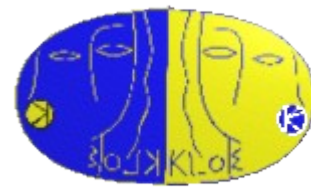


Study of the
 $\eta \rightarrow \pi^+ \pi^- e^+ e^-$
decay at KLOE

Roberto Versaci
on behalf of the KLOE collaboration

Outline



Motivations

KLOE

Data sample

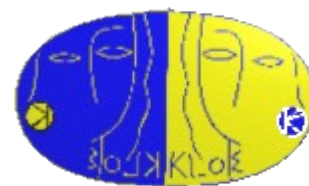
Analysis procedure

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

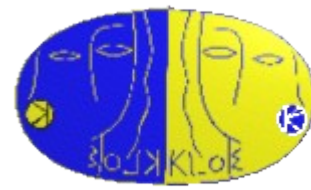
Within SM, A_{CP} is constrained by $BR(\eta \rightarrow \pi\pi)$,

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}

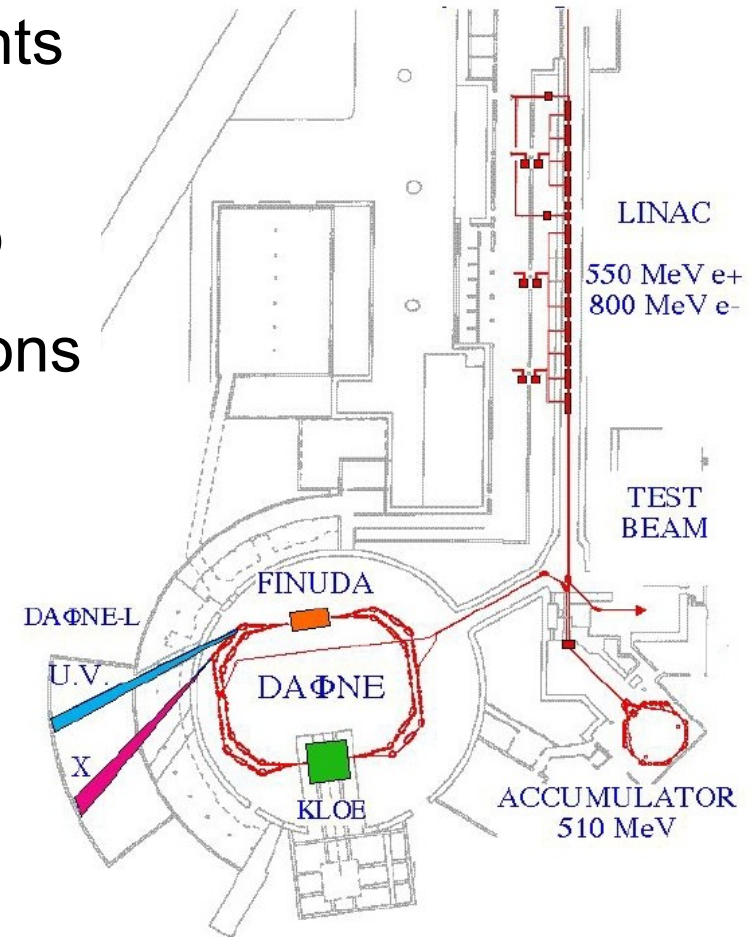
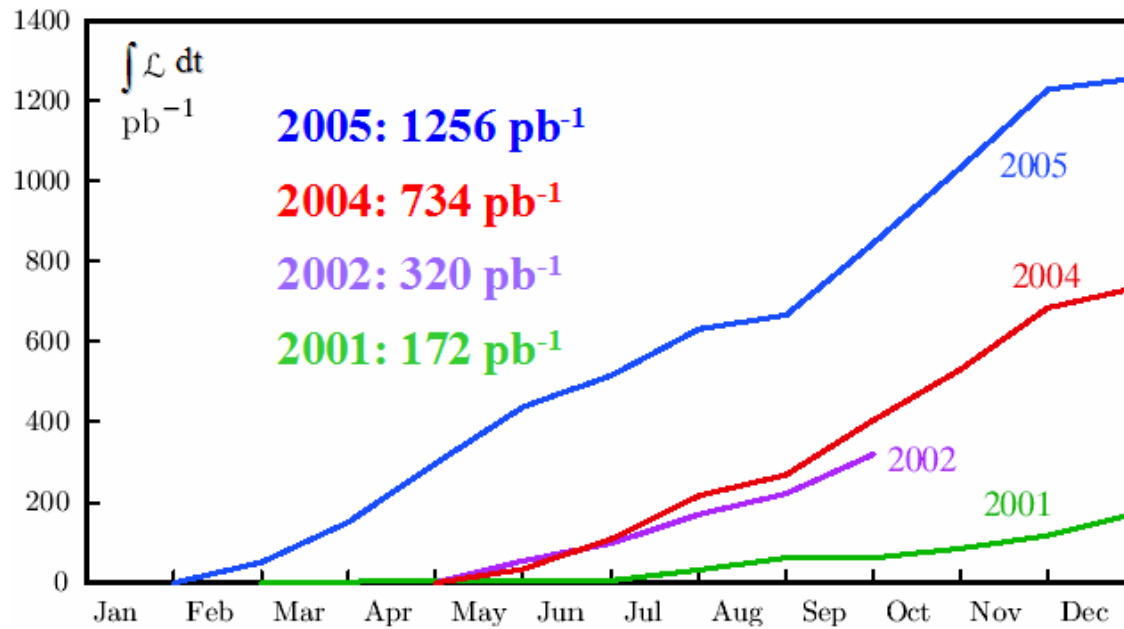
DAΦNE



Double Annular ring For Nice Experiments
electron-positron collider

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

2 rings to minimize beam-beam interactions
12.5 mrad crossing angle

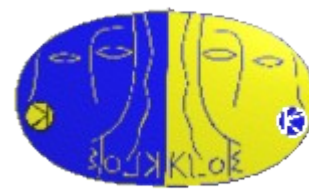


η produced through
 $e^+e^- \rightarrow \phi \rightarrow \eta\gamma$

KLOE Off-peak:

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

K Long Experiment



Spherical beam pipe

10 cm \varnothing , 0.5 mm thick in Be-Al alloy to minimize regeneration, scattering and γ conversion

Large volume drift chamber

4 cm \varnothing , L=3.4 m, carbon-fiber frame, low density gas (90% He – 10% C₄H₁₀), 12582 all stereo squared cells, tungsten and aluminium wires (52140)

