Study of the $\eta \to \pi^+ \pi^- e^+ e^-$ decay at KLOE

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on behalf of the KLOE collaboration

Outline

Motivations

KLOE

Data sample

Analysis procedure

Fit to the data

Branching Ratio

Asymmetry

Motivations

Test of CPV beyond SM Mod. Phys. Lett. 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×V 4 quarks operator with $\Delta s=0$.

Within SM, A_{CP} is constrained by BR($\eta\to\pi\pi$),

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}

DAΦNE

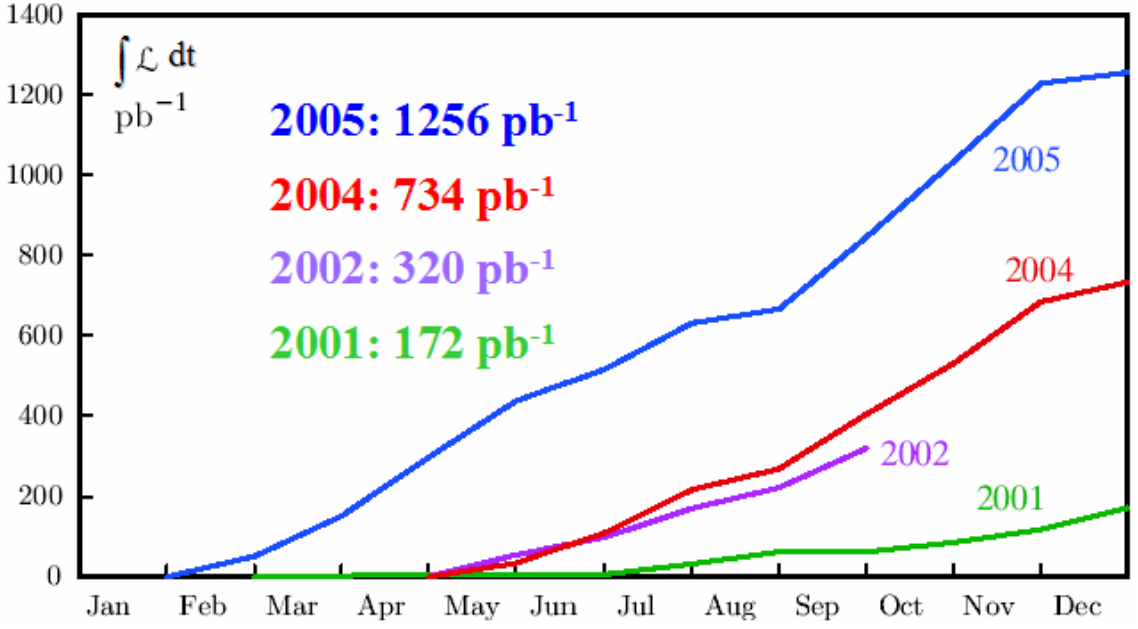
Double **A**nnular ring **F**or **N**ice **E**xperiments

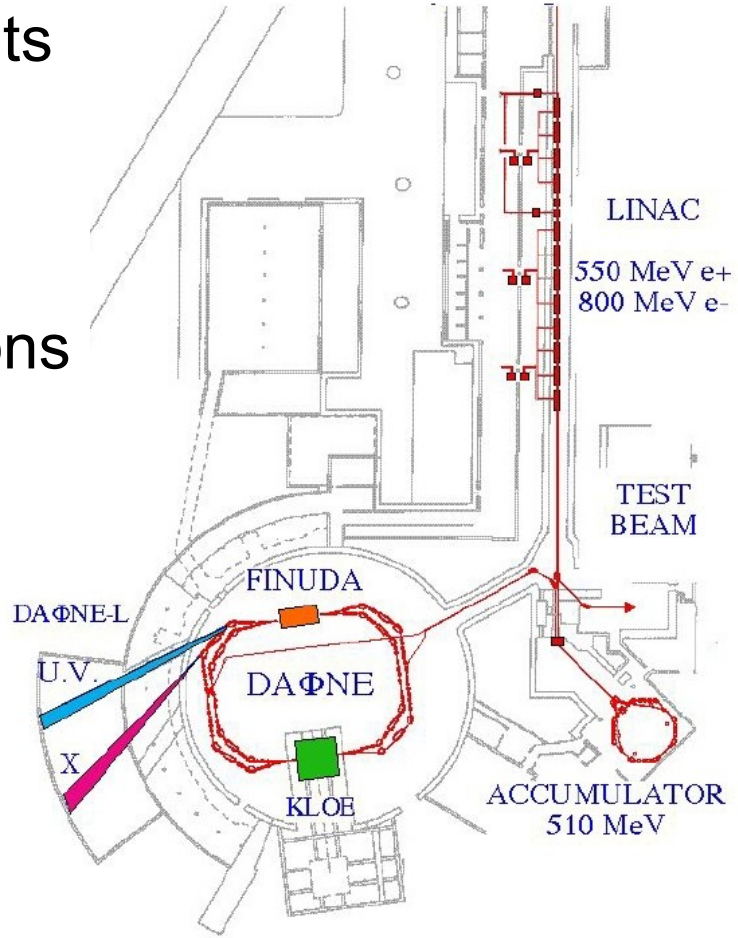
electron-positron collider

$\sqrt{s} = m_\phi = 1.019$ GeV $\sigma(\phi) \approx 3$ mb

2 rings to minimize beam-beam interactions

12.5 mrad crossing angle





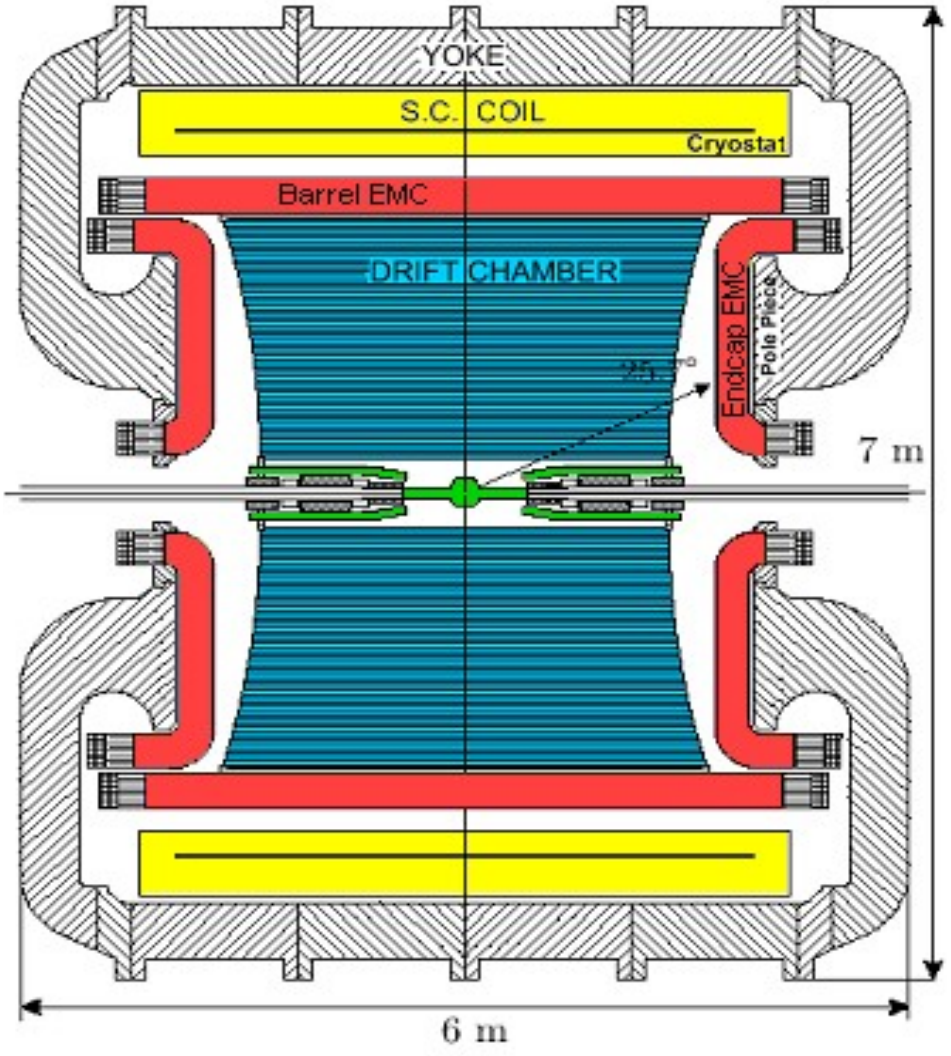
η produced through

$e^+e^- \rightarrow \phi \rightarrow \eta\gamma$

KLOE Off-peak:

4 scan points (~10 pb^{-1}@ 1010, 1018, 1023, 1030 MeV) and ~240 pb^{-1}@ 1 GeV

K LOng Experiment



Spherical ***beam pipe***
10 cm ∅, 0.5 mm thick in Be-Al alloy
to minimize regeneration,
scattering and γ conversion

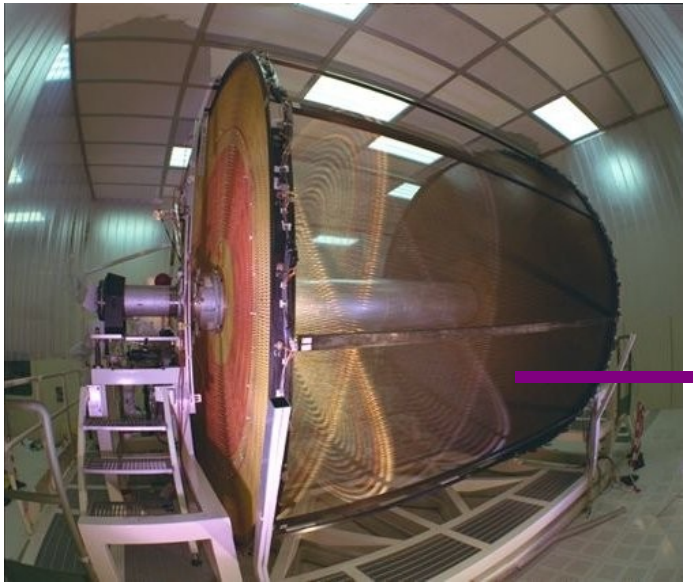
Large volume ***drift chamber***
4 cm ∅, L=3.4 m, carbon-fiber frame,
low density gas (90% He – 10% C_4H_{10}),
12582 all stereo squared cells,
tungsten and aluminium wires (52140)

