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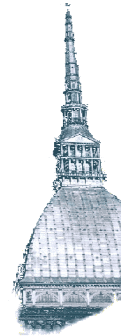


Search for direct CP violation in the charged kaon decays (NA48/2)

Roberta Arcidiacono

Universita' degli Studi di Torino

on behalf of the **NA48/2** collaboration

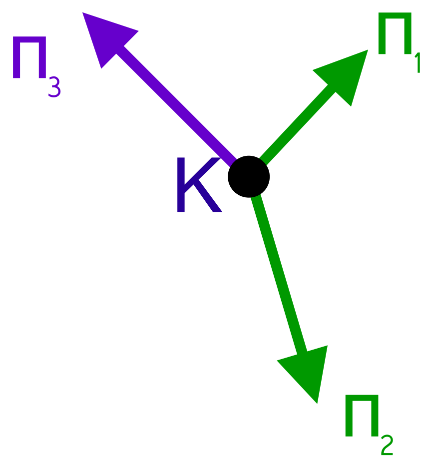
Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

Outline

- Direct CP violation in charged Kaons
- The NA48/2 experimental setup
- Extraction of CPV asymmetries method
- CPV asymmetries in the charged $K^{\pm}\rightarrow\pi^{\pm}\pi^{+}\pi^{+}$ and neutral $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}\pi^{0}$ modes
- Conclusions

Direct CP violation in $K^{\pm} \rightarrow 3\pi$ decays

"charged"	"neutral"
$BR(K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}) = 5.57\%$	$BR(K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}) = 1.73\%$



Kinematics:

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

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

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

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

Matrix element:

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

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

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ $g = 0.652 \pm 0.031$

$|h|, |k| \sim 10^{-2} \ll |g|$

Linear slope g dominates over quadratic terms h,k

Direct CP violation in $K^{\pm}\to 3\pi$ decays

$$A(K\to 3\pi) = a + b \times u$$

$\Delta I = 3/2$ in the 2nd amplitude

Two $\Delta I = \frac{1}{2}$ amplitudes with different weak and strong phases → interference effects on

$$|A(K\to 3\pi)|^2 \propto 1 + g \times u$$

g_+ = K^+ decays

g_- = K^- decays

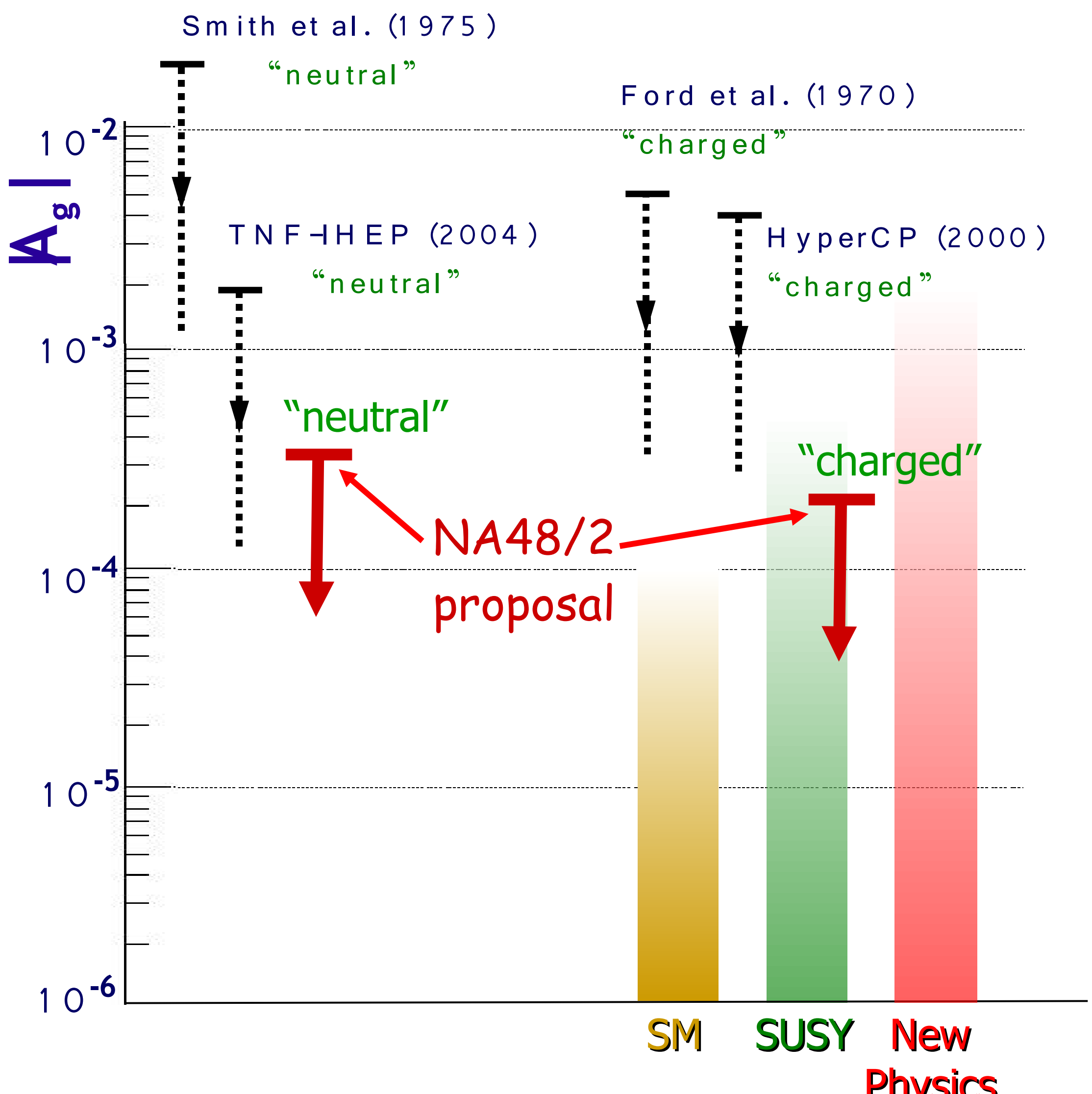
$$A_g \stackrel{\text{def}}{=} \frac{(g_+ - g_-)}{(g_+ + g_-)} = \frac{\delta g}{2g}$$

