Chiral perturbation theory tests

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on behalf of the NA48/2 and NA62 Collaborations

The NA48/2 Collaboration
Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Florence, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Turin, Vienna

The NA62 Collaboration
Birmingham, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, IHEP, INR, Liverpool, Louvain, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, San Luis Potosi, SLAC, Sofia, Triumf, Turin

HQL 2012

June 13th , 2012

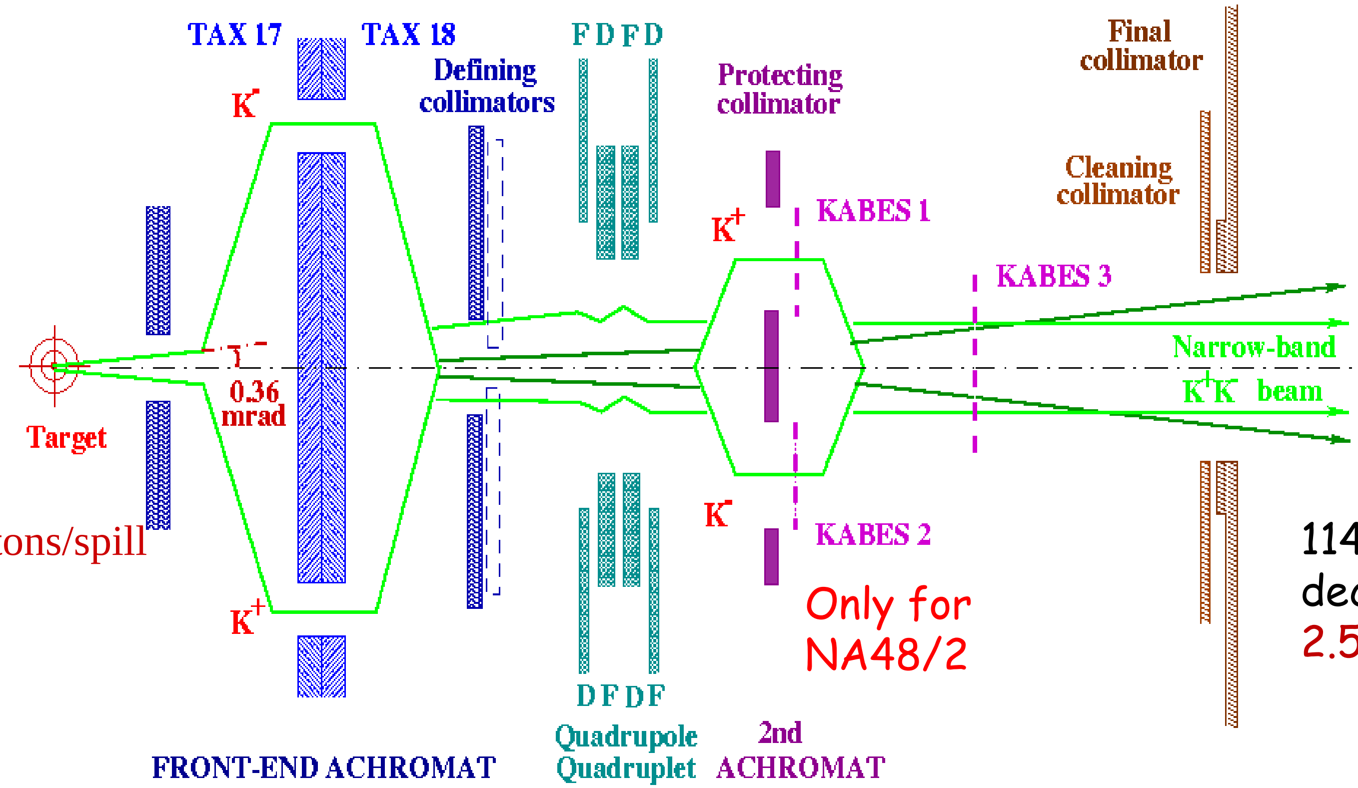
Outline

- The NA48/2-NA62 beam and detector
- NA48/2 - NA62 measurement of $K^{\pm} \to \pi^{\pm}\gamma\gamma$
- NA62 preliminary results on $K^{+} \to e^{\pm}\nu\gamma$
- Progress towards the NA48/2 preliminary results on $K^{\pm} \to \pi^{\pm}\pi^{0}e^{+}e^{-}$

