Measurement of BR ($K_L \to \pi e \nu \gamma$) and first indication of Direct Emission contribution @ KLOE

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for the KLOE collaboration

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Outline

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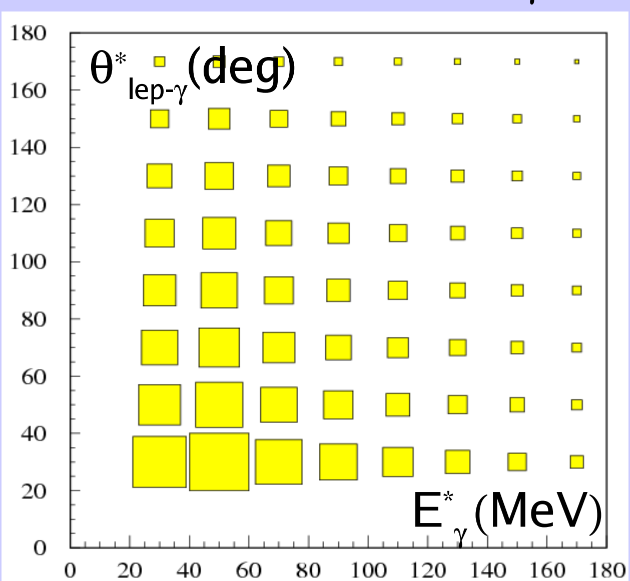
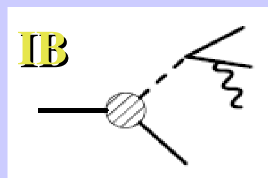
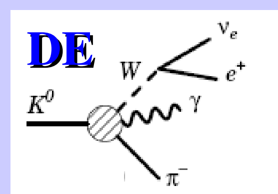
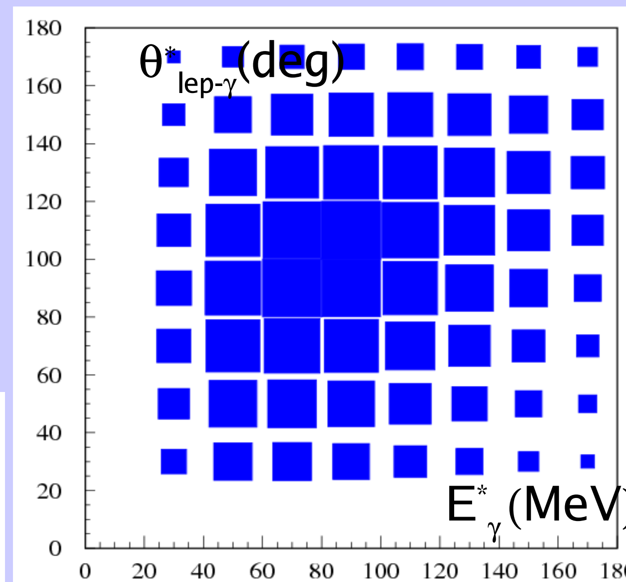
Introduction

- We measure R = **BR**(Ke3γ ; **E^*_γ>30 MeV, $\theta^*_{lep-\gamma}$>20°**) / **BR**(Ke3(γ)), using a 328 pb^{-1} 2001-2002 data sample ;
- Both IB and DE emission contribute to R;
- Separation between IB and DE never measured(*); for the first time the DE contribution is measured ;
- What needs : E^*_γ-$\theta^*_{ele-\gamma}$ analysis + low BKG





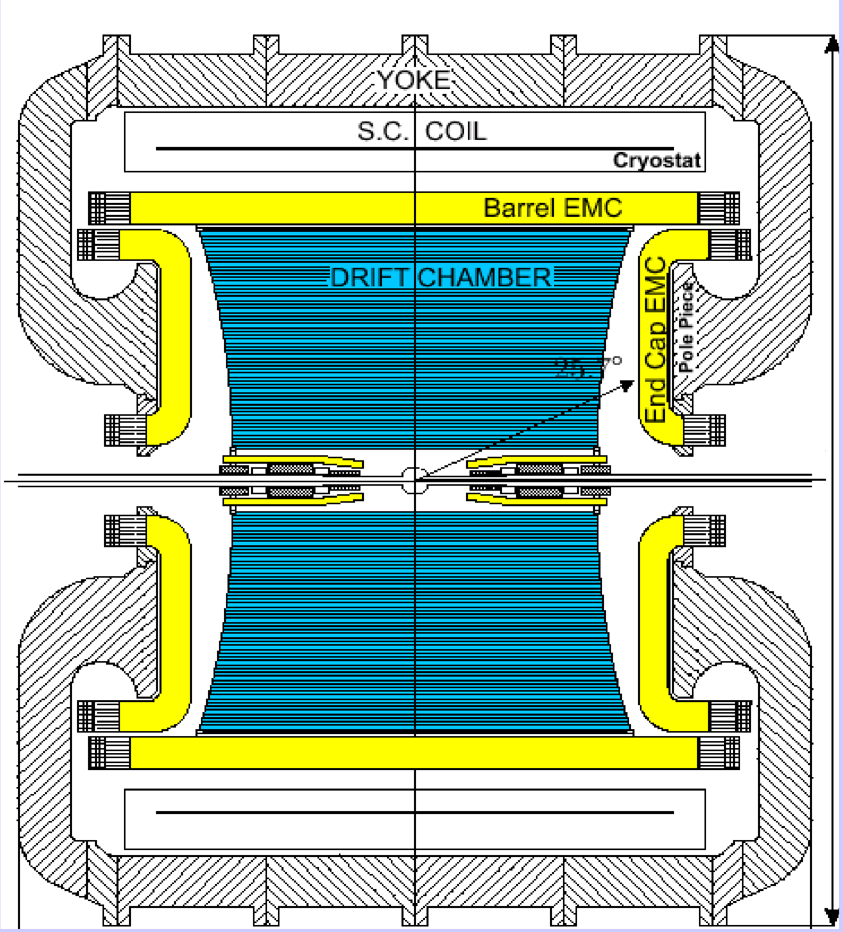




(*) see KteV in the last slide

The KLOE Detector

- **Be beam pipe** (spherical, 10 cm ∅, 0.5 mm thick ;
- **Drift chamber** (∅=4 m, L=3.3 m) ;
  90%**He**+10%**IsoB**, X_0=900m ; 2582 s.w. ;
  $\sigma(p_t)/p_t = 0.4\%$, $\sigma(M_{\pi\pi})$ ~1 MeV ;
  σ_{hit}~150 µm (**xy**), ~2 mm (**z**); σ_{vertex}~1 mm



