



V.Kekelidze

October 26, 2004

Experiment NA48/2

**A Precision Measurement of Charged Kaon
Decay Parameters** (*CERN/SPSC 2000-003*)

Status Report (*SPSC-2004-030*)

Collaboration:

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



Content

- *Physics motivation & Goals*
- *Experiment configuration*
- *Data collected*
- *Asymmetry*
- *Rare decays*
- *First Observation of a Threshold Effect*
- *Leptonic & Semileptonics*
- *Summary*
- *Resources*



Physics motivation

High Precision Study of Charged Kaon Decays

as probes for:

- **Qualitative** tests of the SM
& search for **new physics**
- **High accuracy** tests of low energy QCD (χ PT)
- **Quantitative** tests of different model predictions



Goals

➤ Direct CP violation

in $K^\pm \rightarrow \pi^\pm \pi^\pm \pi^\mp$, $K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$

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

$$M(u) \propto 1 + \mathbf{g} \cdot \mathbf{u}, \quad \mathbf{u} = f(E_{\pi\text{-odd}}^*)$$

$$\delta(A_g) < 2 \cdot 10^{-4} \quad (\text{limited by statistics})$$

Requirements to experiment:

- *high statistics* ($> 2 \cdot 10^9$ decays)
- *stability in time*
- *set-up symmetry*



A_g : theory & experimental limits

$|A_g|$

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

← *experiments by 2002*

new physics

SUSY

NA48/2

SM

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*G.D'Ambrosio,G.Isidori,
G.Martinelli-99*

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I.Scimemi-04

G.D'Ambrosio-97

L.Maiani,N.Paver-95



Goals (continuation)

➤ **K_{e4}** to measure π - π scattering length $\delta(a_0^0) < 1 \cdot 10^{-2}$
required statistics $> 10^6$ (430k)

➤ **Rare decays** to test χ PT & search for **A_{CP}**

$$K^\pm \rightarrow \pi^\pm \gamma \gamma, \quad K^\pm \rightarrow \pi^\pm \pi^0 \gamma_{DE}$$

$$K^\pm \rightarrow \pi^\pm e^+ e^-, \quad K^\pm \rightarrow \pi^\pm \mu^+ \mu^-, K_{e2}^\pm$$

$$K^\pm \rightarrow l^\pm \nu l^+ l^-$$

$$K^\pm \rightarrow \pi^\pm \pi^0 \gamma \gamma, \quad K^\pm \rightarrow \pi^\pm \pi^0 l^+ l^-, \dots \text{ etc.}$$

➤ **Semileptonic decays:**

$$K_{e3}^\pm, K_{\mu3}^\pm$$

BR's \Rightarrow to improve precision of **$|V_{us}|$**

& check **CKM** unitarity,

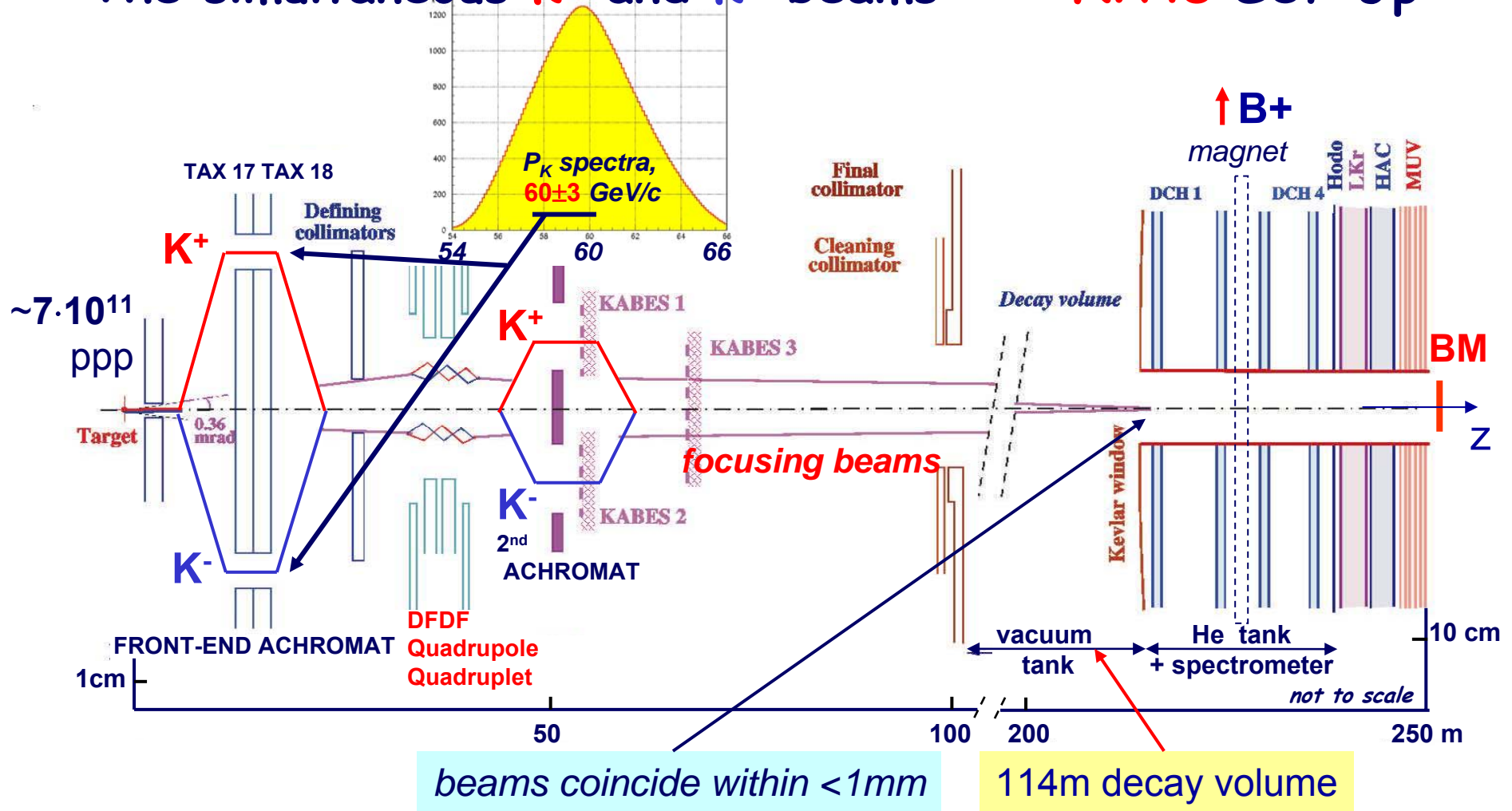
form-factors \Rightarrow to search for **f_T, f_S**



