

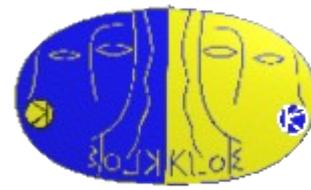
# ***Observation of the $\eta \rightarrow \pi^+ \pi^- e^+ e^-$ decay at KLOE***

Roberto Versaci

on behalf of the KLOE collaboration



# Outline



Motivations

KLOE and  $\eta$  meson

Data sample

Event and track selection

Background rejection

Four tracks invariant mass

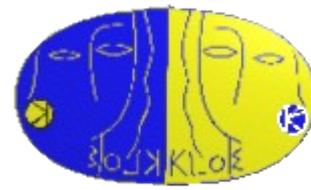
Fit of the spectrum

Preliminary BR

Asymmetry

Conclusion

# Motivations



$\eta$  structure, using virtual photon

Model comparison (VMD,  $\chi$ PT)

**Test of CP violation: Gao model**

Mod.PhysLett.A17  
1583-1588.2002

Angular asymmetry between  $ee$  and  $\pi\pi$  planes,  $A_{CP}$ ,

can be due to unconventional CPV mechanism

described by a  $T \times V$  4 quarks operator with  $\Delta s = 0$ .

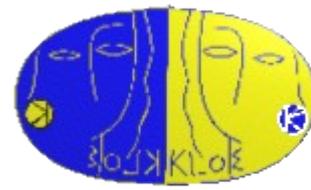
Within SM constrained by  $BR(\eta \rightarrow \pi\pi)$ ,

using the experimental upper limit:  $A_{CP} < 10^{-4}$

using theoretical prediction:  $A_{CP} \sim 10^{-15}$

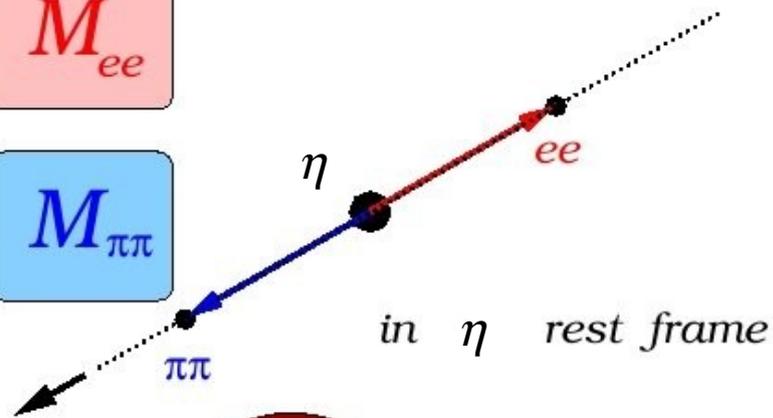
**CPV model predicts an upper bound of  $10^{-2}$**

# Asymmetry

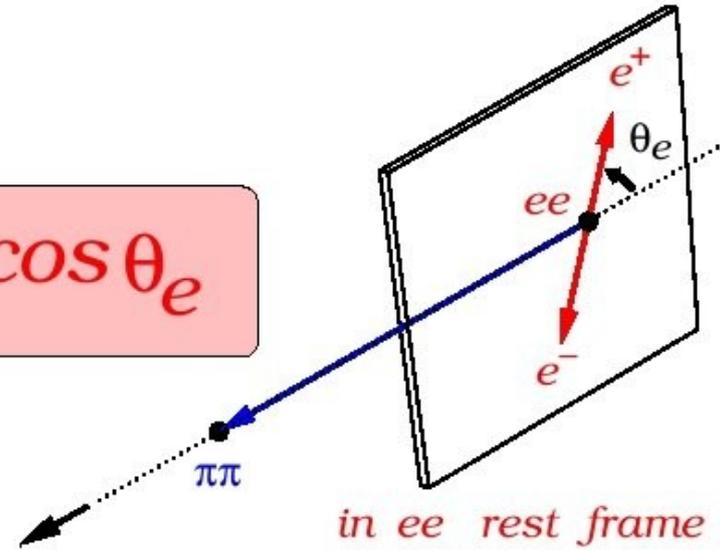


$$M_{ee}$$

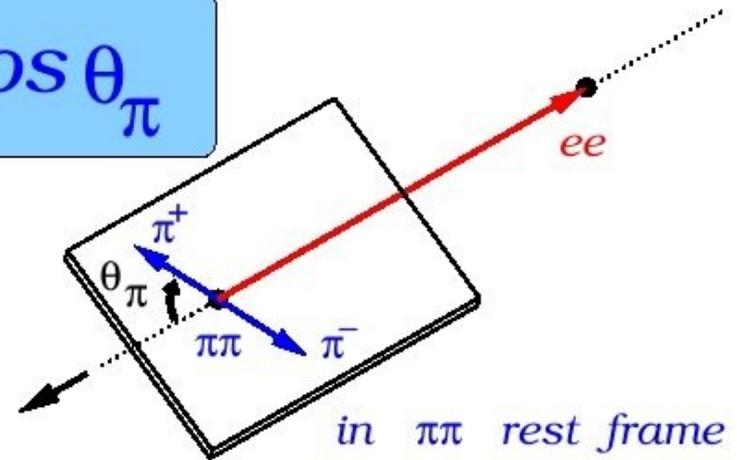
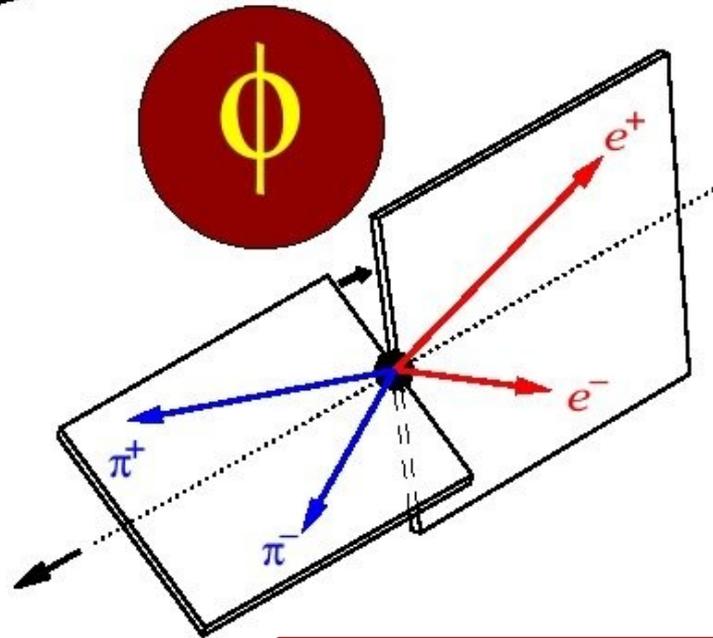
$$M_{\pi\pi}$$



$$\cos \theta_e$$

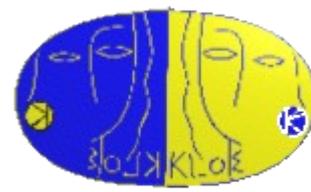


$$\cos \theta_\pi$$



$$\sin \phi \cos \phi = (\hat{n}_{ee} \times \hat{n}_{\pi\pi}) \cdot \hat{z} (\hat{n}_{ee} \cdot \hat{n}_{\pi\pi})$$

