Ke4 decays at Na48/2 experiment at CERN

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on behalf of NA48-CERN collaboration:

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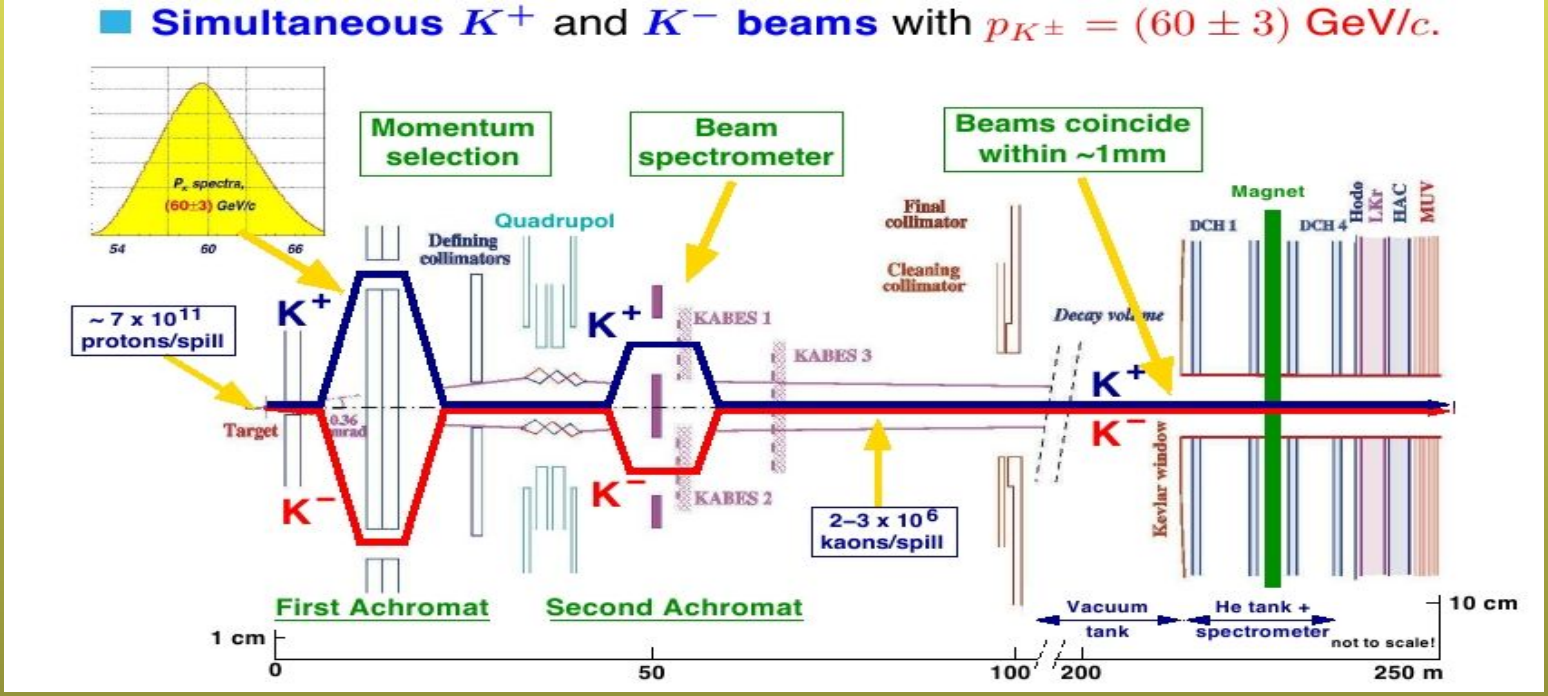
NA48 charged kaon beam

Primarly designed for CP violating charge asymmetries studies in K3p decays

2003 run ~ 50 days + 2004 run ~60 days , 200 TB Data on tape



Simulataneous K+ and K- beams: large charged symmetrization of experimental condition

