

# Highlights on Radiative Kaon and Hyperon decays from NA48/2

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on behalf of the NA48/2 Collaboration

Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz,  
Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

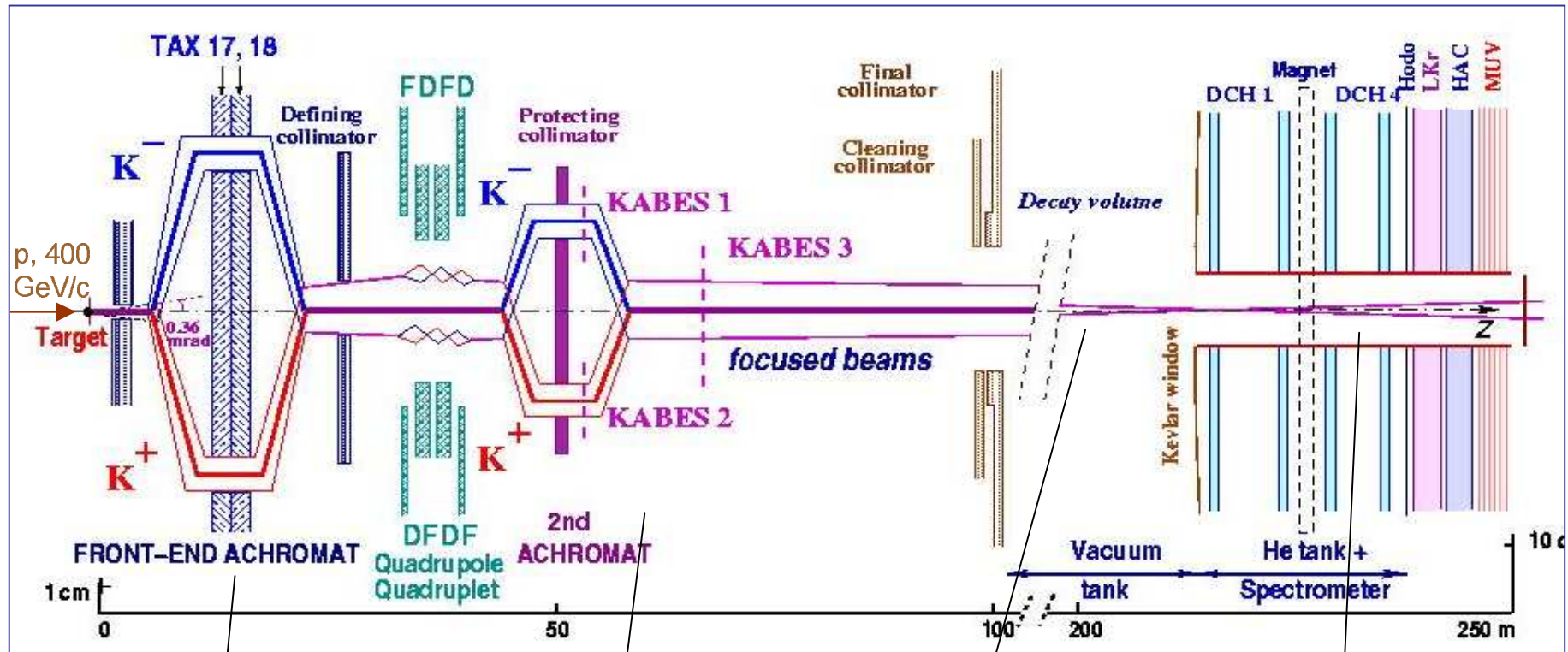
***Menu2007 Conference***

**Julich, Germany, september 10-14, 2007**

# Outline

- $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$  decay
  - decay formalism
  - experimental status
  - NA48/2 measurement
- $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$  decay
  - NA48/2 measurement
- Decay asymmetries of  $\Xi^0 \rightarrow \Lambda \gamma$  and  $\Xi^0 \rightarrow \Sigma^0 \gamma$ 
  - NA48/1 measurement
- $\Xi^0 \rightarrow \Lambda^0 e^+ e^-$ 
  - NA48/1 measurement

# The NA48/2 beam line



- Split +/-
- Select  $P=(60\pm 3)\text{GeV}/c$
- Recombine +/-

Beam Spectrometer  
( resolution 0.7 % )

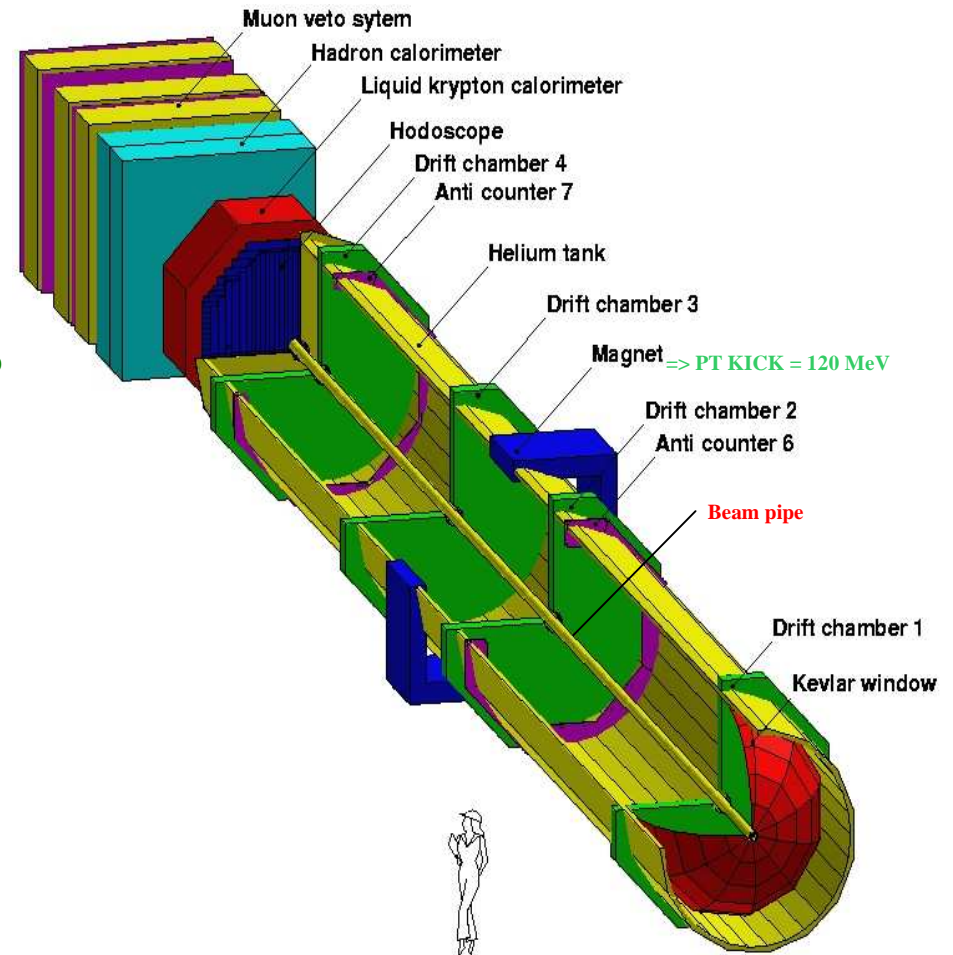
Decay volume (114m)

