In-flight Search for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$: First NA62 Results

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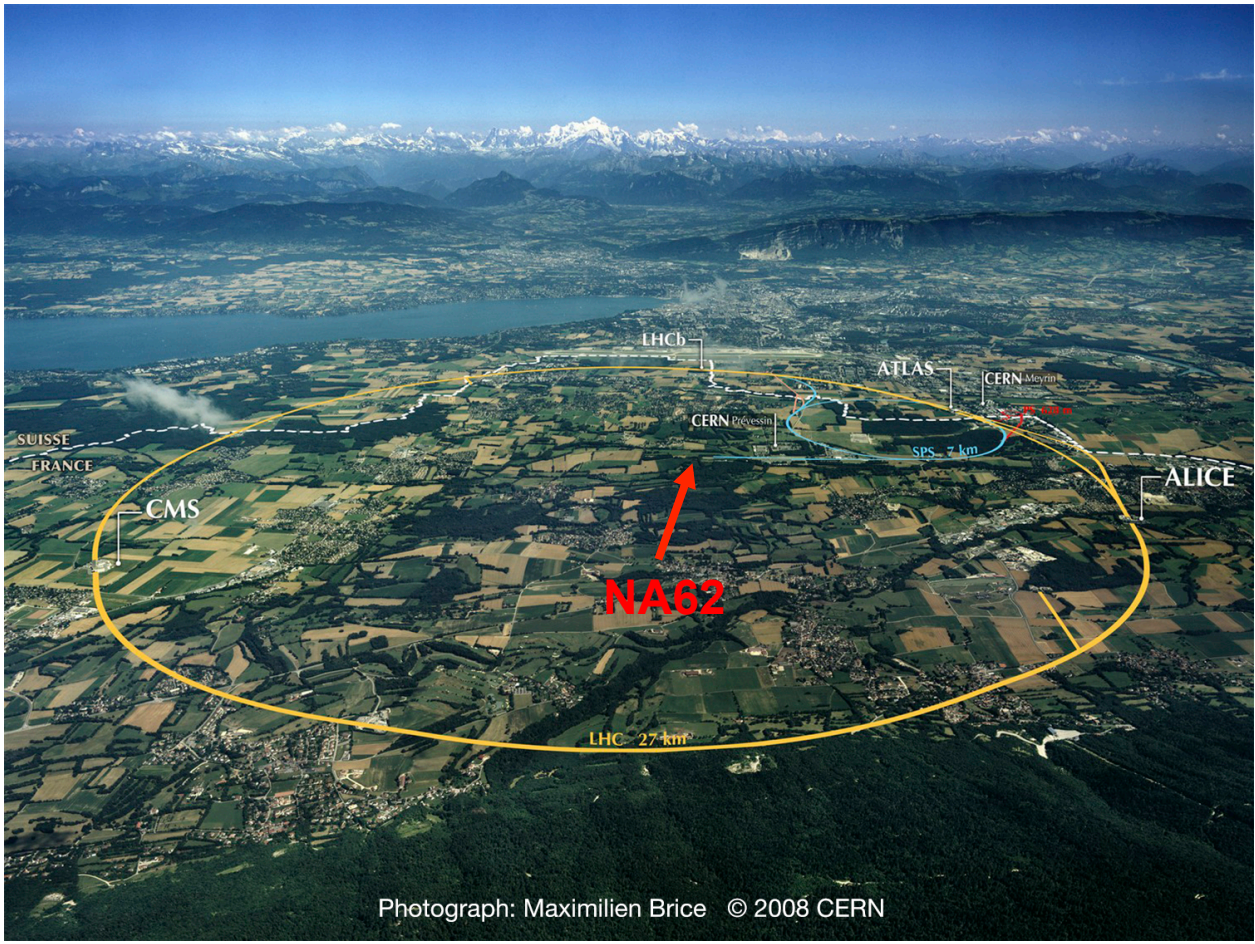
Seventh Workshop on Theory, Phenomenology and Experiments In Flavour Physics FPCapri2018

Anacapri, Capri Island, Italy, June 8-10, 2018

Kaon physics @ NA62

- `14-`18 NA62: $K^+ \to \pi^+ \nu\bar{\nu}$
  - 2014 Pilot run
  - 2015 Commissioning run
  - Full detector installation completed in September 2016
  - First $\pi\nu\bar{\nu}$ dataset in 2016

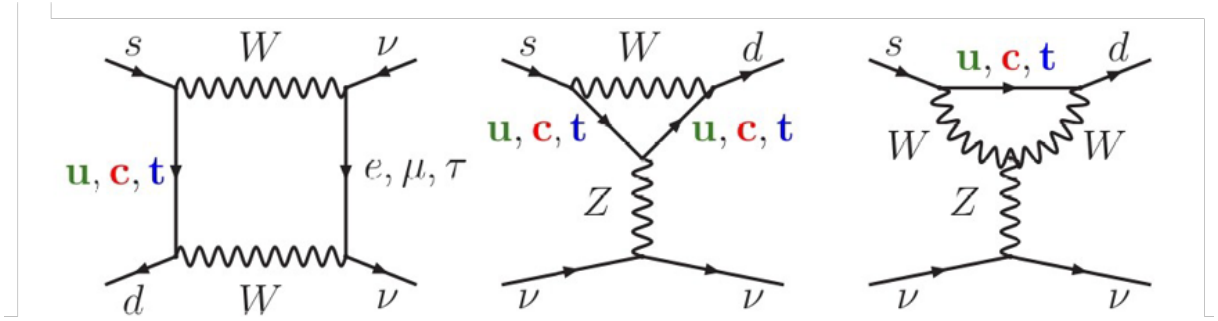
    (This talk)
  - Continuous data-taking until the end of 2018

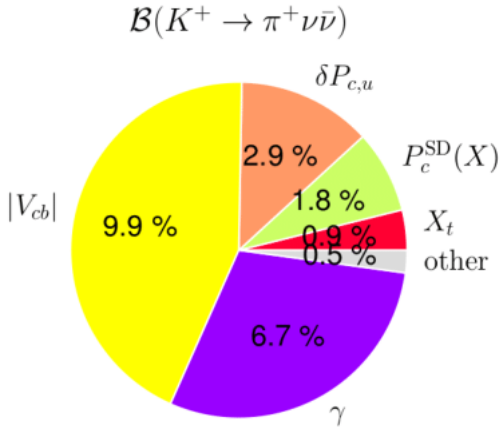


~ 200 participants from: Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, GMU-Fairfax, Ferrara, Firenze, Frascati, Glasgow, Lancaster, Liverpool, Louvain, Mainz, Merced, Moscow, Napoli, Perugia, Pisa, Prague, Protvino, Roma I, Roma II, San Luis Potosi, Sofia, Torino, TRIUMF, Vancouver UBC

The FCNC process $K^+ \to \pi^+ \nu\bar{\nu}$

Theoretical error budget
Buras. et. al., JHEP11(2015)033





- FCNC loop processes: s → d coupling and highest CKM suppression
- Theoretically clean: Short distance contribution
- Hadronic matrix element measured with K_{l3} decays
- SM predictions:[Brod, Gorbahn, Stamou, Phys. Rev.D 83, 034030 (2011), Buras. et. al., JHEP11(2015)033]

