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**

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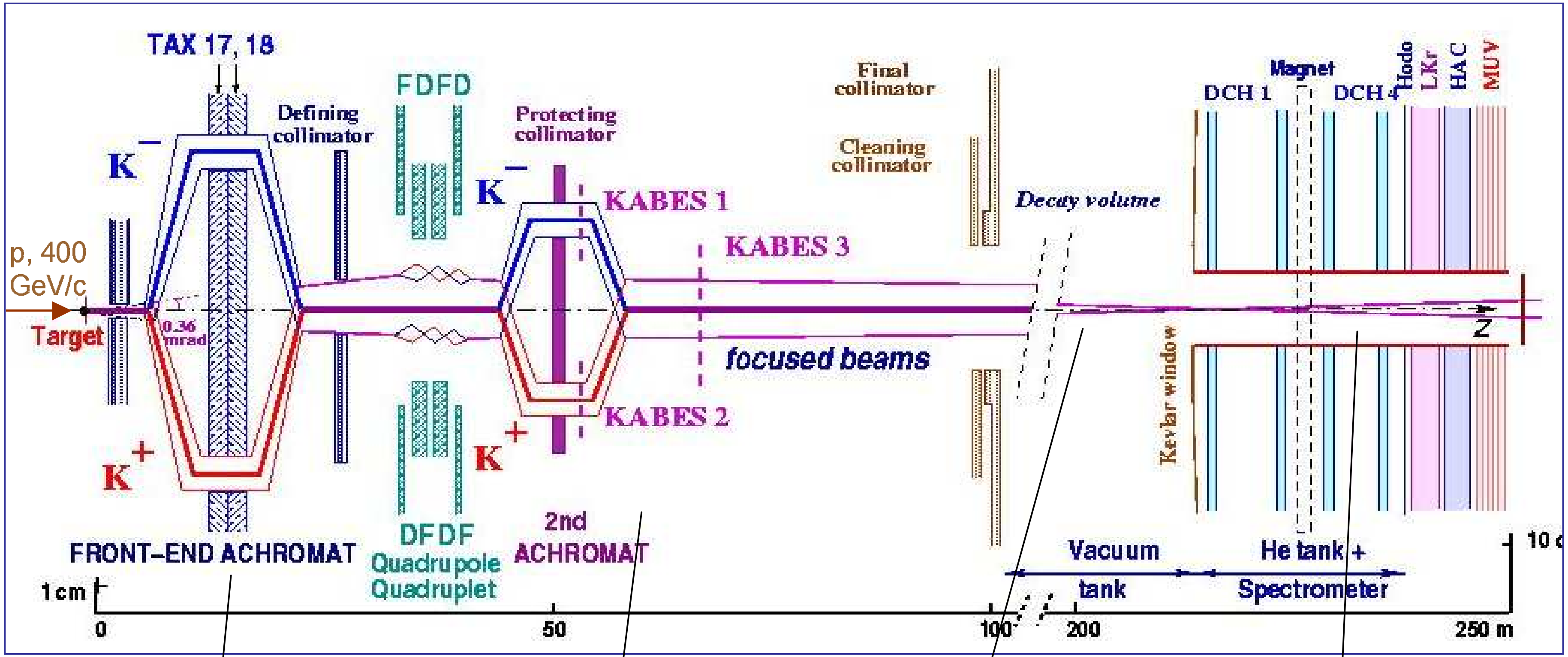
Julich, Germany, september 10-14, 2007

Outline

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

The NA48/2 beam line



Beam Spectrometer
(resolution 0.7 %)

Pion decay products are confined in the beam pipe

- Split +/-
- Select P=(60±3)GeV/c
- Recombine +/-

Decay volume (114m)

The NA48 detector

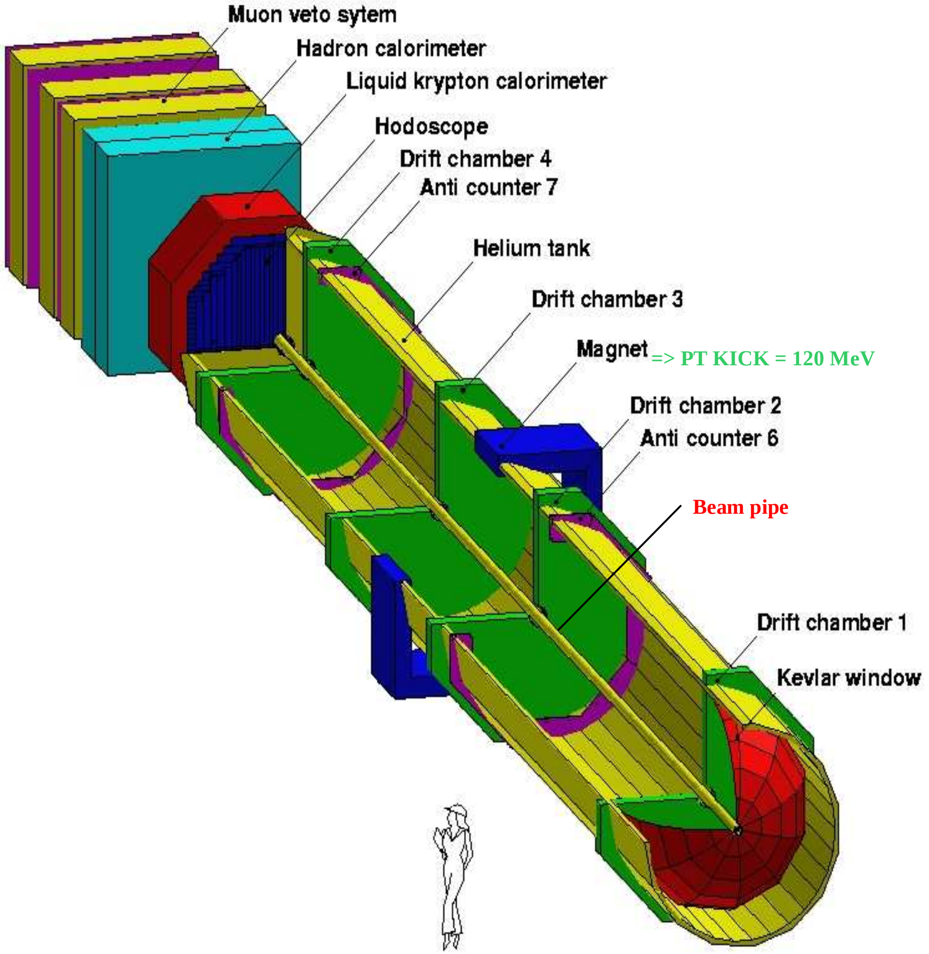
- Magnetic spectrometer (4 DCHs):
  $\Delta p/p = 1.0\% + 0.044\% * p$ [GeV/c]
  $\sigma[M(\pi^+\pi^-\pi^\pm)] \sim 1.7$ Mev/c^2

- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogeneous;
  $\Delta E/E = 3.2\%/\sqrt{E[\mathrm{GeV}]} + 9\%/E[\mathrm{GeV}] + 0.42\%$
  $\sigma_x, \sigma_y \sim 1.5$ mm
  $\sigma[M(\pi^0\pi^0\pi^\pm)] \sim 1.4$ Mev/c^2

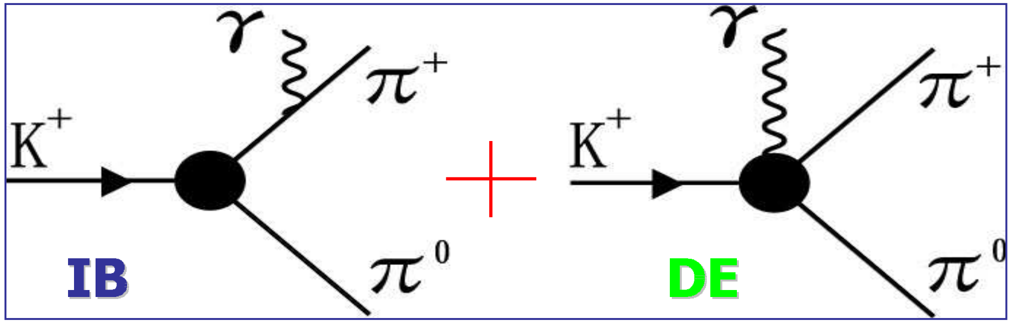
- Scintillators hodoscope (2 planes):
  fast trigger;
  precise time measurement (150ps)

- 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^*_π and **W**) that can be reduced to only one integrating over T^*_π (kinetic energy of $\pi^\pm$ in the kaon rest frame)

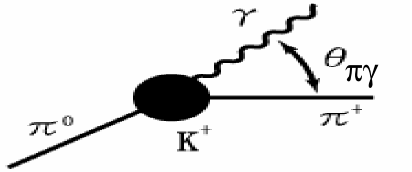
$$\frac{d\Gamma^\pm}{dW} \simeq \left(\frac{d\Gamma^\pm}{dW}\right)_{IB}\left[\underbrace{1}_{\textbf{IB}} + \underbrace{2\left(\frac{m_\pi}{m_K}\right)^2 \underline{W^2}|E|cos((\delta_1-\delta_0)\pm\phi)}_{\textbf{INT}} + \underbrace{\left(\frac{m_\pi}{m_K}\right)^4 \underline{W^4}(|E|^2+|M|^2)}_{\textbf{DE}}\right]$$

Sensitive variable:

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

P_K = 4-momentum of the $K^\pm$
P_π = 4-momentum of the $\pi^\pm$
P_γ = 4-momentum of the γ

$$W^2 = \frac{(E^*_\gamma)^2(E^*_\pi - P^*_\pi \cos\theta_{\pi\gamma})}{m_K m_\pi^2}$$



$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$: 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)

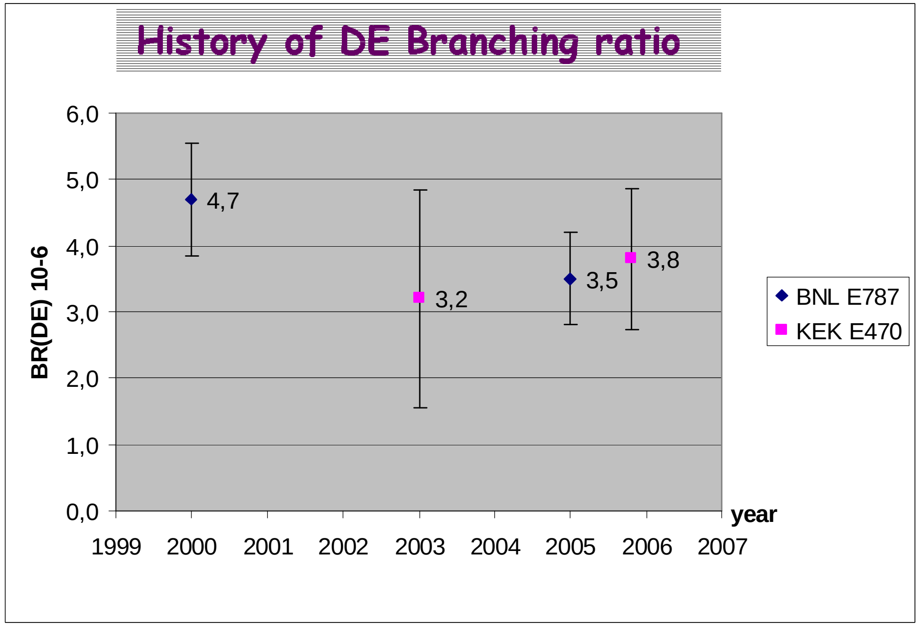
Inner Bremsstrahlung(IB) : BR = $(2.75\pm0.15)\cdot10^{-4}$ $(55<T^*_{\pi}<90$ MeV)

Direct Emission (DE) : BR = $(4.4\pm0.7)\cdot10^{-6}$ $(55<T^*_{\pi}<90$ 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) × 10^6**
E787 [20]	2000	19836	4.7 ± 0.8 ± 0.3
E470 [21]	2003	4434	3.2 ± 1.3 ± 1.0
E787 [22]	2005	20571	$3.5 \pm 0.6^{+0.3}_{-0.4}$
E470 [23]	2005	10154	3.8 ± 0.8 ± 0.7



All the measurements have been performed:

- ✓in the T^{*}_{π} region **55-90 MeV** to avoid $\pi^{\pm}\pi^{0}$ and $\pi^{\pm}\pi^{0}\pi^{0}$ background
- ✓assuming INT = 0

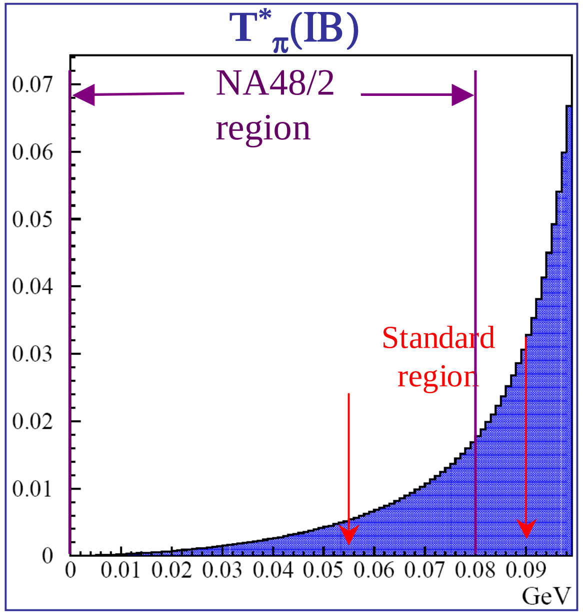
Interference estimations*:

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

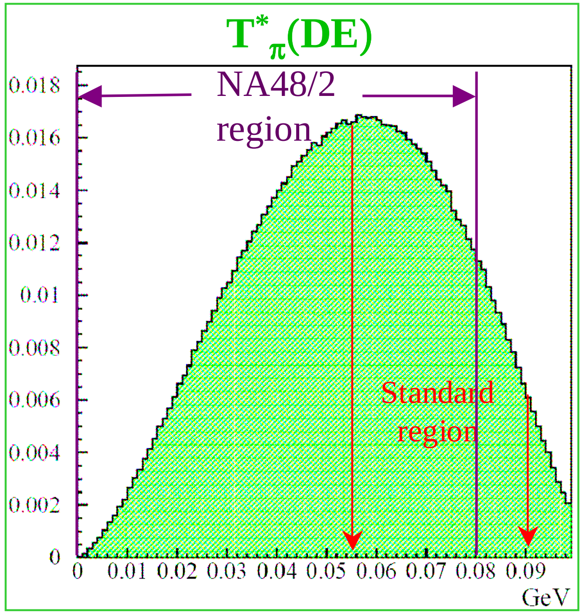
$\mathrm{INT}=(-0.4 \pm 1.6)\%$ of IB **KEK E470**

*not quoted as measurements by authors

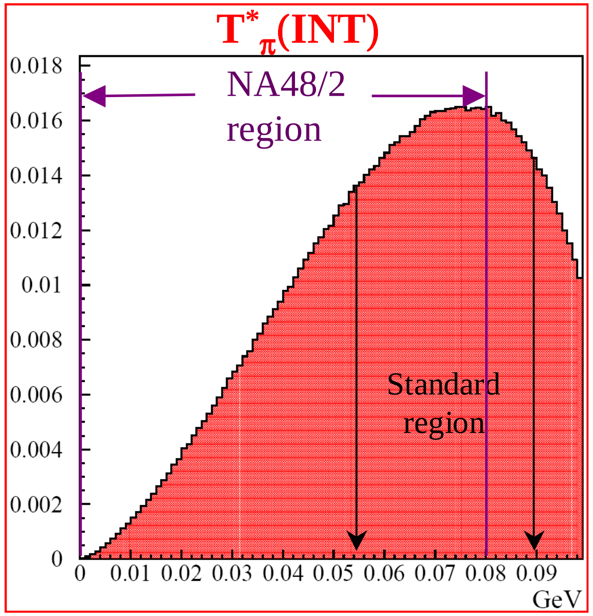
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$: enlarged T^{*}_{π} region



T^{*}_{π}(IB)



T^{*}_{π}(DE)



T^{*}_{π}(INT)

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**

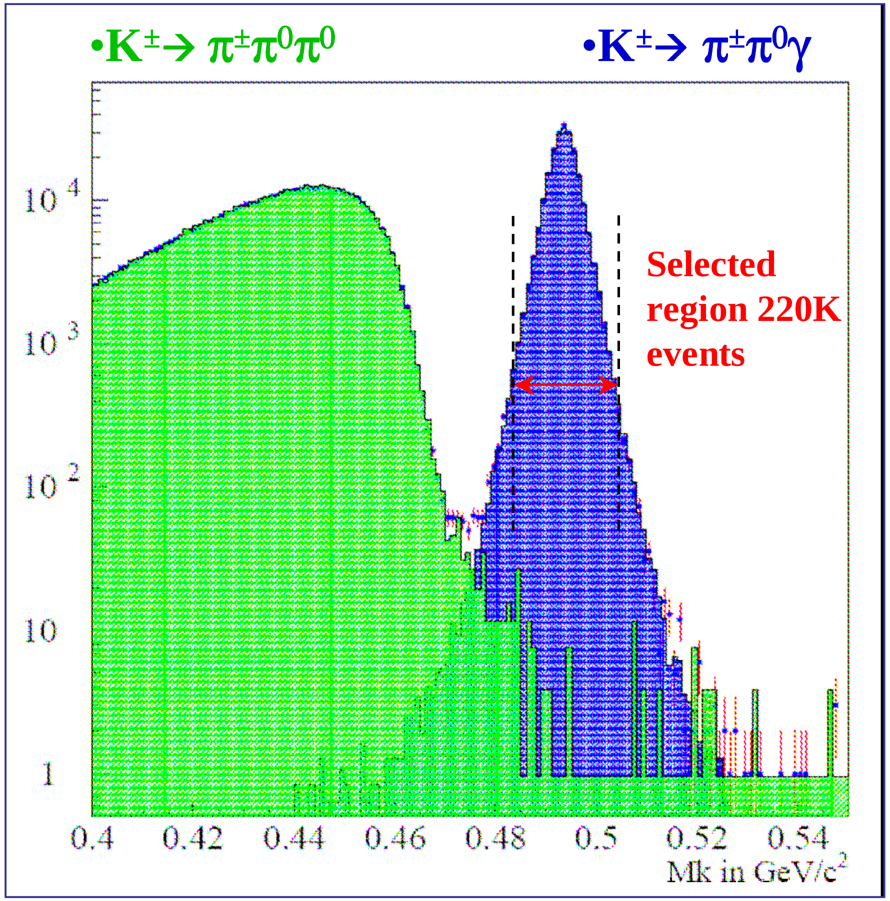
This measurement is performed in the region

$0 < T^{*}_{\pi} < 80$ MeV

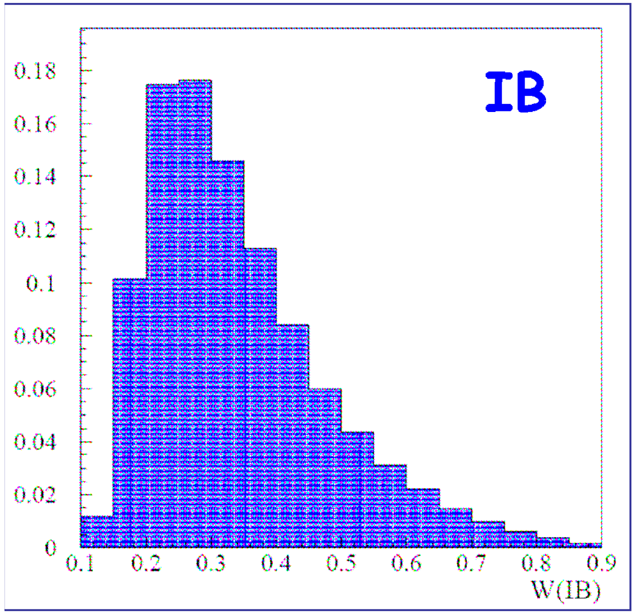
to improve statistics and sensitivity to **DE**

