Recent results from NA48/2 on Ke4 decays
Interpretation in terms of $\pi\,\pi$ scattering lengths

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On behalf of the NA48/2 collaboration:

Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Wien

Outline

- The NA48/2 experiment : for an introduction to beams, detector and performances, refer to previous NA48 talks (A.Dabrowski, A.Winhart, E.Imbergamo, E.Goudzovsky..)
- Ke4 decays ($K^{\pm} \rightarrow e^{\pm} \nu \pi^{+}\pi^{-}$) :
  kinematic variables and Form Factors
- Event selection, reconstruction and form factor extraction
- Ke4 results : Form Factors and phase shift
- Interpretation in terms of $\pi\pi$ scattering lengths
- Conclusion and prospects

The NA48/2 experiment: an introduction

The primary goals :

-Search for CP-violating charge asymmetries (K^+ - K^-) in $K^\pm \to 3\pi$ decays

Two measurements : "charged" $\pi^\pm \pi^+\pi^-$ and "neutral" $\pi^\pm \pi^0\pi^0$ asymmetries

both modes with large BR's of (2-5) 10^{-2}

-Precision study of high statistics $K^\pm \to 3\pi$ decays

(presented by E. Goudzovsky in previous talk)

but also

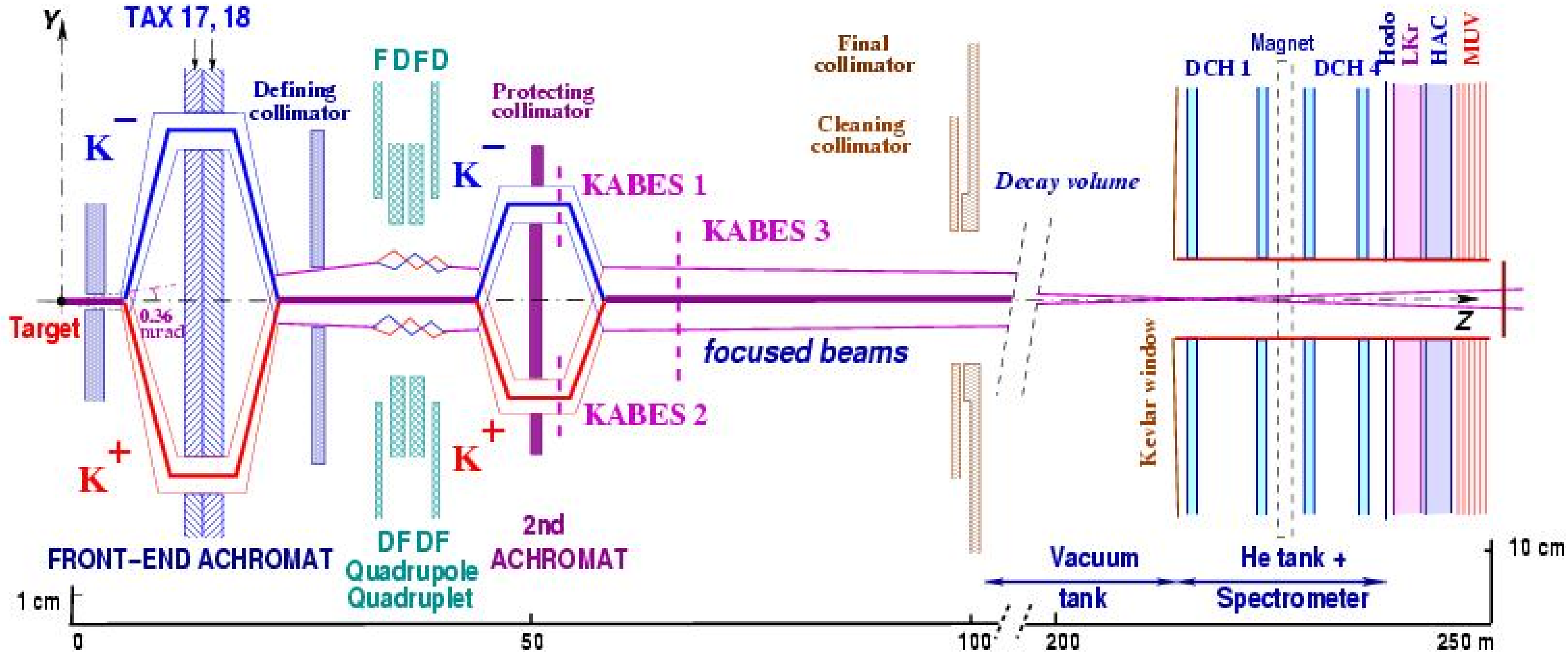
- Study of many rare decays , in particular Ke4 in the "charged" $\pi^+\pi^-e^\pm\nu$ (and "neutral" $\pi^0\pi^0e^\pm\nu$) final state, both modes with small BR's of few 10^{-5} .

  In the $\pi\pi$ scattering process, it is possible to relate amplitudes with different Isospin using dispersion relations (Roy equations) which depend essentially on two parameters, the scattering lengths a_0^0 and a_0^2 .

  Chiral PT predictions for low energy $\pi\pi$ interaction introduce further constrains between a_0^0 and a_0^2 which are related to the size of the quark condensate.

The NA48/2 experiment: beams and detector

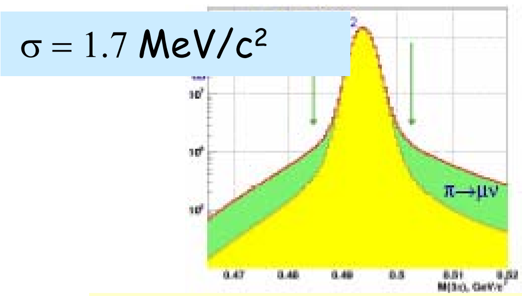
Simultaneous K^+/K^- beams : (60 ± 3) GeV/c



2003 Run ~50 days

2004 Run ~60 days

The NA48/2 experiment: detector performances



($\pi^{\pm}\,\pi^{+}\pi^{-}$) mass GeV/c²

Most important components for Ke4 analysis :

Magnetic spectrometer : 4 high-resolution DCH's

$\Delta p/p = (1.0 \oplus 0.044\ p)\%$ (p in GeV/c)

→ Very good resolution for charged invariant masses (Kaon)

