Joint Annual HEPP and APP Conference
25 - 28 March 2018, University of Bristol

Search for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ at NA62

Angela Romano, on behalf of the NA62 collaboration

Outline:

- The NA62 experiment at CERN SPS
- $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ analysis of 2016 data
- First results

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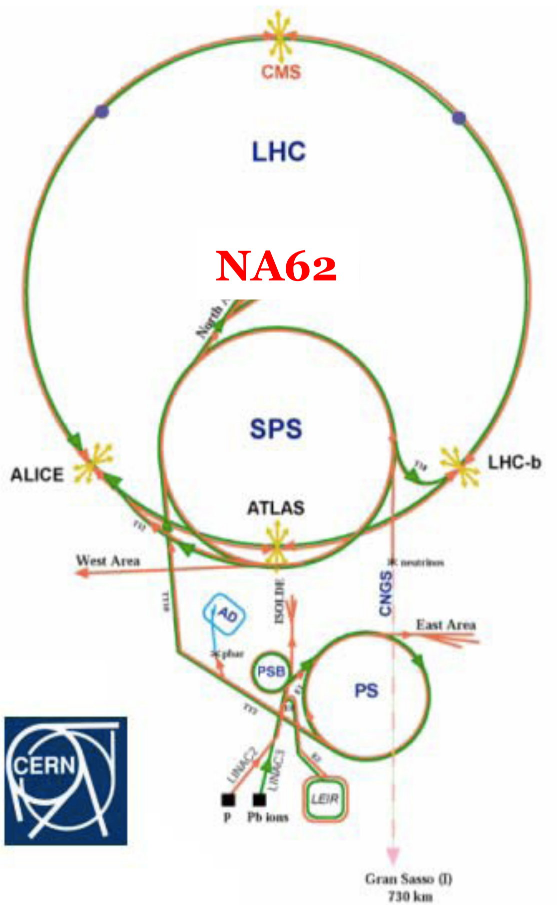
The NA62 experiment

High precision fixed-target Kaon experiment at CERN SPS

Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, Glasgow, Lancaster, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin, Vancouver (UBC)



NA62 Timeline

Dec 2008 - NA62 Approval

2009 - 2014: Detector R&D, Installation

2015 Commissioning

2016 - 2018: Physics Runs

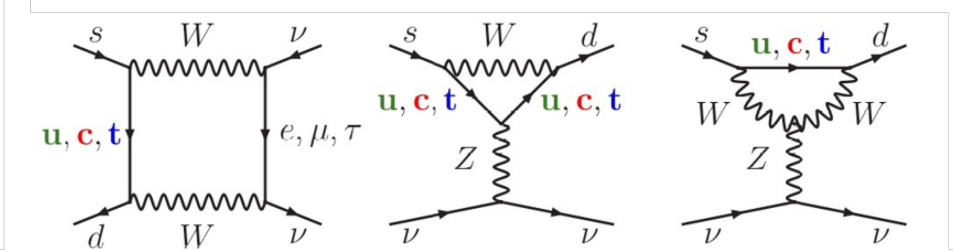
2021 - 2023 Next Physics Runs (TBA)

NA62 primary goal: Measure BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$)

New: K^+ decay-in-flight technique

Motivations for $K^+ \to \pi^+ \nu\bar{\nu}$

Box & Penguin (one-loop) diagrams



✓High sensitivity to New Physics

✓FCNC process forbidden at tree level

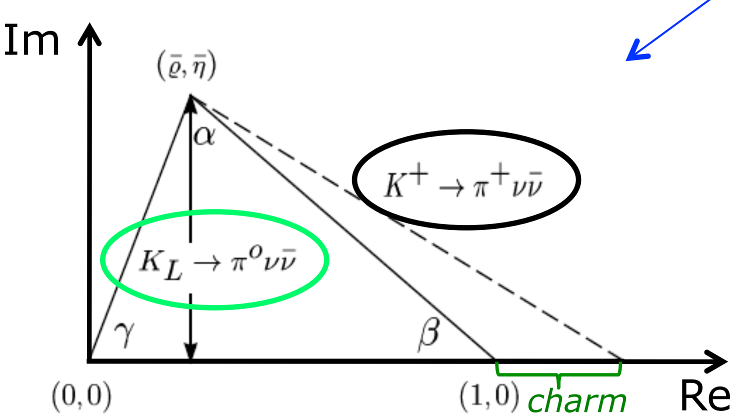
✓ Highly CKM suppressed (BR ~ $|V_{ts}^* V_{td}|^2$)

✓Extraction of V_{td} with minimal (few %) non-parametric uncertainty

Theoretically very clean:

- ✓ dominant short-distance contribution
- ✓ hadronic matrix element extracted from precisely measured BR($K^+ \to \pi^0 e^+ \nu$)

Independent determination of unitary triangle for K meson system (with neutral mode)



$$BR(K^+ \to \pi^+ \bar{\nu}\nu) = (8.4 \pm 1.0) \times 10^{-11}$$

[Buras et al., JHEP 1511 (2015) 033]

error: CKM parametric, dominated by V_{cb}

Indirect searches of NP with high precision studies of rare K decays

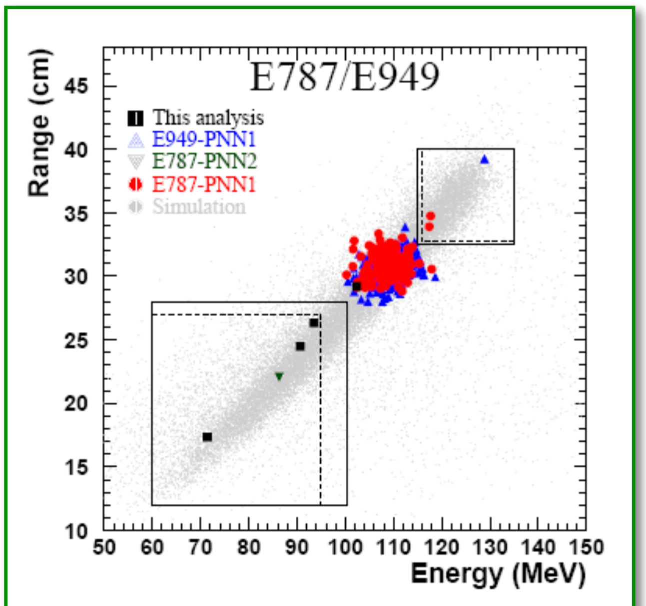
Experimental Status & NP Sensitivity

$BR(K^+ \to \pi^+ \nu\bar{\nu})_{THEORY} = (0.84 \pm 0.10) \times 10^{-10}$

$BR(K^+ \to \pi^+ \nu\bar{\nu})_{EXP} = 1.73^{+1.15}_{-1.05} \times 10^{-10}$

[E787/E949, Phys.Rev.Lett.101, 191802, 2008]