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (8.39 \pm 0.30) \times 10^{-11} \left(\frac{|V_{cb}|}{0.0407}\right)^{2.8} \left(\frac{\gamma}{73.2^\circ}\right)^{0.74} = (8.4 \pm 1.0) \times 10^{-11}$$

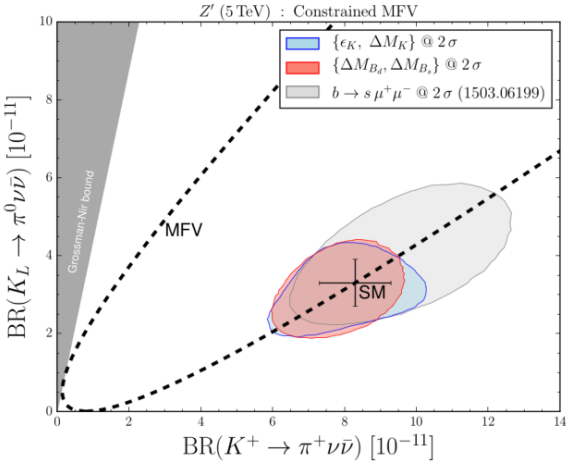
- Experimental result:[Phys. Rev. D 79, 092004 (2009)]

$$BR(K^+ \to \pi^+ \nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \text{ (BNL, "kaon decays at rest")}$$

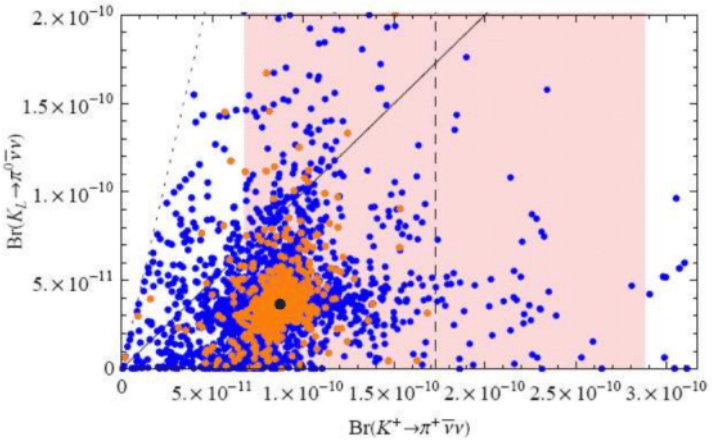
$K^+ \to \pi^+ \nu\bar{\nu}$ Beyond the Standard Model

- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM analyses [Blazek, Matak, Int.J.Mod.Phys. A29 (2014) no.27],[Isidori et al. JHEP 0608 (2006) 064]
- Simplified Z, Z' models [Buras, Buttazzo,Knegjens, JHEP11(2015)166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, Eur.Phys.J. C76 (2016) 182]
- LFU violation models [Isidori et al., Eur. Phys. J. C (2017) 77: 618]
- Constraints from existing measurements (correlations model dependent)
  - Kaon mixing, CKM elements, K, B rare meson decays, NP limits from direct searches

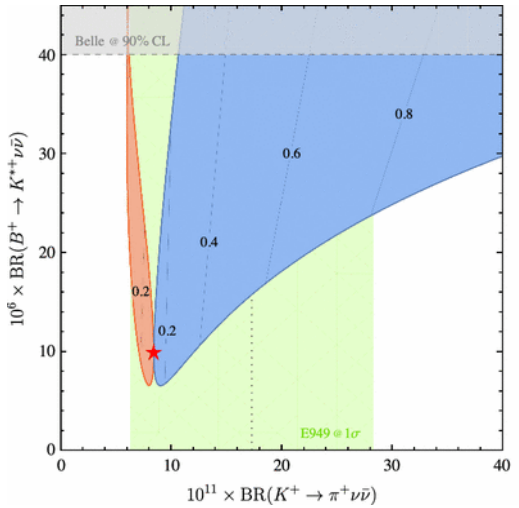
Z'(5 TeV) in Constrained MFV



Randall Sundrum



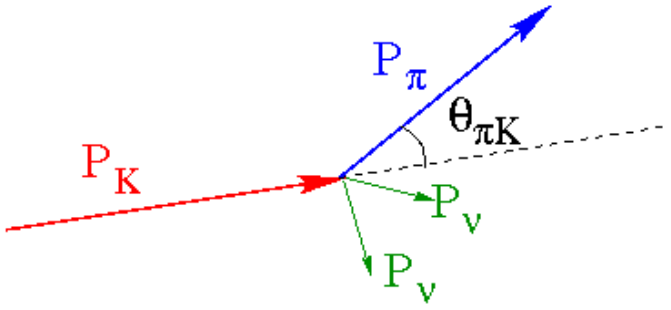
LFU violation

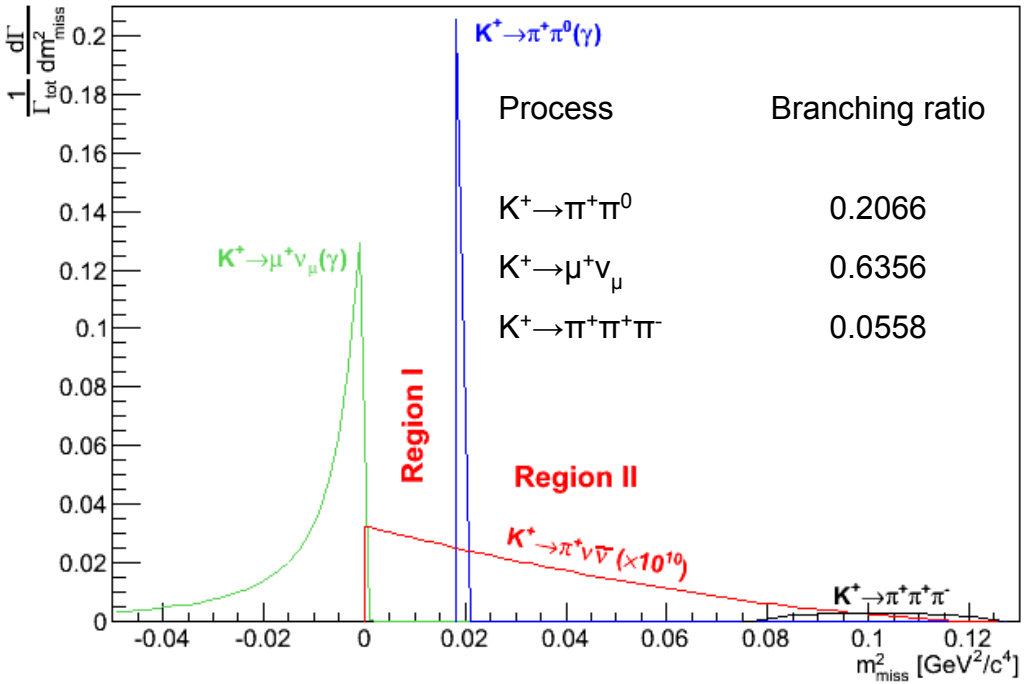


Analysis strategy

NEW

Decay in flight technique $m^2_{miss} = (P_K - P_{\pi^+})^2$





Process	Branching ratio
$K^+\to\pi^+\pi^0$	0.2066
$K^+\to\mu^+\nu_\mu$	0.6356
$K^+\to\pi^+\pi^+\pi^-$	0.0558

