Hadronic cross section measurement with the KLOE experiment in Frascati

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Euridice Collaboration meeting

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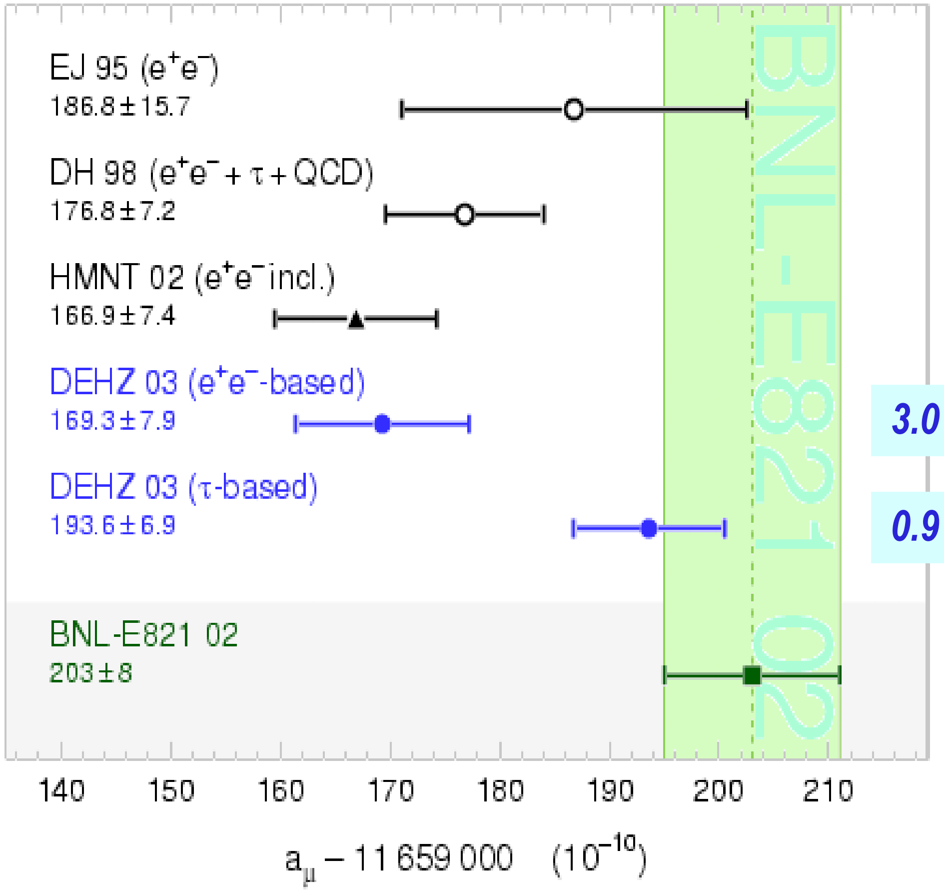
Status on $(g-2)_\mu$:

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



3.0 σ

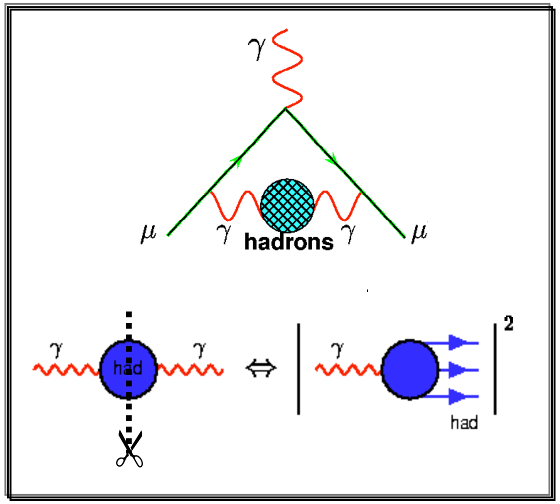
0.9 σ

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

- 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

Dispersion integral:

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



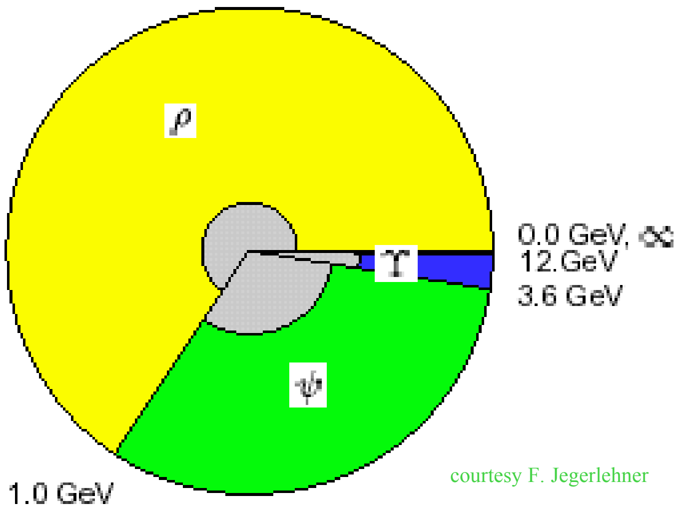
$$a_\mu^{hadr} = \frac{1}{4\pi^3}\left(\int_{4m_\pi^2}^{E_{Cut}^2} ds\, \sigma^{hadr,\exp}(s) K(s) + \int_{E_{Cut}^2}^{\infty} ds\, \sigma^{hadr,pQCD}(s) K(s) \right)$$

- 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. 61% to the total value of a_μ^{hadr}.[Jegerlehner; hep-ph/0104304]

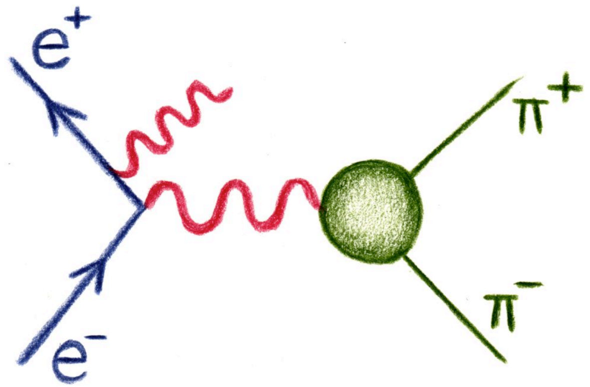


The ρ-meson decays to 100% in $\pi^+\pi^-$, so in this energy region the analysis efforts concentrate on the determination of

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

Radiative Return:

Particle factories have the opportunity to measure the cross-section $\sigma(e^+ e^- \rightarrow hadrons)$ as 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	disadvantage
Data comes as by-product of standard program	Requires precise calculations of ISR → **EVA + Phokhara** MC Generator
Systematic errors from Luminosity, s, … enter **only once** for each point of $M_{hadrons}^2$	Requires good suppression (or understanding) of FSR

DAΦNE: A Φ-Factory

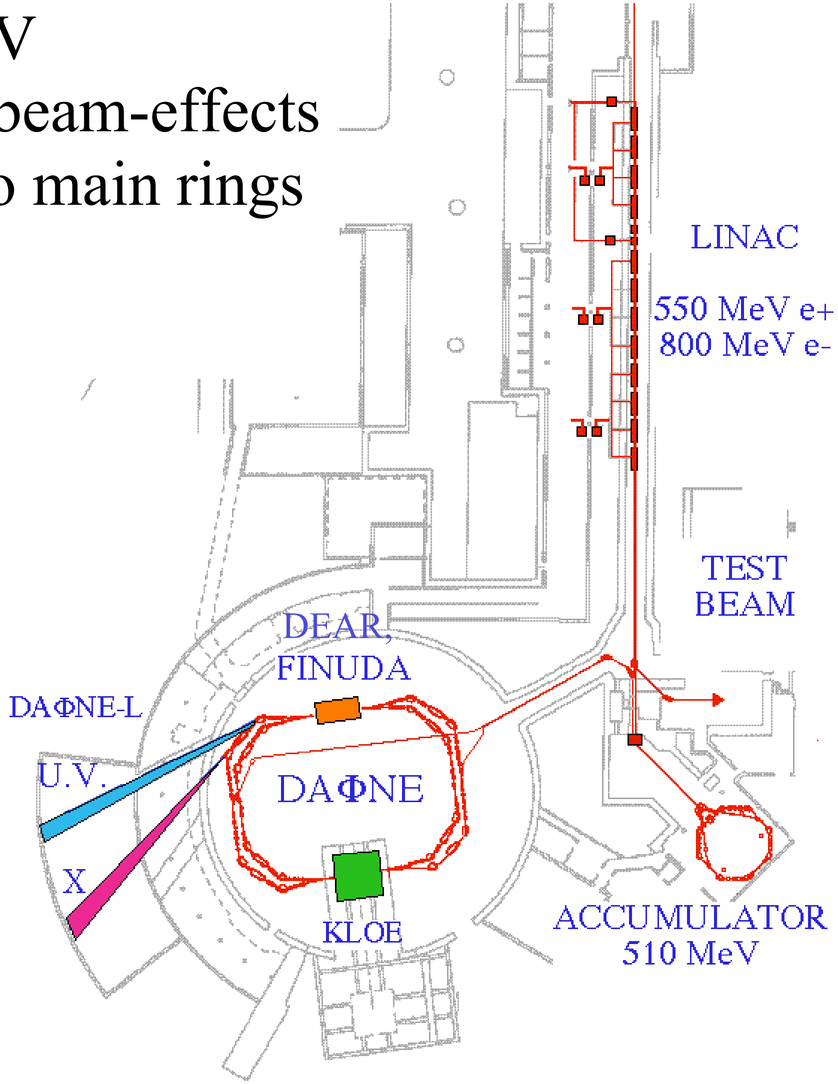
(**D**ouble **A**nnular Φ-Factory for **N**ice **E**xperiments)

