Search for direct CP-violation in charged K decays from NA48/2 experiment

XIII Lomonosov Conference

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

Motivation

- Major milestones in CP-violation history:
  - **1964** – **Indirect** CP-violation in K^0 (Cronin, Christenson, Fitch, Turlay)
  - **1988, 1999** – **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 $K^{\pm}$***
  - **$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ (BR: 5.57%)**
  - **$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ (BR: 1.73%)**

  [Only direct CP-violation in $K^{\pm}$ is possible – no mixing]

CP-Violation parameter A_g

- ***Matrix element:***

$$|M(u,v)|^2 \sim 1 + g \cdot u + h \cdot u^2 + k \cdot v^2 + \ldots$$

- ***Lorentz-invariants:***
  - **$u = (s_3 - s_0)/m_\pi^2$**
  - **$v = (s_2 - s_1)/m_\pi^2$**

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

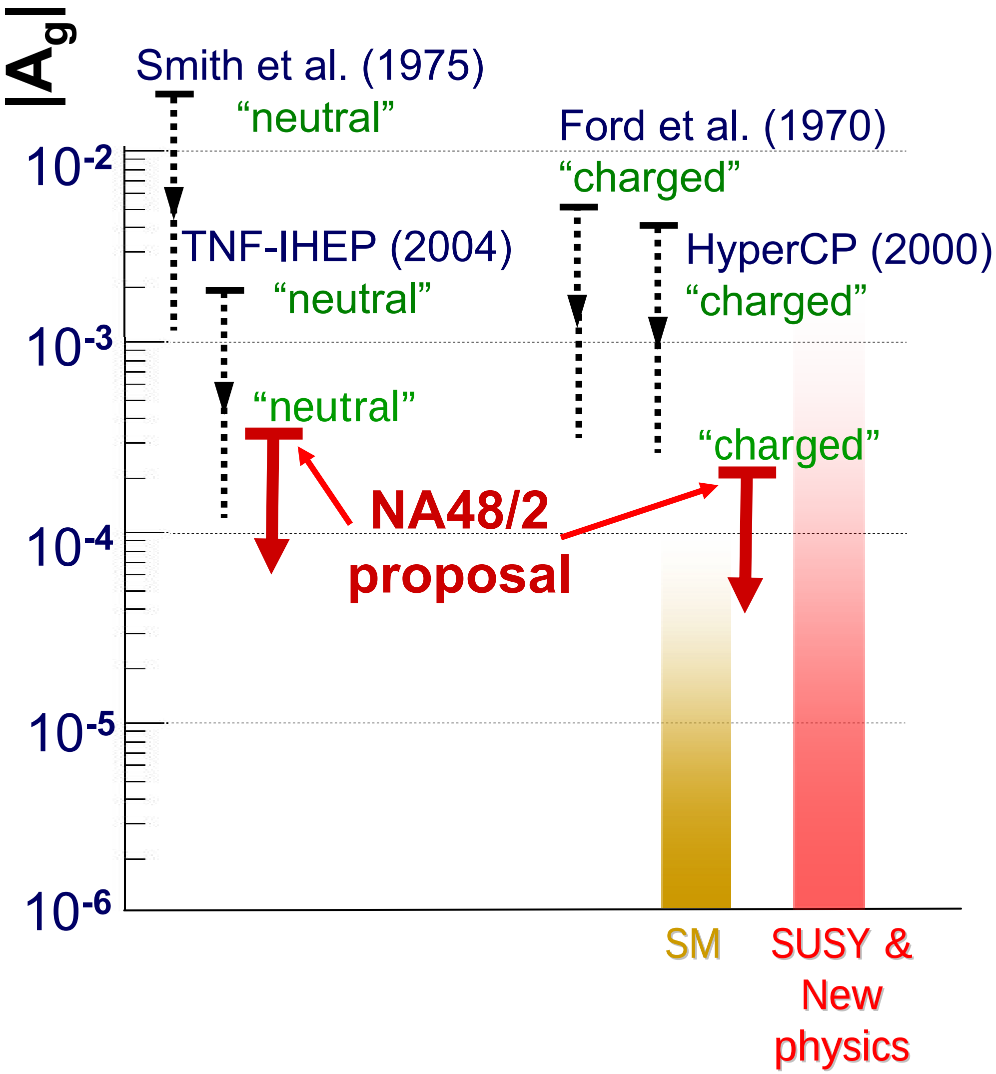
  $s_0 = (s_1+s_2+s_3)/3$

- ***Measured parameters (PDG):***
  - $K^\pm \to \pi^\pm \pi^+ \pi^-$ → g^+ = -0.2154 ± 0.0035
  - $K^\pm \to \pi^\pm \pi^0 \pi^0$ → g^+_0 = 0.638 ± 0.020
  - |h|,|k| << |g|

