$K^+ \to \pi\nu\bar{\nu}$ with NA62: 2016 results and prospects

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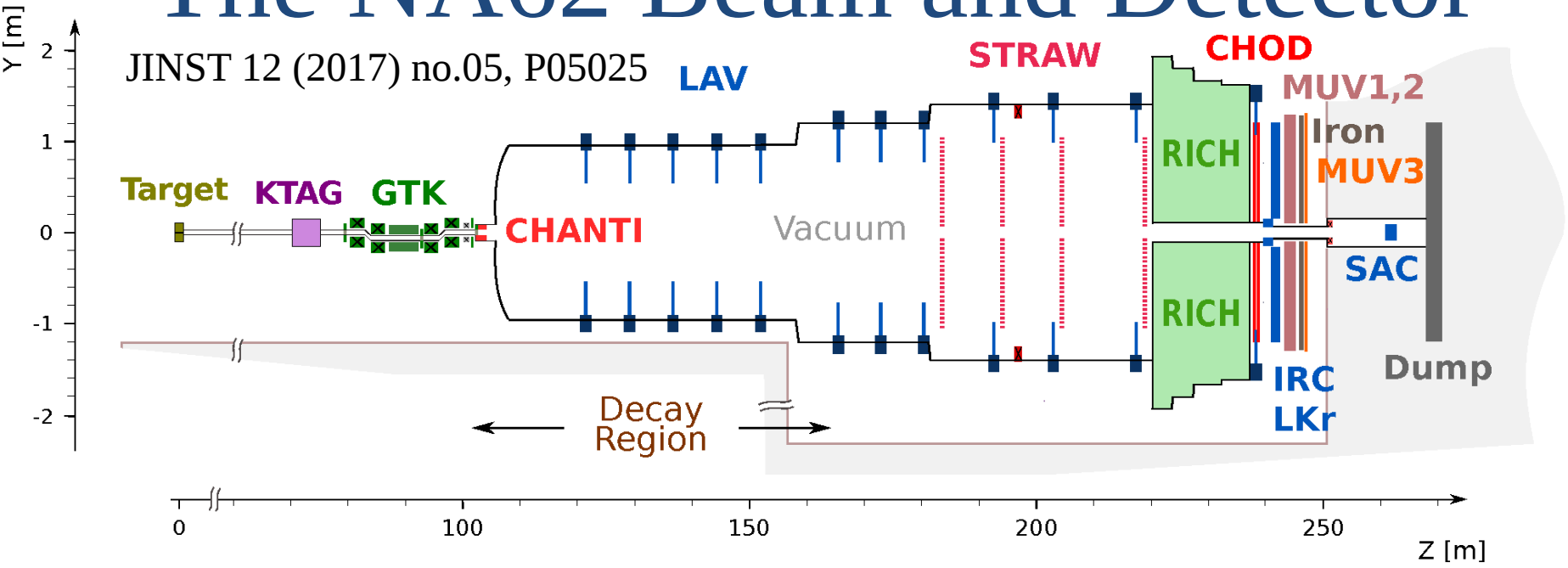
The NA62 Beam and Detector



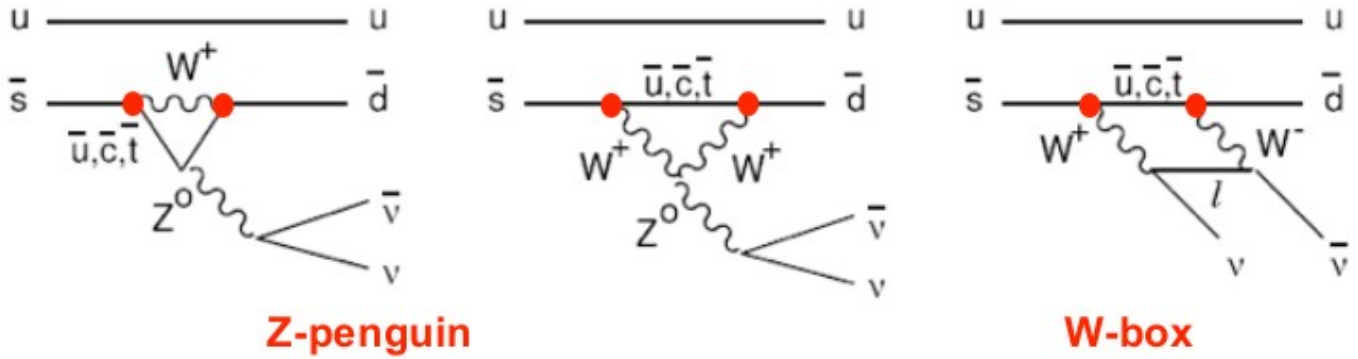
400 GeV/c protons from the SPS on a beryllium target produce secondary charged beam:
6% are 75 GeV/c K^+ (mixed with π and protons).
1% momentum bite, ~100 μrad divergence

~10 MHz of raw input data to the L0 trigger (FPGA) from detectors
~1 MHz of events passing the first trigger level
L1 and L2 trigger (software) guarantee a maximum of 10 kHz of acquisition rate.

$K^+ \to \pi^+ \nu\nu$ in the Standard Model

The $K^+ \to \pi^+ \nu\nu$ process is extremely clean from the theoretical point of view (Matrix Element obtained from the well known Ke3 process): optimal to test the SM

$s \to d\nu\nu$ Flavour-changing neutral current transition (forbidden at tree level) heavily suppressed by GIM.



