ECT*

EUROPEAN CENTRE FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS
TRENTO, ITALY

Hadronic contribution to the muon anomalous magnetic moment

G. Venanzoni LNF/INFN

LC13: Exploring QCD from the infrared regime to heavy flavour scales at B-factories, the LHC and a Linear Collider

Trento 16-20 September 2013

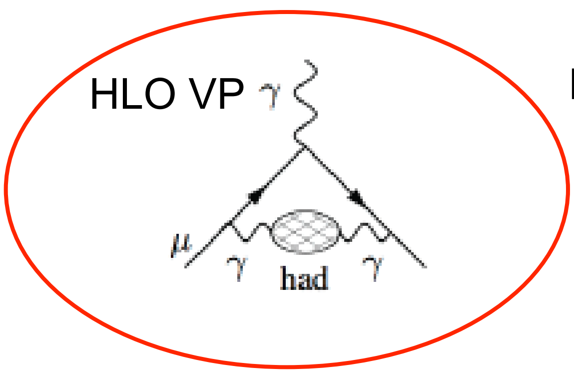
Muon anomaly

$$a_\mu = \frac{(g_\mu - 2)}{2}$$

- Long established discrepancy (>3σ) between SM prediction and BNL E821 exp.

- Theoretical error δa_μ^{SM} (~6×10^{-10}) dominated by HLO VP ($4\div5\times10^{-10}$) and HLbL ($[2.5\div4]\times10^{-10}$). A **twofold** improvement on δa_μ^{SM} from 2001 (thanks to new e^+e^- measurements)!

- Experimental error δa_μ^{EXP} ~6 $\times10^{-10}$ (E821). Plan to reduce it to 1.5 10^{-10} by the new g-2 experiments at FNAL and J-PARC.



See Nyffeler's talk

$a_\mu^{HLO} = (690.9\pm\mathbf{4.4})10^{-10}$ [Eidelman, TAU08]

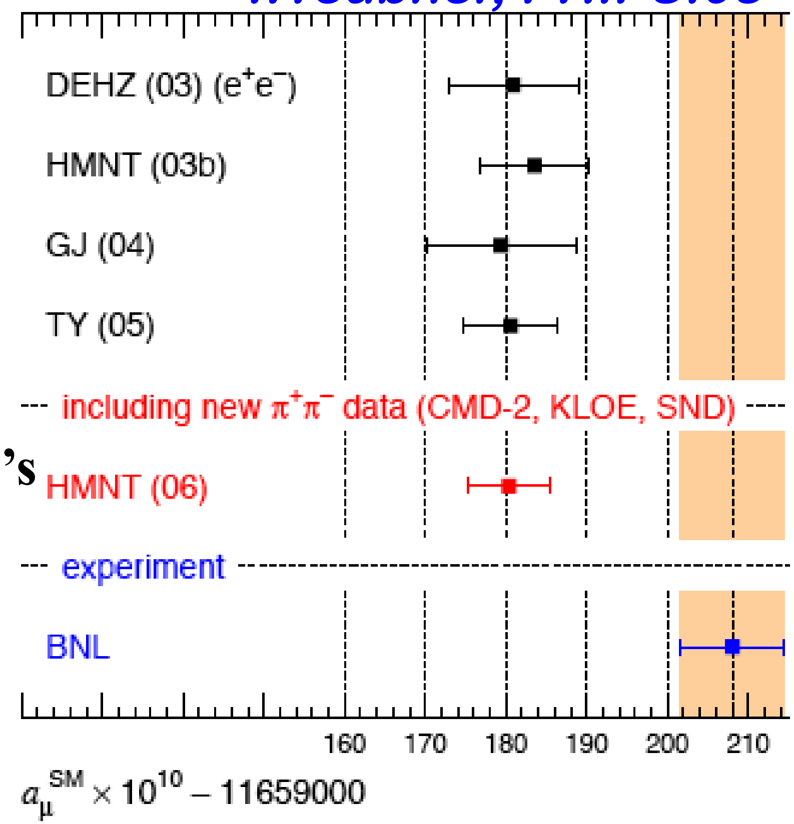
$a_\mu^{HLbL} = (10.5\pm2.6)10^{-10}$ [Prades, dR&V. 08]
$(11 \pm 4)10^{-10}$ (Jegerlehner, Nyffler)

δa_μ^{HLO} ~0.7%

δa_μ^{HLbL} ~25-40%

a_μ^{SM} compared to BNL world av.

T.Teubner, PHIPSI08

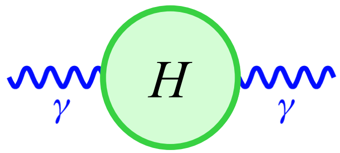


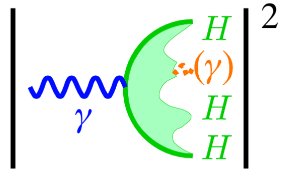
$$a_\mu^{EXP} - a_\mu^{TH} = (27.6 \pm 8.1)\cdot 10^{-10}, \ \sim 3.4\sigma$$

In 2001 $a_\mu^{EXP} - a_\mu^{TH} = (23\pm16)\cdot10^{-10}$

a_μ^{HLO}:

L.O. Hadronic contribution to a_μ can be estimated by means of a dispersion integral:





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

$1\,/\,s^2$ makes low energy contributions especially important:

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

in the range < 1 GeV contributes to 70% !

$$R(s) = \frac{\sigma_{tot}(e^+e^- \rightarrow \gamma^* \rightarrow q\,\bar{q} \rightarrow hadrons)}{\sigma_{tot}(e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-)}$$

- K(s) = analytic kernel-function
- above sufficiently high energy value, typically 2…5 GeV, use *pQCD*

Input:

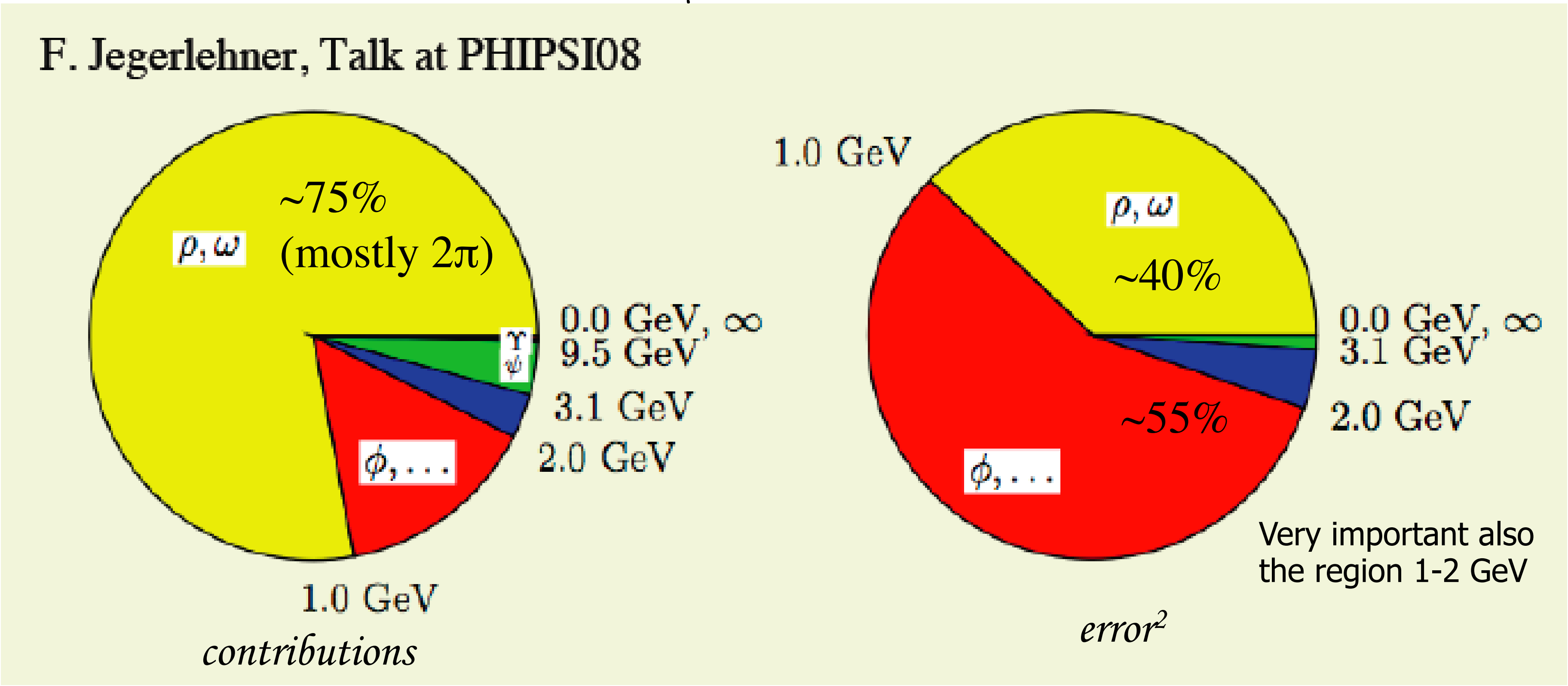
a) hadronic electron-positron cross section data (G.dR 69, E.J.95, A.D.H.'97,….)

b) hadronic τ- decays, which can be used with the help of the CVC-theorem and an isospin rotation (plus isospin breaking corrections) (A., D., H. '97)

Dispersion Integral: $a_\mu^{HLO} = \int_{4m_\pi^2}^{\infty} \sigma_{had}(s) K(s) ds$

K(s)~1/s

Contribution of different energy regions to the dispersion integral and the error to a_μ^{HLO}



Experimental errors on σ^{had} translate into theoretical uncertainty of a_μ^{had}!

→ Needs precision measurements!

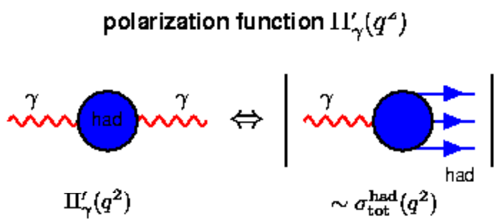
$\delta a_\mu^{exp} \rightarrow$ 1.5 10^{-10} = 0.2% on a_μ^{HLO}

New g-2 exp.

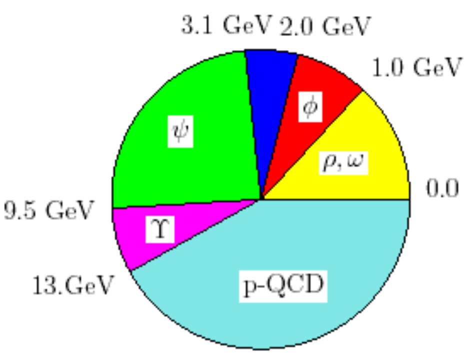
$\alpha_{em}(M_Z)$ and EW fit of the SM (M_{Higgs})

$$\alpha(M_Z) = \frac{\alpha(0)}{1-\Delta\alpha(M_Z)}$$

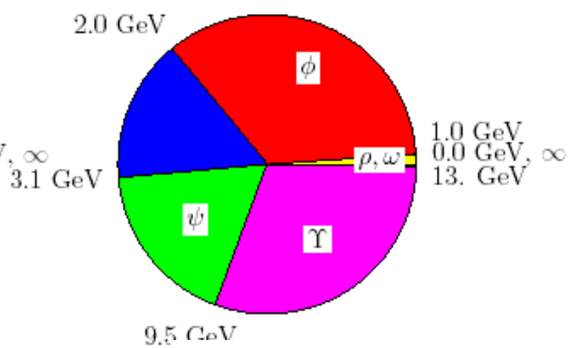
$\Delta\alpha = \Delta\alpha_l + \Delta\alpha^{(5)}_{had} + \Delta\alpha_{top}$



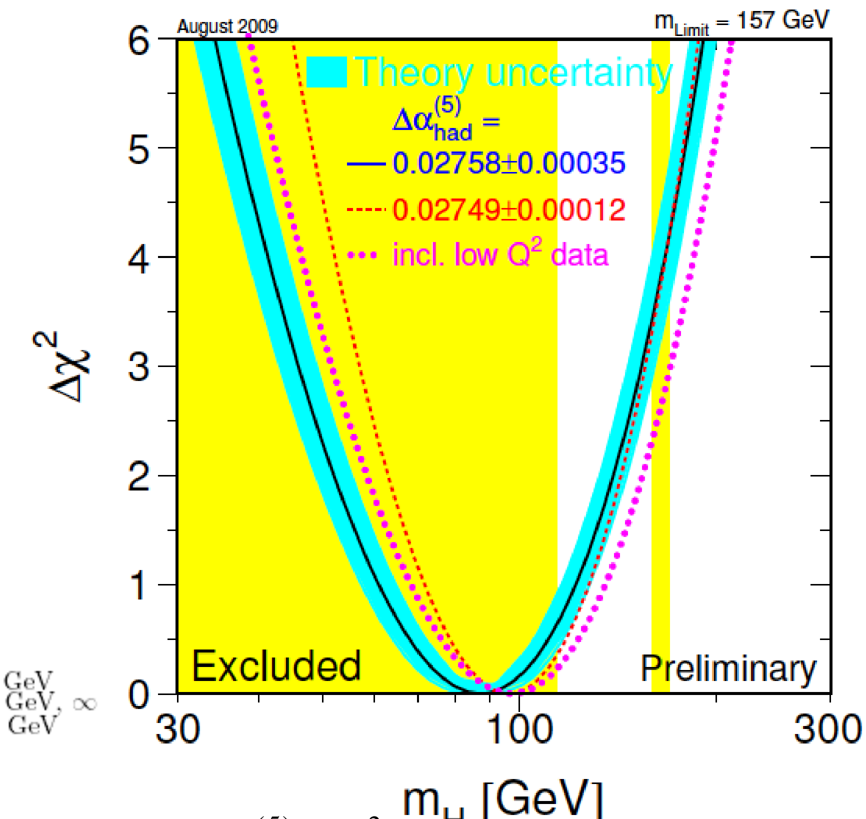
$$\Delta\alpha^{(5)}_{had}(M_Z^2) = -\frac{\alpha M_Z^2}{3\pi}\mathrm{Re}\int_{4m_\pi^2}^{\infty} ds \frac{R(s)}{s(s-M_Z^2-i\varepsilon)}$$



$\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$



$\delta^2\Delta\alpha^{(5)}_{\rm had}(M_Z^2)$



$$\Delta\alpha^{(5)}_{had}(M_Z^2) = 0.027607 \pm 0.000225$$

$$\alpha^{-1}(M_Z^2) = 128.947 \pm 0.035$$

$$\alpha^{-1}(0) = 137.0359895 \pm 0.0000061$$

FJ08

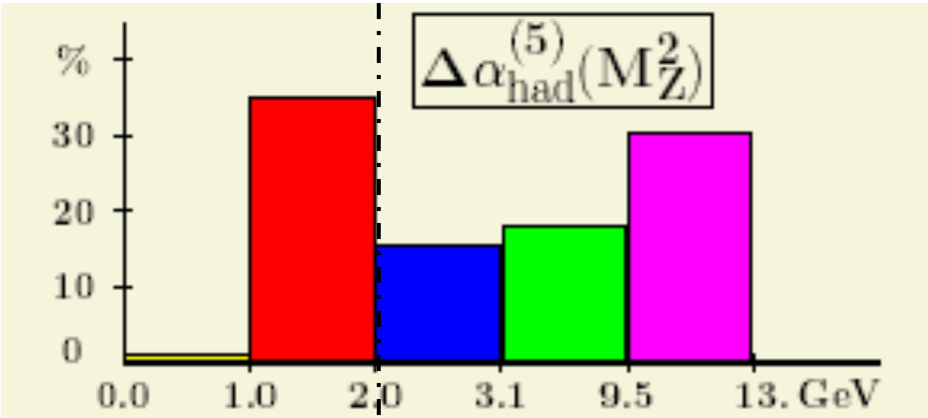
$\delta\alpha(M_Z)/\alpha(M_Z) \sim 2\times10^{-4} \rightarrow 5\times10^{-5}$

Requirement from ILC (6x improvement)

Comparison of error profiles for $\alpha_{em}(M_Z)$

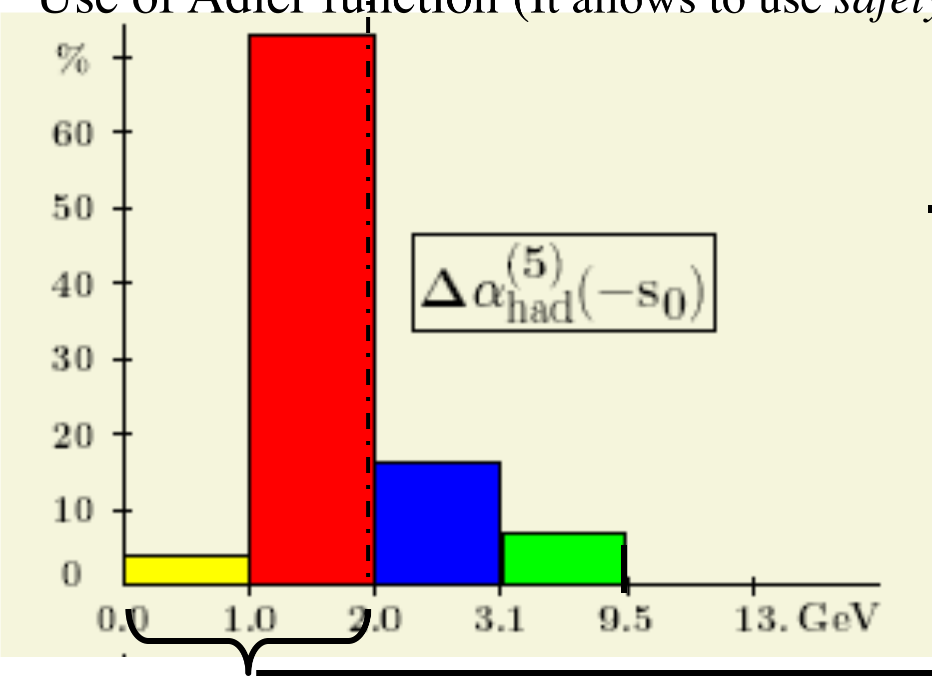
Direct integration of energy points

F. Jegerlehner, Nucl. Phys. B 181-182 (2008) 135



$\delta\sigma$ at 1% in the region **$\sqrt{s}$ < 10 GeV**
$\Rightarrow$ improvement of ~**3** in $\delta\alpha(M_Z)$

Use of Adler function (It allows to use *safely* pQCD down to 2.5 GeV)



1% in the region 1<$\sqrt{s}$ < 2.5 GeV
$\Rightarrow$ improvement of ~5 on $\delta\alpha(M_Z)$

$2m_\pi < \sqrt{s} < 2$ GeV
Extremely important:
- **80%** of $\delta\Delta\alpha^{(5)}_{had}$ (using Adler function)
- **95%** of δa_μ

Cross section data:

Two approaches:

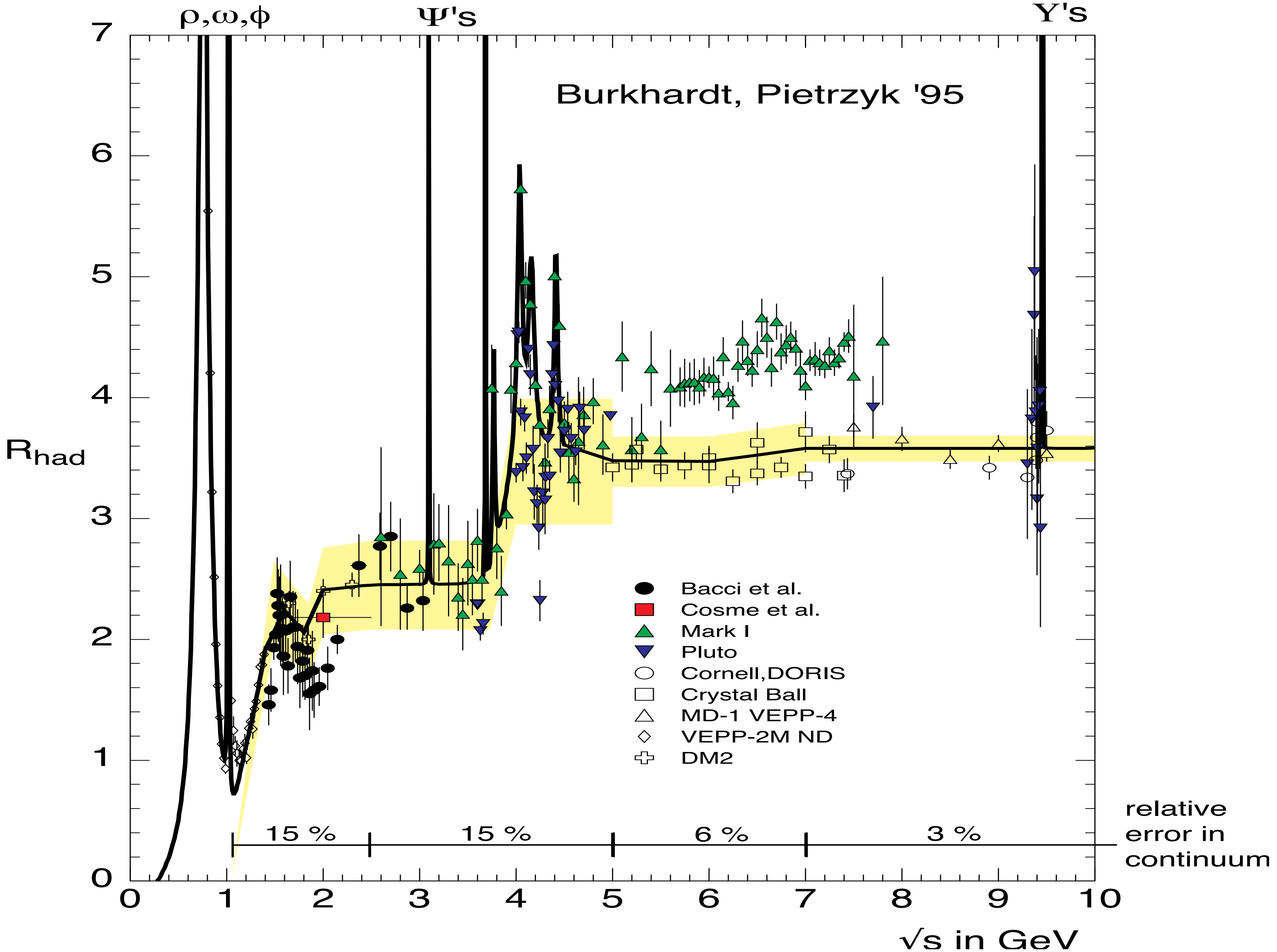
Energy scan (CMD2, SND, BES,CLEO):

- energy of colliding beams is changed to the desired value
- “direct” measurement of cross sections
- needs dedicated accelerator/physics program
- needs to measure luminosity and beam energy for every data point

Radiative return (KLOE, BABAR, BELLE,BESIII?):

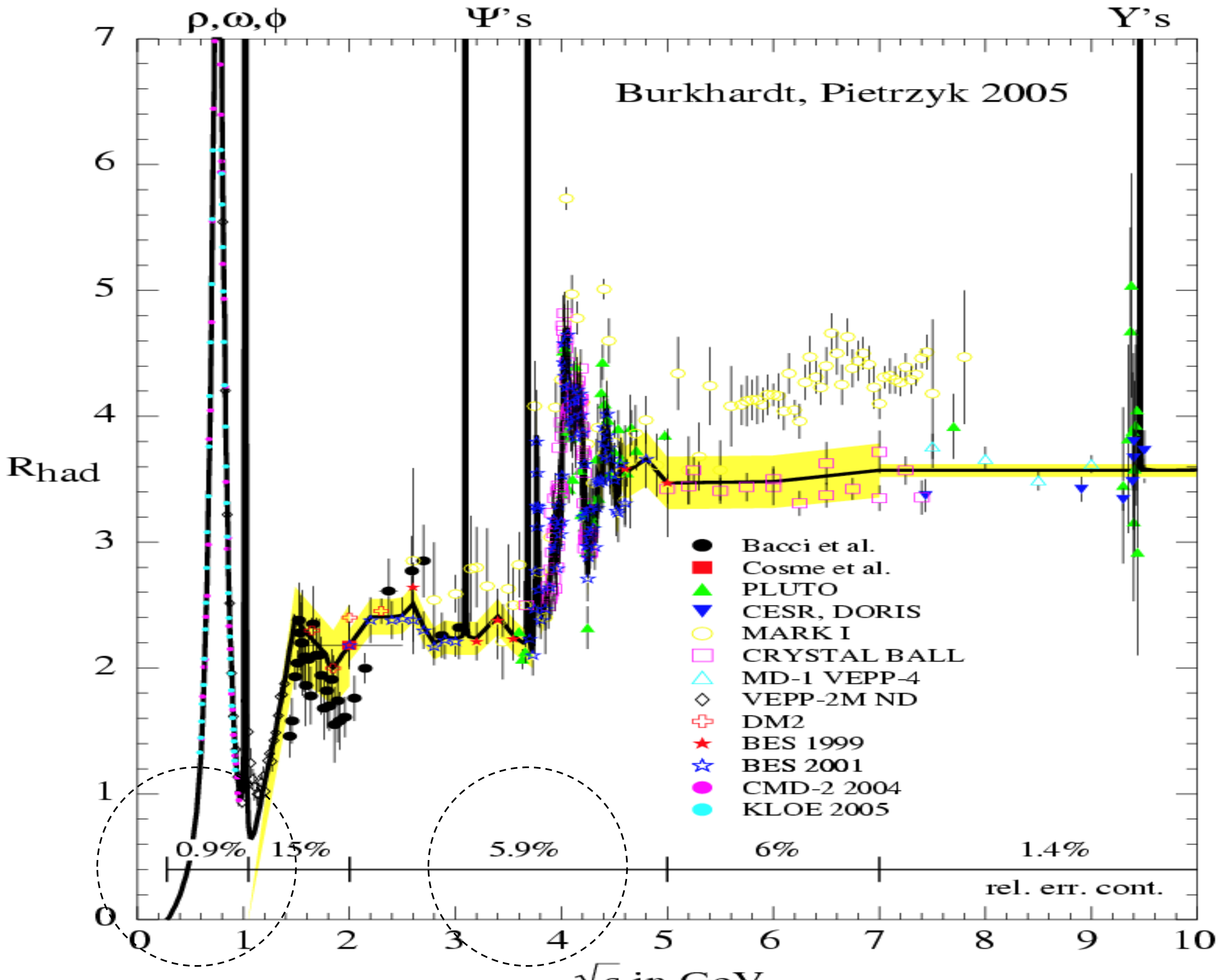
- runs at fixed-energy machines (meson factories)
- use initial state radiation process to access lower lying energies or resonances
- data come as by-product of standard physics program
- requires precise theoretical calculation of the radiator function
- luminosity and beam energy enter only once for all energy points
- needs larger integrated luminosity

