Study of the rare decay $K^{\pm} \longrightarrow \pi^{\pm}\gamma\gamma$

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on behalf of the NA48 and NA62 collaboration

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Outline

- NA48/NA62 experiments at CERN
- $K^{\pm} \to \pi^{\pm}\gamma\gamma$
- Conclusion

NA48/NA62 experiments at CERN

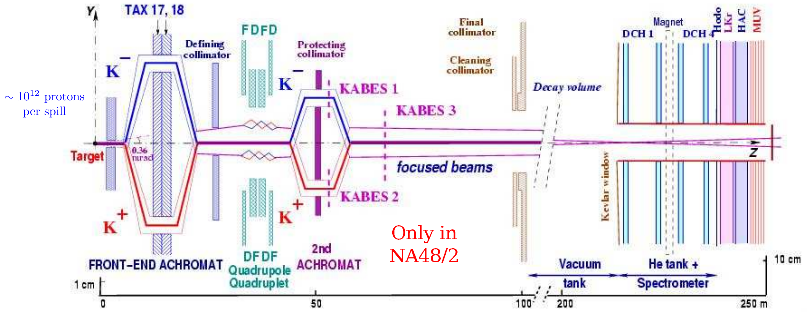
Ancestor: NA31

NA48	1997 ε'/ε run $K_L + K_S$
	1998 ε'/ε run $K_L + K_S$
	1999 ε'/ε run $K_L + K_S$; K_S Hi. Int.
	2000 K_L only; K_S High Intensity; *NO Spectrometer*
	2001 ε'/ε run $K_L + K_S$; K_S High Int.
NA48/1	2002 K_S High Intensity
NA48/2	2003 $K^{\pm}$ High Intensity
	2004 $K^{\pm}$ High Intensity
NA62 R_K	2007/08: $K^+_{e2}/K^+_{\mu 2}$ runs
NA62	2007–2012: R&D
	2014: Start $K^+ \to \pi^+ \nu\bar{\nu}$

NA48/2 collaboration: Cambridge, CERN, Chicago, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Vienna

NA62 collaboration: Birmingham, Bratislava, Bristol, CERN, Dubna, Fairfax, Ferrara, Firenze, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Napoli, Perugia, Pisa, Prague, Roma I, Roma II, San Luis Potosí, Stanford, Sofia, Torino

NA48/2 & NA62 Beam line



NA48/2 K^+/K^- simultaneous beams

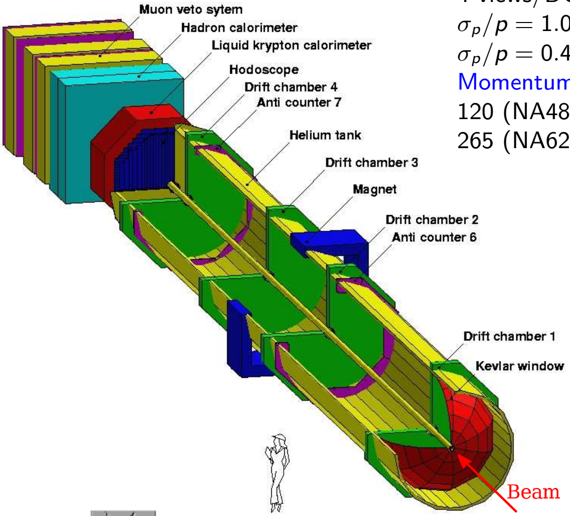
$P_K = (60 \pm 3)$ GeV/c

NA62 K^+/K^- both simultaneous beams and single beams (mostly K^+ beam, optimized for R_k measurement)

$P_K = (74 \pm 1.4)$ GeV/c

Decay volume: 114 m long

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



Principal subdetectors:

Magnetic spectrometer (p in Gev/c):

4 views/DCH;

$\sigma_p/p = 1.02\% \oplus 0.044\% \times p$ (NA48/2);

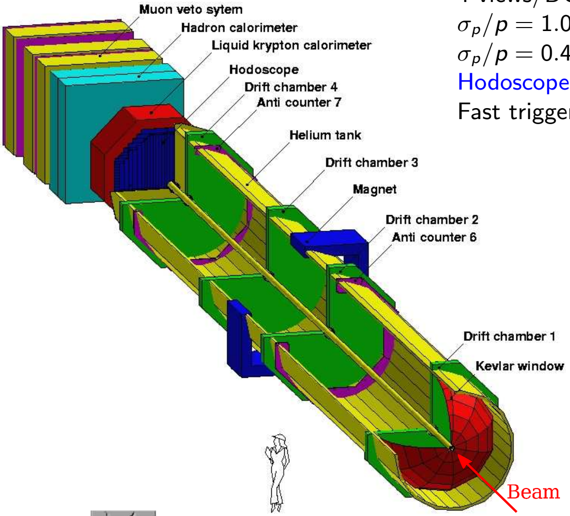
$\sigma_p/p = 0.48\% \oplus 0.009\% \times p$ (NA62);