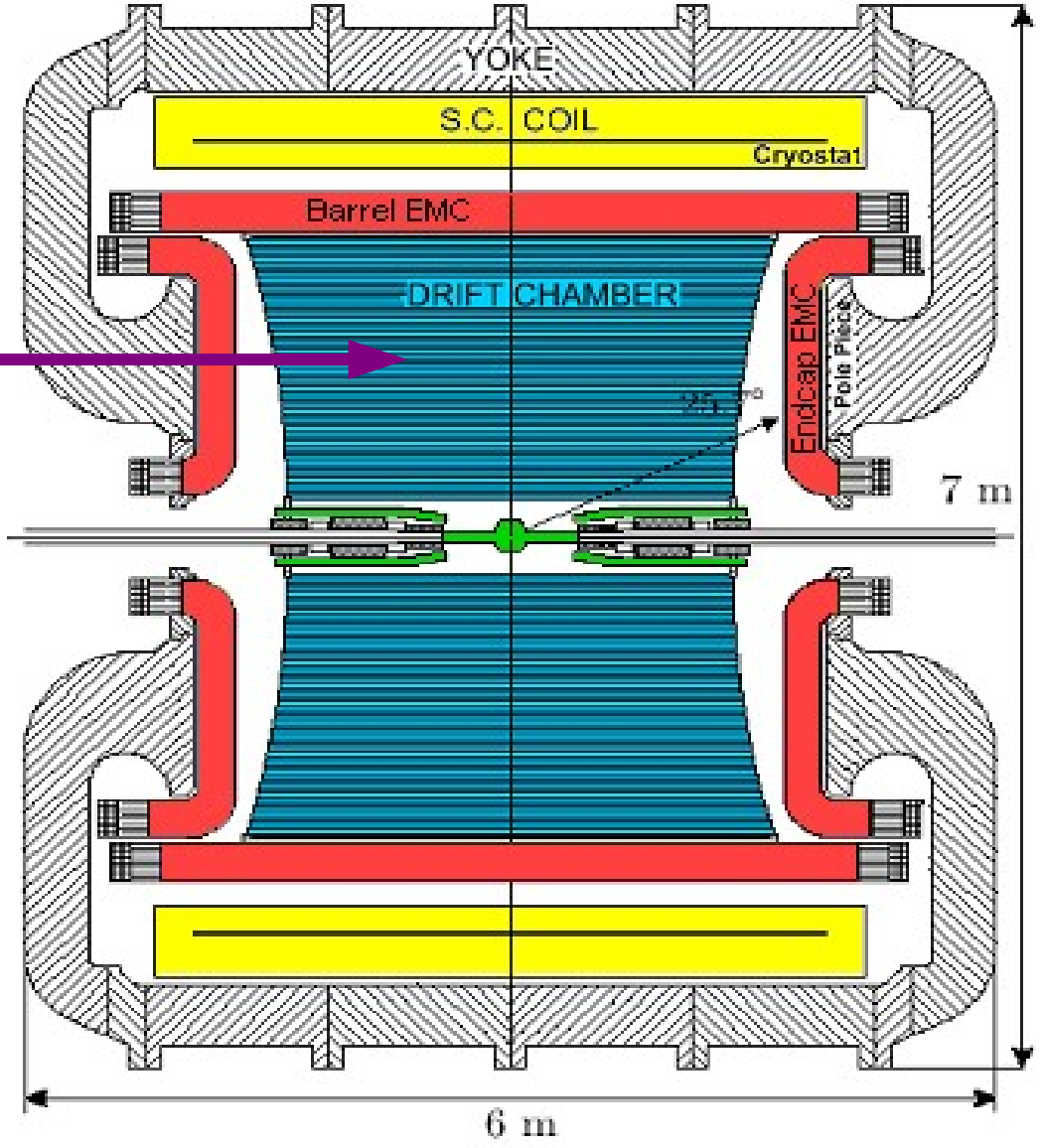
~4π ***calorimeter***, 4880 cells
15X_0 thick, 0.5 mm lead
1mm∅ scintillating fibers

Superconducting coil B = 0.52 T

Remind: λ_L = 3.5m

KLOE – Drift Chamber





$\sigma_{r\phi}$ = 150 μm

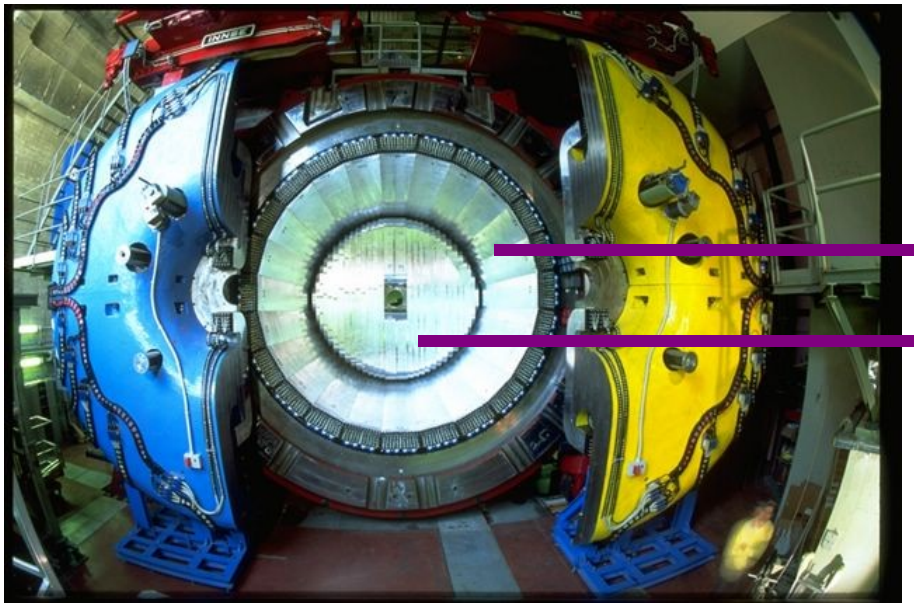
σ_z = 2 mm

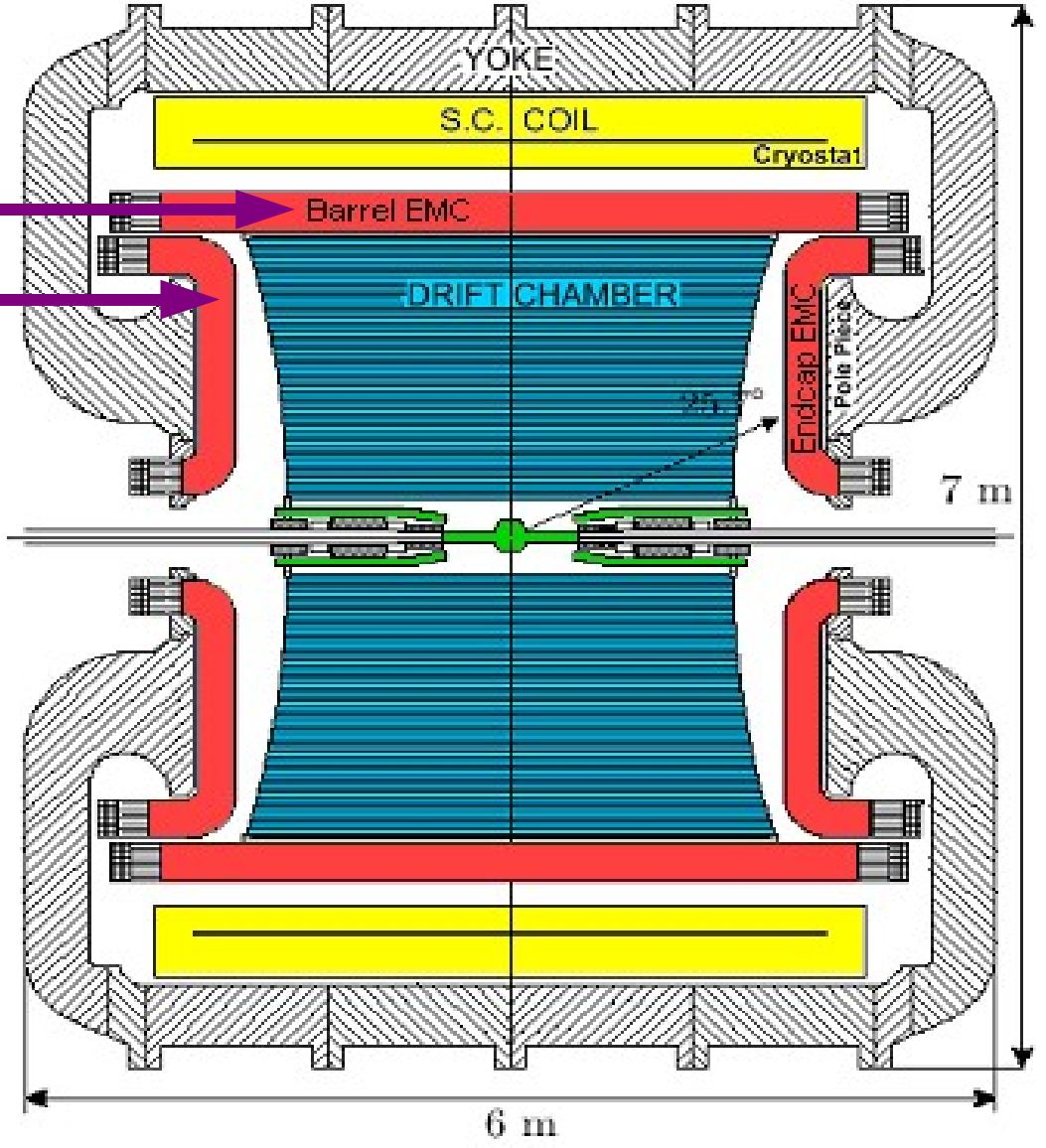
$\sigma_p/p \sim 4 \times 10^{-3}$

$\sigma_{vertex} \sim 3$ mm

$\sigma(m_{\pi\pi}) \sim 1$ MeV

KLOE – EM Calorimeter





σ_t = 57 ps / √(E[GeV]) ⊕ 100 ps

σ_E = 0.057 / √(E[GeV])

σ_{shower} = 1.3 cm / √(E[GeV])

$\sigma_{vertex}(\gamma\gamma)$ = 1.5 cm ($K_L \rightarrow \pi^+\pi^-\pi^0$)

ε > 95% for E_γ > 20 MeV

π/e PID based on TOF

Data sample

1733 pb^{-1} data 2004/05

242 pb^{-1} data off-peak ($\sqrt{s}$ = 1000 MeV)

(to study background from continuum)