- 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%

$p_{K^\pm} = 127 \mathrm{MeV/c}$

$p_{K_{L,S}} = 110 \mathrm{MeV/c}$



KLOE:

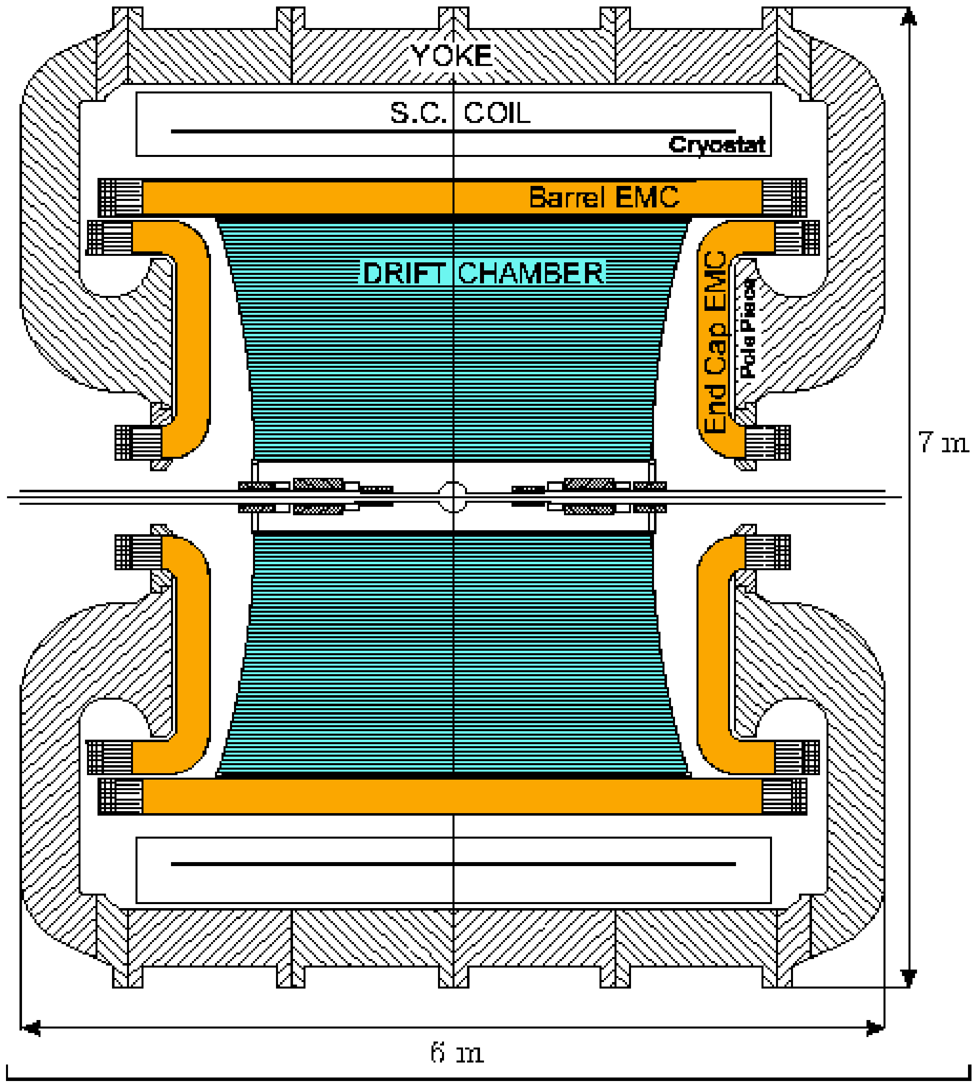
(KLOng Experiment)

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

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

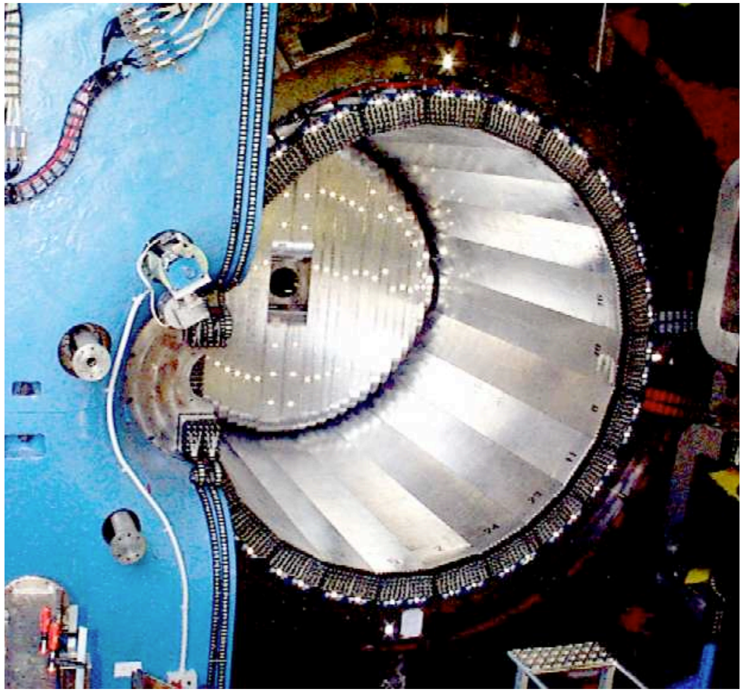
- **Driftchamber:**
  12582 Sense Wires
  52140 wires in total

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



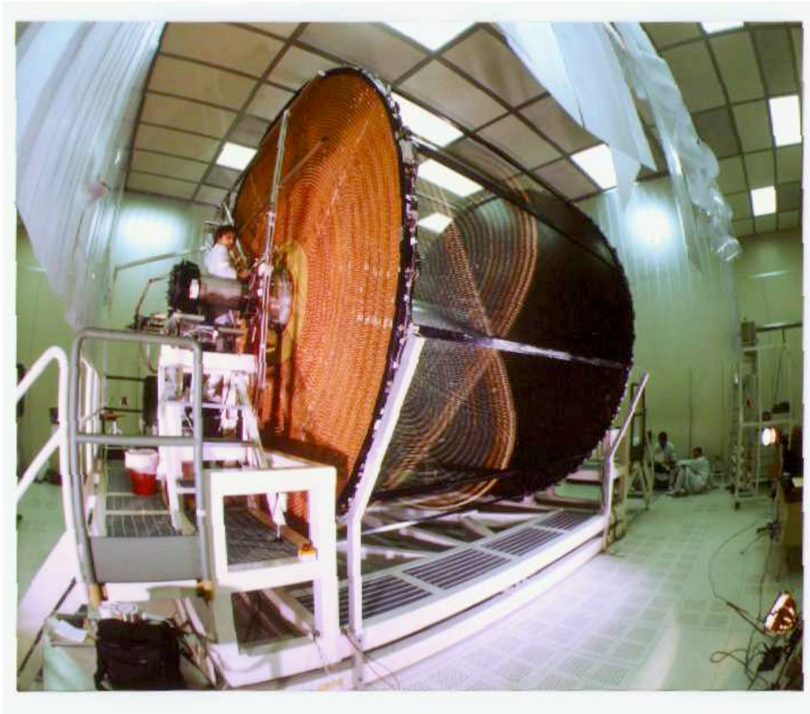
KLOE:

$\sigma_E/E = 5.7\% / \sqrt{E(GeV)}$
$\sigma_T = 54\ ps / \sqrt{E(GeV)} \oplus 50\ ps$
(Bunch length contribution subtracted from constant term)



Electromagnetic calorimeter

Driftchamber



$\sigma_p/p = 0.4\%$ (for 90^0 tracks)
$\sigma_{xy} \approx 150\ \mu m$, $\sigma_z \approx 2\ mm$

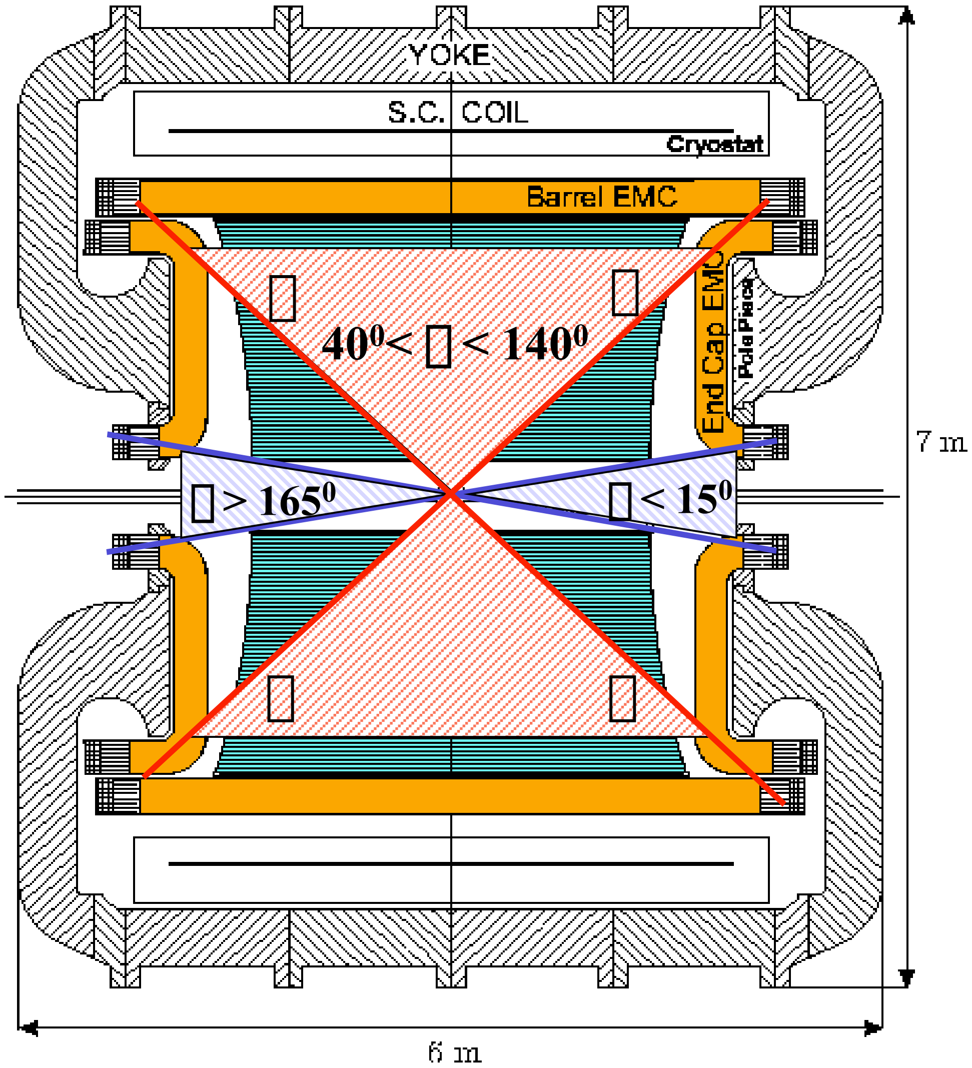
Signal selection:

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 missing momentum $p_{\pi\pi}$



The choice of this kinematical region was motivated by:

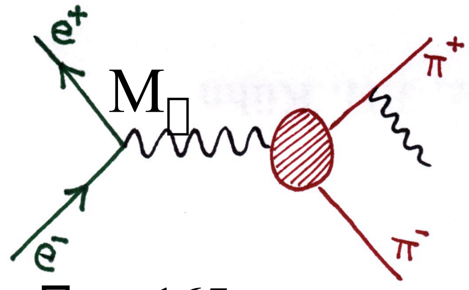
- reduced background contamination
- small relative contribution of **FSR**

FSR suppression:

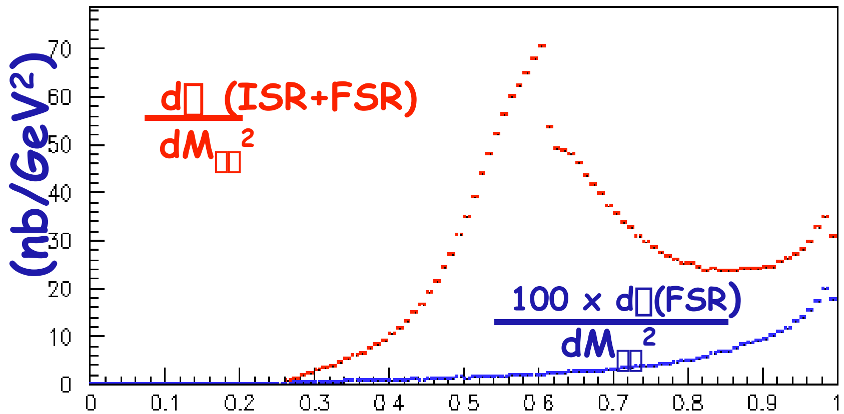
Our approach is to treat **F**inal **S**tate **R**adiation of the pions as a „background“ and suppress it in the measurement using kinematical cuts.

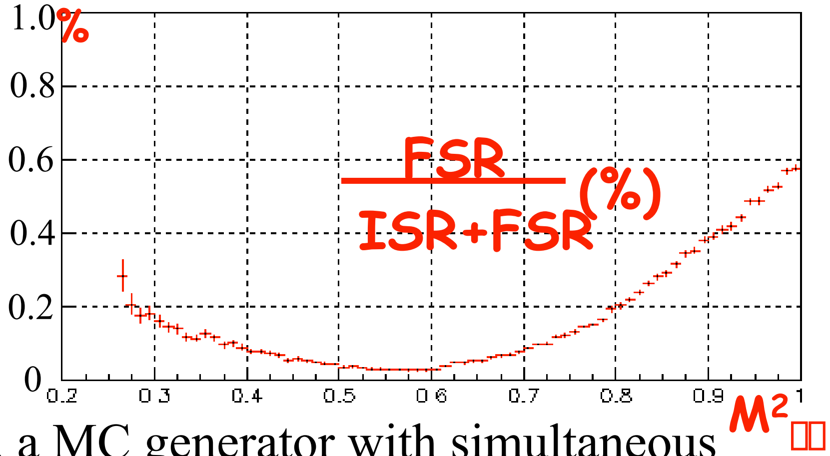
Initial **S**tate **R**adiation and **F**inal **S**tate **R**adiation contribution have been evaluated with the EVA-MC-Generator (Binner, Kühn, Melnikov, Phys. Lett. B 459, 1999)**:**

EVA contains LO FSR from pions produced at the collison energy (M_{ϕ} at DAΦNE), treating pions as pointlike particles



Contributions for LO ISR and LO FSR for **$\theta_{\pi\pi}$< 15° or $\theta_{\pi\pi}$> 165° :**



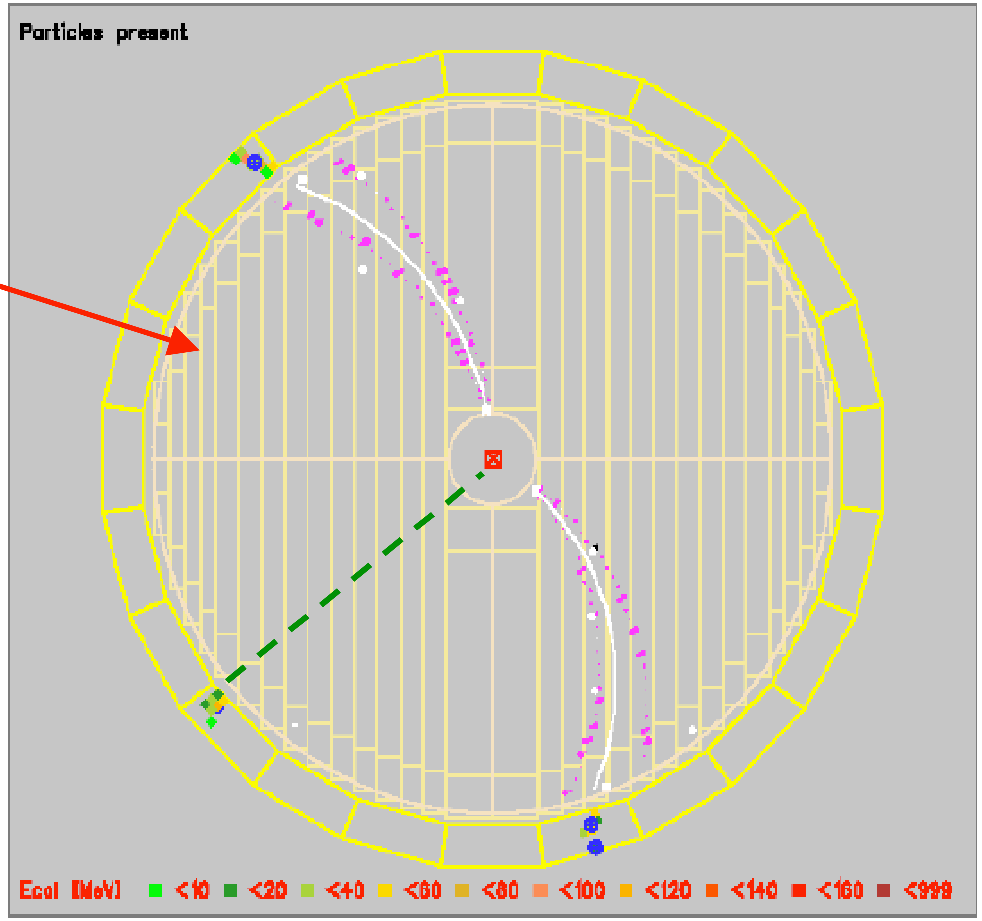


For a more detailed evaluation of FSR contribution, a MC generator with simultaneous occurrence of ISR and FSR is needed

➔ next version of Phokhara generator (Czyz,Kühn,Rodrigo et al.)

