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Recent results from the NA62 experiment at CERN

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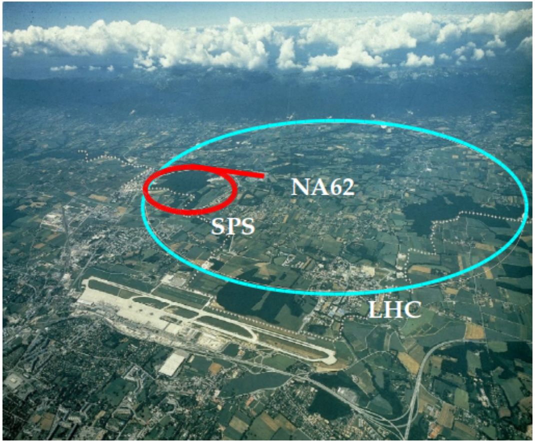
Outline

- NA62 experiment at CERN
- Status of the $K^+ \to \pi^+ \nu \bar{\nu}$ measurement and NA62 physics program
- Recent measurements of rare decays
  - $K^+ \to \pi^+ \mu^+ \mu^-$ [JHEP 11 (2022) 011]
  - $K^+ \to \pi^0 e^+ \nu \gamma$ [JHEP 09 (2023) 040]
  - $K^+ \to \pi^+ \gamma \gamma$ [PLB 850 (2024) 138513]
  - $\pi^0 \to e^+ e^-$ (new preliminary)

NA62 detector

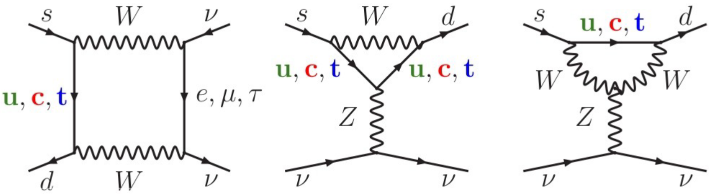
NA62 experiment

- Fixed target experiment at CERN in the *North Area*
- Using 400 GeV/c proton beam from Super Proton Synchrotron (SPS)
- Protons hit a beryllium target $\rightarrow$ secondary 75 GeV/c hadron beam
- Decays of charged kaons from the hadron beam studied using a decay-in-flight technique
- Main goal: Measure the branching ratio of the ultra-rare kaon decay $K^+ \rightarrow \pi^+ \nu\bar{\nu}$



Motivation for $K \to \pi\nu\bar{\nu}$ measurements

- Flavour-changing-neutral-current (FCNC) decays forbidden at tree level
  Box and penguin diagrams:



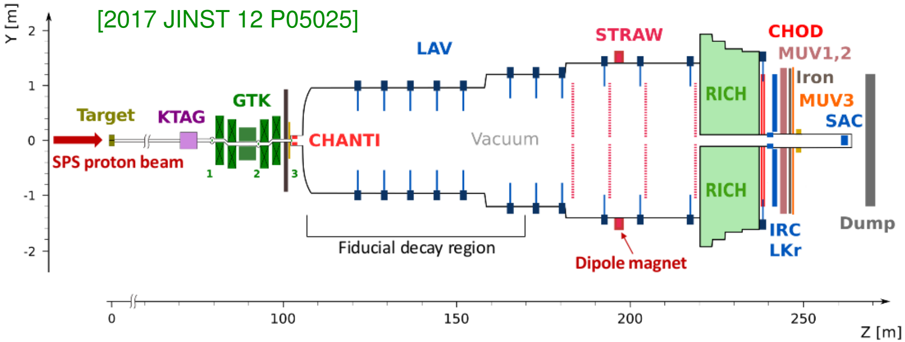
- Highly CKM suppressed, branching ratio $\mathcal{B} \sim |V_{ts}V_{td}|^2$
- Theoretically very clean $\to$ precise predictions from the Standard Model, $\mathcal{B} \sim \mathcal{O}(10^{-10})$
- Sensitive to contributions from new physics
- Measurements of $K^+ \to \pi^+\nu\bar{\nu}$ at NA62 and of $K_L \to \pi^0\nu\bar{\nu}$ at KOTO (Japan)
  a) Disagreement with the Standard Model prediction $\to$ new physics signal
  b) Agreement with the prediction $\to$ important info about the SM parameters

NA62 timeline

- Experiment approved in 2008
- Detector installation completed in 2016
- Data taking:
  - Run 1: 2016 – 2018
  - Run 2: 2021 – CERN Long Shutdown 3
- Proposal for future kaon program at CERN (HIKE) was *not* approved

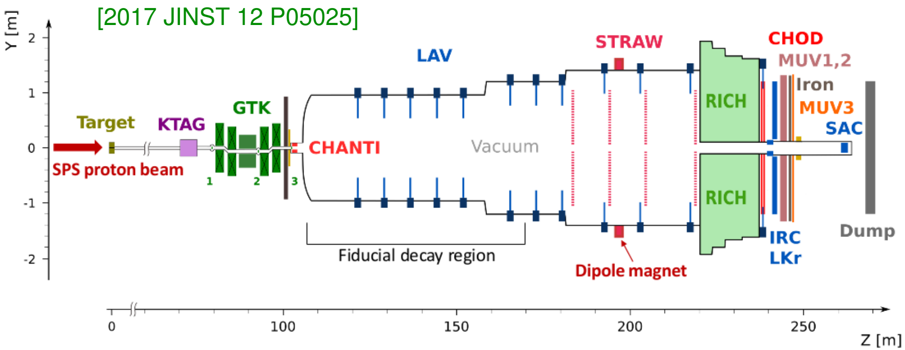
  $\rightarrow$ Measurements of K^+ decays at NA62 will be the most precise for a long time