3447 pb^{-1} MC all ϕ meson decays 2004/05

50506 pb^{-1} MC signal only

FSR simulated using PHOTOS

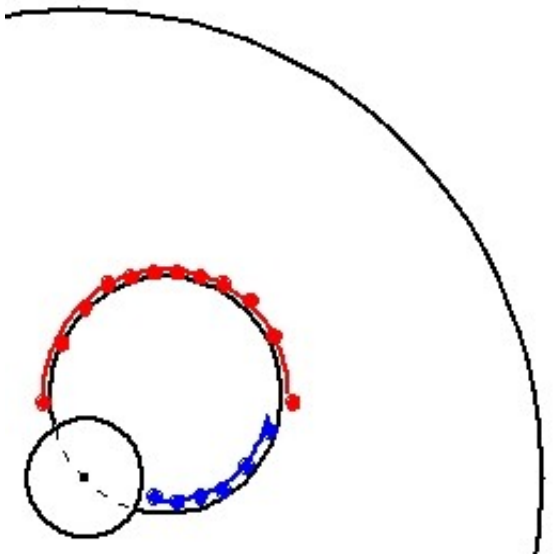
MC has been produced having
run by run background simulation

Event selection

1 high energy prompt neutral cluster ($E_{cl} \geq 250$ MeV)

Tracks are required to came from a cylinder around the IP:

$R \leq 4$ cm $h/2 = 10$ cm



Check on broken tracks is applied:

$\Delta P_T < 4.5$ MeV $\Delta P_Z < 3$ MeV

≥ 2 positive and ≥ 2 negative tracks are requested

Tracks are ordered by momentum

Particle IDentification

Performed using TOF

We evaluate $\Delta t = t_{track} - t_{cluster}$ in both electron (Δt_e) and pion (Δt_π) hypothesis

We also look for decay vertex along the track

Wrong mass assignment leads to a distorsion of the $\pi\pi ee$ invariant mass spectrum

Kinematic fit

A kinematic fit to the ϕ meson is performed for all the events having # good tracks ≥ 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 ϕ momentum

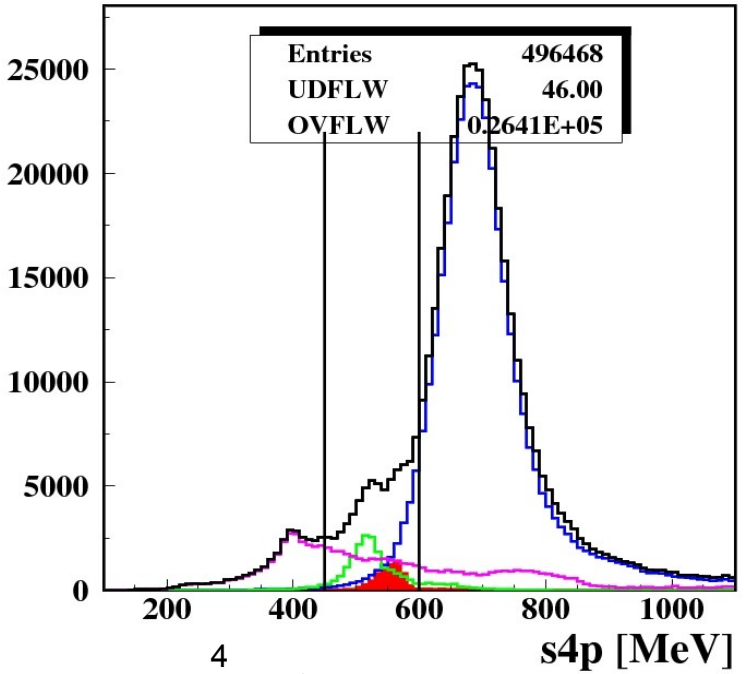
The 5 constraints are:

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

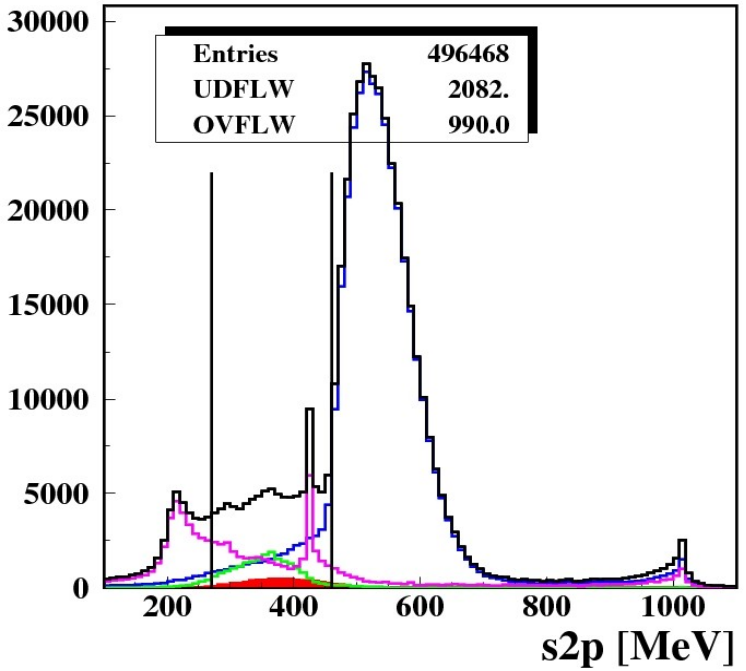
Event selection

1. **EVCL** ≥ 4 tracks and 1 high energy prompt neutral cluster
2. **Momenta** 450 < s4p < 600 MeV .and. 270 < s2p < 460 MeV
3. χ^2_{KF} $\chi^2_{KF} < 4000$

At this level we perform the fit to get the scale factors

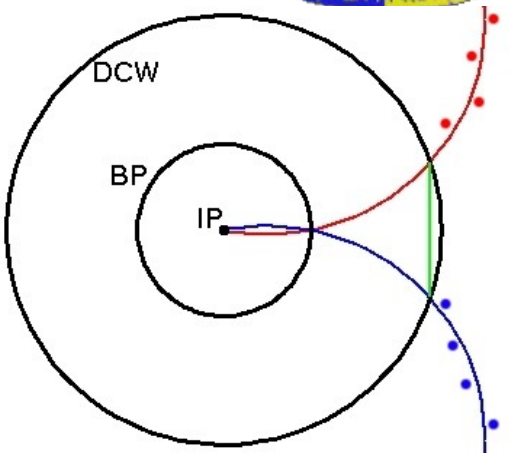


$$\sum_{i=1}^{4} |\vec{p}_i| = s4p$$



$$s2p = |P(p^{+}1)| + |P(p^{-}1)|$$

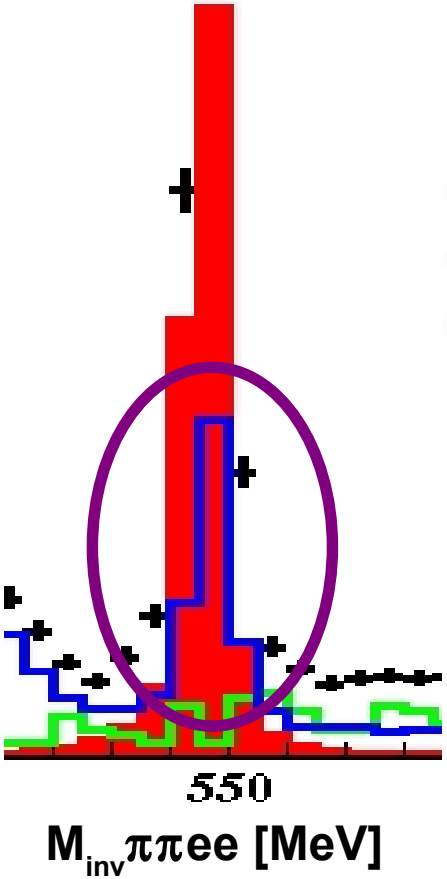
$\eta \to \pi\pi\gamma$ background



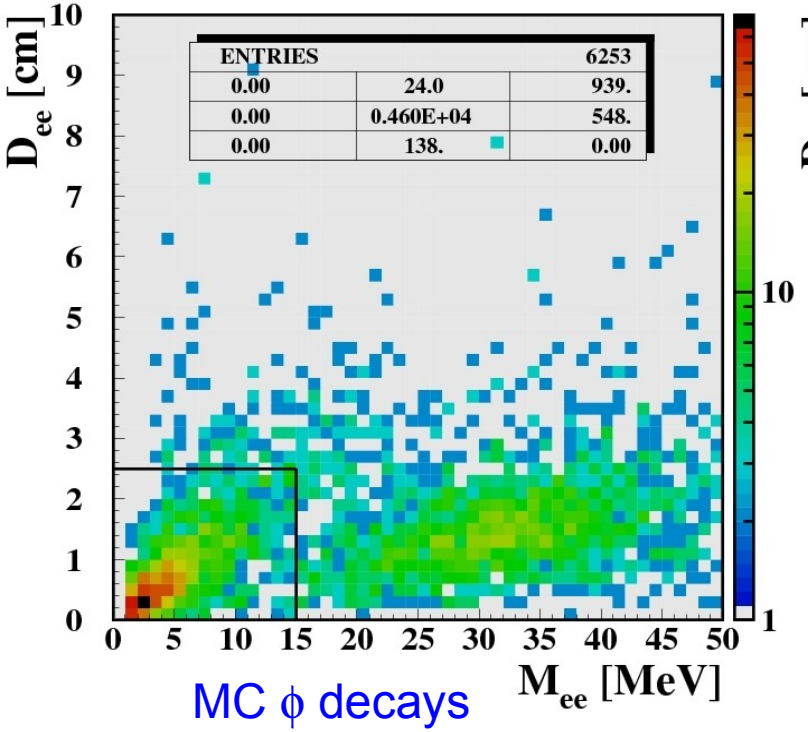
photon conversion on BP produces signal signature

