Rencontres de Blois : 3rd-8th June 2018

NA62 Search for $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ in 2016 Data

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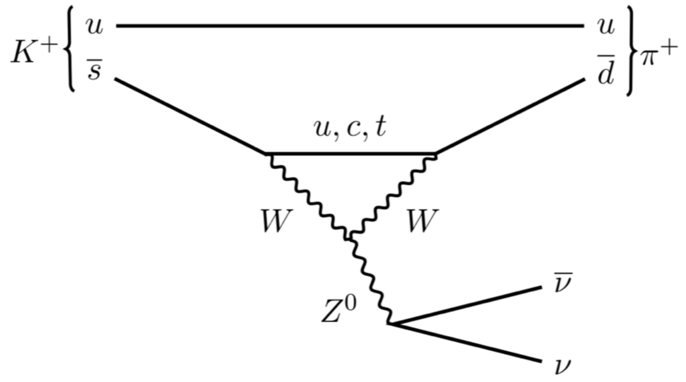
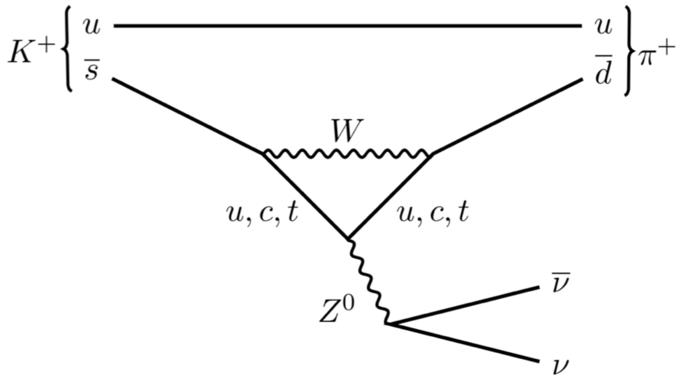
Overview

- The ultra-rare $K^+ \to \pi^+ \nu\bar{\nu}$ decay.
- The NA62 experiment at CERN.
- Results of analysis of 2016 data :
  - Selection.
  - Background rejection.
  - Single Event Sensitivity (SES).
  - Background studies.
  - Result.
- Outlook for NA62.

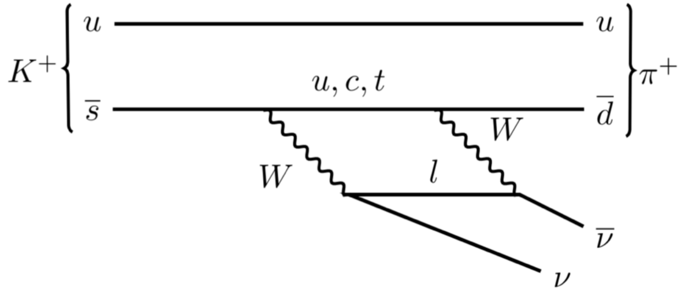
The ultra-rare $K^+ \to \pi^+ \nu \bar{\nu}$ decay



(a) Z^0 penguin diagram.

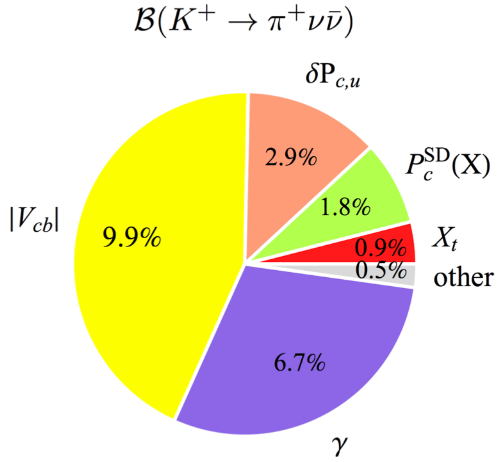


(b) Z^0 penguin diagram.



(c) W box diagram.

- **FCNC loop process:** $\bar{s} \to \bar{d}$ transition, dramatic CKM suppression.
- **Theoretically clean:**
  - Dominated by short distance effects.
  - Hadronic matrix elements precisely known from K_{l3} decays.
- **Precise theoretical prediction:** [Buras et al. : JHEP 1511 (2015) 033]



Uncertainty budget
[Buras et al. : JHEP 1511 (2015) 033]

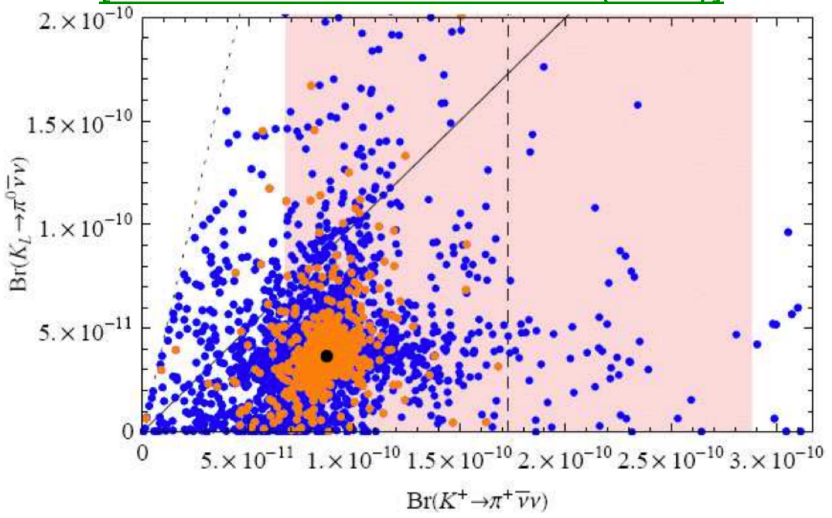
$$\therefore\ Br(K^+ \to \pi^+ \nu \bar{\nu}) = (8.38 \pm 0.30) \times 10^{-11} \left[\frac{|V_{cb}|}{40.7 \times 10^{-3}}\right]^{2.8} \left[\frac{\gamma}{73.2^\circ}\right]^{0.74} = (8.4 \pm 1.0) \times 10^{-11}$$

- **Potential sensitivity to NP.**
- **NA62 primary goal:** Precise experimental measurement of $Br(K^+ \to \pi^+ \nu \bar{\nu})$.

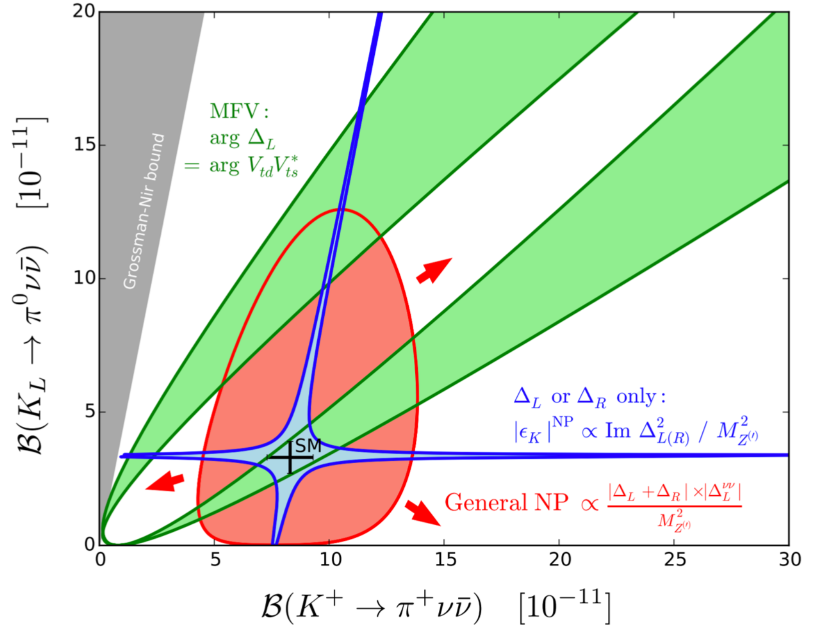
NP Prospects for $K^+ \to \pi^+ \nu\bar{\nu}$ decay

- Randall-Sundrum (warped extra dimension) with Custodial protection [Blanke et al. JHEP 0903:108 (2009)]
- Supersymmetry (MSSM) [Blažek & Maták Int.J.Mod.Phys. A29 (2014)] [Isidori et al JHEP 0608:064 (2006)]
- Simplified Z, Z' models [Buras et al. JHEP11,166 (2015)]
- Littlest Higgs model with T-parity [Blanke et al. Eur.Phys.J. C76 (2016) no.4, 182]
- Lepton Flavour Universality Violation (LFUV) [Bordone et al. Eur. Phys. J. C (2017) 77:618]
- Previous constrains on the models from: $K^0 - \overline{K^0}$ mixing, rare K and B decays, CKM matrix element measurements, LFUV anomalies, direct searches for NP.

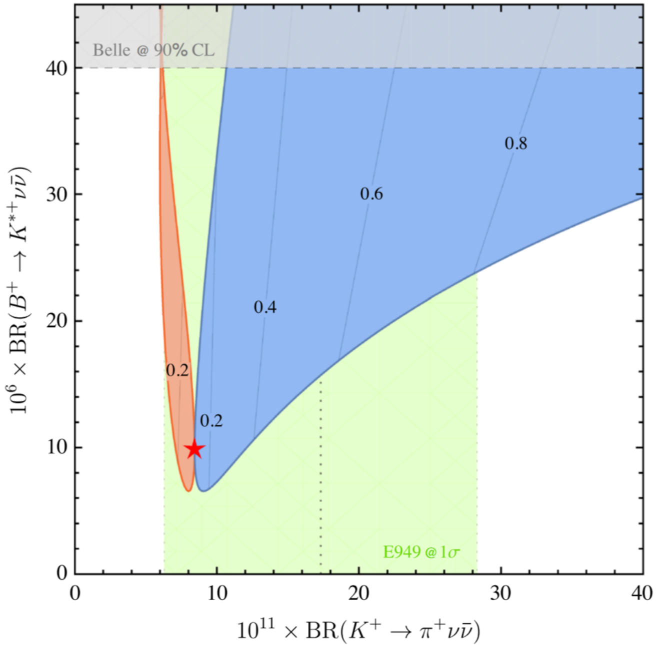
Randall-Sundrum + Custodial Protection
[Blanke et al. JHEP 0903:108 (2009)]



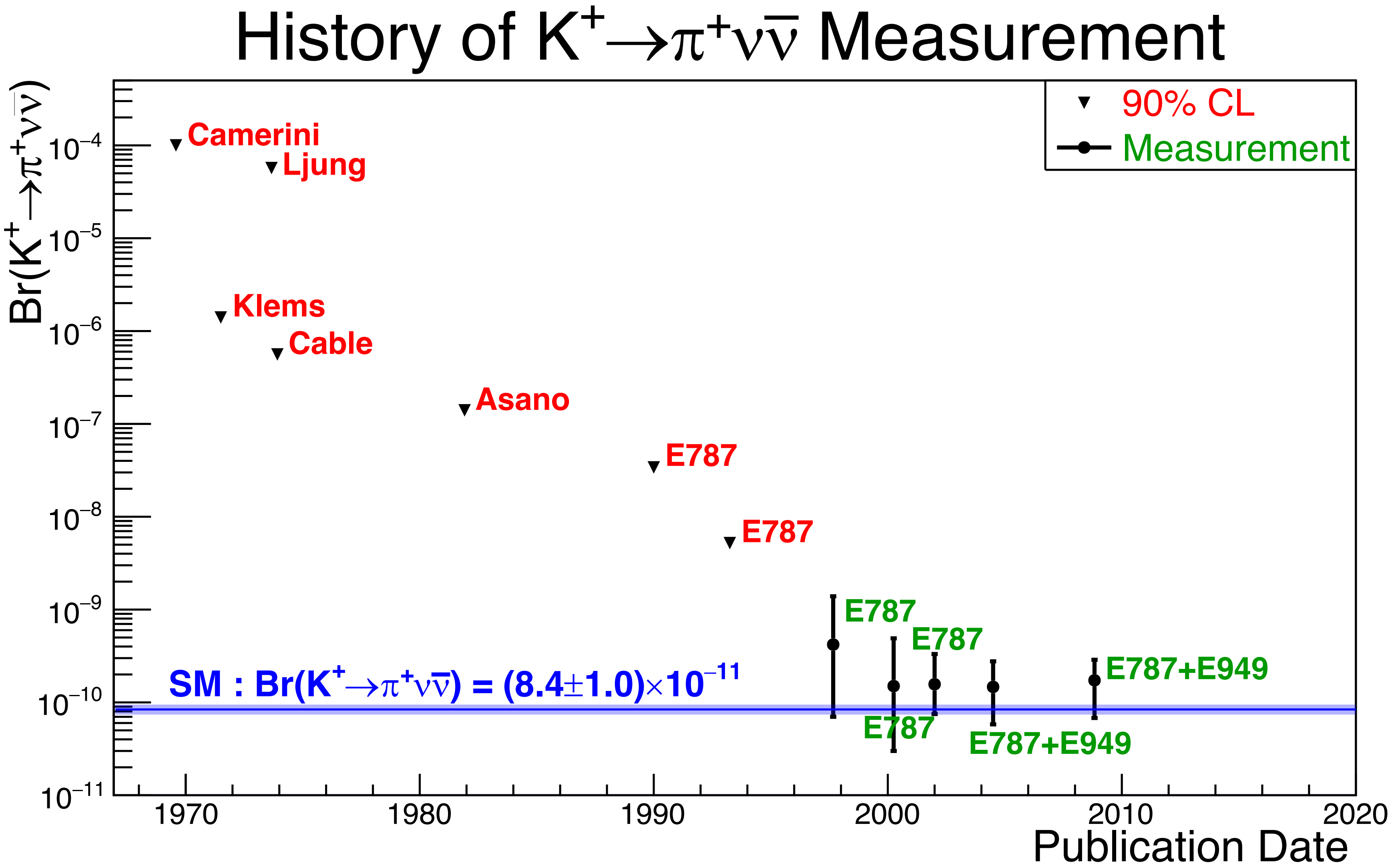
[Buras et al. JHEP11,166 (2015)]