NA62 beam



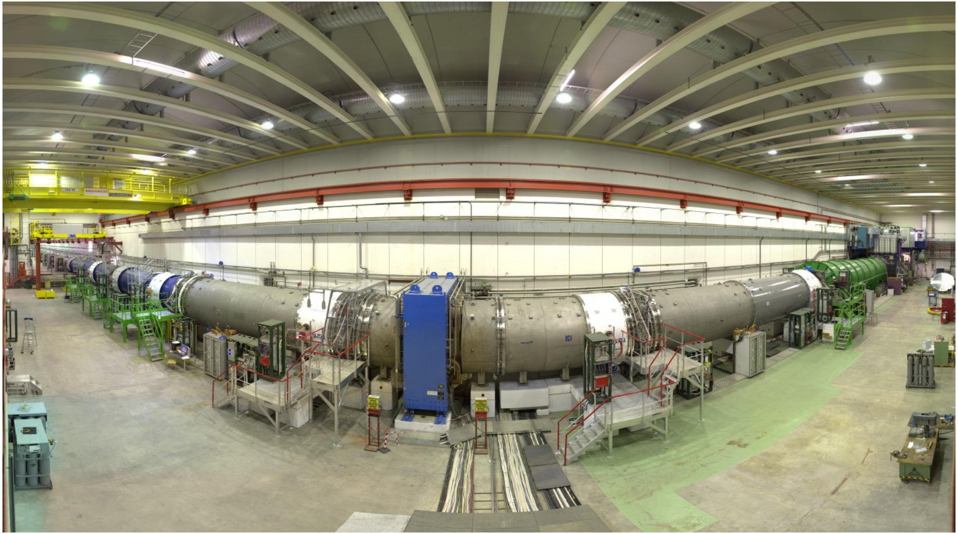
- SPS beam: 400 GeV/c proton on beryllium target
- Secondary hadron 75 GeV/c beam
- 70% pions, 24% protons, 6% **kaons**
- Nominal beam particle rate (at GTK3): 750 *MHz*
- Average beam particle rate during 2018 data-taking: 450 – 500 *MHz*

NA62 detector

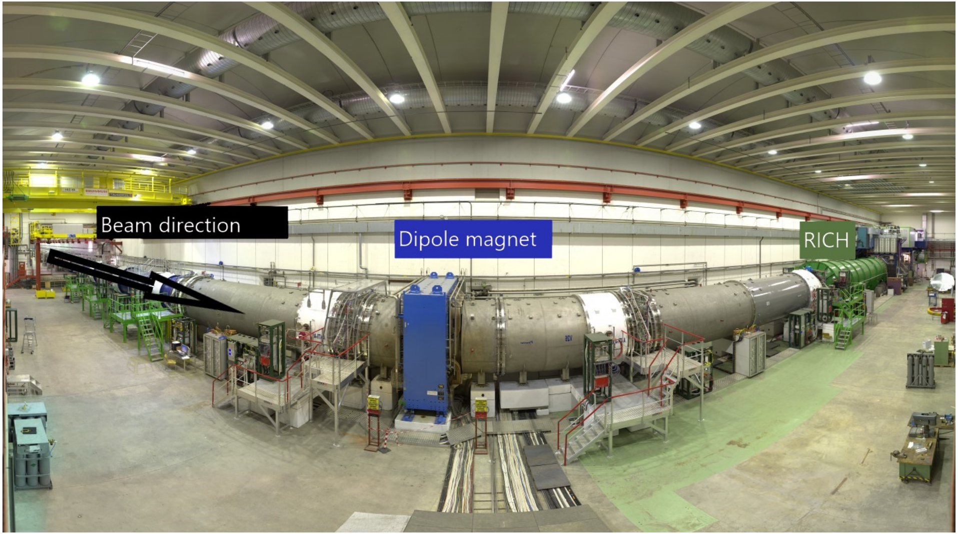


- **KTAG**: differential Cherenkov counter
- **GTK**: Si pixel beam tracker
- CHANTI: stations of plastic scintillator bars
- LAV: lead glass ring calorimeters
- **STRAW**: straw magnetic spectrometer
- **RICH**: Ring Imaging Cherenkov counter
- **CHOD**: planes of scintillator tiles and slabs
- IRC: inner ring shashlik calorimeter
- **LKr**: liquid krypton electromagnetic calorimeter
- MUV1,2: hadron calorimeter
- **MUV3**: plane of scintillator tiles for muon ID
- SAC: small angle shashlik calorimeter

NA62 detector



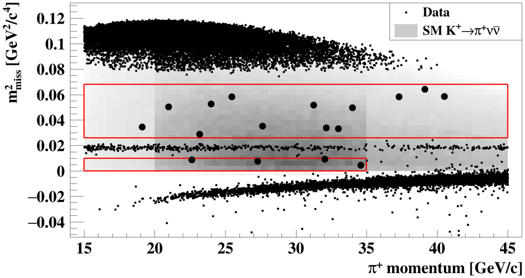
NA62 detector

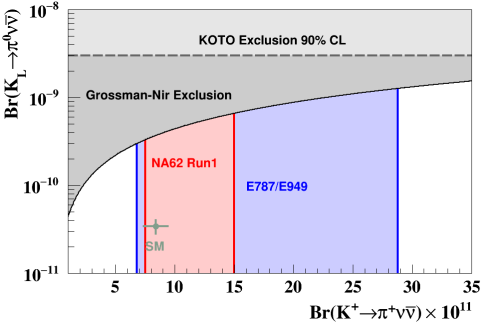


- SM prediction: $\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\text{SM}} = (8.4 \pm 1.0) \times 10^{-11}$ [JHEP 11 (2015) 033]
- NA62 Run 1 = 2016 – 2018 data:
  20 signal candidates, expected background: 7.0 events [JHEP 06 (2021) 093]