NA48/2 experiment configuration

The simultaneous K^+ and K^- beams

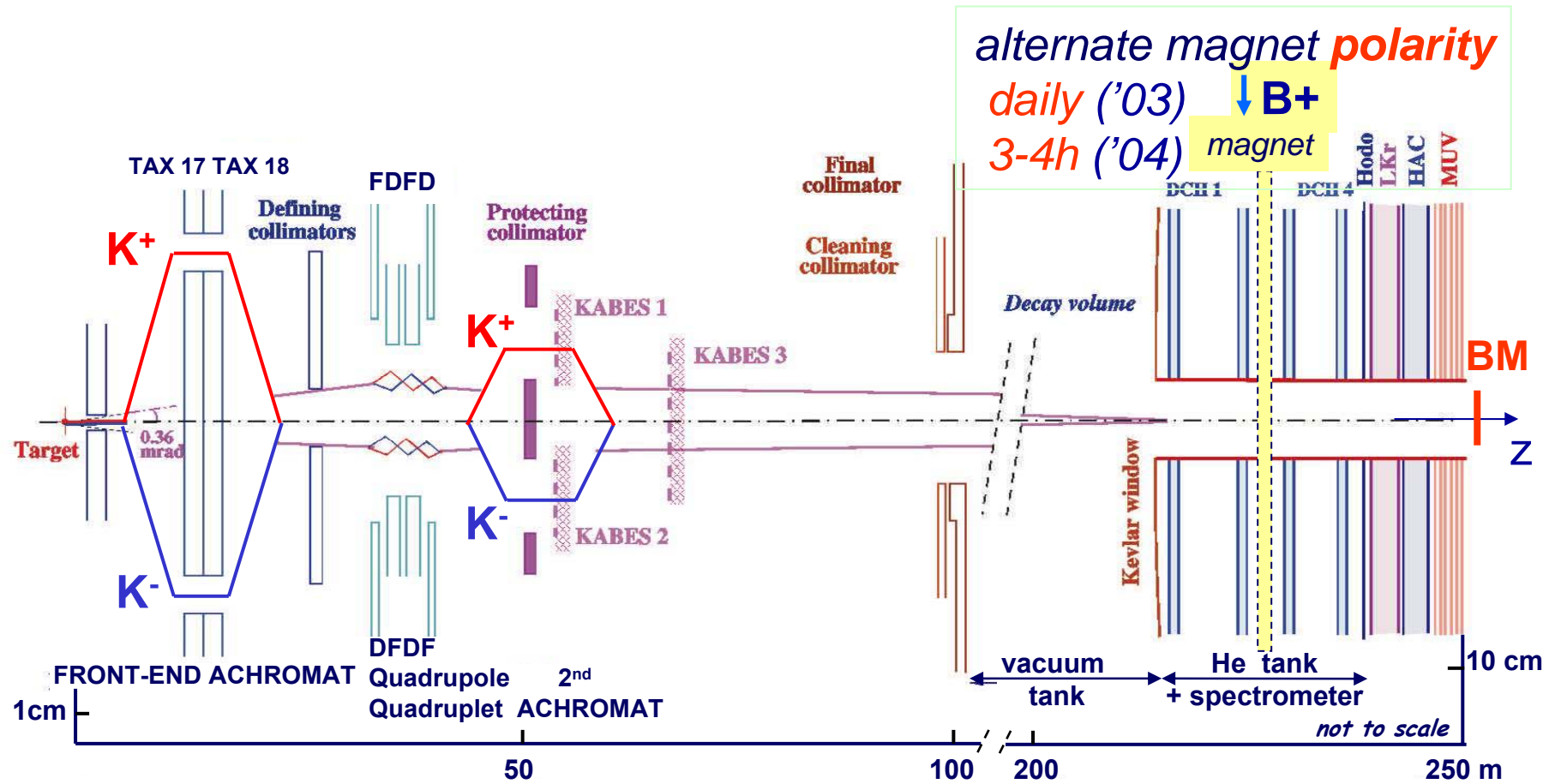
NA48 Set-Up





NA48/2 experiment configuration

NA48 Set-Up



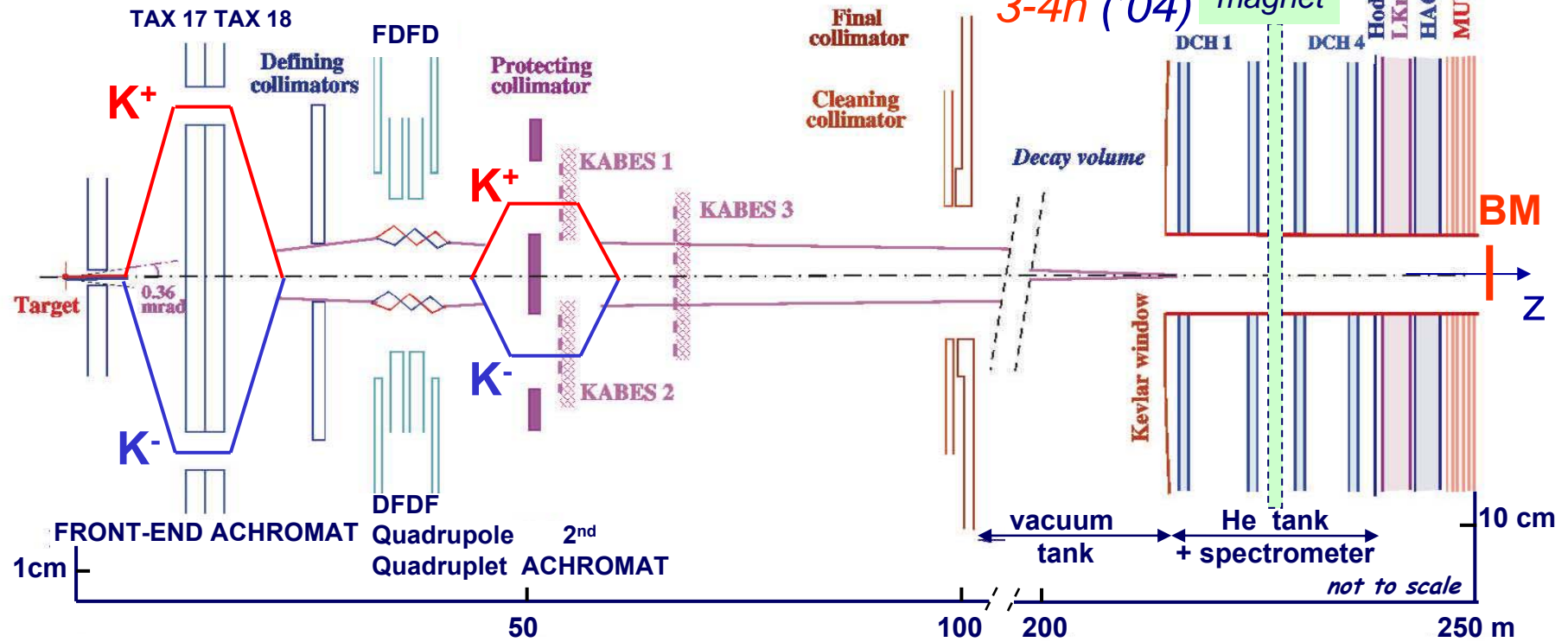


NA48/2 experiment configuration

NA48 Set-Up

alternate magnet *polarity*

daily ('03) \uparrow B+ magnet
3-4h ('04)

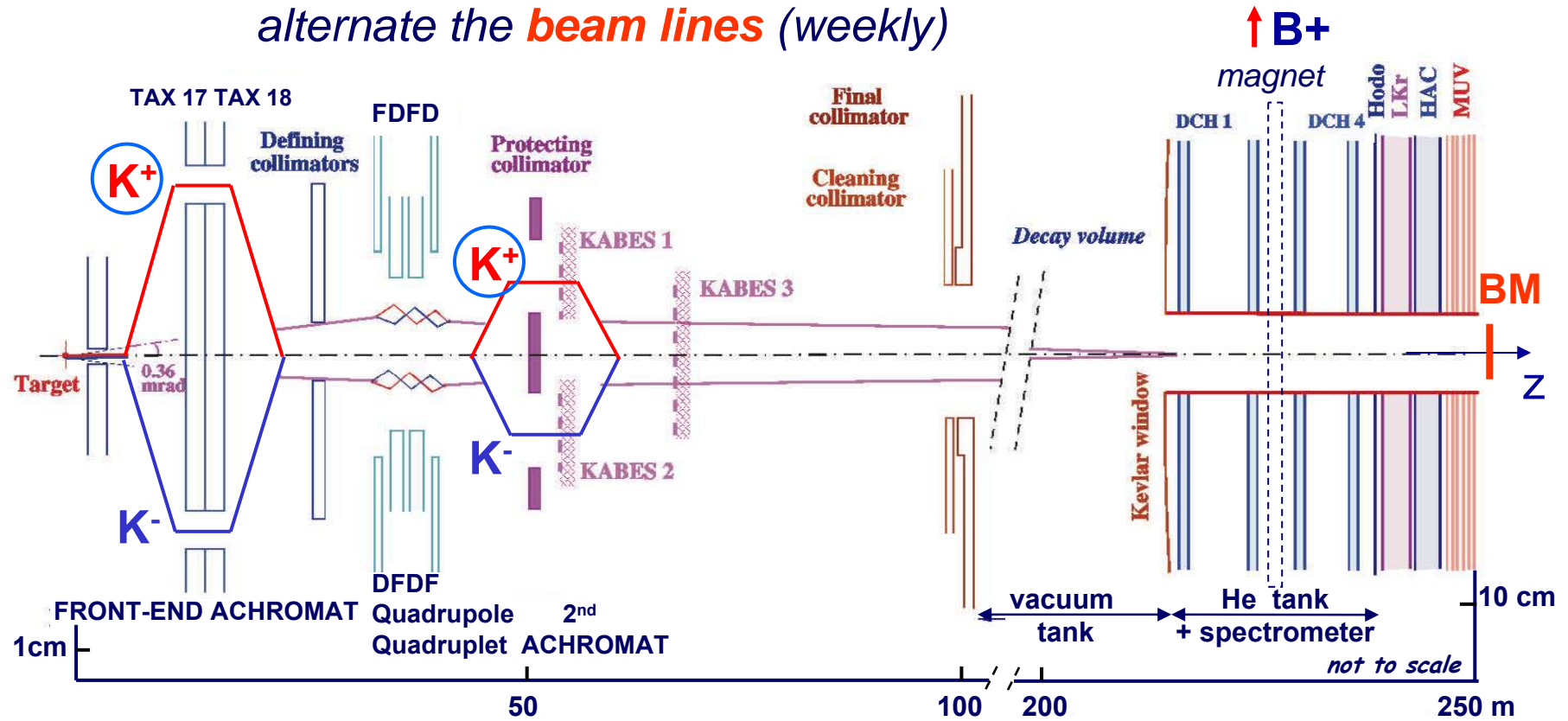




NA48/2 experiment configuration

The simultaneous K^+ and K^- beams

alternate the *beam lines* (weekly)

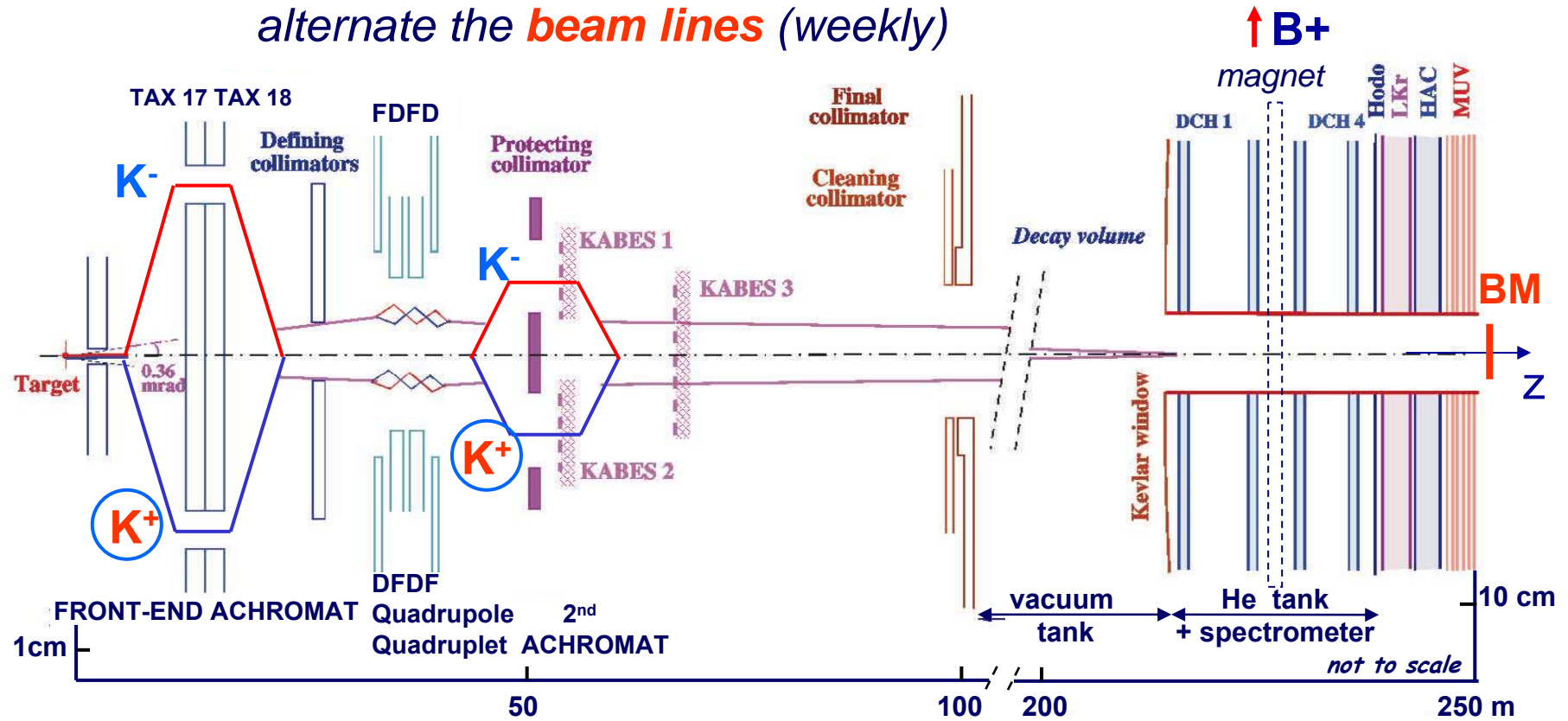




NA48/2 experiment configuration

The simultaneous K^+ and K^- beams

alternate the *beam lines* (weekly)





