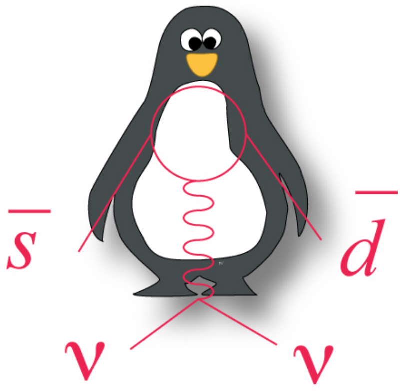

The $K^+ \to \pi^+ \gamma\gamma$ decay at NA62

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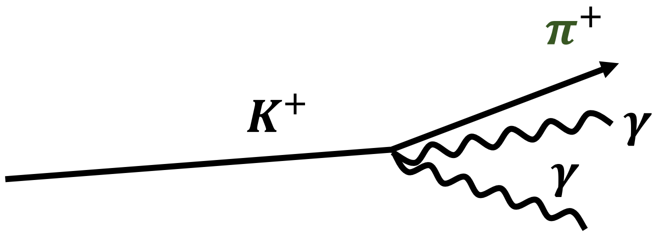
University of Bristol, 26 March 2018

Outline

- The $K^+ \rightarrow \pi^+\gamma\gamma$ decay
- Previous measurements
- The NA62 experiment and detector
- Goals and strategy for measuring $K^+ \rightarrow \pi^+\gamma\gamma$
- Main backgrounds
- Strategy and selection
- Data MC/comparisons
- Status and prospects

The $K^+ \to \pi^+ \gamma\gamma$ decay



- Rare decay: $\mathbf{BR = (1.01 \pm 0.06) \times 10^{-6}}$ (PDG 2017)
- Described by the **Chiral Perturbation Theory (ChPT)**
  Effective field theory for the study of weak interactions at low energy (**non-perturbative QCD**)

Previous measurements by NA48/2 and NA62 at CERN

NA48/2 (2003-2004 min bias):
- Simultaneous K^+ and K^- beams at 60 GeV/c
- **149 decay candidates observed**
- 15.5 ± 0.7 background contamination

NA62 (2007 min bias):
- Single and simultaneous K^+ and K^- beams at 74 GeV/c
- **232 decay candidates observed**
- 17.4 ± 1.1 background contamination

Combined analysis

BR=$(1.003 \pm 0.056) \times 10^{-6}$ (model dependent)

The $K^+ \to \pi^+ \gamma\gamma$ decay (2)

In ChPT:

Differential Decay rate

Loop amplitudes (→ A, B) — Pole amplitude (→ C)

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

- No tree-level contribution $O(p^2)$
- $O(p^4)$: leading contribution – only from A!
- $O(p^6)$: also B and D amplitudes contribute
  - $\frac{d\Gamma}{dz}$ component at low z
- Leading amplitude $A^{(4)}(z)$ determined by single parameter $\hat{c}$ related to ChPT lagrangian coefficients

→ **Measuring the BR allows to determine $\hat{c}$**

NA48/2 & NA62: $\hat{c}_6$=1.86 ± 0.25

$$\mathbf{y} = \frac{\boldsymbol{k} \cdot (\boldsymbol{q_1} - \boldsymbol{q_2})}{\boldsymbol{M_K^2}}$$

