

# Search for direct CP-violation in $K^{\pm} \rightarrow \pi^{\pm} \pi^0 \pi^0$ decays (from NA48/2 at CERN SPS)

QUARKS 2006

SPASIMIR BALEV  
Joint Institute for Nuclear Research

On behalf of NA48/2 Collaboration:  
*Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze,  
Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino,  
Vienna*

# Overview

- ◆ Introduction
- ◆ NA48/2 experiment
- ◆  $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$  selection
- ◆ CP-violation measurement method
- ◆ Systematic uncertainties
- ◆ Result
- ◆ Result in  $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$  decay mode
- ◆ Conclusions

# History of CP-violation

- ◆ Major milestones in CP-violation history:
  - **1964** – **Indirect** CP-violation in  $K^0$  (Cronin, Christenson, Fitch, Turlay)
  - **1988-2001** – **Direct** CP-violation in  $K^0$  (NA31, E731, NA48, KTeV)
  - **2001** – **Indirect** CP-violation in  $B^0$  (Babar, Belle)
  - **2004** – **Direct** CP-violation in  $B^0$  (Belle, Babar)
  
- ◆ Look for **direct CP-violation in  $K^\pm$**   
 [Only direct CP-violation in  $K^\pm$  is possible – no mixing]
  
- ◆ Best choice of  $K^\pm$  decays to look for direct CP-violation:  
 **$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$  (BR: 1.73%)** and  **$K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$  (BR: 5.57%)**

# CP-Violation parameter $A_g$

## Matrix element:

$$|M(\mathbf{u}, \mathbf{v})|^2 \sim 1 + \mathbf{g} \cdot \mathbf{u} + h \cdot \mathbf{u}^2 + k \cdot \mathbf{v}^2 + \dots$$

## Lorentz-invariants:

- $\mathbf{u} = (\mathbf{s}_3 - \mathbf{s}_0) / m_\pi^2$

- $\mathbf{v} = (\mathbf{s}_2 - \mathbf{s}_1) / m_\pi^2$

$$s_i = (P_K - P_{\pi_i})^2, \quad i=1,2,3 \quad (3 = \text{odd } \pi)$$

$$s_0 = (s_1 + s_2 + s_3) / 3$$

## Measured parameters (PDG):

- $K^\pm \rightarrow \pi^\pm \pi^+ \pi^- \rightarrow \mathbf{g}^+ = -0.2154 \pm 0.0035$

- $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \rightarrow \mathbf{g}_0^+ = 0.638 \pm 0.020$

- $|h|, |k| \ll |g|$

## CP-violation parameter:

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

$A_g \neq 0$  indicates direct CP-violation

# Previous measurements of $A_g$

## ◆ Charged" mode $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ :

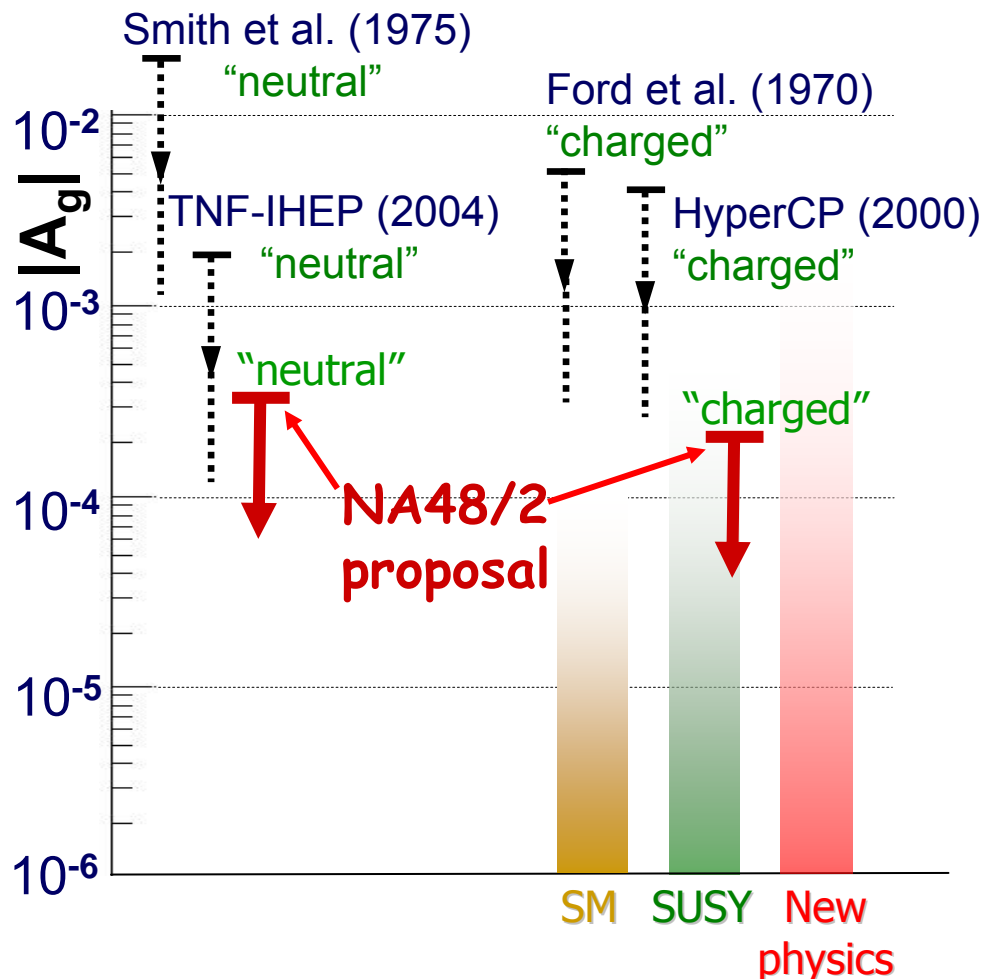
- Ford et al. at BNL (1970):  $A_g = (-70 \pm 53) \cdot 10^{-4}$ ;  
Statistics: 3.2M  $K^\pm$ ;
- HyperCP at FNAL, **prelim.** (2000):  $A_g = (22 \pm 15_{\text{stat}} \pm 37_{\text{syst}}) \cdot 10^{-4}$ ;  
Statistics: 54M  $K^\pm$ ;

[ W.-S. Choong PhD thesis, LBNL-47014 Berkeley 2000.]

## ◆ "Neutral" mode $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ :

- Smith et al. at CERN-PS (1975):  $A_g^0 = (19 \pm 125) \cdot 10^{-4}$ ;  
Statistics: 0.12M  $K^\pm$ ;
- TNF at IHEP Protvino (2005):  $A_g^0 = (2 \pm 19) \cdot 10^{-4}$ ;  
Statistics: 0.62M  $K^\pm$ .

# Experiment and Theory



SM estimates vary within an order of magnitude (few  $10^{-6}$ ... $8 \times 10^{-5}$ ).

Models beyond SM predict possible enhancement partially within the reach of NA48/2.

Asymmetry in decay widths expected to be smaller than in Dalitz-plot slopes (SM  $\sim 10^{-7}$ ... $10^{-6}$ ).

# NA48/2 goal and strategy

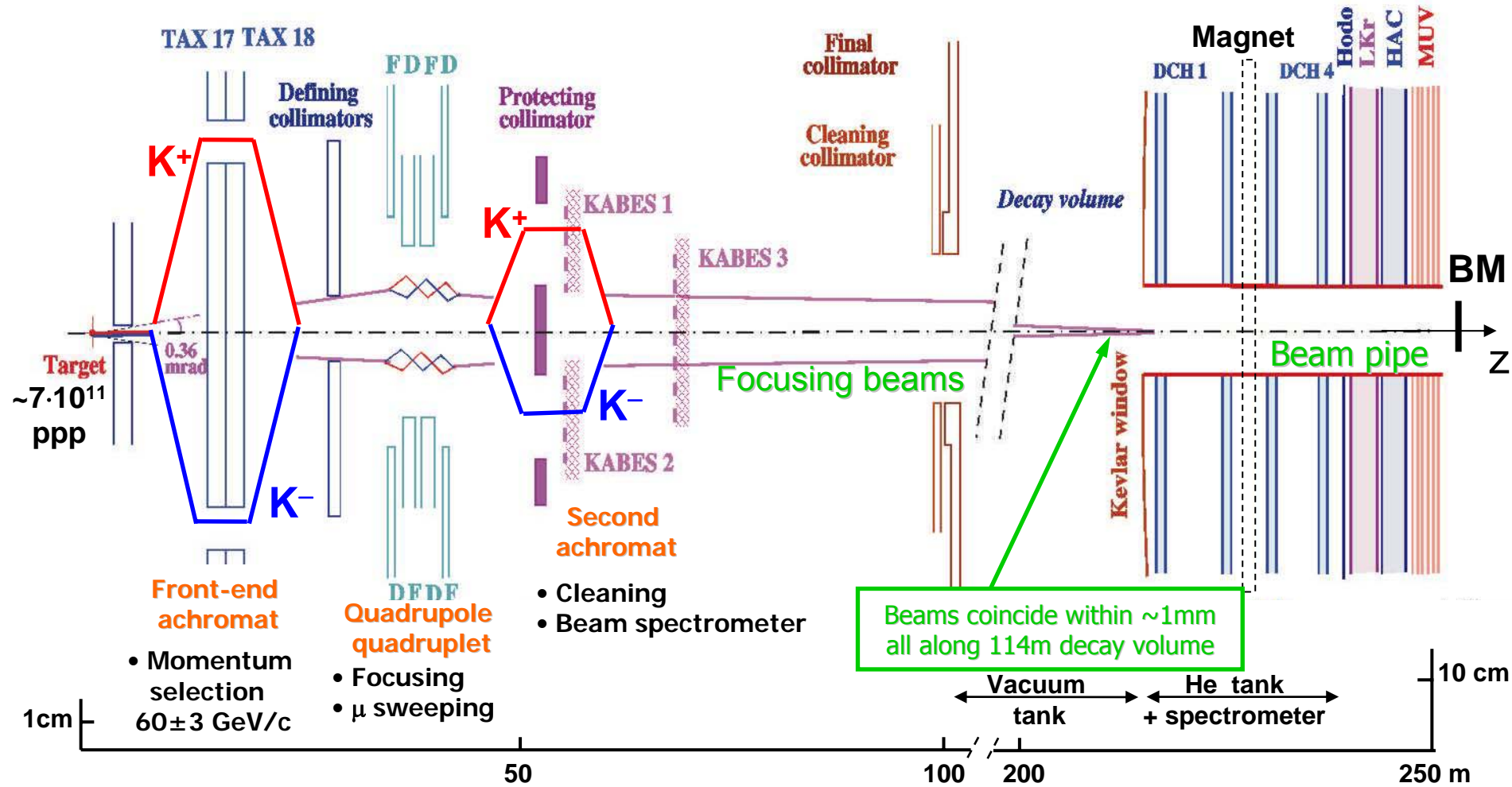
## ◆ Primary NA48/2 goal:

- Measure slope asymmetries in “charged” and “neutral” modes with high accuracy.

## ◆ NA48/2 strategy:

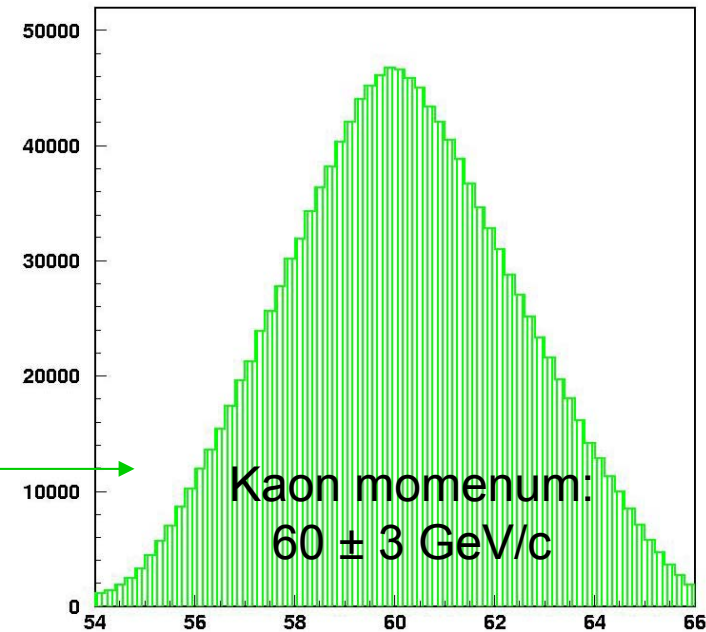
- Two **simultaneous**  $K^+$  and  $K^-$  beams, **superimposed** in space, with momentum spectra  $(60 \pm 3)$  GeV/c;
- Detect **asymmetry** exclusively considering **slopes** of ratios of normalized U distributions;
- **Equalize  $K^+$  and  $K^-$  acceptances** by frequently alternating polarities of relevant magnets.

