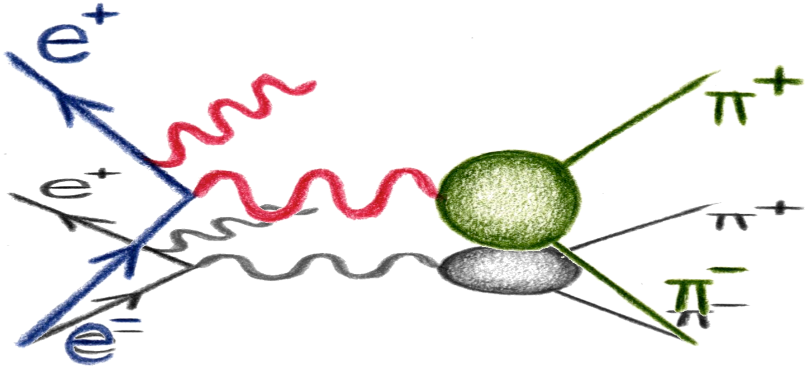
Measurement of $\sigma(e^+e^- \rightarrow \pi^+\pi^-\gamma(\gamma))$ and the dipion contribution to the muon anomaly with the KLOE detector

The KLOE Collaboration



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(for the $\pi\pi\gamma$ group)

Blessing Meeting, Frascati, 22.9.2008

Introduction

The basic idea of this analysis is to measure the (ISR) - radiative cross section $d\sigma_{\pi\pi\gamma(\gamma)}/dM_{\pi\pi}^2$:

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

Then extract $\sigma_{\pi\pi}$ from $d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ via theoretical radiator function $H(s, M_{\pi\pi}^2)$:

$$\sigma_{\pi\pi}\left(\mathrm{M}^2_{\pi\pi}\right) \approx s\,\frac{\mathrm{d}\sigma_{\pi\pi\gamma(\gamma)}\left(\mathrm{M}^2_{\pi\pi}\right)}{\mathrm{dM}^2_{\pi\pi}} \cdot \frac{1}{\mathrm{H}(\mathrm{s},\mathrm{M}^2_{\pi\pi})}$$

Inserting $\sigma_{\pi\pi}$ into a dispersion integral allows to evaluate the dipion contribution to the muon anomaly, $\Delta \mathbf{a}_\mu^{\pi\pi}$:

$$\Delta^{\pi\pi} a_\mu = \frac{1}{4\pi^3} \int_{4m_\pi^2}^{\infty} \sigma_{\pi\pi}(s) K(s) ds$$

Introduction

At PHIPSI08 in april, Federico presented the following value for $\Delta a_\mu^{\pi\pi}$:

$$\Delta a_\mu^{\pi\pi}(0.35\text{-}0.95\text{GeV2}) = (389.2 \pm 0.6_{stat} \pm 3.0_{sys} \pm 2.0_{th}) \cdot 10^{-10}$$

Since then, the following things have changed in the analysis:

- **Experimental corrections to the luminosity cross section have been rechecked, increase eff. VLAB cross section by 0.5%**
- **Background contribution from $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ events is subtracted from spectrum, and 50% of it is taken as uncertainty (before full contribution has been taken as uncertainty)**
- Error for FSR (model + experimental treatment) of 0.3% added to theory error
- Error for PID and TCL reduced to negligible
- Uncertainty from unfolding procedure does not enter anymore in the dispersion integral
- Increased Monte Carlo statistics for acceptance evaluation
- Use of covariance matrix in propagation of statistical error

$$\Delta a_\mu^{\pi\pi}(0.35\text{-}0.95\text{GeV}^2) = (387.6 \pm 0.5_{stat} \pm 2.5_{sys} \pm 2.3_{theo})\cdot 10^{-10}$$

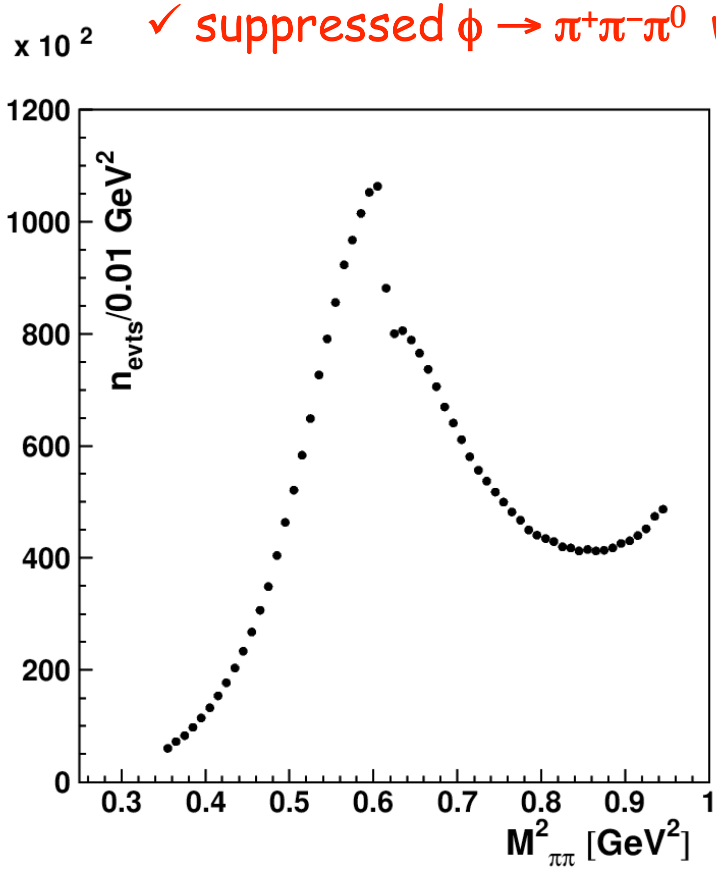
It is this number we want to be blessed (plus the analysis for $d\sigma_{\pi\pi\gamma(\gamma)}/dM^2$ and $\sigma_{\pi\pi}$ from which it is derived)

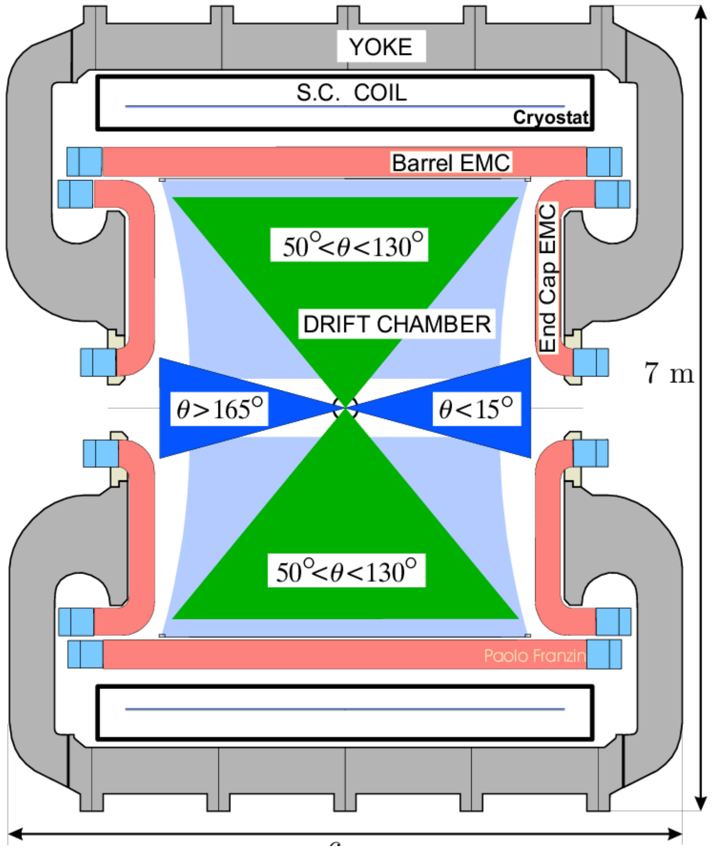
Event Selection

a) 2 tracks with $50^o < \theta_{track} < 130^o$
b) small angle γ ($\theta_{\pi\pi} < 15^o$ or $> 165^o$)

kinematics: $\vec{p}_\gamma = \vec{p}_{miss} = -(\vec{p}_+ + \vec{p}_-)$

✓ high statistics for ISR
✓ low relative FSR contribution
✓ suppressed $\phi \to \pi^+\pi^-\pi^0$ wrt the signal





statistics: $242pb^{-1}$

3.1 Mill. Events between 0.35 and 0.95 GeV^2

Event selection

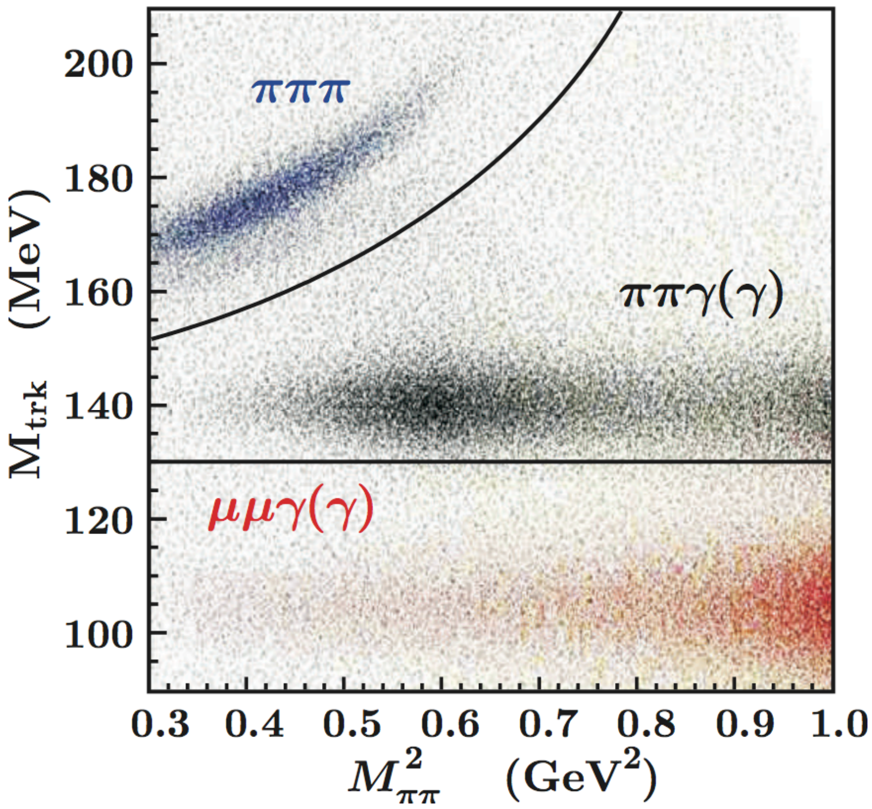
- Experimental challenge: Fight background from
  - $\phi \rightarrow \pi^+\pi^-\pi^0$
  - $e^+e^- \rightarrow e^+e^- \gamma$
  - $e^+e^- \rightarrow \mu^+\mu^- \gamma$,

  separated by means of kinematical cuts in *trackmass* M_{Trk}
  (defined by 4-momentum conservation under the hypothesis of 2 tracks with equal mass and a γ)

$$\left(\sqrt{s} - \sqrt{p_1^2 + M_{trk}^2} - \sqrt{p_2^2 + M_{trk}^2}\right)^2 - (p_1 + p_2)^2 = 0$$

and *Missing Mass* M_{miss}
(defined by 4-momentum conservation under the hypothesis of $e^+e^- \rightarrow \pi^+\pi^-$**x**

$$M_{\text{miss}} = \sqrt{E_X^2 - p_X^2}$$



To further clean the samples from radiative Bhabha events, a particle ID estimator for each charged track based on Calorimeter Information and Time-of-Flight is used.

Improvements

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

error table in the published work PLB606(2005)12

improved machine conditions (luminosity and background) in the new data set

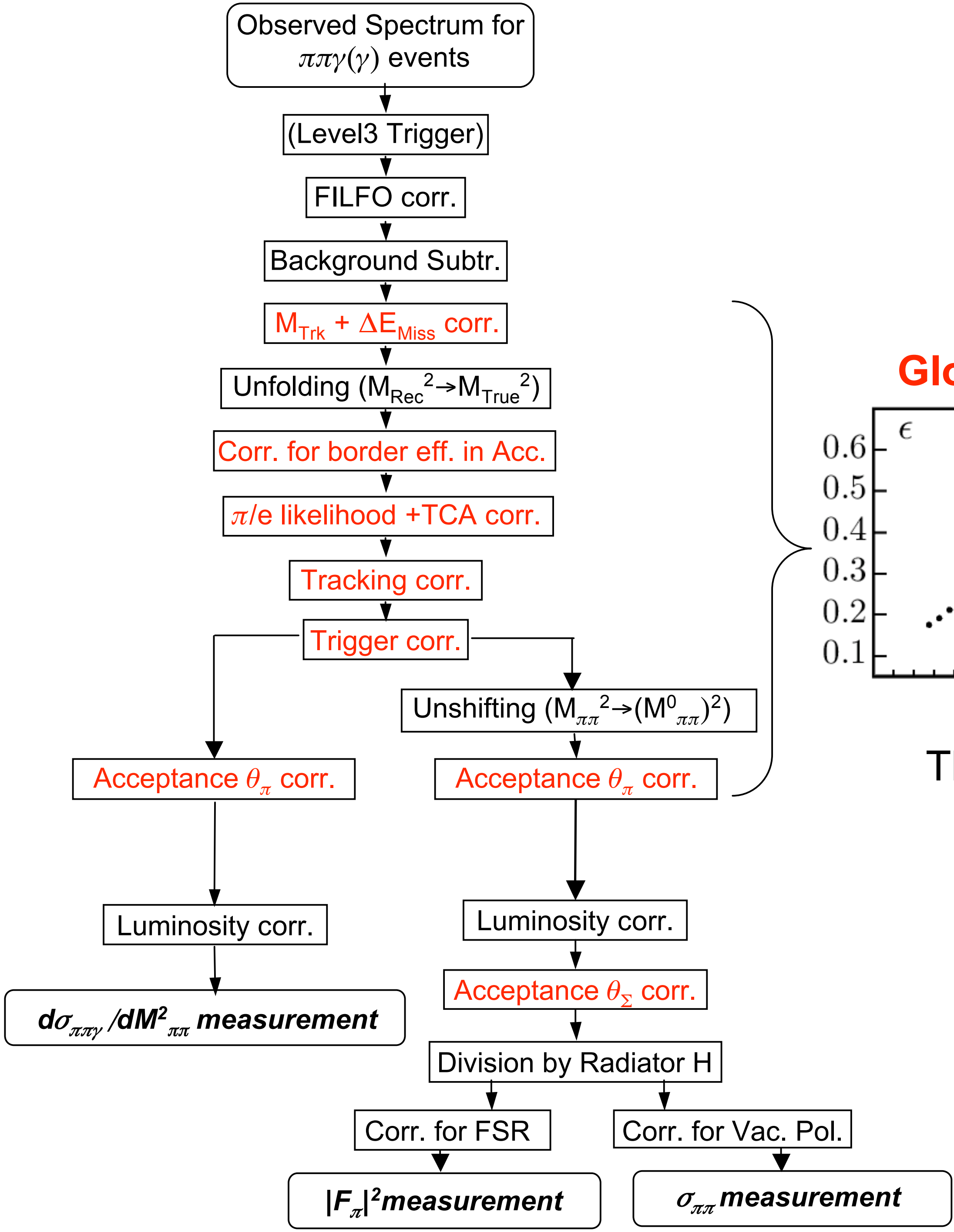
Reconstruction filter	0.6%
Background	0.3%
M_{trk} cuts	0.2%
Particle ID	0.1%
Tracking	0.3%
Vertex	0.3%
Trigger	0.3%
Acceptance	0.3%
Unfolding	0.2%
Luminosity $(0.5_{th} \oplus 0.3_{exp})\%$	0.6%

improved offline-event filter reduces systematic uncertainty to < 0.1%

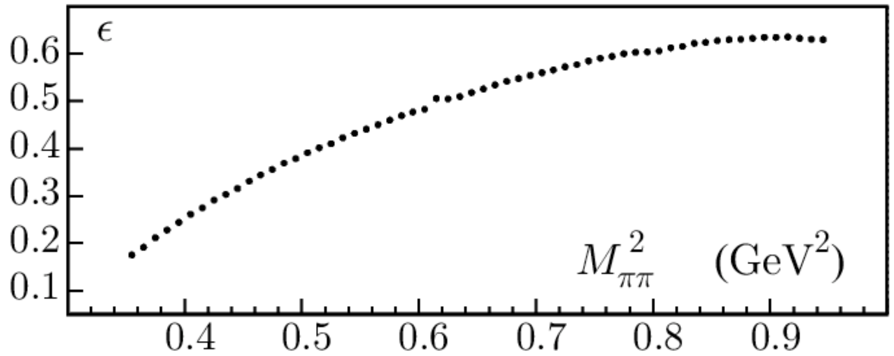
improvements (no vertex requirement) on the selection

30% inefficiency (veto of cosmic rays) recovered by introducing 3rd level trigger

new generator **BABAYAGA@NLO**, error on σ_{Bhabha} from 0.5% to 0.1%



Global Monte Carlo efficiency:

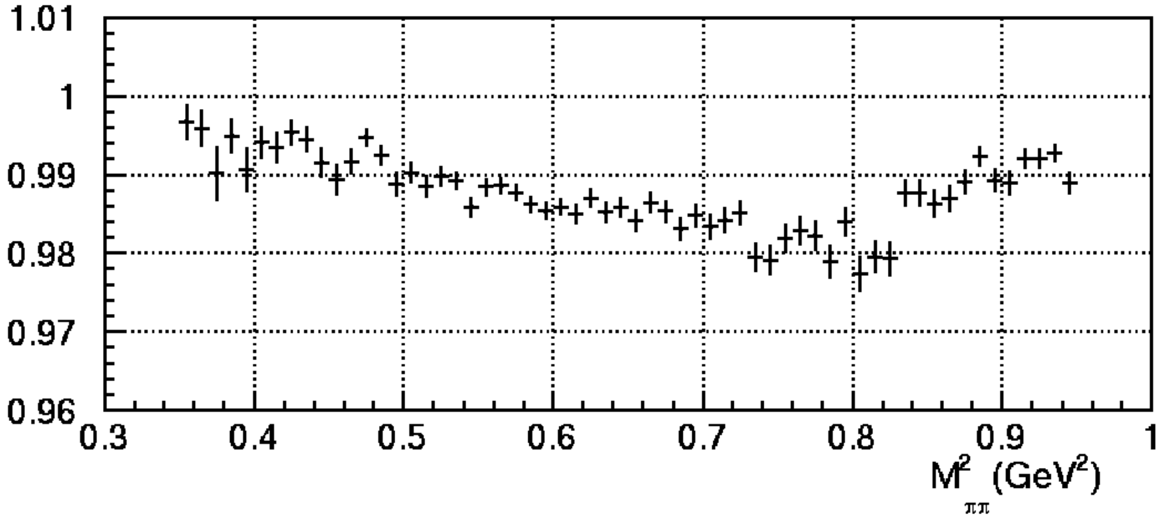


Then correct for $\varepsilon_{MC}/\varepsilon_{data}$

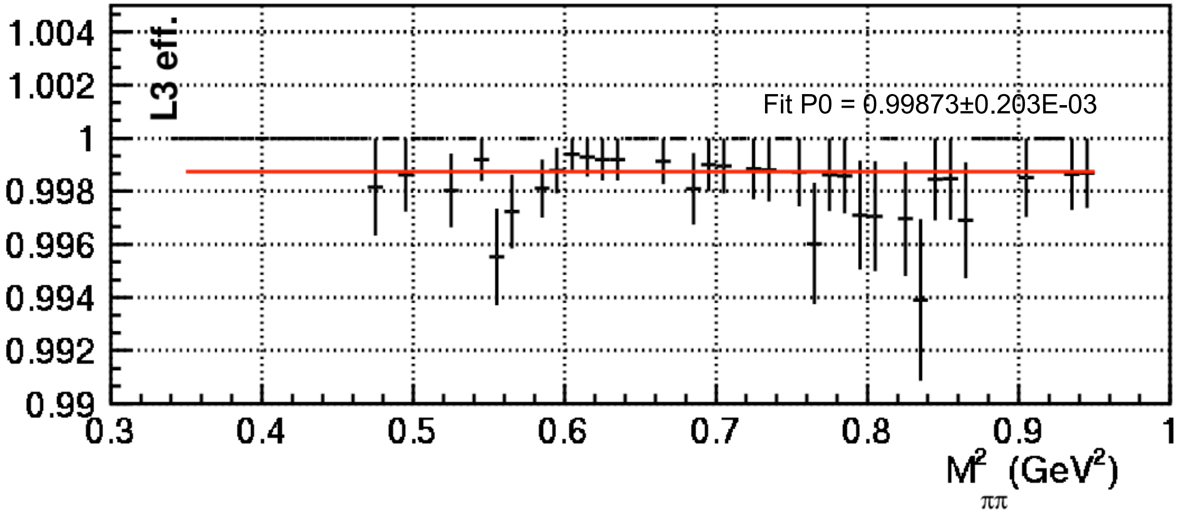
FILFO and L3:

Both effects estimated via downscaled control samples after all analysis cuts:

FILFO:



L3:



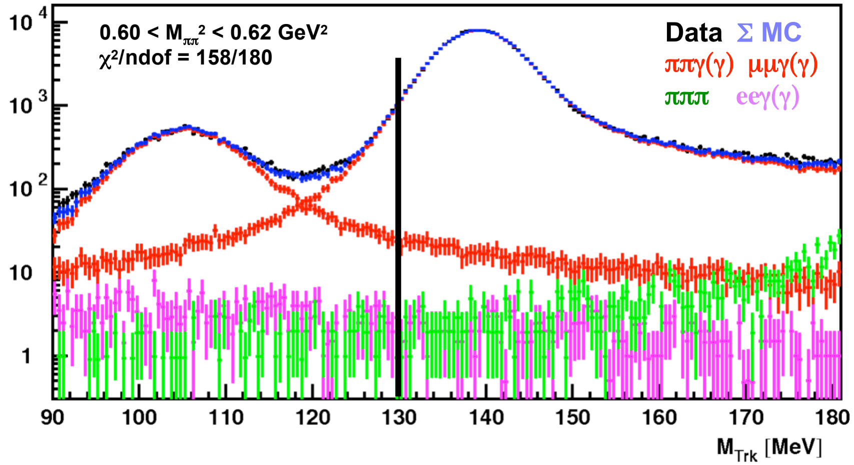
0.1% taken as uncertainty on the spectrum due to L3 trigger.

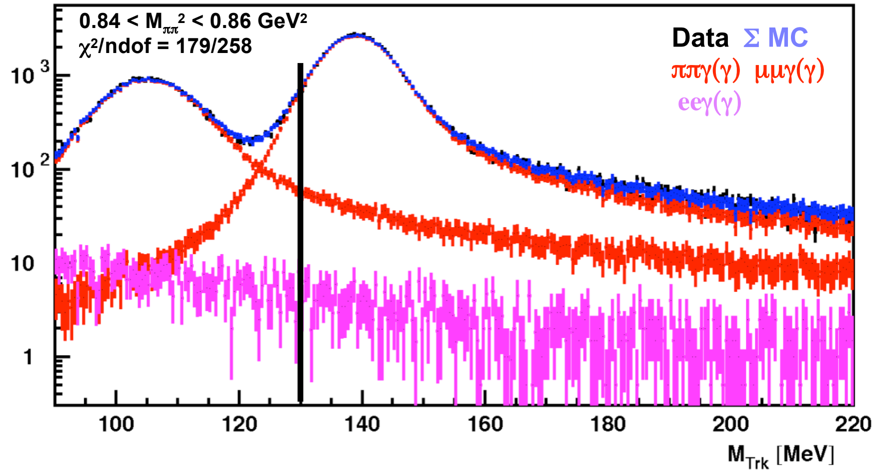
Background

Background is estimated by a fit of signal($\pi\pi\gamma$)+background($\mu\mu\gamma$,$\pi\pi\pi$,$ee\gamma$) MC distributions (in 32 slices of $M^2_{\pi\pi}$) to the data distribution in M_{Trk} with free normalization parameters

Monte Carlo distributions are corrected to obtain better agreement with the data (BV corrections are used as the standard corrections).

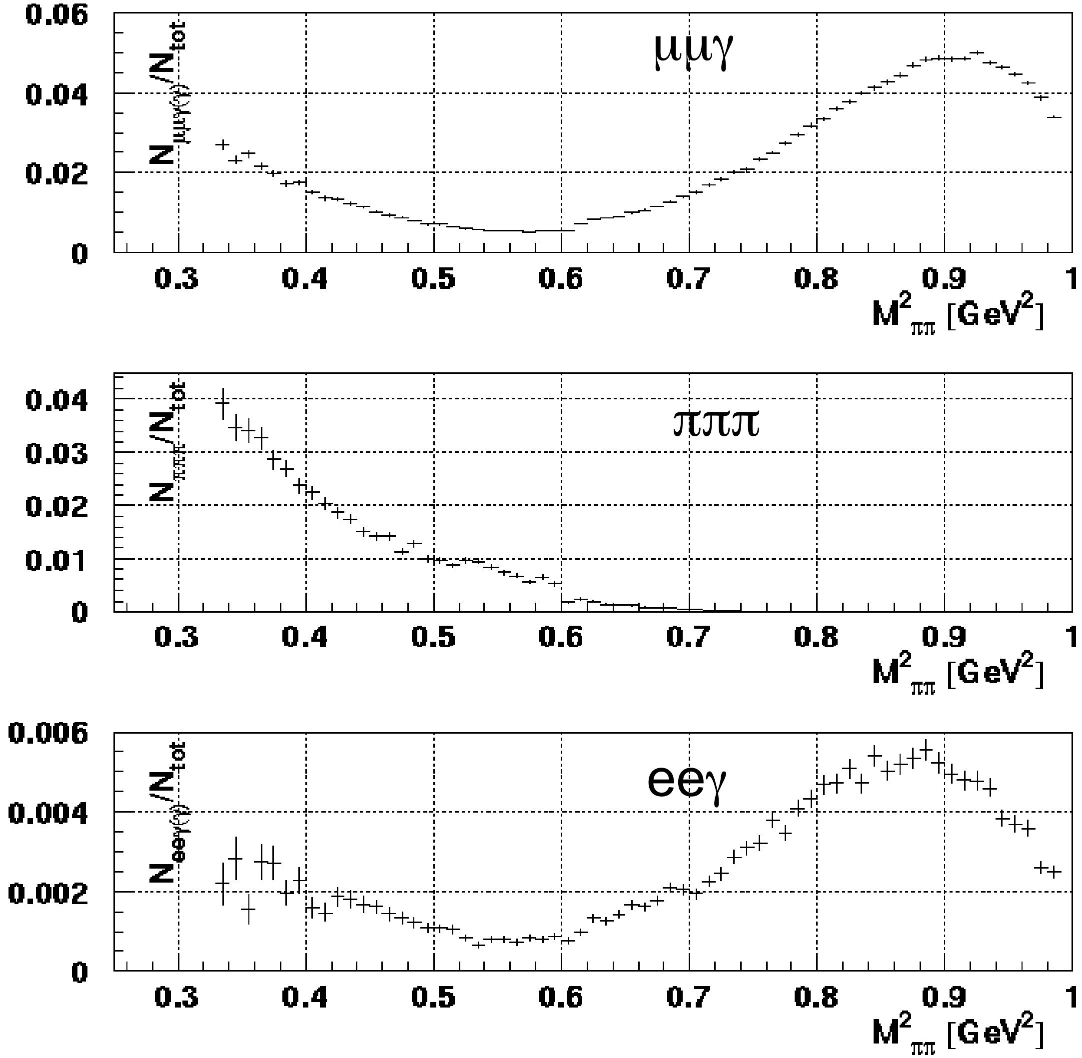
The fit is then performed using
- between 0.32 - 0.60 GeV^2: binwidth of 1.0 MeV in M_{Trk}, 4 MC sources, $ee\gamma$ norm. param. fixed to 1.0
- between 0.60 - 0.70 GeV^2: binwidth of 0.5 MeV in M_{Trk}, 4 MC sources, $ee\gamma$ and $\pi\pi\pi$ norm.. param. fixed to 1.0
- between 0.32 - 0.60 GeV^2: binwidth of 1.0 MeV in M_{Trk}, 3 MC sources, $ee\gamma$ norm. param. fixed to 1.0





Background

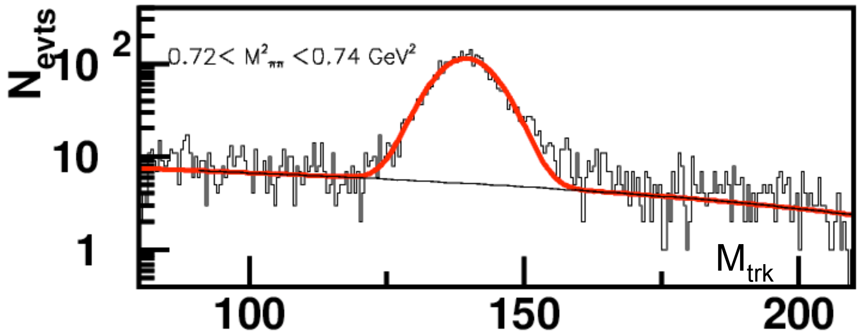
Background fraction as obtained from the background fit for the 3 channels $\mu\mu\gamma$, $\pi\pi\pi$ and $ee\gamma$:



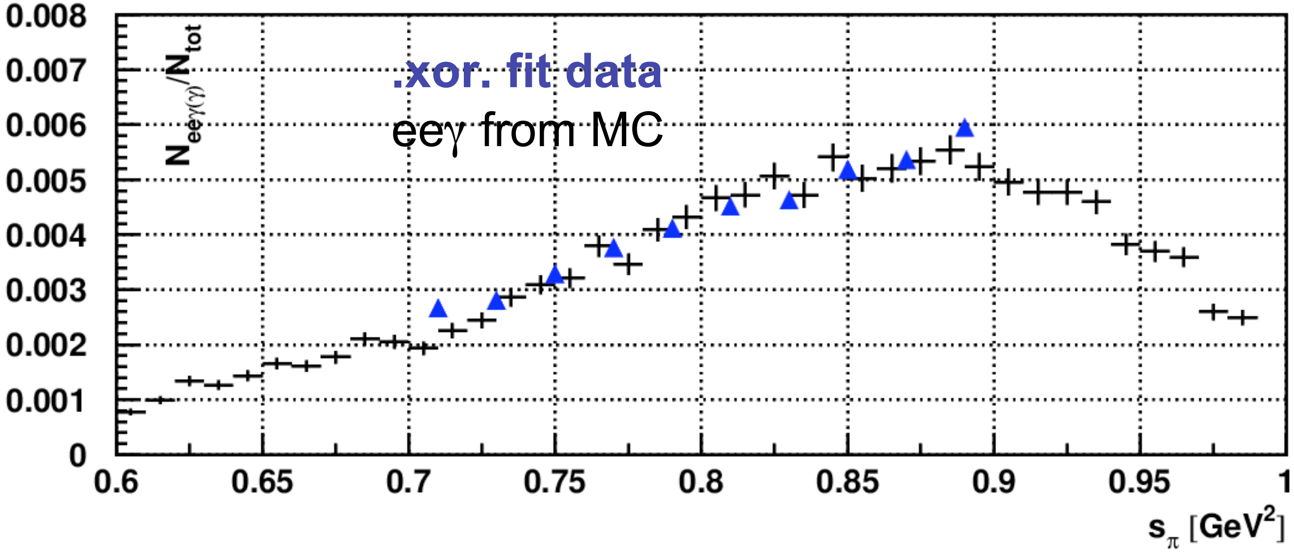
Background

Cross check on normalization of eeγ Monte Carlo sample:

Fit data M_{trk} distributions selected with .xor. of PID with a Gaussian ($\pi\pi\gamma$ signal) and a polynomial tail (eeγ background), and obtain fractional eeγ contribution from the ratio of the integrals.

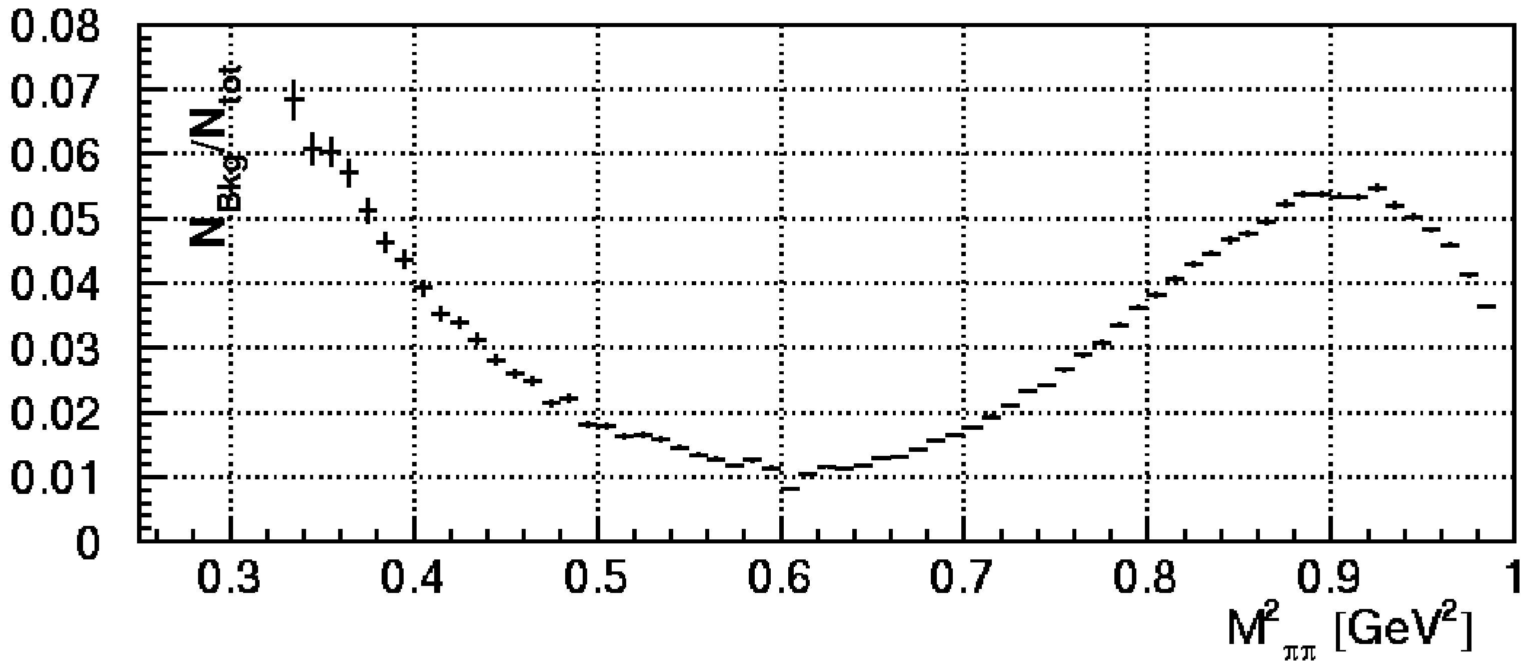


The result can then be confronted with the fractional contribution from Monte Carlo used in the fit:



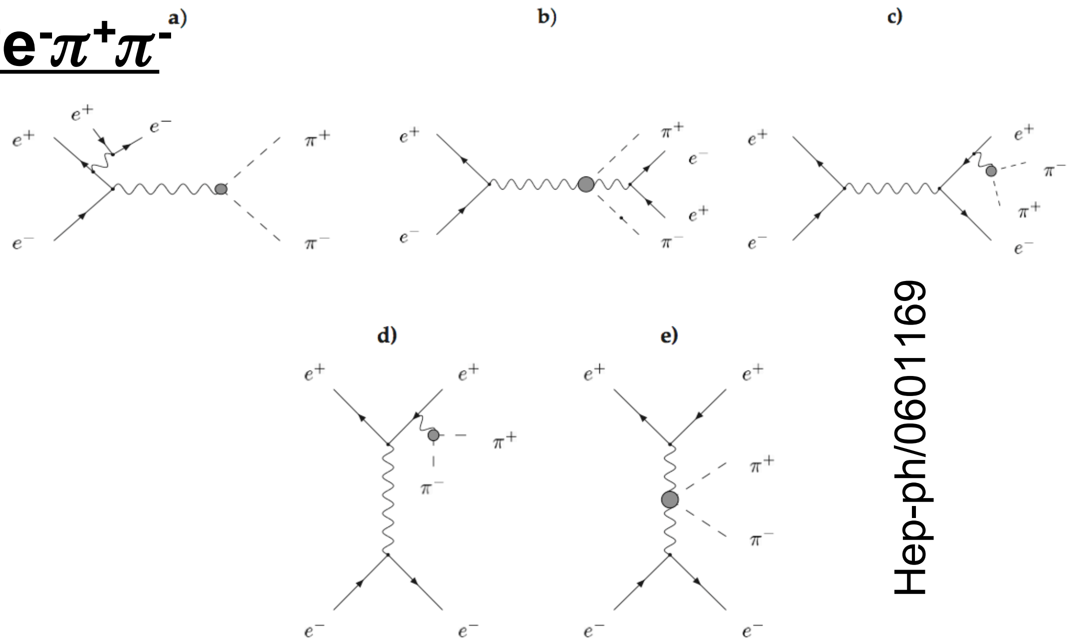
Background

Combined background fraction as obtained from the background fit for the 3 channels $\mu\mu\gamma$, $\pi\pi\pi$ and $ee\gamma$:



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

We estimate the contribution of $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ using the EKHARA generator (Czyz et al.), and using reconstructed tracks from $\phi \rightarrow \eta\gamma \rightarrow (ee\pi\pi)\gamma$ Monte Carlo to estimate the track reconstruction efficiency for electron and pion tracks.