- ***CP-violation parameter:***

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

- ***$A_g \neq 0$ indicates direct CP-violation***



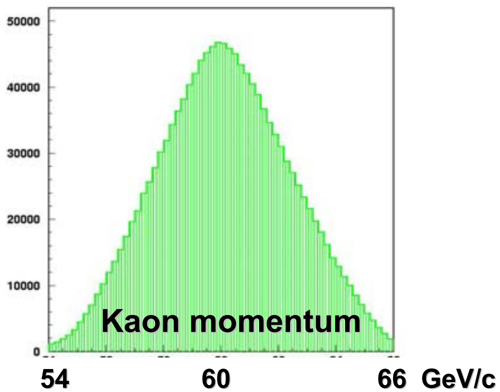
The experimental precision until NA48/2 was at the level of **few 10^{-3}** in both decay modes

SM estimates vary within an order of magnitude (few 10^{-6}…$8x10^{-5}$).

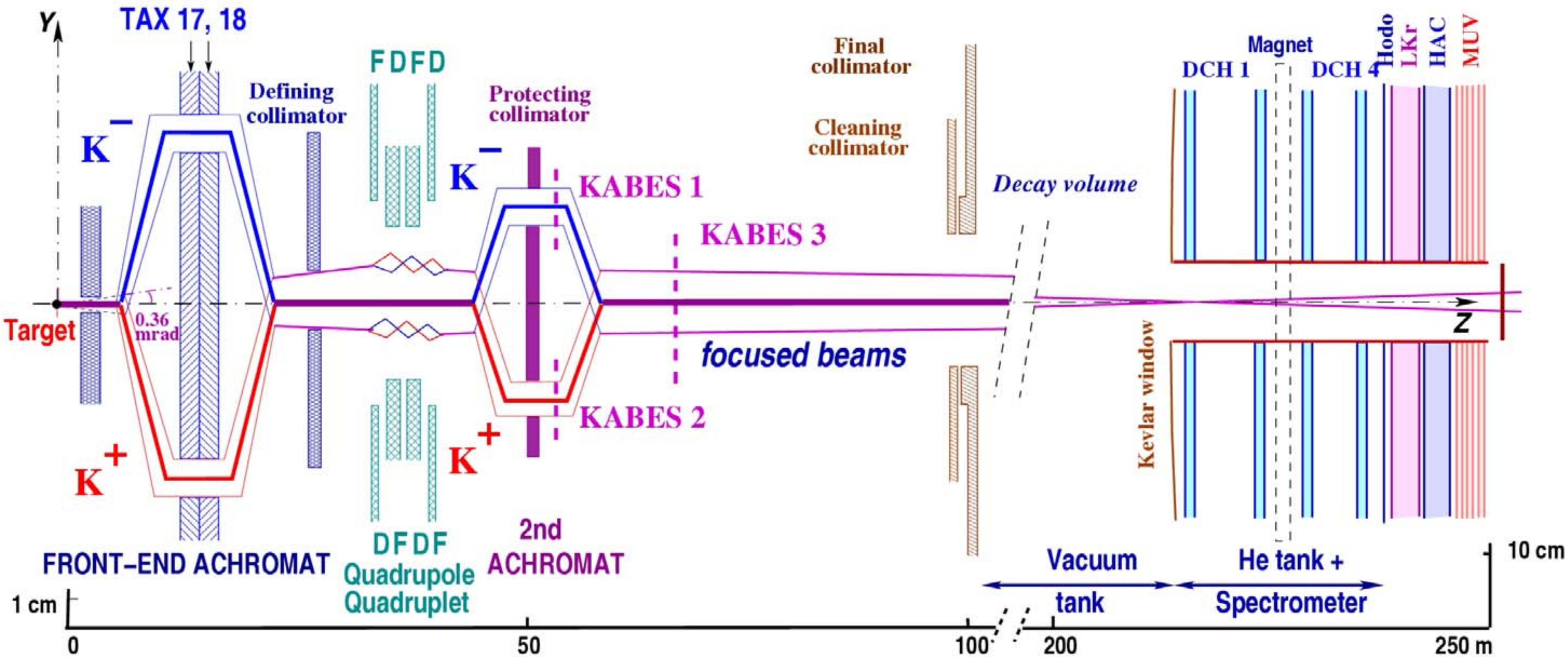
Models beyond SM predict possible enhancements partially within the reach of NA48/2.