Pion decay products are  
confined in the beam pipe

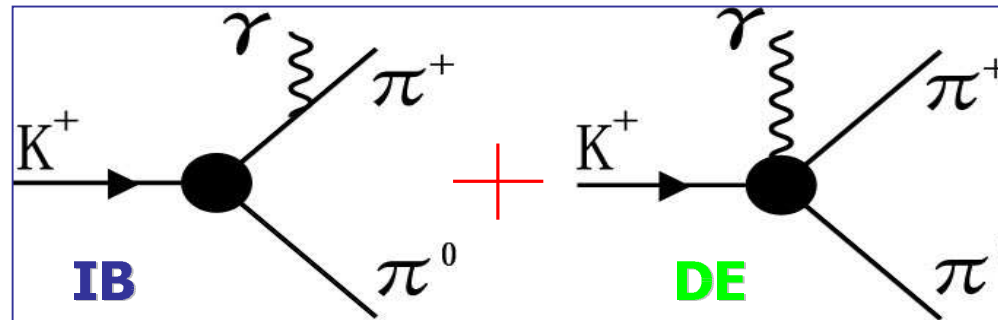
# The NA48 detector

- Magnetic spectrometer (4 DCHs):  
 $\Delta p/p = 1.0\% + 0.044\% \cdot p$  [GeV/c]  
 $\sigma[M(\pi^+\pi^-\pi^\pm)] \sim 1.7 \text{ Mev}/c^2$
- Liquid Krypton EM calorimeter (LKr)  
High granularity, quasi-homogeneous;  
 $\Delta E/E = 3.2\%/\sqrt{E[\text{GeV}]} + 9\%/E[\text{GeV}] + 0.42\%$   
 $\sigma_x, \sigma_y \sim 1.5 \text{ mm}$   
 $\sigma[M(\pi^0\pi^0\pi^\pm)] \sim 1.4 \text{ Mev}/c^2$
- Scintillators hodoscope (2 planes):  
fast trigger;  
precise time measurement (150ps)
- hadron calorimeter
- muon veto counters
- photon vetoes

L1 trigger: hodoscope and DCH multiplicity  
L2 trigger: on-line data processing



# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : decay process



$\Gamma^\pm$  depends on 2 variables ( $T_\pi^*$  and  $W$ ) that can be reduced to only one integrating over  $T_\pi^*$  (kinetic energy of  $\pi^\pm$  in the kaon rest frame)

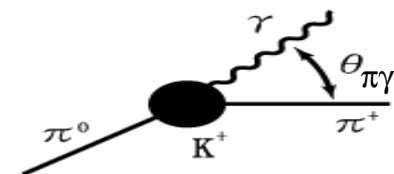
$$\frac{d\Gamma^\pm}{dW} \simeq \left( \frac{d\Gamma^\pm}{dW} \right)_{IB} \left[ \underbrace{1}_{IB} + \underbrace{2 \left( \frac{m_\pi}{m_K} \right)^2 W^2 |E| \cos((\delta_1 - \delta_0) \pm \phi)}_{INT} + \underbrace{\left( \frac{m_\pi}{m_K} \right)^4 W^4 (|E|^2 + |M|^2)}_{DE} \right]$$

**Sensitive variable:**

$$W^2 = \frac{(P_K \cdot P_\gamma)(P_\pi \cdot P_\gamma)}{(m_K m_\pi)^2}$$

$\mathbf{P}_K$  = 4-momentum of the  $K^\pm$   
 $\mathbf{P}_\pi$  = 4-momentum of the  $\pi^\pm$   
 $\mathbf{P}_\gamma$  = 4-momentum of the  $\gamma$

$$W^2 = \frac{(E_\gamma^*)^2 (E_\pi^* - P_\pi^* \cos \theta_{\pi\gamma})}{m_K m_\pi^2}$$



# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : decay amplitudes

Two types of contributions:

Electric dipole (E)

Magnetic dipole (M)

IB dominates the E amplitude but does not contribute to M

DE shows up at order  $O(p^4)$  in CHPT: generates both E and M terms

INT occurs only in E amplitude

From PDG (2006)

Inner Bremsstrahlung (IB) : BR =  $(2.75 \pm 0.15) \cdot 10^{-4}$  ( $55 < T_\pi^* < 90$  MeV)

Direct Emission (DE) : BR =  $(4.4 \pm 0.7) \cdot 10^{-6}$  ( $55 < T_\pi^* < 90$  MeV)

Interference (INT) : not yet measured

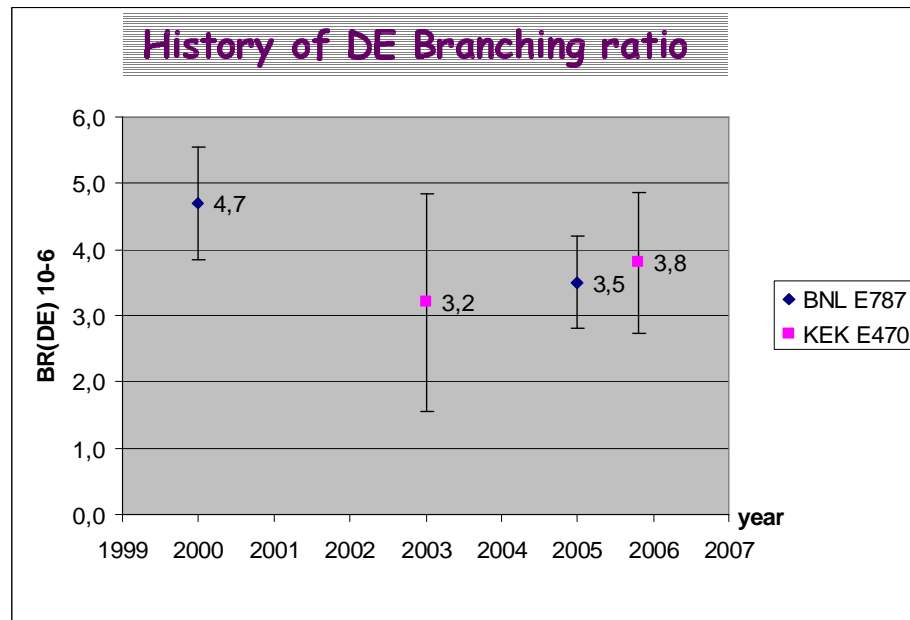
# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ :

## experimental results for DE and INT.

| Experiment | Year | # Events | BR(DE) $\times 10^6$        |
|------------|------|----------|-----------------------------|
| E787 [20]  | 2000 | 19836    | $4.7 \pm 0.8 \pm 0.3$       |
| E470 [21]  | 2003 | 4434     | $3.2 \pm 1.3 \pm 1.0$       |
| E787 [22]  | 2005 | 20571    | $3.5 \pm 0.6^{+0.3}_{-0.4}$ |
| E470 [23]  | 2005 | 10154    | $3.8 \pm 0.8 \pm 0.7$       |

All the measurements have been performed:

- ✓ in the  $T_\pi^*$  region **55-90 MeV** to avoid  $\pi^\pm \pi^0$  and  $\pi^\pm \pi^0 \pi^0$  background
- ✓ assuming INT = 0



