

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: First results from the NA62 experiment at CERN SPS

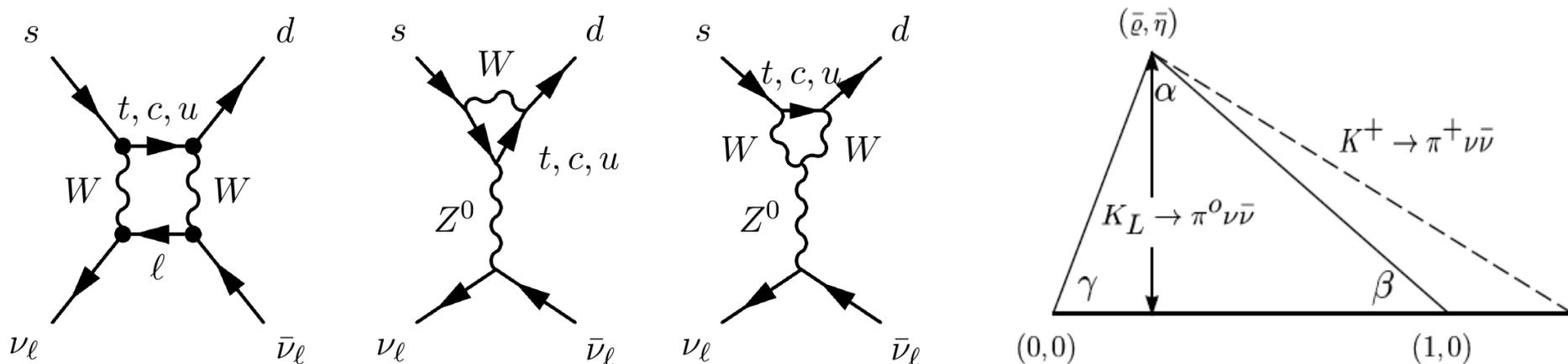
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Outline:

- Theoretical Motivations
- The NA62 experiment
- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ selection
- Results
- Conclusions and prospects

*39th International Conference on High Energy Physics
Seoul, South Korea – 07/07/2018*

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$: Motivations



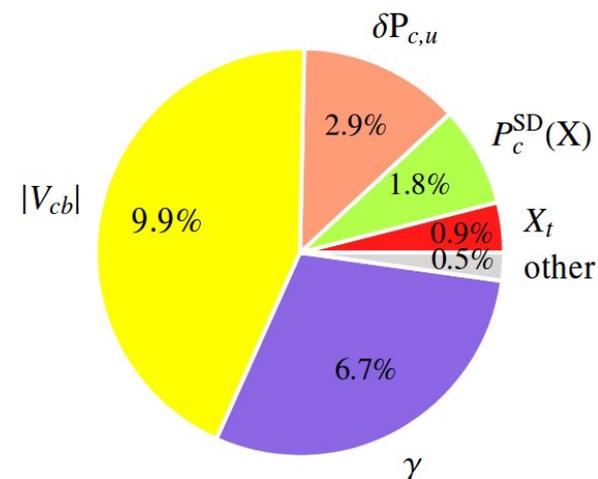
- FCNC forbidden at tree level: 1-loop contributions as leading order
 - Highly CKM suppressed: $BR(K^+ \rightarrow \pi^+ \nu \bar{\nu}) \sim |V_{ts}^* V_{td}|^2 \sim \lambda^{10}$
 - Dominated by short-distance contribution (top quark)
 - Hadronic matrix element from $BR(K^\pm \rightarrow e^\pm \pi^0 \nu)$
- } high sensitivity to new physics
- } high-precision theoretical prediction

SM prediction [Buras *et al.*, JHEP 1511 (2015) 033]:

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

Experimental result [E787/E949, PRD 79 (2009) 092004]:

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



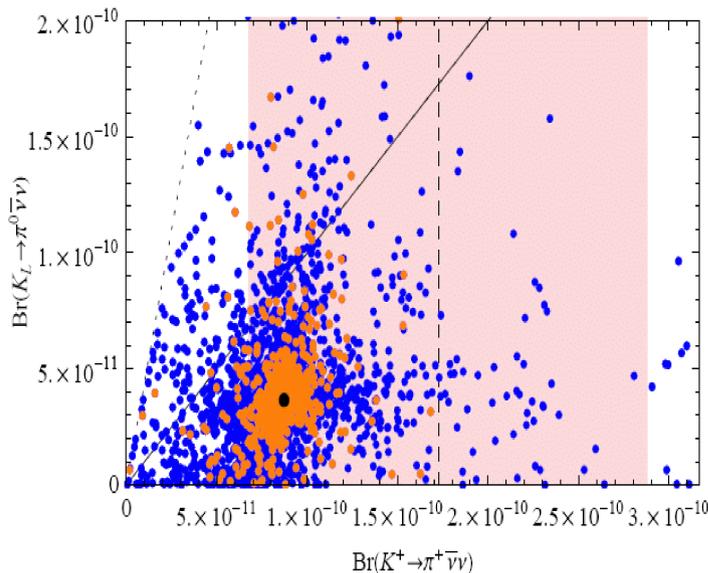
$K^+ \rightarrow \pi^+ \bar{\nu} \nu$: New Physics scenarios



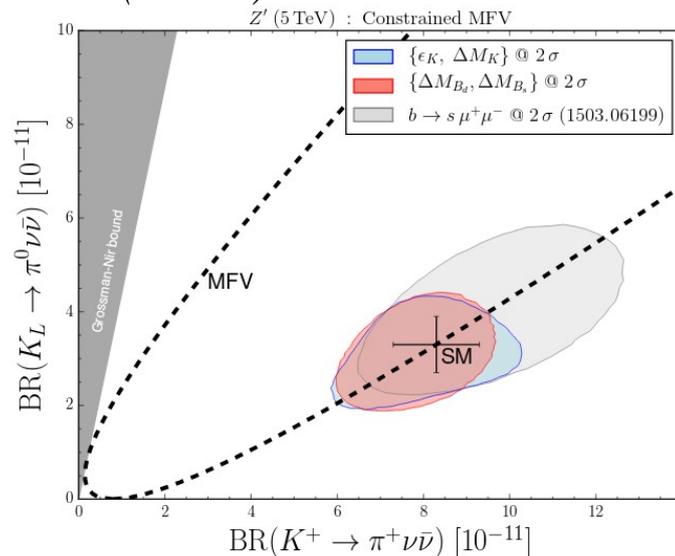
- Custodial Randall-Sundrum [Blanke *et al.*, JHEP 0903 (2009) 108]
- MSSM analyses [Blazek and Matak, Int. J. Mod. Phys. A 29 (2014) 1450162]
[Isidori *et al.*, JHEP 0608 (2006) 064]
- Simplified Z, Z' models [Buras, Buttazzo, Kneijens, JHEP 1511 (2015) 166]
- Littlest Higgs with T-Parity [Blanke *et al.*, EPJ C76 (2016) 182]
- LFU violation models [Isidori *et al.*, EPJ C77 (2017) 618]
- Constraints from existing measurements (correlations model dependent)

Kaon mixing, CKM elements, K, B rare meson decays, NP limits from direct searches