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu})_{\text{NA62}} = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9_{\text{syst}}) \times 10^{-11}$$

17 events observed in 2018 data:





NA62 physics

Broad physics program at NA62:

- Main goal: $\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu})$ measurement, analysis of Run 2 data ongoing
- Searches for lepton number and lepton flavour violating decays
  $\to$ e.g. $K^+ \to \pi^-(\pi^0)e^+e^+$ [PLB 830 (2022) 137172]
- Searches for very rare decays
  $\to$ e.g. $K^+ \to \pi^+e^+e^+e^-e^-$ [PLB 846 (2023) 138193]
- Searches for feebly interacting particles
  a) Kaon mode: search for FIP production and/or decay [PLB 807 (2020) 135599]
  e.g. heavy neutral lepton search in $K^+ \to \ell^+\nu_H$ [PLB 816 (2021) 136259]
  b) Beam dump mode: e.g. dark photon search $A' \to \mu^+\mu^-$ [JHEP 09 (2023) 035]
- Precision measurements of rare kaon and pion decays,
  Following analyses of 2017–2018 data presented in **this seminar:**

$\to$ $K^+ \to \pi^+\mu^+\mu^-$ decay [JHEP 11 (2022) 011]

$\to$ $K^+ \to \pi^0e^+\nu\gamma$ decay [JHEP 09 (2023) 040]

$\to$ $K^+ \to \pi^+\gamma\gamma$ decay [PLB 850 (2024) 138513]

$\to$ $\pi^0 \to e^+e^-$ decay (new preliminary)

NA62 physics – precision measurements

- Following analyses of 2017–2018 data (Run 1) presented in **this seminar:**

$\rightarrow$ $K^+ \rightarrow \pi^+\mu^+\mu^-$ decay	[JHEP 11 (2022) 011]
$\rightarrow$ $K^+ \rightarrow \pi^0 e^+\nu\gamma$ decay	[JHEP 09 (2023) 040]
$\rightarrow$ $K^+ \rightarrow \pi^+\gamma\gamma$ decay	[PLB 850 (2024) 138513]
$\rightarrow$ $\pi^0 \rightarrow e^+e^-$ decay	(new preliminary)

- Features of these measurements:
  - Rare decays described by an effective theory, e.g. Chiral Perturbation Theory
  - Free parameters are present in differential decay widths (form factors, etc.)
    $\rightarrow$ parameters are then measured together with branching fractions
  - Measurements provide important information about various fundamental questions; Lepton flavour universality, T-symmetry violation, Axion-like particle searches, Hadronic light-by-light scattering contribution to $(g-2)_\mu, \ldots$
- Run 2 data analyses starting
- Prague group plays a leading role in the Precision measurements working group at NA62

$K^+ \to \pi^+\mu^+\mu^-$: Overview

$K^\pm \to \pi^\pm \ell^+ \ell^-$ decays ($\ell = e, \mu$)

- Flavour-changing neutral-current processes
- Kinematic variable $z = m^2(\ell^+\ell^-)/m_K^2$
- Dominant contribution via virtual photon exchange $K^\pm \to \pi^\pm \gamma^* \to \pi^\pm \ell^+ \ell^-$
- Form factor of the $K^\pm \to \pi^\pm \gamma^*$ transition: $W(z)$
- Chiral Perturbation Theory parameterization of $W(z)$ at $\mathcal{O}(p^6)$:

$$W(z) = G_F m_K^2 (a_+ + b_+ z) + W^{\pi\pi}(z)$$

a_+, b_+: real parameters

$W^{\pi\pi}(z)$: complex function, two-pion loop

Main goals of the NA62 $K^+ \to \pi^+\mu^+\mu^-$ measurement:

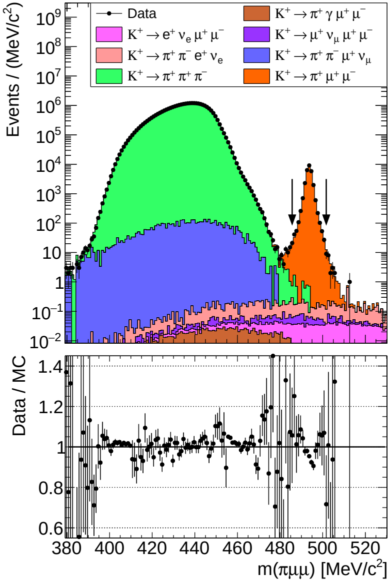
- Measure model-independent branching fraction $\mathcal{B}_{\pi\mu\mu}$
- Measure function $|W(z)|^2$
- Determine FF parameters a_+ and b_+

$K^+ \to \pi^+\mu^+\mu^-$ sample:

- Data: **27679 events observed**
- Normalization using $K^+ \to \pi^+\pi^+\pi^-$: $N(K^+\text{decays}) \approx 3.5 \times 10^{12}$
- Expected background: ≈ 8 events

Analysis:

- Data divided into 50 equipopulated bins in z:
$$\left(\frac{d\Gamma(z)}{dz}\right)_i = \frac{N_{\pi\mu\mu,i}}{A_{\pi\mu\mu,i}} \cdot \frac{1}{\Delta z_i} \cdot \frac{1}{N_K} \cdot \frac{\hbar}{\tau_K}$$
- Integrating $d\Gamma(z)/dz \to$ model-independent $\mathcal{B}$
- $|W(z)|^2$ function values extracted from $d\Gamma(z)/dz$
- Fit of $|W(z)|^2$ data points $\to$ ChPT form factor parameter measurement

