$K^{\pm} \rightarrow \pi^{\pm} \pi^{0}_{\gamma\gamma}$ e+ e- analysis

NA62 Collaboration meeting

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NA48/2 rare decay session

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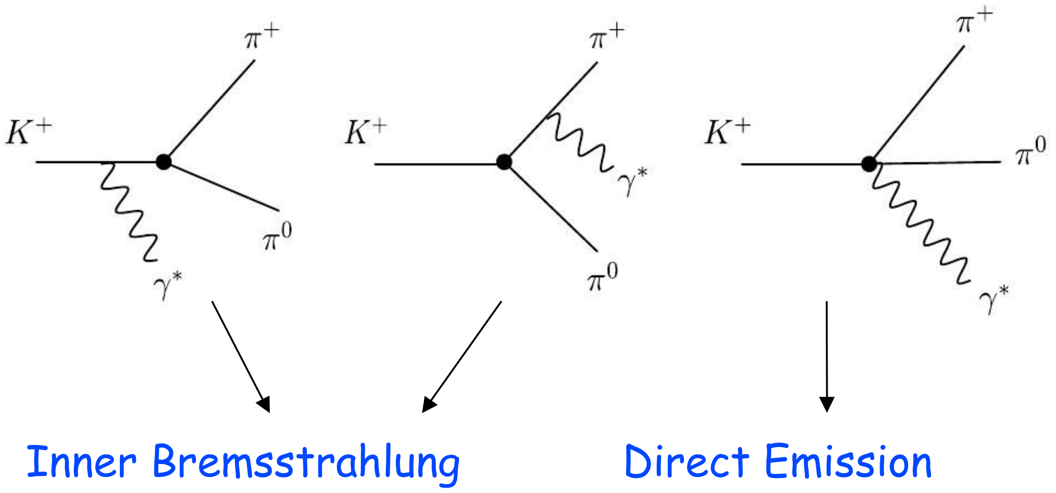
Introduction



$$\Gamma_{total} = \int |A|^2 d\Phi$$

$$|A|^2 = const.*(|A_E|^2 + |A_M|^2 + A_{EM})/q^4$$

A_E=electric(Brem+DE), A_M=magnetic and

A_{EM}= interference term, $q^2 = Mee^2$

- **Theoretical papers**

  1) L.Cappiello, O.Cata, G. D'Ambrosio, Dao Neng Gao, " $K^\pm \rightarrow \pi^\pm \pi^0$ e+e- :a novel short-distance probe", Eur.Phys.J.C 72 (2012)

  2) H. Pichl, "$K^\pm \rightarrow \pi^\pm \pi^0$ e+e- decays and chiral low energy constants", Eur.Phys.J.C20 (2001)

  3) S. Gevorkyan "Different approaches to calculate $K^\pm \rightarrow \pi^\pm \pi^0$ e+e- decay width", Eur. Phys. J. C (2014) 74:

- **First experimental observation**

Reminder

Last year – NA62 Collaboration in Liverpool, August 2013

- I and Mauro had an agreement of ~ 1.5% for the signal (K2pp0ee) and the reference channel (K2piDalitz)
- We used MC list with no radiative corrections for $K^{\pm} \to \pi^{\pm} \pi^{0} e^{+} e^{-}$
- The main contributions for the signal were generated – Inner Bremsstrahlung (IB) and direct emission (DE)
- Electric Interference missed in order to have complete tree-level description of the K2pp0ee

The 1st MC list of K2pp0ee is based on the article:

L.Cappiello, O.Cata, G. D'Ambrosio, Dao Neng Gao, " $K^{\pm} \to \pi^{\pm} \pi^{0}$ e+e- :a novel short-distance probe", Eur.Phys.J.C 72 (2012)

→ tanks to Mauro

The 2nd MC list is based on the paper:

H. Pichl, "$K^{\pm} \to \pi^{\pm} \pi^{0}$ e+e- decays and chiral low energy constants", Eur.Phys.J.C20 (2001)

→ the generator was realized on rewritten Pichl's formulation of the matrix element in Ke4 variables

by S. Gevorkyan /"Different approaches to calculate $K^{\pm} \to \pi^{\pm} \pi^{0}$ e+e- decay width", Eur. Phys. J. C (2014) 74: 2860/

Reminder – MC status: Comparison between the generators based on the two papers

Papers: H. Pichl and L.Cappiello, O.Cata, G. D'Ambrosio, Dao Neng Gao paper – NO RADIATIVE CORRECTIONS:

Mee > MeV	Cappiello etc. MC – IB	Pichl MC – IB	Cappiello etc. MC – DE	Pichl MC – DE
1.022	1	1	1	1
2	0.736	0.735	0.865	0.856
4	0.467	0.463	0.693	0.687
8	0.263	0.2616	0.519	0.515
15	0.135	0.133	0.363	0.359
35	0.0373	0.0368	0.167	0.174
55	0.0136	0.0134	0.082	0.088
85	0.00332	0.00330	0.026	0.031
100	0.00154	0.00154	0.013	0.016
120	0.00051	0.00055	0.005	0.007
140	0.00015	0.00016	0.0016	0.0025

H. Pichl is corrected (due to S.Gevorkyan).

Both generators based on different papers are in a perfect agreement for the main contributions –Inner Bremsstrahlung and Direct Emission.

MC: Electric Interference

The Electric Interference (BE) is implemented in private cmc007 by using the following expression (thanks to Oscar Cata):

T11*(F1_B*F1_DE) + T22*(F2_B*F2_DE) + T12*(F1_B*F2_DE + F1_DE*F2_B)

Mee > cut MeV	Cappiello et. al. El. Interference BE	MC generator
1.022	1	1
2	0.849	0.853
4	0.662	0.6742
8	0.473	0.4868
15	0.356	0.3276
35	0.116	0.145
55	0.0453	0.0713
85	0.00857 ~ 0.01	0.0242
100	0.00288	0.0141
120	1.6e-04	0.0063
140	-2.72e-04	0.0026
180	-4.83e-04	0.0001

Not perfect agreement for all kinematic region

but

the generator coincides pretty good for this interval of Mee-distribution where we have ~90% of statistics.

Present MC status:

Now we have all contributions (IB, DE, Electric INT) simulated by cmc007 where the INT between magnetic and electric parts is 0 in tree-level description. We have MC list with Coulomb correction+PHOTOS due to Mauro for the dominant IB contribution.

Thanks to Evgueni there are available 2 MC lists for K2piDalitz with rad.corr. of pi0Dalitz decay – K2pi rad.corr+pi0Dalitz Mikaelian-Smith (MS) corr.; K2pi rad.corr+Prague rad.corr.

Radiation of real photons from pi0Dalitz decay is not simulated in any of these two MC lists.

We use in the analysis MC list of K2pi (Gatti) + Photos of pi0Dalitz decay (due to Mauro)

Selection criteria

Use the full 2003 data (SS0-1-2-3) –

Ke4 split list (thanks to Spasimir) /Only good bursts for PHYS, DCH, MBX, LKR, HODC ;

At least one 3 track vertex satisfying the criteria below ; At least 1 cluster;

Zvertex to be within (-2000. : 8000.) cm ; Distance between vertex tracks

at DCH1 > 1 cm; At least one electron (P>1.5GeV and E/p >0.8) /

Hard cuts are implemented as far as Evgueni showed that the acceptance and differential decay rate for pi0Dalitz have very steep (opposite) slopes at low e+e- /requirement for Mee > 10 MeV/.