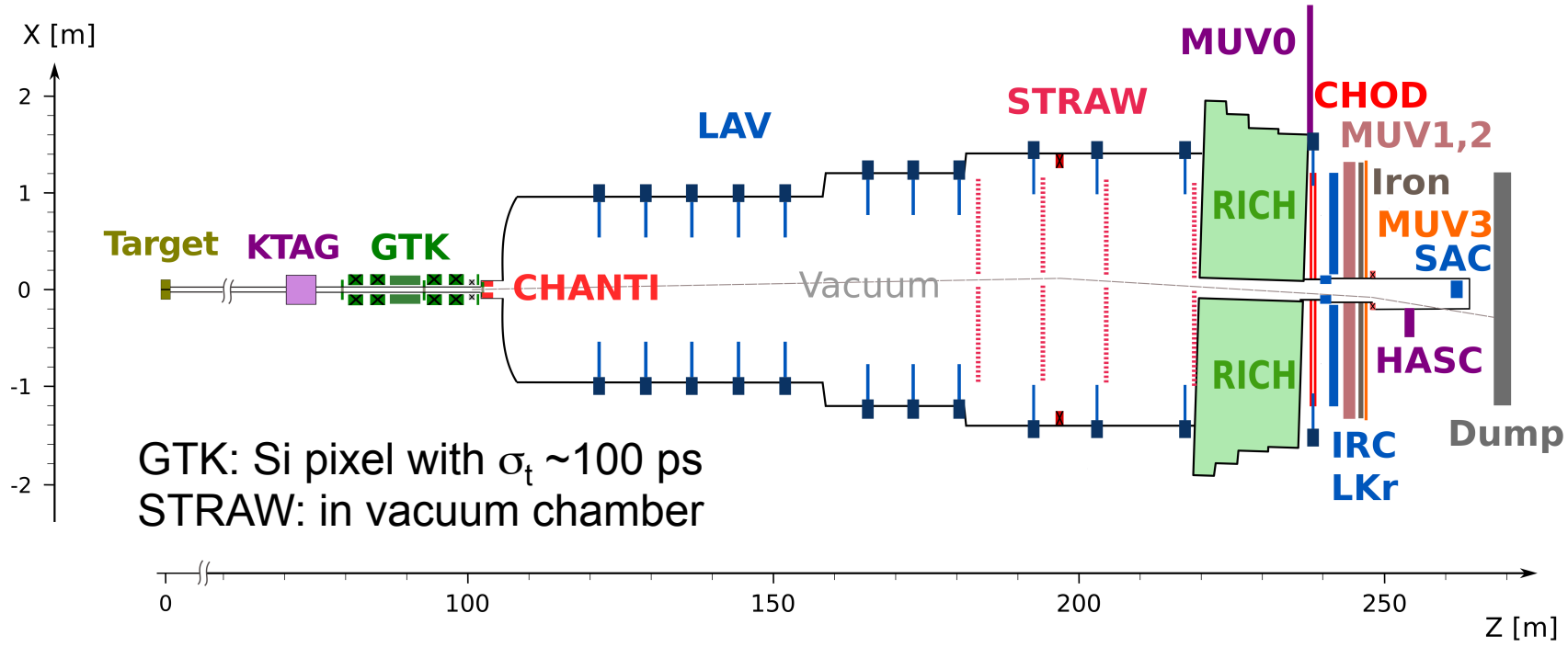
- Keystones of the analysis:
  - Timing between sub-detectors ~ O(100 ps)
  - Kinematic suppression ~ O(10^4)
  - Muon suppression > 10^7
  - π^0 suppression (from $K^+\to\pi^+\pi^0$) > 10^7
- Signal and background control regions are kept blind throughout the analysis

\+

$15 < P_{\pi^+} < 35$ GeV/c
Particle ID(Cherenkov detectors)
Particle ID(Calorimeters)
Photon veto

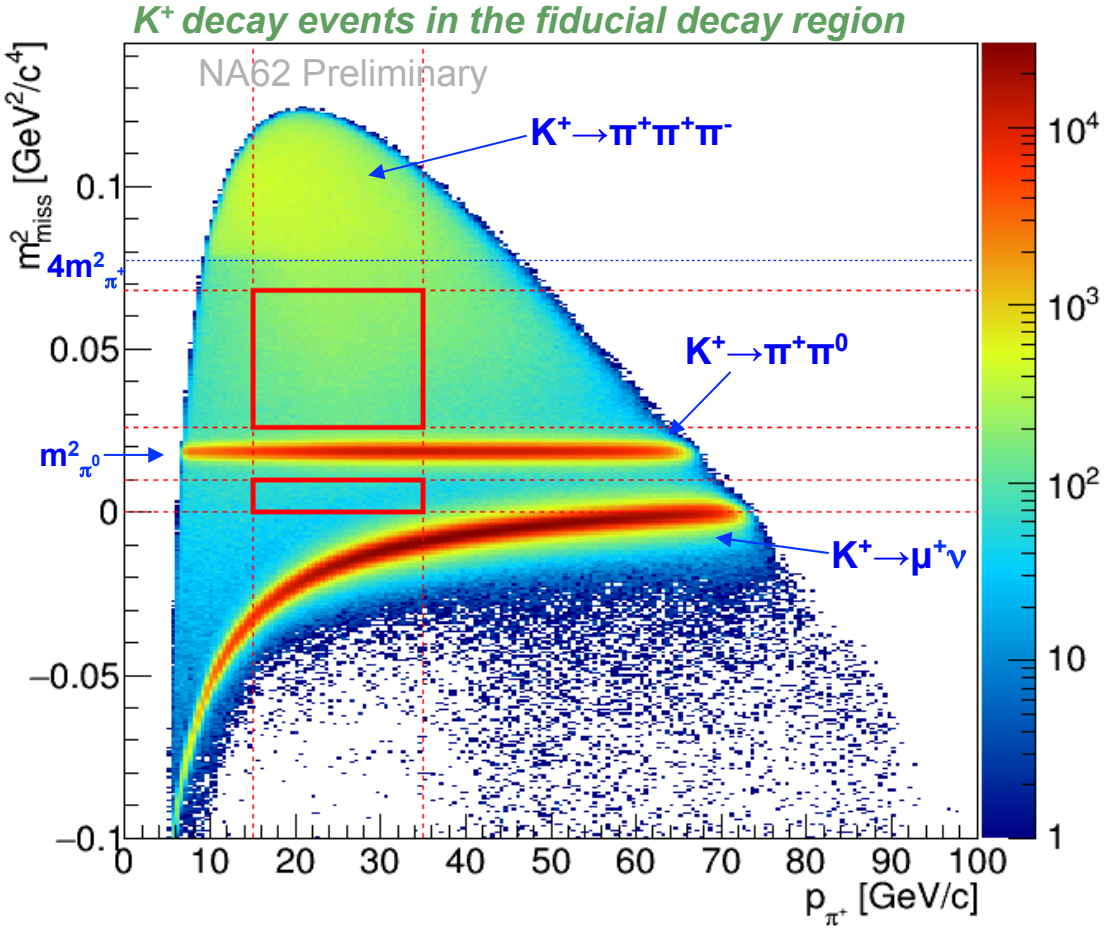
NA62 beam and detector

NA62 beam and detector



- **SPS Beam:**
  - 400 GeV/c protons
  - 2.10^{12} protons/spill
  - 3.5s spill
- **Secondary positive Beam:**
  - 75 GeV/c momentum, 1 % bite
  - 100 mrad divergence (RMS)
  - 60x30 mm^2 transverse size
  - $K^+(6\%)/p^+(70\%)/p(24\%)$
  - $33x10^{11}$ ppp on T10 (750 MHz at GTK3)
- **Decay Region:**
  - 60 m long fiducial region
  - ~ 5 MHz K^+ decay rate
  - Vacuum ~ $O(10^{-6})$ mbar

