NA48/NA62 Results and Perspectives

Manuel Hita-Hochgesand

Johannes Gutenberg Universität Mainz

on behalf of the ***NA48/2*** *Collaboration:*

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

QCD@Work 2010

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Outline

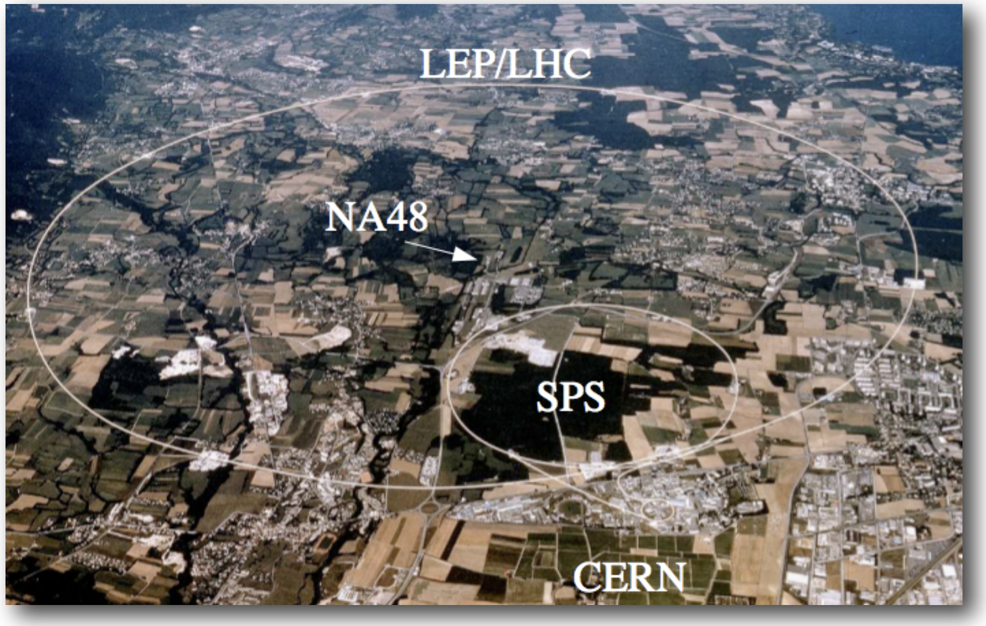
- NA48/2-Experiment.
- $\mathbf{K}^{\pm} \rightarrow \pi^{+}\pi^{-}e^{\pm}\nu \quad (K_{e4})$
  - Form factor and phase shift.
  - $\pi\pi$ scattering lengths a_0^0 and a_0^2.
- $\mathbf{K}^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma \quad (K_{2\pi(\gamma)})$
  - *DE* and *INT* fraction.
  - Test of CPV.
- $\mathbf{K}^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$
  - Branching ratio.
- NA62 Perspectives
- Summary and outlook

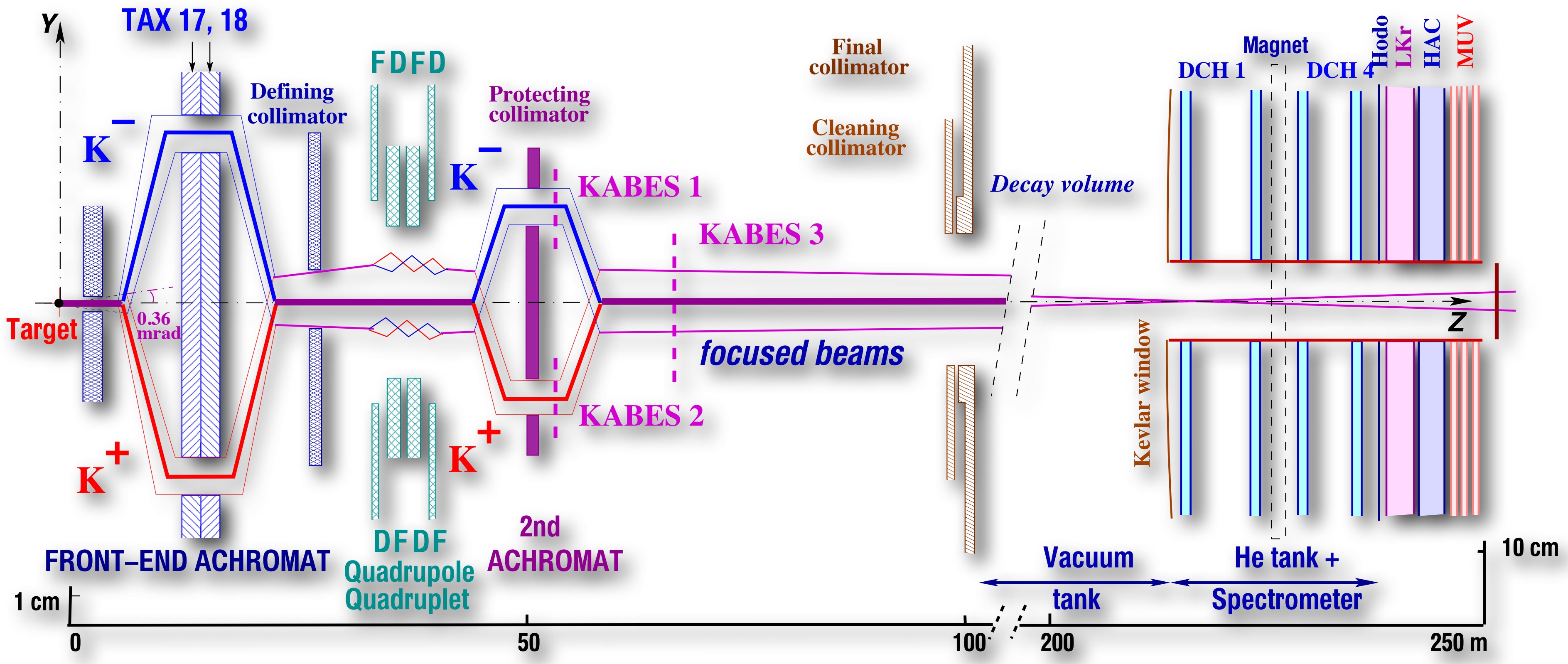
NA48/2-Experiment

- **NA48/2:** is a **fixed target** experiment in the **N**orth **A**rea of the **SPS**
- **400 GeV** protons from the **SPS**
- **Simultaneous** $\mathrm{K}^{\pm}$-Beam with

$$\mathrm{p}_{K^{\pm}} = (60 \pm 3)\ \mathrm{GeV}$$

- 6.3×10^{7} particles per pulse





NA48/2-Experiment

Main detector components:

- **Magnetic Spectrometer**

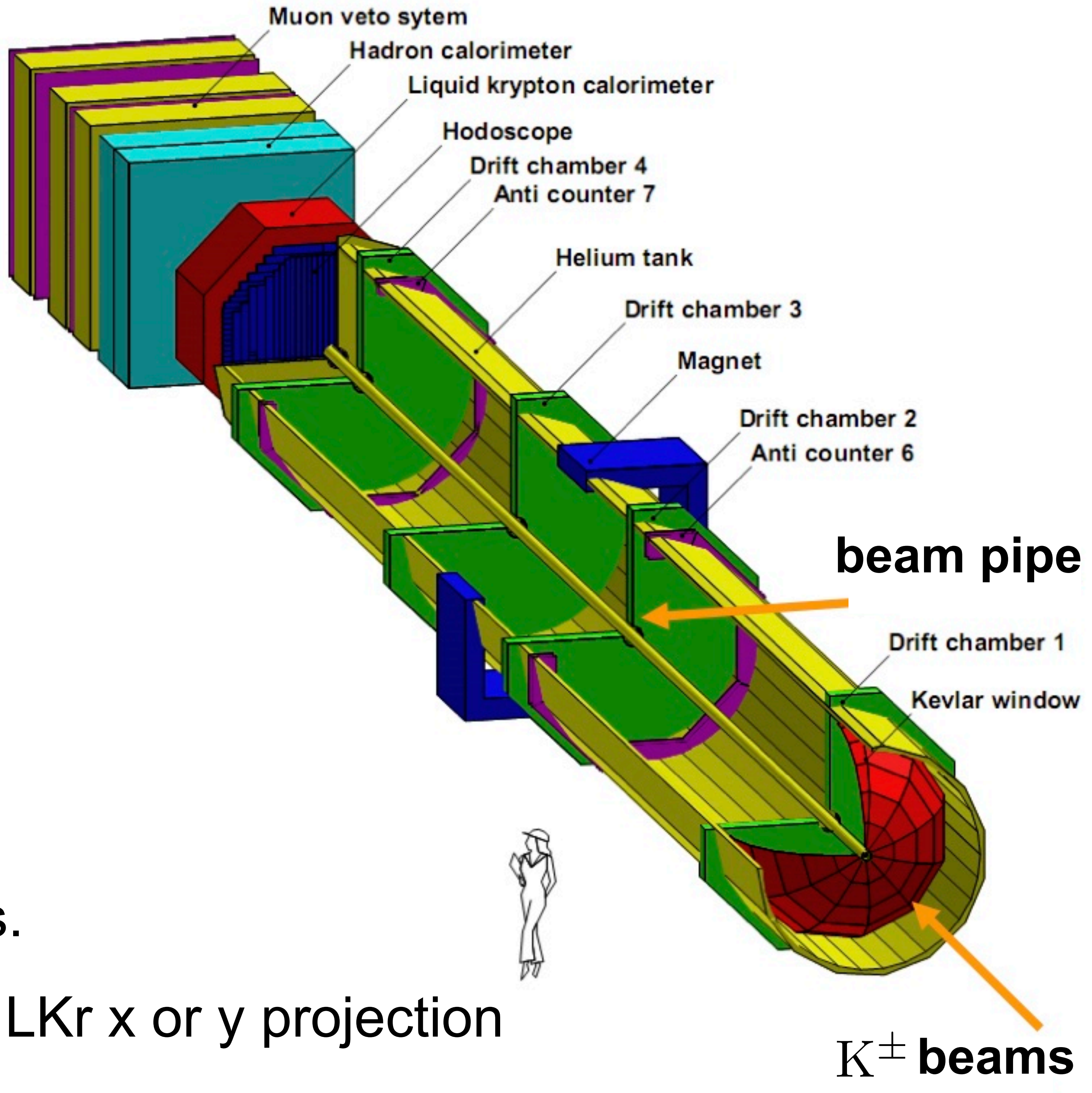
$$\frac{\sigma_p}{p} = 1.02\% \oplus 0.044\% \frac{p}{\mathrm{GeV}/c}$$

~ 1% resolution for charged particles with p=20 GeV/c

- **Liquid Krypton EM Calorimeter**

$$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E/\mathrm{GeV}}} \oplus \frac{9.0\%}{E/\mathrm{GeV}} \oplus 0.42\%$$

1.4% resolution for particles with E=20 GeV



Main trigger modes:

- **Charged trigger:** 3 charged tracks.
- **Neutral trigger:** >=2 em cluster in LKr x or y projection

In 2003 and 2004 total of 18×10^9 triggers collected in 110 days

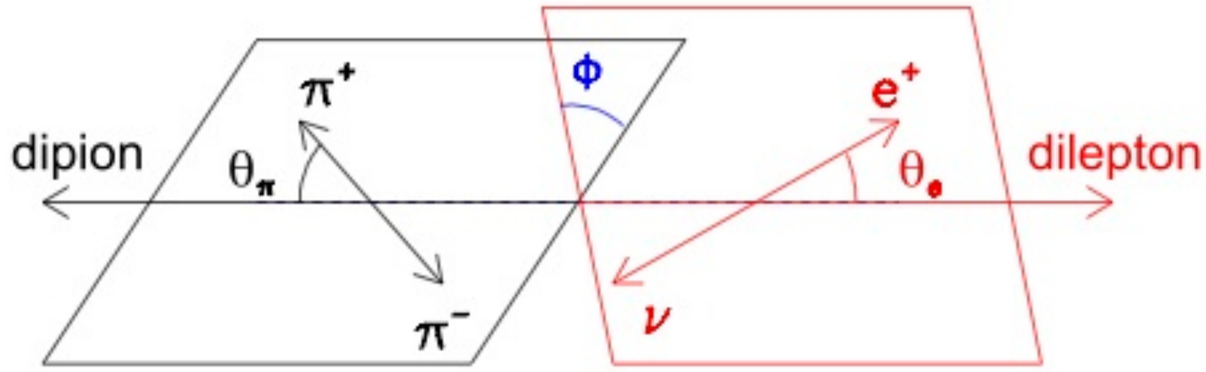
K_{e4} : Theory

Decay characteristics:

- **4-body decay:** 5 independent parameters

  Cabibbo-Maksymowicz variables:

  $S_\pi(M^2_{\pi\pi}), S_e(M^2_{e\nu}), \cos\theta_\pi, \cos\theta_e, \Phi$



Transition amplitude:

$$\frac{G_w}{\sqrt{2}} V^*_{us} \langle \pi^+\pi^- | V^\lambda - A^\lambda | K^+ \rangle \bar{u}_\nu \gamma_\lambda (1-\gamma_5) v_e$$

$$\langle \pi^+\pi^- | A^\lambda | K^+ \rangle = \frac{-i}{\sqrt{m_K}} \left(F\,(\mathbf{p}_{\pi^+} + \mathbf{p}_{\pi^-})^\lambda + G\,(\mathbf{p}_{\pi^+} - \mathbf{p}_{\pi^-})^\lambda + R\,(\mathbf{p}_e + \mathbf{p}_\nu)^\lambda \right)$$

$$\langle \pi^+\pi^- | V^\lambda | K^+ \rangle = \frac{-H}{m_K^3} \epsilon^{\lambda\mu\rho\sigma} (\mathbf{p}_{\pi^+} + \mathbf{p}_{\pi^-} + \mathbf{p}_e + \mathbf{p}_\nu)_\mu \times (\mathbf{p}_{\pi^+} + \mathbf{p}_{\pi^-})_\rho (\mathbf{p}_{\pi^+} - \mathbf{p}_{\pi^-})_\sigma$$

Axial form factors : $F \; G \; R$ (no R contribution in K_{e4} because it is proportional to m_l^2)

Vector form factor : H

Partial wave expansion:

$$F = F_s e^{i\delta_s} + F_p e^{i\delta_p} \cos\theta_\pi + d \text{ wave} \ldots$$

$$G = G_p e^{i\delta_g} + d \text{ wave} \ldots$$

$$H = H_p e^{i\delta_h} + d \text{ wave} \ldots$$

Expansion in q^2 and S_e/m_π^2:

$$F_s = f_s + f_s' q^2 + f_s'' q^4 + f_e' S_e/4m_\pi^2 + \ldots$$

$$F_p = f_p + f_p' q^2 + \ldots$$

$$G_p = g_p + g_p' q^2 + \ldots$$

$$H_p = h_p + h_p' q^2 + \ldots$$

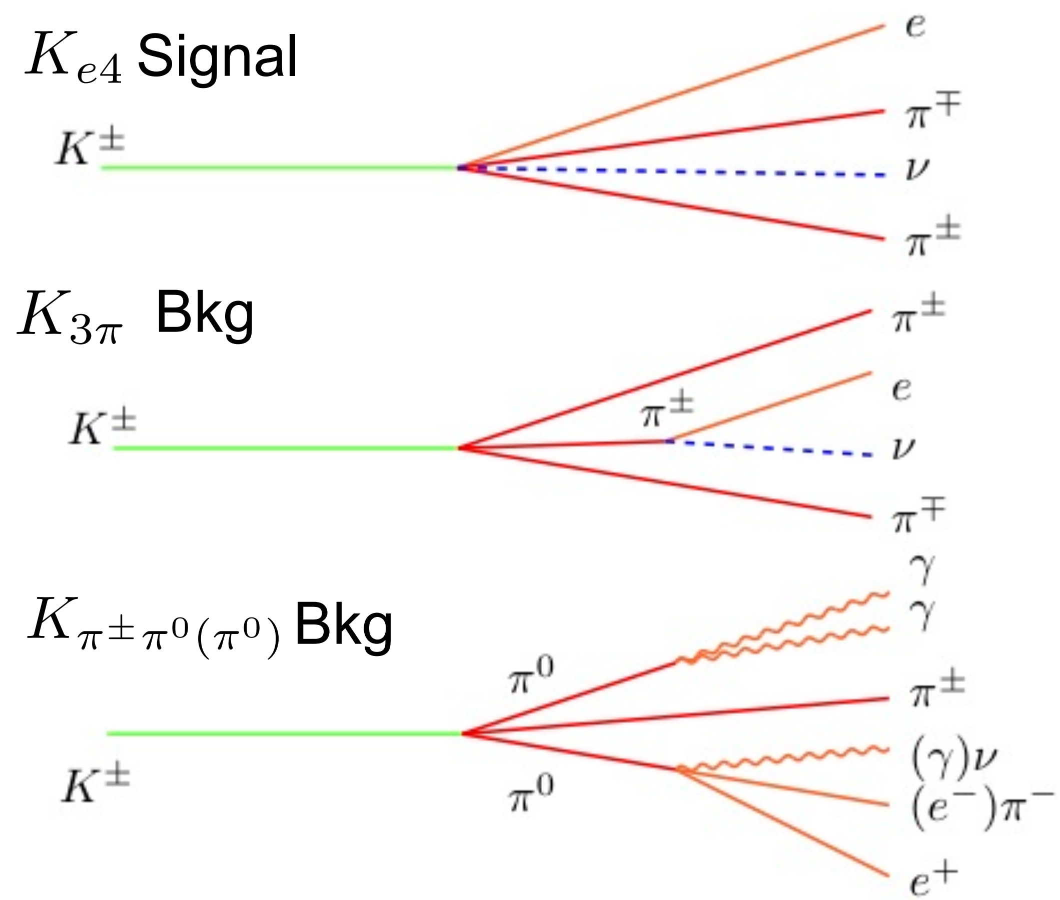
$$\delta(q^2) = \delta_s - \delta_p \,. \qquad q^2 = (S_\pi/4m_\pi^2) - 1$$

Fit parameters: $F_s, F_p, G_p, H_p, \delta$

K_{e4} : Selection and Background rejection

K_{e4} selection:

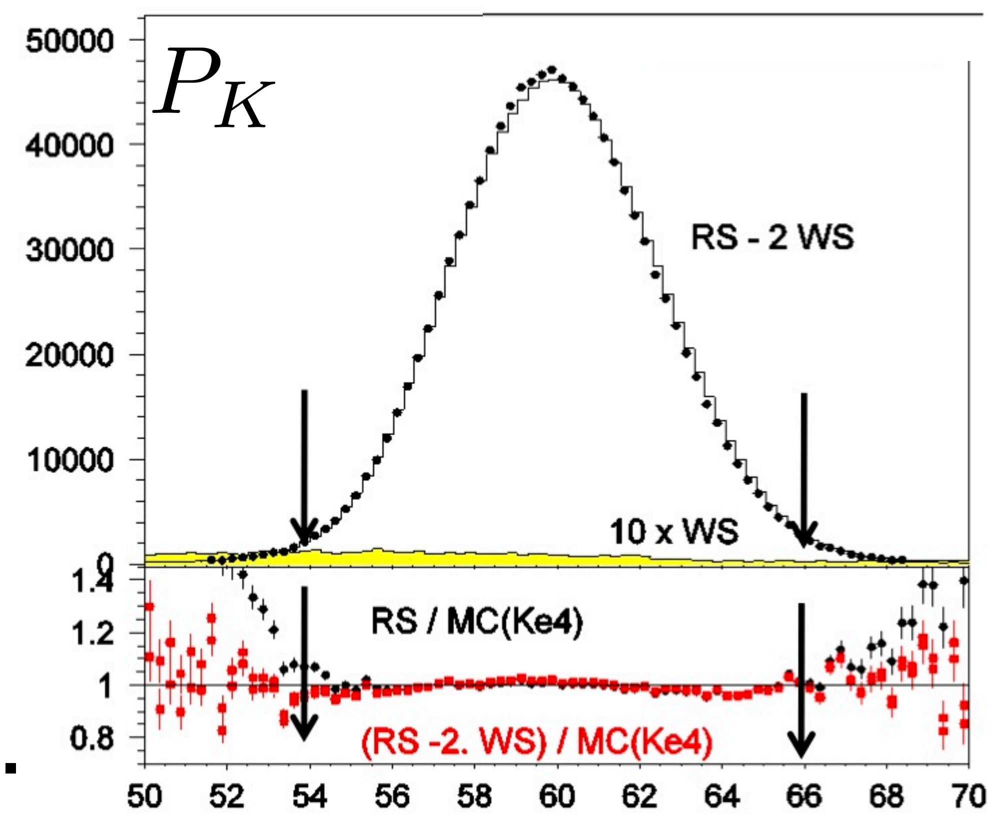
- **3 charged tracks** and a **good vertex**
- **2 opposite sign pions, 1 electron (E/P~1)**
- **missing transverse momentum** and **energy**
- **reconstructed Kaon energy (** $E_\nu = |\mathbf{p}_\nu|$ **)**



Background:

- $K^\pm \to \pi^\pm\pi^+\pi^-$ decay with pion decay, or pion misidentification as an electron.
- $K^\pm \to \pi^\pm\pi^0(\pi^0)$ decay followed by the dalitz decay of a pion, a misidentification of the electron as a charged pion and an undetected photons.

  ellipse cut in $M_{3\pi} - p_t$ plane.
  linear discriminant variables based on shower properties.
- estimation of the background using wrong-sign event rates in the data.



- **background/signal-ratio: 0.6% (2 WS/RS).**

K_{e4}: fitting procedure

full event sample (2003 and 2004): **1.13 million K_{e4} decays**

Using **iso-populated boxes** in the 5-dimensional space of the Ca.Ma. variables, one defines a grid of:

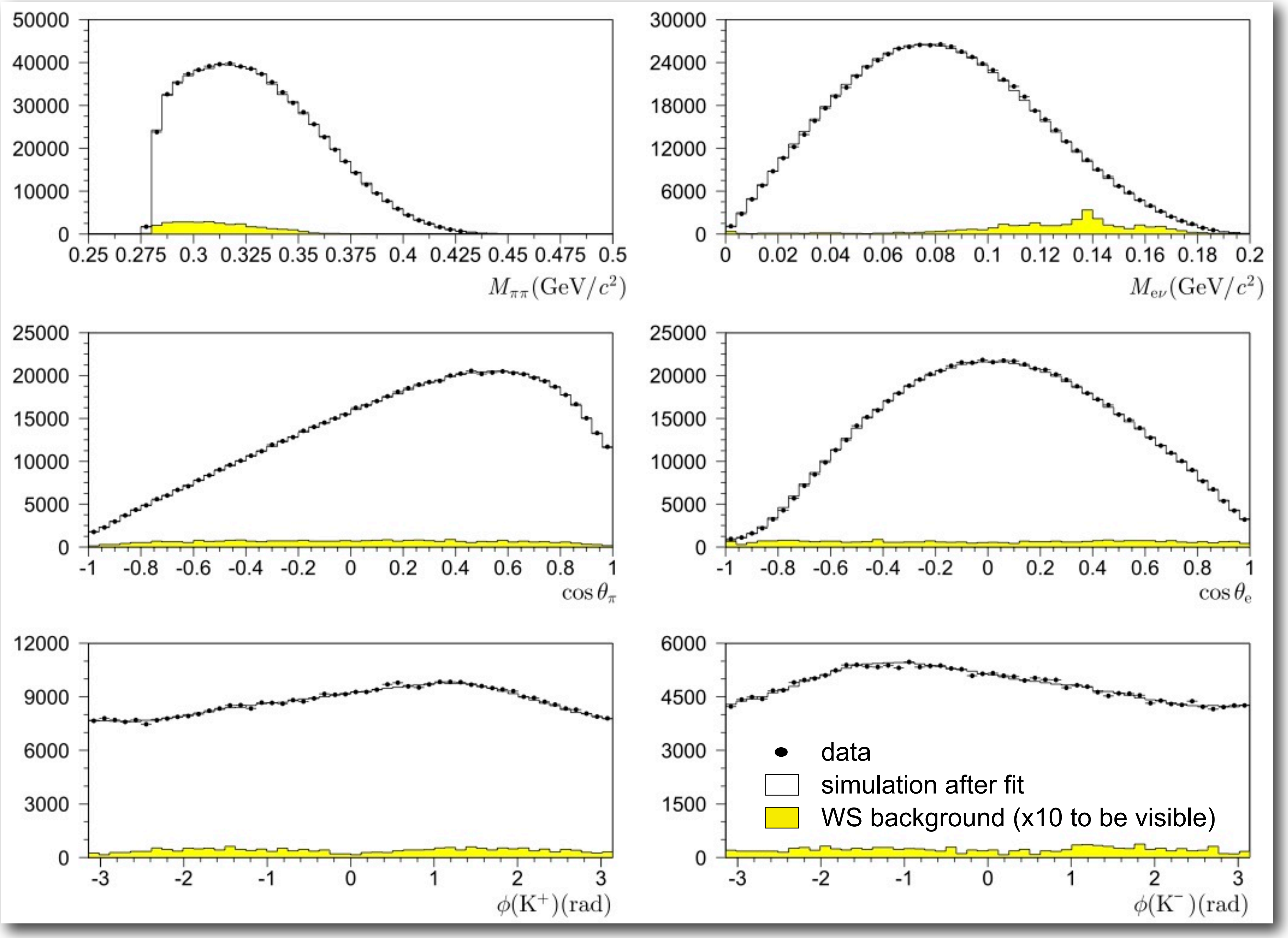
$$10(M_{\pi\pi}) \times 5(M_{e\nu}) \times 5(\cos\theta_e) \times 5(\cos\theta_\pi) \times 12(\phi) = 15000 \text{ Boxes}$$

The set of Form Factor values is used to minimise a **log-likelihood estimator** well suited for small numbers of data event/bin and taking into account the statistics of the simulation (simulated and expected events/bin)

Assuming constant Form Factors over single boxes, K^+ and K^- samples fitted separately in **10 independent $M_{\pi\pi}$ bins/slices** and then combined in each slice according to their statistical error

Data	K^+- sample: (726400 events)	48 events/box
	K^-- sample: (404400 events)	27 events/box
MC	K^+- sample: (17.4 million events)	1160 events/box
	K^-- sample: (9.7 million events)	650 events/box

K_{e4} : Data/MC-compairison after the fit



- **Background** (in yellow) **X 10** to be visible.
- **CP symmetry** shown in the **opposite distribution** of $\phi(K^+)$ and $\phi(K^-)$.

