

Preliminary results
on direct CP violation
in charged K decays at NA48/2

Riccardo Fantechi

INFN - Sezione di Pisa

On behalf of the NA48 collaboration

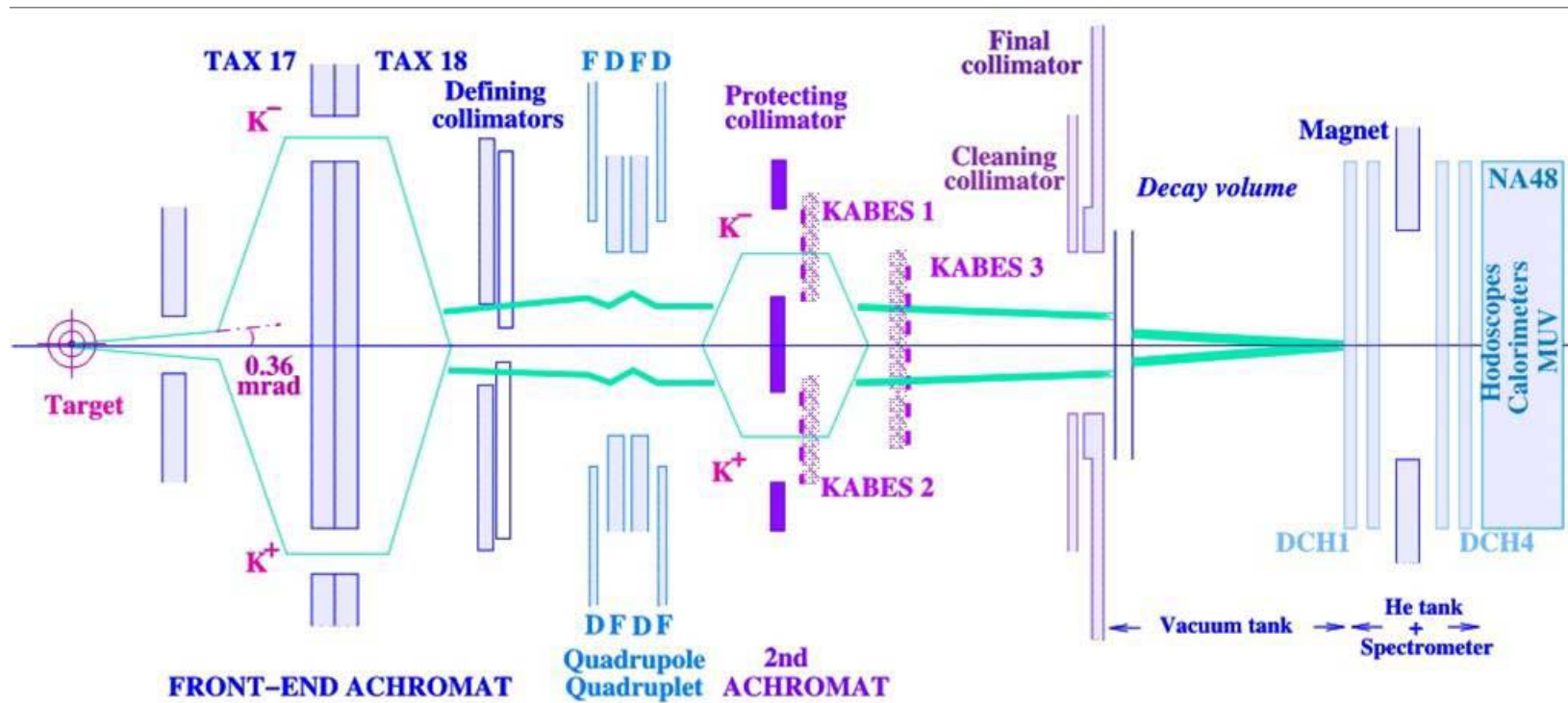
QCD04 - Montpellier, July 8th, 2004

The NA48/2 experiment

- Exploit the good detector and the unique beam setup with simultaneous positive and negative charged kaons to:
 - Measure CP violation in the decays $K^\pm \rightarrow \pi^+ \pi^- \pi^\pm$ and $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$
 - Measure the π - π scattering parameter a_0^0 in K_{e4} decays
 - Study rare charged kaon decays: tests of Chiral Perturbation Theory, measure of V_{us}

The beam line

60 GeV K beam, 1% momentum spread, $5 \cdot 10^6$ Kaon decays/pulse (5.2s/16.8s)
Kabes to measure the momentum better than 1%



The detector

Main detector components:

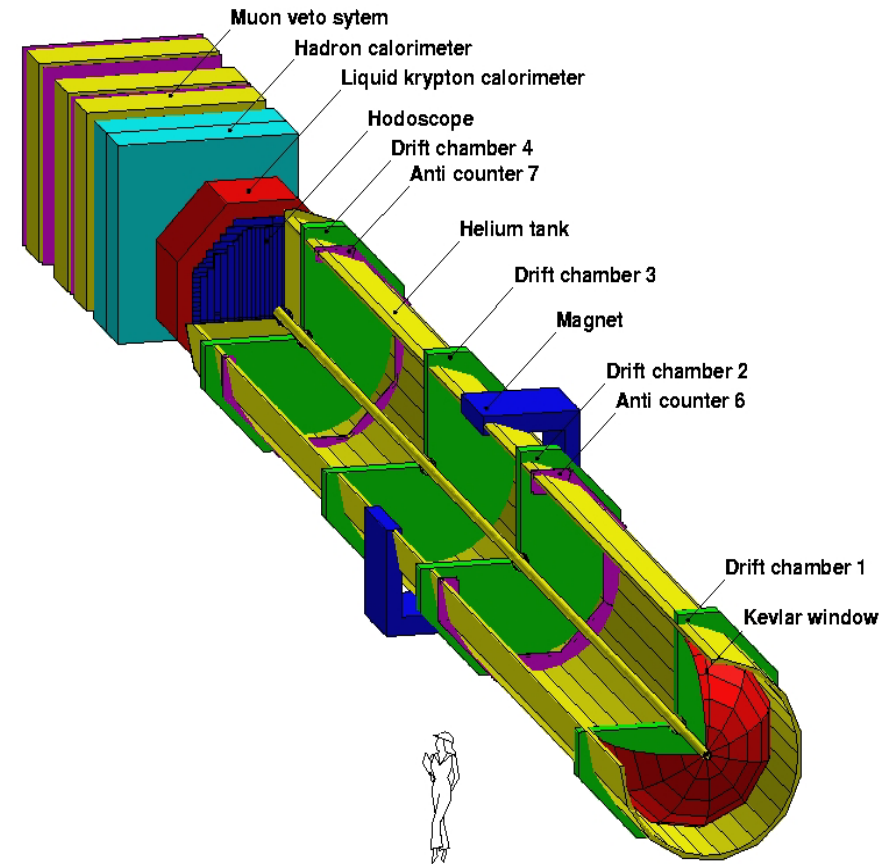
Magnetic spectrometer (4 DCHs):

