NA62 status and plans

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on behalf of the NA62UK collaboration

Outline:

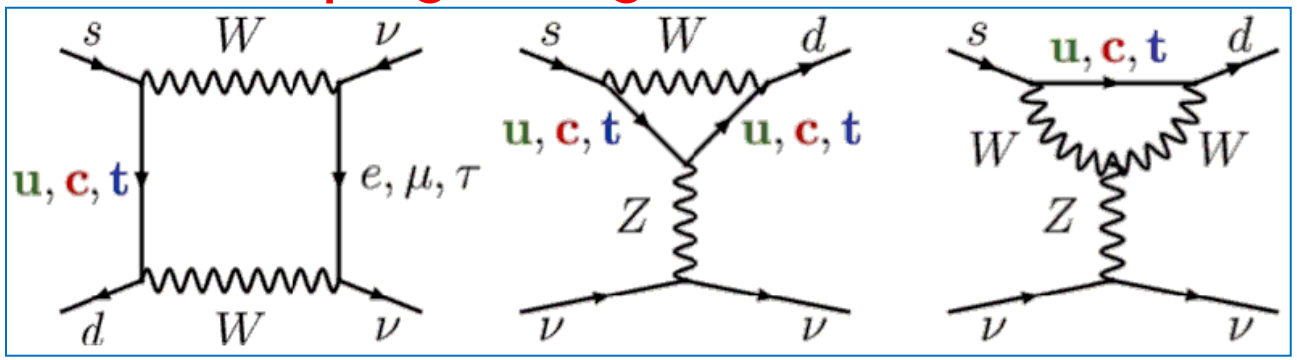
1) Introduction: rare kaon decays
2) NA62 status and UK involvement
3) Results and prospects on the $K^+ \to \pi^+ \nu\nu$ measurement
4) Highlights of the broader NA62 physics programme
5) Summary

PPAP community meeting

RAL • 17 July 2018

Rare kaon decays: $K \to \pi \nu \bar{\nu}$

SM: box and penguin diagrams



Ultra-rare decays with the highest CKM suppression:

$$A \sim (m_t/m_W)^2 |V^*_{ts} V_{td}| \sim \lambda^5$$

- SM precision surpasses any other FCNC process involving quarks.
- Measurement of $|V_{td}|$ complementary to those from B–$\bar{B}$ mixing or $B^0 \to \rho\gamma$.
- Main focus of kaon physics: measurement of both $K^+ \to \pi^+ \nu\nu$ and $K_L \to \pi^0 \nu\nu$ decays.

SM branching ratios

Buras et al., JHEP 1511 (2015) 033

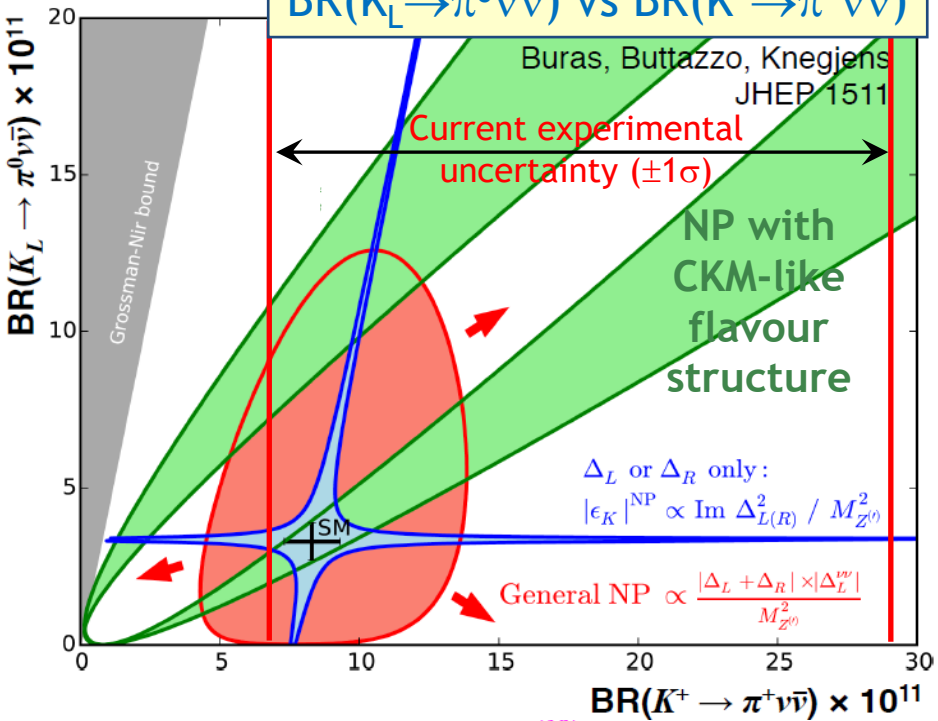
Mode	$BR_{SM} \times 10^{11}$
$K^+ \to \pi^+ \nu\bar{\nu}(\gamma)$	8.4±1.0
$K_L \to \pi^0 \nu\bar{\nu}$	3.4±0.6

The uncertainties are largely parametric (CKM)

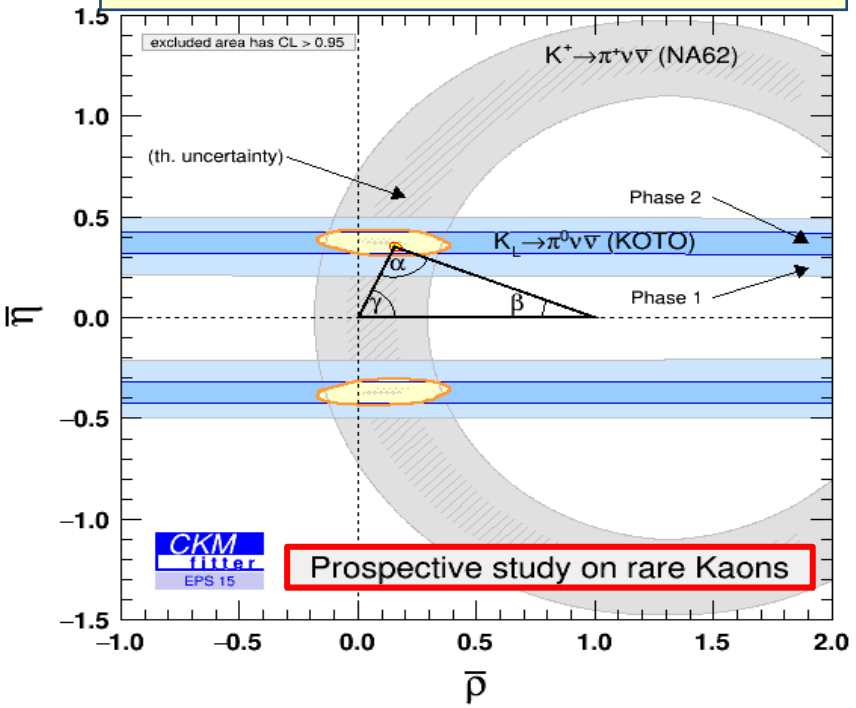
Theoretically clean, almost unexplored, sensitive to new physics.