NA48/2 runs





Statistics

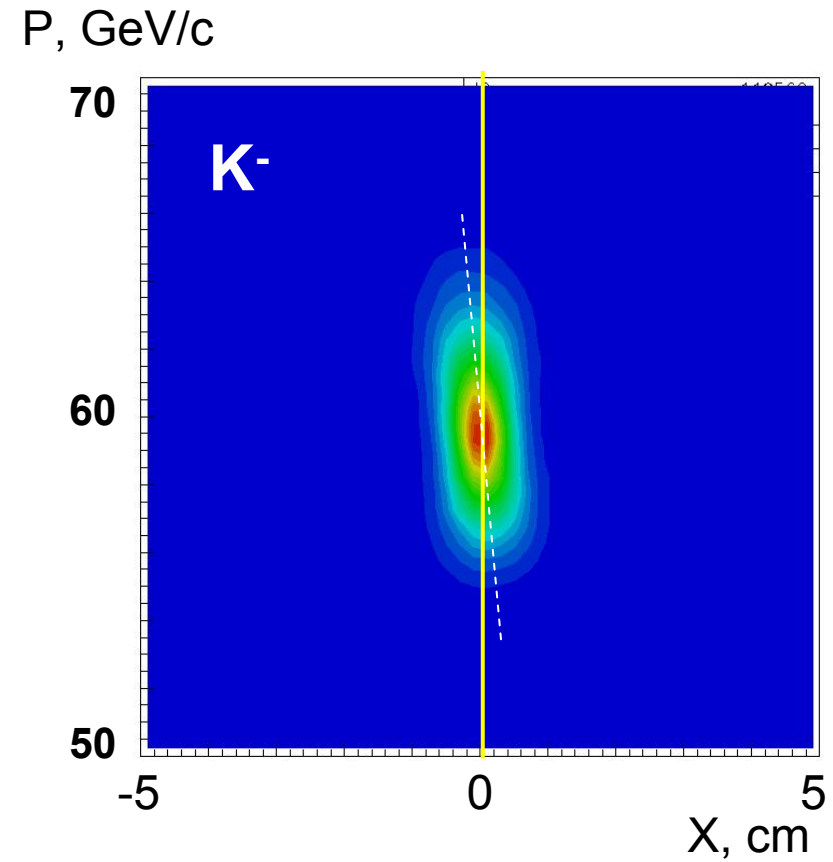
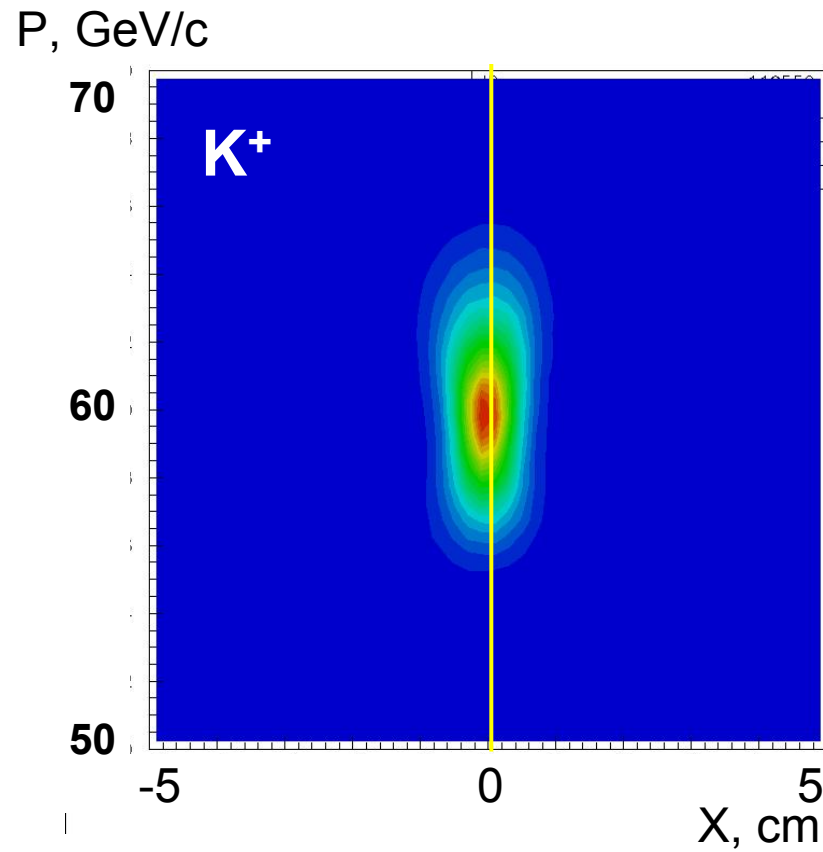
Run	recorded events, 10^6		# of Super-Samples (complete cycles)
	$K^{\pm} \rightarrow \pi^- \pi^+ \pi^{\pm}$	$K^{\pm} \rightarrow \pi^0 \pi^0 \pi^{\pm}$	
2003-I	~ 600	~20	non-stable conditions
2003-II	1 300	50	3 (<i>analyzed</i>)
2004	2150	130	5
Total	~ 4 050	~ 200	8

analysis is well advanced for

~ **1 month** of data taking in **2003** at stable conditions

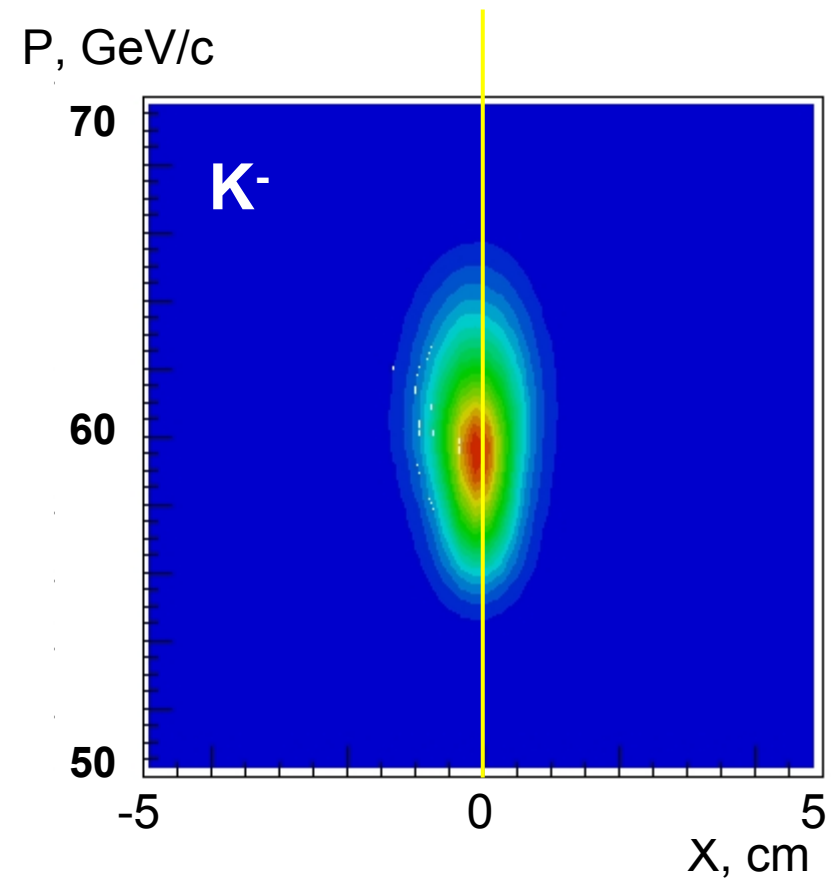
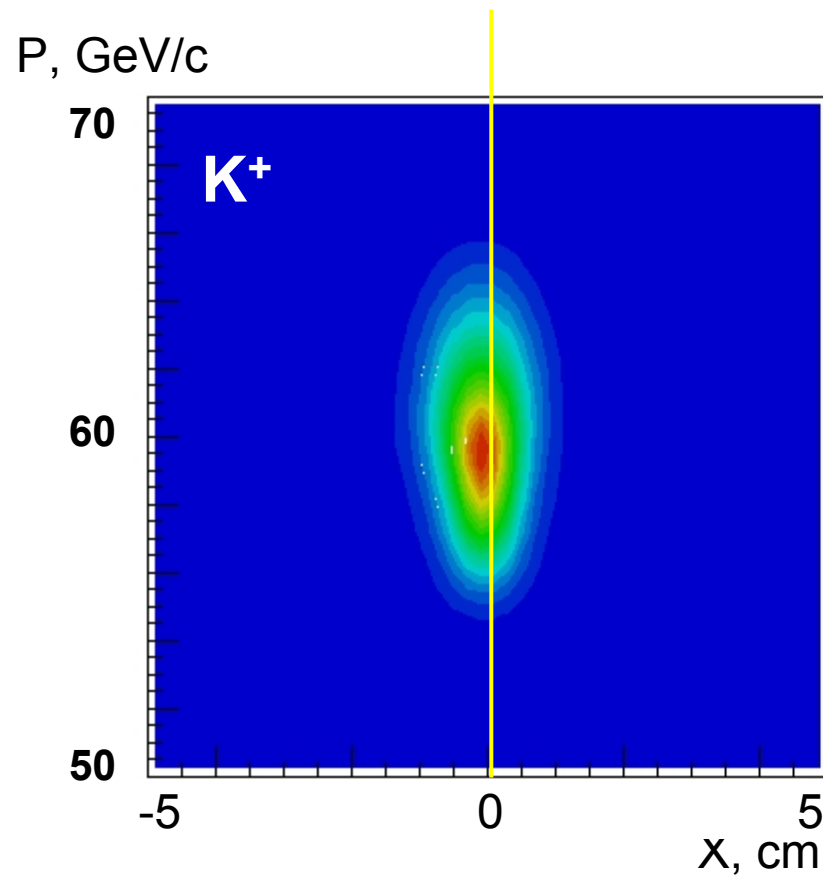


Beam position on DCH1 in 2003 (P_K vs X)





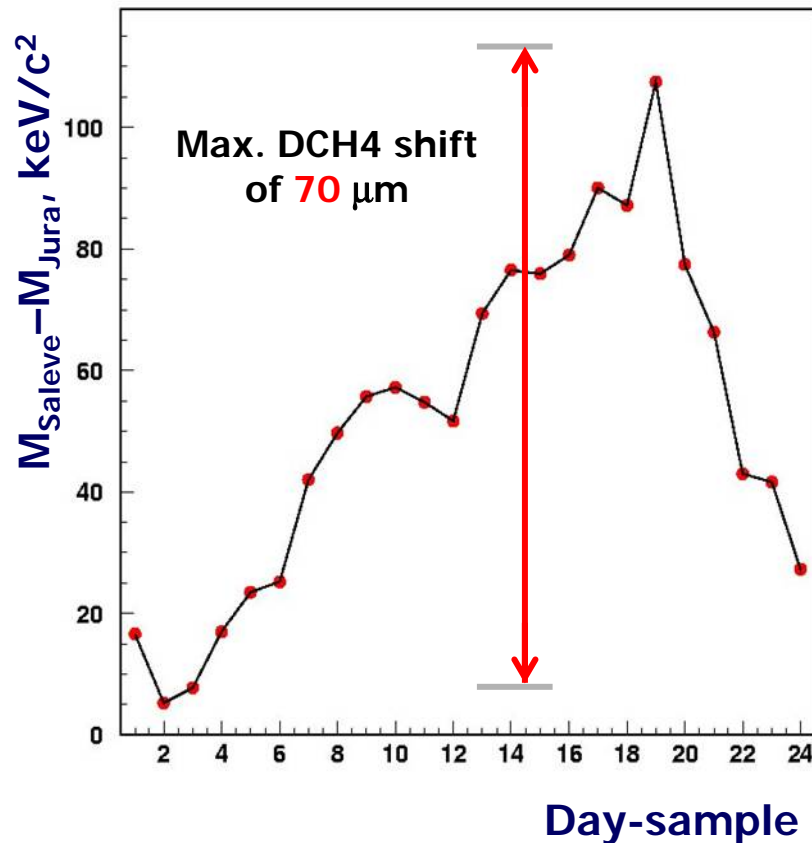
Beam position on DCH1 in 2004 (P_K vs X)





Spectrometer calibration in 2003

Time-dependence of alignment



3 μ -run interpolation

Momentum correction for residual misalignment:

- $P = P_0 \cdot (1 + \beta) \cdot (1 + qb\alpha P_0)$
 P_0 – measured momentum;
 P – corrected momentum;
 q – track charge;
 b – magnetic field sign.
- **Time-dependent corrections:**
 - β – for magnetic field integral
 - α – for spectrometer misalignment

Run 2004 has more stable geometry (+ regular μ -runs)



Asymmetry Analysis

SS1-3:

~1 month of running in 2003



Selection criteria

- radial cuts around the beam centres (in DCH1,4)
to ***symmetrize*** acceptances
- day-by-day definition of the beam COG's in each momentum bin
to ***reduce*** acceptance ***variations in time***