slope asymmetry $A_g \neq 0$

→ direct CP violation

Channels with high statistics, simple selection and low background level

A_g status before NA48/2



THEORY:

SM contribution: many theoretical computations from several groups Large uncertainties.

Predictions in range few 10^{-6}... 5×10^{-5}

Some enhancements possible **beyond SM**, partially in the reach of NA48/2

NA48 data taking history

Study of direct CP violation in neutral Kaons (ε'/ε), charged Kaons (A_g) and GIM suppressed very rare Kaon decays (future)

Year	Exp	Beam	Physics goal
1997	NA48	K_L+K_S	ε/ε
1998	NA48	K_L+K_S	ε/ε , Rare Kl decays
1999	NA48	K_L+K_S	ε/ε , Rare Kl decays
		K_L	Ke3/Kμ3
		HI K_S	Ks/hyperon decays
2000	NA48	K_L	ε/ε checks, neutral Kl decays
	NA48	η	ε/ε checks
	NA48/1	HI K_S	Neutral Ks decays, η_{000}
2001	NA48	K_L+K_S	ε/ε
2002	NA48/1	HI K_S	Neutral Ks decays, η_{000}
2003	NA48/2	K^+/K^-	Direct CPV in $K^\pm \rightarrow (3\pi)^\pm$ Rare $K^\pm$ decays
2004	NA48/2	K^+/K^-	
FUTURE		› 2008 very rare Kaon decays	

see also B.Bloch & C. Morales talks @PASCOS06

NA48/2 experiment (@CERN SPS)

