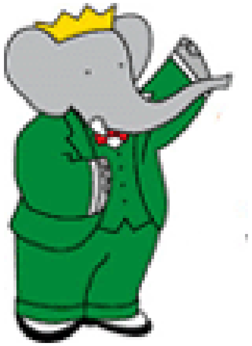
BaBar results on $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$ and the muon g-2 prediction

LiangLiang WANG

(Joint Ph.D Thesis)

Michel DAVIER (LAL-Orsay)
ChangZheng YUAN (IHEP-Beijing)



- g-2 context
- physics goals
- analysis steps
- $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$
- $e^+e^- \rightarrow \pi^+\pi^-(\gamma)$
- discussion

Results still preliminary!

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Hadronic vacuum polarization and muon *g*–2

Contributions to the Standard Model (SM) Prediction:

$$a_\mu \equiv \left(\frac{g-2}{2}\right)_\mu = a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{had}} + a_\mu^{\mathrm{weak}}$$

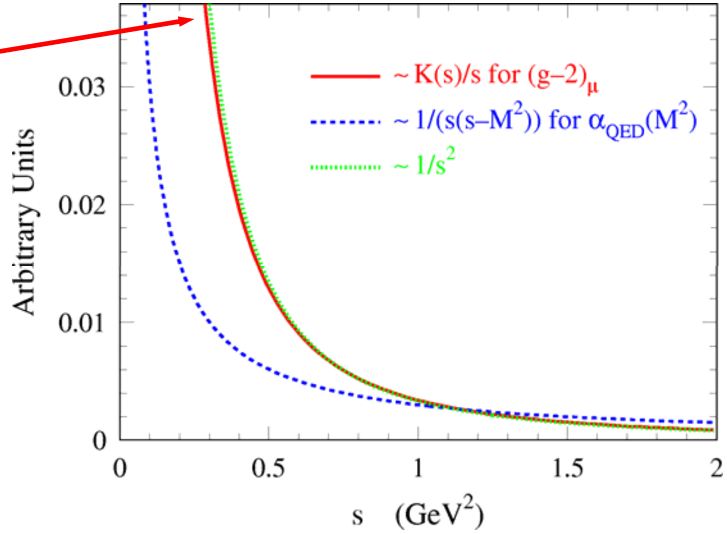
Born: $\sigma^{(0)}(s) = \sigma(s)\left(\alpha/\alpha(s)\right)^2$

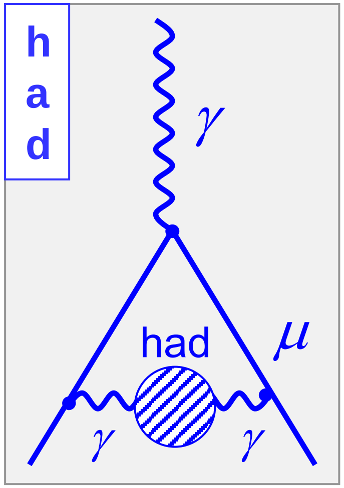
$$12\pi\,\mathrm{Im}\Pi_\gamma(s) = \frac{\sigma^0\left[e^+e^- \to \mathrm{hadrons}(\gamma)\right]}{\sigma_{pt}} \equiv R(s)$$

Dominant uncertainty from lowest order hadronic piece. Cannot be calculated from QCD (“first principles”) – but: we can use experiment

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

⇒need good data on e⁺e⁻→hadrons at low energies





Situation since 2006

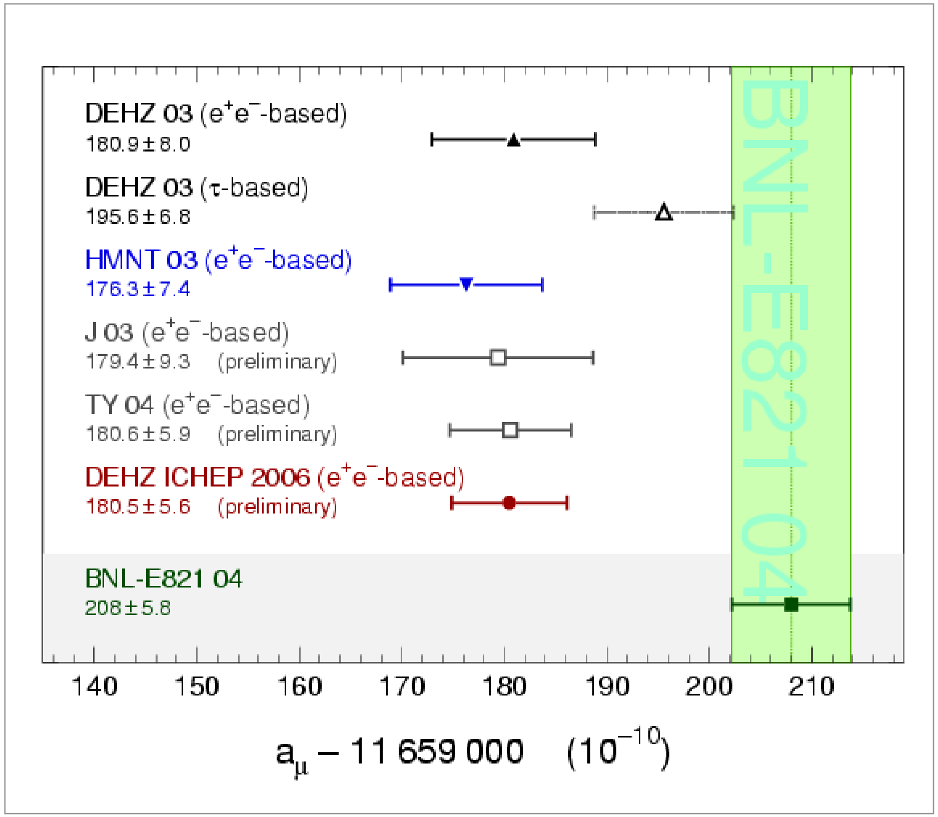
$$a_\mu^{\text{had}}[ee] = (690.9 \pm 4.4) \times 10^{-10}$$

$$a_\mu[ee] = (11\,659\,180.5 \pm 4.4_{\text{had}} \pm 3.5_{\text{LBL}} \pm 0.2_{\text{QED+EW}}) \times 10^{-10}$$

including:

Hadronic HO	$-(9.8 \pm 0.1) \times 10^{-10}$
Hadronic LBL	$+(12.0 \pm 3.5) \times 10^{-10}$
Electroweak	$(15.4 \pm 0.2) \times 10^{-10}$
QED	$(11\,658\,471.9 \pm 0.1) \times 10^{-10}$

- Knecht-Nyffeler, Phys.Rev.Lett. 88 (2002) 071802
- Melnikov-Vainshtein, hep-ph/0312226
- Davier-Marciano, Ann. Rev. Nucl. Part. Sc. (2004)
- Kinoshita-Nio (2006)



BNL E821 (2004):

$$a_\mu^{\text{exp}} = (11\,659\,208.0 \pm 6.3)\ 10^{-10}$$

Observed Difference with BNL using e^+e^-:

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

➡ 3.3 „standard deviations“

Goals of the analysis

- Measure $R_{\pi\pi} = \sigma_{\pi\pi} / \sigma_{pt}$ (also R_{KK}) with high accuracy for vacuum polarization calculations, using the ISR method
- $\pi\pi$ channel contributes 73% of a_μ^{had}
- Dominant uncertainty also from $\pi\pi$
- Also important to increase precision on $\alpha(M_Z^2)$ (EW tests, ILC)
- Present systematic precision of e^+e^- experiments

  CMD-2 0.8% SND 1.5% in agreement

  KLOE (ISR from 1.02 GeV) 2005 1.3% some deviation in shape

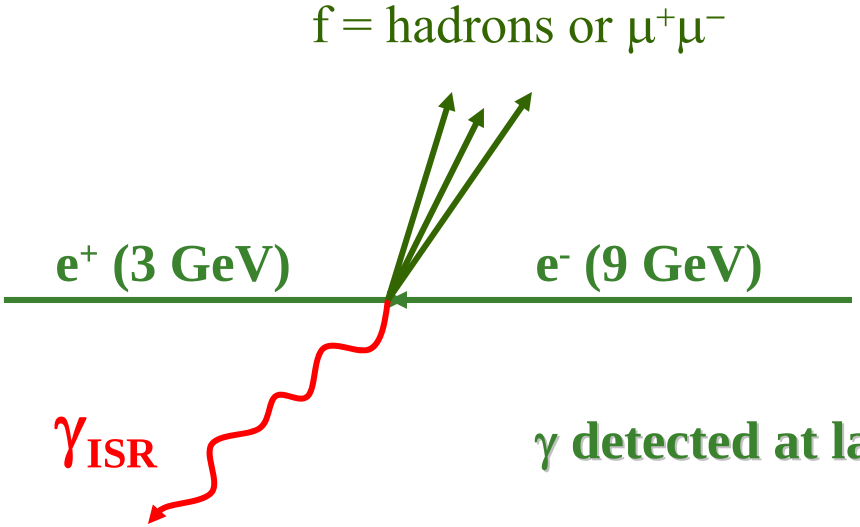
  2008 0.8% deviation smaller
- Compare to spectral functions from τ decays

  discrepancy τ/e^+e^- evaluations $(3.0 \pm 1.1)\%$

$\Rightarrow$ aim for a measurement with <1% accuracy

great interest to clarify the situation as magnitude of possible discrepancy with SM is of the order of SUSY contributions with masses of a few 100 GeV

ISR method at BaBar : e+e- → γ f



Arbuzov 98’, Binner 99’, Benayoun 99’

$$\frac{d\sigma(s,x)}{dx} = W(s,x)\sigma_f\left[s(1-x)\right]$$

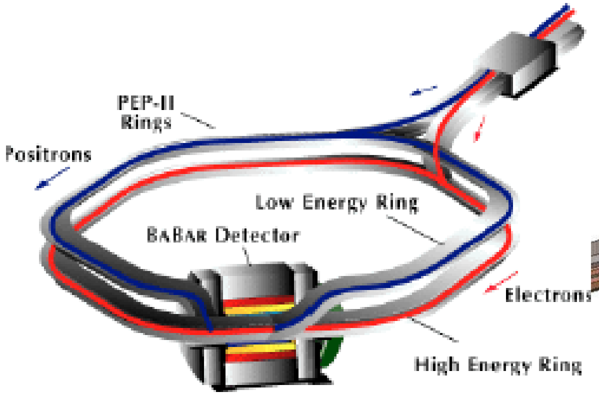
$$x = \frac{2E^*_\gamma}{\sqrt{s}}$$

γ detected at large angle in BaBar

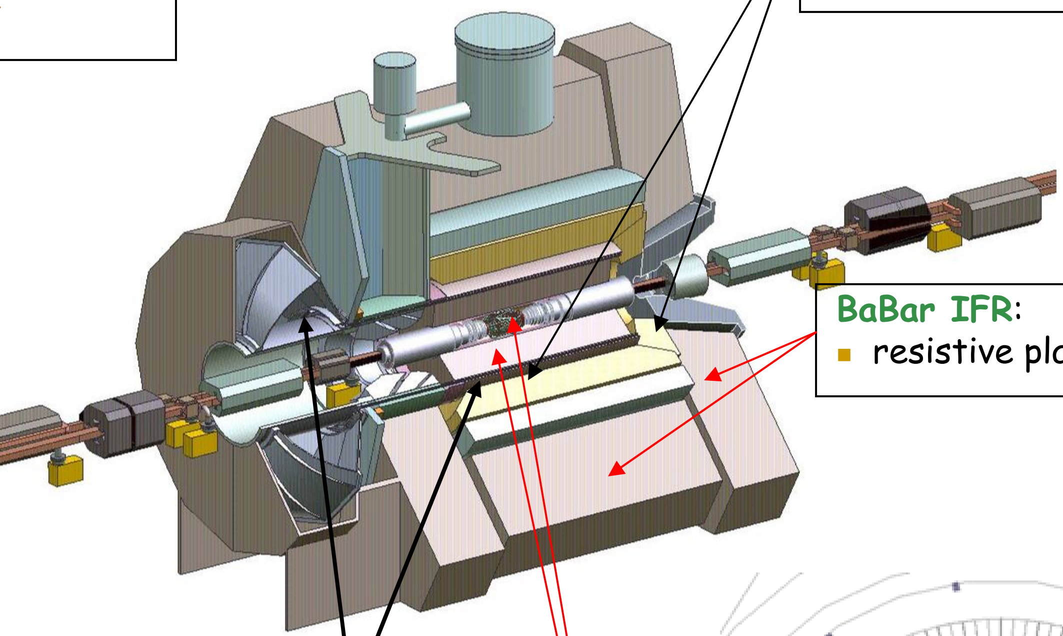
Big advantage of ISR: all mass spectrum covered at once, from threshold to 4-5 GeV (at BaBar), with same detector and analysis

BaBar at PEP II

- **PEP-II** is an asymmetric e^+e^- collider operating at CM energy of $\Upsilon(4S)$.
- Integrated luminosity = 531 fb^{-1}



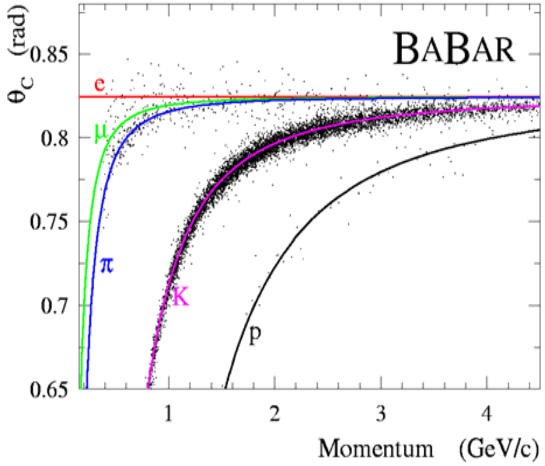
BaBar EMC:
- 6580 CsI(Tl) crystals, resolution ~1-2 % high E.

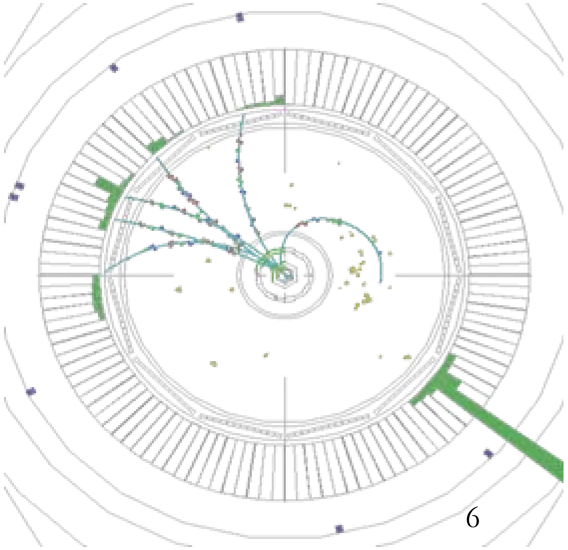


BaBar IFR:
- resistive plate chambers

BaBar DIRC
- particle ID up to 4-5 GeV/c

BaBar SVT and DCH
- precision tracking



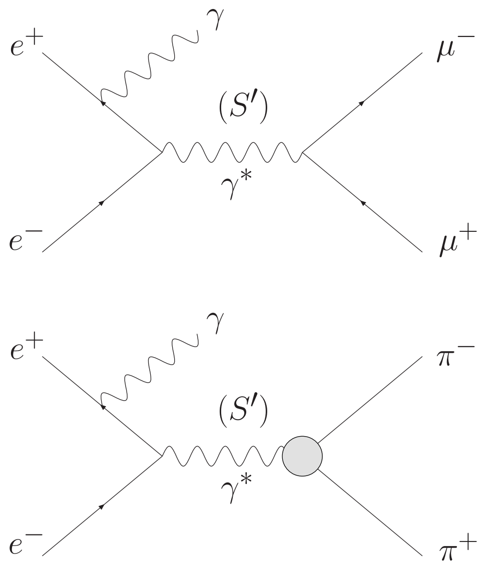


The relevant processes

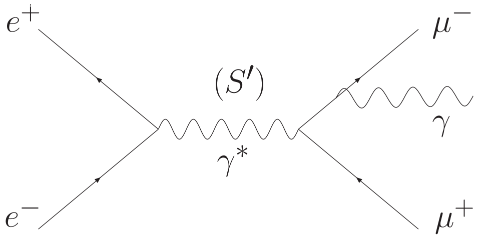
$$x = 2E^*_\gamma/\sqrt{s}$$

$$s' = s(1-x)$$

ISR

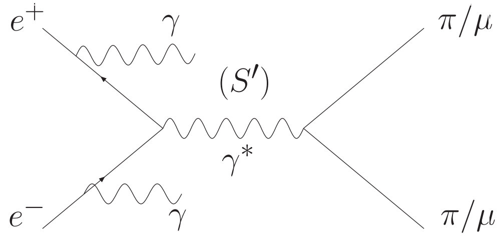


FSR

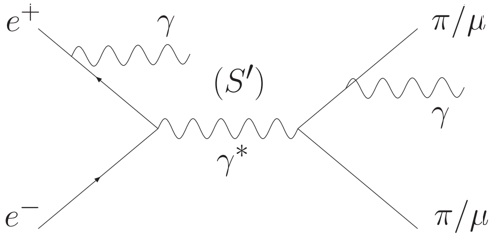


LO FSR negligible for ππ at s~(10.6 GeV)^2

ISR + additional ISR



ISR + additional FSR



The measurement and analysis steps

use 230.8 fb^{-1} (U(4S) on-peak & off peak) data

- Triggers (L1 hardware, L3 software), background-filter
- ISR photon at large angle in EMC (CM energy >3 GeV)
- 1 (for efficiency) or 2 (for physics) tracks of good quality (P>1 GeV)
- identification of the charged particles
- separate ππ/KK/μμ event samples
- kinematic fit (not using ISR photon energy) including 1 additional photon
- obtain all efficiencies (trigger, filter, tracking, ID, fit) from same data
- Consistency checks for μμ (QED test, ISR luminosity) and ππ
- Unfolding of mass spectra
- Unblinding R: measure ratio of ππγ(γ) to μμγ(γ) cross sections to cancel

ee luminosity
additional ISR
vacuum polarization
ISR photon efficiency

} otherwise 2-3% syst error

- still need to correct for $|\mathrm{FSR}|^2$ contribution in μμγ(γ) and additional FSR, both calculated in QED, but also checked in data (ISR-FSR interference, additional detected photons)

$$\mathrm{R}_{\exp}(s) = \frac{\sigma[\pi\pi\gamma(\gamma)](s)}{\sigma[\mu\mu\gamma(\gamma)](s)} = \frac{\sigma^0[\pi\pi(\gamma)](s)}{(1+\delta_{FSR}^{\mu\mu})\sigma^0[\mu\mu(\gamma)](s)} = \frac{R(s)}{(1+\delta_{FSR}^{\mu\mu})(1+\delta_{addFSR}^{\mu\mu})}$$

