# $K^+ \to \pi^+ \nu\bar{\nu}$ : first NA62 results


*Speaker: Radoslav Marchevski*

*On behalf of the NA62 collaboration*


*Moriond EW Conference, 10–17th March 2018, La Thuile, Italy,*


GEFÖRDERT VOM

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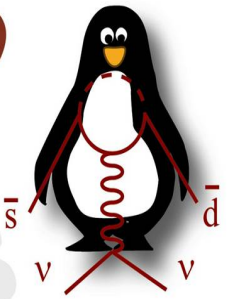
JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Symmetry Breaking


NA62 P326

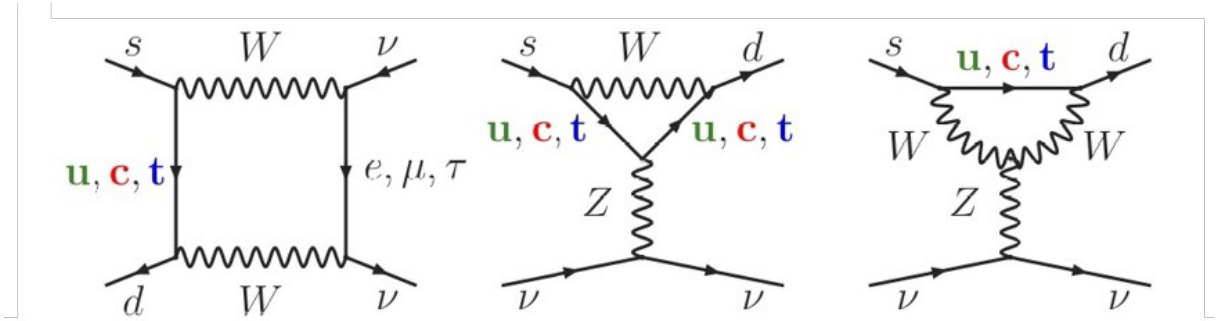


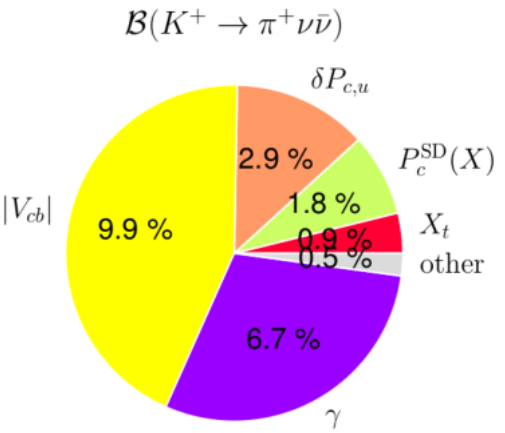
# Kaon physics @ NA62

- `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 ]

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

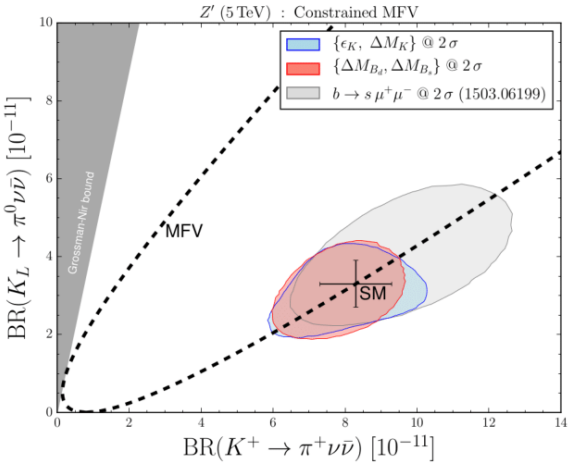
- Experimental result:[Phys. Rev. D 79, 092004 (2009)]

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

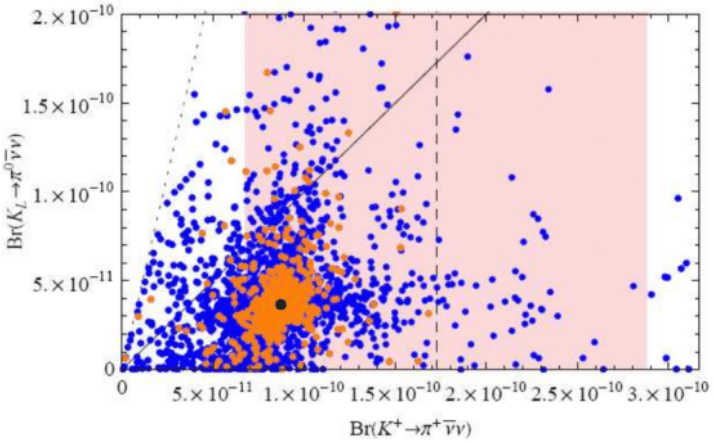
# $K^+ \to \pi^+ \nu\bar{\nu}$ beyond the Standard Model

