Euroflavour 2008, Durham

WG6: Review of MC tools

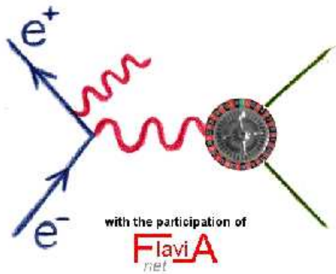
H. CZYŻ, IF, UŚ, Katowice

WG6 - Radiative Return and MC Tools

Group coordinators: H. Czyż, J.H. Kühn

wider structure:

Working Group on Rad. Corrections and MC Generators for Low Energies



Group coordinators: H. Czyż, G. Venanzoni (Frascati,KLOE)

Meetings:

* Frascati, 16-17 October 2006
* Frascati, 25-26 June 2007
* Frascati, 11 April 2008
* Beijing, 9-11 October 2008

The subjects covered:

- Monte Carlo generators for Luminosity
- Monte Carlo generators for e^+e^- annihilation into leptons and hadrons FlaviA net
- Monte Carlo generators for e^+e^- annihilation into hadrons plus an energetic photon from initial state radiation (ISR) FlaviA net
- Monte Carlo generators for τ production and decays FlaviA net

People involved

Beijing: Wang, Zhang
Berlin: Jegerlehner
Bologna: Caffo, Remiddi
Cracov: Grzelińska, Jadach, Wąs
Dubna: Arbuzov, Kuraev
Frascati: Isidori, Mueller, Pacetti, Pancheri, Shekhovtsova,Venanzoni
Karlsruhe: Beltrame, Kluge, Kühn,
Katowice: Czyż, Gluza, Kołodziej
Mainz: Denig
Novosibirsk: Eidelman, Fedotovich, Sibidanov, Solodov
Padova: Passera
Parma: Trentadue
Pavia: Carloni-Calame, Montagna, Piccinini
Rome: Baldini, Bini, Greco, Nguyen
Valencia: Rodrigo
Zeuthen: Riemann

Experiments involved

BaBar

BELLE

BES-III

CMD2

KLOE

SND

MC generators

BABAYAGA

KKMC FlaviA net

MCGPJ

PHOKHARA FlaviA net

PHOTOS FlaviA net

TAUOLA FlaviA net

Why Beijing...by Wang Ping

Luminosity

BabaYaga and its theoretical accuracy

Carlo M. Carloni Calame

INFN, Sezione di Pavia

Working Group on Radiative corrections and generators for low energy hadronic cross section and luminosity

based on hep-ph/0607181 (accepted by **NPB**)

in collaboration with G. Balossini, G. Montagna, O. Nicrosini, F. Piccinini

C. M. Carloni Calame (INFN) | The new BabaYaga | October 16-17, 2006 | 1 / 16

Luminosity

Estimate of the theoretical accuracy

- switching off VP, tuned comparisons with independent calculations/approaches (`Labspv`, `Bhwide`)
  - ⋆ $\Delta\sigma/\sigma < 0.03\%$ on cross sections
  - ⋆ up-to-0.5% differences between `BabaYaga` and `Bhwide` in distribution tails
- comparison with existing perturbative 2-loop calculations
  - ⋆ currently available
    1. Penin: complete virtual 2-loop photonic corrections (for $Q^2 \gg m_e^2$) plus real radiation in the soft limit
    2. Bonciani et al.: virtual $N_F = 1$ [only electron in the loops] fermionic contributions plus real radiation in the soft limit
  - ⋆ the photonic and $N_F = 1$ $\mathcal{O}(\alpha^2)$ content of the S+V part in the `BabaYaga` matched formula can be easily extracted. The terms to be directely compared to 1. and 2. can be read out!
  - ⋆ the impact of the missing $\mathcal{O}(\alpha^2)$ S+V corrections can be quantified within realistic setup

C. M. Carloni Calame (INFN) | The new `BabaYaga` | October 16-17, 2006 | 7 / 16

Luminosity

Summary of theoretical errors

- for Bhabha cross section, within realistic setup for luminometry, the theoretical errors of the new `BabaYaga` are summarized

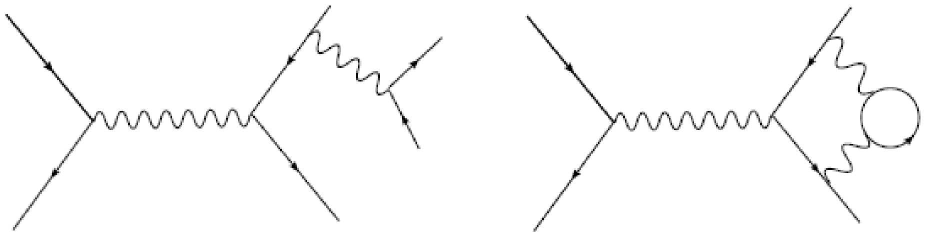
$\lvert\delta^{err}\rvert$ (%)	(a)	(b)	(c)	(d)
$\lvert\delta^{err}_{VP}\rvert$	0.01	0.00	0.02	0.04
$\lvert\delta^{err}_{pairs}\rvert$	0.02	0.03	0.03	0.04
$\lvert\delta^{err}_{H,H}\rvert$	0.00	0.00	0.00	0.00
$\lvert\delta^{err}_{phot+N_f=1}\rvert$	0.01	0.01	0.00	0.01
$\lvert\delta^{err}_{SV,H}\rvert$	0.05	0.05	0.05	0.05
$\lvert\delta^{err}_{total}\rvert$	0.09	0.09	0.10	0.14

Table: LABS (a) (c), VLABS (b) (d), 1.02 GeV (a) (b), 10 GeV (c) (d)

Luminosity

Light-pair corrections (real & virtual)

- They contribute at $\mathcal{O}(\alpha^2)$, VPC (part of 2-loop $N_F = 1$) and RPC largely cancel. Not included in `BabaYaga`.



- To estimate the impact, VPC evaluated as in Jadach et al. ('97); Kniehl ('90); Burgers ('85); Barbieri et al. ('72); RPC evaluated in soft approximation as in Arbuzov et al. ('97)
- the correction does not exceed 0.05% in LABS [1] and VLABS [2] at 1 and 10 GeV (see `hep-ph/0607181`)

[1] $20^\circ < \vartheta_\pm < 160^\circ$
[2] $55^\circ < \vartheta_\pm < 125^\circ$

Luminosity

T. Riemann, WG on RC and MC for Low Energies, Frascati, 2008 1

Hadronic corrections to Bhabha scattering

Tord Riemann, DESY, Zeuthen
based on work with:
S. Actis (RWTH Aachen), M. Czakon (U. Würzburg)
and J. Gluza (Sileasian U. Katowice)

Working Group on Radiative Corrections and Generators for Low Energy Hadronic Cross Section and Luminosity
11 April 2008, Frascati

- Introduction: Two-loop corrections to Bhabha Scattering
- Leptonic contributions with $m_e^2 << m_f^2 << s, t$
  ACGR: NPB 786 (2007) [arXiv:0704.2400]
- Leptonic contributions with $m_e^2 << m_f^2, s, t$
  ACGR: APP B38 (2007) [arXiv:0710.5111] → see also talk by Roberto Bonziani
- Hadronic contributions
  ACGR: PRL 100 (2008) [arXiv:0711.53847]
- Summary

Luminosity

T. Riemann, WG on RC and MC for Low Energies, Frascati, 2008 25

Summary

- We determine the $N_f = 2$ contributions to 2-loop Bhabha scattering, including the hadronic corrections
- They are small, but non-negligible at the scale 10^{-3} ($\rightarrow$ No LEP influencing)
- Agreement for $m_e^2 << m_l^2 << s, t, u$ with:
  "Two-loop QED corrections to Bhabha scattering"
  Thomas Becher, Kirill Melnikov, arXiv:0704.3582 [hep-ph], JHEP
- Agreement for $m_e^2 << m_l^2, s, t, u$ with:
  "Two-Loop Heavy-Flavor Contribution to Bhabha Scattering",
  Roberto Bonciani, Andrea Ferroglia, Sacha Penin, arXiv:0710.4775v3 [hep-ph]
- To be evaluated yet:
  $\longrightarrow$ 1-loop diagrams with real photon emission, interfering with real (Born) radiation, including 5-point functions
- Also: $\longrightarrow$ Real pair production
- Both items were studied already by Andrei Arbuzov, Kuraev, Shaitchatdenov (1998, small photon mass)

PHOTOS

1

PHOTOS Monte Carlo – its phase-space and benchmarks

Z. Was

Institute of Nuclear Physics, Krakow *and* CERN-PH, Geneva

talk include contributions of:

P. Golonka

CERN IT/CO-BE , Geneva, Institute of Nuclear Physics, Krakow

G. Nanava

JINR, Dubna, Russia, Institute of Nuclear Physics, Krakow

PHOTOS

Purpose of the talk

Because QED corrections affect interpretation of measured quantities: cut off induced corrections to the rates, to parity sensitive asymmetries, CKM ...

PHOTOS was used for many years in low precision regime for that purpose by practically all experiments.

Precision requirements increased; responsability on the project grows.

We have completed re-amalysis of program content in some of its aspects:

-1- matrix elements for $Z \to l\bar{l}$; QED.

-2- matrix elements for $B \to K\bar{\pi}$; scalar QED.

-3- phase space *of no approximations*, **also for multiple photon radiation!** On mass-shell iterative relations are attracting attention, technique used in PHOTOS may become useful outside QED?

Z. Was

TAUOLA

1

Precision simulations with TAUOLA

Z. Wąs

Institute of Nuclear Physics, PAN, Kraków, Poland

Main messages:

- What is new or important for the users of our package TAUOLA
- Different perspectives:
- TAUOLA decays into 5 scalars with full ME now, not real progress yet.
- MC-TESTER for automated comparisons and benchmark database.
- universal interface of TAUOLA, bridge between medium and high energy
- Practical problems of encapsulation. C or not to C: coordination
- Summary

My web page is at http://home.cern.ch/wasm

Z. Was — Frascati, April 11, 2008

TAUOLA

TAUOLA: basic structure these assumptions remain!

