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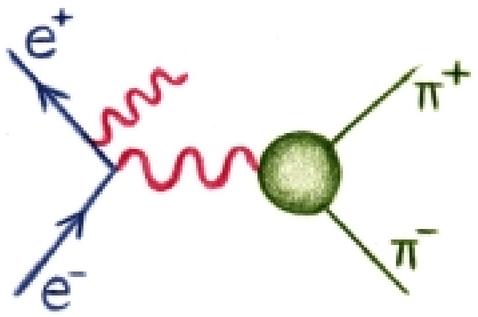
RADCOR 2002
Kloster Banz, Sept. 8-13 2002

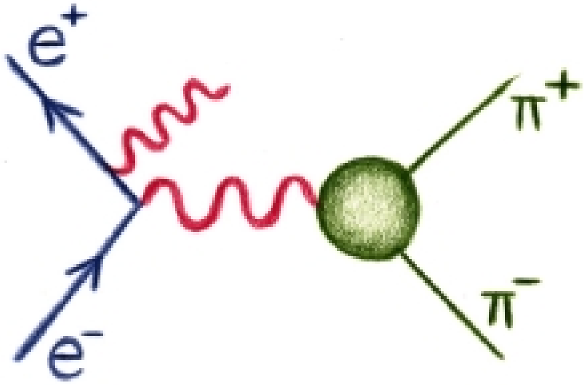
Measuring Hadronic Cross Sections via Radiative Return



- Radiative Return
- KLOE Measurement ($\pi^+\pi^-$)
- BABAR, Summary

Radiative Return

➨ Particle factories have the opportunity to measure the cross-section $\sigma(e^+ e^- \to hadrons)$ as function of the hadronic c.m.s energy $M^2_{hadrons}$ by using the **radiative return method**.



$$\frac{d\sigma(e^+ e^- \to hadrons + \gamma)}{dM_{hadrons}}$$

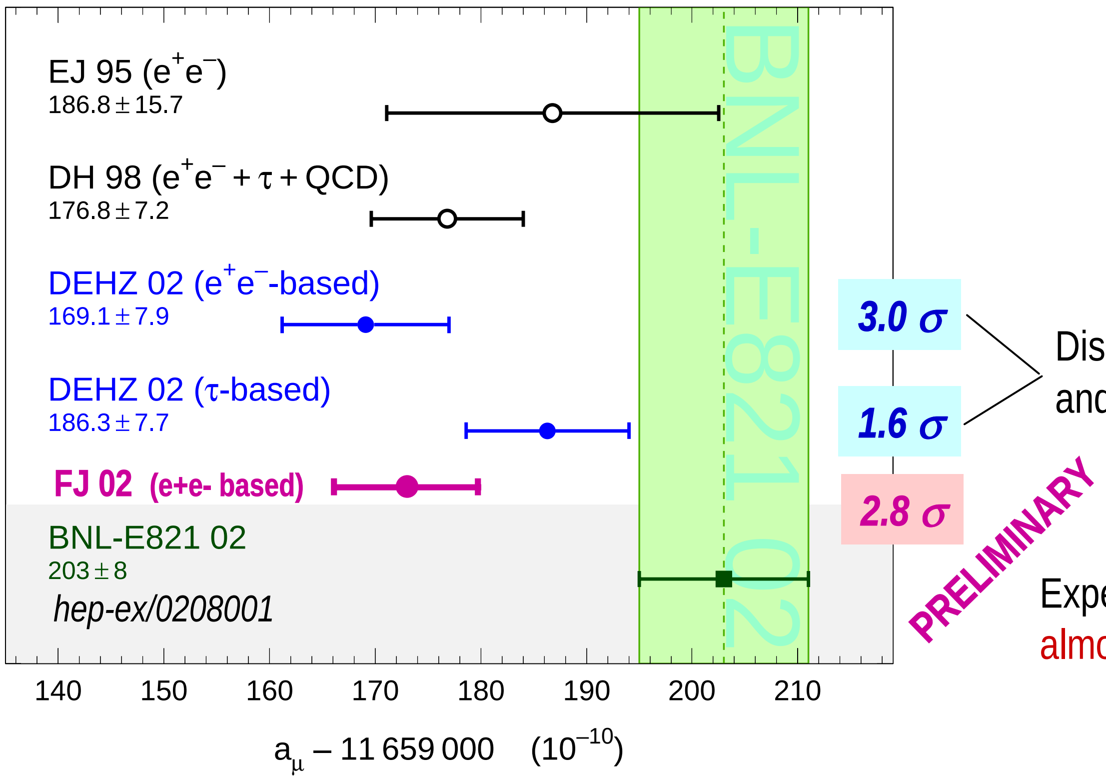
➨ This method (S. Binner, J.H. Kühn, K. Melnikov, Phys. Lett. B 459, 1999) is a **complementary approach** to the standard energy scan.

disadvantage	**advantage**
Requires precise calculations of ISR	Data comes as by-product of standard program
➨ **EVA + Phokhara** MC Generator	***Radiative Corrections have to be calculated only and NOT for each point of s***
Requires good suppression of FSR	Systematic errors from Luminosity, $\sqrt{s}$, … enter **only once**

STATUS OF a_μ

➨ In August this year the new measurement of a_μ and new theoretical estimates have been presented to the community

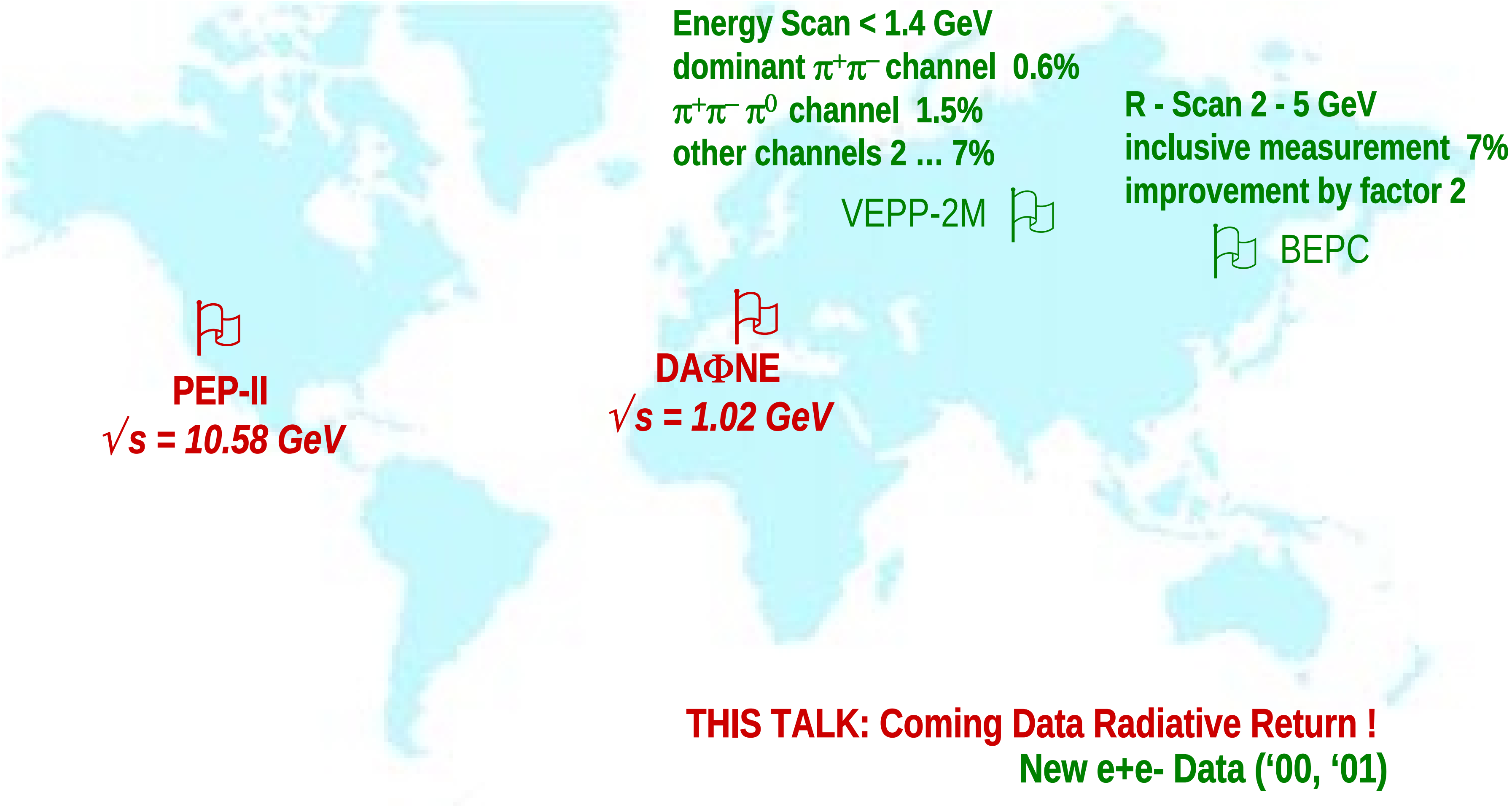
Davier, Eidelman, Höcker, Zhang: hep-ph/0208177



