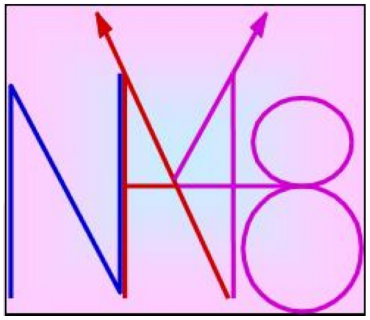
ChPT test at NA48 and NA62 experiment at CERN



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on behalf of the NA48/2 and NA62 collaborations

QCD2014 – Montpellier (France), 30 June – 4 July 2014

Outline:

- The $K \rightarrow \pi\gamma\gamma$ process
- The NA48/2 and NA62-R_K (2007) Apparatus
- Analysis strategy and signal selection
- Results
- NA48/2 and NA62 combined results
- Conclusions

The K → πγγ process (1)

In the ChPT framework the differential decay amplitude is:

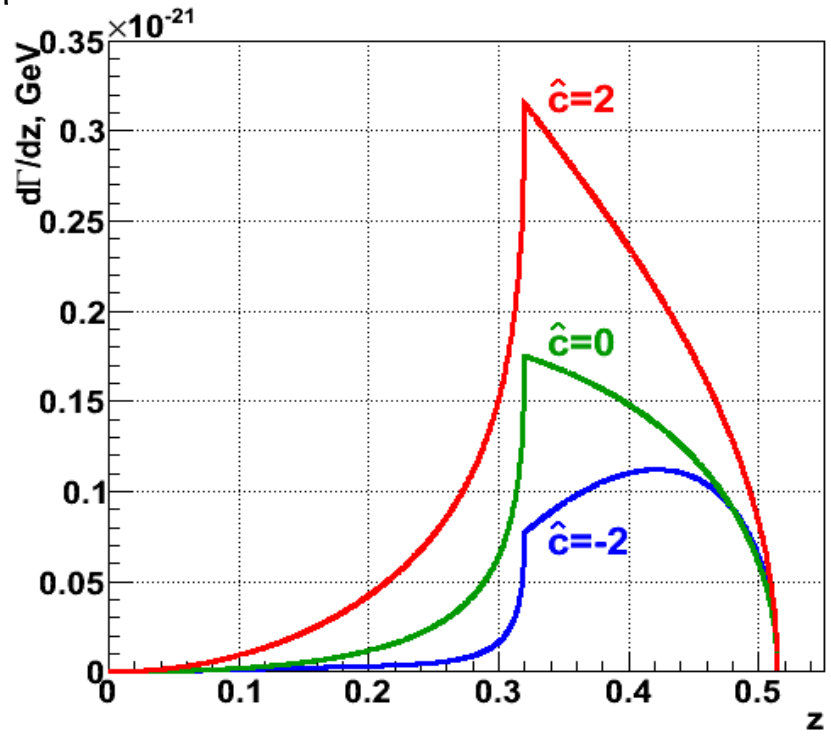
$$\frac{\delta\Gamma}{\delta y \delta z}(\hat{c}, y, z) = \frac{m_K}{2^9 \pi^3}\left[z^2\left(|A(\hat{c}, z, y^2) + B(z)|^2 + |C(z)|^2\right) + \left(y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z)\right)^2 |B(z)|^2\right]$$

$$y = \frac{p(q1 - q2)}{m_K^2} \qquad z = \frac{(q1 + q2)^2}{m_K^2} = \frac{m_{\gamma\gamma}^2}{m_K^2}$$

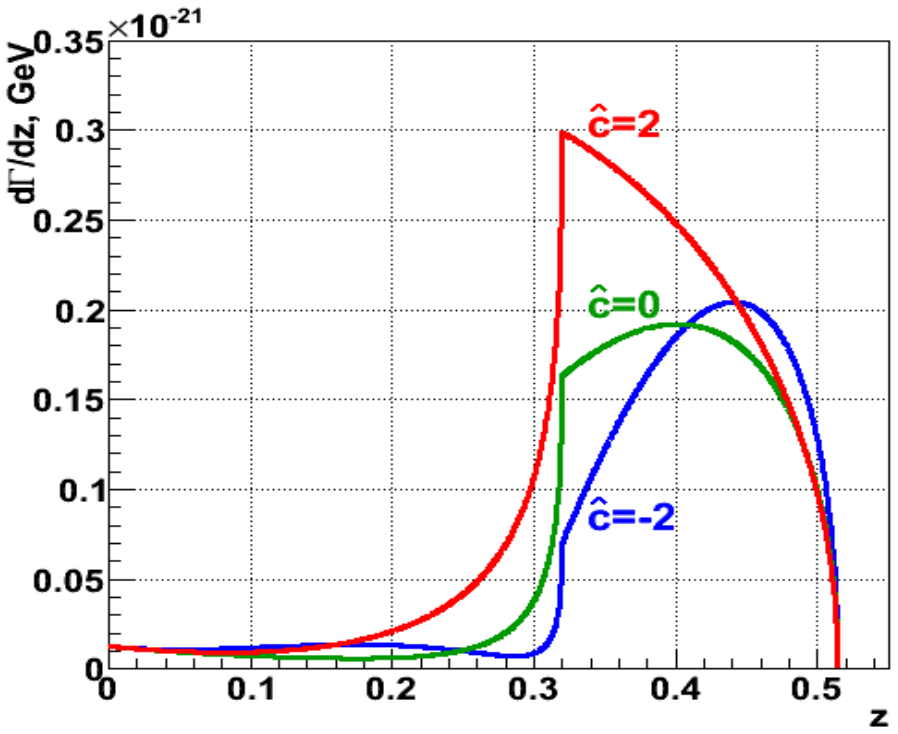
- A and B are the loop amplitudes, C is the pole amplitude
- At leading order $O(p^4)$ only the A contribution is present and gives a cusp at $m_{\gamma\gamma}=m_{2\pi}$
- At next-to-leading order $O(p^6)$ the B contribution appears and becomes dominant at low z
- Rate and scpectrum depend on the unknown O(1) parameter ĉ
- $O(p^6)$ framework involves additional 10 parameters

