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

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- *Experiment configuration*
- *Data collected*
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- *Rare decays*
- *First Observation of a Threshold Effect*
- *Leptonic & Semileptonics*
- *Summary*
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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 (χPT)
- **Quantitative** tests of different model predictions

Goals

- **Direct CP violation**

in $K^{\pm} \to \pi^{\pm} \pi^{\pm} \pi^{\mp}$, $K^{\pm} \to \pi^{\pm} \pi^{0} \pi^{0}$

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

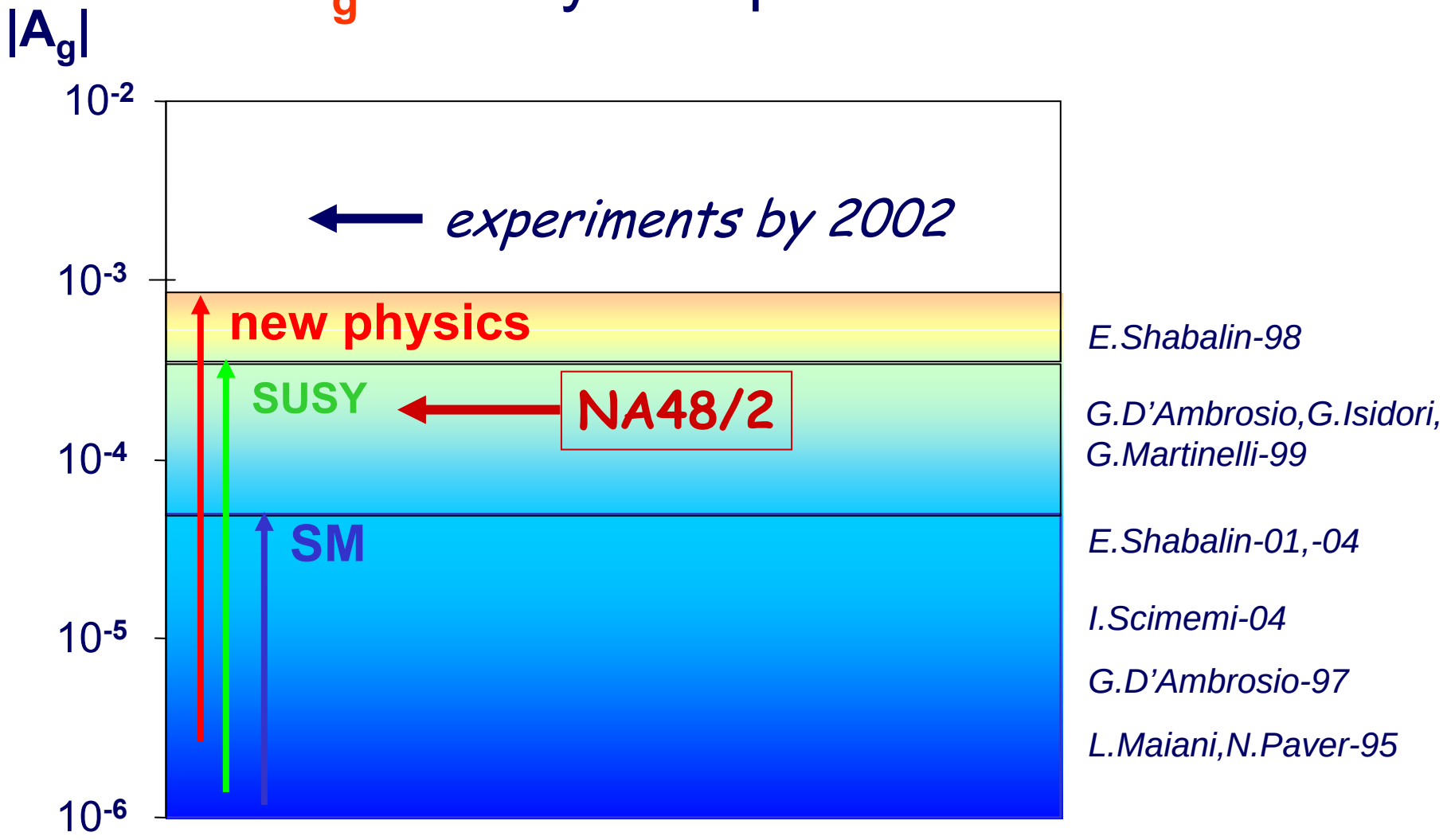
$$M(u) \propto 1 + g \cdot u, \quad u = f(E^*_{\pi-odd})$$

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

Requirements to experiment:

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

A_g: theory & experimental limits



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 χPT & search for* **A_{CP}**

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

  $K^{\pm} \to \pi^{\pm} e^+ e^-$, $K^{\pm} \to \pi^{\pm} \mu^+ \mu^-$, $K^{\pm}_{e2}$

  $K^{\pm} \to l^{\pm} \nu\, l^+ l^-$

  $K^{\pm} \to \pi^{\pm} \pi^0 \gamma\gamma$, $K^{\pm} \to \pi^{\pm} \pi^0 l^+ l^-$, … etc.

- **Semileptonic decays**: $K^{\pm}_{e3}$, $K^{\pm}_{\mu 3}$

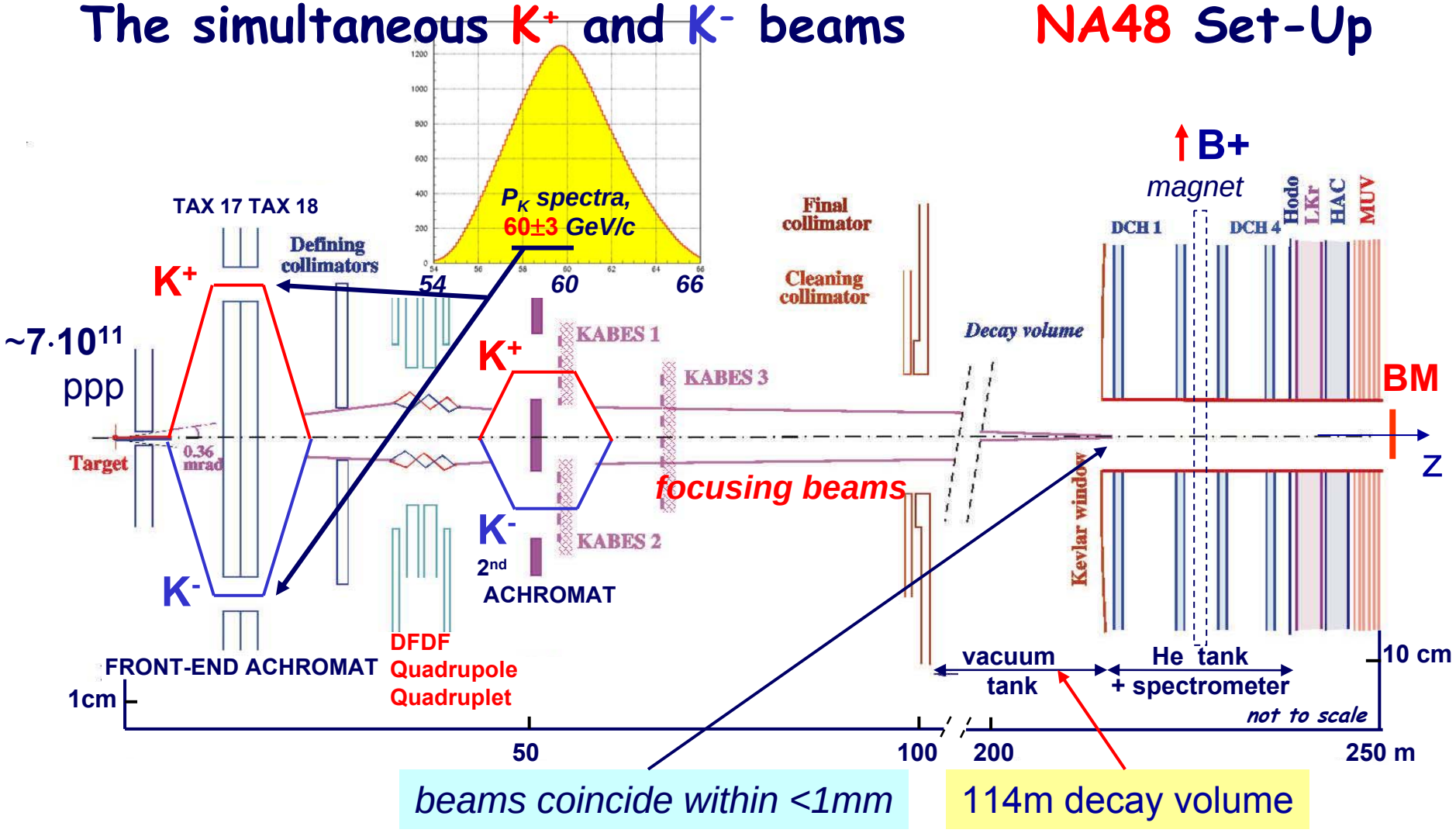
  BR's $\Rightarrow$ *to improve precision of* $|V_{us}|$
  & *check* **CKM** unitarity,