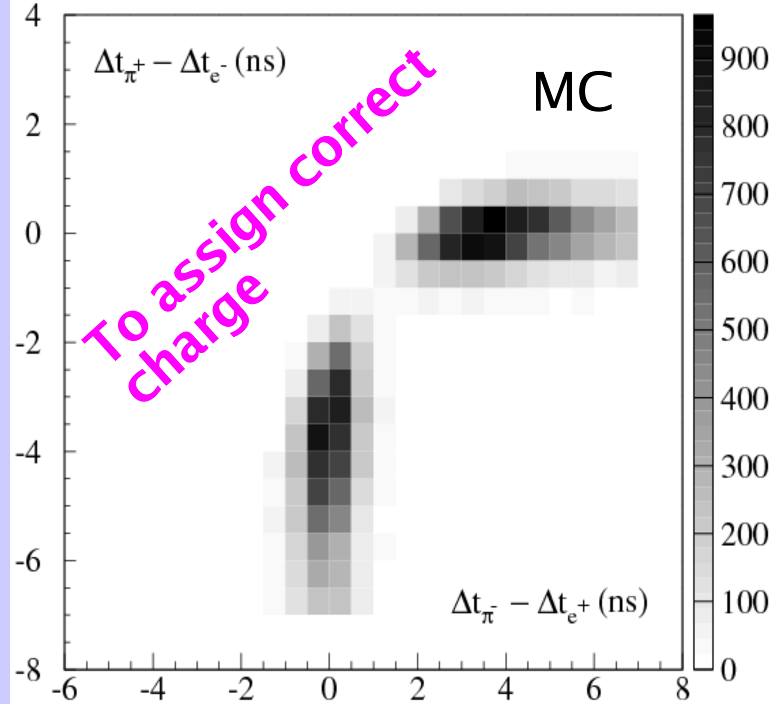
- **Electromagnetic calorimeter**
  Lead/scintillating fibers 4880 PMT's ;
  $\sigma_E/E = 5.7\% /\sqrt{E(GeV)}$;
  $\sigma_t = 54$ ps $/\sqrt{E(GeV)} \oplus 100$ ps ;
  $\sigma_L(\gamma\gamma)$~ **1.5 cm** (π^0 from $K_L \rightarrow \pi^+\pi^-\pi^0$)

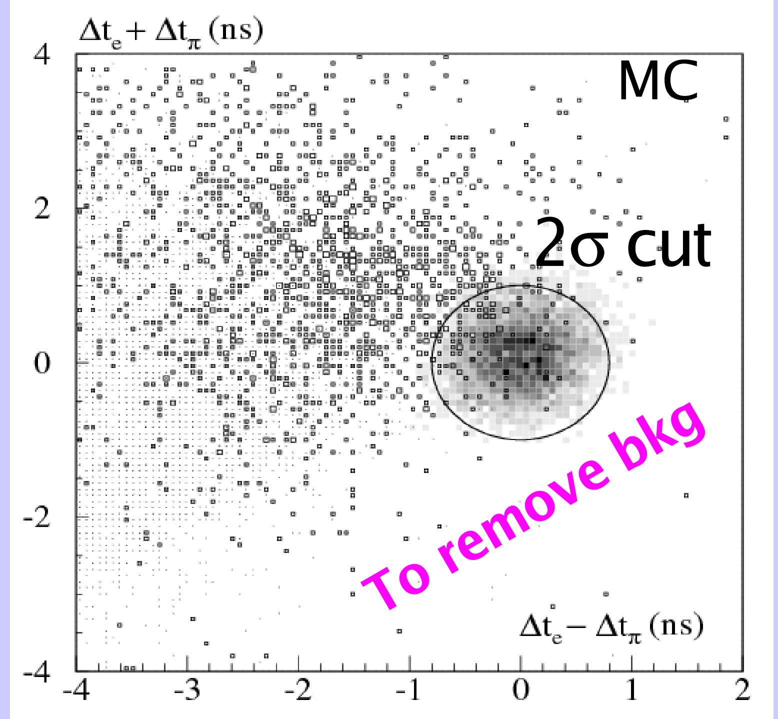
- **Superconducting coil**: B = 0.52 T

Inclusive Ke3(γ) Sample Selection

- **TAG**: $K_S \to \pi^+\pi^-$;
- **TRACKING** : distance < $f(r_{XY})$ w.r.t. K_L direction;
- **VERTEX:** FV=(35-150)xy and 120z;
- **TCA**: track-cluster distance < 30 cm
- **KINE CUTS**: $(E_{miss} - p_{miss})$ in different mass hypo -> ~ 12 % bkg
- **PID** with TOF : $\Delta t_i = t_{CLU} - t_{EXP}(m)$

- **After selection ~ 3×10⁶ $K_{e3(\gamma)}$**
- **Bkg = 0.7 %**



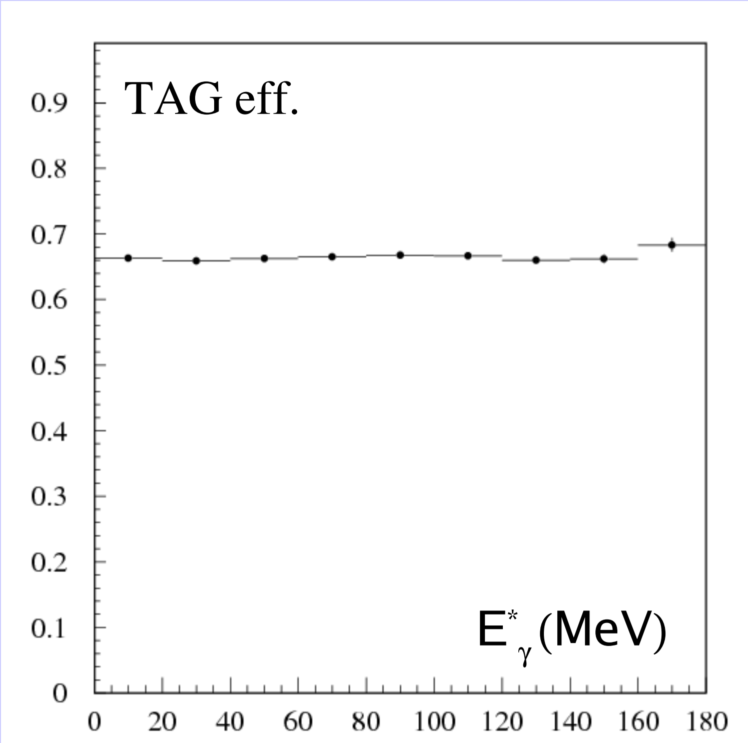


Efficiency

- All efficiencies (TRK, VTX, CLU and TCA) are checked and corrected from different control samples ;

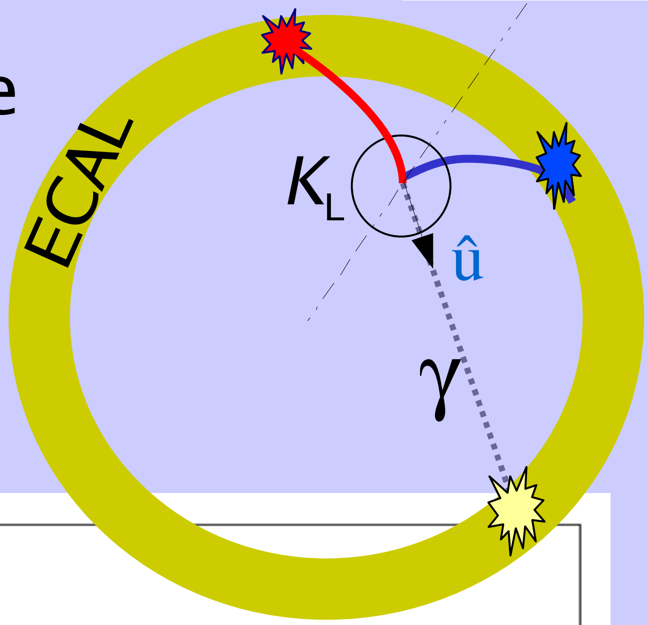
- TRK+VTX (~54%) :
  CS = $\pi^+\pi^-\pi^0$ (98%) + K_{e3}(95%)
  —> $\delta\varepsilon$ ~2%

- CLU+TCA (~70%) :
  CS = K_{e3} (99.5%)
  —> $\delta\varepsilon$ ~1% for $e^\pm$
  —> $\delta\varepsilon$ ~ 3% and a 30% difference is found for π^- and π^+