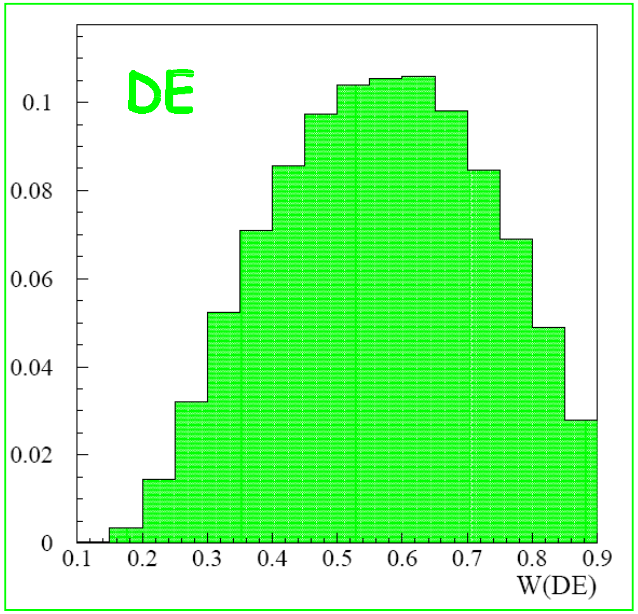
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$: the selected data sample

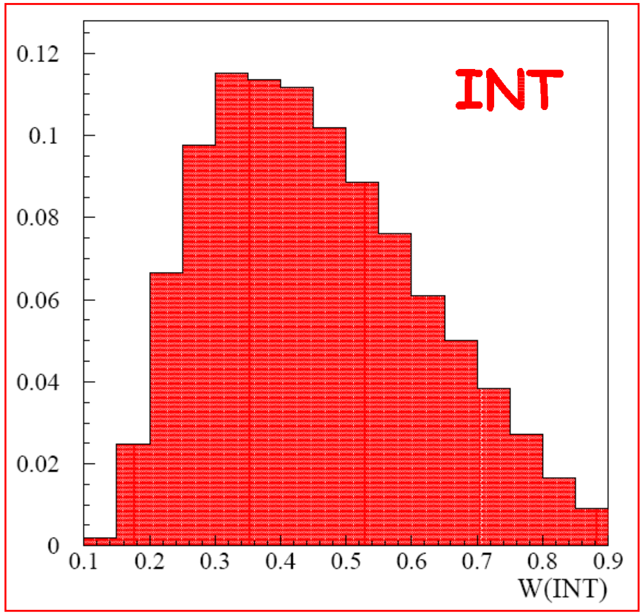
- Event selection
  - requirements on tracks
  - requirements on LKR clusters
  - effort into photons pairing
  - requirements on the event closure
- All **physical BG** can be explained in terms of $\pi^{\pm}\pi^{0}\pi^{0}$ events only
- Very small contribution from accidentals is neglected
- γ mistagging probability (self background) is order of ‰



