K→3π decay results by NA48/2 at CERN SPS

"HQL 2006 "

Munich 16-20 October

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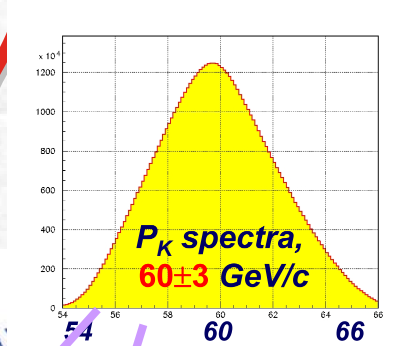
On behalf of the ***NA48/2*** collaboration:

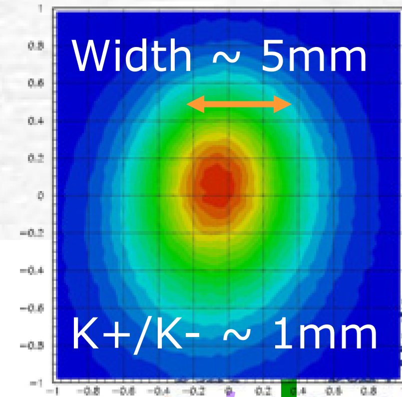
Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

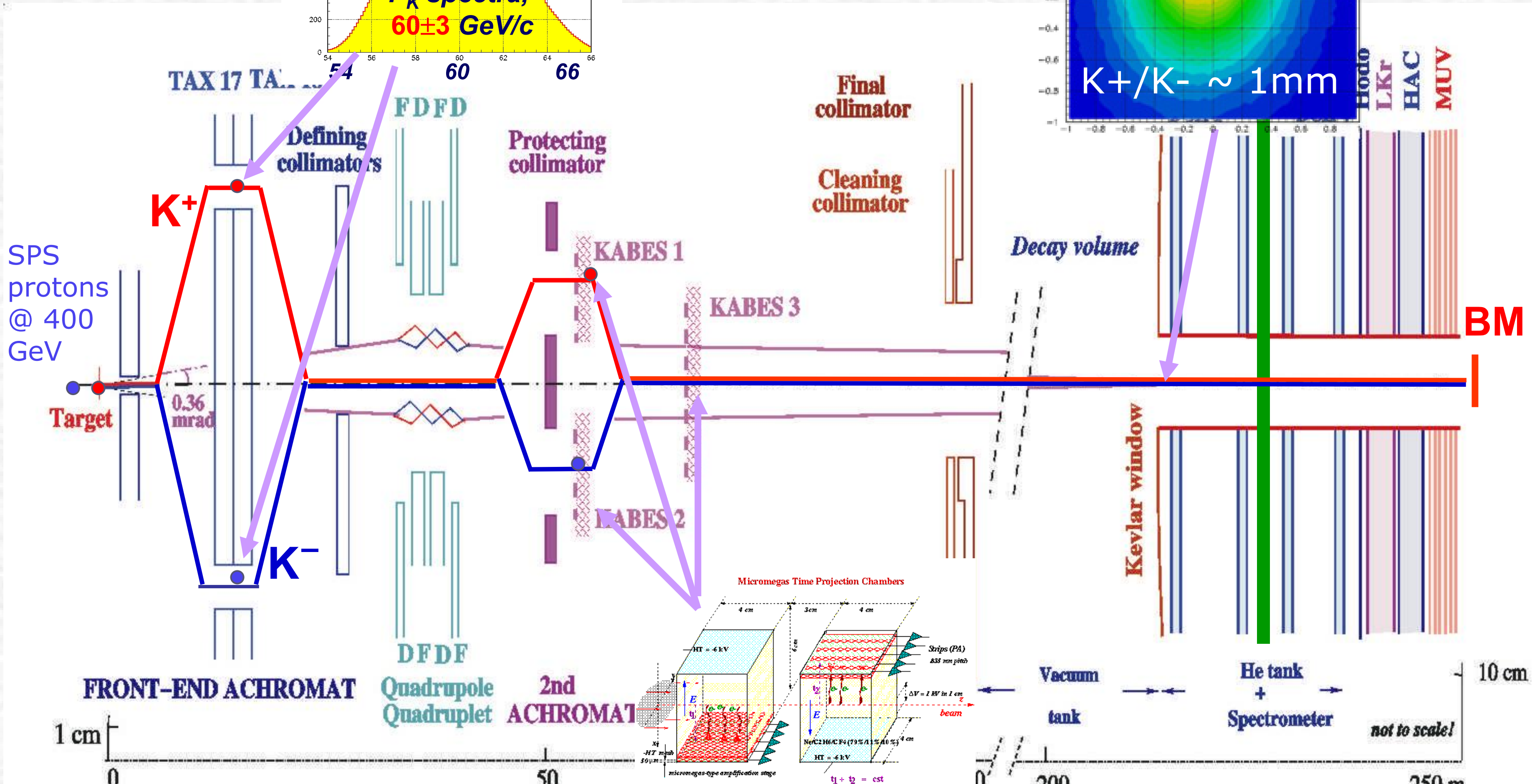
Outline

- NA48/2 experiment
- Direct CP violation and linear slope asymmetry
  - $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$ "neutral" asymmetry
  - $K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$ "charged" asymmetry
- Dalitz Plot parameters measurement
  - $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: g,h,k
  - $K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$: g,h,k
- Conclusions

NA48/ Beams







Simultaneus, unseparated, focused beams

$\delta p/p=0.7\%$

$\delta x,y \approx 100\mu m$

NA48/2: The detector

Spectrometer:

$\sigma_p/p = 1.0\% + 0.044\%\ p$ [p in GeV/*c*]

LKR calorimeter:

$\sigma_E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

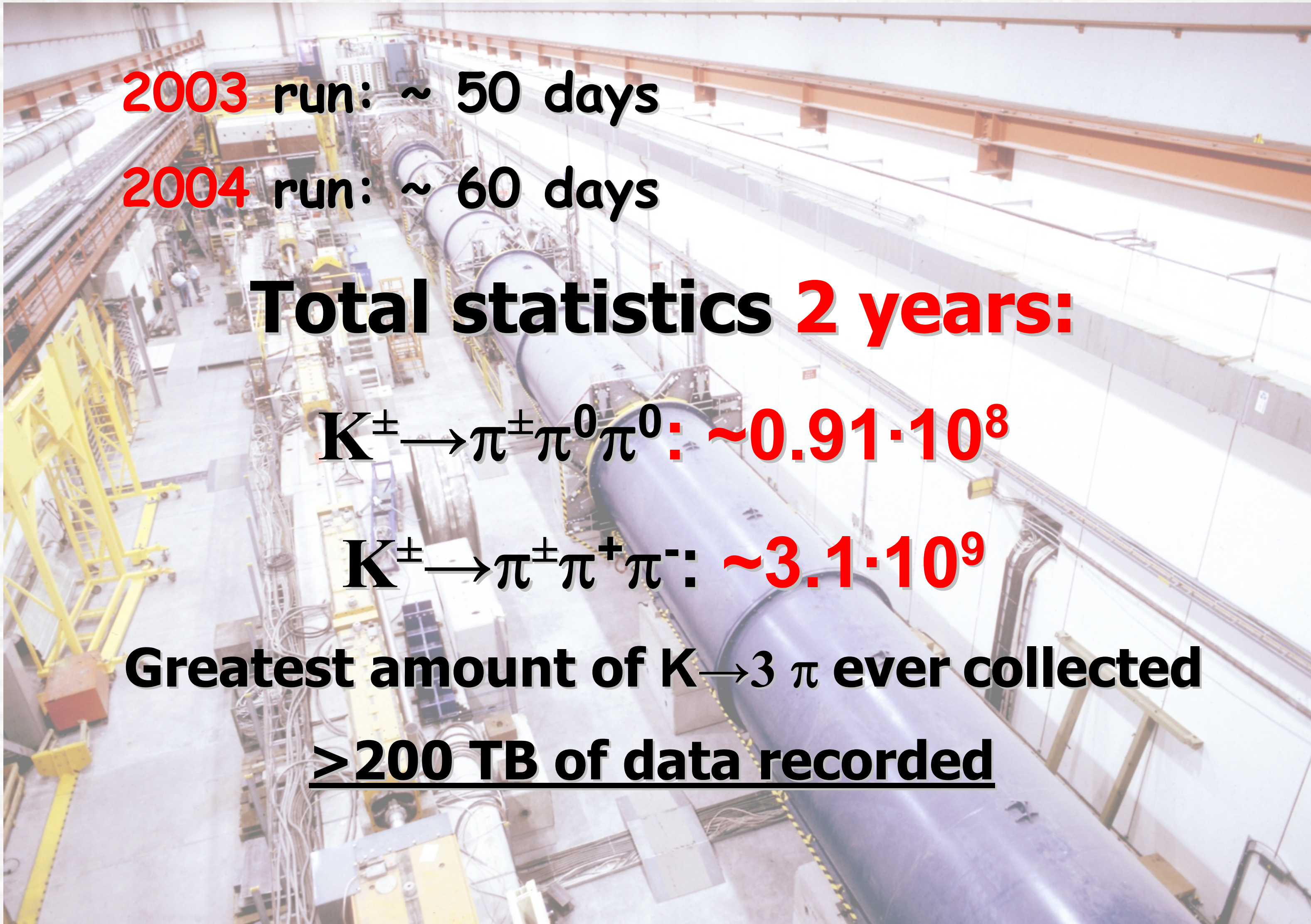
Hodoscope, **HAC**,**MUV**, **vetos**

Kabes

Beam Monitor

Only the Spectrometer, the LKr and the Hodoscope are directly involved in the $K \rightarrow 3\pi$ analysis.

NA48/2: data taking



2003 run: ~ 50 days

2004 run: ~ 60 days

Total statistics 2 years:

$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: ~$0.91\cdot10^{8}$

$K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$: ~$3.1\cdot10^{9}$

Greatest amount of $K\rightarrow3\pi$ ever collected

<u>>200 TB of data recorded</u>

Direct CP violation: linear slope asymmetry

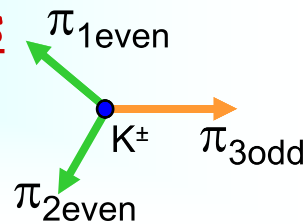
Direct CP violation in $K \to 3\pi$

- Experimentally is very hard to detect CP violation in the partial decay widths
- Comparison of the Dalitz plot density between K+ and K-

Dalitz variables

$u=(s_3-s_0)/m_\pi^2$

$v=(s_2-s_1)/m_\pi^2$



$S_i=(P_K-P_{\pi,i})^2 \quad i=1,2,3$ (3=odd π)

$3S_0=m_K^2+m_\pi^2+2m_{\pi 0}^2$

Matrix element:

$$|M(u,v)|^2 \sim 1+gu+hu^2+kv^2+\ldots$$

$$A_g = \frac{g^+ - g^-}{g^+ + g^-}$$

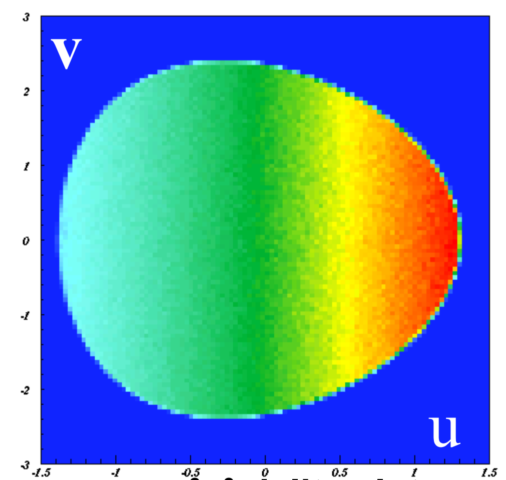
$A_g \neq 0$

Direct CP violation!!!

$g_c=-0.215$

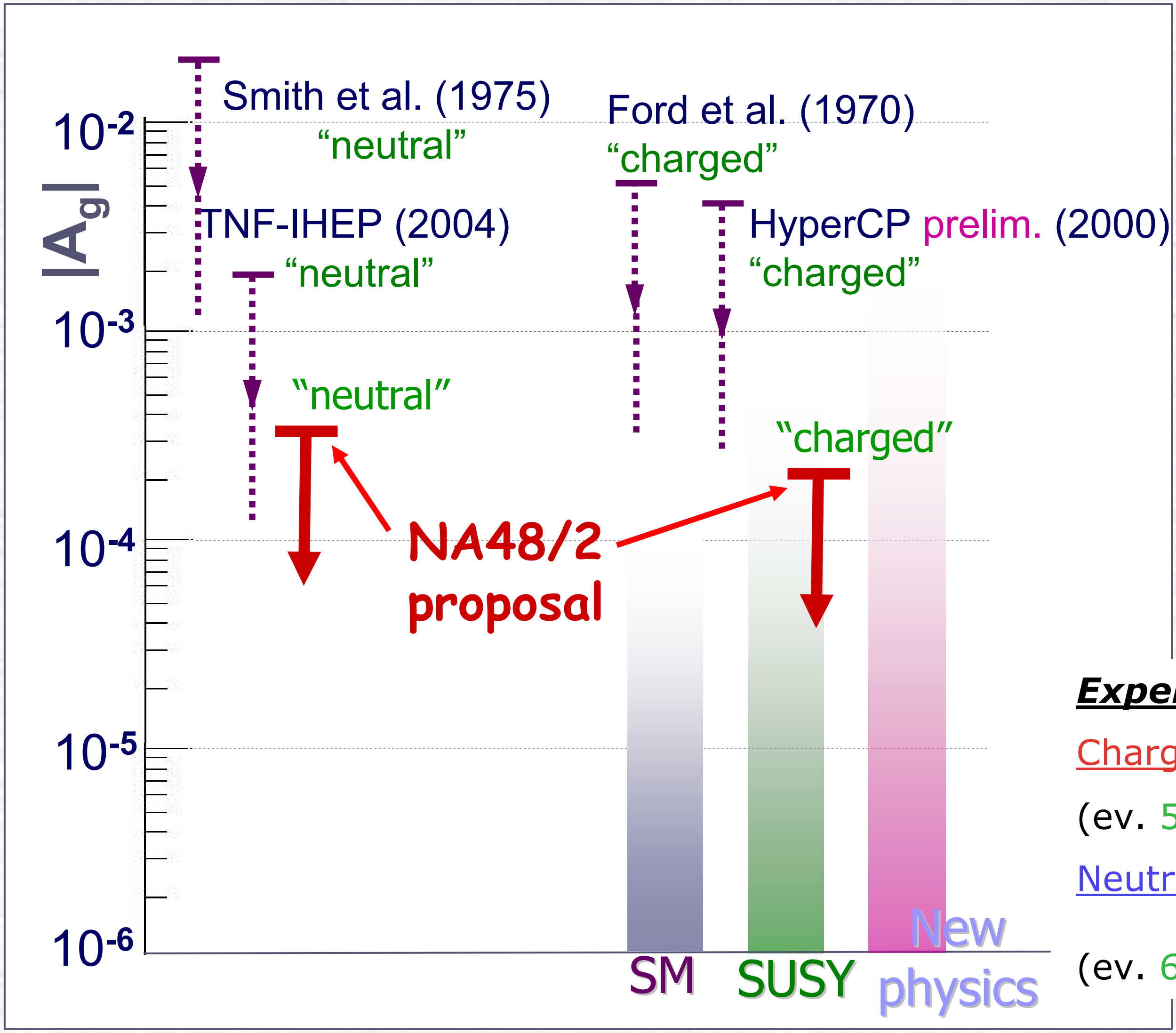
$g_n=0.638$

$h,k << g$



$K \to \pi\pi^0\pi^0$ dalitz plot

Theoretical prediction and experimental results



- SM theoretical prediction in the range 10^{-6} - $5 \cdot 10^{-5}$
- Models beyond the SM predict **enhancement** of the A_g value