$\pi^+\pi^-\gamma$ event selection:

Event Display DIDONE



$\pi^+\pi^-\gamma$ events are selected by asking for two tracks connected to a vertex in the IR with both tracks $40° < \theta_\pi < 140°$

E_γ and θ_γ are then evaluated using the momenta of the two tracks

Some background channels are selected together with the signal:

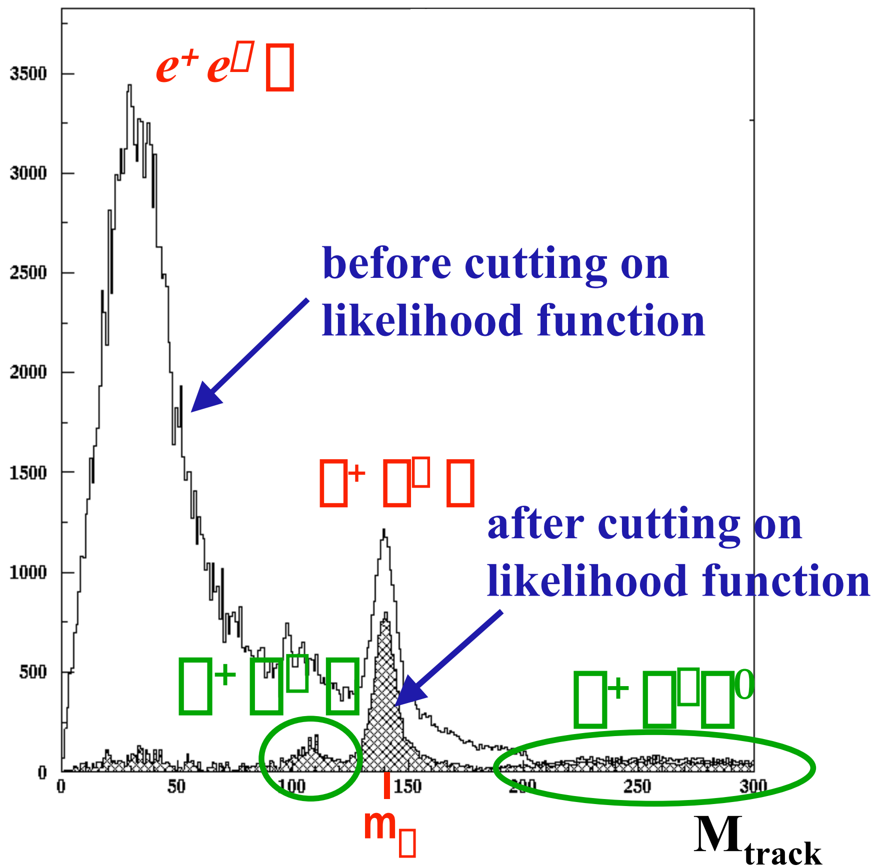
- $e^+e^- \to e^+e^-\gamma$
- $e^+e^- \to \mu^+\mu^-\gamma$
- $e^+e^- \to \phi \to \pi^+\pi^-\pi^0$

Background subtraction:

To reduce Bhabha contamination, a μ-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.



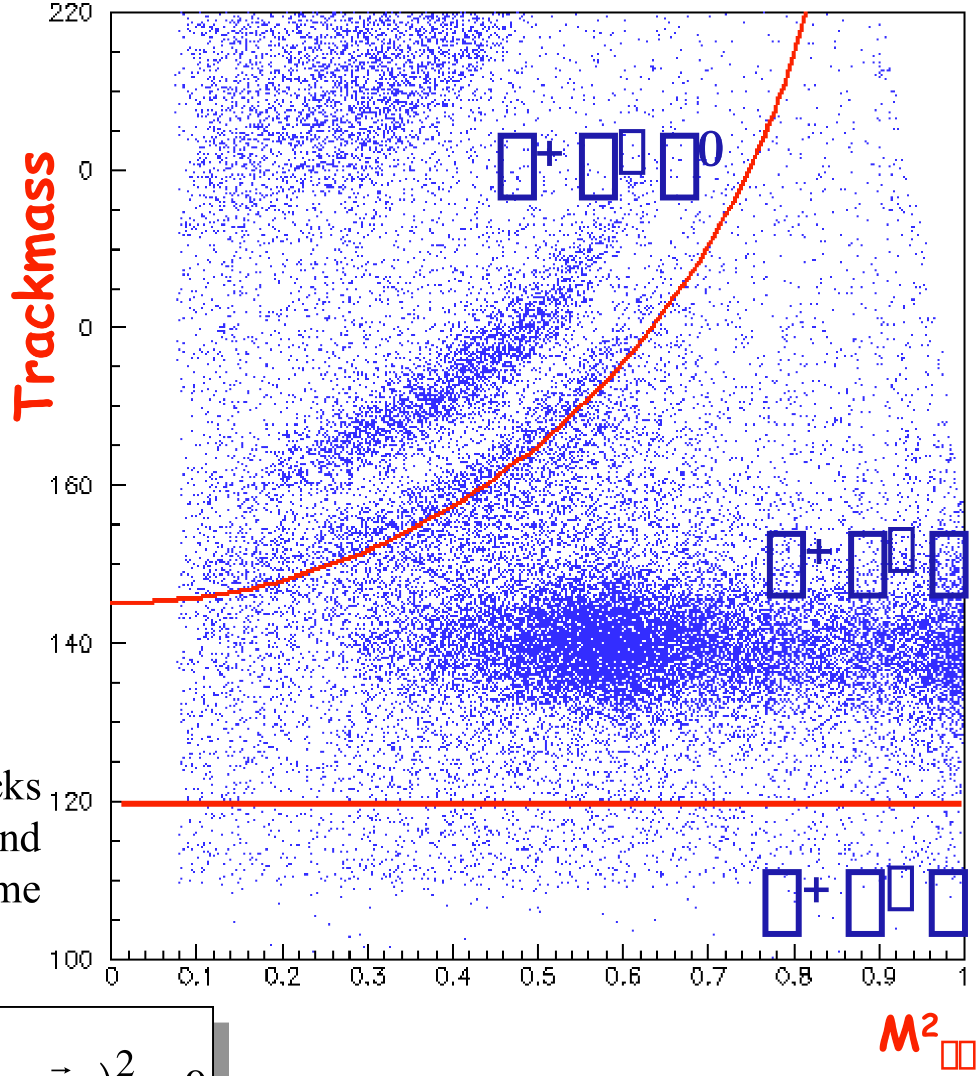
Background subtraction:

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

□+ □□ □background (M_{track}□104 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}:

$$q^2_{\Box} = \Box M_{\Box} \Box \sqrt{\vec{p}_1^{\,2} + M_{trk}^2} \Box \sqrt{\vec{p}_2^{\,2} + M_{trk}^2} \Box^2 \Box (\vec{p}_1 + \vec{p}_2)^2 = 0$$

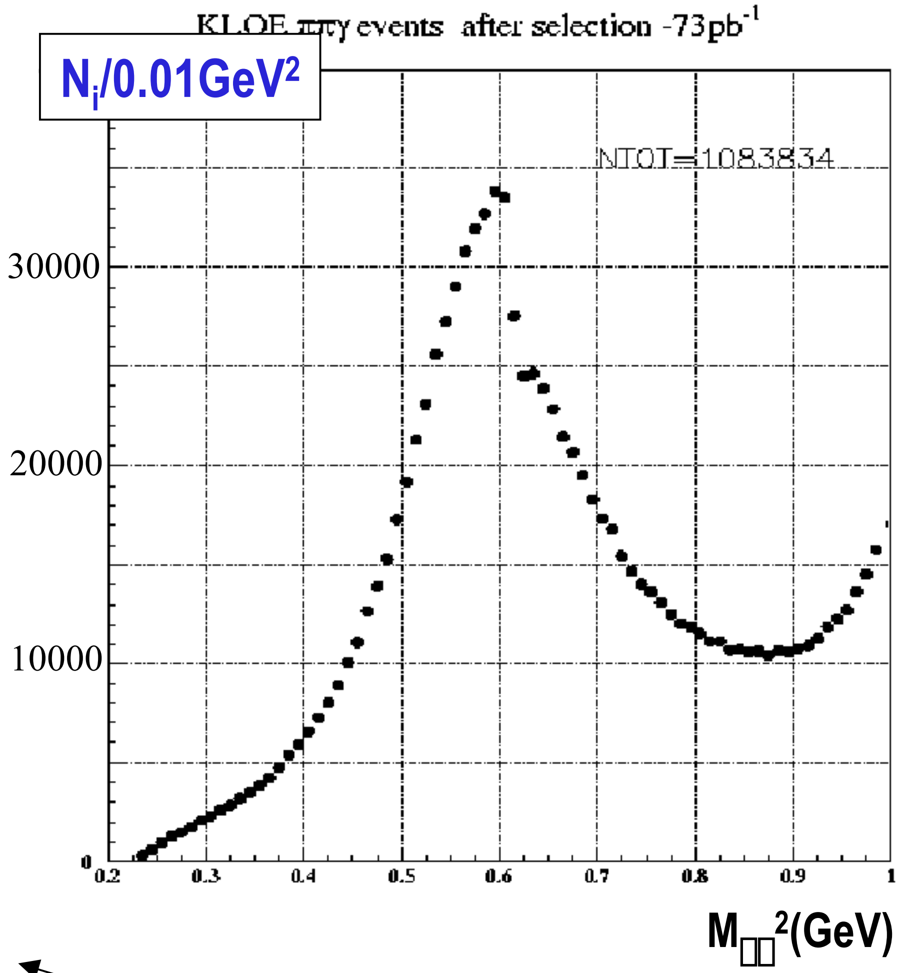


$M_{\pi\pi}^2$- Spectrum:

In a preliminary „exercise“ to extract the pion form factor, we analyzed *73 pb^{-1}* of 2001 data according to the analysis items discussed

after selection: **1 083 834 events**

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



Signal

Background

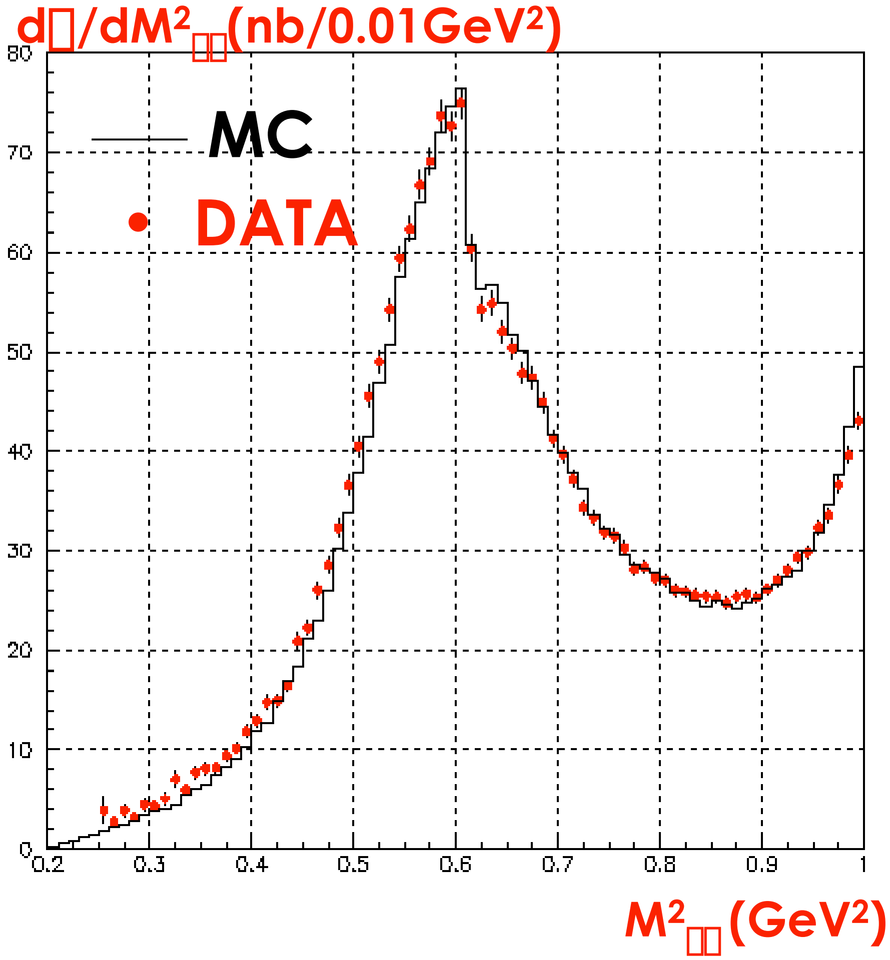
$$\frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \frac{N^{obs} - N^{bkg}}{\Delta M^2_{\pi\pi}} \cdot \frac{1}{\varepsilon_{Select.}} \cdot \frac{1}{L}$$

Luminosity

Selection efficiency

$d\sigma/M_{\pi\pi}^2$:

DATA is compared with the MC generator **PHOKHARA (NLO),** whose output has been interfaced with the detector simulation program.

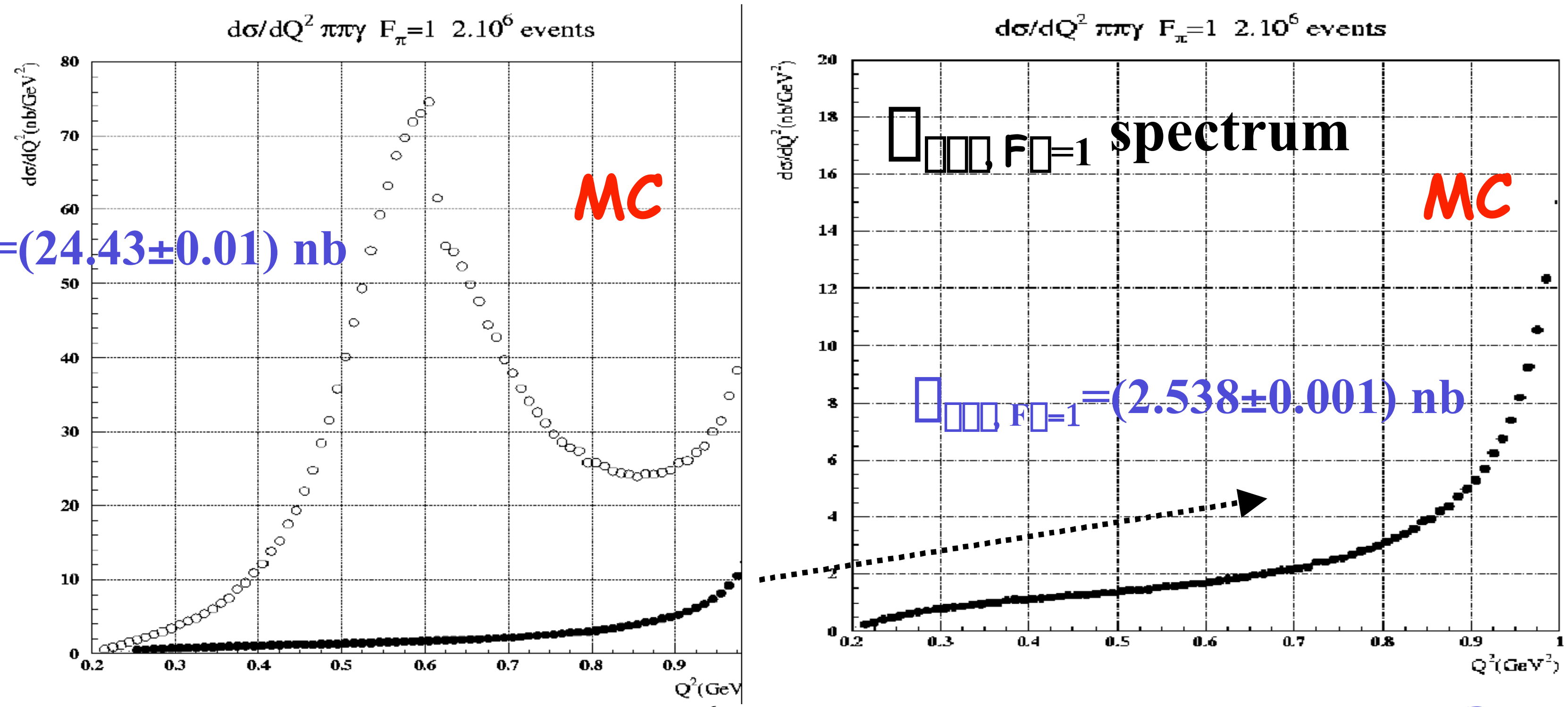


Only statistical errors have been taken into account!

Extraction of pion form factor:

We divide the **$\pi^+\pi^-\gamma$ cross section** by the **cross section $\pi^+\pi^-\gamma$ for "pointlike" pions** which is obtained from the **MC generator Phokhara** by **setting $F_\pi = 1$.**

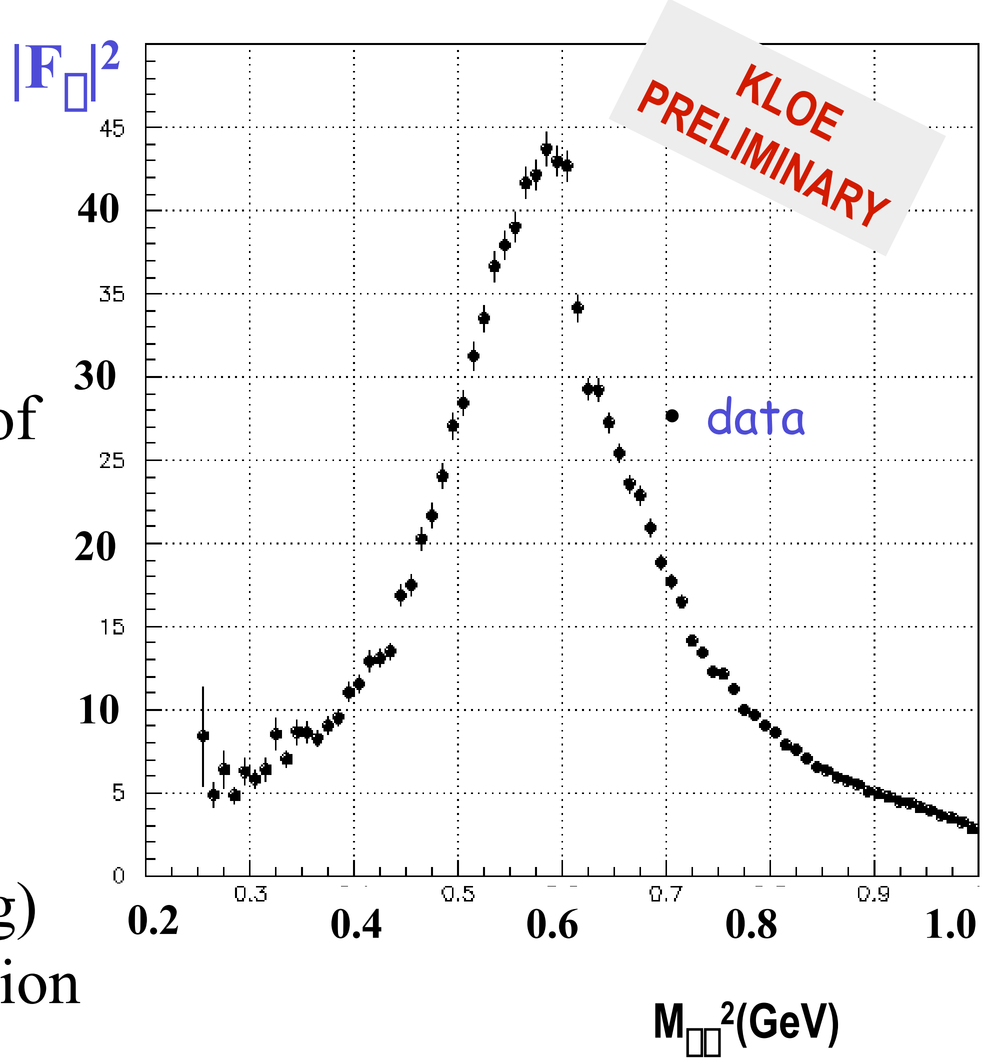
$$|F_\pi(M^2_{\pi\pi})|^2 = \frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{d\sigma_{\pi\pi\gamma,F_\pi=1}(M^2_{\pi\pi})}$$



$\sigma_{\pi\pi\gamma,\,F_\pi=1}$ was computed with $2*10^6$ events of Monte Carlo (PHOKHARA) with $F_\pi=1$, with the acceptance cuts of the analysis: $\theta_\gamma<15^\circ$ ($\theta_\gamma>165^\circ$), $40^\circ<\theta_\pi<140^\circ$

Pion form factor:

In this way, we got 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

Luminosity:

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

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

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

Bhabha - Candidates

Theoret. Generators with rad. corrections (Prec. 0.5%)

Berends(Drago/Venanzoni)

BABAYAGA*

Background (□□□ ...)