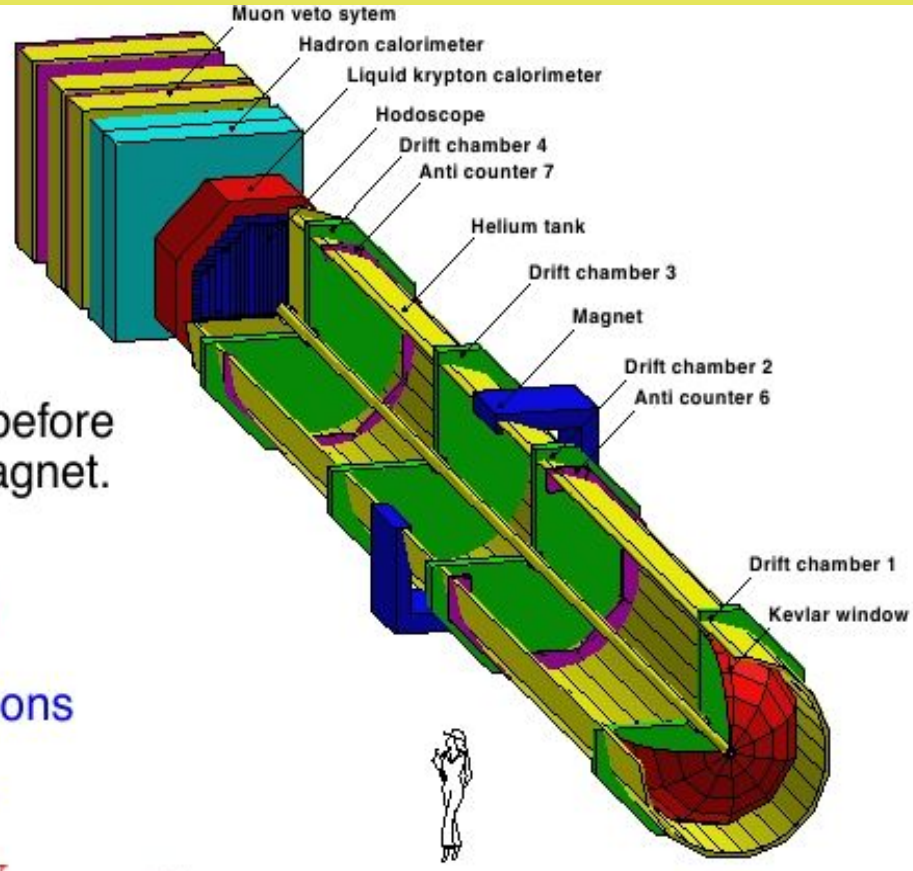
Beams coincide within ~1 mm all along the 114m decay volume flux ratio K+/K- ~1.8

NA48 detector

Main detector components:

- **Magnet spectrometer**
  - Two drift chambers each before and after spectrometer magnet.
  - Momentum resolution: $\leq 1\%$ for 20 GeV/c tracks.
- Anti-counters for photons, muons
- **Liquid Krypton Calorimeter**

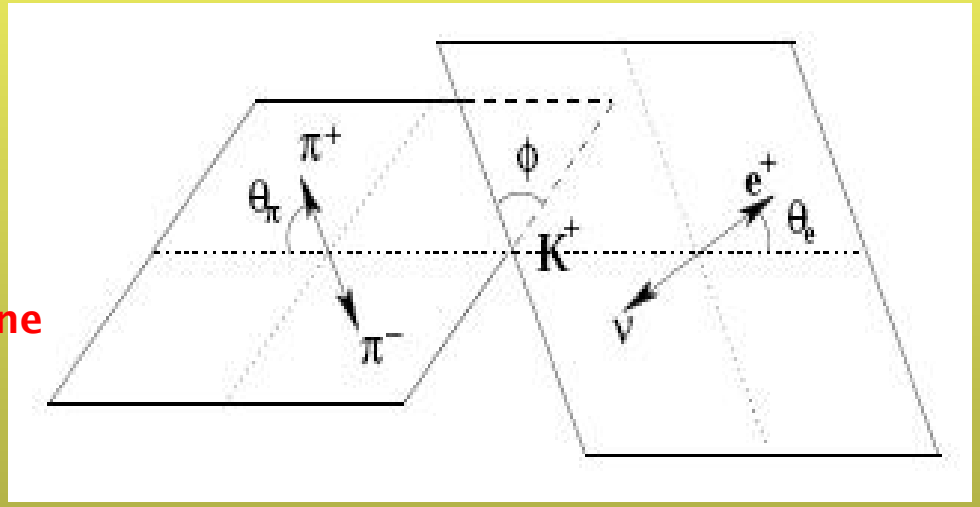
$$\frac{\Delta E}{E} = \frac{3.2\%}{\sqrt{E[\mathrm{GeV}]}} \oplus \frac{90\ \mathrm{MeV}}{E} \oplus 0.42\%$$



