Precise measurement of Ke4 form factors and BR at the NA48/2 experiment

Stefano Venditti
University of Pisa & INFN
On behalf of the NA48/2 collaboration

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UNIVERSITÀ DI PISA

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OUTLINE

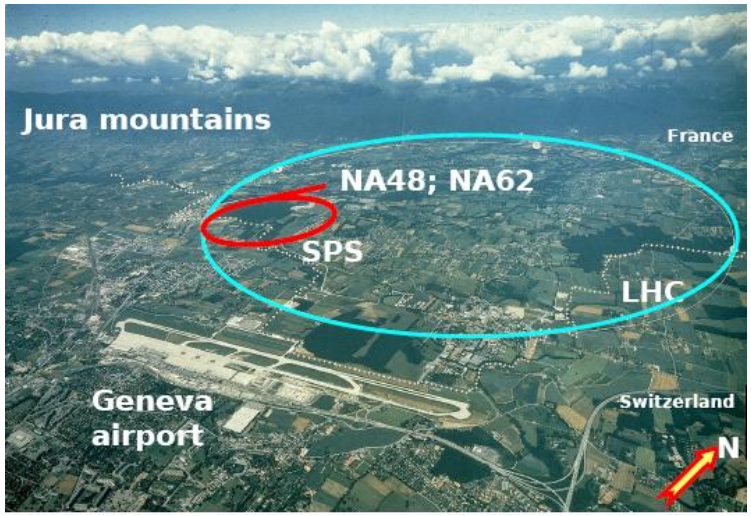
- NA48/2 experiment: detectors and collected data;

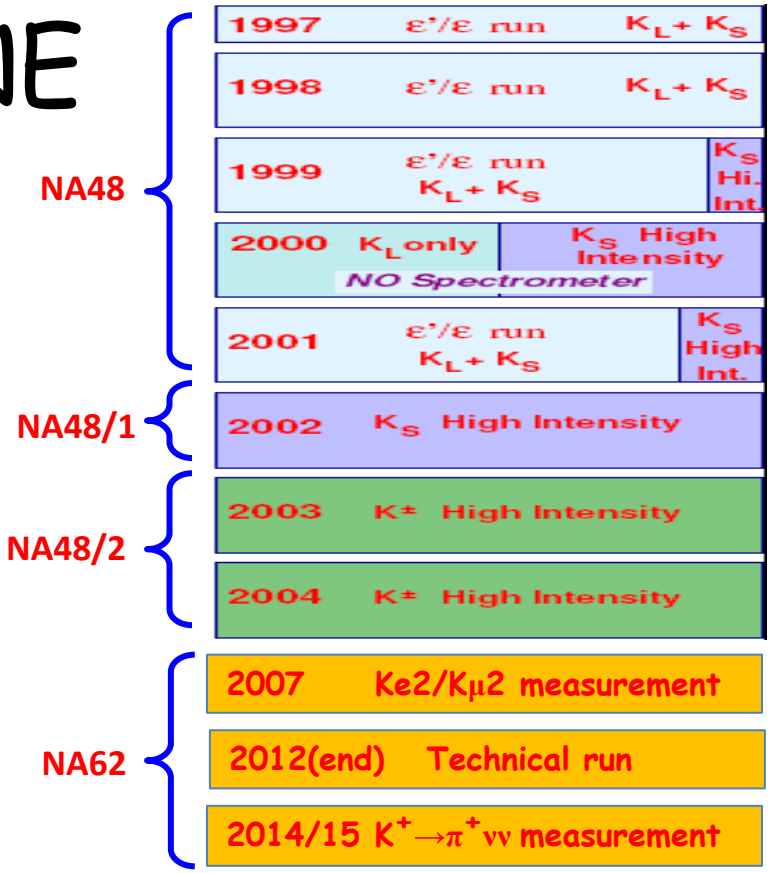
$K^{\pm} \rightarrow e^{\pm}\nu\pi^{+}\pi^{-}$ (Ke4c):

- Form factor and BR estimation;

$K^{\pm} \rightarrow e^{\pm}\nu\pi^{0}\pi^{0}$ (Ke4n):

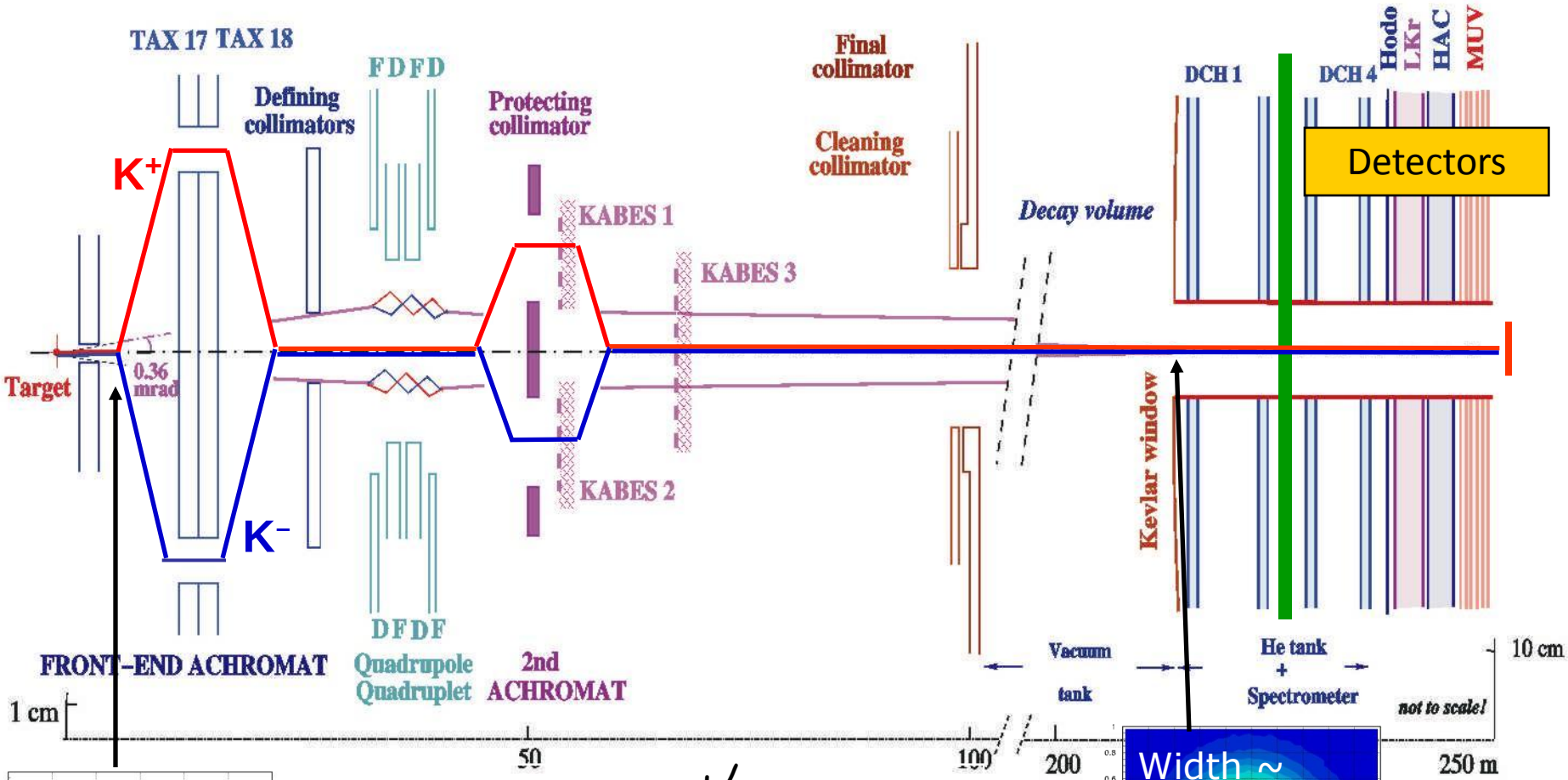
- Form factor and BR estimation;
- Conclusions.