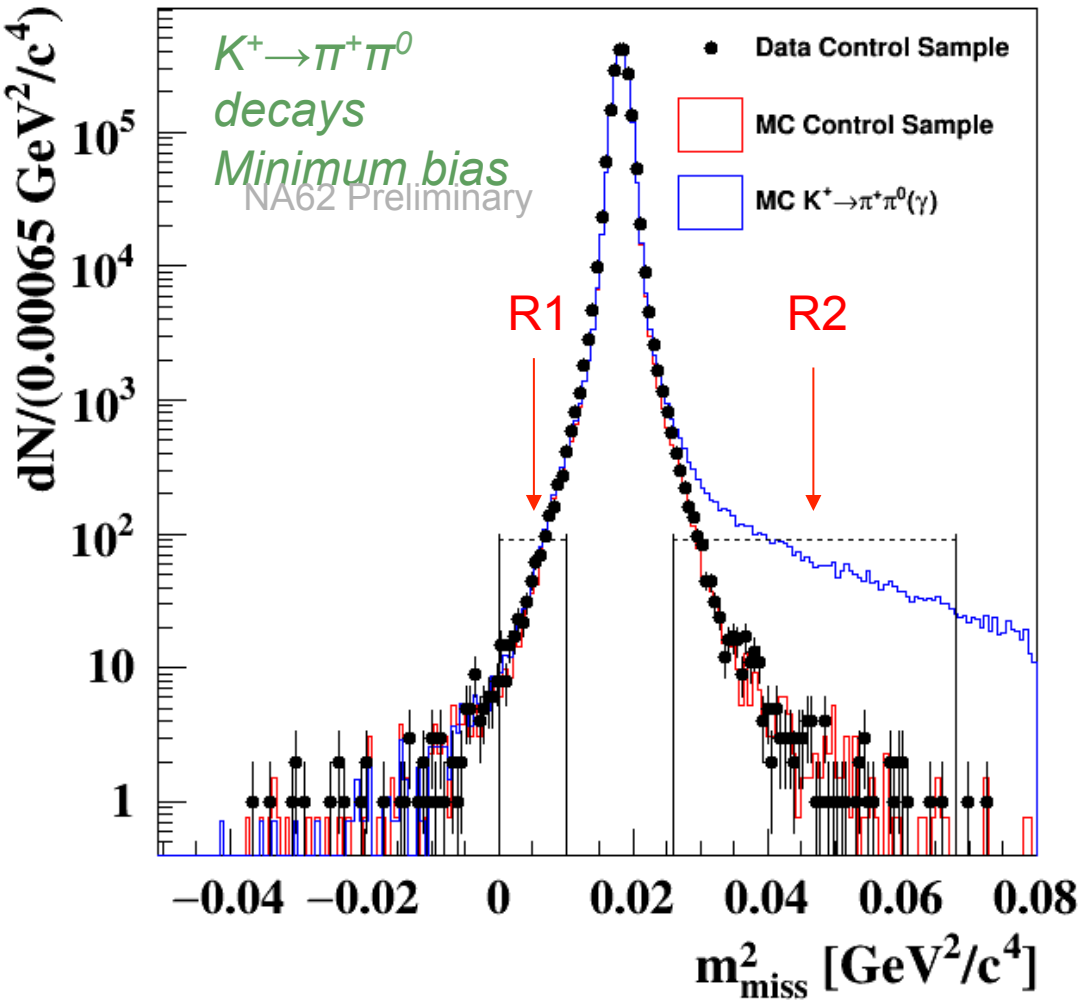
Signal selection



- Selection criteria
  - single track decay topology
  - π^+ identification
  - photon rejection
  - multi-track rejection

- Performance
  - $\epsilon_{\mu^+} = 1 \cdot 10^{-8} (64\%\ \pi^+ \text{ efficiency})$
  - $\epsilon_{\pi^0} = 3 \cdot 10^{-8}$
  - $\sigma(m^2_{miss}) = 1 \cdot 10^{-3}\ \text{GeV}^2/c^4$
  - $\sigma_T \sim O(100\ \text{ps})$

Signal region definition

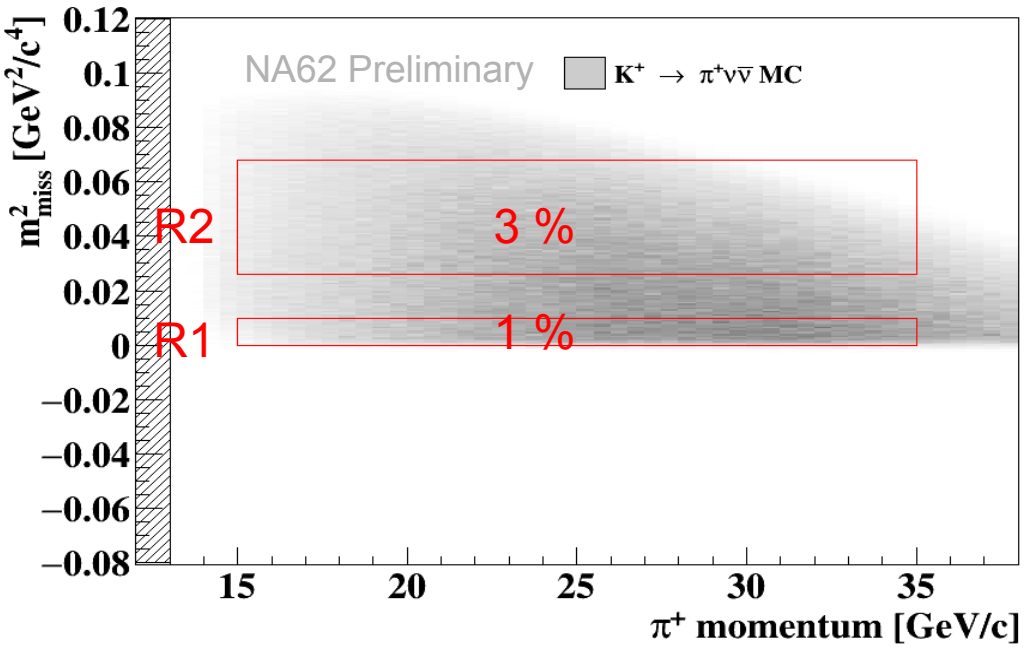


- Three ways to compute the m^2_{miss}
  - m^2_{miss}(STRAW, GTK)
  - m^2_{miss} (RICH, GTK)
  - m^2_{miss} (STRAW, Beam)
- Protects against mis-reconstruction
- Kinematic suppression
  - Measured using data
  - Samples of $K_{\pi\pi}$ and $K_{\mu\nu}$
  - Selected using calorimeters
- Fraction of events in signal regions

$$K^+ \to \pi^+\pi^0 \sim 1 \cdot 10^{-3}$$ (resolution tails)

$$K^+ \to \mu^+\nu_\mu \sim 3 \cdot 10^{-4}$$

Single Event Sensitivity (SES)

