

Perugia



Recent results of the NA48 experiment

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On behalf of the NA48 Collaboration

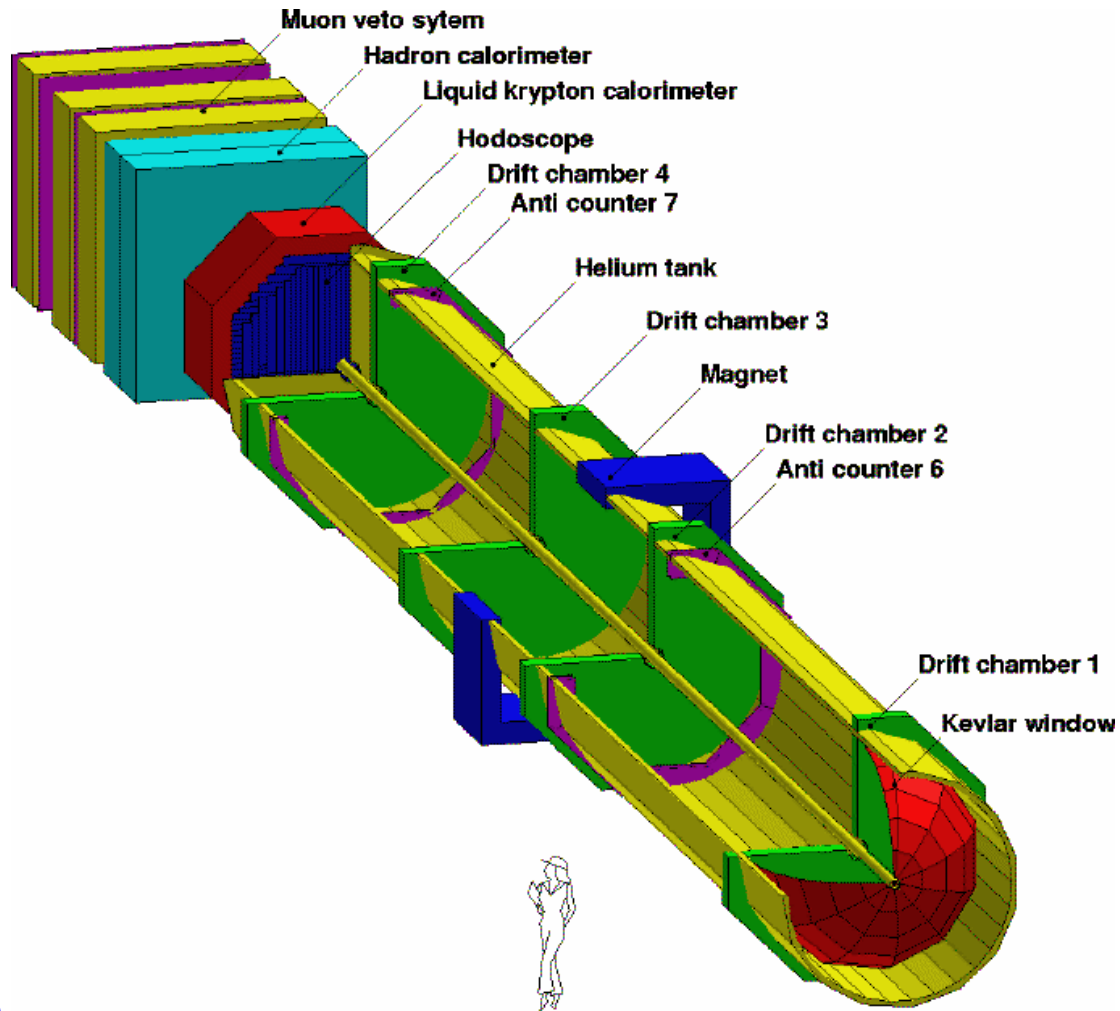
XLIInd Rencontres de Moriond EW

La Thuile 13/03/2007

Outline

- o NA48 history and detector
- o NA48/2 recent results in charged Kaon decays
 - o Dalitz plot asymmetry in $K_{3\pi c}$ and $K_{3\pi n}$
 - o First evidence of INT term in $K^{\pm} \rightarrow \pi^{\pm} \pi^0 \gamma$
 - o First measurement of $K^{\pm} \rightarrow \pi^{\pm} e^+ e^- \gamma$
 - o Measurement of semileptonic decay rates and V_{us}
 - o Lepton universality in $R_K = K_{e2}/K_{\mu2}$
- o NA48/1 hyperons
 - o First measurement of the $\Xi^0 \rightarrow \Lambda e^+ e^-$
- o NA48 results in K_L decays
 - o $K_{L\mu3}$ form factors

NA48 detector



LKr EM calorimeter

$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{0.1}{E} \oplus 0.5\%$$

$$\sigma_{x,y} < 1.3\text{mm}$$

Spectrometer

- 4 Drift Chambers
- Magnet

$$\frac{\sigma(p)}{p} = 1.0\% \oplus 0.044 \times p(\text{GeV})$$

$$\sigma_{VTX}^{x,y} \sim 2\text{mm}$$

10 years of History

NA48(1997-2001):

Direct CP-Violation in neutral K

$$> \text{Re}(\varepsilon'/\varepsilon) = (14.7 \pm 2.2) \cdot 10^{-4}$$

NA48/1(2002):

Rare K_S decays and hyperons

NA48/2(2003-2004):