LFUV
[Bordone et al. Eur. Phys. J. C (2017) 77:618]



Experimental Context : $Br(K^+ \to \pi^+ \nu\bar{\nu})$ Measurement



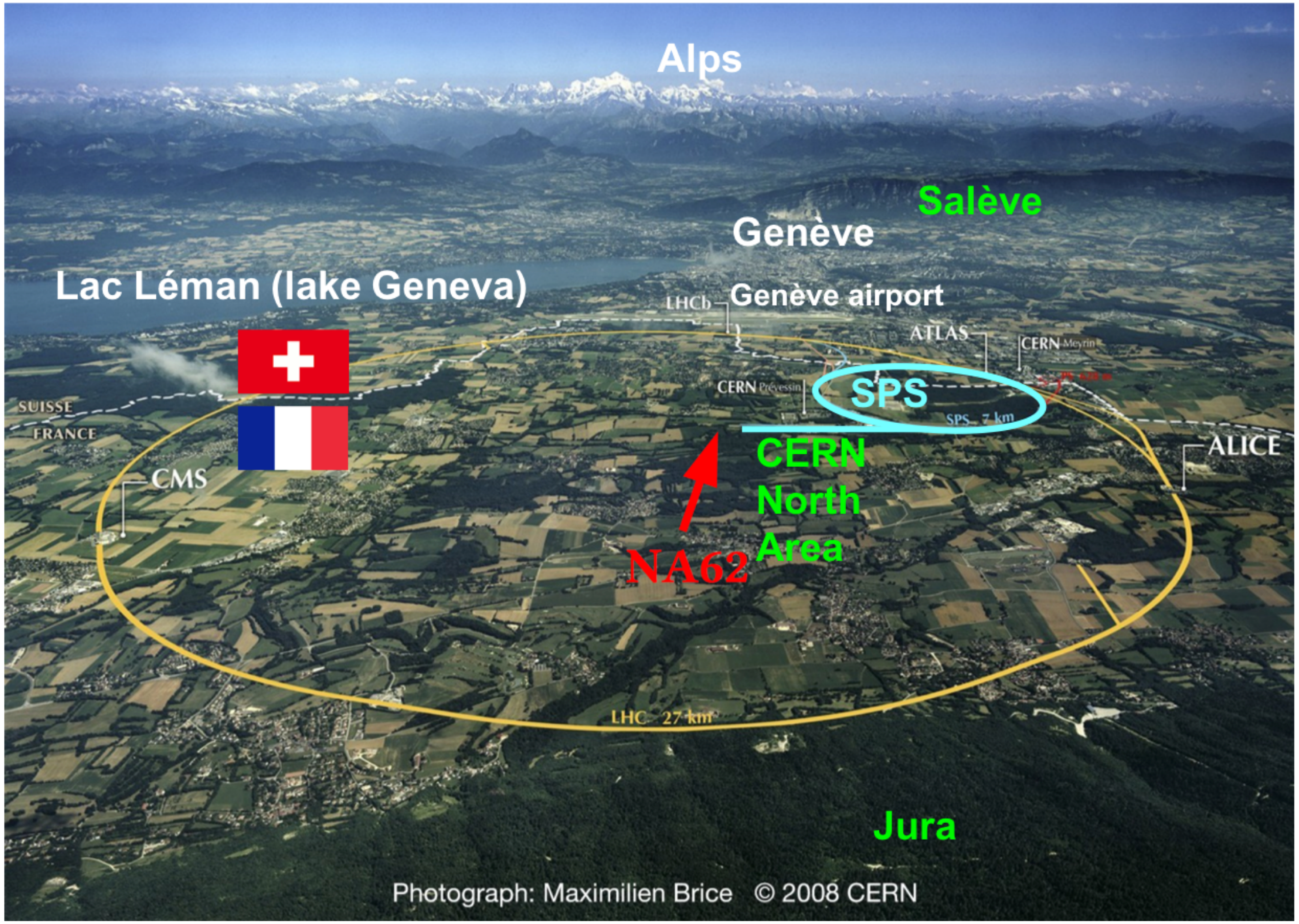
Final BNL E787+E949 result : [Artamonov et al. PhysRevLett.101.191802 (2008)]

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

The NA62 Experiment at CERN

~200 collaborators from ~30 institutions :

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



- **Primary goal:** Measurement of $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu})$.
- **New Technique:** K decay-in-flight.
- **Requirements:**
  - 10^{13} K^+ decays
  - Signal acceptance $\mathcal{O}(10\%)$
  - $\mathcal{O}(10^{12})$ Background rejection
- **Broader Physics programme :** [SPSC NA62 (2018)]
  - Rare K^+ decays (e.g $K^+ \rightarrow \pi^+\mu^+\mu^-$).
  - LNV/LFV K^+ decays (e.g $K^+ \rightarrow \pi^- l_2{}^+ l_1{}^+$).
  - Exotics (e.g HNL : [PhysLett.B,778 (2018)]).
- **Data Taking :**
  - 2015 Commissioning run.
  - 2016 Commissioning + Physics run (30 days) [this talk].
  - 2017 Physics run (160 days).
  - 2018 Physics run in progress (217 days scheduled).

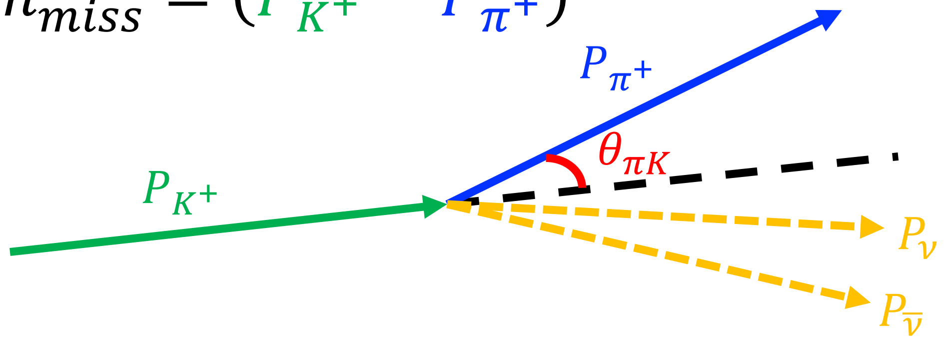
The NA62 Strategy

NA62 Keystones

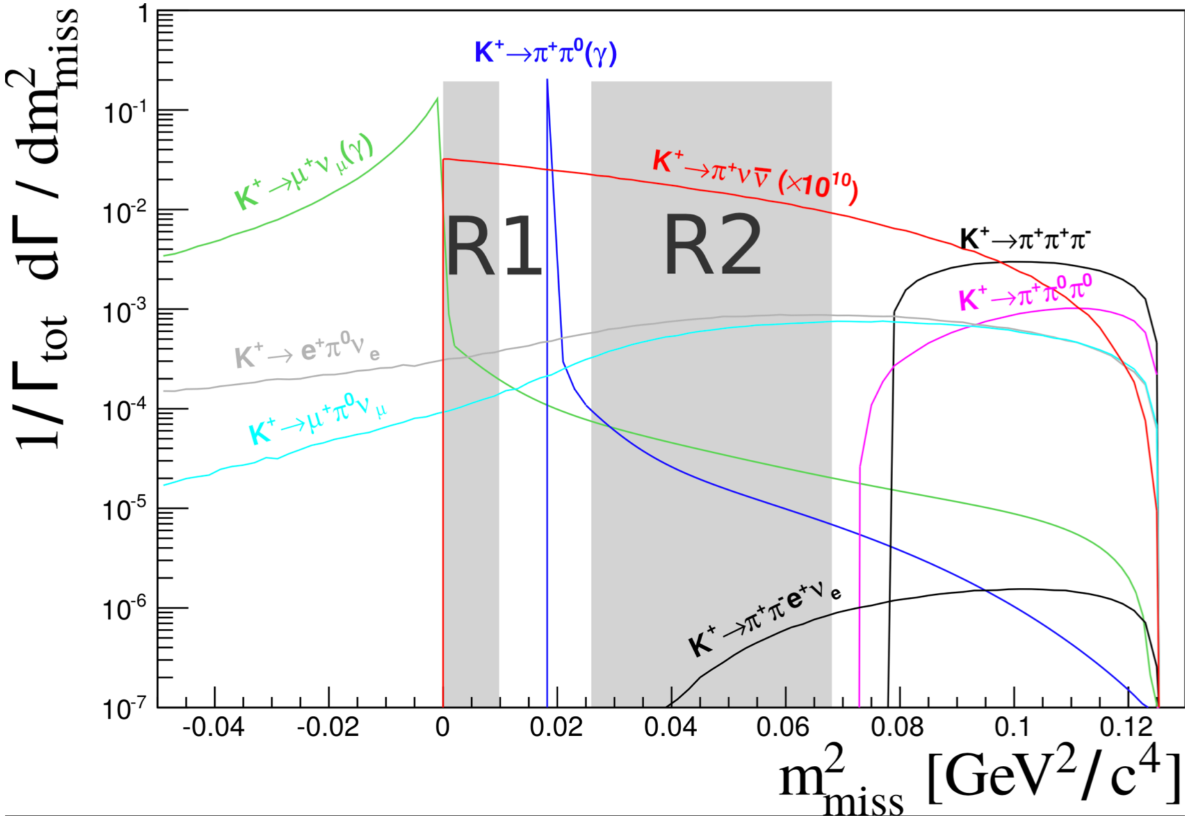
- $\mathcal{O}(100)$ ps timing between sub-detectors.
- $\mathcal{O}(10^4)$ background suppression from kinematics.
- $> 10^7$ muon rejection.
- $> 10^7$ rejection of π^0 from $K^+ \to \pi^+\pi^0$.

Process	Branching Ratio [PDG]
$K^+ \to \mu^+\nu_\mu$	0.6356 ± 0.0011
$K^+ \to \pi^+\pi^0$	0.2067 ± 0.0008
$K^+ \to \pi^+\pi^+\pi^-$	0.05583 ± 0.00024
$K^+ \to \pi^+\pi^- e^+\nu_e$	$(4.247 \pm 0.024)\times10^{-5}$
$\boldsymbol{K^+ \to \pi^+\nu\bar{\nu}}$	[SM] $\boldsymbol{(8.4 \pm 1.0)\times10^{-11}}$

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

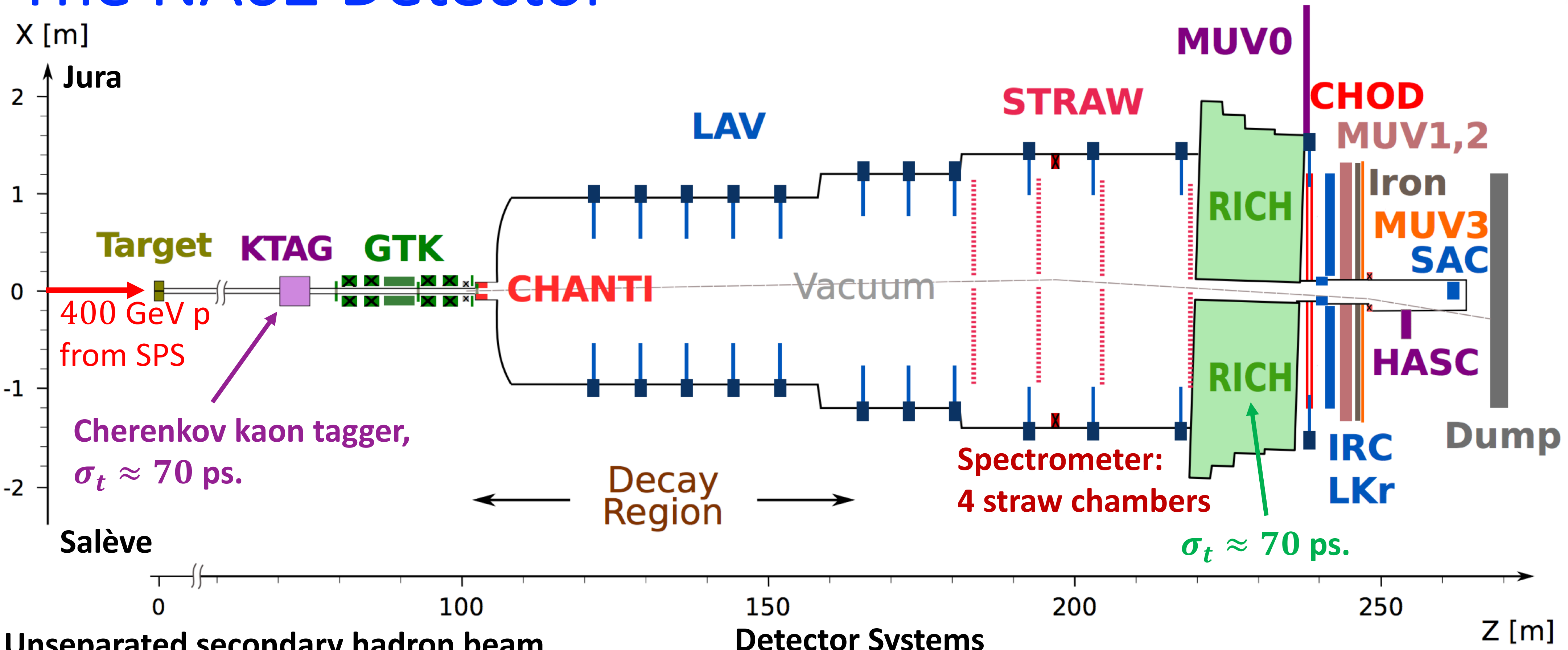


- **Kinematic suppression:** restrict to R1 & R2 with $15 < p_{\pi^+} < 35$ GeV.
- **Muon rejection:** PID (Cherenkov detectors + Calorimeters)
- $\boldsymbol{\pi^0}$ **rejection:** photon vetos.