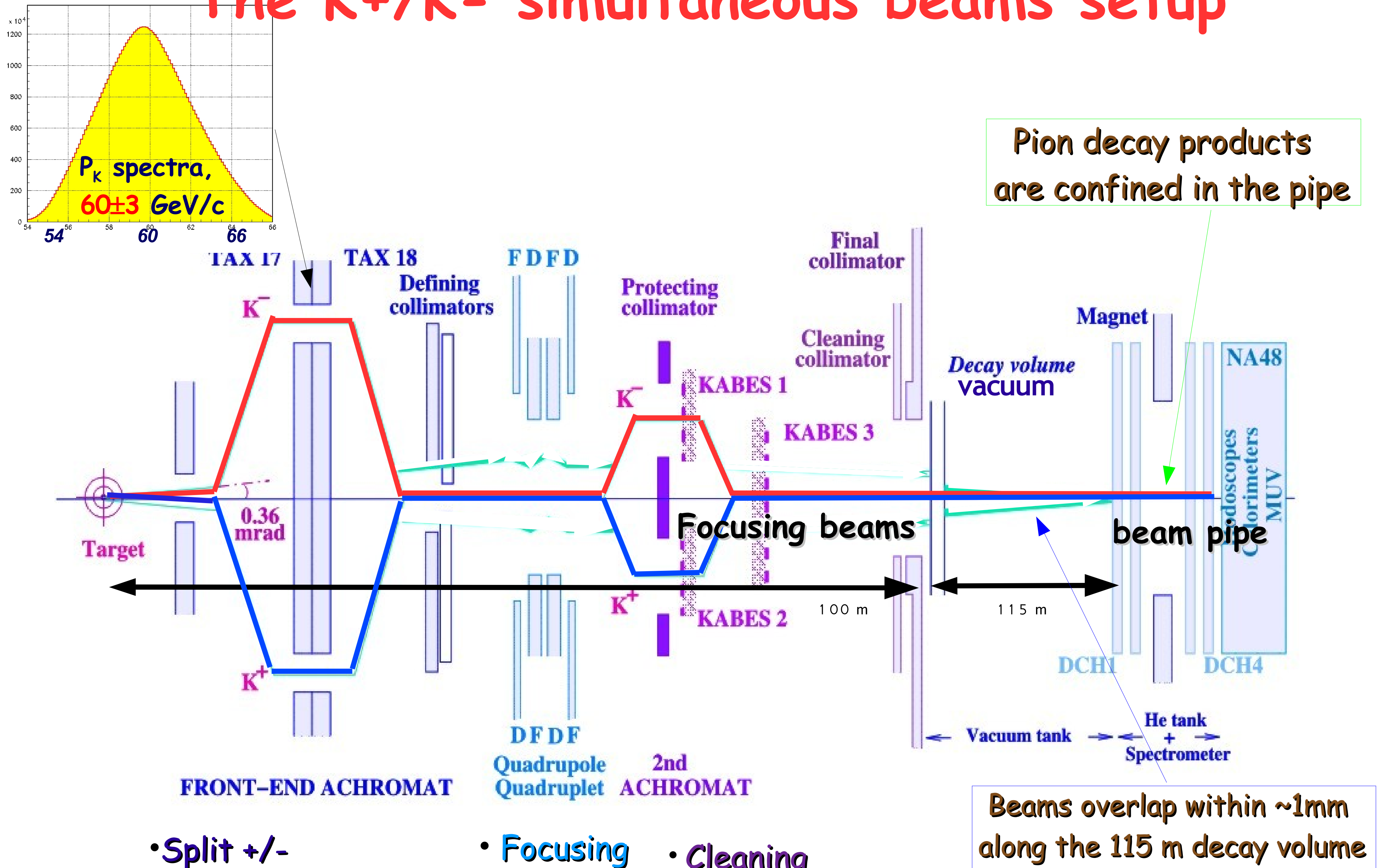
Primary NA48/2 goal

- Measure slope asymmetry A_g in "charged" and "neutral" modes with high accuracy (few 10^{-4})

Experimental strategy

- Use two simultaneous K^+ and K^- beams, superimposed in space, with momentum spectra (60±3) GeV/c
- Detect asymmetry exclusively via slopes of ratios of normalized "u" distributions
- Equalize K^+ and K^- acceptances by frequently alternating polarities of beam line and spectrometer magnets