Data at '95



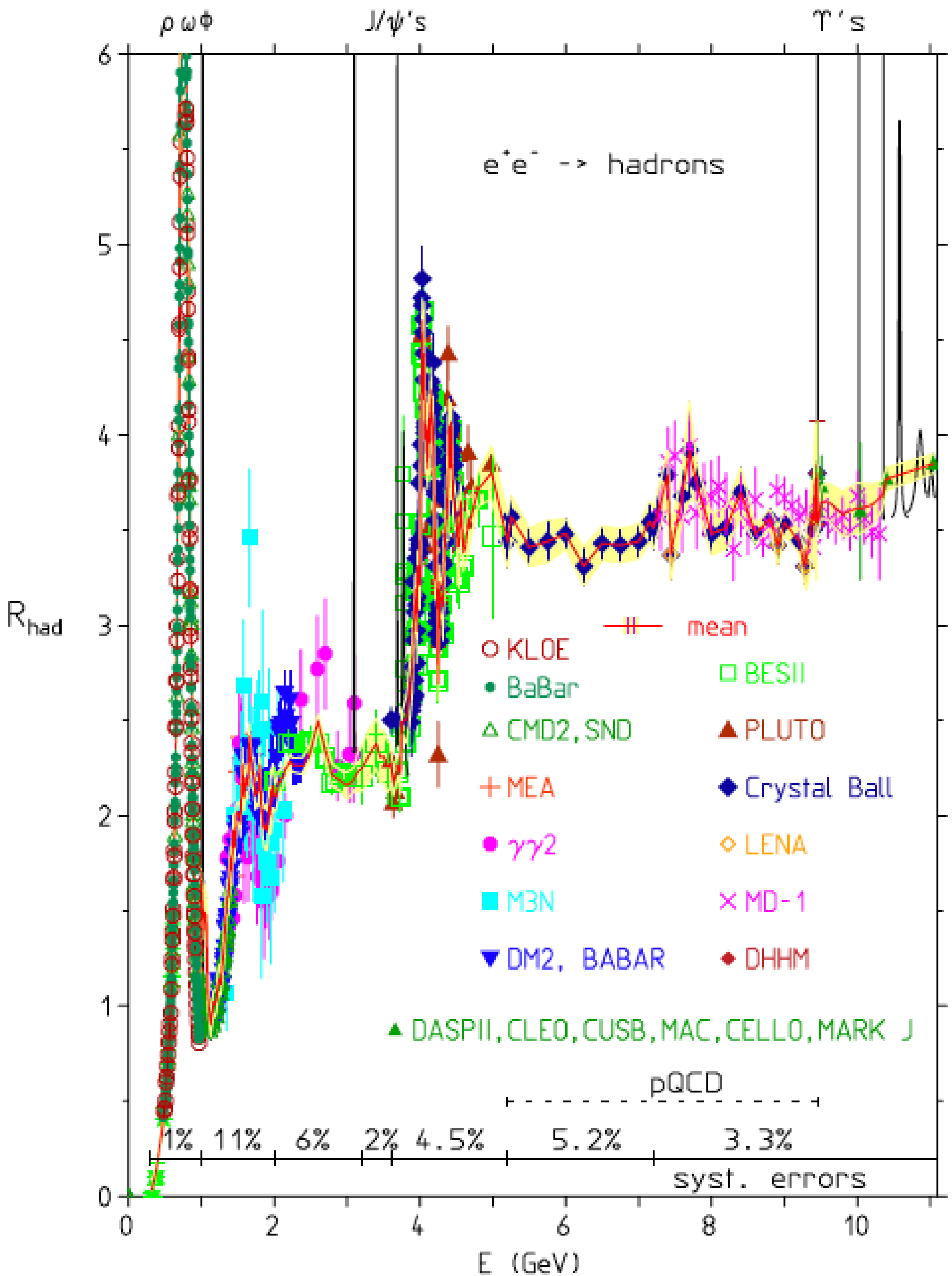
ρ,ω,φ
Ψ's
Υ's
Burkhardt, Pietrzyk '95
R_had
Bacci et al.
Cosme et al.
Mark I
Pluto
Cornell,DORIS
Crystal Ball
MD-1 VEPP-4
VEPP-2M ND
DM2
15 %
15 %
6 %
3 %
relative
error in
continuum
√s in GeV
0
1
2
3
4
5
6
7
8
9
10

Data at '05

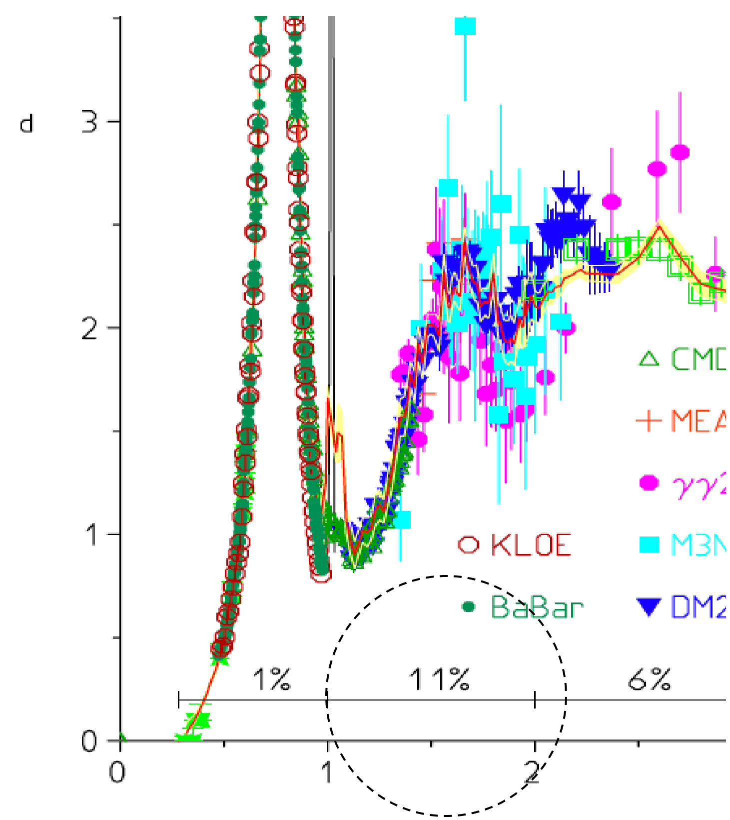


ρ,ω,φ
Ψ's
Υ's
Burkhardt, Pietrzyk 2005
Rhad
Bacci et al.
Cosme et al.
PLUTO
CESR, DORIS
MARK I
CRYSTAL BALL
MD-1 VEPP-4
VEPP-2M ND
DM2
BES 1999
BES 2001
CMD-2 2004
KLOE 2005
0.9%
15%
5.9%
6%
1.4%
rel. err. cont.
√s in GeV

Data at 2012 (F.J.)

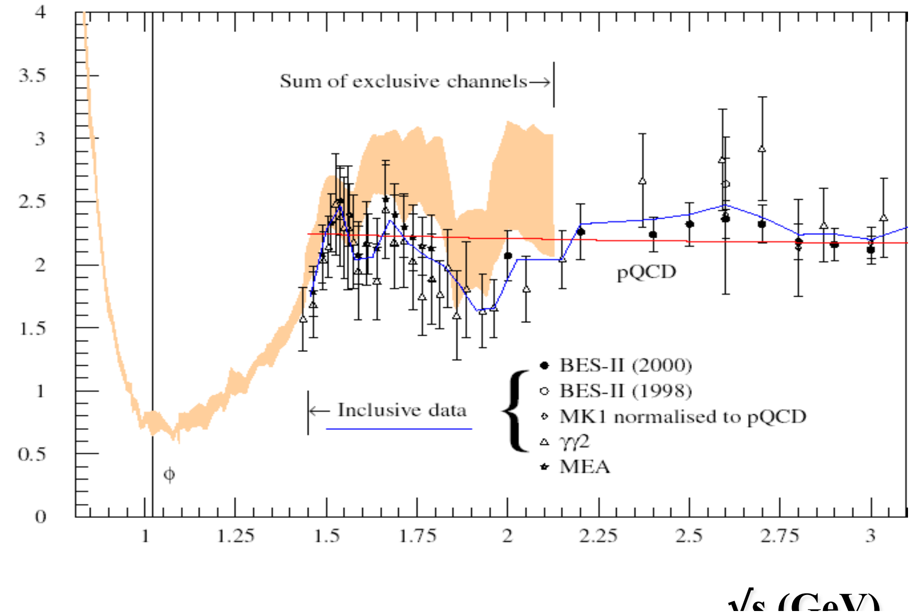


Many improvements (mostly due to BaBar ISR).
However the region below 2.5 GeV is still poorly known ($\delta R \sim 5\text{-}15\%$)



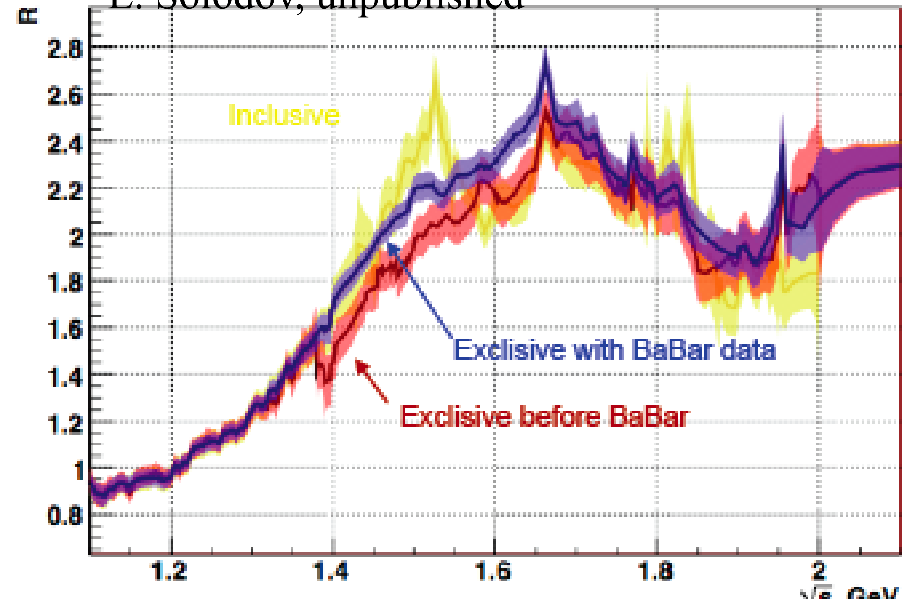
Exclusive vs inclusive measurements?

T. Teubner 08



1) Most recent inclusive measurements: MEA and B antiB, with **total** integrated luminosity of **200 nb^{-1}** (one hour of data taking at 10^{32} cm^{-2} sec-1).**10% stat.+ 15% syst. Errors**

E. Solodov, unpublished



2) New BaBar data is improving a lot this region. However still the question on the completeness of exclusive data vs systematics of old inclusive measurements

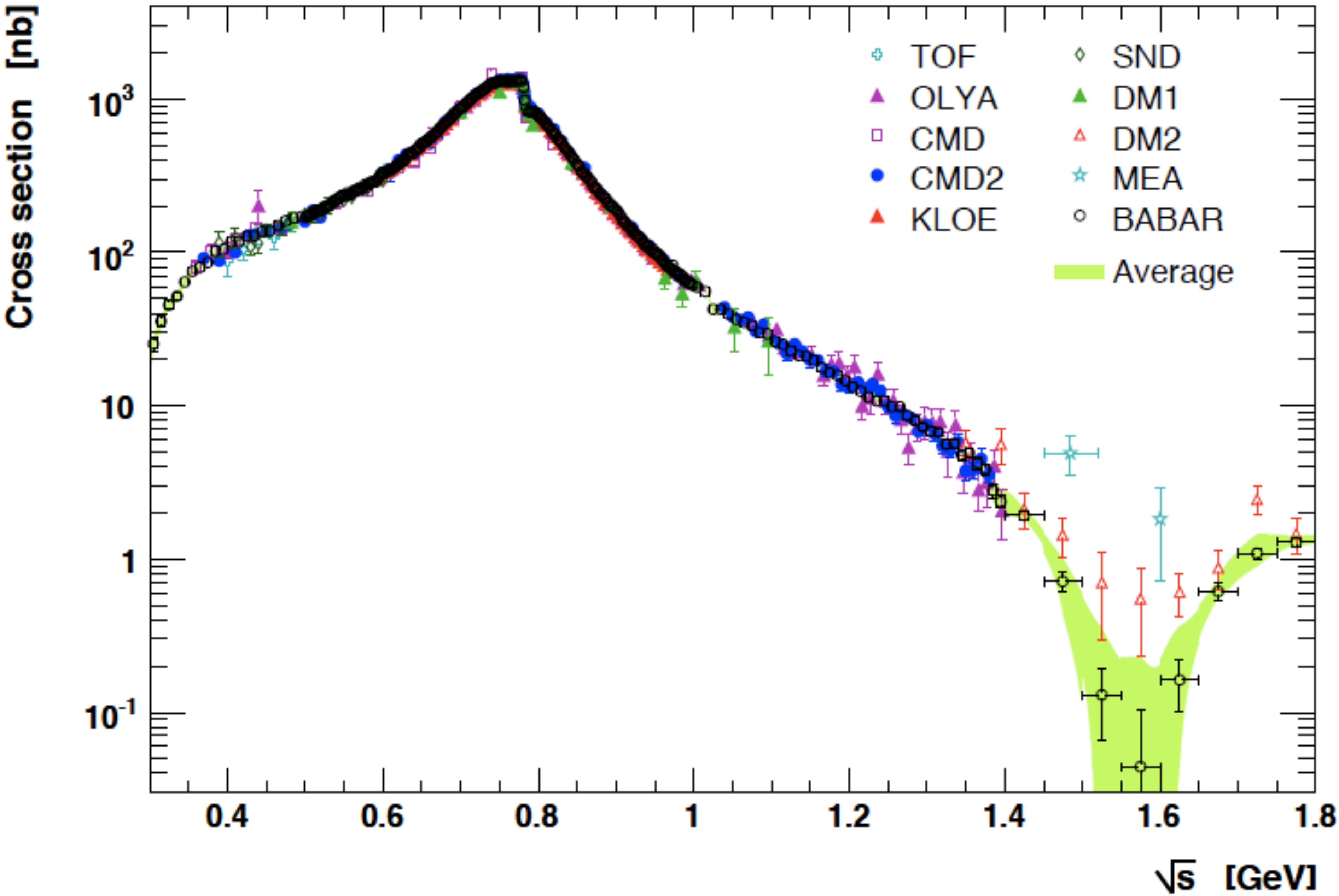
Main contributions to a_μ^{HLO} and $\Delta\alpha(M_Z)$

Channel		$a_\mu^{\rm had,LO}$ $[10^{-10}]$	$\Delta\alpha_{\rm had}(M_Z^2)$ $[10^{-4}]$
$\pi^0\gamma$		$4.42 \pm 0.08 \pm 0.13 \pm 0.12$	$0.36 \pm 0.01 \pm 0.01 \pm 0.01$
$\eta\gamma$		$0.64 \pm 0.02 \pm 0.01 \pm 0.01$	$0.08 \pm 0.00 \pm 0.00 \pm 0.00$
$\pi^+\pi^-$		$507.80 \pm 1.22 \pm 2.50 \pm 0.56$	$34.43 \pm 0.07 \pm 0.17 \pm 0.04$
$\pi^+\pi^-\pi^0$	**new meas**	$46.00 \pm 0.42 \pm 1.03 \pm 0.98$	$4.58 \pm 0.04 \pm 0.11 \pm 0.09$
$2\pi^+2\pi^-$		$13.35 \pm 0.10 \pm 0.43 \pm 0.29$	$3.49 \pm 0.03 \pm 0.12 \pm 0.08$
$\pi^+\pi^-2\pi^0$		$18.01 \pm 0.14 \pm 1.17 \pm 0.40$	$4.43 \pm 0.03 \pm 0.29 \pm 0.10$
$2\pi^+2\pi^-\pi^0$ (η excl.)		$0.72 \pm 0.04 \pm 0.07 \pm 0.03$	$0.22 \pm 0.01 \pm 0.02 \pm 0.01$
$\pi^+\pi^-3\pi^0$ (η excl., from isospin)		$0.36 \pm 0.02 \pm 0.03 \pm 0.01$	$0.11 \pm 0.01 \pm 0.01 \pm 0.00$
$3\pi^+3\pi^-$		$0.12 \pm 0.01 \pm 0.01 \pm 0.00$	$0.04 \pm 0.00 \pm 0.00 \pm 0.00$
$2\pi^+2\pi^-2\pi^0$ (η excl.)		$0.70 \pm 0.05 \pm 0.04 \pm 0.09$	$0.25 \pm 0.02 \pm 0.02 \pm 0.03$
$\pi^+\pi^-4\pi^0$ (η excl., from isospin)		$0.11 \pm 0.01 \pm 0.11 \pm 0.00$	$0.04 \pm 0.00 \pm 0.04 \pm 0.00$
$\eta\pi^+\pi^-$		$1.15 \pm 0.06 \pm 0.08 \pm 0.03$	$0.33 \pm 0.02 \pm 0.02 \pm 0.01$
$\eta\omega$		$0.47 \pm 0.04 \pm 0.00 \pm 0.05$	$0.15 \pm 0.01 \pm 0.00 \pm 0.02$
$\eta 2\pi^+2\pi^-$		$0.02 \pm 0.01 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00 \pm 0.00$
$\eta\pi^+\pi^-2\pi^0$ (estimated)		$0.02 \pm 0.01 \pm 0.01 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00 \pm 0.00$
$\omega\pi^0$ ($\omega \to \pi^0\gamma$)		$0.89 \pm 0.02 \pm 0.06 \pm 0.02$	$0.18 \pm 0.00 \pm 0.02 \pm 0.00$
$\omega\pi^+\pi^-, \omega 2\pi^0$ ($\omega \to \pi^0\gamma$)		$0.08 \pm 0.00 \pm 0.01 \pm 0.00$	$0.03 \pm 0.00 \pm 0.00 \pm 0.00$
ω (non-$3\pi, \pi\gamma, \eta\gamma$)		$0.36 \pm 0.00 \pm 0.01 \pm 0.00$	$0.03 \pm 0.00 \pm 0.00 \pm 0.00$
K^+K^-	**new meas**	$21.63 \pm 0.27 \pm 0.58 \pm 0.36$	$3.13 \pm 0.04 \pm 0.08 \pm 0.05$
$K_S^0K_L^0$		$12.96 \pm 0.18 \pm 0.25 \pm 0.24$	$1.75 \pm 0.02 \pm 0.03 \pm 0.03$
ϕ (non-$K\overline{K}, 3\pi, \pi\gamma, \eta\gamma$)		$0.05 \pm 0.00 \pm 0.00 \pm 0.00$	$0.01 \pm 0.00 \pm 0.00 \pm 0.00$
$K\overline{K}\pi$ (partly from isospin)		$2.39 \pm 0.07 \pm 0.12 \pm 0.08$	$0.76 \pm 0.02 \pm 0.04 \pm 0.02$
$K\overline{K}2\pi$ (partly from isospin)		$1.35 \pm 0.09 \pm 0.38 \pm 0.03$	$0.48 \pm 0.03 \pm 0.14 \pm 0.01$
$K\overline{K}3\pi$ (partly from isospin)		$-0.03 \pm 0.01 \pm 0.02 \pm 0.00$	$-0.01 \pm 0.00 \pm 0.01 \pm 0.00$
$\phi\eta$		$0.36 \pm 0.02 \pm 0.02 \pm 0.01$	$0.13 \pm 0.01 \pm 0.01 \pm 0.00$
$\omega K\overline{K}$ ($\omega \to \pi^0\gamma$)		$0.00 \pm 0.00 \pm 0.00 \pm 0.00$	$0.00 \pm 0.00 \pm 0.00 \pm 0.00$

M. Davier et al. Eur.Phys.J. C71 (2011) 1515

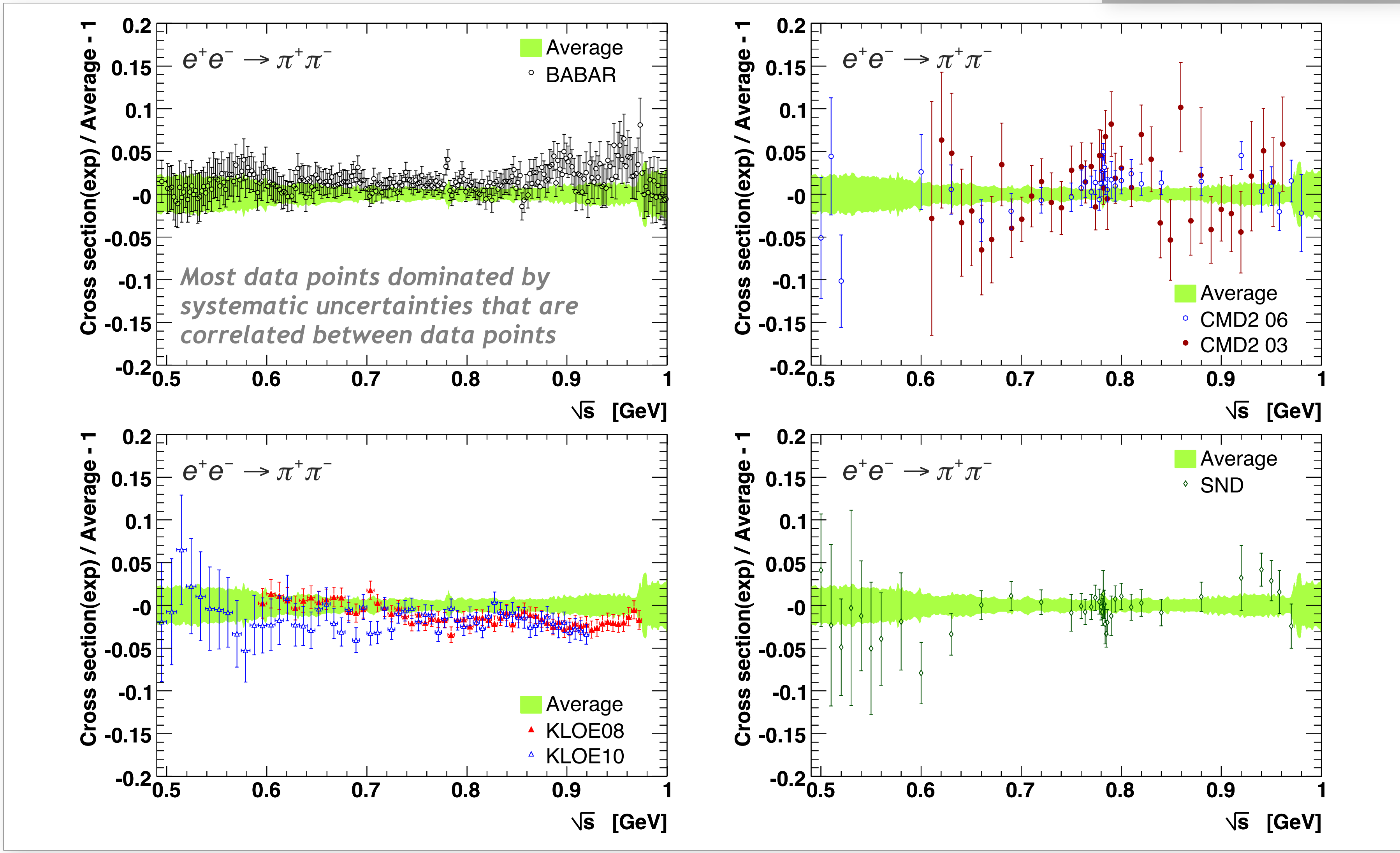
$$e^+e^- \rightarrow \pi^+\pi^-$$

Measured cross section for $e^+e^- \to \pi^+\pi^-$ (2010)



Situation of Two-pion channel

Davier *et al.*, EPJ C 71, 1515 (2011)



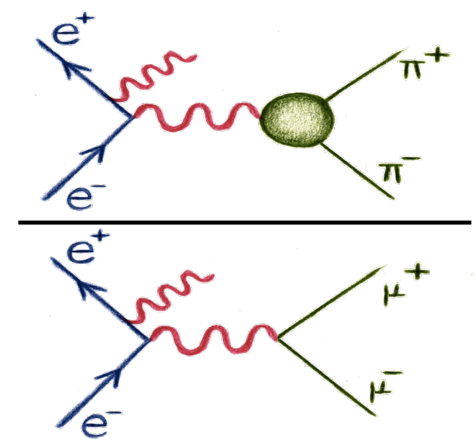
A. Hoecker LP11

New (2013): KLOE $\sigma_{\pi\pi}$ from $\pi\pi\gamma/\mu\mu\gamma$

An alternative way to obtain $|F_\pi|^2$ is the bin-by-bin ratio of pion over muon yields (instead of using absolute normalization with Bhabhas).

$$|F_\pi(s')|^2 \approx \frac{4(1+2m_\mu^2/s')\beta_\mu}{\beta_\pi^3} \quad \frac{d\sigma_{\pi\pi\gamma}/ds'}{d\sigma_{\mu\mu\gamma}/ds'}$$

kinematical factor (s_{mm}^{Born} / s_{pp}^{Born}) — meas. quantities



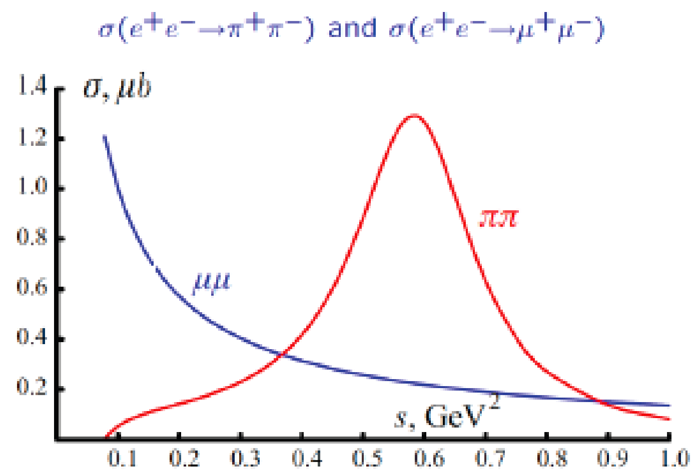
Many radiative corrections drop out:

- *radiator function*
- *int. luminosity from Bhabhas*
- *Vacuum polarization*

Separation btw $\pi\pi\gamma$ and $\mu\mu\gamma$ using M_{TRK}

- *muons:* $M_{Trk} < 115$ *MeV*
- *pions :* $M_{Trk} > 130$ *MeV*

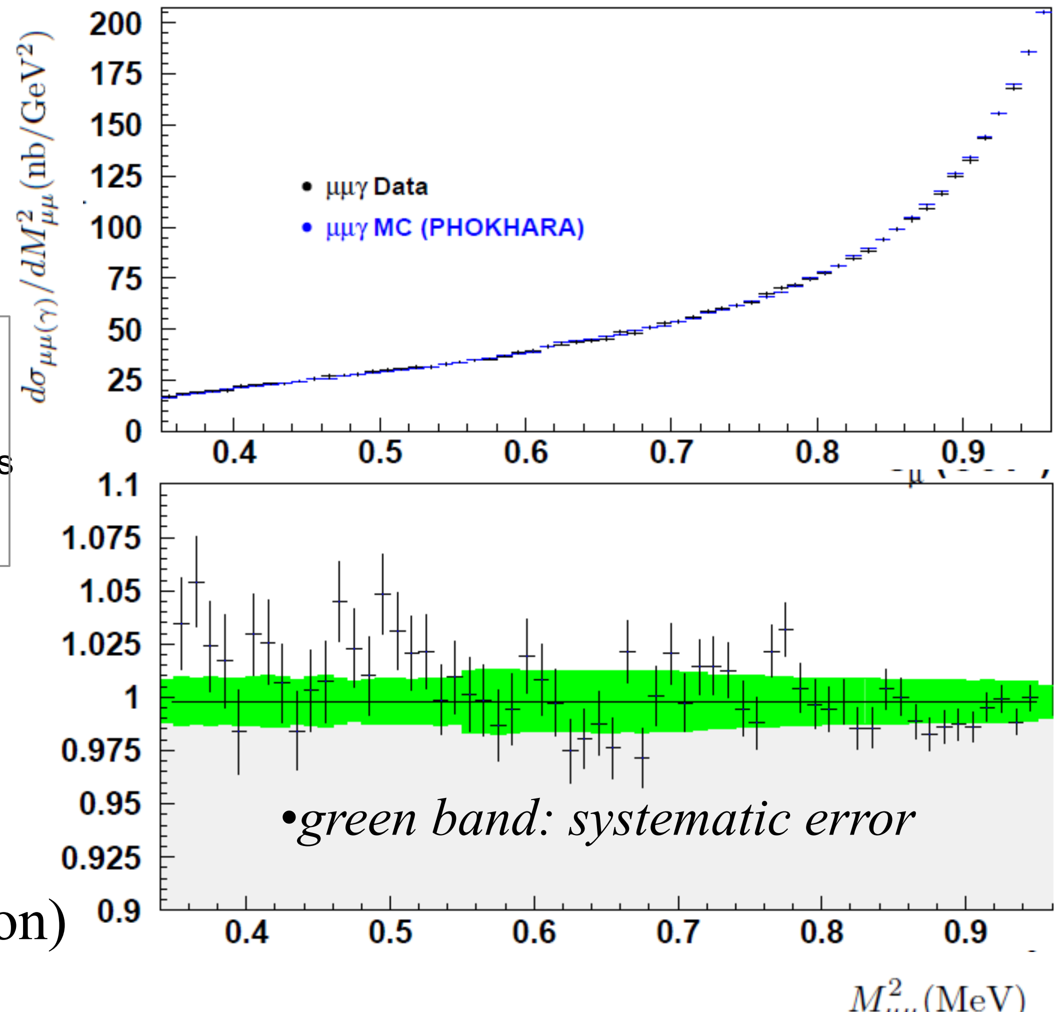
Very important control of π/μ separation in the ρ region! ($\sigma_{\pi\pi} >> \sigma_{\mu\mu}$)



μμγ cross section: data/MC comparison

$$\frac{d\sigma^{obs}_{\mu\mu\gamma(\gamma)}}{dM^2_{\mu\mu}} = \frac{\Delta N_{Obs} - \Delta N_{Bkg}}{\Delta M^2_{\mu\mu}} \cdot \frac{1}{\varepsilon_{Sel}} \cdot \frac{1}{\int L dt}$$