Direct CP-Violation in charged K

$$> A_g(K^\pm \rightarrow \pi^\pm \pi^+ \pi^-) \quad (K_{3\pi C})$$

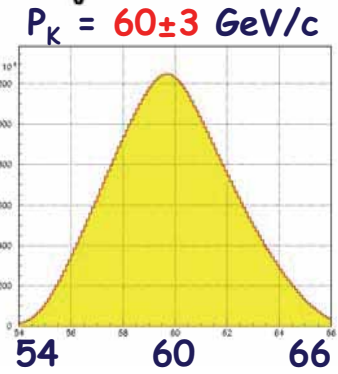
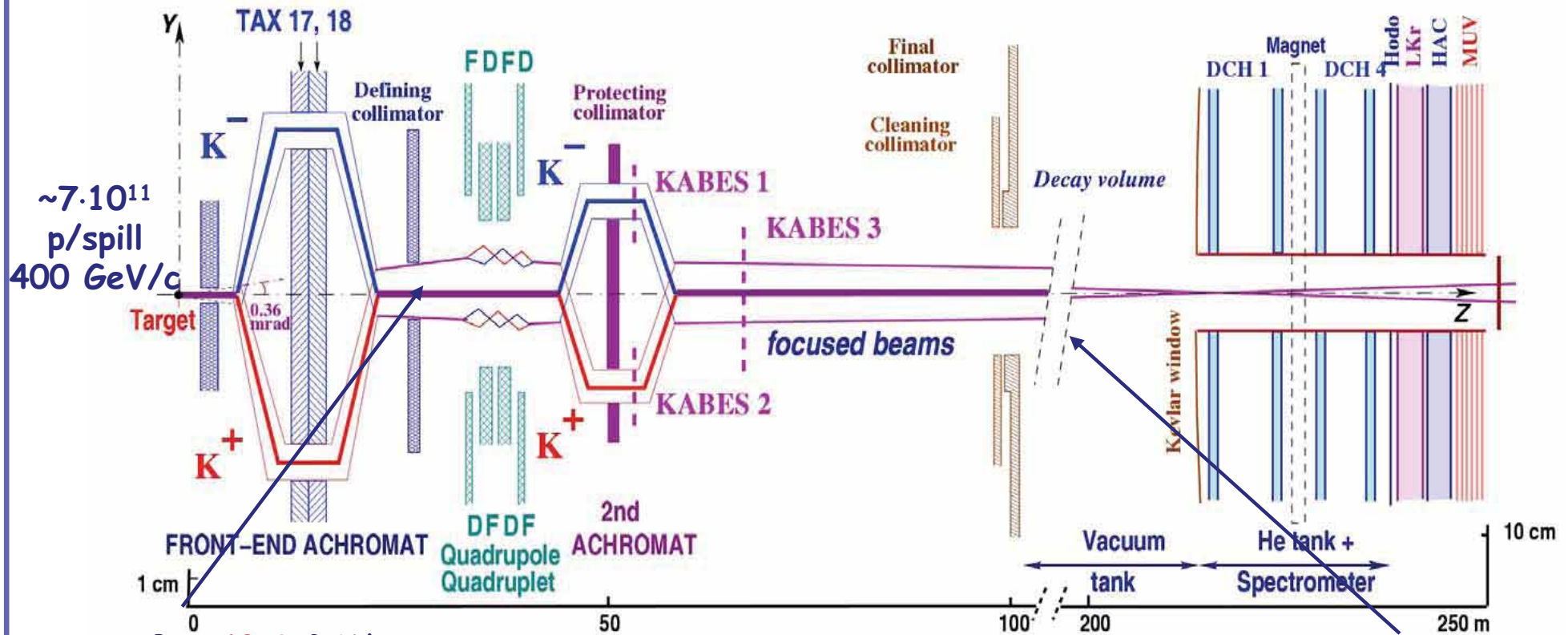
$$> A_g(K^\pm \rightarrow \pi^\pm \pi^0 \pi^0) \quad (K_{3\pi n})$$

...and many other results in semileptonic and rare decays

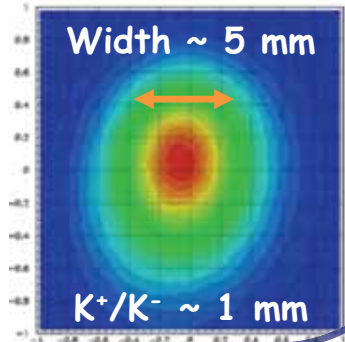
1997 1998	ε'/ε run $K_L + K_S$	$K_L + K_S$
1999	ε'/ε run $K_L + K_S$	K_S Hi. Int.
2000	K_L only <i>NO Spectrometer</i>	K_S High Intensity
2001	ε'/ε run $K_L + K_S$	K_S High Int.
2002	K_S High Intensity	
2003 2004	K^\pm High Intensity	

NA48/2 charged Kaon decays

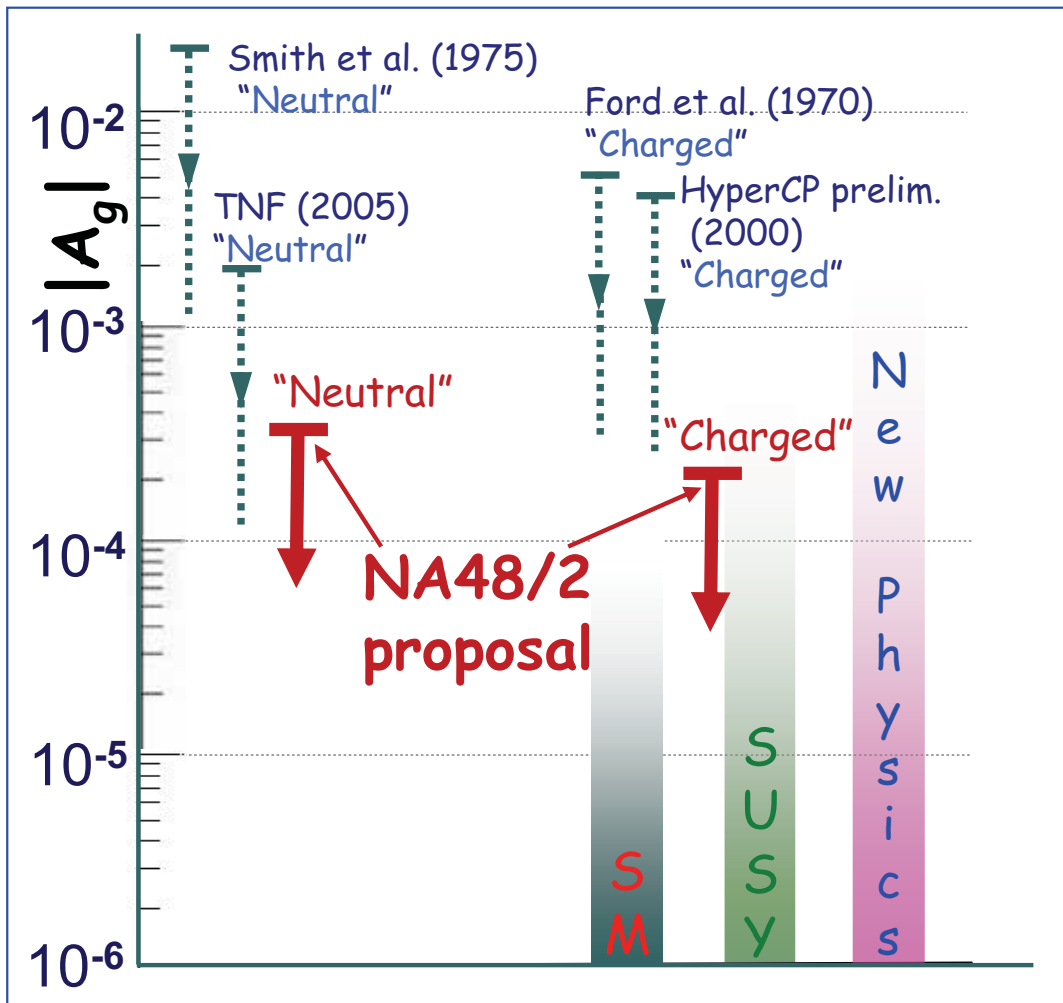
Simultaneous K^\pm Beam



Simultaneous K^+ and K^- beams:
 Flux ratio: $K^+/K^- \sim 1.8$
 large charge symmetrization of
 experimental conditions