# BR: theory & experiment



Jarlskog, Pilkuhn 1967

$$0.0065 \times \text{BR}(\eta \rightarrow \pi^+ \pi^- \gamma)$$

$$(3.05 \pm 0.07) \times 10^{-4}$$

From PDG06

Picciotto, Richardson 1993

$$(3.2 \pm 0.3) \times 10^{-4}$$

Faessler et al. 2000

$$3.6 \times 10^{-4}$$

Borasoy, Nissler 2007

$$(2.99^{+0.06}_{-0.09}) \times 10^{-4}$$

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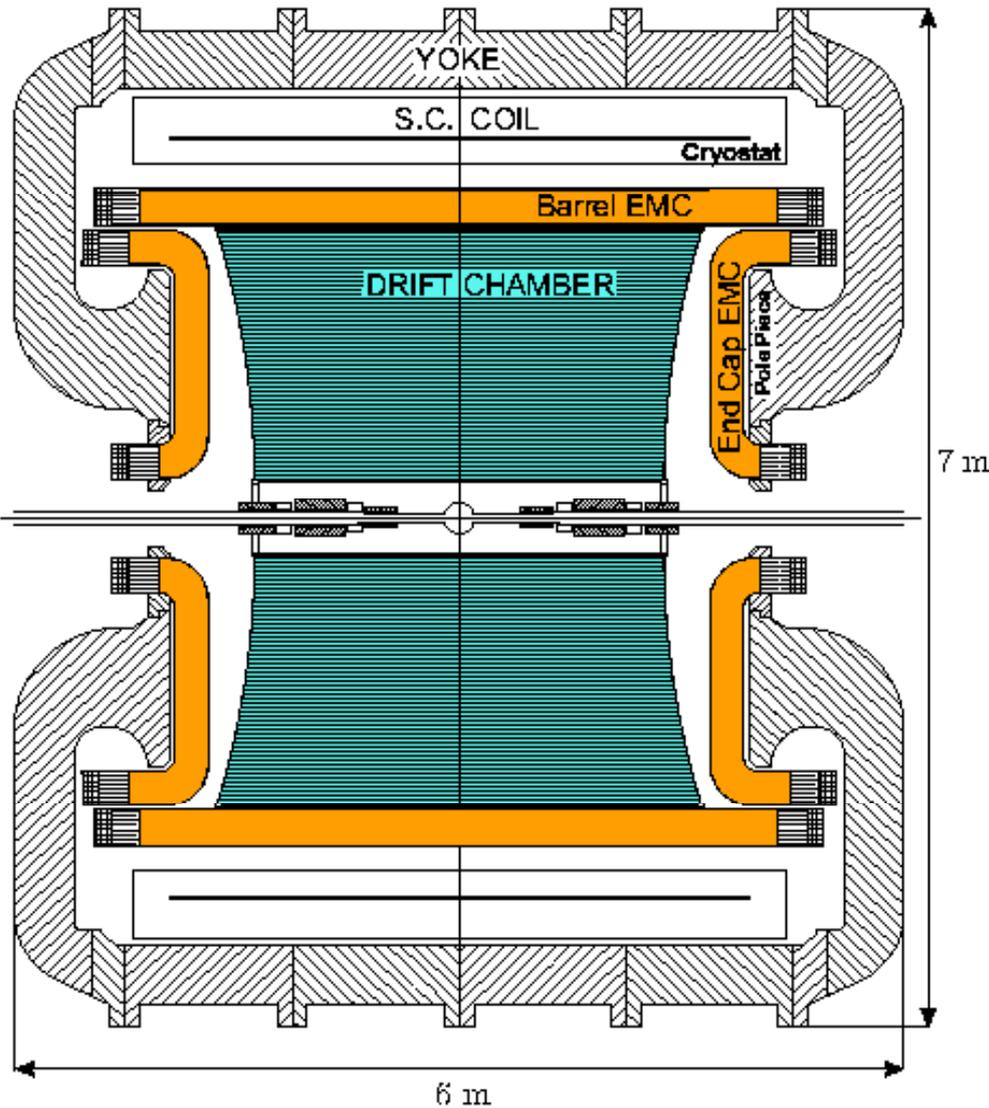
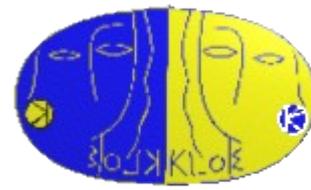
CMD-2 (4 events)

$$(3.7^{+2.5}_{-1.8 \text{ stat}} \pm 0.3_{\text{syst}}) \times 10^{-4}$$

CELSIUS-WASA (16 events)

$$(4.3 \pm 1.3_{\text{stat}} \pm 0.4_{\text{syst}}) \times 10^{-4}$$

# K Long Experiment



Spherical **beam pipe**  
10 cm  $\varnothing$ , 0.5 mm thick in Be-Al alloy  
to minimize regeneration,  
scattering and  $\gamma$  conversion

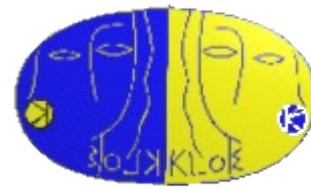
Large volume **drift chamber**  
4 cm  $\varnothing$ , L=3.4 m, carbon-fiber frame,  
low density gas (90% He – 10% C<sub>4</sub>H<sub>10</sub>),  
12582 all stereo squared cells,  
tungsten and aluminium wires (52140)

$\sim 4\pi$  **calorimeter**, 4880 cells  
15X<sub>0</sub> thick, 0.5 mm lead  
1mm  $\varnothing$  scintillating fibers

**Superconducting coil** B = 0.52 T

Remind:  $\lambda_L = 3.5\text{m}$

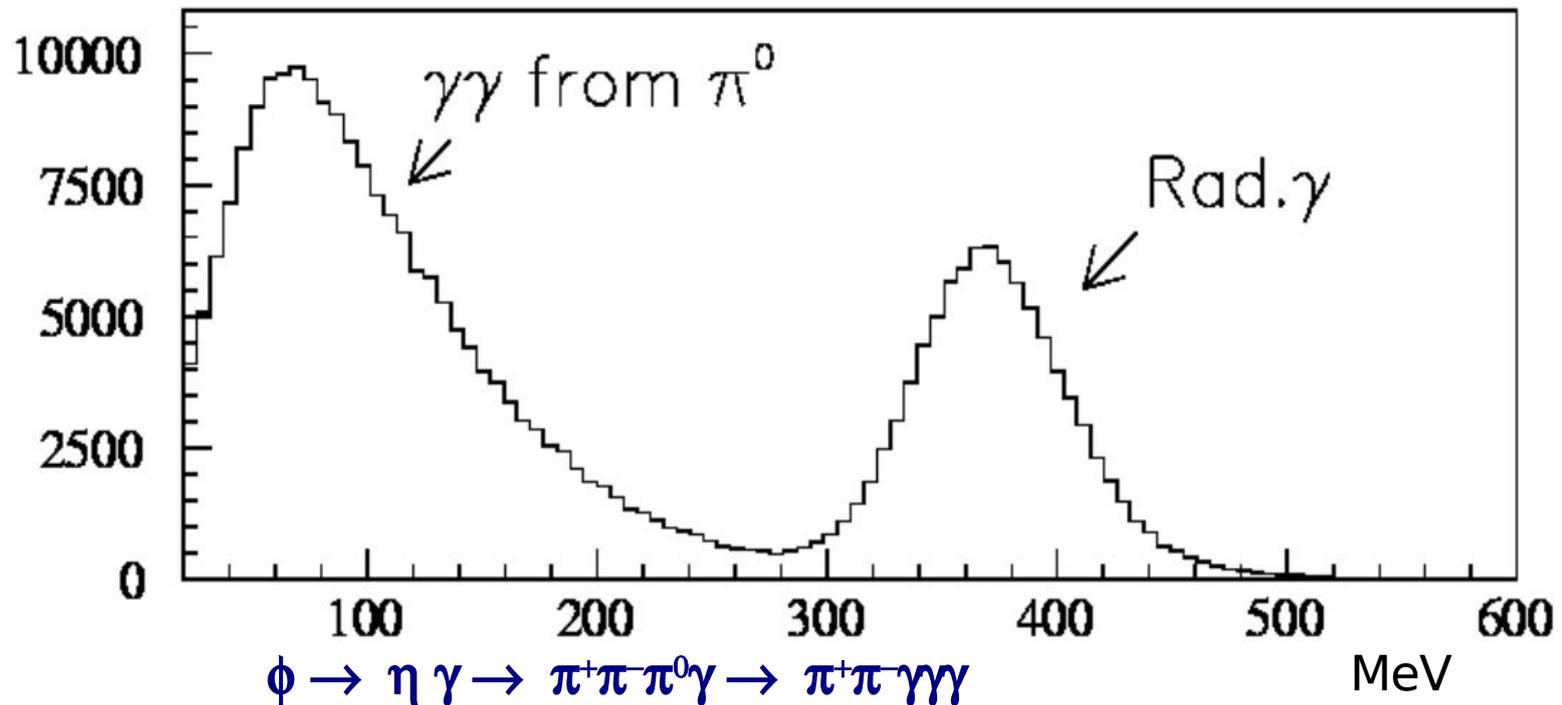
# *$\eta$ production at KLOE*



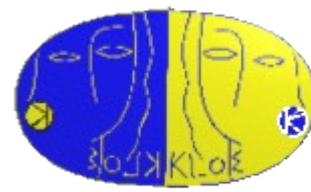
DAΦNE is an  $e^+e^-$  collider running at  $\sqrt{s} = M_\phi$   
 $\eta$  produced through transition  $\phi \rightarrow \eta\gamma$  (BR=0.013)