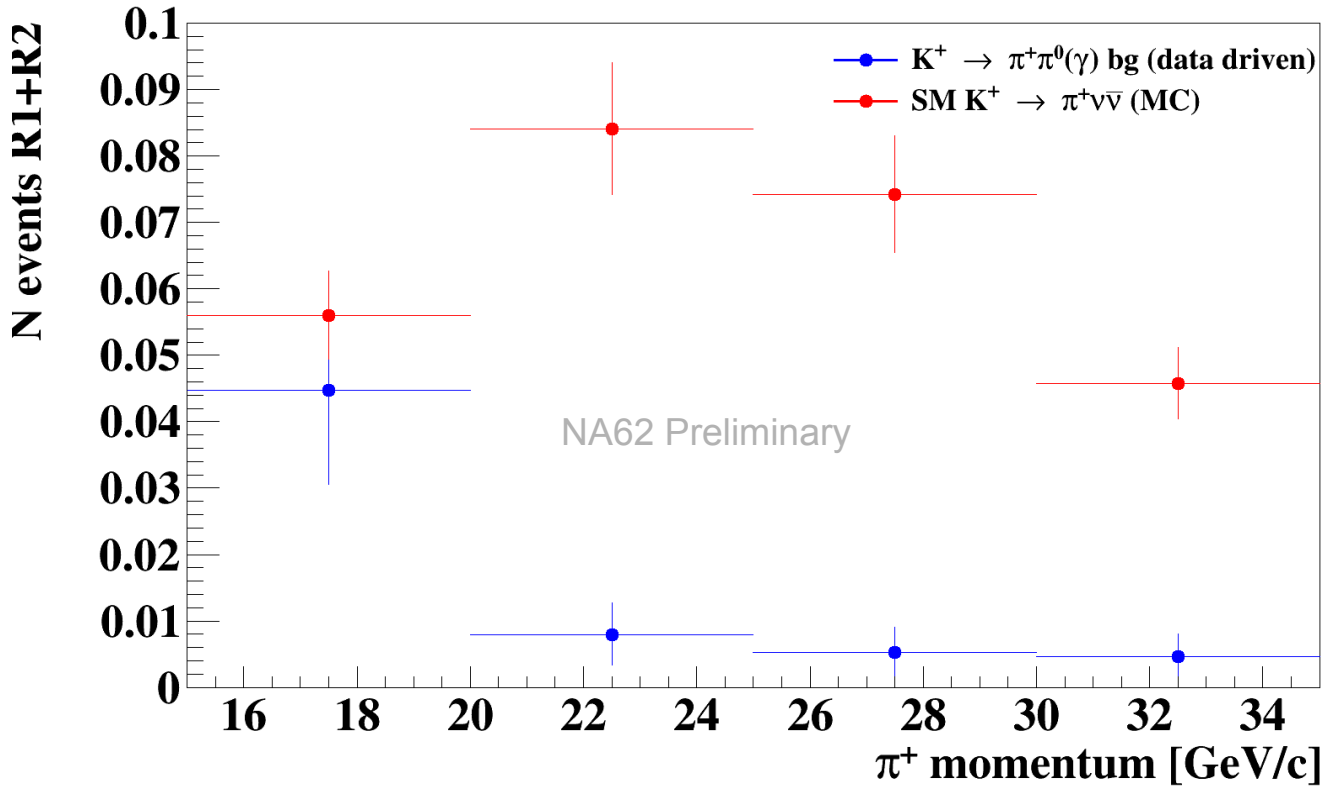


Source	δSES (10^{-10})
Random Veto	± 0.17
N_K	± 0.05
Trigger efficiency	± 0.04
Definition of $\pi^+\pi^0$ region	± 0.10
Momentum spectrum	± 0.01
Simulation of $\pi+$ interactions	± 0.09
Extra activity	± 0.02
GTK Pileup simulation	± 0.02
Total	± 0.24

- Signal acceptance : 4 %
- Normalization acceptance : 10 %
- Control triggered $K^+ \to \pi^+\pi^0$ used for normalization
- Number of kaon decays in the fiducial volume : $N_K = 1.21(2) \times 10^{11}$