The K+/K- simultaneous beams setup



- Split +/-
- Select momentum
- Recombine +/-

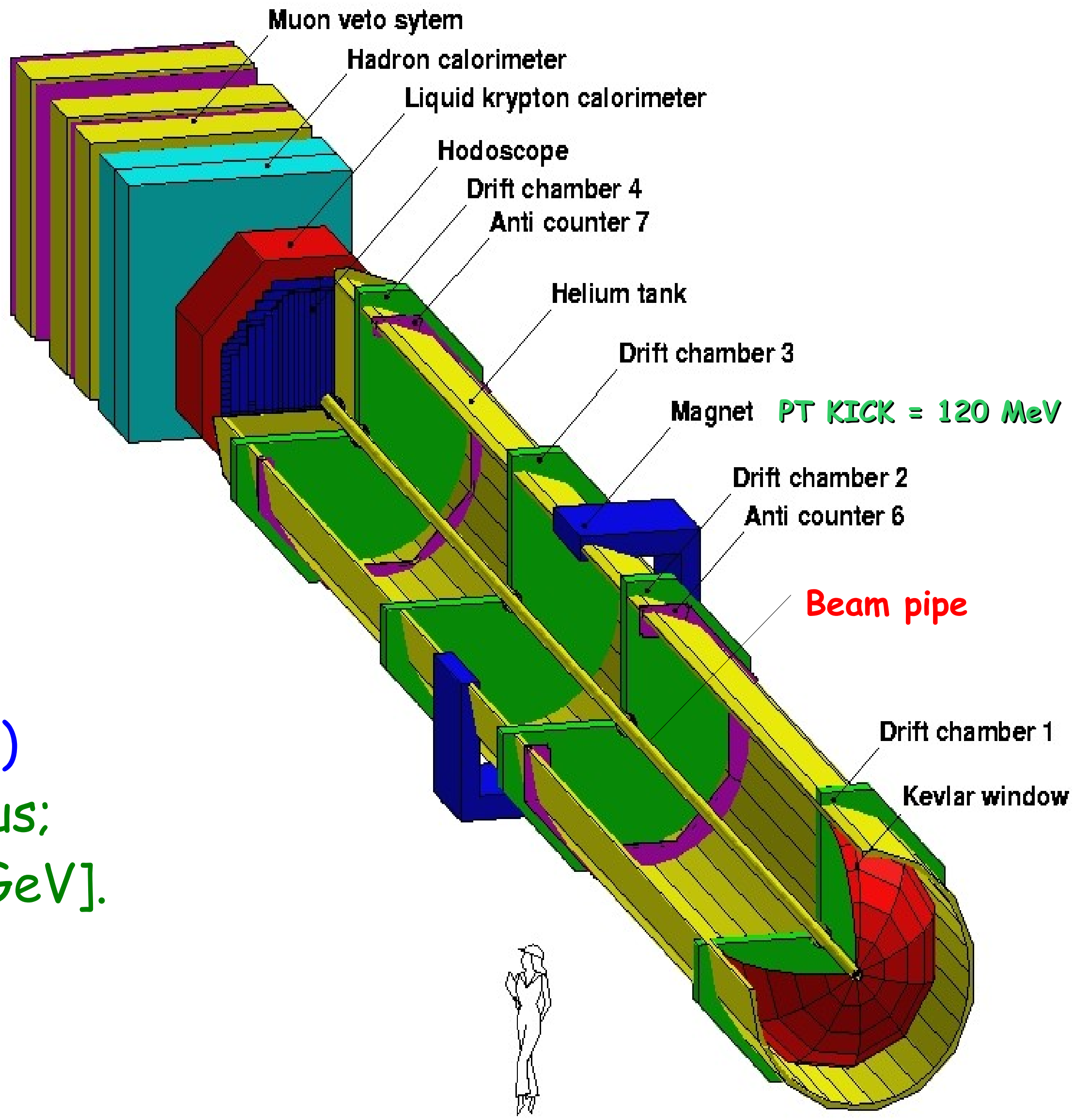
- Focusing
- Muon sweeping

- Cleaning
- Beam spectrometer

The detector

Main detector components:

- Magnetic spectrometer (4 DCHs):
  4 views/DCH → high efficiency;
  $\Delta p/p = 1.0\% + 0.044\% * p$ [GeV/c]
- Hodoscope
  fast trigger;
  precise time measurement (150ps).
- Liquid Krypton EM calorimeter (LKr)
  High granularity, quasi-homogeneous;
  $\Delta E/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [GeV].
- Hadron calorimeter, muon veto counters, photon vetoes



Strategy: extraction of A_g

- Record K into 3-pion Dalitz plot as a function of (u,v).
- Project K^+ and K^- Dalitz plots onto u-axis: obtain $N^+(u)$, $N^-(u)$
- If acceptance of K+ and K- is equal, Δg evaluated from a fit to the ratio R(u):

$g+ = -0.2154 \pm 0.0035$
$g- = 0.652 \pm 0.031$

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

- From the slope difference Δg, extract the asymmetry $A_g = \Delta g/2g$

