$K^+ \to \pi^+ \nu\nu$: first result from NA62

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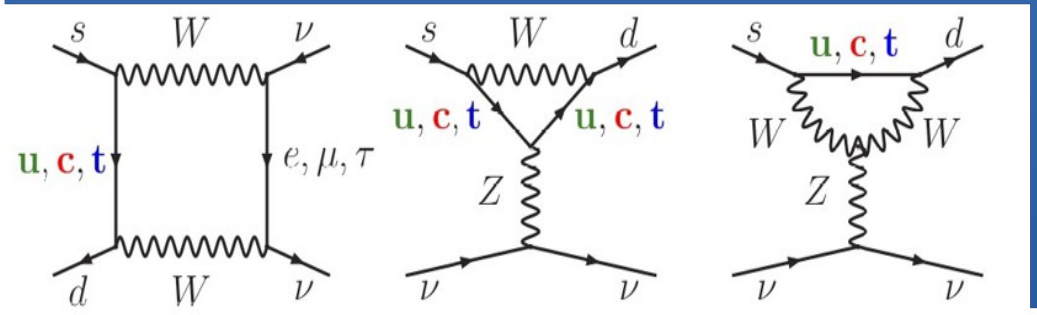
$K^+ \to \pi^+ \nu\nu$: motivation

FCNC loop process, highly suppressed, theoretically very clean

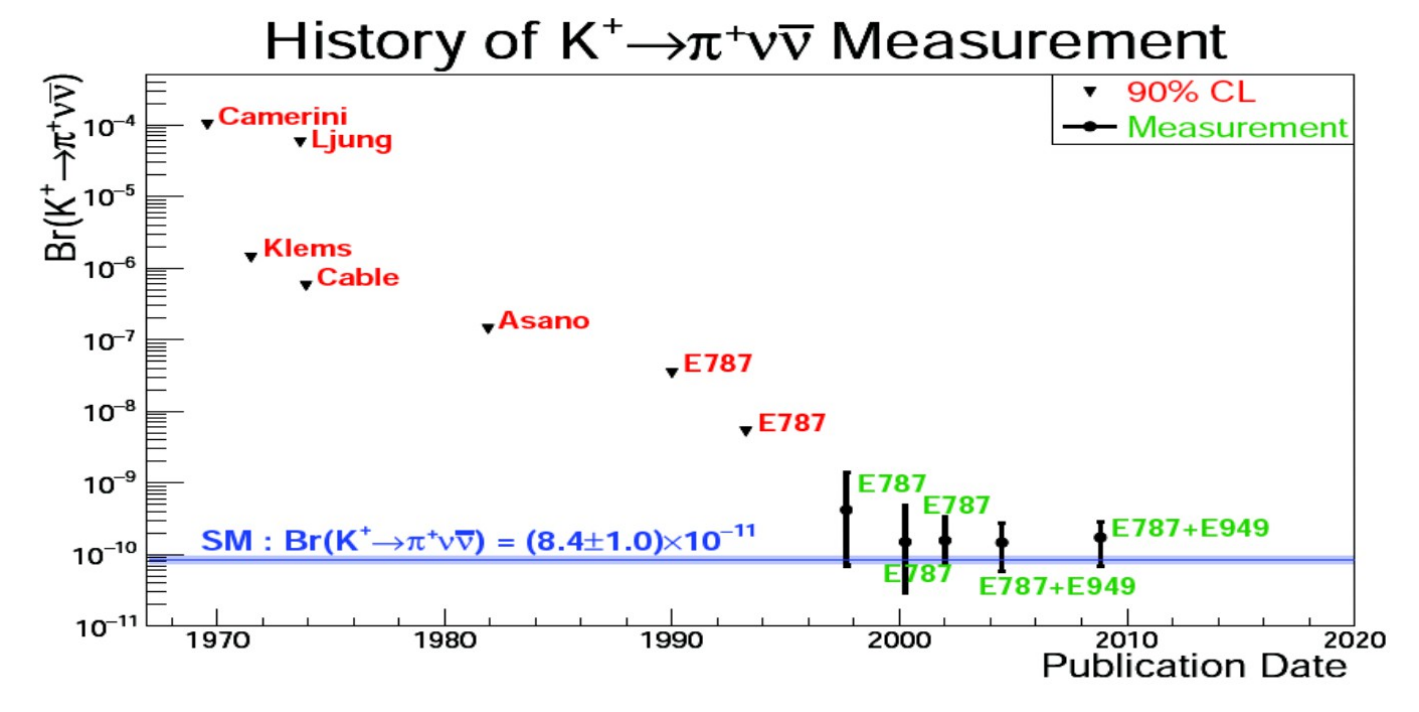


Well calculated inside the Standard Model [A.J. Buras et al., JHEP 1511 (2015) 033]

$$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \cdot \left[\frac{|V_{cb}|}{40.7 \times 10^{-3}}\right]^{2.8} \left[\frac{\gamma}{73.2^\circ}\right]^{0.74}$$

