Precise test of Cabibbo-Kobayashi-Maskawa matrix unitarity

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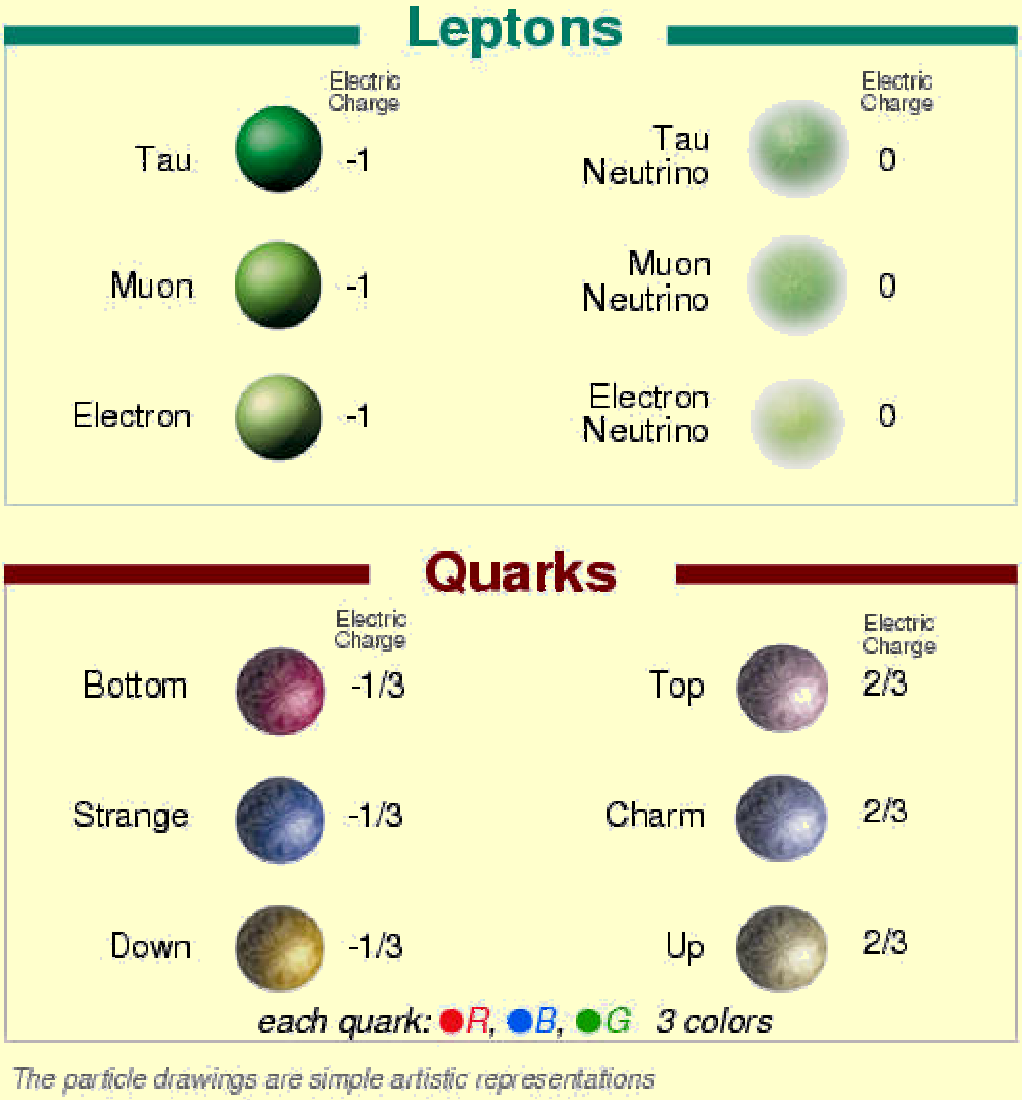
Introduction

- CKM quark mixing matrix
- CKM unitarity
- NA48 experimental setup
- Measurement of Br(K^0_Le3)/Br(2tr)
- Br(K^0_Le3)
- Measurement of Br($K^0_L \rightarrow 3\pi^0$)
- Measurement of Br($K^\pm$e3)
- Extraction of V_{us}
- K^0_Le3 form factors
- The radiative decay Br(K^0_Le3γ)
- Conclusions

Introduction

CKM - Introduction

Fundamental particles



Leptons

	Electric Charge		Electric Charge
Tau	-1	Tau Neutrino	0
Muon	-1	Muon Neutrino	0
Electron	-1	Electron Neutrino	0

Quarks

	Electric Charge		Electric Charge
Bottom	-1/3	Top	2/3
Strange	-1/3	Charm	2/3
Down	-1/3	Up	2/3

each quark: ●R, ●B, ●G 3 colors

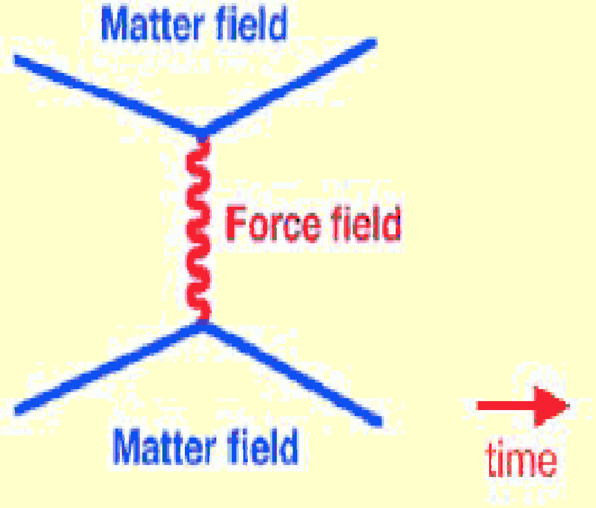
The particle drawings are simple artistic representations

Interactions of the fundamental particles

Forces are transmitted by the exchange of (force) particles between (matter) particles

Explains the differences between forces
To verify : look for force particles

$$\text{Range of a Force} \ \alpha \ \frac{1}{\text{mass of exchange particle}}$$



Observe 4 forces
There are 4 different types of force fields

Standard Model

In QFT – the local invariance of **L** defines the interactions

Electromagnetic Interactions: γ

Quantum Electrodynamics (QED) U(1)

In the Standard Model

QED + Weak Interactions: γ, Z^0, $W^\pm$

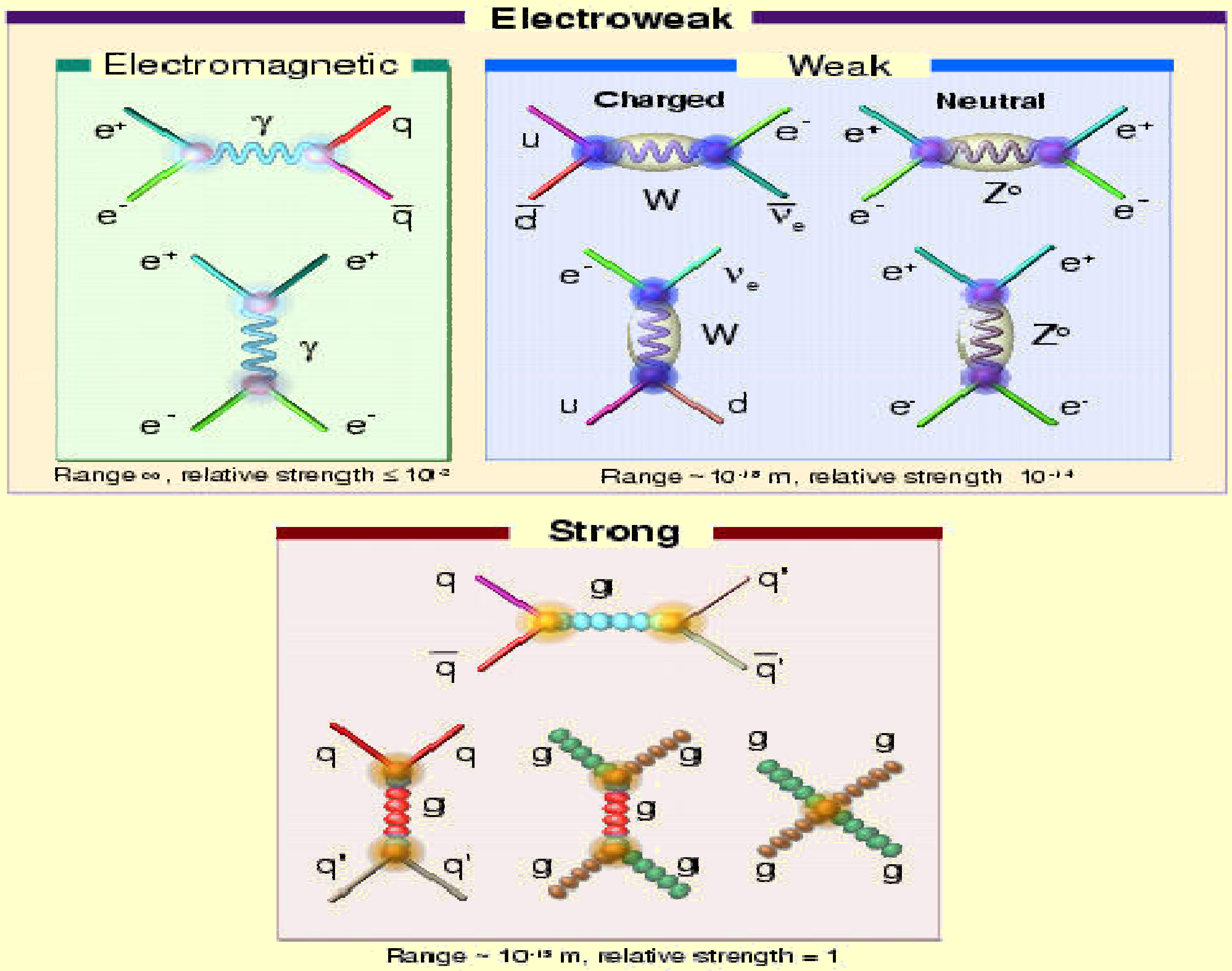
Electroweak Theory $SU(2)_L \otimes U(1)_Y$

Strong Interaction **8 Gluons**

Quantum Chromodynamics (QCD) $SU_c(3)$

Interactions

Interactions: coupling of forces to matter



Standard Model

LEPTONS

- Do not participate in strong interactions
- Spin ½
- Observed as free particles
- Pointlike (r < few x 10^{-17}cm)

QUARKS

- Strong interactions bind them into hadrons
- Not observed as free particle – confinement
- Spin ½ ; pointlike; (r < few x 10^{-17}cm)
- $Q_u = 2/3$; $Q_d = -1/3$

