

Measurements of radiative processes at NA48

Mauro Piccini
CERN

on behalf of the NA48/2 Collaboration

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

HEP2007 - Manchester, UK, 19-25 July 2007

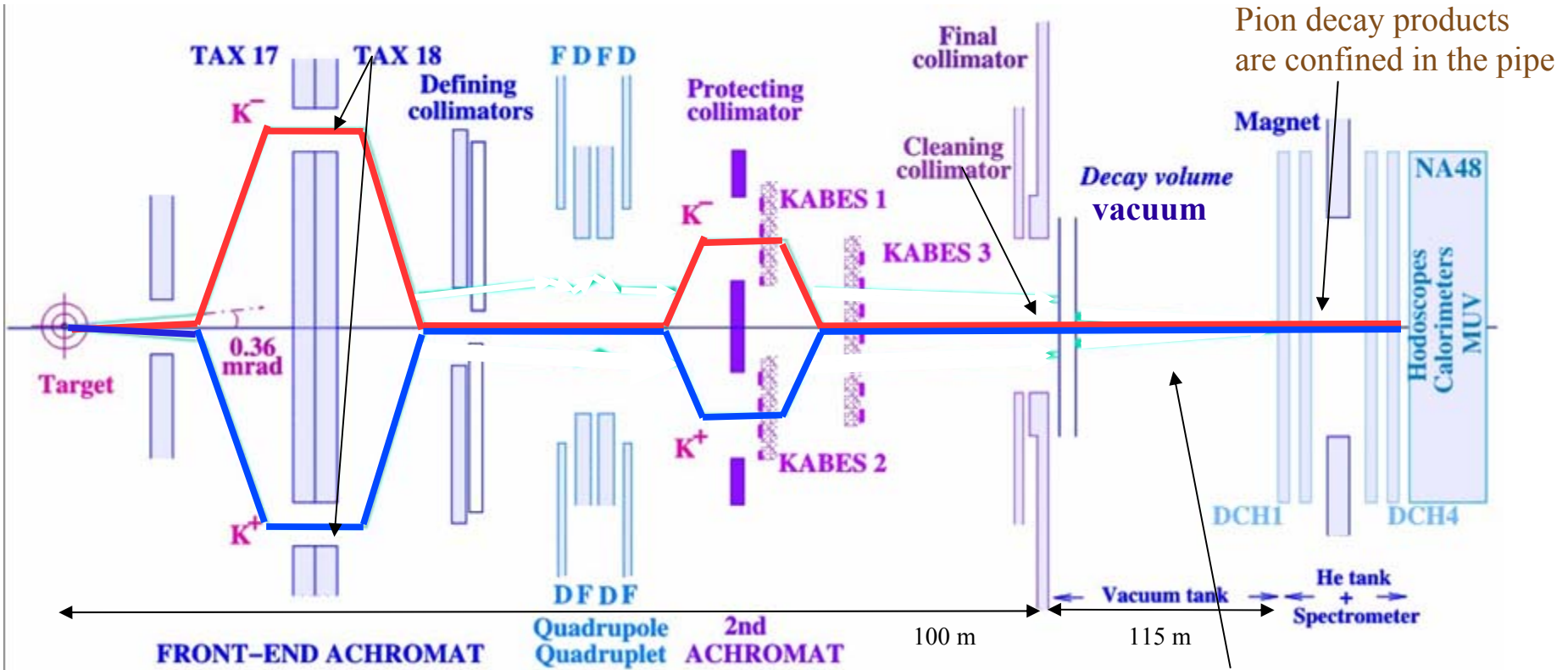
Outline

- $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ decay
 - Formalism
 - Experimental status
 - NA48/2 measurement (preliminary)

- $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$ decay
 - NA48/2 first evidence (preliminary)

- $\Xi^0 \rightarrow \Lambda \gamma$ end $\Xi^0 \rightarrow \Lambda^0 e^+ e^-$
 - NA48/1 measurement (final)

The NA48/2 beam line



Pion decay products are confined in the pipe

Decay volume vacuum

Beams overlap within ~1mm through the 115m long decay volume (vacuum 10^{-5} mbar)

- Split +/-
- Select P (60 ± 3) GeV/c
- Recombine +/-
- Focusing
- Muon sweeping
- Cleaning
- Beam spectrometer (resolution 0.7 %)

The NA48 detector

- Magnetic spectrometer (4 DCHs):

$$\Delta p/p = 1.0\% + 0.044\% \cdot p \text{ [GeV/c]}$$

$\pi^+\pi^-\pi^\pm$ mass resolution about 1.7 MeV/c

- Liquid Krypton EM calorimeter (LKr)

High granularity, quasi-homogenous;

$$\Delta E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%[\text{GeV}]$$

$$\sigma_x, \sigma_y \sim 1.5 \text{ mm}$$

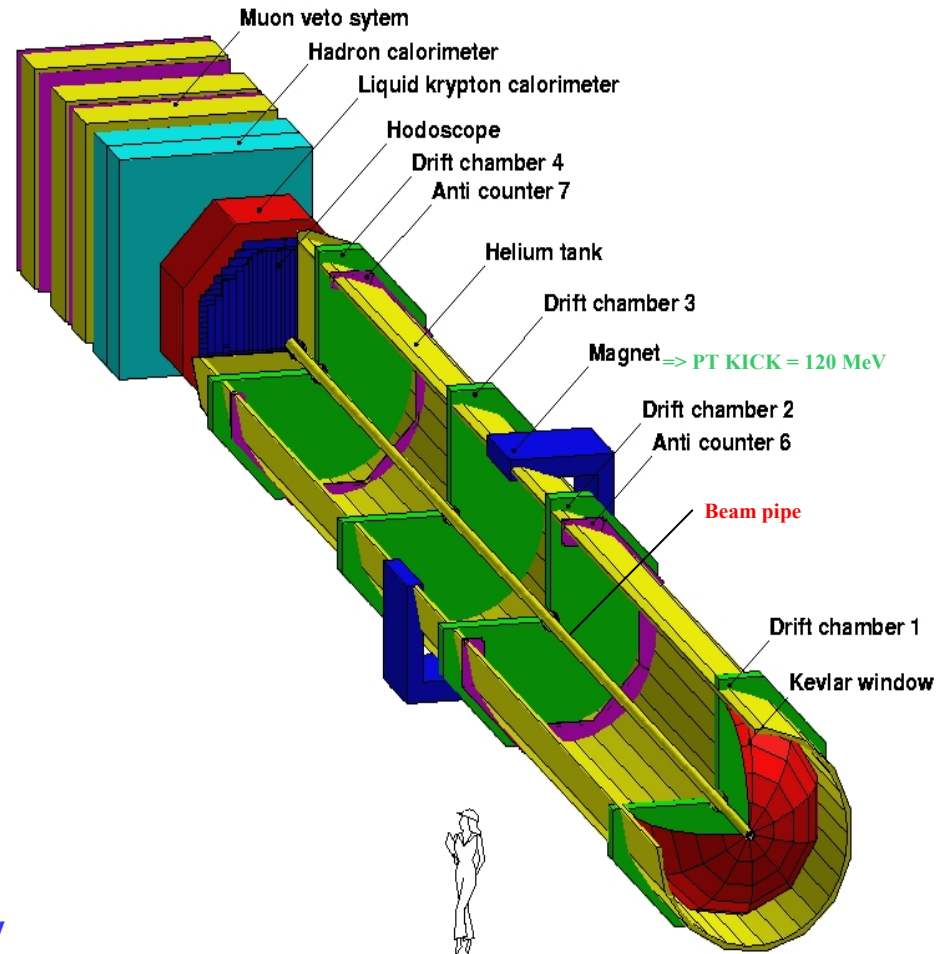
$\pi^0\pi^0\pi^\pm$ mass resolution about 1.4 MeV/c

