ChPT tests at NA62

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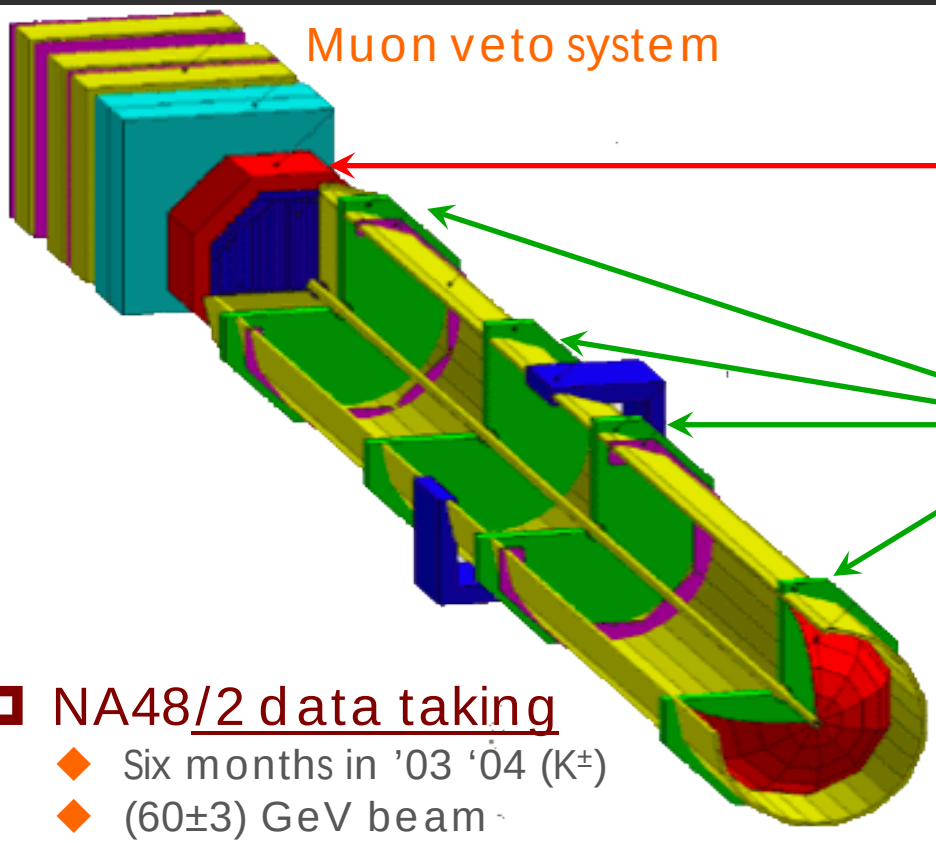
On behalf of the NA62 collaboration

XTh quark confinement and hadron spectrum
Tum campus, Munich 8-12 October 2012

Outline

- NA48/2 and NA62 experiments at CERN SPS
- $K^{\pm}$ ChPT studies history in NA48/2
- NA62 measurement of $K^{\pm} \longrightarrow \pi\ \gamma\gamma$ (new preliminary)
- NA62 $K^{\pm} \longrightarrow e\ \nu(\gamma)$ analysis (in progress)
- Ongoing investigations
- Conclusion

