New results on **kaon decays** from **NA48/2**

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on behalf of the **NA48/2** Collaboration:
Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

XLIIIrd Rencontres de Moriond
La Thuile, March 13th, 2008

Outline

New Measurements of ChPT Parameters

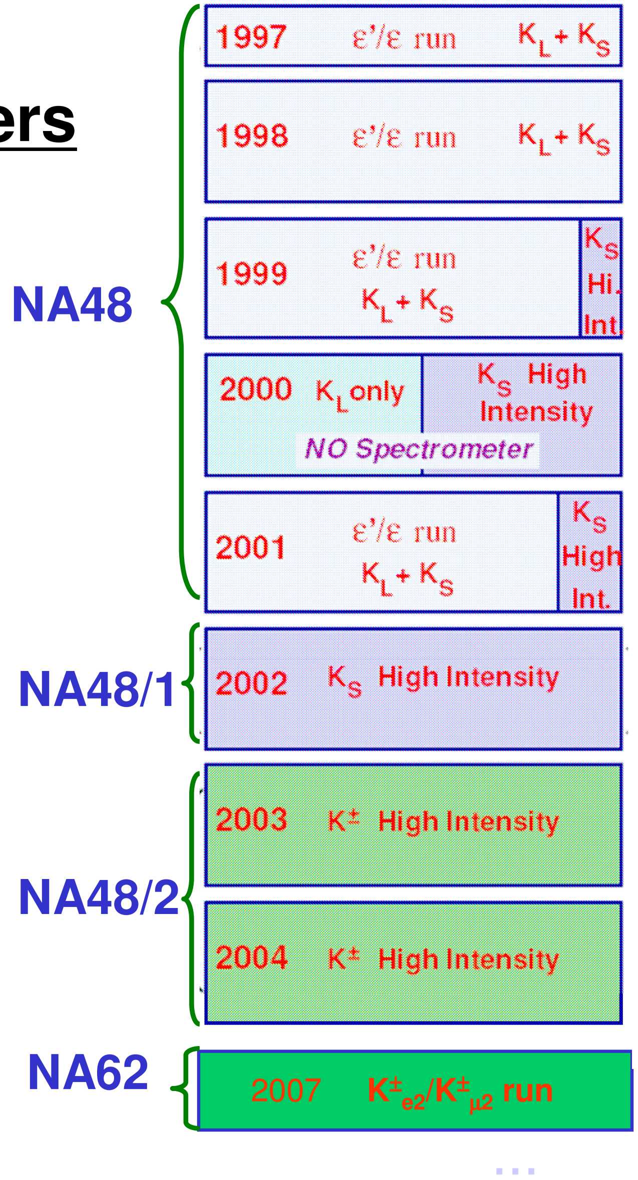
★ The NA48/2 Experiment.

★ $\pi\pi$-Scattering lengths in $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ and $K^{\pm} \rightarrow \pi^{+}\pi^{-}e^{\pm}\nu$.

★ Precise study of $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ and $K^{\pm} \rightarrow \pi^{\pm}e^{+}e^{-}\gamma$.

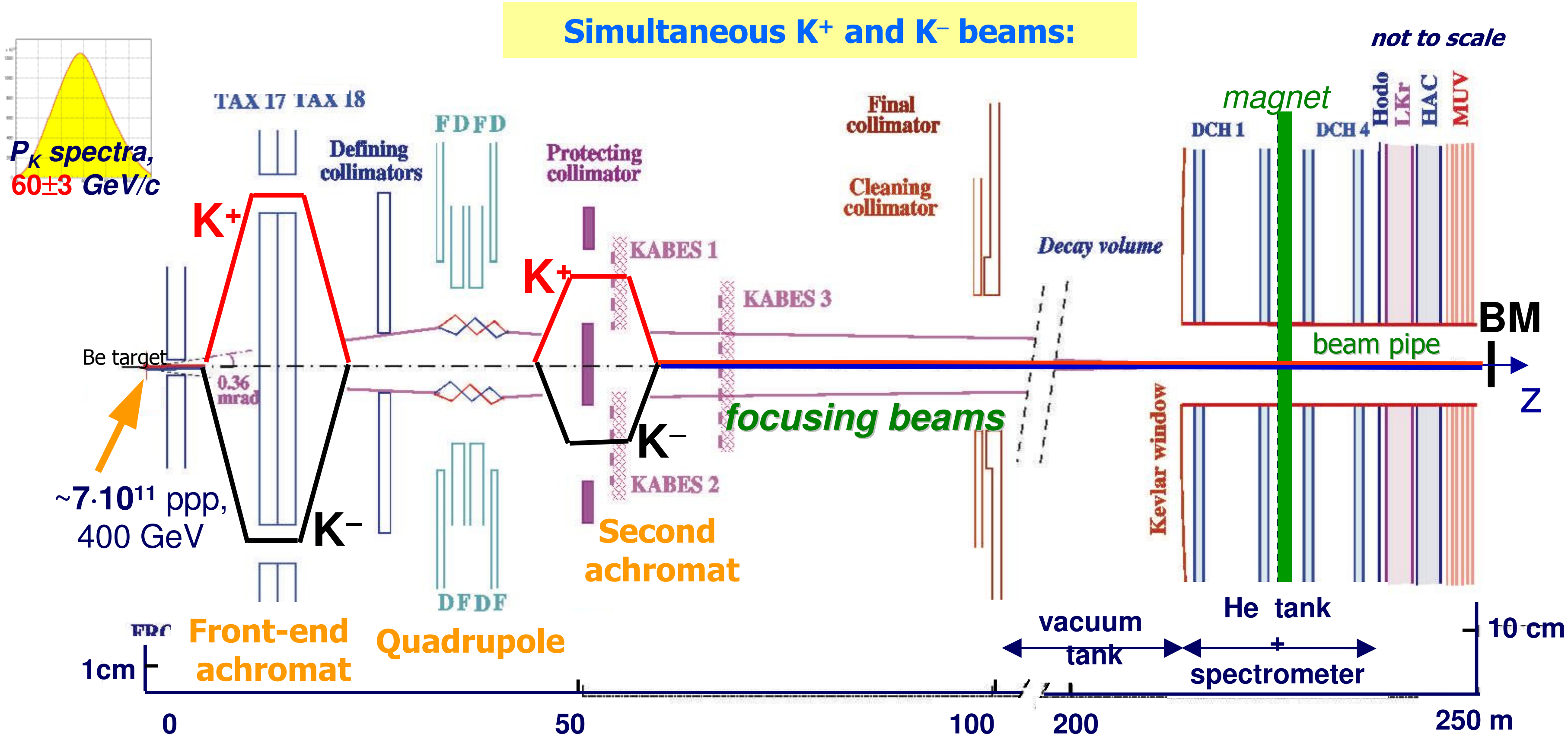
★ BR and form factors from $K^{\pm} \rightarrow \pi^{\pm}e^{+}e^{-}$.

★ Summary.



The NA48/2 Experiment

Fixed target kaon experiment at CERN's SPS.
• Designed for precision measurement of charge asymmetries in $K_{3\pi}$;
• Other goals: $\pi\pi$ scattering, ChPT, lepton universality, CKM unitarity tests, etc.



The NA48/2 Experiment

Main detector components:

- Magnet spectrometer (4 DCHs):

  1% resolution for p=20 GeV/c.

- Liquid Krypton EM calorimeter (LKr)

  1.6% energy resolution for E_{γ}=20 GeV/c.

Two main trigger modes:

- Charged. Devoted to $K^{\pm} \rightarrow \pi^{\pm}\pi^{+}\pi^{-}$ selection:

  3 charged tracks.

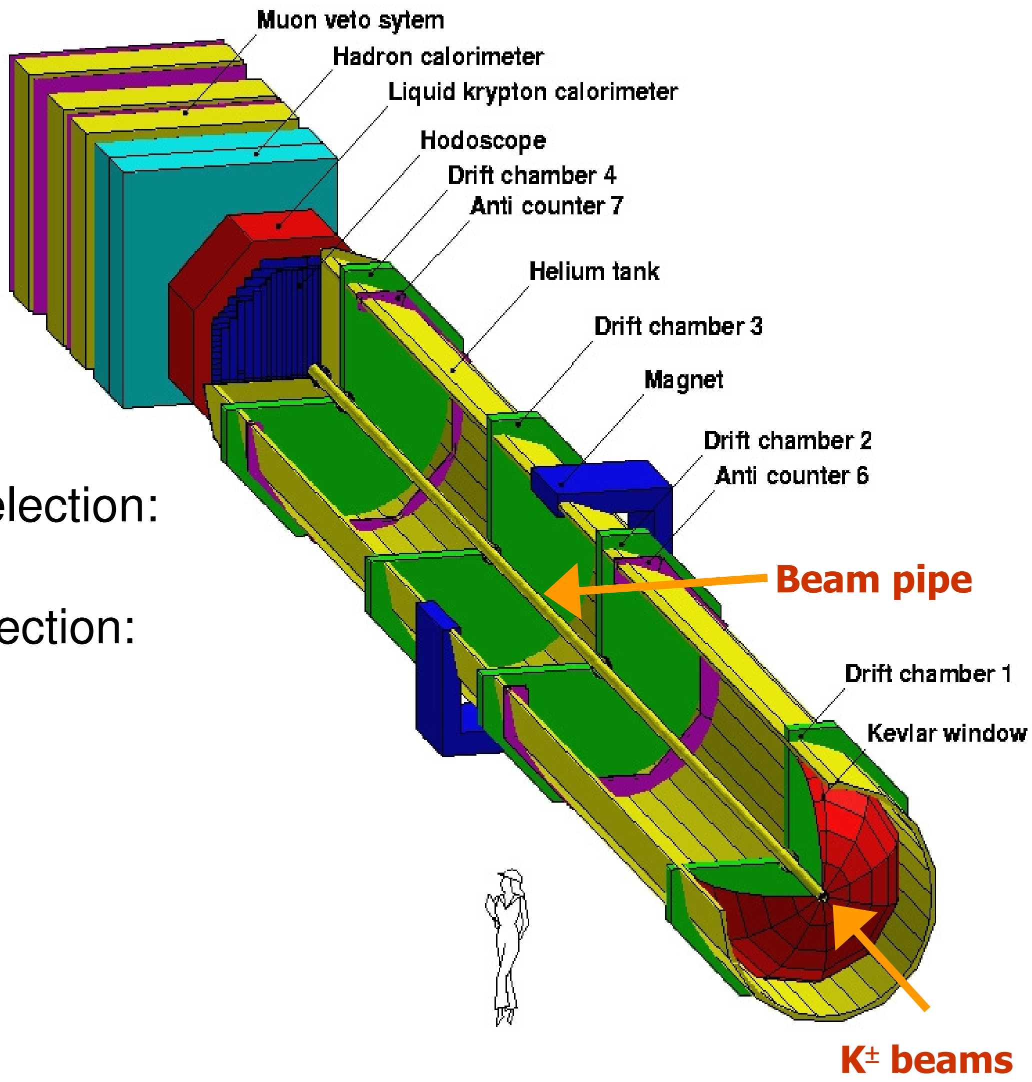
- Neutral. Devoted to $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ selection:

  > 2 em clusters in LKr x or y projection

Total statistics (2003-2004):

$K^{\pm} \rightarrow \pi^{-}\pi^{+}\pi^{\pm}$: ~$4{\cdot}10^{9}$

$K^{\pm} \rightarrow \pi^{0}\pi^{0}\pi^{\pm}$: ~$1{\cdot}10^{8}$



$\pi^+\pi^-$ Scattering in $K^\pm \to \pi^\pm\pi^0\pi^0$
&
$K^\pm \to \pi^+\pi^- e^\pm\nu$ (K_{e4})

$\pi^+\pi^-$ Scattering in $K^\pm \to \pi^\pm\pi^0\pi^0$ & $K^\pm \to \pi^+\pi^- e^\pm\nu$

Motivation:

- At low energies, s-wave $\pi\pi$-scattering lengths for isospin 0 and 2, $a_{0,2}$,are **fundamental parameters of ChPT**.

