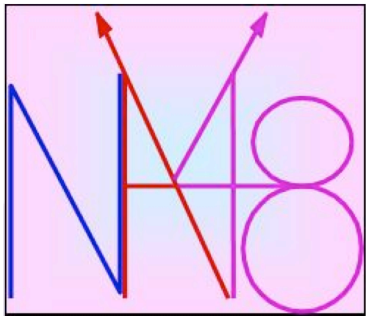
Moriond QCD 2013 – La Thuile, Italy – 11 March 2012

# Study of the rare decay $K^{+-} \rightarrow \pi^{+-}\gamma\gamma$



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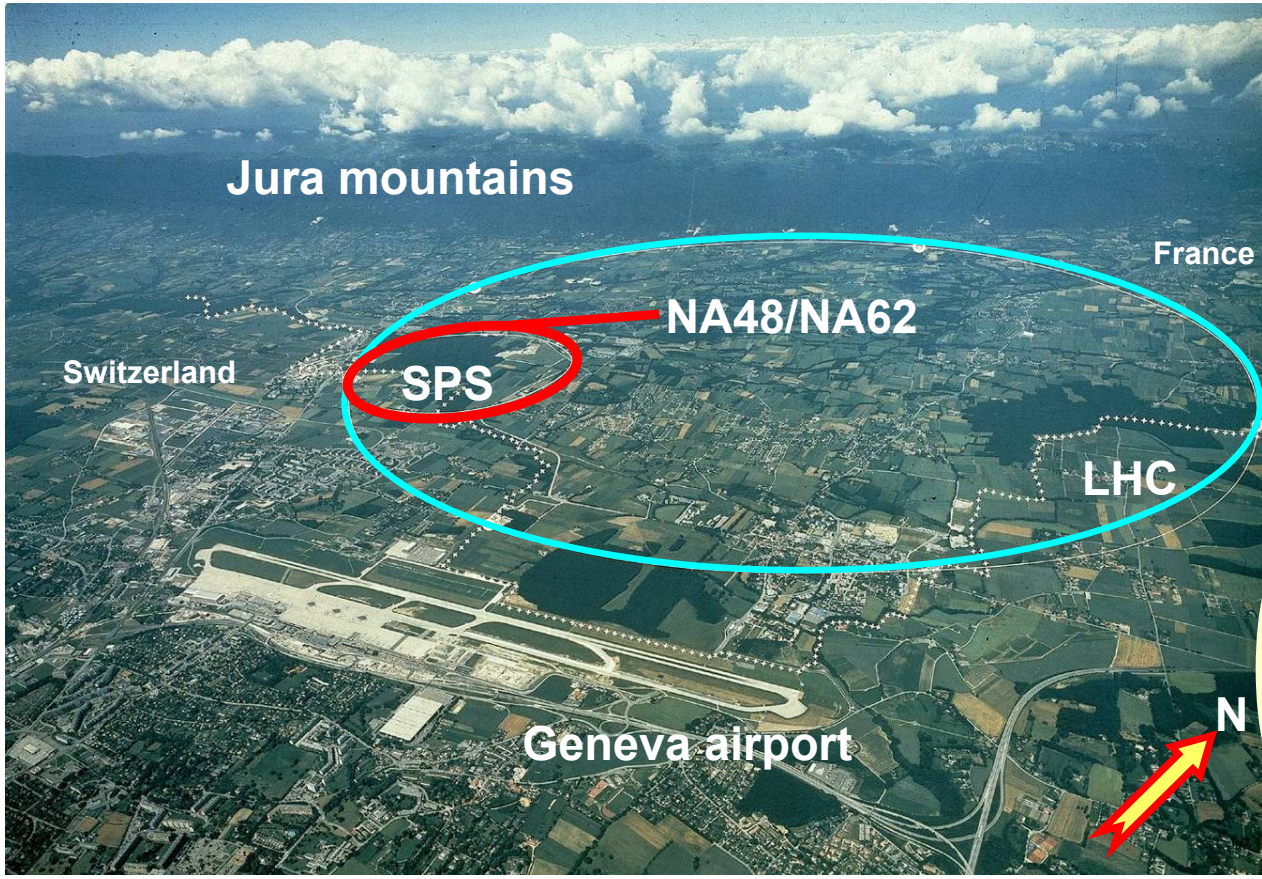
on behalf of the NA48 and NA62 collaborations

# Outline:

- The NA48 experiment
  - Location and beam line
  - The detector
- The $K^{+-} \rightarrow \pi^{+-}\gamma\gamma$ decay
  - Theoretical framework and motivations
  - Data from 2004 and 2007 runs
  - Preliminary results
- Summary and outlook (NA62)