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



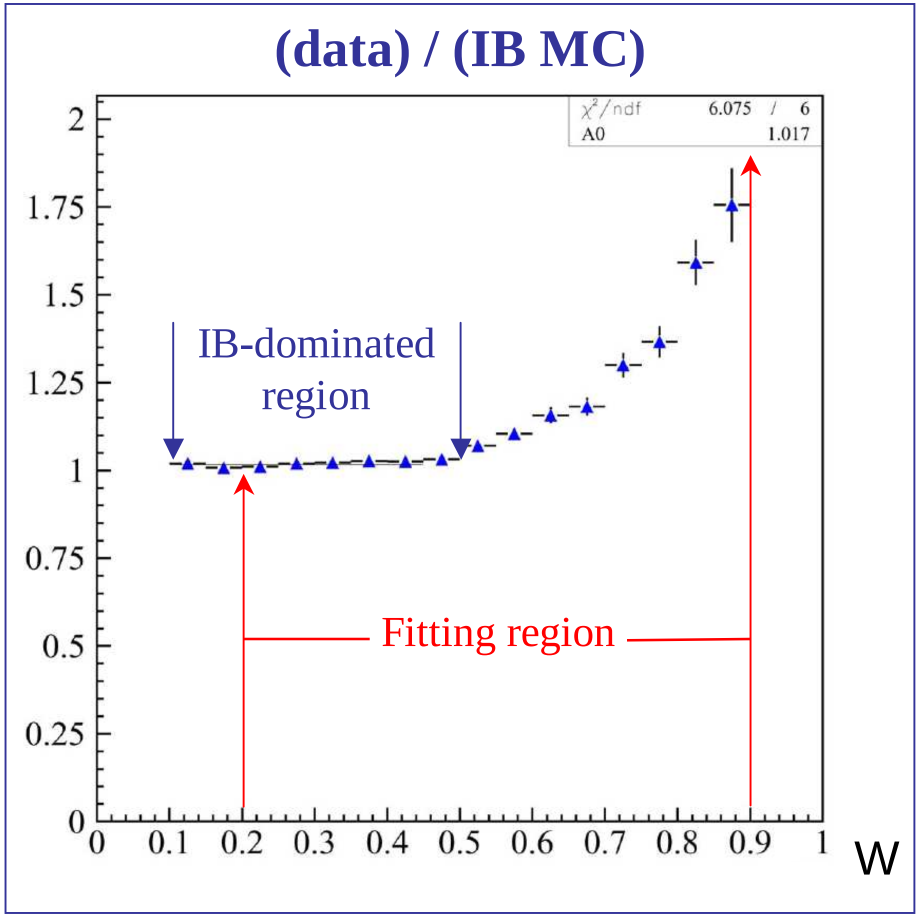




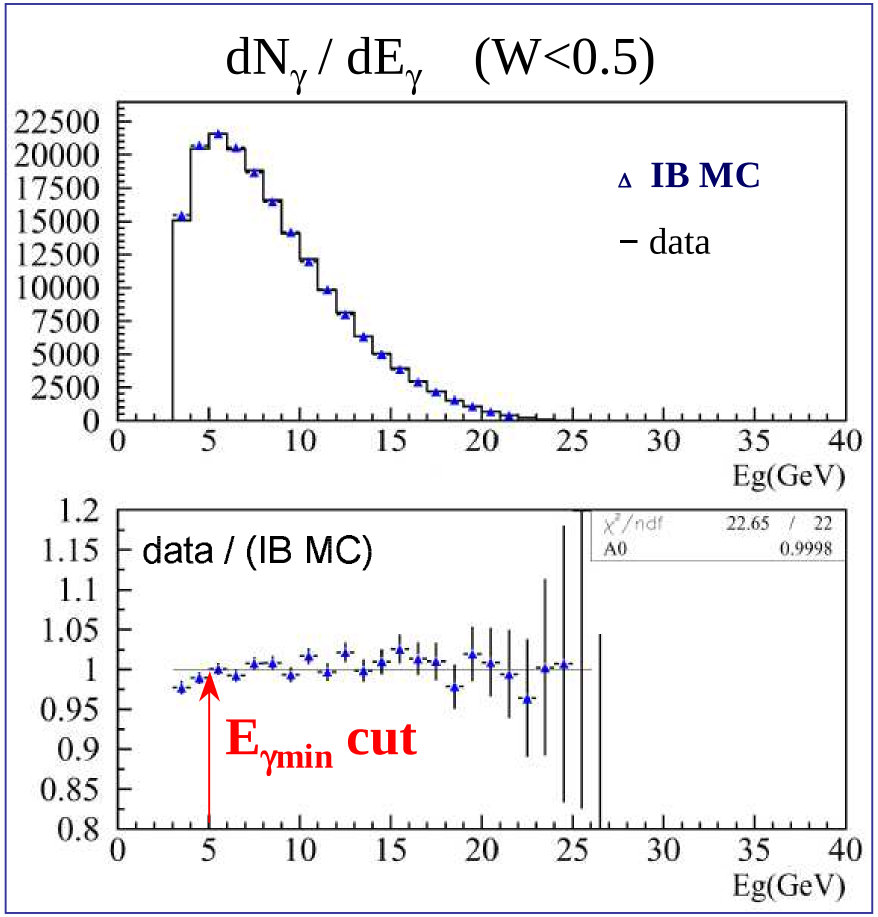
- 3 MC data samples for the 3 contributions to the decay

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

IB-MC normalized W spectrum



Radiated γ energy spectrum



- IB contribution is very well reproduced by MC

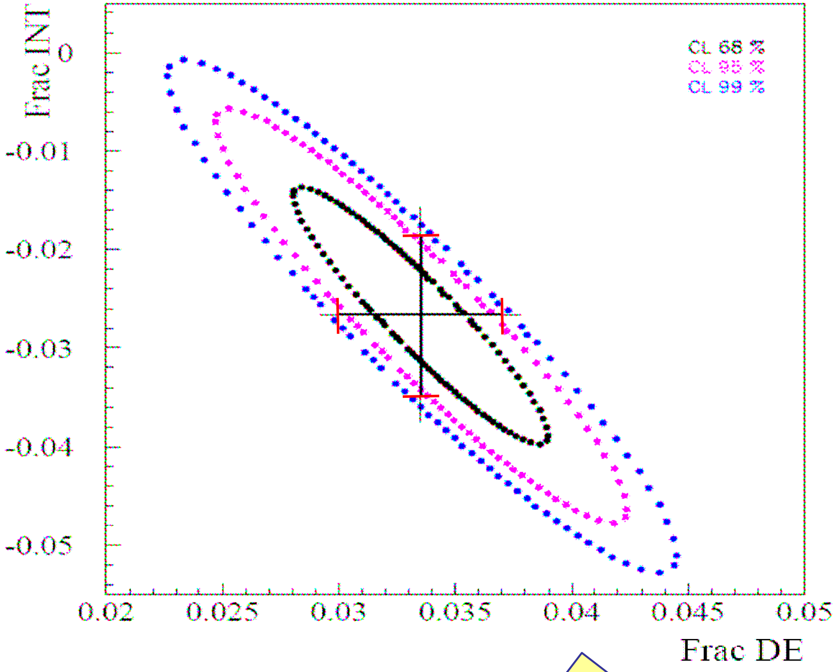
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$: fit results (2003 data)

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

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

- systematic dominated by trigger efficiency
- parameters are highly correlated

correlation coefficient: **ρ = -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)

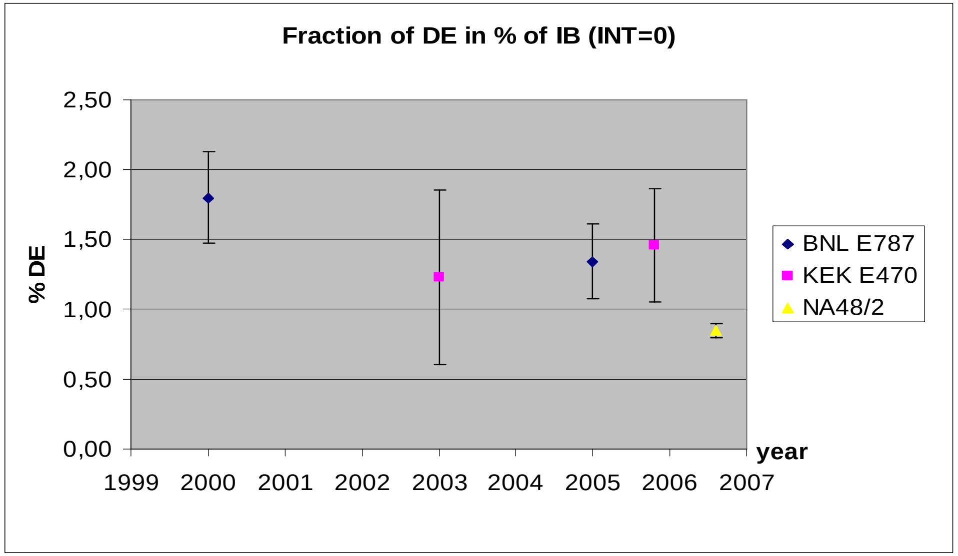
2004 data set: higher (x4) statistics and lower systematic due to trigger

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$: 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

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



Consistent, although the analysis of fit's residuals shows a bad χ^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)

$K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma$: first observation

Naïve estimation of the BR:
$BR(K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma) = BR(K^{\pm}\text{->}\pi^{\pm}\gamma\gamma)\cdot 2\alpha \sim 1.6\cdot 10^{-8}$

Theoretical expectation (χPt based, Gabbiani 99):
$BR(K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma) = (\ 0.9 - 1.6\ )\cdot 10^{-8}$