- Results on ππ cross section and calculation of dispersion integral for a_μ^{had}

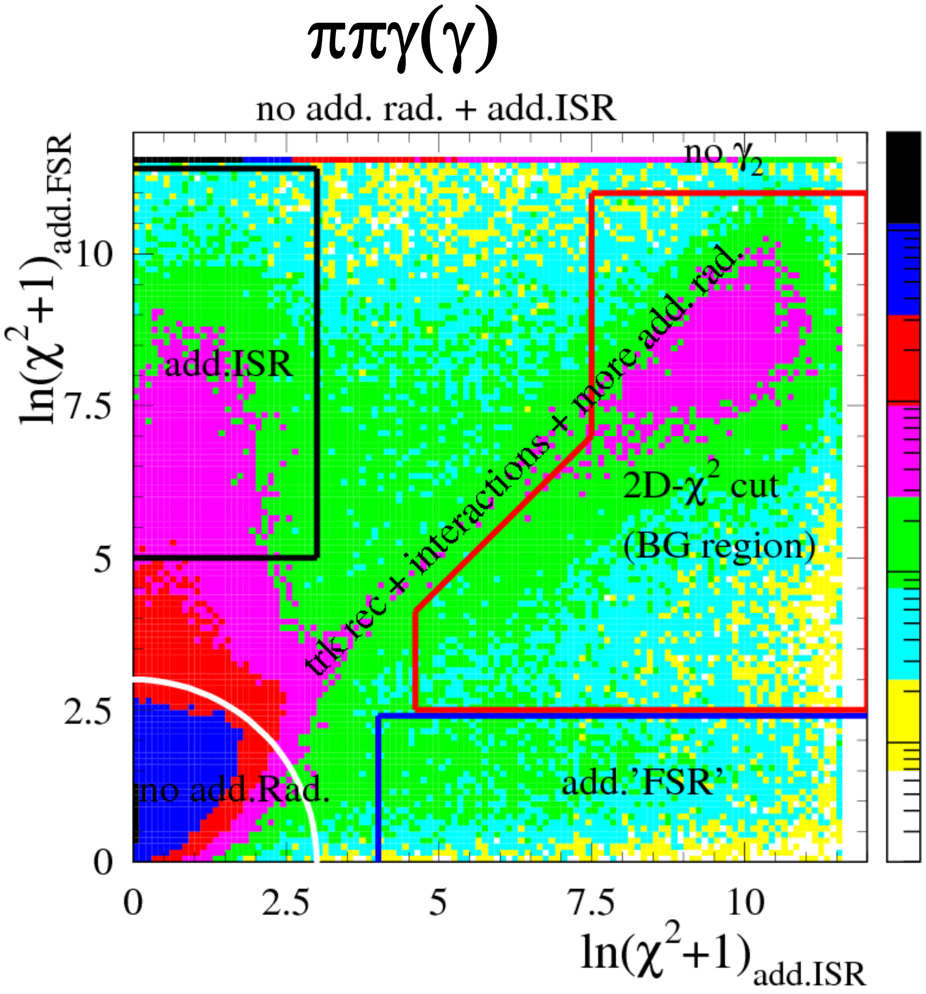
MC generators

- Acceptance and efficiencies determined initially from simulation, with data/MC corrections applied
- Large simulated samples, typically 10 × data, using AfkQed generator

- AfkQed: lowest-order QED with additional radiation:
    - ISR with structure function method, γ assumed collinear to the beams and with limited energy
    - FSR using PHOTOS
    - similar to EVA (Phokhara ancestor)
- Phokhara 4.0: (almost) exact second-order QED matrix element (2 FSR missing), limited to one extra photon

- Studies comparing Phokhara and AfkQed at 4-vector level with fast simulation

Kinematic fitting

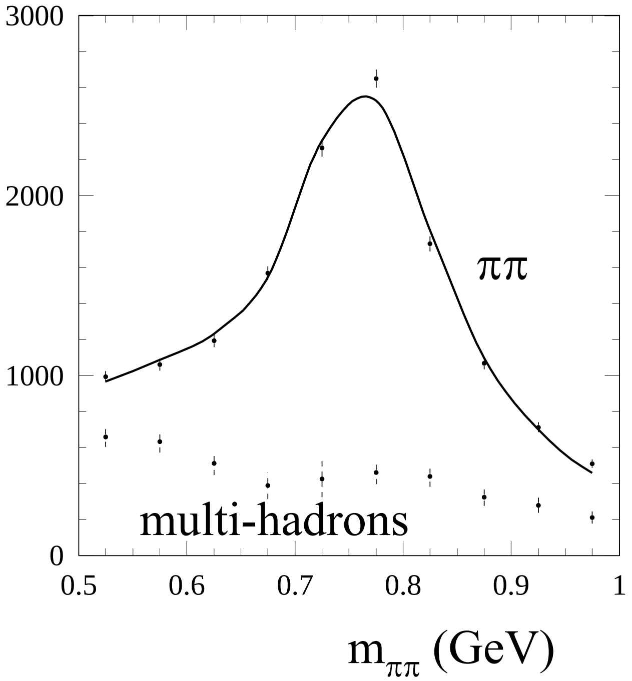


- kinematic fits to X X $\gamma_{ISR}\,\gamma_{add}$
- ISR photon defined as highest energy
- Add. ISR fit: γ_{add} assumed along beams
- Add. ‘FSR’ if γ_{add} detected
- Each event recorded on 2D plot
- Typical regions defined
- Loose χ^2 cut (outside BG region in plot)
  for μμ and ππ in central ρ region
- Tight χ^2 cut (ln(χ^2+1)<3)
  for ππ in ρ tail region

Backgrounds in $\pi\pi\gamma$

- background larger with loose χ^2 cut used in 0.5-1.0 GeV mass range
- $q\bar{q}$ and multi-hadronic ISR background from MC samples + normalization from data using signals from $\pi^0 \to \gamma_{ISR}\gamma$ ($q\bar{q}$), and ω and ϕ ($\pi\pi\pi^0\gamma$)
- global test in background-rich region near cut boundary

Fitted BG/predicted = 0.968±0.037



BG fractions in 10^{-3} at $m_{\pi\pi}$ values

process	0.525 GeV	0.775 GeV	0.975 GeV
$\mu\mu$	2.98 ± 0.16	0.25 ± 0.01	1.95 ± 0.11
KK	0.08 ± 0.01	0.01 ± 0.01	0.08 ± 0.01
$\gamma 2\pi\pi^0$	8.04 ± 0.41	0.39 ± 0.05	0.88 ± 0.19
$q\bar{q}$	1.11 ± 0.17	0.26 ± 0.03	1.81 ± 0.19
$\gamma 2\pi 2\pi^0$	1.29 ± 0.16	0.06 ± 0.01	0.46 ± 0.09
$\gamma 4\pi$	0.20 ± 0.04	0.09 ± 0.01	0.24 ± 0.06
$\gamma p\bar{p}$	0.22 ± 0.02	0.04 ± 0.01	0.52 ± 0.06
$\gamma\eta 2\pi$	0.02 ± 0.01	0.03 ± 0.01	0.09 ± 0.01
$\gamma K_S K_L$	0.18 ± 0.03	0.01 ± 0.01	0.10 ± 0.02
$\gamma 4\pi 2\pi^0$	< 0.01	< 0.01	< 0.01
$\tau\tau$	0.17 ± 0.03	0.04 ± 0.01	0.31 ± 0.05
γee	0.63 ± 0.63	0.03 ± 0.03	0.27 ± 0.27
total	14.88 ± 0.81	1.19 ± 0.07	6.61 ± 0.42

Checking Known Distributions

Cosθ^* in XX CM /γ

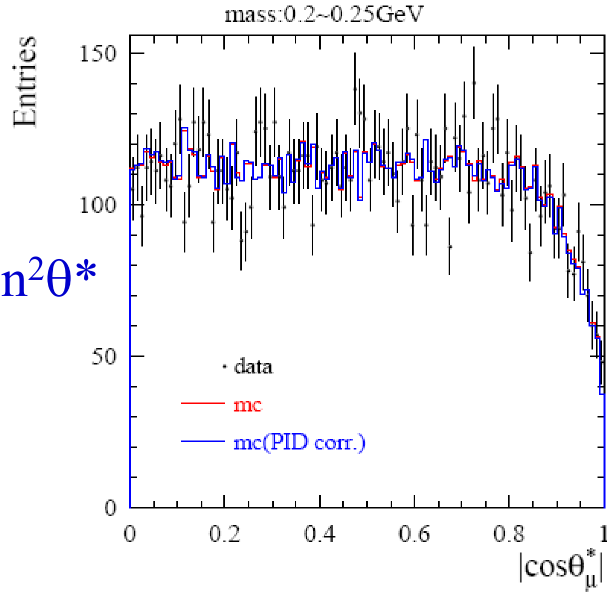
μμ

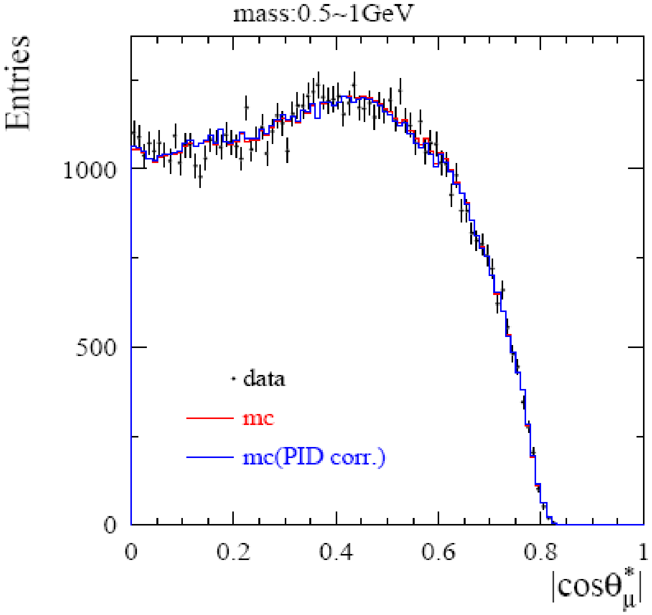
$\sim 1+\cos^2\theta^*+(1-\beta^2_\mu)\sin^2\theta^*$

=>

flat at threshold $\beta_\mu \rightarrow 0$

$1+\cos^2\theta^*$ $\beta_\mu \rightarrow 1$

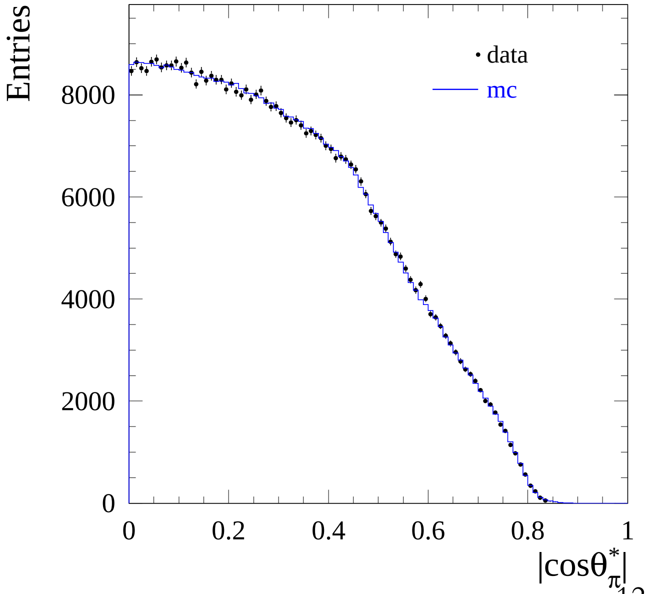




ππ

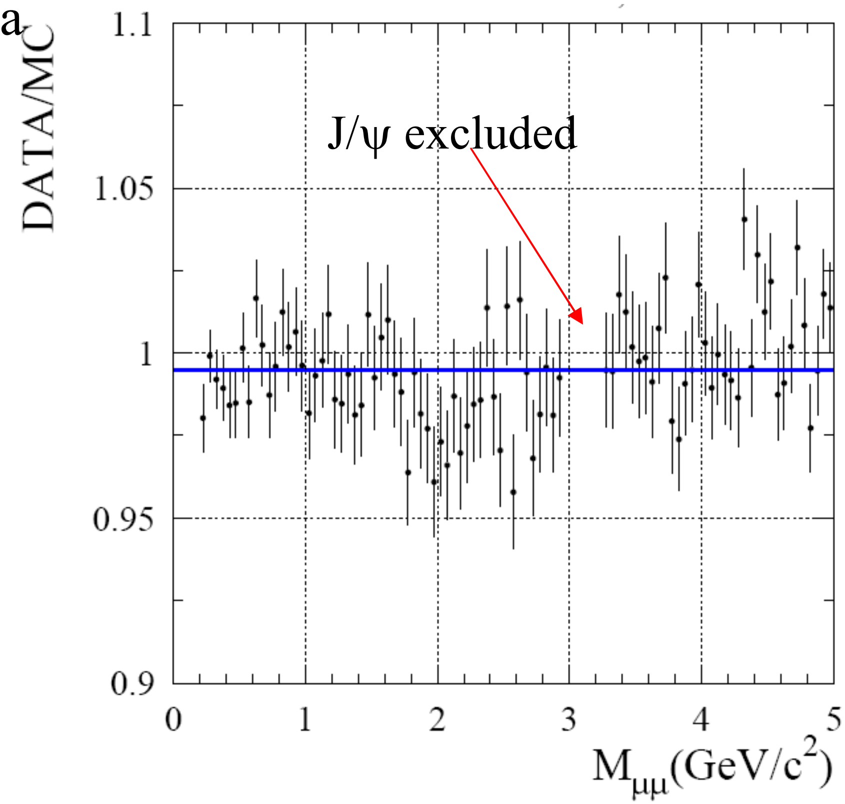
$\sin^2\theta^*$ $\forall\ \beta_\pi$

P>1 GeV track requirement ⇒ loss at cosθ^*~1



QED test with μμγ sample

- absolute comparison of μμ mass spectra in data and in simulation
- simulation corrected for data/MC efficiencies
- AfkQed corrected for incorrect NLO using Phokhara
- results for different running periods consistent: (7.9 ±7.5) 10^{-3}
- agreement with QED within 1.2%