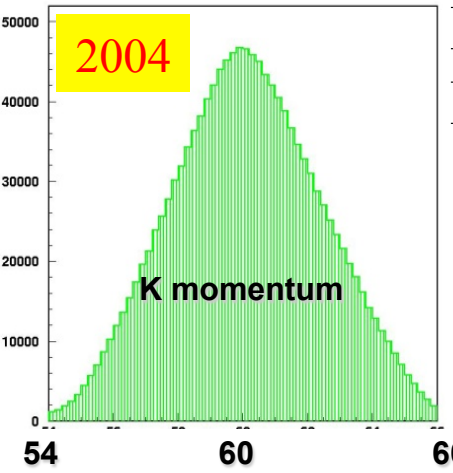
# NA48 and NA62

| | | |
|---|---|---|
| 1997: $K_L+K_S$ | | NA48 Discovery of direct CPV |
| 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 | |
| 2002: $K_S$/Hyperons | | NA48/1 |
| 2003: $K^+ + K^-$ | | NA48/2 |
| 2004: $K^+ + K^-$ | | |
| 2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests | NA62 $R_K$ phase |
| 2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$ | tests | |
| 2007-2013: Design & construction<br>2014-2016: Data Taking | | NA62 golden $K^+ \to \pi\nu\bar{\nu}$ |




**NA62:** Birmingham, Bristol, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Naples, Perugia, Pisa, Rome I, Rome II, Saclay, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin

# The NA48 experiment




$K^+$ and $K^-$ superimposed in space

Flux ratio: $K^+/K^- \sim 1.8$

**Kaon momentum:**

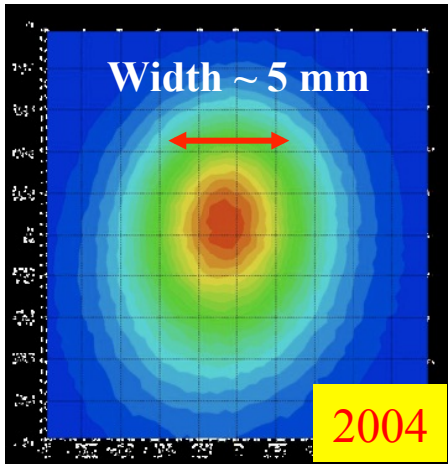
**60±3 GeV/c (2004)**

**74±1 GeV/c (2007)**

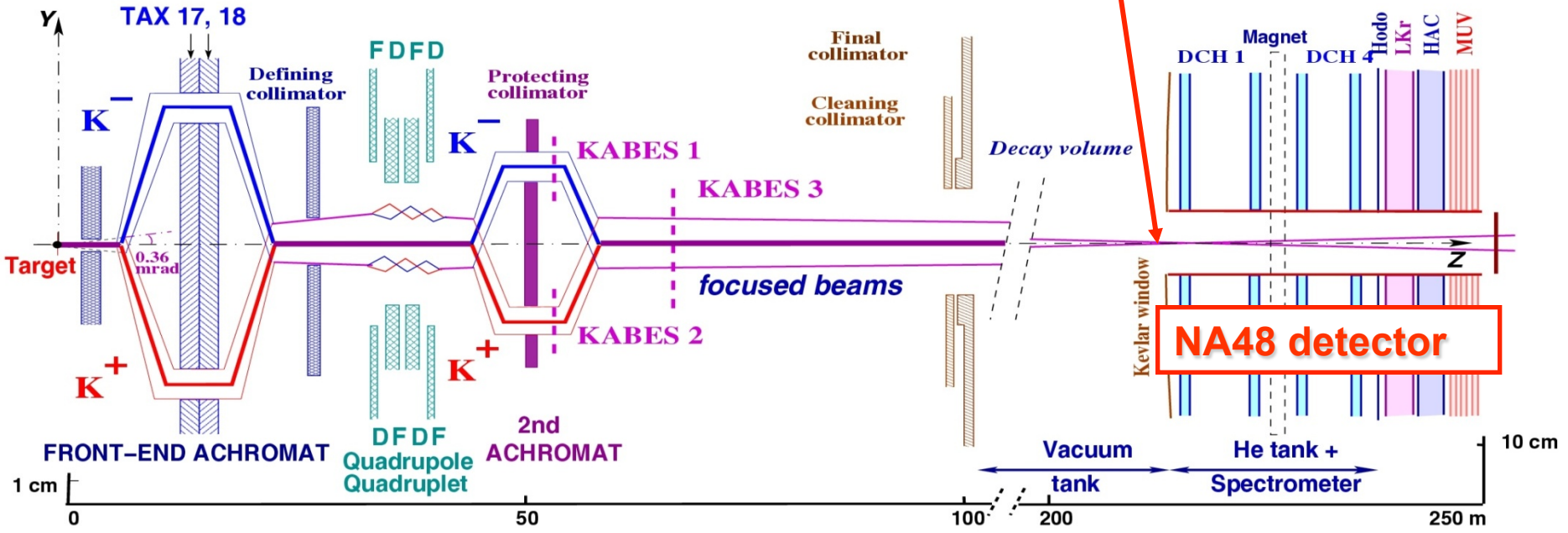
**Data taking:**

2004 – 3 days

2007 – 90 days




Beams **coincide within 1 mm**



# The NA48 Detector

Magnetic spectrometer (4 DCHs):

4 views: redundancy ⇒ efficiency

2004: $\sigma(p)/p = 1.0\% + 0.044\%p$ [GeV/$c$]

