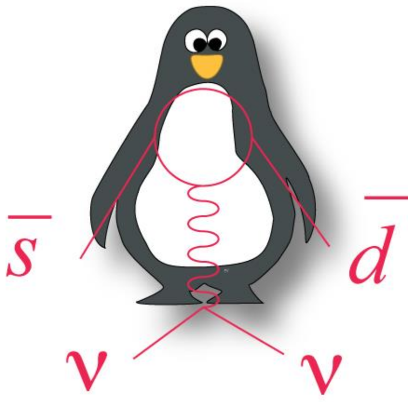
NA62 status and plans



Chris Parkinson, for NA62-UK

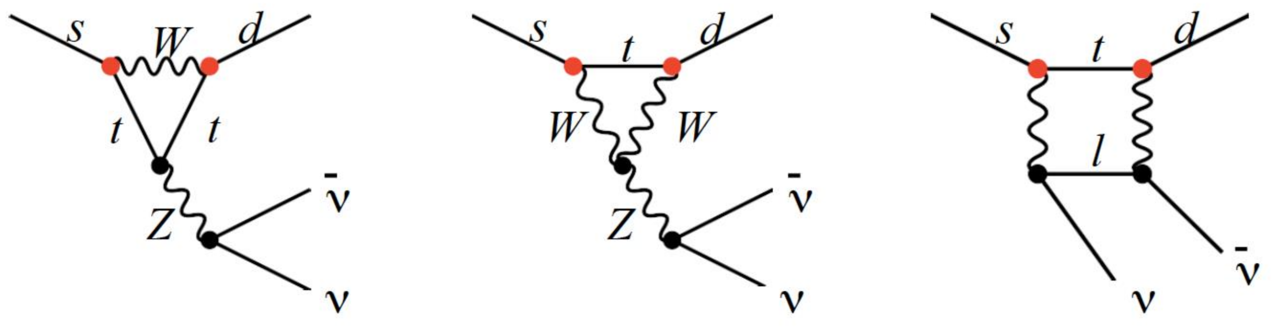
PPAP Community Meeting, Birmingham, September 2019

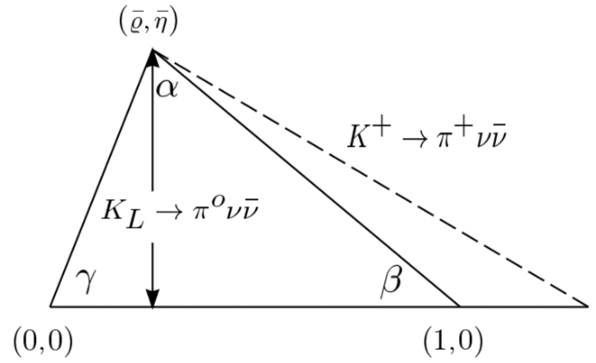
Outline

1. Introduction to NA62 and status of the $K^+ \to \pi^+ \nu \bar{\nu}$ analysis
2. Other physics results and prospects
3. Future plans and big ideas

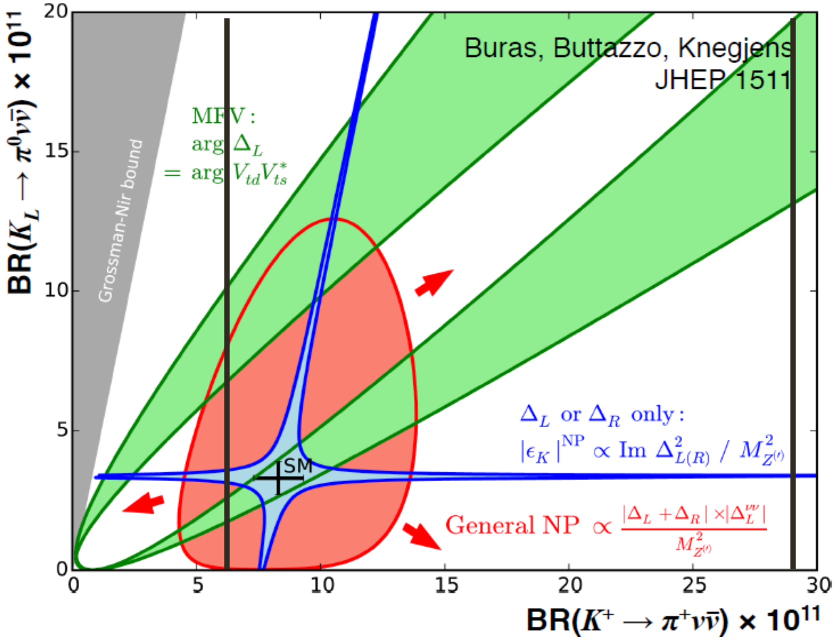
Motivation to study the $K^+ \to \pi^+ \nu\bar{\nu}$ decay

- FCNC loop processes: $s \to d$ coupling and highest CKM suppression





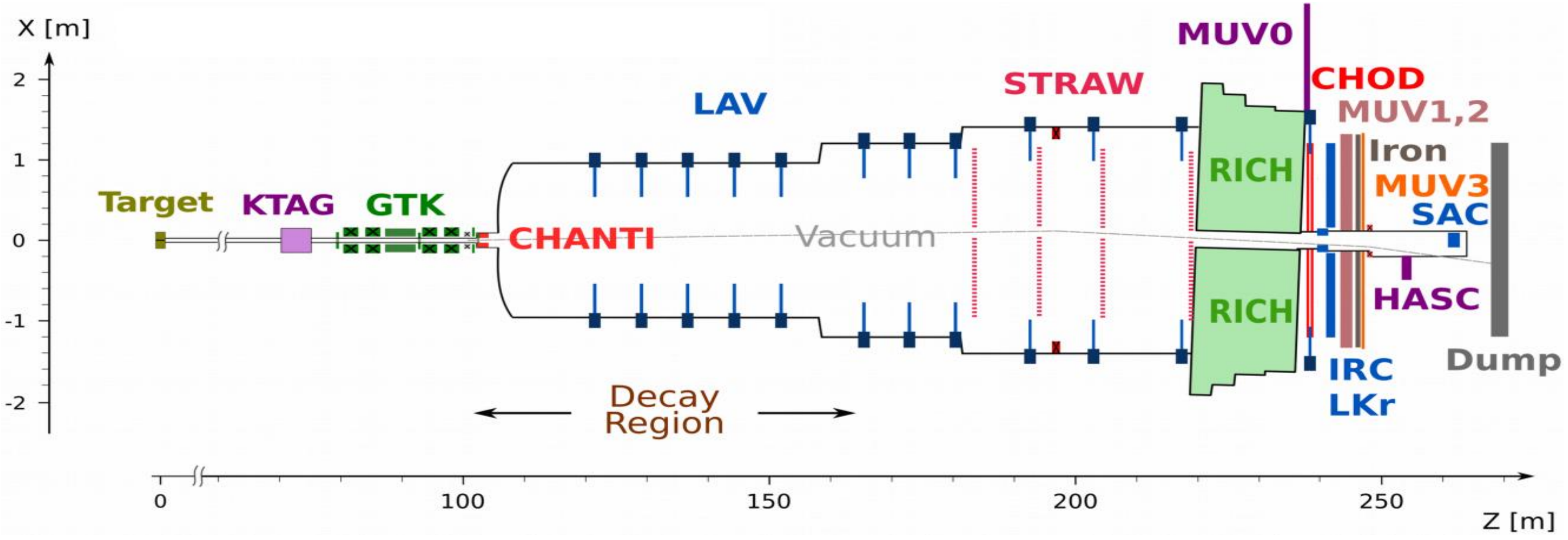
- Very clean theoretically
  - Short distance contribution with tiny hadronic uncertainties.
- Complementarity with B physics in probing BSM flavour sector



- SM prediction [Buras et al. JHEP 1511 (2015) 33]

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \cdot 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^\circ}\right)^{0.74} = (0.84 \pm 0.10) \cdot 10^{-10}$$