Current theoretical prediction (A.J Buras at al. JHEP 1511 (2015) 033):

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

- Intrinsic theoretical uncertainty ~3%
- Main contribution to the error coming from uncertainty of SM inputs

Current experimental result (E787 and E949 collaboration at BNL):

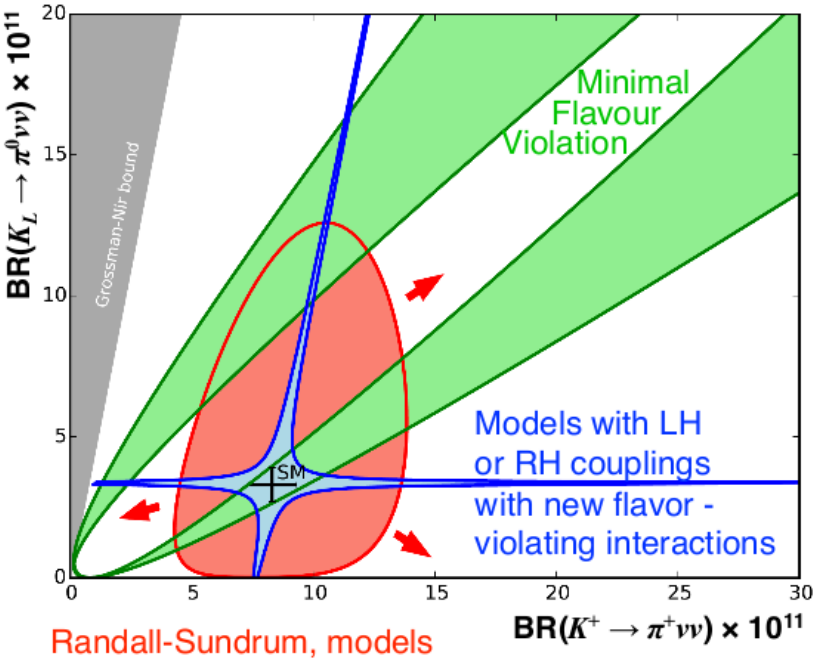
$BR(K^+ \to \pi^+ \nu\nu)_{EXP} = (17.3\,^{+11.5}_{-10.5}) \cdot 10^{-11}$

- Stopped kaon experiment
- 7 events observed

$K^+ \to \pi^+ \nu\nu$ and NP

Many models beyond the SM make predictions of the two $K \to \pi\nu\nu$ Branching Ratios

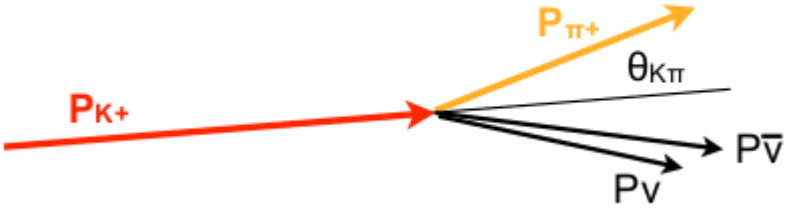
- Simplified Z, Z' models [Buras, Buttazzo,Knegjens, JHEP 1511 (2015) 166]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM non-MFV [Tanimoto, Yamamoto, PTEP 2016 (2016) no.12, 123B02; Blazek, Matak, IntlJModPhys.A 29 (2014), 1450162; Isidori et al. JHEP 0608 (2006) 064]
- LFU violation models [Isidori et. al., Eur. Phys. J. C (2017) 77]



NA62 Time scale and requirements

- 2014 Pilot Run
- 2015 Commissioning Run
- 2016 Commissioning + Physics Run: Results presented here
- 2017 + 2018 Physics Runs
- 2019 – 2020 LS2, no beam