Conservative cuts:

$$R_{\pi}(\text{DCH1}) > 11.5 \text{ cm}$$

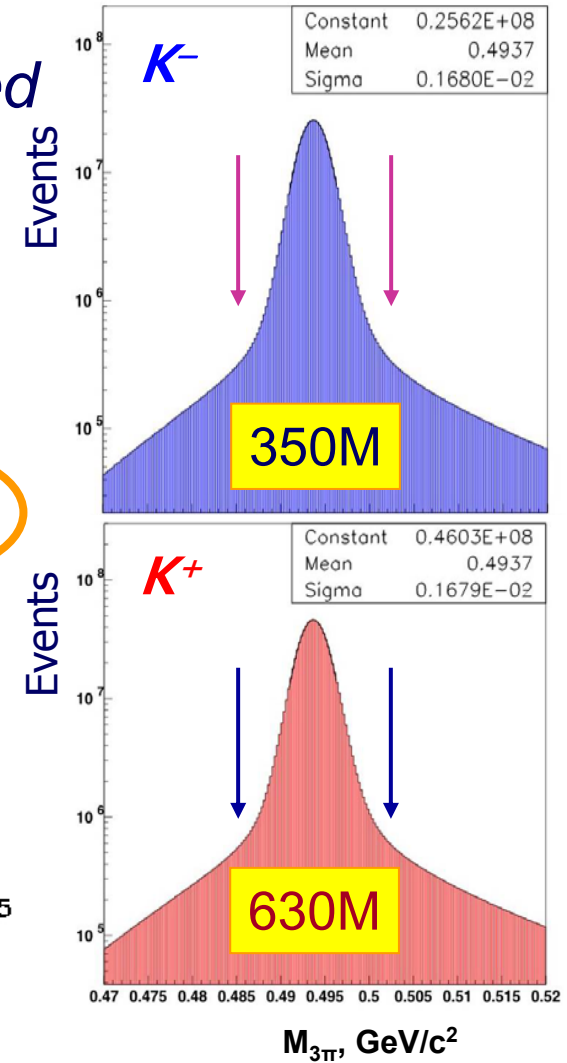
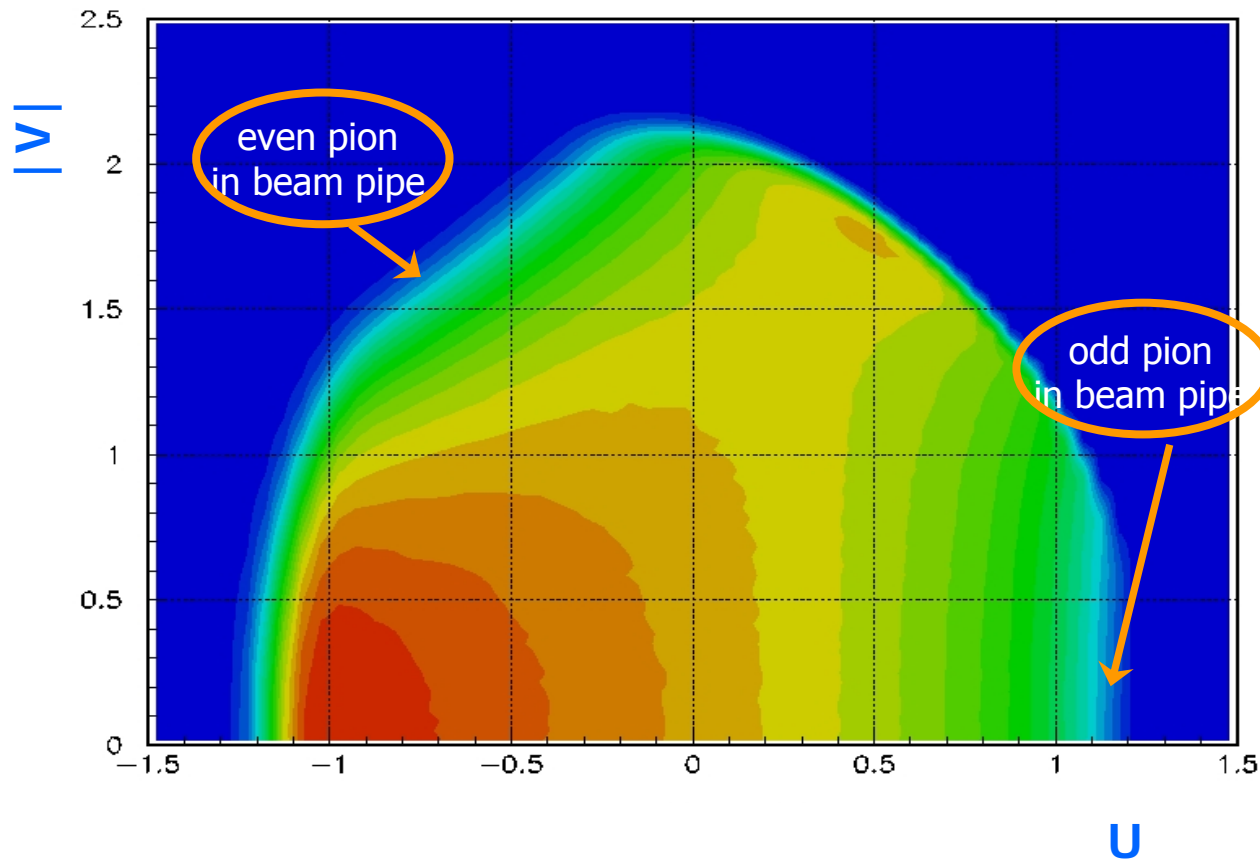
$$R_{\pi}(\text{DCH4}) > 13.5 \text{ cm}$$

leave 75% of raw statistics
(***beam stability dependent***)



Dalitz plot for $K^\pm \rightarrow \pi^\pm \pi^+ \pi^-$ & $M(3\pi)$

SS1-3 data: > 980 million events selected





A_g measurement (*acceptance cancellation*)

Physical asymmetries:

- A_S → slope of ratio $U(K^+ B^+) / U(K^- B^-)$
- A_J → slope of ratio $U(K^+ B^-) / U(K^- B^+)$

Apparatus-induced asymmetries:

- A^+ → slope of ratio $U(K^+ B^+) / U(K^+ B^-)$
- A^- → slope of ratio $U(K^- B^+) / U(K^- B^-)$

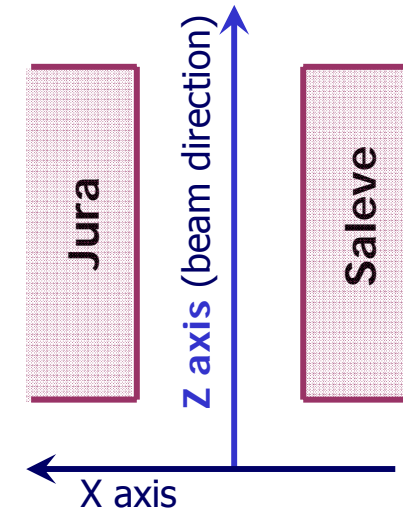
- $A_{SJ} = (A_S + A_J)/2 \approx \Delta g = A_g \cdot 2g \Rightarrow$ *physics asymmetries*
(to mask the results A_{SJ} , A_S & A_J are presented with **OFFSETS** !)

- $A^\pm = (A^+ + A^-)/2 = (A_S - A_J)/2$

\Rightarrow *asymmetry induced by the experimental setup*

(many of the effects observed in A^\pm cancel in A_{SJ})