# NA48/2 beam line schematics



# Beam properties

Beam	K <sup>+</sup>	K <sup>-</sup>
Primary proton momentum (GeV/c)	400	
Duty cycle (s/s)	5.2/16.8	
Protons on target per cycle	7x10 <sup>11</sup>	
Production angle (mrad)	0	
Beam acceptance (mrad)	±0.36	
Beam momentum (GeV/c)	60 ± 3	
Beamline length (m)	102	
$p / \bar{p}$ per cycle (10 <sup>6</sup> )	8.6	0.9
$\pi^+ / \pi^-$ per cycle (10 <sup>6</sup> )	33.2	24.6
K <sup>+</sup> / K <sup>-</sup> per cycle (10 <sup>6</sup> )	3.1	1.8
Decay region (m)	114	



→ Pion decay products stay in beam pipe...

# NA48 detector

## Magnetic spectrometer (4 DCHs):

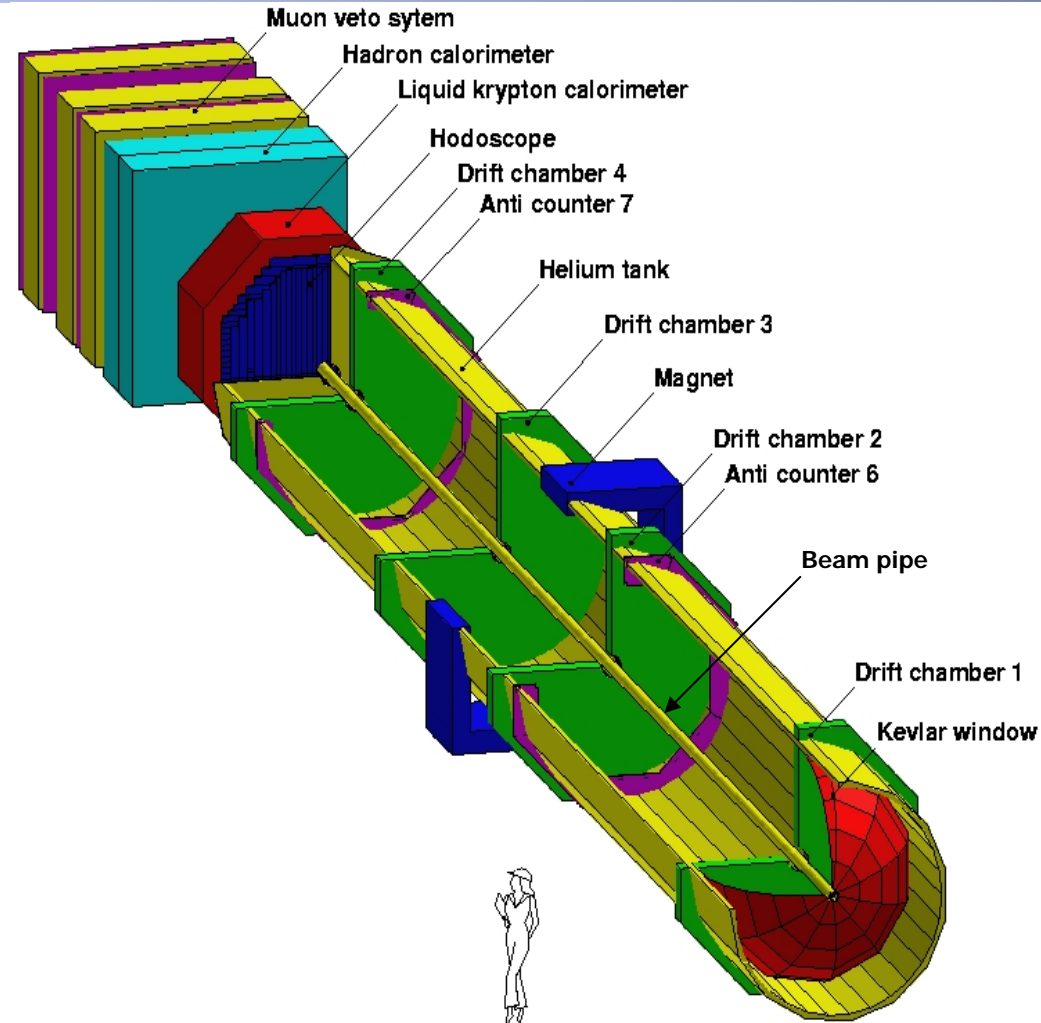
- redundancy  $\Rightarrow$  high efficiency;
- $\Delta p/p = 1.0\% \oplus 0.044\% * p$  [GeV/c]

## Hodoscope

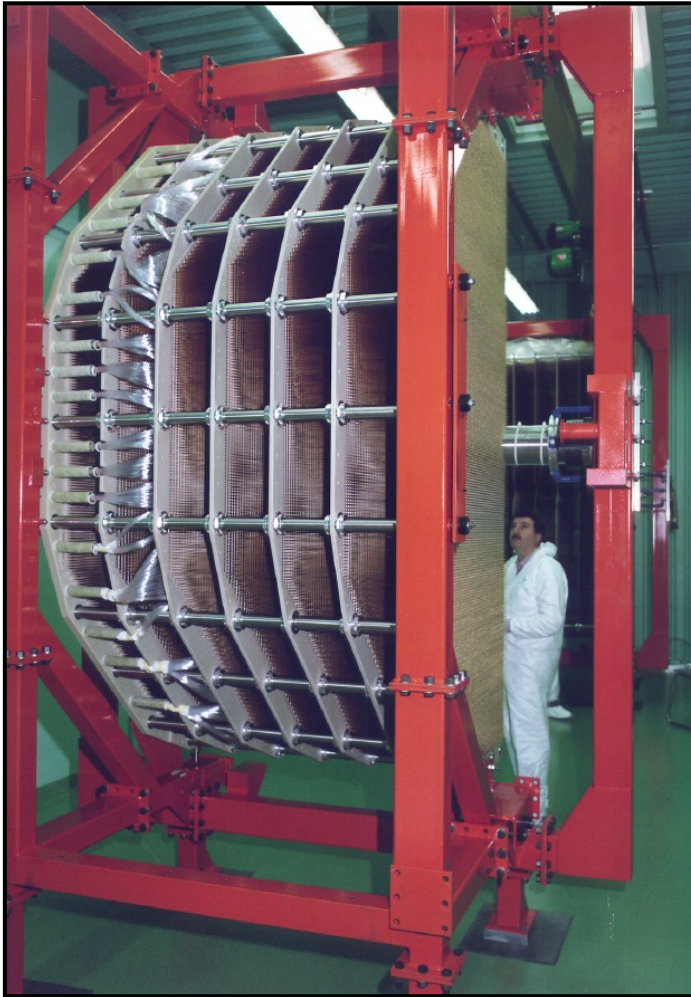
- fast trigger;
- precise time measurement.

## Liquid Krypton EM calorimeter (LKr)

- see next slide



# Liquid Krypton Calorimeter



- ◆ Quasi-homogeneous ionization chamber
- ◆ Active volume of  $\sim 10 \text{ m}^3$  liquid krypton
- ◆ 13248 projective cells,  $2 \times 2 \text{ cm}^2$

- ◆ **Energy resolution** [E in GeV]:

$$\frac{\sigma(E)}{E} = \frac{0.032}{\sqrt{E}} \oplus \frac{0.09}{E} \oplus 0.0042$$

$$\sigma(E) \approx 142 \text{ MeV for } E = 10 \text{ GeV}$$

- ◆ **Space resolution** [E in GeV]:

$$\sigma_x = \sigma_y = \frac{0.42}{\sqrt{E}} \oplus 0.06 \text{ cm}$$

$$\sigma(x) = \sigma(y) \approx 1.5 \text{ mm for } E = 10 \text{ GeV}$$

# Trigger logic

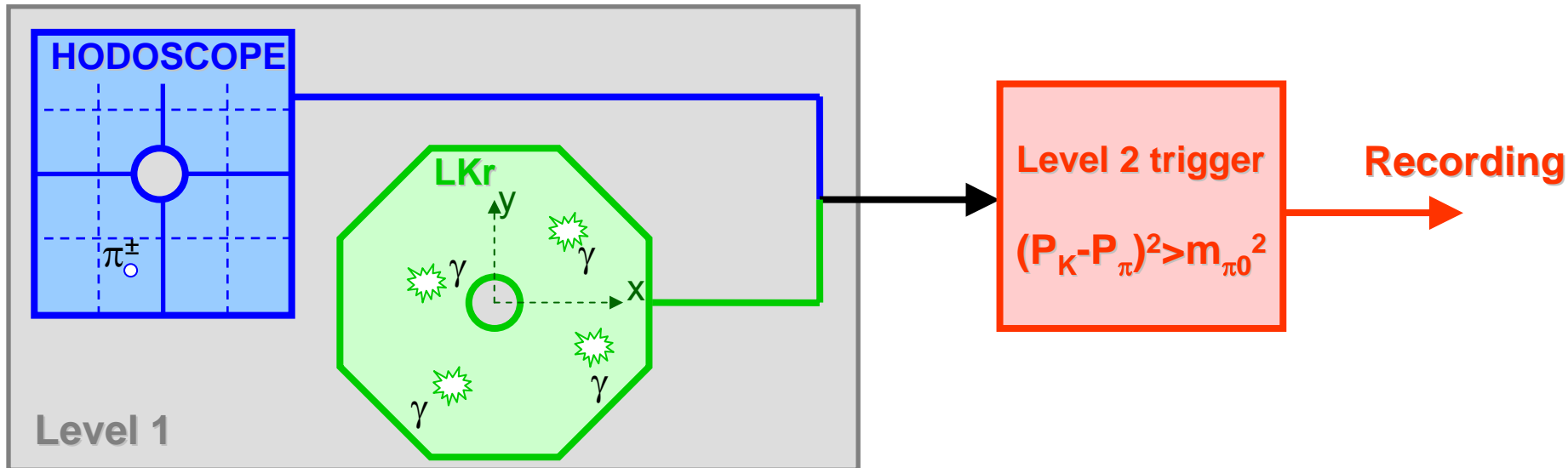
## ◆ Trigger for $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ :

### Level 1:

“**Charged**” signal from Hodoscope ( $\geq 1$  hit)

“**Neutral**” signal from LKr ( $\geq 3$  peaks in X- or Y-projection in LKr)

Level 2: Suppress dominant mode:  $K^\pm \rightarrow \pi^\pm \pi^0$  by missing mass requirement



## ◆ Downscaled control triggers:

- Trigger efficiency measurements.

# Selection criteria

- ◆ At least one charged particle with momentum  $p > 5 \text{ GeV}/c$
- ◆ At least 4 photons with  $E_g > 3 \text{ GeV}$  detected in the Liquid Krypton (LKr) calorimeter
- ◆ Geometrical cuts to eliminate detector edge effects (near beam tube and near outer edges of drift chambers and LKr calorimeter)
- ◆ Distance between photons at LKr  $> 10 \text{ cm}$
- ◆ Distance between photons and charged particle at LKr  $> 15 \text{ cm}$  (to prevent overlapping of showers produced by  $\gamma$ 's and  $\pi^\pm$ )
- ◆ Timing cuts for the charged particle and photon clusters to ensure they are from the same decay:
  - $|\langle T_\gamma \rangle - T_{\gamma^i}| < 5 \text{ ns}$ ,  $i=1,2,3,4$ ;
  - $|\langle T_\gamma \rangle - T_{\pi^\pm}| < 20 \text{ ns}$ .

