Recent results of the NA48 experiment

Mauro Raggi
On behalf of the NA48 Collaboration

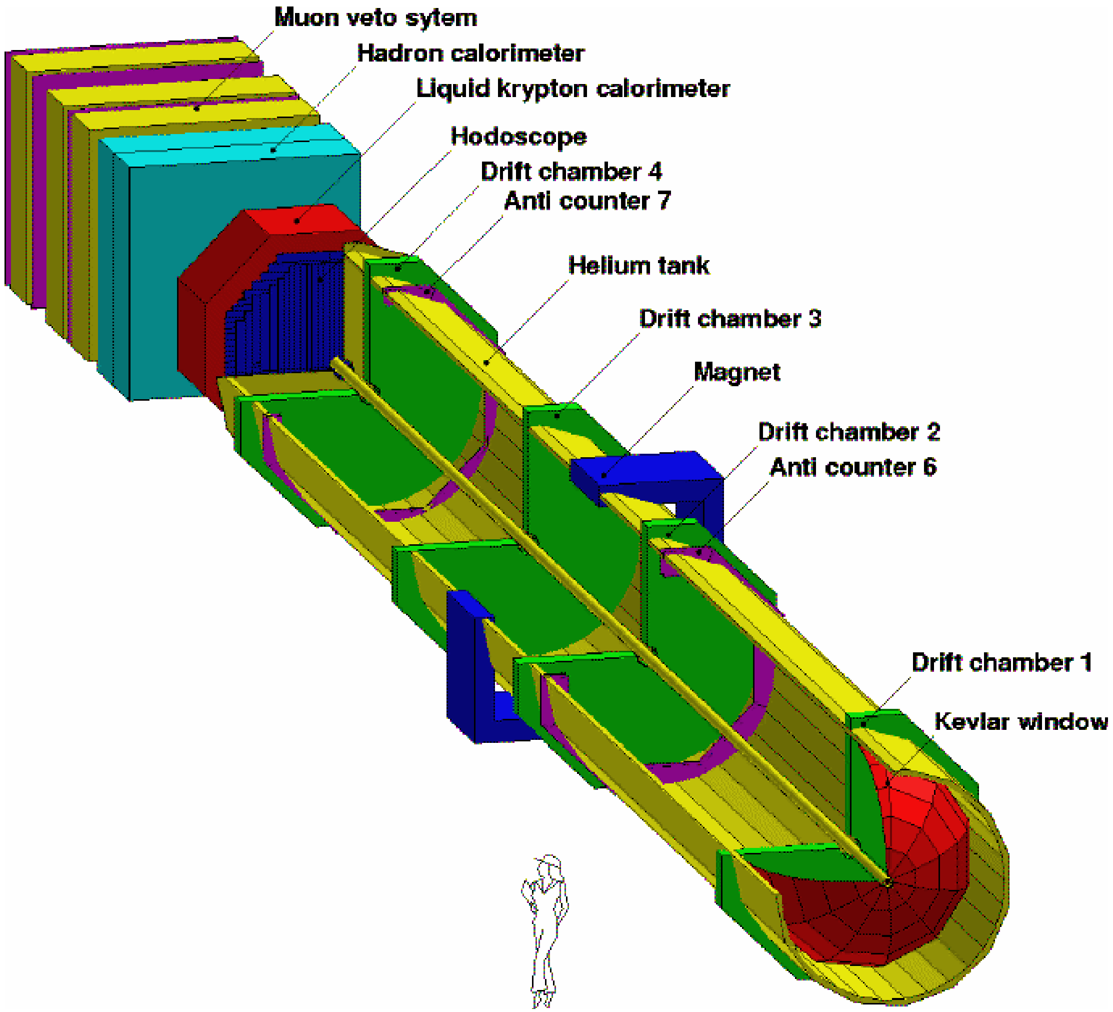
XLII[nd] Rencontres de Moriond EW

La Thuile 13/03/2007

Outline

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

NA48 detector



LKr EM calorimeter

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

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

Spectrometer

- 4 Drift Chambers
- Magnet

$$\frac{\sigma(p)}{p} = 1.\% \oplus 0.044 \times p(GeV)$$

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

10 years of History

NA48(1997-2001):

Direct CP-Violation in neutral K

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

NA48/1(2002):

Rare K_S decays and hyperons

NA48/2(2003-2004):

Direct CP-Violation in charged K

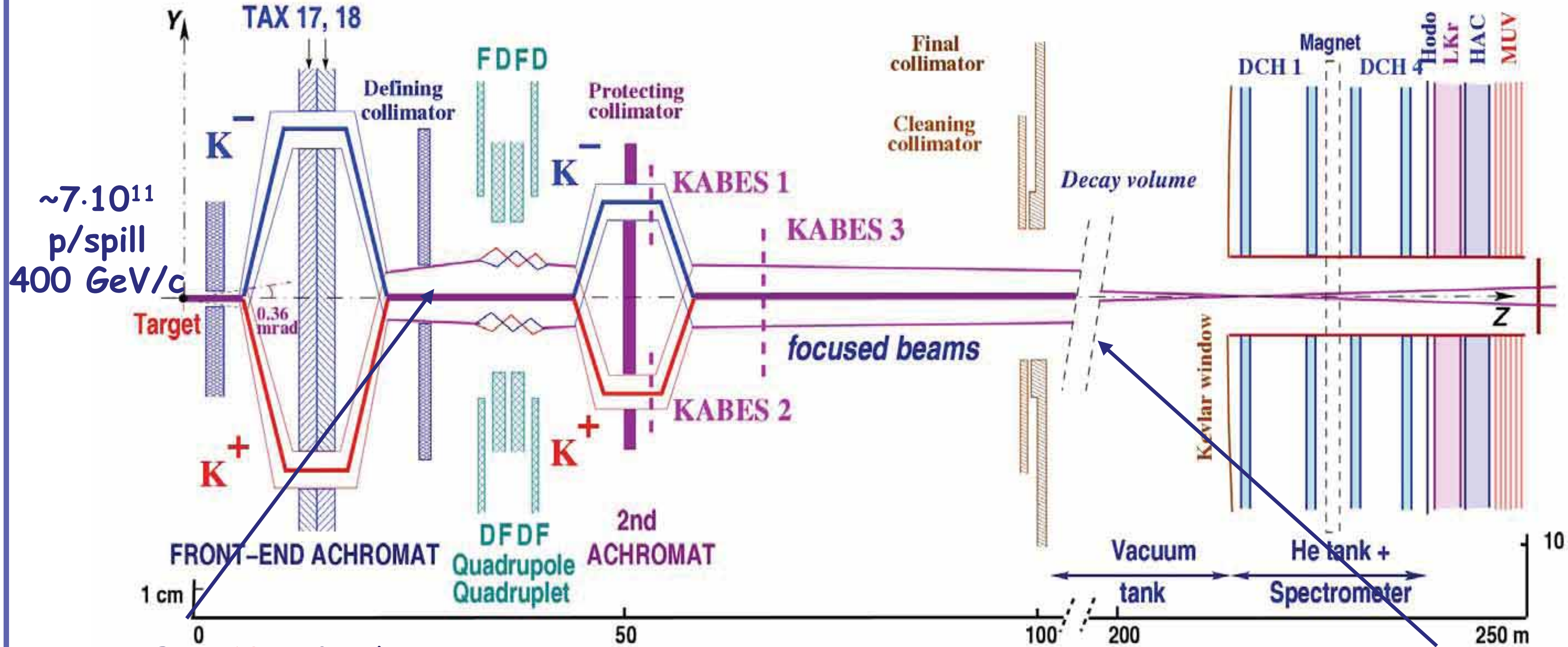
- $A_g(K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-})$ $(K_{3\pi c})$
- $A_g(K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0})$ $(K_{3\pi n})$