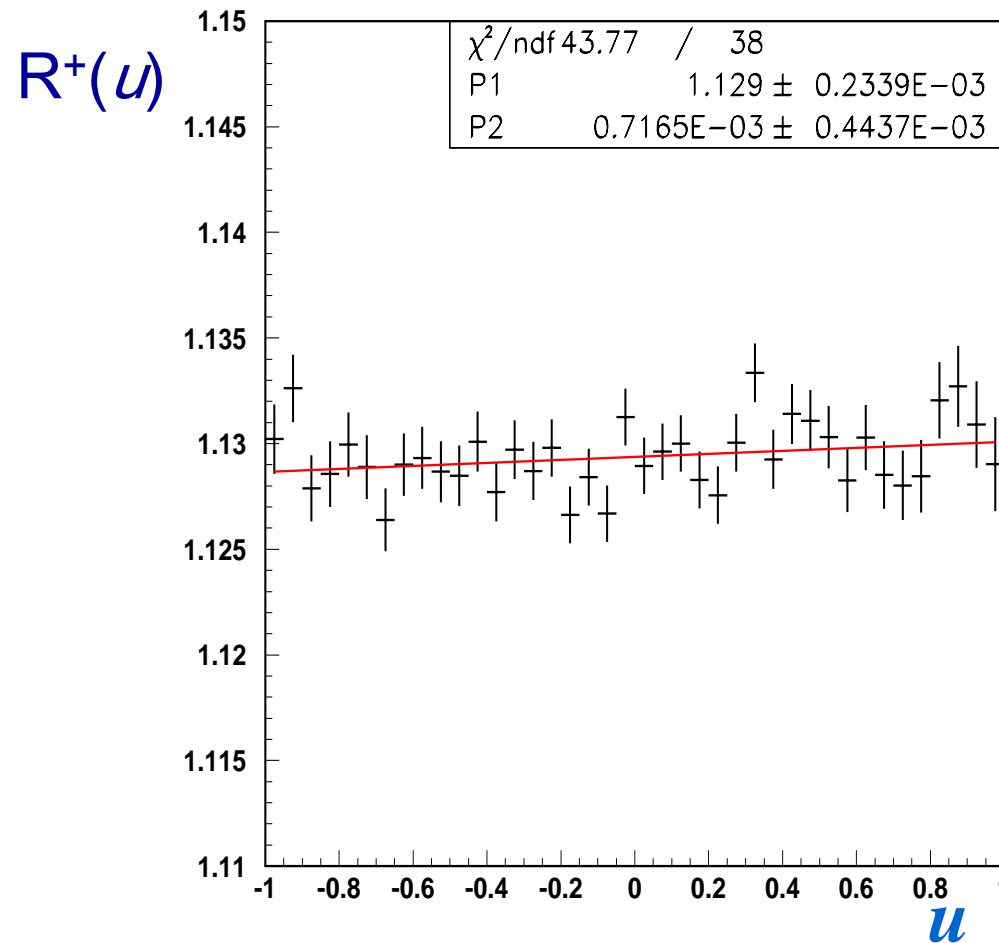
Top view of the setup





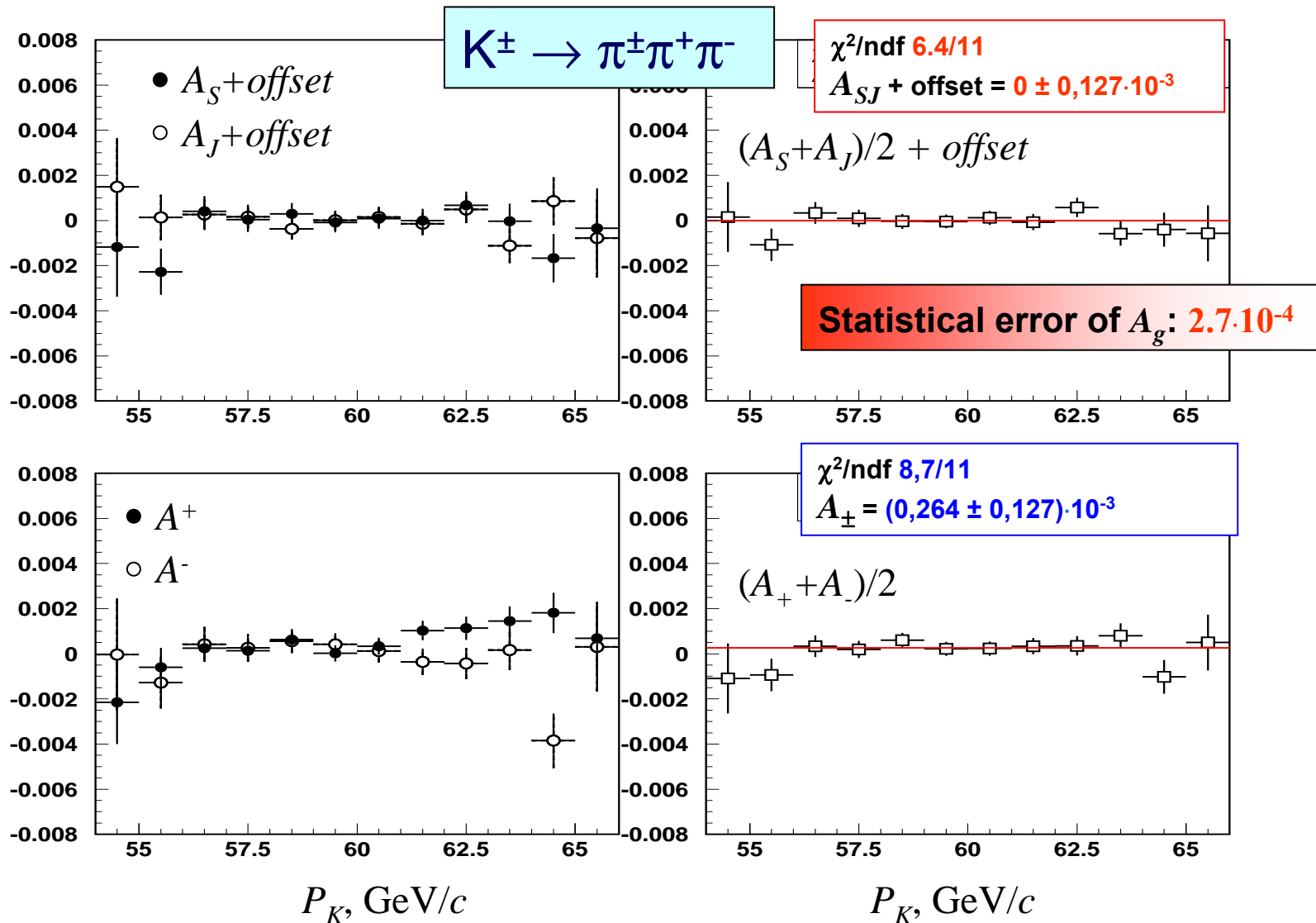
Ratio of u -spectra for P_K : 58-59 GeV/c