Monochromatic recoil photon (363 MeV)

very powerful for event ID



# ***Data sample***

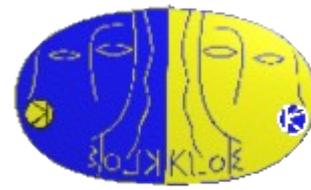


622 pb<sup>-1</sup> data

46 × 10<sup>3</sup> pb<sup>-1</sup> MC signal

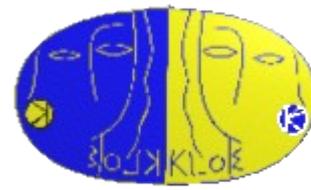
1723 pb<sup>-1</sup> MC background

run by run simulation



# ***Event and Track selection***

# ***Event selection***

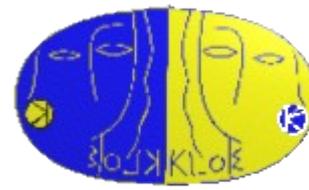


Dedicated algorithm developed:

- $\geq 4$  tracks from the Interaction Point
- 1 high energy neutral cluster ( $E_{cl} \geq 250$  MeV)
- 0 medium energy neutral cluster ( $50 \leq E_{cl} \leq 250$  MeV)

**Downscaled sample** of events with 3 tracks from the IP

# Track selection



Tracks are required to come from a **cylinder around the IP**:

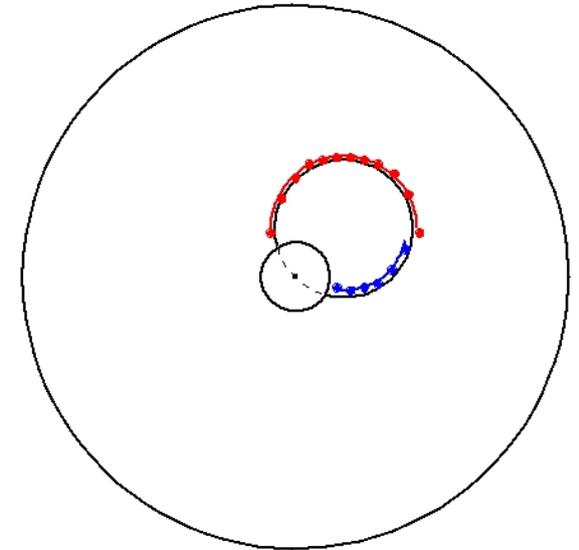
$$R \leq 4 \text{ cm}$$

$$h/2 = 10 \text{ cm}$$

Check on broken tracks is applied:

$$\Delta P_T < 4.5 \text{ MeV}$$

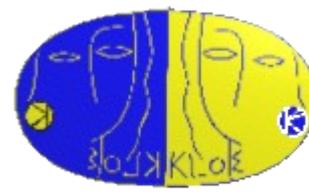
$$\Delta P_Z < 3 \text{ MeV}$$



$\geq 2$  **positive** and  $\geq 2$  **negative** tracks are requested

Tracks are **ordered by momentum**

# Track selection



Tracks are required to come from a **cylinder around the IP**:

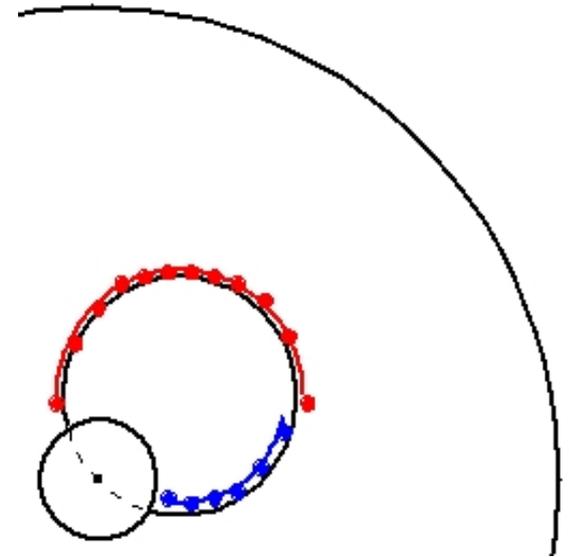
$$R \leq 4 \text{ cm}$$

$$h/2 = 10 \text{ cm}$$

Check on broken tracks is applied:

$$\Delta P_T < 4.5 \text{ MeV}$$

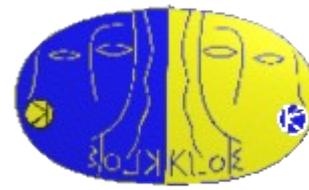
$$\Delta P_Z < 3 \text{ MeV}$$



$\geq 2$  **positive** and  $\geq 2$  **negative** tracks are requested

Tracks are **ordered by momentum**

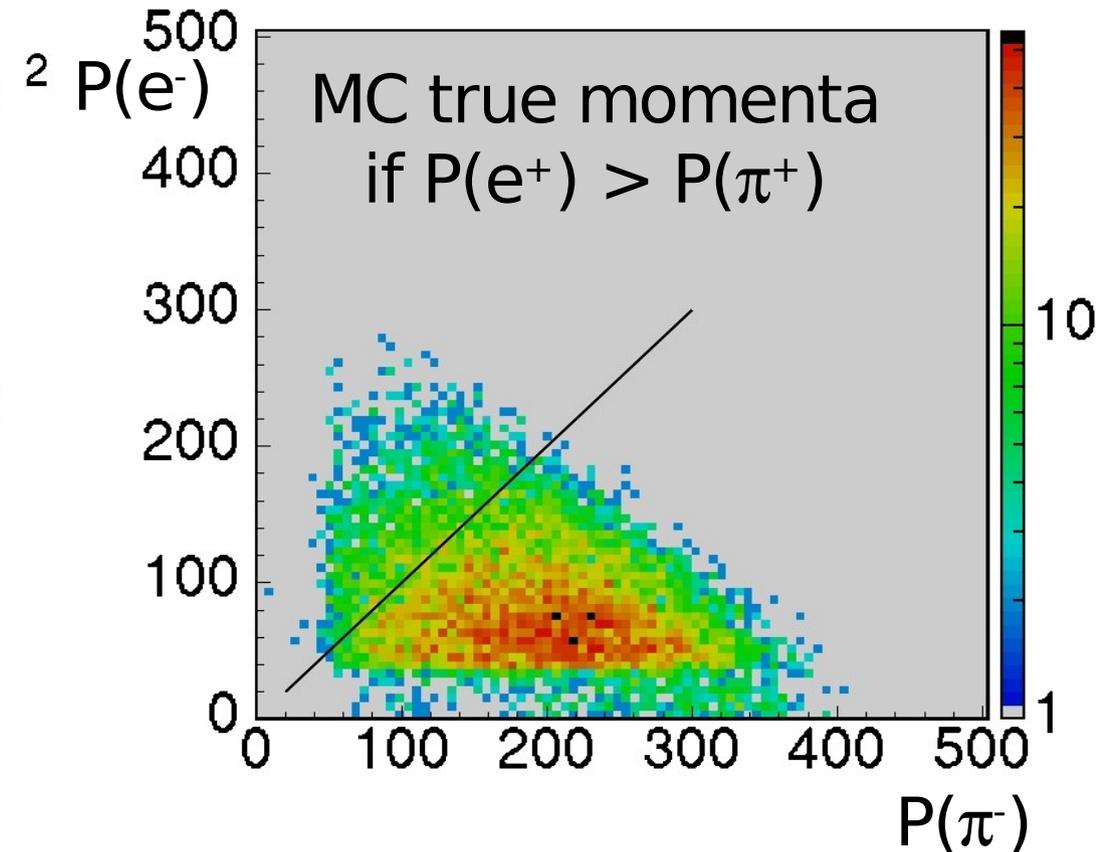
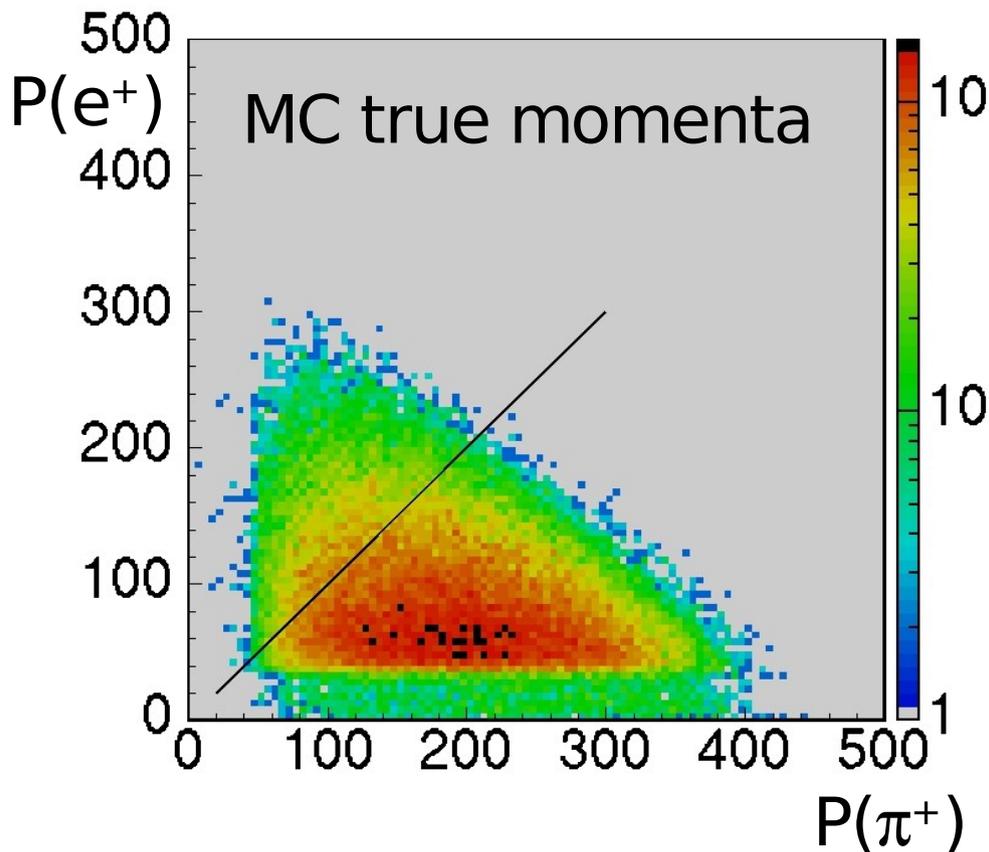
# Track identification

