Rare kaon and hyperon decays in NA48 experiment

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on behalf of the NA48/2 Collaboration

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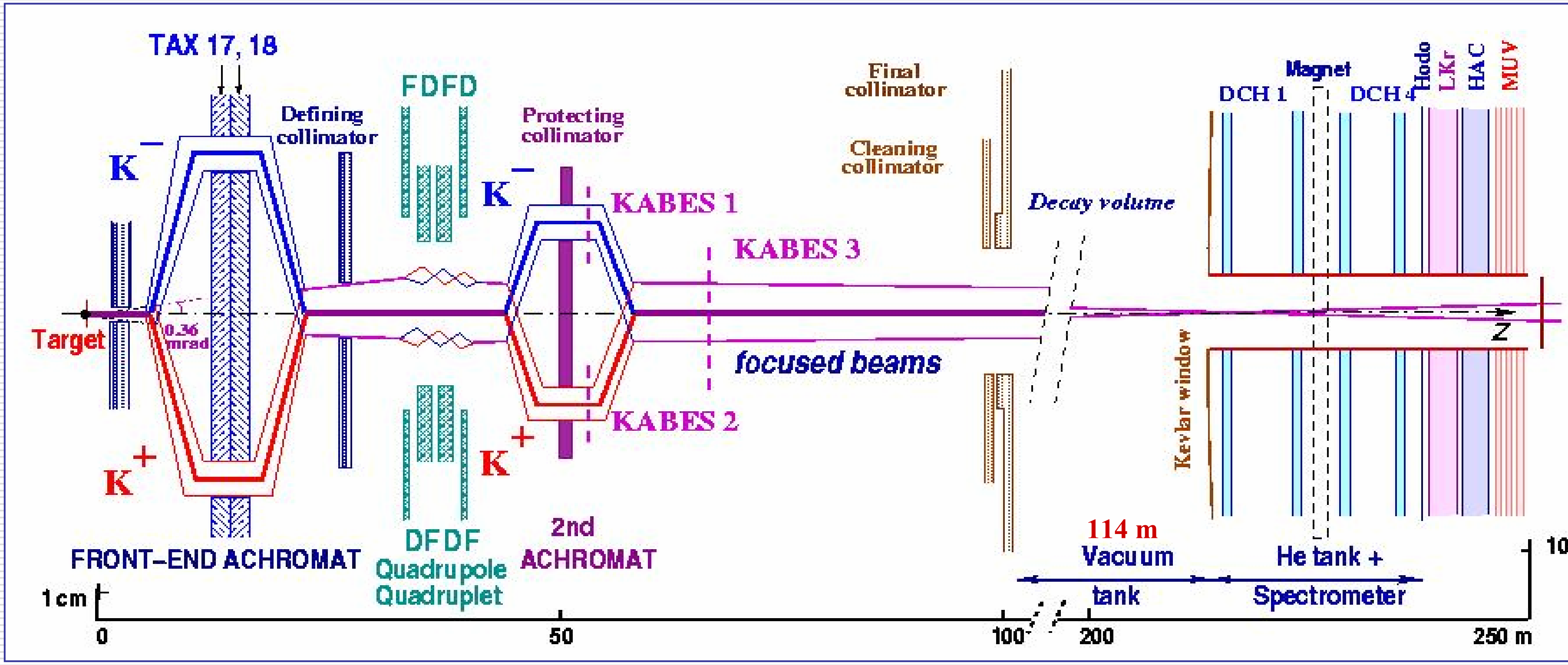
13th Lomonosov Conference on Elementary Particle Physics
Moscow, Russia, August 23-29, 2007

Outline

- $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$ 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
- $\Xi^{0}\rightarrow\Lambda^{0}e^{+}e^{-}$ decay
  - NA48/1 measurement

The NA48/2 beam line



- ✓Primary proton beam ➔ p = 400 GeV/c (7×10^{11} ppp)
- ✓Simultaneous K^+/K^- beams ➔ p = (60 ± 3) GeV/c
- ✓K^+/K^- beam flux ➔ 3.8 (2.6) Ø 10^7 ppp

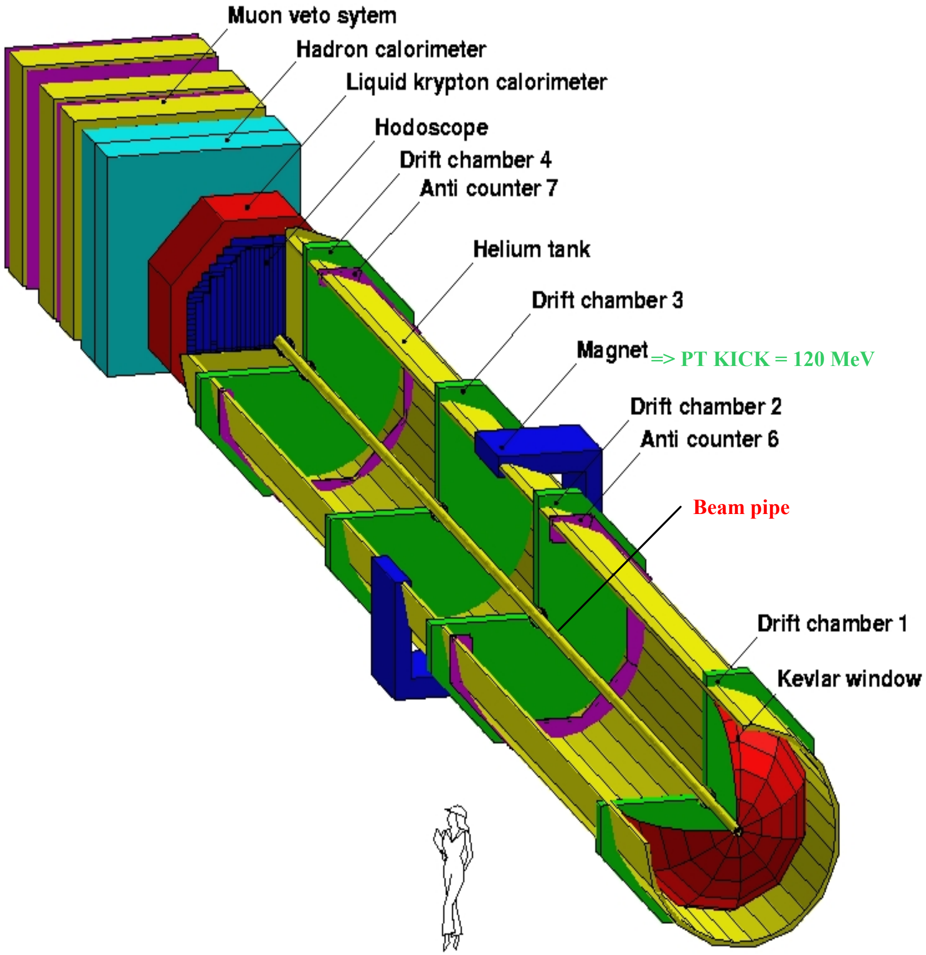
The NA48 detector

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

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

- Hodoscope
  fast trigger;
  precise time measurement (150ps).