J/ψ excluded

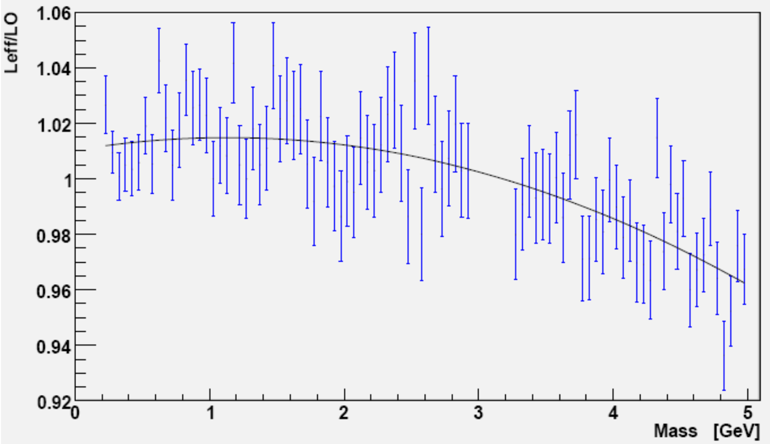
$$\frac{\sigma^{data}_{\mu\mu\gamma(\gamma)}}{\sigma^{NLO\ QED}_{\mu\mu\gamma(\gamma)}} = 1 - (5.2 \pm 1.5 \pm 6.9 \pm 9.4) \times 10^{-3}$$

(0.2 – 5.0 GeV)

ISR γ efficiency 5.2 syst.
trig/track/PID 4.0

BaBar ee luminosity

Systematic Uncertainties



μμ ISR lumi
fitted w.r.t.
LO formula

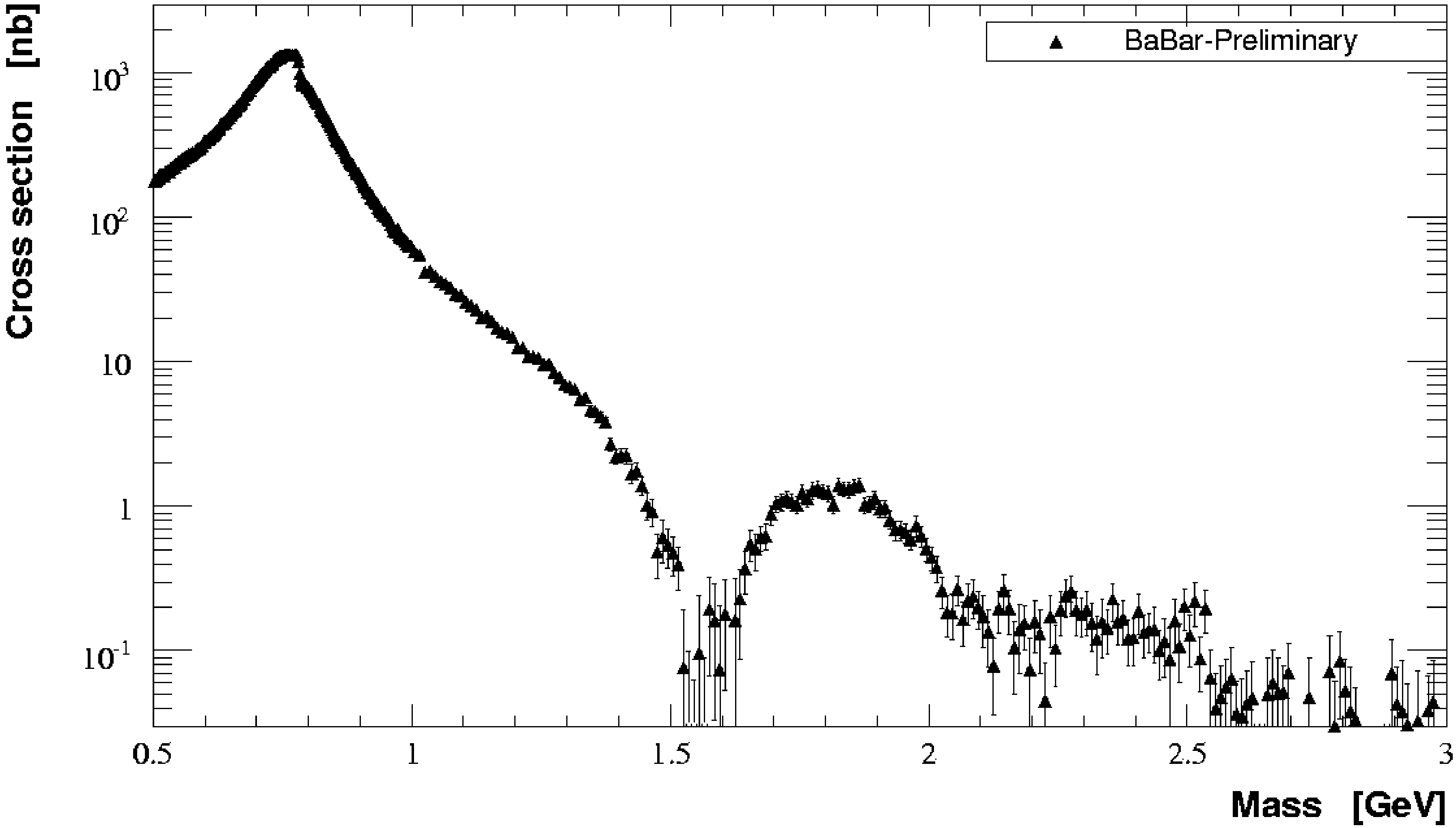
sources	uncertainties (in 10^{-3})
statistics	2.1
fitting	1.2
trigger	-
tracking	1.3
μ-ID	2.9
acceptance	2.0
sum	4.5

ππ

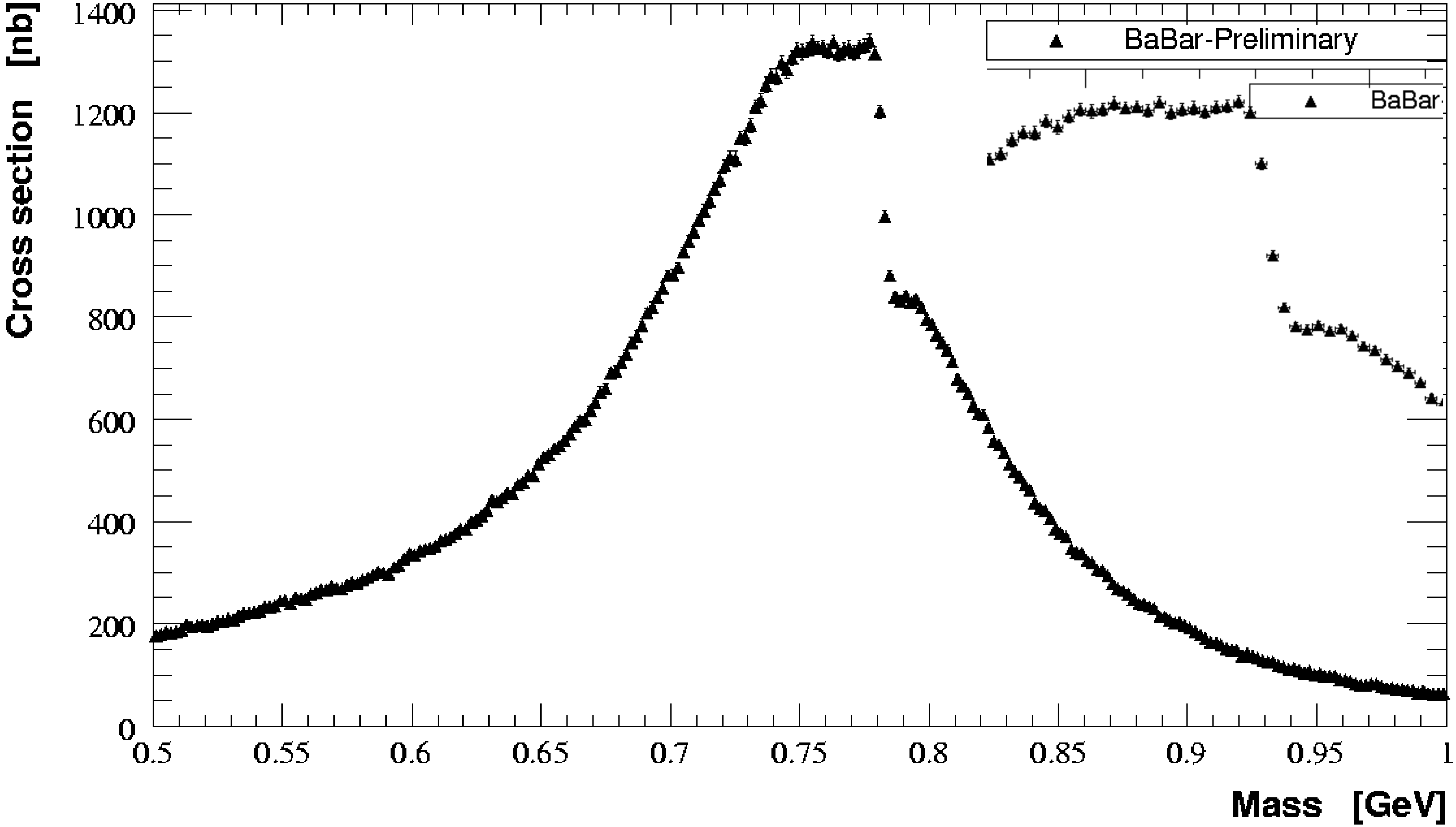
sources	0.4–0.6	0.6–0.9	0.9–1.2	1.2–1.4	1.4–3.0
trigger/ filter	1.5	0.8	0.5	0.5	0.5
tracking	2.1	1.1	1.7	3.1	3.1
π-ID	5.2	2.4	4.2	10.1	10.1
background	5.2	0.4	1.0	7.0	12.0
acceptance	1.0	1.0	1.0	1.0	1.0
kinematic fit (χ^2)	1.8	0.7	1.8	2.8	2.8
correlated $\mu\mu$ ID loss	3.0	1.3	2.0	3.0	10.0
sum $\pi\pi$	7.5	3.3	5.5	13.4	19.1
for $\pi\pi$ cross section	8.7	5.6	7.1	14.1	19.6

increased to 20. for preliminary results, pending investigations

BaBar results

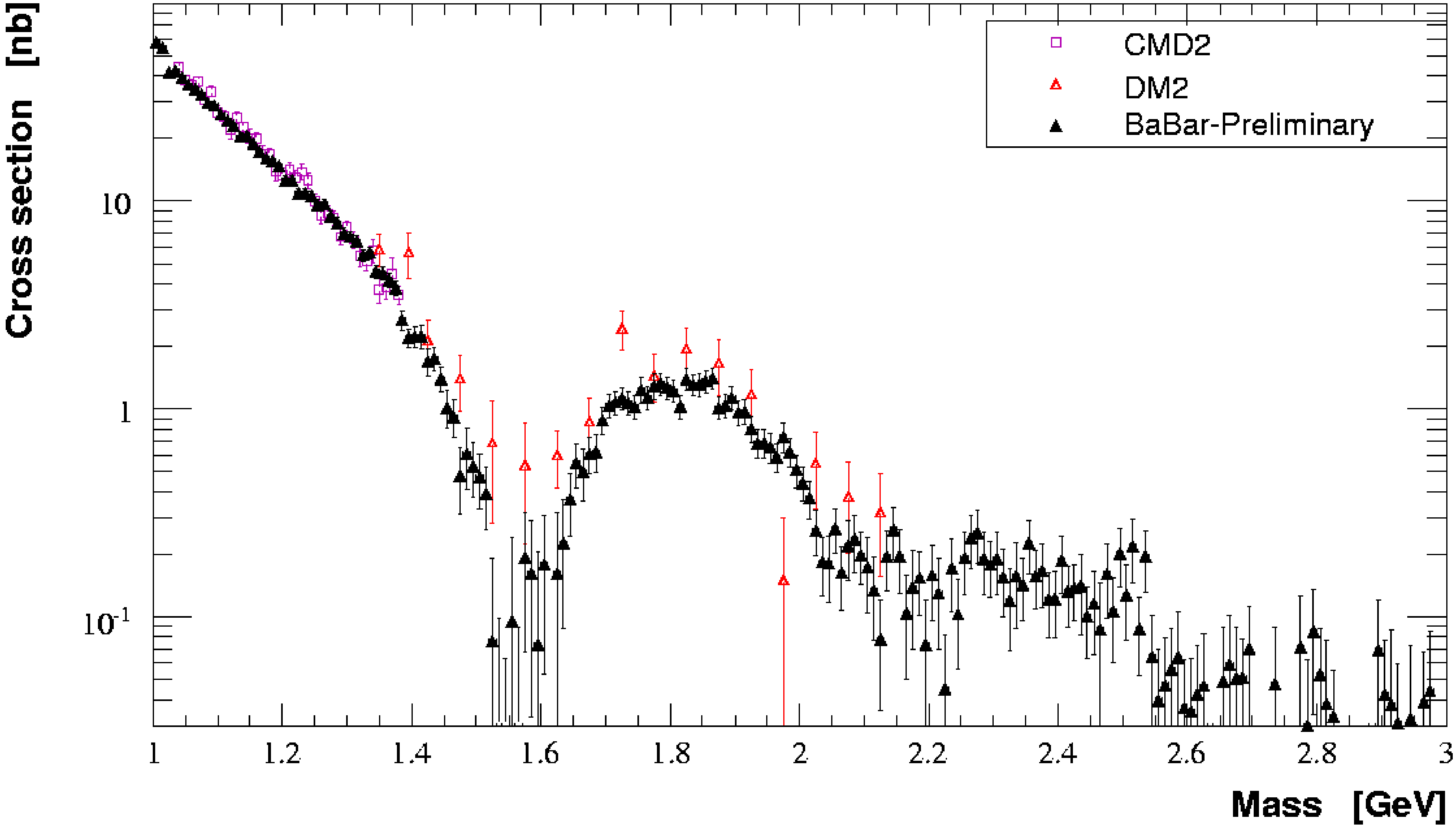


BaBar results in ρ region

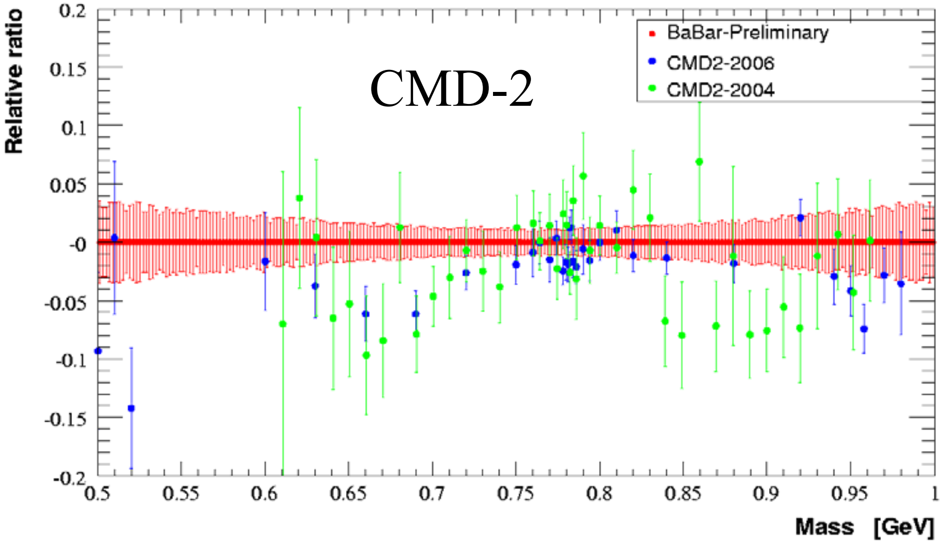


BaBar vs. other experiments at large mass

- structures observed at large mass: deep dip (1.6 GeV), wider dip (2.2 GeV)
- interferences between higher-mass vector mesons