Family (Generation) Structure

$$\begin{pmatrix} \nu'_j & u'_j \\ l'_j & d'_j \end{pmatrix}$$

$N_G = 3$

Standard Model

Three Families $\begin{pmatrix} \nu_e & u \\ e^- & d' \end{pmatrix}$ $\begin{pmatrix} \nu_\mu & c \\ \mu^- & s' \end{pmatrix}$ $\begin{pmatrix} \nu_\tau & t \\ \tau^- & b' \end{pmatrix}$

Family Structure

$$\begin{pmatrix} \nu_l & q_u \\ l_j & q_d \end{pmatrix} \equiv \left\{ \begin{pmatrix} \nu_l \\ l^- \end{pmatrix}_L, (\nu_l)_R, l_R^- \right\}; \left\{ \begin{pmatrix} q_u \\ q_d \end{pmatrix}_L, (q_u)_R, (q_d)_R \right\}$$

Charged Currents W±

Left-handed fermions only

Flavor changing: $\nu_l \Longleftrightarrow l$, $q_u \Longleftrightarrow q_d$

Neutral Currents γ, Z

Flavor Conserving $f_i \Longleftrightarrow f_i$

Standard Model

PROBLEM WITH MASS SCALES

Gauge Symmetry → $m_\gamma = 0$ Good

$M_W = M_Z = 0$ Bad!

$$M_W = 80.43 \text{ GeV}$$

$$M_Z = 91.19 \text{ GeV}$$

Moreover $\mathcal{L}_{m_f} \equiv -m_f \bar{f} f = -m_f (\bar{f}_L f_R + \bar{f}_R f_L)$

Also Forbidden by Gauge Symmetry → $m_f = 0 \quad \forall f$

All Particles Massless

Spontaneous Symmetry Breaking

In the SM masses are generated trough

Spontaneous Symmetry Breaking (**SSB**) – Higgs Mechanism

Introduce Scalar Higgs doublet → The Lagrangian is invariant

However its vacuum state is degenerate – $|<0|\Phi_0|0>| = \frac{v}{\sqrt{2}}$

Choice of the vacuum state – leads to SSB

$SU(2)_L \times U(1)_Y \rightarrow U(1)_Q$

Couplings with gauge bosons and fermions – induce mass terms

Price – new particle **H-boson** – to be discovered

Fermion Masses

$$\begin{pmatrix} \mathbf{v}'_j & \mathbf{u}'_j \\ \mathbf{l}'_j & \mathbf{d}'_j \end{pmatrix}$$

N_G=3 identical copies : f' are massles weak eigenstates

Scalar doublet couples with fermions – allowed by the Gauge Symmetry

⬇ **SSB**

$$L_Y = -\left(1+\frac{H}{v}\right)[\overline{d'_L} M'_d d'_R + \overline{u'_L} M'_u u'_R + \overline{l'_L} M'_l l'_R + h.c.]$$

Arbitrary Non-Diagonal Complex Mass Matrices

$$[M'_d, M'_u, M'_l]_{jk} = -[c^{(d)}_{jk}, c^{(d)}_{jk}, c^{(d)}_{jk}]\frac{v}{\sqrt{2}}$$

Diagonalization of Mass Matrices

$$M'_f = S_f^+ M_f S_f U_f \qquad S_f^+ S_f = 1 \qquad U_f^+ U_f = 1$$

$$\boxed{L_Y = -\left(1 + \frac{H}{v}\right)[\bar{d} M_d d + \bar{u} M_u u + \bar{l} M_l l]}$$

$$M_u = diag(m_u, m_c, m_t) \quad M_d = diag(m_d, m_s, m_b) \quad M_l = diag(m_e, m_\mu, m_\tau)$$

$$\boxed{f_L = S_f f'_L} \qquad \boxed{f_R = S_f U_f f'_R}$$

Mass Eigenstates # Weak Eigenstates

$$\overline{f'_L} f'_L = \overline{f_L} f_L \qquad \overline{f'_R} f'_R = \overline{f_R} f_R \qquad \Longrightarrow \qquad L'_{NC} = L_{NC}$$

$$\overline{u'_L} d'_L = \overline{u_L} V d_L \qquad \boxed{V = S_u S_d^+} \qquad \Longrightarrow \qquad L'_{CC} \neq L_{CC}$$

Quark Mixing

CKM Matrix

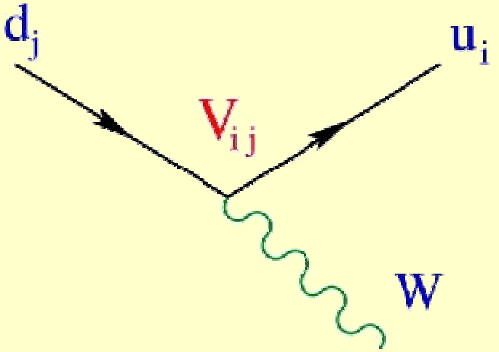
Quark Mixing

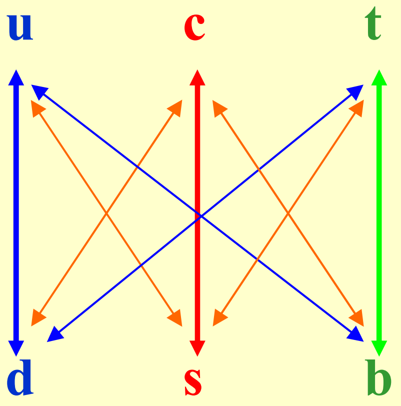
$$L_{NC}^{Z} = \frac{e}{2\sin\theta_W \cos\theta_W} Z_\mu \sum_f \overline{f}\gamma_\mu [v_f - a_f \gamma_5] f$$

Flavour Conserving Neutral Current

$$L_{CC}^{W} = \frac{g}{2\sqrt{2}} W_\mu^+ [\sum_{ij} \overline{u_i}\gamma^\mu (1-\gamma_5) V_{ij} d_j + \sum_l \overline{\upsilon_l}\gamma^\mu (1-\gamma_5) l_j] + h.c.$$

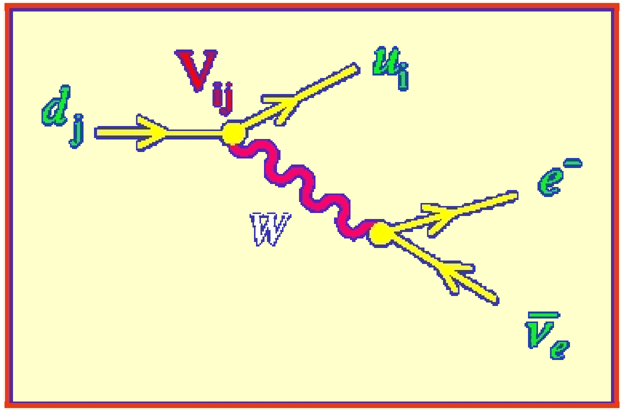
Flavour Changing Charged Current





Measurement of V_{ij}

The elements of the matrix V_{ij} are determined by the experiment



$$\Gamma(d_j \to u_i e^- \overline{\nu}_e) \propto |V_{ij}|^2$$

We measure decays of hadrons (no free quarks)

Problem – QCD Perturbation theory fails (low energy, bound states)

Effective low-energy QCD based models

Chiral Perturbation Theory (χPT)

Significant theoretical input (Uncertainties)

CKM Unitarity

Unitarity of CKM matrix leads to a number of relations between V_{ij}

In particular for the first row

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$

Most precisely measured elements of CKM

PDG 2004 data

$|V_{ud}|$ - well determined from measurement of

super allowed nuclear β-decays

free neutron life time

$|V_{ud}| = 0.9738 \pm 0.0005$

$|V_{ub}| = (3.67 \pm 0.47).10^{-3}$ - ($|V_{ub}|^2 \approx 10^{-5}$ negligible)

SM prediction

$|V_{us}| = 0.2274 \pm 0.0021$

CKM Unitarity

Experimental value

|Vus| = 0.2200 ± 0.0026

Δ|Vus| = 0.0074 ± 0.0033 ~2.2 σ discrepancy

To solve the problem – measurement with precision ~ 1% (limited by theory)

Semileptonic decays $K \rightarrow \pi e \nu$ best for determination of |Vus|

The Ke3 matrix element is parameterized by one form factor

$$\boxed{M = C\frac{G_F}{\sqrt{2}} V_{us} l^{\mu} f_{+}^{(o)}(t)(p_K + p_{\pi})_{\mu}}$$

Vector current transition matrix element

$$\boxed{f_{+}^{(o)}(t)(p_K + p_{\pi})_{\mu} = < \pi | V_{\mu}^{4} - iV_{\mu}^{5} | K >}$$

$$\boxed{f_{+}^{(o)}(t) = f_{+}^{(o)}(0)[1 + \lambda_{+} \frac{t}{m_{\pi^{\pm}}^{2}}]}$$

λ_+ experimentally measured

CKM Unitarity

Experimental data ~ 30 years old

Recent measurements - K^+e3 (E865, 2003), NA48 and
K^0e3 - (KTeV), NA48,KLOE,prel

are significantly above previous results.

Accuracy – better then 1%

Some definitions

Γ(A→B+C+….) - full decay probability (width)

If there are N possible ways in which particle A decays

Γ_i (i=1,2,...N) – partial probability for a given channel

$Br_i = \Gamma_i / \Gamma$ – Branching fraction (ratio)