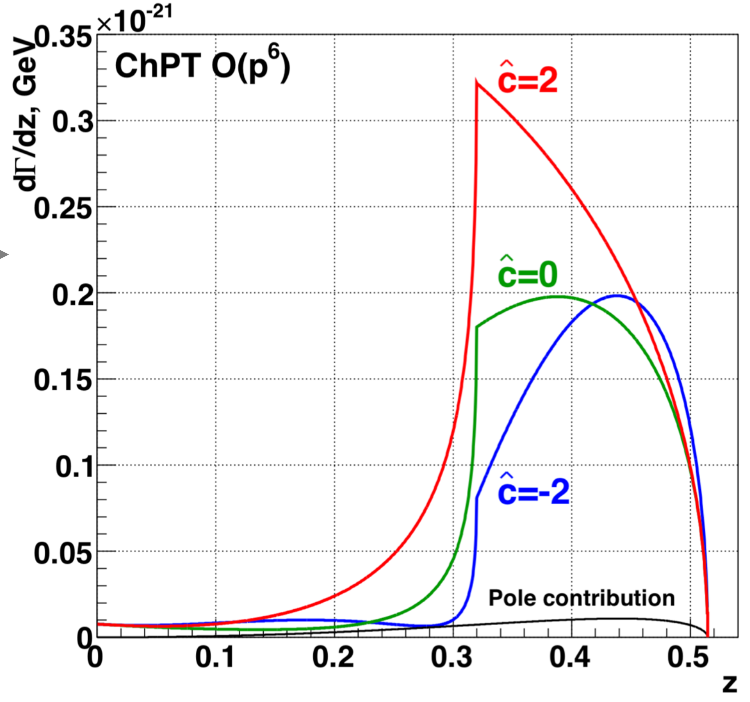
$$\mathbf{z} = \frac{(\mathbf{q_1}+\mathbf{q_2})^2}{\mathbf{M_K^2}} = \left(\frac{\mathbf{m_{\gamma\gamma}}}{\mathbf{M_K}}\right)^2$$

q_1, q_2, k = 4-momenta of γ_1, γ_2, K

Physical region:

$0 \le z \le (1 - r_\pi)^2$=0.515

with ($r_\pi = M_\pi / M_K$)



J.R. Batley et al., Phys. Lett. B730 (2014) 141.

The NA62 experiment and detector

- North Area SPS experiment designed for the ultra-rare decay $K^+ \to \pi^+ \nu \bar{\nu}$
- Fixed target experiment; first period of data-taking 2016-2017

❖ **KTAG (Kaon ID)**
Differential Cherenkov detector
Very high time resolution ($\sigma_t \sim 70$ ps)

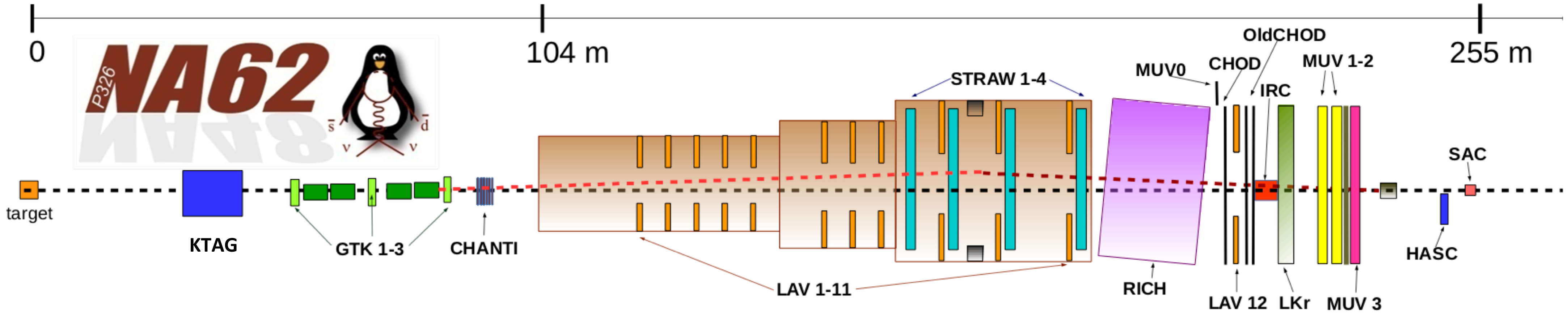
❖ **STRAW (Decay product tracker)**
4 Straw chambers in vacuum + magnet
$\sigma_{dx,dy} \sim 130\ \mu m$

❖ **LKr (EM calorimeter)**
$\sigma_{dx,dy} \sim 1\ mm$, cell size $2 \times 2\ cm^2$