$K_{e3\gamma}$ Signal Selection

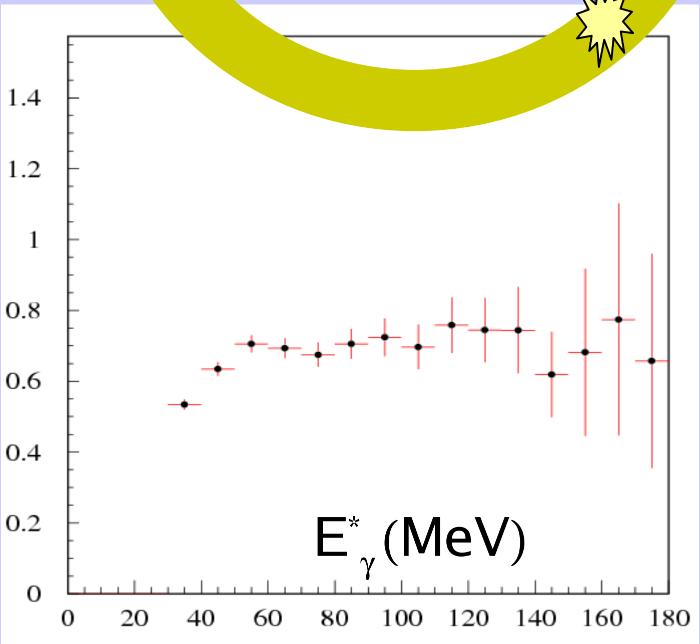
- **L**ooks for a photon within $8\sigma_R$ from the K_L charged vertex and $E_{CLU\text{-}\gamma} > 25$ MeV



- **U**ses the cluster position to close the kinematic and evaluate the photon energy :

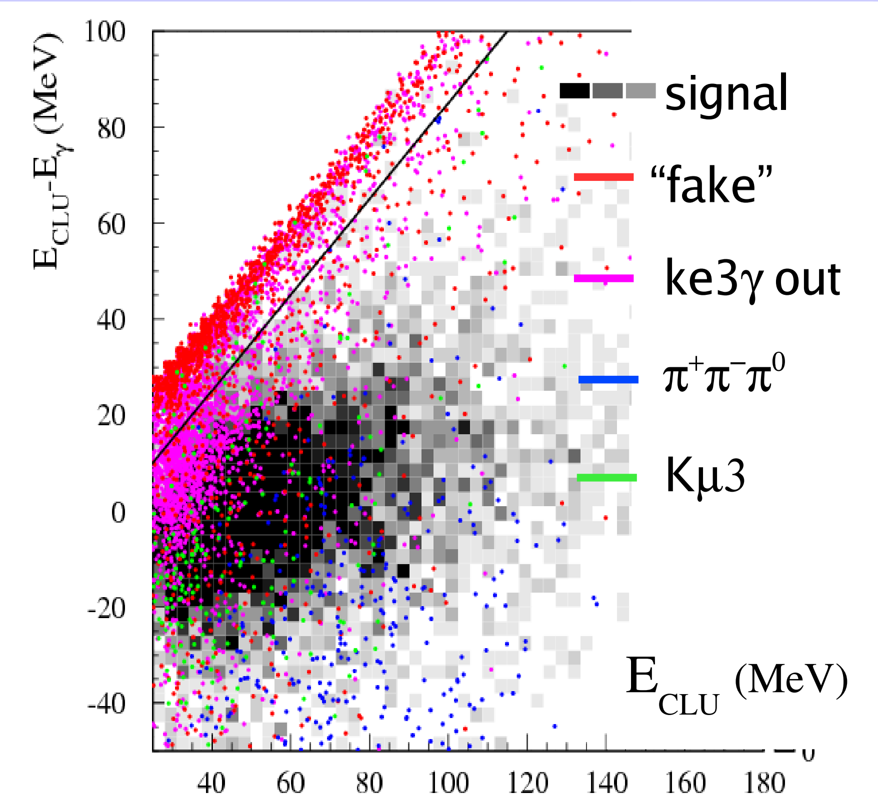
$$p^2_\nu = 0 = (p_K - p_\pi - p_e - p_\gamma)^2$$