2007: $\sigma(p)/p = 0.47\% + 0.020\%p$ [GeV/$c$]

Charged hodoscope (scintillators):

Fast trigger and precise time measurement (~200 ps on single track)

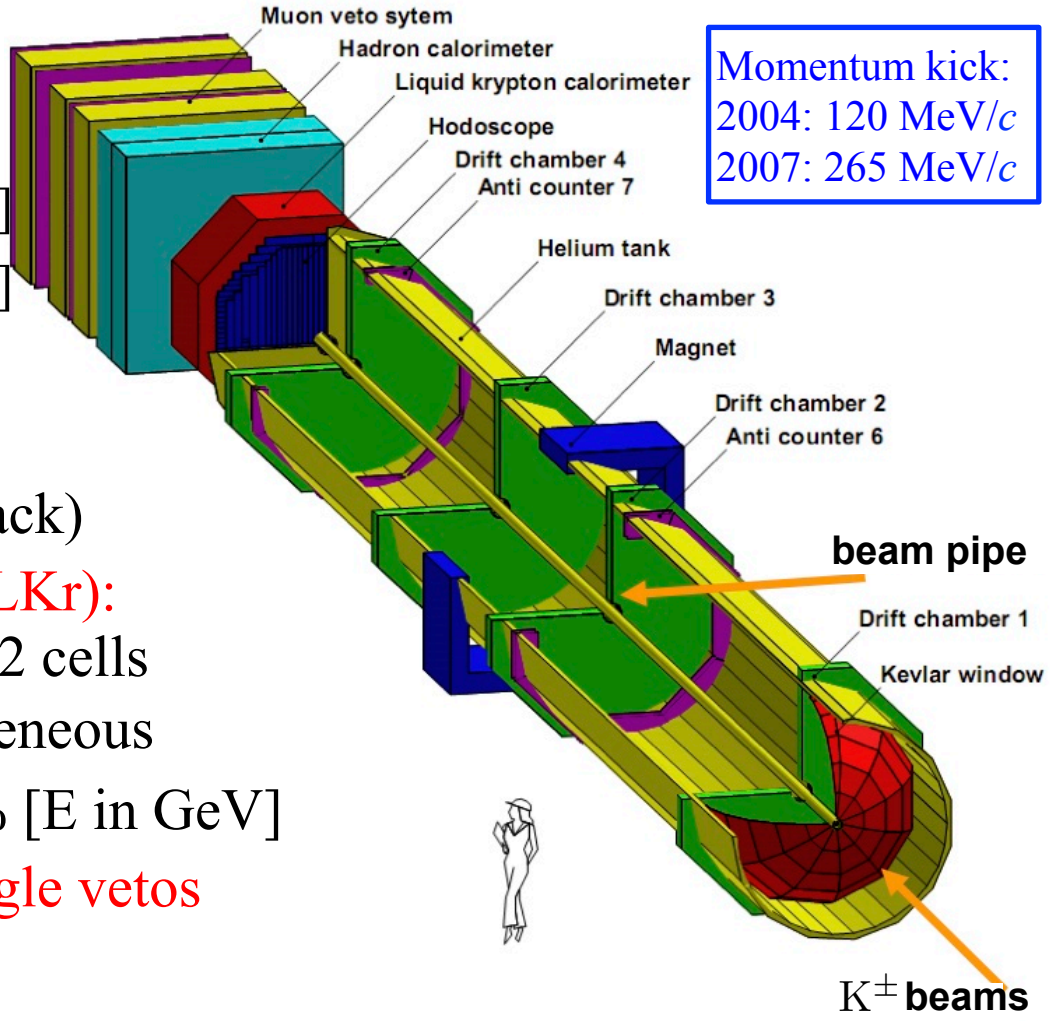
Liquid Krypton E.M. Calorimeter (LKr):

10 $m^3$ (~22 t), 1.25 m (27 $X_0$), 13212 cells

granularity: 2x2 $cm^2$, quasi-homogeneous

$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

Then hadronic calorimeter, large angle vetos and muon counter (scintillators)




Momentum kick:
2004: 120 MeV/$c$
2007: 265 MeV/$c$

**Trigger:**

***L1:*** Hodoscope, DCH multiplicity, $E_{LKr}$, LKr projections

***L2:*** ON-line processing of DCH information

# $K^{+-} \to \pi^{+-}\gamma\gamma$: introduction

**ChPT description:**

Rate and spectrum depend on a single unknown O(1) parameter ĉ.