- Hodoscope

fast trigger;

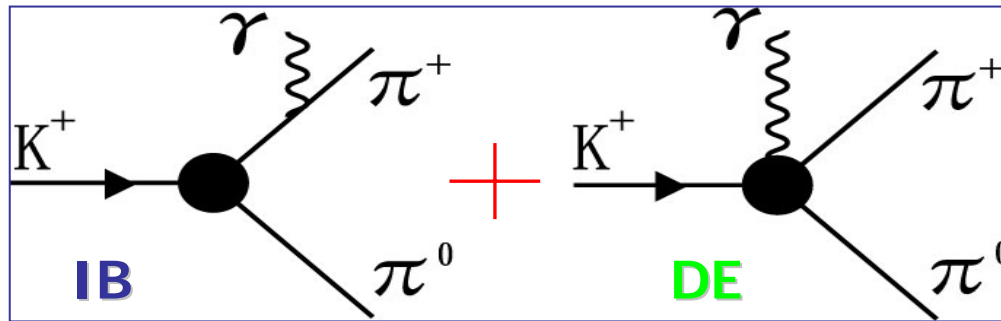
precise time measurement (200ps).

- Hadron calorimeter, muon veto counters, photon vetoes.



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

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (decay formalism)



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

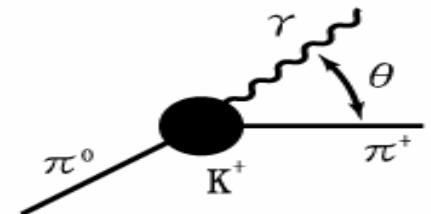
Γ^\pm depends on 2 variables (T_π^* and W) that can be reduced to only one integrating over T_π^*

Sensitive variable:

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

P_K^* = 4-momentum of the K^\pm
 P_π^* = 4-momentum of the π^\pm
 P_γ^* = 4-momentum of the γ

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



$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (amplitudes)

Two types of contributions:

Electric ($J=|l\pm 1$) 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

Status of the art before NA48/II measurement:

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

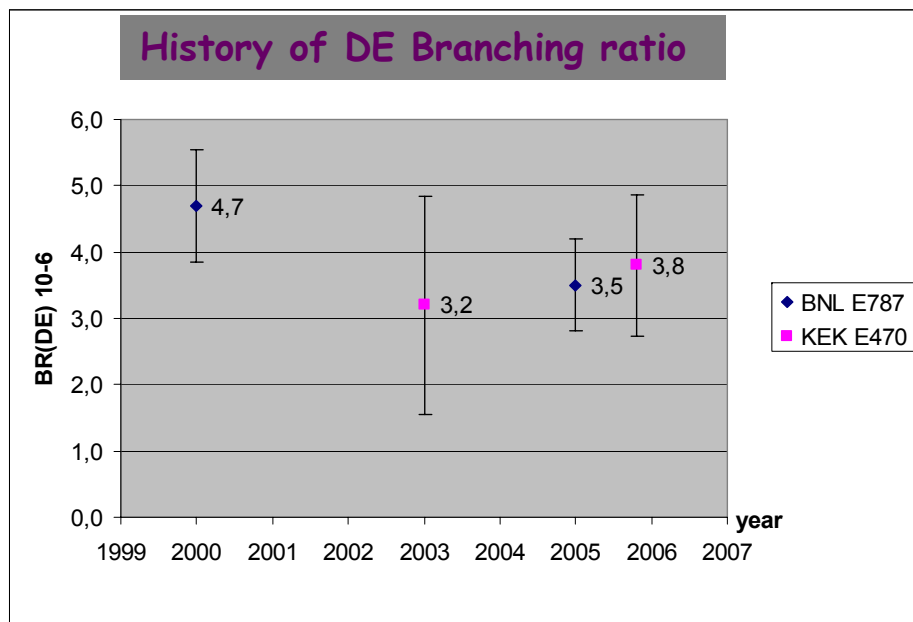
$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (exp results for DE and INT)

Experiment	Year	# Events	BR(DE) $\times 10^6$
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^*_π region **55-90 MeV** to avoid $\pi^\pm \pi^0$ and $\pi^\pm \pi^0 \pi^0$ background