Hep-ph/0601169

Now, events have to fulfill (at least) the following cuts to end up in our spectrum:

At least one good pair with

$0 < \rho_{PCA} < 8$ cm ; $0 < |z_{PCA}| < 7$ cm ; $\rho_{FH} < 8$ cm

From $\phi \rightarrow \eta\gamma \rightarrow (ee\pi\pi)\gamma$

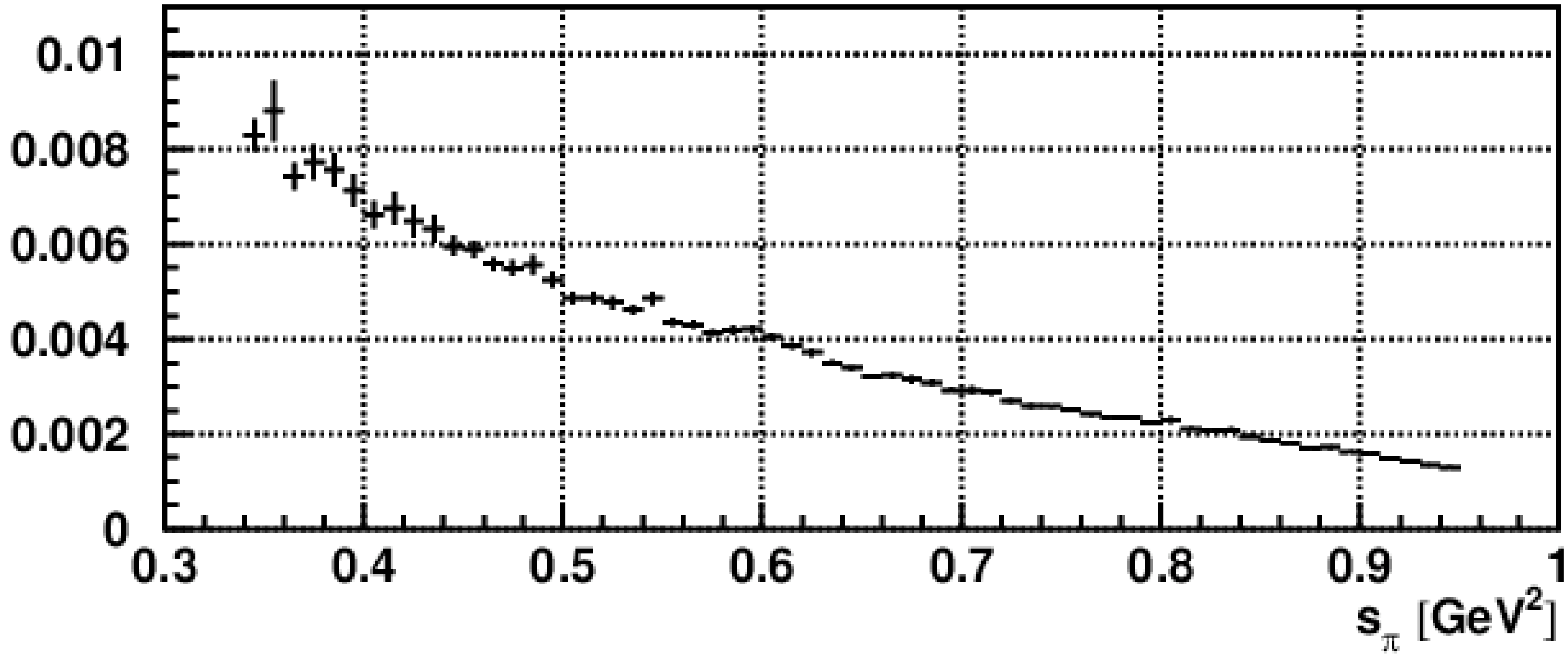
$50^0 < \theta_{Track} < 130^0$; $p_{T,Track} > 160$ MeV ; $|p_{Z,Track}| > 90$ MeV

150 MeV $< |p_1| + |p_2| <$ 1020 MeV
(-220) MeV $< \Delta E_{Miss} <$ 120 MeV
$\theta_\Sigma < 15^0$ or $\theta_\Sigma > 165^0$
130 MeV $<$ Trackmass $M_{Trk} <$ elliptical cut in M_{Trk} vs $M_{\pi\pi}$-plane
at least one of the tracks in the pair is a pion

From EKHARA

One obtaines track reconstruction efficiencies of $\varepsilon_{e+,e-} \approx 0.98$ and $\varepsilon_{\pi+,\pi-} \approx 0.94$

Upscaling then the effective EKHARA cross section (50pb) with 241.4pb^{-1} and comparing to the spectrum of signal events gives as relative contribution from $e^+e^- \rightarrow e^+e^-\pi^+\pi^-$ events:



We subtract the full contribution from our spectrum, and an error of 50% is taken as an uncertainty on our measurement.

Background

Additional background checks:

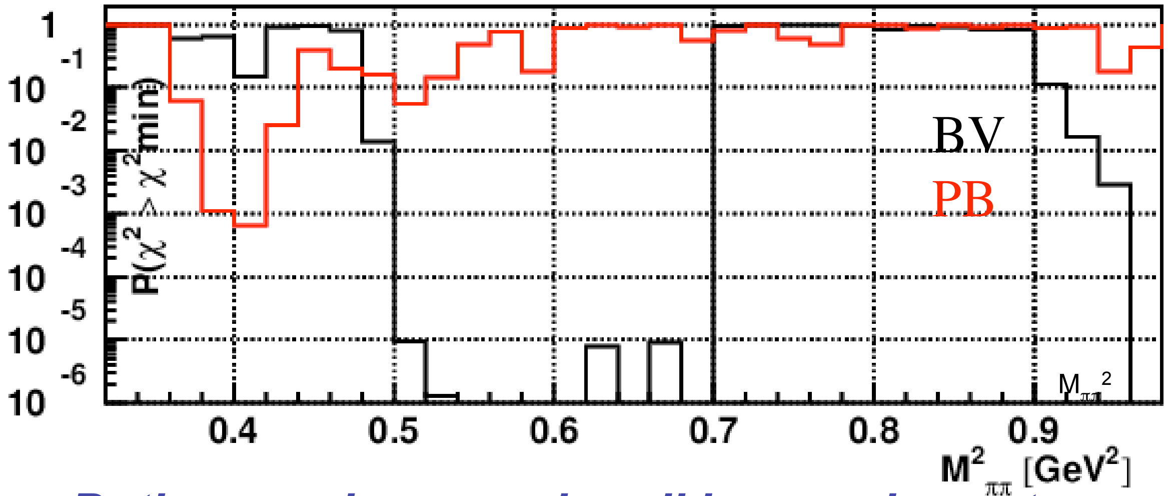
$e^+e^- \to e^+e^-\mu^+\mu^-$:	Checked with NEXTCALIBUR generator, contribution negligible
$\phi \to (f_0+\sigma)\gamma \to \pi\pi\gamma$: $\phi \to \pi\rho \to \pi(\pi\gamma)$:	Checked with PHOKHARA 6.1 generator, contribution negligible
$e^+e^- \to \omega\gamma_{ISR} \to \pi\pi\pi\gamma$:	Checked with PHOKHARA 3 generator interfaced with GEANFI, cut by ΔM_{miss}>120 MeV, contribution negligible

We have found no additional contributions to our spectrum other than the ones discussed on the previous slides.

Effect of different „Tuning“ of MonteCarlo

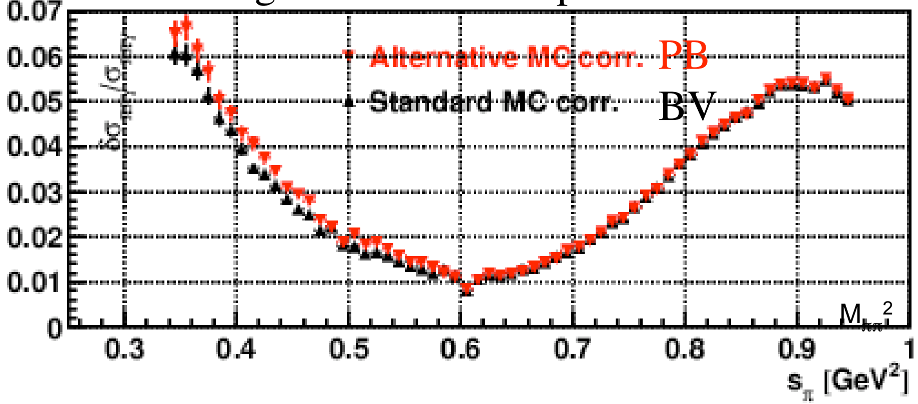
MonteCarlo momenta and θ–angles of tracks get tuned to match data distributions (M_{Trk}). We use a prescription developed by B. Valeriani (+C. Bini). Paolo Beltrame has developed a different procedure, which can be used to estimate the uncertainty the „Tuning“ gives to the background fit.

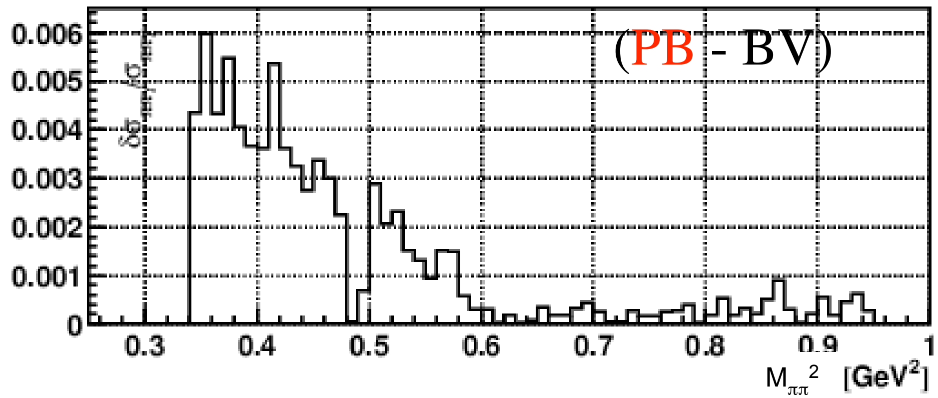
Prob($\chi^2 > \chi^2_{min}$) from background fit:



Both procedures work well in complementary regions $M_{\pi\pi}^2$.

Rel. background contr. to spectrum



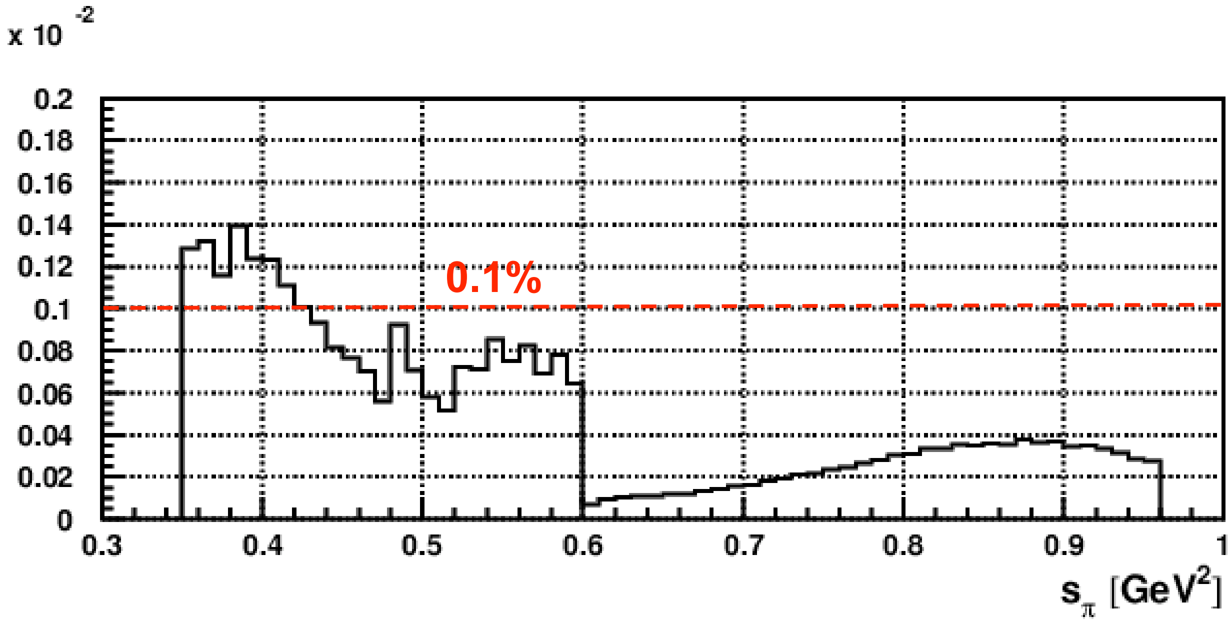


Few per mill difference below 0.6 GeV^2.

Background

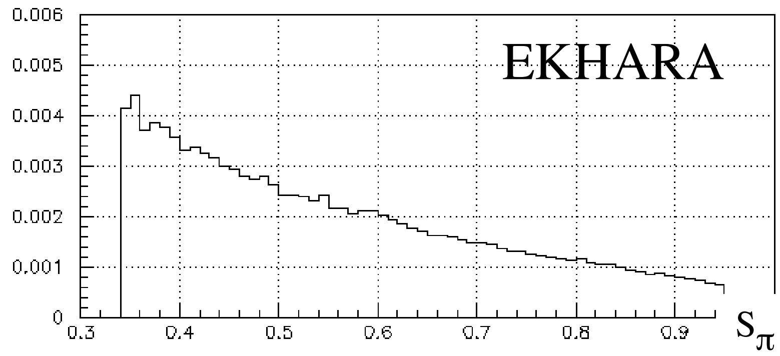
Uncertainty due to the errors on the normalization parameters obtained in the fit procedure:

- error on parameter gets scaled by factor $\sqrt{\frac{\chi^2_{min}}{ndf}}$ if Prob($\chi^2 > \chi^2_{min}$) is smaller than 5%.
- errors then get propagated on $\sigma_{\pi\pi\gamma}$ taking into account the correlation between the normalization factors for $\mu\mu\gamma$ and $\pi\pi\pi$ events:

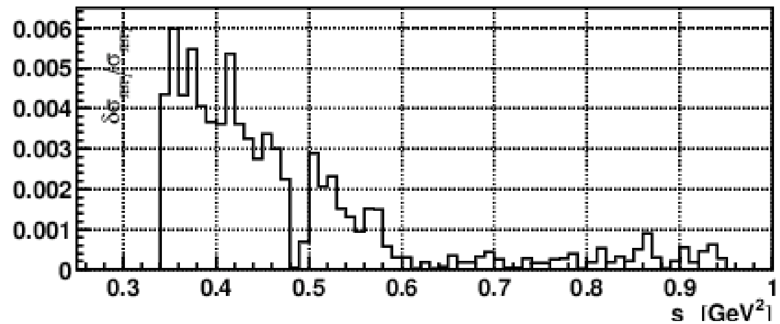


Background

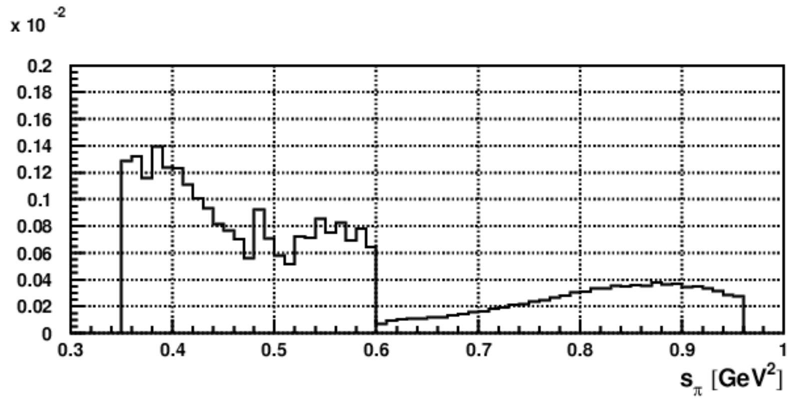
Systematic error on background evaluation:



• ee → ee ππ (EKHARA)



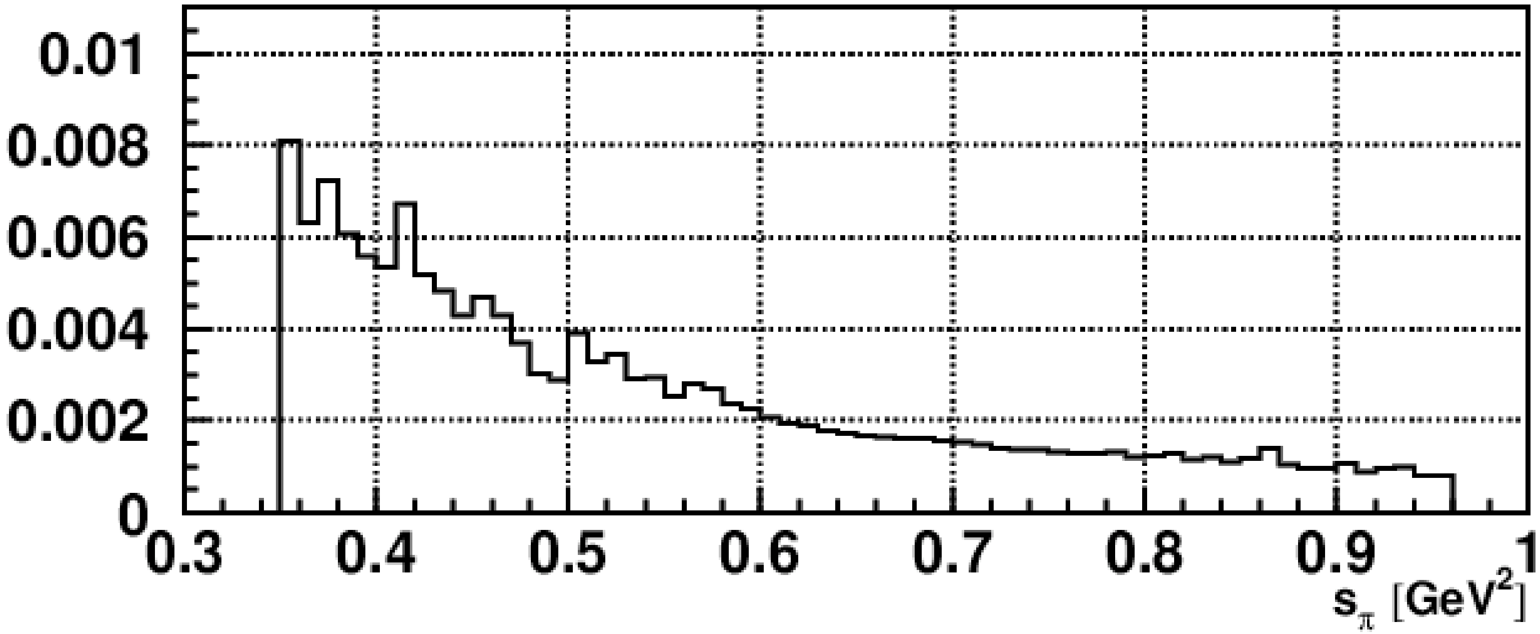
• Diff. for BV- and PB Tuning



• error from normalization parameters obtained from fit

Background

Adding the different contributions quadratically, one obtains the rel. systematic uncertainty from background on the measurement:

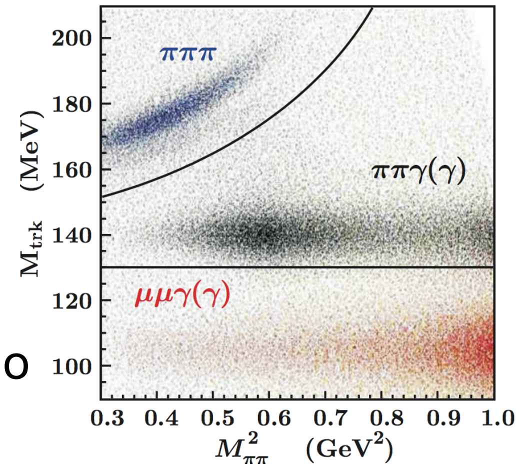


M_{Trk} efficiency

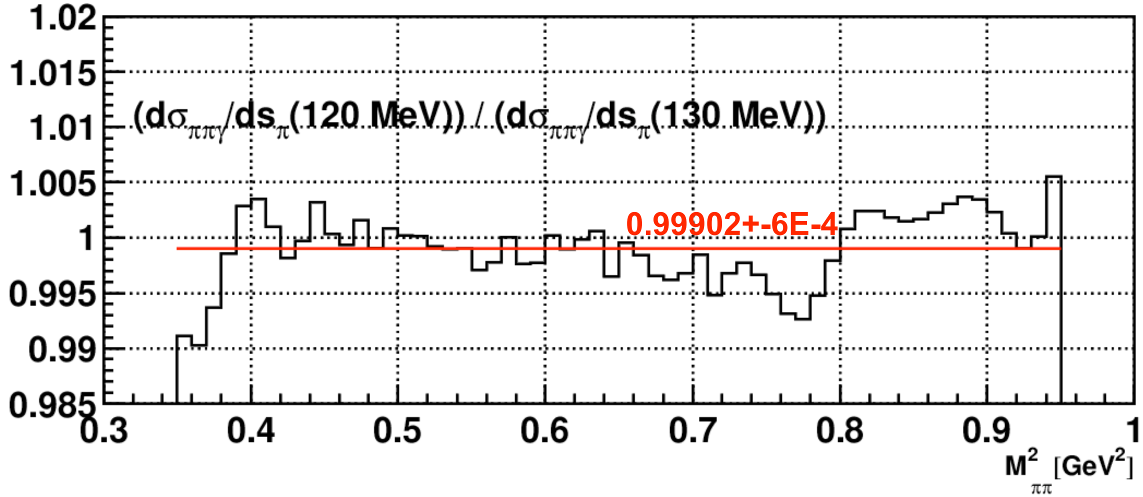
The efficiency for M_{Trk} is taken directly from Monte Carlo as a function of $(M^2_{\pi\pi})^{rec}$, after applying the same momenta corrections which were used in the background fit.

It is a part of the *Global Monte Carlo efficiency.*

Given the very good agreement between data and Monte Carlo distributions in M_{trk} as found in the background fit, we do not apply a correction of $\varepsilon_{MC}/\varepsilon_{data}$.



To estimate the uncertainty, the cut on M_{Trk}=130 MeV has been changed to 120 MeV. A 0.1% effect is observed.



As a similar effect is expected from the variation of the $M^2_{\pi\pi}$-dependent cut, we take a value of 0.2% as the uncertainty due to the estimation of the M_{Trk}-efficiency .

Unfolding

a) By Matrix-Multiplication

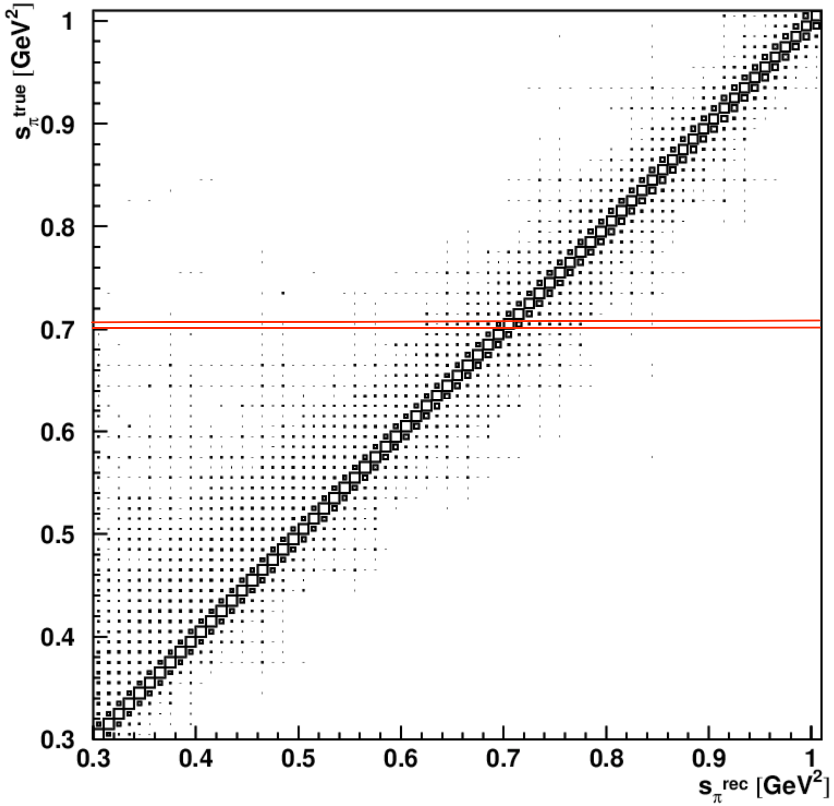
Create Probability-Matrix P_{ij} from MonteCarlo population matrix in (M^2_{rec}, M^2_{true})

$$\boxed{N_{i,}\text{true} = \sum_j P(N_i,\text{true} \mid N_j,\text{rec}) \cdot N_j, \text{rec}}$$

b) Using Bayes Theorem

- method based on Bayes' theorem
  - no matrix inversion needed
  - can be applied to multidimensional problems
  - iterative algorithm; can start with a uniform distribution
- Bayes formula: $P(C_i|E_j) = \frac{P(E_j|C_i)P(C_i)}{\sum_{l=1}^{n_C} P(E_j|C_l)P(C_l)}$ "true", normalized distribution
  - "if we observe a single event "(effect E_j)", the probability that it has been due to the i-th cause "(C_i)," is proportional to the probability of the cause times probability of the cause to produce the effect"

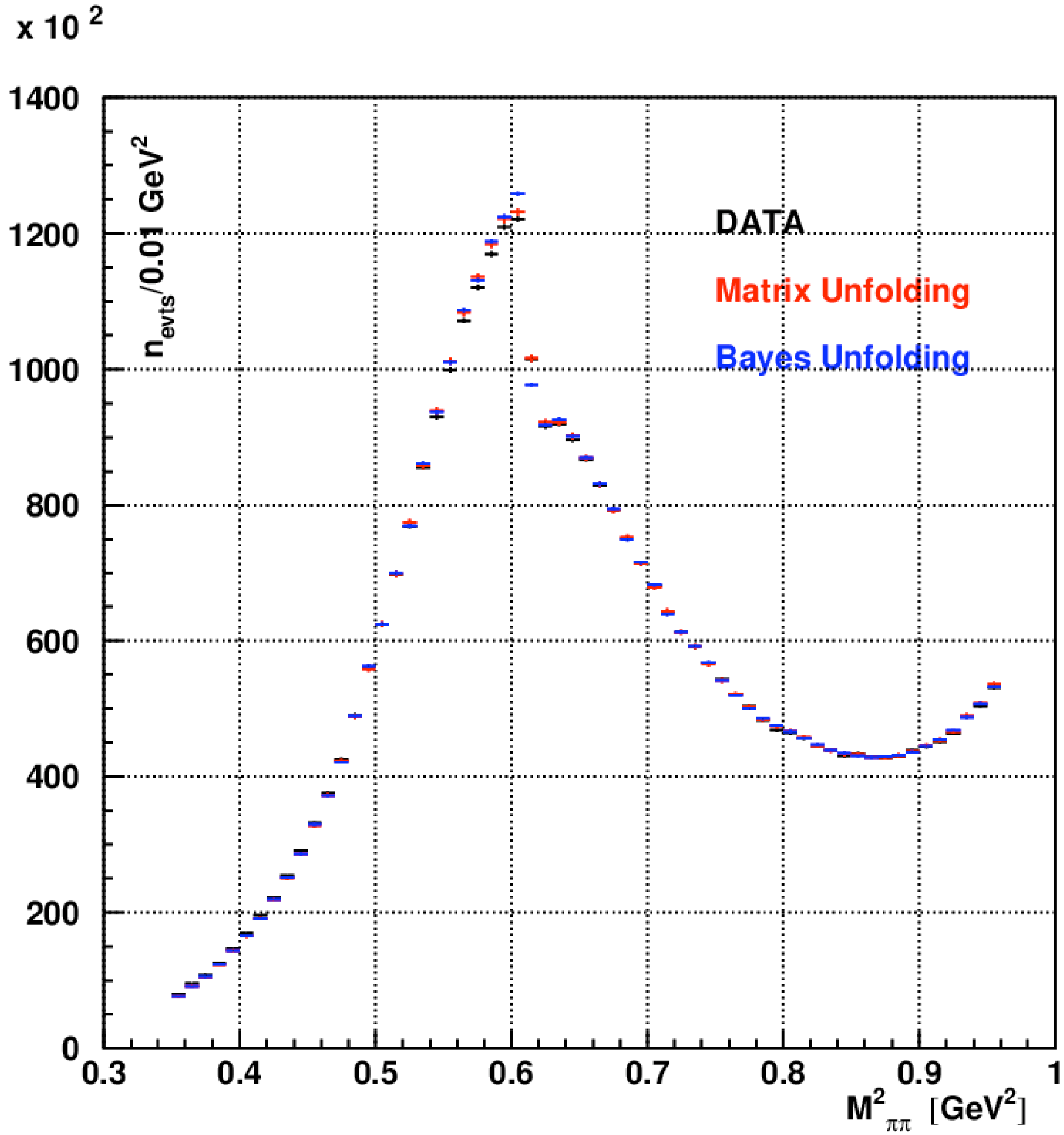
D'Agostini



Needs $P(C_i)$, $P(E_j|C_i)$ from MonteCarlo. $P(C_i)$ needs not be too precise, gets iterated (I use $P(C_i)=N_i/N_{tot}$). $P(E_j|C_i)$ is obtained from the Matrix above.

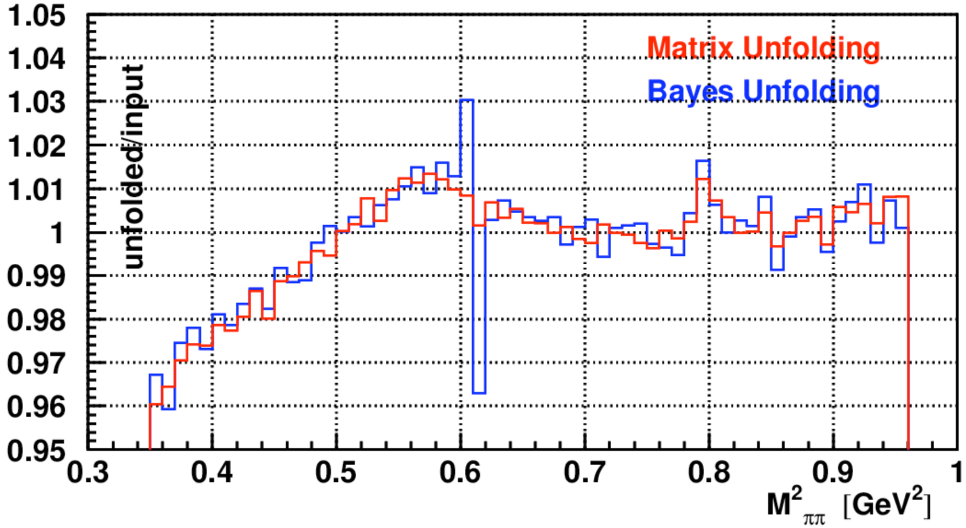
Unfolding

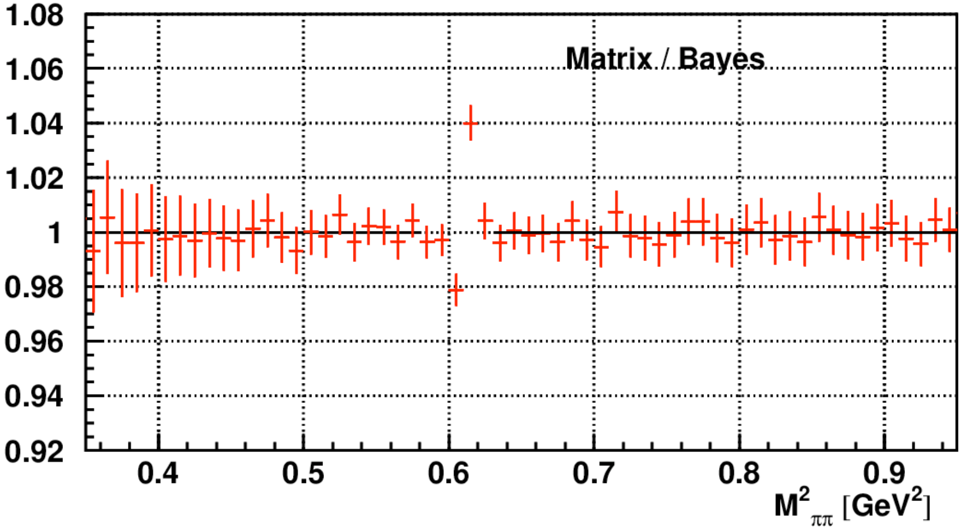
Applying both methods to the data spectrum yields very similar results.