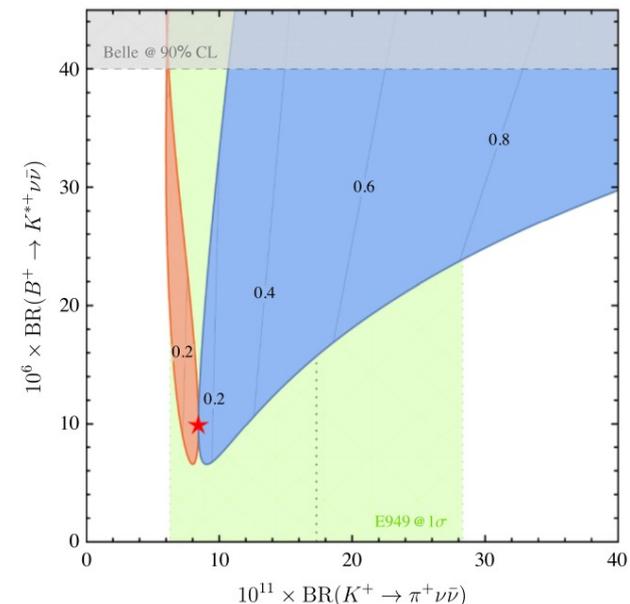
Randall-Sundrum



Z'(5 TeV) in Constrained MFV



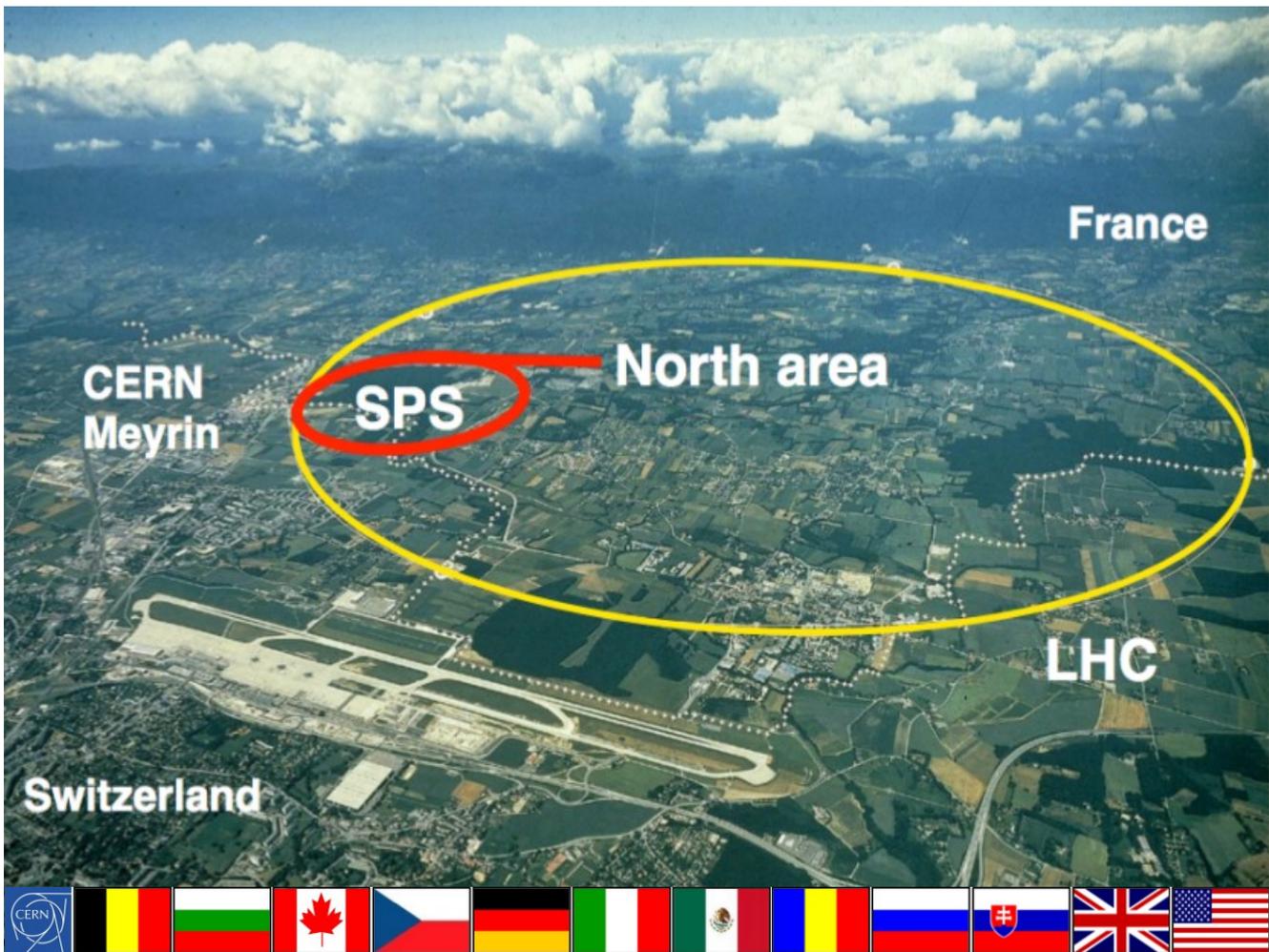
LFU violation



The NA62 experiment @ CERN



NA62 is the last from a long tradition of fixed-target Kaon experiments in the CERN North Area



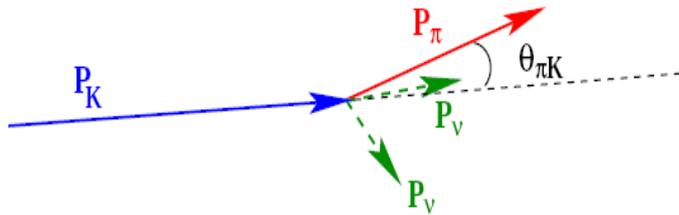
History of NA48/NA62 experiments		
1997 ↓ 2001	NA48 (K_S/K_L)	Re ϵ'/ϵ Discovery of direct CPV
2002	NA48/1 (K_S /hyperons)	Rare K_S and hyperon decays
2003 ↓ 2004	NA48/2 (K^+/K^-)	Direct CPV, Rare K^+/K^- decays
2007 ↓ 2008	NA62- R_K (K^+/K^-)	$R_K = K_{e2}^+/K_{\mu 2}^+$, Rare K^+/K^- decays
2015 ↓ -	NA62 (K^+)	$K^+ \rightarrow \pi^+ \nu \bar{\nu}$, Rare K^+ and π^0 decays

NA62: currently ~ 200 participants, 29 institutions from 12 countries

First $\pi \nu \nu$ data set: ~ one month of 2016 data with the full detector (**this talk**)

$K^+ \rightarrow \pi^+ \nu \bar{\nu}$ in NA62: strategy

NEW
Decay in flight
technique



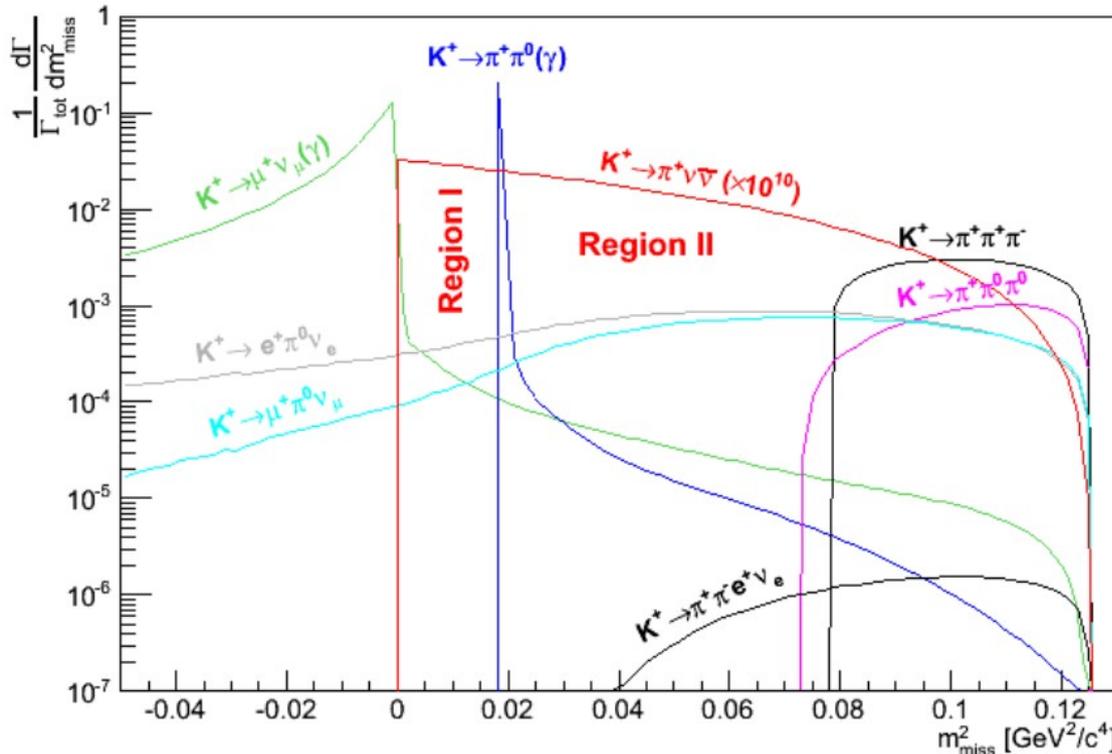
$$m_{\text{miss}}^2 = (\mathbf{P}_K - \mathbf{P}_\pi)^2$$