The NA62 experiment



- Measurement of incoming K^+ $[p_{K^+} = (75 \pm 1\%)\ \mathrm{GeV/c}]$
  - Timing by **KTAG** ($\sigma_t \approx 70$ ps); position/momentum by **GTK**
- Measurement of outing π^+ $[15 < p_{\pi^+} < 35\ \mathrm{GeV/c}]$
  - Timing by **RICH** ($\sigma_t \approx 70$ ps); position/momentum by **STRAW**
- Hermetic photon veto (**LAV, LKr, IRC, SAC**): $\pi^0 \to \gamma\gamma$ suppression at 1.4×10^{-8}
- Particle identification (**RICH**, **LKr**, **MUV**, **HASC**): muon suppression at 1×10^{-8}
- Kinematic rejection at 1×10^{-3} for $K^+ \to \pi^+\pi^0$ and 3×10^{-4} for $K^+ \to \mu^+\nu(\gamma)$

UK involvement

- **Spokesperson (Prof. C. Lazzeroni, Uni. Birmingham)**
- **Vice-spokesperson (Dr. G. Ruggiero, Uni. Lancaster)**
- Coordination of the high-level (software) trigger
- Coordination of computing and software
- Coordination of 2 of 4 analysis working groups ($K^+ \to \pi^+ \nu\bar{\nu}$ and rare decays)

- **Other responsibilities:**
  - Full responsibility for the KTAG detector
  - Full responsibility for the Run Control system
  - Development and operation of the RICH/CHOD/MUV3 hardware trigger
  - Run coordination: 3 of 12 (2017); 3 of 17 (2018);
  - Responsibility for the GRID infrastructure (and production of simulated events)
  - Editorial board membership: 3 of 10

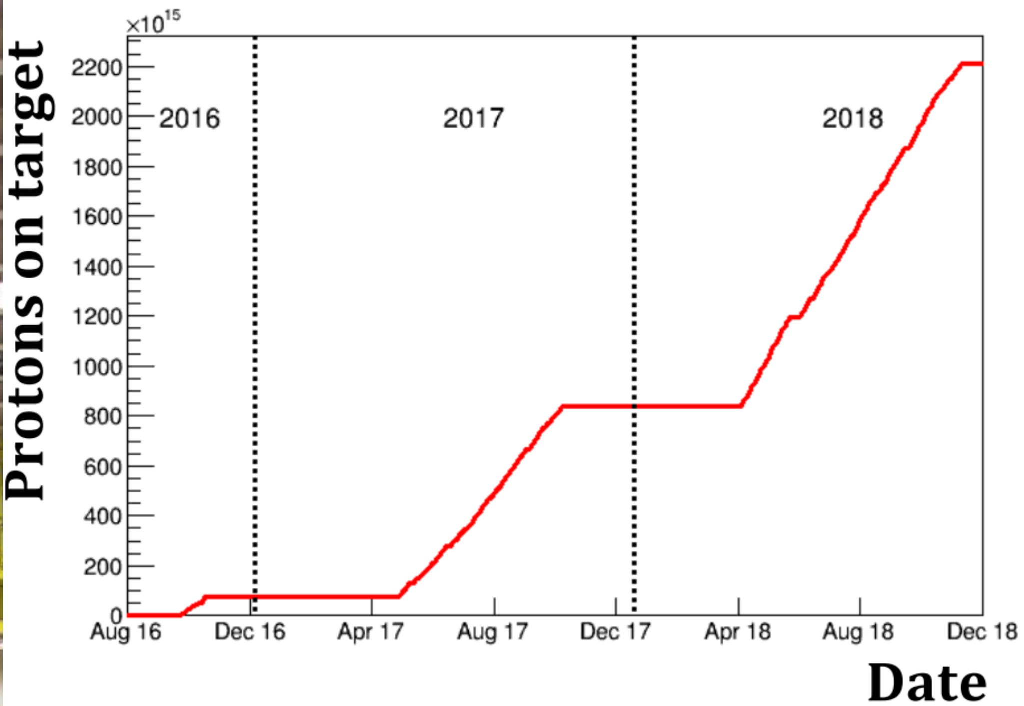
NA62 status

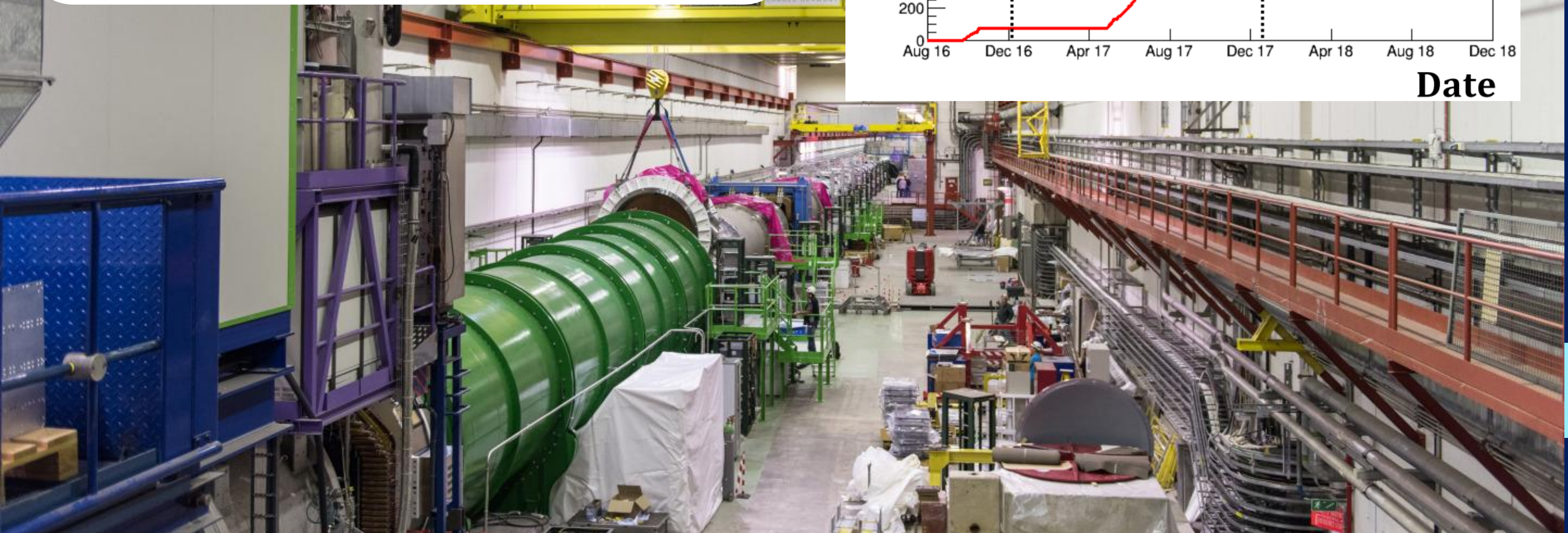
Three years of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ data taking:

2016: $\sim 1 \times 10^{11}\ K^+$ decays

2017: $\sim 2 \times 10^{12}\ K^+$ decays

2018: $\sim 4 \times 10^{12}\ K^+$ decays



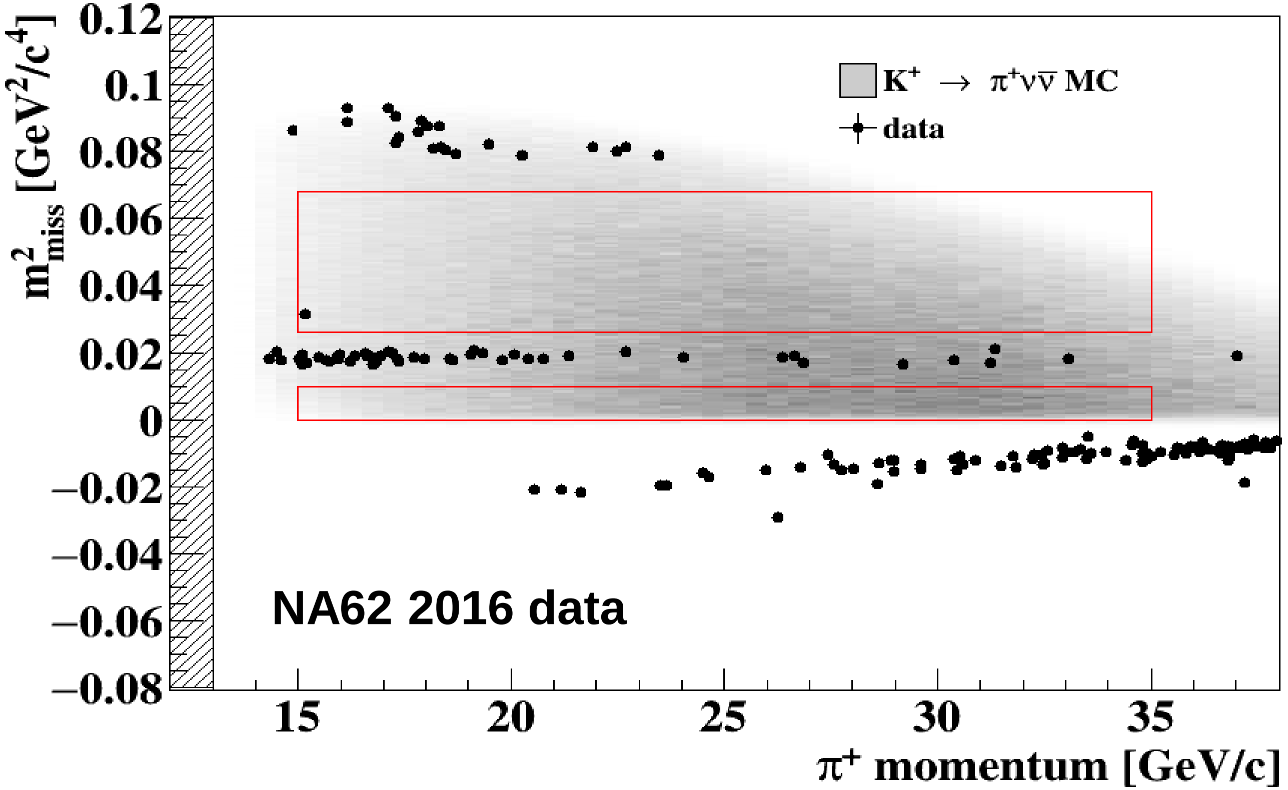


Status of the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis (2016)

- Result presented last year based on the 2016 data **now published:** [Phys. Lett. B 791 (2019) 156]
- **UK leadership**

- $1.21 \times 10^{11}\ K^+$ decays
  $(5 \times 10^4$ spills
  10×10^{11} protons per spill)

- $A(K^+ \to \pi^+ \nu\bar{\nu}) \sim 4\%$
- $N^{exp} = 0.267 \pm 0.001_{stat} \pm 0.020_{syst} \pm 0.032_{ext}$
- $N^{bkg} = 0.152^{+0.092}_{-0.033}|_{stat} \pm 0.013_{syst}$



- One event observed in signal region 2
- $BF(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10}$ @ 95% CL

Status of the $K^+ \to \pi^+\nu\bar{\nu}$ analysis (2017)

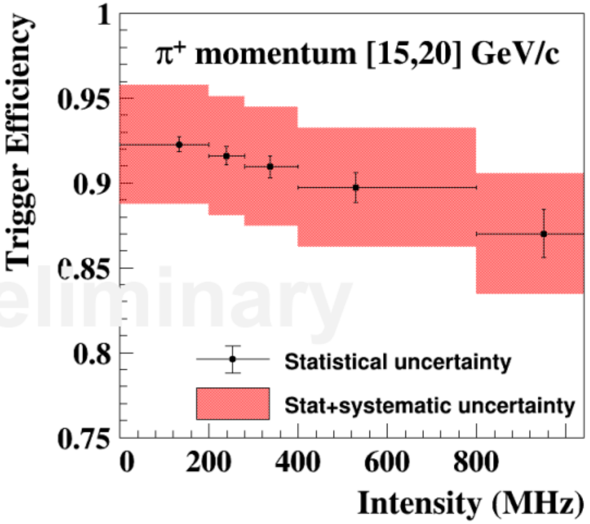
UK leadership

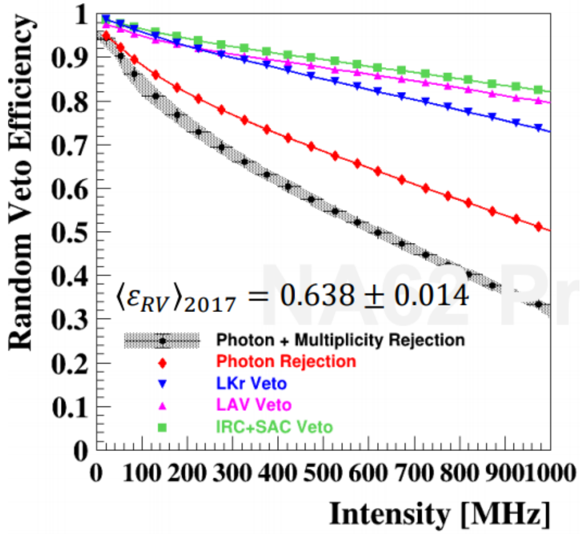
- Analysis of the 2017 data has just finished. Results [presented at Kaon conference](#) on Tuesday
- Sample of 2×10^{12} K^+ decays collected over 160 days ($\sim 3 \times 10^5$ spills, 19×10^{11} protons per spill,

$$A(K^+ \to \pi^+\nu\bar{\nu}) \sim 3\%$$

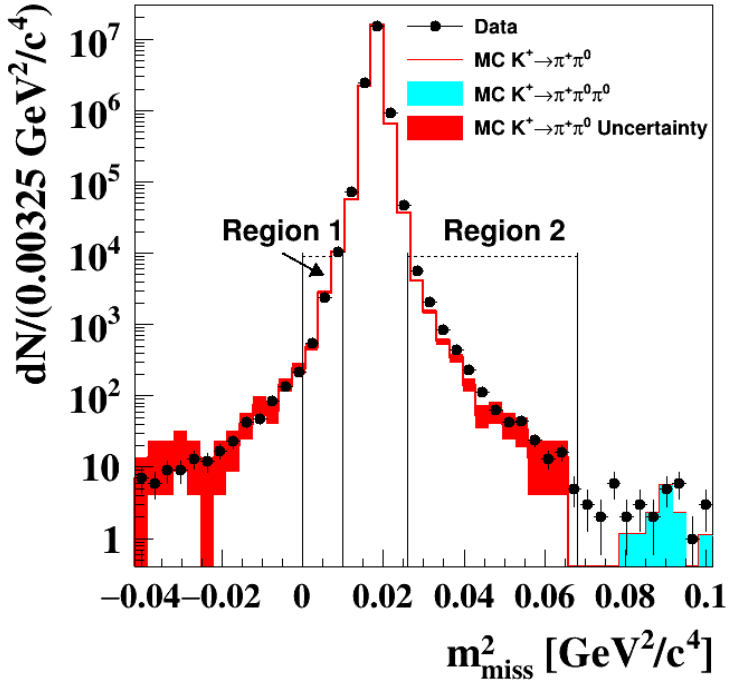
Process	Expected events
$\boxed{K^+ \to \pi^+\nu\bar{\nu}\ \text{(SM)}}$	$\boxed{2.16 \pm 0.12_{stat} \pm 0.26_{ext}}$
$K^+ \to \pi^+\pi^0(\gamma)$ IB	$0.29 \pm 0.03_{stat} \pm 0.03_{syst}$
$K^+ \to \mu^+\nu_\mu(\gamma)$ IB	$0.11 \pm 0.02_{stat} \pm 0.03_{syst}$
$K^+ \to \mu^+\nu_\mu(\mu^+ \to e^+\text{decay})$	$0.04 \pm 0.02_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu_e$	$0.12 \pm 0.05_{stat} \pm 0.03_{syst}$
$K^+ \to \pi^+\pi^-\pi^+$	$0.02 \pm 0.02_{syst}$
$K^+ \to \pi^+\gamma\gamma$	$0.005 \pm 0.005_{syst}$
$K^+ \to l^+\pi^0\nu_l$	negligible
Upstream background	$0.9 \pm 0.2_{stat} \pm 0.2_{syst}$
Total background	$1.5 \pm 0.2_{stat} \pm 0.2_{syst}$