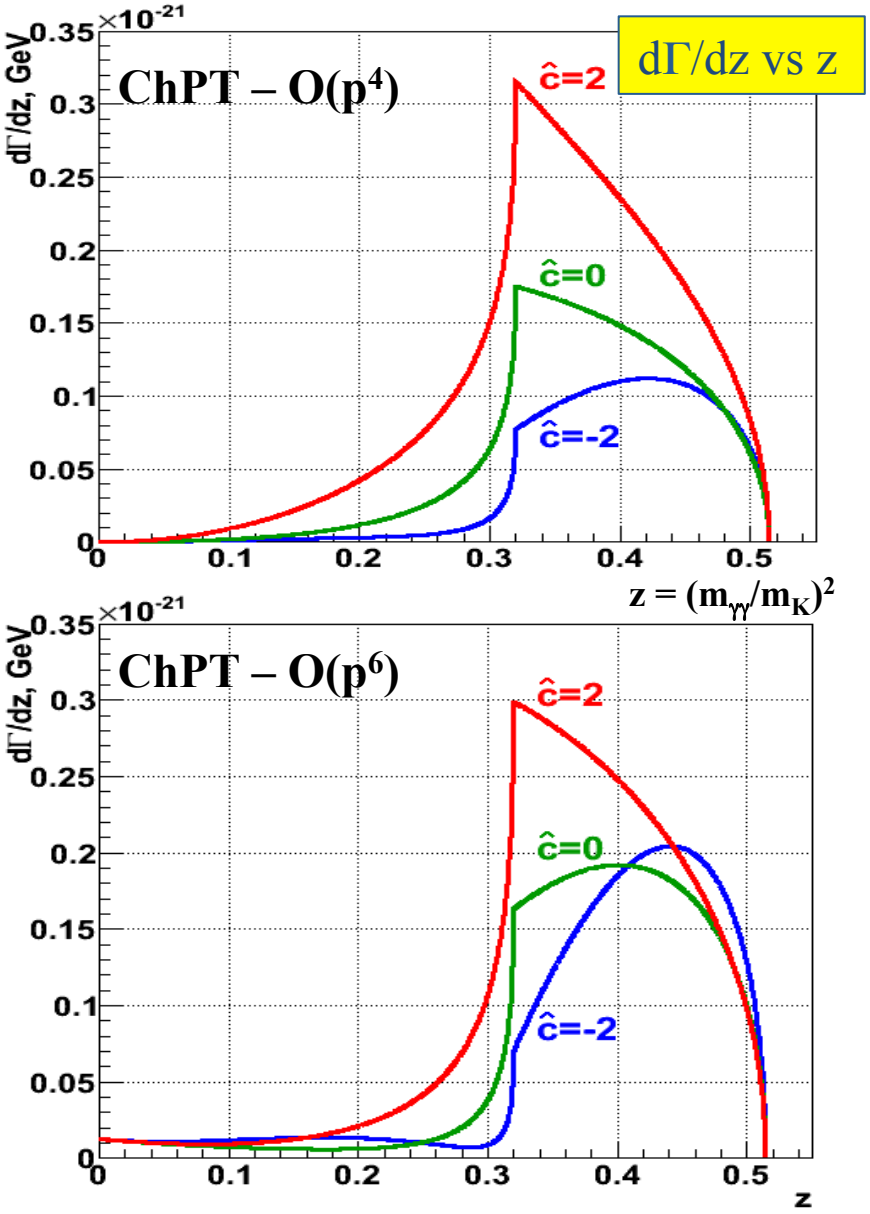
Leading contribution at $O(p^4)$ loop:

**cusp at 2π threshold**

[Ecker, Pich, de Rafael, NPB303 (1988) 665]

$O(p^6)$ "unitary corrections" increase BR at low ĉ and result in a non-zero rate at $m_{\gamma\gamma} \to 0$.

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




**Experimental status:**

- BNL E787: 31 candidates, BR=(1.10±0.32)×10⁻⁶. $O(p^6)$ full kinematic range [PRL79 (1997) 4079]
- NA48/2 (2003-2004): in the main data set measurement hindered by low trigger efficiency
- New strategy: minimum bias trigger samples from NA48/2 and NA62.