- Phase space.
- Matrix elements
- Leptonic decays: $\tau \rightarrow e(\mu)\nu_\tau\nu(\gamma)$.
- Electroweak vertex is clear and universal up to 0.1 % precision level..
- Semileptonic decays are different : Hadronic current need to remain experiments' property, in cases experiment wish so.
- The last point enforces constraint for program organization and requests good communication between experimentalists, model builders and TAUOLA authors.
- Also points to low energy e^+e^- data and models. Presence/absence of isospin symmetry need to be adressed.

MCGPJ

Systematic treatment of second order NLO QED radiative corrections to exclusive observables

Andrej Arbuzov

Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna, Russia

Talk at the Radio MontecarLow workshop, Frascati, 11th April 2008

MCGPJ: A. Arbuzov

Outlook

- The ansatz for the treatment of $\mathcal{O}\left(\alpha^2 L^1\right)$ QED radiative corrections to exclusive observables is described
- The ansatz is suited for MC simulations
- Many processes can be treated in this way
- $\mathcal{O}\left(\alpha^2 L^0\right)$ contributions can be put into the same structure
- MCGPJ can be upgraded
- MC integrator and generator for Bhabha scattering is under development (upgrade of SAMBHA MC)

The reason we need R(s)

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

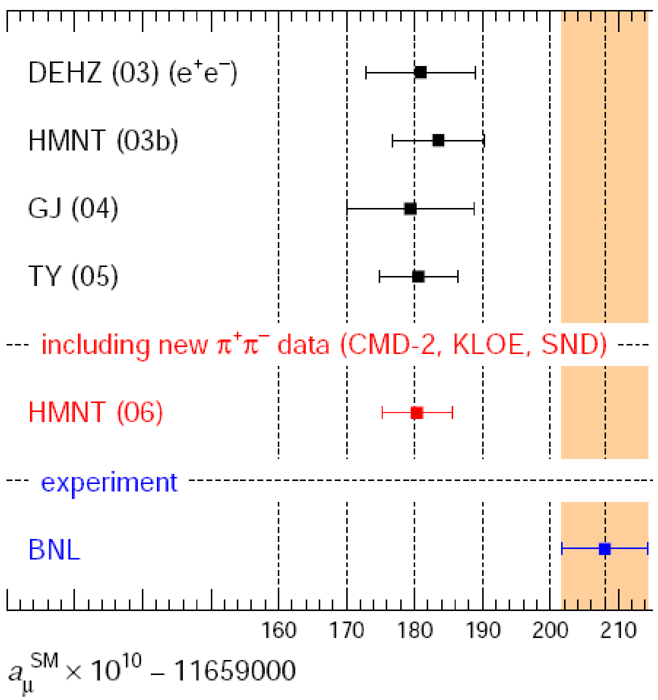
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma_{\rm point}}$$

One has to measure :

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

a_μ, T. Teubner, Liverpool

a_μ^{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]:

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

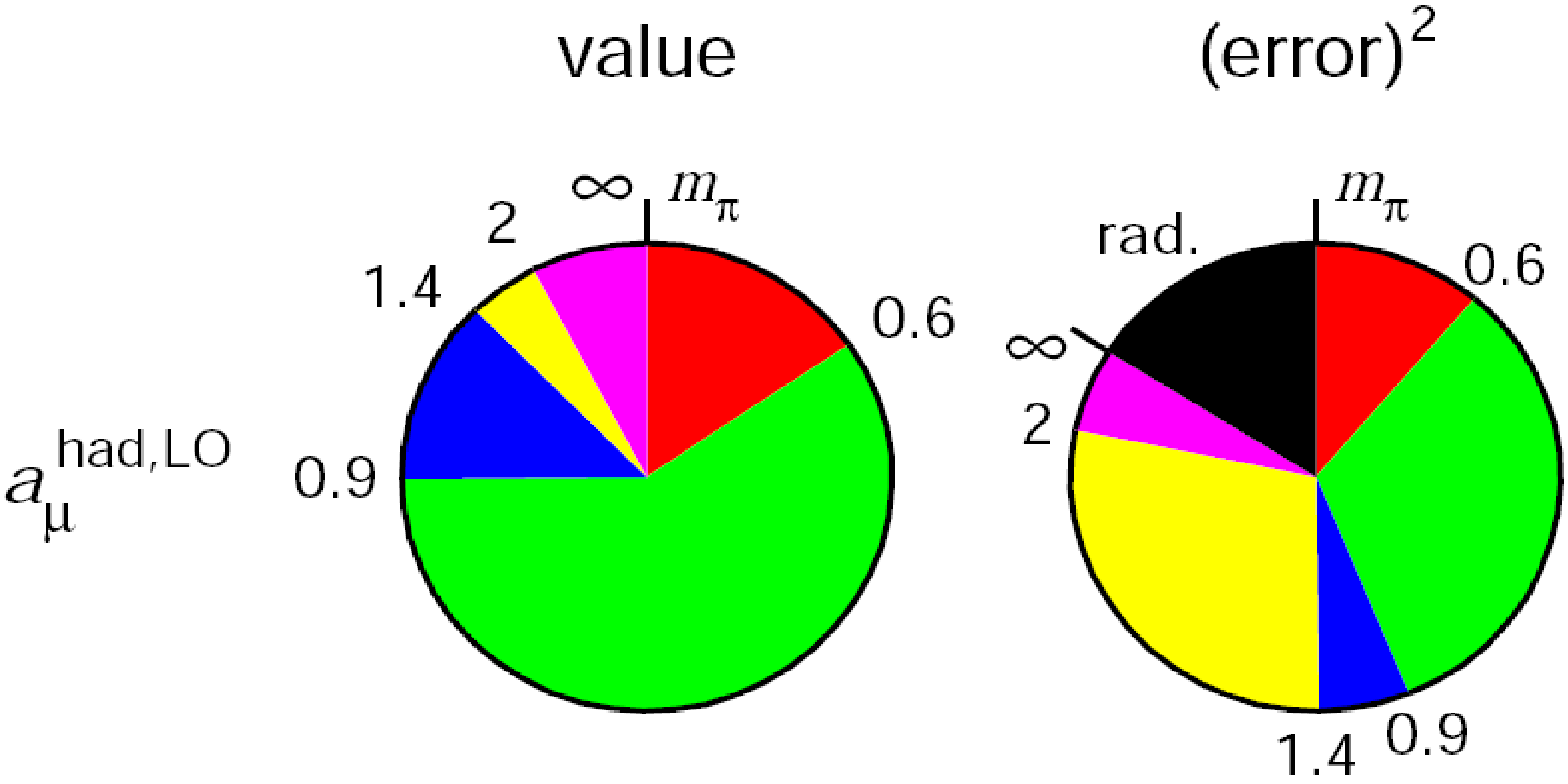
$\longrightarrow a_\mu = 116\,592\,080(63) \times 10^{-11}$ $(0.5ppm)$

▶ With this input HMNT get:

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

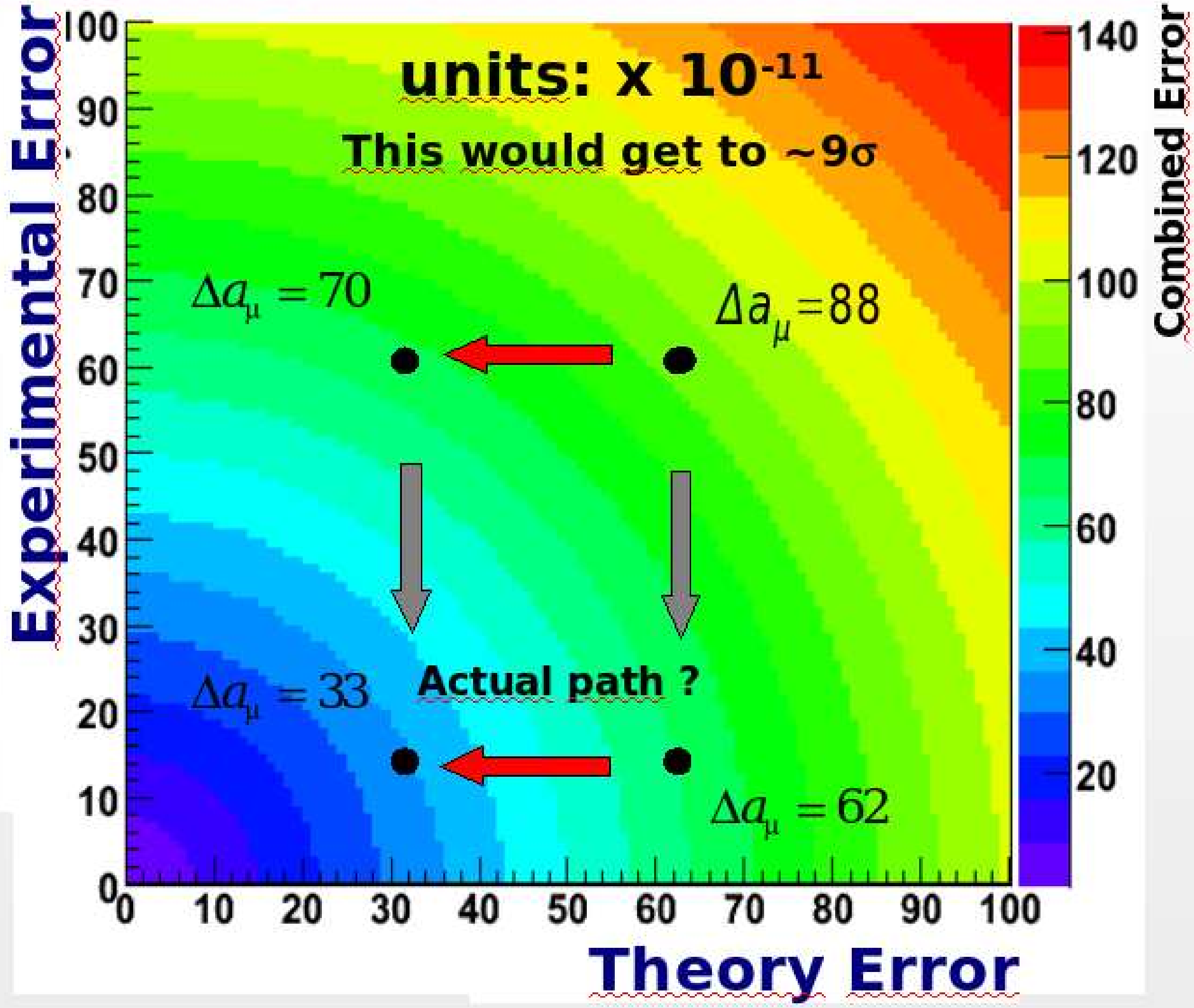
.. Discrepancy increased .. still not fully conclusive .. constrain SUSY ..