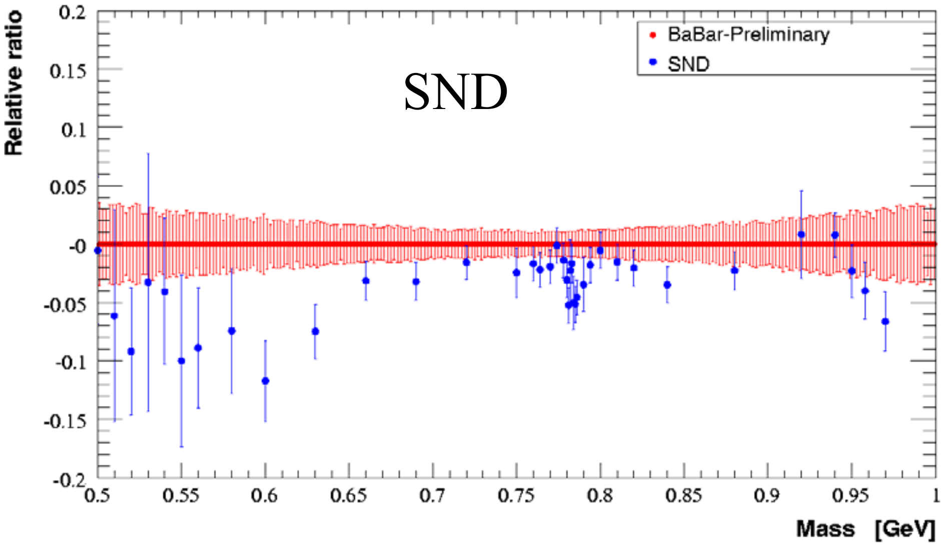
BaBar vs.CMD-2 and SND (0.5-1.0 GeV)



direct relative comparison of cross sections in the corresponding 2-MeV BaBar bins (interpolation with 2 bins)

deviation from 1 of ratio w.r.t. BaBar

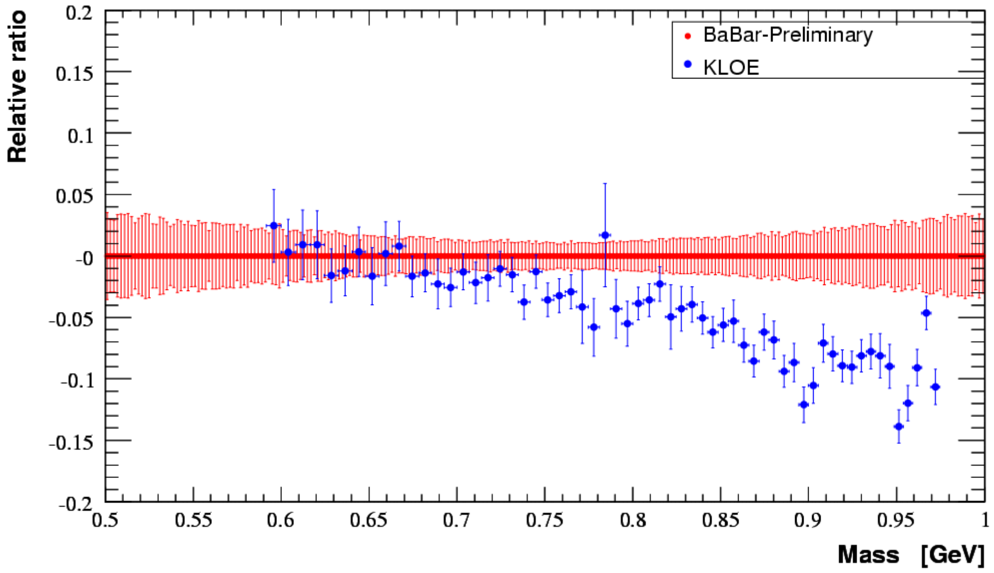
stat + syst errors included



both CMD-2 and SND determine $e^+e^- \to \pi^+\pi^-$ cross section through the ratio $(\pi\pi+\mu\mu)/ee$ with assumed QED leptonic cross sections

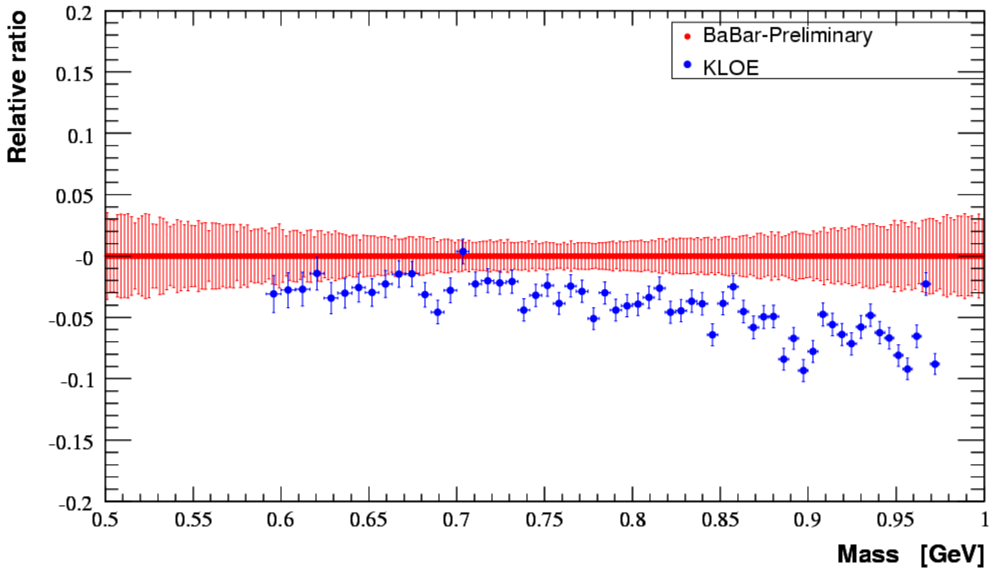
published and revised (rad. corr.)

BaBar vs.KLOE (0.5-1.0 GeV)



ISR method from $\phi(1020)$
only $\pi+\pi-$ detected
no $\mu+\mu-$ analysis yet
ISR luminosity from Phokhara

KLOE 2005



KLOE Dec. 2008
new data, found bias in cosmic
veto for 2005 (superseded)
smaller systematic errors

Computing $a_\mu^{\pi\pi}$

$$a_\mu^{\pi\pi(\gamma),LO} = \frac{1}{4\pi^3}\int_{4m_\pi^2}^{\infty} ds\, K(s)\, \sigma^0_{\pi\pi(\gamma)}(s) \ ,$$

where $K(s)$ is the QED kernel,

$$K(s) = x^2\left(1-\frac{x^2}{2}\right) + (1+x)^2\left(1+\frac{1}{x^2}\right)\left[\ln(1+x) - x + \frac{x^2}{2}\right] + x^2\,\frac{1+x}{1-x}\ln x \ ,$$

with $x = (1-\beta_\mu)/(1+\beta_\mu)$ and $\beta_\mu = (1-4m_\mu^2/s)^{1/2}$.

!preliminary!

	$a_\mu^{\pi\pi}$ (×10^{-10})	(DEHZ 2006)	ALEPH-CLEO-OPAL (DEHZ 2003)	(2008)
$m_{\pi\pi}$ (GeV)	present BaBar	previous e^+e^-	τ (A-C-O)	τ (Belle)
0.28–0.5	not ready	$55.6 \pm 0.8 \pm 0.9$	$56.0 \pm 1.6 \pm 0.3$	-
0.5–1.8	$462.5 \pm 0.9 \pm 3.1$	$449.0 \pm 3.0 \pm 0.9$	$464.0 \pm 3.2 \pm 2.3$	-
0.28–1.8	–	$504.6 \pm 3.1 \pm 1.0$	$520.1 \pm 3.6 \pm 2.6$	$519.1 \pm 3.0 \pm 2.5$

FSR correction was missing in Belle, published value 523.5 ± 3.0 ± 2.5

Direct comparison 0.630-0.958 GeV			
	BaBar		369.3 ± 0.8 ± 2.2
	CMD-2	94-95	362.1 ± 2.4 ± 2.2
	CMD-2	98	361.5 ± 1.7 ± 2.9
	SND		361.0 ± 1.2 ± 4.7

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

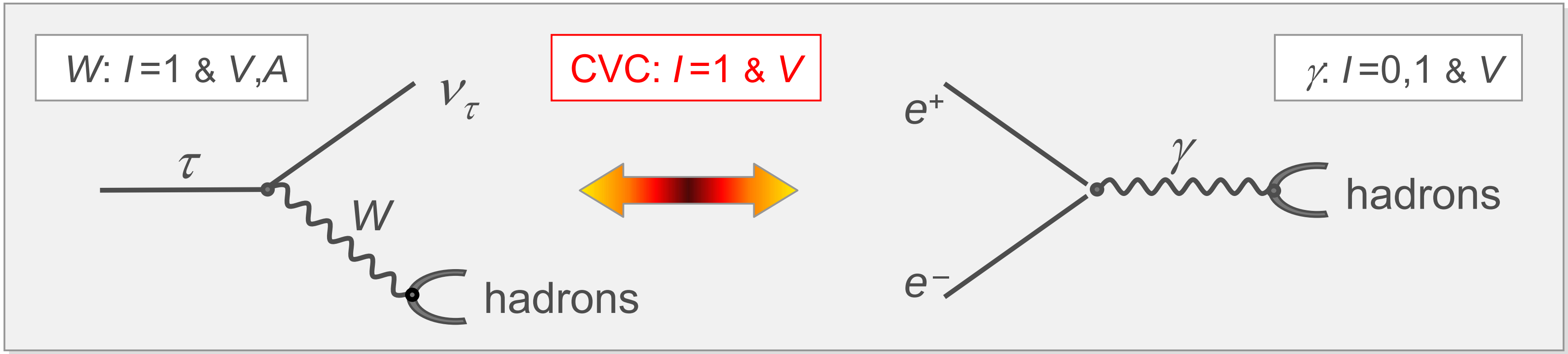
  some discrepancy with CMD-2 and SND mostly below ρ
  larger disagreement with KLOE
  (better agreement with τ results, especially Belle)
- (Contribution to a_μ from BaBar agrees better with τ results)
- Deviation between BNL measurement and theory prediction would be reduced using preliminary BaBar ππ data

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

The final results is coming soon!

Backup Slides

Connecting τ and ee spectral funct. with CVC



Hadronic physics factorizes in Spectral Functions :

CVC: SU(2)

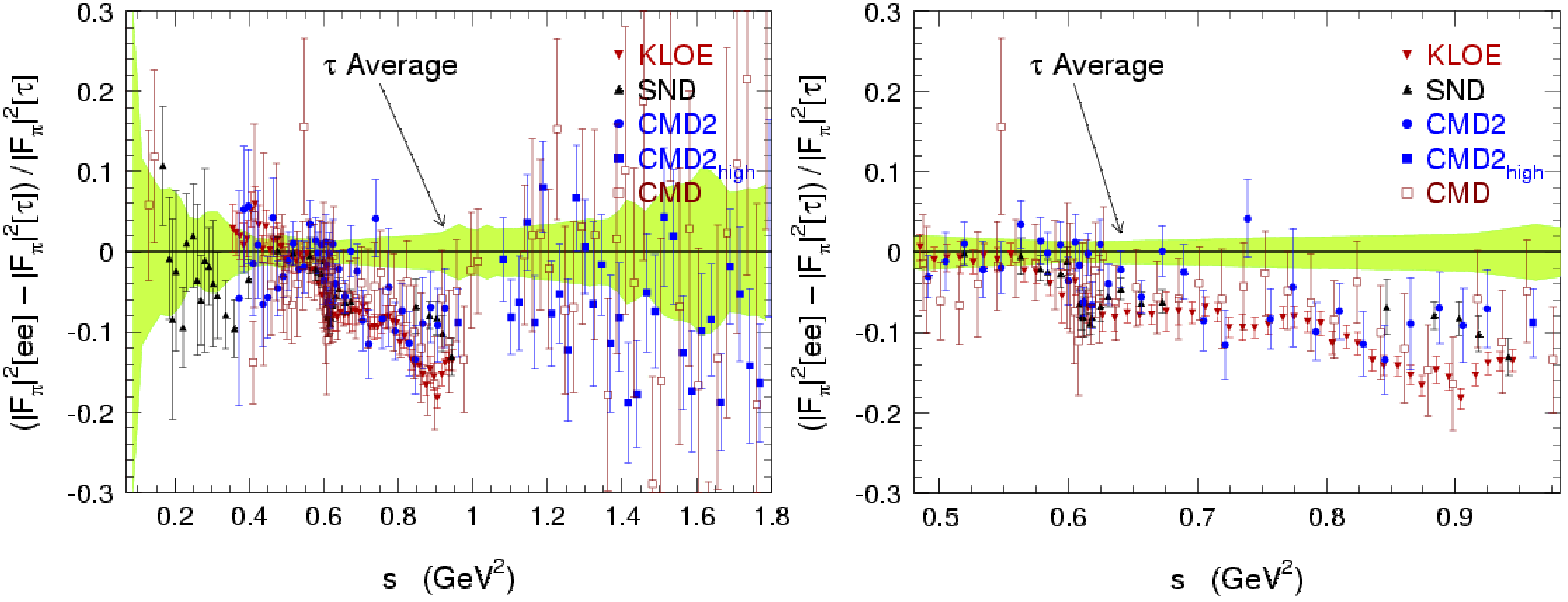
$$\boxed{\sigma^{(I=1)}\left[e^+e^- \to \pi^+\pi^-\right] = \frac{4\pi\alpha^2}{s}\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]}$$

fundamental ingredient relating long distance (resonances) to short distance description (QCD)

$$\upsilon\left[\tau^- \to \pi^-\pi^0\nu_\tau\right] \propto \underbrace{\frac{\mathrm{BR}\left[\tau^- \to \pi^-\pi^0\nu_\tau\right]}{\mathrm{BR}\left[\tau^- \to e^-\bar{\nu}_e\nu_\tau\right]}}_{\text{branching fractions}} \underbrace{\frac{1}{N_{\pi\pi^0}}\frac{dN_{\pi\pi^0}}{ds}}_{\text{mass spectrum}} \underbrace{\frac{m_\tau^2}{\left(1-s/m_\tau^2\right)^2\left(1+s/m_\tau^2\right)}}_{\text{kinematic factor (PS)}}$$

SU(2) breaking (EM): short/long distance and mass corrections, ρ–ω interference

e^+e^-- τ Data Comparison since 2006



⇒problems: overall normalization

shape (especially above ρ)

Next steps in BaBar analysis

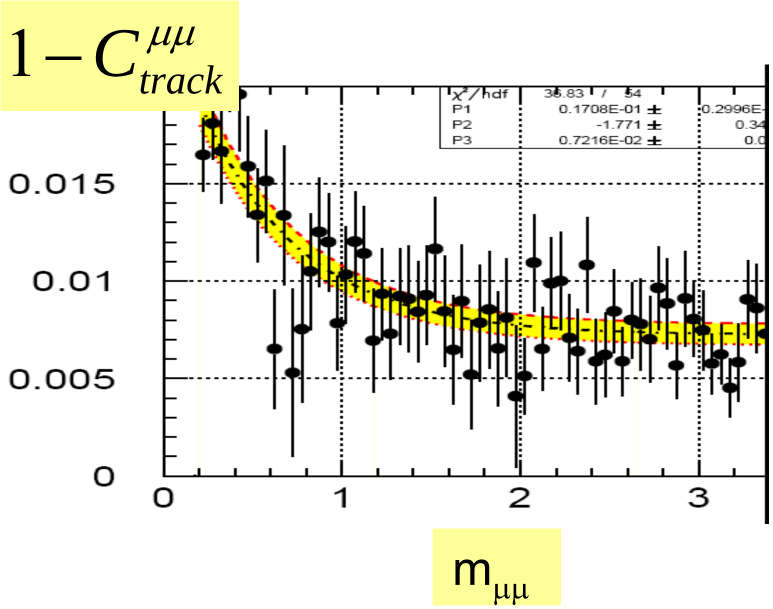
- still preliminary results (presented at Tau Workshop, Sept. 2008)
- data not shown below 0.5 GeV: problems noticed (near threshold)
- also new consistency check between loose and tight χ^2 not satisfactory (systematic uncertainty enlarged)
- problems now understood
- new results in progress
- BaBar review
- final results in a couple of months

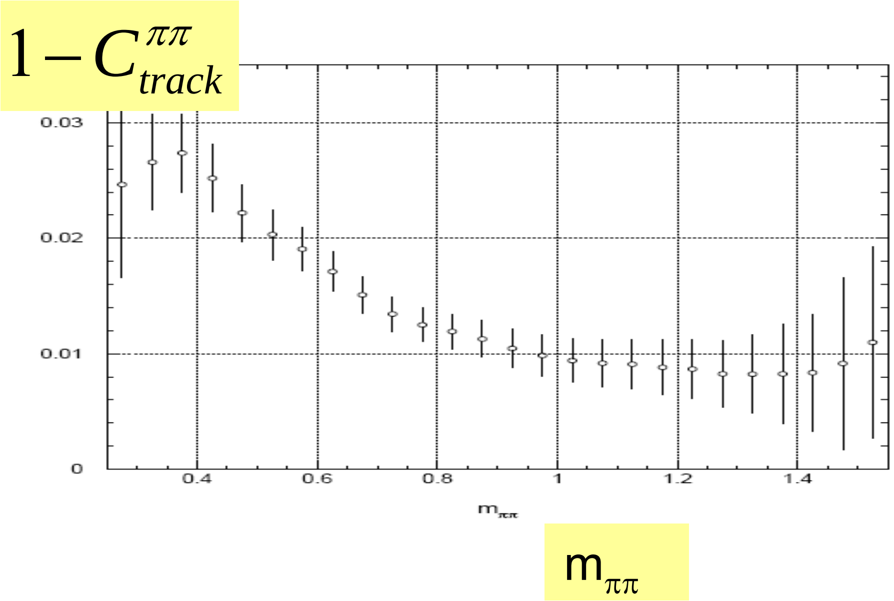
Data/MC tracking correction to $\pi\pi\gamma,\mu\mu\gamma$ cross sections