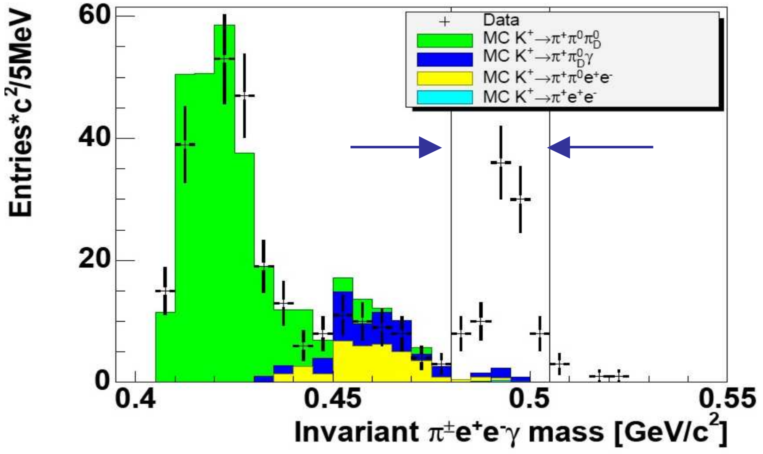
Event sample:

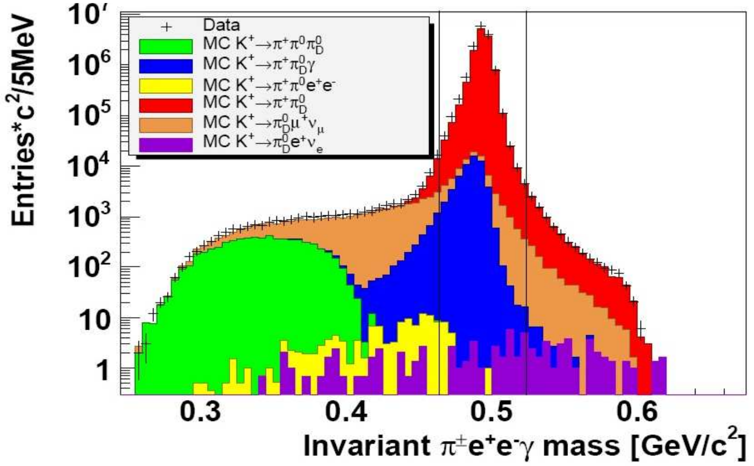
92 candidate events with

1 ±1 accidental background
5.1±1.7 physical background

Normalization channel:

$K^{\pm}\text{->}\pi^{\pm}\pi^{0}_{D}$: **14M events**

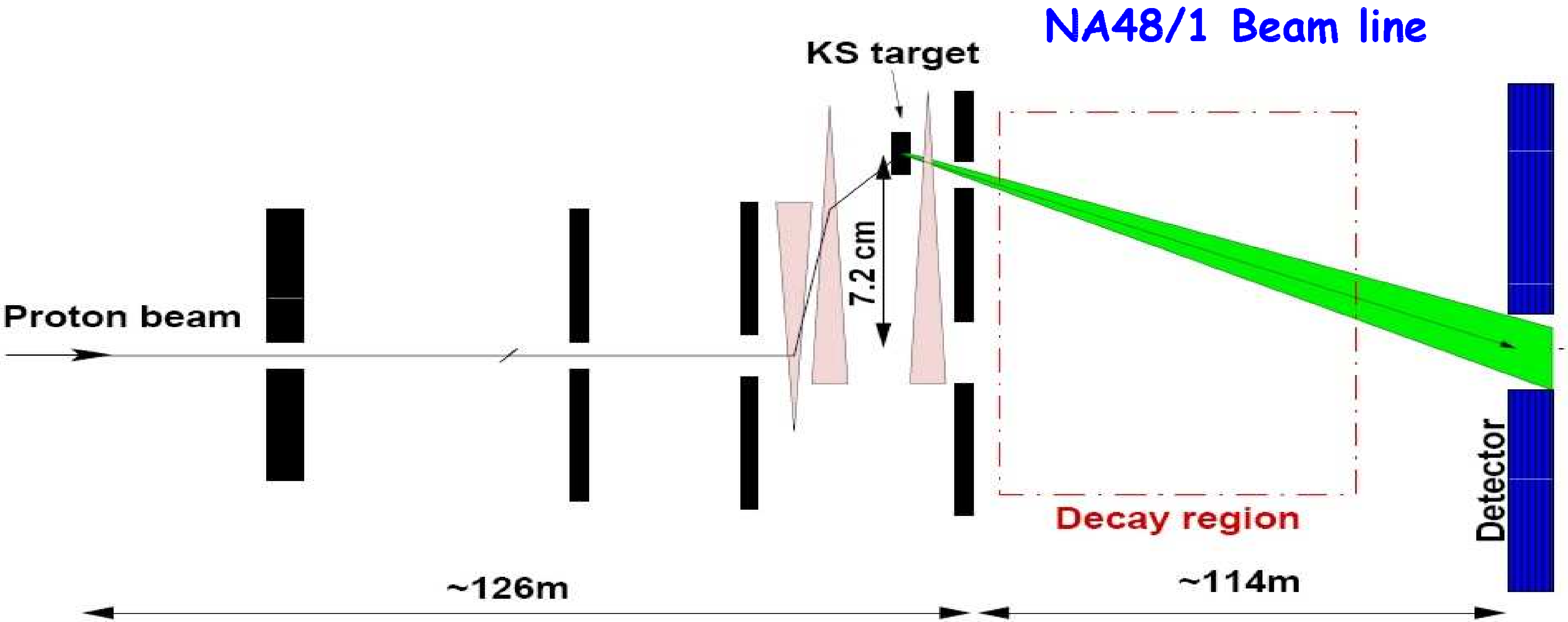




NA48/2
Preliminary

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

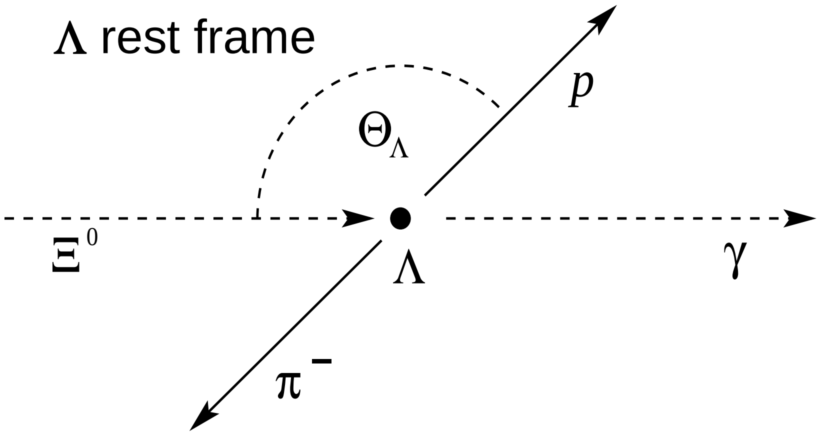
Radiative Hyperon decays from NA48/1

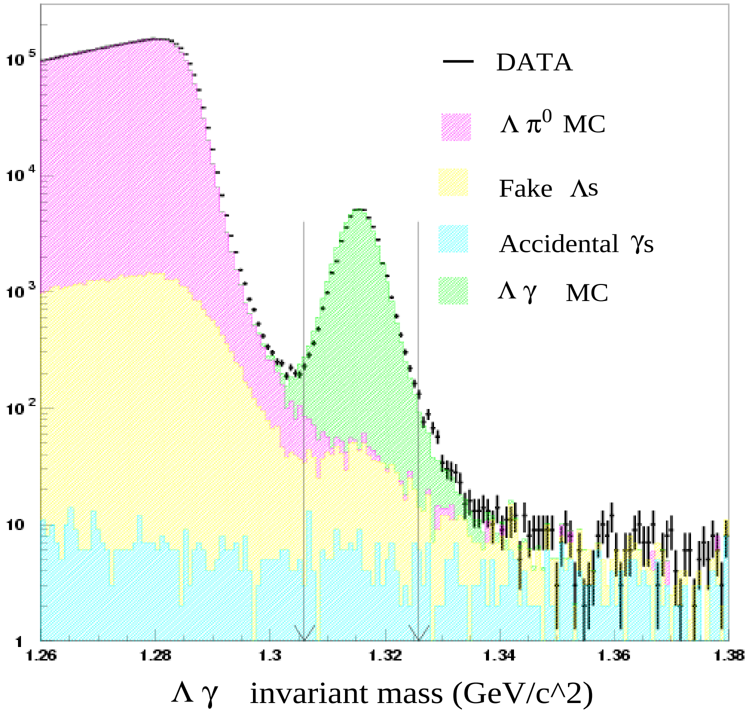


- same detector as NA48/2
- neutral beam: decays mainly from K_s, Ξ^0, Λ

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

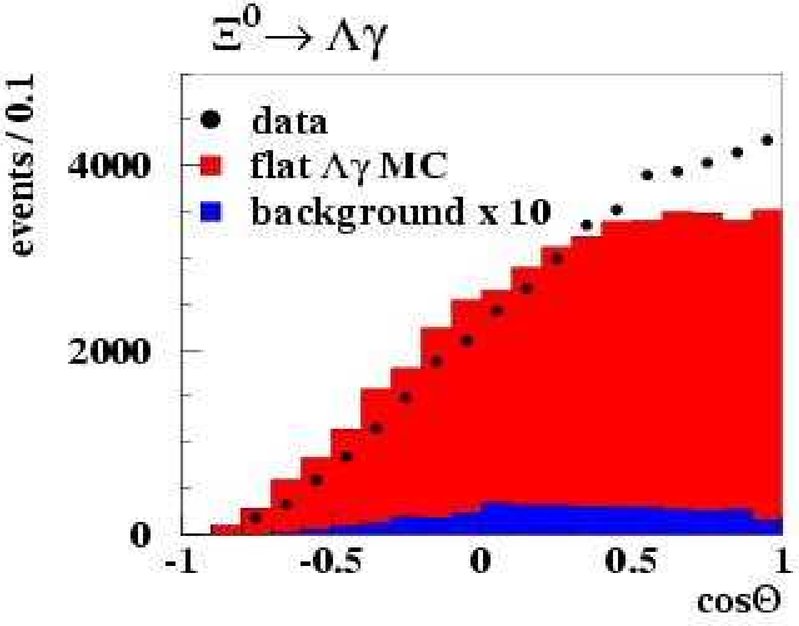
- **Use $\Lambda \rightarrow p\pi^-$ decay as analyser**
- **$dN/d\cos\Theta_\Lambda \propto 1 - \alpha_\Lambda \alpha_\Xi \cos\Theta_\Lambda$**
- **$\alpha_\Lambda = 0.642 \pm 0.013$ (PDG)**

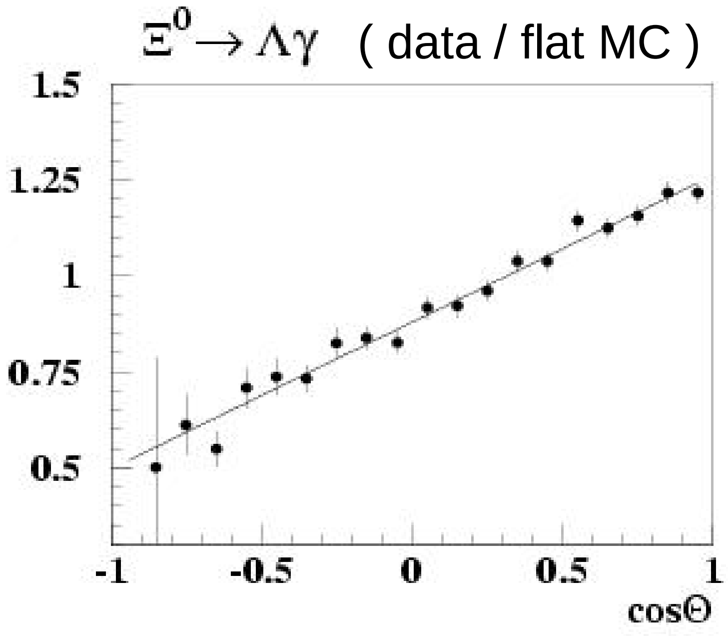




- **43814 $\Xi^0 \rightarrow \Lambda\,\gamma$ events selected**
- **0.8 % background**