# $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ reconstruction

For each photon pair  $(i,k)$  reconstruct common vertex along beam axis under the assumption of  $\pi^0 \rightarrow \gamma\gamma$  decay

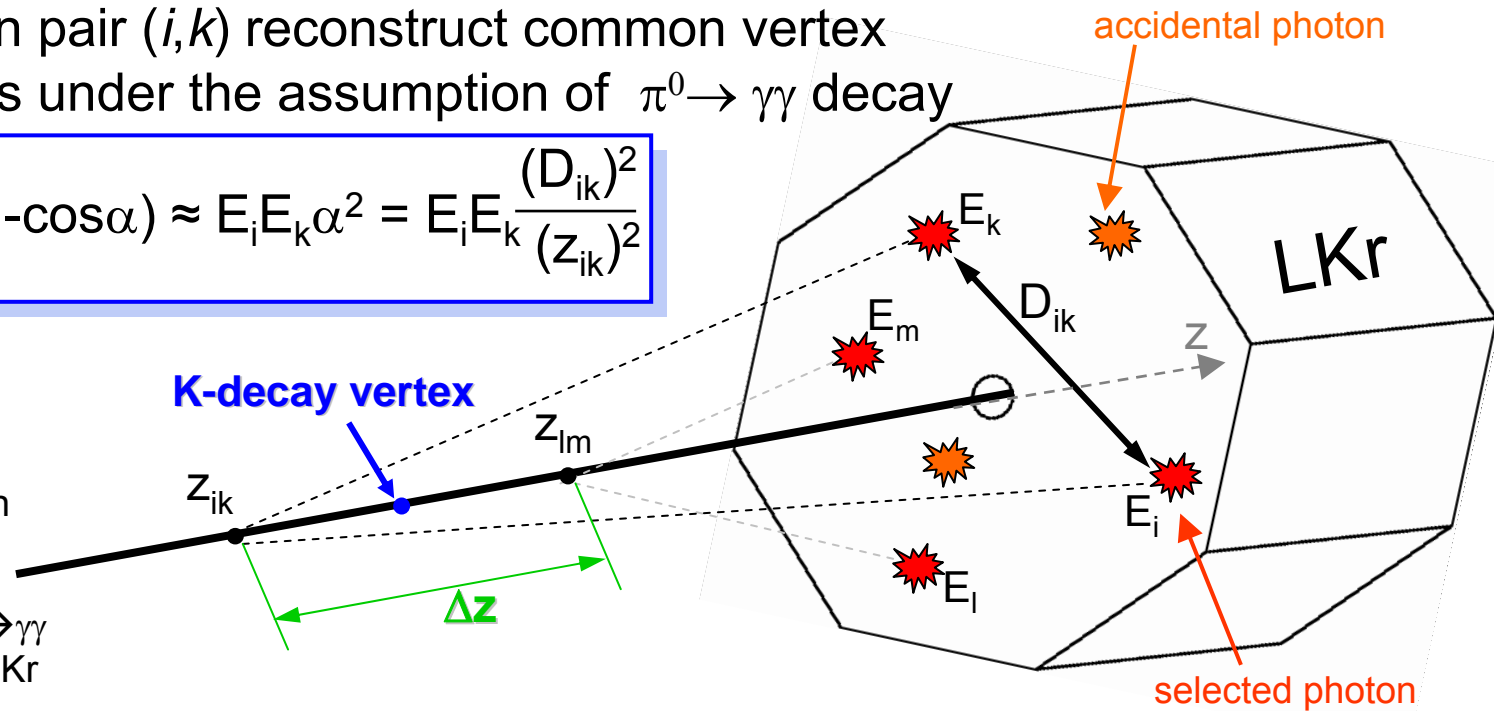
$$m_0^2 = 2E_i E_k (1 - \cos\alpha) \approx E_i E_k \alpha^2 = E_i E_k \frac{(D_{ik})^2}{(z_{ik})^2}$$

$m_0^2$  – mass of  $\pi^0$

$E_i, E_k$  – energy of  $\gamma_i, \gamma_k$

$D_{ik}$  – distance between  $\gamma_i$  and  $\gamma_k$  on LKr

$z_{ik}$  – distance from  $\pi^0 \rightarrow \gamma\gamma$  decay vertex to LKr



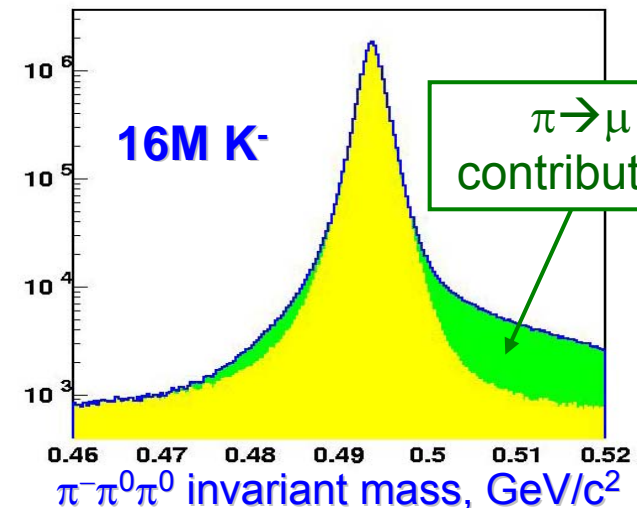
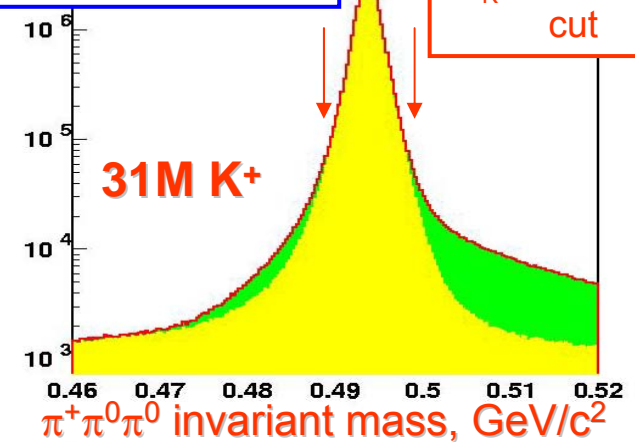
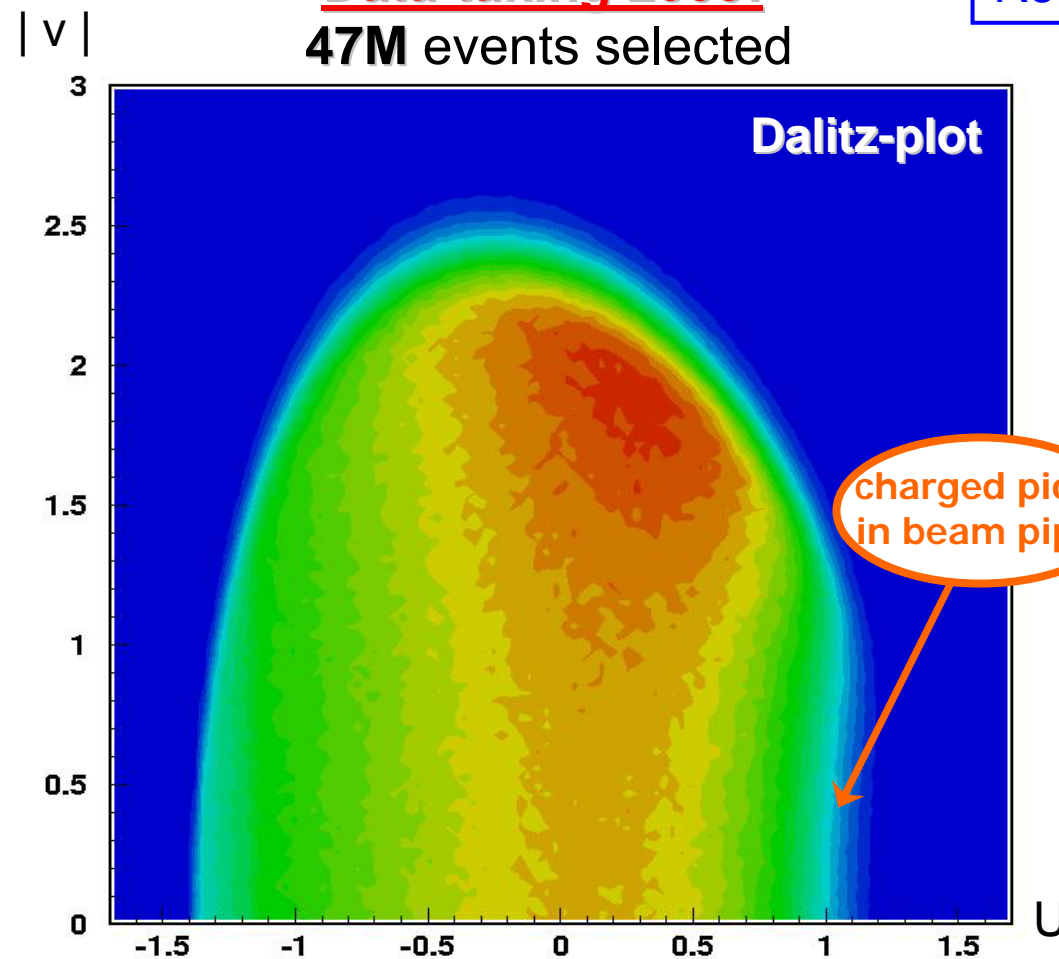
- ◆ Among all possible  $\gamma$ -pairs select a couple with minimum difference  $|\Delta z| = |z_{ik} - z_{lm}| < 500 \text{ cm}$  ( $i, k \neq l, m$ )
- ◆ The average of these two z-coordinates is taken as a **K-decay vertex**.

# Selected event properties

**Data-taking 2003:**  
47M events selected

Resolution:  $0.9 \text{ MeV}/c^2$

$M_K^{\text{PDG}} \pm 6 \text{ MeV}$   
cut



# $A_g$ measurement strategy

- ◆  $|M^\pm(u,v)|^2 \sim 1 + g^\pm u + hu^2 + kv^2 + \dots$
- ◆ Project onto  $u$  axis (integration over  $v$ )
- ◆ If **acceptance is equal** for  $K^+$  and  $K^-$ ,  $A_g$  can be extracted from a **fit to the ratio  $R(u)$** :

$$R(u) = \frac{N^+(u)}{N^-(u)} = n \frac{1 + g^+ \cdot u + h \cdot u^2 + \dots}{1 + g^- \cdot u + h \cdot u^2 + \dots} \approx n \left[ 1 + \frac{\Delta g \cdot u}{1 + g \cdot u + h \cdot u^2} \right]$$

$\Delta g = g^+ - g^- \ll 1$

normalization  $\rightarrow$   $A_g = \Delta g / 2g$   $\leftarrow$   $g_{\text{PDG}} = 0.638 \pm 0.020$

- ◆ For  **$u$  calculation** we use the energy of the two neutral pions in laboratory frame  $\rightarrow$  only information from LKr is needed