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

NA48/2 Beam Line



Simultaneous K⁺ and K⁻ beams, **superimposed** in space, with momentum spectra **(60±3) GeV/c**.



NA48 detector

Magnetic spectrometer (4 DCHs):

- redundancy ⇒ high efficiency;
- $\Delta p/p = 1.0\% \oplus 0.044\% * p$ [GeV/c]
- **Full reconstruction of $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$**

Hodoscope

- fast trigger;
- precise time measurement.

Liquid Krypton EM calorimeter (LKr)

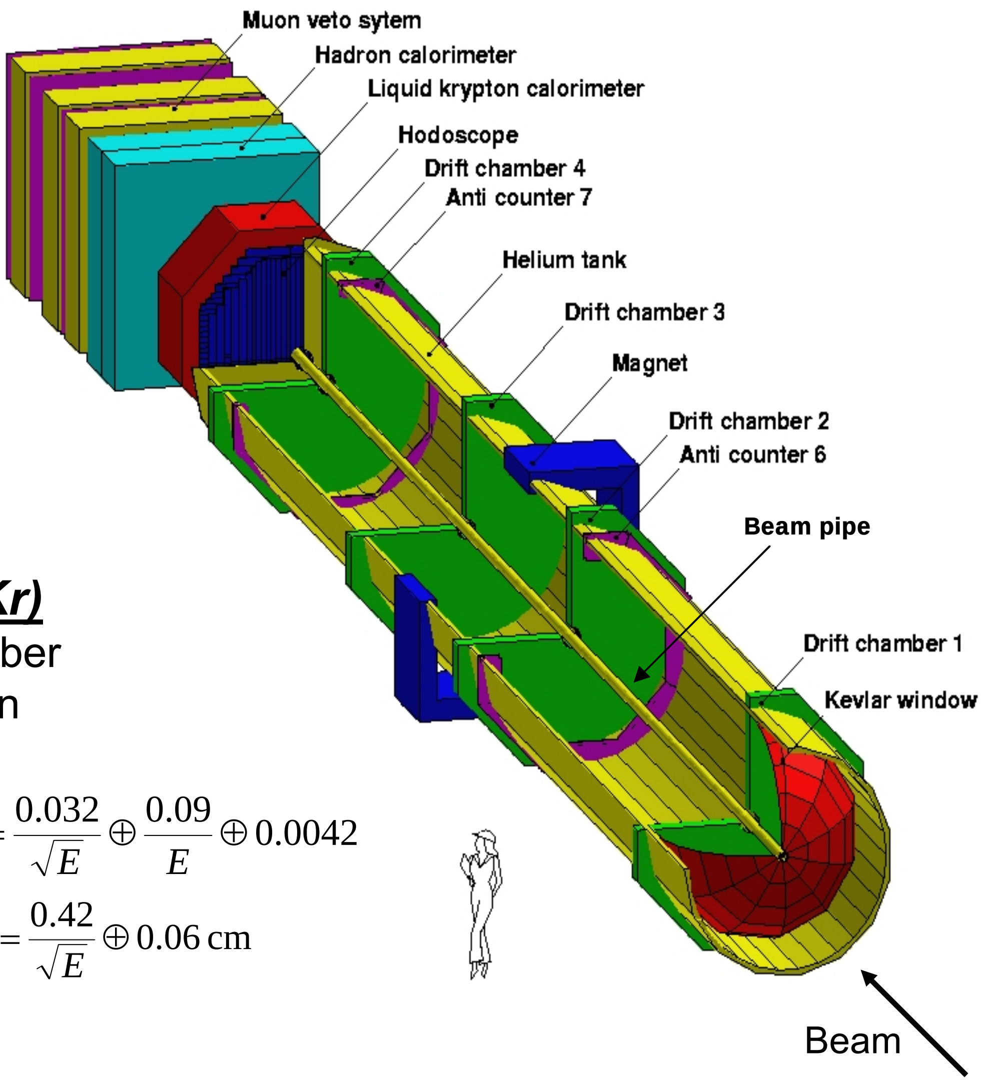
- Quasi-homogeneous ionization chamber
- Active volume of ~10 m^3 liquid krypton
- 13248 cells, 2x2 cm^2
- Energy resolution (E in GeV):
  ($\sigma(E) \approx$ 142 MeV for E = 10 GeV)

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

- Space resolution (E in GeV):
  ($\sigma(x) = \sigma(y) \approx$ 1.5 mm for E = 10 GeV)