The NA62 Detector

[NA62 Detector Paper, 2017 JINST 12 P05025]



Unseparated secondary hadron beam

- Composition : $70\% \ \pi^+$, $24\% \ p$, $6\% \ K^+$
- $p_{K^+} = 75$ GeV.
- Nominal intensity : 33×10^{11} protons/SPS spill. ($\sim$750 MHz rate at GTK3)
- $\sim$5 MHz K^+ decays in $\sim$60 m decay region.

Detector Systems

- **Spectrometers:** GTK (upstream) and STRAWs (downstream).
- **PID (1):** Cherenkov detectors: KTAG (K^+), RICH (π/μ separation).
- **PID (2):** Calorimeters (ECAL = LKr , HCALs = MUV1&2).
- **Photon vetos:** (hermetic for $0-50$ mrad) 12LAVs, 2SAVs (IRC&SAC), LKr.
- **Muon veto:** MUV3.
- **Additional detectors:** NA48-CHOD, CHOD, CHANTI, MUV0, HASC.

Analysis Procedure

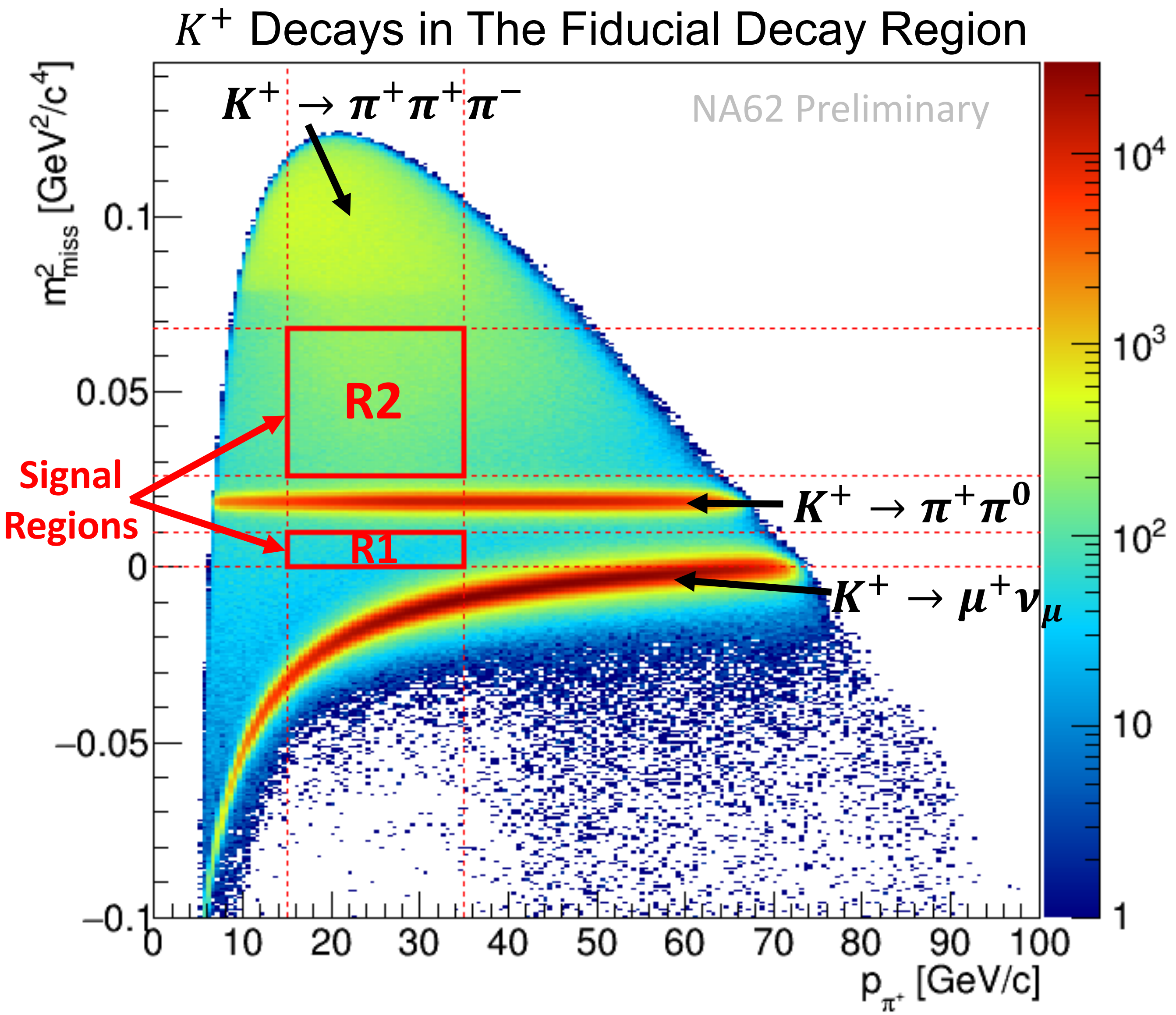
Data Sample

- **~4 weeks of 2016 data**, $(1.21 \pm 0.02)\times 10^{11}\ K^{+}$ decays in fiducial volume.
- Dedicated $\pi\nu\bar{\nu}$ trigger stream + minimum bias Control trigger (downscaled).

Analysis

1. Selection
   - **Blind analysis procedure:** signal and control regions blinded for whole analysis.
2. Determination of the Singe Event Sensitivity (SES)
3. Estimation and validation of expected background
   - $K^{+} \to \pi^{+}\pi^{0}(\gamma)$, $K^{+} \to \mu^{+}\nu_{\mu}(\gamma)$, $K^{+} \to \pi^{+}\pi^{+}\pi^{-}$, $K^{+} \to \pi^{+}\pi^{-}e^{+}\nu_{e}$, upstream.
4. Un-blinding control and signal regions and results.

Signal Selection



Selection Sketch (cut-based analysis)

- Single downstream track.
- Match downstream track to a K^+ upstream.
- ID downstream track as a π^+.
- Photon rejection.
- Reject additional activity.

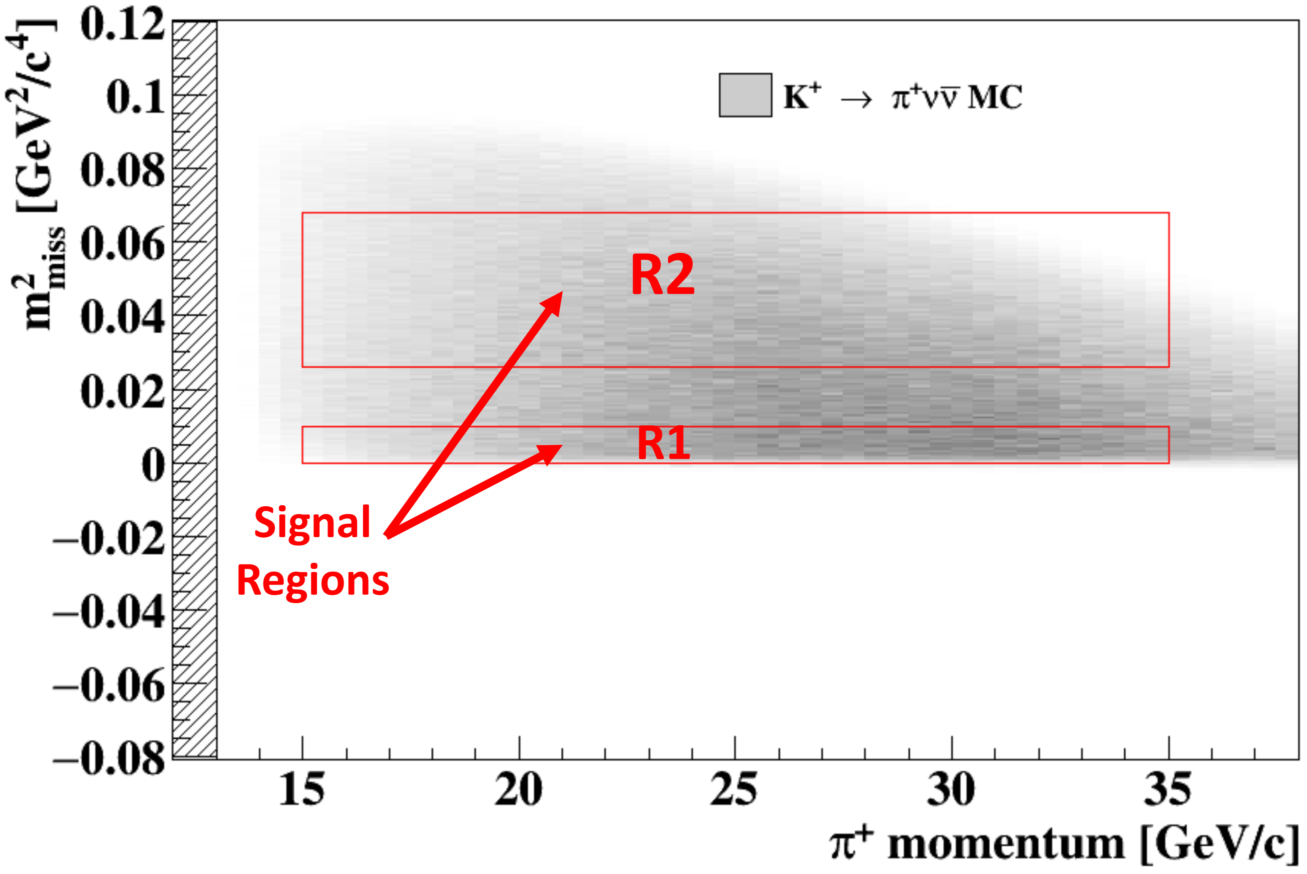
Signal Region Definition

- $15 < p_{\pi^+} < 35$ GeV
- R1 & R2 in $m^2_{miss} = (P_K - P_\pi)^2$
  - 3 definitions (Protects against mis-reconstruction):
    - $m^2_{miss}(STRAW, GTK)$
    - $m^2_{miss}(RICH, GTK)$
    - $m^2_{miss}(STRAW, Beam)$

Performance (2016 data)

- PID : $\varepsilon_{\pi^+} = 64\%$, $\varepsilon_{\mu^+} = 1\times10^{-8}$
- π^0 rejection : $\varepsilon_{\pi^0} = 3\times10^{-8}$
- $\sigma(m^2_{miss}) = 1\times10^{-3}$ GeV²
- $\sigma(t) = \mathcal{O}(100 \text{ ps})$

Single Event Sensitivity (SES)