The K → πγγ process (2)

$O(p^4)$ [Ecker, Pich, de Raphael NPB303 (1988) 665]



$O(p^6)$ [D'Ambrosio, Portoles PLB386 (1996) 403]

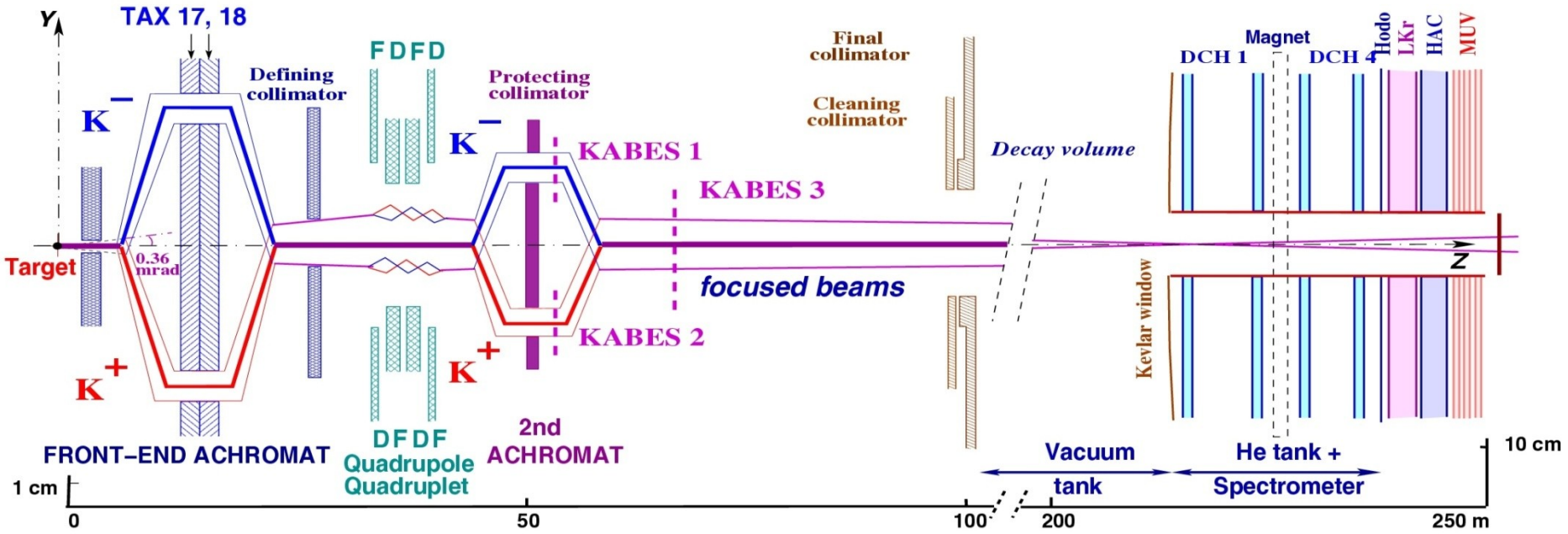


A cusp visible at 2π threshold $z = 0.320$

Due to the appearance of the B contribution at $O(p^6)$ non-zero differential decay amplitude at $z = 0$

y^2 - dependence of the differential decay amplitude arising at next-to-leading order $O(p^6)$

The beam line



NA48/2 data taking

✔ 4 months in 2003 ($K^{\pm}$)

✔ 4 months in 2004 ($K^{\pm}$)

For this analysis used 2 minimum-bias trigger samples

NA62-R_K

✔ 4 months in 2007 (mostly K^{+})