❖ **LAV, SAV, MUV3 (Veto systems)**

❖ **CHOD and Old CHOD (trigger)**

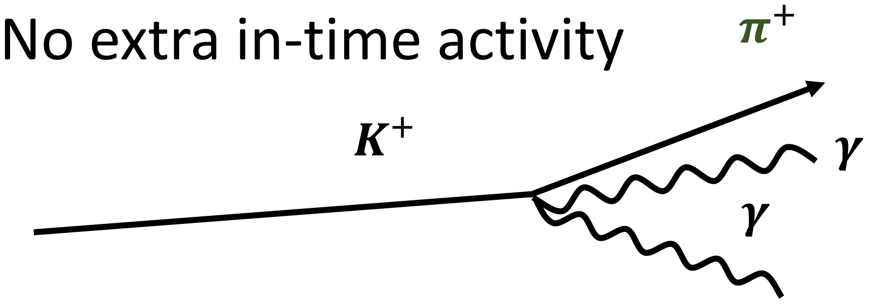
❖ **RICH Precise timing** ($\sigma_t < 100\ ps$)



Strategy for measuring $K^+ \to \pi^+\gamma\gamma$

Experimental signature:

- 1 positive track in the spectrometer (π^+)
- 2 photon clusters in EM calorimeter
- No extra in-time activity



Normalization channel: $K^+ \to \pi^+\pi^0$

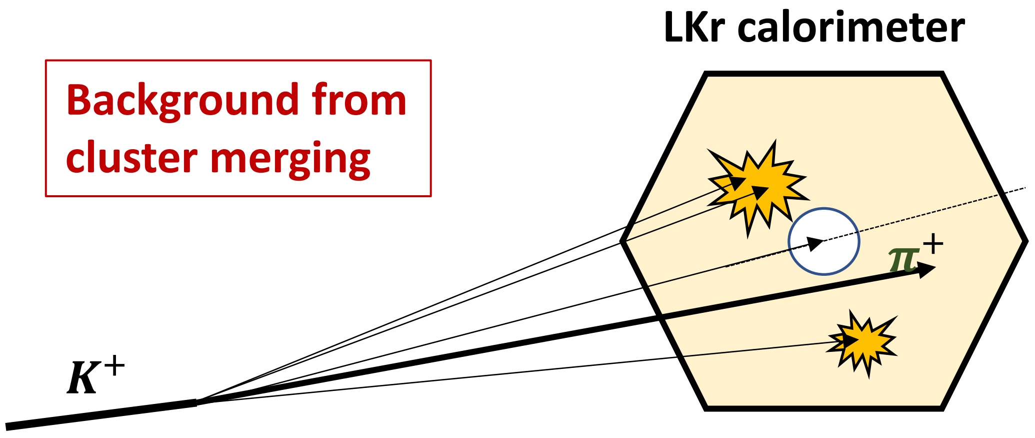
same signature as $K^+ \to \pi^+\gamma\gamma$
except photon pair invariant mass:

- $K^+ \to \pi^+\gamma\gamma$: $m_{\gamma\gamma} > 231.6$ MeV/c^2
- $K^+ \to \pi^+\pi^0$: $m_{\gamma\gamma}$ compatible with M_{π^0}

Backgrounds:

Decay channel	BR
$K^+ \to \pi^+\pi^0(\gamma)$	(20.67±0.08)%
$K^+ \to \pi^+\pi^0\pi^0$	(1.760±0.023)%

(PDG 2017)



Signal selection (1 track and 2 clusters)

1 Trigger lines

- Control trigger (minimum bias)
- "Non-muon" trigger

2 Filter

- Loose quality cuts for tracks and clusters
- Loose cuts on combinatorial total momentum
- **Reduce data by a factor 20**

3 Build "event candidates"

- **Vertex matching**:
  - Group tracks belonging to same decay vertex
- **Time matching**:
  - Group clusters and tracks according to timing cuts

4 Ask exactly 1 event candidate in time group

(against muon halo, extra K)

5 Select "1 track and 2 clusters"

- Event candidate has exactly 1 track and 2 clusters
- Cluster are not associated to the track (away from track extrapolation at the calorimeter)