Decay in flight technique



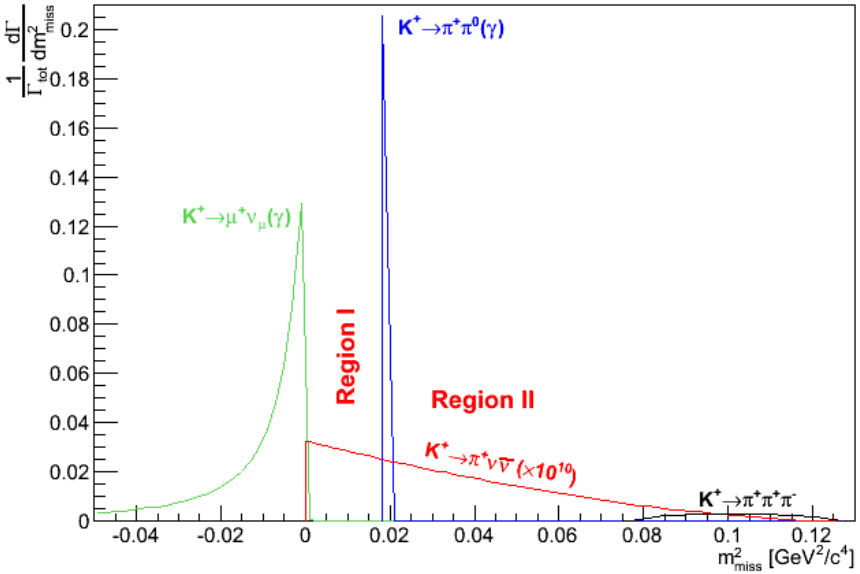
Main requirements

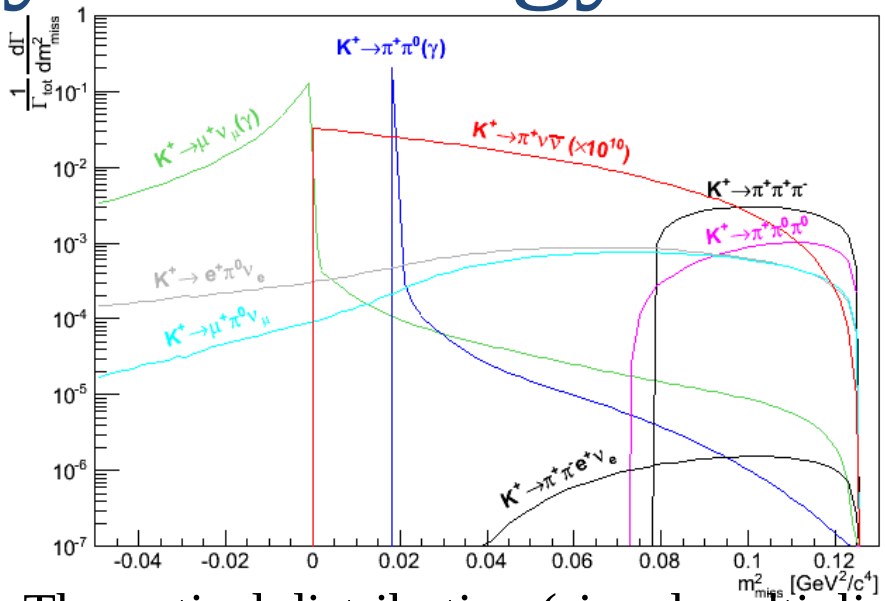
- O(100 ps) timing between sub-detectors
- O(10^4) background rejection from kinematics
- O(10^7) photon rejection ($K^+ \to \pi^+\pi^0$, $\pi^0 \to \gamma\gamma$)
- O(10^7) PID mainly for muon rejection ($K^+ \to \mu^+\nu$)

NA62 Analysis strategy

Fundamental variable

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





Theoretical distribution (signal multiplied for a factor 10^{10})

2 signal regions on each side of the $K^+\to\pi^+\pi^0$ peak

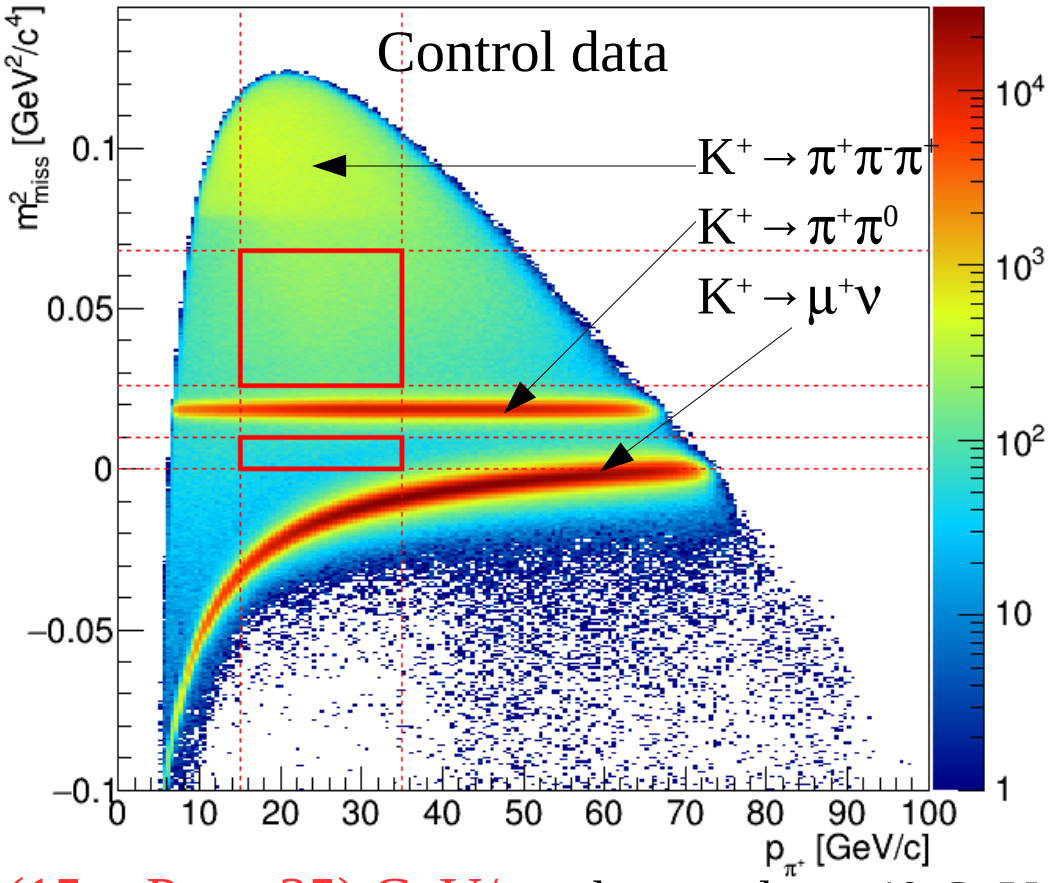
Background entering in the signal regions:

$K^+\to\pi^+\pi^0$,$K^+\to\mu^+\nu$ non gaussian resolution and radiative tails

$K^+\to\pi^+\pi^-\pi^+$ non gaussian resolution

Others due to the presence of neutrino in the final state

2016 Data Sample



- **Timing π^+:**
  $\sigma(T_{RICH})$~100 ps
- **Timing K^+:**
  $\sigma(T_{KTAG})$~80 ps, $\sigma(T_{GTK})$~100 ps
- **K^+ - π^+ matching:**
  intersection between GTK and Straw tracks σ(CDA)~1.5 mm
  (110 < Z < 165) m
- **Muon identification**
  $\varepsilon(\mu^+)=1\cdot10^{-8}$ (64% pion efficiency)
- **Photon rejection**
  $\varepsilon(\pi^0)=3\cdot10^{-8}$