- 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

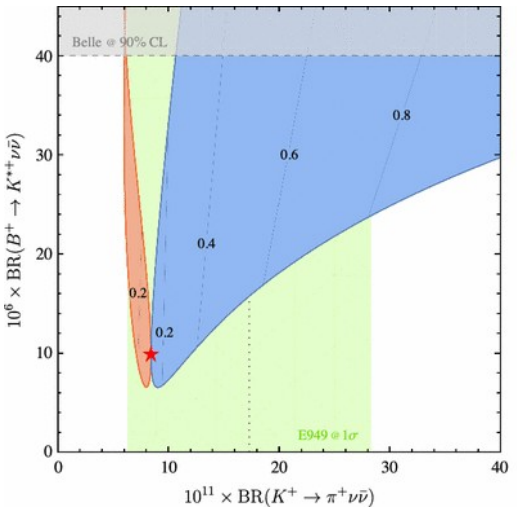
*Z'(5 TeV) in Constrained MFV*




*Randall Sundrum*




*LFU violation*

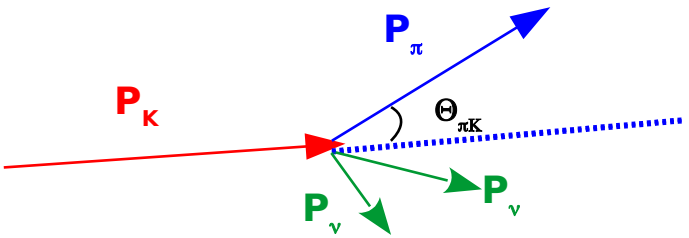


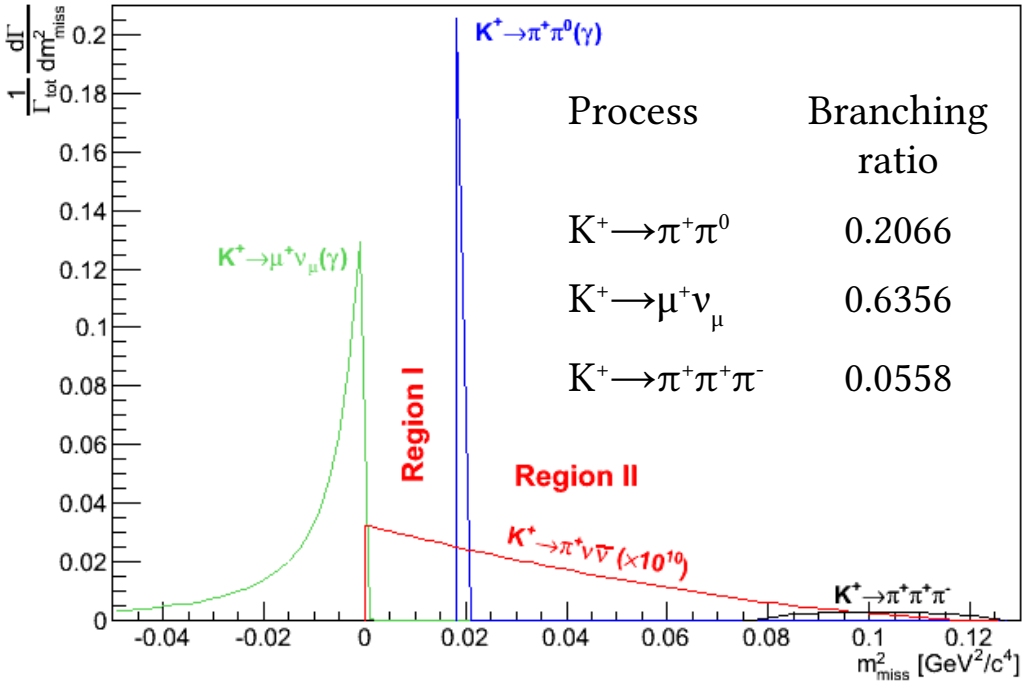
# Analysis strategy

**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 > $10^7$
  - $\pi^0$ suppression (from $K^+ \to \pi^+\pi^0$ ) > $10^7$
- Signal and background control regions are kept blind throughout the analysis

+

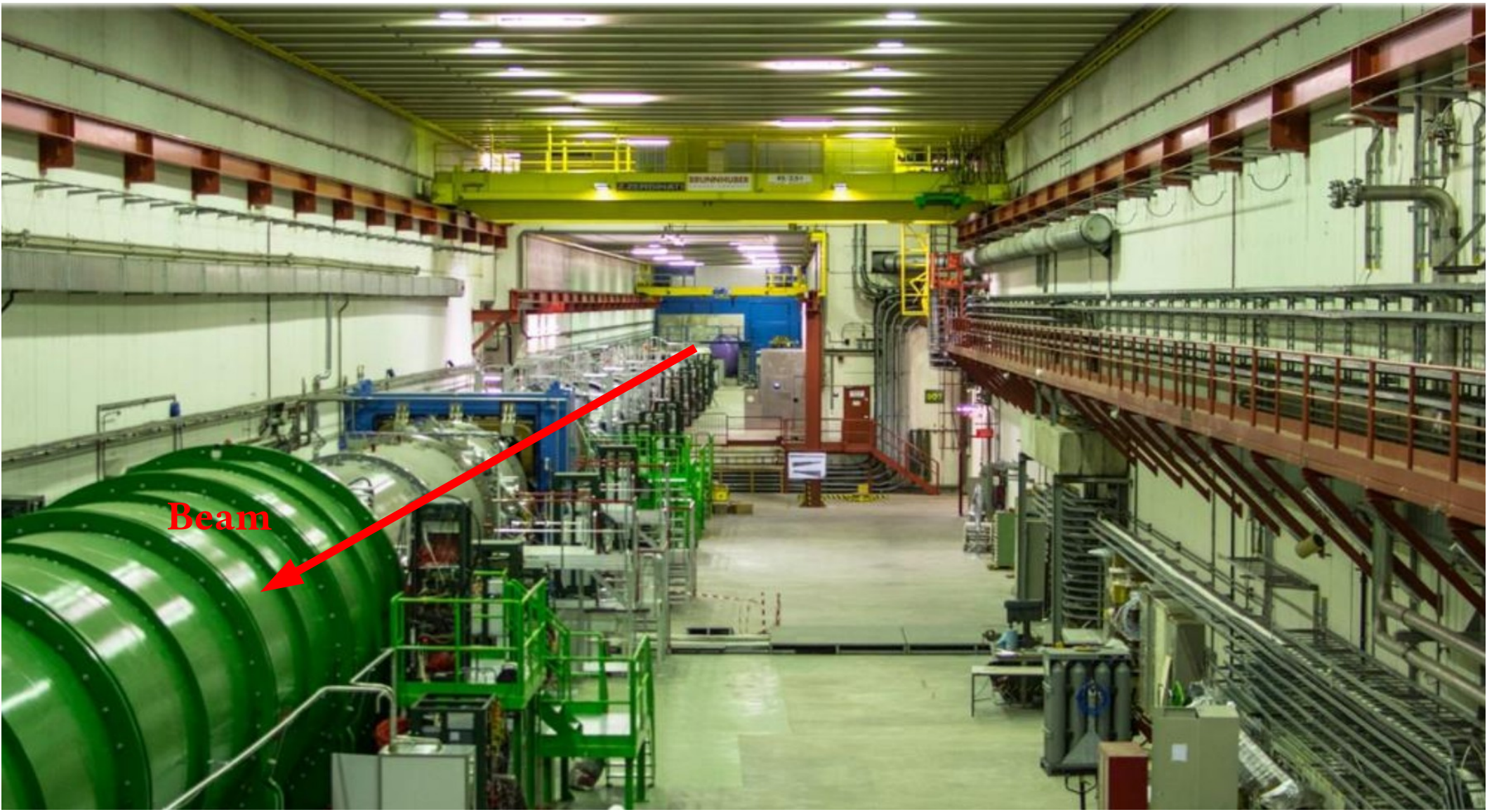
$15 < P_{\pi^+} < 35$ GeV/c

Particle ID(Cherenkov detectors)