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

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

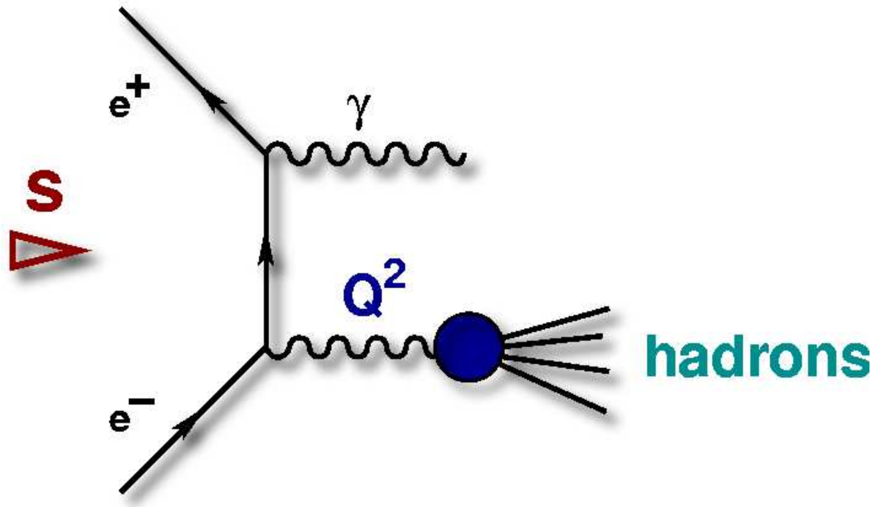
- Wait for final results and contributions of multi-hadronic modes

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

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.]

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

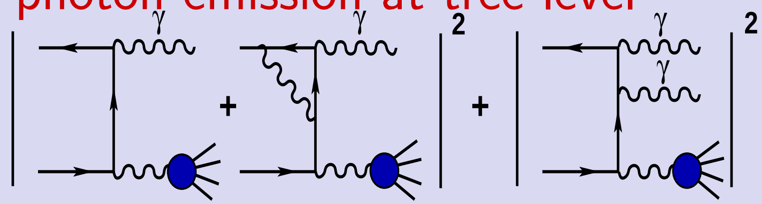
- ISR at LO + Structure Function

[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/

From EVA to ...

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

- ISR at LO + Structure Function

[Czyż, Kühn]

→

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

- upgraded by BaBar - not public (?)
- PHOTOS [Barberio et al.] for FSR

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.]

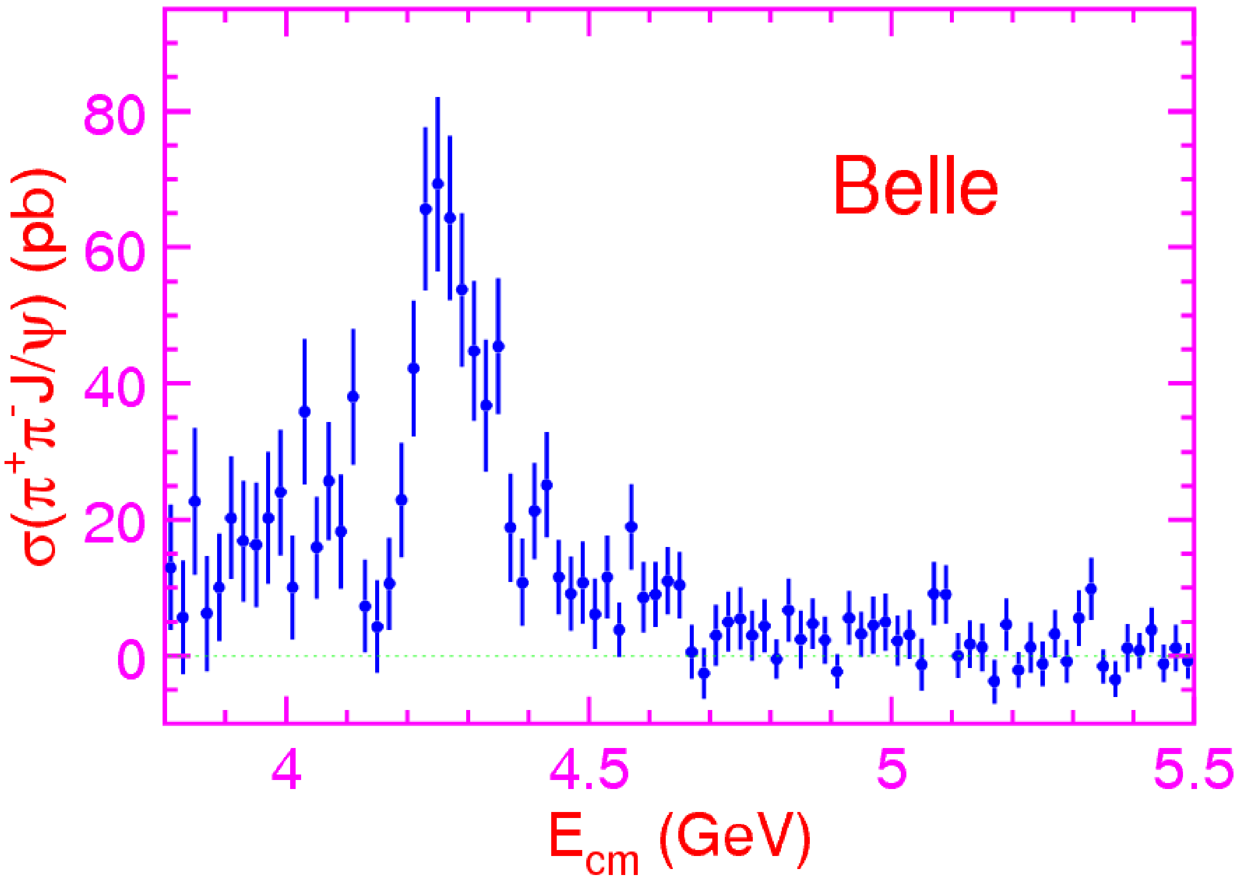
→

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

- FSR studies

[Pancheri,Shekhovtsova,Venanzoni]

Y(4260) via radiative return



BELLE: Phys.Rev.Lett.99:182004,2007.

Status of PHOKHARA

in collaboration with

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

4π revisited

- experimental situation: τ vs. e^+e^- data
- new model predictions

Narrow resonances - FSR

Conclusions

Isospin relations: 4π

$$\langle \pi^+ \pi^- \pi_1^0 \pi_2^0 | J_\mu^3 | 0 \rangle = J_\mu(p_1, p_2, p^+, p^-)$$

$$\langle \pi_1^+ \pi_2^+ \pi_1^- \pi_2^- | J_\mu^3 | 0 \rangle =$$
$$J_\mu(p_2^+, p_2^-, p_1^+, p_1^-) \quad + J_\mu(p_1^+, p_2^-, p_2^+, p_1^-)$$
$$+ J_\mu(p_2^+, p_1^-, p_1^+, p_2^-) \quad + J_\mu(p_1^+, p_1^-, p_2^+, p_2^-)$$

$$\langle \pi^- \pi_1^0 \pi_2^0 \pi_3^0 | J_\mu^- | 0 \rangle =$$
$$J_\mu(p_2, p_3, p^-, p_1) + J_\mu(p_1, p_3, p^-, p_2) + J_\mu(p_1, p_2, p^-, p_3)$$

$$\langle \pi_1^- \pi_2^- \pi^+ \pi^0 | J_\mu^- | 0 \rangle =$$
$$J_\mu(p^+, p_2, p_1, p^0) \quad + J_\mu(p^+, p_1, p_2, p^0)$$