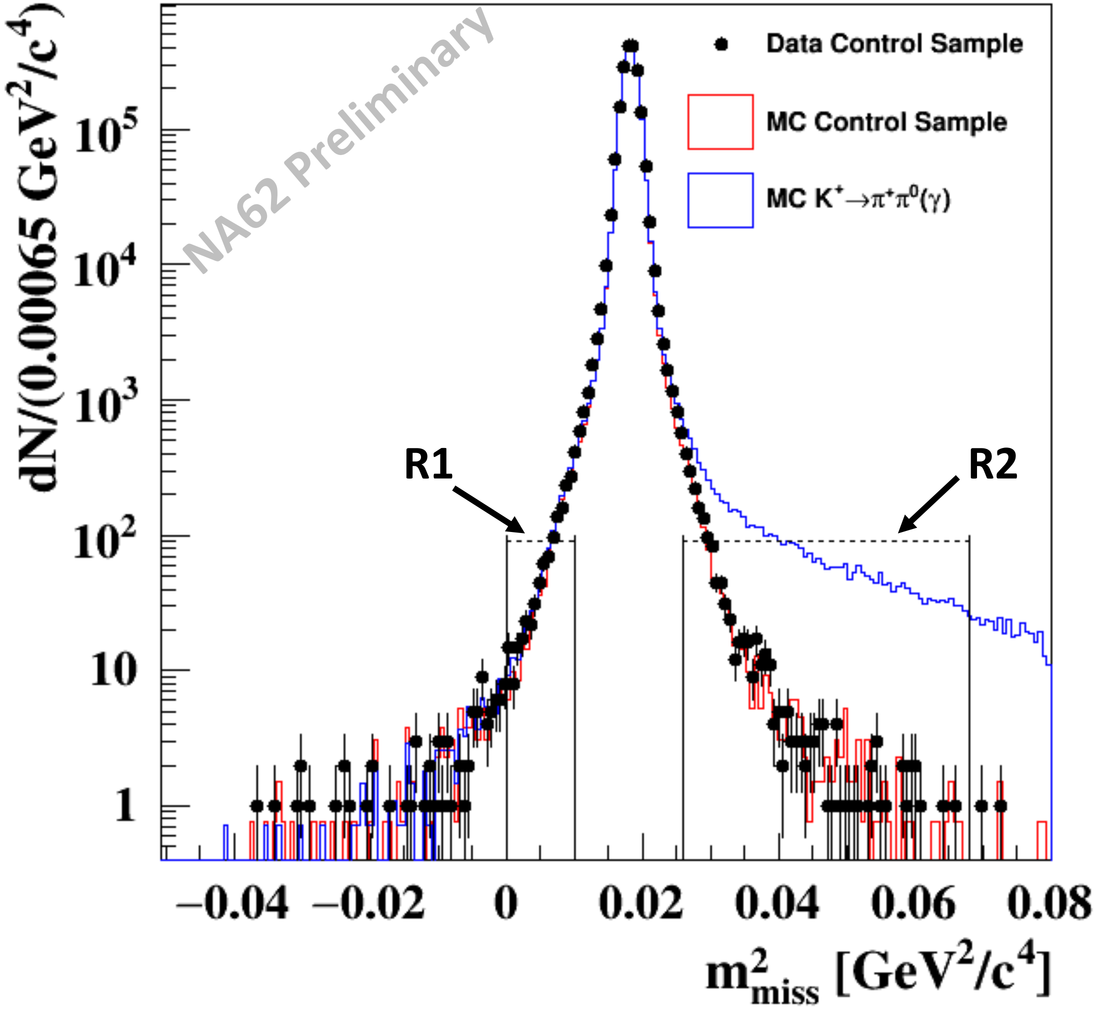
Systematics Breakdown

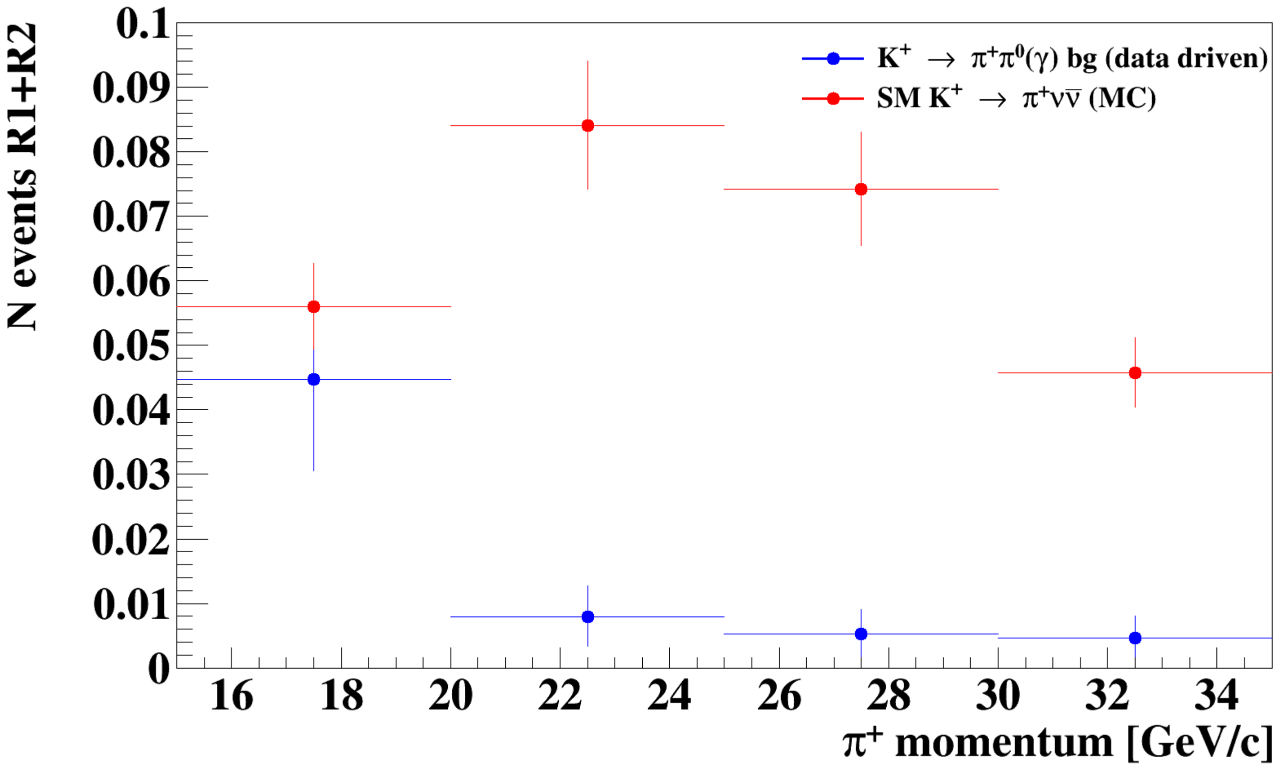
Source	δSES (10^{-10})
Random veto	±0.17
Definition of $\pi^+\pi^0$ region	±0.10
$A_{\pi\nu\nu}$	±0.09
N_K	±0.05
Trigger efficiency	±0.04
Extra activity	±0.02
Pileup simulation	±0.02
Momentum spectrum	±0.01
Total	±0.24

- **Signal Acceptance:** 4% (3% R2, 1% R1).
- **Normalisation:** $K^+ \to \pi^+\pi^0$ from control trigger. Acceptance: 10%, $N_K = (1.21 \pm 0.02)\times10^{11}$.

$$SES = (3.15 \pm 0.01(stat) \pm 0.24(syst))\times10^{-10}$$

Background Expectation (1) : $K^+ \rightarrow \pi^+\pi^0(\gamma)$

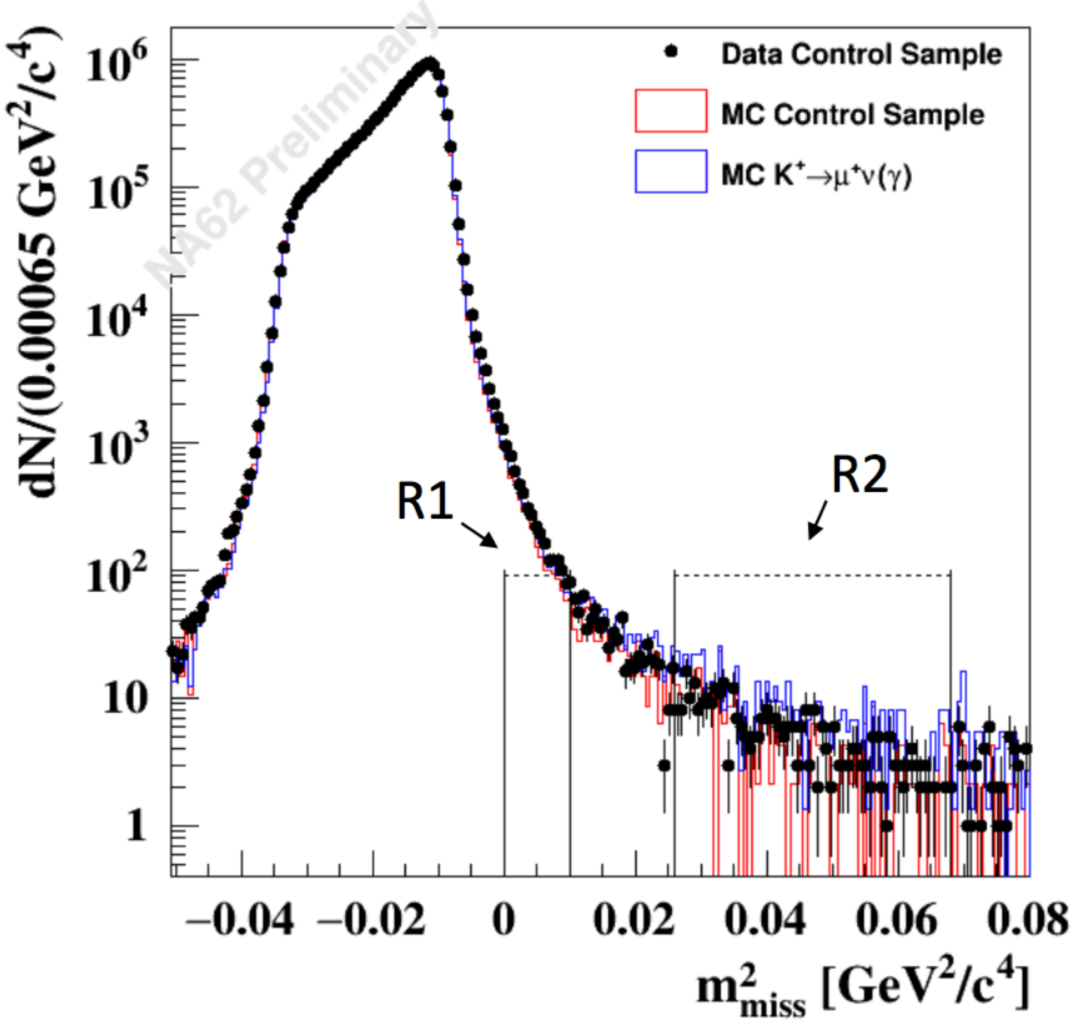


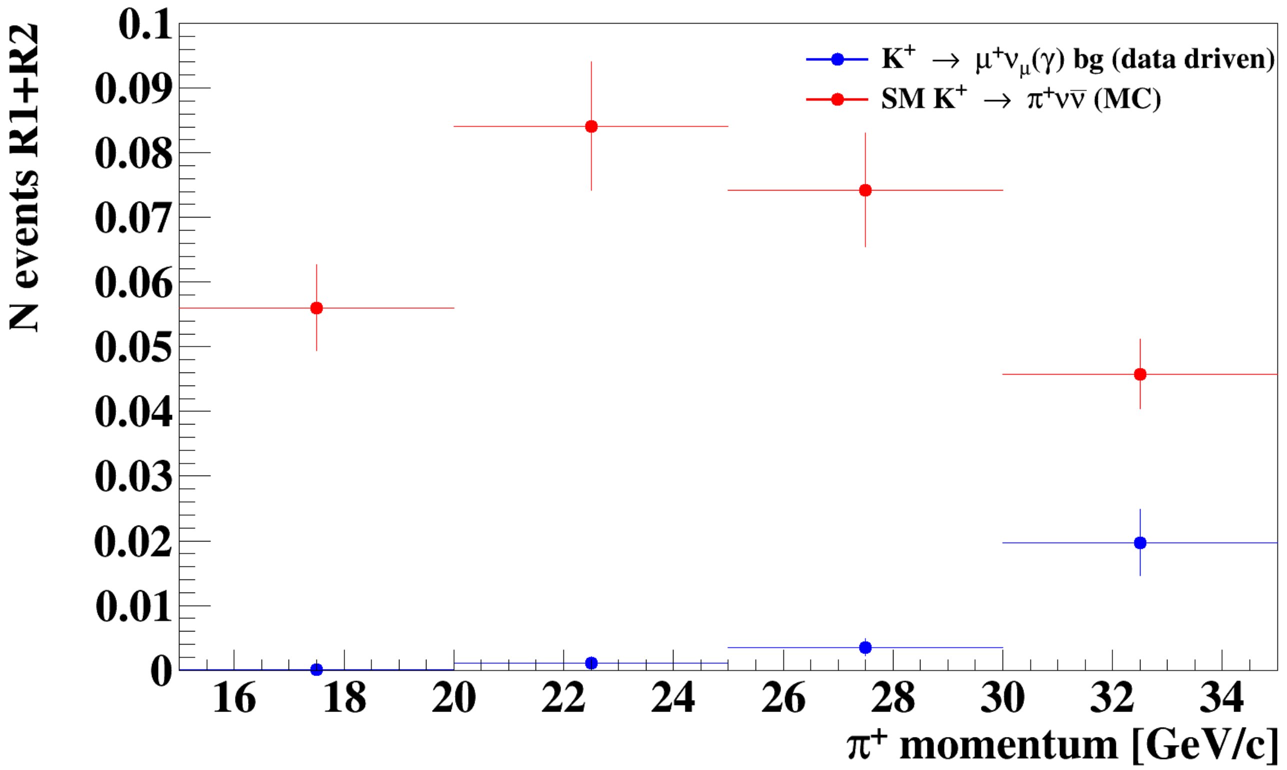


- Expected # of background events in signal regions, from data driven studies of the kinematic tails.
- From MC: $\pi^0\gamma$ rejection is 30x better than π^0 rejection.

