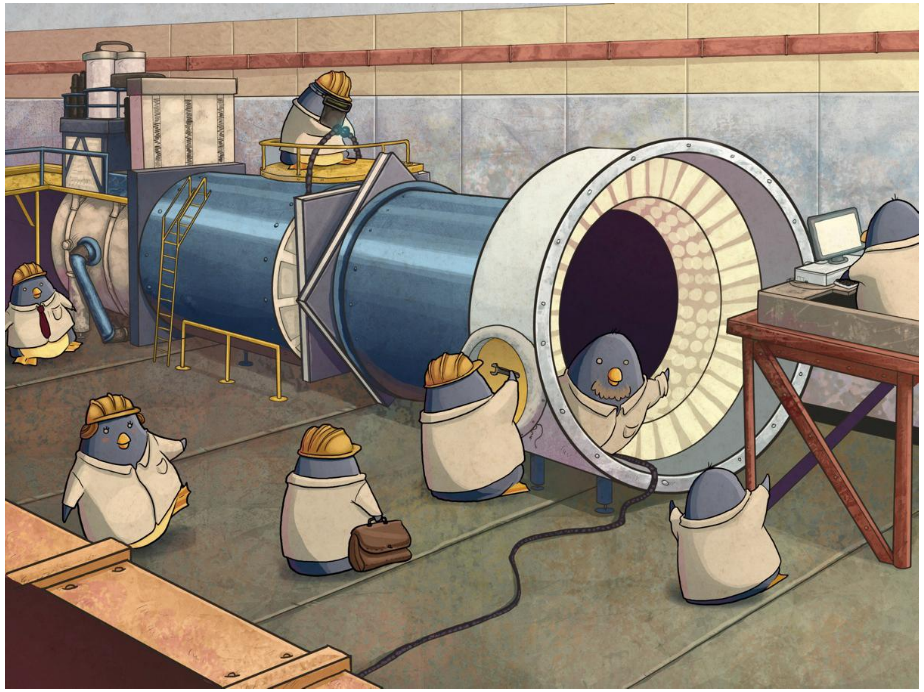
Results and prospects of the NA62 experiment at CERN



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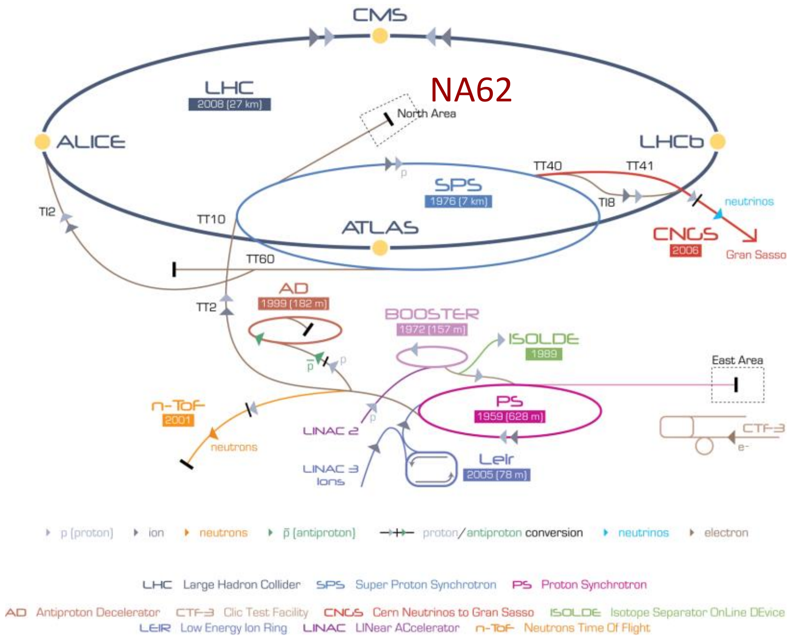
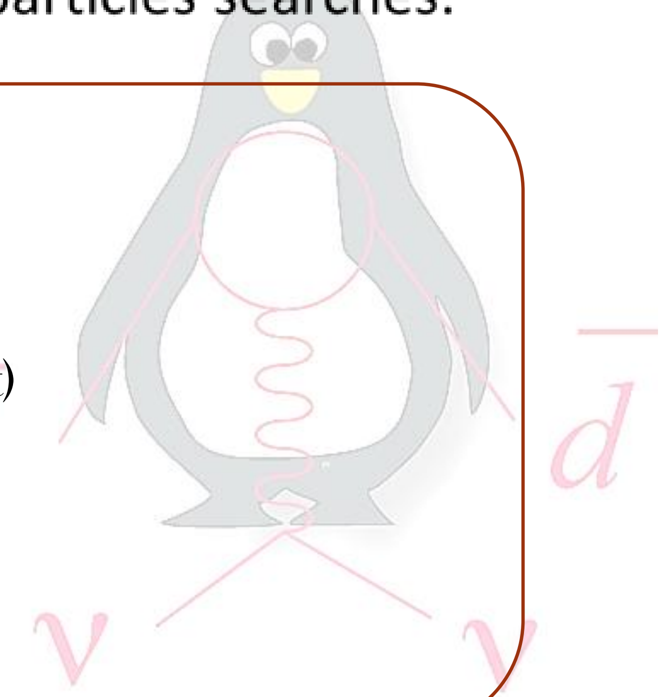
The NA62 Experiment