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

NA48/2 experiment configuration

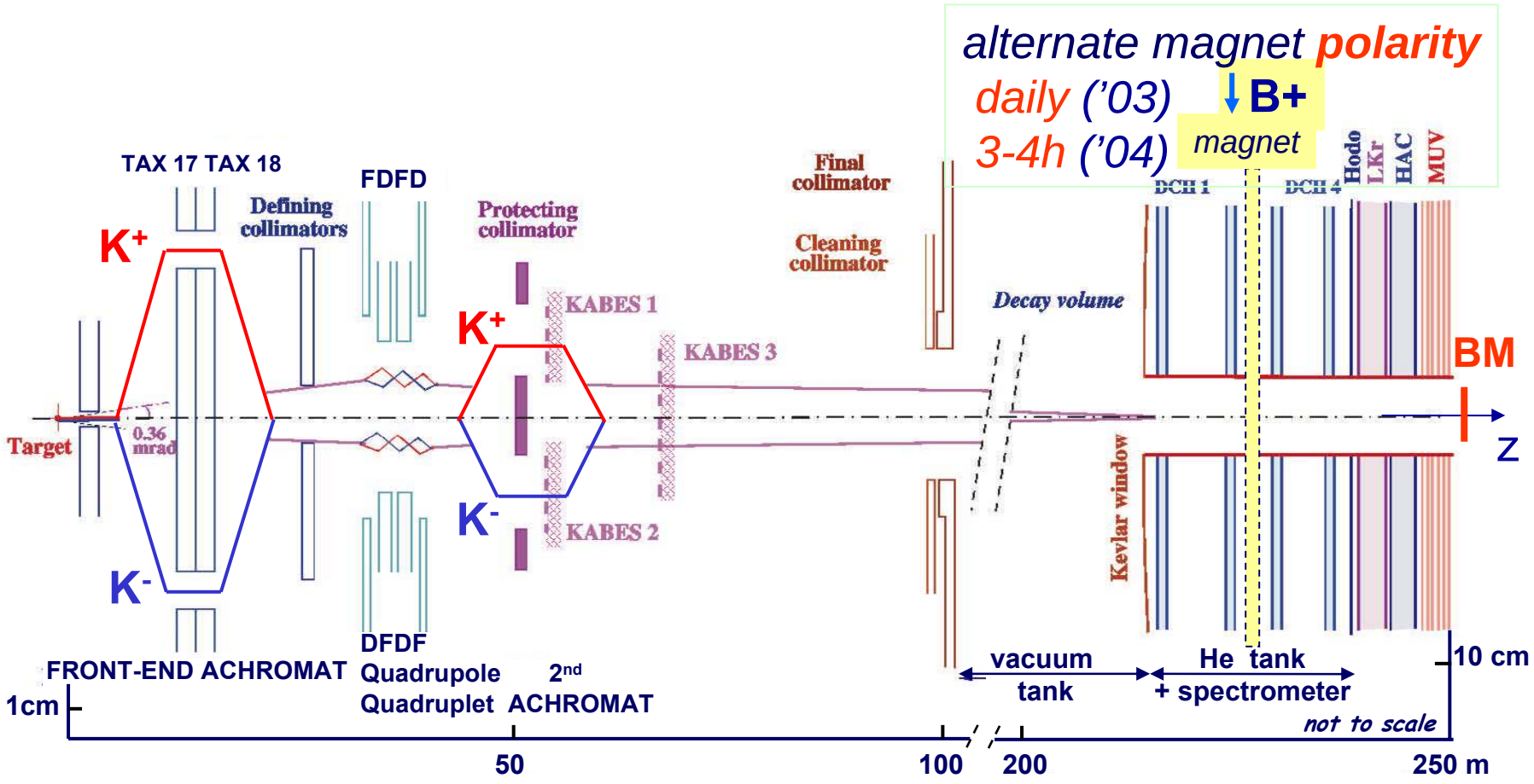
The simultaneous K^+ and K^- beams

NA48 Set-Up



NA48/2 experiment configuration

NA48 Set-Up



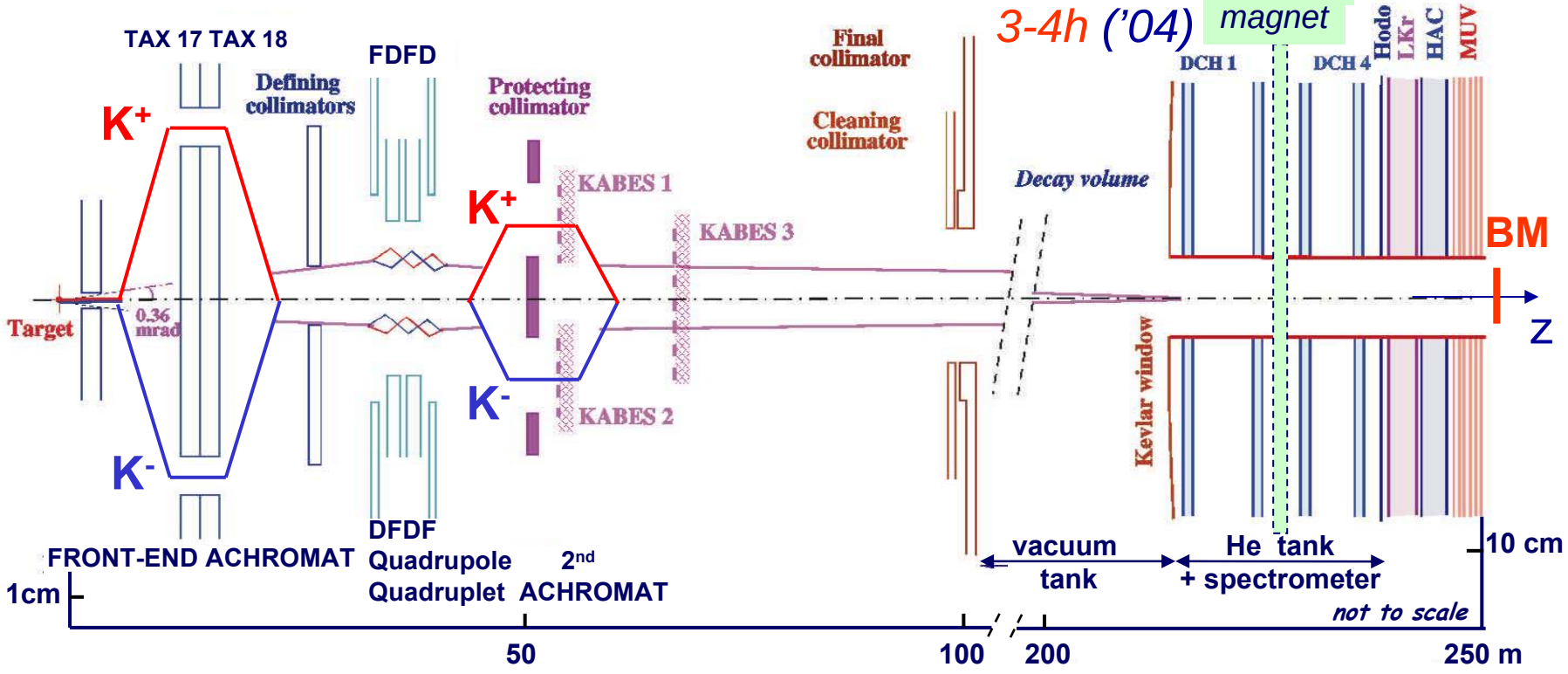
NA48/2 experiment configuration

NA48 Set-Up

*alternate magnet **polarity***

daily ('03) ↑ **B+**

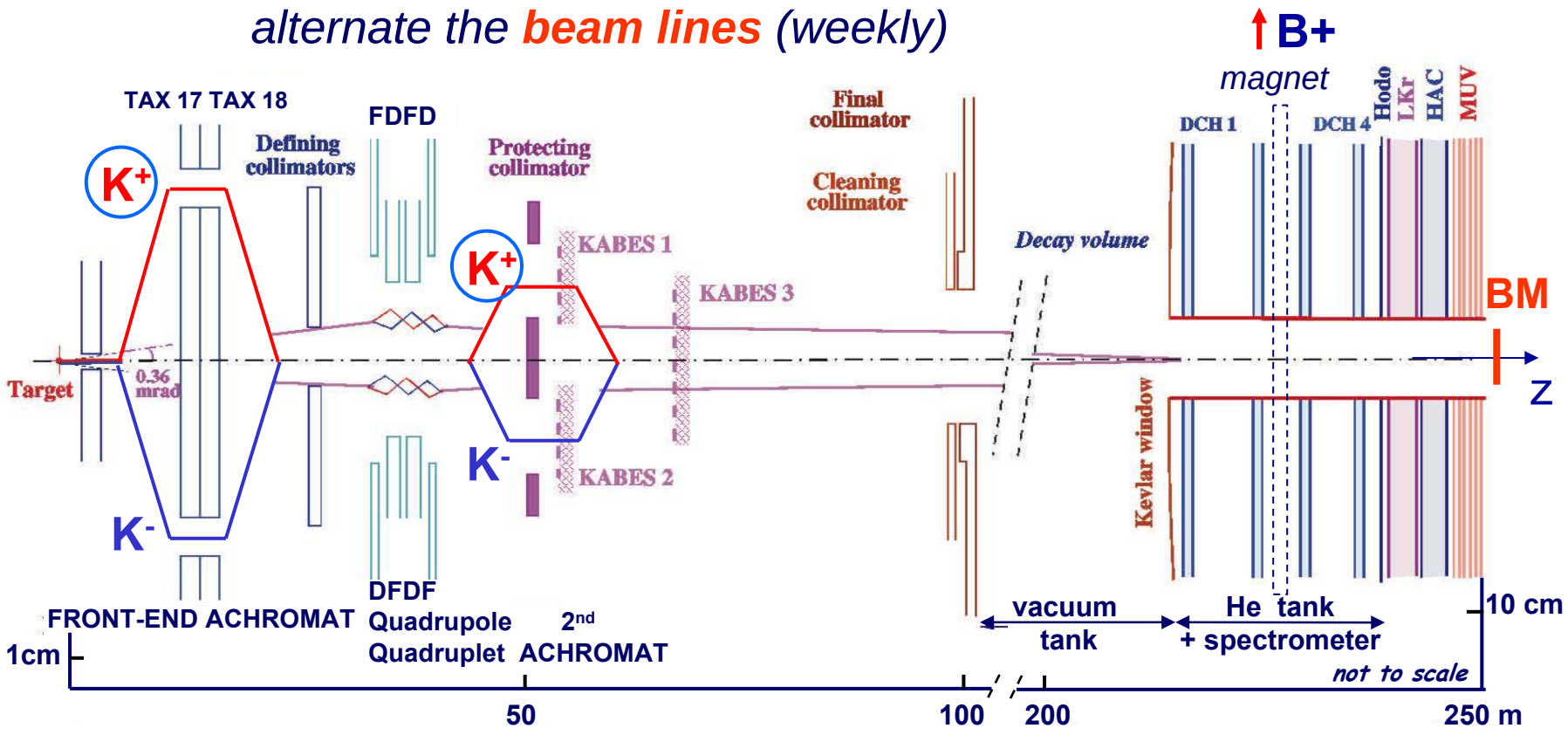
3-4h ('04) *magnet*



NA48/2 experiment configuration

The simultaneous K^+ and K^- beams

*alternate the **beam lines** (weekly)*



NA48/2 experiment configuration