- **$\pi\pi$-Scattering lengths directly connected to M_π:**

$$a_0, a_2 \propto M_\pi^2 + O(m^2)$$ [Weinberg, 1966]

and to quark condensate:

$$M_\pi \sim (m_u + m_d) \cdot |\langle 0|\bar{q}q|0\rangle| / F_\pi^2$$ [Colangelo,Gasser, Leutwyler (2000)]

→ **Measurement of a_0,a_2 crucial test for ChPT**

Two clean measurements of scattering lengths $a_{0,2}$ **in NA48/2**:

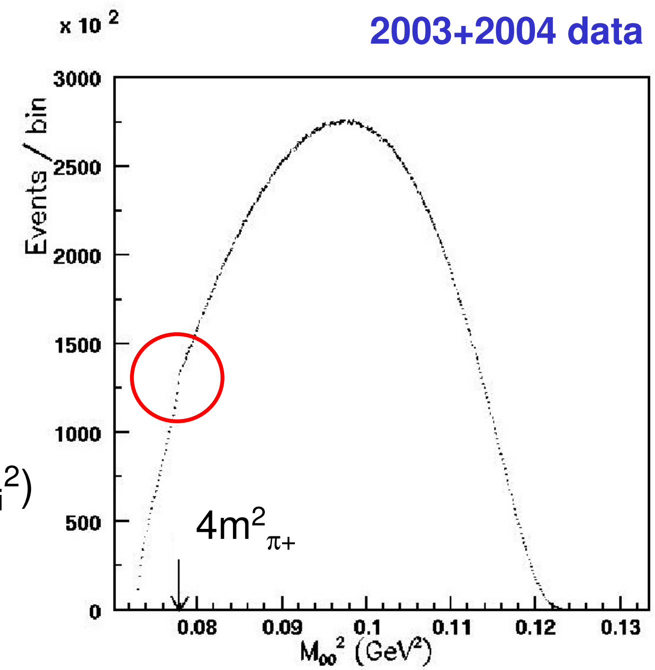
- Wigner-**cusp** effect **in $K^\pm \to \pi^\pm\pi^0\pi^0$** decays;

- **δ in $K^\pm \to \pi^+\pi^- e^\pm\nu$** decays.

$\pi^+\pi^-$ Scattering in $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$

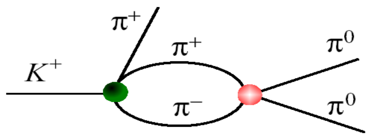
~ $60{\cdot}10^6$ $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$ in 2003 + 80% of 2004. Background negligible.

Original motivation: search for **pionium** decay signature **in M_{00}**: $K^\pm \rightarrow \pi^\pm(\pi^+\pi^-)_{atom} \rightarrow \pi^\pm(\pi^0\pi^0)$
$\Rightarrow$Unexpected observation of cusp at $M_{00} = 2m_{\pi+}$.



<u>Interpretation :</u>

- [N. Cabibbo PRL 93 (2004) 12181]:



$\mathcal{M}_{rescattering} \propto -(a_0-a_2)$ real and negative for $M_{00} < 2m_{\pi+}$.
$\mathcal{M}_{rescattering} \propto (a_0-a_2)i$ imaginary for $M_{00} > 2m_{\pi+}$.

- 2nd order rescattering corrections + Isospin breaking $+O(a_i^2)$
  [N. Cabibbo, G. Isidori, JHEP03 (2005) 021].

<u>Method of measurement :</u>

Fit to:

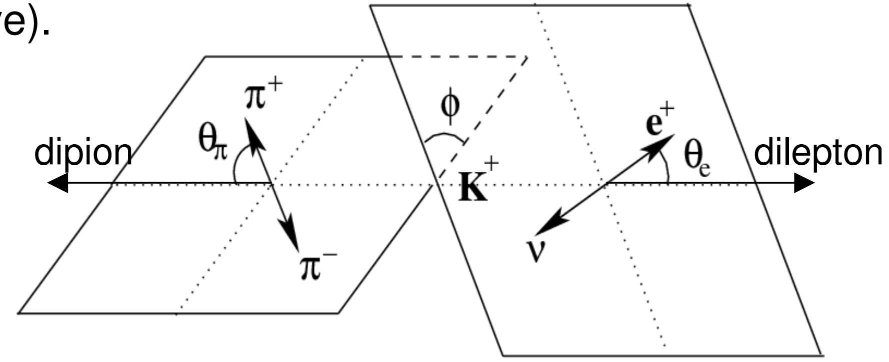
$$\frac{\partial\Gamma}{\partial M_{00}} = N \cdot F(a_0-a_2, a_2, g, h, M_{00})$$

with **5 free parameters,** and **g** and **h** slope parameters from PDG matrix element ($|\mathcal{M}|^2 = 1 + gu + hu^2$).

$\pi^+\pi^-$ Scattering in $K^\pm \rightarrow \pi^+\pi^- e^\pm \nu$

~ $677{\cdot}10^3$ K_{e4} in 2003; 0.5% Background.

Decay amplitude described by **form factors partial wave expanded**.
δ_0 = $\pi^+\pi^-$ scattering phase shift for I=0, L=0 (s-wave),
δ_1 = $\pi^+\pi^-$ scattering phase shift for I=1, L=1 (p-wave).
Decay rate depends on $\delta = \delta_0 - \delta_1$ with $\boldsymbol{\delta = \delta(M_{\pi\pi})}$.

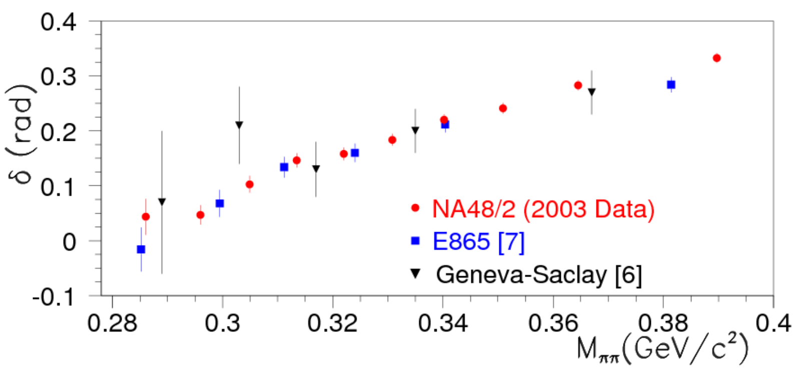


Five independent kinematic variables
(Cabibbo-Maksymowicz variables):

- $M_{\pi\pi}$: invariant **di-pion mass** squared;
- $M_{e\nu}$: invariant **di-lepton mass** squared;
- θ_π : **angle of π^+** in $\pi\pi$ rest frame wrt $\pi\pi$ direction of flight in K rest frame;
- θ_e : **angle of e^+** in **$e\nu$** rest frame wrt **$e\nu$** direction of flight in **K** rest frame;
- Φ : **angle of $\pi\pi$** decay plane **wrt $e\nu$** decay plane.

Method of Measurement : In each $M_{\pi\pi}$ bin, simultaneous fit to K_{e4} **form factors** and δ in the 4 other dimensions.

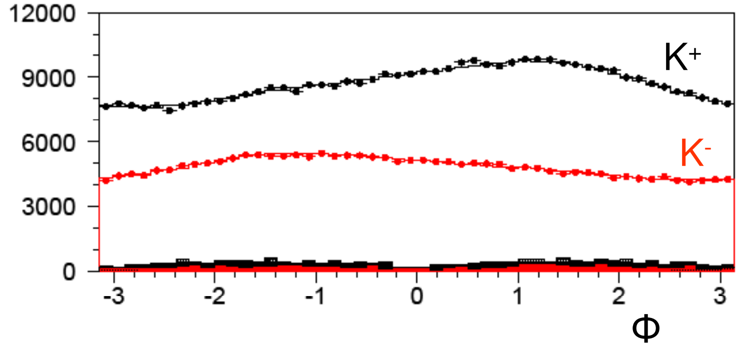
Roy equations relate δ with $\pi\pi$ scattering lengths.