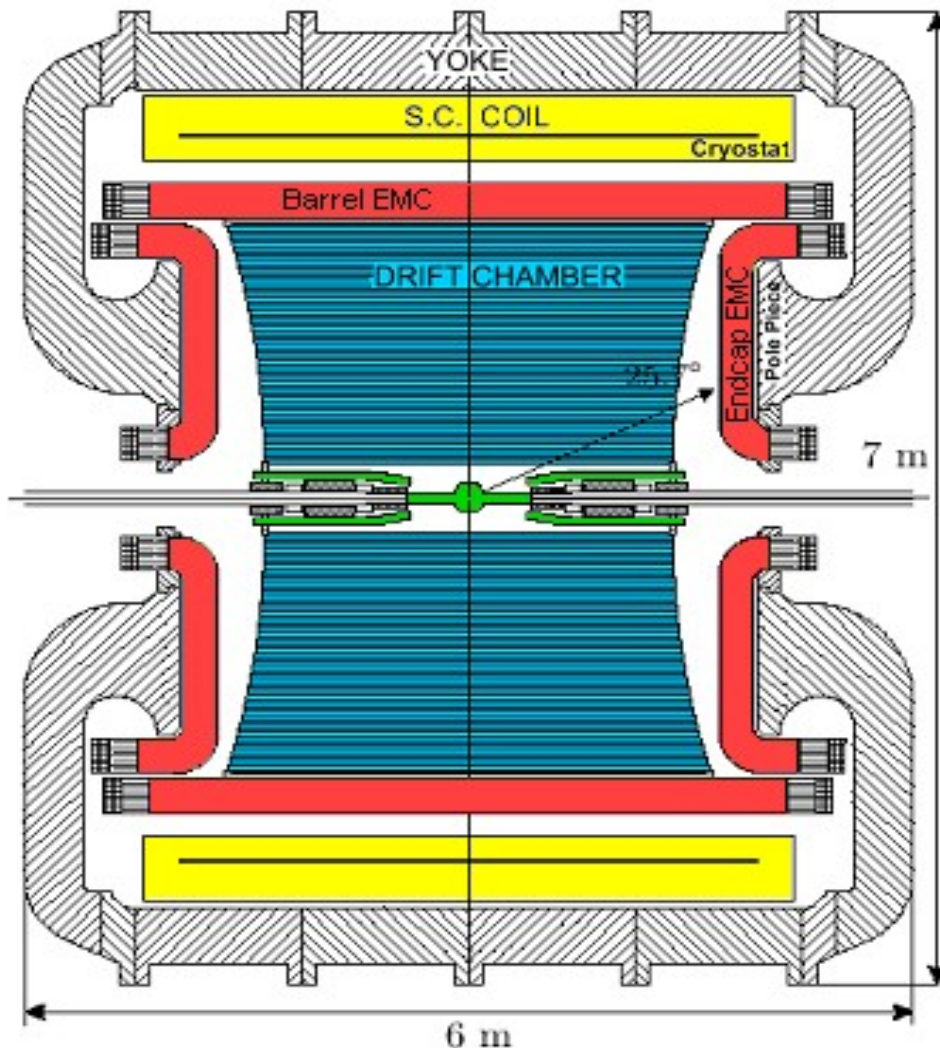
$\sim 4\pi$ calorimeter, 4880 cells

15X₀ thick, 0.5 mm lead

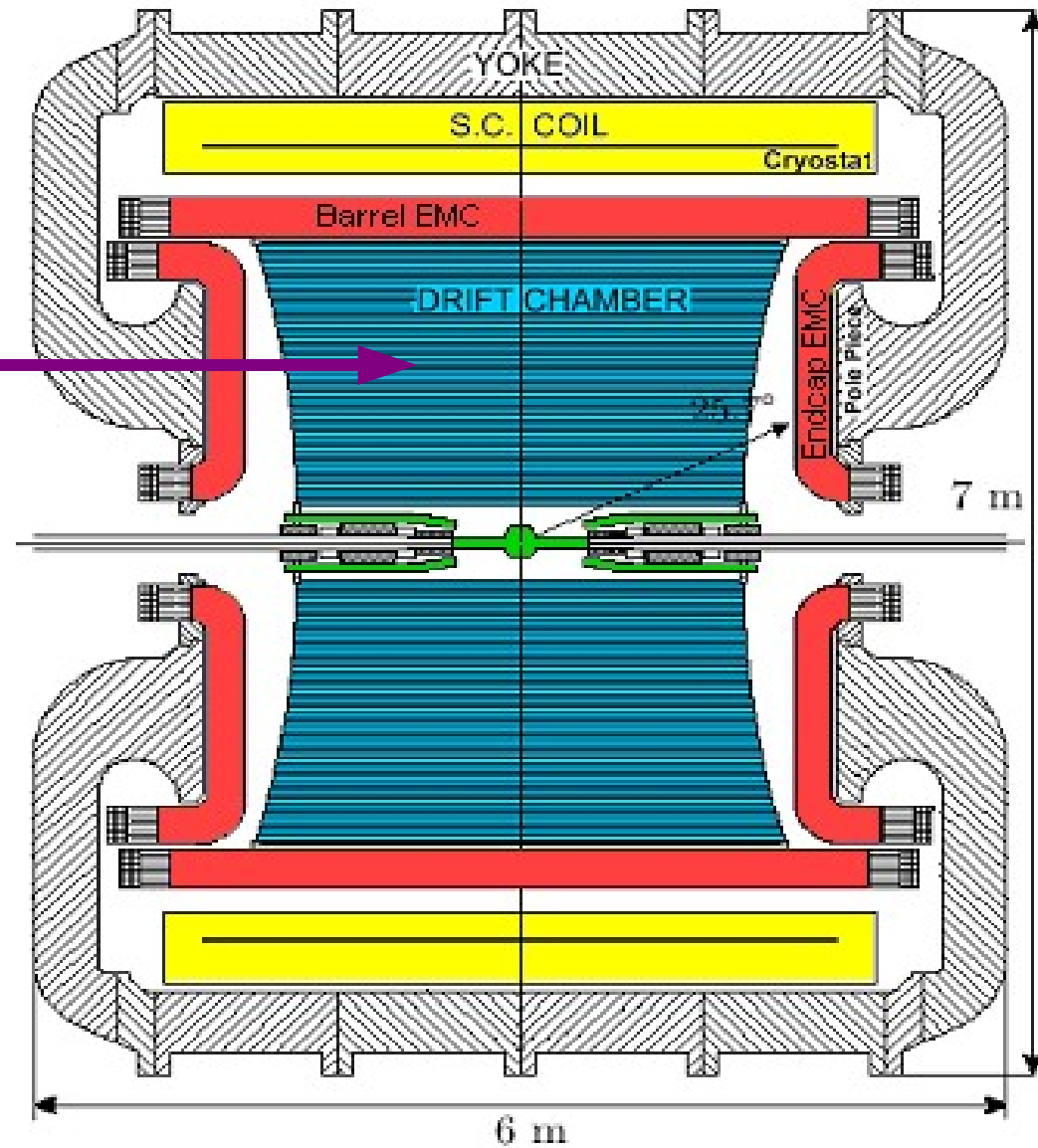
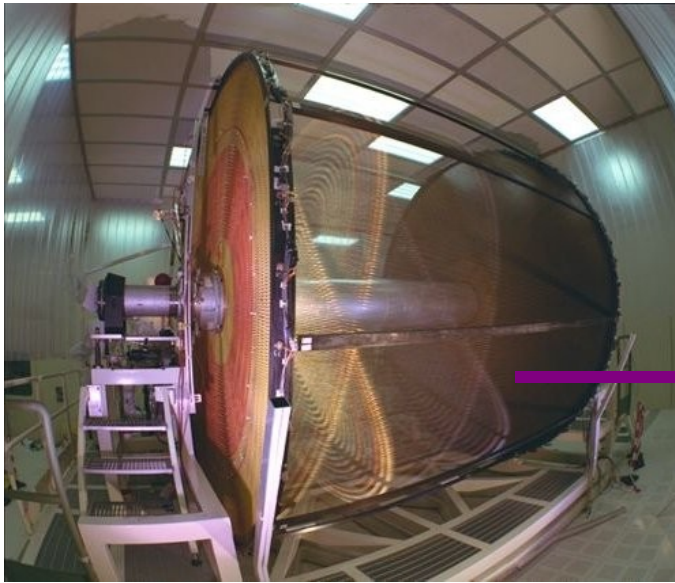
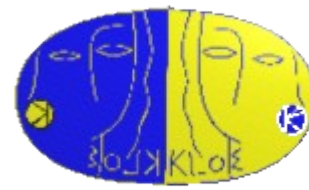
1mm \varnothing scintillating fibers

Superconducting coil B = 0.52 T

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



KLOE – Drift Chamber



$$\sigma_{r\phi} = 150 \mu\text{m}$$

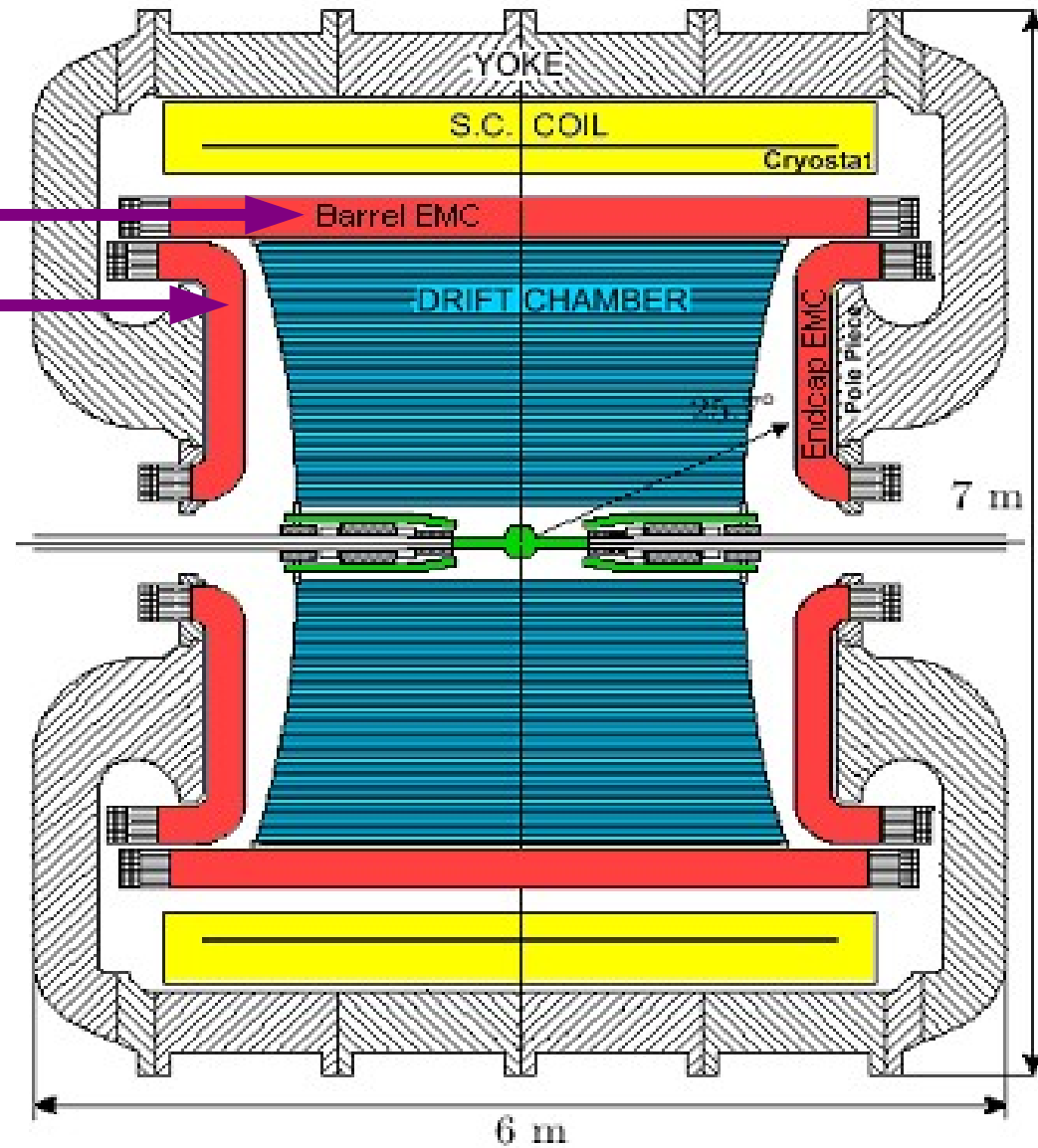
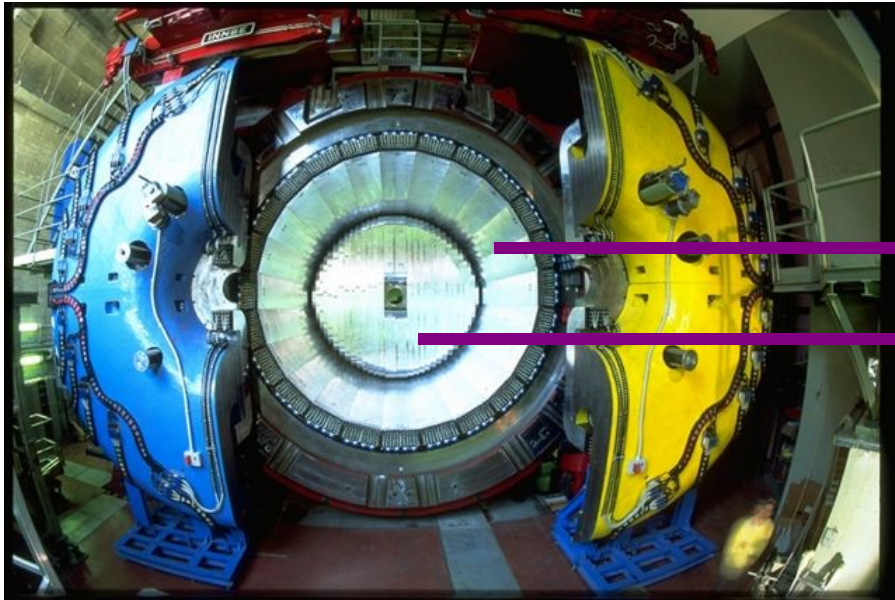
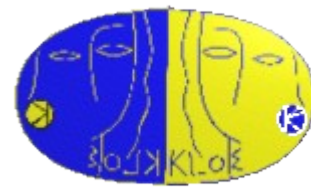
$$\sigma_z = 2 \text{ mm}$$

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

$$\sigma_{\text{vertex}} \sim 3 \text{ mm}$$

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

KLOE – EM Calorimeter



$$\sigma_t = 57 \text{ ps} / \sqrt{(E[\text{GeV}])} \oplus 100 \text{ ps}$$

$$\sigma_E = 0.057 / \sqrt{(E[\text{GeV}])}$$

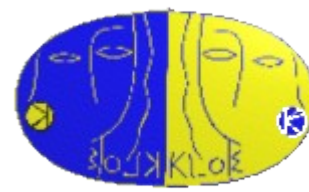
$$\sigma_{\text{shower}} = 1.3 \text{ cm} / \sqrt{(E[\text{GeV}])}$$

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

$$\varepsilon > 95\% \text{ for } E_\gamma > 20 \text{ MeV}$$

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)

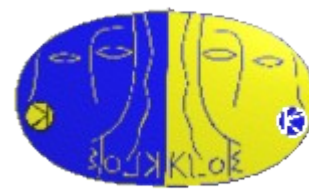
3447 pb⁻¹ MC all ϕ meson decays 2004/05

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 come from a cylinder around the IP:

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

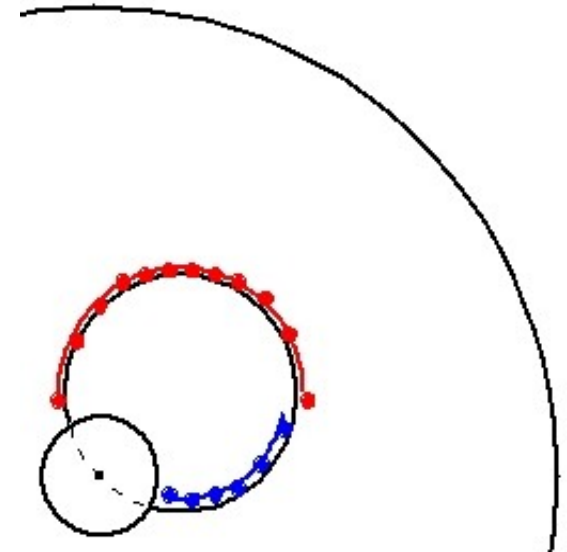
$$h/2 = 10 \text{ cm}$$

Check on broken tracks is applied:

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

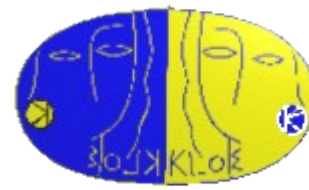
$$\Delta P_Z < 3 \text{ MeV}$$

≥ 2 positive and ≥ 2 negative tracks are requested



Tracks are ordered by momentum

Particle Identification



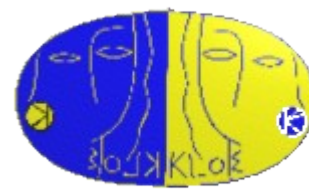
Performed using TOF

We evaluate $\Delta t = t_{\text{track}} - t_{\text{cluster}}$ 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 distortion 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

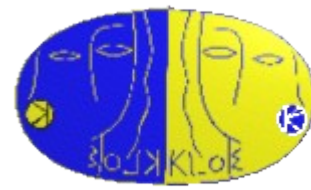
The 22 inputs are:

- 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:

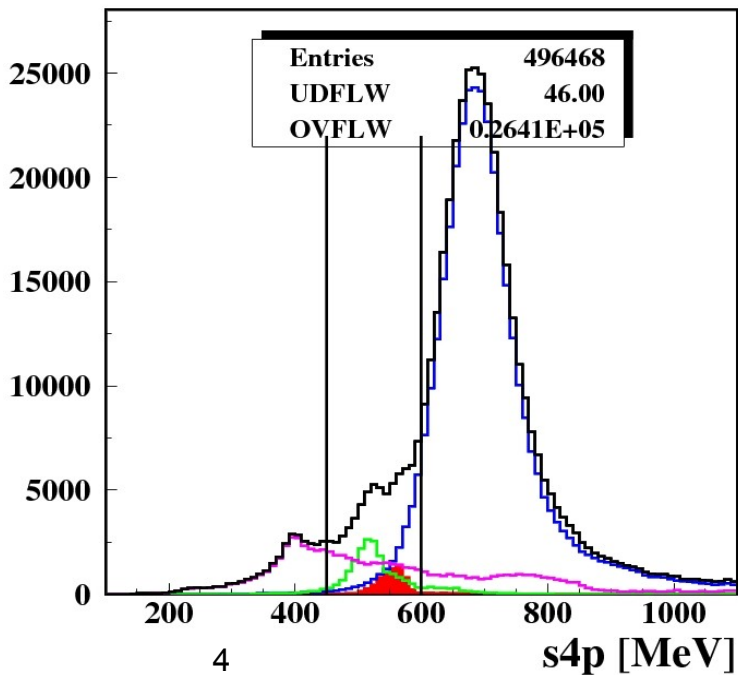
- Four momentum conservation
- Photon time of flight ($cT_{\gamma} = R_{\gamma}$)

Event selection

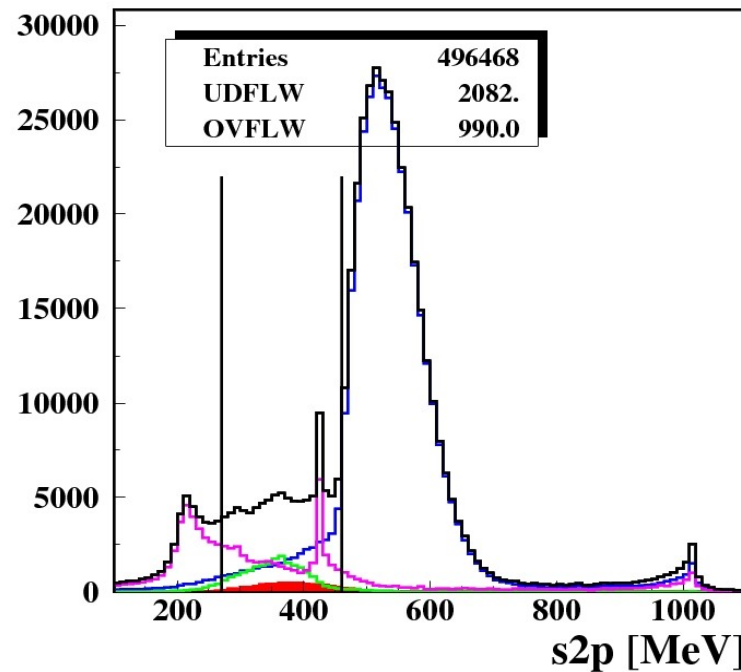


1. **EVCL** ≥ 4 tracks and 1 high energy prompt neutral cluster
2. **Momenta** $450 < s_{4p} < 600$ MeV .and. $270 < s_{2p} < 460$ MeV
3. χ^2_{KF} $\chi^2_{KF} < 4000$

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

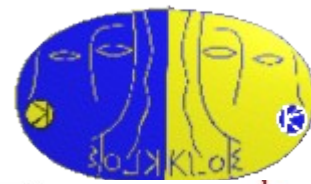


$$\sum_{i=1}^4 |\vec{p}_i| = s_{4p}$$



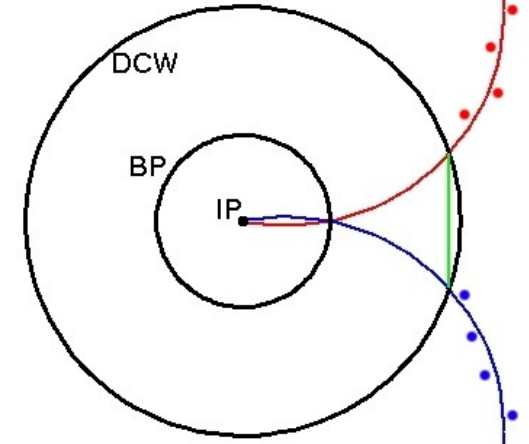
$$s_{2p} = |P(p^{+1})| + |P(p^{-1})|$$

$\eta \rightarrow \pi\pi\gamma$ background

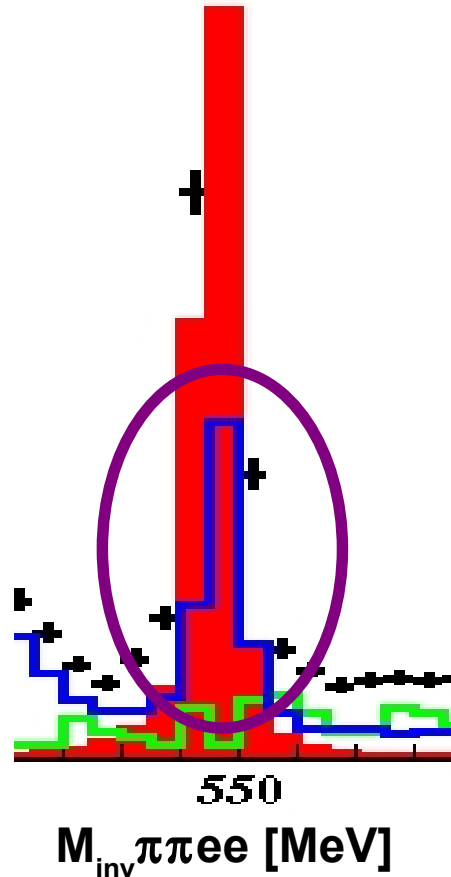


†

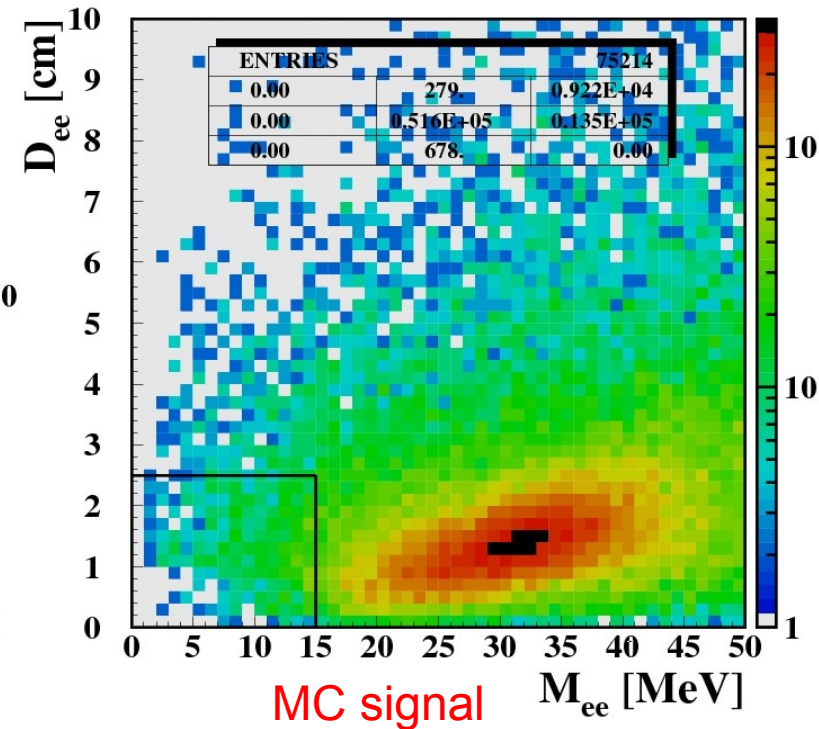
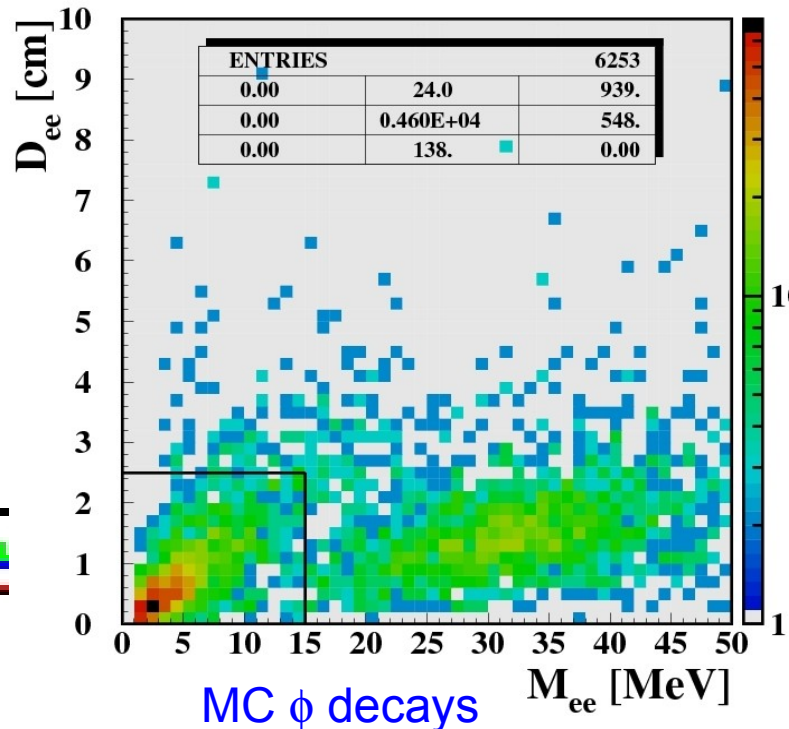
photon conversion on BP
 produces signal signature
 $M_{inv}(e^+e^-)$ and $Dist(e^+e^-)$ are
 zero at the conversion point