Corrections used in the selection criteria: ⇒

Name of correction	Data	MC
Lkr nonlinearity	yes	no
Projectivity	yes	yes
Alpha and beta	yes	yes
Blue field	yes	yes

Common selection criteria for the signal and the normalization channel:

3 < Number of clusters < 8

Number of tracks to be < 10

Good vertex:

Z vertex within (-1000 – 8000) cm

N tracks in vertex == 3

Good tracks:

12 cm < R DCH1 < 135 cm

12 cm < R DCH4 < 135 cm

2 GeV< P tracks < 60. GeV

Track quality > 0.7

Time of tracks to be within (116 – 154) ns

Good clusters

Lkr octagon cut

2 GeV < Energy clusters < 60 GeV

Distance cluster to cluster > 10 cm

Distance cluster to dead cell > 2 cm

Status cluster < 4

Selection criteria – I

$K \rightarrow \pi\,\pi^0\, e+\, e-$	$K \rightarrow \pi\,\pi^0 \rightarrow \pi\, e+\, e-\, \gamma$
N good clusters >= 4	**N good clusters >= 3**
N good clusters with no assoc.trk = 2	N good clusters with no assoc.trk = 1
Energy gamma-clusters > 3 GeV	Energy gamma-clusters > 3 GeV
N good clusters with assoc. trk >= 2	N good clusters with assoc. trk >= 2
N good tracks = 3	N good tracks = 3
N e+ = 1 && Ne- = 1 → E/P > 0.85	N e+ = 1 && Ne- = 1 → E/P > 0.85
N π = 1 → E/p < 0.85	N π = 1 → E/p < 0.85
N vertex =1 && Q vertex = ± 1	N vertex =1 && Q vertex = ± 1
	(av. Time e-/e+ – time γ) to be within 5 ns
Momentum of e+/e- > 2 GeV	**Momentum of e+/e- > 3 GeV NEW**
Check vertex consists of e+, e-, π	Check vertex consists of e+, e-, π
Chi2 vertex < 25 cm	Chi2 vertex < 25 cm
Dist. Between e+ & e- > 0.25 cm at DCH1	Dist. Between e+ & e- > 0.25 cm at DCH1
Z vertex within (-1000 – 8000) cm	Z vertex within (-1000 – 8000) cm
COG < 2cm	COG < 2cm
Mee > 3 MeV NEW	**Mee > 10 MeV NEW**

Selection criteria – II

$K \to \pi\,\pi^0$ e+ e-	$K \to \pi\,\pi^0 \to \pi$ e+ e- γ
Dist. Extrapolated non deflected e+/e- & γ >2 cm at LKr	Dist. Extrapolated non deflected e+/e- & γ >2 cm at LKr
Abs(Mee $\gamma 1/\gamma 2$ – Mπ0) < 7 MeV NEW	----------------
----------------	**Momentum charged pion > 10 GeV NEW**
M $\pi\pi$ > 120 MeV NEW	-------------------
Energy reconstructed K within (54 – 66) GeV	Energy reconstructed K within (54 – 66) GeV
Abs(Mass K - MK_PDG) < 10 MeV	Abs(Mass K - MK_PDG) < 10 MeV

Normalization channel ($K \to \pi\,\pi^0 \to \pi$ e+ e- γ) :

Mee > 10 MeV && Pe > 3 GeV reduces the statistics more than 50%

Signal channel ($K \to \pi\,\pi^0$ e+ e-) :

M$\pi\pi$ > 120 reduces $K \to \pi\pi^0\pi^0$ Dalitz BGR with a factor of 7

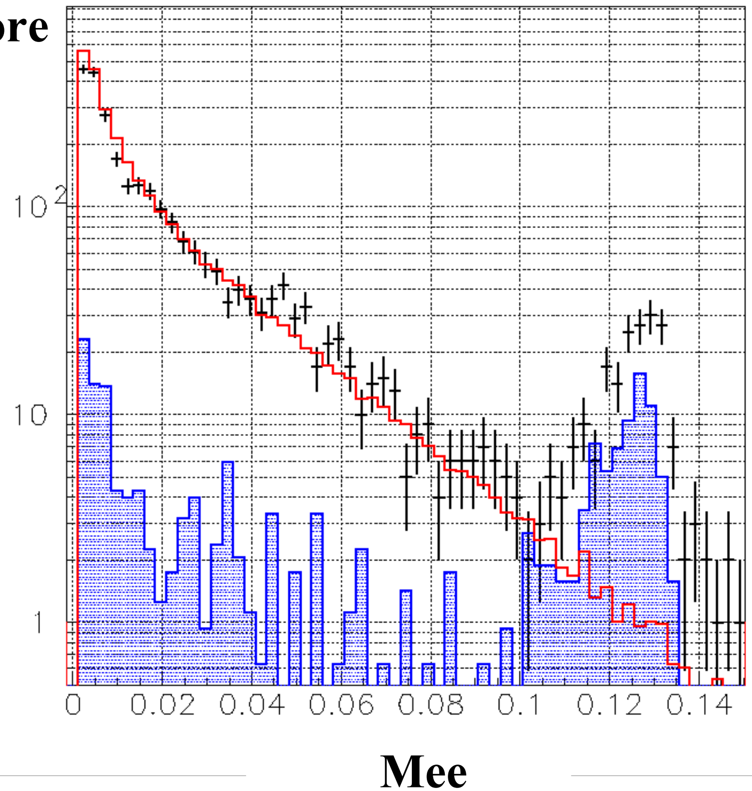
abs(Mee g - Mπ PDG) > 7 MeV reduces K2$\pi\pi^0$Dalitz(γ) BGR with a factor of 2.5

Mee – background status of signal

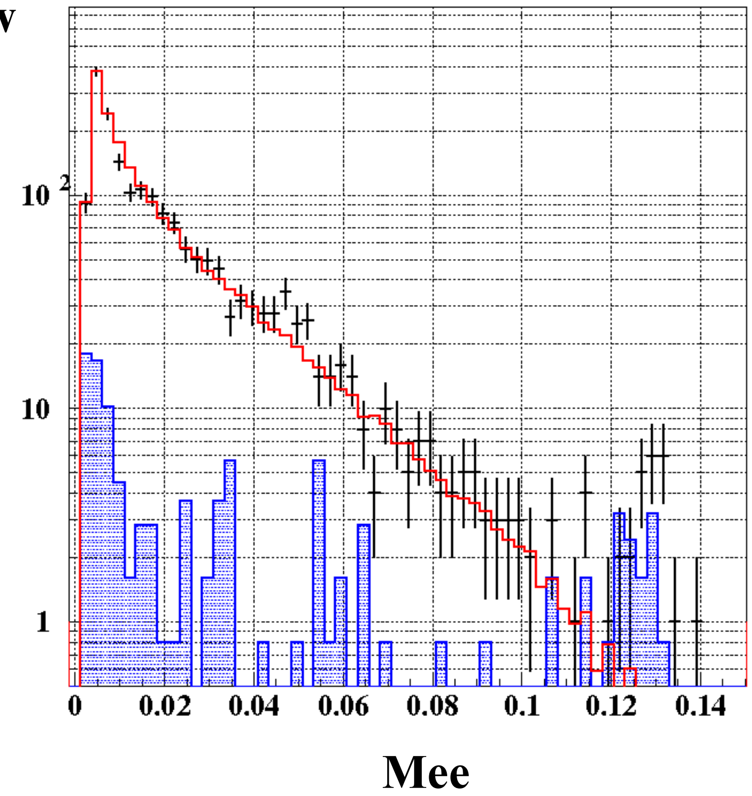
Background suppression after implementating of the new cut $M\pi\pi$> 120 MeV and abs(Mee $\gamma1/\gamma2$ – $M\pi0$) < 7 MeV.