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

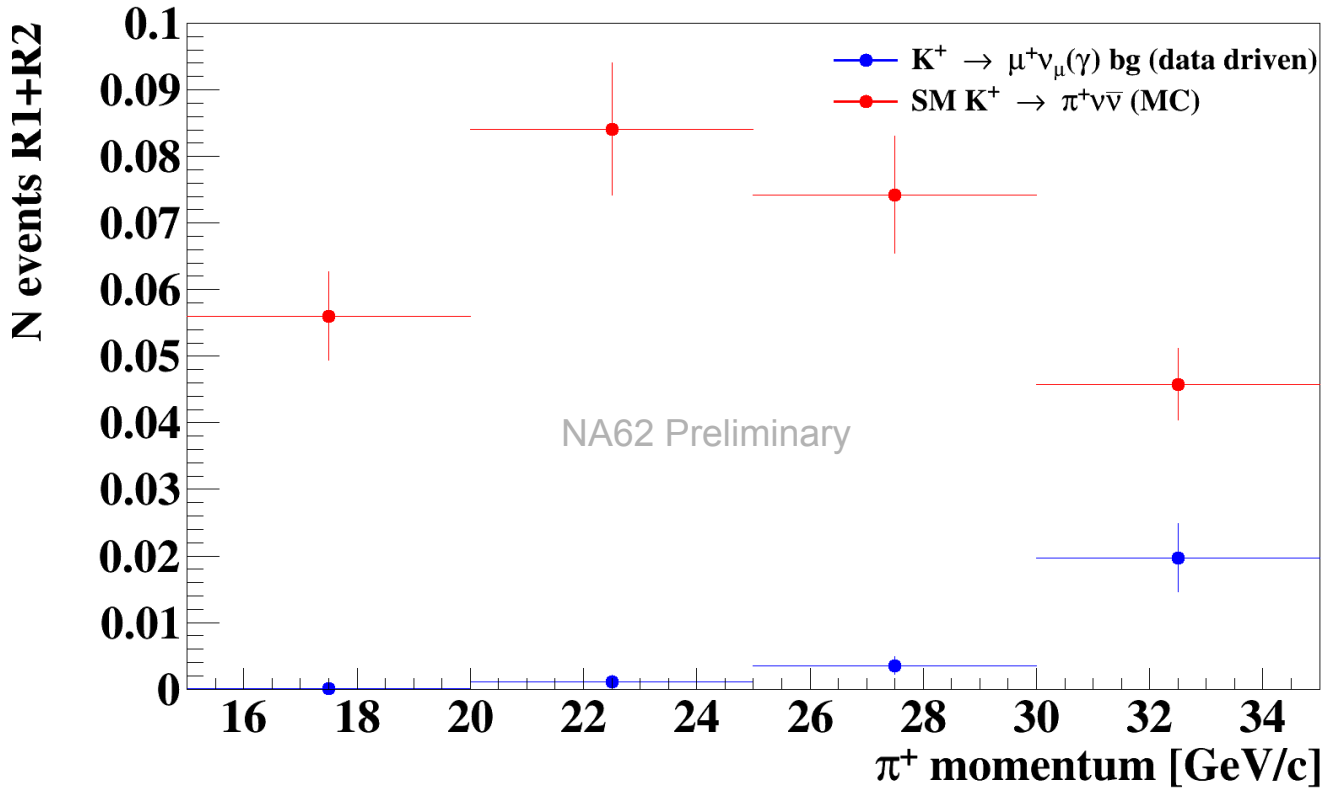
$K^+ \to \pi^+\pi^0(\gamma)$ background



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

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

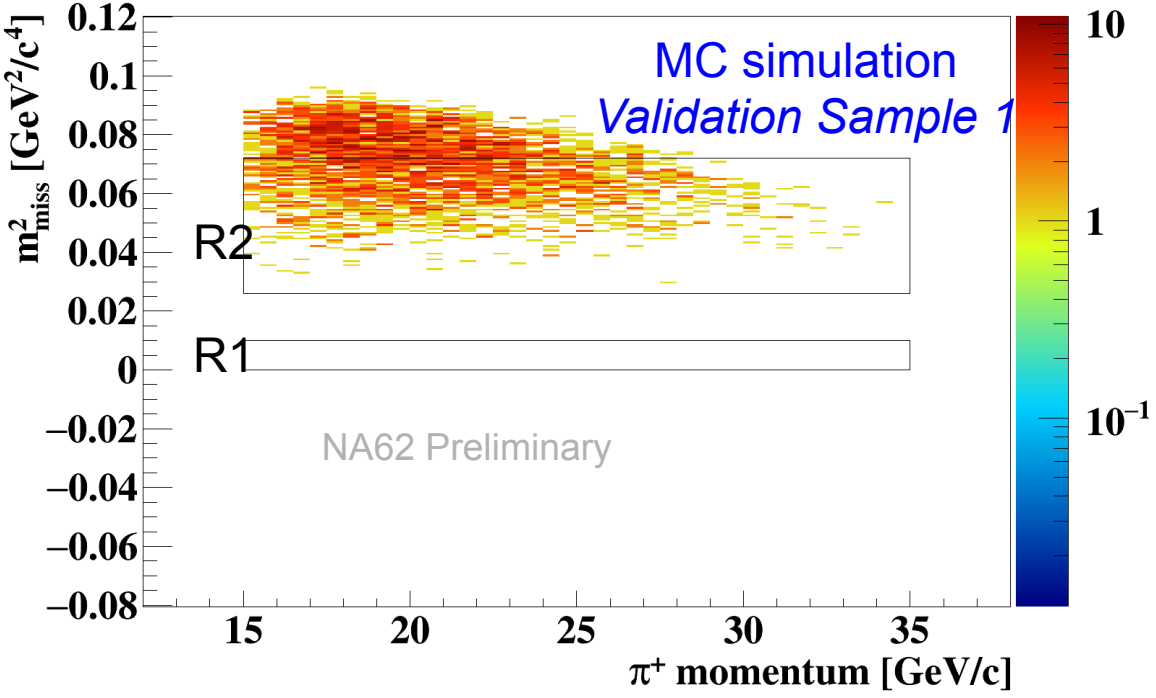
$K^+ \to \mu^+ \nu_\mu(\gamma)$ background



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

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

$K^+ \to \pi^+\pi^-e^+\nu_e(K_{e4})$ background



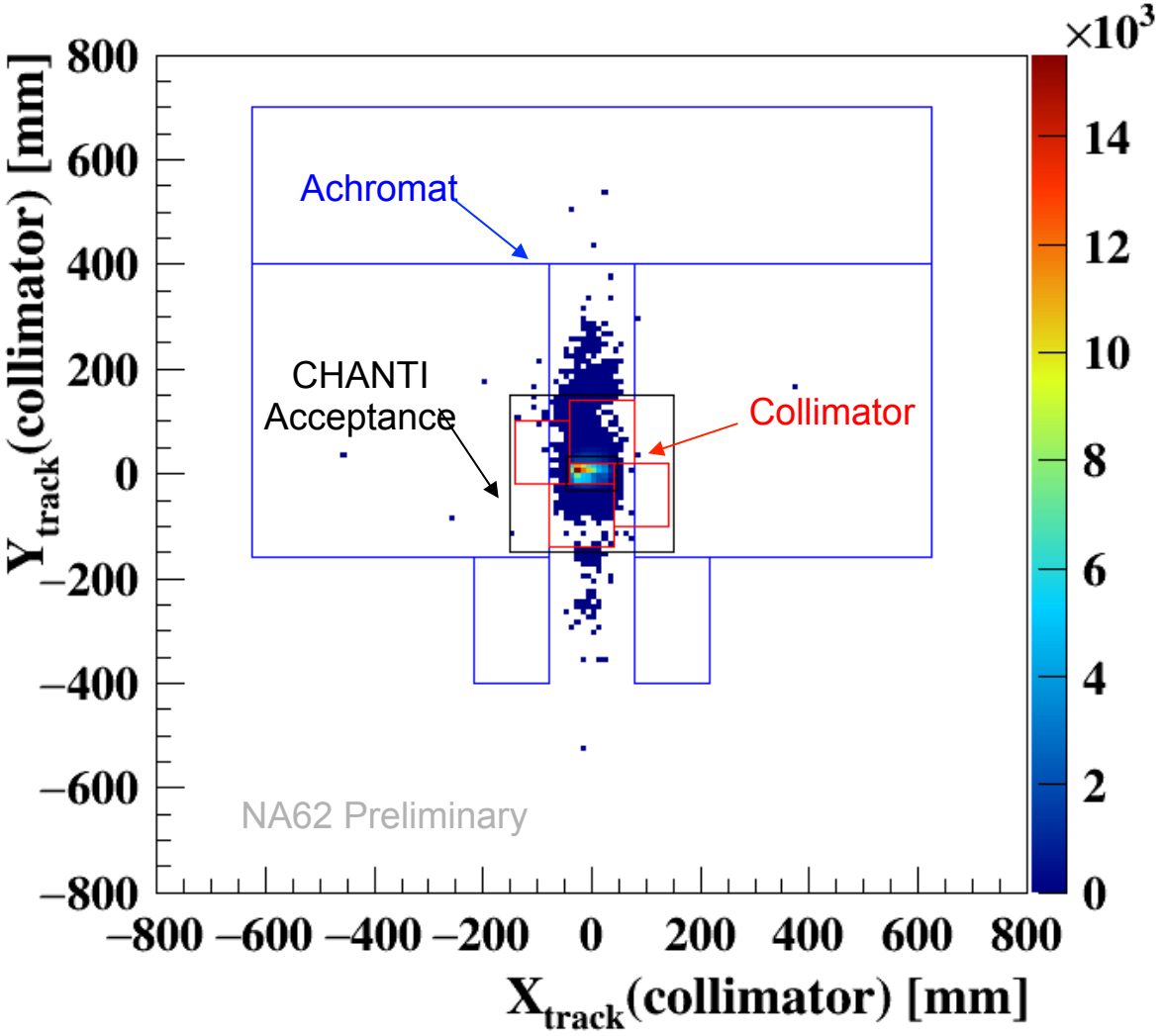
Validation sample	N expected	N observed
1	15.5(4)	8
2	4.0(4)	2
3	3.2(2)	3
4	0.7(1)	1
5	1.2(1)	5