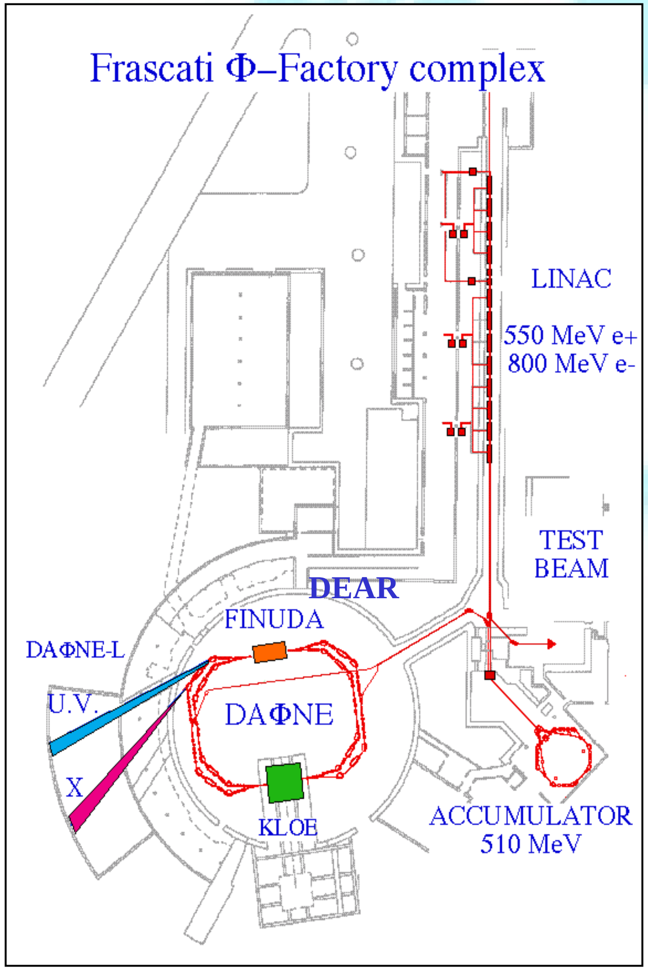
Disagreement between e^+e^- based and τ based evaluations

Experiment and Theory with almost identical errors ($\pm\, 8\cdot 10^{-10}$):

NEW MEASUREMENTS



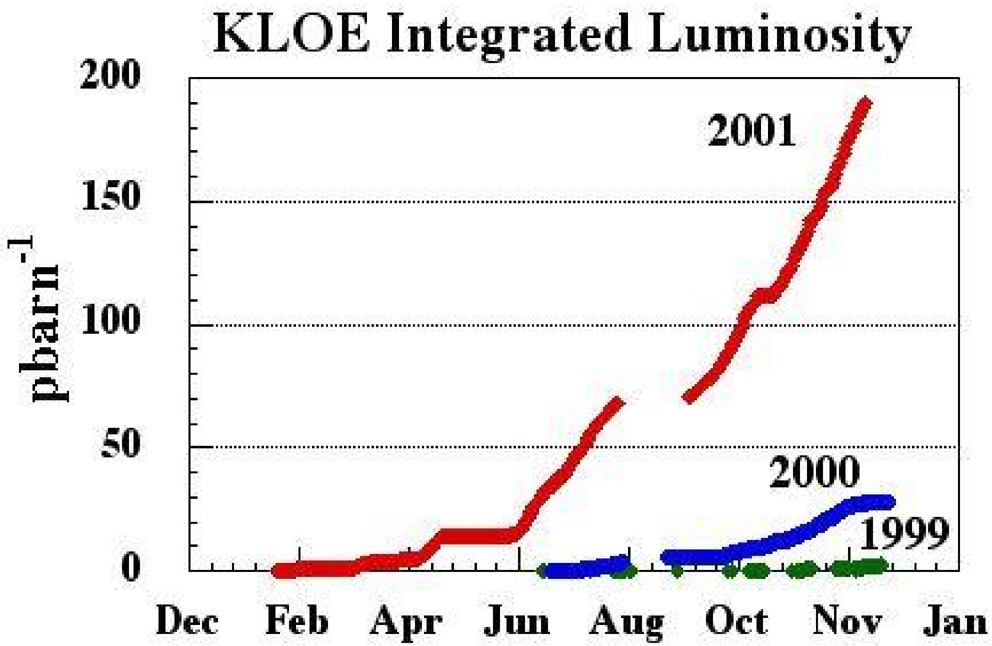
- ➨ **Very interesting new e+e- data** has lowered the theoretical error for the muon anomaly
- ➨ **Cross check of low energy cross section data** mandatory to understand 3.0 σ effect !



KLOE @ DAΦNE

➨ $\sqrt{s}$ **= 1.02 GeV**

DAΦNE COLLIDER



1999 run : **2.5 pb^{-1}** *machine and detector studies*

2000 run : **25 pb^{-1}**
7.5 x 10^{7} ϕ
published results

2001 run: **190 pb^{-1}**
5.7 x 10^{8} ϕ
analysis in progress

2002 run: since 03/05 - 04/09 **220 pb^{-1}**
DAΦNE Backgr. reduced factor 2 ..3

Present day performance:

	peak	average
L(cm^{-2} s^{-1})	**7·10^{31}**	**5·10^{31}**
$\int_{day}$ L dt (pb^{-1})	**3.8**	**3.0**

Winter shutdown (from Oct. '02):
Insertion of new Interaction Point
with variable Quadrupole rotation

HADRONIC CROSS SECTION

- We perform an **absolute cross section measurement** for the $\pi^+\pi^-\gamma$ **final state** which requires to study the following analysis items:

Signal, Background

$$\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \frac{N^{obs} - N^{bkg}}{\Delta M^2_{\pi\pi}} \times \frac{1}{\varepsilon_{Select.} \cdot \varepsilon_{Accept.}} \times \frac{1}{L}$$