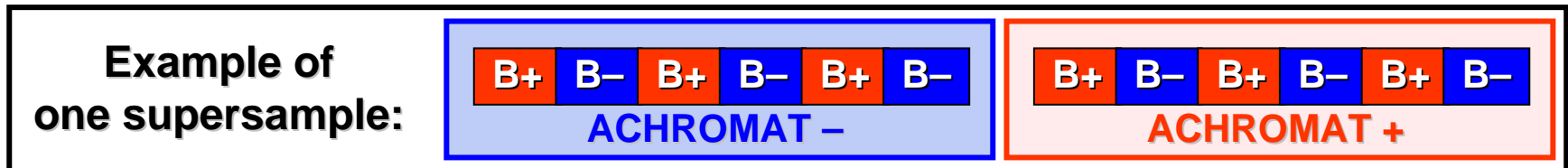
$$u = \frac{M_{00}^2 - s_0}{m_\pi^2}$$

# Data-taking strategy and statistics



## Supersample data taking strategy:

- **achromat** polarity **A** (the path of  $K^+$  and  $K^-$  beams) was reversed on **weekly** basis;
- each supersample contains at least 2 periods with different achromat polarities;
- **spectrometer magnet** **B** polarity was reversed on **daily** basis;



## Statistics selected for $A_g$ measurement, events $\times 10^6$

Super-sample	Dates <b>2003</b>	Sub-samples	Achromat A+		Achromat A-	
			$K^+$	$K^-$	$K^+$	$K^-$
I	22.06-25.07	22	8.53	4.63	7.87	4.51
II	6.08-3.09	16	6.17	3.44	4.00	2.22
III	3.09-7.09	4	1.84	1.02	1.87	1.04
Total		42	Total events selected			<b>47.14</b>

# Possible U-spectra ratios

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

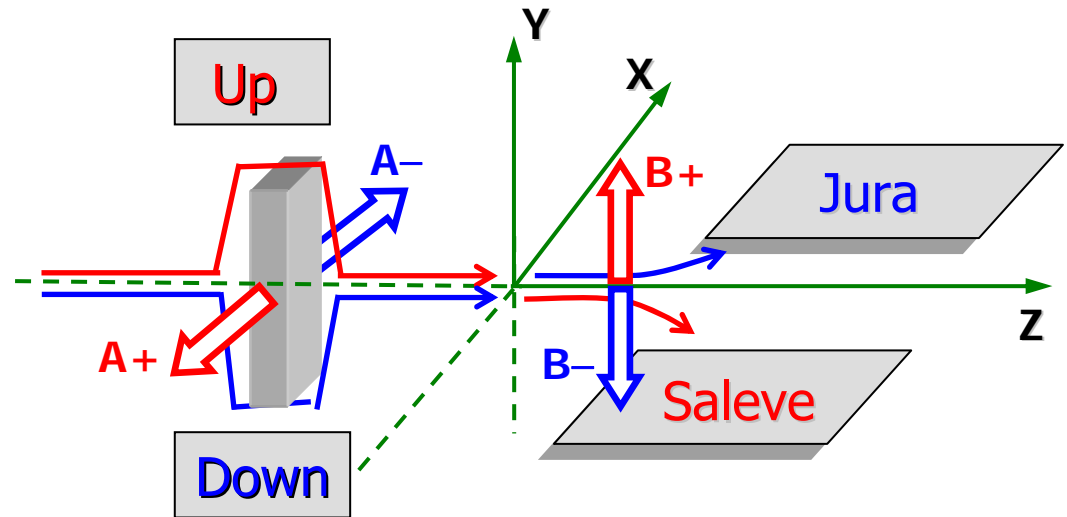
$$R_{UJ} = \frac{N(A+B-K+)}{N(A+B+K-)}$$

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

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

Indices of ratios correspond to:

- beamline polarity (U/D);
- kaon deviation in spectrometer magnet field (S/J).



- ◆ 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**)

# Apparatus asymmetries cancellation

$$R = R_{US} * R_{UJ} * R_{DS} * R_{DJ} \Rightarrow \text{fit with } f(u) = n \cdot (1 + 4\Delta g \cdot u / (1 + g \cdot u + h \cdot u^2))$$

## ◆ 3-fold cancellation of systematic biases:

- **global time-variable biases** ( $K^+/K^-$  simultaneously recorded);
- **beam line biases** ( $K^+$  beam up /  $K^-$  beam up etc.);
- **detector asymmetries** ( $K^+$  toward Saleve /  $K^-$  toward Saleve etc.).

## ◆ In addition, acceptance is defined respecting azimuthal symmetry:

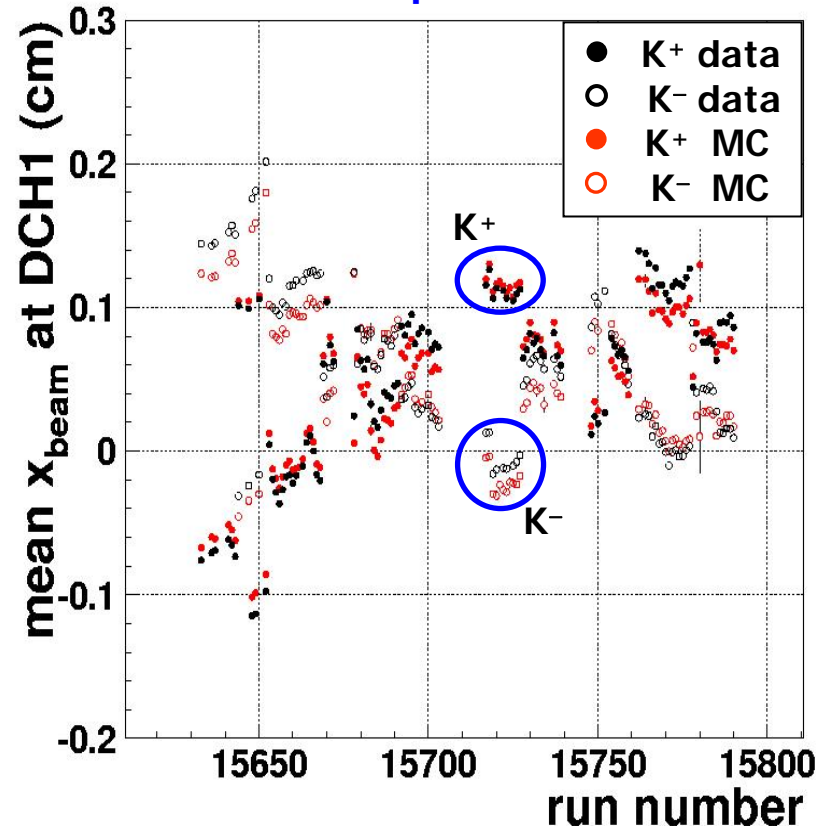
- effects of **permanent (irreversible) fields** (Earth, vacuum magnetization) cancel

## ◆ The result is sensitive only to time variations of small asymmetry in experimental conditions with a characteristic time smaller than corresponding field-alternation period (beam – week, detector – day).

# Monte-Carlo simulation

- ◆ Due to acceptance cancellations, the analysis does not rely on Monte Carlo.
- ◆ MC is mainly used for systematic study.
- ◆ Properties of NA48/2 MC:
  - Based on GEANT;
  - Full detector geometry and material description;
  - Local DCH inefficiencies simulated;
  - Variations of beam geometry and DCH alignment are followed;
  - Simulated statistics 10 times larger than experimental one.

Example of data/MC agreement:  
mean beam positions @DCH1

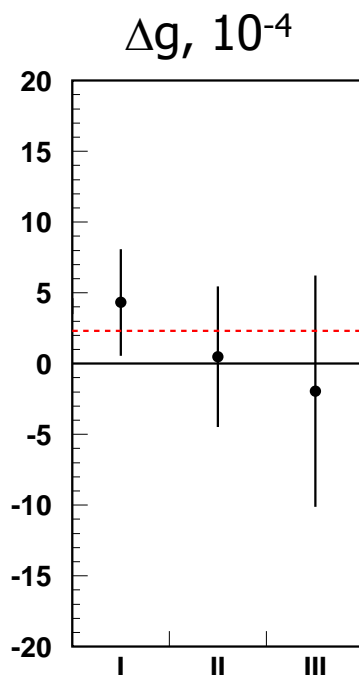


# $\Delta g$ by supersamples

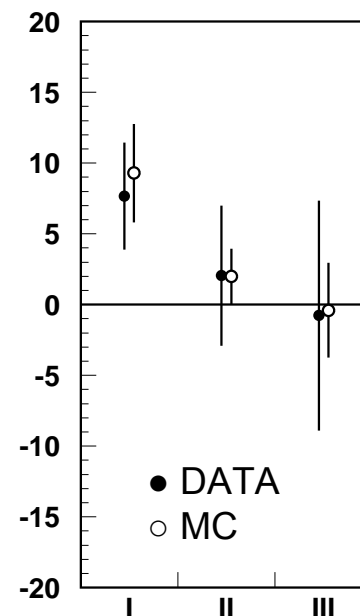
$\Delta g$  in  $10^{-4}$

SS I	$4.3 \pm 3.8$
SS II	$0.5 \pm 5.0$
SS III	$-2.0 \pm 8.2$
<b>Total:</b>	<b><math>2.3 \pm 2.8</math></b>
$\chi^2/\text{ndf}$	<b>0.7/2</b>

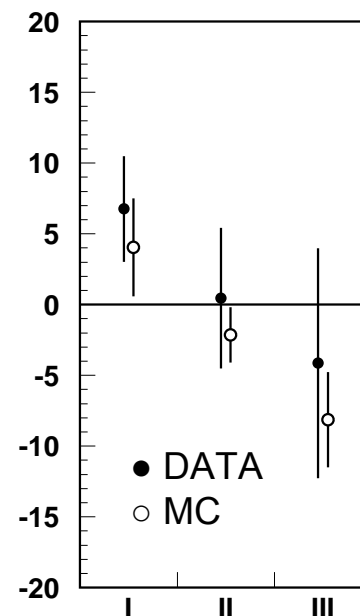
$$A_g = \Delta g / 2g$$



Left-right apparatus asymmetry in  $10^{-4}$

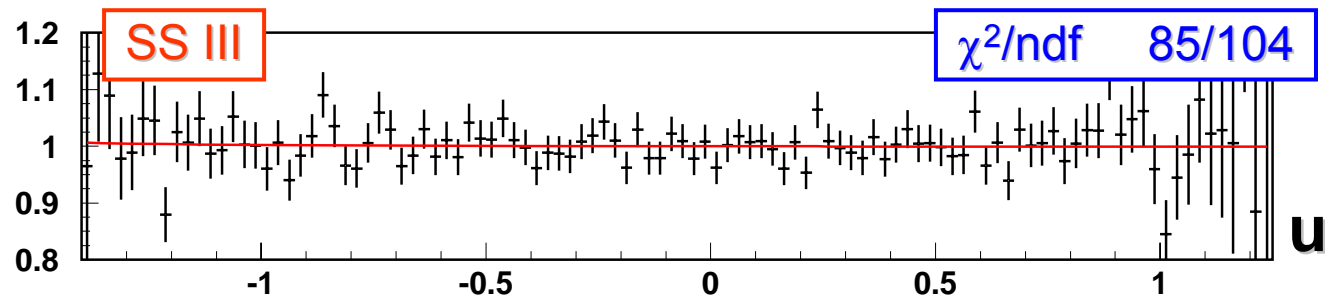
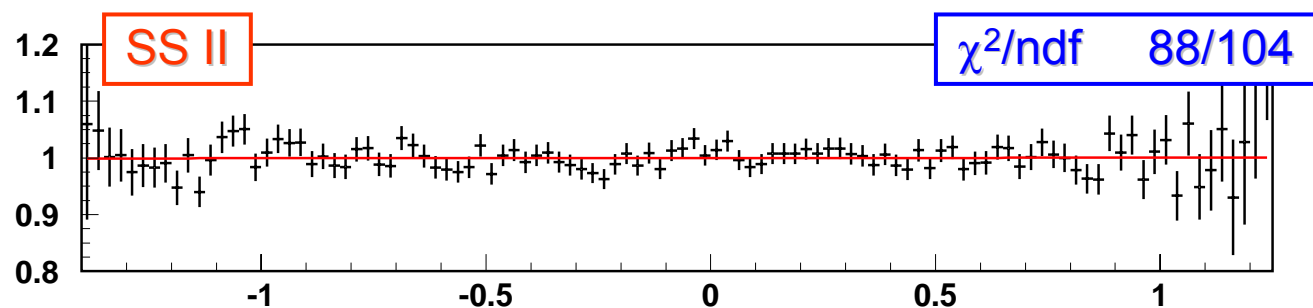
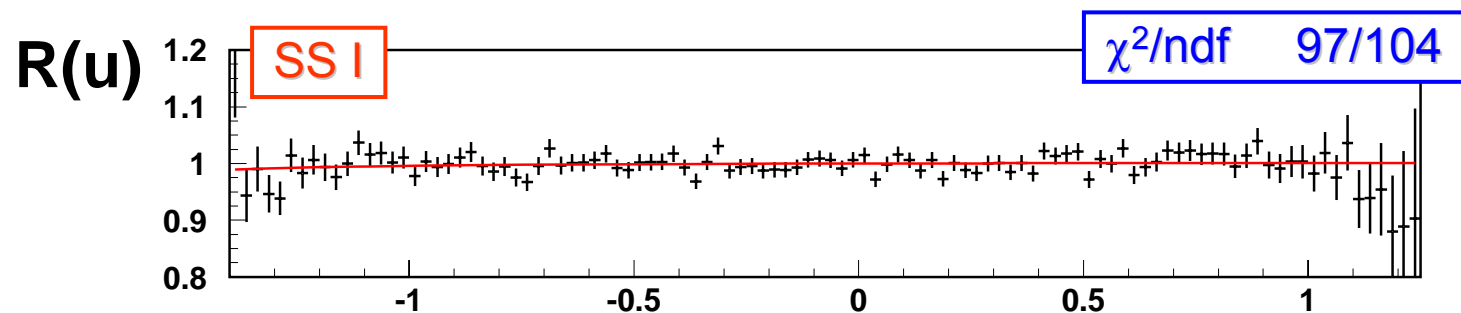