$$R^+(u) = U(K^+ B^+) / U(K^+ B^-)$$



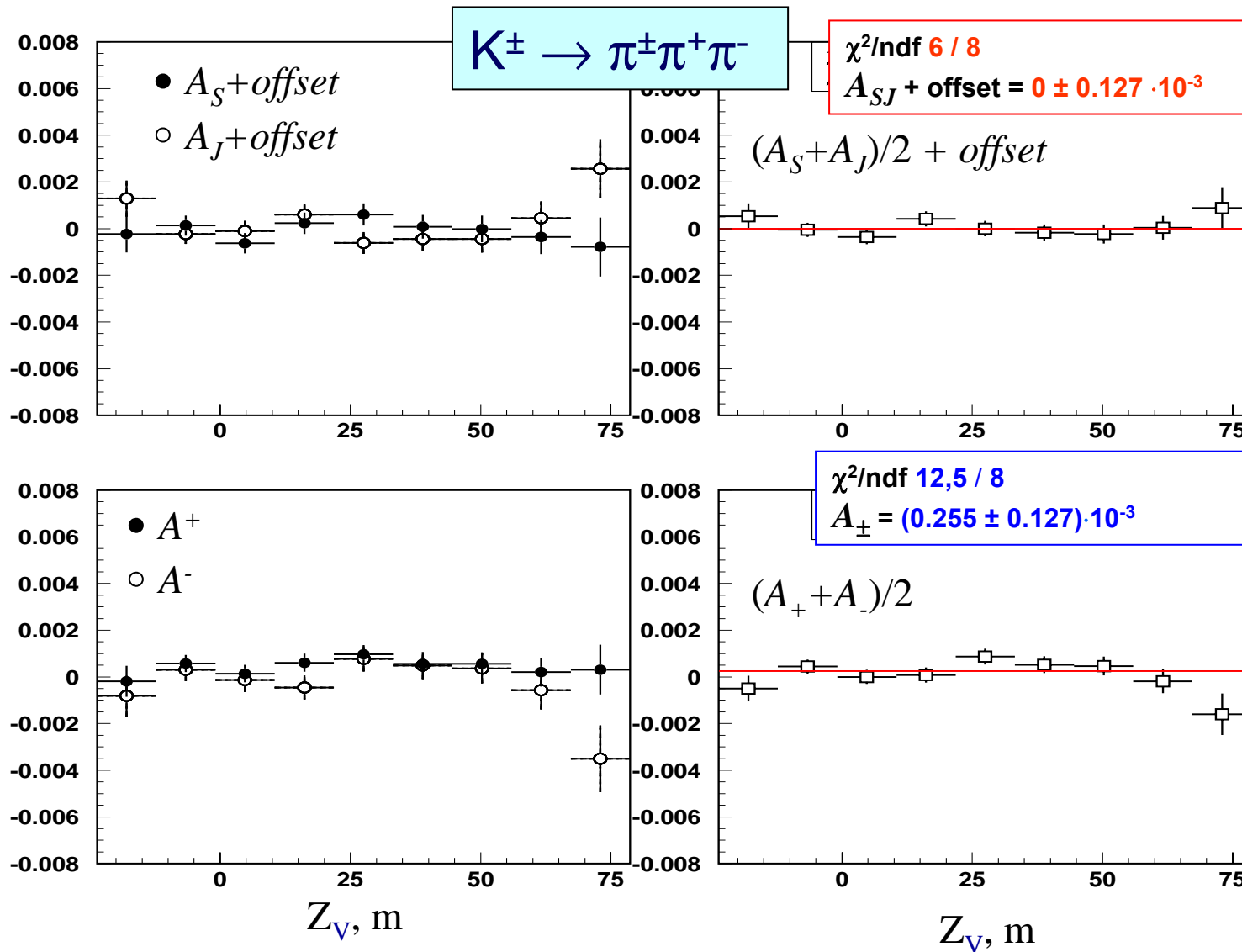


Asymmetry in P_K bins



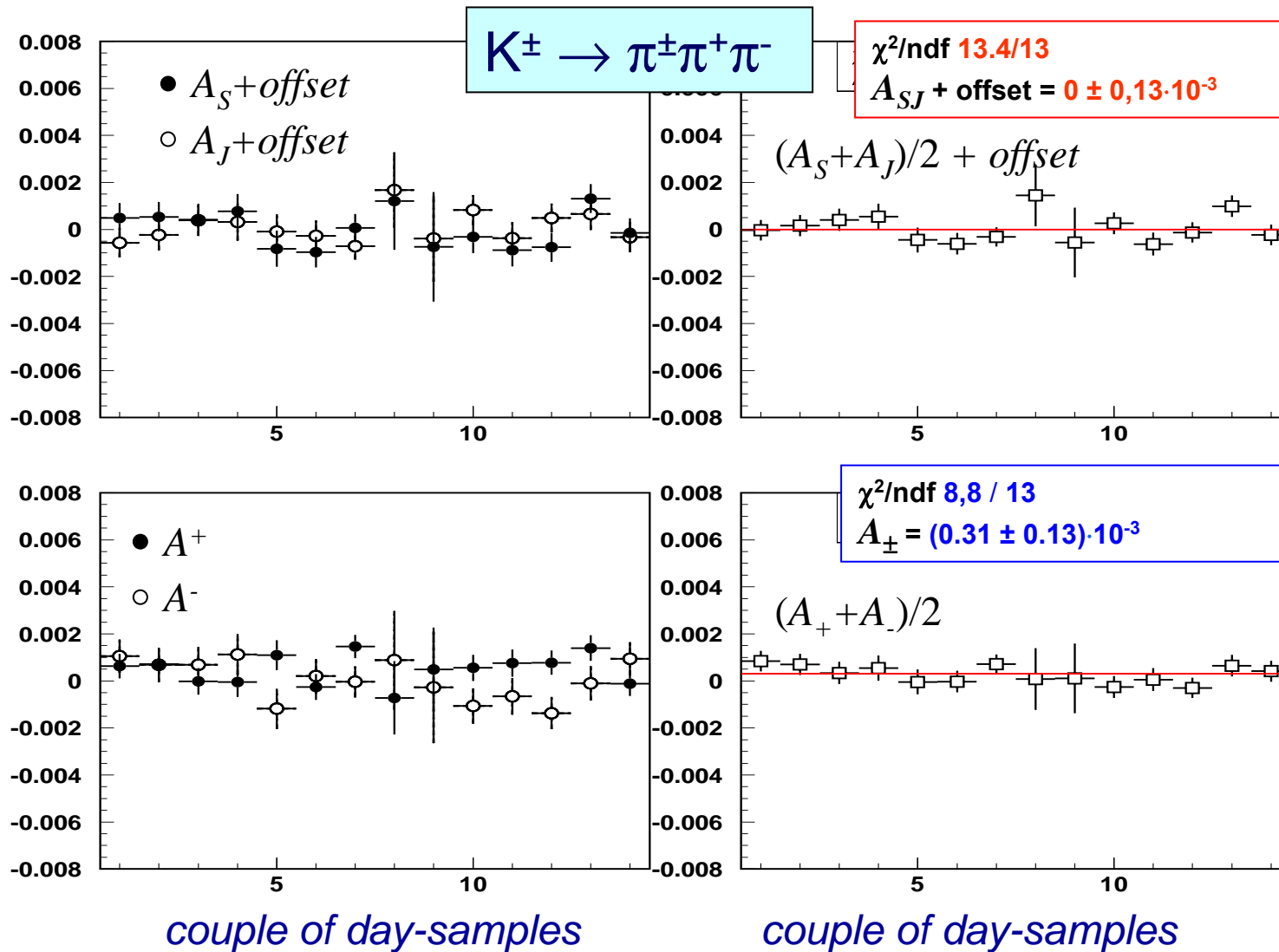


Asymmetry in Z_{vrtx} bins





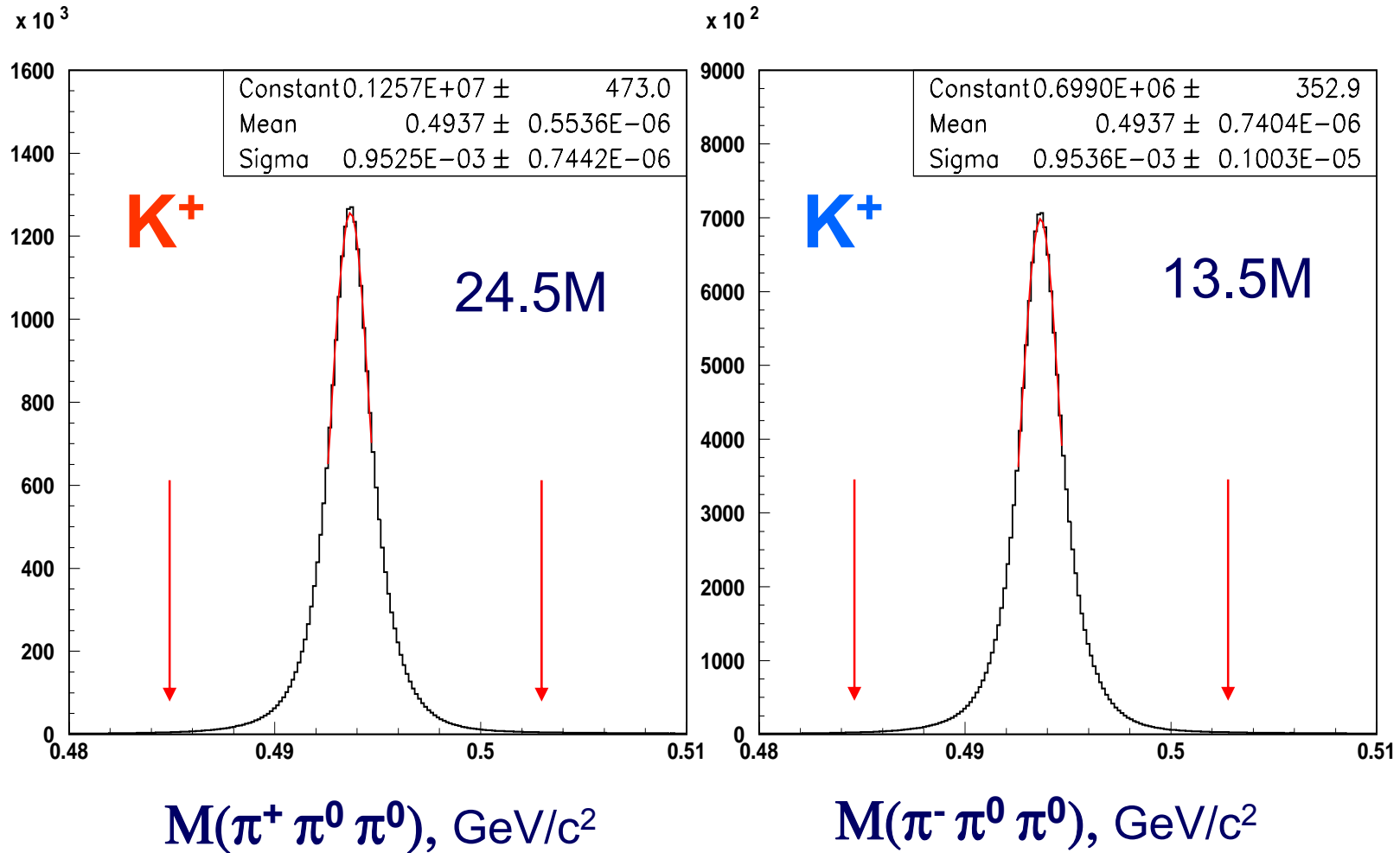
Asymmetry time dependence





$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0$ decay selected

38 millions





Results on A_g

one month of NA48/2 data taking in 2003:

- $K^\pm \rightarrow \pi^+ \pi^- \pi^\pm$ $A_g^c = (\blacksquare \pm 2.7) \cdot 10^{-4}$
- $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$ (38M events) $A_g^0 = (\blacksquare \pm 5.0) \cdot 10^{-4}$

*uncertainties dominated by the **statistical errors!***

■ Other experiment data on A_g^c

- BNL (1970): $(-7.0 \pm 5.3) \cdot 10^{-3}$
- FNAL, HyperCP –2000 (*preliminary*) $(2.2 \pm 1.5 \pm 3.7) \cdot 10^{-3}$

■ Serpukhov data on A_g^0

- I.V.Ajinenko et al., PLB567(2003)159.: $(5.1 \pm 2.8) \cdot 10^{-3}$
- G.A.Akopdzhanov, hep-ex/0406008 *prelim.*: $(0.2 \pm 1.9) \cdot 10^{-3}$



Rare Decays

SS1-3:

~1 month of running in 2003

 $K^{\pm} \rightarrow \pi^+ \pi^- e^{\pm} \nu$ (K_{e4}) decays

➤ Physics interest:

- Low energy $\pi\text{-}\pi$ scattering length

predicted by χ PT first principles

$$a_0^0 = 0.220 \pm 0.005 \quad \text{related to the } q\bar{q} \text{ QCD condensate}$$

[Colangelo, Gasser, Leutwyler, *hep-ph/0103088*]

- a_0^0 can be determined from the form-factors of K_{e4} decays

➤ Previous measurements:

- Geneva-Saclay (1977): 30,000 events
- Brookhaven E865 (2001): 400,000 events

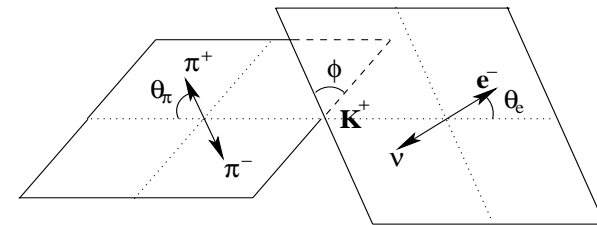
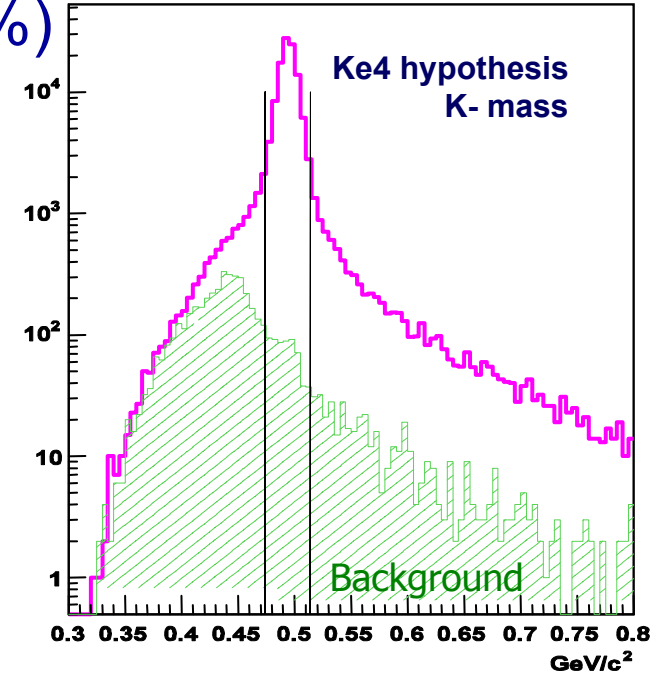
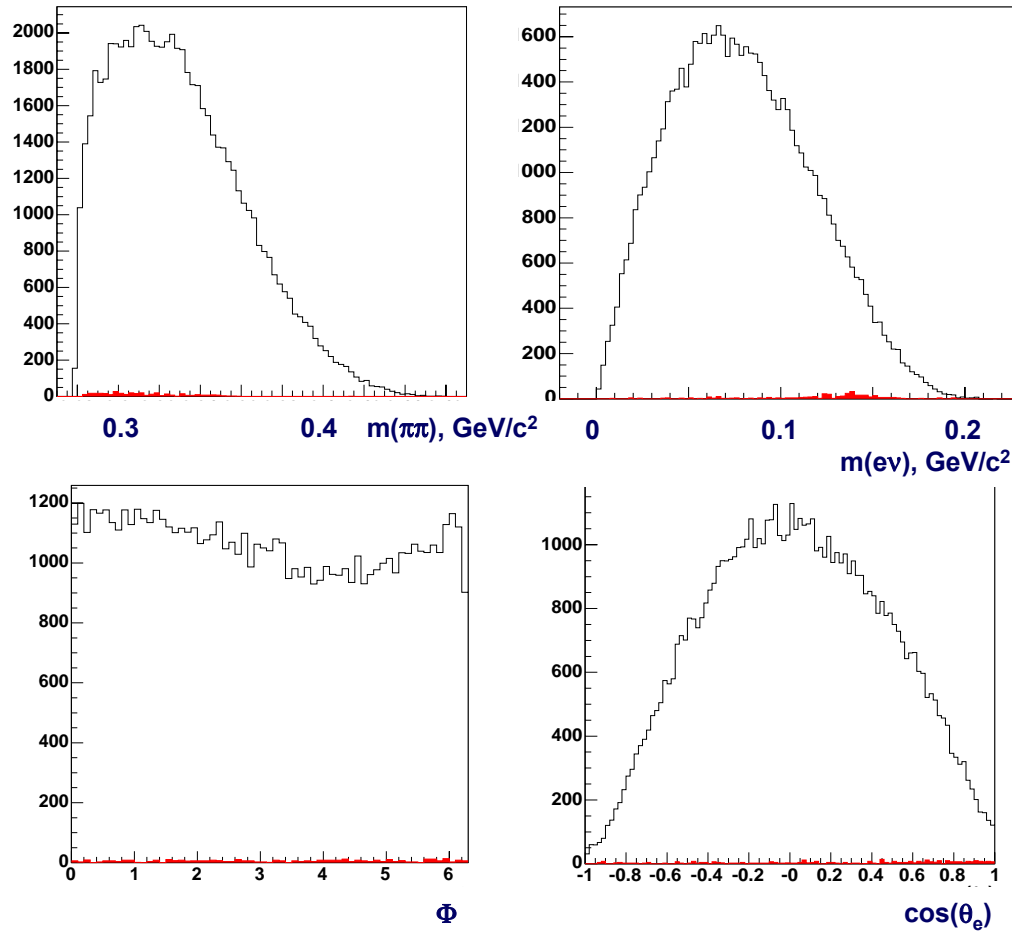
$$a_0^0 = 0.216 \pm 0.013_{\text{stat}}$$

- 2 experiments: *errors* > *theoretical uncertainties*



$K^\pm \rightarrow \pi^+ \pi^- e^\pm \nu$ (K_{e4}) selection (preliminary)

2003 data: > 500k (background ~0.6%)