The NA48/2-NA62 Beam

NA48/2 beam (2003-2004): simultaneous K^+/K^-

NA62 beam (2007-2008): K^+/K^- optimized for R_K measurement



1.8×10^{12} protons/spill
400 GeV/c

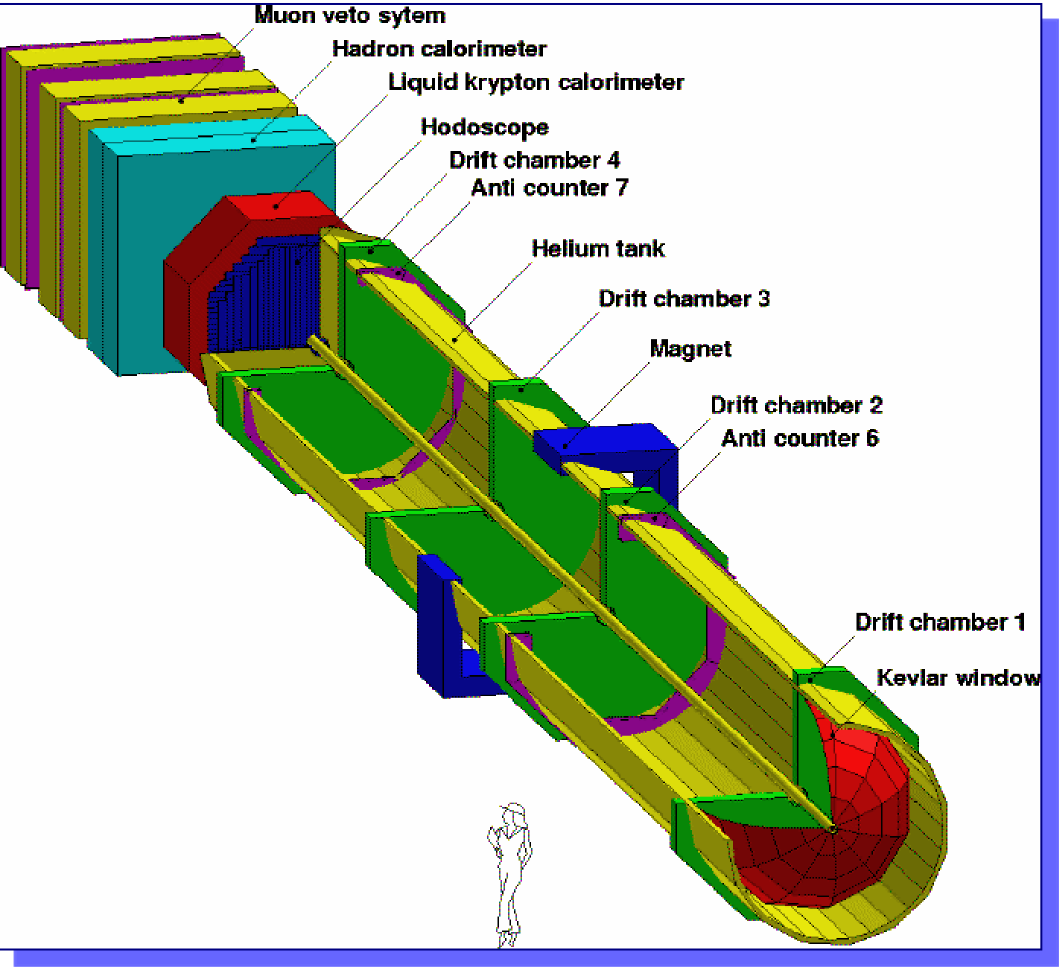
Only for NA48/2

114 m long decay volume
2.5×10^{7} K/spill

P_K = 60 GeV/c
P_K = 74 GeV/c

K decays in the vacuum tank: 22% (18%)
Beam size: 4x4 mm^2, 10x10 μr

The NA48/2-NA62 Detector



Maximum spectrometer P_T kick to improve missing mass resolution

LKr Calorimeter:

$\sigma(E)/E \cong 3.2\%/\sqrt{E} \oplus 9\%/E \oplus 0.42\%$

$\sigma(E)$ ~1%, $\sigma(x)$, $\sigma(y)$ ~1 mm

Spectrometer:

$\sigma(P)/P \cong 0.48\% \oplus 0.009\ P[GeV/c]\%$

Scintillator hodoscope: fast trigger and good time resolution (150 ps)

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

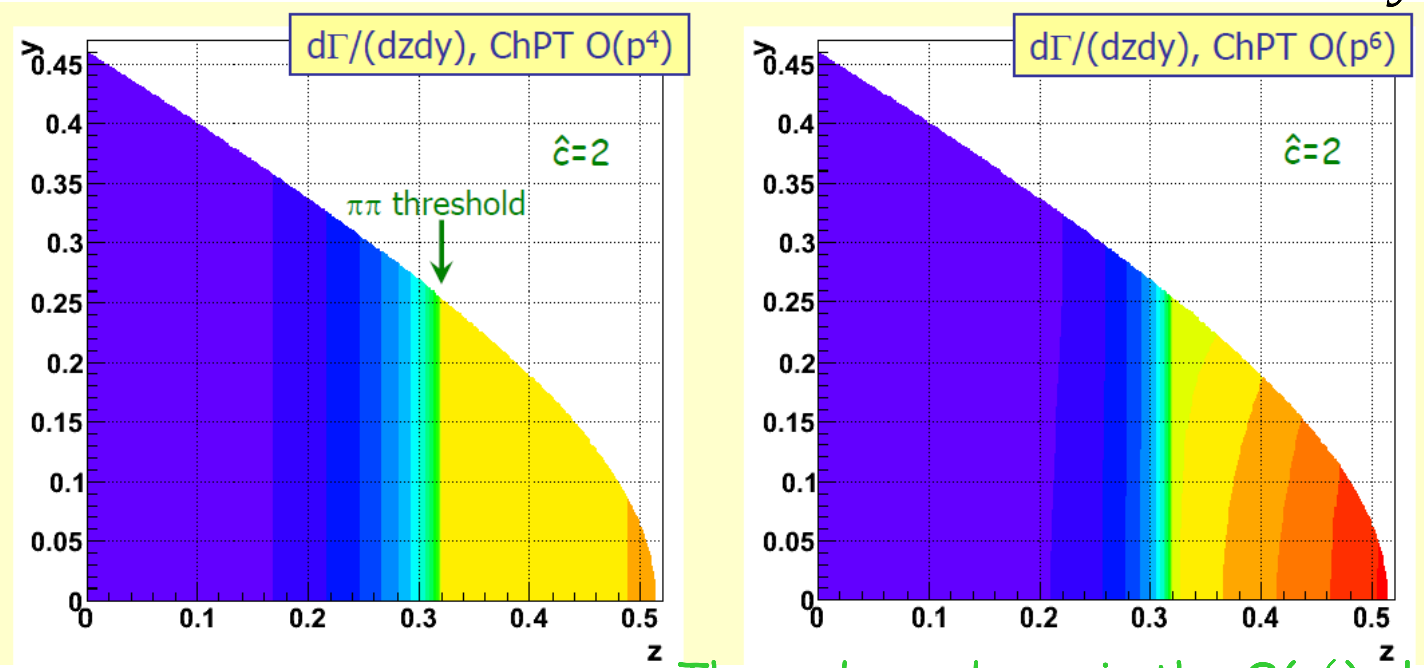
$K^\pm \to \pi^\pm\gamma\gamma$ CHPT description