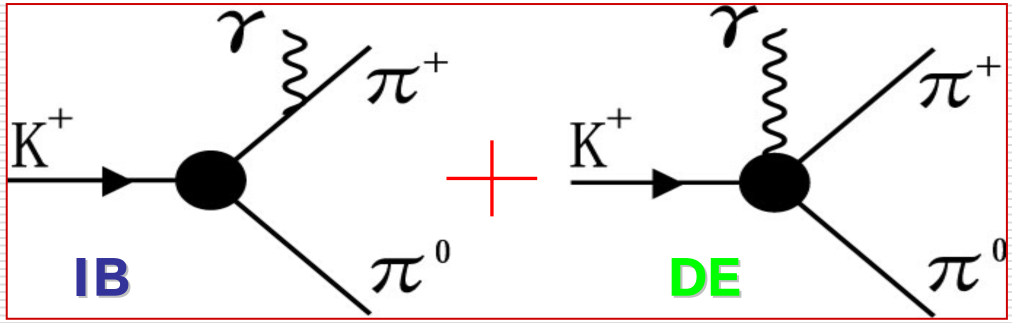
- Hadron calorimeter, muon veto counters, photon vetoes.



LV1 trigger: hodoscope and DCH multiplicity
LV2 trigger: on-line data processing

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

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Decay formalism.



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

IB **INT** **DE**

$\Gamma^{\pm}$ depends on 2 variables (T^*_π and ***W***) that can be reduced to only one integrating over T^*_π

IB, **DE** and **INT** components can be separated kinematically using the Lorentz invariant variable ***W*** which is defined as follows:

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

P^*_K = 4-momentum of the $K^{\pm}$
P^*_π = 4-momentum of the $\pi^{\pm}$
P^*_γ = 4-momentum of the γ

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Amplitudes.

Two types of contributions:

Electric (J=l±1) dipole (E)

Magnetic (J=l) dipole (M)

Electric contributions are dominated by the Inner Bremsstrahlung term

DE shows up only at order $O(p^4)$ in CHPT: is generated by both E and M contributions

INT term is sensitive to E only

Inner Bremsstrahlung(IB) : $(2.75 \pm 0.15)\cdot 10^{-4}$ PDG (2006) ($55 < T^{*}_{\pi} < 90$ MeV)

Direct Emission (DE) : $(4.4 \pm 0.7)\cdot 10^{-6}$ PDG (2006) ($55 < T^{*}_{\pi} < 90$ MeV)

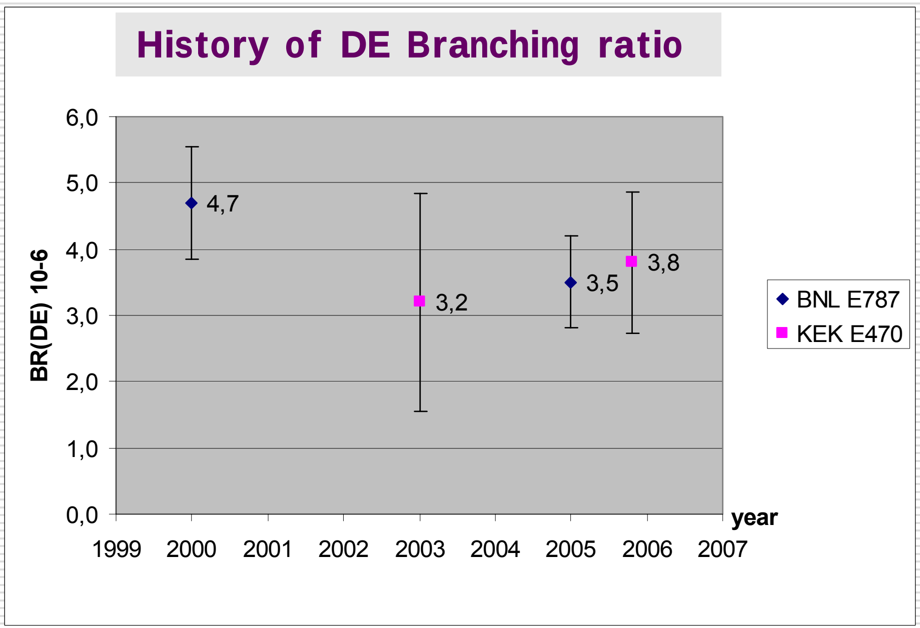
Interference (INT) : not yet measured

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Exp results for DE and INT.

Experiment	Year	# Events	BR(DE) × 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^*_{π} region **55-90 MeV** to avoid $\pi^{\pm}\pi^{0}$ and $\pi^{\pm}\pi^{0}\pi^{0}$ background
- ✓assuming INT = 0



Interference estimations*:

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

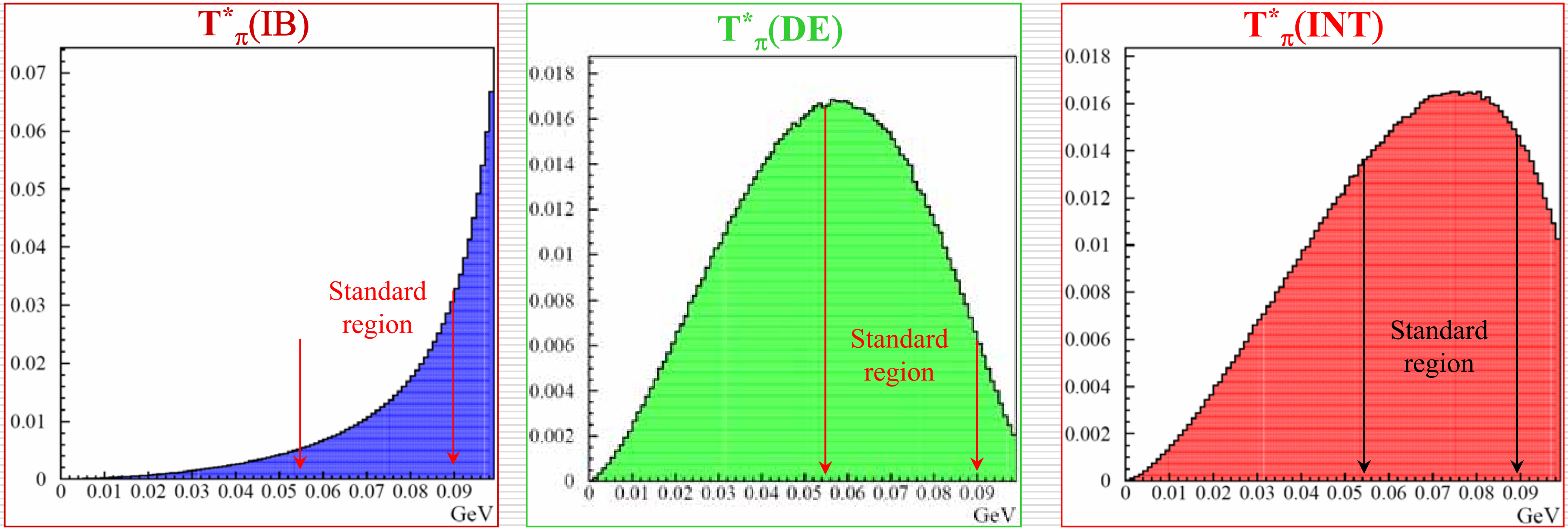
$$\mathrm{INT} = (-0.4 \pm 1.6)\%\ \text{of IB}$$ **KEK E470**

*not quoted as measurements by authors

What's new in NA48/2 measurement

- In flight Kaon decays
- Both K^+ and K^- in the beam (possibility to check CP violation)
- Very high statistics (220k $\pi^{\pm}\pi^{0}\gamma$ candidates, 124k used in the fit)
- Enlarged T^*_{π} region in the low energy part (**0 <T^*_{π}< 80 MeV**)
- **Negligible background** contribution **< 1%** of the **DE** component
- Good **W resolution** mainly in the high statistic region
- More bins in the fit to enhance sensitivity to **INT**
- **Order ‰ γ mistagging probability** for **IB**, **DE** and **INT**
- Fit with free interference term

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Enlarged T^*_π region.



Use standard region **55<T^*_π<90 MeV** as 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^*_π < 80 MeV

to improve statistics and sensitivity to **DE**

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. The selected data sample.