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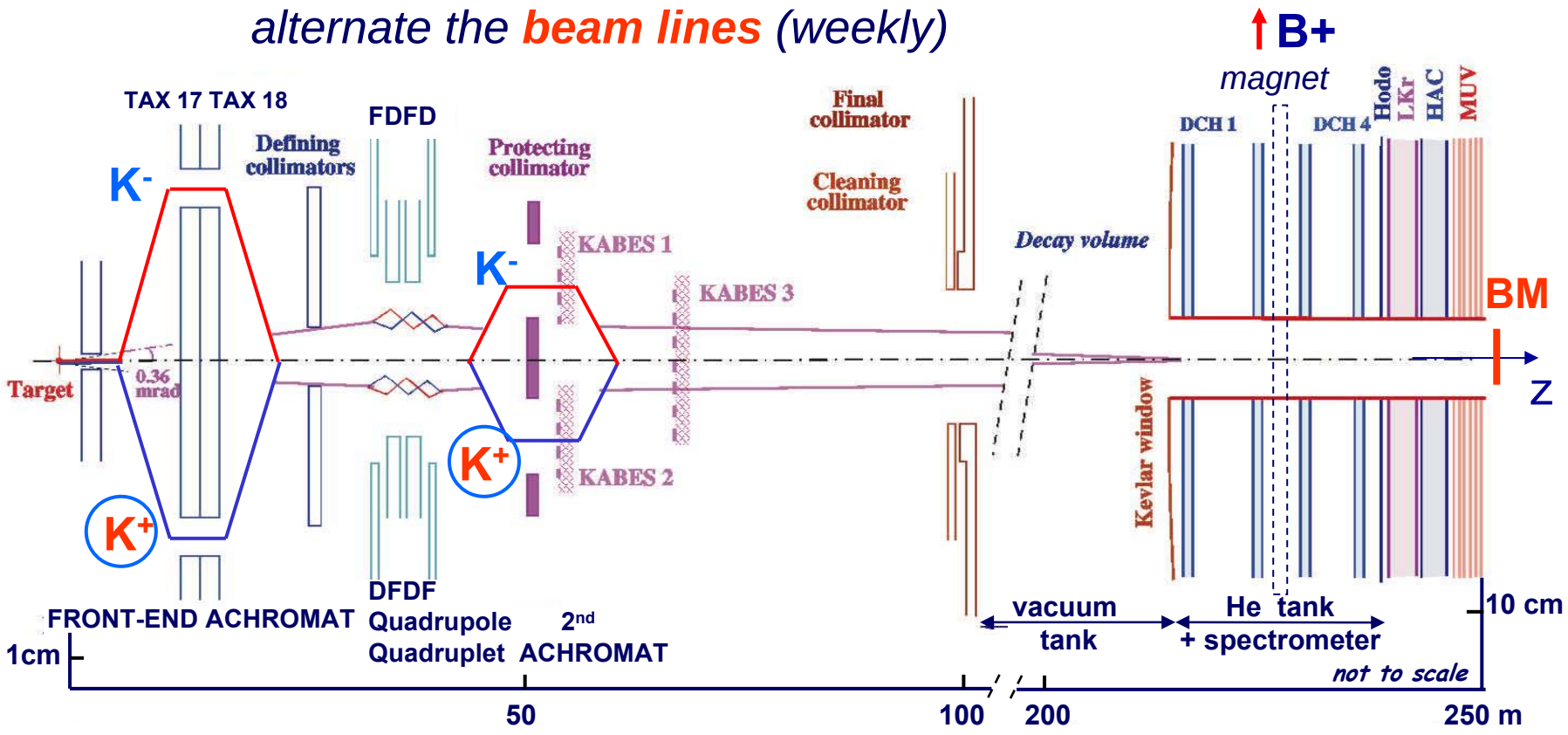


NA48/2 runs

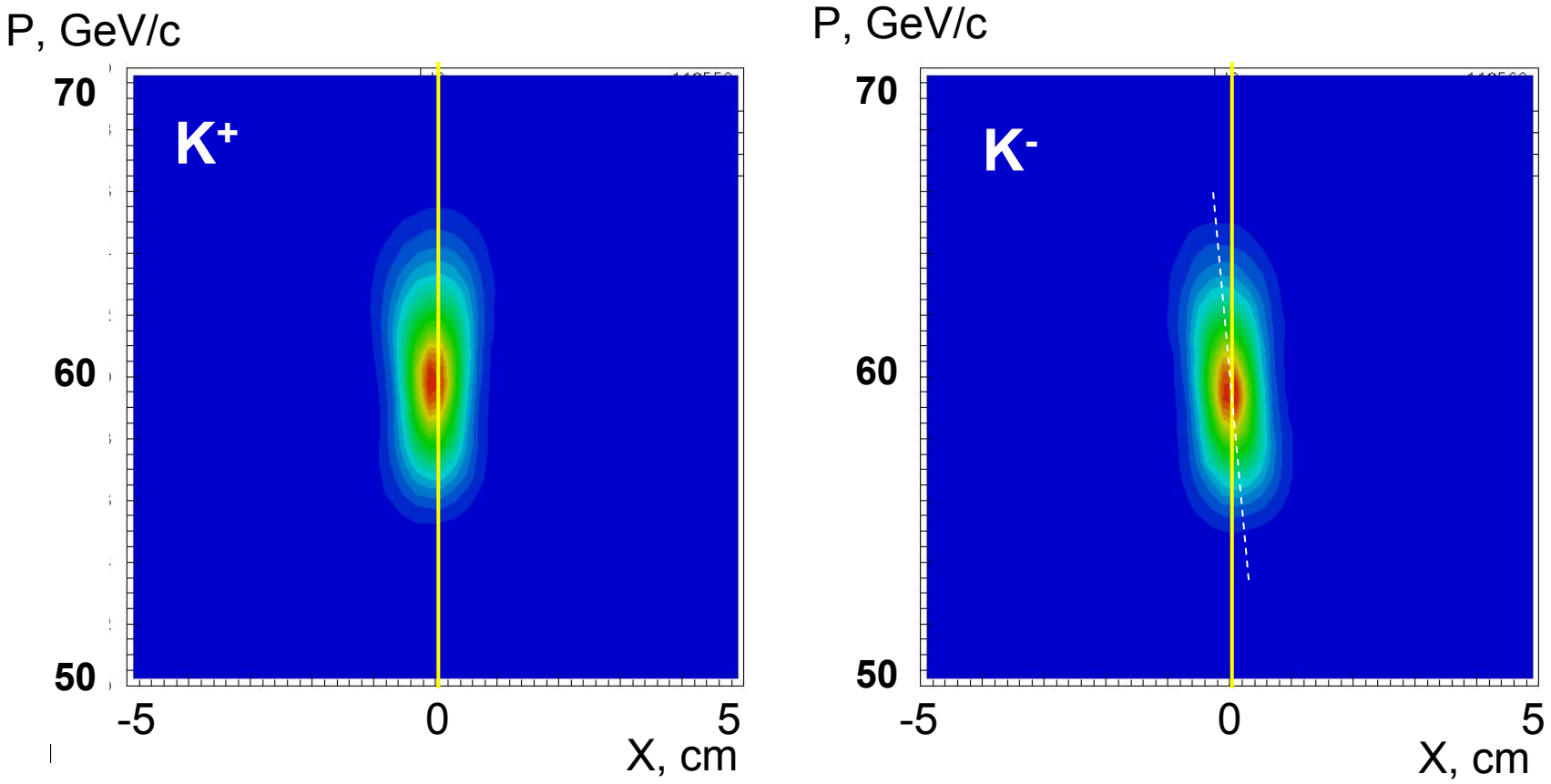

2003 run: ~ 50 days
(~ 1 month stable conditions)
2004 run: ~ 60 days
~ 200 TB of data recorded

Statistics

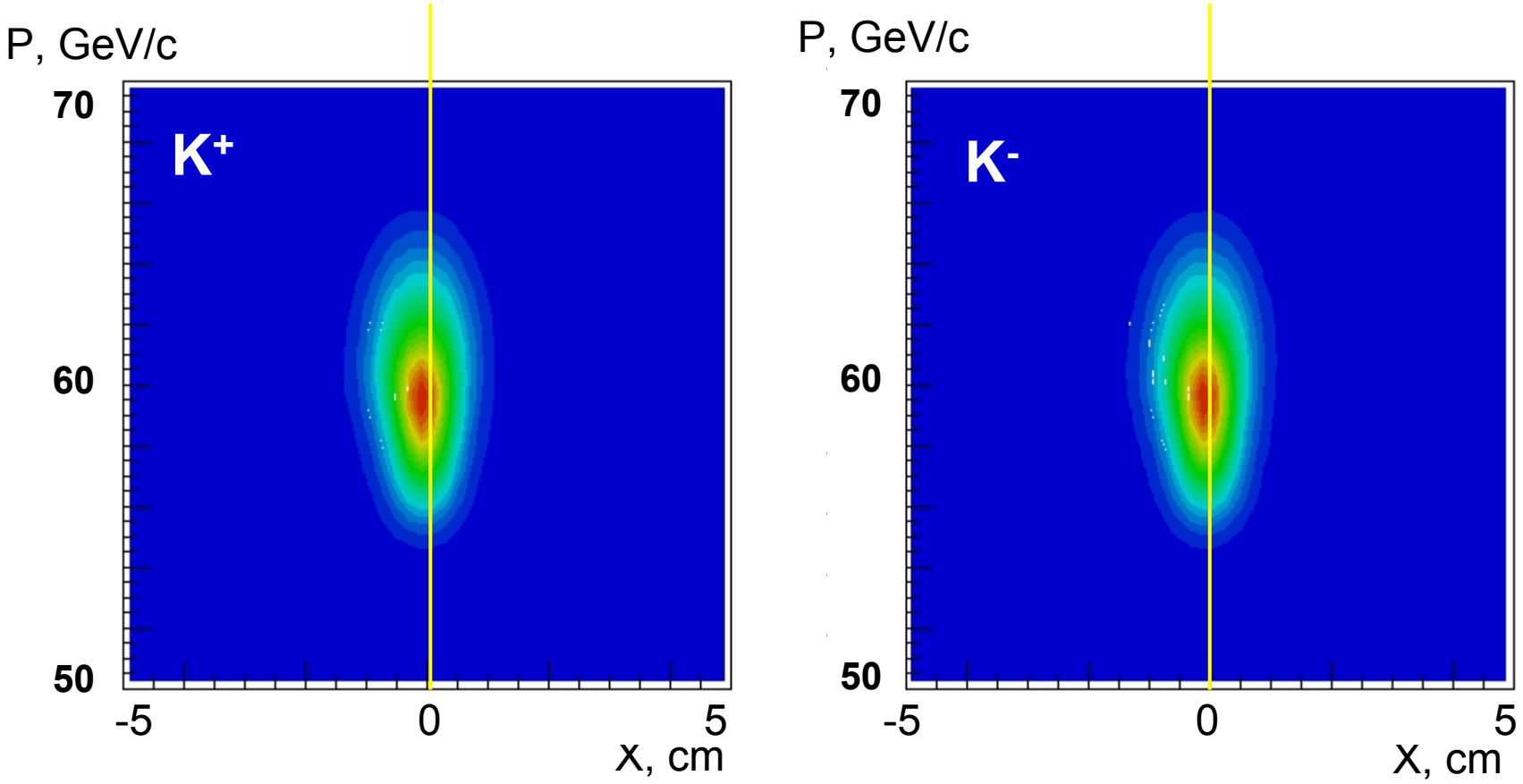
	*recorded events, **10** ^{6}*		# of **S**uper-**S**amples
Run	$K^{\pm} \to \pi^{-} \pi^{+} \pi^{\pm}$	$K^{\pm} \to \pi^{0} \pi^{0} \pi^{\pm}$	(*complete cycles*)
2003-I	~ 600	~20	*non-stable conditions*
2003-II	**1 300**	**50**	**3 (*analyzed*)**
2004	**2150**	**130**	**5**
Total	**~ 4 050**	**~ 200**	**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)