Black → DATA **RED → MC $\pi\pi^0$ee** **Blue → K3πDalitz + K2πDalitz(γ)**

Before



Now

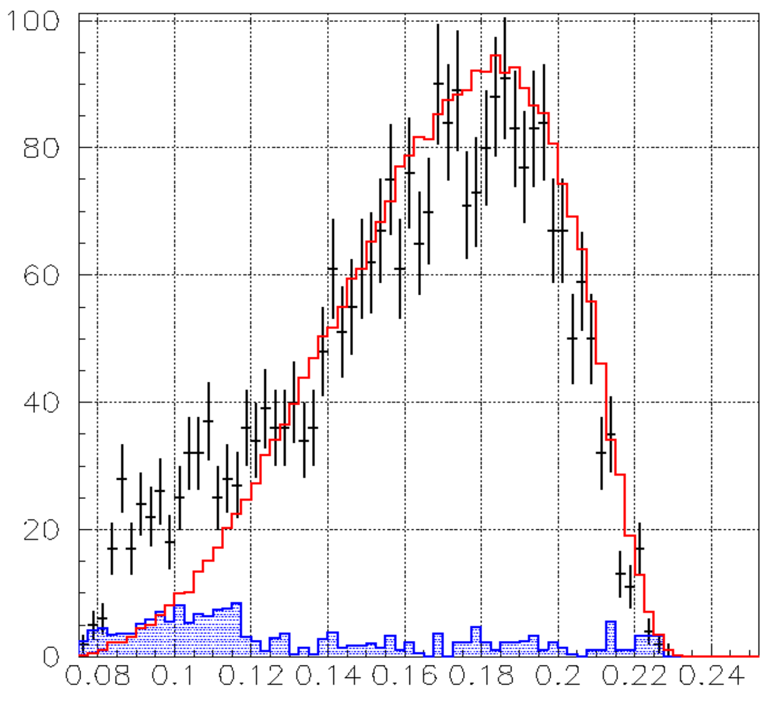


Mee – background status of signal

Background suppression after implementating of the new cut Mππ> 120 MeV and abs(Mee γ1/γ2 – Mπ0) < 7 MeV.

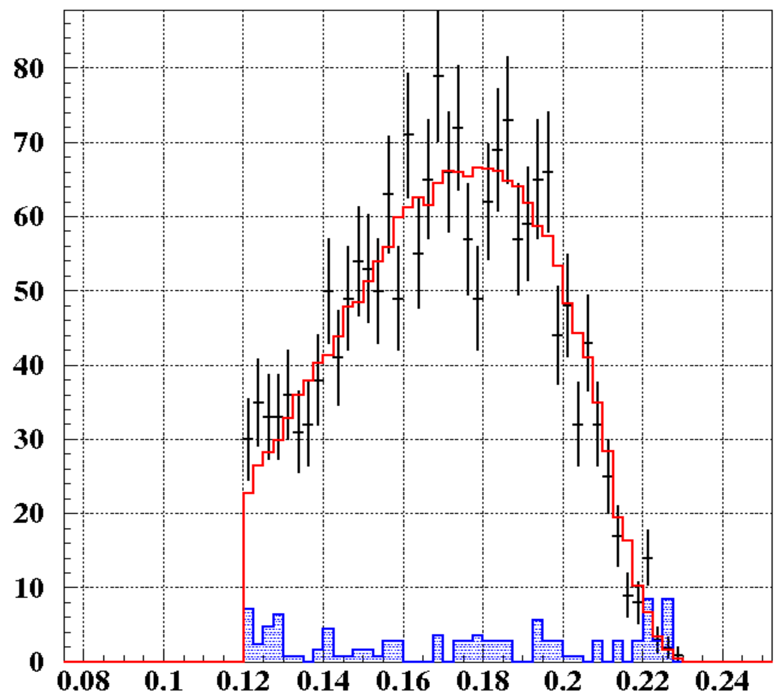
Black → DATA **RED → MC $\pi\pi^0$ee** **Blue → K3πDalitz + K2πDalitz(γ)**