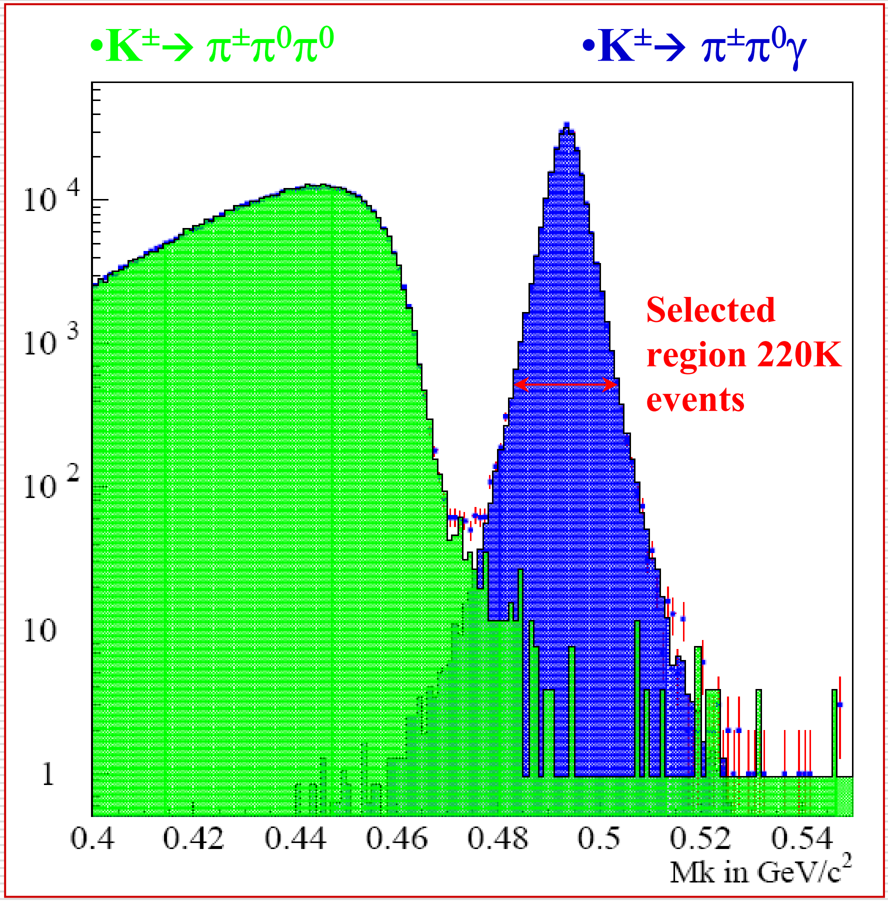
➢Event selection

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

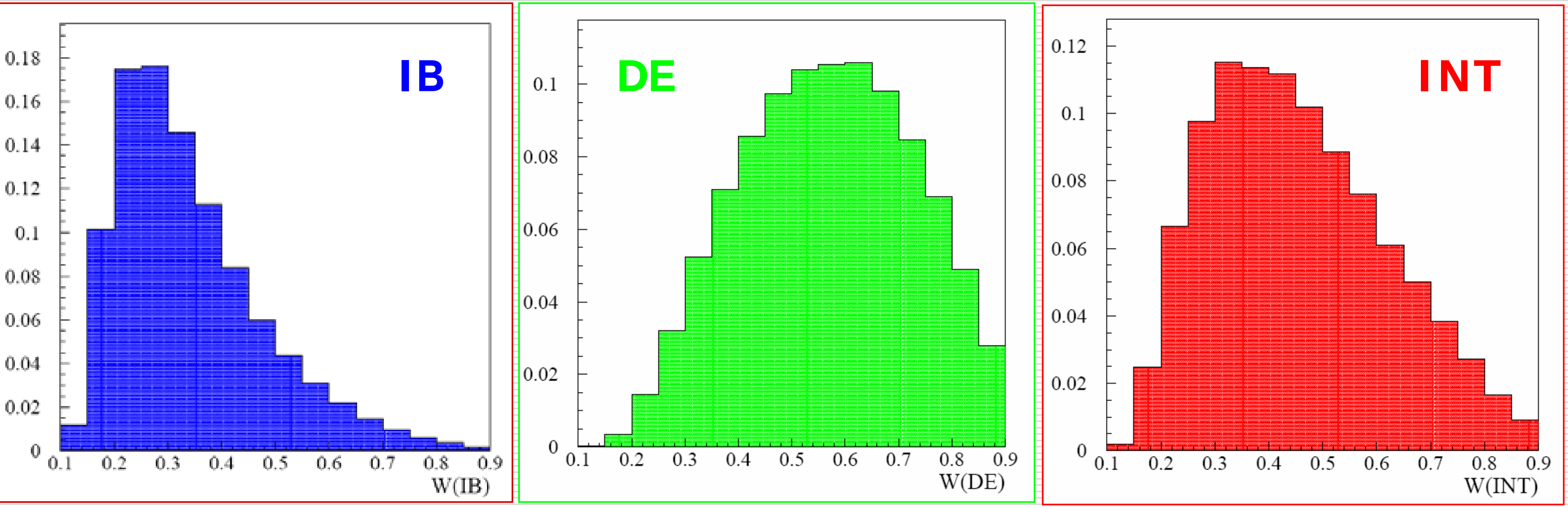
➢All **physical BG** can be explained in terms of $\pi^{\pm}\pi^{0}\pi^{0}$ events only

➢Very small contribution from accidentals is neglected

➢ γ mistagging probability (a self background) is order of ‰



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



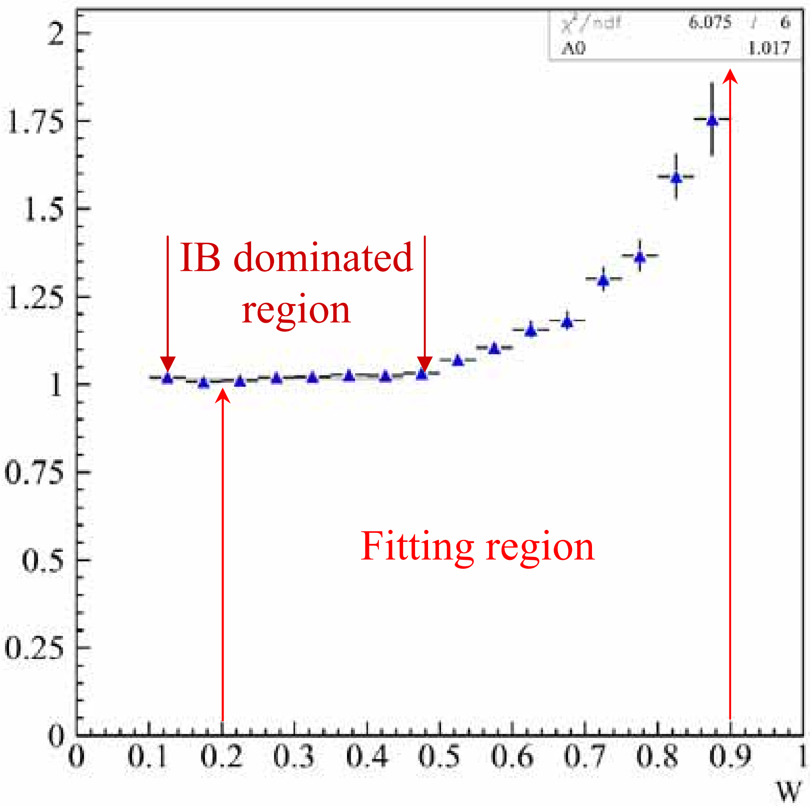
- 3 MC data samples for the 3 contributions to the decay