- single track efficiency
- correlated loss probability f_0
- probability to produce more than 2 tracks f_3

$$C^{\mu\mu}_{track} = \left(\frac{\varepsilon^{data}_{track}}{\varepsilon^{MC}_{track}}\right)^2 \frac{(1-f_0-f_3)^{data}}{(1-f_0-f_3)^{MC}}$$

and similarly for $\pi\pi$



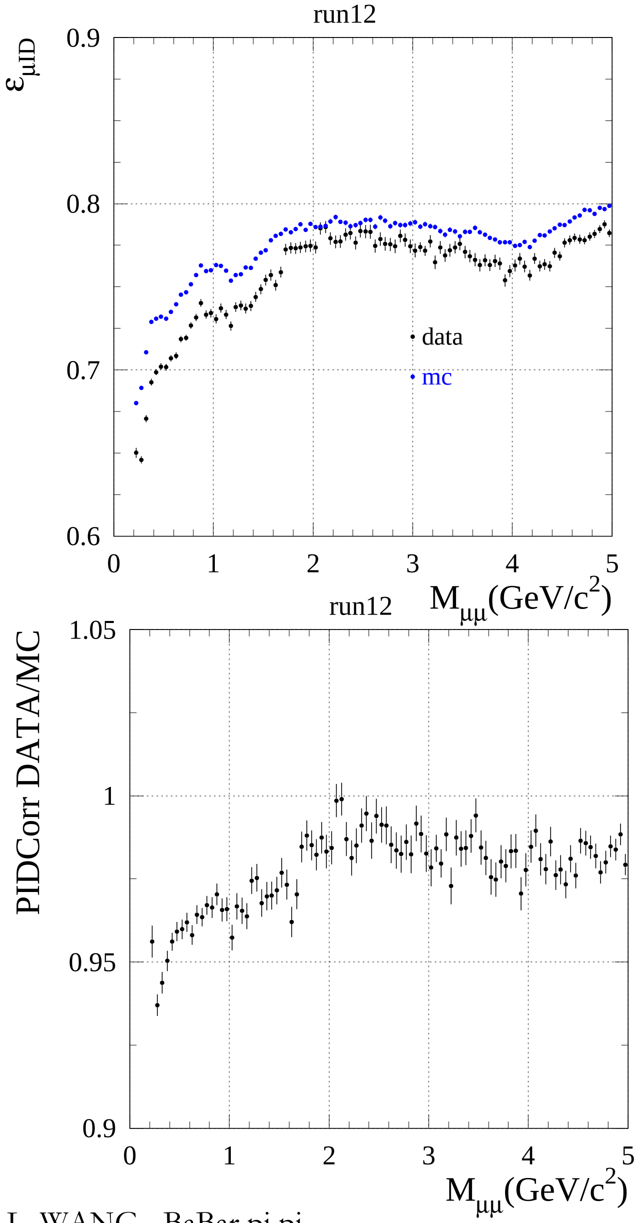


Analysis steps

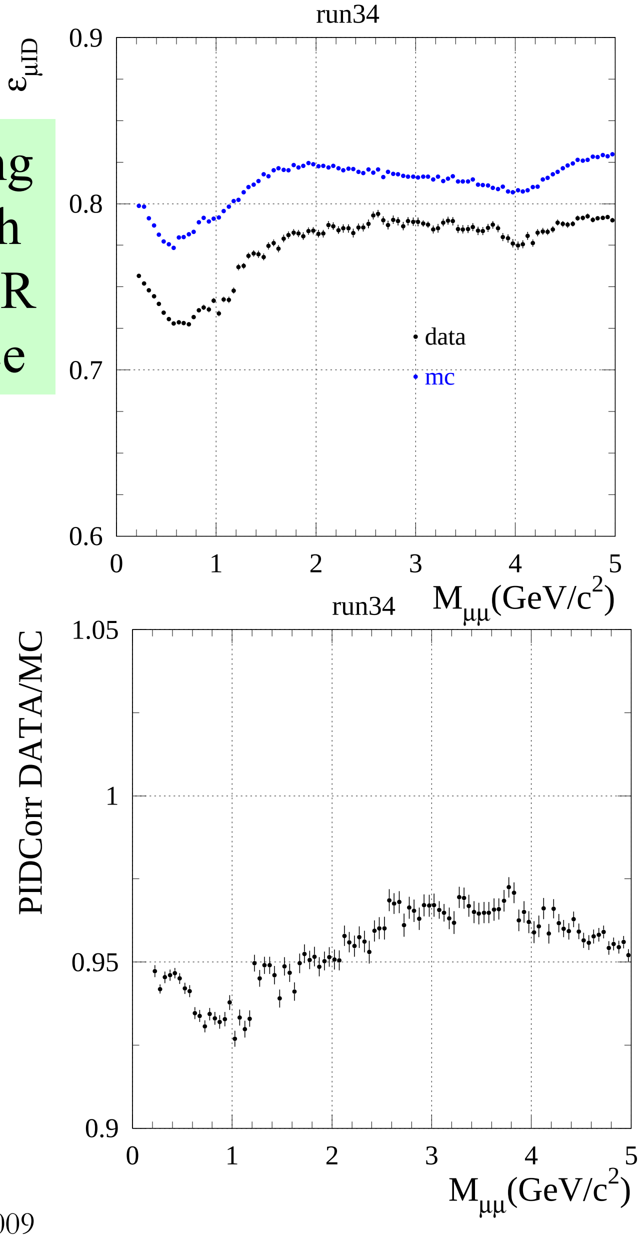
- Triggers (L1 hardware, L3 software), background-filter efficiencies
- Tracking efficiency
- Particle ID matrix (ID and mis-ID efficiencies)
  - μ
  - π
  - K
- Kinematic fitting
  - reduce non 2-body backgrounds
  - χ^2 cut efficiency
    - additional radiation (ISR and FSR)
    - secondary interactions
- Unfolding of mass spectra
- Geometrical acceptance
- Consistency checks for $\mu\mu$ (QED test, ISR luminosity) and $\pi\pi$
- Unblinding R
- Results on $\pi\pi$ cross section and calculation of dispersion integral

⇕ Preliminary
Final

PID correction to μμ cross section

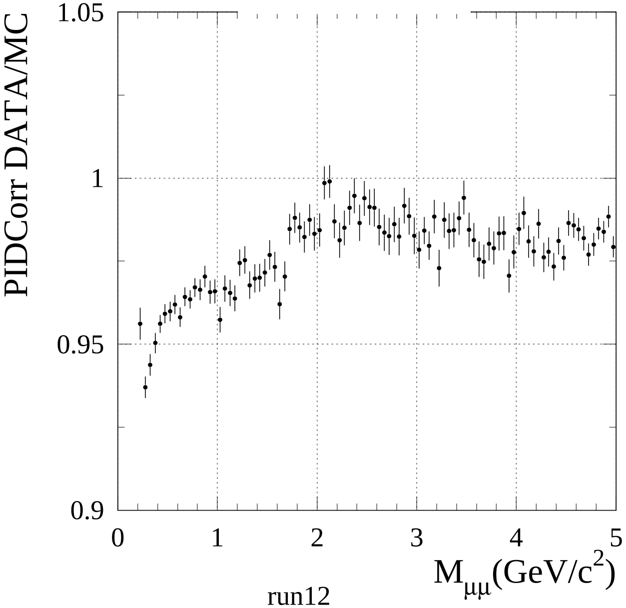


Two running periods with different IFR performance

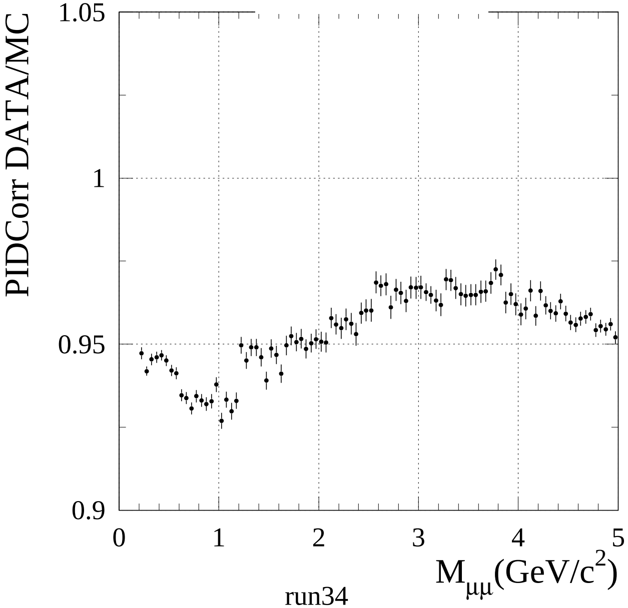


Data/MC PID corrections to $\mu\mu$ and $\pi\pi$ cross sections

Runs 1-2



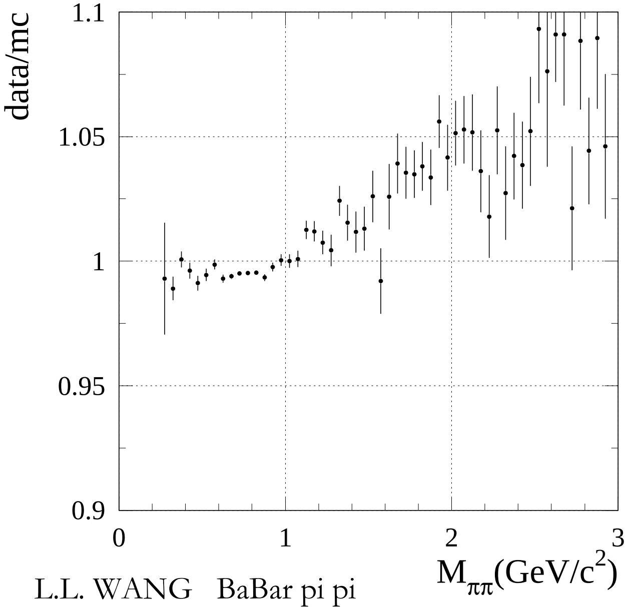
Runs 3-4



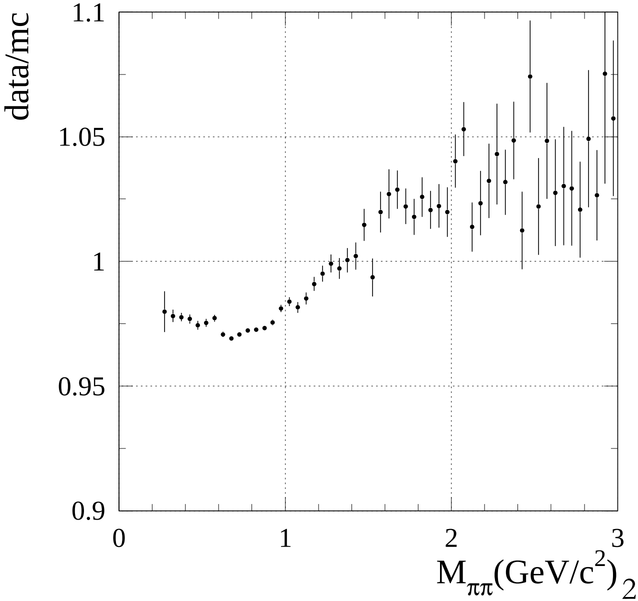
$\mu\mu\gamma$

Two running periods with different IFR performance

run12



run34

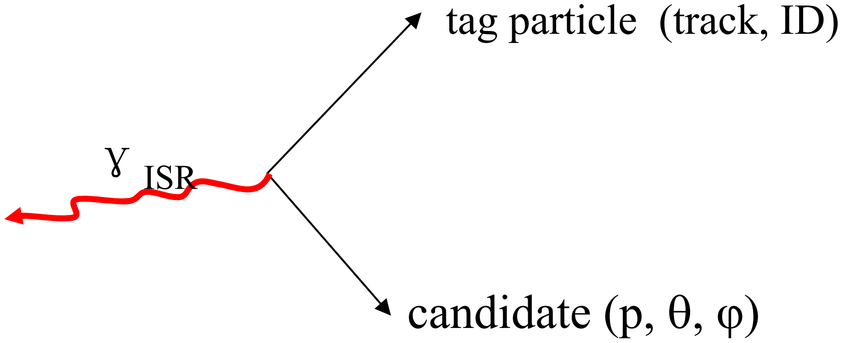


$\pi\pi\gamma$

Measurement of π-ID efficiencies

- 'π' ID is a set of negative conditions
- use π sample from ISR-produced ρ with π_h tag:
  $0.6<m_{\pi\pi}<0.9$ GeV impurity = $(3.7\pm0.5)\ 10^{-3}$
- ID and mis-ID efficiencies stored in 2D maps
- unlike muons, efficiency sample is not from isolated tracks
- biases from tagging and correlated loss studied with MC
  10^{-3} level

Particle-related efficiency measurements


tag particle (track, ID)

γ_{ISR}

candidate (p, θ, φ)

- benefit from pair production for particle ID
- kinematically constrained events
- efficiency automatically averaged over running periods
- measurement in the same environment as for physics, in fact same events!
- applied to particle ID with π/K/μ samples, tracking, study of secondary interactions…
- assumes that efficiencies of the 2 particles are uncorrelated
- in practice not true ⇒ this is where 95% of the work goes!
  study of 2-particle overlap in the detector (trigger,tracking, EMC, IFR) required
  a large effort to reach per mil accuracies (hence the duration of the analysis)

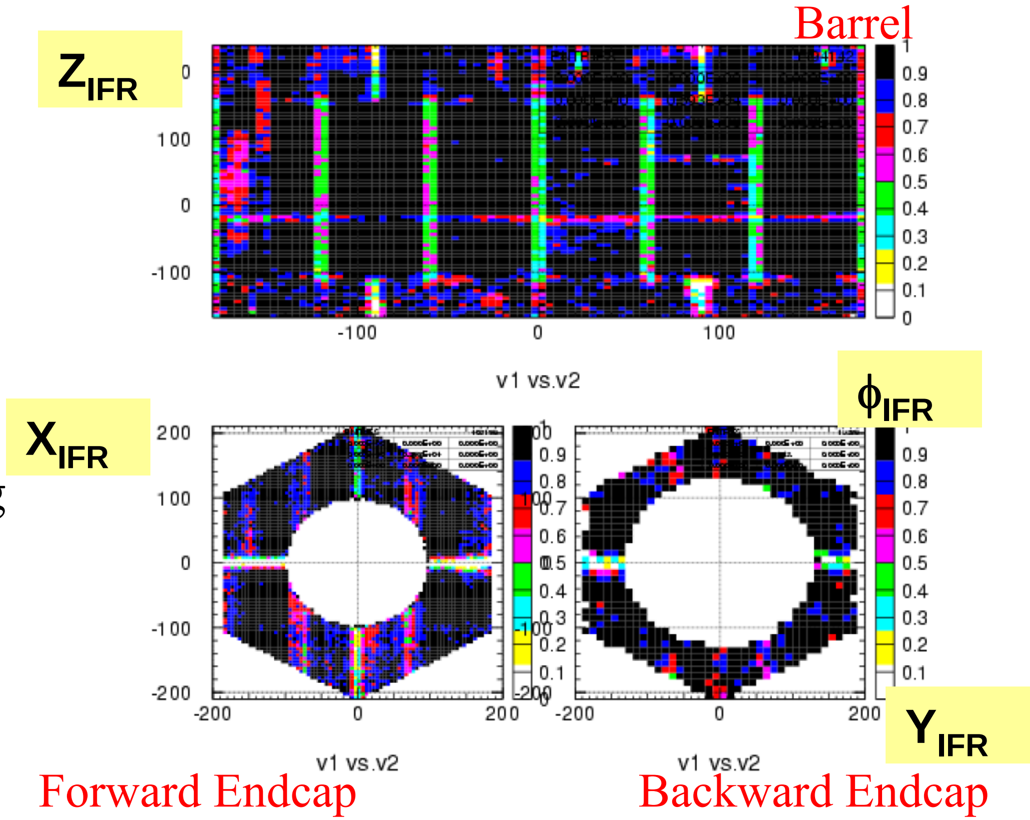
Particle identification

- Particle identification required to separate XXγ final processes
- Define 5 ID classes using cuts and PID selectors (complete and orthogonal set)
- Electrons rejected at track definition level (E_{cal}, dE/dx)
- All ID efficiencies measured

$$\varepsilon_{x \to I}$$

- a tighter π ID (π_h) is used for tagging in efficiency measurements and to further reject background in low cross section regions.