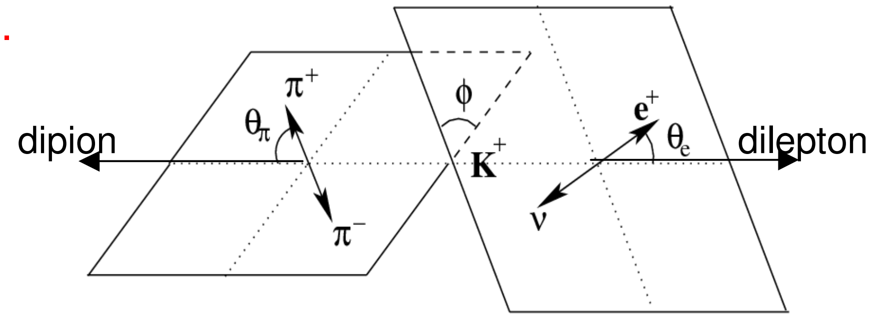


$\pi^+\pi^-$ Scattering in $K^\pm \to \pi^+\pi^- e^\pm \nu$

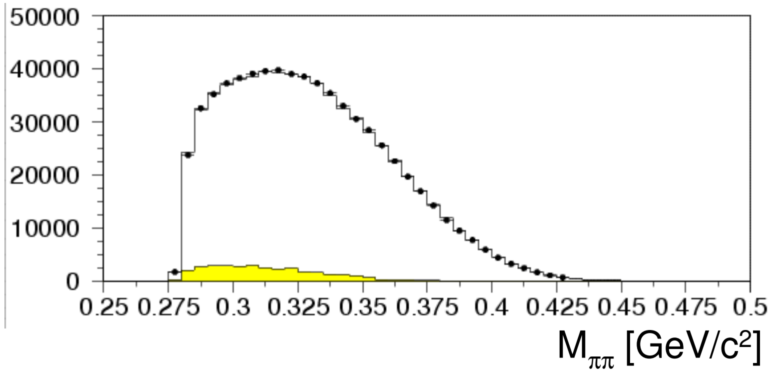
Five independent kinematic variables

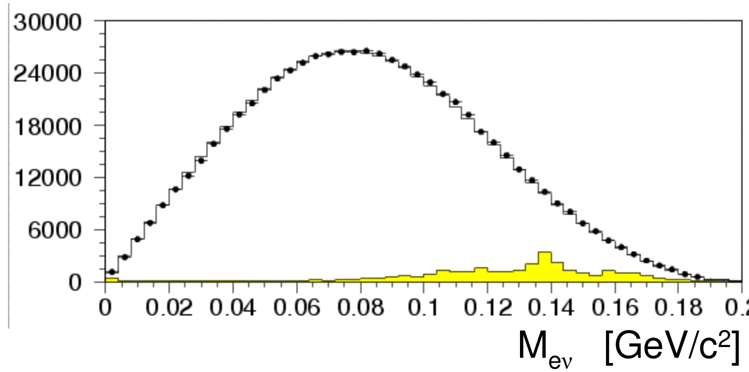
(Cabibbo-Maksymowicz variables): $M_{\pi\pi}, M_{e\nu}, \theta_\pi, \theta_e, \Phi$.

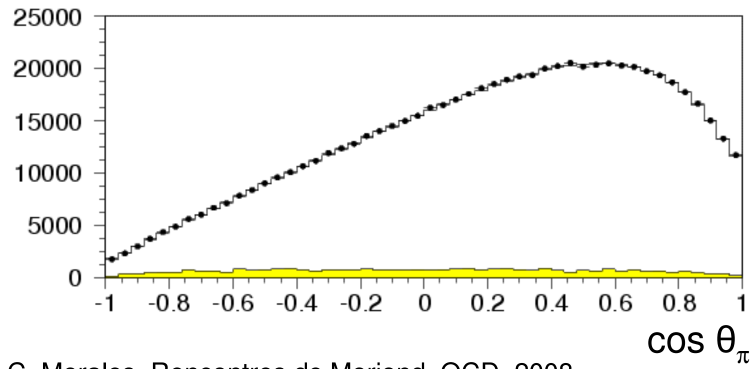


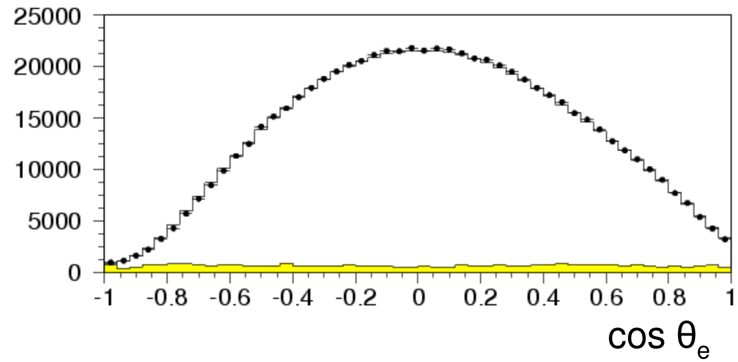


Background 10 times scaled in all plots to make it visible!









$\pi^+\pi^-$ Scattering in $K^\pm \to \pi^\pm\pi^0\pi^0$ & $K^\pm \to \pi^+\pi^- e^\pm\nu$

- $K^\pm \to \pi^\pm\pi^0\pi^0$ results:

(preliminary)

$$(a_0 - a_2)\, m_{\pi+} = 0.261 \pm 0.006_{stat} \pm 0.003_{syst} \pm 0.001_{ext} \pm 0.013_{theory}$$

$$a_2 m_{\pi+} = -0.037 \pm 0.013_{stat} \pm 0.009_{syst} \pm 0.002_{ext}$$

with ρ=–0.92:

$$a_0 m_{\pi+} = 0.224 \pm 0.008_{stat} \pm 0.006_{syst} \pm 0.003_{ext} \pm 0.013_{theory}$$

Theoretical uncertainty: 5% due to neglected higher order terms and radiative corrections.

- **Ke4** results:

[http://dx.doi.org/10.1140/epjc/s10052-008-0547-0]

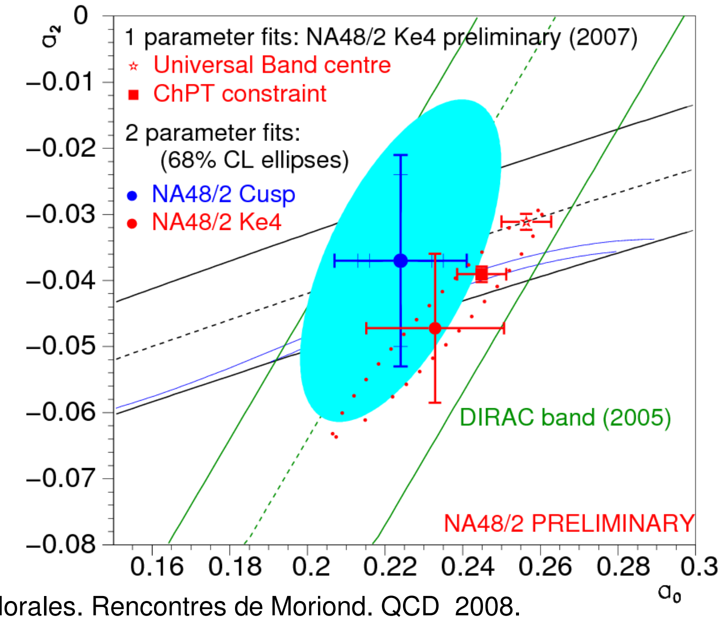
(1-par fit + univ band) $a_0 = 0.256 \pm 0.006_{stat} \pm 0.002_{syst}\ {}^{+0.018}_{-0.017}{}_{theo}$

(2-par fit) $a_0 = 0.233 \pm 0.016_{stat} \pm 0.007_{syst}$

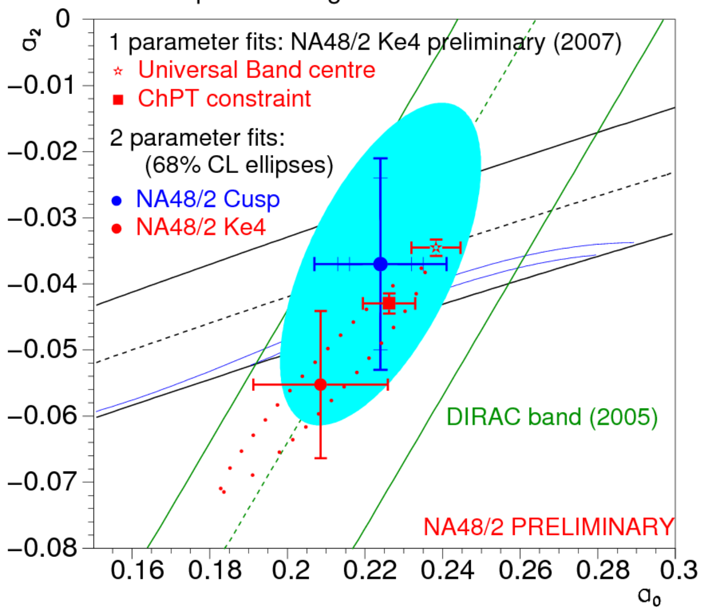
with ρ=0.967: $a_2 = -0.047 \pm 0.011_{stat} \pm 0.004_{syst}$

Note: corrections for isospin breaking shift a_0 by -0.02 and a_2 by -0.004 [J. Gasser].

no isospin breaking corrections



with isospin breaking corrections



$$K^{\pm} \rightarrow \pi^{\pm} \gamma\gamma \quad \& \quad K^{\pm} \rightarrow \pi^{\pm} e^{+} e^{-} \gamma$$

$K^\pm \to \pi^\pm\gamma\gamma$ in ChPT

- <u>$K^\pm \to \pi^\pm\gamma\gamma$:</u>

$$\frac{\partial^2\Gamma}{\partial y\,\partial z} = \frac{m_K}{2^9\pi^3}\left[z^2\left(|A+B|^2+|C|^2\right) + \underbrace{\left(y^2-\tfrac{1}{4}\lambda(1,r_\pi^2,z)\right)^2}_{\text{Important at low } m_{\gamma\gamma}}\left(|B|^2+|D|^2\right)\right]$$

$$y = \frac{p\cdot(q_1-q_2)}{m_K^2}, \quad z = \frac{(q_1+q_2)^2}{m_K^2}$$

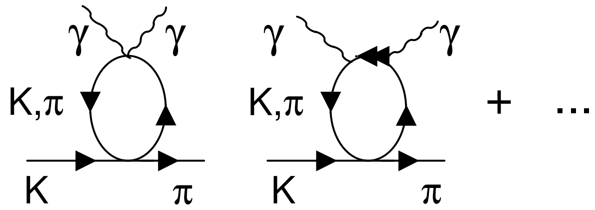
(only z dynamically relevant)

At order O(4):

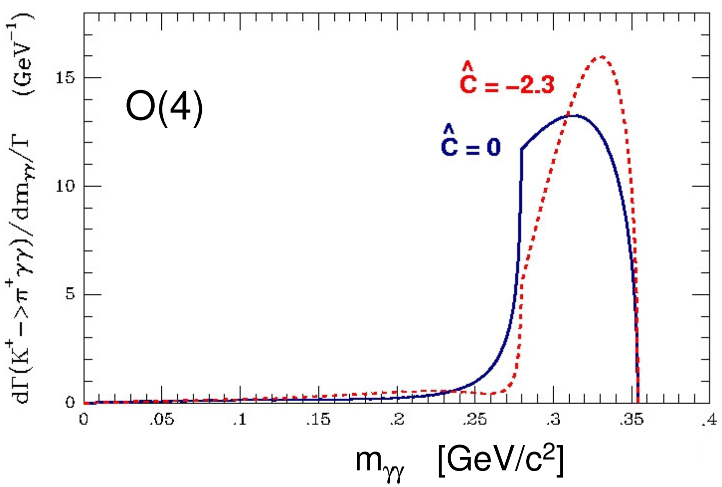
[G. Ecker, A. Pich, E. de Rafael, Nucl.Phys.B303(1988) 665]