Unfolding

Confronting the Matrix- with the Bayesian unfolding gives significant difference only around $\rho-\omega$ region:





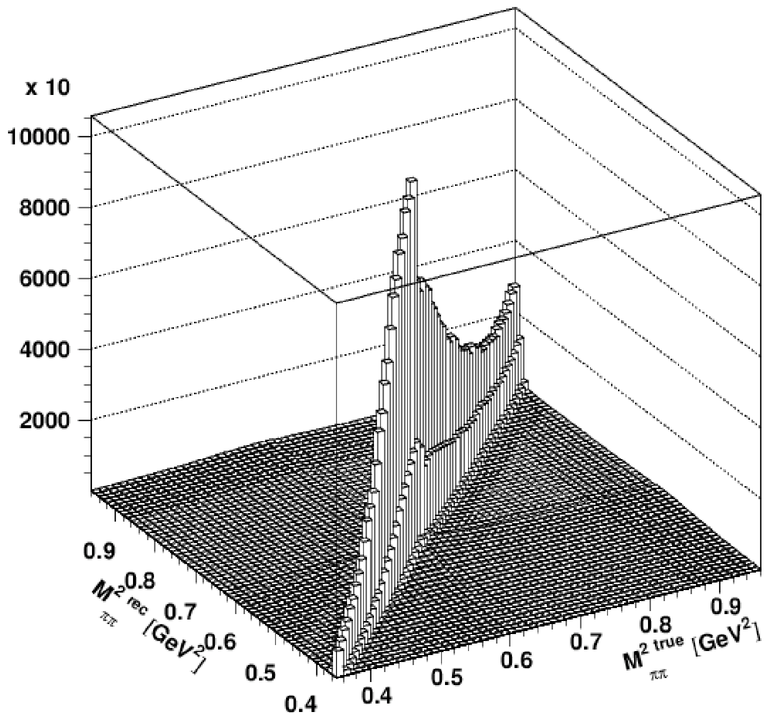
Unfolding

We use the Bayesian unfolding in the analysis, and use the absolute difference with the Matrix method as systematic uncertainty on the spectrum between 0.58 -0.62 GeV^2

$M^2_{\pi\pi}$ (GeV^2)	0.58	0.59	0.6	0.61	0.62
$\delta_{unf}(\%)$	0.4	0.3	2.1	4.0	0.4

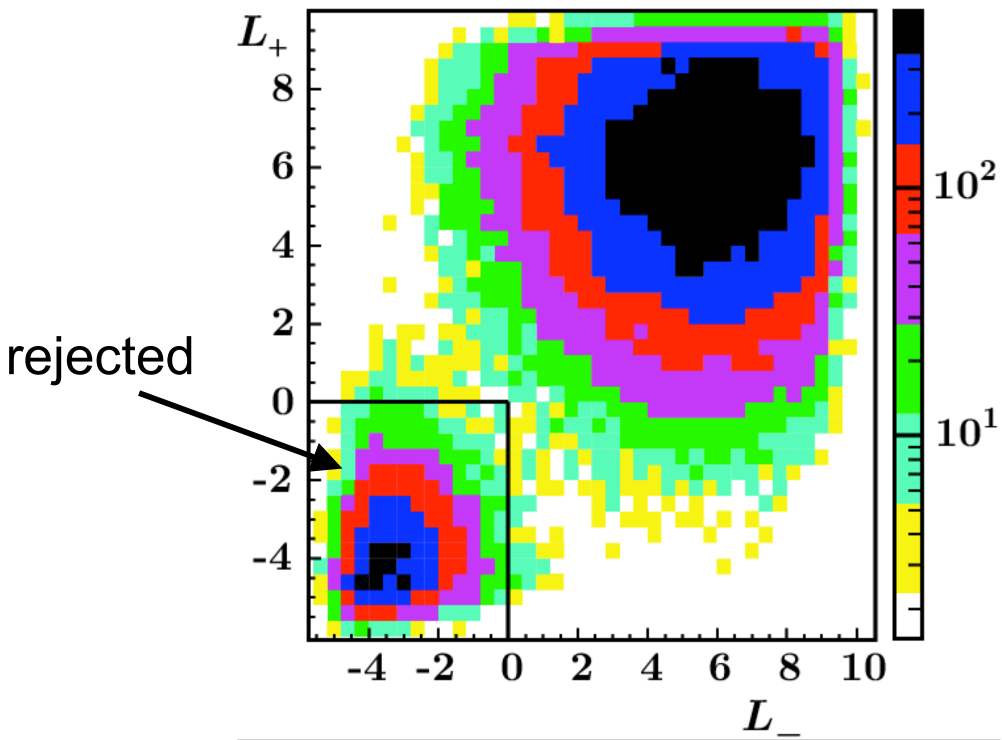
However, since the unfolding conserves the total number of events, and just migrates events between adjacent bins, it does not give a systematic effect on the dispersion integral for $\Delta^{\pi\pi}a_\mu$!

The covariance matrix from the unfolding has to be considered in the determination of the statistical error of $\Delta^{\pi\pi}a_\mu$



π/e ID and TCA

π/e separation is done using a PID estimator* using calorimeter information and TOF. At least one track has to be identified as a pion, i.e. at least one track needs to have an associated cluster with L=log (L_e/L_π) > 0. This *.or.* selection gives very high efficiency on the $\pi\pi\gamma$ signal (100%) for the PID, while rejecting a large fraction of the Bhabha events.



*PID procedure used for e/π discrimination, B. Valeriani KLOE Memo 295, developed for the 2001 $\pi\pi\gamma$ analysis, re-modelled with 2002 data)

π/e ID and TCA

Efficiency to find the pion cluster (1)

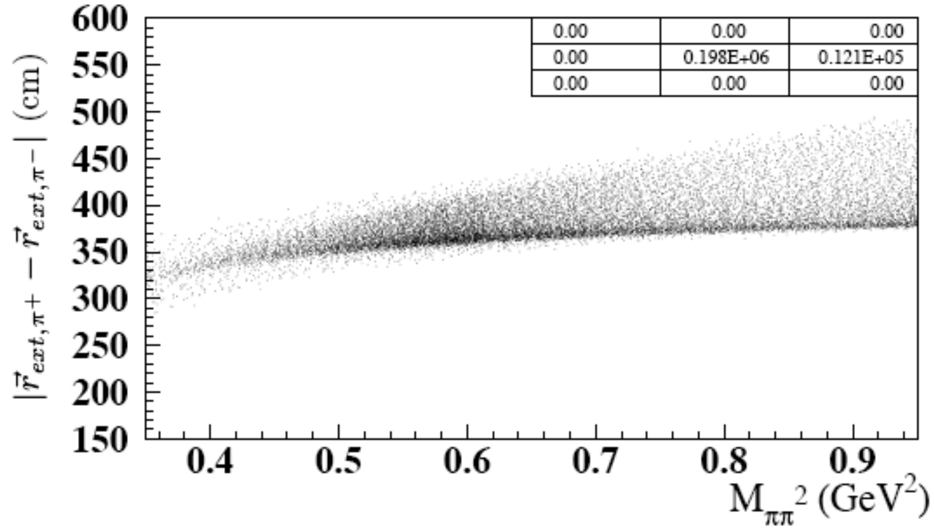
normalization sample

- usual tracks, acceptance and m_{trk} selection
- each track extrapolated to the ECAL with NEWEXTRATOM
- small angle requirement, $\theta_{\pi\pi} < 15^o$

a tagging track with 2 ECAL trigger sectors fired (i.e. the other track needs not to have a cluster) and $\log L_\pi/L_e > 0$

look for a cluster with $\log L_\pi/L_e > 0$ ($\underline{\text{DEF}}$ efficient) within a sphere of 90 cm radius as a function of track momentum and polar angle

Efficiency to find the pion cluster (2)



the choice of 90 cm (driven by trigger studies) does not introduce overlap between the pions: the distance between the extrapolated points to the ECAL is larger than 3 m for the region of interest

efficiency is evaluated for single track and then mapped into $M_{\pi\pi}^2$ using MC

for a given $M_{\pi\pi}^2$ bin:

$$\varepsilon_{TCL}(M_{\pi\pi}^2) = \frac{1}{N}\sum_{k=1}^{n} \nu_k\, \varepsilon_k$$

n = # of different $(\theta_+, p_+, \theta_-, p_-)$ configurations
ν = frequency for the k-th configuration
N = sum of all configurations for that bin

$$\varepsilon_k = 1 - \left[1 - \varepsilon^{data}_{\pi^+\pi^-\gamma}(\theta_{\pi^+}, p_{\pi^+})\right]\left[1 - \varepsilon^{data}_{\pi^+\pi^-\gamma}(\theta_{\pi^-}, p_{\pi^-})\right] \quad \rightarrow \quad \varepsilon^{data}_{\pi^+\pi^-\gamma}(M^2_{\pi\pi})$$

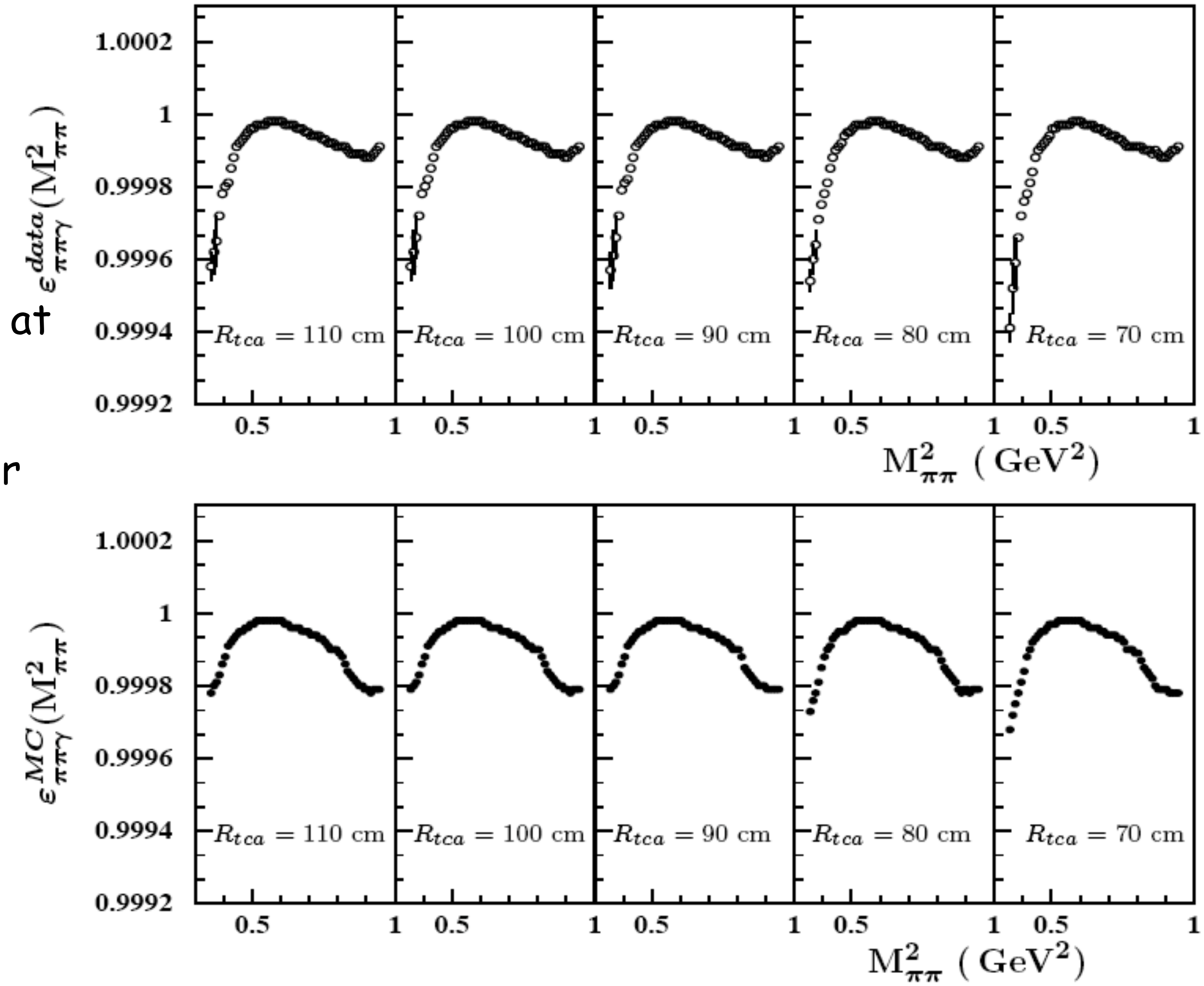
$$\varepsilon_k = 1 - \left[1 - \varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^+}, p_{\pi^+})\right]\left[1 - \varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^-}, p_{\pi^-})\right] \quad \rightarrow \quad \varepsilon^{MC}_{\pi^+\pi^-\gamma}(M^2_{\pi\pi})$$

Efficiency to find the pion cluster (3)

$$C_{data/MC} = \frac{\varepsilon^{data}}{\varepsilon^{MC}}$$

data/MC correction at R=90 cm is ~ 1

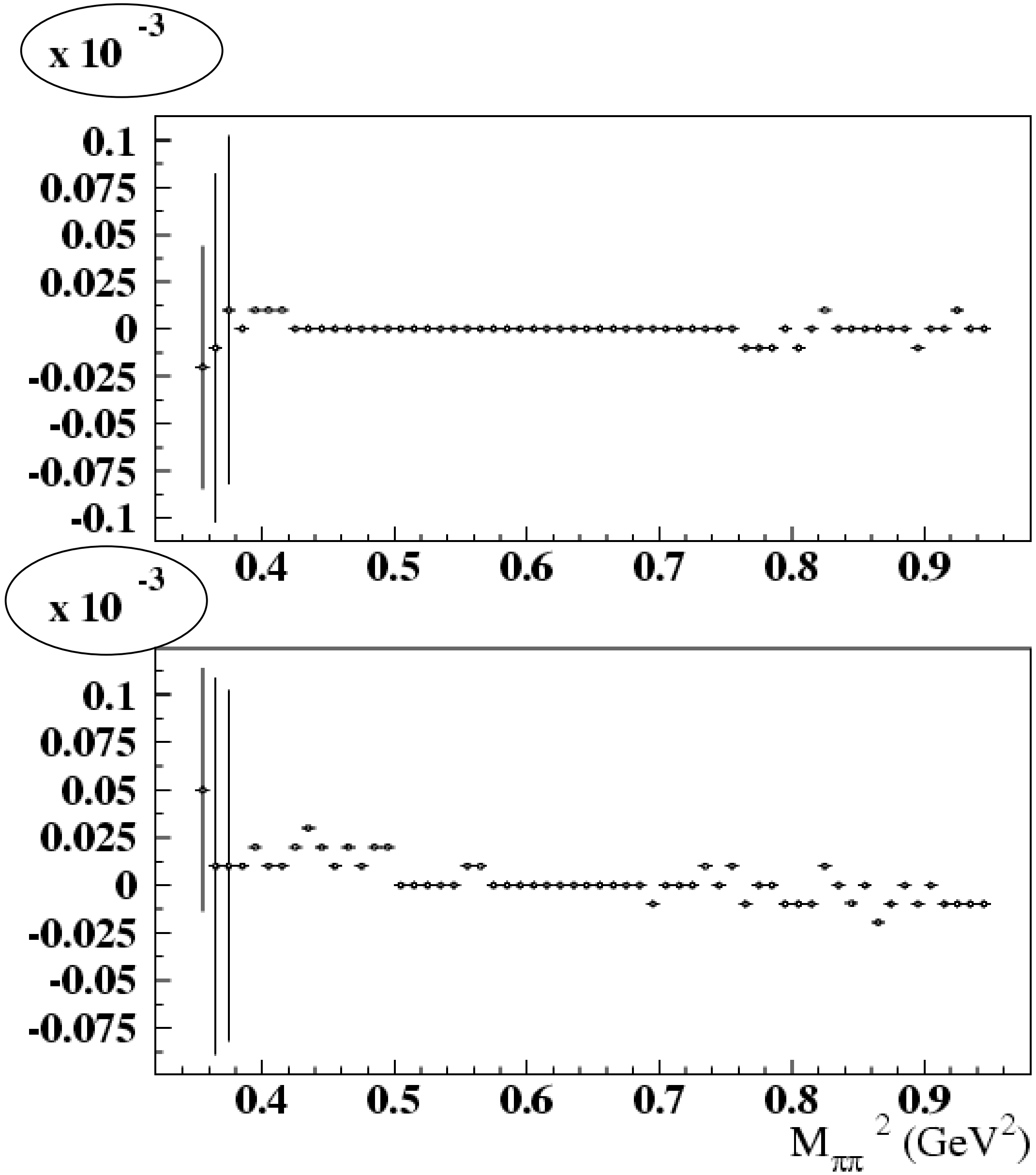
the systematic error is given varying the association radius, the effect on the correction data/MC is negligible



Efficiency to find the pion cluster (4)

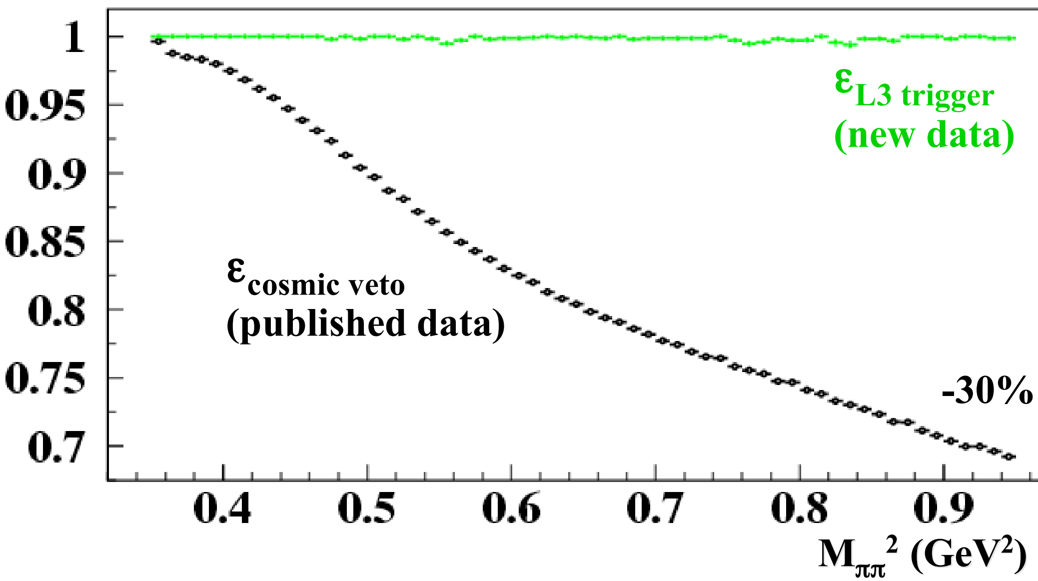
$$\frac{C_{data/MC}(90cm) - C_{data/MC}(70cm)}{C_{data/MC}(90cm)}$$

$$\frac{C_{data/MC}(90cm) - C_{data/MC}(110cm)}{C_{data/MC}(90cm)}$$



Negligible uncertainty

Trigger improvements

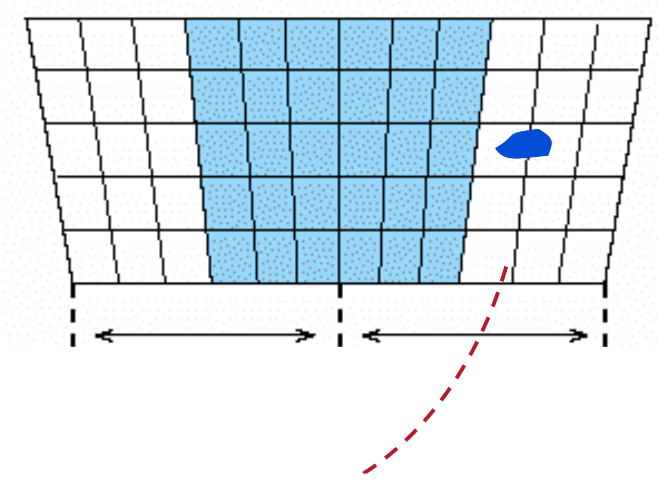


the main source (hardware veto of cosmic rays) of inefficiency in the 2005 published result has been removed

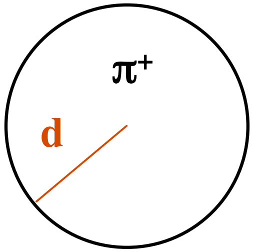
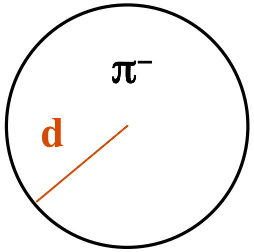
Also new: Make sure that event is triggered by the (pion) tracks (to exclude “Rest-of-the-event”-trigger)

Trigger corrections:

self-trigger pions

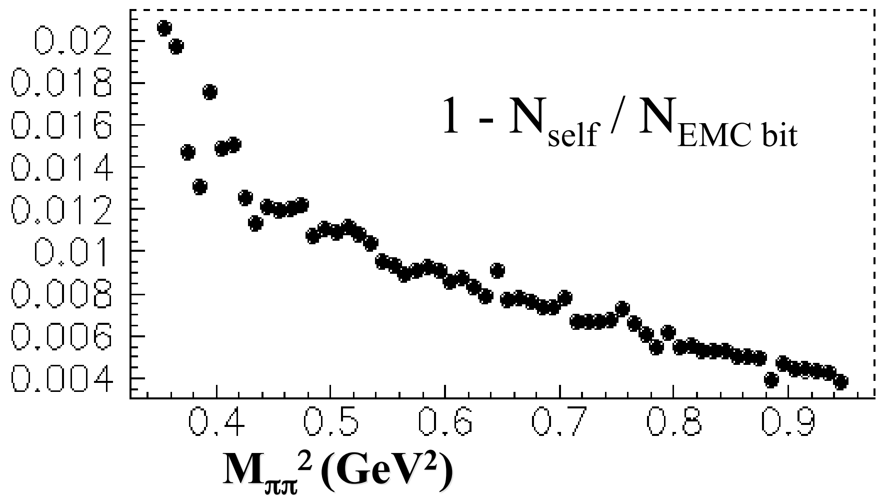


- each track extrapolated to the EMC à la T. Spadaro
- classify all clusters such that they belong to spheres:

either  or 

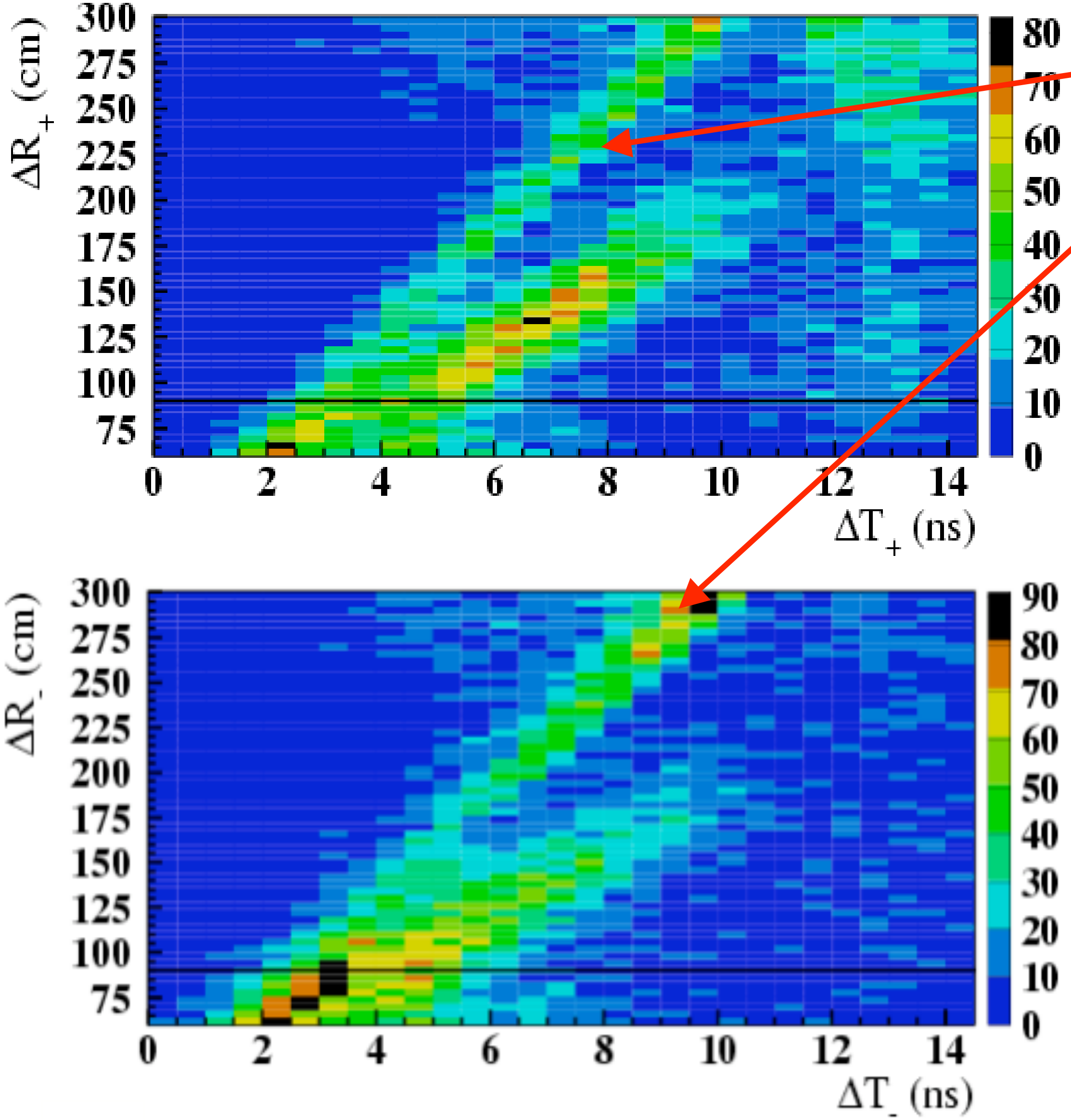
d = distance btw cluster centroid and the extrap'd point of the track

- each category may have associated 0, 1, 2 trigger sectors
- events selected if at least 2 sectors associated to pions



less efficient than in the past, but much reduced systematics (was 0.3% → 0.1%)

Trigger systematics: choice of R (MC)



well known slope: 30 cm/ns
photons originated by pions

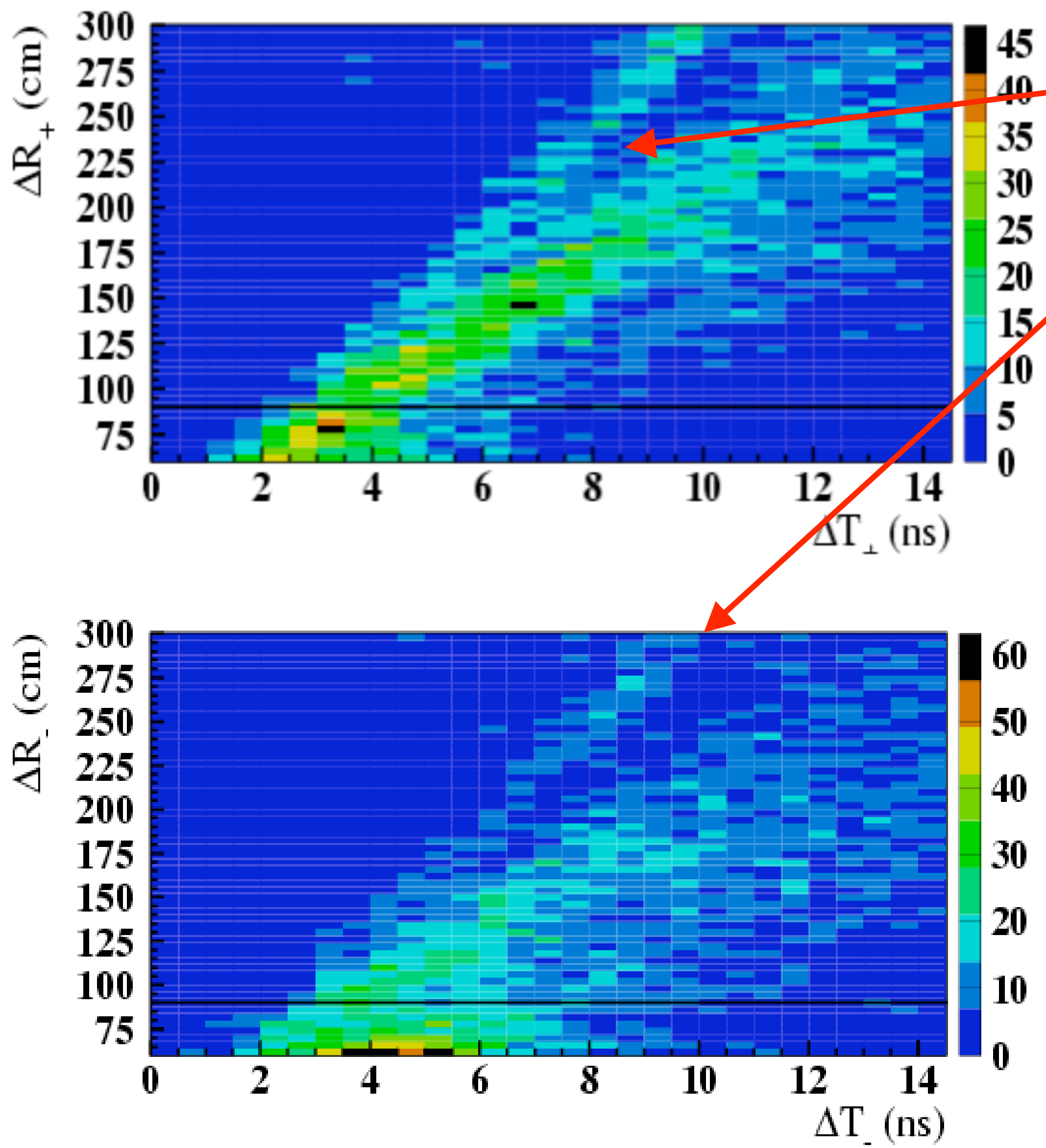
$$\Delta R = |\vec{x}_{clu} - \vec{x}_{ext}|$$

$$\Delta T = t_{clu} - t_{\max}$$

$t_{\max}$ = time of most energetic cluster within 60 cm from extrapolated point

we started with sphere radius = 60 cm, better increase to 90 cm to include more clusters that belong to pions

Trigger systematics: choice of R (data)



well known slope, 30 cm/ns
photons originated by pions

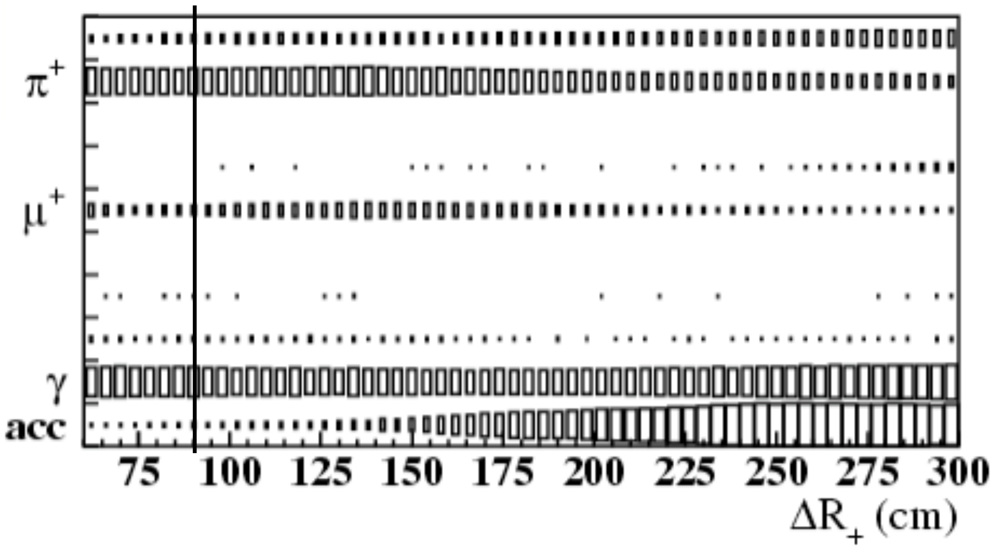
$$\Delta R = | \vec{x}_{clu} - \vec{x}_{ext} |$$

$$\Delta T = t_{clu} - t_{max}$$

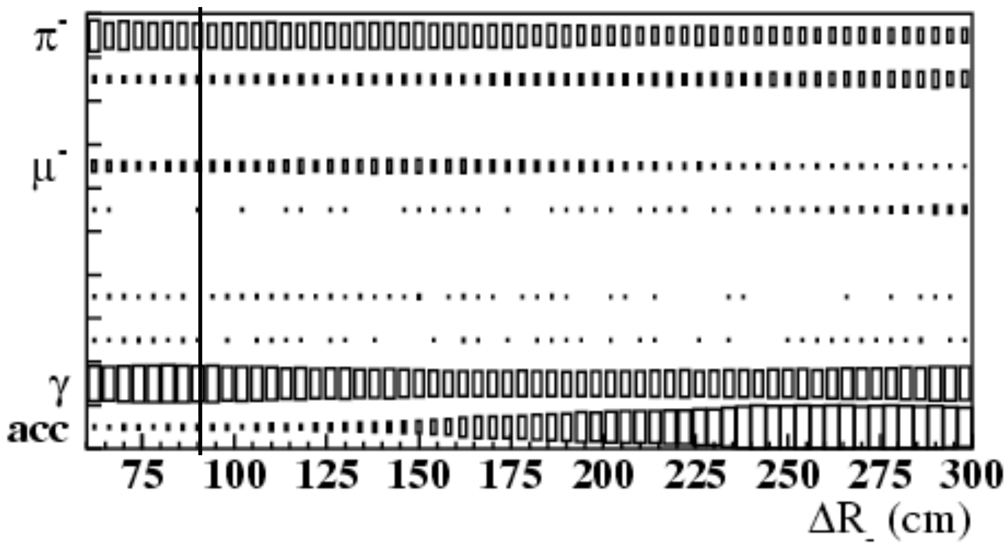
$\mathbf{t}_{\mathbf{max}}$ = time of most energetic cluster within 60 cm from extrapolated point

data hint to a smaller
$\pi^{\pm}\,\mathrm{N} \rightarrow \pi^0\,\mathrm{X}$ cross section
than in MC

MC confirmation: identity of the clusters



radius = 90 cm allows to include more clusters (e.g. photons) belonging to the pions and still not adding accidentals