Kaon beam momentum

✔ NA48/2 (2003 -2004) (60.0 ± 2.2)GeV/c

✔ NA62-RK (2007) (74.0 ± 1.4) GeV/c

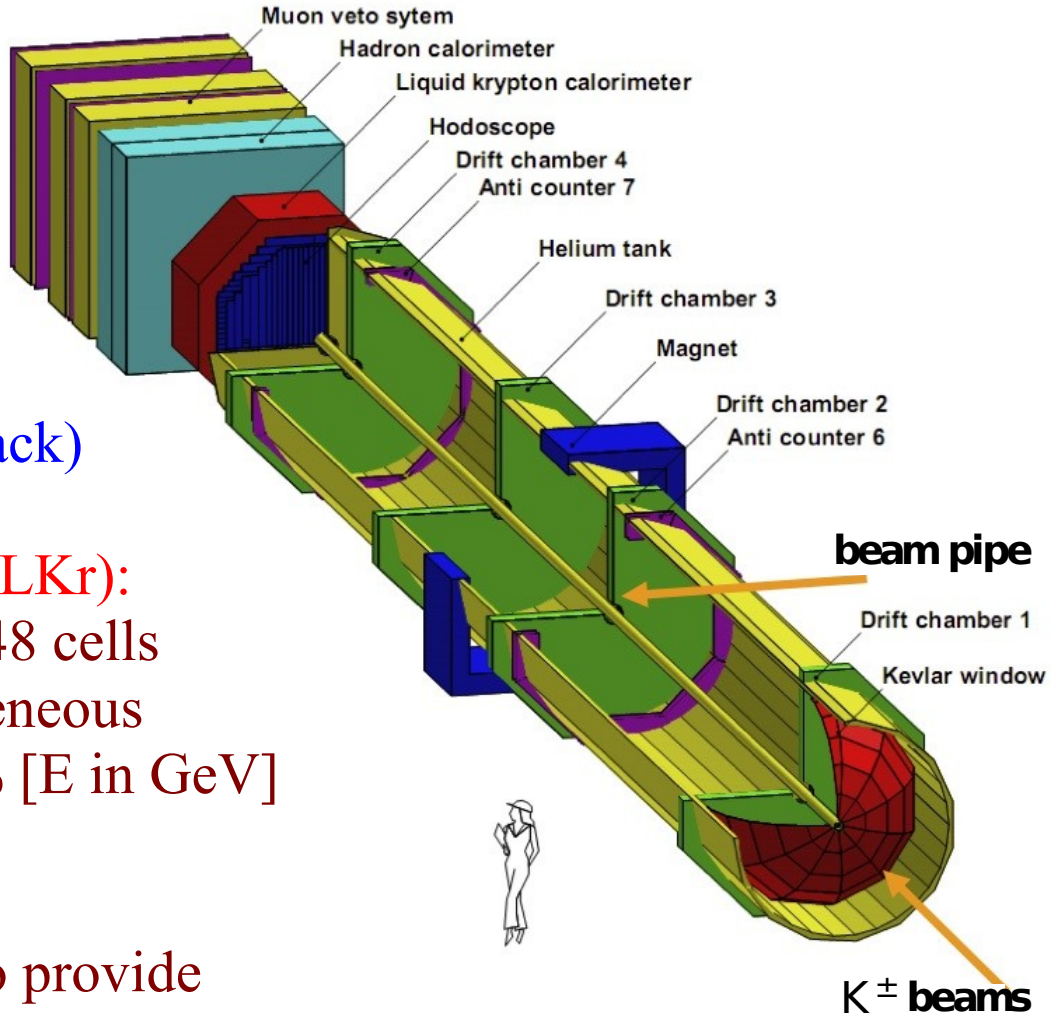
The NA48/2 Detector

Magnetic spectrometer (4 DCHs):
4 views: redundancy ⇒ efficiency
$\sigma(p)/p = 1.0\% + 0.044\% \, p$ [GeV/c]

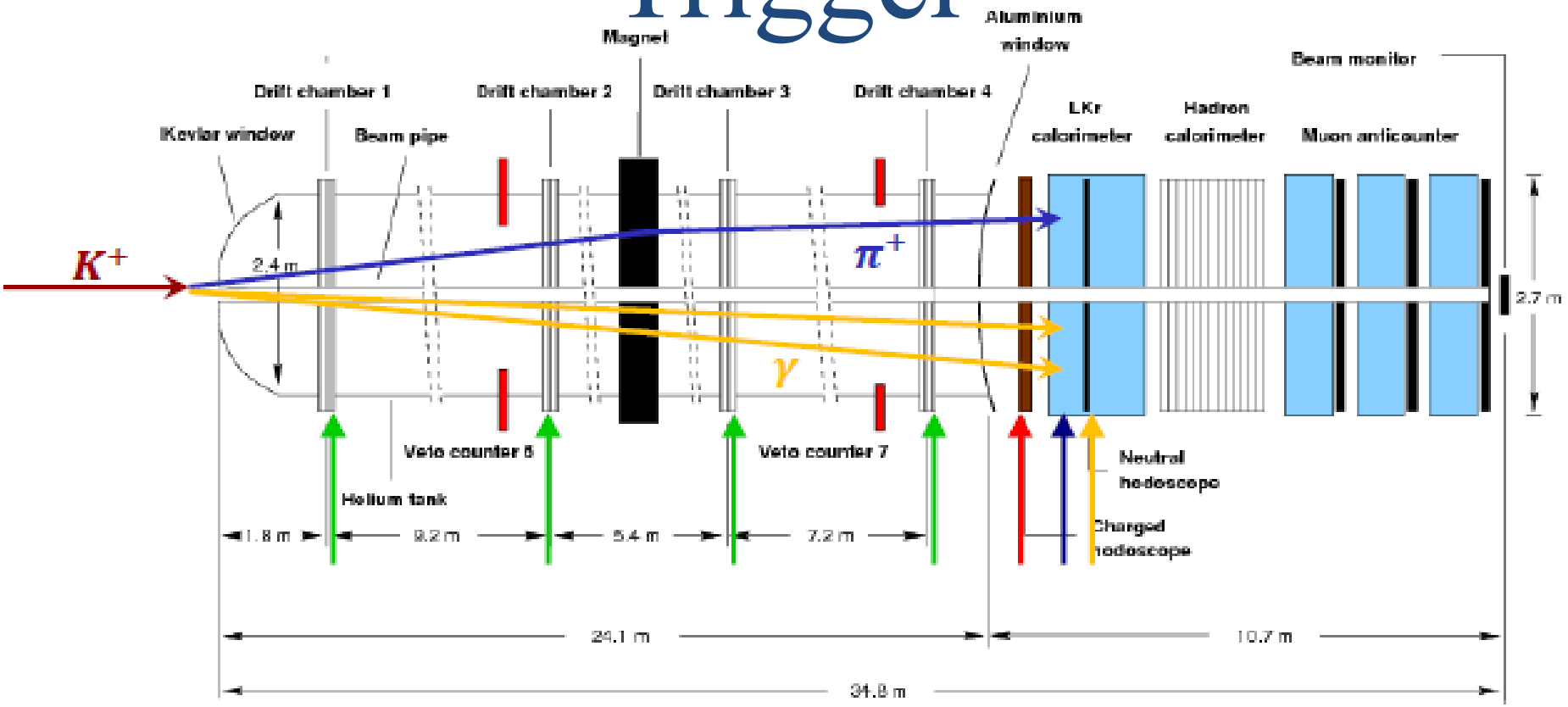
Charged hodoscope (scintillators):
Fast trigger and precise time measurement (~200 ps on single track)