Ke4 formalism

Five kinematics variables Ca. Ma. variables
(Cabibbo Maksymovic , 1965)

$m(\pi\pi)$ **di-pion invariant mass**
$m(e\nu)$ **di-lepton invaiant mass**
θ_e **lepton emission angle**
θ_π **pion emission angle**
ϕ **angle between lepton and pion plane**



Partial wave expansion of the amplitude into S and P wave (**Pais Treiman, 1968**) and Watson Theorem (T-invariance)

two phases δ_S δ_P

F,G = 2 complex axial Form Factor

$$F = F_S e^{i\delta S} + F_P e^{i\delta P} \cos\theta_P$$

$$G = G_P e^{i\delta G}$$

H = 1 compex Vector Form Factor

$$H = H_P e^{i\delta H}$$

The fit parameter (real) are:

$$F_S , F_P , G_P , H_P , \delta = \delta_S - \delta_P$$

Map the distribution of the Ca. Ma. variables in the five dimensional space with 4 real form factor and only one phases shift, assuming identical phases for all the p wave form factor F,G;H.

Dalitz plot density proportional to FS

ChPT and Ke4 decays

label	decay	BR prediction	BR PDG	#events
Ke4 +-	$K^+ \to e^+ \nu \pi^+ \pi^-$	$(3.91 \pm 0.17)\ 10^{-5}$	$(4.09 \pm 0.10)\ 10^{-5}$	418000
Ke4 00	$K^+ \to e^+ \nu \pi^0 \pi^0$	$(2.01 \pm 0.11)\ 10^{-5}$	$(2.20 \pm 0.40)\ 10^{-5}$	37
Ke4 0-	$K^0 \to e^+ \nu \pi^0 \pi^-$	$(4.69 \pm 0.87)\ 10^{-5}$	$(5.20 \pm 0.11)\ 10^{-5}$	6131

Predictions: Using Form Factor calculation by ChPT at O(p2,p4,p6)

(Bijnens, Colangelo, Gasser Nucl. Phys B427 1994)

Isospin symmetry (mu = md =0 , α (QED) = 0)

$$\Gamma(+-) = \tfrac{1}{2}\,\Gamma(0-) + 2\Gamma(00)$$

Contribution to Ke4 decays from NA48

Ke4 decays in the (+-) mode have extensively studied with 1.1 million decays and published as **Eur. Phys. C70 (2010) 635**

Precise determination of all form factor and their energy variation

Precise determination of the S wave pp scattering length in **I=0 and I=2 states**

$$F_s = f_s\left(1 + \frac{f'_s}{f_s}q^2 + \frac{f''_s}{f_s}q^4 + \frac{f'_e}{f_s} \times \frac{m_{el}^2}{4m_p^2}\right)$$

$$\frac{G_p}{f_s} = \frac{g_p}{f_s} + \frac{g'_p}{f_s}q^2$$

Branching ratio measurement will fix the form factor absolute values

	value	stat.	syst.
f'_s / f_s	0.152	± 0.007	± 0.005
f''_s / f_s	-0.073	± 0.007	± 0.006
f'_e / f_s	0.068	± 0.006	± 0.007
f'_p / f_s	-0.048	± 0.003	± 0.004
g_p / f_s	0.868	± 0.010	± 0.010
g'_p / f_s	0.089	± 0.017	± 0.013
h_p / f_s	-0.398	± 0.015	± 0.008

Ke4(+-) branching fraction measurement

K+ -> $e^+\nu\pi^+\pi^-$ relative to the abundant and similar topology mode K+ -> $\pi+\pi+\pi-$

$$BR(Ke4) = BR(K3\pi) \times \frac{N4 - Nbgk}{N3} \times \frac{A3}{A4} \times \frac{\epsilon(K3\pi)}{\epsilon(Ke4)}$$