I will come back to this later





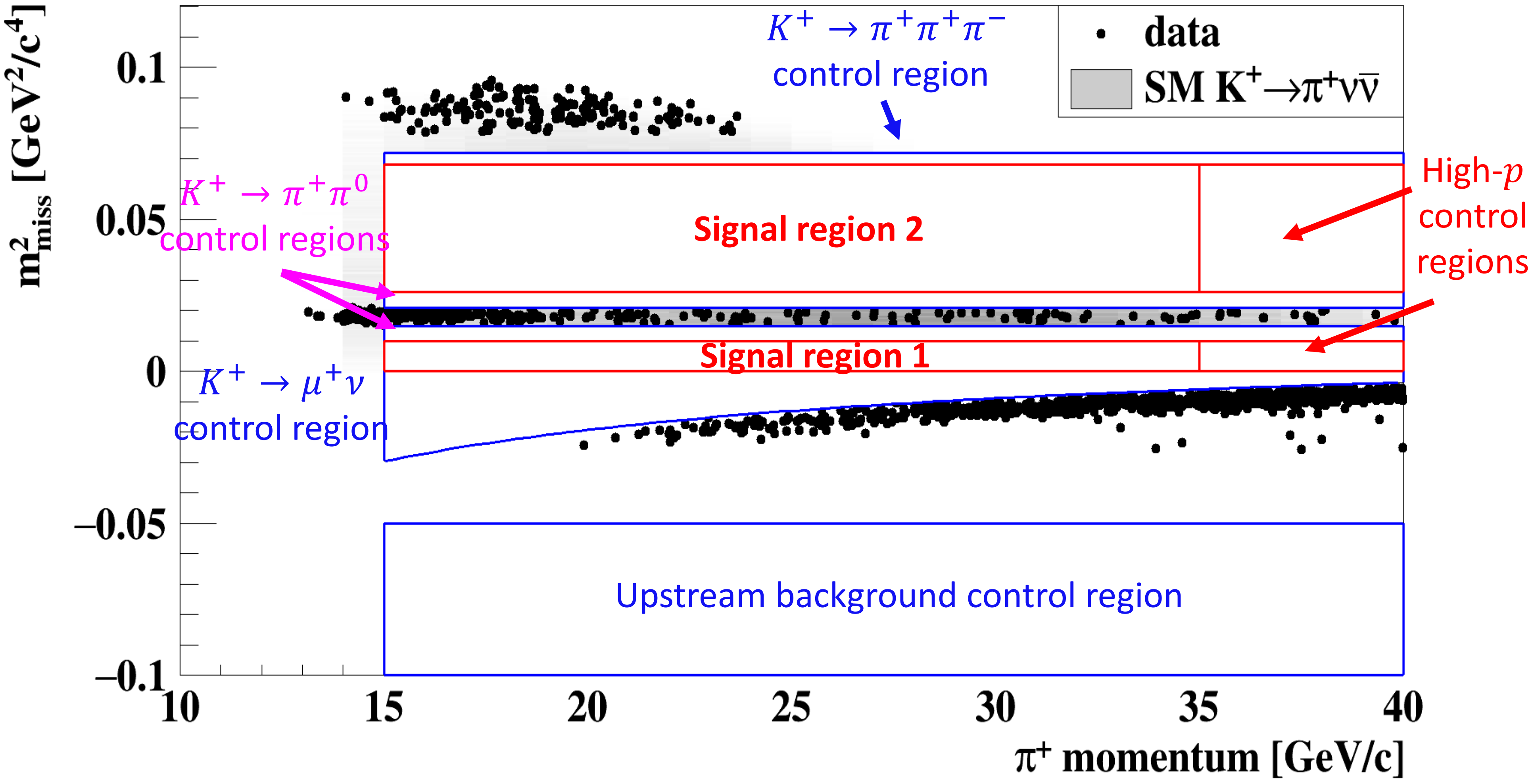
$$\sigma(m^2_{miss}) \sim 10^{-3}\ \text{GeV}/\text{c}^2$$



Status of the $K^+ \to \pi^+\nu\bar{\nu}$ analysis (2017)

UK leadership

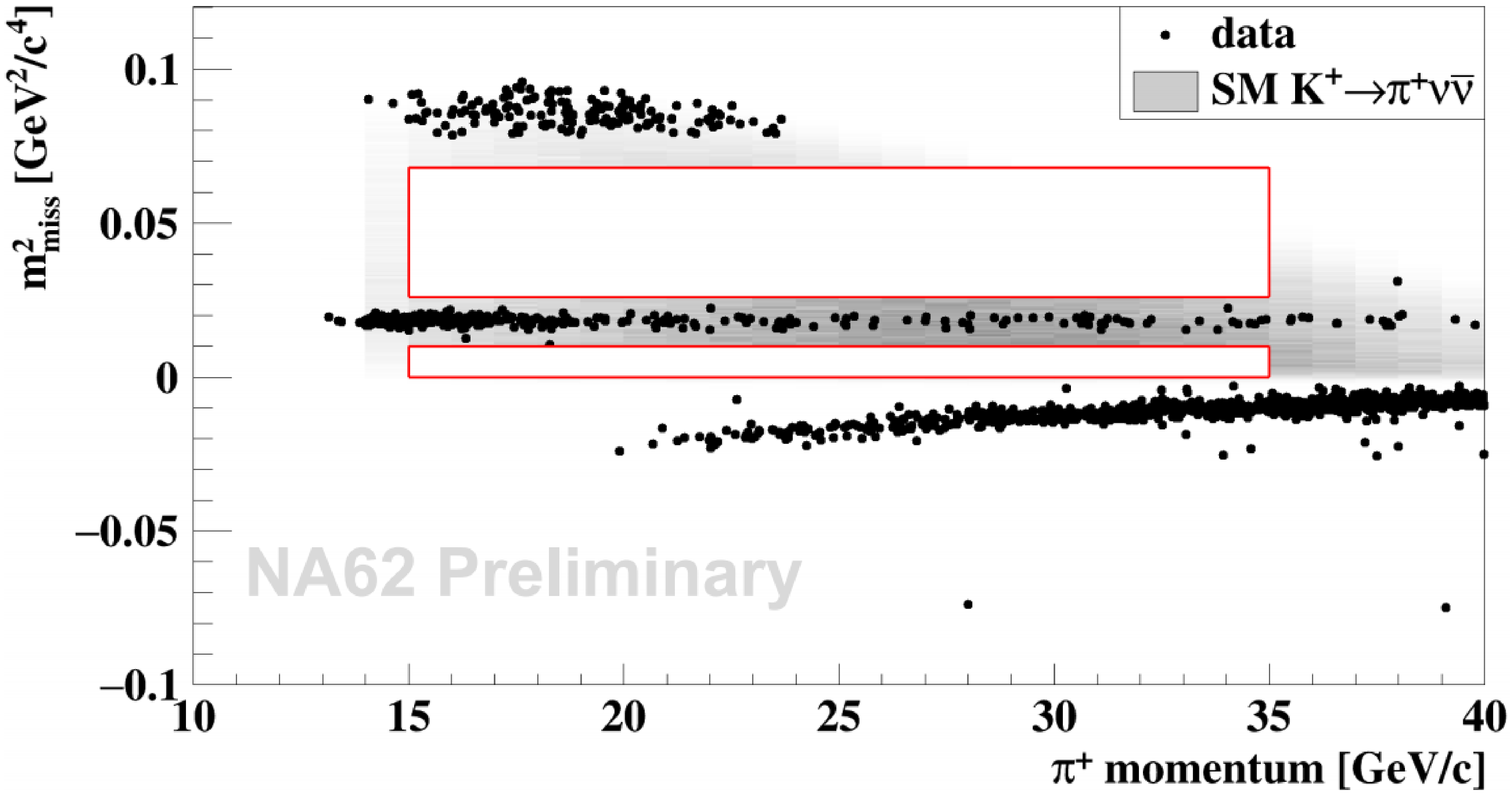
- Analysis of the 2017 data has just finished. Results [presented at Kaon conference]() on Tuesday
- Sample of 2×10^{12} K^+ decays collected over 160 days ($\sim 3 \times 10^5$ spills, 19×10^{11} protons per spill, 3 sec. spills)



Status of the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis (2017)