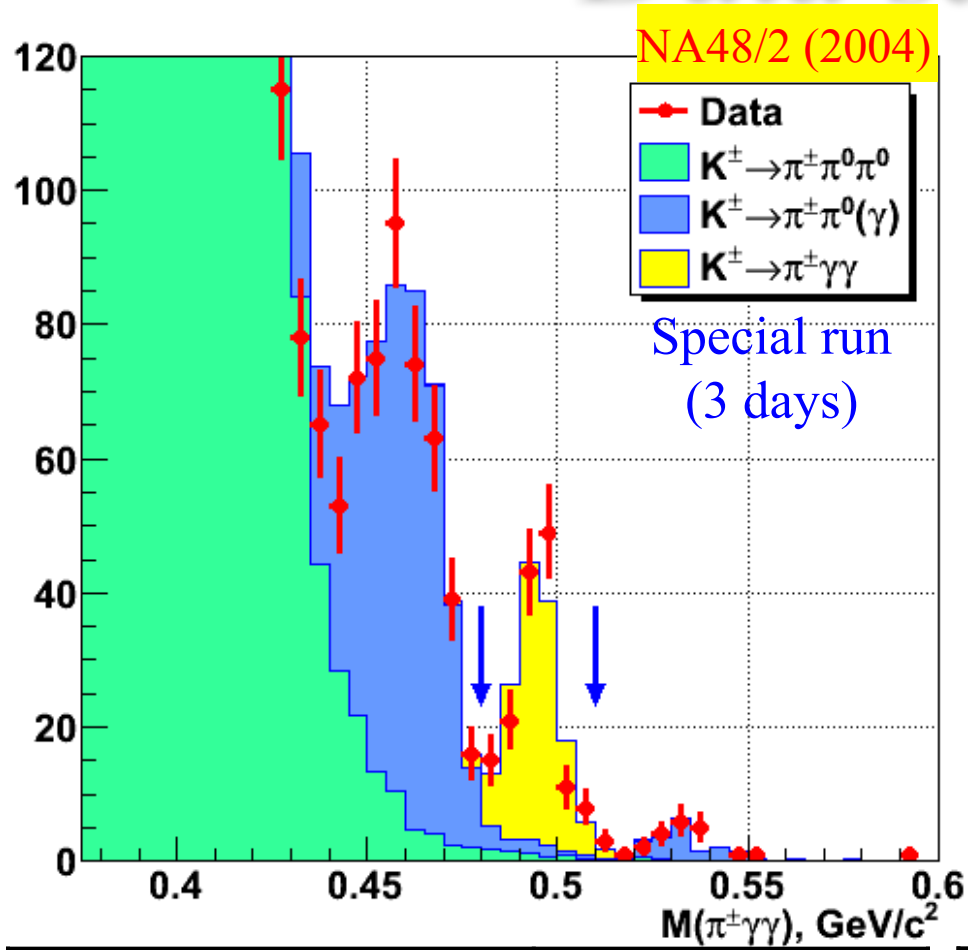
# Selection

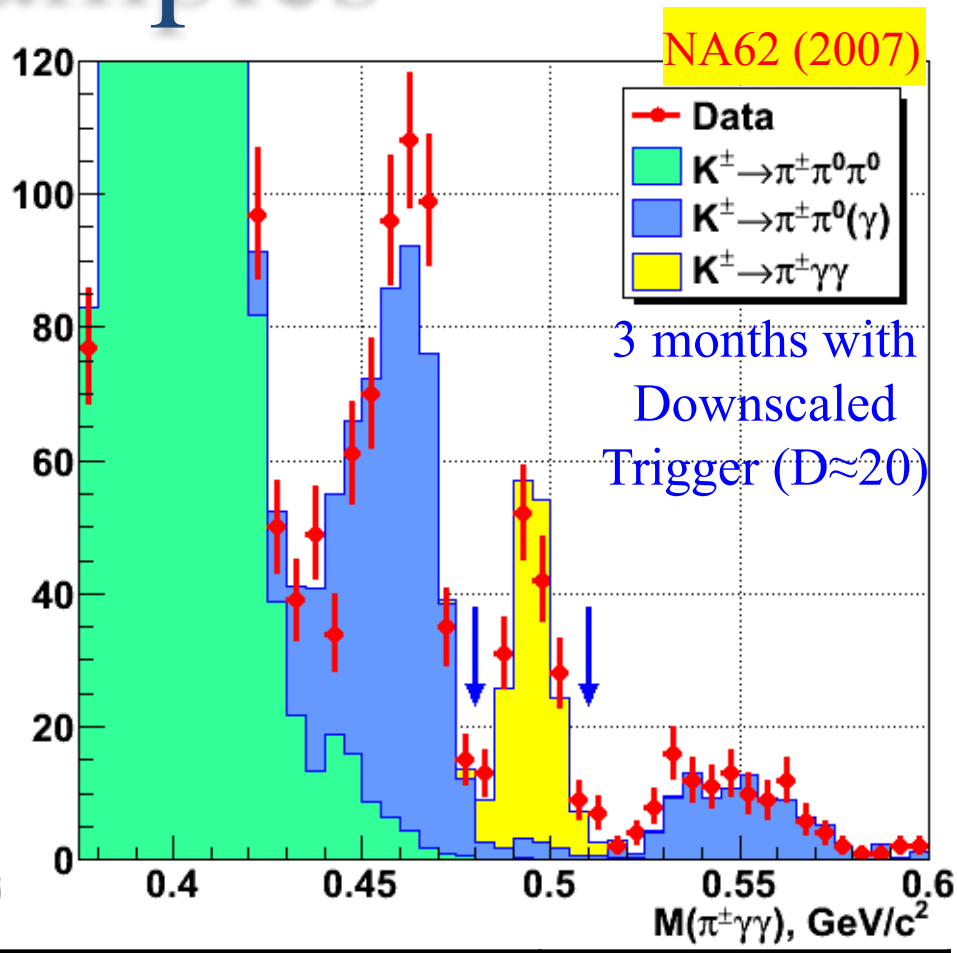
- One and only one reconstructed track in the acceptance of the main detectors
- z of the decay inside the fiducial decay volume (62 m region)

Vertex defined by the Closest Distant of Approach (CDA) between the tracked pion and the nominal $K^{\pm}$ beam directions

- Reconstructed track momentum: 10 (8) < p < 40 (50) GeV/*c* for the NA48/2 (NA62) data
- E/p<0.85 E: energy deposited by the track in the LKr
  p: track momentum measured by the spectrometer
- Two independent clusters in the LKr with E > 3 GeV
- Both clusters in time with the reconstructed track
- The reconstructed $\pi^{\pm}\gamma\gamma$ invariant mass should be in the range (0.48-0.51) GeV/$c^2$
  (15 MeV/$c^2$ from $K^{\pm}$ mass)
- $0.2 < z = (m_{\gamma\gamma}/m_K)^2 < 0.54$ ($z = 0.075$ for $\pi^{\pm}\pi^0$ decays)