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

- **Essential for $K^{\pm} \to \pi^{\pm}\pi^{0}\pi^{0}$ mode**



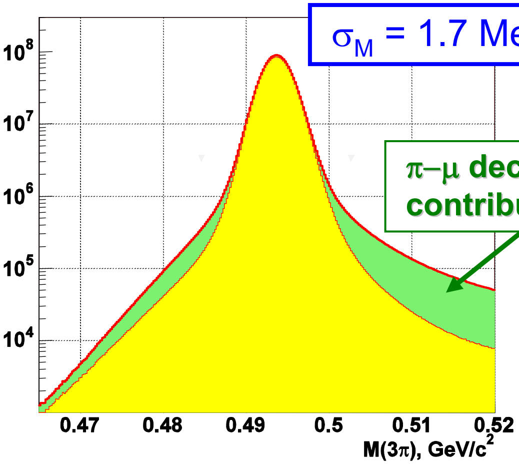
NA48/2 data taking: completed

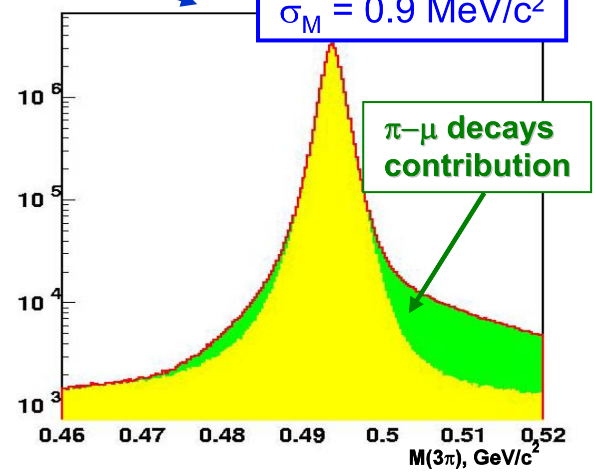
A view of the NA48/2 beam line

- **2003** run: ~ 50 days
- **2004** run: ~ 60 days
- Total statistics in 2 years:
  - **$K^{\pm} \to \pi^{-}\pi^{+}\pi^{\pm}$: > $3 \cdot 10^{9}$**
  - **$K^{\pm} \to \pi^{0}\pi^{0}\pi^{\pm}$: > $1 \cdot 10^{8}$**
- Rare $K^{\pm}$ decays: BR's down to 10^{-9} can be measured
- **>200 TB of data recorded**

