ChPT tests at the NA48/2 and NA62 experiments at CERN

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On behalf of the NA48/2 and NA62 Collaborations

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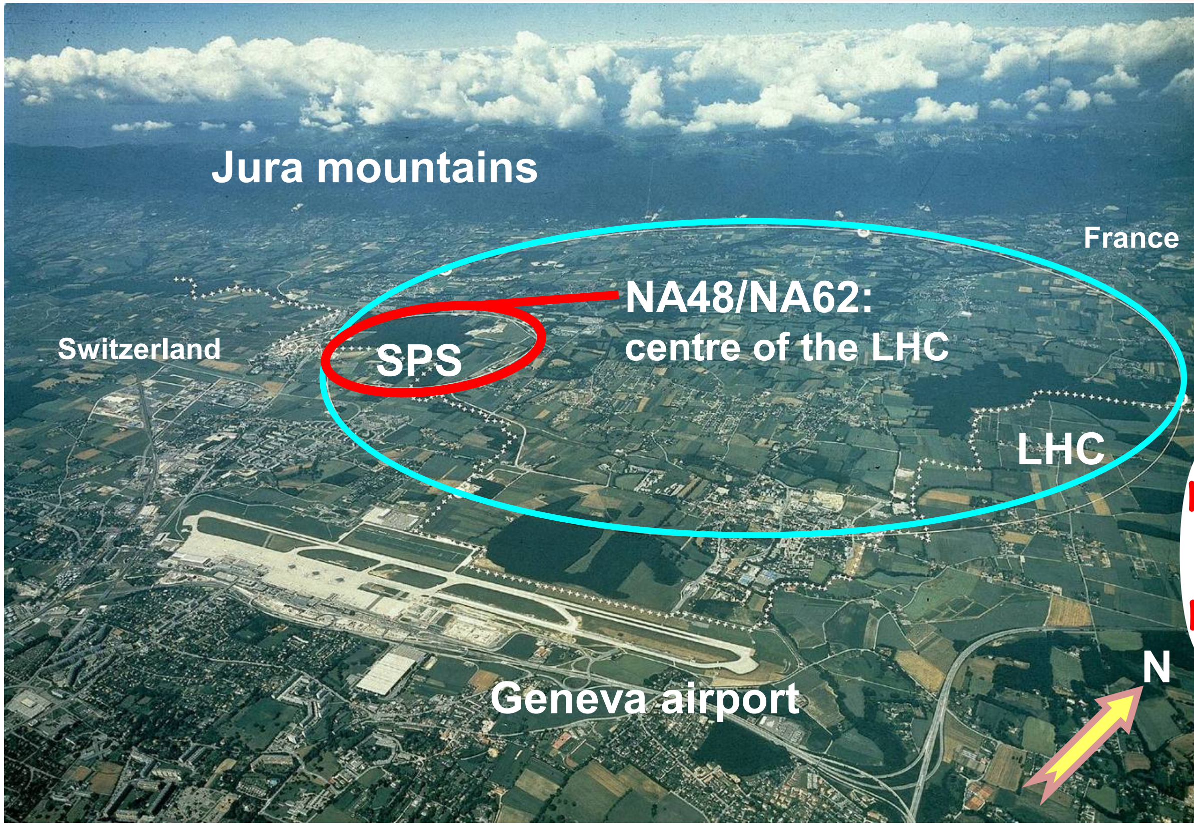
Outlook

- NA48/2 – NA62: the CERN Kaon facility
- $K^{\pm} \to \pi^{\pm}\gamma\gamma$: theory
- $K^{\pm} \to \pi^{\pm}\gamma\gamma$: data analysis
- $K^{\pm} \to \pi^{\pm}\gamma\gamma$: BR and $\hat{c}$ parameter (NA48/2–NA62)
- Conclusions

The NA48 and NA62 Experiments



Earlier: NA31

NA48 discovery of direct CPV
- 1997: ε'/ε: K_L+K_S
- 1998: K_L+K_S
- 1999: K_L+K_S | K_S HI
- 2000: K_L only | K_S HI
- 2001: K_L+K_S | K_S HI