$$\Delta p/p = 0.5\% + 0.009\% * p \text{ [GeV/c]}$$

Liquid Krypton EM calorimeter

$$\Delta E/E = 3.2/\sqrt{E} + 9\%/E + 0.42\%$$

• Hadron calorimeter, photon vetos,
muon veto counters



The trigger

- **Main triggers**
 - 3 track trigger (98% efficiency)
 - $K^\pm \rightarrow 3\pi^\pm$ ["charged" mode]
 - K_{e4}
 - Events with π^0 Dalitz decays
 - $K^\pm \rightarrow e^+e^-e\nu$, $K^\pm \rightarrow e^+e^-\nu$, $K^\pm \rightarrow \pi^+\pi^-e\nu$, $K^\pm \rightarrow \pi^+\pi^-\nu$
 - 1-track events with $(P_K - P_\pi)^2 > m_{\pi^0}^2$
 - $K^\pm \rightarrow \pi^0\pi^0\pi^\pm$ ["neutral" mode]
 - $K^\pm \rightarrow \pi^\pm\pi^0\gamma$, $K^\pm \rightarrow \pi^\pm\gamma\gamma$
 - Suppress $K^\pm \rightarrow \pi^\pm\pi^0$
 - Downscaled triggers for many 1 track channels and for the monitoring of efficiencies

NA48/2 - Run 2003

- Data period 19/6 - 10/9
 - About 30 days lost mainly for SPS problems
 - Expected statistics reduced
 - Part of the data taking period devoted to learning
 - It was the first time we run with charged beams!
 - Express analysis on a .5 billion sample done to prepare the report to the SPSC, looking at the main systematics
- Up to now the last month of data taking has been used for the analysis
 - Request for data taking in 2004 to complete the statistics

Direct CP violation in K^\pm decays

- K^\pm decay matrix
 - $|M(u,v)|^2 \propto 1 + g^*u + h^*u^2 + k^*v^2$
 - $g_c = -0.214$
 - $g_n = 0.652$
 - u, v Dalitz plot variables $u = (s_3 - s_0)/m_\pi^2, v = (s_1 - s_2)/m_\pi^2$, where s_3 refers to the odd pion
 - Direct CP violation $\Rightarrow A_g \equiv (g^+ - g^-)/(g^+ + g^-) \neq 0$
 - Theory predicts values for A_g between 10^{-6} and 10^{-4}
 - Scimemi (2003): 10^{-5} ok for SM, $>5 \cdot 10^{-5}$ new physics
 - $\Delta(A_g) \approx F \sqrt{1/N_+ + 1/N_-}$
 - where F is 3.7 for charged mode and 0.7 for neutral
 - Need $>10^{10}$ decays in charged mode for $\Delta A_g \sim 10^{-4}$

Direct CP violation in K^\pm decays

- Data taking strategy

- Measure
$$R(u) = \frac{\int dv |M^+(u, v)|^2}{\int dv |M^-(u, v)|^2} \approx 1 + u * (g^+ - g^-)$$

- which relies on acceptance cancellation between K^+ and K^-

- Data are taken under the following conditions:

- Simultaneous K^+ and K^- beams in the same fiducial volume
- Alternate the spectrometer field to equalise acceptances even if the detector has localised imperfections
- Alternate the achromat settings to symmetrize the paths taken by the beams
- Ratios are measured in momentum bins

- Simulation shows that total systematic error is $\leq 5 \cdot 10^{-5}$

- Precision limited by statistics

Analysis strategy

- Use only slopes of ratios
 - Define $A_S(N_{B+K+}/N_{B-K-})$ and $A_J(N_{B+K-}/N_{B-K+})$
 - A L/R asymmetry stable in time doesn't affect A_S or A_J
 - L/R symmetric changes would affect both, but not the average
 - $0.5*(A_S+A_J) \neq 0 \Rightarrow$ CP violation
 - Define $A_+(N_{B+K+}/N_{B-K+})$ and $A_-(N_{B+K-}/N_{B-K-})$
 - L/R symmetric changes would affect both, but not the average
 - L/R asymmetries (now stable in time: B is the same) compensate in the average
 - $0.5*(A_+ + A_-) \neq 0$ is an indication of residual asymmetries

A_S, A_J : s,j stand for Saleve, Jura, the right, left sides of our detector

Analysis strategy

- **Undetected asymmetries**
 - Problems occur when an undetected asymmetry change in the acceptance occurs during or between runs
 - The automatic compensation doesn't work
 - Need for an independent and careful monitor of the detector during the run
 - Some precautions has been taken during the setup to minimize these problems
 - i.e. the readout of the drift chambers has been rewired such that a fault in one card will reflect on symmetric set of wires
 - Frequent inversion of the spectrometer field will reduce the effect of undetected asymmetries
 - Inversion every day in 2003, now every 3 hours