Measuring $|A_g|$



Kinematic variables:

$$s_i = (P_K - P_{\pi i})^2, i = 1-3 \quad (3 = \pi_{\text{odd}})$$

$$s_0 = (s_1 + s_2 + s_3) / 3$$

$$u = (s_3 - s_0) / m_{\pi}^2$$

$$v = (s_2 - s_1) / m_{\pi}^2$$

Matrix element expansion:

$$|M(u,v)|^2 \sim 1 + gu + hu^2 + kv^2$$

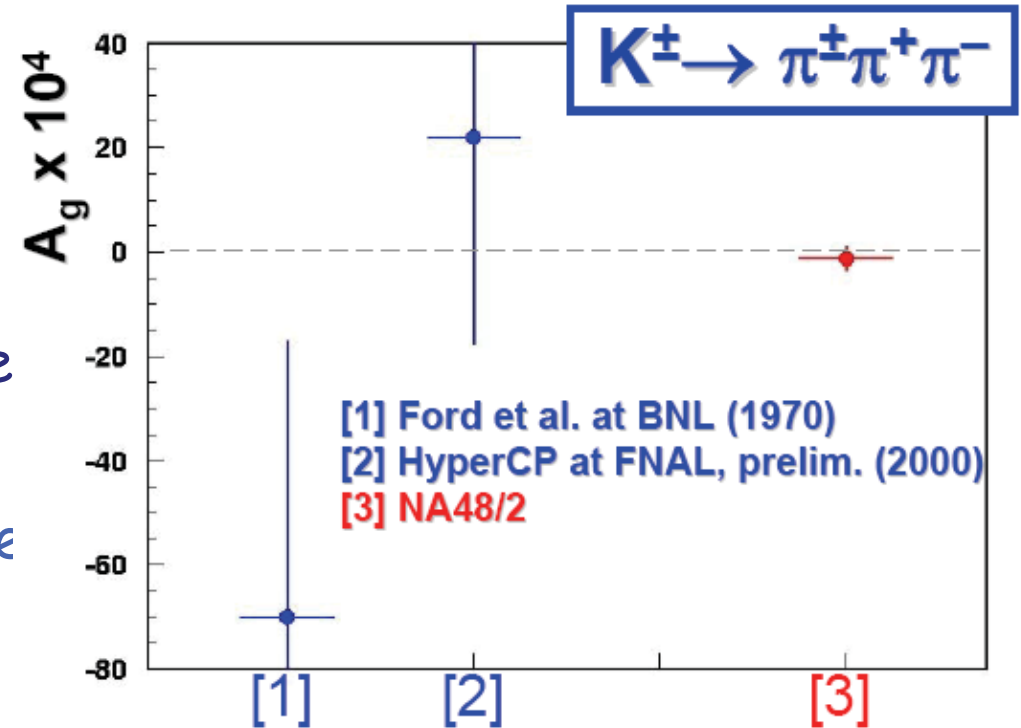
Direct CP violating quantity:
slope asymmetry

$$A_g = (g^+ - g^-) / (g^+ + g^-) \neq 0$$

SM theoretical prediction: $10^{-6} \div 5 \cdot 10^{-5}$

Latest result in $K_{3\pi C}$ asymmetry

- > $3.1 \cdot 10^9 K_{3\pi C}$: 2.0 K^+ 1.1 K^-
- > A factor ~ 20 better precision than previous measurements
- > Statistical uncertainties dominate
- > No CP violation observed
- > Result compatible with the Standard Model predictions



Final 2003+2004

2003 + 2004 FINAL RESULT

$$A_g = (-1.5 \pm 1.5_{\text{stat}} \pm 0.9_{\text{trig}} \pm 1.1_{\text{syst}}) \cdot 10^{-4}$$

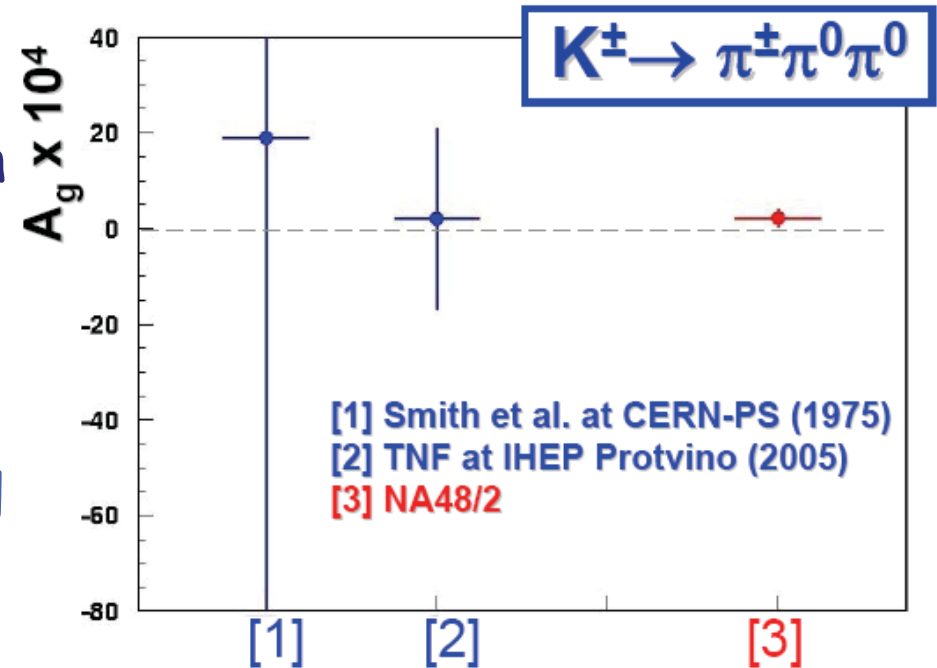
$$= (-1.5 \pm 2.1) \cdot 10^{-4}$$

Final 2003 result published:
 PLB634 (2006) 474-482

Based on the full 2003+2004 data sample

Latest result in $K_{3\pi n}$ asymmetry

- > $91 \cdot 10^6 K_{3\pi n}$: 59 K^+ 32 K^-
- > A factor ~ 10 higher precision than the previous measurements
- > Statistical uncertainties dominate
- > No CP violation found.
- > Compatible with the Standard Model predictions



Final 2003+2004

2003 + 2004 FINAL RESULT

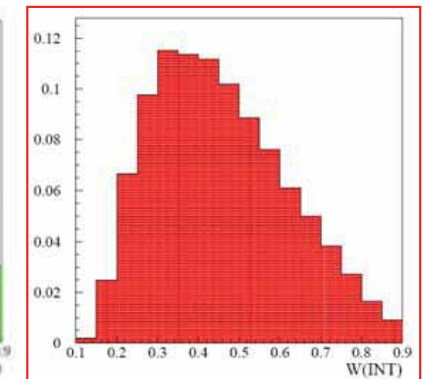
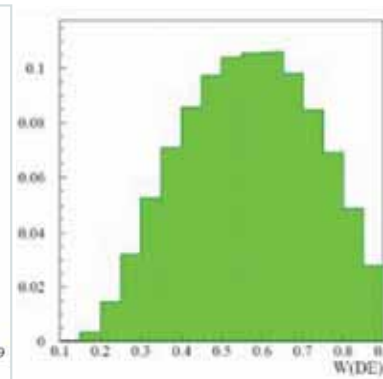
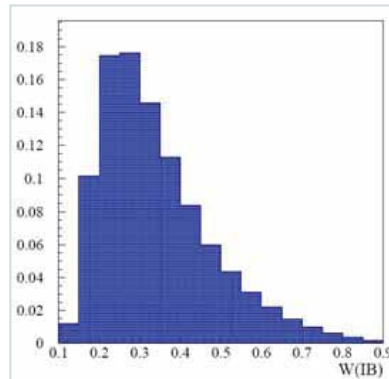
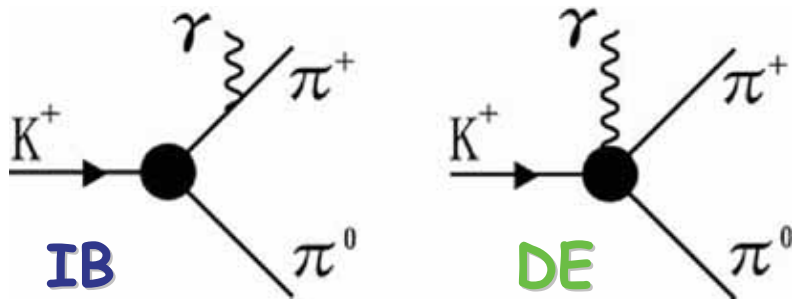
$$A_g = (1.8 \pm 1.7_{\text{stat}} \pm 0.5_{\text{syst}}) \cdot 10^{-4}$$