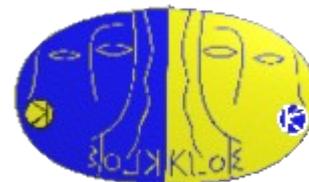


Higher momentum tracks assigned to pion

Assumption correct on 84% of cases

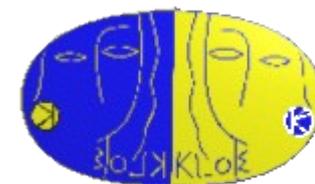
Possible to improve with TOF





# ***Two steps across background rejection***

# Background rejection - step 1



$$450 \text{ MeV} < \sum_{i=1}^4 |\vec{p}_i| < 600 \text{ MeV}$$

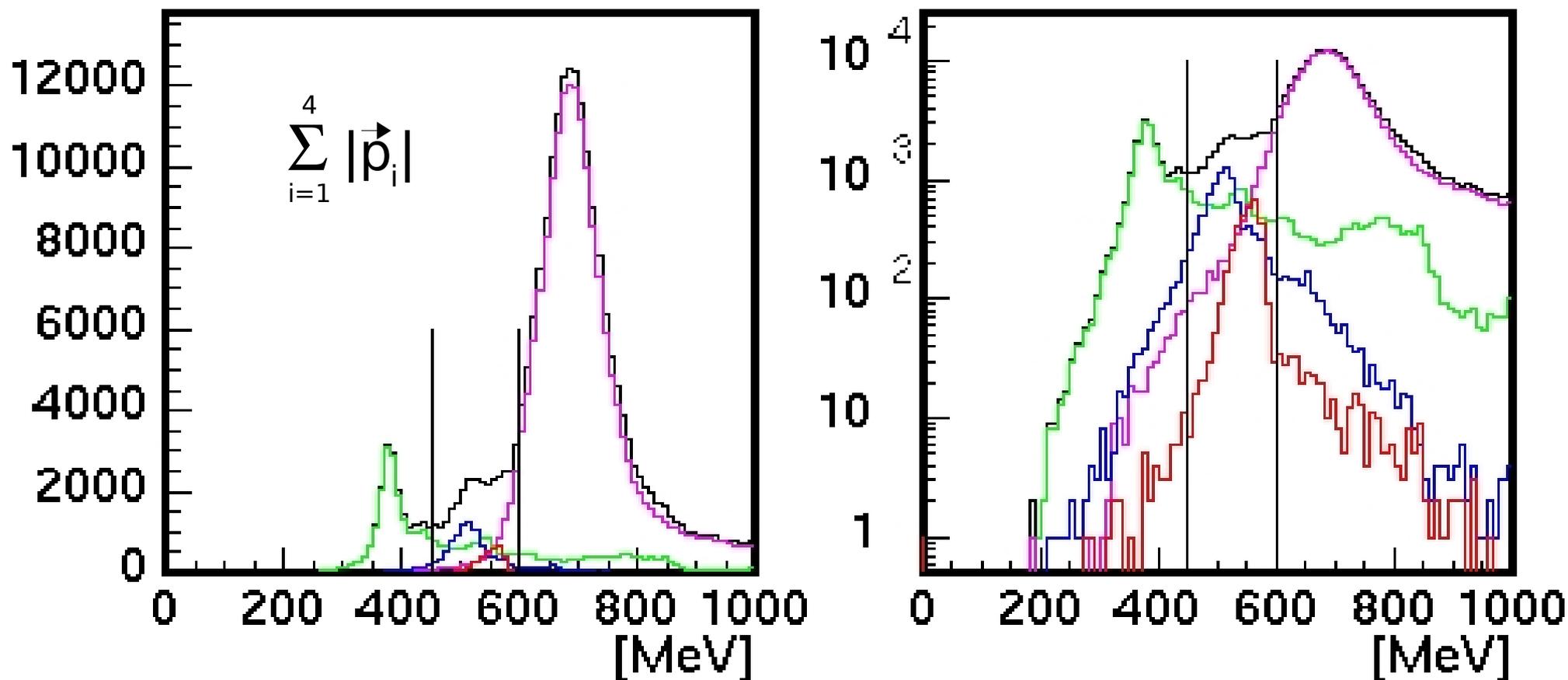
Total

$\phi \rightarrow \eta\gamma$

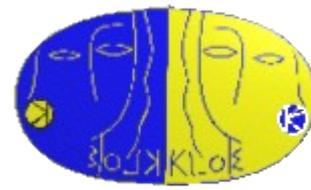
$\phi \rightarrow \rho\pi + \pi^+\pi^-\pi^0$

Signal  $\eta \rightarrow \pi^+\pi^-e^+e^-$

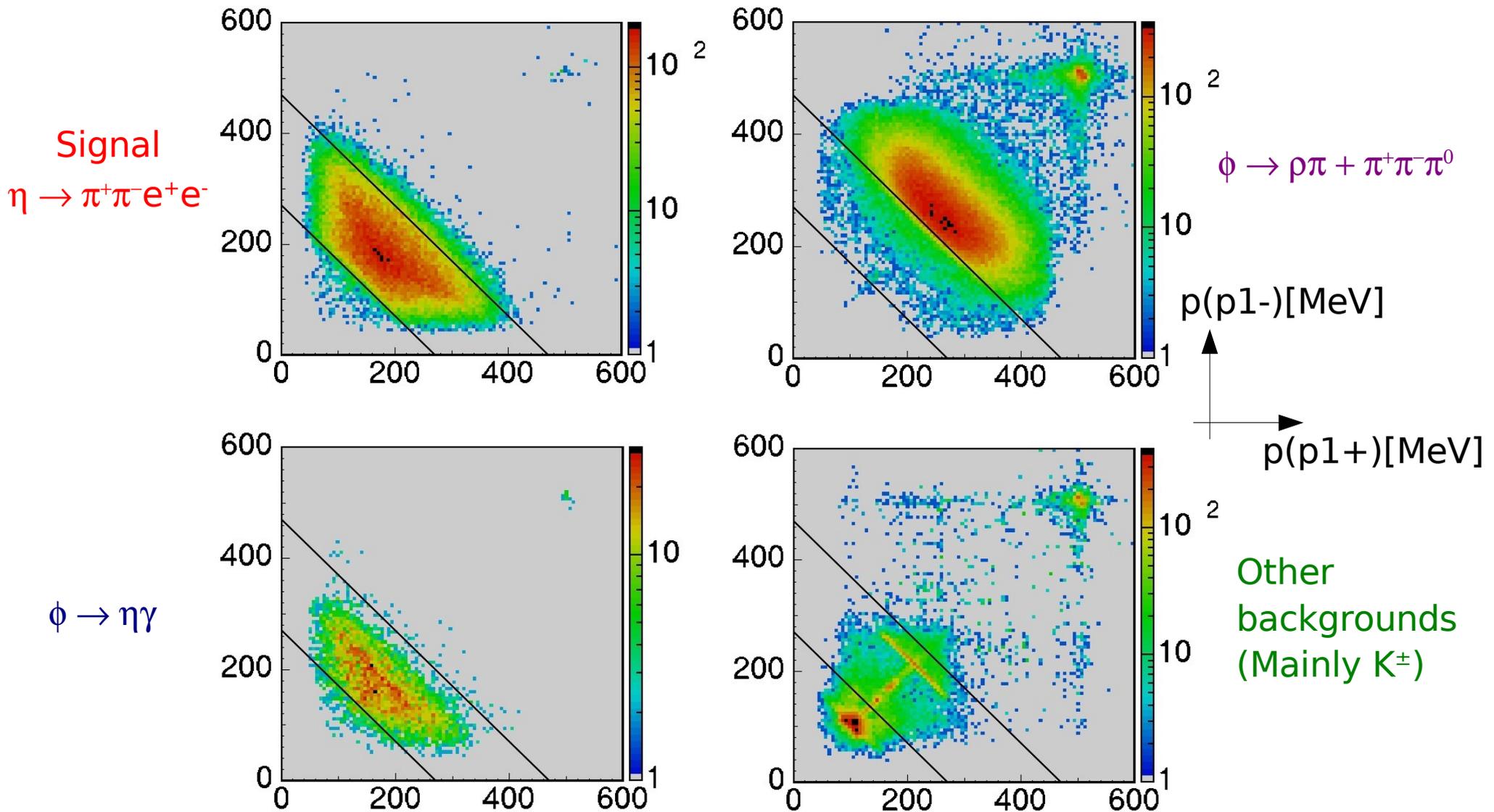
Other backgrounds (mainly  $K^\pm$ )