K_{e4} : form factor fit results

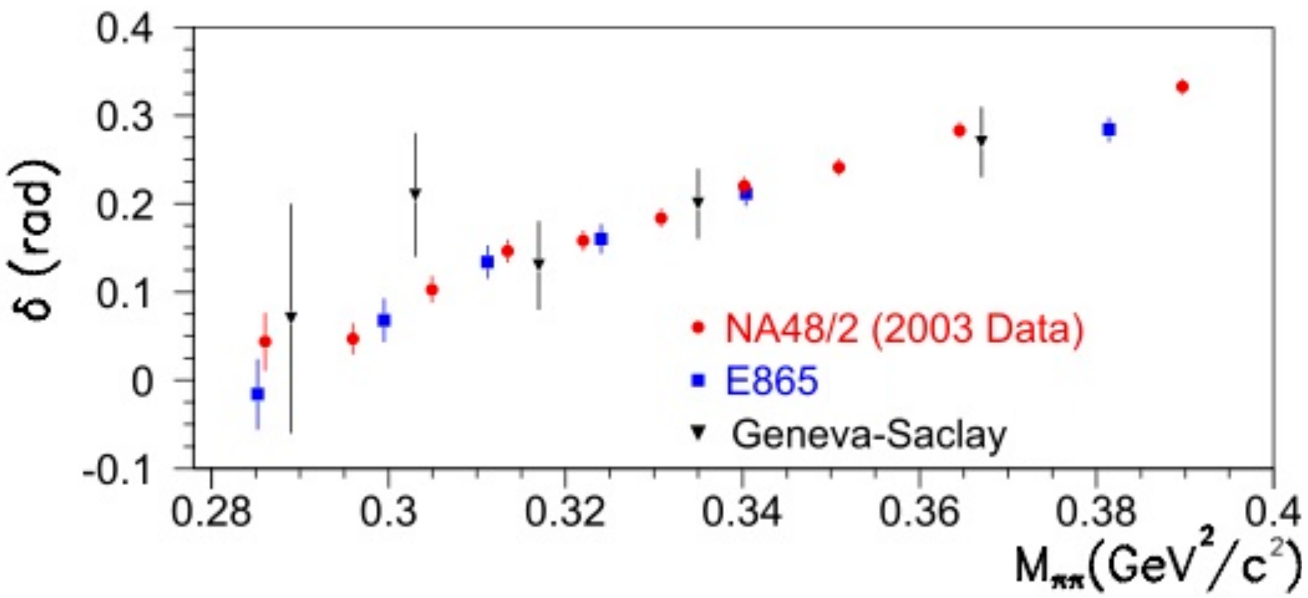
- All the **form factors** are measured **relatively to** f_s (no measurement of the branching ratio yet).
- **Systematics** from **background, electron-ID and acceptance control** and about same size as the statistical errors or smaller.
- **first evidence** of $f_e^{'} \neq 0$ and $f_p \neq 0$.

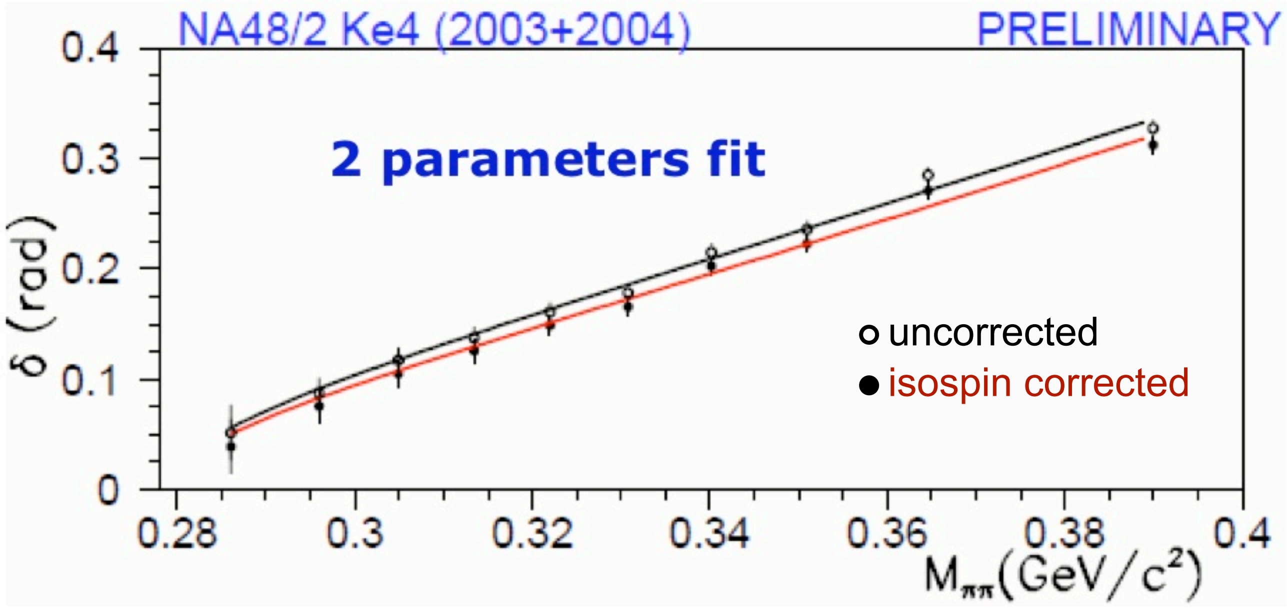
$$
\begin{aligned}
\mathrm{f}_s^{'}/f_s &= 0.152 \pm 0.007_{\mathrm{stat}} \pm 0.005_{\mathrm{syst}} \\
\mathrm{f}_s^{''}/f_s &= -0.073 \pm 0.007_{\mathrm{stat}} \pm 0.006_{\mathrm{syst}} \\
\mathrm{f}_e^{'}/f_s &= 0.068 \pm 0.006_{\mathrm{stat}} \pm 0.007_{\mathrm{syst}} \\
\mathrm{f}_p/f_s &= -0.048 \pm 0.003_{\mathrm{stat}} \pm 0.004_{\mathrm{syst}} \\
\mathrm{g}_p/f_s &= 0.868 \pm 0.010_{\mathrm{stat}} \pm 0.010_{\mathrm{syst}} \\
\mathrm{g}_p^{'}/f_s &= 0.089 \pm 0.017_{\mathrm{stat}} \pm 0.013_{\mathrm{syst}} \\
\mathrm{h}_p/f_s &= -0.398 \pm 0.015_{\mathrm{stat}} \pm 0.008_{\mathrm{syst}}
\end{aligned}
$$

K_{e4}: δ-dependence and $\pi\pi$ scattering lengths

- The extraction of pion **scattering lengths** from the fitted $\delta = \delta_\mathbf{s} - \delta_\mathbf{p}$ phase shift needs external theoretical and experimental inputs:
  - The **Roy equations** provide the relation between δ and a_0 and a_2 (as two subtraction const.) the S-wave scattering (isospin sym. assumption).
  - Extrapolating experimental data from the $M_{\pi\pi} > 0.8\ \mathrm{GeV/c^2}$ it's possible to fit the result in the threshold region (the uncertainty from the experimental data defines the **Universal Band**)

(Ananthanarayan,Colangelo,Gasser,Leutwyler Phys.Rept.353 (2001) 207-279)
(Descotes-Genon, Fuchs, Girlanda,Stern Eur.Phys.J.C24 (2002) 469-483)
(Kaminski, Pelaez, Yndurain Phys.Rev.D77 (2008))





- The fit of the experimental points using the **Roy equations** allows to extract the a_0 and a_2 values.
- **Isospin corrections** (generated by the pion and quark mass differeces) result in a 11 to 15 mrad shift in δ can not be ignored.

(Gasser et. al. Eur. Phys. J. C59 (2009) 777)

K_{e4}: δ-dependence and $\pi\pi$ scattering lengths

two parameter fit:

(correlation 97%)

$$a_0 = 0.2220 \pm 0.0128_{stat} \pm 0.0050_{syst} \pm 0.0037_{theo}$$
$$a_2 = -0.0432 \pm 0.0086_{stat} \pm 0.0034_{syst} \pm 0.0028_{theo}$$

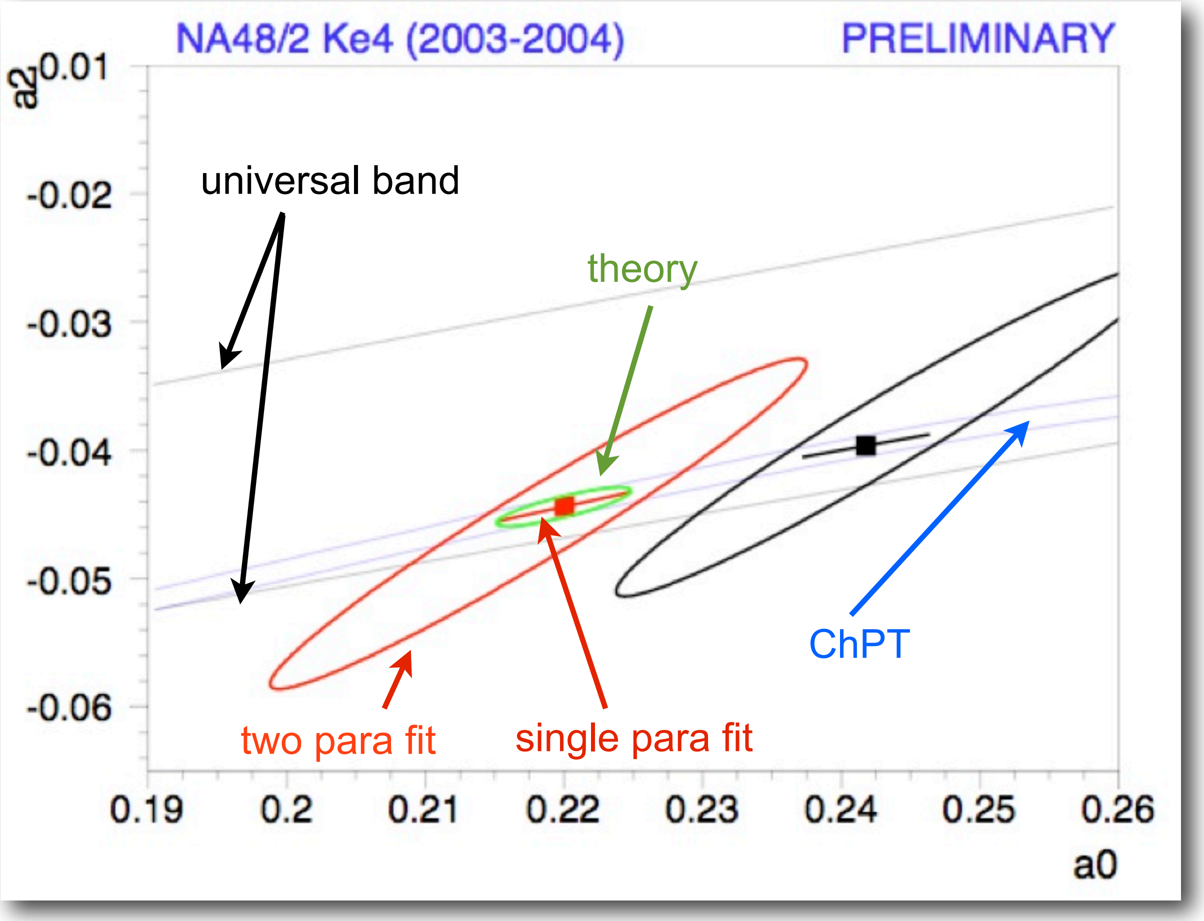
Single parameter fit:

(a_2 constraint to ChPT prediction)

$$a_0 = 0.2206 \pm 0.0049_{stat} \pm 0.0018_{syst} \pm 0.0064_{theo}$$

Theory prediction: *(CGL NPB603(2001),PRL86(2001))*

$$a_0 = 0.2220 \pm 0.005$$
$$a_2 = -0.0444 \pm 0.0010$$



- **Systematic errors** from **background estimation** and **electron-ID**.
- **Theoretical error** evaluated from control of **isospin corrections** & inputs to **Roy equation** numerical solutions.