BR(Ke4)~4 10^{-5}: yesterday's signal is today background

- Background estimated with 400 million MC generated $K^+ \to \pi^+\pi^-e^+\nu_e$ 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



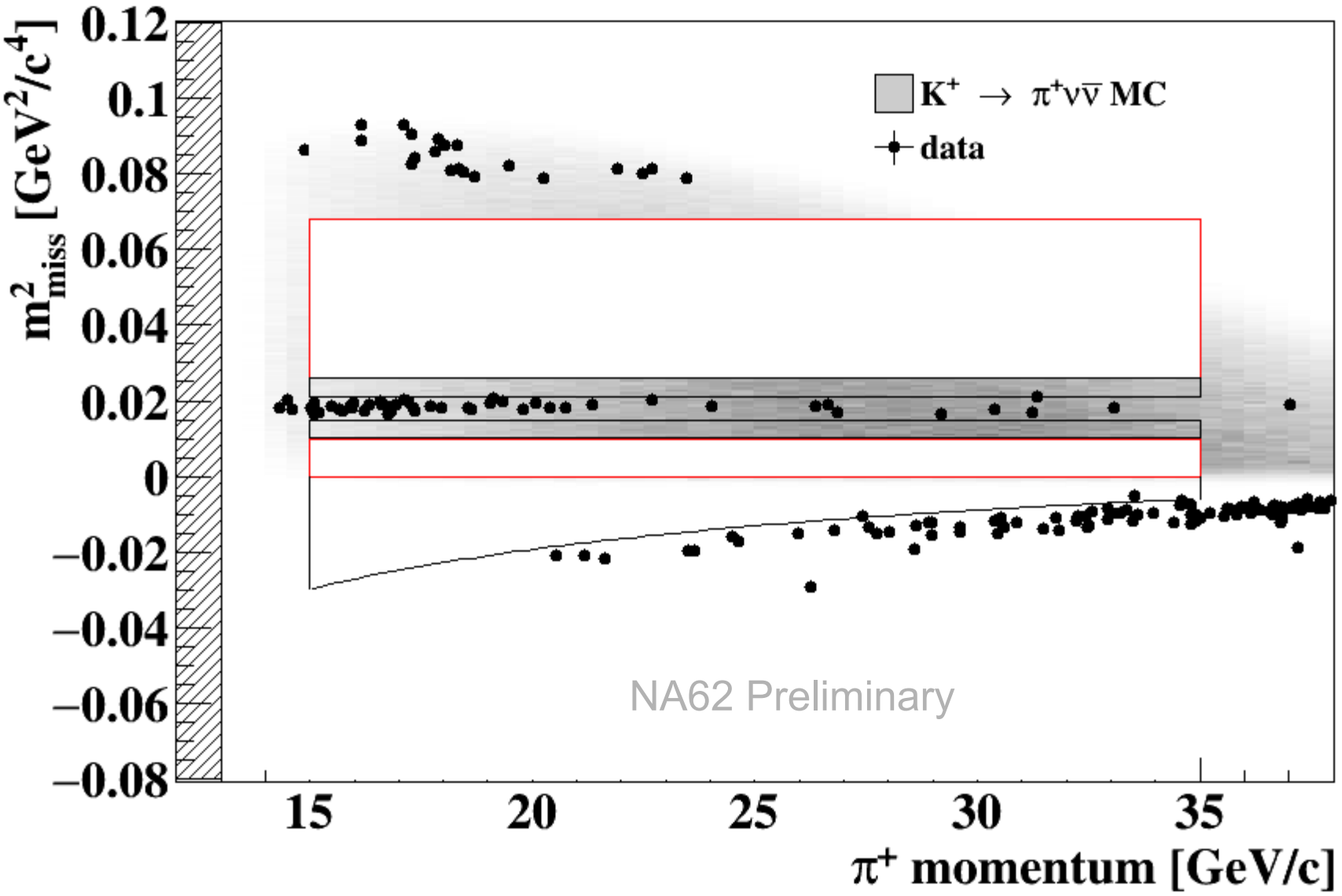
- Accidental particles from the beam line
- Pions from interactions with beam spectrometer material
- Kaon-pion matching and geometrical cuts effective
- Data driven estimation