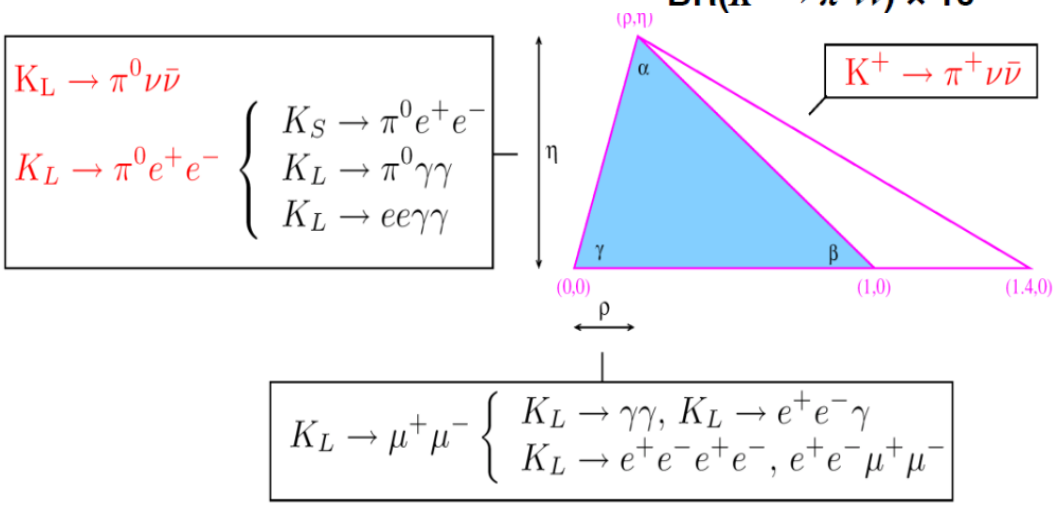
Status of theory and experiment

BR($K_L \to \pi^0 \nu\bar{\nu}$) vs BR($K^+ \to \pi^+ \nu\bar{\nu}$)



CKM unitarity triangle with kaons

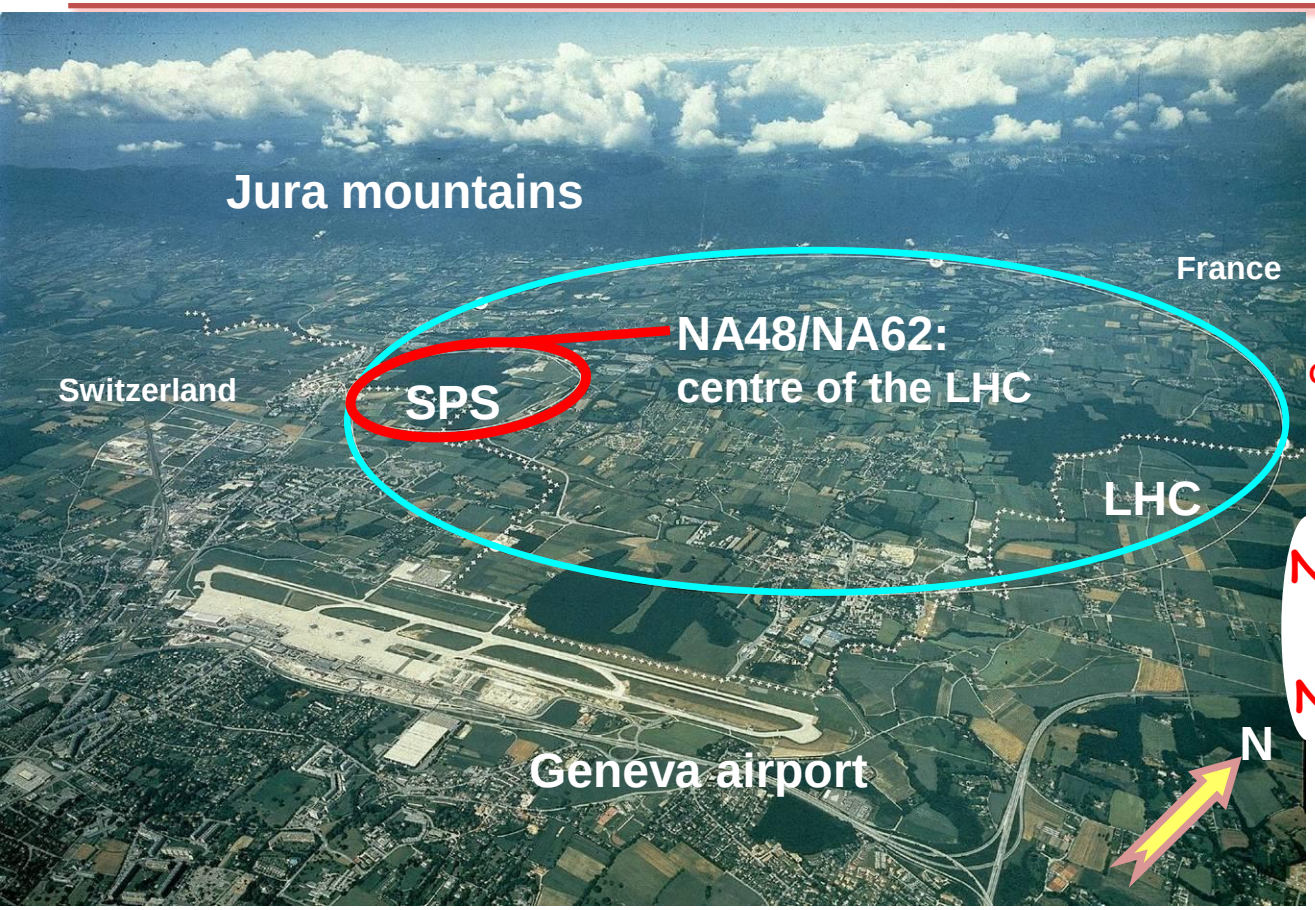




- Kaon measurements alone can fully constrain the unitarity triangle.
- Complementary to B physics in the description of NP flavour dynamics.

NA62 status and UK involvement

NA62 experiment at CERN



Earlier: NA31

NA48 discovery of direct CPV	1997: ε'/ε: K_L+K_S	
	1998: K_L+K_S	
	1999: K_L+K_S	K_S HI
	2000: K_L only	K_S HI
	2001: K_L+K_S	K_S HI
NA48/1	2002: K_S/hyperons	
NA48/2	2003: K^+/K^-	
	2004: K^+/K^-	
NA62 R_K run	2007: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
	2008: $K^{\pm}_{e2}/K^{\pm}_{\mu 2}$	tests
NA62	2015: commissioning	
	2016–18: physics run	