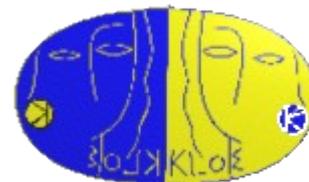


# Background rejection - step 2



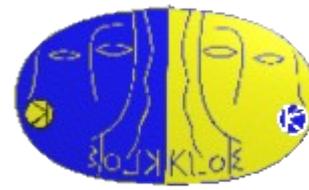
$$270 < |P(p^+1)| + |P(p^-1)| < 470 \text{ MeV}$$





# Fit of the $\pi e e$ invariant mass

# ***Kinematic fit***



- Recall that  $\eta$  production at KLOE:  $e^+e^- \rightarrow \phi \rightarrow \eta\gamma$   
A kinematic fit to the  $\phi$  meson is performed for all the events having **# good tracks  $\geq 4$**

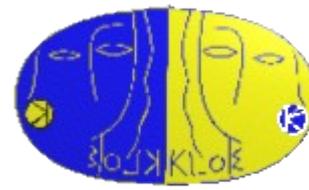
The **22 inputs** are:

- 4 tracks x 3 momenta
- $x, y, z, E, t$  of the neutral cluster
- $x, y, z$  of the IP
- $\sqrt{s}$  and  $\phi$  momentum

The **5 constraints** are:

- Four momentum conservation
- Photon time of flight ( $cT_\gamma = R_\gamma$ )

# Fit results



$\pi\pi e e$  invariant mass  
reconstructed using  
the output of  
the kinematic fit

Total

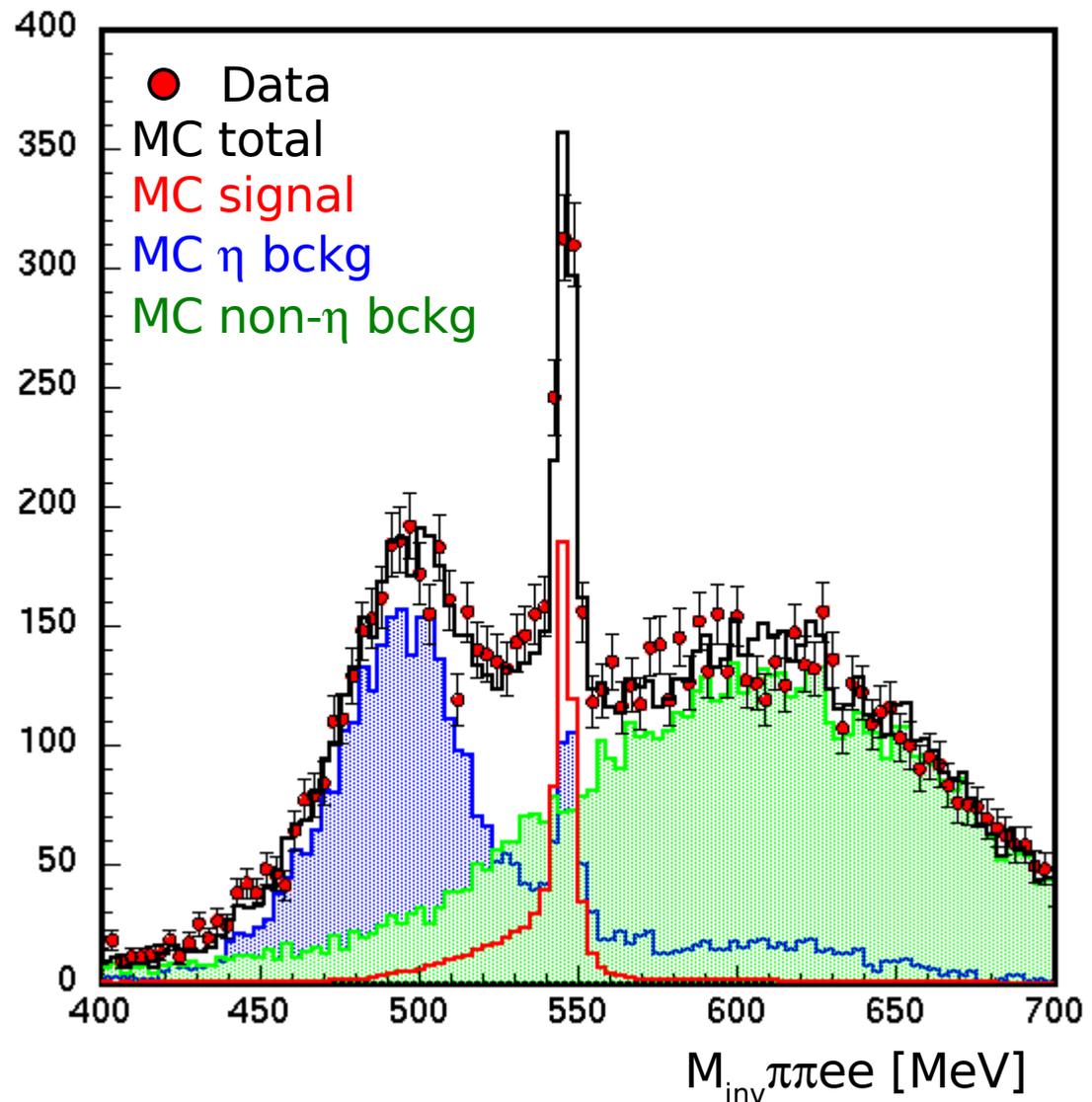
Signal  $\eta \rightarrow \pi^+\pi^-e^+e^-$

Other  $\eta$  decays

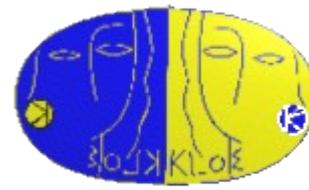
(mainly:  $\eta \rightarrow \pi^+\pi^-\pi^0 \oplus \eta \rightarrow \pi^+\pi^-\gamma$ )

Other non  $\eta$  backgrounds

(mainly:  $\rho\pi \oplus K^\pm$ )