- based on 7 candidates
- stopped Kaon technique

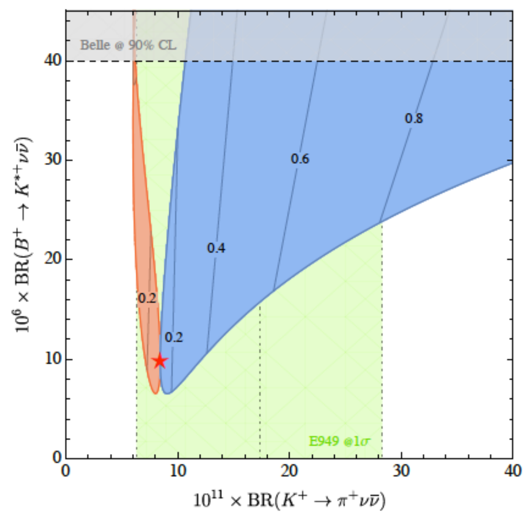


(7 candidates E787+E949)

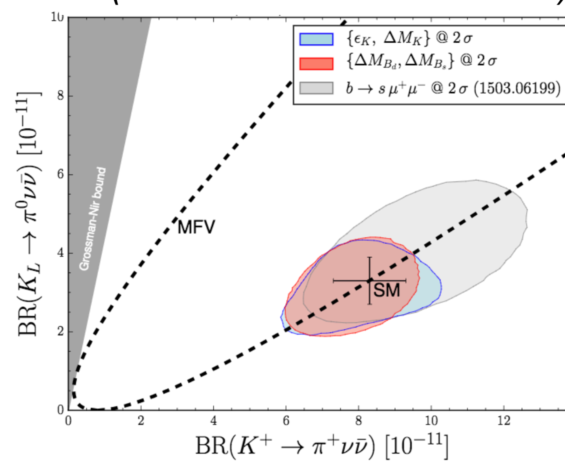
Discrimination among NP scenarios

[Buras, Buttazzo,Knegjens, JHEP11(2015)166]

LFU violation



Z'(5 TeV in Constrained MFV)



[Isidori et al., Eur. Phys. J. C (2017) 77: 618]

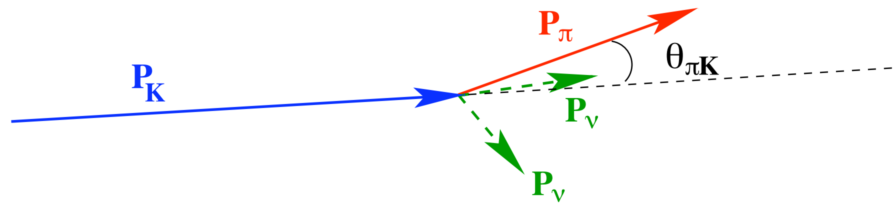
$K \to \pi\nu\bar{\nu}$ probes of unique sensitivity for NP models among B and K decays

(NP searches complementary/alternative to LHC)

$K^+ \to \pi^+ \nu \bar{\nu}$ Signal & Backgrounds

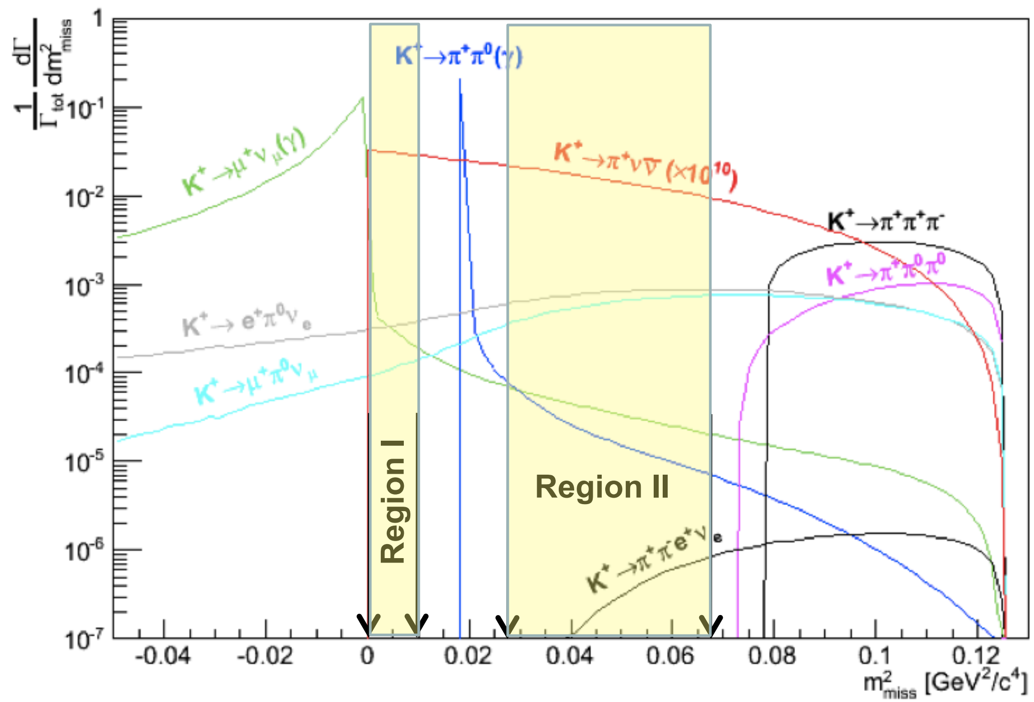
Signal $K^+ \to \pi^+ \nu \bar{\nu}$:

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



Main kaon decay backgrounds

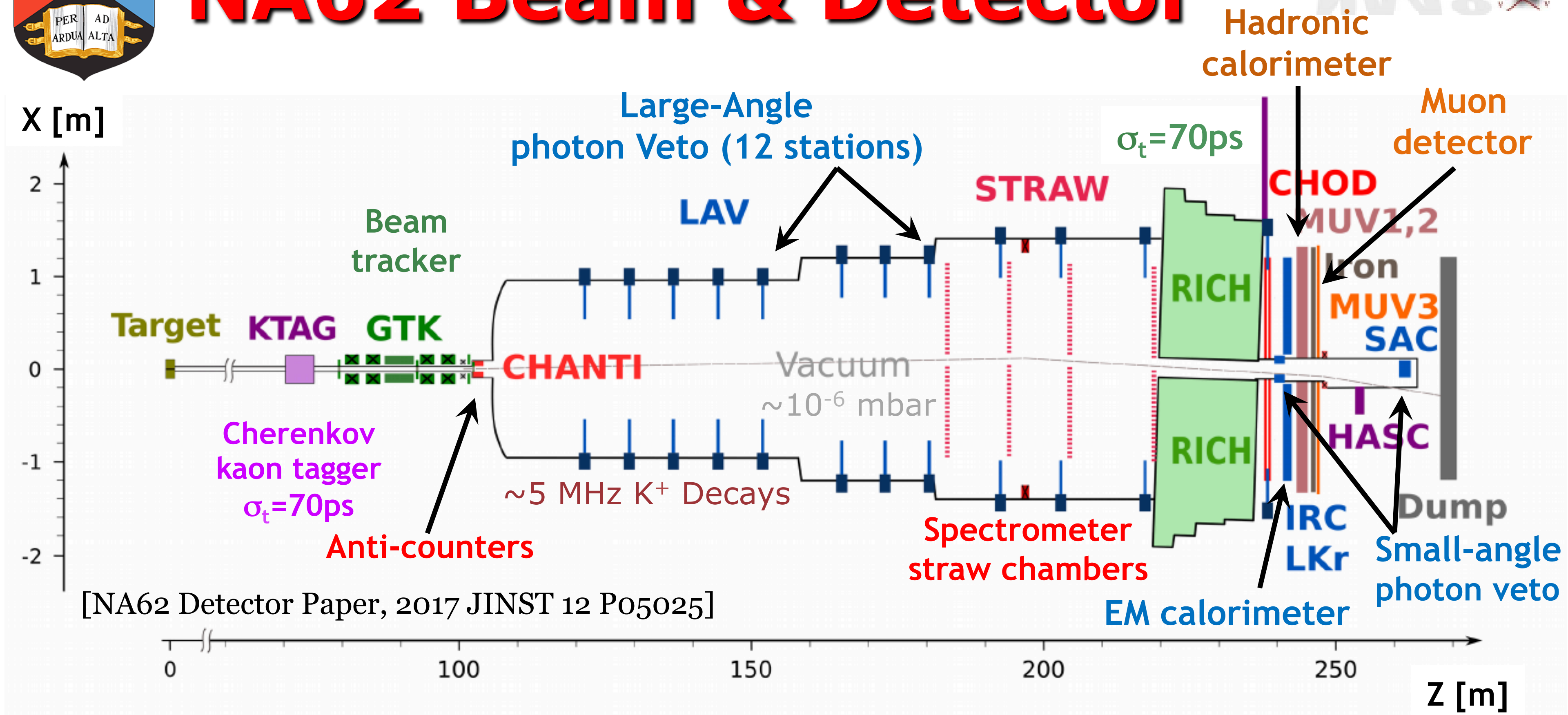
Process	Branching ratio
$K^+ \to \mu^+ \nu_\mu (\gamma)$	63.5%
$K^+ \to \pi^+ \pi^0 (\gamma)$	20.7%
$K^+ \to \pi^+ \pi^+ \pi^-$	5.6%
$K^+ \to \pi^+ \pi^- e^+ \nu_e$	4.3×10^{-5}



Sign & Bkg control regions kept blind throughout the analysis

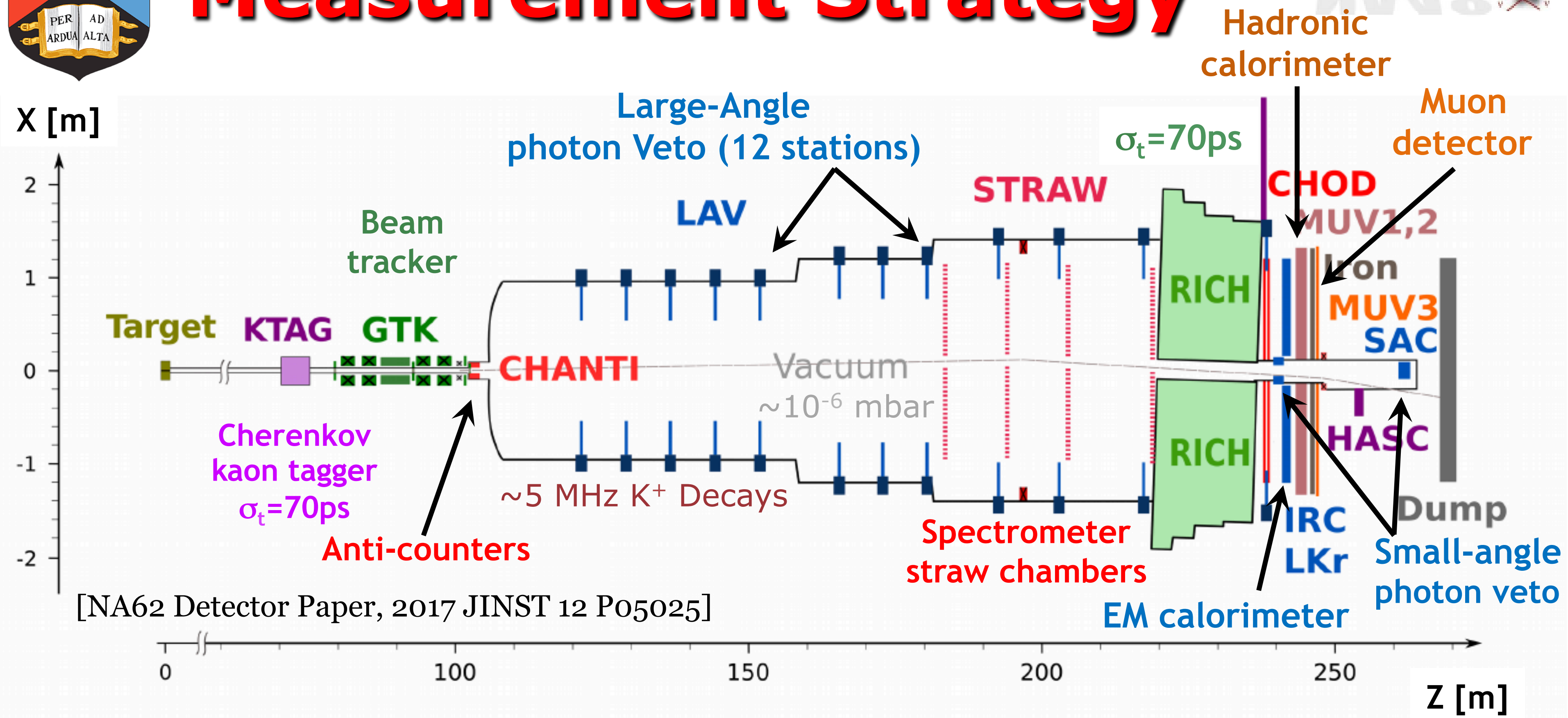
Background rejection relies on **Kinematics** ($15 GeV/c < P_\pi < 35 GeV/c$; m^2_{miss}) used in conjunction with **Particle ID**, **Veto systems** and **sub-ns timing**

NA62 Beam & Detector



- SPS protons on Be target (PoT): 400 GeV/c, ~10^{12} PoT/sec , 3.5 sec/spill
- Un-separated hadron beam: π^+(70%)/K^+(6%)/p(24%)
- 750MHz beam rate @GTK (45MHz K^+ component)
- K^+: 75GeV/c (±1%), divergence < 100μrad, (60 x 30) mm² transverse size
- 10% of K^+ decays in 60 m fiducial volume (FV)

Measurement Strategy



Keystones from detector design:

- Timing between sub-detectors ~ O(100ps)
- Kinematic rejection ~O(10^4) for $K^+ \to \pi^+\pi^0$, $K^+ \to \mu^+\nu$ bkg channels
- Particle ID: muon suppression (from $K \to \mu^+\nu$) > 10^7
- Photon veto: $\pi^0 \to \gamma\gamma$ suppression (from $K^+ \to \pi^+\pi^0$) > 10^7