- **Keystones of the analysis:**

- Precise tracking
- Particle ID (in particular π/μ)
- Photon veto
- Precise timing $\sim O(100 \text{ ps})$

- **Analysis strategy:**

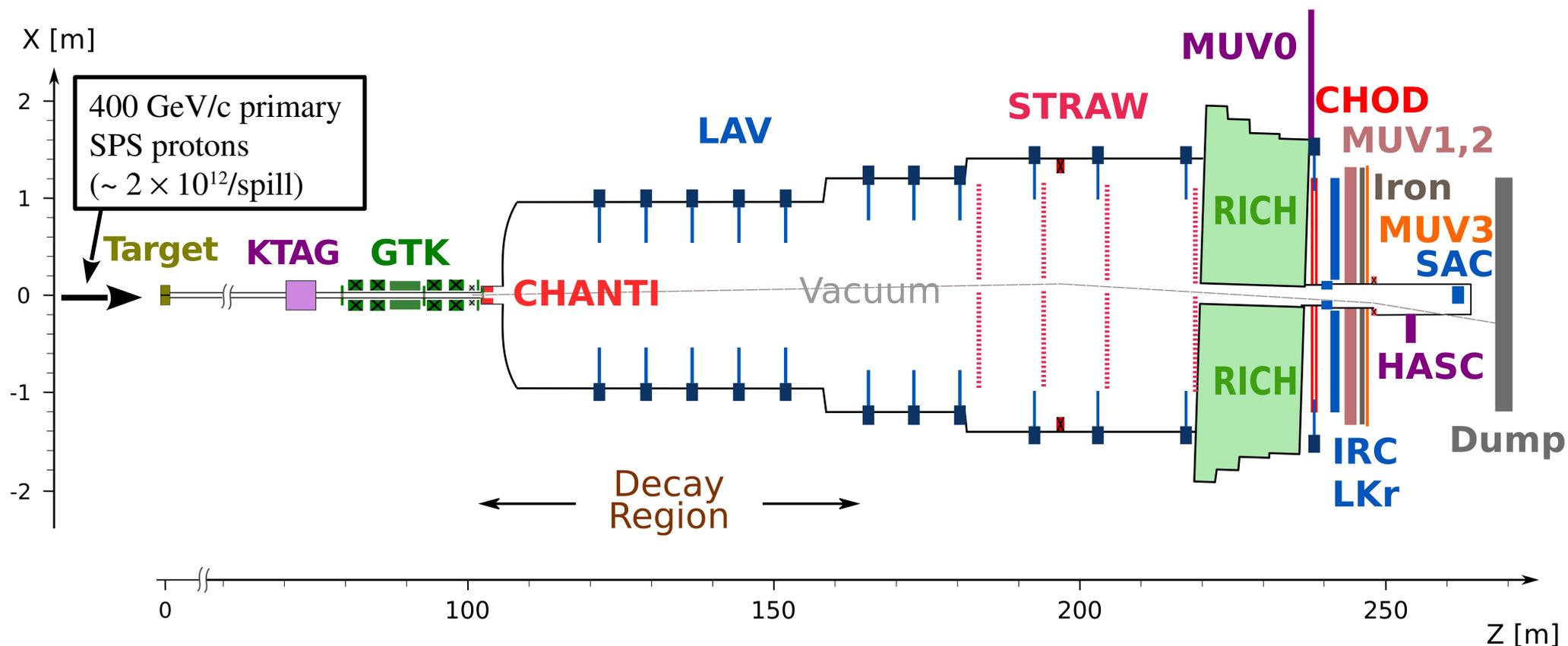
Signal and Background Control Regions kept blind throughout the analysis



$$15 \text{ GeV}/c < p_\pi < 35 \text{ GeV}/c$$

- + Particle ID (Cherenkov detectors)
- Particle ID (Calorimeters)
- Photon veto

The NA62 beam and detector



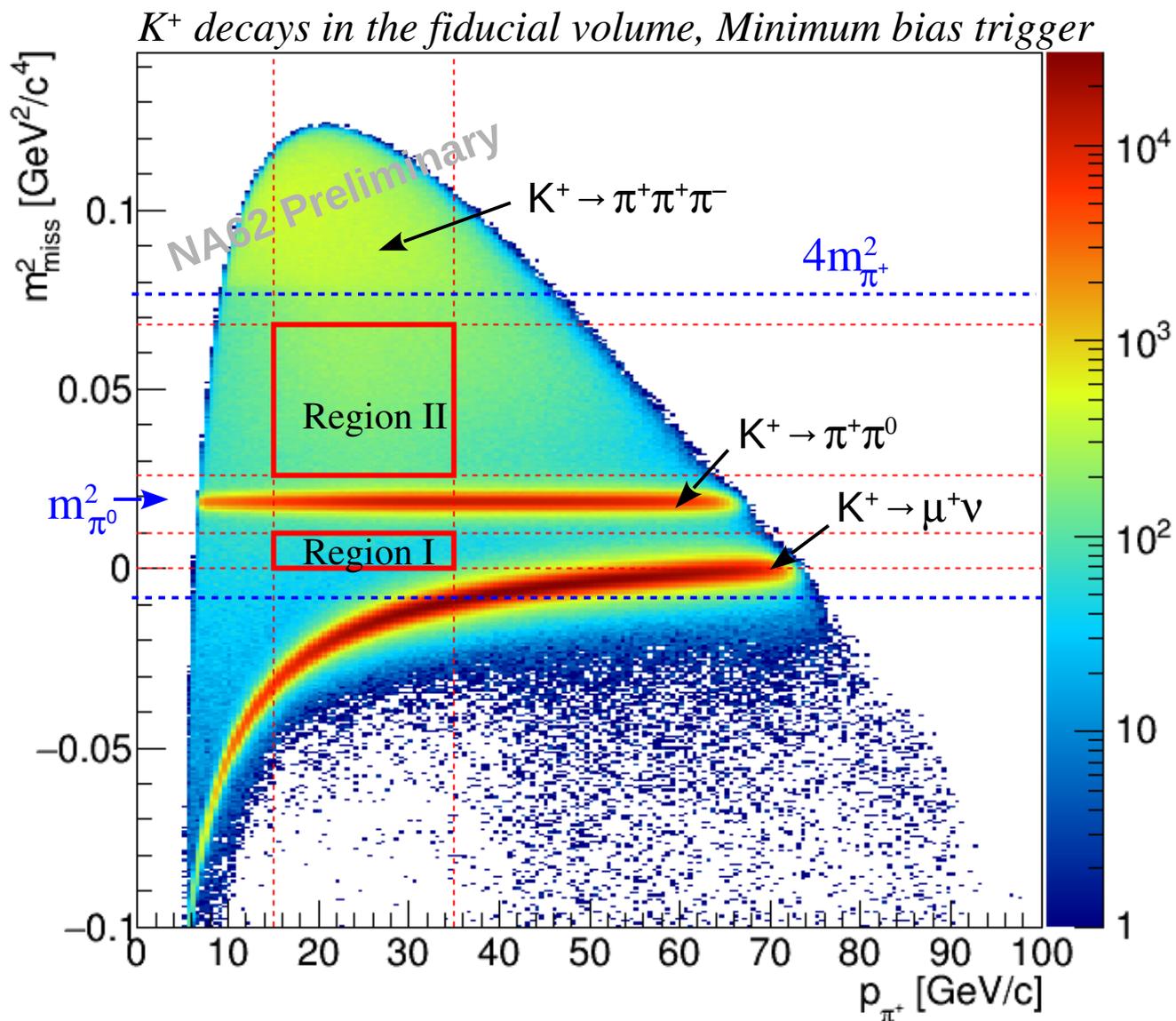
Secondary hadron beam:

- Composition: K^+ (6%) / π^+ (70%) / p (24%)
- $p = 75$ GeV/c, $\Delta p/p \sim 1\%$
- 100 μ rad divergence (RMS)
- 60×30 mm² transverse size
- Intensity: 750 MHz (45 MHz K^+)