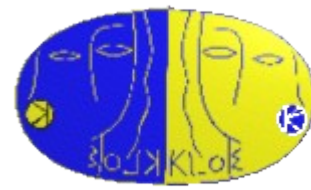
Data
 MC signal
 MC ϕ decays
 Data offpeak



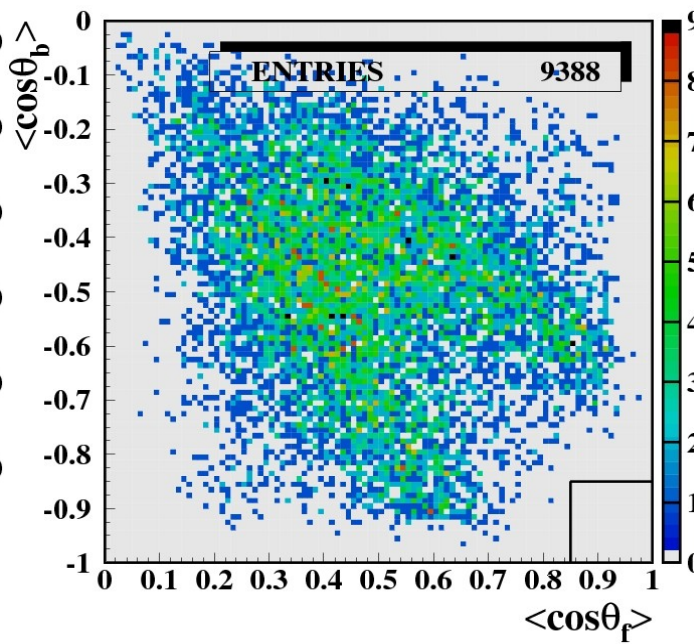
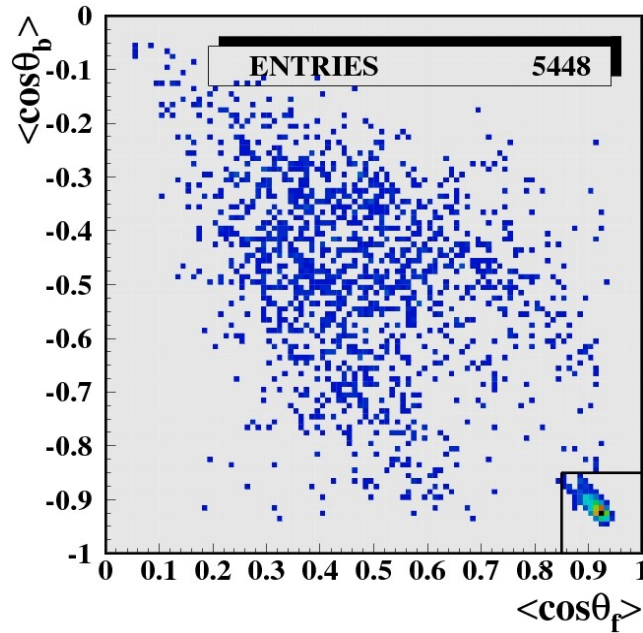
$M_{ee}@BP > 15$ MeV .or. $D_{ee}@BP > 2.5$ cm



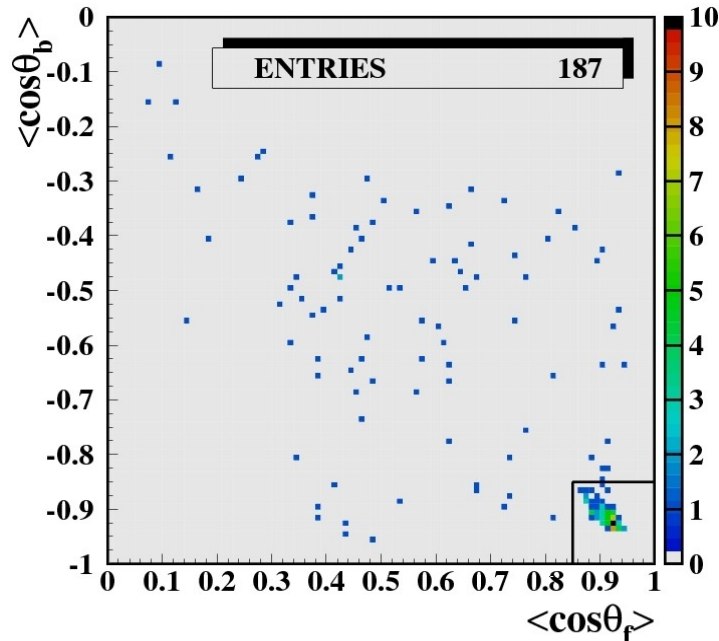
Non physical background



Data



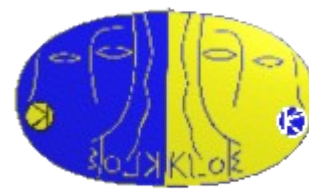
MC
 ϕ decays



$\langle \cos\theta_f \rangle < 0.85$. and .
 $\langle \cos\theta_b \rangle > -0.85$

Due to events with particles hitting the quadrupoles

Analysis summary



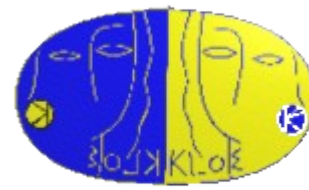
1. **EVCL** ≥ 4 tracks and 1 high energy prompt neutral cluster
2. **Momenta** $450 < s_{4p} < 600$ MeV .and. $270 < s_{2p} < 460$ MeV
3. **χ^2_{KF}** $\chi^2_{KF} < 4000$

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

4. **Conversions** $M_{ee} > 15$ MeV .or. $D_{ee} > 2.5$ 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

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

\sqrt{s} has been accounted for



Fit result

Data

Total

MC ϕ decays

Off-peak data

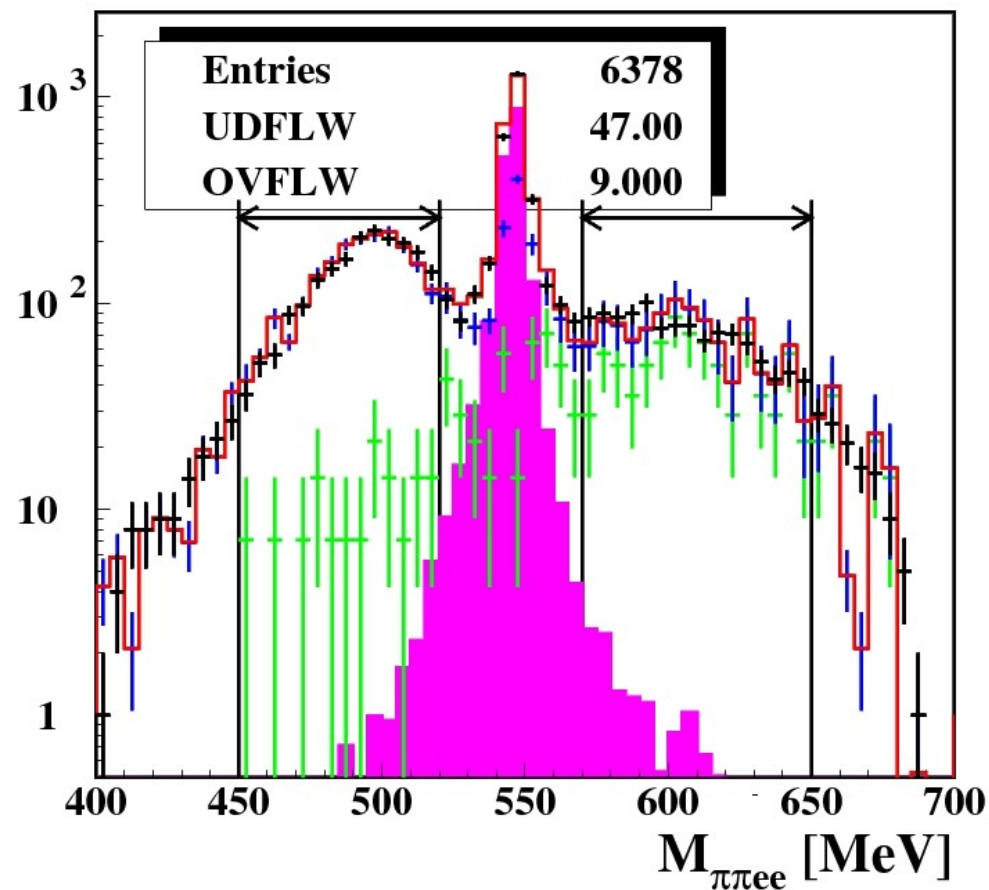
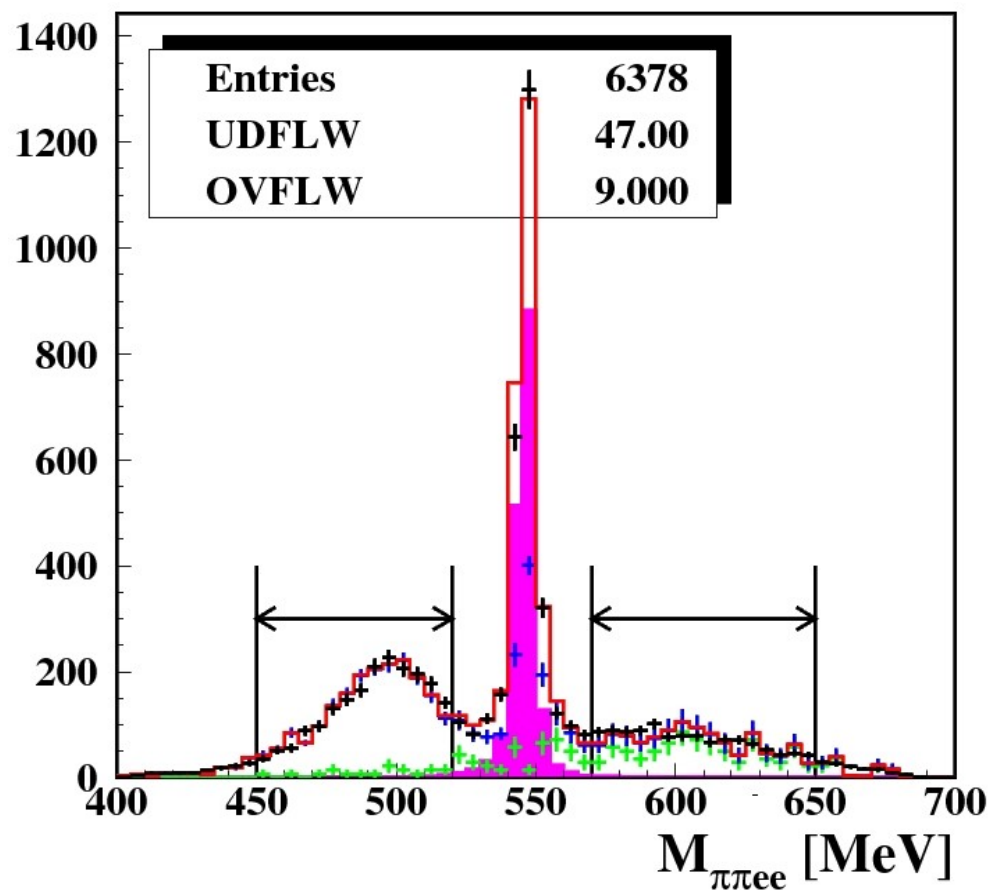
Signal MC