Liquid Krypton E.M. Calorimeter (LKr):
10 m^3 (~22 t), 1.25 m (27 X_0), 13248 cells
granularity: 2x2 cm^2, quasi-homogeneous
$\sigma(E)/E = 3.2\%/\sqrt{E} + 9\%/E + 0.42\%$ [E in GeV]

Neutral hodoscope
Inside the calorimeter at ~ 9.5 X_0 to provide neutral trigger



Trigger



NA48/2: Special runs in 2003 and 2004 with minimum bias trigger
Q1 & (ELKr > 10 GeV)

NA62-RK: 90 days in 2007 with a combination of minimum bias triggers (downscaled)
Q1 & (TRACK) ~ 20%
Q1 & (TRACK) & (ELKr > 10 GeV) ~ 60%
NHOD signal ~20%

Analysis strategy

- ✗ Select $K \rightarrow \pi\gamma\gamma$ candidates
- ✗ Select event corresponding to normalization channel $K \rightarrow \pi\pi^0$ ($\pi^0 \rightarrow \gamma\gamma$)
- ✗ Measure Model-Independent (MI) Branching Ratio
- ✗ Extract $\hat{c}$ from z-spectrum
- ✗ Evaluate Model-Dependent (MD) Branching Ratio from $\hat{c}$
- ✗ Compare the measurements with the previous result

Event selection

Common cuts between signal and normalization selection:

✗ One final state charged particle (π)

✗ Reconstructed vertex inside fiducial decay region (98 m)

✗ Track momentum between:

10 and 40 GeV/c NA48/2 (2003-2004)

8 and 50 GeV/c NA62 (2007)

✗ $E/p < 0.85$ for pion identification

✗ Reconstructed kaon mass, $m(\pi\gamma\gamma)$, between 0.48 and 0.51 GeV/c^2

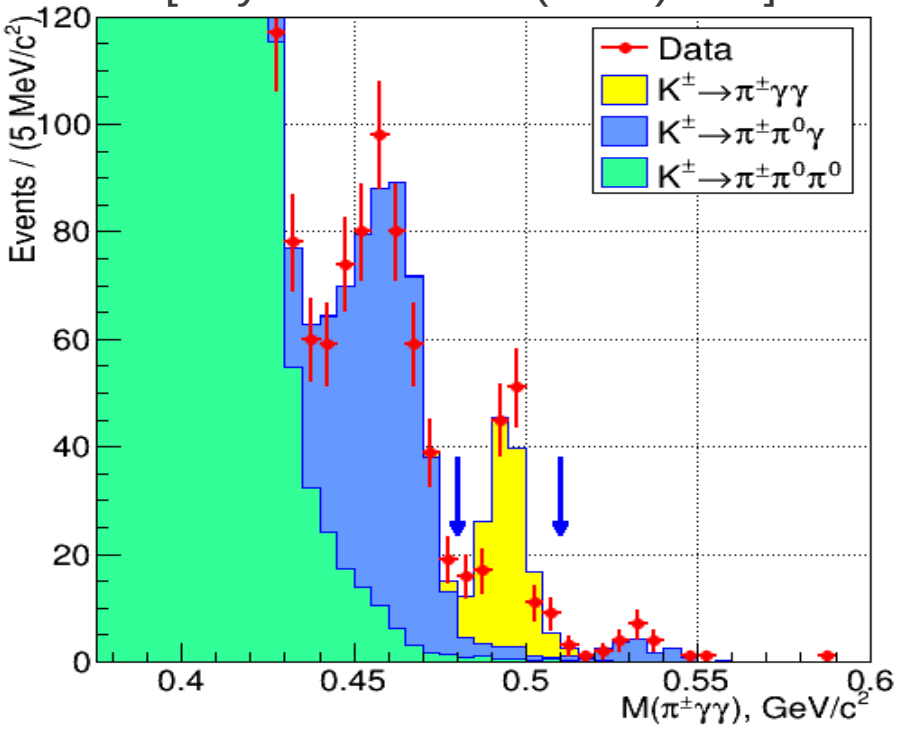
Specific cuts for signal and normalization selection:

✔ $z > 0.2$ for signal (background suppression)