Decay region:

- 60 m long fiducial volume
- Vacuum $\sim O(10^{-6})$ mbar
- ~ 5 MHz K^+ decay rate

Signal selection



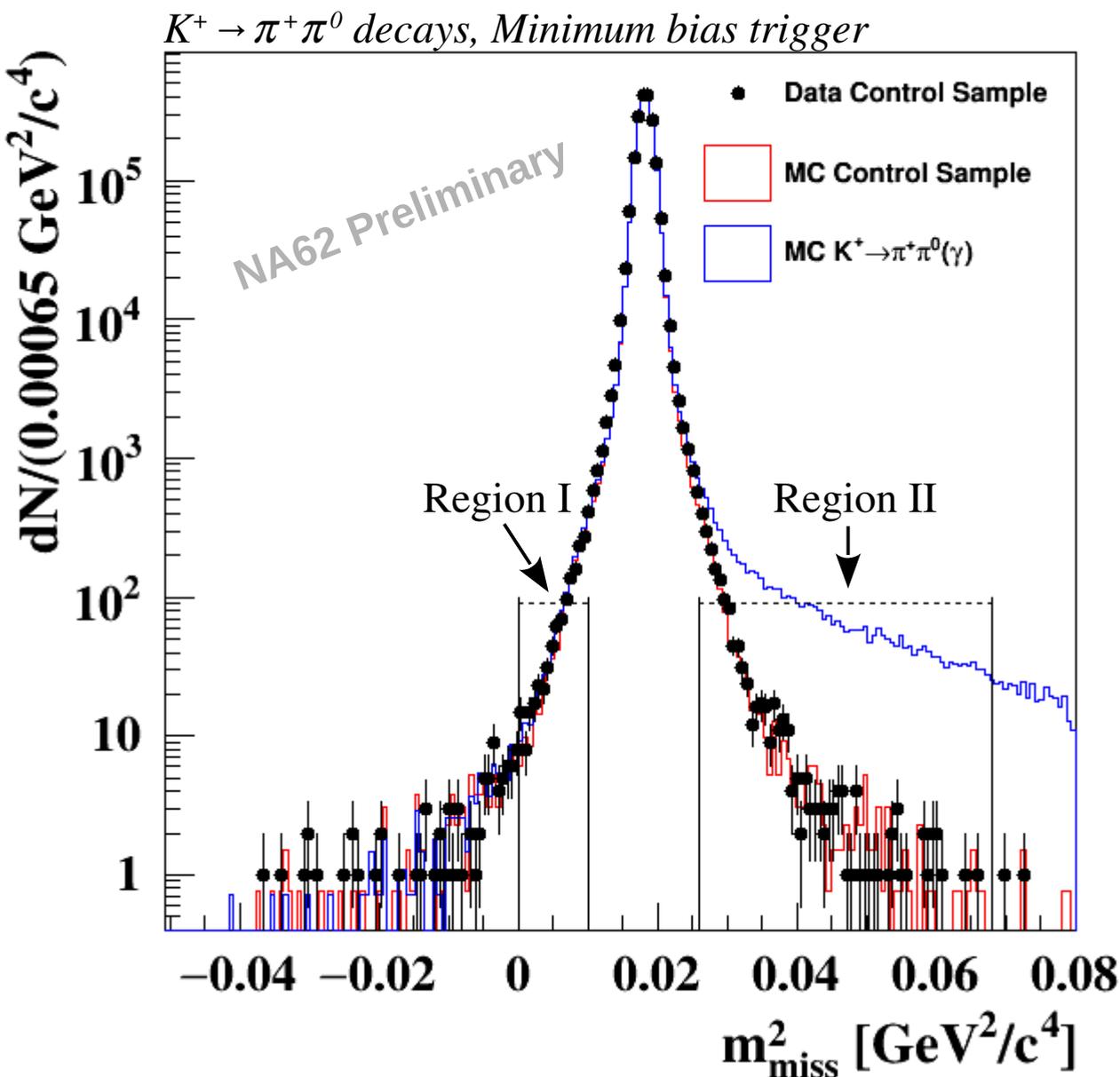
Selection criteria:

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

Performances:

- $\sigma(m_{\text{miss}}^2) = 10^{-3} \text{ GeV}^2/c^4$
- $\epsilon(\mu^+) = 10^{-8}$, $\epsilon(\pi^+) = 64\%$
- $\epsilon(\pi^0) = 3 \times 10^{-8}$
- $\sigma(\text{time}) \sim \text{O}(100 \text{ ps})$

Signal region definition



Three ways to compute m_{miss}^2

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

Protects against mis-reconstruction

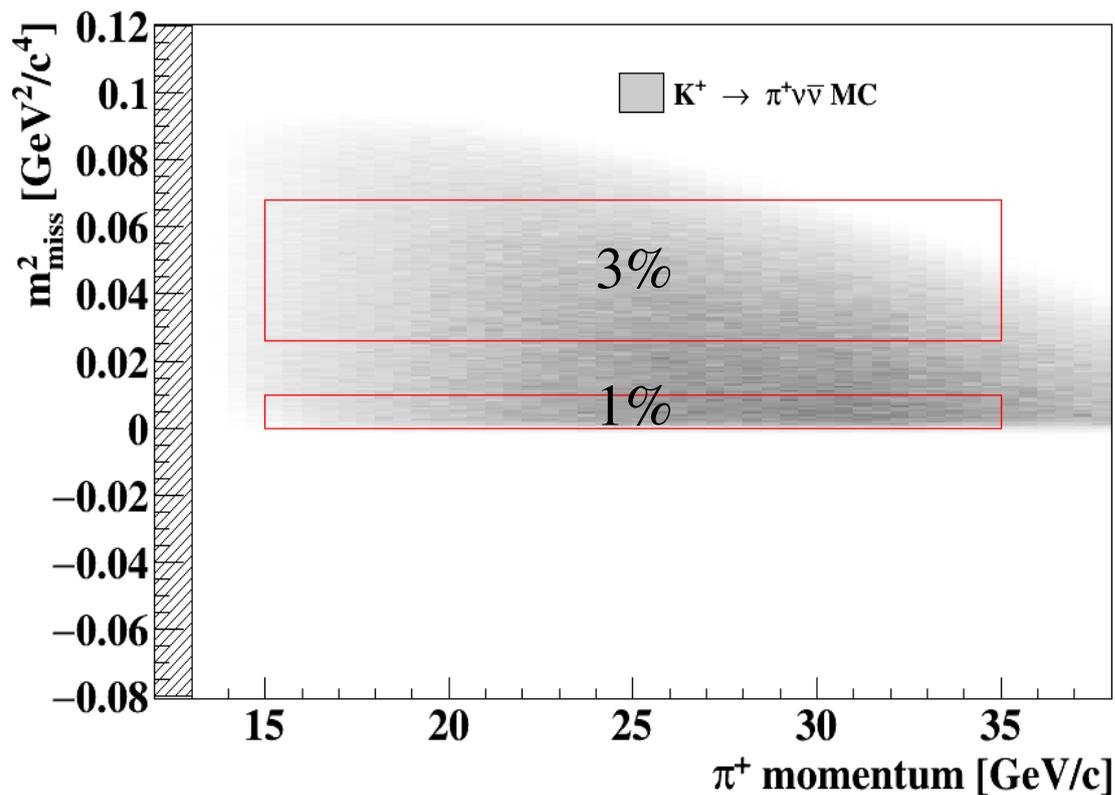
Kinematic suppression

Measured from data using $K^+ \rightarrow \pi^+ \pi^0$ and $K^+ \rightarrow \mu^+ \nu$ decays, selected using calorimeters

Fraction of events in Signal Regions

- $K^+ \rightarrow \pi^+ \pi^0 \sim 10^{-3}$ (resolution tails)
- $K^+ \rightarrow \mu^+ \nu \sim 3 \times 10^{-4}$

Single Event Sensitivity (SES)