$$\chi^2/\text{dof} = 32.5/30$$

$$P(\chi^2) = 0.35$$

$$SF_{\text{ap}} = 0.528 \pm 0.009$$

$$SF_{\text{op}} = 7.14 \pm 0.03$$





Fit result

Data

Total

MC ϕ decays

Off-peak data

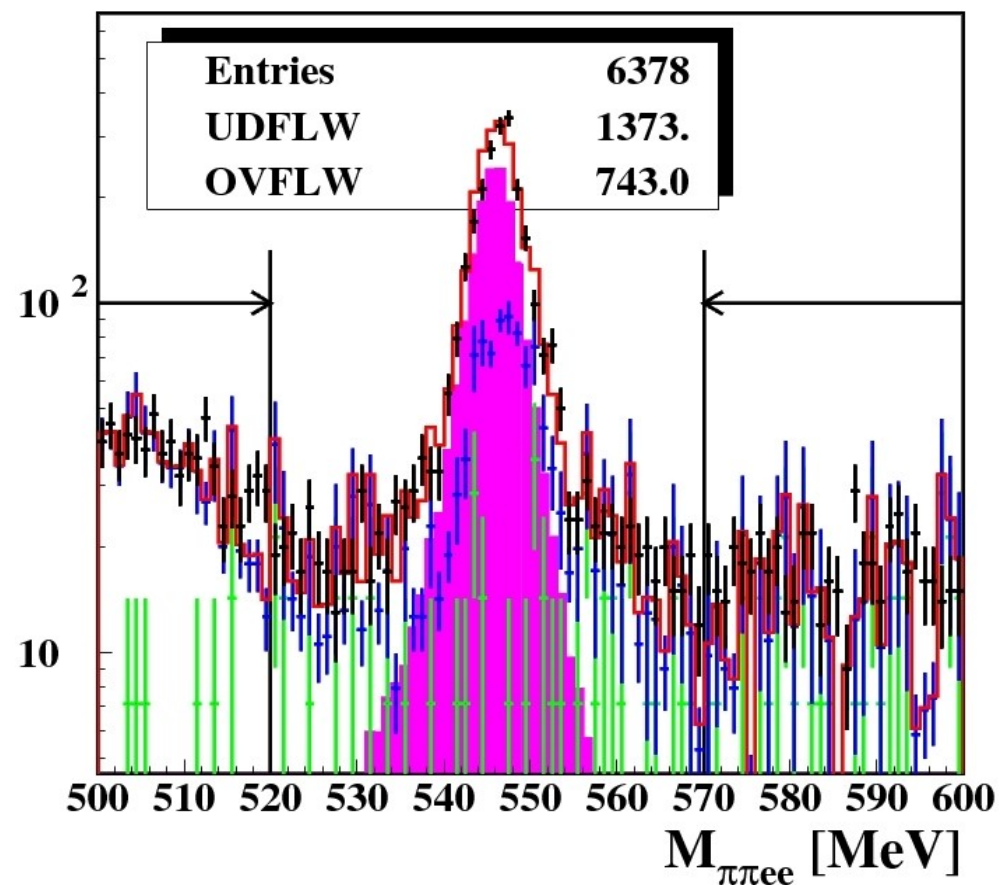
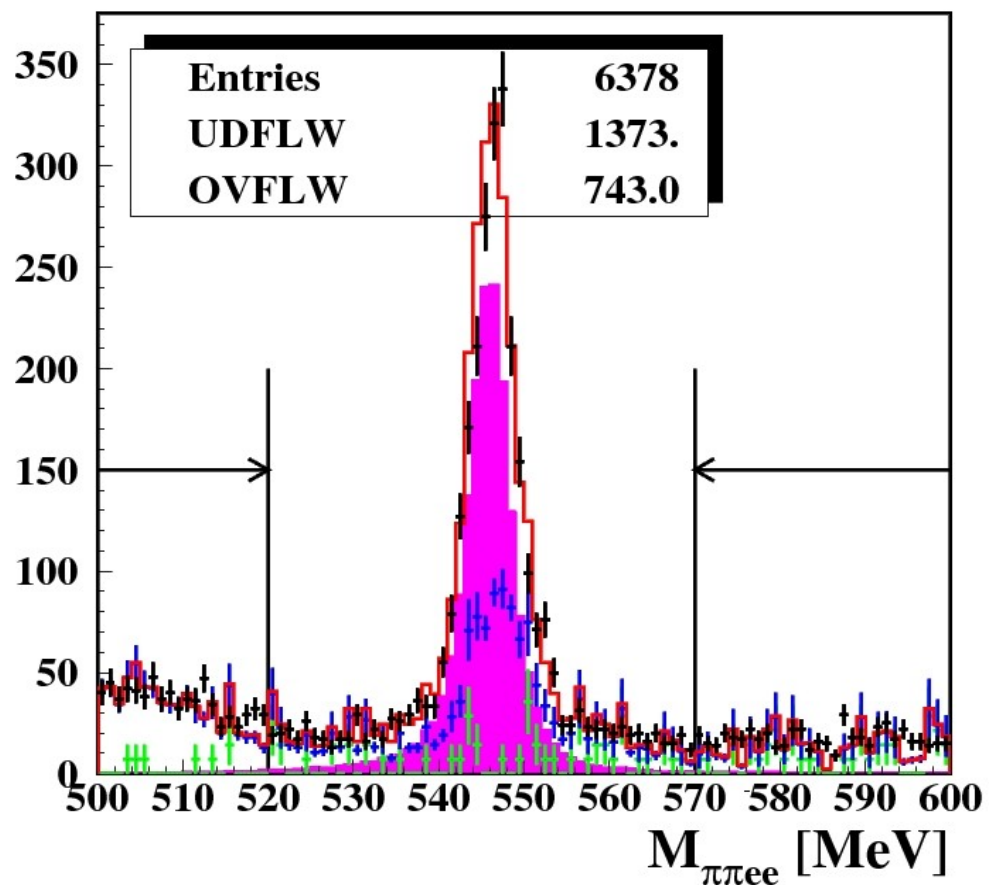
Signal MC