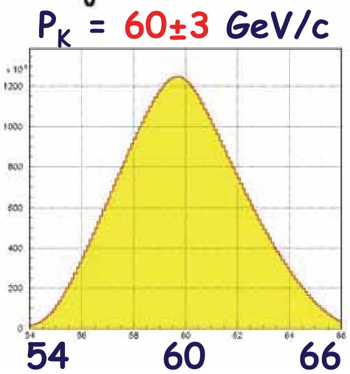
…and many other results in semileptonic and rare decays

1997 1998	ε'/ε run	$K_L + K_S$
1999	ε'/ε run $K_L + K_S$	K_S Hi. Int.
2000	K_L only (NO Spectrometer)	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	

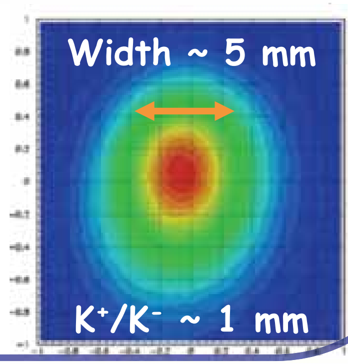
NA48/2 charged Kaon decays

Simultaneous $K^{\pm}$ Beam

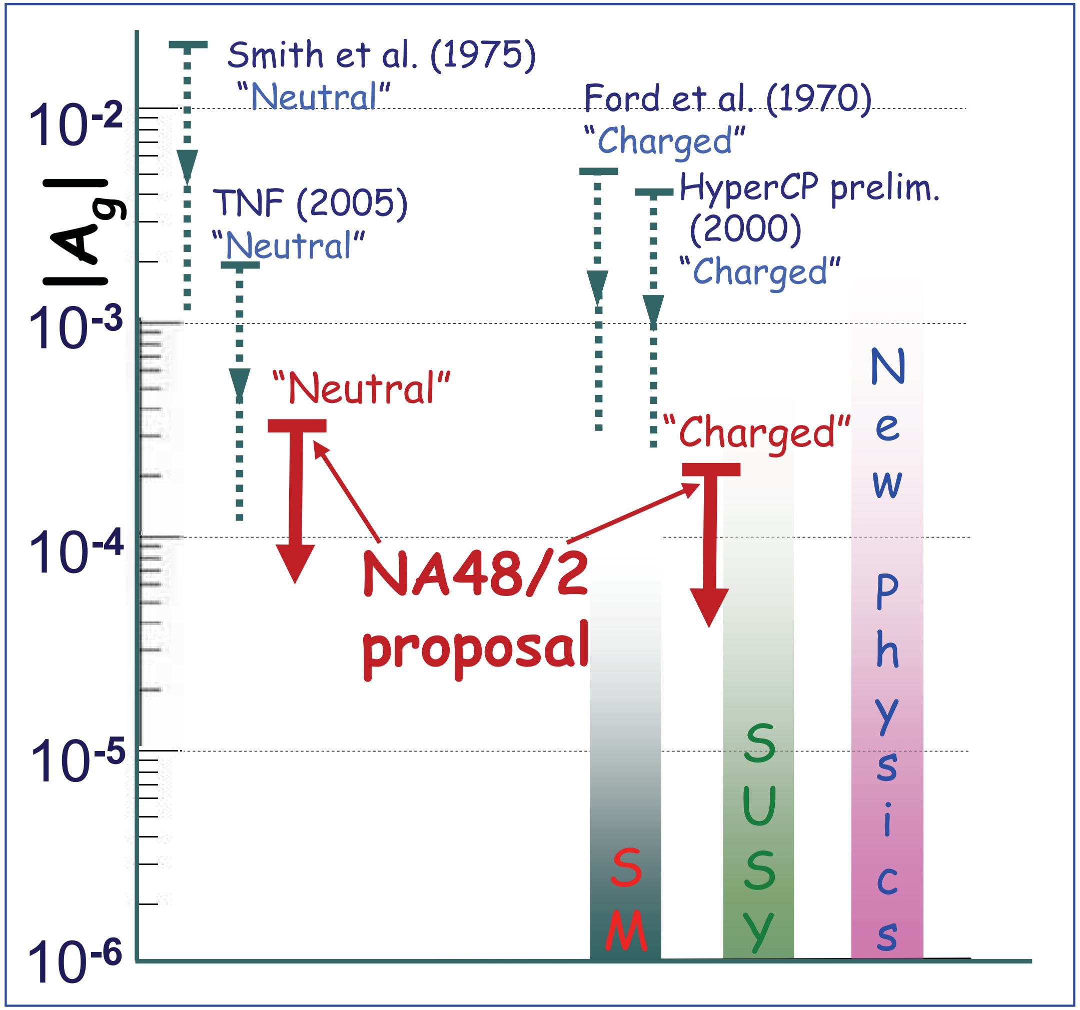




Simultaneous K^+ and K^- beams:
Flux ratio: $K^+/K^- \sim 1.8$
large charge symmetrization of experimental conditions