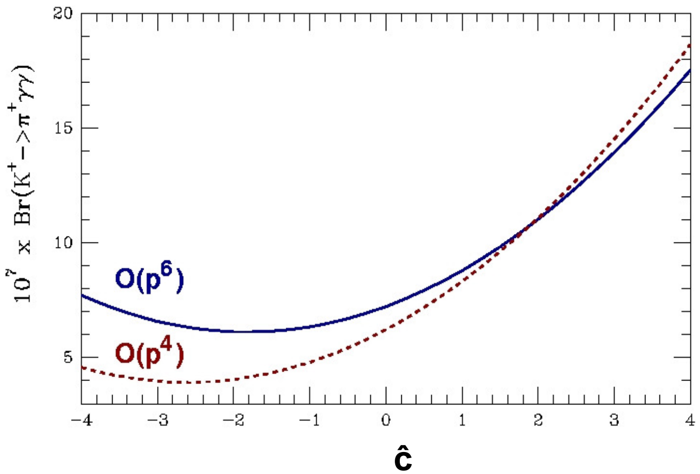
- **A(z,ĉ)** contains: **Loops** + **ĉ (O(1)).**
  A changes slope (⇒ cusp) at $\mathbf{m_{\gamma\gamma} = 2m_{\pi+}}$

- **C(z)** contains Wess-Zumino **poles and tadpoles**.
  [M. Gerard, C. Smith, S. Trine, hep-ph/0508189]



At order O(6): Unitarity correction effects. **Could increase BR in 30%- 40%.**
[G. D'Ambrosio, J. Portolés. Nucl.Phys. B386 (1996), 403].





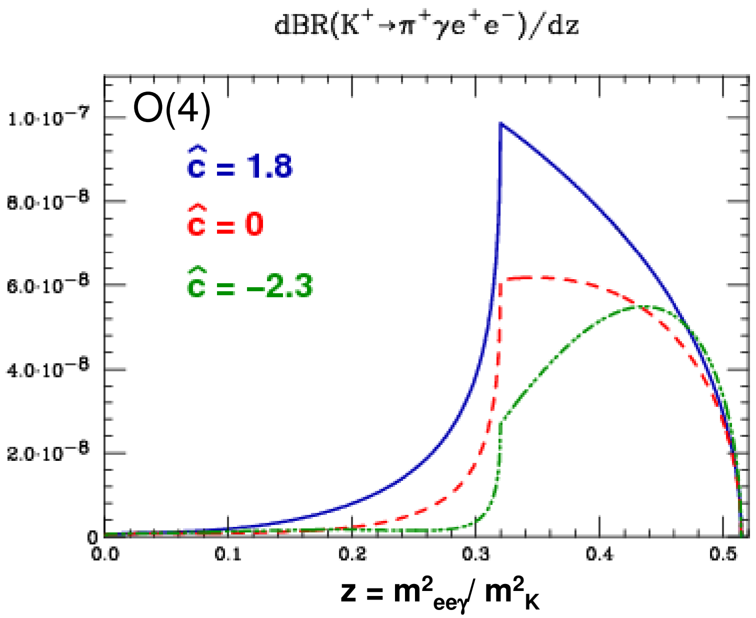
$K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma$ in ChPT

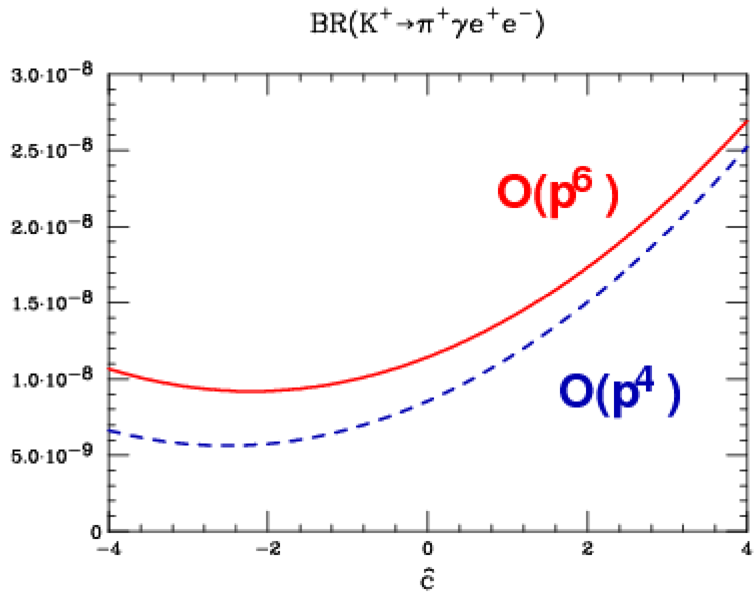
- $K^{\pm}\to \pi^{\pm}e^{+}e^{-}\gamma$ similar to $K^{\pm}\to \pi^{\pm}\gamma\gamma$ **with γ-conversion**.

-Like for $K^{\pm}\to \pi^{\pm}\gamma\gamma$, **ĉ determines** the value of **BR** and **$m_{ee\gamma}$** spectrum shape.

$$\Gamma(O(4)) = \underbrace{(2.80 + 0.87\hat{c} + 0.14\hat{c}^2}_{\text{Loops}} \underbrace{+0.23)}_{\text{Wess-Zumino}} \cdot 10^{-23}\ \text{GeV}$$

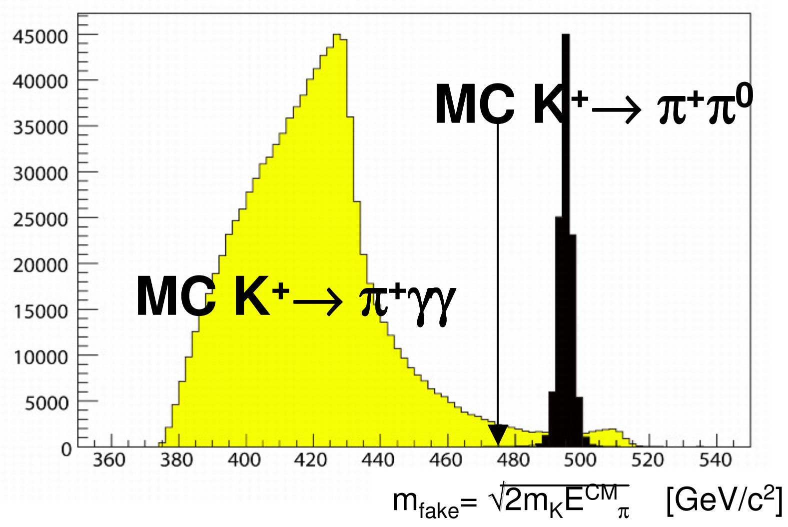
- **O(6)** unitarity corrections **could increase BR** in **30%-40%** [F. Gabbiani._Phys.Rev.Lett. D59 (1999), 094022].





$Br(K^{\pm}\rightarrow\pi^{\pm}\gamma\gamma)$

$$BR(\pi^{\pm}\gamma\gamma) = \frac{1}{\Phi_{flux}} \times \frac{(\#\pi^{\pm}\gamma\gamma) - (\#bkg)}{Acc(\pi^{\pm}\gamma\gamma) \times Eff}$$



- Bad trigger conditions:
  - **Selected through neutral trigger:**
    L1 required more than 2 clusters in e.m. calorimeter ⇒ **50% efficiency.**
    L2 rejected $K^{\pm}\rightarrow\pi^{\pm}\pi^{0}$ decays (BR=20.92%!!) cutting on E^{CM}_{π}: **80%** efficient.

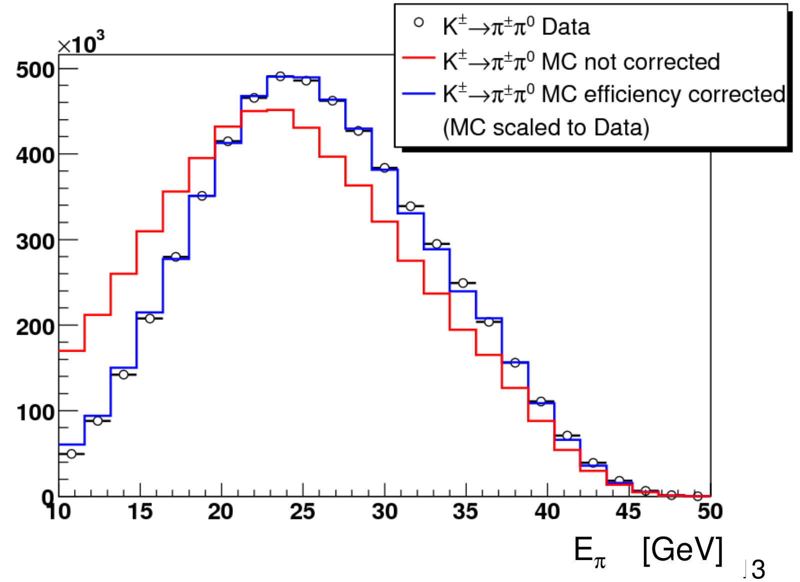
- Due to **low** amount of **statistics**, trigger efficiencies not measured with $K^{\pm}\rightarrow\pi^{\pm}\gamma\gamma$ data.
  - Solution: **use background** events

& study dependencies on kinematic variables:

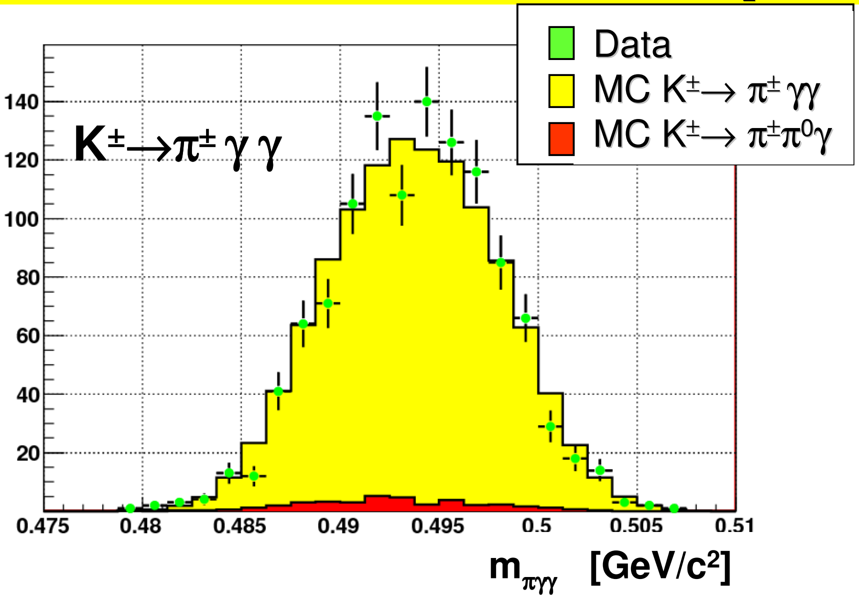
$Eff^{L1}(p_{track},d_{c1c2})$, $Eff^{L2}(p_{track},z_{vertex},r_{beampipe})$

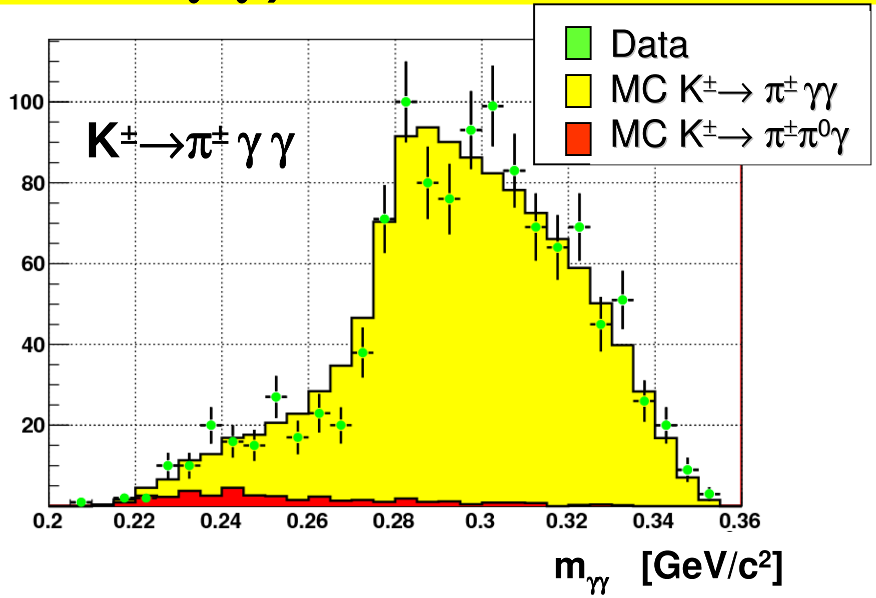
& use MC $K^{\pm}\rightarrow\pi^{\pm}\gamma\gamma$ to "reshape" variables and integrate

$$Eff^{L1,L2} = \frac{\Sigma_n\ (\#MC(v_1,...v_n) \times Eff^{L1,L2}(v_1,...v_n))}{\Sigma_n\ (\#MC(v_1,...v_n))}$$



Br ($K^{\pm} \to \pi^{\pm}\gamma\gamma$)





1164 $K^{\pm} \to \pi^{\pm}\gamma\gamma$ candidates in 40% of NA48/2. 3.3% Background mainly from $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ (IB).
Sample ~ 40 times larger than the previous world sample!

Result :

$$BR(K^{\pm} \to \pi^{\pm}\gamma\gamma, \hat{c}=2, O(6)) = (1.07 \pm 0.04_{stat} \pm 0.08_{syst}) \cdot 10^{-6}$$

(preliminary)

Systematics: Main contributions arising from efficiency measurement method.

- **Model independent** measurement and **ĉ** extraction in preparation.

Previous measurement: BNL E787 (1997). 31 candidates with 5 background events [PDG2006].

$Br(K^{\pm} \to \pi^{+}\gamma\gamma) = (1.10 \pm 0.32) \cdot 10^{-6}$; $\hat{c} = 1.8 \pm 0.6$

Br and ĉ extraction in $K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma$

- Unlike $K^{\pm}\to\pi^{\pm}\gamma\gamma$, decay **selected through charged trigger** (3 charged tracks).

- **All NA48/2** data sample used .

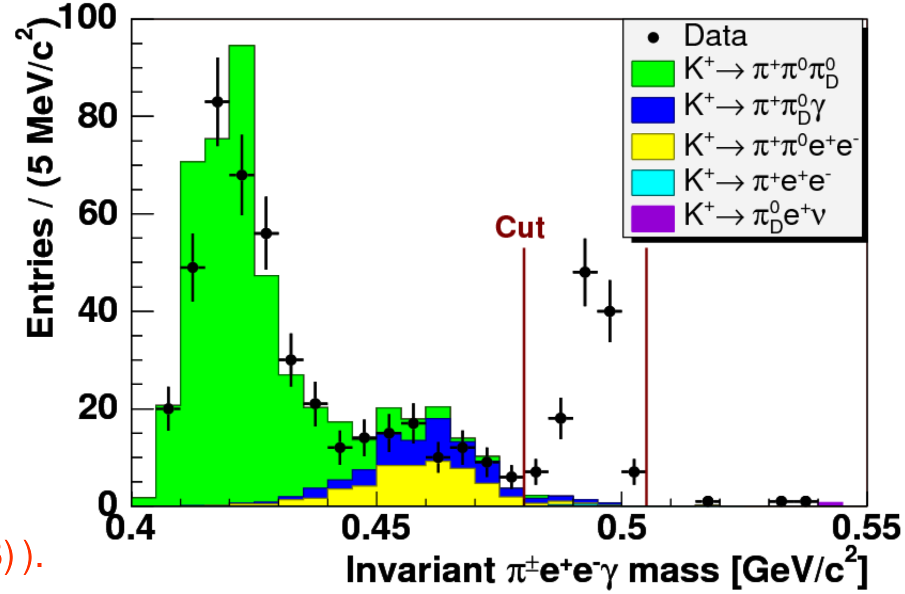
120 $K^{\pm}\to\pi^{\pm}e^{+}e^{-}\gamma$ candidates.

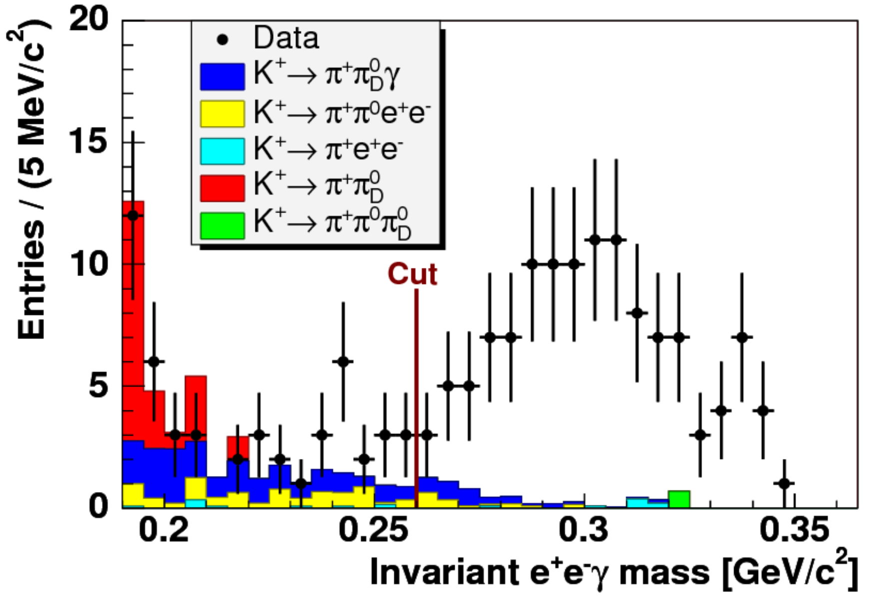
7.3 ± 1.7 estimated background ($K^{\pm}\to\pi^{\pm}\pi^{0}_{D}\gamma$ (IB)).

FIRST OBSERVATION OF THIS DECAY!

- Normalization channel:

$K^{\pm}\to\pi^{\pm}\pi^{0}_{D}\to\pi^{\pm}e^{+}e^{-}\gamma$ 14M events.





Br and ĉ extraction in $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma$

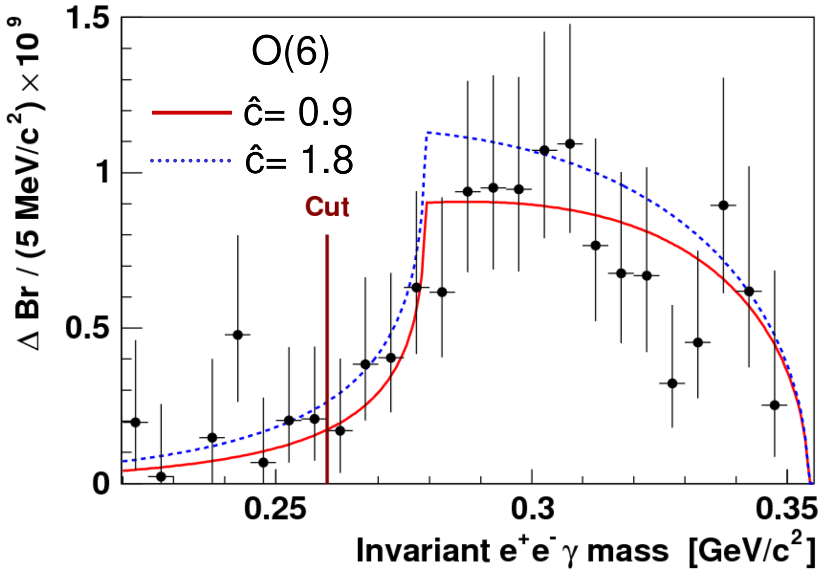
Results: [NA48/2 Collaboration, PLB 659 (2008) 493]

• **Model independent** measurement performed evaluating $\mathbf{d\Gamma_{\pi\gamma\gamma}/dz}$ and integrating over whole z region ($z = \mathbf{m^2_{ee\gamma} / m^2_K}$).