$$\chi^2/\text{dof} = 32.5/30$$

$$P(\chi^2) = 0.35$$

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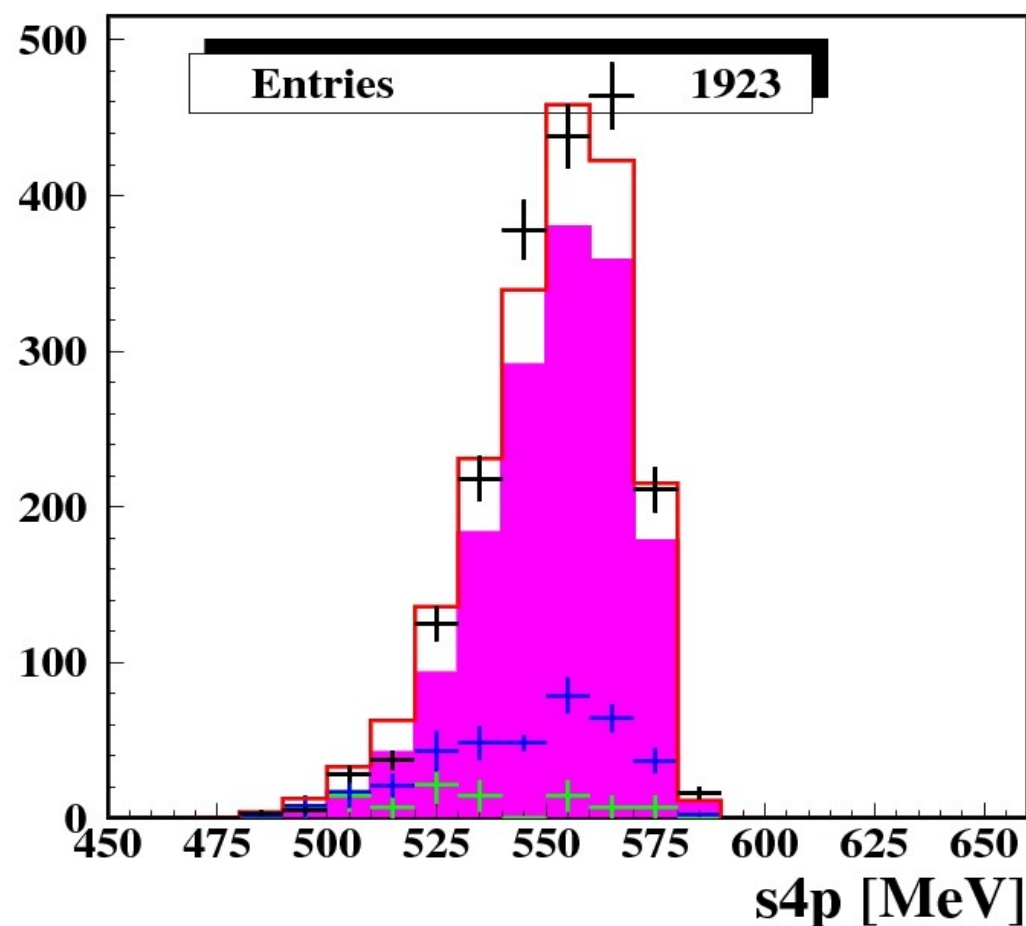
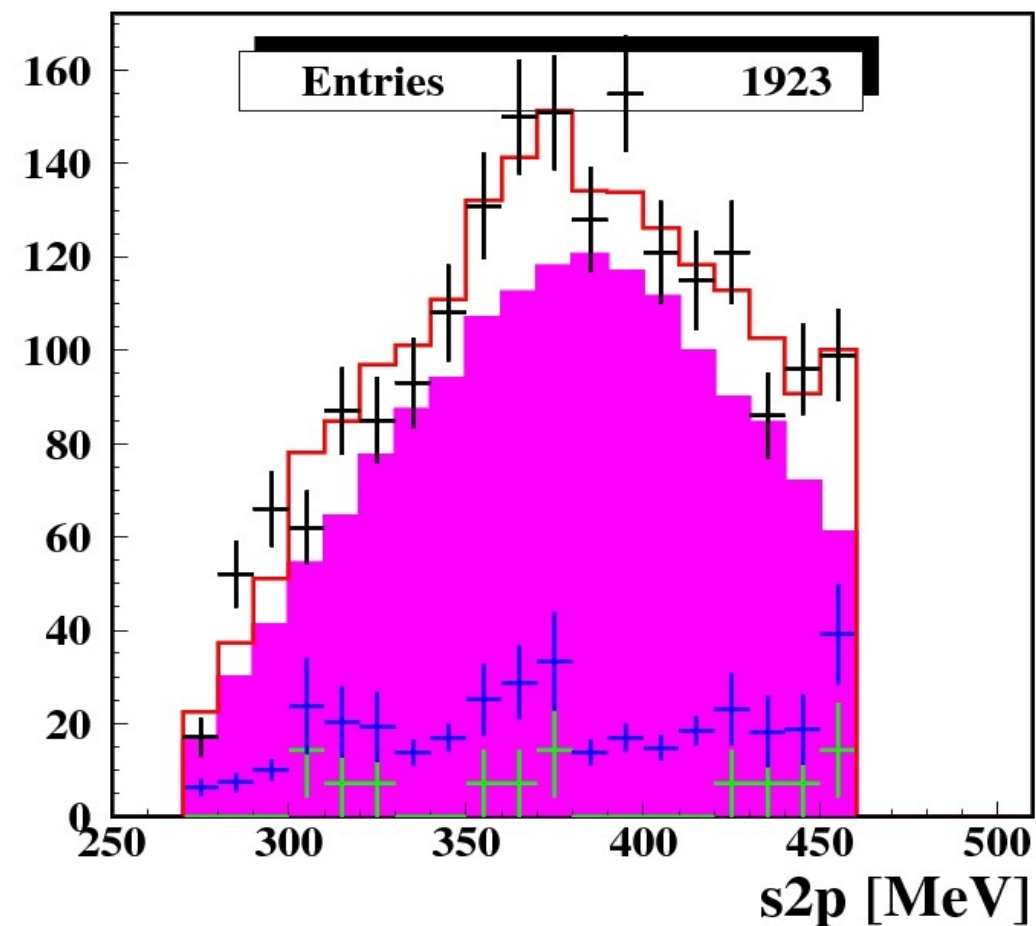
$$SF_{\text{op}} = 7.14 \pm 0.03$$



Data-MC comparison



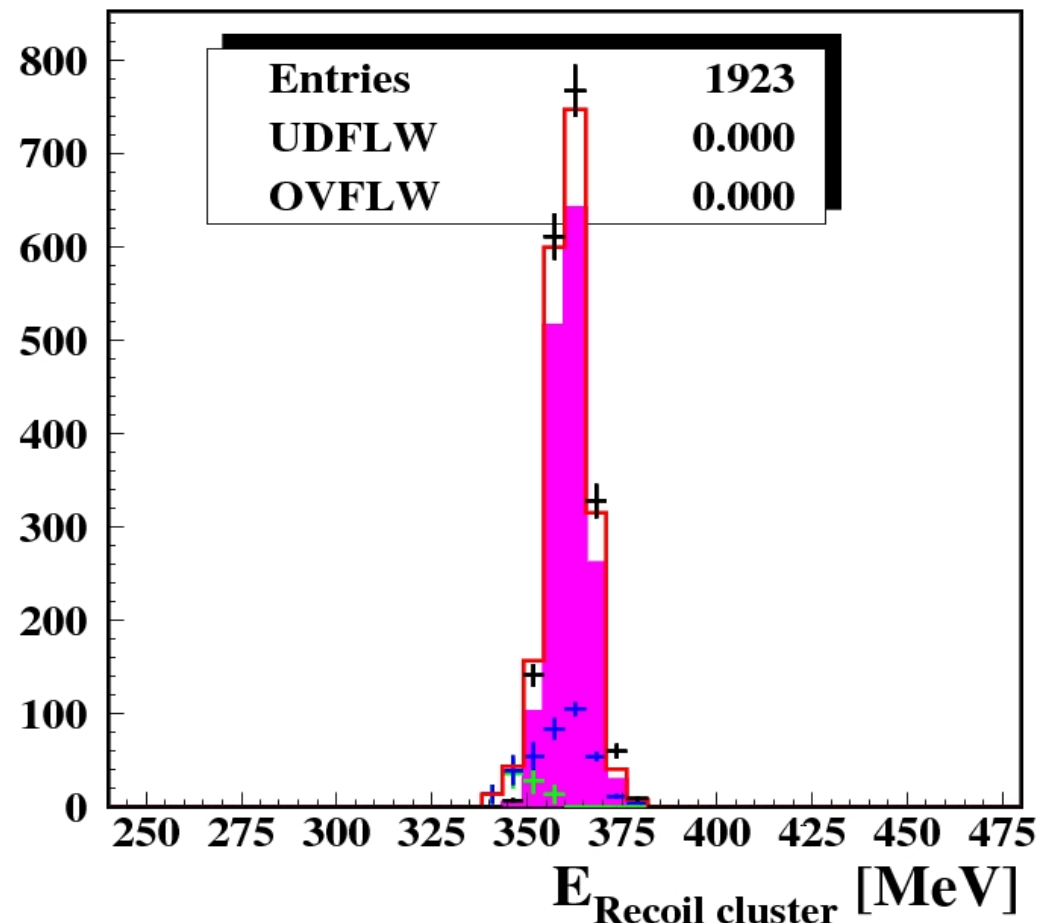
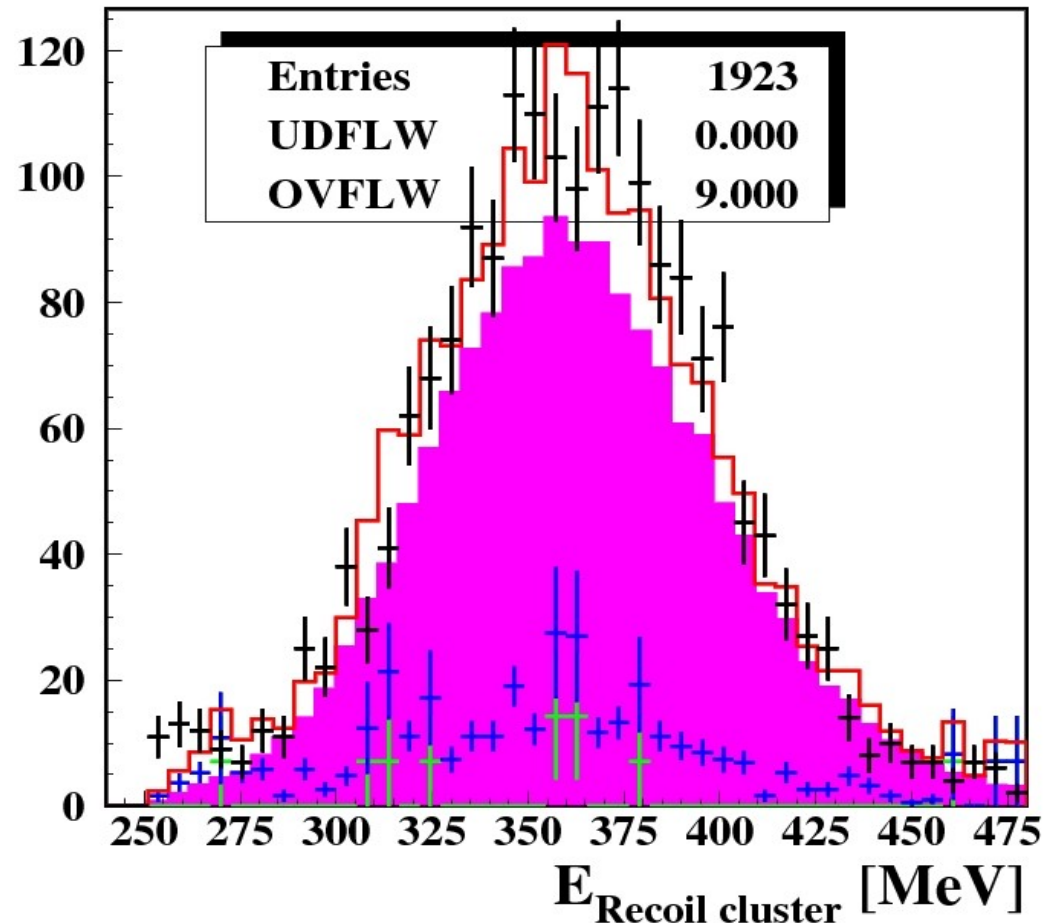
Data
Total
MC all_phys
Off-peak data
Signal MC