Trigger efficiencies: single pion method

- multiplicities are evaluated: e.g. $P_{0,1,2}(\theta_\pm, p_\pm)$ = probability for the π^+ or π^- of firing 0,1,2 trigger sectors
- single conditioned probabilities are built in an unbiased way,

  e.g. $P_{0,1,2}(\theta_+, p_+)$ is estimated as the probability provided that the π^- have fired 2 trigger sectors and viceversa

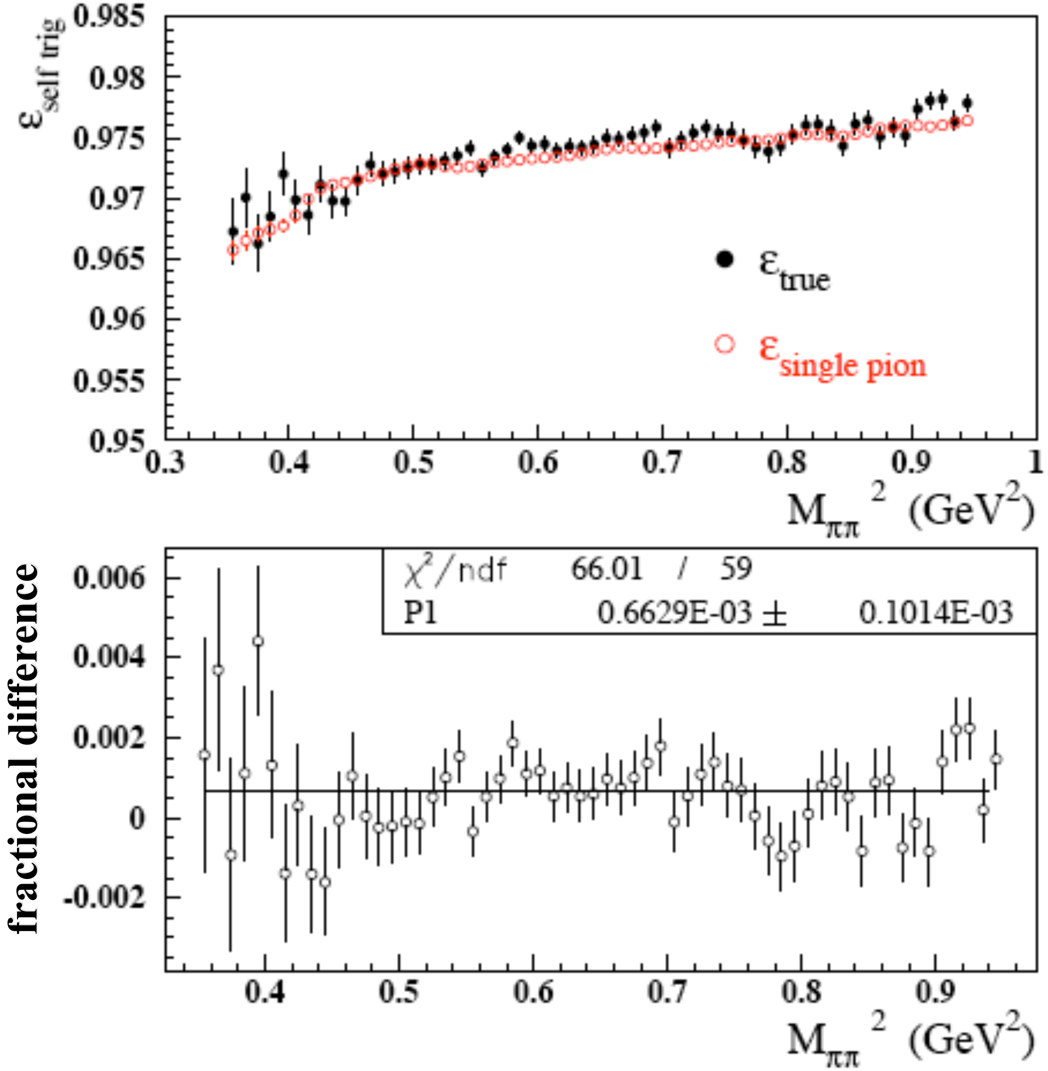
for a given $M_{\pi\pi}^2$ bin:

$$\varepsilon_{trig}(M_{\pi\pi}^2) = \frac{1}{N}\sum_{k=1}^{n} \nu_k \, \varepsilon_k$$

n = # of different $(\theta_+, p_+, \theta_-, p_-)$ configurations
ν = frequency for the k-th configuration
N = sum of all configurations for that bin

$$\varepsilon_k = 1 - P_1(\theta_+, p_+)P_0(\theta_-, p_-) - P_0(\theta_+, p_+)P_1(\theta_-, p_-) - P_0(\theta_+, p_+)P_0(\theta_-, p_-)$$

Trigger single pion method: systematics



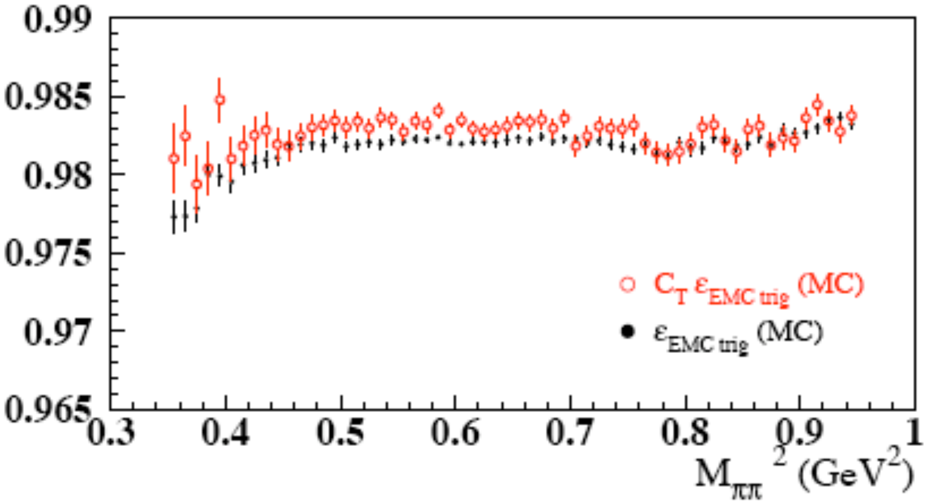
the method is checked on MC, against, the "true estimate", i.e. N_{2sec}/N_{gen} after standard analysis cuts

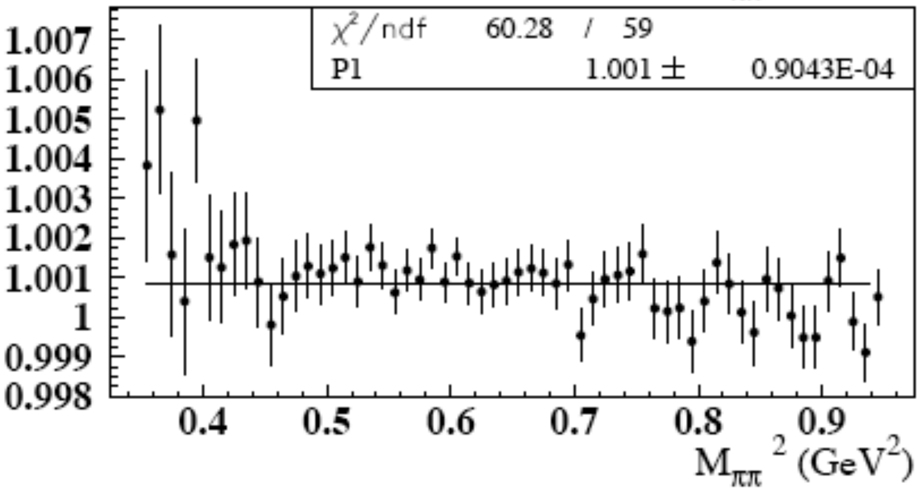
negligible uncertainty

Systematics with the DC trigger

$$\text{N. of events with EMC trigger} = \varepsilon_{\text{EMC}} N_{\text{TOT}} = N_{\text{EMC}}$$
$$\text{N. of events with DC trigger} = \varepsilon_{\text{DC}} N_{\text{TOT}} = N_{\text{DC}}$$
$$\text{N. of events with both triggers} = \varepsilon_{\text{EMC}} \varepsilon_{\text{DC}} C_T N_{\text{TOT}} = N_{\text{BOTH}}$$

conventions as in the trigger NIM,A492:134,2002



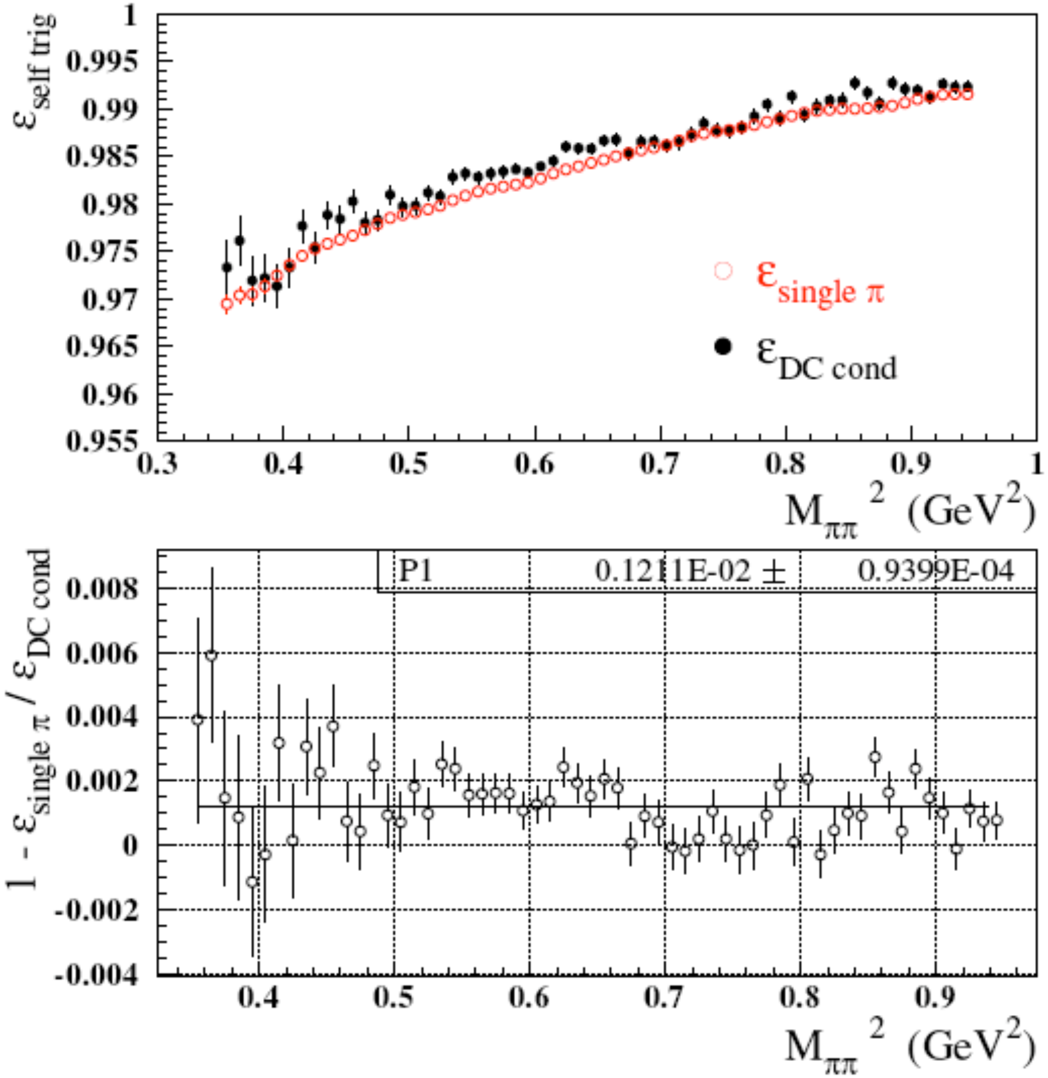


Monte Carlo studies prove that $C_T \approx 1$

for $\pi^+\pi^-\gamma$ events of this analysis.

EMC conditioned to the DC trigger is a good estimator for the efficiency

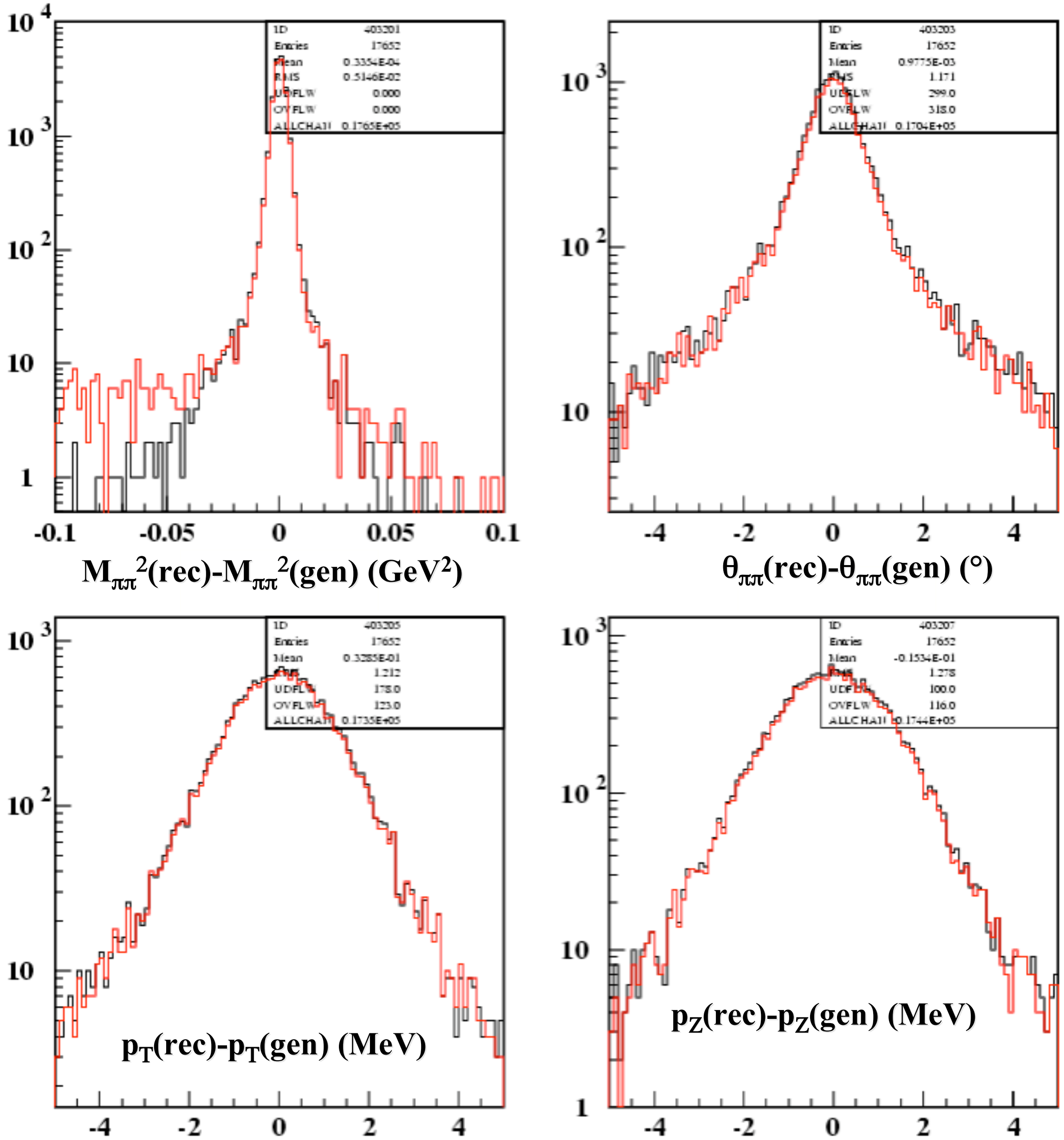
Systematic error



fractional difference between the 2 estimators

Tracking: No vertex required

no loss in resolution from momenta at the PCA, rather than at the vertex



- momenta at the PCA
- momenta at the VTX

Tracking corrections: $\pi^+\pi^-\pi^0$ data selection

- at least a "good tagging track" (first hit with ρ_{FH} < **50 cm,** point of closest approach (PCA) of backward track extrapolation must have ρ_{PCA} < **8 cm** and $|z_{PCA}|$ < **7 cm)**
- the track must have associated (`newextratom`) cluster with log $L_\pi/L_e > 1$ (it also provides with t_0 correction)
- 2 and only 2 clusters ("good photons") prompt (according to `ECL_NEURAD`) and neutral (not associated to the tagging track, nor to `TCLO` links) with E > 50 MeV and distant each other > 60 cm
- photons are χ^2-constrained as

measurements
$(2\times)$ E_γ = photon cluster energy $(2\times)$ $\underline{r}_\gamma$ = γ cluster space coordinates $(2\times)$ t_γ = γ cluster time
constraints
$m^2_{\gamma\gamma} = m^2_{\pi 0}$ $m^2_{miss}(\sum E_i, \lvert\sum \underline{p}_i\rvert) = m^2_{\pi+}$ $(2\times)$ $t_\gamma - \lvert\underline{r}_\gamma\rvert / c = 0$

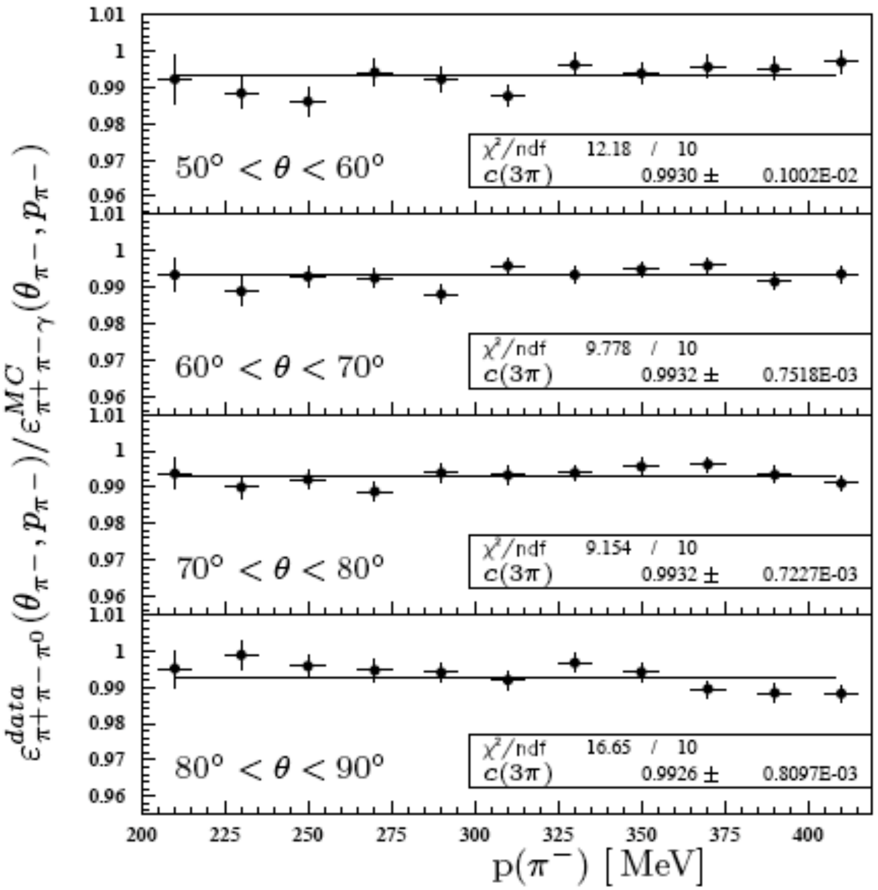
to cure the coordinate along the fiber → polar angle of the exp track

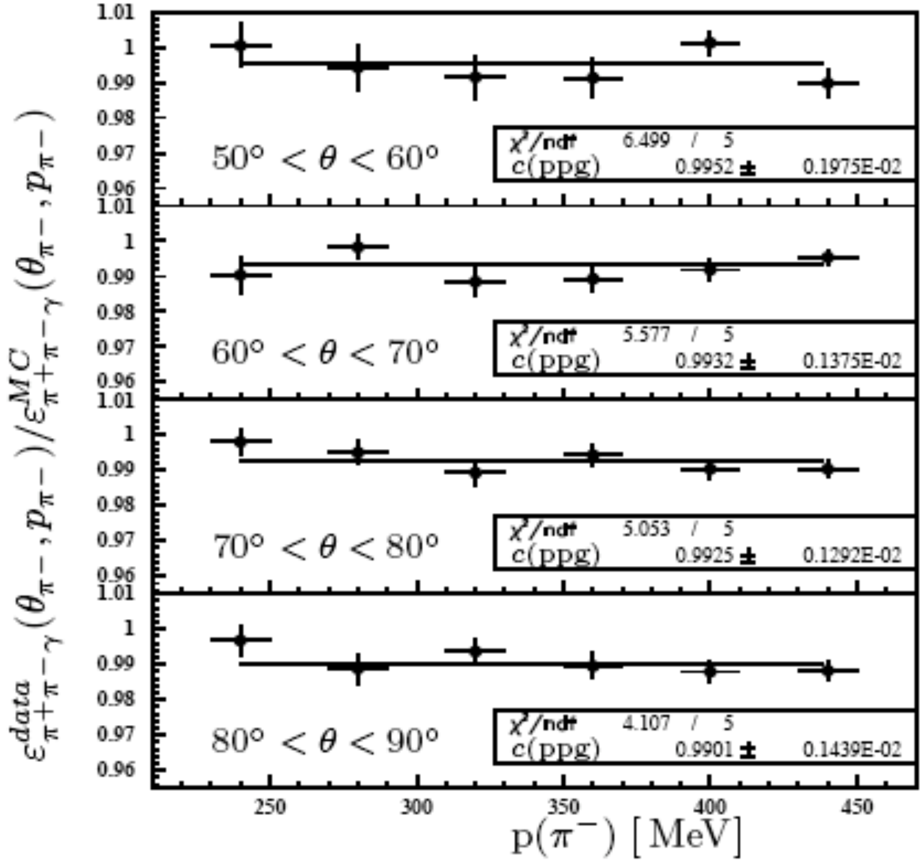
to cure the photon energies resolution

Tracking corrections: $\pi^+\pi^-\gamma$ data & MC selection

- at least a "good tagging track" (first hit with ρ_{FH} < **50 cm,** point of closest approach (PCA) of backward track extrapolation must have ρ_{PCA} < **8 cm** and $|z_{PCA}|$ < **7 cm)**
- the track must have associated (`newextratom`) cluster with log $L_\pi/L_e > 1$ (it also provides with t0 correction)
- 1 and only 1 cluster ("good photon") prompt (according to `ECL_NEURAD`) and neutral (not associated to the tagging track, nor to `TCLO` links) with E > 50 MeV
- the tagging track must have momentum ptag > 460 MeV (to throw $\pi^+\pi^-\pi^0$ events away), the expected track must have mass (built from 4 momentum conservation) M_{miss} > 120 MeV and MLP < 0.3, to suppress $\mu^+\mu^-\gamma$

Data/MC corrections from $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\gamma$





Tracking correction and systematics

for a given $M_{\pi\pi}^2$ bin:

$$\varepsilon_{trk}(M_{\pi\pi}^2) = \frac{1}{N}\sum_{k=1}^{n} \nu_k \, \varepsilon_k$$

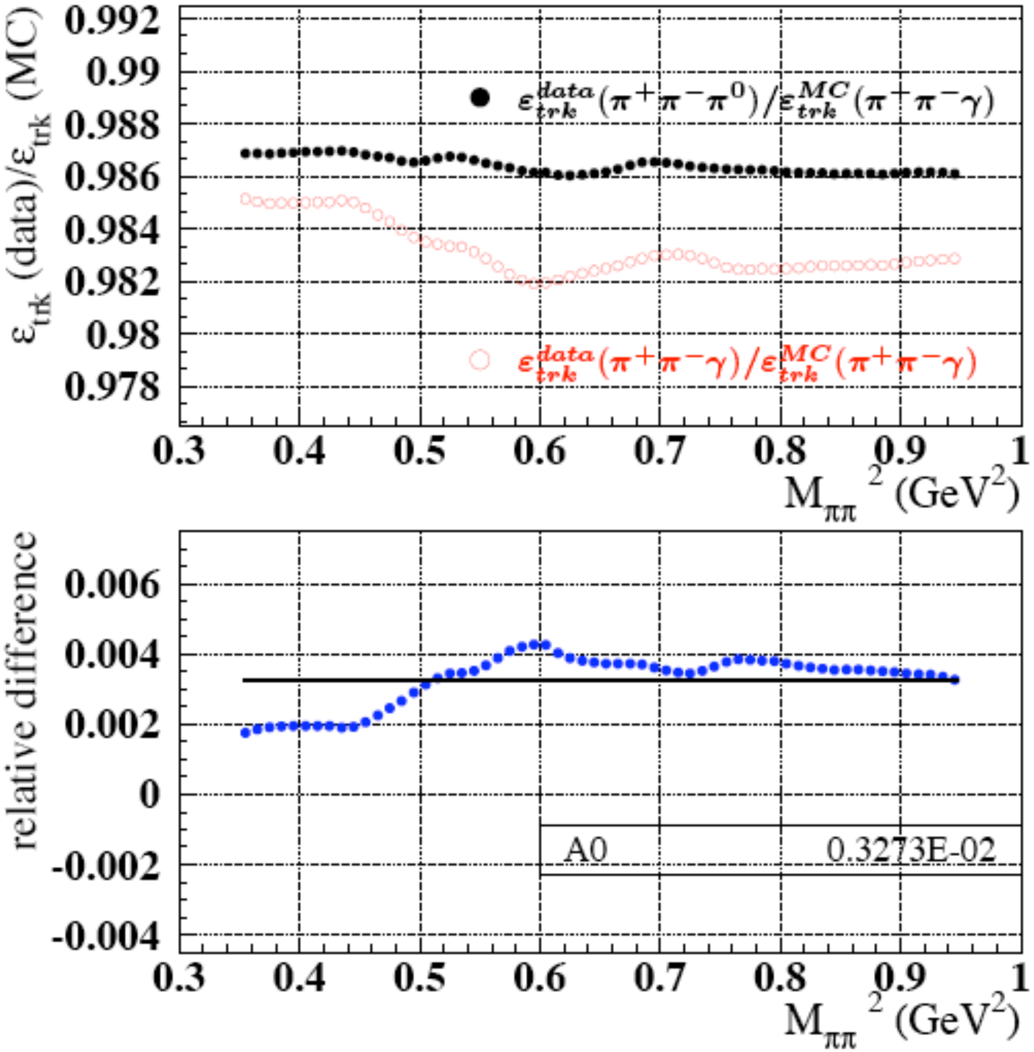
n = # of different $(\theta_+, p_+, \theta_-, p_-)$ configurations
ν = frequency for the k-th configuration
N = sum of all configurations for that bin

$$\varepsilon_k = \varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^+}, p_{\pi^+})\varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^-}, p_{\pi^-}) \quad \rightarrow \quad \varepsilon^{MC}_{\pi^+\pi^-\gamma}(M^2_{\pi\pi})$$

$$\varepsilon_k = c_{3\pi}(\theta_{\pi^+})c_{3\pi}(\theta_{\pi^-})\varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^+}, p_{\pi^+})\varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^-}, p_{\pi^-}) \quad \rightarrow \quad \varepsilon^{data}_{\pi^+\pi^-\pi^0}(M^2_{\pi\pi})$$

$$\varepsilon_k = c_{\mathrm{ppg}}(\theta_{\pi^+})c_{\mathrm{ppg}}(\theta_{\pi^-})\varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^+}, p_{\pi^+})\varepsilon^{MC}_{\pi^+\pi^-\gamma}(\theta_{\pi^-}, p_{\pi^-}) \quad \rightarrow \quad \varepsilon^{data}_{\pi^+\pi^-\gamma}(M^2_{\pi\pi})$$

Tracking correction and systematics



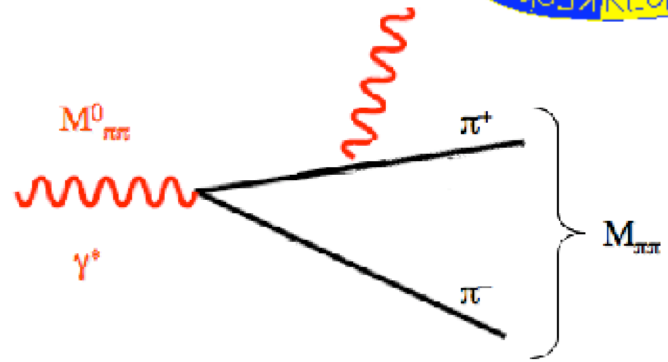
while 3p are statistically significant, ppg bring information also on momentum range > 400 MeV

the data/mc used is from 3p

systematic error given by the fractional difference between the 2 samples

„Unshifting“: $M^2_{\pi\pi} \rightarrow (M^0_{\pi\pi})^2$

Photon emissions from the pions changes the measured value of $M^2_{\pi\pi}$ from the invariant mass squared of the virtual photon produced in the $e^+ e^-$ collision, $(M^0_{\pi\pi})^2$



$$\boxed{M^2_{\pi\pi} \le (M^0_{\pi\pi})^2}$$

Use special version of PHOKHARA which allows to determine whether photon comes from initial or final state → build matrix which relates $M^2_{\pi\pi}$ to $(M^0_{\pi\pi})^2$.

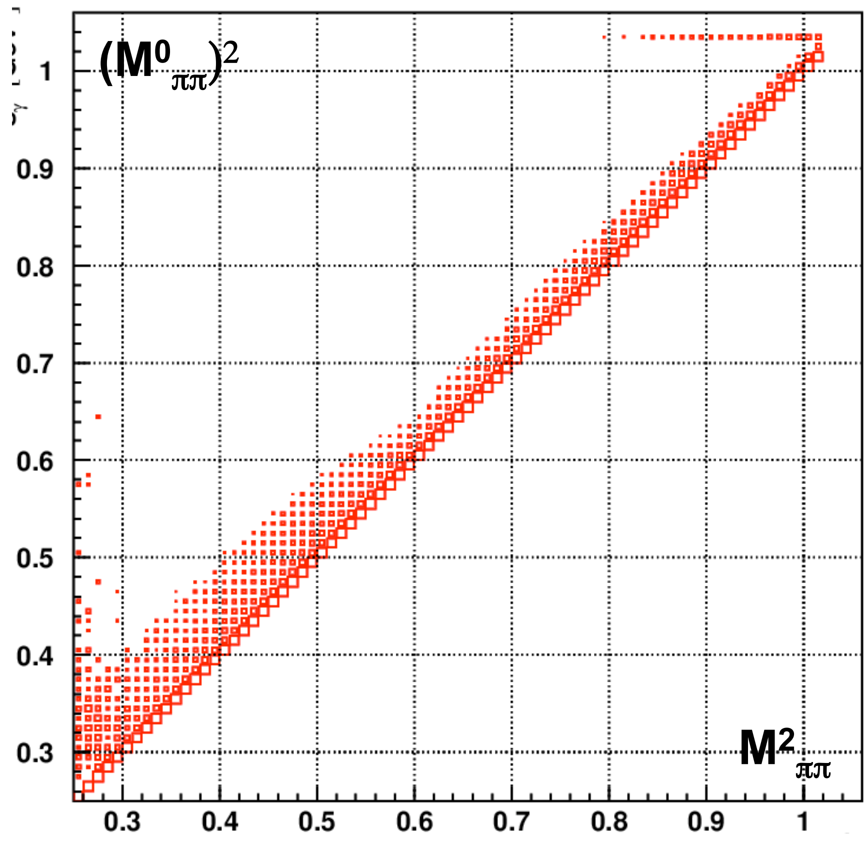
ISR only:

$$(M^0_{\pi\pi})^2 = M^2_{\pi\pi}$$

FSR photon present:

$$(M^0_{\pi\pi})^2 = M^2_{\pi\pi\gamma(FSR)}$$

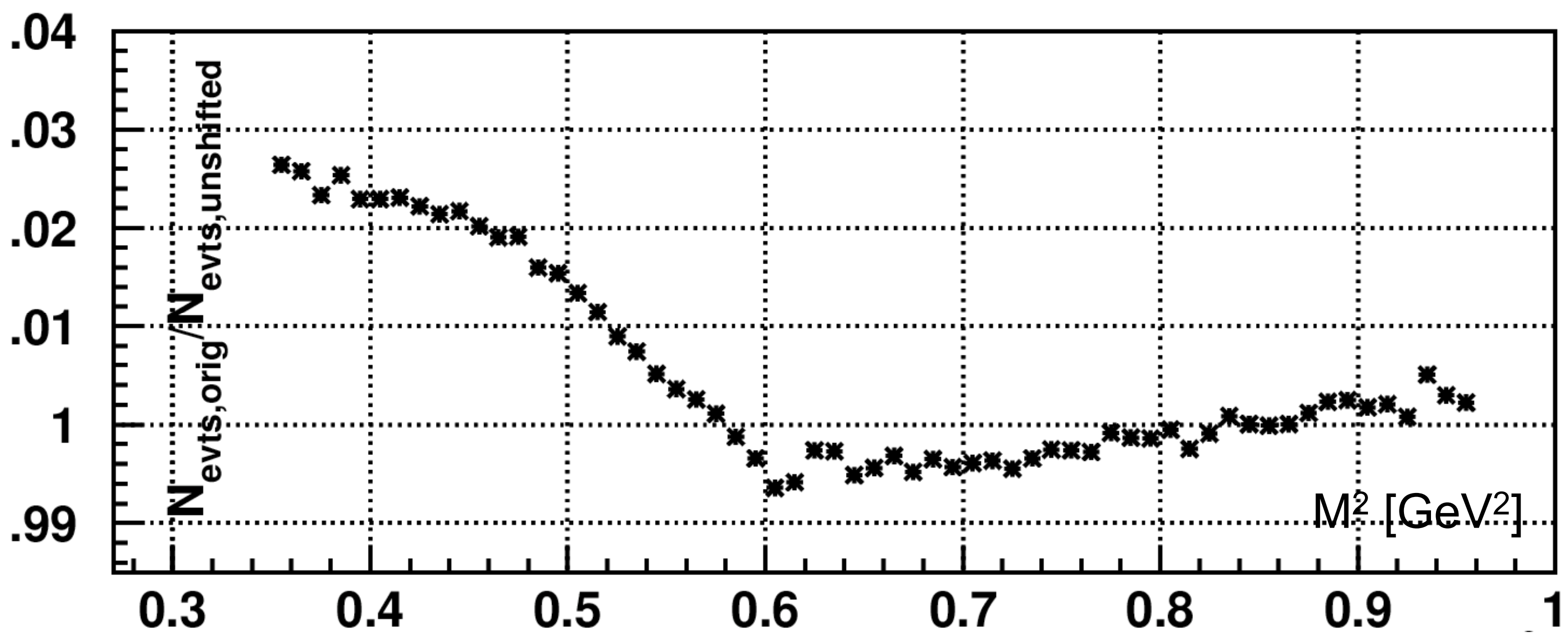
$e^+e^- \rightarrow \pi^+\pi^-\gamma_{FSR}$ events ("lo FSR") are "unshifted" to $(M^0_{\pi\pi})^2 = 1.04\ GeV^2$



„Unshifting“: $M^2_{\pi\pi} \rightarrow (M^0_{\pi\pi})^2$

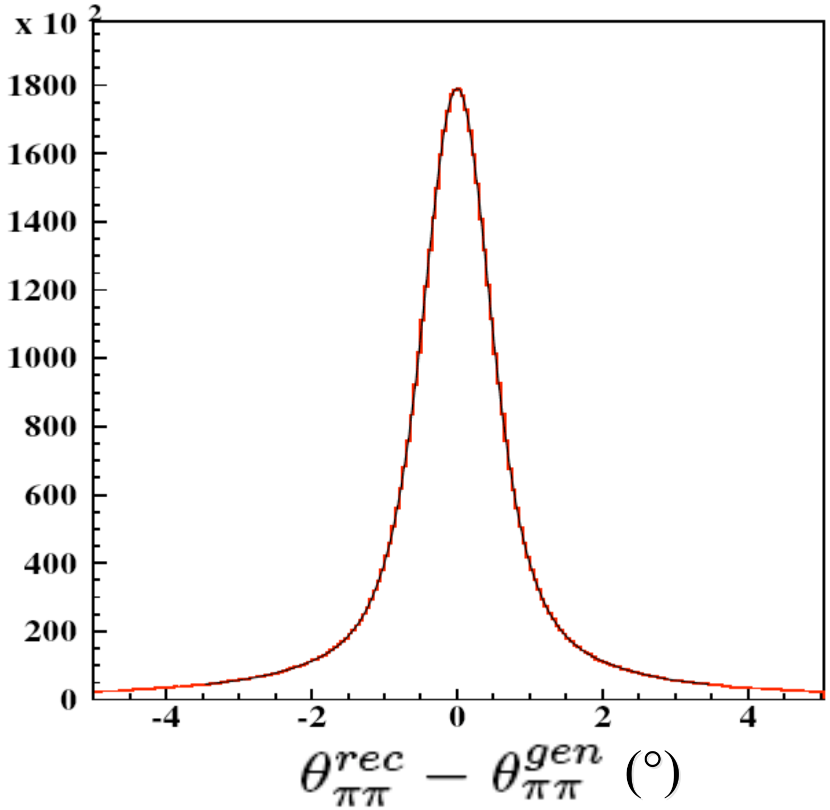
We use a matrix multiplication (similar to the one used in the estimation of the unfolding uncertainty) to “unshift” the spectrum and pass from $M^2_{\pi\pi}$ to $(M^0_{\pi\pi})^2$.