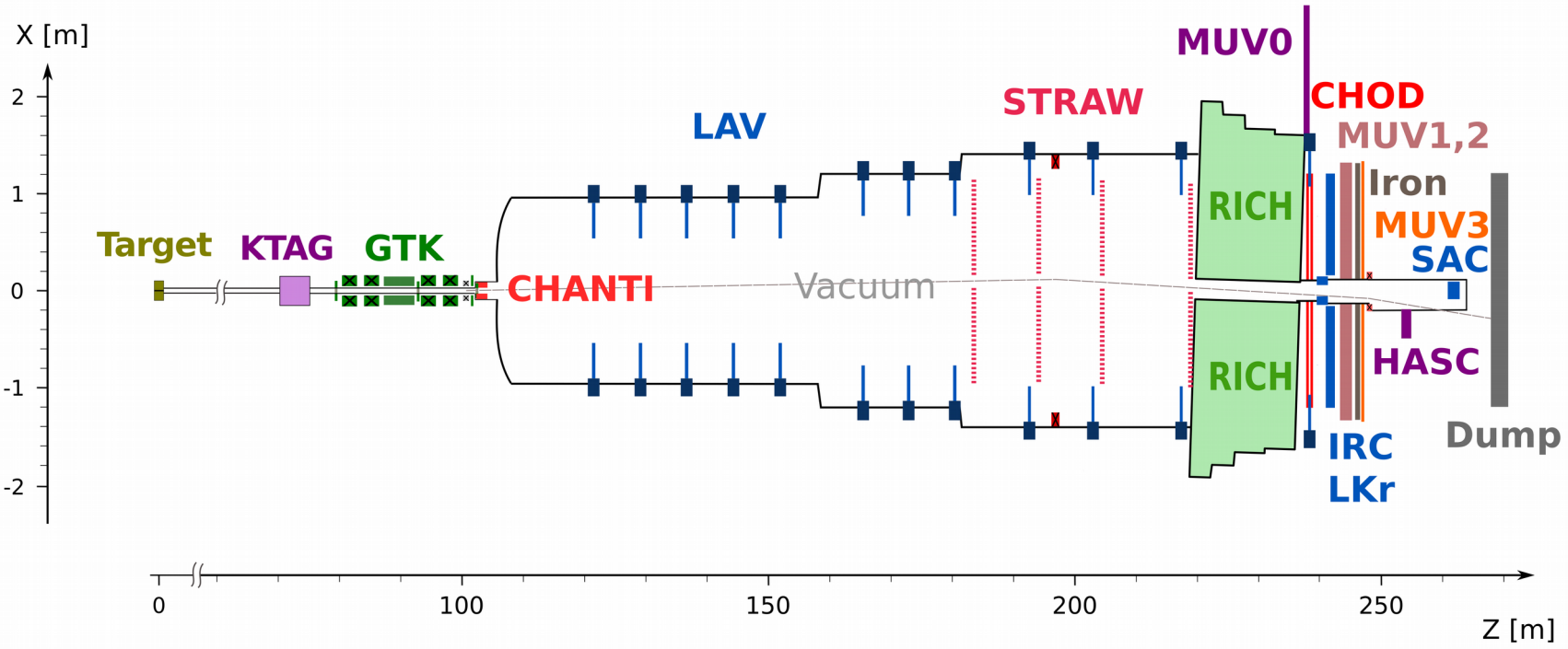
Particle ID(Calorimeters)