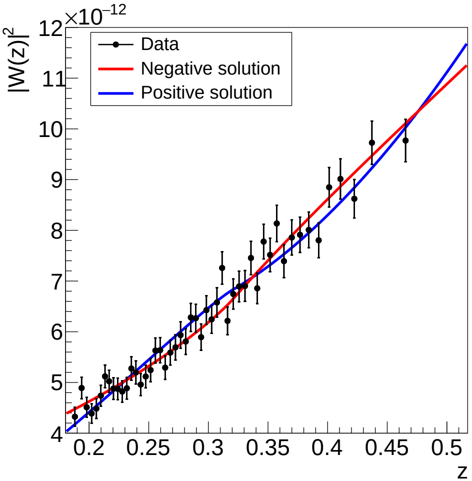


$K^+ \to \pi^+\mu^+\mu^-$: Measurement results

Form factor parameters:

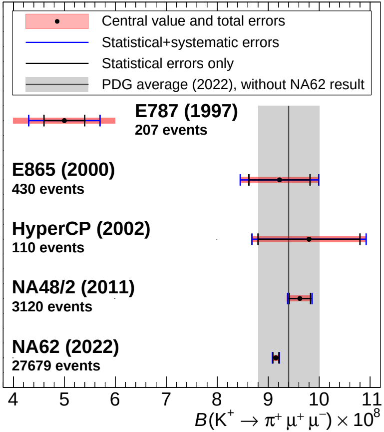
- Two possible solutions:
  a_+, b_+: both *negative* or *positive* values
- Preferred negative solution
  $\chi^2/\text{ndf} = 45.1/48$ (p-value $= 0.59$):

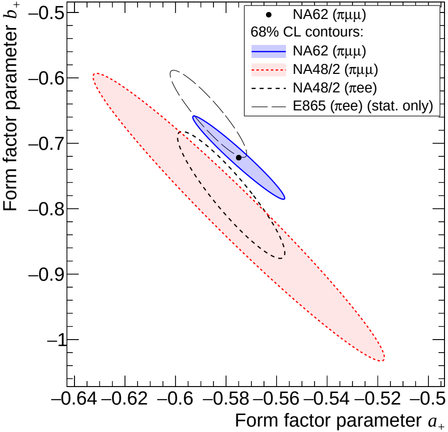
$$a_+ = -0.575 \pm 0.013$$
$$b_+ = -0.722 \pm 0.043$$
$$\text{correlation } \rho(a_+, b_+) = -0.972$$



Branching fraction: $\mathcal{B}_{\pi\mu\mu} = (9.15 \pm 0.08) \times 10^{-8}$

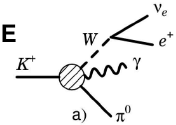
$K^+ \to \pi^+\mu^+\mu^-$: Comparison with previous measurements



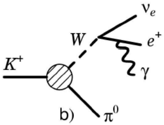


- At least **factor of 3** improvement wrt previous $K_{\pi\mu\mu}$ measurements
- Measurements are compatible
  $\rightarrow$ Agreement in a_+, b_+ from $K_{\pi\mu\mu}$ and $K_{\pi ee}$ $\rightarrow$ lepton flavour universality ✓

DE



IB



Inner Bremsstrahlung (IB) decay amplitude:
$\to$ divergent for $E_\gamma \to 0$ and $\theta_{e,\gamma} \to 0$

Theoretical predictions and experimental measurements for **3 sets** of cuts:
minimal E_γ and $\theta_{e,\gamma}$ (in K^+ rest frame)

$$R_j = \frac{\mathcal{B}(Ke3\gamma^j)}{\mathcal{B}(Ke3)} = \frac{\mathcal{B}(K^+ \to \pi^0 e^+ \nu \gamma \mid E_\gamma^j,\ \theta_{e,\gamma}^j)}{\mathcal{B}(K^+ \to \pi^0 e^+ \nu(\gamma))}$$

	E_γ cut	$\theta_{e,\gamma}$ cut	$O(p^6)$ *ChPT* [EPJ C 50, 557]	ISTRA+	OKA
R_1 $(\times 10^2)$	$E_\gamma > 10$ *MeV*	$\theta_{e,\gamma} > 10°$	1.804 ± 0.021	$1.81 \pm 0.03 \pm 0.07$	$1.990 \pm 0.017 \pm 0.021$
R_2 $(\times 10^2)$	$E_\gamma > 30$ *MeV*	$\theta_{e,\gamma} > 20°$	0.640 ± 0.008	$0.63 \pm 0.02 \pm 0.03$	$0.587 \pm 0.010 \pm 0.015$
R_3 $(\times 10^2)$	$E_\gamma > 10$ *MeV*	$0.6 < \cos\theta_{e,\gamma} < 0.9$	0.559 ± 0.006	$0.47 \pm 0.02 \pm 0.03$	$0.532 \pm 0.010 \pm 0.012$

T-odd observable ξ (K^+ rest frame): $\xi = \dfrac{\vec{p_\gamma} \cdot (\vec{p_e} \times \vec{p_\pi})}{m_K^3}$; Asymmetry: $A_\xi = \dfrac{N_+ - N_-}{N_+ + N_-}$

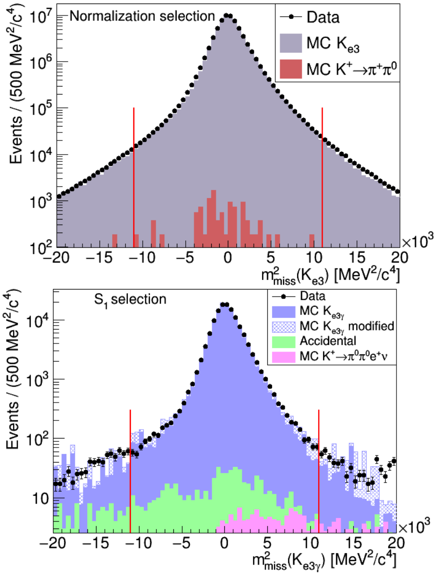
$K^+ \to \pi^0 e^+ \nu\gamma$: Samples and analysis