* isolated muons $M\mu\mu > 2.5$ GeV
→ efficiency maps (p, v_1, v_2)
impurity $(1.1 \pm 0.1)\ 10^{-3}$
* correlated efficiencies/close tracks
→ maps (dv_1, dv_2)

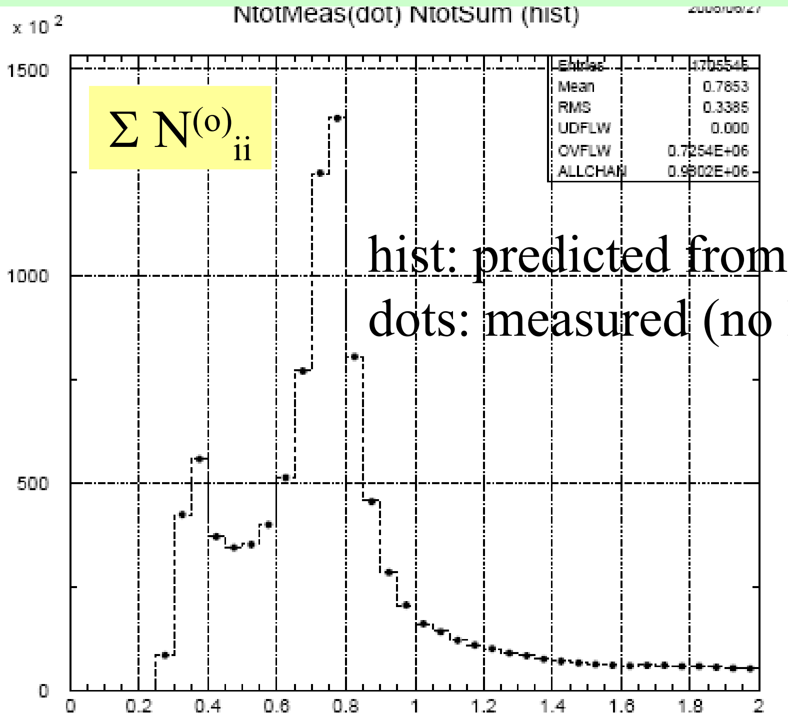


PID separation and Global Test

$$\begin{aligned} N_{'\pi\pi'} &= N^{(0)}_{\mu\mu}\varepsilon_{\mu\mu\to'\pi\pi'} + N^{(0)}_{\pi\pi}\varepsilon_{\pi\pi\to'\pi\pi'} + N^{(0)}_{KK}\varepsilon_{KK\to'\pi\pi'} + N_{ee/'\pi\pi'} \\ N_{'\mu\mu'} &= N^{(0)}_{\mu\mu}\varepsilon_{\mu\mu\to'\mu\mu'} + N^{(0)}_{\pi\pi}\varepsilon_{\pi\pi\to'\mu\mu'} + N^{(0)}_{KK}\varepsilon_{KK\to'\mu\mu'} \\ N_{'KK'} &= N^{(0)}_{\mu\mu}\varepsilon_{\mu\mu\to'KK'} + N^{(0)}_{\pi\pi}\varepsilon_{\pi\pi\to'KK'} + N^{(0)}_{KK}\varepsilon_{KK\to'KK'} \end{aligned}$$

All ‘xx’ ⇒ solve for all $xx^{(0)}$ and compare with no-ID spectrum and estimated syst. error

(small $\bar{p}p$ contribution subtracted statistically)

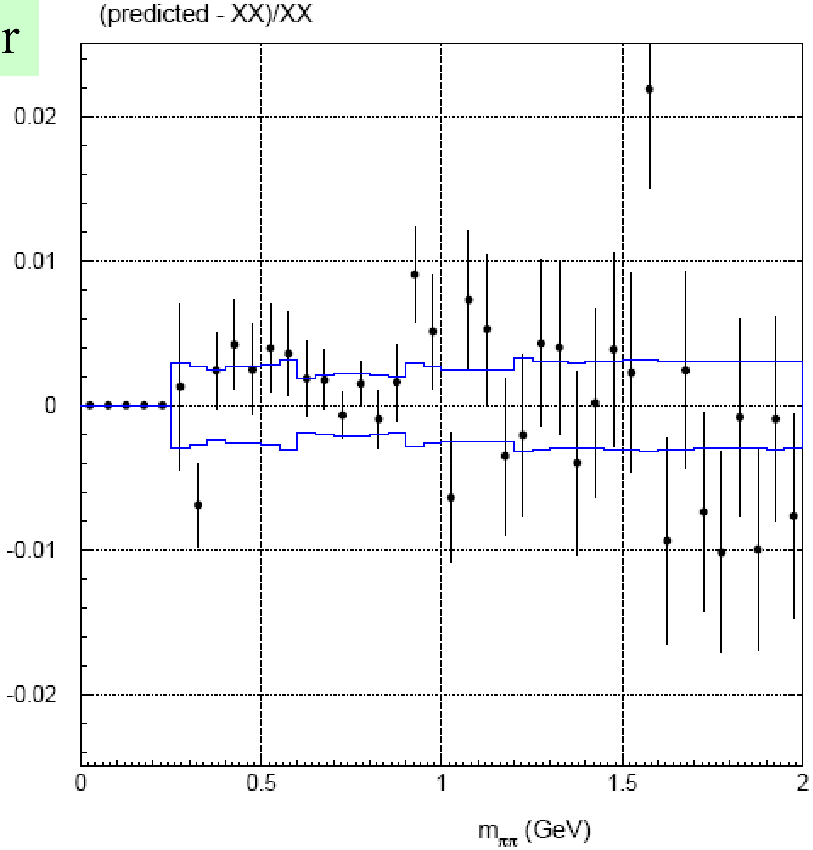


$\Sigma N^{(o)}_{ii}$

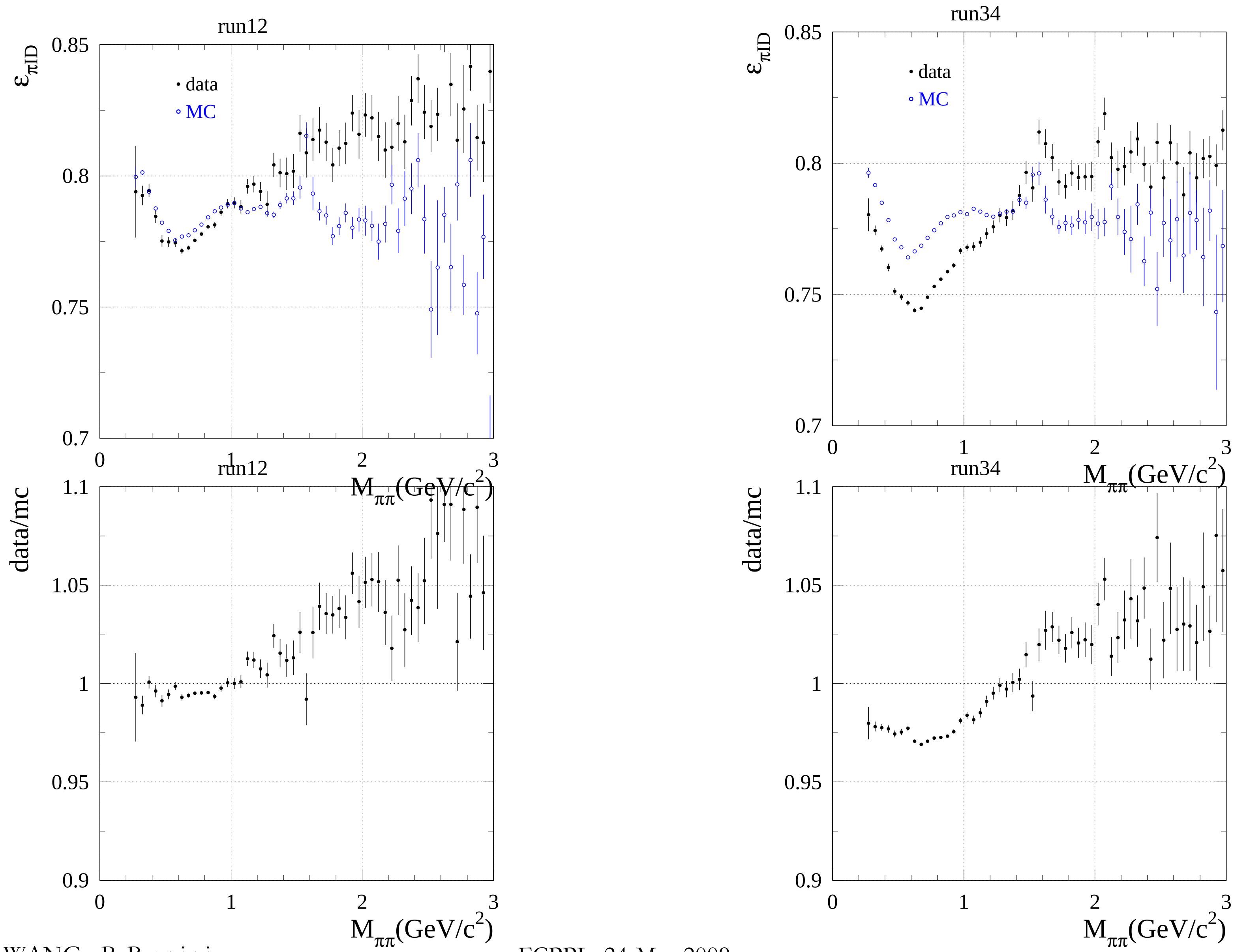
hist: predicted from PID

dots: measured (no ID)

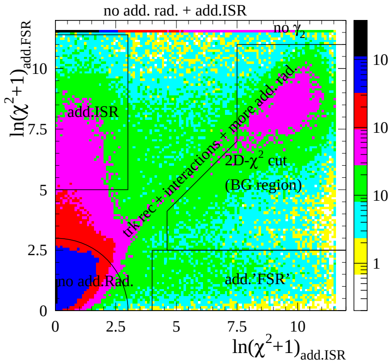
$m_{\pi\pi}$ (GeV)

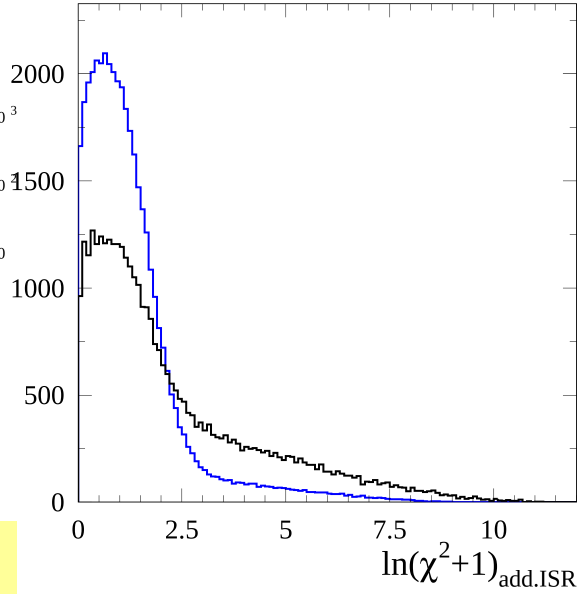


PID correction to ππ cross section

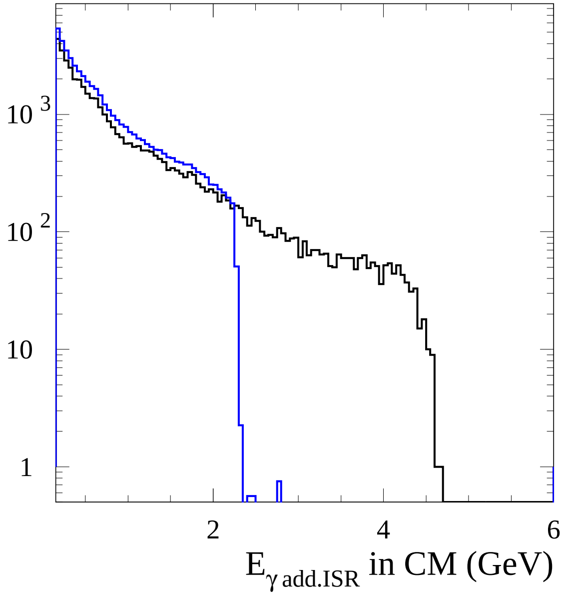


Additional ISR



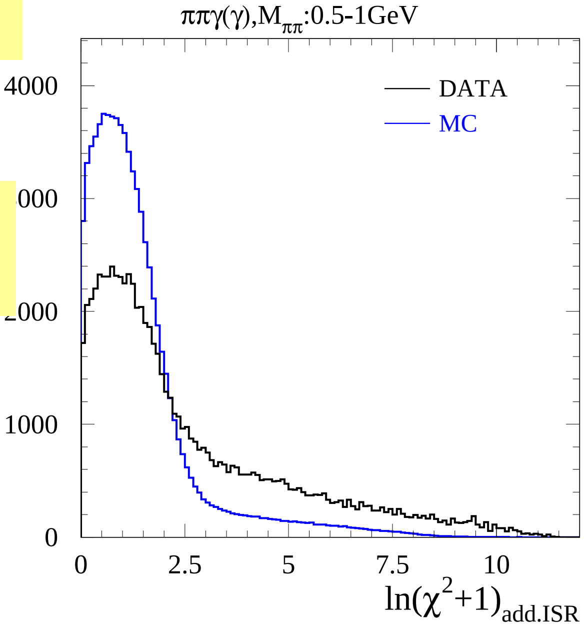


μμγγ

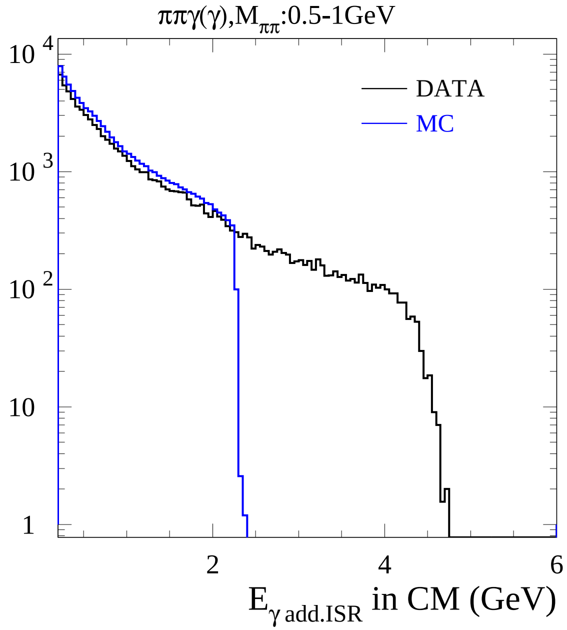


Angular distribution of add. ISR /beams!