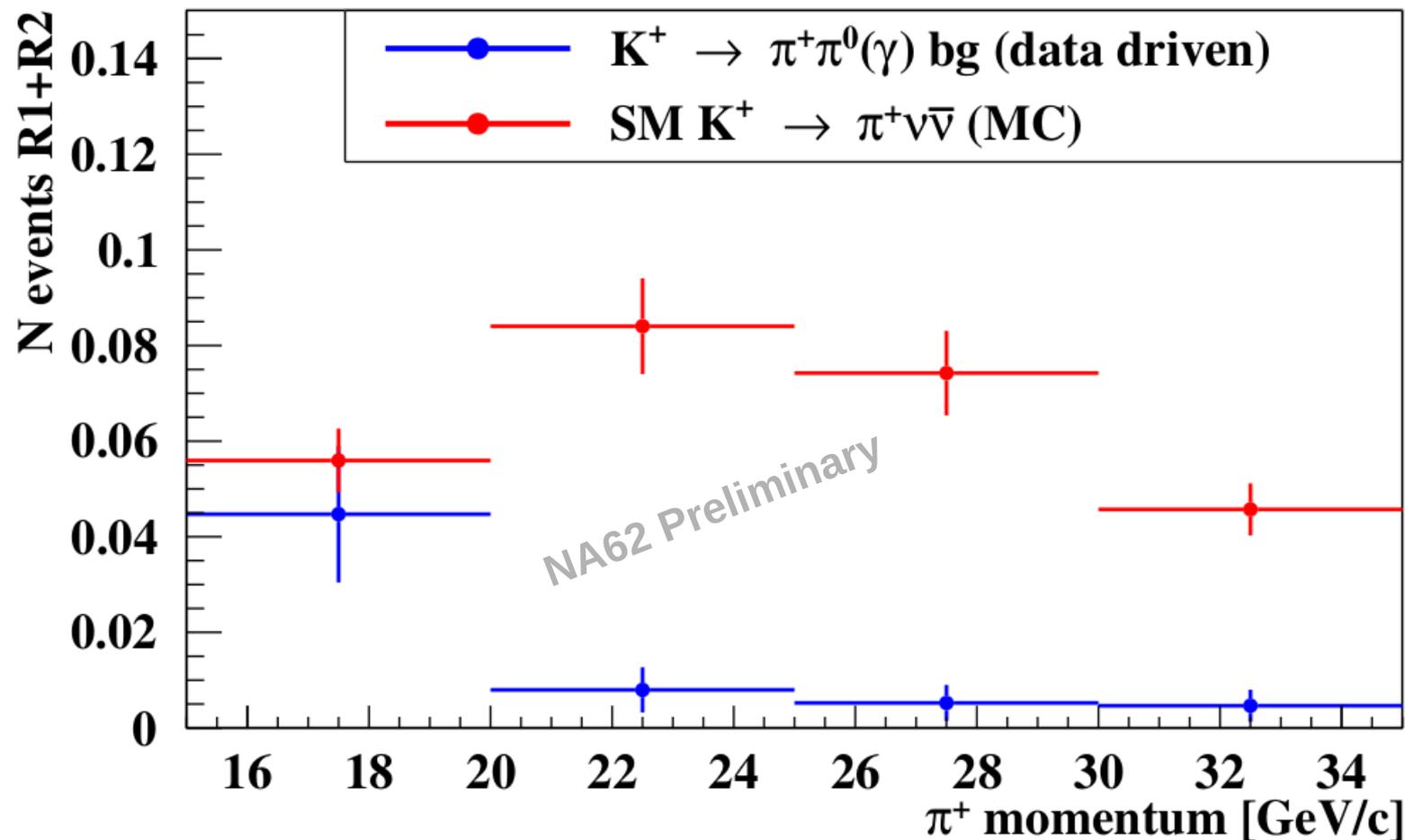


Source	δSES (10^{-10})
Definition of $\pi^+\pi^0$ region	0.10
Random veto	0.09
N_K	0.05
Trigger efficiency	0.04
Simulation of π^+ interactions	0.03
GTK pileup simulation	0.02
Extra activity	0.02
Momentum spectrum	0.01
Total	0.24

- Signal acceptance: 4%
- Normalisation ($K^+ \rightarrow \pi^+\pi^0$, min bias) acceptance: 10%
- Number of kaon decays in the fiducial volume: $N_K = (1.21 \pm 0.02) \times 10^{-10}$

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

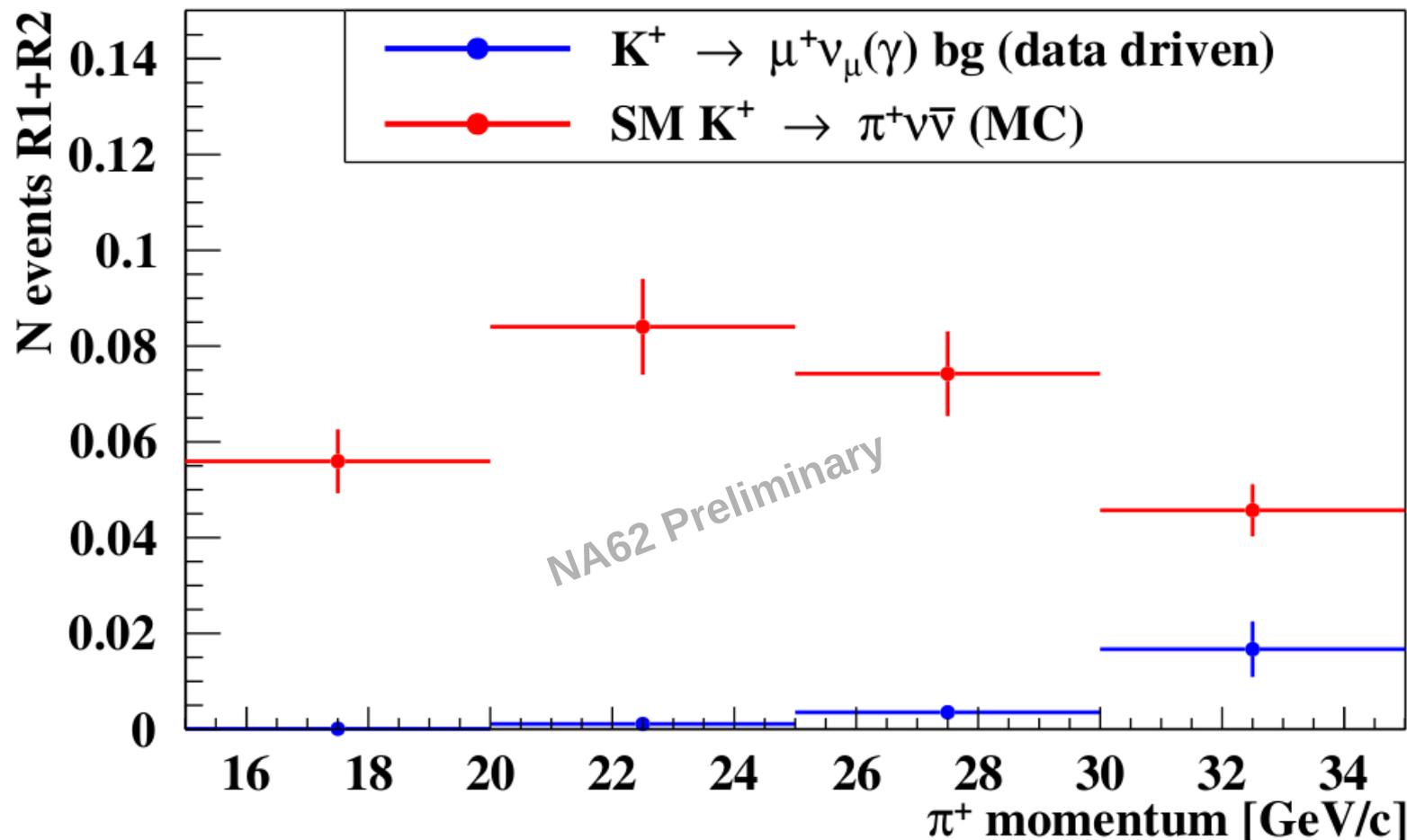
$K^+ \rightarrow \pi^+\pi^0(\gamma)$ background



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

$$N_{\pi\pi(\gamma)}^{\text{bkg}} = 0.064 \pm 0.007_{\text{stat}} \pm 0.006_{\text{syst}}$$