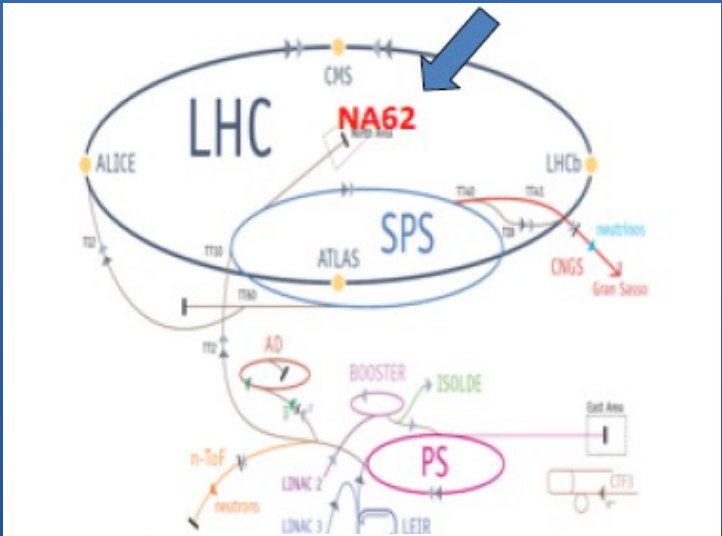
Generic NP: not necessarily suppressed, can probe very high scales ~100 TeV → complementary to LHC in a search for New Physics

The NA62 goal



The goal: to perform the BR measurement with a 10% precision, comparable with the theoretical (SM) prediction

The Na62 experiment



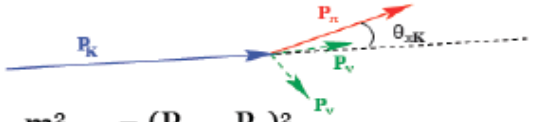
~200 participants, 30 institutions

- 2008: NA62 Approval
- 2009-14: Detector R&D
- 2014: Pilot Run
- 2015: Commissioning Run
- **2016-18: Physics Runs**

NA62 aim: collect O(100) SM $K^+ \to \pi^+ \nu\nu$ decays
using a novel decay-in-flight technique.

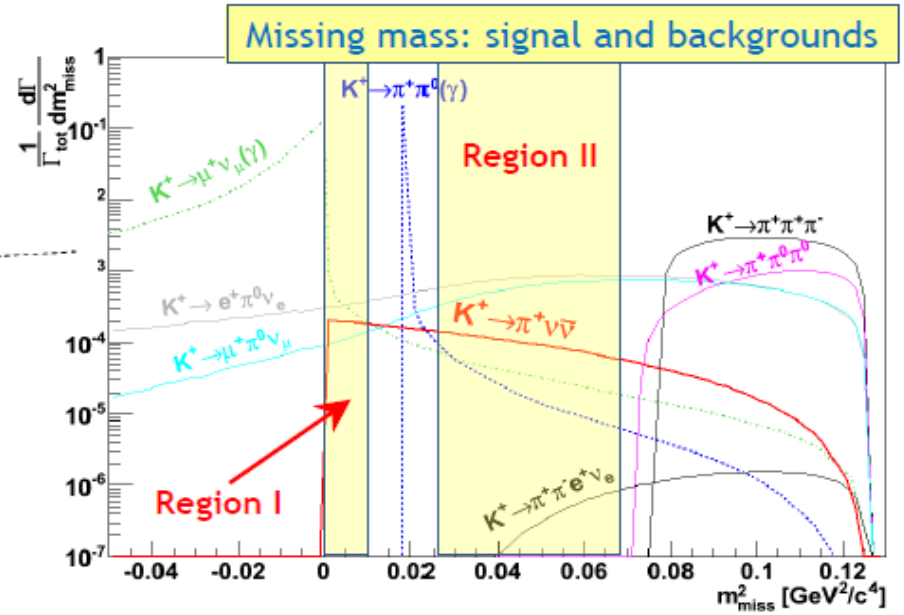
Signal and Background

Main kaon decays Background:



$$m^2_{miss} = (P_K - P_\pi)^2$$

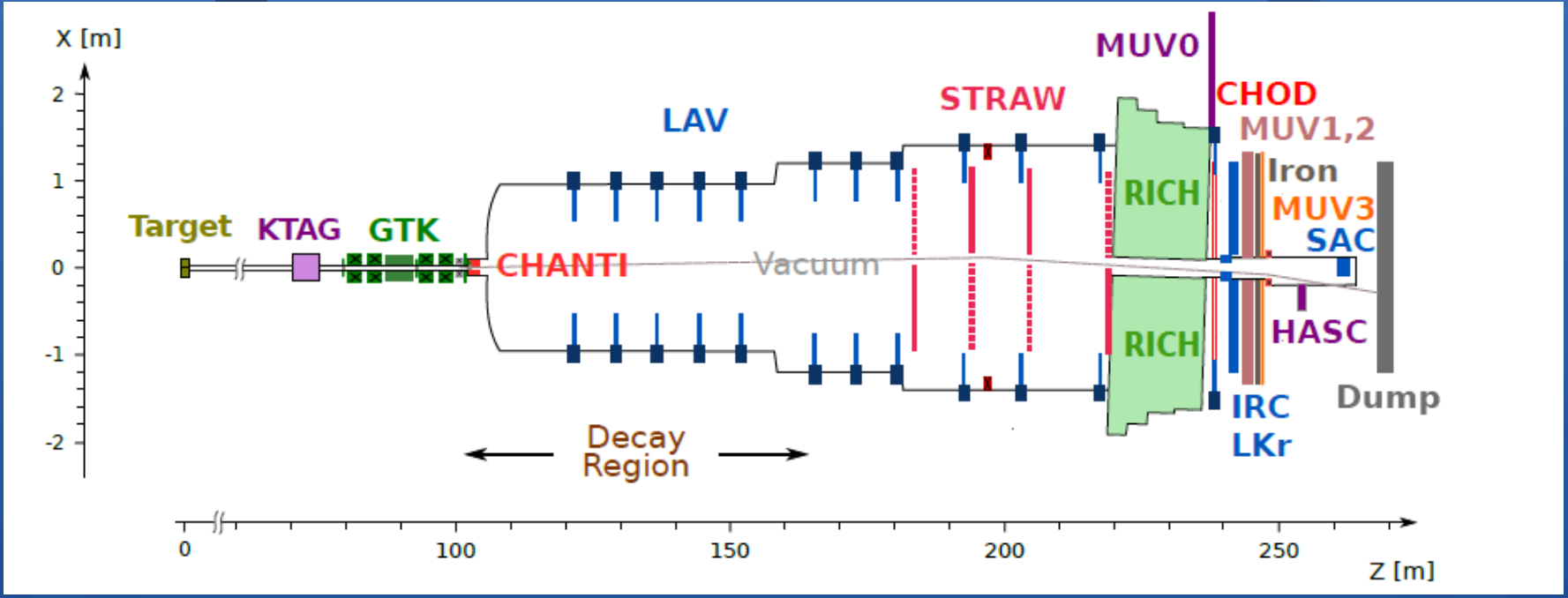
Other background:
Beam-gas interactions
Upstream interactions



92% of total BR(K^+):
Outside the signal kinematic region (m_{miss}, 15 GeV/c< P(π) < 35 GeV/c).
Signal region is split into Region I and Region II by the $K^+\to\pi^+\pi^0$ peak.

8% of total BR(K^+) including multi-body:
Span across the signal region (not rejected by kinematic criteria).
Rejection relies on photon veto system, Particle ID, sub-ns timing.

