

# New results on kaon decays from NA48

Marco Gersabeck

on behalf of the NA48 collaboration

Institut für Physik, Universität Mainz

QCD 2006, Montpellier, 04 July 2006

# New results on kaon decays from NA48

- ▶ The NA48 experiment
- ▶  $K_L \rightarrow \pi^+ \pi^-$  ( $BR$ ,  $|\eta_{+-}|$ )
- ▶  $K_L \rightarrow \pi^\pm \mu^\mp \nu$  (form factors)
- ▶  $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ , (DE, INT)
- ▶ Summary

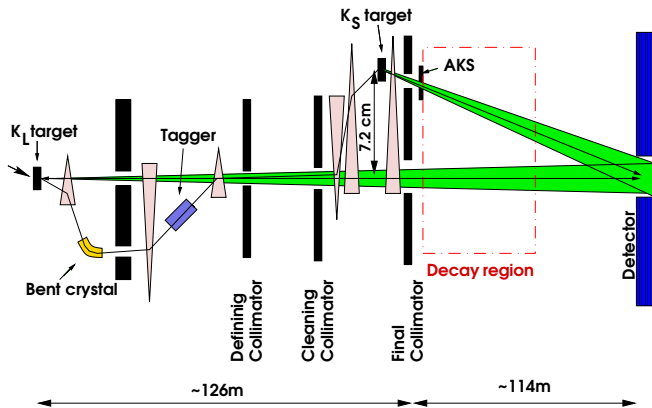
# Data taking periods

- ▶ NA48 (1997-2001)
  - $\Re(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \times 10^{-4}$
  - $K_L$  minimum bias run in 1999
- ▶ NA48/1 (2002)
  - $K_S$  decays
  - hyperon decays (M. Piccini)
- ▶ NA48/2 (2003+2004)
  - CPV in charged kaons (A. Norton)
  - rare decays (radiative,  $K_{l4}$  (B. Bloch-Devau), ...)
  - semileptonic

1997	$\varepsilon'/\varepsilon$ run	$K_L + K_S$
1998	$\varepsilon'/\varepsilon$ run	$K_L + K_S$
1999	$\varepsilon'/\varepsilon$ run $K_L + K_S$	$K_L$ only $K_S$ High Int.
2000	$K_L$ only	$K_S$ High Intensity <i>NO Spectrometer</i>
2001	$\varepsilon'/\varepsilon$ run $K_L + K_S$	$K_S$ High Int.
2002	$K_S$ High Intensity	
2003	$K^\pm$ High Intensity	
2004	$K^\pm$ High Intensity	

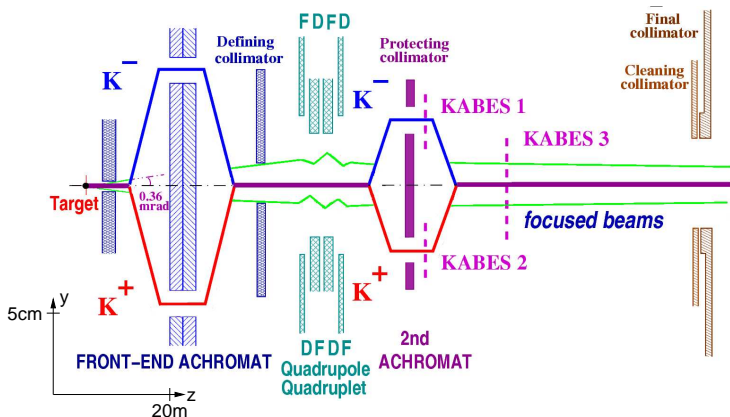
# A beamline for neutral kaons

- ▶ NA48:  $K_L$  and  $K_S$  simultaneously
- ▶ NA48/1:  $K_S$  only



# A beamline for charged kaons

- ▶ NA48/2:  $K^+$  and  $K^-$  simultaneously,  $p_K = (60 \pm 3) \text{ GeV}/c$



# The NA48 detector

## ▶ Magnetic spectrometer

Neutral kaons:

$$\sigma(p)/p \approx 0.5 \% \oplus 0.009 p \%$$

$$p_{\perp}^{kick} = 0.265 \text{ GeV}/c$$

Charged kaons:

$$\sigma(p)/p \approx 1.02 \% \oplus 0.044 p \%$$

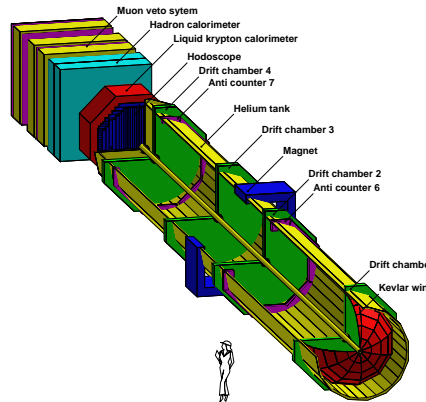
$$p_{\perp}^{kick} = 0.121 \text{ GeV}/c$$