	$K^+ \rightarrow \pi^+\pi^0$	$K^+ \rightarrow \pi^+\pi^0\gamma$
R1	$0.022 \pm 0.004(stat) \pm 0.002(syst)$	0
R2	$0.037 \pm 0.006(stat) \pm 0.003(syst)$	$0.005 \pm 0.005(syst)$

Background Expectation (2) : $K^+ \rightarrow \mu^+\nu_\mu(\gamma)$

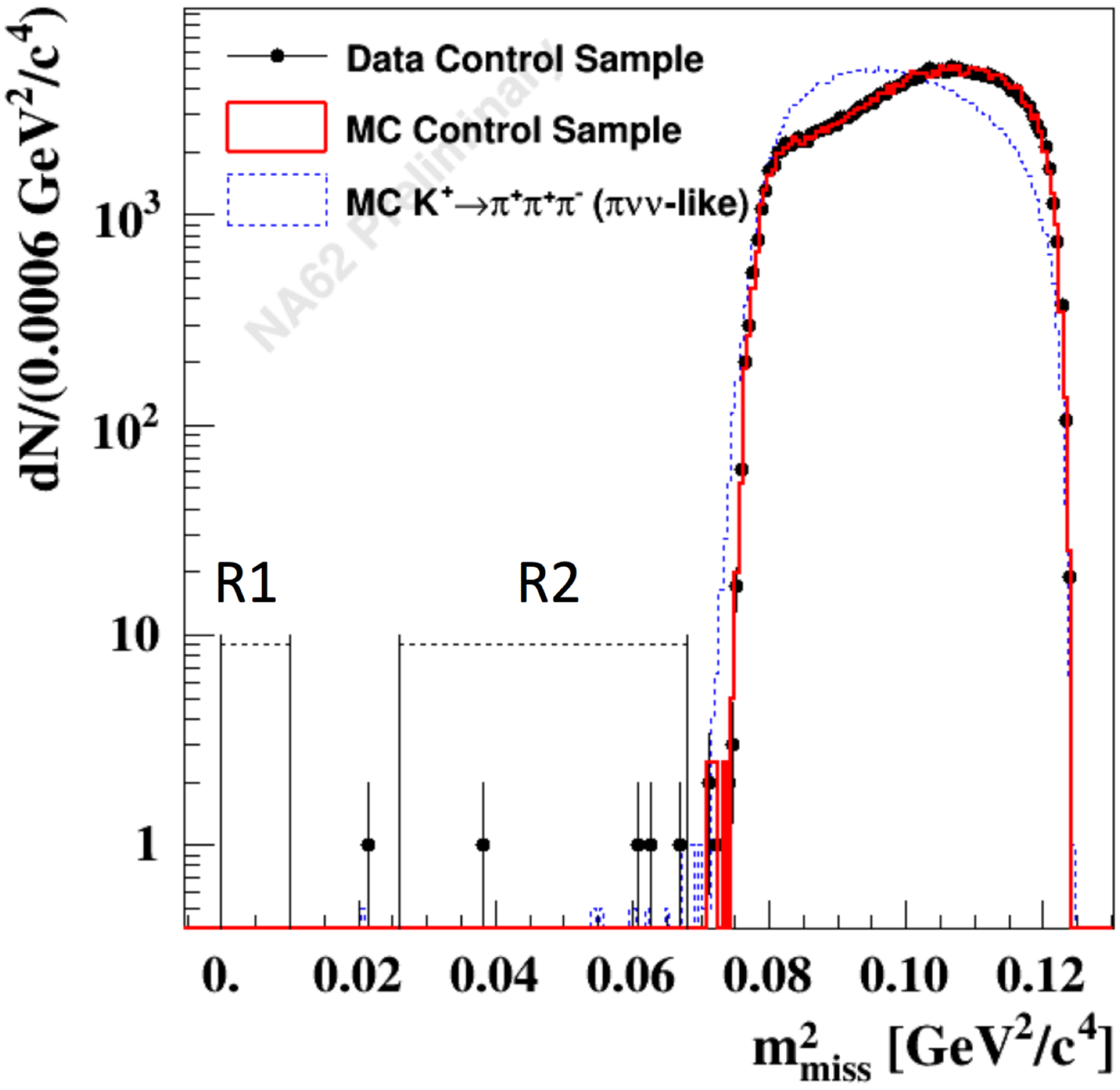




- Expected # of background events in signal regions, from data driven studies of the kinematic tails.

	$K^+ \rightarrow \mu^+\nu_\mu(\gamma)$
R1	$0.019 \pm 0.003(stat) \pm 0.003(syst)$
R2	$0.0012 \pm 0.0002(stat) \pm 0.0006(syst)$

Background Expectation (3) : $K^+ \rightarrow \pi^+\pi^+\pi^-$

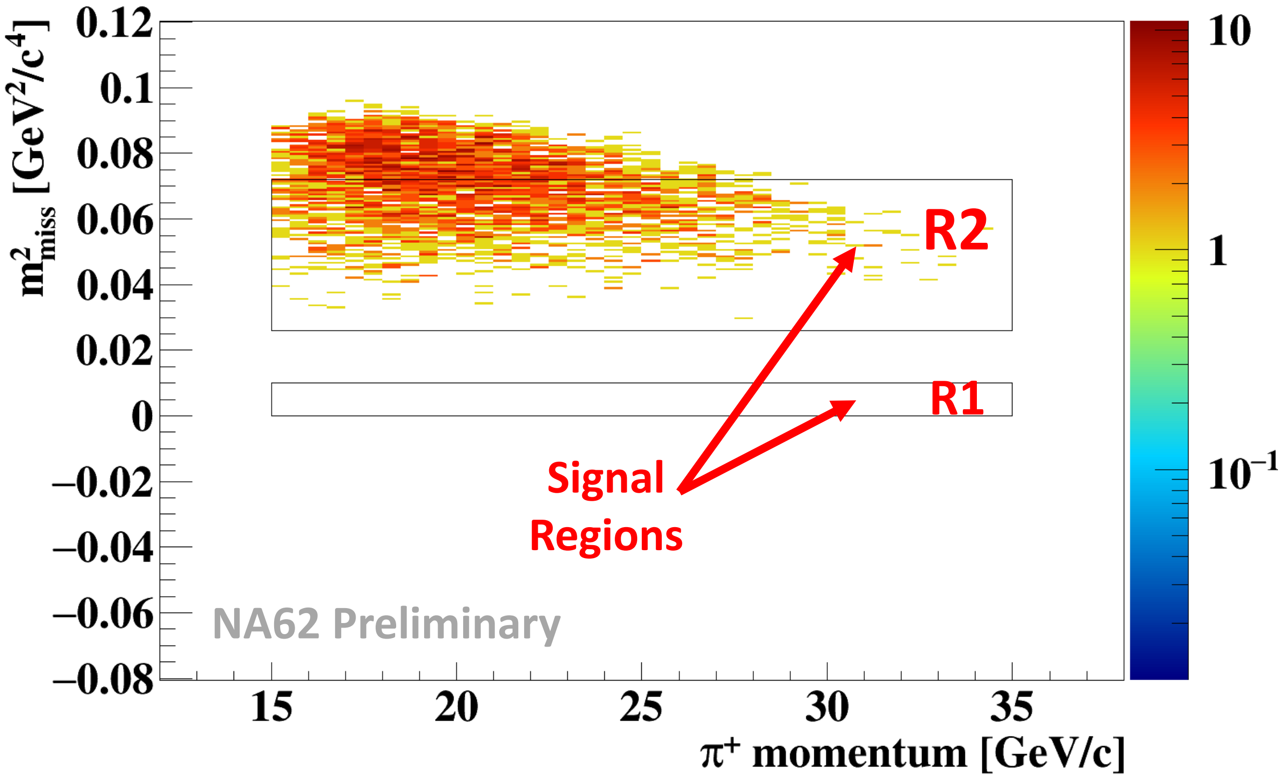


- Kinematic tail fraction determined from a control sample of $K^+ \rightarrow \pi^+\pi^+\pi^-$ events selected by tagging a $\pi^+\pi^-$ pair.
- Corrected for biases induced by the control sample selection using MC studies.
- Expectation (R1+R2) :

$$N_{\pi\pi\pi}^{exp} = 0.002 \pm 0.001(stat) \pm 0.002(syst)$$

Background Expectation (4) : $K^+ \rightarrow \pi^+\pi^-e^+\nu_e$

MC simulation $K^+ \rightarrow \pi^+\pi^-e^+\nu_e$ Validation sample 1



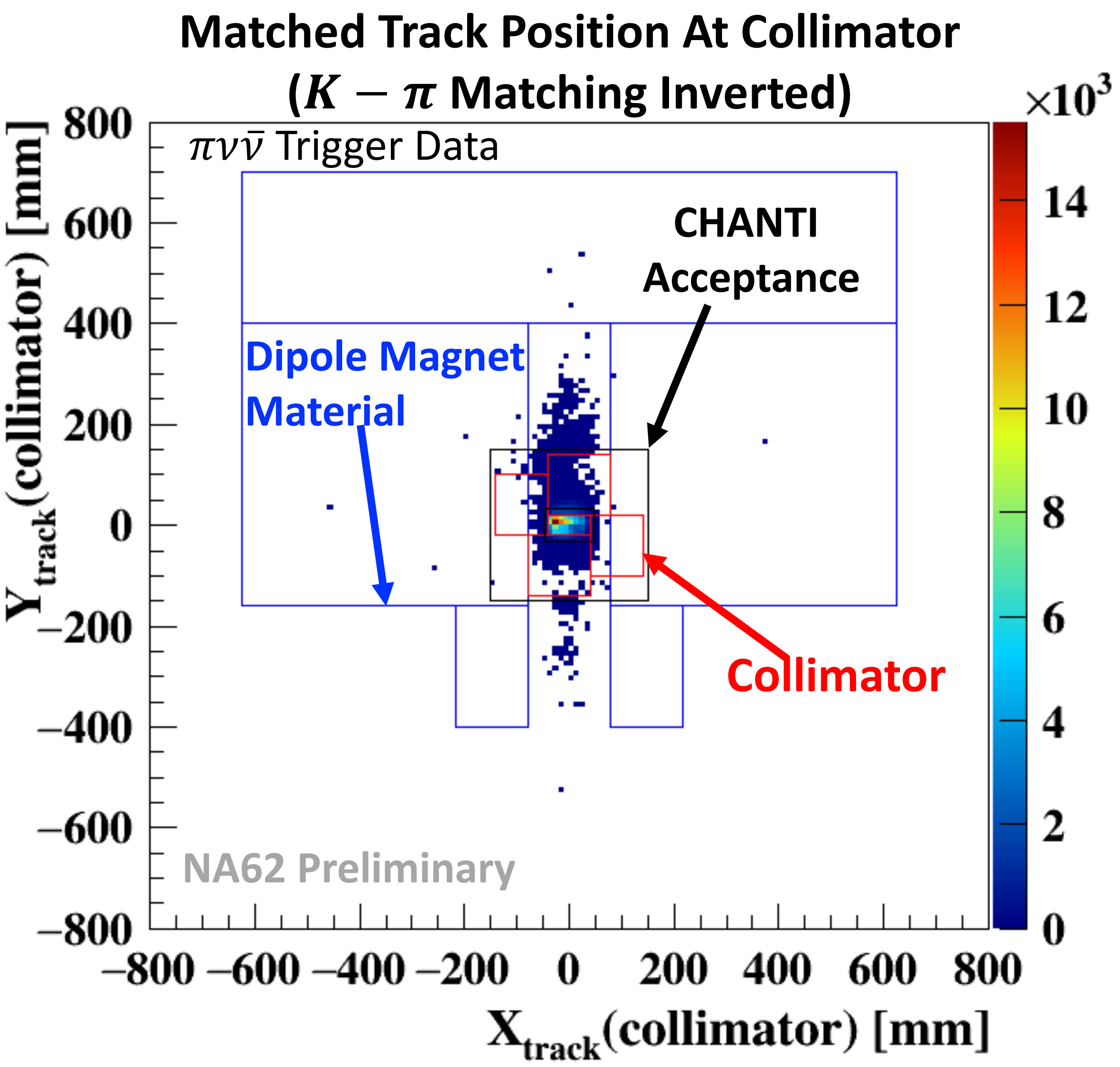
- Validated using 5 different control samples selected with five different selections.