- NA62: High precision fixed-target Kaon experiment at CERN SPS
- Main goal: precise measurement of BR($K^+ \to \pi^+\nu\bar{\nu}$) with 10% accuracy
- Broader physics program: LFV / LNV in K^+ decays, hidden sector particles searches.



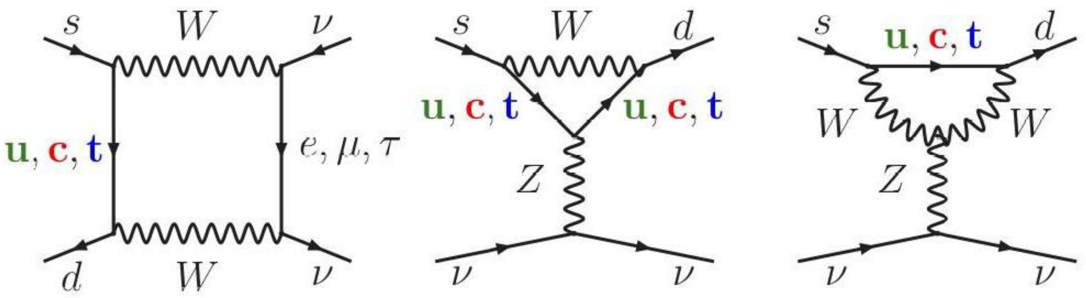
NA62 Timeline

- December 2008: NA62 Approval
- 2009 – 2012: detector R&D
- Oct 2012: NA62 Technical Run (partial layout)
- 2013 - 2014: Installation/Commissioning
- Oct 2014: NA62 Pilot Run (partial layout)
- 2015 : Commissioning run
- 2016 - 2018: Physics Runs
- Proposed runs after LS2 under discussion



Accelerator schedule	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
LHC	Run 2				LS2		Run 3			LS3			Run 4
SPS										NA stop	SPS stop		

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



- High sensitivity to New Physics
- FCNC process forbidden at tree level
- Highly CKM suppressed (BR ~ $|V_{ts}{}^* V_{td}|^2$)
- Extraction of V_{td} with minimal (few %) uncertainty

- Very clean theoretically:

  Short distance contribution; hadronic matrix element extracted from precisely measured $BR(K^+ \to \pi^0 e^+ \upsilon)$).
- SM predictions:

  $BR(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = (8.4 \pm 1.0) \times 10^{-11}$
  $BR(K_L \to \pi^0 \upsilon\bar{\upsilon}) = (3.4 \pm 0.6) \times 10^{-11}$ [Buras et al. JHEP 1511 (2015) 33]
- Experimental Result:

  $BR(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$ [Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)]
  $BR(K_L \to \pi^0 \upsilon\bar{\upsilon}) < 2.6 \times 10^{-8}$ (90% C.L) [Phys. Rev. D 81, 072004 (2010)]

NA62 Goal

measure BR to 10% precision

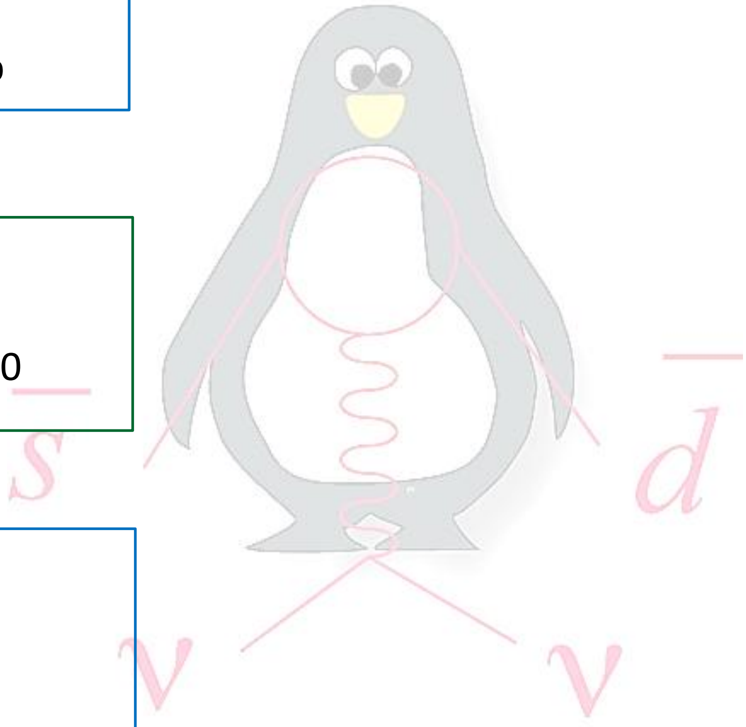
- Signal acceptance ~10%
- 100 signal event and background < 20%