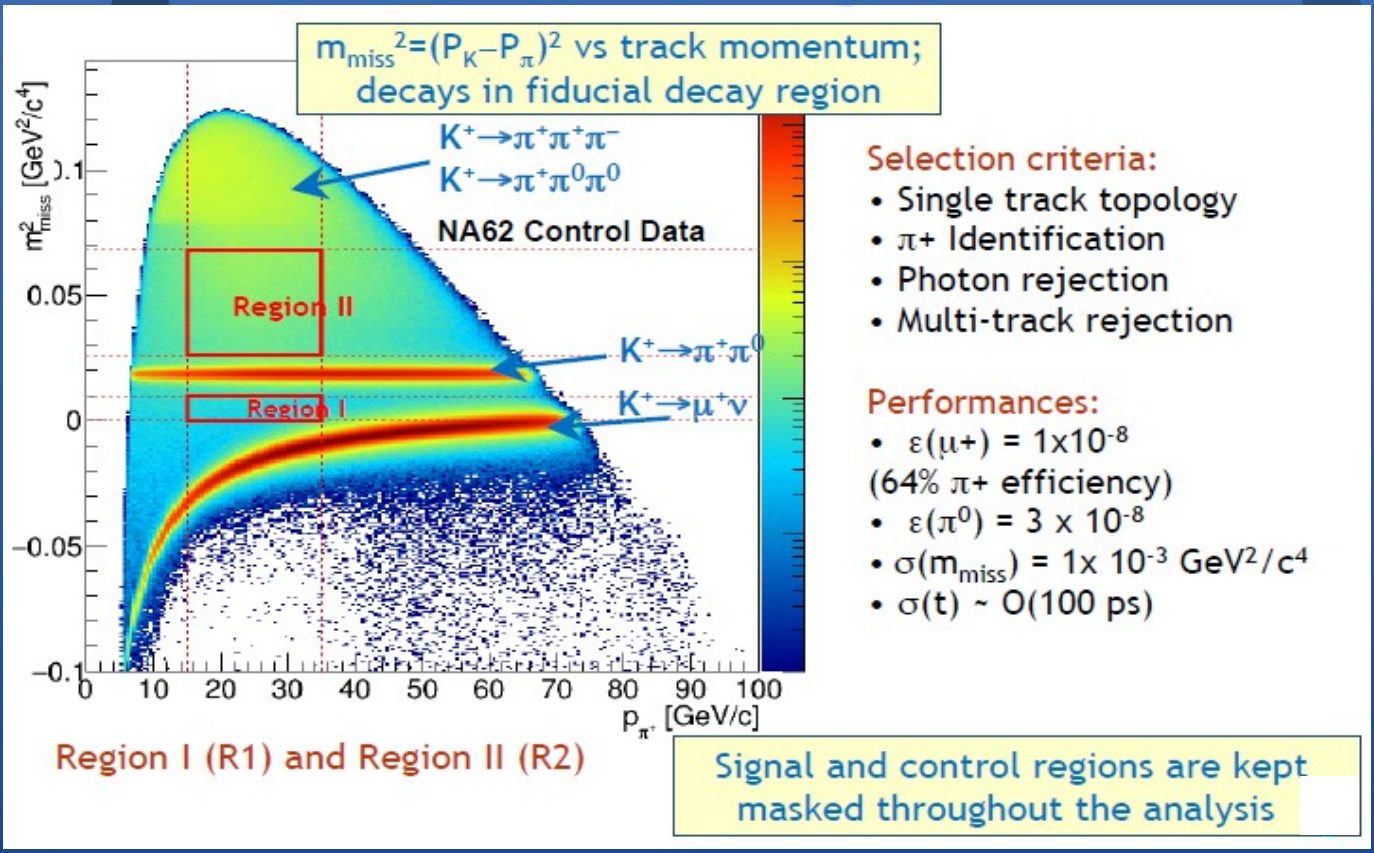
The NA62 detector



Un-separated hadron ($p/\pi^+/K^+$) beam.
SPS protons: 400 GeV, 3×10^{12}/spill.
K^+: 75GeV/c (±1%), divergence < 100μrad.
800 MHz beam rate; 45 MHz K^+ rate;
~5 MHz K^+ decays in fiducial volume

Timing between sub-detectors O(100 ps).
Kinematic rejection $O(10^4)$ for $K^+\to\pi^+\pi^0$ and $K\to\mu^+\nu$.
Photon veto: $\pi^0\to\gamma\gamma$ decay suppression from $K^+\to\pi^+\pi^0$ $>10^{-7}$.
Particle ID (RICH+LKr+HAC+MUV): muon suppression from $K\to\mu^+\nu$ $> 10^{-7}$.

Signal selection



Selection criteria:

- Single track topology
- π+ Identification
- Photon rejection
- Multi-track rejection

Performances:

- $\varepsilon(\mu+) = 1\times10^{-8}$

(64% π+ efficiency)

- $\varepsilon(\pi^0) = 3 \times 10^{-8}$
- $\sigma(m_{miss}) = 1\times 10^{-3}$ GeV^2/c^4
- $\sigma(t)$ ~ O(100 ps)

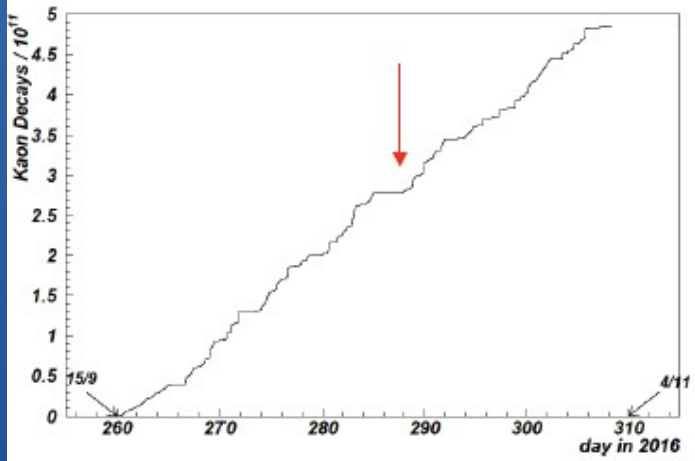
Signal and control regions are kept masked throughout the analysis

Na62 “Luminosity”

2016 run

13×10^{11} ppp on target (40% nominal)

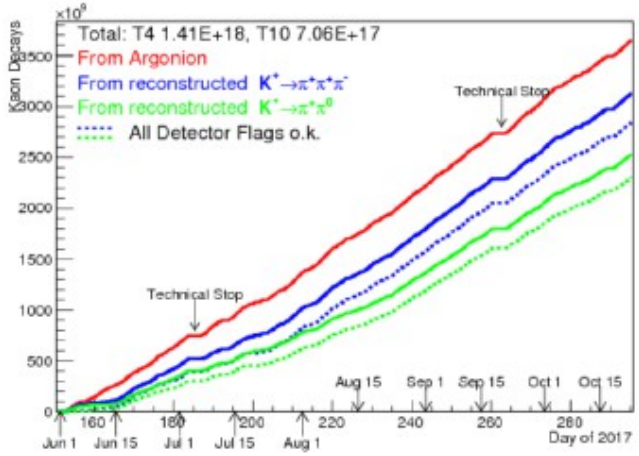
$\sim 1 \times 10^{11}$ K^+ decays useful for $\pi\nu\nu$