Photon veto

# NA62 beam and detector

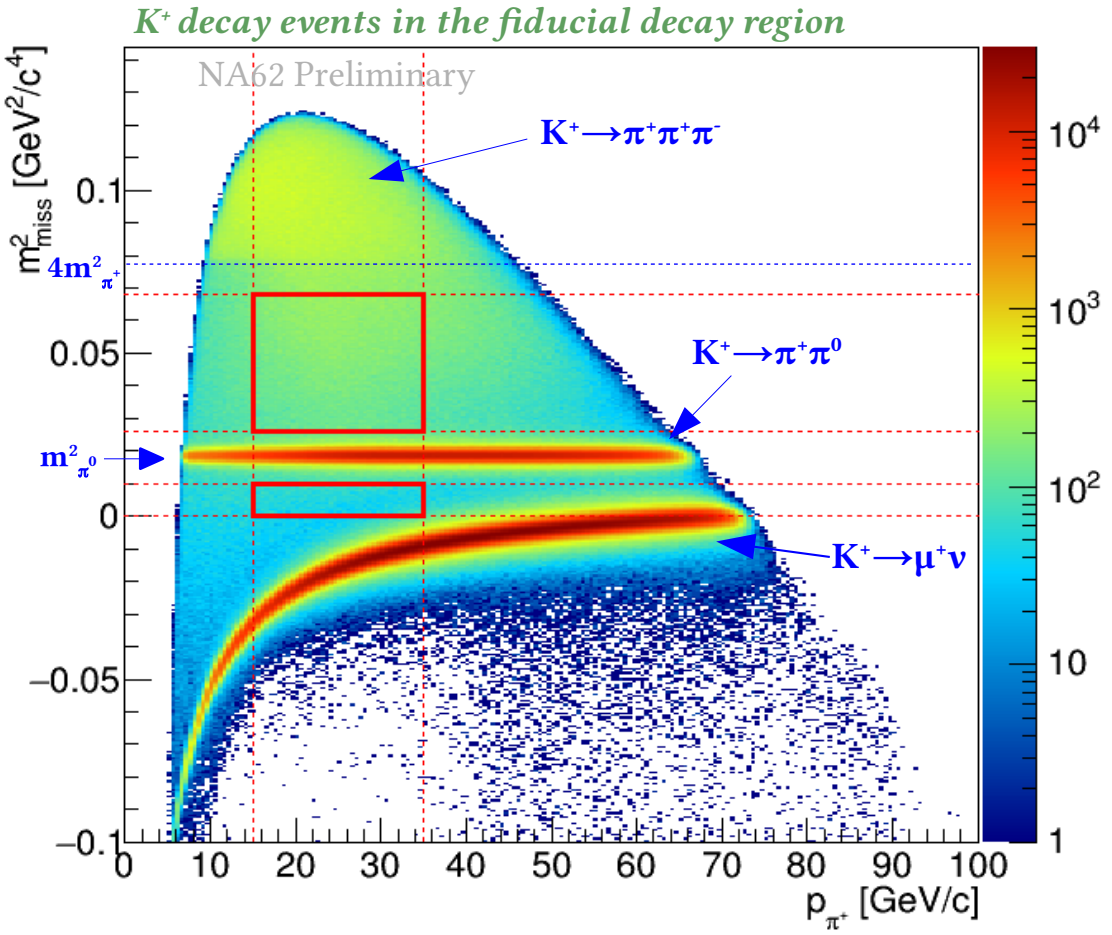


# NA62 beam and detector




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

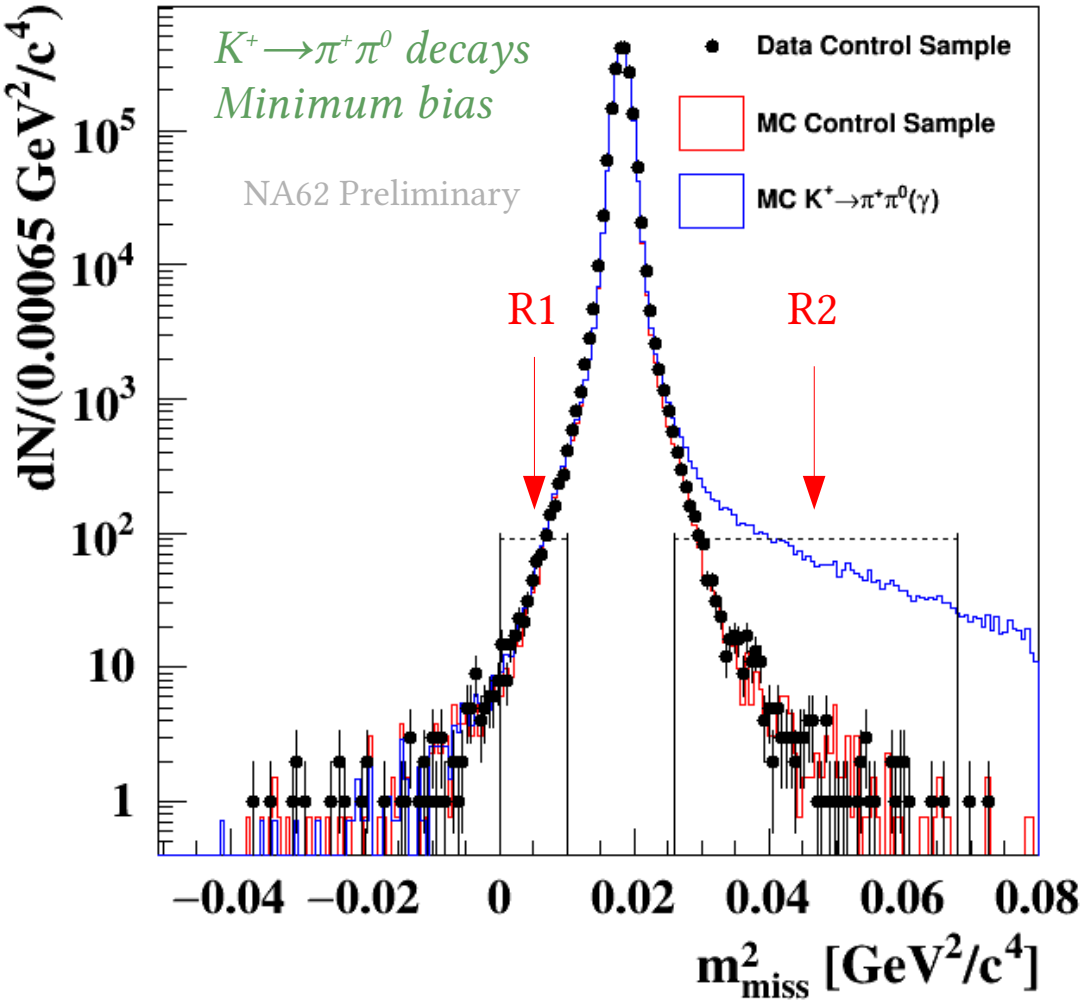
# Signal selection




- Selection criteria
  - single track decay topology
  - $\pi^+$ identification
  - photon rejection
  - multi-track rejection

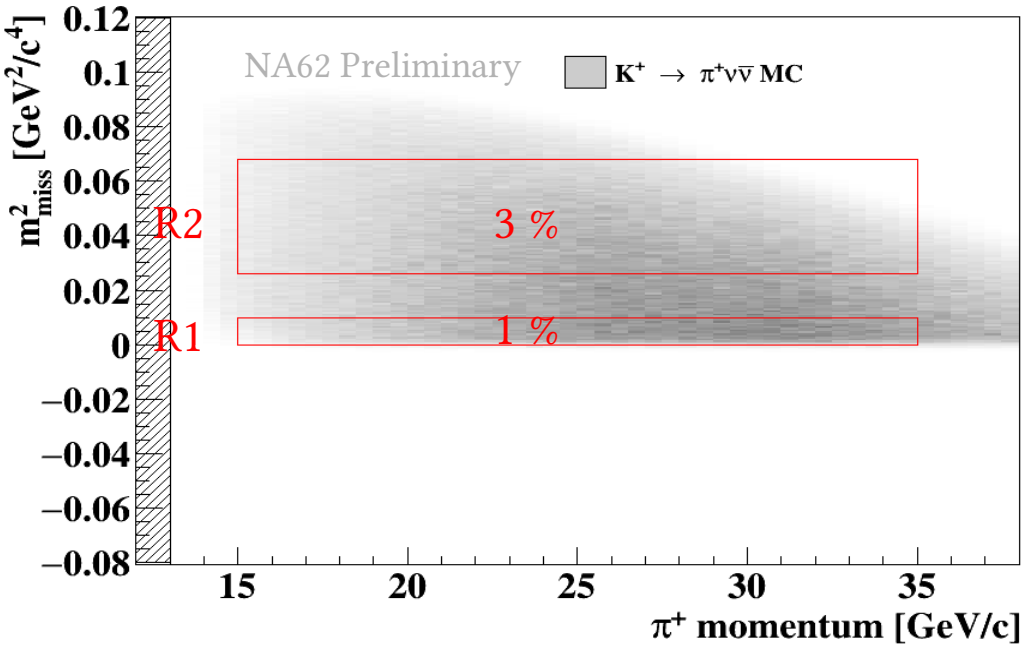
- Performance
  - $\epsilon_{\mu^+} = 1 \cdot 10^{-8} (64\%\ \pi^+ \text{ efficiency})$
  - $\epsilon_{\pi^0} = 3 \cdot 10^{-8}$
  - $\sigma(m^2_{miss}) = 1 \cdot 10^{-3}\ \text{GeV}^2/c^4$
  - $\sigma_T \sim O(100\ \text{ps})$