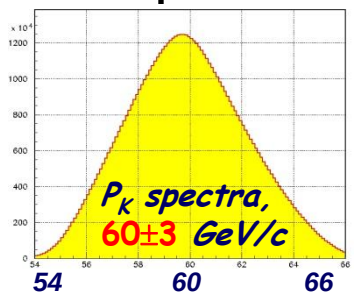




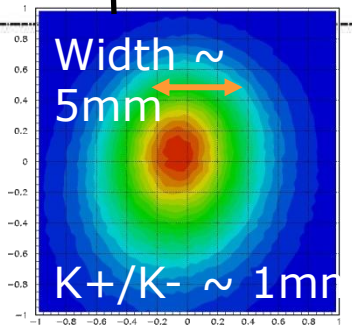
NA48/2 EXPERIMENT

Primary goal: search of the CP violating charged asymmetry in K3π decays



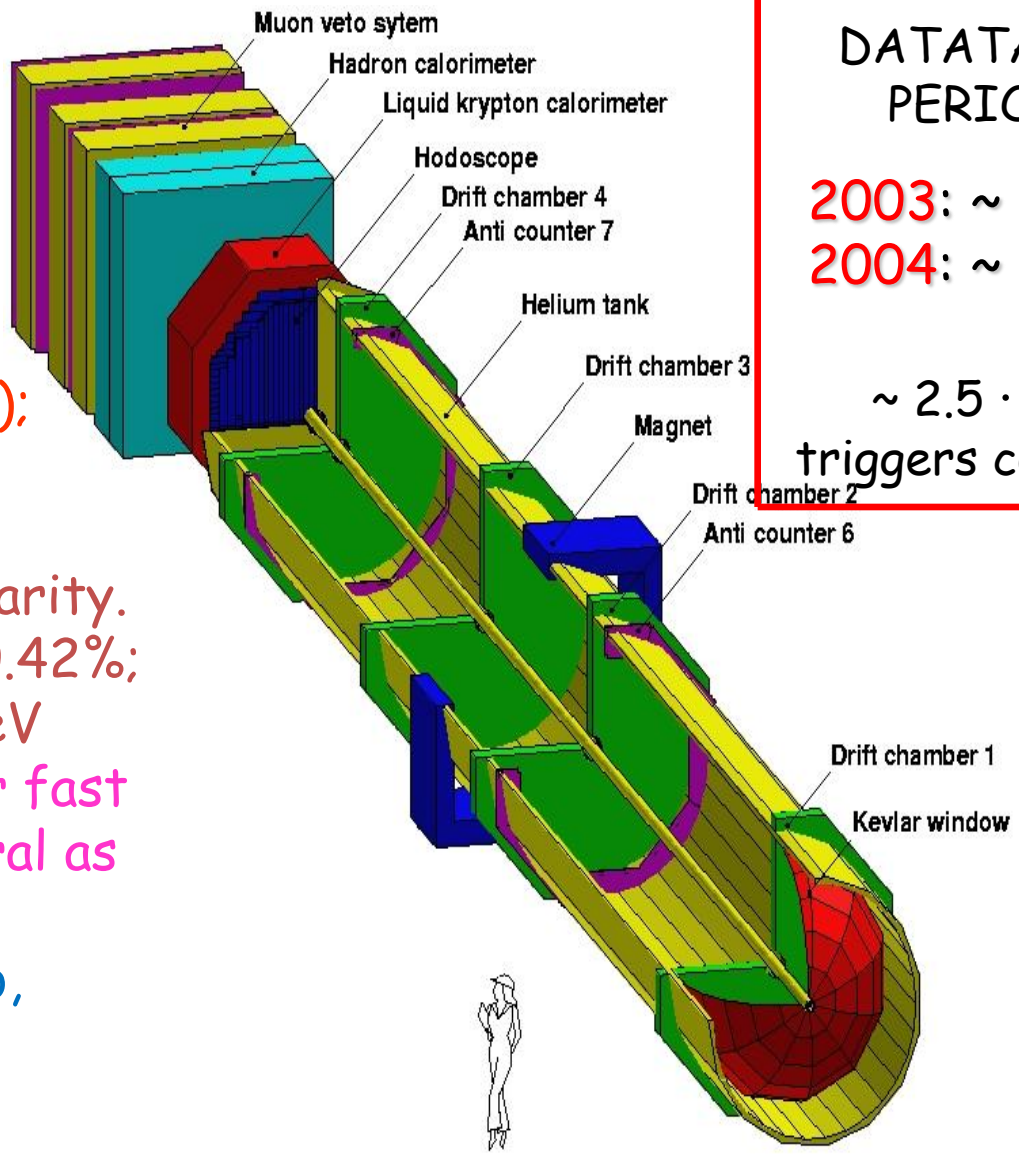


- Simultaneous $K^{+/-}$ beams
- 400 GeV protons fom SPS
- K^+/K^- flux~1.8
- 6.3 x 10^7 p.p.p.



NA48/2 DETECTORS

- Spectrometer:
4 DCHs -> redundancy.
$\sigma_p/p = 1.0\% + 0.044\% \times p(GeV)$;
- Liquid Krypton EM calorimeter:
13248 cells -> high granularity.
$\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$;
$\sigma x = \sigma_y$ ~1.5 mm @ E=10 GeV
- Hodoscopes: charged for fast trigger (σ_t~150 ps), neutral as control trigger.
- Muon veto, Hadronic calo, Kabes (P_K measurement), photon vetoes.