$\Sigma Br_i = 1$

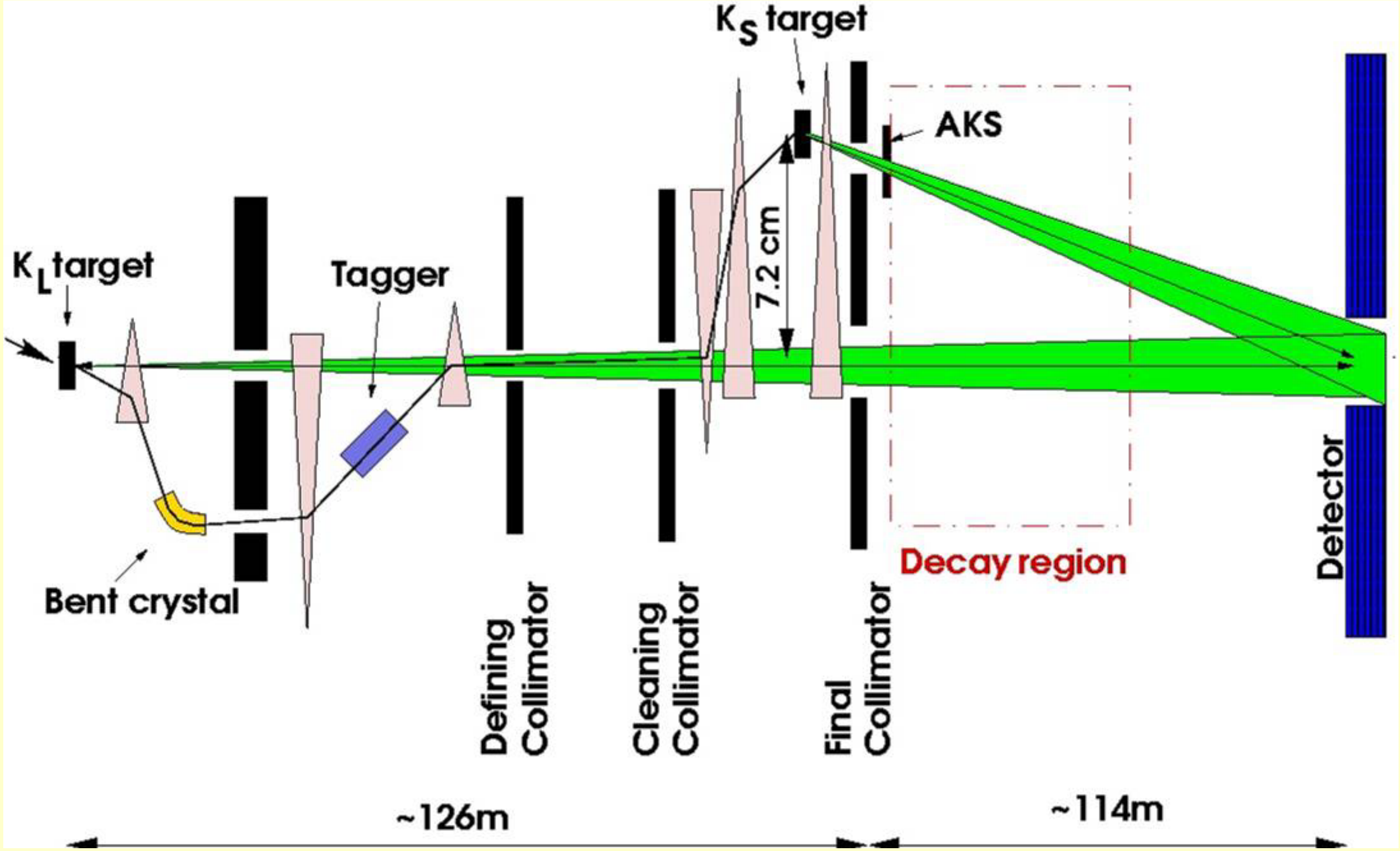
NA48 Experiment

NA48 Experiment

Situated at SPS accelerator in CERN, Geneva

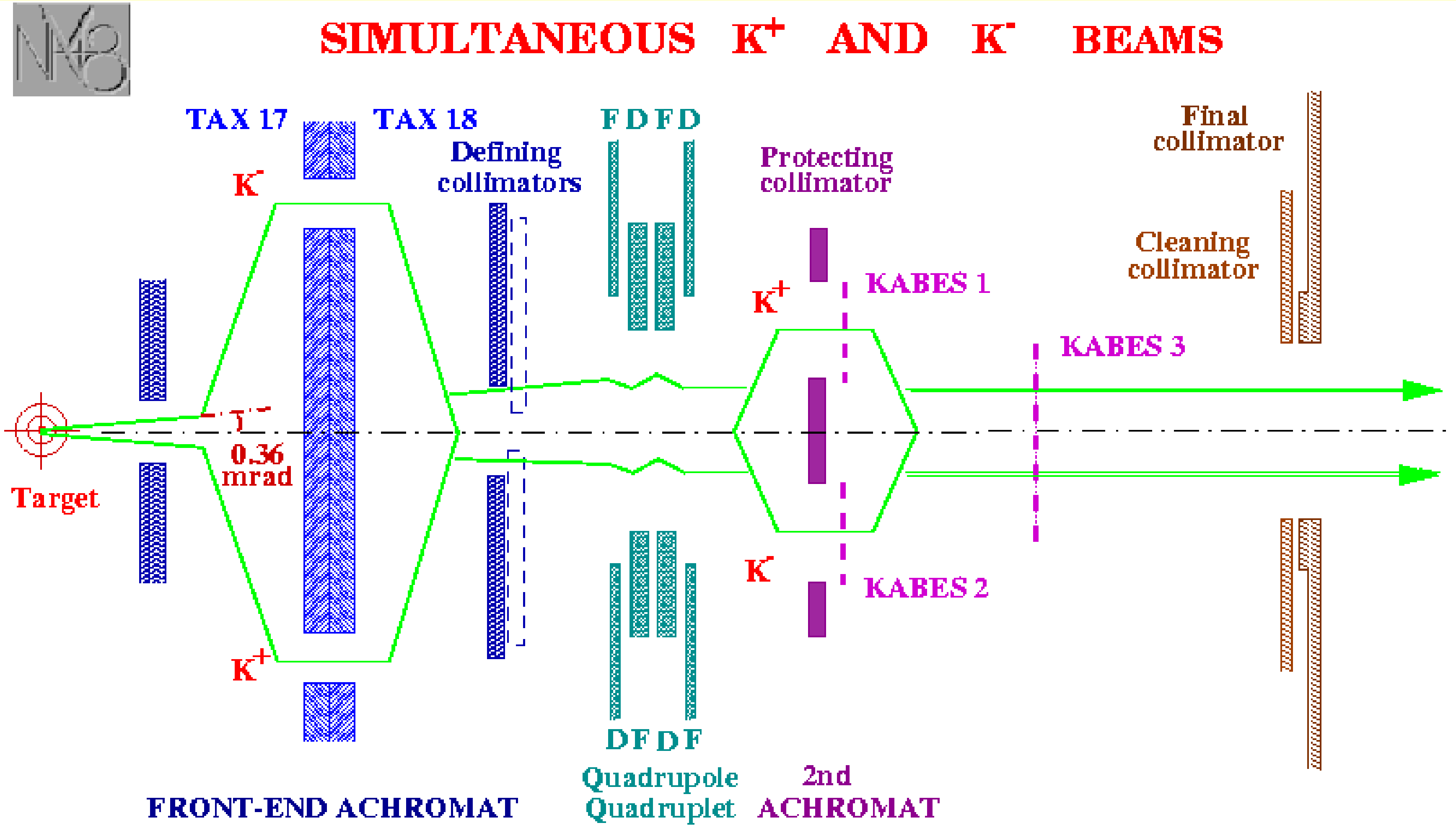
Designed for measurement of direct CP-violation and rare Kaon decays

Simultaneous K_L and K_s beams with momentum (20-200) GeV/c



NA48/2

In 2003 NA48 beam line was upgraded to transport simultaneous K^+ and K^- beams



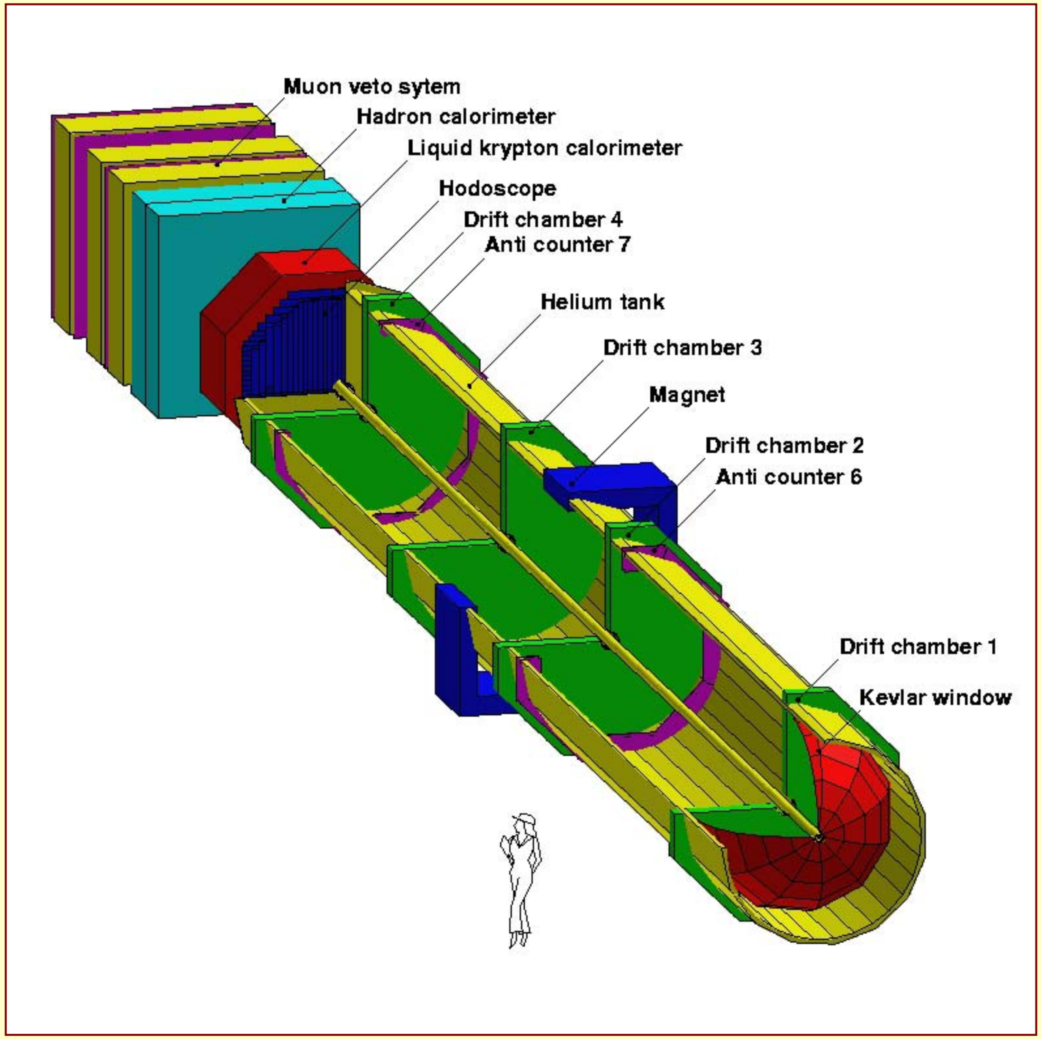
NA48 experiment

❑Main detector components

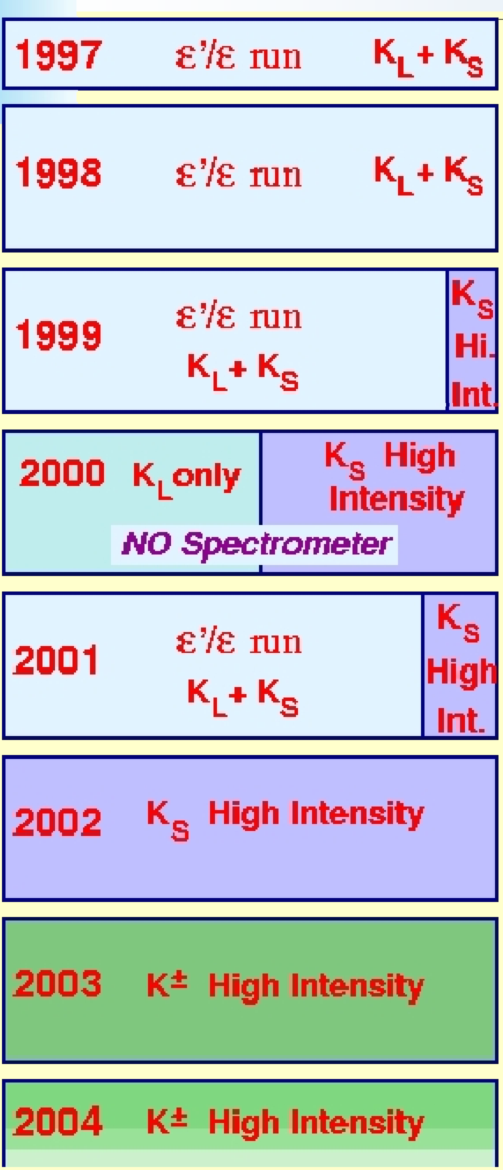
- ❖Magnet spectrometer
  - ➢Two drift chambers before and two after spectrometer magnet
  - ➢Momentum resolution < 1% for 20 GeV/c momentum
- ❖Scintillator hodoscope (200 ps)
- ❖Liquid Krypton Calorimeter

$$\frac{\delta E}{E} = \frac{3.2\%}{\sqrt{E[GeV]}} \oplus \frac{90MeV}{E} \oplus 0.42\%$$