The agreement between the two generators is (0.1±0.1)%

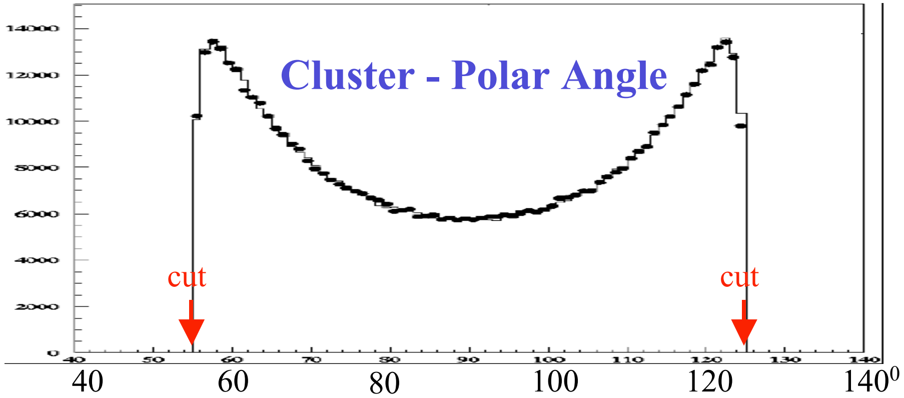
* *C.M.C. Calame et.al. Nucl. Phys., B 584 (2000)*

The systematics of the luminosity measurement are given by:

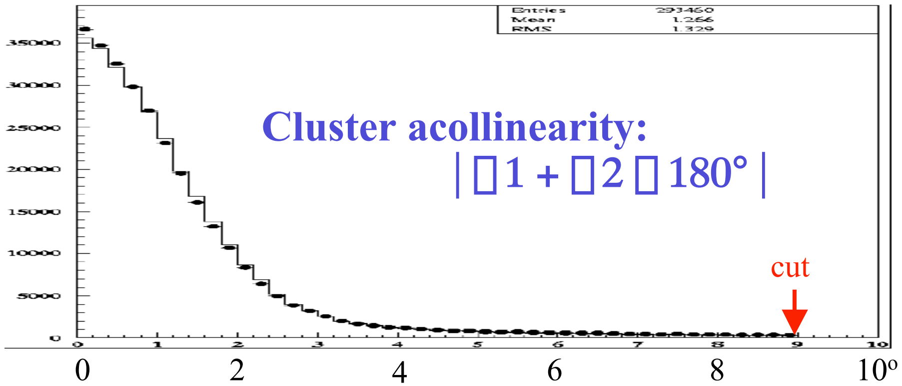
- Differences between MC and Data
- Variations in time due to changes in running conditions

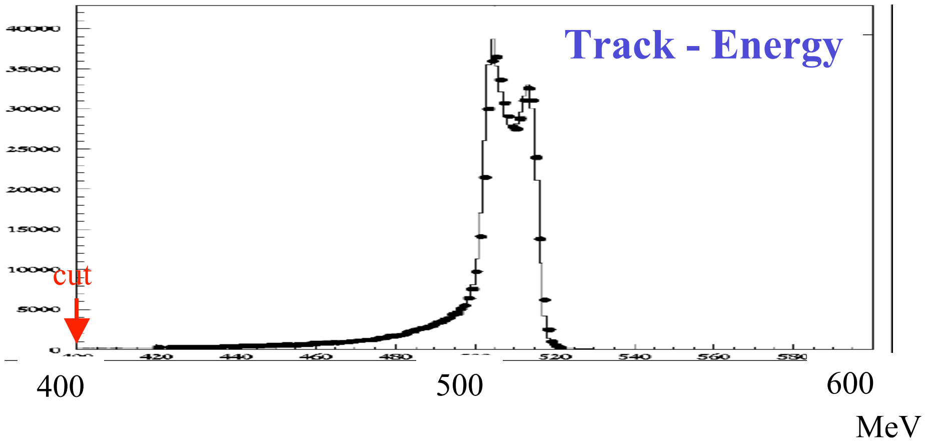
Luminosity: Data vs. MC

- Data
- Monte Carlo



The only critical cut is the cut on the polar angle of the cluster, where border effects can arise due to difference for MC and data. The systematic error due to this effect has been estimated to be ≤0.3%





MC and Data distributions agree very well

Systematic Effect due to Accep. Cuts ≤0.3%

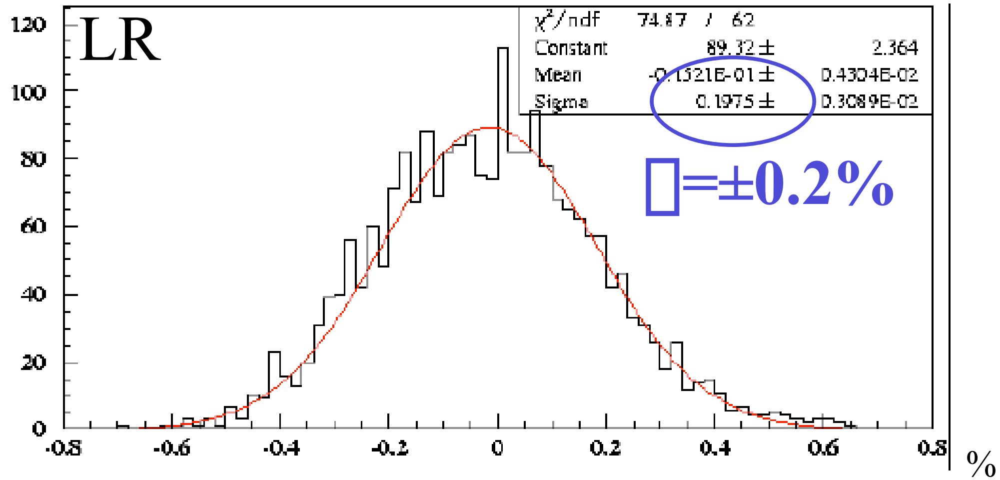
Luminosity:

Running conditions have been checked on a run-by-run basis

Left-right asymmetry for bhabha-clusters:

$$LR = \frac{N(55^o - 90^o) - N(90^o - 125^o)}{N(55^o - 90^o) + N(90^o - 125^o)}$$

1% L-R-Asymmetry: □L / L < 0.1 %
➔Polar Angle Cut not affected



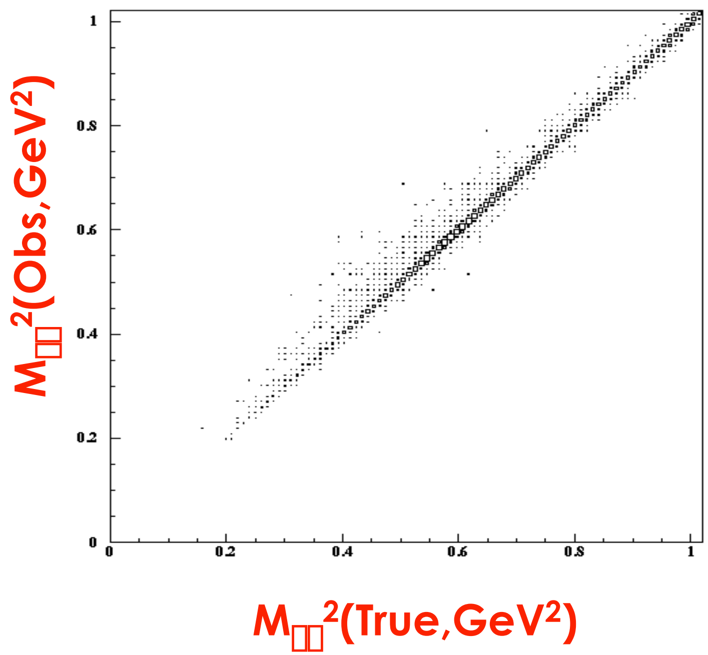
Further checks have been performed on fluctuations of cluster- and tracking efficiency, cluster energy and momentum of the tracks

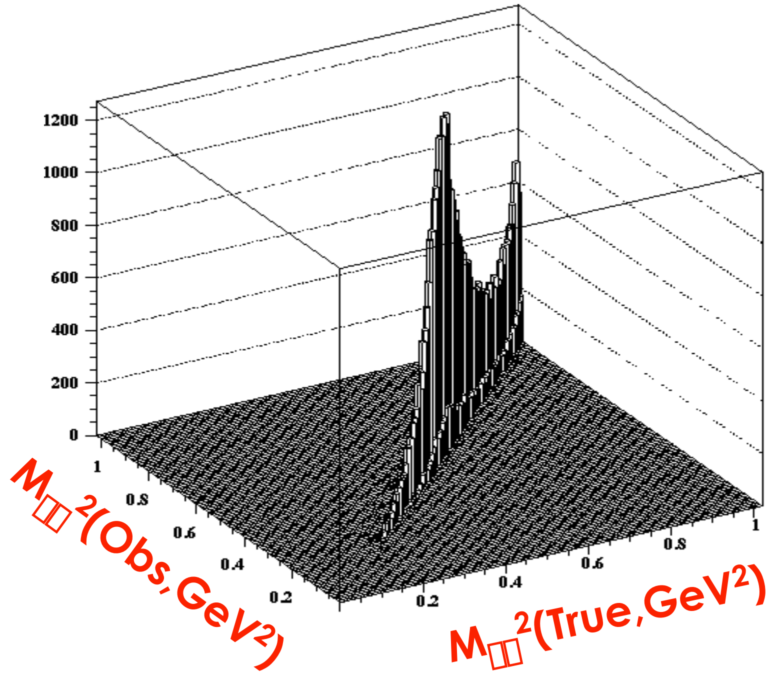
➔ **No limitation for luminosity precision < 1% found**
final precision is currently under evaluation

Detector resolution:

The detector resolution has been studied using MC:

The theoretical MC generator creates a „true“ spectrum of $M_{\square\square}^2$ which is then passed through the detector simulation program. The „observed“ spectrum is „smeared“ due to the finite resolution in the detector simuation.