DATATAKING PERIODS:

2003: ~ 50 days
2004: ~ 60 days

~ $2.5 \cdot 10^{10}$ triggers collected

Ke4: Formalism

4 body decay:(+-) and (00)

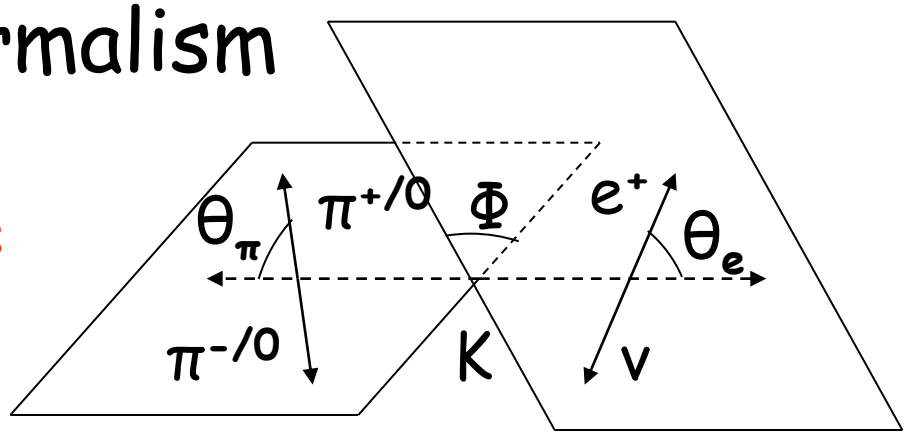
(+-): 5 independent variables

Using Cabibbo-Maksymowicz variables:

$S_\pi(M^2_{\pi\pi}), S_e(M^2_{ev}), \cos\theta_\pi, \cos\theta_e, \Phi$

(00): only 3 variables

$S_\pi(M^2_{\pi\pi}), S_e(M^2_{ev}), \cos\theta_e$



Ke4(+-) hadronic ME: $\langle\pi^+\pi^-|A_\lambda+V_\lambda|K\rangle=(1/M_K)[FP_\lambda+GQ_\lambda+R(K-P)_\lambda+(H/M^2)\varepsilon_{\lambda\mu\nu\sigma}K_\mu P_\nu Q_\sigma]$

(P_λ=dipion ; Q_λ=dilepton; K_λ=Kaon 4 vectors)

F,G,R: axial form factors

H: vector form factor

Partial wave expansion of amplitude(s,p):

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

$G = G_p e^{i\delta g}$

$H = H_p e^{i\delta h}$

R contribution negligible in Ke4 since it enters multiplied by m_e^2/Se (but it is relevant in Kμ4)

In Ke4(00) only the Fs form factor enters the ME

Fit parameters (real): F_s , F_p , G_p , H_p , $\delta=\delta_s-\delta_p$ (+-); F_s(00)

Ke4: Theory

At low energy (~ 1 GeV) QCD cannot be used because we are far from perturbative regime. An effective field theory (like ChPT) can describe the decays in terms of external momenta and light quark masses

Isospin symmetry translates into a relation between Ke4 decay rates ($m_u=m_d=0$)

$$\Gamma(Kl4^{\pm})=1/2\Gamma(Kl4^{0-}) +2\Gamma(Kl4^{00}) \qquad (l=e,\mu)$$

$$BR(Kl4^{\pm})=0.121xBR(Kl4^{0-}) +2BR(Kl4^{00}) \qquad (l=e,\mu)$$

$Kl4^{\pm} = K^{+} \rightarrow e+\nu\pi^{+}\pi^{-}$ $\quad Kl4^{0-} = K^{0} \rightarrow e+\nu\pi^{0}\pi^{-}$ $\quad Kl4^{00} = K^{+} \rightarrow e+\nu\pi^{0}\pi^{0}$

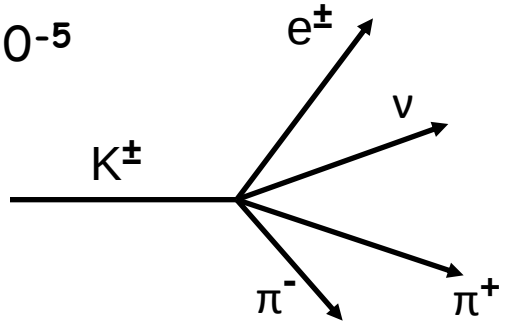
Predictions from ChPT using form factors at $O(p^2,p^4,p^6)$ using S118 value as input (Bijnens, Colangelo, Gasser, Nucl. Phys. B427 1994):

Channel	Rate (s-1)	BR prediction (10-5)	BR from PDG(10-5)
$Ke4^{\pm}$ (input)	3160±140	3.91±0.17	4.09±0.10
$Ke4^{0-}$	917±170	4.69±0.87	5.20±0.11
$Ke4^{00}$	1625±90	2.01±0.11	2.20±0.40

- relation between rates and BRs verified within exp errors
- new measurements will provide a test of ChPT