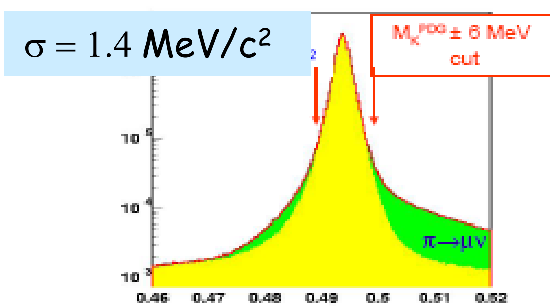
LKr electromagnetic calorimeter : quasi-homogenous and high granularity

$\Delta E/E = (3.2/\sqrt{E} \oplus 9.0/E \oplus 0.42)\%$ (E in GeV)

$\sigma_x = \sigma_y \sim 1.5$ mm for E=10 GeV

→ Very good resolution for neutrals ($\pi 0$)

→ E/p ratio for e/π discrimination



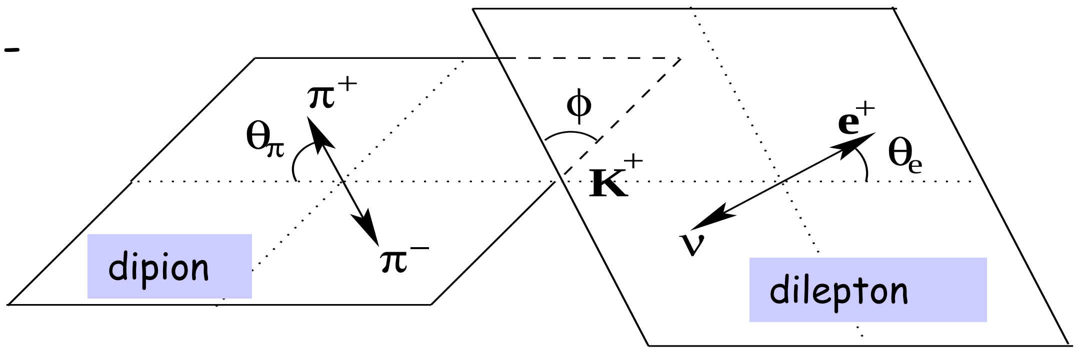
($\pi^{\pm}\,\pi^{0}\pi^{0}$) mass GeV/c²

Ke4 charged decays : formalism

Five kinematic variables (Cabibbo-Maksymowicz):

S_π ($M^2_{\pi\pi}$), S_e ($M^2_{e\nu}$),

$\cos\theta_\pi$, $\cos\theta_e$ and ϕ.



partial wave expansion of the amplitude:

F, G = Axial Form Factors

$F = F_s e^{i\delta s} + F_p e^{i\delta p} \cos\theta_\pi$ + d-wave term…

$G = G_p e^{i\delta g}$ + d-wave term…

H = Vector Form Factor

$H = H_p e^{i\delta h}$ + d-wave term…

expansion in powers of q^2 , $Se/4m\pi^2$

($q^2 = (S_\pi / 4m_\pi^2 - 1)$)

$$F_s = f_s + f_s' q^2 + f_s'' q^4 + f_e \left(S_e / 4m_\pi^{\ 2}\right) + ..$$

$$F_p = f_p + f_p' q^2 + ..$$

$$G_p = g_p + g_p' q^2 + ..$$

$$H_p = h_p + h_p' q^2 + ..$$

The fit parameters are : F_s F_p G_p H_p and $\delta = \delta_s - \delta_p$

Ke4 decays: event selection and background rejection

Signal ($\pi^+\pi^- e^\pm \nu$) Topology : 3 charged tracks , two opposite sign pions, 1 electron (LKr info E/p), some missing energy and p_T (neutrino)

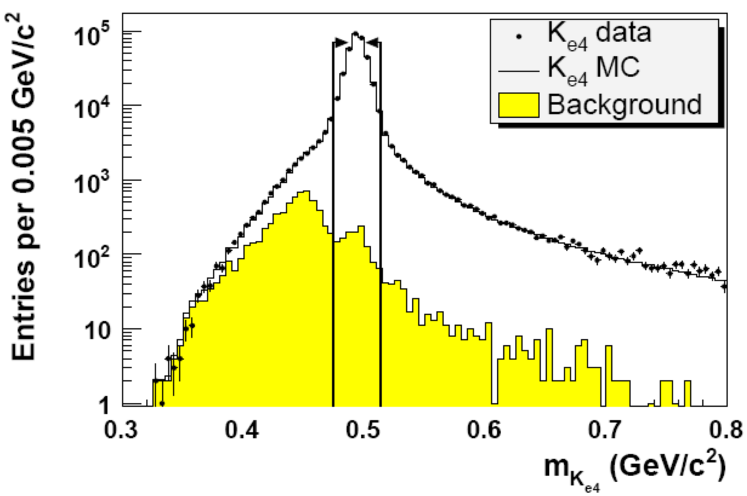
Background : main sources

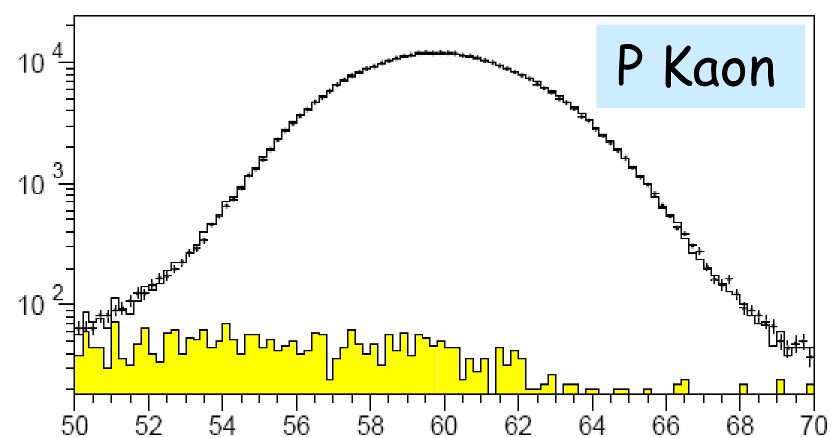
$\pi^\pm \pi^+ \pi^-$ decay + $\pi \to e \nu$ decay (dominant) or + π misidentified as e

$\pi^\pm \pi^0(\pi^0)$ decay + π^0 Dalitz decay ($e^+e^-\gamma$) + e misidentified as π and γ (s) undetected

Control from data sample : Wrong Sign events have the same total charge as signal events but e^- and $\pi^+ \pi^+$ for K^+ decays ($e+$ and $\pi^- \pi^-$ for K^- decays). Depending on the process, background events appear in signal (Right Sign) events with the same rate or twice the rate of the WS events

Total background level can be kept at ~ 0.5 % relative level





Ke4 charged decays : 2003 Data sample

Using iso-populated bins in the 5-dimension space of the C.M. variables, ($M_{\pi\pi}$, $M_{e\nu}$, $\cos\theta_{\pi}$, $\cos\theta_{e}$ and ϕ) one defines a grid of

10x5x5x5x12=15000 boxes.