Luminosity

Selections-Efficiency, Acceptance

- We divide the $\pi^+\pi^-\gamma$ **cross section** by the **radiation function** $H(M_{\pi\pi}^2)$ which is obtained from the **MC generator Phokhara** (next talk by Czyz) by **setting** $F_\pi = 1$ **.**

$$\left|F_\pi(M^2_{\pi\pi})\right|^2 = \frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{H_i(M^2_{\pi\pi})} = \frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{d\sigma_{\pi\pi\gamma,F_\pi=1}(M^2_{\pi\pi})}$$

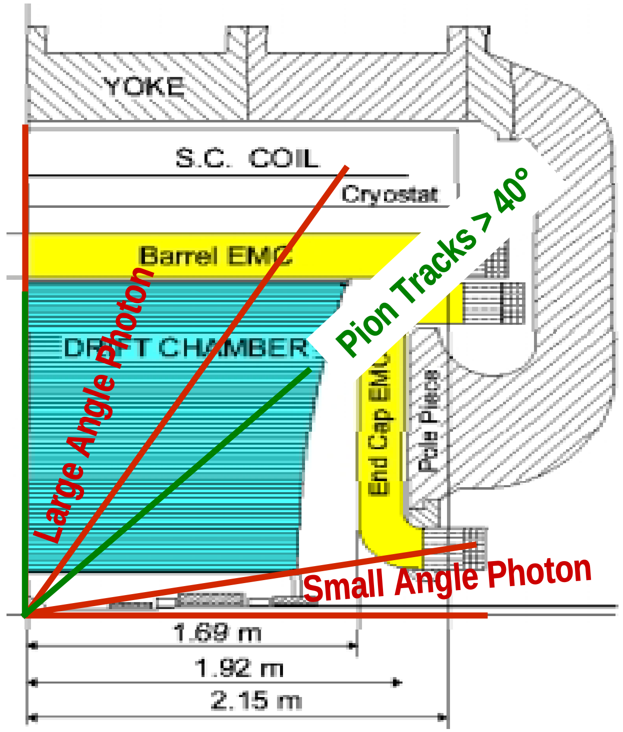
Signal Selection

➨ For the **selection of the $\pi\pi\gamma$ - Signal** two fiducial volume regions have been worked out:

Pion Tracks are measured at angles **$40^o < \theta_\pi < 140^o$**

- **Large angle (LA):** $55^o < \theta_\gamma < 125^o$
  allows a **tagging** of the radiative photon

- **Small angle (SA):** $\theta_{\pi\pi} < 15^o$ or $\theta_{\pi\pi} > 165^o$
  photon cannot be efficiently detected with EmC
  untagged measurement in which we cut on the missing momentum $\theta_{\pi\pi}$

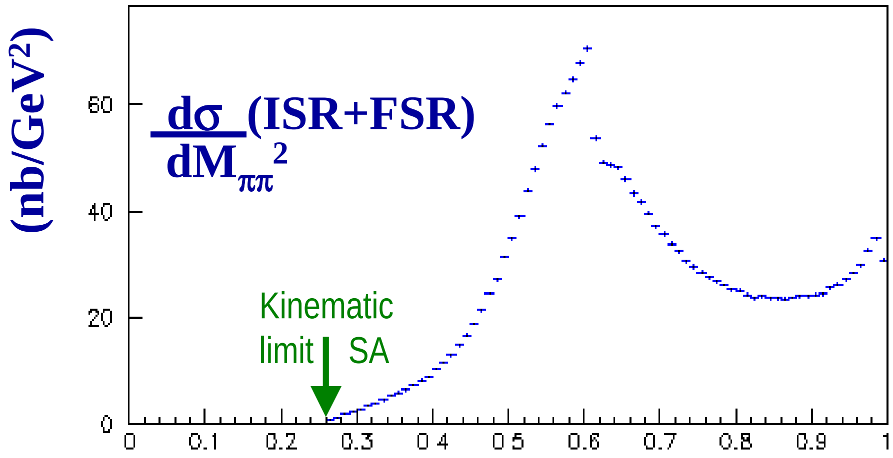


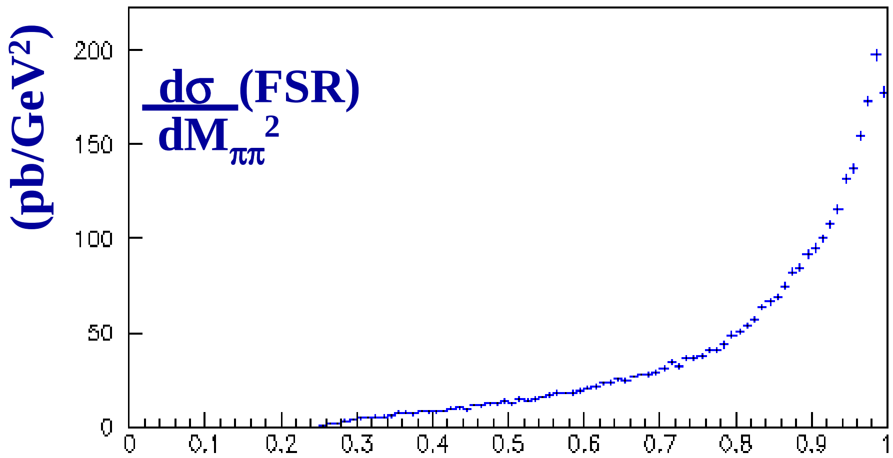
In this presentation I will concentrate on the **small angle analysis** which is in a very advanced state and which allows to cover $0.28\ GeV^2 < M^2_{\pi\pi} < 1.0\ GeV^2$

➨ The two kinematical regions differ for:
- $\pi\pi\gamma$ cross sections (SA: 21nb, LA: 3nb)
- background contamination
- $M^2_{\pi\pi}$ spectrum shape
- relative contribution of **FSR**

FSR SUPPRESSION

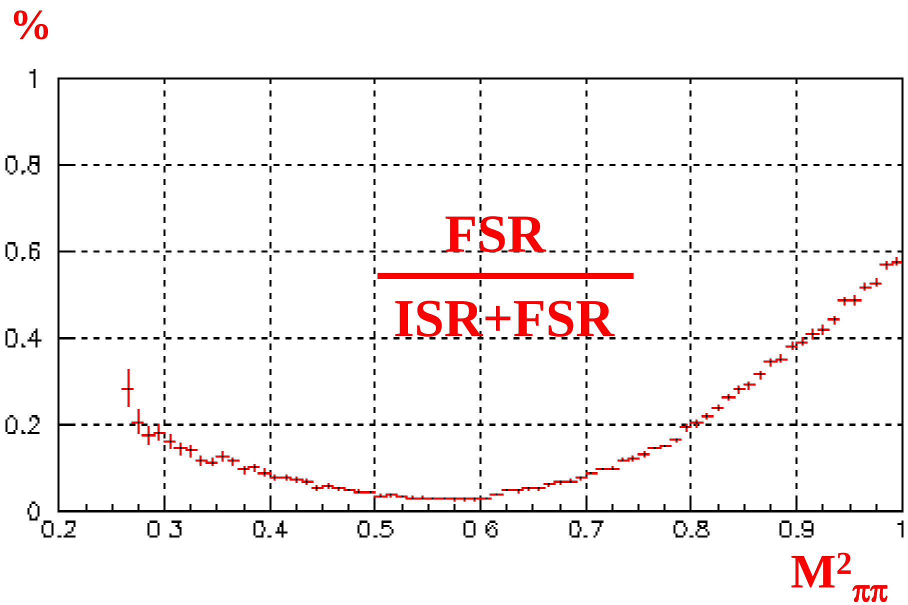
Plots: MC generator EVA for Small-Angle-Analysis





The relative contribution of ISR and FSR depends strongly on the polar angle and the energy of the photon.