Validation Sample	N Expected	N Observed
Bifurcation (+)	15.5 + 0.4	8
Bifurcation (-)	4.0 ± 0.4	2
BIF+RICH(-)	3.2 ± 0.2	3
Full (-)	0.7 ± 0.1	1
Full+RICH(-)	1.2 ± 0.1	5

- Background estimated from study of $\sim 4 \times 10^8$ MC $K^+ \rightarrow \pi^+\pi^-e^+\nu_e$ events, (R1+R2):

$$N^{exp}_{\pi\pi e\nu} = 0.018^{+0.024}_{-0.017}(stat) \pm 0.009(syst)$$

Background Expectation (5) : Upstream Background



- Upstream background sources:
  - Decays along beamline.
  - Interactions with beam spectrometer material (GTK3) producing π^+.
  - Track mismatching.
- Effective $K^+ - \pi^+$ matching procedure minimises effect.
- Data-driven estimation of remaining background (R1+R2).

$$N^{exp}_{UpstreamBg} = 0.050^{+0.090}_{-0.030}$$

Expectation Summary

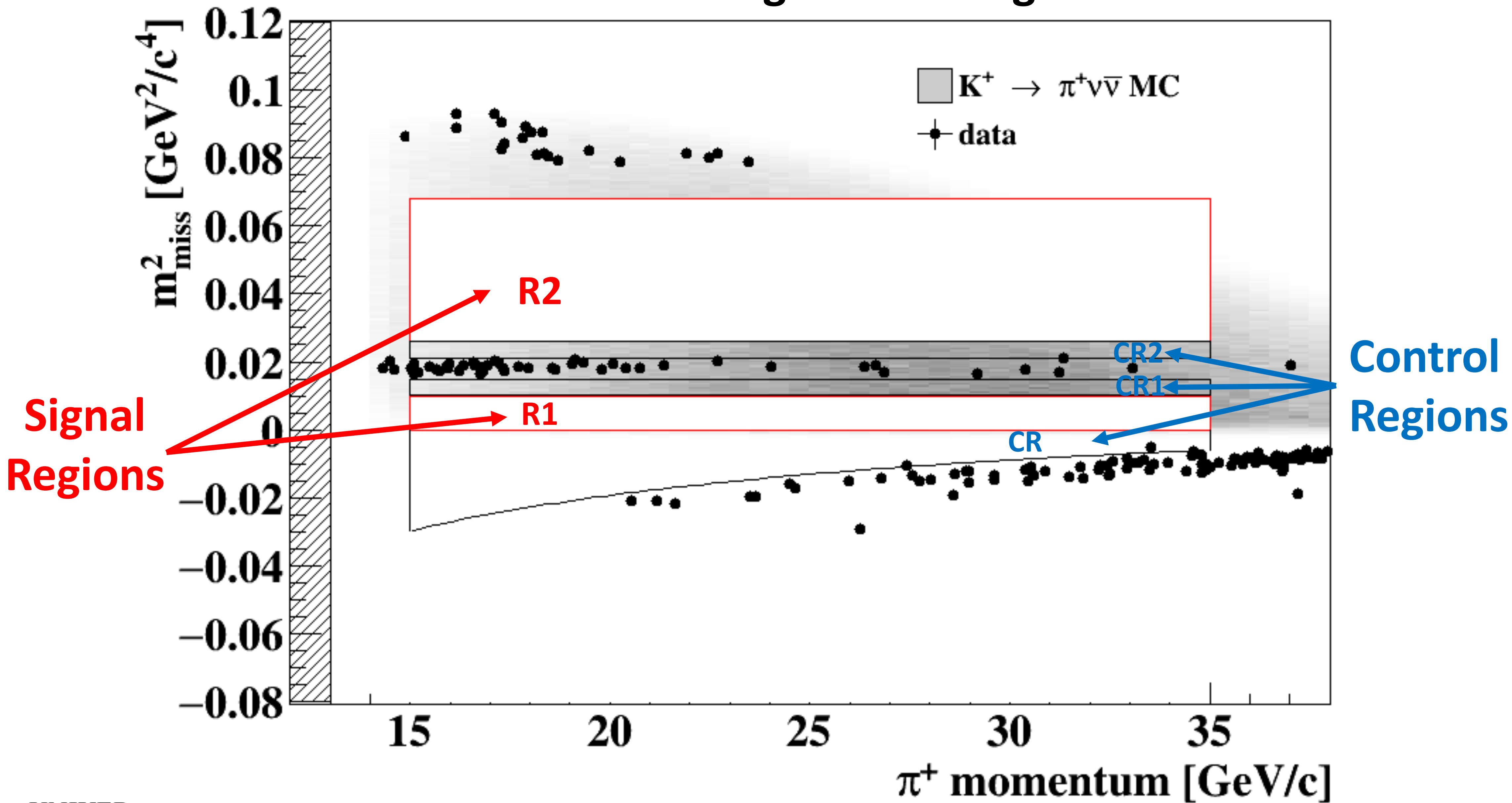
	Expected # of Events in Signal Regions (R1+R2)
Signal : $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ (SM)	$0.267 \pm 0.001(stat) \pm 0.020(syst) \pm 0.032(ext)$
Total Background	$0.15 \pm 0.09(stat) \pm 0.01(syst)$

Background breakdown:

Background Process	Expected # of Events in Signal Regions (R1+R2)
$K^+ \rightarrow \pi^+\pi^0(\gamma)$ IB	$0.064 \pm 0.007(stat) \pm 0.006(syst)$
$K^+ \rightarrow \mu^+\nu_\mu\ (\gamma)$ IB	$0.020 \pm 0.003(stat) \pm 0.003(syst)$
$K^+ \rightarrow \pi^+\pi^+\pi^-$	$0.002 \pm 0.001(stat) \pm 0.002(syst)$
$K^+ \rightarrow \pi^+\pi^- e^+\nu_e$	$0.018^{+0.024}_{-0.017}(stat) \pm 0.009(syst)$
Upstream	$0.050^{+0.090}_{-0.030}(stat)$

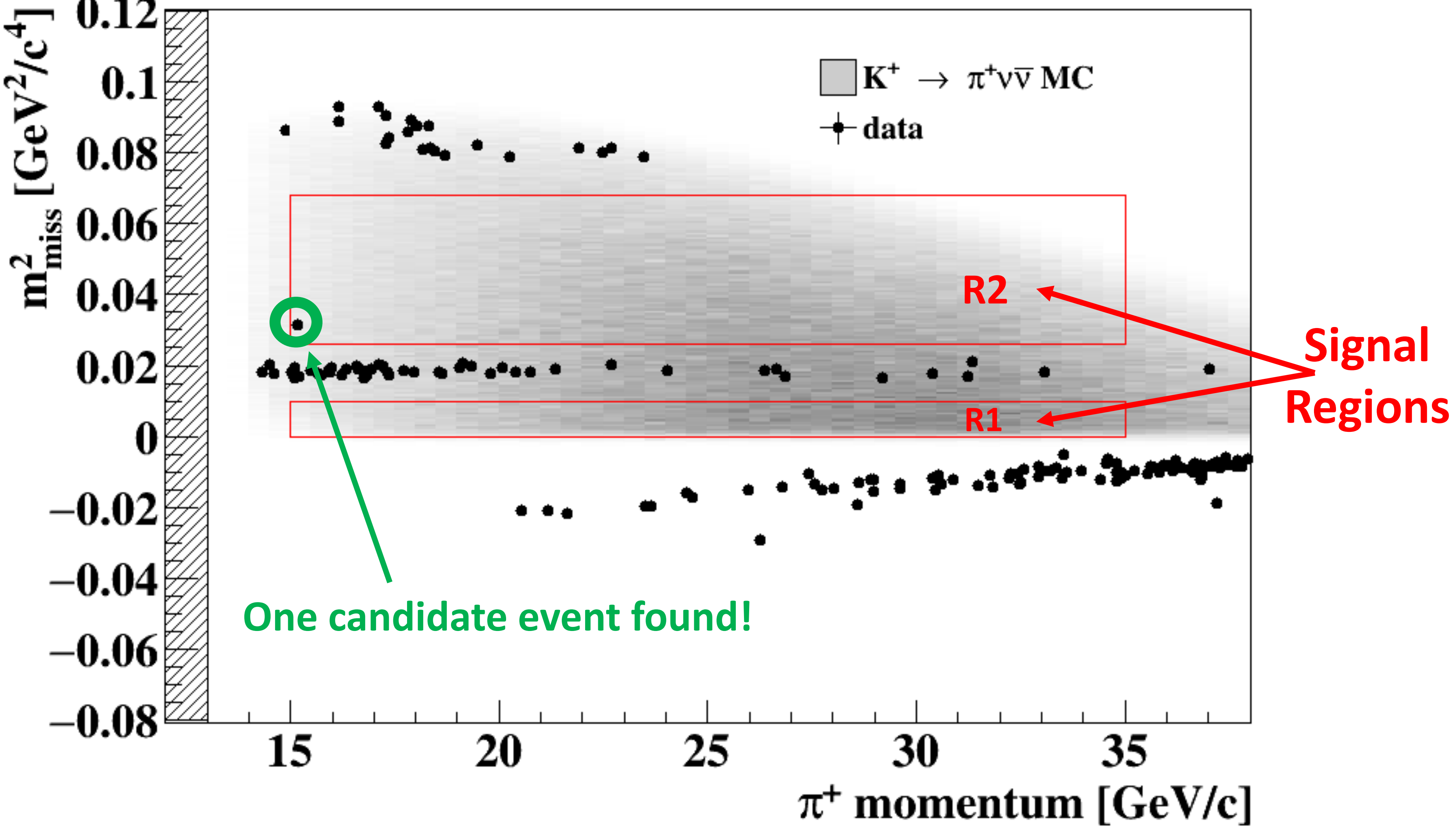
Result

Unblinding Control Regions



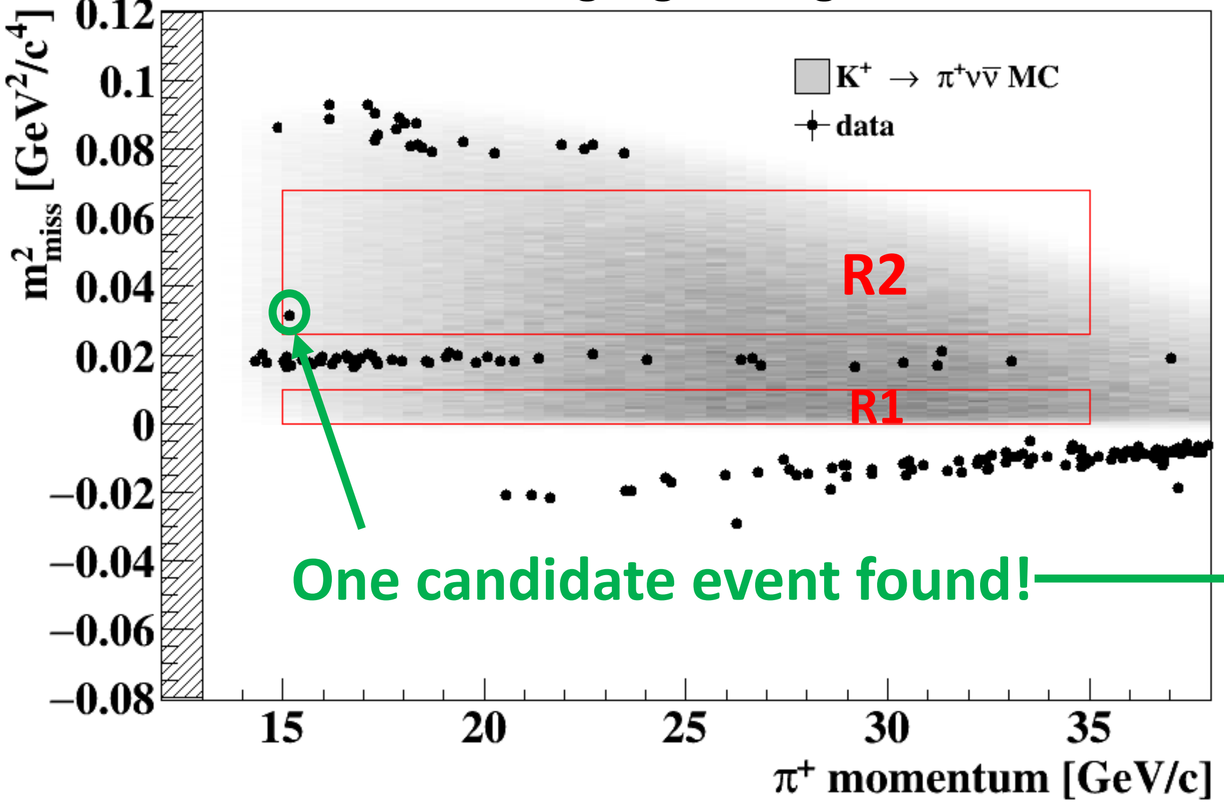
Result

Unblinding Signal Regions

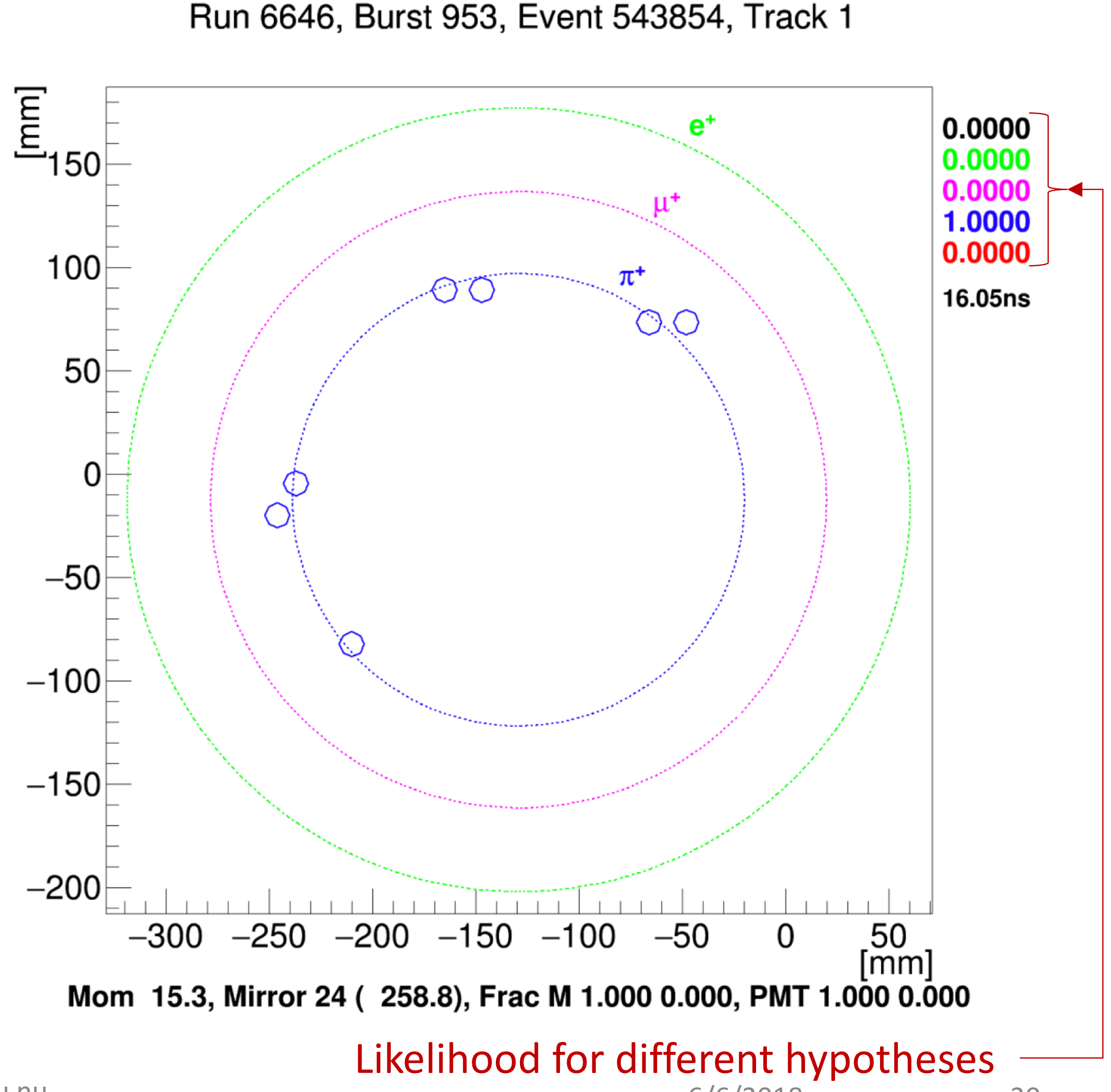


Result

Unblinding Signal Regions



RICH Display For Candidate Event



Preliminary Results [Paper in preparation]

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

	Expected # of Events in Signal Regions (R1+R2)
Signal : $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ (SM)	$0.267 \pm 0.001(\text{stat}) \pm 0.020(\text{syst}) \pm 0.032(\text{ext})$
Total Background	$0.15 \pm 0.09(\text{stat}) \pm 0.01(\text{syst})$

Observed : 1 event in R2.