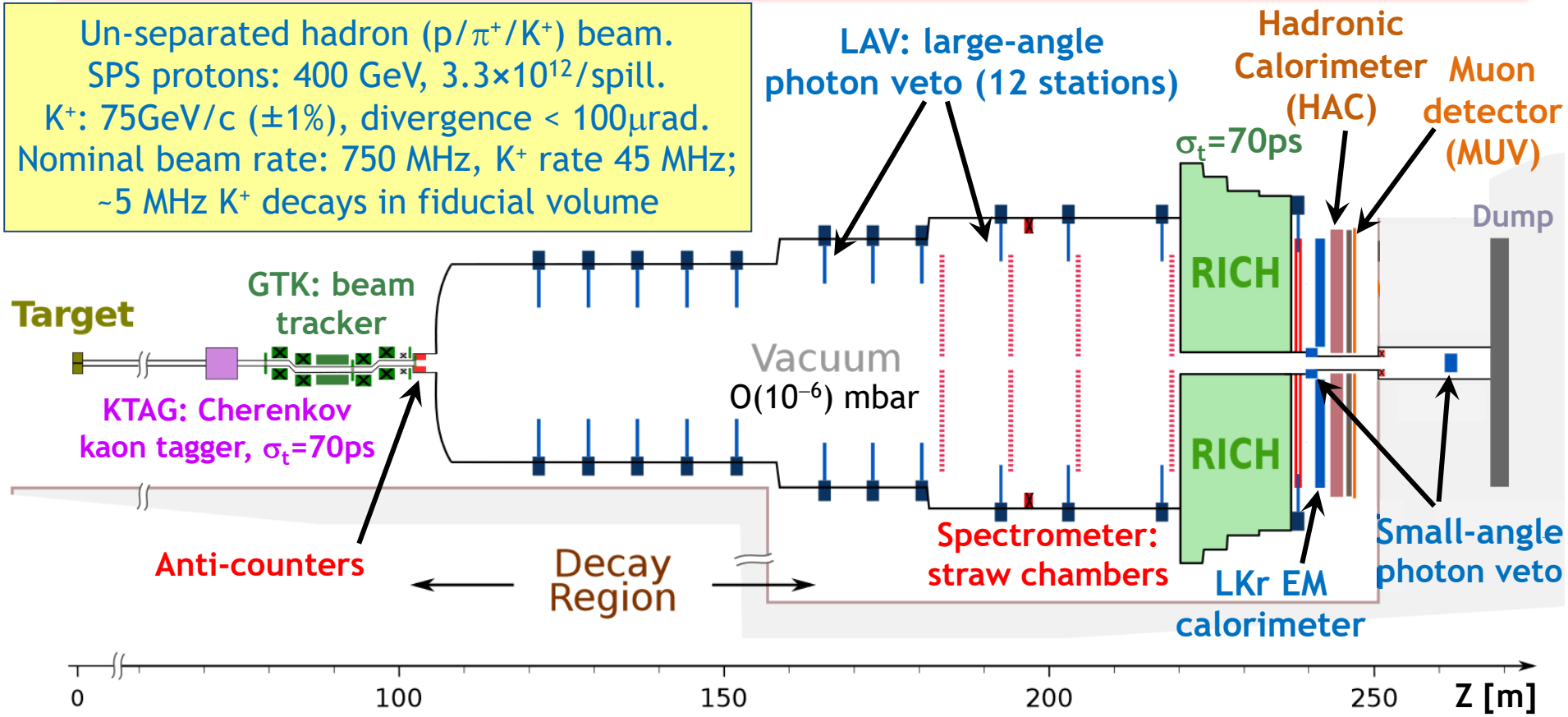
Main NA62 goal: $K^+ \to \pi^+ \nu\nu$ measurement to 10% precision with a novel decay-in-flight technique.

NA62UK: Birmingham, Bristol, Glasgow, Lancaster (13% of the collaboration).

JINST 12 (2017) P05025

NA62 detector

Un-separated hadron ($p/\pi^+/K^+$) beam.
SPS protons: 400 GeV, 3.3×10^{12}/spill.
K^+: 75GeV/c (±1%), divergence < 100μrad.
Nominal beam rate: 750 MHz, K^+ rate 45 MHz;
~5 MHz K^+ decays in fiducial volume



- Pion momentum 15 GeV/c<p<35 GeV/c: missing energy of at least 40 GeV.
- Hermetic photon veto: $\pi^0\to\gamma\gamma$ decay suppression = 3×10^{-8}.
- Particle ID (RICH+LKr+HAC+MUV): muon suppression = 1×10^{-8}.
- Kinematic rejection factors (limited by beam pileup & MCS tails):
  1×10^{-3} for $K^+\to\pi^+\pi^0$, 3×10^{-4} for $K\to\mu^+\nu$.

Data collection

- Commissioning run **2015**: minimum bias (**~1%** of nominal beam intensity).
- Physics run **2016** (**40%** intensity, limited by beam quality):
  1.2×10^{11} K^+ useful decays (1 month) for **$K^+\to\pi^+\nu\nu$** analysis; **analysis completed**
- Physics run **2017** (**65%** intensity): **~3×10^{12}** useful **K^+** decays.
- Physics run **2018** started in April, **218** days scheduled.

NA62: UK leadership

Hardware, trigger, computing:

- full responsibility for the **KTAG subdetector**;
- full responsibility for the **Run Control** system;
- development and operation of multiplicity+muon+RICH **L0 trigger**;
- **high-level trigger** coordination;
- **run coordinators**: 3 out of 12 (in 2017), 3 out of 17 (in 2018);
- **computing and software** coordination;
- responsibility for the **GRID infrastructure**.

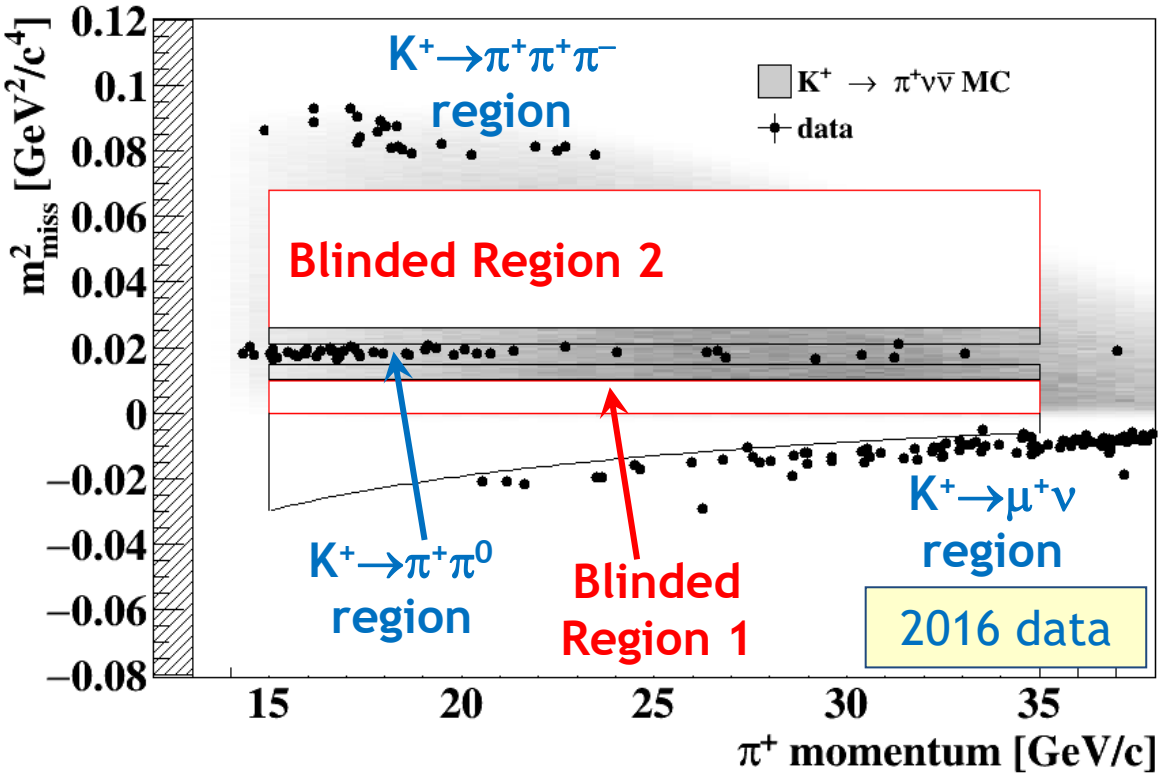
Physics exploitation:

- overall **physics coordination**;
- coordination of 2 out of 3 **physics WGs** ($K \to \pi\nu\nu$, rare decays);
- **Editorial Board** membership: 3 out of 10;
- **Conference Committee** chair;
- **Physics Beyond Colliders** representatives: 2 out of 4.