In the Small Angle - Analysis (untagged method) the **contribution of FSR** can be kept **below 1%**



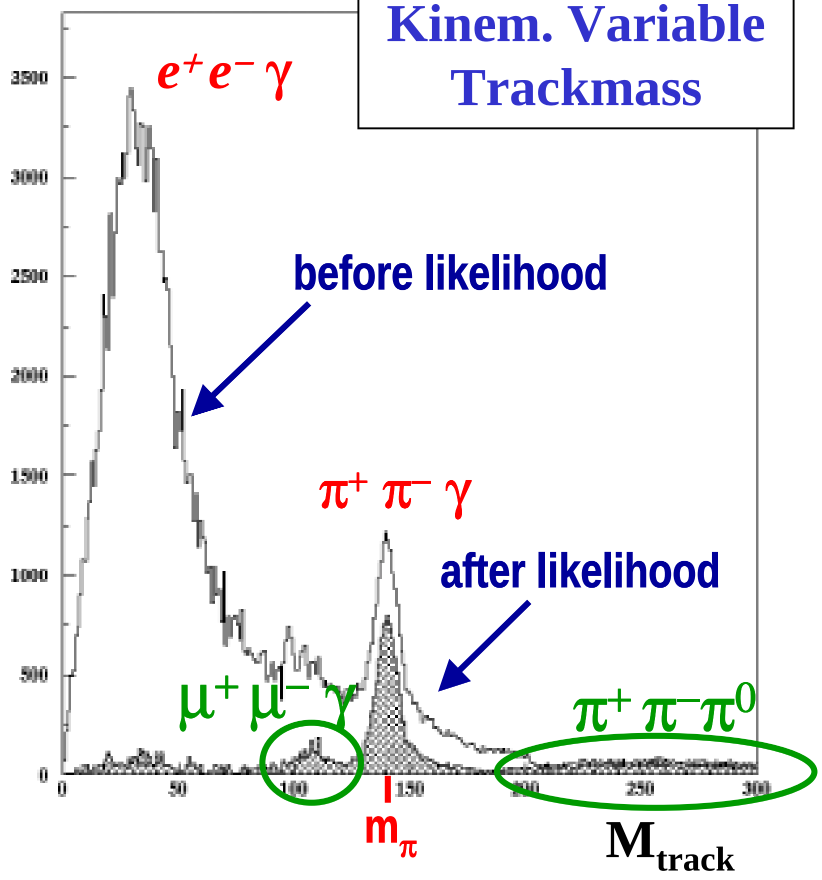
BACKGROUND

- The main source of background are **Radiative Bhabha events** which enter our $\pi\pi\gamma$ selection

- A **likelihood method** has been worked out which allows an efficient **separation** of **pions from electrons**

  Method uses information from the EmCalorim.:
  - Time of Flight of Tracks
  - Signature of the energy deposit of Tracks

- Effect of the Method becomes visible in the **Trackmass distribution** which is a kinematical variable obtained by solving 4-momentum-conservation:



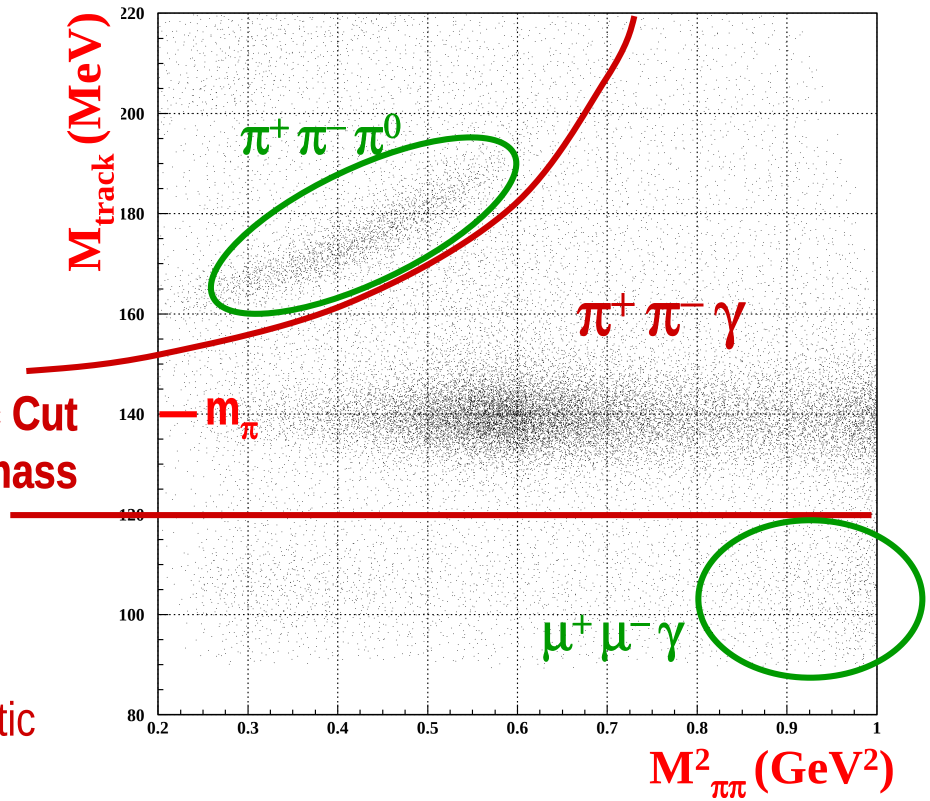
$$\left(M_\phi - \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} - \sqrt{\vec{p}_2^{\,2} + M_{trk}^2}\right)^2 - (\vec{p}_1 + \vec{p}_2)^2 = q_\gamma^2 = 0$$

BACKGROUND

- **Additional sources** of background can be seen also in the M_{track} - distribution:

  - $\pi^+ \pi^- \pi^0$ at high values of M_{track} which is however $M_{\pi\pi}^2$ dependent
  - $\mu^+ \mu^- \gamma$ at $M_{track} \approx 104$ MeV

→ **Kinematic Cut on Trackmass**



- Cutting in the **2dim plane M_{track} vs. $M^2_{\pi\pi}$** at large values of $M_{\pi\pi}$ $\pi^+\pi^-\pi^0$ not problematic

- remaining contamination (tails in selection interval) estimated from MC **(below 1 %)**