- ❖Hadron Calorimeter
- ❖Muon Veto system
- ❖Beams – $K^0_L, K^0_s, K^\pm$



NA48 data



1997 ε'/ε run $K_L + K_S$

1998 ε'/ε run $K_L + K_S$

1999 ε'/ε run $K_L + K_S$ | K_S Hi. Int.

2000 K_L only | K_S High Intensity

NO Spectrometer

2001 ε'/ε run $K_L + K_S$ | K_S High Int.

2002 K_S High Intensity

2003 K± High Intensity

2004 K± High Intensity

NA48: 1997 – 2001

- Direct CP violation $(\mathrm{Re}(\epsilon'/\epsilon))$
- K_L **decays** (e.g. $K^0_{e3} \to |V_{us}|$)

NA48/1: 2000, 2002

- High-intensity run for rare K_S **decays.**
- **Hyperon decays** (Ξ^0, Λ) $(\to |V_{us}|)$
- Neutral K_S decays (2000)

NA48/2: 2003 – 2004

- Search for direct CPV in $K^{\pm}$ **decays.**
- Rare decays
  $(K_{e4}, K^+ \to \pi^+ e^+ e^-, K^+ \to \pi^+ \gamma\gamma, \ldots)$
- Semileptonic decays $(K^+_{e3} \to |V_{us}|)$

New NA48 results

Vus measurement

$K^0_L \rightarrow \pi e \nu$

- Semileptonic K_L decays $K^0_L \rightarrow \pi l \nu$
  - Data from special minimum bias run 1999 with pure K^0_L beam
  - Very high statistics available – 80 million triggers taken
- General idea
  - Normalize to as many as possible channels
  - Data selection and analysis - as simple as possible
- Measure the ratio $Br(K^0_L\ e3)/Br(2tr)$ 2tr = all K^0_L decays with two charged particles in the spectrometer
  - Normalization on

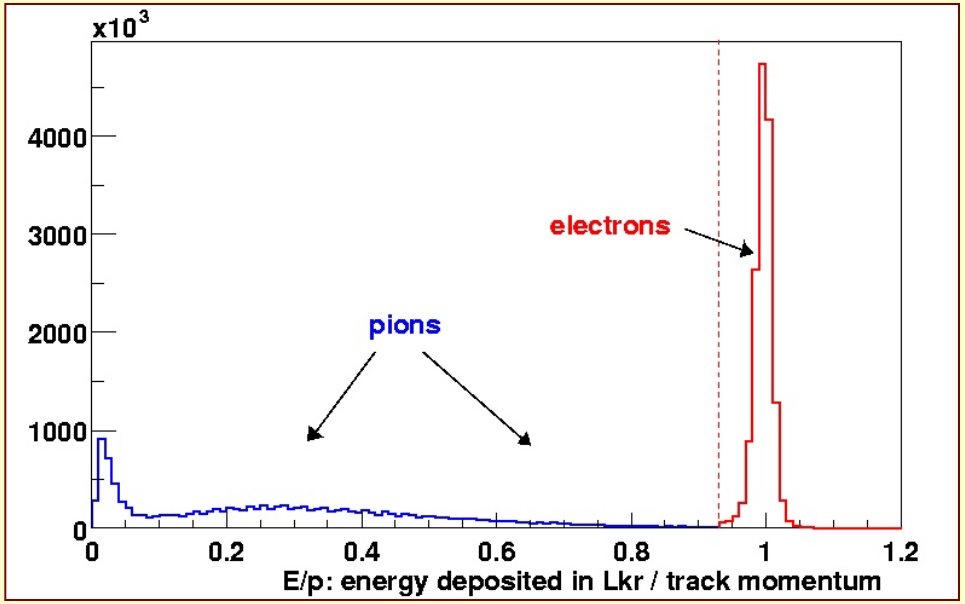
$$Br(2tr) = 1.0048 - Br(K^0_L \rightarrow 3\pi^0)$$

is experimentally known

$K^0_L \to \pi e \nu$

- Main selection criteria for 2 track sample
  - Two tracks with opposite charges
  - Decay vertex between 8 m and 33 m from final collimator
  - Track separation in LKr > 25 cm
  - Track momenta > 10 GeV
  - Psum = P1 + P2 > 60 GeV

12.6 million 2 track events



- $K^0_L \to \pi e \nu$ selection – the same but
- One of the tracks to be an electron
  - E(LKr)/p > 0.93

$K^0_L \rightarrow \pi e \nu$

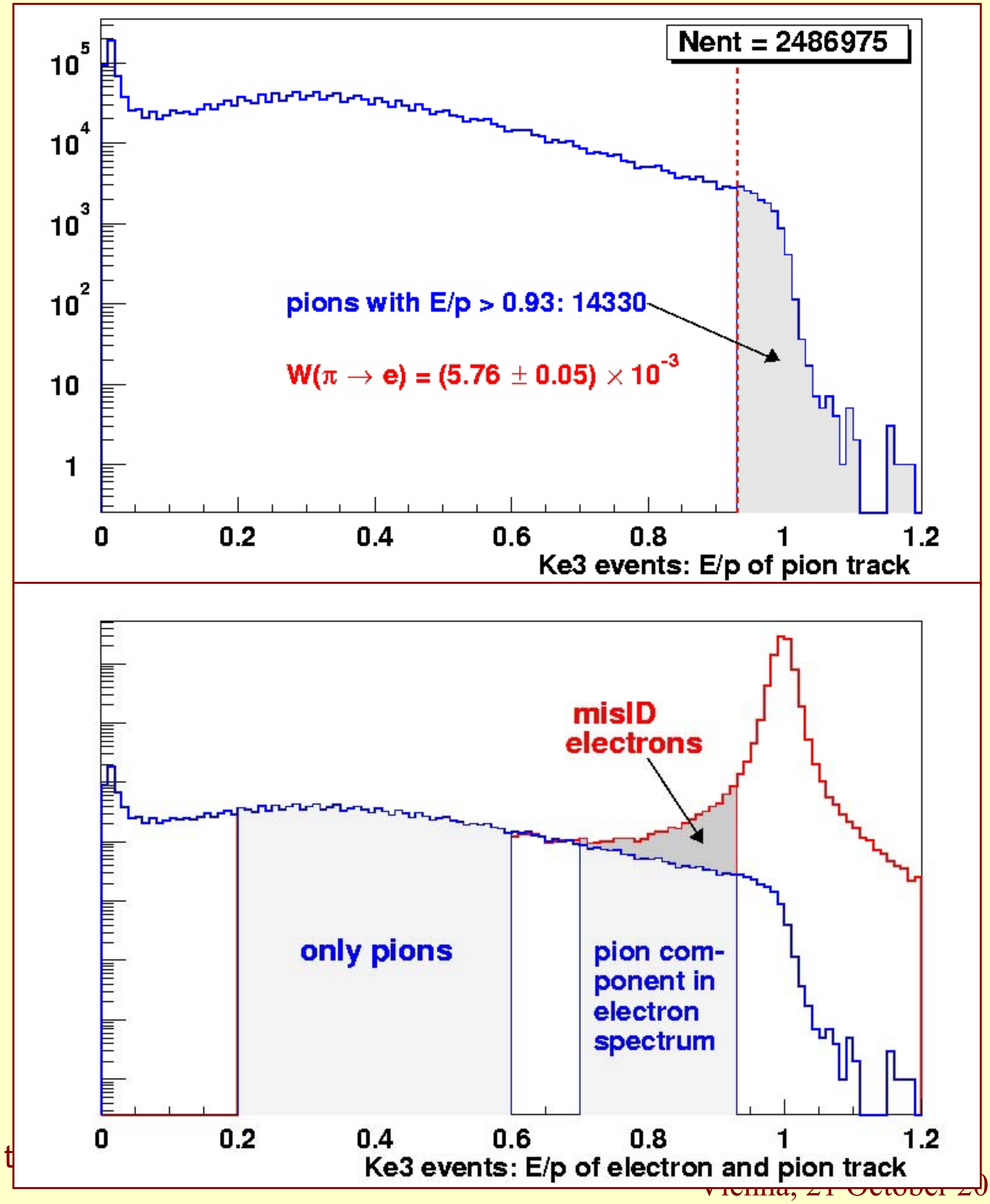
- ❖Background to K_{e3} sample
  - ➢BG from $K\mu3$ and $K3\pi$ with $\pi^\pm$ misidentified as $e^\pm$
  - ➢Estimate the BG from K_{e3} data with identified $e^\pm$ ($E/p > 1$)

    $P(\pi \rightarrow e) = 5.8.10^{-3}$

- ❖Inefficiency of electron ID
  - ➢Estimate $e^\pm$ inefficiency from K_{e3} data with identified $\pi^\pm$ ($0.3<E/p < 0.7$)