$M_{inv}(e^+e^-)$ and $Dist(e^+e^-)$ are zero at the conversion point

Data
MC signal
MC ϕ decays
Data offpeak



Mee@BP > 15 MeV .or. Dee@BP > 2.5 cm



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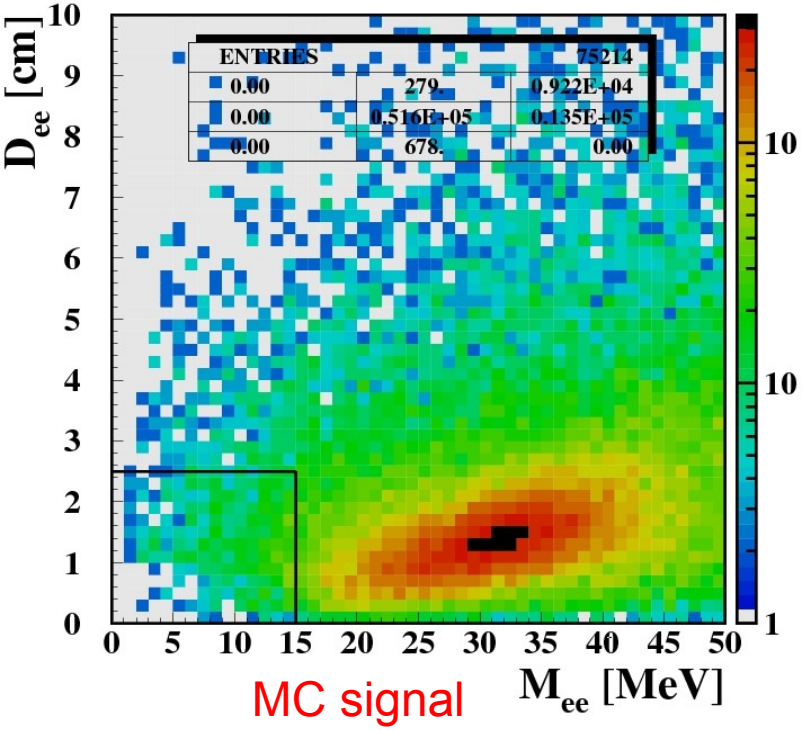
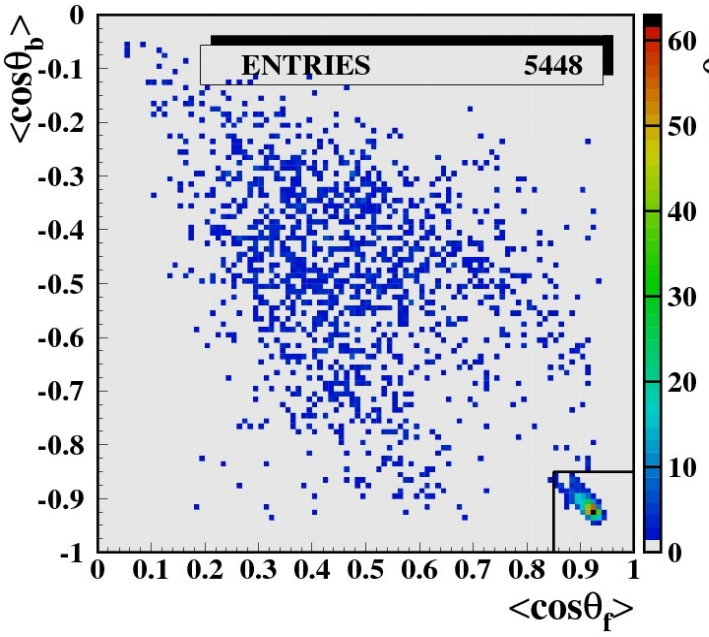
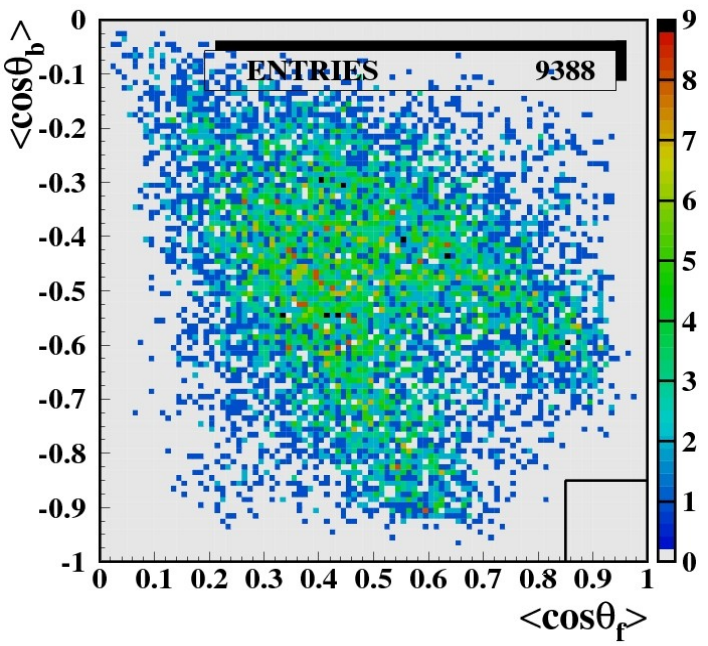


MC signal

Non physical background

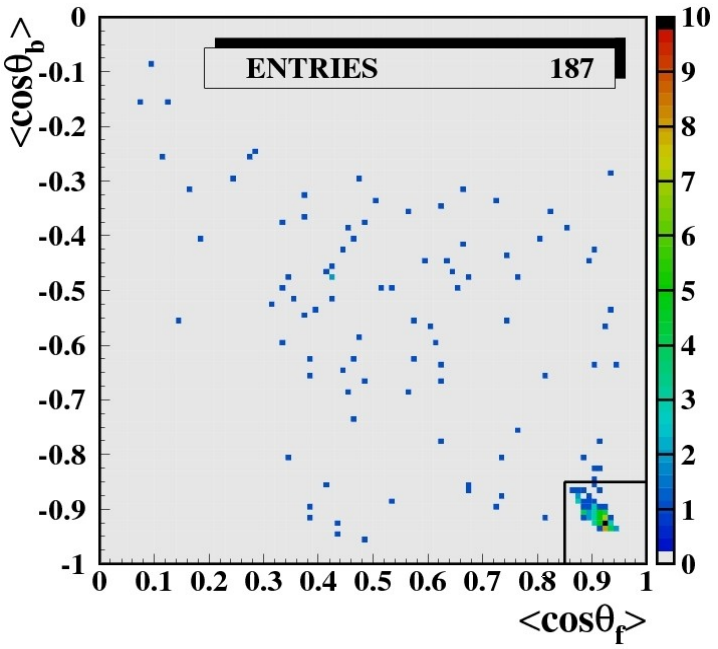
Data





MC
ϕ decays

offpeak data



$\langle\cos\theta_f\rangle < 0.85$ .and.

$\langle\cos\theta_b\rangle > -0.85$

Due to events with particles hitting the quadrupoles

Analysis summary

1. **EVCL** ≥ 4 tracks and 1 high energy prompt neutral cluster
2. **Momenta** 450 < s4p < 600 MeV `.and.` 270 < s2p < 460 MeV
3. **χ^2_{KF}** $\chi^2_{KF} < 4000$

At this level we perform the fit to get the scale factors

4. **Conversions** Mee > 15 MeV `.or.` Dee > 2.5 cm (@BP)
5. **Low θ** $\langle\cos\theta_f\rangle < 0.85$ `.and.` $\langle\cos\theta_b\rangle > -0.85$
6. **$M_{\pi\pi ee}$** $535 < M_{\pi\pi ee} < 555$ MeV

At this level we count

Fit description

- Stand alone program using HBOOK and MINUIT
- Fit performed on sidebands:

  [420.,530.] MeV U [560.,680.] MeV
- Components used:

  MC ϕ decays and off-peak data
- Off-peak data scale factor fixed using luminosity

