar\Lambda} - \alpha_\Lambda\frac{Im(G_MG_E^*)}{\sqrt{\tau}}\sin(2\theta_{\bar\Lambda})\left(n^y_{\pi^-}-n^y_{\pi^+}\right) \\
& +\alpha_\Lambda^2\frac{Re(G_MG_E^*)}{\sqrt{\tau}}\sin(2\theta_{\bar\Lambda})\left(n^z_{\pi^-}n^x_{\pi^+}+n^z_{\pi^+}n^x_{\pi^-}\right) \\
& -\alpha_\Lambda^2\left(\frac{1}{\tau}|G_E|^2+|G_M|^2\right)\sin^2\theta_{\bar\Lambda}\;\; n^x_{\pi^+}n^x_{\pi^-} \\
& -\alpha_\Lambda^2\left(\frac{1}{\tau}|G_E|^2-|G_M|^2\right)\sin^2\theta_{\bar\Lambda}\;\; n^y_{\pi^+}n^y_{\pi^-} \\
& +\alpha_\Lambda^2\left(\frac{1}{\tau}|G_E|^2\sin^2\theta_{\bar\Lambda}-|G_M|^2\left(1+\cos^2\theta_{\bar\Lambda}\right)\right)\;\; n^z_{\pi^+}n^z_{\pi^-}\Bigg\}
\end{aligned}
$$

$\theta_{\bar\Lambda}$ - $\bar{Q}$ rest frame with the z-axis opposite to the photon direction

The cross section

FF from Körner et al. Phys. Rev. D 16 (1977) 2165



At $\boldsymbol{B}$-factories we expect about 130 events per 100 fb^{-1}.

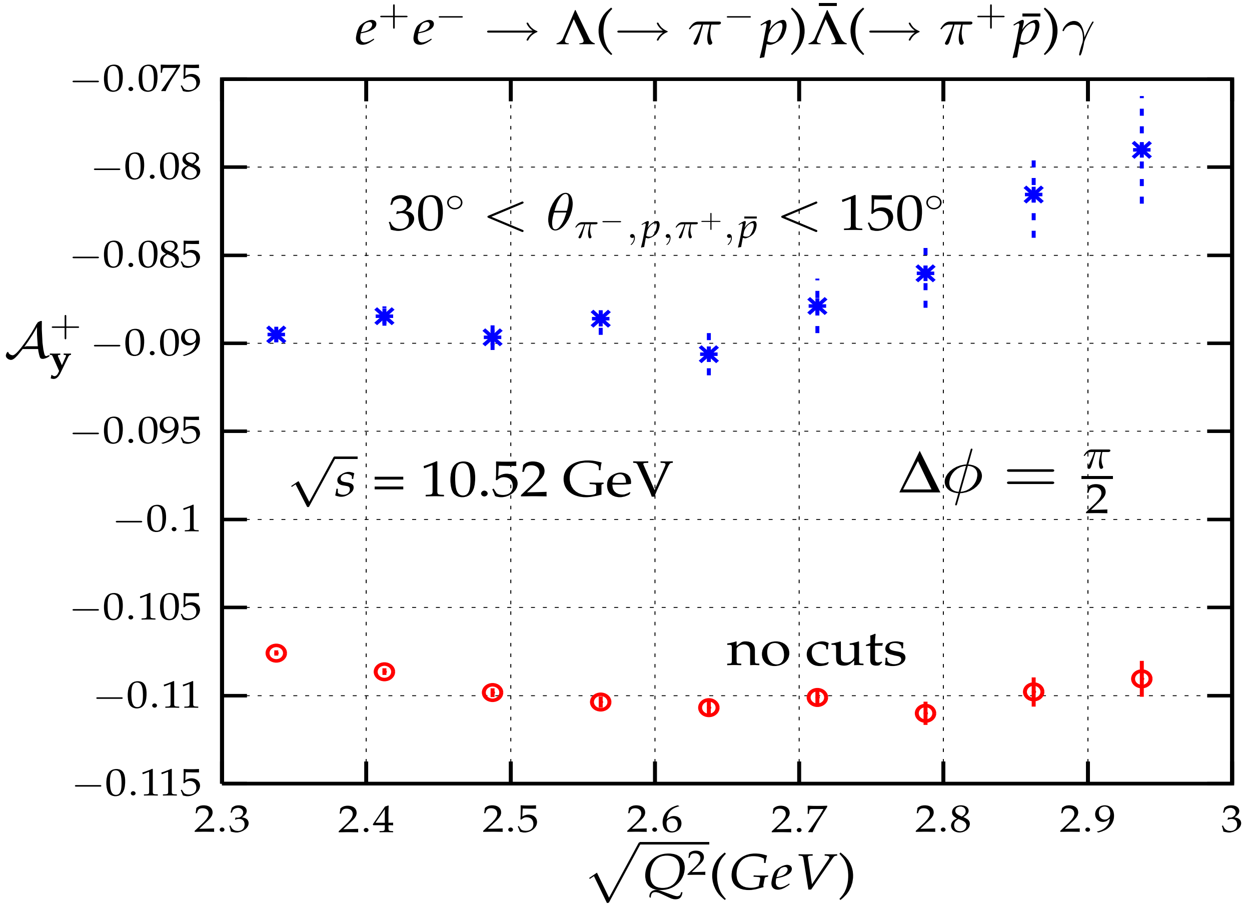
At $\sqrt{s} = 3.77 GeV$ we expect about 220 events per 10 fb^{-1}.