$BR(K^{\pm}\rightarrow \pi^{\pm}e^{+}e^{-}\gamma,\ m_{ee\gamma} > 260\ MeV/c^2) = (1.19 \pm 0.12_{stat} \pm 0.04_{syst})x10^{-8}$
$BR(K^{\pm}\rightarrow \pi^{\pm}e^{+}e^{-}\gamma) = (1.29 \pm 0.13_{stat} \pm 0.03_{\hat{c}})x10^{-8}$

• **Model dependent** measurement: use $Br(m_{ee\gamma})$ to extract **ĉ** by fitting to the absolute O(6) ChPT prediction [F. Gabbiani, Phys.Rev.Lett. D59 (1999), 094022].

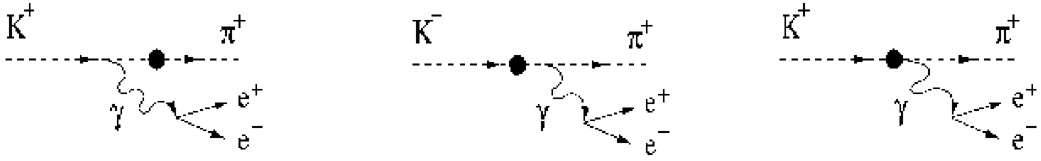
ĉ = 0.90 ± 0.45
χ^2/ndof = 8.1/17
96.4% probability

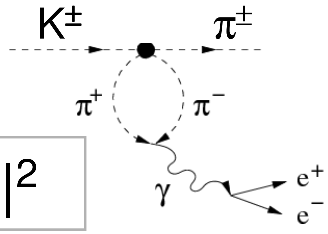


$K^{\pm} \rightarrow \pi^{\pm} e^{+} e^{-}$

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

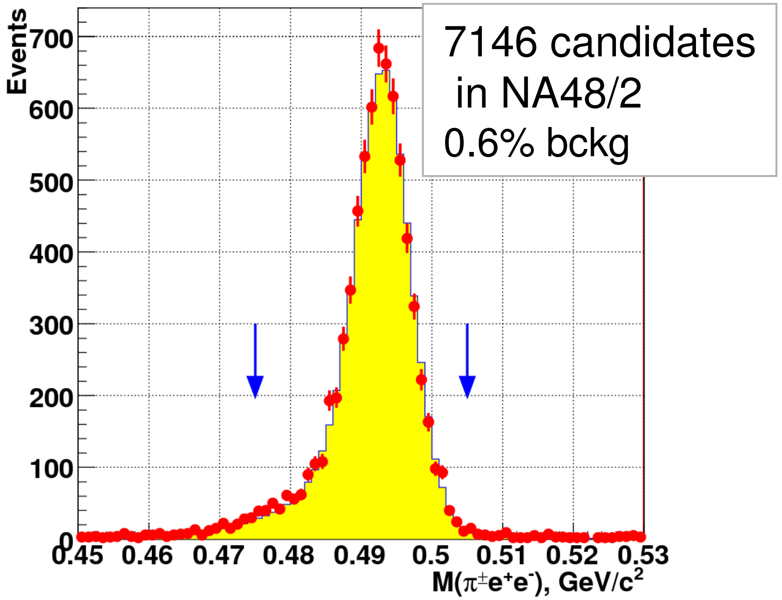
- **FCNC suppressed** process $K^\pm \to \pi^\pm \gamma^* \to \pi^\pm l^+ l^-$ proceeding through **one-photon exchange**.

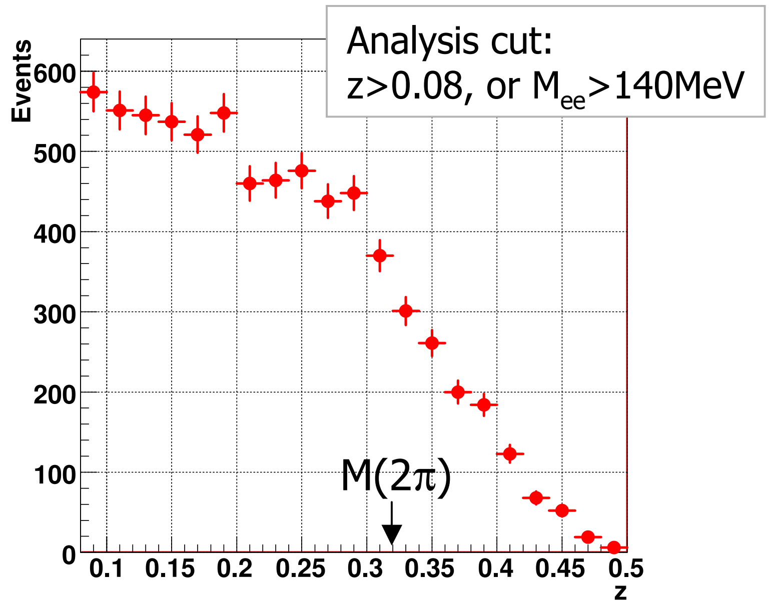




$$d\Gamma_{\pi ee}/dz \sim \phi(z) \cdot |W(z)|^2$$

$z = (M_{ee}/M_K)^2$, $\phi(z)$ phase space factor.





W(z) Form-factor:

(1) polynomial: $W(z) = G_F M_K^2 \cdot f_0 \cdot (1+\delta z)$

(2) ChPT O(p⁶): $W(z) = G_F M_K^2 \cdot (a_+ + b_+ z) + W^{\pi\pi}(z)$
[JHEP 8 (1998) 4]

(3) Dubna ChPT: $W(z) = W(M_a, M_\rho, z)$
[hep-ph/0611175]

⇒ **Form factors** determine model-dependent BR.

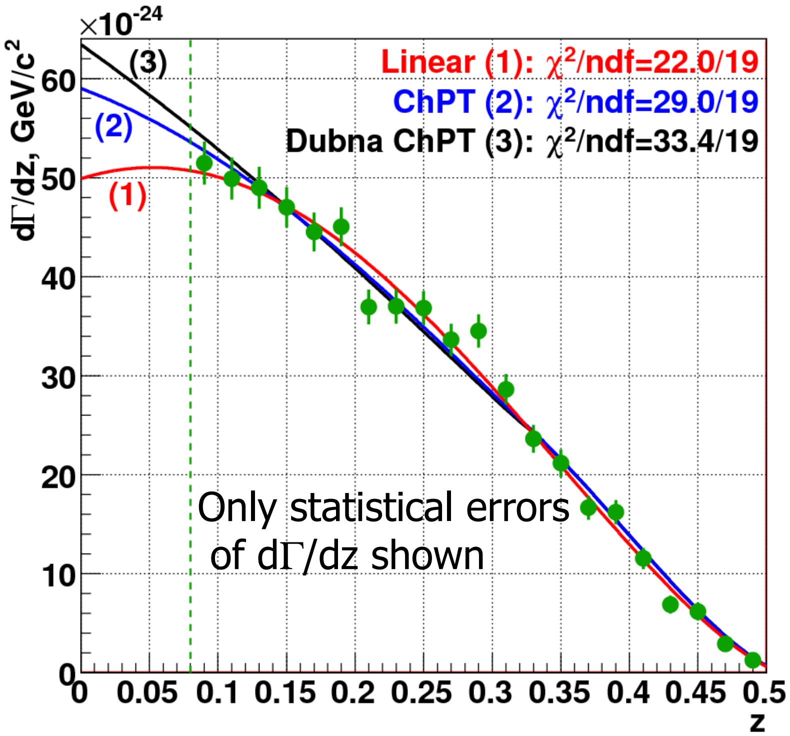
Br and form factors in $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}$

(preliminary)

- **Model-independent Br** computed integrating $d\Gamma/dz$:

$$BR(K^{\pm}\rightarrow \pi^{\pm}e^{+}e^{-}, z > 0.08) = (2.26 \pm 0.03_{stat} \pm 0.03_{syst} \pm 0.06_{ext})\cdot 10^{-7}$$

- **Model-dependent** method: fit z, obtain form factors and plug them into theoretical prediction of Br for numerical integration.



(1)
$$\delta = 2.35 \pm 0.15_{stat} \pm 0.09_{syst}$$
$$f_0 = 0.532 \pm 0.012_{stat} \pm 0.008_{syst} \pm 0.008_{ext}$$
$$BR = (3.02 \pm 0.04_{stat} \pm 0.04_{syst} \pm 0.08_{ext})\cdot 10^{-7}$$

(2)
$$a_{+} = -0.579 \pm 0.012_{stat} \pm 0.008_{syst} \pm 0.007_{ext}$$
$$b_{+} = -0.798 \pm 0.053_{stat} \pm 0.037_{syst} \pm 0.017_{ext}$$
$$BR = (3.11 \pm 0.04_{stat} \pm 0.04_{syst} \pm 0.08_{ext})\cdot 10^{-7}$$

(3)
$$M_a = 0.965 \pm 0.028_{stat} \pm 0.018_{syst} \pm 0.002_{ext}$$
$$M_{\rho} = 0.711 \pm 0.010_{stat} \pm 0.007_{syst} \pm 0.002_{ext}$$
$$BR = (3.15 \pm 0.04_{stat} \pm 0.04_{syst} \pm 0.08_{ext})\cdot 10^{-7}$$

$$BR(K^{\pm}\rightarrow \pi^{\pm}e^{+}e^{-}) = (3.08\pm 0.12)\times 10^{-7}$$

$$\Delta(K^{\pm}_{\pi ee}) = \frac{(Br^{+} - Br^{-})}{(Br^{+} + Br^{-})} = (-2.1\pm 1.5_{stat}\pm 0.3_{syst})\%$$

Summary

New Measurements by NA48/2 of ChPT Parameters

★ $\pi\pi$ - **Scattering lengths from $K^{\pm}\rightarrow \pi^{\pm}\pi^{0}\pi^{0}$ and $K^{\pm}\rightarrow\pi^{+}\pi^{-}e^{\pm}\nu$.**

→ Full 2004 being worked on and fitting different theoretical expressions (Bern).

→ Isospin breaking symmetry corrections for Ke4 need to be evaluated and included.

★ **Precise study of the $K^{\pm}\rightarrow\pi^{\pm}\gamma\gamma$ decay.**

→ **BR** measurement in agreement with ChPT.

→ shape analysis and a larger sample (2004 data) coming soon.

★ **First observation of the $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}\gamma$ decay.**

→ **BR** and **ĉ** measurement in agreement with ChPT.

★ **Precise study of $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}$.**

→ Precision comparable with world's best.

→ **BR** and **form factor** measurements in agreement with ChPT and other measurements.

→ First limit on **CPV** asymmetry.