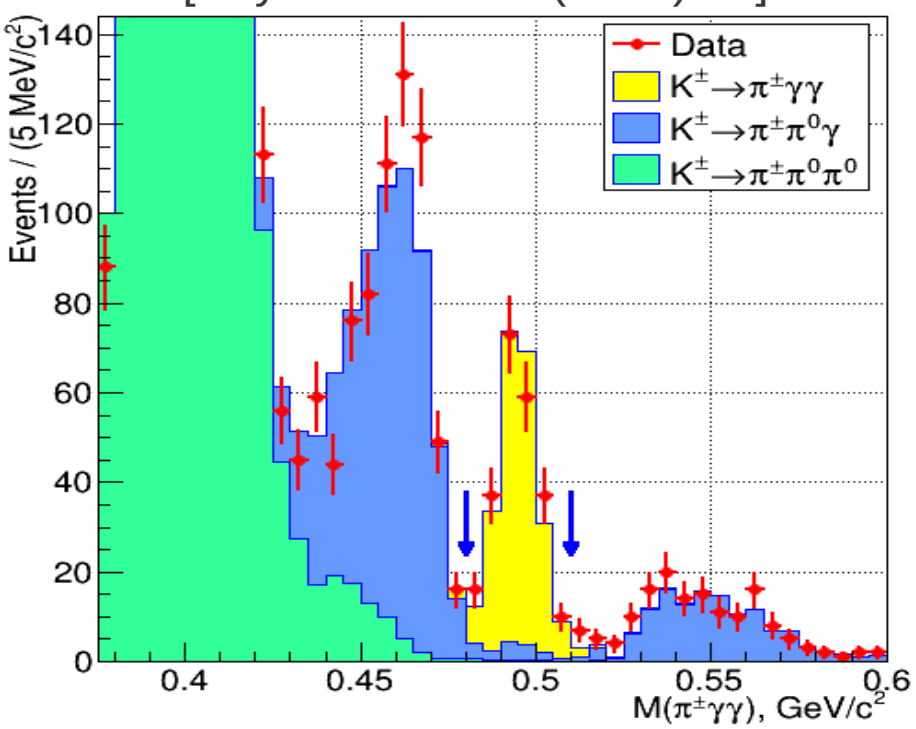
✔ $0.064 < z < 0.086$ for normalization ($z \sim 0.075$ corresponds to $m_{\gamma\gamma} \sim m_{\pi 0}$)

Data samples (1)

NA48/2 (2003-2004)
[Phys. Lett. **B730**(2014) 141]



NA62-RK (2007)
[Phys. Lett. **B732**(2014) 65]

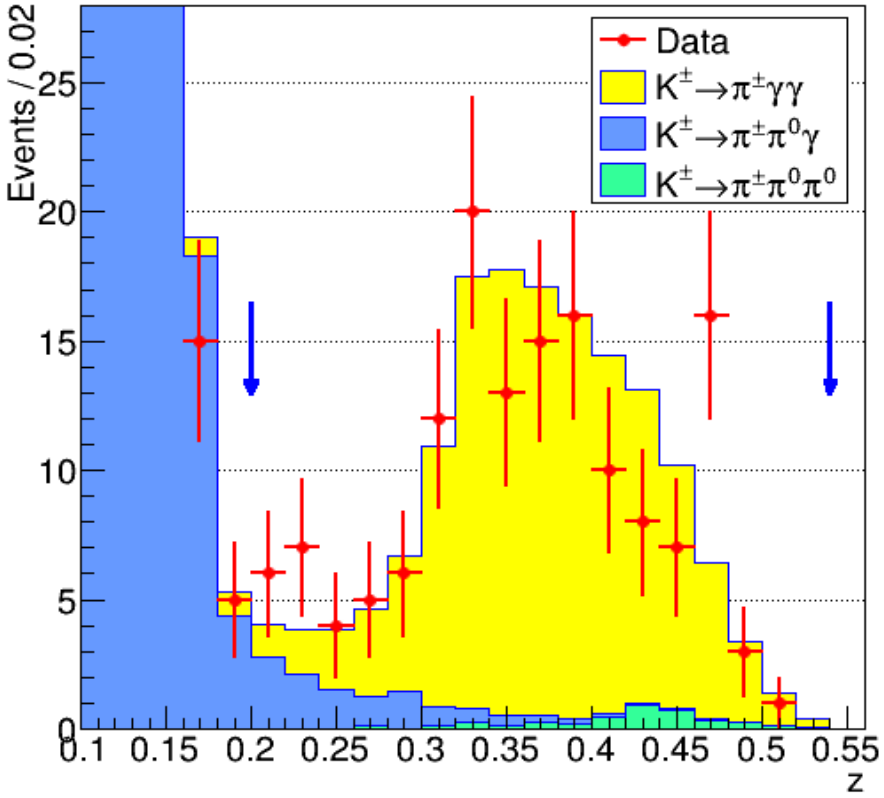


$K^{\pm} \to \pi^{\pm}\gamma\gamma$ candidates	149
$K^{\pm} \to \pi^{\pm}\pi^0(\gamma)$ backgrounds	11.4 ± 0.6
$K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ backgrounds	4.1 ± 0.4
$K^{\pm} \to \pi^{\pm}\gamma\gamma$ signal	133