Selected events properties

3π invariant mass



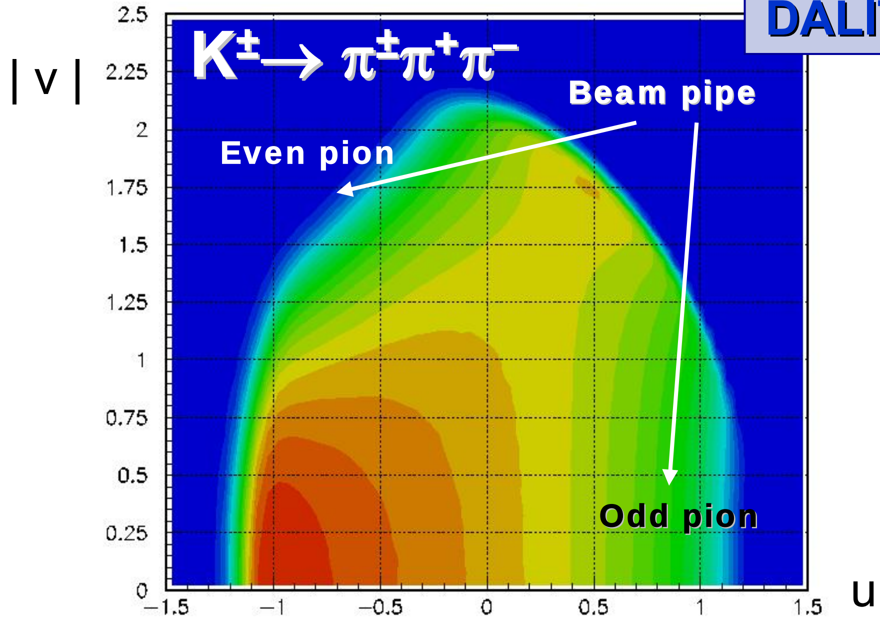


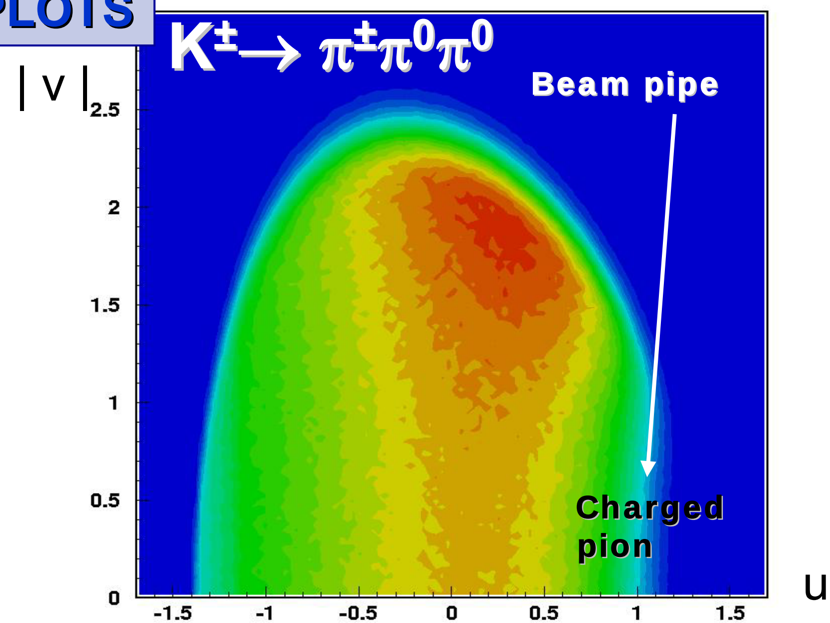
STATISTICS

$K^\pm \to \pi^\pm\pi^+\pi^-$	
K+	2.0 x 10^9
K−	1.1 x 10^9
TOT	3.1 x 10^9

$K^\pm \to \pi^\pm\pi^0\pi^0$	
K+	59 x 10^6
K−	32 x 10^6
TOT	91 x 10^6

DALITZ PLOTS





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)
- For ***equal K⁺ and K⁻ acceptance***, A_g can be extracted from a fit to the ratio R(u):

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

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

normalization

$A_g = \Delta g / 2g$

- The normalization is a free parameter in the fit and Δg does not depend on it.
- For the “charged” mode a fit with linear function is suitable due to smallness of the slope g.
- U-calculation:
  - In “charged mode” → only the magnetic spectrometer is used
  - In “neutral mode” → only the calorimeter is used