# Data samples

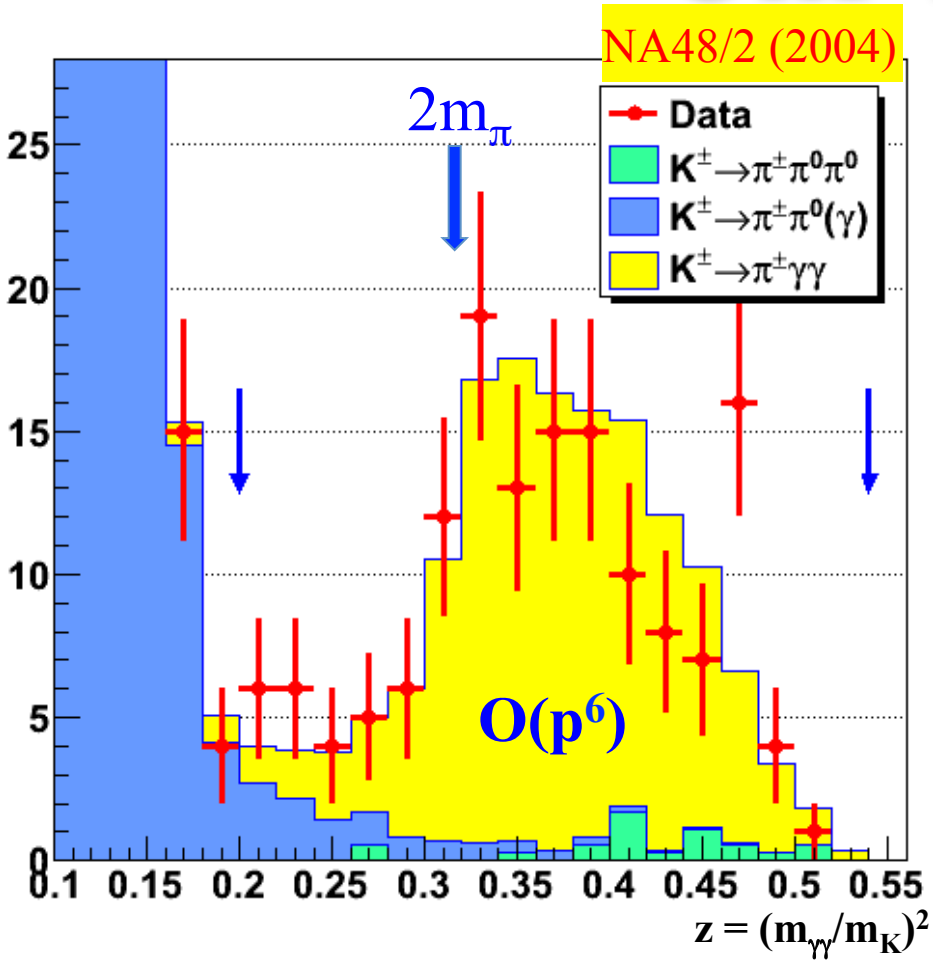


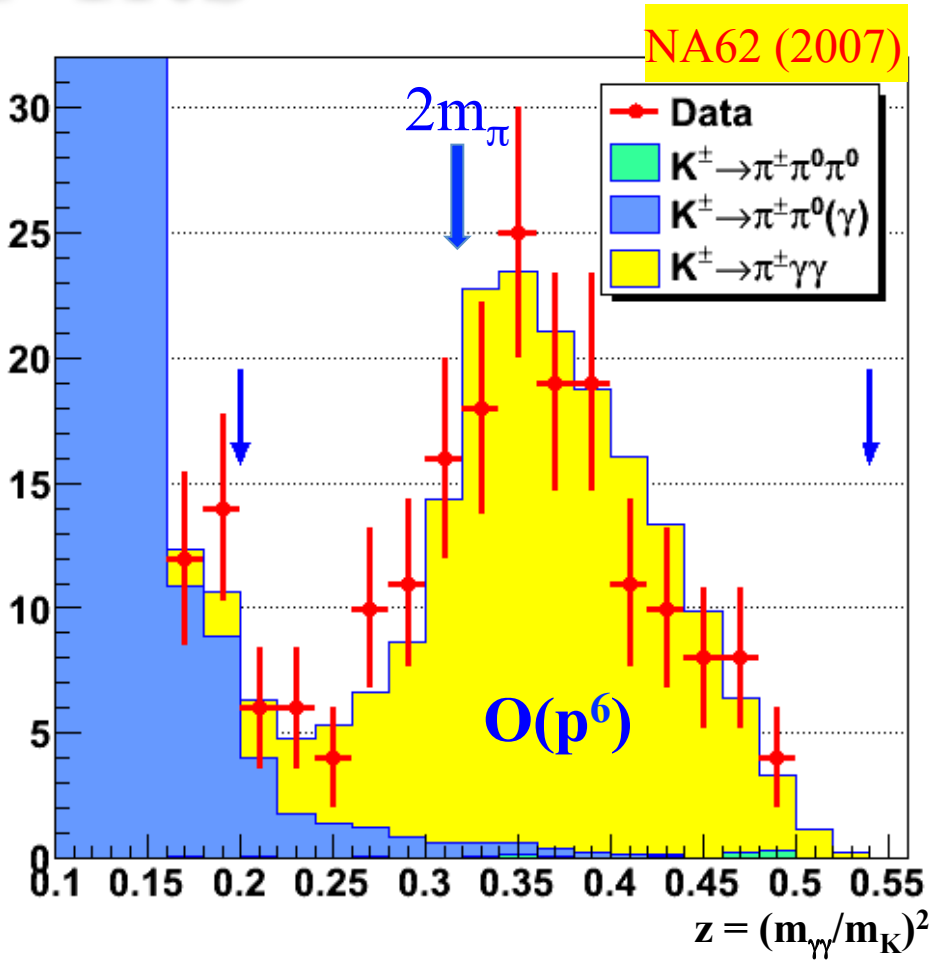




| | |
|---|---|
| $K_{\pi\gamma\gamma}$ candidates | 147 |
| $K_{2\pi(\gamma)}$ background | 11.0 ± 0.8 |
| $K_{3\pi}$ background | 5.9 ± 0.7 |
| $K_{\pi\gamma\gamma}$ signal | 130 ± 12 |

| | |
|---|---|
| $K_{\pi\gamma\gamma}$ 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 |

# ChPT fits




→Visible region is above the $K^\pm \to \pi^\pm\pi^0$ peak: $z > 0.2$, or $m_{\gamma\gamma} > 220$ MeV/c$^2$

→Cusp-like behaviour at $z = (2m_\pi/m_K)^2$ is clearly observed.