Effect as evaluated from Monte Carlo:



Relative increase of events with 1 γ_{ISR} and 1 γ_{FSR} over pure ISR events at low values of $M^2_{\pi\pi}$ increases the effect in this region.

Acceptance



the angular cut is moved up to 1 degree above and below the used value

$\chi^2/\mathrm{dof} = 149.9/132$, CL= 13.5%,

```
COVARIANCE MATRIX CALCULATED SUCCESSFULLY

FCN=    149.9138      FROM MIGRAD    STATUS=CONVERGED     336 CALLS       613 TOT.
                      EDM=   0.49E-05     STRATEGY= 2      ERROR MATRIX ACCURATE

 EXT PARAMETER                                       STEP         FIRST
 NO.   NAME         VALUE           ERROR            SIZE       DERIVATIVE
  1   offset       -0.32534E-03   0.30526E-03   0.18310E-05  -0.26652E-02
  2   Norm 1Gaus     85294.         2506.3        0.64938       0.40673E-05
  3   sigma 1Gau    0.36611       0.33319E-02   0.24729E-05     1.3485
  4   Norm 2Gaus     70534.         2116.3        0.43197       0.80796E-05
  5   sigma 2Gau    0.61746       0.81921E-02   0.26279E-05     1.2417
  6   Norm 3Gaus     19659.         499.12        0.16584       0.43134E-04
  7   sigma 3Gau     1.4297       0.20933E-01   0.72103E-05     0.98993
```

Acceptance: varying the cuts

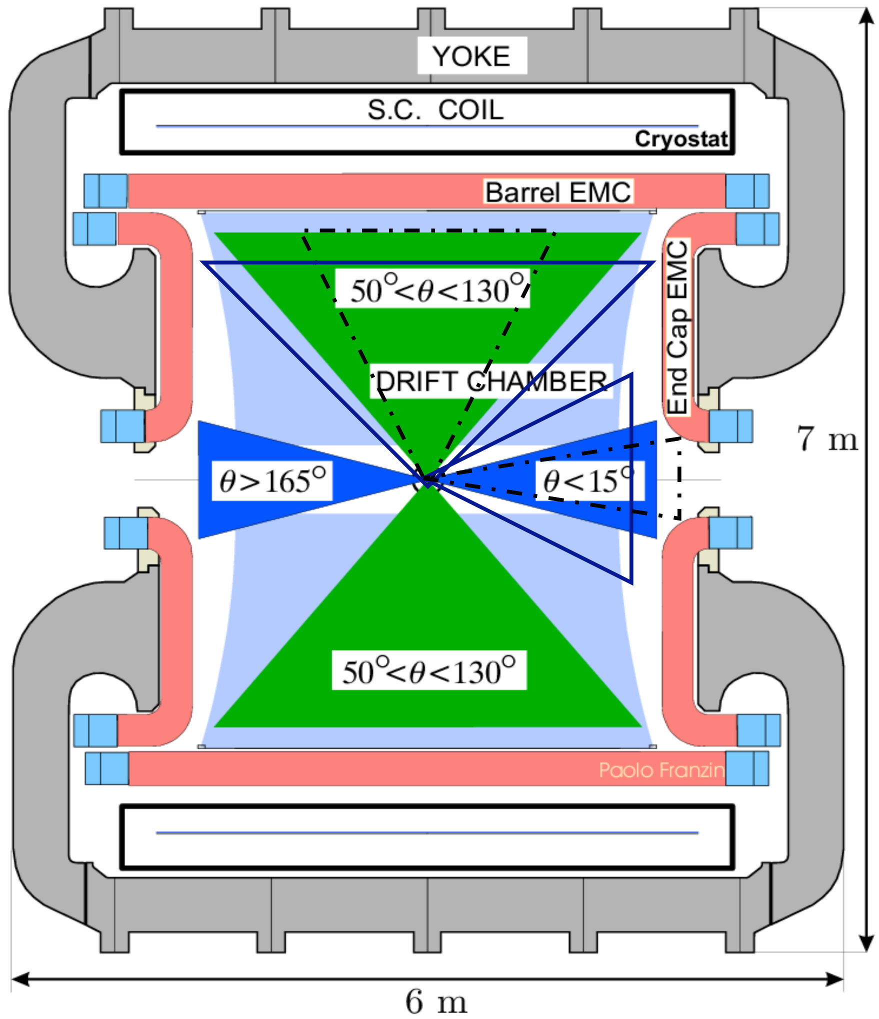
in a way similar to the acceptance studied for the luminosity (KLOE Note 202) we quantified the impact of enlarging/reducing the fiducial volume

$$\frac{\Delta\mathcal{L}}{\mathcal{L}} = \frac{\Delta N_{\mathrm{data}}}{N_{\mathrm{data}}} - \frac{\Delta\sigma_{\mathrm{Geanfi}}}{\sigma_{\mathrm{Geanfi}}}$$

just 1 observable, but now we have a spectrum

$$\frac{N_{\mathrm{MC}}(\theta_{\pi\pi} < \theta_{\mathrm{cut}})}{N_{\mathrm{MC}}(\theta_{\pi\pi} < 15^{\circ})} - \frac{N_{\mathrm{data}}(\theta_{\pi\pi} < \theta_{\mathrm{cut}})}{N_{\mathrm{data}}(\theta_{\pi\pi} < 15^{\circ})}$$

evaluated in $M_{\pi\pi}^2$ slices

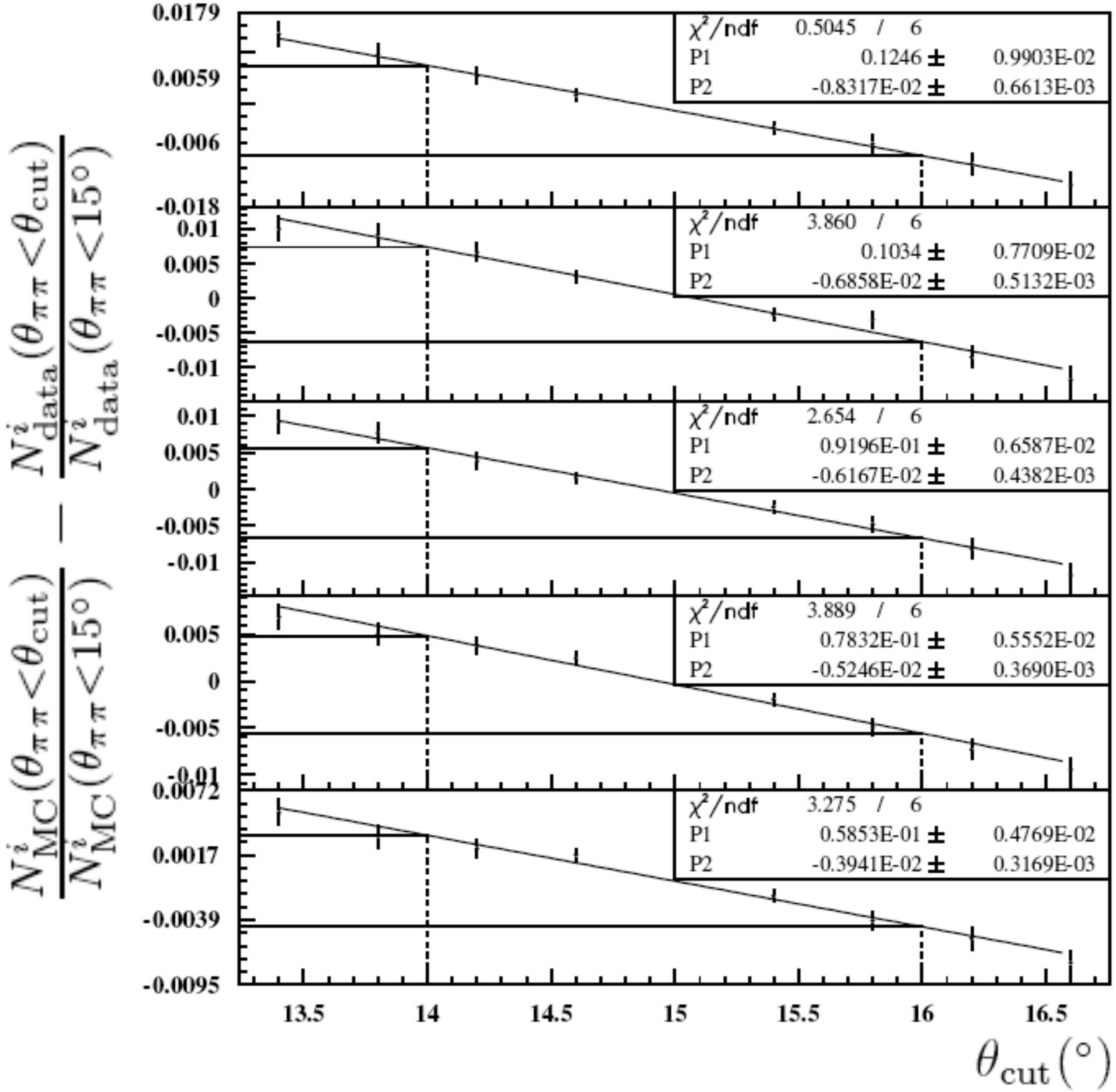


Acceptance on γ direction

the spectrum variation is linear as a function of the cut, so the excursion at ± 1 degree is taken as systematic error

$M^2_{\pi\pi}$ range (GeV^2)	Systematic error (%)
$0.35 \leq M^2_{\pi\pi} < 0.39$	0.6
$0.39 \leq M^2_{\pi\pi} < 0.43$	0.5
$0.43 \leq M^2_{\pi\pi} < 0.45$	0.4
$0.45 \leq M^2_{\pi\pi} < 0.49$	0.3
$0.49 \leq M^2_{\pi\pi} < 0.51$	0.2
$0.51 \leq M^2_{\pi\pi} < 0.64$	0.1
$0.64 \leq M^2_{\pi\pi} < 0.95$	-

Acceptance on γ direction



$0.35 < M_{\pi\pi}^2 < 0.37$ GeV^2

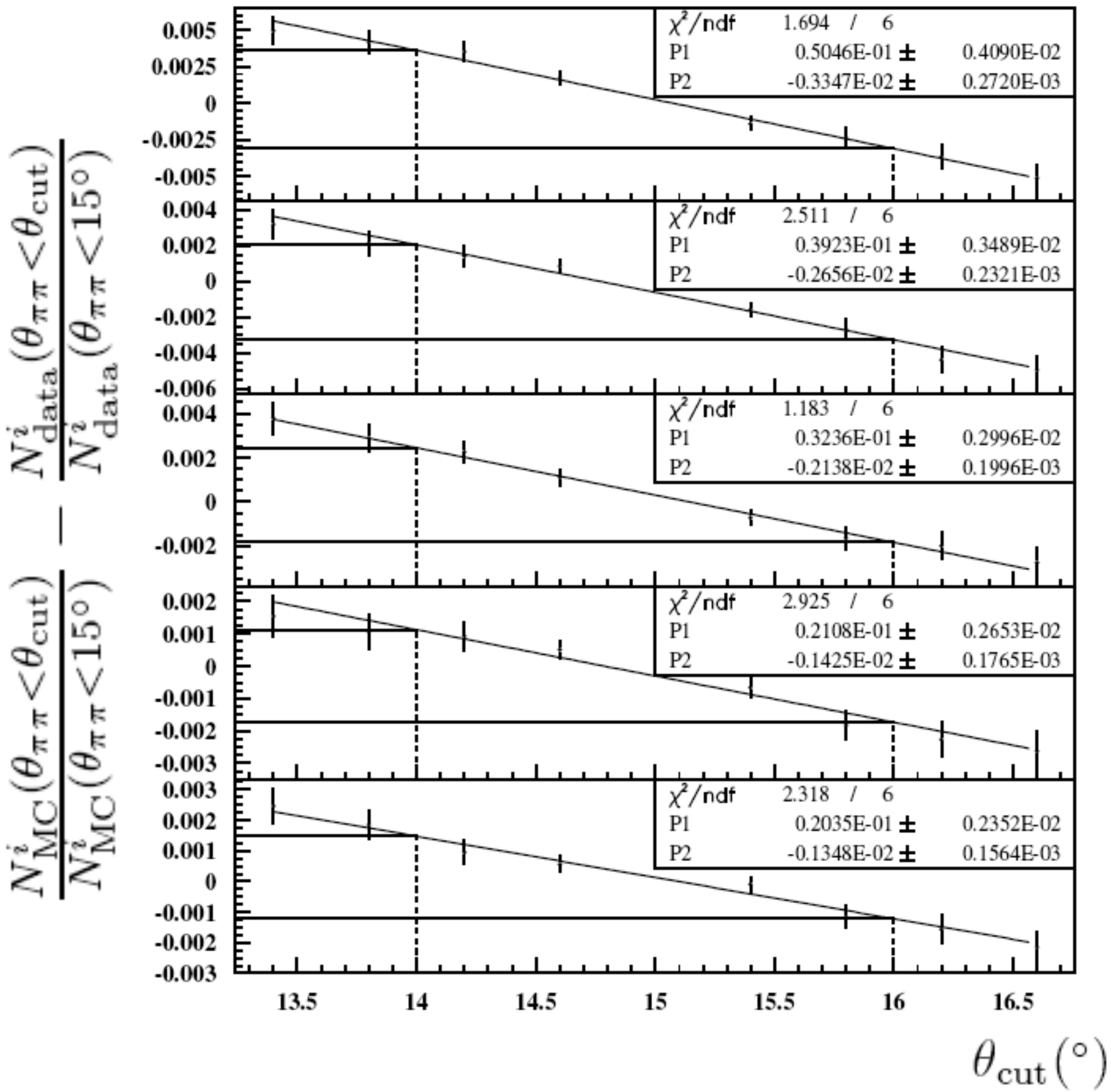
$0.37 < M_{\pi\pi}^2 < 0.39$ GeV^2

$0.39 < M_{\pi\pi}^2 < 0.41$ GeV^2

$0.41 < M_{\pi\pi}^2 < 0.43$ GeV^2

$0.43 < M_{\pi\pi}^2 < 0.45$ GeV^2

Acceptance on γ direction



$0.45 < M_{\pi\pi}^2 < 0.47$ GeV^2

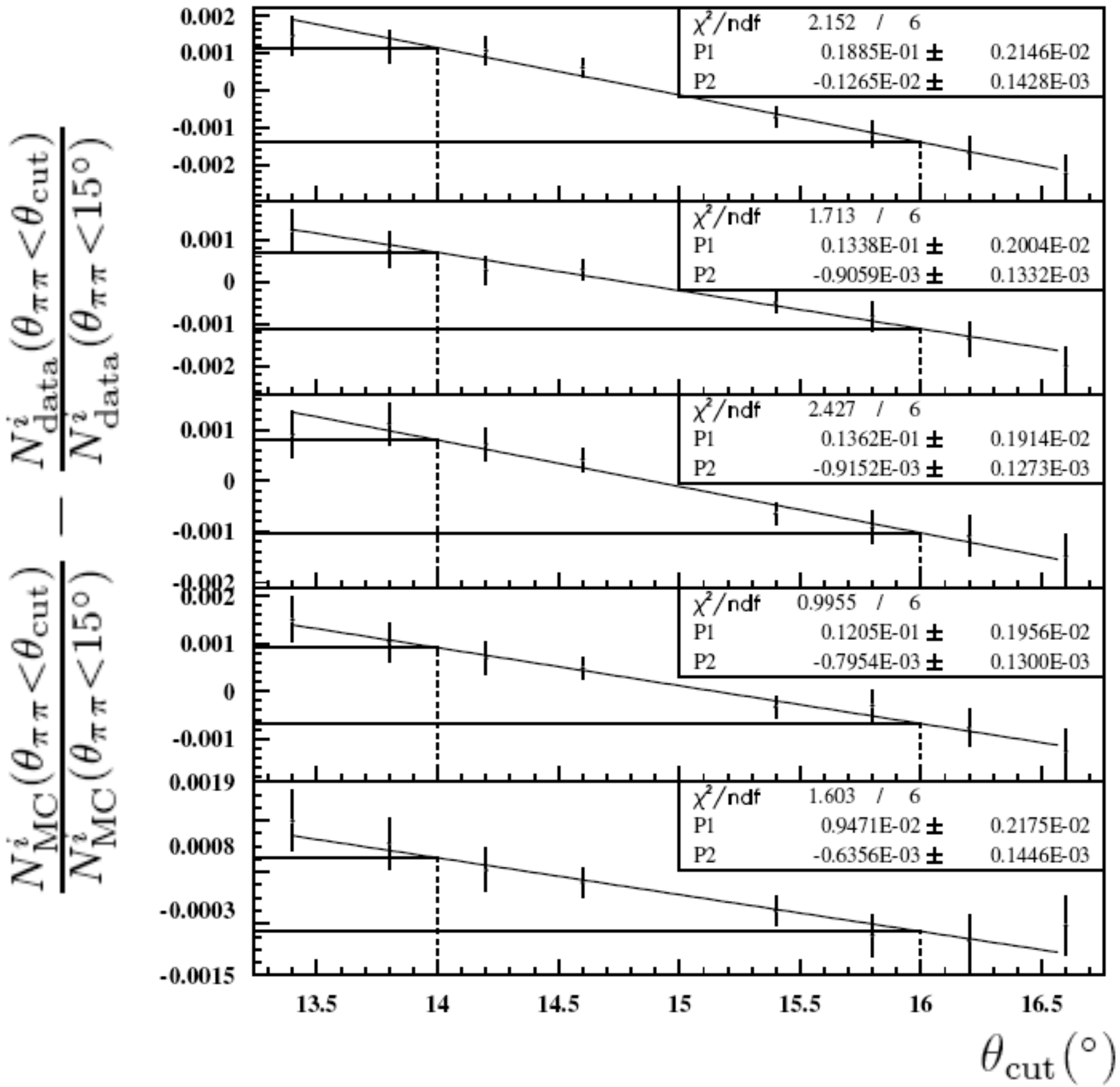
$0.47 < M_{\pi\pi}^2 < 0.49$ GeV^2

$0.49 < M_{\pi\pi}^2 < 0.51$ GeV^2

$0.51 < M_{\pi\pi}^2 < 0.53$ GeV^2

$0.53 < M_{\pi\pi}^2 < 0.55$ GeV^2

Acceptance on γ direction



$0.55 < M_{\pi\pi}^2 < 0.57\ GeV^2$

$0.57 < M_{\pi\pi}^2 < 0.59\ GeV^2$

$0.59 < M_{\pi\pi}^2 < 0.61\ GeV^2$

$0.61 < M_{\pi\pi}^2 < 0.63\ GeV^2$

$0.63 < M_{\pi\pi}^2 < 0.65\ GeV^2$

Luminosity:

KLOE measures $\mathcal{L}$ with Bhabha scattering

F. Ambrosino et al. (KLOE Coll.)
Eur.Phys.J.C47:589-596,2006

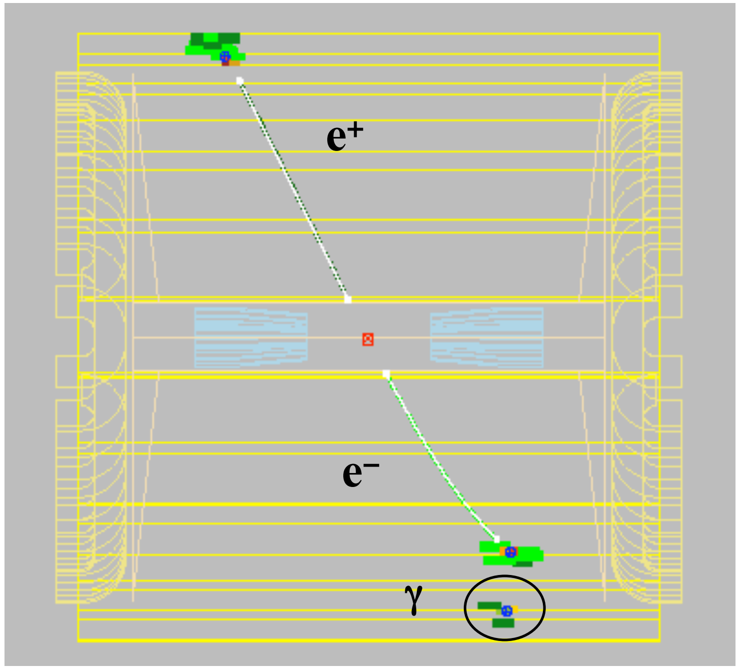
$55° < \theta < 125°$

acollinearity < 9°

$p \geq 400$ MeV

$$\boxed{\int \mathcal{L}\,\mathrm{d}t = \frac{N_{obs} - N_{bkg}}{\sigma_{eff}}}$$

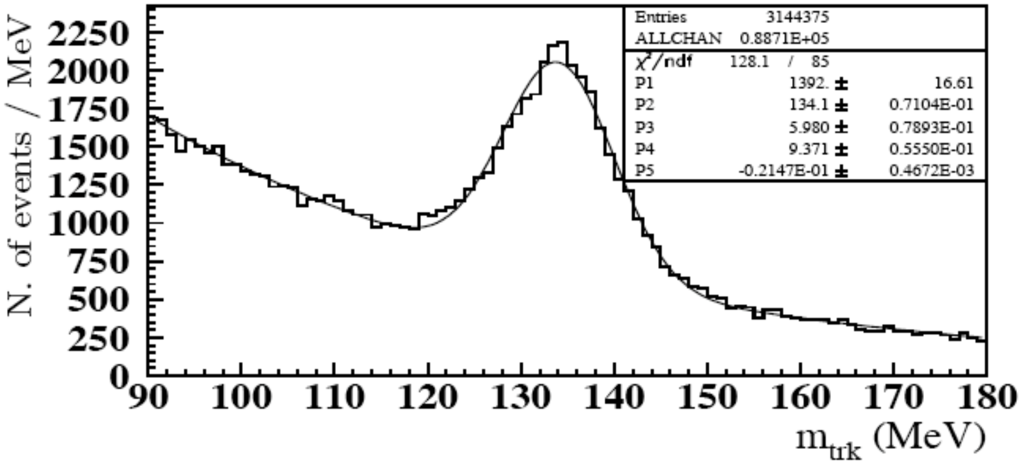
generator used for σ_{eff}
BABAYAGA (Pavia group):
C. M.C. Calame et al., NPB758 (2006) 22

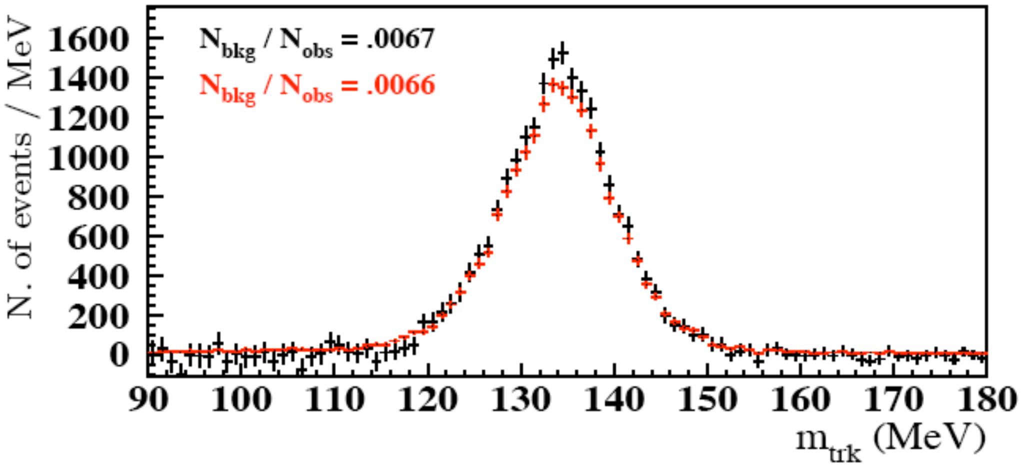


new version (**BABAYAGA@NLO**) gives 0.7% decrease in cross section, and better accuracy: 0.1%

Systematics on Luminosity	
Theory	0.1 %
Experiment	0.3 %
TOTAL 0.1 % th ⊕ 0.3% exp = 0.3%	

VLAB analysis on 2002 data





no more Cosmic Veto, twofold implication:
more efficient, but
with more $\pi^+\pi^-$ background

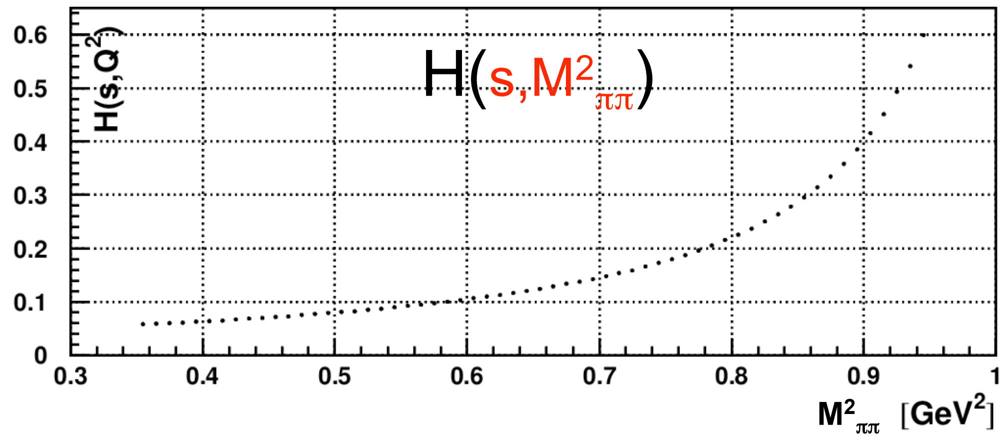
	2001	2002
relative theoretical error on $\sigma_{\rm eff}$	0.5%	0.1%
background correction	−0.6%	−0.7%
cosmic veto efficiency	+0.4%	negligible
relative error on $\mathcal{L}$: $\delta_{th} \oplus \delta_{exp}$	0.6%	0.3%

Radiator function

- **ISR-Process calculated at NLO-level**
  PHOKHARA generator (*Czyż, Kühn et.al*)
  Theoretical Precision: *0.5%*

$$s \cdot \frac{d\sigma_{\pi\pi\gamma}}{dM^2_{\pi\pi}} = \sigma_{\pi\pi}(s) \times H(s,M^2_{\pi\pi})$$

s is the collider energy.

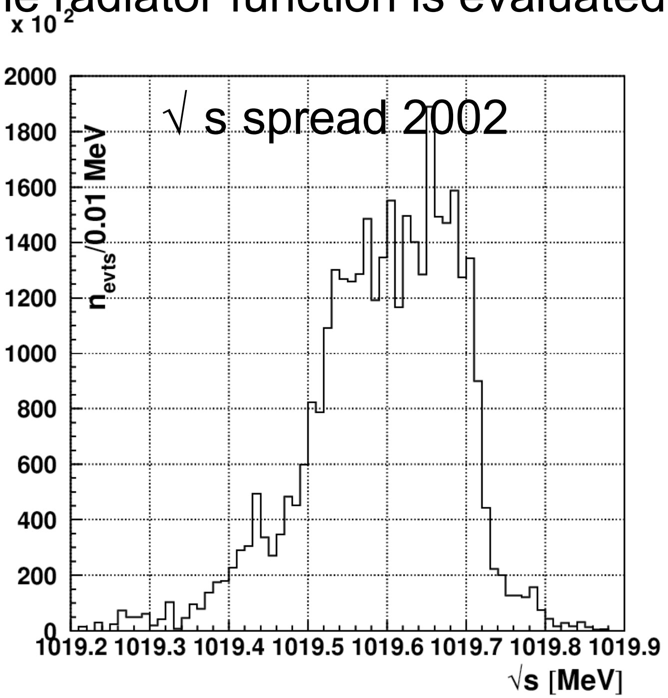


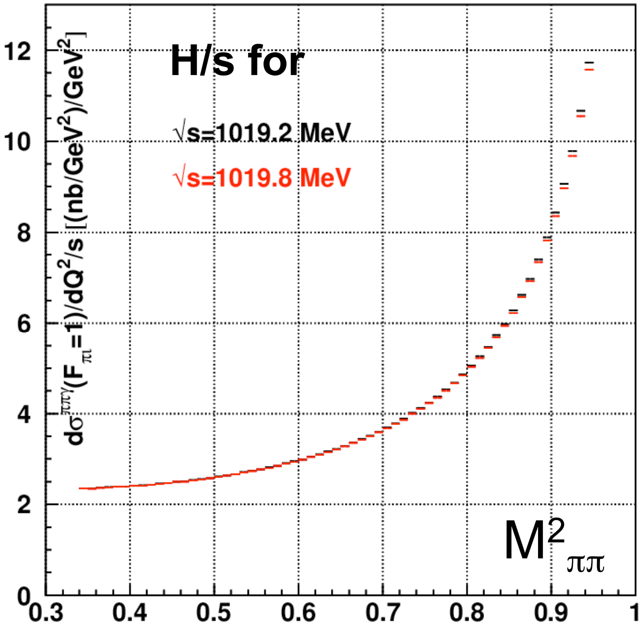
We obtain the radiator function technically by setting $|F_\pi|^2=1$ in the PHOKHARA Monte Carlo generator, and generate ISR events inclusive in θ_π and $\theta_{\pi\pi}$:

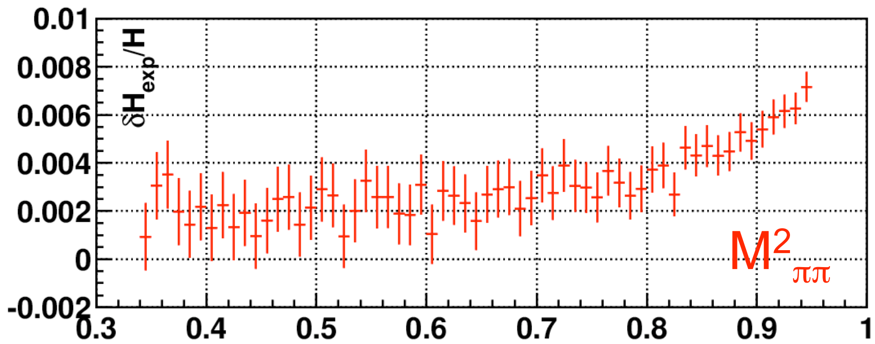
$$H(s,M^2_{\pi\pi}) = s \times \frac{3M^2_{\pi\pi}}{\pi\alpha^2\beta^3_\pi} \times \left.\frac{d\sigma_{\pi\pi\gamma}(M^2_{\pi\pi})}{dM^2_{\pi\pi}}\right|^{MC}_{|F_\pi(M^2_{\pi\pi})|^2=1}$$

Radiator function

In addition to the theoretical uncertainty of the radiator of 0.5%, we evaluate an experimental uncertainty due to the spread in $\sqrt{s}$ during the data taking in 2002, as the radiator function is evaluated at the nominal value of $\sqrt{s}$ = 1.019456 GeV





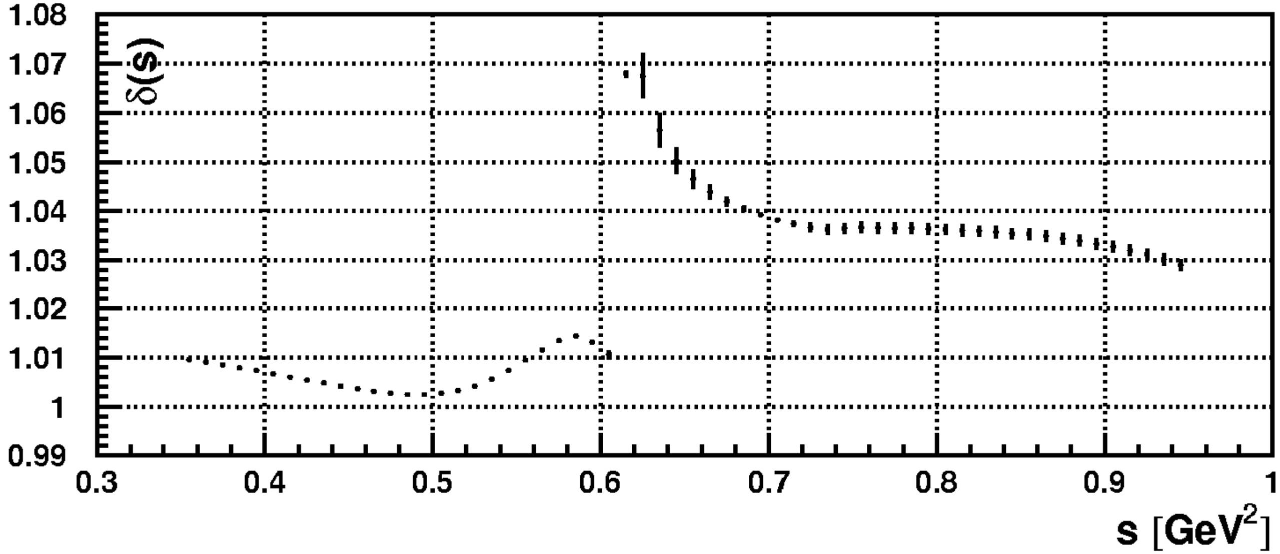


We take half the rel. difference between the radiator functions obtained at $\sqrt{s}$ = 1.0192 GeV and $\sqrt{s}$ = 1.0198 GeV as the experimental syst. uncertainty on the radiator function.