$(15 < P_{\pi^+} < 35)$ GeV/c to have at least 40 GeV of energy deposition on LKr (helpful for the $K^+ \to \pi^+\pi^0$ rejection)

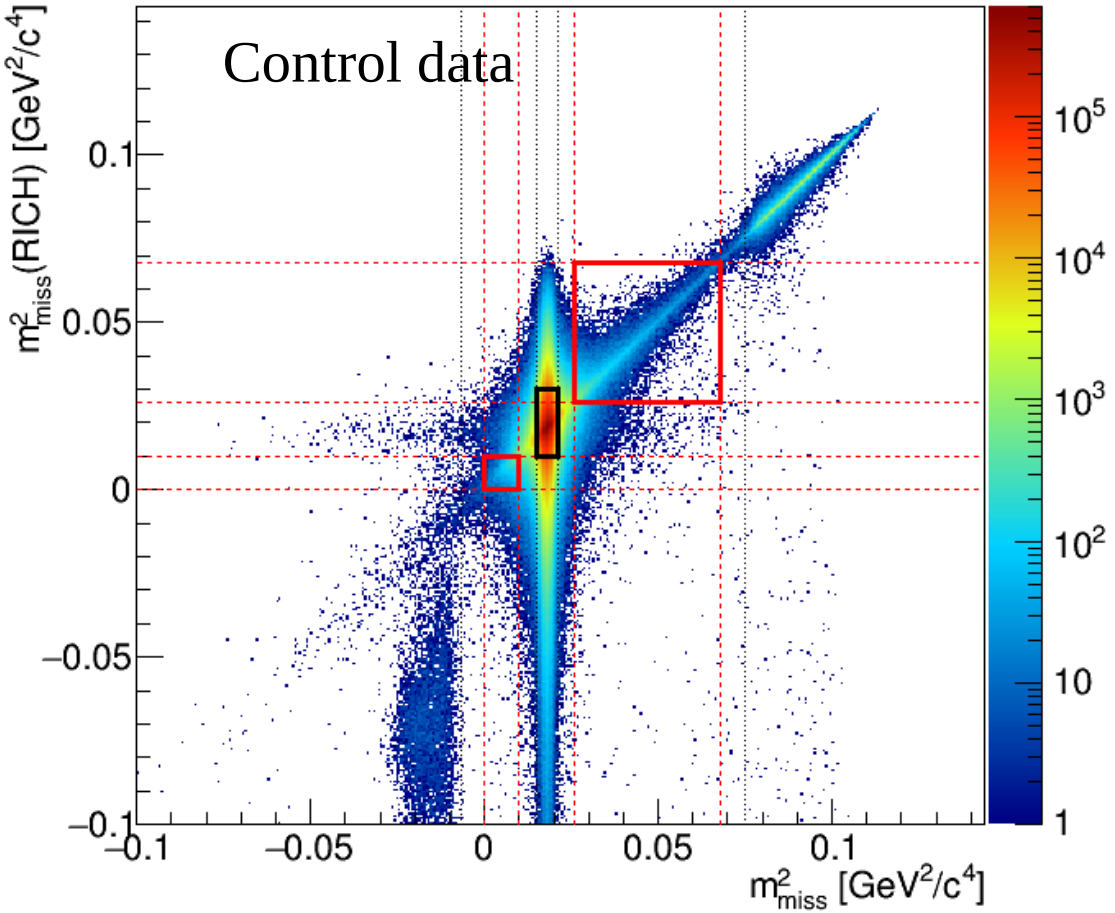
The squared missing mass

3 different ways to evaluate the main NA62 kinematic discriminant:

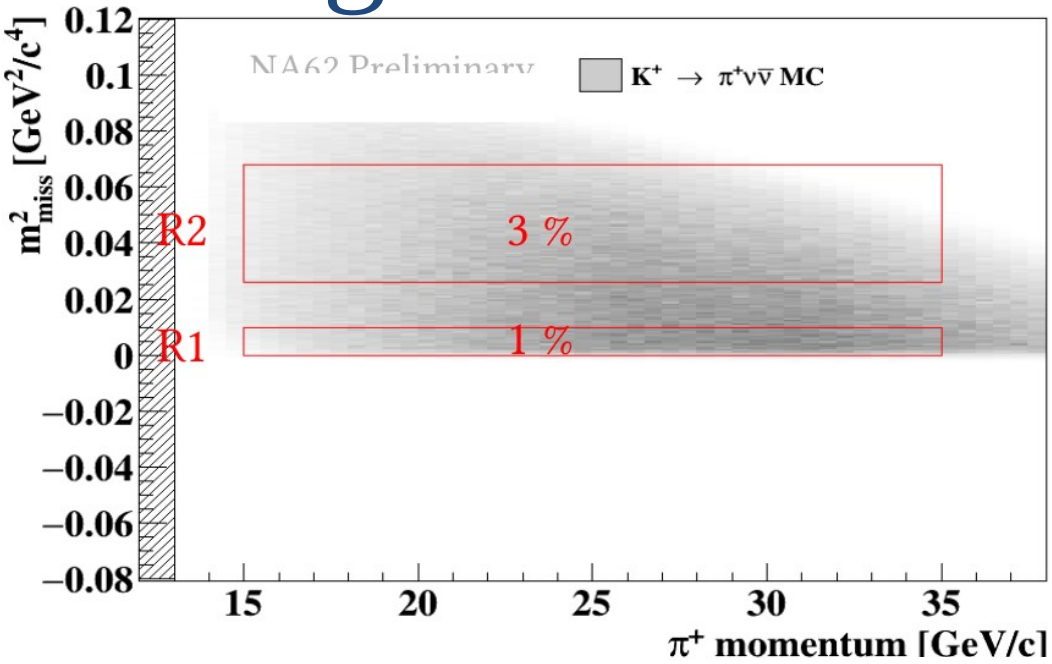
$m^2_{miss}(RICH) = (P_{K+}^{GTK} - P_{\pi+}^{RICH})^2$