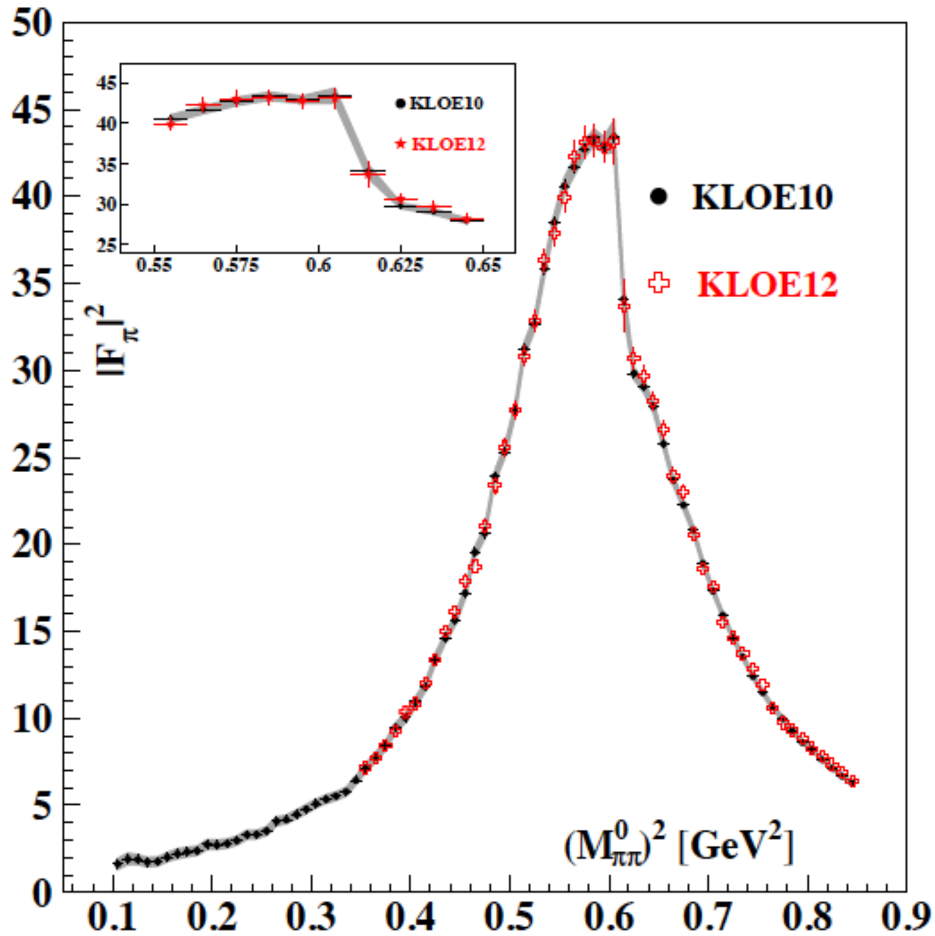
$$\frac{d\sigma^{DATA}_{\mu\mu\gamma(\gamma)}}{d\sigma^{MC}_{\mu\mu\gamma(\gamma)}} = 0.998 \pm 0.001_{stat} \pm 0.011_{sys}$$



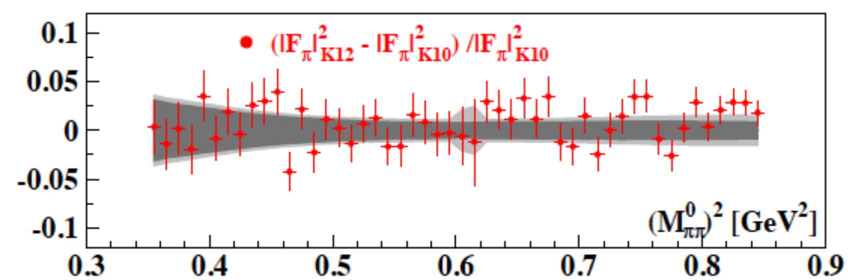
- The systematic error has been averaged on $M^2_{\mu\mu}$
- Good agreement with PHOKHARA MC (NLO Calculation)
- Consistency check of Radiator function, Luminosity, etc…

Comparison of results: KLOE12 vs KLOE10

KLOE12 result compared to KLOE10:



Fractional difference:



band: KLOE10 error

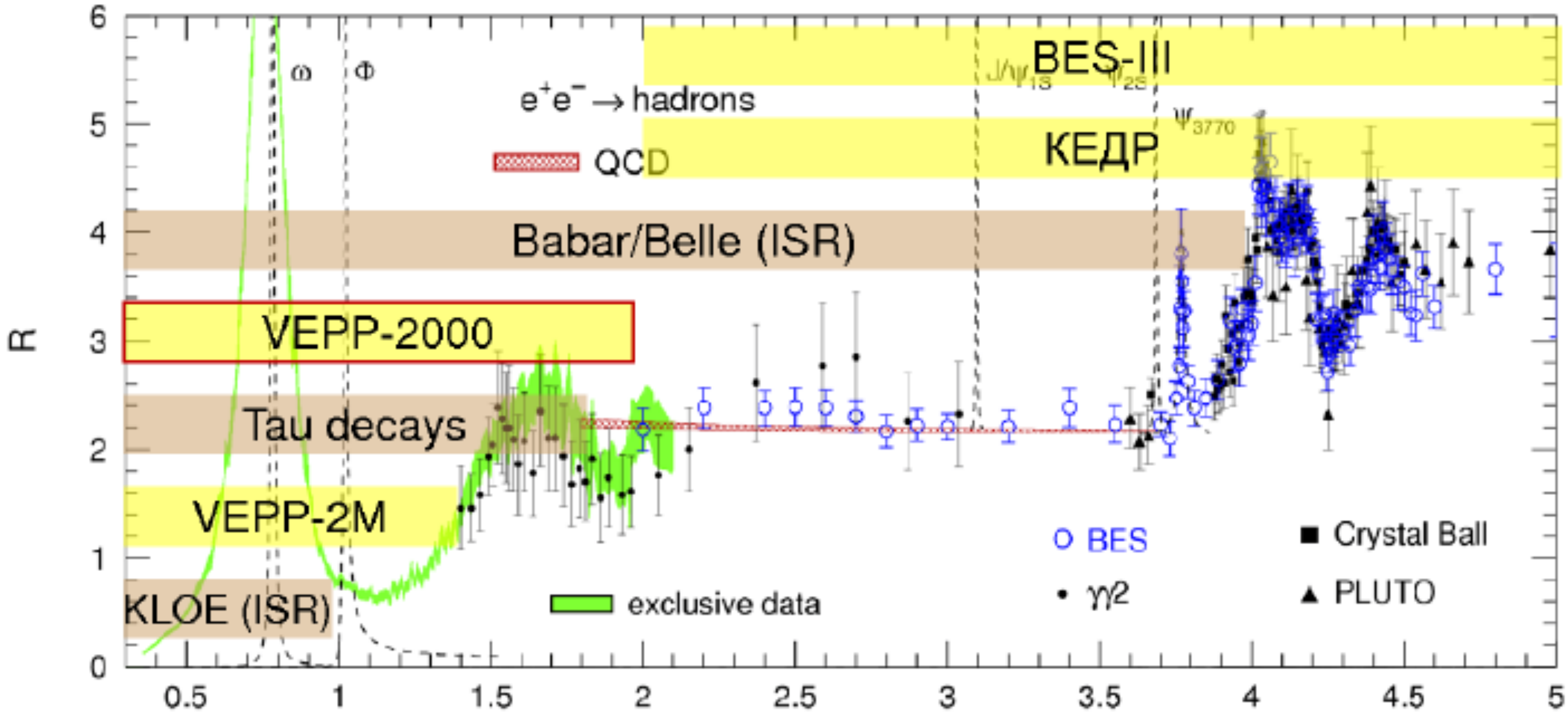
Excellent agreement between the two independent measurements!

Analysis	$a_\mu^{\pi\pi}(0.35 - 0.85\ \text{GeV}^2) \times 10^{10}$
KLOE12	$377.4 \pm 1.1_{stat} \pm 2.7_{sys+theo}$
KLOE10	$376.6 \pm 0.9_{stat} \pm 3.3_{sys+theo}$

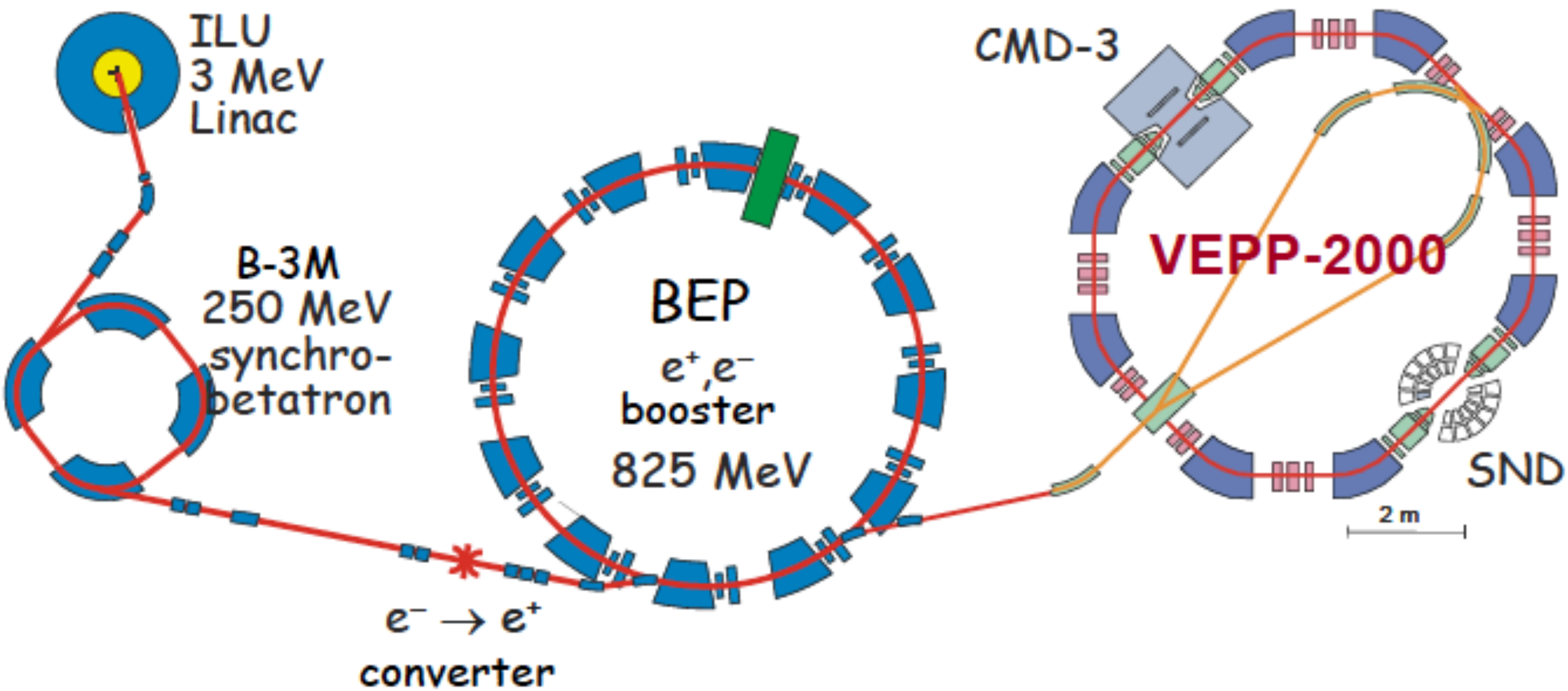
- **PLB 720 (2013) 336–343**

New measurements at the horizon

VEPP-2000 and the world



VEPP-2000

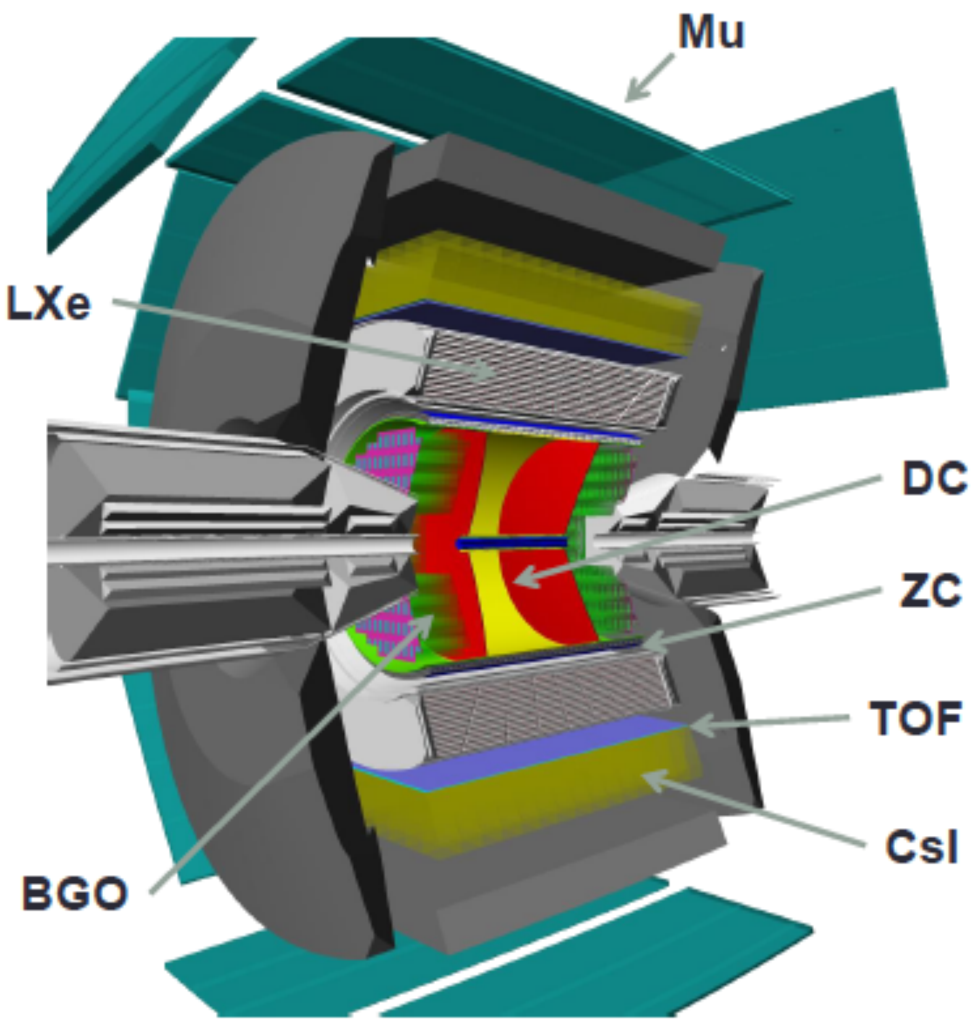


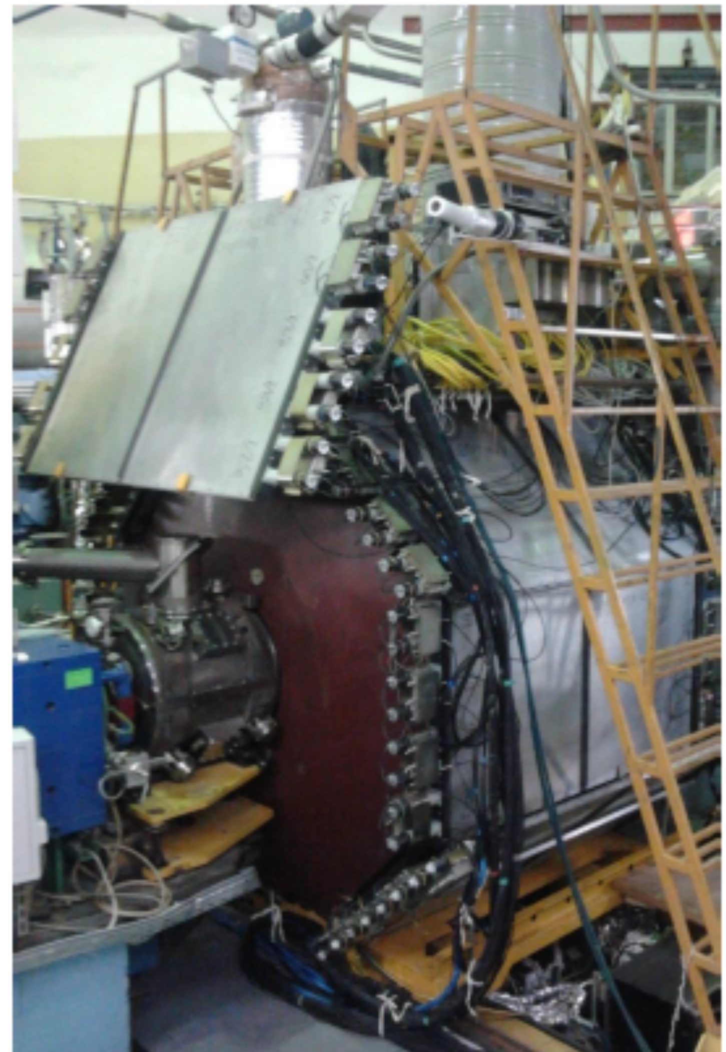
Maximum c.m. energy is 2 GeV, project luminosity is $L = 10^{32} 1/cm^2 s$ at $\sqrt{s} = 2$ GeV

Unique optics, “round beams”, allows to reach higher luminosity

Experiments with two detectors, CMD-3 and SND, started by the end of 2010

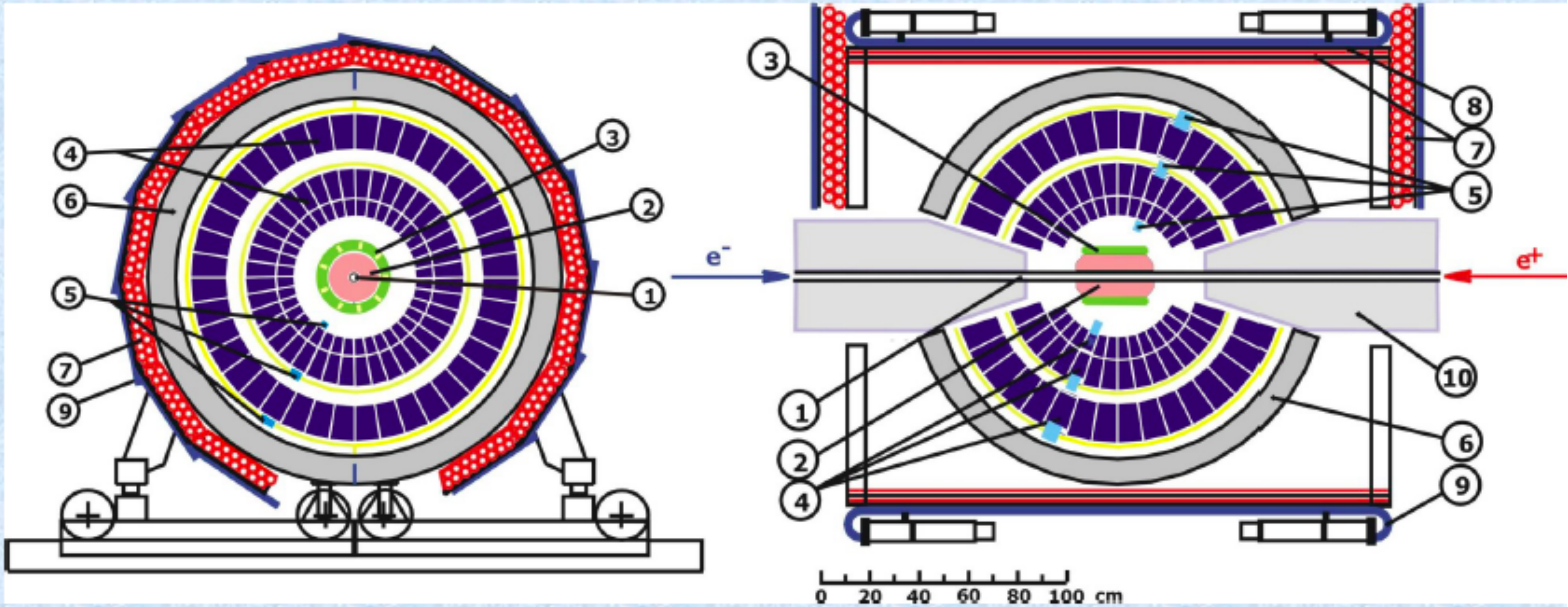
Detector CMD-3





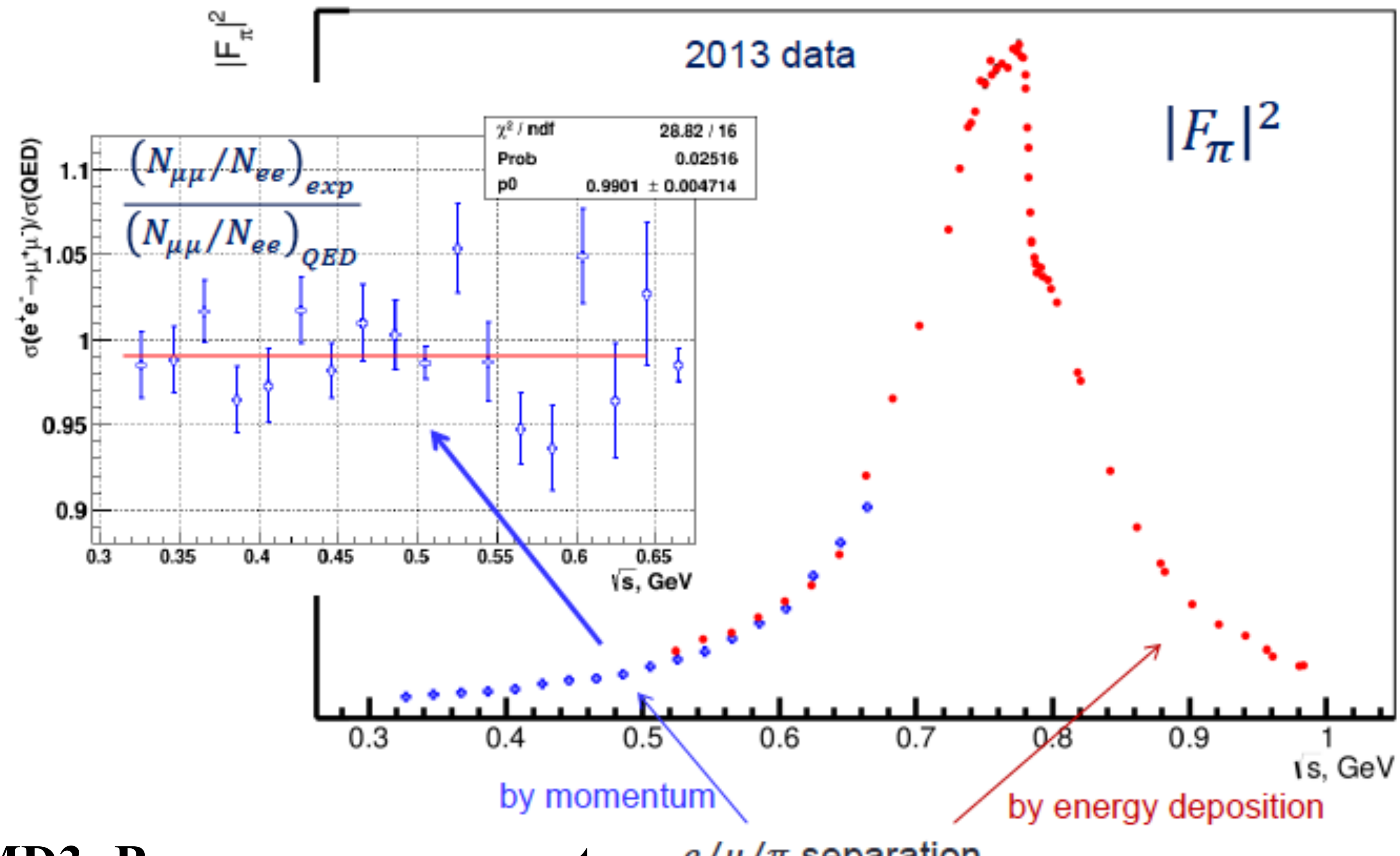
SND for VEPP-2000

NIM A449 (2000) 125-139



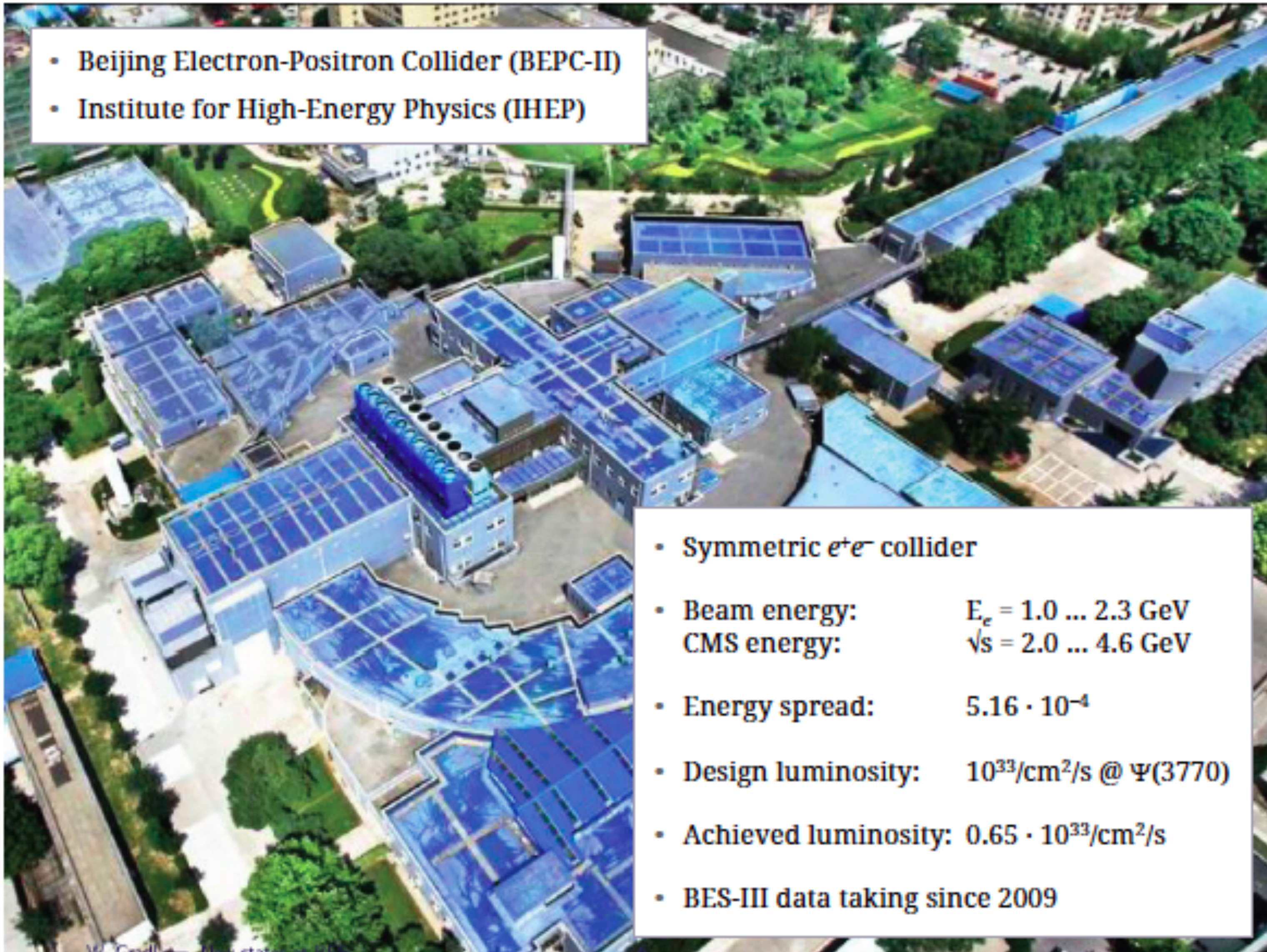
1 – beam pipe, 2 – tracking system, 3 – aerogel cherenkov counter , 4 – NaI(Tl) crystals, 5 – phototriodes, 6 – iron muon absorber, 7–9 – muon detector, 10 – focusing solenoids.