Time instabilities

- The following instabilities has been found and studied thoroughly to correct the data
 - Time dependence of the spectrometer magnetic field
 - Time dependence of spectrometer alignment
 - Time dependence of beam geometry

Spectrometer calibration

- A correction has been applied to the momenta of the charged pions

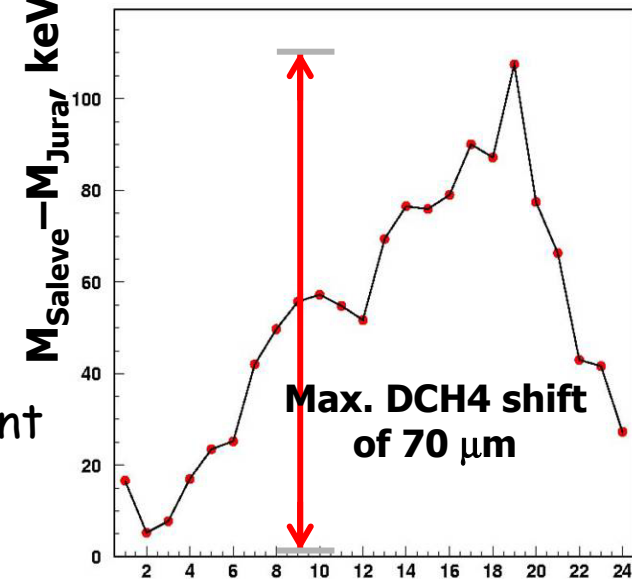
- $P = P_0 * (1 + \beta) * (1 + qb\alpha P_0)$

- P_0 measured momentum
- P corrected momentum
- q track charge
- b magnetic field sign

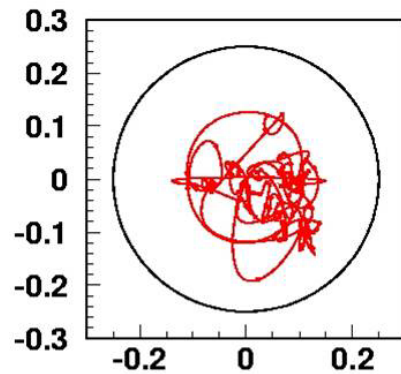
- Time dependent parameters

- α related to the DCH misalignment
 - Computed imposing $M_+ = M_-$
- β related to the B field integral
 - Impose then $M_+ = M_- = M_{PDG}$

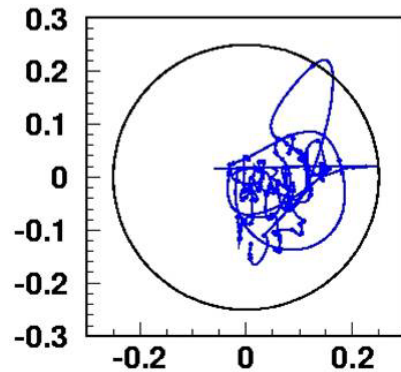
Time-dependence of alignment



Beam movements

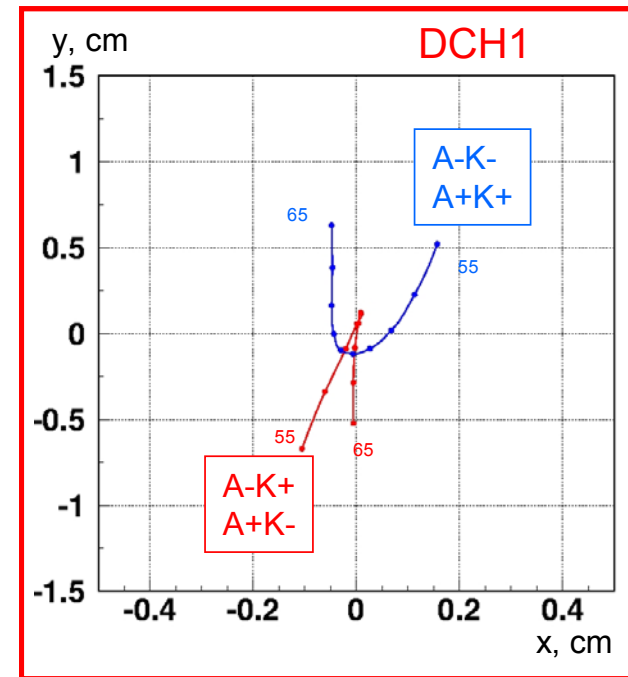


K^+



K^-

Beam COG movement as a function of the run



Momentum dependence of the beam position
Need to study A_s, A_j in bin of momentum

Beam geometry

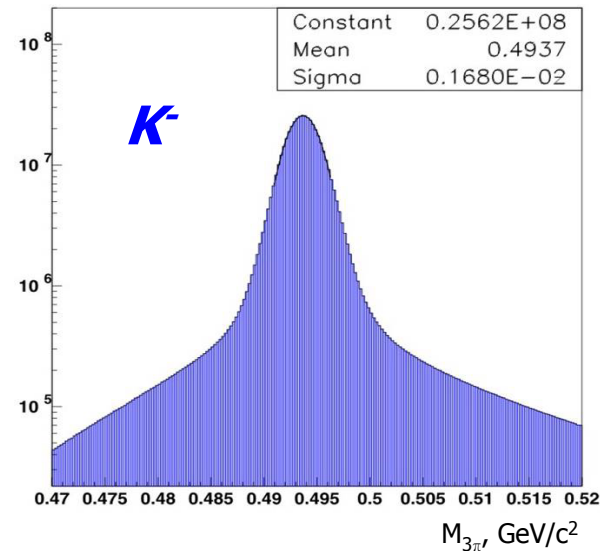
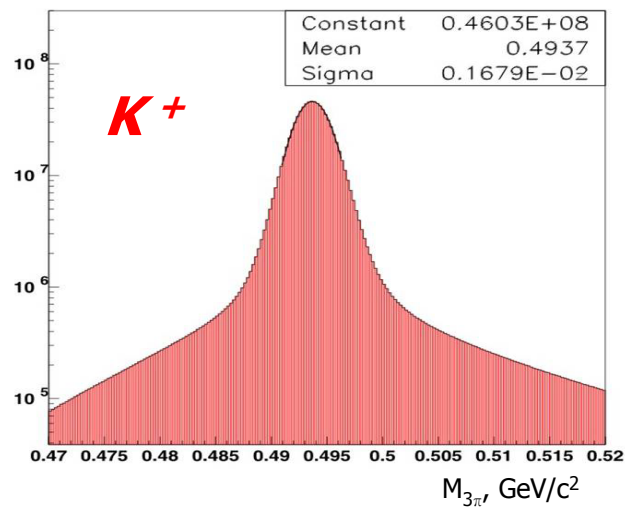
- **Sensitivity to the beam geometry**