2017 run

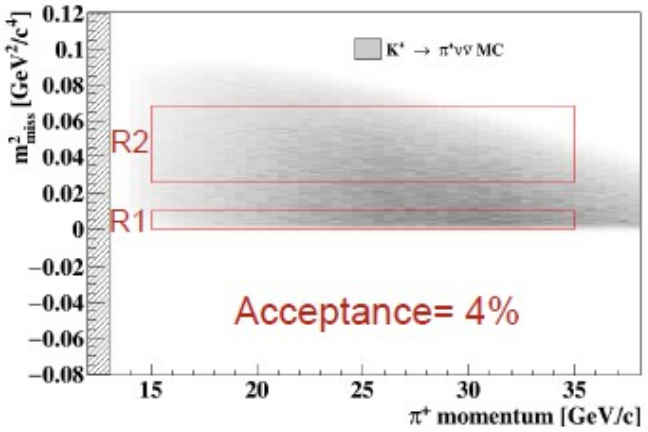
20×10^{11} ppp on target (60% nominal)

$> 3 \times 10^{12}$ K^+ decays collected



Result today presented on 2016 $\pi\nu\nu$ data (4 weeks of data taking)

Single Event Sensitivity



Uncertainties:

Source	δSES (10^{-10})
Random Veto	±0.17
N_K	±0.05
Trigger efficiency	±0.04
Definition of $\pi^+\pi^0$ region	±0.10
Momentum spectrum	±0.01
Simulation of π+ interactions	±0.09
Extra activity	±0.02
GTK Pileup simulation	±0.02
Total	±0.24

Control trigger $K^+ \to \pi^+\pi^0$ used for normalization (10% acceptance)
Number of kaon decays in the fiducial volume: $N_K = 1.21(2) \times 10^{11}$

$$SES = (3.15 \pm 0.01_{stat} \pm 0.24_{sys}) \times 10^{-10}$$

Background summary

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

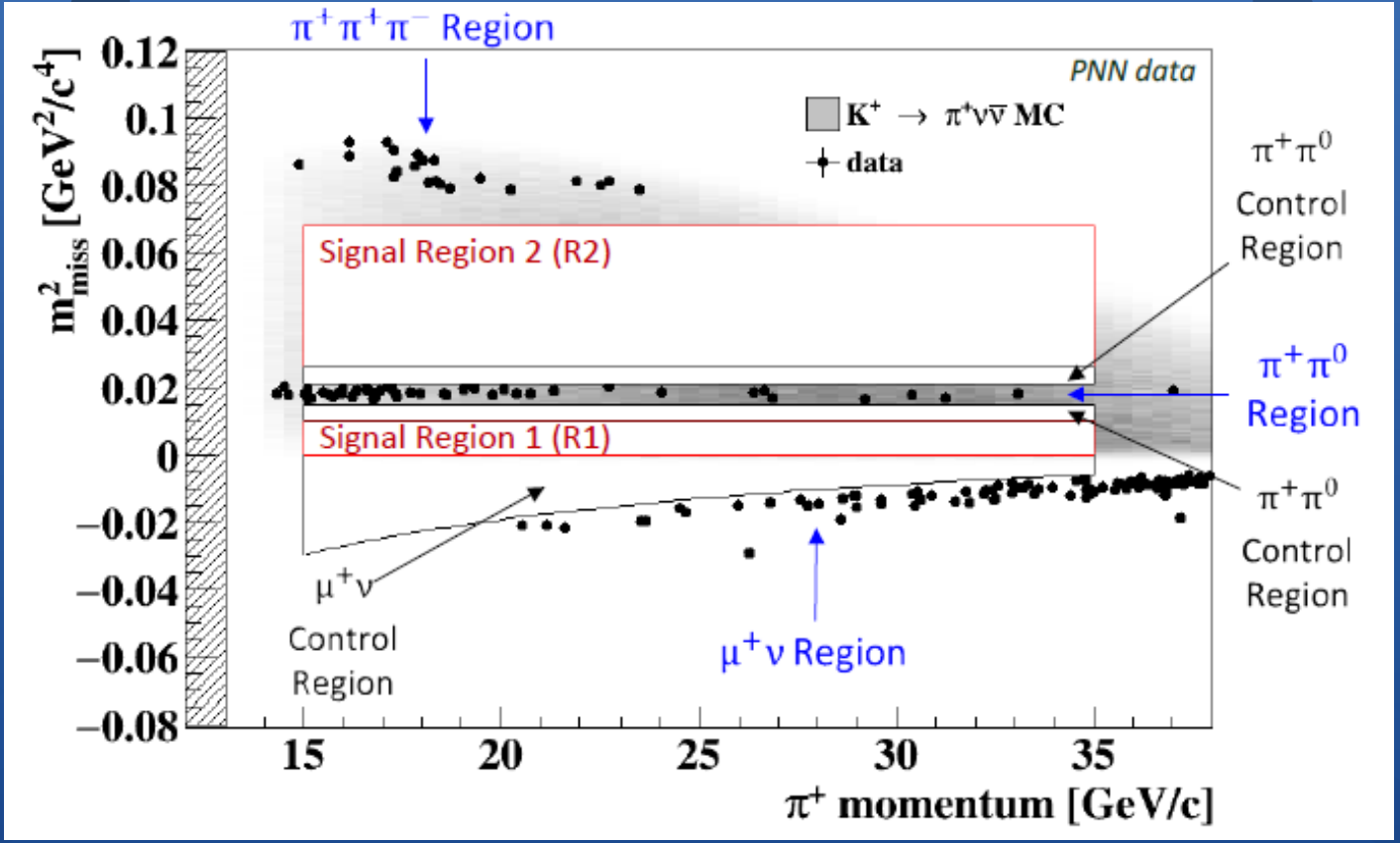
$K^+ \to \pi^+\pi^0$ (γ) Data driven - Control region: 1 observed (1.5 expected)

