Measurement of the e^+e^- hadronic cross section at DAΦNE via radiative return

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(for the KLOE collaboration)

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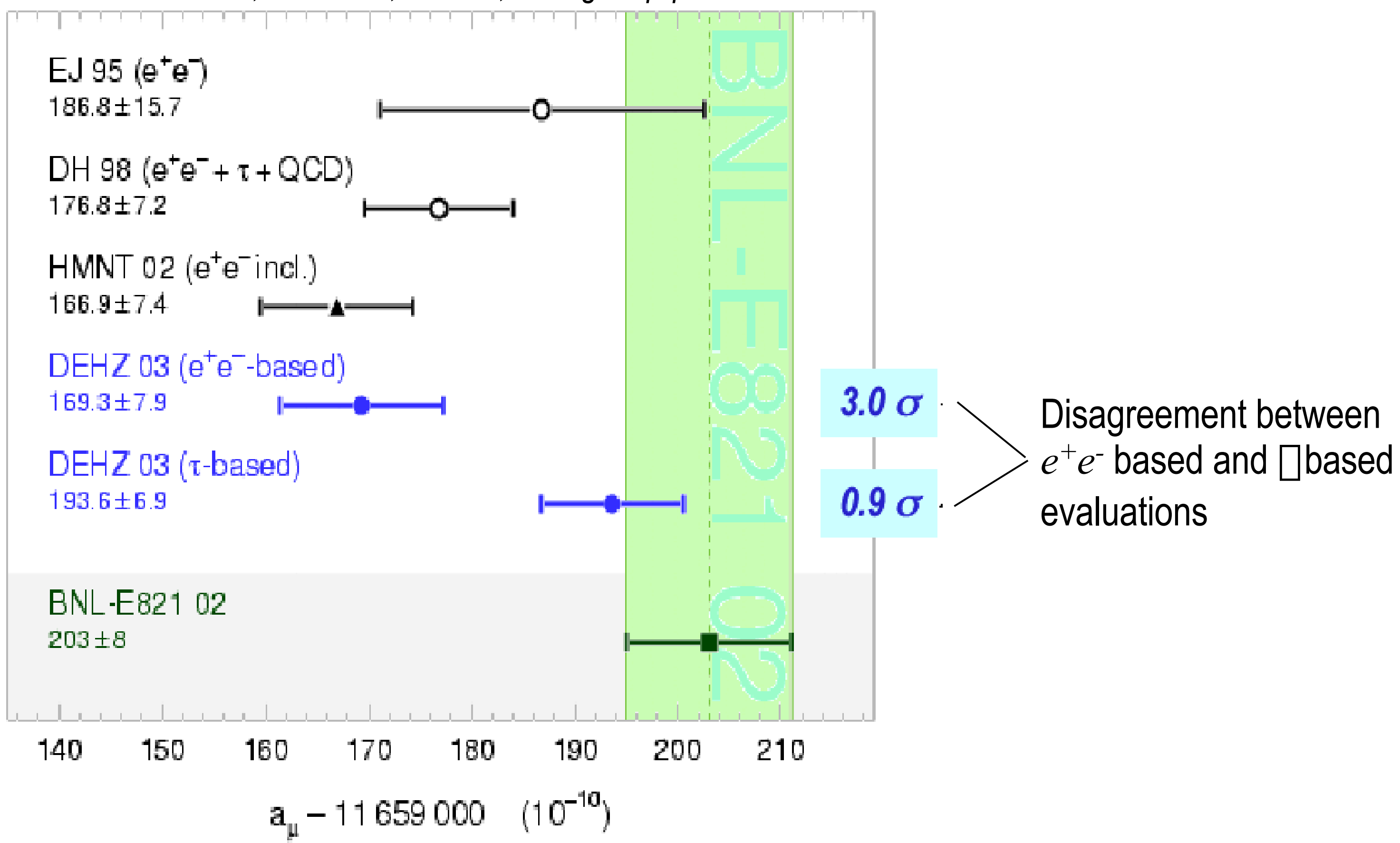
Status on $(g-2)_\mu$:

Davier, Eidelman, Höcker, Zhang: hep-ph/0208177v3

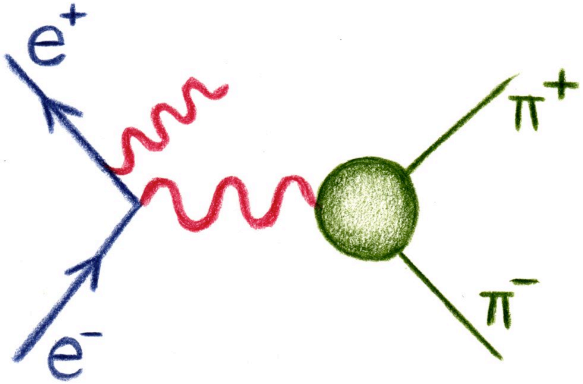


• The nature of the difference in the two theoretical evaluations of a_μ^{had} has to be understood in order to claim a discrepancy between (SM-)theory and experiment

• More and better information on the hadronic contribution to the SM calculation of a_μ could help to clarify this difference and (together with a further reduction of the experimental error) give the discrepancy between theory and experiment a higher significance

$\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ with ISR:

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



$$\frac{d\sigma(e^+ e^- \rightarrow hadrons + \gamma)}{dM^2_{hadrons}}$$

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

advantage

Data comes as by-product of standard program

Systematic errors from Luminosity, $\sqrt{s}$, ... enter only once for each point of $M_{hadrons}^2$

disadvantage

Requires precise calculations of Initial State Rad.

➔ EVA + Phokhara MC Generator

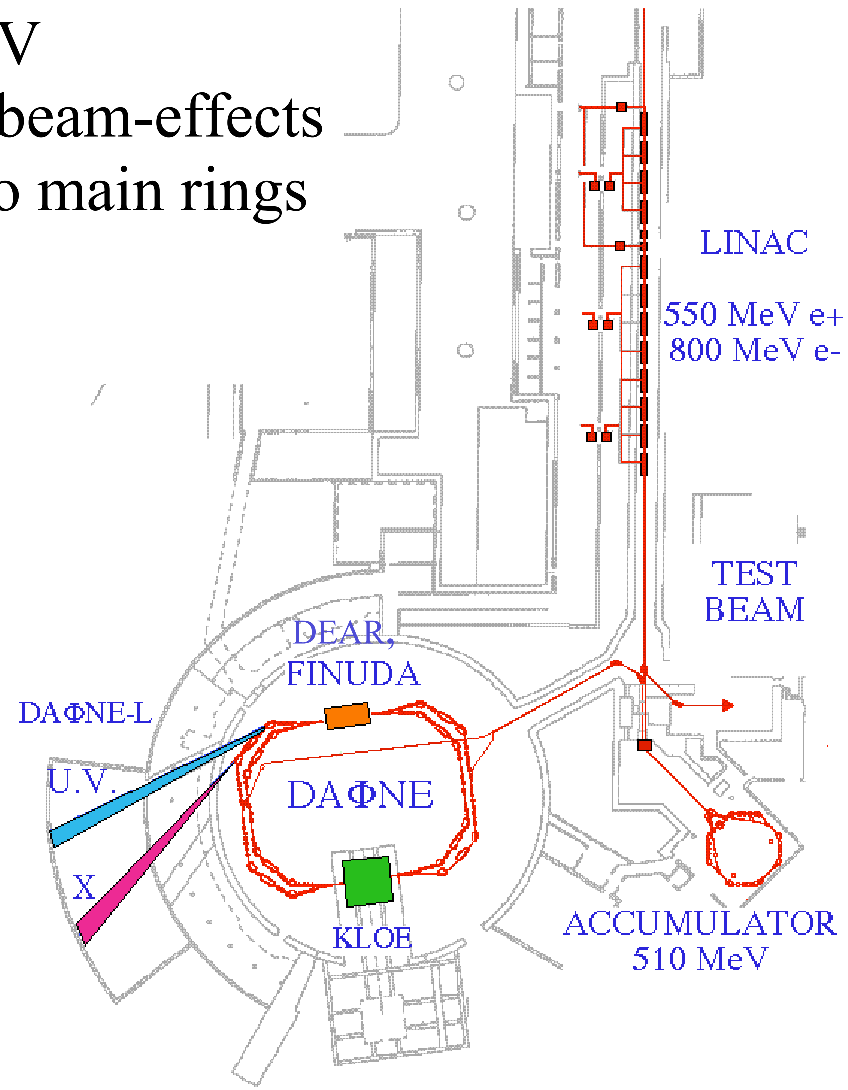
Requires good suppression (or understanding) of Final State Rad.