$K^+ \to \pi^+ \nu \bar{\nu}$ Signal Selection

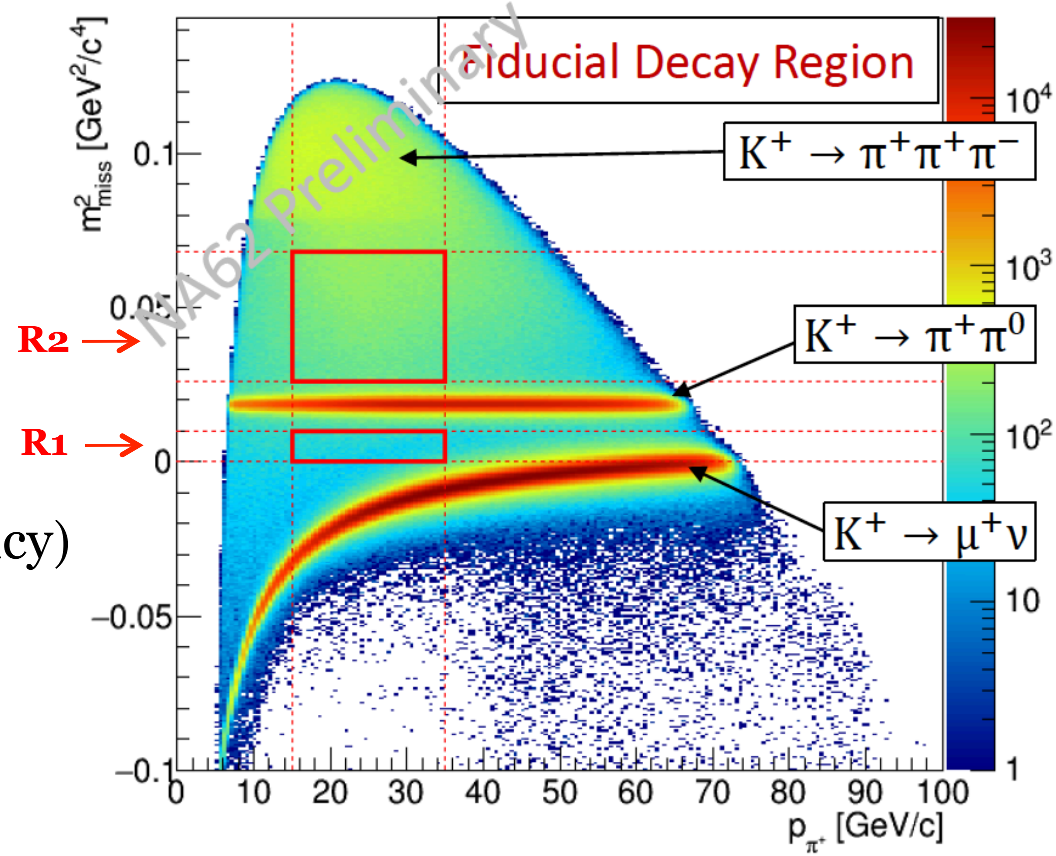
$m^2_{miss} = m^2_{miss}$ (GTK, STRAW) = $(P_K - P_\pi)^2$
m_π mass hypothesis

Selection criteria:

- Single track topology
- π^+ identification
- Photon rejection
- Multi-track rejection

Performances:

- $\varepsilon(\mu^+) = 1 \cdot 10^{-8}$ (64% π^+ efficiency)
- $\varepsilon(\pi^0) = 3 \cdot 10^{-8}$
- $\sigma(m^2_{miss}) = 1 \cdot 10^{-3}$ GeV²/c⁴
- $\sigma_T \sim O(100ps)$



Signal Region 1 (R1), Signal Region 2 (R2)

$K^+ \to \pi^+ \nu \bar{\nu}$ Signal Regions

Consider different projections of

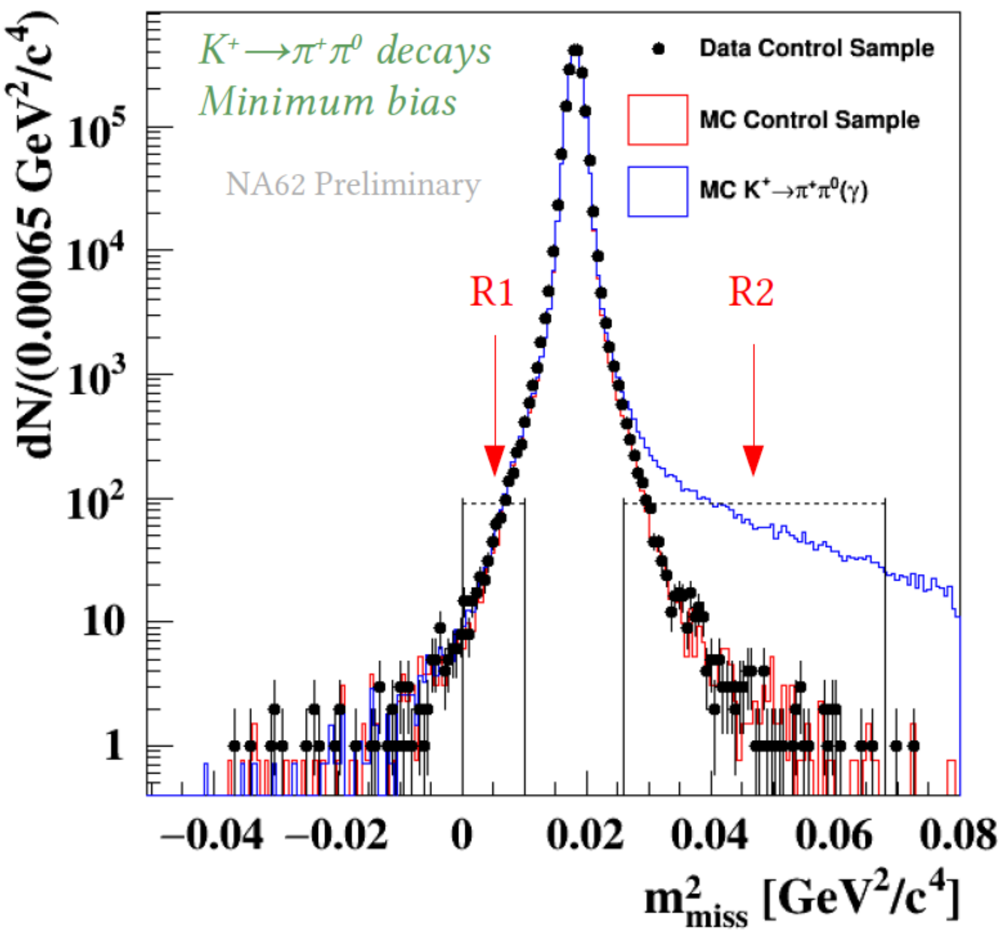
$m^2_{miss} = (P_K - P_\pi)^2$

- m^2_{miss} (GTK, STRAW)
- m^2_{miss} (GTK, RICH)
- m^2_{miss} (Beam, STRAW)