Momentum kick (Mev/c):

120 (NA48/2);

265 (NA62);

NA48/2 & NA62 detectors: Hodoscope



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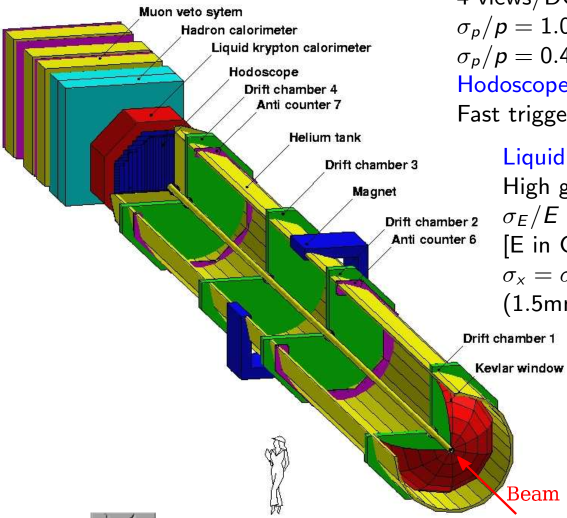
Hodoscope:

Fast trigger, $\sigma_t = 150$ps;



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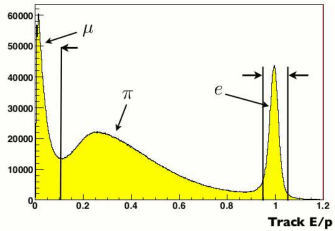
Liquid Krypton EM calorimeter:

High granularity, quasi-homogeneous;

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

$\sigma_x = \sigma_y = 4.2\text{mm}/\sqrt{E} \oplus 0.6\text{mm}$ (1.5mm@10GeV)



Theory: Chiral perturbation description (1)

In chiral perturbation theory the double differential rate in $K \longrightarrow \pi\gamma\gamma$ decays is

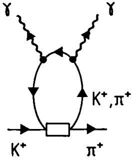
$$\frac{\partial^2\Gamma}{\partial y \partial z} = \frac{M_K}{2^9\pi^3}\left\{ z^2\left(|A+B|^2+|C|^2\right) + \left[y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z)\right]^2\left(|B|^2+|D|^2\right)\right\}$$

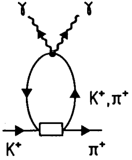
with no tree-level contributions of $O(p^2)$.

$$z = \frac{(P_{\gamma_1}+P_{\gamma_2})^2}{m_K^2} = \left(\frac{m_{\gamma\gamma}}{m_K}\right)^2 \qquad y = \frac{P_K\left(P_{\gamma_1}-P_{\gamma_2}\right)}{m_K^2}$$

$$\lambda(a,b,c) = a^2+b^2+c^2-2(ab+bc+ca) \qquad r_\pi = \frac{m_\pi}{m_K}$$

A, B, C and D are invariant amplitudes functions of z and y.
Rate and spectrum depend on a single unknown $O(1)$ parameter $\hat{c}$.





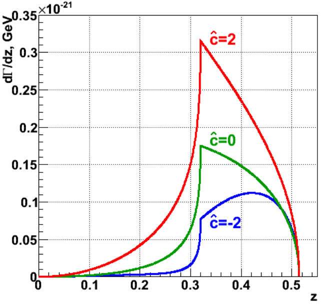
Theory: Chiral perturbation description (2)

- Rate and spectrum depend on a single unknown $O(1)$ parameter $\hat{c}$.
- Cusp at $\pi^+\pi^-$ threshold $m_{\gamma\gamma} = 2m_{\pi^\pm}$ ($z \sim 0.32$).

$O(p^4)$

B and *D* amplitudes are still zero

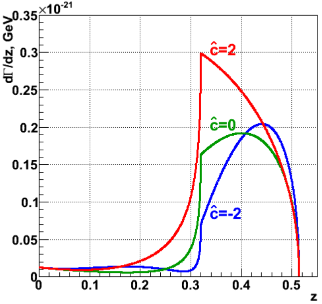
[Ecker, Pich, de Rafael NPB303(1988) 665]



$O(p^6)$

"Unitary corrections" increase BR at low $\hat{c}$ and result in a non-zero rate at $m_{\gamma\gamma} \to 0$.