$e^+e^- \to \pi^+\pi^-$: very preliminary results



CMD3: By scan measurement

BES-III and BEPC-II



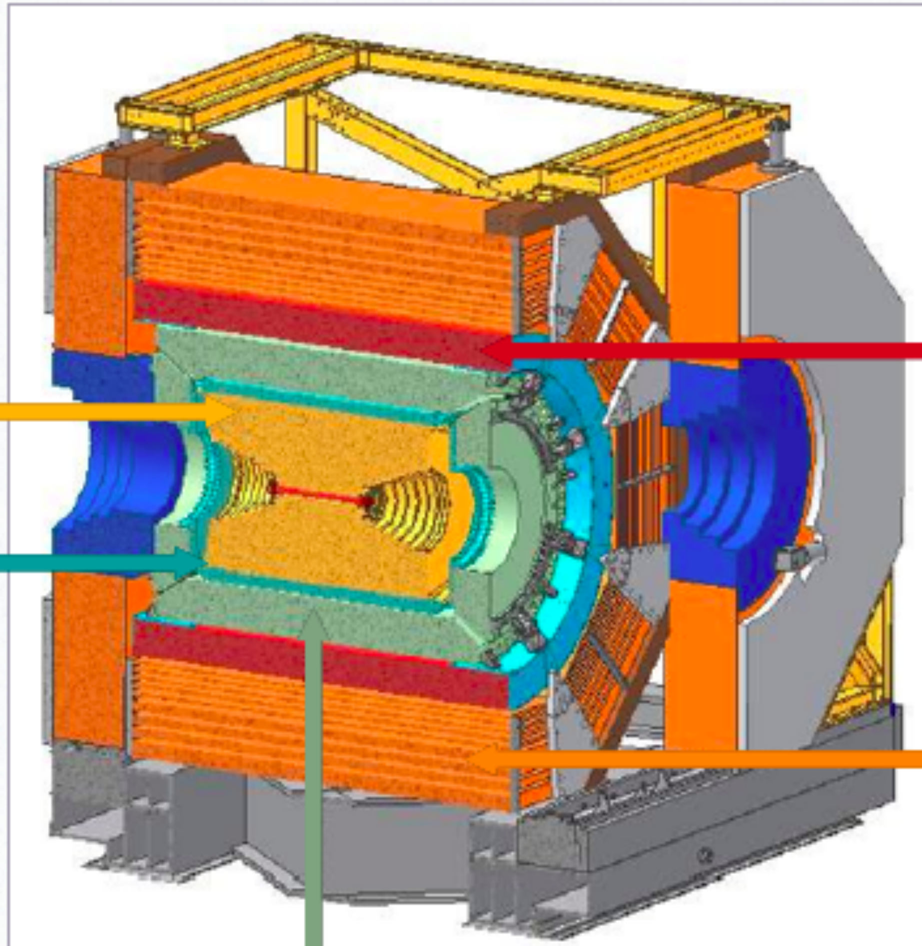
- Beijing Electron-Positron Collider (BEPC-II)
- Institute for High-Energy Physics (IHEP)

- Symmetric e^+e^- collider
- Beam energy: $E_e = 1.0 \ldots 2.3$ GeV
  CMS energy: $\sqrt{s} = 2.0 \ldots 4.6$ GeV
- Energy spread: $5.16 \cdot 10^{-4}$
- Design luminosity: $10^{33}/\mathrm{cm}^2/\mathrm{s}$ @ $\Psi(3770)$
- Achieved luminosity: $0.65 \cdot 10^{33}/\mathrm{cm}^2/\mathrm{s}$
- BES-III data taking since 2009

BES-III detector systems

Cylindrical drift chamber
- σ_p/p = 0.5% @ 1 GeV

Super-conducting magnet
- B = 1.0 T



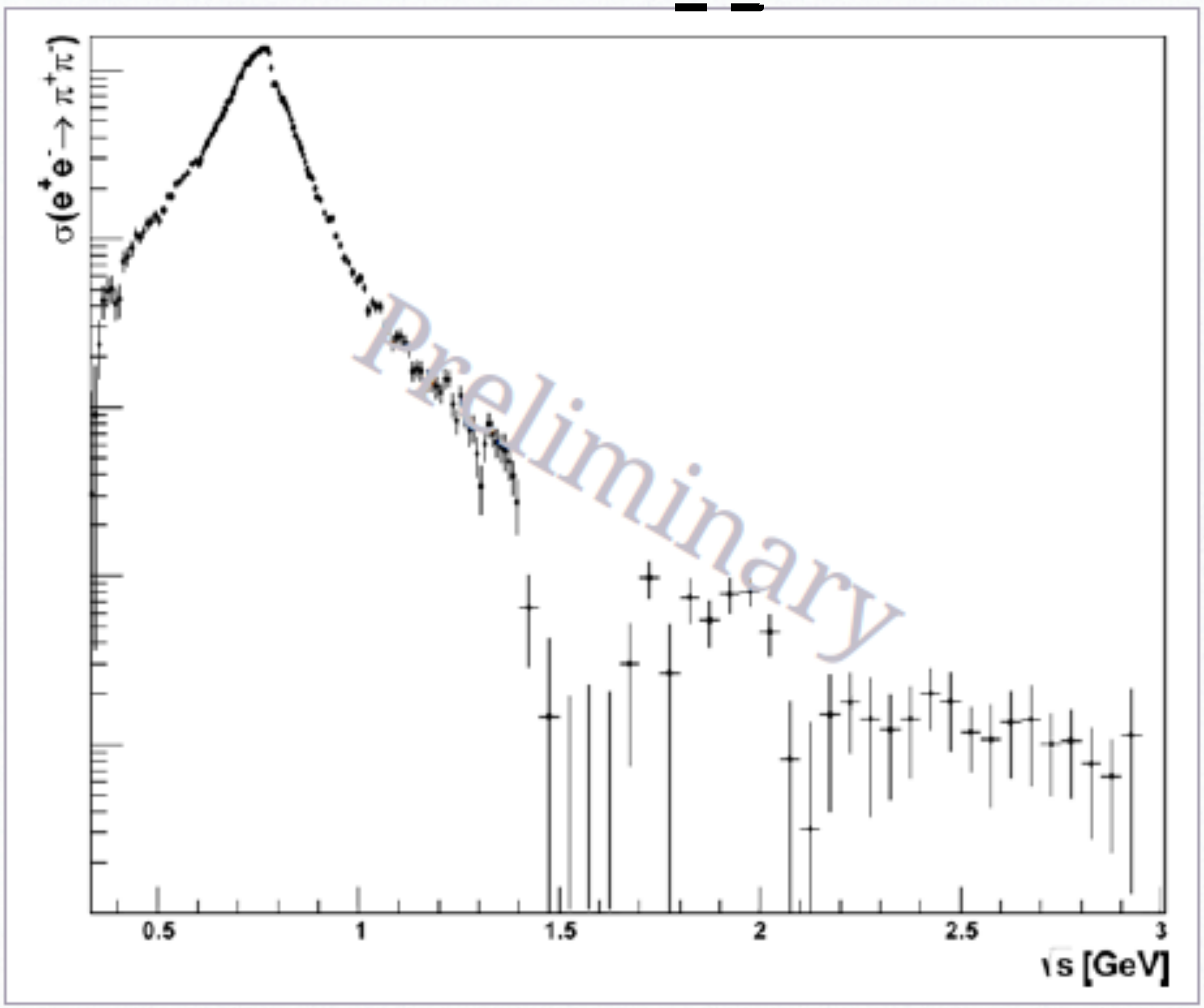
Time of Flight
- σ_T = 90 ps (Barrel)
  110 ps (Endcap)

EM calorimeter (CsI)
- $\sigma_E/\sqrt{E}$ = 2.5% @ 1 GeV

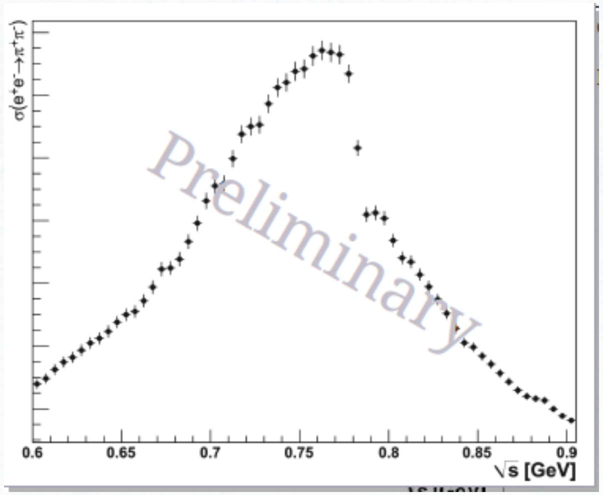
Muon chamber
- 8-9 layers RPC

$e^+e^- \to \pi^+\pi^-$ cross section *(preliminary)*

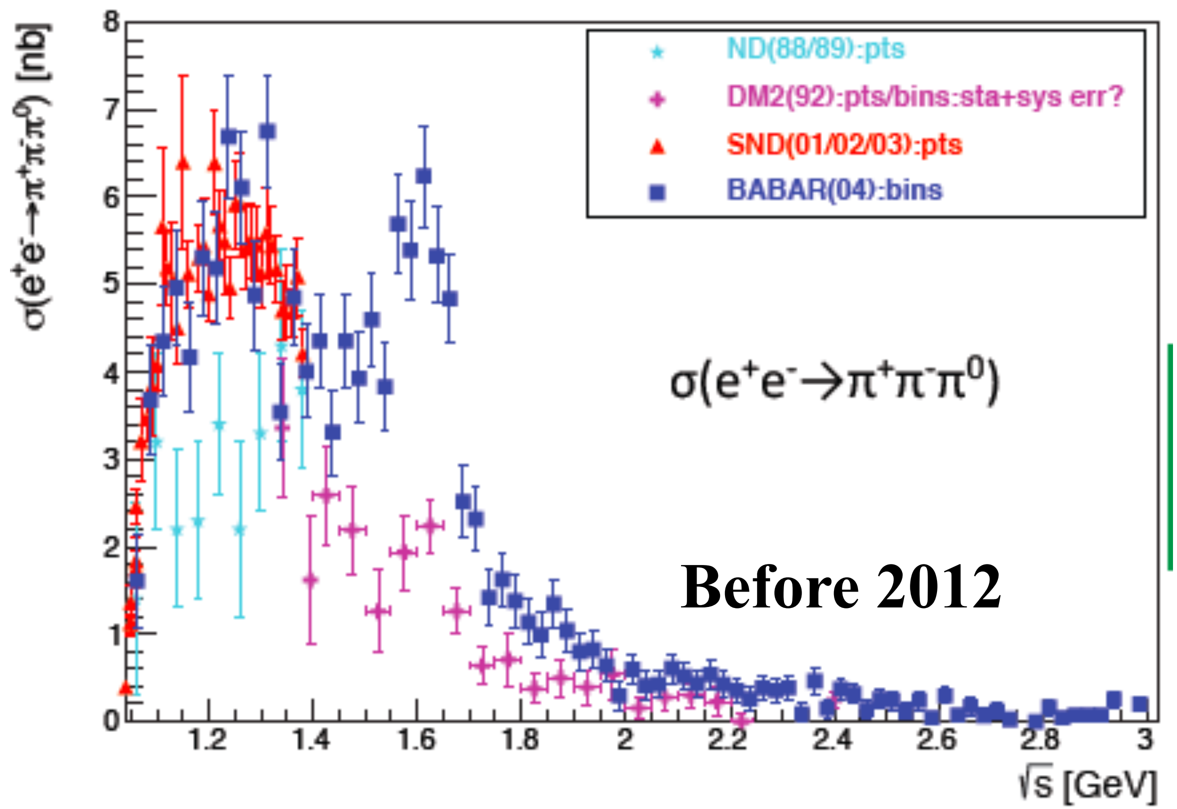
$\pi^+\pi^-$ cross section – extracted from ISR $\pi^+\pi^-\gamma$ data



- **BES-III data**
  2.9 fb^{-1} @ 3.770 GeV, tagged ISR
- **Wide energy range**
  up to ~3 GeV
- **No FSR correction yet**

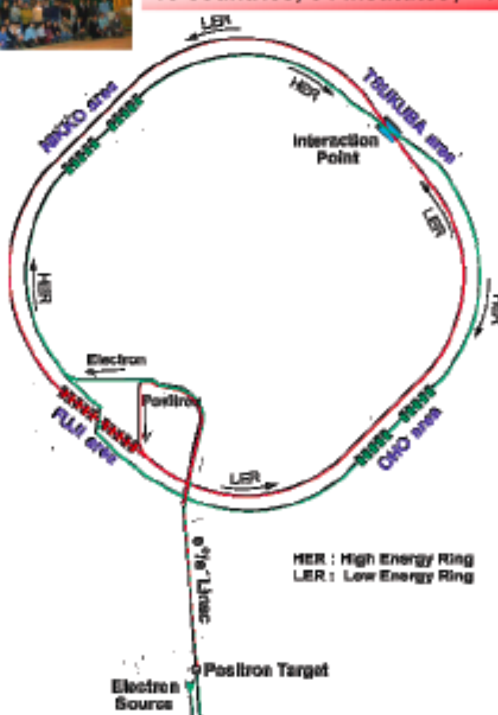


$e^+e^- \rightarrow \pi^+\pi^-\pi^0$

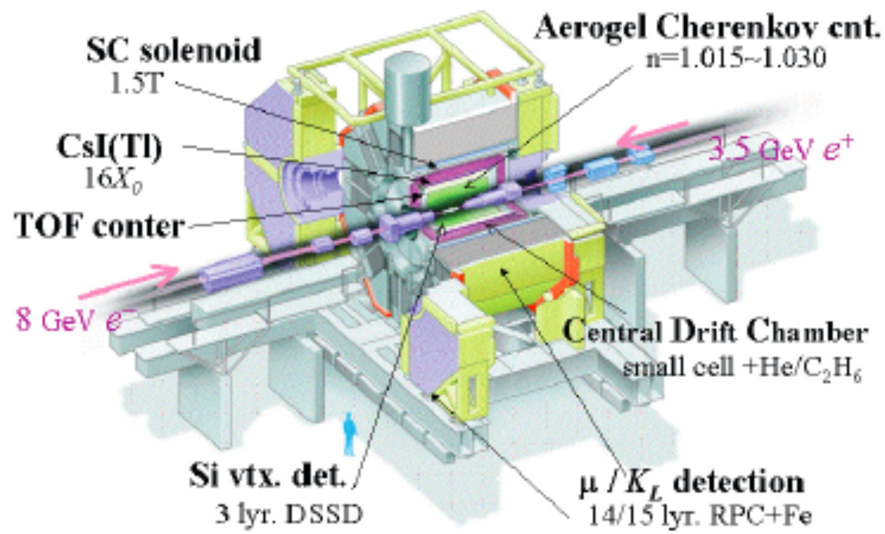


Before 2012

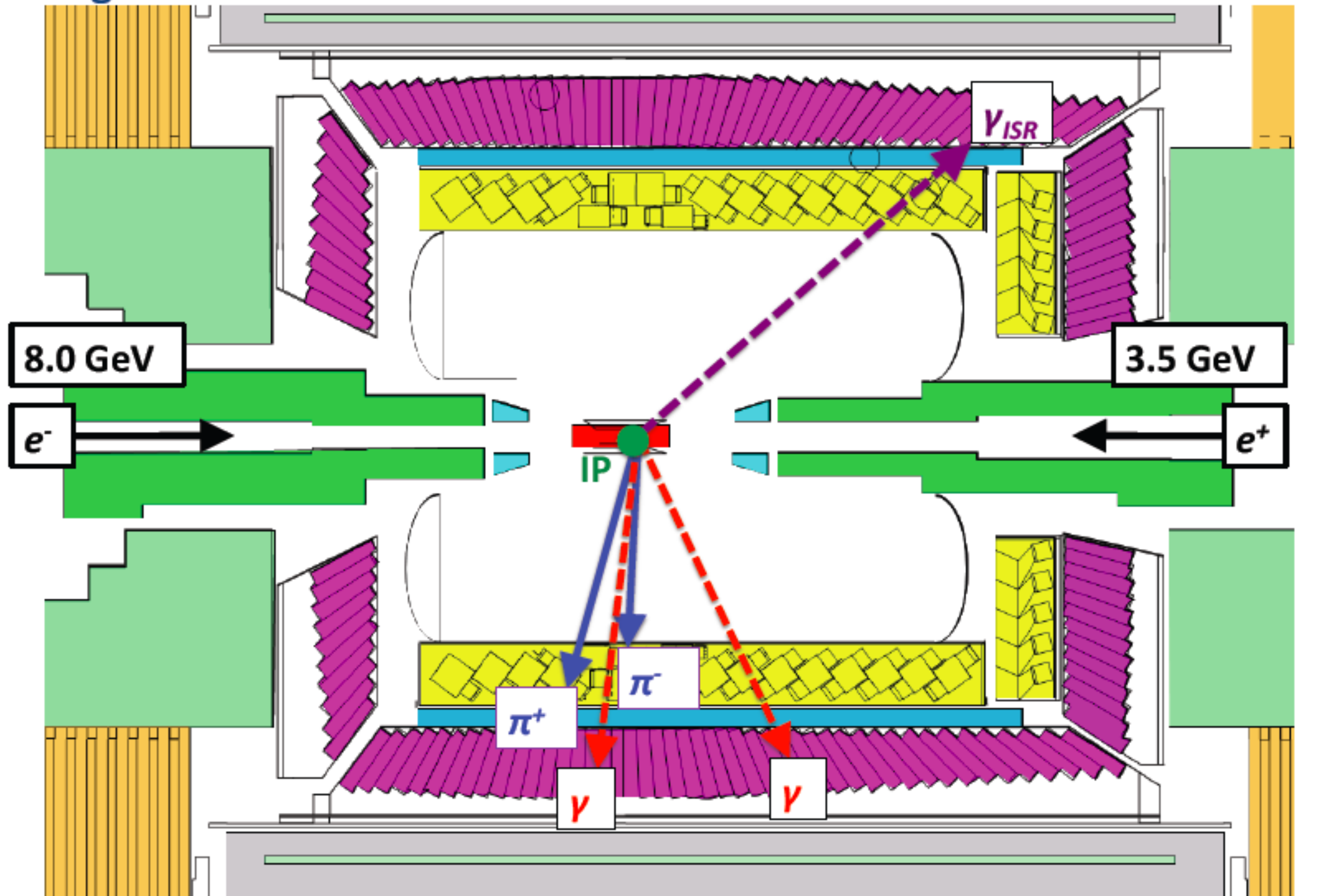
The international Belle experiment operates at a B-Factory, and uses a general purpose detector.



Belle Detector



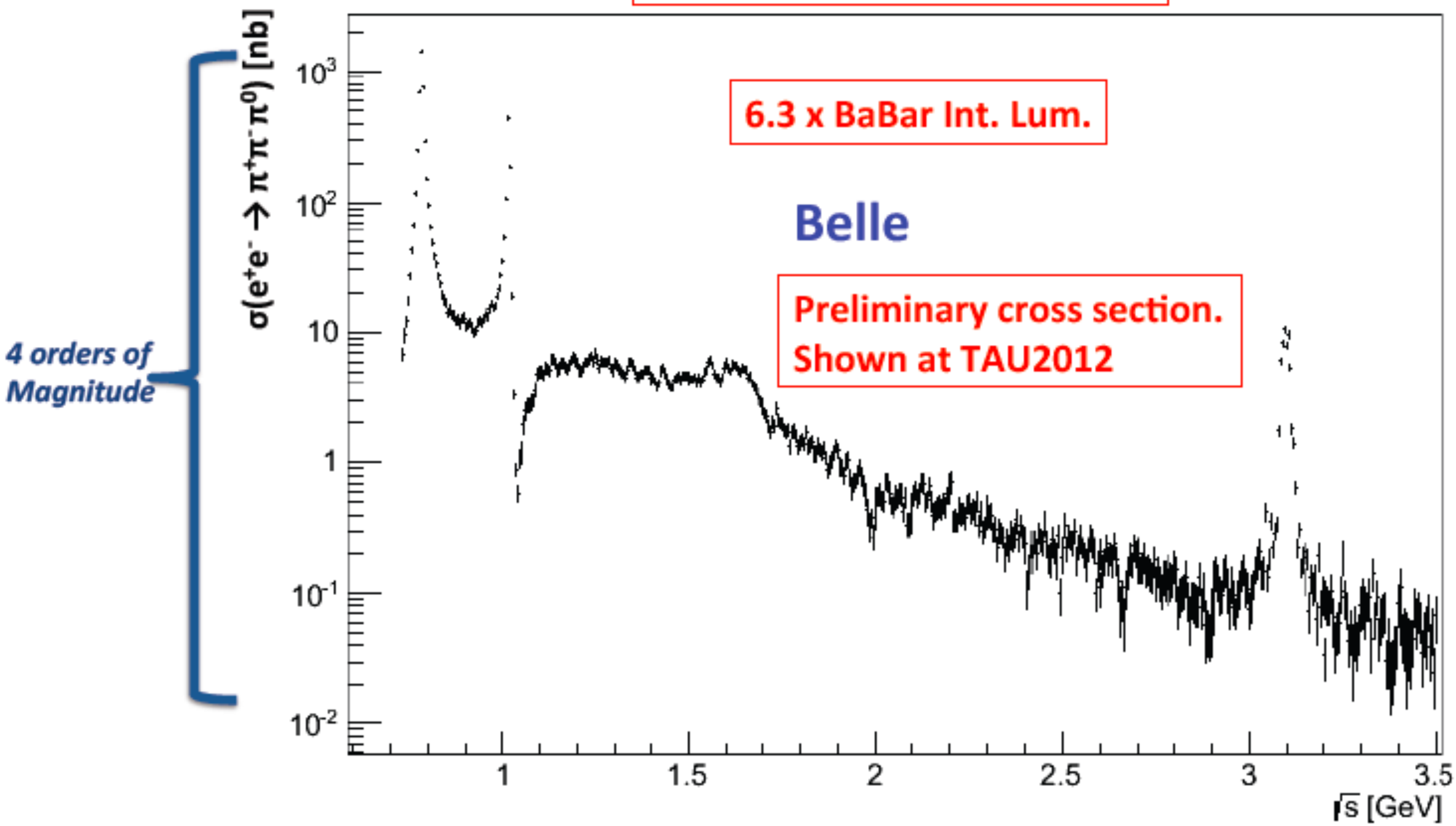
Fixed-energy colliders can measure a wide range of center-of-mass energies via ISR. Example: $e^+e^- \rightarrow \gamma_{ISR} M_{had} \rightarrow \gamma_{ISR}\pi^+\pi^-\pi^0 \rightarrow \gamma_{ISR}\pi^+\pi^-\gamma\gamma$



Low energy (> 3 GeV) cross section measurements are focused precision measurements.

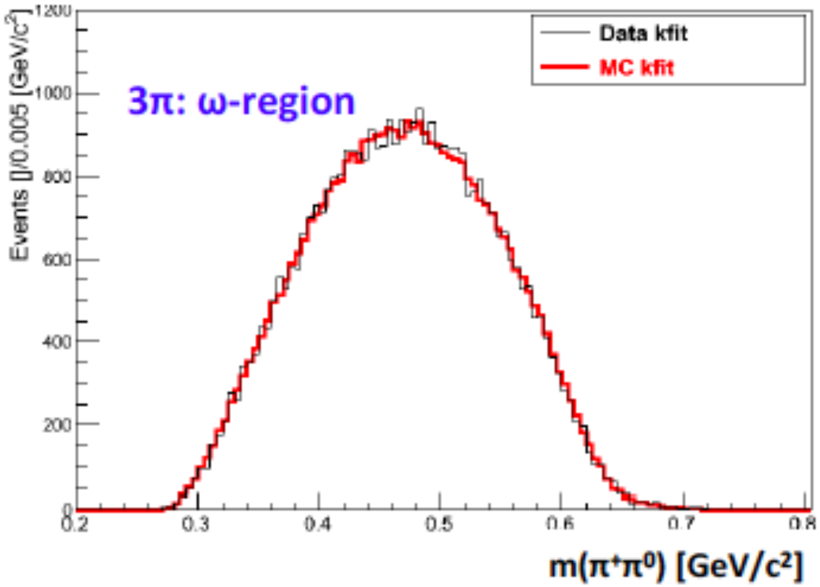
$$e^+e^- \rightarrow \pi^+\pi^-\pi^0$$

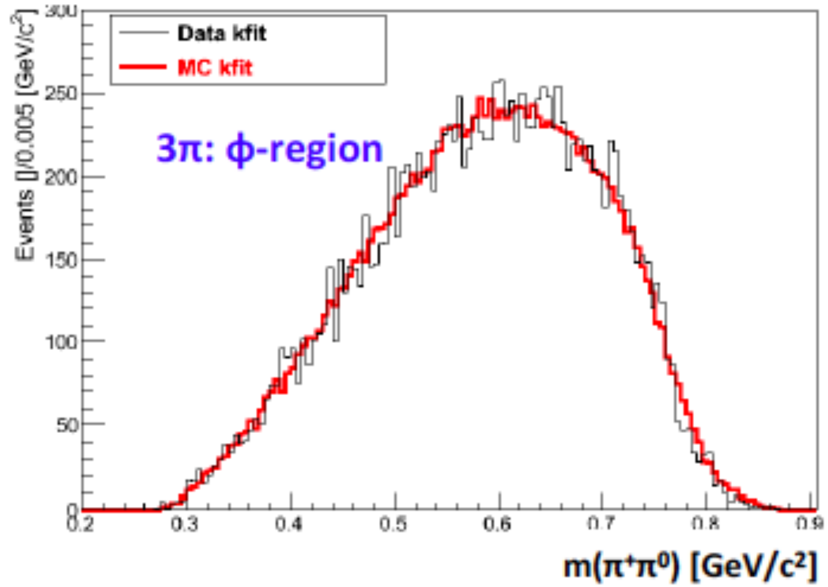
Belle systematic error goal is 5%.



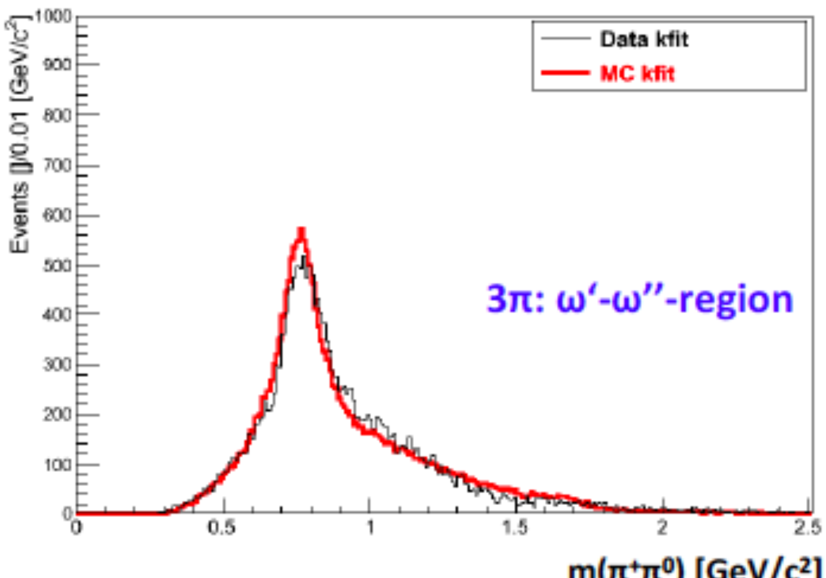
Systematic errors, background leakage, and small radiative correction checks to be completed in near future

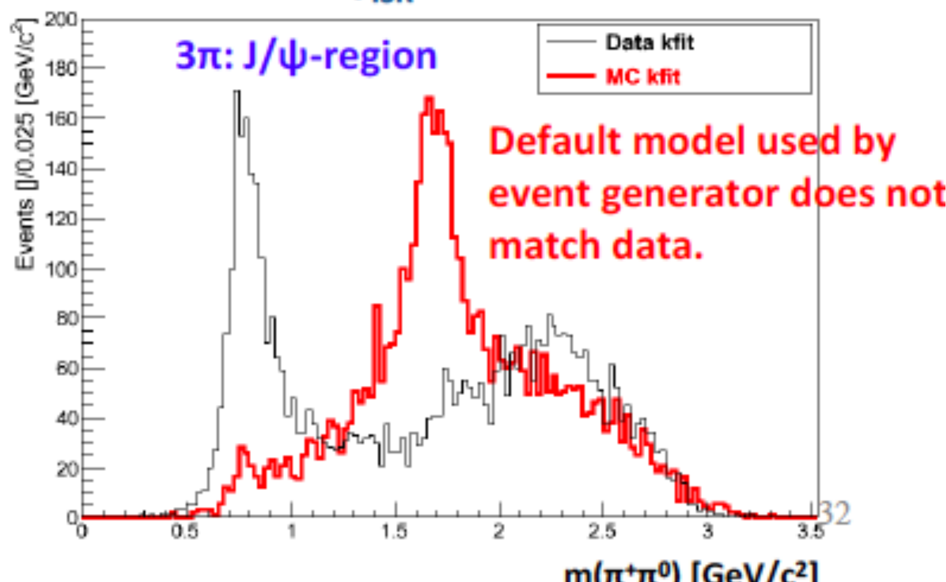
Belle cross section measurements are also interested in looking at intermediate states.