$K^+ \to \mu^+\nu$ (γ) Data driven - Control region: 2 observed (1.1 expected)

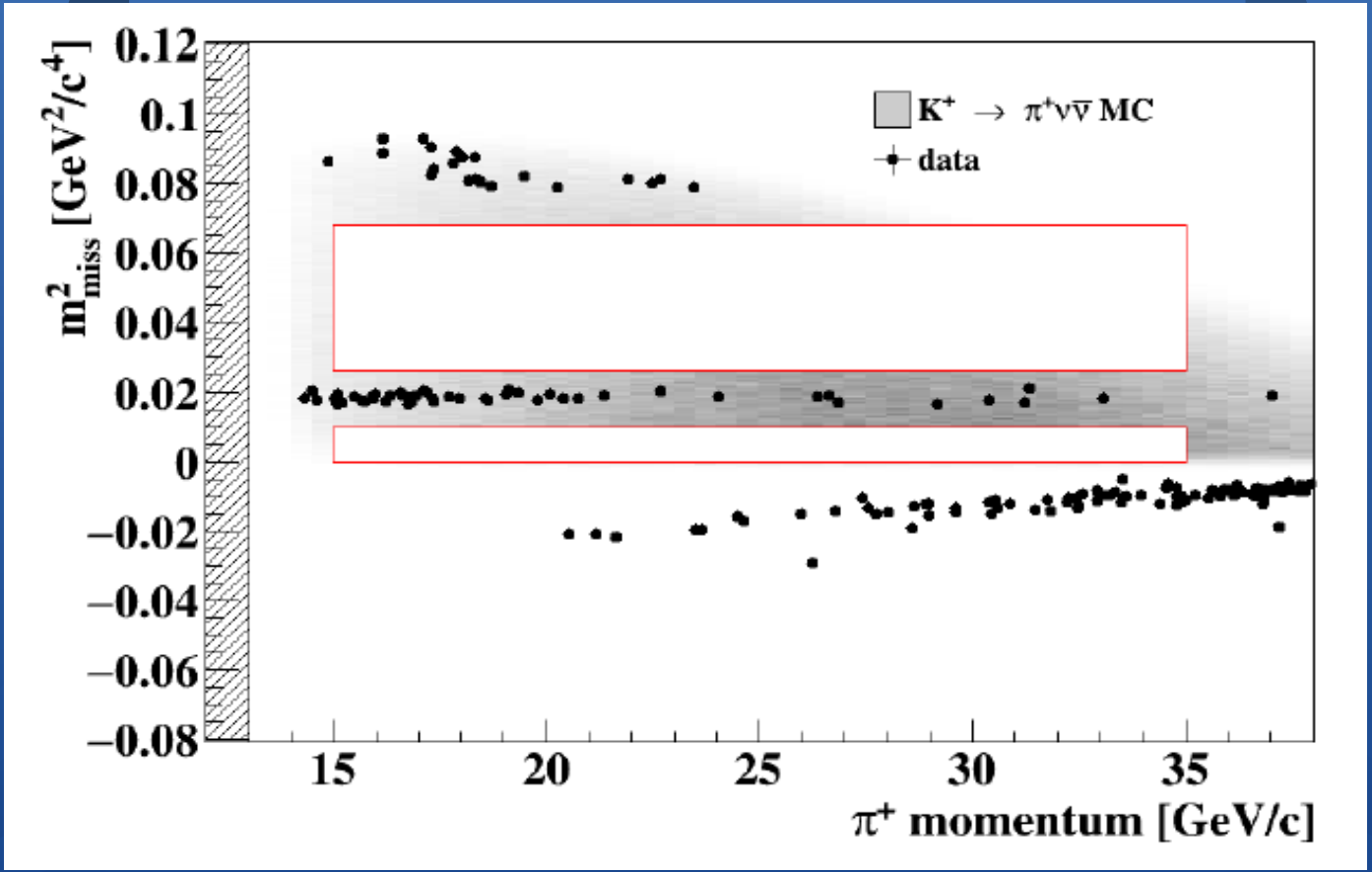
$K^+ \to \pi^+\pi^- e^+ \nu_e$ Estimated with 400M MC decays - good agreement across 5 validation samples

Upstream background (accidentals and interactions)
Data driven - Controlled by geometrical and kaon-pion matching