NA48/NA62 have published 4 physics papers in 2017/18; all principal authors are UK physicists

$K^+ \to \pi^+ \nu\nu$ measurement: results and prospects

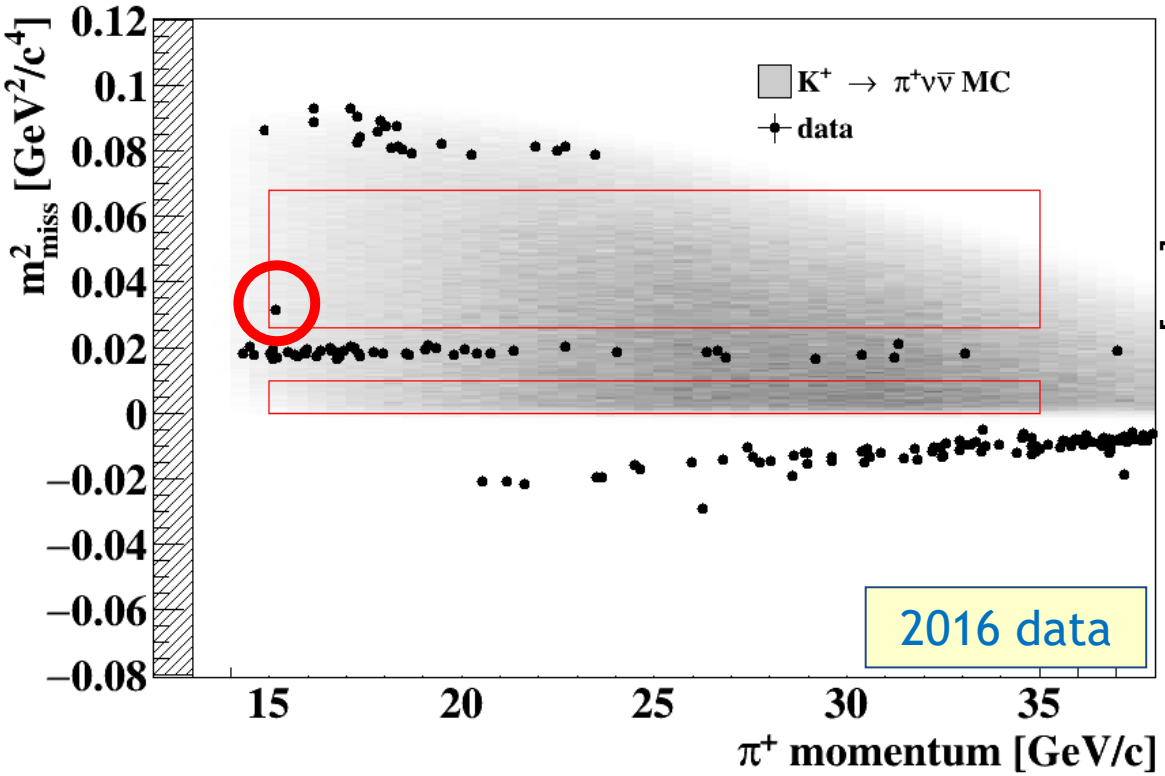
2016 data

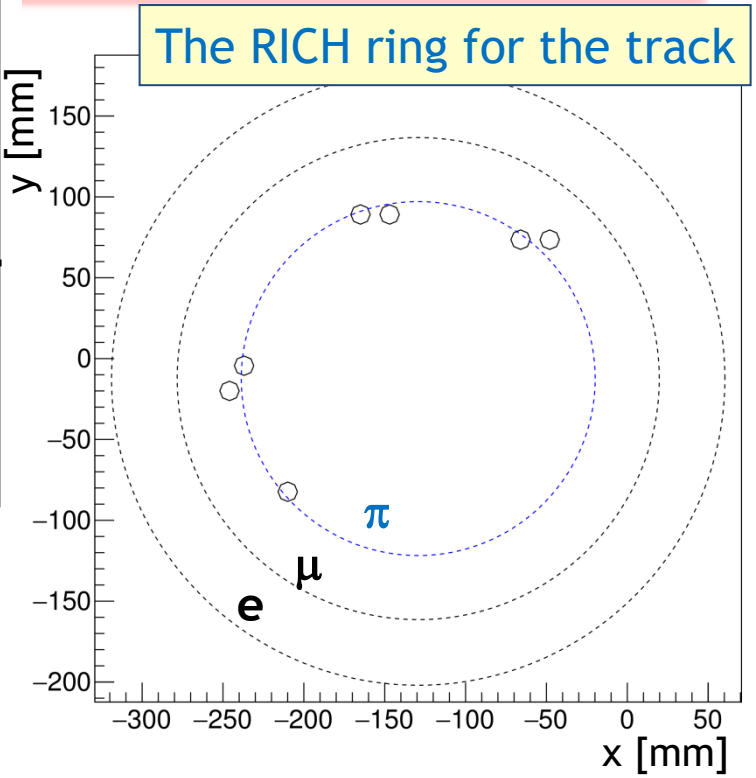


Process	Expected events in R1 + R2
$K^+ \to \pi^+\nu\bar{\nu}$ (SM)	$0.267 \pm 0.001_{stat} \pm 0.029_{syst} \pm 0.032_{ext}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu_\mu(\gamma)$ IB	$0.020 \pm 0.003_{stat} \pm 0.003_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu_e$	$0.018^{+0.024}_{-0.017}\|_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^+\pi^-\pi^+$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
Upstream background	$0.050^{+0.090}_{-0.030}$
Total background	$0.15 \pm 0.09_{stat} \pm 0.01_{syst}$

- Data sample: one month at 40% of nominal intensity.
- Number of kaon decays: $N_K=(1.21\pm0.02_{syst})\times10^{11}$.
- The analysis procedure is fully established.
- Background estimates are mostly data-driven.
- Signal acceptance: $A_{\pi\nu\nu}=(4.0\pm0.1)\%$.
- Single-event sensitivity: SES = $(3.15\pm0.24)\times10^{-10}$.

2016 result





One $K^+ \to \pi^+\nu\nu$ candidate observed:
$BR(K^+ \to \pi^+\nu\nu) < 11\times10^{-10}$ at 90% CL.