$$= (1.8 \pm 1.8) \cdot 10^{-4}$$

Final 2003 result published:
 PLB638 (2006) 22-29

Based on the full 2003+2004 data sample

The radiative decay $K^\pm \rightarrow \pi^\pm \pi^0 \gamma$



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

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

- Inner Bremsstrahlung (IB) : $(2.75 \pm 0.15) \cdot 10^{-4}$ PDG ($55 < T_\pi^* < 90$ MeV)
- Direct Emission (DE) : $(4.4 \pm 0.8) \cdot 10^{-6}$ PDG ($55 < T_\pi^* < 90$ MeV)
- Interference (INT) : not yet measured

All measurements have been performed with INT set to zero!

What's new in this measurement

Both K^+ and K^- (can check the CP)

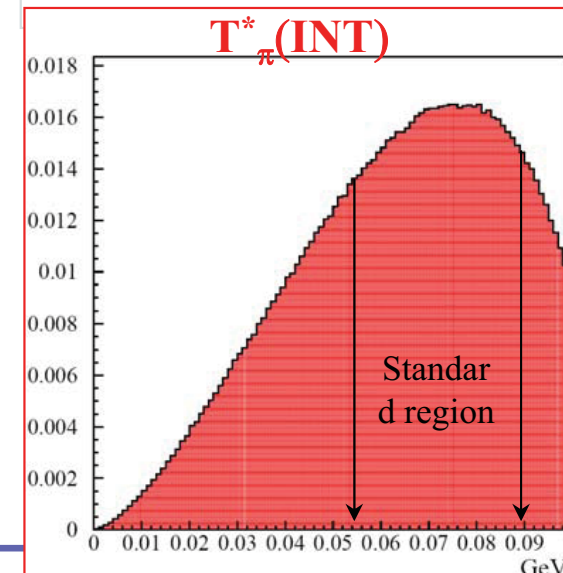
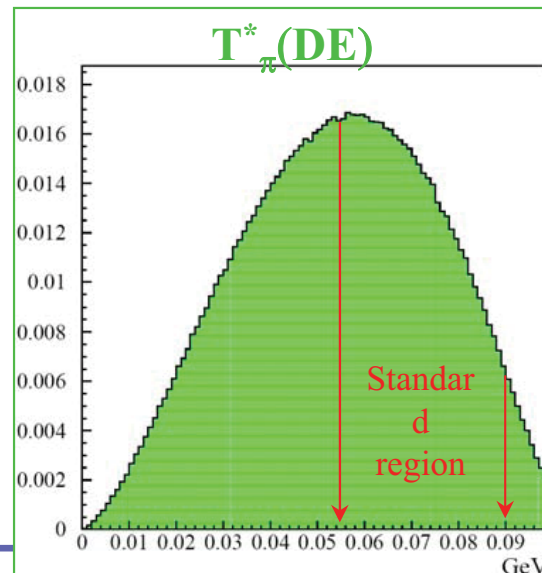
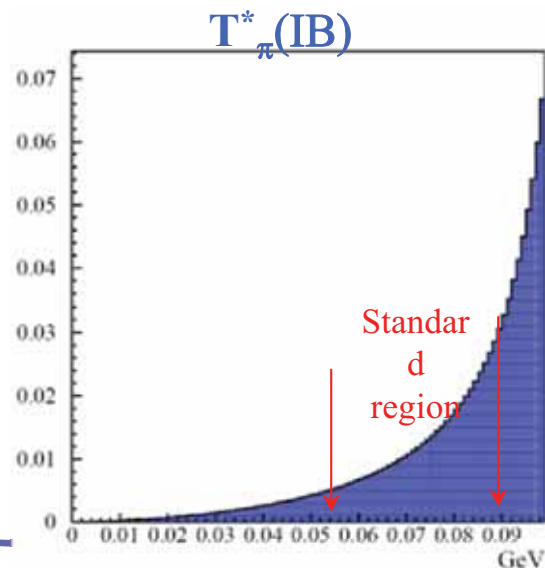
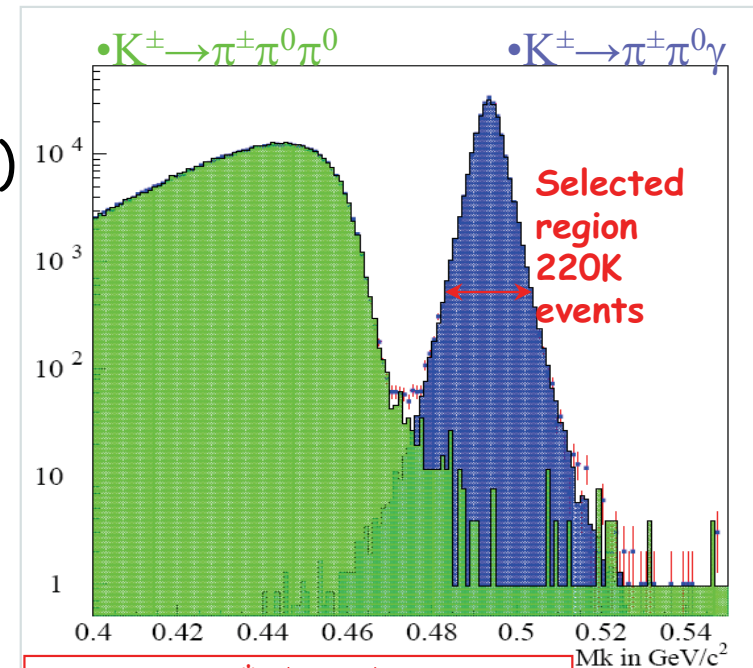
Very high statistics (124K events part of '03 only)

Enlarged T_π^* region ($0 < T_\pi^* < 80$ MeV)

Negligible background < 1% of the DE component

More bins in the fit to enhance sensitivity to INT

Order % γ mistagging for IB, DE and INT



DE and INT measurement

Fit performed with free INT term
Use extended ML for $0.2 < W < 0.9$ range

Fit the W data spectrum using MC shapes:

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

Systematic dominated by Trigger efficiency.

First evidence of non zero INT term!