NA48/1
- 2002: K_S/hyperons

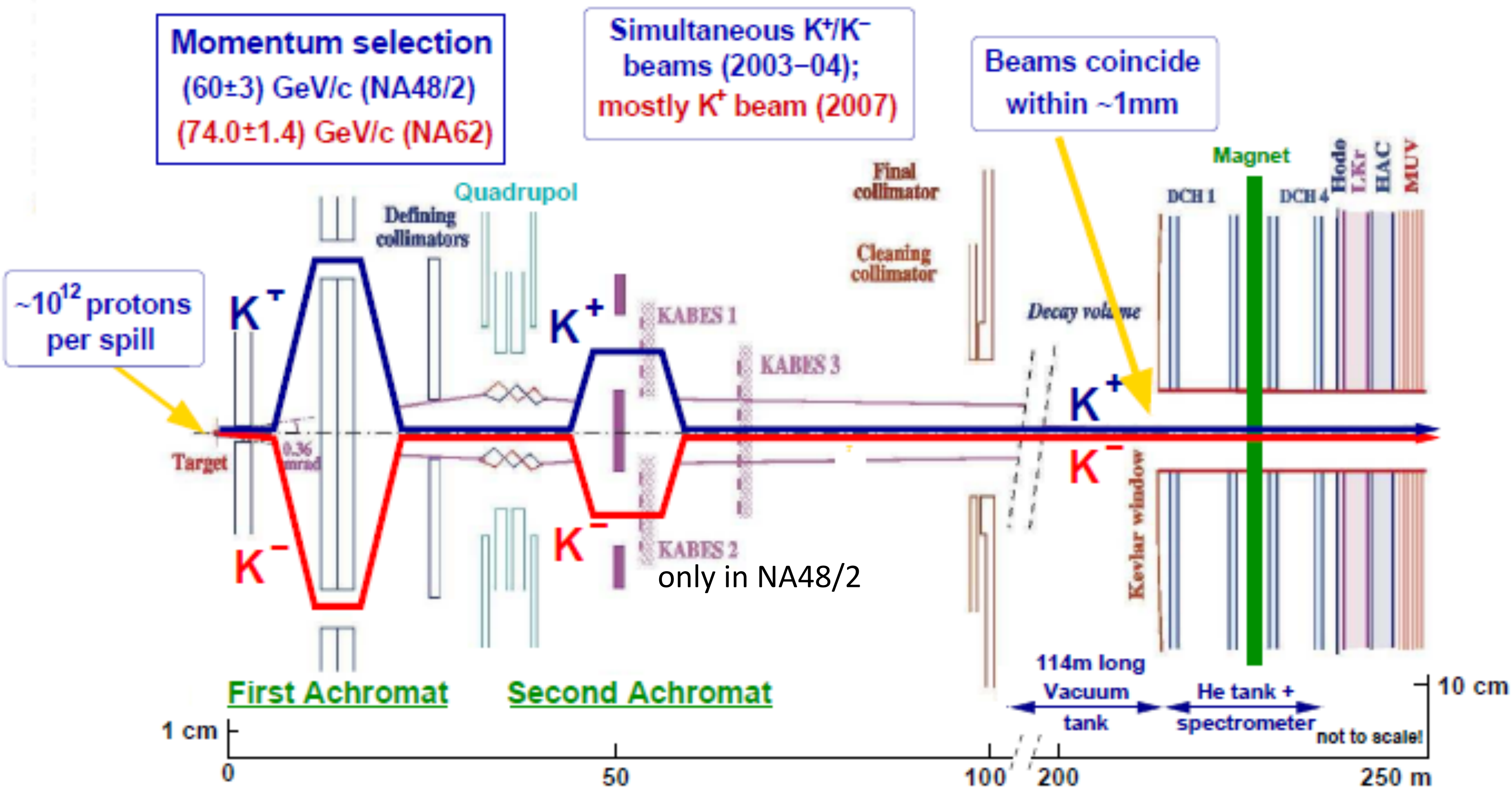
NA48/2
- 2003: K^+/K^-
- 2004: K^+/K^-

NA62 R_K phase
- 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests
- 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests

NA62
- 2012: technical run
- *2014:* 1st $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ run

Kaon decay in flight experiments.
NA62: currently ~200 participants, 29 institutions