BUT! there are experimental asymmetries which do not cancel in the simple ratio R(u)

To cancel the charge-asymmetry in detector illumination and beam optics

Beam line (achromat) polarity (A) reversed on weekly basis

Spectrometer magnet polarity (B) reversed on few hours basis

Strategy: L/R asymmetry cancellation

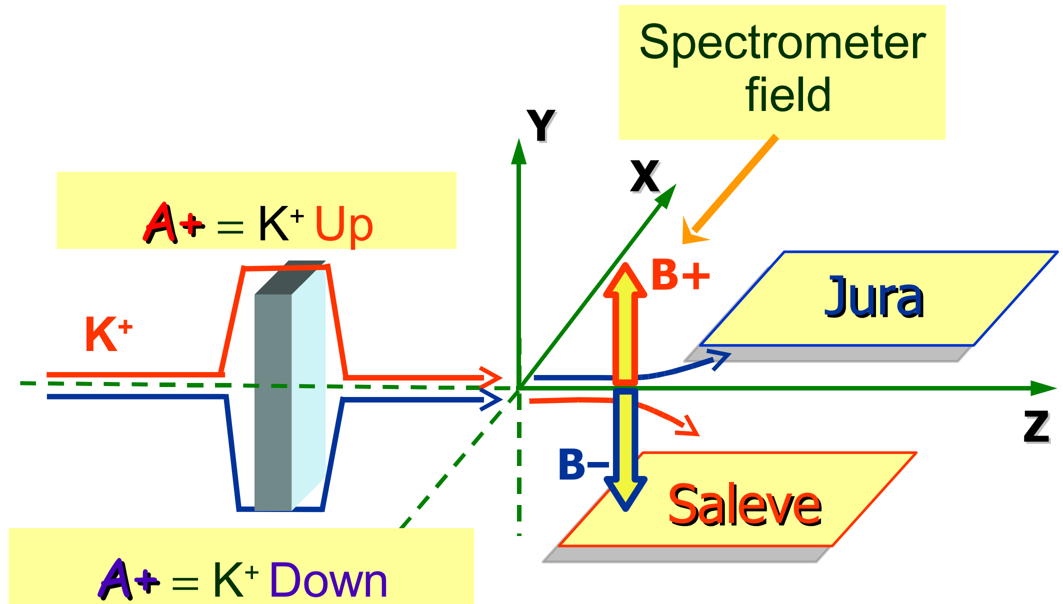
Detector left-right asymmetry cancels
in 4 single ratios of K^+ over K^- N(u) distributions:

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

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

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

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



Indexes correspond to:
beamline polarity (U / D), left/right direction of kaon deviation in spectrometer (S / J)
K samples in numerator and denominator illuminate the same parts of the detector

Strategy: additional cancellations

Use a quadruple ratio to cancel also global time instabilities and beam-line biases:

Normalization   Slope difference

$$R_4 = R_{US} \times R_{UJ} \times R_{DS} \times R_{DJ} \Rightarrow R_4(u) = n\,(1+4\,\Delta g\,u)$$

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

Data samples

- Data taking: 2003 + 2004
- Effective days: ~50 + ~60
- Amount of data recorded: ~16·10^9 triggers ~200 TB
- Sensitivity to rare K decays: BR's down to 10^{-9}

$3.1 \cdot 10^9$ $K^\pm \to \pi^\pm\pi^+\pi^-$	$\sim 0.1 \cdot 10^9$ $K^\pm \to \pi^\pm\pi^0\pi^0$

- ONLY SPECTROMETER
  - Ghost track suppression
  - Select 3-track vertex with smallest χ^2
  - Track time consistency cuts
  - Decay vertex within the fiducial volume
  - Transverse momentum cut

- ONLY LKR & SPECTROMETER
  - At least 4 photons with E > 3 GeV/c
  - At least 1 tracks with p > 5 GeV/c
  - Track-photons time consistency
  - Decay vertex and impact points within the fiducial volume
  - Fiducial distance γ-γ (10 cm) and γ-track (15 cm)

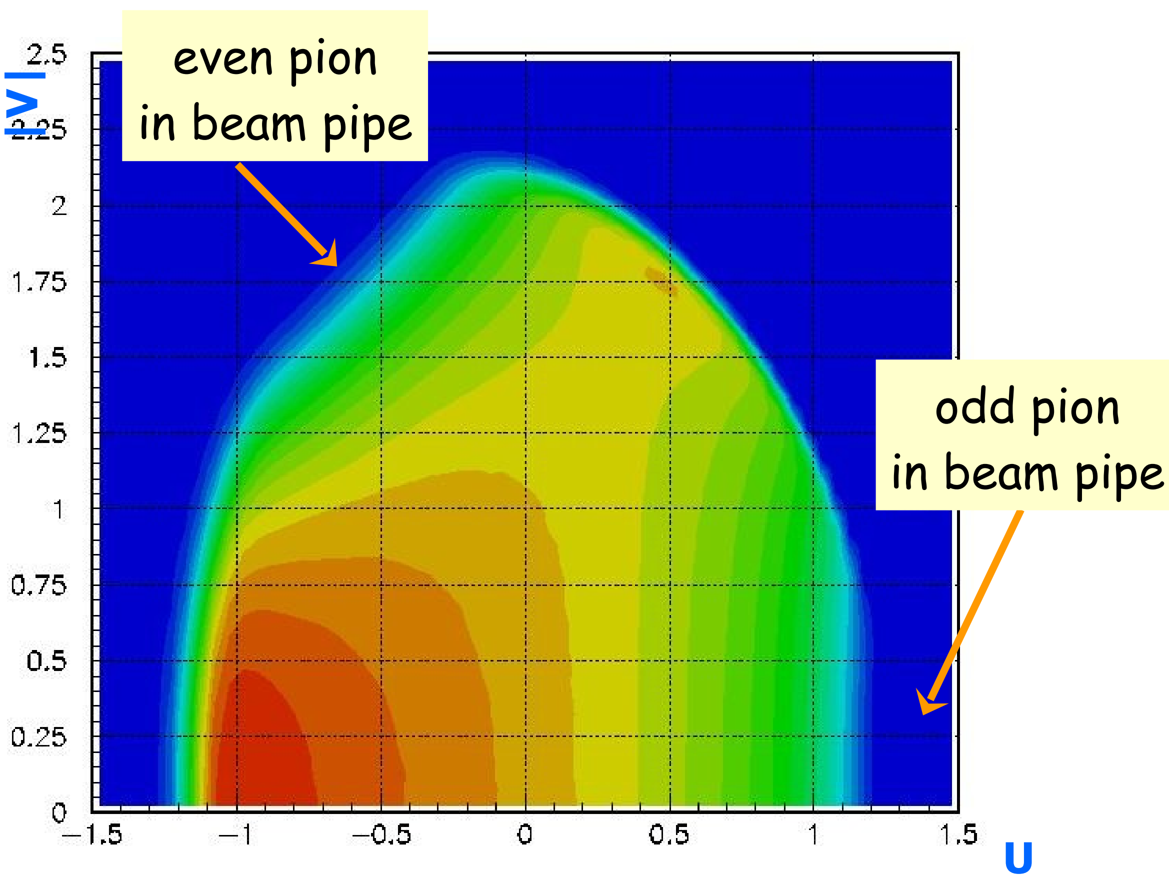
NO RELEVANT BACKGROUND

Dalitz plot of $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$

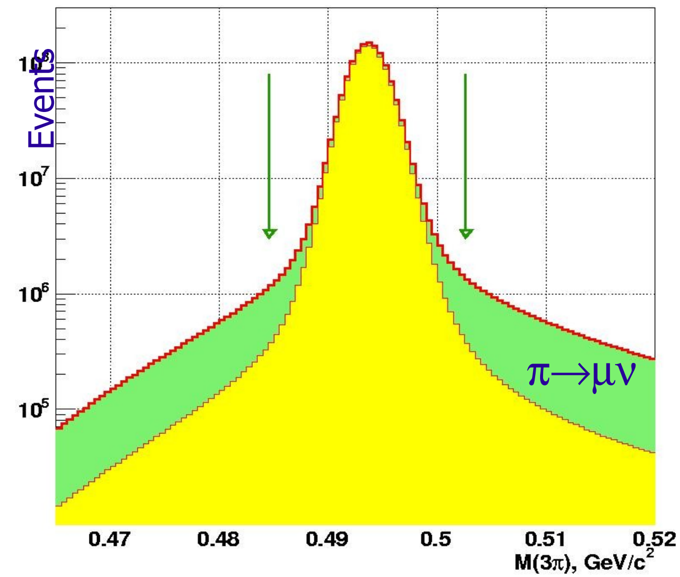
Full statistics:

3.1×10^{9} events selected

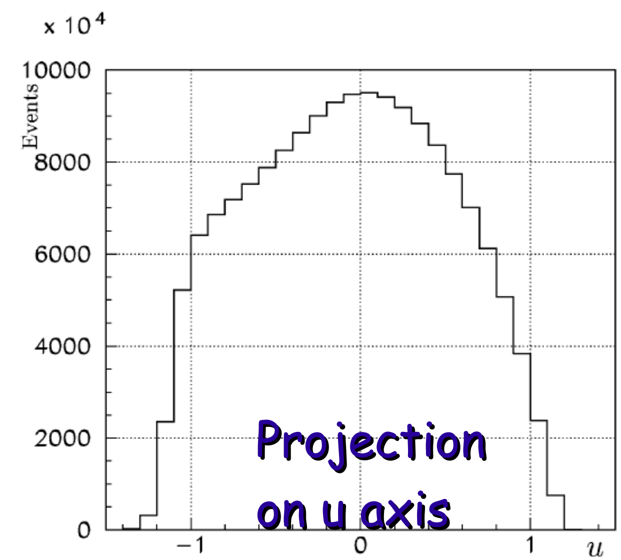
($K^{+} / K^{-} \sim 1.8$)



$\sigma \sim 1.7$ MeV/c^2



$\pi^{+}\pi^{-}\pi^{+}$ invariant mass (GeV/c^2)