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

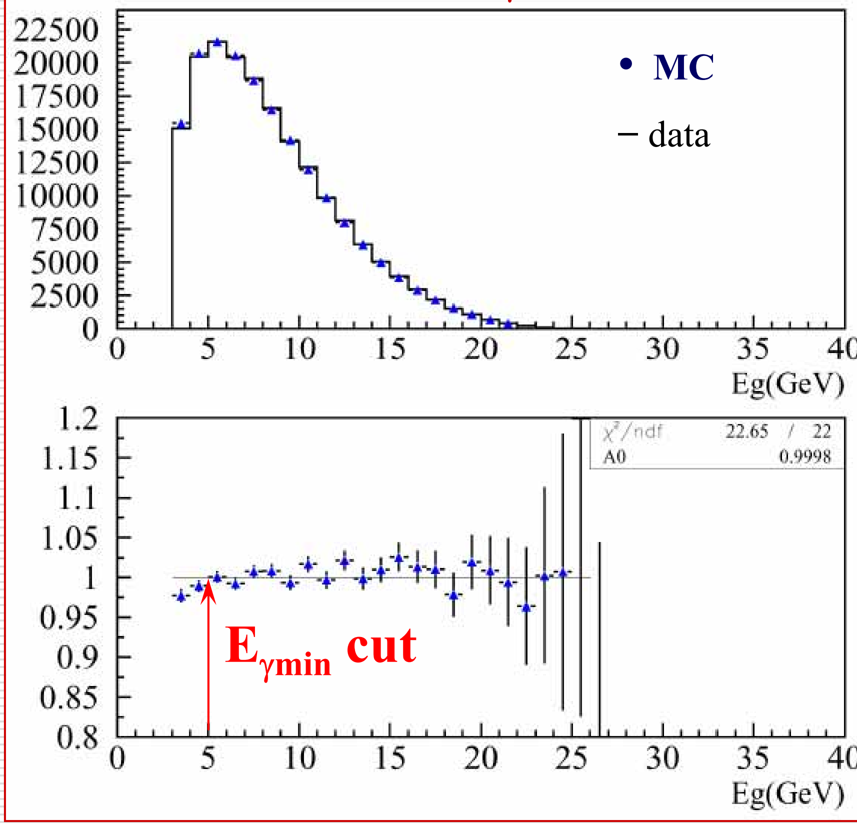
IB dominated part of the W spectrum

Radiated γ energy (**IB** dominated)

W(Data)/W (IB_{MC})



Data MC for E_γ (W<0.5)



- IB contribution is very well reproduced by MC

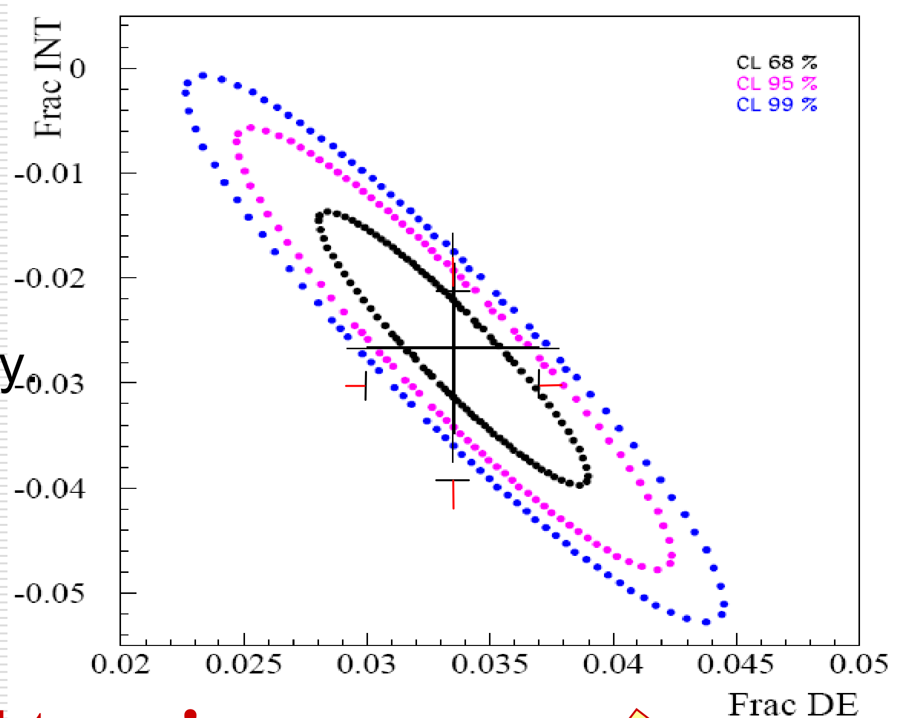
$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Fit results.

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

$$\mathbf{W_{dat}=(1-\alpha-\beta)W_{IB}+\alpha W_{DE}+\beta W_{INT}}$$

- systematic dominated by Trigger efficiency
- parameters are highly correlated

 correlation coefficient: **ρ = -0.92**



First evidence of non zero INT term!

NA48/2 Preliminary

Frac(DE)$_{0<T^*_\pi<80\ MeV}$	=	**(3.35 ± 0.35 ± 0.25)%**
Frac(INT)$_{0<T^*_\pi<80\ MeV}$	=	**(-2.67 ± 0.81 ± 0.73)%**

2004 data set: x4 # events and lower systematic due to trigger

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Comparison.

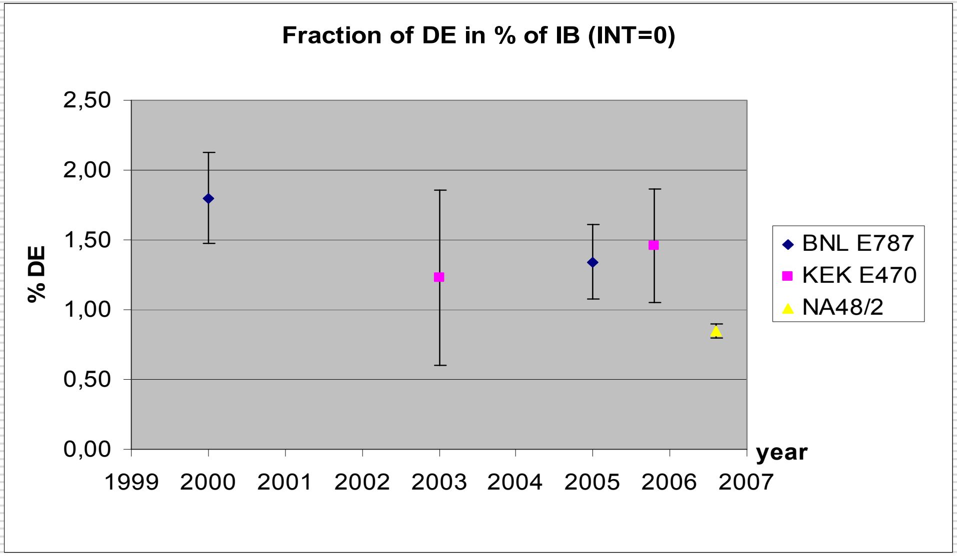
✓ For comparison with previous experiments the fraction of DE has been also measured, with:

- INT = 0
- $55 < T^{*}_{\pi} < 90$ MeV

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

Consistent, although the analysis of fit's residuals shows a bad χ^2

Indication for a non-null INT term



$$K^{\pm} \rightarrow \pi^{\pm} e^{+} e^{-} \gamma$$

$K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma$. BR measurement.