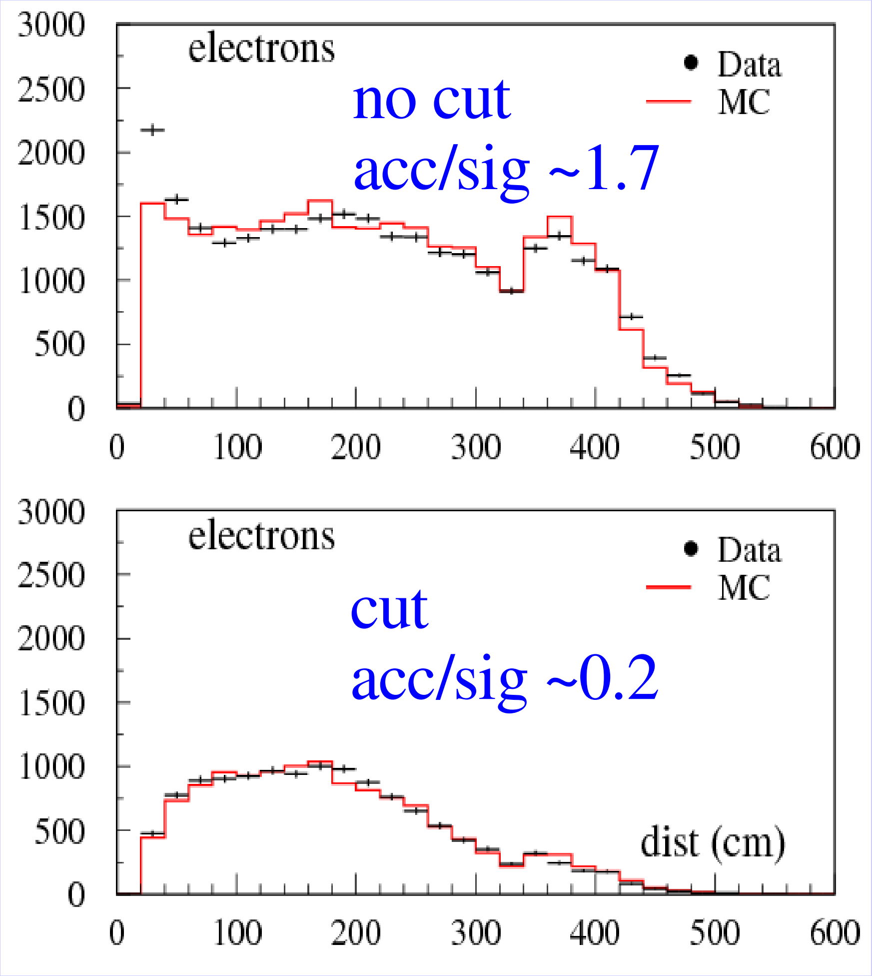
$$\vec{p}_\gamma = E_\gamma \hat{u}$$



Rejection of Accidentals

- We remove accidentals applying a 2d-cut



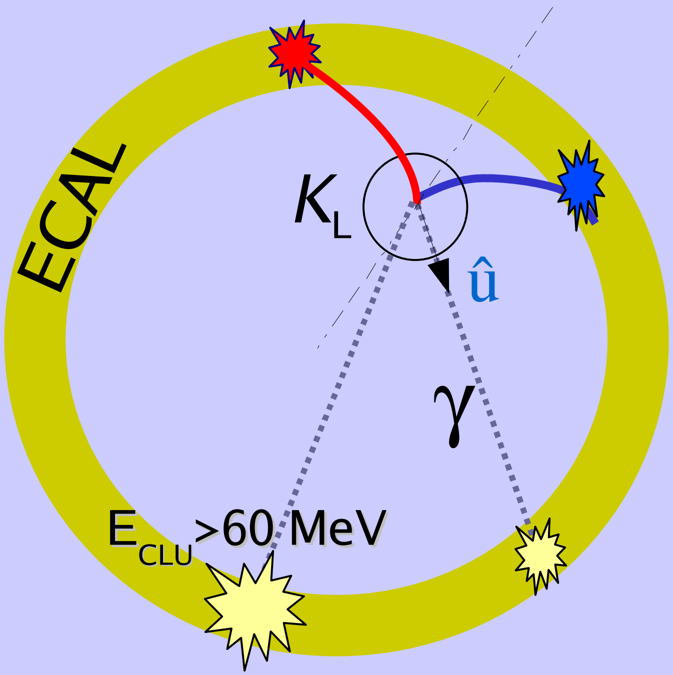


After cut ~ 8×10^3 $K_{e3\gamma}$

CLU_{ELE}-CLU_{γ} distance

Control Sample (CS) from $\pi^+\pi^-\pi^0$

- Needed to correct NV-CHV distance, cluster energy, efficiency and to train neural net



- We require:

  1- narrow window on missing mass

  2- tight kinematic cuts to remove bkg

  3- one hard tagging γ

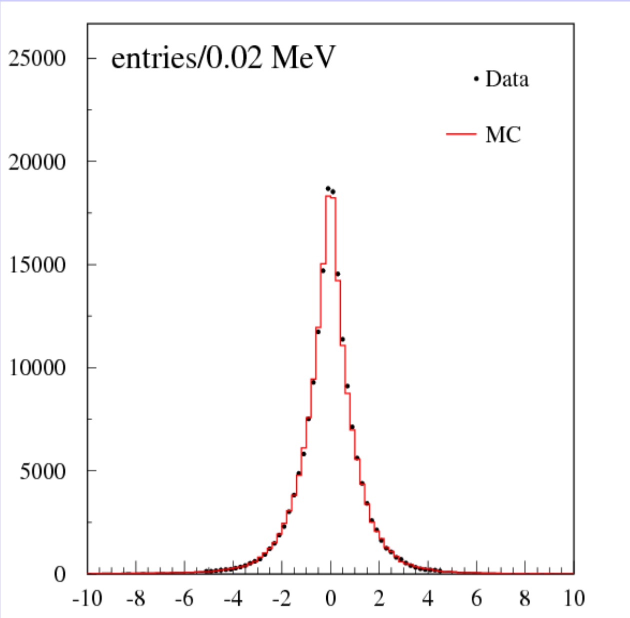
- The tagged photon reconstruction is similar to the photon energy reconstruction for the signal :

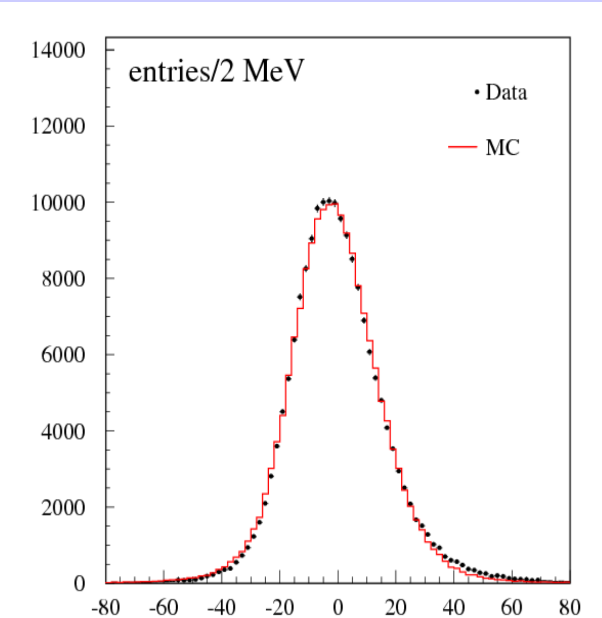
$$p^2_{\gamma-hard} = 0 = (p_K - p_\pi - p_\pi - \boldsymbol{p_\gamma})^2$$

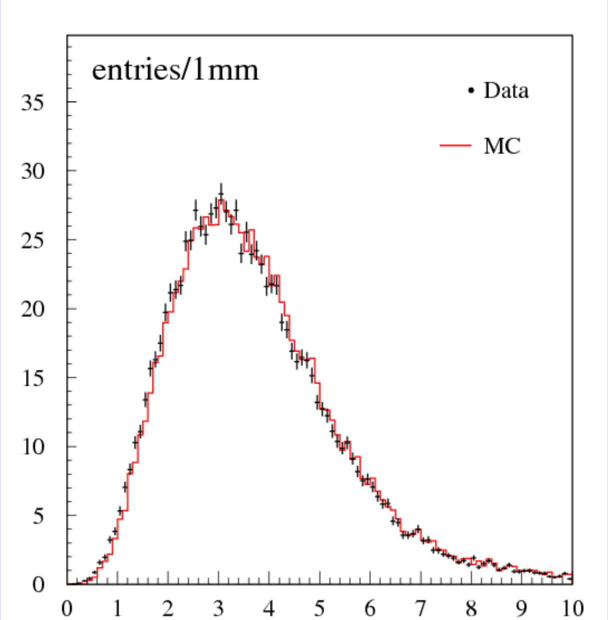
$$p^2_\nu = 0 = (p_K - p_\pi - p_e - \boldsymbol{p_\gamma})^2$$

$\mathcal{P} \sim 99.8\%$

CS: DT-MC comparison







$E^*_\gamma - E^*_\gamma(\text{true})$ (MeV)

$E_{CLU} - E^{lab}_\gamma$ (MeV)

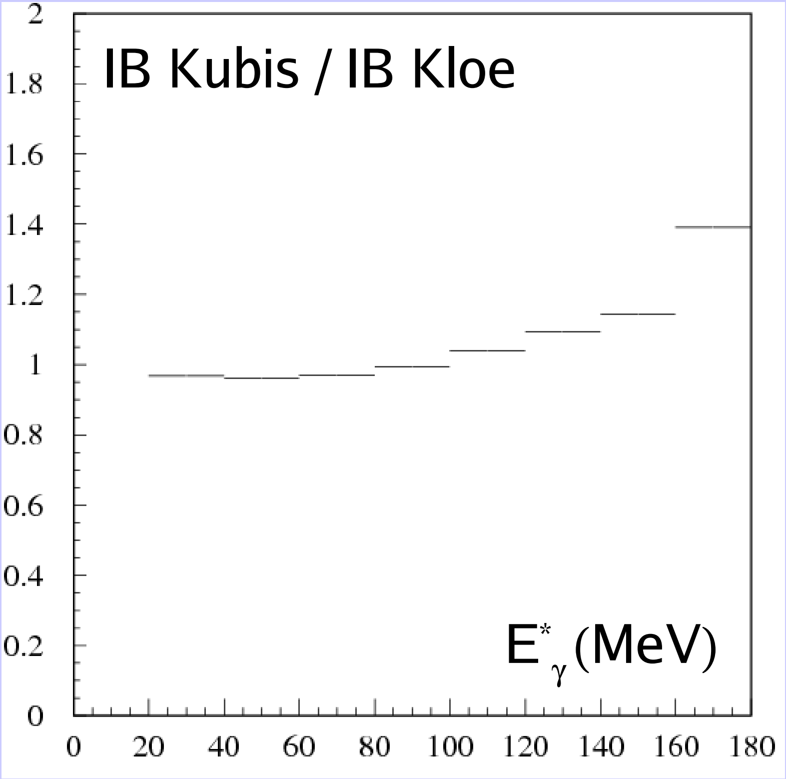
$|\vec{X}_{CHV} - \vec{X}_{NV}|$ (cm)

- Efficiency correction from CS < 2%

Monte Carlo Reliability

- *BR*($K_{e3\gamma}$) is largely dominated by the IB, as the DE contribution via IB–DE interference is ~1% level (pure DE is negligibly). DE e ects becomes more significant at high energy, but the number of events is severely reduced.