Backup Slides

Other NA48/2 Results

★ Measurement of direct **CP violating charge asymmetries** of the Dalitz plot linear slopes $A_g = (g^+ - g^-)/(g^+ + g^-)$ in $K^\pm \to \pi^\pm\pi^+\pi^-$ and $K^\pm \to \pi^\pm\pi^0\pi^0$:

$A_g^c = (-1.5 \pm 2.2)\cdot 10^{-4}$ from $3.11\cdot 10^9$ $K^\pm \to \pi^\pm\pi^+\pi^-$ decays,

$A_g^n = (1.8 \pm 1.8)\cdot 10^{-4}$ from $9.13\cdot 10^7$ $K^\pm \to \pi^\pm\pi^0\pi^0$ decays.

In agreement with SM. Measurements statistically limited [Eur. Phys. J. C52, 875-891 (2007)].

★ First measurement of Direct Emission and Interference terms in $K^\pm \to \pi^\pm\pi^0\gamma$ has been performed in the region 0 MeV < T_π^* < 80 MeV :

- **Frac(DE)** = $(3.35 \pm 0.35_{stat} \pm 0.25_{syst})$ %
- **Frac(INT)** = $(-2.67 \pm 0.81_{stat} \pm 0.73_{syst})$ %
- **First evidence** of a non vanishig **interference term**.

★ **Semileptonic** channels [Eur. Phys. J. C50, 329--340 (2007)] :

- $R_{Ke3/K2\pi} = (0.2496 \pm 0.0009_{stat} \pm 0.0004_{syst})$
- $R_{K\mu3/K2\pi} = (0.1637 \pm 0.0006_{stat} \pm 0.0003_{syst})$
- $R_{K\mu3/Ke3} = (0.656 \pm 0.003_{stat} \pm 0.001_{syst})$

★ **Leptonic** channels:

- $R_{Ke2/K\mu2} = (2.416 \pm 0.043_{stat} \pm 0.024_{syst})$ [4670 evts, 2003 preliminary]
- $R_{Ke2/K\mu2} = (2.455 \pm 0.045_{stat} \pm 0.041_{syst})$ [3407 evts, 2004 preliminary]

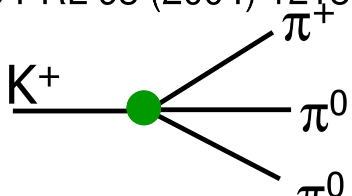
$\pi^+\pi^-$ Scattering in $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$

Theoretical interpretation :

$\mathcal{M}(K^\pm \rightarrow \pi^\pm\pi^0\pi^0) = \mathcal{M}_0 + \mathcal{M}_1$

At first order:

(N. Cabibbo PRL 93 (2004) 12181)



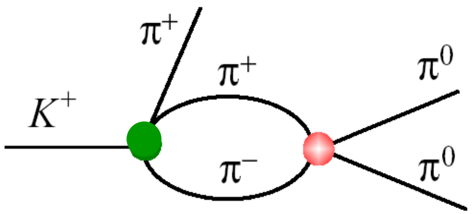
$\mathcal{M}_0 \propto 1 + g_0 u/2 + h' u^2/2 + k' v^2/2$

Kaon rest frame:

$\mathbf{u} = 2m_K \cdot (m_K/3 - E_{odd})/m_\pi^2$

$\mathbf{v} = 2m_K \cdot (E_1 - E_2)/m_\pi^2$

$[g_0 \approx g_{PDG},\ h' \approx h_{PDG} - g^2_{PDG}/4,\ k'_{PDG} \approx k]$



$\mathcal{M}_1$ real and negative for $\mathbf{M^2_{00} < 4m^2_{\pi+}}$:

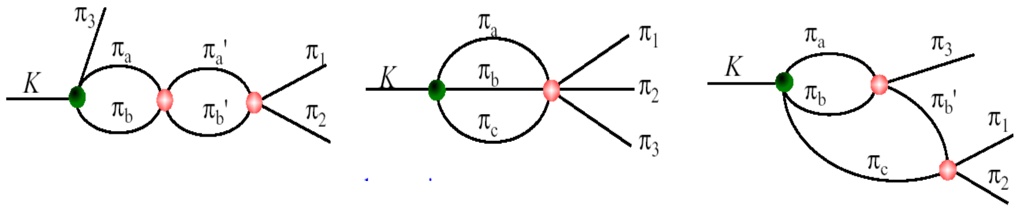
$\mathcal{M}_1 \propto -(a_0 - a_2) m_{\pi+} \mathcal{M}_{3\pi,th} \cdot \pi\sqrt{(4m_{\pi+}^2/M^2_{00} - 1)}$

$\mathcal{M}_1$ imaginary for $\mathbf{M^2_{00} > 4m^2_{\pi+}}$:

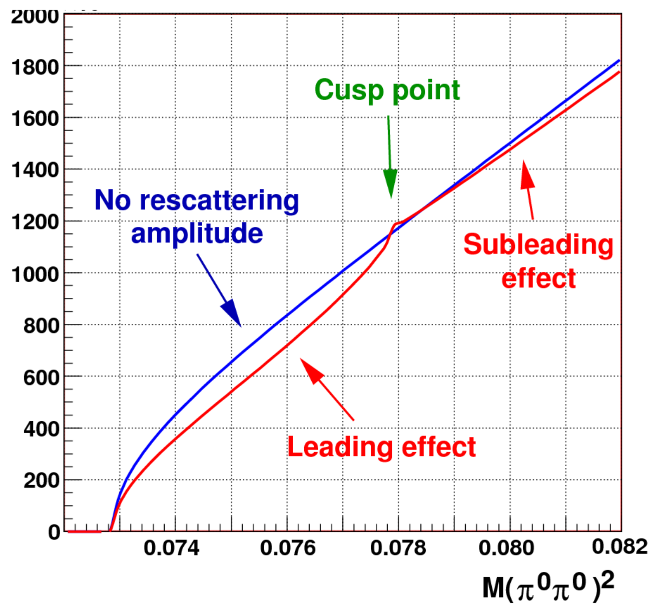
$\mathcal{M}_1 \propto -(a_0 - a_2) m_{\pi+} \mathcal{M}_{3\pi,th} \cdot (-i)\pi\sqrt{(1 - 4m_{\pi+}^2/M^2_{00})}$

2nd order: (N. Cabibbo, G. Isidori, JHEP03 (2005) 021)

- All other rescattering corrections: $\pi^0\pi^0 \rightarrow \pi^0\pi^0$, $\pi^+\pi^0 \rightarrow \pi^+\pi^0$,…
- 5 S-wave scattering lengths dependent on a_0 and a_2
- Isospin symmetry breaking in
- Two-loop level $O(a_i^2)$ corrections:



⇒separate **determination of a_2** possible



$\pi^+\pi^-$ Scattering in $K^\pm \to \pi^\pm\pi^0\pi^0$ & $K^\pm \to \pi^+\pi^- e^\pm\nu$

Previous determinations:

•**$K^\pm \to \pi^+ \pi^- e^\pm \nu(\nu)$ decays:**

- **Geneva-Saclay** ('76): ~30000 events.

- **BNL E865**('03): 400000 events, Isospin symmetry breaking corrections not applied. Measured a0 and a2 and obtained:

$$(a_0 - a_2) m_{\pi+} = 0.258 \pm 0.013$$

•**Pionium ($\pi^+\pi^-$ atom) lifetime**: $\Gamma_{pionium} \propto (a_0 - a_2)^2$

- **DIRAC** ('05): $|a_0 - a_2|\, m_{\pi+} = 0.264^{+0.020}_{-0.011}$

•Precise prediction within **ChPT** [Colangelo,Gasser,Leutwyler (2000)]

$$a_0 m_{\pi+} = 0.220 \pm 0.005\ ,$$
$$a_2 m_{\pi+} = -\,0.0444 \pm 0.0010$$

Br ($K^{\pm} \to \pi^{\pm}\gamma\gamma$)

- **A model independent** measurement of **Br** in preparation:

Br measured in bins of $m_{\gamma\gamma}$ (or **z = $m^2_{\gamma\gamma}$/ m^2_K**) (including acceptances, efficiencies and background) and integrated over whole **$d\Gamma_{\pi\gamma\gamma}$/dz** range.

⇒This allows to extract **ĉ** using measured Br($m_{\gamma\gamma}$) and fitting to absolute O(6) ChPT prediction [G. Ecker, A. Pich and E. de Rafael, Nucl.Phys. B386 (1996), 403]

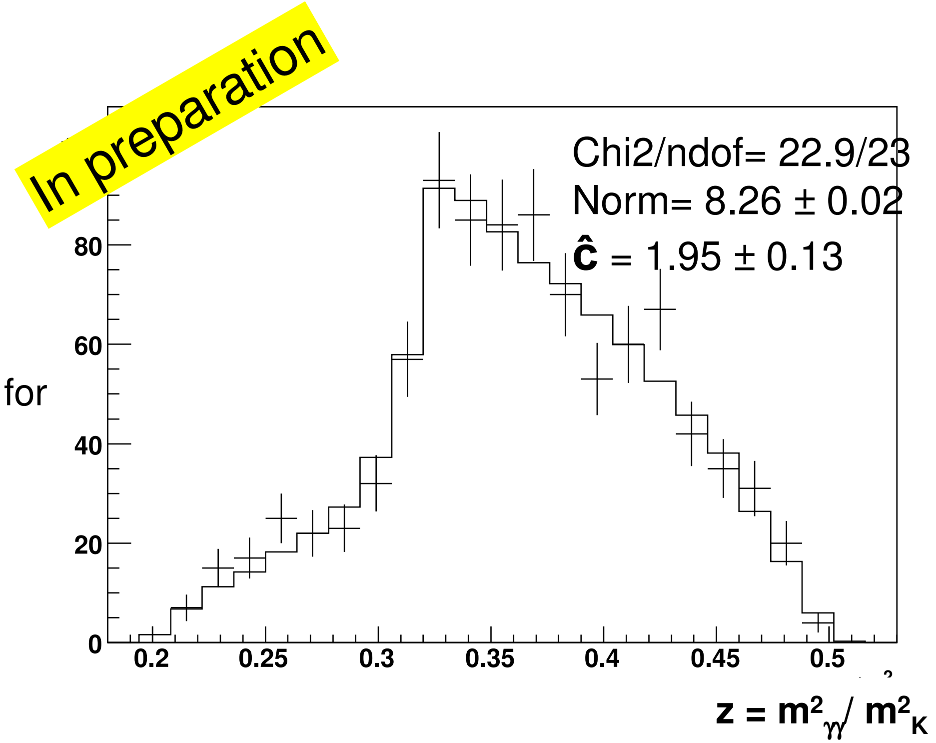
Other approach (step by step):

1.- Assume no vector mesons and discard poles

⇒ only **ĉ** free parameter [G. D'Ambrosio, J. Portolés. Nucl.Phys. B386 (1996), 403].