Before



Mππ

Now



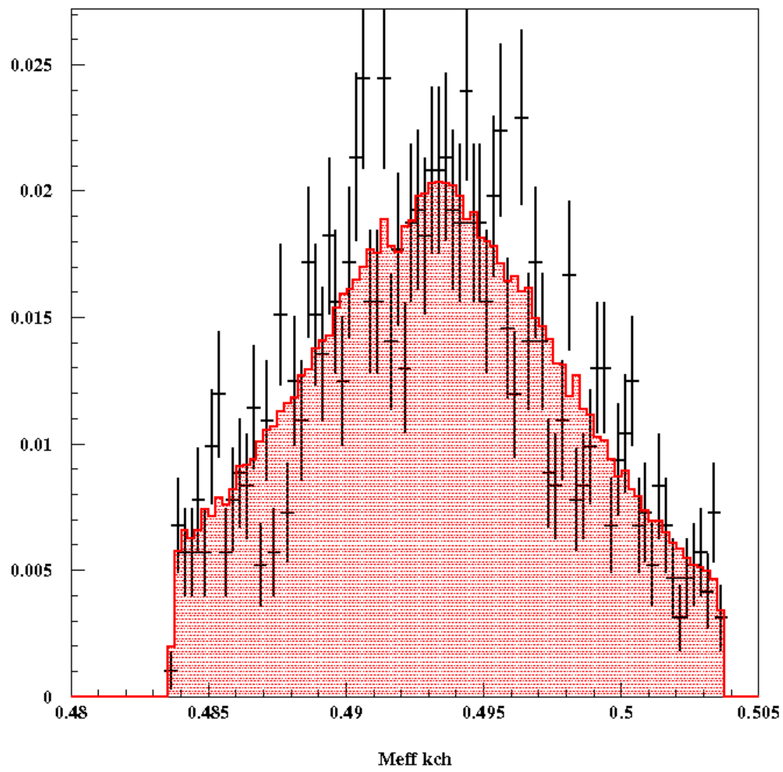
Mππ

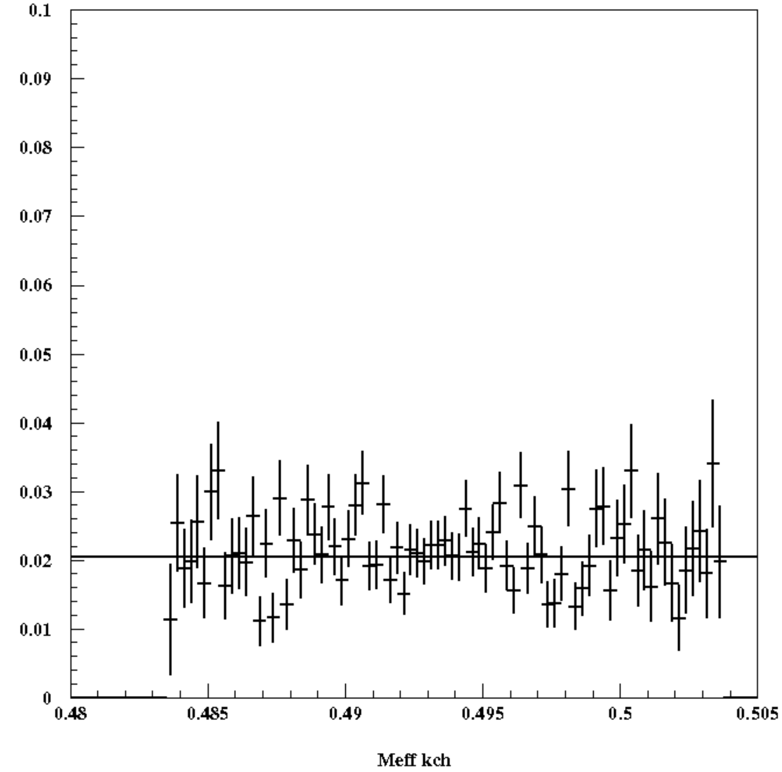
Table of comparison between both analyses

	Milena	Mauro	Difference
N data pp0ee	1916 ± 44	1916 ±44	0%
MC IB no rad.corr → Acc.	5.786e-03 ± 1.351e-05		
MC IB rad.corr. → Acc	5.495e-03 ± 1.853e-05	5.495e-03 ± 1.872e-05	0.11%
MC DE → Acc	2.023e-02 ± 4.639e-05	2.024e-02 ± 4.74e-05	0.05%
MC El.Int. → Acc	2.222e-02 ± 7.999e-05	2.235e-02 ± 7.820 e-05	0.58%
MC k3pDalitz → Acc	8.450e-07 ± 1.289e-07	9.173e-06 ± 1.367e-07	7.8%
MC K2pDalitz → Acc	1.431e-07 ± 2.920e-08	1.393e-07 ± 2.971e-08	1.6%
Trig.Eff. (loose cuts) pp0ee	9.832e-01 ± 7.440e-03	9.8693e-01±6.49e-03	0.38%
N data pp0Dalitz	6702346 ± 2589	6714917 ± 2591	0.19%
MC K2piDalitz+Photos → Acc	3.559e-02 ± 1.482e-05	3.556e-02 ± 1.474e-05	0.11%
Trig.Eff. pp0Dalitz	9.798e-01 ± 5.249e-04	9.7635e-01 ± 4.37e-04	0.39%

	Milena	Mauro	Diff.
MC Kmu3Dal → Acc	1.0806e-04 ± 2.374e-06	------------------	
N kmu3Dal BGR [events]	3369.45	3365.46	0.12%
Kaon flux – regarding BGR	7.9201e+10 ± 2.362e+09	7.97159e+10 ± 2.398e+09	0.65%
N BGR K3piDalitz [events]	27.67 ± 4.31	29.5 ± 4.4	6.1%
N BGR K2piDalitz [events]	27.48 ± 4.39	26.3 ± 5.7	4.2%
N total BGR events	55.1 ± 7.4	55.8 ± 7.4	1.3%
N pp0ee BGR subtraction	1860.85 ± 44.39	1860.2 ± 51.2	0.04%
Br(pp0ee)	**(4.06196 ± 0.16814)e-06**	**(4.05405 ± 0.156012)e-06**	**0.2%**