- KLOE MC [(1)], $\mathcal{O}(p^2)$ accuracy ~ few % for $K_{e3\gamma}$ after integration, but DE contribution ~1% IB -> δ(DE)~100%
- We use a stand alone MC production for IB and DE , $\mathcal{O}(p^6)$ [(2)]



KUBIS-MC~14 mill, KLOE-MC~270000

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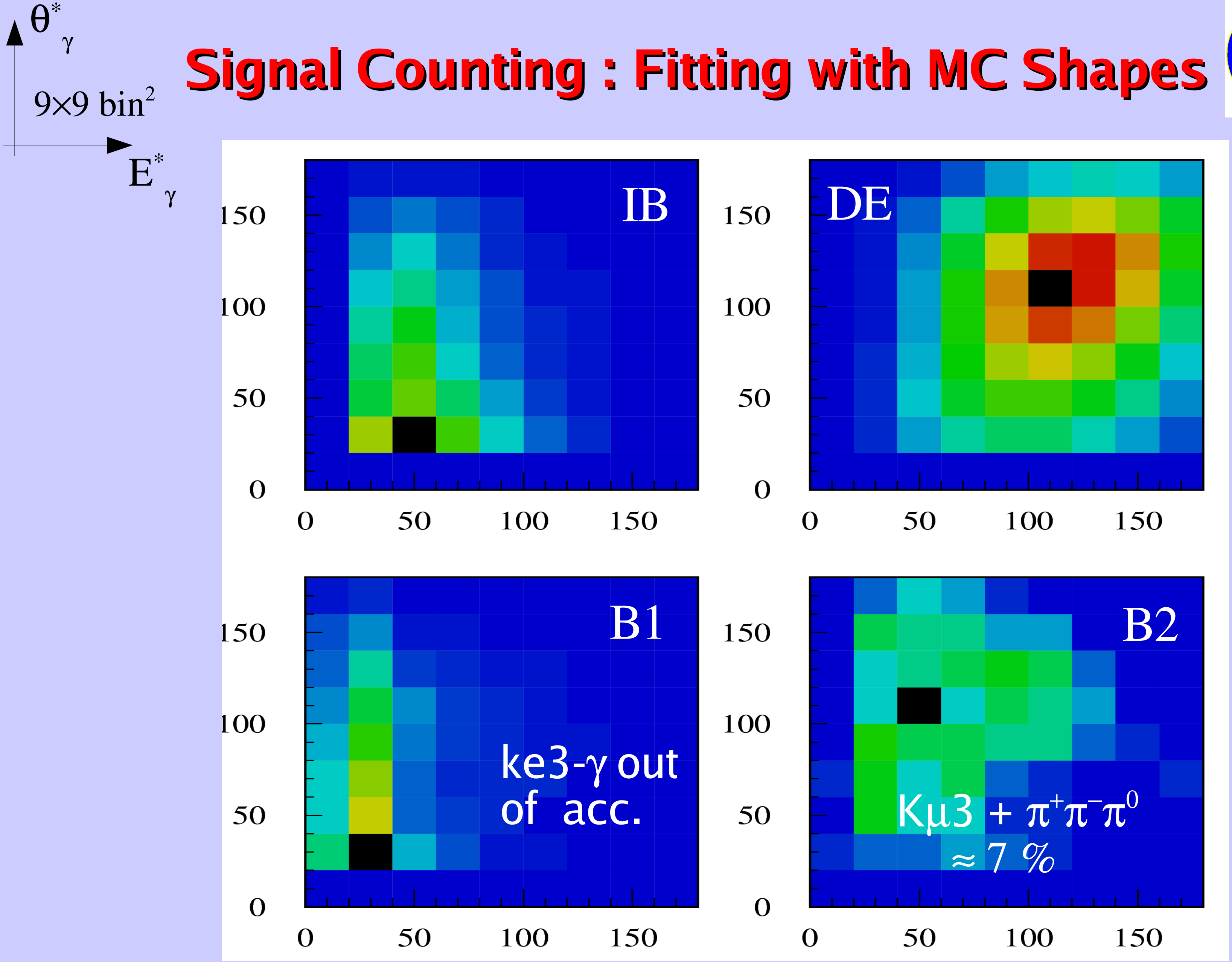
(1) C.Gatti, "*Monte Carlo Simulation for radiative kaon decay*" **Eur.Phys. J** C45 (2006) 417

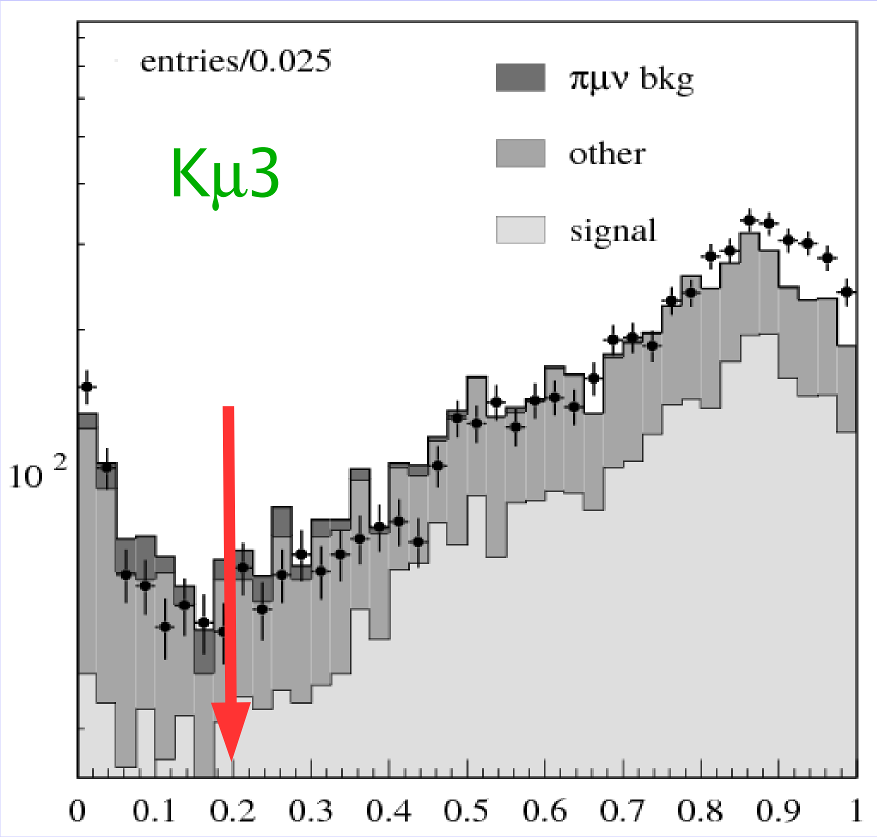
(2) *J. Gasser, B. Kubis, N. Paver, M. Verbeni* **Eur.Phys. J** C40 (2005) 205