# Fit results



**# events = 733(62)**

$$\chi^2 = 92/97$$

$$P(\chi^2) = 0.61$$

Total

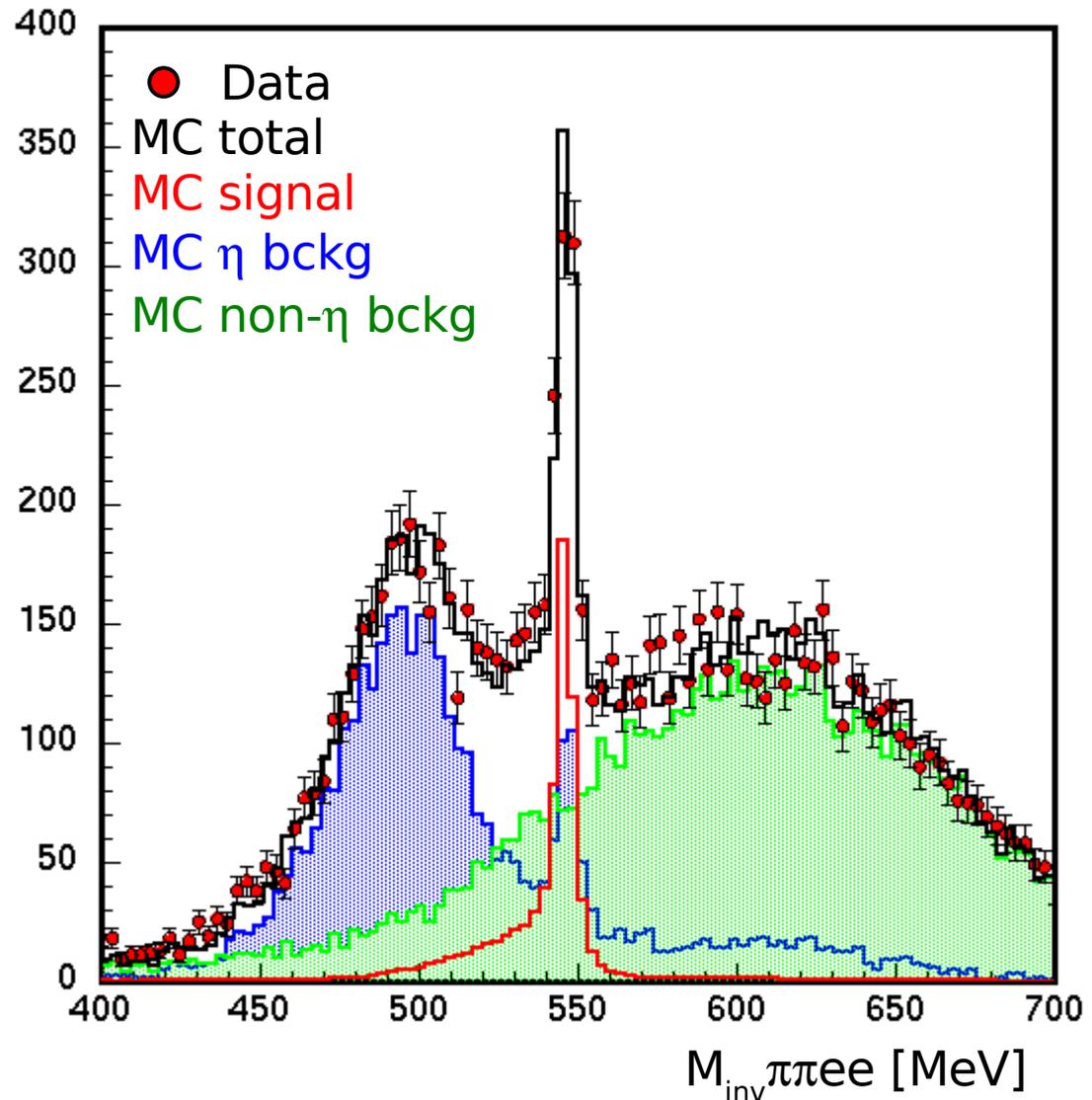
Signal  $\eta \rightarrow \pi^+\pi^-e^+e^-$

Other  $\eta$  decays

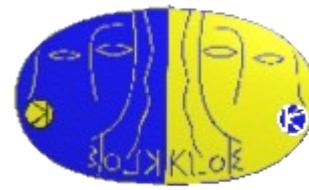
(mainly:  $\eta \rightarrow \pi^+\pi^-\pi^0 \oplus \eta \rightarrow \pi^+\pi^-\gamma$ )

Other non  $\eta$  backgrounds

(mainly:  $\rho\pi \oplus K^\pm$ )



# Fit results



## Fit is stable wrt:

1-fit range

2-binning

3-background modeling

Reference is:

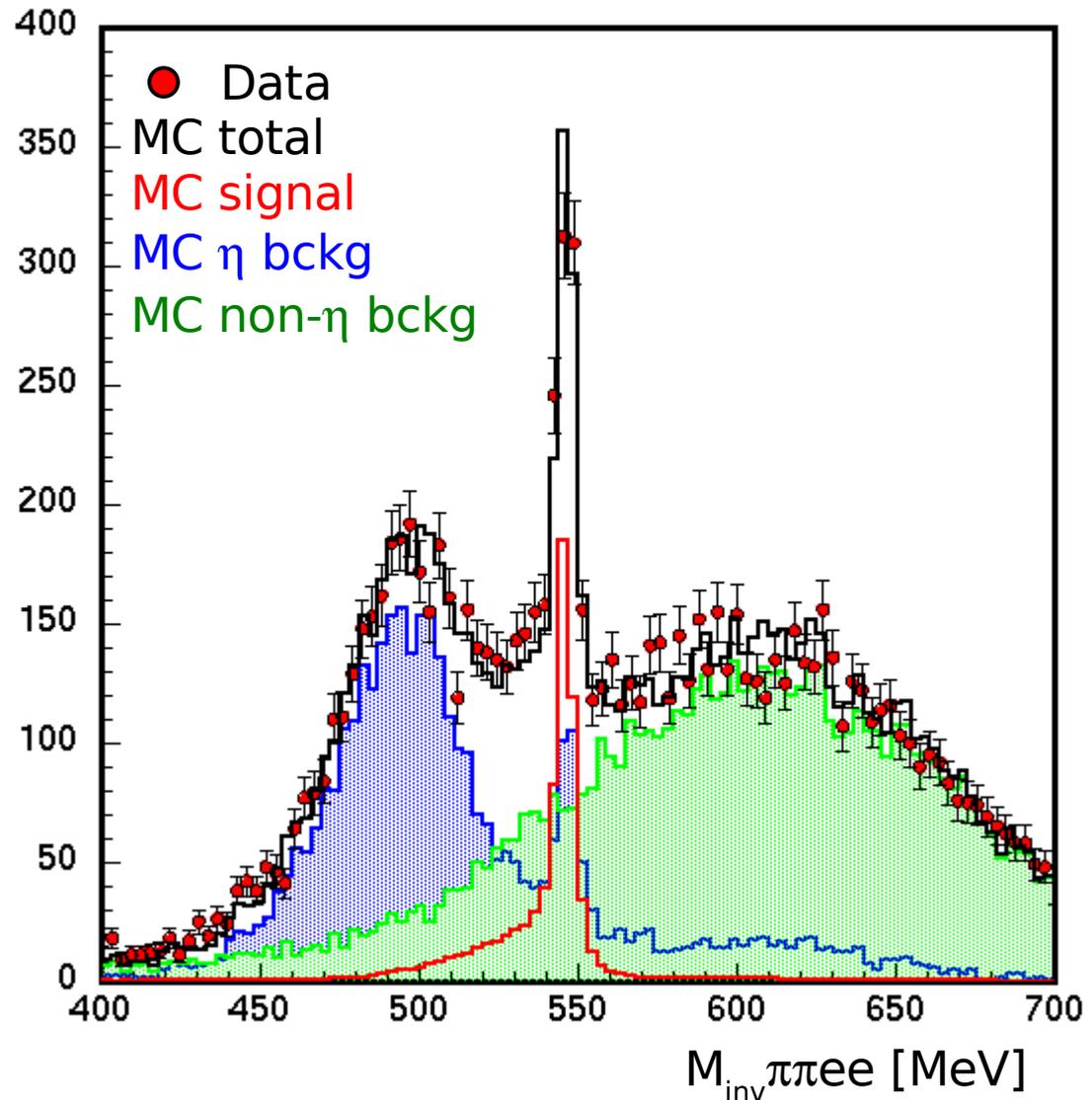
[400:700] MeV

3 MeV per bin

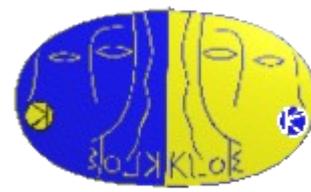
fit = signal

+ other  $\eta$  decays

+ non  $\eta$  backgrounds

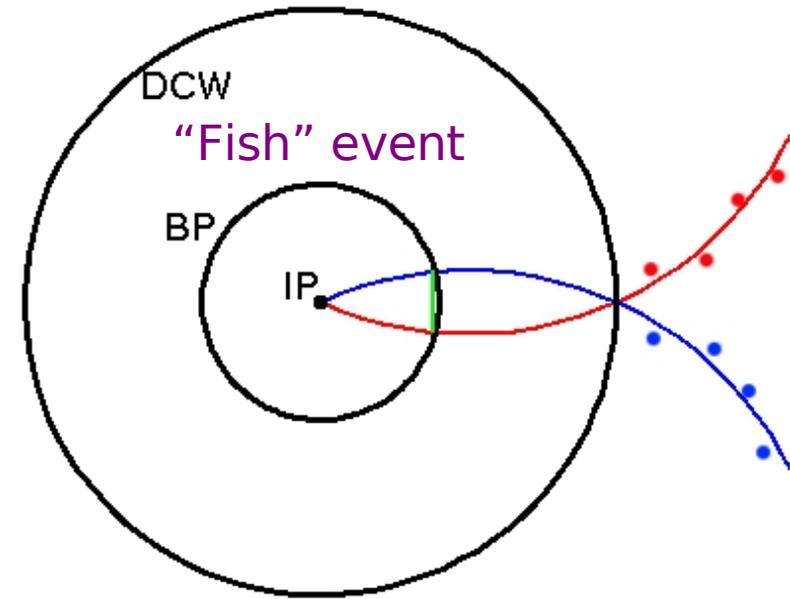
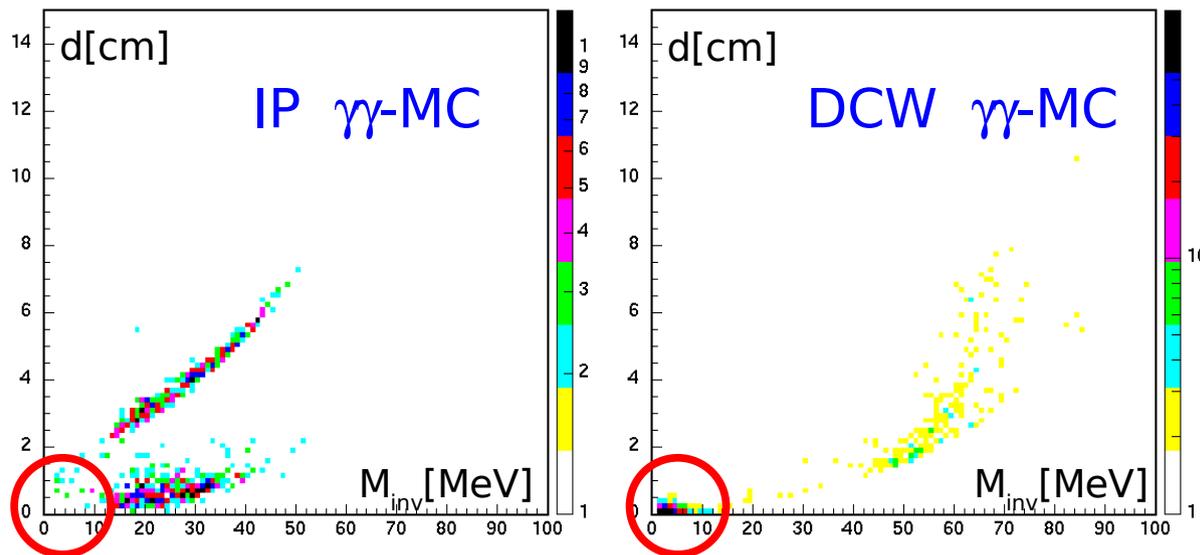


# $\eta \rightarrow \pi^+\pi^-\gamma$ background



Has the same signature of the signal ( $\eta \rightarrow \pi^+\pi^-\gamma \rightarrow \pi^+\pi^-e^+e^-$ )  
when photon converts on the Beam Pipe or on DC Wall

Disentangled using  $M_{inv}(e^+e^-)$   
and distance between tracks

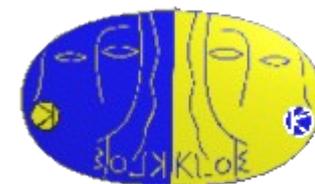


arXiv:0707.1601

In MC  $BR(\eta \rightarrow \pi^+\pi^-\gamma)$  from PDG

reduced by 15% by CLEO

# BR evaluation



$$BR = \frac{N_{\pi\pi ee}}{N_{\eta}} \cdot \frac{1}{\epsilon} = \frac{N_{\pi\pi ee \text{ Fit DATA}}}{\sigma_{\phi} \cdot L \cdot BR(\phi \rightarrow \eta\gamma)} \cdot \frac{1}{\epsilon}$$

#events = 733(62)

efficiency = 0.1175(5)

Reconstruction efficiency from MC

Correction expected ~5-10%

Systematics

Normalization

Event counting

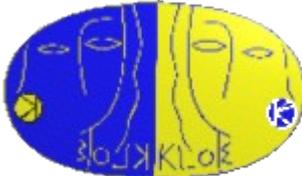
Efficiency

Cuts on momenta

under  
evaluation

$$BR(\eta \rightarrow \pi^+\pi^-e^+e^-) = (2.4 \pm 0.2_{\text{Stat.}} \pm 0.4_{\text{Syst.}}) \times 10^{-4}$$