Mass $K^{\pm}$ $\quad$ $K \rightarrow \pi\, \pi^0\, e^+ e^-$

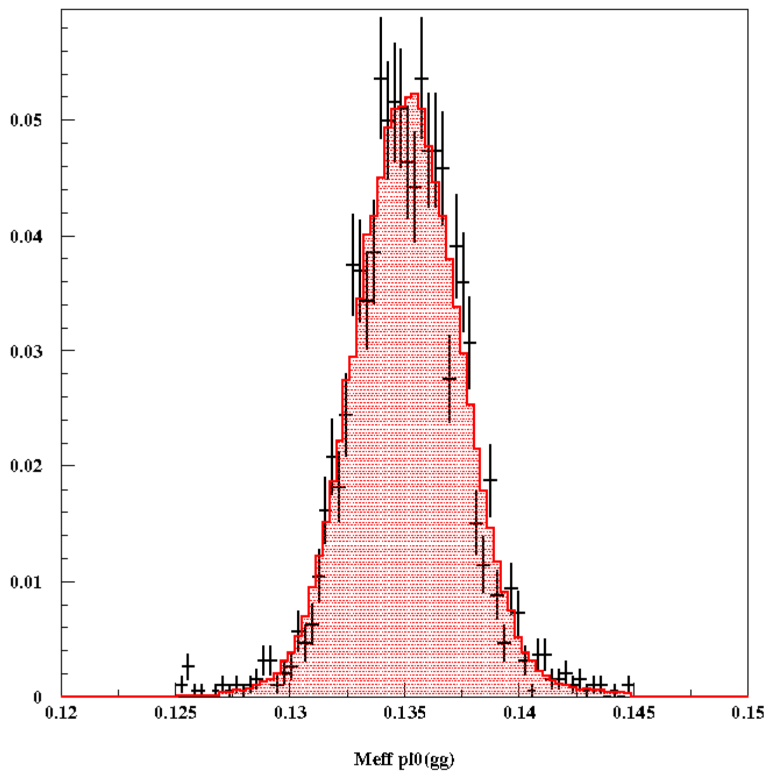


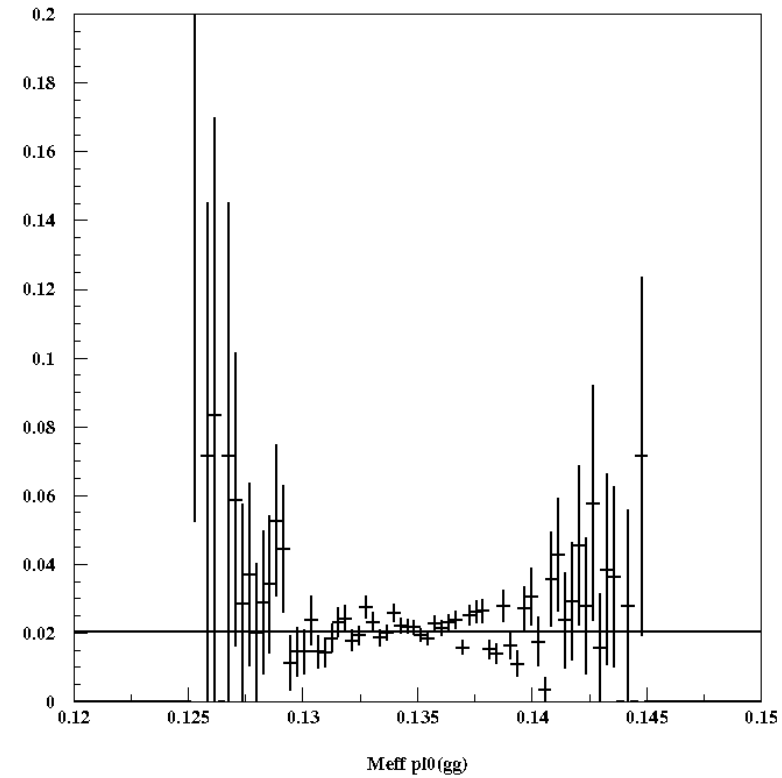


data mean=(0.4933 ± 0.1535e-03) sigma=(0.5325e-02 ± 0.1597e-03)

mc mean=(0.4931 ± 0.1287e-04) sigma=(0.5611e-02 ± 0.25323e-04)

Mass π^0 $K \rightarrow \pi \pi^0 e^+ e^-$

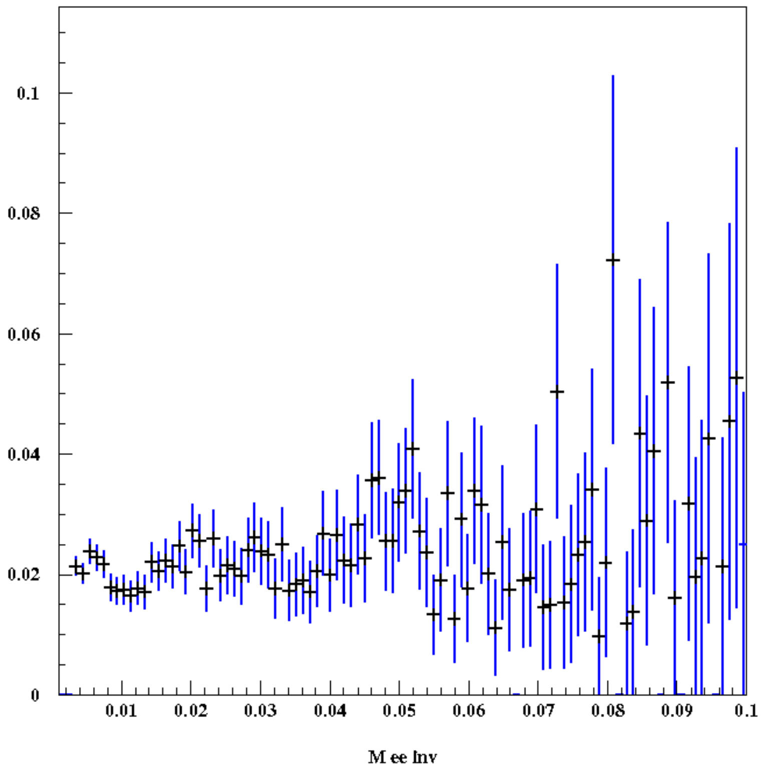




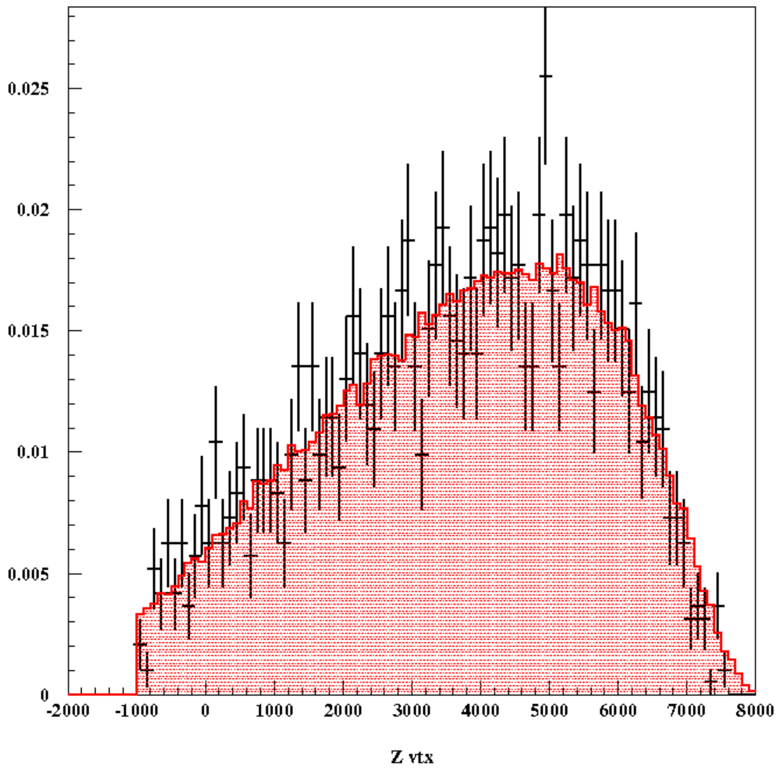
data mean=(0.1351 ± 0.51328e-04) sigma=(0.21525e-02 ±0.38431e-04)

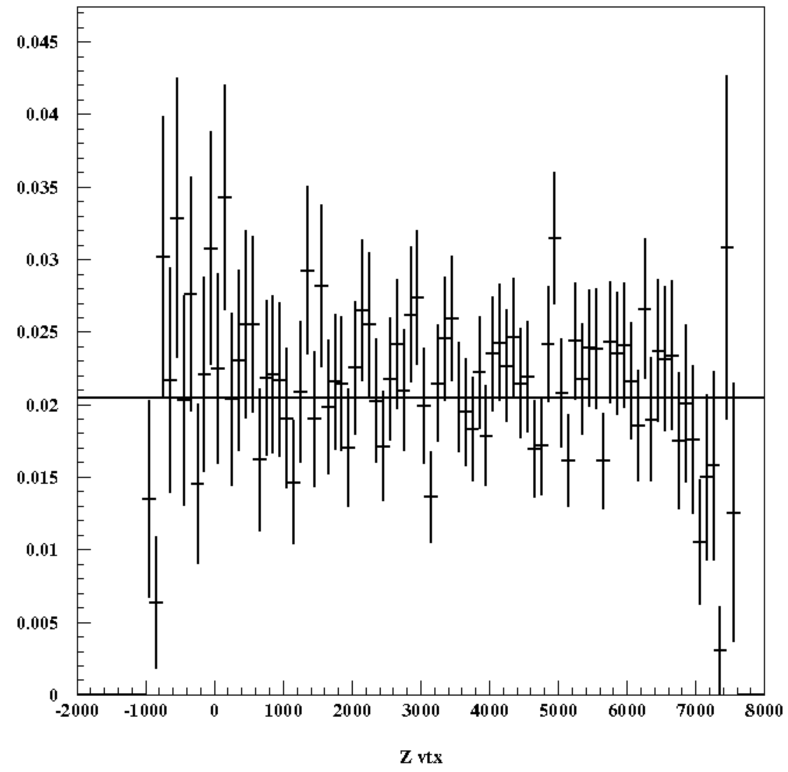
mc mean=(0.13514 ± 0.36844e-05) sigma=(0.22928e-02 ± 0.6064e-05)