The set of Form Factor values is used to minimize a log-likelihood estimator well suited for small numbers of data events/bin and taking into account the statistics of the simulation (simulated and expected events/bin).

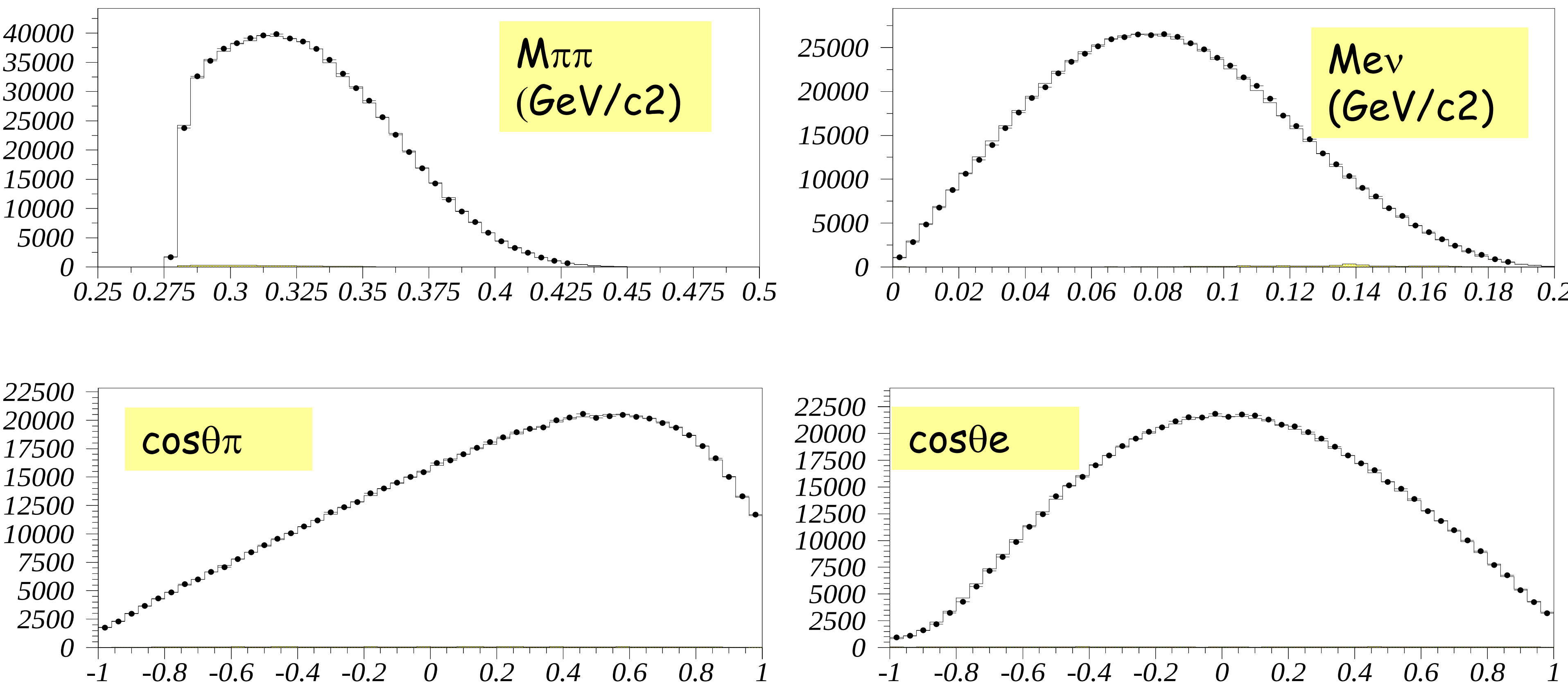
K^+ sample (435654 events)	29 events/box
K^- sample (241856 events)	16 events/box
MC K+ sample (10.0 Millions events)	~667 events/box
MC K- sample (5.6 Millions events)	~373 events/box

Ratio K+/K- ~ 1.8 both in Data and MC (run by run basis)
Ratio MC/Data ~ 23. both for K+ and K- (run by run basis)

Ke4 charged decays : the mass and cosθ distributions

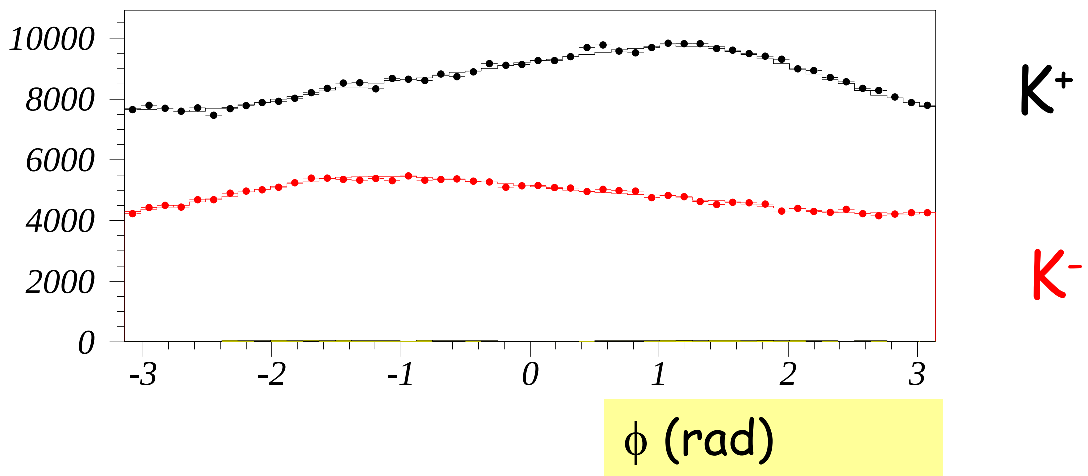
K^+ and K^- samples fitted separately, results combined

data (symbols), simulation after fit (hist.) and background (hardly visible)