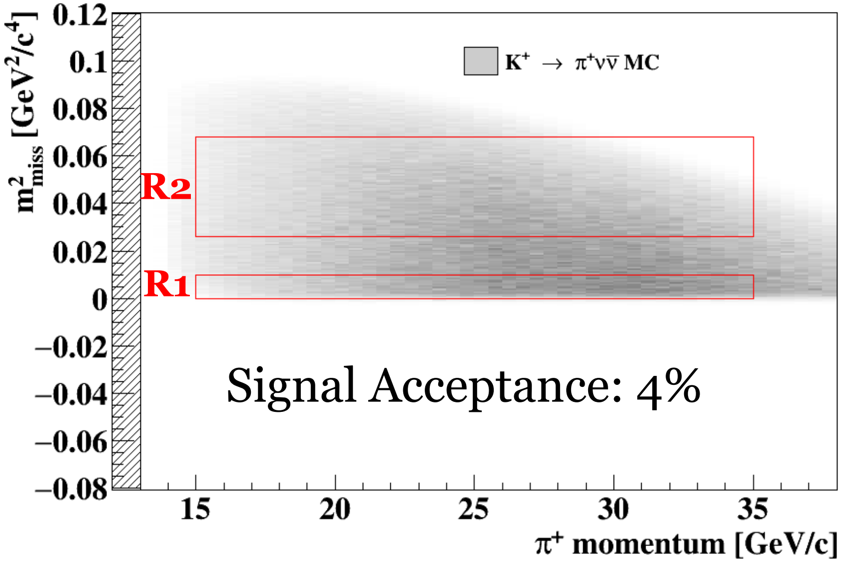
Address non-gaussian tails in the bkg distributions due to mis-reconstruction

Kinematic suppression:

- measured on data
- samples selected using calorimeters
- $K^+ \to \pi^+ \pi^0 \sim 1 \cdot 10^{-3}$ (resolution tails)
- $K \to \mu^+ \nu \sim 3 \cdot 10^{-4}$



Single Event Sensitivity



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

Control trigger **$K^+ \rightarrow \pi^+\pi^0$** used for normalisation: acceptance 10%

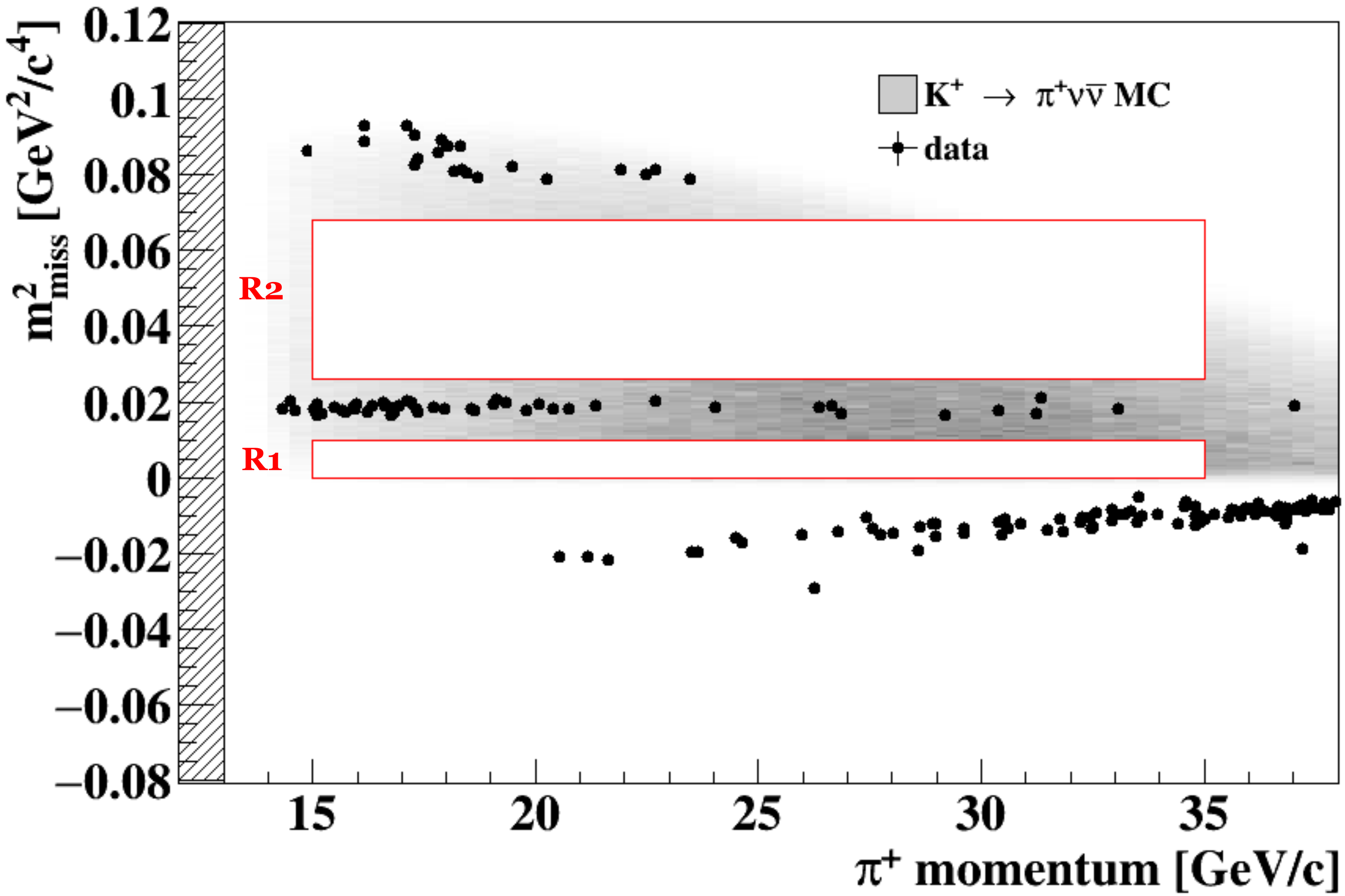
Number of kaon decays (N_K) in fiducial volume