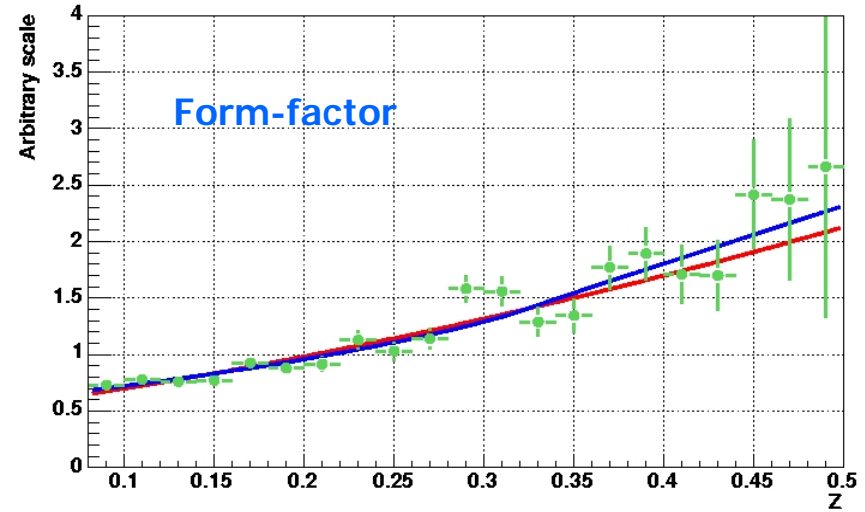
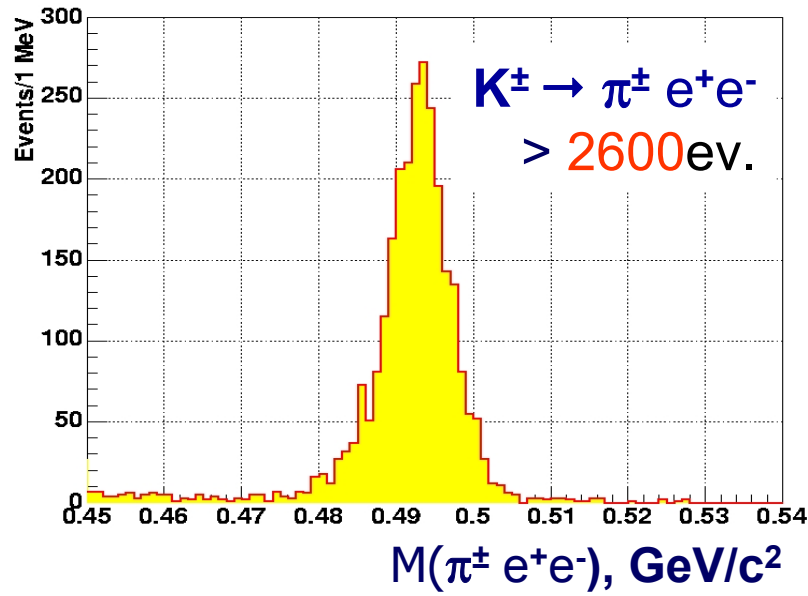


Cabibbo-Maksymowicz variables [backgr. in red]

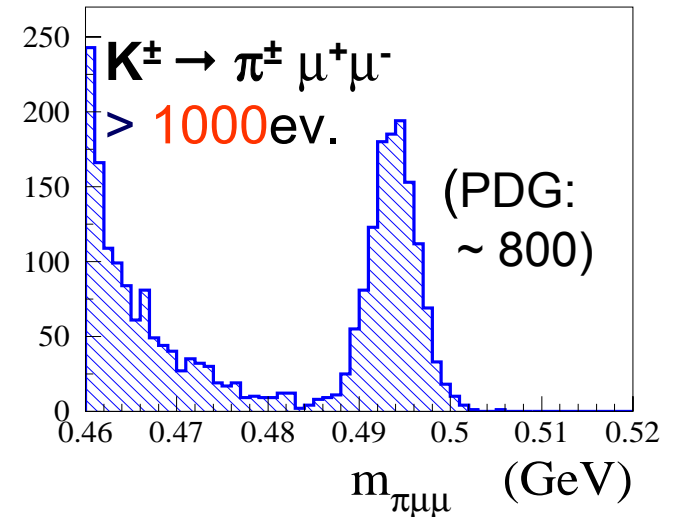
2004 data: expected > 500k



$K^\pm \rightarrow \pi^\pm e^+ e^-$ & $K^\pm \rightarrow \pi^\pm \mu^+ \mu^-$ selection (preliminary)



- low background (1-2%)
- expected data sample in 2003-2004 comparable to the World best sample



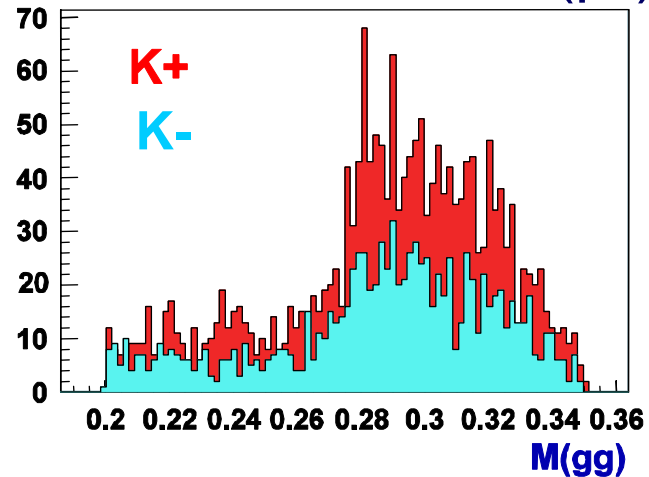
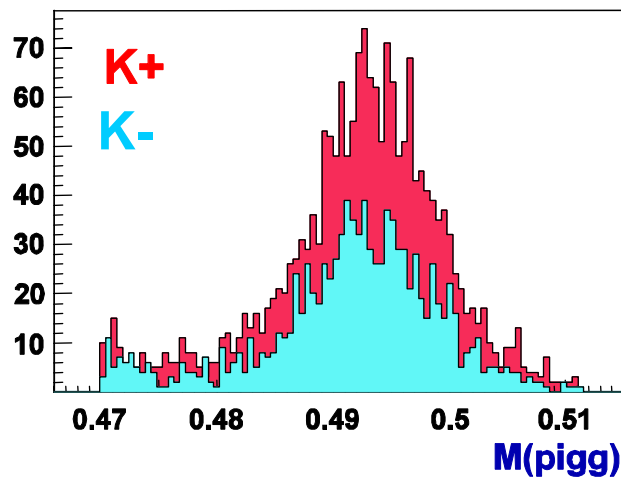


$K^\pm \rightarrow \pi^\pm \gamma \gamma$ decay selection (*preliminary*)

Physics interest:

- $O(p^2)$ χ PT amplitude vanishes;
- $O(p^4)$ amplitude is computed
(up to an unknown parameter);
- Fit of $M_{\gamma\gamma}$ distribution to check

$O(p^6)$ χ PT expansion.



first
NA48/2 data

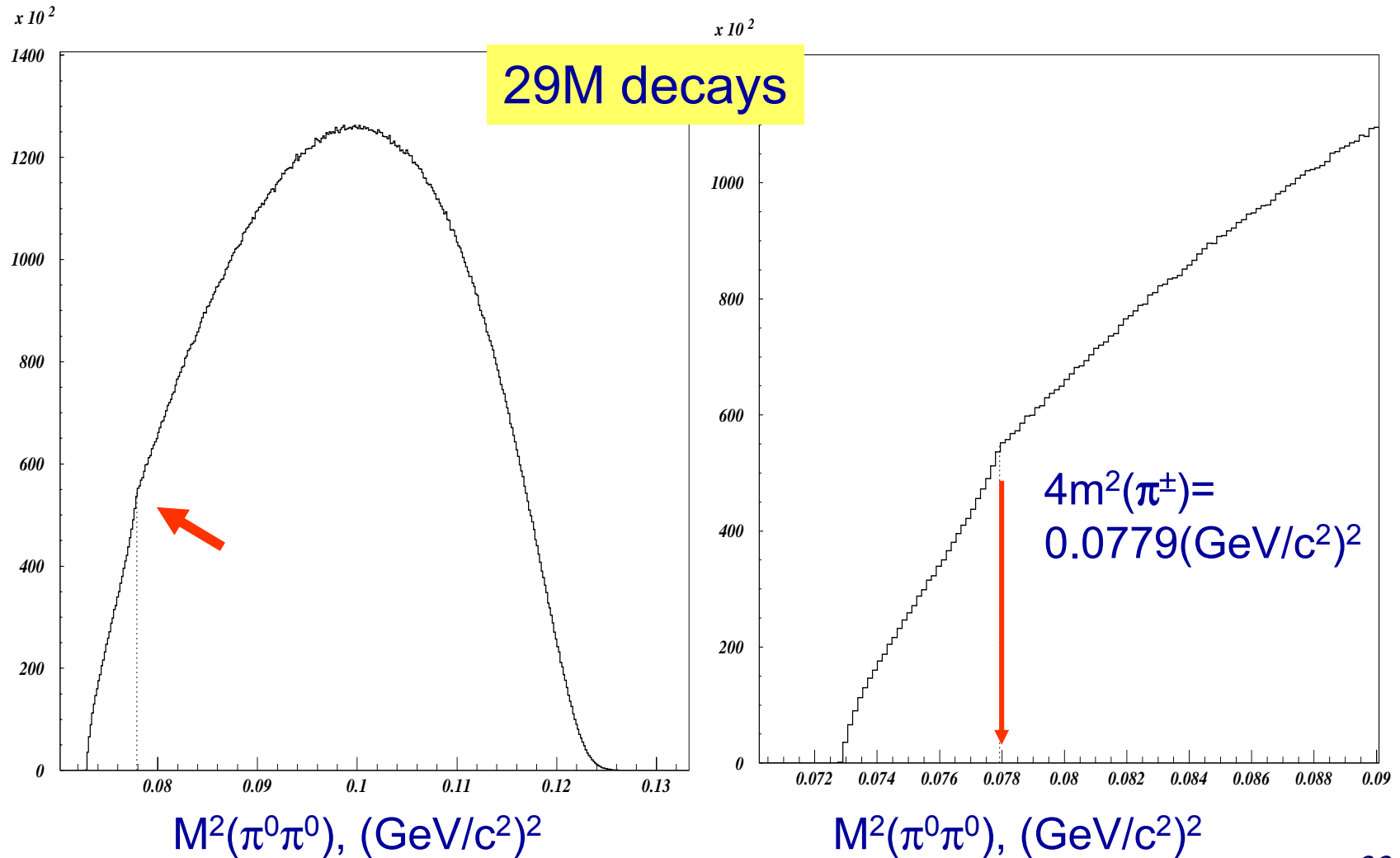
$\sim 100 \times$
world statistics



Part of SS1-3, *run 2003*



First Observation of the $\pi^+\pi^-$ -threshold in $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$ decays





Measurement of a_0 - a_2 pion scattering lengths from $K^\pm \rightarrow (3\pi)^\pm$ decays

A threshold effect in $M(\pi^0\pi^0)$ has been observed for the first time thanks to

- *high resolution in energy*
- *high statistics collected*

The re-scattering of $\pi^+ \pi^- \rightarrow \pi^0 \pi^0$ in the decay $K^\pm \rightarrow \pi^+ \pi^- \pi^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$ allows to study of a_0 - a_2 in a very accurate way