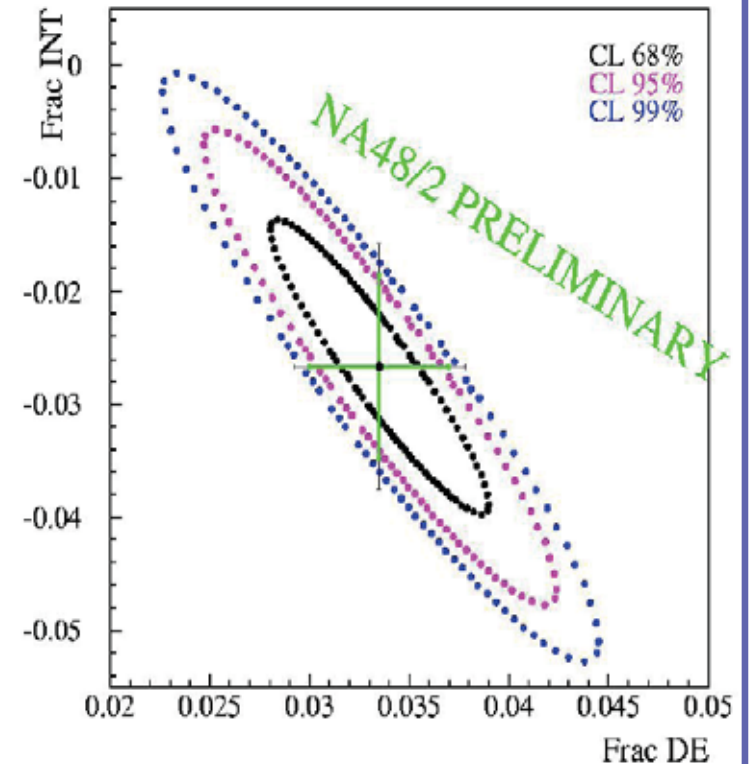
Parameters are highly correlated $\rho = -0.92$

Preliminary 2003

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

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

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



First observation of $K^\pm \rightarrow \pi^\pm e^+ e^- \gamma$

Never observed before

Quite similar to the decay $K^\pm \rightarrow \pi^\pm \gamma \gamma$

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 (Gabbiani 99):

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

Event sample:

92 candidates events with

1±1 accidental background

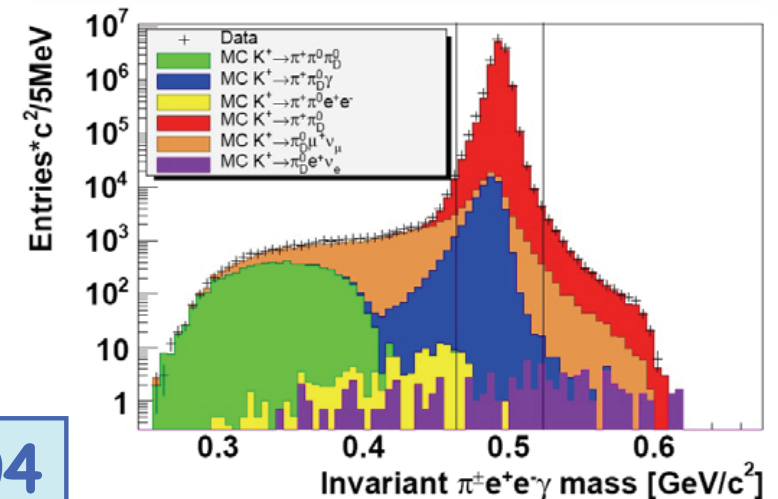
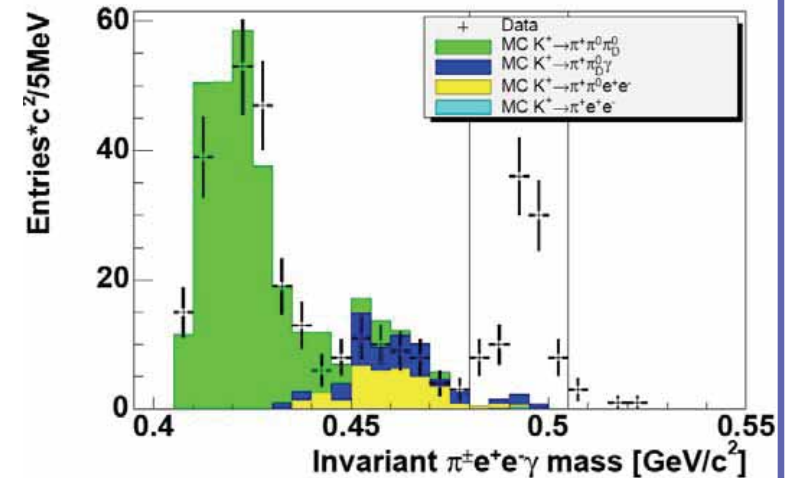
5.1±1.7 physical background

Normalization channel:

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

Preliminary 2003+2004

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



Semileptonic decays: $K_{e3}^\pm, K_{\mu3}^\pm$

Each BR is needed for the global fit to V_{us} in the CKM matrix

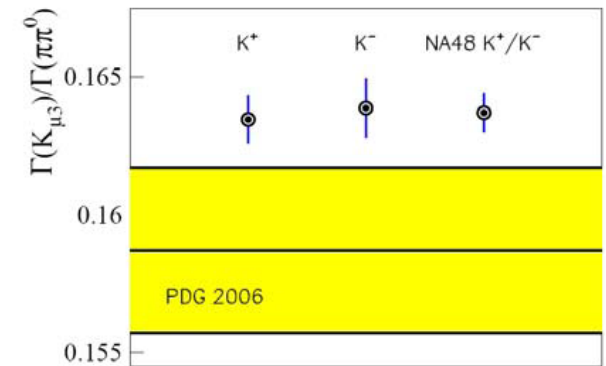
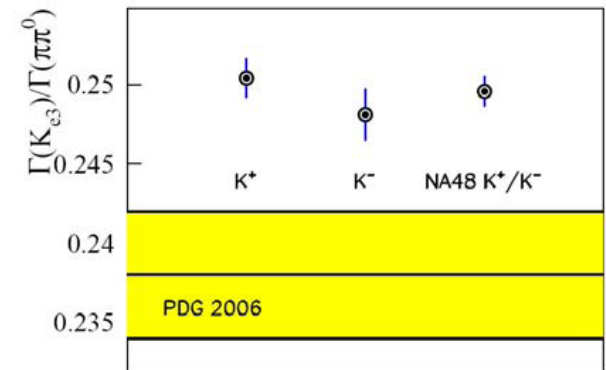
#events	K^+	K^-
K_{e3}	56000	31000
$K_{\mu3}$	49000	28000
$K_{2\pi}$	462000	256000

Ratios of the decay amplitudes:

$$\begin{aligned} \text{Br}(K_{e3})/\text{Br}(K_{2\pi}) &= 0.2496 \pm 0.0009_{\text{stat}} \pm 0.0004_{\text{syst}} \\ \text{Br}(K_{\mu3})/\text{Br}(K_{2\pi}) &= 0.1637 \pm 0.0006_{\text{stat}} \pm 0.0003_{\text{syst}} \\ \text{Br}(K_{\mu3})/\text{Br}(K_{e3}) &= 0.656 \pm 0.003_{\text{stat}} \pm 0.001_{\text{syst}} \end{aligned}$$