Results using Rolke-Lopez method :

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

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

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

Compatible with SM : $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0)\times 10^{-11}$ [Buras et al. : JHEP 1511 (2015) 033]

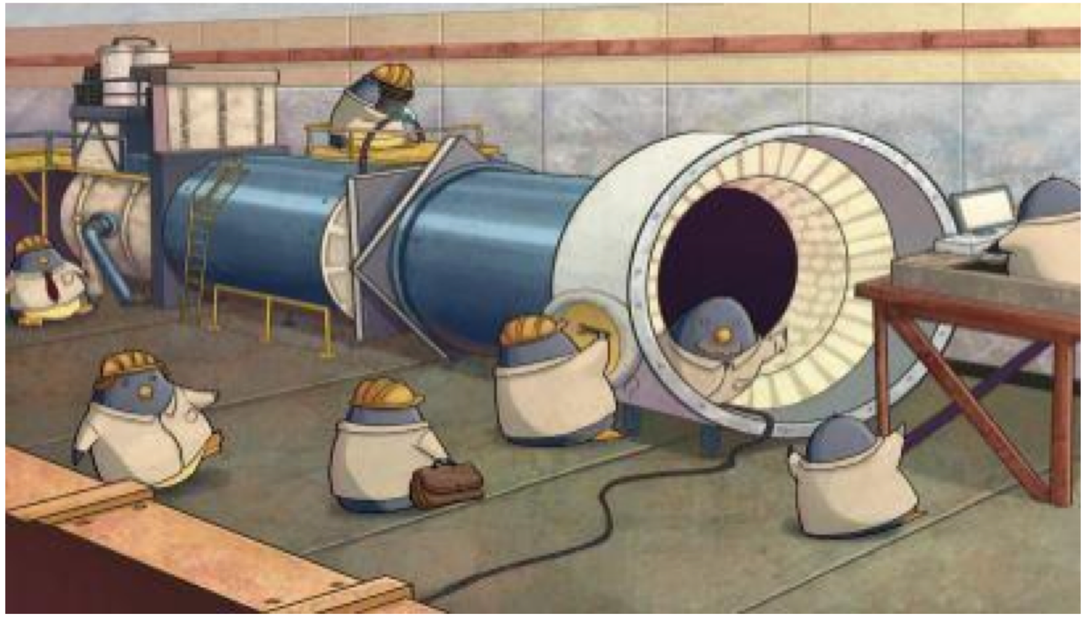
And BNL experimental result : $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) = \left(17.3^{+11.5}_{-10.5}\right)\times 10^{-11}$ [Artamonov et al. PhysRevLett.101.191802 (2008)]

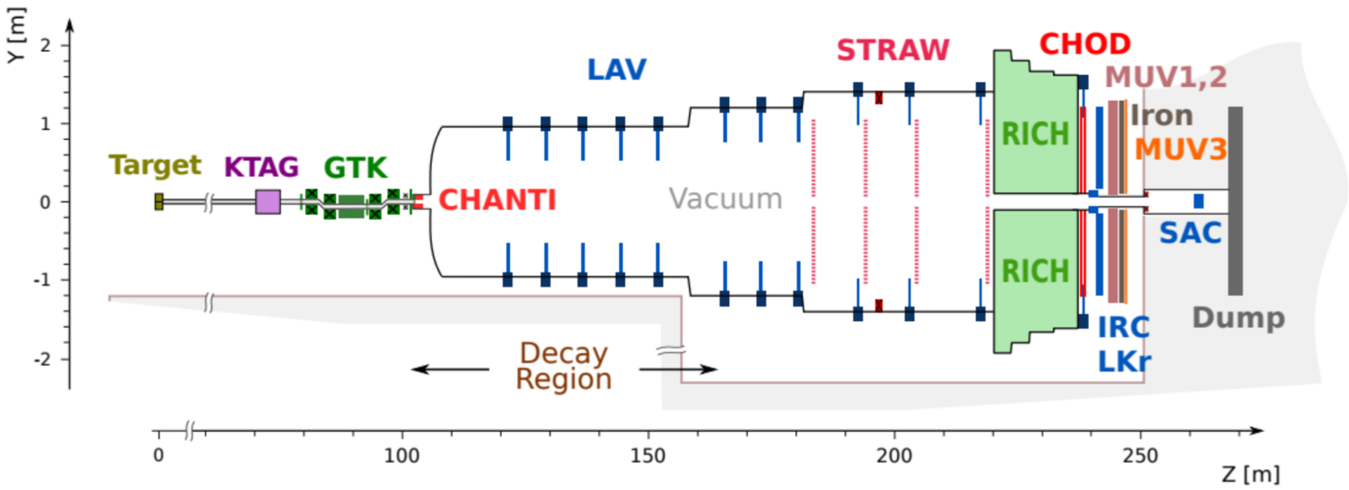
→ K^+ Decay at rest

Conclusions and Outlook for NA62

- Preliminary Results [Paper in preparation]
  - **1 candidate event in 2016 data** (~ 4 weeks of data taking).
  - Preliminary result : $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu}) < 11 \times 10^{-10}$ @ 90% CL compatible with SM and previous experiment.
- **The new NA62 K^+ decay-in-flight technique works.**
- Good quality data taken throughout 2017
  - $\sim$**20 times more data** than presented here.
  - Expected reduction of upstream background, improved reconstruction efficiency and studies to improve signal acceptance.
- 218 days of running in progress in 2018.
- Expect ~ 20 SM $K^+ \rightarrow \pi^+ \nu\bar{\nu}$ events before LS2.

Supplemental





$K^+ \to \pi^+ \nu\bar{\nu}$ Branching Ratio

Buras et al. : JHEP 1511 (2015) 033

NA62

Messica&Smith : Phys.Rev.D76:034017,2007

Isospin breaking effects : $r_K = \frac{f_+^{K^+\pi^+}(0)}{f_+^{K^0\pi^+}(0)}$

K^+ Form Factors : $f_+^{K^i\pi^j}(q^2) = f_+^{K^i\pi^j}(0)\left(1 + \lambda_+^{ij\prime}\frac{q^2}{m_{\pi^\pm}^2} + \lambda_+^{ij\prime\prime}\frac{q^4}{2m_{\pi^\pm}^4}\right)$

where $i, j = +, L$ (precisely measured from K_{l3} decays).

K^+ lifetime

Phase space integral : $\mathfrak{I}_\nu^+ = \int_0^{(1-r_\pi^2)} \lambda_\pi \left|\frac{f_+^{K^+\pi^+}(z)}{f_+^{K^+\pi^+}(0)}\right| dz$,

$$\kappa_+^\nu = \frac{G_F^2 m_K^5 \alpha(M_Z)^2}{256\pi^5 \sin^4(\theta_W)} |V_{us}|^8 \tau_+ \left(r_K |V_{us} \times f_+^{K^0\pi^+}(0)|_{exp}\right)^2 \mathfrak{I}_\nu^{+2}$$

where $z = \frac{q^2}{M_K^2}$ and $\lambda_\pi = \lambda^2(1, z, r_\pi^2)$ and $r_\pi = \frac{m_{\pi^\pm}}{m_{K^+}}$.

$\lambda = |V_{us}|$,

$x_t = \frac{m_t^2}{M_W^2}$,

$\lambda_i = V_{is}^* V_{id}$

($i = u, c, t$: dominated by t with small c contribution)

Sum over 3 ν generations

$$\kappa_+ = (5.173 \pm 0.025) \times 10^{-11} \left[\frac{\lambda}{0.225}\right]^8$$

(Small) long-distance QED corrections : $\Delta_{EM} = -0.003$

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+(1 + \Delta_{EM})\left[\left(\frac{\mathrm{Im}(\lambda_t)}{\lambda^5} X(x_t)\right)^2 + \left(\frac{\mathrm{Re}(\lambda_c)}{\lambda} P_c(X) + \frac{\mathrm{Re}(\lambda_c)}{\lambda^5} X(x_t)\right)^2\right]$$

t loop function :

$$X(x_t) = X_0(x_t) + \frac{\alpha_s}{4\pi} X_1(x_t) + \frac{\alpha}{4\pi} X_{EW}(x_t) = 1.481 \pm 0.005(th) \pm 0.008(exp)$$

Leading order result

NLO QCD correction

EW correction

c loop function : $P_c(X) = P_c^{SD}(X) + \delta P_{c,u}$

Short distance component : $P_c^{SD}(X) = \frac{1}{\lambda^4}\left[\frac{2}{3} X_{NNL}^e + \frac{1}{2} X_{NNL}^\tau\right]$

Where X_{NNL}^l are from QCD NLO & NNLO calculations.

$l = e$ vs τ : important for c since $m_c < m_\tau$ but not for t ($m_t \gg m_\tau$)

Long distance contributions: Isidori et. al : Nucl.Phys. B718 (2005) 319-338

$$\delta P_{c,u} = \frac{1}{3} \sum_{l=e,\mu,\tau} \langle P_Z(q^2) + P_{WW}^l(q^2) \rangle$$

<an average over the phase space> . It is then shown that :

$$\delta P_{c,u} \approx \frac{\pi^2 F^2}{\lambda^2 M_W^2}\left[\frac{4|G_8|}{\sqrt{2} G_F} - \frac{4}{3}\right] = 0.04 \pm 0.02$$

$K^+ \to \pi^+ \nu\bar{\nu}$ Branching Ratio

Buras et al. : JHEP 1511 (2015) 033

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+(1+\Delta_{EM})\left[\left(\frac{\mathrm{Im}(\lambda_t)}{\lambda^5}X(x_t)\right)^2 + \left(\frac{\mathrm{Re}(\lambda_c)}{\lambda}P_c(X) + \frac{\mathrm{Re}(\lambda_c)}{\lambda^5}X(x_t)\right)^2\right]$$

Buras method A : using experimentally driven inputs from tree-level measurements of $|V_{us}|$, $|V_{cb}|$, $|V_{ub}|$ and γ :

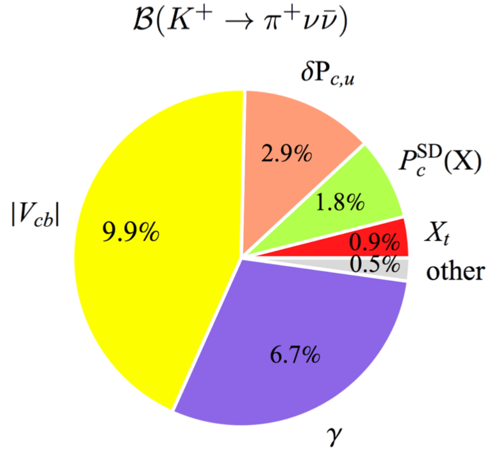
$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (8.38 \pm 0.30)\times 10^{-11}\left[\frac{|V_{cb}|}{40.7\times 10^{-3}}\right]^{2.8}\left[\frac{\gamma}{73.2°}\right]^{0.74}$$

$|V_{ub}|_{avg} = (3.88 \pm 0.29)\times 10^{-3}$
$|V_{cb}|_{avg} = (40.7 \pm 1.4)\times 10^{-3}$
$\lambda = |V_{us}| = 0.2252 \pm 0.0009$
$\gamma = (73.2^{+6.3}_{-7.0})°$

$$Re(\lambda_t) \approx |V_{ub}||V_{cb}|\cos(\gamma(1-2\lambda^2)) + (|V_{ub}|^2 - |V_{cb}|^2)\lambda\left(1-\frac{\lambda^2}{2}\right)$$

$$Im(\lambda_t) \approx |V_{ub}||V_{cb}|\sin(\gamma)$$

$$Re(\lambda_c) \approx -\lambda\left(1-\frac{\lambda^2}{2}\right)$$



Uncertainty budget

$$\therefore\ Br(K^+ \to \pi^+ \nu\bar{\nu}) = (8.38 \pm 0.30)\times 10^{-11}\left[\frac{|V_{cb}|}{40.7\times 10^{-3}}\right]^{2.8}\left[\frac{\gamma}{73.2°}\right]^{0.74} = (8.4 \pm 1.0)\times 10^{-11}$$

Buras method B : experimental measurements augmented with averaging – assume SM and use ε_K, ΔM_s, ΔM_D and $S_{\psi K_s}$

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = (9.11 \pm 0.72)\times 10^{-11}$$

Single Event Sensitivity Definition

[G. Ruggiero, CERN Seminar (March 2018)]

- Signal : $K^+ \rightarrow \pi^+\nu\bar{\nu}$ from $\pi\nu\bar{\nu}$ trigger.
- Normalisation : $K^+ \rightarrow \pi^+\pi^0$ from control (Min. bias) trigger.
  - Use same $K^+ \rightarrow \pi^+\nu\bar{\nu}$ selection but multiplicity rejection is not applied and m^2_{miss} cuts are modified.

$$N_K = \frac{N_{\pi\pi} D}{A_{\pi\pi} Br_{\pi\pi}}$$

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

N_K : Number of K^+ decays (in fiducial volume).
$N_{\pi\pi} \sim 6\times10^6$: number of $K^+ \rightarrow \pi^+\pi^0$ events selected.
$A_{\mu\mu} \sim 0.10$: acceptance for $K^+ \rightarrow \pi^+\pi^0$ normalisation channel.
$D = 400$: control trigger downscaling factor.