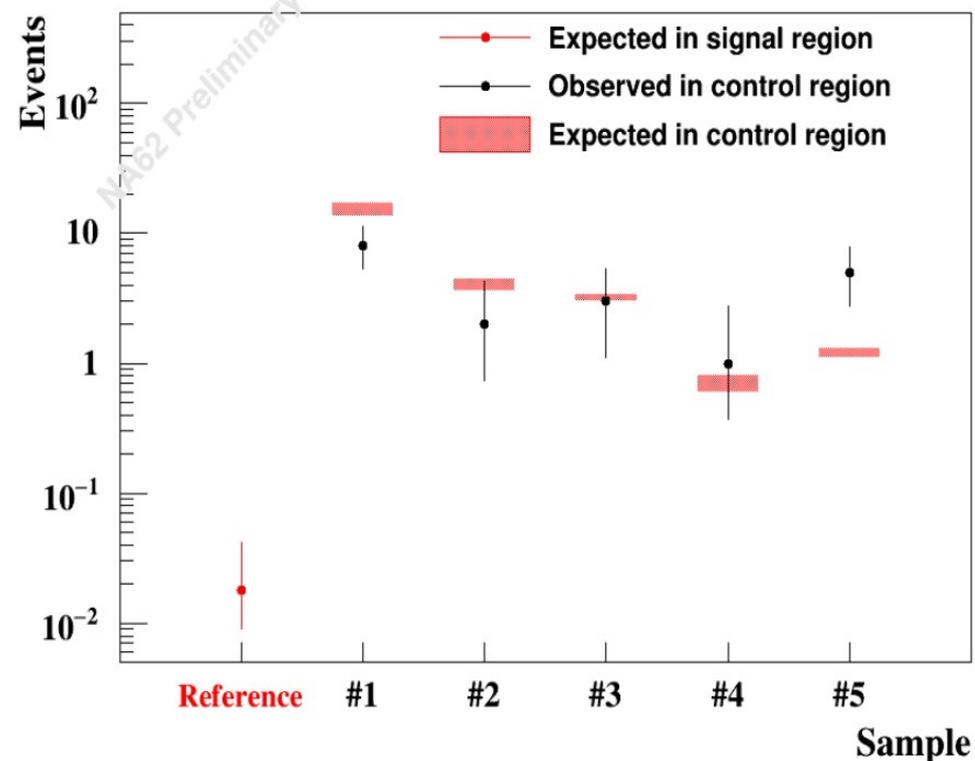
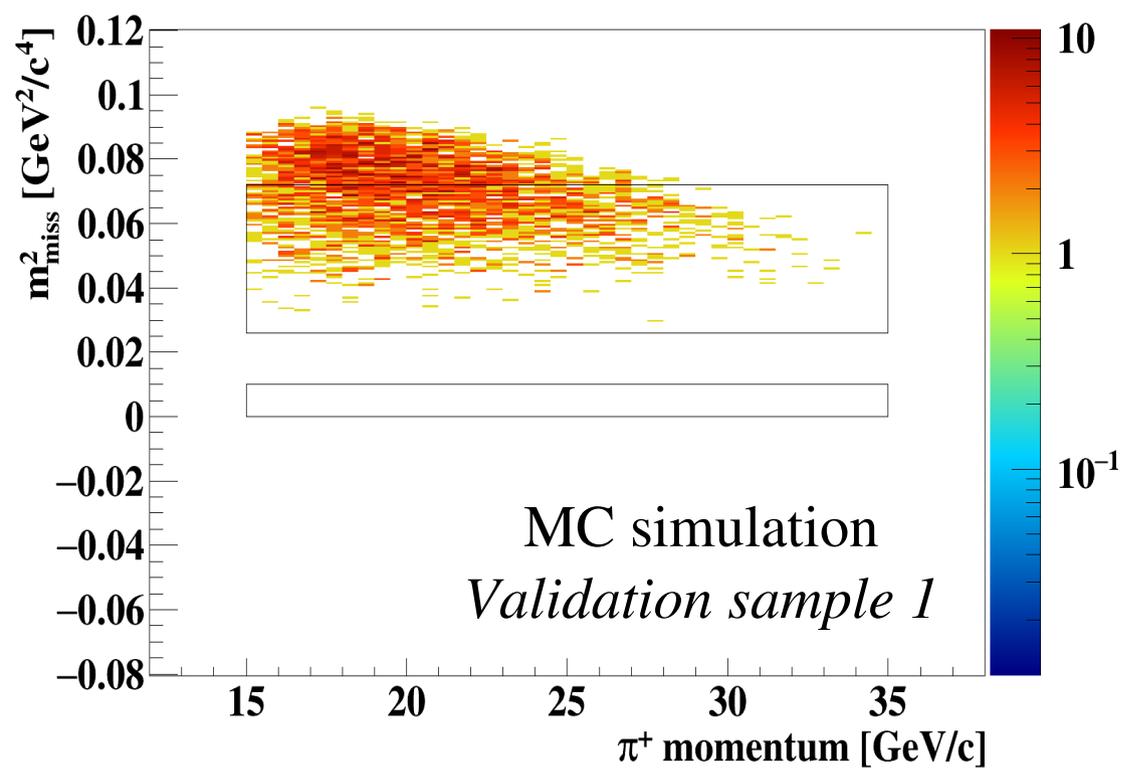
$K^+ \rightarrow \mu^+ \nu(\gamma)$ background



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

$$N_{\mu\nu(\gamma)}^{\text{bkg}} = 0.020 \pm 0.003_{\text{stat}} \pm 0.003_{\text{syst}}$$