- The acceptance is defined by the beam pipe
- Need to introduce radial time dependent cuts at the drift chambers to symmetrize:

$$|R_{\pi_i} - \langle R_K \rangle| > R_0 \quad \text{where } \langle R_K \rangle \text{ is a function of kaon sign, momentum and time}$$

- Better choice still under study, time could be burst by burst or run by run

Statistics in charged mode

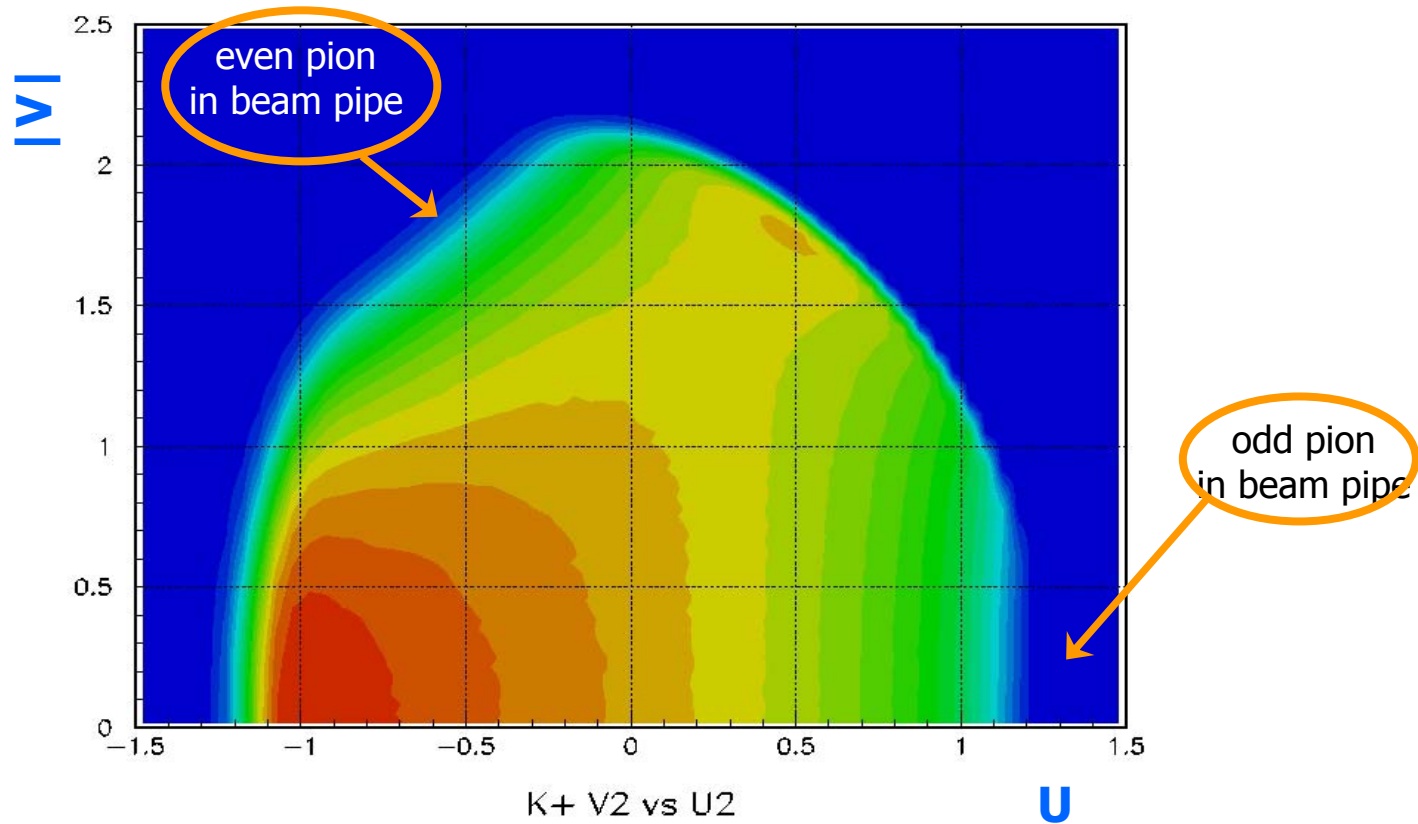


Selected events: 720 million K^+ , 400 million K^-

In the following physical asymmetries will be shown with offsets (blind analysis)