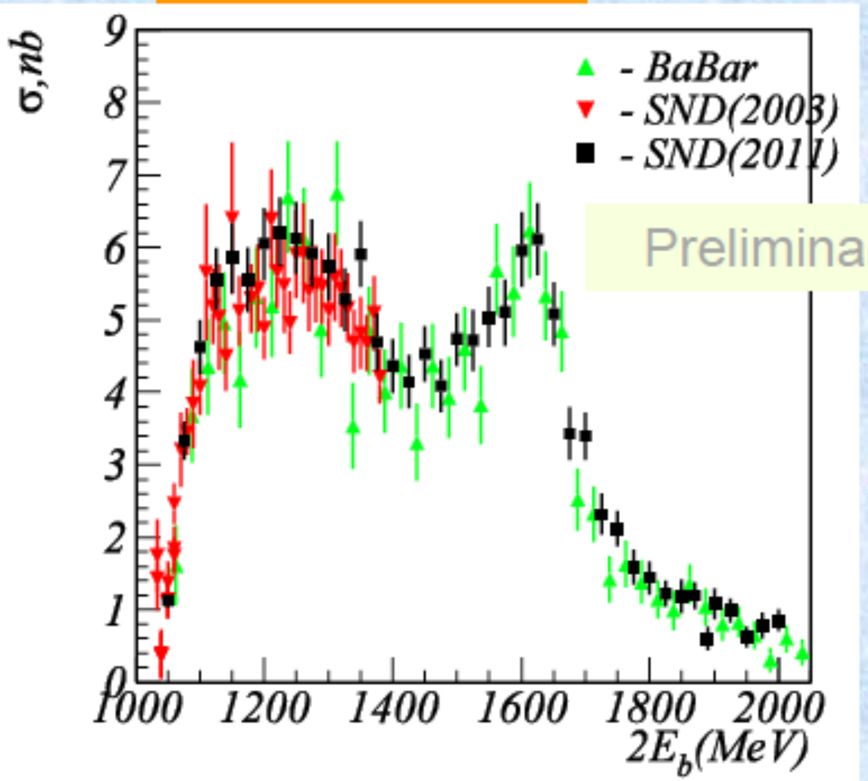
Belle $m(\pi^+\pi^0)$ distributions for $e^+e^- \rightarrow \pi^+\pi^-\pi^0\gamma_{ISR}$.





Process $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ ($22 pb^{-1}$)

Cross section



Selection criteria :

– 2 central charged particles

– 2 γ's

– $\Delta\varphi_{ch.} > 10°$

– total energy dep. $(0.3\text{-}0.8)E_{beam}$

Kinematic fit:

– $\chi^2_R < 40$, $\chi^2_{\pi+\pi-\gamma\gamma} < 40$;

Fit to $M_{\pi 0}$ spectrum (effect + background)

Spectrum is a sum of contributions from ω(782), ω′(1420), ω″(1650).

Only statistical errors

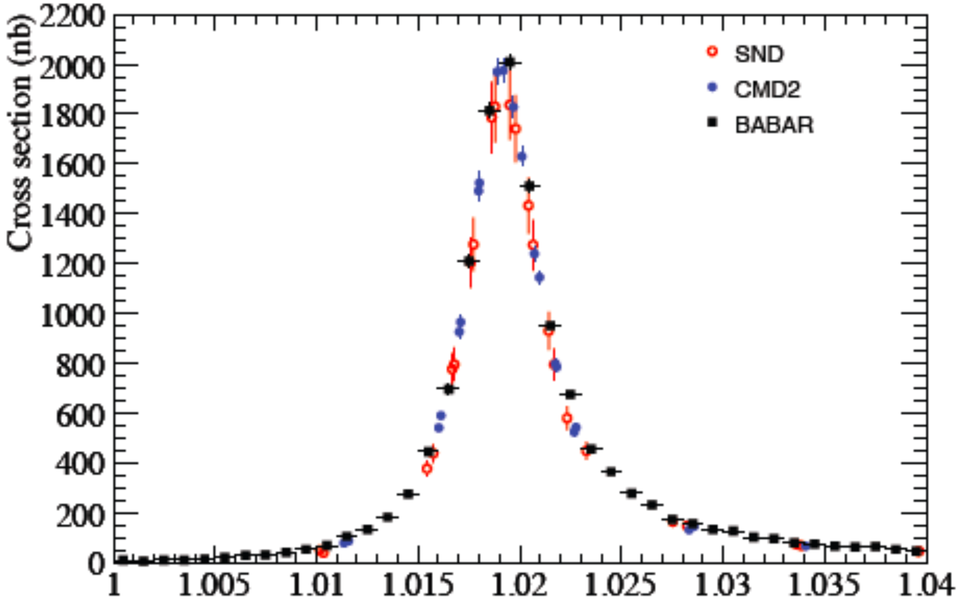
Systematic: ~5%

$$e^+e^- \rightarrow K^+K^-$$

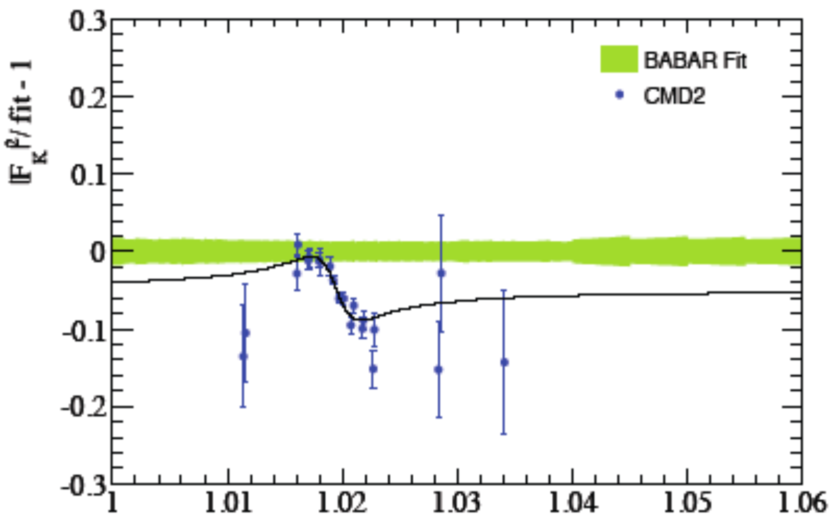
σ_{had}: some recent new data: $K^+K^-(\gamma)$ from BaBar

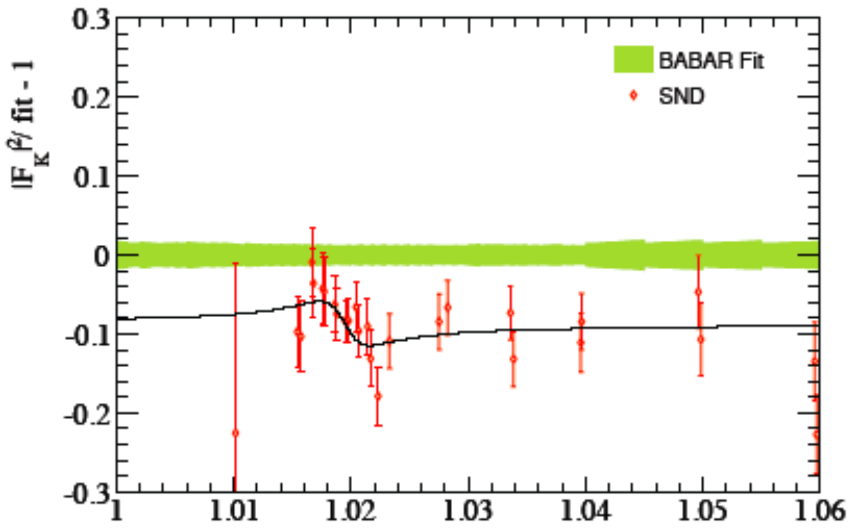
arXiv:1306.3600,

- $a_\mu = 22.94 \pm 0.18 \pm 0.22$ up to 1.8 GeV
  vs. $21.63 \pm 0.27 \pm 0.68$ for combined previous data
- significant shift up
- may need to take into account mass shift for best combination



- Comp. plots BaBar vs Novosibirsk:





Other important channels

Motivation of ISR study at BaBar

- Low energy e^+e^- cross section dominates in hadronic contribution to a_μ = (g-2)/2 of muon
- Direct e^+e^- data in 1.4 - 2.5 GeV region have very low statistic
- New inputs for the hadron spectroscopy at low masses and charmonium region

- ISR at BaBar gives competitive statistic
- BaBar has excellent capability for ISR study
- All major hadronic processes are under study (green == published)

$e^+e^- \to 2\mu\gamma,\ 2\pi\gamma,\ 2K\gamma,\ 2p\gamma,\ 2\Lambda\gamma,\ 2\Sigma\gamma,\ \Lambda\Sigma\gamma,\ \Lambda_c\Lambda_c\gamma$

$e^+e^- \to 3\pi\gamma$

$e^+e^- \to 2(\pi^+\pi^-)\gamma,\ K^+K^-\pi^+\pi^-\gamma,\ K^+K^-\pi^0\pi^0\gamma,\ 2(K^+K^-)\gamma$

$e^+e^- \to 2(\pi^+\pi^-)\pi^0\pi^0\gamma,\ 3(\pi^+\pi^-)\gamma,\ K^+K^-2(\pi^+\pi^-)\gamma$

$e^+e^- \to \pi^+\pi^-\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\pi^0\pi^0\gamma,\ \pi^+\pi^-\pi^0\eta\gamma$ ...

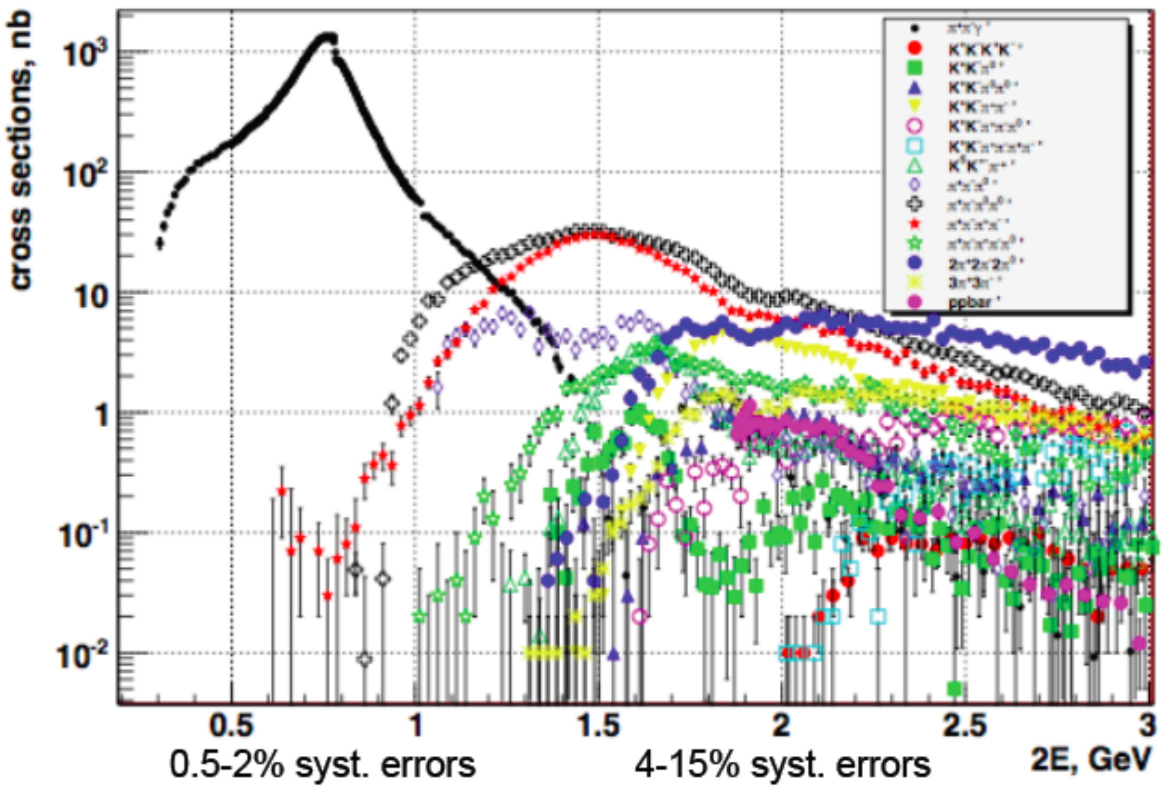
$e^+e^- \to K^+K^-\pi^0\gamma,\ K^+K^-\eta\gamma$ $(KK^*\gamma,\ \phi\pi^0\gamma,\ \phi\eta\gamma\ ...)$

$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^0/\eta\gamma,\ K^+K^-\pi^+\pi^-\pi^0/\eta\gamma$

$e^+e^- \to KK_S\pi\pi^0/\eta\gamma\ ,\ K_SK_L\ ,K_SK_L\pi^+\pi^-,\ K_SK_S\pi^+\pi^-(K^+K^-)$

Some reactions are being updated to full BaBar data with ~500fb^{-1}
(talk by V. Druzhinin on $e^+e^- \to 2p\gamma$)

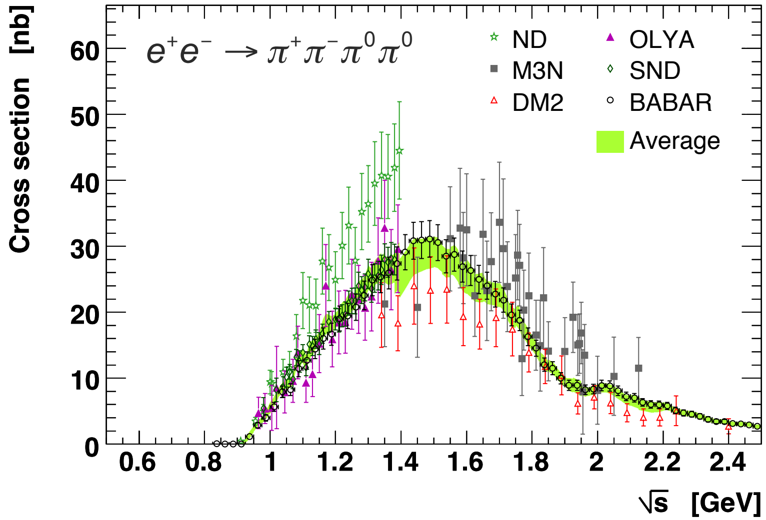
BaBar measurements summary

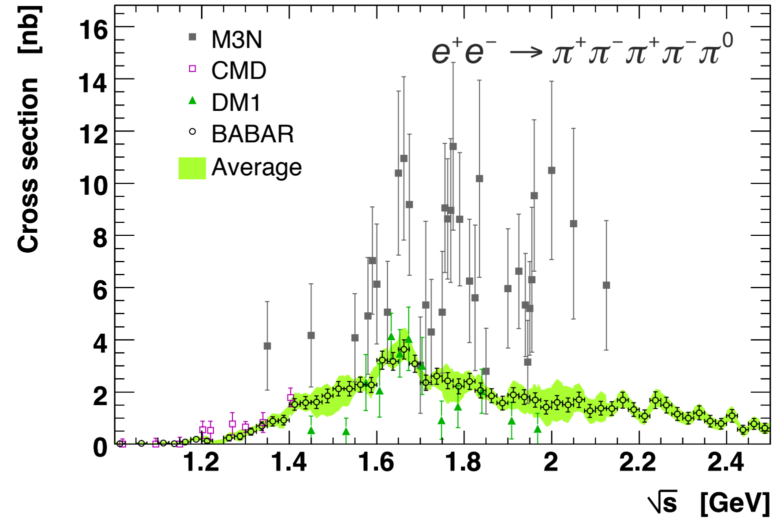


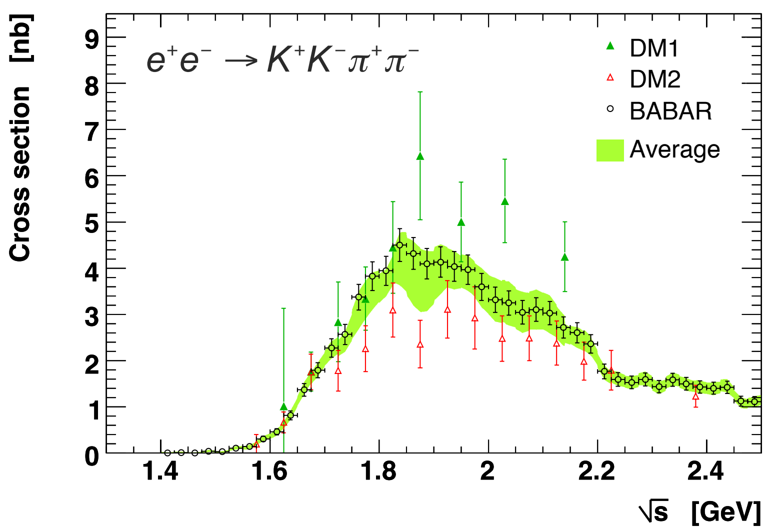
To calculate R in the energy range 1-2 GeV the processes $\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K_SK_L, $K_SK_L\pi\pi$, $K_SK^+\pi^-\pi^0$ are under study.
The $\pi^+\pi^-2\pi^0$ is still preliminary. Work is in progress.

Multihadron channels between 1 and 2.5 GeV

Davier *et al.*, EPJ C 71, 1515 (2011)







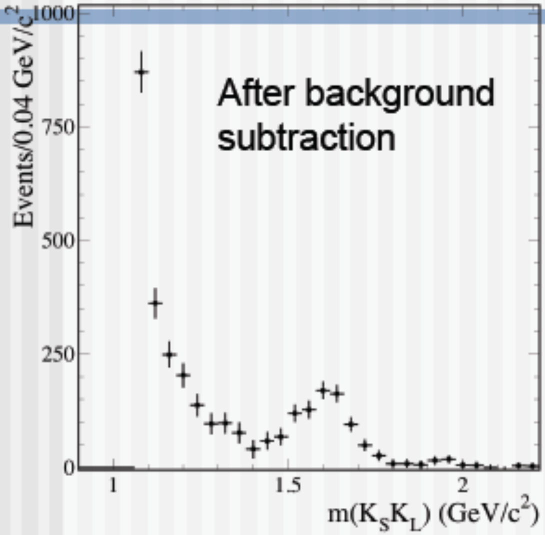
BABAR measured (almost) all the exclusive $e^+e^- \to$ hadrons modes

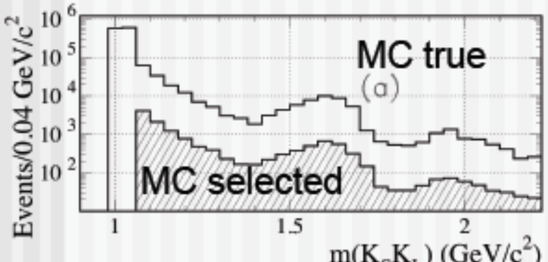
Many inconsistencies resolved

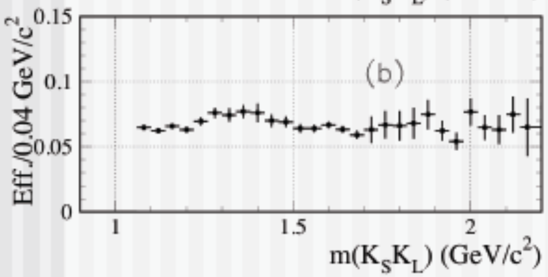
Huge impact on hadronic vacuum polarisation calculation

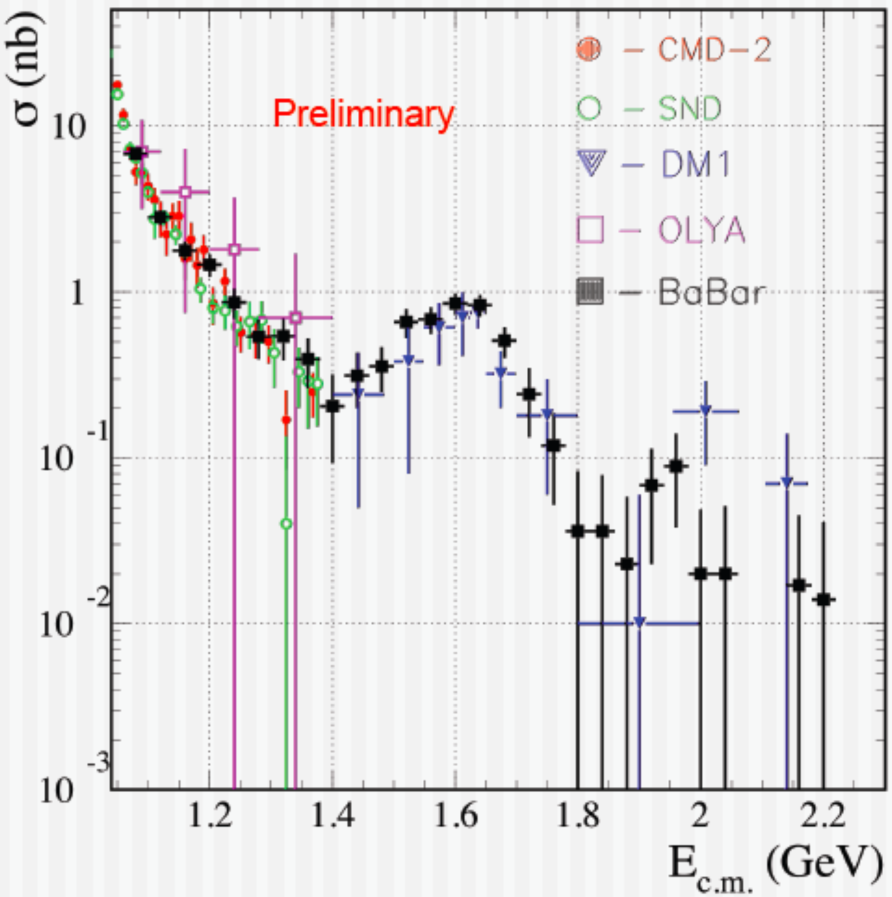
A.Hoecker LP 11

$e^+e^- \to K_S K_L$ cross section



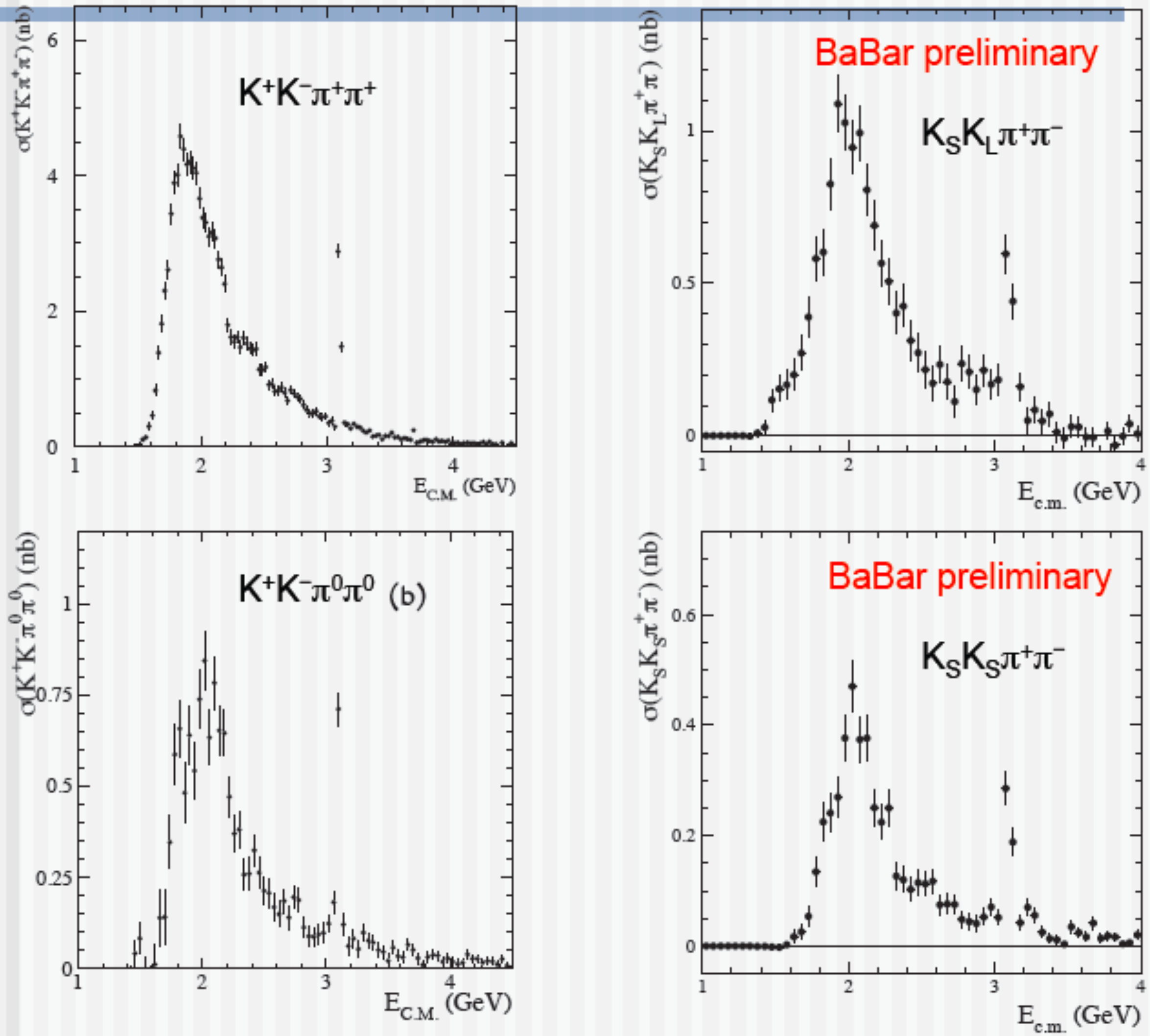






Systematic error ~10% (~30% for σ<0.3 nb), dominated by background subtraction procedure.

The cross sections comparison



$K^+K^-\pi^+\pi^+$ vs. $K^+K^-\pi^0\pi^0$ vs. $K_SK_L\pi^+\pi^-$ vs. $K_SK_S\pi^+\pi^-$

Only $K^*(892)^+K^*(892)^-$ contribution can be compared using iso-spin relations:

E. Solodov,
Phipsi13, Rome,
9-12 September 2013

$N(K^+K^-\pi^+\pi^-) = 548 \pm 263$ eff= 22% ($K^*(892)^0K^*(892)^0$)

$N(K^+K^-\pi^0\pi^0) = 1750 \pm 60$ eff= 8%

$N(K_SK_L\pi^+\pi^-) = 2098 \pm 209$ eff= 5%

$N(K_SK_S\pi^+\pi^-) = 742 \pm 104$ eff= 4.5%

Iso-spin relations: ArXiv:1010.4180 (Davier)

$N(K^+K^-\pi^0\pi^0) = ¼\, N(K^0\underline{K}^0\,\pi^+\pi^-)$
$N(K_SK_L\pi^+\pi^-) = ½\, N(K^0\underline{K}^0\,\pi^+\pi^-)$
$N(K_SK_S\pi^+\pi^-) = N(K_LK_L\pi^+\pi^-) = ¼\, N(K^0\underline{K}^0\,\pi^+\pi^-)$

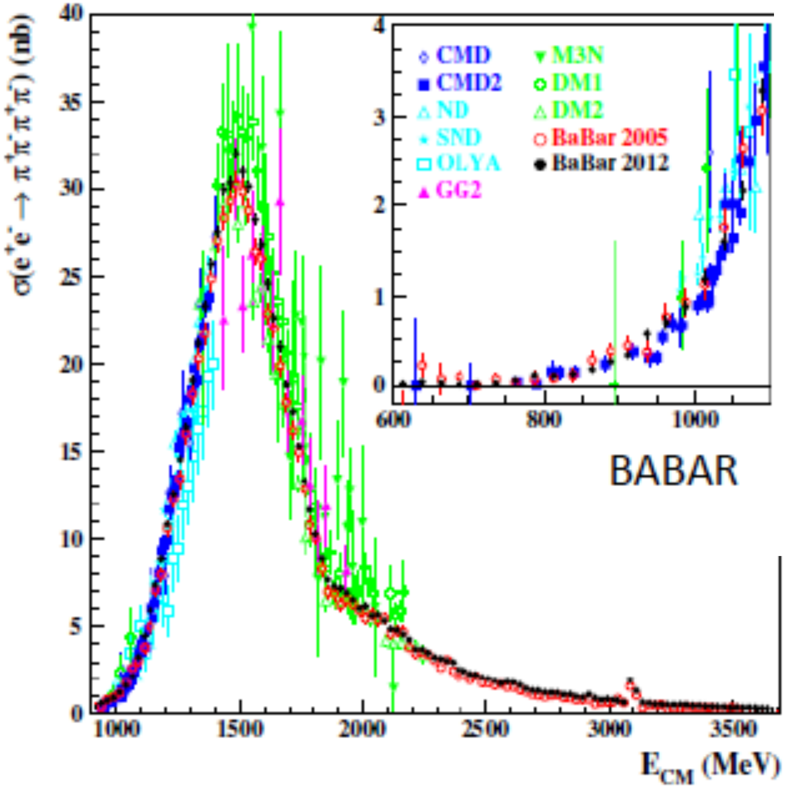
Should be (after efficiency correction) :

2188 ± 76 ~ 2098 ± 209 ~ 1648 ± 232 Some tension (~2 sigma)

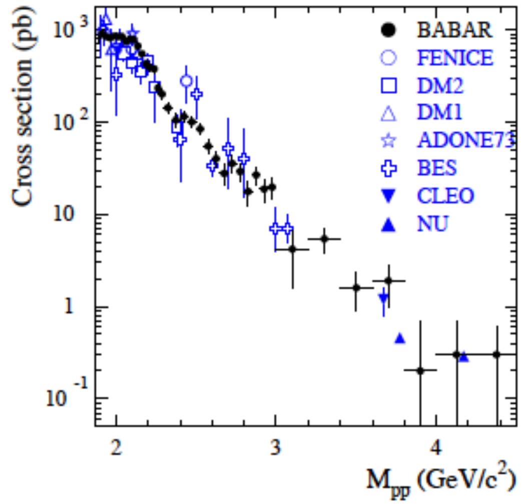
30% 63% 50% of all events – how the rest are related?
to g-2 relation?