Ke4$^{+/-}$ analysis: selection and BG rejection

Ke4-> 3 charged tracks (2 opposite sign pions), BR ~ $4 \cdot 10^{-5}$

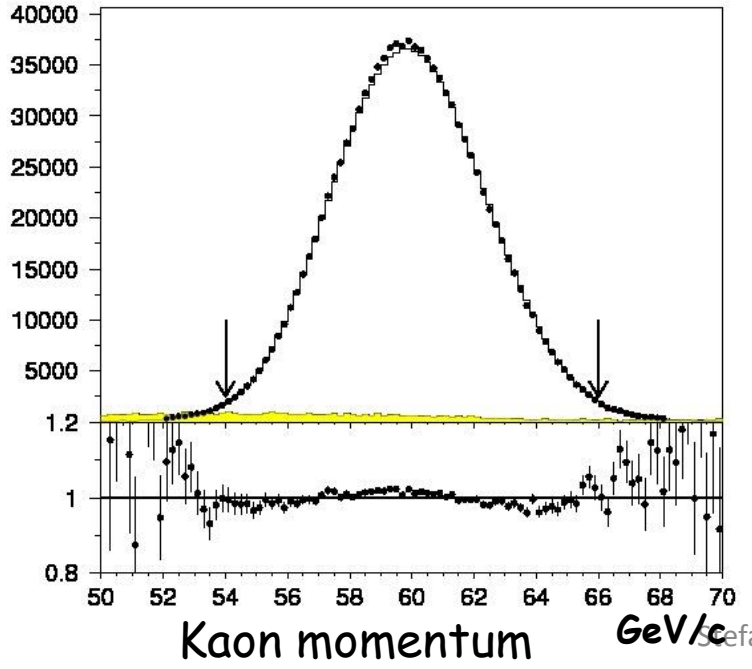


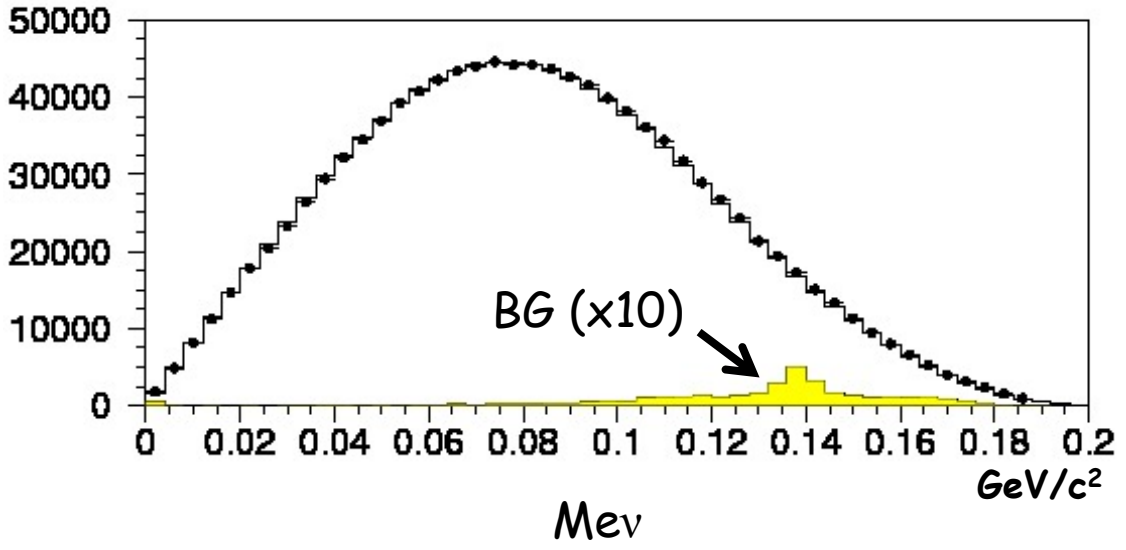
- Spectrometer for momenta measurement;
- Calorimeter info used to tag electron and pions (E/p);
- Missing energy and Pt cuts.

Main BG sources:

- $\pi^{\pm}\pi^{+}\pi^{-}$, with π->ev decay in flight or π misidentified as e;
- $\pi^{\pm}\pi^{0}$,$\pi^{\pm}\pi^{0}\pi^{0}$,with π^{0}->$e^{+}e^{-}\gamma$ Dalitz decay, $\pi^{\pm}/e^{\pm}$ misID and γ(s) undetected.

Elliptic cut in ($M_{3\pi}$, p_T) plane to reject BG, residual BG at the level of 0.5%, checked using wrong sign events ($K^{-}\rightarrow e^{+}\pi^{-}\pi^{-}\nu$, $K^{+}\rightarrow e^{-}\pi^{+}\pi^{+}\nu$)





$Ke4^{+/-}$: form factor measurement

Ke4 form factors in the charged mode have been measured on 1.13 million events. The result has been published in Eur. Phys. C70 (2010) 635

- Iso-populated $10(M_{\pi\pi})x5(Mev)x5(\cos\theta_e)x5(\cos\theta_\pi)x12(\Phi)=15000$ bins
- Form factor values minimize a DATA-MC estimator
- Ten independent fits in $M_{\pi\pi}$ bins, assuming constant f.f. over single bins.

Relative f.f.	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

f.f. expansion wrt S_e, q^2:

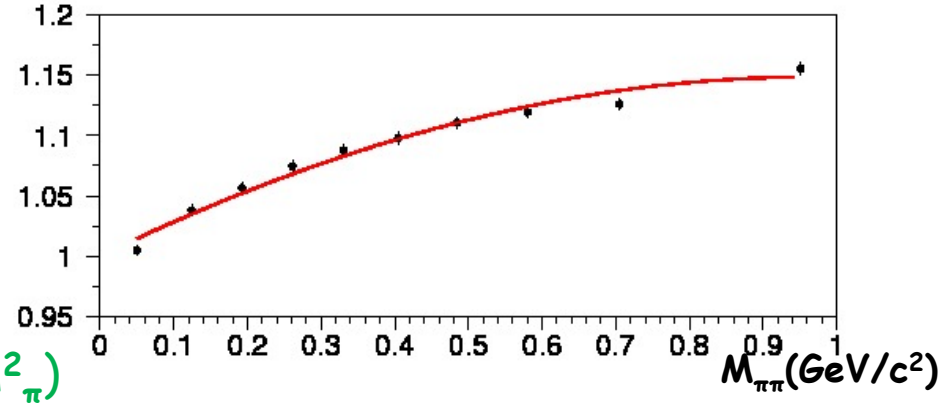
$F_s=f_s+f'_s q^2+f''_s q^4+f'_e(S_e/4m_\pi^2)+\ldots$

$F_p=f_p+f'_p q^2+\ldots$

$G_p=g_p+g'_p q^2+\ldots$

$H_p=h_p+h'_p q^2+\ldots$

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



$F_s \sim f_s(1+f'_s/f_s\, q^2 + f''_s/f_s\, q^4 + f'_e/f_s\, S_e/4m^2_\pi)$

K^+: Data: 0.73M events, 48 evts/bin
MC: 17.4 M events, ~1160 evts/bin
K^-: Data: 0.40 events, 27 evts/bin
MC: 9.7 M events, ~650 evts/bin

Without a BR measurement only relative f.f. (e.g. g_p/f_s) are measurable, the common factor fs being obtained from the BR value

$Ke4^{+/-}$: BR measurement

- A measurement of the BR allows to measure absolute form factors
- Computation of relative Ke4 BR with respect to the similar mode $K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$ ($K3\pi$), use of BR($K3\pi$) value from PDG to obtain BR(Ke4)

$$BR(Ke4) = \frac{N_{Ke4} - BG_{Ke4}}{N_{K3\pi} - BG_{K3\pi}} \times \frac{A_{K3\pi} \times \varepsilon_{K3\pi}}{A_{Ke4} \times \varepsilon_{Ke4}} \times BR(K3\pi)$$

N=# of events BG=background events A=channel acceptance ε=trigger efficiency

- $N_{Ke4}=1.11\times10^{6}$ $BG_{Ke4}=0.95\%\ N_{Ke4}$ $N_{K3\pi}=1.9\times10^{9}$ $BG_{K3\pi}$ negligible
- Acceptances from NA48 GEANT 3 based simulation: $A_{Ke4}=18.22\%$, $A_{K3\pi}=24.18\%$
- Trigger efficiencies from minimum bias triggers: $\varepsilon_{Ke4}=98.3\%$, $\varepsilon_{K3\pi}=97.5\%$

BR($K3\pi$) from PDG: $(4.09\pm0.10)\times10^{-5}$, 0.72% error on BR(Ke4)

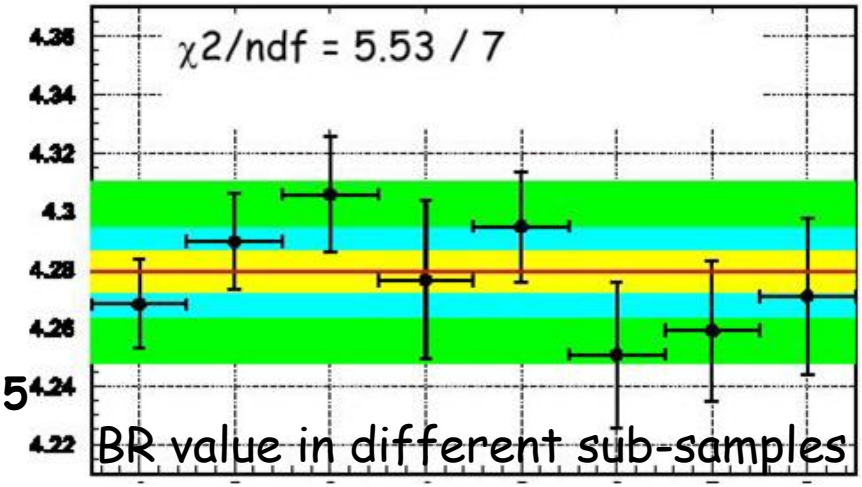
$Ke4^{+/-}$: BR measurement

Systematic uncertainties	%
Acceptance and beam geometry	0.18
Muon Vetoing	0.16
Accidental activity	0.15
Background	0.14
Particle ID	0.09
Radiative effects	0.08
Independent analysis	0.10