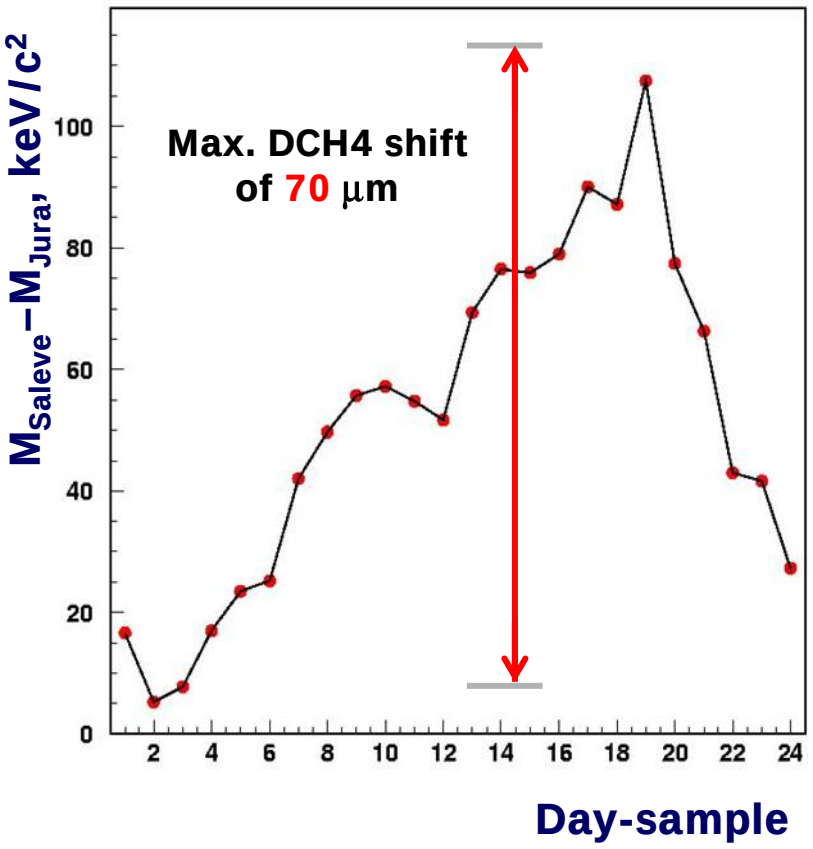


Beam position on DCH1 in 2004 (P_K vs X)



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_π(DCH1) > 11.5 cm

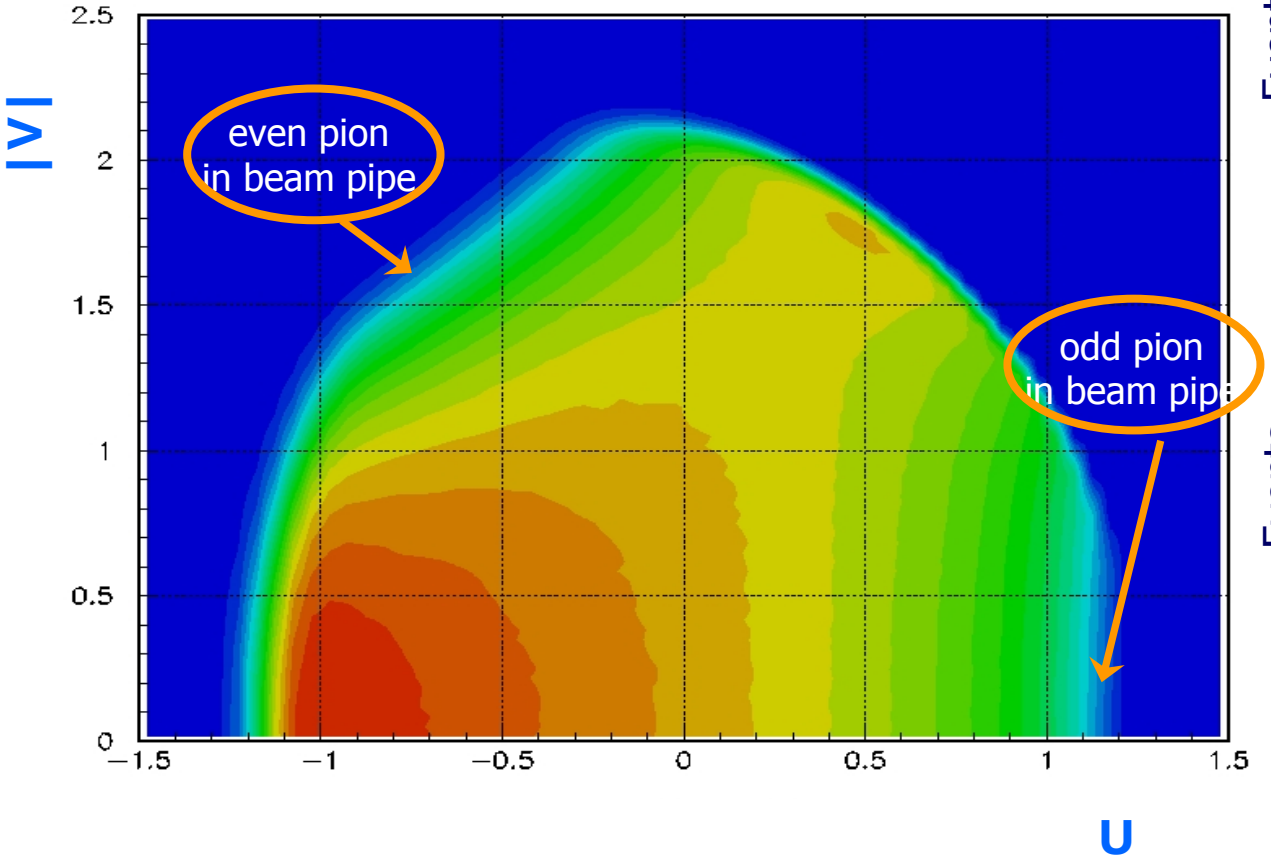
R_π(DCH4) > 13.5 cm

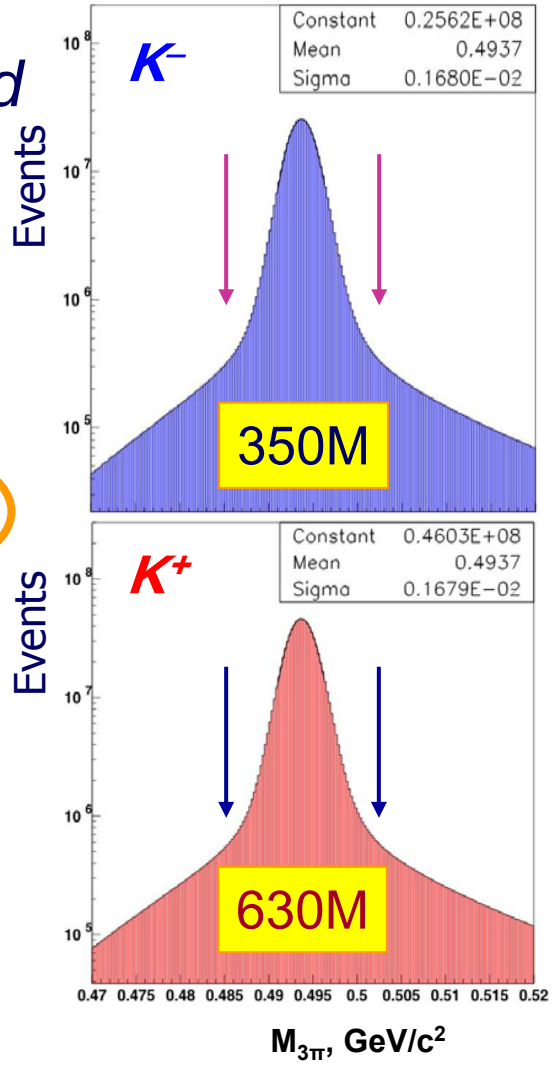
leave 75% of raw statistics

(*beam stability dependent*)

Dalitz plot for $K^{\pm} \to \pi^{\pm} \pi^{+} \pi^{-}$ & M(3π)

***SS**1-3 data: > **980** million events selected*





A_g measurement *(acceptance cancellation)*

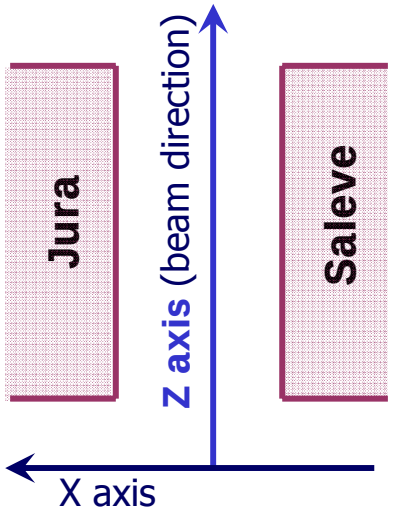
Physical asymmetries:

- 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-)

Top view of the setup



- $A_{SJ} = (A_S + A_J)/2 \approx \Delta g = A_g \cdot 2g$ ⇒ *physics asymmetries*

(to mask the results A_{SJ}, A_S & A_J are presented with **OFFSETS !**)

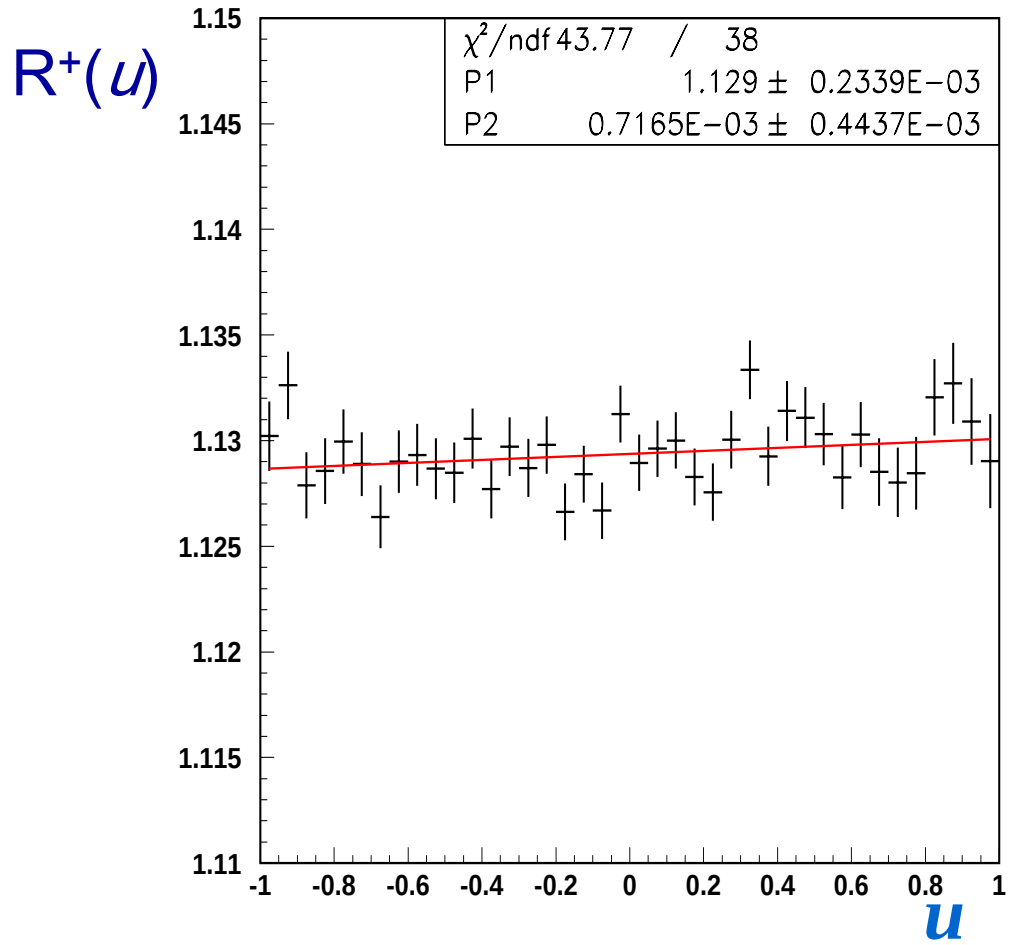
- $A^{\pm} = (A^+ + A^-)/2 = (A_S - A_J)/2$