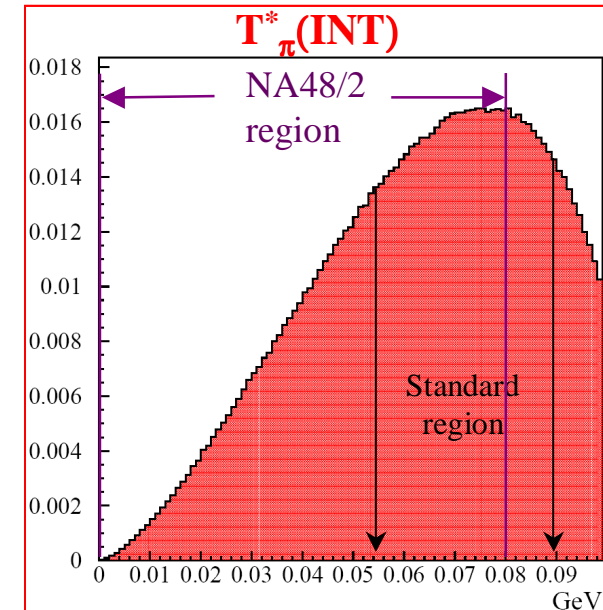
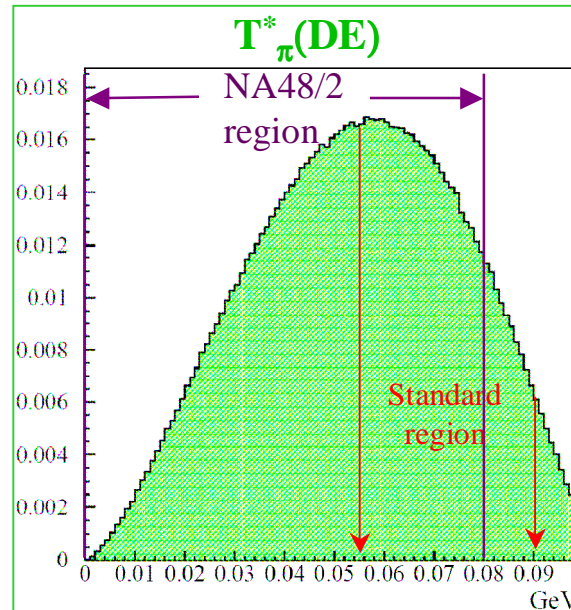
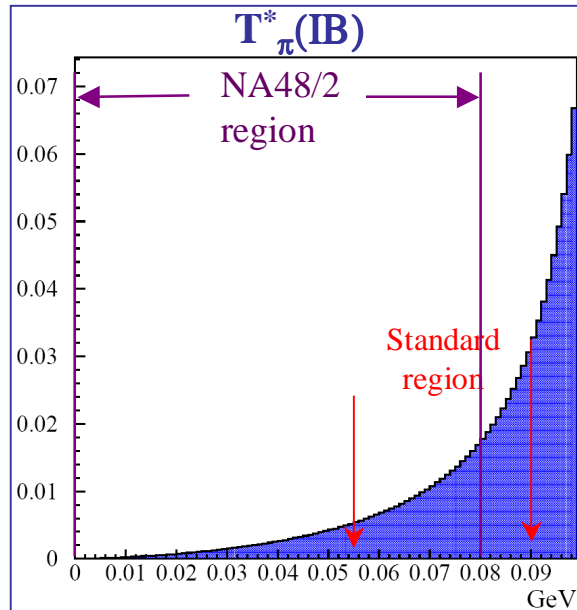
### Interference estimations\*:

$$\text{INT} = (-0.58^{+0.91}_{-0.83})\% \text{ of IB} \quad \text{BNL E787}$$

$$\text{INT} = (-0.4 \pm 1.6)\% \text{ of IB} \quad \text{KEK E470}$$

\*not quoted as measurements by authors

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : enlarged $T_\pi^*$ region



Standard region  $55 < T_\pi^* < 90$  MeV is a safe choice for BG rejection

But.... region  $< 55$  MeV is the most interesting to measure **DE** and **INT**

This measurement is performed in the region

$$0 < T_\pi^* < 80 \text{ MeV}$$

to improve statistics and sensitivity to **DE**

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : the selected data sample

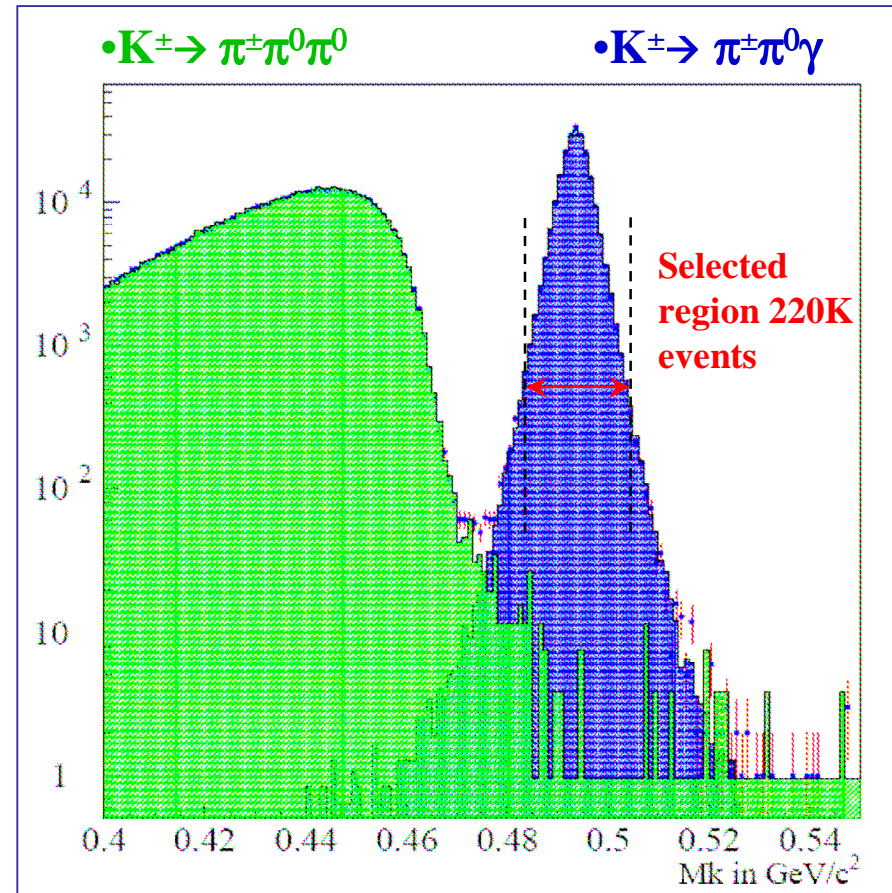
## ➤ Event selection

- requirements on tracks
- requirements on LKR clusters
- effort into photons pairing
- requirements on the event closure