- The spectrum and the rate are function only of the parameter $\hat{c}$

- Leading contribution at $O(p^4)$, a stringent test of ChPT (D'Ambrosio, Portoles, PLB 386 (1996) 403)

$$z = \frac{(P_{\gamma 1} + P_{\gamma 2})^2}{m_K^2}$$

$$y = \frac{P_K (P_{\gamma 1} - P_{\gamma 2})}{m_K^2}$$

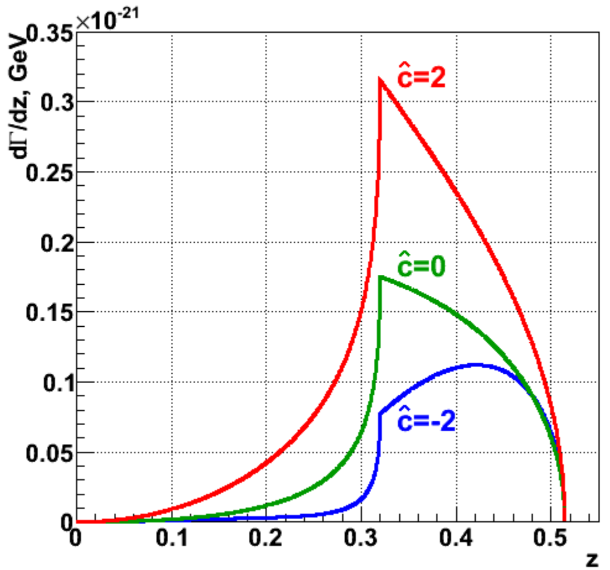


The y-dependence in the $O(p^6)$ plot is due to corrections from $K \to 3\pi$

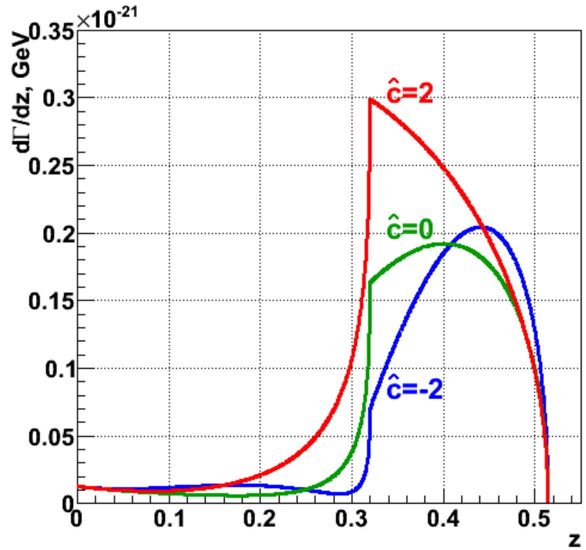
$K^{\pm} \to \pi^{\pm}\gamma\gamma$ CHPT description

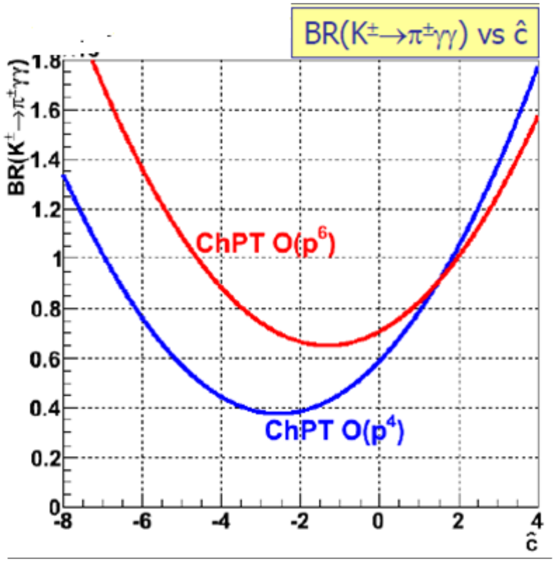
- The spectrum in z has a cusp-like structure at the 2π threshold
- In the $O(p^6)$ spectrum, unitarity corrections can increase the BR at low $\hat{c}$ with a non-zero rate at $M_{gg} \to 0$

Ecker, Pich, de Rafael, Phys. B303 (1988), 665



D'Ambrosio, Portoles, PLB 386 (1996) 403





Experimental status: E787 (BNL), 31 events
BR=$(1.10\pm0.32)\times10^{-6}$ (full kinematic range)
[PRL79 (1997) 4079]