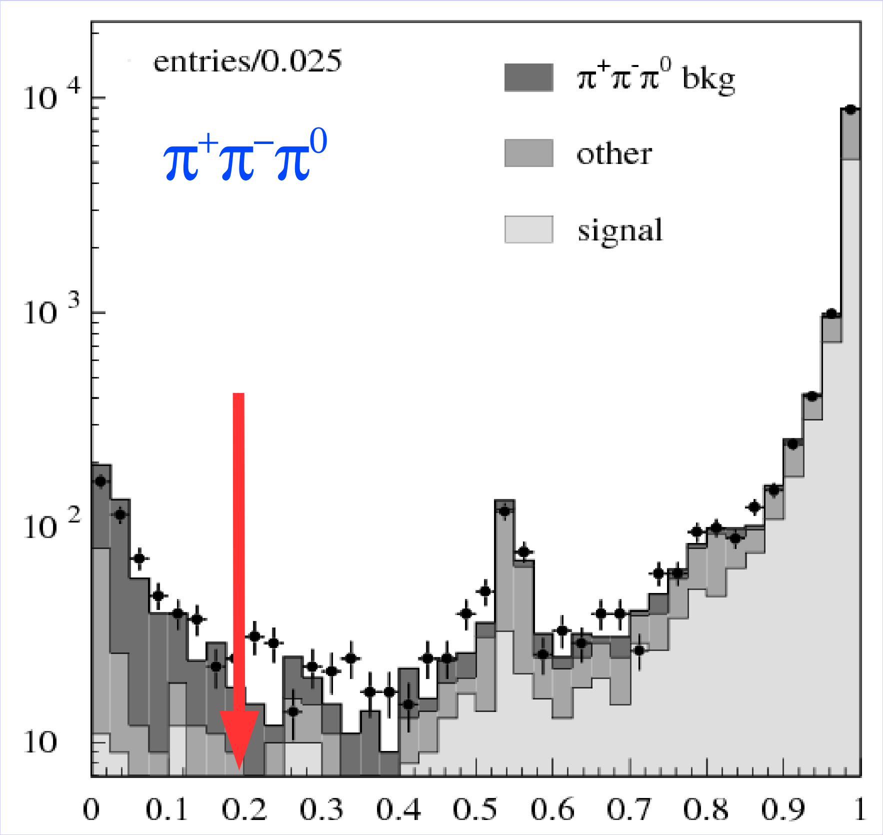
Signal Counting : Fitting with MC Shapes



B2 reduction

- NN output to remove B2 background :
- Kμ3 : trained with calorimetric informations (centroid, p/E)
- $\pi^+\pi^-\pi^0$: trained with kinematic informations



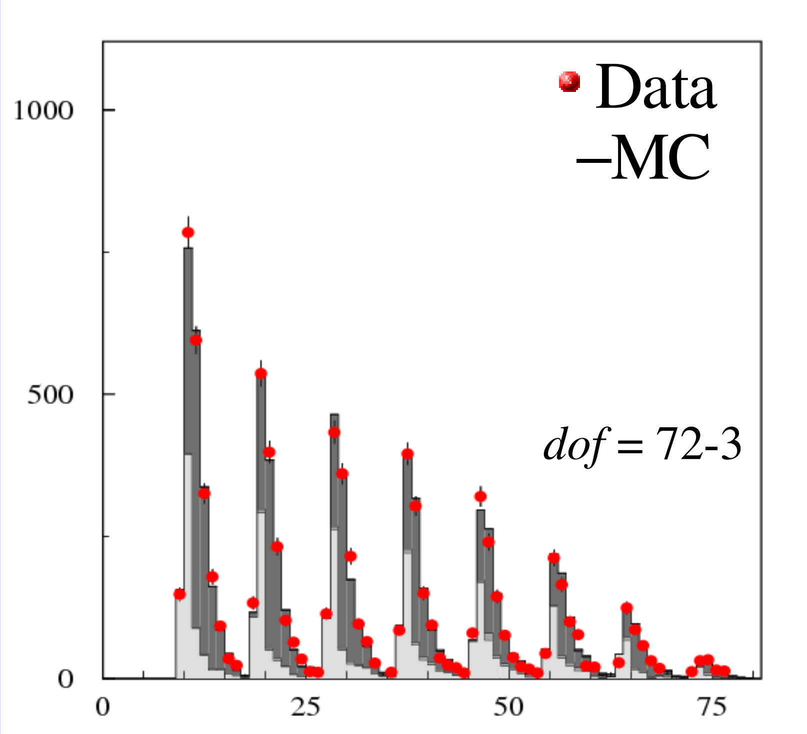


BKG: 2.5% => 1.4%

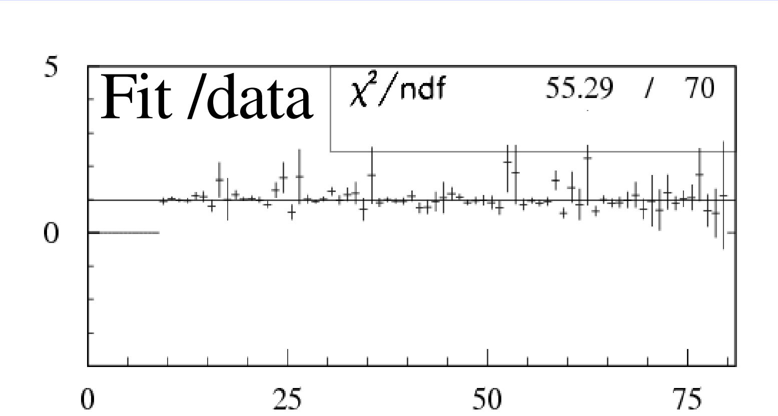
BKG: 4.2% => 0.4%

Fit Result

- Inputs => 4 MC shapes
- **free parameters = IB + B1 + DE normalization**
- **fixed** = B2, from MC normalized to Data
- **Goodness of fit** => χ^2/dof = 60/69



θ-slices re-arranged shape



Fit parameter correlation

Par	1	2	3
1	1	-0.59	-0.25
2		1	-0.02
3			1

DE contribution

- The information on the SD terms is contained in the e ective strength ⟨X⟩(1) that multiplies $f(E^*_\gamma)$, defined in the formula :

$$\frac{d\Gamma}{dE^*_\gamma} = \frac{d\Gamma_{IB}}{dE^*_\gamma} + \langle X \rangle f(E^*_\gamma)$$

- The authors(1) quote, in *ChPT@O*(p^6): $\langle X \rangle = -1.2 \pm 0.4$

- From IB and DE counting, taking into account the different efficiency for IB and DE photons, KLOE measures :