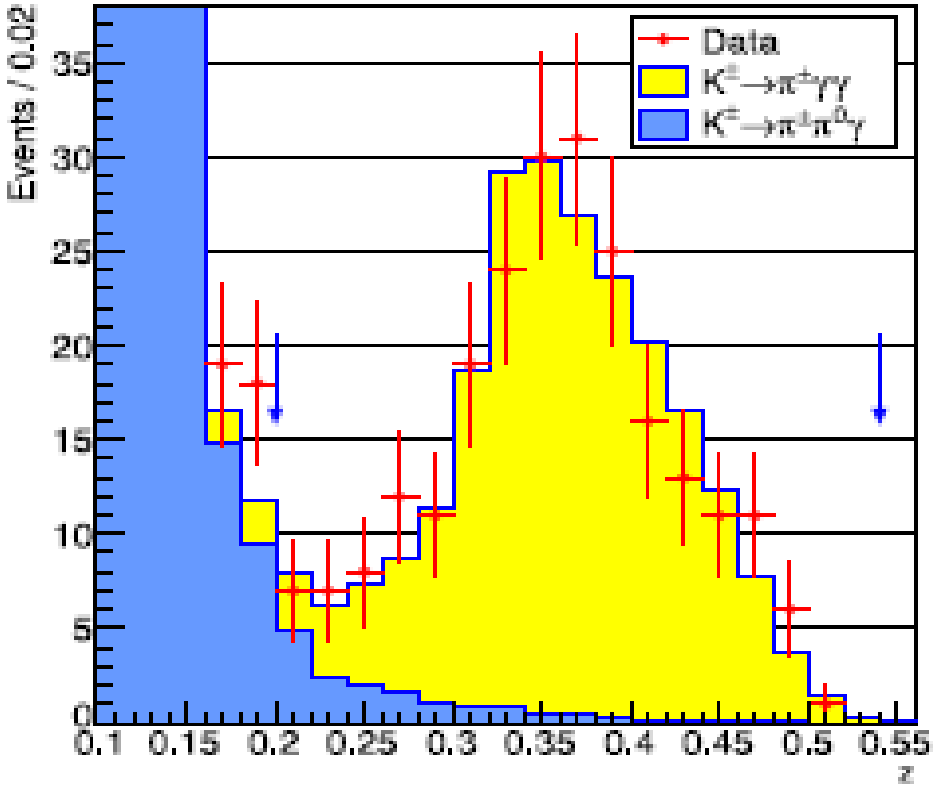
$K^{\pm} \to \pi^{\pm}\gamma\gamma$ candidates	232
$K^{\pm} \to \pi^{\pm}\pi^0(\gamma)$ backgrounds	15.3 ± 1.1
$K^{\pm} \to \pi^{\pm}\pi^0\pi^0$ backgrounds	2.1 ± 0.3
$K^{\pm} \to \pi^{\pm}\gamma\gamma$ signal	215

Data samples (2)

NA48/2 (2003-2004)
[Phys. Lett. **B730**(2014) 141]



NA62-RK (2007)
[Phys. Lett. **B732**(2014) 65]



A cusp like behaviour around z ~ 0.32 as expected!

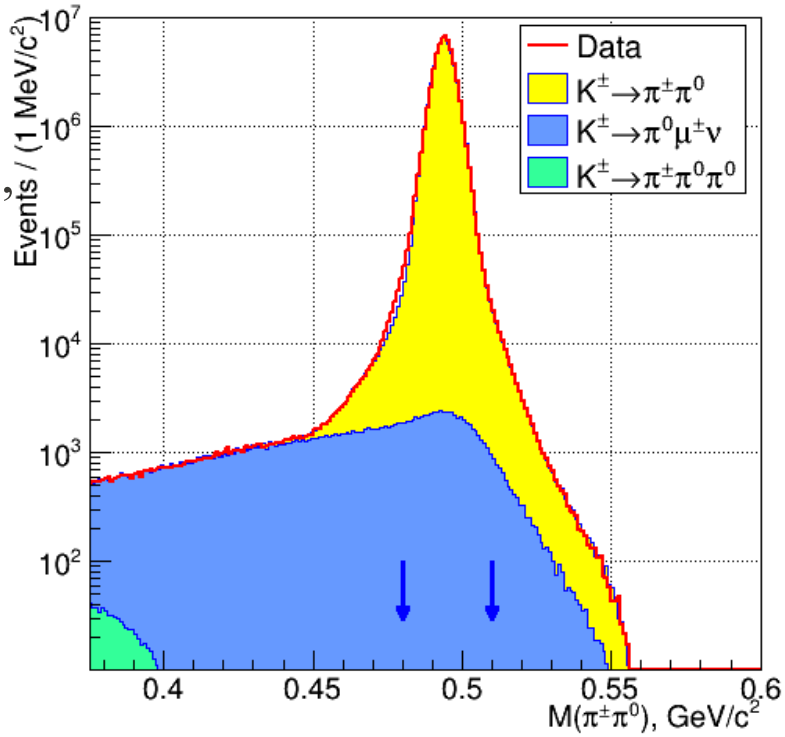
Results: MI BR

NA62-RK (2007)
[Phys. Lett. **B732**(2014) 65]