PDG 2010 VALUE:

$BR(Ke4^{+/-})=(4.09\pm0.10)\cdot10^{-5}$

- based on ~400k events
- measured on K^+ only
- dominated by systematics



PRELIMINARY RESULTS

$BR(Ke4^{+})=(4.277\pm0.009_{stat+trig})\cdot10^{-5}$

$BR(Ke4^{-})=(4.283\pm0.012_{stat+trig})\cdot10^{-5}$ NEVER MEASURED BEFORE

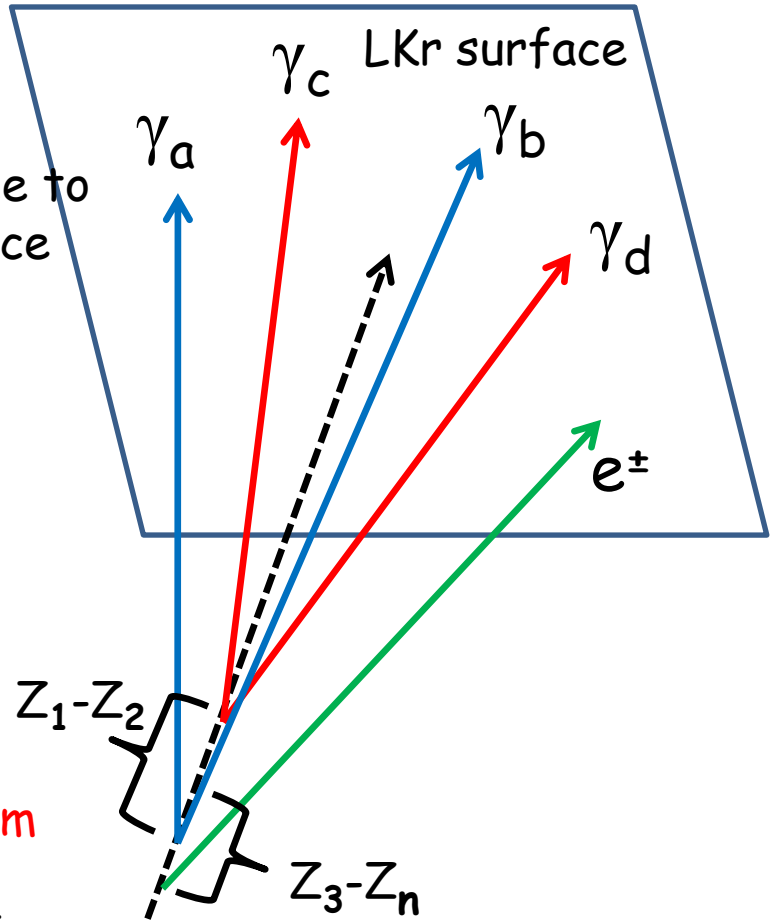
$BR(Ke4^{+/-})=(4.279\pm0.004_{stat}\pm0.005_{trig}\pm0.015_{syst}\pm0.031_{ext})\cdot10^{-5}$

$=(4.279\pm0.035)\cdot10^{-5}$ Dominated by external error ($BR_{K3\pi}$)

Ke4^{00} Analysis: selection and BG rejection

One charged track in the DCHs, 5 clusters in the LKr calorimeter

RECONSTRUCTION



- Use pion mass and cluster position on LKr surface to compute π^0 decay vertex position ($D_{ab,cd}$=distance between γs from π^0)

$$Z_{1(2)} = Z_{LKr} - \frac{D_{ab(cd)}\sqrt{E_{a(c)}E_{b(d)}}}{M_{\pi^0}}$$

$Z_{1,2}$=distance of the reconstructed π^0 vertices

- $|Z_1 - Z_2| < 500$ cm
- $Z_n=(Z_1+Z_2)/2$ within [-16,+90] m range
- Association with charged track if $|Z_3-Z_n|<800$ cm

Z_3 = charged track CDA position along the beam line
$Z_{1,2}$=reconstructed π^0 vertices position along the beam line
Z_{LKr}= LKr position along the beam line

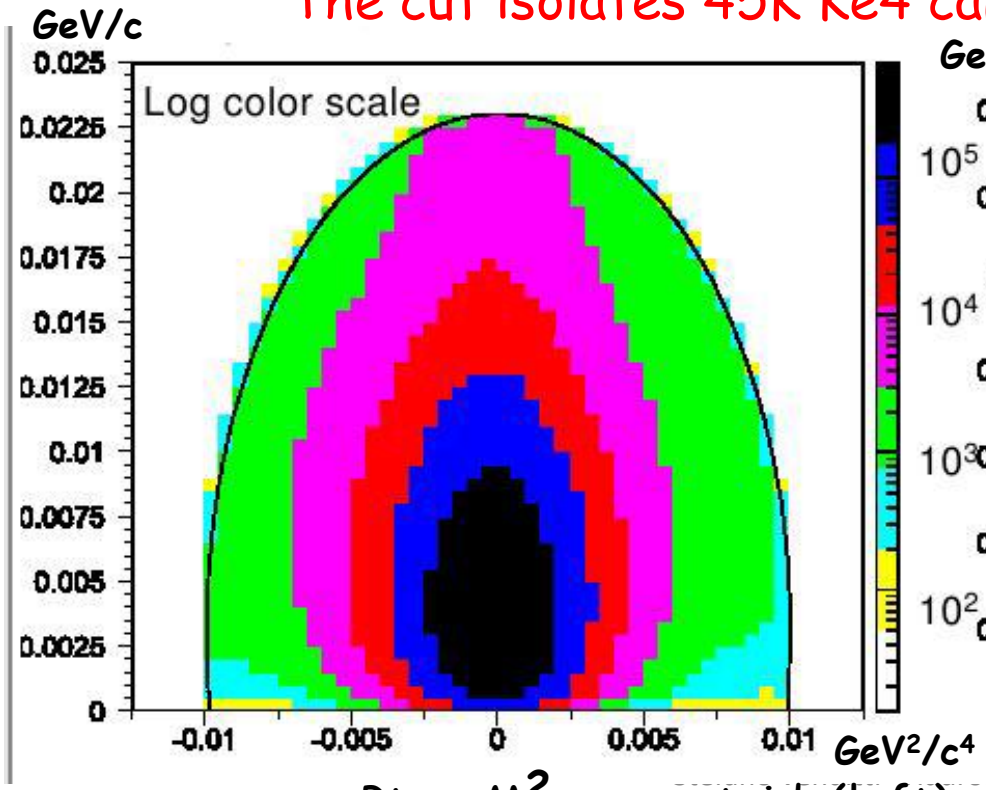
Ke4^{00} Analysis: selection and BG rejection