⇒ *asymmetry induced by the experimental setup*

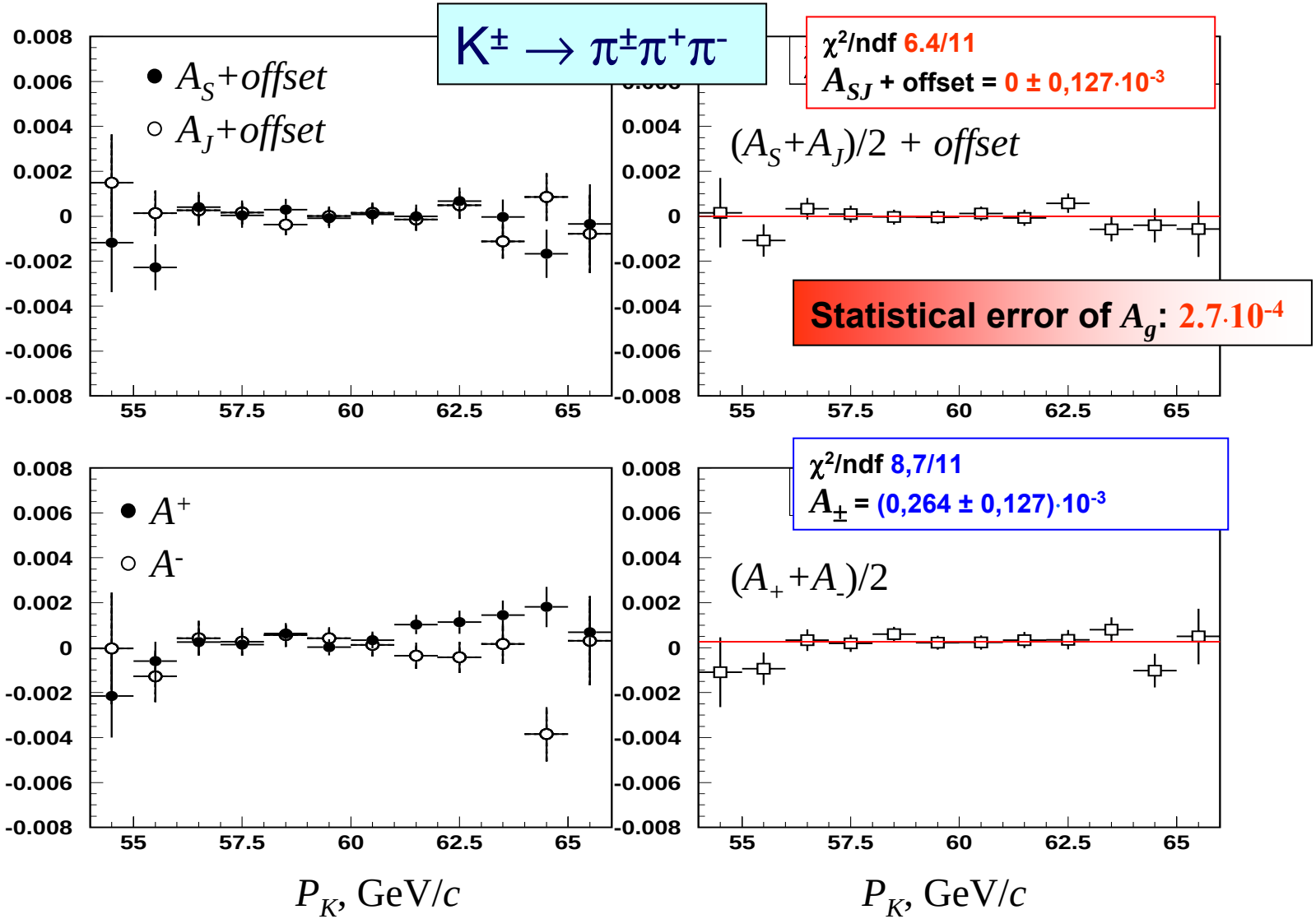
(many of the effects observed in $A^{\pm}$ cancel in A_{SJ})

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

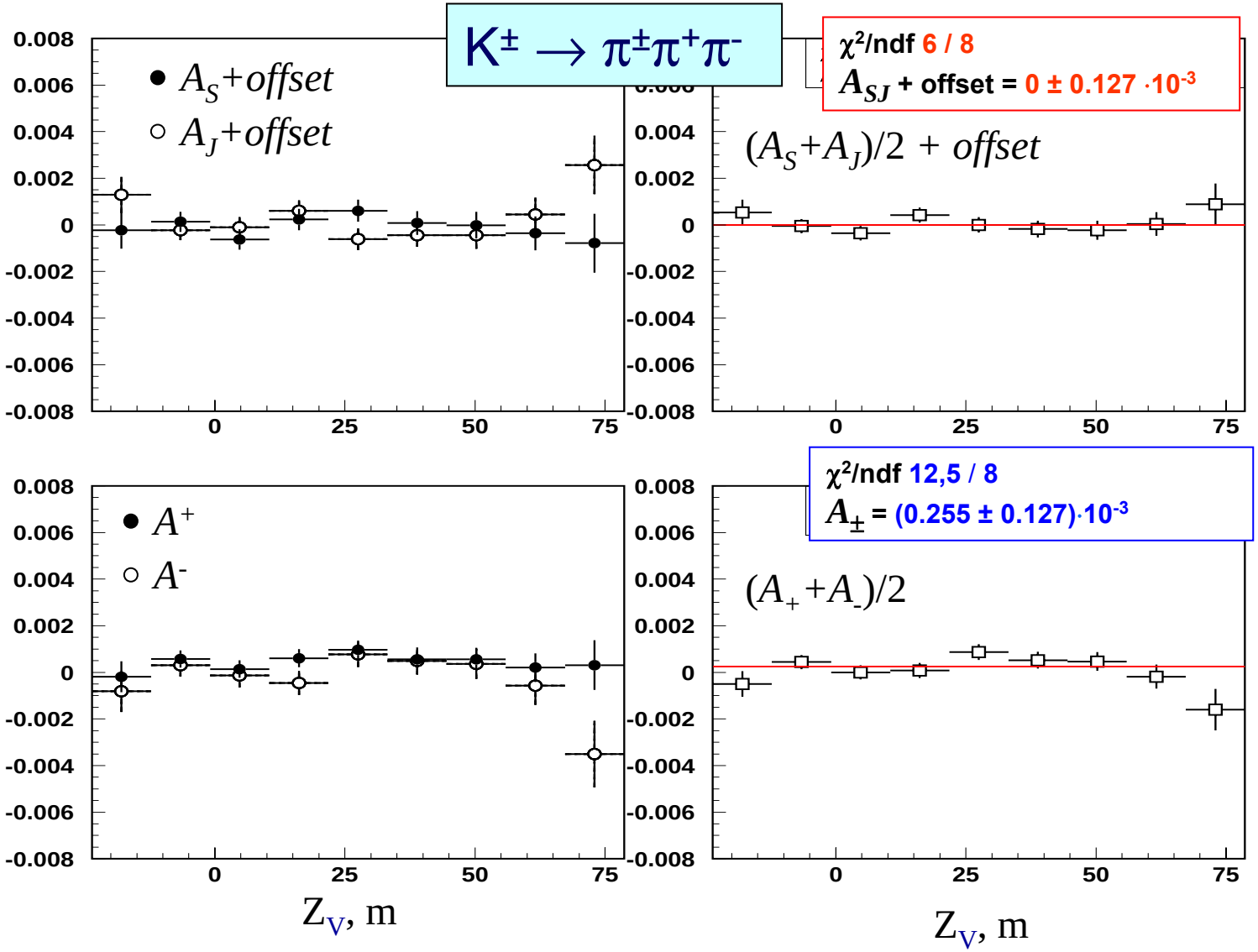
$R^+(u)$= U(K^+ B+) / U(K^+ B-)