2016 Analysis goal:

assess the sensitivity at the level of 10^{-10}

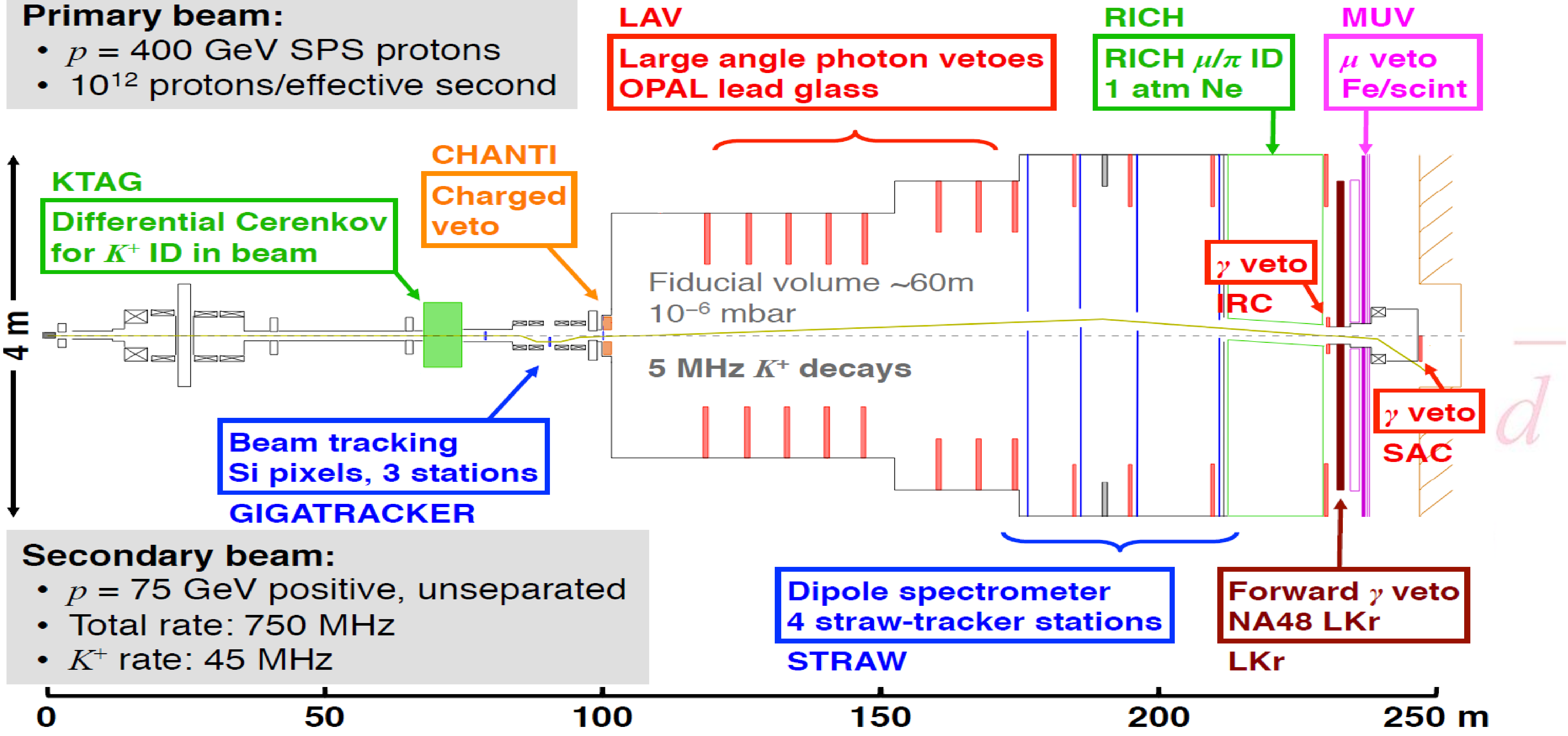
In this talk:

- analysis of 2.3×10^{10} K^+ decays
- $\mathcal{O}(5\%)$ 2016 data



NA62 Layout

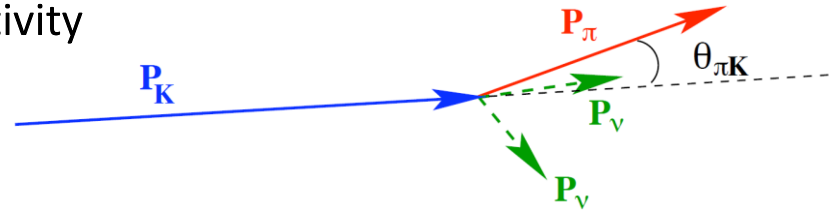
Primary beam:
- p = 400 GeV SPS protons
- 10^{12} protons/effective second