Experimental results:

Charged mode: $A_g^c = (22 \pm 15 \pm 37) \cdot 10^{-4}$

(ev. $54 \cdot 10^6$)

Neutral mode: $A_g^n = (2 \pm 19) \cdot 10^{-4}$

(ev. $620 \cdot 10^3$)

Method to extract A_g

- Assuming the polinomial matrix element expansion The difference between K+ and K- linear slopes in 3π decays ($\Delta g = g^+ - g^-$), could be extracted from the U projections using:

$$R(u) = \frac{N^+(u)}{N^-(u)} \propto N\left(\frac{1 + g^+u + hu^2 + \ldots}{1 + g^-u + hu^2 + \ldots}\right) \approx N\left(1 + \frac{\Delta g u}{1 + gu + hu^2}\right)$$

"neutral"
$g^0 = 0.638 \pm 0.020$

$$R(u) = \frac{N^+(u)}{N^-(u)} \propto N\left(\frac{1 + g^+u + hu^2 + \ldots}{1 + g^-u + hu^2 + \ldots}\right) \approx N(1 + \Delta g u)$$

"charged"
$g^+ = -0.2154 \pm 0.0035$

$$A_g = \frac{\Delta g}{2g}$$

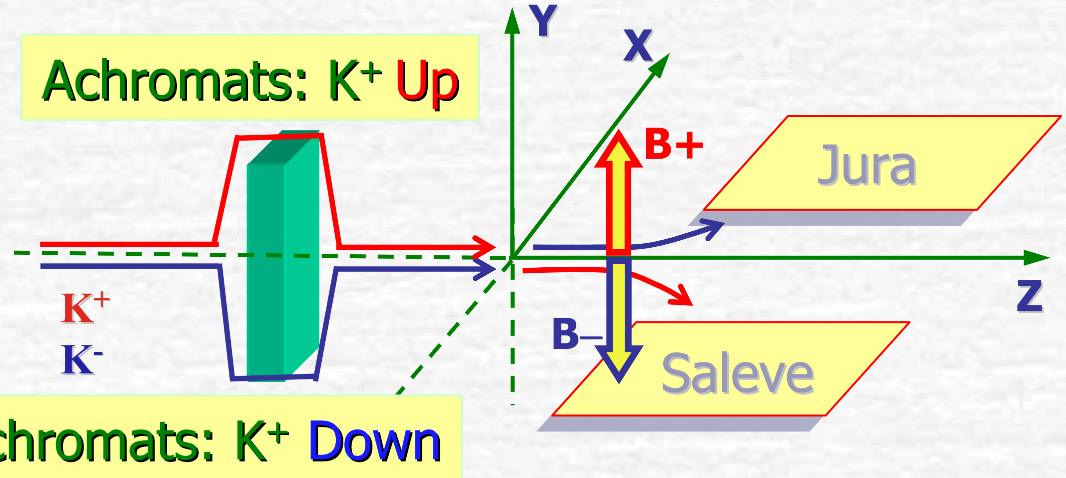
This is valid only if K+ and K- beams and acceptance are the same!!!

The presence of magnetic fields (both in beam and detector sector) introduces **instrumental asymmetries** that don't cancel in the simple ratio

Acceptance equalization principle

- **Achromats** (A) polarity reversed: weekly in 2003, 1 day in 2004
- **Spectrometer magnet** (B) polarity reversed: 1 day in 2003, 3 hours in 2004

* Jura and Saleve are the mountains outside of the CERN



$$R_{US} = \frac{N(A+B+K+)}{N(A+B-K-)}$$

$$R_{UJ} = \frac{N(A+B-K+)}{N(A+B+K-)}$$

$$R_{DS} = \frac{N(A-B+K+)}{N(A-B-K-)}$$

$$R_{DJ} = \frac{N(A-B-K+)}{N(A-B+K-)}$$

- In each ratio the charged pions are deflected towards the **same side** of the detector (*left-right asymmetry cancels out*)
- In each ratio the event at the numerator and denominator are collected in **subsequent period** of data taking *(global time variations)*
- The whole data taking is subdivided periods in which all the field configurations are present (*Super Sample SS*)

Acceptance equalization: 4-ratio

double ratios:

$R_U = R_{US} * R_{UJ} \approx n(1+\Delta g_U/f(u))^2$

$R_D = R_{DS} * R_{DJ} \approx n(1+\Delta g_D/f(u))^2$

Same achromat: global time variation (B field inversion) cancellation

$R_S = R_{US} * R_{DS} \approx n(1+\Delta g_S/f(u))^2$

$R_J = R_{UJ} * R_{DJ} \approx n(1+\Delta g_J/f(u))^2$

Same side (J/S): beam geometry difference cancellation

$\Delta g_{UD} = (\Delta g_U - \Delta g_D)/2$ → up-down apparatus asymmetry

$\Delta g_{LR} = (\Delta g_S - \Delta g_J)/2$ → left-right apparatus asymmetry

4-ple ratio:

$R_4 = R_{US} * R_{UJ} * R_{DS} * R_{DJ} \approx n(1+\Delta g/f(u))^4$

- In the 4-ratio there is a 3-fold cancellation
  - Left-right detector asymmetry
  - Global time variation
  - Beam line induced differences

MC-independent approach:

A detailed MC is used for systematics studies.

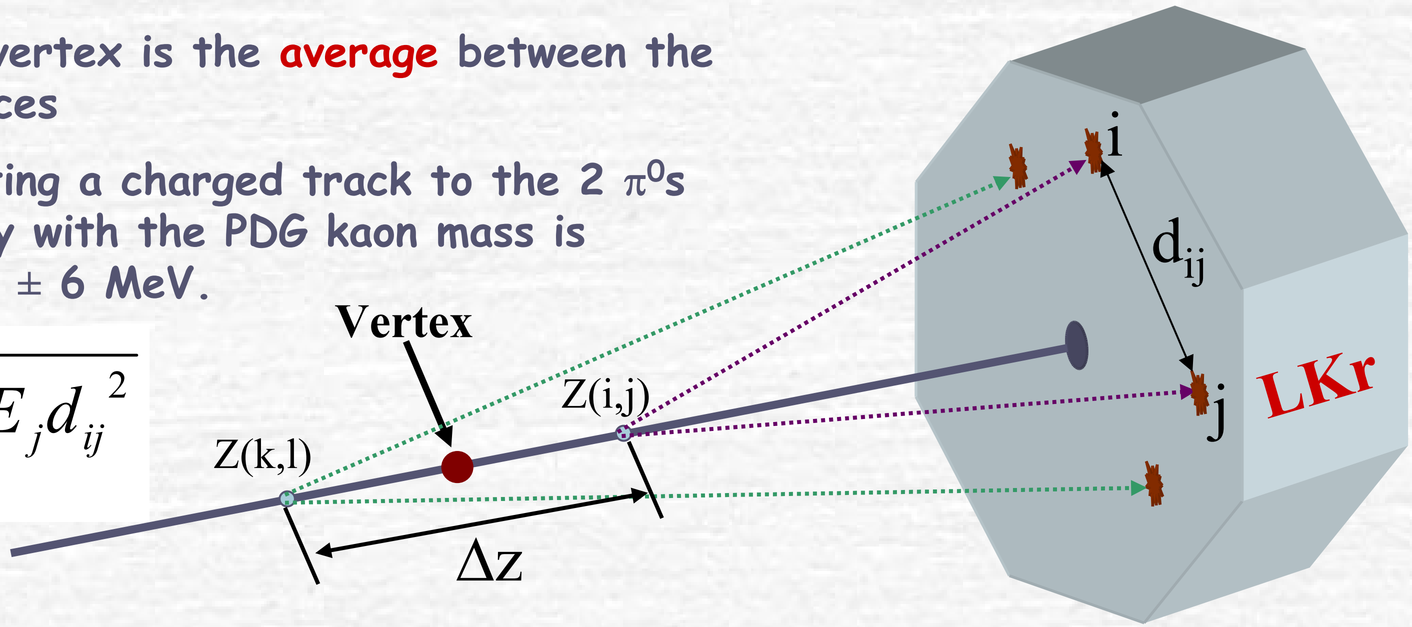
The result is sensitive only to the time variation of acceptance COUPLED to space non uniformity with a characteristic time smaller than the fields alternation period .

$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: Selection & recostruction

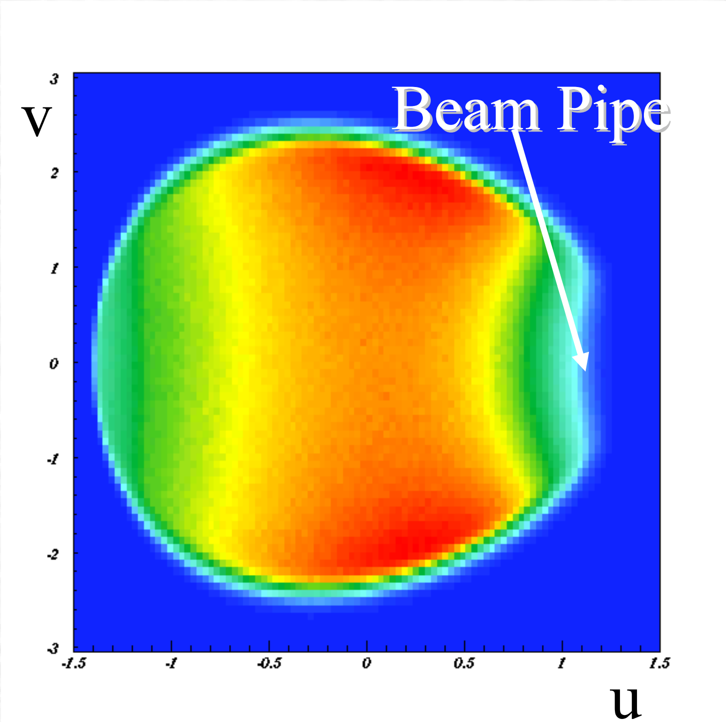
- *Online selection*: Trigger in 2 Levels:
  - **L1**: CHOD signal (**Q1**: one charged particle) + LKr signal (**NTPEAK**: four gammas)
  - **L2**: Online charged pion missing mass far from the π^0 mass

- *Offline selection*: among all the possible γ pairings, the couple for which $|\Delta z|$ is smallest is selected
  - The K-decay vertex is the **average** between the two decay vertices
  - After associating a charged track to the 2 π^0s the compatibility with the PDG kaon mass is requested to be $\pm$ 6 MeV.

$$Z_{ij} \approx \frac{1}{m_{\pi^0}}\sqrt{E_i E_j d_{ij}^{\;2}}$$



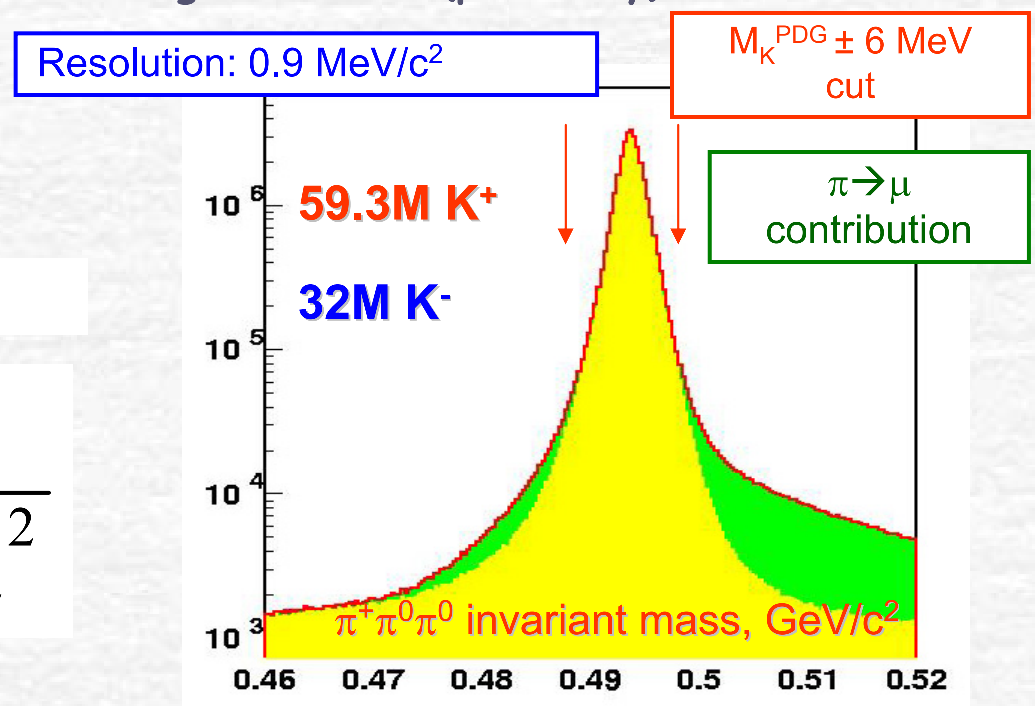
$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: Selected events