    $P(e \rightarrow \pi) = 4.9.10^{-3}$

Selected 6.7 million K_{e3}



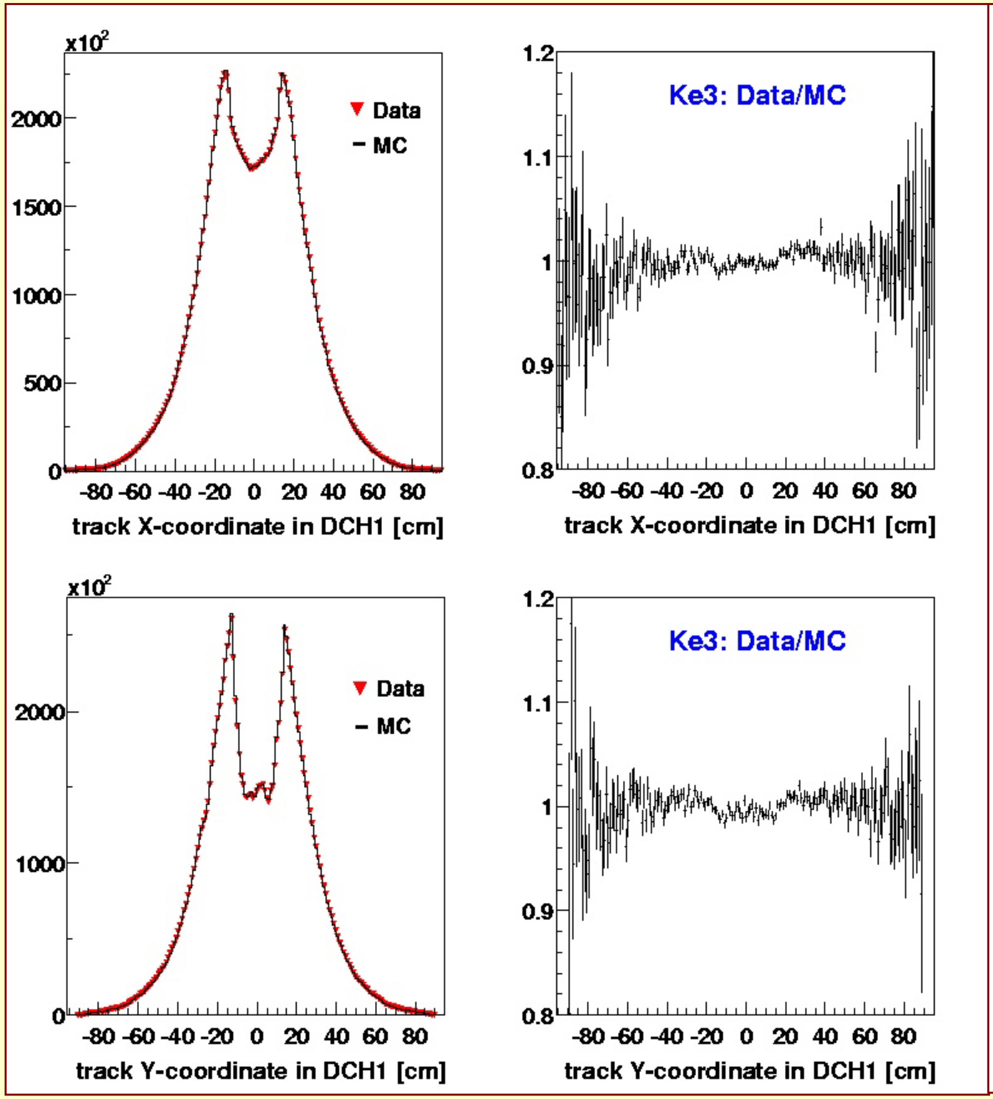
$K^0_L \rightarrow \pi e \nu$

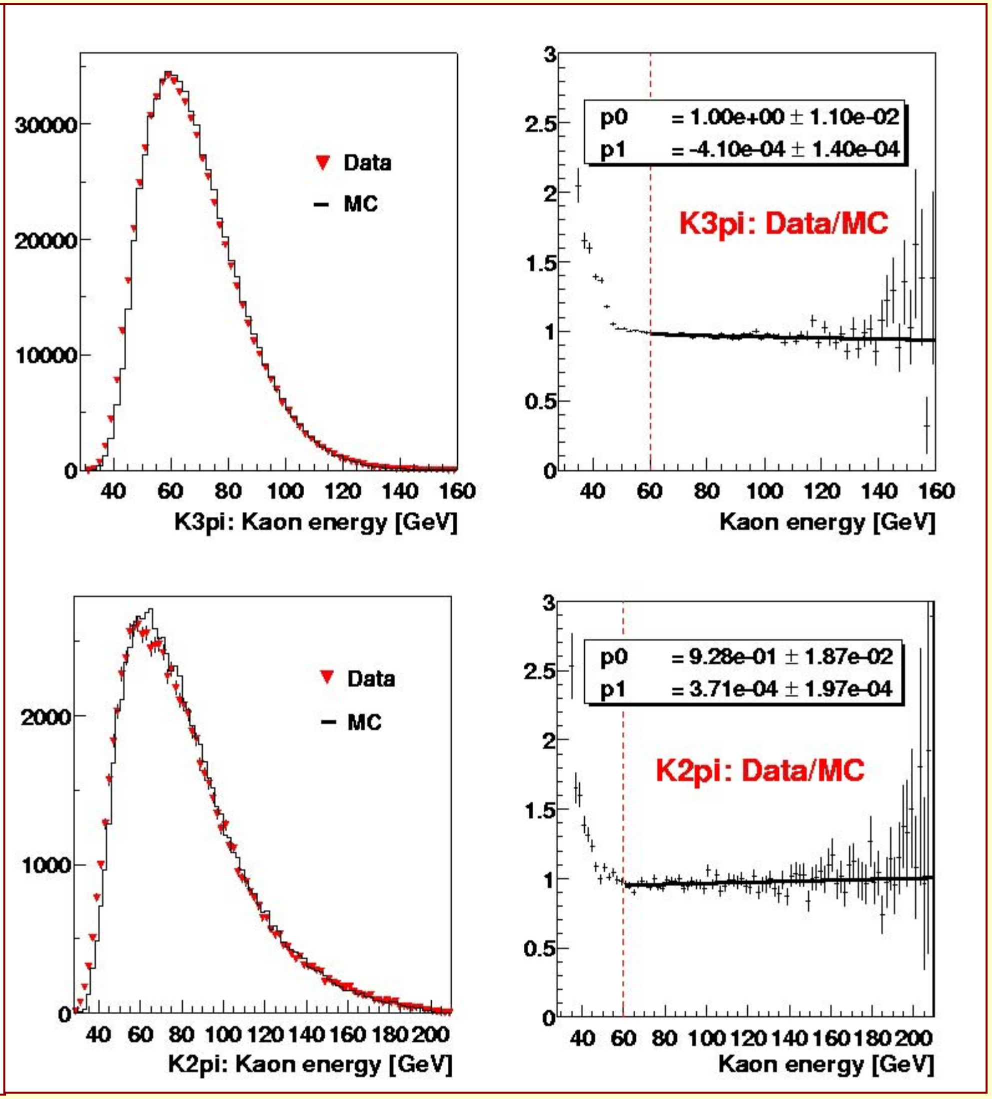
- Monte Carlo simulation of detector acceptance
  - All two track channels involved – (Ke3, Kμ3, K3π,K2π,K3π^0_D)
  - For average 2-track acceptance use Br fractions
  - Average from PDG and KTeV (Bμ3/Be3, B3π/Be3,….)

$$A_{2tr} = 0.2412 \pm 0.0004$$

- Ke3 simulation includes radiative corrections and Ke3γ with real photons Ginsberg (Phys.Rev. 171, 1675(1968)+ errata)
- Good agreement between MC and data except for high momentum K^0_L
- Systematic errors
  - Main contribution comes from inexact knowledge of beam momentum (can be reconstructed only up to quadratic ambiguity)
  - For measurement of beam momentum distribution – K2pi and K3pi decays
  - Experimental uncertainty of 0.7% on measured ratio
- Statistical errors are negligible

$K^0_L \rightarrow \pi e \nu$





$K^0_L \rightarrow \pi e \nu$

Experimental result

$\boxed{Br(K^0_L\ e3)/Br(2tr) = 0.4978 \pm 0.0035}$

To determine $Br(K^0_L \rightarrow \pi e \nu)$ we need $Br(K^0_L \rightarrow 3\pi^0)$

PDG04: $Br(K^0_L \rightarrow 3\pi^0) = 0.2105 \pm 0.0028$

KTeV $Br(K^0_L \rightarrow 3\pi^0) = 0.1945 \pm 0.0018$?

Average according PDG prescription

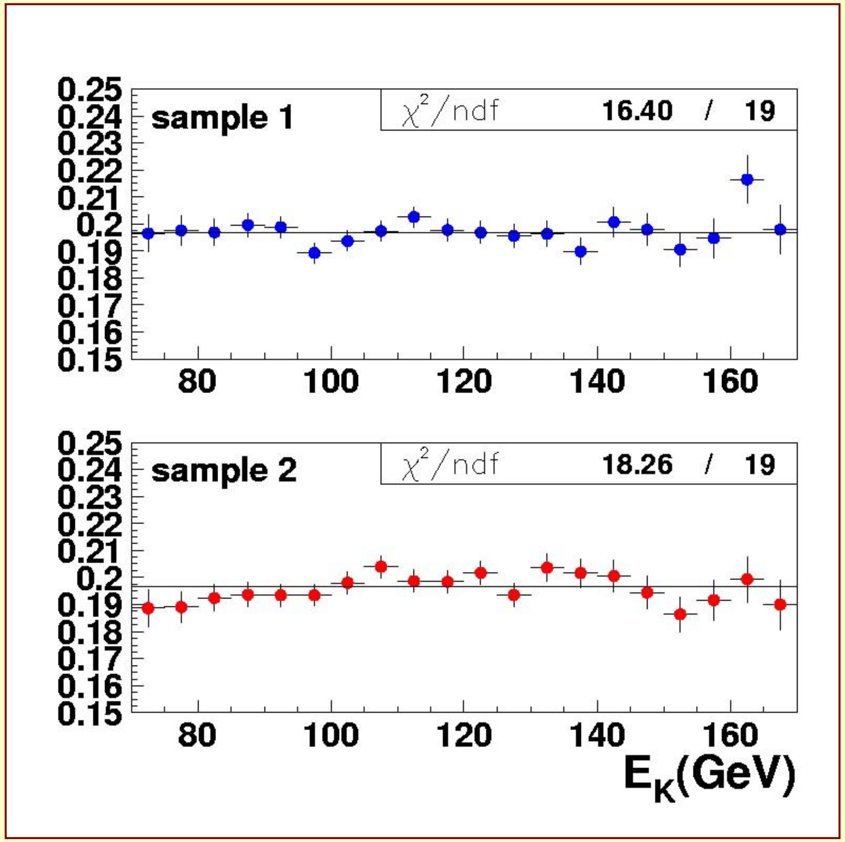
$Br(K^0_L \rightarrow 3\pi^0) = 0.1992 \pm 0.0070$

$\boxed{Br(K^0_L\ e3) = 0.4010 \pm 0.0028_{exp} \pm 0.0035_{norm}}$

Measurement of Br($K^0_L \rightarrow 3\pi^0$)