J. H. Kühn (1999)

Isospin relations: 4π

$$\int J_\mu^{em} (J_\nu^{em})^* \; d\bar{\Phi}_n(Q; q_1, \ldots, q_n)$$
$$= \frac{1}{6\pi} \left(Q_\mu Q_\nu - g_{\mu\nu} Q^2 \right) \; R(Q^2)$$

$$R(Q^2) = \sigma(e^+e^- \to hadrons)(Q^2)/\sigma_{point}$$

Isospin relations: 4π

$$\frac{d\Gamma_{\tau\to\nu+hadrons}}{dQ^2}$$

$$= 2\;\Gamma_e\frac{|V_{ud}|^2 S_{EW}}{m_\tau^2}\left(1-\frac{Q^2}{m_\tau^2}\right)^2\left(1+2\frac{Q^2}{m_\tau^2}\right)R^\tau\left(Q^2\right)$$

$$\int\; J^-_\mu J^{-\,*}_\nu\;\; d\bar{\Phi}_n(Q;q_1,\ldots,q_n) =$$

$$\frac{1}{3\pi}\left(Q_\mu Q_\nu - g_{\mu\nu}Q^2\right)\;R^\tau(Q^2)$$

Isospin relations: 4π

$$R^{\tau}(-\;0\;0\;0) = \frac{1}{2}\,R(+\;+\;-\;-)$$

$$R^{\tau}(-\;-\;+\;0) = \frac{1}{2}\,R(+\;+\;-\;-) + R(+\;-\;0\;0)$$

Isospin relations: 4π; exp. situation

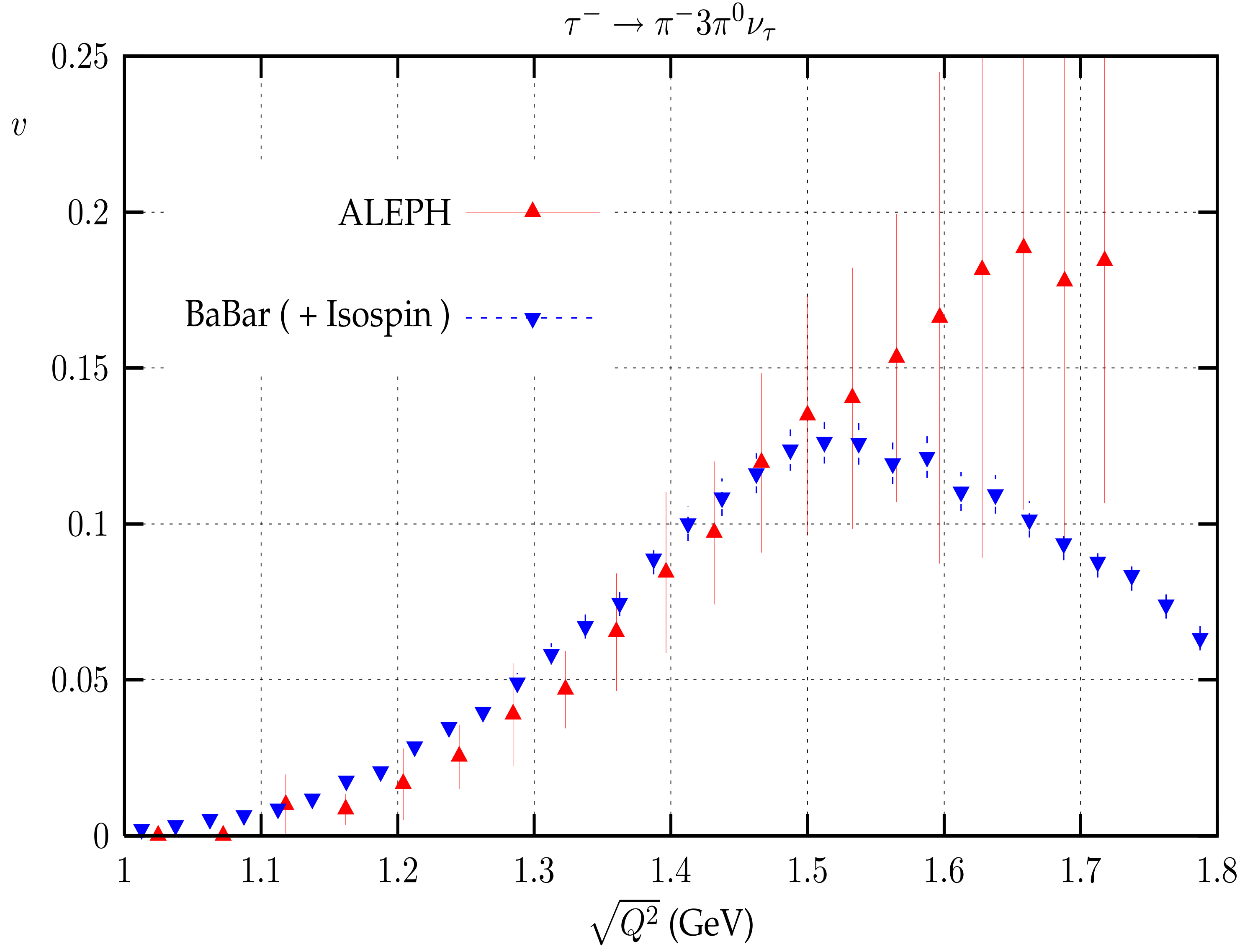
$e^+e^- \to 2\pi^+2\pi^-$: BaBar, CMD2, SND