BR($K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$)=(1.73±0.04)%

$$u = \left(M_{00}{}^{2} - s_{0}\right)\frac{1}{m_{\pi}{}^{2}}$$

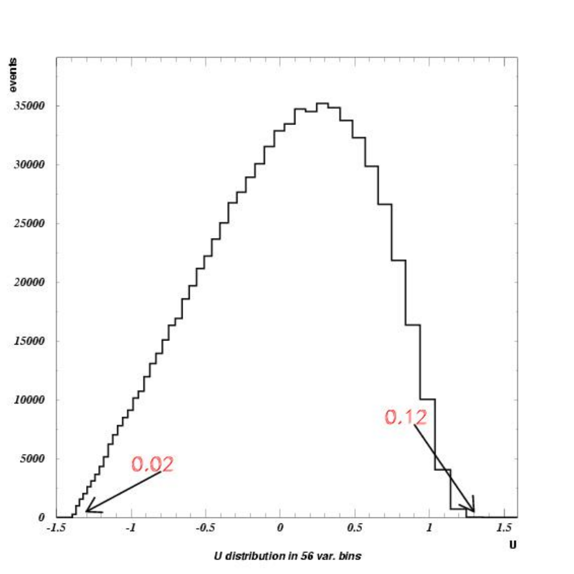
- The u variable is reconstructed using the **LKr only**
- M_{00} is the $\pi^0\pi^0$ mass
- M_{00} can be also defined as the missing π^+ mass employing DCH and KABES (cross check)
- More than $91 \cdot 10^6$ events are selected
- Background free (pratically)

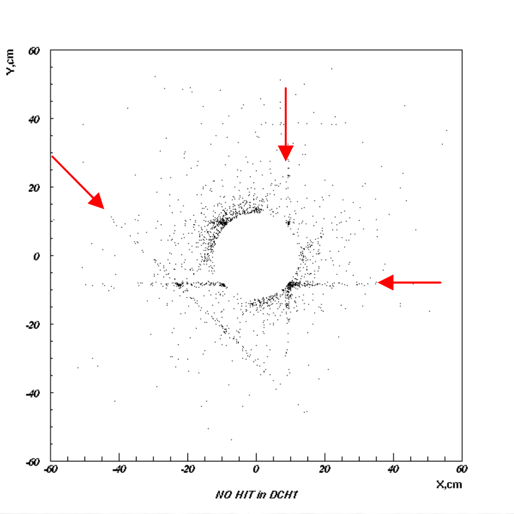


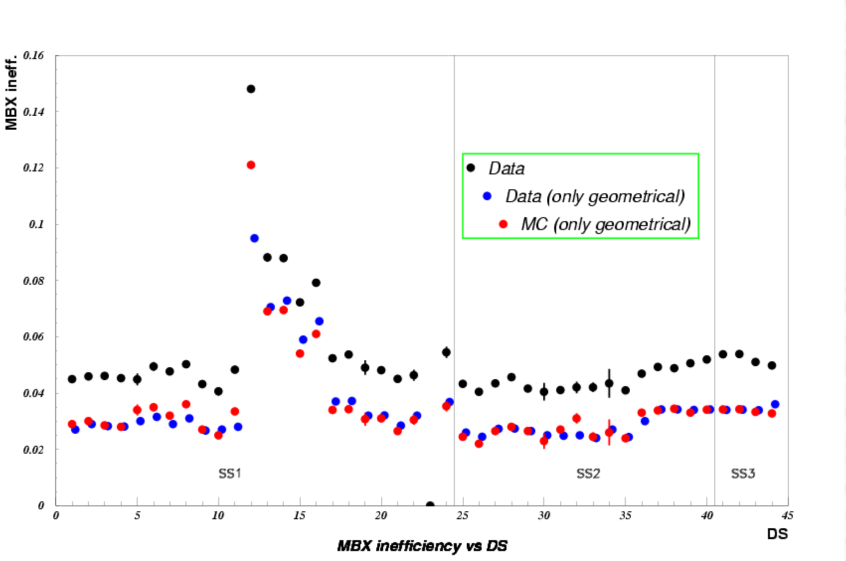
$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: systematics

- Thanks to the 4-uple ratio cancellations, in first approximation all main system biases cancel.

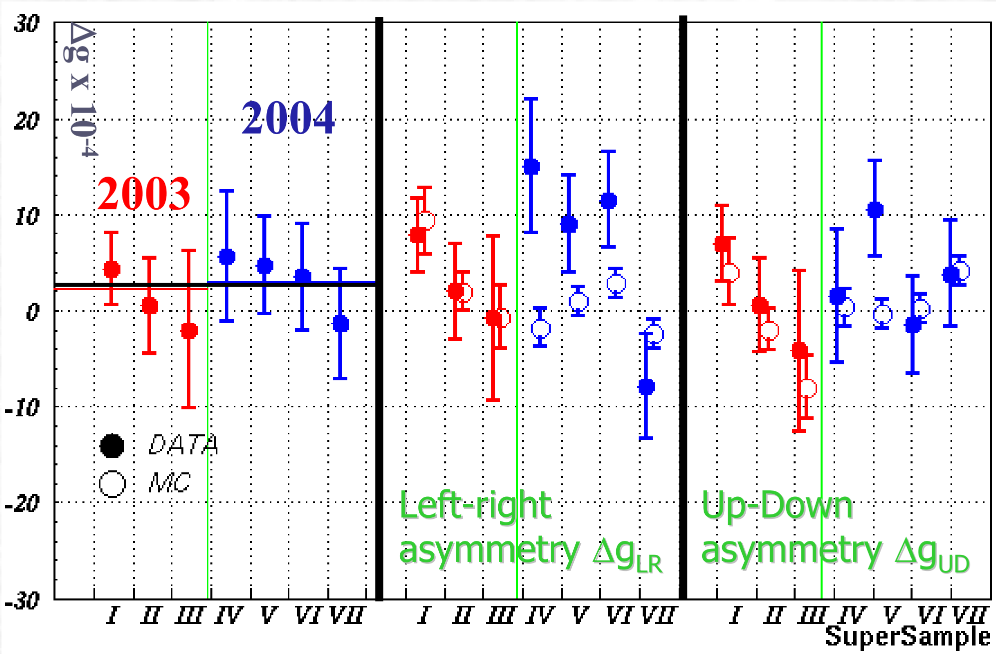
- Several sources of systematic uncertainty are studied. (for instance: **resolution effects** are studied using U distribution with bin width proportional to the U resolution, the **L2 trigger geometrical** component is studied using a detailed MC)







$K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$: Results



Systematics effect		Δg x10^{-4}
LKr related	U resolution & fitting	±0.2
	LKr non-linearity	±0.1
	Showers overlapping	±0.5
Pion decay		±0.2
Spectrometer alignment & momentum scale		±0.1
Pile-up		±0.2
Trigger	L1: charged signal	±0.1
	L1: neutral signal	±0.8
	L2: MassBox	±0.6
Total		±1.2
External		±0.3

Slope difference (03+04 prelim. result):

$\Delta g = (2.7 \pm 2.0_{stat.} \pm 1.2_{syst} \pm 0.3_{ext.})\times 10^{-4}$

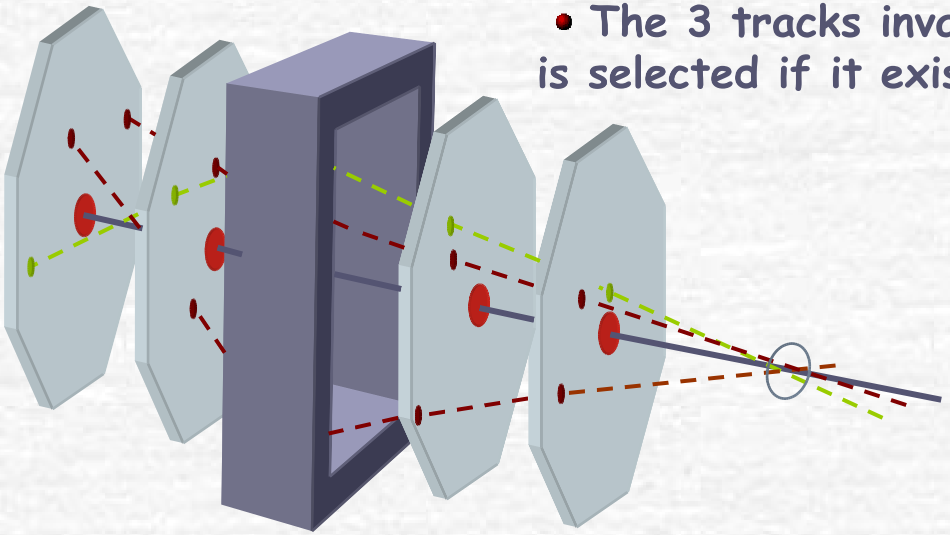
Charge asymmetry parameter (03+04 prelim. result):

$A_g^0 = (2.1 \pm 1.6_{stat.} \pm 1.0_{syst} \pm 0.2_{ext})\times 10^{-4} = (2.1 \pm 1.9)\times 10^{-4}$

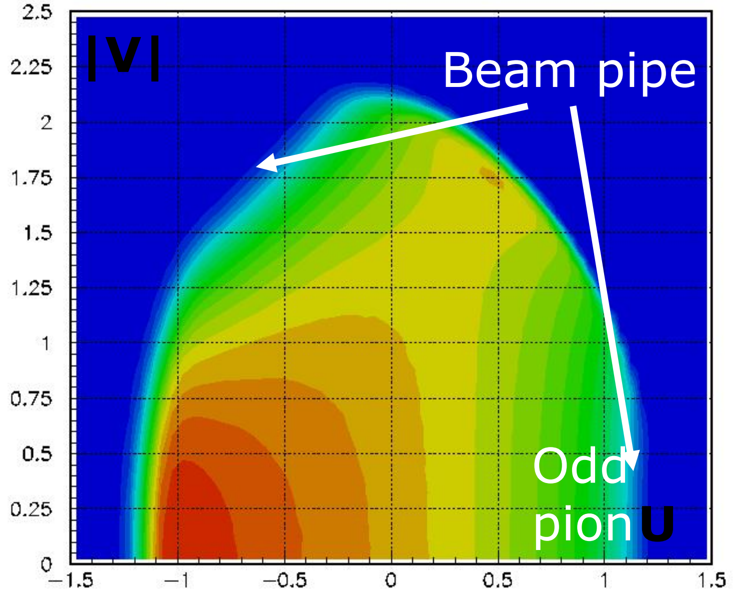
$K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$: Selection & recostruction

- *Online selection*: Trigger in 2 Levels:
  - **L1**: CHOD signal (**Q2**: at least two charged particles)
  - **L2**: Fast three tracks and vertex reconstruction

- *Offline selection*: the events with at least 3 "good" tracks are selected.
  - The K-decay vertex is obtained propagating the tracks through the "blue field" (Earth magnetic field into the decay region)
  - The 3 tracks invariant mass is recostructed. The event is selected if it exists at least one combination within ± 9 MeV from the K nominal mass.



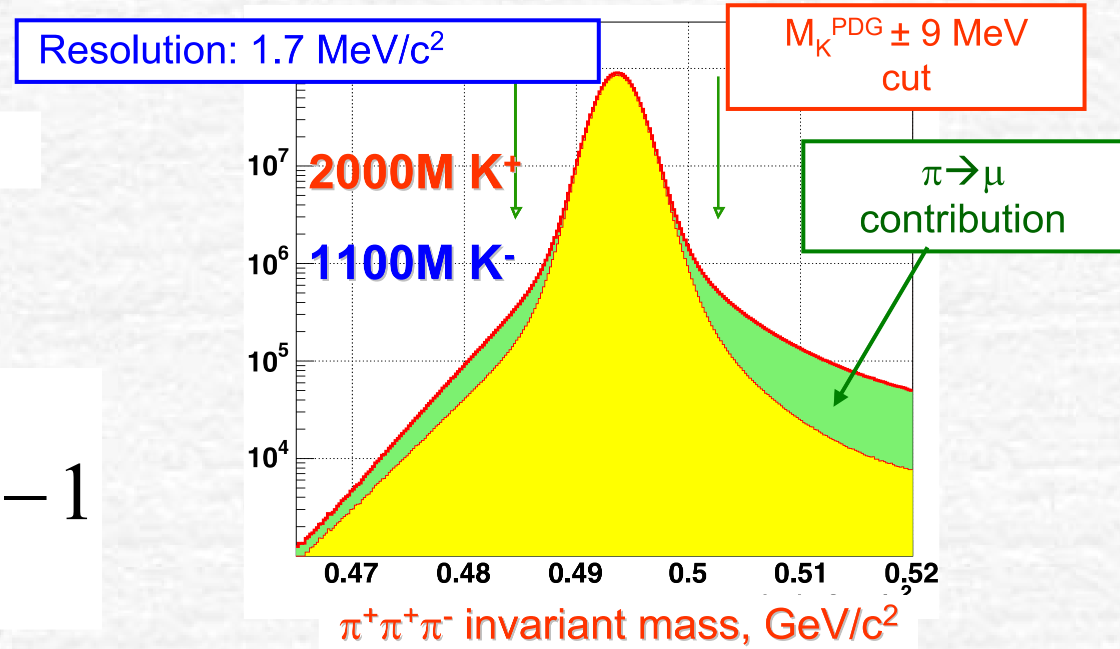
$K^\pm \to \pi^\pm\pi^+\pi^-$: Selected events



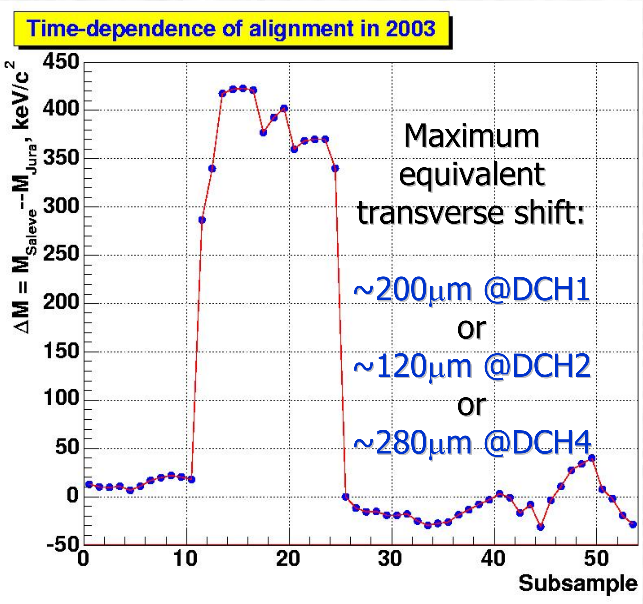
$BR(K^\pm \to \pi^\pm\pi^+\pi^-) = (5.576 \pm 0.031)\%$