  because of its small statistics

  $SF_{offpeak} = L_{data} / L_{offpeak} = 7.14$

  $\sqrt{s}$ has been accounted for

Fit result

Data

Total

MC ϕ decays

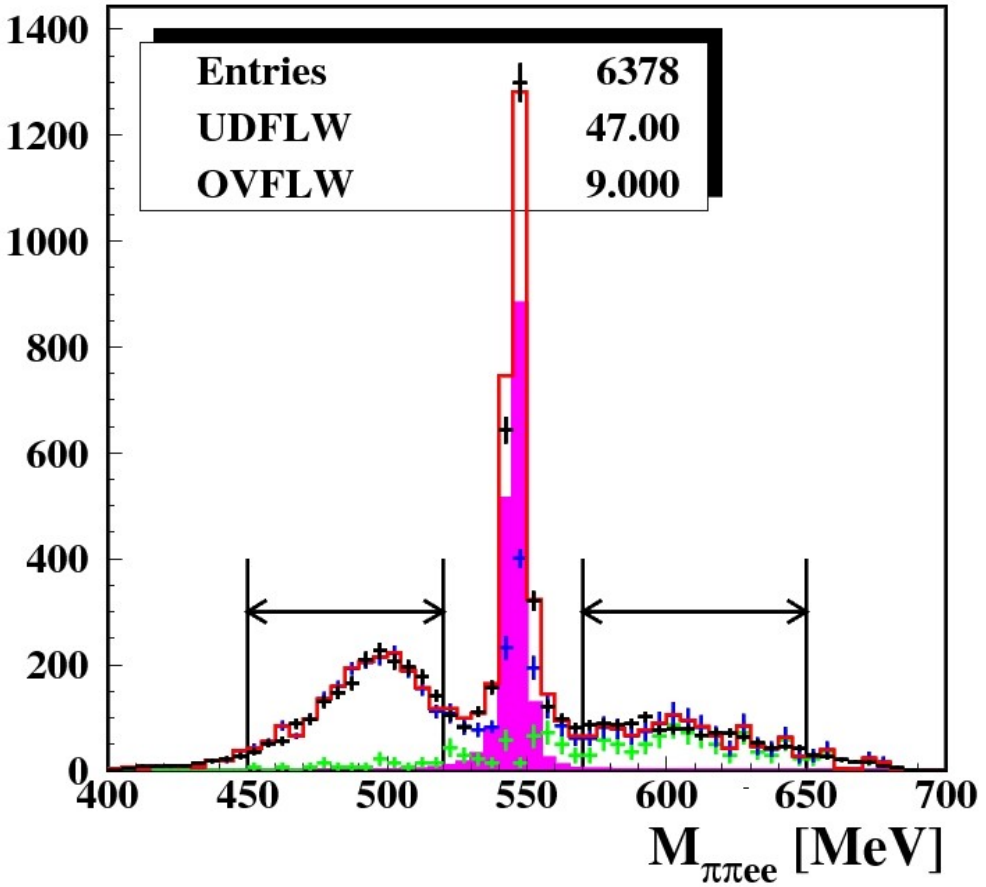
Off-peak data

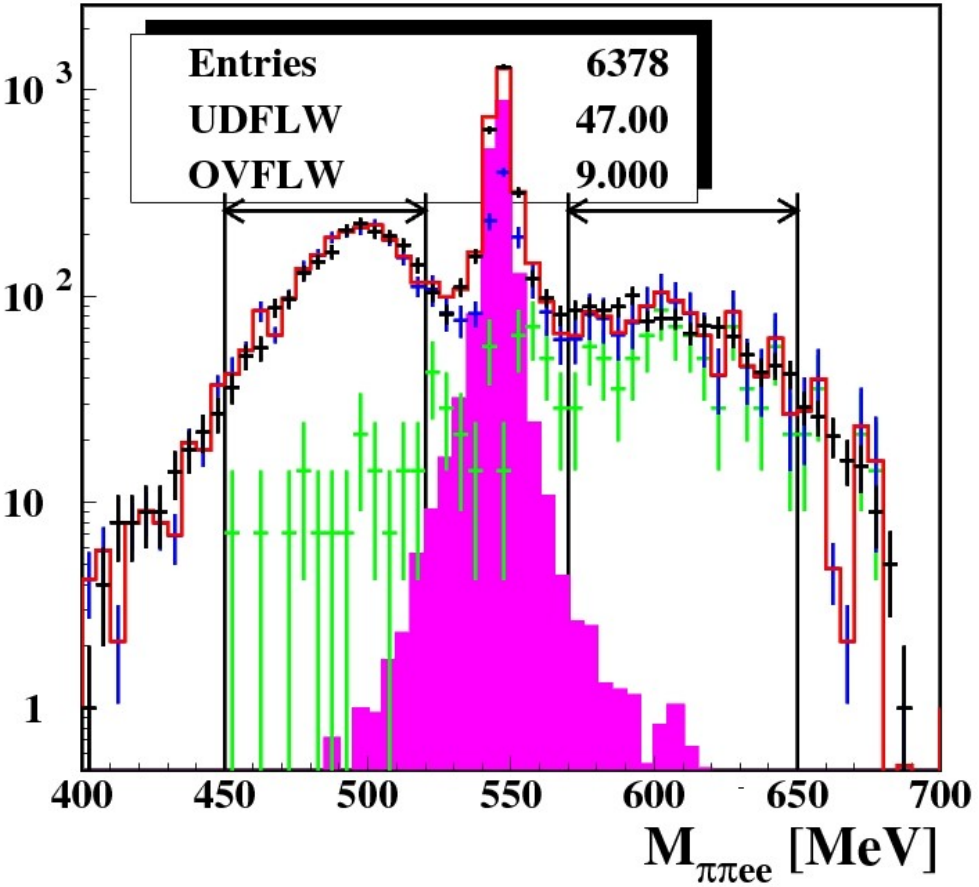
Signal MC

χ^2/dof = 32.5/30 $P(\chi^2)$ = 0.35

SF_{ap} = 0.528 ± 0.009

SF_{op} = 7.14 ± 0.03





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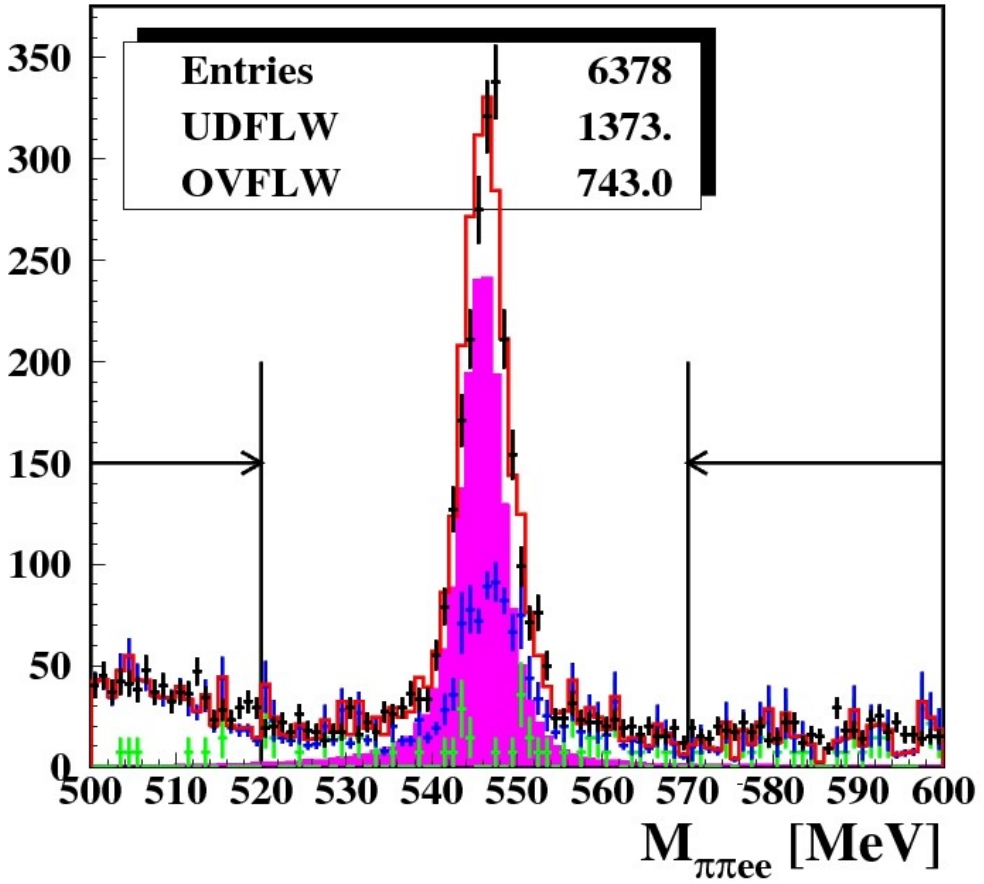
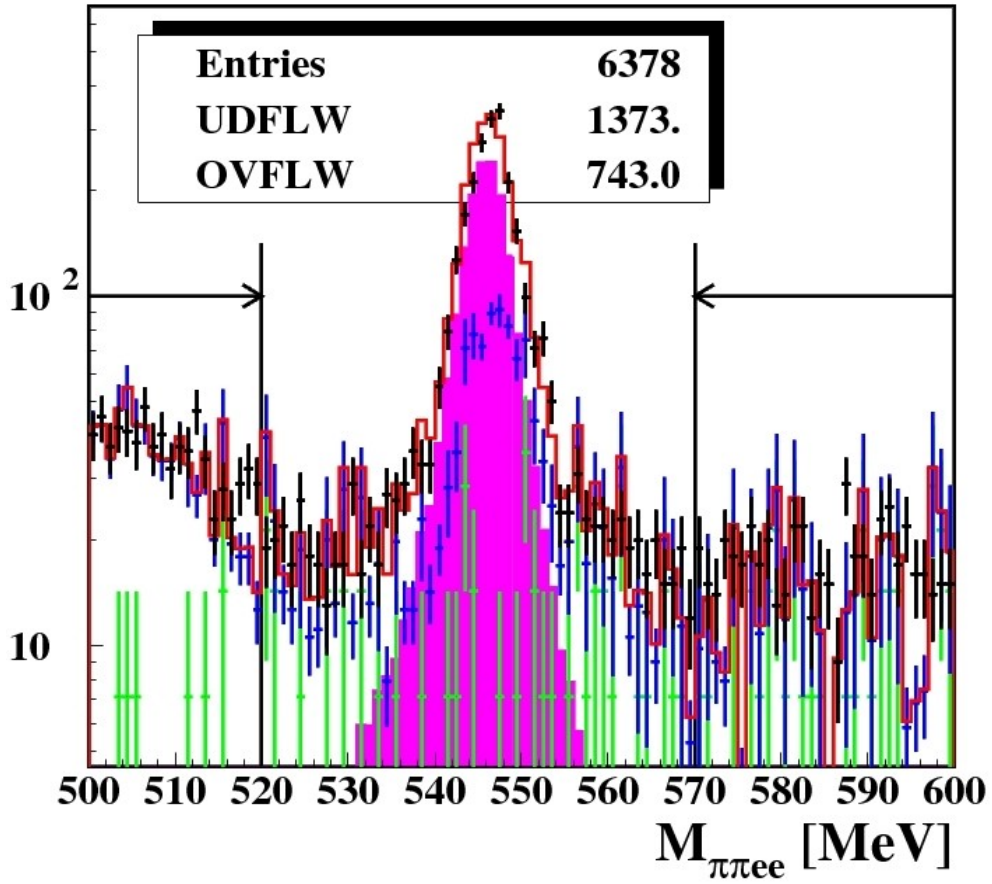
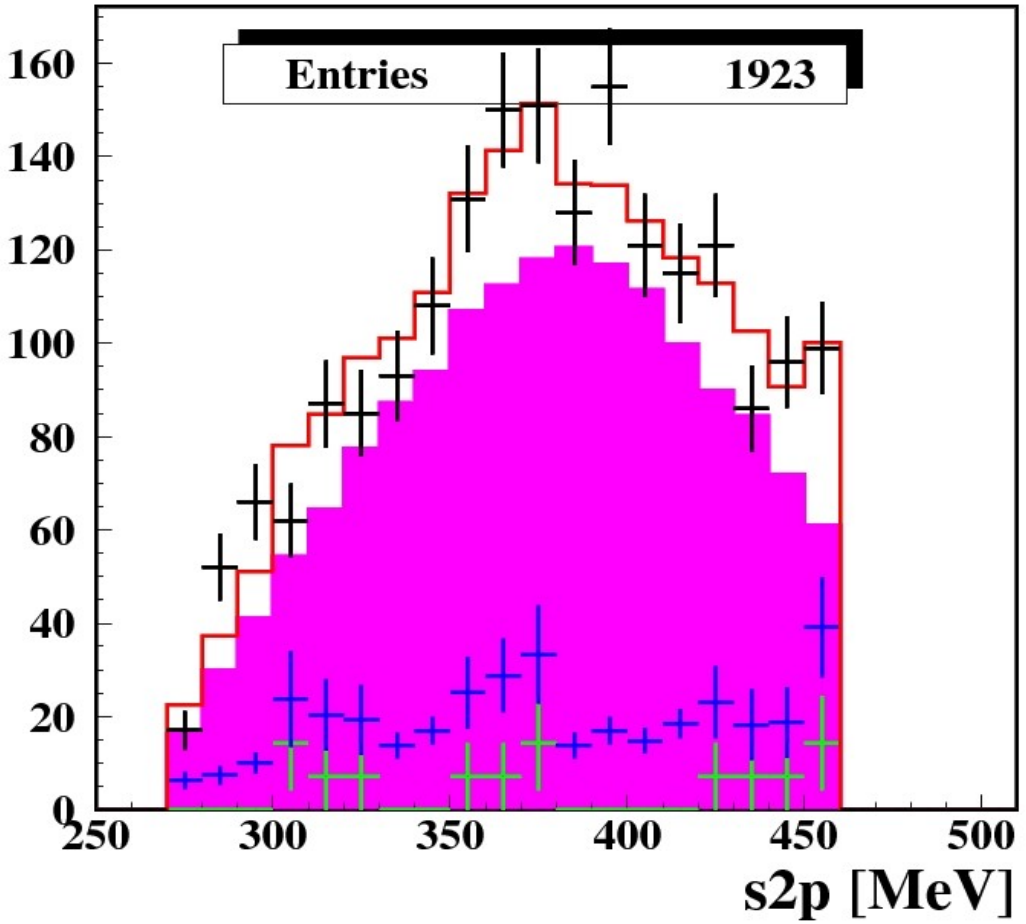
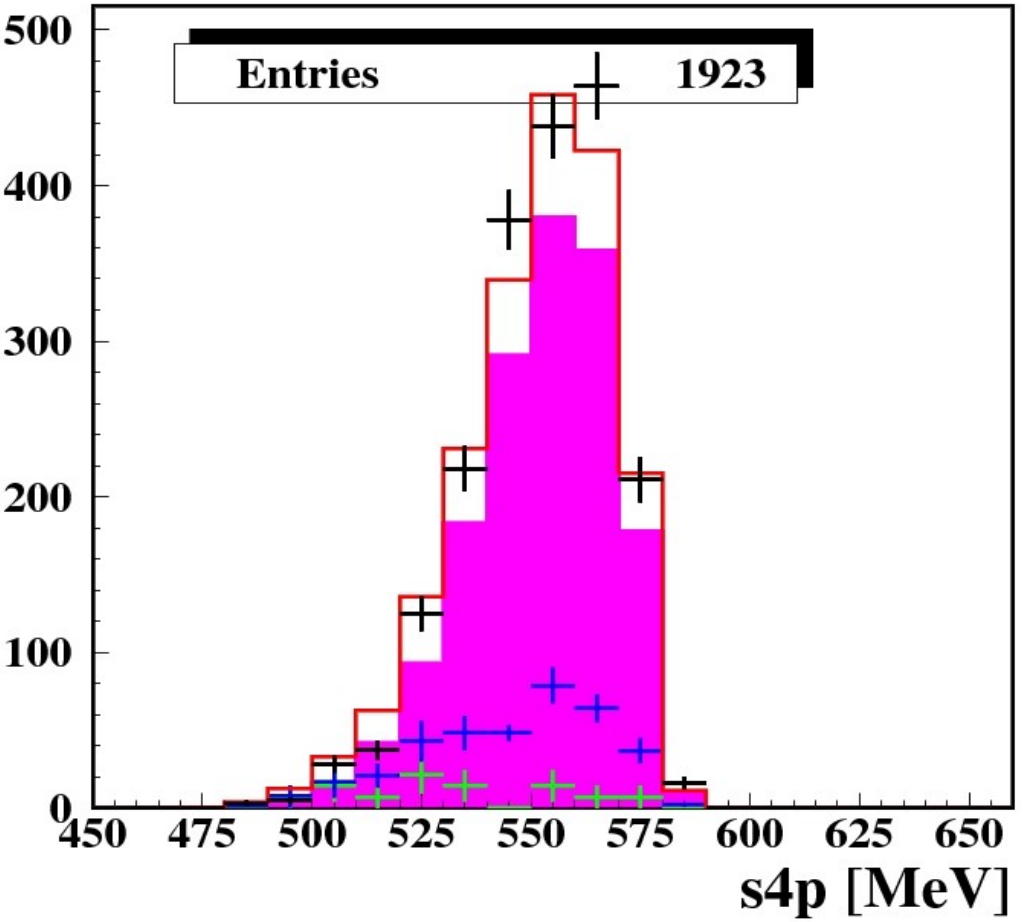