The NA48/2 and NA62(R_K) beam line

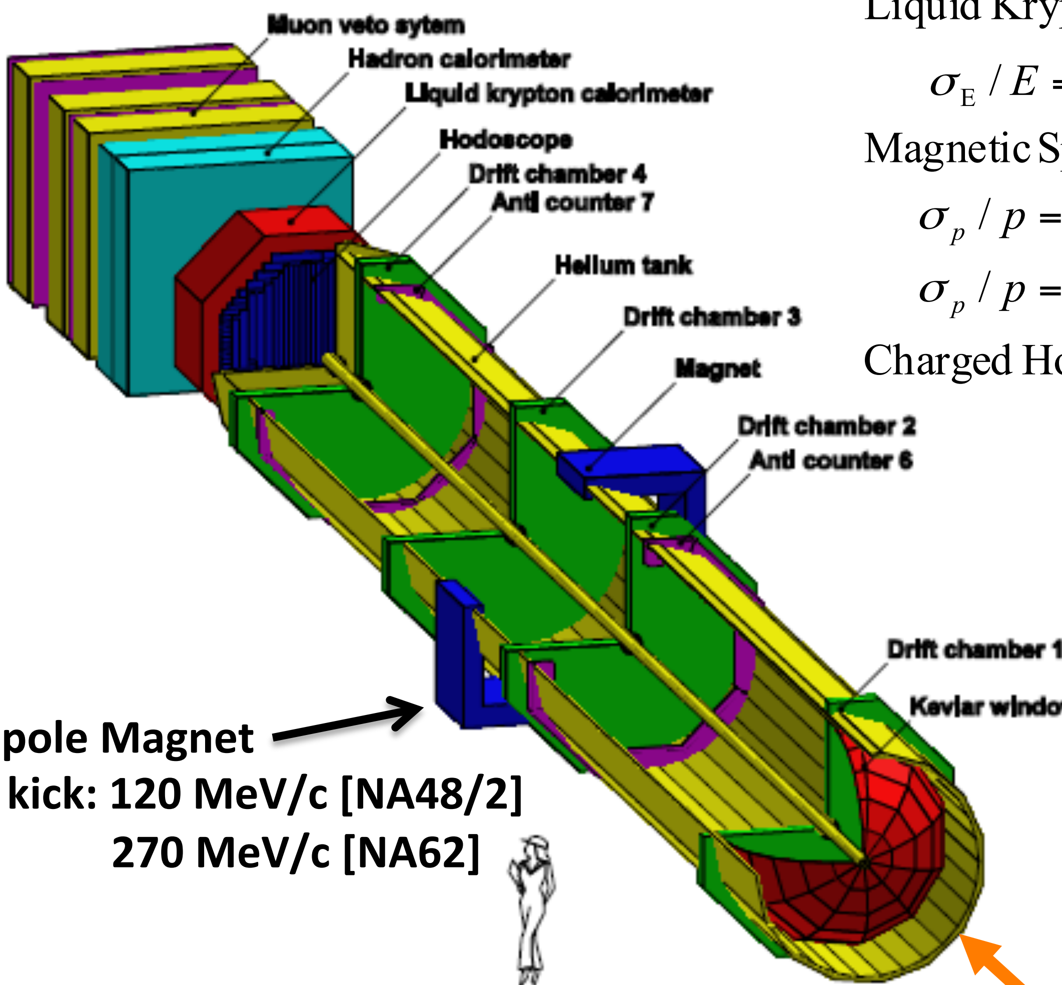


2.5×10^7 K/spill

K decays in the vacuum tank: 22% (18%)

Beam size: 4x4 mm², 10x10 μrad

NA48-NA62 detectors



Dipole Magnet
P_t kick: 120 MeV/c [NA48/2]
270 MeV/c [NA62]

Liquid Krypton Calorimeter :

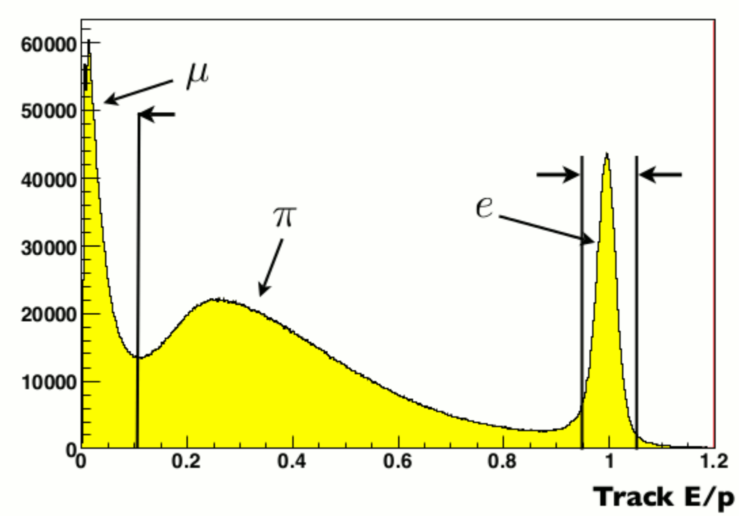
$$\sigma_E / E = 3.2\% / \sqrt{E} \oplus 9\% / E \oplus 0.42\% \quad [E \text{ in GeV}]$$

Magnetic Spectrometer $(p \text{ in GeV/c})$:

$$\sigma_p / p = 1.00\% \oplus 0.044\% \times p \quad [\text{NA48/2}]$$

$$\sigma_p / p = 0.48\% \oplus 0.009\% \times p \quad [\text{NA62}]$$

Charged Hodoscope : $\sigma_t = 150$ ps



ChPT description

$z=(m_{\gamma\gamma}/m_K)^2$

$y=p_K\cdot(q_{\gamma1}-q_{\gamma2})/m_K^2$

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

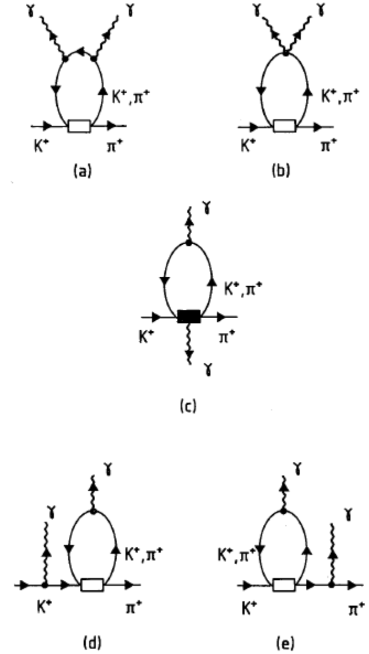


Fig. 5

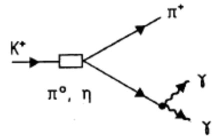


Fig. 7

NO $\mathcal{O}(p^2)$ contribution

Rate depends on a single unknown parameter $\hat{c}$

Leading order $\mathcal{O}(p^4)$ and $\mathcal{O}(p^6)$ unitary corrections:

$$\frac{\partial\Gamma}{\partial y\partial z}=\frac{m_K}{2^9\pi^3}\left[z^2\left(\left|A\left(\hat{c},z,y^2\right)+B(z)\right|^2+\left|C(z)\right|^2\right)+\left(y^2-\frac{1}{4}\lambda\left(1,r_\pi^2,z\right)\right)^2\left|B(z)\right|^2\right]$$

$r_\pi=m_\pi/m_K$

A and B are loop amplitudes
B appears at $\mathcal{O}(p^6)$ but dominates at low z
C is pole amplitude (few percent of the rate)
Weak dependence on y

[D'Ambrosio, Portoles PLB386(1996) 403]