✓ assuming INT = 0



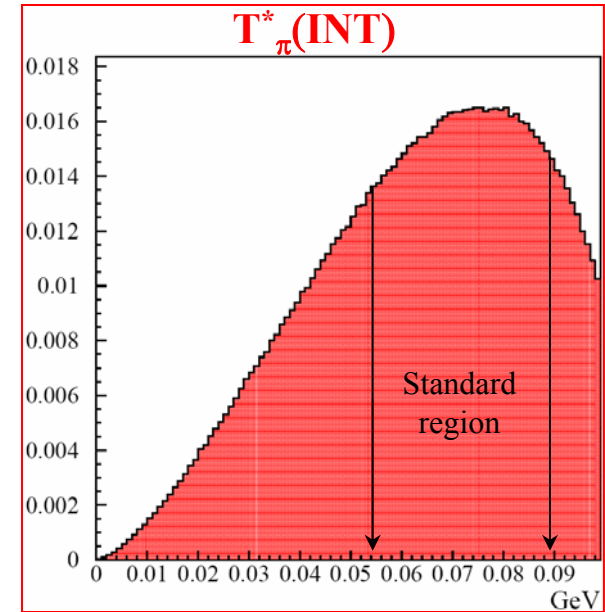
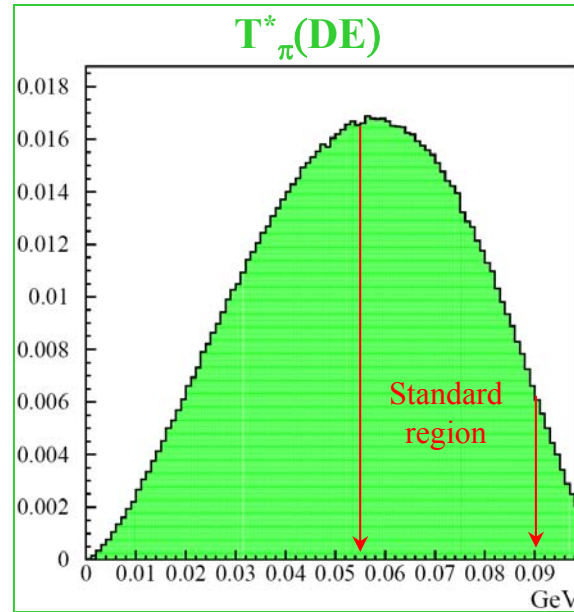
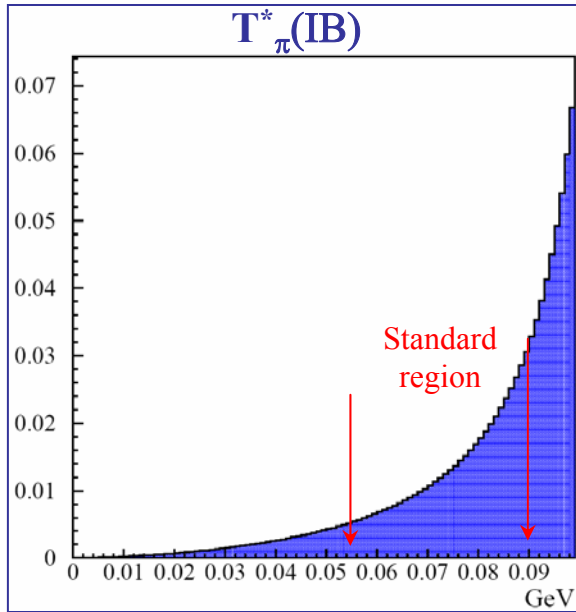
Interference estimations*:

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

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

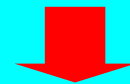
*not quoted as measurements by authors

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (enlarged T_π^* region)



Use standard region $55 < T_\pi^* < 90$ 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

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

to improve statistics and sensitivity to DE

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (the selected data sample)