- Br($K^0_L \rightarrow 3\pi^0$) is the main experimental uncertainty on Br(K^0_L e3)
  - PDG (Kreutz et al 1995) inconsistent with new KTeV result by $\approx 5\,\sigma$
  - Measure Br($K_L \rightarrow \pi^0\pi^0\pi^0$)/ Br($Ks \rightarrow \pi^0\pi^0$)
  - Br($Ks \rightarrow \pi^0\pi^0$) $= 0.3104 \pm 0.0014$ well measured
- NA48/1 data, 2000:
  - High intensity Ks beam
  - No material (DCH etc) between collimator and LKr calorimeter
  - Ideal for measurement of neutral Kaon decays
- We used only small amount of 2000 data
  - ~200 000 $K_L \rightarrow \pi^0\pi^0\pi^0$
  - ~600 000 $Ks \rightarrow \pi^0\pi^0$
  - Two independent samples
  - Same number of K_L and K_s is produced on the target

Measurement of Br($K^0_L \rightarrow 3\pi^0$)



❖Main systematic

➢LKr energy scale	±0.0020
➢Effective target position	±0.0017
➢K_L life time:	±0.0015

$$\boxed{Br(K_L \rightarrow \pi^0\pi^0\pi^0) = 0.1966 \pm 0.0006_{stat} \pm 0.0033_{syst}}$$

Preliminary

In a good agreement with KTeV result

Measurement of Br($K^{\pm} \rightarrow \pi^{0} e^{\pm} \nu$)

- NA48/2 data from 2003
  - Low intensity K^{+}/K^{-} run (8 hours) with minimum bias trigger
- Normalize $K^{\pm} \rightarrow \pi^{0} e^{\pm} \nu$ decay to $K^{\pm} \rightarrow \pi^{\pm} \pi^{0}$

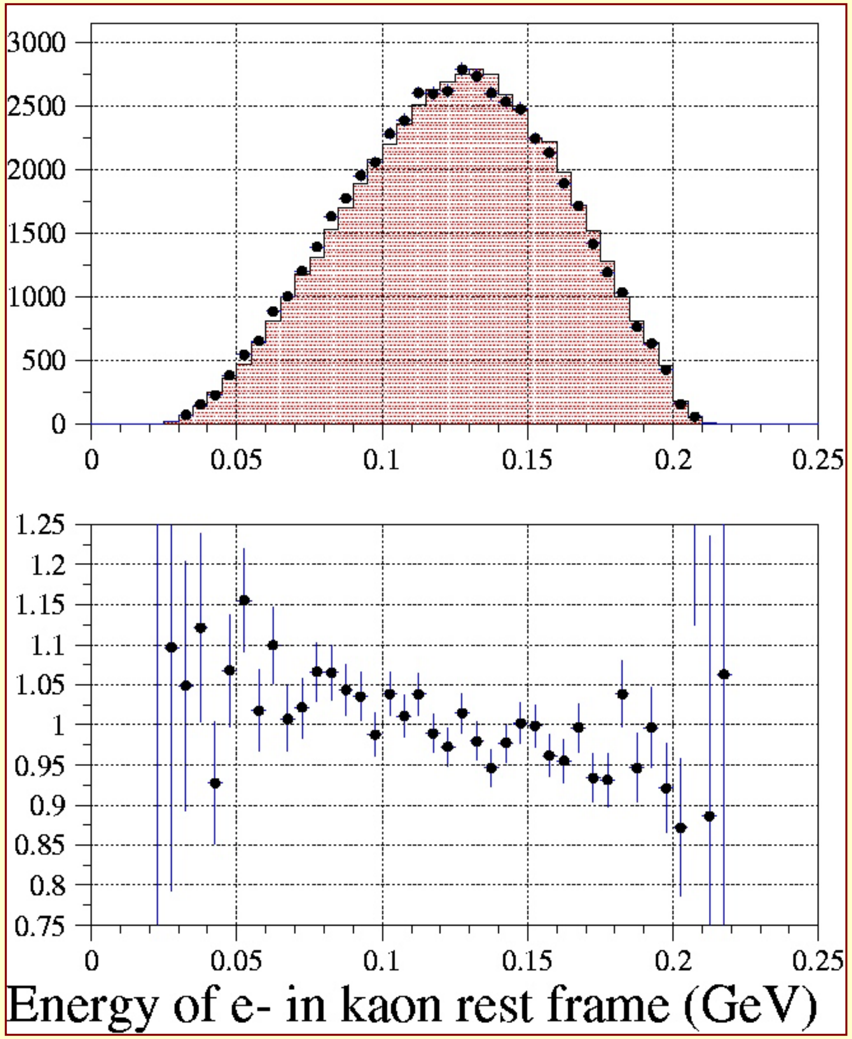
$$\mathrm{Br}(K^{\pm} \rightarrow \pi^{\pm} \pi^{0}) = 0.2113 \pm 0.0014$$

- Selected events

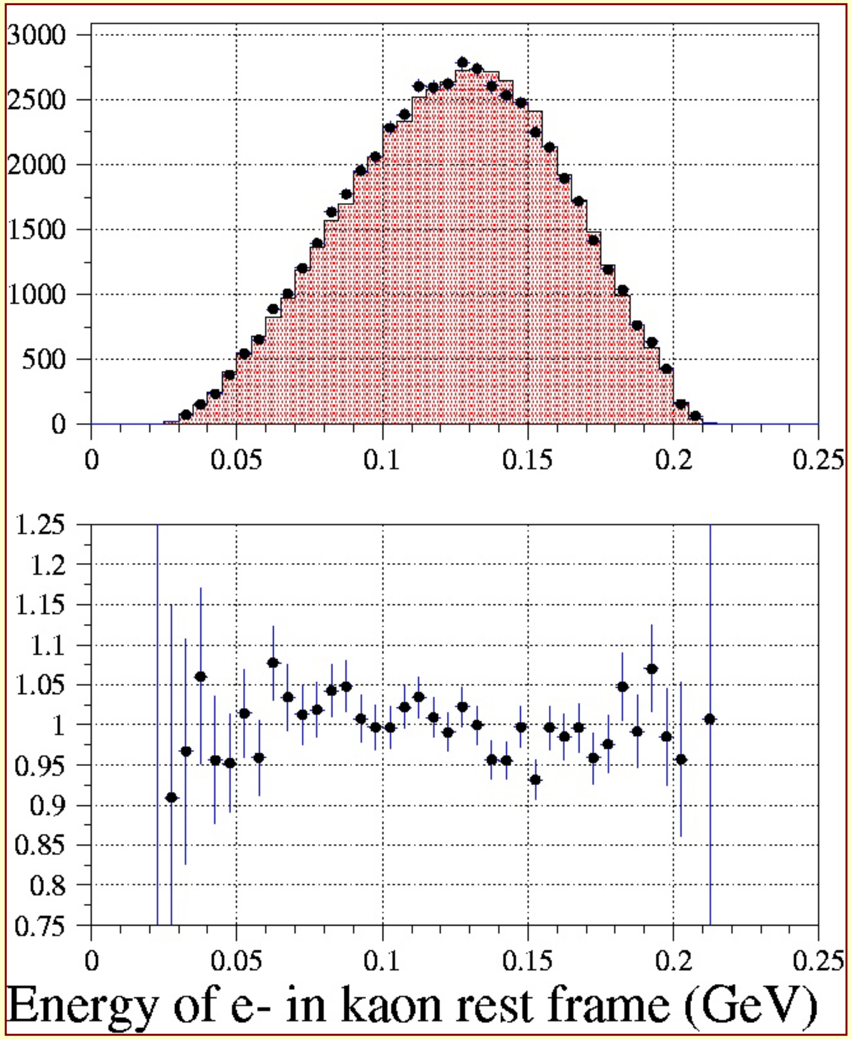
$K^{+} \rightarrow \pi^{0} e^{+} \nu$	59 000 ev.
$K^{-} \rightarrow \pi^{0} e^{-} \nu$	33 000 ev.
$K^{+} \rightarrow \pi^{+} \pi^{0}$	468 000 ev.
$K^{-} \rightarrow \pi^{-} \pi^{0}$	260 000 ev.

- Practically background free
- Systematic
  - Main sources – Detector acceptance, Br($K^{\pm} \rightarrow \pi^{\pm} \pi^{0}$), MC statistic

Measurement of Br($K^{\pm} \rightarrow \pi^{\pm} e\nu$)



Without radiative corrections



With radiative corrections

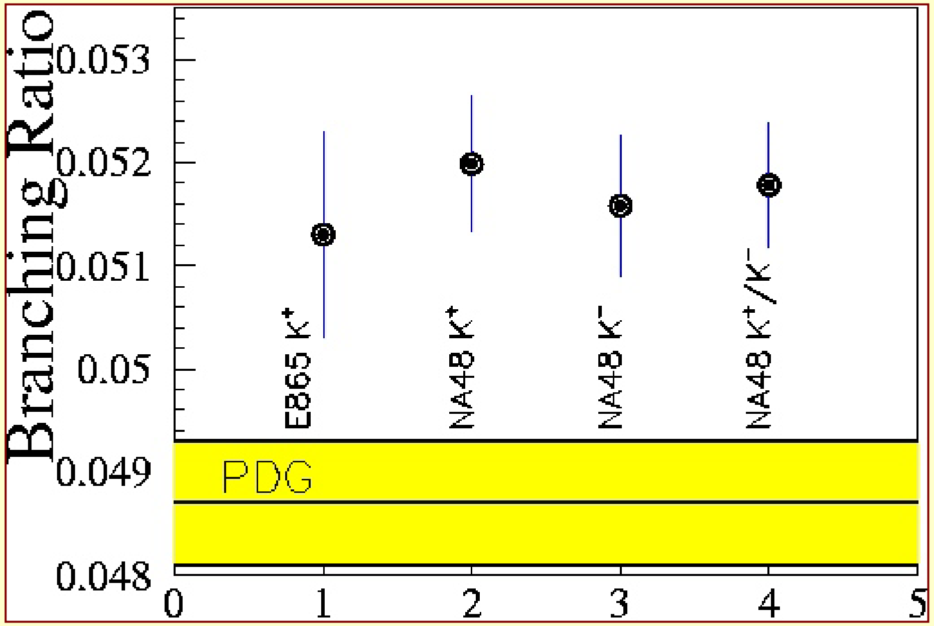
Measurement of Br($K^{\pm} \to \pi^0 e^{\pm} \nu$)

Preliminary NA48/2 result on Br($K^{\pm} \to \pi^0 e^{\pm} \nu$)

Br($K^+ \to \pi^0 e^+ \nu$) = ($5.163 \pm 0.021_{stat} \pm 0.056_{syst}$) %

Br($K^- \to \pi^0 e^- \nu$) = ($5.093 \pm 0.028_{stat} \pm 0.056_{syst}$) %

Br($K^{\pm} \to \pi^0 e^{\pm} \nu$) = ($5.14 \pm 0.02_{stat} \pm 0.06_{syst}$) %



Determination of Vus

|Vus| can be extracted from K → πeν via

$$\boxed{|V_{us}|.f_+^{K\pi}(0)=\sqrt{\frac{128\pi^3\Gamma(Ke3(\gamma))}{C^2G_F^2M_K^5S_{EW}I_K}}}$$

Where:

Sew = 1.0232 – short distance enhancement factor,

$\boxed{I_K(f_+^{K\pi}(t))}$ - phase space integral, $C=\left\{\begin{matrix}1 & K_{e3}^0\\ 1/\sqrt{2} & K_{e3}^+\end{matrix}\right\}$

We followed the prescription for Vus determination proposed in

V.Cirigliano, M. Knecht, H. Neufeld, H. Rupertsberger, P. Talavera, In Eur.Phys.J. C23 p121, 2002

V.Cirigliano, H. Neufeld, H. Pichl, Eur.Phys.J. C35 p53, 2004

Important – to treat all experimental data in the same way!