New cross section results

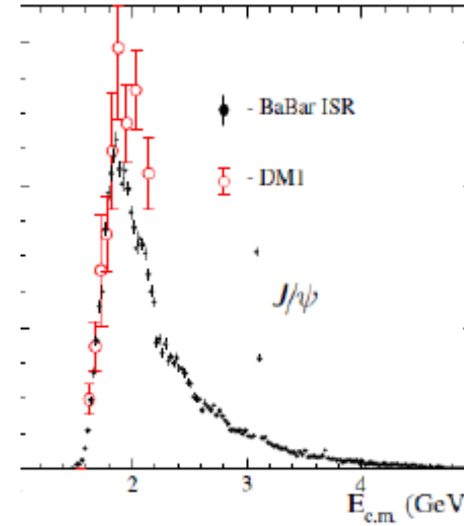
$e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-(\gamma)$



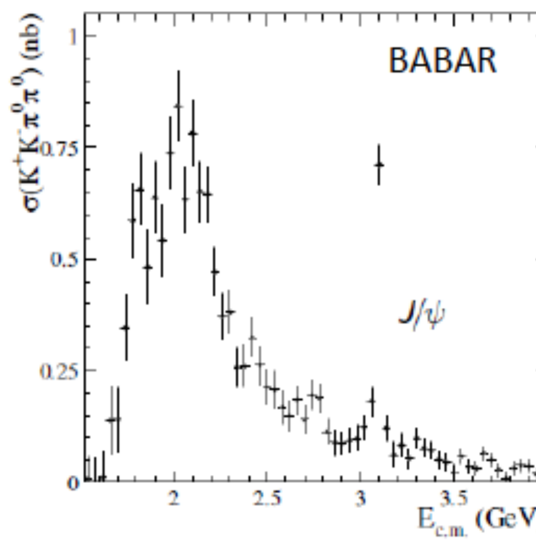
$e^+e^- \rightarrow p\bar{p}$



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



Systematic uncertainties btw 2-15%



$e^+e^- \rightarrow K^+K^-\pi^0\pi^0$

- < 1.4 GeV: agreement with previous *BABAR* results, SND and CMD-2 data
- > 1.4 GeV: highest precision (DM2, 20%)

Physics program

CMD3

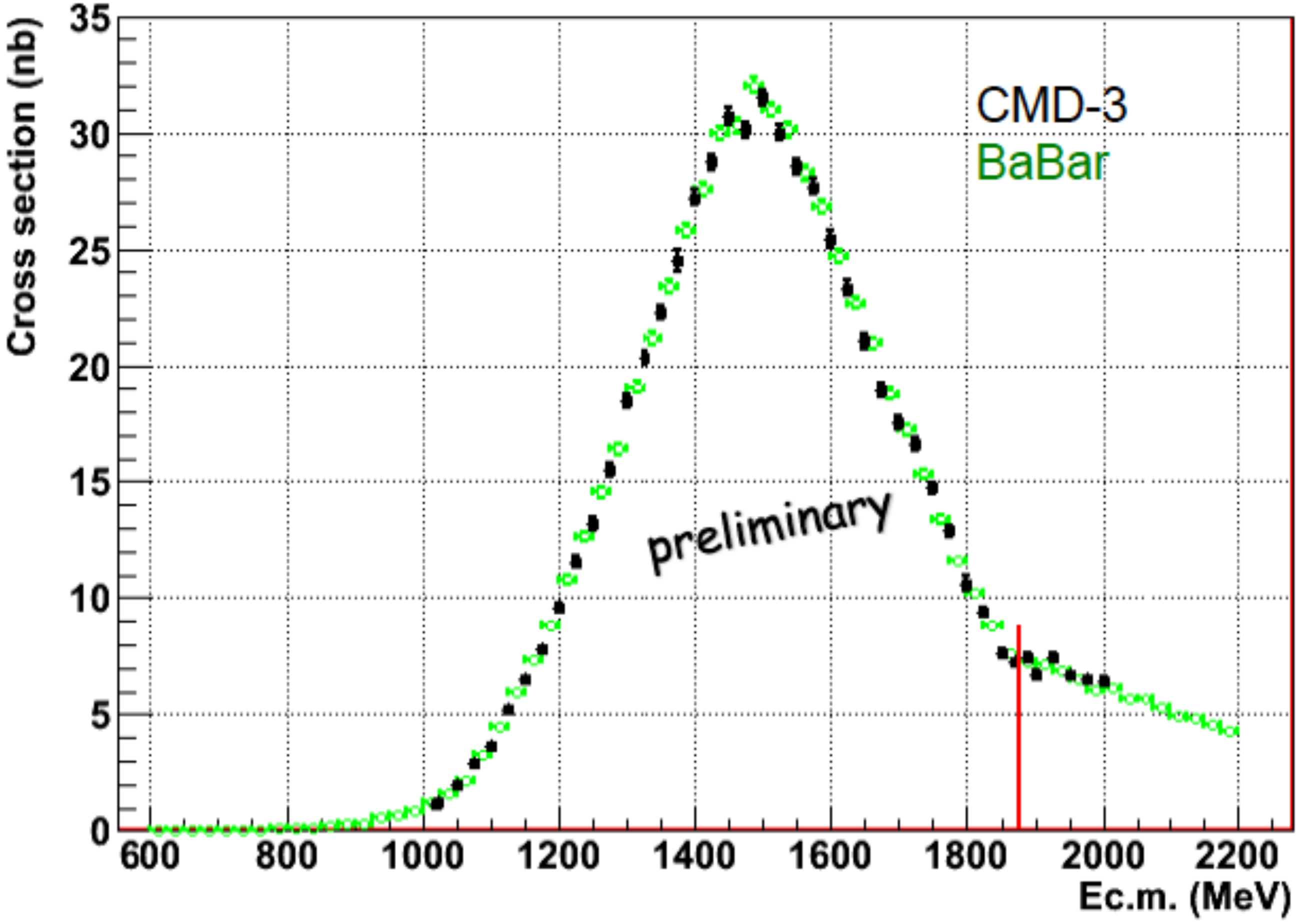
1. Precision measurement of $R = \sigma(e^+e^- \to hadrons)/\,\sigma(e^+e^- \to \mu^+\mu^-)$
   exclusive approach, up to <1% for major modes
2. Study of hadronic final states:
   $$e^+e^- \to 2h, 3h, 4h, \ldots \quad h = \pi, K, \eta$$
3. Study of vector mesons and theirs excitations:
   $$\rho', \rho'', \omega', \varphi', \ldots$$
4. Comparison of cross-sections $e^+e^- \to hadrons\ (T=1)$ with spectral functions of τ-decays
5. Study of nucleon electromagnetic formfactor at threshold
   $$e^+e^- \to p\bar{p}, n\bar{n}$$
6. Measurement of the cross-sections using ISR
7. Study of higher order QED processes

Overall, we plan to collect 0.5 ÷ 1 1/fb

Similar for SND

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

CMD3



Statistical errors 1-2% per point, systematics under study

Dynamics: confirm $a_1(1260)\pi$ dominance, $\rho f_0(600)$, $\rho f_0(980)$ are seen

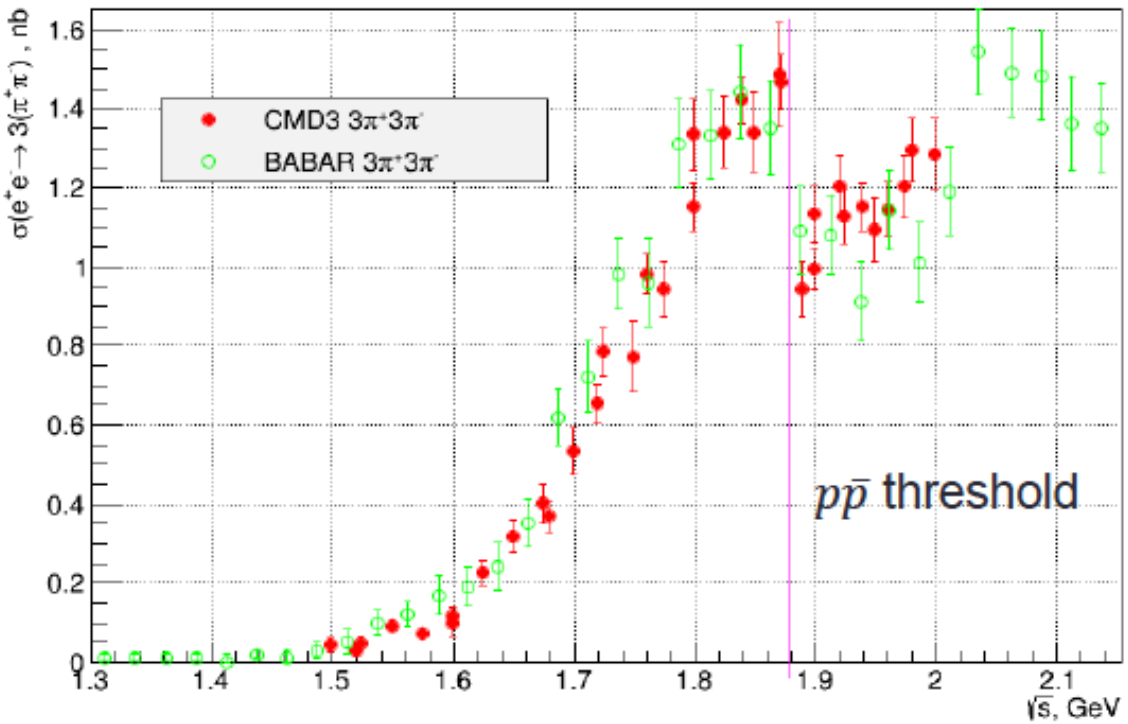
$e^+e^- \to \pi^+\pi^-\pi^+\pi^-\pi^+\pi^-$

CMD3

First result, published by CMD-3:
Phys.Lett. B723 (2013) 82-89

Based on about 22 1/pb, 8000 events selected

Systematic error is 6%, main source is model dependence, will be reduced with more statistics



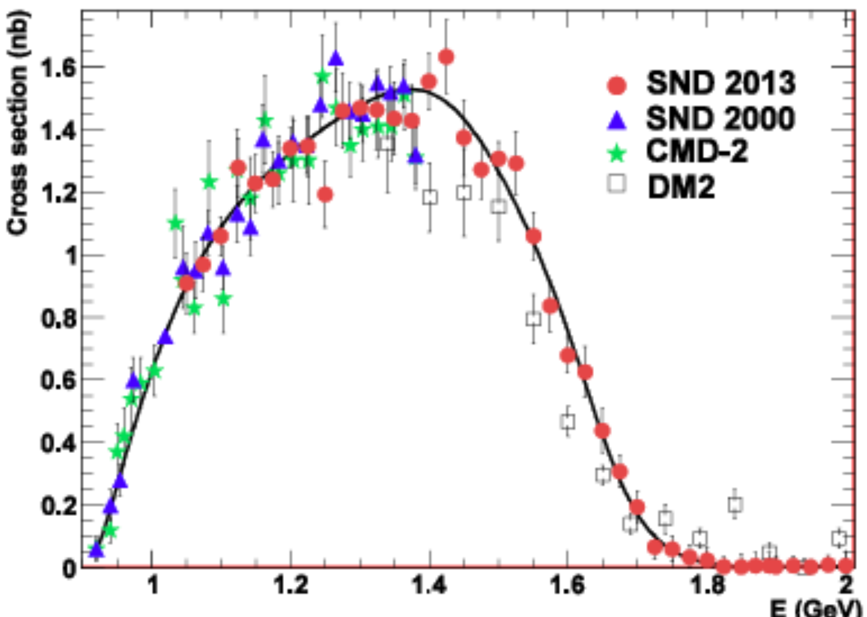
Preliminary studies of dynamics:

- Main production mode: $\rho(770) + 4\pi$ (phase space or $f_0(1370)$)
- Hint of energy dependent dynamics in 1.7-1.9 GeV energy range

Process $e^+e^- \to \omega\pi^0 \to \pi^0\pi^0\gamma$ (30 pb^{-1})

(arXiv:1303.5198[hep-ex])

The most accurate measurement for 2E>1.4GeV



Selection criteria:

$\geq 5\ \gamma$; no charged particles;
total energy depos. > E_{beam};
kinematic fits:
$\chi^2_{5\gamma} < 30$; $\chi^2_{\pi 0\pi 0\gamma} - \chi^2_{5\gamma} < 10$;
$|M_{\pi 0\gamma} - M_{\omega}| < 100$ MeV

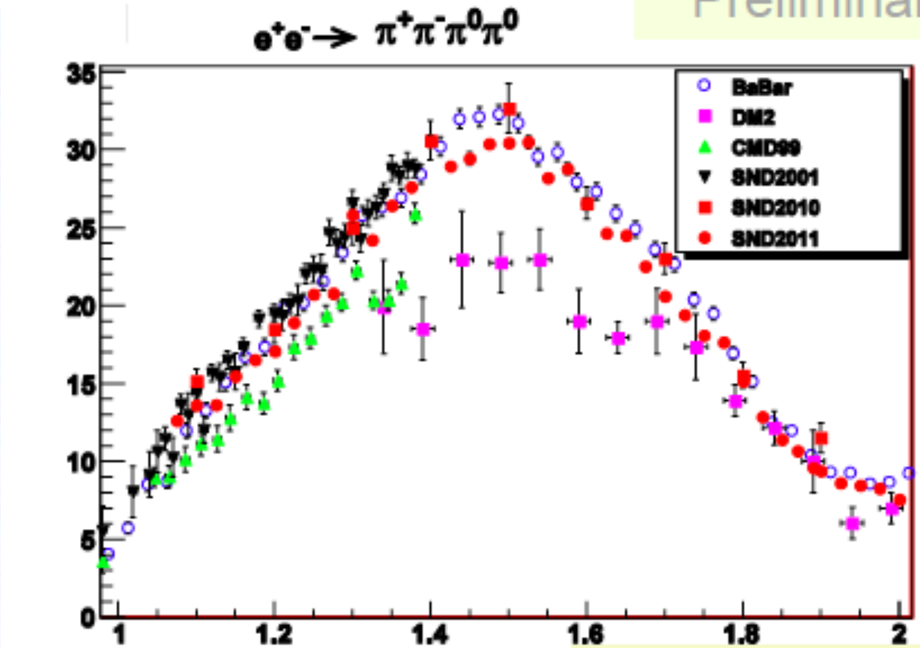
SND using CVC hypothesis:
$Br(\tau^- \to \omega\pi^-\nu_\tau) = (1.96 \pm 0.02 \pm 0.10)\%$
PDG:
$Br(\tau^- \to \omega\pi^-\nu_\tau) = (1.95 \pm 0.08)\%$
No difference within experimental accuracy.

Systematic error: 3.4%
(2E<1.55 GeV)

Fit:
sum of $\rho(770)$, $\rho'(1450)$, $\rho''(1700)$

Process $e^+e^- \longrightarrow \pi^+\pi^-\pi^0\pi^0$ ($30 pb^{-1}$)

Preliminary



Only statistical errors

Systematics ≤ 10%

Selection criteria :

- at least 2 charged particles and 4 γ's;
- 2 tracks are from IP;

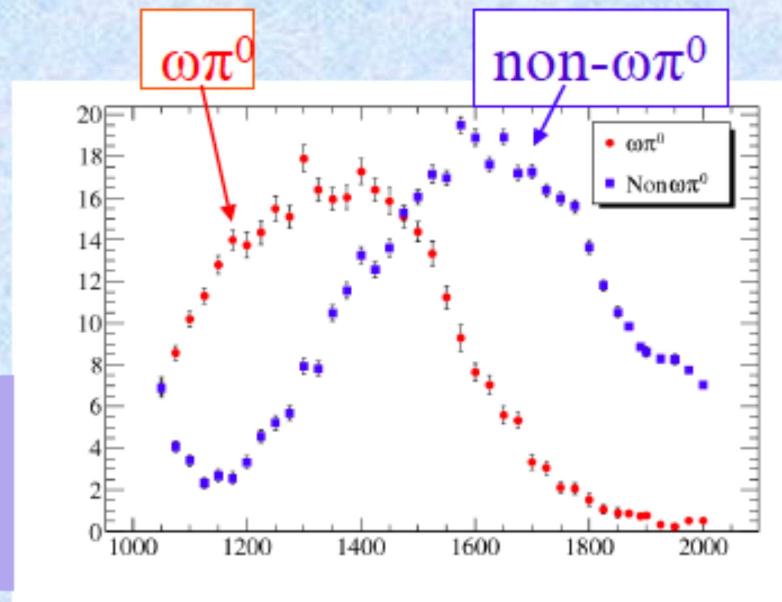
Kinematic fit:

$\chi^2 < 40$

$M_{\pi 0}$ in 70-200 MeV.

The bump is a sum of contributions of ρ(770), ρ′(1450), ρ″(1700).

Main feature –
many intermediate states:
$\omega\pi^0$, $a_1\pi$, $\rho\pi\pi$, $\rho^+\rho^-$, ρf_0.



BES dominates the precision between 2 and 5 GeV

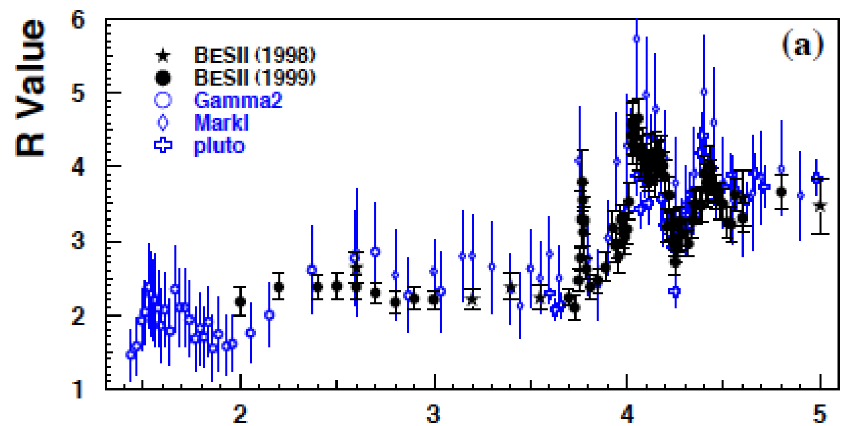
- BESII @ BEPC, Beijing (inclusive measurement) $2 < E_{cm} < 5$ GeV
  - 1998/99 new result of R in $2 < E_{cm} < 5$ GeV from BESII, 91 points with $\sigma_R/R \sim 7\%$ (improvement of a factor **2**)

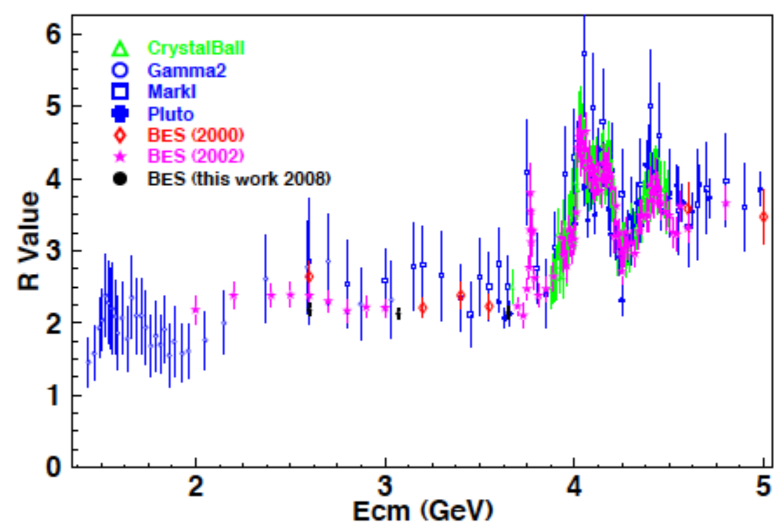
  2008: 3 points (2.6, 3.07 and 3.65 GeV) with 3.5% precision

$$R = \frac{N_{had}^{obs} - N_{bg} - \sum_l N_{ll} - N_{\gamma\gamma}}{\sigma_{\mu\mu}^0 \cdot L \cdot \epsilon_{trg} \cdot \bar{\epsilon}_{had} \cdot (1+\delta)},$$

TABLE II. Contributions to systematic errors: experimental selection of hadronic events, luminosity determination, theoretical modeling of hadronic events, trigger efficiency, radiative corrections and total systematic error. All errors are in percentages (%).

E_{cm} (GeV)	hadron selection	L	M.C. modeling	trigger	radiative correction	total
2.000	7.07	2.81	2.62	0.5	1.06	8.13
3.000	3.30	2.30	2.66	0.5	1.32	5.02
4.000	2.64	2.43	2.25	0.5	1.82	4.64
4.800	3.58	1.74	3.05	0.5	1.02	5.14

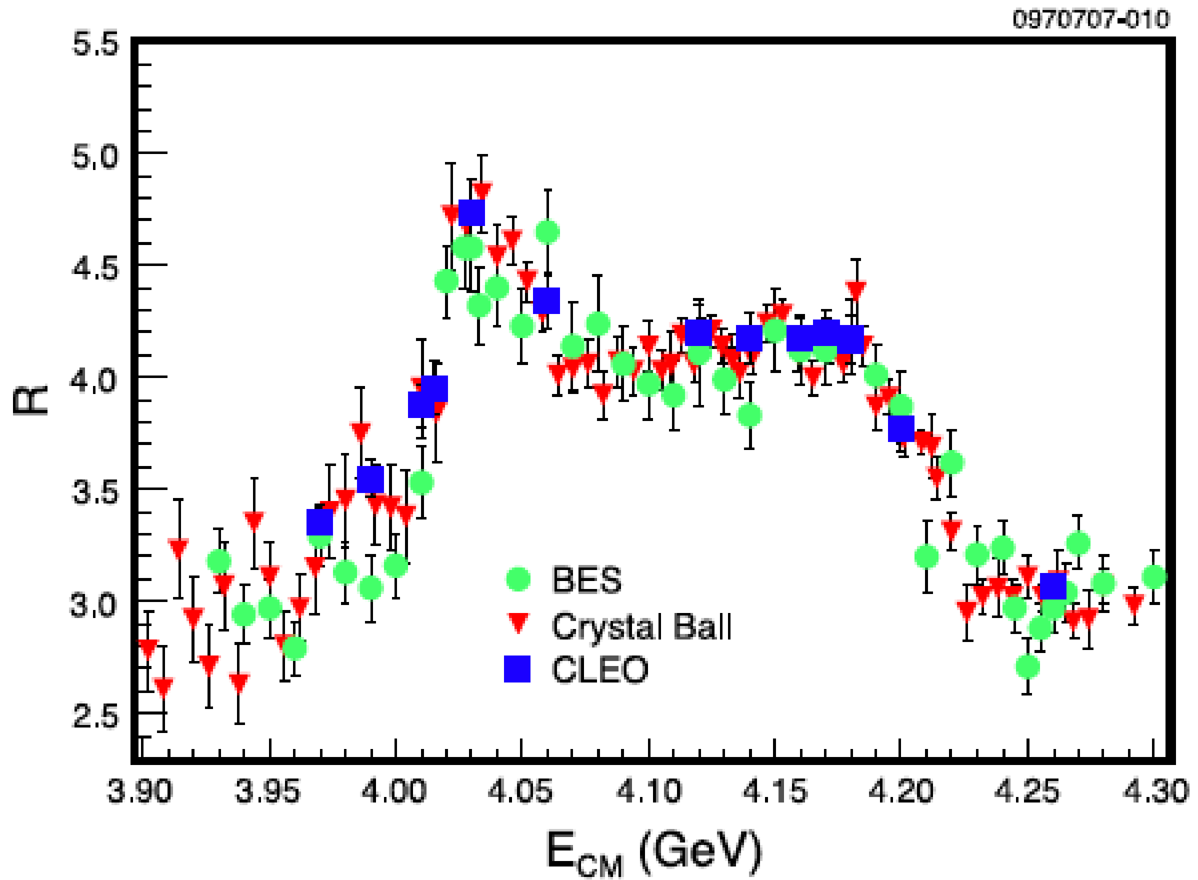




R measurement at CLEO

- CLEO@ CESR, Ithaca (inclusive measurement) $3.9 < E_{cm} < 4.3$ GeV
  - New result on R (inclusive measurement) in $3.97 < E_{cm} < 4.26$ GeV (above the open charm threshold) with a δ_{sys} between 5.2 and 6.1%. In agreement with the sum of exclusive measurement and previous experiments

Energy (MeV)	R (ISR-corrected)
3970	$3.36 \pm 0.04 \pm 0.05$
3990	$3.55 \pm 0.05 \pm 0.06$
4010	$3.88 \pm 0.04 \pm 0.08$
4015	$3.95 \pm 0.08 \pm 0.08$
4030	$4.74 \pm 0.07 \pm 0.12$
4060	$4.34 \pm 0.05 \pm 0.10$
4120	$4.21 \pm 0.06 \pm 0.10$
4140	$4.18 \pm 0.04 \pm 0.10$
4160	$4.18 \pm 0.03 \pm 0.10$
4170	$4.20 \pm 0.01 \pm 0.10$
4180	$4.17 \pm 0.04 \pm 0.10$
4200	$3.77 \pm 0.05 \pm 0.08$
4260	$3.06 \pm 0.02 \pm 0.04$



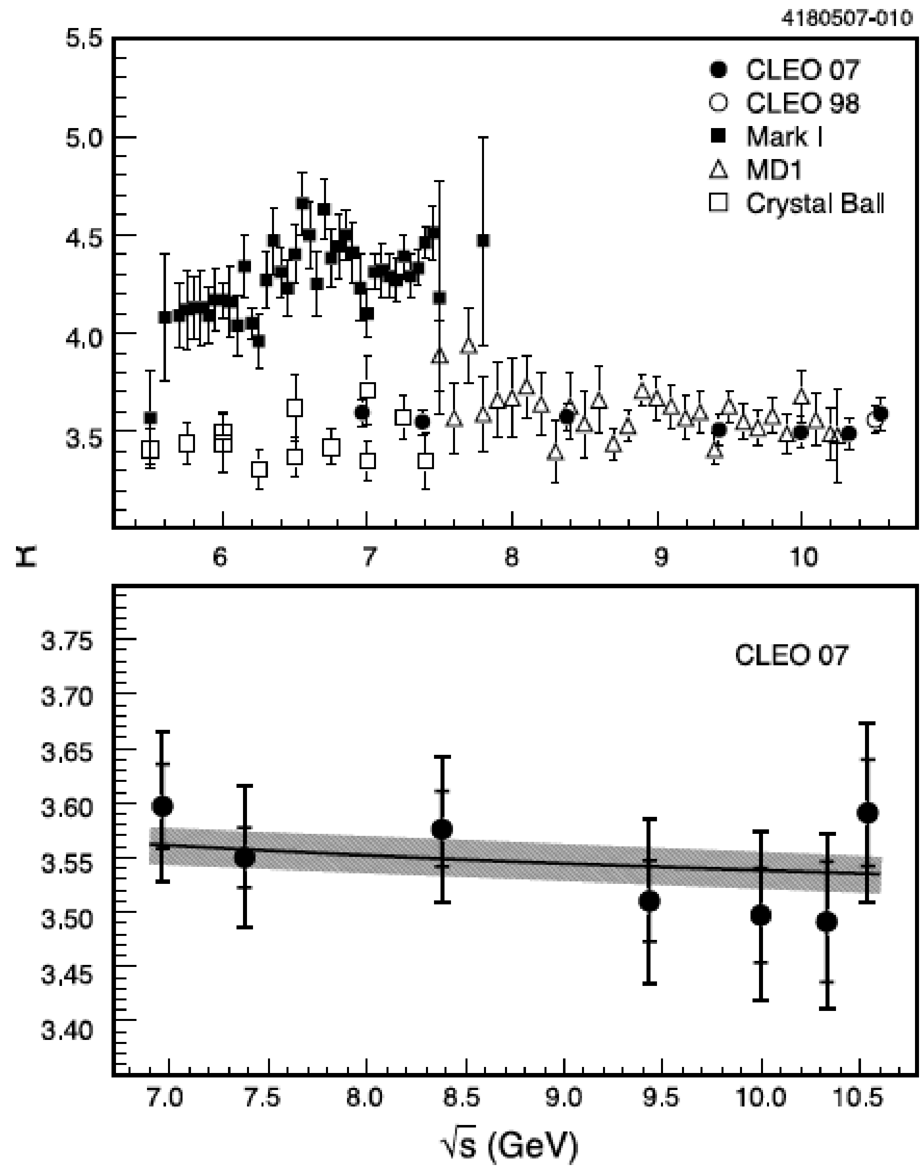
R measurement at CLEO

- CLEO@ CESR, Ithaca (inclusive measurement) 6.9 <E_{cm}<10..5 GeV

  - New result on R (inclusive measurement) in 6.964<E_{cm}<10.538 GeV (7 points) with a δsys of ~ 2%. In agreement with previous experiments (but MARKI) and pQCD (Λ=0.31 GeV)

$$R = \frac{N_{had}(1-f)}{\mathcal{L}\epsilon_{had}(1+\delta)\sigma^0_{\mu\mu}},$$