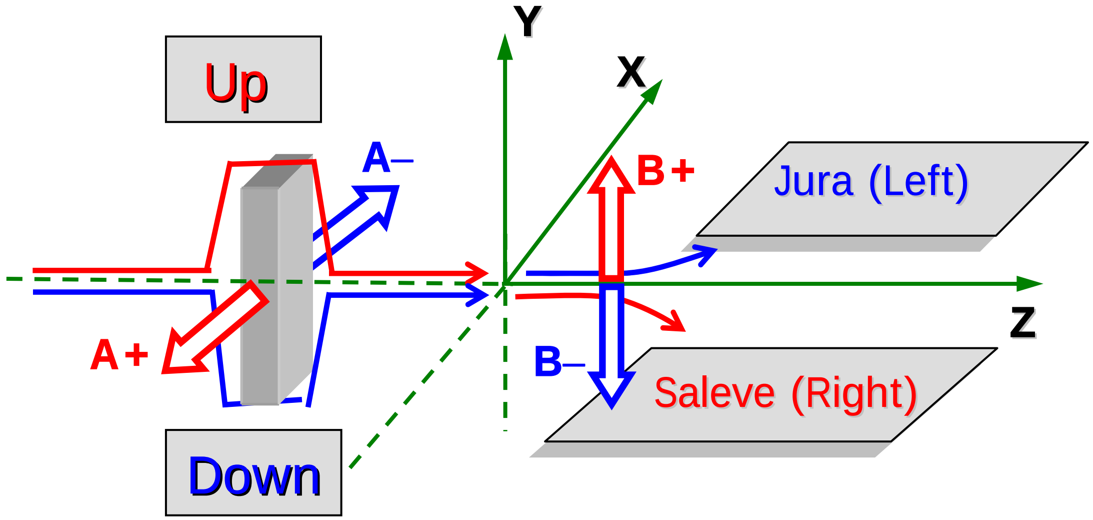
Possible U-spectra ratios

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

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

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

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



Indeces 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

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

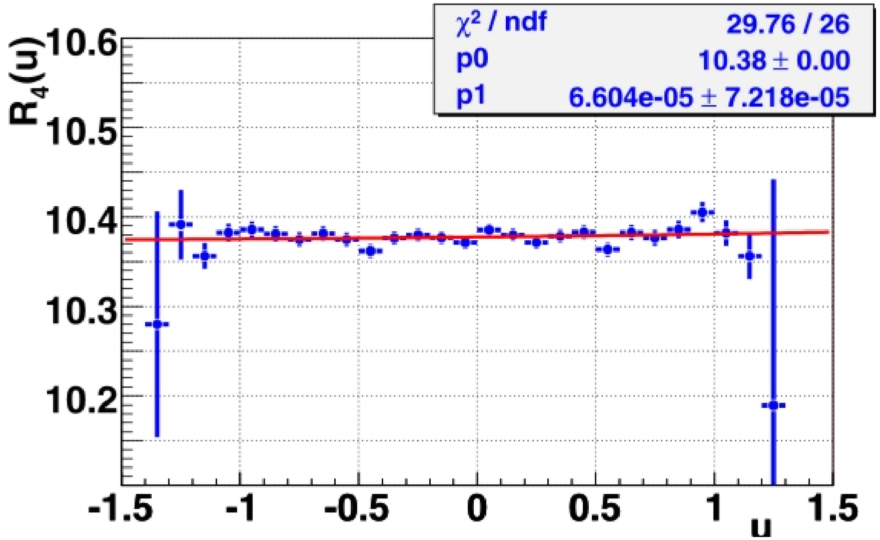
- ***3-fold cancellation of systematic biases:***
  - ***global time-variable biases*** (K^+/K^- simultaneously recorded);
  - ***beam line biases*** (K^+ beam up / K^- beam up etc.);
  - ***detector asymmetries*** (K^+ toward Saleve / K^- toward Saleve etc.).

- In addition, acceptance is defined respecting ***azimuthal symmetry***:
  - effects of ***permanent (irreversible) fields*** (Earth, vacuum magnetization) cancel

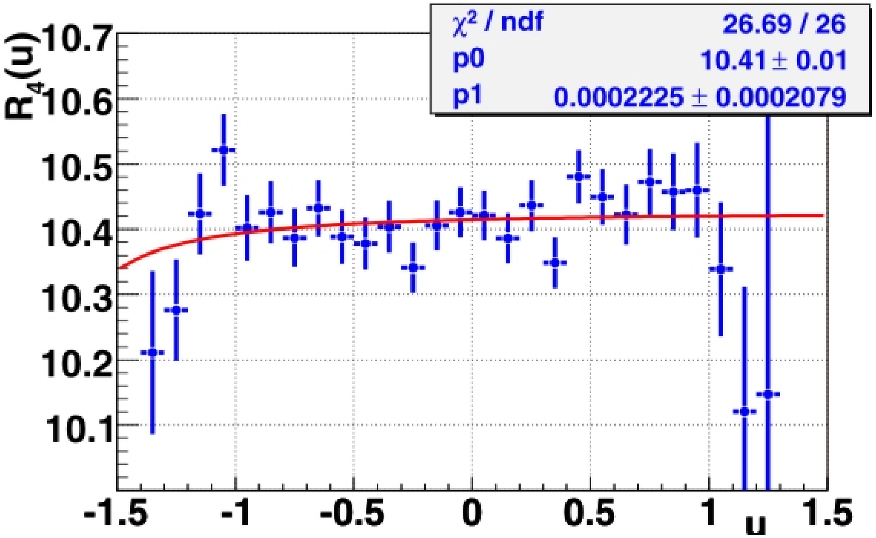
- The result is sensitive only to ***time variations*** of small asymmetry in experimental conditions with a characteristic time smaller than corresponding field-alternation period (beam – week, detector – day).

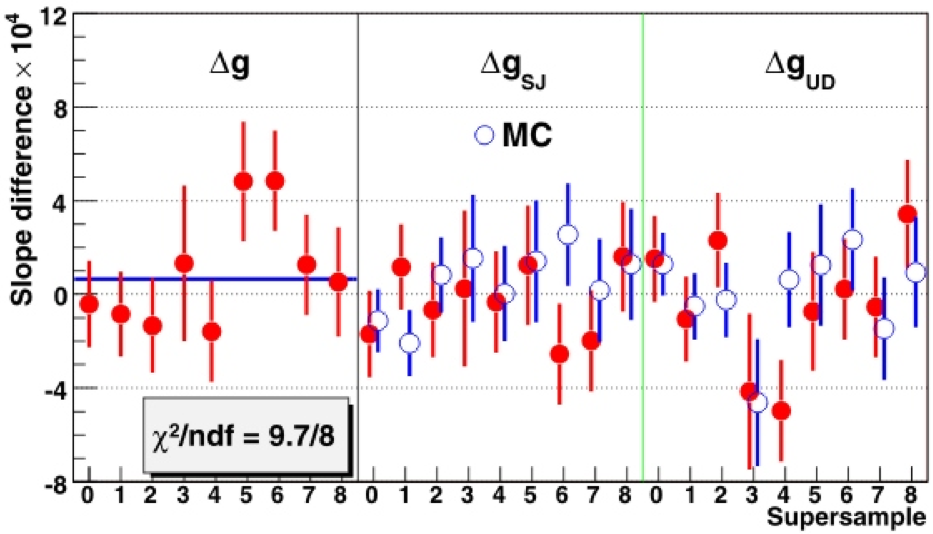
Δg by samples (in 10^{-4})