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



E787 (BNL), 31 candidates with 5 background events
Fit the π^+ spectrum to extract $\hat{c}$

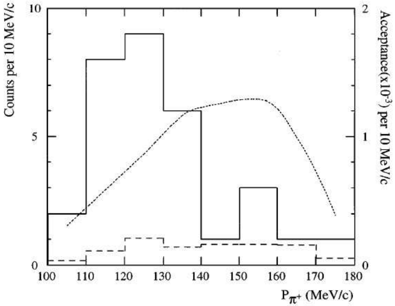


Figure: π^+ momentum distribution for 31 $K^+ \longrightarrow \pi^+\gamma\gamma$ candidates (solid) and for estimated background events (dashed). The acceptance is given by the dotted line.

$\hat{c} = (1.6 \pm 0.6)\ O(p^4)$
$\hat{c} = (1.8 \pm 0.6)\ O(p^6)$

$BR = (1.10 \pm 0.32) \times 10^{-6}$
($O(p^6)$ full kinematic range)

[PRL79 (1997) 4079]

Data samples

- Separate analysis of 2004 (NA48/2) and 2007 (NA62) run data
  - 2004: minimum bias trigger, 3 days data taking
  - 2007: minimum bias triggers downscaled and served as control triggers ($D \approx 20$, 3 months of data taking)
  - Comparable statistics for NA48/2 and NA62 data
  - Different acceptances, different beam momentum
- Combination of the two analyses
  - Accounting for correlated systematics

$K^{\pm} \longrightarrow \pi^{\pm}\gamma\gamma$ selection (1)

The $K^{\pm} \longrightarrow \pi^{\pm}\gamma\gamma$ ($K_{\pi\gamma\gamma}$) decay rate is measured with respect to the normalization decay chain ($K_{2\pi}$):

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

followed by the $\pi^{0} \longrightarrow \gamma\gamma$ decay

Signal and normalization contain the same set of particles in the final state: the principal selection criteria are common for the two modes

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No $K_{\pi\gamma\gamma}$ acceptance loss, but $K_{2\pi}$ acceptance reduced

Differences between the selection conditions for the NA48/2 and NA62 data due to the different central values of kaon momentum and momentum kick of the spectrometer magnet

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$\pi^{\pm}$ identification

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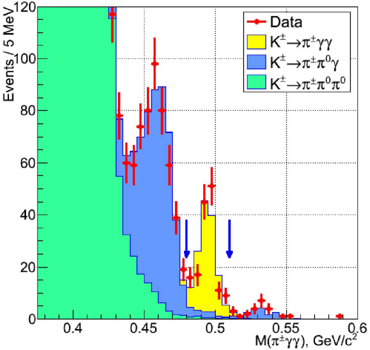
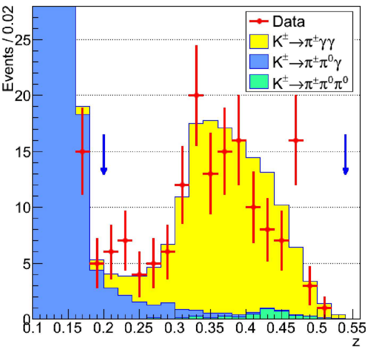
The $K_{\pi\gamma\gamma}$ and $K_{2\pi}$ selection conditions differ only in the di-photon invariant mass requirement.
For the $K_{\pi\gamma\gamma}$:
$0.2 < z = (m_{\gamma\gamma}/m_K)^2 < 0.54$ ($K^{\pm} \longrightarrow \pi^{\pm}\pi^0$ decays peak at z=0.075)

2004 data set - NA48/2



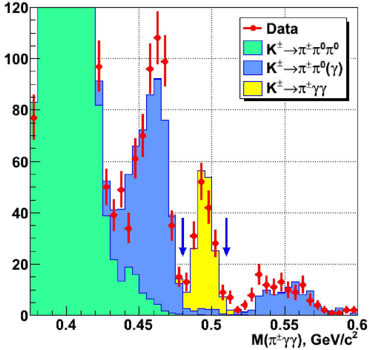


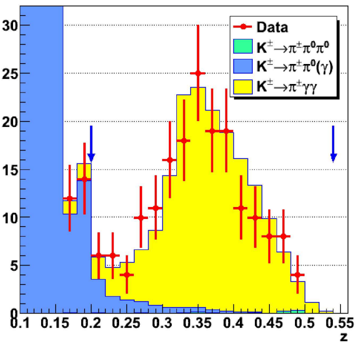
$K_{\pi\gamma\gamma}$ candidates	149
$K_{2\pi(\gamma)}$ background	11.4 ± 0.6
$K_{3\pi}$ background	4.1 ± 0.4
$K_{\pi\gamma\gamma}$ signal	134 ± 12