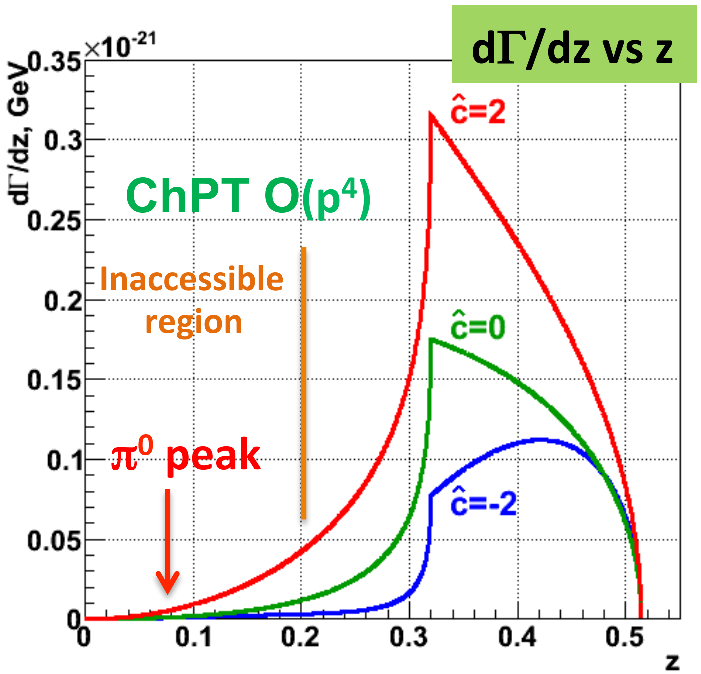
$$\lambda(a,b,c)=a^2+b^2+c^2-2(ab+ac+bc)$$

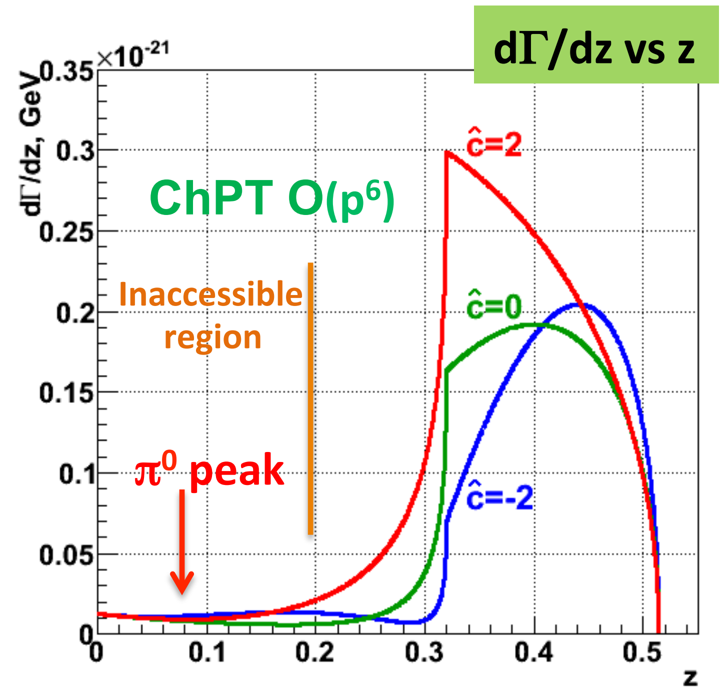
ChPT description

$K^\pm \rightarrow \pi^\pm \gamma\gamma$

$\mathcal{O}(p^4)$: cusp at $\pi^+\pi^-$ threshold
$m_{\gamma\gamma}=2m_{\pi\pm}$ ($z\approx0.32$)
[Ecker, Pich, de Rafael
NPB303(1988) 665]
Rate and Spectrum depend on
a single parameter $\hat{c}$

$\mathcal{O}(p^6)$: Unitarity corrections
Increase BR at low z
Non-zero rate at $m_{\gamma\gamma}=0$
[D'Ambrosio, Portoles
PLB386(1996) 403]





$z=(m_{\gamma\gamma}/m_K)^2$

<u>BNL E787</u>: 31 candidates with 5 bkg events
BR = $(1.10\pm0.32)\times10^{-6}$ [PRL79 (1997) 4079]
$O(p^6)$ full kinematic range

Selection

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

Selection:

- One track compatible with a $\pi^{\pm}$
  - ➢ CDA<3.5 cm w.r.t. beam axis (Vertex Definition)
  - ➢ $10(8) < p_{\pi} < 40(50)$ GeV/c [NA48/2 (NA62)]
  - ➢ $E_{\pi}/p_{\pi} < 0.85$

- Two clusters in the EM calorimeter
  - ➢ $E_{\gamma} > 3$ GeV
  - ➢ Distance γ-γ > 20 cm at the EM calorimeter
  - ➢ Distance γ-$\pi^{\pm}$ > 25 cm at the EM calorimeter