Asymmetry

$$\mathcal{A}_y^{\pm} = \frac{d\sigma(a^{\pm}>0) - d\sigma(a^{\pm}<0)}{d\sigma(a^{\pm}>0) + d\sigma(a^{\pm}<0)}$$

$$a^{+(-)} = \sin(2\theta_{\bar{\Lambda}})\; n^y_{\pi^+(\pi^-)}$$

Asymmetry

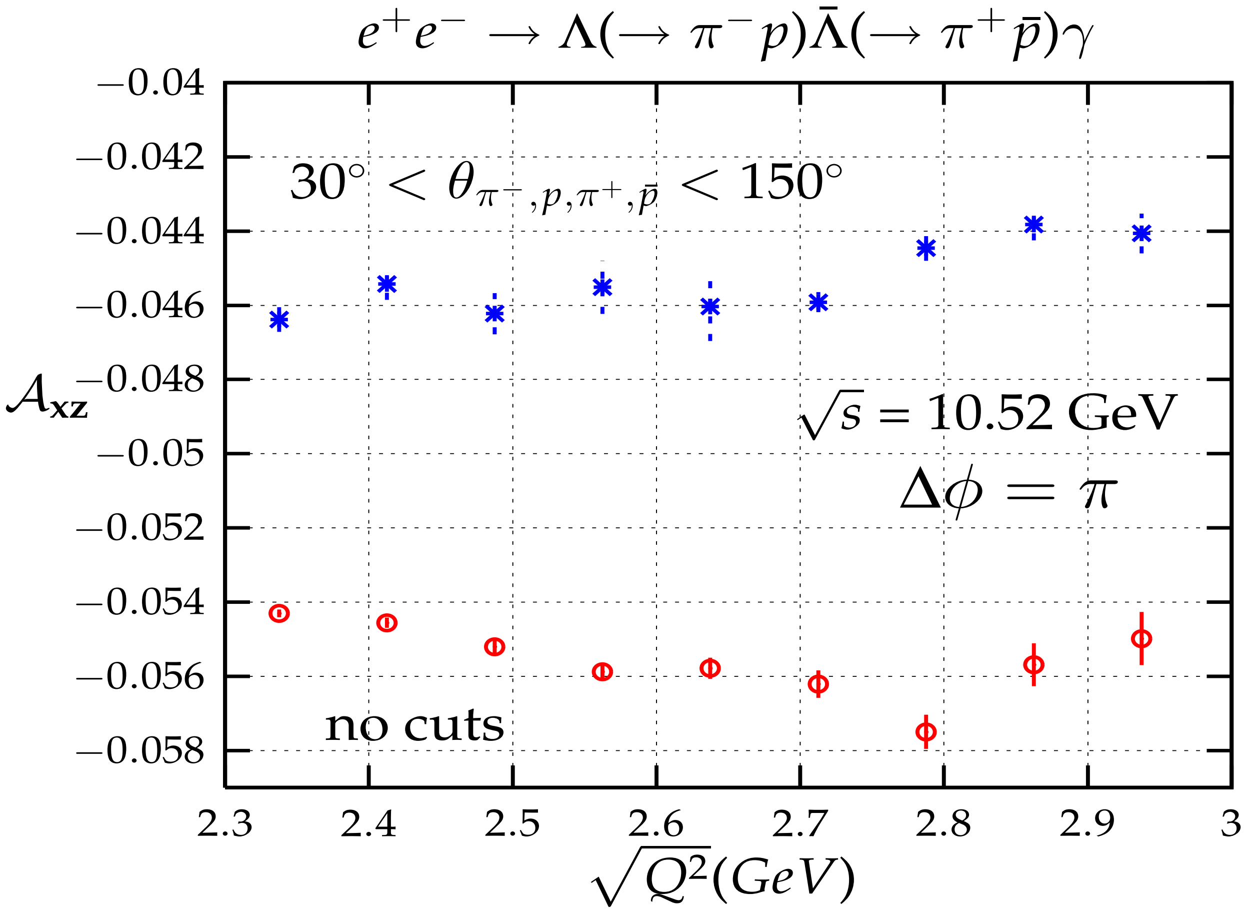

$e^+e^- \to \Lambda(\to \pi^- p)\bar{\Lambda}(\to \pi^+ \bar{p})\gamma$
$30^\circ < \theta_{\pi^-,p,\pi^+,\bar{p}} < 150^\circ$
$\sqrt{s} = 10.52$ GeV
$\Delta\phi = \frac{\pi}{2}$
no cuts
$\mathcal{A}_{\mathbf{y}}^+$
−0.075
−0.08
−0.085
−0.09
−0.095
−0.1
−0.105
−0.11
−0.115
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
$\sqrt{Q^2}(GeV)$

Spin correlations

$$A_{xz} = \frac{d\sigma(\tilde{a}>0) - d\sigma(\tilde{a}<0)}{d\sigma(\tilde{a}>0) + d\sigma(\tilde{a}<0)}$$

$$\tilde{a} = \sin(2\theta_{\bar{\Lambda}}) \times \left(n^z_{\pi^-} n^x_{\pi^+} + n^z_{\pi^+} n^x_{\pi^-} \right)$$

Spin correlations



The cross section

BABAR Collaboration, Phys.Rev.D76:092006,2007.

$$|G_E/G_M| = 1.73^{+0.99}_{-0.57}$$ for $\sqrt{Q^2}$: 2.23 - 2.40 GeV

$$|G_E/G_M| = 0.71^{+0.66}_{-0.71}$$ for $\sqrt{Q^2}$: 2.40 - 2.80 GeV

-0.76 $< \sin(\Delta\phi) <$ 0.98

Summary

- PHOKHARA: ISR accuracy 0.5%
    - aim: ISR accuracy ∼0.2%

soon PHOKHARA7.0 with:

- new 4π, J/ψ and $\psi(2S)$

We look forward for fruitfull collaboration between BESIII and PHOKHARA team