The apparatus induced asymmetries have no offset, to indicate systematics

$K^\pm \rightarrow \pi^+ \pi^- \pi^\pm$ Dalitz plot

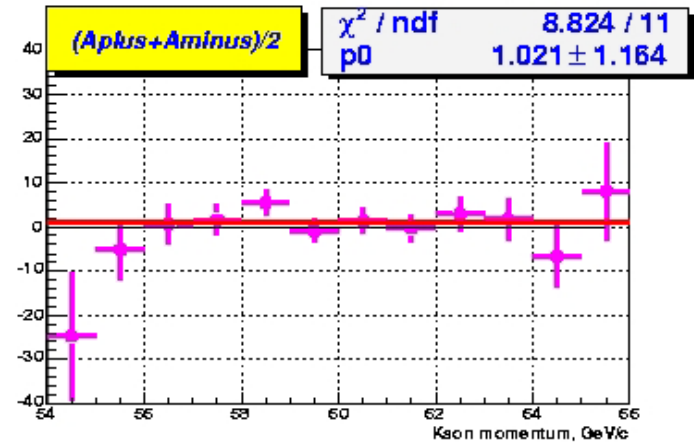
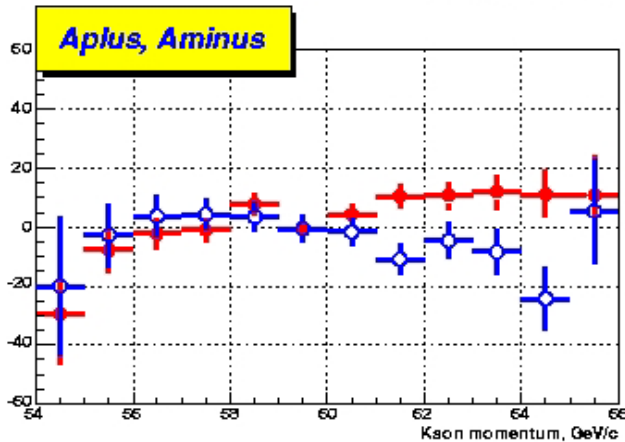
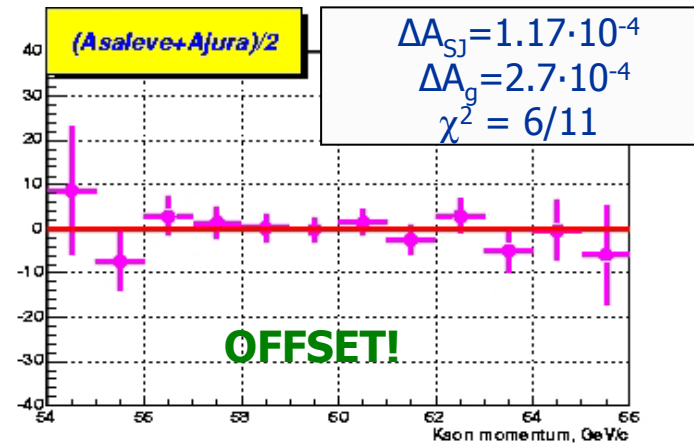
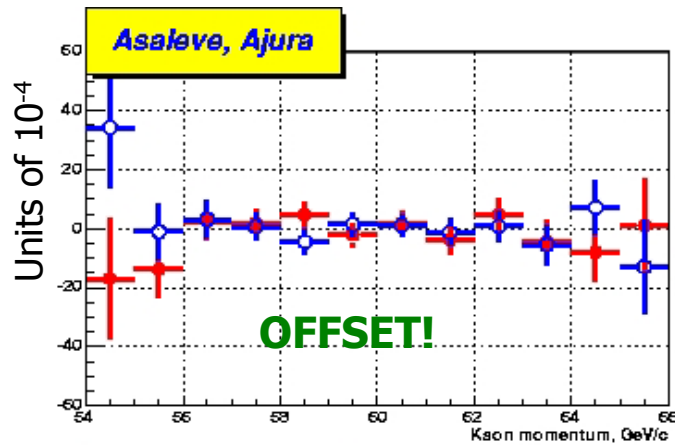