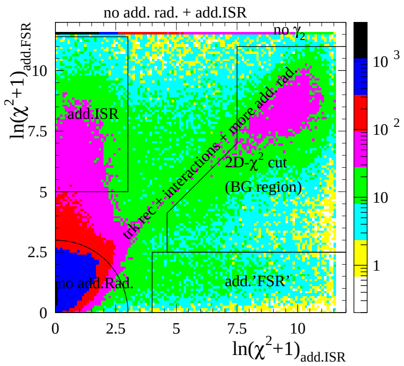
Energy cut-off for add. ISR in AfkQed

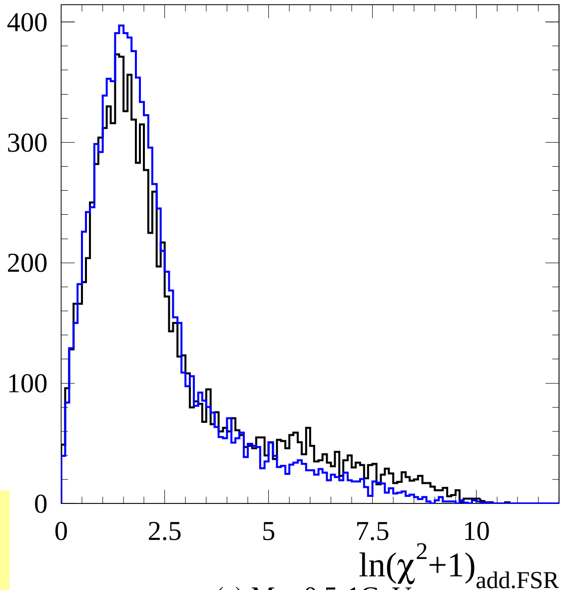


ππγγ

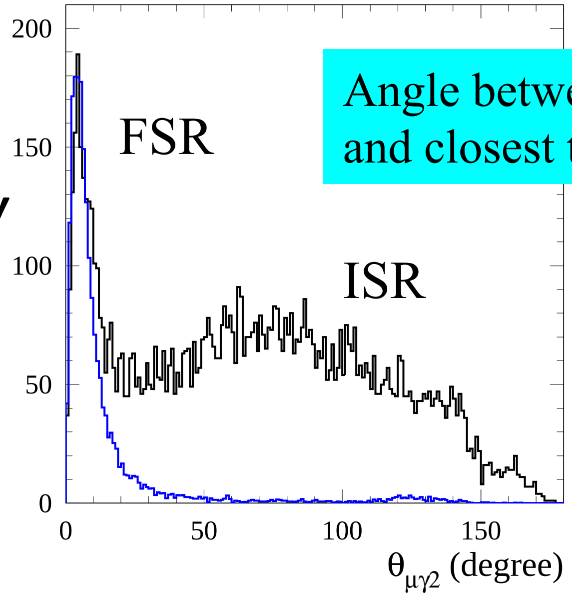


Additional FSR



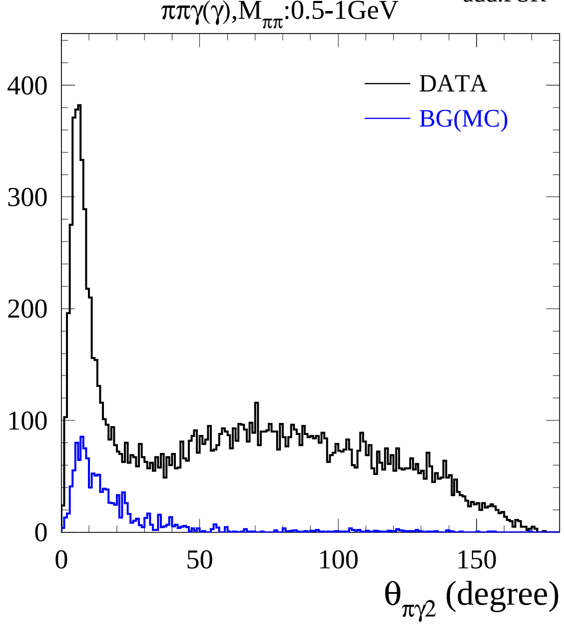


μμγγ

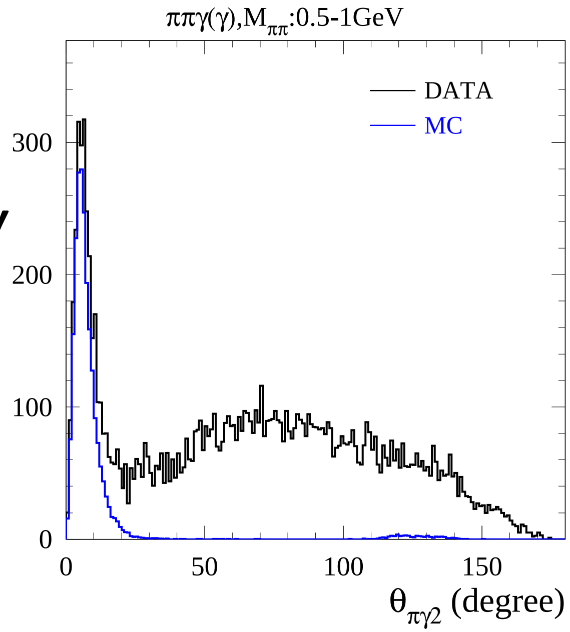


Angle between add γ and closest track

Large-angle add.ISR in data ≠ AfkQed



ππγγ



Evidence for FSR data ~ AfkQed

χ^2 cut Efficiency Correction: Interactions

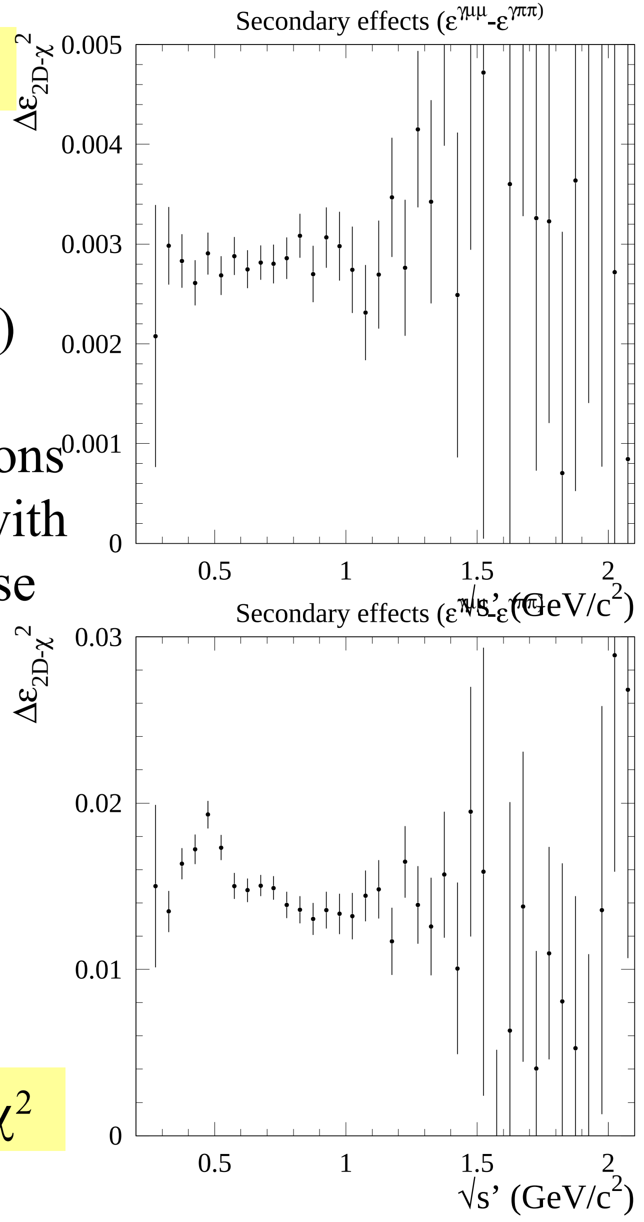
ππγγ

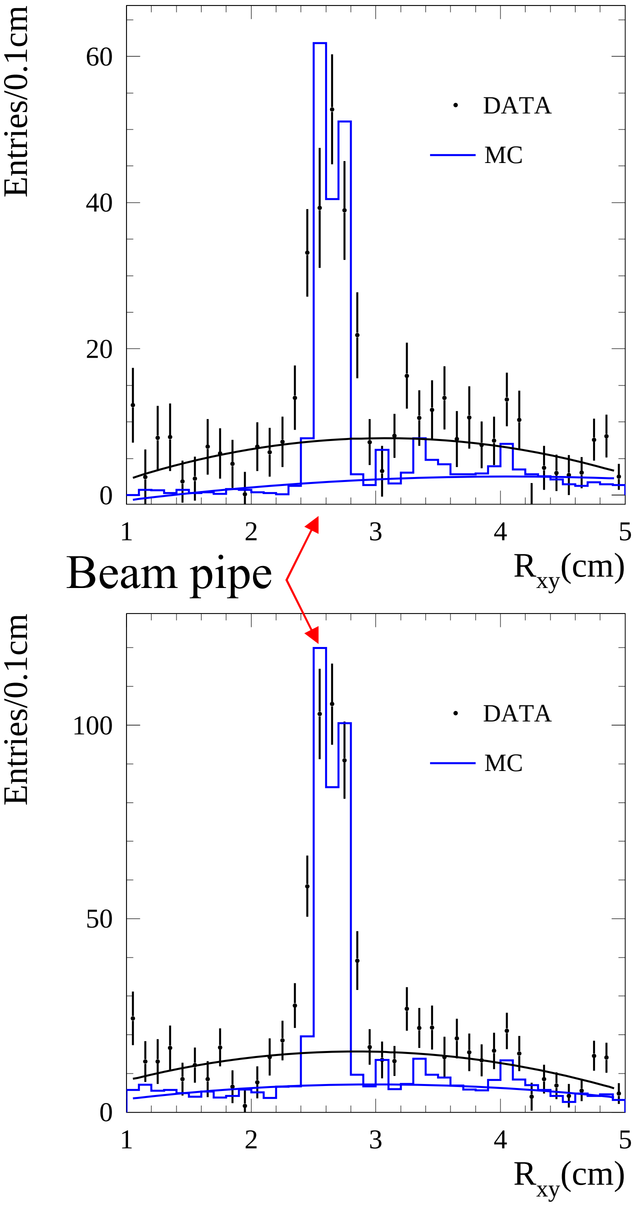
loose χ^2

- secondary interactions mostly from beam pipe (tight doca cut on tracks)
- tag events with interactions using displaced vertex with a ‘bad’ track in transverse plane (R_{xy})
- comparison data/MC

syst error at 10^{-3} level

tight χ^2

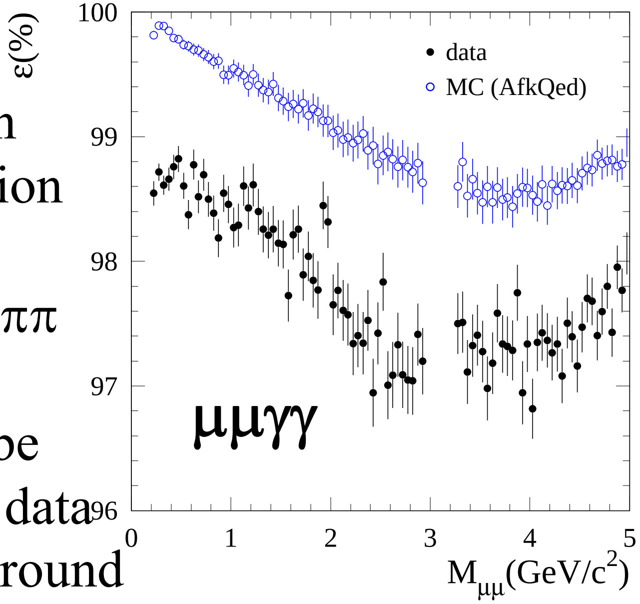


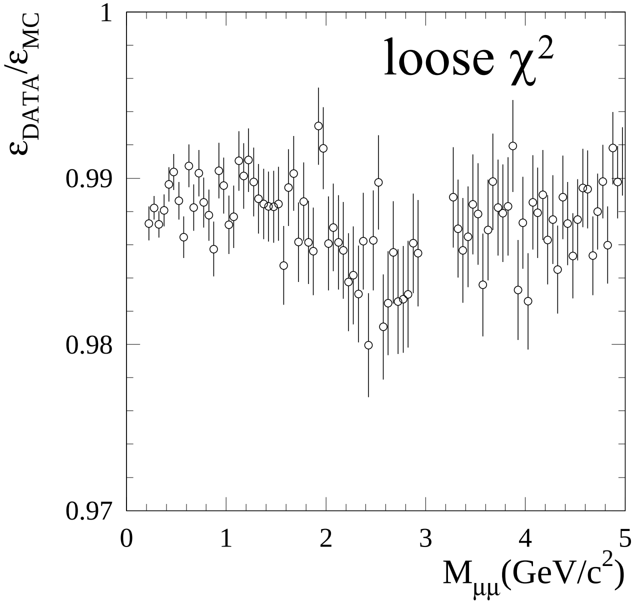


χ^2 cut efficiency correction

- depends on simulation of ISR (FSR), resolution effects (mostly ISR γ direction) for $\mu\mu$ and $\pi\pi$

- χ^2 cut efficiency can be well measured in $\mu\mu$ data because of low background





- main correction from lack of angular distribution for additional ISR in AfkQed
- common correction: 1% for loose χ^2, 7% for tight χ^2

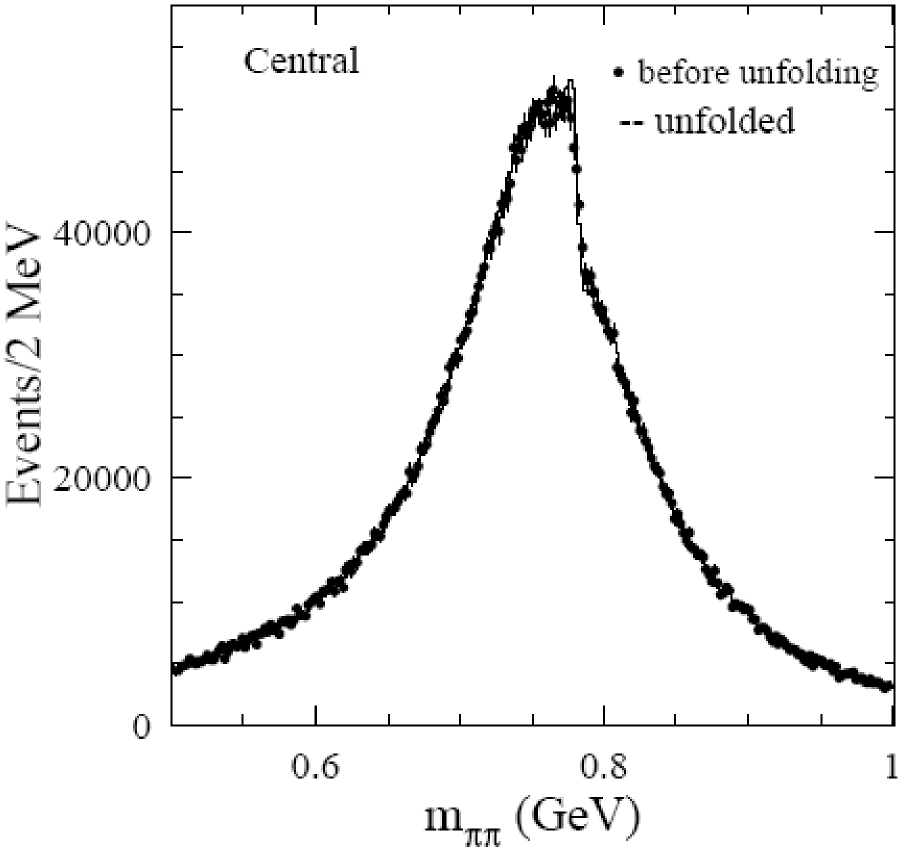
(J/ψ region excluded)

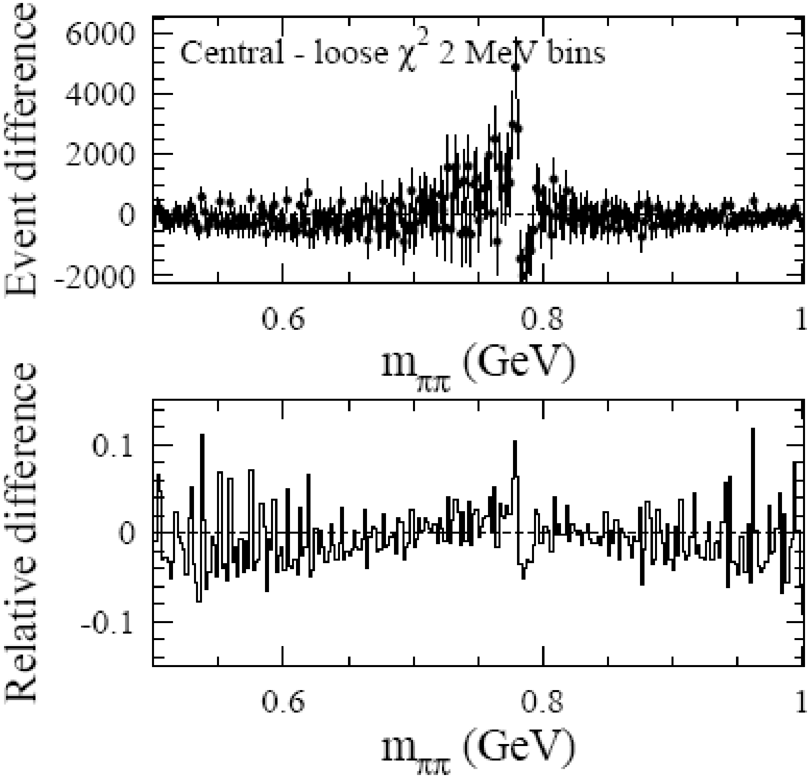
- additional loss for $\pi\pi$ because of interactions studied with sample of interacting events

  correction data/MC

Unfolding the $\pi\pi$ mass spectrum

- measured mass spectrum distorted by resolution effects and FSR ($m_{\pi\pi}$ vs. s')
- unfolding uses mass-transfer matrix from simulation
- 2 MeV bins in 0.5-1.0 GeV mass range, 10 MeV bins outside
- most salient effect in ρ-ω interference region (little effect on $a_\mu^{\pi\pi}$)

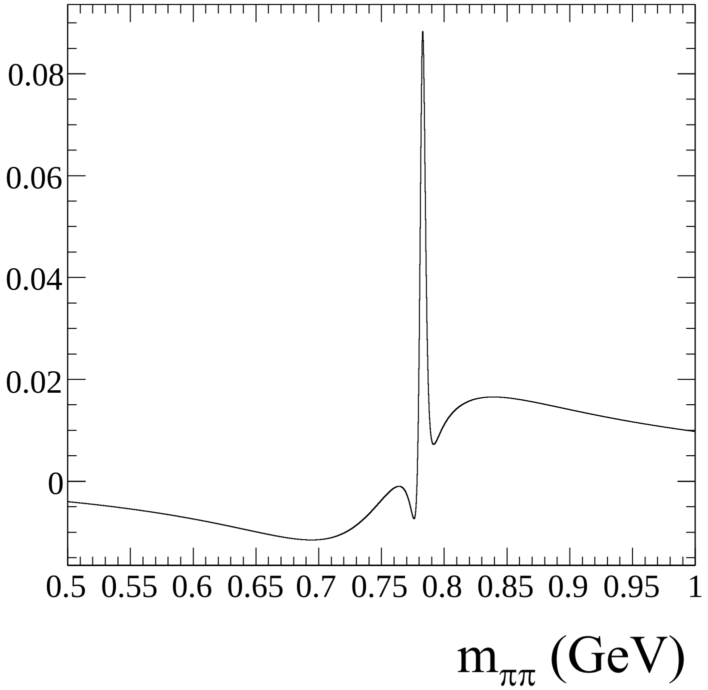




Mass calibration

mass calibration using J/ψ ––> μμ, scaled to ρ region : (0.16 ± 0.16) MeV)
mass resolution 6 MeV

effect of a 1 MeV mass scale shift



SU(2) breaking in τ and ee spectral functions

Electromagnetism does not respect isospin and hence we have to consider isospin breaking when dealing with an experimental precision of better than 1%

Corrections for SU(2) breaking applied to τ data for dominant $\pi^-\pi^+$ contrib.:

- Electroweak radiative corrections:
  - dominant contribution from short distance correction S_{EW} to effective 4-fermion coupling $\propto (1 + 3\alpha(m_\tau)/4\pi)(1+2\langle Q\rangle)\log(M_Z/m_\tau)$
  - subleading corrections calculated and small
  - long distance radiative correction $G_{EM}(s)$ calculated [add FSR to the bare cross section in order to obtain $\pi^-\pi^+(\gamma)$]

Marciano-Sirlin' 88

Braaten-Li' 90

Cirigliano-Ecker-Neufeld' 02
Lopez Castro et al. 06

- Charged/neutral mass splitting:
  - $m_{\pi-} \neq m_{\pi 0}$ leads to phase space (cross sec.) and width (FF) corrections
  - ρ-ω mixing (EM $\omega \to \pi^-\pi^+$ decay) corrected using FF model
  - $m_{\rho-} \neq m_{\rho 0}$ and $\Gamma_{\rho-} \neq \Gamma_{\rho 0}$ [not corrected !]