DAΦNE: A φ-Factory

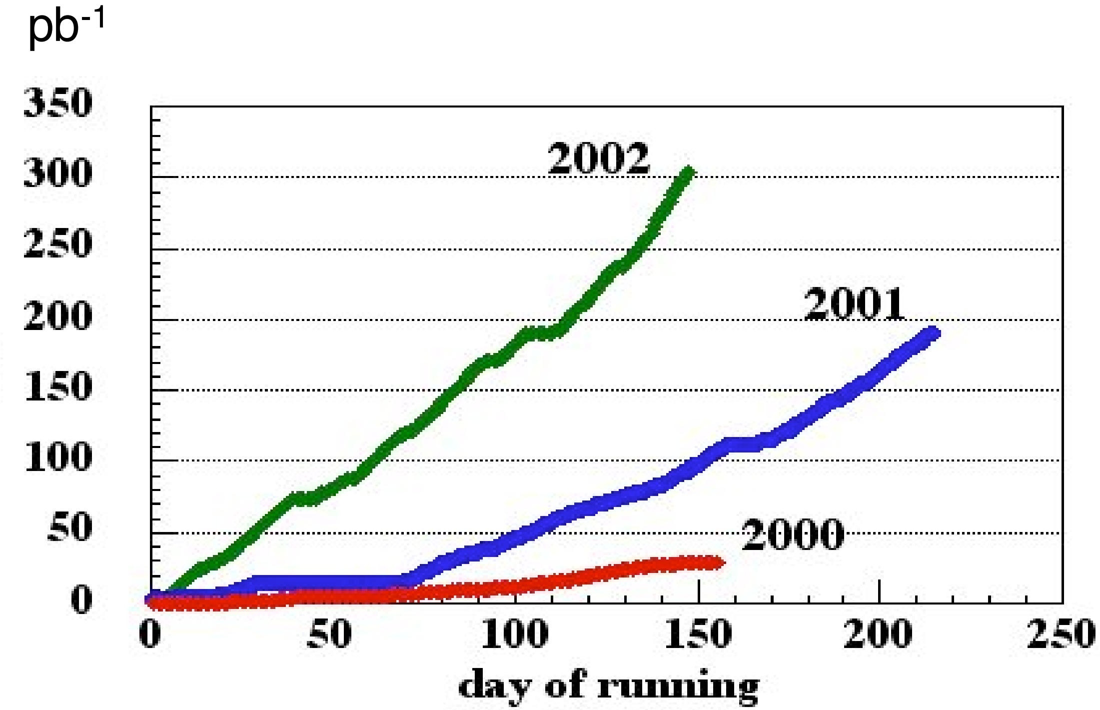
(**D**ouble **A**nnular φ-Factory for **N**ice **E**xperiments)

- e^+e^- - collider with $\sqrt{s} = m_\phi \approx 1.020$ GeV
- two separate rings to minimize beam-beam-effects
- accumulator for efficient injection into main rings
- two interaction points:
  KLOE and DEAR/FINUDA

BR's for selected φ decays	
K^+K^-	49.1%
K_SK_L	34.1%
$\rho\pi + \pi^+\pi^-\pi^0$	15.5%



DA□NE: Performance



2000 run : 25 pb^{-1} 7.5 x 10^7 □

2001 run: 190 pb^{-1} 5.7 x 10^8 □

2002 run: 300 pb^{-1} 9.0 x 10^8 □

DA□NE Backgr. reduced

Peak Luminosity@KLOE IP:	$7.8 \cdot 10^{31} cm^{-2} s^{-1}$
max int. Luminosity in one day:	4.5 pb^{-1}

KLOE:

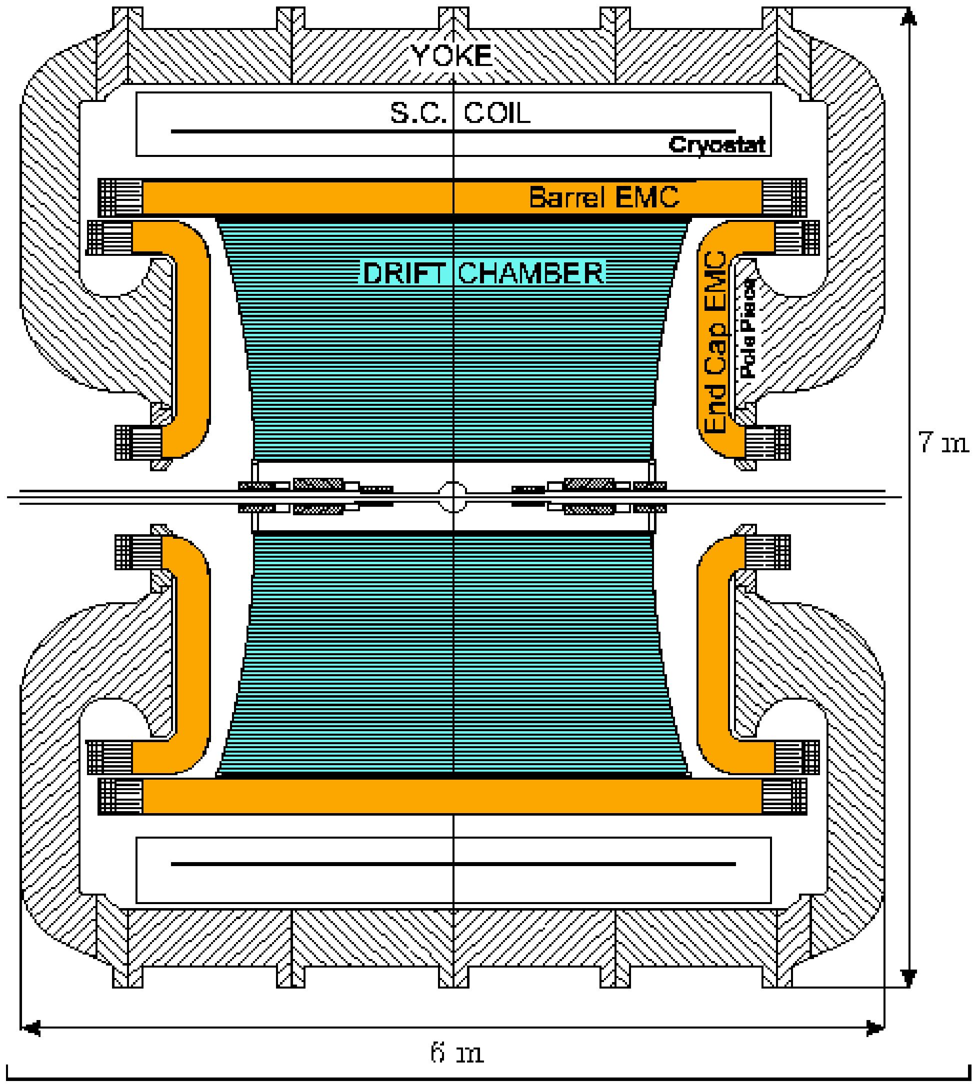
(KLOng Experiment)

- **Magnet:**
  Superconducting coil (B=0.5 T)

- **EM Calorimeter:**
  Lead/Scintillating fibres
  4880 PM

- **Driftchamber:**
  12582 Sense Wires
  52140 wires in total

- **Beryllium Beampipe:**
  R=10 cm, 0.5 mm thick

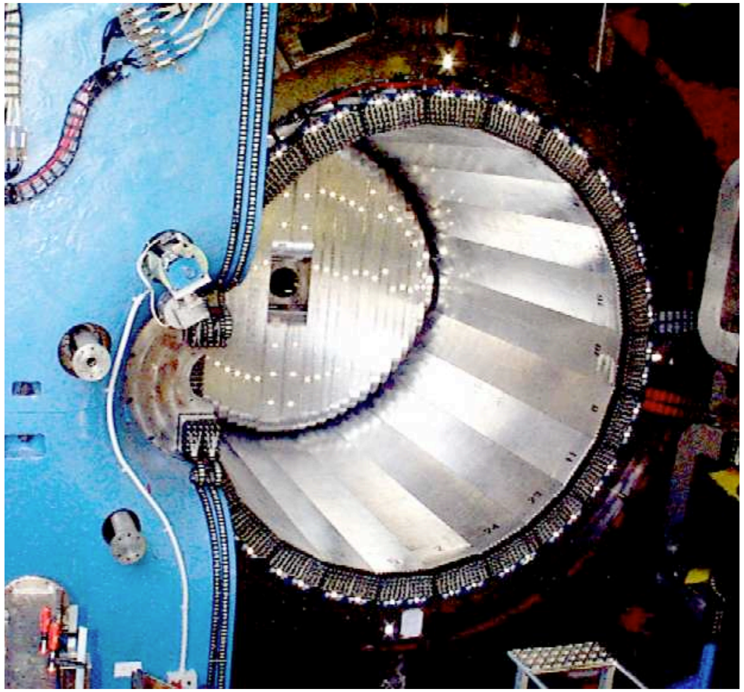


KLOE:

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$

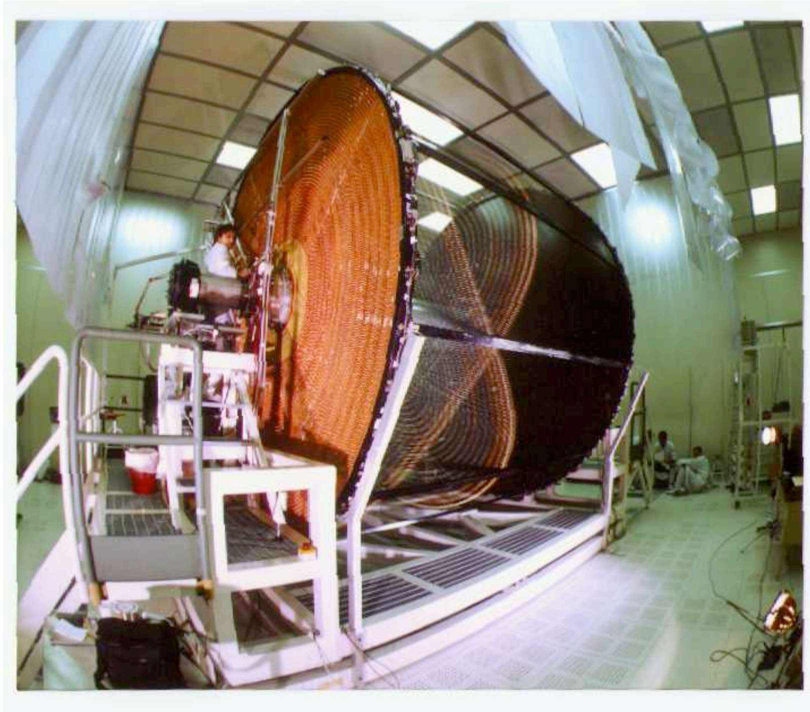
$\sigma_T = 54\ ps / \sqrt{E(GeV)} \oplus 50\ ps$

(Bunch length contribution subtracted from constant term)



Electromagnetic calorimeter

Driftchamber



$\sigma_p/p = 0.4\%$ (for 90^0 tracks)

$\sigma_{xy} \approx 150\ \mu m$, $\sigma_z \approx 2\ mm$

Signal selection:

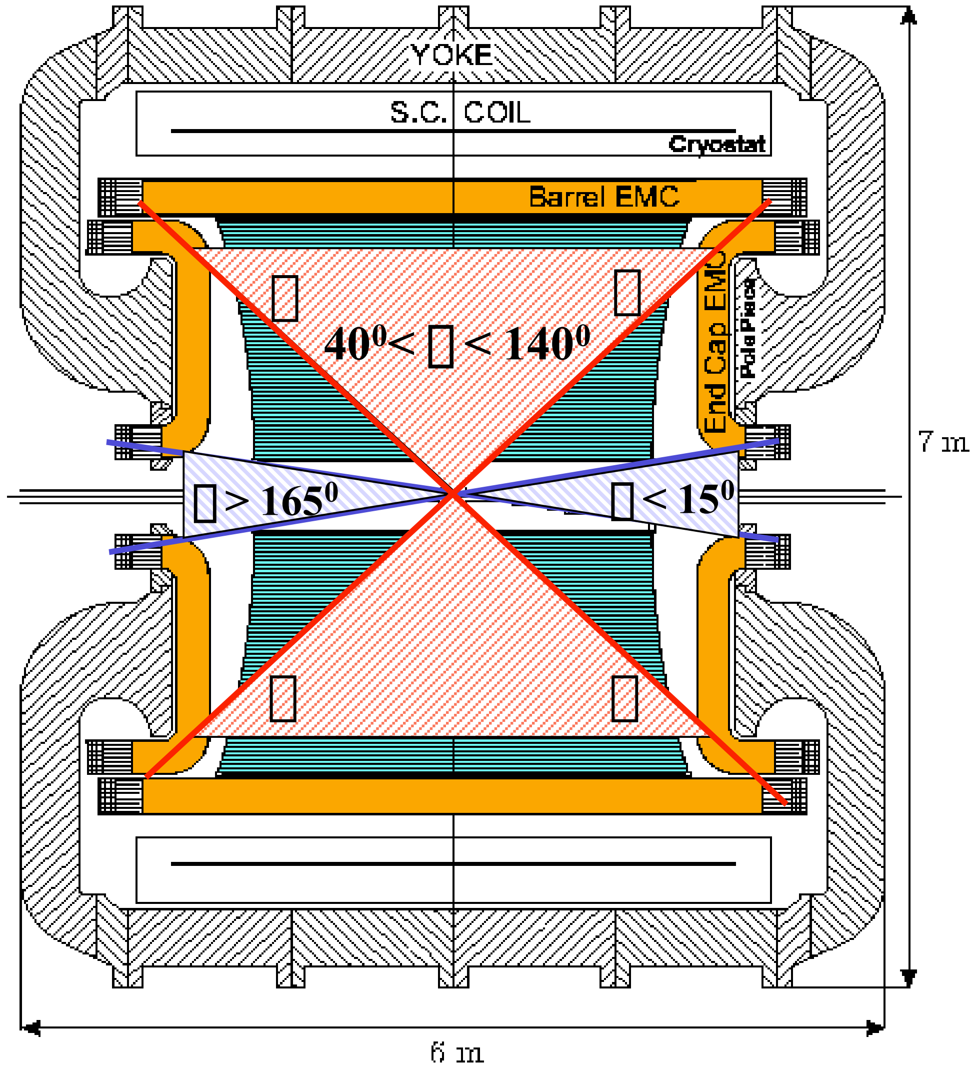
Pion tracks are measured at angles
$40^o < \theta_\pi < 140^o$

Photons are required to be within
$\theta_\gamma < 15^o$ and $\theta_\gamma > 165^o$

Photons cannot be detected efficiently with EmC,
untagged measurement in which we cut on the direction of the missing momentum

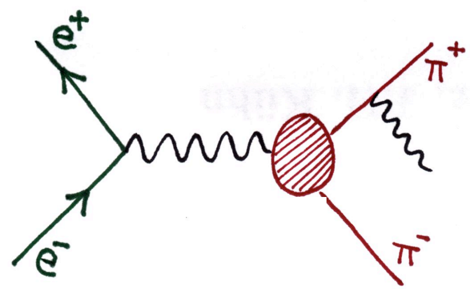
The choice of this kinematical region was motivated by:

- small relative contribution of **FSR**
- reduced background contamination:
  - $e^+e^- \rightarrow e^+e^-\gamma$
  - $e^+e^- \rightarrow \mu^+\mu^-\gamma$
  - $e^+e^- \rightarrow \phi \rightarrow \pi^+\pi^-\pi^0$



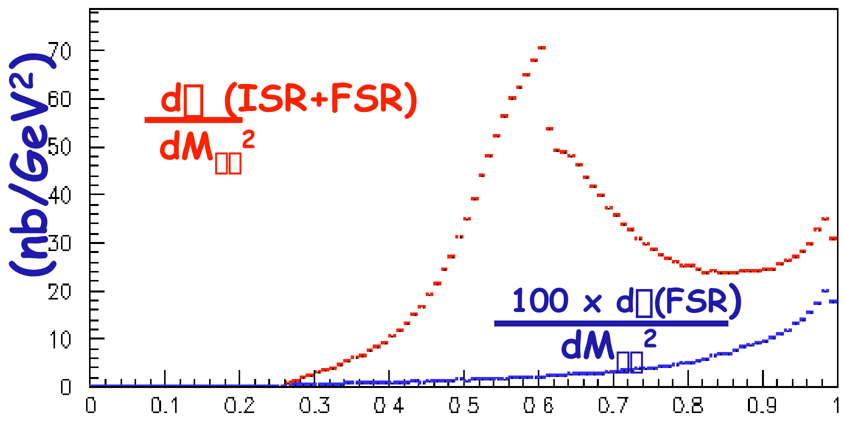
FSR suppression:

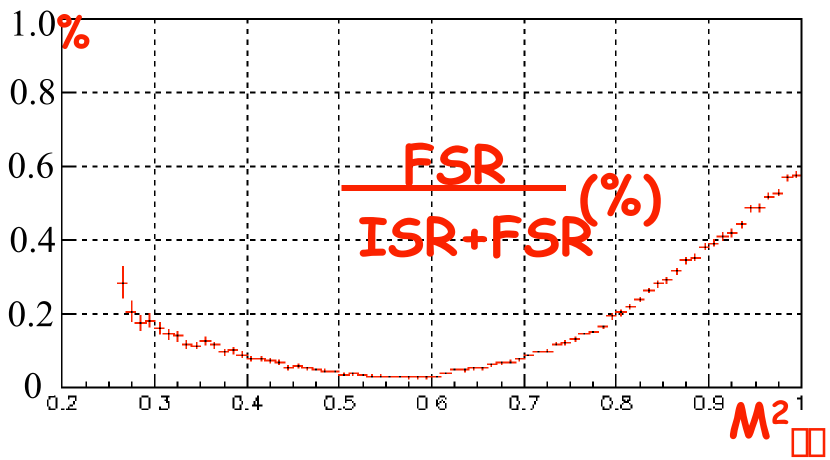
Our approach is to treat **F**inal **S**tate **R**adiation of the pions as a „background“ and suppress it in the measurement using kinematical cuts.