## ▶ Liquid Krypton calorimeter

$$\sigma(E)/E \approx$$

$$3.2 \%/\sqrt{E} \oplus 9 \%/E \oplus 0.42 \%$$

$p$  in GeV/c,  $E$  in GeV



$K_L \rightarrow \pi^+ \pi^-$ 

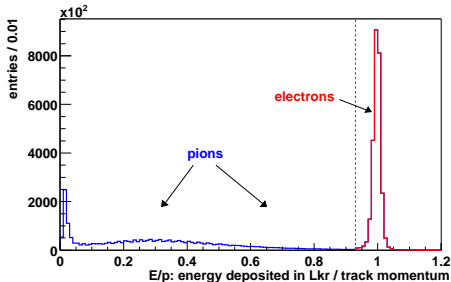
- ▶ Measurement of the ratio  $\Gamma(K_L \rightarrow \pi^+ \pi^-) / \Gamma(K_L \rightarrow \pi^\pm e^\mp \nu)$
- ▶ Extraction of the CP violating parameter  $|\eta_{+-}|$

so far:

- ▶ Poor agreement of KTeV (2004) and KLOE (2006) measurements of  $BR(K_{2\pi})$  and  $|\eta_{+-}|$  with PDG (2004) averages
- ▶ Possibility for clarification:  
Data from special  $K_L$  run in 1999 with simple 2 track trigger

# Event selection

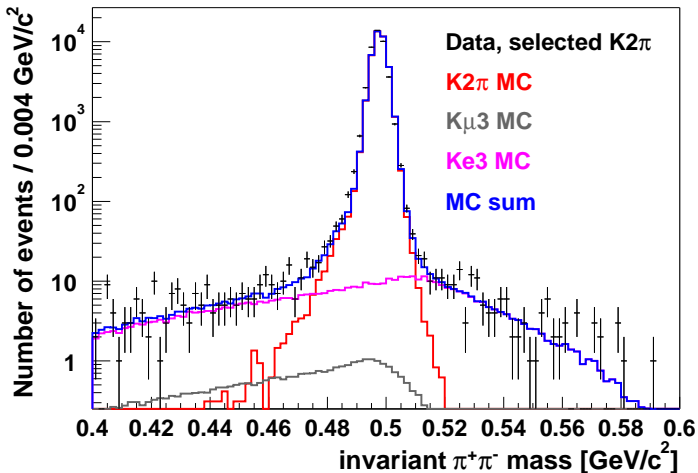
- ▶ 2 good tracks with common vertex in decay region
- ▶  $K_{2\pi}$ :  
 $0.48 \text{ GeV}/c^2 < m_{\pi\pi} < 0.51 \text{ GeV}/c^2$   
small  $p_\perp$ , no muon  
 $E/p < 0.93$  for both tracks  
**41473** selected events
- ▶  $K_{e3}$ :  
one track with  $E/p > 0.93$   
**2663759** selected events



# Corrections

- ▶ Pions producing hits in muon veto
- ▶ Trigger efficiency
- ▶  $E/p$  efficiency
- ▶ background ( $< 0.5\%$  in both channels)
- ▶ Radiative corrections:  
KLOR used for  $K_{e3}$   
PHOTOS (real photon prod. only) used for  $K_{2\pi}$

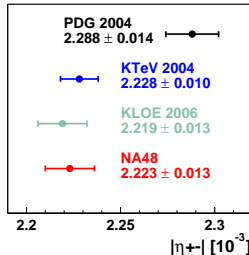
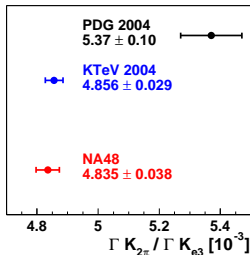
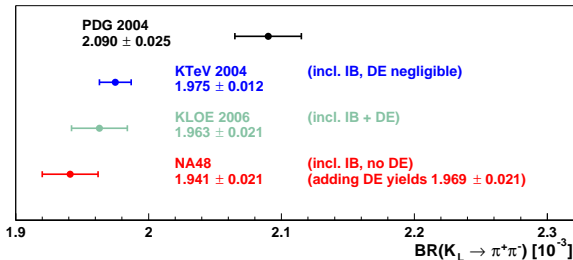
# Reconstructed kaon mass