NA48 goals: measure $\hat{c}$ in the $O(p^4)$ and $O(p^6)$ models

Data samples

- Separate analysis of 2004 and 2007 run data
  - 2004: minimum bias trigger, 3 days data taking
    - 2 hits in the hodoscope planes + E(LKr) > 10 GeV
  - 2007: sample of downscaled control triggers from the run to measure R_K
  - Φ(MinBias 2004) / Φ(Control Triggers 2007) = 0.7
  - Different acceptances, different beam momentum
- Combination of the two analyses
  - Accounting for correlated systematics

Summary of data samples

Signal selected with $z=(M_{\gamma\gamma}/M_K)^2>0.2$ (minimize background)
Normalization sample selected with $|M_{\gamma\gamma}-M_{\pi 0}|<10$ MeV/c^2

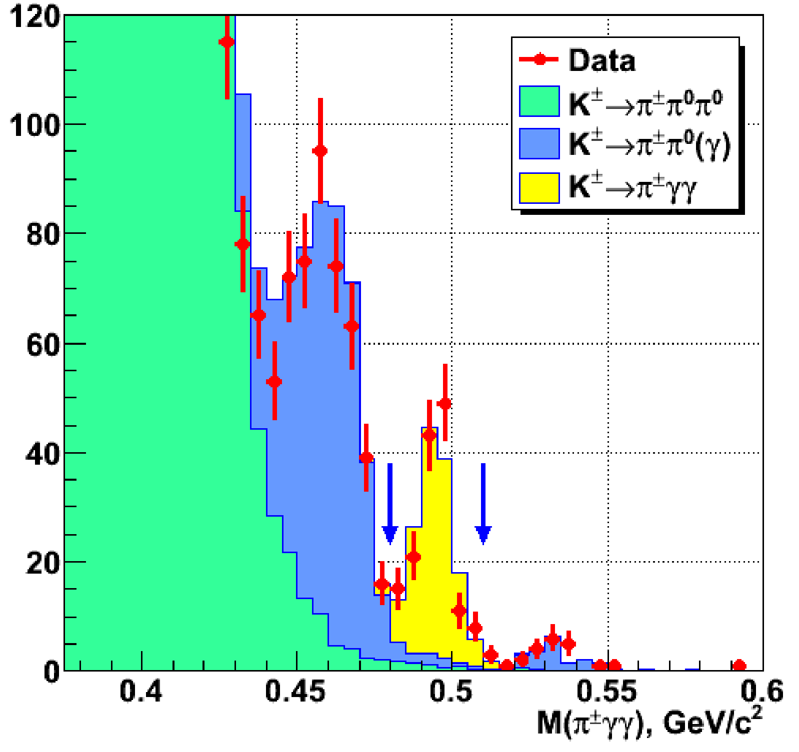
Data set	2004	2007 (Pb)	2007 (noPb)	Total
$N(K_{2\pi}$+BKG), 10^6	35.731	20.523	24.511	80.765
$N(K_{2\pi})$, 10^6	35.687	20.499	24.484	80.670
Acceptance ($K_{2\pi}$)	0.1943	0.1251	0.2489	0.1810
Kaon flux, 10^9	0.8996	0.8029	0.4820	2.1845
$N(K_{\pi\gamma\gamma})$	147	81	94	322
$K_{2\pi(\gamma)}$ background	11.0	5.6	5.6	22.1
$K_{3\pi}$ background	5.9	0.7	0.6	7.2
Acceptance ($K_{\pi\gamma\gamma}$) assuming $O(p^4)$, $\hat{c}=1.7$	0.1654	0.0970	0.1929	0.1463

Mass resolutions:
$\sigma_{\pi\gamma\gamma}$ = 5.9 MeV/c^2
$\sigma_{2\pi}$ = 3.9 MeV/c^2

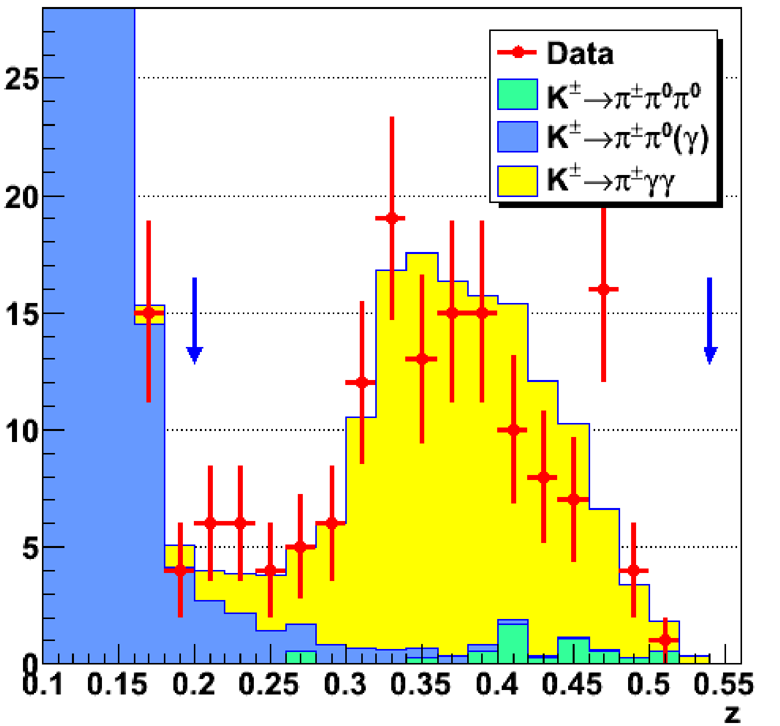
With and without the lead wall used to measure R_k background due to catastrophic muon bremsstrahlung