BNL 949 (K^+ decay at rest): $BR(K^+ \to \pi^+\nu\nu) = (1.73^{+1.15}_{-1.05})\times10^{-10}$

SM prediction: $BR(K^+ \to \pi^+\nu\nu) = (0.84\pm0.10)\times10^{-10}$

- The NA62 decay-in-flight technique works.
- Competitive sensitivity obtained with ~1% of the total expected statistics.
- The first $K^+ \to \pi^+\nu\nu$ paper is in preparation, **led by UK**.

$K^+ \to \pi^+ \nu\nu$ analysis: prospects

Analysis of the 2017 data in progress:

- improvement in statistics by a factor of **20** wrt 2016;
- expect reduction of the upstream background;
- improving reconstruction and analysis to increase overall efficiency.

Data taking of 2018 is in progress:

- further mitigation of the upstream background is expected;
- processing in parallel with data-taking.

Expectation with the 2017+18 data sample: 20 SM events.

- Analysis will provide a solid extrapolation to the ultimate sensitivity achievable after LS2, and input to the European Strategy.

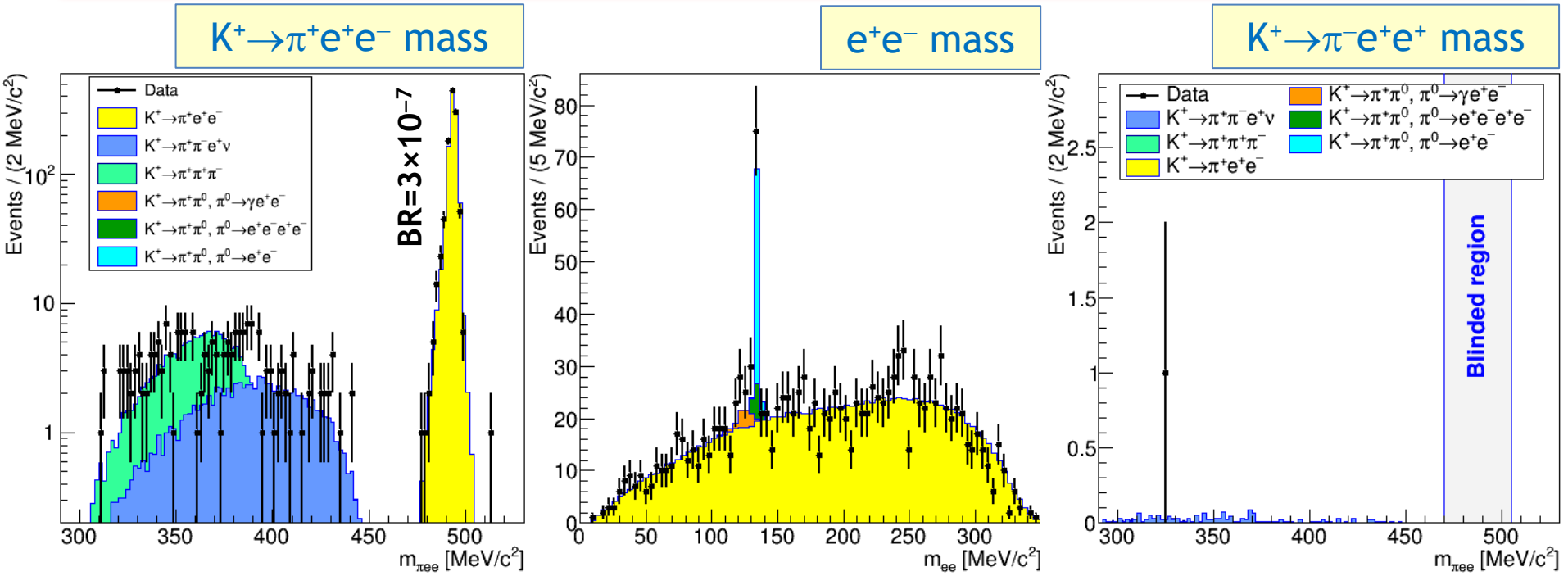
Plans for operation after LS2:

- SPSC has endorsed NA62 data taking for at least 2 years (**2021**, **2022**);
- addendum to proposal to be submitted to SPSC in September 2018;
- developing a strategy to collect **100 SM events**;
- improvements to the trigger are foreseen during LS2;
- **UK funding:** CG request made for M&O Common Fund, manpower for operation and analysis, and travel.

Highlights of the broader physics programme

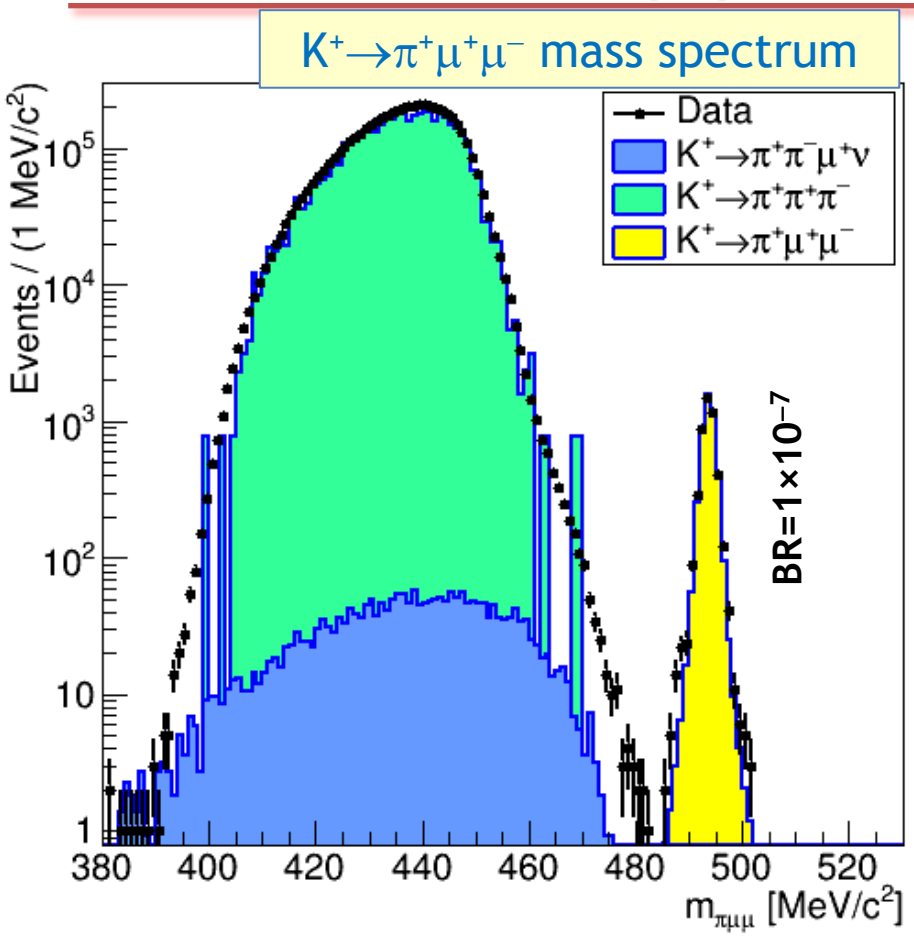
- *UK leads several analyses: searches for lepton flavour violation; searches for heavy neutral lepton production; rare decay measurements.*
- *Further details: NA62 report to CERN SPS committee [CERN-SPSC-2018-010]*