NA48/2: K_{e4} and Cusp Results combined

Two independent measurements:

- 60 millions $K_{3\pi}$-events.
- 1.13 millions K_{e4}-events.

Different systematics:

- Cusp: calorimeter and trigger.
- K_{e4} : electron mis-id and background.

Different theoretical inputs:

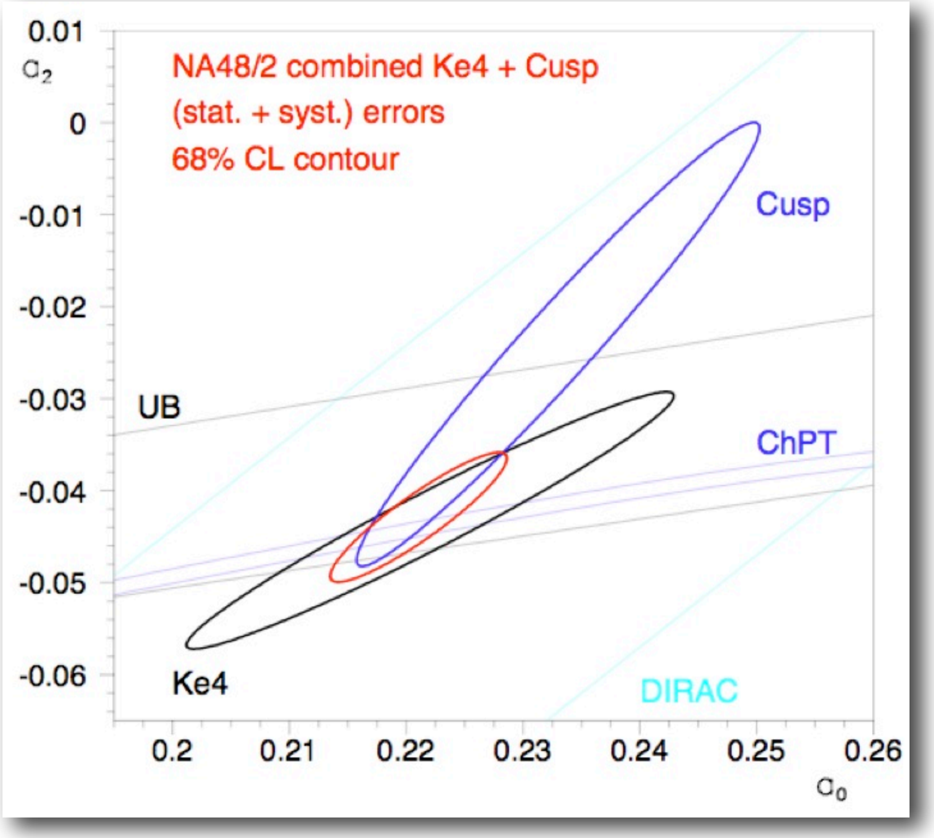
- Cusp: (1 & 2-loop) re-scattering models.

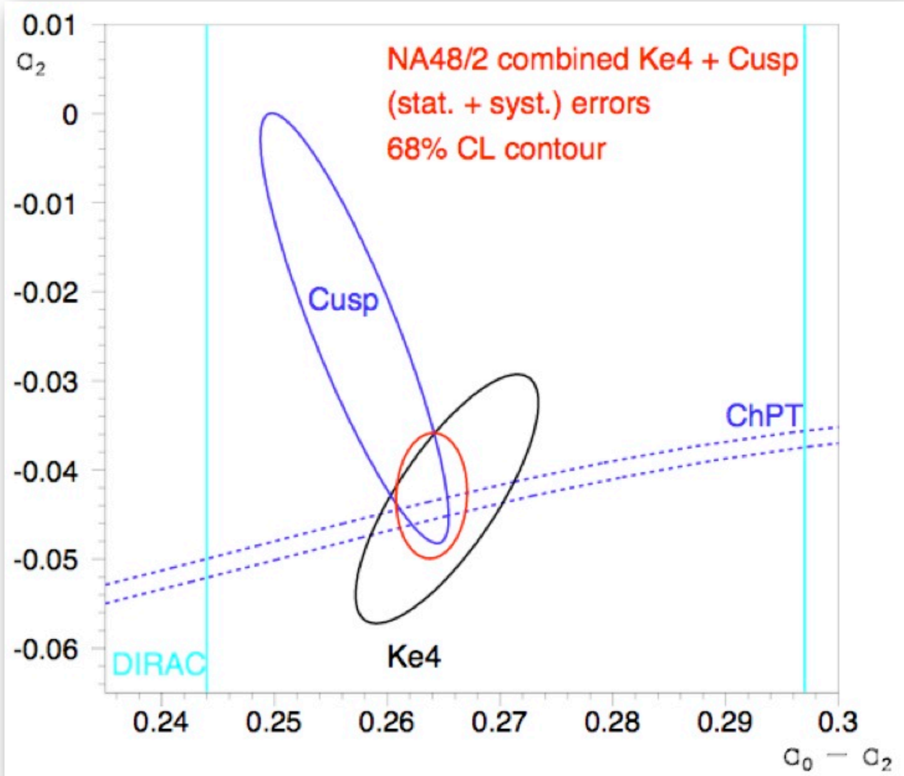
  (Cabibbo,Isidori JHEP 0503 (2005) 21)
  (Bissegger, Fuhrer, Gasser, Kubis, Rusetsky, NPH B806 (2009) 178)
- K_{e4} : Roy equation and isospin breaking corrections.

Combined results:

$$\mathrm{a}_0 = \quad 0.2210 \pm 0.0047_{\mathrm{stat}} \pm 0.0040_{\mathrm{syst}}$$
$$\mathrm{a}_2 = -0.0429 \pm 0.0044_{\mathrm{stat}} \pm 0.0028_{\mathrm{syst}}$$

$$\mathrm{a}_0 - a_2 = \quad 0.2639 \pm 0.0020_{\mathrm{stat}} \pm 0.0015_{\mathrm{syst}}$$
$$\mathrm{a}_2 = -0.0429 \pm 0.0044_{\mathrm{stat}} \pm 0.0028_{\mathrm{syst}}$$

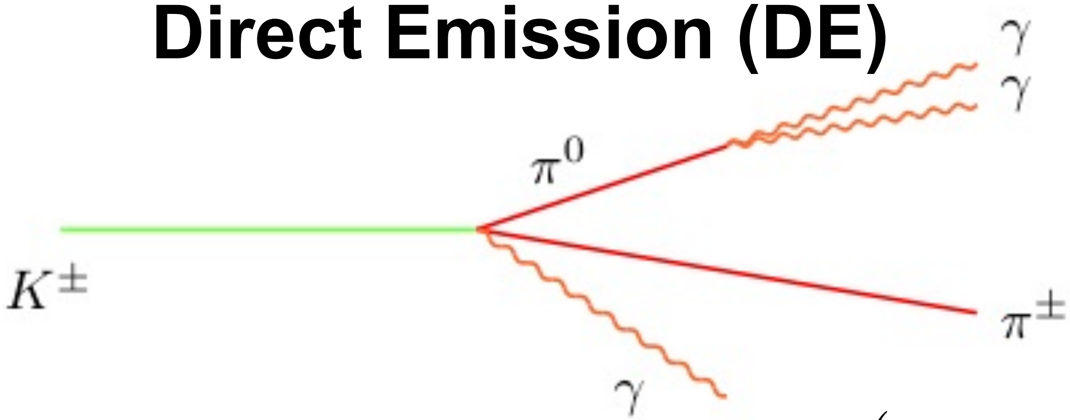




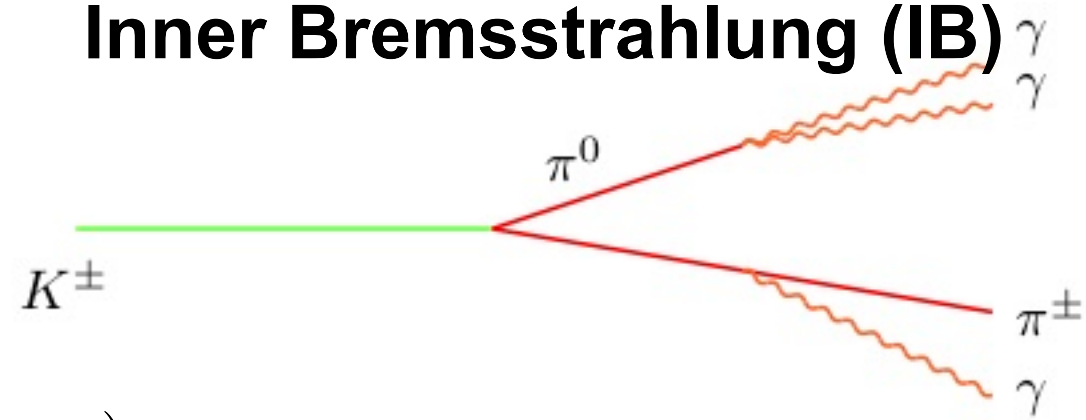
$K_{2\pi\gamma}$: Theory

Decay characteristics: two sources of γ radiation.

Direct Emission (DE)



Inner Bremsstrahlung (IB)



Kinematic variable: $W^2 = \frac{(\mathbf{p}_\pi \cdot \mathbf{p}_\gamma)(\mathbf{p}_\mathrm{K} \cdot \mathbf{p}_\gamma)}{m_K^2 m_\pi^2}$ T_π^* : kinetic energy of the Pion in the kaon cms

$$\frac{\partial\Gamma^\pm}{\partial W} = \frac{\partial\Gamma^\pm_{\mathrm{IB}}}{\partial W}\left[1 + 2m_K^2 m_\pi^2 \cos\left(\pm\phi + \delta_1^1 - \delta_0^2\right)|X_E|W^2 + m_K^4 m_\pi^4\left(|X_E|^2 + |X_M|^2\right)W^4\right]$$

Inner Bremsstrahlung (IB)

known from $K^\pm \to \pi^\pm\pi^0$ and QCD

Interference (INT)

Interference of IB and electric DE (X_E). No prediction.