- Normalization: $K^+ \to \pi^0 e^+ \nu$
  $N(\text{events}) \approx 6.6 \times 10^7$, 10^{-4} background
- $K^+ \to \pi^0 e^+ \nu\gamma$ signal samples, 3 regions S_i:
  - $\to$ $N(\text{events}) \approx 1 \times 10^5$
  - $\to$ Background: $< 1\%$
  - $\to$ Main source of bkg.: accidental activity
- Evaluation of R_j:

$$R_j = \frac{\mathcal{B}(K_{e3\gamma^j})}{\mathcal{B}(K_{e3})} = \frac{N^{\text{obs}}_{Ke3\gamma^j} - N^{\text{bkg}}_{Ke3\gamma^j}}{N^{\text{obs}}_{Ke3} - N^{\text{bkg}}_{Ke3}} \cdot \frac{A_{Ke3}}{A_{Ke3\gamma^j}} \cdot \frac{\epsilon^{\text{trig}}_{Ke3}}{\epsilon^{\text{trig}}_{Ke3\gamma^j}}.$$

- Evaluation of asymmetry:

$$A^{\text{NA62}}_{\xi} = A^{\text{Data}}_{\xi} - A^{\text{MC}}_{\xi}$$



Ratio measurement:

	$O(p^6)$ ChPT	ISTRA+	OKA	**NA62**
R_1 $(\times 10^2)$	1.804 ± 0.021	$1.81 \pm 0.03 \pm 0.07$	$1.990 \pm 0.017 \pm 0.021$	$\mathbf{1.715 \pm 0.005 \pm 0.010}$
R_2 $(\times 10^2)$	0.640 ± 0.008	$0.63 \pm 0.02 \pm 0.03$	$0.587 \pm 0.010 \pm 0.015$	$\mathbf{0.609 \pm 0.003 \pm 0.006}$
R_3 $(\times 10^2)$	0.559 ± 0.006	$0.47 \pm 0.02 \pm 0.03$	$0.532 \pm 0.010 \pm 0.012$	$\mathbf{0.533 \pm 0.003 \pm 0.004}$

- Precision improved by a factor > 2
- About 5% smaller value than ChPT prediction

Asymmetry measurement:

	ISTRA+	OKA	**NA62**
$A_\xi(S_1)$ $(\times 10^3)$		$-0.1 \pm 3.9 \pm 1.7$	$\mathbf{-1.2 \pm 2.8 \pm 1.9}$
$A_\xi(S_2)$ $(\times 10^3)$		$-4.4 \pm 7.9 \pm 1.9$	$\mathbf{-3.4 \pm 4.3 \pm 3.0}$
$A_\xi(S_3)$ $(\times 10^3)$	15 ± 21	$7.0 \pm 8.1 \pm 1.5$	$\mathbf{-9.1 \pm 5.1 \pm 3.5}$

- Compatible with no asymmetry
- Uncertainties still larger than theory expectations

$K^+ \to \pi^+\gamma\gamma$: Overview

- Long-distance dominated radiative decay
- Crucial test of Chiral Perturbation Theory
- Kinematic variables (q_i: photon momenta, p: kaon momentum)

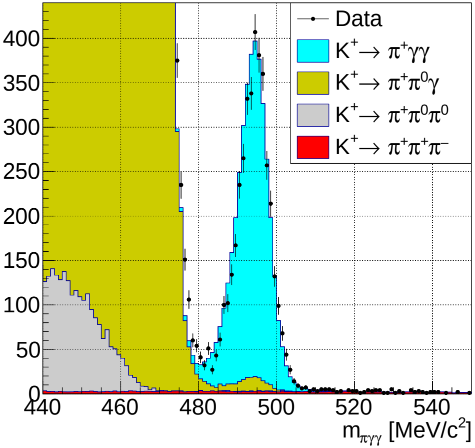
$$z = \frac{(q_1 + q_2)^2}{m_K^2} = \frac{m_{\gamma\gamma}^2}{m_K^2}, \qquad y = \frac{p \cdot (q_1 - q_2)}{m_K^2}$$

- Differential decay width [PLB 386 (1996) 403]:

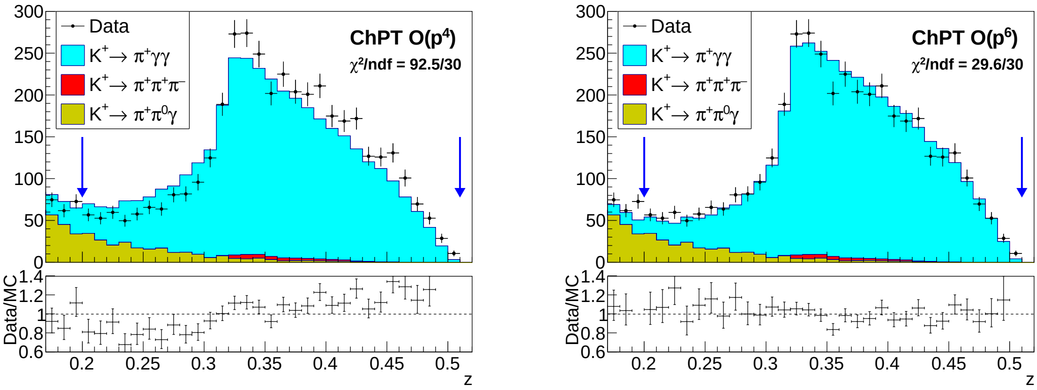
$$\frac{\partial^2 \Gamma}{\partial y\, \partial z} = \frac{m_K}{2^9 \pi^3} \left[z^2 \left(|\, A(\hat{c}, y, z) + B(z)\,|^2 + |\, C(z)\,|^2 \right) + \left(y^2 - \frac{1}{4}\lambda(1, r_\pi^2, z) \right)^2 |B(z)\,|^2 \right]$$