- M_{12} is the even pions invariant mass
- Others definition (CM, kinematic fit, ..), with different resolution in different phase space regions, are useful to study systematics.
- About $3.1 \cdot 10^9$ events are selected with negligible background

$$u = \left(M_{12}^{\ 2} - \frac{m_K^2}{3} \right) \frac{1}{m_\pi^{\ 2}} - 1$$

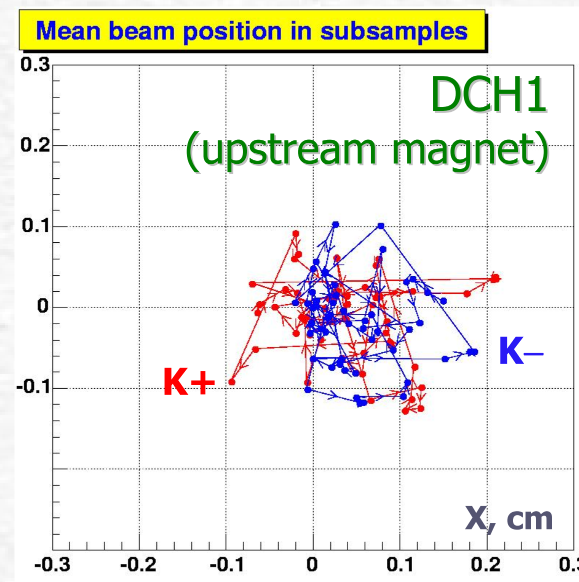


$K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-}$: Systematics

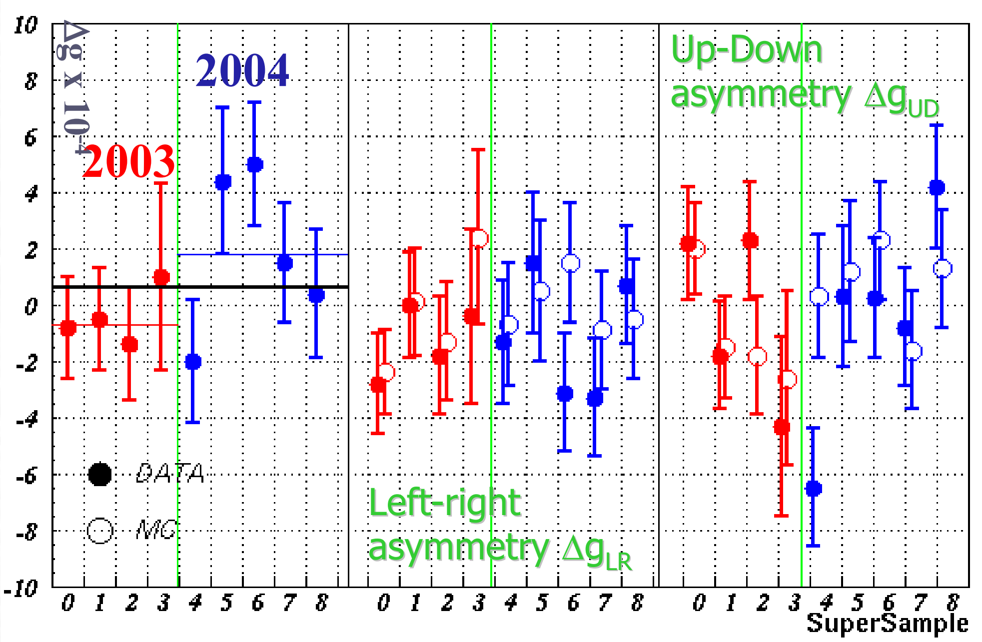


- The small DCH internal misalignment is corrected reweighting the pions momentum. The corrections are deduced by the difference between the K+ and K- reconstructed mass.

- To avoid biases due to the different K+ and K- DCH acceptance, a radial cut around the actual (measured from the Data) K+ and K- beam position is applied ("virtual pipe" cut).



$K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-}$: Results



Systematics effect		Δg x10^{-4}
DCH & beam related	Spectrometer alignment	±0.1
	Momentum scale	±0.1
	Acceptance and beam geometry	±0.2
Pion decay		±0.4
Pile up		±0.2
Resolution effects		±0.3
Trigger	L1: CHOD signal	±0.3
	L2: MassBox	±0.3
Total		±0.7

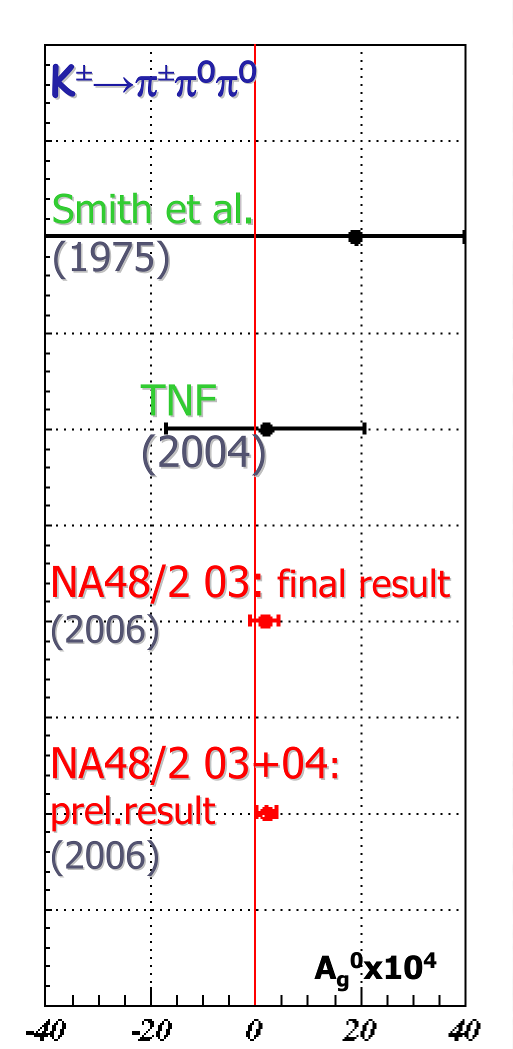
Slope difference (03+04 prelim. result):

$\Delta g = (0.6\pm 0.7_{stat.} \pm 0.7_{syst})\text{x}10^{-4}$

Charge asymmetry parameter (03+04 prelim. result):

$A_g^c = (-1.3 \pm 1.5_{stat.} \pm 1.7_{syst})\text{x}10^{-4} = (-1.3 \pm 2.3)\text{x}10^{-4}$

$K^\pm \to 3\pi$ linear slope asymmetries : Summary



2003 data final result: *

$$A_g^0 = (1.8 \pm 2.2_{stat} \pm 1.3_{syst})x10^{-4}$$

$$A_g^c = (1.6 \pm 2.1_{stat} \pm 2.0_{syst})x10^{-4}$$

2003+2004 data preliminary result:

$$A_g^0 = (2.1 \pm 1.6_{stat} \pm 1.0_{syst})x10^{-4}$$

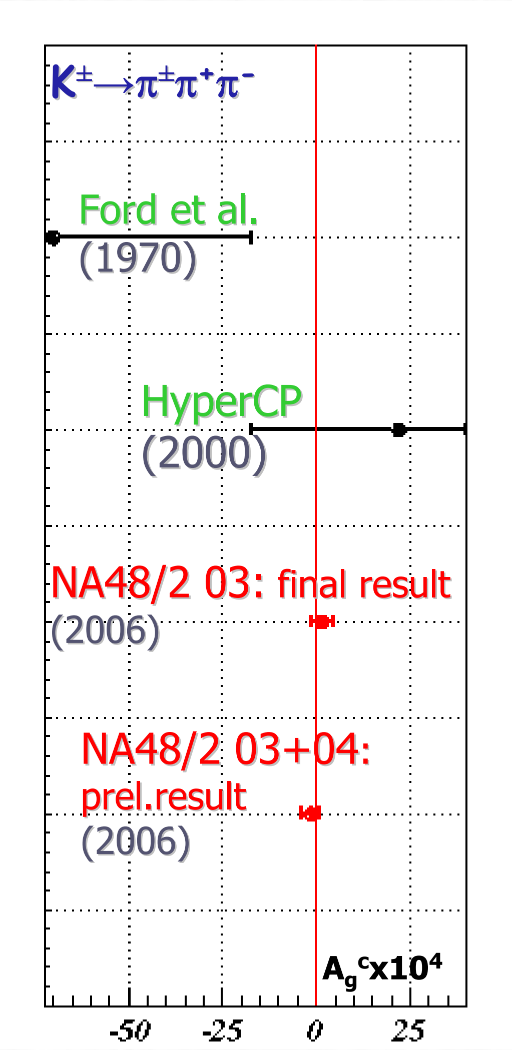
$$A_g^c = (-1.3 \pm 1.5_{stat} \pm 1.7_{syst})x10^{-4}$$

Statistical precision similar in "charged" and "neutral" mode:

- statistics: $N^0/N^\pm \sim 1/30$ ($\surd$=1/5.5)
- slopes: $|g^0/g^\pm| \approx 3$
- More favorable Dalitz-plot distribution: gain factor f~1.5

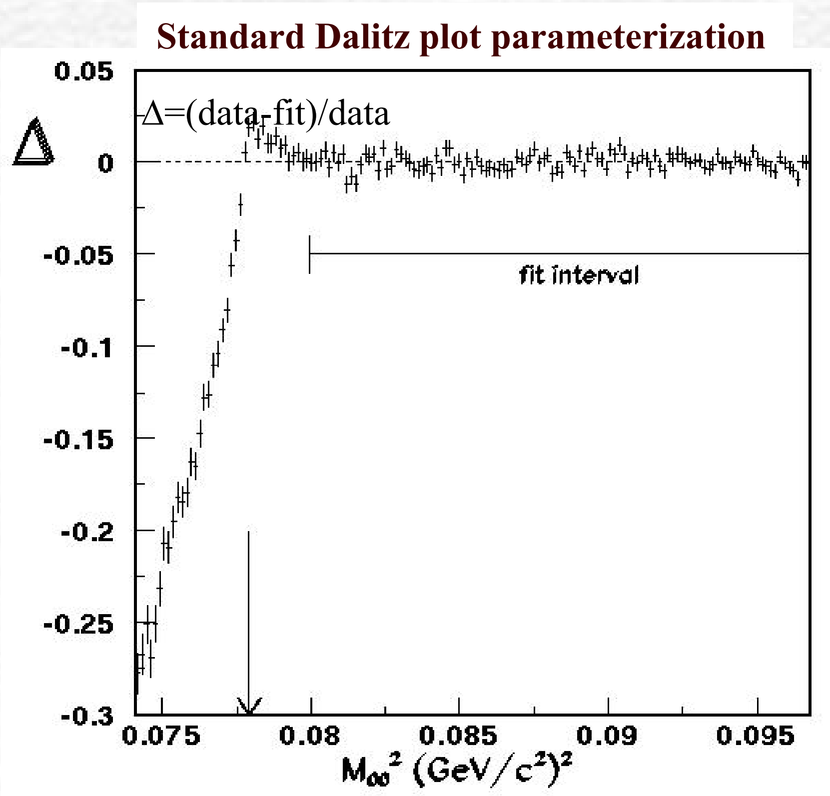
*: Phys.Let.B 634:474-482,2006

Phys.Let.B 638:22-29,2006



Dalitz plot parameters measurement

$K^{\pm} \to \pi^{\pm}\pi^0\pi^0$: Standard parametrization



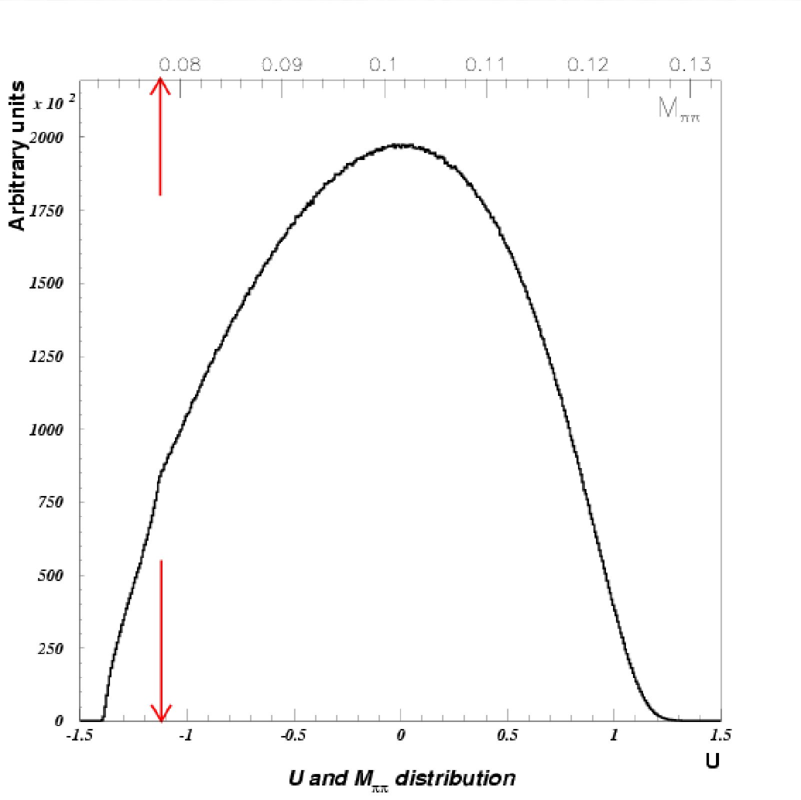
- Attempt to fit with the standard parametrization

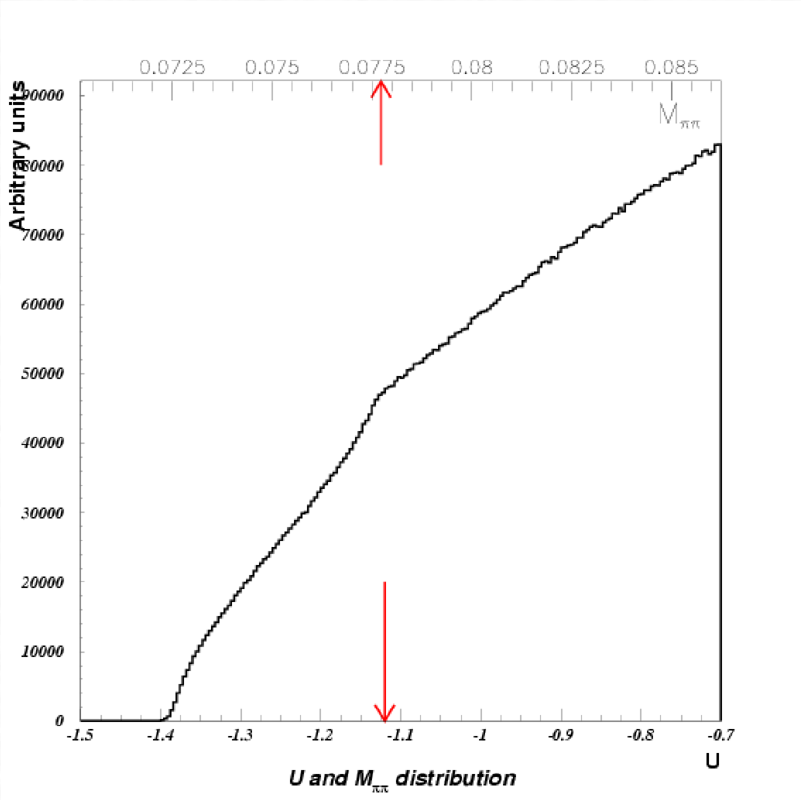
$$|M(u,v)|^2 \sim 1+gu+hu^2+kv^2+\ldots$$