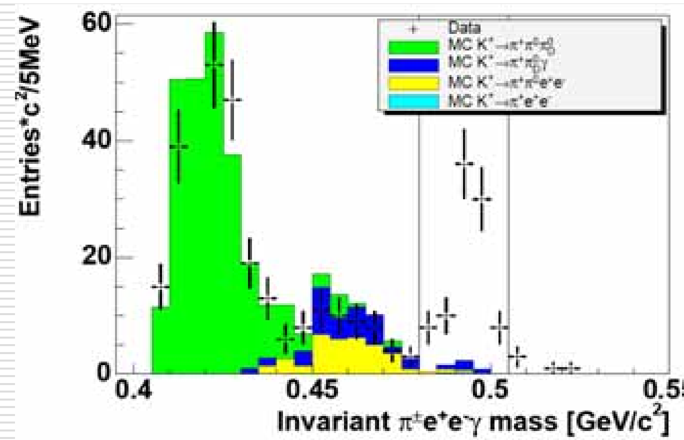
Never observed before

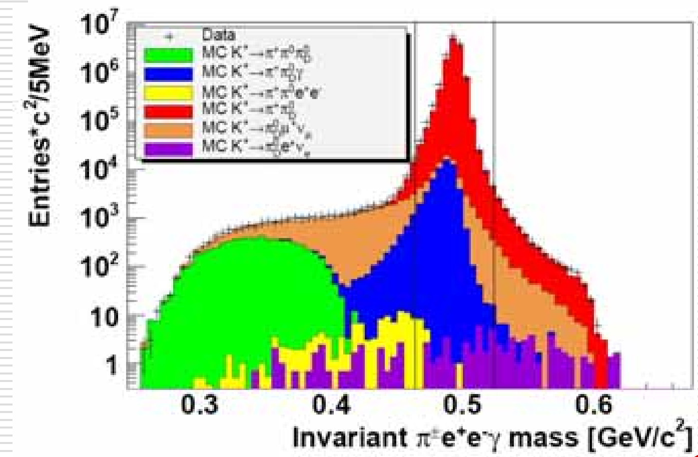
Naïve estimation of the BR:

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

Theoretical expectation (χPt based, Gabbiani 99):

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





Event sample:

92 candidates events with

1±1 accidental background

5.1±1.7 physical background

Normalization channel:

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

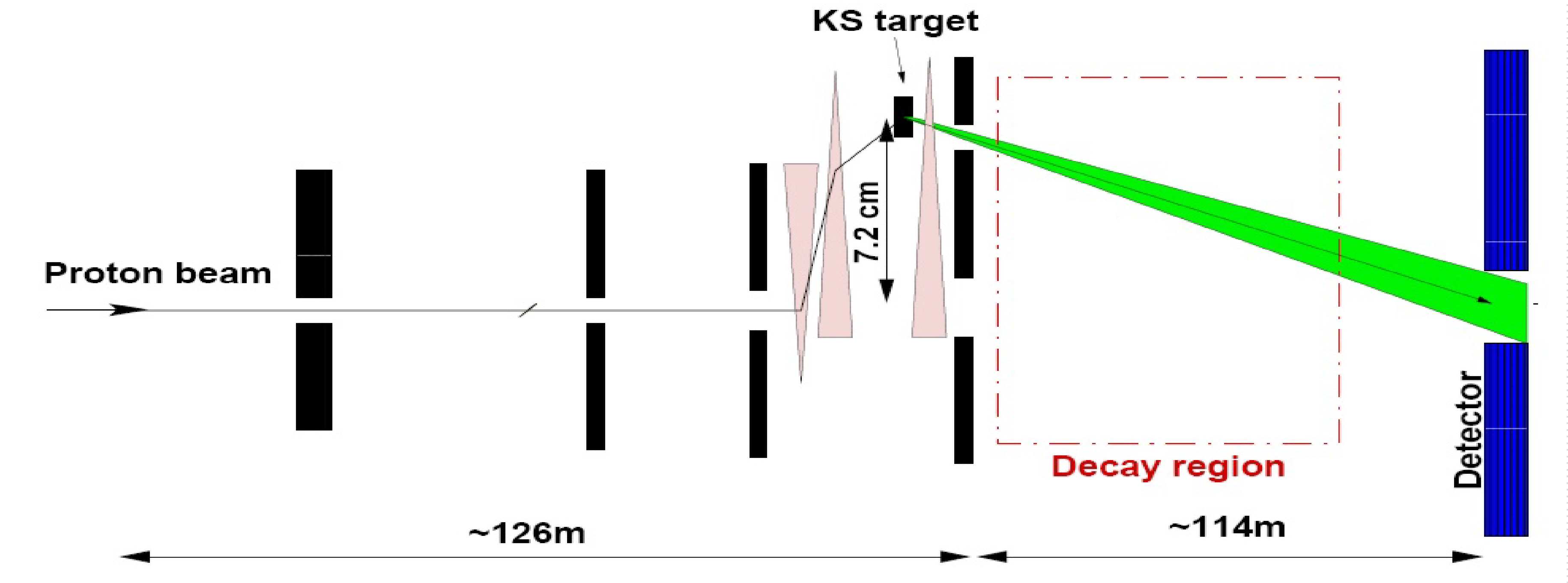
$$BR(K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma) = (1.27\pm0.14_{stat}\pm0.05_{sys})\cdot 10^{-8}$$

NA48/2 Preliminary

Radiative Hyperon decays from NA48/1

Radiative Hyperon decays from NA48/1

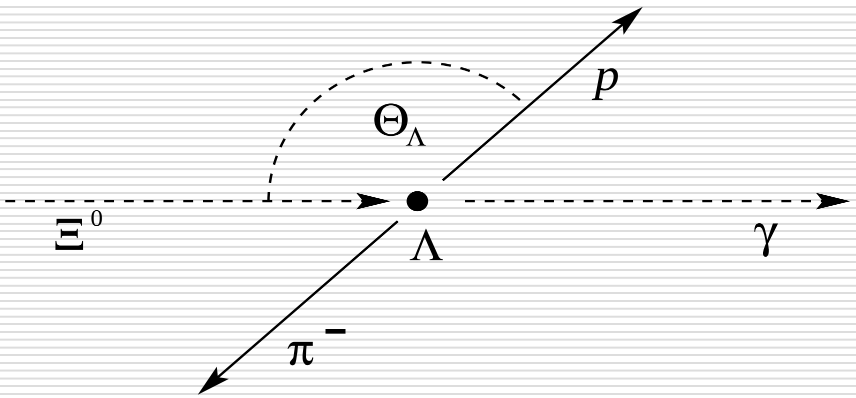
NA48/1 Beam line



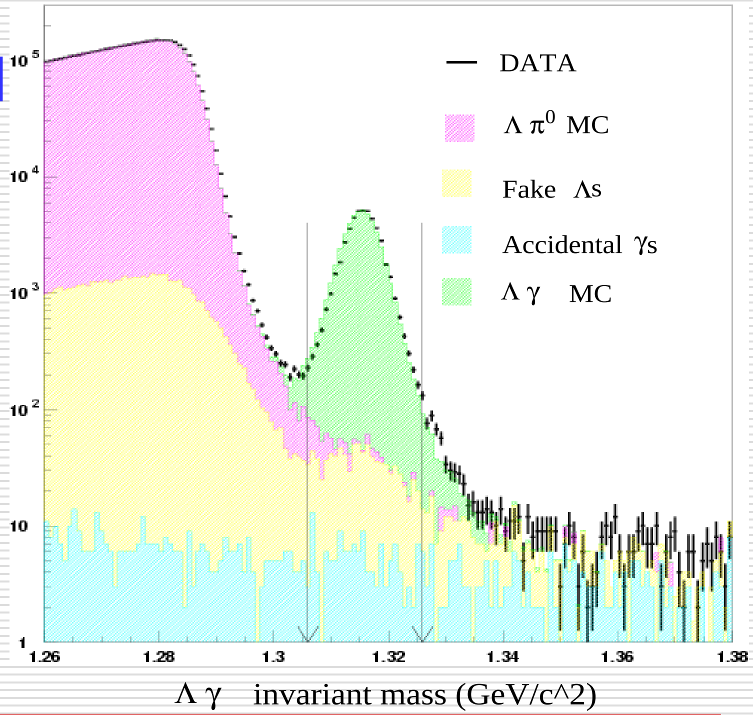
- same detector as NA48/2
- neutral beam: mainly K_s, Ξ^0, Λ