NA48/2 & NA62-R_K detector



LKr EM calorimeter

$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{9\%}{E} \oplus 0.4\%$$

$$\sigma_{x,y} < 1.3mm$$

Spectrometer

- 4 Drift Chambers + Magnet

$$\frac{\sigma(p)}{p}(NA48) = 1.02\% \oplus 0.044\% \times p(GeV/c)$$

$$\frac{\sigma(p)}{p}(NA62) = 0.48\% \oplus 0.009\% \times p(GeV/c)$$

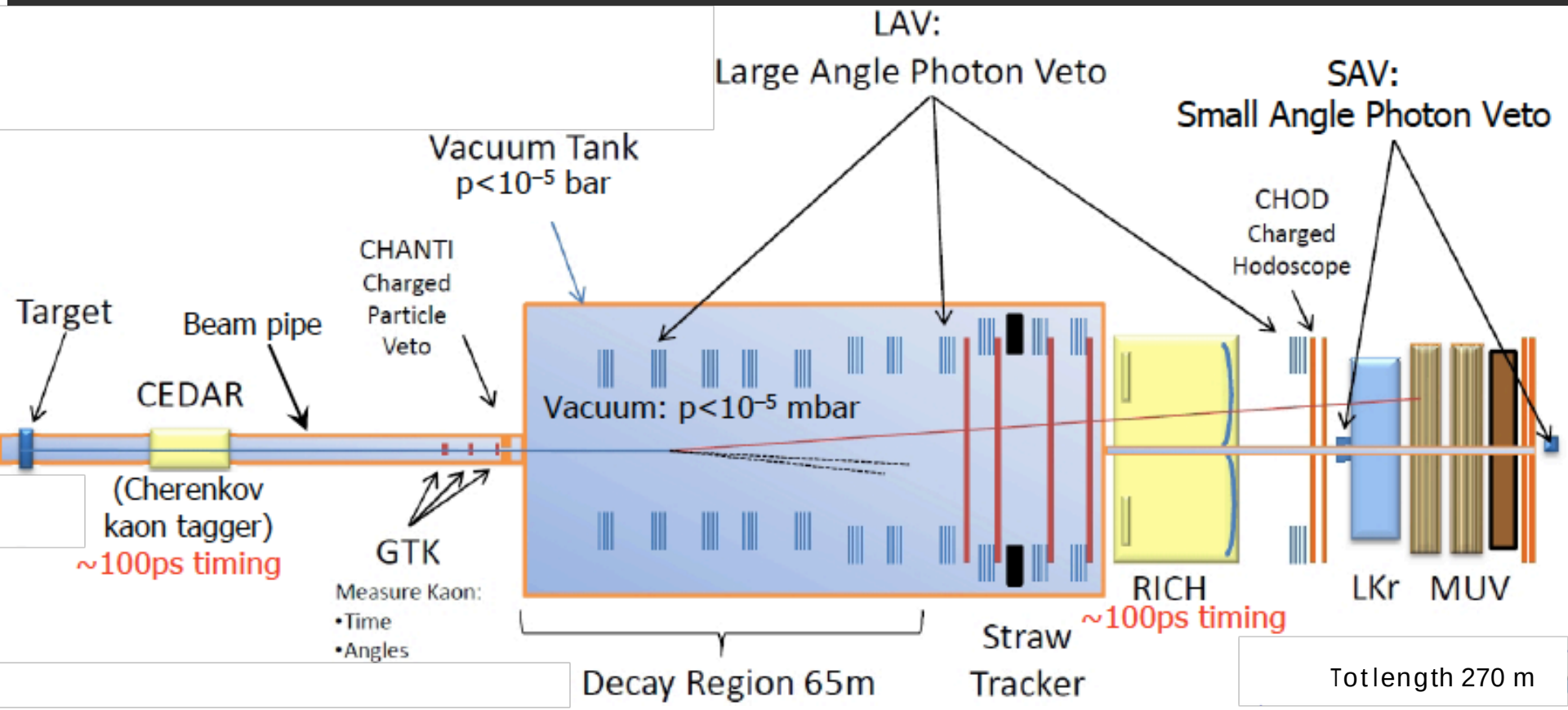
$$\sigma_{VTX}^{x,y} \sim 2mm$$

Trigger Hodoscope

$$\sigma_t \approx 150\,ps$$

- NA48/2 data taking
  - Six months in '03 '04 ($K^{\pm}$)
  - (60±3) GeV beam
- NA62-R_K data taking:
  - Four months in 2007 (mostly K^+ only)
  - (74±1.4) GeV beam
- NA62 data taking:
  - Two years starting from 2014? ($K^+ \to \pi^+\nu\nu$ data)

NA62 experiment $K^+ \longrightarrow \pi^+ \nu\nu$



Increase intensity of existing NA48/2 beam line by a factor 50

produce an unseparated 75-GeV K^+ beam:

~750 MHz beam ~ 50 MHz K^+ ~6 MHz decay in a 60m fiducial volume

Collect 5×10^{12} Kaon decays/year

The ChPT weak chiral lagrangian

- The basic $\Delta S=1$ $O(p^4)$ chiral lagrangian can be written as:

$$L_{\Delta S=1} = L^2_{\Delta S=1} + L^4_{\Delta S=1} = \underbrace{G_8 F^4 \left\langle \lambda_6 D_\mu U^+ D^\mu U \right\rangle}_{K\to 2\pi/3\pi,\,\gamma\gamma} + \underbrace{G_8 F^2 \sum N_i W_i}_{K^+\to\pi^+\gamma\gamma,\,K\to\pi\gamma\gamma}$$

- 37 poorly known N_i coefficients and W_i operators

- Combinations of such couplings are accessible by measuring Kaon decays branching fractions and form factors

- NA48/2 and NA62 have access all the charged modes in the table with very high precision

Decay	$\mathscr{L}^4_{\Delta S=1}$ counterterms
$K^+ \to \pi^+ l^+ l^-$	$N^r_{14} - N^r_{15}$
$K_S \to \pi^0 l^+ l^-$	$2N^r_{14} + N^r_{15}$
$K^\pm \to \pi^\pm \gamma\gamma$	$N_{14} - N_{15} - 2N_{18}$
$K_S \to \pi^+\pi^-\gamma$	$N_{14} - N_{15} - N_{16} - N_{17}$
$K^\pm \to \pi^\pm\pi^0\gamma$	$N_{14} - N_{15} - N_{16} - N_{17}$
$K_L \to \pi^+\pi^- e^+e^-$	$N^r_{14} + 2N^r_{15} - 3(N^r_{16} - N_{17})$
$K^+ \to \pi^+\pi^0 e^+e^-$	$N^r_{14} + 2N^r_{15} - 3(N^r_{16} - N_{17})$
$K_S \to \pi^+\pi^- e^+e^-$	$N^r_{14} - N^r_{15} - 3(N^r_{16} + N_{17})$

History of NA48/2 ChPT tests

Radiative decays:

- $K^{\pm} \longrightarrow \pi\ \pi^0\gamma$ EPJC 68 (2010) 75-87
  - First measurement the DE and INT terms:
  - Access to the chiral parameters (N_{14}-N_{15}-N_{16}-N_{17})
- $K^{\pm} \longrightarrow \pi\ \gamma e^+e^-$ PLB659 (2008) 493-499
  - First BR measurement and first determination of $\hat{c}$ (N_{14}-N_{15}-$2N_{18}$)

Non radiative decays:

- $K^{\pm} \longrightarrow \pi^+\pi^- e\ \nu$ EPJC70 (2010) 635-657, PLB 715 (2012) 105-115
  - Determination of the s-wave $\pi\pi$ scattering length
- $K^{\pm} \longrightarrow \pi\ e^+e^-$, $K^{\pm} \longrightarrow \pi\ \mu^+\mu^-$ (PLB 677 (2009) 246-254, PLB 697 (2011) 107-115)
  - Discrimination among ChPT models
  - Access to (N_{14}-N_{15}) parameters

$K \longrightarrow \pi\ \gamma\gamma$ decay theory

In the ChPT framework the differential rate of the decay $K^{\pm}(p) \longrightarrow \pi^{\pm}(p_3)\gamma(q_1)\gamma(q_2)$ process (no $O(p^2)$ contribution) is:

$$\frac{\partial^2\Gamma}{\partial y \partial z} = \frac{m_{K^{\pm}}}{(8\pi)^3} \cdot \left[z^2 \cdot \left(|A+B|^2 + |C|^2 \right) + \left(y^2 - \frac{1}{4}\lambda\left(1, z, r_\pi^2\right) \right)^2 \cdot \left(|B|^2 + |D|^2 \right) \right]$$

$$y = \frac{p \cdot (q_1 - q_2)}{m_{K^{\pm}}^2} \qquad z = \frac{m_{\gamma\gamma}^2}{m_{K^{\pm}}^2}$$

relevant only @ low $m_{\gamma\gamma}$

- The leading $O(p^4)$ contribution is given by $A(z,\hat{c})$ (loops) which is responsible for a cusp at $m_{\gamma\gamma} = m_{2\pi}$

$$\Gamma_A = (2.80 + 0.87\hat{c} + 0.17\hat{c}^2) \cdot 10^{-20}\, MeV$$

- C (WZW) corresponds to ~10% of A at $O(p^4)$

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

- B, D = 0 @ $O(p^4)$

- The $\hat{c}$ value can be related to fundamental ChPT parameters:

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

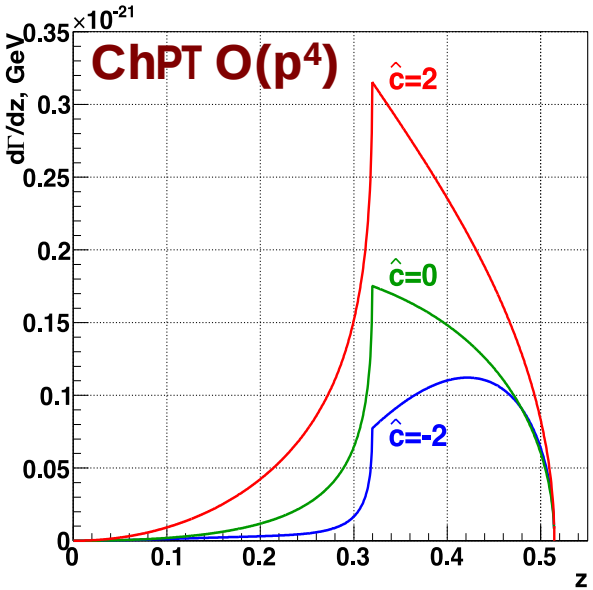
$$\hat{c} = \frac{128\pi^2}{3}\left[3(L_9 + L_{10}) + (N_{14} - N_{15} - 2N_{18})\right]$$

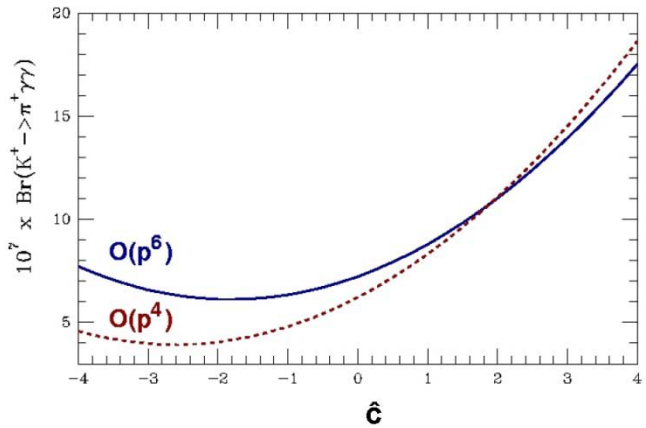
Weak Chiral Lagrangian

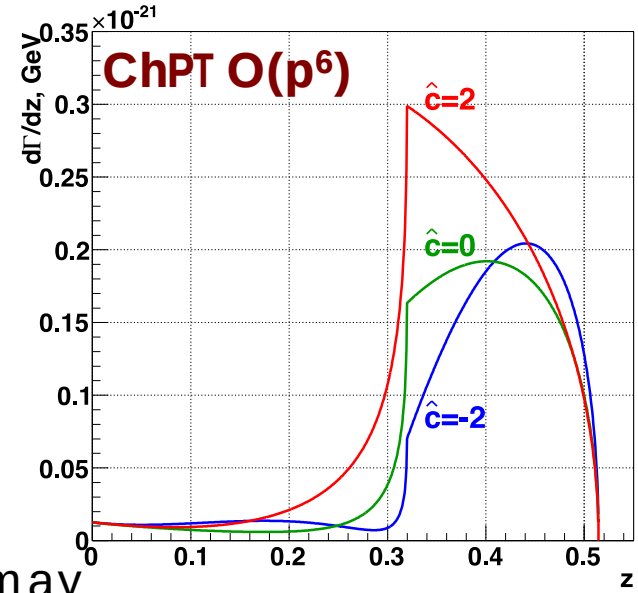
QCD loop and counterterms

$K \longrightarrow \pi\ \gamma\gamma$ decay, ChPt $O(p^4)$ vs $O(p^6)$

- **$O(p^6)$ loop amplitude correction, evaluated from $K \longrightarrow 3\pi$ @ $O(p^4)$**
- **$O(p^6)$ *A* gets y dependence, sizable correction to $d\Gamma/dz$ for $z<z_+$**







$O(p^6)$ unitarity corrections may increase the BR by 30÷40%

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

$K \longrightarrow \pi\ \gamma\gamma$ decay experimental status

Present PDG average based on:

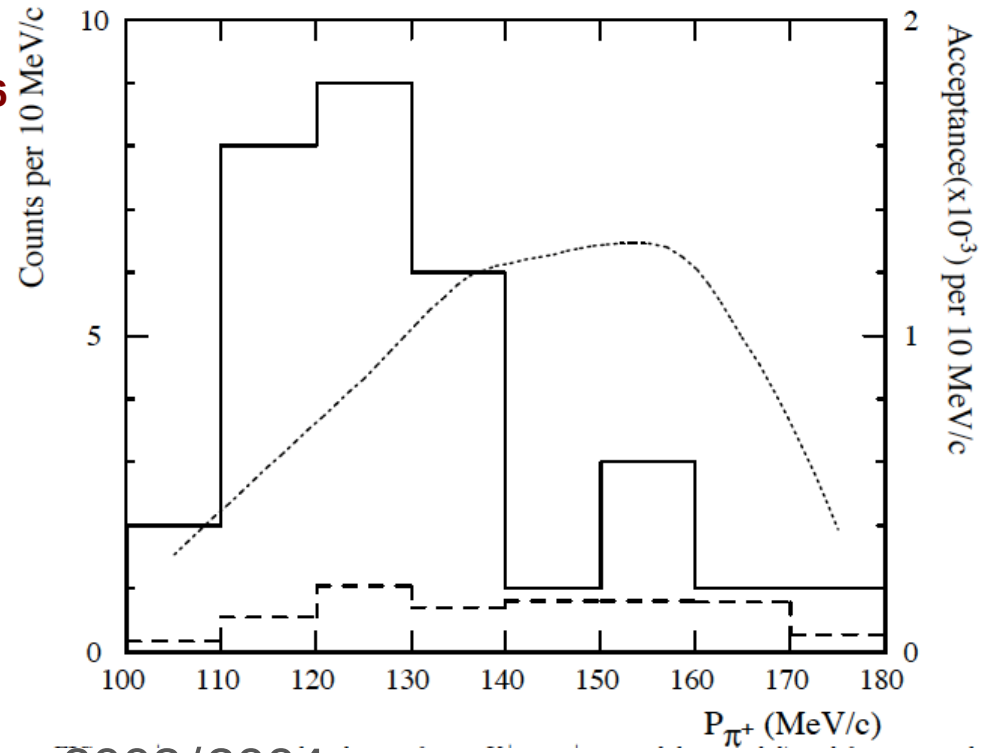
E787 (1997): BR = (1.10 ± 0.32)×10^{-6}

31 candidates, 5 exp. Bkg

$\hat{C}$ value = 1.6 ± 0.6 $O(p^4)$

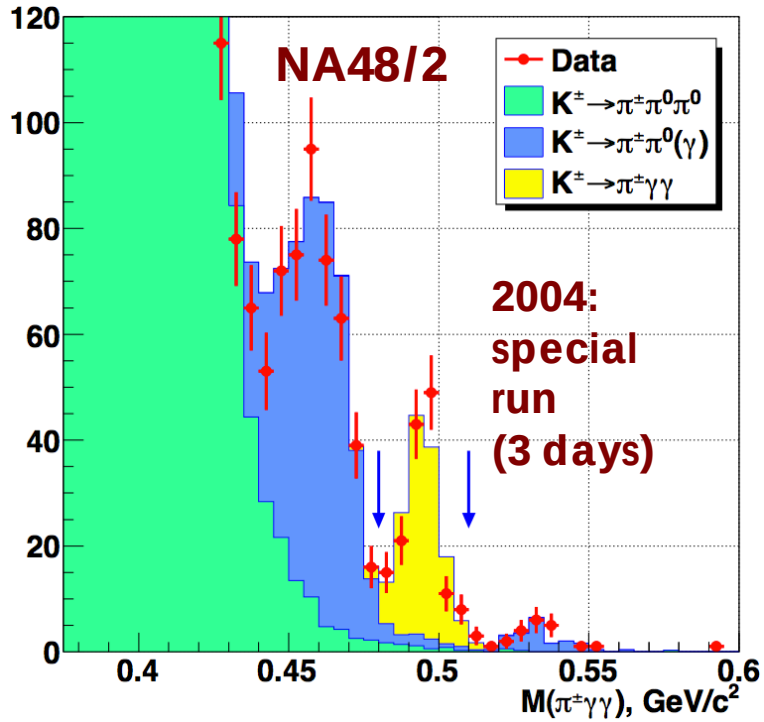
= 1.8 ± 0.6 $O(p^6)$

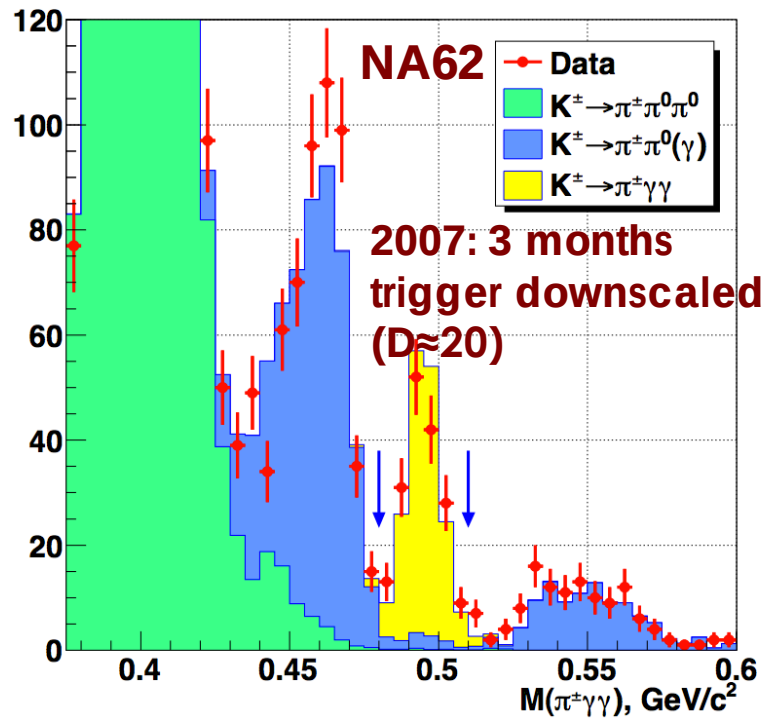
[PRL79 (1997) 4079]



- NA48/2 main data set preliminary 2003/2004: measurement hindered by low trigger efficiency. Abandoned!
- New strategy: minimum bias trigger samples from NA48/2 and NA62.
  - 2004 data taking (3 days special minimum bias run)
  - 2007 data taking (3 month control trigger downscaled by 20)