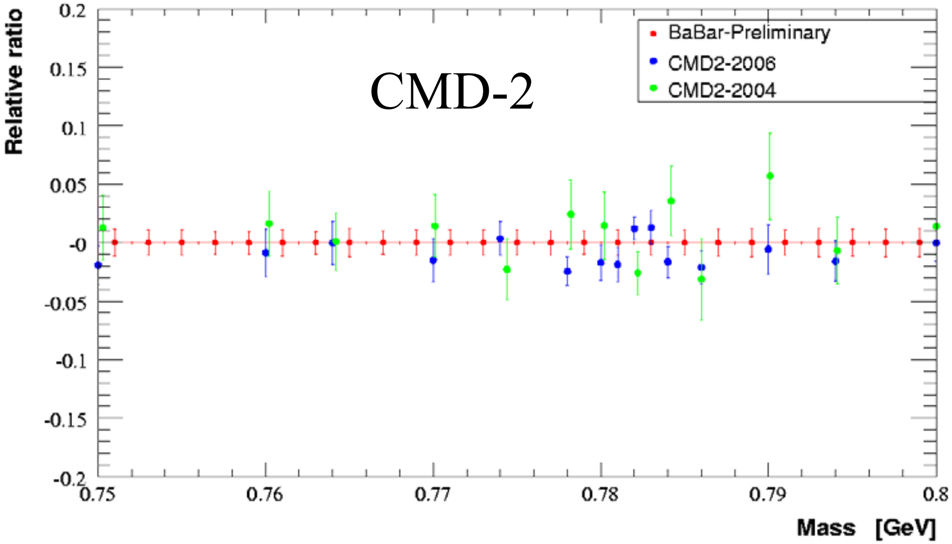
Alemany-Davier-Höcker' 97, Czyż-Kühn' 01

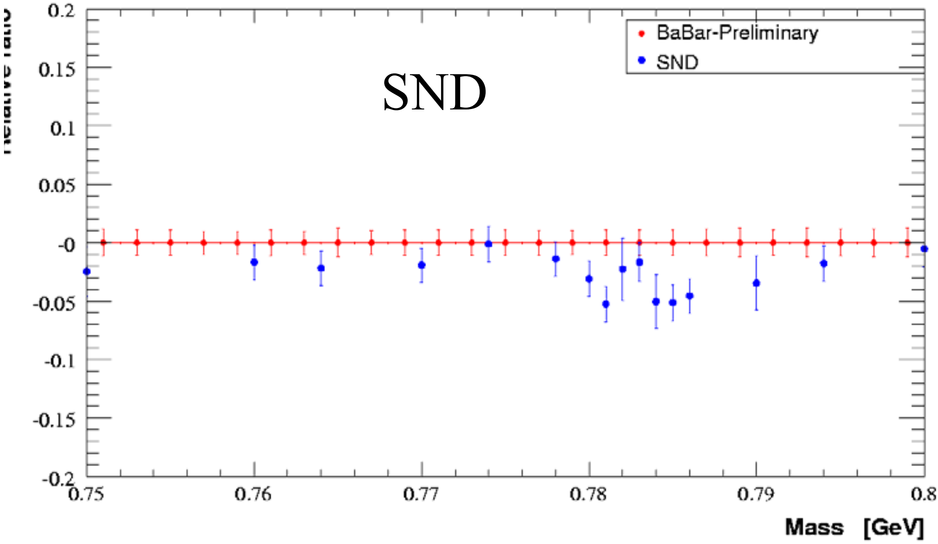
- Electromagnetic decays, like: $\rho \to \pi\pi\gamma$, $\rho \to \pi\gamma$, $\rho \to \eta\gamma$, $\rho \to l^+l^-$
- Quark mass difference $m_u \neq m_d$ generating "second class currents" (negligible)

Lopez Castro et al. 08

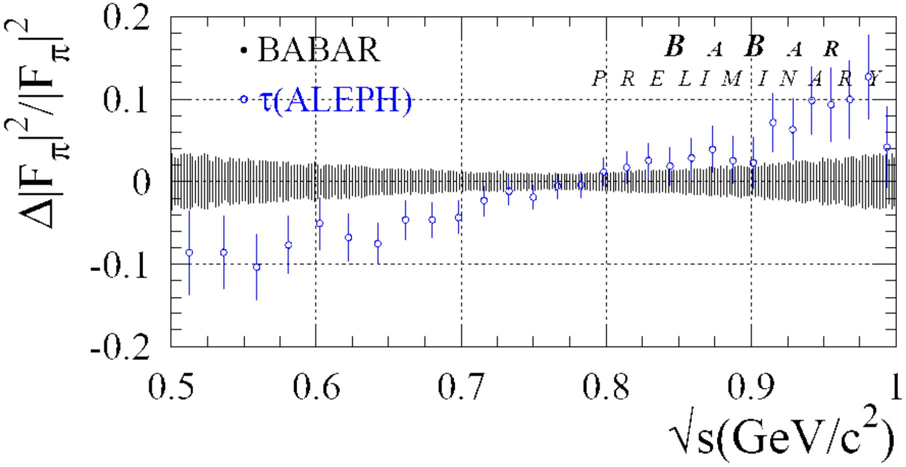
BaBar vs.CMD-2 and SND (ρ–ω interference region)

- mass calibration of BaBar checked with J/ψ →μμ
  - –(0.16 ± 0.16) MeV at ρ peak
- ω mass can be determined through mass distribution fit (in progress)
- Novosibirsk data precisely calibrated using resonant depolarization
- comparison BaBar/CMD-2/SND in ρ-ω interference region shows no evidence for a mass shift





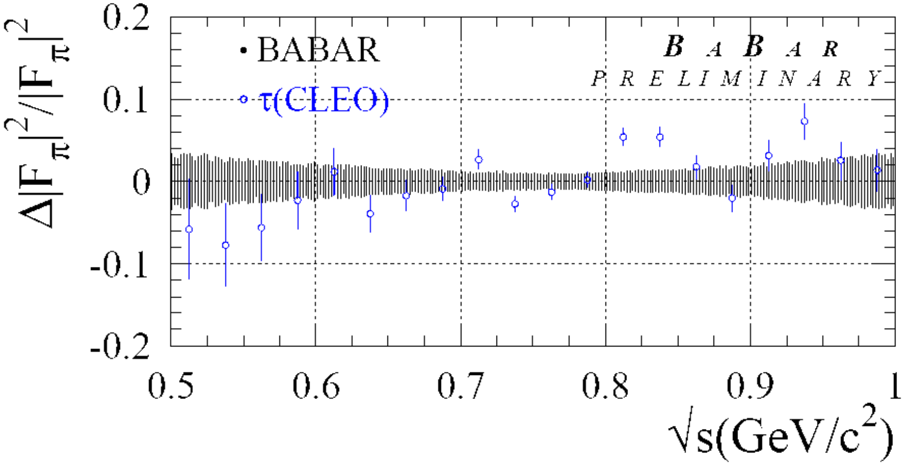
BaBar vs. IB-corrected τ data (0.5-1.0 GeV)

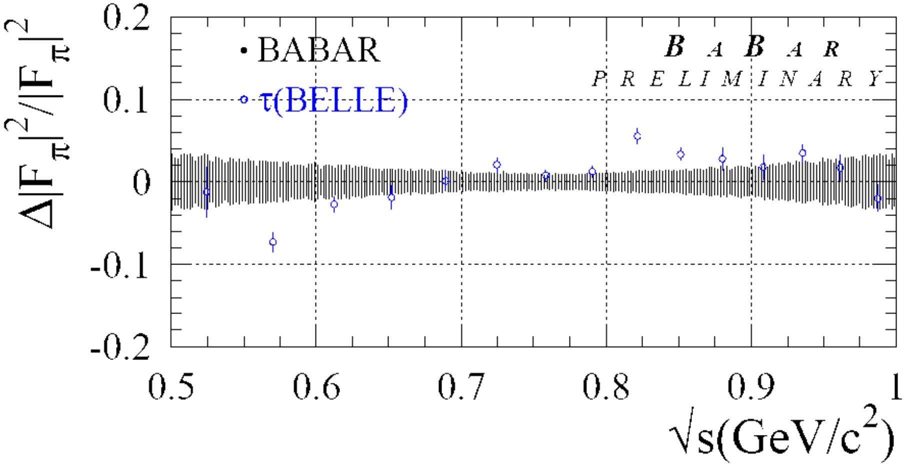


relative comparison w.r.t. BaBar of isospin-breaking corrected τ spectral functions

BaBar data averaged in wider τ bins and corrected for ρ-ω interference

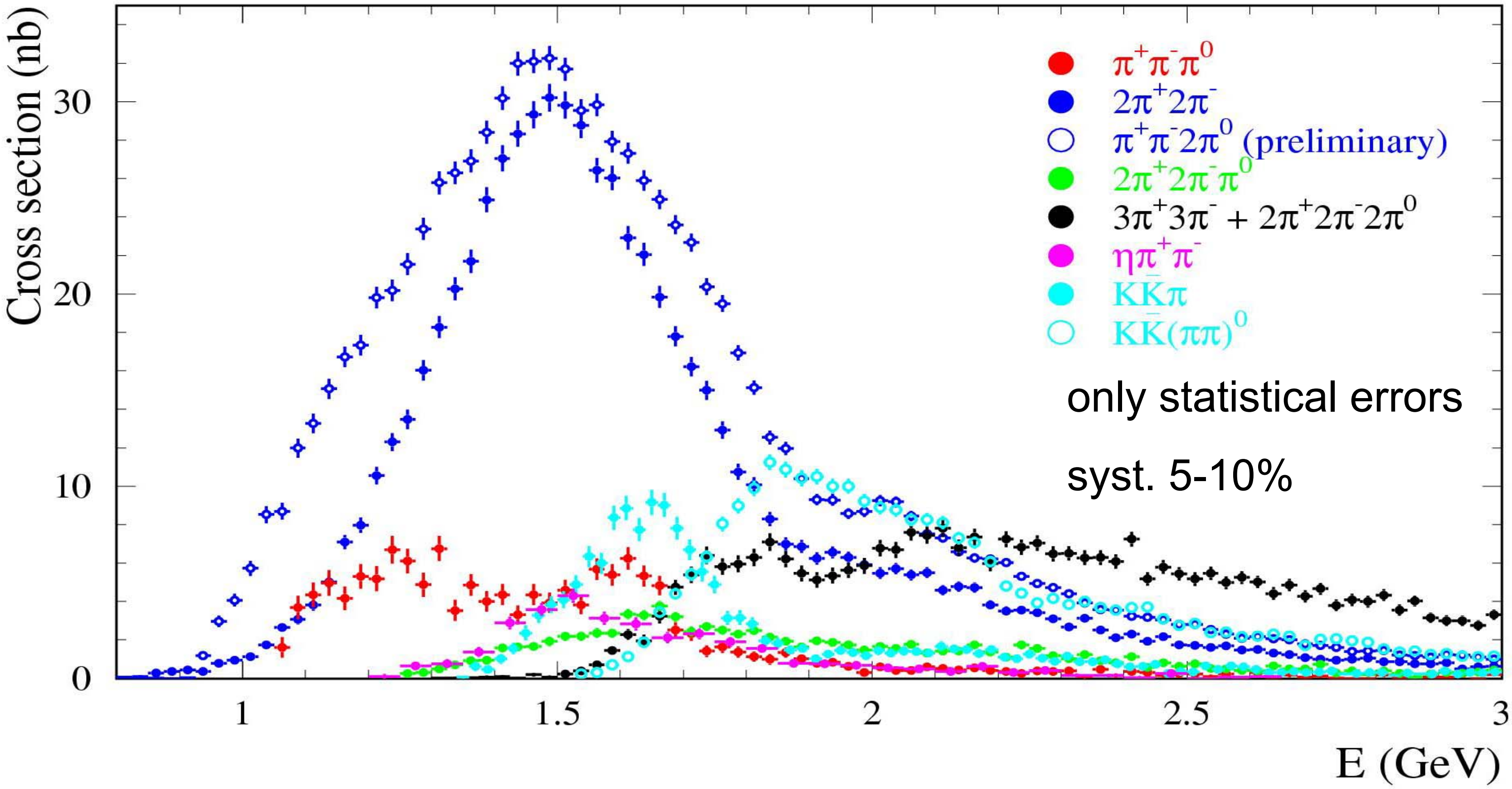
Belle 2008: large statistics





Multihadronic channels: BaBar ISR measurements

many ISR BaBar results already published on $e^+e^-\to$hadrons for larger multiplicities



only statistical errors

syst. 5-10%

to complete the R measurement in the energy range 1-2 GeV the processes $\pi^+\pi^-3\pi^0$, $\pi^+\pi^-4\pi^0$, K^+K^-, K_SK_L, $K_SK_L\pi\pi$, $K_SK^{+-}\pi^{-+}\pi^0$ are being measured

Contributions to a_μ^{had} from multihadronic modes

- The BaBar results are the most precise measurements to date for CM energies greater than 1.4 GeV.

- Examples: contributions to a_μ^{had} ($\times 10^{-10}$) from $\mathbf{2\pi^+ 2\pi^-}$ (0.56 – 1.8 GeV)

from all $e^+ e^-$ exp.	$14.21 \pm 0.87_{exp} \pm 0.23_{rad}$
from all τ data	$12.35 \pm 0.96_{exp} \pm 0.40_{SU(2)}$
from BaBar	$12.95 \pm 0.64_{exp} \pm 0.13_{rad}$

from $\pi^+ \pi^- \pi^0$ (1.055 – 1.8 GeV)

from all $e^+ e^-$ exp.	$2.45 \pm 0.26_{exp} \pm 0.03_{rad}$
from BaBar	$3.31 \pm 0.13_{exp} \pm 0.03_{rad}$

reminder: total 690.9 ± 4.4 (DEHZ 2006)

Outlook for muon g–2 SM prediction

Hadronic LO contribution

- potentially existing e+e– data can reach a precision $\Delta a_{\mu}^{had} = 2.5\ (10^{-10})$
- hopeful that remaining discrepancies will be brought close to quoted systematic uncertainties
- use of τ data limited by knowledge of isospin-breaking corrections: present precision $2.5\ (10^{-10})$, total error $3.9\ (10^{-10})$, work in progress
- new data expected from VEPP-2000 with CMD-2 and SND

Hadronic LBL contribution

- relies only on phenomenological estimates, precision $\Delta a_{\mu}^{hadLBL} = 3.5\ (10^{-10})$
- more progress? lattice?

Other contributions

- QED, electroweak, HO hadronic: $\Delta a_{\mu}^{others} = 0.2\ (10^{-10})$

g–2 experimental error

- BNL E821 (2004) $\Delta a_{\mu}^{exp} = 6.3\ (10^{-10})$
- a new measurement will be needed to match the 'theory' uncertainty