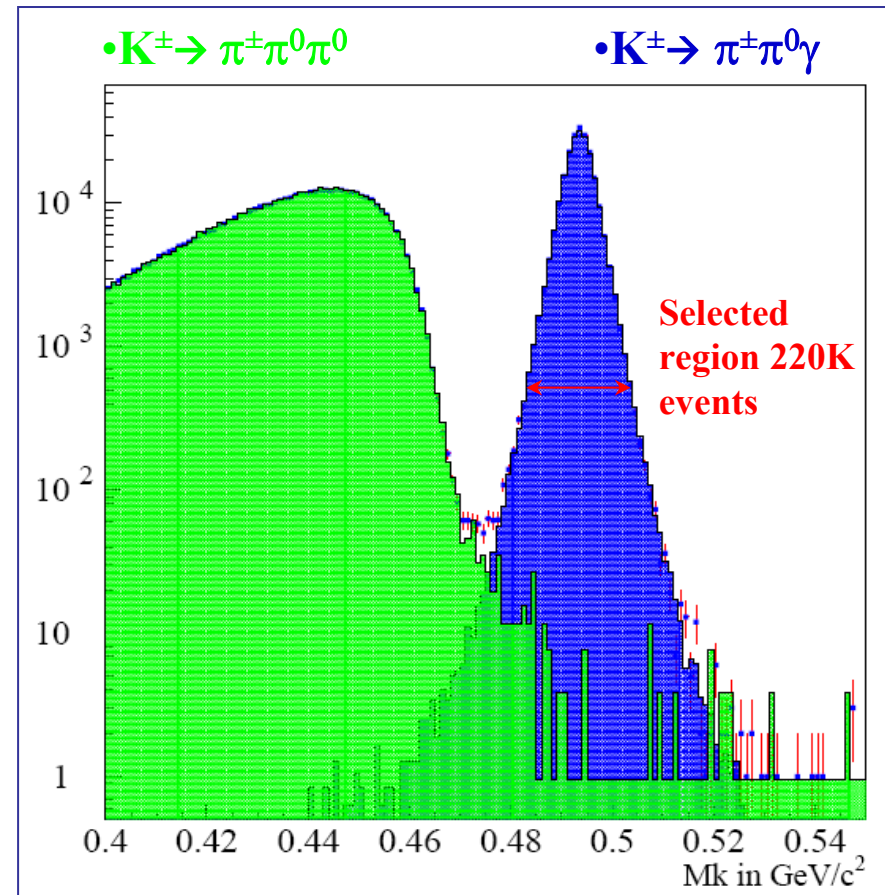
➤ Event selection

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

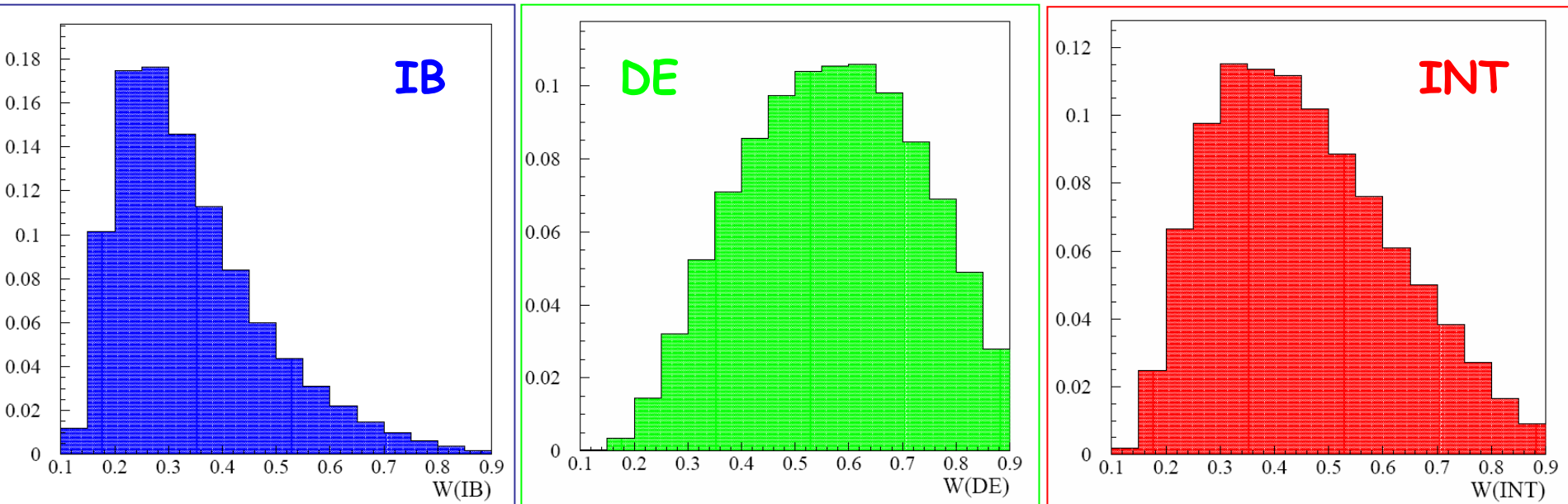
➤ All **physical BG** can be explained in terms of $\pi^\pm \pi^0 \pi^0$ events only

➤ Very small contribution from **accidentals**

➤ γ mistagging probability (“self background”) is order of ‰



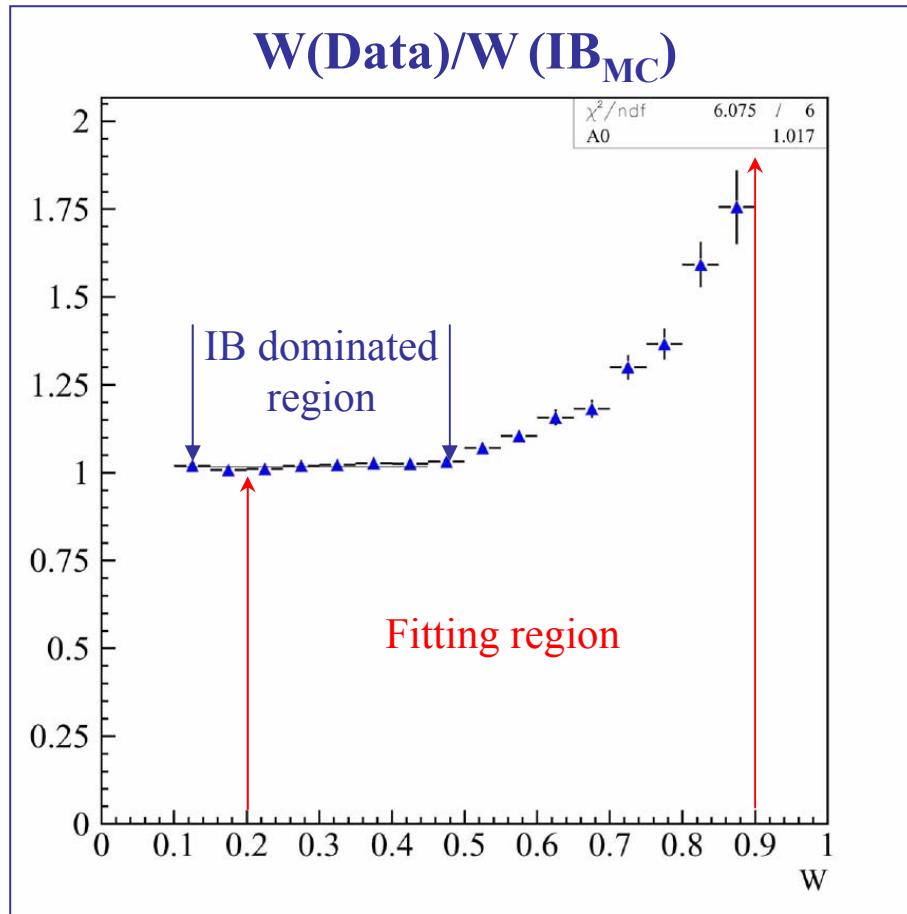
$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (W shapes from MC)



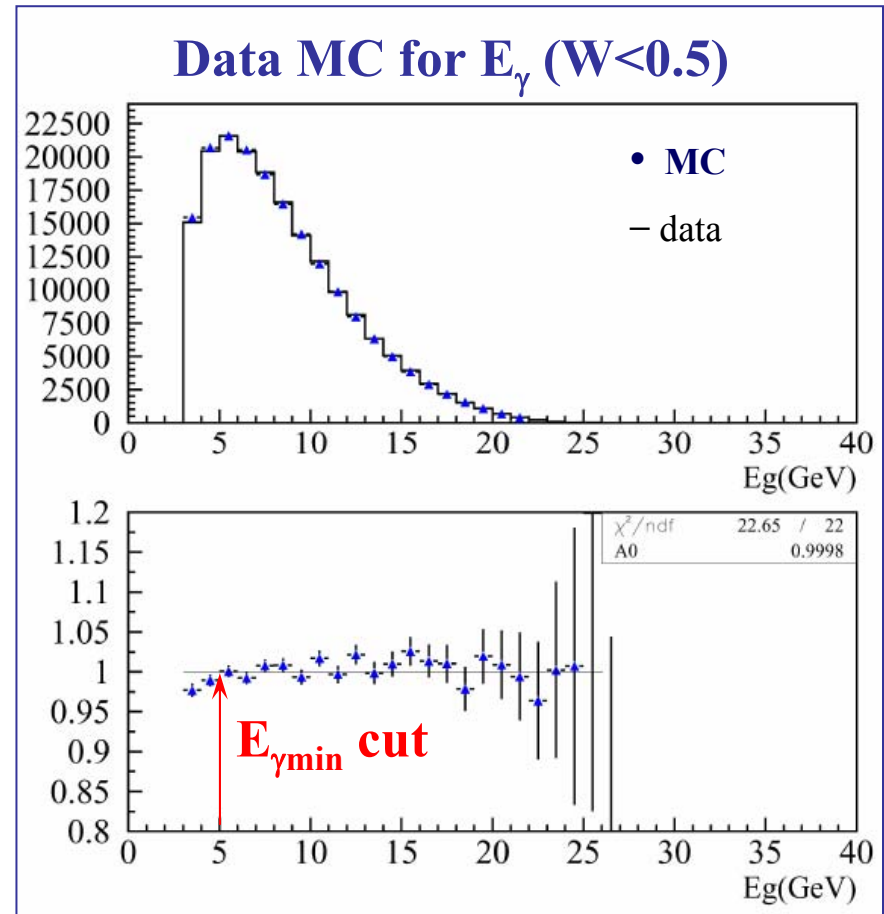
- 3 MC data samples for the 3 contributions to the decay