# 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)

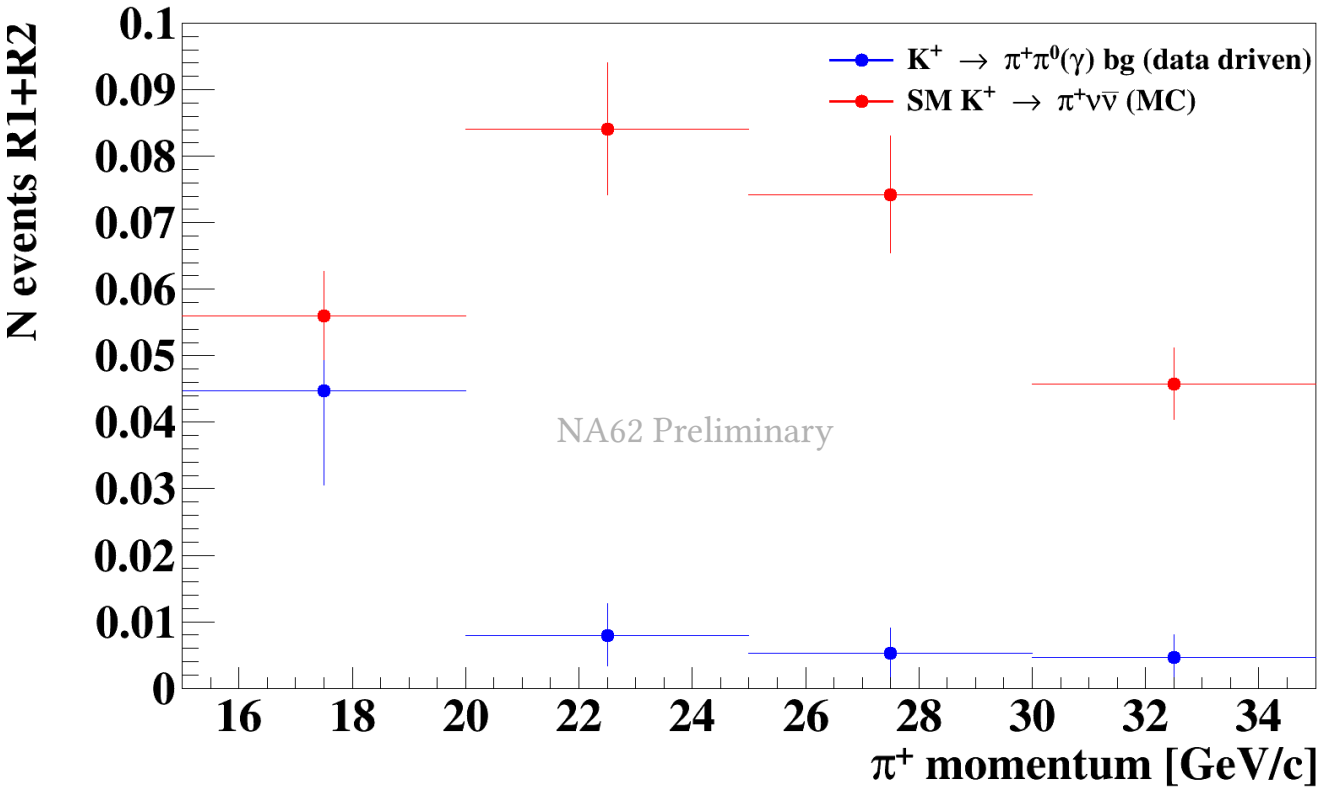



| Source | $\delta SES(10^{-10})$ |
|---|---|
| Random veto | 0.09 |
| $N_K$ | 0.05 |
| Trigger efficiency | 0.04 |
| Definition of $\pi^+\pi^0$ region | 0.10 |
| Momentum spectrum | 0.01 |
| Simulation of $\pi^+$ interactions | 0.03 |
| Extra activity | 0.02 |
| GTK Pileup simulation | 0.02 |
| Total | 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 : $N_K = 1.21(2) \times 10^{11}$

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

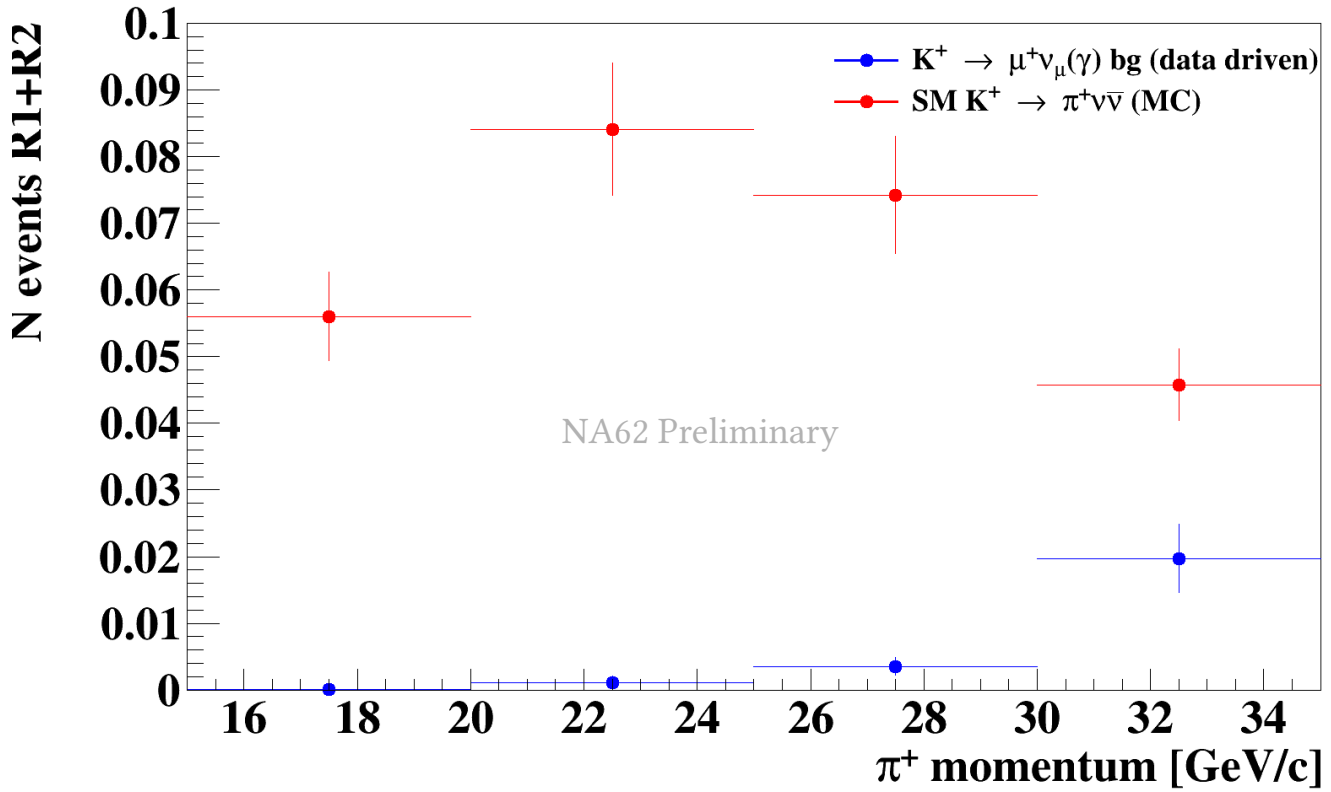
# $K^+ \to \pi^+\pi^0(\gamma)$ background