Using as normalization $\text{BR}(K^\pm \rightarrow \pi^\pm \pi^0) = (20.92 \pm 0.12)\%$ PDG '06:

$$\begin{aligned} \text{Br}(K_{e3}) &= (5.221 \pm 0.019_{\text{stat}} \pm 0.008_{\text{syst}} \pm 0.030_{\text{norm}})\% \\ \text{Br}(K_{\mu3}) &= (3.425 \pm 0.013_{\text{stat}} \pm 0.006_{\text{syst}} \pm 0.020_{\text{norm}})\% \end{aligned}$$



Extraction of V_{us}

Evaluate $|V_{us}|f_+(0)$ for both modes:

$$|V_{us}|f_+(0) = \sqrt{\frac{384\pi^3\Gamma(K_{l3})}{G_F^2 m_K^5 S_{EW} I_K^l (1 + \delta_K^l)}}$$

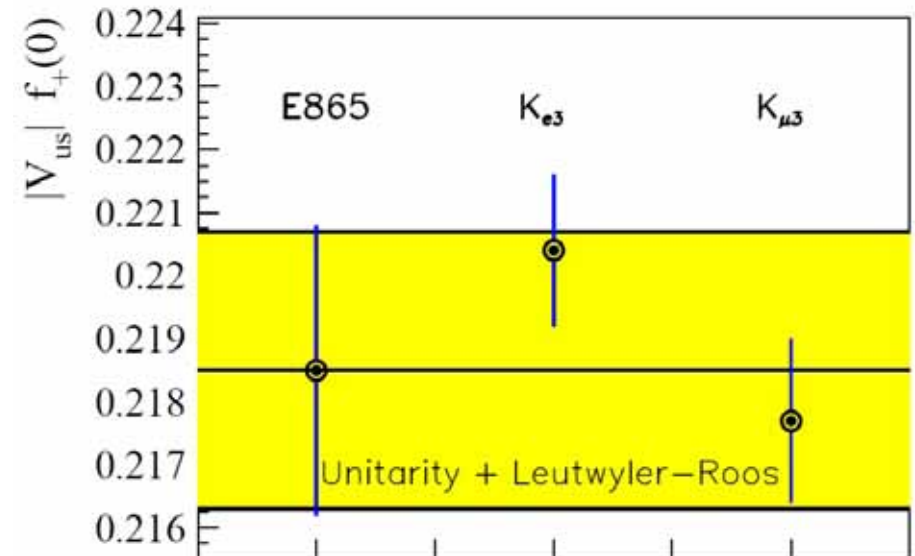
$$K_{e3}: |V_{us}|f_+(0) = 0.2204 \pm 0.0012$$

$$K_{\mu3}: |V_{us}|f_+(0) = 0.2177 \pm 0.0013$$

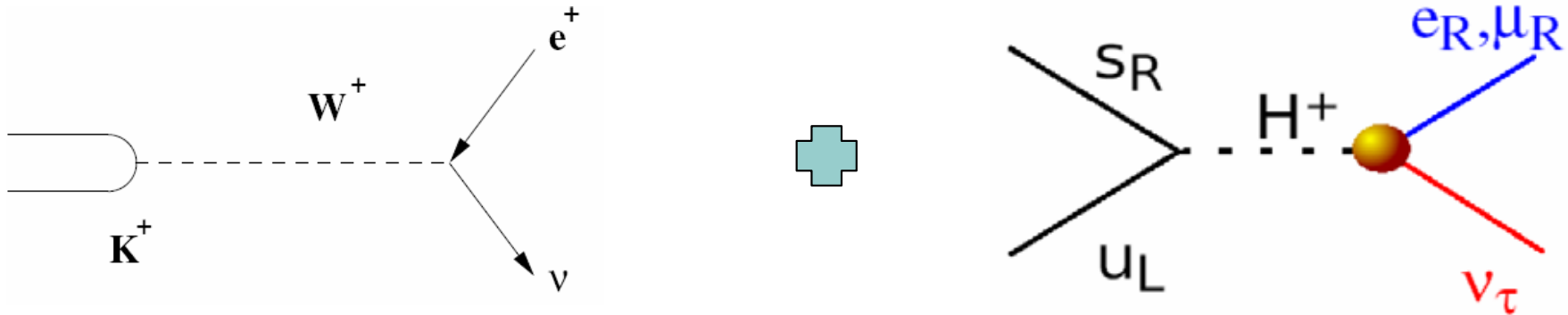
Combine the two results, assuming lepton universality and using $f_+(0)$ from neutral K we get:

$$|V_{us}|f_+(0) = 0.2197 \pm 0.0012$$

$$|V_{us}| = 0.2289 \pm 0.0023$$



SUSY LFV mechanism $K_{e2}/K_{\mu2}$



$$R_{K_{\bullet}}^{LFV} = \frac{\sum_i \Gamma(K \rightarrow e\nu_i)}{\sum_i \Gamma(K \rightarrow \mu\nu_i)} \simeq \frac{\Gamma_{SM}(K \rightarrow e\nu_e) + \Gamma(K \rightarrow e\nu_\tau)}{\Gamma_{SM}(K \rightarrow \mu\nu_\mu)}, \quad i = e, \mu, \tau$$

If $\tan\beta=40$ and $M_{H^\pm}=500 \text{ GeV}$ with $|\Delta_R^{31}|^2 = 5 \cdot 10^{-4}$

$$\Delta r_{K \text{ SUSY}}^{e-\mu} \simeq \left(\frac{m_K^4}{M_{H^\pm}^4} \right) \left(\frac{m_\tau^2}{m_e^2} \right) |\Delta_R^{31}|^2 \tan^6 \beta \approx 10^{-2}$$

A. Masiero: CERN TH seminar

The effect can be as high as 2% and therefore measurable
 PR D74 (2006) 011701 (A. Masiero et al.)

NA48/2 $K_{e2}/K_{\mu2}$ in 2003

Selected events:

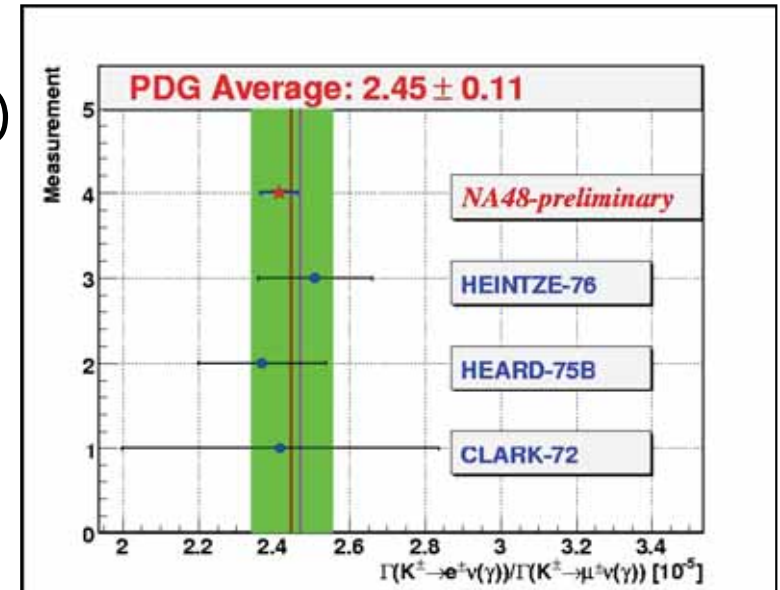
5329 K_{e2} candidates (~14% BG mainly from $K_{\mu2}$)

619179 $K_{\mu2}$ (with negligible background)

Main background source high energy muon Bremsstrahlung in the LKr calorimeter

Analysis of 2004 data in ongoing ...