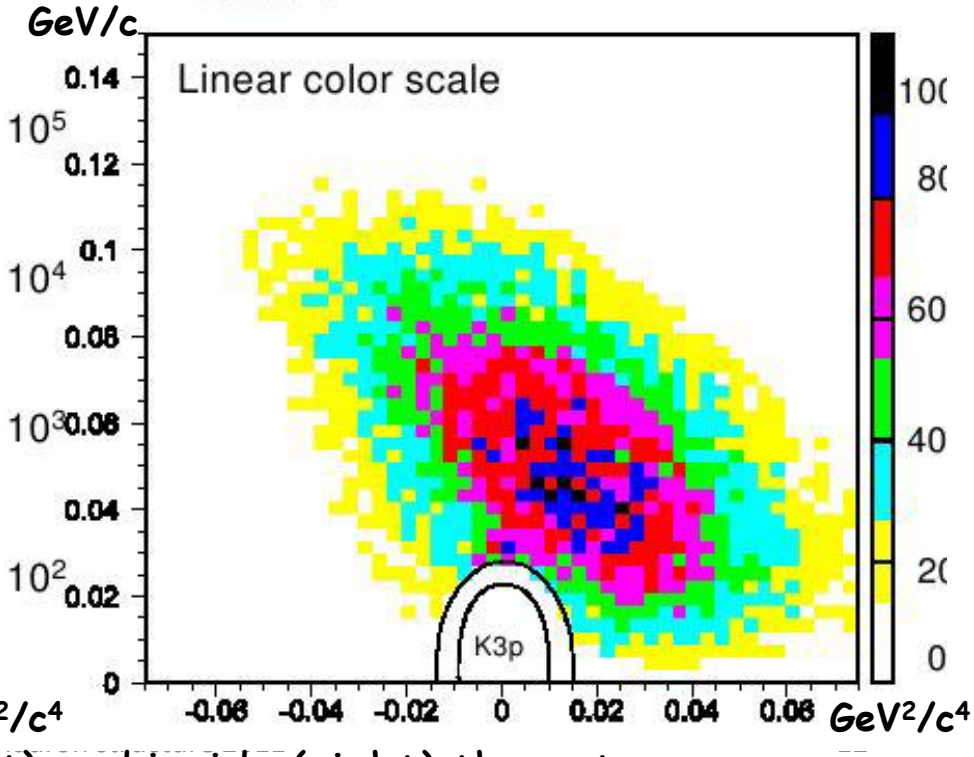
BG rejection: main BG is K3π,elliptic cut applied in (Pt,M_K) plane to reject most of it
Assign π^+ mass to the charged track and compute the 3π invariant mass M_{INV}:

$$M_{INV}^2 = (P_{TRK} + P\pi^0_1 + P\pi^0_2)^2$$

- K3π events peak at $M_{INV} = M_K$ and have a low Pt
- Ke4 events have a broad M_{INV} and a large Pt value because of the undetected ν

The cut isolates 45K Ke4 candidates from 70M K3π



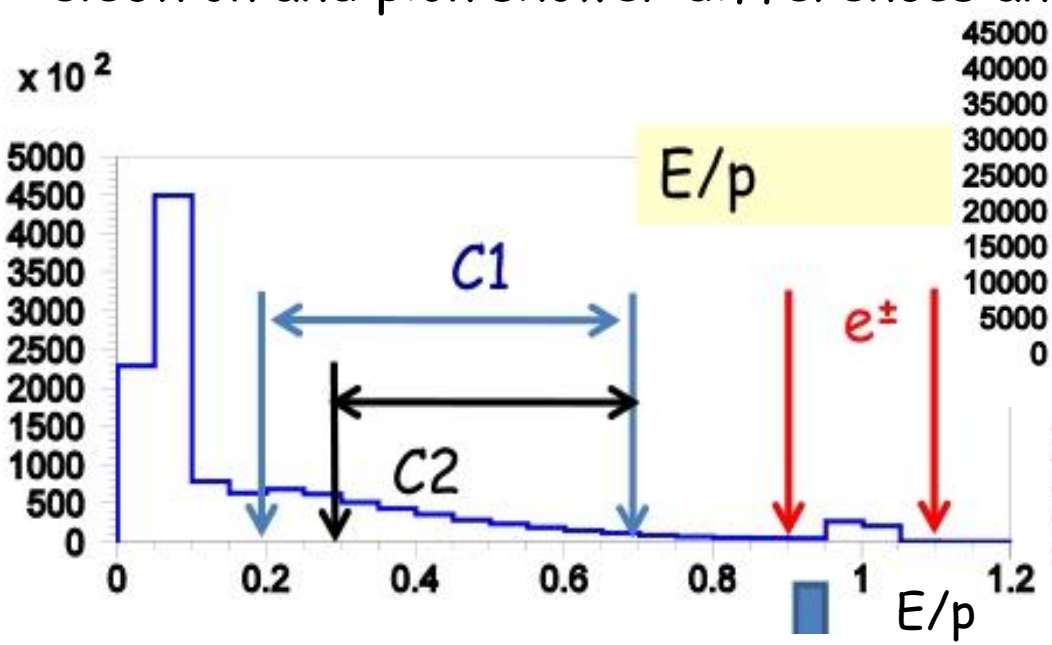


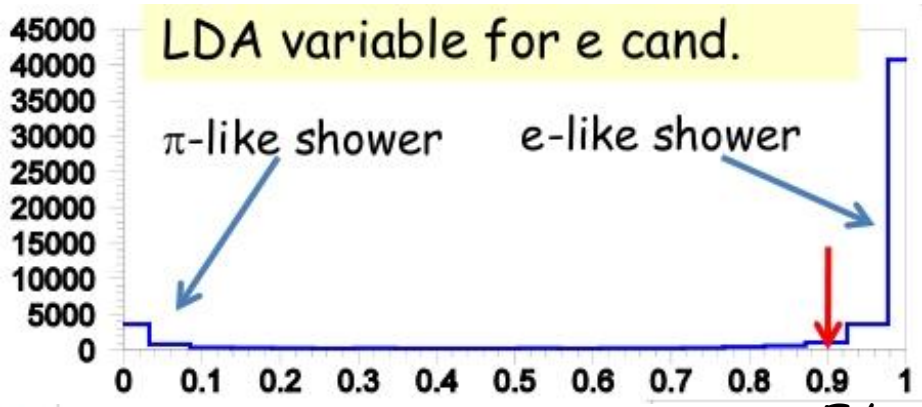
Pt vs M^2_{INV} outside(left) and inside (right) the cut