$e^+e^- \to 2\pi^0\pi^+\pi^-$: BaBar(preliminary), CMD2, SND

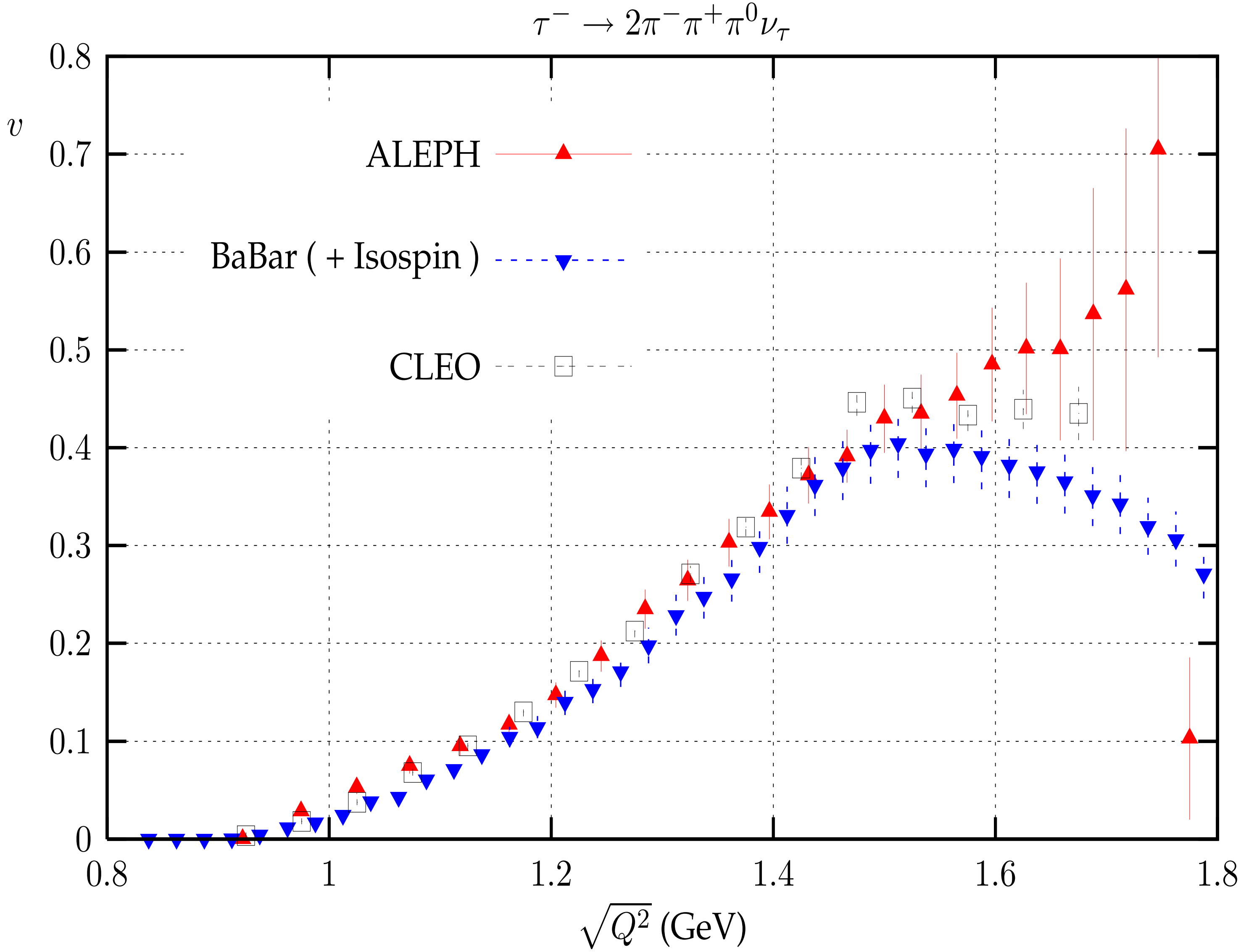
$\tau^- \to \nu 3\pi^0\pi^-$: ALEPH

$\tau^- \to \nu 2\pi^-\pi^+\pi^0$: ALEPH, CLEO

Isospin relations: 4π; exp. situation



Isospin relations: 4π; exp. situation

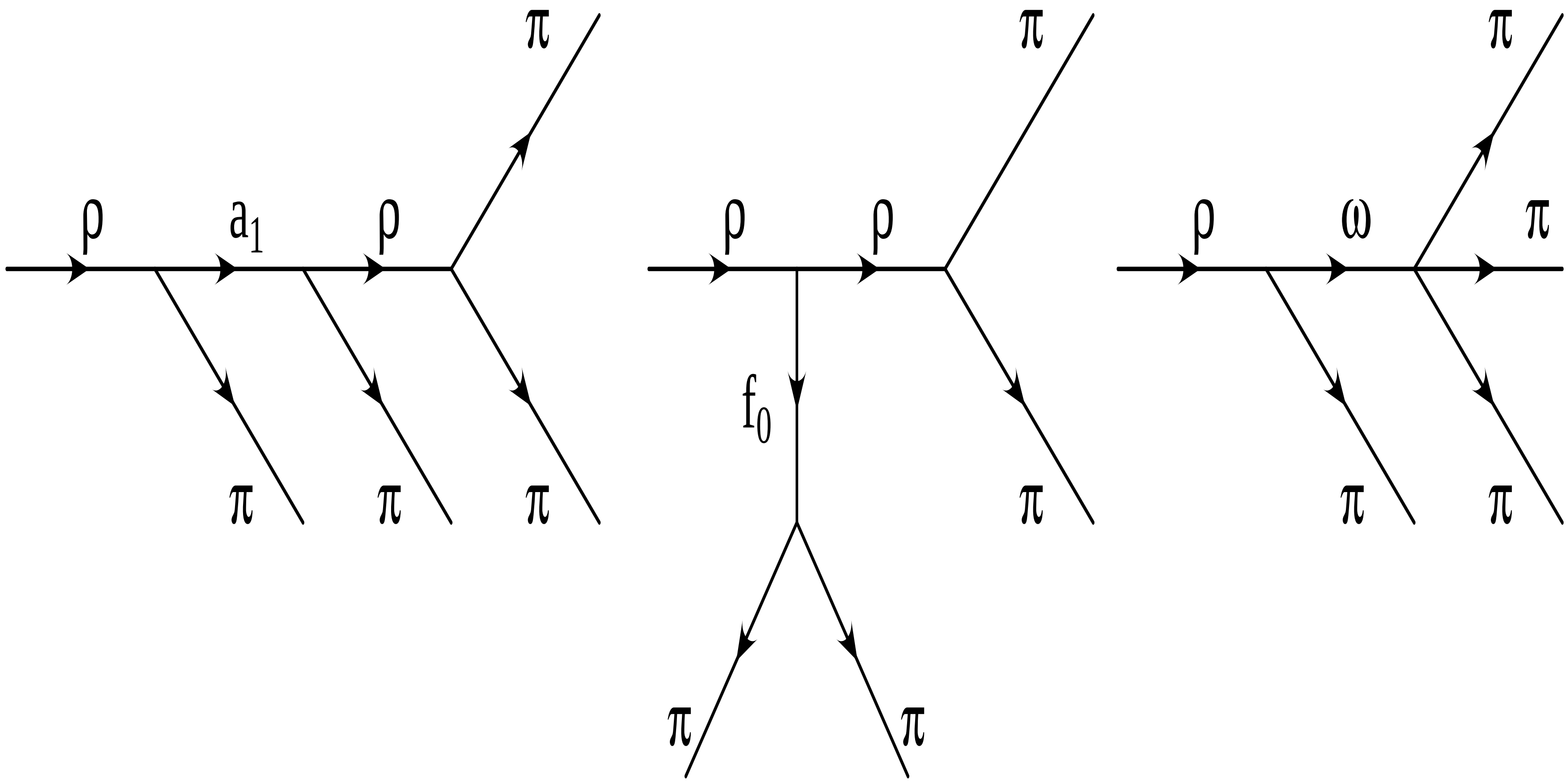


4π: exp. situation

- $\pi\omega(\to \pi^+\pi^-\pi^0)$: CLEO, BaBar(prel.)

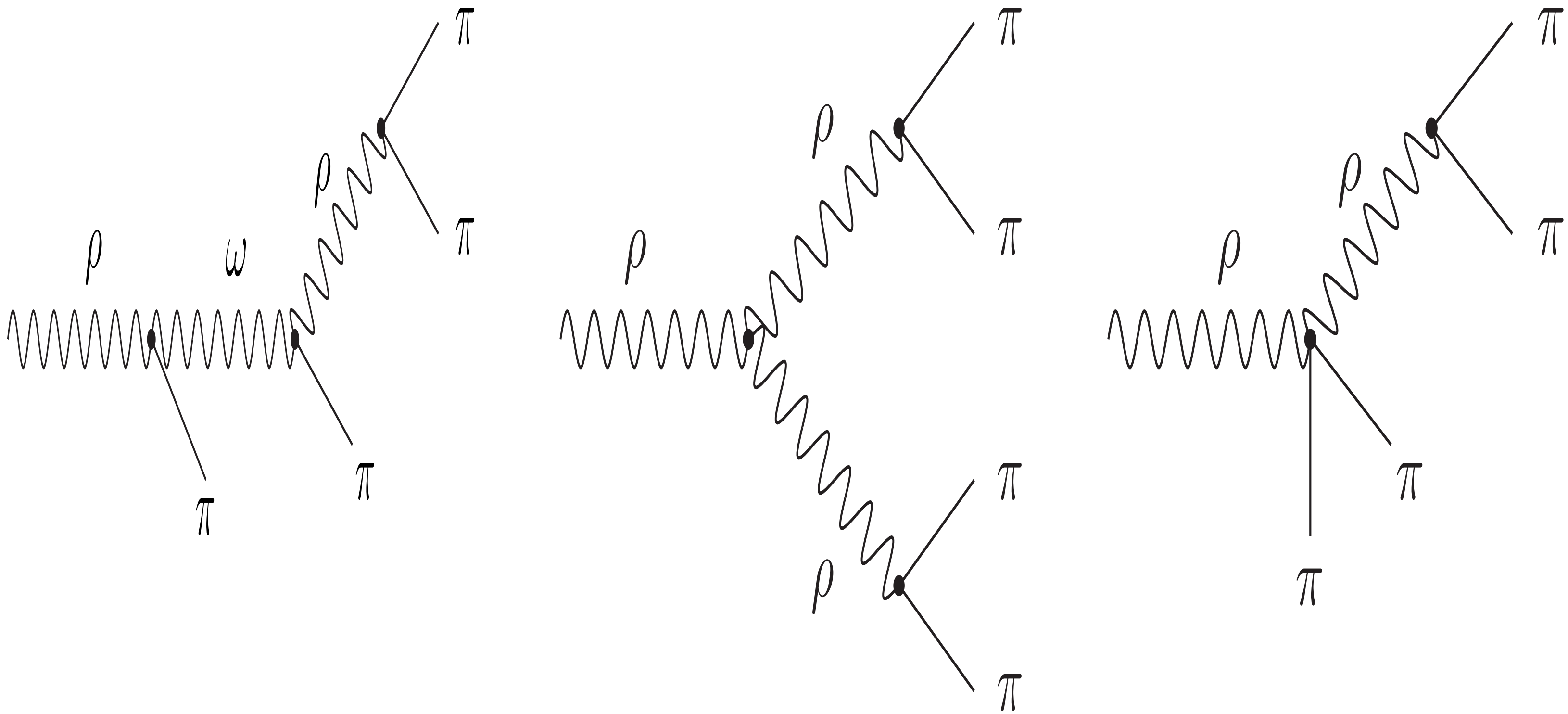
- $\rho \to \rho(\to \pi\pi)\rho(\to \pi\pi)$: BaBar(prel.)

The model



H.C., J.H. Kühn (2000)

The model



H.C., J.H. Kühn, A. Wapienik (2008)

H.C., A. Grzelińska, J.H. Kühn, G. Rodrigo(2006)

The model

$$\mathcal{L}_\rho = \frac{1}{4}\vec{F}_{\mu\nu} \cdot \vec{F}^{\mu\nu} + \frac{1}{2}(\overrightarrow{D^\mu\phi}) \cdot (\overrightarrow{D_\mu\phi})$$

$$+ \frac{1}{2}m_\pi^2\vec{\phi} \cdot \vec{\phi} + \frac{1}{2}m_\rho^2\vec{\rho}_\mu \cdot \vec{\rho}^\mu$$

$$\overrightarrow{D_\mu\phi} = \partial_\mu\vec{\phi} + g\left(\vec{\rho}_\mu \times \vec{\phi}\right)$$

$$\vec{F}_{\mu\nu} = \partial_\mu\vec{\rho}_\nu - \partial_\nu\vec{\rho}_\mu - g\,\vec{\rho}_\mu \times \vec{\rho}_\nu$$

The fit

$$m_{\rho'}, m_{\rho''}, m_{\rho'''}, \Gamma_{\rho'}, \Gamma_{\rho''}, \Gamma_{\rho'''}$$