Data-MC comparison



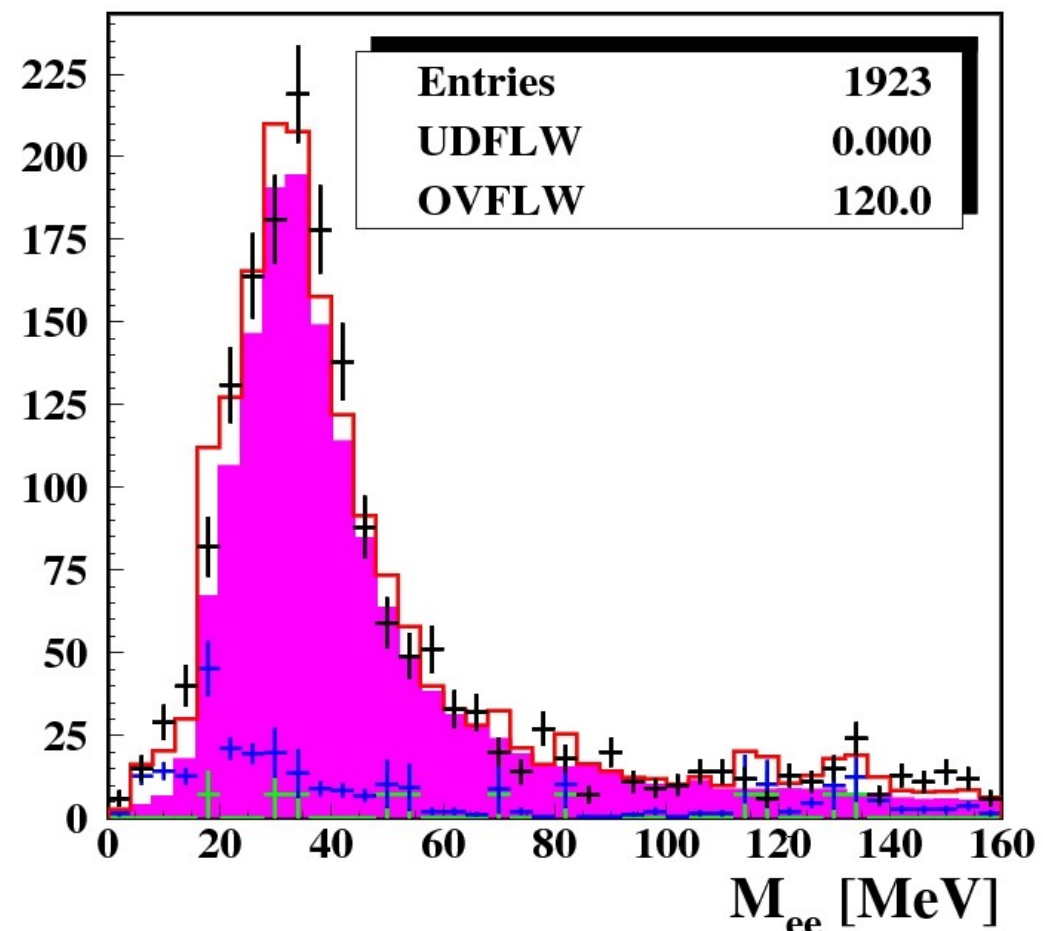
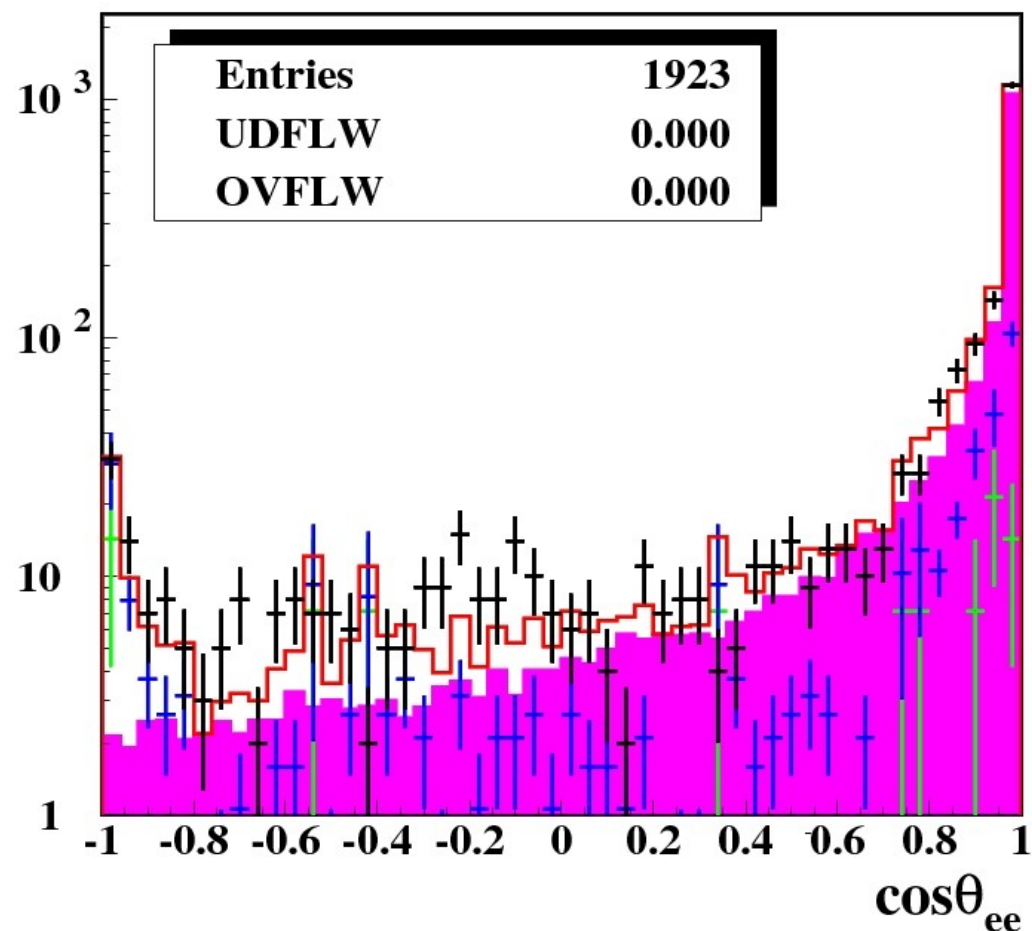
Data
Total
MC all_phys
Off-peak data
Signal MC



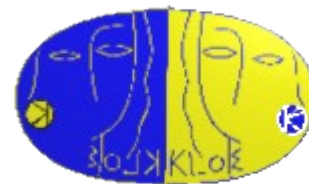
Data-MC comparison



Data
Total
MC all_phys
Off-peak data
Signal MC



BR evaluation



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

Number of events

1555 ± 52

Efficiency

0.0803 ± 0.0003

Luminosity

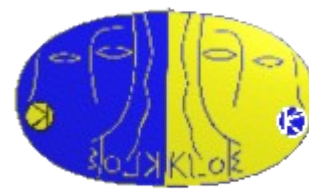
$(1733 \pm 10) \text{ pb}^{-1}$

Cross section

$(41.7 \pm 0.6) \text{ nb}$

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

Systematics



Evaluated varying:

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

Total:

$0.58 \cdot 10^{-5}$



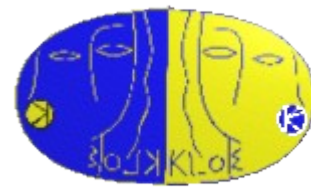
Analysis cuts:

- 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 $0.01 \cdot 10^{-5}$
- $M\pi\pi ee$ $0.04 \cdot 10^{-5}$
- low θ $0.03 \cdot 10^{-5}$

Total:

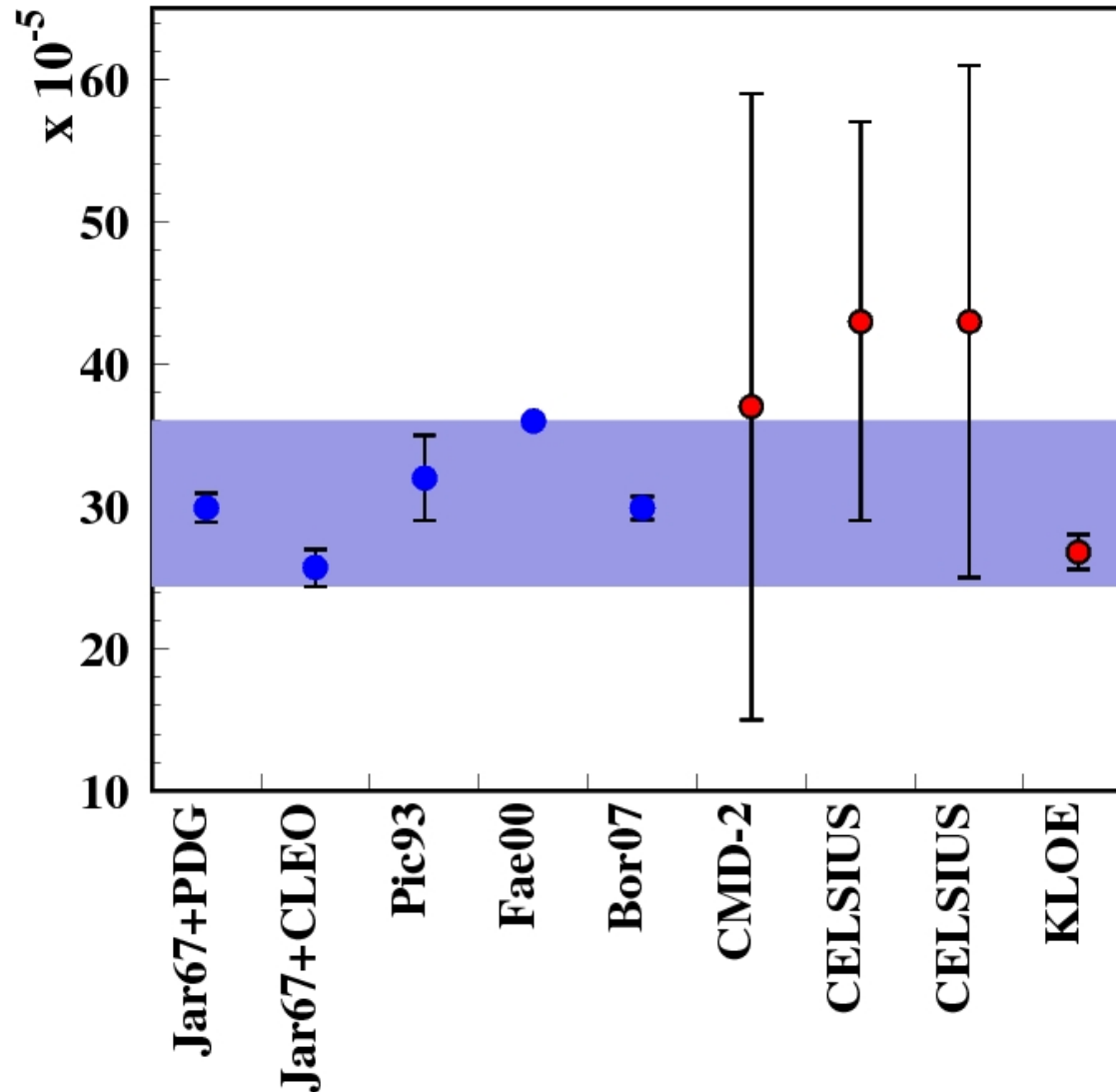
$0.55 \cdot 10^{-5}$

BR evaluation



Paper in preparation

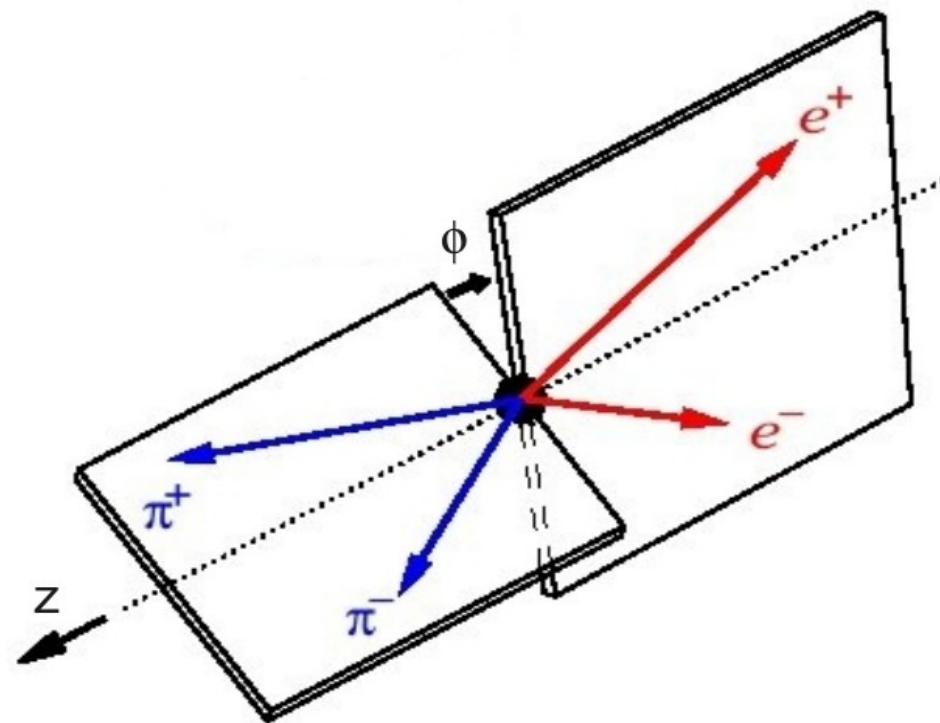
$$\text{BR}(\eta \rightarrow \pi^+ \pi^- e^+ e^- (\gamma)) = (26.8 \pm 0.9_{\text{Stat.}} \pm 0.4_{\text{Norm.}} \pm 0.6_{\text{Syst.}}) \cdot 10^{-5}$$