$K^+ \rightarrow \pi^+\pi^-e^+\nu$ (K_{e4}) background

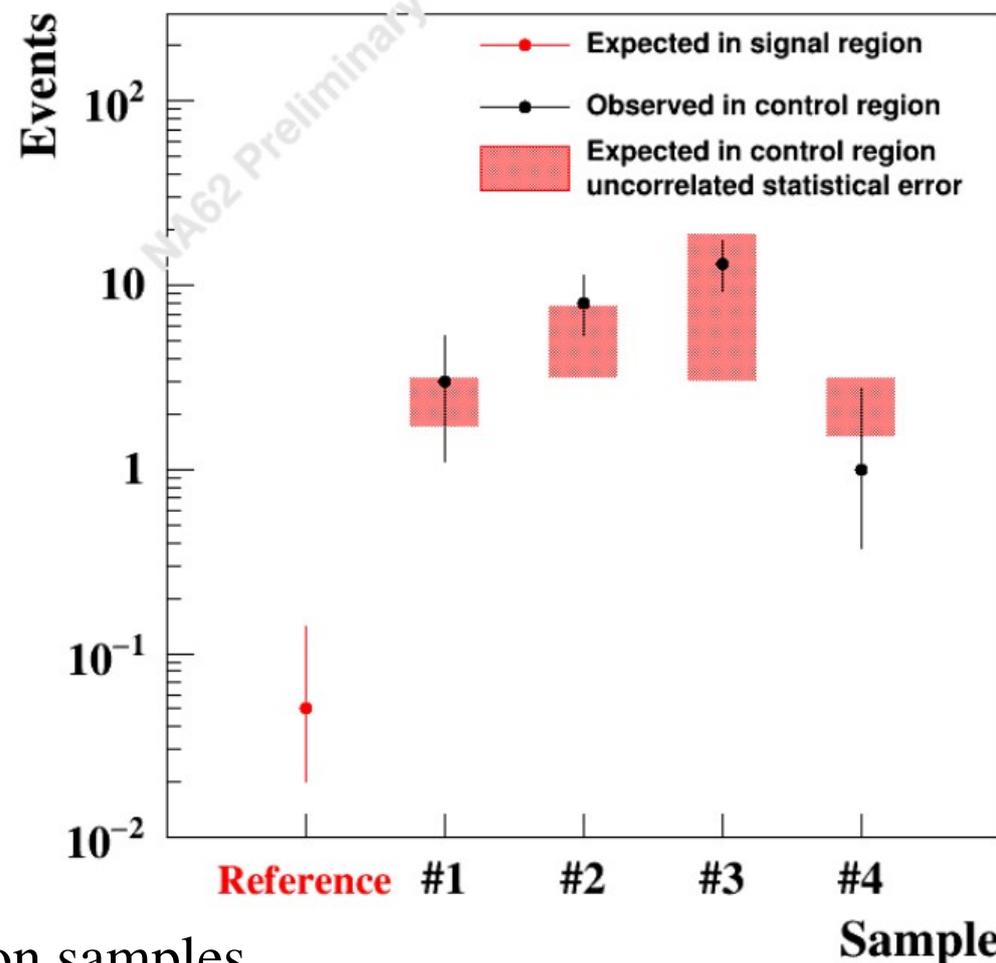
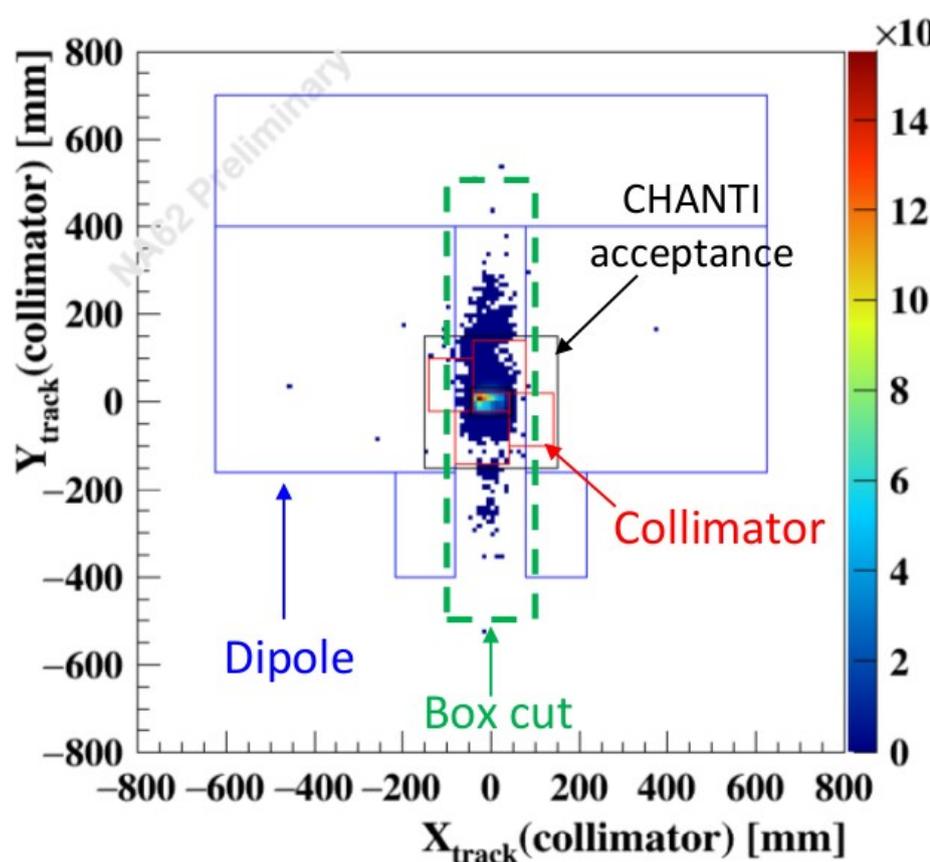


- Background estimated with 400 million MC generated $K^+ \rightarrow \pi^+\pi^-e^+\nu$ decays
- Good agreement across the 5 validation samples

$$N_{Ke4}^{\text{bkg}} = 0.018_{-0.017}^{+0.024}_{\text{stat}} \pm 0.009_{\text{syst}}$$

Upstream background

- Decays along the beam line; beam particle interactions in GTK
- Random track matched in GTK and/or possible additional energy not detected



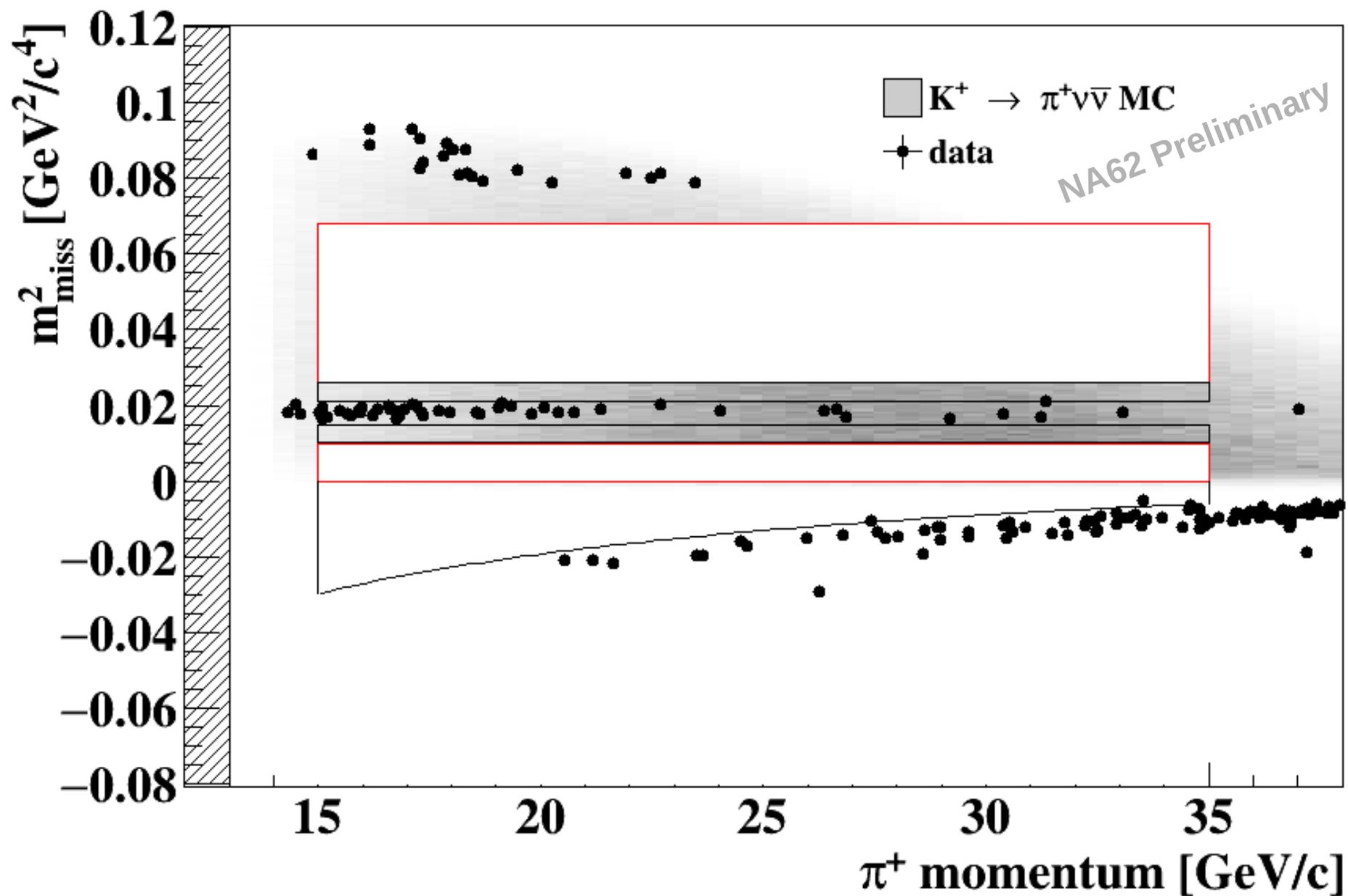
- Data driven background estimation
- Good agreement across the 4 validation samples