KLOE : $\langle X \rangle = (-2.3 \pm 1.3_{stat})$

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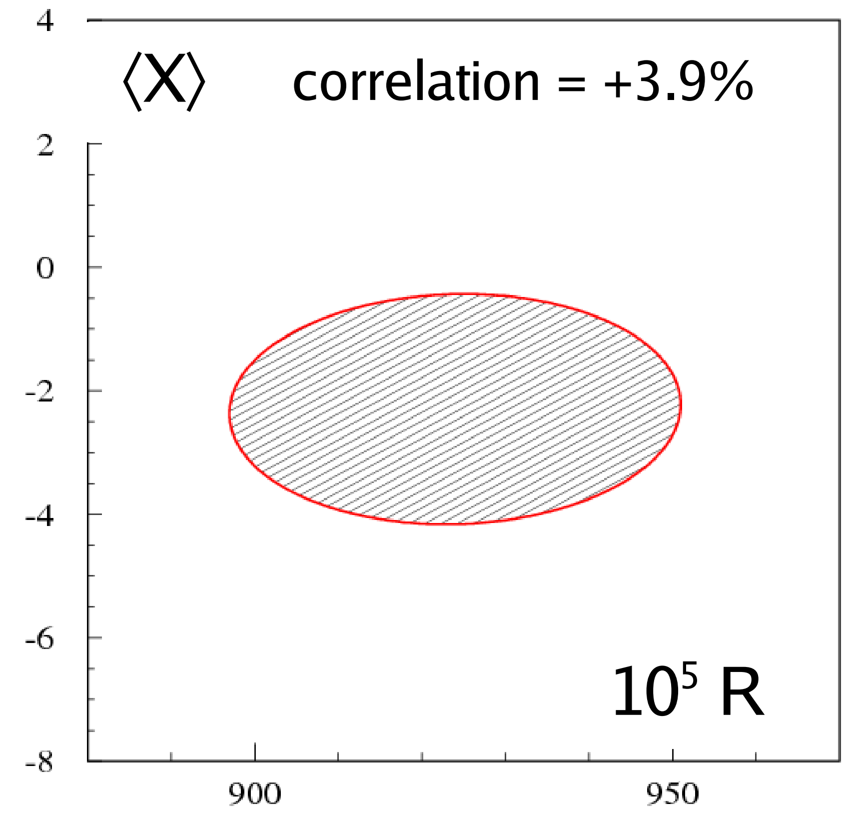
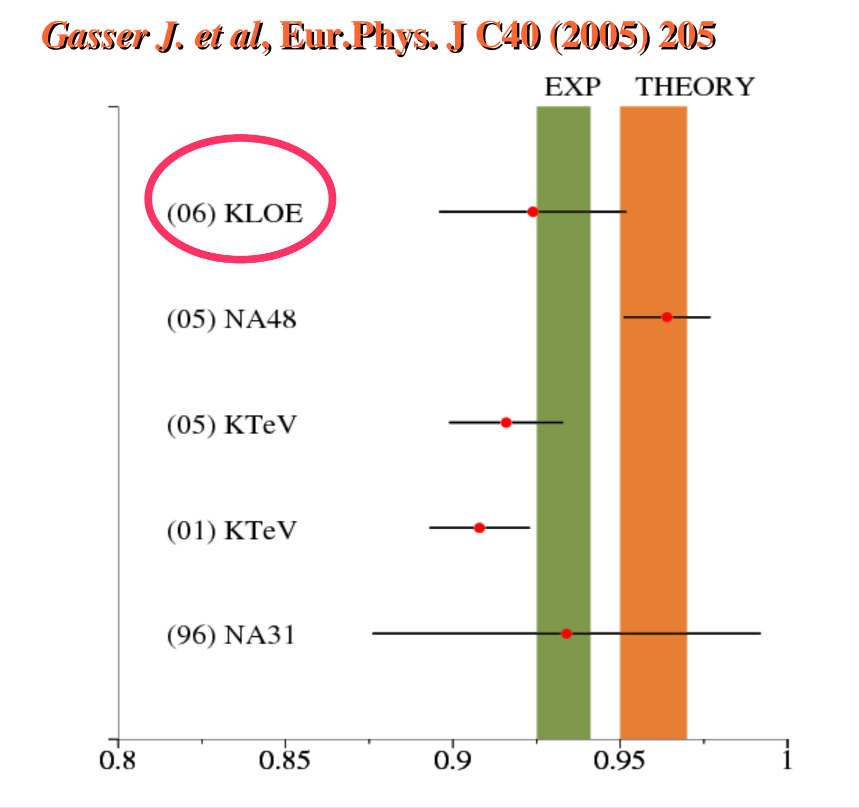
(1) *Gasser J. et al*, **Eur.Phys. J** C40 (2005) 205

Systematics

Source	$10^5 \times \Delta R$	ΔX
• Tagging	4.0	0.7
• Tracking	1.5	0.8
• TCA ~	5.5	0.1
• Kine. cut	~0	~0
• TOF cut	1.3	0.5
• P-miscal	3.5	0.2
• P-resol.	7.2	0.4
• FV	3.0	0.5
• Rejection of acc.	5.2	0.4
• NV acceptance	2.9	0.3
• BKG rejection	9.0	0.1
TOTAL	**15.5**	**1.4**

Results





$$\langle X \rangle = (-2.3 \pm 1.3_{stat} \pm 1.4_{syst})$$

$$R = (924 \pm 23_{stat} \pm 16_{syst}) \times 10^{-5}$$

Gasser: $\langle X \rangle = -1.2 \pm 0.4$

DE Result: Comparison with KTeV

- KTeV measurement refers to a phenomenological model for DE , the FFS model [(1)], based on four parameters. No enough sensitivity to measure all parameters -> *soft kaon approximation* ;
- *Gasser J.* relates the ⟨X⟩ parameters with the FFS parameters :

$$\langle X\rangle = \underbrace{1.4\,\langle A\rangle}_{-1.9} + \underbrace{0.4\,\langle B\rangle}_{+0.1} + \underbrace{\langle C\rangle}_{+0.1} + \underbrace{0.4\,\langle D\rangle}_{-0.1} + \underbrace{1.5\,M_K^2 \dot{f}_+(0)}_{+0.6} = \mathbf{-1.2}$$

where ⟨…⟩ are the structure-dependent terms ;

In the *soft kaon approximation* (A=B=0) KTeV [(2)] measures:

C = -5 ± 10 , D = 5 ± 20

KTeV measurement does not allow one to draw a definitive conclusion on ⟨X⟩

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(1) **Fearing, Fishbach, Smith**; for example *Fearing et al.*, **Phys.Rev.D2** (1970)

(2) *A. Alavi-Harati et al.*, **Phys.Rev.D64** (2001)

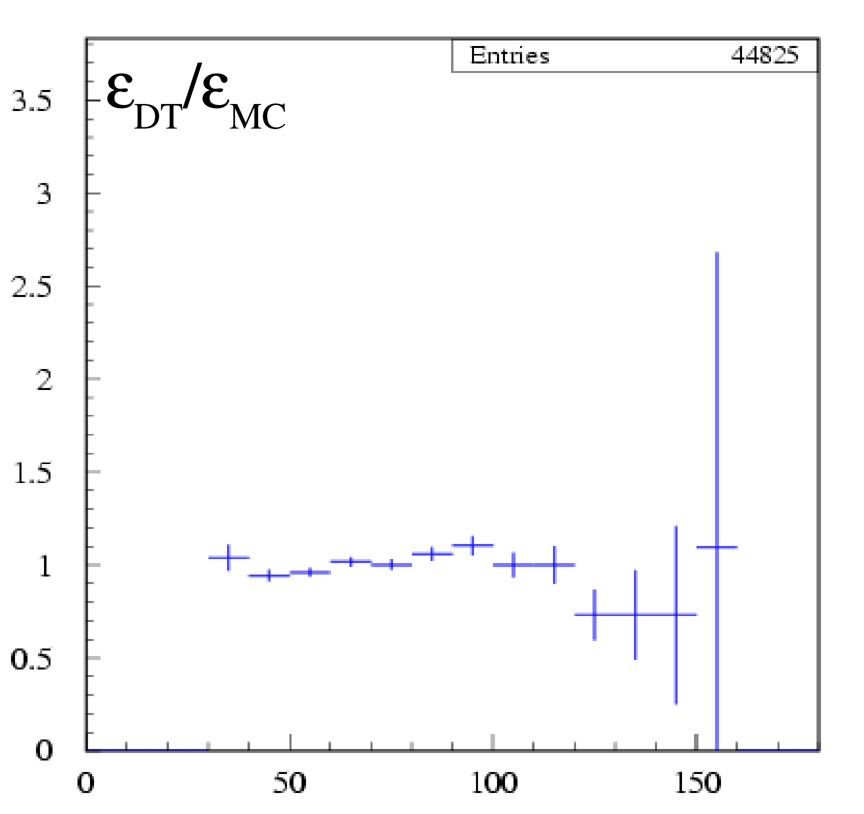
Conclusion

- **DE:** first measurement of DE contribution; it is in agreement with $\chi PT@O(p^6)$ prediction ;
- **R**: our accuracy on R is not sufficient to solve experimental disagreement ;
- KLOE uses only 1/5th of whole statistic (a 3σ significance for DE could be achieved) ;
- We thank ***B. Kubis*** for the use of his Monte Carlo generator code.