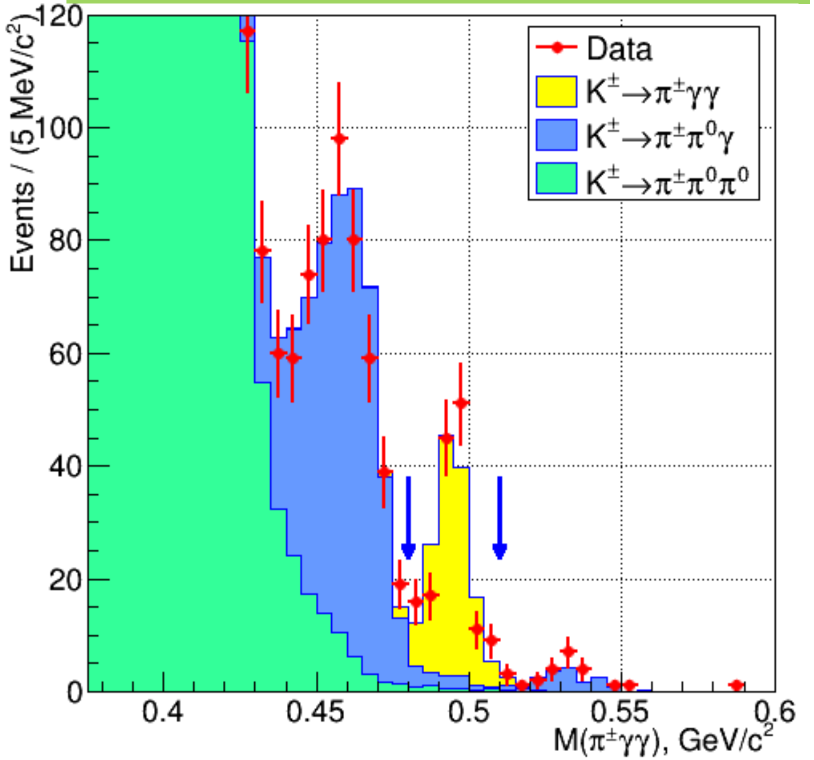
- γ-γ invariant mass ($z = (m_{\gamma\gamma}/m_K)^2$), $(m_{\pi 0}/m_K)^2 = 0.075$
  - ➢ $z > 0.2$ (signal candidates $K^{\pm} \to \pi^{\pm}\gamma\gamma$)
  - ➢ $0.064 < z < 0.086$ (norm.candidate $K^{\pm} \to \pi^{\pm}\pi^{0}$)

$\pi\gamma\gamma$ invariant mass

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

Minimum bias trigger

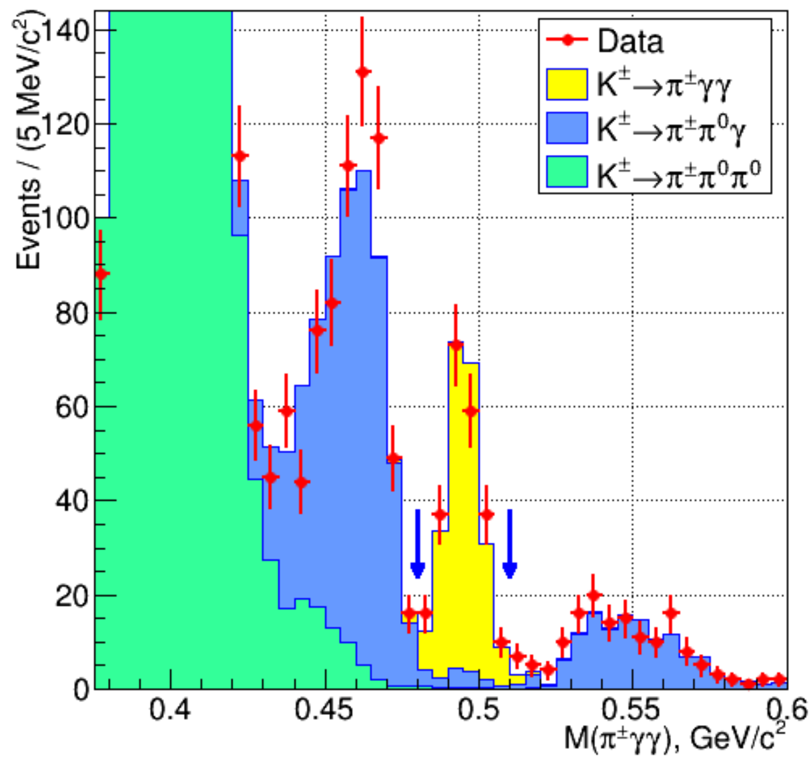
NA48/2 (2004): special run (3 days)



$K_{\pi\gamma\gamma}$ candidates	**149**
$K_{2\pi(\gamma)}$ background	**11.4±0.6**
$K_{3\pi}$ background	**4.1±0.4**
$K_{\pi\gamma\gamma}$ signal	**134±12**

downscaled trigger D≈20

NA62 (2007): full run (3 months)