Measuring $|A_g|$



Kinematic variables:

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

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

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

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

Matrix element expansion:

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

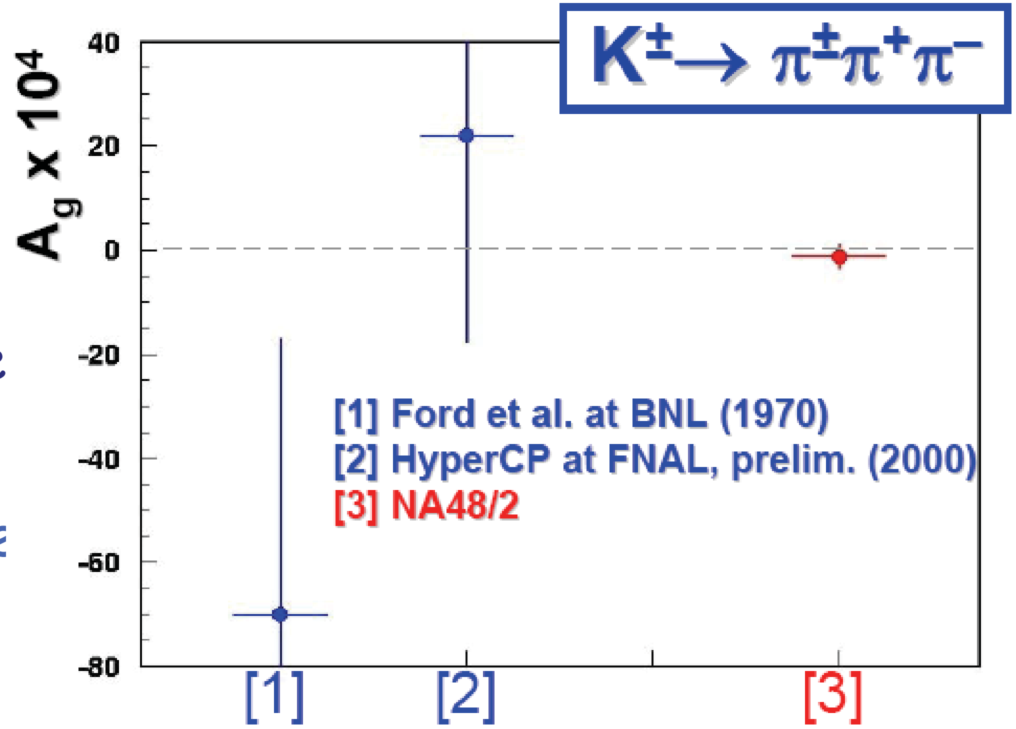
Direct CP violating quantity: slope asymmetry

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

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

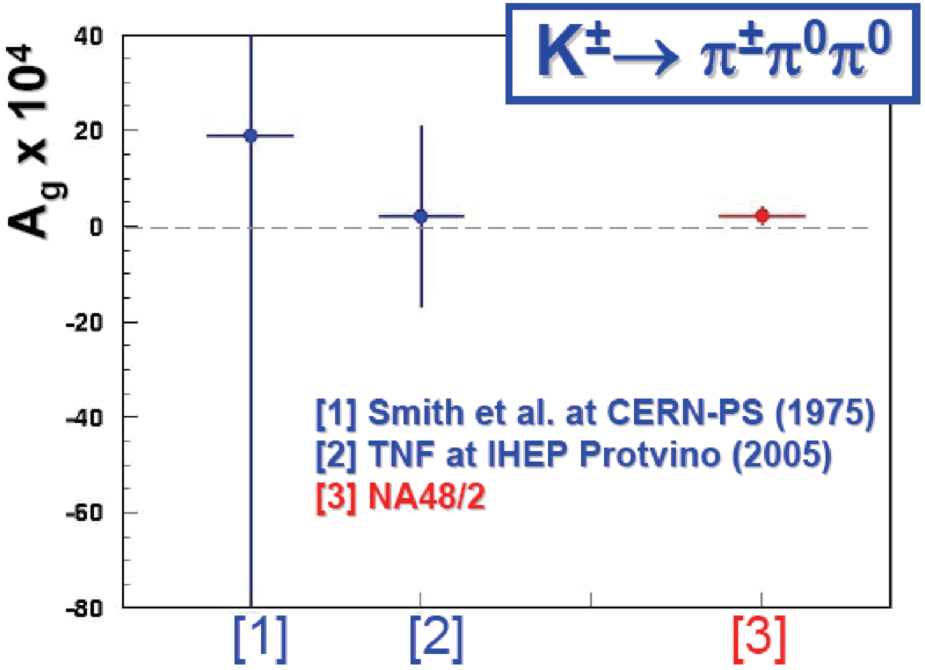
$$A_g = (-1.5 \pm 1.5_{stat} \pm 0.9_{trig} \pm 1.1_{syst}) \cdot 10^{-4}$$
$$= (-1.5 \pm 2.1) \cdot 10^{-4}$$