Minimum bias data samples





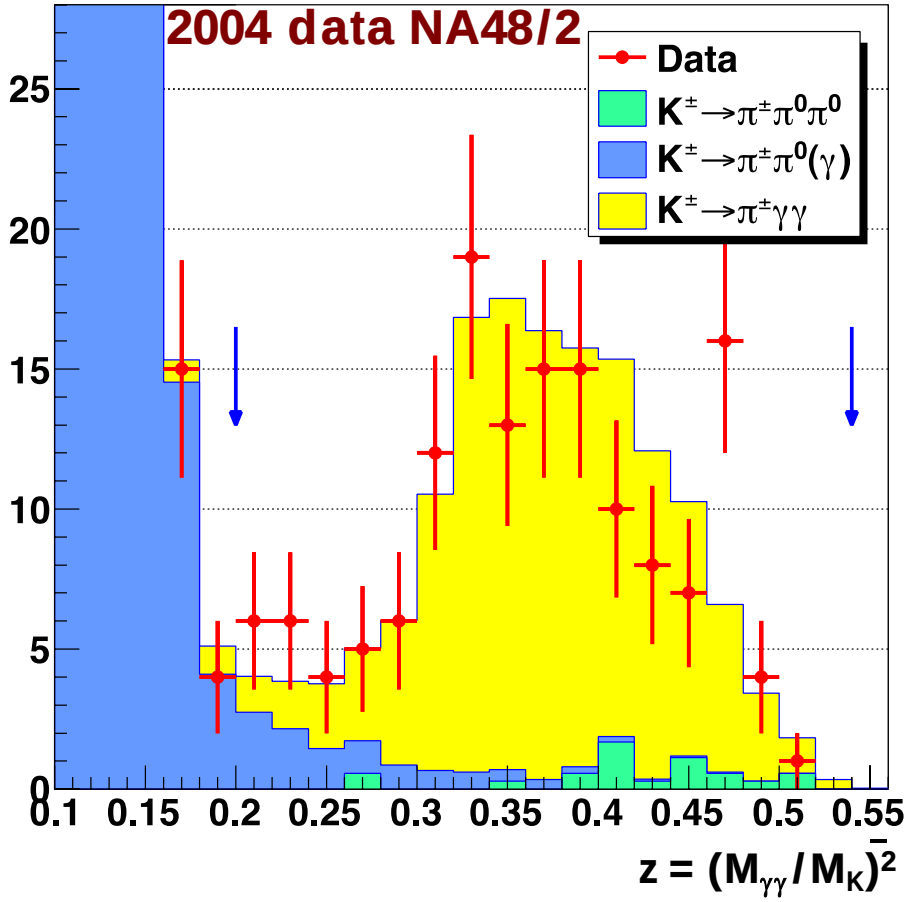
$\pi\ \gamma\gamma$ candidates	147
BG($\pi\ \pi^0\gamma$)	11.0±0.8
BG($\pi\ \pi^0\pi^0$)	5.9±0.7
Signal ($\pi\ \gamma\gamma$)	130±12

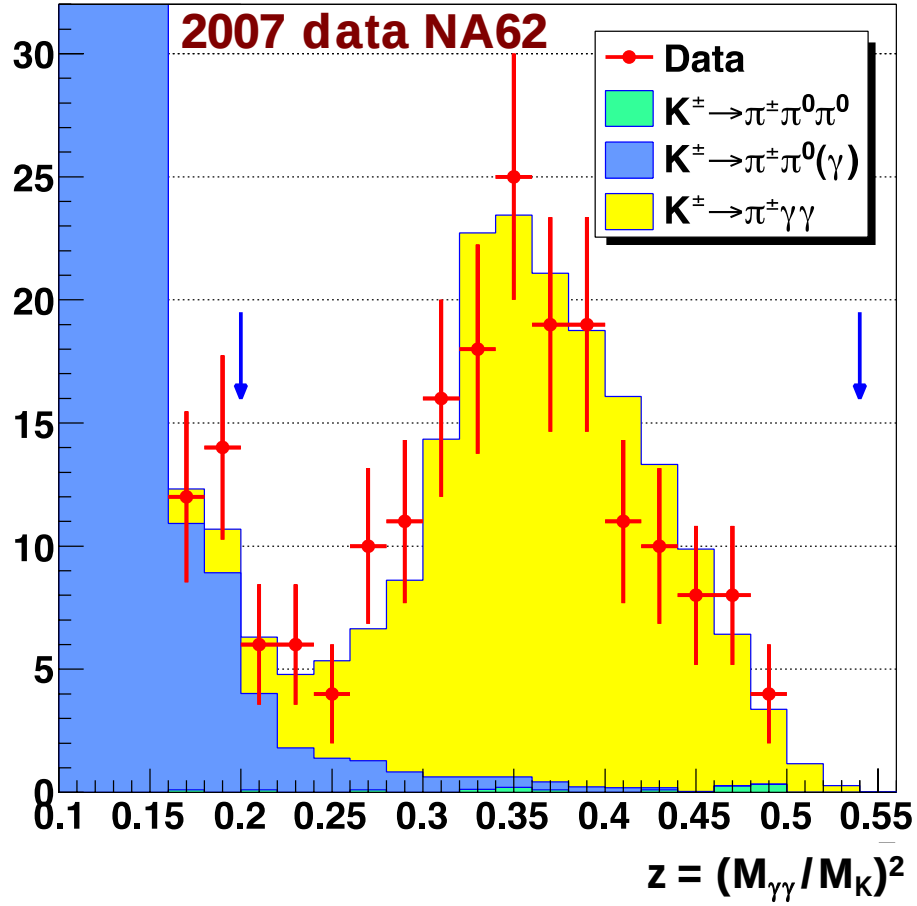
$\pi\ \gamma\gamma$ candidates	175
BG($\pi\ \pi^0\gamma$)	11.1±1.0
BG($\pi\ \pi^0\pi^0$)	1.3±0.3
Signal ($\pi\ \gamma\gamma$)	163±13

~300 candidates 10 times the present world sample

$K \to \pi\gamma\gamma$ ChPT fit $O(p^6)$

$\pi\pi\gamma$ background limits sensitivity to $z \geq 0.2$





ChPT $O(p^4)$: $\hat{c} = 1.36 \pm 0.34$
ChPT $O(p^6)$: $\hat{c} = 1.67 \pm 0.40$