2004 data set

Mass spectrum



ChPT $O(p^6)$ fit



$K_{\pi\gamma\gamma}$ candidates	147
$K_{2\pi(\gamma)}$ background	11.0±0.8
$K_{3\pi}$ background	5.9±0.7
$K_{\pi\gamma\gamma}$ signal	130±12

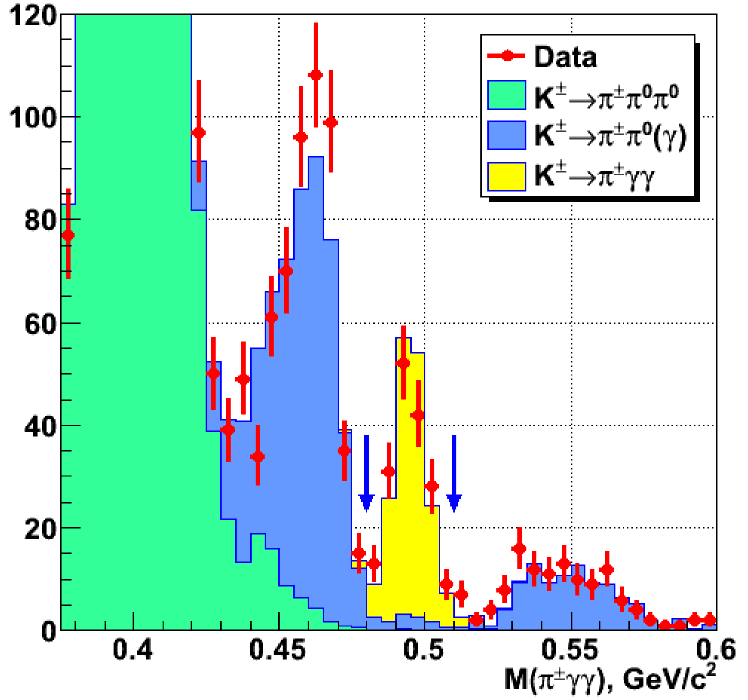
Fit results

$O(p^4)$ $\hat{c} = 1.36 \pm 0.33_{st} \pm 0.07_{sy} = 1.36 \pm 0.34$

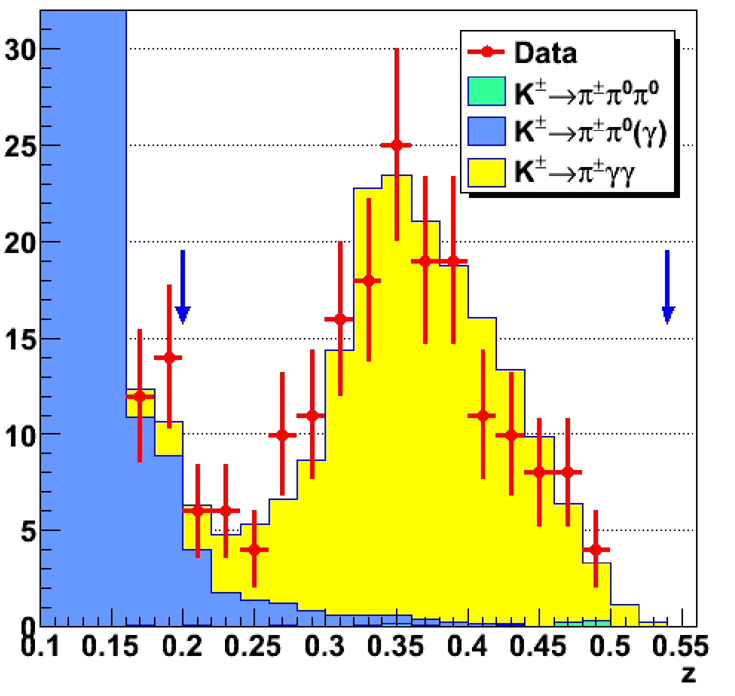
$O(p^6)$ $\hat{c} = 1.67 \pm 0.39_{st} \pm 0.09_{sy} = 1.67 \pm 0.40$

2007 data set

Mass spectrum



ChPT $O(p^6)$ fit



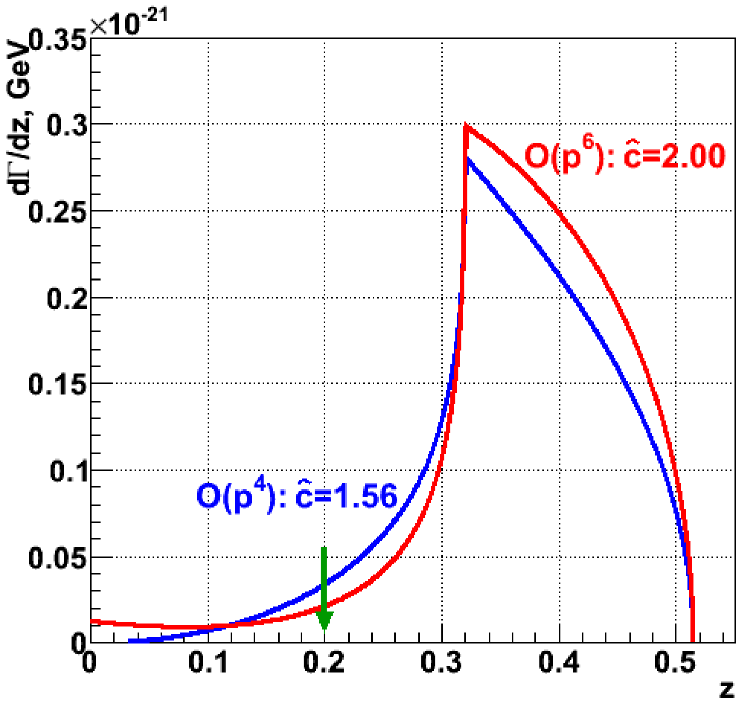
$K_{\pi\gamma\gamma}$ candidates	175
$K_{2\pi(\gamma)}$ background	11.1±1.0
$K_{3\pi}$ background	1.3±0.3
$K_{\pi\gamma\gamma}$ signal	163±13