N4 Ke4 candidates : 1.11×10^6

Nbgk (relative to Ke4) : 0.95%

N3 K3π candidates : 1.9×10^9

Acceptance (Geant3 based simulation)
A4 Ke4 Acceptance: 18.22 % A3 K3π acceptance : 24.18%

trigger efficiency (measured using control triggers)
ε(ke4) = 98.3 % ε(k3π) = 97.5 %

BR(K3π) = (5.59 ± 0.04) %
corresponding to 0.72% external error on BR(Ke4)

Ke4(+-) branching fraction measurement

Systematic Uncertainty	[%]
Acceptance and beam geometry	0.18
Muon Vetoing	0.16
Accidental activity	0.15
Background	0.14
Particle ID	0.09
Radiative effect	0.08
Independent analysis	0.10

BR (ke4 +-) = (4.279 ± 0.004 stat ± 0.005 trig ±0.015 syst± 0.031 ext) x 10^{-5}

BR(ke4 +-) = (4.279 ± 0.035 tot) x 10^{-5}

Ke4(00) BR measurement and reconstruction

K+ -> $e^+\nu\pi^0\pi^0$ relative to the abundant and similar topology mode
K+ -> $\pi+\pi0\,\pi0$ extensively studied by NA48

Eur. Phys. J C52 (2007) 875 (CP violating Asymmetry in the Dalitz plot)
Eur. Phys. J C64 (2009) 589 (pp scattering length measurement)

BR(K3π) = (1.761 ± 0.022) % corresponding to 1.25% external relative error

EVENT RECONSTRUCTION :

2 π0 mass constraint

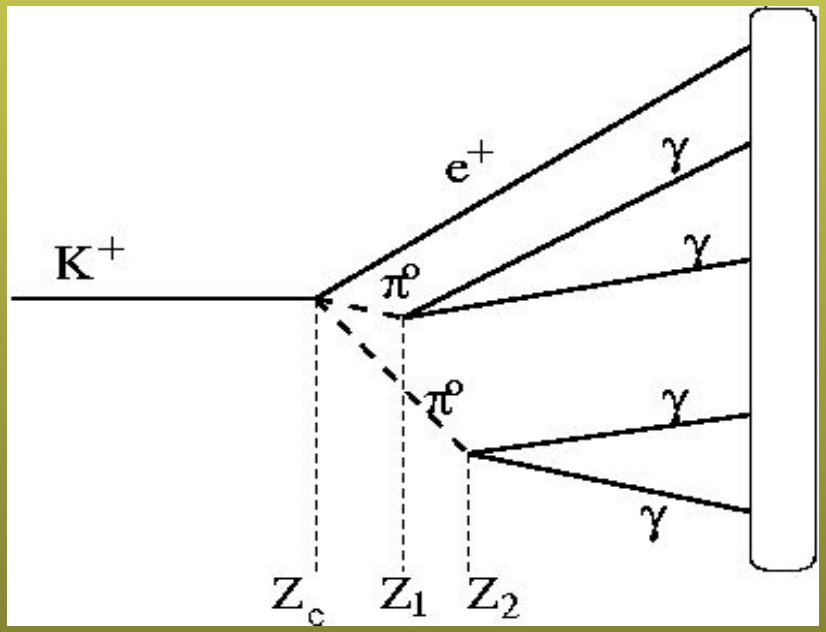
neutral vertexing | Z1 – Z2| < 500 cm

fiducial volume –16 < 0.5(z1+z2) < 90 m

charge vertexing ZC (CDA to beam line)