ChPT $O(p^4)$: $\hat{c} = 1.71 \pm 0.30$
ChPT $O(p^6)$: $\hat{c} = 2.21 \pm 0.32$

Fit results combined samples

BR(K $\longrightarrow \pi\ \gamma\gamma$) = (1.01 ± 0.06)·10^{-6} (NA62-RK+NA48/2 model dependent)

E787: BR = (1.10 ± 0.32)×10^{-6}

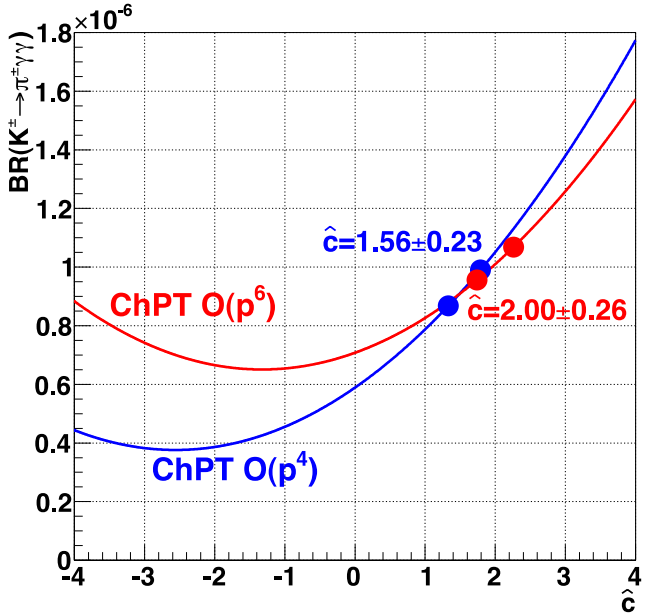
Preliminary

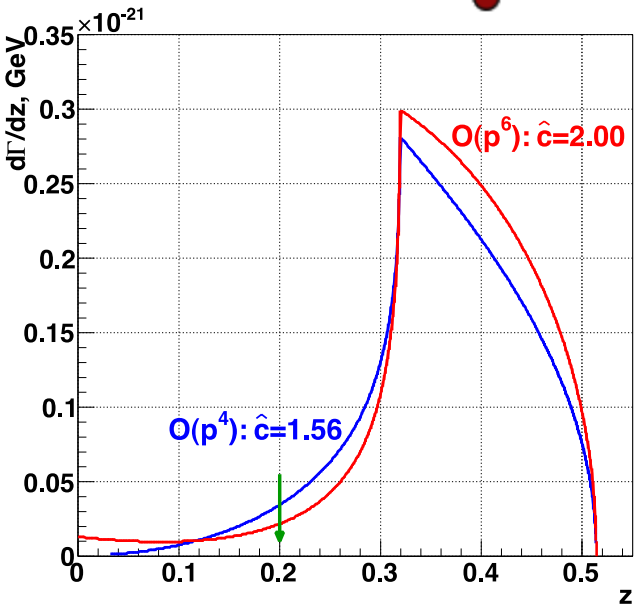
ĉ preliminary results for combined samples (NA48/2 and NA62-RK):