- The 1D fit is reliable only in the region **above $2m_{\pi+}$**

- The fit in the whole U range (or $M^2_{\pi0\pi0}$) gives a **χ^2/ndf = 9225/149** while for $M^2_{\pi0\pi0}$>0.08 we have **χ^2/ndf = 133/110**

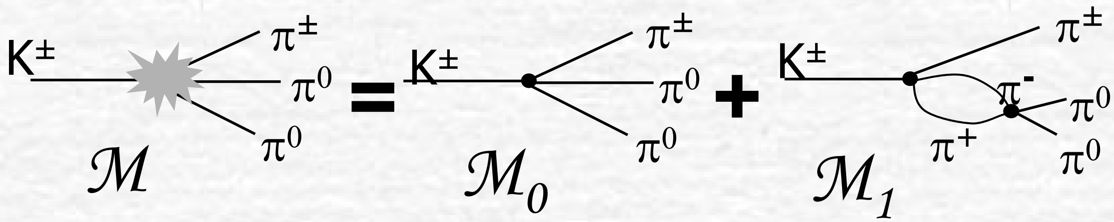
$K^{\pm} \to \pi^{\pm}\pi^0\pi^0$: Cusp

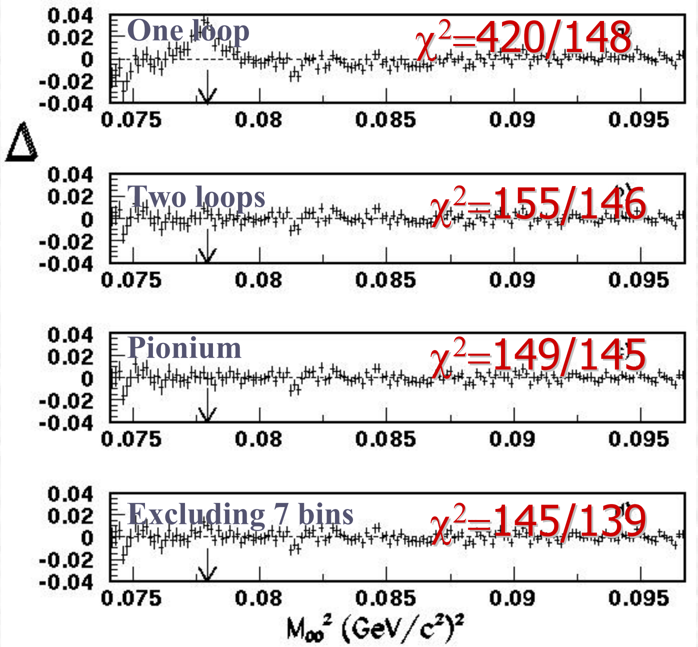




- The high statistics and the good resolution allow to see a "cusp" in the U (or $M^2_{\pi 0 \pi 0}$) distribution in the position of $2m_{\pi+}$

$K^\pm \to \pi^\pm \pi^0 \pi^0$: rescattering contribution





- The M1 contribution is real below and immaginary above threshold

$$s_{\pi\pi} > 4m^2_{\pi^+} \qquad |M^2| = (M_0)^2 + |M_1^2|$$

$$s_{\pi\pi} < 4m^2_{\pi^+} \qquad |M^2| = (M_0)^2 + (M_1^2) + 2M_0M_1$$

- The cusp behaviour is proportional to the (a0-a2) scattering lenghts. (see Lucia Masetti's talk) $(a0-a2)m_\pi = 0.268 \pm 0.010_{stat} \pm 0.004_{syst} \pm 0.013_{th}$
- The χ^2 improuves including the 2 loops and the pionium contribution
- the final fit is performed excluding 7 bins around the cusp position

Cabibbo *Phys. Rev. Lett. 93, 121801 (2004)*

Cabibbo,Isidori JHEP 0503 (2005) 21

$K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$: new parametrization & results

- Including the 2 loops contributions a second cusp appears above threshold

- The standard parametrization is not enough to described the $K^{\pm} \rightarrow \pi^{\pm}\pi^0\pi^0$ dynamics

- The 2D fit shows the presence of a **non vanish k terms** (the fit is performed in bin of $\cos\theta$, angle between π^+ and π^0)

- Setting k=0 (the quadratic v slope) the results of the fit are (*Phys.Lett. B633:173-283,2006*) (23×10^6 events (2003)):

$g=0.645 \pm 0.004_{stat} \pm 0.009_{syst}$

$h'=-0.047 \pm 0.012_{stat} \pm 0.011_{syst}$

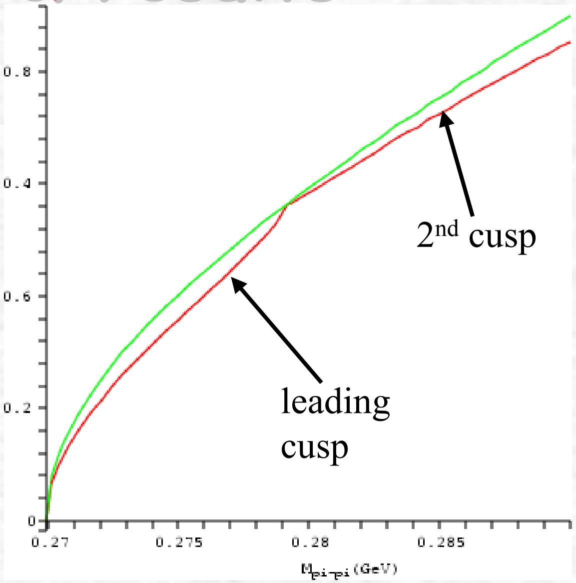
$(h'+(1/4)g^2=h)$

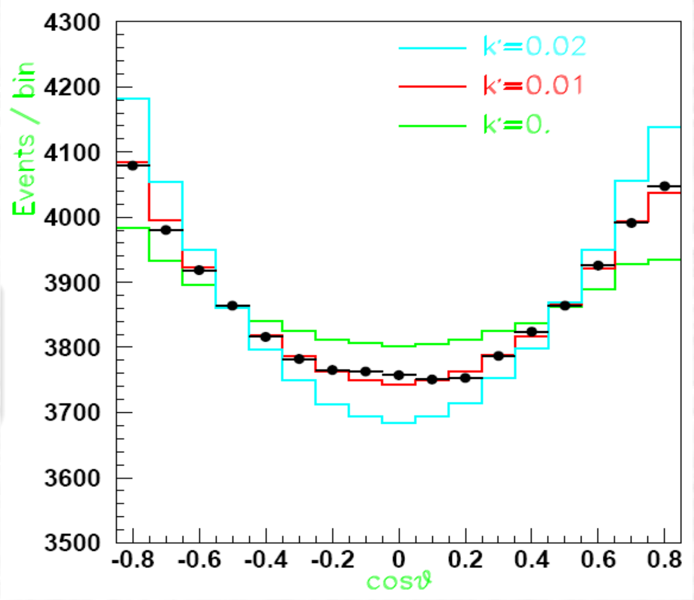
- The data are compatible with (**preliminary**):

$k= 0.0097 \pm 0.0003_{stat} \pm 0.0008_{syst}$

ISTRA+: k=0.001±0.001±0.002 (252K events)

- (a0-a2) is not affected by the k term, but g and h are influenced by a non zero k term (2% and 25%)

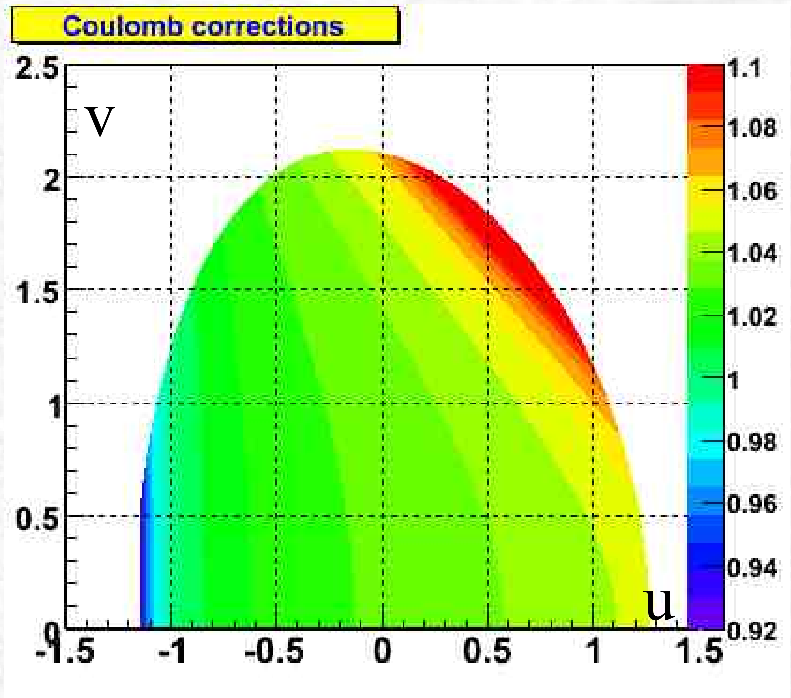




$K^\pm \to \pi^\pm \pi^+ \pi^-$: Dalitz plot

$$d\Gamma/dudv \sim C(u,v) \times (1 + gu + hu^2 + kv^2)$$

$$C(u,v) = \prod_{i,j=1,2,3} \frac{2\pi\alpha e_i e_j}{\beta_{ij}\left(\exp\left(\frac{2\pi\alpha e_i e_j}{\beta_{ij}}\right) - 1\right)}$$

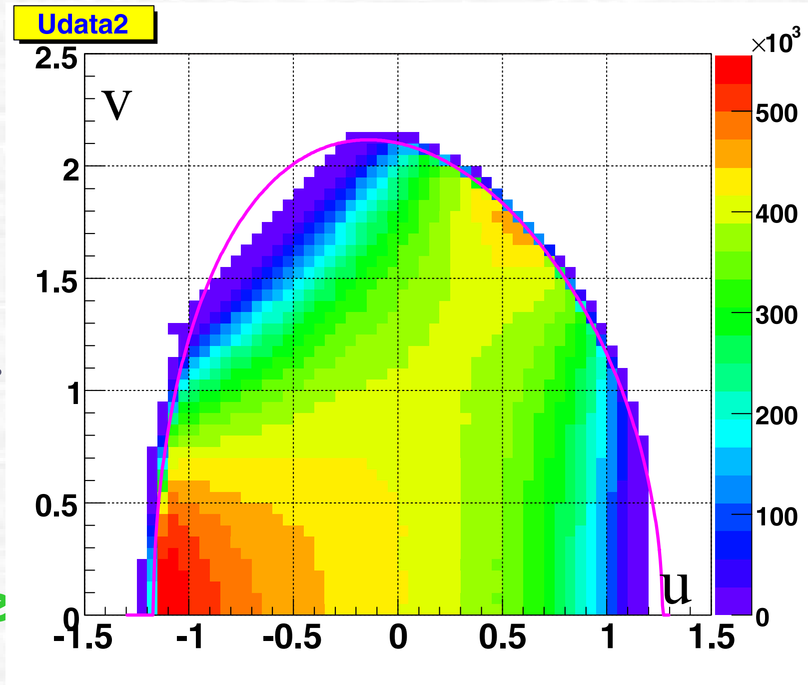


- Rescattering effects neglected
- Present PDG values from experiment in 1970s
- Validation of the simple polinomial expansion with our precision

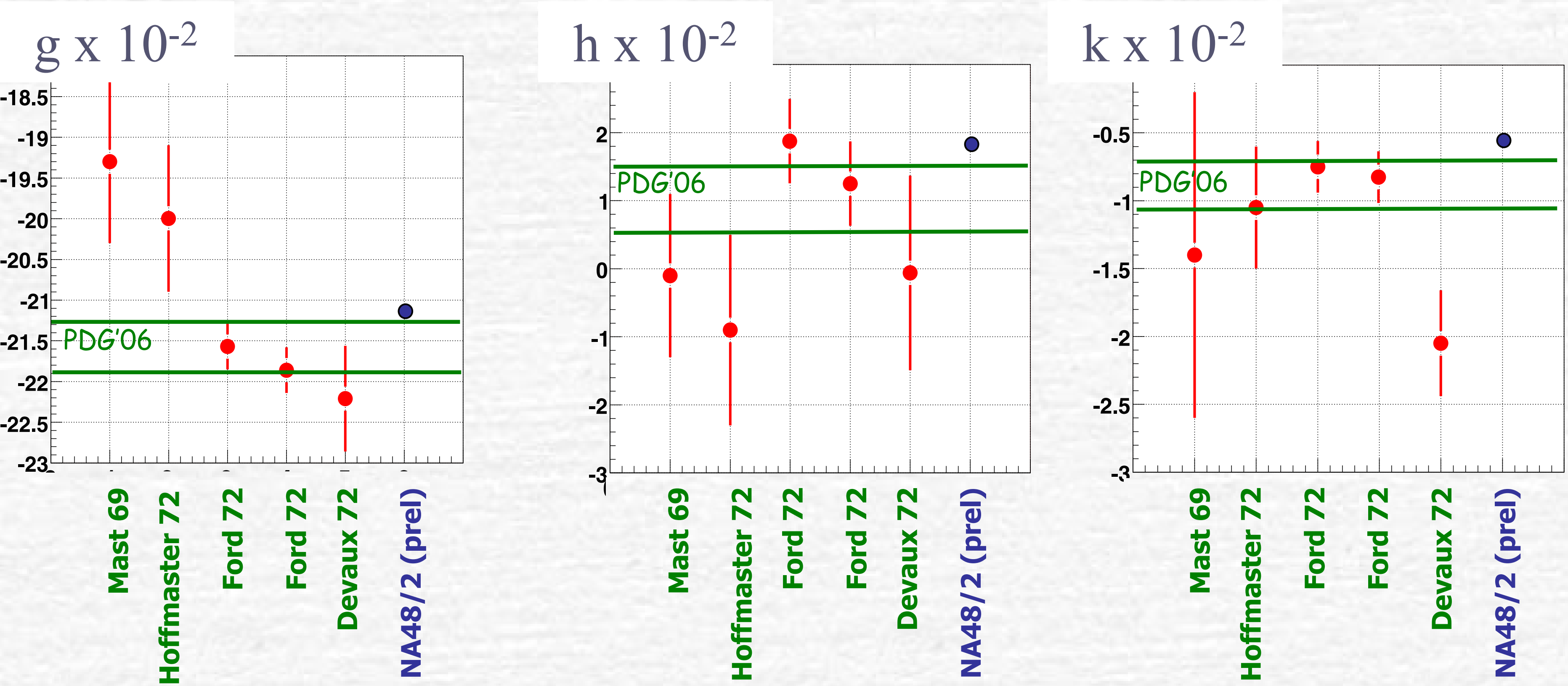
$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$: Fit

$$\chi^2(g,h,k,N) = \sum_{u,v} \frac{(F_{data} - NF_{MC})^2}{\delta F_{data}^2 + N^2 F_{MC}^2}$$