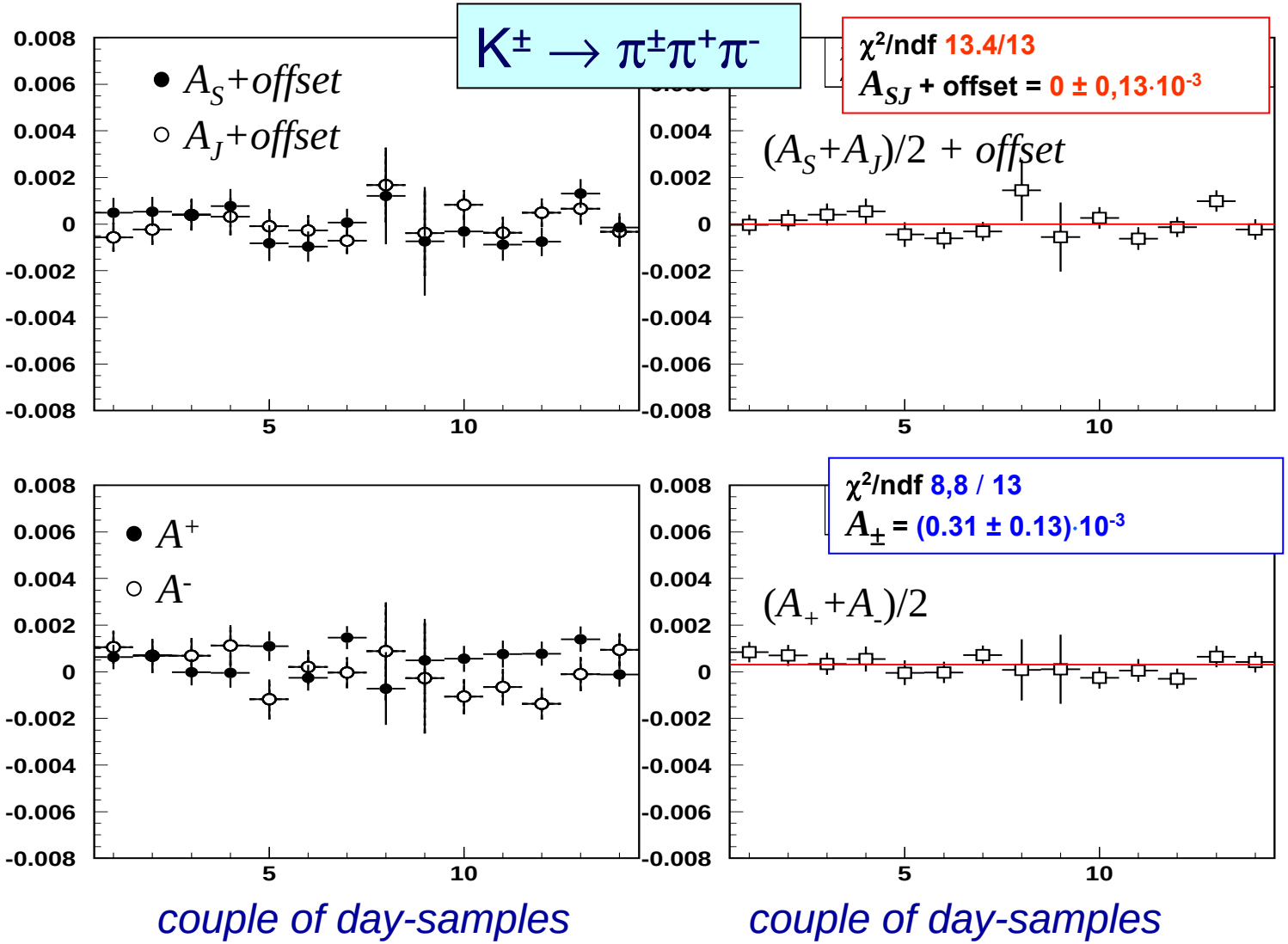
Asymmetry in P_K bins



Asymmetry in Z_{vrtx} bins

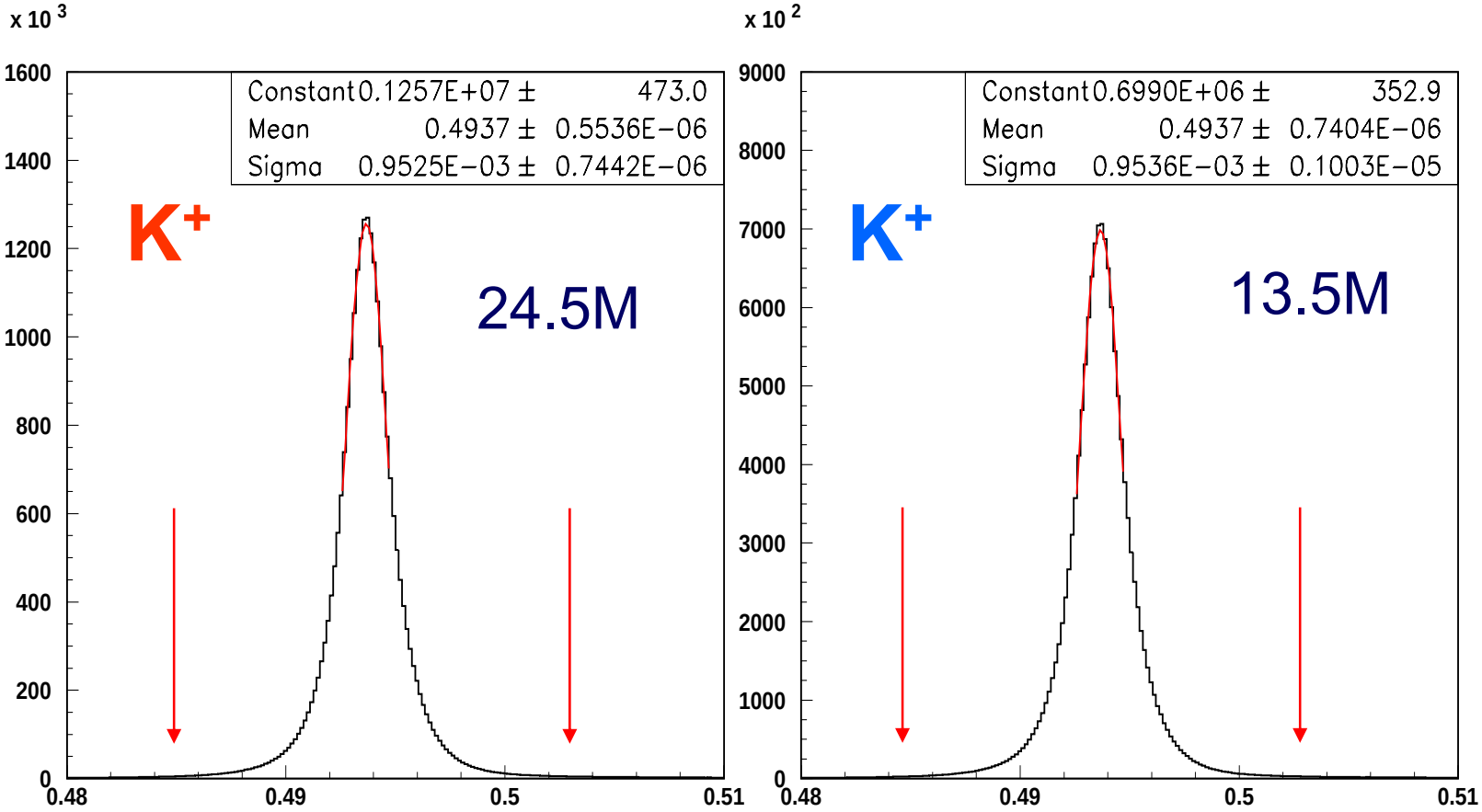


Asymmetry time dependence



$K^{\pm} \to \pi^{\pm} \pi^0 \pi^0$ decay selected

38 millions



$M(\pi^+ \pi^0 \pi^0)$, GeV/c^2 $M(\pi^- \pi^0 \pi^0)$, GeV/c^2

Results on A_g

one month of **NA48/2** data taking in **2003**:

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

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

- Physics interest:
  - Low energy π–π scattering length

    predicted by χPT first principles

    a_0^0 **= 0.220 ± 0.005** *related to the $q\bar{q}$ QCD condensate*

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

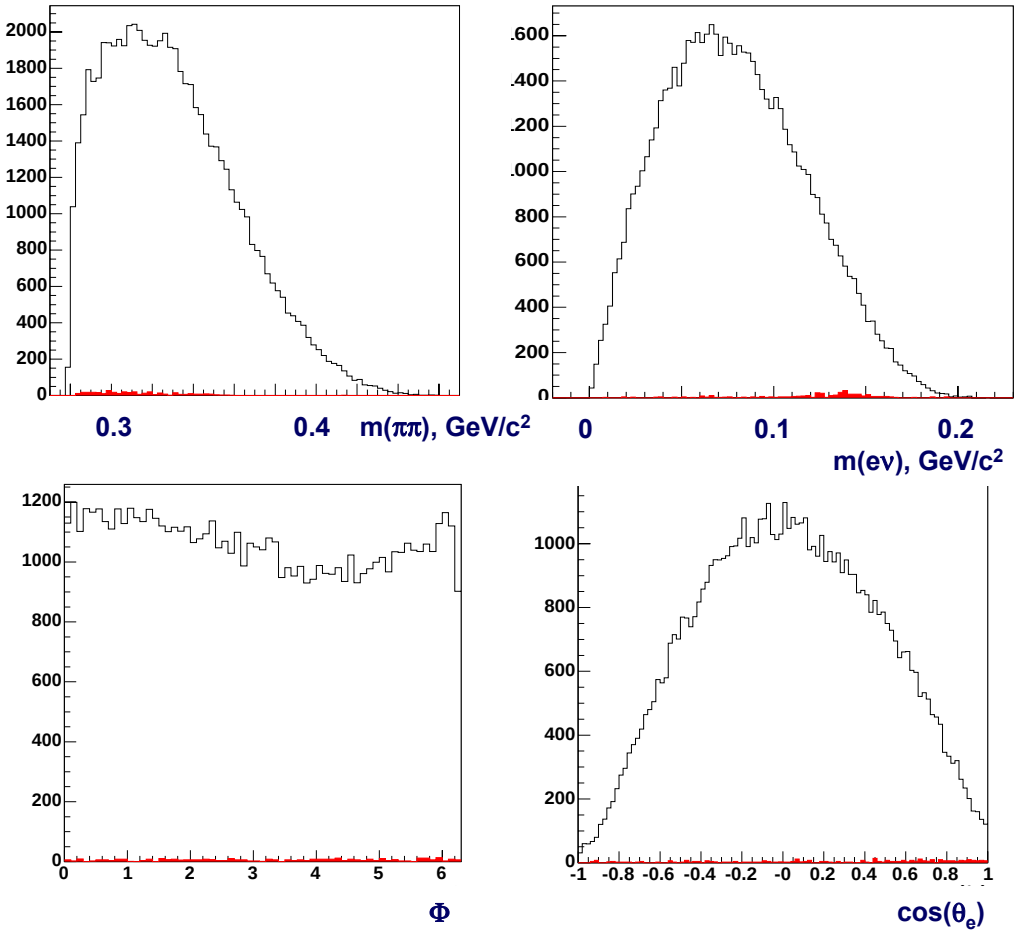
  - a_0^0 can be determined from the form-factors of **K_{e4}** decays

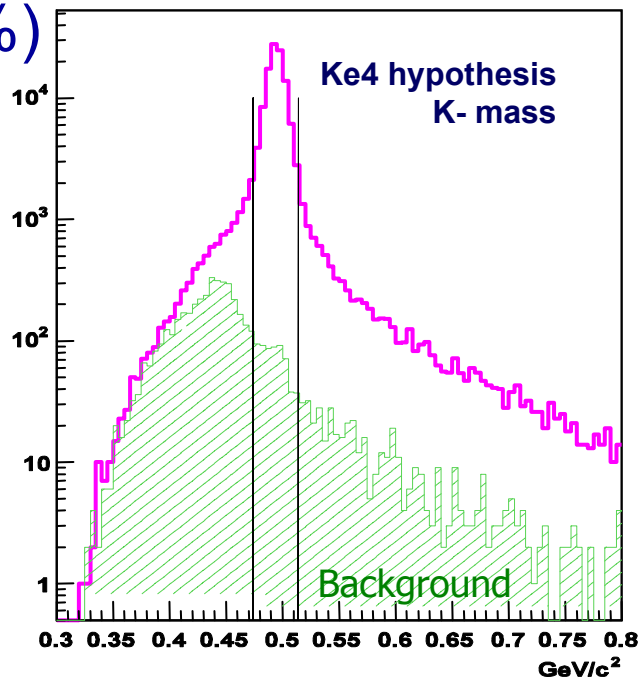
- Previous measurements:
  - Geneva-Saclay (1977): 30,000 events
  - Brookhaven E865 (2001): 400,000 events

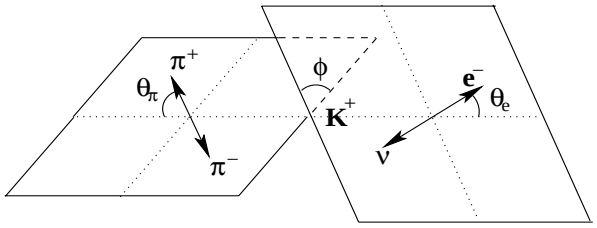
    a_0^0 **= 0.216 ± 0.013$_{stat}$**
  - 2 experiments: *errors > theoretical uncertainties*