# Results

- ▶  $\Gamma(K_{2\pi})/\Gamma(K_{e3}) = (4.835 \pm 0.038) \times 10^{-3}$   
 subtract  $(0.180 \pm 0.009)\%$  coming from  $K_L \rightarrow \pi^+ \pi^- \gamma (DE)$
- ▶  $BR(K_L \rightarrow \pi^+ \pi^- + \pi^+ \pi^- \gamma (IB)) = (1.941 \pm 0.021) \times 10^{-3}$   
 using  $BR(K_L \rightarrow \pi e \nu) = 0.4022 \pm 0.0031$   
 (NA48 updated due to change in  $BR(K_L \rightarrow \pi^0 \pi^0 \pi^0)$ )
- ▶  $|\eta_{+-}| = \sqrt{\frac{BR(K_L \rightarrow \pi^+ \pi^-)}{BR(K_S \rightarrow \pi^+ \pi^-)} \cdot \frac{\tau_{KS}}{\tau_{KL}}} = (2.223 \pm 0.013) \times 10^{-3}$   
 using  $\tau_{KS} = (0.89598 \pm 0.00070) \times 10^{-10} \text{ s}$  (NA48 2002),  
 $\tau_{KL} = (5.084 \pm 0.023) \times 10^{-8} \text{ s}$  (KLOE 2006),  
 $BR(K_S \rightarrow \pi^+ \pi^-) = 0.69169 \pm 0.00051$  (KLOE 2006)

# Comparison with other results



# Measurement of form factors

$2.6 \cdot 10^6$  selected  $K_L \rightarrow \pi^\pm \mu^\mp \nu$  events from min. bias  $K_L$  run in 1999

$$\mathcal{M} = \frac{G}{\sqrt{2}} V_{us} [f_+(t)(P_K + P_\pi)^\mu \bar{u}_l \gamma_\mu (1 + \gamma_5) u_\nu + f_-(t) m_l \bar{u}_l (1 + \gamma_5) u_\nu]$$

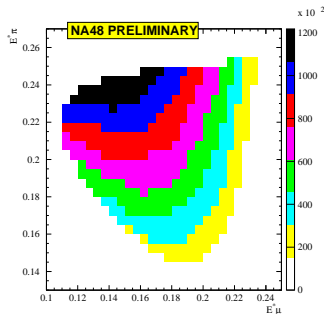
$$f_0(t) = f_+(t) + \frac{t}{(m_K^2 - m_\pi^2)} f_-(t), \quad \text{with} \quad f_{\pm 0}(t) = f_{\pm 0}(0)(1 + \lambda_{\pm 0} t/m_\pi^2)$$

for  $f_{+0}(t)$  to be linear in  $t = (P_K - P_\pi)^2$ ,  $\lambda_-$  has to be 0

Preliminary results from dalitz plot fit:

$$\lambda_+ = 0.0260 \pm 0.0007_{stat} \pm 0.0010_{syst}$$

$$\lambda_0 = 0.0120 \pm 0.0008_{stat} \pm 0.0015_{syst}$$



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

Measurement of Inner Bremsstrahlung (IB), Direct Emission (DE), and their Interference (INT) in the decay  $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$

$$\Gamma \sim \underbrace{\frac{p_\pi^2 \sin^2 \theta}{(m_K/2 - \omega_0)^2}}_{IB} \left[ 1 + \underbrace{2 \left( \frac{m_\pi}{m_K} \right)^2 W^2 |E| \cos(\delta \pm \phi)}_{INT} + \underbrace{\left( \frac{m_\pi}{m_K} \right)^4 W^4 (|E|^2 + |M|^2)}_{DE} \right]$$

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

INT only due to electric amplitude E,  
DE caused by electric *and* magnetic amplitude