4 couplings in a_1- part

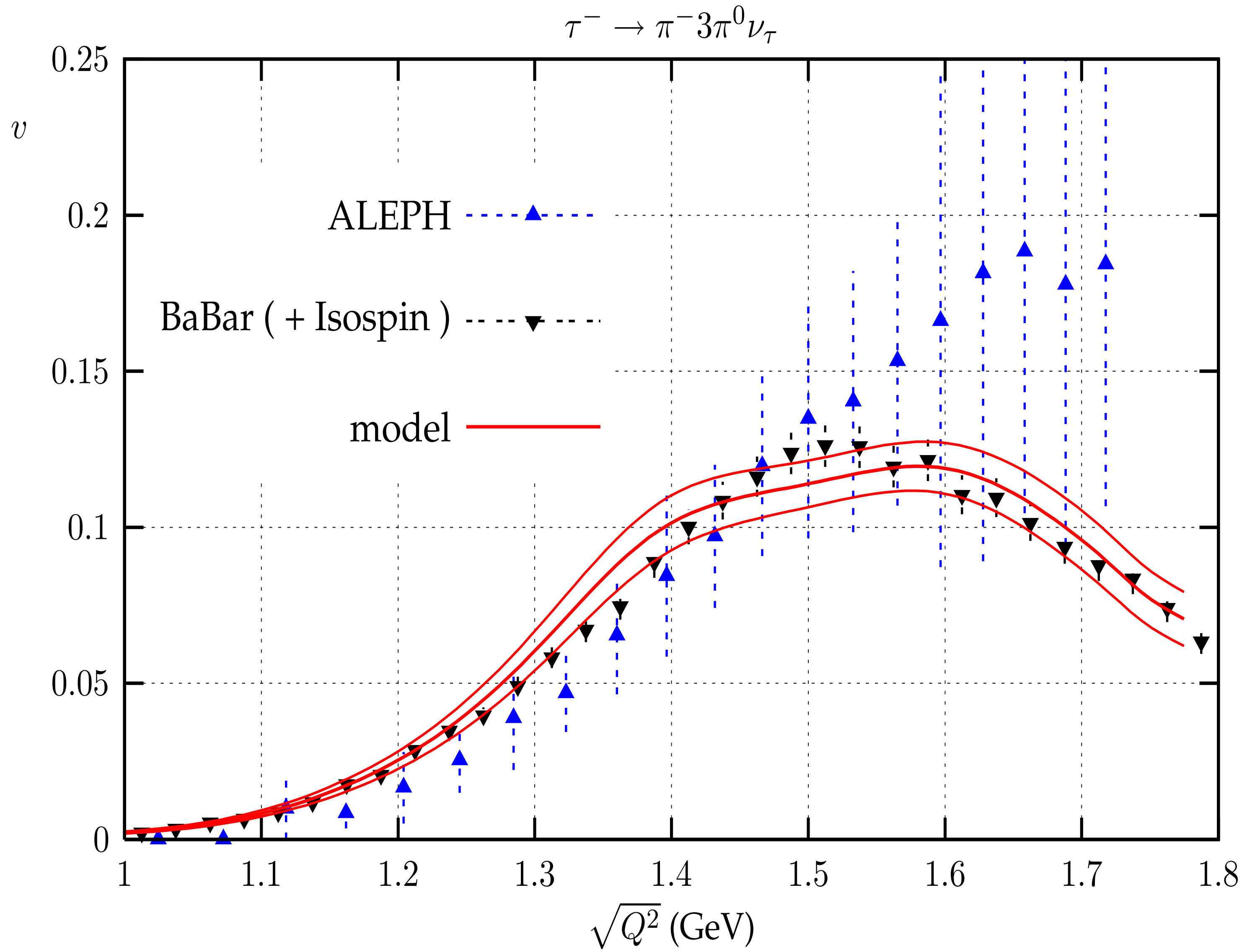
4 couplings in f_0- part

4 couplings in ω- part

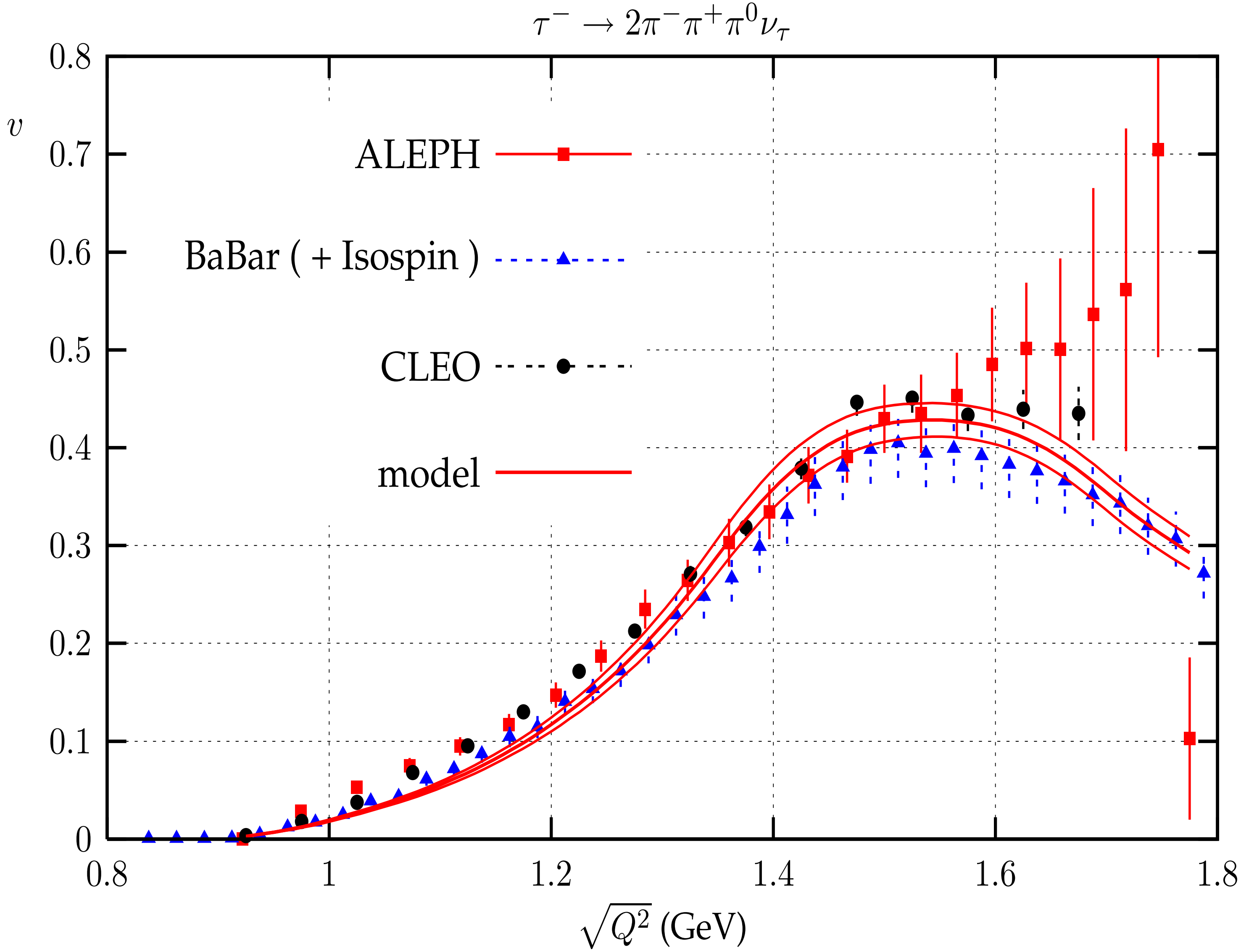
1 coupling in ρ- part

$$\chi^2 = 275 \;, \quad n_{d.o.f} = 287$$

Comparing with τ data



Comparing with τ data



Comparing with τ data

	$\mathrm{Br}(\tau- \to \nu_\tau 2\pi^-\pi^+\pi^0)$
PDG06	$(4.46\pm 0.06)\%$
model	$(4.12 \pm 0.21)\%$
BaBar (CVC)	$(3.98 \pm 0.30)\%$

	$\mathrm{Br}(\tau- \to \nu_\tau \pi^-\omega(\pi^-\pi^+\pi^0))$
PDG06	$(1.77\pm 0.1)\%$
model	$(1.60 \pm 0.13)\%$
BaBar (CVC)	$(1.57 \pm 0.31)\%$

Comparing with τ data

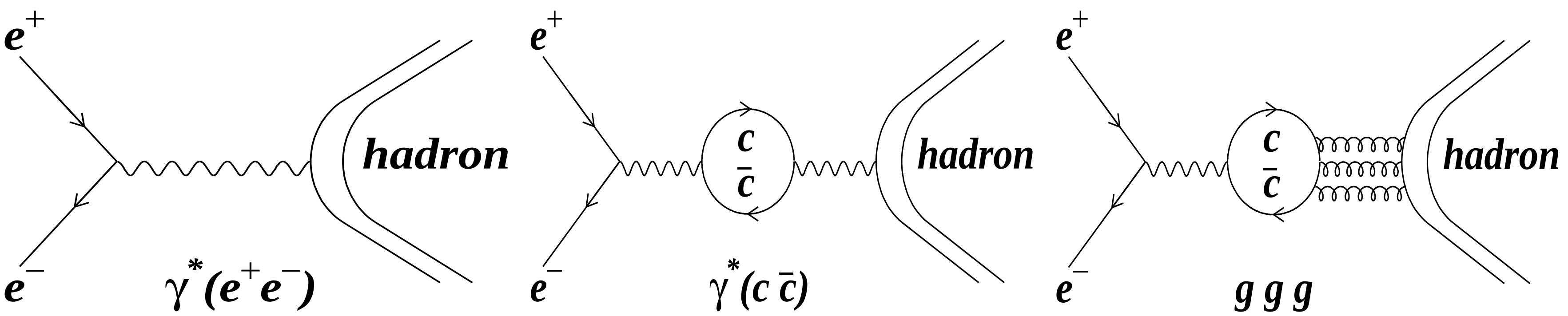
	$\mathrm{Br}(\tau- \to \nu_\tau \pi^- 3\pi^0)$
PDG06	$(1.04 \pm 0.08)\%$
model	$(1.06 \pm 0.09)\%$
BaBar (CVC)	$(1.02 \pm 0.05)\%$

Narrow Resonances

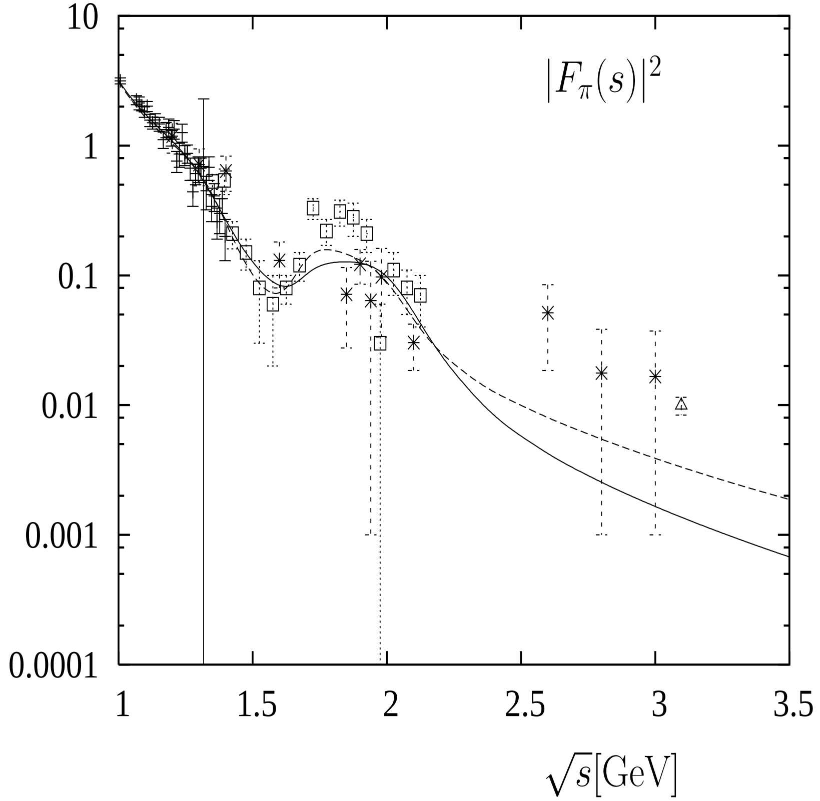
$$e^+e^- \to J/\psi\ (\psi(2S))\gamma \to \pi^+\pi^-, \mu^+\mu^-, KK + \gamma(\gamma)$$