Up-down apparatus asymmetry in  $10^{-4}$



Supersample

# Quality of the fits



# $\Delta g$ – preliminary result

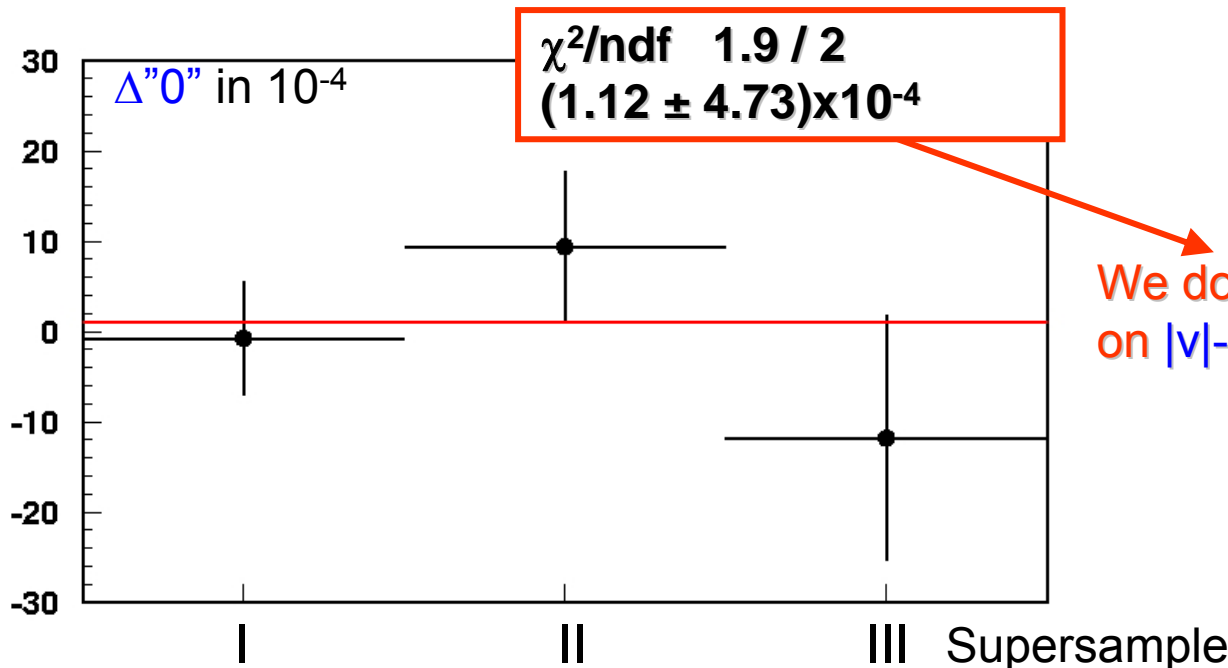
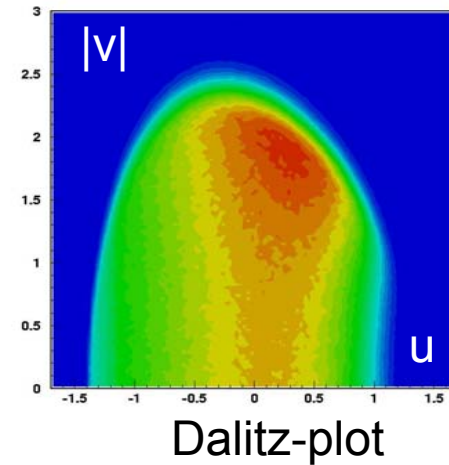
- ◆ Result on  $\Delta g$  (by studying more than 47M  $K^\pm$  decays):

$$\Delta g = (2.3 \pm 2.8) \times 10^{-4}$$

- ◆ The result is **free of systematics** in the first approximation due to the implemented method of cancellation of various apparatus imperfections.
- ◆ However, the checks of **possible systematic contributions** have been done, and corresponding uncertainties were obtained.

# Asymmetry on $|v|$ -slope check

- ◆  $|M^\pm(u,v)|^2 \sim 1 + g^\pm u + \text{"0"}|v| + hu^2 + kv^2 + \dots$
- ◆ Project the Dalitz-plot onto  $|v|$  axis.
- ◆ Use the described analysis method
- ◆ ... but for  $R(|v|) = R_{US}(|v|) * R_{UJ}(|v|) * R_{DS}(|v|) * R_{DJ}(|v|)$ .
- ◆ Use **linear fit**.



# Systematic uncertainties of $\Delta g$

Systematic effect		Effect on $\Delta g \times 10^4$
LKr	U calculation & fitting	$\pm 0.4$
	LKr nonlinearity	$\pm 0.1$
	Showers overlapping	$\pm 0.5$
Pion decay		$\pm 0.5$
Spectrometer alignment and Momentum scale		$< \pm 0.1$
Beam geometry		$\pm 0.3$
Accidentals		$\pm 0.2$
L1 trigger:	Charged signal	$\pm 0.1$
	Neutral signal	$\pm 1.3$ (statistical)
L2 trigger:	Mass Box	$\pm 0.4$
Total systematic uncertainty		$\pm 1.0$
Trigger statistical uncertainty		$\pm 1.3$
Total		$\pm 1.6$
External		$\pm 0.3$

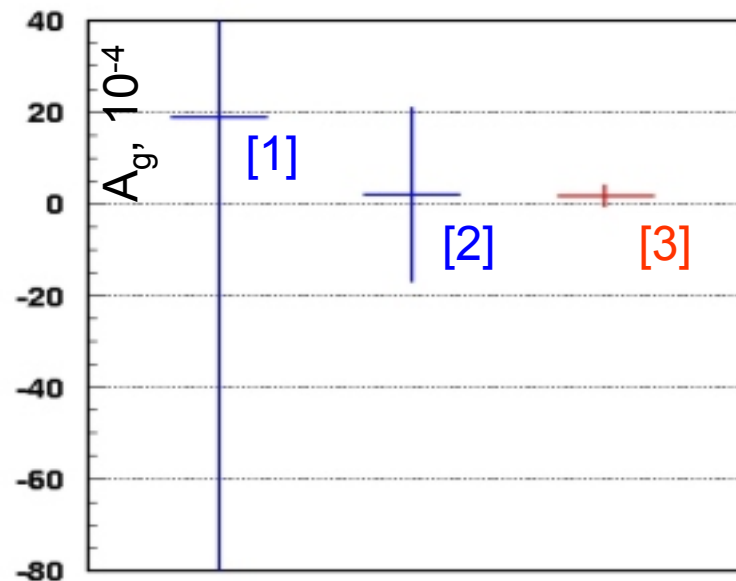
# Final result: 2003 data

## Slope difference:

$$\Delta g = (2.3 \pm 2.8_{\text{stat.}} \pm 1.3_{\text{stat.(trig.)}} \pm 1.0_{\text{syst.}} \pm 0.3_{\text{ext.}}) \times 10^{-4} = (2.3 \pm 3.3) \times 10^{-4}$$

## Charge asymmetry parameter:

$$A_g = (1.8 \pm 2.2_{\text{stat.}} \pm 1.0_{\text{stat.(trig.)}} \pm 0.8_{\text{syst.}} \pm 0.2_{\text{ext.}}) \times 10^{-4} = (1.8 \pm 2.6) \times 10^{-4}$$

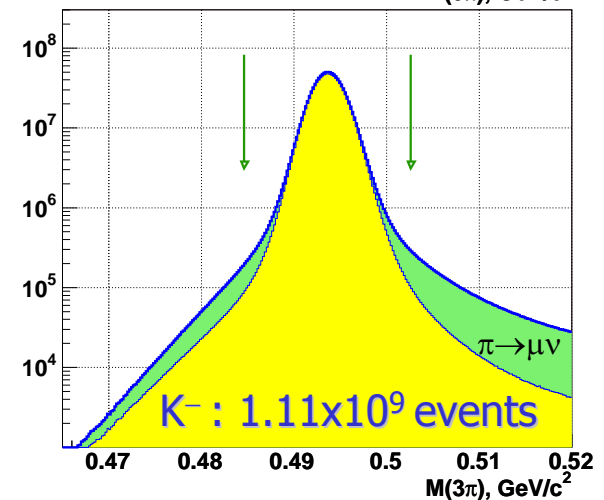
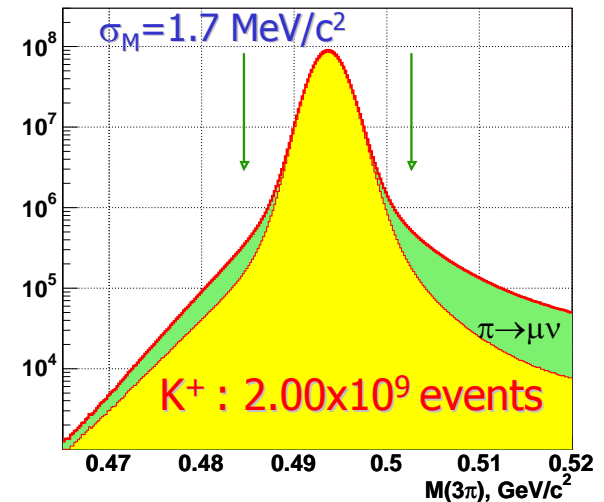
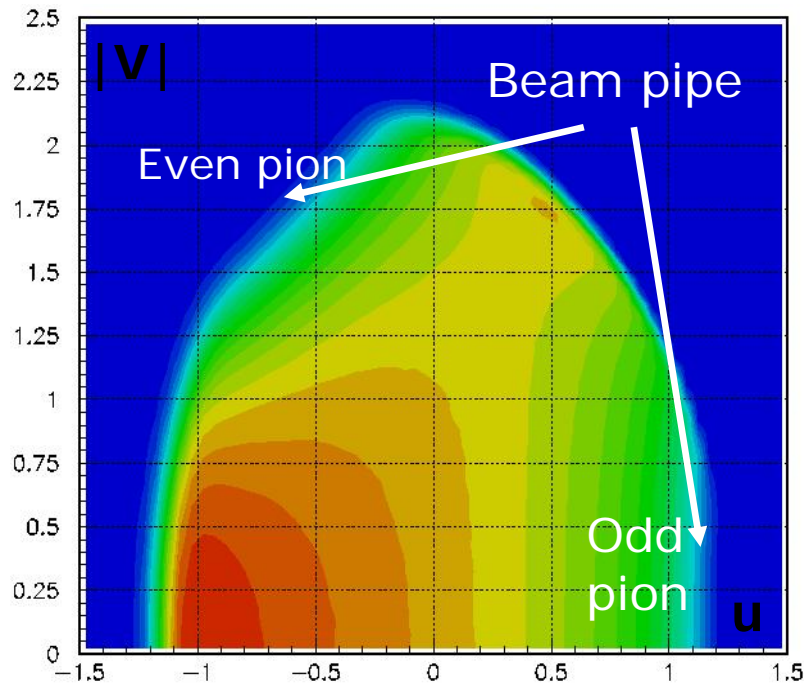


- [1] Smith et. al (1975)
- [2] TNF (2005)
- [3] NA48/2 2003 Final

Final 2003 result  
accepted by PLB  
for publishing.