Initial **S**tate **R**adiation and **F**inal **S**tate **R**adiation contribution have been evaluated with MC (Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999):

Contribution of **FSR <1%** for our selection cuts (i.e. model dependence negligible)



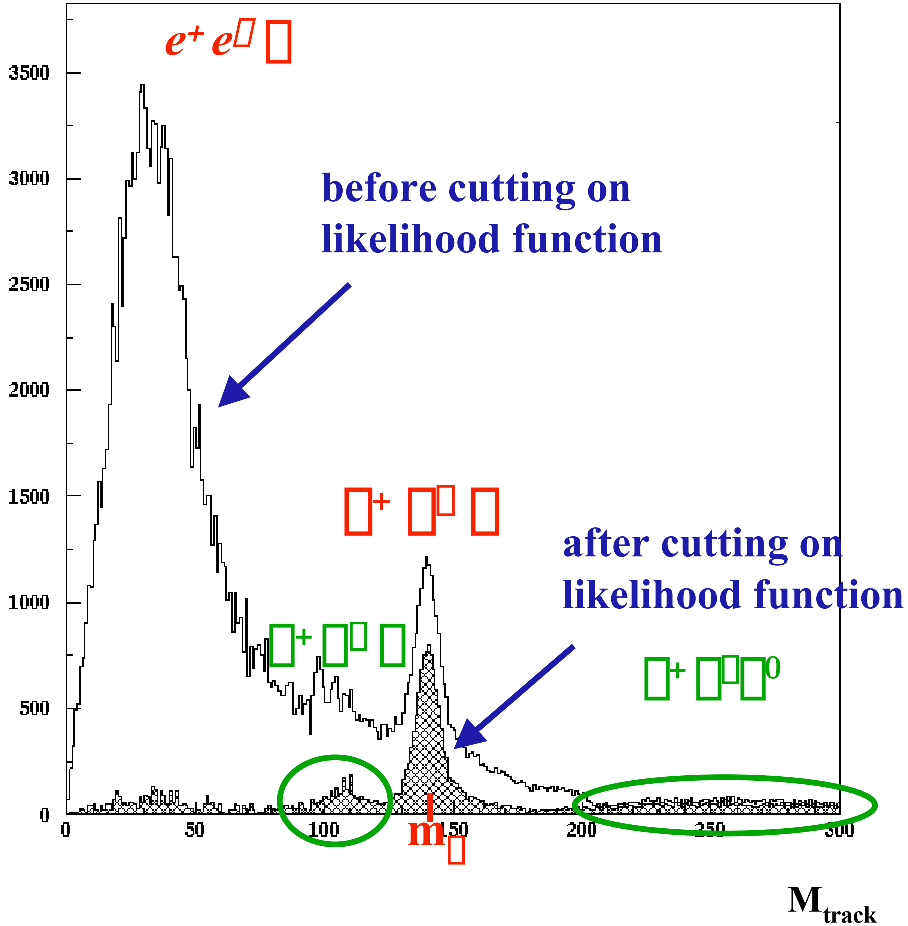


Background subtraction:

To reduce Bhabha contamination, a π-e-separation is performed using a Likelihood function based on:

- **TOF of charged clusters**
- **Shape and energy deposition of the "charged" cluster**

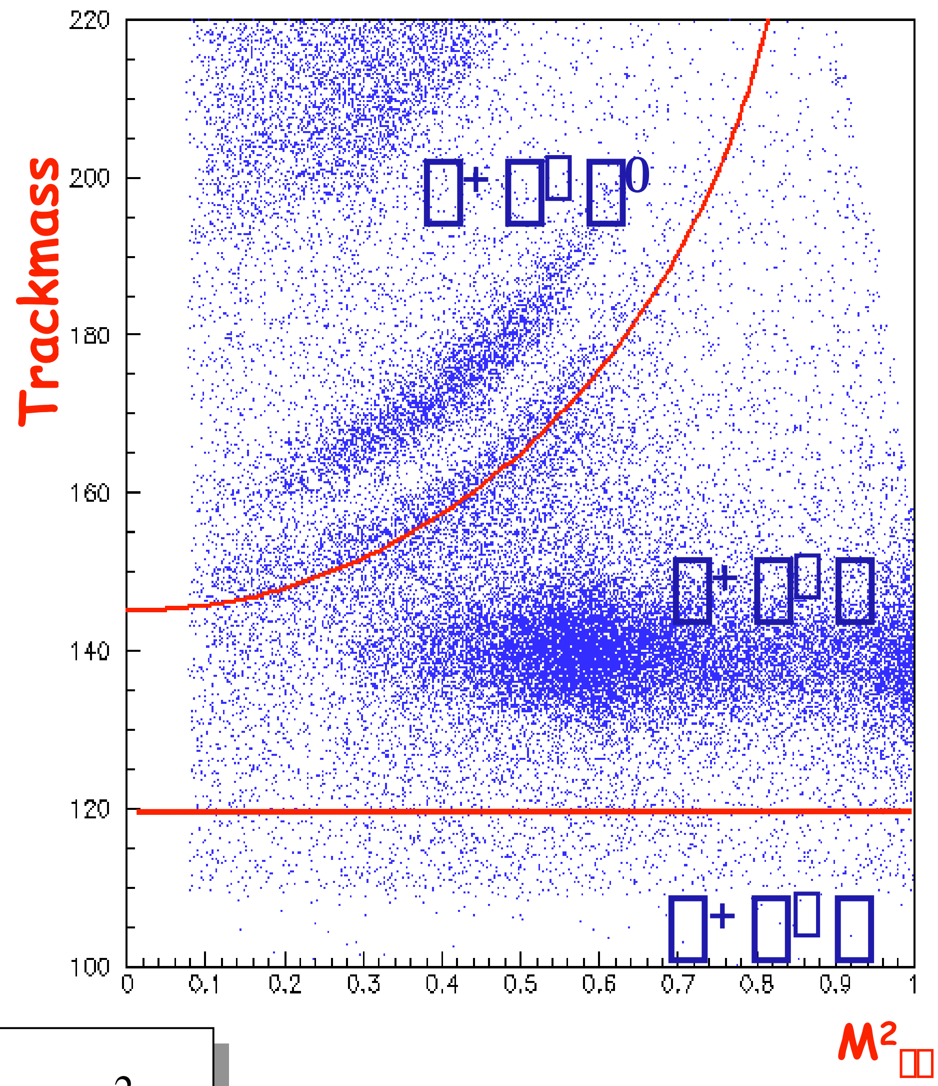
The event is selected if one of the charged tracks is identified to be a pion.



Background subtraction:

The signal is further selected by performing a cut in the kinetical variable **trackmass** in order to reduce $□^{+}□^{□}□^{0}$ **background**

$□^{+}□^{□}□$ background (M_{track}□105 MeV) is rejected by a cut on M_{track} =120 MeV



The trackmass is the particle mass for the two tracks obtained by using the 4-momentum-conservation and the assumption that both particles have the same mass M_{trk}:

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

$M_{\pi\pi}^2$- Spectrum:

In a preliminary attempt to extract the pion form factor, we analyzed *73 pb⁻¹* of 2001 data according to the analysis items discussed