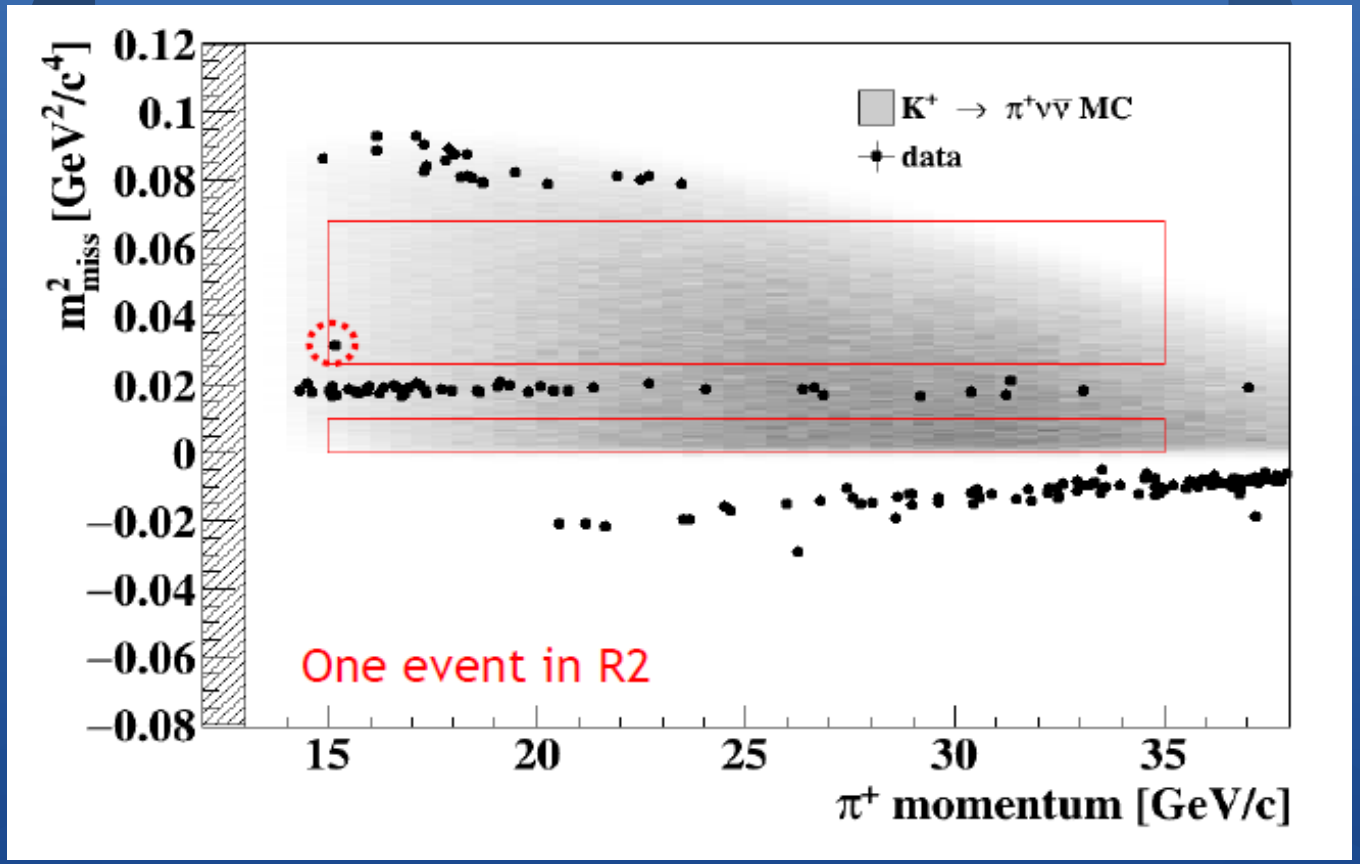
Data 2016 Sample



Data 2016 result



Data 2016 Result



Data 2016 Results

Events observed	1
Single Event Sensitivity	$(3.15 \pm 0.01_{\text{stat}} \pm 0.24_{\text{syst}}) \times 10^{-10}$
Expected Background	$0.15 \pm 0.09_{\text{stat}} \pm 0.01_{\textit{syst}}$

Obtained Upper Limit:

$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) < 11 \times 10^{-10}$ @ 90 % CL
$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10}$ @ 95 % CL

For Comparison:

$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = 2.8^{+4.4}_{-2.3} \times 10^{-10}$ @ 68 % CL
$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = (0.84 \pm 0.10) \times 10^{-10}$ SM prediction
$\mathcal{B}(K^+ \to \pi^+ \nu\bar{\nu}) = 1.73^{+1.15}_{-1.05} \times 10^{-10}$ BNL 949/E787

NA62 $K^+ \to \pi^+ \nu\nu$ prospects

Analysis of data collected in 2017 started:

- ✓ 20 times more data than the presented statistics
- ✓ Expect improvement on signal acceptance, background reduction and reconstruction efficiency

2018 data taking on-going (April - November 2018)