|zc – zn| < 800 cm

No P-ID at this point : 2 π0 + 1 charged track

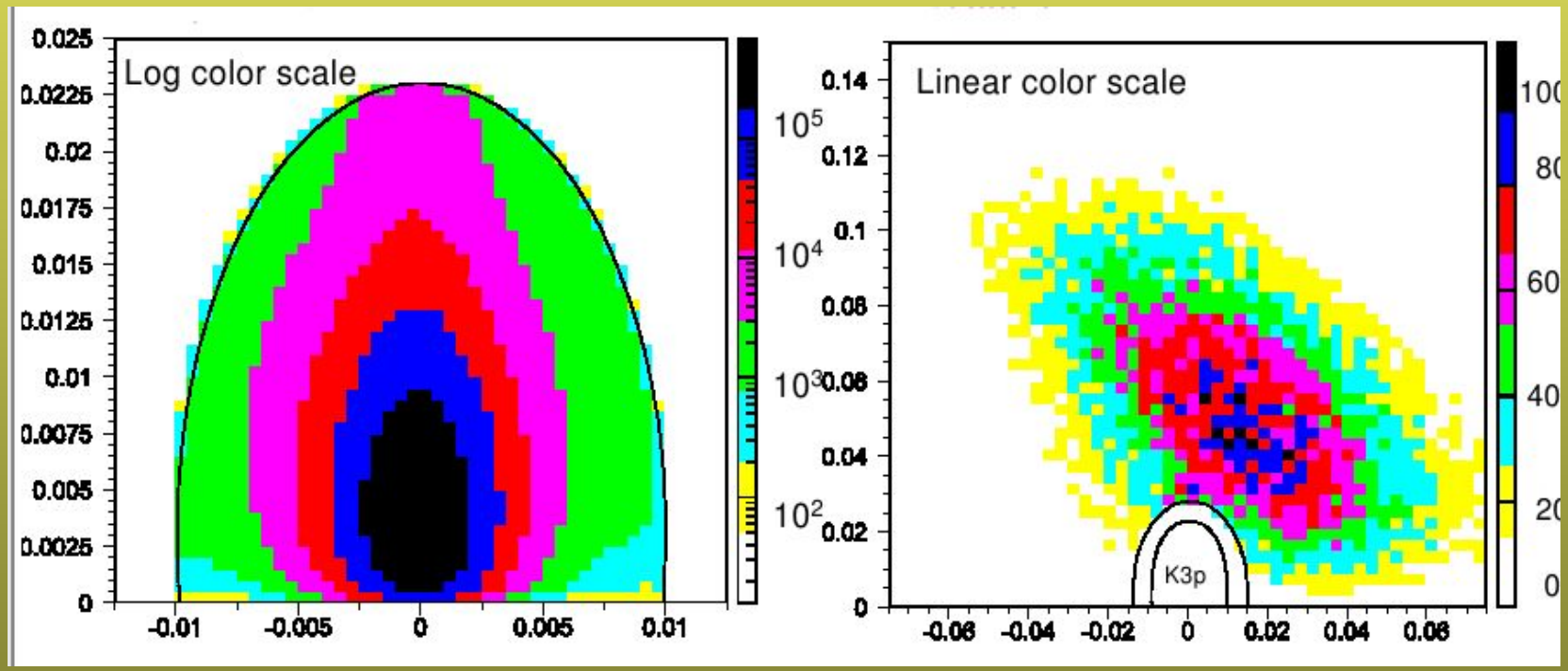


Ke4 signal selection

Assign to the charged track Mπ mass and compute invariant mass and the transverse momentum to the beam line.

K3π cluster at low pt and low Mk

Ke4 events have larger pt and larger spread of the invariant mass (missing ν)



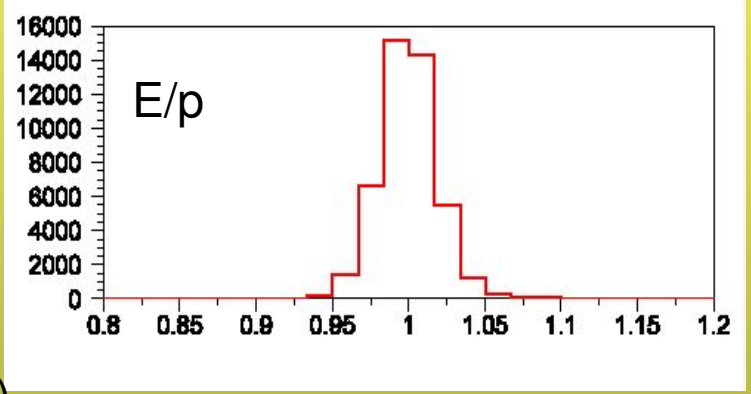
Pt vs M3π – M(Kaon) [GeV]

elliptic cut separate 70 M k3p from 45K ke4 candidates

Ke4(00) Background rejection

Electron identification:

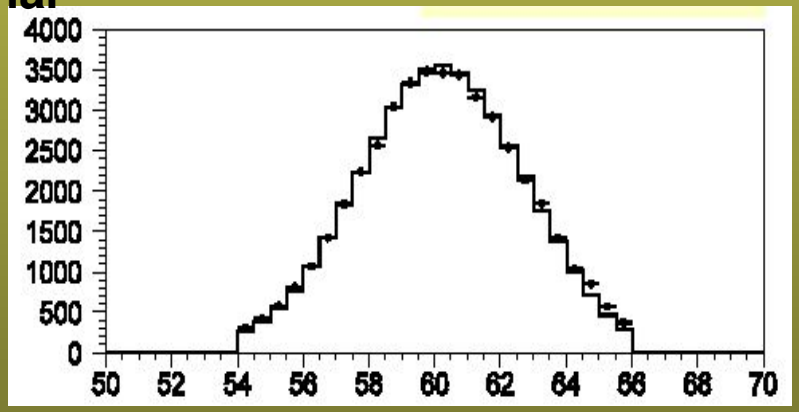
Energy(LKR)/p (spectro) ~ 1



extra fake-electron rejection using a dedicated variable (Linear Discr.) based on shower properties (i.e. lateral shower profile) and trained on real and fake electrons from data.

Residual fake-electron BKG estimated from control region as 1.3 % relative to Ke4 signal

Kaon momentum [GeV]

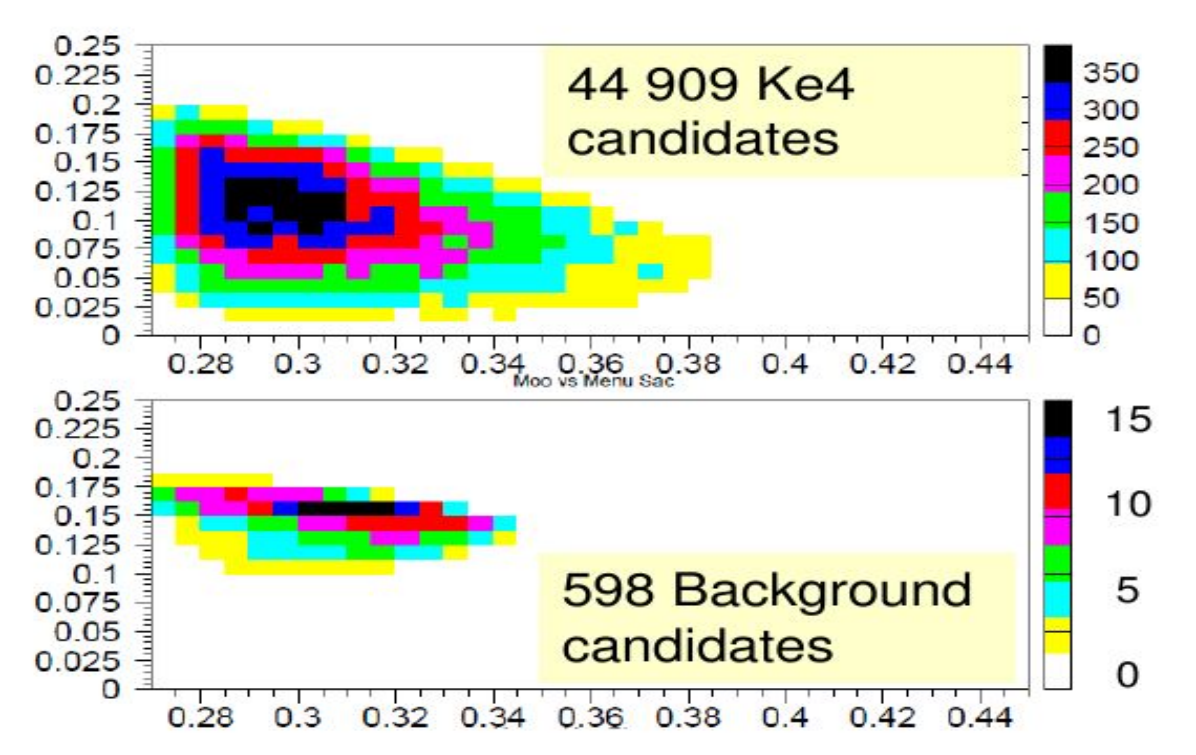


Kaon momentum reconstruction imposing energy- momentum conservation and neutrino mass = 0
(plot before BGK subtraction)