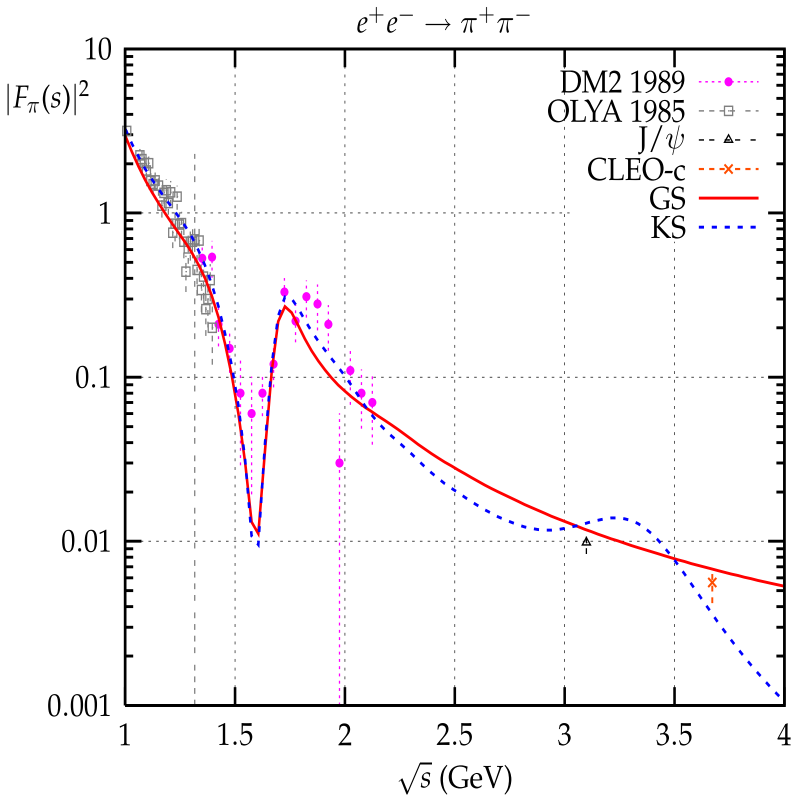
$$J/\psi \quad \to \quad M_{J/\psi} = 3096.916\ \text{MeV}, \quad \Gamma_{J/\psi} = 93.4\ \text{keV}$$

$$\psi(2S) \quad \to \quad M_{\psi(2S)} = 3686.093\ \text{MeV}, \quad \Gamma_{\psi(2S)} = 337\ \text{keV}$$