→ The spectrum and rate depend on one parameter $\hat{c}$
→ $B(z)$ appears at ChPT $\mathcal{O}(p^6)$
→ Goal: measure $\hat{c}_6$ and the corresponding branching fraction

- Signal selection
  - Single positive track identified as π^+
  - Pion track matched with a K^+ track
  - Two γ clusters in LKr
  - Kinematic constraints on $m_{\pi\gamma\gamma}$ and $p_{\pi\gamma\gamma}$
  - $z \in (0.20, 0.51)$
- Normalization selection: done using $K^+ \to \pi^+\pi^0, \pi^0 \to \gamma\gamma$ with $z \in (0.04, 0.12)$
- Main background is due to $K^+ \to \pi^+\pi^0\gamma, \pi^0 \to \gamma\gamma$ decay; cluster merging in calorimeter

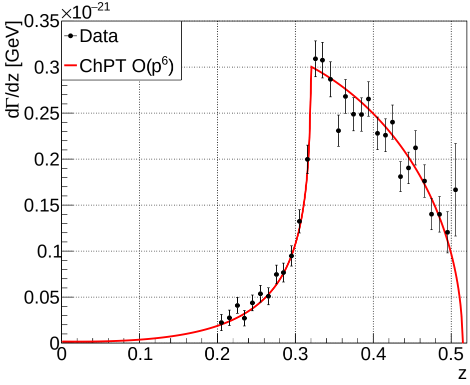


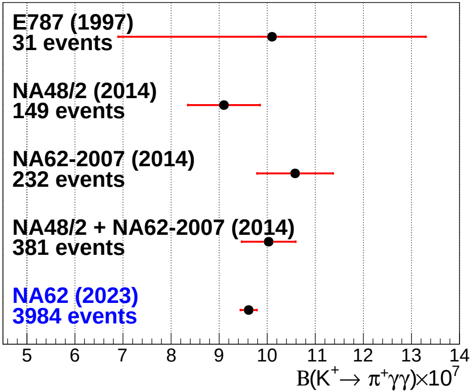
$K^+ \to \pi^+\gamma\gamma$ results



- 3984 observed events; 291 $\pm$ 14 events - expected background
- $\hat{c}$ parameter measured in ChPT $\mathcal{O}(p^4)$ and $\mathcal{O}(p^6)$ using χ^2 minimization
- ChPT $\mathcal{O}(p^4)$ p-value: 2.7×10^{-8}: not sufficient to describe the di-photon mass spectrum
- ChPT $\mathcal{O}(p^6)$ p-value: 0.49

$K^+ \to \pi^+\gamma\gamma$ results





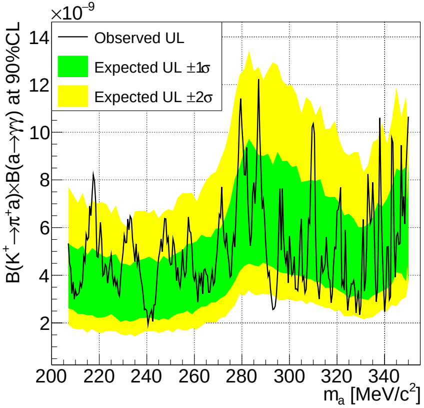
$$\hat{c} = 1.144 \pm 0.069_{\text{stat.}} \pm 0.034_{\text{syst.}}$$

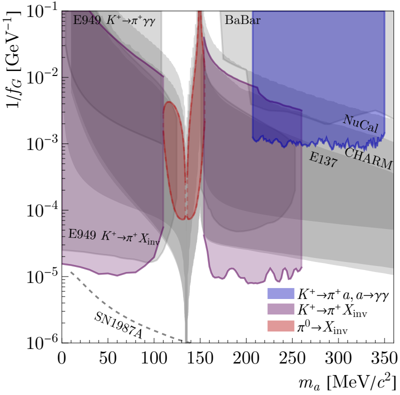
$$\mathcal{B}_{\text{ChPT}\mathcal{O}(p^6)}(K^+ \to \pi^+\gamma\gamma) = (9.61 \pm 0.15_{\text{stat.}} \pm 0.07_{\text{syst.}}) \cdot 10^{-7}$$

$$\mathcal{B}_{\text{MI}}(K^+ \to \pi^+\gamma\gamma | z > 0.20) = (9.46 \pm 0.19_{\text{stat.}} \pm 0.07_{\text{syst.}}) \cdot 10^{-7}$$

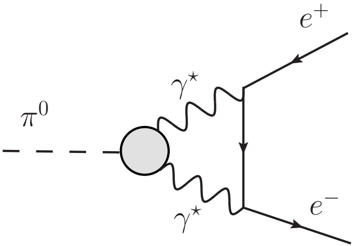
First search for ALP in $K^+ \to \pi^+ A$, $A \to \gamma\gamma$ decays

- Peak search over $m_a = \sqrt{(P_K - P_\pi)^2}$ in the range 207 - 350 MeV/c^2 in steps of 0.5 MeV/c^2
- m_a resolution: from 2.0 MeV/c^2 to 0.2 MeV/c^2 across the search range
- In each m_a hypothesis, background estimated from simulations and UL on number of signal events using CLs method





$\pi^0 \to e^+e^-$: Overview



- Experimentally observable:

$$\mathcal{B}(\pi^0 \to e^+e^-(\gamma), x > x_{\text{cut}}), \quad x = m_{ee}^2/m_{\pi^0}^2$$