Data-MC comparison

Data
Total
MC `all_phys`
Off-peak data
Signal MC





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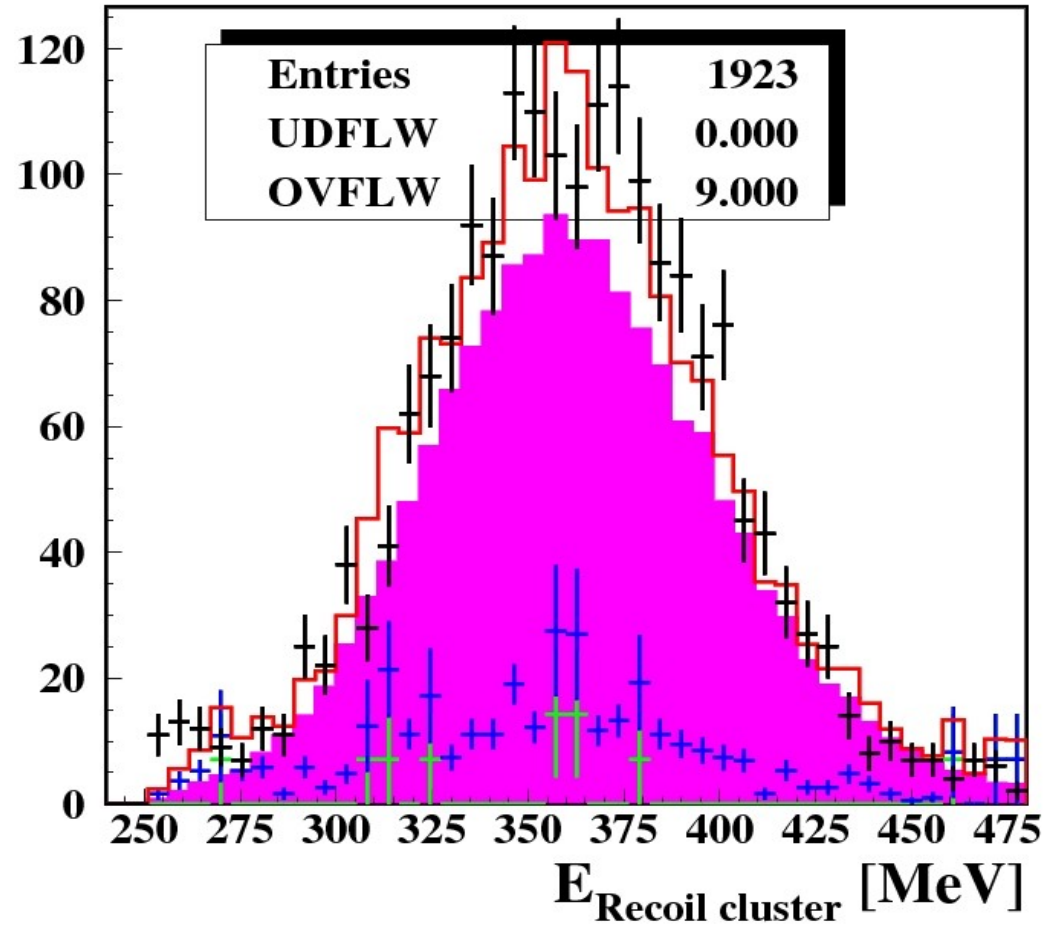