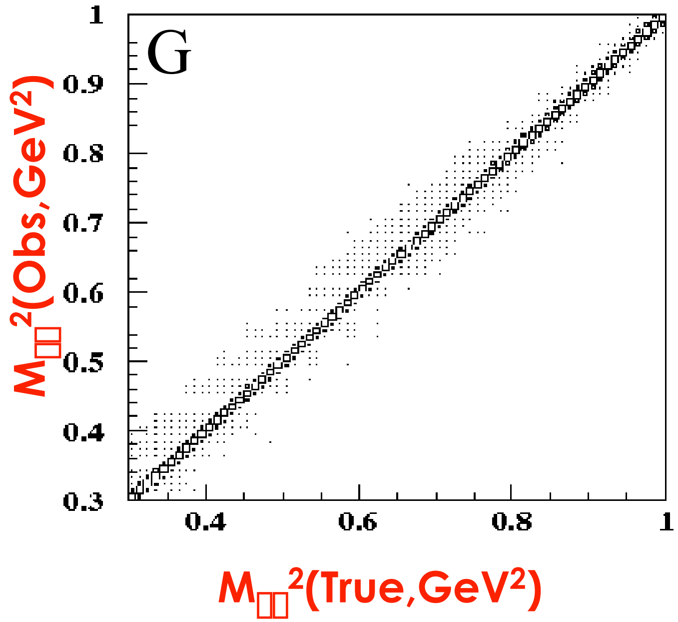
Graphical representations of the „smearing“

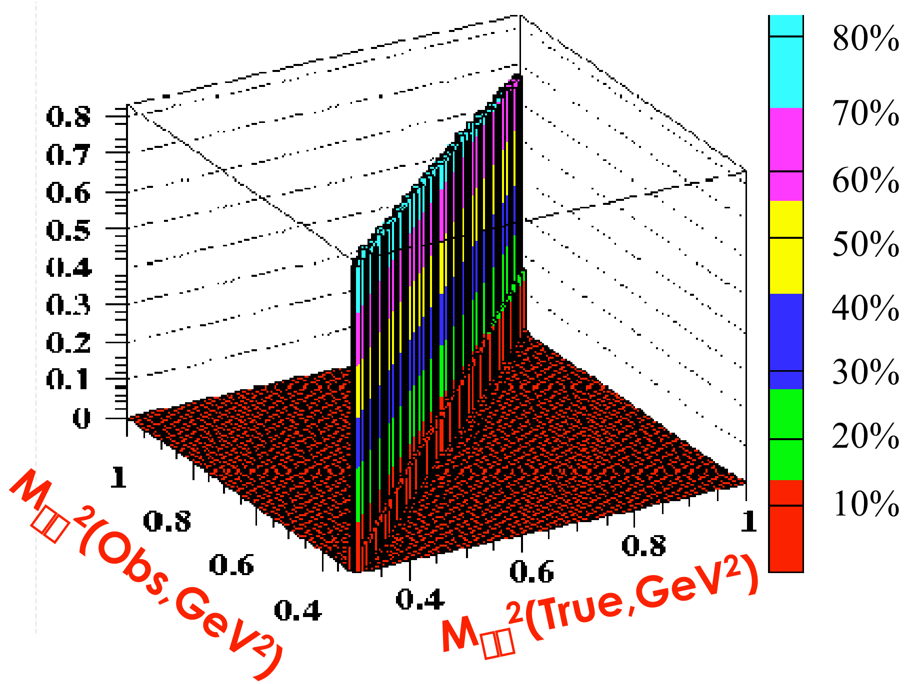
Detector resolution:

A smearing matrix relates the true to the observed value:

$$N_j^{obs} = \sum_i G_{j,i} N_i^{true} \quad ; \quad N_i^{true} = \sum_j G_{i,j}^{-1} N_j^{obs}$$

Thanks to the good resolution for $M_{\pi\pi}^2$ of KLOE ($\delta M_{\pi\pi}^2 \approx 0.2$•bin width) , the matrix G is almost diagonal:

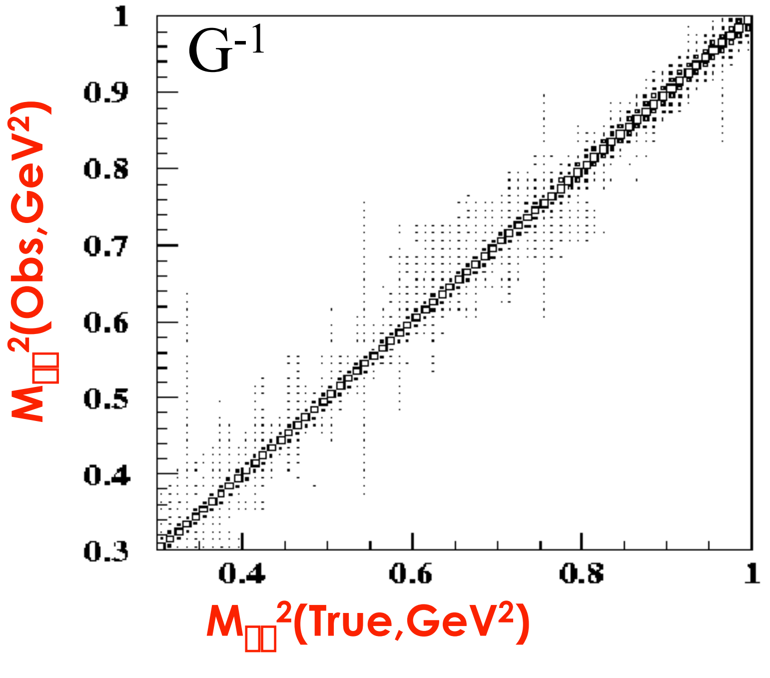


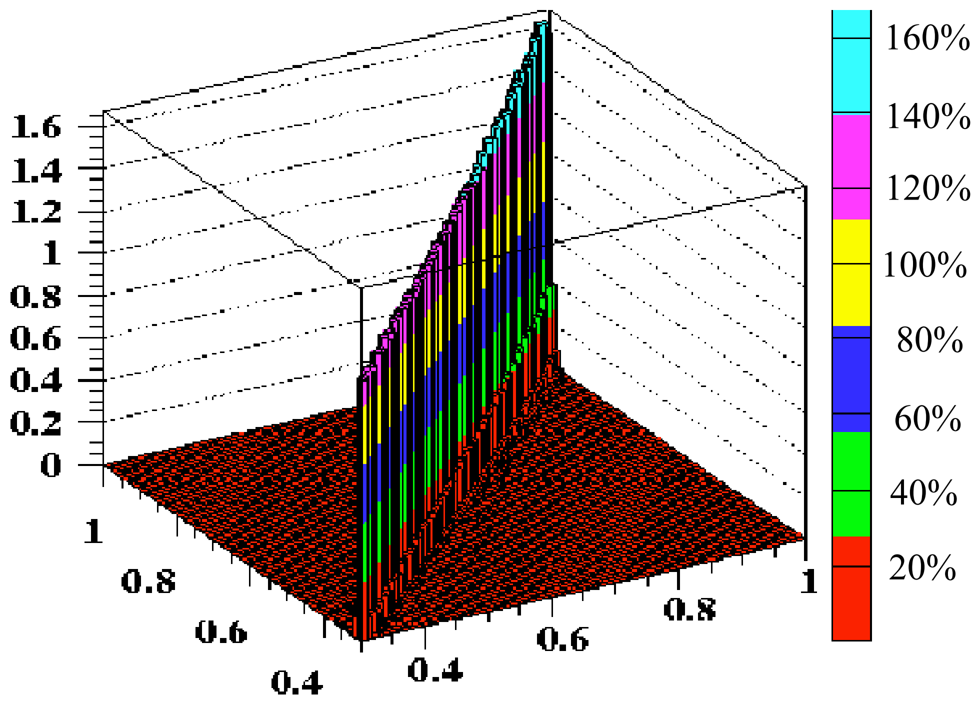


Most of the population is on the diagonal (~70%) or in the adjacent bins (15%): Under this conditions, inverting the smearing matrix is enough to obtain the unfolded $M_{\pi\pi}^2$ spectrum.