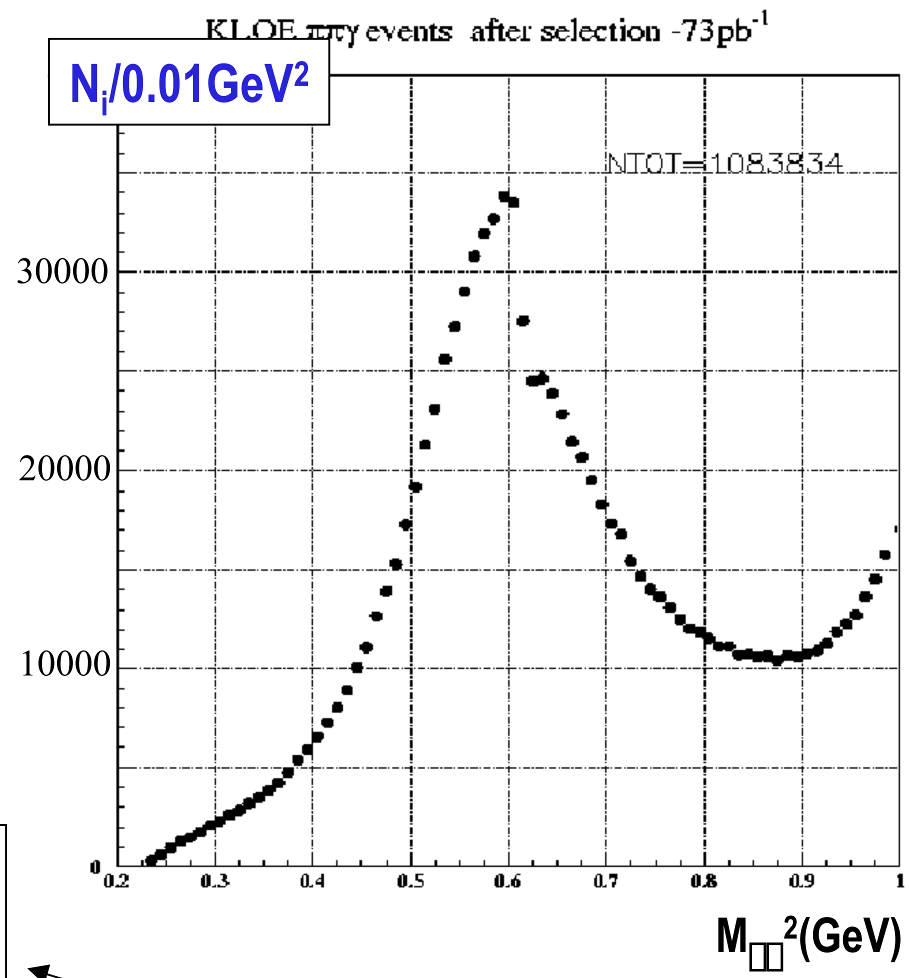
after selection: **1 100 000 events**

statistical error/bin < 1%
for $M_{\pi\pi}^2 > 0.45$ GeV²

Signal — Background

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

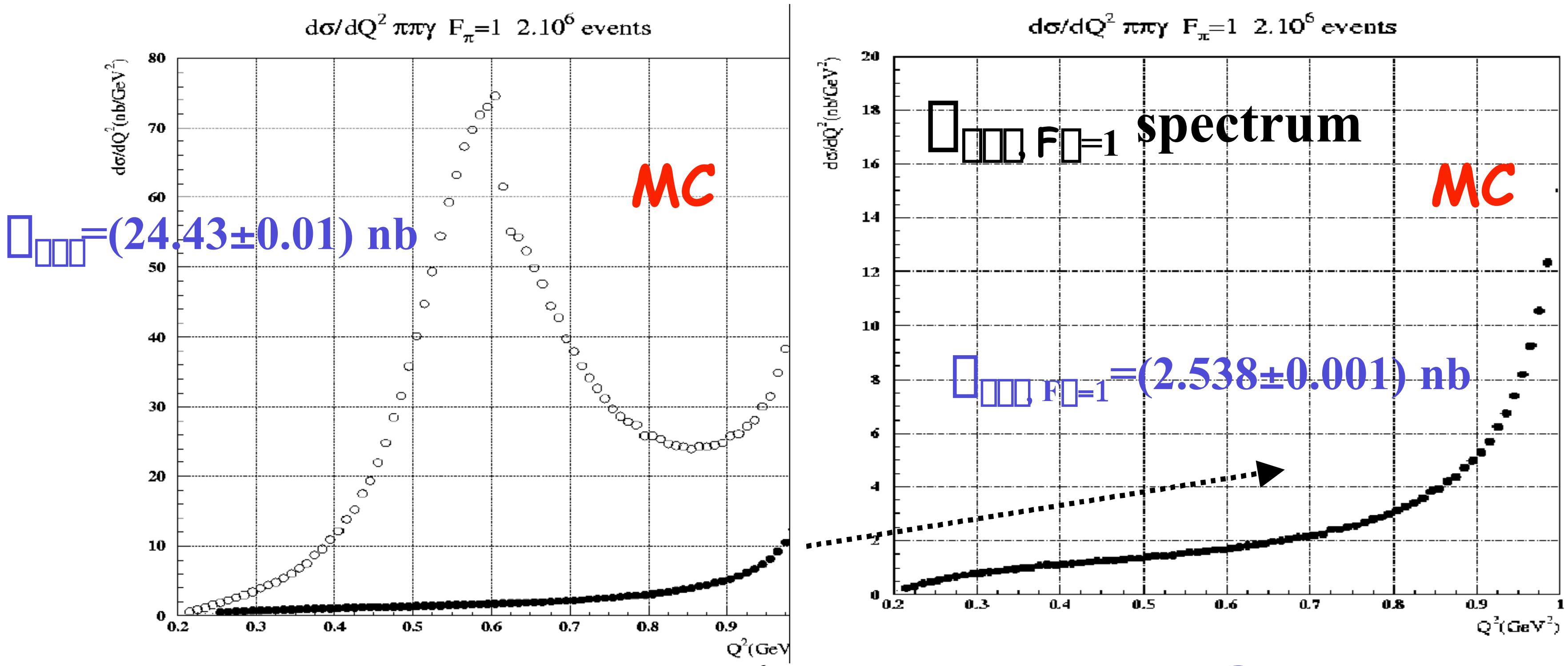
Selection efficiency — Luminosity



Extraction of pion form factor:

We divide the **□+□□□ cross section** by the **cross section □+□□□ for "pointlike" pions** which is obtained from the **MC generator** by **setting F□ = 1 .**

$$|F_{□}(M^2_{□□})|^2 = \frac{d□_{□□□}(M^2_{□□})}{d□_{□□□,F_{□}=1}(M^2_{□□})}$$



□□□□, F□=1 was computed with $2*10^6$ events of Monte Carlo with F□=1, with the acceptance cuts of the analysis: □□<15□ (□□>165□), 40□<□□<140□

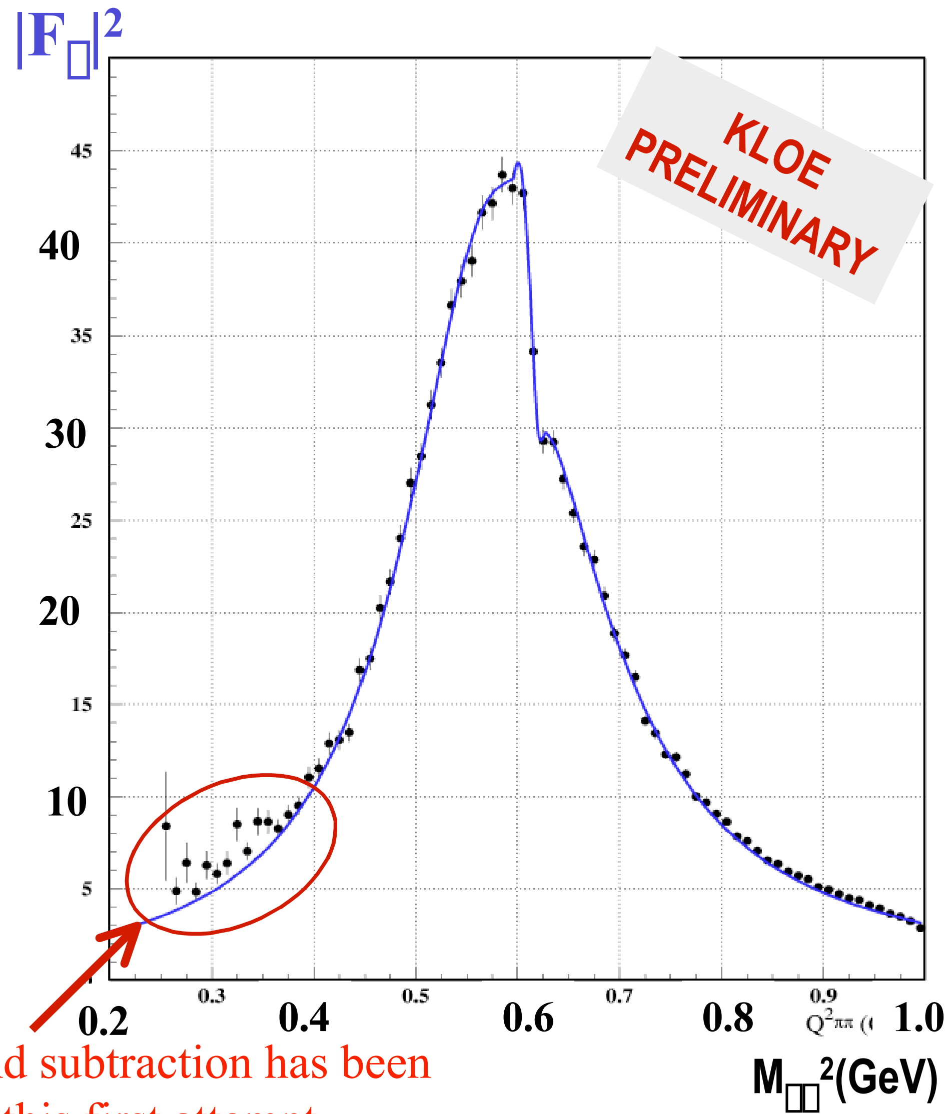
Pion form factor:

Correcting for efficiencies, normalising to luminosity and dividing the spectrum $d\sigma/dM^2_{\pi\pi}$ by the radiation function $H(M_{\pi\pi}^2)$, we get a preliminary extraction of the pion form factor.