- The results are obtained minimizing the χ^2, where F represents the population in the (u,v) bin.
- 0.47x10⁹ (in 2003 data sample) events analized for preliminary result
- The main contributions to the systematic uncertainty come from the pion momentum resolution and the trigger



$K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{-}$: results



NA48/2 preliminary results:

$g=(-21.131\pm0.009_{stat}\pm0.012_{syst})\%$

$h=(1.829\pm0.015_{stat}\pm0.036_{syst})\%$

$k=(-0.467\pm0.005_{stat}\pm0.011_{syst})\%$

- One order of magnitude better than previous experiments
- Not perfect agreement with PDG values based on 1970s results

$K^\pm \to 3\pi$ Dalitz plot: Summary

$K^\pm \to \pi^\pm\pi^0\pi^0$:

- The standard M expansion is not enough to describe the 3 pions dynamics.
- The contribution of the $\pi^+\pi^- \to \pi^0\pi^0$ **rescattering** cannot be neglected (the (a0-a2) scattering lenght can be deduced from this effect)
- **k term different from zero** observed for the first time
- The Dalitz plot parameters are measured with this new approach (different definition)

$g=0.645\pm0.004_{stat}\pm0.009_{syst}$ (with k=0)

$h'=-0.047\pm0.012_{stat}\pm0.011_{syst}$ (with k=0)

$k=0.0097\pm0.0003_{stat}\pm0.0008_{syst}$ (preliminary)

$K^\pm \to \pi^\pm\pi^+\pi^-$:

- Rescattering effects and radiative corrections neglected (first step)
- **Factor ~10 improvement** with respect to previous measurement
- Standard parametrization is valid

(Preliminary)

$g=(-21.131\pm0.009_{stat}\pm0.012_{syst})\%$

$h=(1.829\pm0.015_{stat}\pm0.036_{syst})\%$

$k=(-0.467\pm0.005_{stat}\pm0.011_{syst})\%$

Conclusions

- Charge $K \rightarrow 3\pi$ asymmetry measurement at level of few 10^{-4} is consistent with SM prediction

- The NA48/2 results, both in charged and neutral mode, supersede previous measurements of one order of magnitude

2003+2004 data preliminary result:

$A_g^0 = (2.1 \pm 1.6_{stat} \pm 1.0_{syst})x10^{-4}$ ($91 \cdot 10^6$ events)

$A_g^c = (-1.3 \pm 1.5_{stat} \pm 1.7_{syst})x10^{-4}$ ($3.1 \cdot 10^9$ events)

- The Dalitz plot shape in the neutral mode is influenced by $\pi^+\pi^- \rightarrow \pi^0\pi^0$ **rescattering**

- The $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$ **k term** is measured different from zero (preliminary)

- The $K^\pm \rightarrow \pi^\pm\pi^+\pi^-$ slopes are measured with a factor **~10 improvement** w.r.t. previous measurement (in 1970s) (preliminary)

Spares

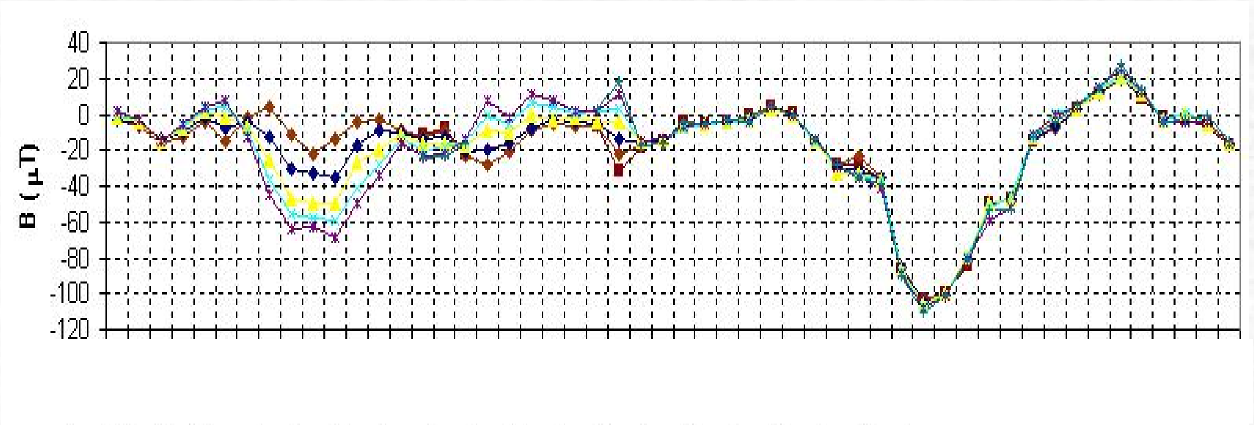
Theoretical predictions

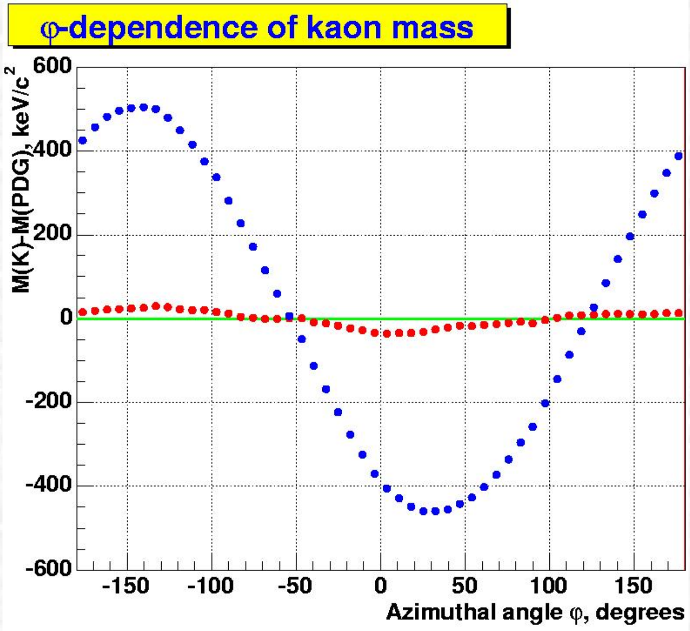
Standard Model	L.Maiani, N.Paver '95	$(2.3 \pm 0.6) \times 10^{-6}$
	A. Bel'kov '95	$< 4 \times 10^{-4}$
	G.D'Ambrosio, G.Isidori '98	$< 10^{-5}$
	E.Shabalin '01	$< 3 \times 10^{-5}$
	E.Gamiz, J.Prades, I.Scimemi '03	$(-2.4 \pm 1.2) \times 10^{-5}$
	E.Shabalin '05 (La Thuile'05)	$< 8 \times 10^{-5}$
SUSY	G.D'Ambrosio, G.Isidori, G.Martinelli	$\sim 10^{-4}$
New physics	E.Shabalin '98 [Weinberg model of extended Higgs doublet]	$\sim 4 \times 10^{-4}$
	I.Scimemi '04	$> 3 \times 10^{-5}$

Experimental results

"Charged" mode $K^{\pm}\to 3\pi^{\pm}$	Ford et al. (1970) at BNL **$A_g=(-7.0\pm5.3)\cdot10^{-3}$** Statistics: 3.2M $K^{\pm}$
	HyperCP prelim. (2000) at FNAL **$A_g=(2.2\pm1.5\pm3.7)\cdot10^{-3}$** Statistics: 390M K^{+}, 1.6M K Preliminary, published as PhD thesis
"Neutral" mode $K^{\pm}\to\pi^{\pm}\pi^{0}\pi^{0}$	Smith et al. (1975) at CERN-PS **$A_g=(1.9\pm12.3)\cdot10^{-3}$** Statistics: 28000 $K^{\pm}$
	TNF-IHEP Protvino (2004) **$A_g=(0.2\pm1.9)\cdot10^{-3}$** Statistics: 0.52M $K^{\pm}$

Stray magnetic field





The Earth field (*Blue Field*) was **directly measured** and used at the vertex recostruction level. The residual systematics is $\delta\Delta<10^{-5}$

$$\frac{\text{P kick(stray field)}}{\text{P kick(spectrometer)}} \approx 10^{-4}$$

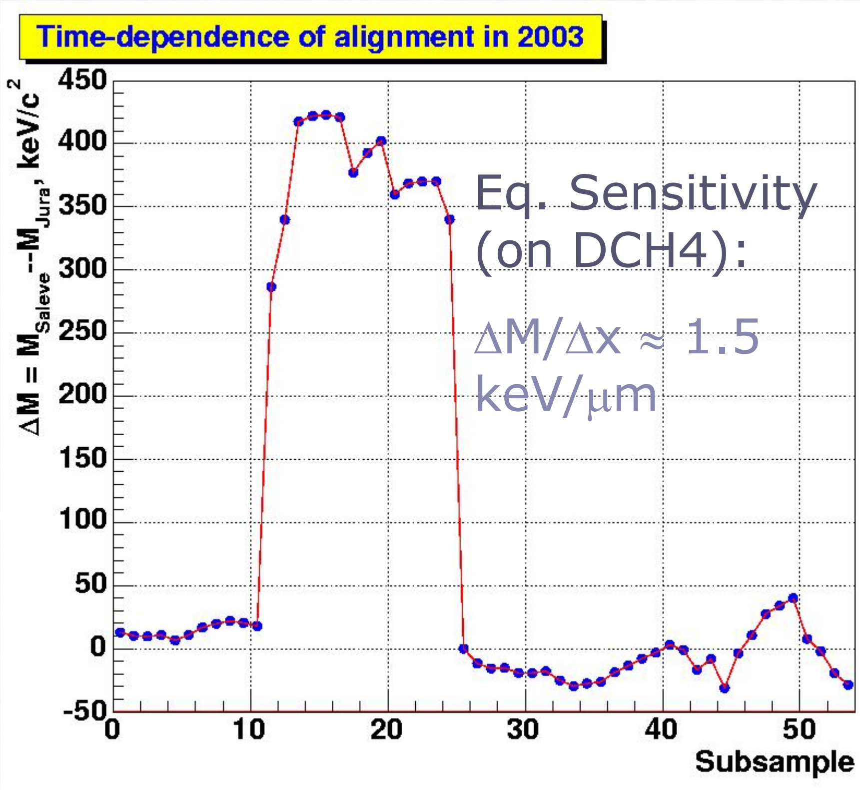
Spectrometer alignment

- The kaon mass depends from the time variation of the spectrometer alignment
- The mis-alignment gives a mis-measurement of the charged pion momentum
- The reconstructed invariant K mass is used to fine tune the spectrometer by imposing (α correction) :

$$M_{K+} = M_{K-}$$

- The non-perfect field alternation is tuned by imposing (β correction):

$$M_{K+-} = M_{Kpdg}$$

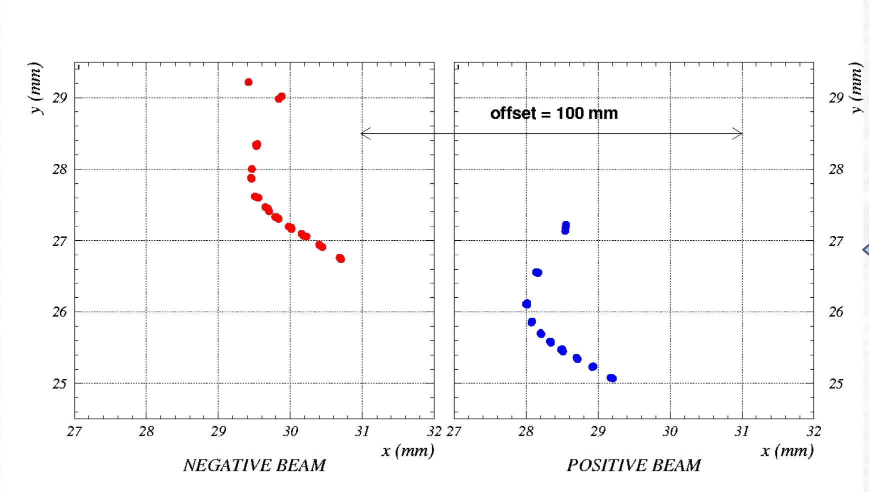


Kaon sign B sign

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

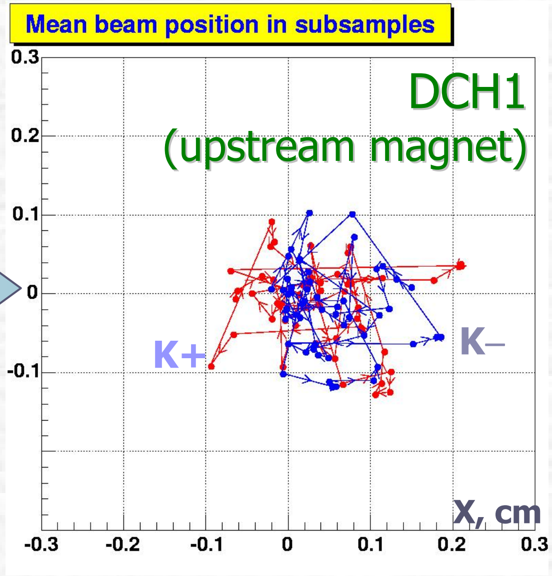
Raw momentum

Beam movements



- ***Short time scale movement***: the beam moves during the SPS spill
  - Monitored with an high resolution beam monitor on the beams
  - The 2 beam movement is "coherent"
  - No effect in the 4-uple ratio

- ***Large time scale movement***: the beam positions change every run
  - Acceptance largely defined by central beam hole edge (~10 cm radius)
  - The cut is defined around the actual beam position obtained with the c.o.g. measured run by run, for both charges as a function of the K momentum ("**virtual pipe**" cut)