Asymmetry

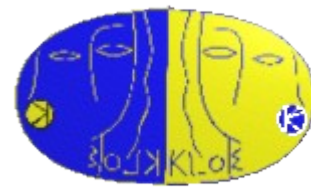


$$A_{\phi} = \frac{N_{\sin\phi\cos\phi>0} - N_{\sin\phi\cos\phi<0}}{N_{\sin\phi\cos\phi>0} + N_{\sin\phi\cos\phi<0}}$$



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

Asymmetry

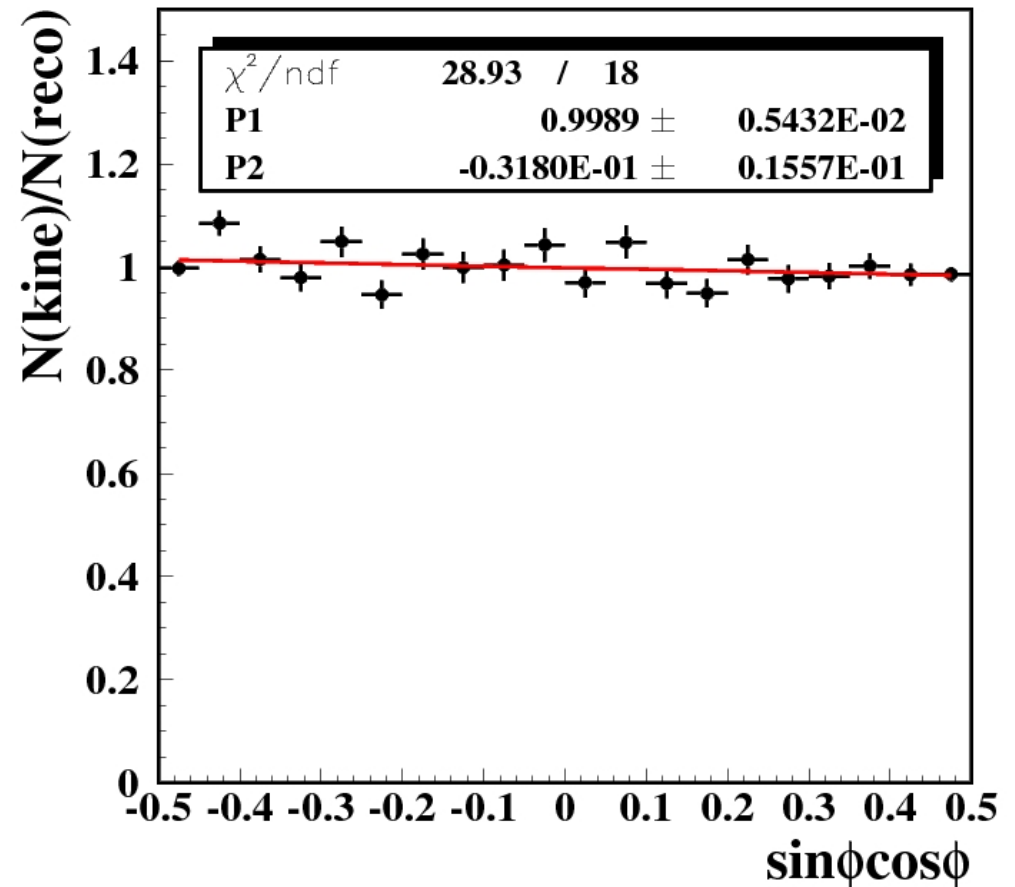
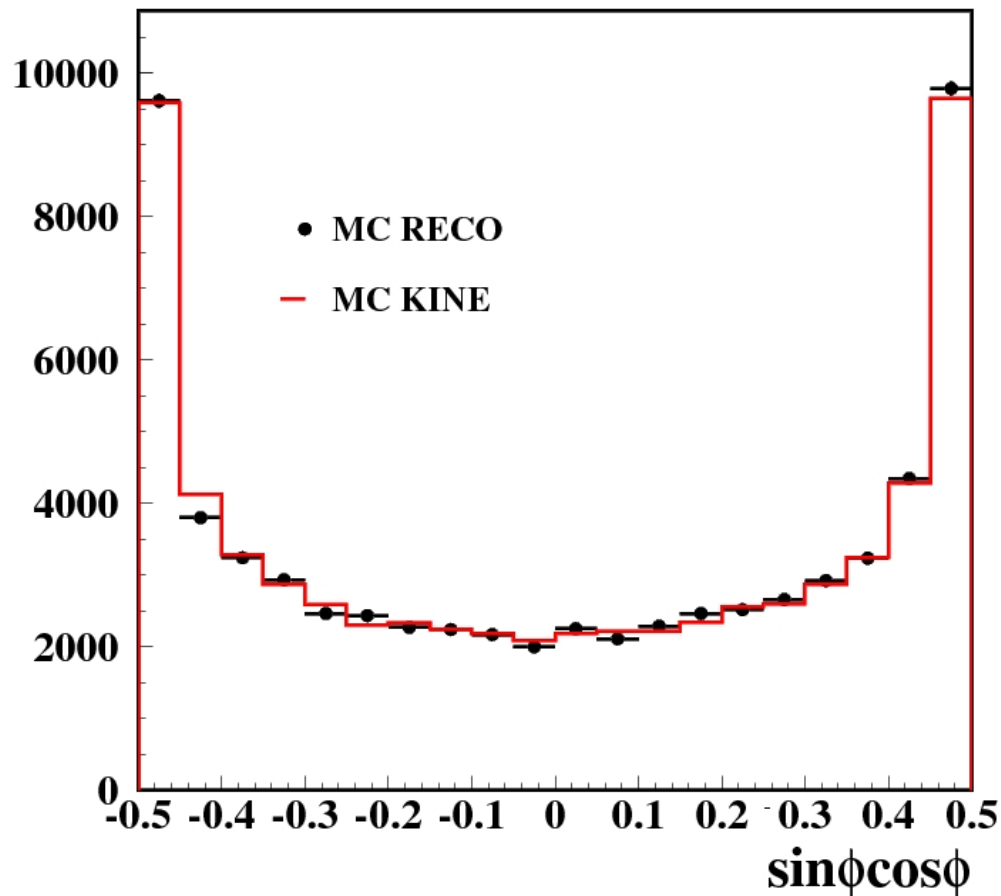


Generated A_ϕ spectrum

not distorted by the analysis

Particle misidentification leads to
distorsion of reconstructed A_ϕ

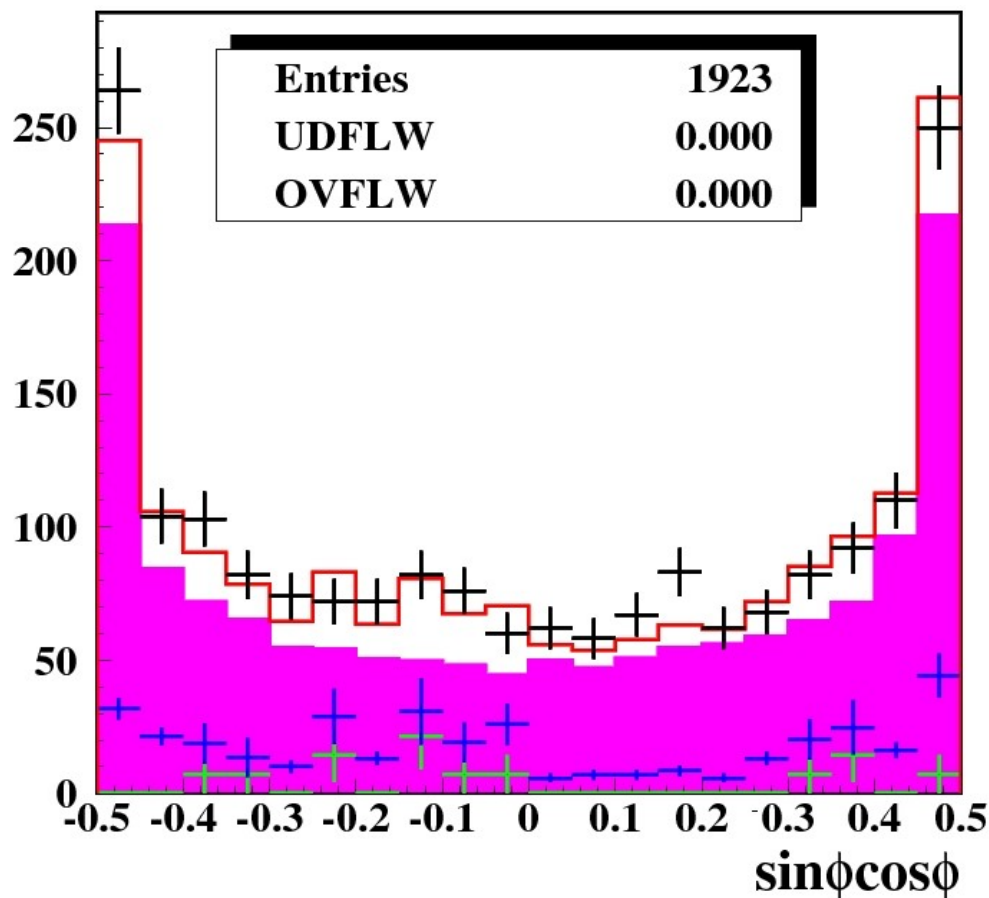
Linear correction applied
Corresponding systematics
evaluated changing slope $\pm 1\sigma$



Asymmetry



Paper in preparation



Data
 Total
 MC all_phys
 Off-peak data
 Signal MC

First Measurement!

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

↓ Evaluated ↓

as for the BR changing the slope $\pm 1\sigma$