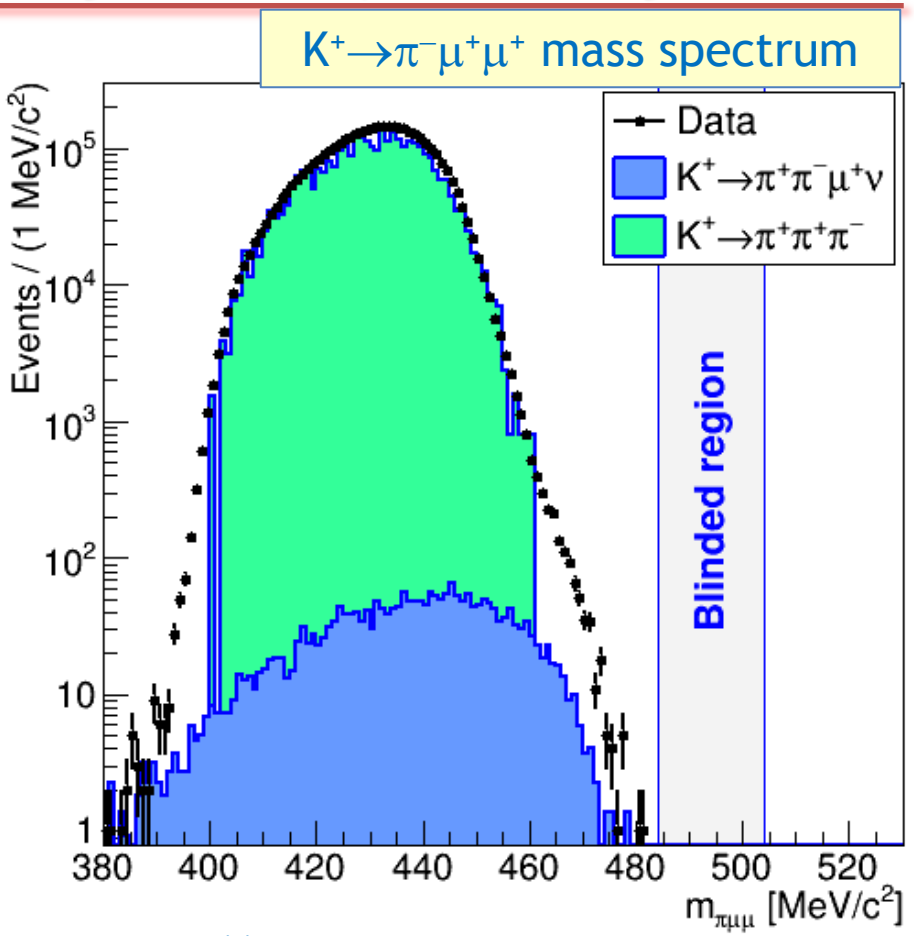
$K^+ \to \pi ee$ analyses (led by UK)



- Dedicated (downscaled) 3-track trigger lines are in operation.
- About **30%** of the 2016+2017 data set: **1.3×10^{11} K^+** decays.
- For **$m_{ee} > 140$ MeV/c^2**, background-free **$K^+ \to \pi^+ e^+ e^-$** sample, **1.1k** events.
- First observation of **$K^+ \to \pi^+ e^+ e^-$** in the region **$m_{ee} < 140$ MeV/c^2**.
- Search for **$K^+ \to \pi^- e^+ e^+$** is not limited by background; **SES=2×10^{-10}**.
- Search for **$K^+ \to \pi^+ X$**, **$X \to e^+ e^-$**, **$10 < m_X < 100$ MeV/c^2**: **SES~10^{-9}** for lifetime **$\ll 1$ ns**.

$K^+ \to \pi\mu\mu$ analyses (led by UK)





- About **30%** of the 2016+2017 data set: **6.3×10^{11} K^+** decays.
- World's largest **$K^+ \to \pi^+\mu^+\mu^-$** sample: **4.6k** events.
- Expect a competitive **$K^+ \to \pi^+\mu^+\mu^-$** measurement with **~10k** events: **LU test**.
- Search for **$K^+ \to \pi^-\mu^+\mu^+$** is not limited by background; **SES=2×10^{-11}**.
- Search for **$K^+ \to \pi^+X$**, **$X \to \mu^+\mu^-$**: **SES~10^{-10}** for lifetimes up to **O(1 ns)**.

Summary

- **UK participation in NA62 since 2011:**
  - ✓ Capital funding and manpower for detector construction and operation: ERC Advanced, ERC Starting and Royal Society Grants.
  - ✓ Now in exploitation mode, supported by STFC grant.
  - ✓ Extremely **good value for STFC investment**.
  - ✓ Strong UK leadership: overall and in **physics analysis**.
- **NA62 run 2016–2018:**
  - ✓ Data sample **2016** analysed: **BR($K^+ \to \pi^+ \nu\nu$)<11×10^{-10}** at **90%** CL.
  - ✓ Data sample **2017** has 20 times more useful data.
  - ✓ Run **2018** in progress, expect **20 SM $K_{\pi\nu\nu}$ events** in total.
  - ✓ A number of other rare decay measurements and searches for new physics are in progress.
- **NA62 run 2021–2023:**
  - ✓ Data taking for a least two years endorsed by the SPSC.
  - ✓ Working on a strategy to reach **100 SM $K_{\pi\nu\nu}$ events** by **2022.**
  - ✓ Possible options for running in **2023** are under discussion (rare decays, beam dump mode, …).

Backup

Search for $K^+ \to \ell^+ N$ (2015 data)