Secondary beam:
- p = 75 GeV positive, unseparated
- Total rate: 750 MHz
- K^+ rate: 45 MHz

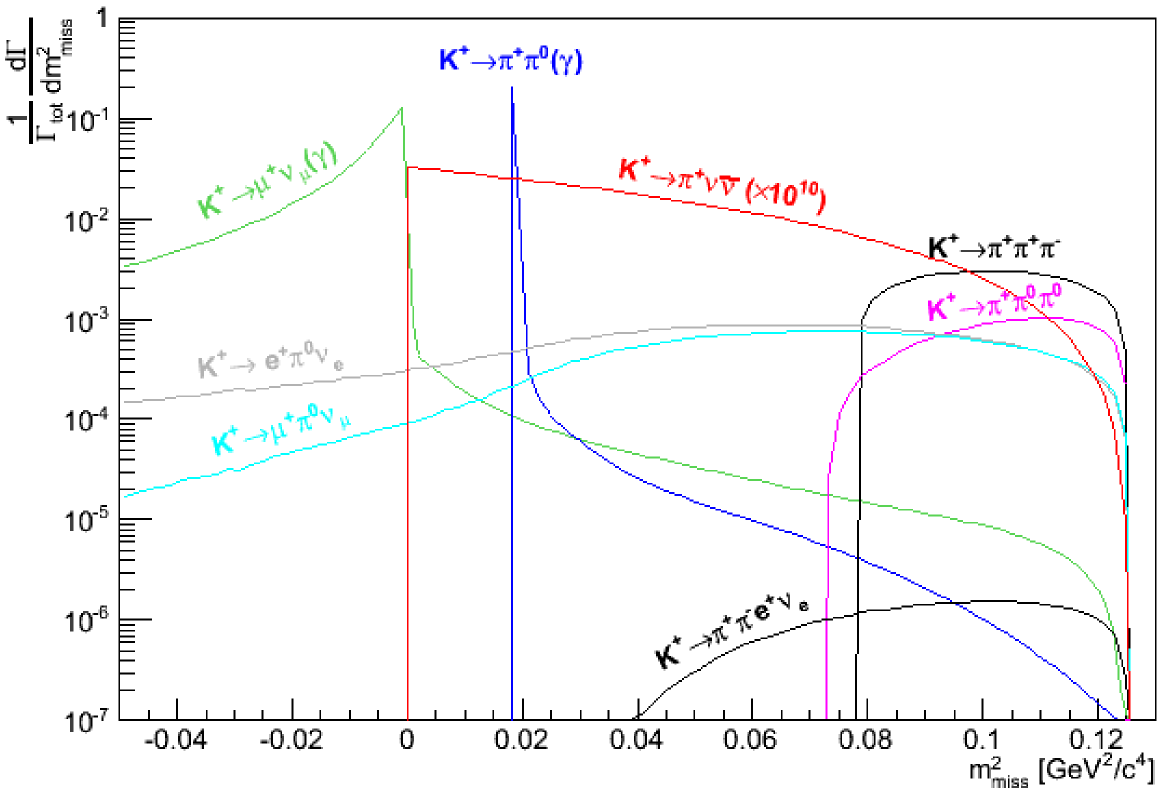
Analysis Strategy

- Signal: 1 beam track, 1 charged track, notting else
- Background: K^+ decay modes; beam activity
- Kinematics: $m^2_{miss} = (P_{K^+} - P_{\pi^+})^2$



Key analysis requirements:

- 2 signal regions in m^2_{miss}
- 15 < P_{π^+} <35 GeV/c
- 65 m long decay region