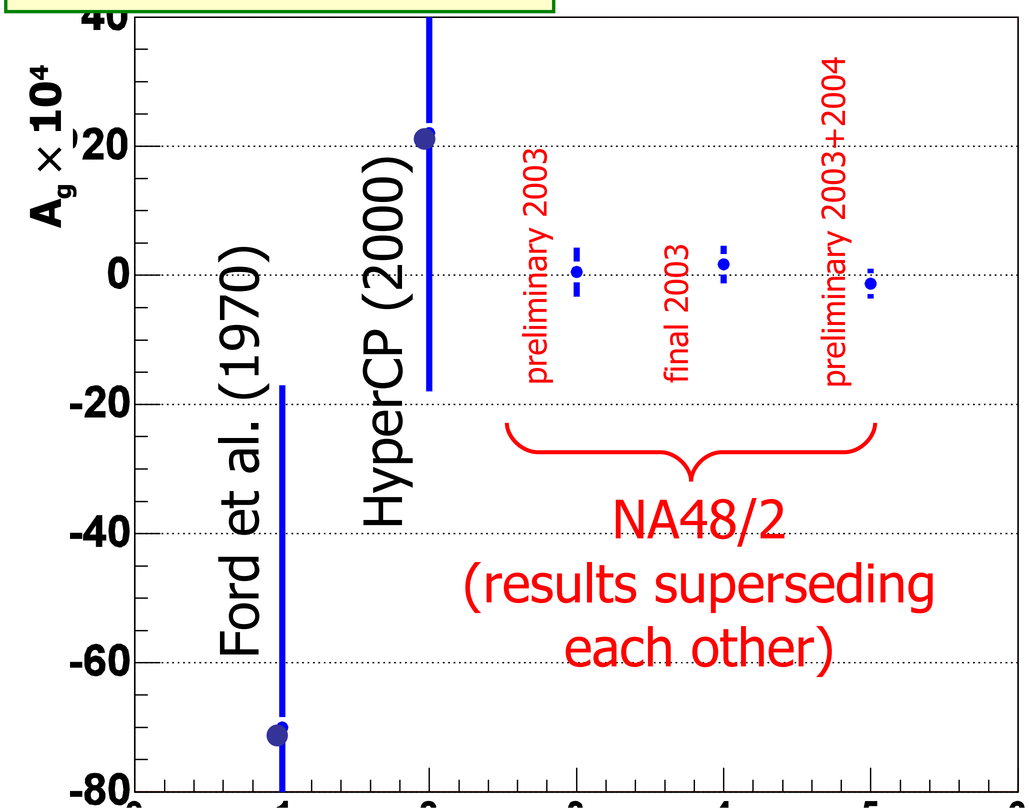


A^C_g measurement results

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

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

Measurements of A^C_g



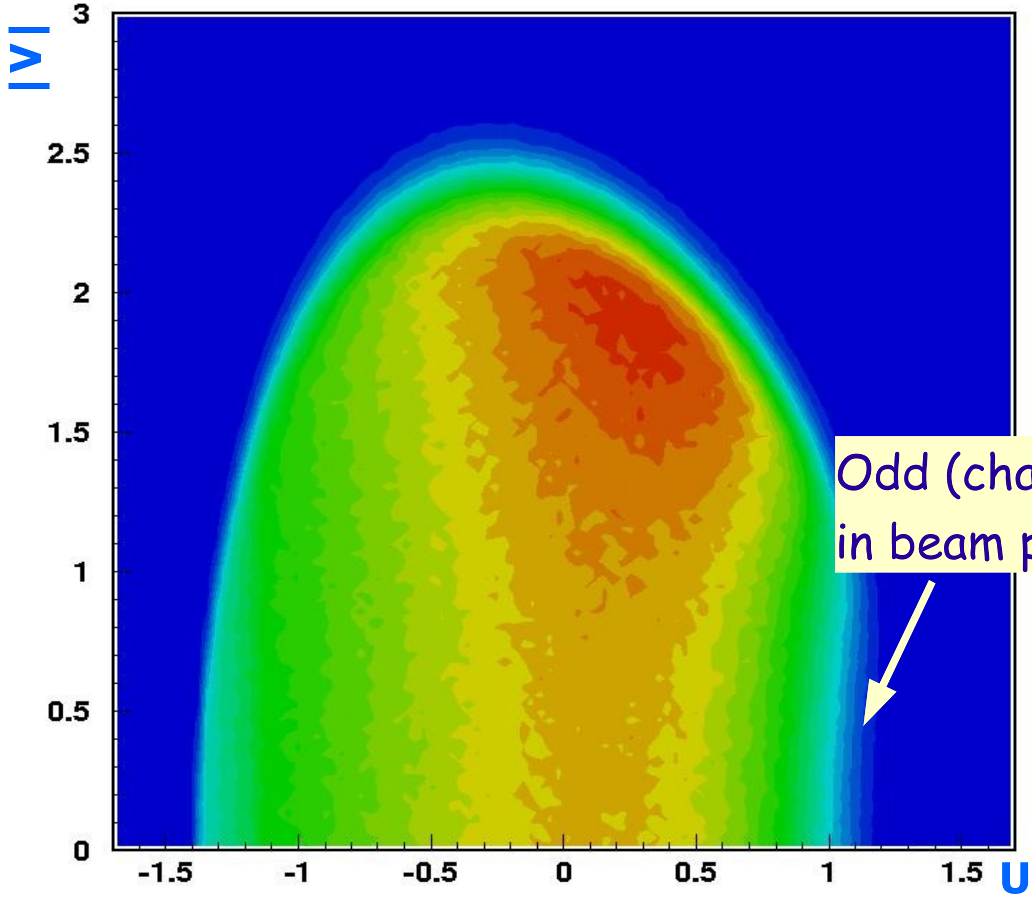
Published result 2003 data:
PLB 634 (2006) 474
2003+ 2004 preliminary

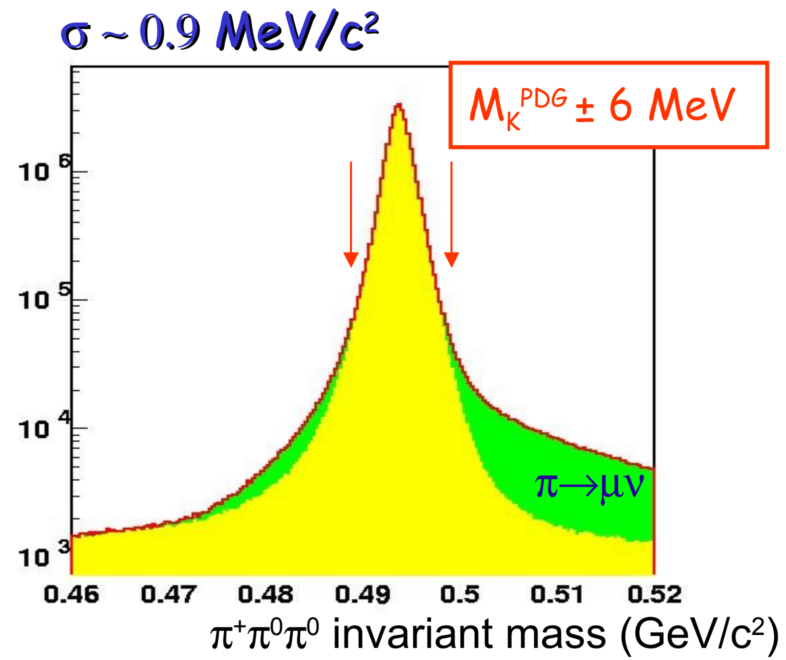
Dalitz plot of $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$