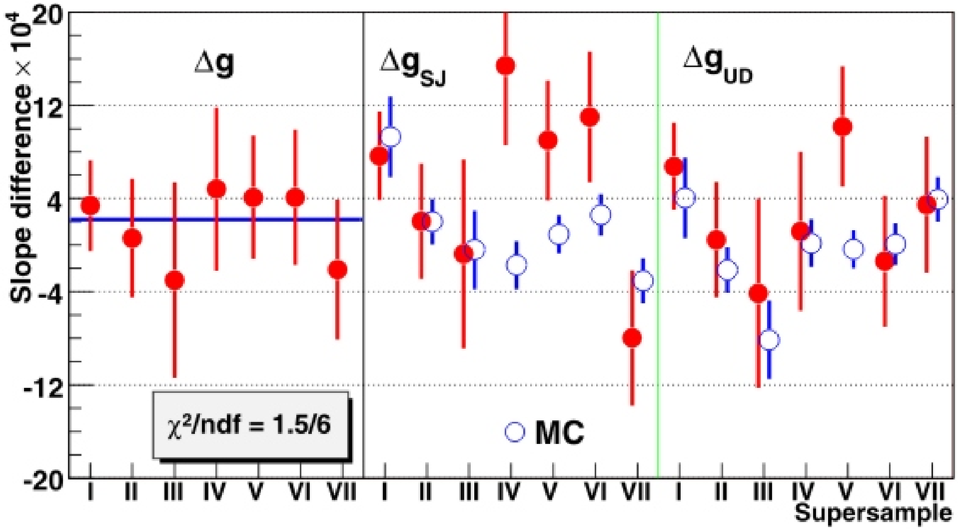
$K^\pm \to \pi^\pm\pi^+\pi^-$



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







Systematic uncertainties of Δg

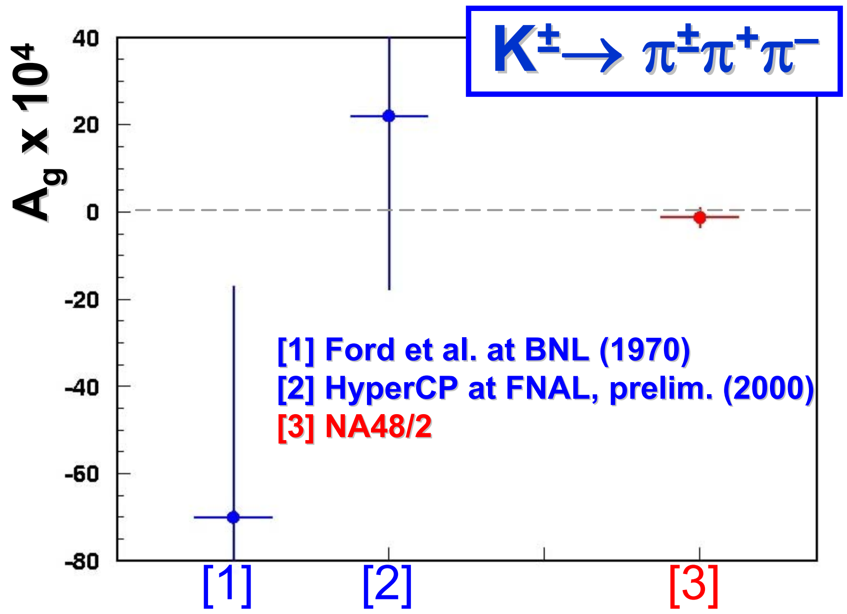
$K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

Systematic effect	Effect on $\Delta g \times 10^4$
Spectrometer alignment	±0.1
Spectrometer magnetic field	±0.3
Beam geometry / stray magn. field	±0.2
Accidental activity (pile-up)	±0.2
Resolution effects	±0.2
Total systematic uncertainty	±0.5
L1 trigger: uncertainty only	±0.3
L2 trigger: correction	–0.1±0.3
Total trigger correction	–0.1±0.4
Systematic & trigger uncertainty	±0.7