- $N_K = 1.21(2) \times 10^{11}$

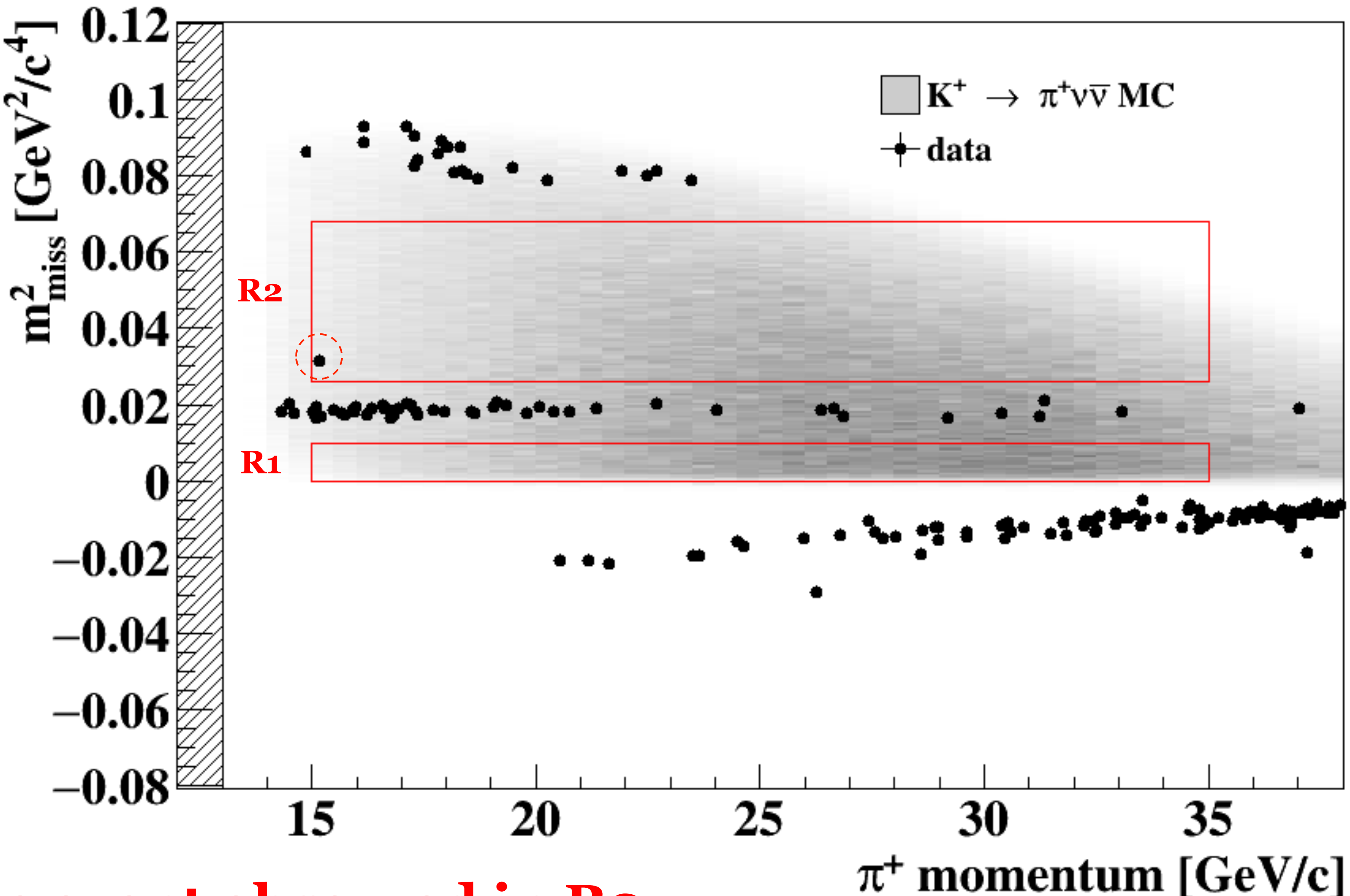
Single Event Sensitivity (SES)

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

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Results



$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ Results



One event observed in R2

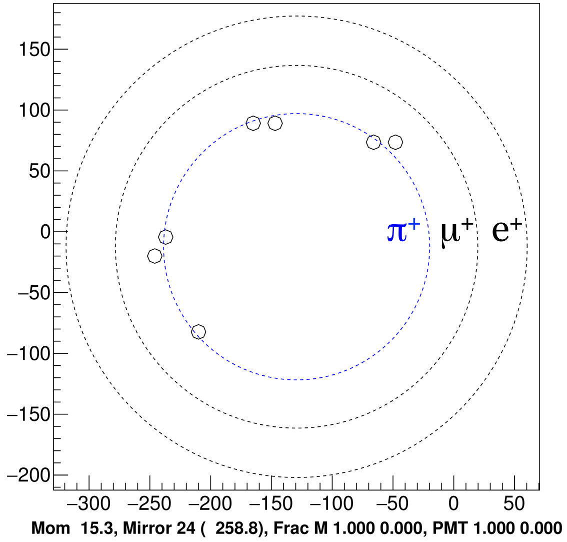
$K^+ \to \pi^+ \nu\bar{\nu}$ Results

- One event observed in signal region R2
- Full exploitation of the CLs method in progress
- The results are compatible with the Standard Model

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) < 11 \times 10^{-10} \text{ @ } 90\% \ CL$$

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10} \text{ @ } 95\% \ CL$$

RICH ring for the event



For comparison:

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = 28^{+44}_{-23} \times 10^{-11} \text{ @ } 68\% \ CL$$

$$BR(K^+ \to \pi^+ \nu\bar{\nu})_{SM} = (8.4 \pm 1.0) \times 10^{-11}$$

$$BR(K^+ \to \pi^+ \nu\bar{\nu})_{exp} = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$$

Conclusions

- SM sensitivity for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ reached with the completion of 2016 data analysis
- The novel NA62 decay-in-flight technique works
- One event observed in 2016 data (expect 0.3 SM in R1+R2)

$$BR(K^+ \rightarrow \pi^+ \nu \overline{\nu}) < 14 \times 10^{-10} \text{ @ } 95\% \; CL$$

Conclusions

- SM sensitivity for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ reached with the completion of 2016 data analysis
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$$BR(K^+ \rightarrow \pi^+ \nu\overline{\nu}) < 14 \times 10^{-10} \; @ \; 95\% \; CL$$

Prospects:

Analysis of data collected in 2017 started

- data sample x20 larger than presented stats
- expect improvements on signal acceptance, efficiency and S/B ratio

Data taking scheduled for April-November 2018

Expect ~20 SM events before LS2

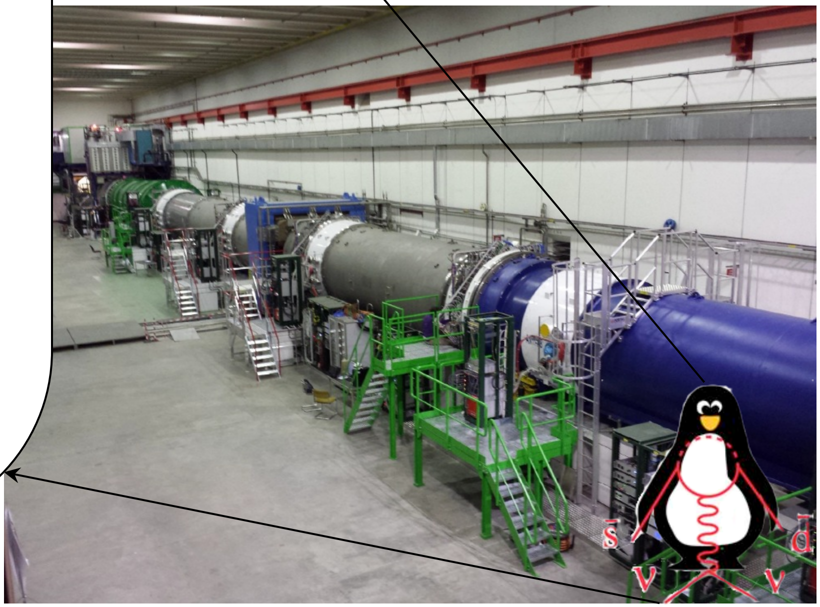
Data taking after 2018 to be approved

Conclusions

➢ ...ompletion of 2016 data analysis

...n R1+R2)

... @ 95% CL



➢ ...