**PRELIMINARY**

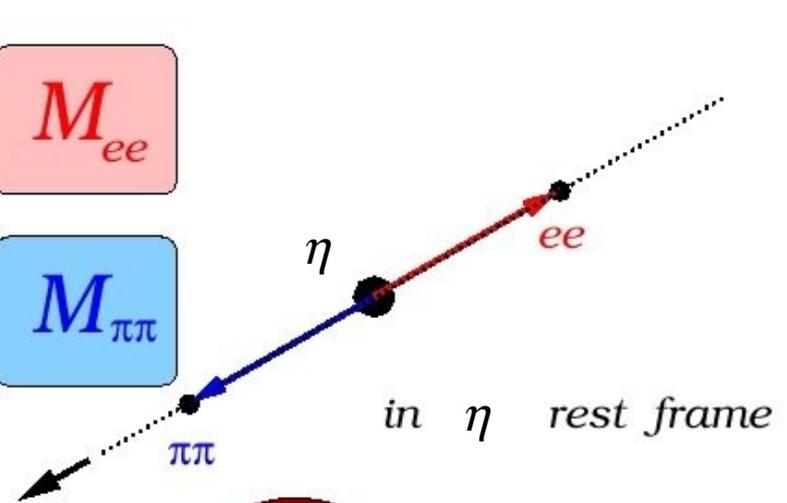


Remind

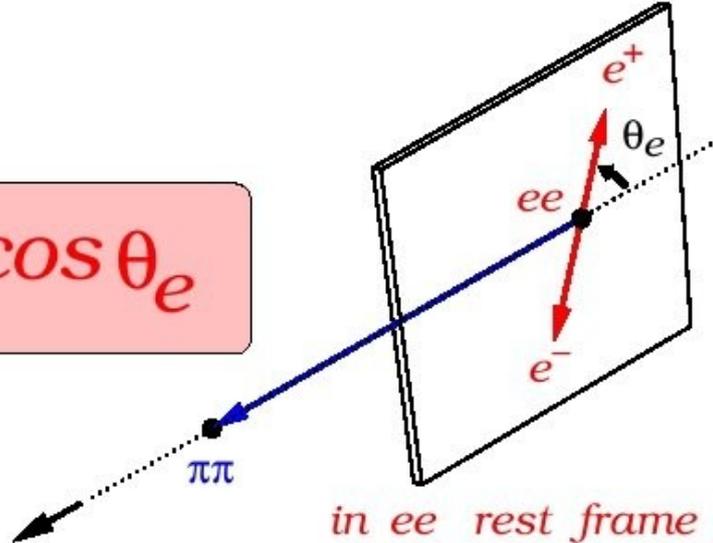
# Asymmetry

$M_{ee}$

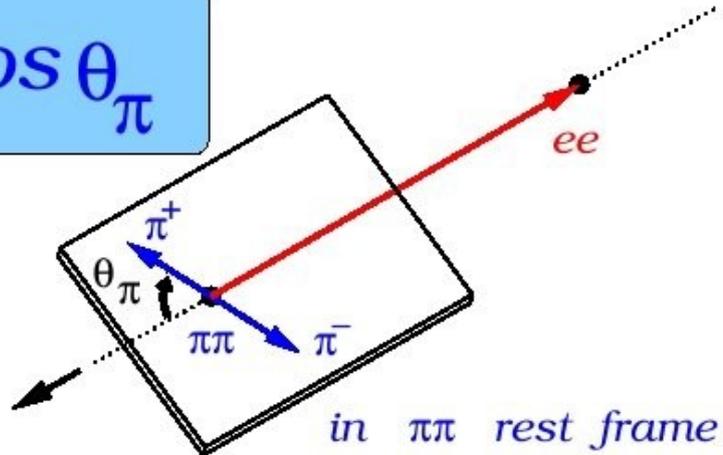
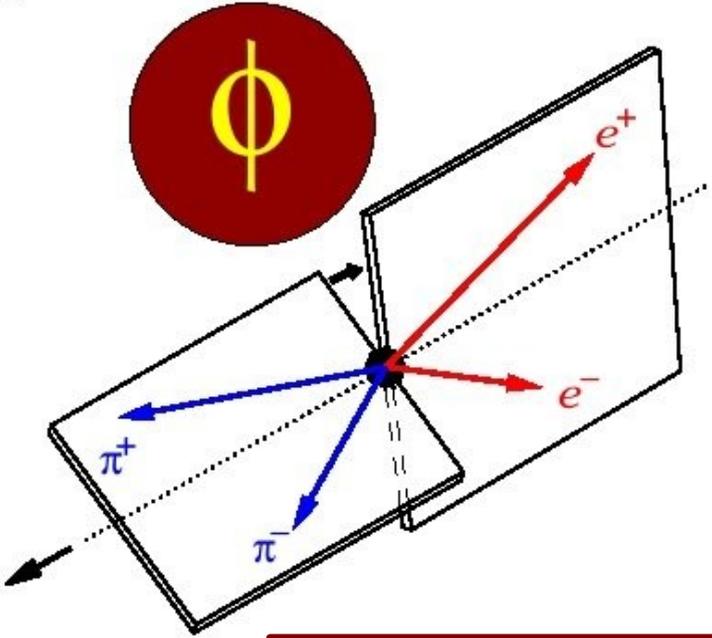
$M_{\pi\pi}$



$\cos \theta_e$

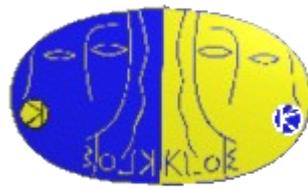


$\cos \theta_\pi$



$$\sin \phi \cos \phi = (\hat{n}_{ee} \times \hat{n}_{\pi\pi}) \cdot \hat{z} (\hat{n}_{ee} \cdot \hat{n}_{\pi\pi})$$

# Asymmetry

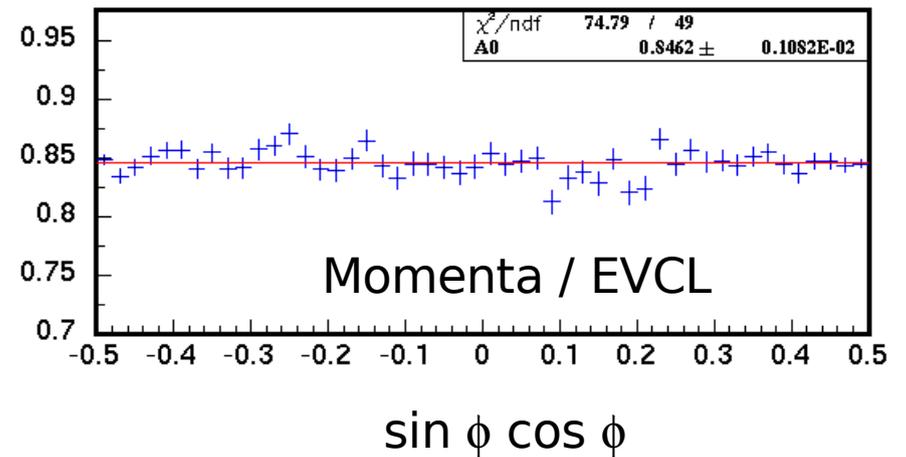
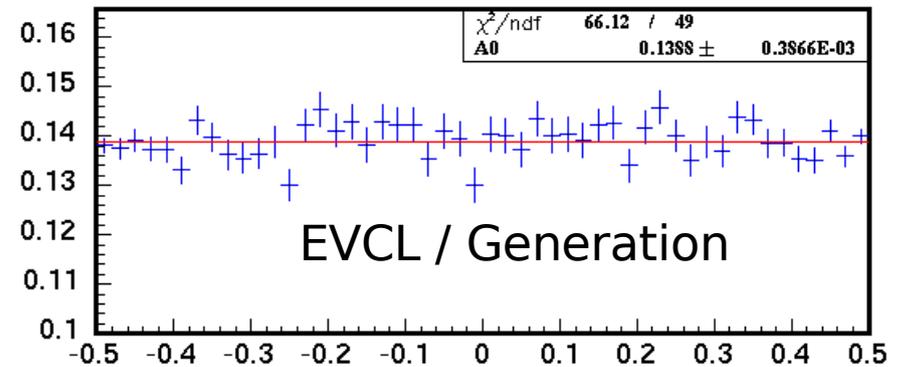
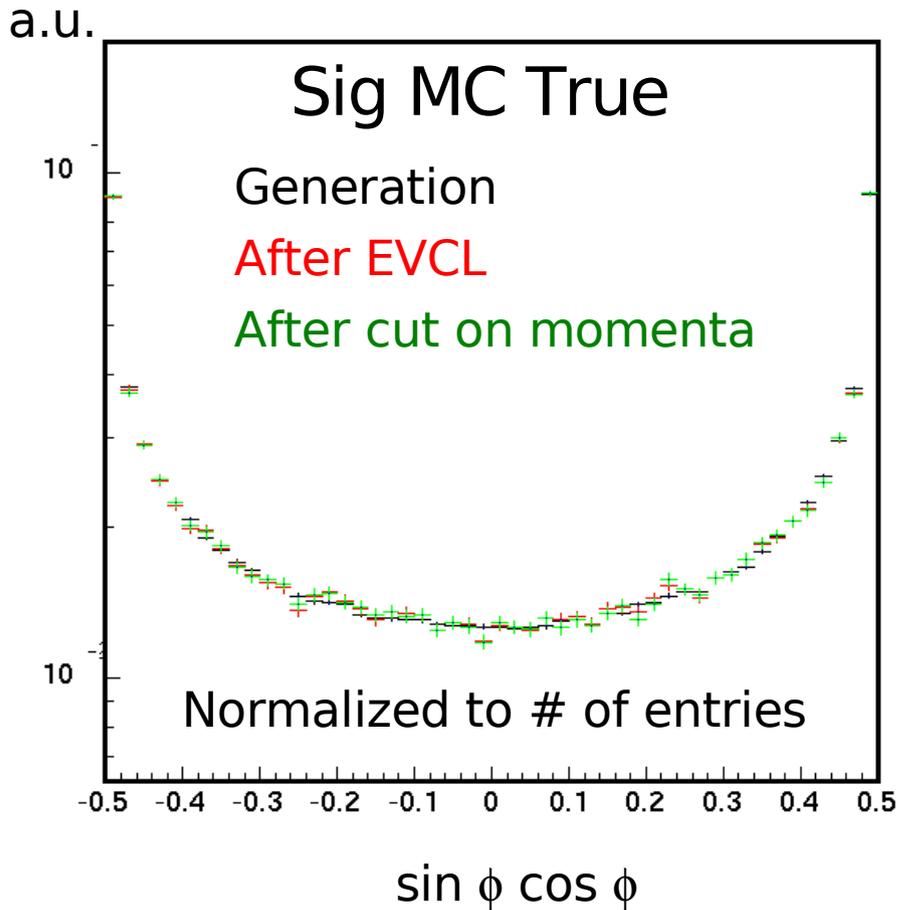


Distortion at each step

$$N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}$$

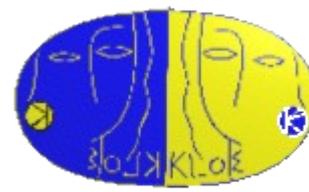
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$$N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}$$



The asymmetry is not affected by efficiencies

# Conclusions



**About 700 signal events have been observed!**

~40 times more than what has been seen previously

**PRELIMINARY**

$$BR(\eta \rightarrow \pi^+\pi^-e^+e^-) = (2.4 \pm 0.2_{\text{Stat.}} \pm 0.4_{\text{Syst.}}) \times 10^{-4}$$

Asymmetry measurement is feasible with KLOE

- Efficiency to be corrected for Data/MC ratio ~5-10% effect
- Improvement in PID using TOF
- Identification of photon conversion to **further reduce background** in the signal mass region ( $\eta \rightarrow \pi^+\pi^-\gamma$ )
- **Increase statistics** both MC( $\times 2$ ) and data( $\times 3$ )