Ke4 charged decays : the ϕ distributions

CP symmetry : (K+) ϕ distribution is opposite of (K-) ϕ distribution



Ratio K+/K- = 1.8

Ke4 charged decays : getting F,G,H form factors and phase shift

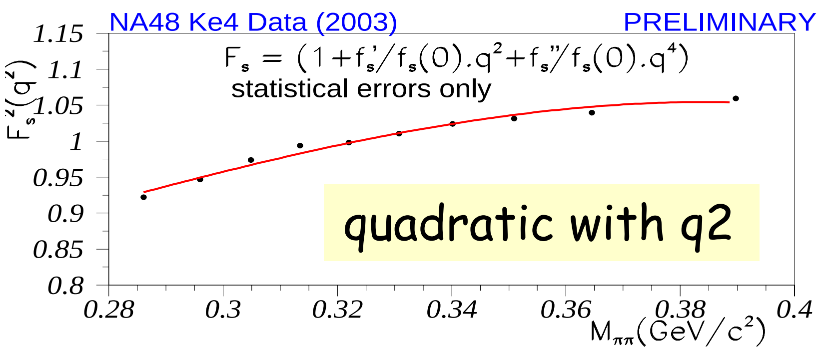
Ten independent fits, one in each $M_{\pi\pi}$ bin, assuming ~constant form factors over each box. This allows a model independent analysis.

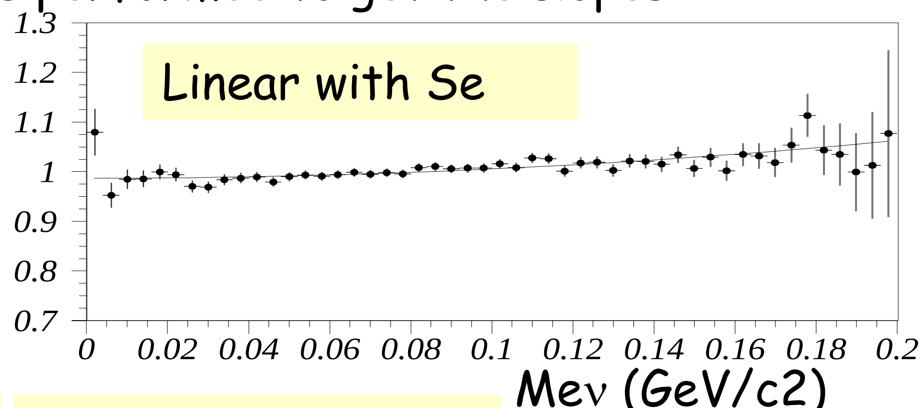
Without the overall normalization (Branching fraction), one can quote relative form factors and their variations with q^2,q^4 ($q^2 = (S_\pi/4m_\pi^2 - 1)$) and $Se/4m_\pi^2$

Fs^2 is obtained from the relative bin to bin normalization Data/MC after fit

If projected along Meν, a residual variation is observed.

A 2-dimension fit of the normalization is performed to get the slopes



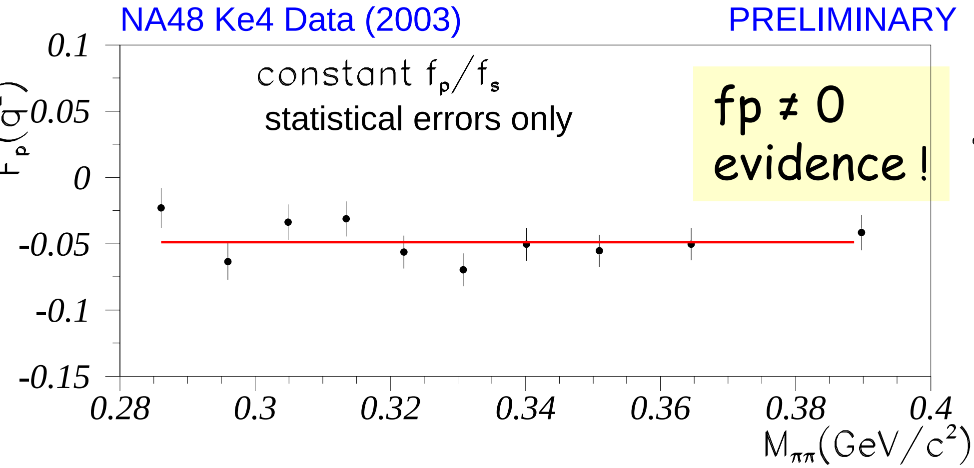


The 3 slopes are correlated

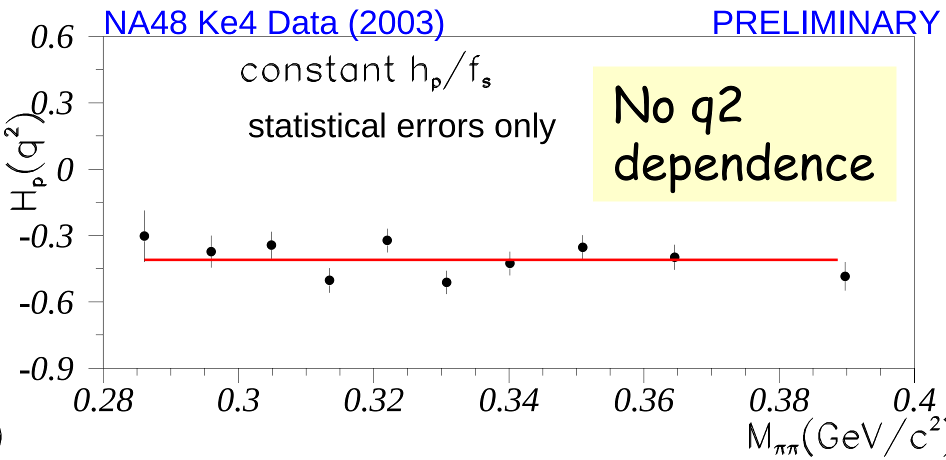
$Fs^2 \propto (1 + f's\, q^2 + f''s\, q^4 + f'e\, Se/4m\pi^2)^2$