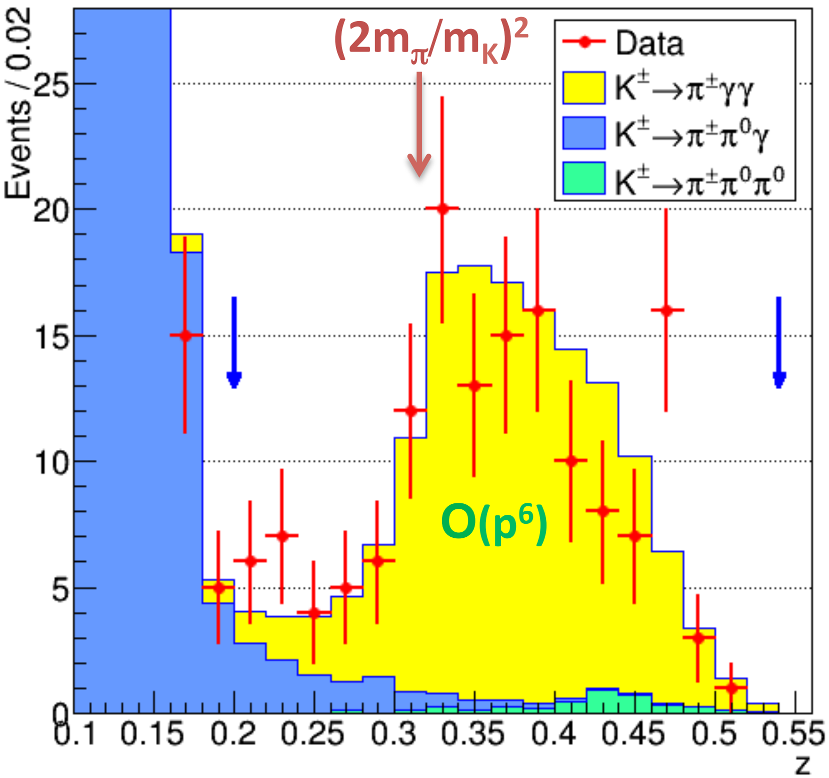


$K_{\pi\gamma\gamma}$ candidates	**232**
$K_{2\pi(\gamma)}$ background	**15.3±1.1**
$K_{3\pi}$ background	**2.1±0.3**
$K_{\pi\gamma\gamma}$ signal	**215±15**

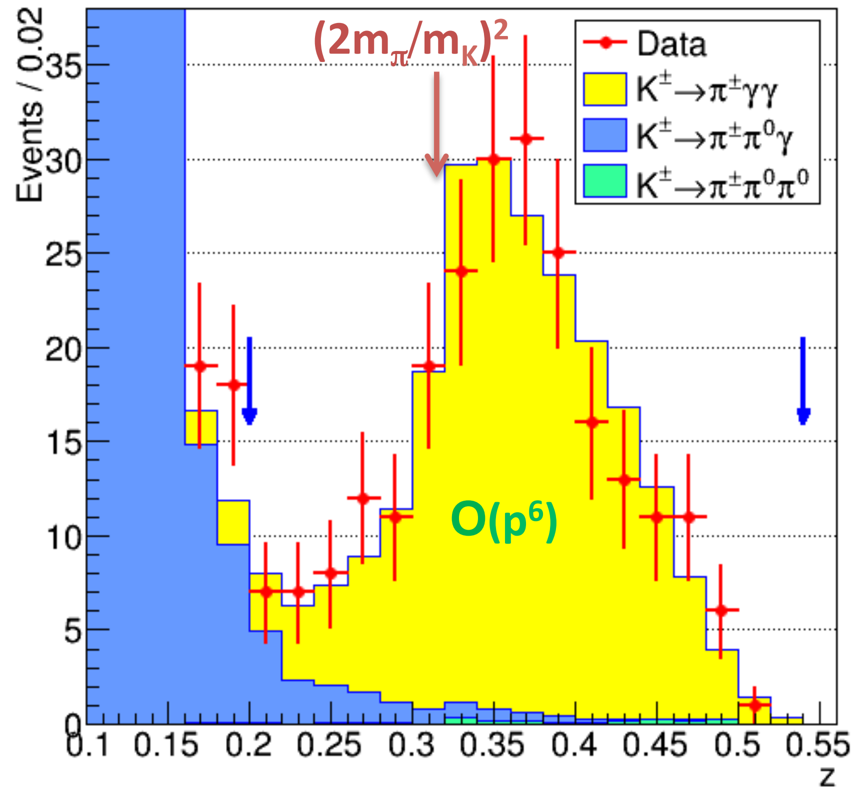
z parameter distribution

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

NA48/2 (2004)



NA62 (2007)



$K^+ \rightarrow \pi^+\pi^0$ peak is outside the plot ($m_{\gamma\gamma}$=135 MeV or z=0.075)
Signal region: z>0.2 or $m_{\gamma\gamma}$> 220 MeV/c^2 (blue arrows)
Data support the ChPT prediction of a cusp at the $m_{\gamma\gamma}=2m_\pi$ threshold

$z=(m_{\gamma\gamma}/m_K)^2$

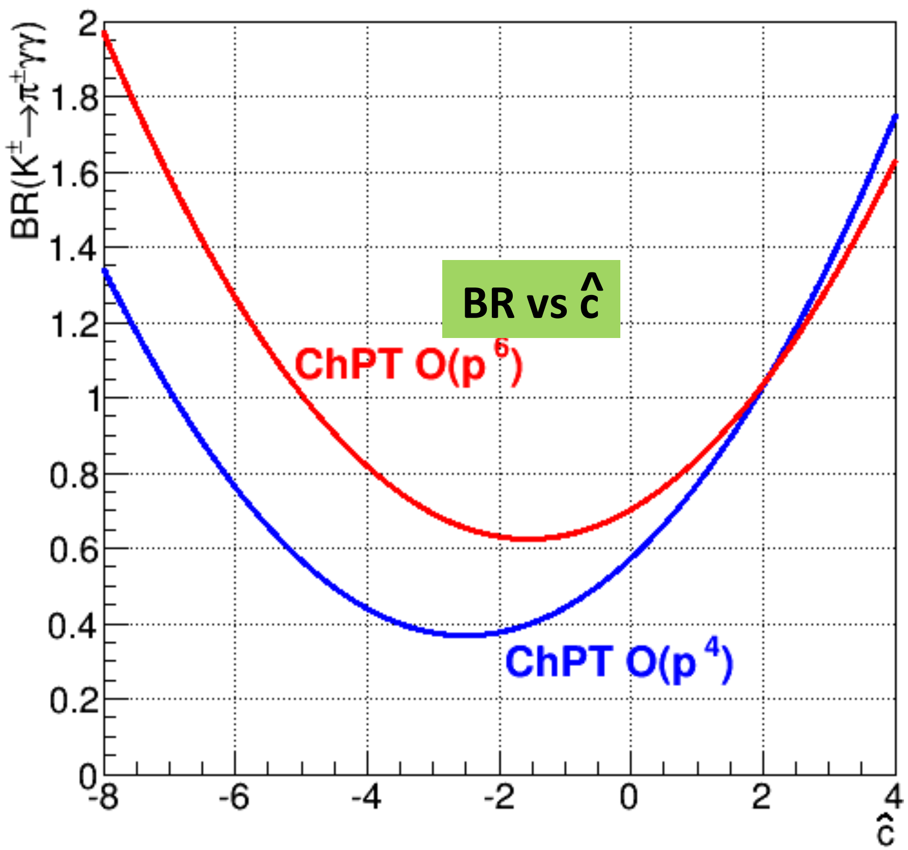
Not able to discriminate $O(p^4)$ from $O(p^6)$