UK leadership

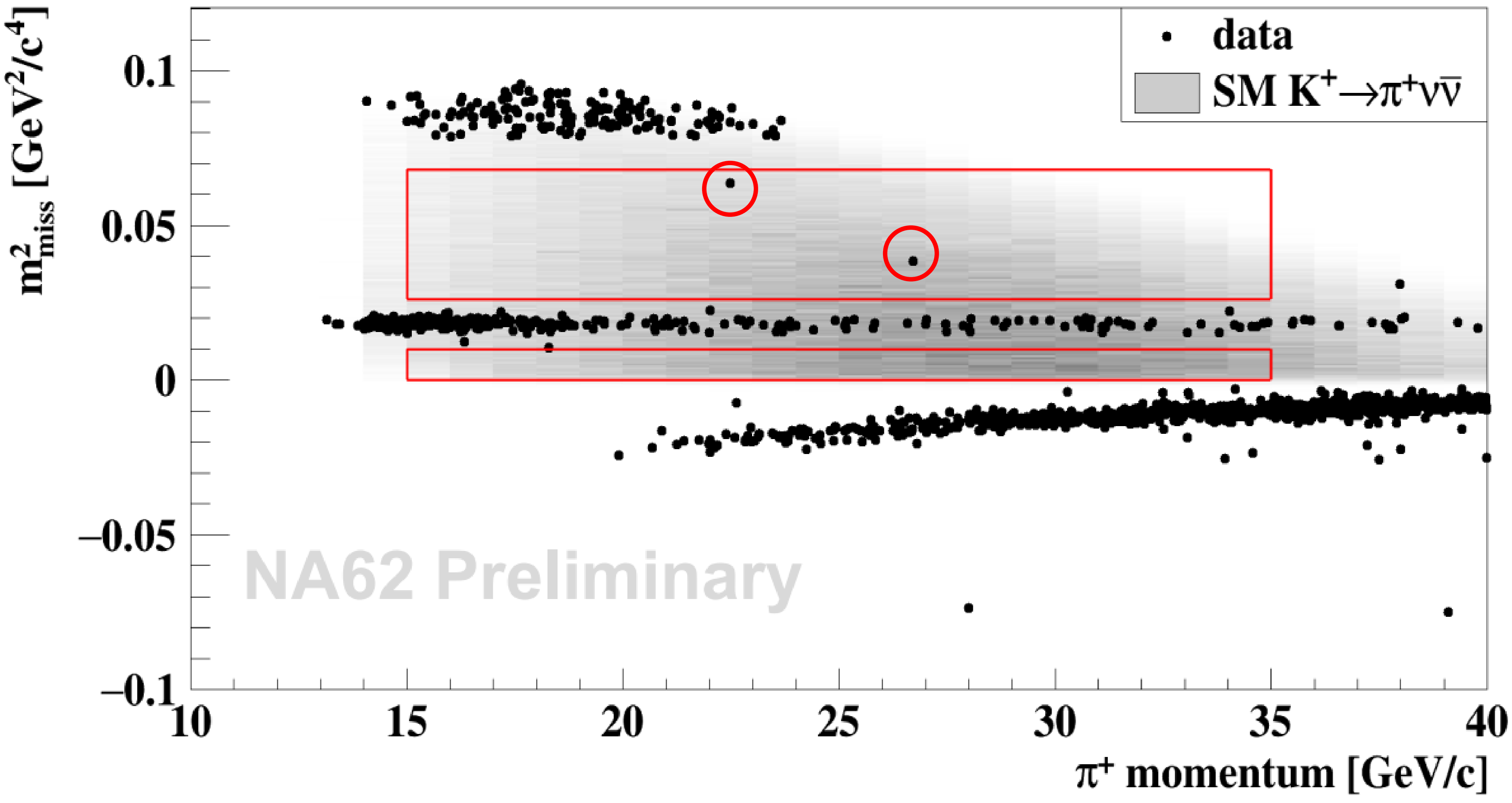
- Final plot before unblinding. All background estimates validated in control regions



Status of the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis (2017)

UK leadership

- Two events observed in the signal region!



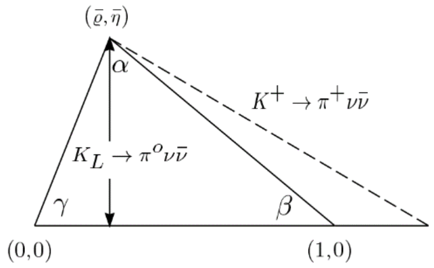
Interpretation

See [here] for full presentation at Kaon 2019

- **2016+2017 data:** $\mathbf{s.e.s.} = (\mathbf{0.346} \pm \mathbf{0.017}) \times \mathbf{10^{-10}}, \boldsymbol{s^{obs}} = \mathbf{3}, \boldsymbol{b^{exp}} = \mathbf{1.65} \pm \mathbf{0.31}$
- CLs limit @ 95% CL:
  - Observed: $BF(K^+ \to \pi^+ \nu\bar{\nu}) < 2.44 \times 10^{-10}$
  - Expected: $BF(K^+ \to \pi^+ \nu\bar{\nu}) < 1.62 \times 10^{-10}$

- Two-sided 68% band: $BF(K^+ \to \pi^+ \nu\bar{\nu}) = (0.47^{+0.72}_{-0.47}) \times 10^{-10}$

- Also $K^+ \to \pi^+ X, X \to inv.$ at the π^0 mass:
  - Observed: $BF(\pi^0 \to inv.) < 4.4 \times 10^{-9}$ @ 90% CL



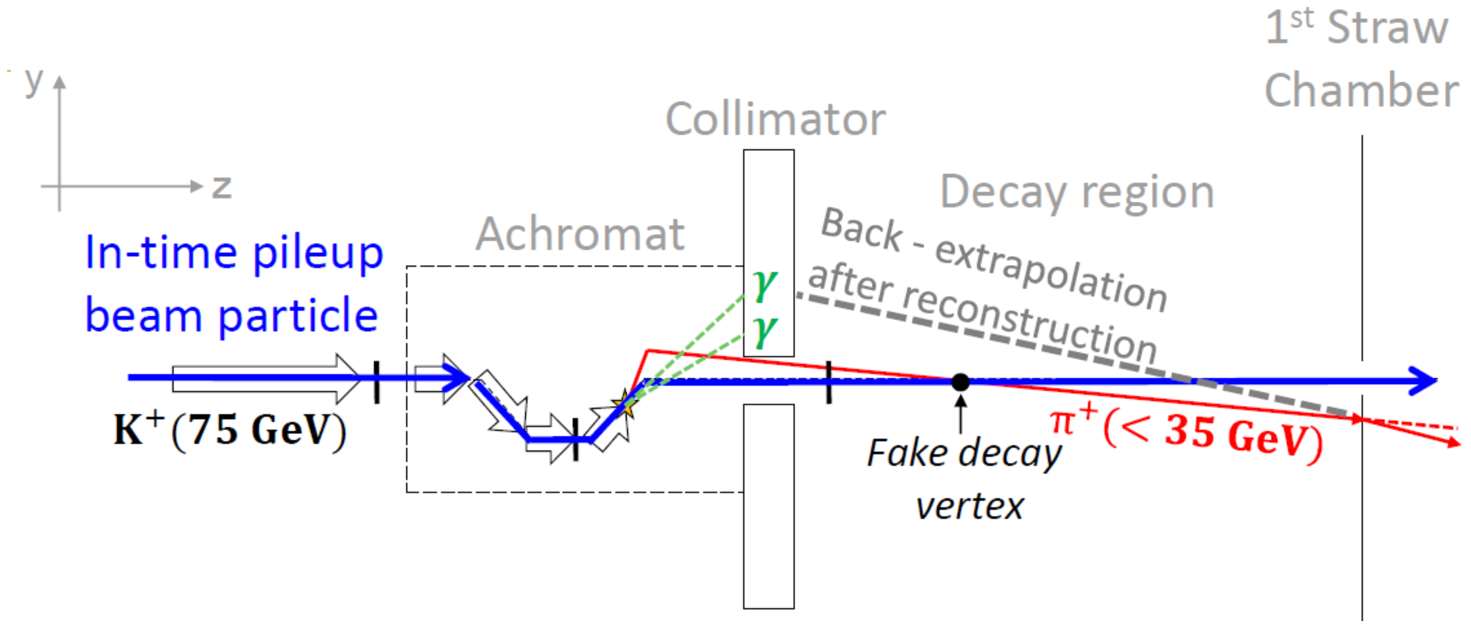
- Exploiting correlation between charged and neutral mode:

  Grossman-Nir limit: $BF(K_L \to \pi^0 \nu\bar{\nu}) < 8.14 \times 10^{-10}$ @ 90% CL

- Also! New results from KOTO: $\mathrm{BF}(K_L \to \pi^0 \nu\bar{\nu}) < 3.0 \times 10^{-9}$ [PRL122 (2019) 021802]

Future prospects (2018, LS2 onwards)