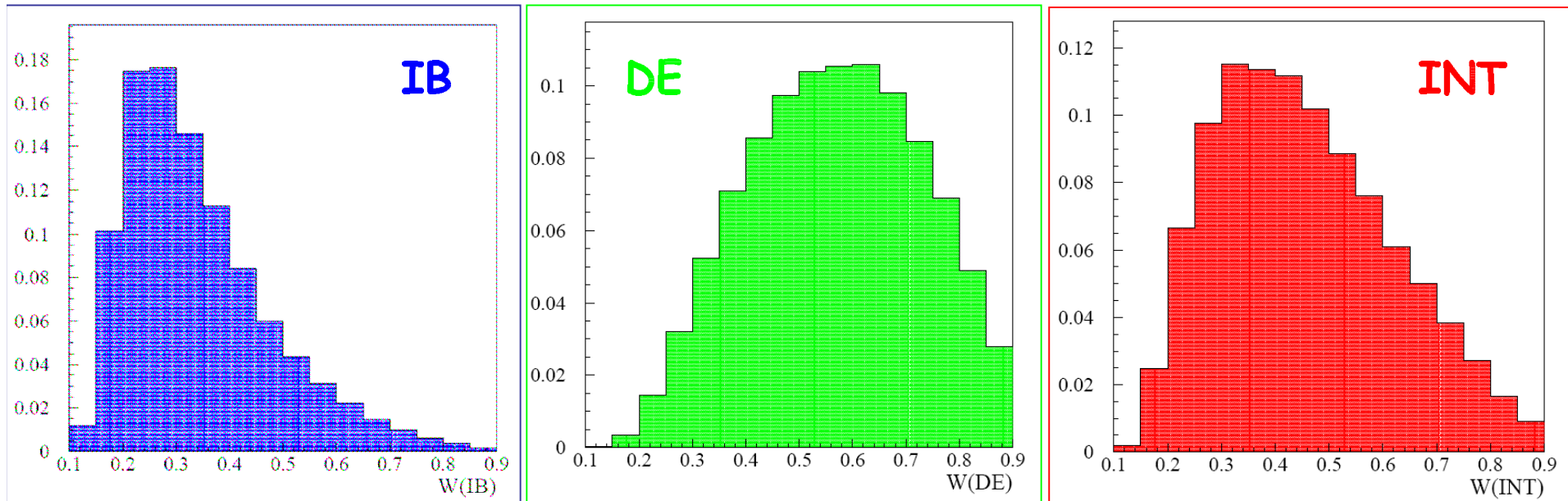
➤ All **physical BG** can be explained in terms of  $\pi^\pm \pi^0 \pi^0$  events only

➤ Very small contribution from **accidentals** is neglected

➤  $\gamma$  mistagging probability (self background) is order of ‰



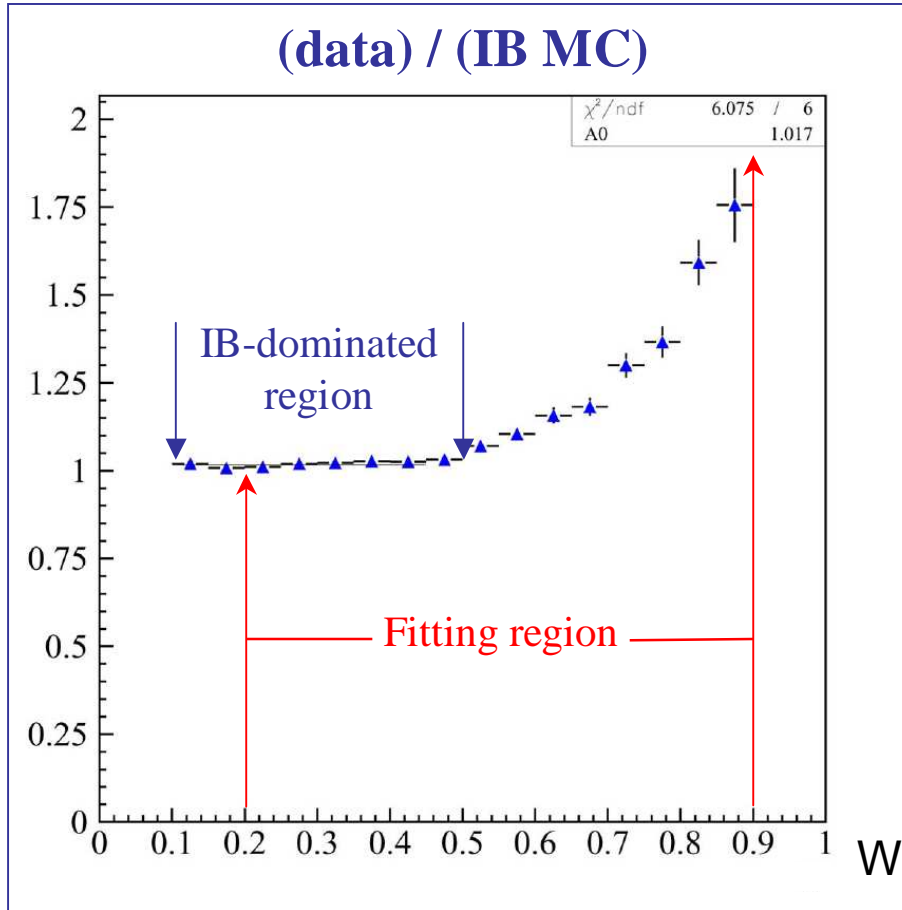
# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : W shapes from MC



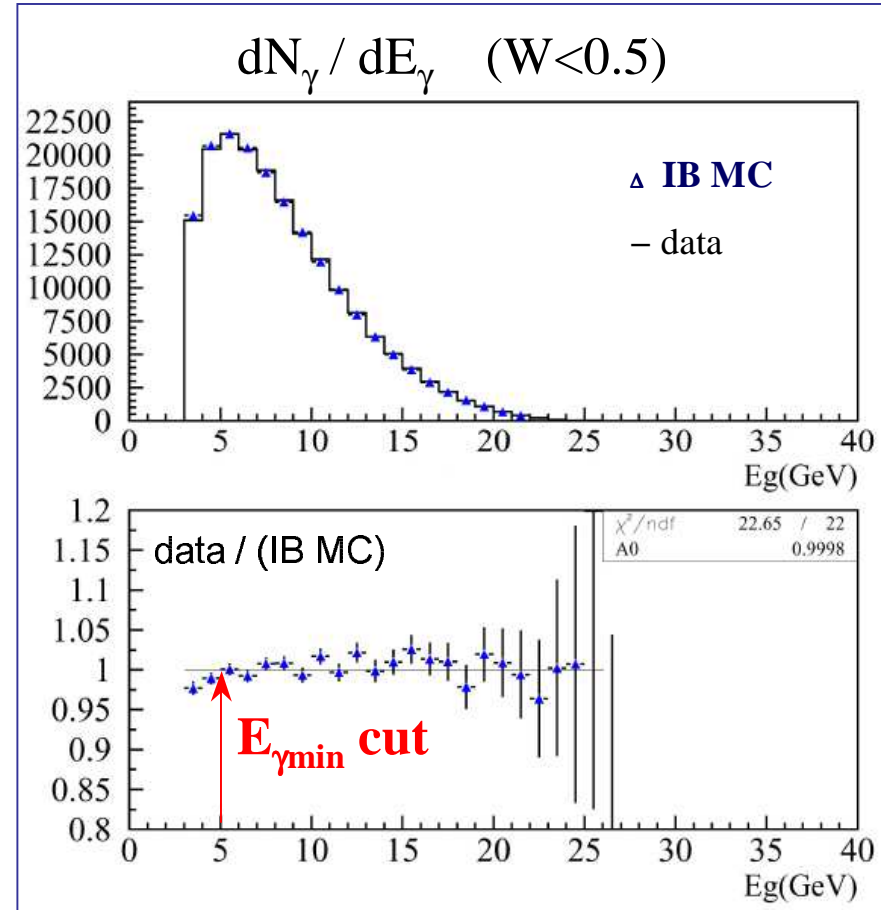
- 3 MC data samples for the 3 contributions to the decay

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ . Data-MC comparison.