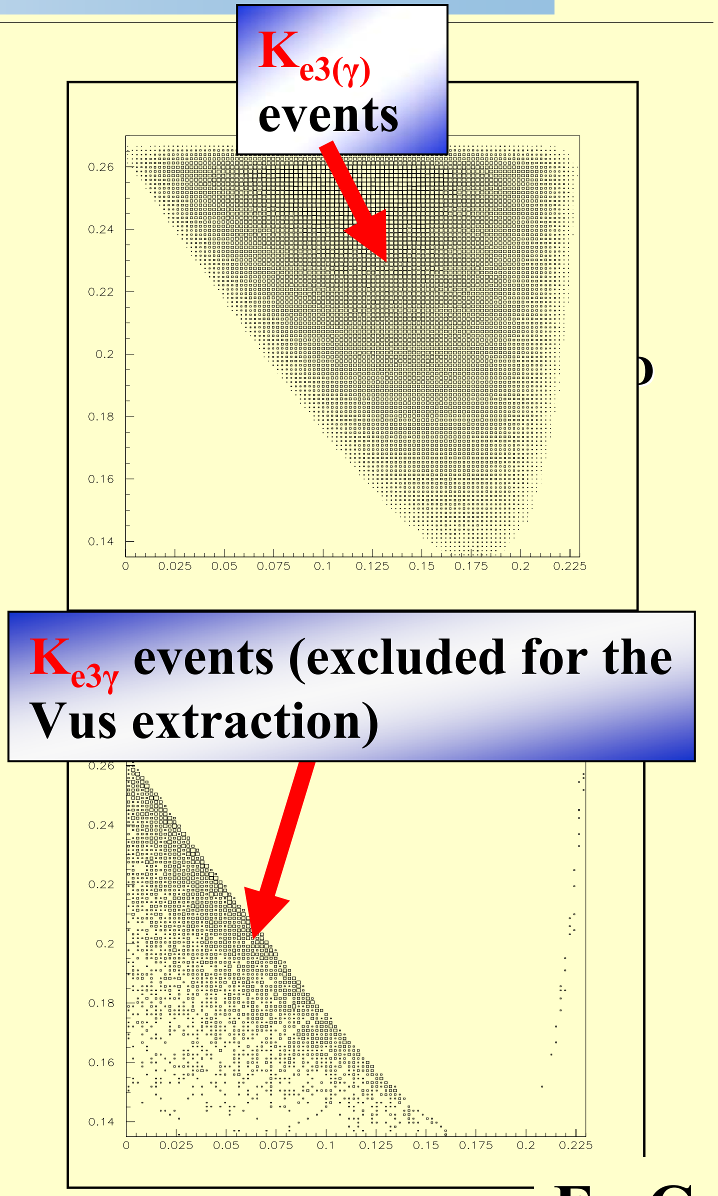
Radiative corrections (including virtual and real photons)! A few %

Determination of V_{us}

Prescription

- Accept all photon energies
- Accept all angles between pion and positron
- Accept only pion and positron energies within the original 3-body Dalitz plot.
- Inclusive rate obtained by integrating over the original domain

For calculation of $I_K(f_+)$ we used linear parameterization of $f_+(t)$ with corresponding PDG values for λ_+



$K_{e3(\gamma)}$ events

$K_{e3\gamma}$ events (excluded for the Vus extraction)

Determination of Vus

Calculation of $f_{+}^{K\pi}(0)$

Calculation using χPT with virtual photons and leptons

- **Isospin breaking by the quark masses up to $O((m_u-m_d)p^2)$**
- **Isospin conserving contribution from SU(3) breaking $O(p^6)$**
- **Electromagnetic effects up to $O(e^2p^2)$**
- **To extract V_{us} we used the following values**

$$f_{+}^{K^0\pi^+}(0) = 0.981 \pm 0.010$$

$$f_{+}^{K^+\pi^0}(0) = 1.002 \pm 0.010$$

The main uncertainty (~1%) comes from $O(p^6)$ contribution

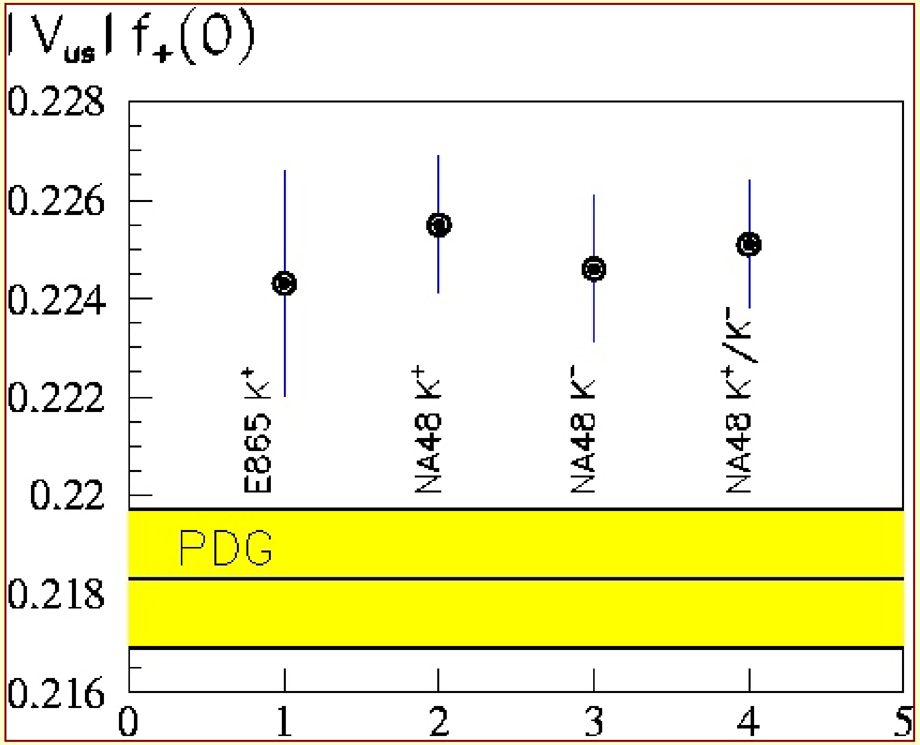
Determination of $V_{us}f_+(0)$

$$|V_{us}|.f_+^{K^0\pi^+}(0)=0.2146\pm0.0016$$

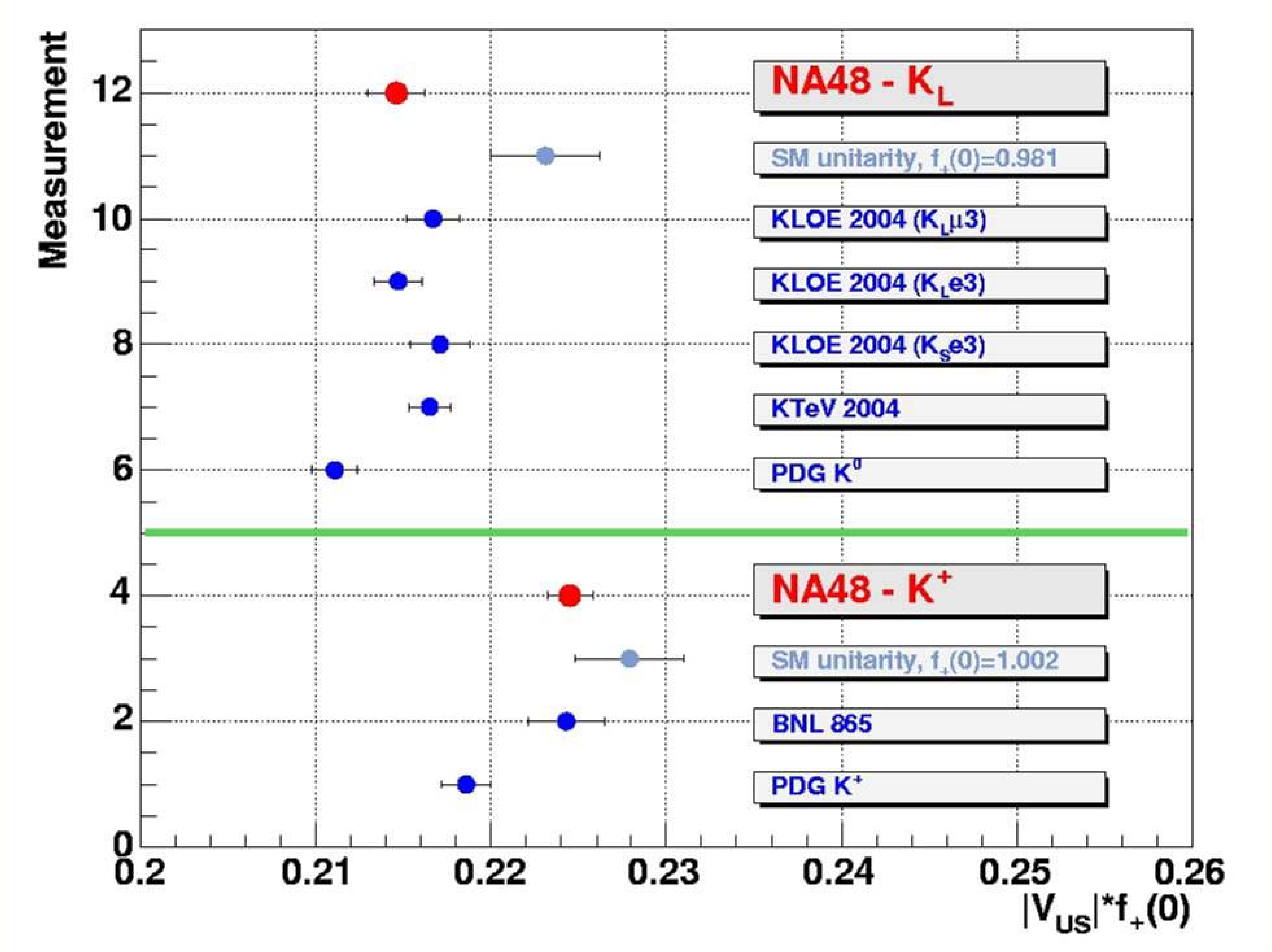
$$|V_{us}|.f_+^{K^+\pi^0}(0)=0.2250\pm0.0013$$