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

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



Single Event Sensitivity (SES)



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

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

j = π⁺ momentum bin

number of K⁺ decays

signal acceptance

random veto efficiency

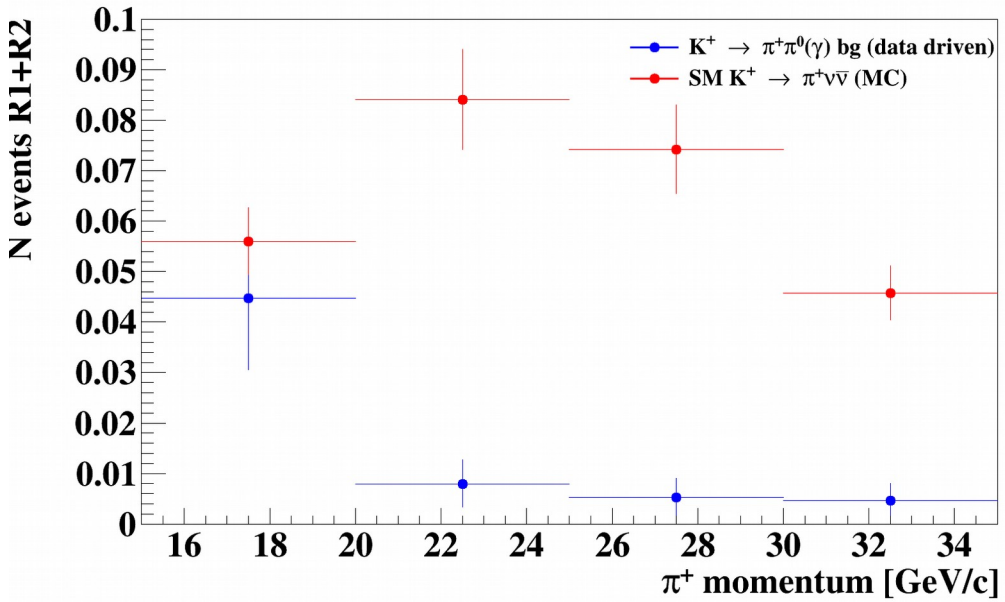
trigger efficiency

- Total signal acceptance: 4%
- Normalization signal acceptance: 10%
- $K^+ \rightarrow \pi^+\pi^0$ selected with Control Trigger used as normalization
- Number of Kaon decays in the fiducial volume, N_K: $(1.21 \pm 0.02) \cdot 10^{11}$

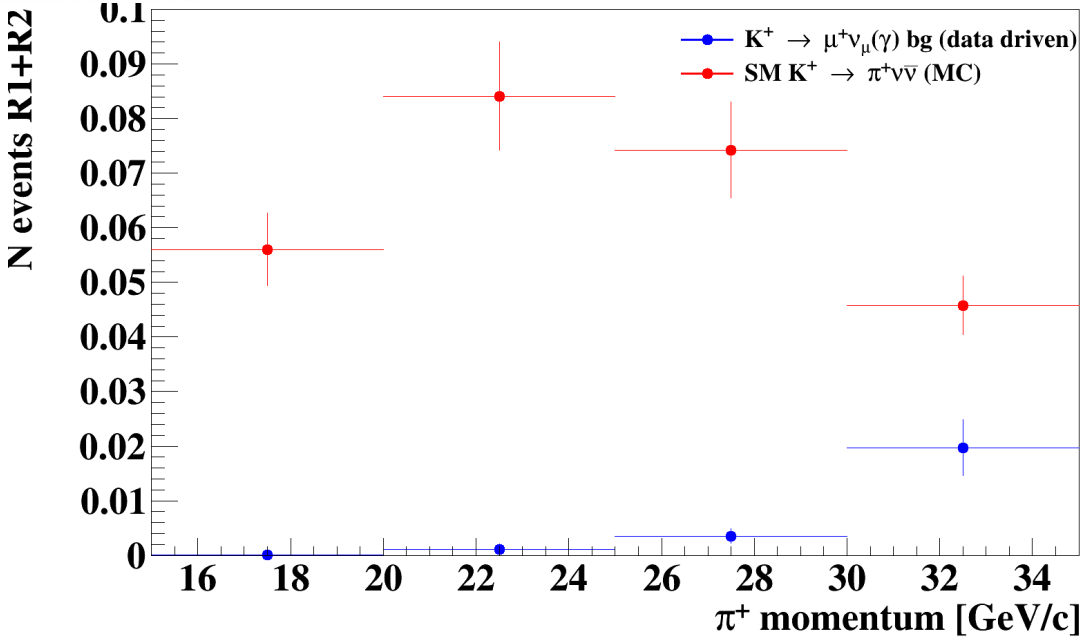
$$SES = (3.15 \pm 0.01_{stat} \pm 0.24_{sys}) \cdot 10^{-10}$$