# Method

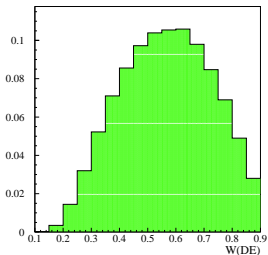
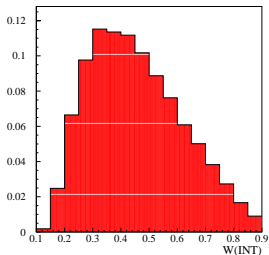
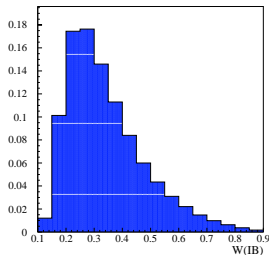
- ▶ IB: soft  $\gamma$  radiated off from  $\pi$
- ▶ DE: hard  $\gamma$  produced in decay vertex
- ▶ W is product of  $\gamma$  energy in pion and kaon CMS respectively
- ▶ W distribution different for IB and DE
- ▶ Fit W distribution to obtain relative contributions of IB, DE and INT

# W distributions (MC)

IB

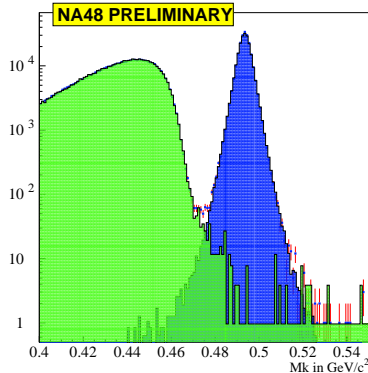
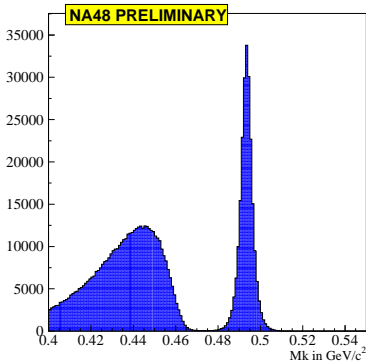
INT

DE



# Reconstructed kaon mass

230317 selected  $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$  events with  
 $0.48 \text{ GeV}/c^2 < m_K < 0.51 \text{ GeV}/c^2$   
from  $\sim 1$  month data taking in 2003



# W distribution (data)

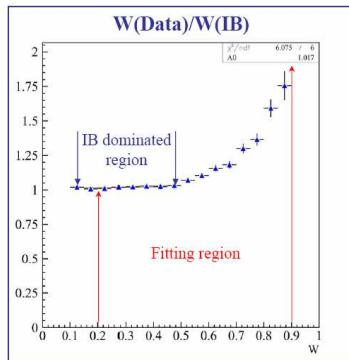
Further cuts:

$E_\gamma > 5$  GeV to avoid large L1 trigger inefficiencies

$0.2 < W < 0.9$  to avoid resolution effects at very low/high values for W

$0 \text{ MeV} < T_\pi^* < 80 \text{ MeV}$ , upper cut due to trigger cut against  $K^\pm \rightarrow \pi^\pm \pi^0$  events, lower cut applied by other experiments to suppress  $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$  events not necessary

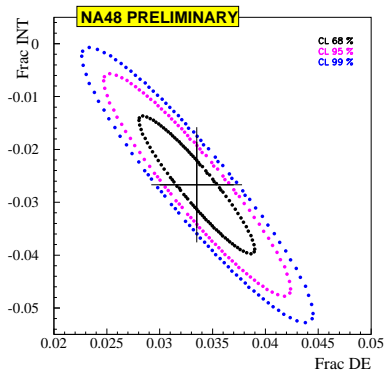
result:  $\sim 124000$  events used for fit



# Preliminary result

$$\text{frac}(DE) = (3.35 \pm 0.35_{\text{stat}} \pm 0.25_{\text{syst}})\%$$

$$\text{frac}(INT) = (-2.67 \pm 0.81_{\text{stat}} \pm 0.73_{\text{syst}})\%$$



For comparison: Fit with  $INT = 0$  and  $55 \text{ MeV} < T_\pi^* < 90 \text{ MeV}$  results in a value  $\sim 1.5\sigma$  lower than BNL E787 (2005) and KEK E470 (2006).

## ► Summary

- $K_L \rightarrow \pi^+ \pi^-$ : results contradicting PDG04 confirmed
- $K_L \rightarrow \pi^\pm \mu^\mp \nu$ : precise form factor measurement
- $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$ :  $3\sigma$  evidence for INT

## ► Outlook

- Some analyses on neutral kaons still ongoing
- Many more rare and semileptonic charged kaon decays being analysed, partly close to publication
- More results in the following talks
- Future experiment to measure  $K^\pm \rightarrow \pi^\pm \nu \bar{\nu}$  in R&D phase