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

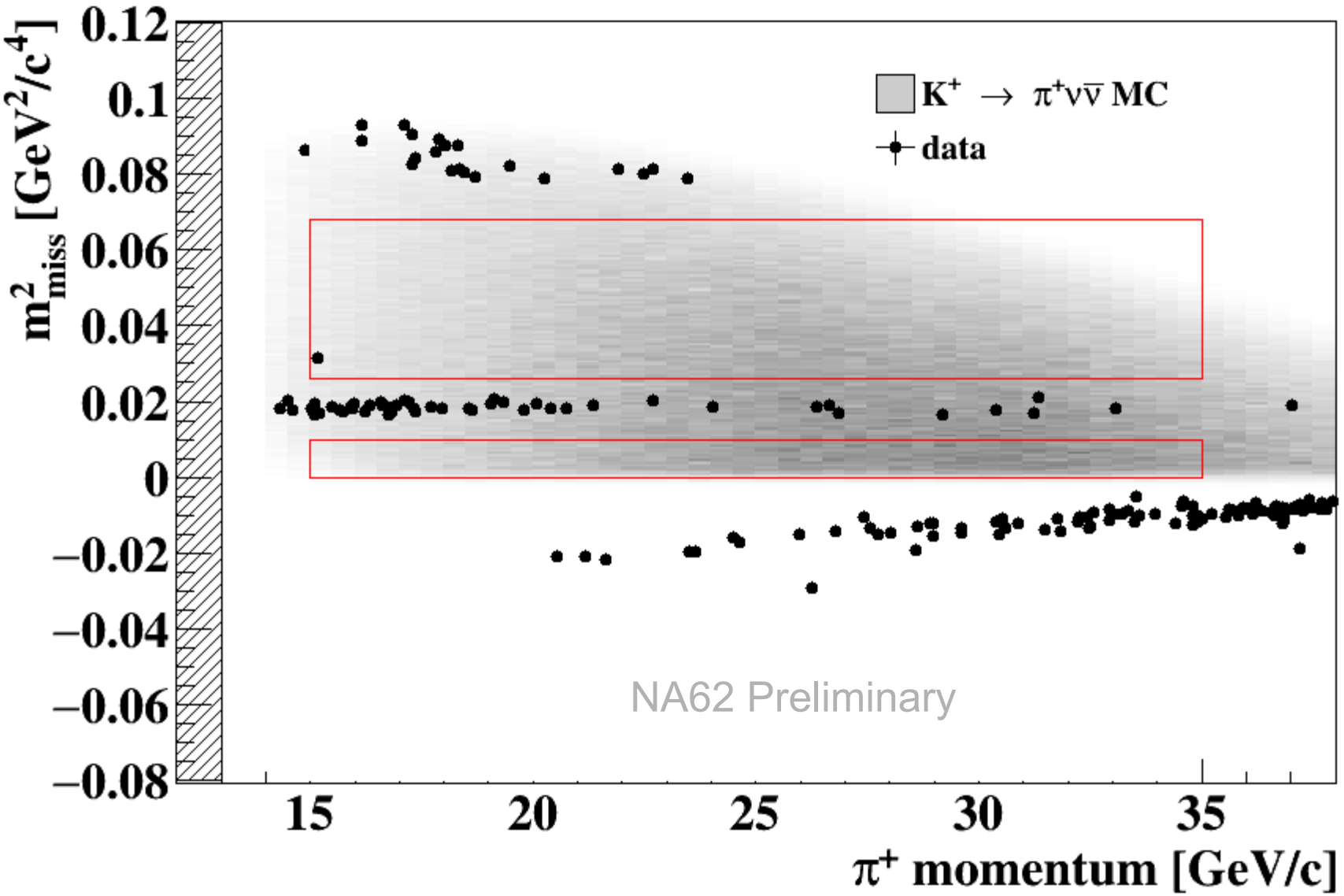
Background summary

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	$0.050^{+0.090}_{-0.030}\vert_{stat}$

Results

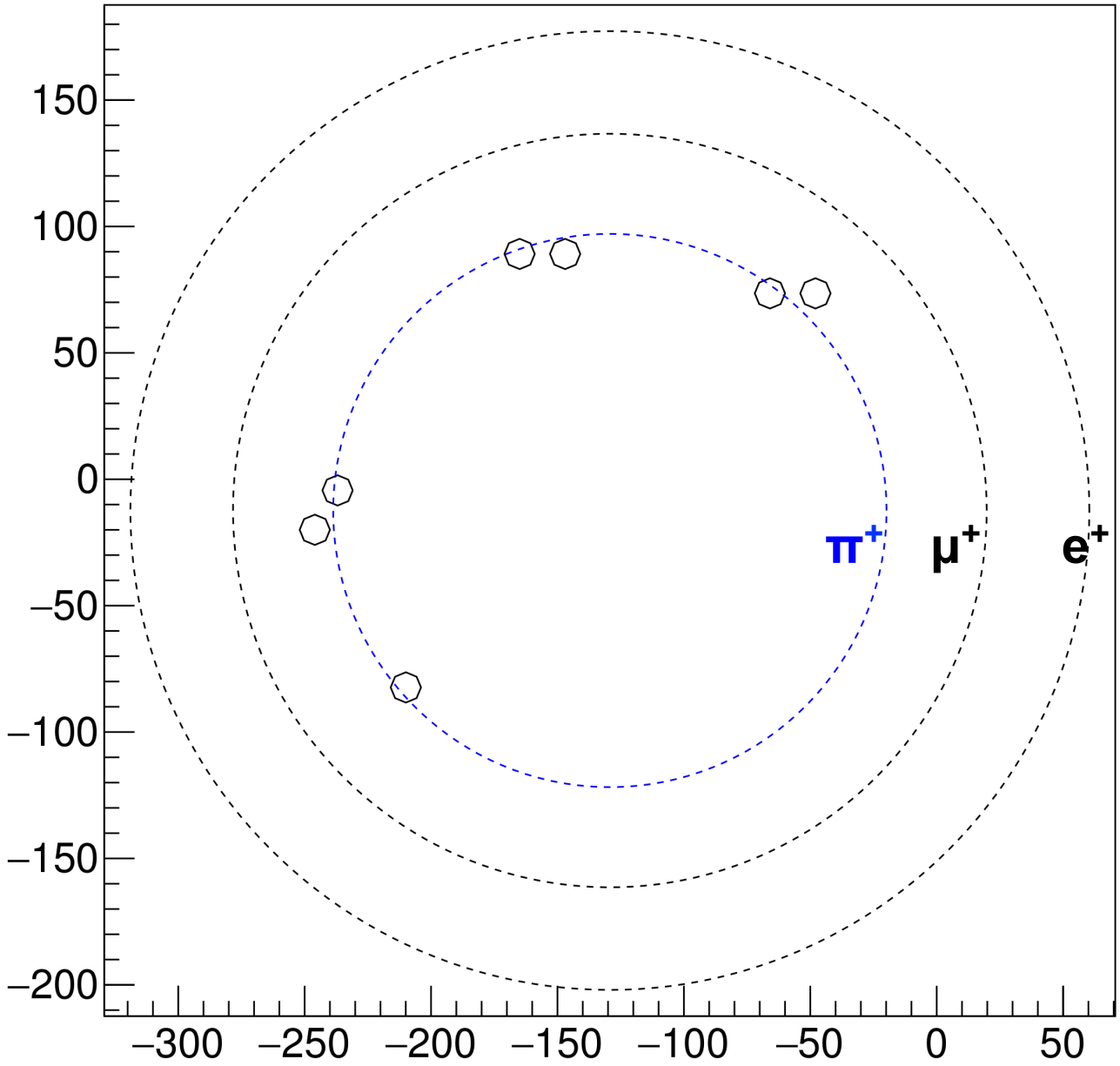

m^2_{miss} [GeV^2/c^4]
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
15
20
25
30
35
π^+ momentum [GeV/c]
$K^+ \rightarrow \pi^+\nu\bar{\nu}$ MC
data
NA62 Preliminary

Results



One event observed

Results: RICH ring for the event



Results

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

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

- One event observed in Region 2
- Full exploitation of the CLs method in progress
- The results are compatible with the Standard Model
- For comparison: $BR(K^+ \to \pi^+ \nu\overline{\nu}) = 28^{+44}_{-23} \times 10^{-11} \ @ \ 68\% \ CL$

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

$$BR(K^+ \to \pi^+ \nu\overline{\nu})_{exp} = (17.3^{+11.5}_{-10.5}) \times 10^{-11} \ \text{(BNL, "kaon decays at rest")}$$

Prospects

- Processing of 2017 data on-going
  - ~ 20 times more data than the presented statistics
  - Expected reduction of upstream background
  - Methods to improve the reconstruction efficiency under study
- 2018 data taking under way
  - Further mitigation of the upstream background is expected
  - Processing in parallel with data taking
  - Final 2018 reprocessing expected beginning 2019
- Expect ~ 20 SM events from the 2017+2018 data sample. The analysis of this sample should provide:
  - Input to the European Strategy for Particle Physics
  - Solid extrapolation to the ultimate sensitivity of NA62 achievable after LS2

Summary

- The new NA62 decay in flight technique works
- One event observed in the 2016 data
- $BR(K^+ \to \pi^+ \nu\bar{\nu}) < 14 \times 10^{-10}$ @ 95% CL