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

Fully correlated systematic errors

$\hat{c}$ =	O(p^4)	O(p^6)
NA48/2 (2004)	$1.37 \pm 0.33_{stat} \pm 0.14_{syst}$	$1.41 \pm 0.38_{stat} \pm 0.11_{syst}$
NA62 (2007)	$1.93 \pm 0.26_{stat} \pm 0.08_{syst}$	$2.10 \pm 0.28_{stat} \pm 0.18_{syst}$
Combined	$1.72 \pm 0.20_{stat} \pm 0.06_{syst}$= **1.72±0.21**	$1.86 \pm 0.23_{stat} \pm 0.11_{syst}$= **1.86±0.25**

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



Using the fitted value of $\hat{c}$
Using the $\mathcal{O}(p^6)$ dependence of the BR on $\hat{c}$
A Model Dependent BR can be calculated

$BR_{ChPT} = (1.003 \pm 0.056) \times 10^{-6}$

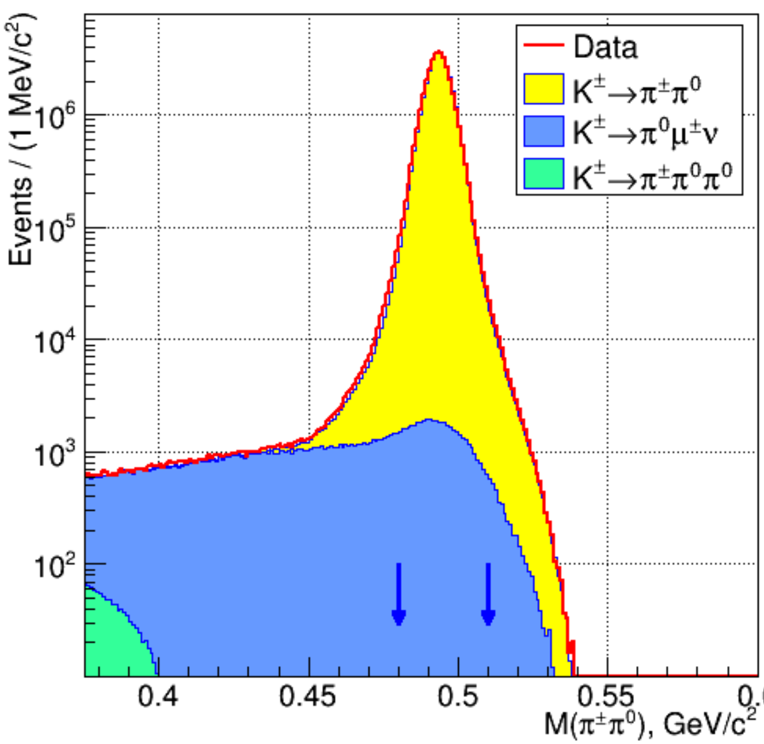
Model Dependent BR: full kinematic range

$\pi^{\pm}\pi^{0}$ invariant mass

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

Minimum bias trigger

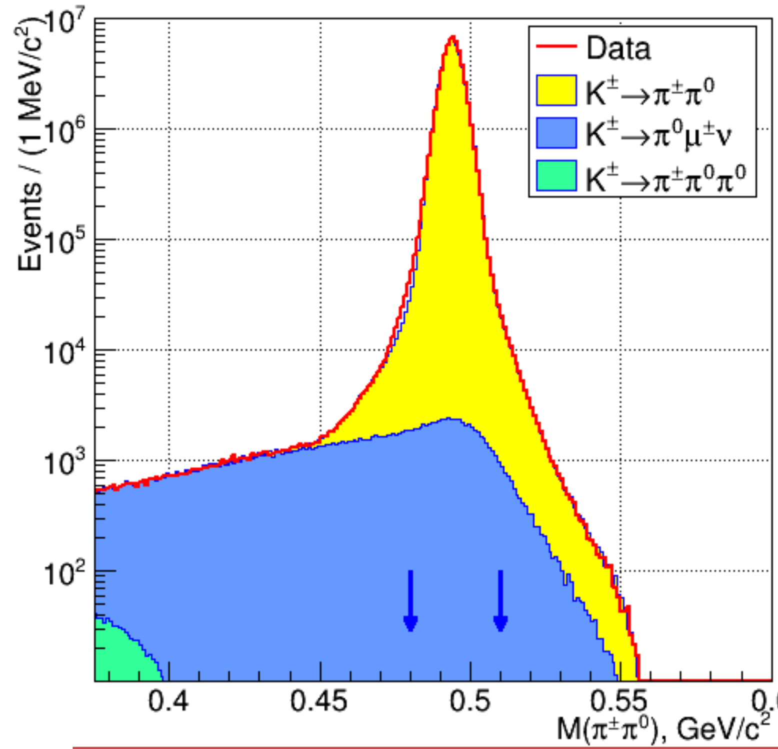
NA48/2 (2004): special run (3 days)