Direct Emission (DE)

two terms ($\mathcal{O}(p^4)$ ChPT):

- X_M: magnetic part with 2 contributions
  - reducible Wess-Zumino-Witten functional (chiral anomaly)
  - direct (not known)
- X_E : electric part: no prediction in ChPT

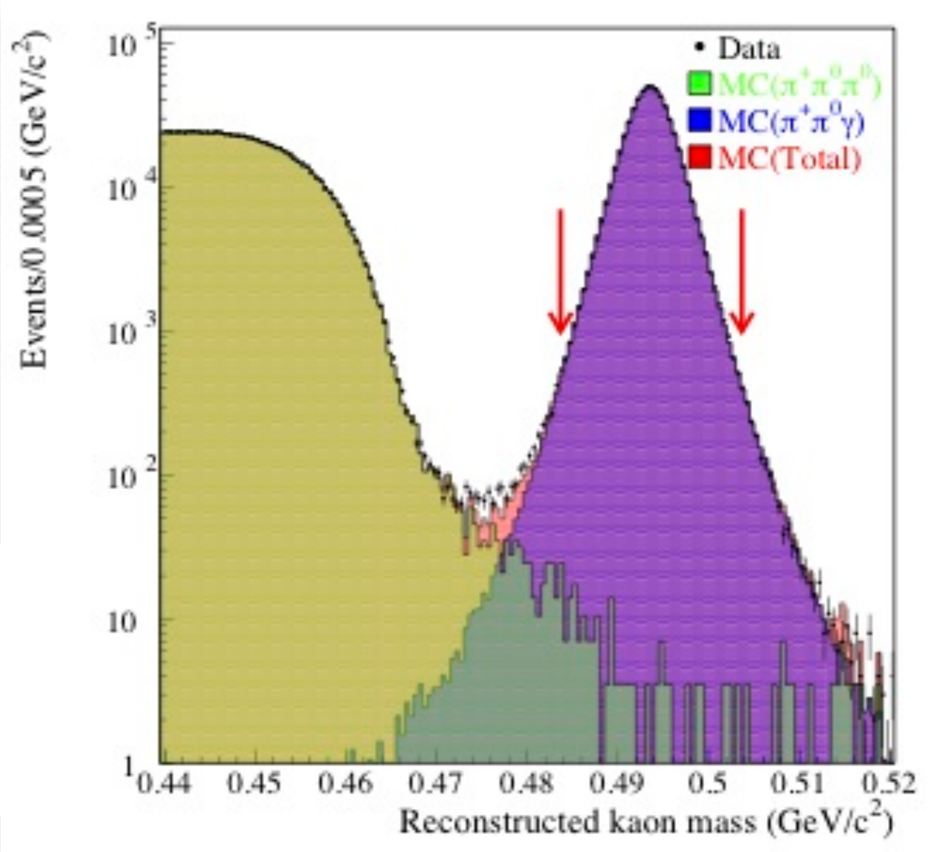
Current PDG Values:

$(2.75 \pm 0.15) \times 10^{-4}$ $55\ \mathrm{MeV} < \mathrm{T}_\pi^* < 90\ \mathrm{MeV}$	Not yet measured	$(4.4 \pm 0.8) \times 10^{-6}$ $55\ \mathrm{MeV} < \mathrm{T}_\pi^* < 90\ \mathrm{MeV}$

$K_{2\pi\gamma}$: Data sample

New NA48/2 measurement:

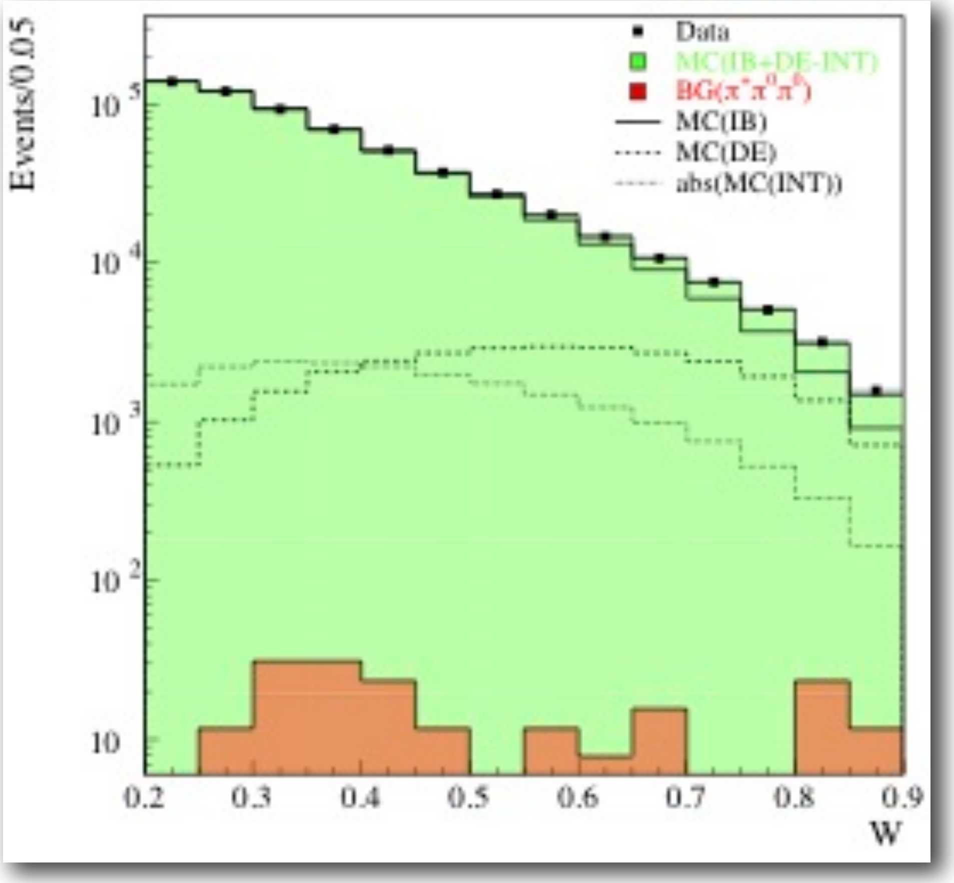
- **Simultaneous** K^+/K^- **beams** (⇨ **CPV test** possible).
- **Larger** T^*_π **region** available: $0 \text{ MeV} < T^*_\pi < 80 \text{ MeV}$
- **Background < 0.01 %**(negligible) (mainly from $K^\pm \to \pi^\pm\pi^0\pi^0$)
- γ **mistagging probability** < 0.1%.



Total $K^\pm \to \pi^\pm\pi^0\gamma$ data sample:

- more than **1 million events.**
- for the fit: restrict to $0.2 < W < 0.9$ and $E_\gamma > 5\ GeV$

⇨ **still 600k** $K_{2\pi\gamma}$ **candidates.**



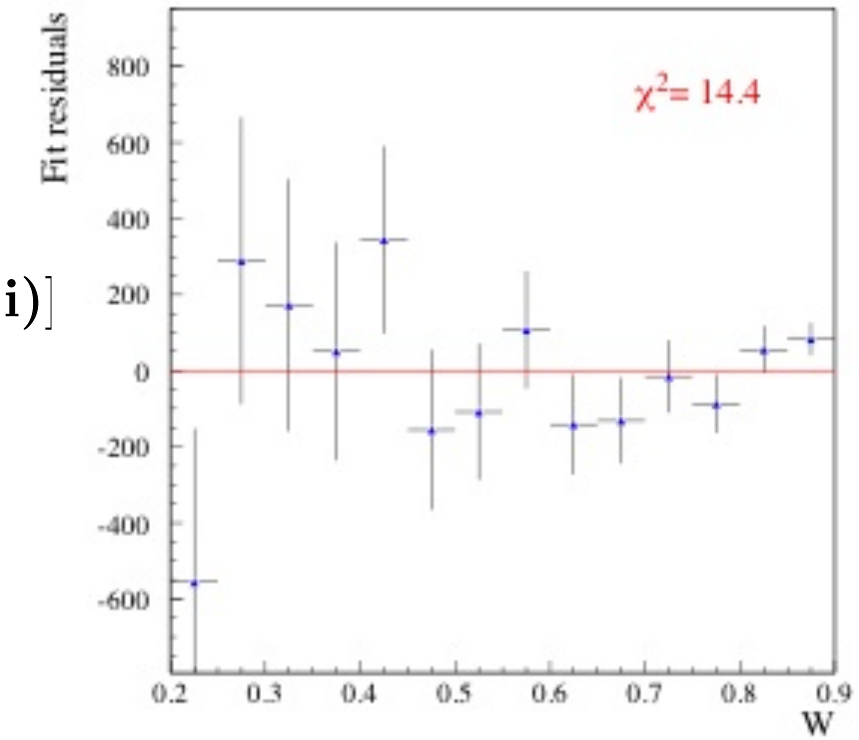
$K_{2\pi\gamma}$: Fit

Extended Maximum Likelihood fit

in bins of W corrected by **acceptance** with Monte Carlo

$$\mathbf{Data(i)} = N_0\left[(1-\alpha-\beta)\cdot\mathbf{IB_{MC}(i)} + \alpha\cdot\mathbf{INT_{MC}(i)} + \beta\cdot\mathbf{DE_{MC}(i)}\right]$$

$$\mathbf{Frac(DE)} = (\ 3.32 \pm 0.15)\times 10^{-2}$$
$$\mathbf{Frac(INT)} = (-2.35 \pm 0.35)\times 10^{-2}$$



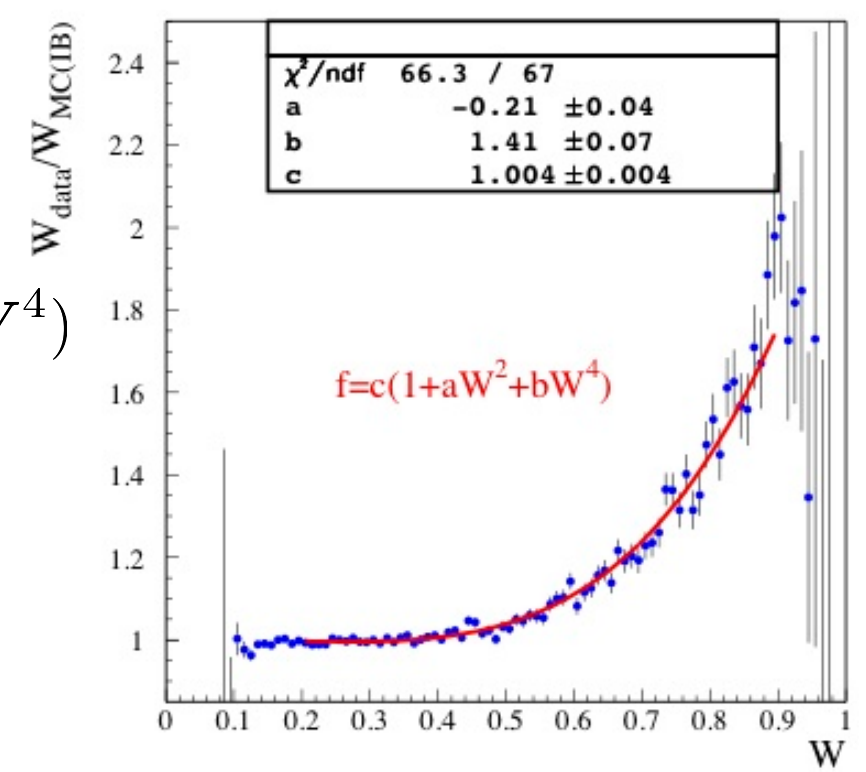
$$\mathrm{Frac(DE)} = \frac{\mathrm{Br(DE)}}{\mathrm{Br(IB)}} \qquad \mathrm{Frac(INT)} = \frac{\mathrm{Br(INT)}}{\mathrm{Br(IB)}} \qquad 0\ \mathrm{MeV} < \mathrm{T}^*_\pi < 80\ \mathrm{MeV}$$

Polynominal fit

Assumes **same acceptance** as a function of W for IB, DE and INT

Fit ratio $W(\mathrm{Data})/\mathrm{W(MC_{IB})}$ with: $f(\boldsymbol{W}) = c(1 + a\boldsymbol{W}^2 + b\boldsymbol{W}^4)$

$$\mathbf{Frac(DE)} = (\ 3.19 \pm 0.16)\times 10^{-2}$$
$$\mathbf{Frac(INT)} = (-2.21 \pm 0.41)\times 10^{-2}$$

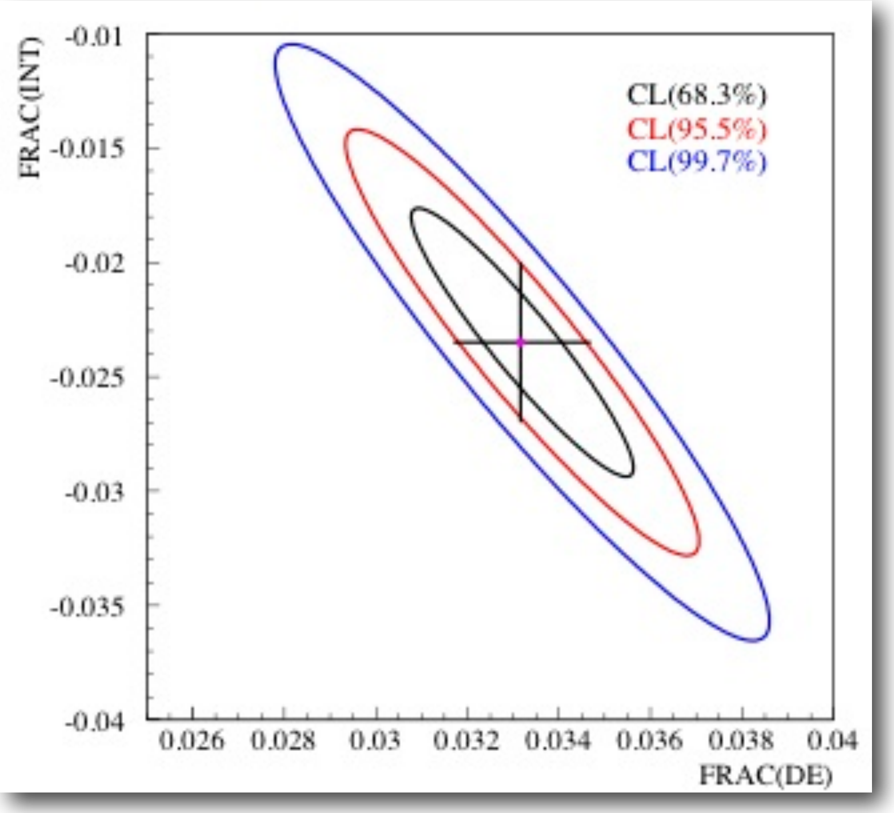


Fit with **no interference term** shows **disagreement**.