  - Dalitz decay $\pi^0 \to \gamma e^+e^-$ dominant in low-x region
  - For $x > x_{\text{cut}} = 0.95$, Dalitz decay $\approx 3.3\%$ of $\mathcal{B}(\pi^0 \to e^+e^-(\gamma))$

- Previous best measurement by KTeV [Phys.Rev.D 75 (2007) 012004]

$$\mathcal{B}_{\text{KTeV}}(\pi^0 \to e^+e^-(\gamma), x > 0.95) = (6.44 \pm 0.25 \pm 0.22) \times 10^{-8}$$

- Using latest radiative corrections in [JHEP 10 (2011) 122], [Eur.Phys.J.C 74 (2014) 8, 3010], the result can be extrapolated and compared with theory:

- Diagram considered in theoretical predictions leading to $\mathcal{B}(\pi^0 \to e^+e^-, \text{no-rad})$ for various $\pi^0 \to \gamma^\star\gamma^\star$ transition form factors.

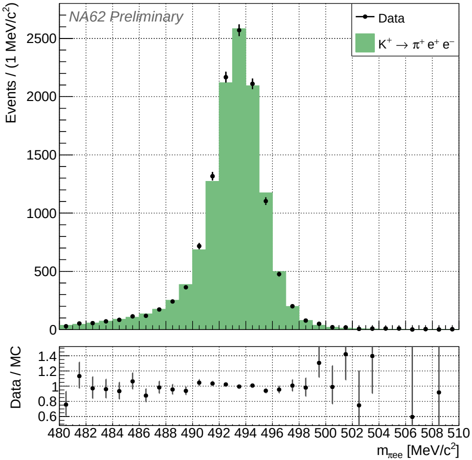
	$\mathcal{B}(\pi^0 \to e^+e^-, \text{no-rad}) \times 10^8$
KTeV, PRD 75 (2007)	6.84(35)
Knecht et al., PRL 83 (1999)	6.2(3)
Dorokhov and Ivanov, PRD 75 (2007)	6.23(9)
Husek and Leupold, EPJC 75 (2015)	6.12(6)
Hoferichter et al., PRL 128 (2022)	6.25(3)

$\pi^0 \to e^+e^-$: Data sample and trigger

- Data sample collected by NA62 in 2017 and 2018
- Signal decay mode: $K^+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^- \equiv K^+ \to \pi^+\pi^0_{ee}$
  - Latest radiative corrections included in the simulation
- Normalization decay mode: $K^+ \to \pi^+e^+e^-$
  - Identical final state as the signal, common selection criteria $\to$ cancellation of systematics
  - Selecting almost background-free region $m_{ee} > 140\,\text{MeV}$
- *Multi-track electron* trigger line used to collect both $K^+ \to \pi^+\pi^0_{ee}$ and $K^+ \to \pi^+e^+e^-$
  - Downscaling factor $D_{eMT} = 8$
  - Level-0: RICH, CHOD, LKr
  - Level-1: KTAG, Straw
  - Total trigger efficiency $\approx$ 90% for both signal and normalization
- Backgrounds for the signal decay mode:
  - $K^+ \to \pi^+e^+e^-$: irreducible, flat in the signal region close to the π^0 mass
  - $K^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma e^+e^- \equiv K^+ \to \pi^+\pi^0_D$
    a) Large-x tail of the π^0 Dalitz decay distribution
    b) Photon conversion in STRAW + selection of a $e^\pm$ track from the conversion
  - $K^+ \to \pi^+\pi^0$, $\pi^0 \to e^+e^-e^+e^- \equiv K^+ \to \pi^+\pi^0_{DD}$, π^0 double Dalitz decay with two undetected $e^\pm$

Common selection criteria for $K^+ \to \pi^+\pi^0_{ee}$ and $K^+ \to \pi^+e^+e^-$

- Three track vertex topology (STRAW)
- Timing cuts (CHOD, KTAG)
- Kinematic constraints on total and transverse momenta of the vertex
- Particle ID using LKr + STRAW and decay kinematics
  - π^+: $E/p < 0.9$
  - $e^\pm$: $E/p \in (0.9, 1.1)$
  - Total invariant mass: $m_{\pi ee} \in (480\ ,\ 510)$ MeV
  - Di-electron invariant mass: $m_{ee} > 130$ MeV
- Background suppression:
  - Using STRAW hit information to reject $e^\pm$ tracks from γ conversions
  - Reject events with a track segment reconstructed in the first two STRAW chambers compatible with the vertex



$K^+ \to \pi^+ e^+ e^-$ normalization sample

- Common selection applied
- Normalization region:

$$m_{ee} \in (140\ ,\ 360)\ \text{MeV}$$

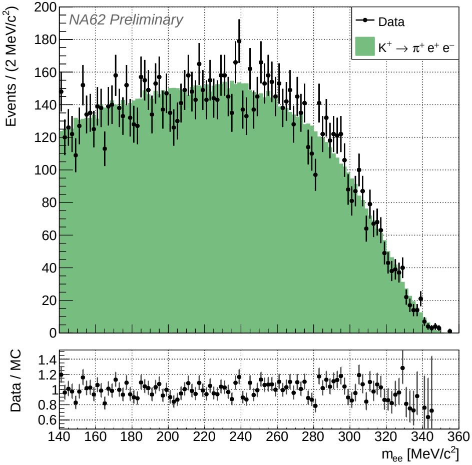
- Number of observed events: 12160
- Acceptance:

$$A(K^+ \to \pi^+ e^+ e^-) = (4.70 \pm 0.01_{\text{stat}})\%$$

- Sample purity $> 99.9\%$
- Effective number of kaon decays:

$$N_K = (8.62 \pm 0.08_{\text{stat}} \pm 0.26_{\text{ext}}) \times 10^{11}$$

  - External uncertainty from $\mathcal{B}_{\text{PDG}}(K^+ \to \pi^+ e^+ e^-) = (3.00 \pm 0.09) \times 10^{-7}$