The next step is to refine the analysis with the full statistics of 2001 (ca. 170 pb^{-1}).

Current work is focused on:

- Efficiency estimation
- Luminosity
- Detector resolution (unfolding)
- Residual background subtraction



No background subtraction has been performed on this first attempt

Luminosity:

KLOE uses "Large Angle Bhabhas"
(σ_{eff} = 430 nb) to measure the luminosity:

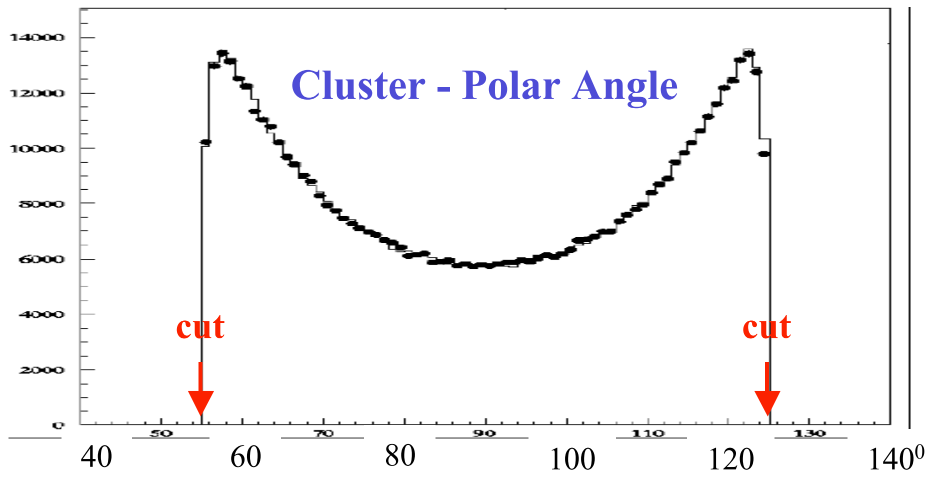
- **$55° < \theta_{+-} < 125°$**
- **Acoll. < 9 °**
- **$E_{+-} \geq$ 400 MeV**

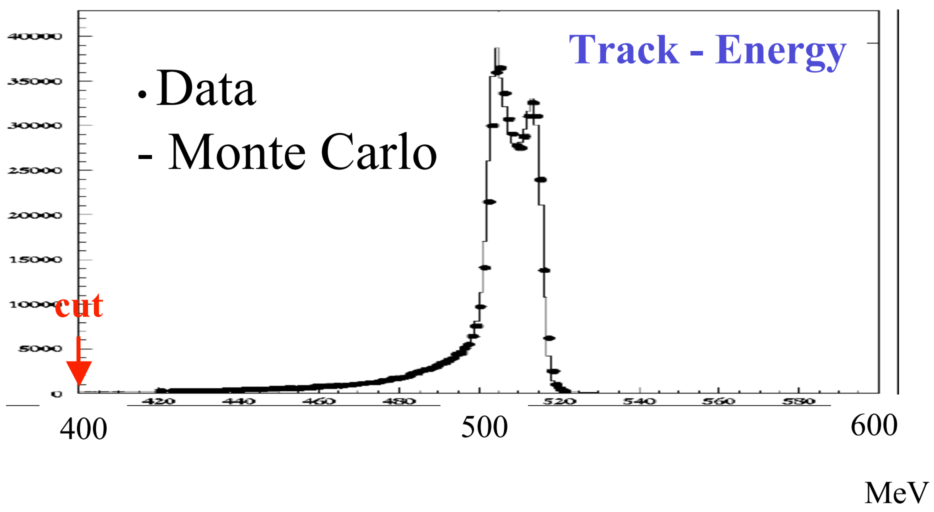
$$\int L\,dt = \frac{N_{Bhabhas}(\theta)\cdot(1-\delta_{Background})}{\sigma^{MC}(E)}$$

Bhabha - Candidates

Theoret. Generators
with rad. corrections

Background
(□□□ ...)





Luminosity:

We use 2 independent theoretical generators to calculate the effective cross section for the actual selection cuts:

1) Berends (Drago, Venanzoni)
2) BABAYAGA (Calame, Montagna)*

Agreement = (0.1±0.1)%

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

Systematics

Difference DATA-MC:
Acceptance
Efficiencies (EmC, DC)

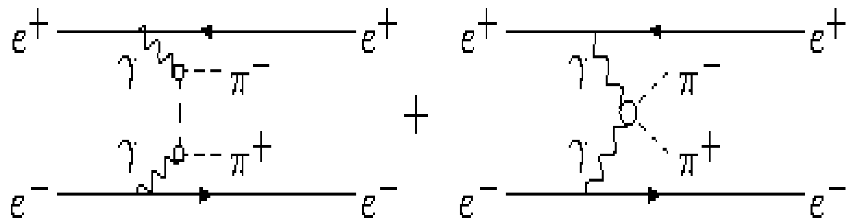
Running Conditions:
Changing s , $\mathbf{p}_{\square}$, beam position
Calibration of EmC and Drift Chamber

No limitation for luminosity precision < 1% found

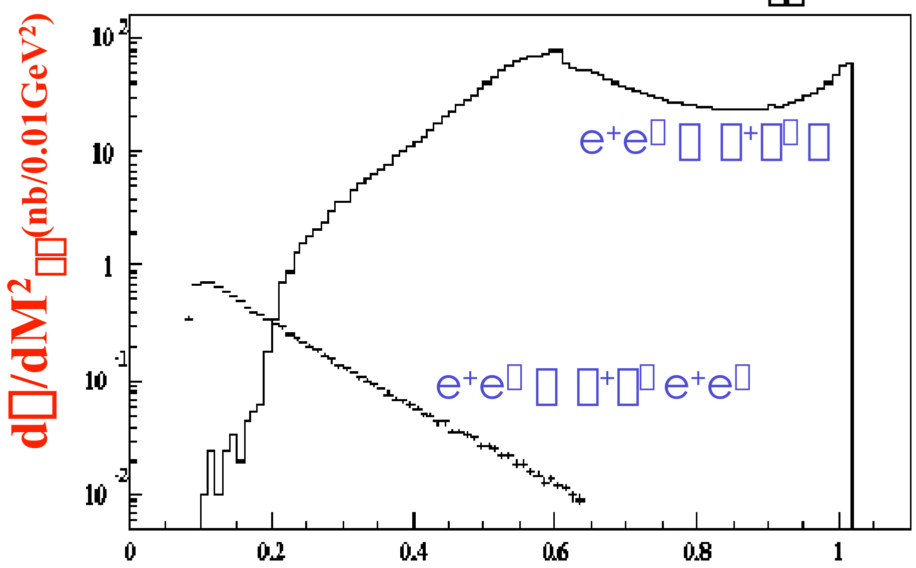
➔ final precision is currently under evaluation

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

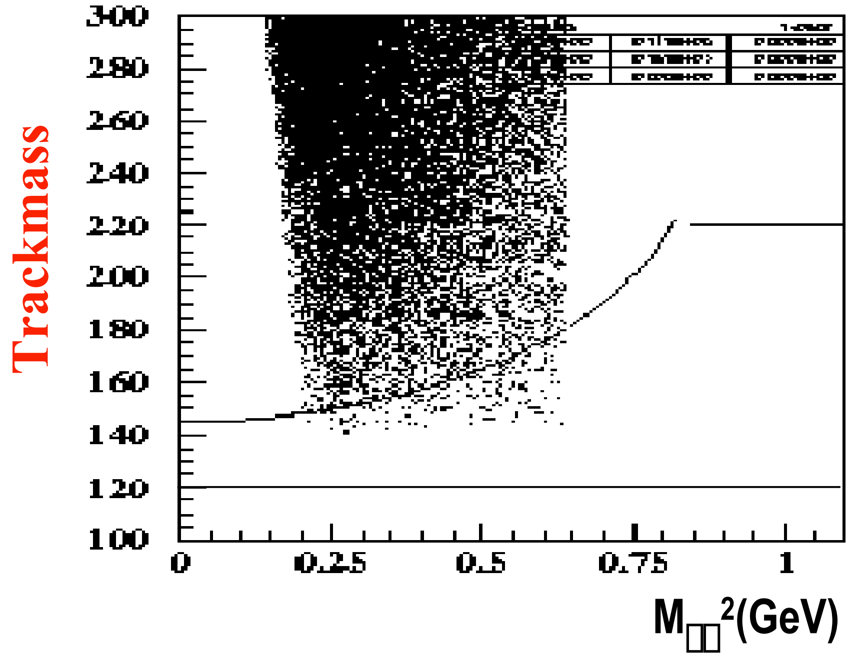
This process could create a background for our analysis if the electron and the positron go along the beampipe and can not be detected.