Fit to ChPT O(p^4): ĉ = 1.56(22)$_{stat}$(7)$_{syst}$ = **1.56(23)**

Fit to ChPT O(p^6): ĉ = 2.00(24)$_{stat}$(9)$_{syst}$ = **2.00(26)**

Preliminary

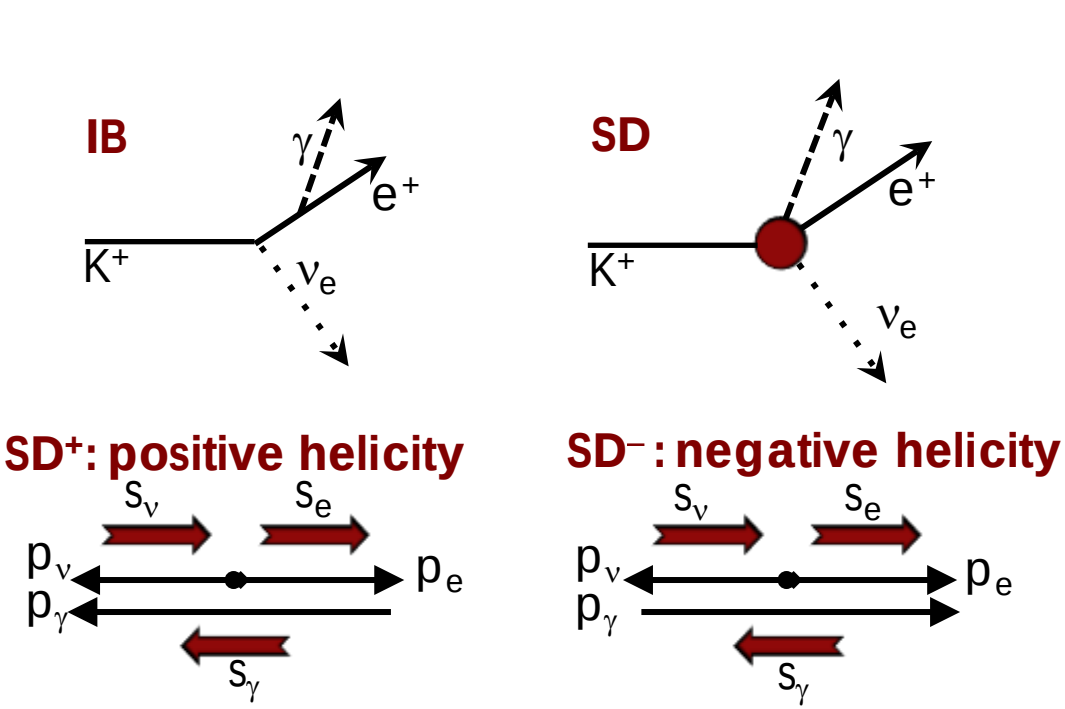


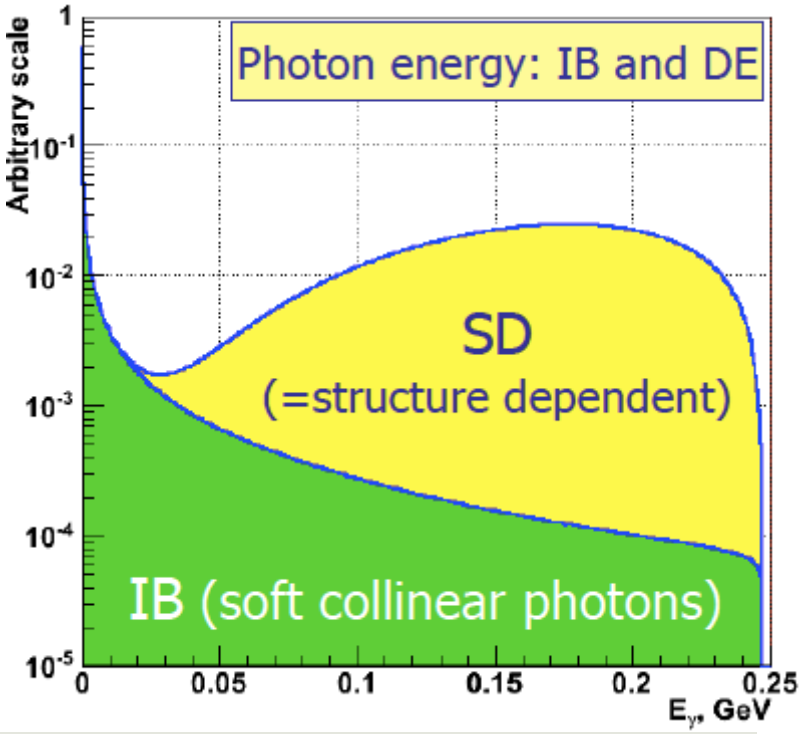


ChPT O(p^4) vs O(p^6) models cannot be discriminated so far.
Discrimination can be reached by NA62 (~50K-100K events potential)

$K^+ \longrightarrow e^+\nu_e(\gamma)$ decay

- The decay $K^+ \longrightarrow e^+\nu_e$ is highly helicity suppressed $(m_e^2/m_\mu^2) \approx 10^{-5}$
- IB of electron or kaon is a pure QED process (very well known)
- The SD transition is not helicity suppressed as the $e^\pm\nu(\gamma)_{IB}$.
  - SD+ and SD– : same order as IB INT: negligible





Decay rate theory and experiments

$$\frac{d^2\Gamma}{dxdy}(SD) = \frac{m_K^5 \alpha G_F^2 |V_{us}|^2}{64\pi^2} \times [(F_V + F_A)^2 f_{SD+}(x,y) + (F_V - F_A)^2 f_{SD-}(x,y)]$$

$$x = \frac{2E_\gamma^*}{M_K}, \qquad y = \frac{2E_e^*}{M_K}$$

f_{SD+}, f_{SD-} known functions of kinematics

F_V, F_A vector and axial form factors

At $O(e^2p^4)$, FF's F_V and F_A are constant, $O(e^2p^6)$ F_V has a slope :

$$F_V(p^2) = \frac{m_K}{4\sqrt{(2)}\pi^2 F_K} + \mathcal{O}(p^6), \qquad F_V(p^6) = F_V(0)(1 + \frac{\lambda p^2}{M_K^2}), \qquad \lambda \approx 0.4$$

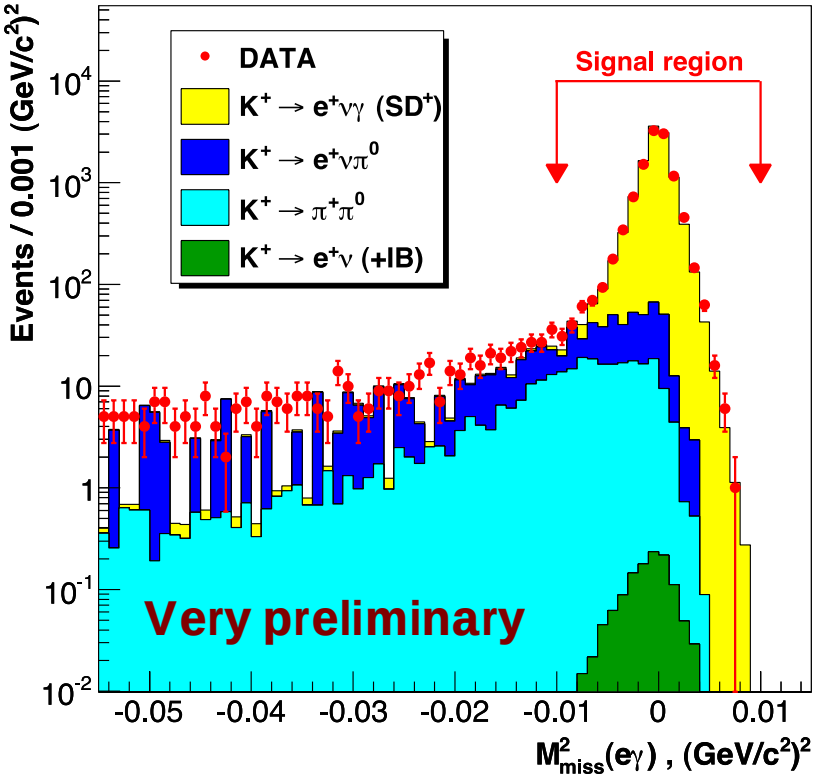
$$F_A(p^2) = \frac{4\sqrt{2}m_K}{F_K}(l_9^r + l_1^r 0) + \mathcal{O}(p^6),$$