IB-MC normalized  $W$  spectrum



Radiated  $\gamma$  energy spectrum



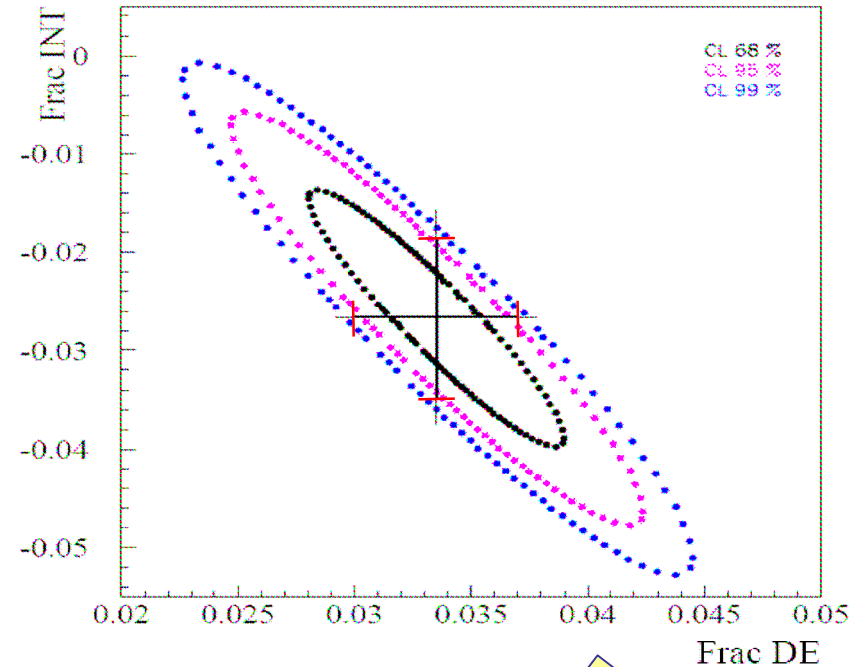
- IB contribution is very well reproduced by MC

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : fit results (2003 data)

- fit the W data spectrum using MC shapes with the weights to be extracted:

$$N(W)_{\text{data}} = (1 - \alpha - \beta)N(W)_{\text{IB}} + \alpha N(W)_{\text{DE}} + \beta N(W)_{\text{INT}}$$

- systematic dominated by trigger efficiency
- parameters are highly correlated  
correlation coefficient:  $\rho = -0.92$



**First evidence of non zero INT term!**

$$\text{Frac(DE)}_{0 < T^* \pi < 80 \text{ MeV}} = (3.35 \pm 0.35 \pm 0.25)\%$$

$$\text{Frac(INT)}_{0 < T^* \pi < 80 \text{ MeV}} = (-2.67 \pm 0.81 \pm 0.73)\%$$

NA48/2  
Preliminary  
(2003 data)

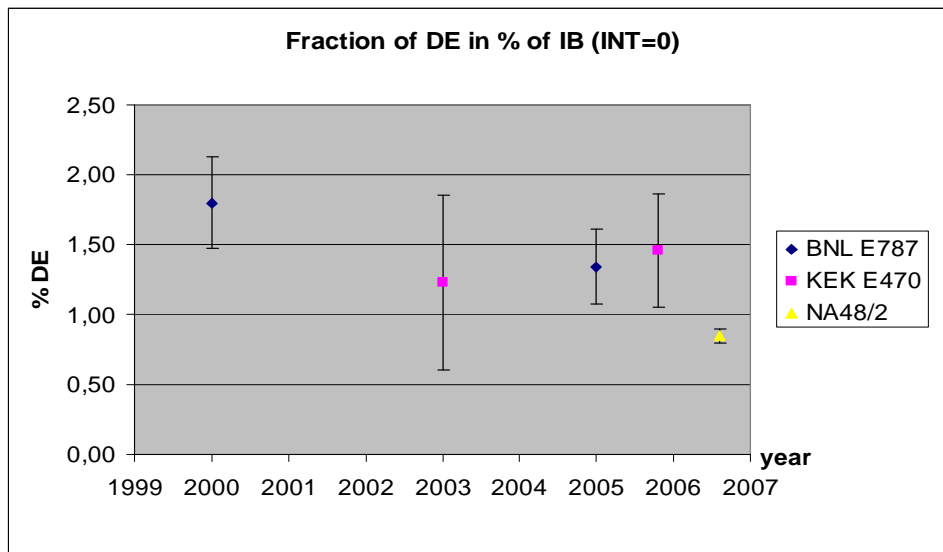
2004 data set: higher (x4) statistics and lower systematic due to trigger

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : comparison to other exp.

✓ For comparison with previous experiments the fraction of DE has also been measured:

- assuming  $INT = 0$
- using data with  $55 < T_\pi^* < 90$  MeV

$$\text{Frac(DE)}_{55 < T_\pi^* < 90 \text{ MeV}} = (0.85 \pm 0.05 \pm 0.02)\%$$



Consistent, although the analysis of fit's residuals shows a bad  $\chi^2$



Indication for a non-zero INT term

# $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ : outlook

✓ from D'Ambrosio and Cappiello hep-ph/0702292v2 (19 April 2007)  
new input to  $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$  dynamics:

$d\Gamma^\pm/dW$  should include a form factor dependent on  $W$

→  $W$  shapes in MC samples need to be recomputed (**DE shape only**)

→ the fit as well

→ modifications are expected on **DE** and **INT** fractions

✓ complete NA48/2 data set (2003+2004) being analysed:

→ larger statistics (4x);

→ lower systematics (trigger)

# $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$ : first observation

Naive estimation of the BR:

$$BR(K^\pm \rightarrow \pi^\pm e^+ e^- \gamma) = BR(K^\pm \rightarrow \pi^\pm \gamma \gamma) \cdot 2\alpha \sim 1.6 \cdot 10^{-8}$$