$A_{\pi\nu\bar{\nu}} \sim 0.04$: Signal acceptance.
$\varepsilon_{RV} \sim 0.76$: Random veto efficiency.
$\varepsilon_{trig} \sim 0.87$: $\pi\nu\bar{\nu}$ Trigger efficiency.
All in 4 momentum bins, j,(5 GeV width, 15 – 35 GeV)

$$N_K = (1.21 \pm 0.02)\times10^{11}$$

$$SES = (3.15 \pm 0.01(stat) \pm 0.24(syst))\times10^{-10}$$

$\pi\nu\bar{\nu}$ Background Analysis (e.g. $K^+ \to \pi^+\pi^0$)

$\pi\nu\bar{\nu}$ Analysis

- For the analysis the number of $K^+ \to \pi^+\pi^0$ ($K_{2\pi}$) background events in a given region $\mathcal{R}$ is estimated using :

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

- $f_j^{kin}(\mathcal{R})$ is the kinematic tail fraction of $K_{2\pi}$ events entering into region $\mathcal{R}$ and momentum bin j.
- $f_j^{kin}(\mathcal{R})$ is measured from data by selecting a $K_{2\pi}$ control sample by tagging the π^0 from two photons in the LKr and from MC using a $K_{2\pi}$ sample with 300 MHz pileup tracks in GTK.

Results :

- $N_{\pi\pi}^{exp}(CR1) = 0.52 \pm 0.08(stat) \pm 0.03(syst)$
- $N_{\pi\pi}^{exp}(R1) = 0.022 \pm 0.004(stat) \pm 0.002(syst)$

Background Expectation (4) : $K^+ \rightarrow \pi^+\pi^-e^+\nu_e$

- Validated using 5 different control samples selected with five different selections.

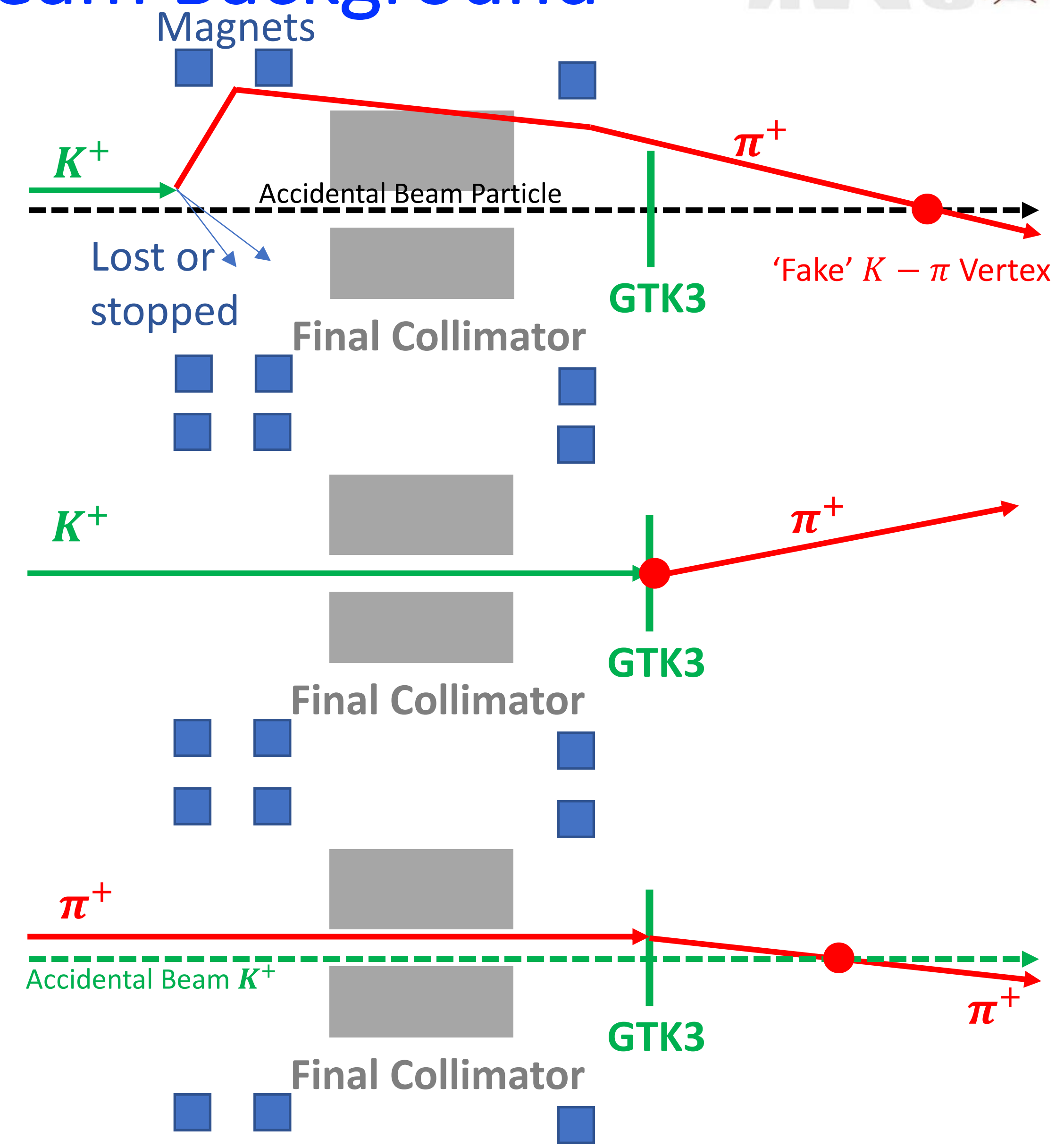
Validation Sample	Sample Selection	N Expected	N Observed
Bifurcation (+)	Bifurcated selection (invert photon and multiplicity (extra activity) veto cuts) applied to a positive track. (No RICH selection applied).	$15.5 + 0.4$	8
Bifurcation (-)	Bifurcated selection (invert photon and multiplicity (extra activity) veto cuts) applied to a negative track. (No RICH selection applied).	4.0 ± 0.4	2
BIF+RICH(-)	As above but with RICH applied for –ve track.	3.2 ± 0.2	3
Full (-)	Full $\pi^- + nothing$ selection (RICH not applied).	0.7 ± 0.1	1
Full+RICH(-)	Full $\pi^- + nothing$ selection (RICH selection applied for –ve track).	1.2 ± 0.1	5

- Background estimated from study of $\sim 4\times10^8$ MC $K^+ \rightarrow \pi^+\pi^-e^+\nu_e$ events, (R1+R2) :

$$N^{exp}_{\pi\pi e\nu} = 0.018^{+0.024}_{-0.017}(stat) \pm 0.009(syst)$$

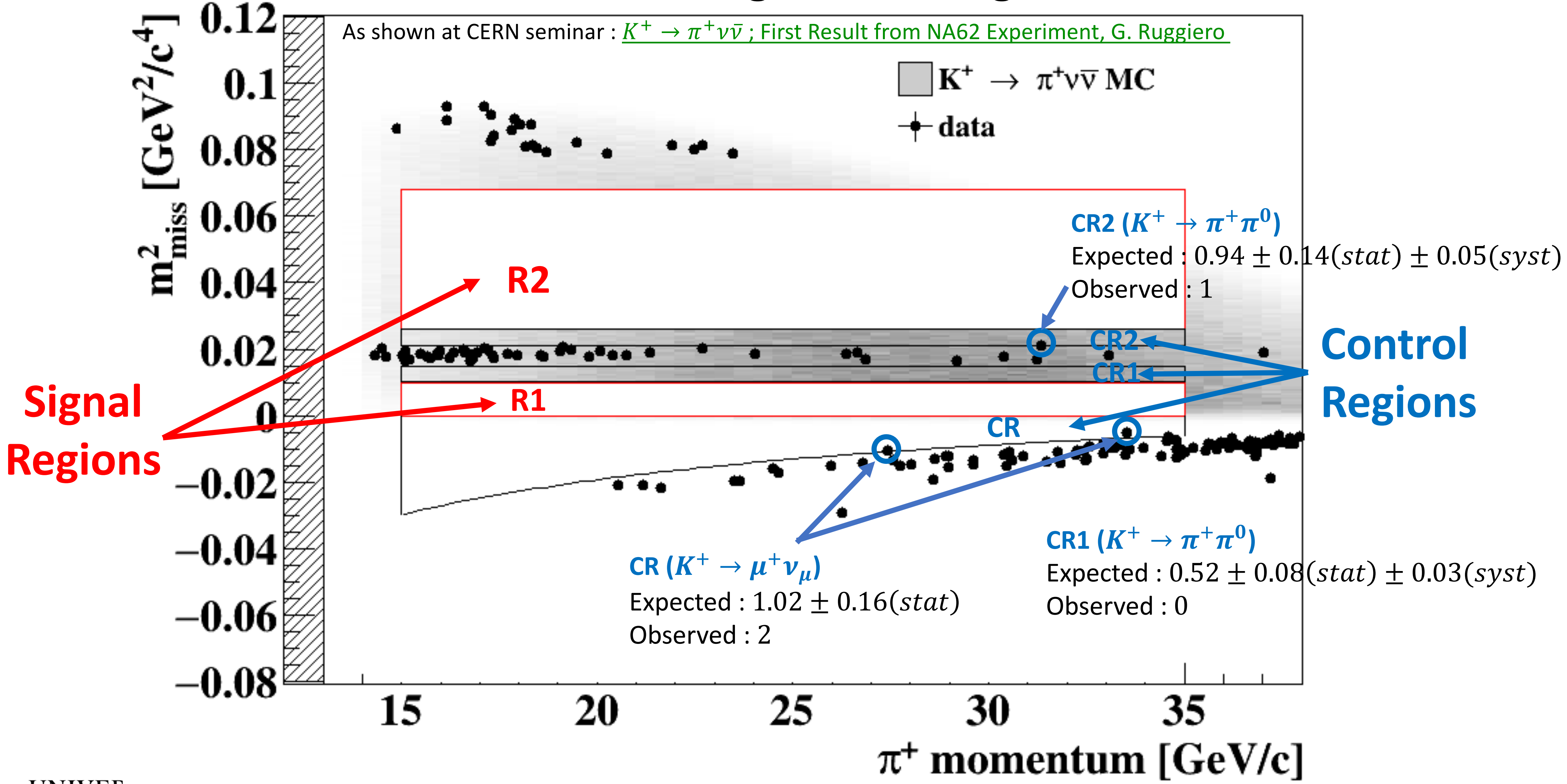
Background Expectation (5) : Upstream Background

- Upstream background sources:
  - **K^+ Decays along beamline.**
    - Extra particles (e.g π^0) stopped but π^+ could reach decay region.
    - π^+ then matched to accidental beam particle.
  - **Beam K^+ Interactions with GTK3**
    - K^+ interactions producing π^+.
    - Vertex misreconstructed.
  - **Beam π^+ Interactions with GTK3**
    - π^+ interactions/scattering.
    - Match to accidental beam K^+ .



Result

Unblinding Control Regions



NA62 Broader Physics Program

[NA62 SPSC Report 2018]

- Primary goal: measurement of $Br(K^+ \to \pi^+ \nu\bar{\nu}) = (8.4 \pm 1.0)\times10^{-11}$
- However with a very large sample of K^+ decays and a versatile detector and trigger system a broader physics program is being explored:

1. Rare kaon decays
   - e.g. $K^+ \to \pi^+\mu^+\mu^-$
2. Forbidden kaon decays (LFV, LNV)
   - e.g. $K^+ \to \pi^- l_1^+ l_2^+, K^+ \to \pi^+ l_1^+ l_2^-$ (for $l_1 l_2 = ee, \mu\mu, e\mu$)
3. Exotics
   - e.g. Heavy Neutral Lepton (HNL) [Phys.Lett.B 778 (2018)]