$K_{\pi\pm\pi 0}$ candidates **3.628×10^{7}**

downscaled trigger D≈20

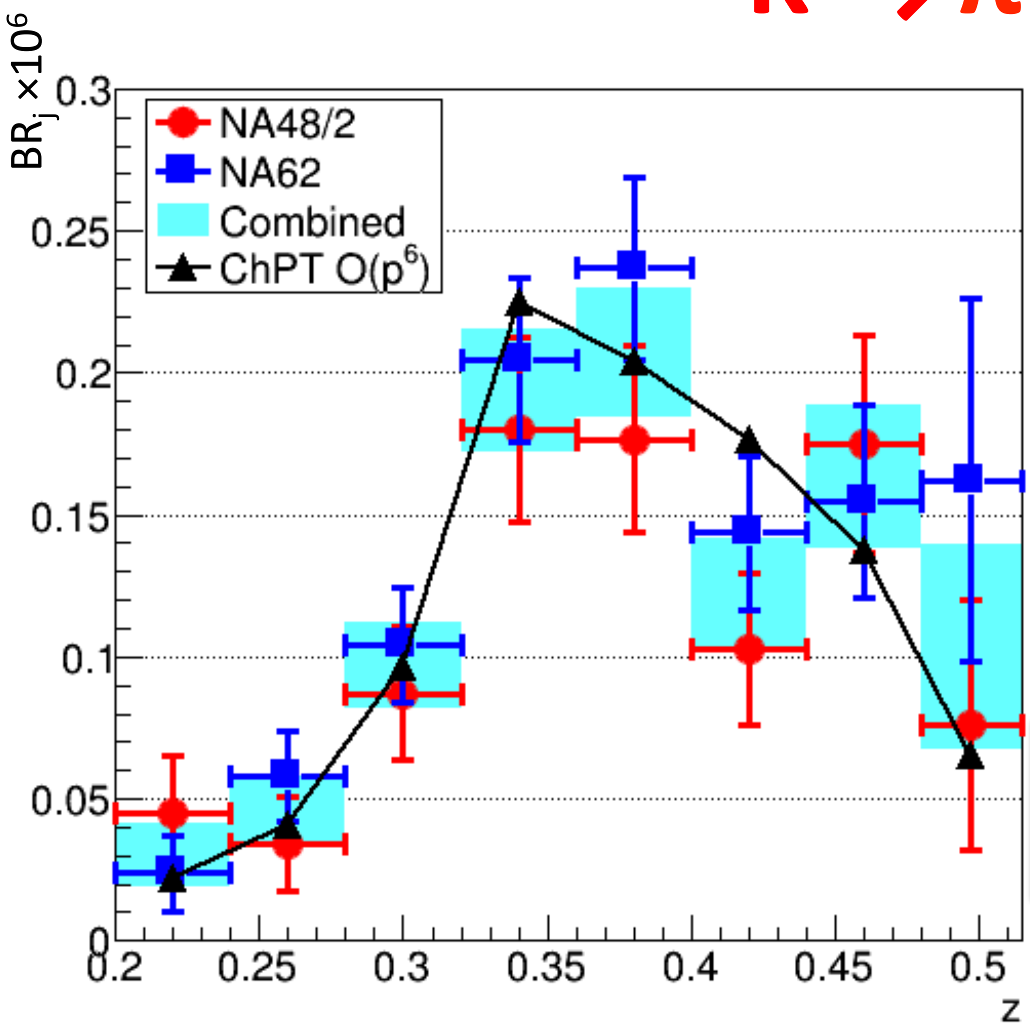
NA62 (2007): full run (3 months)



$K_{\pi\pm\pi 0}$ candidates **5.488×10^{7}**

Normalization Channel

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



$\pi^{\pm}\pi^{0}$ as normalization channel

Calculate BR in bins of z

Final Results with 349 events (after background subtraction)

Model Independent BR

BR_{MI} (z>0.2) = $(0.965 \pm 0.061_{stat} \pm 0.014_{syst}) \times 10^{-6}$

$z=(m_{\gamma\gamma}/m_K)^2$

Conclusions

- Improved test of ChPT using $K^{\pm}\rightarrow\pi^{\pm}\gamma\gamma$
- Cusp behaviour supported by data
- Published papers

➢ **PLB 730 (2013) 141 (NA48/2)**

➢ **PLB 732 (2014) 65 (NA62)**

$\hat{c}$ =	$O(p^4)$	$O(p^6)$
Combined	1.72±0.21	1.86±0.25

$BR_{ChPT} = (1.003\pm0.056)\times10^{-6}$ Model Dependent, full kinematic range

$BR_{MI}\ (z>0.2) = (0.965\pm0.063)\times10^{-6}$ Model Independent