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



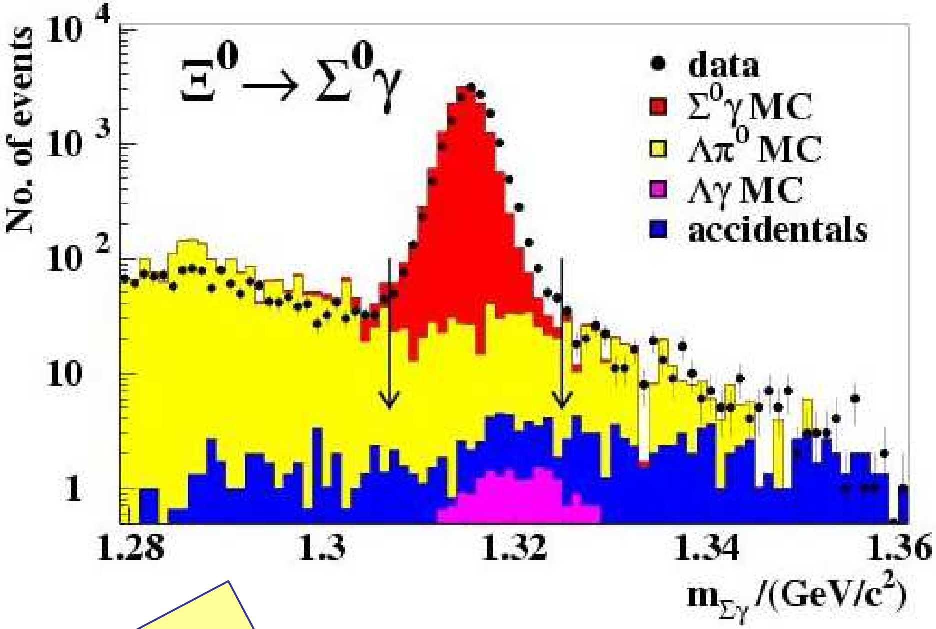


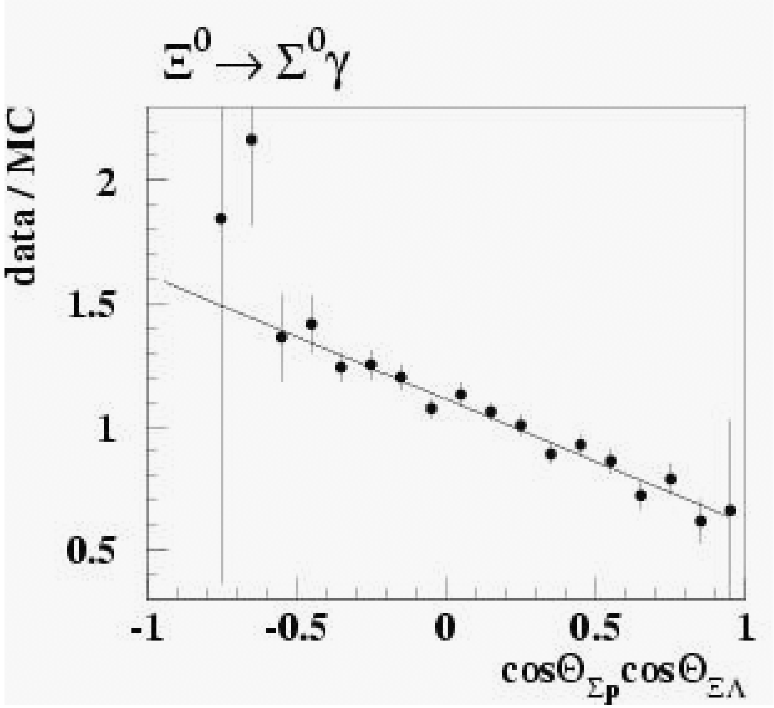
NA48/1
Preliminary

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

$\Xi^0 \rightarrow \Sigma^0 \gamma$ 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**
- ☐ **≈ 3% background**

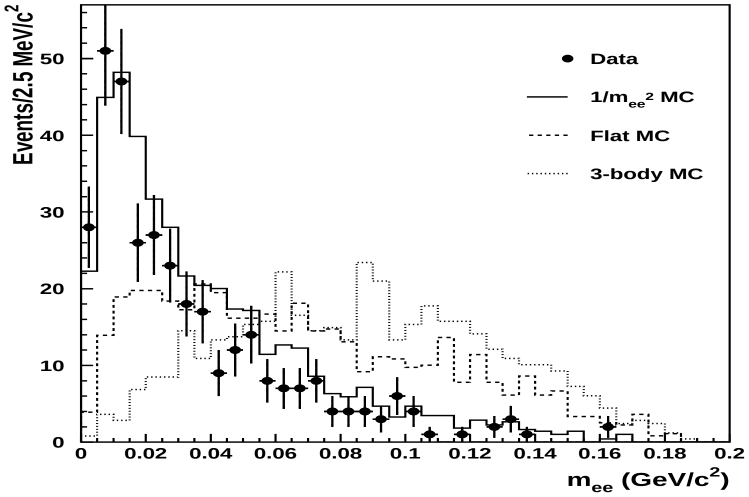




NA48/1 Preliminary

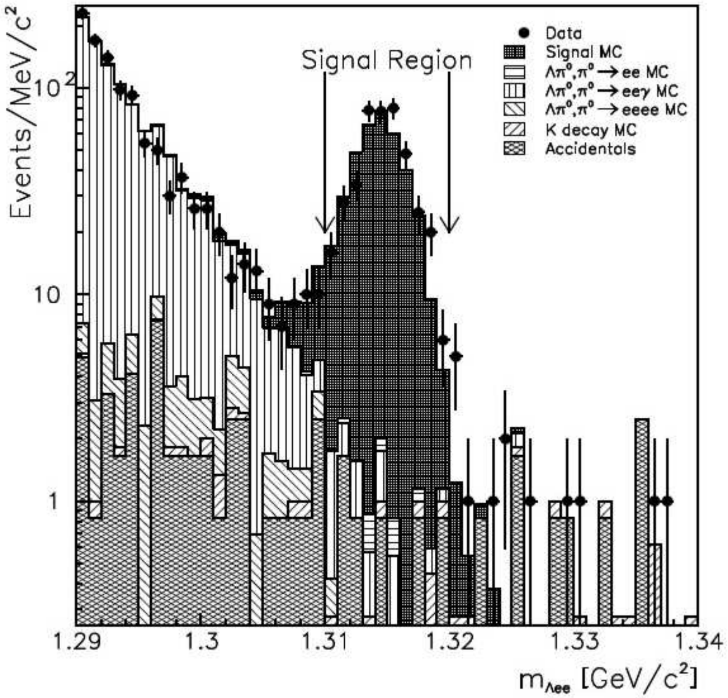
$$\alpha(\Xi^0 \rightarrow \Sigma^0 \gamma) = -0.68 \pm 0.03_{stat} \pm 0.07_{syst}$$

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



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

Theor. expectation (QED based, Bernstein 65):
$BR(\Xi^0 \rightarrow \Lambda e{+}e^-) = (\ 6.4 - 7.3\ ) \cdot 10^{-6}$



Event sample:

412 candidates events with

7±5 accidental background

8±3 physical background

Normalization channel:

$\Xi \text{->} \Lambda\pi^0_D$: **30K events**

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

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

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Conclusion

- **NA48/2** recent results in charged radiative Kaon decays
  - first evidence of non-zero **INT** term in $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\gamma$
  - first observation and BR measurement of $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma$

- **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 $\Xi^{0}\rightarrow\Lambda e^{+}e^{-}$ decay, measurement of BR and decay asymmetry