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

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





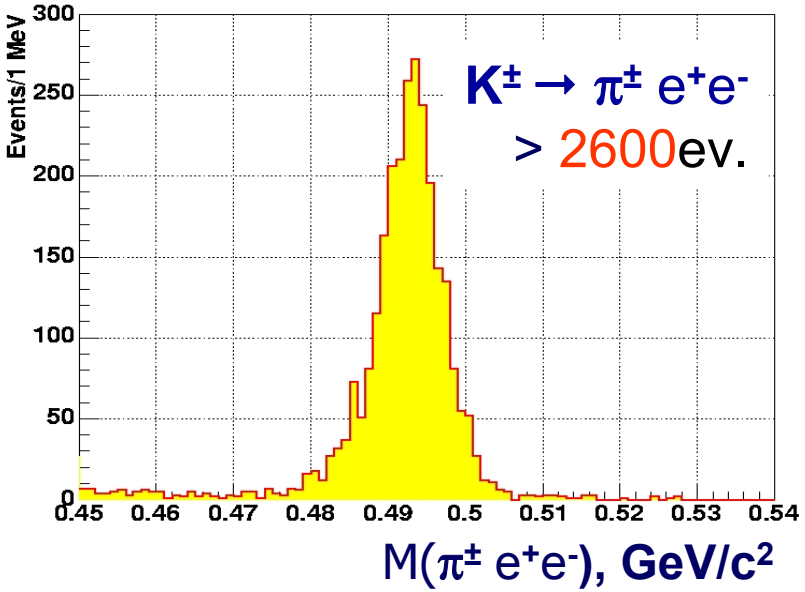


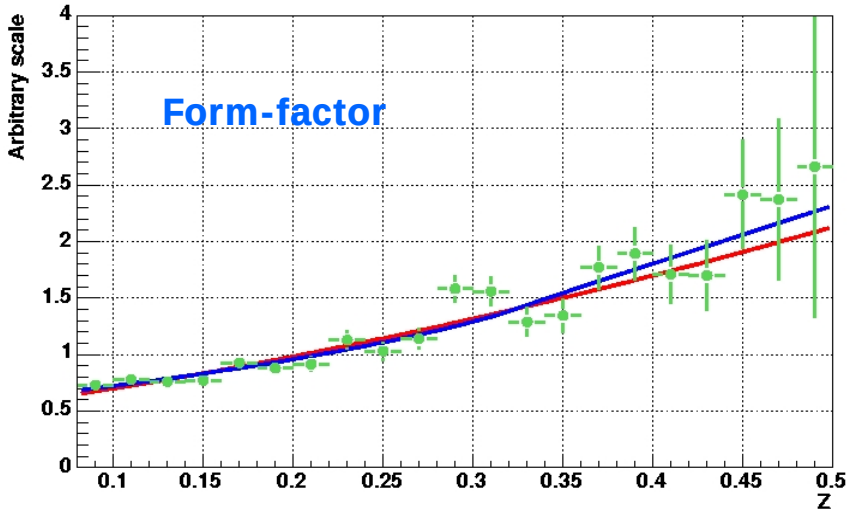
Cabibbo-Maksymowicz variables [backgr. in red]

2004 data: expected > **500**k

$K^{\pm}\to\pi^{\pm}e^{+}e^{-}$ & $K^{\pm}\to\pi^{\pm}\mu^{+}\mu^{-}$ selection

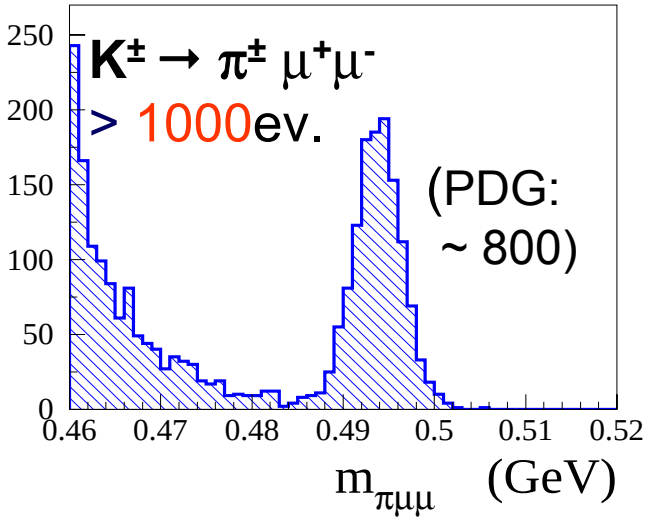
(preliminary)





- low background (1-2%)

- expected data sample in 2003-2004
  comparable to the World best sample



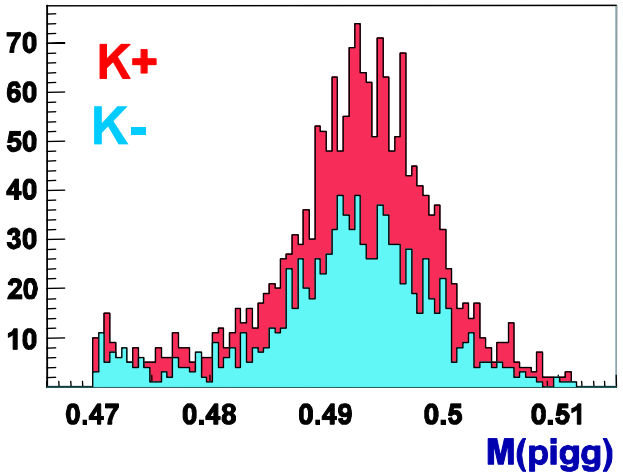
$K^{\pm} \to \pi^{\pm}\gamma\gamma$ decay selection *(preliminary)*

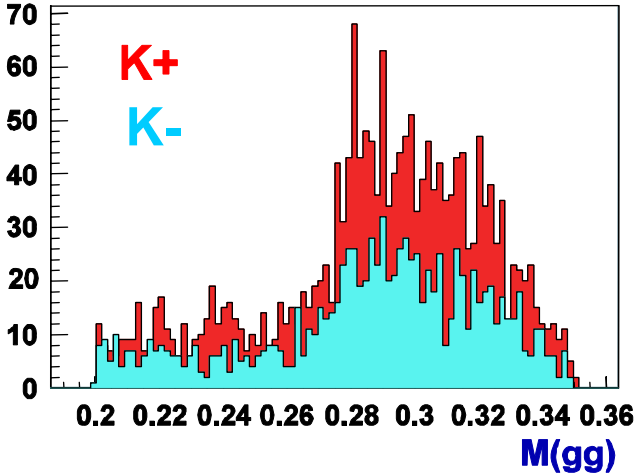
Physics interest:

- $O(p^2)$ χPT amplitude vanishes;
- $O(p^4)$ amplitude is computed

  (up to an unknown parameter);
- Fit of $M_{\gamma\gamma}$ distribution to check

  $O(p^6)$ χPT expansion.





first **NA48/2** data

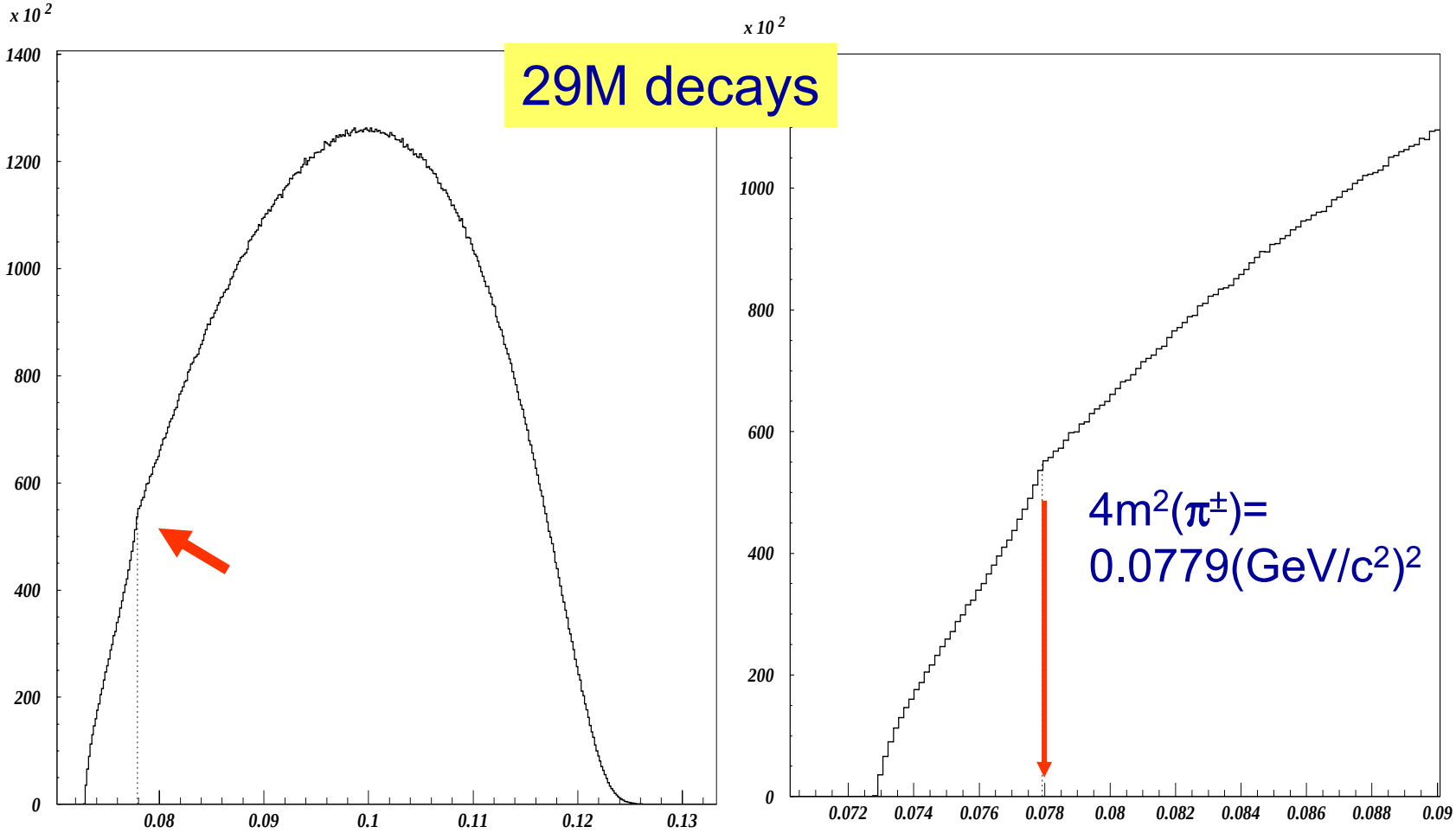
~ 100 x *world statistics*

New Effect

Part of SS1-3, *run 2003*

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

29M decays



$M^2(\pi^0\pi^0)$, $(GeV/c^2)^2$ $M^2(\pi^0\pi^0)$, $(GeV/c^2)^2$

Measurement of a_0-a_2 pion scattering lengths from $K^{\pm} \to (3\pi)^{\pm}$ 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*