Detector resolution:

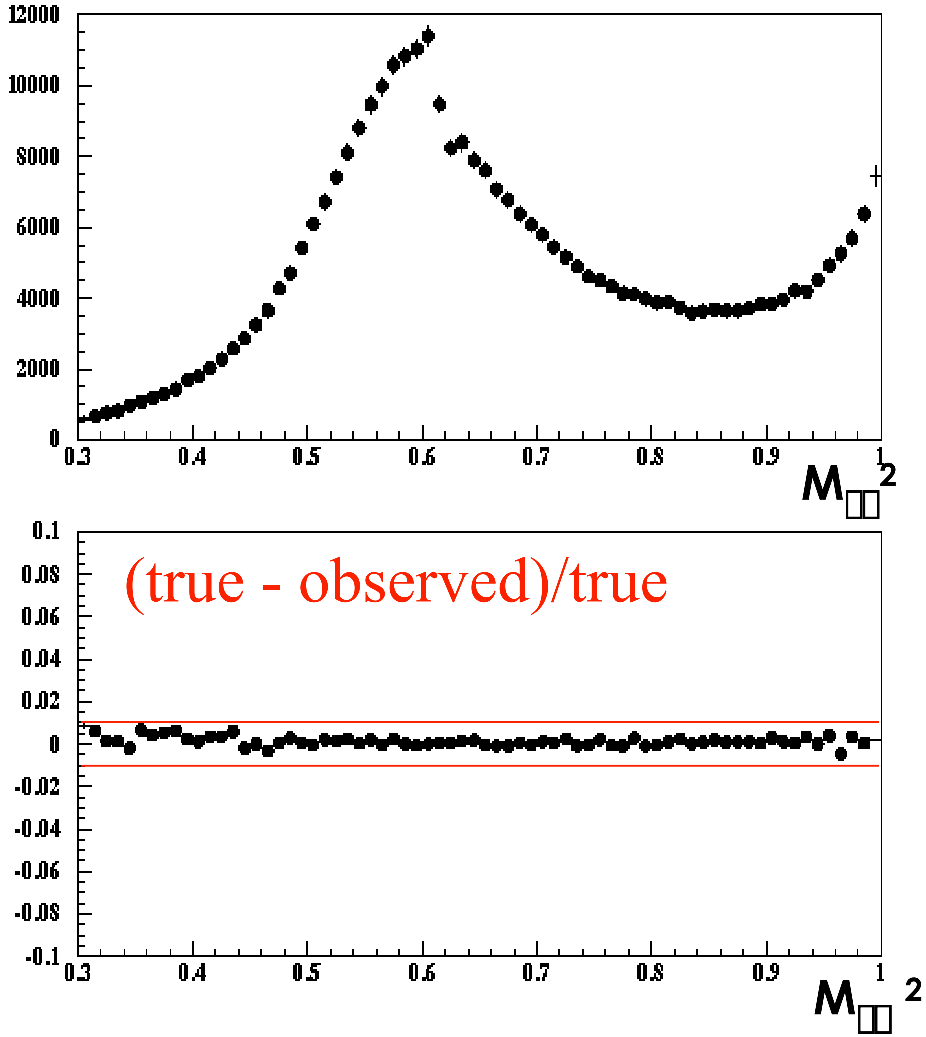
The invertion of matrix G yields a matrix G^{-1} that looks similar to G:





Detector resolution:

- The method has been successfully applied to a MC sample of 1 Mio. events.
- From the reconstructed spectrum obtained at the end of the analysis chain, the unfolded distribution has been computed by inverting the $M_{\pi\pi}^2$ smearing matrix.
- This distribution has been compared with the generated MC $M_{\pi\pi}^2$ distribution.



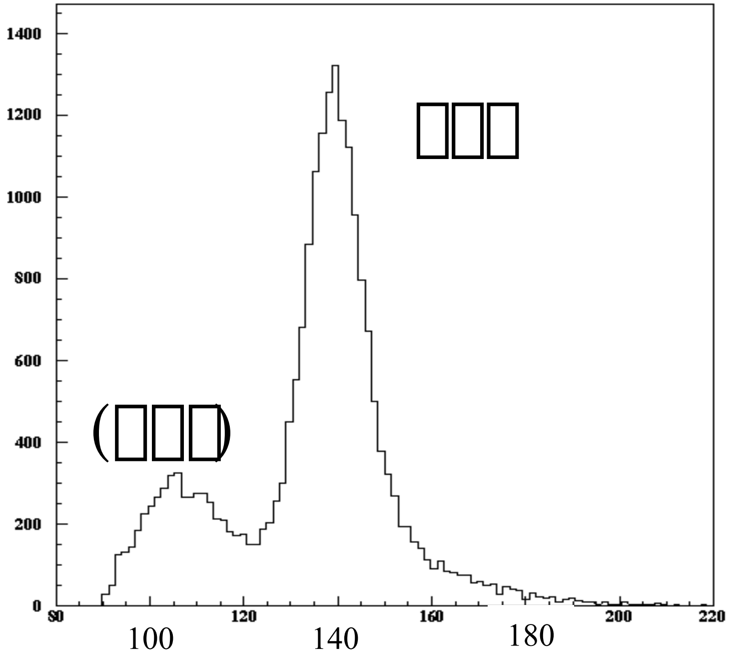
Residual background:

After the π-e-separation, a residual contamination of Bhabha events still remains.

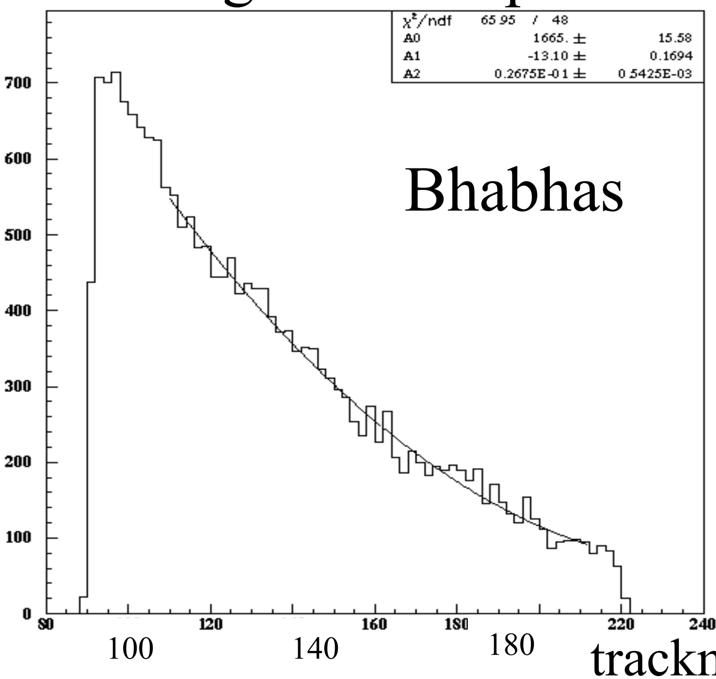
For each region of $M_{\pi\pi}^2$, we find the shape of the trackmass distribution for signal and background:

- **SIGNAL**: both tracks must be selected as pions by the π-e-separation
- **BACKGROUND**: both tracks must be selected as electron tracks

Signal shape



Background shape



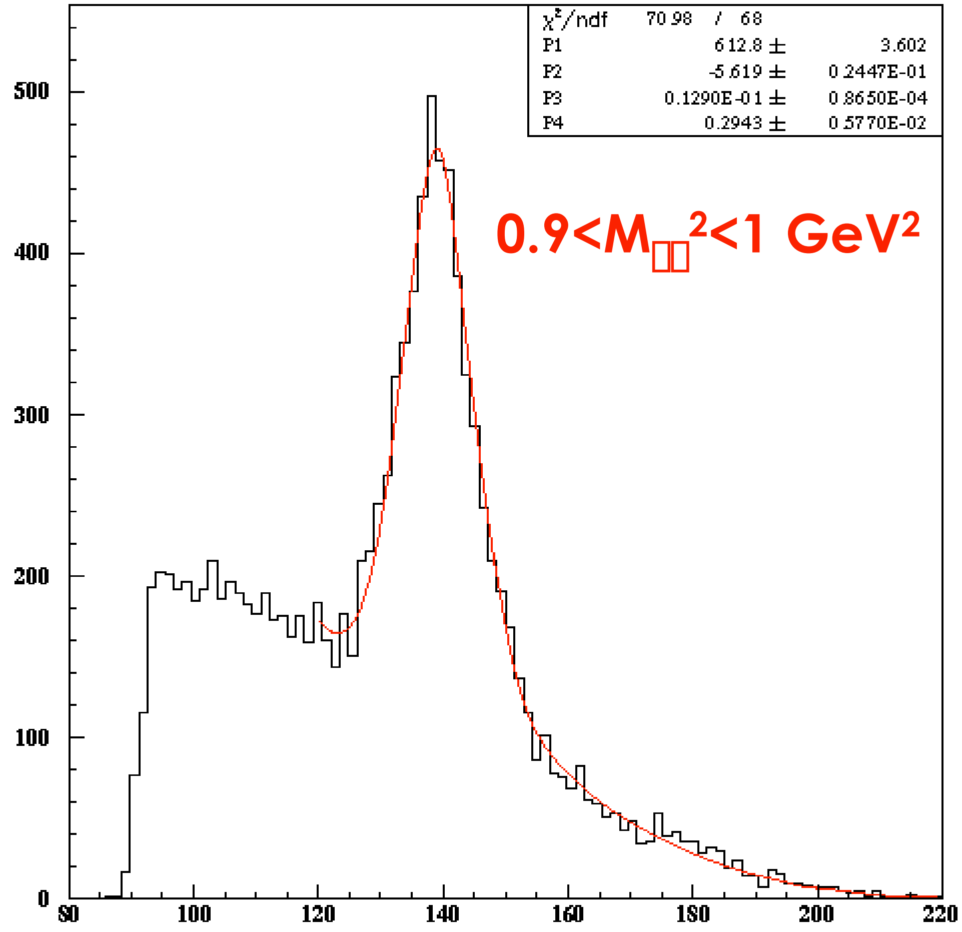
trackmass (MeV)

Residual background:

For each bin the sum of the two distributions has been fitted to DATA.

Background contamination found:

0.9-1 GeV^2	4.1%
0.8-0.9 GeV^2	3.5%
0.7-0.8 GeV^2	1.5%
0.6-0.7 GeV^2	0.3%



The precision of this evaluation is better than 10%.

Conclusions:

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

- 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!