$K_{2\pi\gamma}$: Final result

Final NA48/2 result for $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma$ fractions:

$$\mathbf{Frac(DE)}_{0<T_{\pi}^{*}<80\ \mathrm{MeV}} = (\ 3.32 \pm 0.15_{\mathrm{stat}} \pm 0.14_{\mathrm{syst}}) \times 10^{-2}$$
$$\mathbf{Frac(INT)}_{0<T_{\pi}^{*}<80\ \mathrm{MeV}} = (-2.35 \pm 0.35_{\mathrm{stat}} \pm 0.39_{\mathrm{syst}}) \times 10^{-2}$$



Approximation for extracting X_E and X_M:

- $\phi = 0$
- $\cos(\delta_1^1 - \delta_0^2) = \cos 6.6^{\circ} \approx 1$
- $\mathrm{X}_E = \frac{\mathrm{Frac(INT)}}{2\cdot 0.105\cdot m_k^2 m_\pi^2}$ $\mathrm{X}_M = \sqrt{\frac{\mathrm{Frac(DE)} - \mathrm{m}_\mathrm{k}^4 \mathrm{m}_\pi^4 |\mathrm{X_E}|^2 0.0227}{0.0227\cdot m_k^4 m_\pi^4}}$

Magnetic and electric component of DE (first measurement):

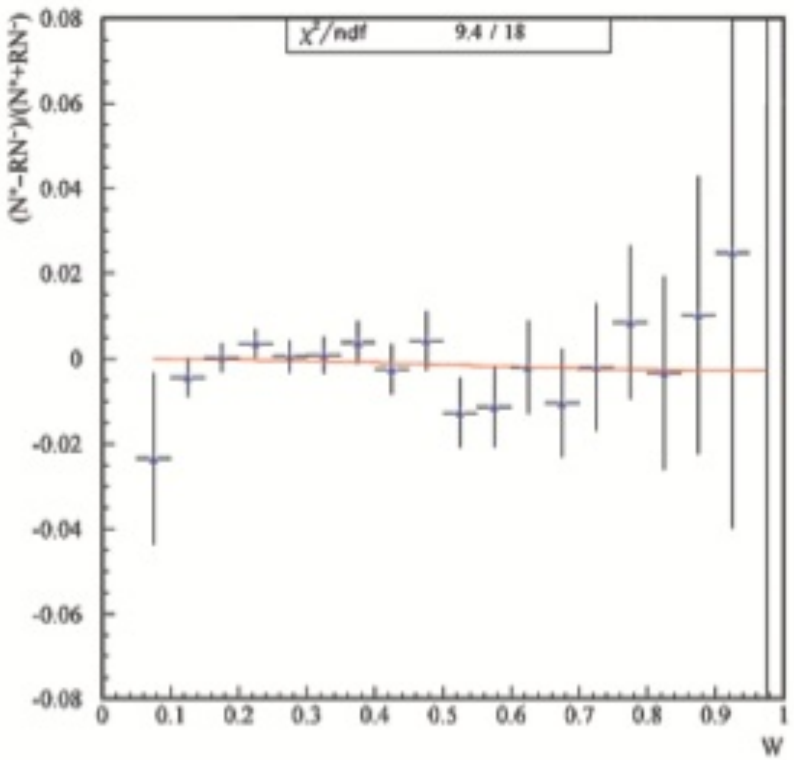
$$\mathrm{X}_E = (-24 \pm 4_{\mathrm{stat}} \pm 4_{\mathrm{syst}})\mathrm{GeV}^{-4}$$
$$\mathrm{X}_M = (244 \pm 6_{\mathrm{stat}} \pm 6_{\mathrm{syst}})\mathrm{GeV}^{-4}$$

Wess-Zumino-Witten **chiral anomaly prediction:** $\mathrm{X}_M \approx 270\ \mathrm{GeV}^{-4}$

⇨ NA48/2 X_M measurement points to **WZW reducible anomaly only**

$K_{2\pi\gamma}$: CPV studies

Asymmetry in the total rate:



$$A_N = \frac{\Gamma^+ - \Gamma^-}{\Gamma^+ + \Gamma^-} = \frac{N_{\pi^+\pi^0\gamma} - R \cdot N_{\pi^-\pi^0\gamma}}{N_{\pi^+\pi^0\gamma} + R \cdot N_{\pi^-\pi^0\gamma}}$$

with $R = N_{K^+}/N_{K^-} = 1.7998(4)$ **from** $K^\pm \to \pi^\pm\pi^0\pi^0$

$$A_N = (0.0 \pm 1.0_{\text{stat}} \pm 0.6_{\text{syst}}) \times 10^{-3}$$
$$|A_N| < 1.5 \times 10^{-3} \quad (90\%\ \text{CL})$$

⇨ **First limit** on $\sin\phi$: $\sin\phi = -0.01 \pm 0.43$, $|\sin\phi| < 0.56$ (90%CL)

Asymmetry in the Dalitz plot:

using the W **spectrum:** $$\frac{d\Gamma^\pm}{dW} = \frac{d\Gamma^\pm_{\text{IB}}}{dW}(1 + (a \pm e)W^2 + bW^4)$$

$$A_W = e \int \frac{\text{INT}}{\text{IB}} = (-0.6 \pm 1.0) \times 10^{-3}$$

compatible with A_N

⇨ **no CP asymmetry observed in** $K^\pm \to \pi^\pm\pi^0\gamma$

$K^{\pm} \to \pi^{\pm}\gamma\gamma$: Theorie

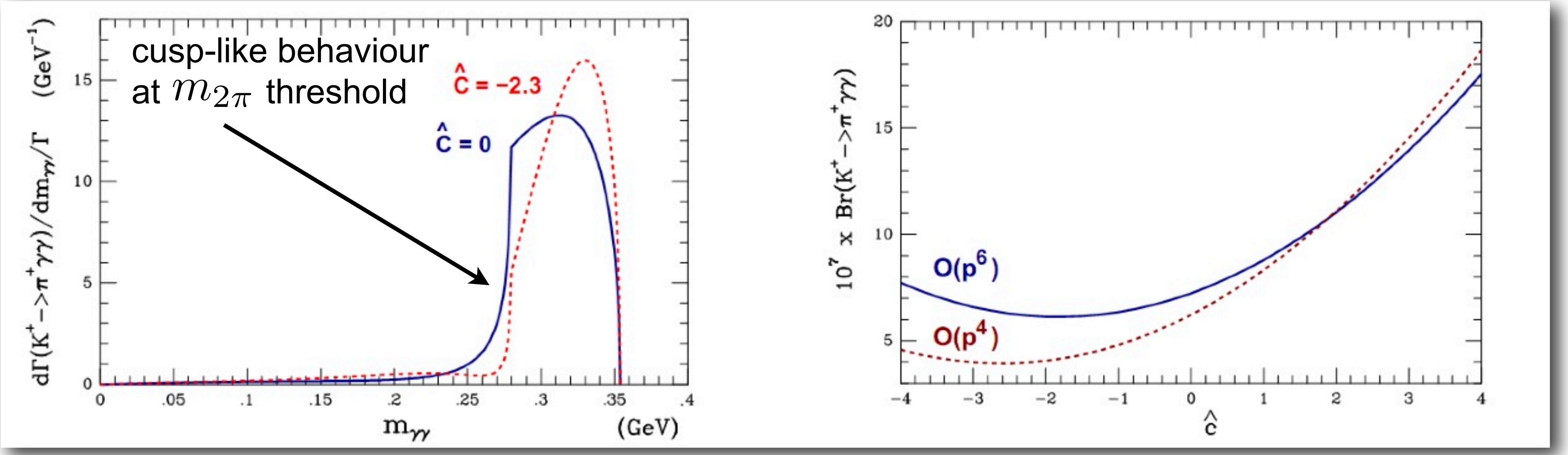
In the Chiral Perturbation Theory framework the **differential rate** of the decay $K^{\pm}(p) \to \pi^{\pm}(p_3)\gamma(q_1)\gamma(q_2)$ (no $\mathcal{O}(p^2)$ contribution) is:

$$\frac{\partial^2\Gamma}{\partial y \partial z} = \frac{m_{K^\pm}}{(8\pi)^3} \cdot \left[z^2 \cdot \left(|A+B|^2 + |C|^2\right) + \left(y^2 - \frac{1}{4}\lambda\left(1, z, r_\pi^2\right)\right)^2 \cdot \left(|B|^2 + |D|^2\right)\right]$$

$$y = \frac{p \cdot (q_1 - q_2)}{m_{K^\pm}^2} \qquad z = \frac{(q_1+q_2)^2}{m_{K^\pm}^2} = \frac{m_{\gamma\gamma}^2}{m_{K^\pm}^2}$$

- The **leading contribution** at $\mathcal{O}(p^4)$ is given by $A(z, \hat{c})$ (loops) which is responsible for a cusp at $m_{\gamma\gamma} = m_{2\pi}$.
- $C(z)$ (generated by Wess-Zumino-Witten funktional) corresponds to ~ 10% of A at $\mathcal{O}(p^4)$.
- B and D vanisch at $\mathcal{O}(p^4)$.
- $\mathcal{O}(p^6)$ **unitarity corrections** can increase the BR by 30 - 40%

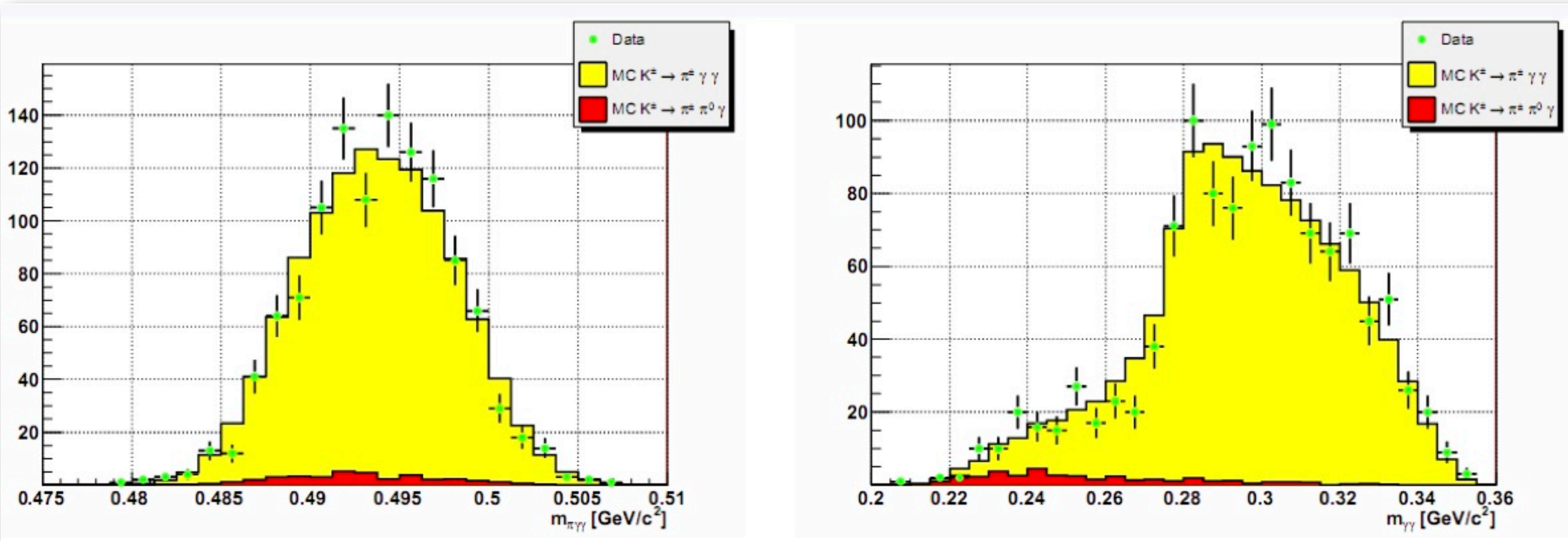
[D'Ambrosio, Portoles, Nucl. Phys. B386 (1996), 403]



$K^{\pm} \to \pi^{\pm}\gamma\gamma$: Branching Fraction

1164 $K^{\pm} \to \pi^{\pm}\gamma\gamma$ **candidates** in 40% of NA48/2 data.