Expect 20 SM events before LS2

Data taking after LS2 recommended by SPSC, to be approved

The new NA62 decay in flight technique works

Spare Slides

SES Definition

- Normalization: $K^+ \to \pi^+\pi^0$ from control data
- Same $\pi^+\nu\bar{\nu}$ selection: γ, multiplicity rejection not applied; m^2_{miss} cuts modified

$$N_K = \frac{N_{\pi\pi} \cdot D}{A_{\pi\pi} \cdot BR_{\pi\pi}}$$

$$SES = \frac{1}{N_K \sum_j \left(A^j_{\pi\nu\nu} \cdot \epsilon^j_{RV} \cdot \epsilon^j_{trig}\right)}$$

N_K	Number of K^+ decays
$N_{\pi\pi} \sim 6 \cdot 10^6$	Number of $K^+ \to \pi^+\pi^0$
$A_{\pi\pi} \sim 0.1$	Normalization acceptance
$D = 400$	Control Trigger Downscaling

ϵ_{RV}	Random veto efficiency
ϵ_{trig}	Trigger efficiency
$A_{\pi\nu\nu}$	Signal acceptance
J	π^+ momentum bin

$$N_{K^+} = (1.21 \pm 0.02) \times 10^{11}$$

$K^+ \to \pi^+\pi^0$ Background

Events in $\pi^+\pi^0$ region after $\pi^+\nu\bar{\nu}$ selection

$$N_{\pi\pi}^{exp}(region) = \sum_j \left[N_{\pi\pi}(\pi^+\pi^0)_j \cdot f_j^{kin}(region) \right]$$

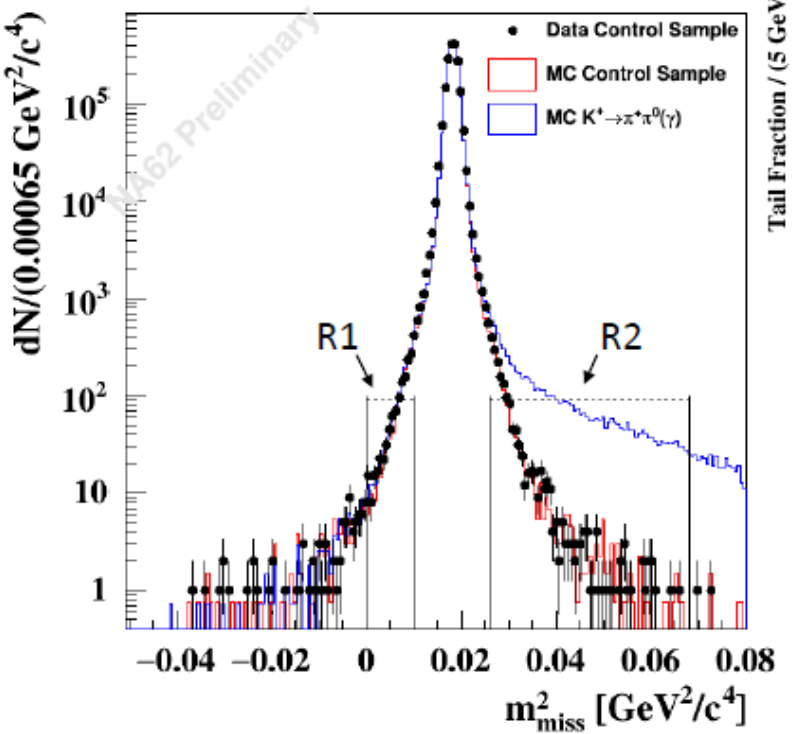
Expected events

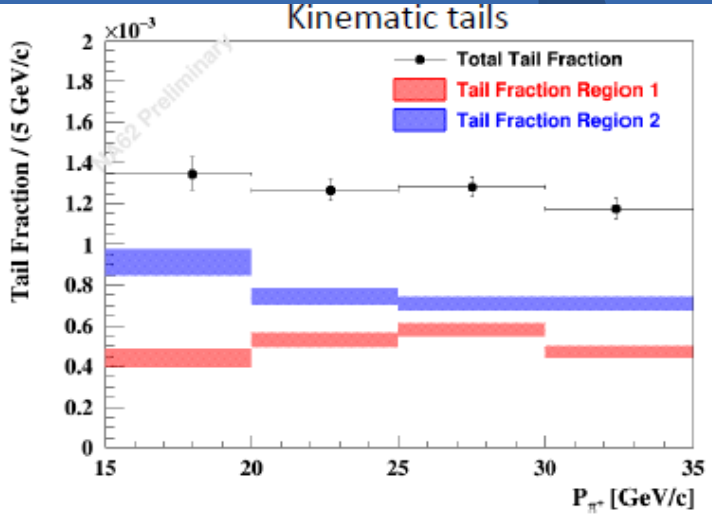
j: π^+ momentum bin

Fraction of events in region *region*

- $f_j^{kin}(region)$ measured: $\pi^+\pi^0$ sample selected tagging the π^0 with 2 γ's in LKr
- MC studies with and without π^0 tagging
- π^0 and kinematic rejection assumed independent

$K^+ \to \pi^+\pi^0$ Background





Number of expected events

Region	$\pi^+\pi^0$
R1	$0.022 \pm 0.004_{stat} \pm 0.002_{syst}$
R2	$0.037 \pm 0.006_{stat} \pm 0.003_{syst}$