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

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

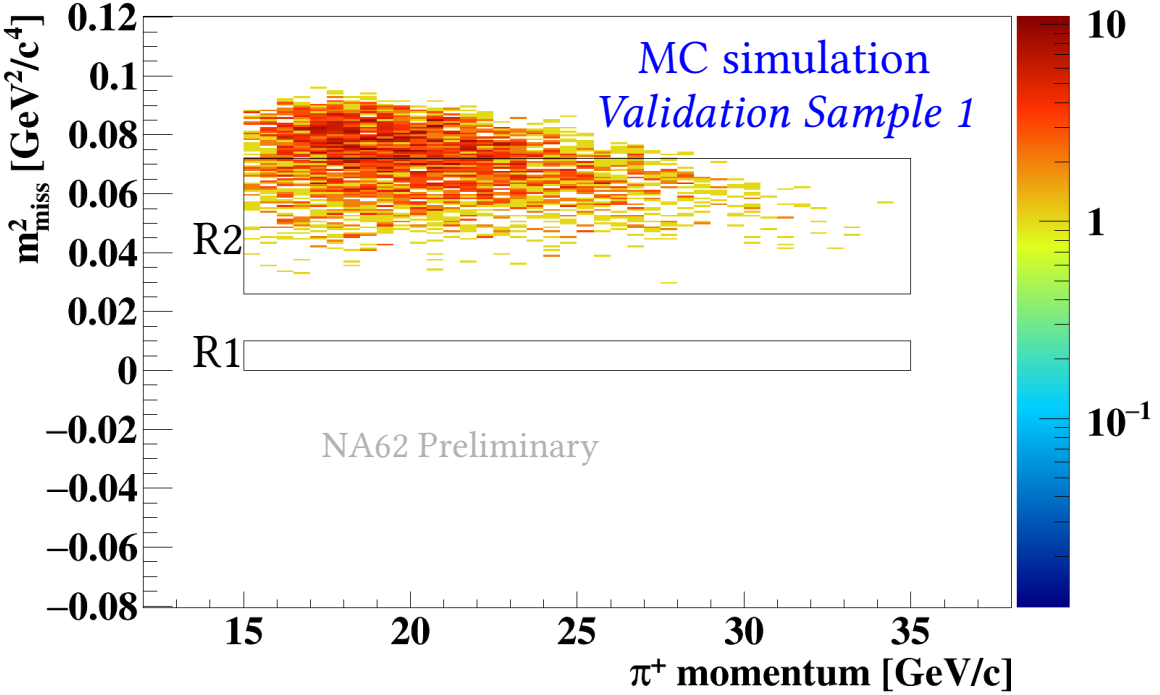
# $K^+ \to \mu^+ \nu_\mu(\gamma)$ background




- 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

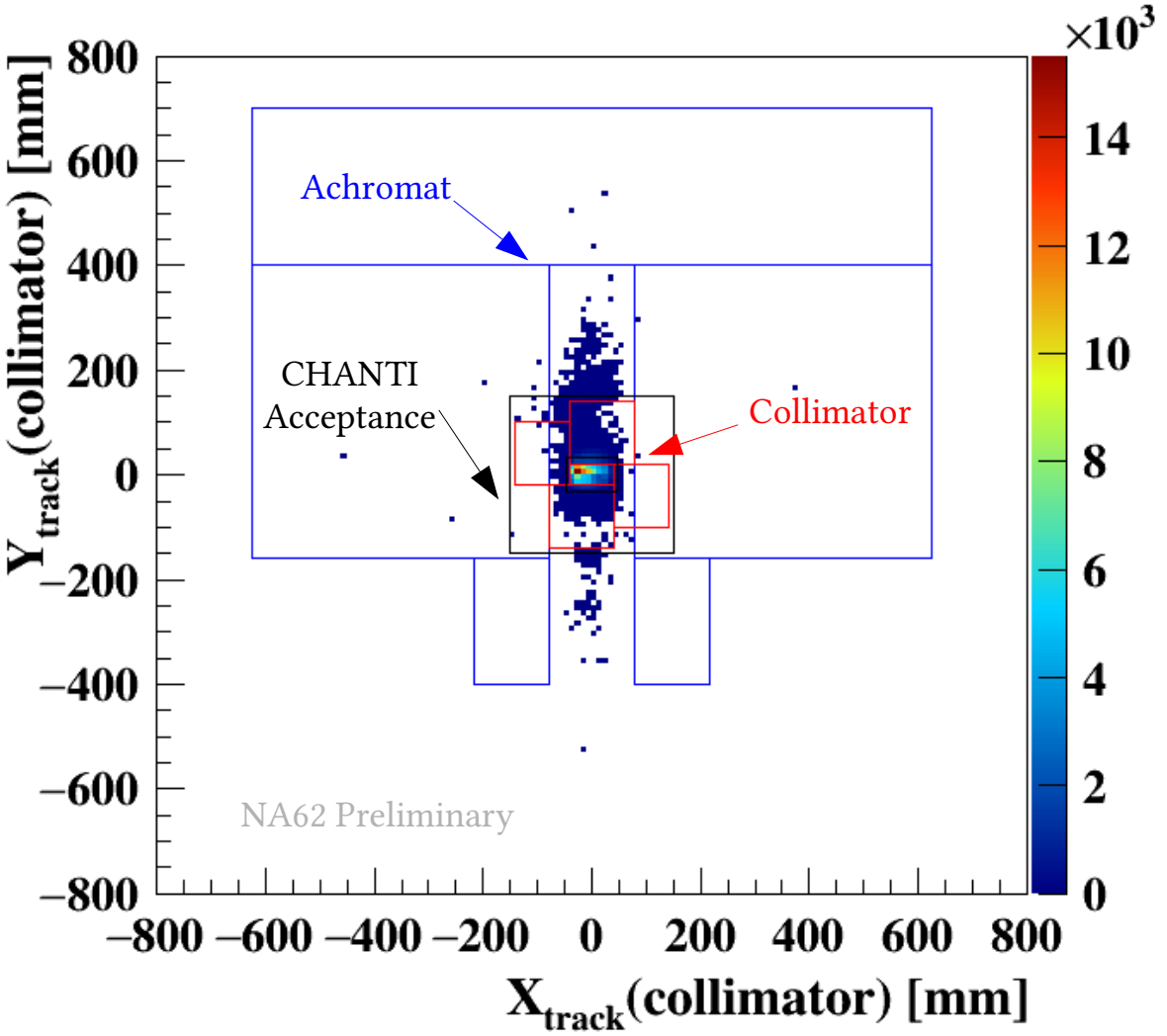



| Validation sample | N expected | N observed |
|---|---|---|
| 1 | 15.5(4) | 8 |
| 2 | 4.0(4) | 2 |
| 3 | 3.2(2) | 3 |
| 4 | 0.7(1) | 1 |
| 5 | 1.2(1) | 5 |