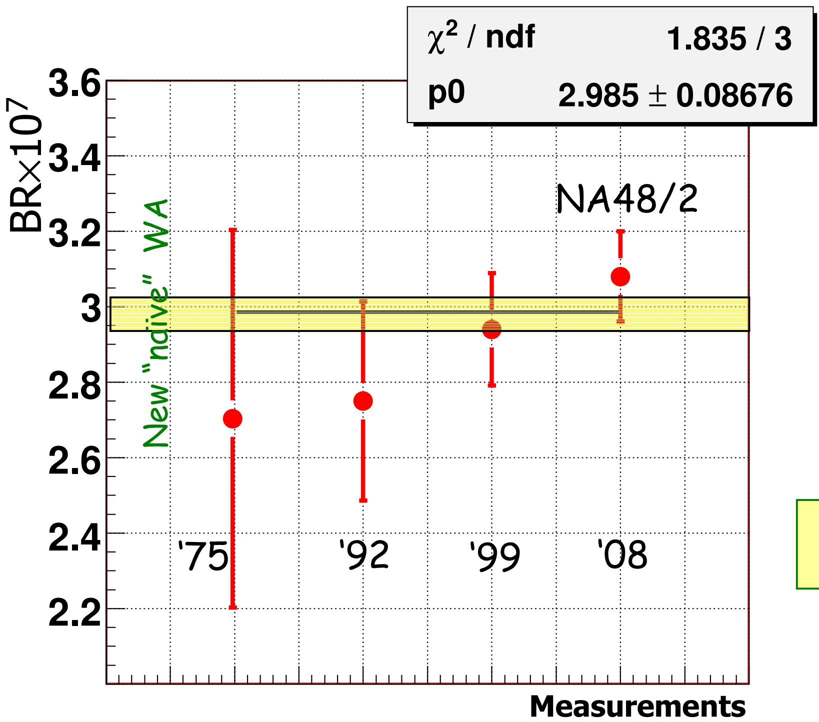
2.- Test for **poles**: include their contribution and fit simultaneously **ĉ** and **G8s** ⇒ exclude some ranges for G8s [M. Gerard, C. Smith, S. Trine, hep-ph/0508189].

3.- To test for **vector mesons**, include the eta_i, see if they come out large in fit, and if they approximately follow the VMD ansatz.



$BR(K^{\pm}\to\pi^{\pm}e^{+}e^{-})$

Measurement	Sample	$BR\times10^{7}$
Bloch et al., PL 56 (1975) B201	41 (K^{+})	2.70±0.50
Alliegro et al. [E777], PRL 68 (1992) 278	500 (K^{+})	2.75±0.26
Appel et al. [E865], PRL 83 (1999) 4482	10,300 (K^{+})	2.94±0.15
NA48/2 preliminary (2008)	7,100 ($K^{\pm}$)	3.08±0.12



Comparison of E865 vs NA48/2 results:
dismissing correlated errors
(normalization and model dependence)
and using the same PDG $BR(K\to2\pi)$

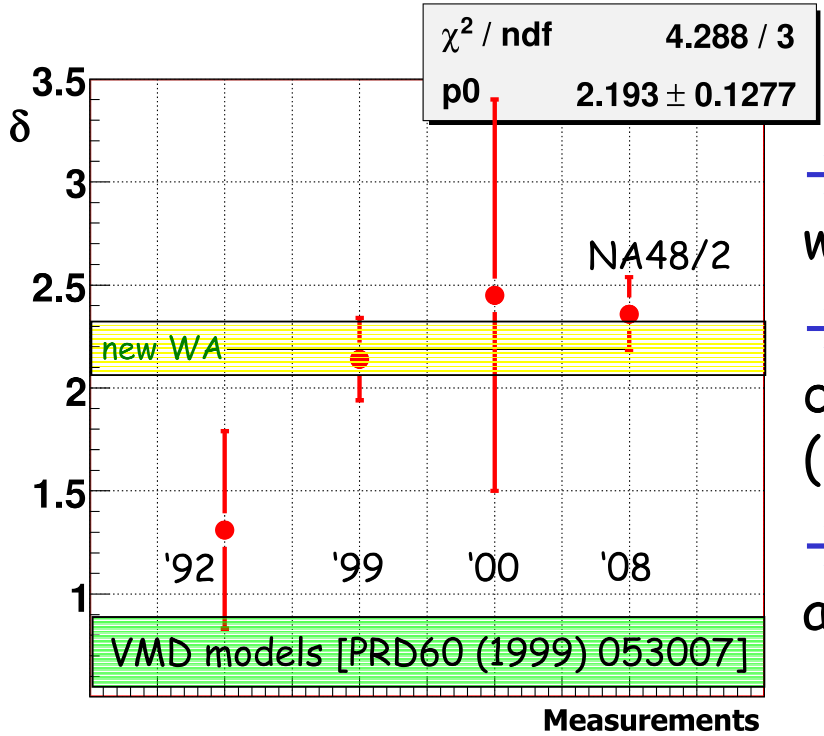
BR [E865, linear FF] = 2.88±0.11;
BR [NA48, linear FF] = 3.056±0.056.

δ(BR) = (0.176±0.123) → 1.4σ difference

[15% probability]

δ -Form Factor of $K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}$

Measurement	Process	Result
Alliegro et al. [E777], PRL 68 (1992) 278	$K^{+}\rightarrow\pi^{+}e^{+}e^{-}$	1.31±0.48
Appel et al. [E865], PRL 83 (1999) 4482	$K^{+}\rightarrow\pi^{+}e^{+}e^{-}$	2.14±0.20
Ma et al. [E865], PRL 84 (2000) 2580	$K^{+}\rightarrow\pi^{+}\mu^{+}\mu^{-}$	$2.45^{+1.30}_{-0.95}$
NA48/2 preliminary (2008)	$K^{\pm}\rightarrow\pi^{\pm}e^{+}e^{-}$	2.35±0.18



→ NA48/2 measurement of δ is compatible with the earlier results, has good precision;

→ A contradiction of the data to the meson dominance models observed earlier ($\delta=(m_K/m_\rho)^2$) is further confirmed;

→ NA48/2 values of (f_0, a_+, b_+) are in agreement with BNL E865 ones.

Leptonic and semileptonic modes

Γ_1	$e^+\nu_e$		$(1.55 \pm 0.07) \times 10^{-5}$	
Γ_2	$\mu^+\nu_\mu$		(63.44 ± 0.14) %	S=1.2
Γ_3	$\pi^0 e^+\nu_e$ Called K^+_{e3}.		(4.98 ± 0.07) %	S=1.3
Γ_4	$\pi^0\mu^+\nu_\mu$ Called $K^+_{\mu3}$.		(3.32 ± 0.06) %	S=1.2
Γ_5	$\pi^0\pi^0 e^+\nu_e$		$(2.2 \pm 0.4) \times 10^{-5}$	
Γ_6	$\pi^+\pi^- e^+\nu_e$		$(4.09 \pm 0.09) \times 10^{-5}$	
Γ_7	$\pi^+\pi^-\mu^+\nu_\mu$		$(1.4 \pm 0.9) \times 10^{-5}$	
Γ_8	$\pi^0\pi^0\pi^0 e^+\nu_e$		$< 3.5 \times 10^{-6}$	CL=90%

Hadronic modes

Γ_9	$\pi^+\pi^0$		(20.92 ± 0.12) %	S=1.1
Γ_{10}	$\pi^+\pi^0\pi^0$		(1.757 ± 0.024) %	S=1.1
Γ_{11}	$\pi^+\pi^+\pi^-$		(5.590 ± 0.031) %	S=1.1

Leptonic and semileptonic modes with photons

Γ_{12}	$\mu^+\nu_\mu\gamma$	[a,b]	$(6.2 \pm 0.8) \times 10^{-3}$	
Γ_{13}	$\mu^+\nu_\mu\gamma(\mathrm{SD}^+)$	[c]	$< 3.0 \times 10^{-5}$	CL=90%
Γ_{14}	$\mu^+\nu_\mu\gamma(\mathrm{SD}^+\mathrm{INT})$	[c]	$< 2.7 \times 10^{-5}$	CL=90%
Γ_{15}	$\mu^+\nu_\mu\gamma(\mathrm{SD}^- + \mathrm{SD}^-\mathrm{INT})$	[c]	$< 2.6 \times 10^{-4}$	CL=90%
Γ_{16}	$e^+\nu_e\gamma(\mathrm{SD}^+)$	[c]	$(1.52 \pm 0.23) \times 10^{-5}$	
Γ_{17}	$e^+\nu_e\gamma(\mathrm{SD}^-)$	[c]	$< 1.6 \times 10^{-4}$	CL=90%
Γ_{18}	$\pi^0 e^+\nu_e\gamma$	[a,b]	$(2.69 \pm 0.20) \times 10^{-4}$	
Γ_{19}	$\pi^0 e^+\nu_e\gamma(\mathrm{SD})$	[c]	$< 5.3 \times 10^{-5}$	CL=90%
Γ_{20}	$\pi^0\mu^+\nu_\mu\gamma$	[a,b]	$(2.4 \pm 0.8) \times 10^{-5}$	
Γ_{21}	$\pi^0\pi^0 e^+\nu_e\gamma$		$< 5 \times 10^{-6}$	CL=90%

Hadronic modes with photons

Γ_{22}	$\pi^+\pi^0\gamma$	[a,b]	$(2.75 \pm 0.15) \times 10^{-4}$	
Γ_{23}	$\pi^+\pi^0\gamma(\mathrm{DE})$	[b,d]	$(4.4 \pm 0.7) \times 10^{-6}$	
Γ_{24}	$\pi^+\pi^0\pi^0\gamma$	[a,b]	$(7.6 {}^{+6.0}_{-3.0}) \times 10^{-6}$	
Γ_{25}	$\pi^+\pi^+\pi^-\gamma$	[a,b]	$(1.04 \pm 0.31) \times 10^{-4}$	
Γ_{26}	$\pi^+\gamma\gamma$	[b]	$(1.10 \pm 0.32) \times 10^{-6}$	
Γ_{27}	$\pi^+ 3\gamma$	[b]	$< 1.0 \times 10^{-4}$	CL=90%

Leptonic modes with $\ell\overline{\ell}$ pairs

Γ_{28}	$e^+\nu_e\nu\overline{\nu}$		$< 6 \times 10^{-5}$	CL=90%