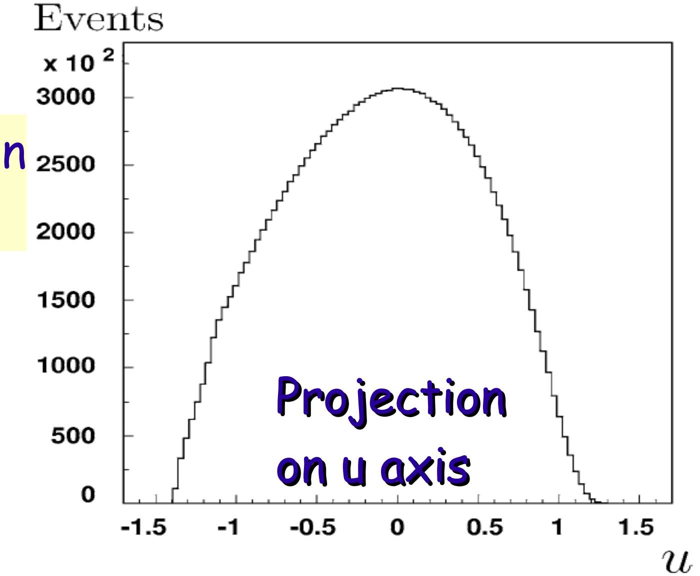
Full statistics:

91×10^6 events selected

($K^+ / K^- \sim 1.8$)





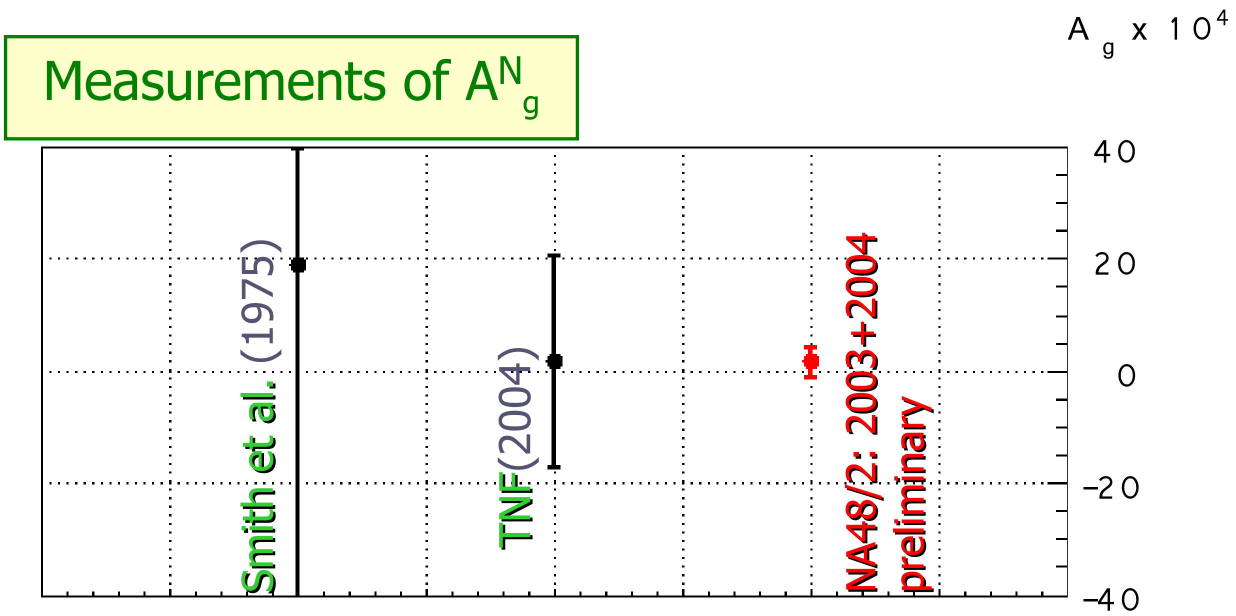


A^N_g measurement results

$A^N_g = (2.1 \pm 1.6_{stat} \pm 1.0_{syst} \pm 0.2_{ext}) \times 10^{-4}$

$\mathbf{A^N_g = (2.1 \pm 1.9) \times 10^{-4}}$

Published result:
PLB 638 (2006) 22
2003+2004 preliminary



Conclusions

- $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ mode:
  - Preliminary NA48/2 result on full statistics:

    $A^{C}_{g} = (-1.3 \pm 2.3) \cdot 10^{-4}$

(for 2003 data PLB 634 (2006) 474)

- $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ mode:
  - Preliminary NA48/2 result on full statistics:

    $A^{N}_{g} = (+2.1 \pm 1.9) \cdot 10^{-4}$

(for 2003 data PLB 638 (2006) 22)

- Errors are dominated by statistics.
- Results 10 times more accurate than past measurements
- No CPV $A^{C,N}_{g}$ found at few 10^{-4}
- Results are not in disagreement with SM predictions