Mee $K \rightarrow \pi\, \pi^0\, e^+ e^-$

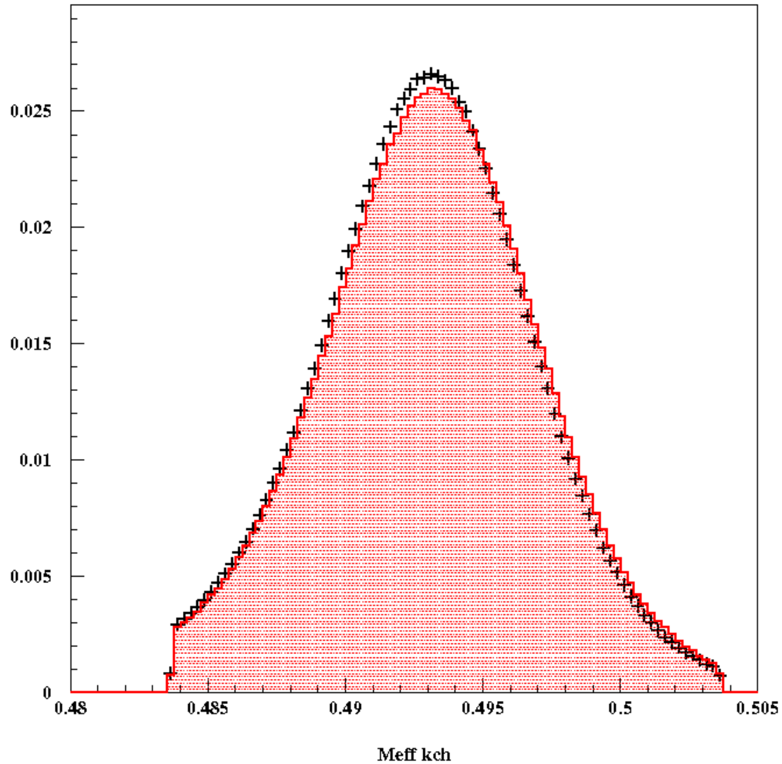


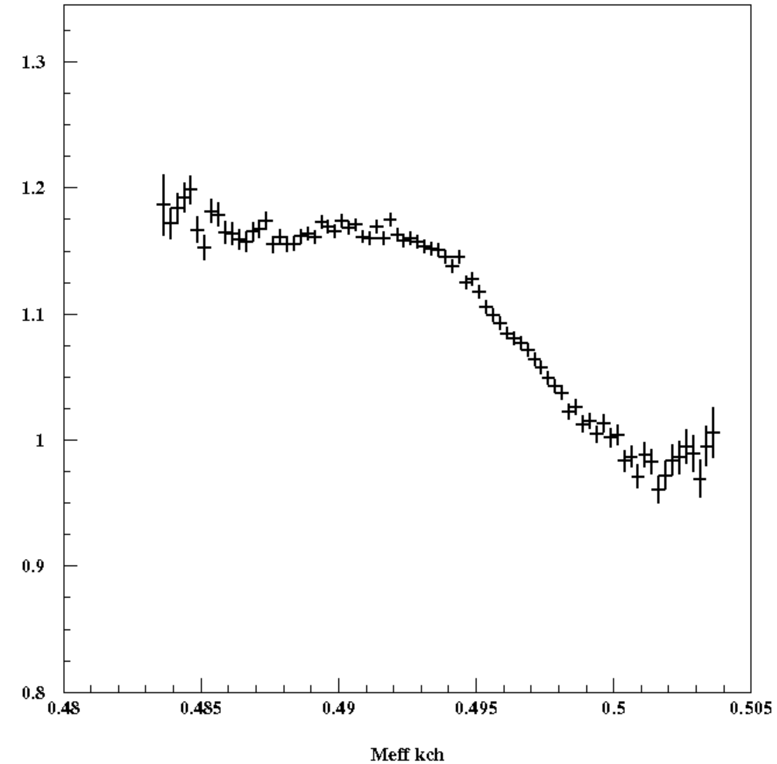
Z coord. vertex $K \rightarrow \pi \pi^0 e^+ e^-$