# $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ Selection

- ◆ Only **spectrometer** involved in the reconstruction
- ◆ **Acceptance limited** mostly by the **beam pipe** in DCH
- ◆  $3.11 \times 10^9$  events selected in the 2003+2004 sample
- ◆ Totally different systematics wrt the neutral analysis



# $K^{\pm} \rightarrow \pi^{\pm} \pi^+ \pi^-$ Systematics

Systematic effect	Effect on $\Delta g \times 10^4$
Spectrometer alignment	$\pm 0.1$
Momentum scale	$\pm 0.1$
Acceptance and beam geometry	$\pm 0.2$
Pion decay	$\pm 0.4$
Accidental activity (pile-up)	$\pm 0.2$
Resolution effects	$\pm 0.3$
Total systematic uncertainty	$\pm 0.6$
L1 trigger: uncertainty only	$\pm 0.3$
L2 trigger: correction	$-0.1 \pm 0.3$
Total trigger correction	$-0.1 \pm 0.4$
Systematic & trigger uncertainty	$\pm 0.7$
Raw $\Delta g$	$0.7 \pm 0.7$
$\Delta g$ corrected for L2 inefficiency	$0.6 \pm 0.7$

# $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ 2003+2004 preliminary result

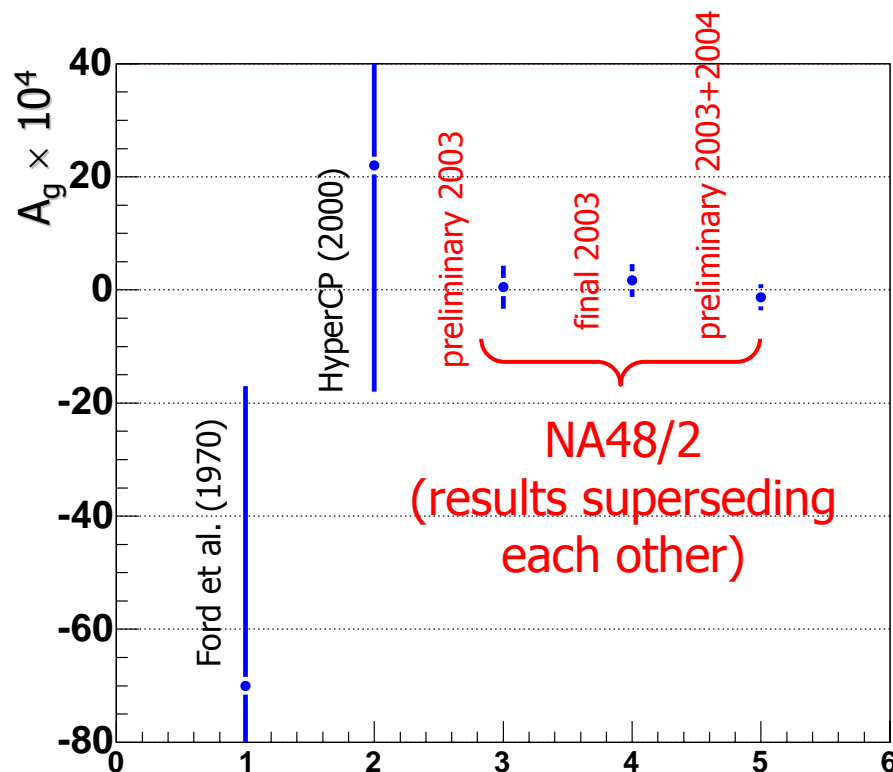
$$A_g = (-1.3 \pm 1.5_{\text{stat}} \pm 0.9_{\text{trig}} \pm 1.4_{\text{syst}}) \times 10^{-4}$$

$$= (-1.3 \pm 2.3) \times 10^{-4}$$

Final result for 2003

published in PLB:

J.R. Batley et al. (NA48/2  
Collaboration), Phys. Lett.  
B634 (2006) 474.



# Conclusions

- ◆ The final result on the direct CP-violation parameter  $A_g^0$  in  $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$  based on 2003 sample (1/2 of the whole statistics) is:

$$A_g^0 = (1.8 \pm 2.2_{\text{stat.}} \pm 1.0_{\text{stat.(trig.)}} \pm 0.8_{\text{syst.}} \pm 0.2_{\text{ext.}}) \times 10^{-4} \\ = (1.8 \pm 2.6) \times 10^{-4}$$

- ◆ The preliminary result for  $A_g$  in  $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$  based on 2003+2004 sample (whole statistics) is:

$$A_g = (-1.3 \pm 1.5_{\text{stat.}} \pm 0.9_{\text{stat.(trig.)}} \pm 1.4_{\text{syst.}}) \times 10^{-4} \\ = (-1.3 \pm 2.3) \times 10^{-4}$$

- ◆ Both results have 10 times better precision than the previous measurements; the goal of NA48/2 is reached;
- ◆ The errors are dominated by statistics;
- ◆ The result is consistent with the predictions of the Standard Model.

# Theoretical predictions on $A_g$

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 (priv.comm./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	$> 3 \times 10^{-5}$

# Cancellations: magnetic fields

- ◆ Charge-asymmetric effects due to
  - coupling of **permanent magnetic fields** with (alternating) **spectrometer magnetic field**;
  - **global time instabilities** (i.e. non-perfect inversion of spectrometer magnet)  
[IMPORTANT: SIMULTANEOUS BEAMS!]
 cancel by averaging Saleve and Jura ratios:

$$R_U = R_{US} * R_{UJ} \quad \Rightarrow \text{fit with } f(u) = \mathbf{n} \cdot (1 + 2\Delta_U u / (1 + gu))$$

$$R_D = R_{DS} * R_{DJ} \quad \Rightarrow \text{fit with } f(u) = \mathbf{n} \cdot (1 + 2\Delta_D u / (1 + gu))$$

- ◆ Effects of upper & lower **beam geometry difference** cancel by averaging Up and Down ratios:

$$R_S = R_{US} * R_{DS} \quad \Rightarrow \text{fit with } f(u) = \mathbf{n} \cdot (1 + 2\Delta_S u / (1 + gu))$$

$$R_J = R_{UJ} * R_{DJ} \quad \Rightarrow \text{fit with } f(u) = \mathbf{n} \cdot (1 + 2\Delta_J u / (1 + gu))$$

$(\Delta_U - \Delta_D)/2 \rightarrow$  **up-down apparatus asymmetry** } **Cancel in quadruple ratio**  
 $(\Delta_S - \Delta_J)/2 \rightarrow$  **left-right apparatus asymmetry** }

# Trigger systematic uncertainties



## 1 track trigger:

- Level 1: require coincidence of two signals:
  - **Hodoscope signal** (from the track);
  - **LKr signal** (from the photons).
- Level 2:
  - fast on-line reconstruction of the track momentum;
  - calculate missing mass, which should not be consistent with  $\pi^0$  mass  $\rightarrow$  reject the main  $K^\pm \rightarrow \pi^\pm \pi^0$  background



## Measurement of trigger systematics method:

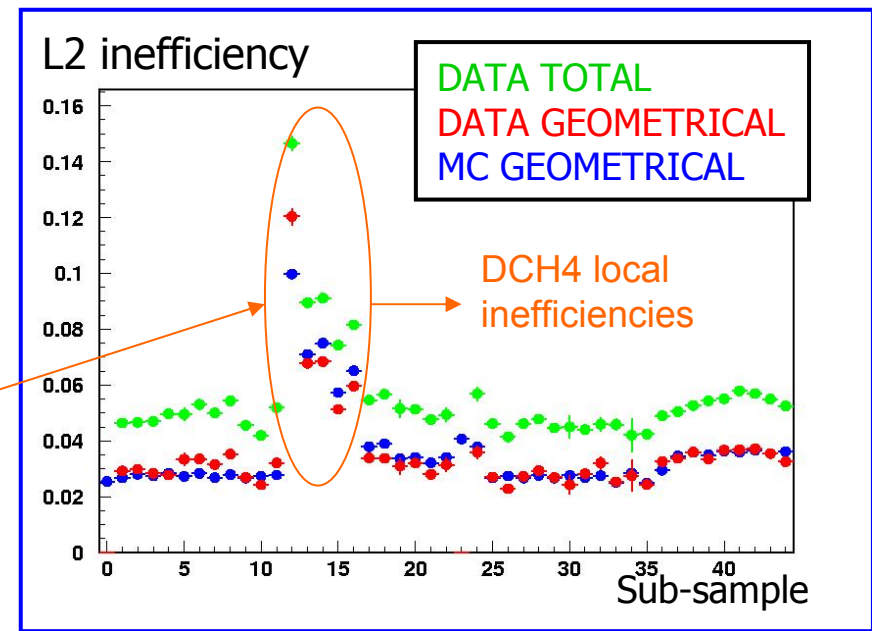
- for each subsample obtain the **trigger efficiency as a function of U** by using control sample (with trigger, uncorrelated to the measured one)
- **correct the measured U spectra** for trigger inefficiency and calculate  $\Delta g$  with the standard method (using quadruple ratio for each supersample)
- the systematic is extracted from the **difference** between “corrected” and “uncorrected” to trigger inefficiency  $\Delta g$ ;
- this procedure is used for each component of the trigger signal **separately**.

# L1 trigger systematic uncertainties

- ◆ **HODOSCOPE SIGNAL:** (1 hit)
  - Inefficiency sources:
    - geometrical inefficiency;
    - dead time inefficiency.
  - Overall inefficiency at the level of **0.25%**.
  - Systematic uncertainty from Hodoscope signal inefficiency →  **$0.6 \cdot 10^{-4}$**
  
- ◆ **LKr SIGNAL:** ( $\geq 3$  peaks in X- or Y-projection)
  - Inefficiency at the level of **0.7%** in the beginning and **~3%** in the end of 2003 data-taking.
  - Systematic uncertainty from LKr signal inefficiency →  **$1.3 \cdot 10^{-4}$**
  
- ◆ The obtained systematic uncertainties from L1 trigger inefficiency are **limited by statistics** in the control sample.