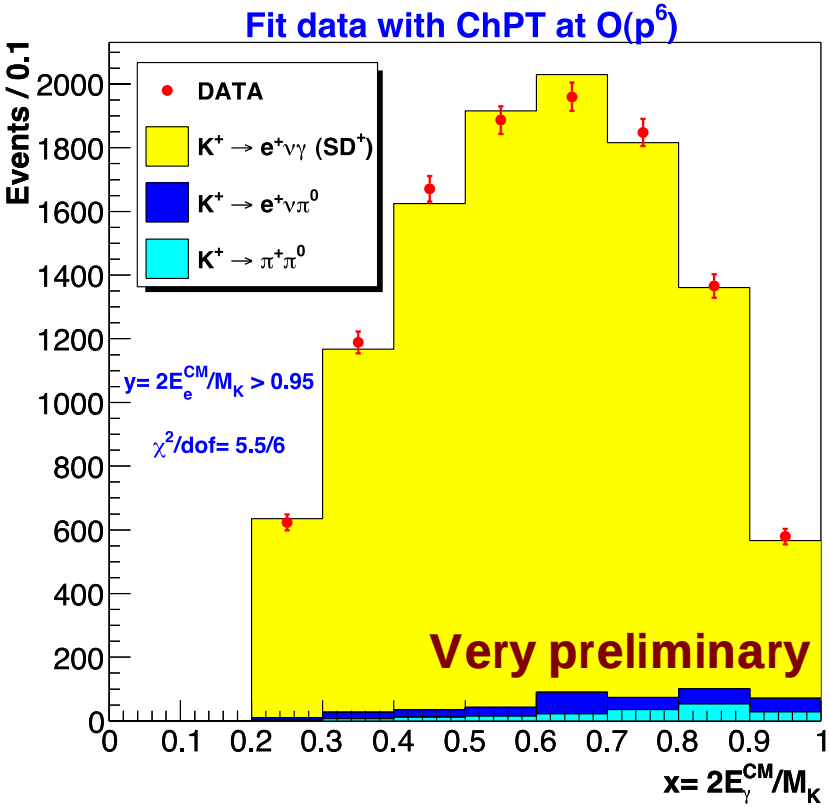
- KLOE measurement 2009
  - 1484±64 events for $E^*\gamma$ >10 MeV and p^*_e >200 MeV:
  - $\delta\Gamma(SD^+)/\Gamma(SD^+)$ ~ 4% with 1500 cts, bkg contributes to error
  - No sensitivity to SD^-
  - Fair agreement with χPt $O(p^4)$
  - Data favour slope for F_V, $\lambda = 0.38(20)_{sta}(2)_{syst}$, but can't state $\lambda \neq 0$ @ >2σ

EPJC 64 (2009) 627

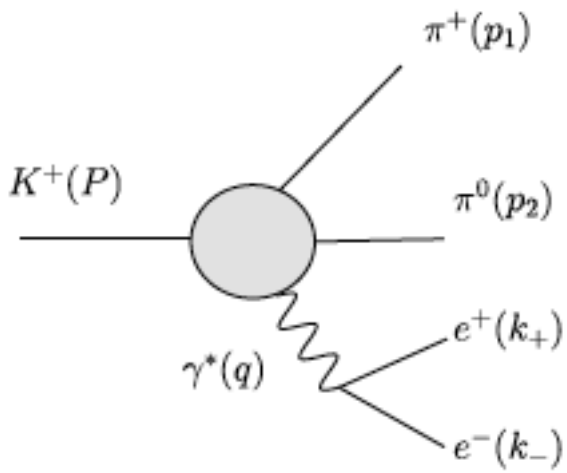
$K \longrightarrow e\ \nu_e(\gamma)$ decay NA62 analsys

- Selection of SD component, many steps common to the R_K analysis
- $\pi^+\pi^0$, Ke3 backgrounds $\longrightarrow$ photon explicitly detected + tighter *e* PID
- ~10K events with P^*_e>234 MeV, ~ 7% acc., ~5% bkg
- Analysis in progress, plan is to perform a model-independent FF measurement





Next to come... $K^{\pm} \longrightarrow \pi\ \pi^0\gamma^* \longrightarrow \pi\ \pi^0 e^+e^-$



$$\frac{d^3\Gamma}{dE_\gamma^* dT_c^* dq^2} = \frac{d^3\Gamma_B}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_E}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_M}{dE_\gamma^* dT_c^* dq^2} + \frac{d^3\Gamma_{\rm int}}{dE_\gamma^* dT_c^* dq^2},$$

EPJC (2012) 72:1872

- As other radiative decays $K^{\pm} \longrightarrow \pi\ \pi^0 e^+e^-$ is long-distance dominated:
  - Electric interference can be used to confirm the measurement made in $\pi\ \pi^0\gamma$
  - Magnetic interference is genuine $\pi\pi ee$ and can be used to extract the sign of the magnetic term.
  - P violating observables in the dilepton pair coupling can be used to access short distance physics using K^+ only (NA62)
  - Charge asymmetry not contaminated by indirect CP violation (as in K^0)
- Never observed so far:
  - Few thousand candidates already identified in NA48/2 data sample
  - Up to ~100K can be expected in NA62

Conclusion

- NA48/2 and NA62 gave an important contribution to ChPT test at low energies measuring kaon decays:
  - $\pi\ \pi^0\gamma$, $\pi\ \gamma e^+e^-$
  - $\pi^+\pi^-e^\pm\nu_e$, $\pi^\pm e^+e^-$, $\pi\ \mu^+\mu^-$
- Recent preliminary result has been released on $\pi\ \gamma\gamma$:
  - **BR(K $\rightarrow\pi\ \gamma\gamma$) = (1.01 ± 0.06)·$10^{-6}$**
  - $\hat{c} = 1.56(22)_{stat}(7)_{syst}$ = **1.56(23) O(p^4) FIT**
  - $\hat{c} = 2.00(24)_{stat}(9)_{syst}$ = **2.00(26) O(p^6) FIT**
- Advanced analysis is in progress in the $e^+\nu_e\gamma$(SD) channel
- Improved precision in all the channels is possible in the NA62
  - At least 1 order of magnitude higher statistics (1x10^{13} K^+ in 2 years)
  - Better particle ID and photon rejection
- Due to trigger bandwidth not all decays will be collected
  - Any theoretical input on interesting measurements is welcome