EFFICIENCIES

Trigger

Reconstr. Filter

Event Classification

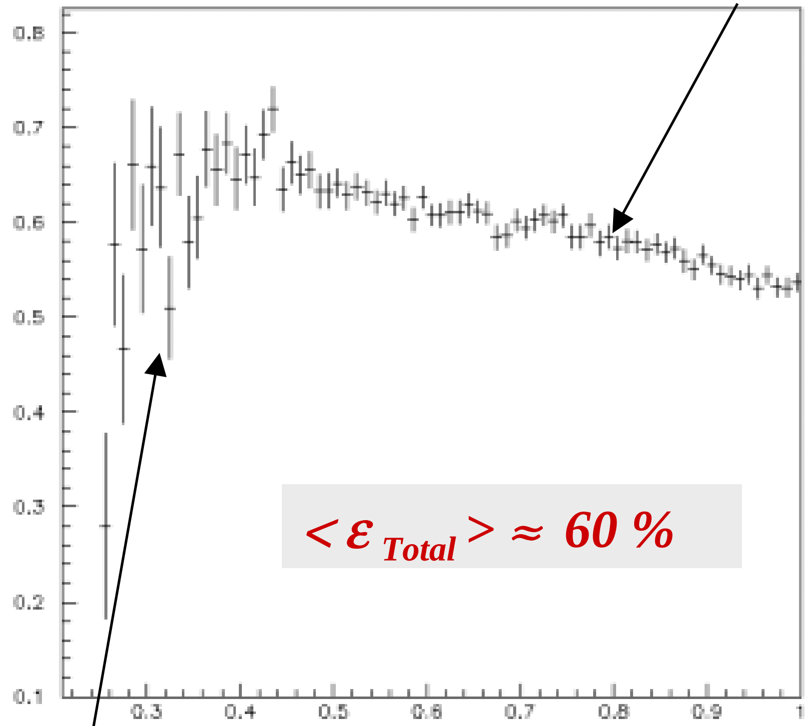
Tracking - Eff., Vertex - Eff.

Likelihood

Trackmass

ε_{Total}

Errors above 0.5 GeV^2
better than 2% per bin



$< \varepsilon_{Total} > \approx 60\ \%$

Big errors at low $M_{\pi\pi}^2$ due to
low MC statistics for Trackmass

$M_{\pi\pi}^2$ [GeV^2]

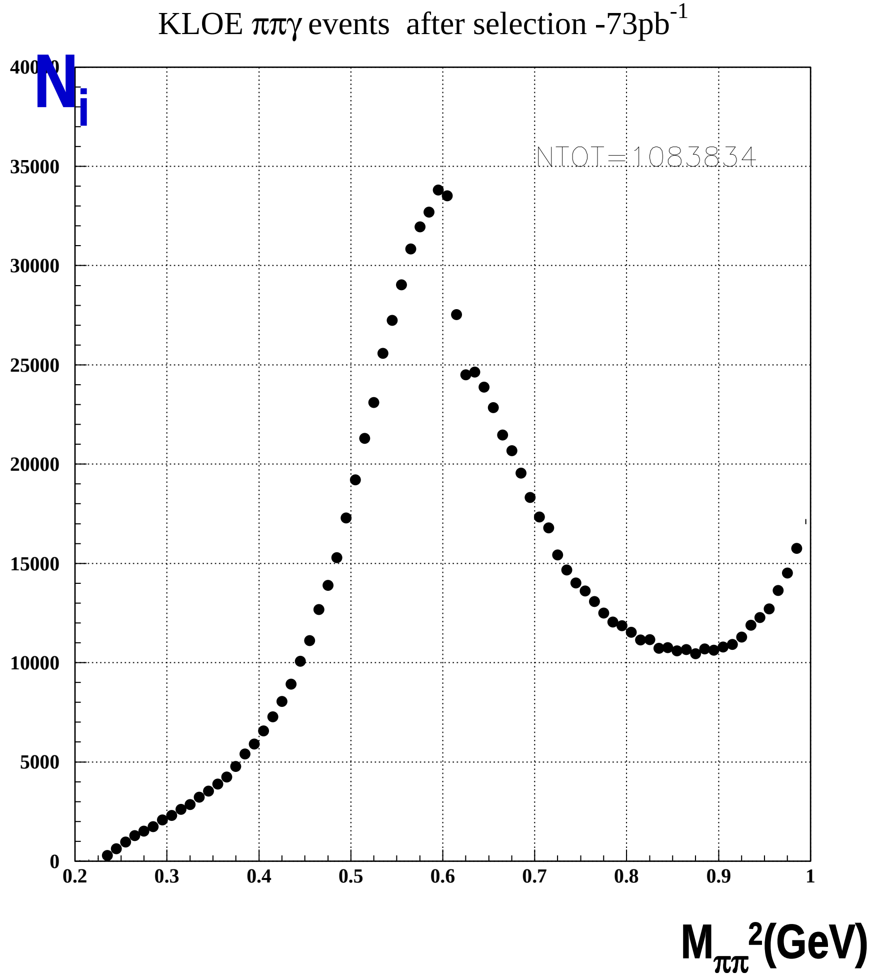
blue = estimated from data
red = estimated from MC

PION FORM FACTOR

- **We analyzed *73 pb^{-1}*** of 2001 data according to the analysis items discussed

after selection: **1 083 834 events**
KLOE data set by 09/02: ca. *500 pb^{-1}*

50 bins with statistical error/bin < 1%
for $M_{\pi\pi}^2 > 0.45 GeV^2$



- **Normalizing to Luminosity** and dividing by the **Radiation Function *$H(M_{\pi\pi}^2)$*** gives the **Pion Form Factor**

PION FORM FACTOR

- Data points have been fitted with the **Kühn-Santamaria-Parametrization**

$$F_\pi(Q^2) = \frac{BW_\rho \dfrac{(1+\alpha BW_\omega)}{1+\alpha} + \beta BW_{\rho'}}{1+\beta}$$

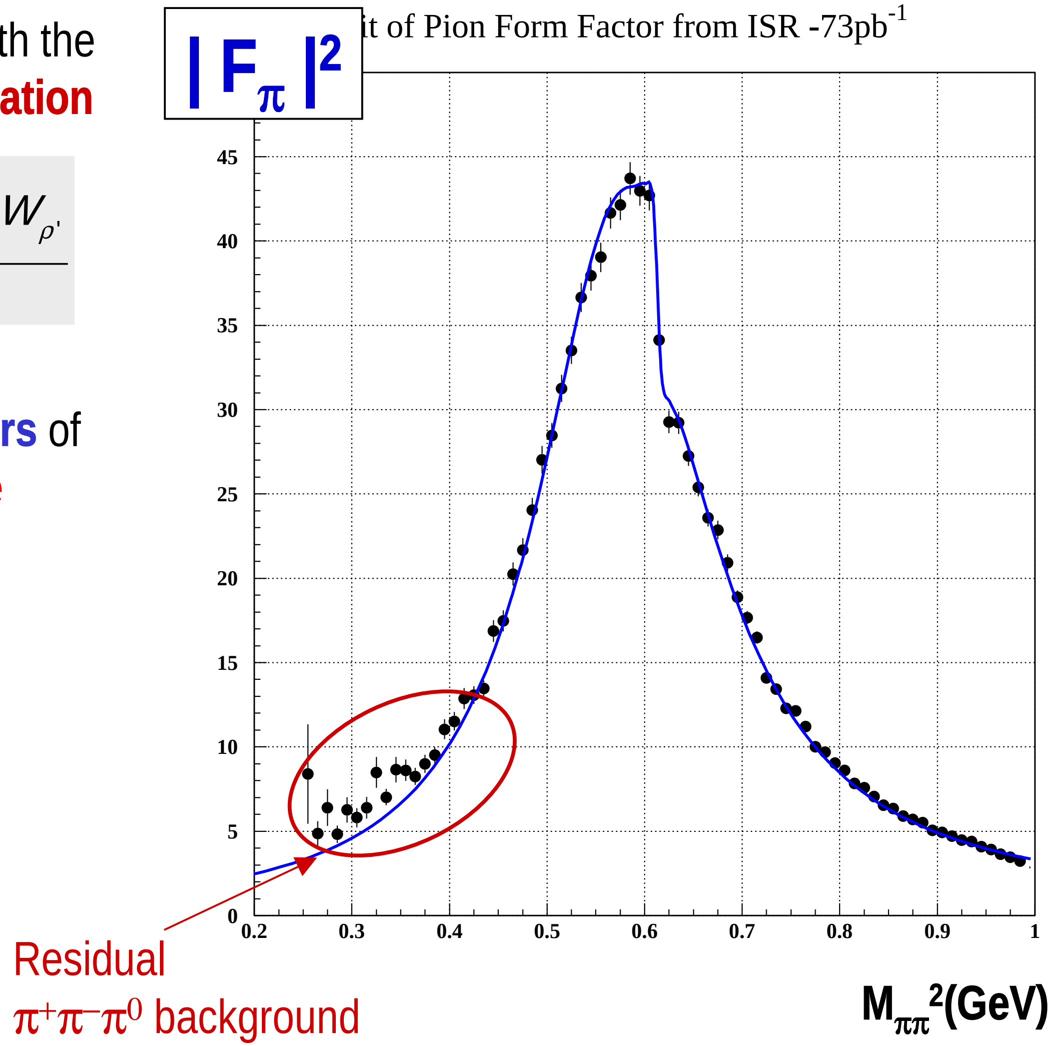
- **m_ρ, Γ_ρ α, β are free parameters** of the fit, while m_ω Γ_ω $m_{\rho'}$ $\Gamma_{\rho'}$ are fixed to CMD-2 values