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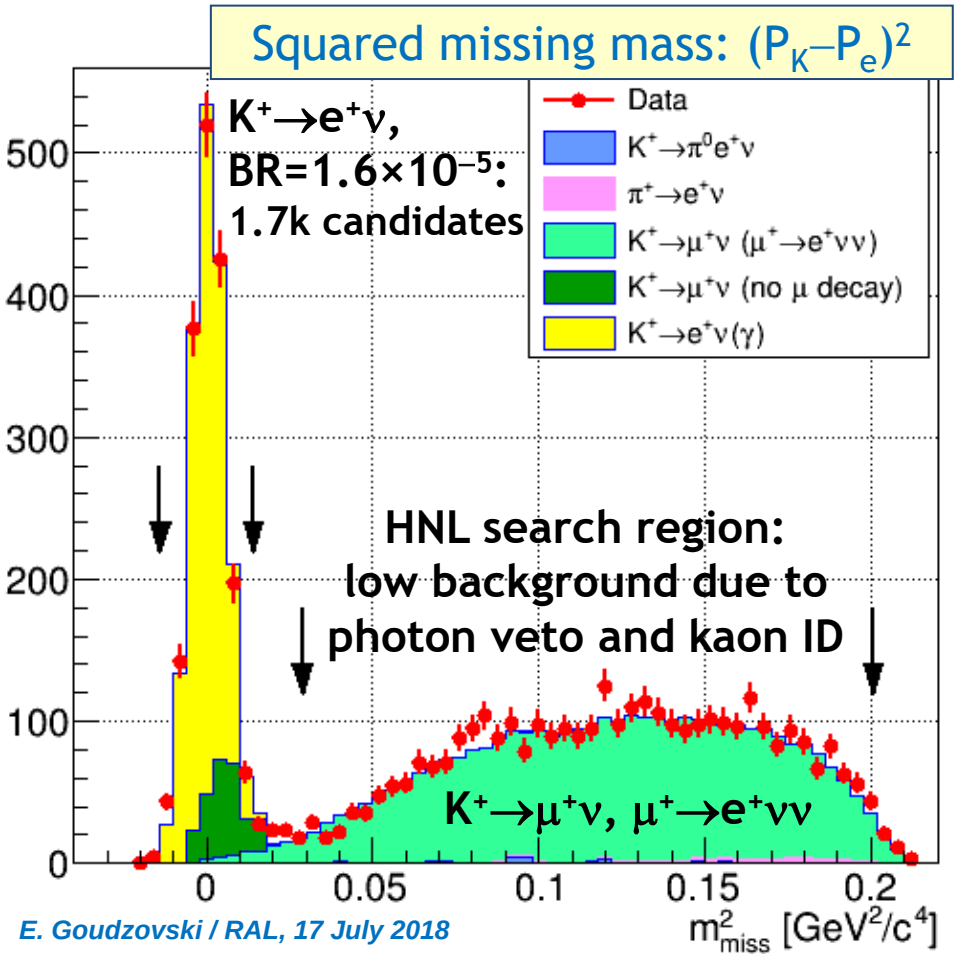
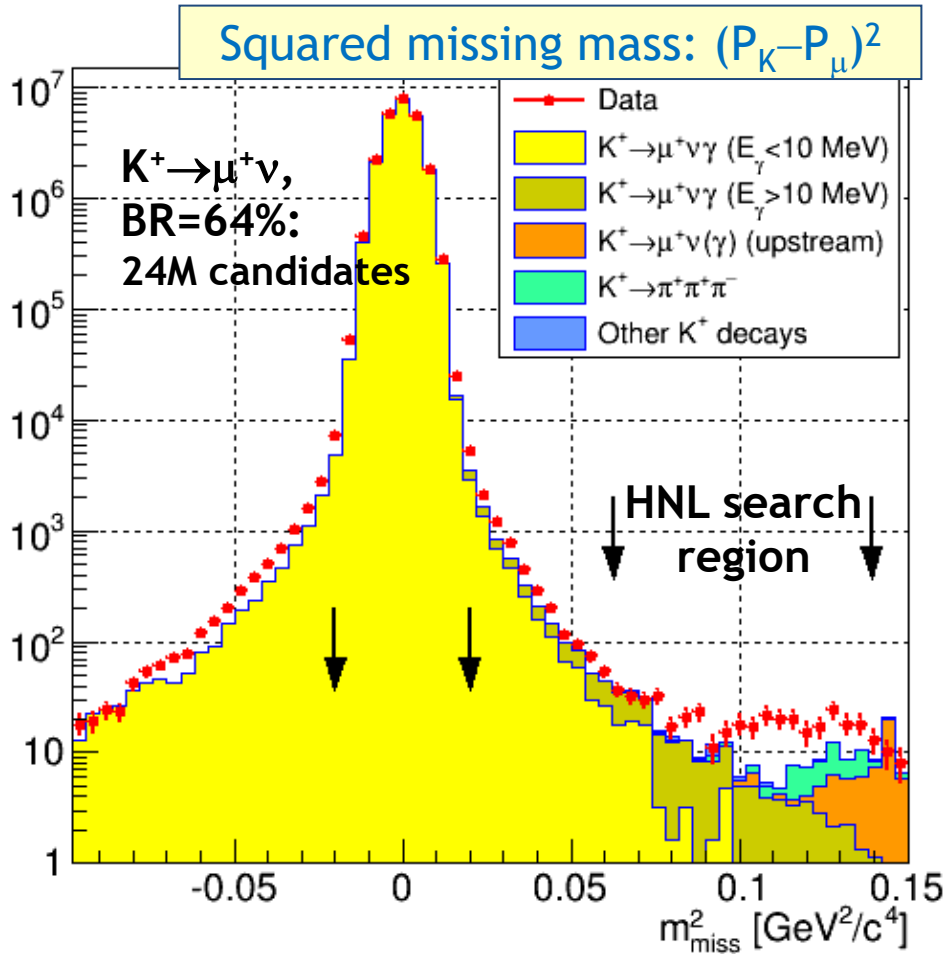
- Minimum bias data (**1%** intensity); **12k** spills (**5** days).
- Numbers of K^+ decays in fiducial volume:
  $N_K = (3.01 \pm 0.11) \times 10^8$ in positron case; $N_K = (1.06 \pm 0.12) \times 10^8$ in muon case.
- Beam tracker not available: kaon momentum is estimated as the beam average.
- HNL production signal: **a spike above continuous missing mass spectrum**.