Mass $K^{\pm}$ $K \rightarrow \pi \pi^0 (e^+ e^- \gamma)$

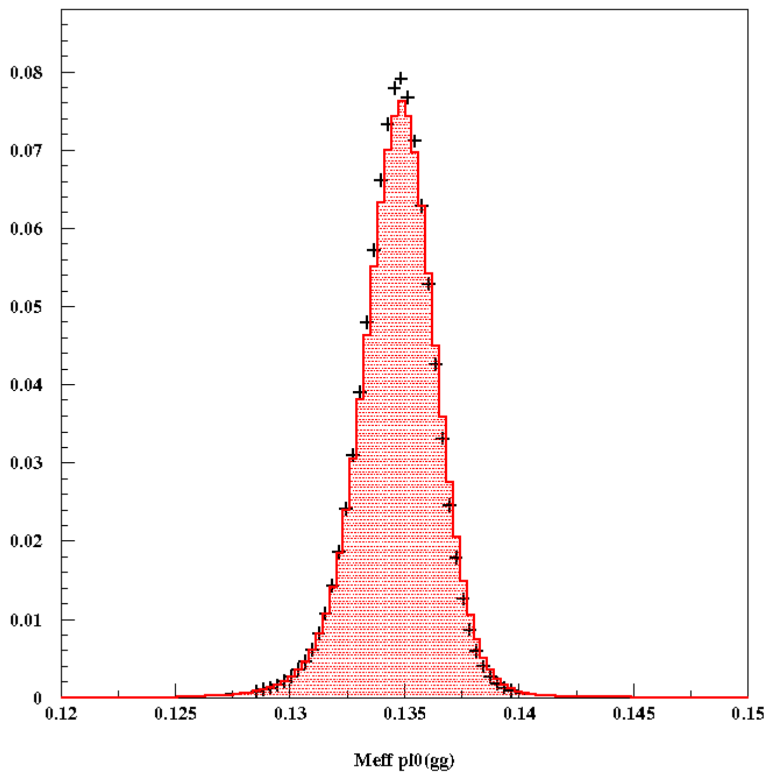


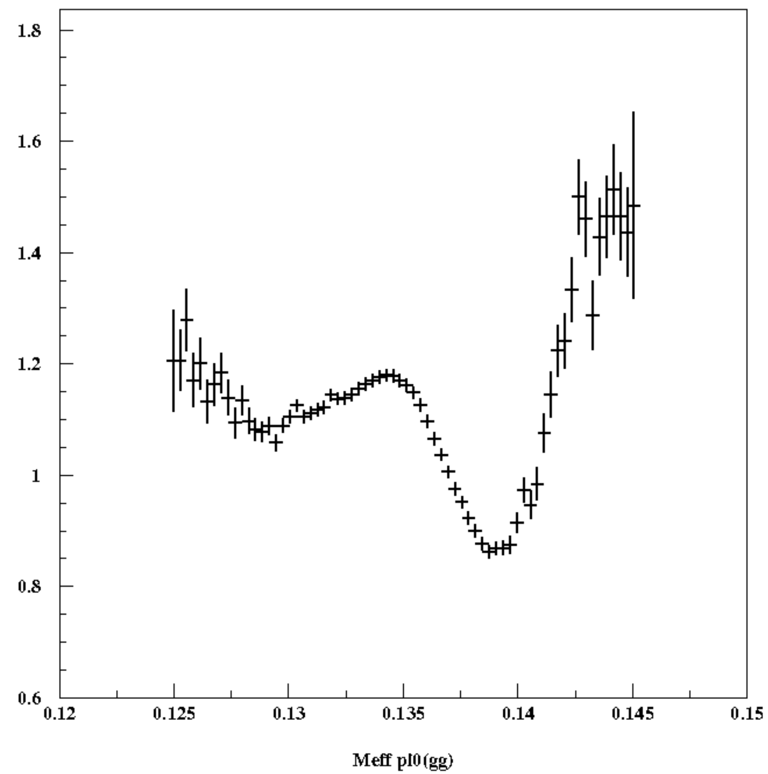


data mean=(0.4929 ± 0.1722e-05) sigma=(0.3864e-02 ± 0.1544e-05)

mc mean=(0.4931±0.1357e-05) sigma=(0.3955e-02 ± 0.1856e-05)

Mass π^0 $\qquad K \rightarrow \pi\,\pi^0\,(e^+e^-\,\gamma)$

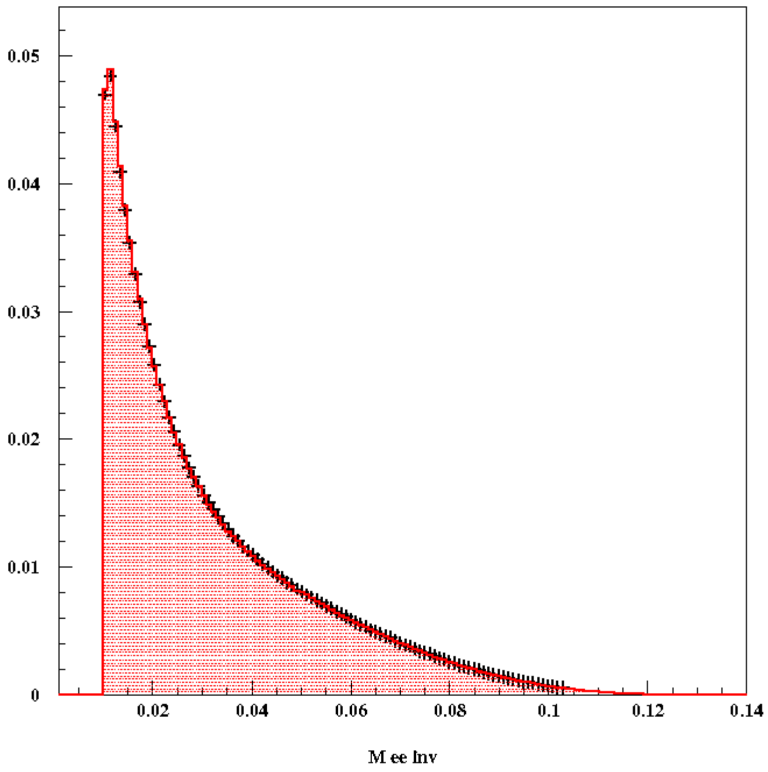


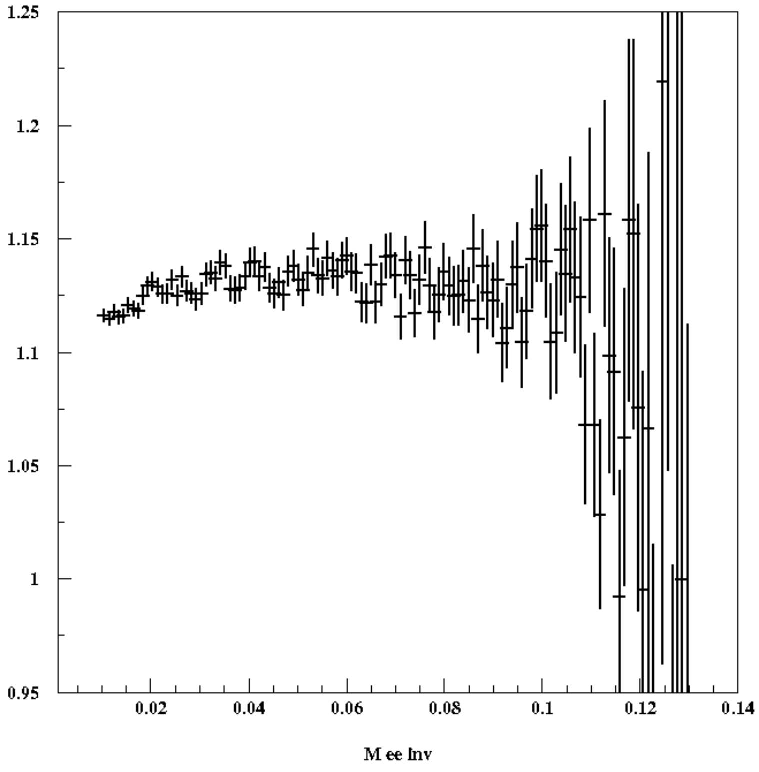


data mean=(0.1347 +- 0.4656e-06) sigma=(0.1502e-02 +- 0.6113e-06)

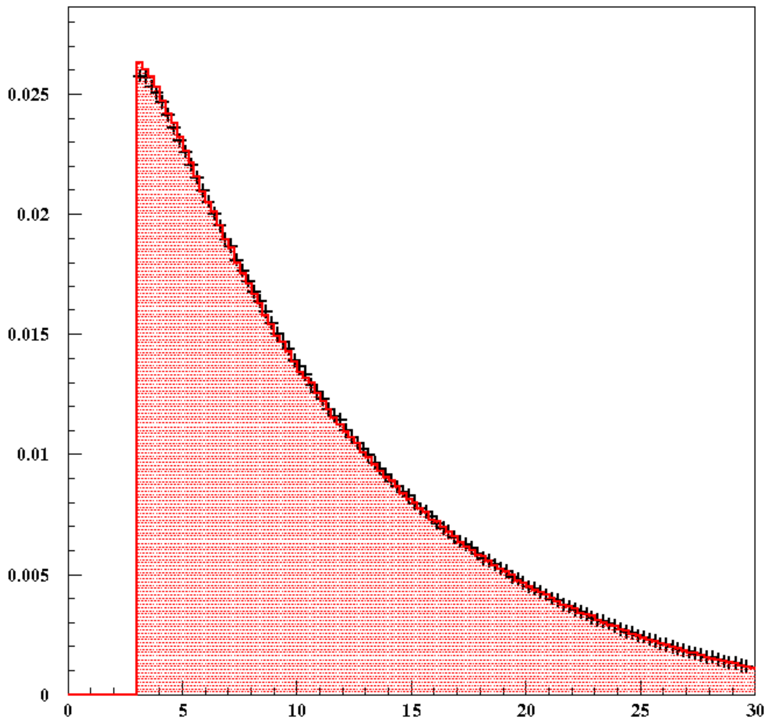
mc mean=(0.1348 +- 0.522e-06) sigma=(0.1560e-02+- 0.7036e-06)