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



2003 + 2004 FINAL RESULT

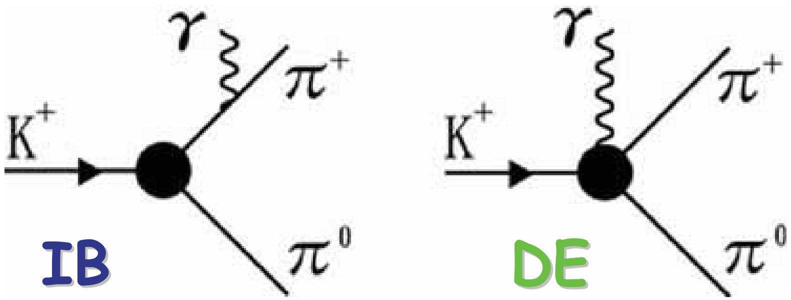
Final 2003+2004

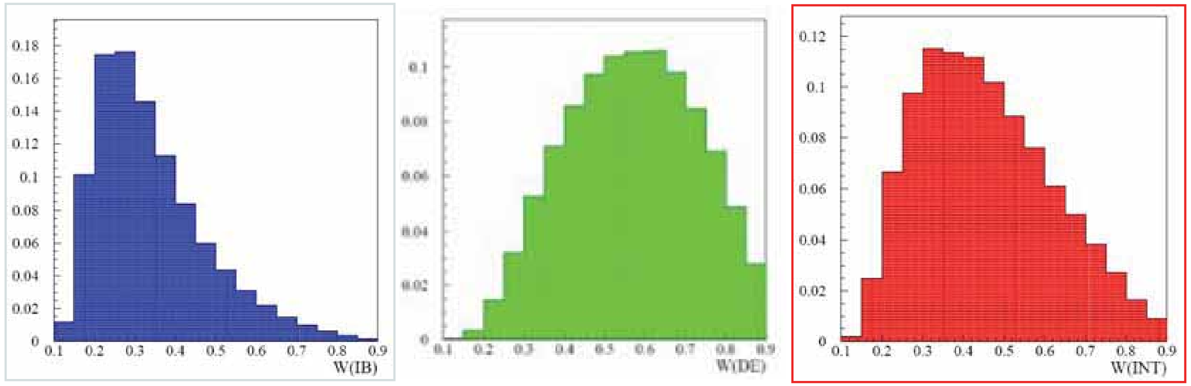
$$A_g = (1.8 \pm 1.7_{stat} \pm 0.5_{syst}) \cdot 10^{-4}$$
$$= (1.8 \pm 1.8) \cdot 10^{-4}$$

Based on the full 2003+2004 data sample

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

The radiative decay $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$





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

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

IB — INT — DE

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)

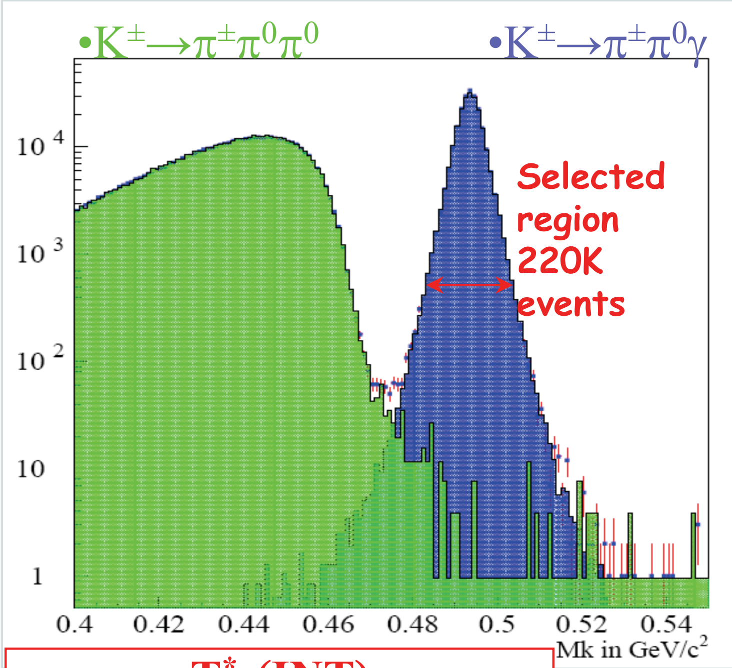
Very high statistics (124K events part of '03 only)

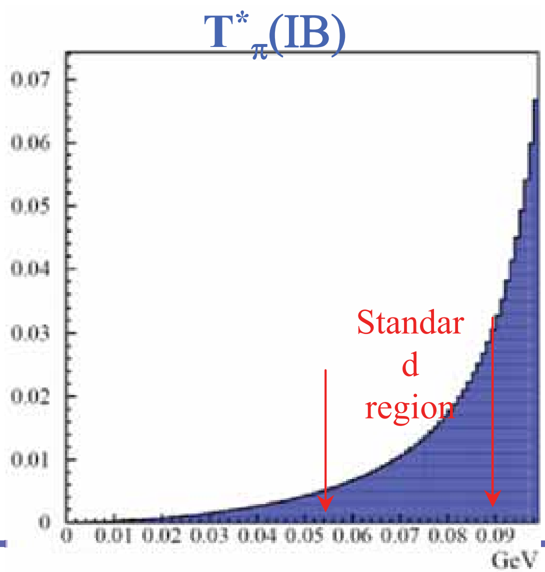
Enlarged T^*_π region ($0<T^*_\pi<80$ MeV)

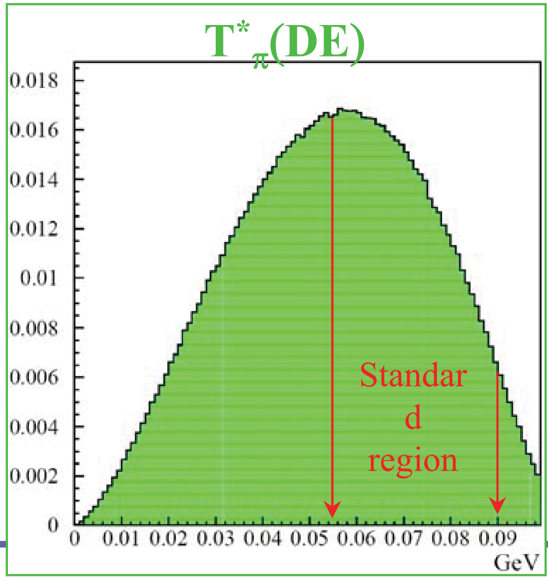
Negligible background< 1% of the DE component