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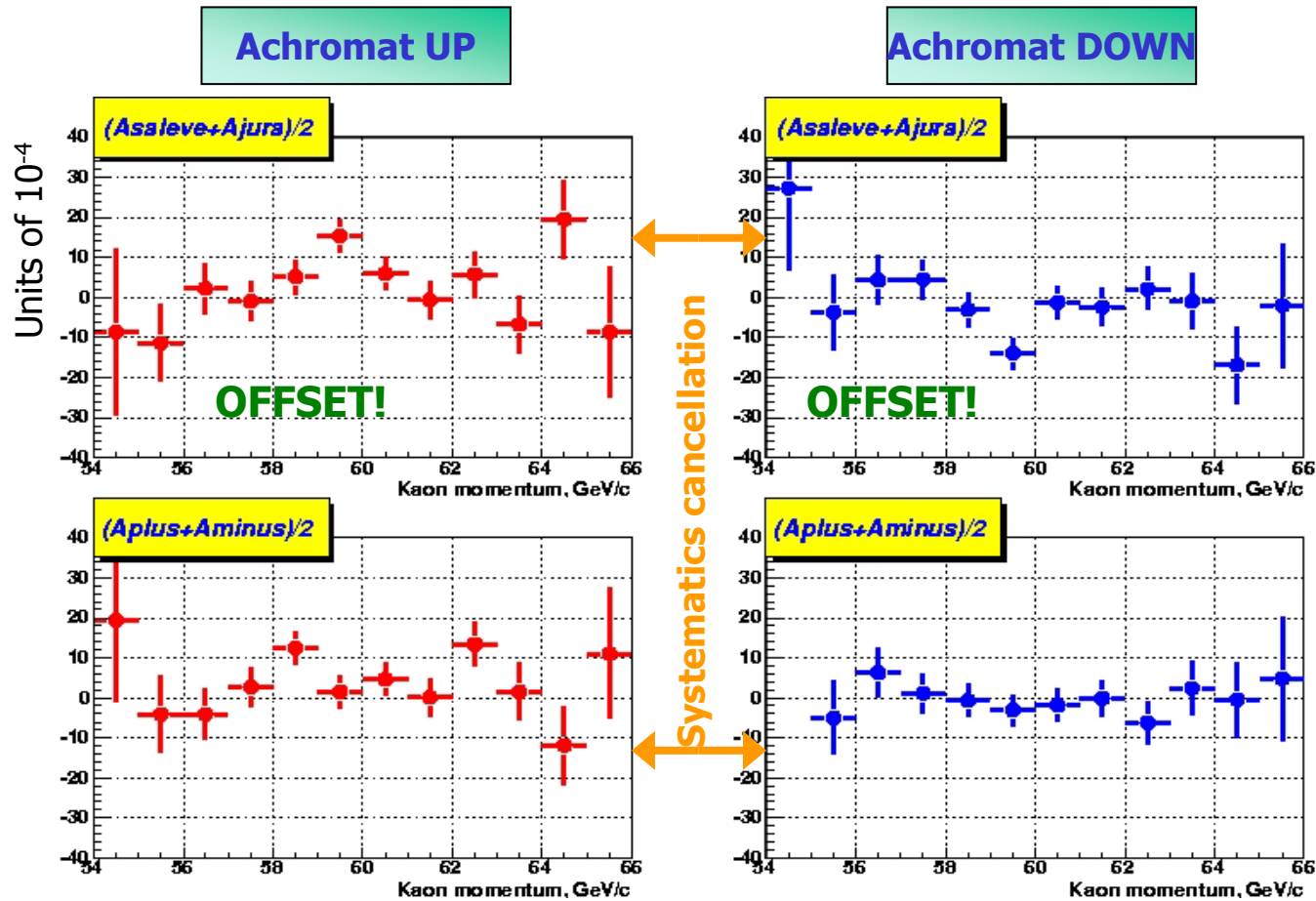
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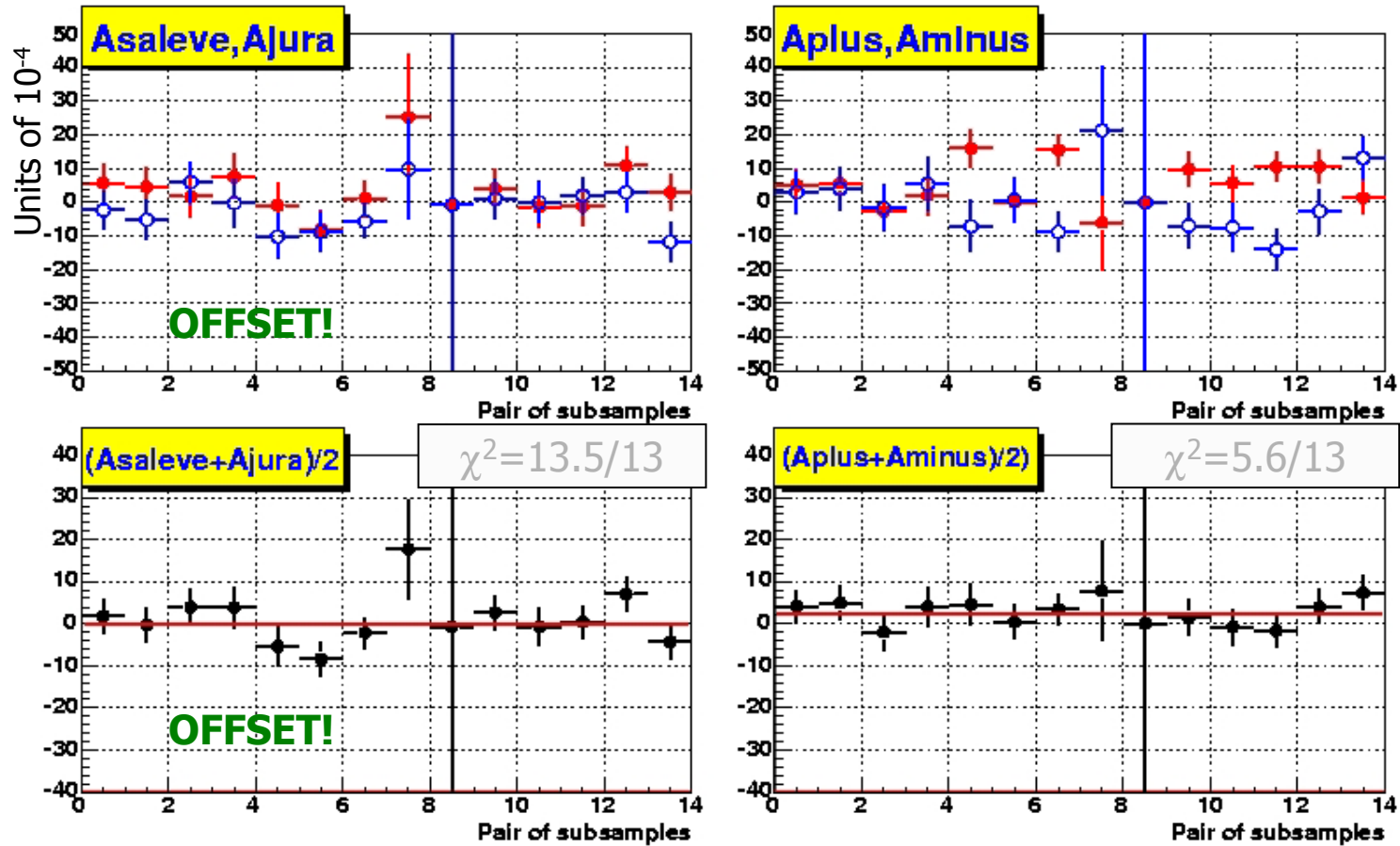
Asymmetries vs momentum



Differences wrt achromat orientation



Time stability of the asymmetries



Neutral mode analysis

- Analysis is not advanced as in the charged mode
- Interesting differences
 - Kinematics of the decay is reconstructed with the photon energy measured in the LKr calorimeter
 - Systematics sources are different
 - The expected statistical error, despite the lower number of decays, is still $\Delta A_g \sim 5 \cdot 10^{-4}$
- Statistics used in the analysis: 23.2 millions K^+ and 12.9 million K^-