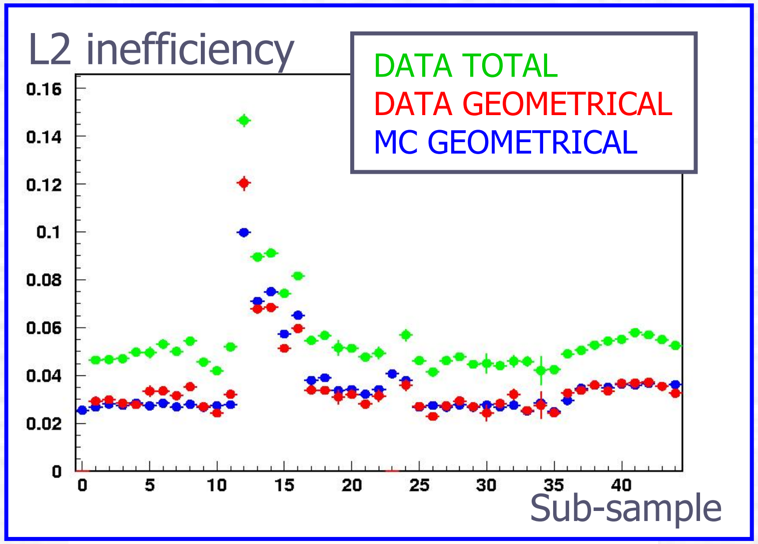


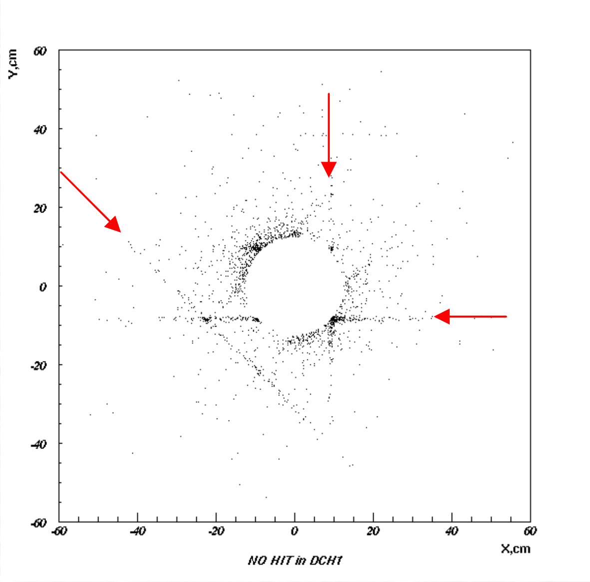
$K^\pm \to \pi^\pm \pi^0 \pi^0$: trigger systematics

Q1: The inefficiency is measured with all the 1-track events (0.25%). Systematics of $0.1 \cdot 10^{-4}$. No trigger correction

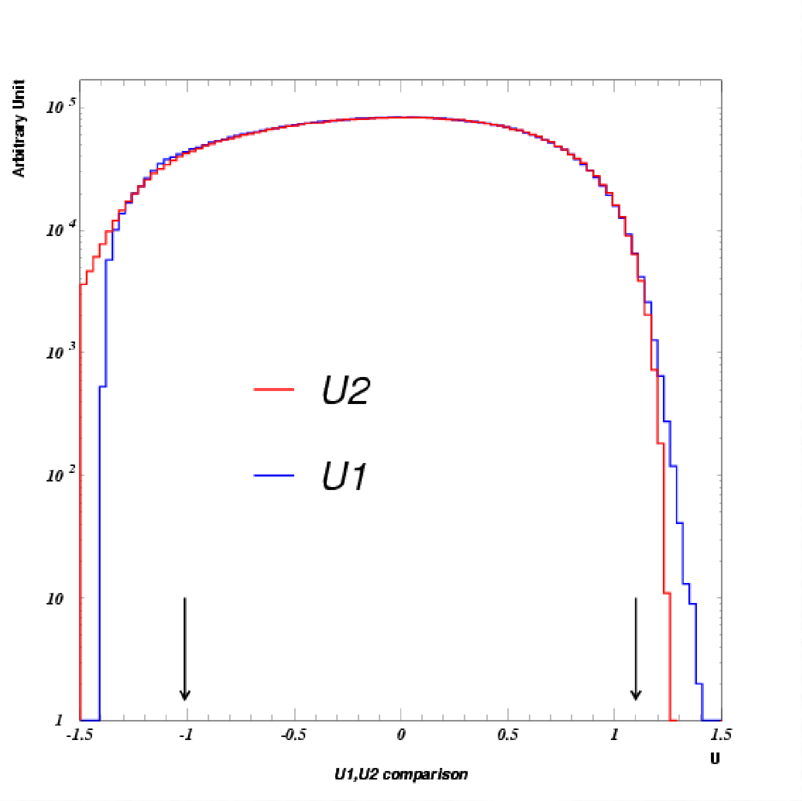
NTPEAK: for technical problems the efficiency isn't the same at the beginning and at the end of the run (from 0.7% to 3%). The systematics estimation is limited by the statistics in the control sample: $1.3 \cdot 10^{-4}$. No trigger correction

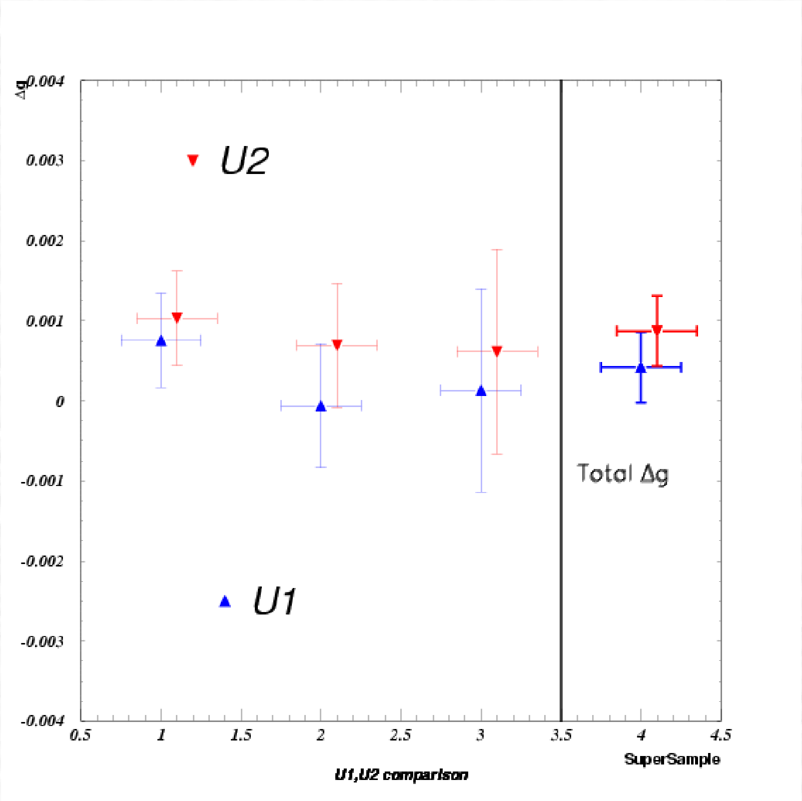
L2: 70% of the L2 inefficiency is due to the DCHs wires inefficiency. The systematic uncertainty is obtained exploiting the MC simulation: $0.4 \cdot 10^{-4}$. No trigger correction





U2 asymmetry (2003 sample)





- At the very Dalitz plot edge the U1 and U2 distributions are different due to the different resolution
- The asymmetry results, for U1 and U2, are in agreement

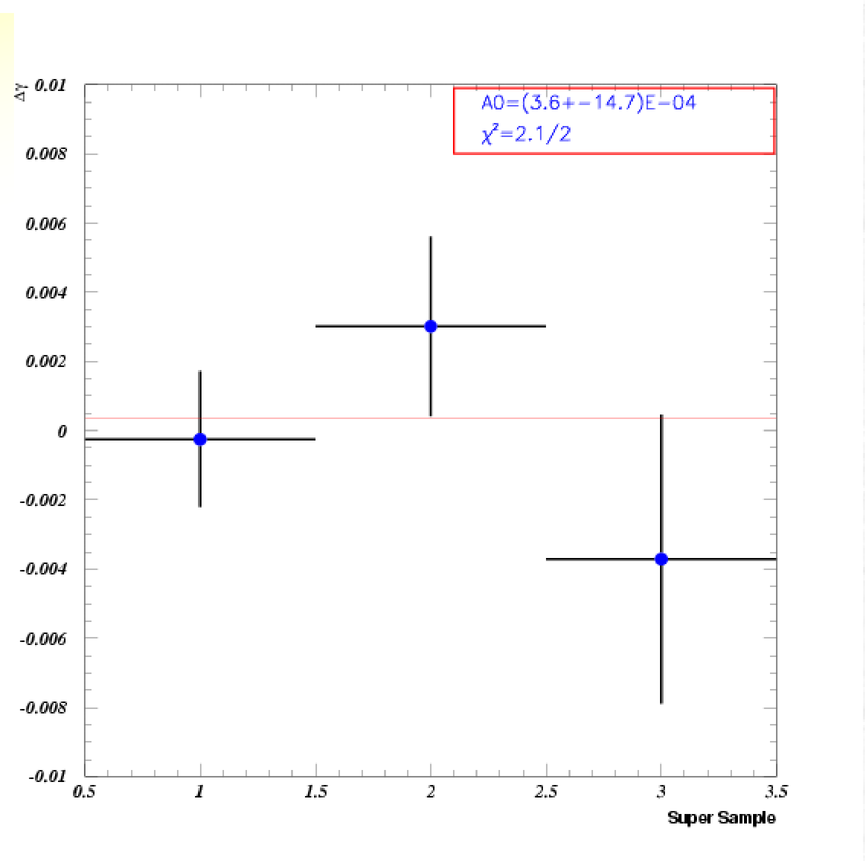
V asymmetry (2003 sample)

"wrong" Matrix element:

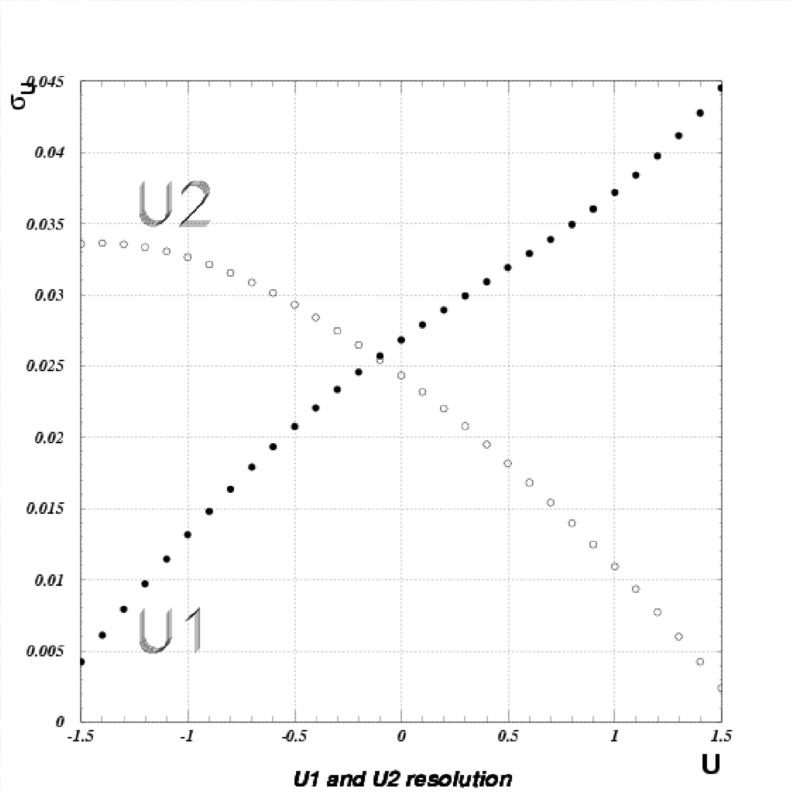
$|M(u,v)|^2 \sim 1 + gu + \gamma\mathbf{v} + hu^2 + kv^2 + \ldots$

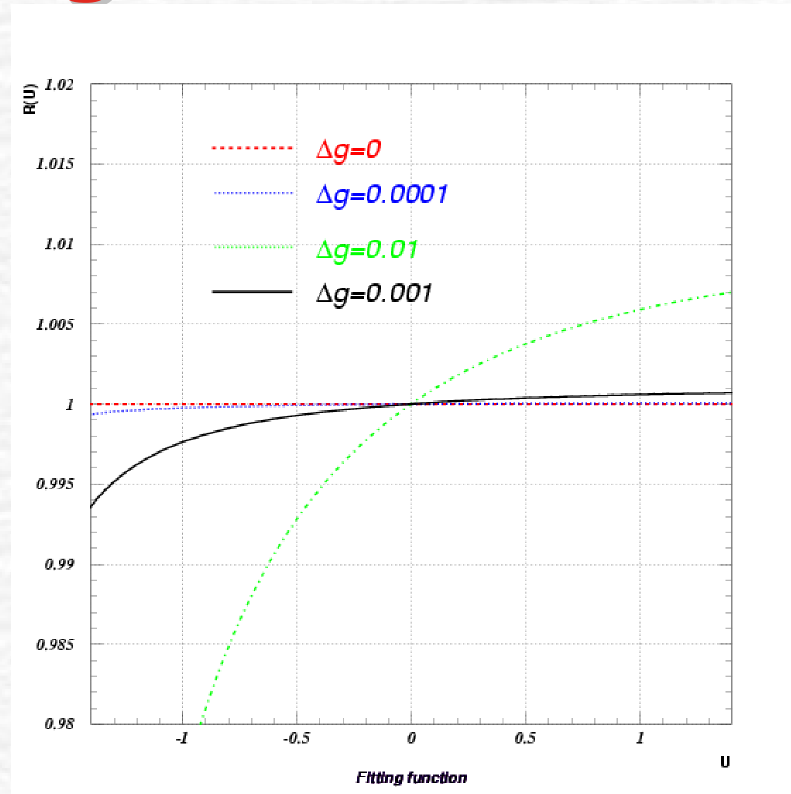
- The 4uplo ratio is constructed like in the U case to extract $\Delta\gamma$.