$$N_{\text{upstream}}^{\text{bkg}} = 0.050^{+0.090}_{-0.030\text{stat}}$$

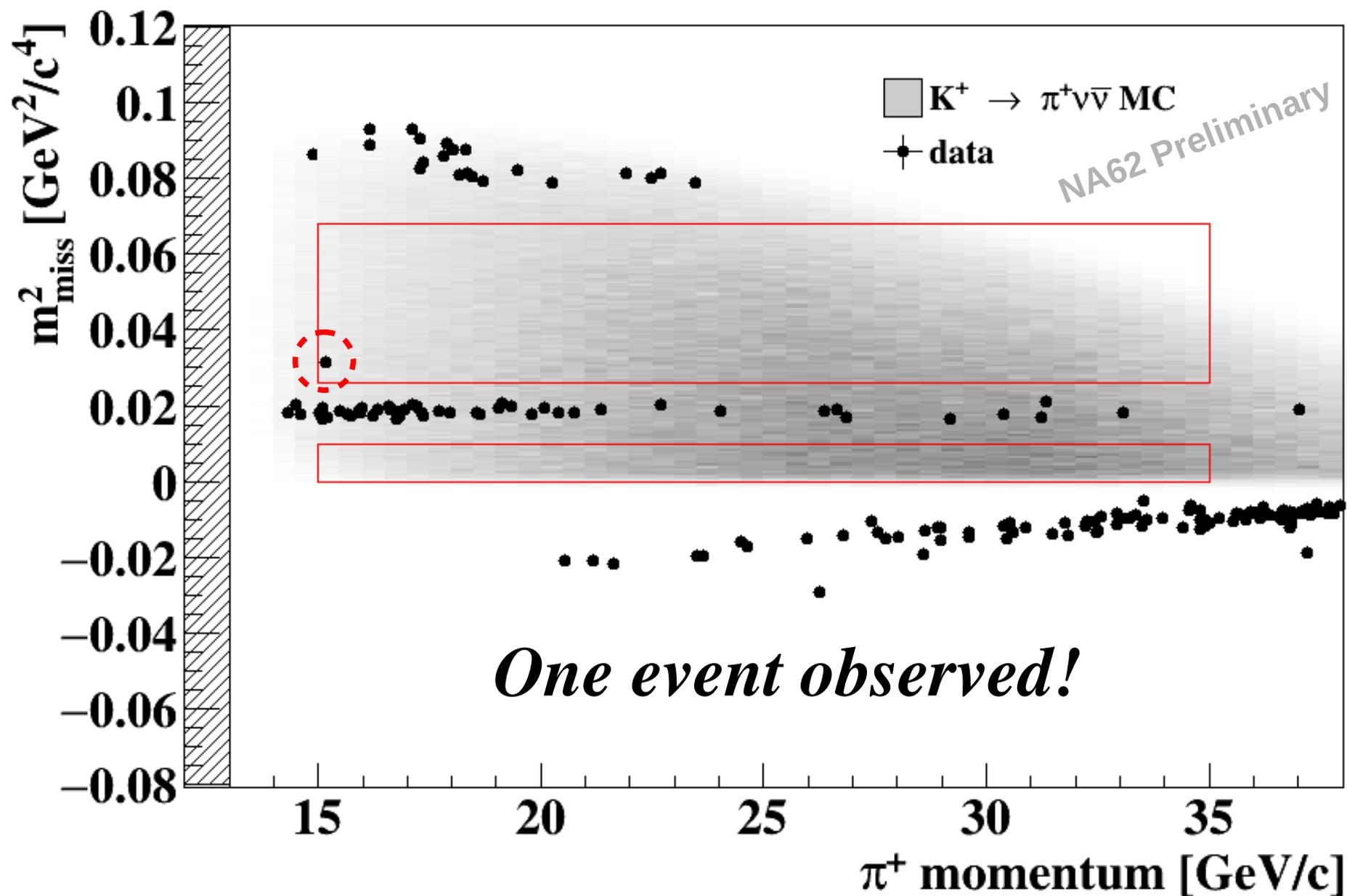
Signal Region Expectations

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

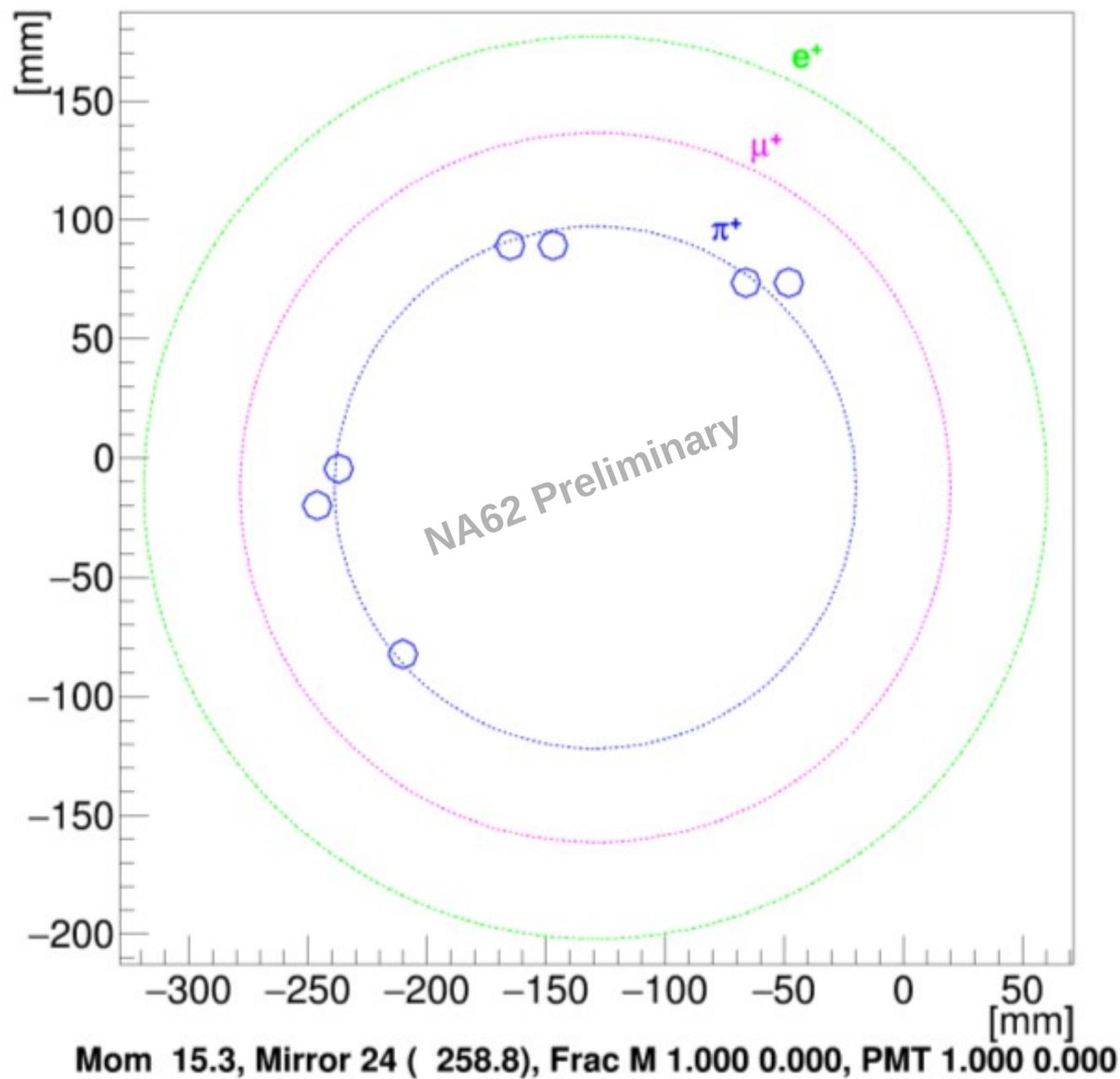
Results



Results



Results: RICH ring for the event



Results

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

- **Obtained Upper Limit:**

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

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

$$[\text{Expected: } \text{BR}(\text{K}^+ \rightarrow \pi^+ \nu \bar{\nu}) < 10 \times 10^{-10} \text{ @ 95\% CL}]$$

- For comparison:

$$\text{BR}(\text{K}^+ \rightarrow \pi^+ \nu \bar{\nu}) < (2.8_{-2.3}^{+4.4}) \times 10^{-10} \text{ @ 68\% CL}$$

- Results consistent with the Standard Model

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

Conclusions & Prospects

- **The new NA62 decay-in-flight technique to study $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ works**
 - One event observed in 2016 data
 - $\text{BR}(K^+ \rightarrow \pi^+ \nu \bar{\nu}) < 14 \times 10^{-10}$ @95% CL
- **Processing of 2017 data ongoing:**
 - 20 more than the presented statistic
 - Upstream background reduction expected
 - Methods to improve signal efficiency under study
- **2018 data taking under way:**
 - Further mitigation of the upstream background is expected
 - Processing on parallel with data-taking
 - Final 2018 reprocessing expected by beginning 2019

Expected about 20 SM events from the 2017+2018 data sample