(about 40 times more than previous world statistic)



- **Background:** 3.3 % mainly from $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$
- **Systematics:** mainly from trigger efficiency determination.

Assume ChPT $\mathcal{O}(p^6)$ **and** $\hat{c} = 2$ *preliminary*

$$\mathbf{Br}(K^{\pm} \to \pi^{\pm}\gamma\gamma)_{\hat{c}=2,\mathcal{O}(p^6)} = (1.07 \pm 0.04_{\text{stat}} \pm 0.08_{\text{syst}}) \times 10^{-6}$$

- **Model independent measurement and** $\hat{c}$ **extraction in preparation.**

NA62 Perspectives

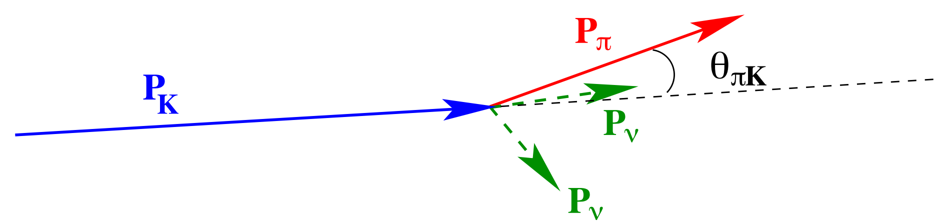
Main purpose: $K^+ \to \pi^+ \nu \bar{\nu}$

- Strongly suppressed $(< 10^{-10})$
- Theoretically clean calculation.
- almost unexplored by experiment.
- **sensitive to new physics**.

	$\mathrm{Br}(K^+ \to \pi^+ \nu \bar{\nu})[10^{-11}]$
Standard Model	8.0 ± 1.1
MFV (hep-ph/0310208)	19.1
EEWP (NP B697 133)	7.5 ± 2.1
EDSQ (hep-ph/0407021)	15
MSSM (hep-ph/0408142)	40
BNL E787/E949 (7 events)	$17.3^{+11.5}_{-10.5}$

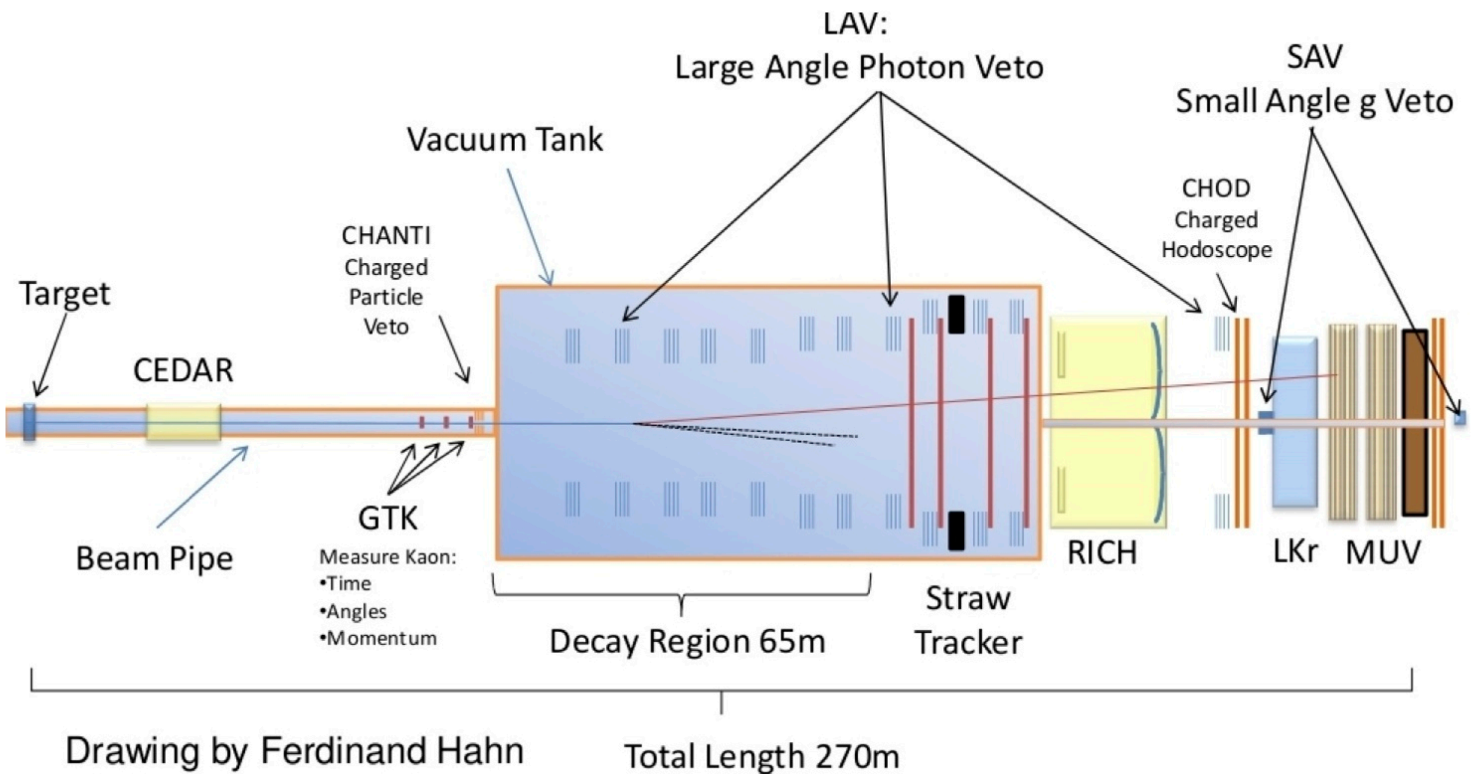
Experimental aim:

- $\mathcal{O}(100)$ events in two years of data taking.
- 10% background.

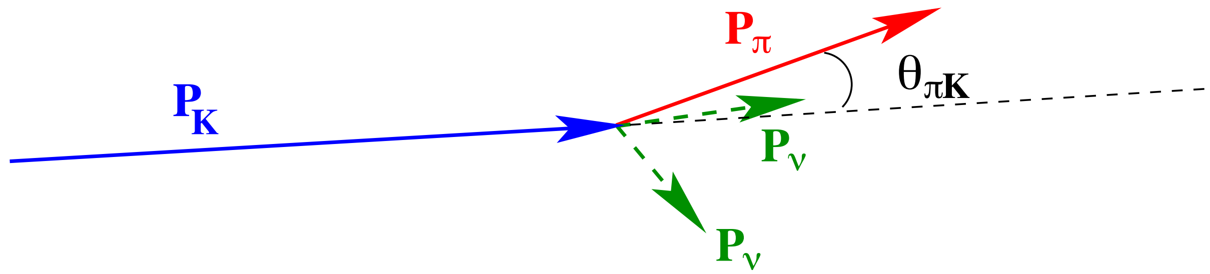


Background rejection:

- Kinematical rejection.
  - Beam tracker: P_K
  - Straw tracker: P_π
- Partical ID.
  - Calorimeters: γ
  - CEDAR: Kaon identification
  - RICH / MUV: $\pi / \mu / e$ separation

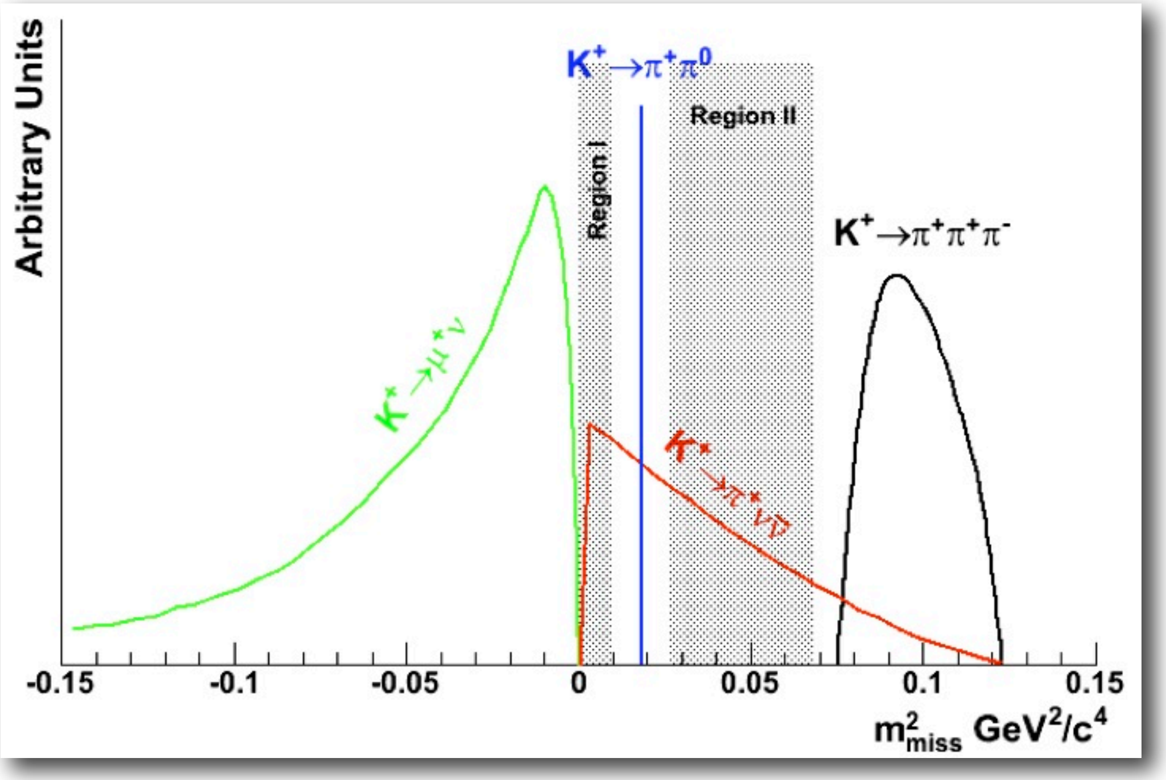


$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: Background



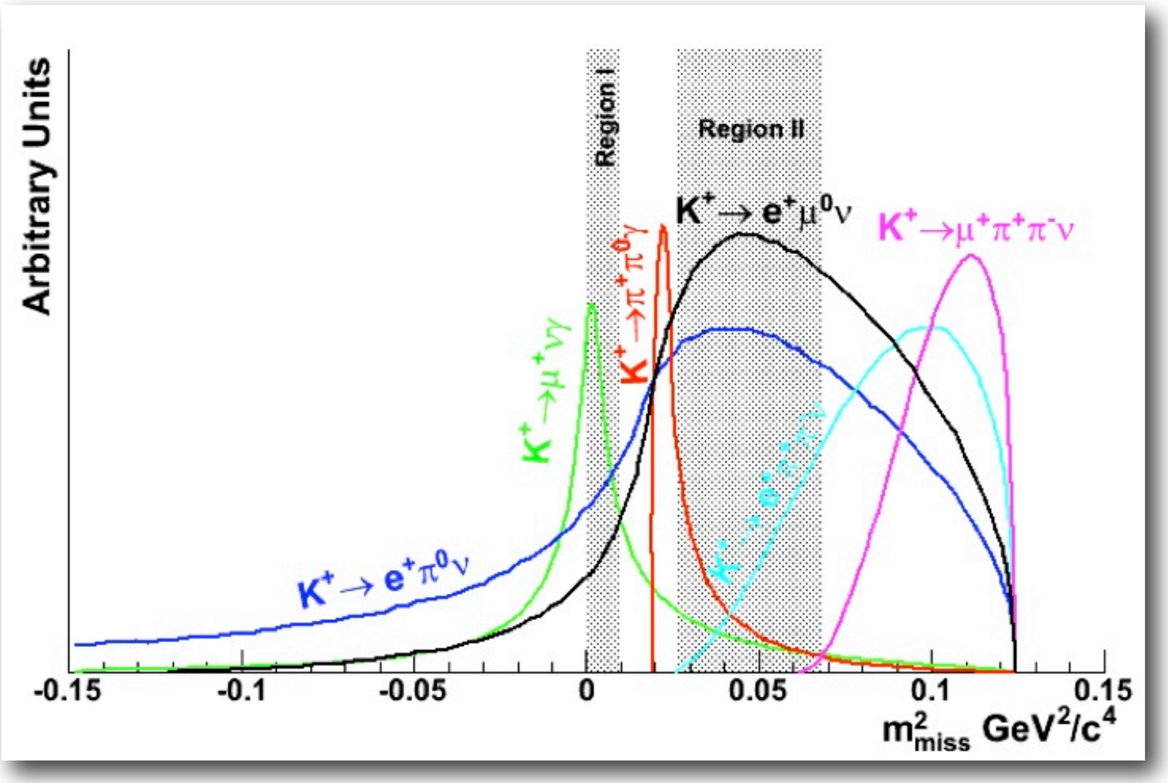
$$m^2_{miss} \approx m^2_k \left(1 - \frac{|P_\pi|}{|P_K|}\right) + m^2_\pi \left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\Theta^2_{\pi K}$$