- Signal and normalization events collected with the same trigger
- No dependence on: beam flux and compositions, downscaling factors and data taking periods
- z-region divided into small bins
- Bin content dependence on y is small (<10%)

$$B_j = (N_j - N_j^B) / (N_K A_j)$$

events | background | acceptance | Total K decays



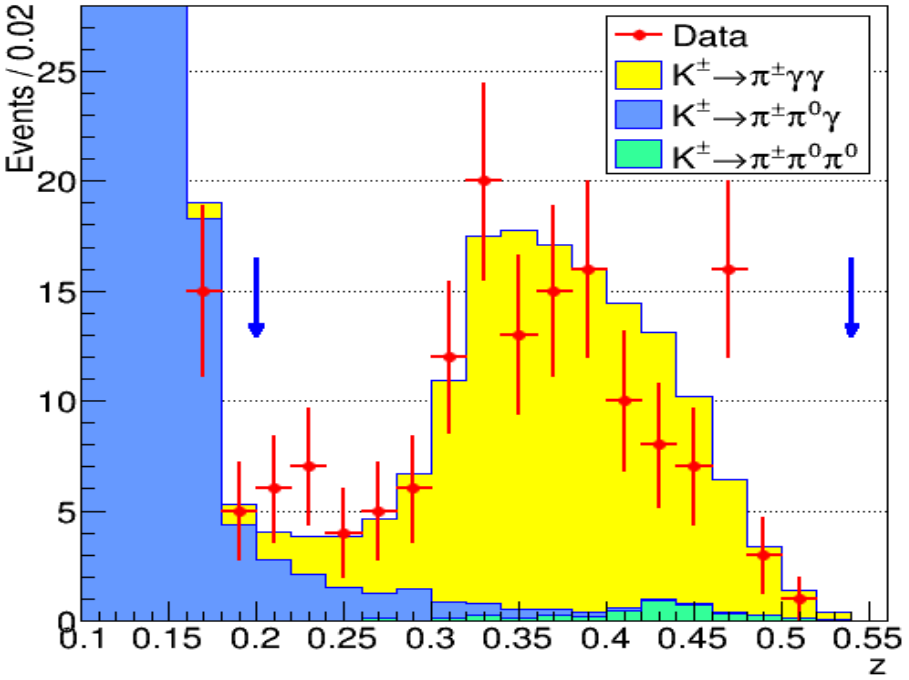
Sum over z-bin

NA48/2 (2003-2004) [Phys. Lett. **B730**(2014) 141]:
$B_{MI}(z>0.2)=(0.877 \pm 0.087\ stat \pm 0.017\ syst) \times 10^{-6}$

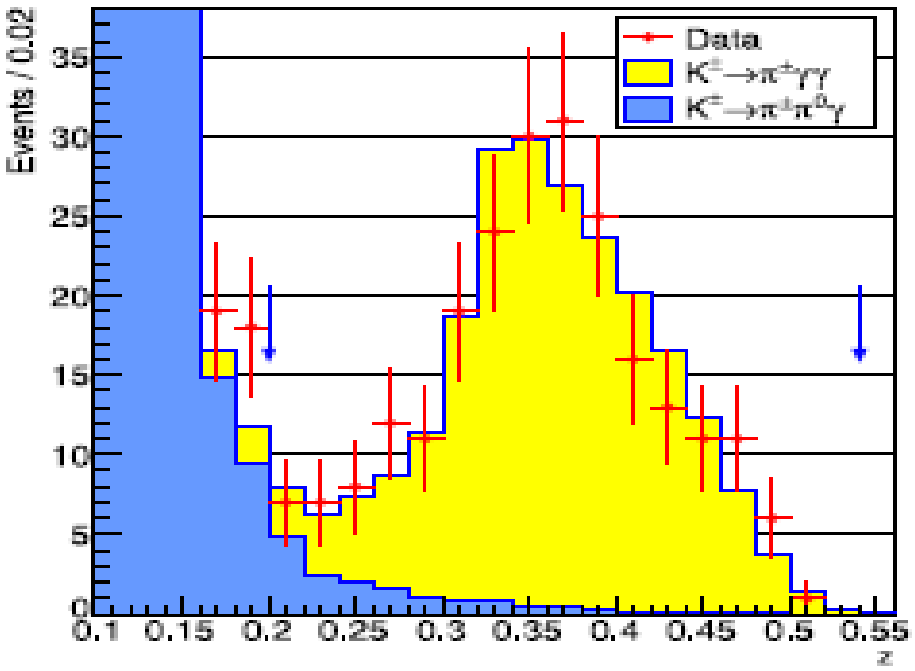
NA62-RK (2007) [Phys. Lett. **B732**(2014) 65]:
$B_{MI}(z>0.2)=(1.088 \pm 0.093\ stat \pm 0.027\ syst) \times 10^{-6}$

Results: ChPT fits

NA48/2 (2003-2004)
[Phys. Lett. **B730**(2014) 141]



NA62-RK (2007)
[Phys. Lett. **B732**(2014) 65]



ChPT $O(p^4)$ and $O(p^6)$ fit to reconstruct the z-spectrum (max log-likelihood)