ChPT $O(p^4)$:
$\hat{c}=1.36\pm0.33_{stat}\pm0.07_{syst} = 1.36\pm0.34$

ChPT $O(p^6)$:
$\hat{c}=1.67\pm0.39_{stat}\pm0.09_{syst} = 1.67\pm0.40$

2007 data set - NA62



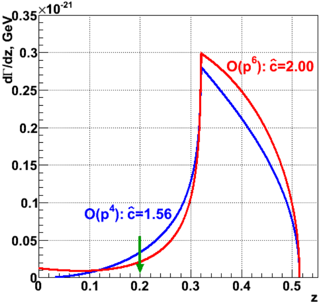


$K_{\pi\gamma\gamma}$ candidates	175
$K_{2\pi(\gamma)}$ background	11.1 ± 1.0
$K_{3\pi}$ background	1.3 ± 0.3
$K_{\pi\gamma\gamma}$ signal	163 ± 13

ChPT $O(p^4)$:
$\hat{c}=1.71\pm0.29_{stat}\pm0.06_{syst} = 1.71\pm0.30$

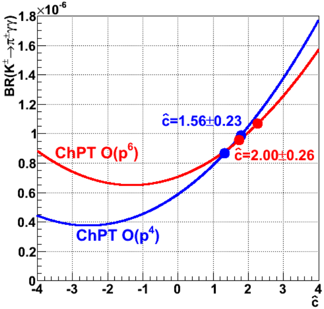
ChPT $O(p^6)$:
$\hat{c}=2.21\pm0.31_{stat}\pm0.08_{syst} = 2.21\pm0.32$

Combined results



- Visible region above the $K^+ \to \pi^+\pi^0$ peak: $z > 0.2$ ($m_{\gamma\gamma} > 221$ MeV/c^2)
- Indications of cusp-like behavior at $2m_\pi$
- ChPT $O(p^4)$ vs $O(p^6)$ models cannot be discriminated

Fit results:
$O(p^4)$:
$\hat{c} = 1.56 \pm 0.22_{stat} \pm 0.07_{syst} = 1.56 \pm 0.23$
$O(p^6)$:
$\hat{c} = 2.00 \pm 0.24_{stat} \pm 0.09_{syst} = 2.00 \pm 0.26$



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

PDG $BR = (1.10 \pm 0.32) \times 10^{-6}$

NA48/2 Model independent Branching Ratio

To compute the model-independent branching fraction in the signal region, $z > 0.2$, partial branching fractions are computed in 8 sufficiently small z bins: acceptance almost independent of kinematical distribution

z range	N_j	N_j^B	A_j	$\mathcal{B}_j \times 10^6$
0.20–0.24	13	4.89	0.194	0.045 ± 0.020
0.24–0.28	9	2.73	0.198	0.034 ± 0.016
0.28–0.32	18	2.33	0.194	0.087 ± 0.024
0.32–0.36	33	1.30	0.190	0.180 ± 0.033
0.36–0.40	31	0.98	0.184	0.177 ± 0.033
0.40–0.44	18	1.61	0.173	0.103 ± 0.027
0.44–0.48	23	1.21	0.135	0.175 ± 0.038
$z > 0.48$	4	0.52	0.049	0.076 ± 0.044

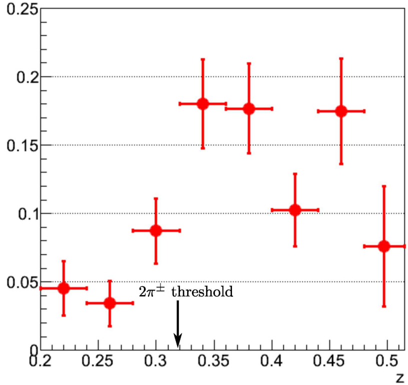


Figure: Model independent Branching Ratio ($\times 10^6$)

$$BR_{MI}(z > 0.2) = (0.877 \pm 0.087_{stat} \pm 0.017_{syst}) \times 10^{-6}$$

Main systematic effect: background estimate (LKr cluster merging)

Conclusions

- Measurements of $\hat{c}$ in both $O(p^6)$ and $O(p^4)$ frame
- BR measurement compatible with PDG but with a smaller error (~ 5 times)
- New result: model-independent $BR(z > 0.2)$
- Final results and publications are in preparation

Thank you for your attention