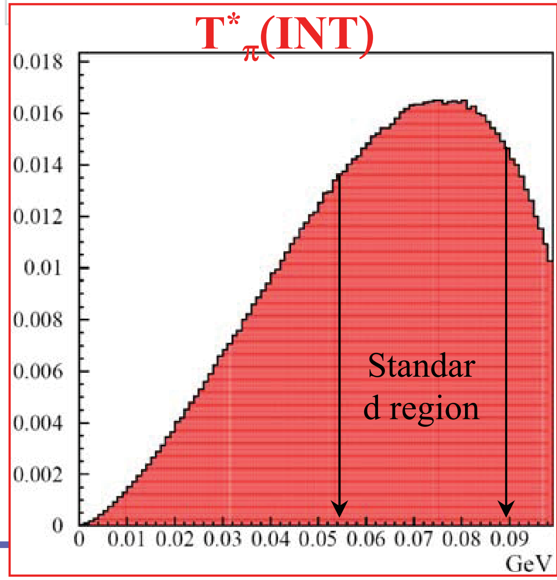
More bins in the fit to enhance sensitivity to INT

Order ‰ γ mistagging for IB, DE and INT







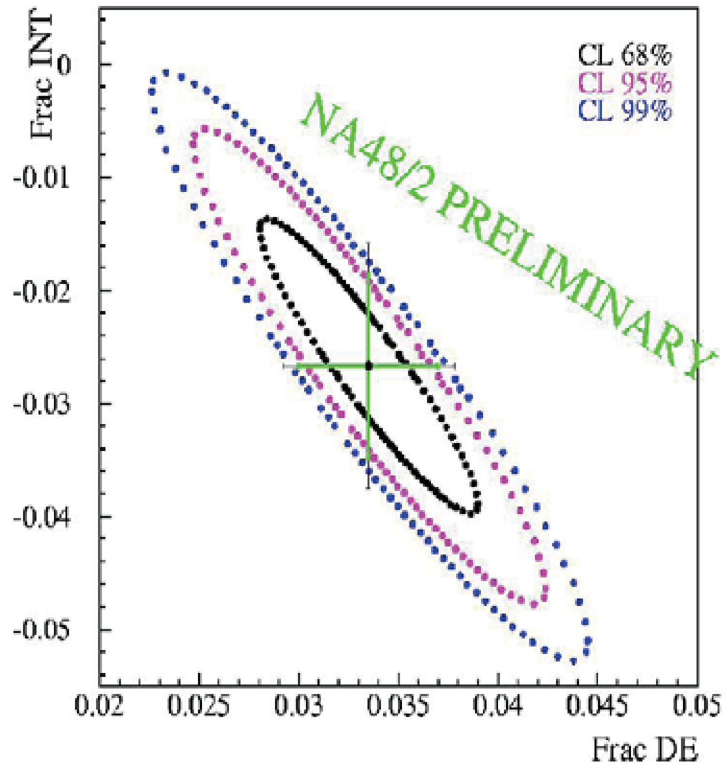


DE and INT measurement

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

Fit the W data spectrum using MC shapes:
$W_{dat}=(1-\alpha-\beta)W_{IB}+\alpha W_{DE}+\beta W_{INT}$

Systematic dominated by Trigger efficiency.
First evidence of non zero INT term!
Parameters are highly correlated $\rho=-0.92$



Preliminary 2003

$\mathrm{Frac(DE)}_{0<T^*\pi<80\ \mathrm{MeV}} = (3.35\pm0.35_{stat}\pm0.25_{syst})\%$

$\mathrm{Frac(INT)}_{0<T^*\pi<80\ \mathrm{MeV}} = (-2.67\pm0.81_{stat}\pm0.73_{syst})\%$

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

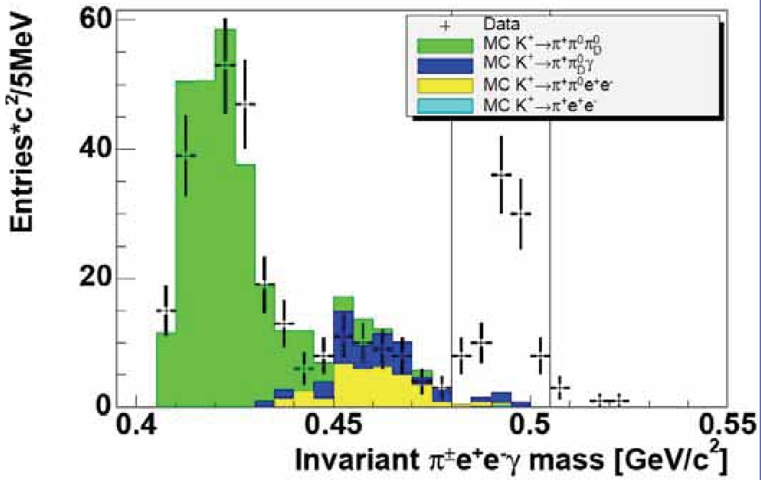
Theoretical expectation (Gabbiani 99):
$BR(K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma)=(0.9\text{-}1.6)\cdot 10^{-8}$

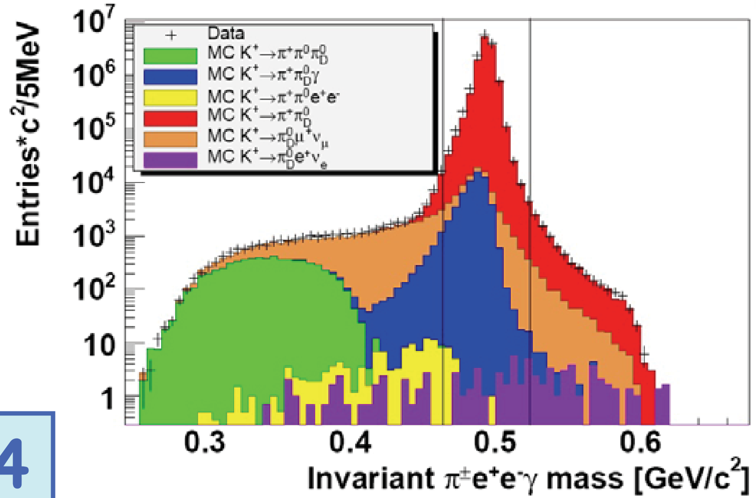
Event sample:

- 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



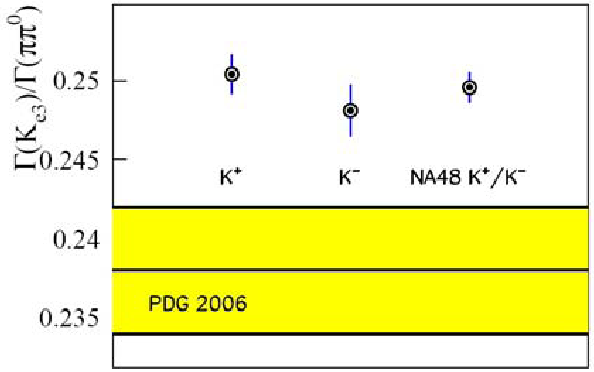


Preliminary 2003+2004

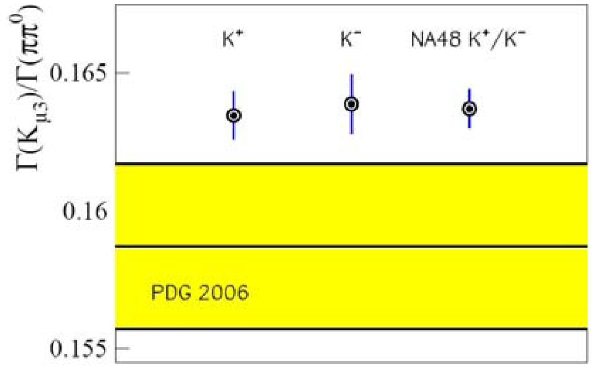
$$BR(K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma)=(1.27\pm0.14_{stat}\pm0.05_{sys})\cdot 10^{-8}$$

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

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:

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

Using as normalization $BR(K^{\pm}\to\pi^{\pm}\pi^0)=(20.92\pm0.12)\%$ PDG '06:

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

Extraction of V_{us}

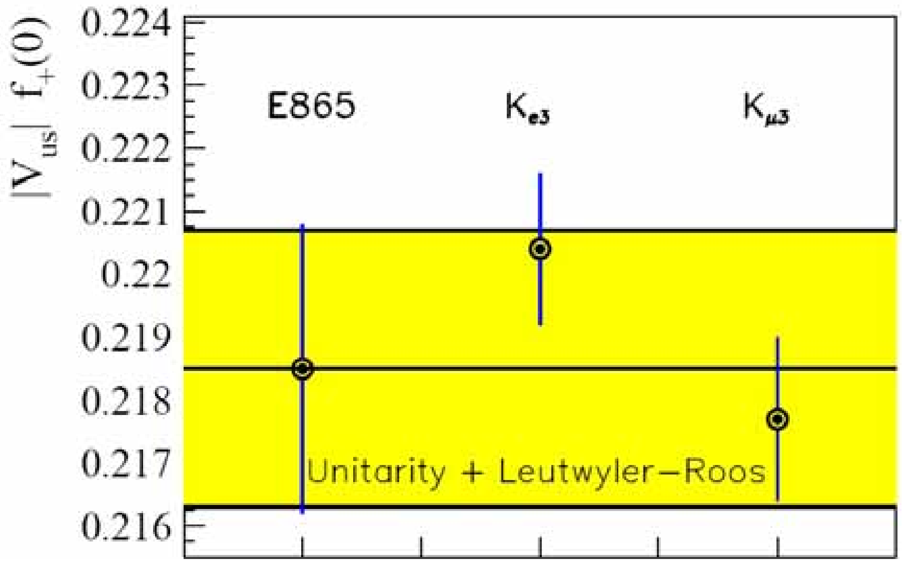
Evaluate $|V_{us}|f_+(0)$ for both modes:

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

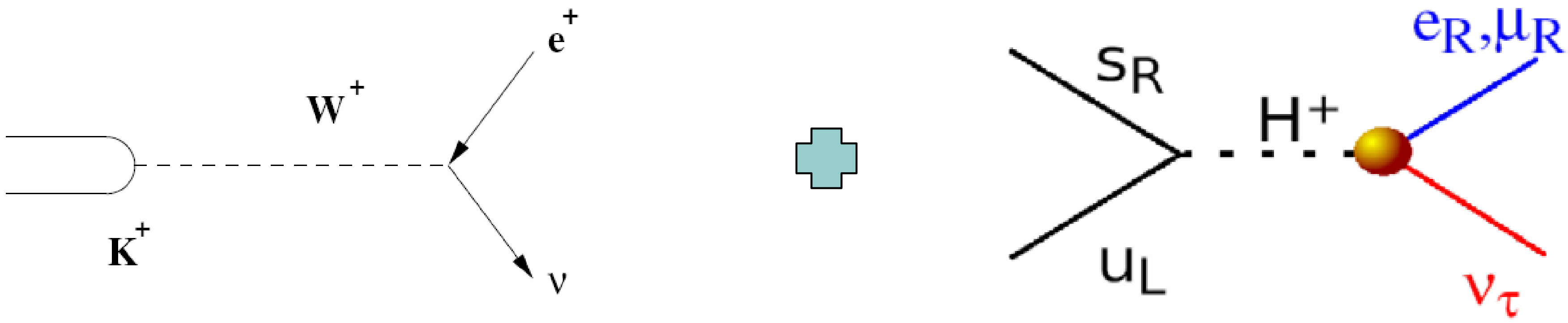
K_{e3}: $|V_{us}|f_+(0) = 0.2204 \pm 0.0012$
$K_{\mu3}$: $|V_{us}|f_+(0) = 0.2177 \pm 0.0013$