Vacuum Polarisation

For use in the dispersive integral for $\Delta^{\pi\pi}a_\mu$, one needs to subtract effects from vacuum polarization (VP) to obtain a *bare* cross section $\sigma^0_{\pi\pi}$:

$$\sigma^0_{\pi\pi}(s) = \sigma^{\text{dressed}}{}_{\pi\pi}(s)\left(\frac{\alpha(0)}{\alpha(s)}\right)^2 = \sigma_{\pi\pi}(s)/\delta(s)$$



Points obtained from F. Jegerlehner's webpage *(the only points which are publicly available!)*

Correction is applied only to the cross section $\sigma^0_{\pi\pi}$ (not on $\sigma_{\pi\pi\gamma}$ and $|F_\pi|^2$).

Error on VP points introduces an relative error on the value of $\Delta^{\pi\pi}a_\mu$ of 0.1%.

Final State Radiation (FSR)

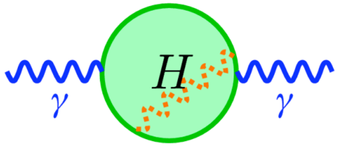
The presence of FSR affects the following items in our analysis:

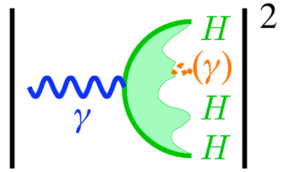
- The M_{trk} distributions used in the background fit and the M_{trk} efficiency.
  Are both performed within the small angle cuts for which FSR is reduced.
  Corrections on Monte Carlo momenta should compensate missing FSR terms
  or wrong model of FSR in PHOKHARA generator.
- The unshifting procedure
  Relies on PHOKHARA Monte Carlo generator and its treatment of FSR.
  (and also how well it allows to distinguish whether photon comes from ISR or FSR)
- The efficiency for $\theta_{\pi\pi}$
  Also here we depend on the PHOKHARA generator and the model of photon radiation
  from pointlike pions.
- The division for the radiator function H(s):
  Relies on the assumption of factorization between ISR and FSR processes.
  This has been tested in our previous publication, a validity within 0.2% was found.

We take the combined error of 0.3% for the uncertainty on the rel. FSR contribution and the model dependence as found in our previous analysis.

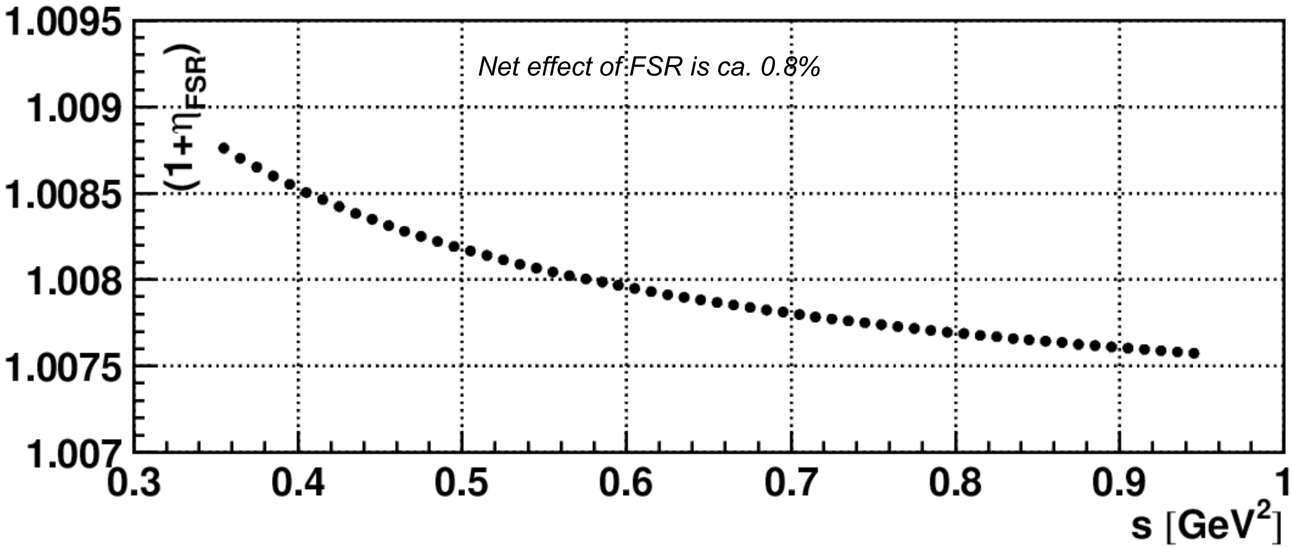
Final State Radiation (FSR)

$\sigma_{\pi\pi}$ needs to be inclusive with respect to final state radiation when used in the dispersive integral. Therefore the analysis has been designed to provide a final spectrum which is inclusive in FSR@$(M^0_{\pi\pi})^2$



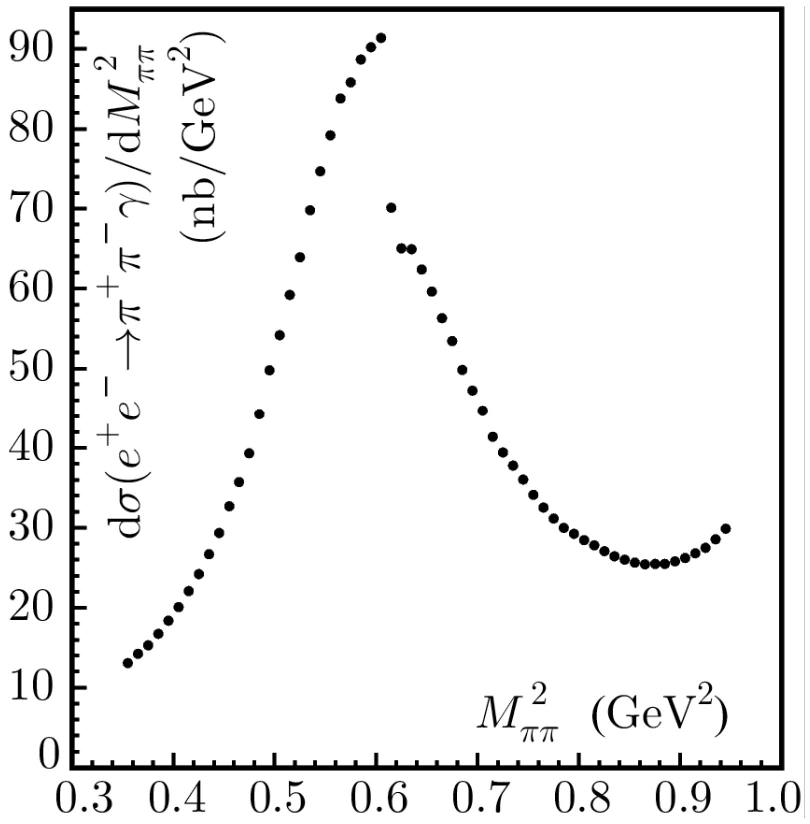


Concerning the $|F_\pi|^2$, we undress the spectrum from FSR by dividing for $(1+\eta_{FSR})$, which is calculated assuming radiation from pointlike pions (sQED)

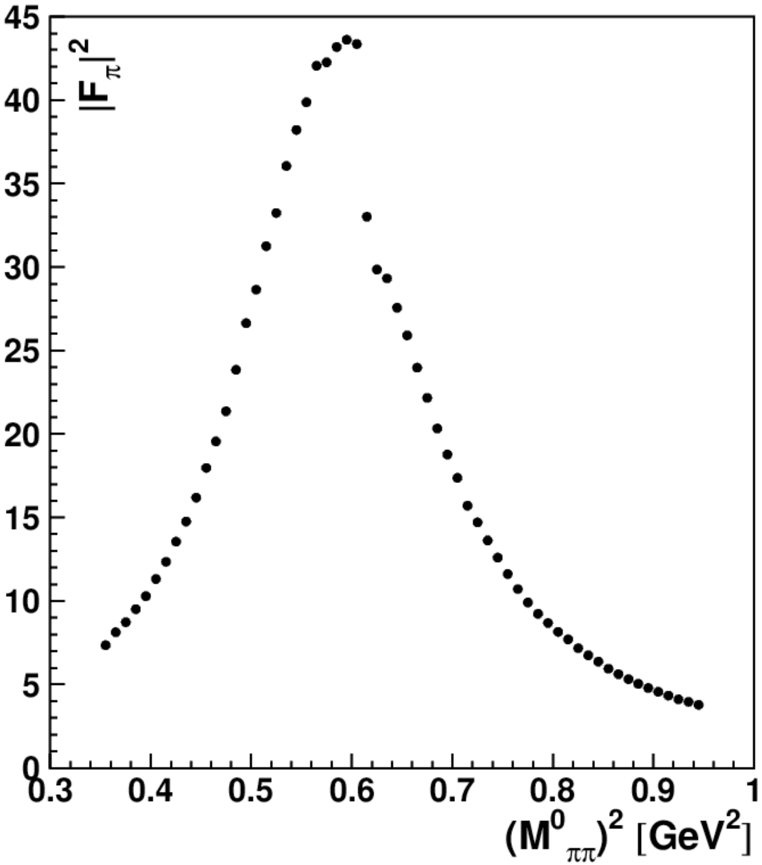


Small angle results from 2002 data:

$d\sigma_{\pi\pi\gamma}/dM^2_{\pi\pi}$, inclusive for VP and FSR as function of $M^2_{\pi\pi}$



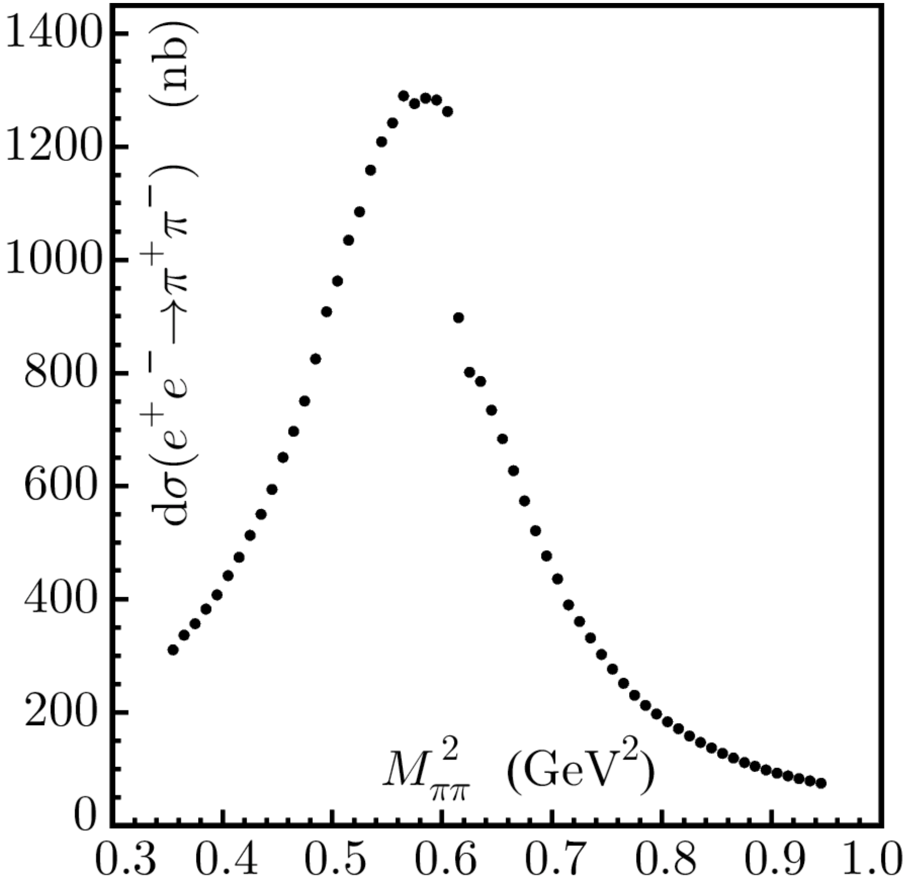
$|F_\pi|^2$, inclusive for VP, FSR subtracted as function of $(M^0_{\pi\pi})^2$



stat. errors only

Small angle result from 2002 data:

$\sigma^0_{\pi\pi}$, undressed from VP, inclusive for FSR
as function of $(M^0_{\pi\pi})^2$



stat. error only

	$\sigma_{\pi\pi\gamma}$	$\sigma^{bare}_{\pi\pi}$	$\|F_\pi\|^2$
Reconstruction Filter	negligible		
Background subtraction	$M^2_{\pi\pi}$ dependent (Tab. 2)		
Trackmass	0.2 % flat in $M^2_{\pi\pi}$		
Particle ID	negligible		
Tracking	0.3 % flat in $M^2_{\pi\pi}$		
Trigger	0.1 % flat in $M^2_{\pi\pi}$		
Unfolding	$M^2_{\pi\pi}$ dependent (Tab. 3)		
Acceptance	$M^2_{\pi\pi}$ dependent (Tab 4)		
L3	0.1 % flat in $M^2_{\pi\pi}$		
Luminosity	0.3 % flat in $M^2_{\pi\pi}$		
FSR resummation	-	0.3 %	
Radiation function ($H(M^2_{\pi\pi})$)	-	0.5 %	
$\sqrt{s}$ dep. of H	-	$M^2_{\pi\pi}$ dependent, (Tab. 6)	
Vacuum Polarization	-	0.1%	-

Small angle result from 2002 data:

Systematic errors on $a_\mu^{\pi\pi}$:

Reconstruction Filter	negligible
Background	0.3%
Trackmass/Miss. Mass	0.2%
π/e-ID and TCA	negligible
Tracking	0.3%
Trigger	0.1%
Acceptance ($\theta_{\pi\pi}$)	0.1%
Acceptance (θ_π)	negligible
Unfolding	negligible
Software Trigger	0.1%
$\sqrt{s}$ dep. Of H	0.2%
Luminosity($0.1_{th} \oplus 0.3_{exp}$)%	0.3%

experimental fractional error on a_μ = 0.6 %

FSR resummation	0.3%
Radiator H	0.5%
Vacuum polarization	0.1%

theoretical fractional error on a_μ = 0.6 %

Evaluating $a_\mu^{\pi\pi}$ with small angle

Dispersion integral for 2π-channel in energy interval $0.35 < M_{\pi\pi}^2 < 0.95$ GeV^2

$$a_\mu^{\pi\pi} = 1/4\pi^3 \int_{0.35\mathrm{GeV}^2}^{0.95\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

We use bin-per-bin-summation to evaluate the integral, K(s) gets evaluated at the middle of the bin. Statistical bin errors get summed in quadrature. Systematic errors are summed linearly.

2005 published result (Phys. Lett. B606 (2005) 12):

$$a_\mu^{\pi\pi}(0.35\text{-}0.95\mathrm{GeV}^2) = (388.7 \pm 0.8_{stat} \pm \pm 3.5_{sys} \pm 3.5_{theo}) \cdot 10^{-10}$$

Applying update for trigger eff. and change in Bhabha-cross section used for luminosity evaluation:

$$a_\mu^{\pi\pi}(0.35\text{-}0.95\mathrm{GeV}^2) = (384.4 \pm 0.8_{stat} \pm 3.5_{sys} \pm 3.0_{theo}) \cdot 10^{-10}$$

2008:

$$\boxed{a_\mu^{\pi\pi}(0.35\text{-}0.95\mathrm{GeV}^2) = (387.6 \pm 0.5_{stat} \pm 2.5_{sys} \pm 2.3_{theo}) \cdot 10^{-10}}$$

0.1% 0.6% 0.6%

Evaluating $a_\mu^{\pi\pi}$ with small angle

Dispersion integral for 2π-channel in energy interval 0.35 $< M_{\pi\pi}^2 <$ 0.95 GeV²

$$a_\mu^{\pi\pi} = 1/4\pi^3 \int_{0.35\mathrm{GeV}^2}^{0.95\mathrm{GeV}^2} ds\, \sigma(e^+e^- \to \pi^+\pi^-)\, K(s)$$

Following Matt's suggestion and using the Background obtained form the fit with PB corrections up to 0.5 GeV², we get the following change on **$a_\mu^{\pi\pi}$(0.35-0.95GeV²):**

2008:

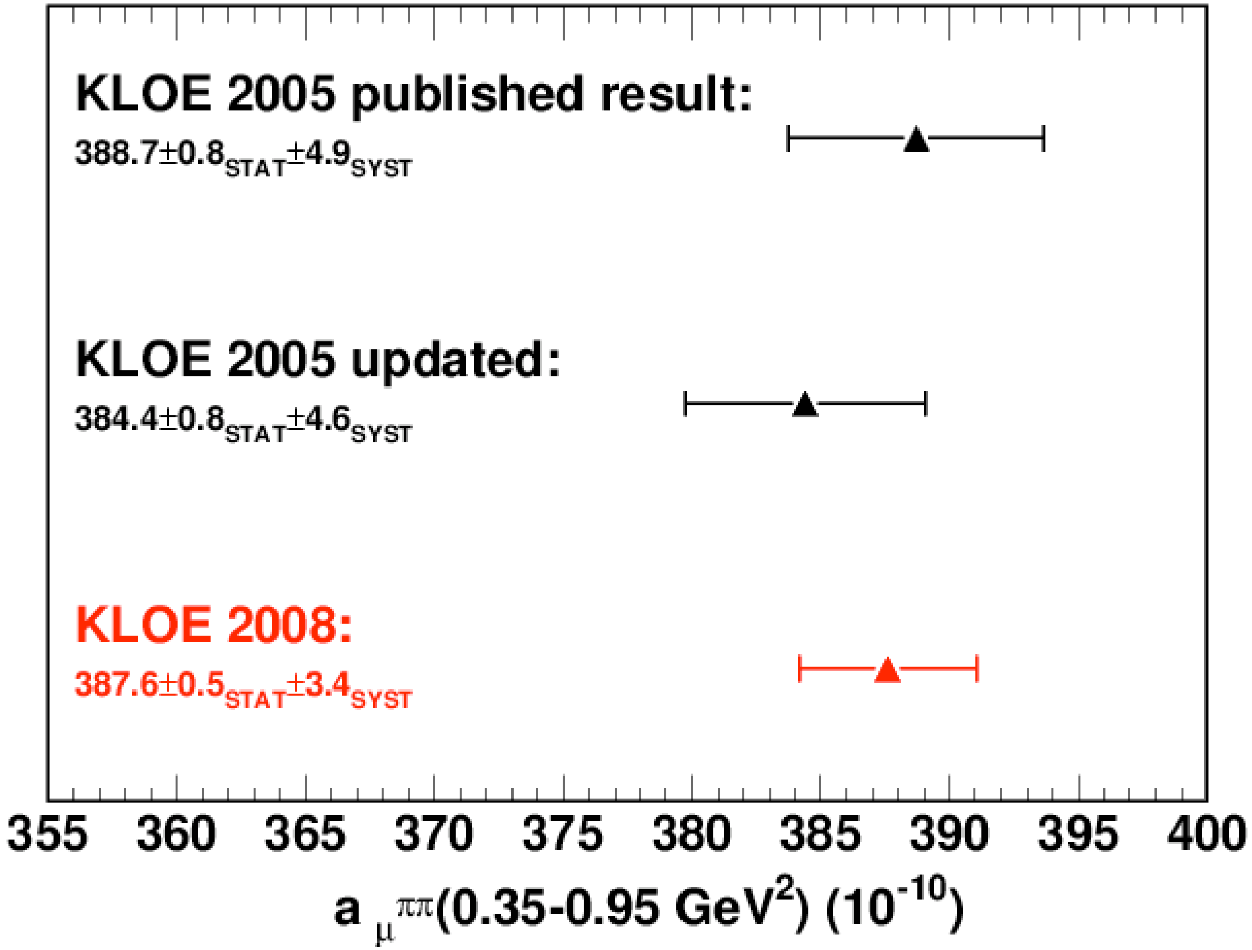
??

$$a_\mu^{\pi\pi}(0.35\text{-}0.95\mathrm{GeV}^2) = (387.2 \pm 0.5_{stat} \pm 2.5_{sys} \pm 2.3_{theo}) \cdot 10^{-10}$$

0.1% 0.6% 0.6%

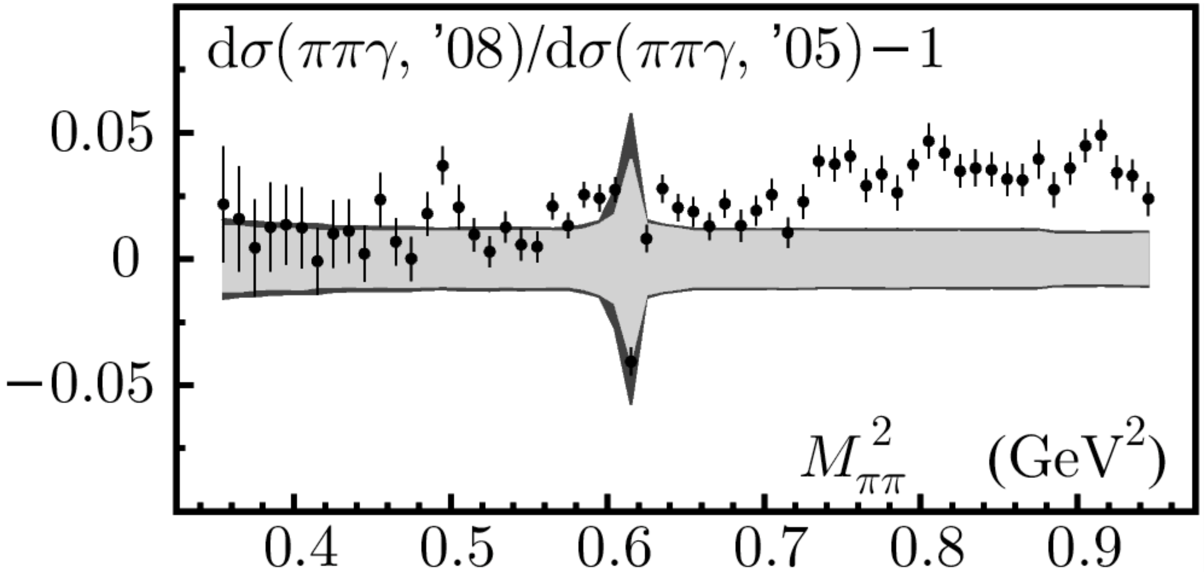
$a_\mu^{\pi\pi}$ Summary:

Summary of the small angle results:



All results are in good agreement

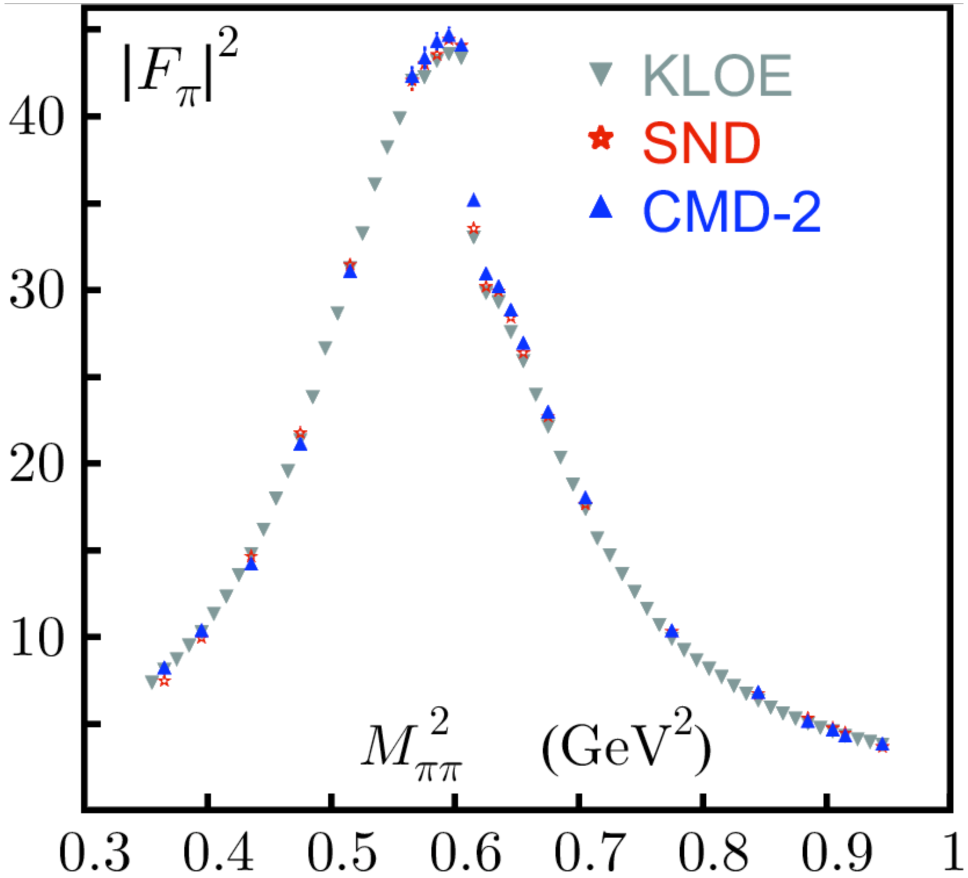
Comparing 2005 with 2008 result:



the 2 analyses are compared before the H division,
i.e. the major common correction
data points include errors due to event counts of the 2 analyses
the band is the systematic error of the ratio

good agreement below 0.7 GeV^2, systematic difference of 3-4% above
<u>we do not average the 2 measurements</u>

Comparison with CMD2 & SND:

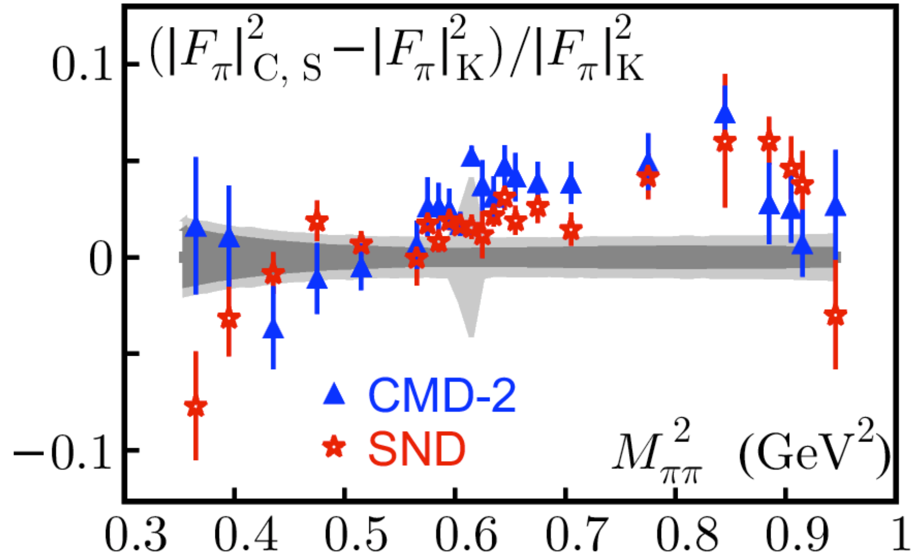


only statistical errors are shown

Novosibirsk results get averaged with

$$\frac{1}{\Delta s}\int^{\Delta s}|F_\pi(s)|^2 ds$$

to compare with binned KLOE result



band: KLOE error
data points: CMD2/SND experiments

$a_\mu^{\pi\pi}$ Summary:

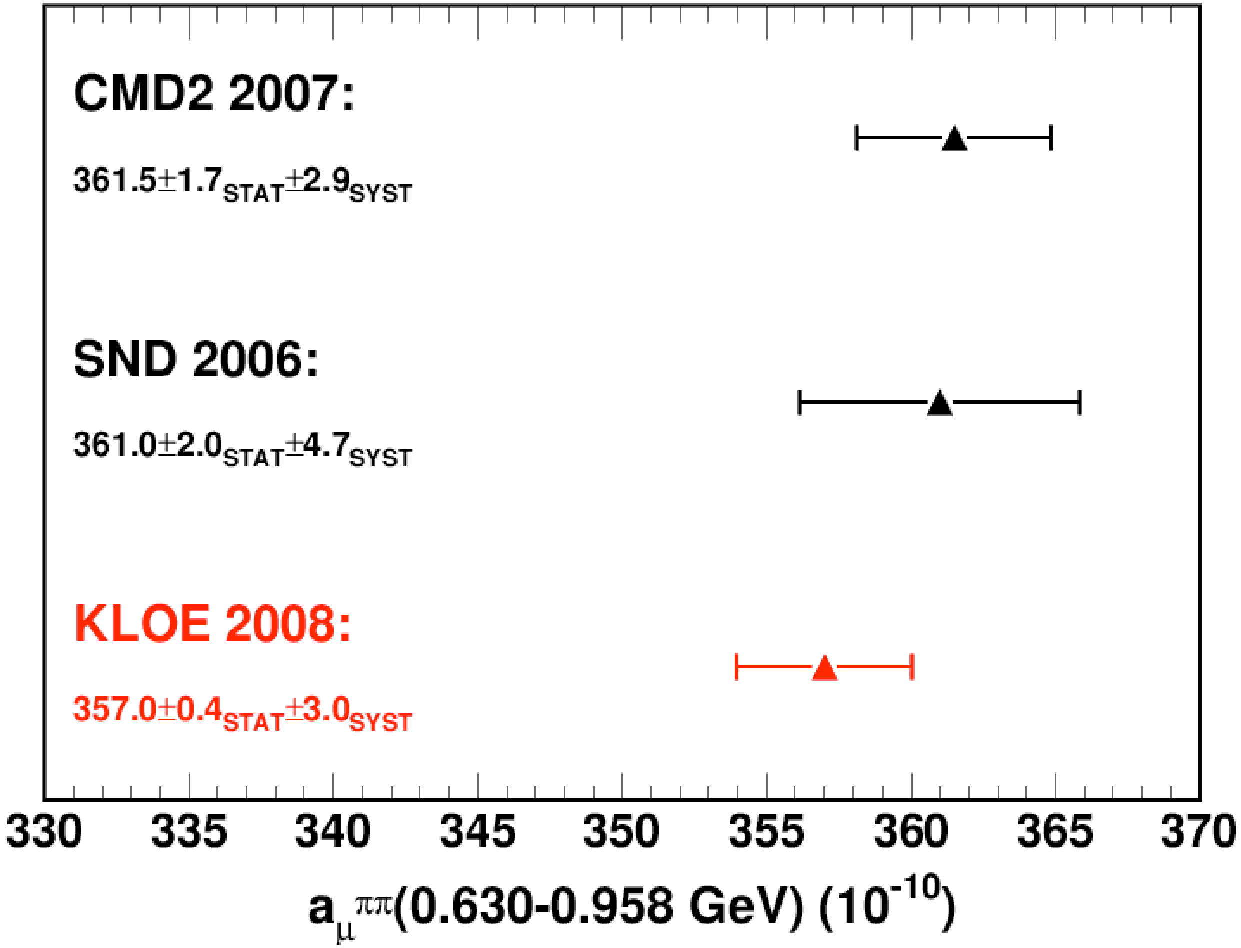
Comparison with $a_\mu^{\pi\pi}$ from CMD2 and SND in the range 0.630-0.958 GeV :

Phys. Lett. B648 (2007) 28

CMD2-2007	$a_\mu^{\pi\pi}(0.630\text{-}0.958\,\mathrm{GeV}) = (361.5 \pm 1.7_{stat} \pm 2.9_{sys}) \cdot 10^{-10}$
SND-2007	$a_\mu^{\pi\pi}(0.630\text{-}0.958\,\mathrm{GeV}) = (361.0 \pm 2.0_{stat} \pm 4.7_{sys}) \cdot 10^{-10}$
KLOE-2008	$a_\mu^{\pi\pi}(0.630\text{-}0.958\,\mathrm{GeV}) = (357.0 \pm 0.4_{stat} \pm 3.0_{sys}) \cdot 10^{-10}$

KLOE result in agreement with CMD2 and SND

$a_\mu^{\pi\pi}$ Summary:



KLOE result in agreement with CMD2 and SND

Conclusions

We have evaluated the contribution to $\Delta a_{\mu}^{\pi\pi}$ in the range between 0.35 - 0.95 GeV^2 using cross section data obtained via ISR events with photon emission at small angles.

- *The result from new data agrees with the updated result from the published KLOE analysis*
- *KLOE results also agree with recent results on* $\Delta a_{\mu}^{\pi\pi}$ *from the CMD2 and SND experiments at VEPP-2M in Novosibirsk*
- *better agreement in spectrum between different experiments than in the past*

The analysis is completed, and we consider the obtained results as final.

The analysis documentation and a paper draft have been written, and have been circulated in the KLOE collaboration with the request for comments.

We'd like to proceed and submit the finalized draft to arXiv/Phys. Lett. B as soon as possible!

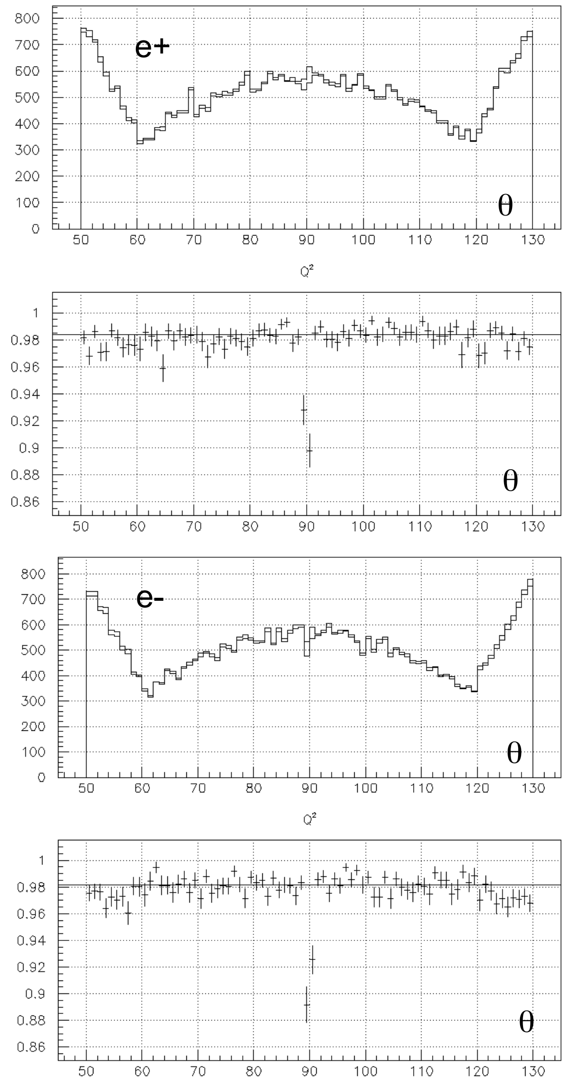
(possibly before the KLOE talk at TAU08 on wednesday)

Spares...