Pion form factor

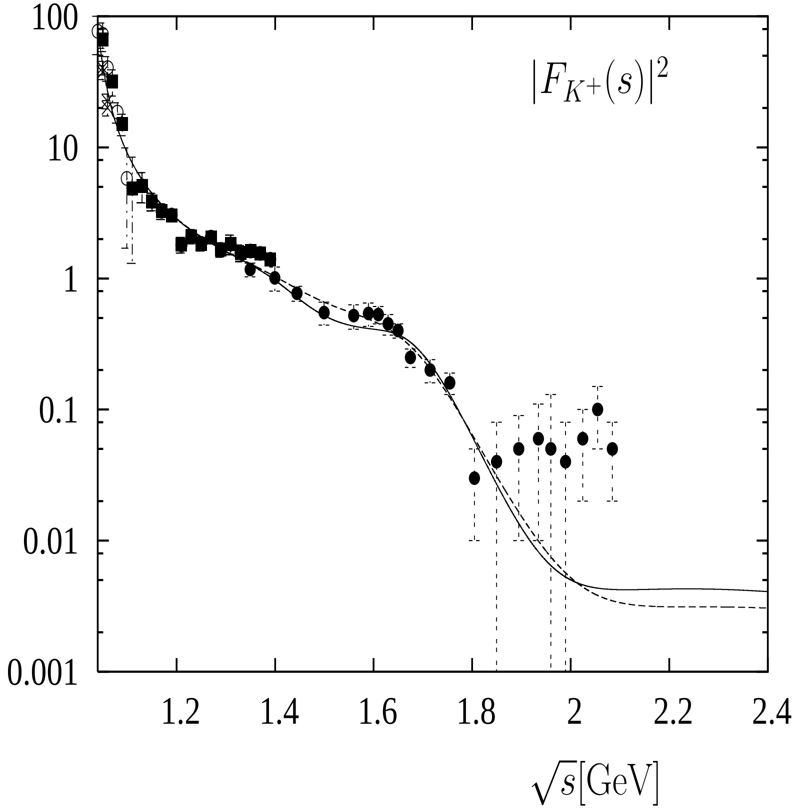


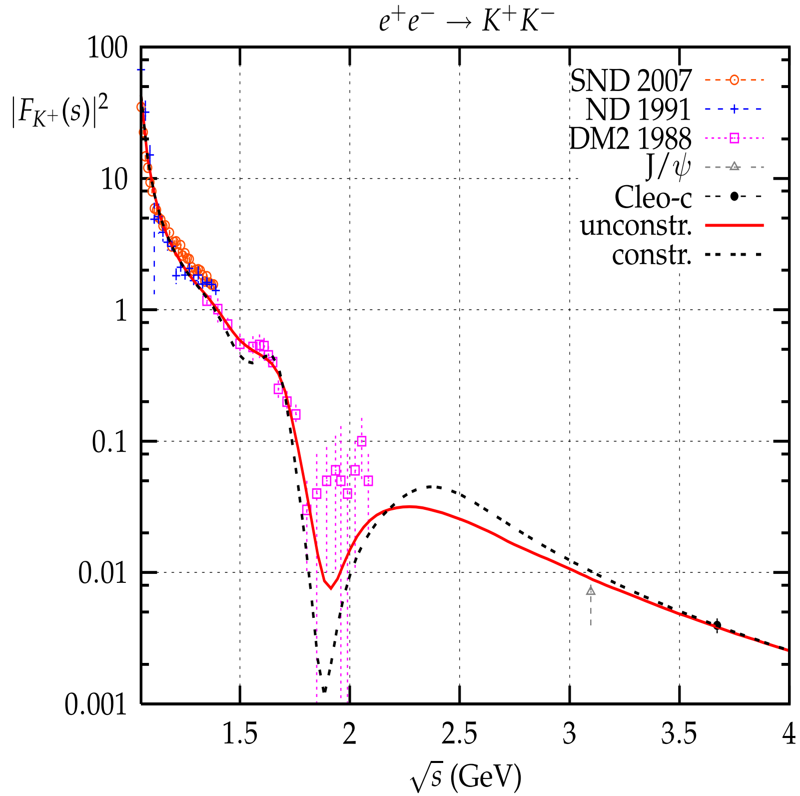


C. Bruch, A. Khodjamirian and J.H. Kühn, Eur. Phys. J. C39(2005)41

H. C., A. Grzelińska, E. Nowak-Kubat and J.H. Kühn, in preparation

Kaon form factor



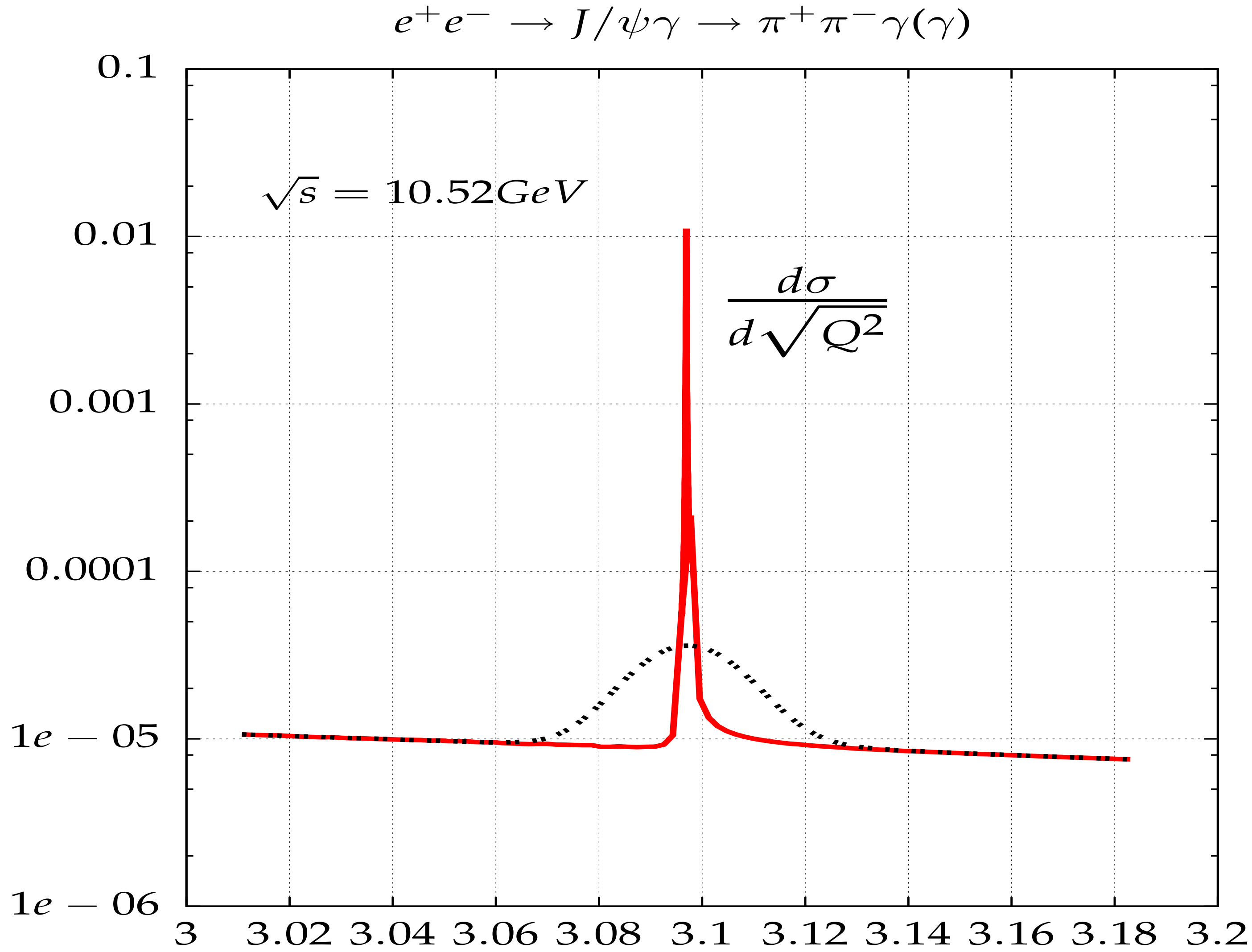


C. Bruch, A. Khodjamirian and J.H. Kühn, Eur. Phys. J. C39(2005)41

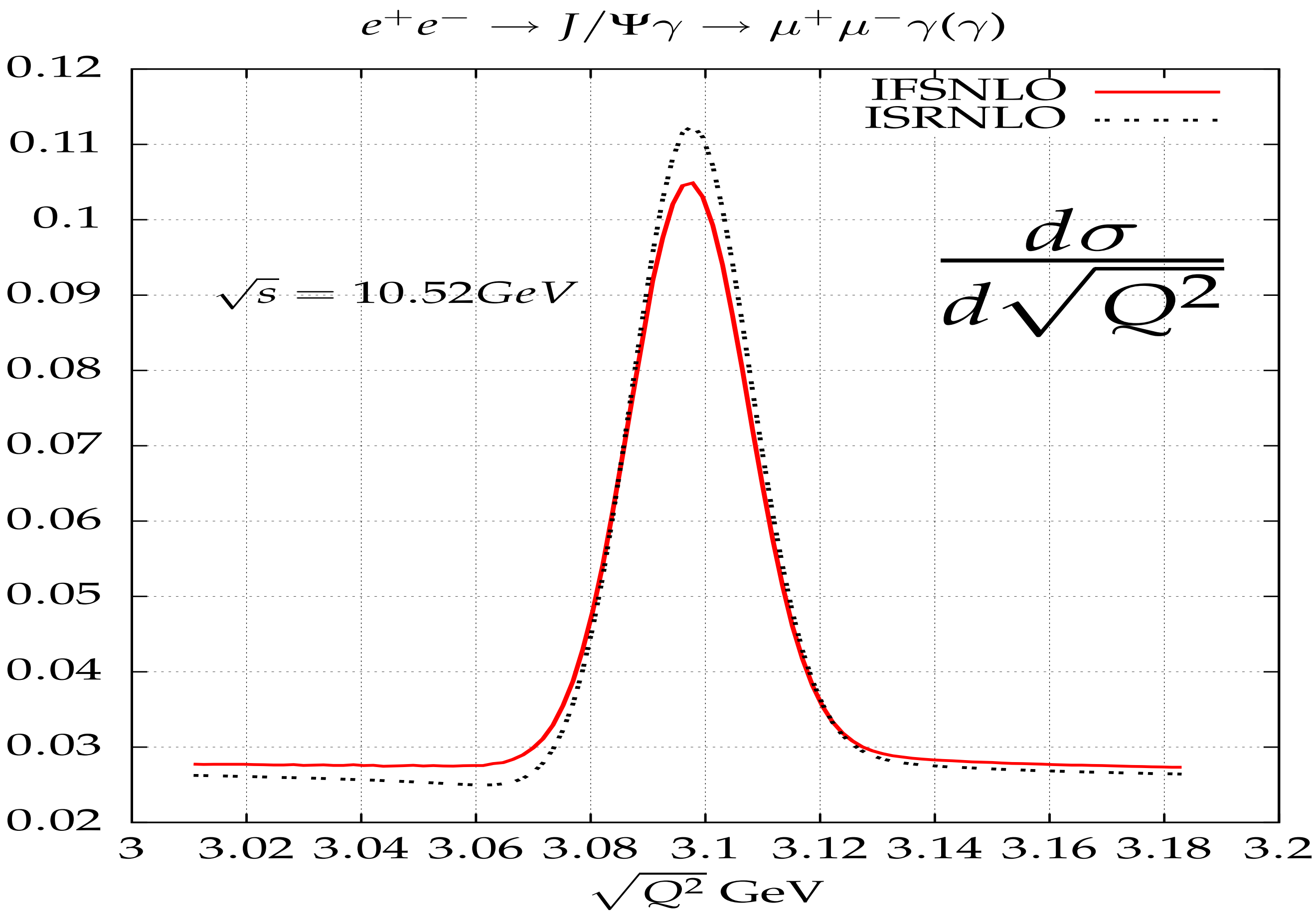
H. C., A. Grzelińska, E. Nowak-Kubat and J.H. Kühn, in preparation

Energy resolution

$\Delta q = 14.5$ MeV



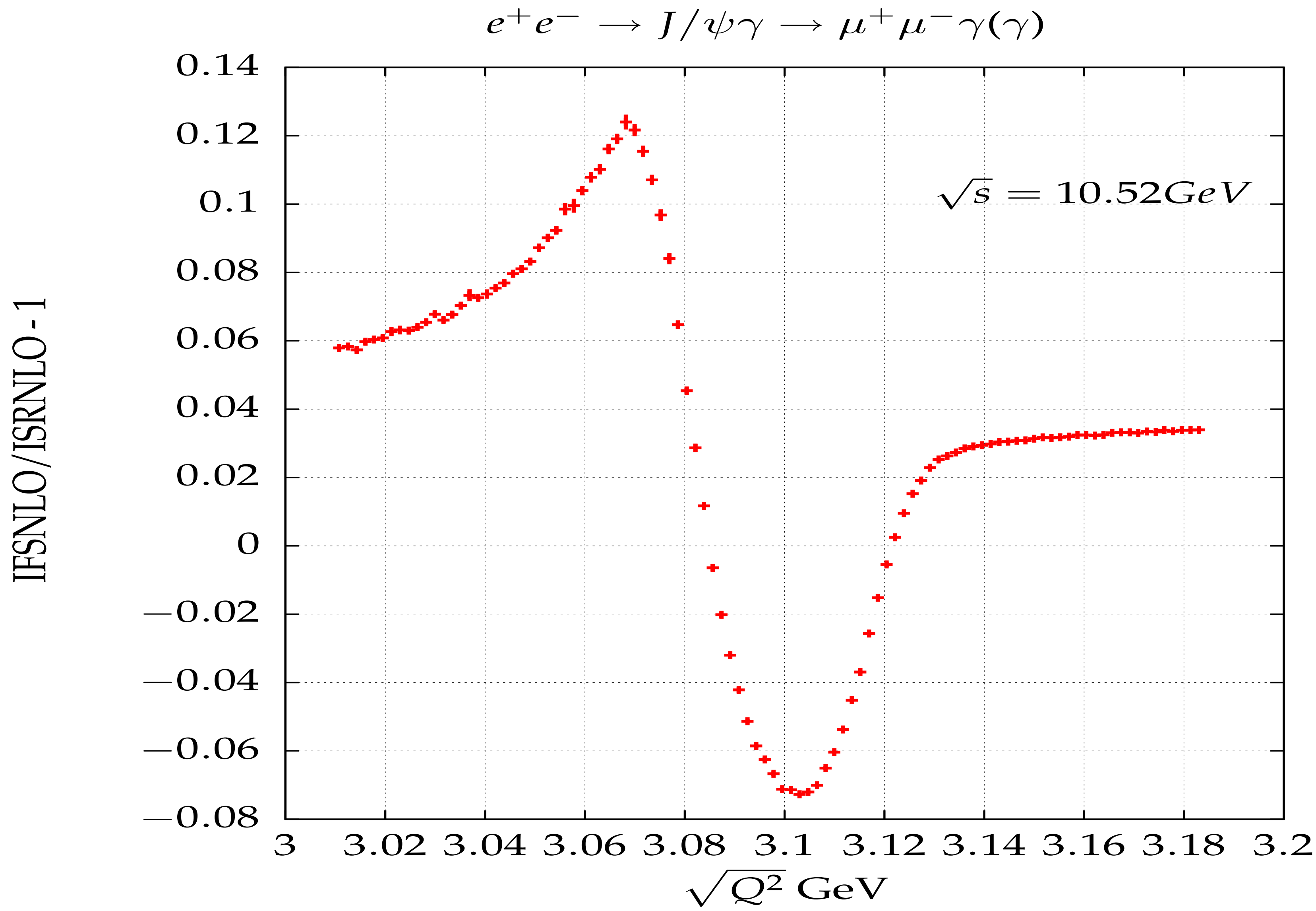
FSR - muons



$\sigma(IFSNLO) = (\ 6.8527 \pm 0.0006\ )$ pb

$\sigma(ISRNLO) = (\ 6.79862 \pm 0.00008\ )$ pb

FSR - muons



$e^+e^- \longrightarrow J/\psi\gamma \longrightarrow \mu^+\mu^-\gamma(\gamma)$
$\sqrt{s} = 10.52 GeV$
IFSNLO/ISRNLO - 1
$\sqrt{Q^2}$ GeV
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
3
3.02
3.04
3.06
3.08
3.1
3.12
3.14
3.16
3.18
3.2

Summary and plans

- 4π channels reanalysis was performed
  - isospin symmetry violation not seen
  - new model proposed and implemented in PHOKHARA

Summary and plans

- soon J/ψ and $\psi(2S)$ in PHOKHARA
  - with FSR corrections included

- PHOKHARA: ISR accuracy 0.5%
  - need for ISR accuracy ∼0.2%