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 $K_{e2}/K_{\mu 2}$



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

If tanβ=40 and M_{H+}=500 GeV with $|\Delta_R^{31}|^2$= $5 \cdot 10^{-4}$

$$\Downarrow$$

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

A. Masiero: CERN TH seminar

The effect can be as high as 2% and therefore measurable

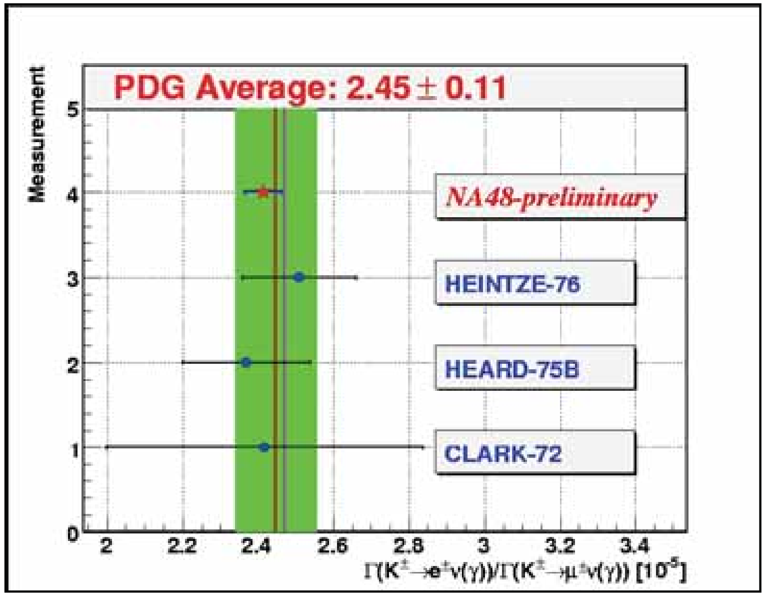
PR D74 (2006) 011701 (A. Masiero et al.)

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

Selected events:
5329 Ke2 candidates (~14% BG mainly from Kμ2)
619179 Kμ2 (with negligible background)

Main background source high energy muon Bremsstrhalung in the LKr calorimeter

Analysis of 2004 data in ongoing …



Preliminary 2003

$$R_K=(2.416\pm0.043_{stat}\pm0.024_{sys})\cdot10^{-5}$$

2% tot err

Dedicated 2007 run:

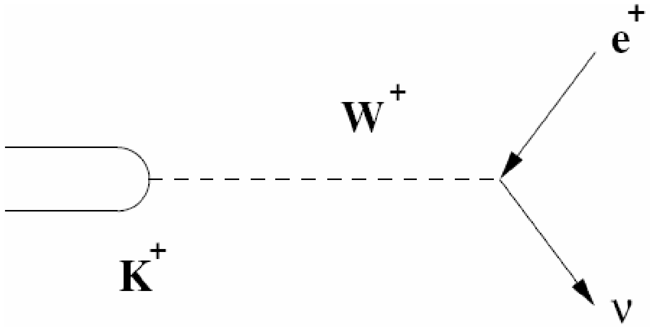
- Statistical error <0.7%
- Direct measurement of muon Bremsstrahlung spectrum in data
- Final result total error <1%

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

Test of lepton universality

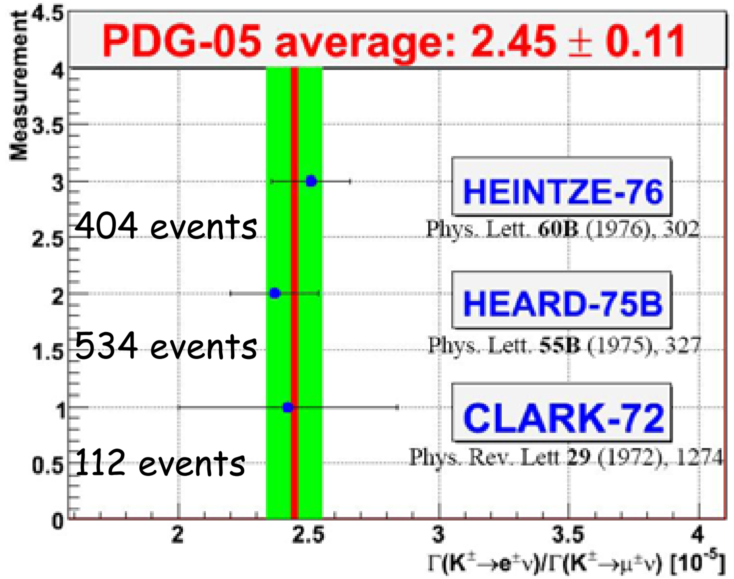
V-A couplings

Within SM



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

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 $K_{L\mu3}$ form factors

Physics interest:

K_{l3} decays provide cleanest way to extract $|V_{us}|$ in CKM matrix

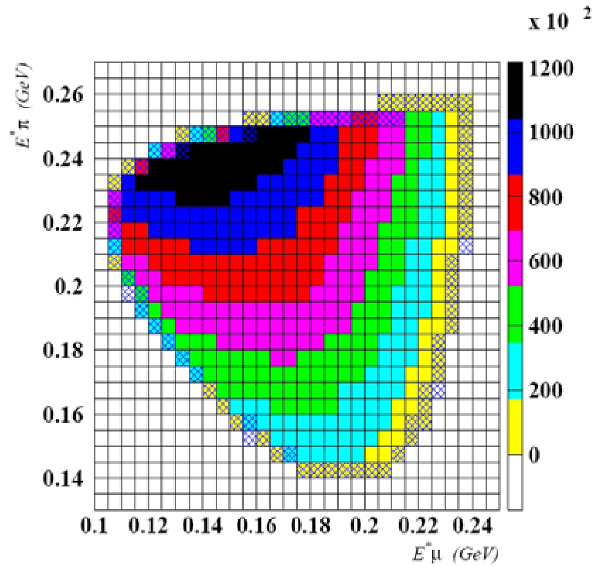
$f_+(0)$ in $|V_{us}|f_+(0)$ can be experimentally constrained from the slope and curvature of f_0 from $K_{\mu3}$

form factors needed to calculate phase space integrals (needed for $|V_{us}|$ extraction)

Data set used:

Dedicated NA48 run in 99: ~2.3×10^6 $K_{\mu3}$ candidates

Form factors extracted by studying the Dalitz plot density



$$\rho(E^*_\mu, E^*_\pi) = \frac{dN^2(E^*_\mu, E^*_\pi)}{dE^*_\mu \, dE^*_\pi} \propto A f_+^2(t) + B f_+(t) f_-(t) + C f_-^2(t)$$

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

Form factors fit results

Vector form factor slopes:

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

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

Scalar form factor slope:

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

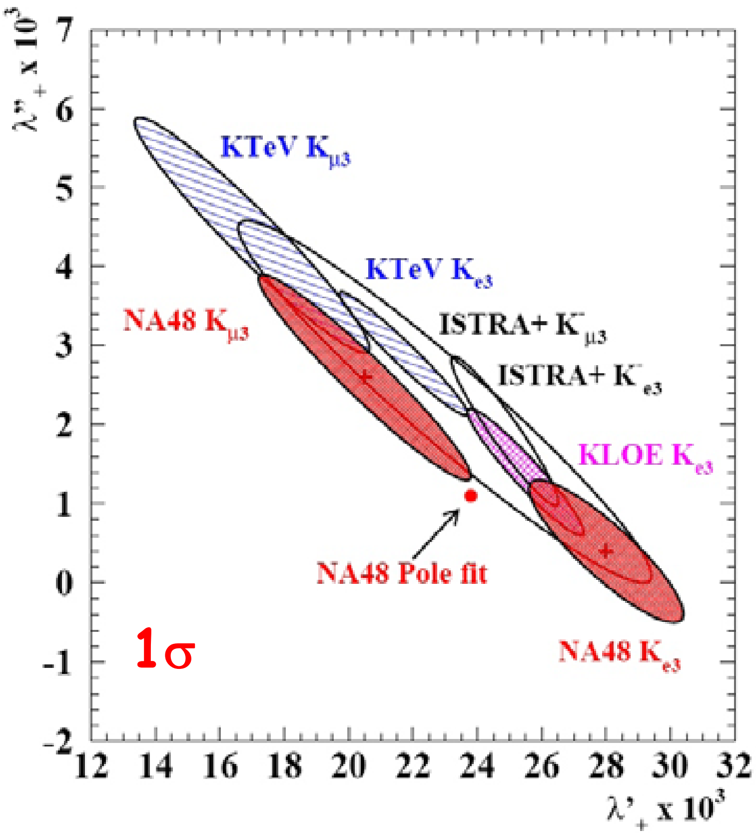
Using linear fits:

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

(well compatible with the recent KTeV measurement)

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

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

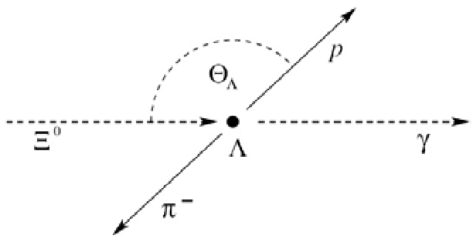
$(7.7 \pm 0.5_{stat} \pm 0.4_{syst}) \cdot 10^{-6}$

systematics dominated by acceptance, polarization and signal modeling

Decay asymmetry measured (preliminary):

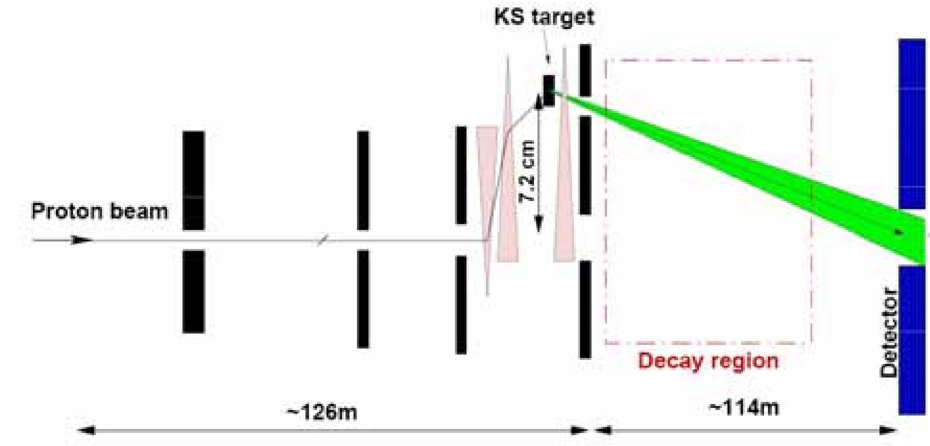
$\alpha_{\Xi} \alpha_{\Lambda}(\Lambda ee) = -0.8 \pm 0.2$

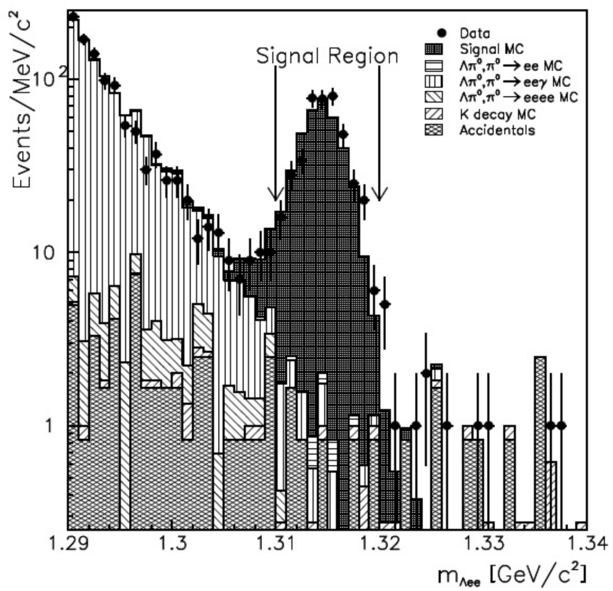
consistent with $\Xi \rightarrow \Lambda \gamma$



$$dN/dcos\Theta_\Lambda = N_0(1 - \alpha_\Xi \alpha_\Lambda cos\Theta_\Lambda)$$

NA48/1 Beam line





Conclusion

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

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

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

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

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

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