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

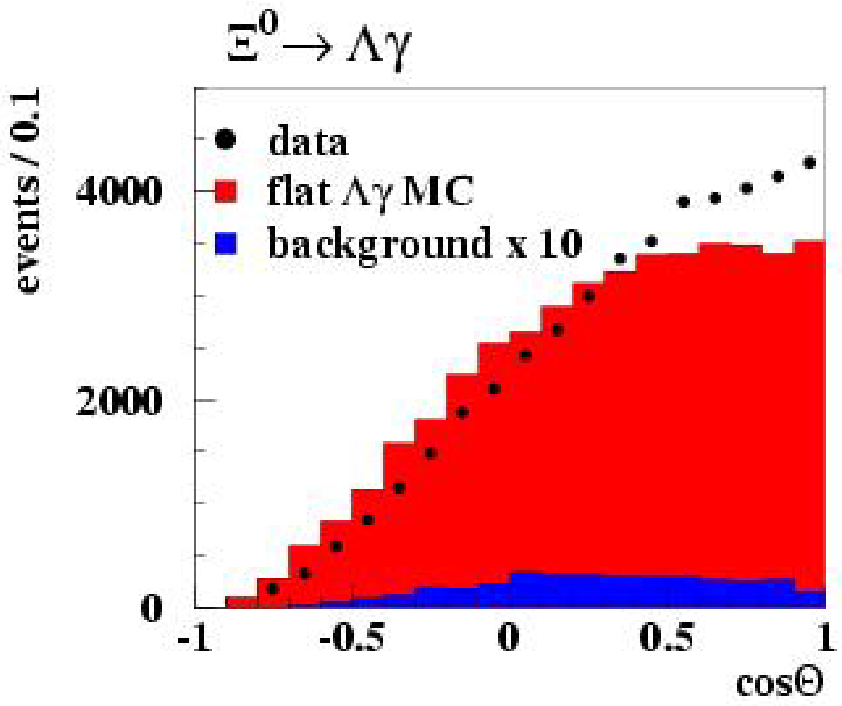
- **Use the $\Lambda \to p\pi^-$ as analyser**
- **$dN/d\cos\Theta \propto 1 - \alpha_\Lambda \alpha_\Xi \cos\Theta$**
- **$\alpha_\Lambda = 0.642 \pm 0.013$ (PDG)**