$K^+ \to \pi^+\pi^0_{ee}$ signal sample

- Common selection applied
- Fit region:

$$m_{ee} \in (130\ ,\ 140)\,\text{MeV}$$

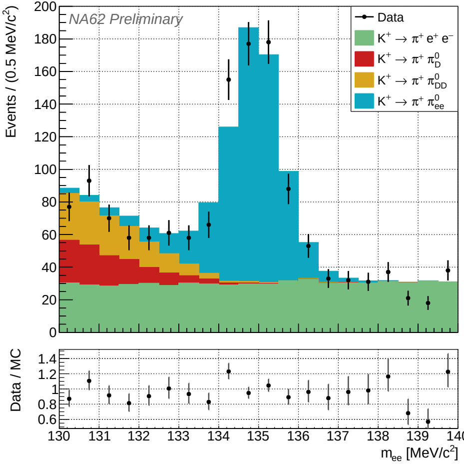
- Signal acceptance ($x_{\text{true}} > 0.95$):

$$A(K^+ \to \pi^+\pi^0_{ee}) = (5.72 \pm 0.02_{\text{stat}})\,\%$$

- Branching fraction of $\pi^0 \to e^+e^-$ obtained by performing maximum likelihood fit of simulated samples to data

$$\mathcal{B}(\pi^0 \to e^+e^-(\gamma), x > 0.95) = (5.86 \pm 0.30_{\text{stat}}) \times 10^{-8}$$

  - Branching fractions of other decays: external input from PDG 2023
  - Fitted signal event yield: 597 ± 29
  - Chi-squared test: $\chi^2/\text{ndf} = 25.3/19$, p-value: 0.152



$\pi^0 \to e^+e^-$: Preliminary result and uncertainties

$$\mathcal{B}_{\text{NA62}}(\pi^0 \to e^+e^-(\gamma), x > 0.95) = (5.86 \pm 0.30_{\text{stat}} \pm 0.11_{\text{syst}} \pm 0.19_{\text{ext}}) \times 10^{-8} = (5.86 \pm 0.37) \times 10^{-8}$$

	$\delta\mathcal{B}$ $[10^{-8}]$	$\delta\mathcal{B}/\mathcal{B}$ [%]
Statistical uncertainty	0.30	5.1
Total external uncertainty	0.19	3.2
Total systematic uncertainty	0.11	1.9
Trigger efficiency	0.07	1.2
Radiative corrections for $\pi^0 \to e^+e^-$	0.05	0.9
Background	0.04	0.7
Reconstruction and particle identification	0.04	0.7
Beam simulation	0.03	0.5

$K^+ \to \pi^+\pi^0, \pi^0 \to e^+e^-$: Summary and outlook

- New preliminary result based on data collected by NA62 in 2017 – 2018:

$$\mathcal{B}_{\text{NA62}}(\pi^0 \to e^+e^-(\gamma), x > 0.95) = (5.86 \pm 0.30_{\text{stat}} \pm 0.11_{\text{syst}} \pm 0.19_{\text{ext}}) \times 10^{-8} = (5.86 \pm 0.37) \times 10^{-8}$$

- Lower central value than in KTeV measurement, but results are compatible:

$$\mathcal{B}_{\text{KTeV}}(\pi^0 \to e^+e^-(\gamma), x > 0.95) = (6.44 \pm 0.33) \times 10^{-8}$$

- Result in agreement with theoretical expectations when extrapolated using radiative corrections:

$$\mathcal{B}_{\text{NA62}}\left(\pi^0 \to e^+e^-, \text{no-rad}\right) = (6.22 \pm 0.39) \times 10^{-8}$$

$$\mathcal{B}_{\text{theory (2022)}}\left(\pi^0 \to e^+e^-, \text{no-rad}\right) = (6.25 \pm 0.03) \times 10^{-8}$$

- External uncertainty dominated by $\mathcal{B}(K^+ \to \pi^+e^+e^-)$, measured by NA48/2 and E865
    - New analysis of $K^+ \to \pi^+e^+e^-$ is planned at NA62
- Ongoing NA62 data taking (2021 – LS3)
    - Optimized multi-track electron trigger line with reduced downscaling
    - Collecting large samples of decays with di-electron final states

Summary

NA62 Run 1 (2016 – 2018):

- Main measurement: $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu}) = (10.6^{+4.0}_{-3.4}|_{\text{stat}} \pm 0.9_{\text{syst}}) \times 10^{-11}$ [JHEP 06 (2021) 093]
- Recent precision measurements by NA62:
  - $\rightarrow$ $K^+ \to \pi^+ \mu^+ \mu^-$ decay [JHEP 11 (2022) 011]
  - $\rightarrow$ $K^+ \to \pi^0 e^+ \nu \gamma$ decay [JHEP 09 (2023) 040]
  - $\rightarrow$ $K^+ \to \pi^+ \gamma\gamma$ decay [PLB 850 (2024) 138513]
  - $\rightarrow$ $\pi^0 \to e^+ e^-$ decay (new preliminary)
- Precision for most of the measurements limited by data statistics

NA62 Run 2 (2021 – CERN Long Shutdown 3):

- Increase in beam intensity
- Beamline and detector improvements for $K^+ \to \pi^+ \nu \bar{\nu}$ measurement
  $\rightarrow$ Target relative precision for $\mathcal{B}(K^+ \to \pi^+ \nu \bar{\nu})$: 15%
- Trigger improvements, reduced downscaling factor for events with $e^+ e^-$ final state
  $\rightarrow$ Large sample of di-electron decays (including $K^+ \to \pi^+ e^+ e^-$) will be collected