	f"s	f'e
f's	-0.96	0.03
f"s		-0.06

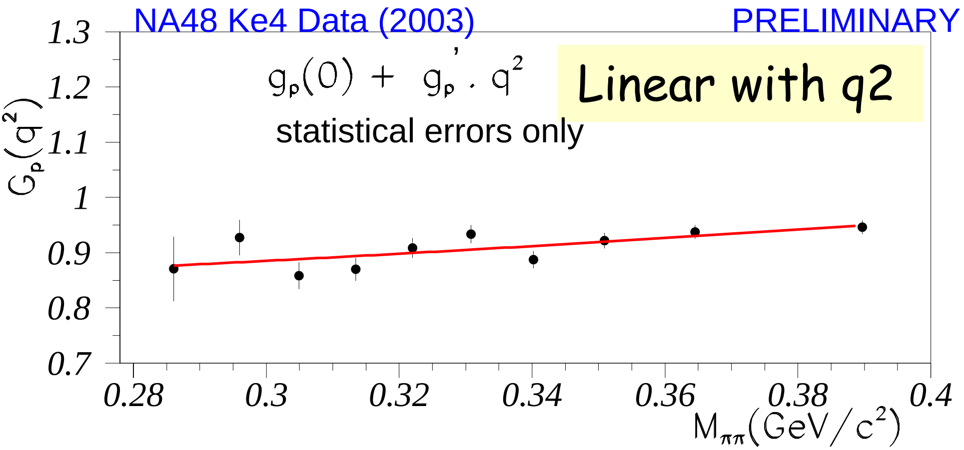
Getting Fp, Gp, Hp



fp ≠ 0 evidence !



No q2 dependence



Linear with q2

Correlation

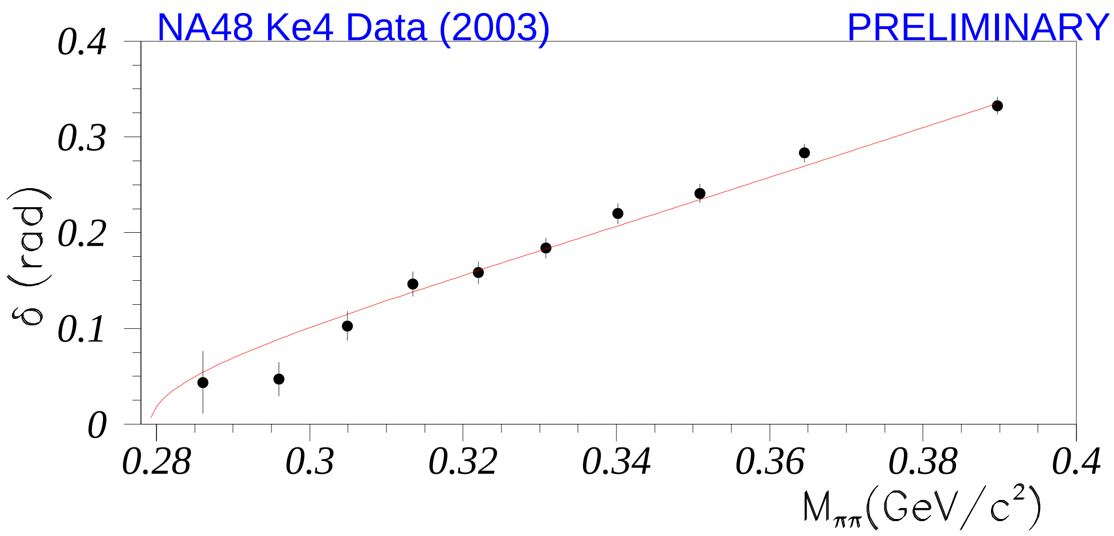
	g'_p
$g_p(0)$	-0.914

Ke4 charged decays : δ form factor and a_0^0

To extract information from the $\delta = (\delta_0^0 - \delta_1^1)$ variation, some external data (I=2 $\pi\pi$ data @Higher energy) and theoretical work are needed :

An example is the numerical solution of Roy equations (ACGL Phys. Rep.353 (2001), DFGS EPJ C24 (2002)) which relates δ and (a_0^0, a_0^2) .

The Universal Band centre line parameterization corresponds to a 1-parameter fit with a fixed relation $a_0^2 = f(a_0^0)$.



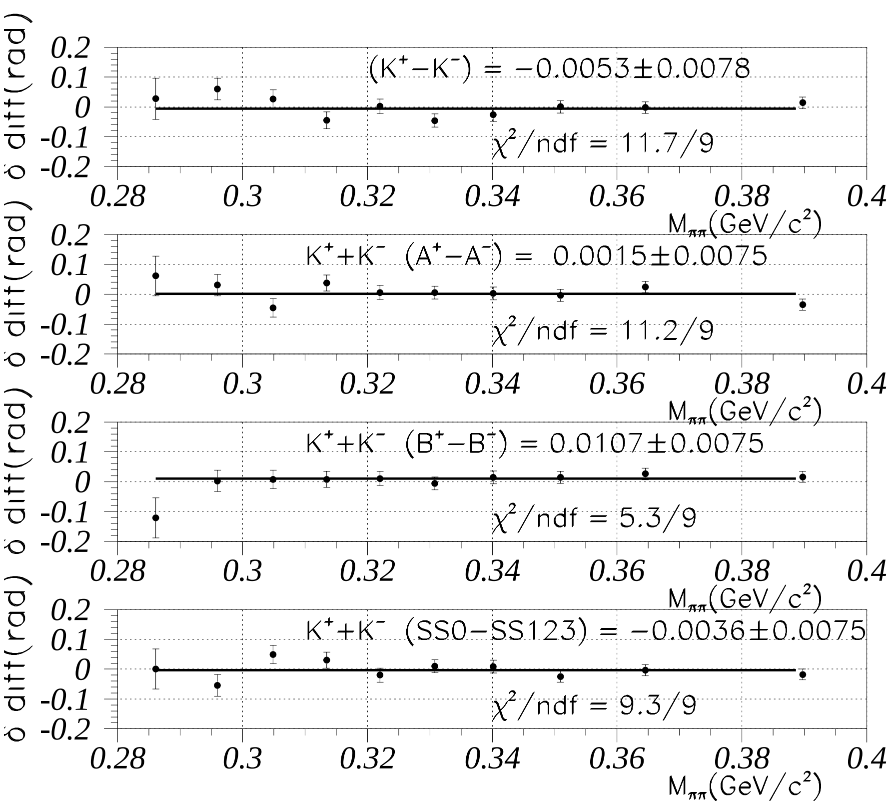
Ke4 charged decays : systematic uncertainties