# Fit results (1)

**PRELIMINARY** **NA48/2 (2004)**

ChPT $O(p^4)$:

$\hat{c} = 1.36 \pm 0.33_{stat} \pm 0.07_{syst} = 1.36 \pm 0.34$

ChPT $O(p^6)$:

$\hat{c} = 1.67 \pm 0.39_{stat} \pm 0.09_{syst} = 1.67 \pm 0.40$

**PRELIMINARY** **NA62 (2007)**

ChPT $O(p^4)$:

$\hat{c} = 1.71 \pm 0.29_{stat} \pm 0.06_{syst} = 1.71 \pm 0.30$

ChPT $O(p^6)$:

$\hat{c} = 2.21 \pm 0.31_{stat} \pm 0.08_{syst} = 2.21 \pm 0.32$

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

**COMBINED** (correlated uncertainties)

ChPT $O(p^4)$:

$\hat{c} = 1.56 \pm 0.22_{stat} \pm 0.07_{syst} = 1.56 \pm 0.23$

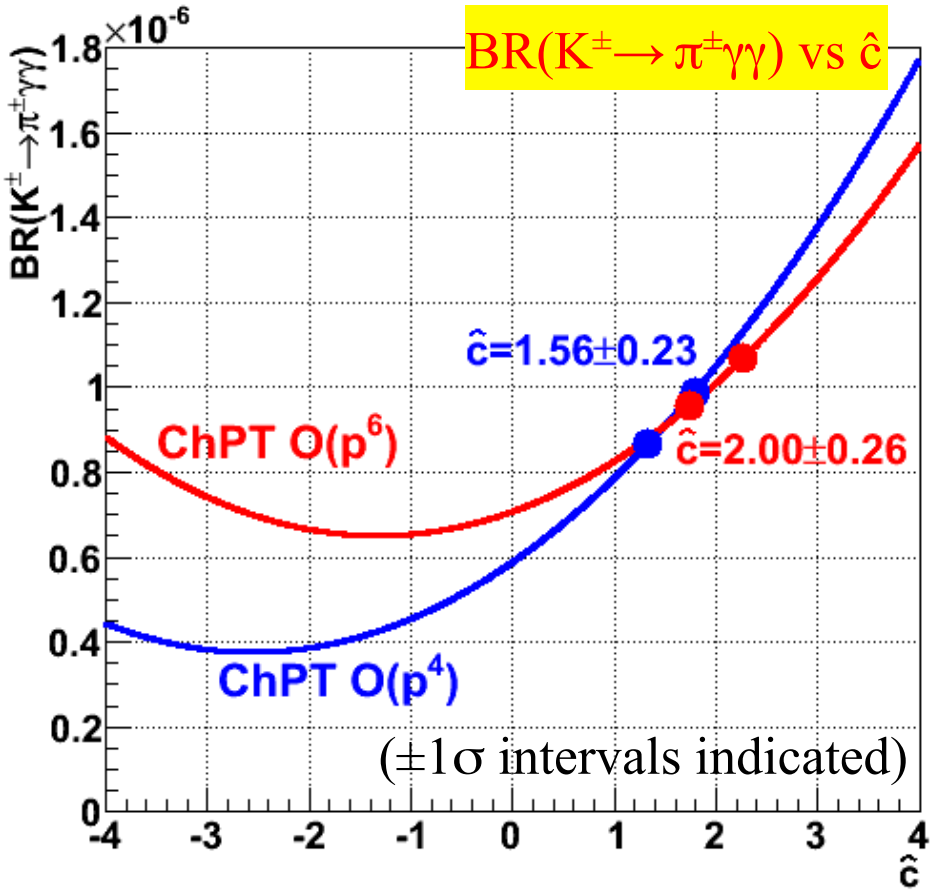
ChPT $O(p^6)$:

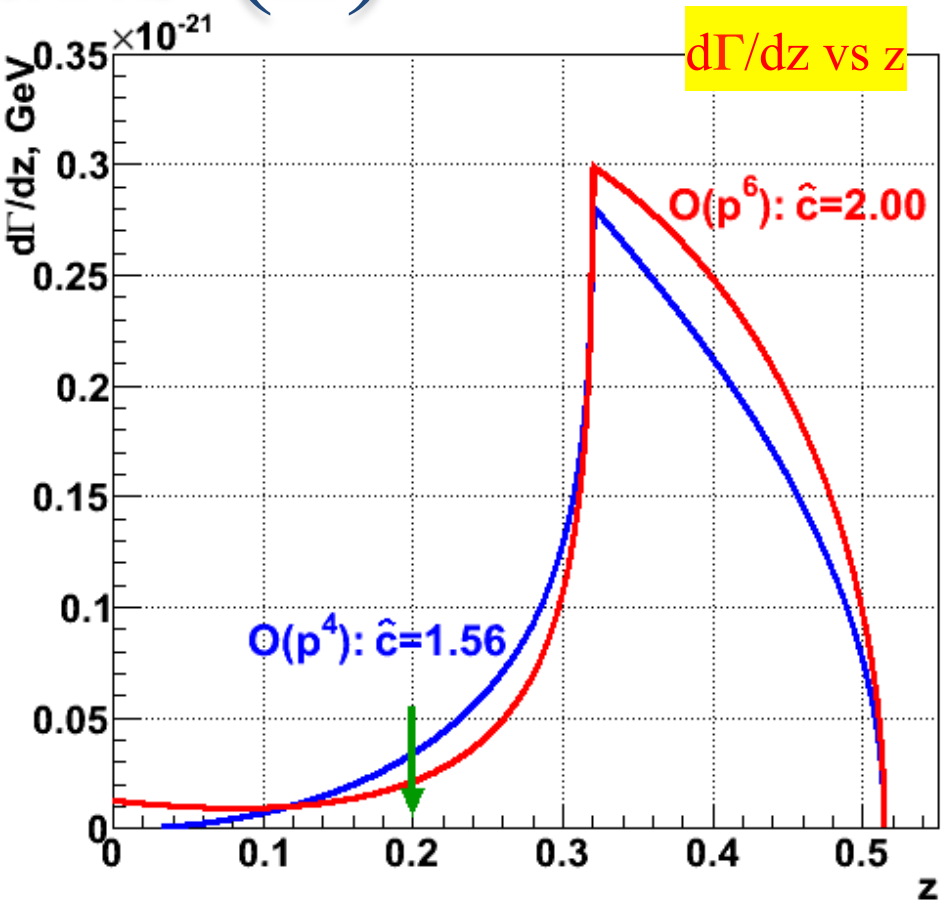
$\hat{c} = 2.00 \pm 0.24_{stat} \pm 0.09_{syst} = 2.00 \pm 0.26$

BR (model dependent): $(1.01 \pm 0.06) \times 10^{-6}$

From PDG: BR = $(1.10 \pm 0.32) \times 10^{-6}$ [PRL79 (1997) 4079]

# Fit results (2)




- Total number of candidates (NA48/2 and NA62): 322
- Background contamination: (9±1)% due to $K^{\pm}\to\pi^{\pm}\pi^0(\gamma)$ and $K^{\pm}\to\pi^{\pm}\pi^0\pi^0$ with
- Very low systematic uncertainties
- ChPT $O(p^4)$ vs $O(p^6)$ models cannot be discriminated

# Summary and outlook

New measurement of the $K^{\pm} \to \pi^{\pm}\gamma\gamma$ decay with minimum bias trigger data from NA48/2 (2004) and NA62 (2007) has been presented:

- New precise experimental data on ChPT parameter $\hat{c}$
- ChPT $O(p^4)$ vs $O(p^6)$ models cannot be discriminated

What's coming next?

Foreseen to start the data taking for the second phase of NA62 in 2014 to measure the Branching Ratio of the very rare decay $K^+ \to \pi^+\nu\bar{\nu}$

- $5\times10^{12}$ $K^+$ decays/year → record SES of $\sim10^{-12}$ on charged kaon decays
- $K^{\pm} \to \pi^{\pm}\gamma\gamma$ (and many other decays…) will be killed by the main trigger, but extra-triggers can be added and special runs could be scheduled
- Good opportunity for new studies, suggestions are welcome!