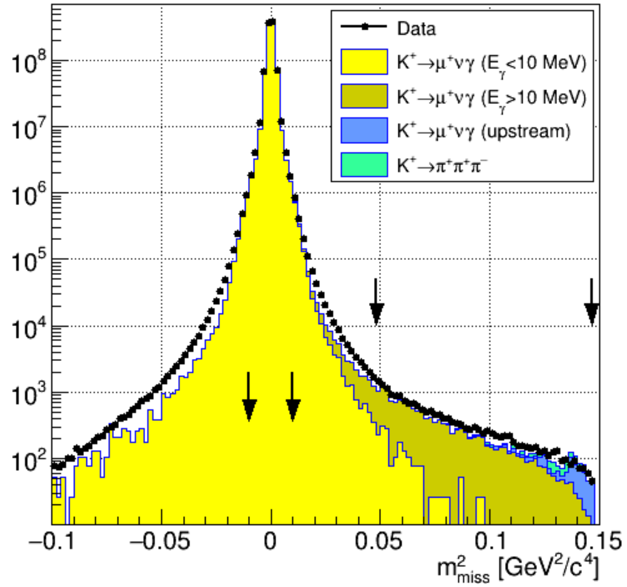
- 2018 prospects: 4×10^{12} K^+ decays, 20% gain in acceptance, optimisation of kaon mistagging
- Leading cause of background in the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis is upstream K^+ decays with pileup tracks



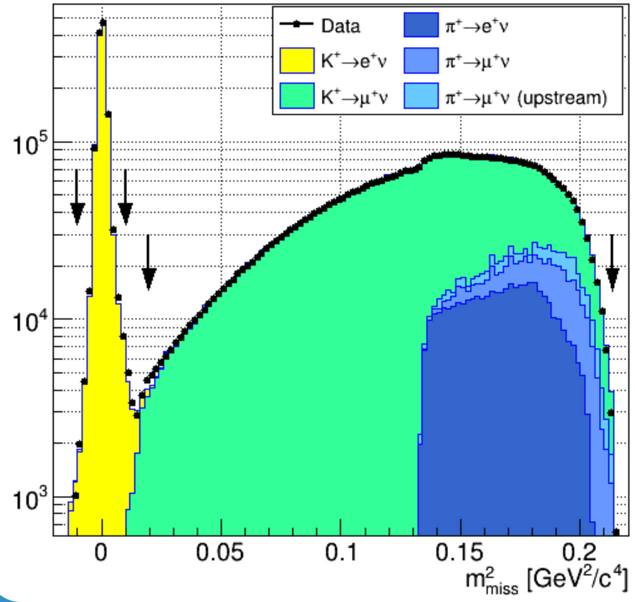
- After LS2:
  - **Add 4th GTK station**: better track fitting with higher efficiency, to identify dangerous pileup tracks
  - **Redesign acromat**: 3 magnet system (with different strengths), to block π^+ from GTK2 interactions
  - **New detector**: technology similar to photon veto, to tag $\pi^0 \to \gamma\gamma$ decays upstream
  - **More kaons**: run at nominal beam intensity with 30×10^{11} protons per spill

Search for heavy neutral lepton production

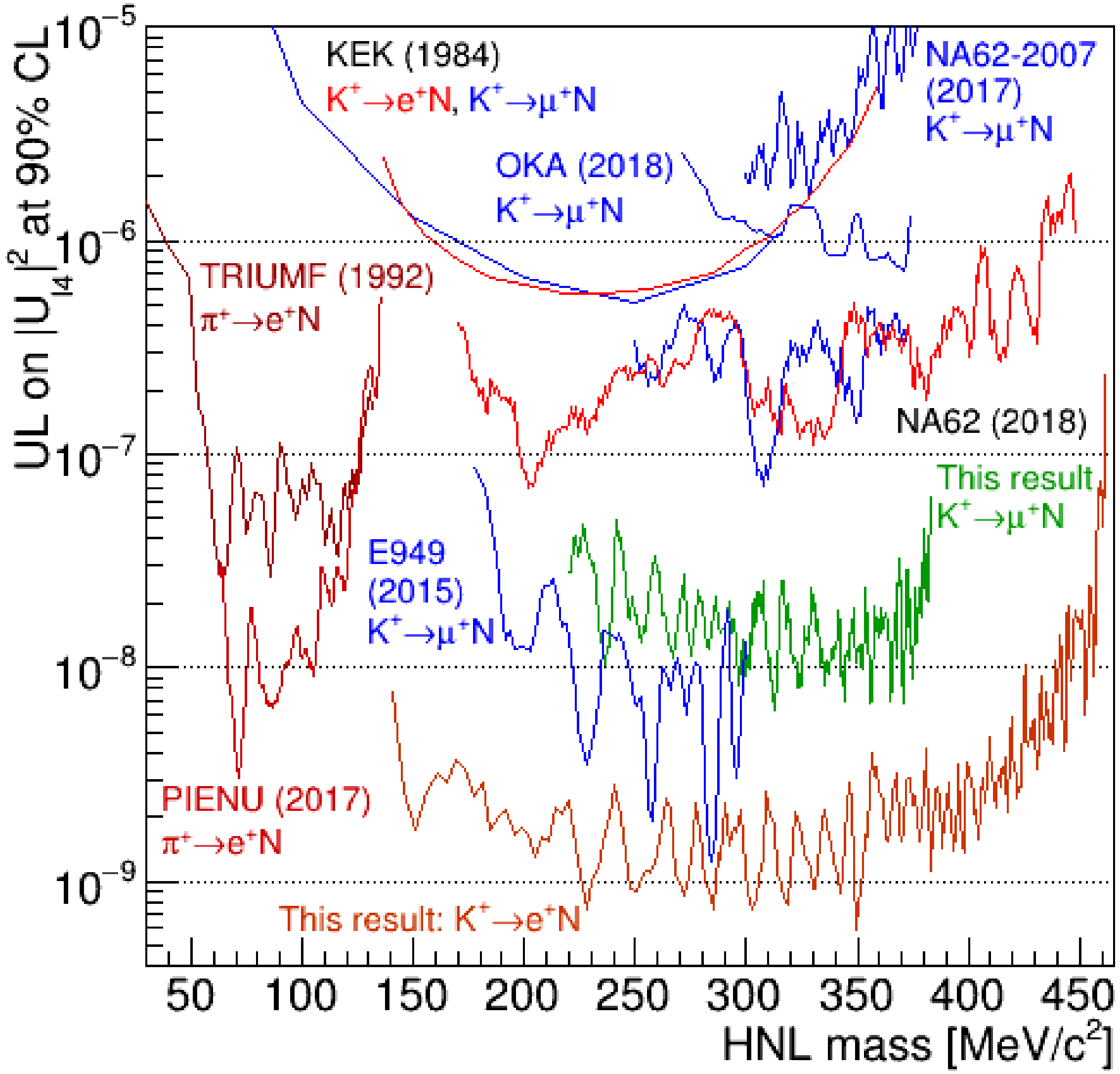
- Based on 2016+17 data. **UK leadership.** First presented [at Kaon 2019]