Ke4(00) Dalitz plot

BKG events cluster at low Mπ0π0 mass and Meν = Mπ as expected if K+ -> π+ π0 π0 is the dominant source

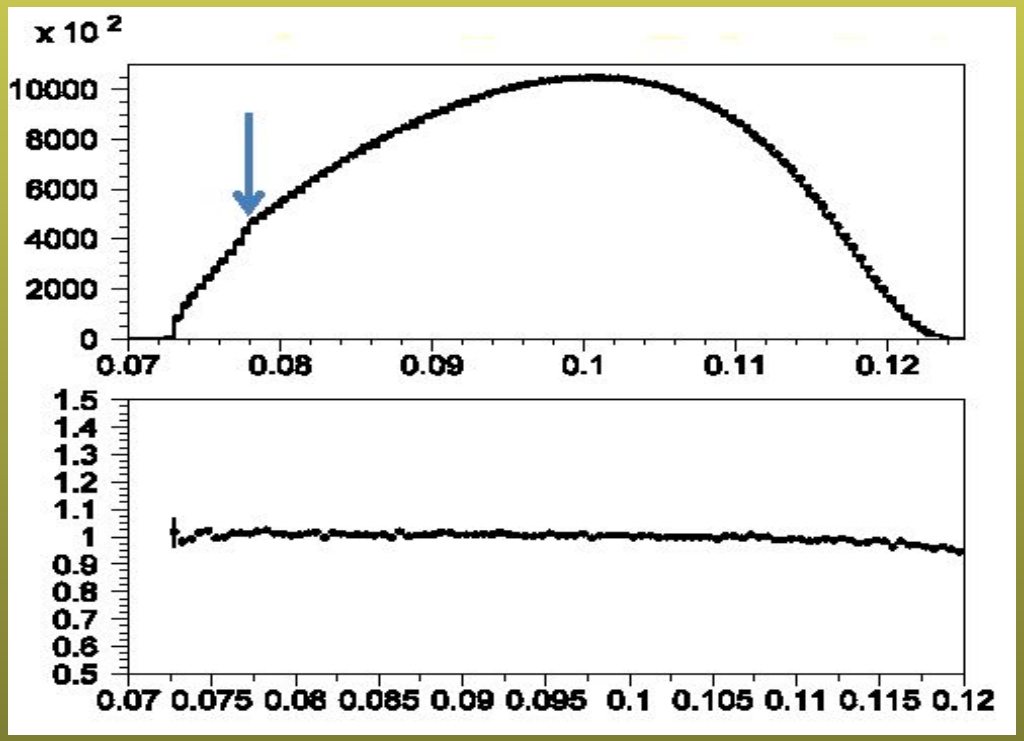
Meν VS Mπ0π0



K3π (00)

Matrix element well modelled (including CUSP) as described by an empirical parametrisation to our data [**Phys. Lett. B 686 (2010) 101**]

Mπ0π0 [Gev ^2]



Ke4 (00): Br measurement

Because of trigger conditions variations with time, BR is measurent in successive subsamples and then combined