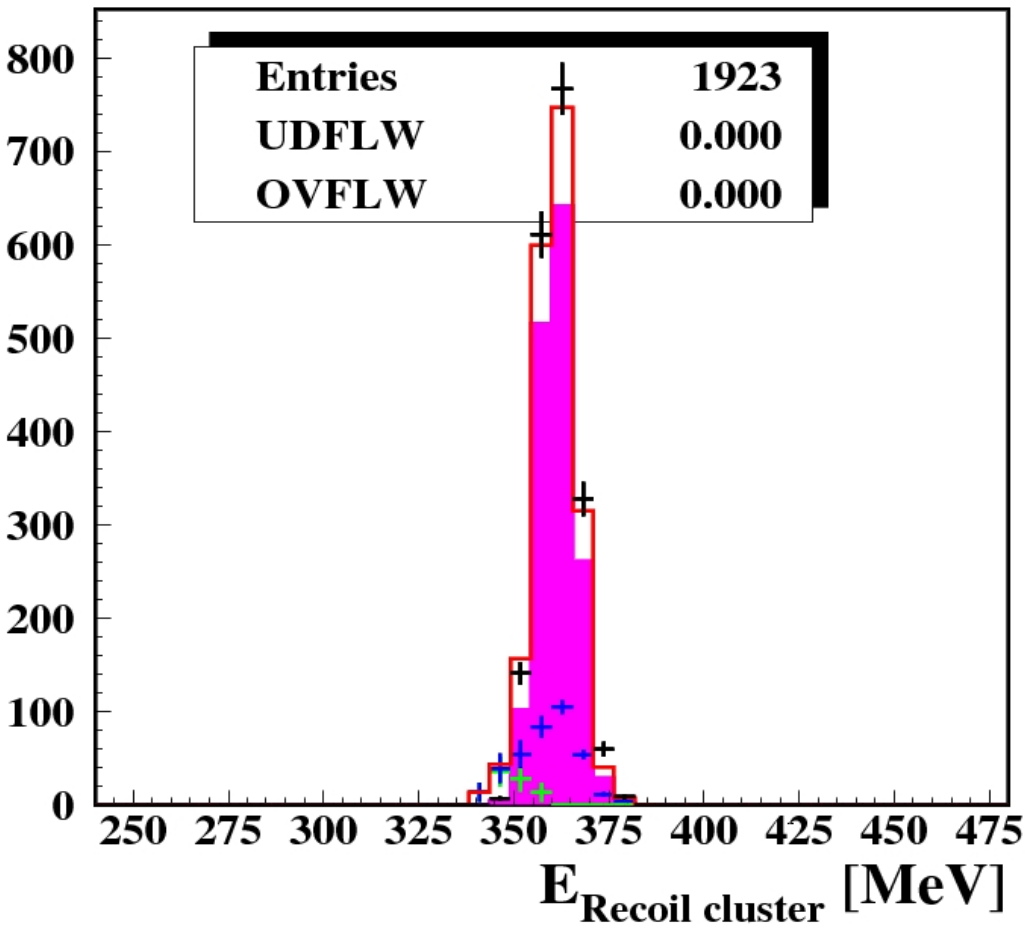

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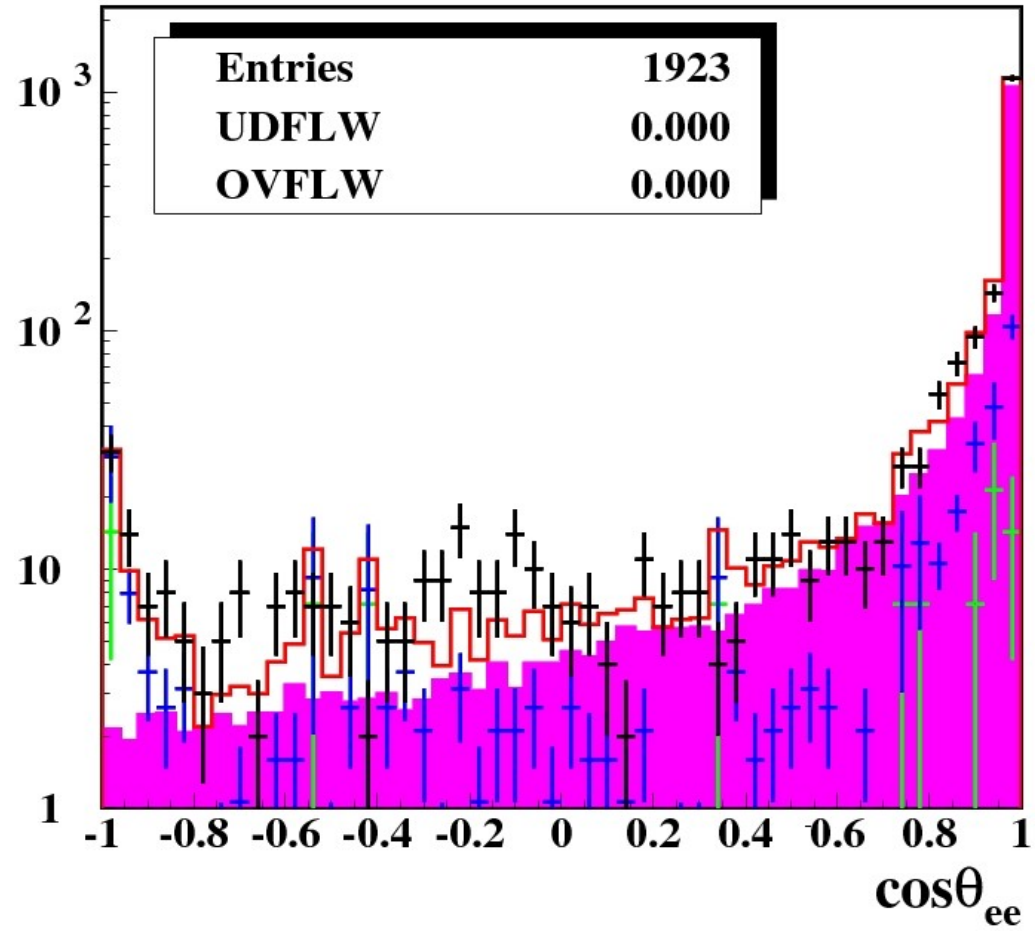
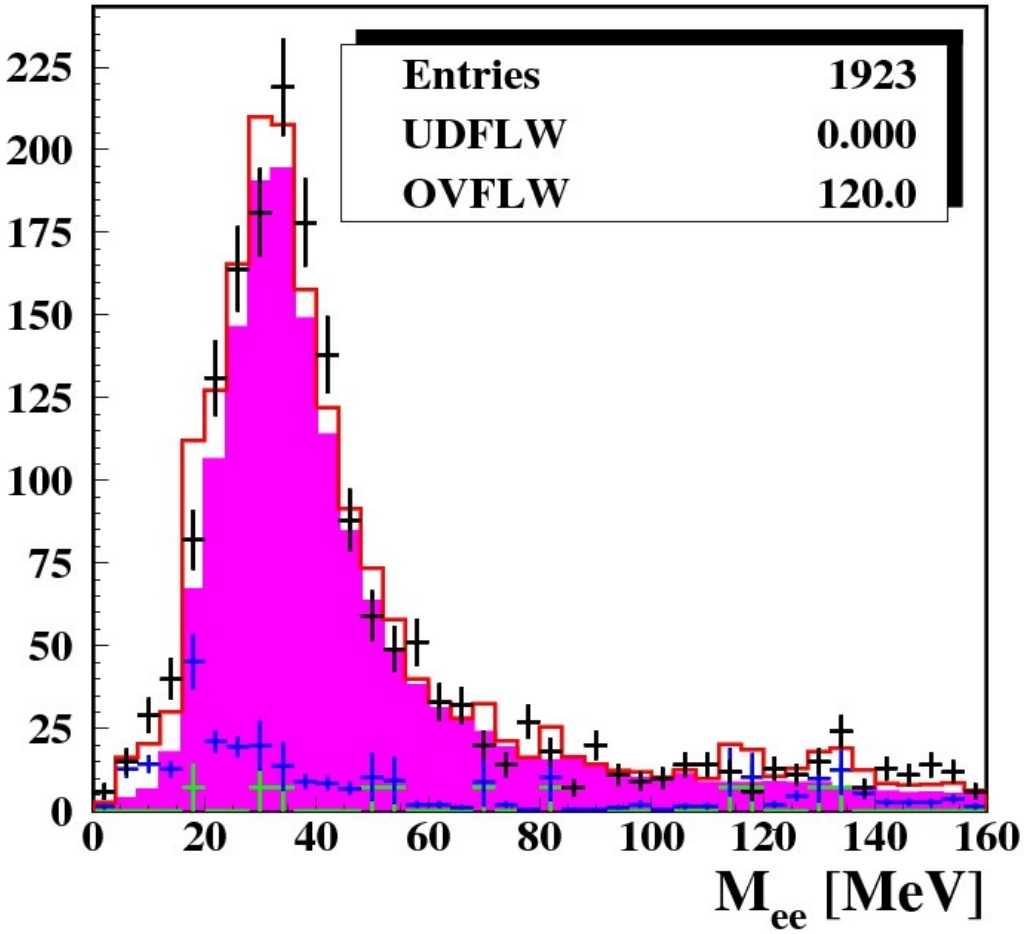




BR evaluation

$$BR = N_{ev} / \varepsilon L \sigma_{\phi \to \eta\gamma}$$

Number of events

1555 ± 52

Efficiency

0.0803 ± 0.0003

Luminosity

(1733 ± 10) pb^{-1}

Cross section

(41.7 ± 0.6) nb

$$BR(\eta \to \pi^+\pi^- e^+e^- (\gamma)) = (26.8 \pm 0.9_{Stat.} \pm 0.4_{Norm.}) \cdot 10^{-5}$$

Systematics

Evaluated varying:

• sidebands range	$0.05 \cdot 10^{-5}$	
• histogram binning	$0.02 \cdot 10^{-5}$	
• SF free/fix with luminosity	$0.18 \cdot 10^{-5}$	Total:
• analysis cuts	$0.55 \cdot 10^{-5}$	**$0.58 \cdot 10^{-5}$**

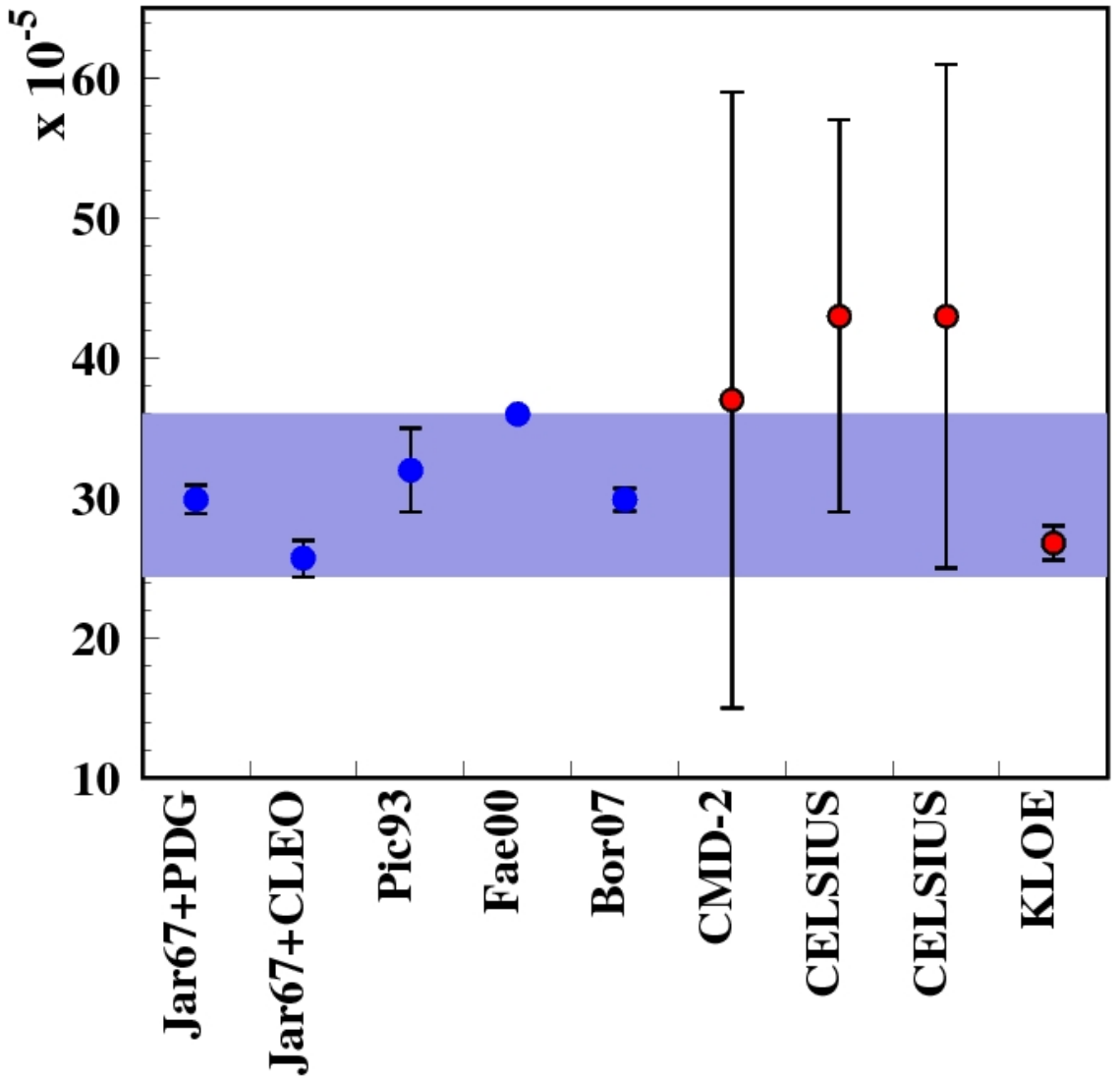
Analysis cuts:

• χ^2_{KF}	$0.15 \cdot 10^{-5}$	
• Dee@BP	$0.03 \cdot 10^{-5}$	
• Mee@BP	$0.46 \cdot 10^{-5}$	
• s2p	$0.25 \cdot 10^{-5}$	
• s4p	$0.01 \cdot 10^{-5}$	
• Mππee	$0.04 \cdot 10^{-5}$	Total:
• low θ	$0.03 \cdot 10^{-5}$	**$0.55 \cdot 10^{-5}$**