Snapshot on systematics :

- Two independent analyses with slightly different approaches (binning, trigger efficiency, fit method..)
- Acceptance control
- Background level and shape control :
- Electron/pion rejection control
- Radiative corrections implementation
- Neglected S_e dependence in the simulation

Possible bin to bin correlations were investigated and taken into account in the overall fit procedure (non diagonal covariance matrix)

Acceptance control



2003: SS0= first 20 days, SS123=last 30 days

Ke4 charged decays : Form Factors results (677 500 decays)

relative Form Factors = FF/Fs(0)

- measured separately for K^+ and K^-,
- combined according to statistical errors,
- Fs obtained from bin to bin normalization,
- Fp, Gp, Hp de-convoluted from observed Fs(q2,Se) variation .

All Form Factors and their variation with the invariant masses now measured with 5 to 15 % relative precision

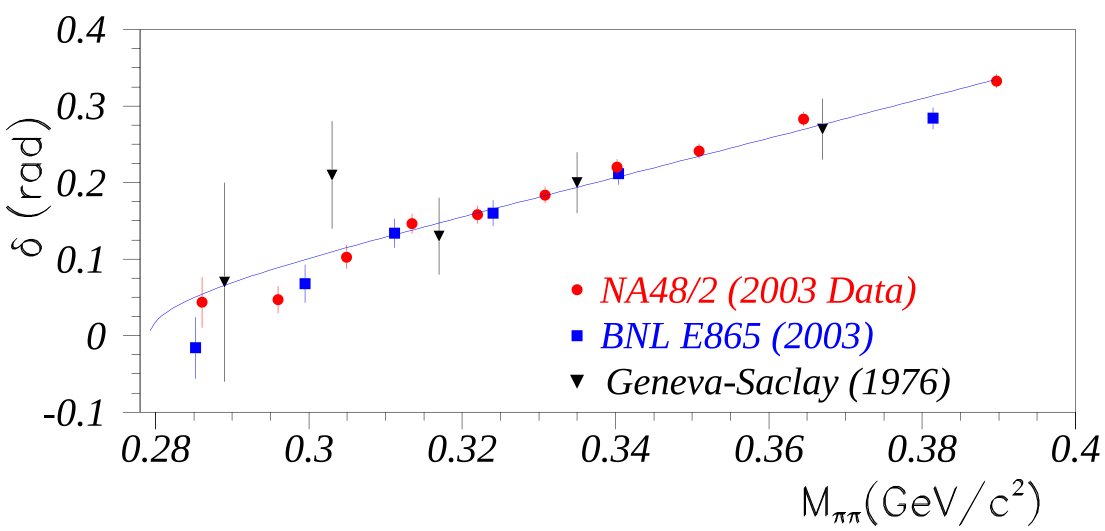
	value ± stat. ± syst.
f_s'/f_s	= 0.165 ± 0.011± 0.006
f_s''/f_s	= -0.092 ± 0.011 ± 0.007
f_e'/f_s	= 0.081± 0.011 ± 0.008
f_p/f_s	= -0.048± 0.004 ± 0.004
g_p/f_s	= 0.873± 0.013 ± 0.012
g_p'/f_s	= 0.081 ± 0.022 ± 0.014
h_p/f_s	= -0.411 ± 0.019± 0.007

Ke4 charged decays : towards π π scattering lengths

Comparison with previous published Ke4 results :

- CERN/PS Geneva-Saclay ~30000 decays (K^+) (Phys. Rev. D15 (1977))
- BNL E865 ~390 000 decays (K^+) (PRL 87 (2001), Phys. Rev. D67 (2003))
- CERN/SPS NA48/2 : preliminary result from ~677 500 decays (K^++K^-) significant acceptance at larger $m_{\pi\pi}$ values, high resolution and low background level.

Universal Band centre line shown (stat. + experimental syst. errors added)

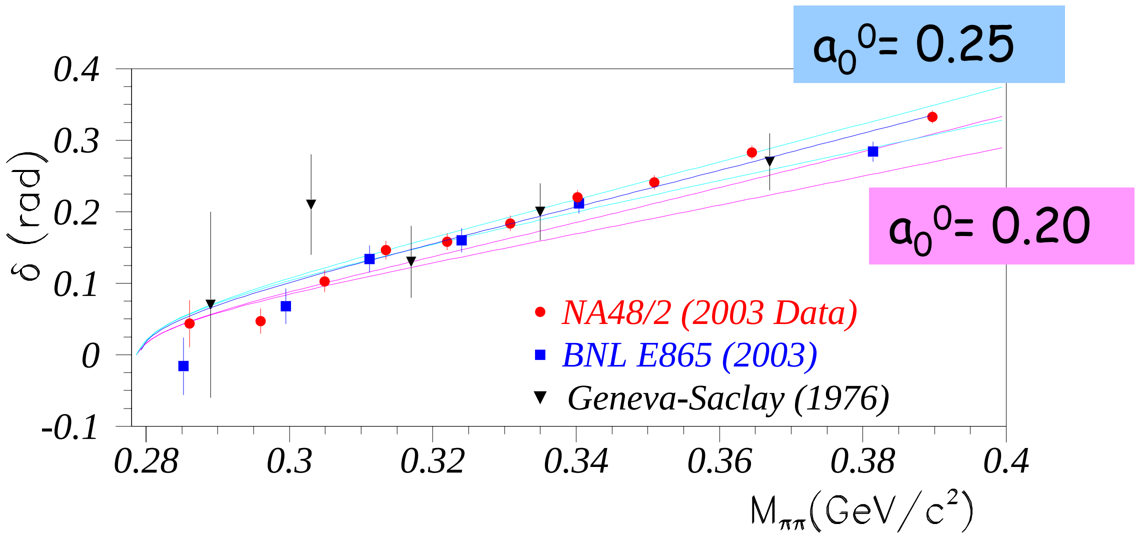


Ke4 phase shift measurements : are they compatible ?