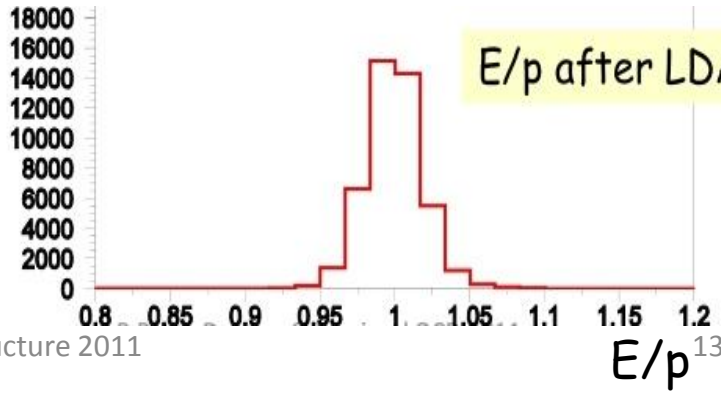
Ke4^{00} Analysis: selection and BG rejection

Electron ID to reject residual events from K3π decay

- Using E_{LKr}/P_{DCH} ,peaking at ~1 for electron. Tracks are selected in the E/p range [0.9-1.1];
- Use of control regions C1 [0.2-0.7] and C2 [0.3-0.7] to estimate the amount of residual pions within the Ke4 cuts;
- Further rejection of pions using a dedicated variable (LDA) based on electron and pion shower differences and tuned on real data.







Ke4^{00} Analysis: selection and BG rejection

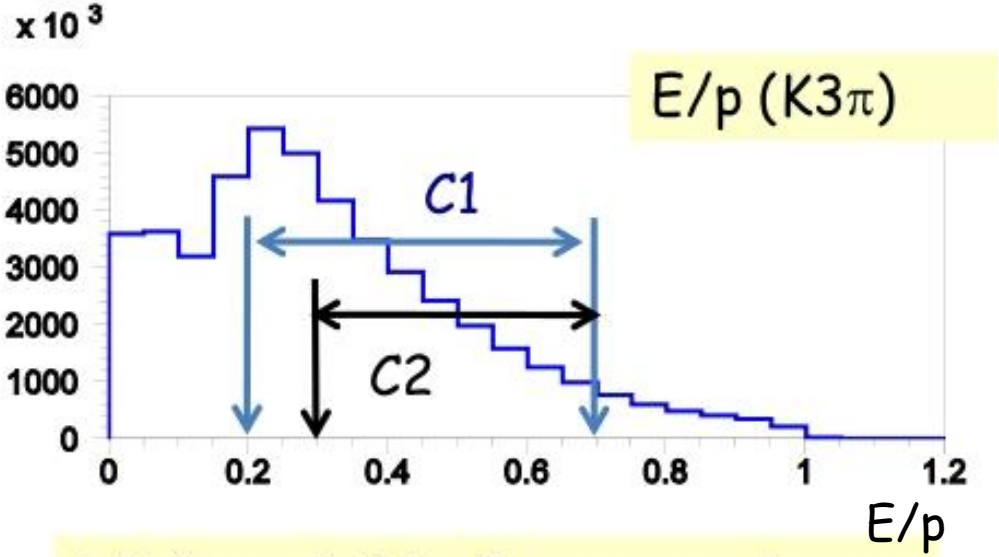
E/p shape from K3π events (kinematic cuts) is used to compute the number of BG events in the Ke4 signal region, assuming that the BG in the control regions C1 and C2 of the Ke4 sample is only due to K3π pions.

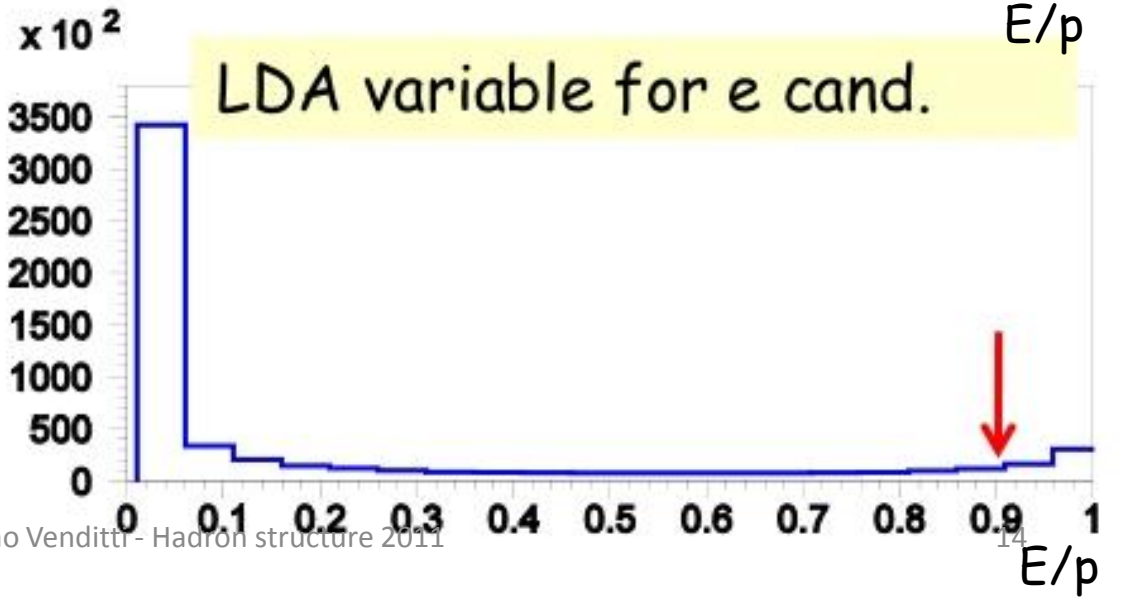
PROCEDURE

- Compute the fraction of K3π events in the cut region wrt events in the control regions (LDA cut included):

e/C1=0.166%
e/C2=0.259%

- Multiply this fraction by the number of events in the Ke4 C1(C2) region. 598 (592) BG events are obtained in the signal region, corresponding to 1.3% of the Ke4 signal





$Ke4^{00}$: BR measurement

Systematic uncertainties	%
Background	0.35
Simulation statistics	0.12
Form factors dependence	0.20
Radiative corrections	0.23
Trigger	0.80
Electron ID	0.10
Beam geometry	0.10
TOTAL	**0.94**