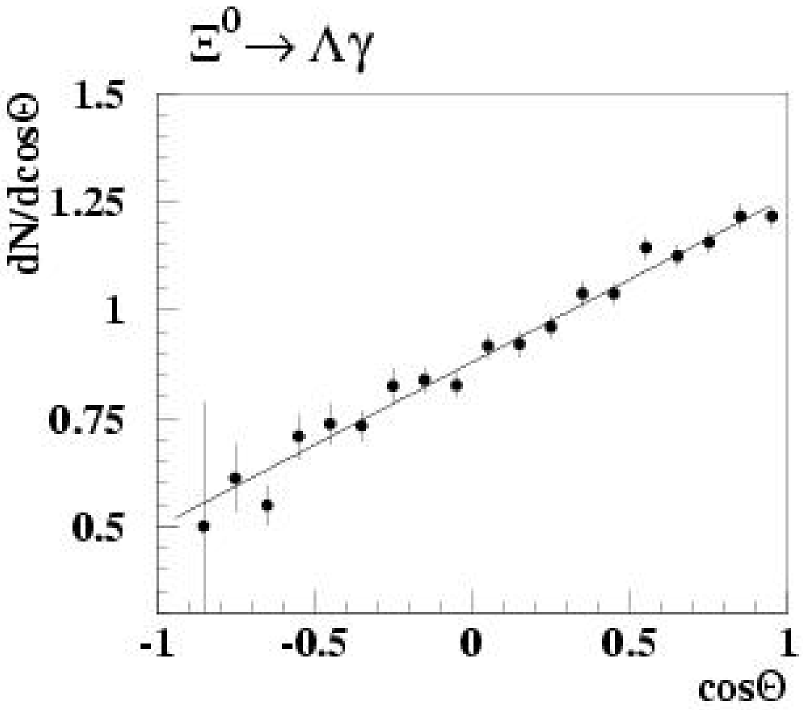


- **43814 $\Xi^0 \to \Lambda\gamma$ events selected**
- **0.8 % background**



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



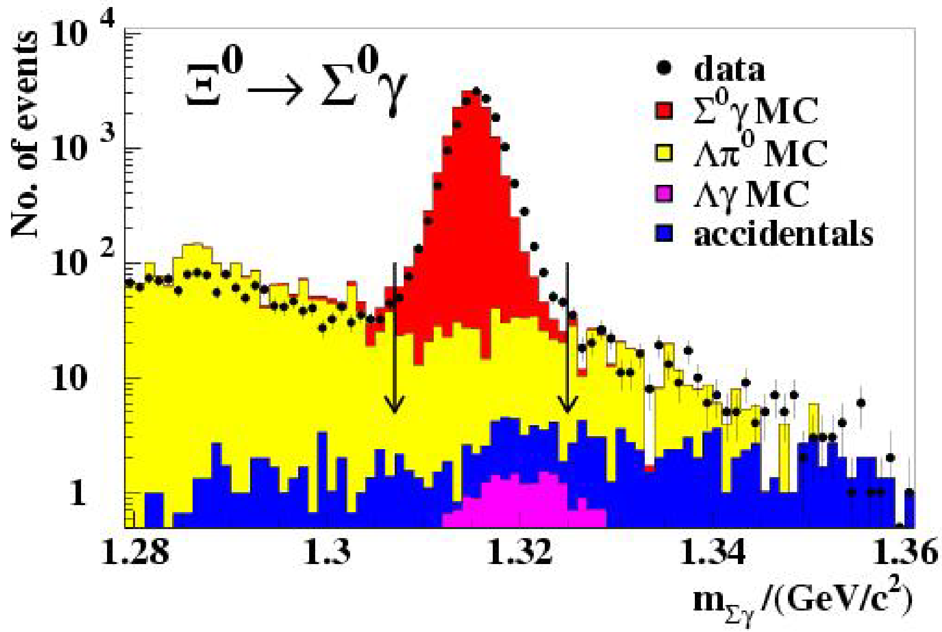


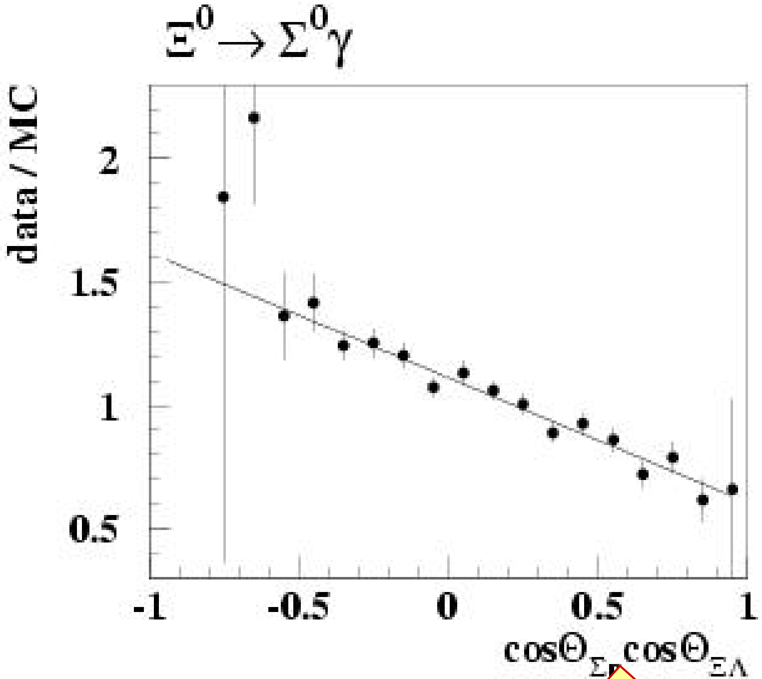
NA48/2 Preliminary

$$\alpha(\Xi^0 \to \Lambda\,\gamma) = -0.68 \pm 0.02 stat \pm 0.06 syst$$

$\Xi^0 \to \Sigma^0\gamma$ decay asymmetry

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





$$\alpha(\Xi^0 \to \Sigma^0 \gamma) = -0.68 \pm 0.03stat \pm 0.07syst$$

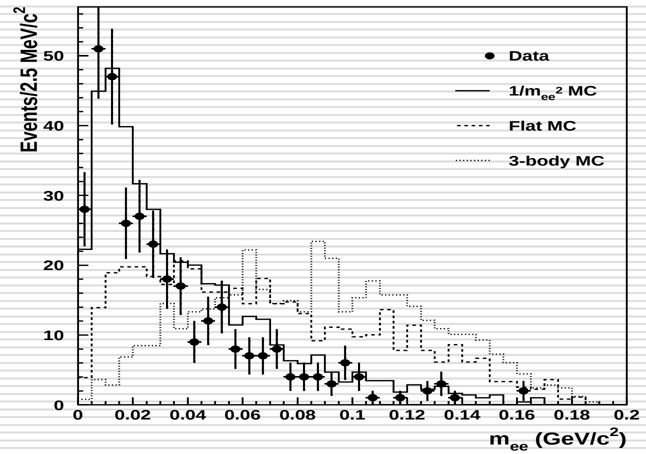
NA48/2 Preliminary

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

Never observed before

Naïve estimation of the BR:
$BR(\Xi^0 \rightarrow \Lambda e^+ e^-) = BR(\Xi^0 \rightarrow \Lambda\gamma)\cdot\alpha \sim 8.8\cdot10^{-6}$

Theoretical expectation (QED based, Bernstein 65):
$BR(\Xi^0 \rightarrow \Lambda e^+ e^-) = (6.4\text{-}7.3)\cdot10^{-6}$



Event sample:

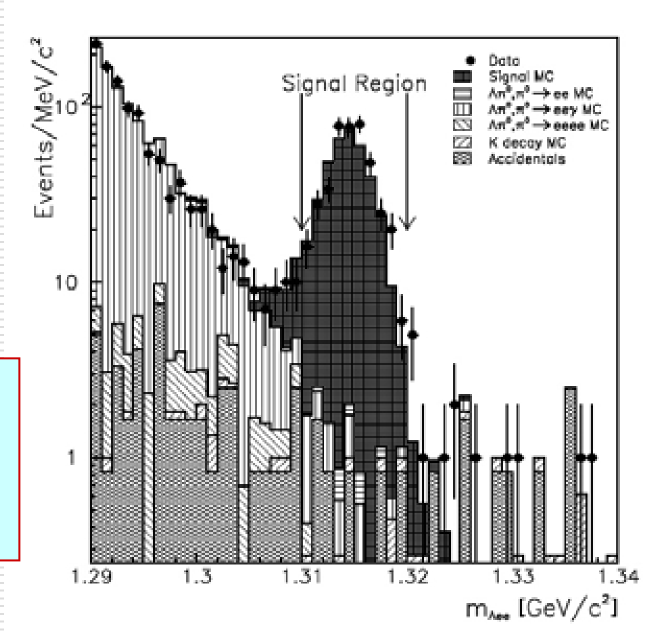
412 candidates events with

7±5 accidental background

8±3 physical background

Normalization channel:

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



$BR(\Xi \rightarrow \Lambda ee) = (7.7 \pm 0.5 stat \pm 0.4 syst)\cdot10^{-6}$

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

NA48/2
Preliminary

Conclusion

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

- **NA48/1** recent results in radiative hyperon decays
  - **new measurement of $\Xi^{0}\to\Lambda\gamma$ and $\Xi^{0}\to\Sigma^{0}\gamma$ decay asymmetries**
  - **first measurement of the $\Xi^{0}\to\Lambda e^{+}e^{-}$ BR and decay asymmetry**

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$. Selection.

Track Selection

- # tracks = 1
- $P_{\pi+}$ > 10 GeV
- E/P < 0.85
- No muon veto hits
- 0 MeV < T^{*}_{π} < 80 MeV

γ Selection

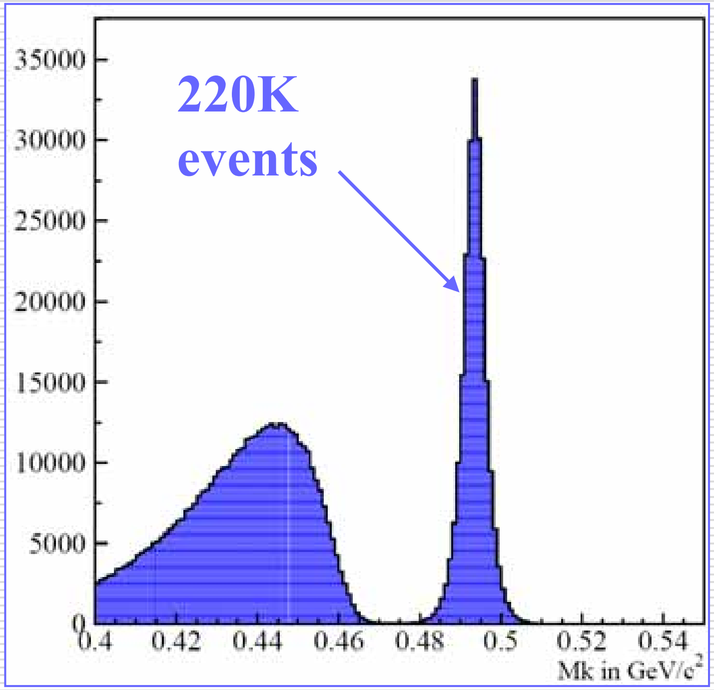
- N_{γ} = 3 (LKr clusters well separated in time)
- Min γ energy > 3 GeV (>5 for the fit)