$K^+ \to \mu^+\nu$
$N_K \approx 4.3 \times 10^9$



$K^+ \to e^+\nu$
$N_K \approx 1.1 \times 10^{12}$



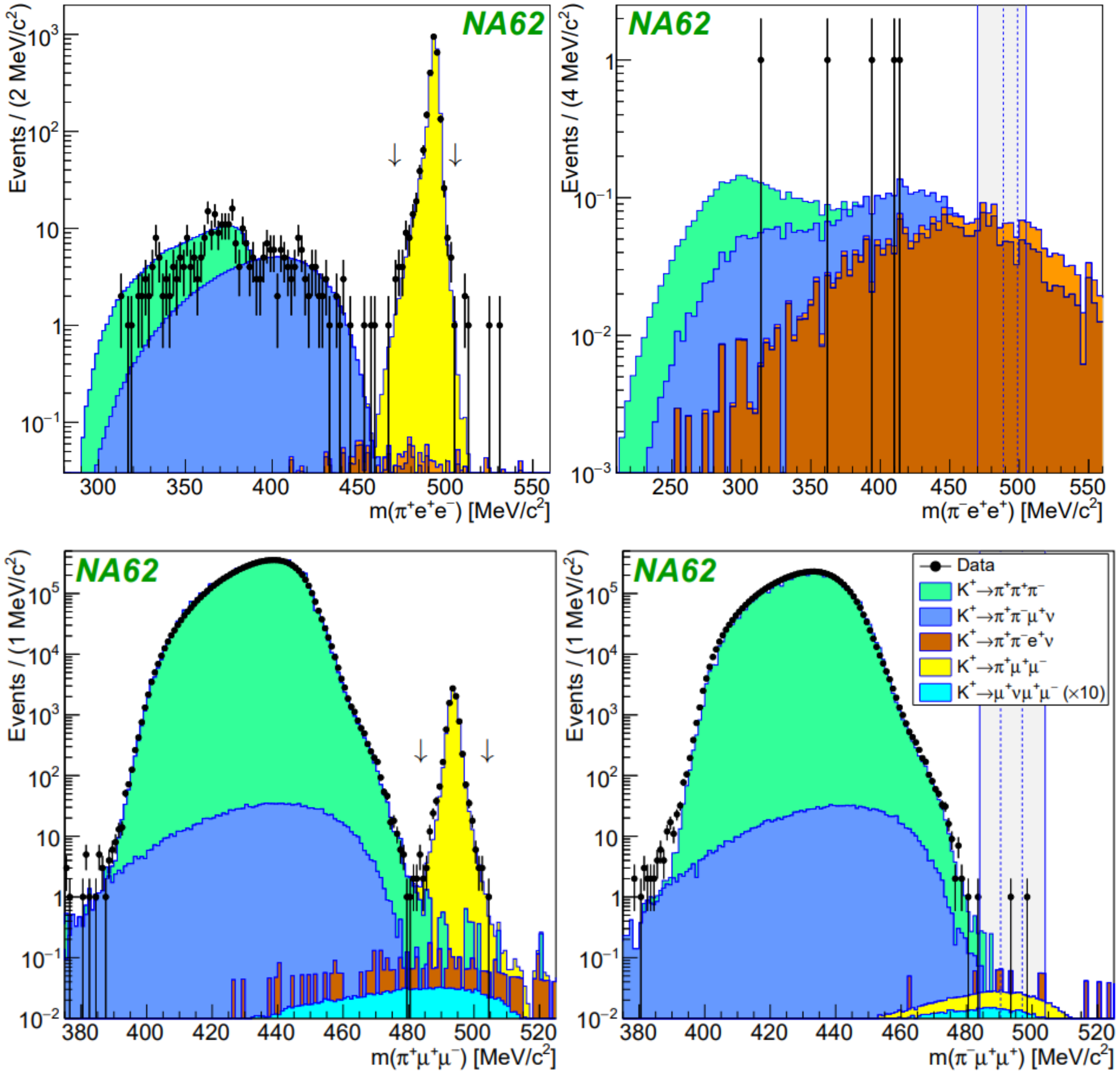
Searches for lepton flavour/number violation

- Search for $K^+ \to \pi^- e^+ e^+$ and $K^+ \to \pi^- \mu^+ \mu^+$ using 2017 data

- UK leadership

- New limits @ 90% CL :
  $BF(K^+ \to \pi^- e^+ e^+) < 2.2 \times 10^{-10}$
  $BF(K^+ \to \pi^- \mu^+ \mu^+) < 4.2 \times 10^{-11}$

[Phys. Lett. B797 (2019) 134794]



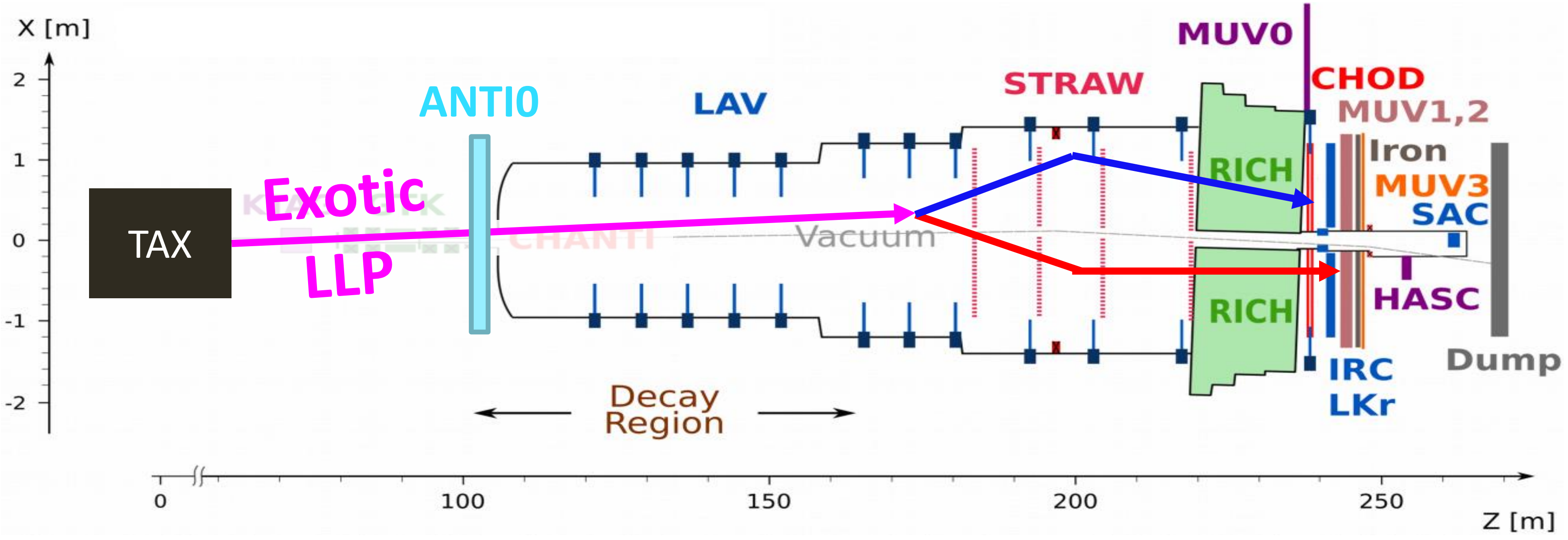
Search for other LFV/LNV processes

- Other LFV/LNV searches are ongoing, with **UK leadership** and excellent prospects
  - $K^+ \to \pi^-\mu^+e^+$ and $K^+ \to \pi^+\mu^-e^+$, $SES_{17} \approx 5 \times 10^{-11}$ (factor ~5 improvement on BNL-E865)
  - $K^+ \to e^-\nu\mu^+\mu^+$, $SES_{17} \approx 5 \times 10^{-11}$(first search for this mode)
  - $K^+ \to \mu^-\nu e^+e^+$,$SES_{17} \approx 1 \times 10^{-10}$ (factor ≈100 improvement on PDG)

  - Analyses are not limited by backgrounds
  - Size of the full 2016–18 dataset is ≈3 times the 2017 dataset

Watch this space!

NA62 as a beam dump experiment



- NA62 (as NA62++) included in the Physics Beyond Colliders programme
- NA62 collaboration intends to **collect 10^{18} protons on target before LS3**
  - Ongoing discussion concerning how exactly this should be achieved

- **New ANTI0 detector** under construction to veto muons produced in the TAX

- Studies to **increase beam intensity by 20-50% above nominal**
  - Detector safety/survivability currently being studied

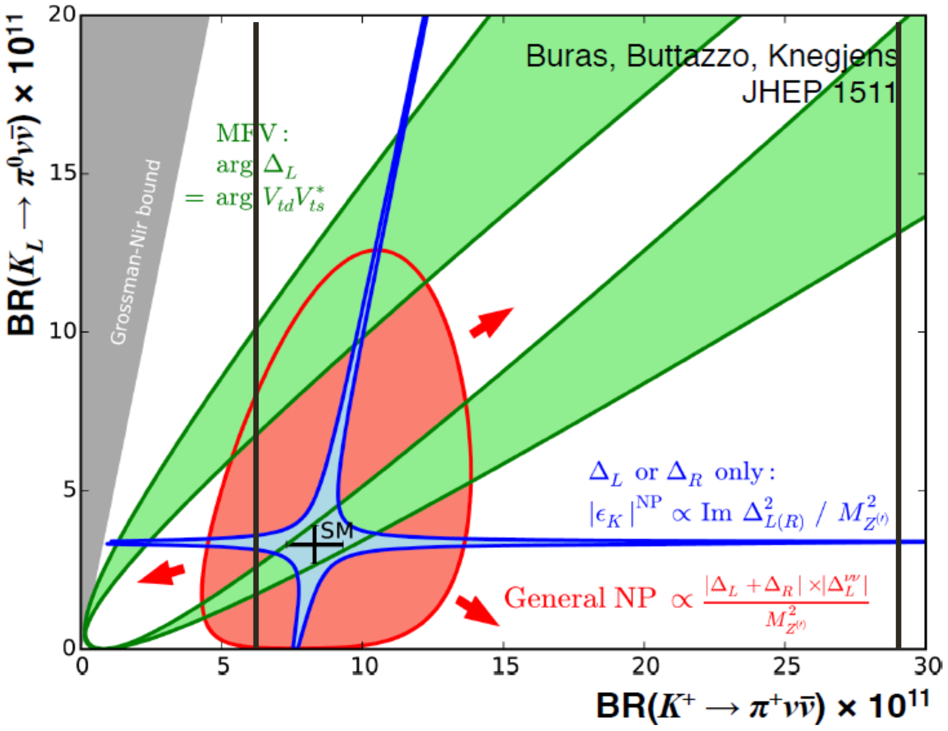
What's the big idea?