From MC*, we expect a background contribution at low values of $M_{\pi\pi}^2$



The background is completely rejected by the trackmass cut:



* Courau et al., in "Workshop on Physics and Detectors for DAΦNE" (INFN 1995)

Conclusions:

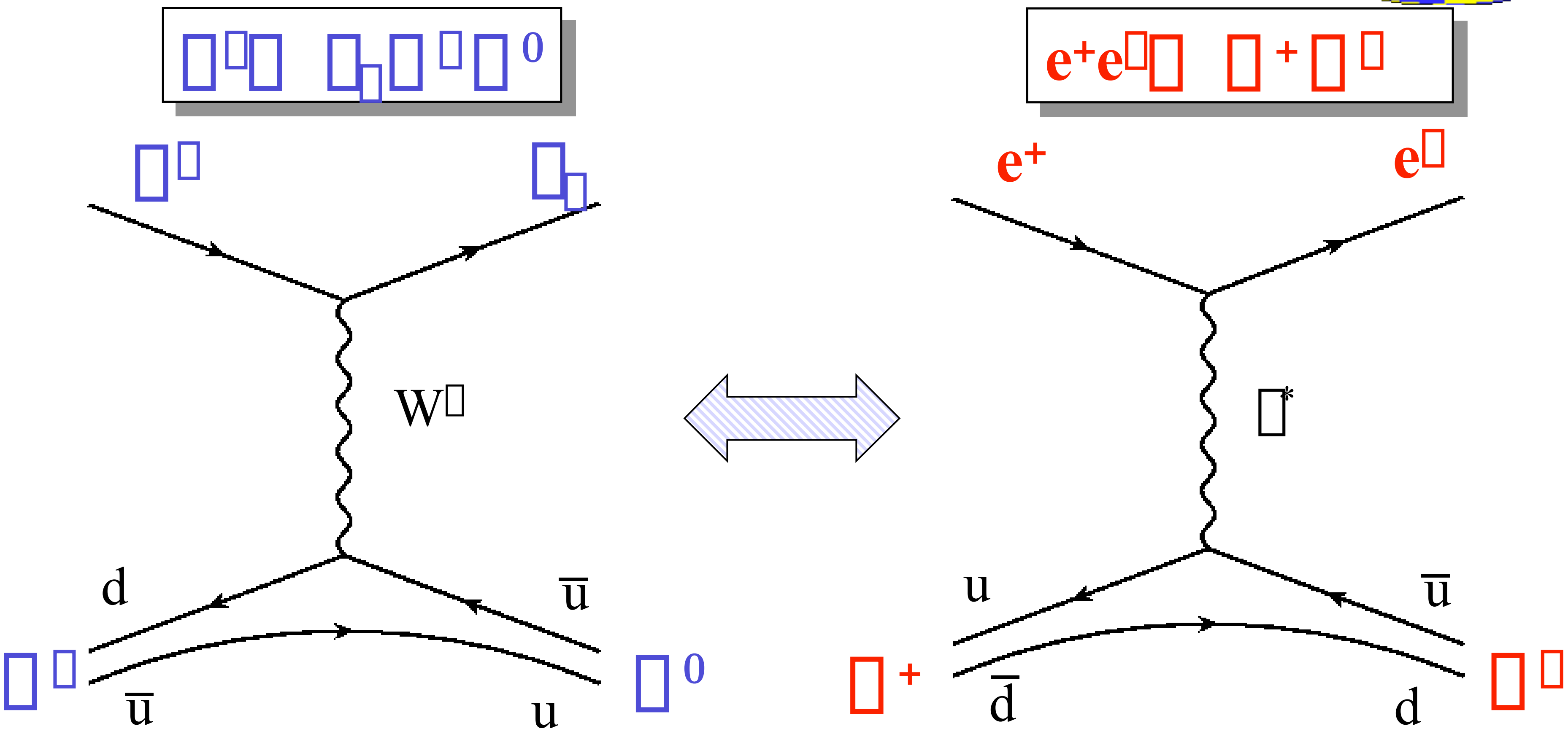
- Last year we have performed an „attempt“ on $73pb^{-1}$ of data in order to test a method of getting the pion form factor from a measurement utilizing the radiative return

- Already with this reduced data sample, there are no limitations by statistics

- Now we are refining this measurement using the full statistics from 2001 ($170\ pb^{-1}$) and evaluating systematics of the measurement (background contaminations, detector resolution etc).

We are in the final phase towards a publication of our results!

τ decays:



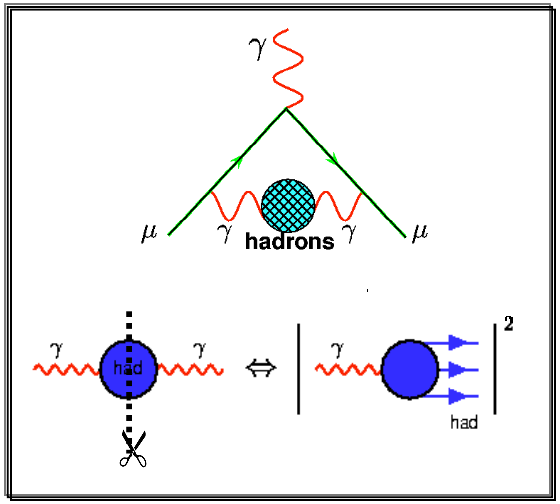
Isospin invariance assumed, one can relate the isovector cross sections $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ to the τ spectral function $v_{\pi^-\pi^0}$:

$$\sigma^{I=1}_{e^+e^- \rightarrow \pi^+\pi^-} = \frac{4\pi\alpha^2}{s} v_{\pi^-\pi^0} \quad , \quad \sqrt{s} \le M_\tau$$

Isospin symmetry breaking effects have to be taken into account!

Dispersion integral:

a_μ^{hadr} can be expressed in terms of $\sigma(e^+e^- \to$ hadrons) by the use of a dispersion integral:

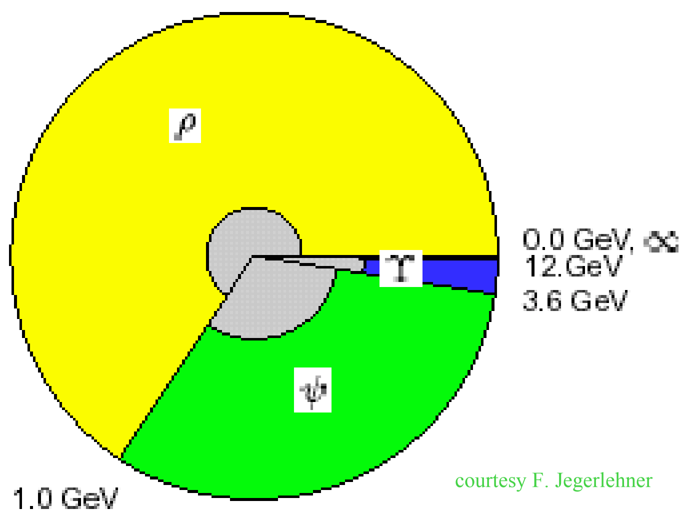


$$a_\mu^{hadr} = \frac{1}{4\pi^3}\left[\int_{4m_\pi^2}^{E_{Cut}^2} ds\, \sigma^{hadr,exp}(s)K(s) + \int_{E_{Cut}^2}^{\infty} ds\, \sigma^{hadr,pQCD}(s)K(s)\right]$$

- E_{cut} is the threshold energy above which pQCD is possible
- s is the c.o.m.-energy squared of the hadronic system
- $K(s)$ is a steady function that goes with $1/s$, ***enhancing low energy contributions of $\sigma^{hadr}(s)$***

Low energy contribution:

The region around the energy of the ρ-meson adds with ca. 72% to the total value of a_μ^{hadr}.[Jegerlehner; hep-ph/0104304]



The ρ-meson decays to 100% in $\pi^+\pi^-$, so in this energy region the analysis efforts concentrate on the determination of

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

Status on $(g-2)_\mu$:

The current status of a_μ from experiment and (SM-) theory:

a_μ^{exp}

$$(g_\mu-2)/2 = (11\,659\,203.0 \pm 8.0) \times 10^{-10}$$ E821, hep-ex/0208001

$a_\mu^{theor,SM}$

$$(g_\mu-2)/2 = a_\mu^{QED} + a_\mu^{had} + a_\mu^{weak}$$

a_μ^{QED}	$= (11\,658\,470.6 \pm 0.3) \times 10^{-10}$	Nucl. Phys. B (Proc. Suppl.) 76, 245
a_μ^{weak}	$= (15.2 \pm 0.1) \times 10^{-10}$	KPPdR hep-ph/0205102
a_μ^{had}	$= (707.6 \pm 6.9) \times 10^{-10}$	based on τ decays
	$= (683.3 \pm 7.8) \times 10^{-10}$	DEHZ hep-ph/0208177 v3 — based on e+e- data

$$a_\mu^{exp} - a_\mu^{theor,SM} = 0.9 - 3.0\ \sigma \text{ difference}$$

- The nature of the difference in the two evaluations of a_μ^{had} is currently not understood
- The reduction of the error on the hadronic contribution to the SM calculation of a_μ could (together with a further reduction of the experimental error) give this discrepancy between theory and experiment a higher significance

a_μ^{had}:

$a_\mu^{had} = a_\mu^{had}(lo) + a_\mu^{had}(nlo) + a_\mu^{had}(lbl)$

(see Davier,Eidelmann,Höcker,Zhang hep-ph/0208177)

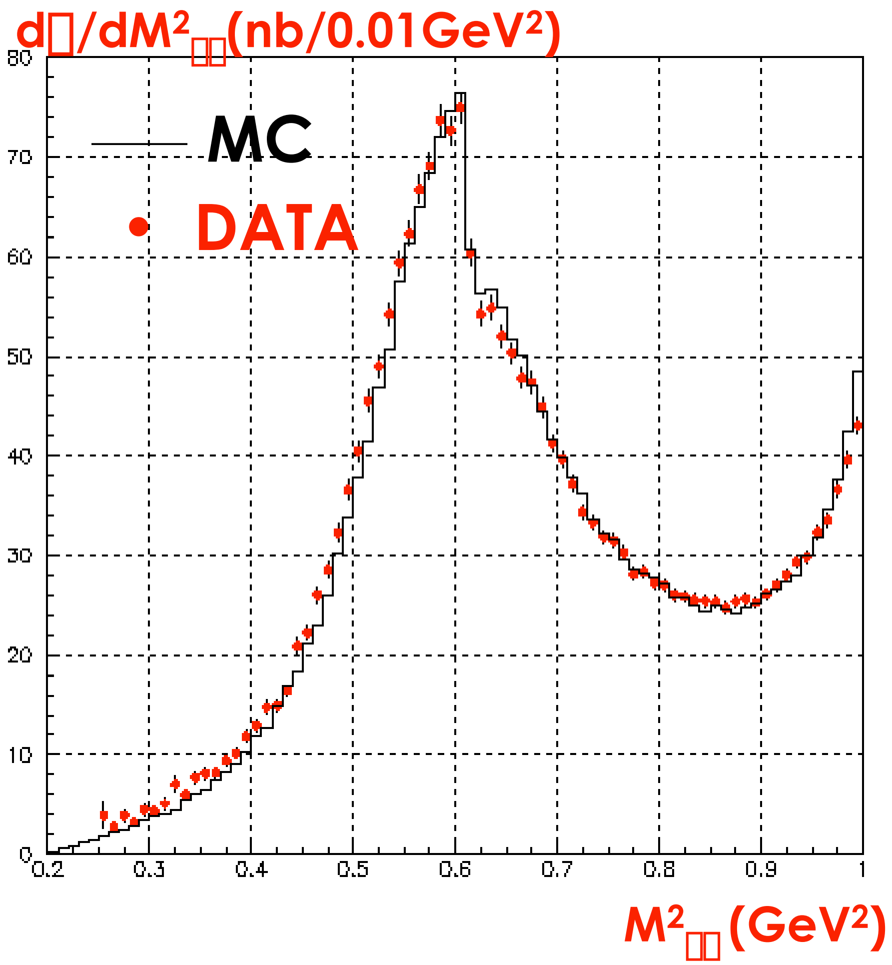
$a_\mu^{had}(lo)$	$=(709.0 \pm 5.9) \times 10^{-10}$	τ based
	$=(684.7 \pm 7.0) \times 10^{-10}$	e+e- based
$a_\mu^{had}(nlo)$	$=(-10.0 \pm 0.6) \times 10^{-10}$	Krause, hep-ph/9607259
$a_\mu^{had}(lbl)$	$=(+8.6 \pm 3.5) \times 10^{-10}$	KN, hep-ph/0111058 BPP, hep-ph/0112255 HK, hep-ph/0112102
a_μ^{had}	$=(707.6 \pm 6.9) \times 10^{-10}$	τ based
	$=(683.3 \pm 7.8) \times 10^{-10}$	e+e- based

$d\square/M_{\square\square}^2$:

DATA compared with the MC

(**MC** output has been interfaced with the detector simulation program)

Only statistical errors have been taken into account!



Pion form factor (prelim.):

Data points have been fitted with the **Gounaris-Sakurai-Parametrization**

$$F_\pi(s) = \frac{BW_\rho^{GS}\left(1+\delta\frac{s}{m_\omega^2}BW_\omega\right)+\beta BW_{\rho'}^{GS}}{1+\beta}$$

(G.J. Gounaris and J.J. Sakurai, Phys.Rev. Lett. 21 (1968), 244)

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

m_ρ = 775.1 ± 0.5 MeV

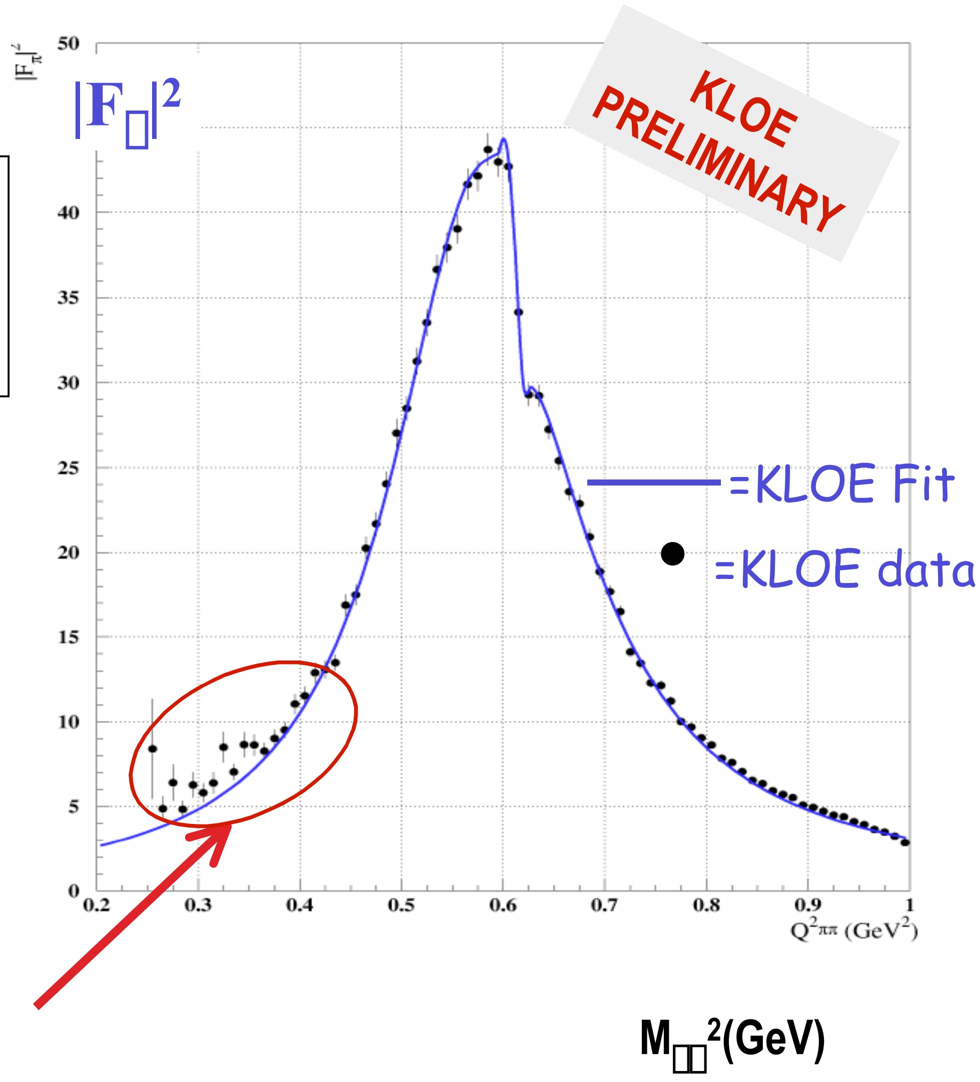
Γ_ρ = 147.1 ± 0.8 MeV

β = -0.08 ± 0.002

$|\delta|$ = (2.893 ± 0.6) • 10^{-3}

ϕ_δ = $(124.8 \pm 9.0)^0$

(Stat. Errors only)



$M_{\pi\pi}^2$(GeV)