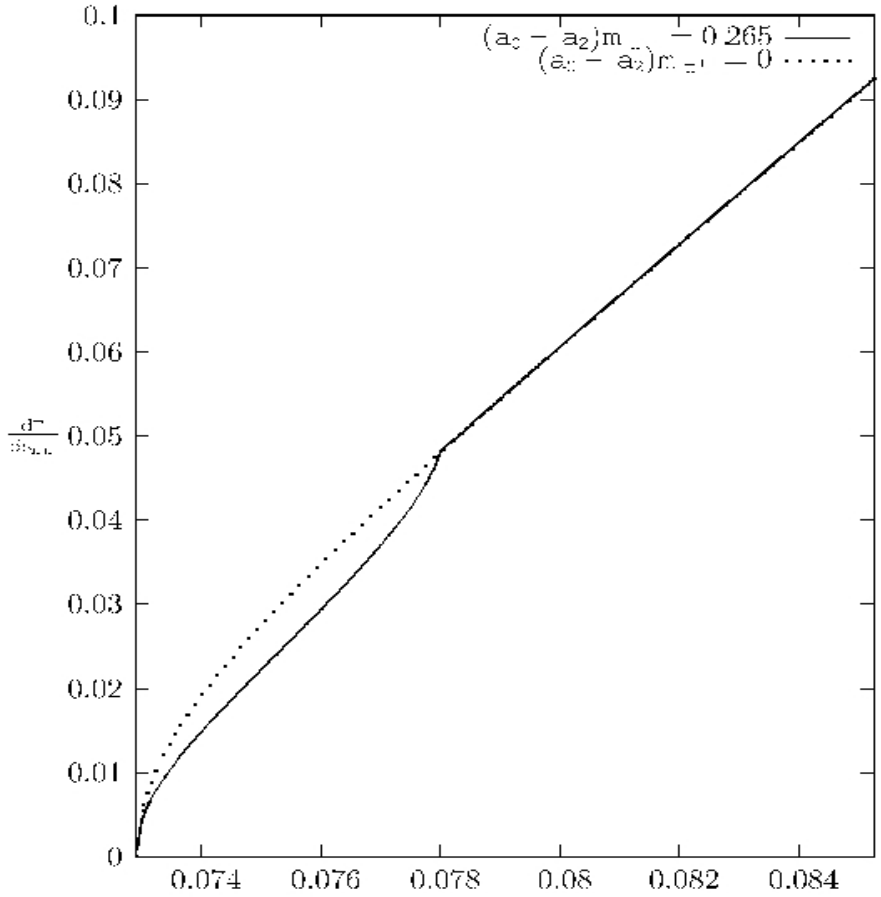
The re-scattering of $\pi^+ \pi^- \to \pi^0 \pi^0$ in the decay $K^{\pm} \to \pi^+ \pi^- \pi^{\pm} \to \pi^0 \pi^0 \pi^{\pm}$ allows to study of a_0-a_2 in a very accurate way

N. Cabibbo
hep-ph 0405001, submited to P.L.B

Model predictions (*N.Cabibbo*)

a_0-a_2 = *0.265* ——

= *0.* - - - -



$M^2(\pi^0\pi^0)$, $(MeV/c^2)^2$

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

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

$\approx 10^{-5}$

$\mathrm{Br},\ \tau_K,\ f_+(0) \Rightarrow \Gamma(K_{e3}) \Rightarrow$ $\lambda = |V_{us}|$

contributes ~50% to the total uncertainty

$K^+ \to \pi^0 e^+ \nu$:

PDG: Br = (**4.86** ± 0.06)%

Recent BNL data (E-865):

Br = (5.17 ± 0.02 ± 0.09 ± 0.04)%

based on ~ 70k events

BR ($K^{\pm} \to \pi^0 e^{\pm} \nu$) *preliminary*

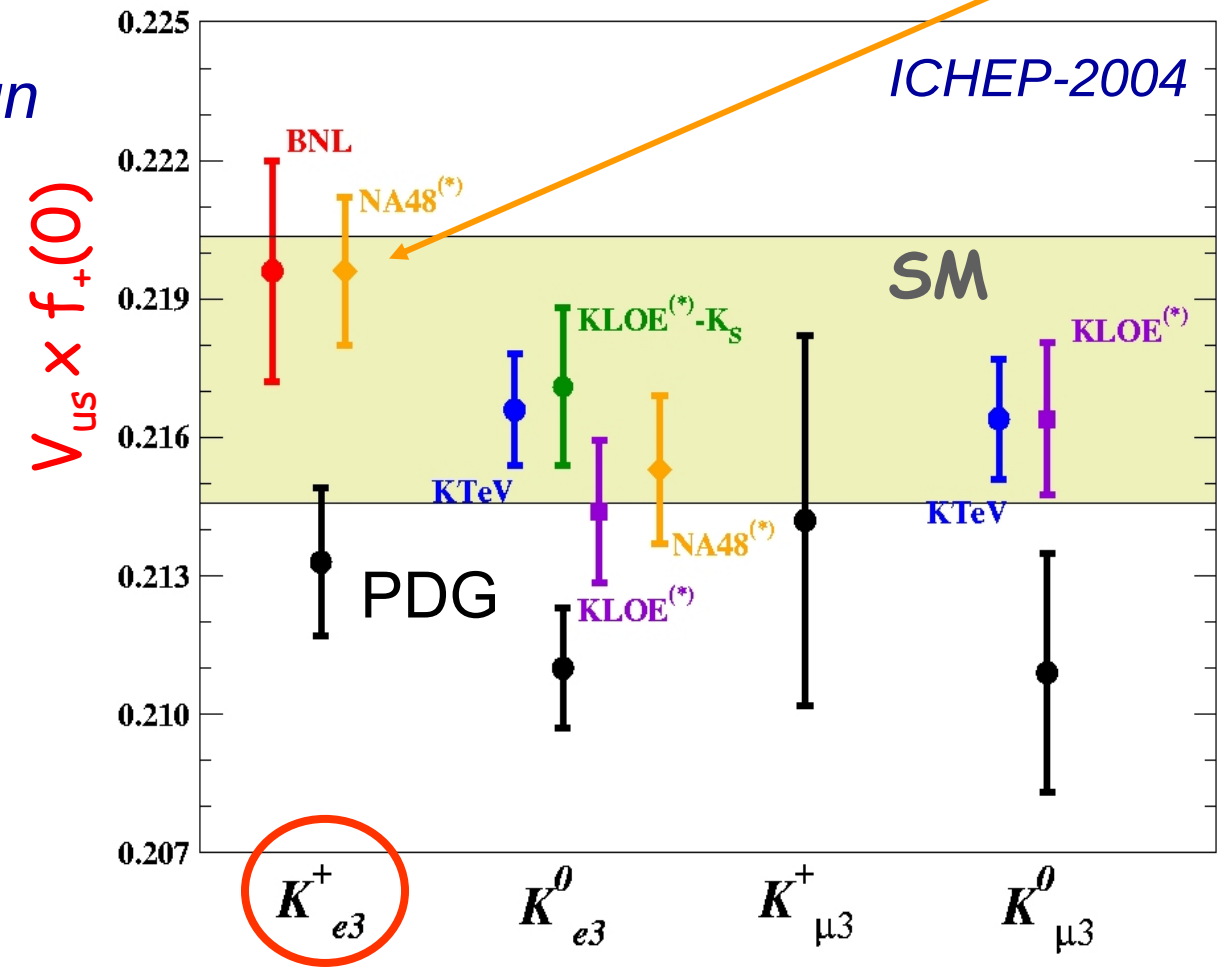
$Br(K_{e3}) = (\mathbf{5.14} \pm 0.02_{stat} \pm 0.06_{syst})\%$

8 hours of 2003 minimum-bias run

$9 \cdot 10^4$ $K^{\pm} \to \pi^0 e^{\pm} \nu$

normalization channel:

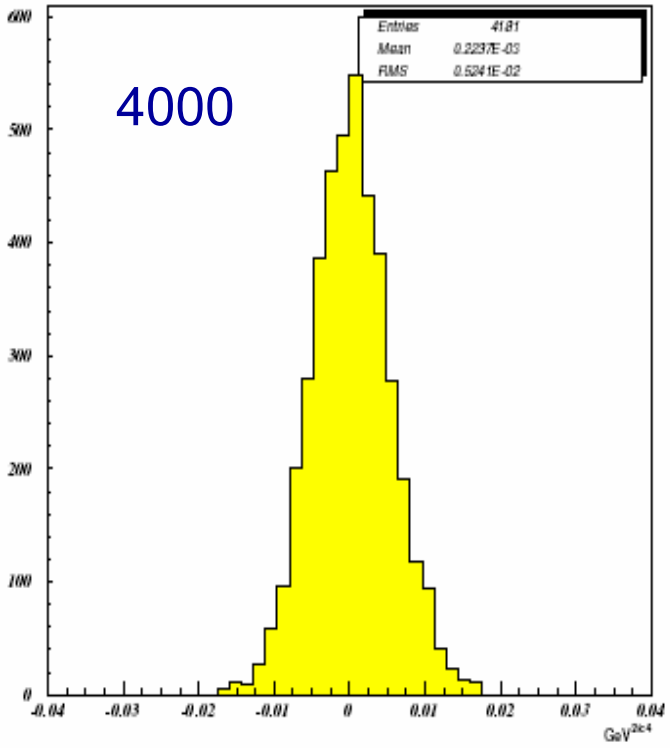
$7 \cdot 10^5$ $K^{+} \to \pi^0 \pi^{\pm}$



Leptonic decay selection

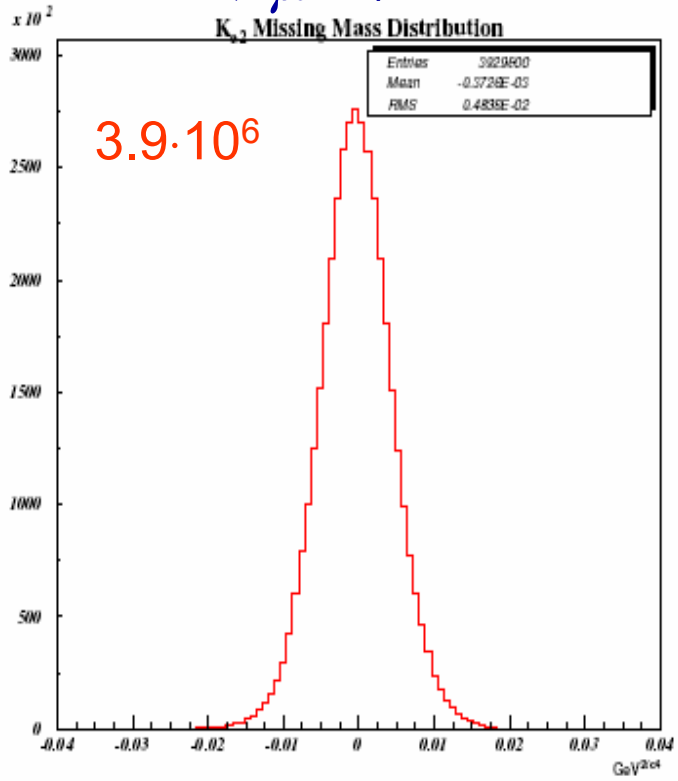
56 hour minimum-bias run in 2004

$K^{\pm} \to e^{\pm} \nu$



(missing mass)^2 ,(GeV/c^2)^2

$K^{\pm} \to \mu^{\pm} \nu$



(missing mass)^2 ,(GeV/c^2)^2

Summary

- **NA48/2** *has completed the data taking*

- ~ **$4 \cdot 10^9$** *of* $K^{\pm} \to \pi^{\pm}\pi^{+}\pi^{-}$ *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 $K^{\pm} \to \pi^0 \pi^0 \pi^{\pm}$ decays*
- *Large multipurpose sample of $K^{\pm}$ decays is accumulated for the study of various rare decays*
- *Most precise measurement of BR($K^{\pm} \to \pi^0 e^{\pm} \nu$) 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