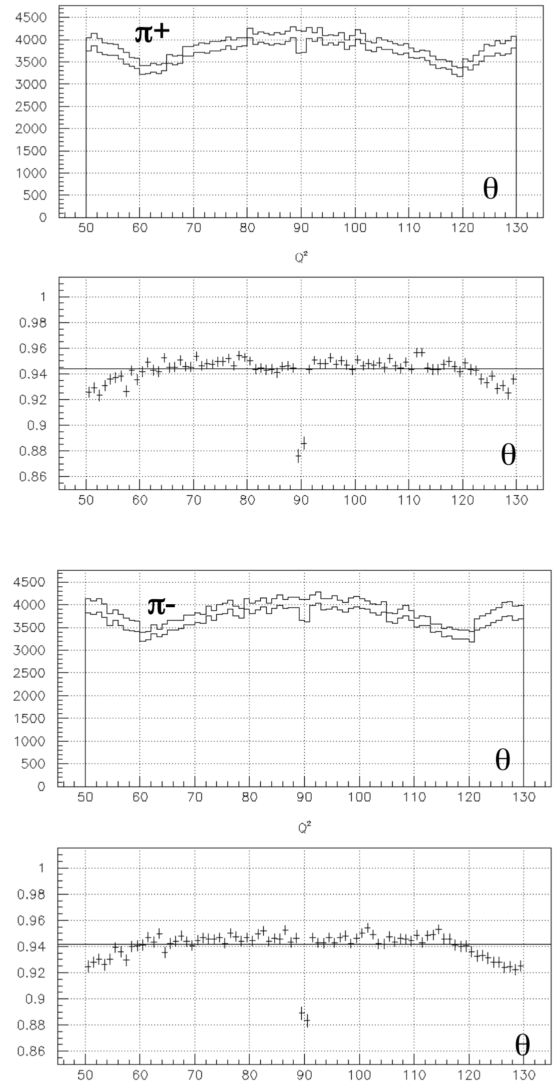
$0 < \rho_{PCA} < 8$ cm ; $0 < |z_{PCA}| < 7$ cm ; $\rho_{FH} < 8$ cm

PCA+FH efficiency for electron and pion tracks obtained from reconstructed $\phi \rightarrow \eta\gamma \rightarrow (ee\pi\pi)\gamma$ events satisfying **$50^0 < \theta_{Track} < 130^0$; $p_{T,Track} > 160$ MeV ; $|p_{Z,Track}| > 90$ MeV**

The efficiencies are then used as (additional) weights in the EKHARA generator.



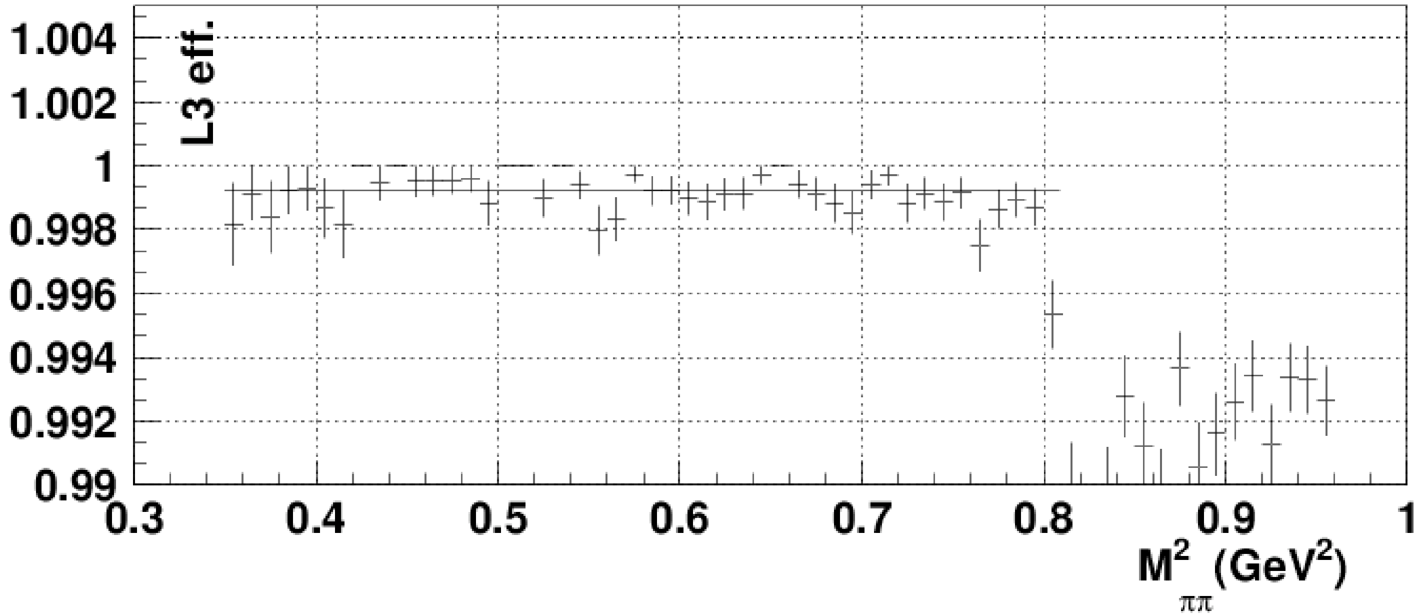
$\varepsilon_{e+,e-} \approx 0.98$



$\varepsilon_{\pi+,\pi-} \approx 0.94$

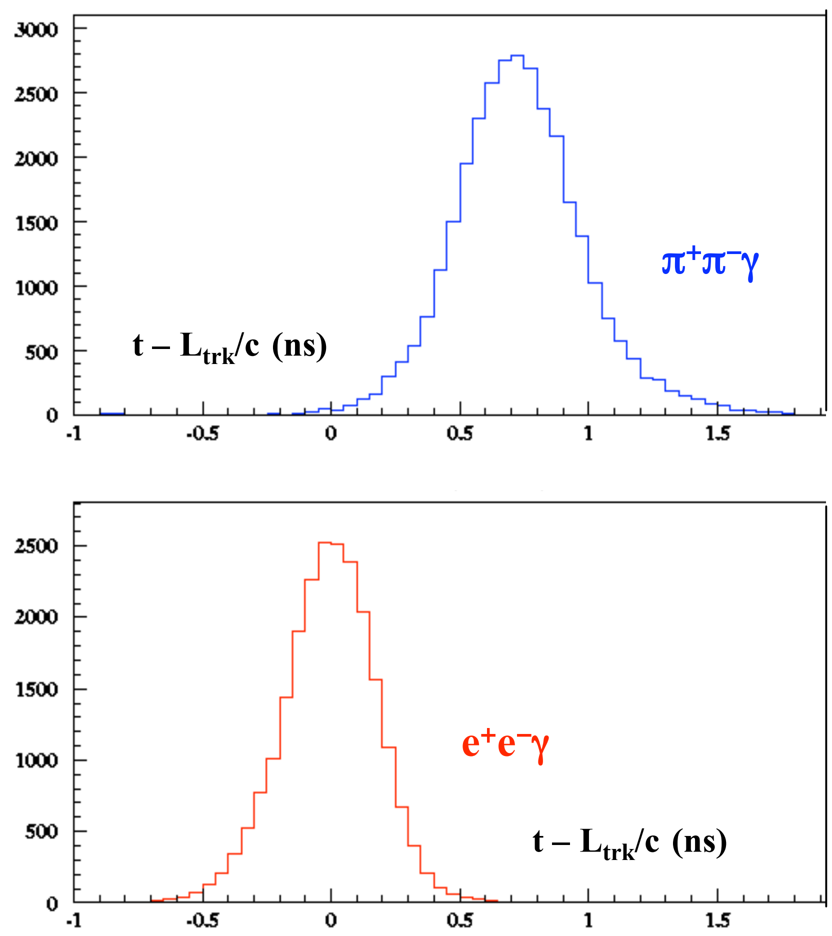
L3:

L3 trigger for events just after the selection of two good tracks and PCA and FH cuts:

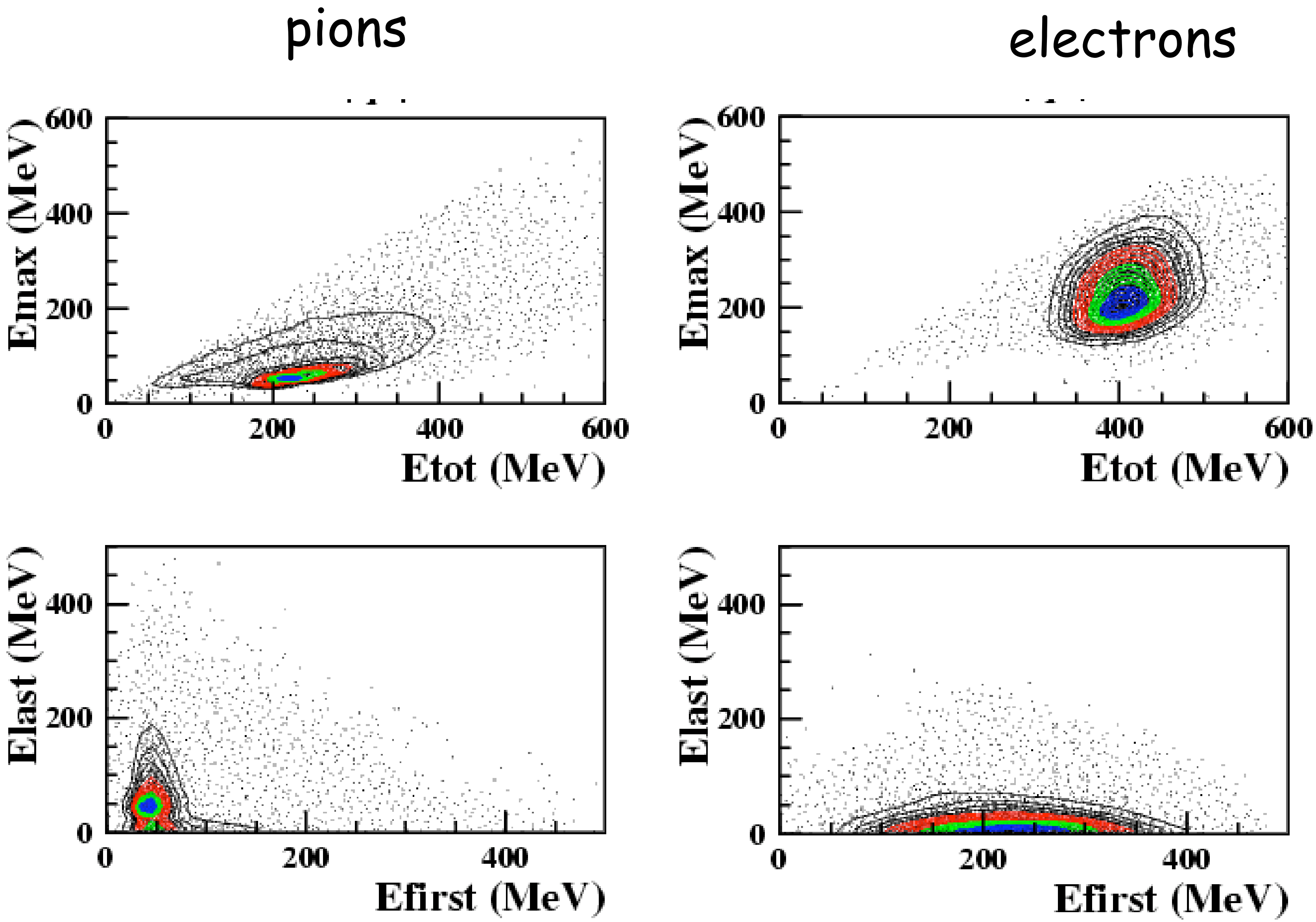


Lower efficiency above 0.8 GeV^2, due to pollution of sample with non-signal events (Cosmics?)

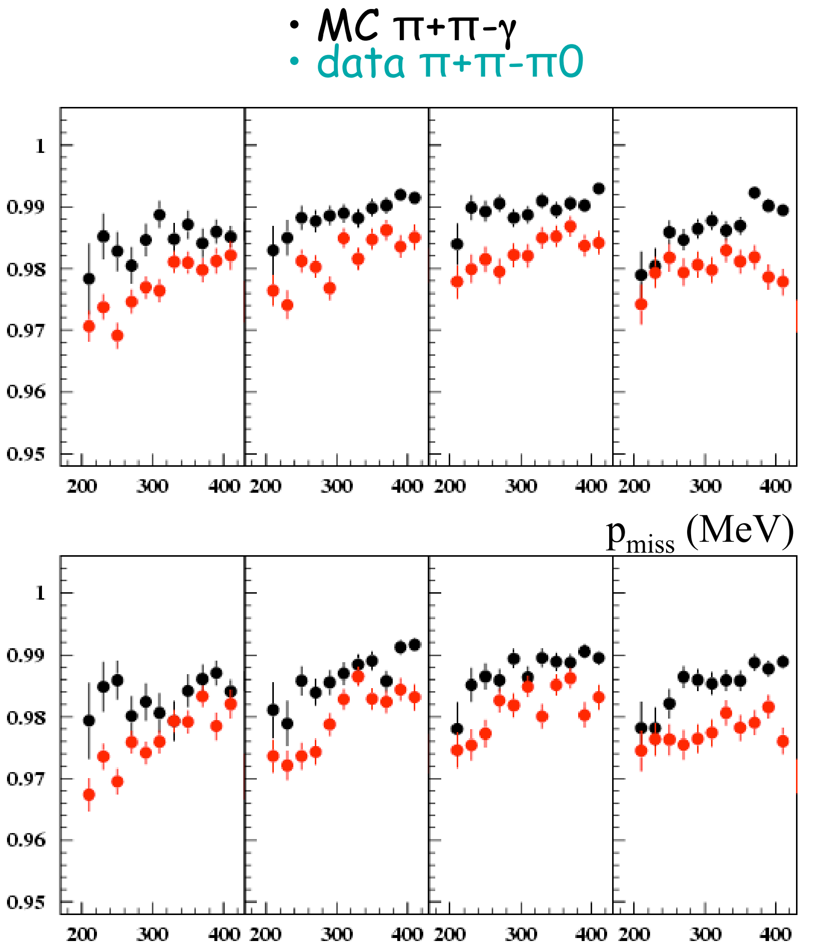
Likelihood variables: time of flight

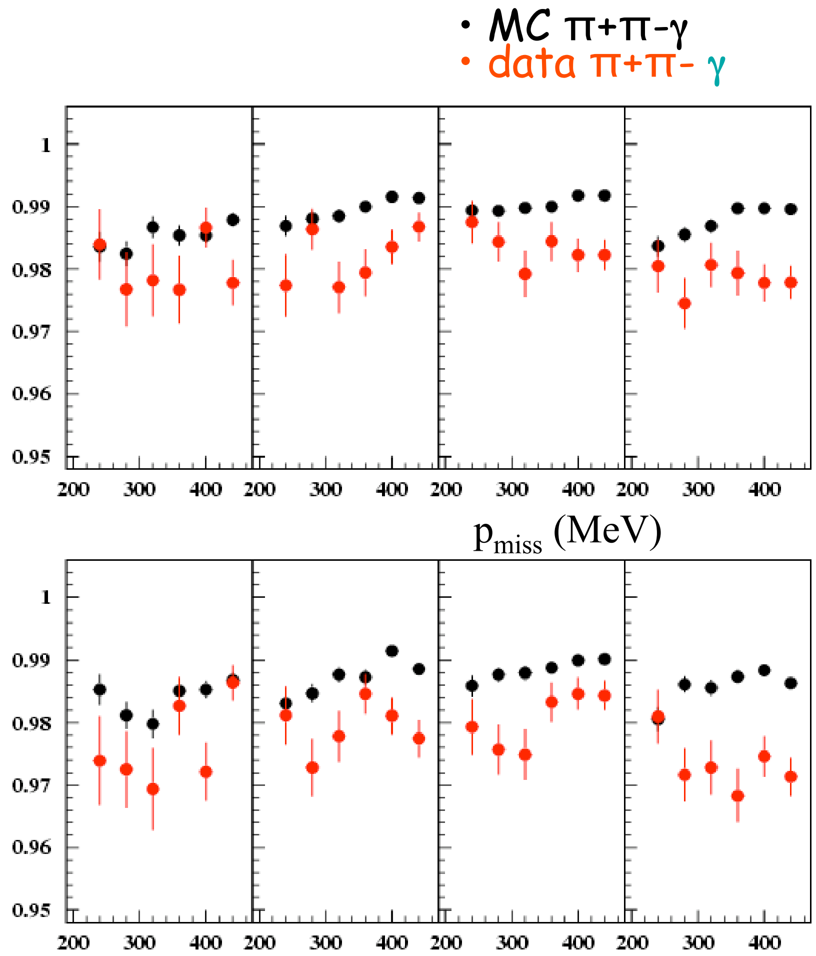


Likelihood variables: energy deposits



Tracking Data/MC corrections





large statistics, background free, but no access to p > 400 MeV

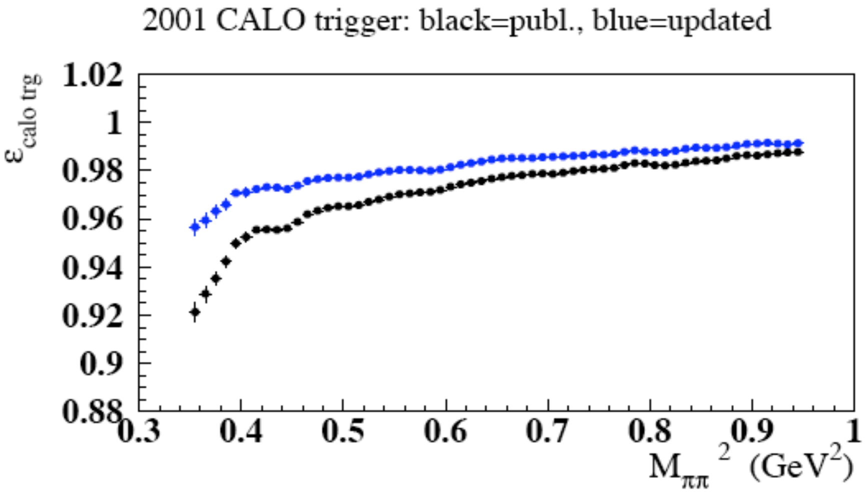
small statistics (hard cuts to minimize contamination), higher momentum

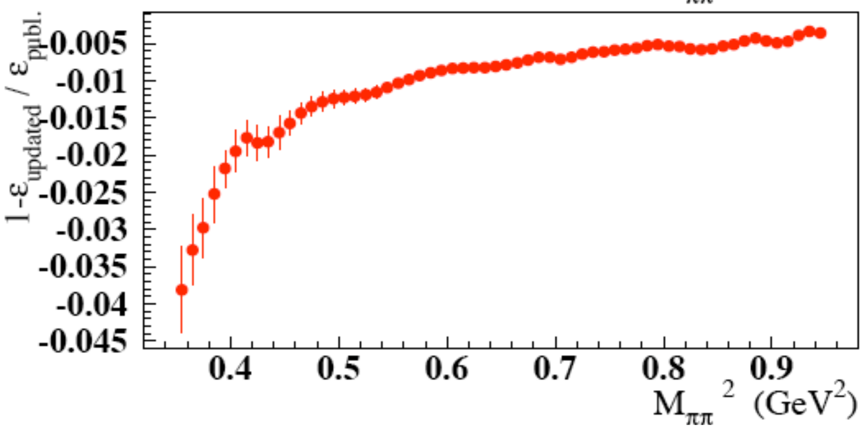
An update: trigger correction for 2001 data

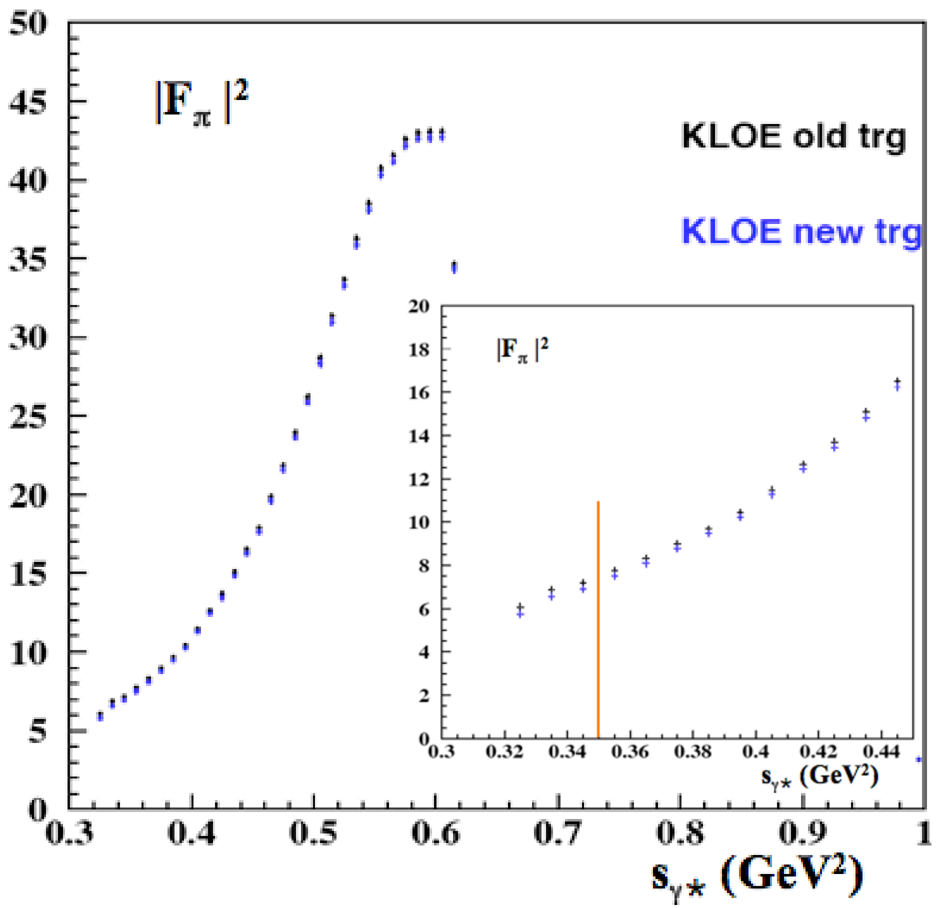
if P(0,1,2)=probability for the π^+, π^- or the rest of firing 0,1,2 trigger sectors,

found a concept bug: probability not conditioned on the presence of the cluster,

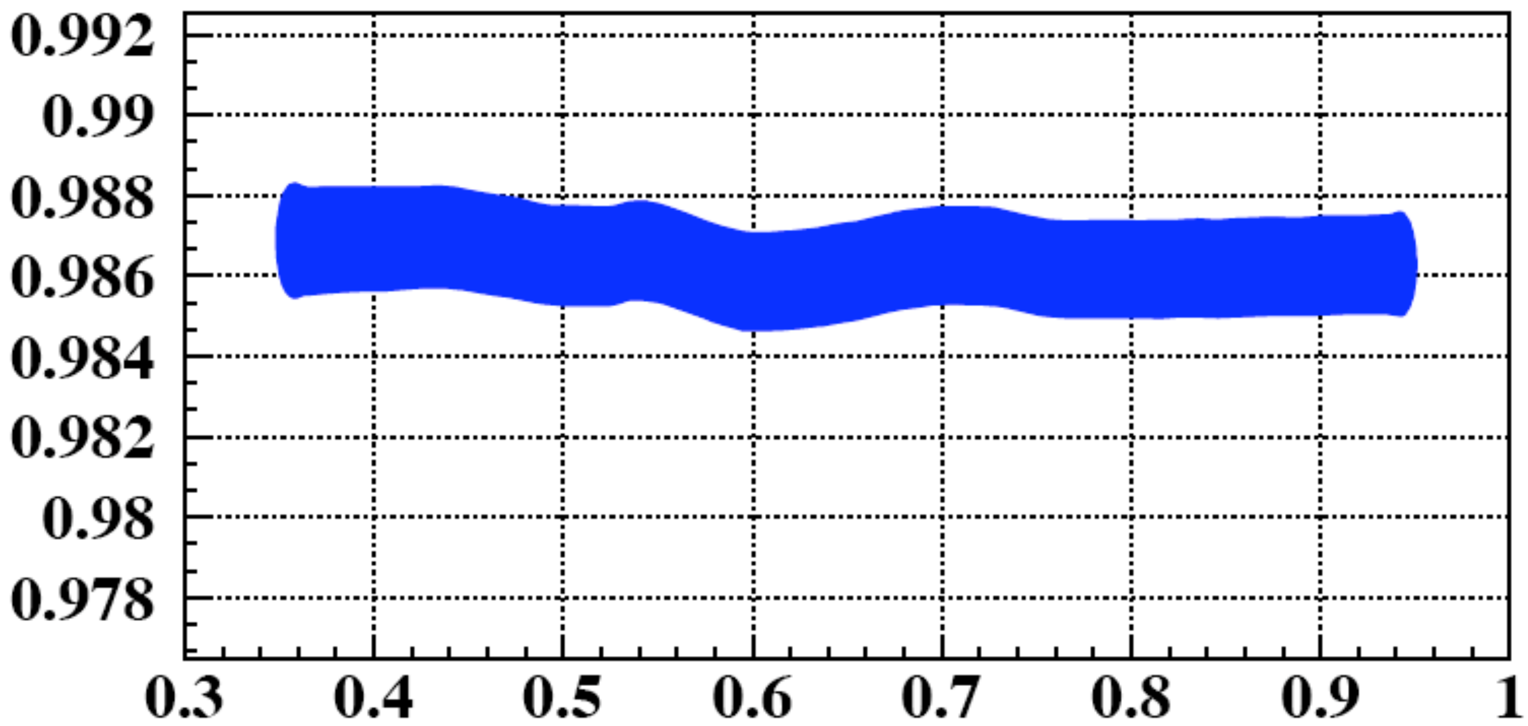
ex.: **P(1 sector ∩ 1 cluster)** instead of **P(1 sector | 1 cluster)**







Tracking correction: statistics impact



statistical errors on the correction factors are propagated in $M_{\pi\pi}$ bins

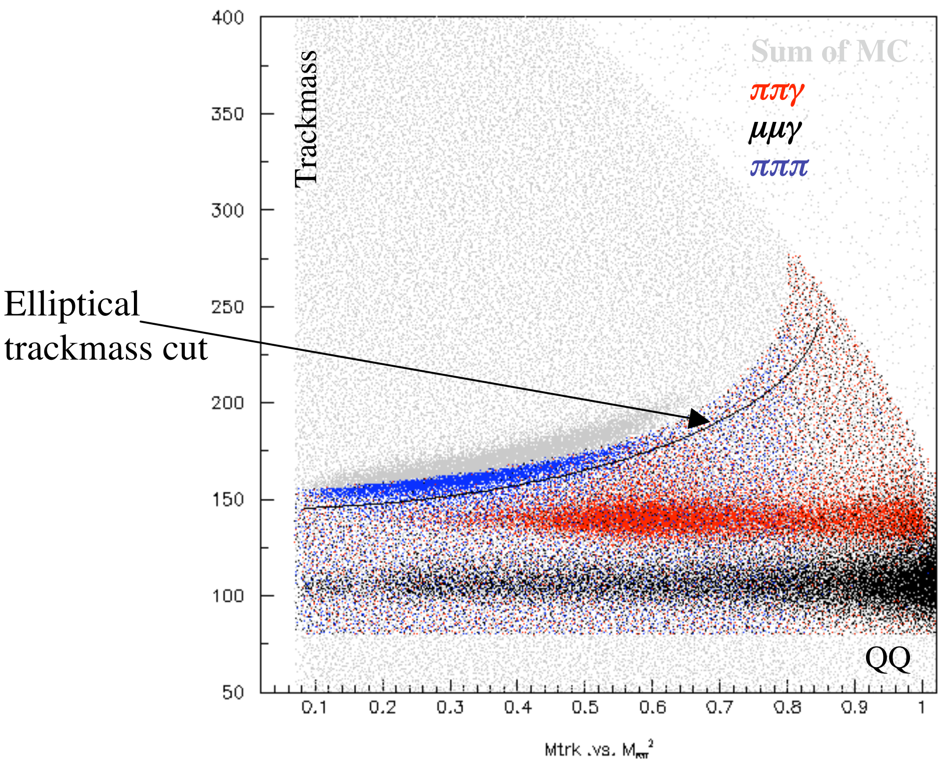
overall 0.1% effect

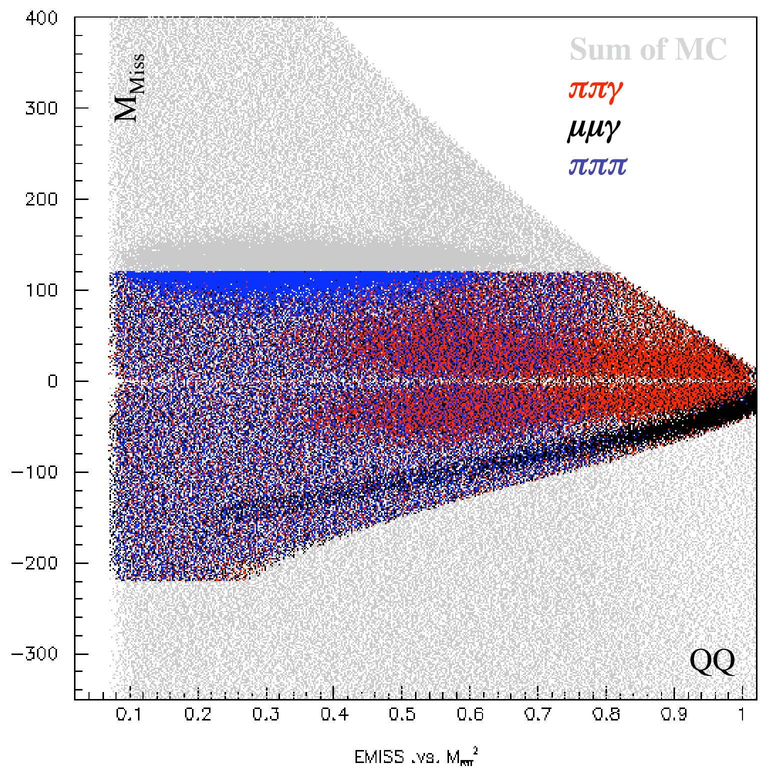
M_{Trk} and M_{miss} Eff.:

Effect of EVCL-cuts in M_{Trk} and* M_{Miss} from MC:

*defined by 4-momentum conservation under the hypothesis of $e^+e^- \to \pi^+\pi^- \mathbf{x}$

$$M_{miss} = \sqrt{E_X^2 - p_X^2}$$





The elliptical cut in M_{Trk} (needed to cut away $\pi\pi\pi$ events) is partially rejecting also nlo-FSR events, and it is sensitive to effects from FSR.

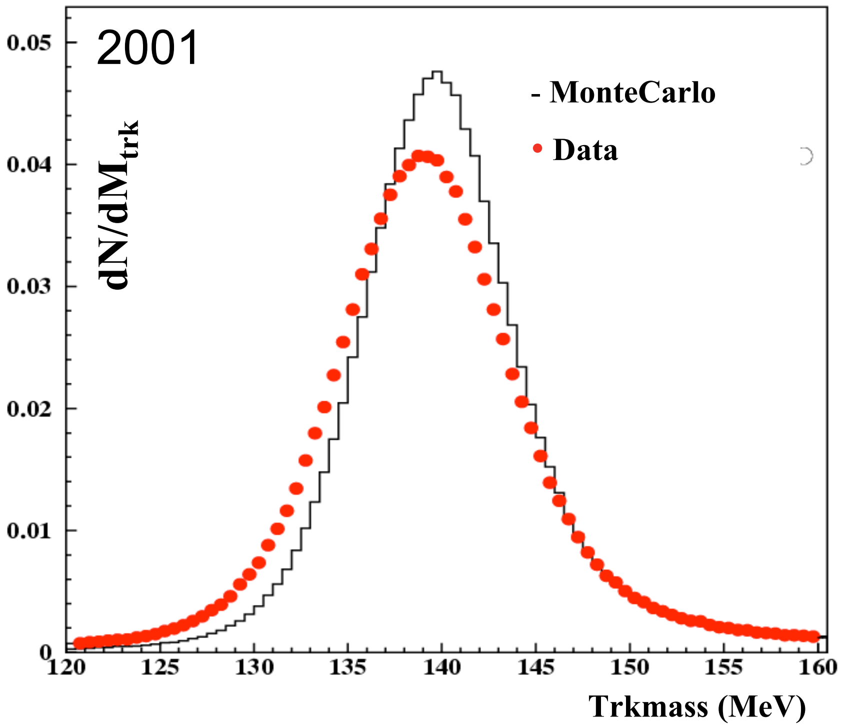
- Cross check eff. with downscaled sample of unstreamed data (UFO events)?
- Possible to release cut in the analysis using 2006 data at $\sqrt{s}$=1 GeV??

„Tuning“ of MC distr.:

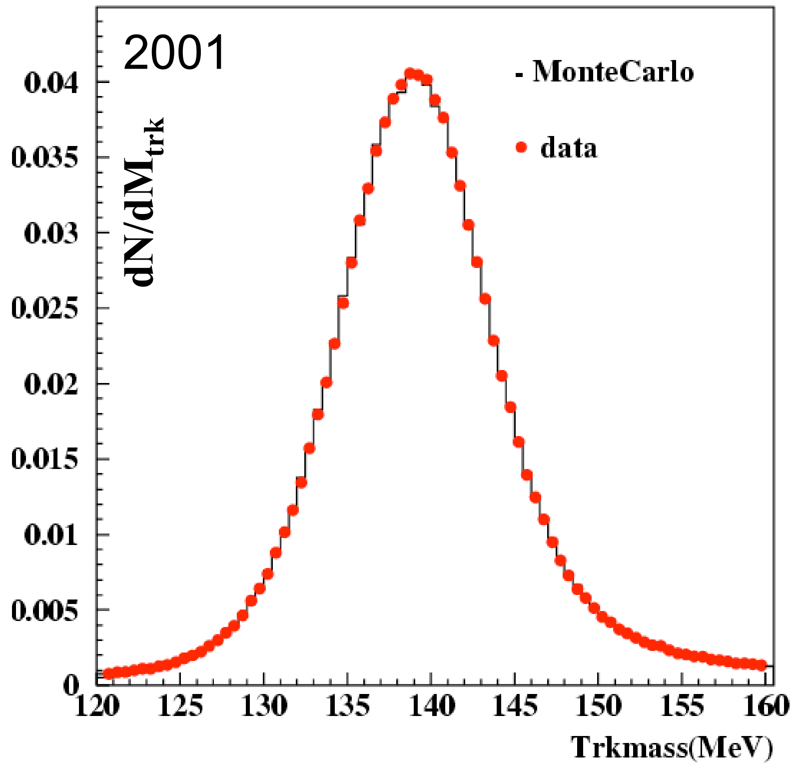
One needs to make sure that MC reproduces data distributions in a satisfactory way

- by matching individual datataking conditions *run-by-run* (int. Luminosity, $\sqrt{s}$, machine background,…)
- by *tuning* (smearing, shifting,…) MonteCarlo distributions in order to accommodate “hidden” effects (miscalibrations,…)

Before curing MC:



After curing MC:



Effect of different “tuning”-methods on background eval., MC eff., etc. contributes to systematic error.