- 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



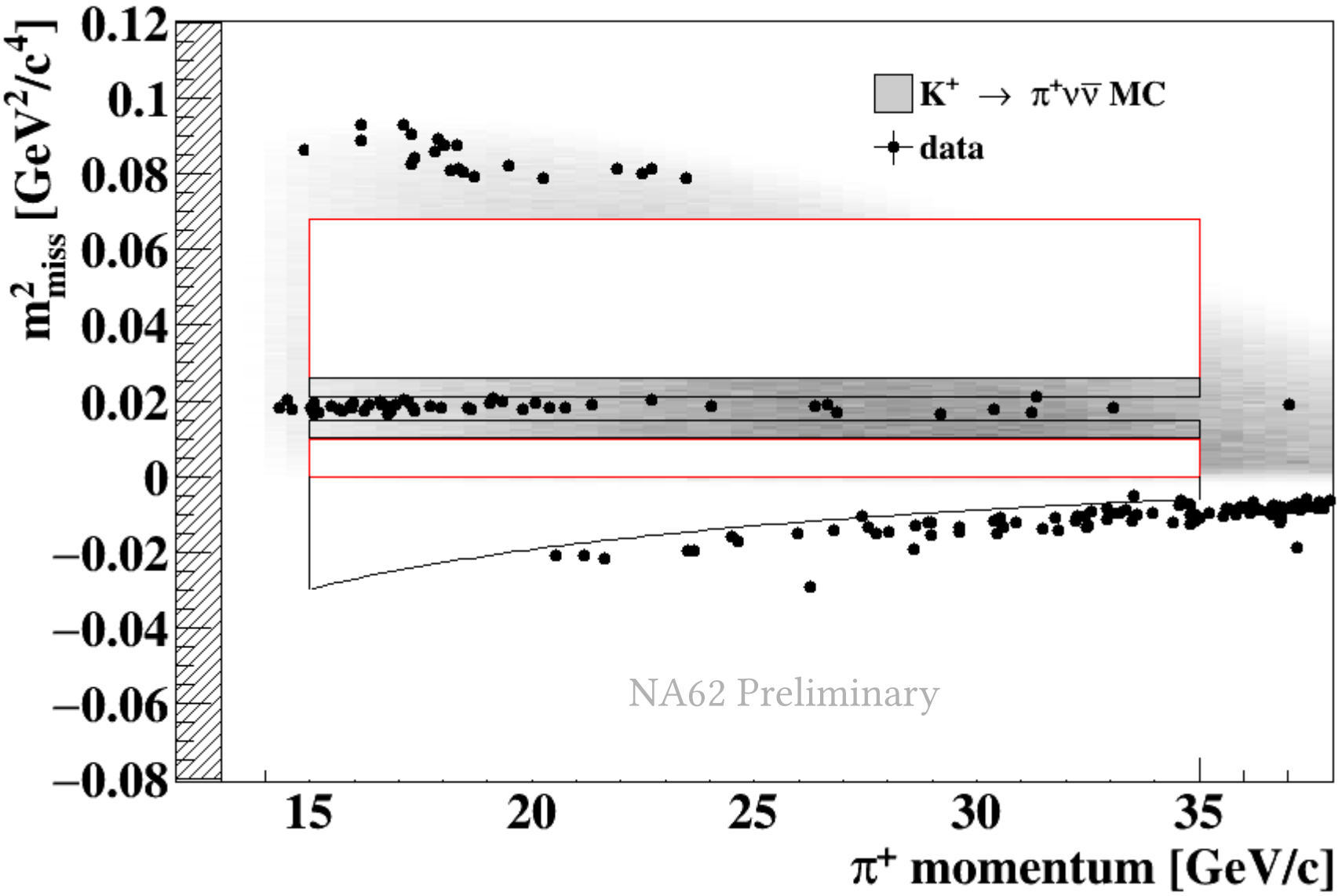

- Accidental particles from the beam line
- Pions from interactions with beam spectrometer material
- Kaon-pion matching and geometrical cuts effective
- Data driven estimation