Kinematically constrained



92 % of the total background

kinematically not constrained

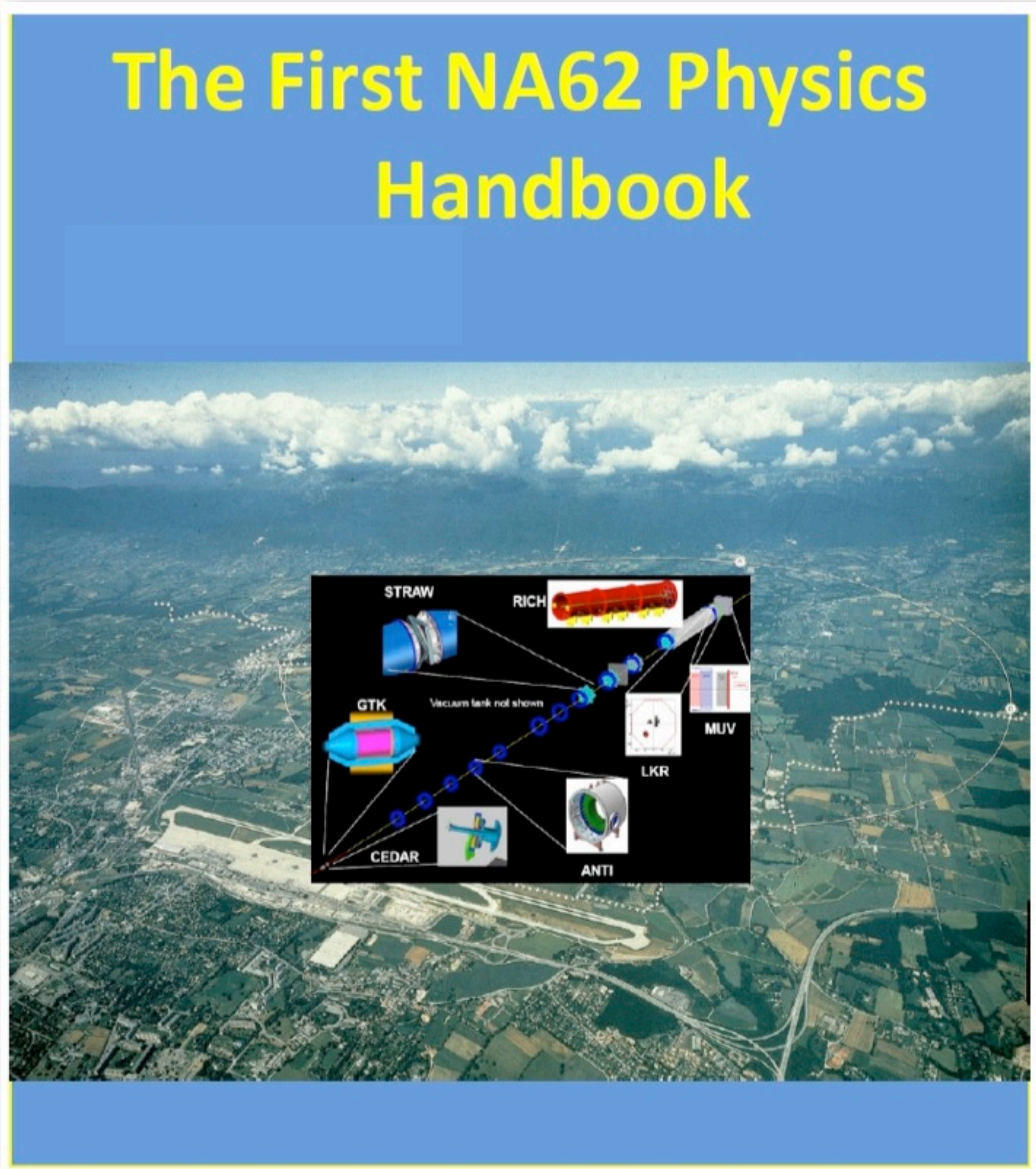


8 % of the total background

- Distribution defines a signal region.
- $K^\pm \rightarrow \pi^\pm\pi^0$ forces to split the region into two parts (**Region I and Region II**).

- Span across the whole signal region.
- Rejection relies on γ **veto** and **PID**.

NA62 : prospects for rare decays and other goals



- much higher statistics possible.
- much smaller background because of major detector improvements (γ veto and PID).

Other physics goals:

- Lepton Flavour Violation: measurement of $K_{e2}/K_{\mu 2}$ to **~0.1% precision**.
- LFV in forbidden decays: searches for $K^+ \rightarrow \pi^- l^+ l^+ \quad K^+ \rightarrow \pi^+ e^\pm \mu^\mp$
- **Heavy neutrinos** (~100 MeV), light **sgoldstinos**.
- **Hadronic** K **decays** and **final-state** $\pi\pi$ interactions in $K_{3\pi}$ and K_{e4} decays.
- ChPT tests with rare kaon/pion decays.

Trigger issues:

- bandwidth for physics still do decide.

Summary and outlook

- **NA48/2 results of rare kaon decays:**

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

- **form factor** measured **relatively to** f_s .
- **first evidence** of $f_e' \neq 0$ and $f_p \neq 0$.
- determination of the $\pi\pi$ **scattering length** with the combination of K_{e4} and the **cusp result**. The **achieved precision** is **competitive** with the **best theoretical prediction**.

$\mathbf{K}^{\pm} \rightarrow \pi^{\pm}\pi^{0}\gamma \quad (K_{2\pi(\gamma)})$

- **first measurement** of the **INT component** in $K_{2\pi\gamma}$ decays.
- compatible with **CP conservation**.

$\mathbf{K}^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$

- presentation of a **Branching ratio measurement** in $\mathcal{O}(p^6)$ and $\hat{c} = 2$.
- **Model independent measurement** and $\hat{c}$ extraction in **preparation.**

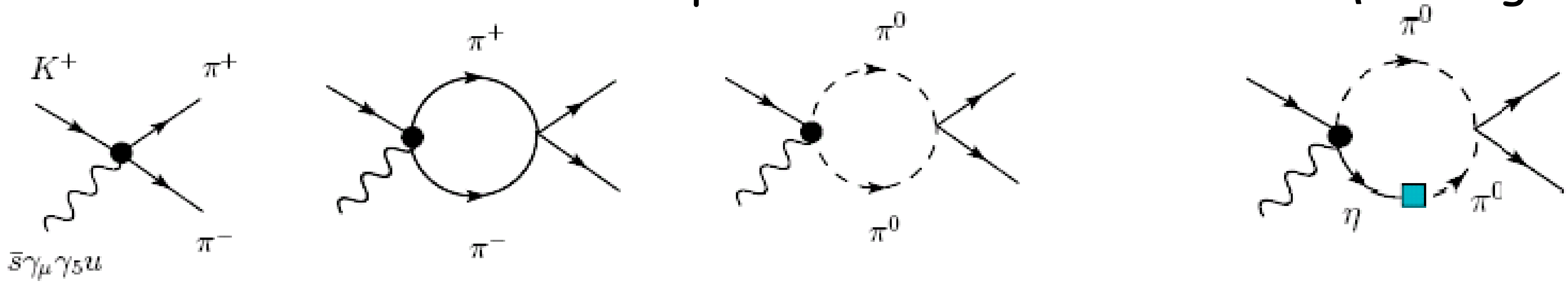
- **looking forward to NA62 possibilities in rare decays and new physics.**

Spares

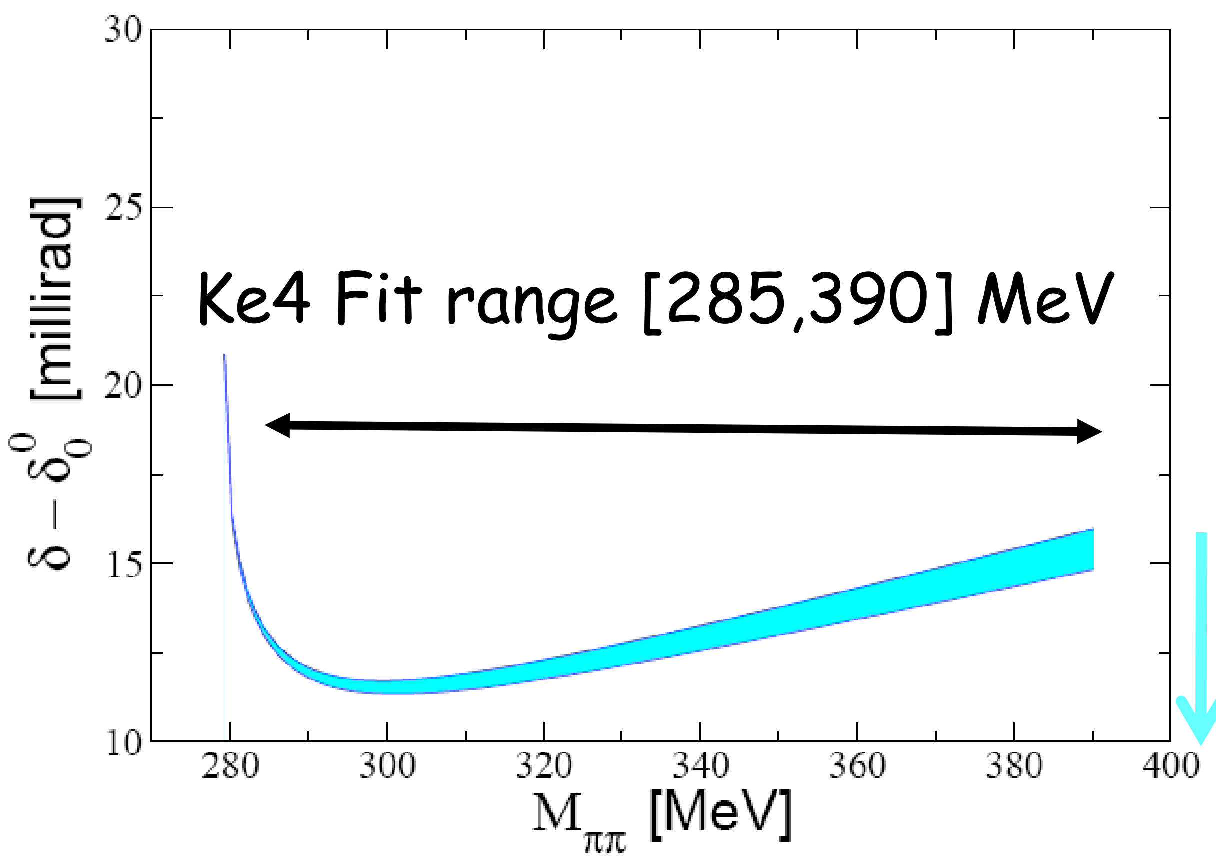
Ke4 charged decays : isospin corrections to δ

CGR EPJ C59 (2009) 777 formulation developed in close contact with NA48

tree — one loop — π^0–η mixing



$\delta_0^0 \rightarrow$ $$\delta = \frac{1}{32\pi F^2}\left\{(4\Delta_\pi + s)\sigma + (s - M_{\pi^0}^2)\left(1 + \frac{3}{2R}\right)\sigma_0\right\}$$



$$\Delta_\pi = M_{\pi^+}^2 - M_{\pi^0}^2,$$

$$\sigma = \sqrt{1 - \frac{4M_\pi^2}{s}},$$

$$R = \frac{m_s - \hat{m}}{m_d - m_u}$$

Correction is ~ 10-15 mrad

Exp. stat precision (δ) is ~ 7-8 mrad

Spares

CUSP effect:

- presence of a structure at the Mπ+π**-** threshold value in the M2π0π0 distribution of K →π π0π0 decay
- NA48/2 data provide an **ALTERNATIVE** way to estimate pion scattering lengths, to be compared with the result obtained in Ke4

- Effect due to the strong π+π- →π0π0 rescattering in the K →π π+π- decay