ε(1+δ)	1%
L	1%
Bckg/Hadr Modeling	0.7%
Dataset variation	0.3%
TOTAL	**1.8%**



$a_\mu=(g_\mu-2)/2$:

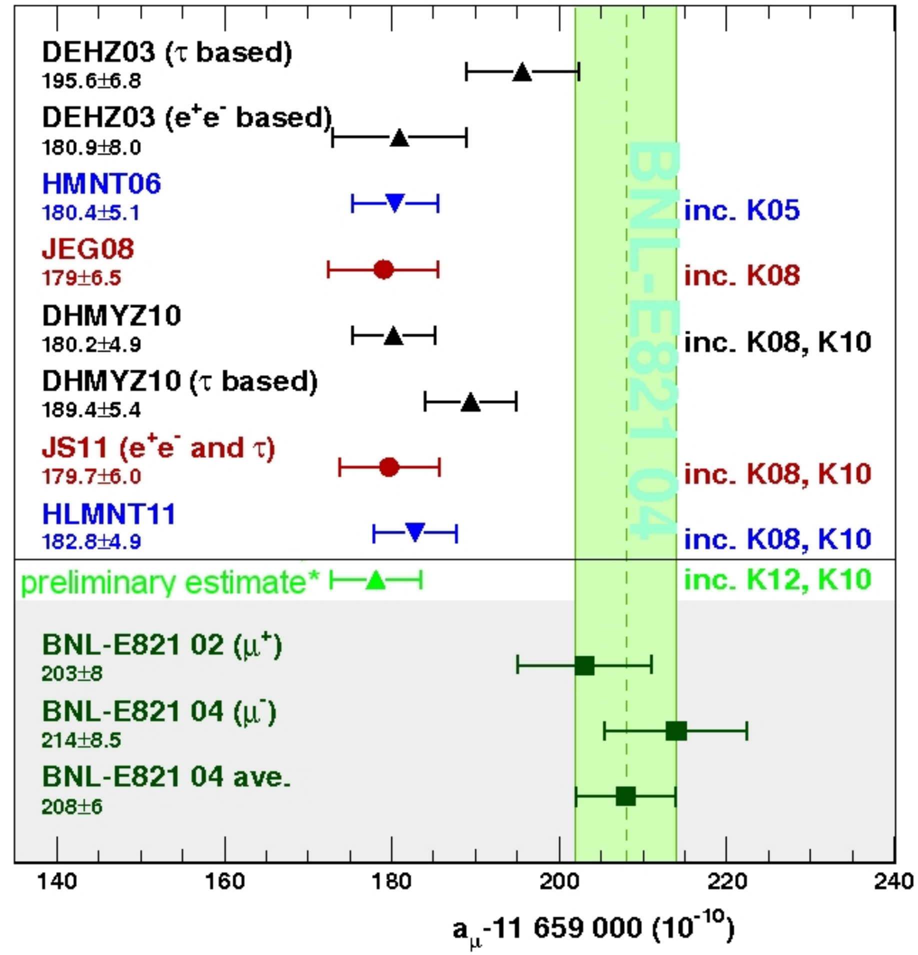
Theoretical predictions compared to the BNL result

- The latest inclusion of all e^+e^- data gives a discrepancy btw a_μ^{SM} and a_μ^{EXP} of 3 to 4σ

- Some differences on $\sigma_{\pi\pi}$ btw different experiments (mainly KLOE/BaBar) to be clarified [Δa_μ^{EXP-SM} =2.4÷3.7σ]

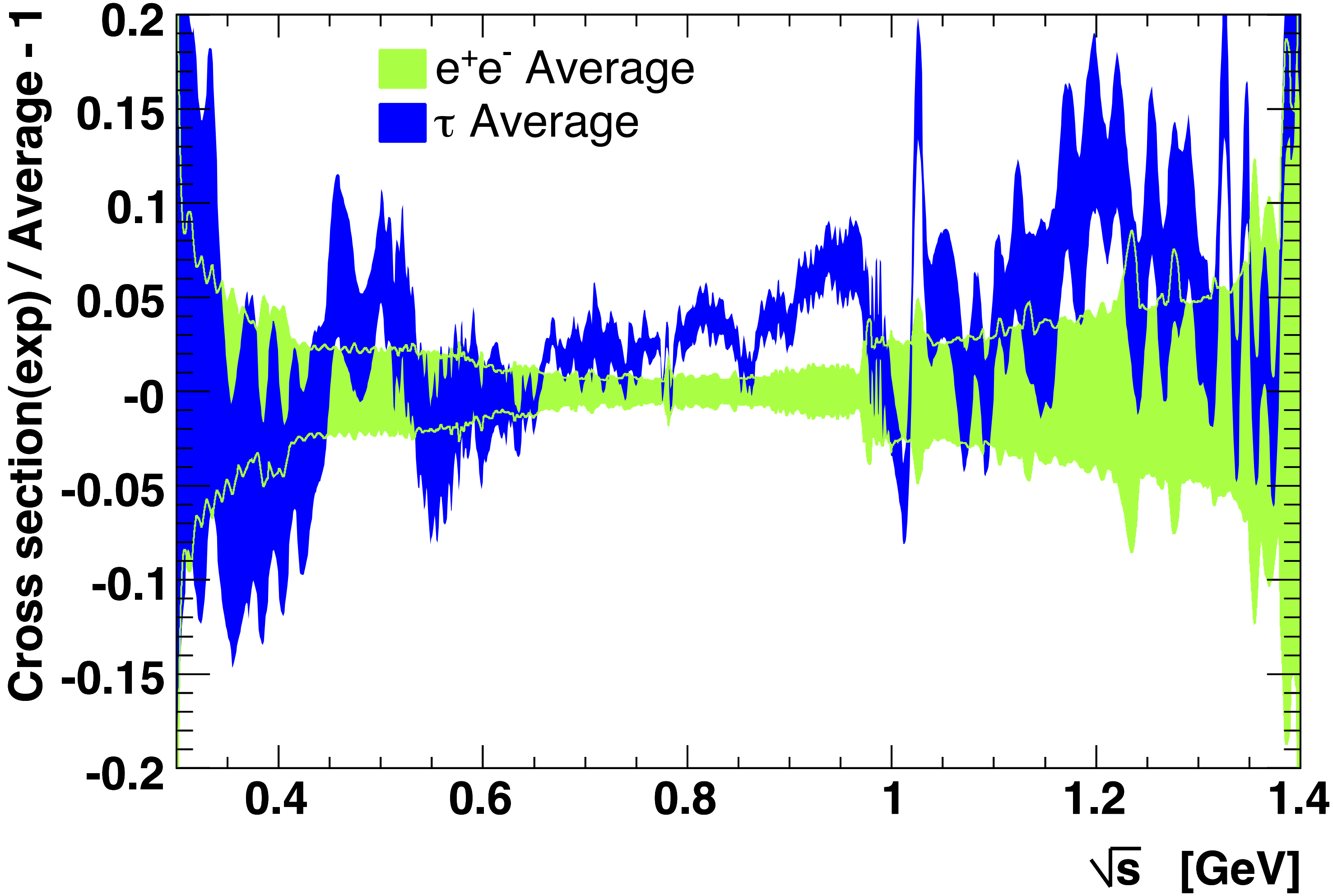
- (Reduced) discrepancy btw ee and τ data (new I. corr.,ee,τ data). JS11 claims to have solved it

- Very important the new g-2 experiments (at FNAL and JPARC)!



* Our extrapolation based on DHMYZ10

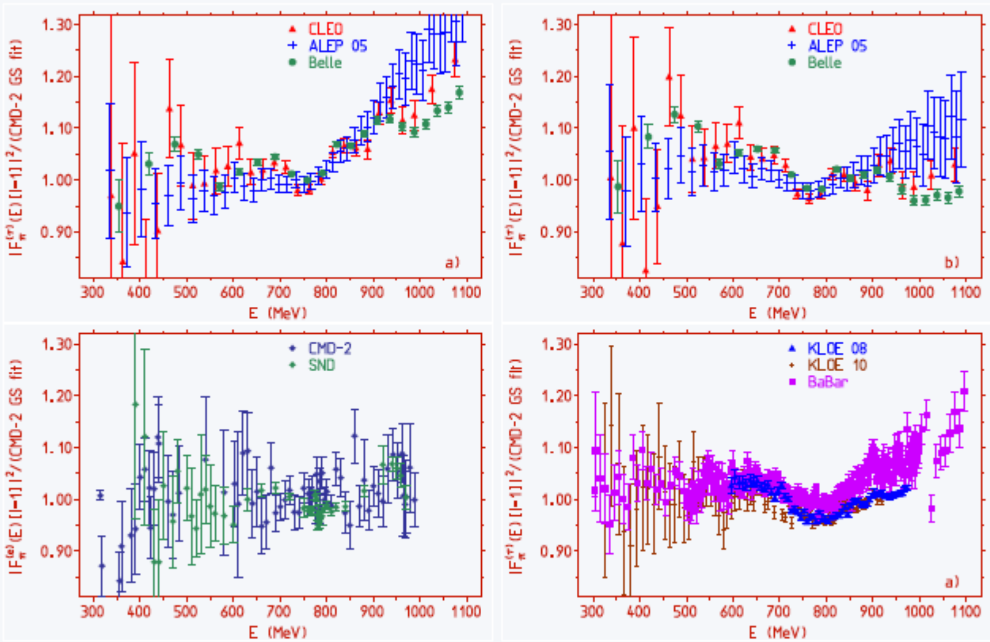
Two-pion e^+e^- vs τ spectral functions



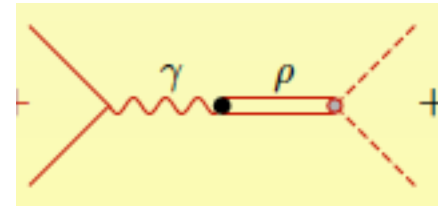
Missing isospin corrections and/or problems with data? Additional data are needed. Meanwhile…

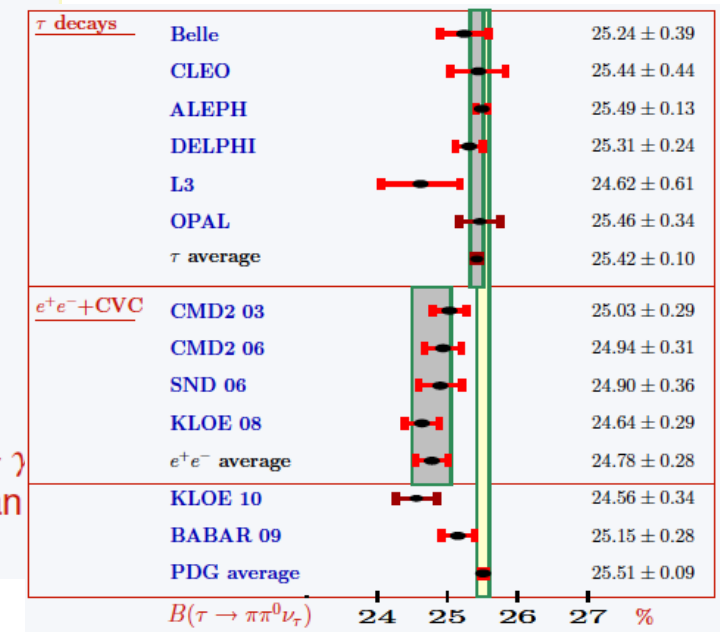
Jegerlehner and Szafron claim that the e^+e^- vs τ is solved if an additional correction ($\rho-\gamma$ loop mix.) is included

F. Jegerlehner and R. Szafron, Eur. Phys. J. C71 (2011) 1632



$|F_\pi(E)|^2$ in units of e^+e^- I=1 (CMD-2 GS fit): a) τ data uncorrected for $\rho-\gamma$ mixing, and b) after correcting for mixing. Lower panel: e^+e^- energy scan data [left] and e^+e^- radiative return data [right]





$$a_\mu^{\mathrm{had,LO}}[e,\tau] = 690.96(1.06)(4.63)\times 10^{-10} \quad (e+\tau)$$

JS 11

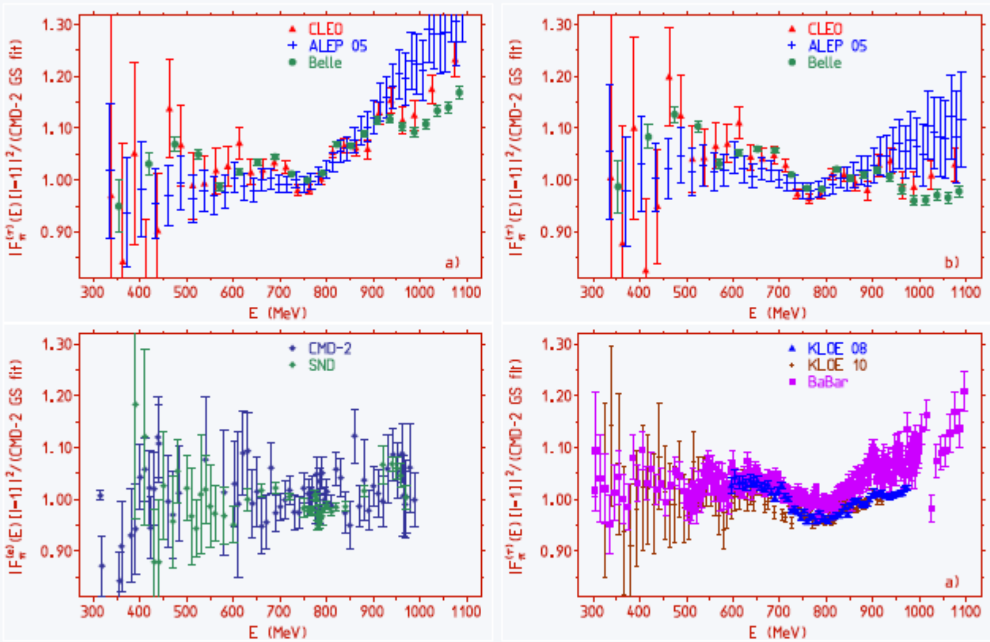
$$a_\mu^{\mathrm{had,LO}}[e^+e^-] = (692.3 \pm 4.2_{ee+QCD})\times 10^{-10}$$

$$a_\mu^{\mathrm{had,LO}}[\tau] = (701.5 \pm 3.5_\tau \pm 1.9_{SU(2)} \pm 2.4_{ee+QCD})\times 10^{-10}$$

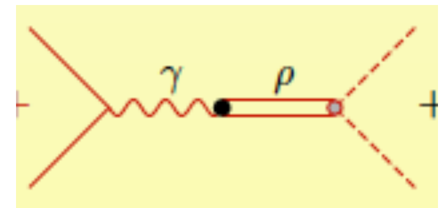
DHMZ 11

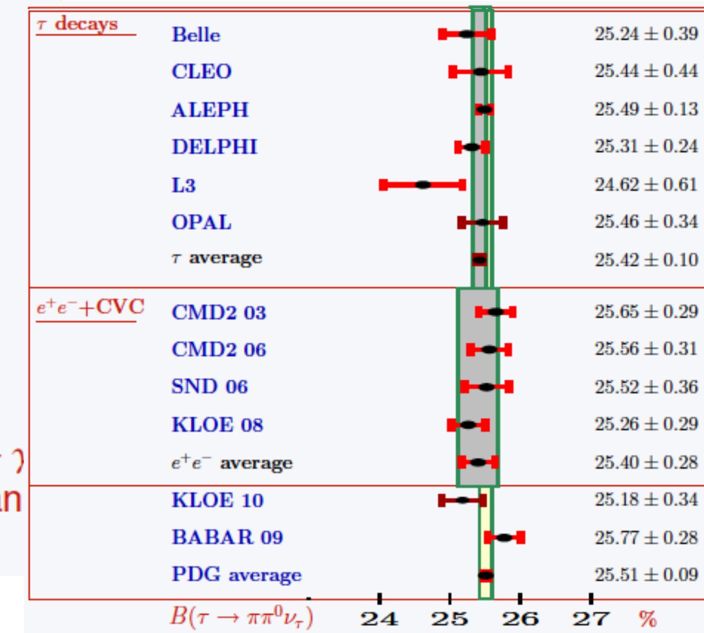
Jegerlehner and Szafron claim that the e^+e^- vs τ is solved if an additional correction ($\rho-\gamma$ loop mix.) is included

F. Jegerlehner and R. Szafron, Eur. Phys. J. C71 (2011) 1632



$|F_\pi(E)|^2$ in units of e^+e^- I=1 (CMD-2 GS fit): a) τ data uncorrected for $\rho-\gamma$ mixing, and b) after correcting for mixing. Lower panel: e^+e^- energy scan data [left] and e^+e^- radiative return data [right]





$$a_\mu^{\mathrm{had,LO}}[e,\tau] = 690.96(1.06)(4.63) \times 10^{-10} \quad (e+\tau)$$

JS 11

$$a_\mu^{\mathrm{had,LO}}[e^+e^-] = (692.3 \pm 4.2_{ee+QCD}) \times 10^{-10}$$

$$a_\mu^{\mathrm{had,LO}}[\tau] = (701.5 \pm 3.5_\tau \pm 1.9_{SU(2)} \pm 2.4_{ee+QCD}) \times 10^{-10}$$

DHMZ 11

An Update of the HLS Estimate of the Muon $g - 2$

M. Benayoun[a], P. David[a], L. DelBuono[a], F. Jegerlehner[b,c]

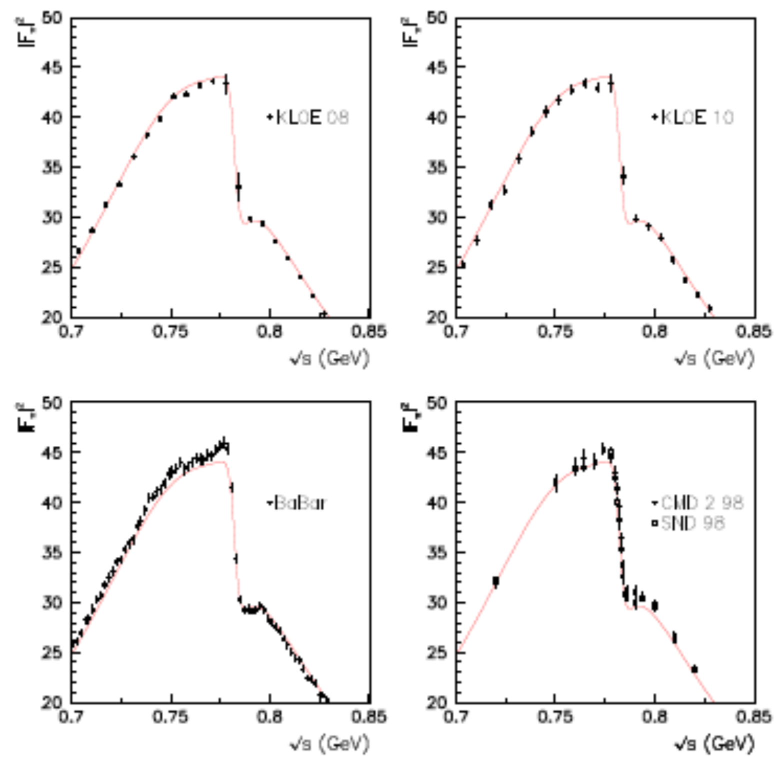
Using the KLOE10 and the scan data samples leads to the most probable value for the muon anomalous moment :

EPJ C73 (2013) 2453

$$a_\mu^{th} = (11\,659\,169.55 + \left[{}^{+1.26}_{-0.59}\right]_\phi \pm 5.21_{th})\, 10^{-10} ,$$

which exhibits a significance for $\Delta a_\mu = a_\mu^{exp} - a_\mu^{th}$ at a $(4.7 \div 4.9)\sigma$ level, significantly larger than the results fully derived by direct numerical integration of the experimental cross sections.

Pion form factor prediction based on τ data and PDG information in excellent agreement with KLOE but not with BaBar



However, the picture becomes quite different in the medium energy region $(0.70 \div 0.85)$ GeV as illustrated by Figure 5. In this region, our τ+PDG prediction follows almost perfectly expectations[21] from both KLOE08 and KLOE10 data and the detailed lineshape at the $\omega - \rho$ interference region is strikingly reproduced. Paradoxically, the NSK data are slightly less fa-

In contrast, the behavior of the BaBar data looks inconsistent with the τ+PDG prediction, especially on the low mass side of the interference region. Actually, the observed overestimate of the BaBar spectrum affects the whole region from threshold to the ω mass but is more important in the range $(0.74 \div 0.78)$ GeV. At higher energies one observes a reasonable agreement

BHLS : A Global VMD Model

- The (Broken) Hidden Local Symmetry (BHLS) model :

➢ is a unified VMD framework encompassing

$e^+e^- \to \pi\pi$ /KKbar /$\pi\gamma$ /$\eta\gamma$ /$\pi\pi\pi$ & $\tau \to \pi\pi\nu_\tau$ & PVγ, P$\gamma\gamma$ decays & ($\eta/\eta' \to \gamma\pi\pi/\gamma\gamma$) & ……

➢ BHLS :: (almost) an empty shell :

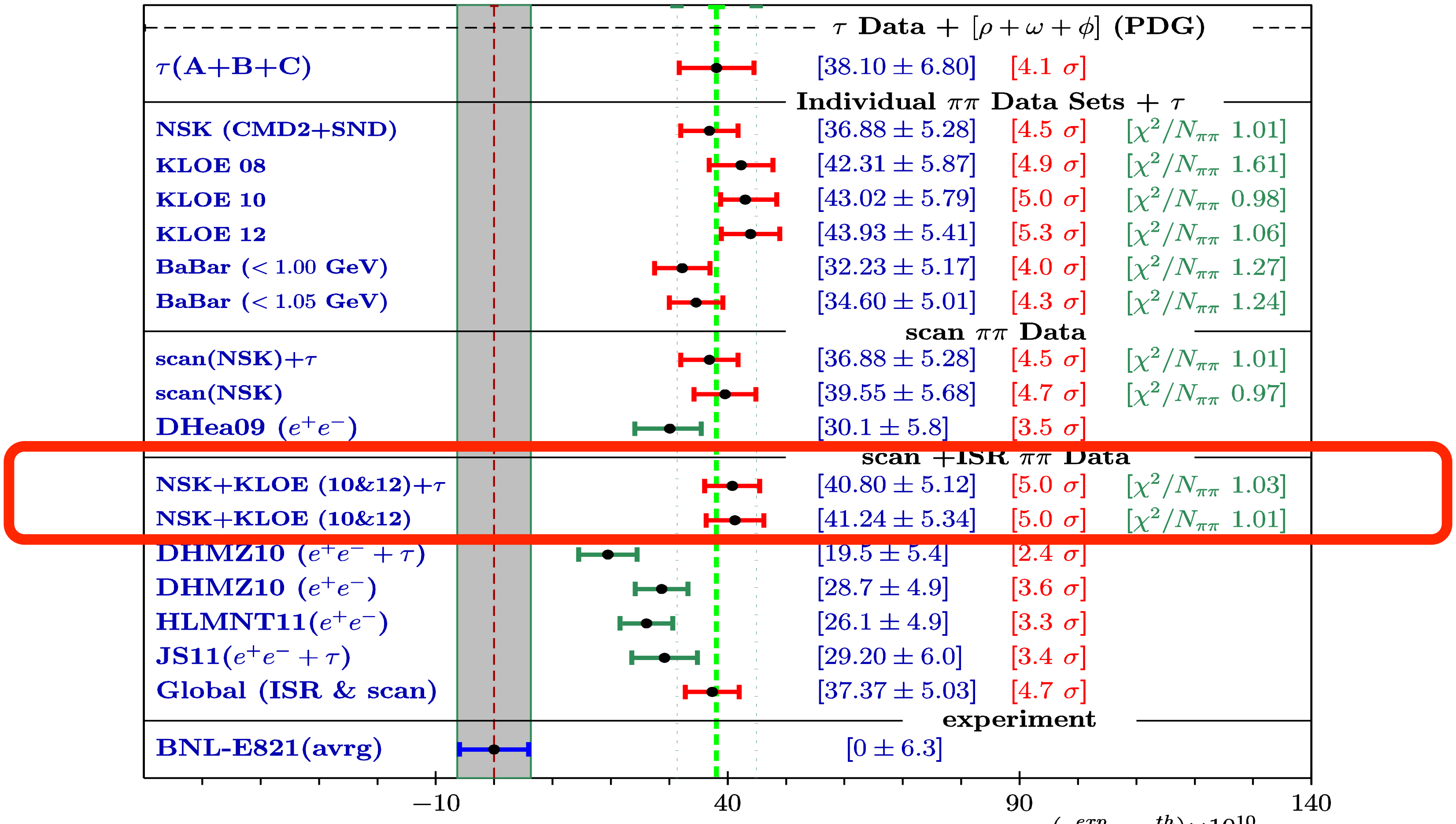
[α_{em}, G_F, f_π, V_{ud}, V_{us}, m_π's, m_K's, m_η, $m_{\eta'}$]

➢ Present Limits :

✓ Up to the ≈ φ mass region (≈ 1.05 GeV)

✓ No scalars mesons, no ρ', no ρ'' ……

g-2 HLS Estimates & Others

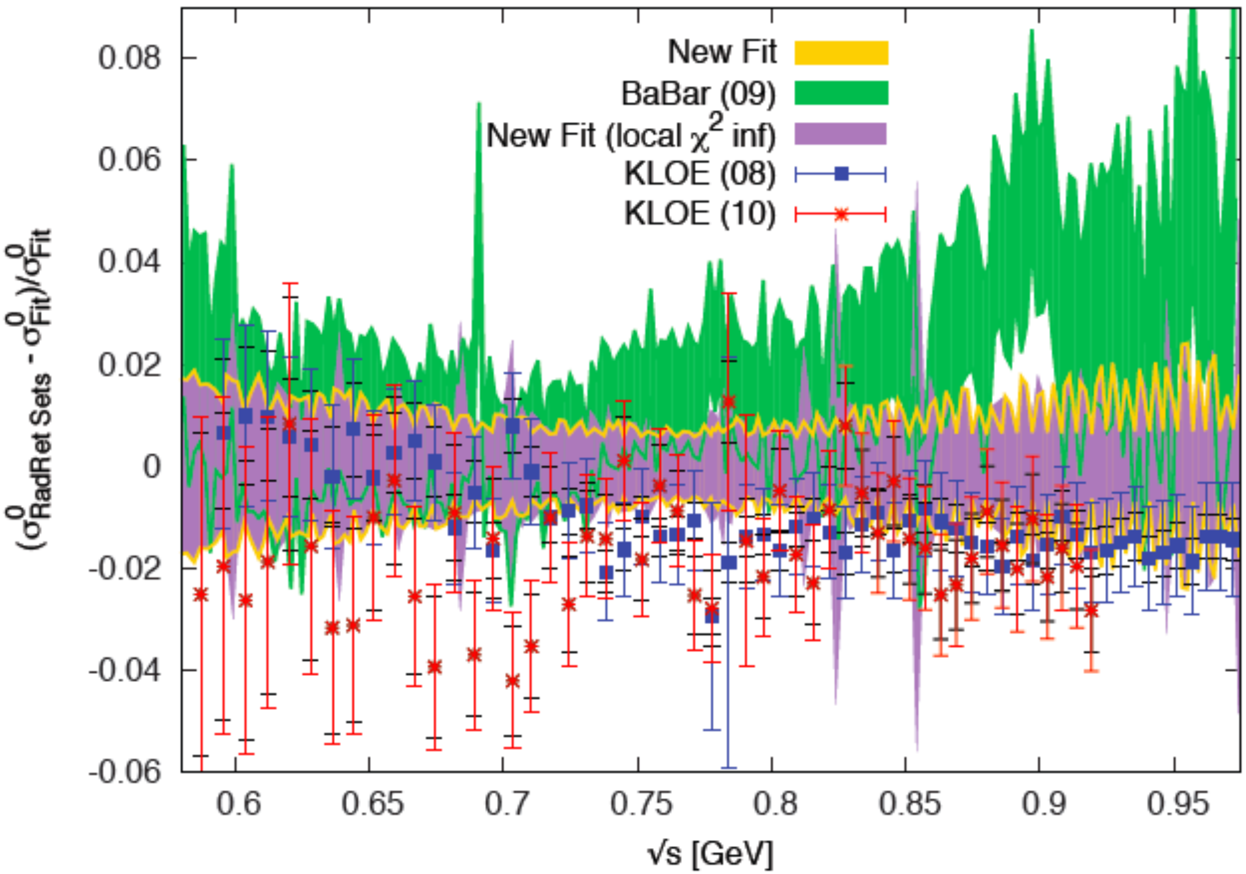


Discrepancy with BNL g-2 value range [4.6 to 5.2] σ

M. Benayoun, PHIPSI13, Rome, 9-12 September 2013

Data combination in the $\pi^+\pi^-$ channel

Radiative Return data in the combined fit of HLMNT 11



T. Teubner, PHIPSI13, Rome, 9-12 September 2013

2π fit: overall $\chi^2_{min}/dof \sim 1.5$

Note: $a_\mu^{\pi\pi,\text{ w/out Rad Ret}} = 498.7 \pm 3.3$ BUT $a_\mu^{\pi\pi,\text{ with Rad Ret}} = 504.2 \pm 3.0$

➔ i.e. a shift of +5.5

Data combination in the $\pi^+\pi^-$ channel

- Benayoun et al: -3.1 from HLS-based fit, -4.3 from KLOE10+12
- HLMNT: +5.5 from KLOE and BaBar (compared to scan only)

- So the extreme difference (~13×10^{-10}) comes mostly from the data input, i.e. if BaBar's 2π is used or not.
  (If used: error relatively poor and inflated in addition.)