Theoretical expectation ( $\chi$ Pt based, Gabbiani 99):

$$BR(K^\pm \rightarrow \pi^\pm e^+ e^- \gamma) = (0.9 - 1.6) \cdot 10^{-8}$$

**Event sample:**

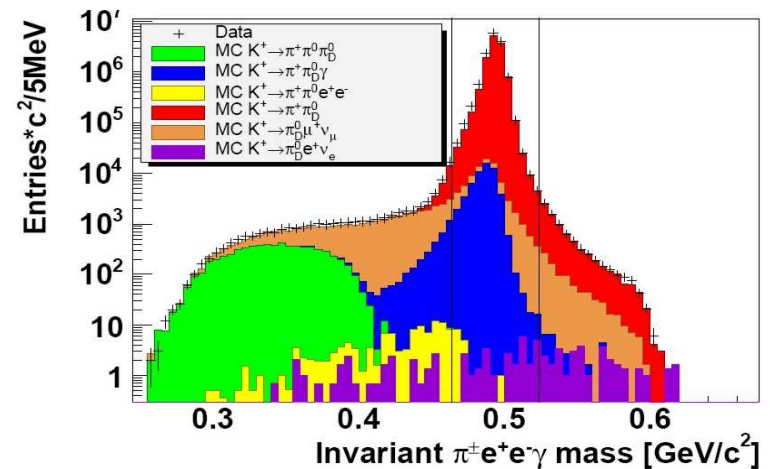
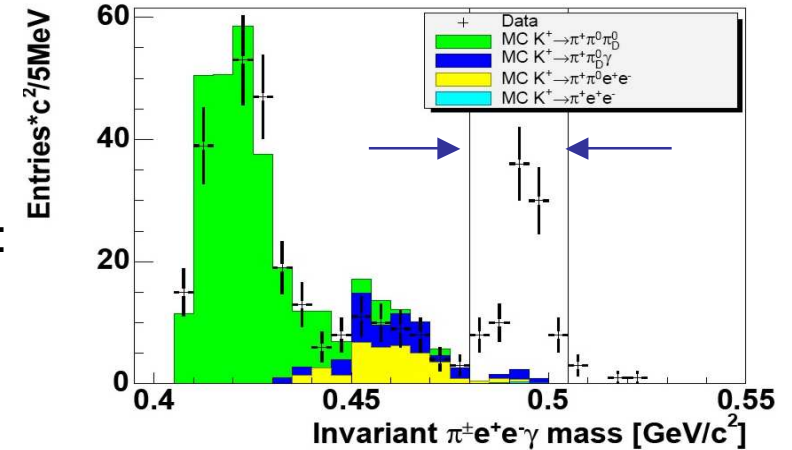
**92 candidate events with**

1  $\pm$  1 accidental background

5.1  $\pm$  1.7 physical background

**Normalization channel:**

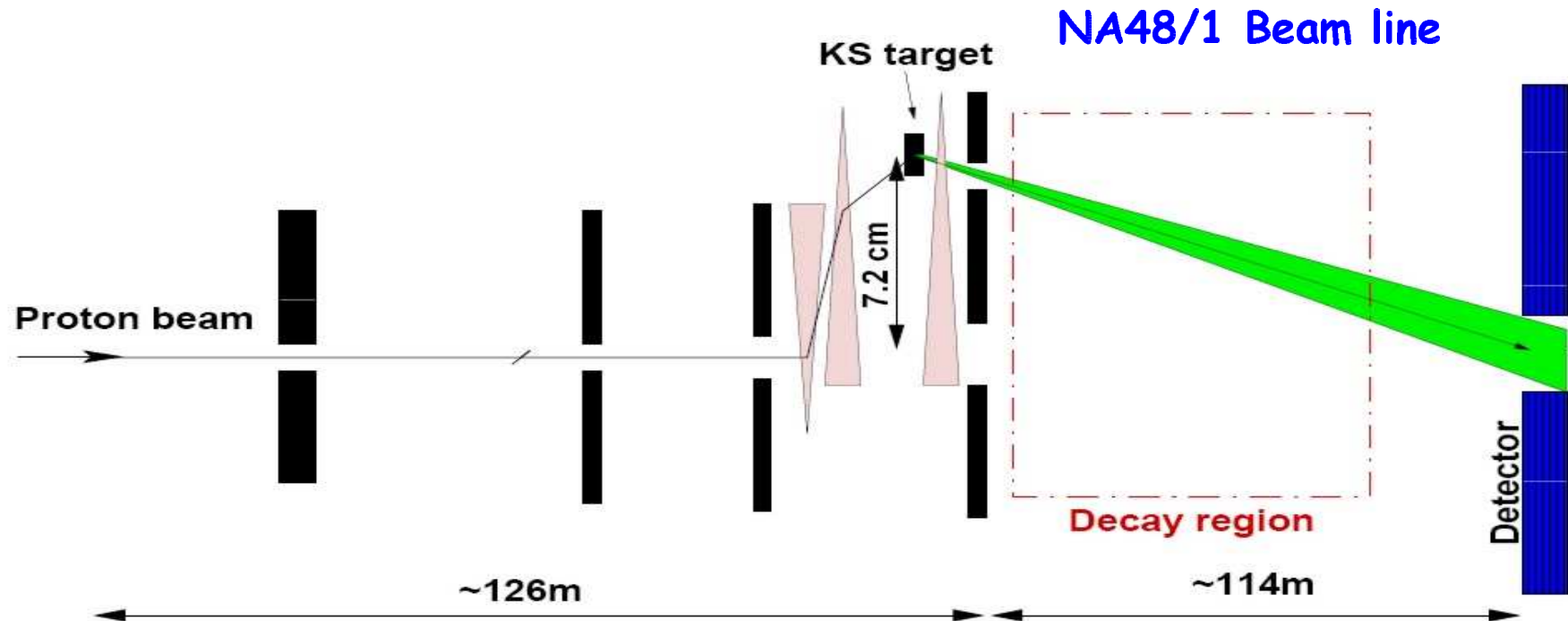
$K^\pm \rightarrow \pi^\pm \pi^0_D$ : 14M events



NA48/2  
Preliminary

$$BR(K^\pm \rightarrow \pi^\pm e^+ e^- \gamma) = (1.27 \pm 0.14 \pm 0.05) \cdot 10^{-8}$$

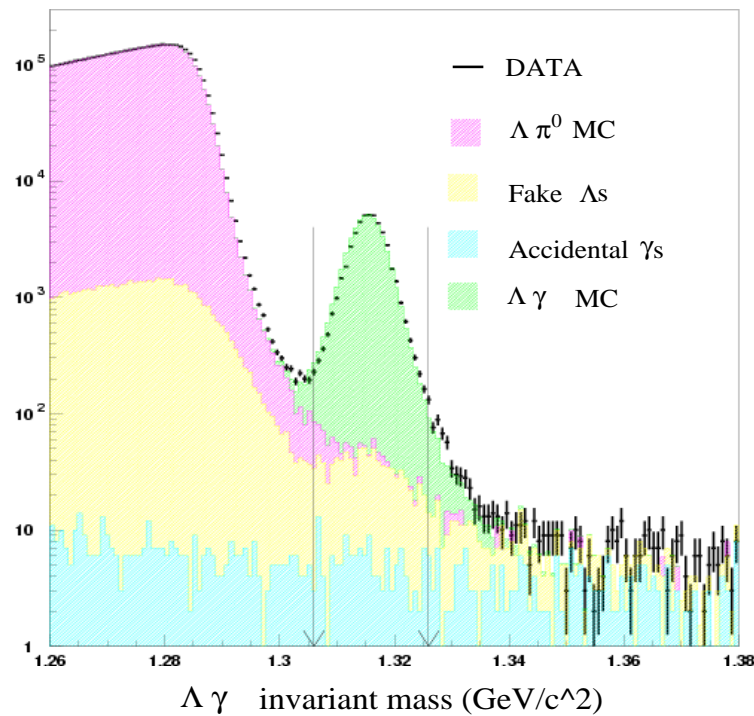
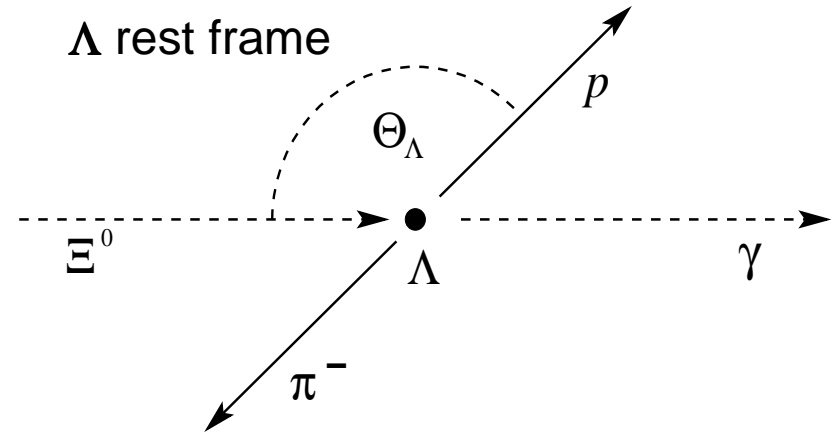
# Radiative Hyperon decays from NA48/1