M_ρ =776.09 ± 0.81 MeV

Γ_ρ =144.46 ±1.55 MeV

α =(1.48 ±0.12) •10^{-3}

β = - 0.1473 ± 0.002



COMPARISON CMD-2

➨ **Refinements**:
- Unfolding of spectrum
- Residual Background Subtraction
- Systematics due to Acceptance Cuts
- Fit to Gounaris-Sakurai

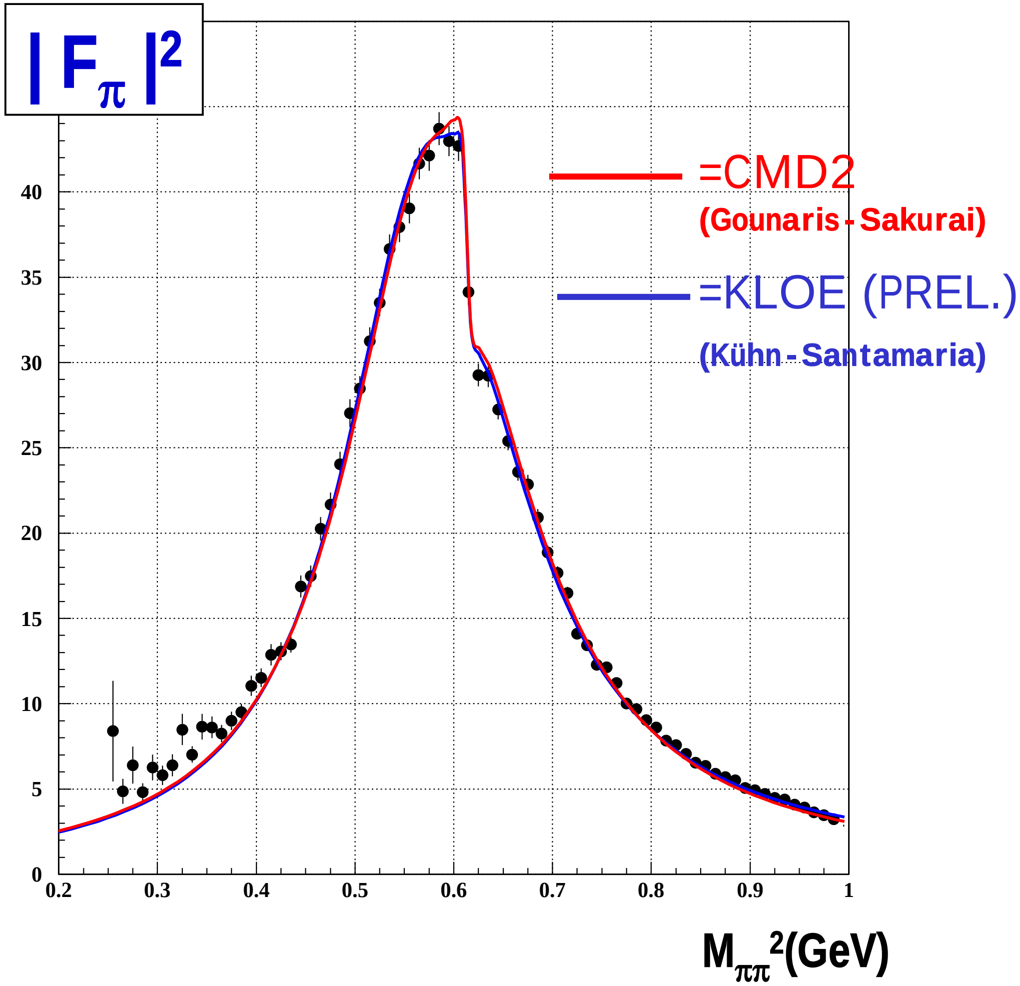
Qualitatively:
excellent agreement with CMD-2 !

Quantitatively: CMD2 uses Gounaris-Sakurai, thus different fit results:

KLOE
M_ρ =776.09 ± 0.81 MeV
Γ_ρ =144.46 ±1.55 MeV

CMD2
M_ρ =0.7726 ± 0.0005 GeV
Γ_ρ =0.1437 ±0.0007 GeV

Fit of Pion Form Factor from ISR -73pb^{-1}



LUMINOSITY MEASUREMENT

Normalization:

use KLOE itself for measurement :

Large Angle Bhabhas (σ_{eff} = 425nb)

- **55° < θ_{+-} < 125 °**
- **Acoll. < 9 °**
- **$E_{+-} \geq$ 400 MeV**

$$\int L dt = \frac{N_{Bhabhas}(\Theta) \cdot (1 - \delta_{Background})}{\sigma^{MC}(E)}$$

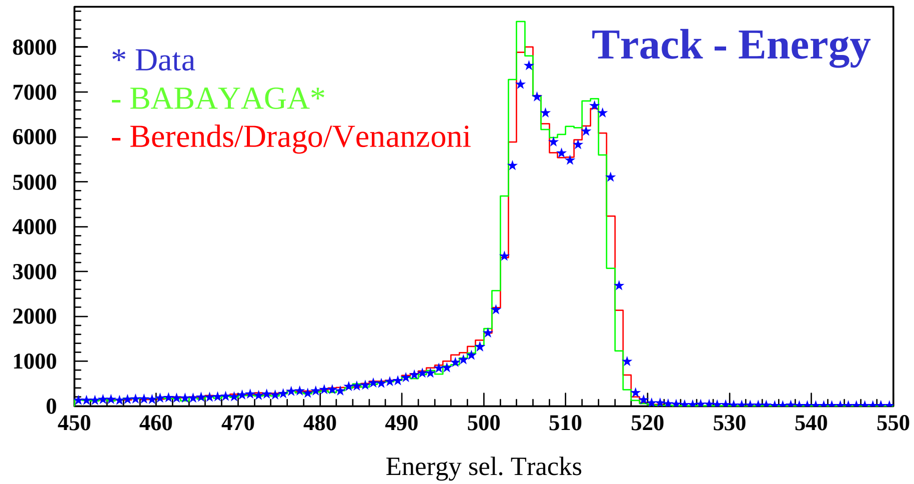
Bhabha - Candidates (Systemat., Accept.)