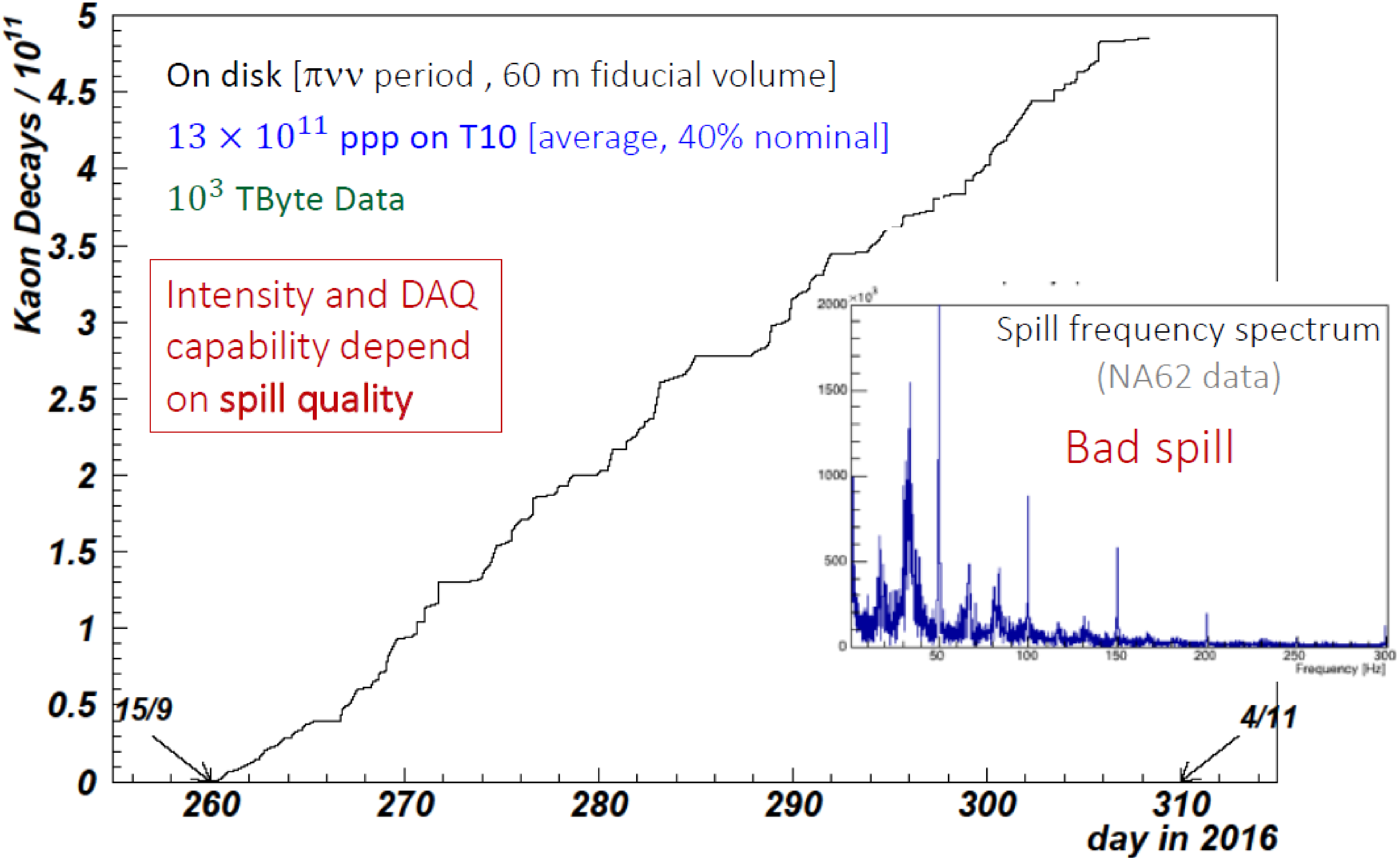
Experimental principles:

1. Precise kinematic reconstruction
2. PID: K upstream, e / μ / π downstream
3. Hermetic γ detection
4. Sub-ns timing

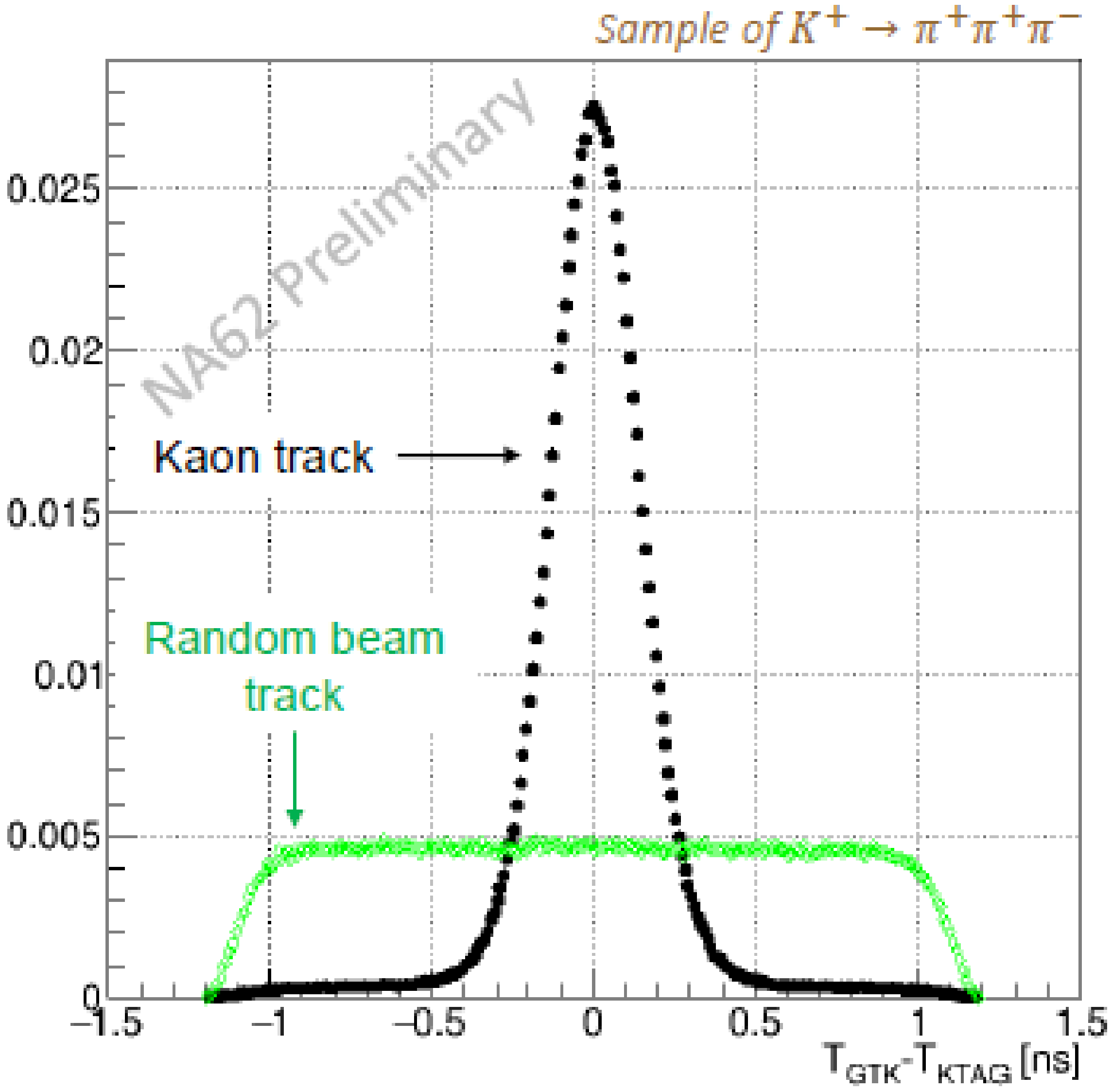
Keystone:

- O (100 ps) Timing between sub-detectors
- O(10^4) background suppression from kinematics
- > 10^7 Muon suppresion
- > 10^7 π^0 (from $K^+ \to \pi^+ \pi^0$) suppresion

2016 Run: Statistics

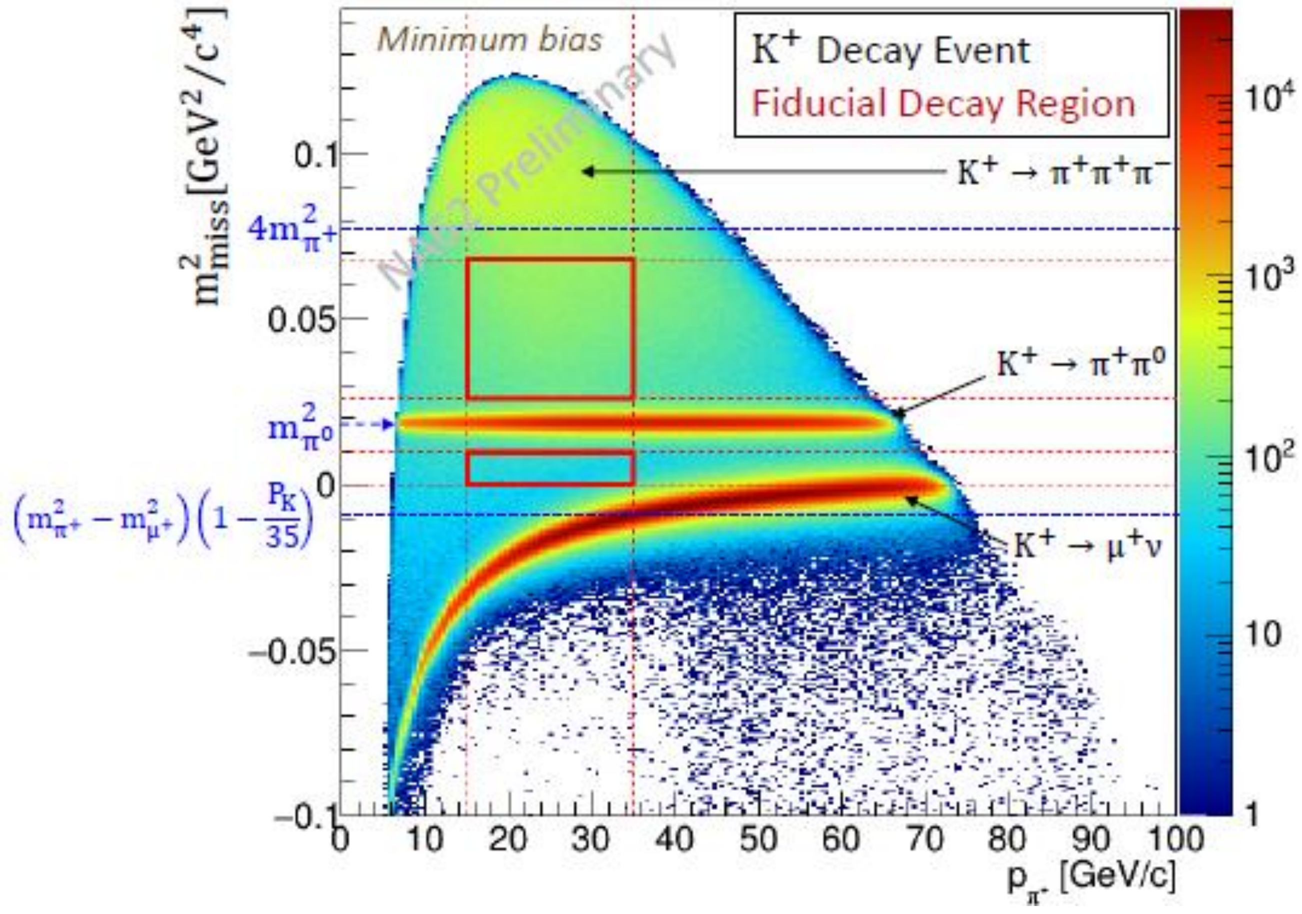


K / π matching



- Timing Kaon: $\sigma(T_{KTAG})$ ~80ps, $\sigma(T_{GTK})$ ~100ps
- Timing Pion: $\sigma(T_{CHOD})$ ~250ps, $\sigma(T_{RICH})$ ~150ps
- Spatial matching: σ(CDA) ~1.5mm
- Mis-tagging probability: ~1.7%
  [40% nominal intensity, 75% efficiency]