$$N_{\pi\nu\nu}(SM) = (0.267 \pm 0.001_{stat} \pm 0.020_{sys} \pm 0.032_{ext})$$

Background evaluation



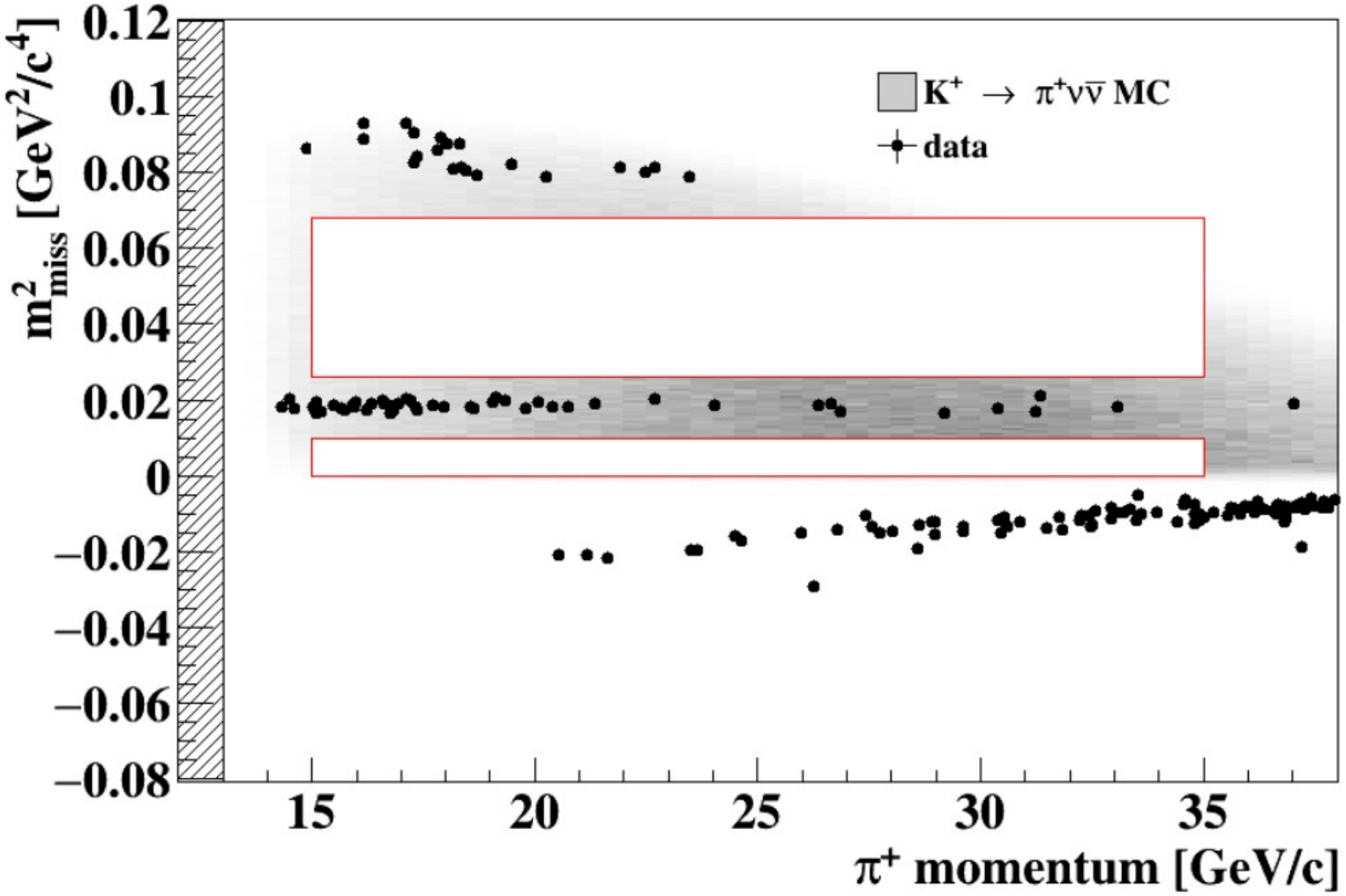
The data driven procedure has been validated using control regions around the signal regions



Summary of backgrounds

Process	Expected events
$K^+ \to \pi^+\pi^0(\gamma)$	$0.064 \pm 0.007_{stat} \pm 0.006_{syst}$
$K^+ \to \mu^+\nu(\gamma)$	$0.020 \pm 0.003_{stat} \pm 0.006_{syst}$
$K^+ \to \pi^+\pi^+\pi^-$	$0.002 \pm 0.001_{stat} \pm 0.002_{syst}$
$K^+ \to \pi^+\pi^-e^+\nu$	$0.013^{+0.017}_{-0.012}\|_{stat} \pm 0.009_{syst}$
$K^+ \to \pi^0\mu^+\nu$, $K^+ \to \pi^0e^+\nu$	< 0.001
$K^+ \to \pi^+\gamma\gamma$	< 0.002
Upstream background	$0.050^{+0.090}_{-0.030}\|_{stat}$
Total background	$0.152^{+0.092}_{-0.033}\|_{stat} \pm 0.013_{syst}$