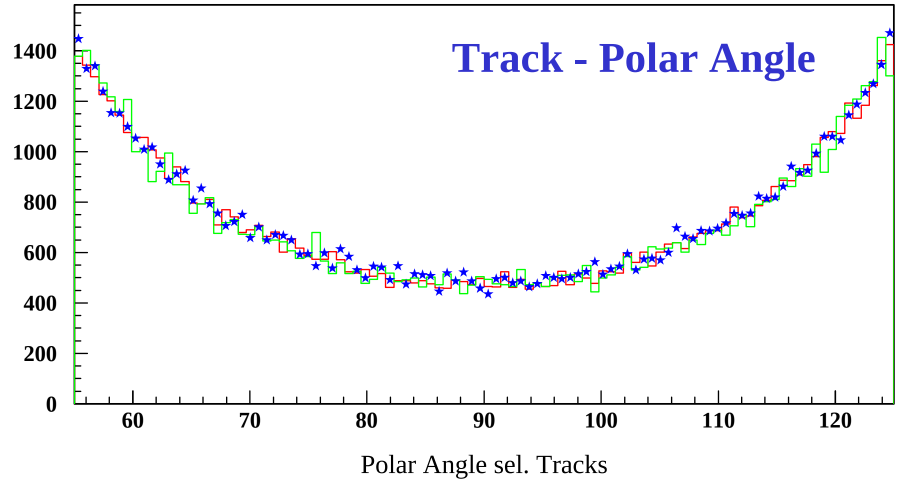
Background ($\pi\pi\gamma$, ...)

Theoret. Generators with rad. corrections

Berends/Drago/Venanzoni

BABAYAGA*





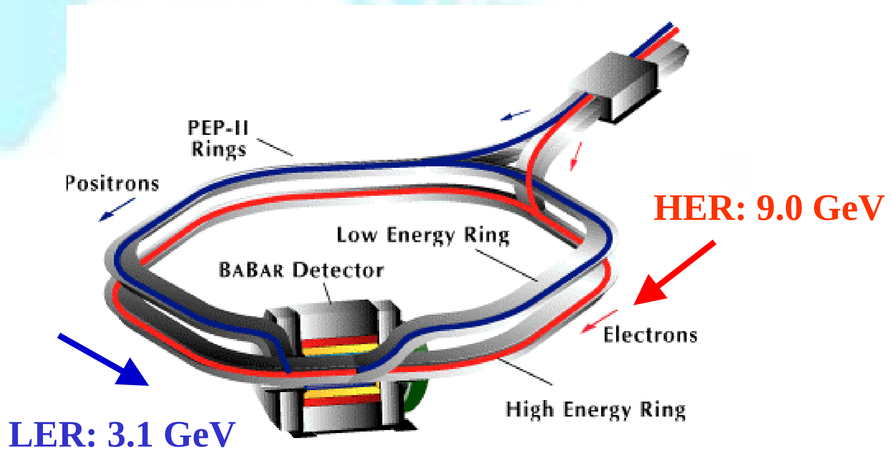
Luminosity- Measurement on Percent Level

agreement with independent $\gamma\gamma$-Counter < 1%

** C.M.C. Calame et.al. Nucl. Phys., B 584 (2000)*

BABAR @ PEP-II

➨ $\sqrt{s}$ = **10.58 GeV**

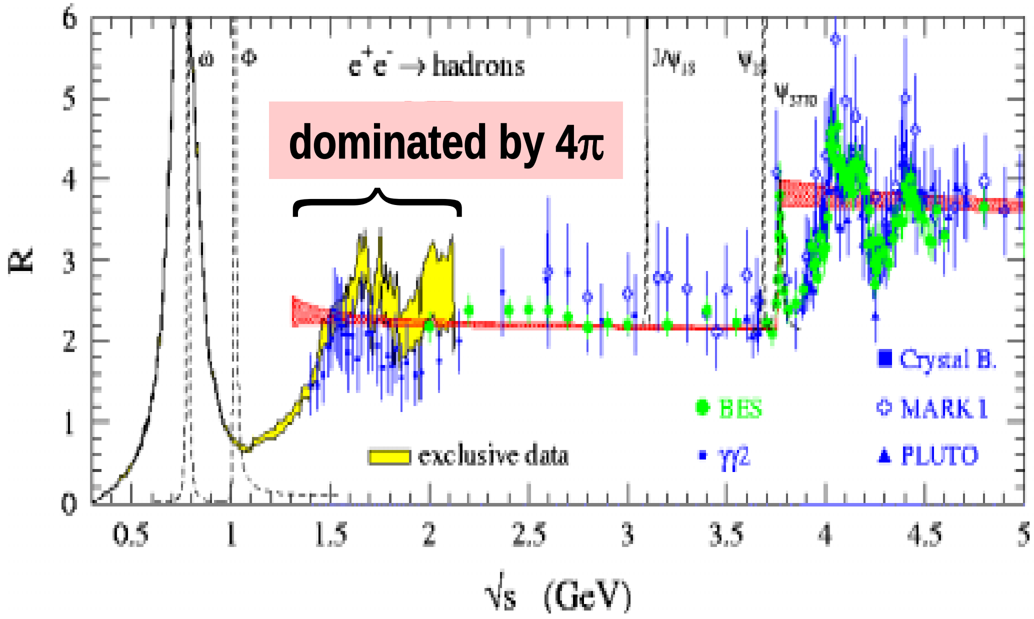


Thanks to Oliver Buchmüller / SLAC

BABAR MEASUREMENT

- **BABAR** ($\sqrt{s} = 10.58$ GeV) can **access via radiative return whole energy range of interest for a_μ** but also a big part of the hadronic contribution of the fine structure const. $\alpha_{hadr.}$

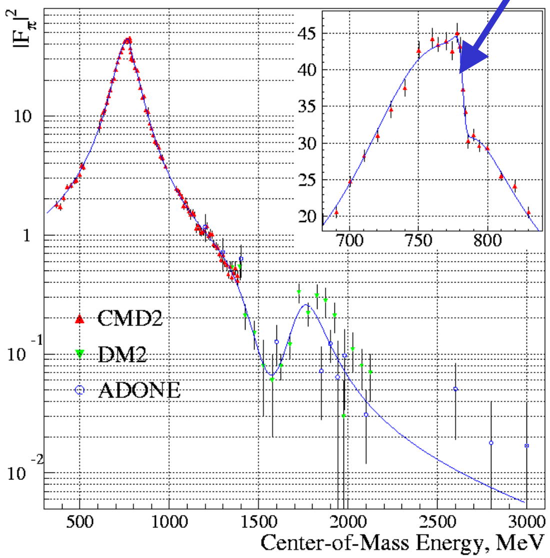
  channels under study: $\pi^+\pi^-$, $\pi^+\pi^- 2\pi$, K^+K^-, $p\bar{p}$, $K^+K^-\pi^0$, 3π, 5π, 6π, 7π, ….