- The result is compatible with zero (only 2003 data plot is shown)



Resolution and fitting function





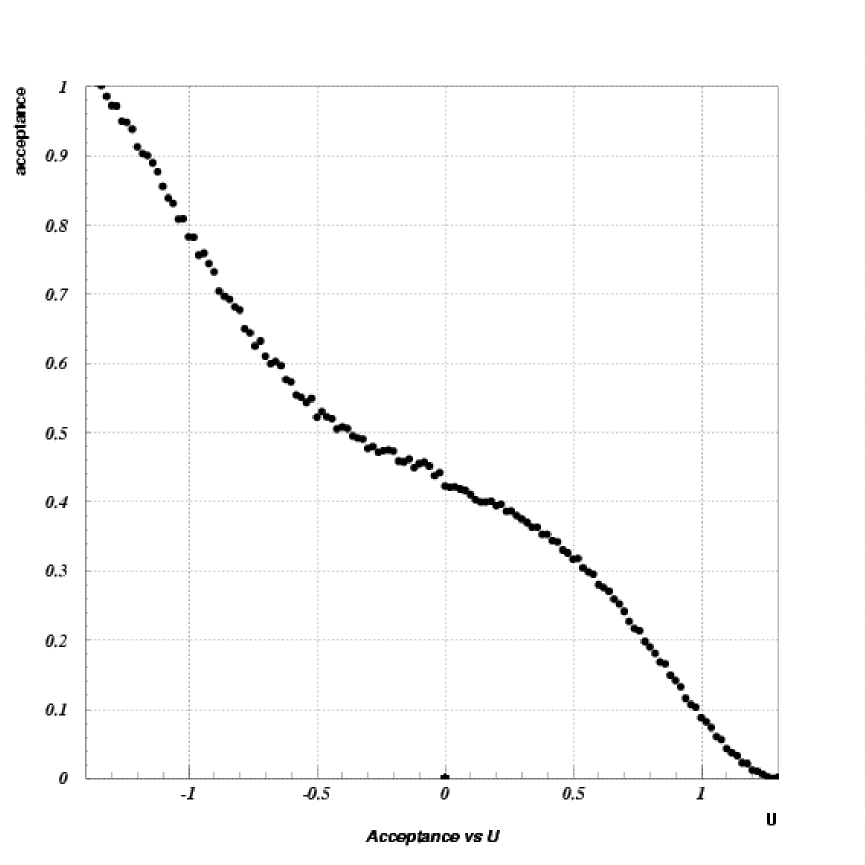
- U1 has best resolution in the region with high acceptance and higher lever arm for the fit

- In the "neutral" fitting function the pole is on the left (good acceptance).

- In the non-aproximated "charged" fitting function the pole is outside the acceptance on the right hand.

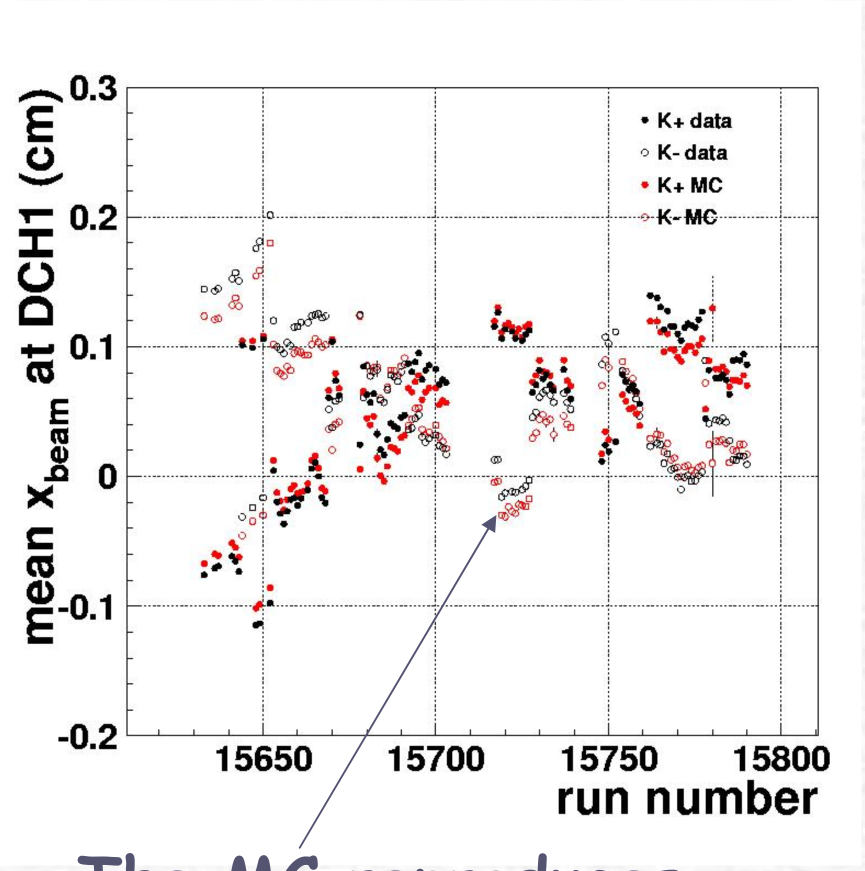
"neutral" Acceptance

- The acceptance as a function of U in the $K \rightarrow \pi\pi^0\pi^0$ is favorable for the fit function employed.



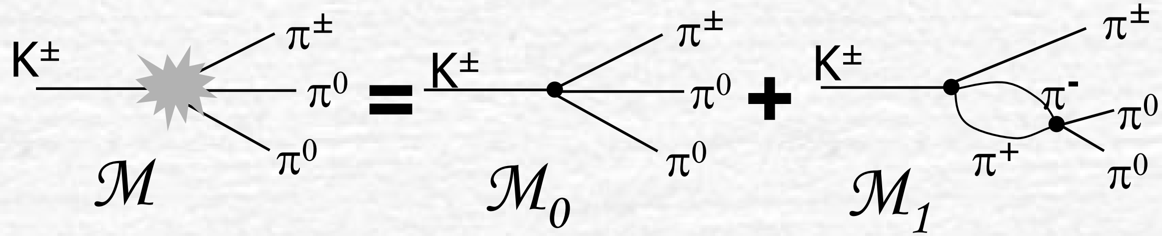
Montecarlo

- Thanks to the experimental principle of the acceptance cancellation **we don't need MC**
- Anyway a detailed **GEANT3** MC was developed for systematic studies and to understand the detector acceptance
- Local DCH inefficiencies and variations of the beam geometry are simulated



The MC reproduces very well the beam behaviour

Cusp effect



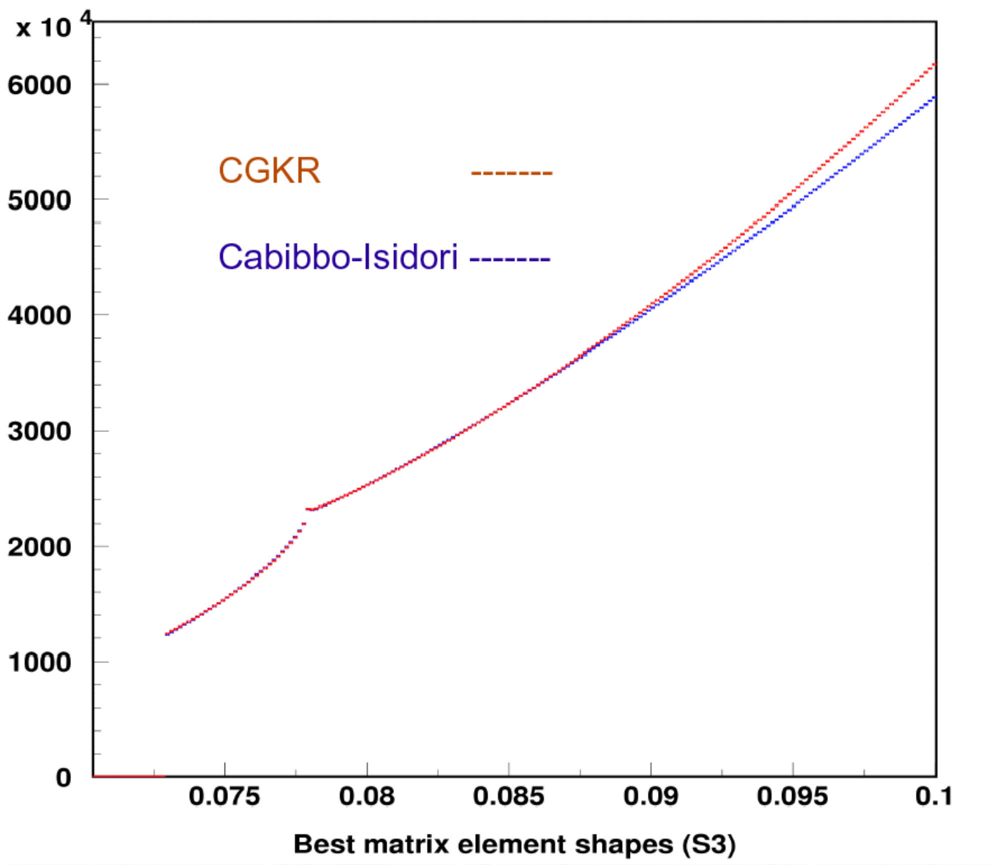
$$s_{\pi\pi} > 4m^2_{\pi^+} \Rightarrow M_1 = i2\frac{(a0-a2)m_{\pi^+}}{3} M_{+,thr}\sqrt{\frac{s_{\pi\pi}-4m^2_{\pi^+}}{s_{\pi\pi}}}$$

$$|M^2| = (M_0)^2 + |M_1^2|$$

$$s_{\pi\pi} < 4m^2_{\pi^+} \Rightarrow M_1 = -2\frac{(a0-a2)m_{\pi^+}}{3} M_{+,thr}\sqrt{\frac{4m^2_{\pi^+}-s_{\pi\pi}}{s_{\pi\pi}}}$$

$$|M^2| = (M_0)^2 + (M_1^2) + 2M_0M_1$$

Colangelo et al. approach



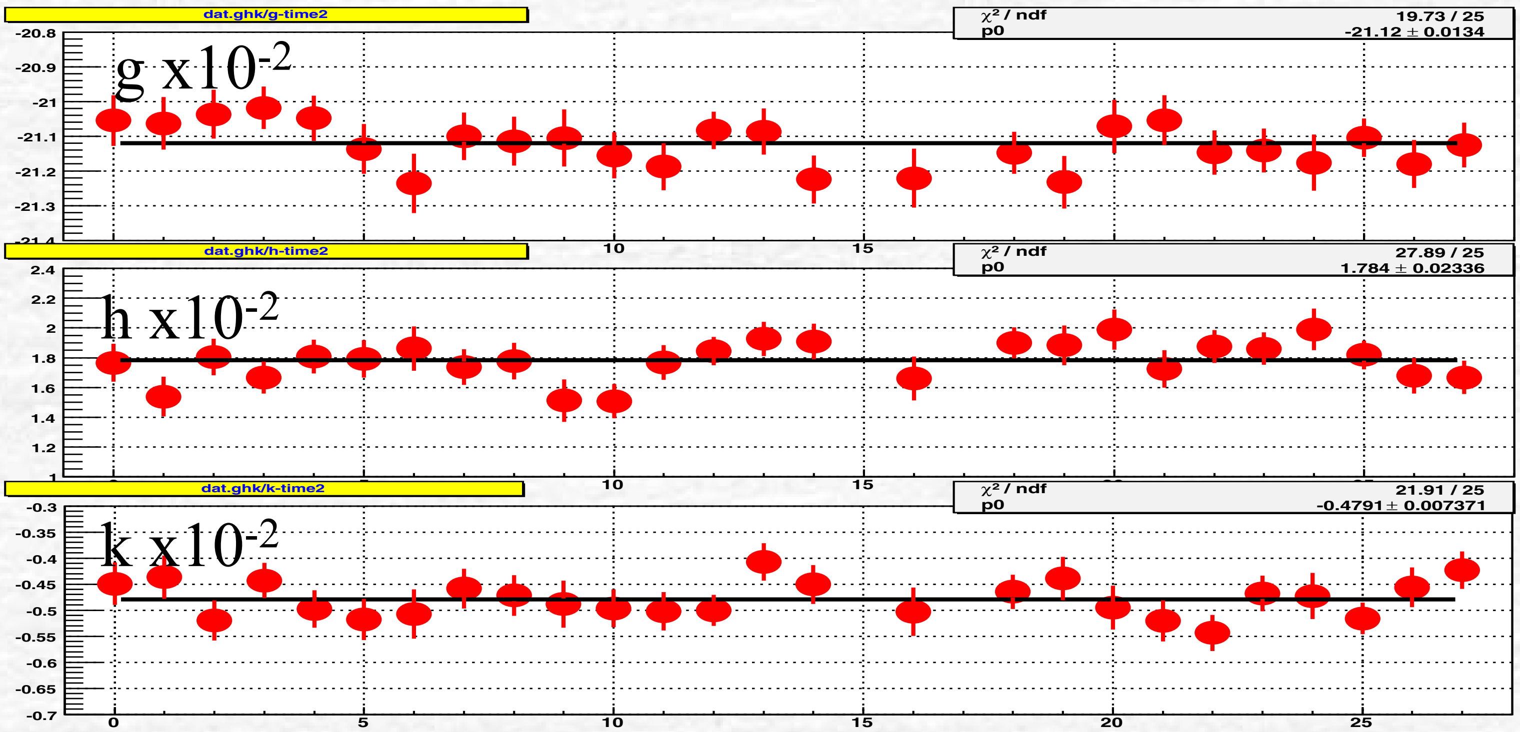
- Different approach
- Non relativistic effective lagrangian
- Possibility to include automatically high order terms and radiative corrections
- Disagreement at large U value
- Work in progress

"Charged" Dalitz Plot systematics

Effect	$g\times10^2$	$h\times10^2$	$k\times10^2$
Pion momentum resolution	±0.004	±0.031	±0.009
Kaon momentum spectrum	±0.001	±0.001	±0.001
Spectrometer alignment	±0.002	±0.002	±0.001
Spectrometer momentum scale	±0.001	±0.002	±0.001
Total systematic error dominated by π momentum resolution	±0.005	±0.031	±0.009
Statistical uncertainty	±0.009	±0.015	±0.005
Trigger correction (L1+L2) (mainly due to HODO inefficiency)	−0.007±0.005	0.118±0.009	0.033±0.003
MC statistical uncertainty	±0.010	±0.017	±0.005
Final result	−21.131±0.015	1.829±0.040	−0.467±0.012
PDG'06	−21.57±0.31	1.07±0.48	−1.01±0.34

Systematics check

The stability of the result has been checked for several variables (longitudinal vertex position, radial cuts, acceptance, Coulomb factor, variation of the binning)



Other analysis

- $K \to \pi\pi^0\gamma$ (Direct photon emission, interference with IB, charge asymmetry)
- $K \to \pi\pi e\nu, \pi^0\pi^0 e\nu, \pi\pi\mu\nu, \pi^0\pi^0\mu\nu$ ((a0-a2) e BR)
- $K \to \pi^0 e\nu, \pi^0\mu\nu$ (Vus (prel.), form factors)
- $K \to \pi^0 e\nu\gamma$ (BR, T violation)
- $K \to \pi\pi^0 ee$ (BR, T violation)
- $K \to \pi\gamma\gamma, \pi\gamma\gamma\gamma$ (ChPt)
- $K \to e\nu, \mu\nu$ (BR, leptonic universality)
- $K \to \pi^0\pi^0\pi^0 e\nu, \pi ee, \pi\mu\mu$ **etc...** (BR,...)
- $K \to \pi^+\pi^0(\gamma\gamma)$ **(new particles search)**

Spares

Spares