Preliminary 2003



$$R_K = (2.416 \pm 0.043_{\text{stat}} \pm 0.024_{\text{sys}}) \cdot 10^{-5}$$

2% tot err

Dedicated 2007 run:

- Statistical error <0.7%
- Direct measurement of muon Bremsstrahlung spectrum in data
- Final result total error <1%

$R_{e2}/R_{\mu2}$ measurement physics

Test of lepton universality

V-A couplings

Within SM

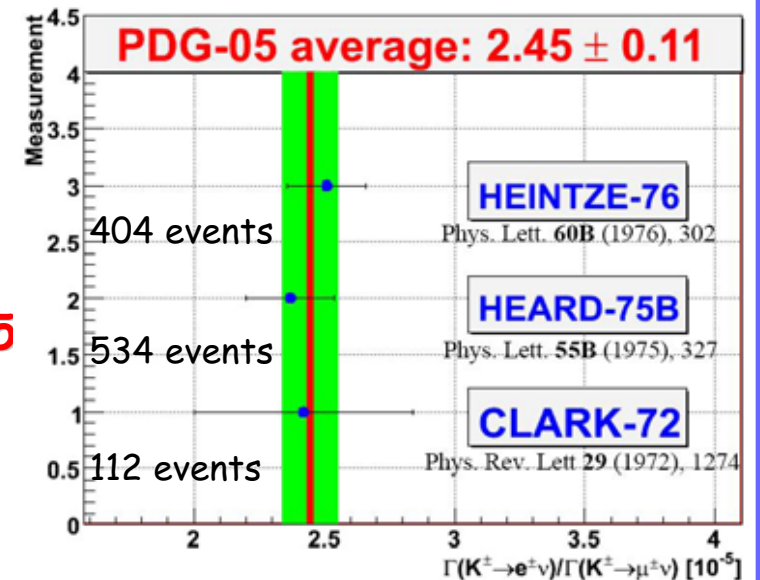
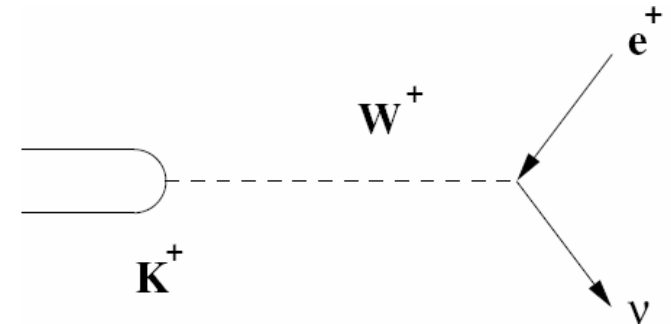
$$R_K = \frac{\Gamma(K \rightarrow e\nu(\gamma))}{\Gamma(K \rightarrow \mu\nu(\gamma))} = \frac{m_e^2}{m_\mu^2} \left(\frac{m_K^2 - m_e^2}{m_K^2 - m_\mu^2} \right)^2 (1 + \delta R_K)$$

Theoretical prediction for

$$R_K = R_K(0)(1 + \delta R_K) = (2.472 \pm 0.001) \cdot 10^{-5}$$

PDG average: $R_K = (2.45 \pm 0.11) \cdot 10^{-5}$

Experimental error 100 times bigger wrt theoretical



NA48 and NA48/1 Neutral Kaons and Hyperons

Physics interest $K_{L\mu 3}$ form factors

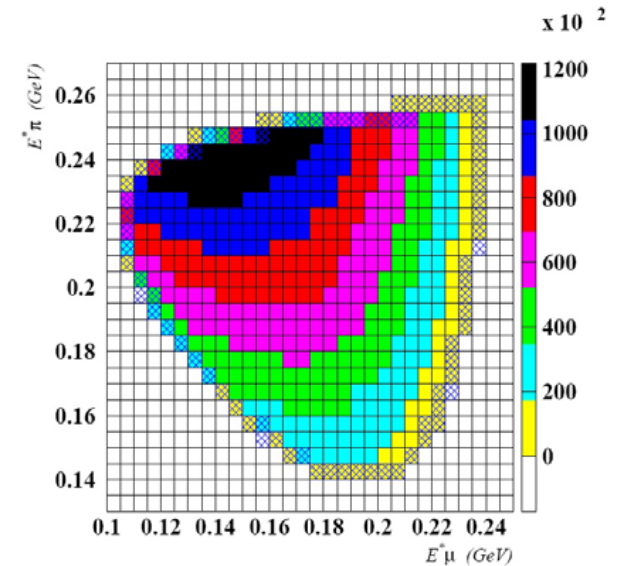
Physics interest:

K_{l3} decays provide cleanest way to extract $|V_{us}|$ in CKM matrix
 $f_+(0)$ in $|V_{us}|f_+(0)$ can be experimentally constrained from the slope and curvature of f_0 from $K_{\mu 3}$
 form factors needed to calculate phase space integrals
 (needed for $|V_{us}|$ extraction)

Data set used:

Dedicated NA48 run in 99: $\sim 2.3 \times 10^6$ $K_{\mu 3}$ candidates

Form factors extracted by studying the Dalitz plot density



$$\rho(E_\mu^*, E_\pi^*) = \frac{dN^2(E_\mu^*, E_\pi^*)}{dE_\mu^* dE_\pi^*} \propto Af_+^2(t) + Bf_+(t)f_-(t) + Cf_-^2(t)$$

$$f_{+,0}(t) = f_+(0) \left[1 + \lambda'_{+,0} t/m_\pi^2 + \frac{1}{2} \lambda''_{+,0} (t/m_\pi^2)^2 \right].$$

Form factors fit results

Vector form factor slopes:

$$\lambda'_+ = (20.5 \pm 2.2_{\text{stat}} \pm 2.4_{\text{syst}}) \cdot 10^{-3}$$

$$\lambda''_+ = (2.6 \pm 0.9_{\text{stat}} \pm 1.0_{\text{syst}}) \cdot 10^{-3}$$

Scalar form factor slope:

$$\lambda_0 = (9.5 \pm 1.1_{\text{stat}} \pm 0.8_{\text{syst}}) \cdot 10^{-3}$$

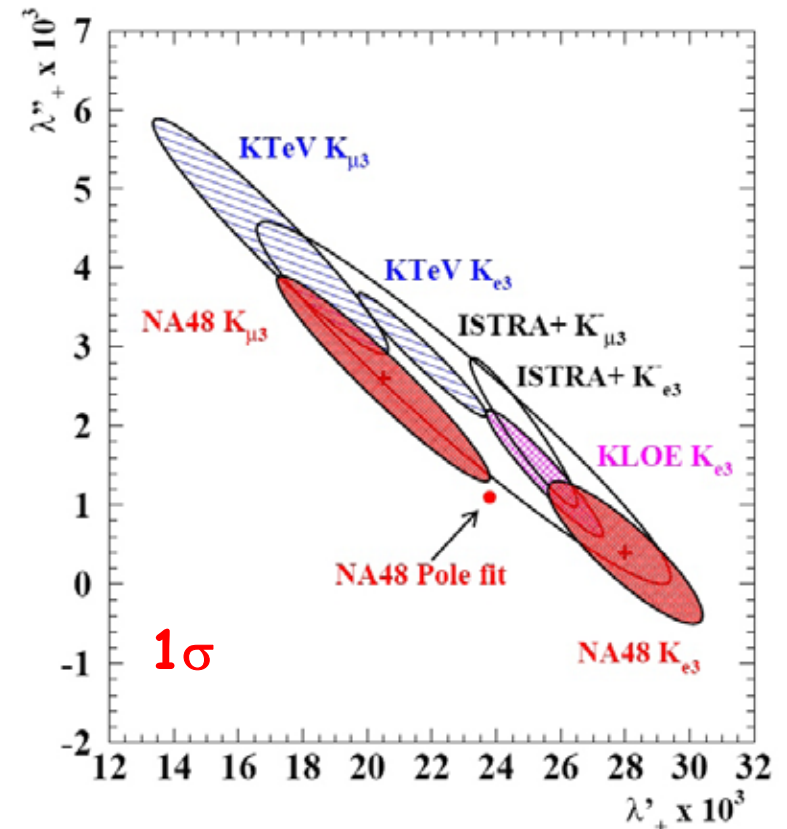
Using linear fits:

$$\lambda_+ = (26.7 \pm 0.6_{\text{stat}} \pm 0.8_{\text{syst}}) \cdot 10^{-3}$$

(well compatible with the recent KTeV measurement)

$$\lambda_0 = (11.7 \pm 0.7_{\text{stat}} \pm 1.0_{\text{syst}}) \cdot 10^{-3}$$

(shifted towards lower values)



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

From 2002 (K_S high intensity) data set

412 candidates

15 events background

Branching ratio of $\Xi^0 \rightarrow \Lambda^0 e^+ e^-$:

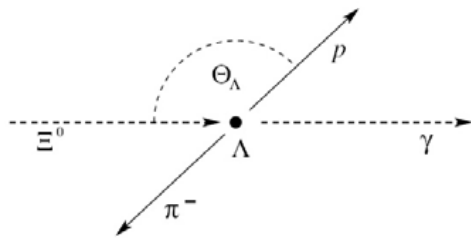
$$(7.7 \pm 0.5_{\text{stat}} \pm 0.4_{\text{syst}}) \cdot 10^{-6}$$

systematics dominated by acceptance, polarization and signal modeling

Decay asymmetry measured (preliminary):

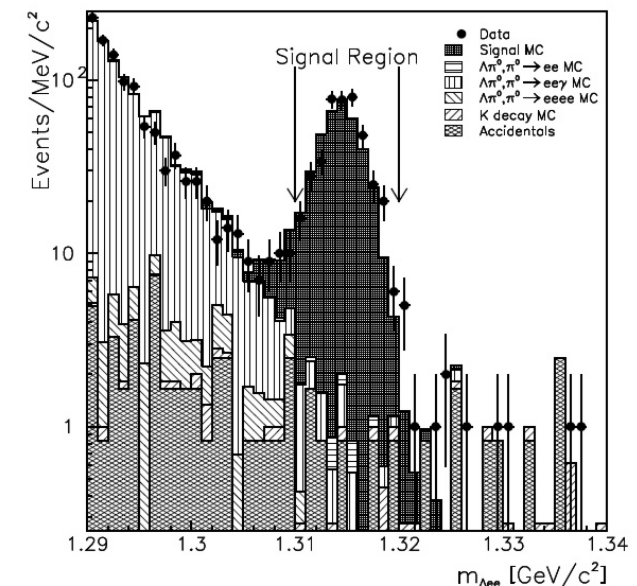
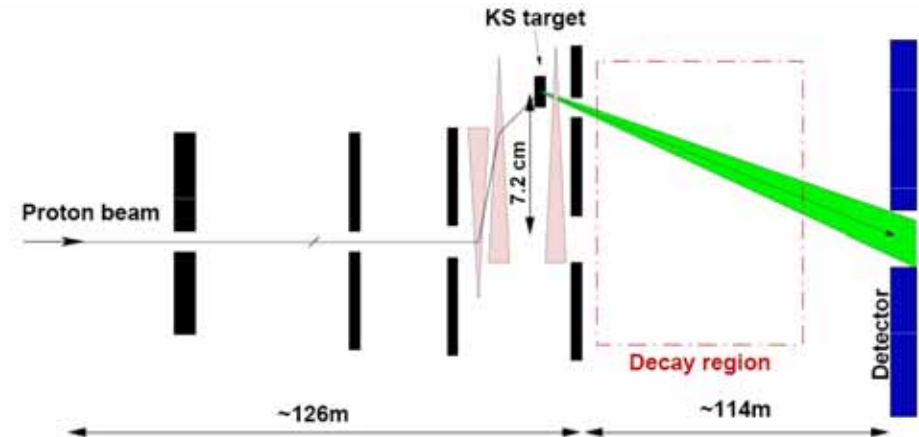
$$\alpha_{\Xi} \alpha_{\Lambda} (\Lambda e e) = -0.8 \pm 0.2$$

consistent with $\Xi \rightarrow \Lambda \gamma$



$$dN/d\cos\Theta_{\Lambda} = N_0(1 - \alpha_{\Xi} \alpha_{\Lambda} \cos\Theta_{\Lambda})$$

NA48/1 Beam line



Conclusion

- o NA48/2 recent results in charged Kaon decays
 - o Final result in Dalitz plot asymmetry in $K_{3\pi C}$ and $K_{3\pi n}$
 - o First evidence of non 0 INT term in $K^{\pm} \rightarrow \pi^{\pm} \pi^0 \gamma$
 - o First measurement of $K^{\pm} \rightarrow \pi^{\pm} e^+ e^- \gamma$
 - o Measurement of semileptonic decay rates and V_{us}
 - o Lepton universality in $R_K = K_{e2} / K_{\mu 2}$
- o NA48/1 hyperons
 - o First measurement of the $\Xi^0 \rightarrow \Lambda e^+ e^-$ and decay asymmetry
- o NA48 results in K_L decays
 - o $K_{L\mu 3}$ form factors

... and more to come in Moriond QCD: $a_0 - a_2$ in cusp & K^{\pm}_{e4} , Dalitz plot slopes

Backup slides

Measurement Strategy

Integrated over v , A_g can be extracted from a fit to the ratio $R(u)$ using the PDG value for g :

$$\Delta g = g^+ - g^- \ll 1$$

$$R(u) = \frac{N^+(u)}{N^-(u)} = n \frac{1 + g^+ \cdot u + h \cdot u^2 + \dots}{1 + g^- \cdot u + h \cdot u^2 + \dots} \sim n \left[1 + \frac{\Delta g \cdot u}{1 + g \cdot u + h \cdot u^2} \right] \rightarrow A_g = \Delta g / 2g$$

- > **Quadruple ratio:** global time instabilities + local beam line biases and left-right detector asymmetry cancellation

$$R = R_{US} \times R_{UJ} \times R_{DS} \times R_{DJ} \Rightarrow f_4(u) = n^4 \cdot (1 + \Delta g \cdot u)^4$$

The method is independent of K^+/K^- flux ratio and relative sizes of the samples (important: simultaneous beams)