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (Data-MC comparison)

IB dominated part of the W spectrum



Radiated γ energy (IB dominated)



- IB contribution is very well reproduced by MC

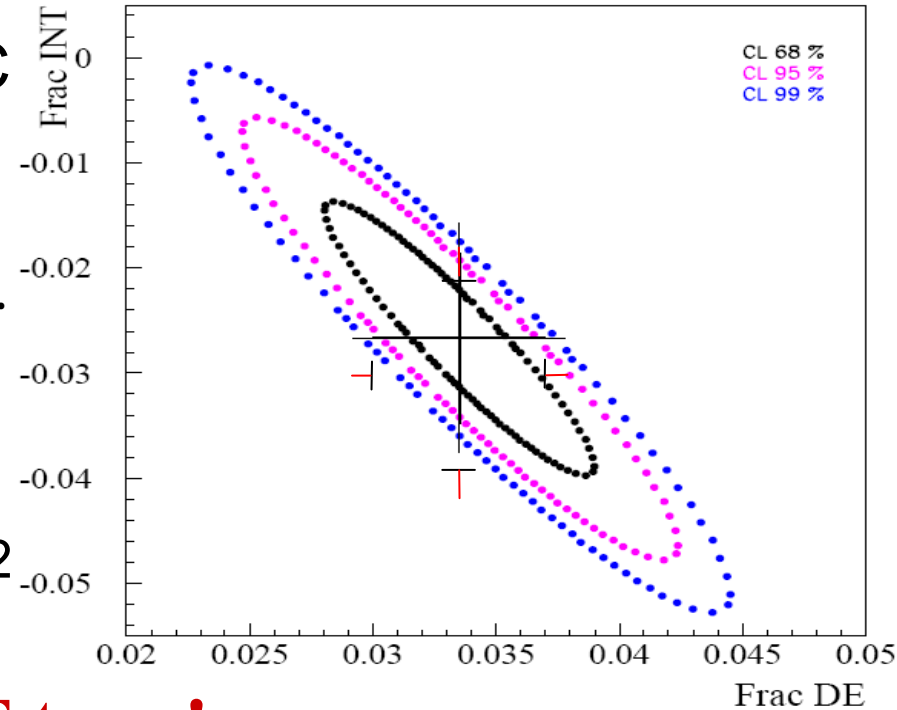
$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (fit results)

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

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

- systematic dominated by Trigger efficiency.

- parameters are highly correlated $r = -0.92$



First evidence of non zero INT term!

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

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

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

$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (comparison to others)

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

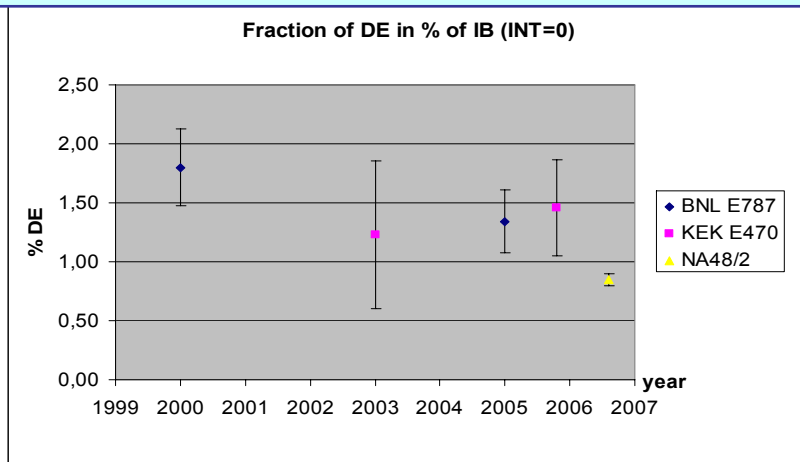
- INT = 0
- $55 < T_\pi^* < 90$ MeV

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

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



Indication for a non-null INT term



$K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ (final remark)

✓ from D'Ambrosio and Cappiello (**Phys.Rev.D75:094014,2007**)

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

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

→ The form factor can induce a fake **positive INT** term

$K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$ (BR measurement)

Never observed before

Naïve estimation of the BR:

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

Theoretical expectation (χ Pt based, Gabbiani 99):

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

Event sample:

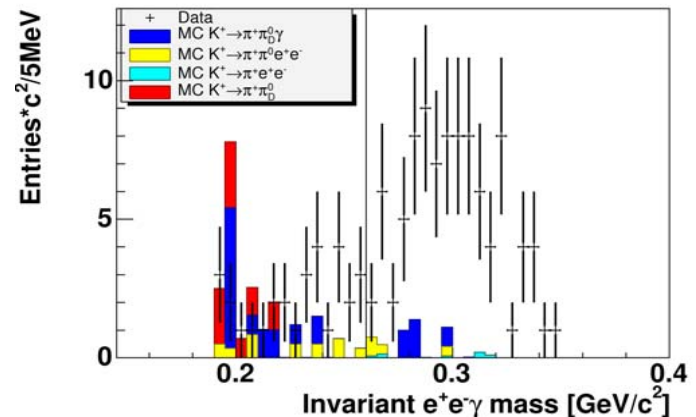
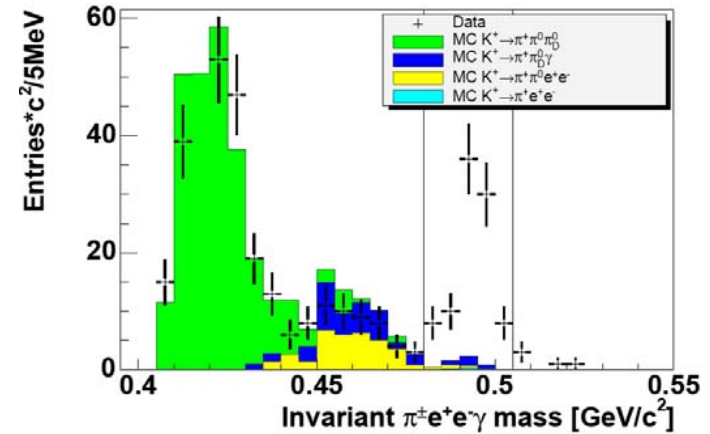
92 candidates events with