Thanks to the "independent bin" analysis, one can replay the scattering length extraction with more elaborated models and combine results from the various experiments even after completion of collaborations !

E865 quotes various values extracted from their Ke4 phase measurements, ranging from $a_0^0 = 0.203$ to $a_0^0 = 0.237$

NA48/2 seems to prefer slightly higher values



Last point of E865 seems somewhat inconsistent with other points (Could that be a problem with the mass value quoted for the last bin ...?)

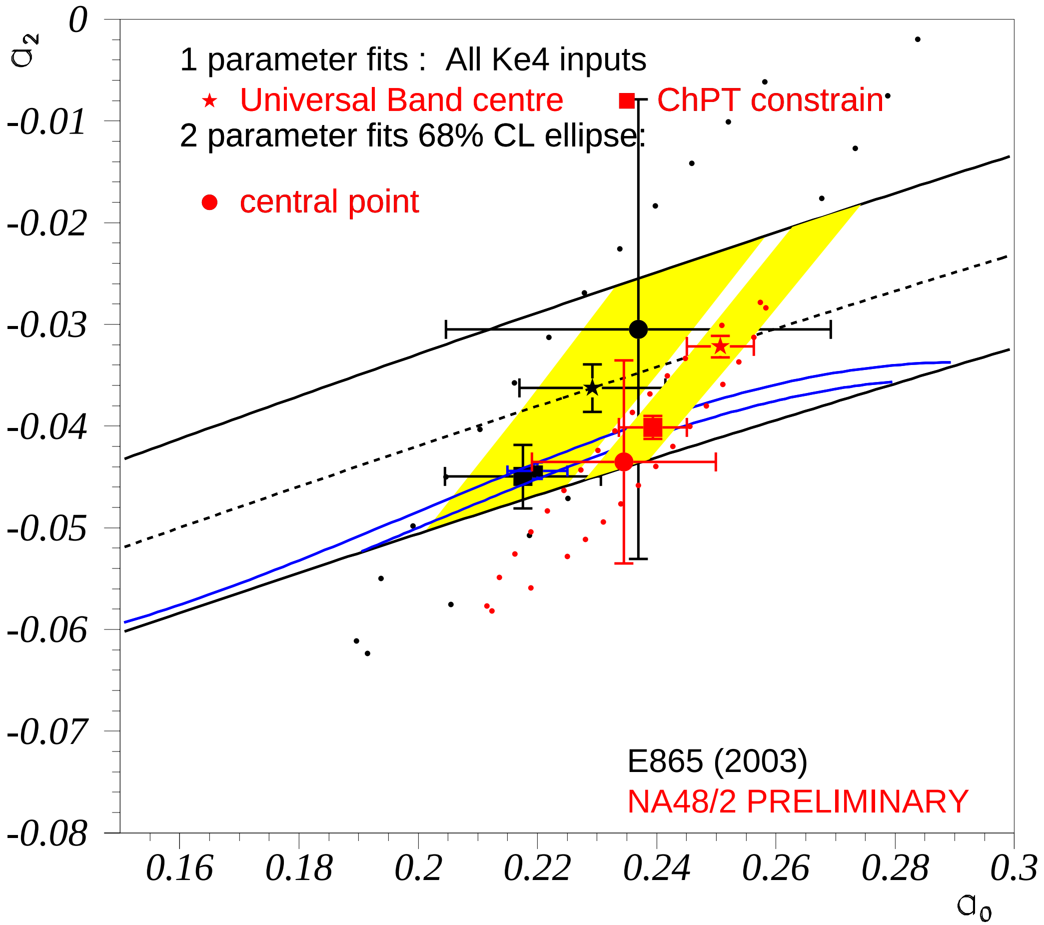
More on scattering lengths extraction

Several formulations exist relating the phase variation to the plane $[a_0^2, a_0^0]$ (ACGL,DFGS and others).

One can scan the allowed regions and even find the "best" $\chi 2$ point in a 2parameter fit.

The 2 experiments favor slightly different regions of the Universal Band with a similar correlation between a_0^0 and a_0^2 (~96%).

(removing the last E865 point brings the two bands closer and decreases the BNL $\chi 2$)



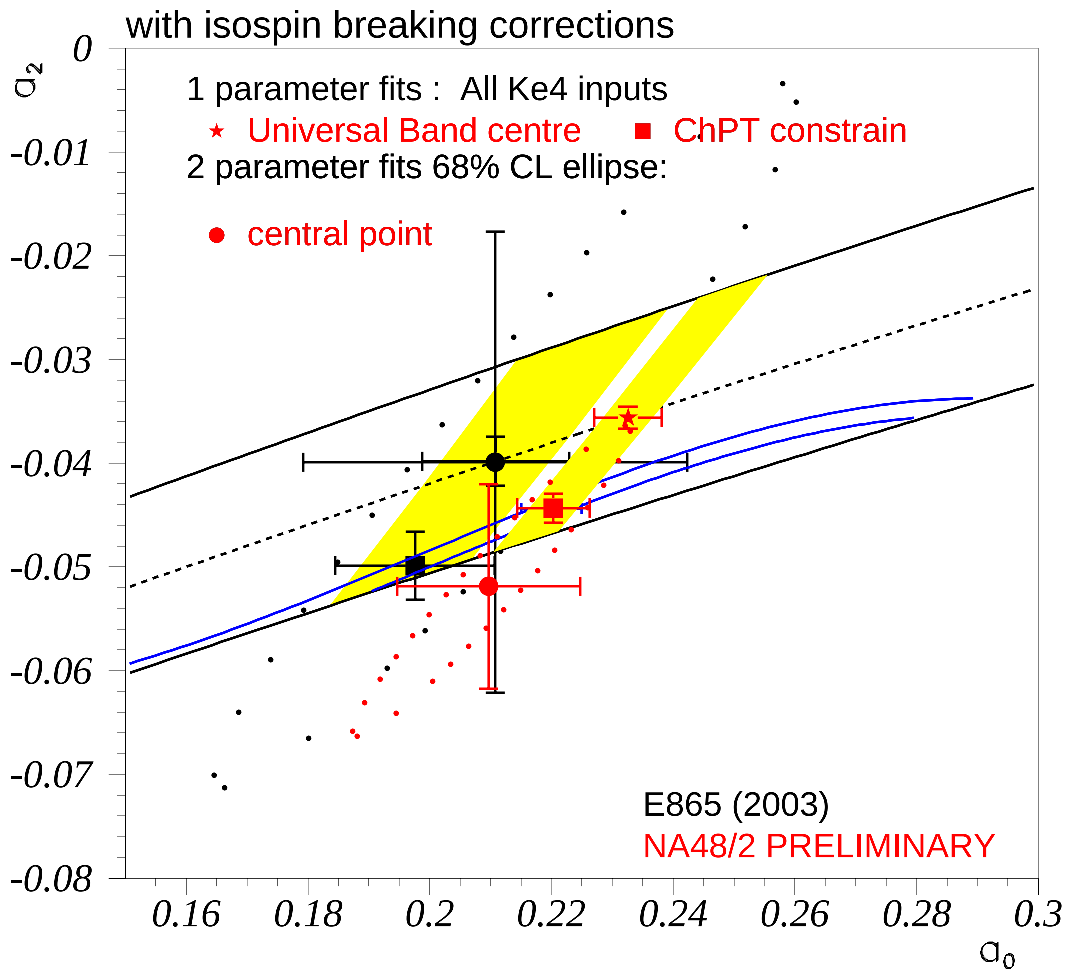
Correcting for isospin symmetry breaking…