$$|V_{us}|.f_+^{K^-\pi^0}(0)=0.2235\pm0.0014$$

$$|V_{us}|.f_+^{K^\pm\pi^0}(0)=0.2245\pm0.0013$$



Determination of $V_{us}f_{+}(0)$



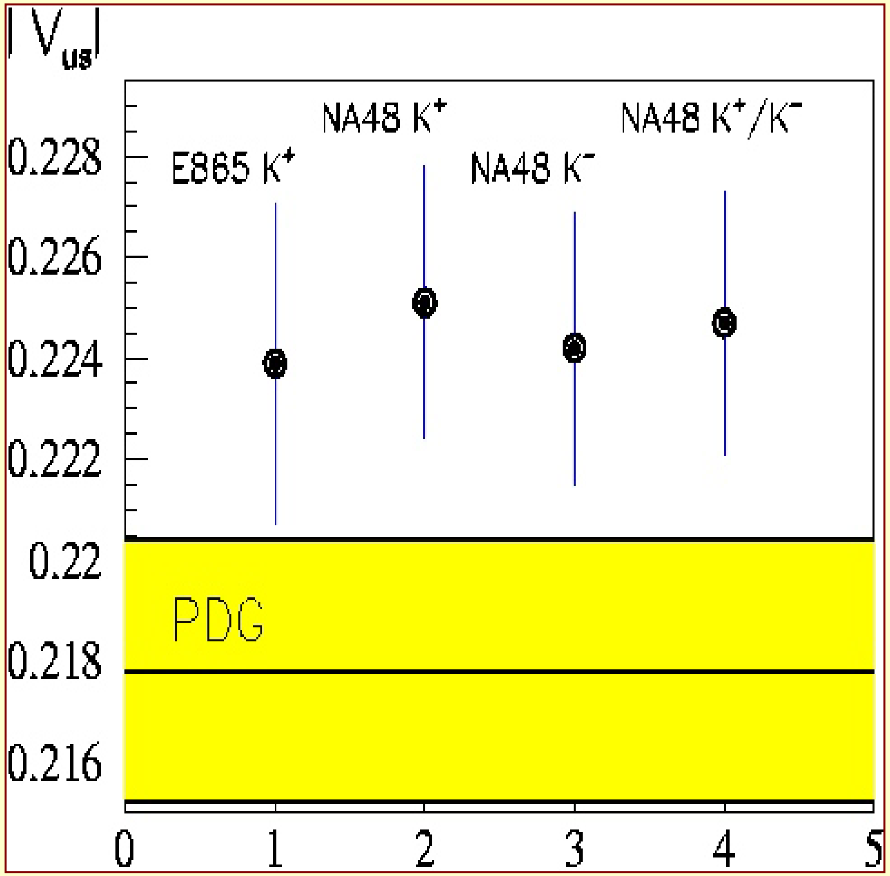
Determination of V_{us}

$$|V_{us}|^{K^0\pi^+}(0) = 0.2187 \pm 0.0016_{\exp} \pm 0.0023_{theor}$$

$$|V_{us}|^{K^+\pi^0}(0) = 0.2246 \pm 0.0013_{\exp} \pm 0.0023_{theor}$$

$$|V_{us}|^{K^-\pi^0}(0) = 0.2231 \pm 0.0014_{\exp} \pm 0.0023_{theor}$$

$$|V_{us}|^{K^\pm\pi^0}(0) = 0.2241 \pm 0.0013_{\exp} \pm 0.0023_{theor}$$



Uncertainty in V_{us} is dominated by the theory!

Determination of V_{us}

Conclusions

Experimental determination of Vus from

- $K^{\pm}$
  - in disagreement with old measurements (PDG)
  - in agreement with BNL result and SM prediction
- K^0_L
  - in disagreement with old measurements (PDG)
  - In agreement with new KTeV and KLOE measurements
  - Still in disagreement with SM prediction ~ 2.5 σ
- Main uncertainty comes from theoretical calculations of $f_+(0)$
  - More accurate calculation of O(p6) contribution required

New NA48 results

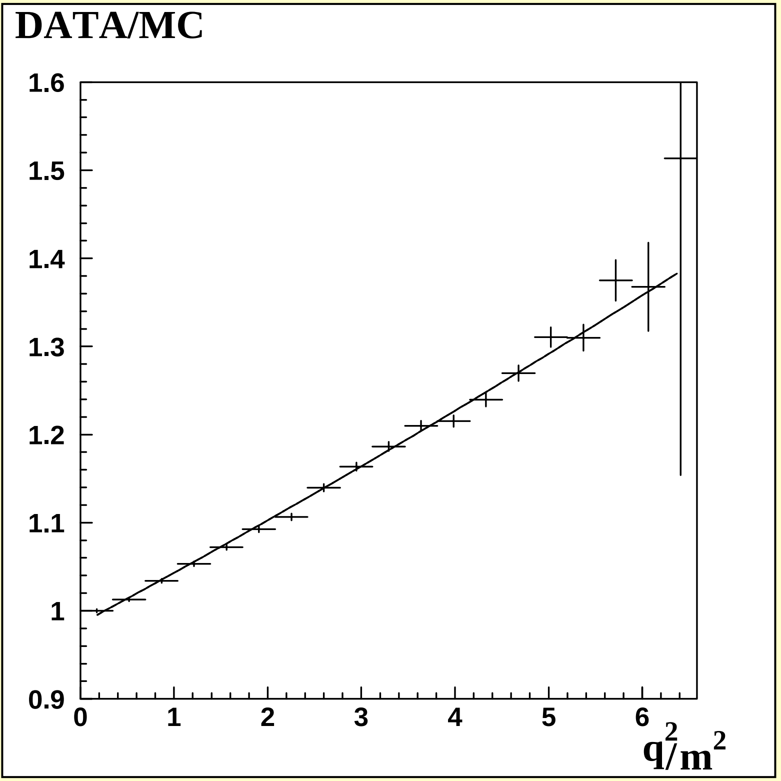
Other results

Ke3 form factors

- ❖ $K_L \to \pi e \nu$ form factors - the same 1999 data
  - ➢5.6 million reconstructed events
  - ➢Result for pure vector interaction

$$\lambda_+ = 0.0288 \pm 0.0005_{stat} \pm 0.0011_{syst}$$

  - ➢Preliminary result for 3-parameter fit:



$$\lambda_+ = 0.0284 \pm 0.0007 \pm 0.0013$$

$$\left|\frac{f_S}{f_+(0)}\right| = 0.015^{+0.007}_{-0.010} \pm 0.0012$$

$$\left|\frac{f_T}{f_+(0)}\right| = 0.05^{+0.03}_{-0.04} \pm 0.03$$

$PDG(2004):$

$$\lambda_+ = 0.0291 \pm 0.0018$$

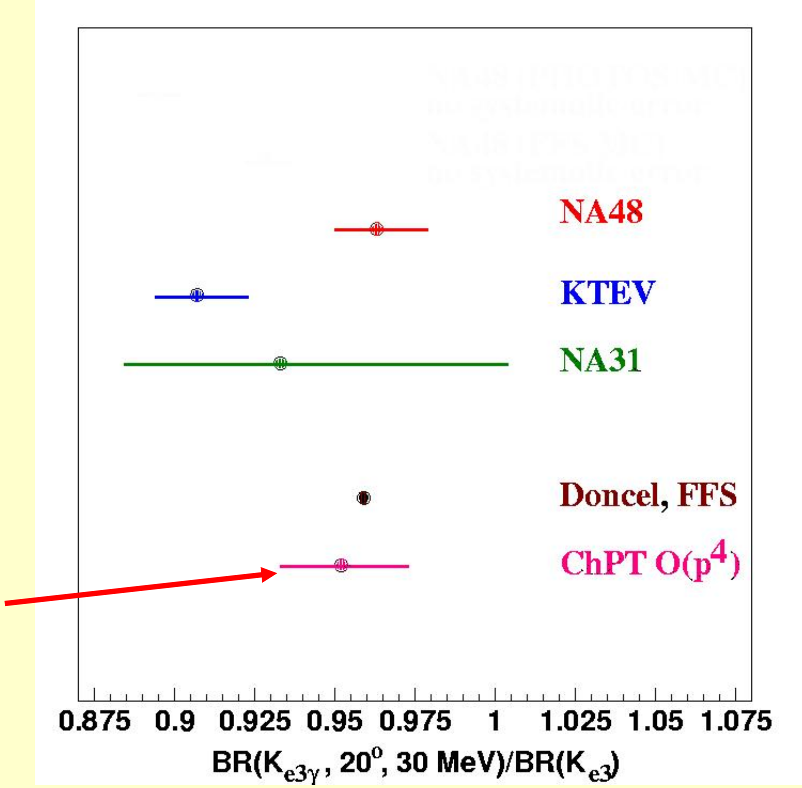
$$\left|\frac{f_S}{f_+(0)}\right| < 0.04$$

$$\left|\frac{f_T}{f_+(0)}\right| < 0.23$$

❖No evidence for scalar and tensor couplings!

$K^0_L \rightarrow \pi e \nu \gamma$

- Data analysis
  - Tight selection in order to suppress background from
    $K_{3\pi}$, K_{e4} and
    K_{e3} + accidental photon
  - Selected events:
    19000 : $K_{e3\gamma}$
    5.6 million : K_{e3}



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Result:

$$\frac{\Gamma(K_{e3\gamma}, E^*_\gamma > 30 MeV, \theta^*_{e\gamma} > 20^\circ)}{\Gamma(K_{e3})} = (0.964 \pm 0.008^{+0.012}_{-0.011})\%$$

- Good agreement with theory predictions!

Conclusions

- PDG values on |Vus| are in poor agreement with unitarity of the CKM matrix
- NA48 has performed |Vus| measurements in K^0_Le3 and $K^\pm$e3 decays
- K_L and $K^\pm$ results are
  - in disagreement with previous PDG values
  - in good agreement with recent results from KTeV and BNL
  - in fair agreement with SM predictions (better for $K^\pm$, worse for K_L)
  - different values from $K^\pm$ and K_L ?!
- More precise values for $f_+(0)$ are needed to solve the unitarity dilemma
- Semileptonic K_L decays
  - $K^0_L \rightarrow \pi e \nu$ form factors
  - Branching fraction for the radiative decay $K^0_L \rightarrow \pi e \nu \gamma$