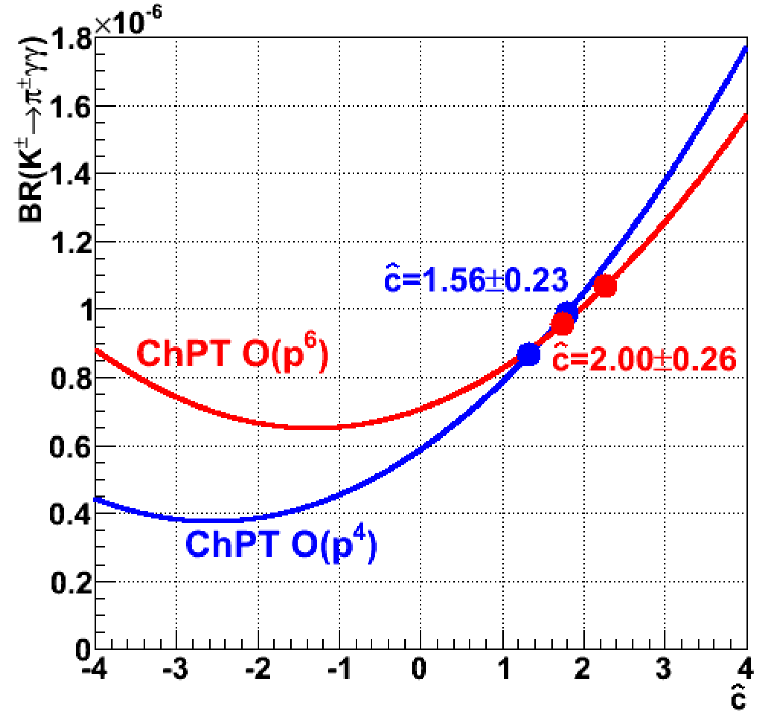
Fit results

$O(p^4)$ $\hat{c} = 1.71 \pm 0.29_{st} \pm 0.06_{sy} = 1.71 \pm 0.30$

$O(p^6)$ $\hat{c} = 2.21 \pm 0.31_{st} \pm 0.08_{sy} = 2.21 \pm 0.32$

Combined results





Visible region above the $K^\pm \to \pi^\pm\pi^0$ peak : z>0.2 or $M_{\gamma\gamma}$>221 MeV/c^2

Cusp-like behavior at $2m_\pi$ is clearly observed
ChPT $O(p^4)$ vs $O(p^6)$ models cannot be discriminated

Model dependent BR = $(1.01\pm0.06)*10^{-6}$
PDG: BR = $(1.10\pm0.32)*10^{-6}$

Combined fit results

$O(p^4)$ $\hat{c} = 1.56\pm0.22_{st}\pm0.07_{sy} = 1.56\pm0.23$

$O(p^6)$ $\hat{c} = 2.00\pm0.24_{st}\pm0.09_{sy} = 2.00\pm0.26$

$K^+ \rightarrow e^+\nu\gamma$

$K^+ \to e^+\nu\gamma$ - Motivations

- SD+ component
  - Receives electro-weak and hadronic contributions
  - Sensitive to kaon structure
  - Differential decay rate expressed in terms of V and A form factors

$$\frac{d^2\Gamma(K^+ \to e^+\nu\gamma, SD^+)}{dxdy} = \frac{G_F^2 \sin^2\theta_c M_K^5 \alpha}{64\pi^2}(V+A)^2(1-x)(x+y-1)^2$$

  - Prediction for form factors from ChPT and from specific models (LFQM, ChPT VMD and ChPT CQM)