1 ± 1 accidental background

5.1 ± 1.7 physical background

Normalization channel:

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

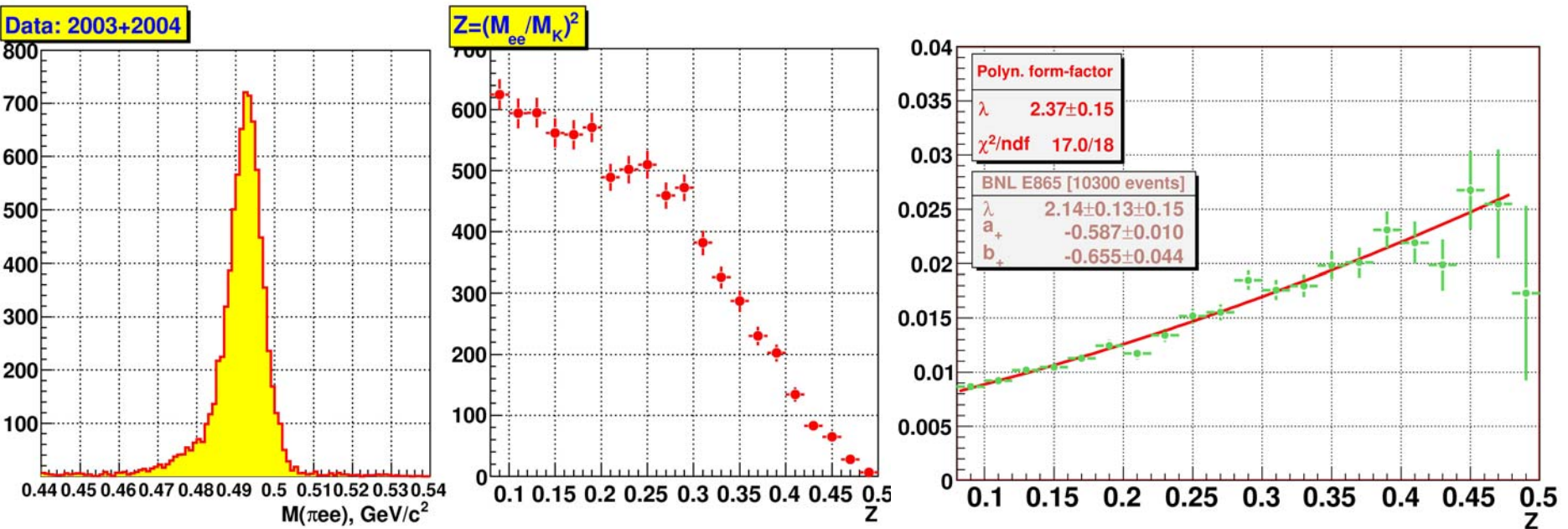


$$\text{BR}(K^\pm \rightarrow \pi^\pm e^+ e^- \gamma) = (1.27 \pm 0.14_{\text{stat}} \pm 0.05_{\text{sys}}) \cdot 10^{-8}$$

$K^\pm \rightarrow \pi^\pm e^+ e^-$ (bkg to $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$)

Flavor changing neutral current decay, $\Delta S=1$ (hep-ph/9808289)

7700 events with a background of 0.6% from 2003 and 2004 runs

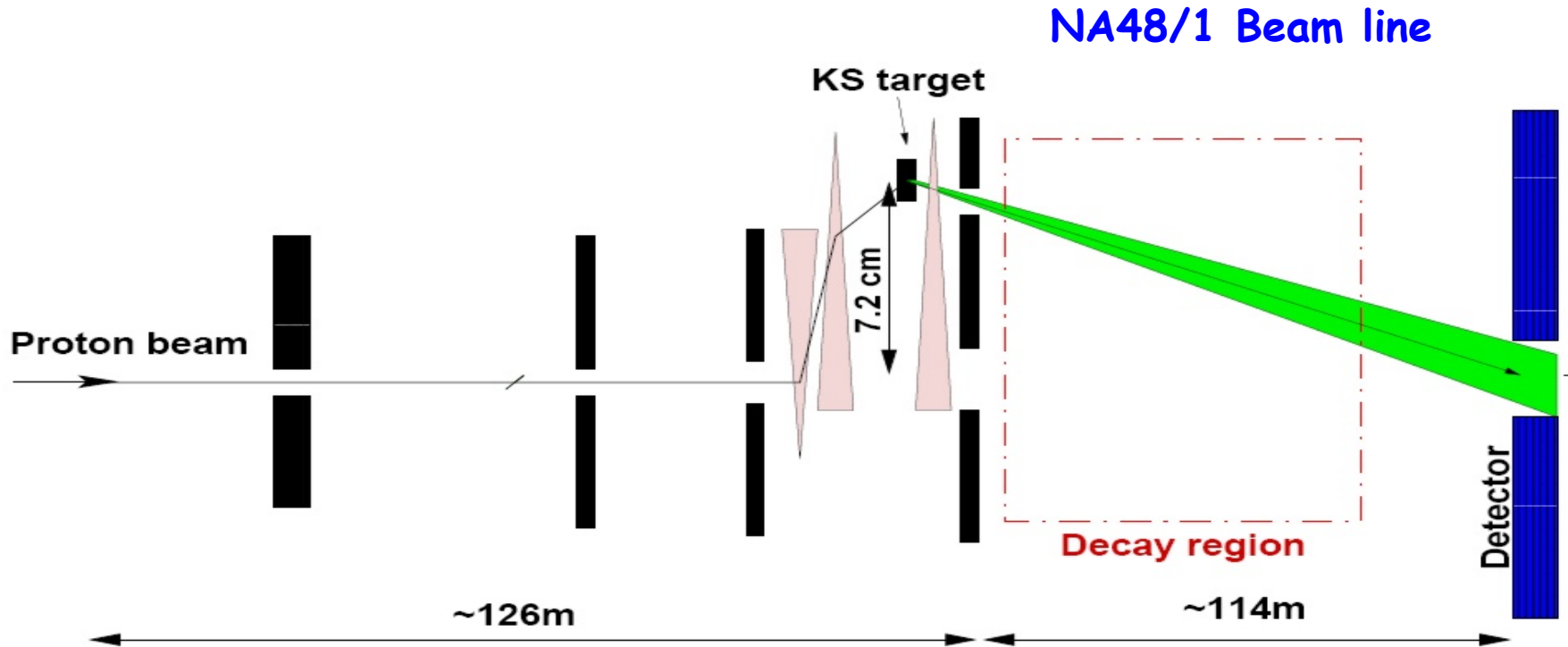


Measurement of the linear slope of the form factor:

$$\lambda = 2.37 \pm 0.17 \text{ (preliminary)}$$

BR measurement is ongoing to extract both a_+ and b_+

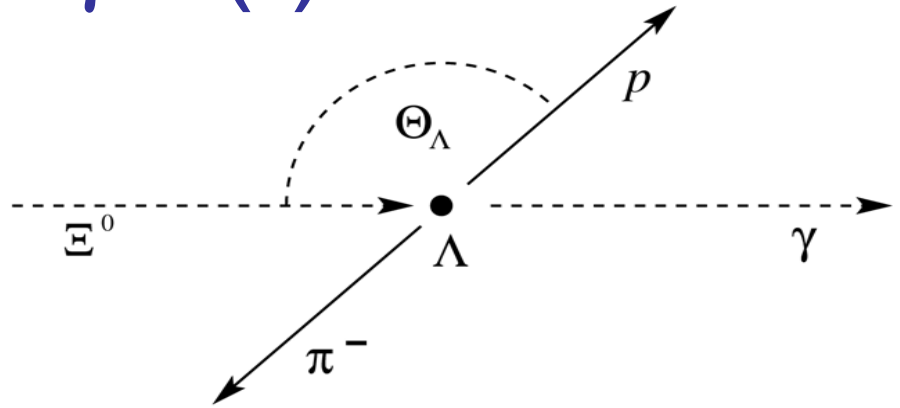
Radiative Hyperon decays from NA48/1



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

$$\Xi^0 \rightarrow \Lambda \gamma \quad (I)$$

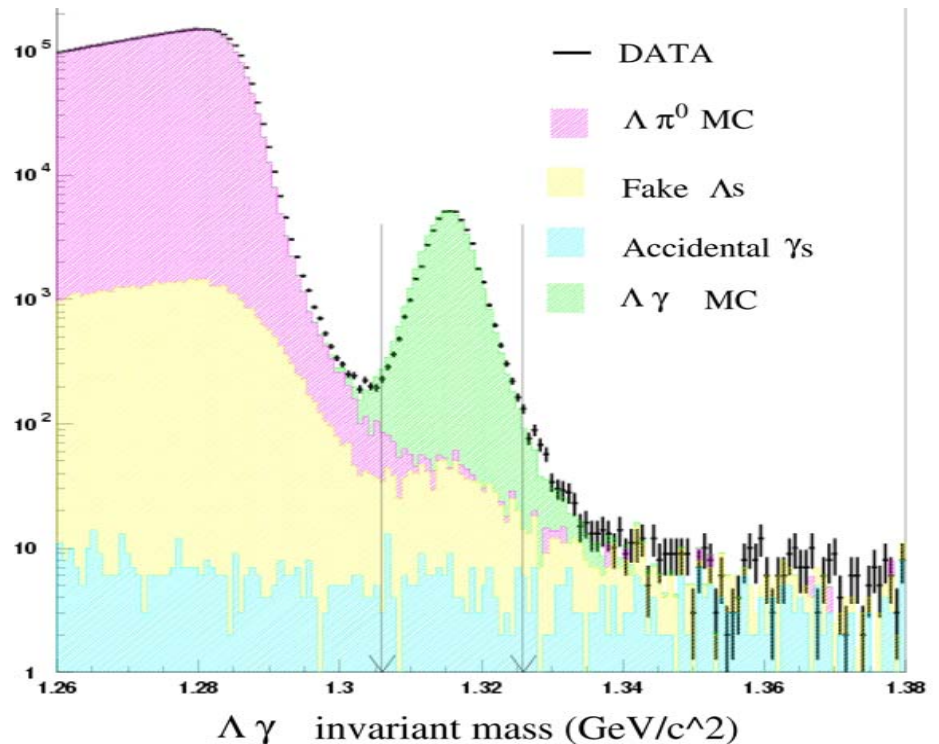
- ❑ Use the $\Lambda \rightarrow p\pi^-$ as analyser
- ❑ $dN/d\cos\Theta \propto 1 - \alpha_\Lambda \alpha_\Xi \cos\Theta$
- ❑ $\alpha_\Lambda = 0.642 \pm 0.013$ (PDG)