2016 Data sample result



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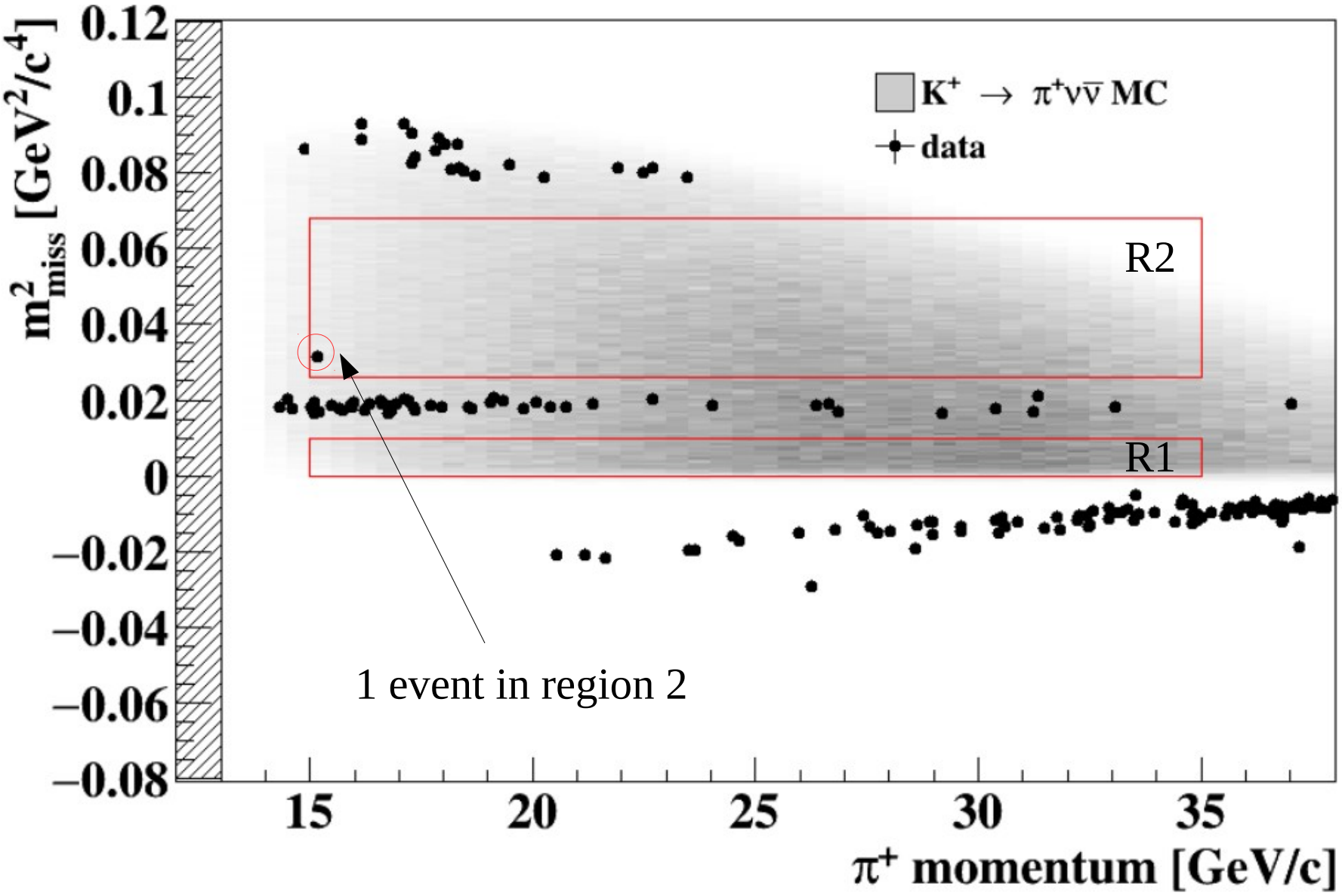
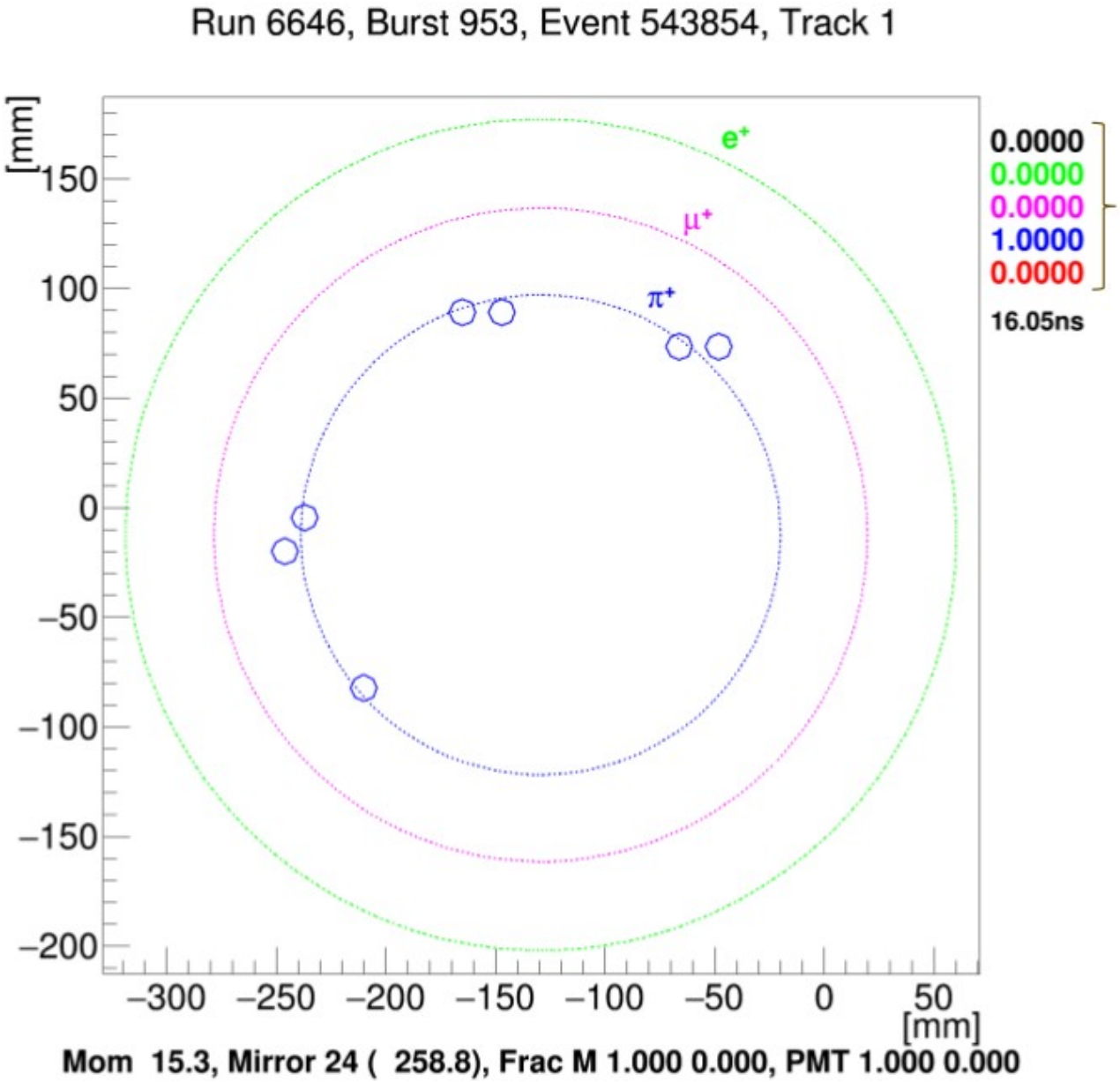