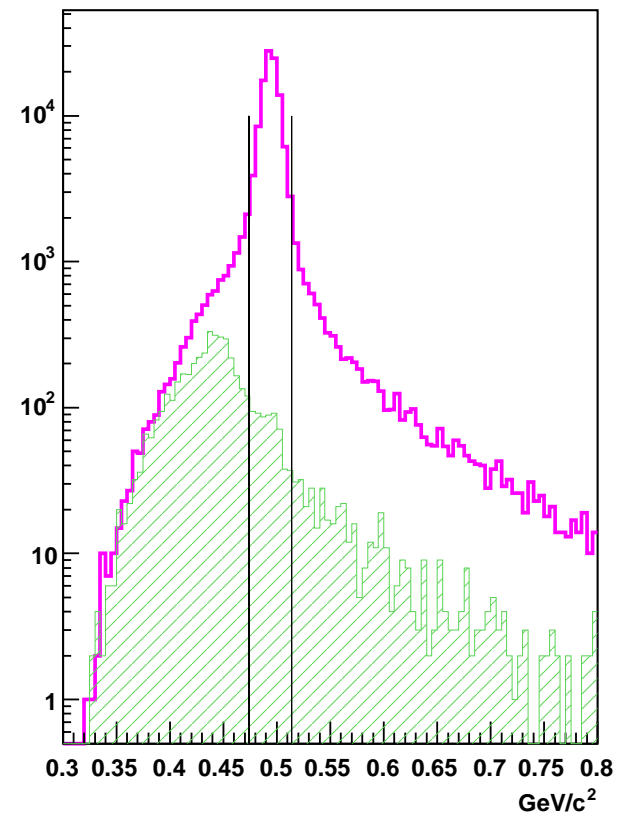
Measurement of K_{e4}

- **Physics interest:**
 - Low energy $\pi\pi$ scattering predicted from Chiral Perturbation Theory first principles.
 - Predicted in ChPT $a_0^0 = 0.220 \pm 0.005$
[Colangelo, Gasser, Leutwyler, hep-ph/0103088]
 - $\pi\pi$ scattering length a_0^0 can be determined from form-factors of K_{e4} decays.
- **Previous measurements:**
 - Geneva-Saclay (1977): 30,000 events
 - Brookhaven E865 (2001): 400,000 events $a_0^0 = 0.216 \pm 0.013$
- **2 experiments, errors > theoretical uncertainties**

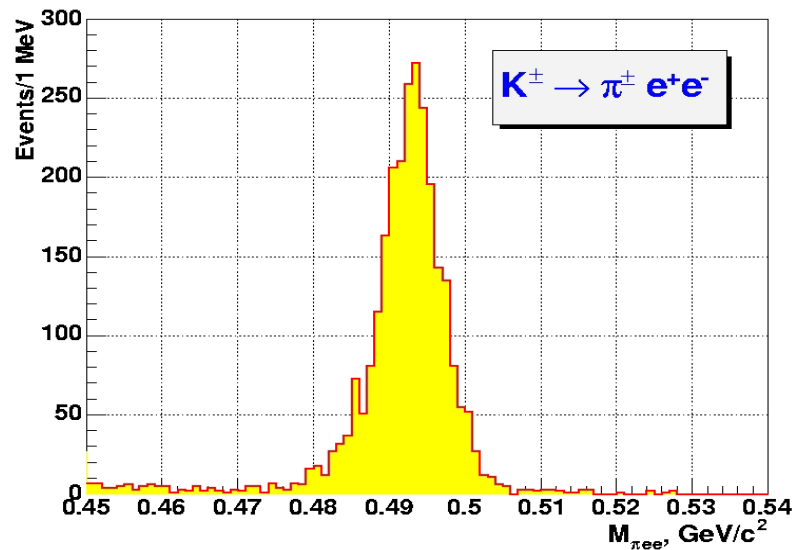
Measurement of K_{e4}

- More than 300k events in one month of data taking.
- Background mainly from $K^{\pm} \rightarrow 3\pi^{\pm}$ and $K^{\pm} \rightarrow \pi^{\pm}\pi^0_{\text{Dalitz}}$ with $\pi \leftrightarrow e$ mis-identification.
 - Use neural network for e/π separation.
- Total background: 0.6%
[determined from wrong-sign $\pi^+\pi^+e^-$ events].
- Expect >500k events from 2003 data
- Aim at a final error < 0.01

Invariant kaon mass $Ke4$ hypothesis

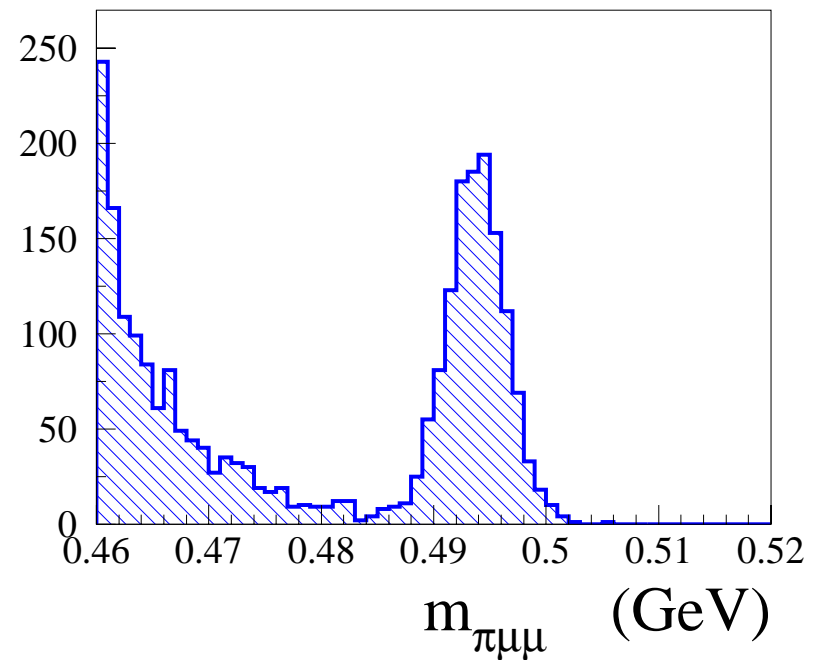


$$K^{\pm} \rightarrow \pi^{\pm} e^{+} e^{-} - K^{\pm} \rightarrow \pi^{\pm} \mu^{+} \mu^{-}$$



More than **2,600** candidates for $m_{ee} > 140$
MeV/c² in 1 month
 Small background (1-2%).