Signal selection ($K^+ \rightarrow \pi^+\gamma\gamma$ and $K^+ \rightarrow \pi^+\pi^0$)

6 **Decay vertex in fiducial volume**
(115 m to 180 m)

7 **π^+ track**
- Geometric acceptance (STRAW, LKr)
- Particle ID:
  E/p < 0.8, No MUV3 association
- Track quality cuts

8 **$\gamma\gamma$ clusters**
- Minimum energy: **4 GeV**
- Space separation **> 25 cm**
- Time separation **< 10 ns**
- No association to any track

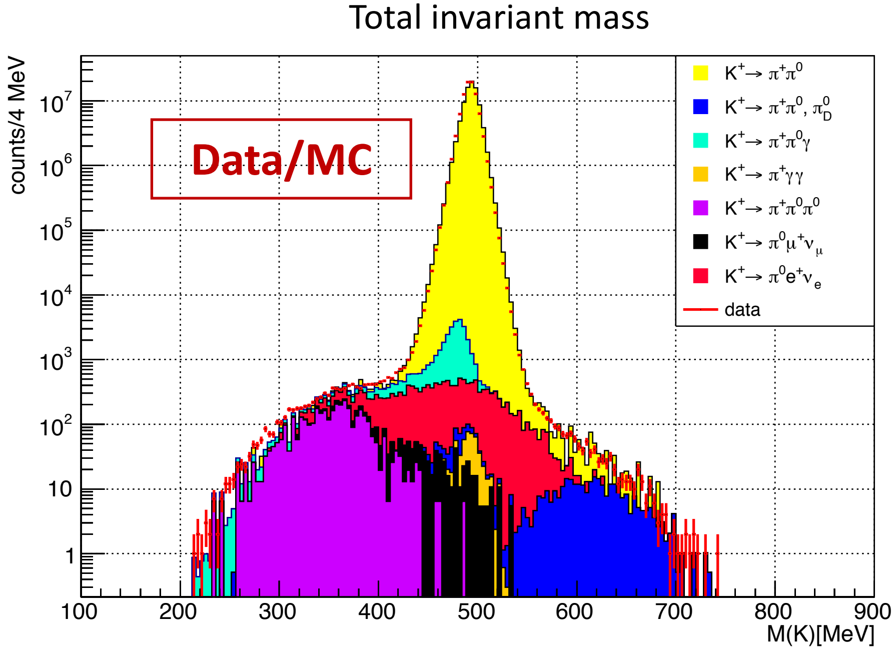
9 **Photon vetoes**
- No activity in LAV and SAV

10 **Kinematic cuts**
- Total momentum: **72.5 GeV to 77.5 GeV**
- Total transverse momentum **< 50 MeV**
- Total invariant mass $\pm 4\ \sigma$ **from** m_K

11 **Photon pair invariant mass**
differentiates signal and normalization
$K^+ \rightarrow \pi^+\pi^0$: $m_{\gamma\gamma}$ within $\pm\ 4\ \sigma$ **from** $m_{\pi 0}$

Preliminary results

- **Data:**
  NA62 2016 and 2017 samples
- **Estimated Kaon flux:** $N_K = 5\times10^9$
- **Acceptance region for signal:** z > 0.22