The event in the RICH



Likelihood value under different mass hypothesis

2016 Branching Ratio result

Paper published last week: Phys. Lett. B 791 (2019) 156-166

$N_{\pi\nu\nu}(SM)=(0.267\pm0.001_{stat}\pm0.020_{sys}\pm0.032_{ext})$

$N_{bkg}= 0.152^{+0.093}_{-0.033stat}\pm0.013_{sys}$

N_K: $(1.21\pm 0.02)\cdot 10^{11}$

Considering 1 observed event

$BR(K^+ \rightarrow \pi^+\nu\nu)<14\cdot10^{-10}$ at 95% CL

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

Some actions taken to mitigate the upstream background:
1) Just before the end of 2017 data taking a copper plug has been installed
2) In the middle of 2018 data taking a new final collimator has been installed

The actions taken to decrease the upstream background are working

The analysis of the whole 2017 sample is ongoing
The background contamination is stable, not increasing with the intensity

We are planning to restart the data taking after LS2 (2019-2020) to reach the 10% precision in the Branching Ratio measurement

Conclusions

The first NA62 $K^+ \to \pi^+\nu\nu$ result based on the analysis of the full 2016 sample has been presented ($1.21 \cdot 10^{11}$ K^+ decays in the fiducial decay volume)

$N_{\pi\nu\nu}(SM)=(0.267\pm0.001_{stat}\pm0.020_{sys}\pm0.032_{ext})$

One event observed region 2

$BR(K^+ \to \pi^+\nu\nu)<14\cdot10^{-10}$ at 95% CL

The analysis of the full 2017 sample is ongoing

Improvements in the background rejection are expected

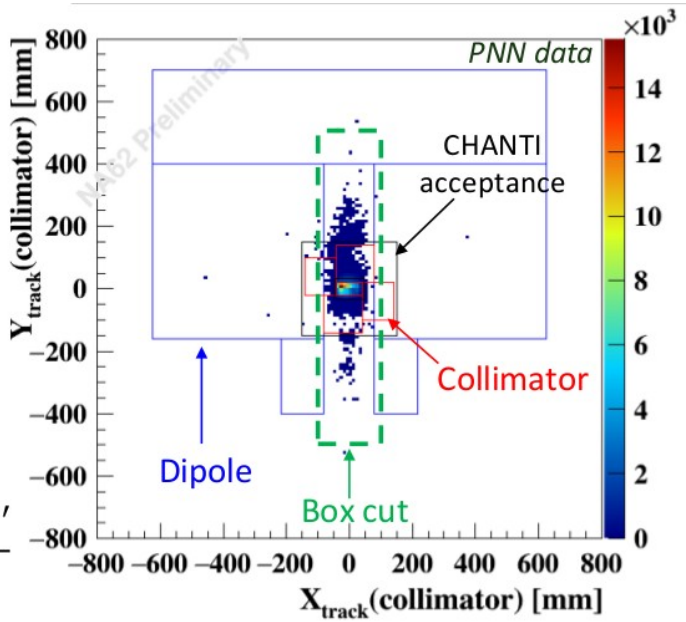
Spares

Upstream background

Bifurcation on PNN trigger inverting π-K matching (cut 1) and Cut box (cut 2)

BCD: reference sample; B'C'D' and B”C”D” control samples → 4 samples studied

A: signal region and A': control region



$$A(\text{exp}) = \frac{B \cdot C}{D}$$

$$A(\text{exp}) = \frac{B' \cdot C'}{D'} \qquad A'(\text{exp}) = \frac{B'' \cdot C''}{D'}$$