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

Systematic effect		Effect on Δg x 10^4
LKr	U calculation & fitting	< ± 0.1
LKr	LKr nonlinearity	< ± 0.1
LKr	Showers overlapping	± 0.5
Spectrometer alignment and Momentum scale		< ± 0.1
Accidental activity (pile-up)		± 0.2
L1 trigger:	Charged signal	± 0.1
L1 trigger:	Neutral signal	± 0.1
L2 trigger:	Mass Box	± 0.3
Total		± 0.6

A_g results

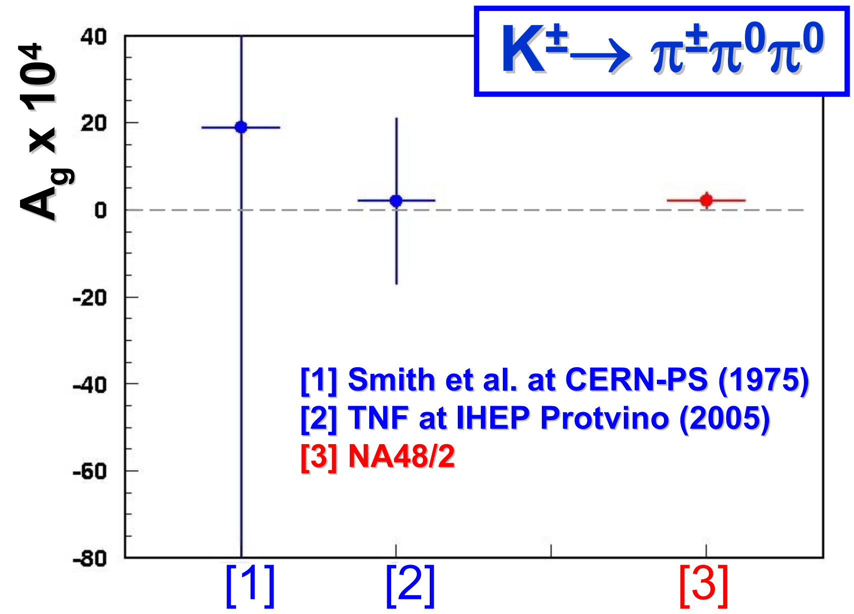


2003 + 2004 FINAL RESULT

CP-violation parameter:

$A_g = (-1.5 \pm 1.5_{stat.} \pm 0.9_{trig.} \pm 1.1_{syst.}) \times 10^{-4}$

$= \mathbf{(-1.5 \pm 2.1) \times 10^{-4}}$



2003 + 2004 FINAL RESULT

CP-violation parameter:

$A_g = (1.8 \pm 1.7_{stat.} \pm 0.5_{syst.}) \times 10^{-4}$

$= \mathbf{(1.8 \pm 1.8) \times 10^{-4}}$

- The results have ***10 times better precision*** than the previous measurements;
- The errors are ***dominated by statistics***;
- The results are consistent with the predictions of the ***Standard Model***.

SPARE SLIDES

Theoretical predictions on A_g

Standard Model	L.Maiani, N.Paver '95	$(2.3\pm0.6)\times10^{-6}$
	A. Bel'kov '95	$<4\times10^{-4}$
	G.D'Ambrosio, G.Isidori '98	$<10^{-5}$
	E.Shabalin '01	$<3\times10^{-5}$
	E.Gamiz, J.Prades, I.Scimemi '03	$(-2.4\pm1.2)\times10^{-5}$
	E.Shabalin '05 (La Thuile'05)	$<8\times10^{-5}$
SUSY	G.D'Ambrosio, G.Isidori, G.Martinelli	$\sim10^{-4}$
New physics	E.Shabalin '98 [Weinberg model of extended Higgs doublet]	$\sim4\times10^{-4}$
	I.Scimemi '04	$>3\times10^{-5}$

Previous measurements of A_g

Charged" mode $K^{\pm}\to\pi^{\pm}\pi^{+}\pi^{-}$:

- Ford et al. at BNL (1970): **$A_g = (-70 \pm 53)\cdot 10^{-4}$**;
  Statistics: 3.2M $K^{\pm}$;
- HyperCP at FNAL, prelim. (2000): **$A_g = (22 \pm 15_{stat} \pm 37_{syst})\cdot 10^{-4}$**;
  Statistics: 54M $K^{\pm}$;
  [W.-S. Choong PhD thesis, LBNL-47014 Berkeley 2000.]

"Neutral" mode $K^{\pm}\to\pi^{\pm}\pi^{0}\pi^{0}$:

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

Instrumental asymmetries

- 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:

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

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

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

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

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

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