Following recent developments (see J.Gasser's talk), one can correct the measured Ke4 phases for isospin symmetry breaking effect before extracting a_0^0. The correction is ~10-12 mrad (negative).

Both bands shift left and down in the $[a_0^2, a_0^0]$ plane

One can replay this exercise with all data points (E865, Geneva-Saclay and NA48).

(The contribution of the last E865 point to the $\chi 2$ is large, 5 units decrease if removed)



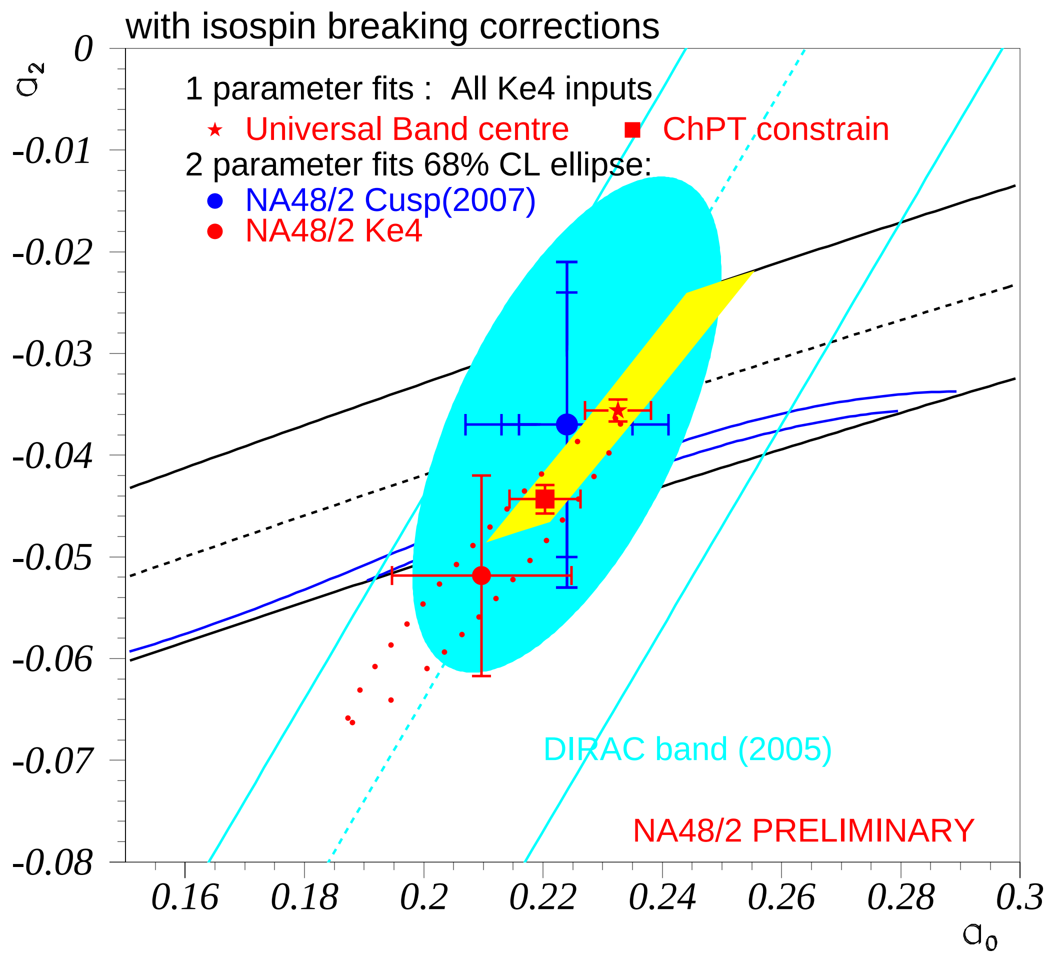
Comparing with results from other channels

As reported in E.Goudzovsky's talk, NA48 also measures a_0^0 and a_0^2 trough rescattering effects in K3π decays ("cusp" effect)

The DIRAC experiment (next talk by L.Tauscher) also brings information through pionium life time

Ke4 phase measurements bring a complementary and independent approach.

Provided the Ke4 isospin symmetry breaking corrections are taken into account, the whole picture becomes quite consistent



Ke4 analysis in NA48/2 : Summary and prospects

Thanks to a very positive collaboration with several theory groups (Bern, Orsay, Madrid, Dubna ..) our understanding of the scattering lengths extraction has improved a lot in the past year. I'm particularly grateful to the Bern group (GC,JG,HL) for very lively discussions and fruitful collaboration

Improvements from NA48 analyzing ~0.68 M Ke4 events (2003):

- Axial and vector Form Factors have been measured with an improved precision, including their variation with the dipion and dilepton masses and evidence for a non zero fp term.
- using a more elaborated theory input, the scattering lengths can be extracted, giving a consistent picture with other measurements and in good agreement with predictions from Chiral symmetry.
- Values of a_0^0 are in the range [0.209, 0.255] ± 0.006 (stat) ± 0.005 (syst) and favor a_0^2 values around -0.045

The analysis of 2004 data should bring the data sample above 1 Million events, allowing further precision in the scattering lengths extraction.