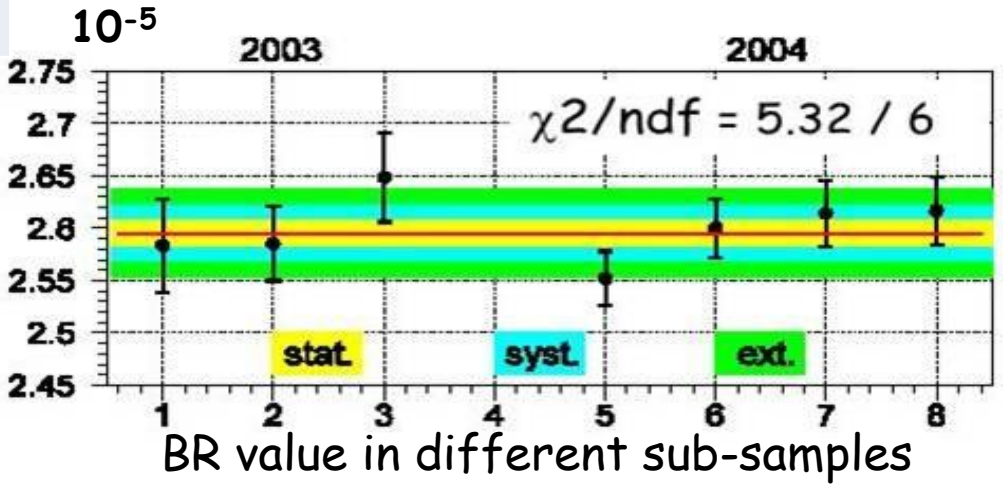
$$BR(Ke4) = \frac{N_{Ke4} - BG_{Ke4}}{N_{K3\pi} - BG_{K3\pi}} \frac{A_{K3\pi} \times \varepsilon_{K3\pi}}{A_{Ke4} \times \varepsilon_{Ke4}} BR(K3\pi)$$

ACCEPTANCES: $A_{K3\pi} = 4.11\%, A_{Ke4} = 1.77\%$

TRIGGER EFF.: ε_{Ke4} in the ange 92% to 98% depending on the period, $\varepsilon_{K3\pi} \sim \varepsilon_{Ke4}$

BR(K3π)=(1.761±0.022)% (1.25% ext error)

N_{Ke4} = 44909
$N_{K3\pi}$ = 70984882
BG_{Ke4} = 598(1.3% of signal)
$BG_{K3\pi}$ negligible



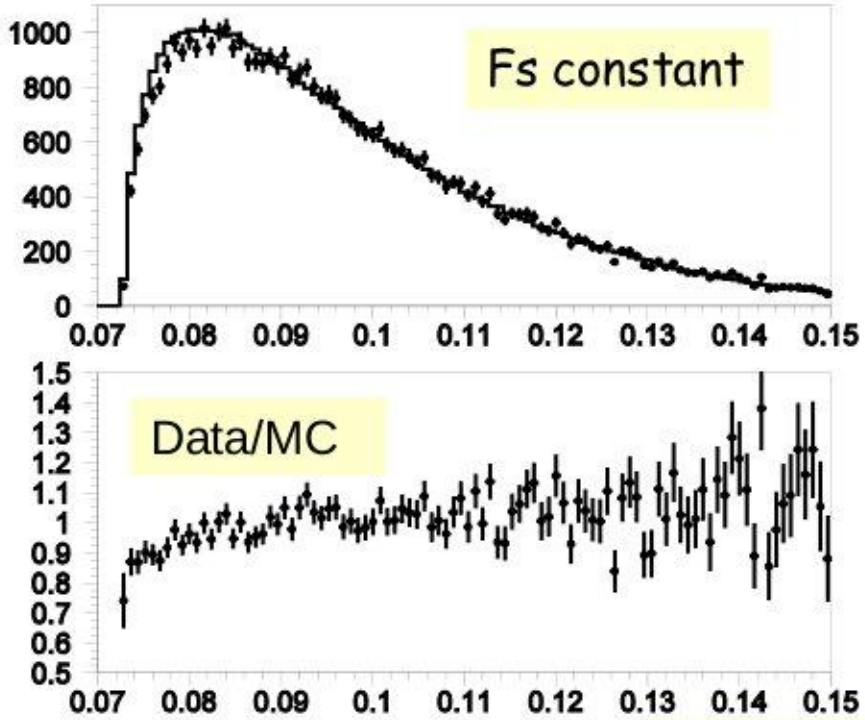
BR value in different sub-samples

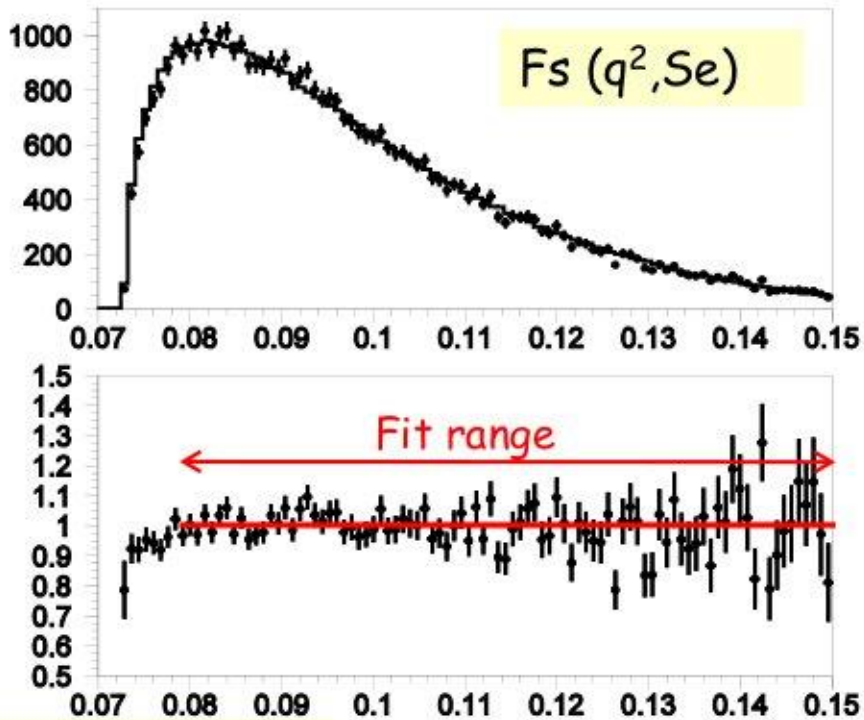
PRELIMINARY RESULT

$$BR(Ke4^{00}) = (2.595 \pm 0.012_{stat} \pm 0.024_{syst} \pm 0.032_{ext}) \cdot 10^{-5}$$

$Ke4^{00}$: form factor measurement

- Only Fs form factor to be measured;
- Low statistics wrt charged Ke4 (45K vs 1.1M events), the same precision cannot be reached;
- $M\pi^0\pi^0$ distribution with MC generated using a constant form factor Fs do not agree well with data; if f.f. from $Ke4^{\pm}$ are used in MC the agreement improves
- The presence of the cusp effect (pion rescattering from charged Ke4) may alter the fit





$(M\pi^0\pi^0)^2$ $(GeV/c^2)^2$

Conclusions

- A preliminary measurement of the $Ke4^{\pm}$ BR has been obtained. It improves the error on the present PDG value by a factor 3 and will allow the estimation of absolute form factor values.
- A preliminary measurement of the $Ke4^{00}$ BR has been obtained, improving the PDG measurement by a factor 10. A first approach to the Fs form factor estimation has been done.
- Future studies may include the $K\mu4$ decay channels (both neutral and charged), which allow to access the R form factor (inaccessible in the electron modes because its contribution to the amplitude is proportional to M^2_{lepton})