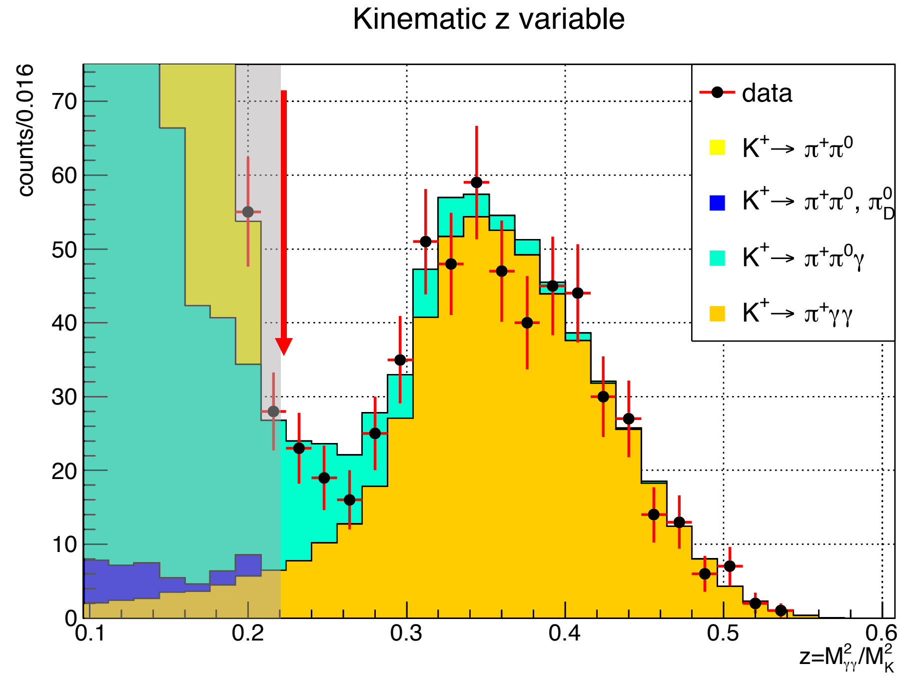
Acceptances and number of expected events

($A = \frac{N_{selected}}{N_{FV}}$):

Decay channel	Acceptance	Nr. exp. ev.
$K^+\to\pi^+\gamma\gamma$	$(9.39 \pm 0.03)\%$	511 ±2
$K^+\to\pi^+\pi^0(\gamma)$	$(2.23 \pm 0.11)\times10^{-5}$	81 ± 4

Small contribution from $K^+\to\pi^+\pi^0\pi^0$ under investigation

About 580 events observed in data sample at z > 0.22



Conclusions and prospects

- A measurement of the decay $\mathbf{K}^{+} \to \boldsymbol{\pi}^{+}\boldsymbol{\gamma\gamma}$ on NA62 2016 and 2017 samples is ongoing
- Largest background from $\boldsymbol{K}^{+} \to \boldsymbol{\pi}^{+}\boldsymbol{\pi}^{0}(\boldsymbol{\gamma})$; small contribution from $\boldsymbol{K}^{+} \to \boldsymbol{\pi}^{+}\boldsymbol{\pi}^{0}\boldsymbol{\pi}^{0}$
- Previous measurements statistics has been matched

Ongoing work:

- Estimate background components due to cluster merging in the calorimeter
- Investigate possible other background mechanisms
- Improve data/MC agreement
- Measurement of the BR
- Study of systematics
- Fit of z distribution for ChPT parameters

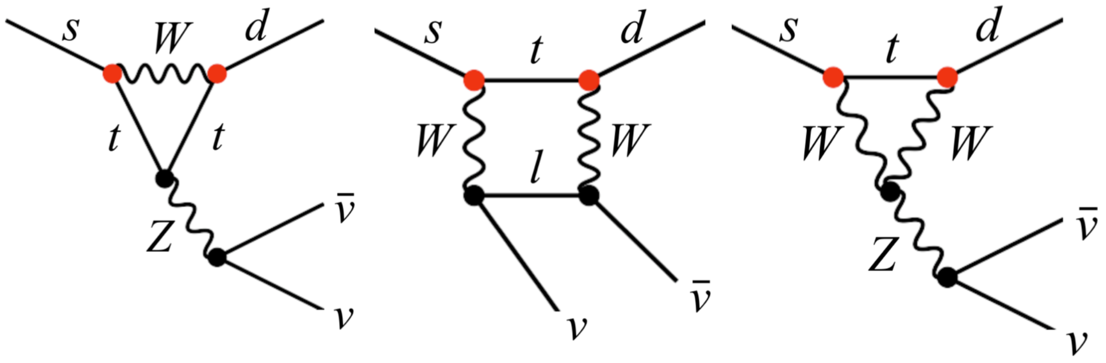
References:

- *G. D'Ambrosio and J. Portoles, Phys. Lett. B386 (1996) 403*
- *Cirigliano, Ecker, Neufeld, Pich, and Portolés, Rev. Mod. Phys. 84, 399*
- *Lazzeroni, C. and others, Phys.Lett. B732 (2014) 65-74*
- *J.R. Batley et al., Phys. Lett. B730 (2014) 141.*

Spares

The $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ decay

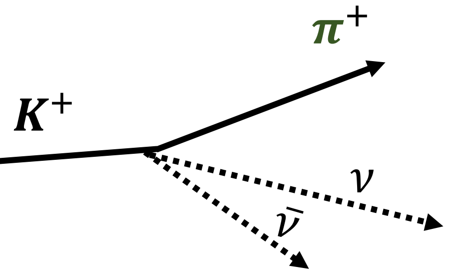
- **Ultra-rare process (BR ~10^{-10})**
- **F**lavour-**C**hanging **N**eutral **C**urrent
- Not allowed at tree level
  → Highly suppressed in the SM
- **Very precise theoretical predictions**
  $$BR = (8.4 \pm 1.0)\times 10^{-11}$$



- **North Area SPS experiment**
- **Currently taking data**
- Technique:
  - High-momentum beam
  - In-flight decay of kaons

Previous measurement:
BNL experiments E787/E949
- Low momentum beam
- Stopped *K*+
- 7 events observed

BR = (17.3 + 11.5 – 10.5) × 10^{-11}



Signature:
- **Matching of K^+ track with π^+ track**
- **Missing energy**

The NA62 detector for $K^+ \to \pi^+ \gamma\gamma$

- North Area SPS experiment
- Optimized for the ultra-rare decay
- First period of data-taking 2016-2017

❖ **KTAG (kaon ID)**
Differential Cherenkov counter
Time resolution: $\boldsymbol{\sigma_t \sim 70\ ps}$

❖ **STRAW spectrometer for decay products**
4 chambers of STRAW tubes in vacuum
Magnet kick 270 MeV/c; space res: $\boldsymbol{\sigma_{dx,dy} \sim 130\ \mu m}$

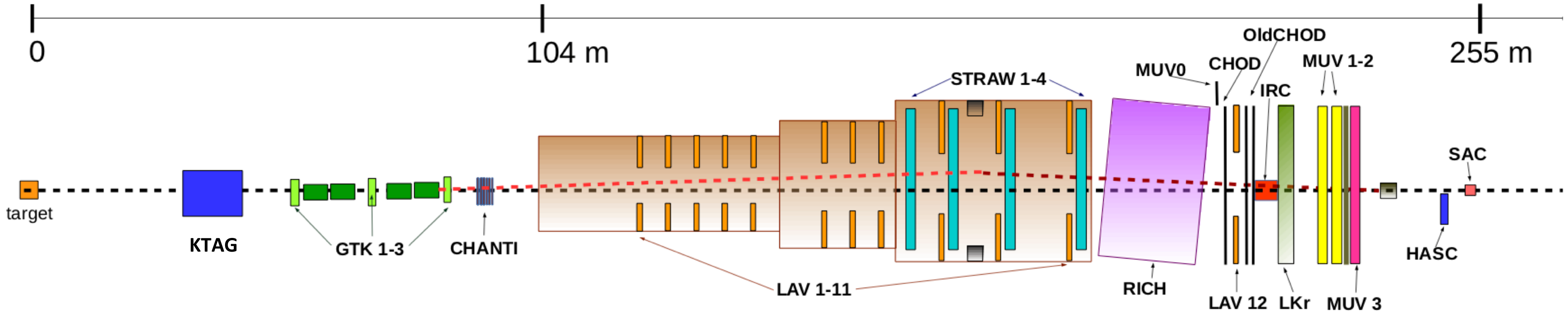
❖ **RICH (π,μ ID)**
Ring Image Cherenkov. Time resolution $\boldsymbol{\sigma_t < 100\ ps}$

❖ **CHOD**
Charged hodoscope; used for control trigger

❖ **LKr EM calorimeter (from NA48)**
Quasi-homogeneous calorimeter; cells size $2{\times}2cm^2$
$\boldsymbol{\sigma_{dx,dy} \sim 1\ mm}$, 10^{-5} inefficiency ($E\gamma$ > 10 GeV)