Discrimination μ/π using neural networks

Multi Layer Perceptrons is a type of Neural Network widely used, interfaced with PAW/HBOOK, also used in kaon analyses

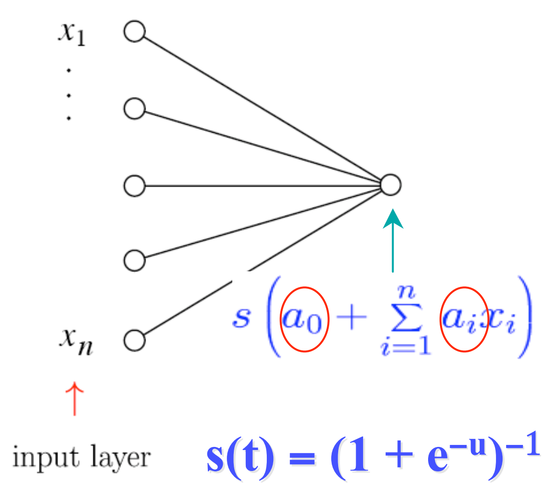
Input quantities are processed through successive layers; at the input layer ⇔ neurons = variables of the problem, in between layers = hidden layers, where variables are free to "interact" → output response

$$\Delta T = T_{clu} - \frac{L_{trk}\sqrt{p_{trk}^2 + m_\mu^2}}{c p_{trk}}$$

$$|\vec{r}_{clu} - \vec{r}_{ext}|$$

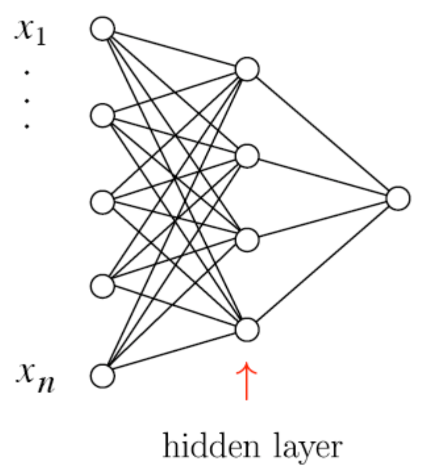
$$\frac{E_{clu}}{\sqrt{p_{trk}^2 + m_\mu^2}}$$

Single Layer

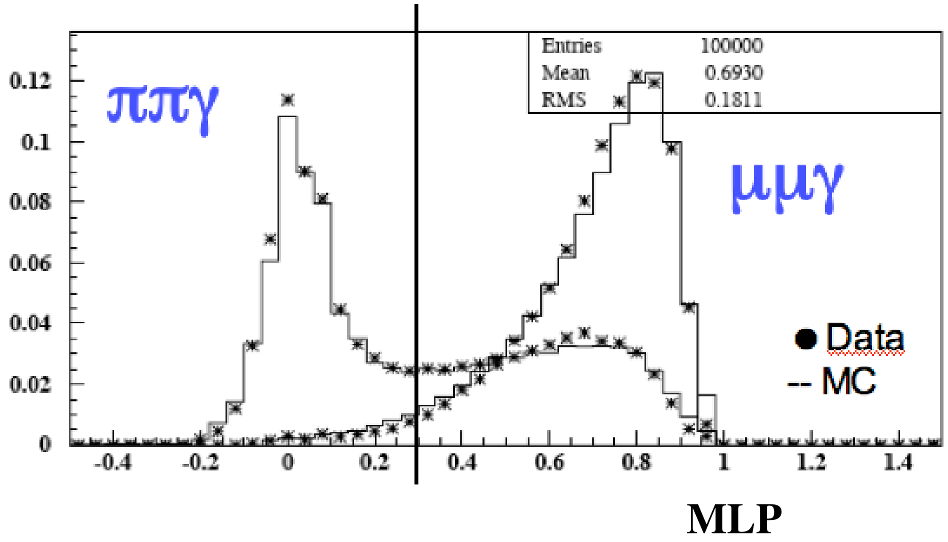


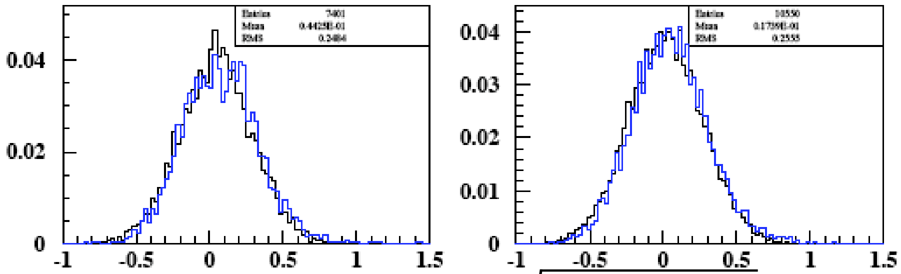
$$s(t) = (1 + e^{-u})^{-1}$$

Multi Layer



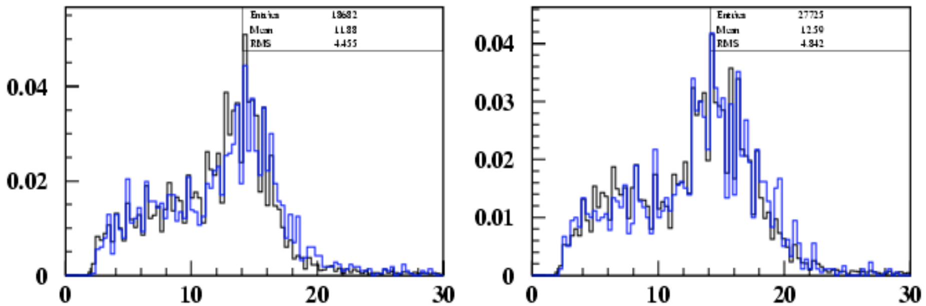
Training and performance of the MLP





$$\Delta T(ns) = T_{clu} - \frac{L_{trk}\sqrt{p_{trk}^2 + m_\mu^2}}{cp_{trk}}$$

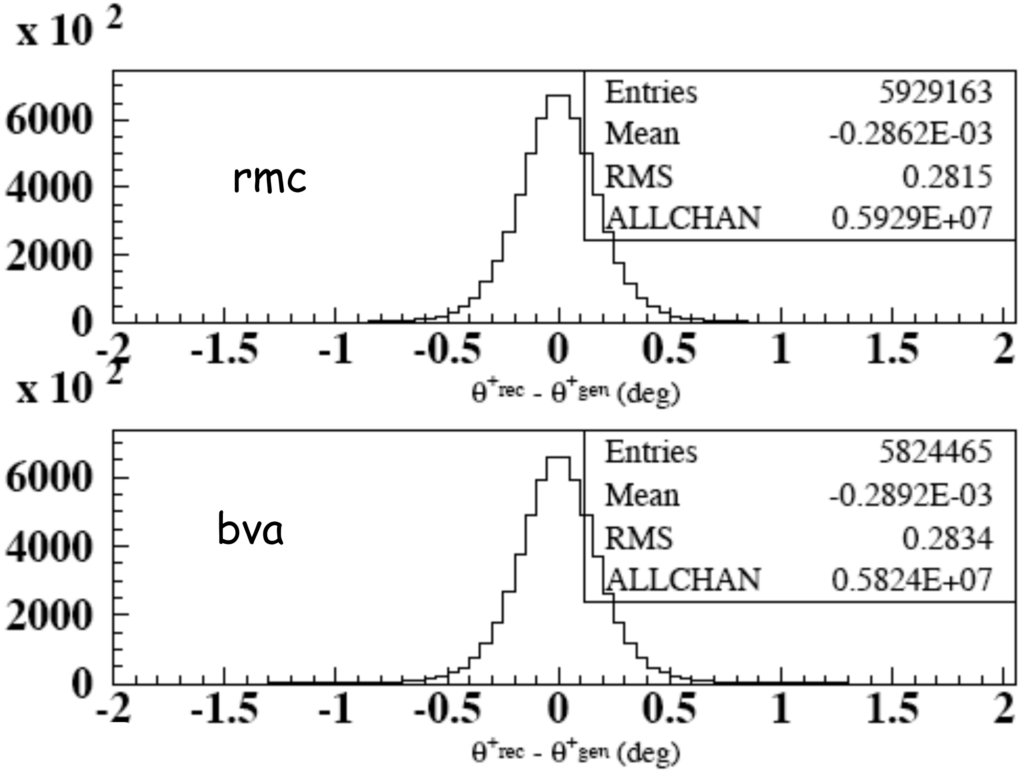
300<p<350 350<p<400



$$|\vec{r}_{clu} - \vec{r}_{ext}|(cm)$$

MLP function developed with the specific aim of single track π/μ discrimination for our analysis, trained on both data and MC samples

Acceptance on track direction



LEGENDA:

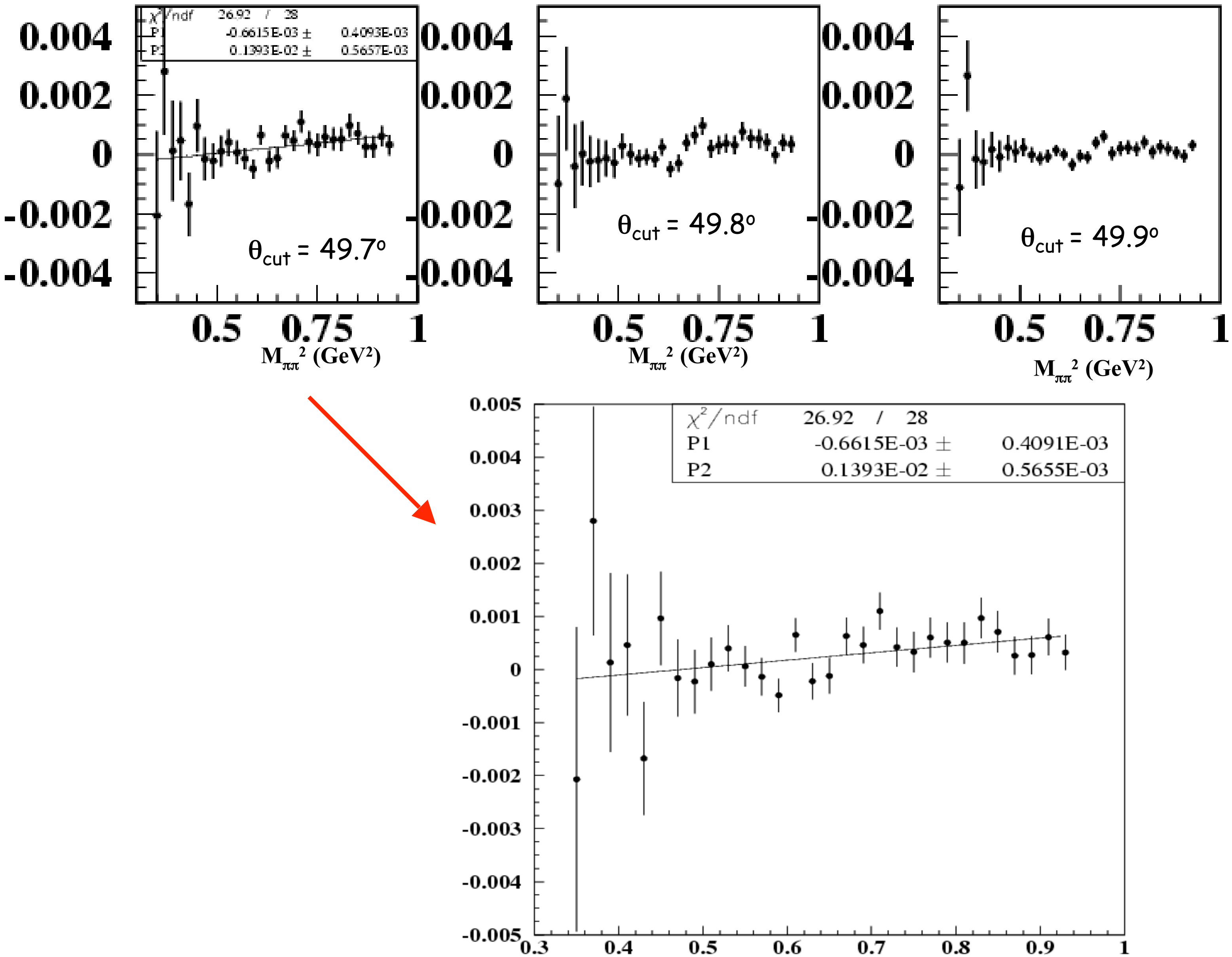
rmc = no smearing at all

bva = Bini-Valeriani

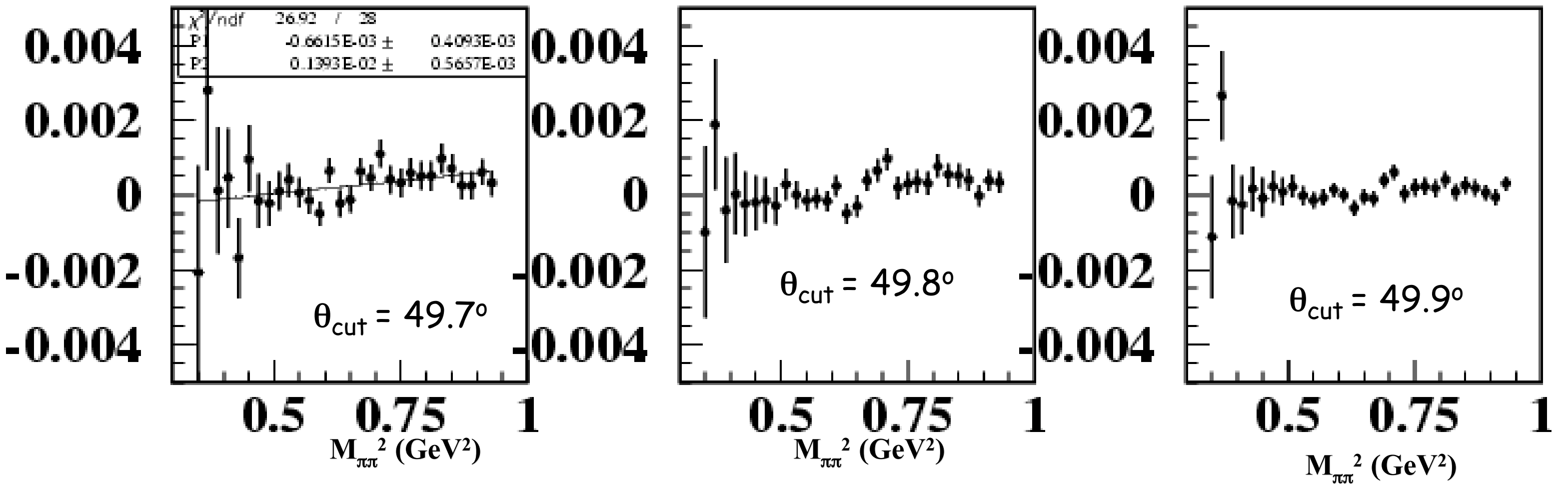
the spectrum excursion up to 0.3^o is studied

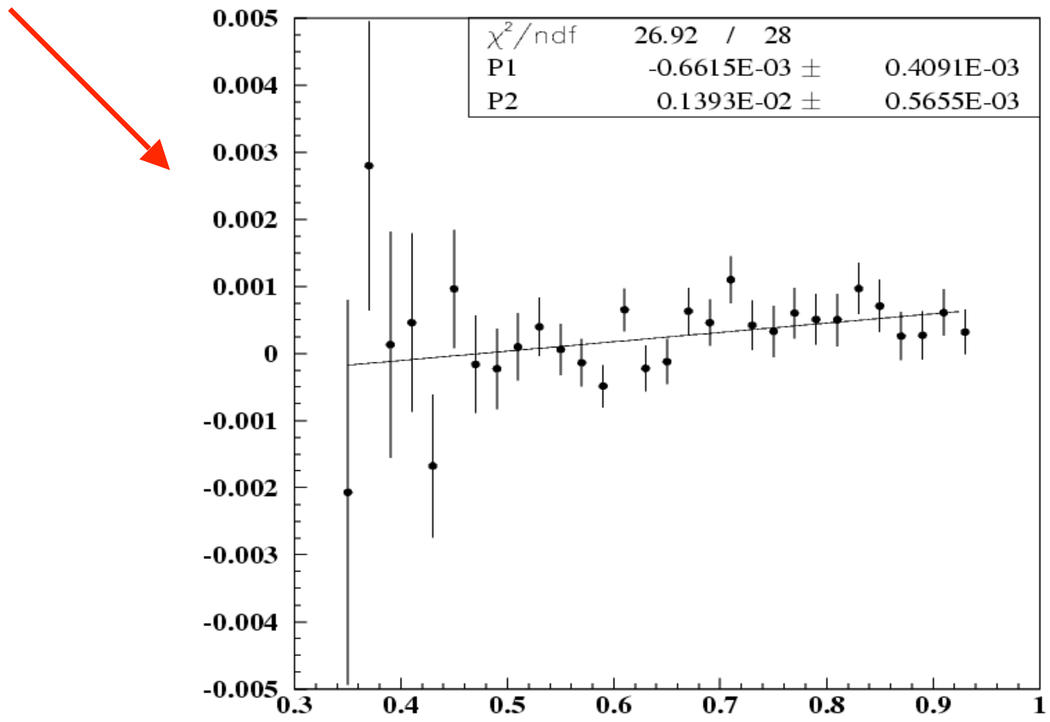
$$\frac{N_i^{MC}(\theta_{cut} < \theta)}{N_i^{MC}(50^o < \theta)} - \frac{N_i^{data}(\theta_{cut} < \theta)}{N_i^{data}(50^o < \theta)}$$

Acceptance on track direction

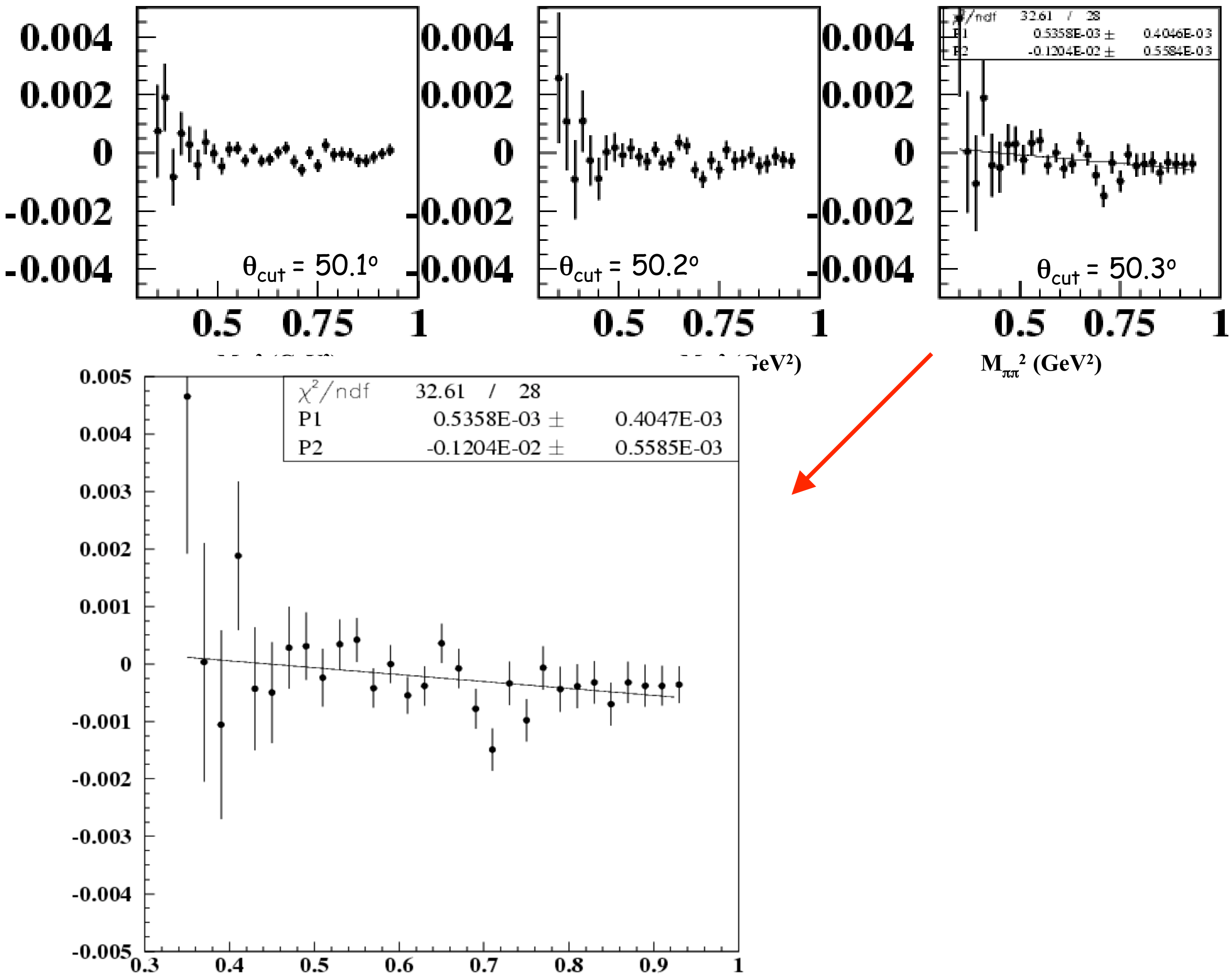


Acceptance on track direction





Acceptance on track direction



Error propagation for mapping

estimator for the efficiency

$$\langle \varepsilon \rangle = \sum_{k=1}^{n} \frac{\nu_k}{N} \varepsilon_k$$

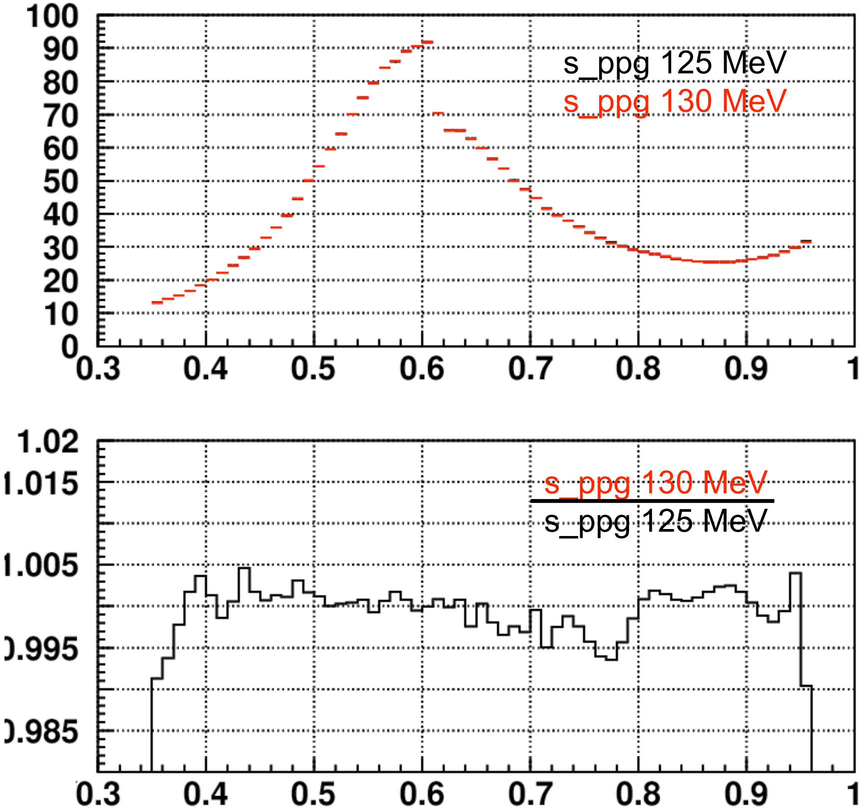
estimator for the variance

$$\sigma_\varepsilon^2 = \frac{n}{n-1}\left[\sum_{k=1}^{n} \frac{\nu_k}{N} \varepsilon_k^2 - \langle \varepsilon \rangle^2\right] + \sum_{j=1}^{n} \left(\frac{\nu_j}{N}\right)^2 \left(\delta \varepsilon_j\right)^2$$

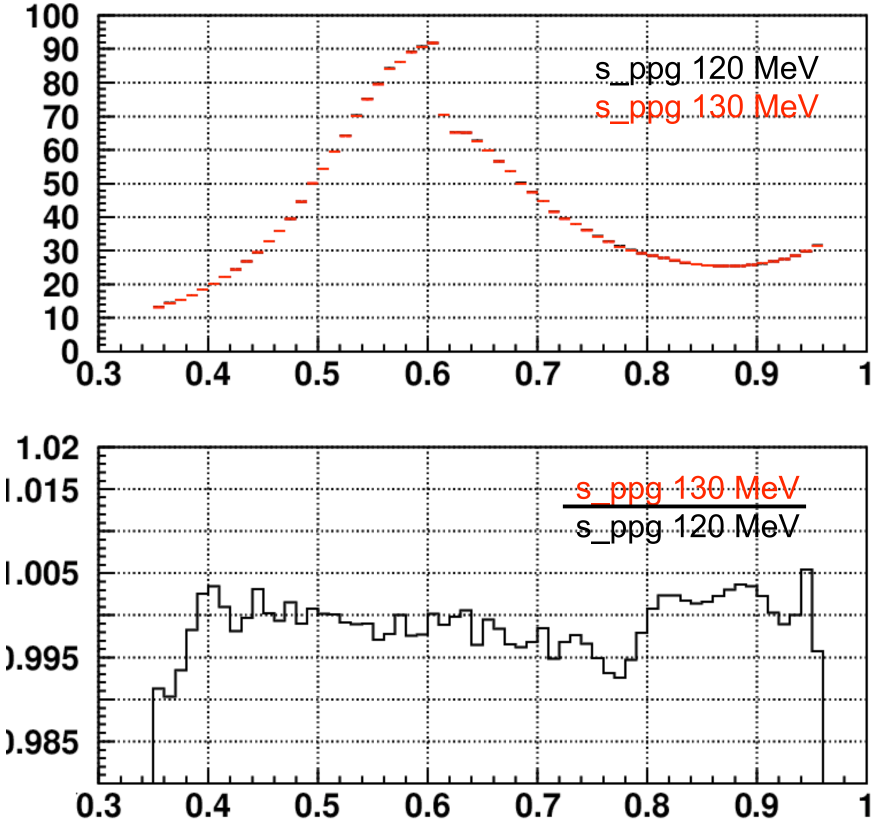
[1] H. Cramer, *Mathematical Methods of Statistics*, Princeton University Press, 1951

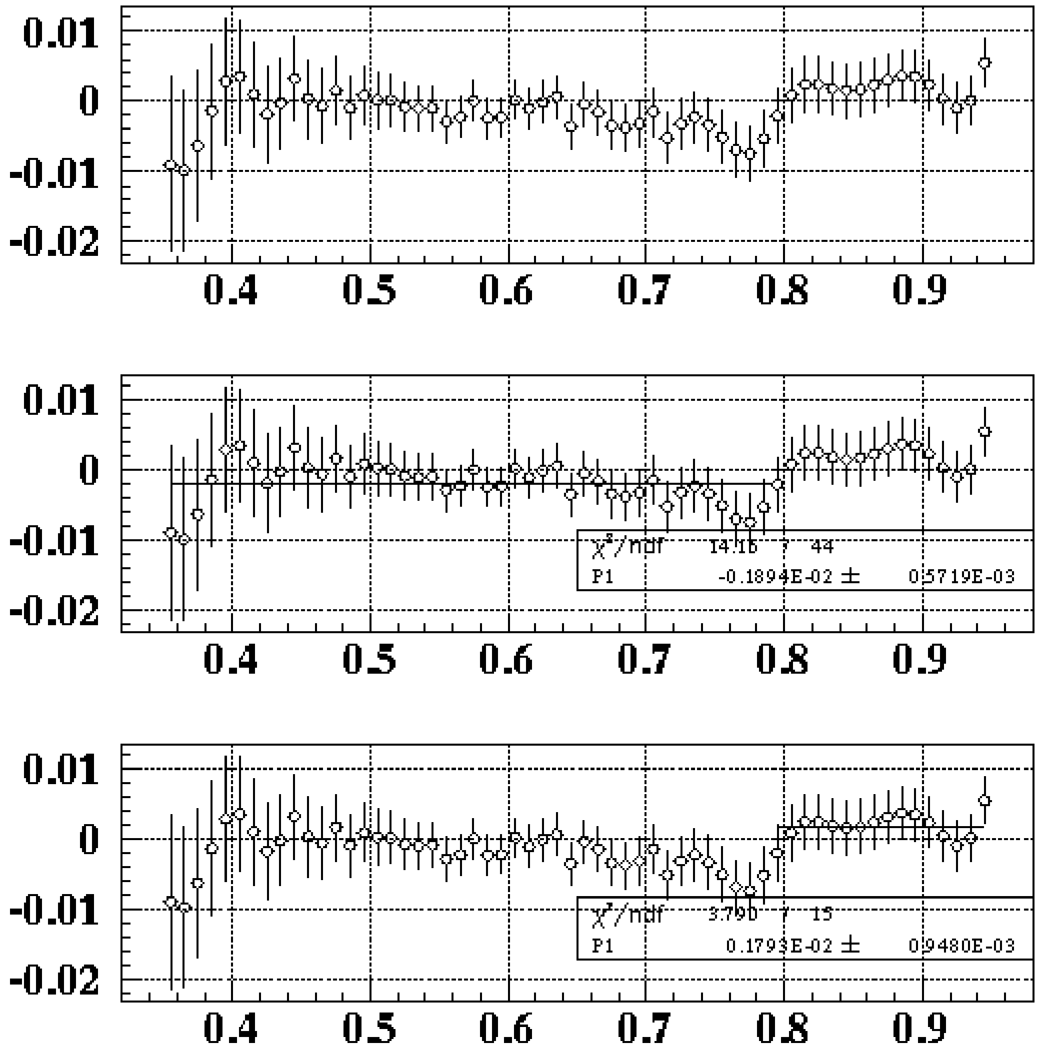
[2] M.G. Kendall & A. Stuart, *The Advanced Theory of Statistics*, Griffin, 1973

Check with M_trk > 125 MeV:

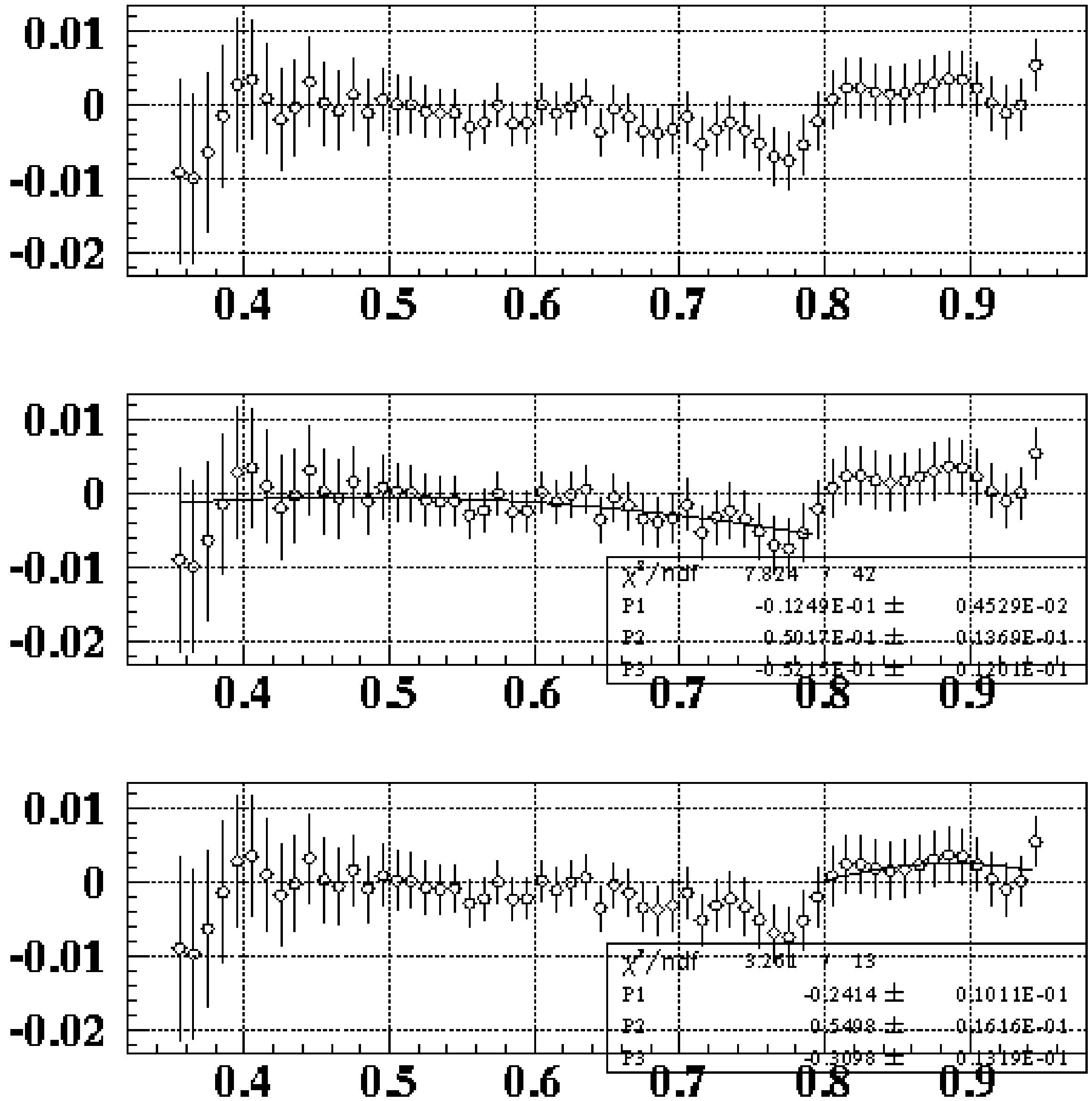


Check with M_trk > 120 MeV:





0.01
0
-0.01
-0.02
0.4
0.5
0.6
0.7
0.8
0.9
χ²/ndf 14.16 / 44
P1 -0.1894E-02 ± 0.5719E-03
χ²/ndf 3.790 / 15
P1 0.1793E-02 ± 0.9480E-03



0.01
0
-0.01
-0.02
0.4
0.5
0.6
0.7
0.8
0.9
χ²/ndf 7.824 / 42
P1 -0.1249E-01 ± 0.4529E-02
P2 0.5017E-01 ± 0.1369E-01
P3 -0.5215E-01 ± 0.1201E-01
χ²/ndf 3.261 / 13
P1 -0.2414 ± 0.1011E-01
P2 0.5408 ± 0.1616E-01
P3 -0.3098 ± 0.1319E-01