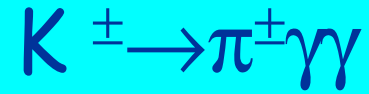
Expect to have at the end of 2004 a
 sample comparable to the world best one



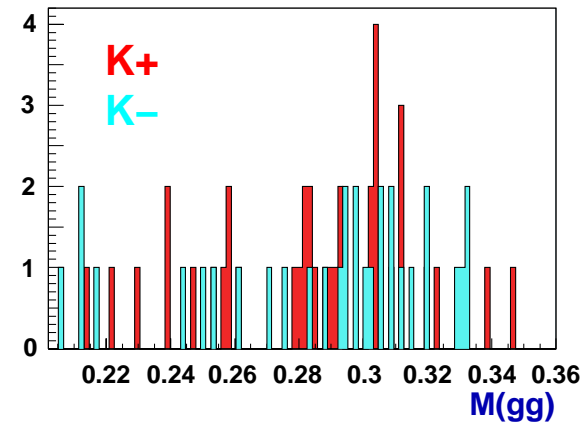
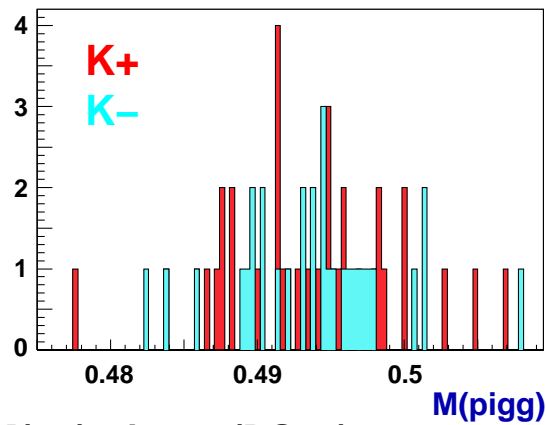
More than **1000** events in 1 month
 Current world sample **800** events

$$K^{\pm} \rightarrow \pi^{\pm} \gamma \gamma$$

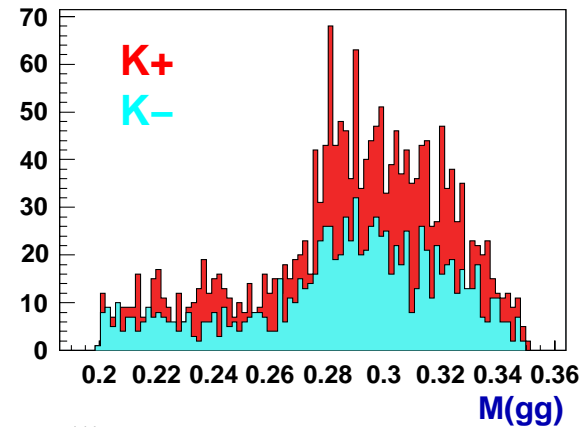
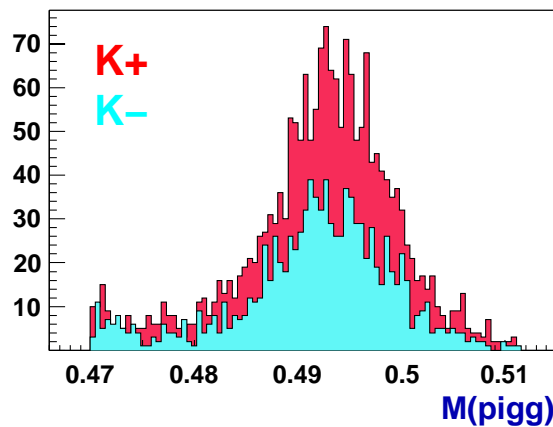
- **Physics interest**
 - $O(p^2)$ ChPT amplitude vanishes, $O(p^4)$ amplitude computed (up to an unknown parameter)
 - Test $O(p^6)$ contribution by fitting the $M_{\gamma\gamma}$ distribution
- **Trigger problem**
 - Due to the cut to reject $\pi^+\pi^0$, the yield of $\pi\gamma\gamma$ is not high
 - Got anyway a better statistics than the 31 events of E787



Neutral trigger (DS=80):



High-M(g γ) trigger (DS=1):



Conclusions

- $K^\pm \rightarrow \pi^+ \pi^- \pi^\pm$
 - In one month of data taking, $>1.1 \cdot 10^9$ decays
 - The most important sources of systematics have been identified and studies are continuing
 - Statistical error on A_g is $\sim 2.7 \cdot 10^{-4}$ \rightarrow will limit the measurement
- $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$
 - In one month of data taking, $4 \cdot 10^7$ decays, error on $A_g \sim 5 \cdot 10^{-4}$
- A large sample of rare charged kaon decays
 - Analysis going on on K_{e4} , K_{e2} , $K_{\mu 2}$, $K^\pm \rightarrow \pi^\pm \gamma \gamma$, $K^\pm \rightarrow \pi^\pm l^+ l^-$
- More statistics can be obtained adding early 2003 data
 - Better studies of misalignments needed
- We are currently taking data to double the actual statistics

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Benefits of high statistics

In $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$, the high statistics allows to detect such effects

Possibility to extract an independent measurement of a_0 - a_2 using a model of the interaction near the $M_{\pi\pi}^2$ threshold

Include in the fit a contribution from the pionic atoms