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

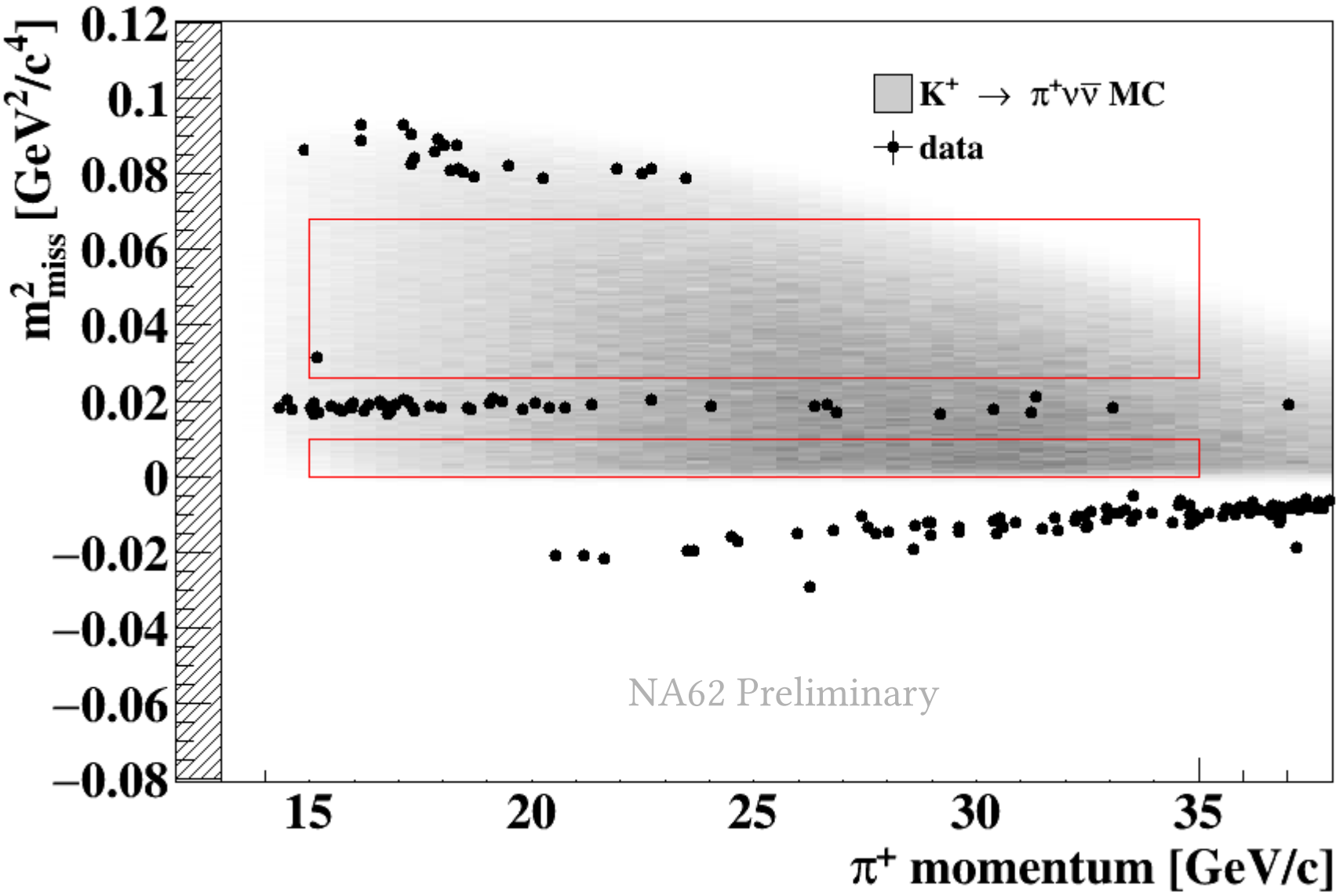
# Background summary

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

# Results

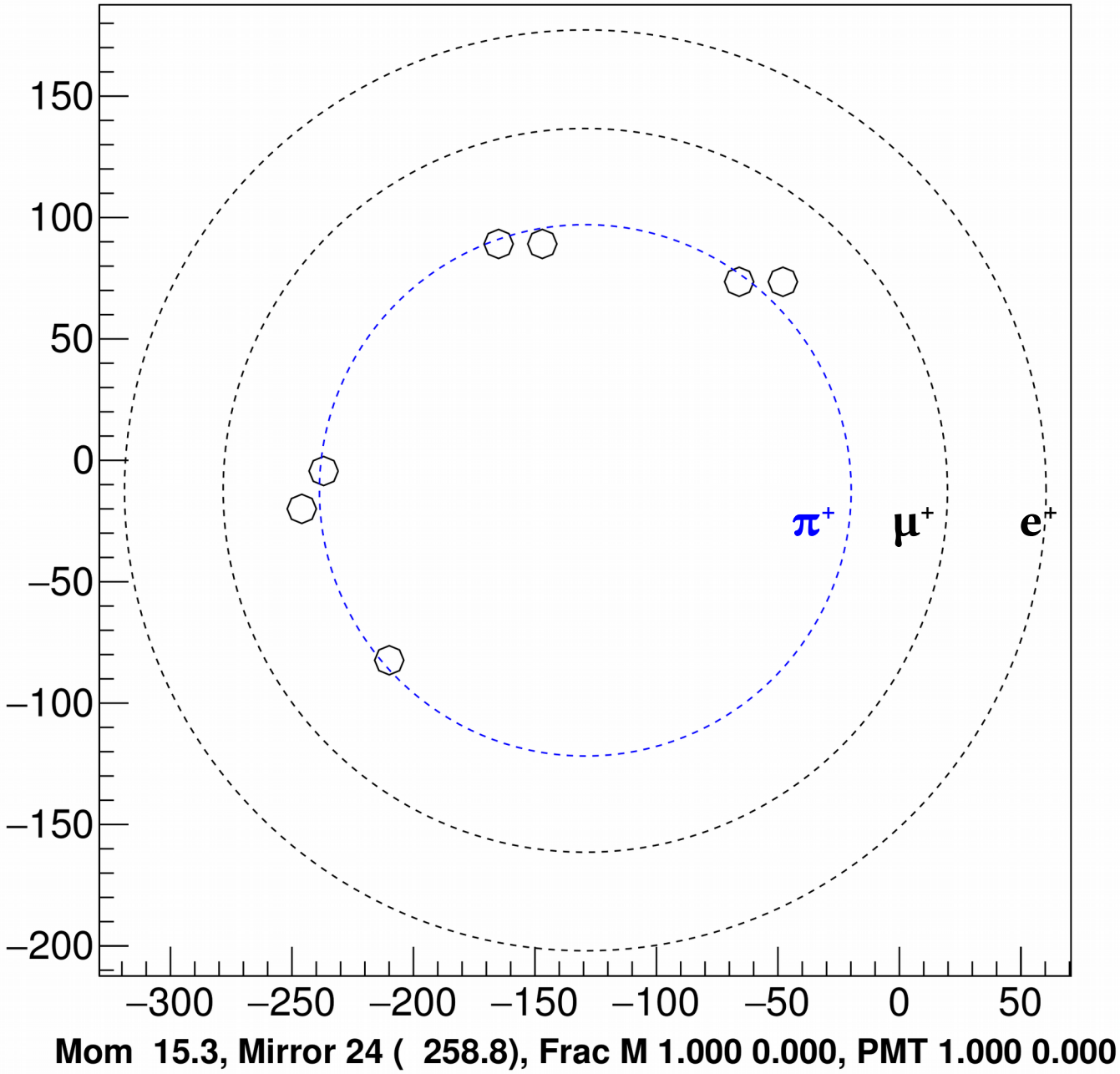

$m^2_{miss}$ [GeV$^2$/c$^4$]
0.12
0.1
0.08
0.06
0.04
0.02
0
−0.02
−0.04
−0.06
−0.08
15
20
25
30
35
π$^+$ momentum [GeV/c]
K$^+$ → π$^+$νν̄ MC
data
NA62 Preliminary

# Results




***One event observed***

# Results: RICH ring for the event



# Results

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

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

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

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

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

# Prospects

- Processing of 2017 data is ongoing
  - ~ 20 times more data than the presented statistics
  - expected reduction of upstream background
  - improvements of the reconstruction efficiency
- Preparing 2018 data taking
  - 218 days including stops
  - ongoing studies to improve the signal acceptance
- ~ 20 SM events expected before LS2
- Running after 2018 to be approved
  - Conditions for ultimate sensitivity under evaluation

# 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% $CL$