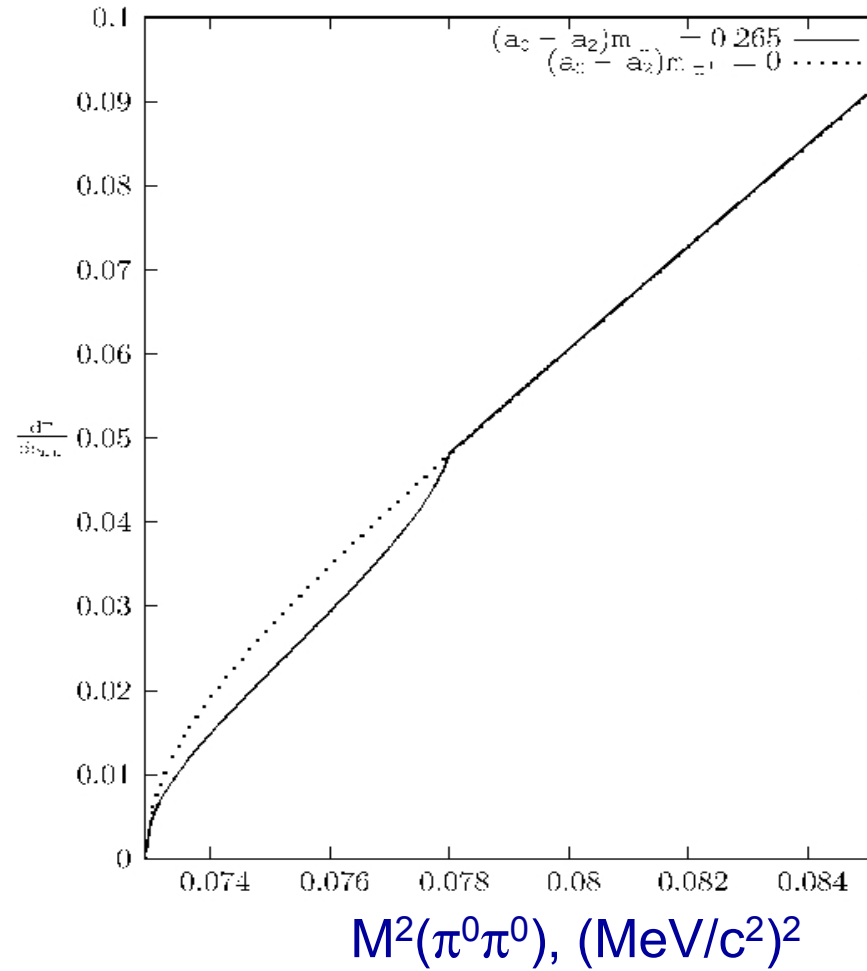
N. Cabibbo

hep-ph 0405001, submitted to P.L.B



Model predictions (*N.Cabibbo*)

$$a_0 - a_2 = 0.265 \quad \text{---}$$
$$= 0. \quad \text{- - -}$$





Leptonics & Semileptonics

**Special minimum-bias runs
in 2003 & 2004**



Semileptonic decays

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

test of CKM **Unitarity**

$$V_{ud} \cdot V_{ud}^* + V_{us} \cdot V_{us}^* + V_{ub} \cdot V_{ub}^* \equiv 1$$

$\approx 10^{-5}$

$$\text{Br}, \tau_K, f_+(0) \Rightarrow \Gamma(K_{e3}) \Rightarrow$$

$$\lambda = |V_{us}|$$

*contributes ~50%
to the total uncertainty*

$$\mathbf{K^+ \rightarrow \pi^0 e^+ \nu:}$$

PDG: $\text{Br} = (4.86 \pm 0.06)\%$

Recent BNL data (E-865):

$$\text{Br} = (5.17 \pm 0.02 \pm 0.09 \pm 0.04)\%$$

based on ~ 70k events



BR ($K^\pm \rightarrow \pi^0 e^\pm \nu$) *preliminary*

$$\text{Br}(K_{e3}) = (5.14 \pm 0.02_{\text{stat}} \pm 0.06_{\text{syst}})\%$$

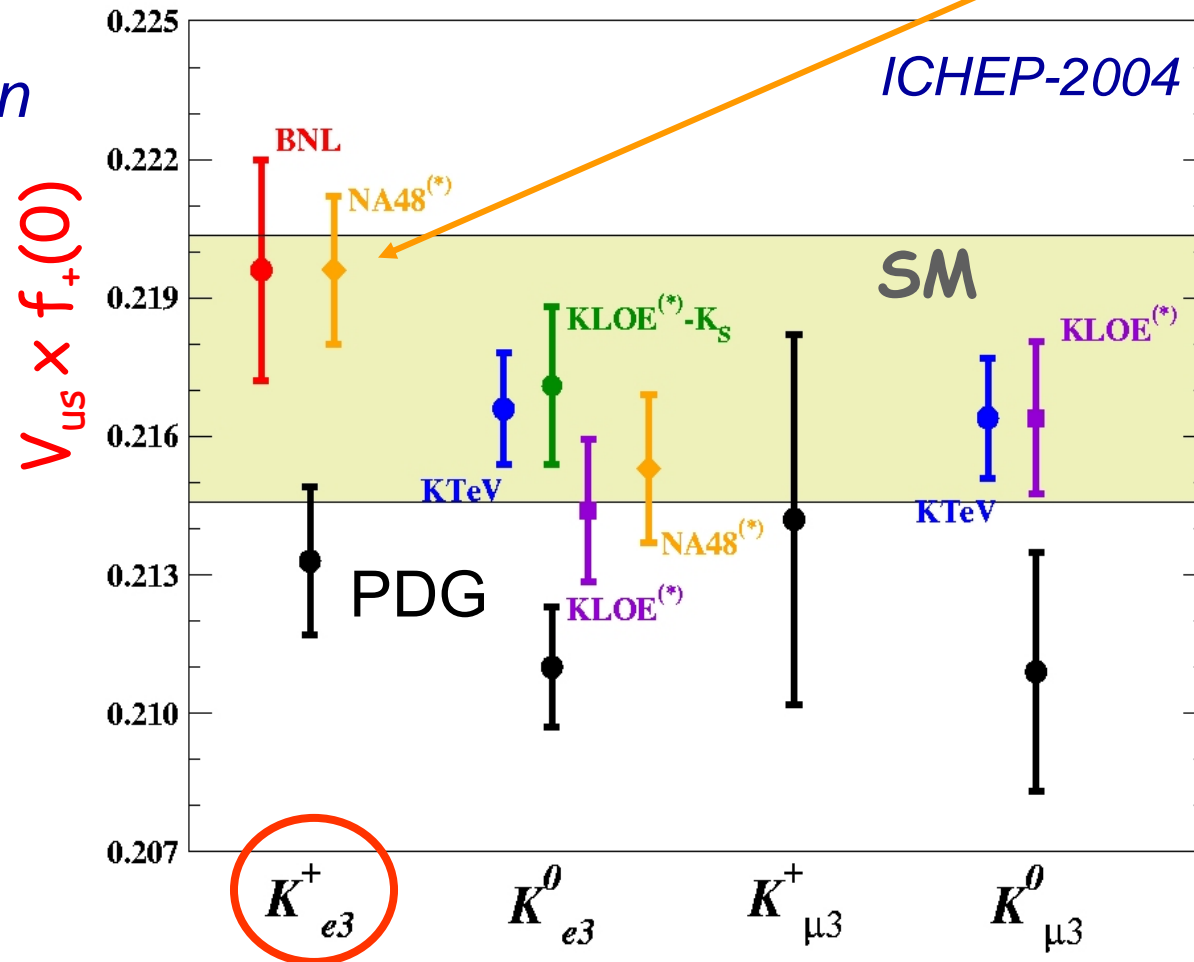
8 hours of 2003
minimum-bias run

$9 \cdot 10^4$

$K^\pm \rightarrow \pi^0 e^\pm \nu$

normalization
channel:

$7 \cdot 10^5 K^+ \rightarrow \pi^0 \pi^\pm$

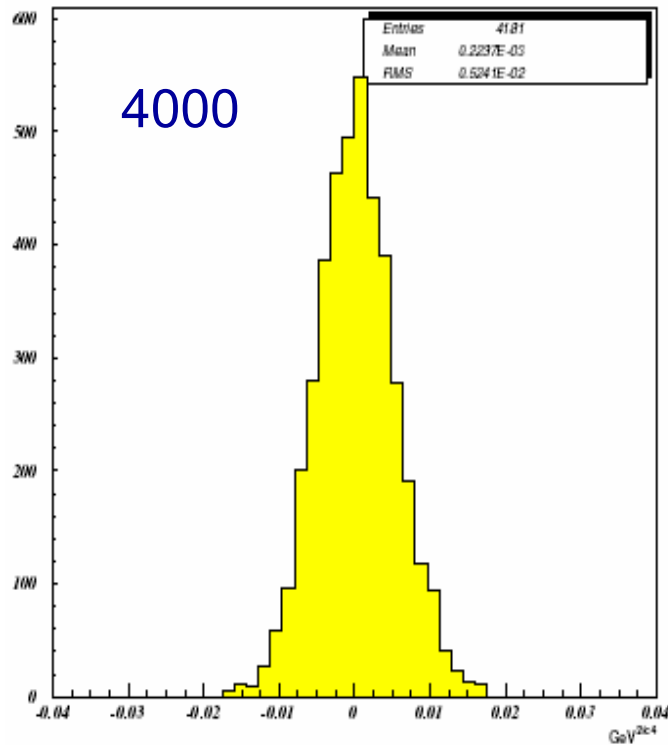




Leptonic decay selection

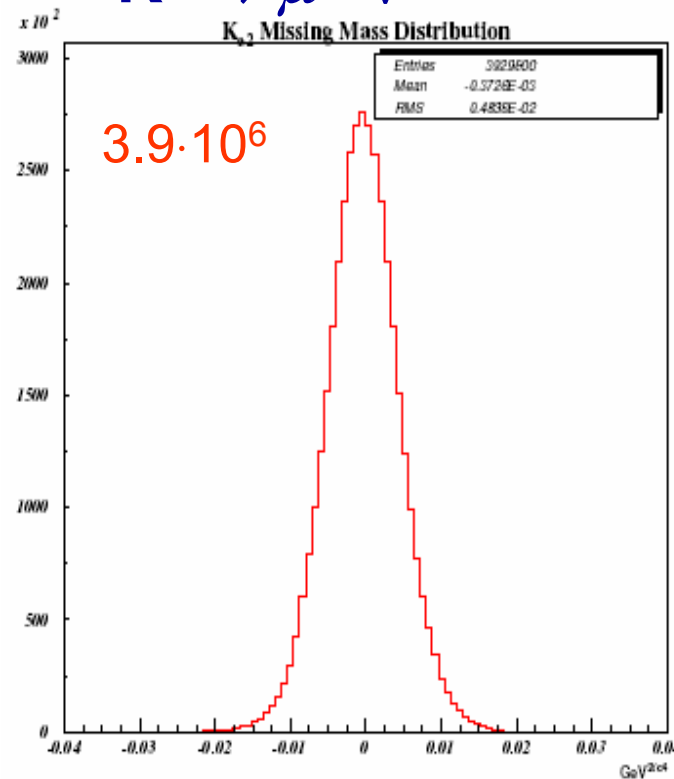
56 hour minimum-bias run in 2004

$K^\pm \rightarrow e^\pm \nu$



$(\text{missing mass})^2, (\text{GeV}/c^2)^2$

$K^\pm \rightarrow \mu^\pm \nu$



$(\text{missing mass})^2, (\text{GeV}/c^2)^2$



Summary

- **NA48/2** *has completed the data taking*
- *~ 4·10⁹ of $K^{\pm} \rightarrow \pi^{\pm} \pi^+ \pi^-$ decays are recorded, which allow to achieve the statistical precision of*

$$\sigma(A_g) < 2 \cdot 10^{-4}$$

- *~1 million K_{e4} decays are accumulated with a low background level*



Summary (cont.)

- *A threshold effect has been observed for the first time*
in $K^\pm \rightarrow \pi^0 \pi^0 \pi^\pm$ decays
- *Large multipurpose sample of K^\pm decays is accumulated for the study of various rare decays*
- *Most precise measurement of $BR(K^\pm \rightarrow \pi^0 e^\pm \nu)$ is performed which has contributed to the CKM unitarity puzzle resolving*



Resources Request for 2005

- **Data storage at CERN:**
CASTOR space ~ 100 TB
reprocessing, MC data
- **CPU power:**
guaranteed share for analysis