Limits on HNL production

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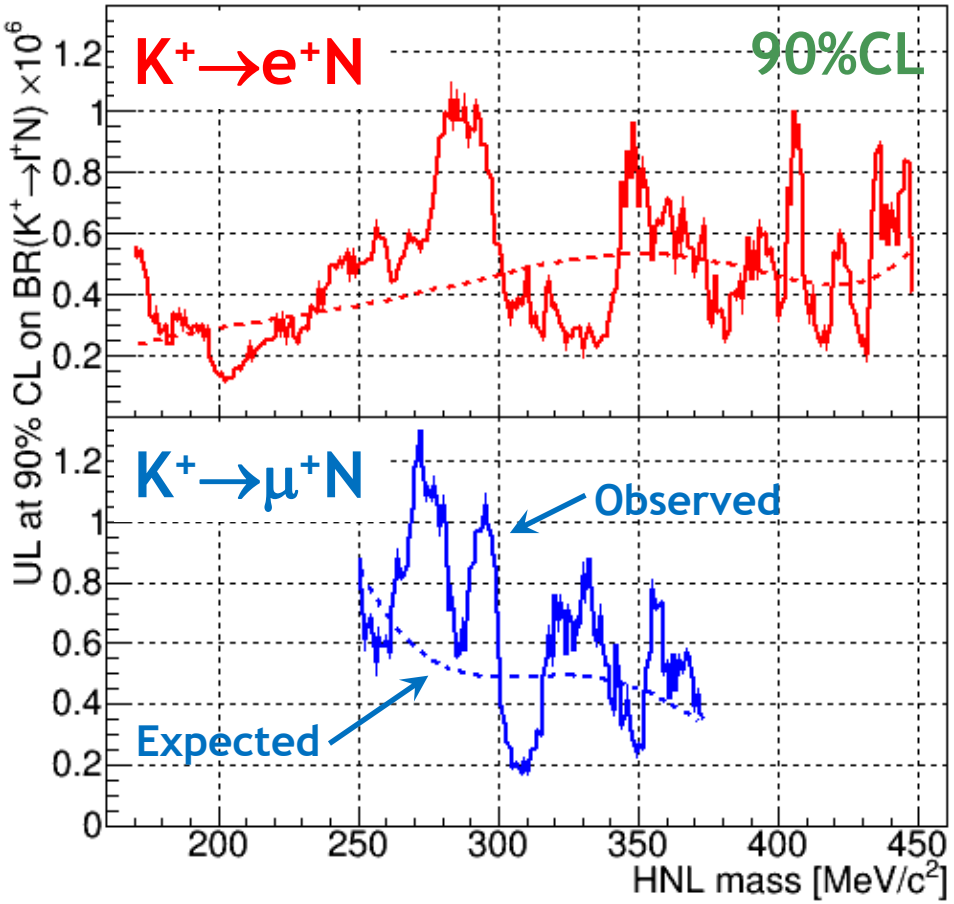
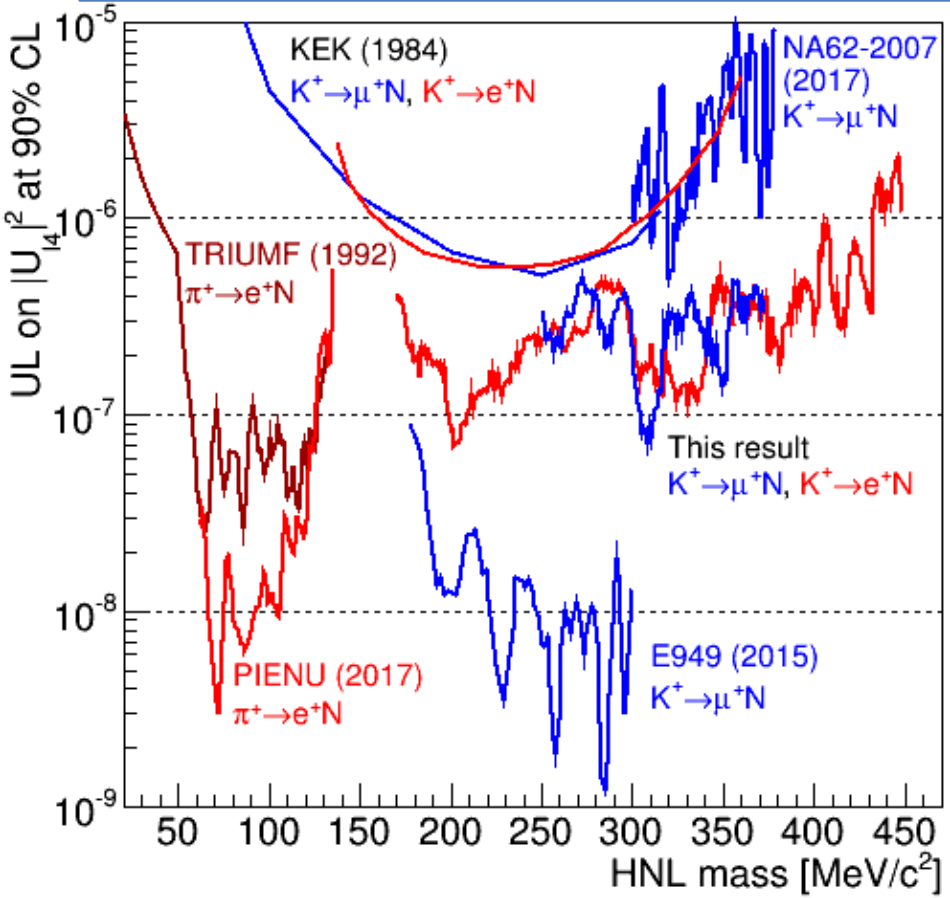
Upper limits on BR($K^+ \to \ell^+ N$)

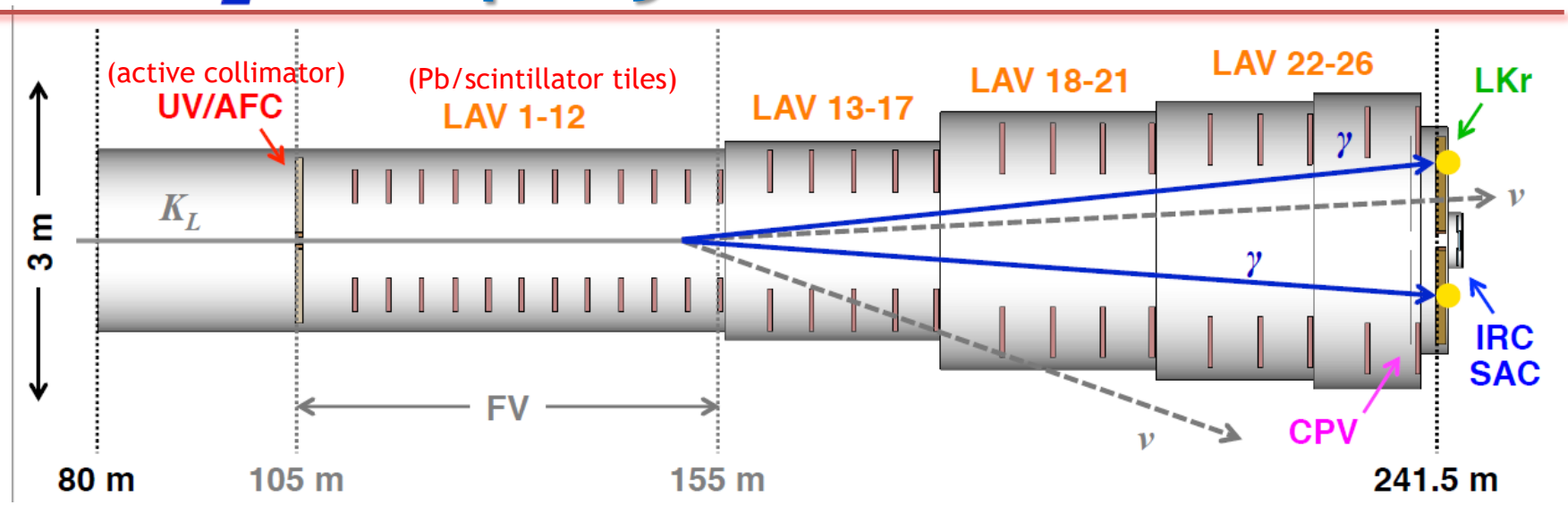


$|U_{\ell 4}|^2$ limits from production searches



- Reached 10^{-6}–10^{-7} limits for $|U_{\ell 4}|^2$ in the 170–448 MeV/c^2 mass range; improvement on the world data in 5 days and without the beam tracker.
- Estimated sensitivity with the full sample: ~10^{-9} for $|U_{e4}|^2$, ~10^{-8} for $|U_{\mu 4}|^2$.

KLEVER project at CERN: 2026+



- A new $K_L \to \pi^0 \nu\nu$ experiment at CERN with SES~0.5×10^{-12} (i.e. 60 SM events) and S/B~1 with 5 years of data taking is under consideration for 2026+.
- Mean K_L momentum of 97 GeV/c: easier photon veto wrt KOTO.
- Longer K_L lifetime, tight collimation: need 5×10^{19} pot/year (6x NA62 intensity).
- Target area and transfer line upgrade is under study.
- Re-use NA62 infrastructure and possibly parts of detector (LKr, HAC).
- Possibly add a tracking system? Then $K_L \to \pi^0 \ell^+ \ell^-$ (BR_{SM}~10^{-11}) are accessible.

Project represented at CERN Physics Beyond Collider study; expression of interest to CERN SPSC in preparation.