- same detector as NA48/2
- neutral beam: decays mainly from  $K_S$ ,  $\Xi^0$ ,  $\Lambda$

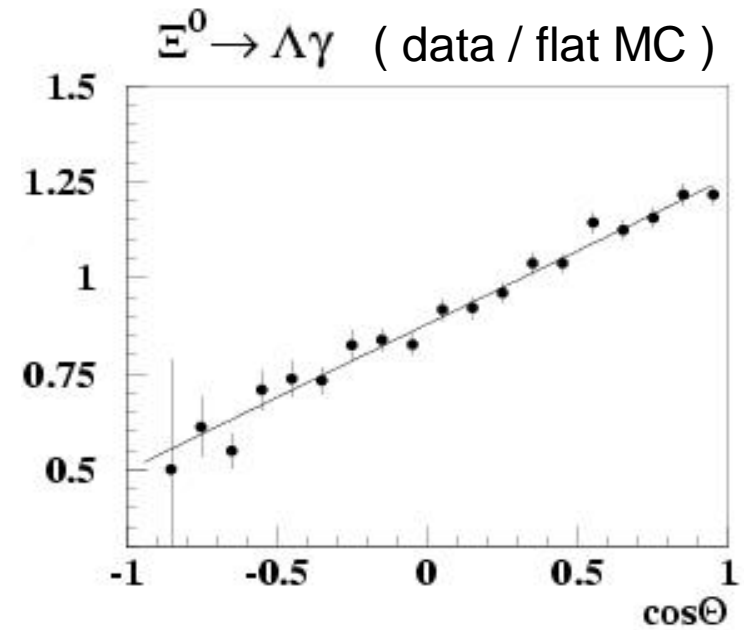
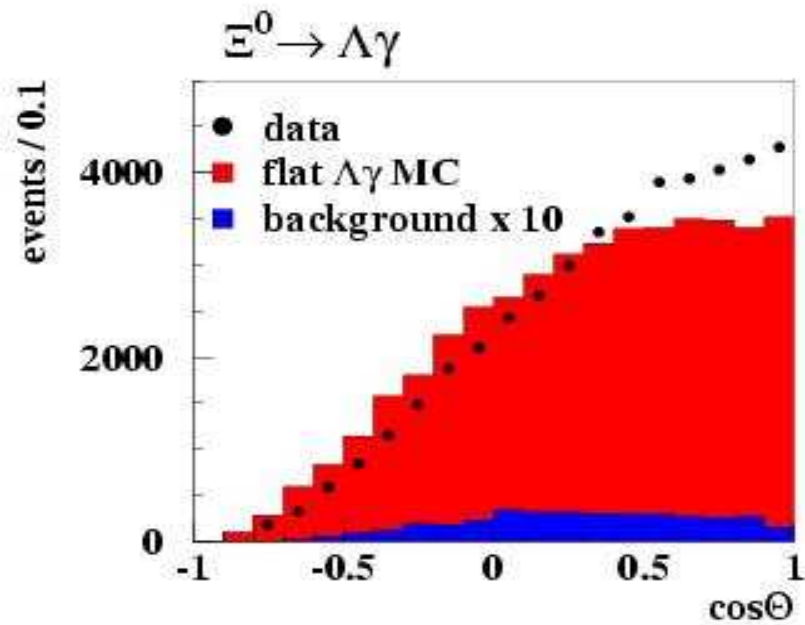
# $\Xi^0 \rightarrow \Lambda \gamma$ decay asymmetry (I)

- ❑ Use  $\Lambda \rightarrow p\pi$  decay as analyser
- ❑  $dN/d\cos\Theta_\Lambda \propto 1 - \alpha_\Lambda \alpha_\Xi \cos\Theta_\Lambda$
- ❑  $\alpha_\Lambda = 0.642 \pm 0.013$  (PDG)



- ❑ 43814  $\Xi^0 \rightarrow \Lambda \gamma$  events selected
- ❑ 0.8 % background

# $\Xi^0 \rightarrow \Lambda \gamma$ decay asymmetry (II)

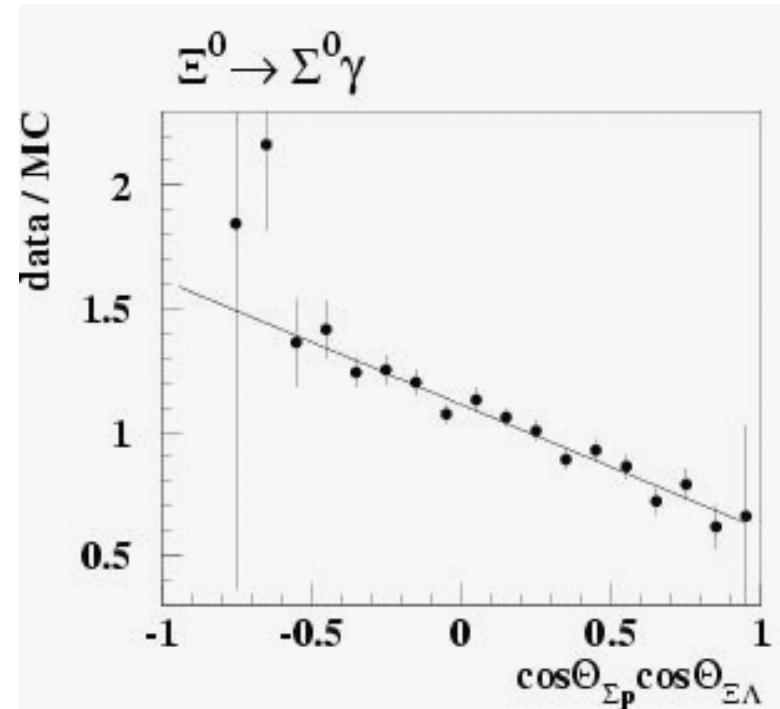
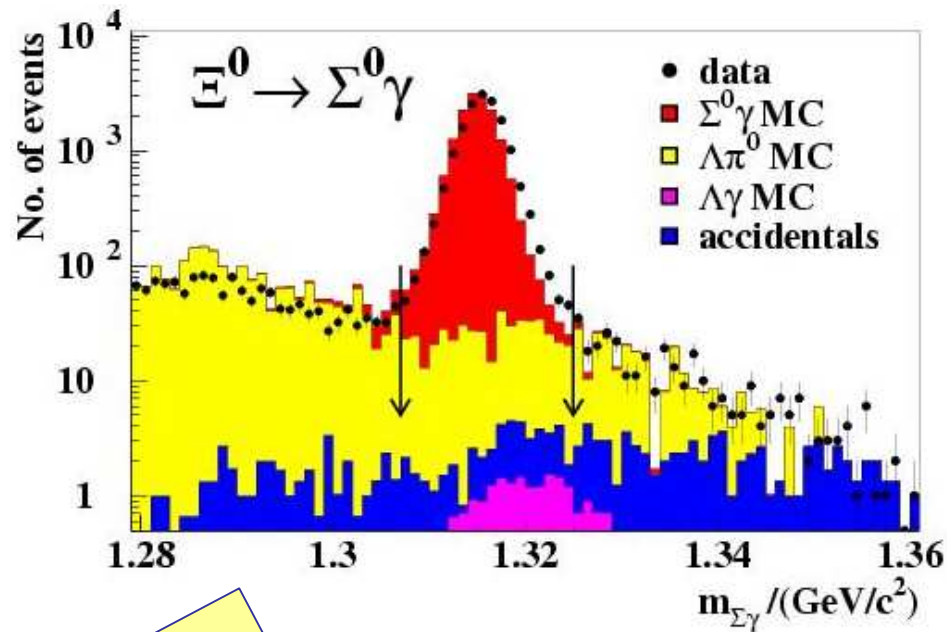