- How to solve this puzzle?

T. Teubner, RMCWG meeting, Frascati, 13 September 2013

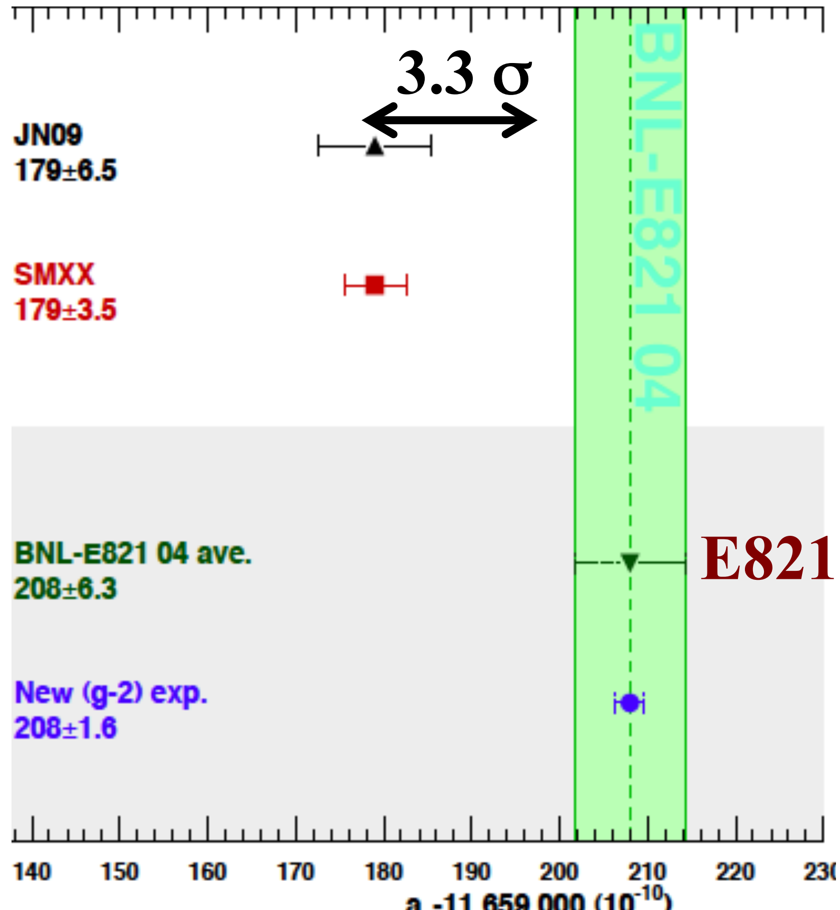
- Future SND, CMD-3, BELLE and BESIII 2π data may dilute the strong significance of BaBar.
  Would be better to find out why the diffferent data sets are not consistent. If this can be achieved the 2π channel would be great!

➔ possible task for our WG: MC checks, comparison of analyses

A rough estimate for g-2: now

$a_\mu^{exp} - a_\mu^{theo,SM} = (27.7 \pm 8.4)10^{-10}$ (3.3σ)

$8.4 = {\sim}5_{HLO} \oplus {\sim}3_{HLbL} \oplus 6_{BNL}$



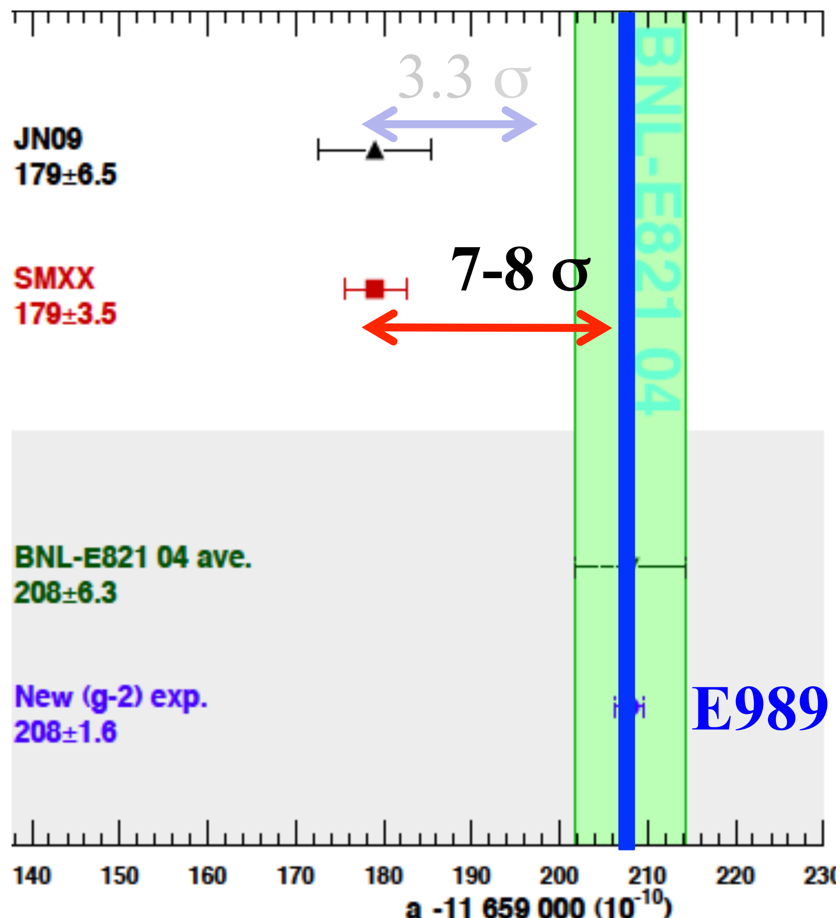
$\delta a_\mu^{HLO} = 5.3 = 3.3(\sqrt{s} < 1GeV) \oplus 3.9(1 < \sqrt{s} < 2GeV) \oplus 1.2(\sqrt{s} > 2GeV)$

A rough estimate for g-2: …and (possible) future

$a_\mu^{exp} - a_\mu^{theo,SM} = (27.7 \pm 8.4)10^{-10}$ (3.3σ)

$8.4 = \sim 5_{HLO} \oplus \sim 3_{HLbL} \oplus 6_{BNL}$

4 3 3 $1.6_{\text{NEW G-2}}$



$a_\mu^{exp} - a_\mu^{theo,SM} = (XXX \pm 3.8)10^{-10}$

If central value is the same → 7-8σ

(if no progress on theory → 5 σ)

$\delta a_\mu^{HLO} \rightarrow 2.6 = 1.9\ (\sqrt{s}<1\text{GeV}) \oplus 1.3\ (1<\sqrt{s}<2\text{GeV}) \oplus 1.2(\sqrt{s}>2\text{GeV})$

This is possible if:

- $\delta\sigma_{HAD} \sim 0.4\%$ $\sqrt{s}<1$GeV (instead of 0.7% as now)

- $\delta\sigma_{HAD} \sim 2\%$ $1<\sqrt{s}<2$GeV (instead of 6% as now)

(Possible with direct scan or ISR at Flavour factories, or new machines like IRIDE)

See M. Ferrario's talk

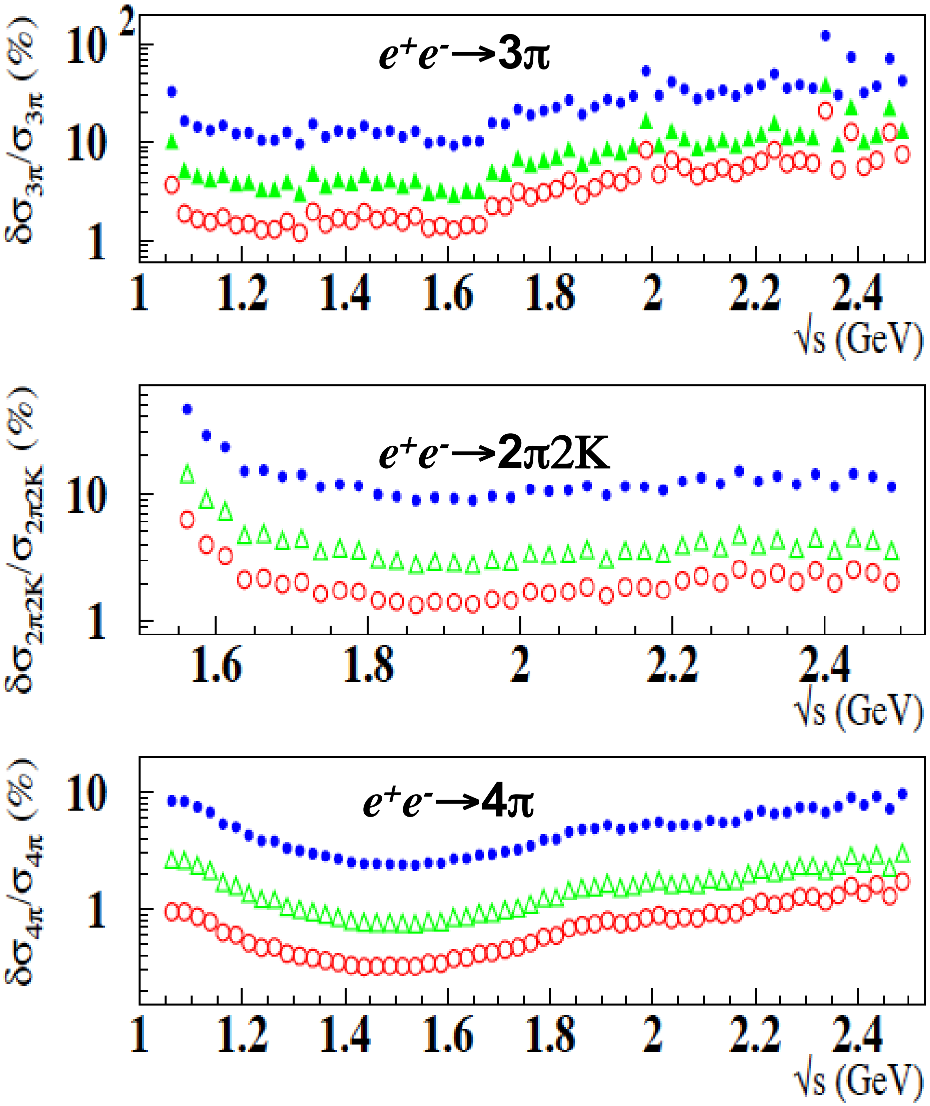
$\delta a_{\mu}^{HLO} = 2.6\ 10^{-10}$ (instead of ~5 as now)

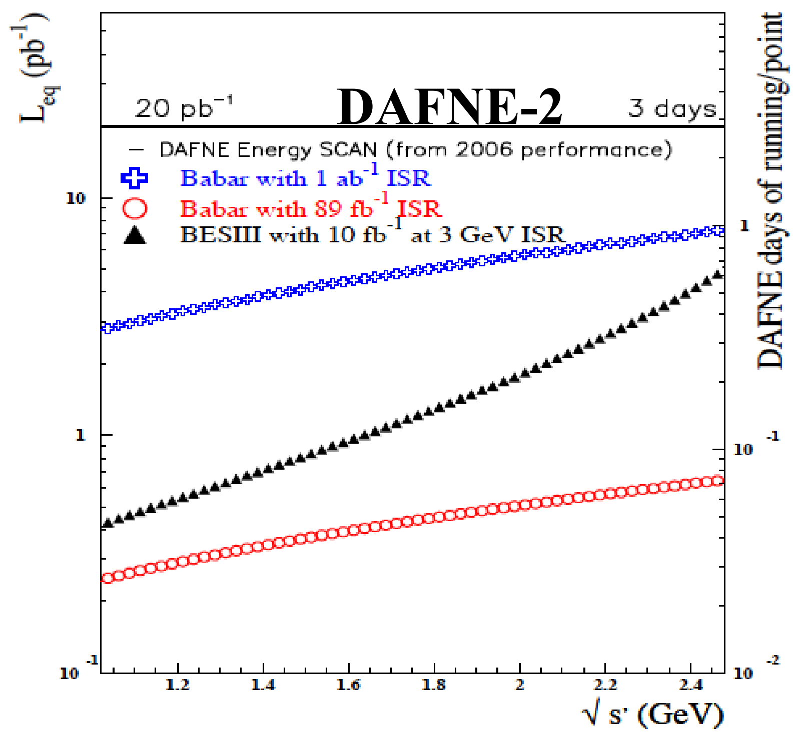
A similar improvement on $\delta\alpha_{em}(Mz)$ using Adler function method

Impact of DAFNE-2 on exclusive channels in the range [1-2.5] GeV with a scan (Statistics only)

arXiv:1007.521

- Published BaBar results: 89 fb^{-1} (ISR)
- ▲ "BaBar" × 10 (890 fb^{-1})
- o DAFNE-2 energy scan: 20 pb^{-1}/point @ L= 10^{32} cm^{-2} s^{-1}, 25 MeV bin ⇒ 1 year data-taking





DAFNE-2 is statistically equivalent to 5÷10 ab^{-1} (Super)B-factory

Conclusion

- Significant improvement a_μ^{HLO} in the last 15 years due to more precise data. Interplay with theorists for the control of RC and development of MC
- ISR opened a new way to precisely measure the hadronic cross sections
- Still some (local) differences between data which current limit precision on a_μ^{HLO}
- New data are expected from DAFNE, VEPP2000, BESIII and (Super)B factories which will continue to improve the region below 5 GeV with ISR. Hopefully new machines (IRIDE, Super τ/c factory)
- These data would allow to reduce of a factor ~2 the uncertainty on a_μ^{HLO} to match the request from the next g-2 experiments (at FNAL and J-PARC). A similar improvement is expected on $\alpha_{em}(Mz)$.

BNL ring arrived at FNAL for the new g-2 experiment

"Well, QED is very nice and impressive, but when everything is so neatly wrapped up in blue bows, with all experiments in exact agreement with each other and with the theory - that is when one is learning **absolutely nothing**.*"*

"On the other hand, when experiments are in hopeless conflict - or when the observations do not make sense according to conventional ideas, or when none of the new models seems to work, in short when the situation is an unholy mess - **that** *is when one is really making hidden progress and a breakthrough is just around the corner!"* [143]

R. Feynman, 1973 Hawaii Summer Institute

Thanks!

SPARE

Conclusions

1/ **HLS model succeeds → (other global approaches)**

2/ **NO signal for (e^+e^- vs τ) puzzle**

3/ **Consistent $\pi^+\pi^-$ data sets : CMD2, SND, KLOE 10 & 12**

4/ $$10^{10} \times \left[a_\mu^{exp} - a_\mu^{th} \right] = 40.80 + \begin{bmatrix} +0.6 \\ -1.3 \end{bmatrix}_\phi + \begin{bmatrix} +0.4 \\ -0.0 \end{bmatrix}_\tau + \begin{bmatrix} +0.0 \\ -2.2 \end{bmatrix}_{mod} \pm 5.12_{th} \pm 6.30_{exp}$$

5/ **Discrepancy with BNL g-2 value range [4.6 to 5.2] σ**

6/ **Additional Breaking schemes may reduce systematics**

M. Benayoun, PHIPSI13, Rome, 9-12 September 2013

Data comb. in the $\pi^+\pi^-$ channel: Benayoun et al

HVP Results with scan & τ data

- (Updated) Central value shifted by ≈ $3\ 10^{-10}$

Channel	Solution B	Direct Estimate
$\pi^+\pi^-$	495.40 ± 1.92	498.53 ± 3.73 (497.72 ± 2.12)
$\pi^0\gamma$	4.61 ± 0.04	3.35 ± 0.11
$\eta\gamma$	0.64 ± 0.01	0.48 ± 0.01
$\eta'\gamma$	0.01 ± 0.00	---
$\pi^+\pi^-\pi^0$	41.16 ± 0.59	43.24 ± 1.47
$K_L K_S$	11.90 ± 0.08	12.31 ± 0.33
K^+K^-	17.59 ± 0.21	17.88 ± 0.54
Total up to 1.05 GeV	571.30 ± 2.02	575.79 ± 4.06

Diff=3.1 units

Data comb. in the $\pi^+\pi^-$ channel: Benayoun et al

↓ another shift by -4.3

Channel	NSK +KLOE 10&12 + τ (ABC < 1 GeV)	scan only(NSK) + τ (ABC < 1GeV)	Direct Estimate
$\pi^+\pi^-$	491.12 ± 1.35	495.40 ± 1.92	498.53 ± 3.73 (497.72 ± 2.12)
$\pi^0\gamma$	4.63 ± 0.04	4.61 ± 0.04	3.35 ± 0.11
$\eta\gamma$	0.64 ± 0.01	0.64 ± 0.01	0.48 ± 0.01
$\eta'\gamma$	0.003 ± 0.000	0.003 ± 0.000	---
$\pi^+\pi^-\pi^0$	40.78 ± 0.64	41.16 ± 0.59	43.24 ± 1.47
$K_L K_S$	11.94 ± 0.08	11.90 ± 0.08	12.31 ± 0.33
K^+K^-	17.48 ± 0.21	17.59 ± 0.21	17.88 ± 0.54
Total up to 1.05 GeV	566.58 ± 1.50	571.30 ± 2.02	575.79 ± 4.06

M.Benayoun *et al*. EPJ C72 (2012) 1848

M.Benayoun *et al* . EPJ C73 (2013) 2453

g-2 & Global Models/Fits

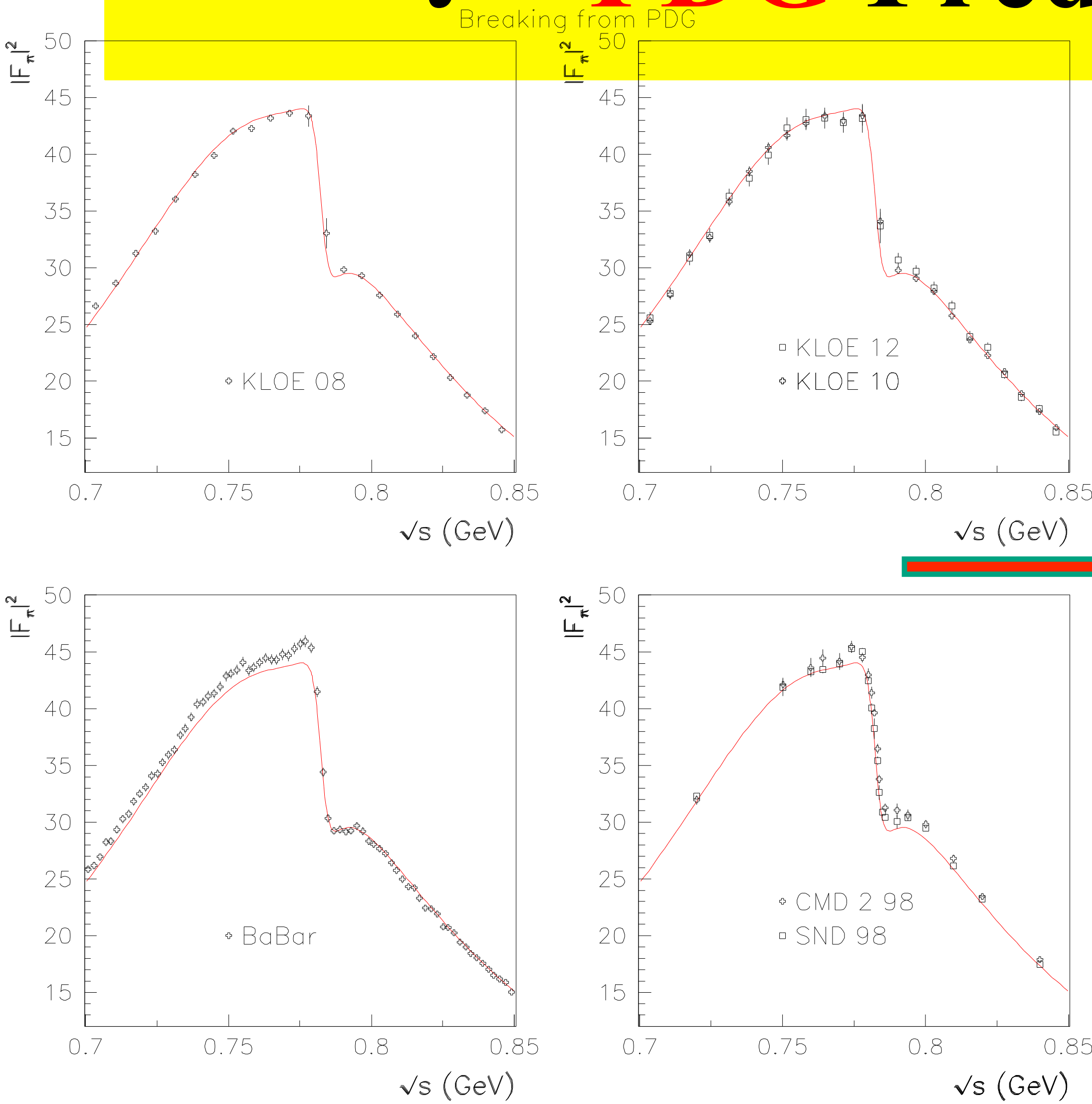
- **NP Hadronic VP contributions to g-2**

$$a_\mu(H_i) = \frac{1}{4\pi^3}\int_{s_{th}}^{s_{cut}} ds\, K(s)\, \sigma(e^+e^- \to H_i, s)$$ ← Measured Xsection

- **Effective Lagrangians imply physics correlations among the** $e^+e^- \to H_i$
- **-> HLS cross-sections derived through a global fit (param. values & error covariance matrix)**

Measured Xsection → Model Xsection (φ)

τ + PDG Predictions



PION Form Factor

0.85 GeV >$m_{\pi\pi}$> 0.70GeV

KLOE's almost perfect!
CMD2&SND ≈ OK
BaBar too large below ω

Radiative corrections are important!

- Unclear treatment of R.C. in old data.
- Reevaluation of RC leads to significant changes in recent data
- New data (CMD-2,SND, KLOE, Babar) paid more attention to :
    - ISR
    - Vacuum Polarization (VP)
    - FSR
- A lot of work for theorists to provide accurate MC generators (and for experimentalists to test it!)

$$\sigma_{bare} = \sigma_{dressed} |1 - \Pi(s)|^2 (1 + C_{FSR})$$

- $\sigma_{\rm dressed} = \frac{N}{\int Ldt \; \varepsilon \; (1+\delta_{\rm ISR})}$
- $\Pi(s) = \Pi_{\rm lep}(s) + \Pi_{\rm had}(s)$

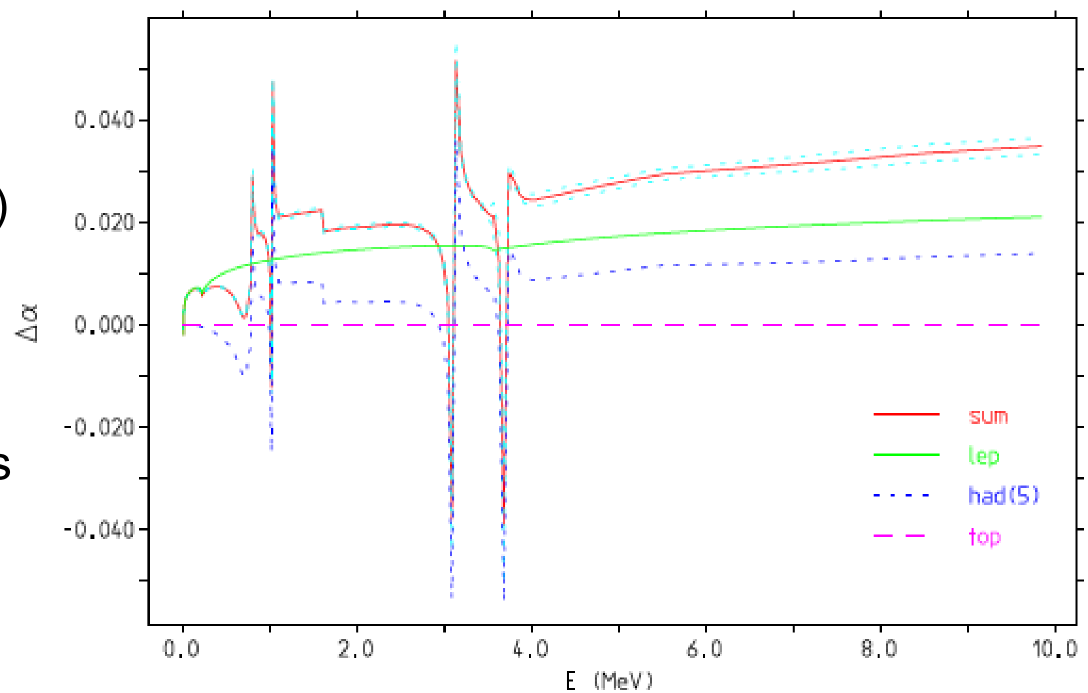


Figure from Fred Jegerlehner

A common effort for RC and Monte Carlo tools

Eur. Phys. J. C (2010) 66: 585–686
DOI 10.1140/epjc/s10052-010-1251-4

THE EUROPEAN PHYSICAL JOURNAL C

Review

Quest for precision in hadronic cross sections at low energy: Monte Carlo tools vs. experimental data

Working Group on Radiative Corrections and Monte Carlo Generators for Low Energies

S. Actis[38], A. Arbuzov[9,e], G. Balossini[32,33], P. Beltrame[13], C. Bignamini[32,33], R. Bonciani[15], C.M. Carloni Calame[35], V. Cherepanov[25,26], M. Czakon[1], H. Czyż[19,a,f,i], A. Denig[22], S. Eidelman[25,26,g], G.V. Fedotovich[25,26,e], A. Ferroglia[23], J. Gluza[19], A. Grzelińska[8], M. Gunia[19], A. Hafner[22], F. Ignatov[25], S. Jadach[8], F. Jegerlehner[3,19,41], A. Kalinowski[29], W. Kluge[17], A. Korchin[20], J.H. Kühn[18], E.A. Kuraev[9], P. Lukin[25], P. Mastrolia[14], G. Montagna[32,33,b,d], S.E. Müller[22,f], F. Nguyen[34,d], O. Nicrosini[33], D. Nomura[36,h], G. Pakhlova[24], G. Pancheri[11], M. Passera[28], A. Penin[10], F. Piccinini[33], W. Płaczek[7], T. Przedzinski[6], E. Remiddi[4,5], T. Riemann[41], G. Rodrigo[37], P. Roig[27], O. Shekhovtsova[11], C.P. Shen[16], A.L. Sibidanov[25], T. Teubner[21,h], L. Trentadue[30,31], G. Venanzoni[11,c,i], J.J. van der Bij[12], P. Wang[2], B.F.L. Ward[39], Z. Was[8,g], M. Worek[40,19], C.Z. Yuan[2]

~60 participants, 13 countries

See www.lnf.infn.it/wg/sighad for more information
(next meeting 11-12 April 2013, ECT*)

"Old" Results on R from energy scan at √s<10 GeV

Place	Ring	Detector	E_{cm}(GeV)	pts	Year
Novosibirsk	VEPP-2M VEPP-2	CMD2,SND Olya,ND,CMD	<1.4 <1.4	128	**01-03** 79-85 97-99
Beijing	BEPC	BESII	2-5	85	**98-99**
Orsay	DCI	M3N,DMI,DM2	1.35-2.13	33	'78
Frascati	Adone	γγ2,MEA, Boson,BCF	1.42-3.09	31	'78
SLAC	Spear	MarkI	2.8-7.8	78	'82
Cornell	CESR	CLEO	3-5		'05
Hamburg	Doris	DASP PLUTO C.Ball LENA	3.1-5.2 3.6-4.8,9.46 5.0-7.4 7.4-9.4	64 27 11 95	'79 '77 '90 '82
Novosibirsk	VEPP-4	MD-1	7.23-10.34	30	'91