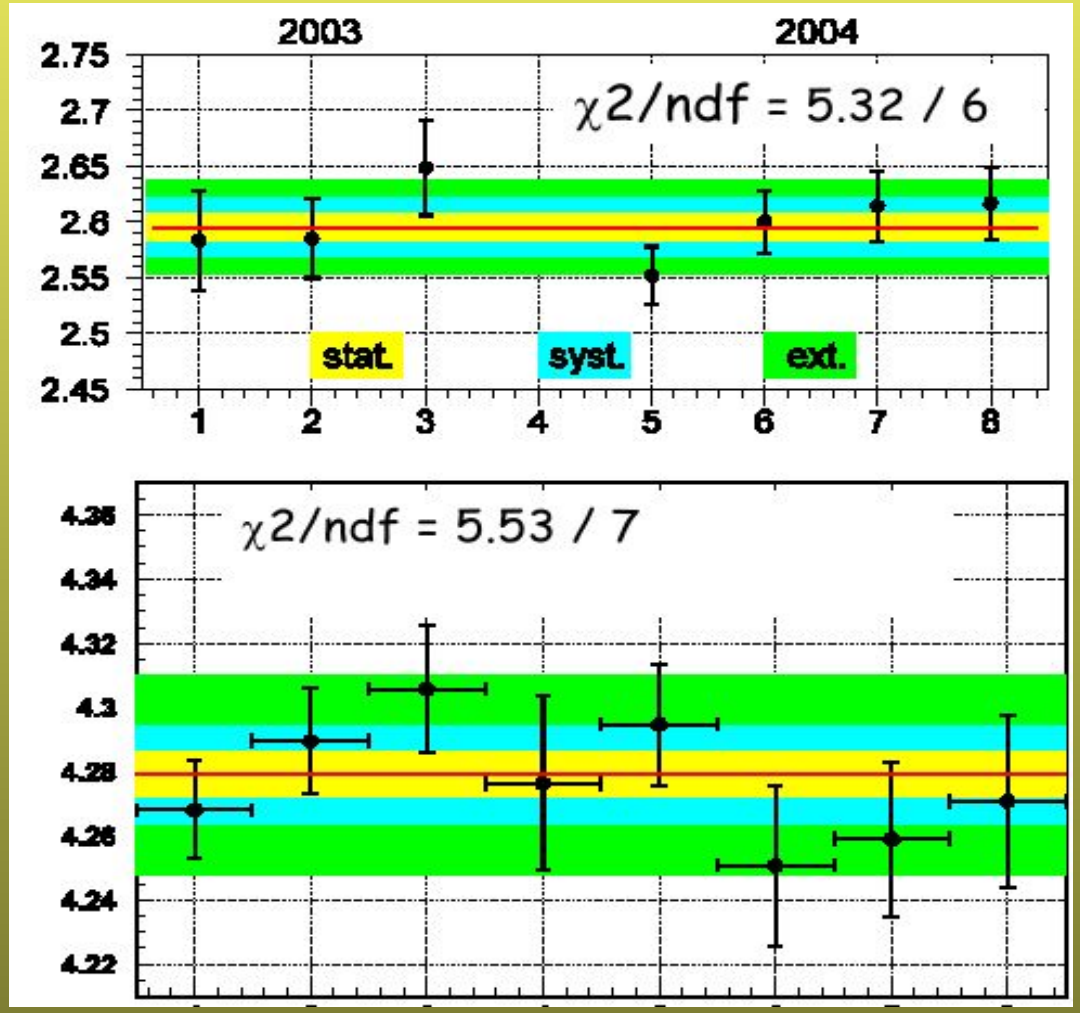
Nke4 candidates: 44909 **Nbkg = 598 (1.3 %)**
Nk3π candidates 70 984 882

Acceptance A4 1.77 % A3 = 4.11 %
Trigger efficiency ε(Ke4) : 92% to 98%
ratio to ε(K3π) ~ 1 but local deviations

Systematic uncertainty [%]	
Background	0.35
Simulation stat	0.12
FF dependence	0.20
Rad. Corr	0.23
Trigger	0.80
e-ID	0.10
Beam geometry	0.10
total	1.00

BR Ke4 (00) =
(2.595 ± 0.012 stat
± 0.025 syst
± 0.032 ext) 10^{-5}

Ke4(00) and (+−) : BR measurements



BR Ke4 (00) =
(2.595 ± 0.012 stat
± 0.025 syst
± 0.032) 10^{-5}

BR Ke4 (+-) =
(4.279 ± 0.007 stat
± 0.015 syst
± 0.031) 10^{-5}

PRELIMINARY

Conclusions

NA48 has analyzed ~1.13 M Ke4 (+-) and 44 K Ke4 (00) events recorded in (2003 + 2004)

1) **Improved measurements for the BR have been obtained**
   BR Ke4 (+-) 0.8% rel. (factor 3 improvements /PDG)
   BR Ke4 (00) 1.6% rel. (factor 10 improvements /PDG)

2) **When finalized, this will allow to give precise absolute values for all form factors of the decays**

3) **First approach to Form Factors shows consistency between (+-) and (00) modes**

4) **This study will complete the overall picture of Ke4 decays and will bring precise measurements to be compared with the most elaborated predictions from ChPT.**