❖ **LAV and SAV (photon veto)**
Cover angular regions 8.5 to 50 mrad, <1 mrad

❖ **MUV3 (muon veto)**
Scintillator hodoscope behind a 80 cm thick iron wall



The $K^+ \to \pi^+ \gamma\gamma$ decay (2)

In ChPT:

Differential Decay rate

Kaon and pion **loop amplitudes** **Pole amplitude**

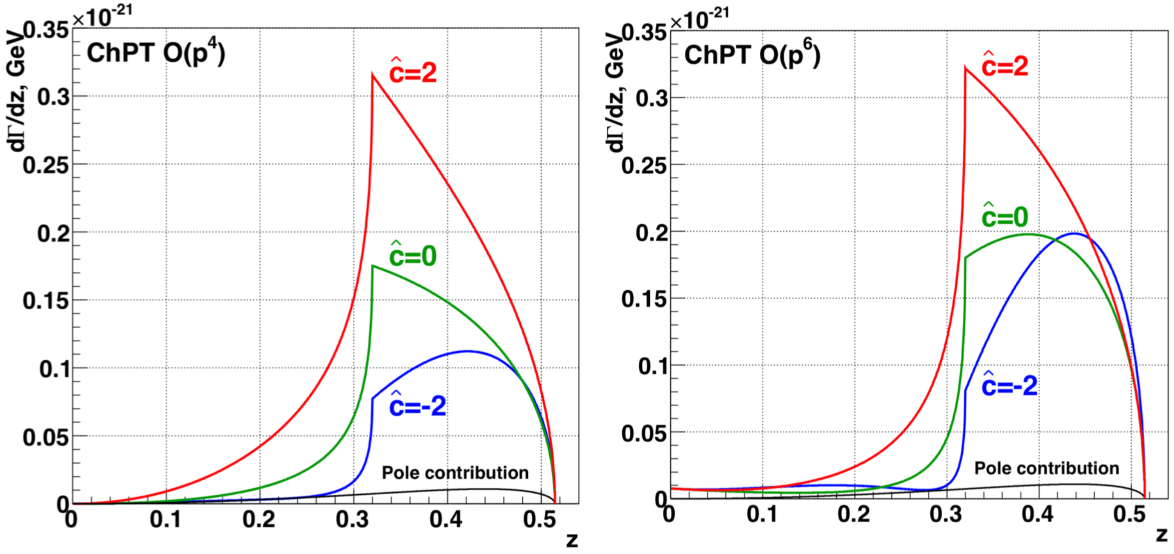
$$\frac{d^2\Gamma}{dydz} = \frac{M_K}{2^9\pi^3}\left\{z^2\left(|A+B|^2+C^2\right)+\left[y^2-\frac{1}{4}\lambda(1,r_\pi^2,z)\right]^2\left(|B|^2+|D|^2\right)\right\}$$

$$y = \frac{(q_1+q_2)^2}{M_K^2} = m_{\gamma\gamma}^2 \qquad z = \frac{k\cdot(q_1-q_2)}{M_K^2}$$

q_1, q_2, k = 4-momenta of $\gamma_1, \gamma_2, \pi^+$

Physical region: $0 \le z \le (1-r_\pi)^2$ with ($r_\pi = M_\pi/M_K$)

- No tree-level contribution O(p^2)
- O(p^4): leading contribution – only from A!
- O(p^6): also B and D amplitudes contribute
  - $\rightarrow \frac{d\Gamma}{dz}$ component at low z



G. D'Ambrosio and J. Portoles, Phys. Lett. B386 (1996) 403

- Leading amplitude $A^{(4)}(z)$ determined by single parameter $\hat{c}$, related to ChPT lagrangian coefficients

→ **Measuring the BR allows to determine $\hat{c}$**

NA48/2 & NA62: $\hat{c}_6$=1.86 ± 0.25

Data/MC comparisons

- some features in data not yet seen in MC: investigations ongoing