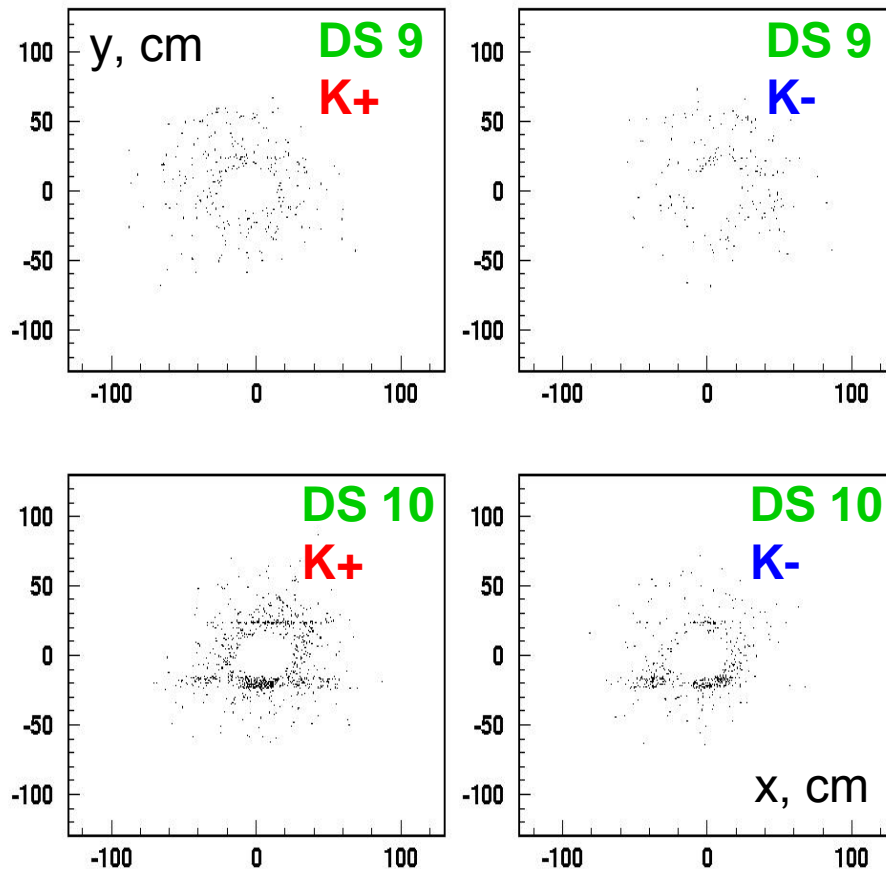
# L2 trigger systematic uncertainty

- ◆ L2 inefficiency (~4-6%) sources:
  - ~73% → geometrical (inefficient wires in DCHs);
  - ~12% → L2 algorithm cannot find proper K-vertex;
  - ~15% → timing effects.
- ◆ Isolate only geometrical part of L2 inefficiency by using several cuts.
- ◆ The geometrical part of L2 inefficiency is very well reproduced in the MC sample.
- ◆ Compare  $\Delta g$  for all MC events and only for the triggered events.
- ◆ Even the period with large L2 inefficiency does not affect  $\Delta g$ .
- ◆ L2 systematic uncertainty obtained →  $0.4 \cdot 10^{-4}$

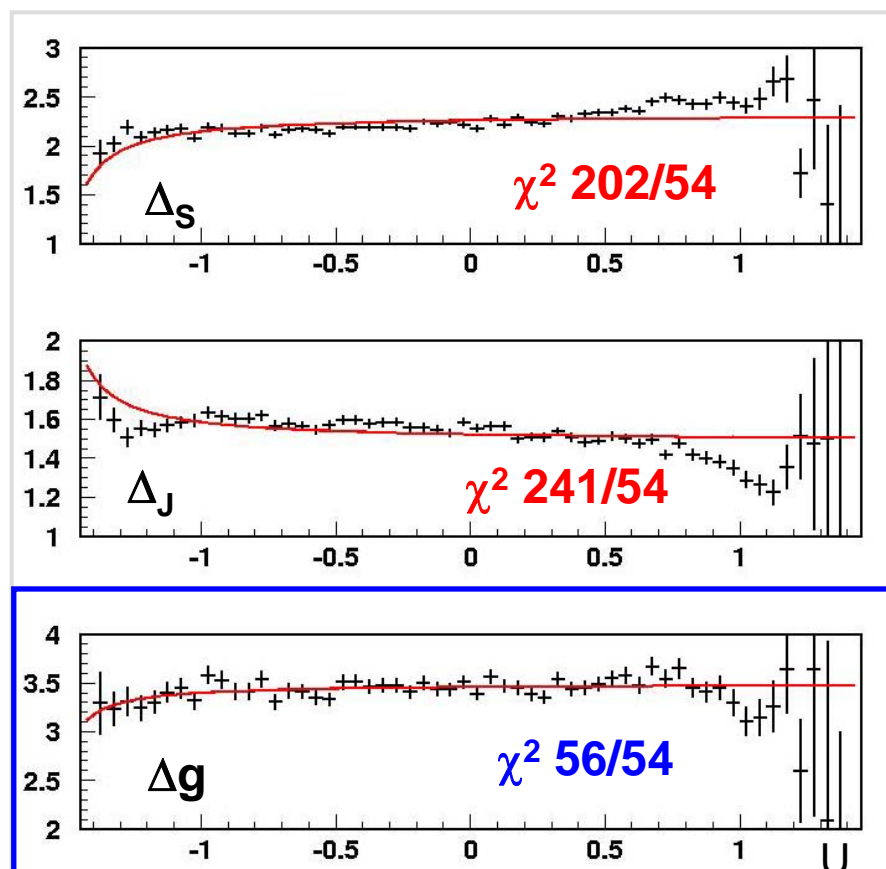


# L2 high inefficiency period

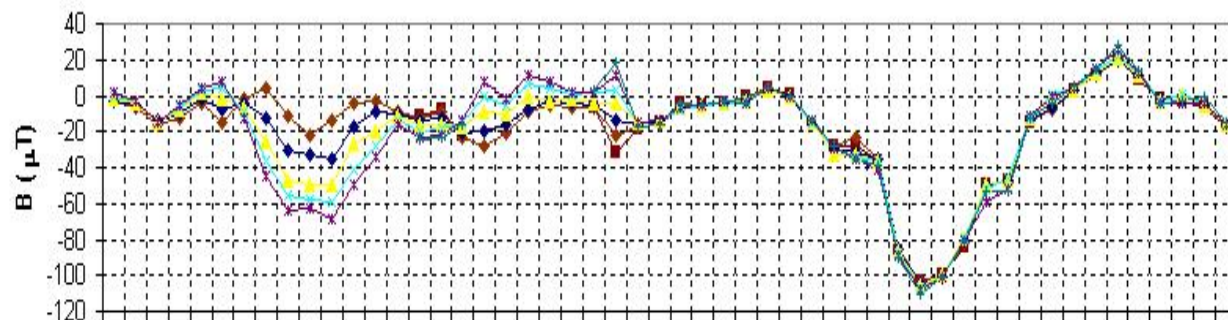
Track on DCH4 for L2 inefficient events



Double ratio fits for subsamples 9 and 10

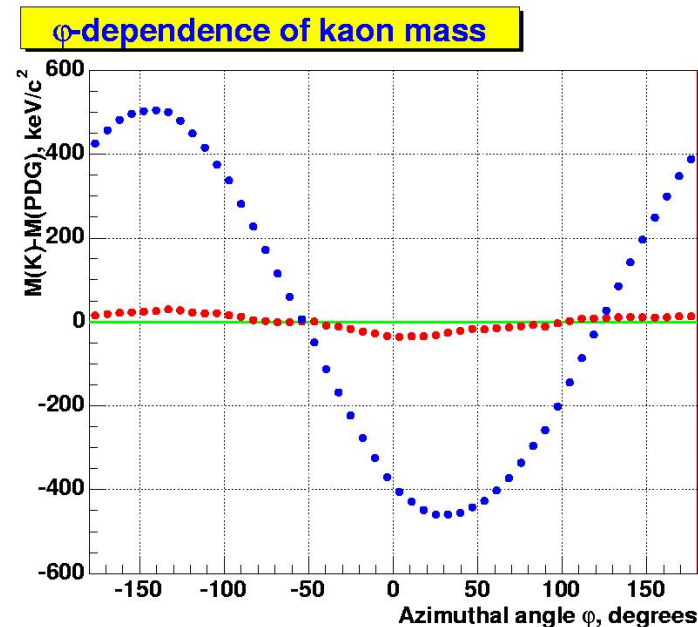


# Stray Magnetic Field



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

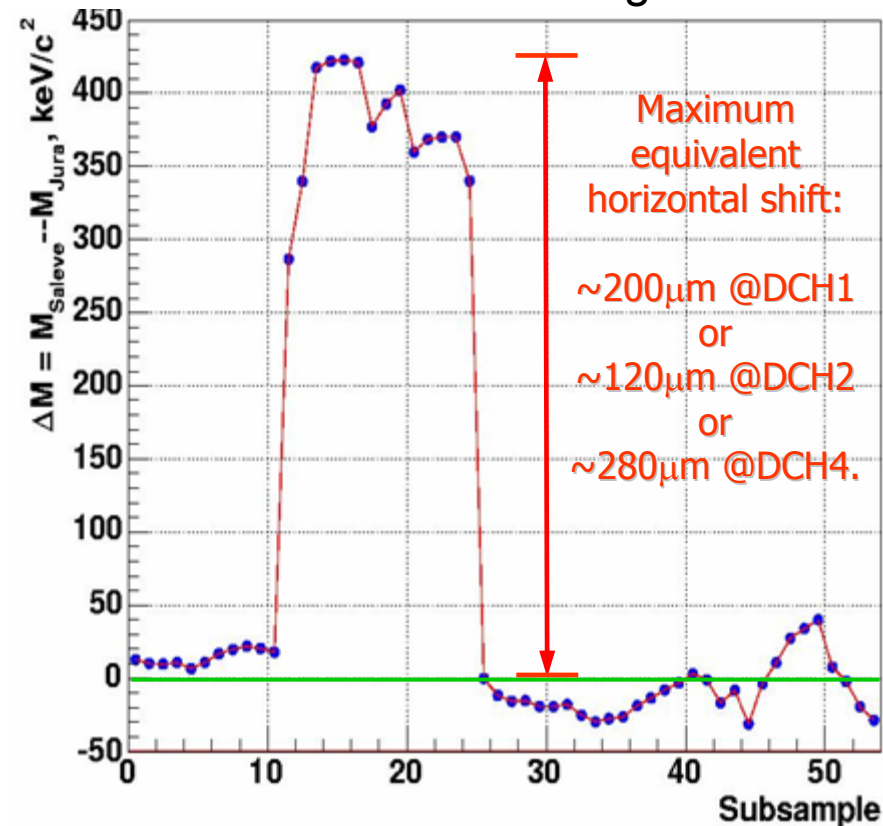
$$\frac{\text{P kick}(\text{stray field})}{\text{P kick}(\text{spectrometer})} \approx 10^{-4}$$



# Spectrometer alignment

- ◆ The observables  $\Delta_S$  and  $\Delta_J$  are sensitive to **time variations** in spectrometer alignment; the effect does not cancel in  $\Delta_g$ .
- ◆ Spectrometer transverse alignment is fine-tuned for each subsample by imposing the **K+** and **K-** to have the same reconstructed mean invariant mass.
- ◆ **Sensitivity** to DCH4 horizontal shift:  
 $\Delta M/\Delta x \approx 1.5 \text{ keV}/\mu\text{m}$ .
- ◆ This correction is essential for the analysis in “charged” mode, but not in “neutral” mode:
  - 1 charged track
  - for U calculation is used information only from LKr
- ◆ Spectrometer alignment systematics  $\rightarrow$   
 **$0.1 \times 10^{-4}$**