Data taking after 2018 to be approved

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SPARES

Angela Romano, on behalf of the NA62 collaboration

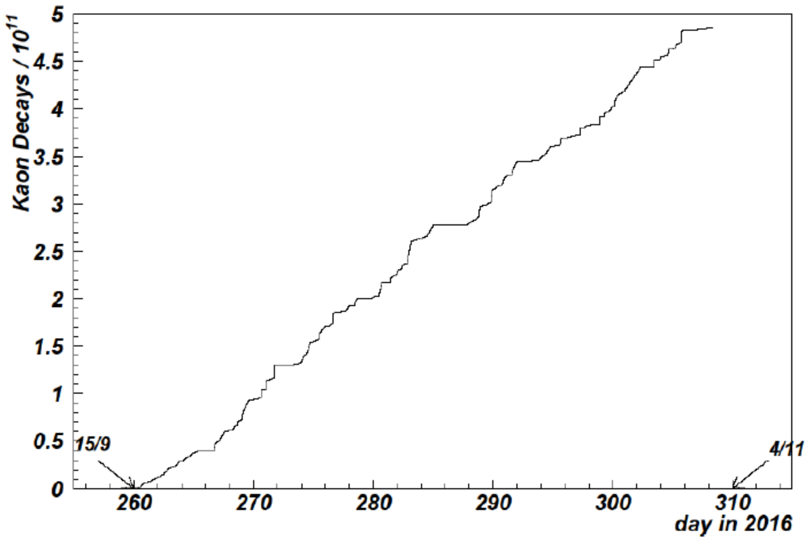
Angela Romano, University of Birmingham (axr@hep.ph.bham.ac.uk)

NA62 "Luminosity"

2016 run

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

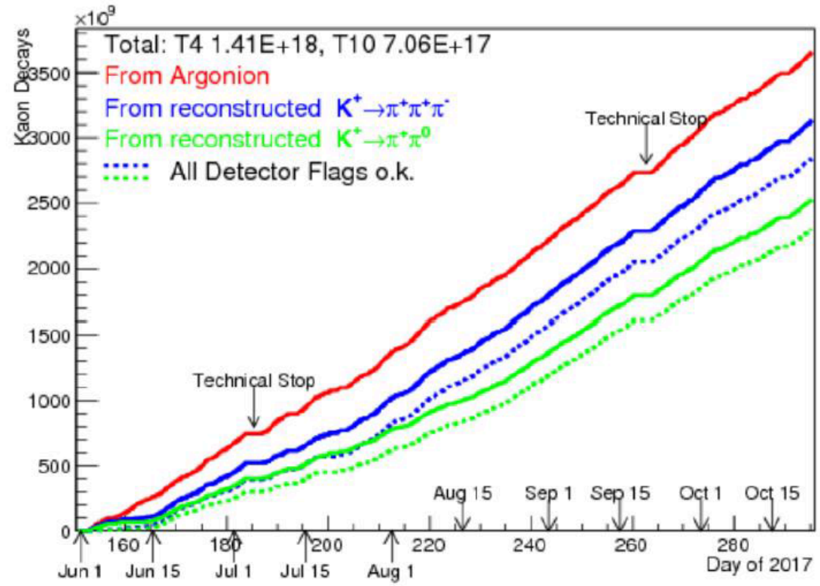
$\sim 1 \times 10^{11}$ K^+ decays useful for $\pi\nu\nu$



2017 run

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

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



Single Event Sensitivity Results

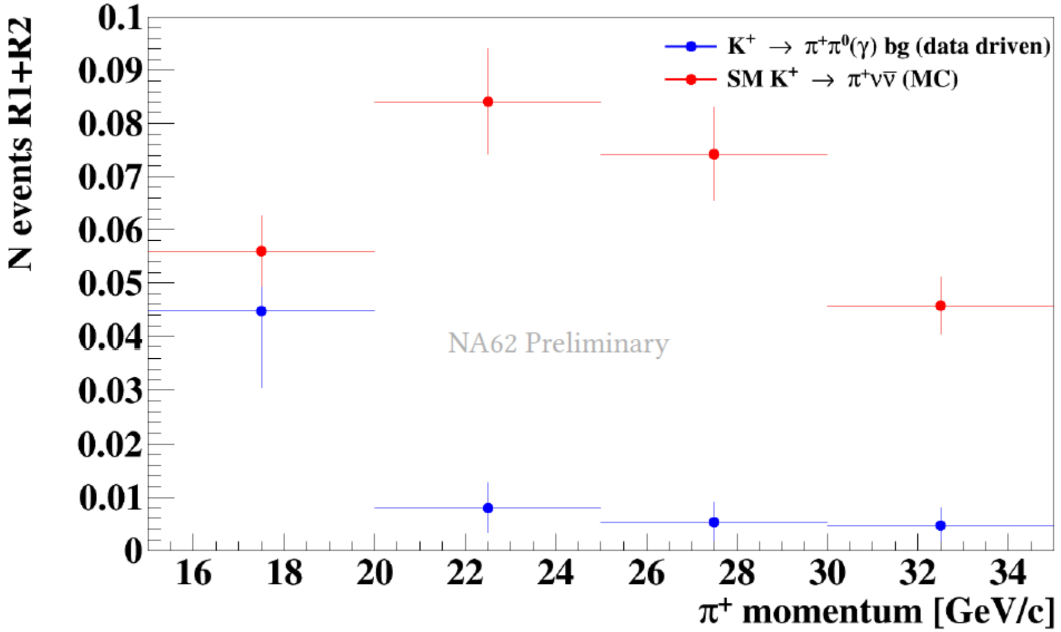
$$SES = (3.15 \pm 0.01_{stat} \pm 0.24_{syst}) \times 10^{-10}$$

Acceptance $K^+ \to \pi^+ \nu\bar{\nu}$	4.0 ± 0.1
PNN trigger efficiency	0.87 ± 0.2
Random veto	0.76 ± 0.04

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 $\pi+$ interactions	± 0.09
Extra activity	± 0.02
GTK Pileup simulation	± 0.02
Total	± 0.24