- Big idea:
  - NA62 has initiated a feasibility study for running at considerably higher intensity
  - 4x higher in K^+ mode, 6x higher in K_L mode. Limited by radiation protection at CERN boundary

- Physics goals:
  - Improve precision on $K^+ \to \pi^+ \nu\bar{\nu}$
  - A complementary measurement of $K_L \to \pi^0 \nu\bar{\nu}$

    (complementary both to NA62,
    and the KOTO experiment at J-PARC)

- Completely **new experiments** are needed
- Both new experiments have a **large commonality** in terms of the upgrades required (hardware, readout) and are **two aspects/phases of the same kaon facility**



What's the big idea?

- Big idea:
  - NA62 has initiated a feasibility study for running at considerably higher intensity
  - 4x higher in K^+ mode, 6x higher in K_L mode. Limited by radiation protection at CERN boundary
- Physics goals:
  - **Improve precision on $\boldsymbol{K^+ \to \pi^+ \nu\bar{\nu}}$**
- 4x more intensity means 4x more stringent timing requirements
  - Challenging for tracking, and most other detectors
  - Especially for detectors in the beam: KTAG and GTK
- However, these challenges are well aligned with other research in the UK (TORCH, LHC upgrades, …)
  - KTAG: require single photon detection with $\sim 40\mathrm{ps}$ resolution at a flux of $10\mathrm{MHz/cm^2}$
  - GTK: $\sim 40\mathrm{ps}$ resolution, radiation hard (no need to improve precision though)

What's the big idea?

- Big idea:
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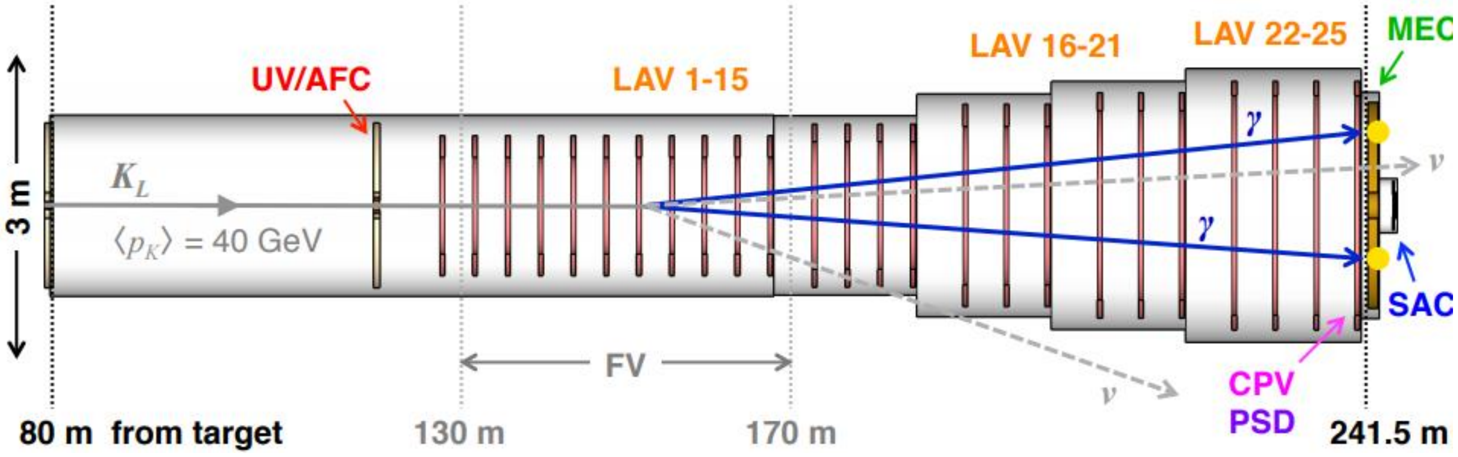
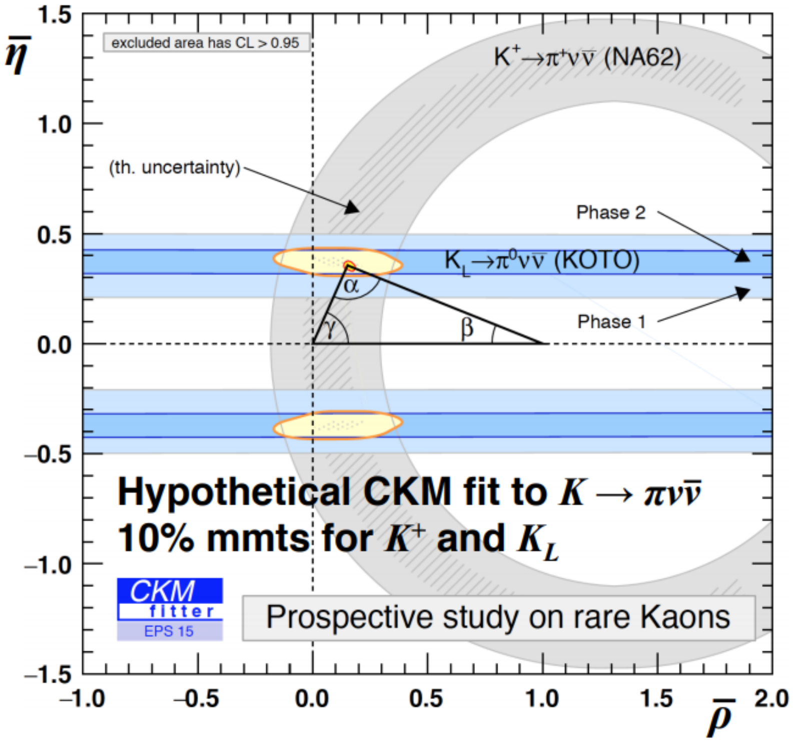
  - 4x higher in K^+ mode, 6x higher in K_L mode. Limited by radiation protection at CERN boundary

- Physics goals:
  - **A complementary measurement of $K_L \to \pi^0 \nu\bar{\nu}$**

- The $K_L EVER$ experiment has been studied extensively

  "K_L Experiment for Very Rare events"





60 SM $K_L \to \pi^0 \nu\nu$
S/B ~ 1
δBR/BR($\pi^0 \nu\nu$) ~ 20%

NA62 Status and plans, PPAP Community meeting 2019 13 Sep. 2019

Summary

- 2016 measurement of $BF(K^+ \to \pi^+ \nu\bar{\nu})$ now published: Phys. Lett. B 791 (2019) 156
- New measurement of $BF(K^+ \to \pi^+ \nu\bar{\nu})$ [link]

  $BF(K^+ \to \pi^+ \nu\bar{\nu}) < 2.44 \times 10^{-10}$ @ 95% CL

  $BF(K^+ \to \pi^+ \nu\bar{\nu}) = (0.47^{+0.72}_{-0.47}) \times 10^{-10}$ (two-sided 68% band)

  $BF(\pi^0 \to inv.) < 4.4 \times 10^{-9}$ @ 90% CL

- Broader physics programme with UK leadership:
  - World's best limits in heavy neutral lepton production [link]
  - World's best limits in LFV and LNV K^+ decays: Phys. Lett. B797 (2019) 134794
- What's next:
  - Perform the $K^+ \to \pi^+ \nu\bar{\nu}$ analysis on the 2018 data
  - Clear goals for Run 3: improve upstream background rejection, NA62++ beam dump experiment
  - Big ideas for after LS3: new experiment(s) required to study $K^+ \to \pi^+ \nu\bar{\nu}$, $K_L \to \pi^0 \nu\bar{\nu}$