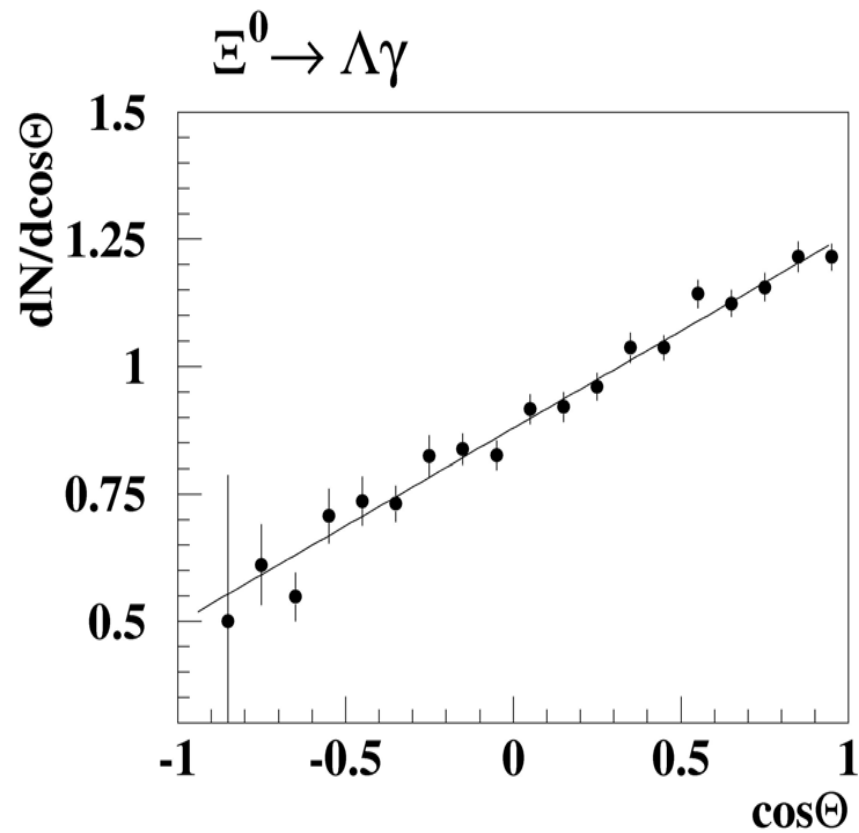
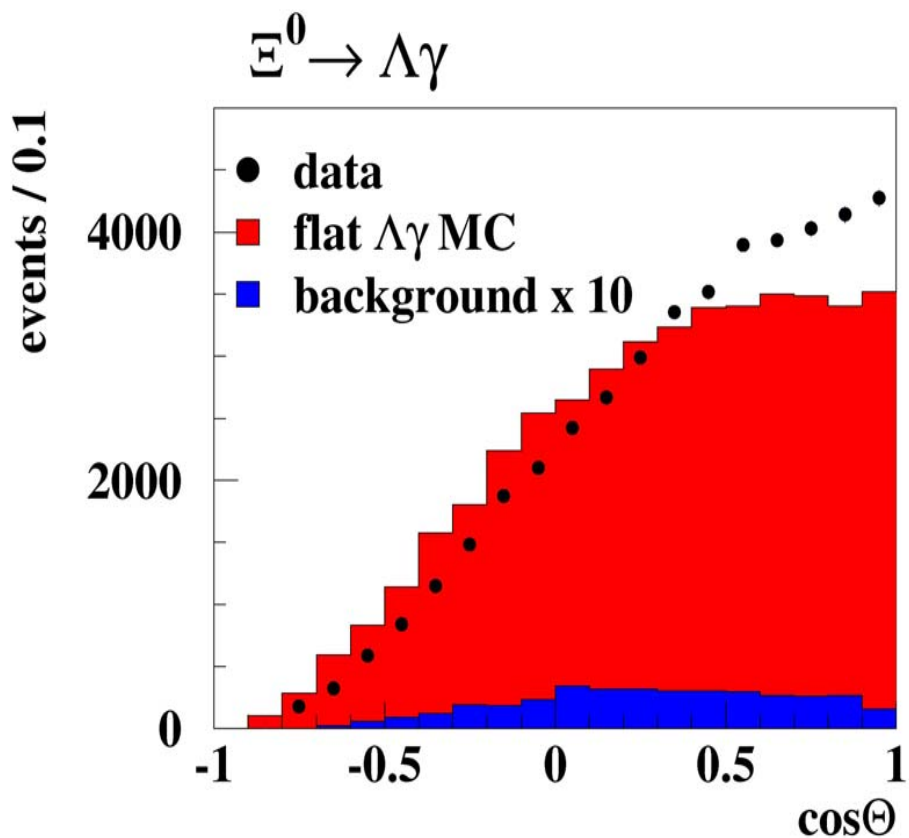
From 2002 run:

43814 $\Xi^0 \rightarrow \Lambda \gamma$ events selected

0.8 % background



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



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

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

Never observed before

Naïve estimation of the BR:

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

Theoretical 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±5 accidental background

8±3 physical background

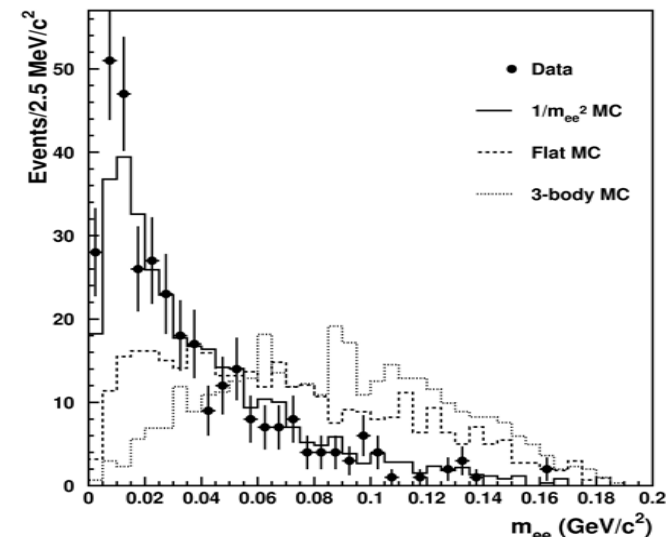
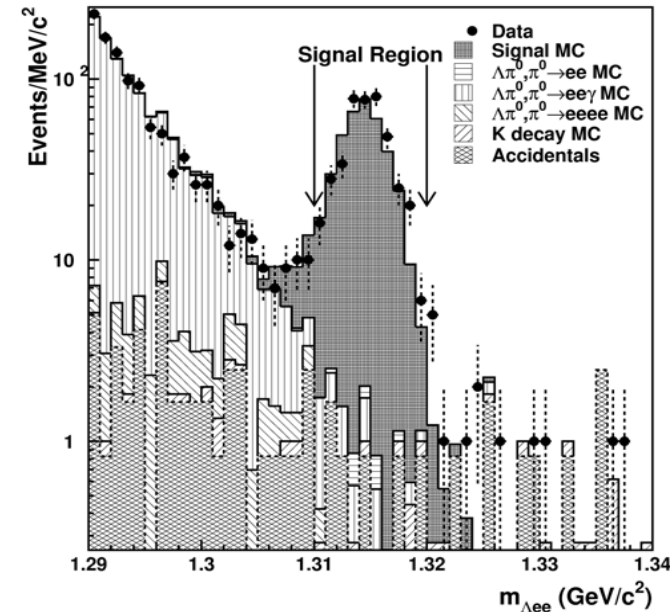
Normalization channel:

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

$$\text{BR}(\Xi \rightarrow \Lambda e e) = 7.7 \pm 0.5_{\text{stat}} \pm 0.4_{\text{syst}} \cdot 10^{-6}$$

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

Phys.Lett.B650:1-8,2007 (hep-ex/0703023)



Conclusion

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

- **NA48/1 results in radiative hyperon decays:**
 - **New measurement of $\Xi^0 \rightarrow \Lambda \gamma$ decay asymmetry**
 - **First evidence of the decay $\Xi^0 \rightarrow \Lambda e^+ e^-$
measurement of BR and decay asymmetry**