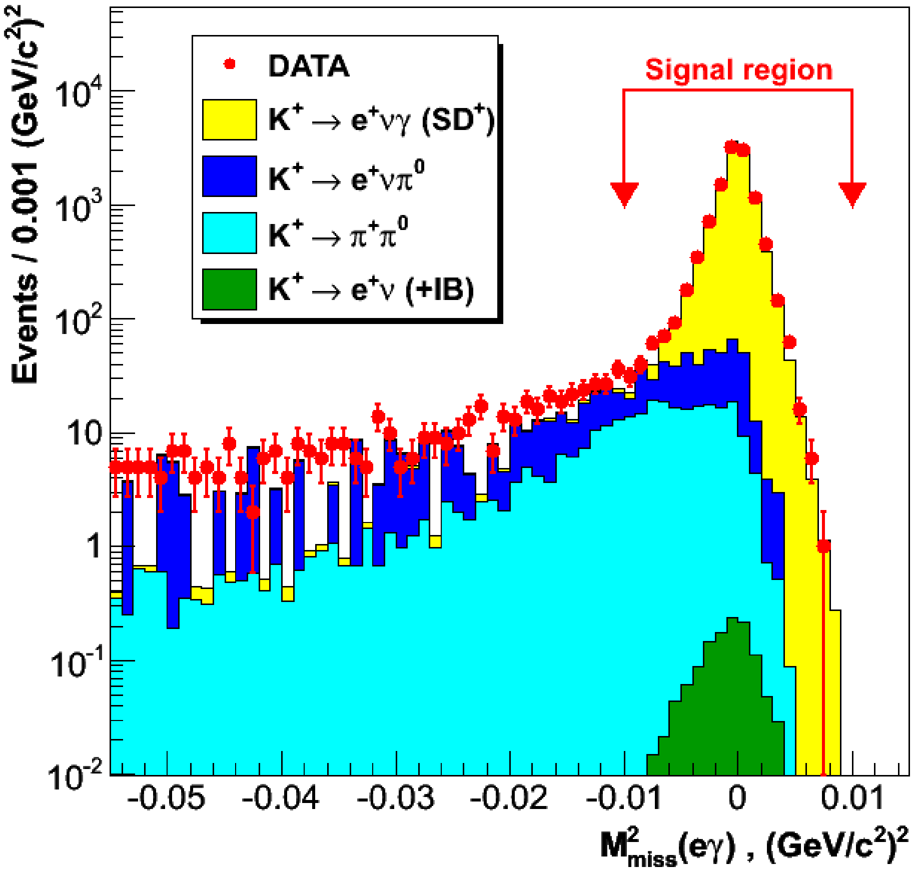
Experimental status

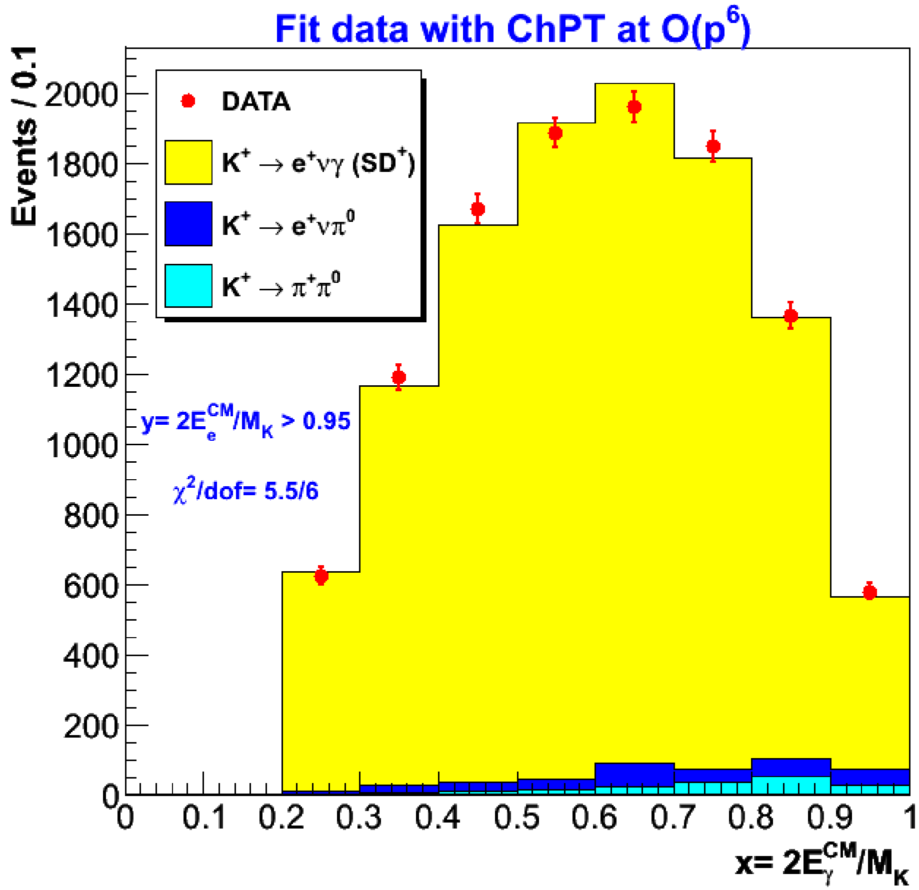
- From PDG 2010
  - $BR(K^+ \to e^+\nu\gamma) = (9.4\pm0.4)*10^{-6}$
    - From KLOE, 1484 events with 10 MeV<E^*_γ<250 MeV and p^*_e>200 MeV/c
- NA62 goals
  - Expect to have 10 times more events
    - Despite reduced kinematical region (50 MeV<E^*_γ<250 MeV, p^*_e>235 MeV/c) to reduce the background
  - Model independent extraction of form factors
  - Validate or not LFQM model
  - Measure ChPT parameters with unprecedented precision

Data sample

- Results presented with 40% of the statistics
  - ~ 10000 events
  - 7% acceptance
  - $K^+ \rightarrow \pi^0 e^+ \nu$ as normalization mode
  - Background contamination: ~5%
  - Expected systematics dominated by the background subtraction