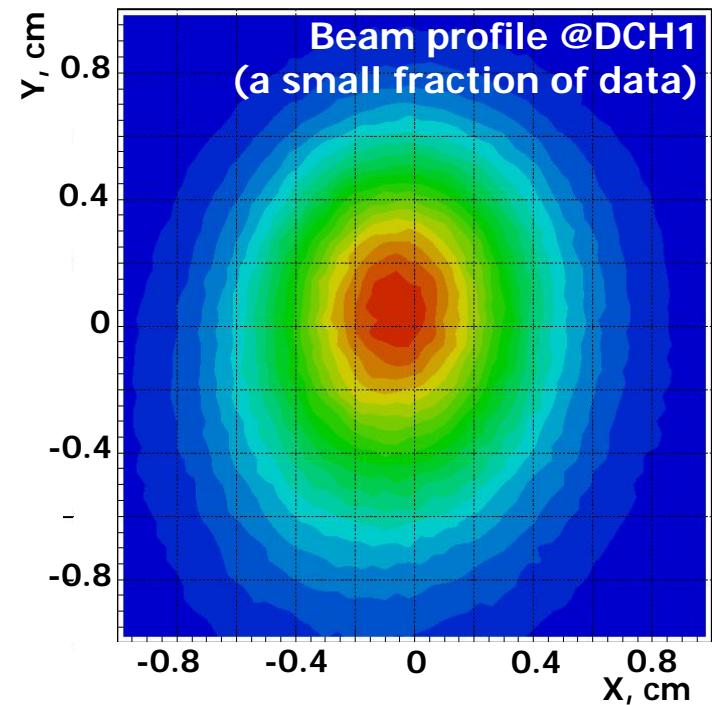
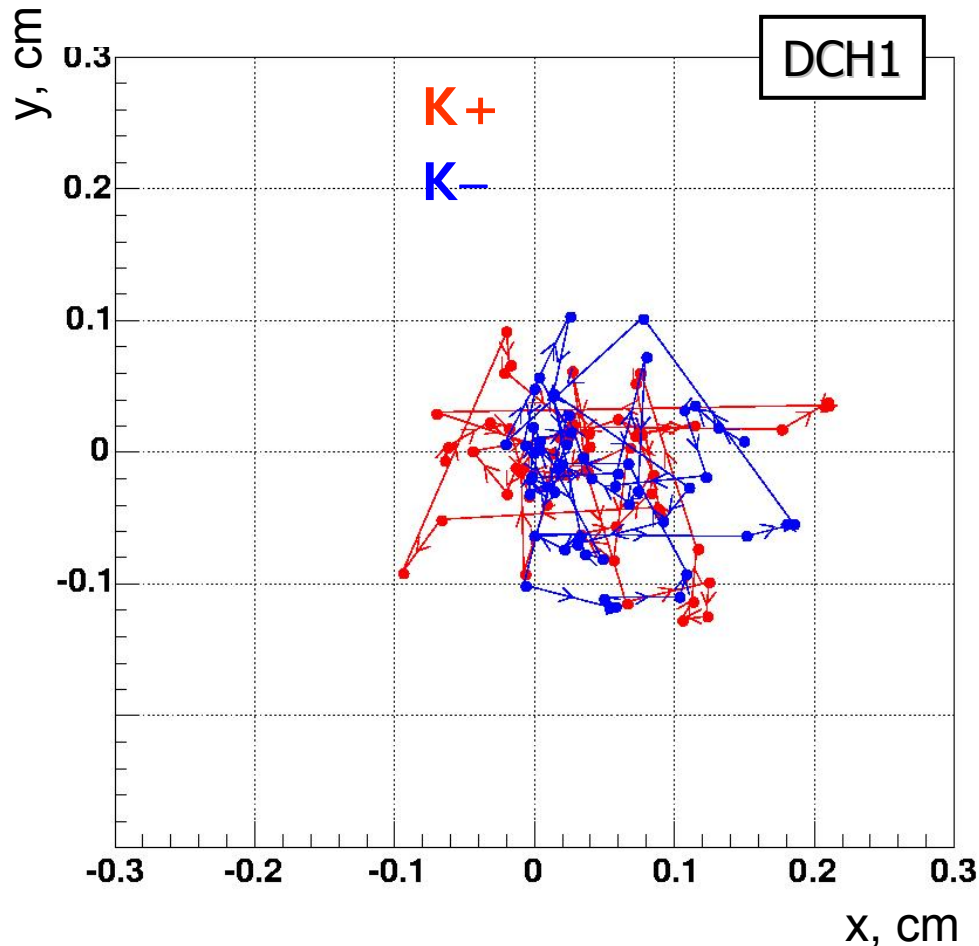
For “charged” mode



# Spectrometer magnetic field

- ◆ Each observable ( $\Delta_S$  and  $\Delta_J$ ) is evaluated with data from both B+ and B- periods: so they are sensitive to non-perfect **inversion of spectrometer magnetic field**;
- ◆ The effect mostly cancels in  $\Delta g$ , due to **simultaneous beams**;
- ◆ However, a correction is made: effective momentum scale is adjusted for each subsample by imposing reconstructed mean invariant kaon mass to be equal to PDG mass.
- ◆ **Sensitivity**:  $\Delta M \approx 100 \text{ keV}$  for typical inversion precision on magnetic field integral of  $\Delta I/I \approx 10^{-3}$ .
- ◆ Upper limit of the systematics due to non-perfect magnetic field inversion  $\rightarrow$   **$0.1 \times 10^{-4}$**

# Beam movement in time

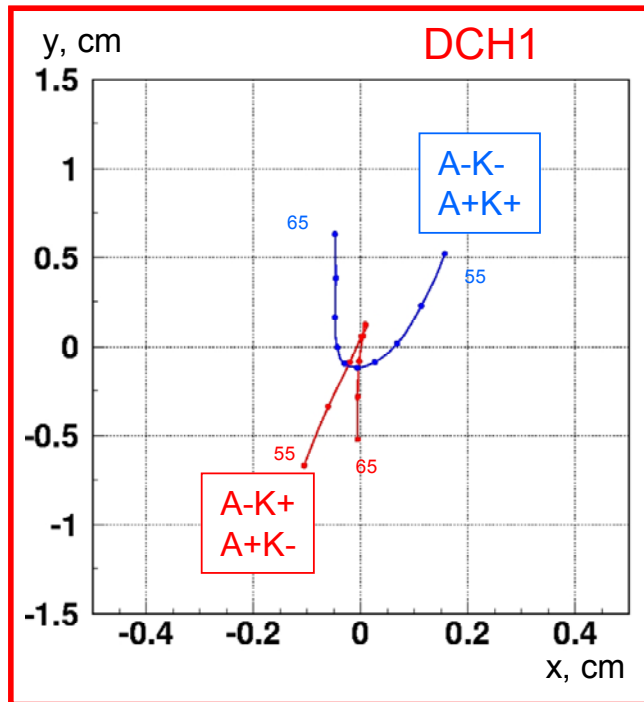


Typical scales:

- Beam movement in time:  $\sim 2\text{mm}$ ;
- Beam width:  $\sim 5\text{mm}$ .

# Momentum dependence of beams

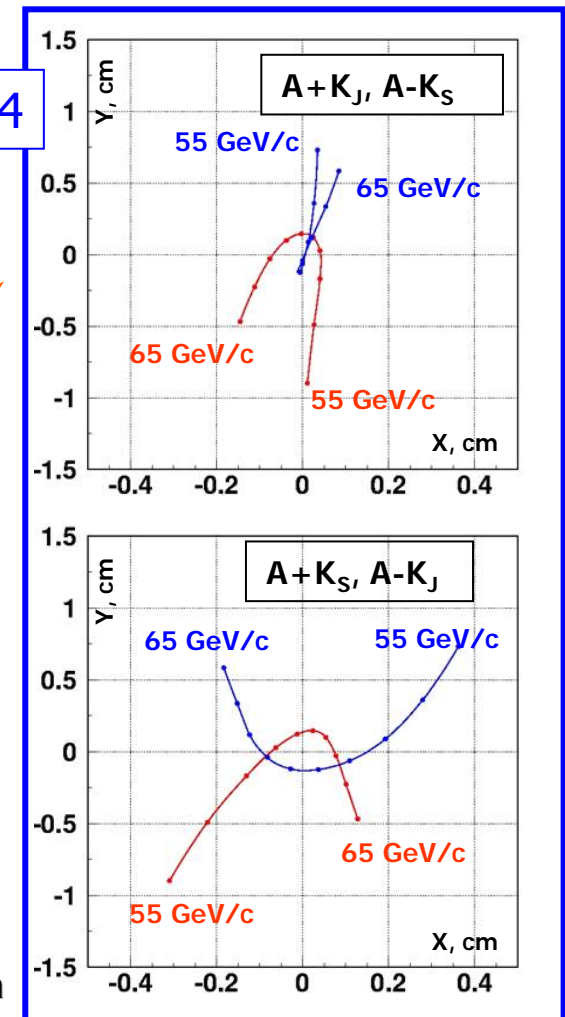
- ◆ Different momentum dependence of mean beam position for upper and lower beams due to slightly different geometric properties of the beam lines;
- ◆ Effect is corrected by the “virtual pipe”;
- ◆ Partial cancellation by achromat inversion.



Split by analyzing  
magnet field

Beam positions  
for various momenta

DCH4

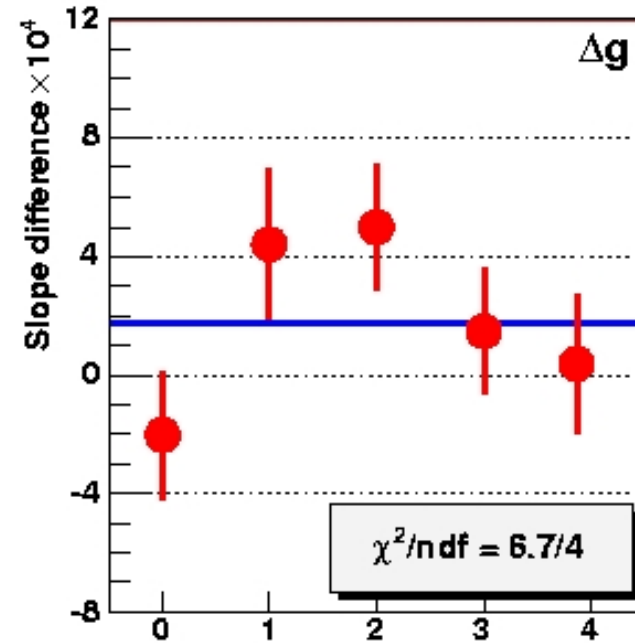
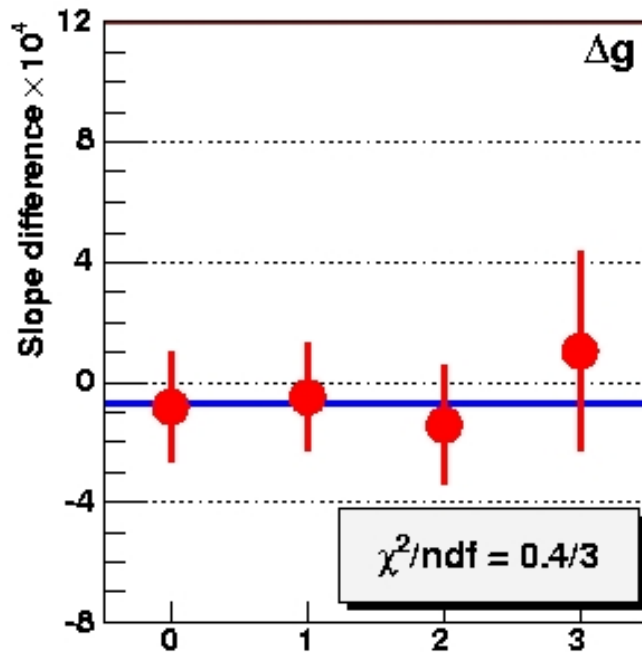


# $A_g$ in $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ 2003 and 2004

## Slope asymmetry

**2003:**  $A_g = (1.6 \pm 2.1_{\text{stat}} \pm 1.4_{\text{trig}} \pm 1.4_{\text{syst}}) \times 10^{-4} = (1.6 \pm 2.9) \times 10^{-4}$

**2004:**  $A_g = (-4.1 \pm 2.2_{\text{stat}} \pm 1.1_{\text{trig}} \pm 1.4_{\text{syst}}) \times 10^{-4} = (-4.1 \pm 2.8) \times 10^{-4}$



# $A_g$ in $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ (Preliminary result)

◆ Was presented 1 November 2005 at CERN

◆ Slope asymmetry:

$$\text{2003: } A_g = \frac{(1.7 \pm 1.7_{\text{stat}} \pm 1.2_{\text{trig(stat)}} \pm 1.3_{\text{syst}} \pm 0.2_{\text{ext}}) \times 10^{-4}}{(1.7 \pm 2.4) \times 10^{-4}} =$$

◆ Main change:

- Improvement of the systematic studies
- Change of fitting function (quadratic term in the matrix element expansion):

$$R(u) \approx N \left( 1 + \frac{\Delta g u}{1 + g u} \right)$$