γ Tagging Optimization

- CHA and NEU vertex compatibility
- Only one compatible NEU vertex

BG Rejection

- COG < 2 cm
- Overlapping γ cuts
- $|M_K - M_{KPDG}|$ < 10 MeV

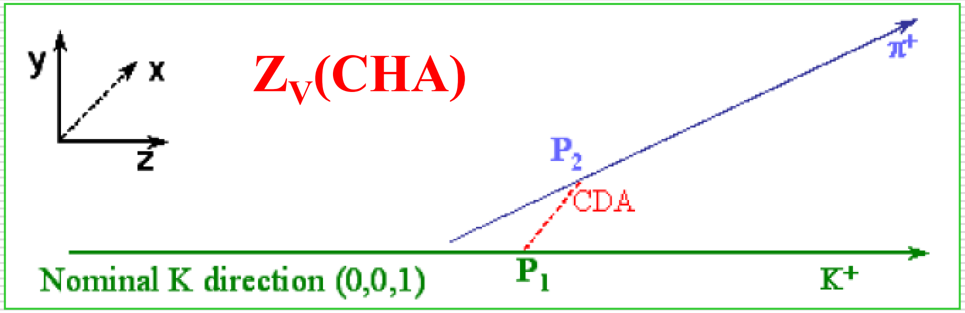


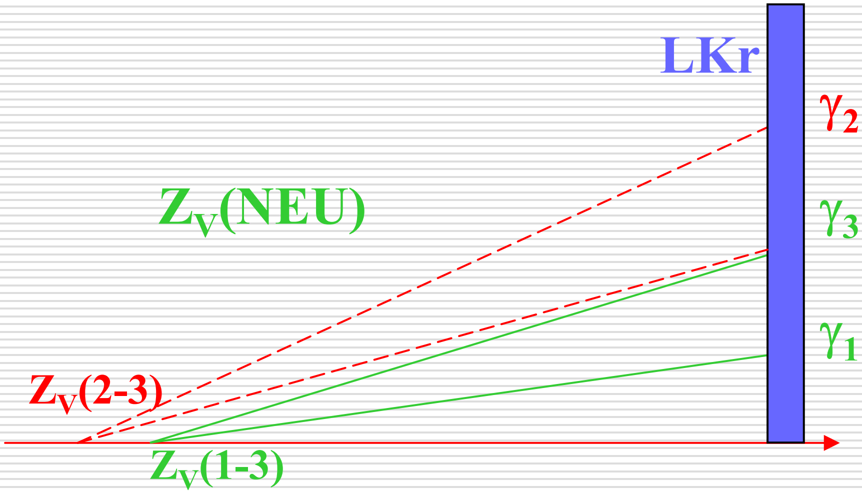
Reconstruction strategy

Two independent determination of K decay vertex:

1) charged vertex Z_V(CHA) using K and π flight directions (DCH)

2) neutral vertex Z_V(NEU) imposing π^0 mass to $\gamma\gamma$ pairs (LKr)



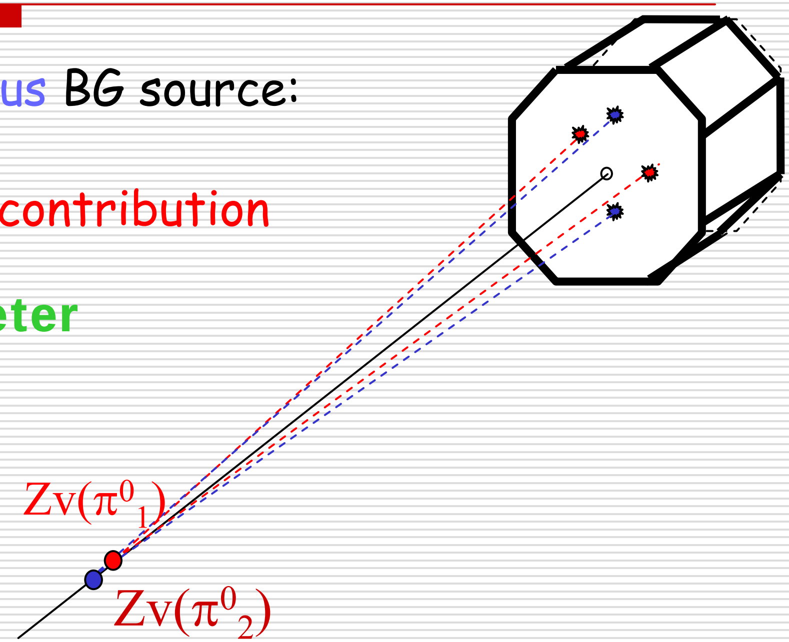


Three Z_V(NEU) combinations:
$Z_V(12)$, $Z_V(23)$, $Z_V(13)$
→ choose the vertex giving the best kaon mass.
↓
identify the radiated γ

Overlapping γ rejection

Overlapped gamma events are a very dangerous BG source:

- M_K, and COG cut automatically satisfied!
- Releasing the T^*_π cut they can give sizable contribution



Powerful rejection using the NA48 calorimeter

- high granularity (2x2 cm cells)

- good Z vertex resolution

Multi step algorithm looped over clusters:

1) Split 1 out of the 3 clusters in two γ of energies:

$\varepsilon\gamma_1 = xE_{CL}$ $\varepsilon\gamma_2 = (1-x)E_{CL}$

→ get 4 γ and reconstruct the event as a $\pi^\pm\pi^0\pi^0$.

2) Compute $Z_V(x)$ pairing the gammas and extract x imposing:

$Zv(\pi^0_1)=Zv(\pi^0_2)$ (The two π^0 come from the same K!)

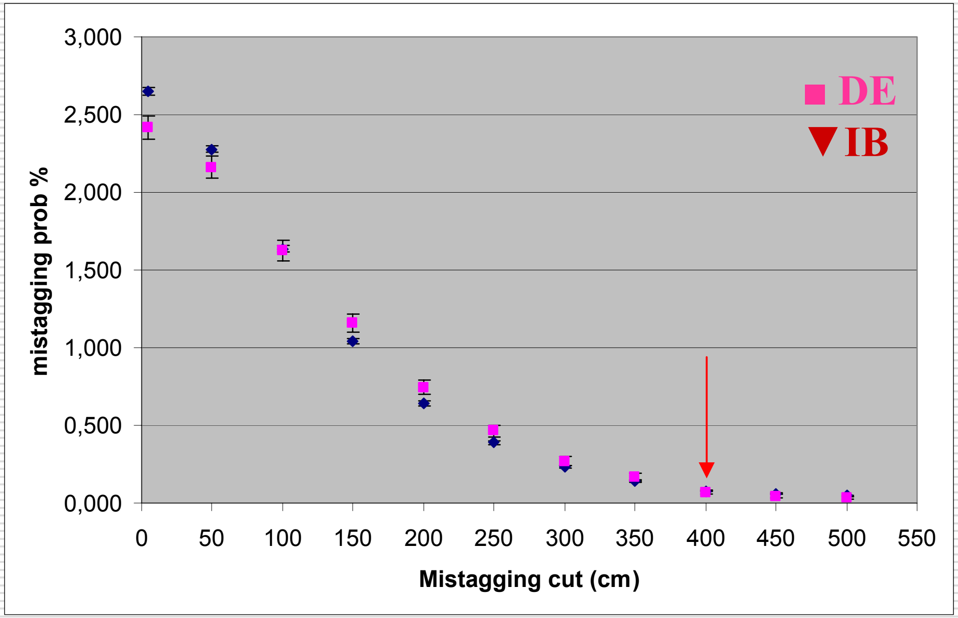
3) Use x in the $Zv(\pi^0_2)$ to get the real $Z_V(neu)$

If $|Zv(CHA)-Zv(neu)|<400$ cm → the γ are really overlapped → **REJECT**

Mistagged γ events: a self BG

Mistagged gamma events behave **like BG** because they can induce fake shapes in the W distribution.

In fact due to the slope of **IB** W distribution they tend to populate the region of high W simulating **DE** events.



The **mistagging probability** has been evaluated in MC as a function of the mistagging cut to be **1.2‰ at 400 cm**

2 steps rejection of mistagged events :

1. Compatibility of charged and neutral vertices (2.5% mistagging)

2. Distance between best and second best neutral vertices > xx cm

Very similar mistagging probabilities for IB and DE events