Mee $K \rightarrow \pi \pi^0 (e^+ e^- \gamma)$

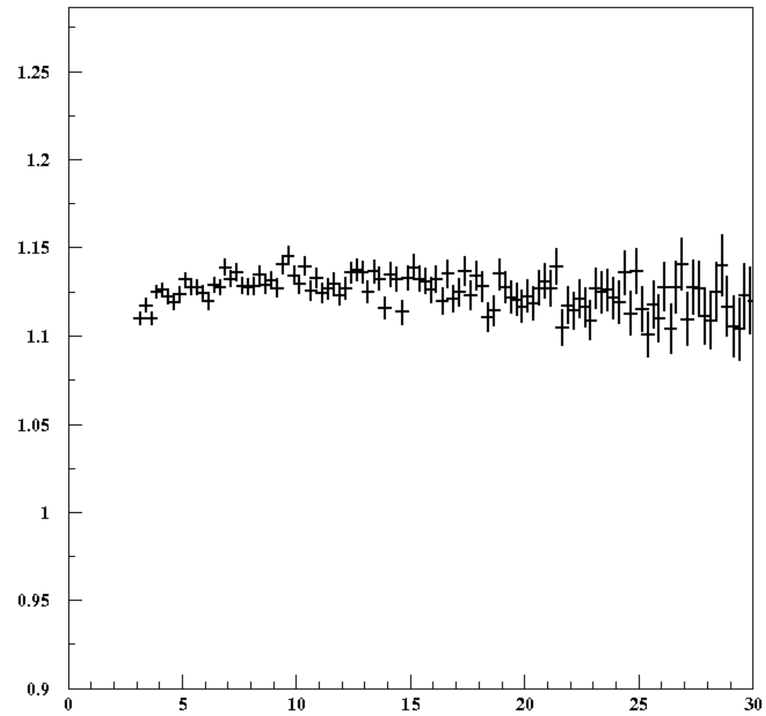




Momentum of electrons $K \rightarrow \pi\,\pi^0\,(e^+e^-\,\gamma)$

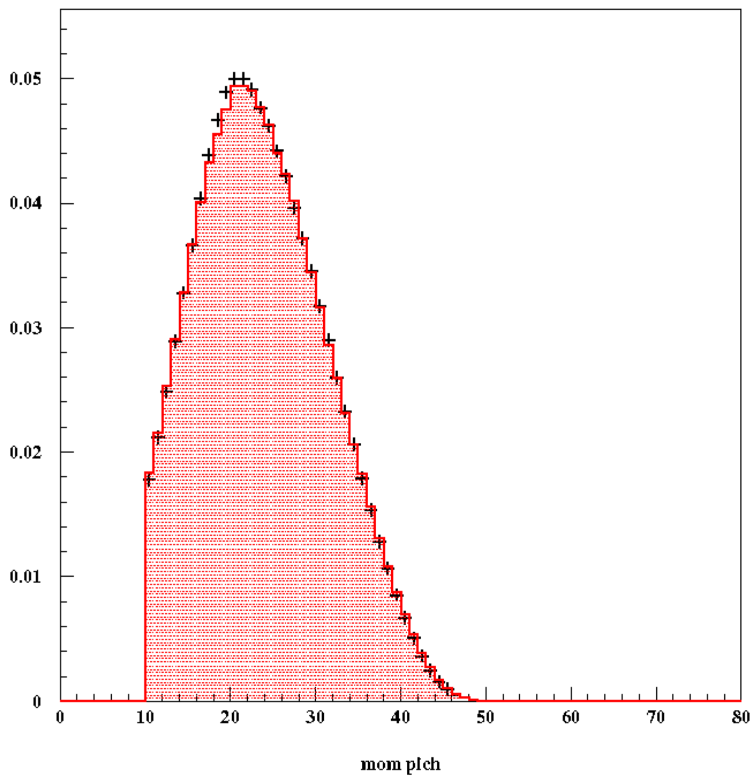


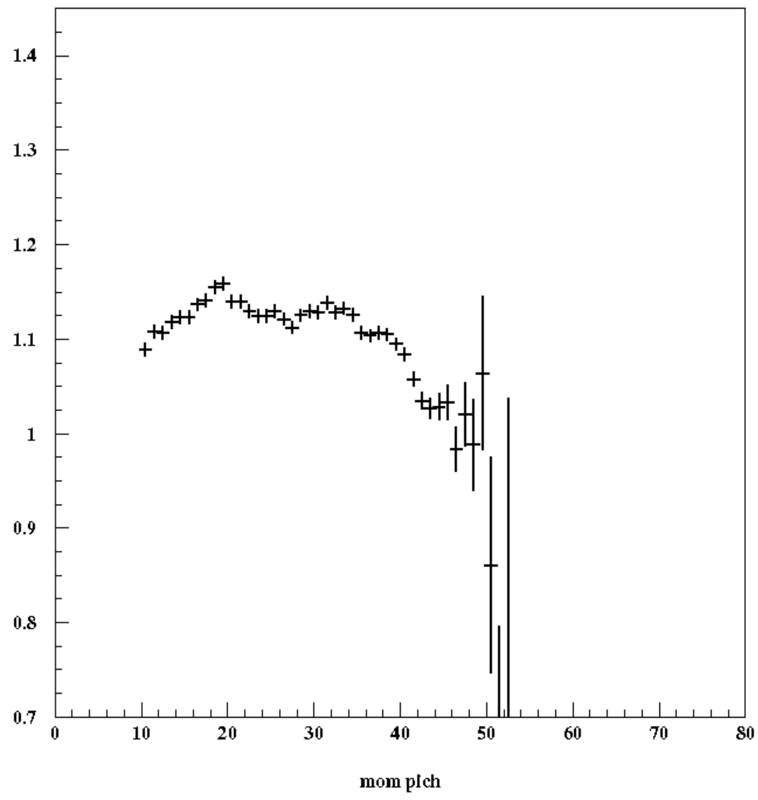
Electrons mom



Electrons mom

Momentum of charged pion $K \to \pi\, \pi^0\, (e^+e^-\, \gamma)$





Conclusion of part I

1) We have MC simulatons of all contributions for the tree-level description of $K \rightarrow \pi\pi^0 ee$

2) We suppressed the background from 10% to 3 %

3) The agreement between both analyses is improved from ~1% to 0.2%

4) Data/MC ratios are in a very good agreement for the signal and the normalization channels