NA48/1  
Preliminary

$$\alpha(\Xi^0 \rightarrow \Lambda \gamma) = -0.68 \pm 0.02_{\text{stat}} \pm 0.06_{\text{syst}}$$

# $\Xi^0 \rightarrow \Sigma^0 \gamma$ decay asymmetry

- Same method as for  $\Xi^0 \rightarrow \Lambda \gamma$ , with one additional decay  $\Sigma^0 \rightarrow \Lambda \gamma$
- 13068  $\Xi^0 \rightarrow \Sigma^0 \gamma$  events selected**
- $\approx 3\%$  background**



NA48/1  
Preliminary

$$\alpha(\Xi^0 \rightarrow \Sigma^0 \gamma) = -0.68 \pm 0.03_{\text{stat}} \pm 0.07_{\text{syst}}$$

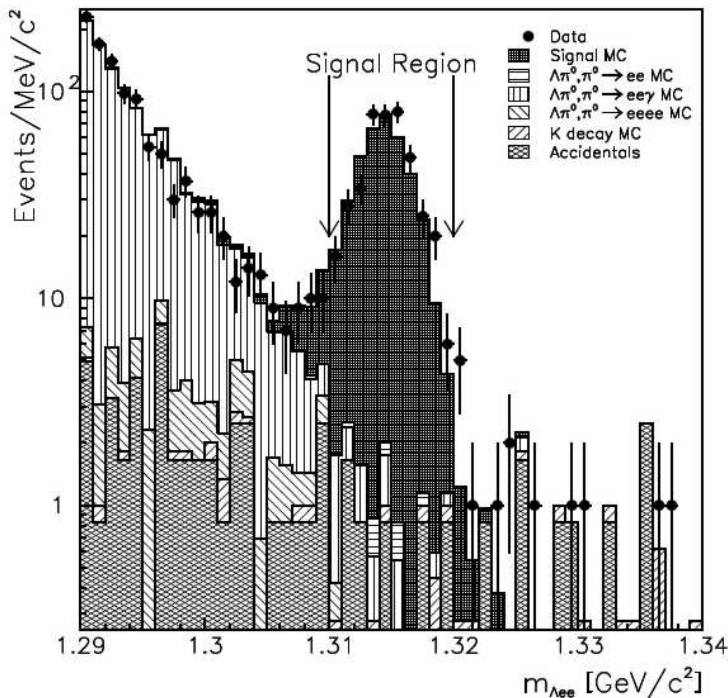
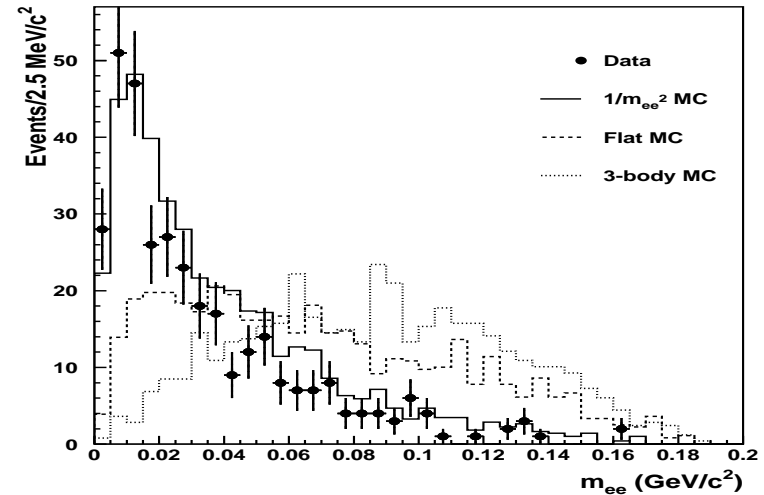
# $\Xi^0 \rightarrow \Lambda^0 e^+ e^-$ first observation

Naïve estimation of the BR:

$$\text{BR}(\Xi^0 \rightarrow \Lambda e^+ e^-) = \text{BR}(\Xi^0 \rightarrow \Lambda \gamma) \cdot \alpha \sim 8.8 \cdot 10^{-6}$$

Theor. expectation (QED based, Bernstein 65):

$$\text{BR}(\Xi^0 \rightarrow \Lambda e^+ e^-) = (6.4 - 7.3) \cdot 10^{-6}$$



**Event sample:**

**412 candidates events with**

$7 \pm 5$  accidental background

$8 \pm 3$  physical background

**Normalization channel:**

$\Xi \rightarrow \Lambda \pi^0$ : 30K events

$$\text{BR}(\Xi \rightarrow \Lambda ee) = (7.7 \pm 0.4_{\text{stat}} \pm 0.4_{\text{syst}}) \cdot 10^{-6}$$

$$\alpha(\Xi \rightarrow \Lambda ee) = -0.8 \pm 0.2$$

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# Conclusion

- **NA48/2** recent results in charged radiative Kaon decays
  - first evidence of non-zero **INT** term in  $\mathbf{K}^{\pm} \rightarrow \pi^{\pm} \pi^0 \gamma$
  - first observation and BR measurement of  $\mathbf{K}^{\pm} \rightarrow \pi^{\pm} \mathbf{e}^+ \mathbf{e}^- \gamma$
- **NA48/1** recent results in radiative hyperon decays
  - new measurement of  $\Xi^0 \rightarrow \Lambda \gamma$  and  $\Xi^0 \rightarrow \Sigma^0 \gamma$  decay asymmetries
  - first observation of the  $\Xi^0 \rightarrow \Lambda \mathbf{e}^+ \mathbf{e}^-$  decay, measurement of BR and decay asymmetry