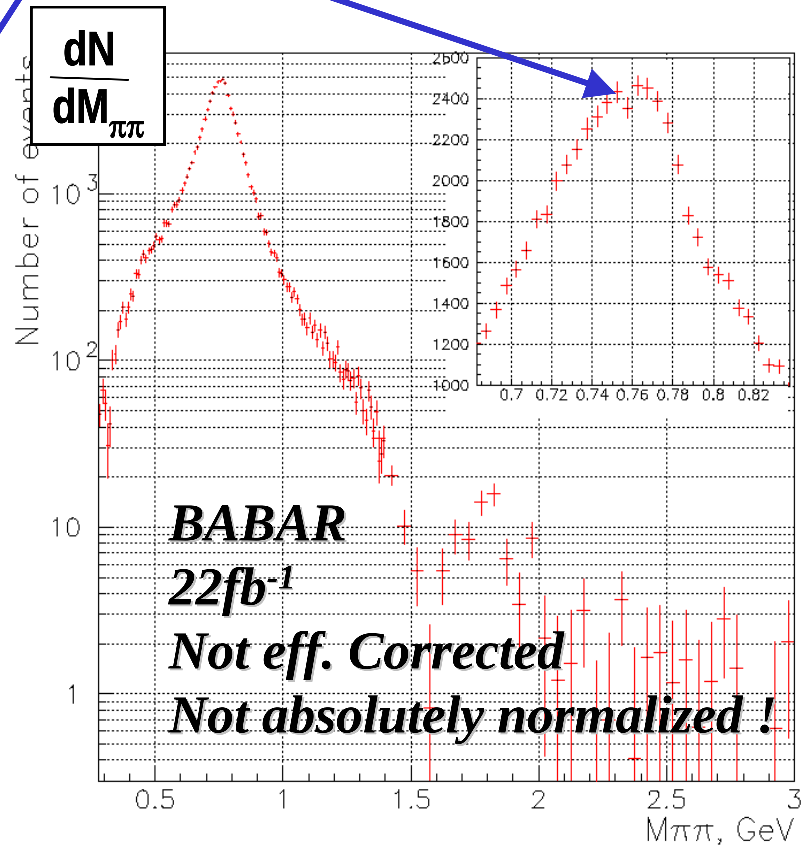


- If the 2π contribution < 1 GeV can be kept on the level of some permille, the **error coming from the 4π contribution < 2GeV** is becoming one of the dominating limitations for a_μ ***AND NO DIRECT MEASUREMENT*** in this energy range (PEP-N project not approved!)

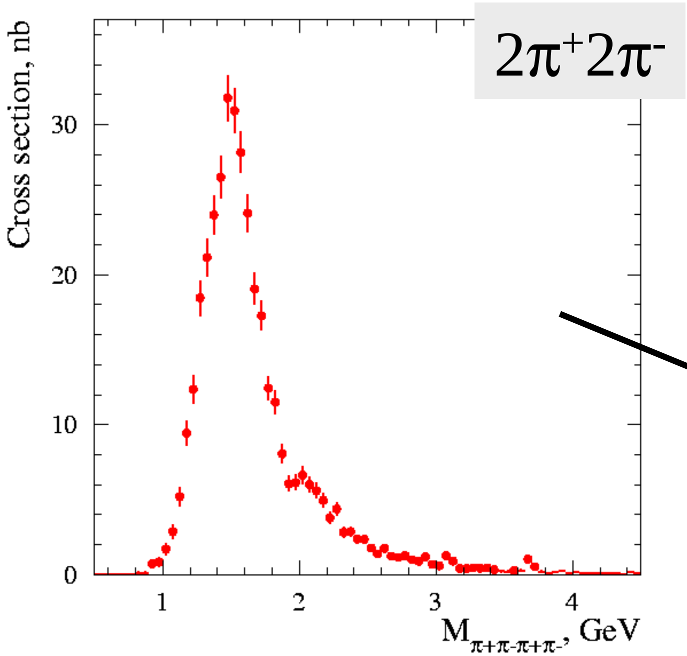
TWO PIONS

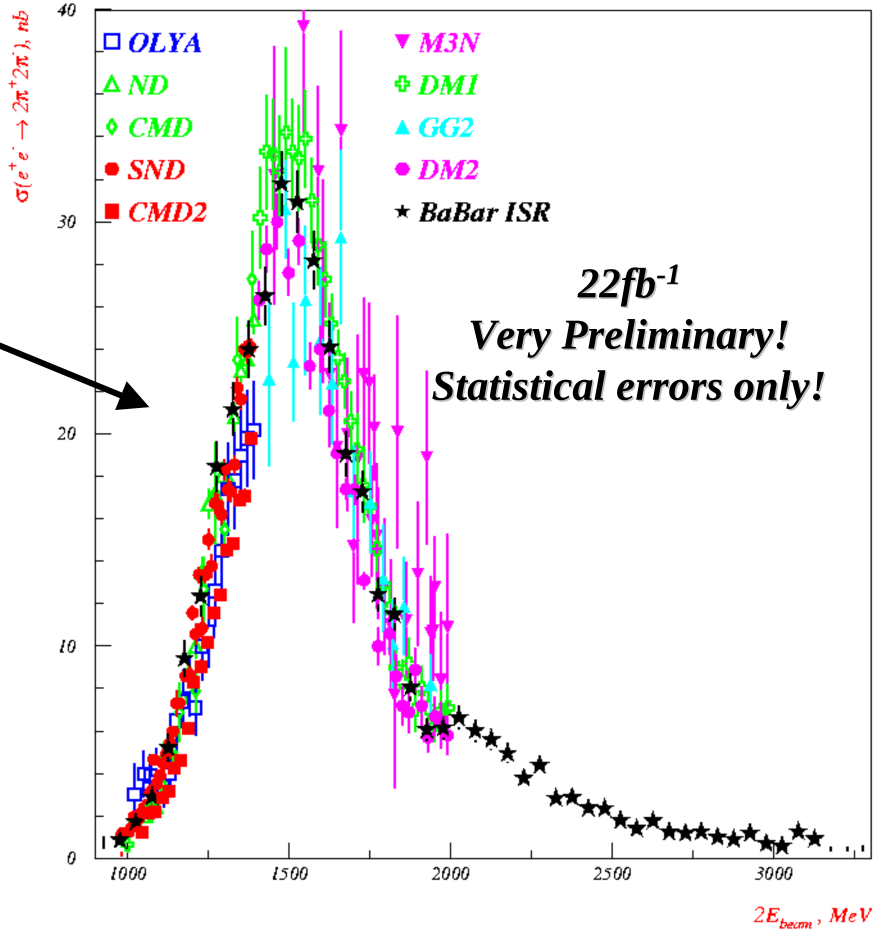
Pion Form Factor with ρ - ω interference





Four Pions





➨ **Normalization to radiative dimuons**

$$\sigma_f(s') = \frac{dN_{f\gamma}}{\varepsilon_{f\gamma} \cdot (1+\delta^f_{rad})} \cdot \frac{1}{dL_{\mu\mu\gamma}(s')}$$

Detection efficiency

Radiative correction **(final state)**

already with $22fb^{-1}$ the whole mass range is covered

➨ **avoids relative normalization problems**

CONCLUSION

Radiative Return is a complementary new Method to measure Hadronic Cross Sections and is currently performed at the **ϕ - factory DAΦNE** and the **b - factory PEP-II**

KLOE @ DAΦNE presented a preliminary result on the **fit to the Pion Form Factor** which is in good agreement with CMD-2

BABAR @ PEP-II shows very encouraging results for different final states; of special interest is the **4-pion final state** which has a non - neglibile contribution to a_μ

Experimental and Theoretical groups are in close contact to improve systematics of the measurement and to allow an interpretation for the evaluation of the hadronic contribution to a_μ.

Improved results are expected for the end of 2002 !
Very interesting to see how much the **systematic errors** can be reduced ?