spares

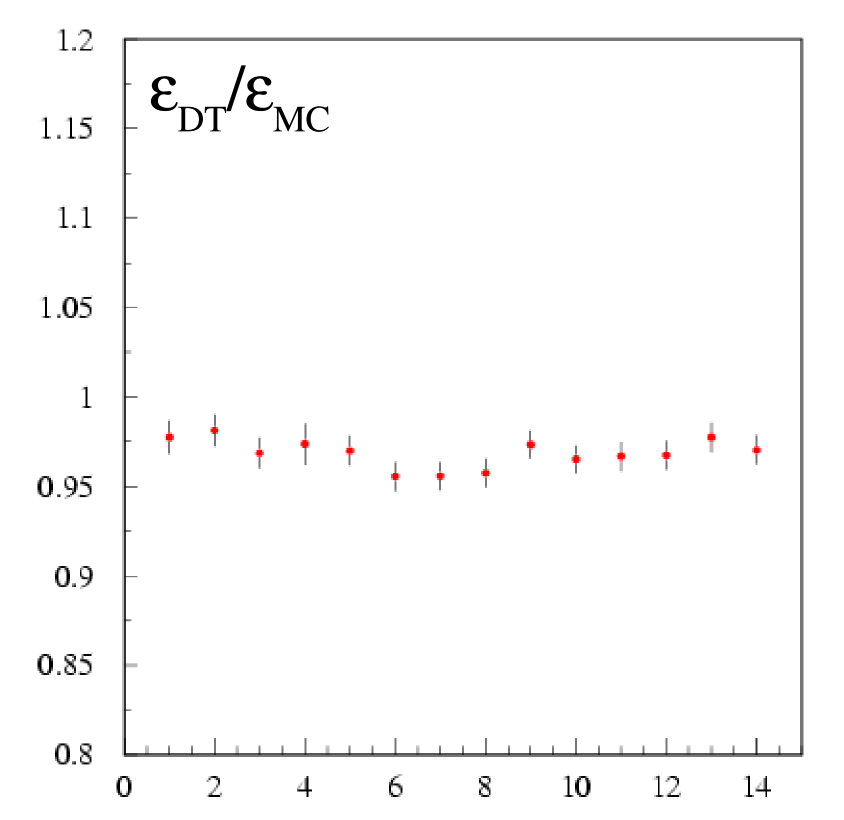
CS: efficiency correction

shape correction



E^*_γ (MeV)

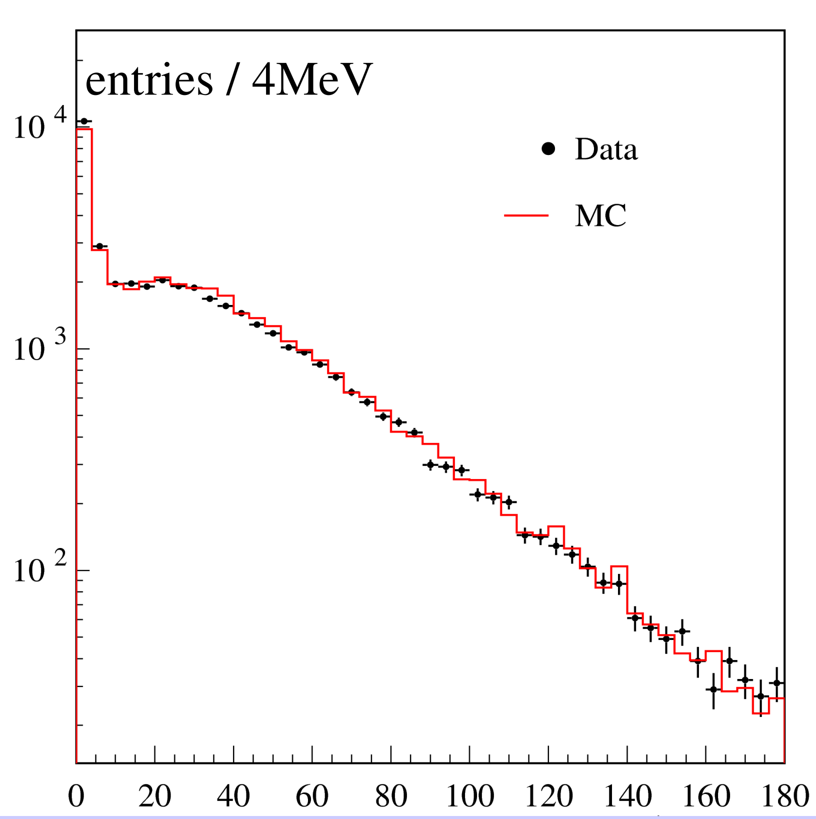
global correction



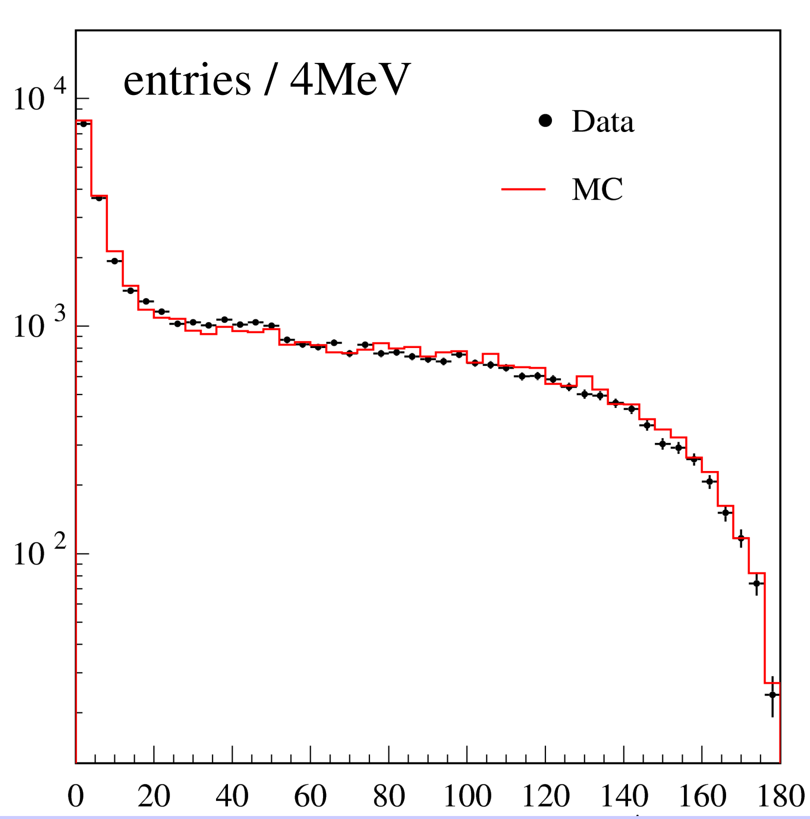
Run period

MC-Data comparison

After photon selection



E^{*}_{γ}(MeV)



$\theta^{*}_{lep-\gamma}$(deg)