BR evaluation

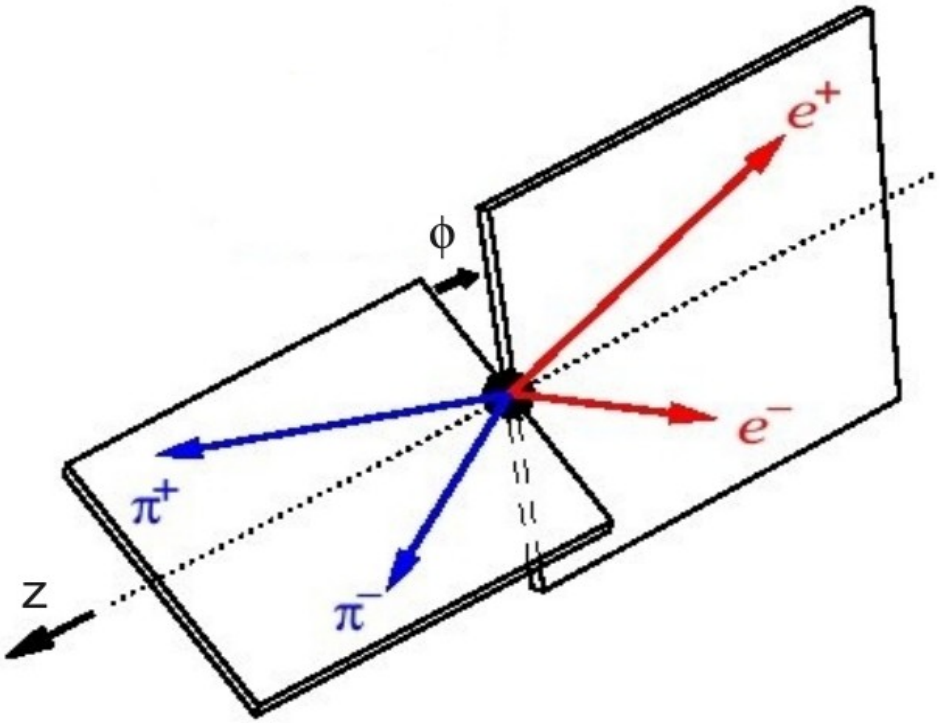
Paper in preparation

$$BR(\eta \to \pi^+ \pi^- e^+ e^- (\gamma)) = (26.8 \pm 0.9_{Stat.} \pm 0.4_{Norm.} \pm 0.6_{Syst.}) \cdot 10^{-5}$$



Asymmetry

$$A_\phi = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}$$



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

Asymmetry

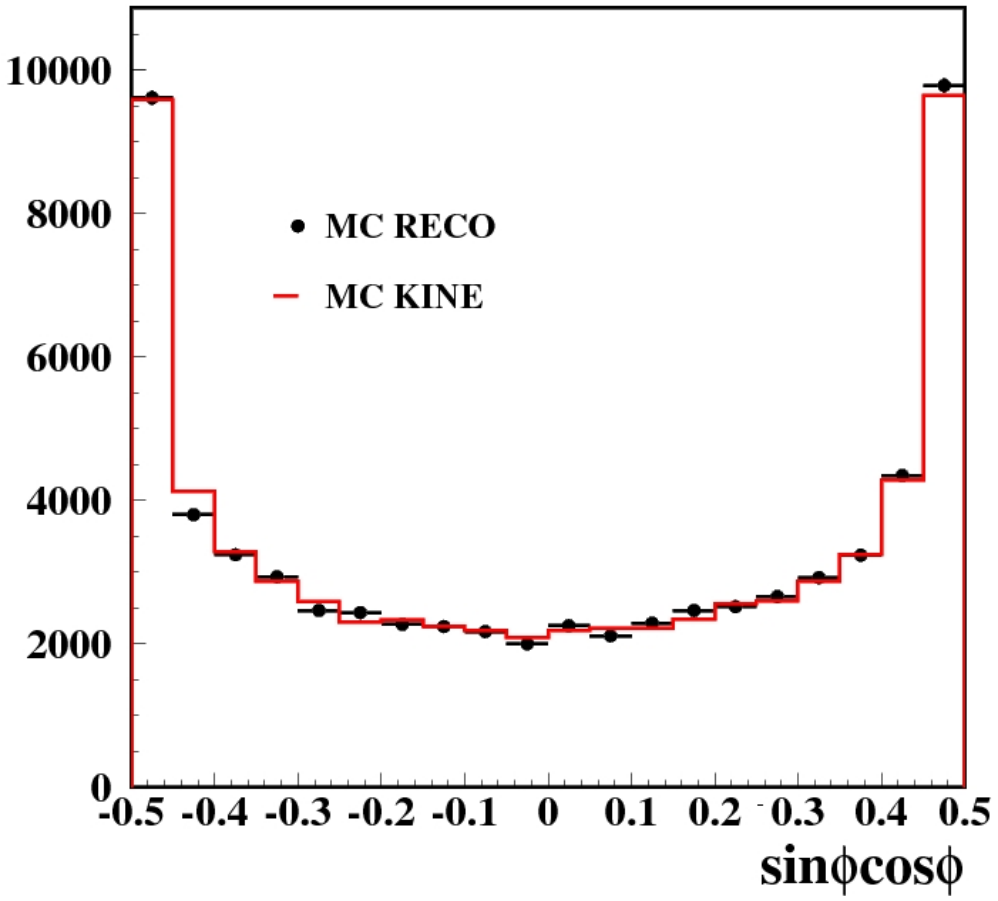
Generated A_ϕ spectrum

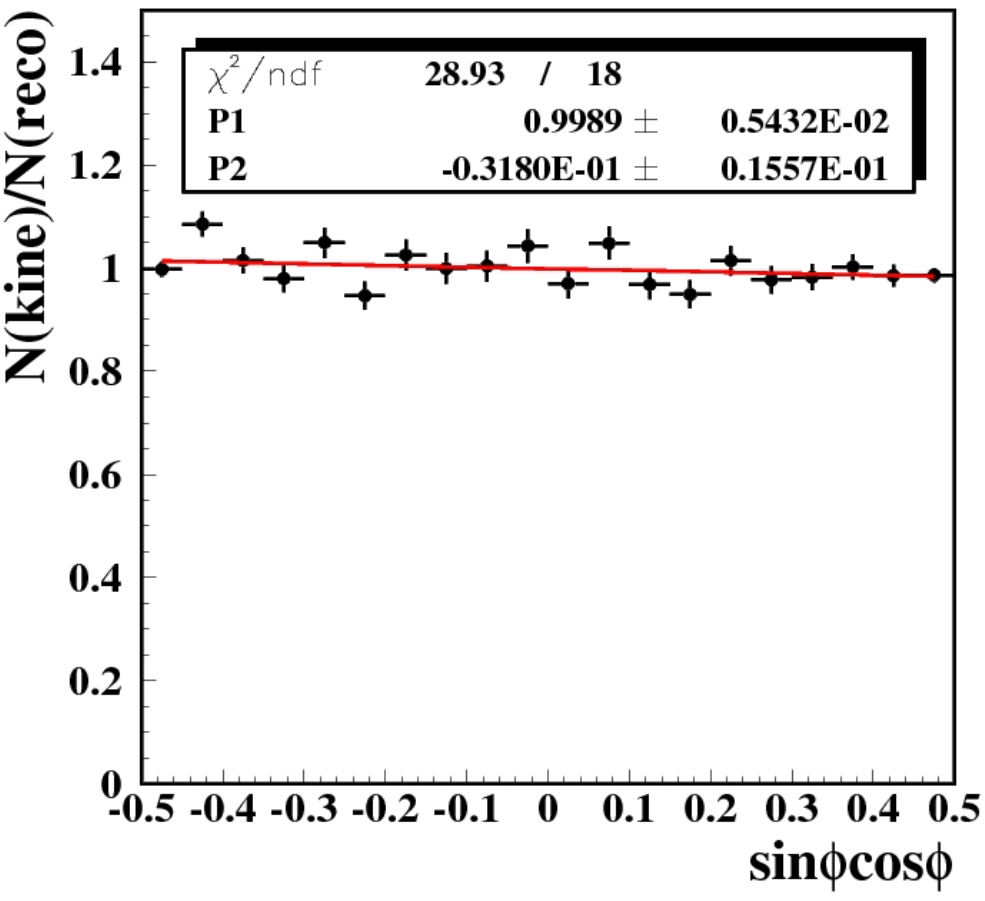
not distorted by the analysis

Particle misidentification leads to distorsion of reconstructed A_ϕ

Linear correction applied

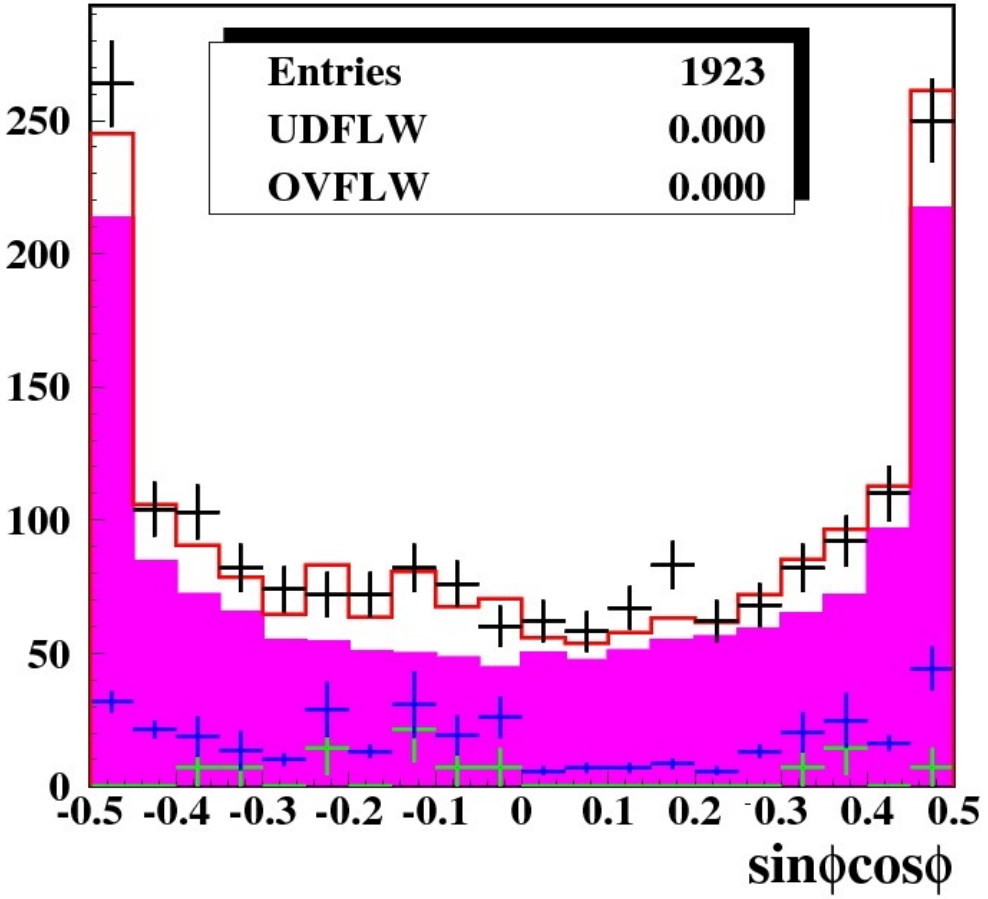
Corresponding systematics evaluated changing slope ±1σ





Asymmetry

Paper in preparation



Data
Total
MC `all_phys`
Off-peak data
Signal MC

First Measurement!

$$A_\phi = (-0.6 \pm 2.5_{Stat.} \pm 1.7_{Syst.} \pm 0.5_{Corr.}) \cdot 10^{-2}$$

↓ Evaluated ↓

as for the BR changing the slope ±1σ