Preliminary results



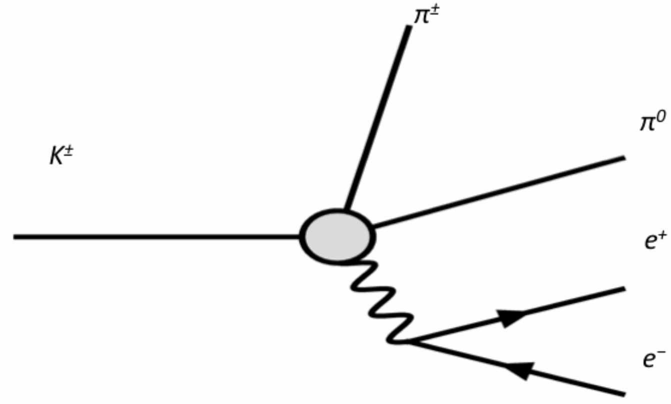


Preliminary result with the richer K^+ sample
The final analysis will also include the K^- sample

$K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$

Physics motivations

- NA48/2 has studied $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ (10^6 decays)
  - Eur.Phys.J. C68 (2010) 75
- Look at internal conversions $\gamma \to e+e-$
- Dependence on electric and magnetic form factors
- The decay has a large sensitivity to CP violation and new physics
- Never observed



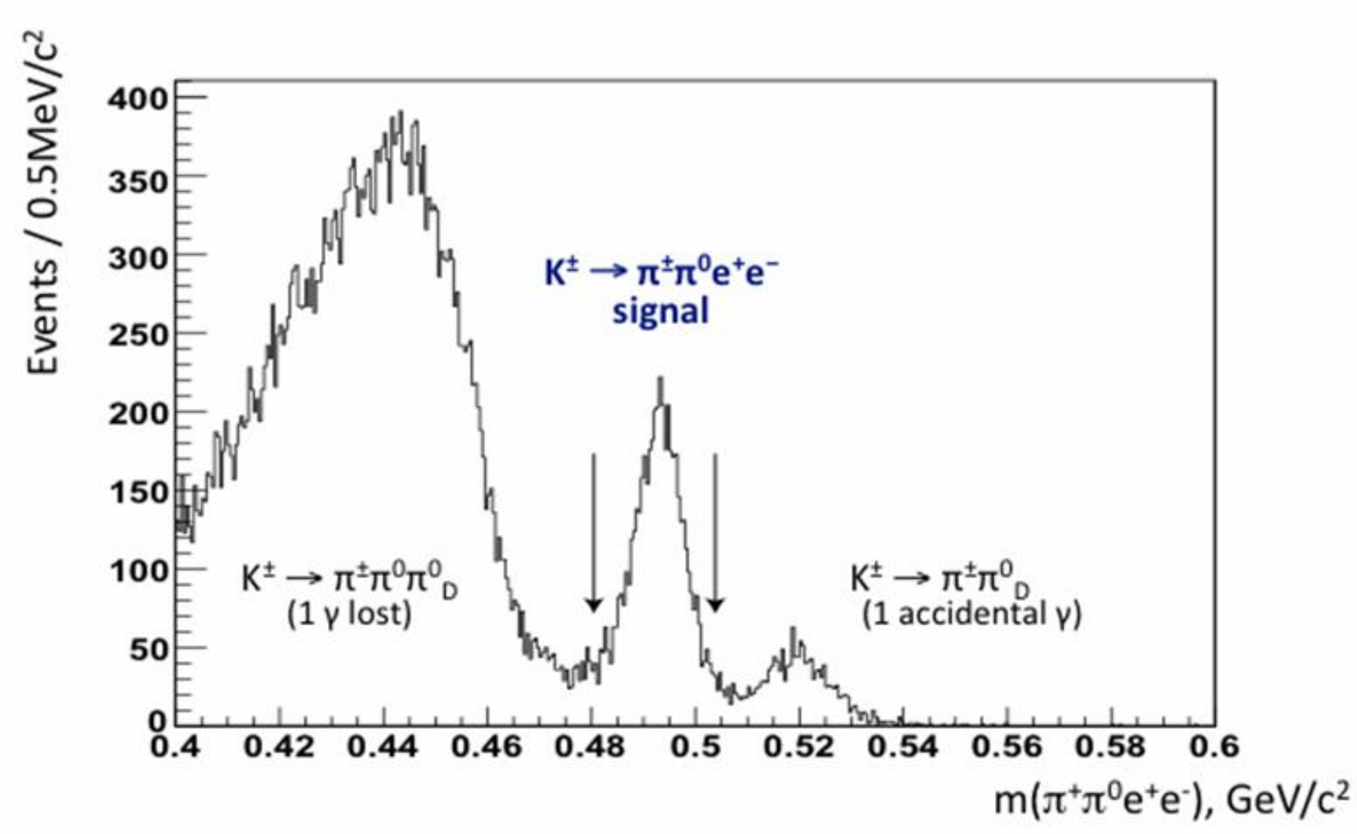
Cappiello, Cata', D'Ambrosio, Gao, arXiv:1112.5184 [hep-ph] (2011)

Preliminary results

All NA48/2 data - Detailed analysis in progress

First observation

~4500 events



Conclusions

- NA48/2 and NA62 rare decays analysis continues

- $K^{\pm} \rightarrow \pi^{\pm}\gamma\gamma$ results with combined 2004 and 2007 data
  - Anyway no discrimination between $O(p^4)$ and $O(p^6)$
- Preliminary results for the decay $K^{+} \rightarrow e^{+}\nu\gamma$
- First observation of the decay $K^{\pm} \rightarrow \pi^{\pm}\pi^{0}e^{+}e^{-}$

- The collaboration is preparing the new detector for the measurement of $K^{\pm} \rightarrow \pi^{\pm}\nu\nu$
  - High beam intensity will allow collection of downscaled events to continue the studies on rare kaon decays