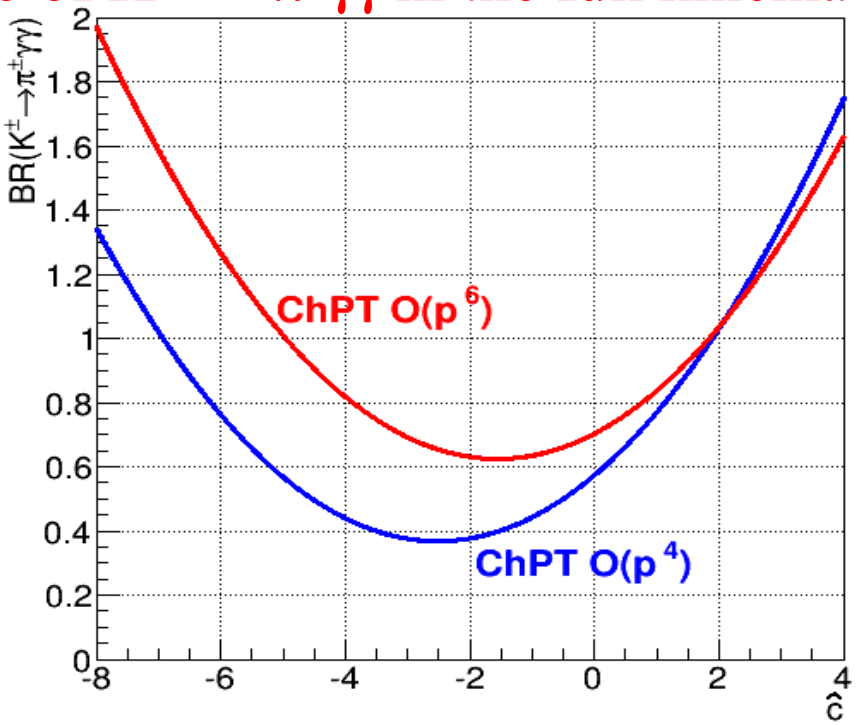
ChPT $O(p^4)$: $\hat{c}_4 = 1.37 \pm 0.33\ stat \pm 0.14\ syst$
ChPT $O(p^6)$: $\hat{c}_6 = 1.41 \pm 0.38\ stat \pm 0.11\ syst$

ChPT $O(p^4)$: $\hat{c}_4 = 1.93 \pm 0.26\ stat \pm 0.08\ syst$
ChPT $O(p^6)$: $\hat{c}_6 = 2.10 \pm 0.28\ stat \pm 0.18\ syst$

✔ Data consistent with both ChPT descriptions
✔ Systematic uncertainty dominated by background estimations

Results: MD BR

Using the measured ĉ we can obtain the Model-Dependent Branching Ratio of $K^{\pm} \to \pi^{\pm}\gamma\gamma$ in the full kinematic region



Integrating the ChPT $O(p^6)$ differential decay rate

NA48/2 (2003,2004) $BR_{ChPT} = (0.910 \pm 0.072\ stat \pm 0.022\ syst) \times 10^{-6}$

NA62-R_K (2007) $BR_{ChPT} = (1.058 \pm 0.066\ stat \pm 0.044\ syst) \times 10^{-6}$

Combined Results

Same set of external parameter used in the measurement of NA48/2 and NA62 ĉ parameters

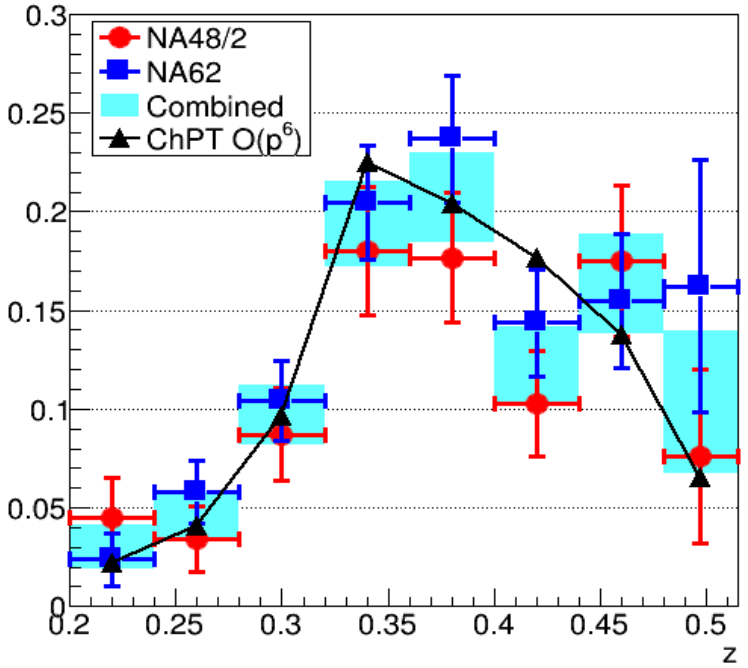
Systematic uncertainty dominated by background evaluation

Combined

[Phys. Lett. **B732**(2014) 65]

$\hat{c}_4 = 1.72 \pm 0.20\ stat \pm 0.06\ syst$

$\hat{c}_6 = 1.86 \pm 0.23\ stat \pm 0.11\ syst$



Integrating the ChPT $O(p^6)$ differential decay rate with combined $\hat{c}_6$

$BR_{ChPT} = (1.003 \pm 0.051\ stat \pm 0.024\ syst) \times 10^{-6}$

PDG [BNL E787 (31 events)]: $BR_6 = (1.1 \pm 0.3 \pm 0.1) \times 10^{-6}$

Conclusions

- The $K \rightarrow \pi\gamma\gamma$ decay has been studied at NA48/2 (149 candidates) and at NA62 (232 candidates)
  - NA48/2 (2003-2004) [Phys. Lett. **B730**(2014) 141]
  - NA62-RK (2007) [Phys. Lett. **B732**(2014) 65]

- Data ara in agreement with ChPT predictions (observation of a cusp)

- The $\hat{c}$ ChPT parameter extracted from the measured z-spectrum

- Data in agreement with both $O(p^4)$ and $O(p^6)$ ChPT models

- Both $\hat{c}$ and BR obtained an improved precision