$K^+ \to \pi^+\pi^0(\gamma)$ Background

R.Marchevski @ Moriond EW2018

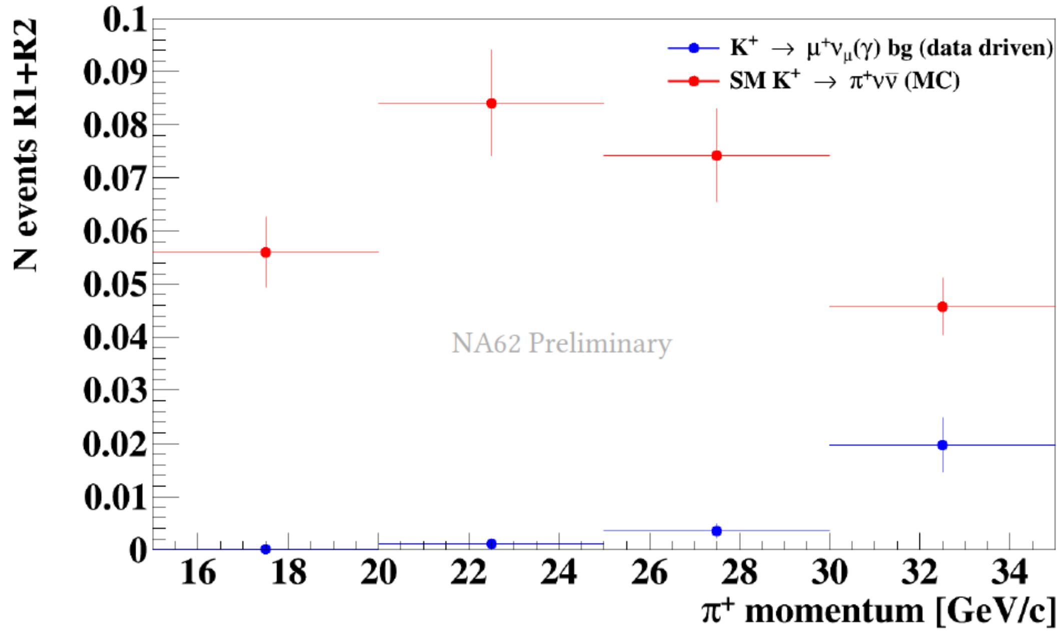


- Data driven background estimation
- Control region validation: 1 event observed (1.5 expected)

$$N^{bg}_{\pi\pi(\gamma)} = 0.064 \pm 0.007_{stat} \pm 0.006_{syst}$$

$K^+ \to \mu^+\nu_\mu(\gamma)$ Background

R.Marchevski @ Moriond EW2018

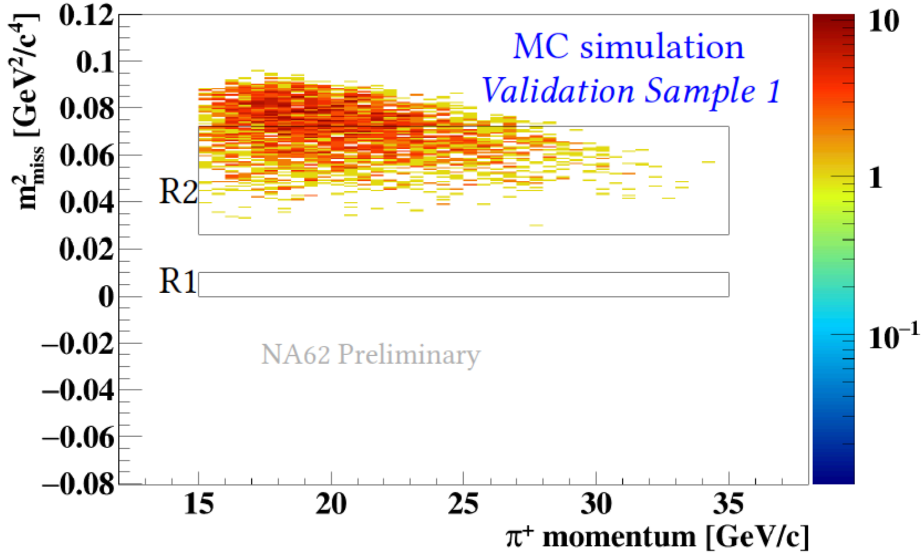


- Data driven background estimation
- Control region validation: 2 event observed (1.1 expected)

$$N^{bg}_{\mu\nu(\gamma)} = 0.020 \pm 0.003_{stat} \pm 0.003_{syst}$$

$K^+ \rightarrow \pi^+\pi^- e^+\nu_e$ Background

R.Marchevski @ Moriond EW2018



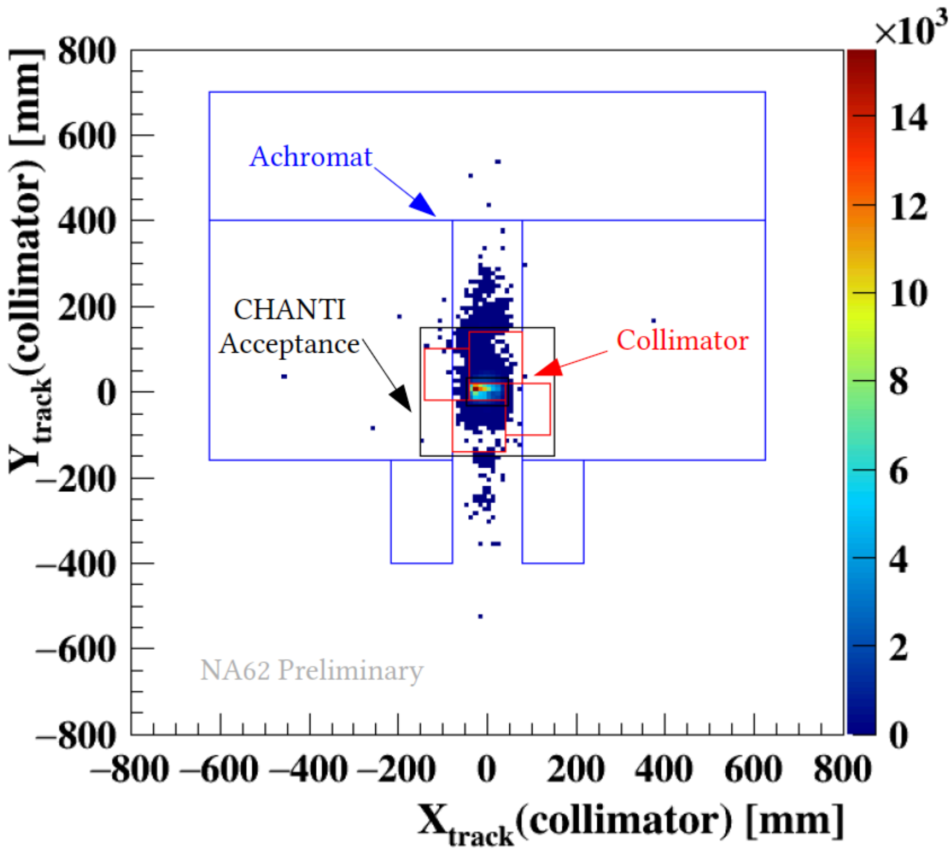
Validation sample	N expected	N observed
1	15.5(4)	8
2	4.0(4)	2
3	3.2(2)	3
4	0.7(1)	1
5	1.2(1)	5

- Background estimated with 400 million MC generated $K^+ \rightarrow \pi^+\pi^- e^+\nu_e$ decays
- Good agreement across the 5 validation samples

$$N^{bg}_{K_{e4}} = 0.018^{+0.024}_{-0.017}|_{stat} \pm 0.009_{syst}$$

Upstream background

R.Marchevski @ Moriond EW2018



- Accidental particles from the beam line
- Pions from interactions with beam spectrometer material
- Kaon-pion matching and geometrical cuts effective
- Data driven estimation

$$N^{bg}_{upstream} = 0.050^{+0.090}_{-0.030}$$