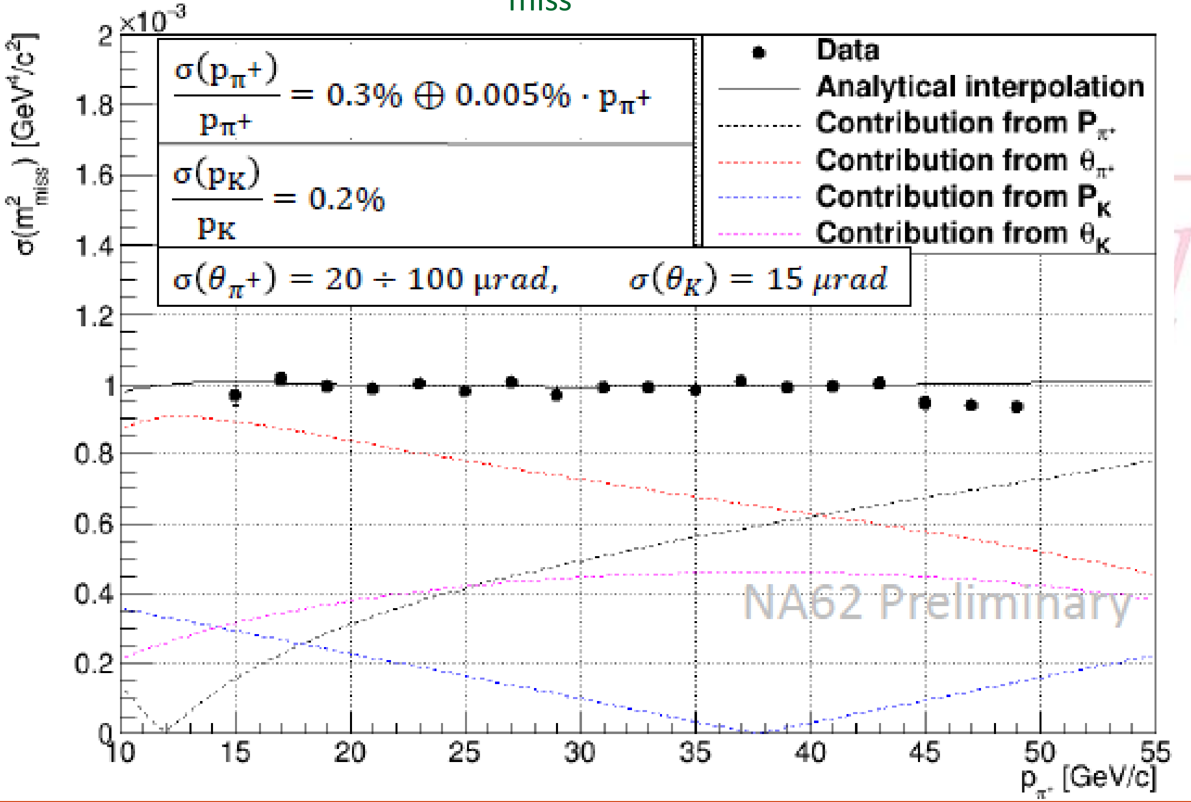
Signal Selection



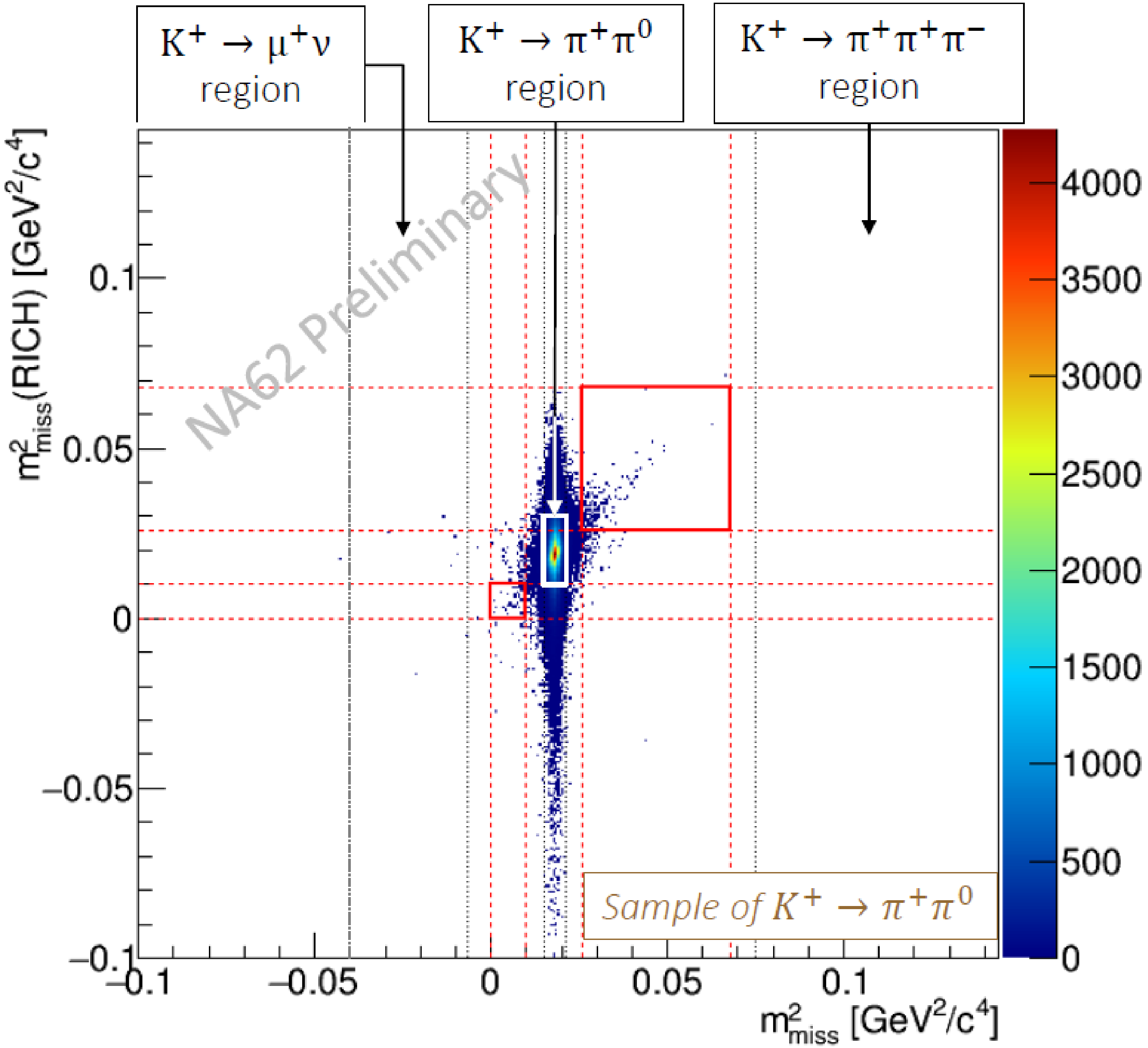
πνν selection:

- K^+ Decay Event
- Fiducial Decay Region
- Particle ID: π^+
- Photon rejection
- Multiple charged particle rejection
- Kinematic Selection of the Signal Regions

M^2_{miss} Resolution



Signal and Background Regions



m^2_{miss} , p_{π^+}

m^2_{miss}(RICH) → p_{π^+} RICH (m_{π^+})

m^2_{miss}(No GTK) → p_{K^+} nominal

Kinematical suppression

- Measured on data
- $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu$
- Selected using calorimeters

Fraction of events in signal regions

$K^+ \to \pi^+\pi^0$ $\sim 6 \times 10^{-4}$

$K^+ \to \mu^+\nu$ $\sim 3 \times 10^{-4}$

Particle ID: π^+ - μ^+ Separation

Particle ID with calorimeters

$\eta(\mu) \div \varepsilon(\pi) \sim 10^{-5} \div 80\%$

- LKr, MUV1,2, MUV3
- MVA: E, E sharing, cluster shape

Particle ID with RICH

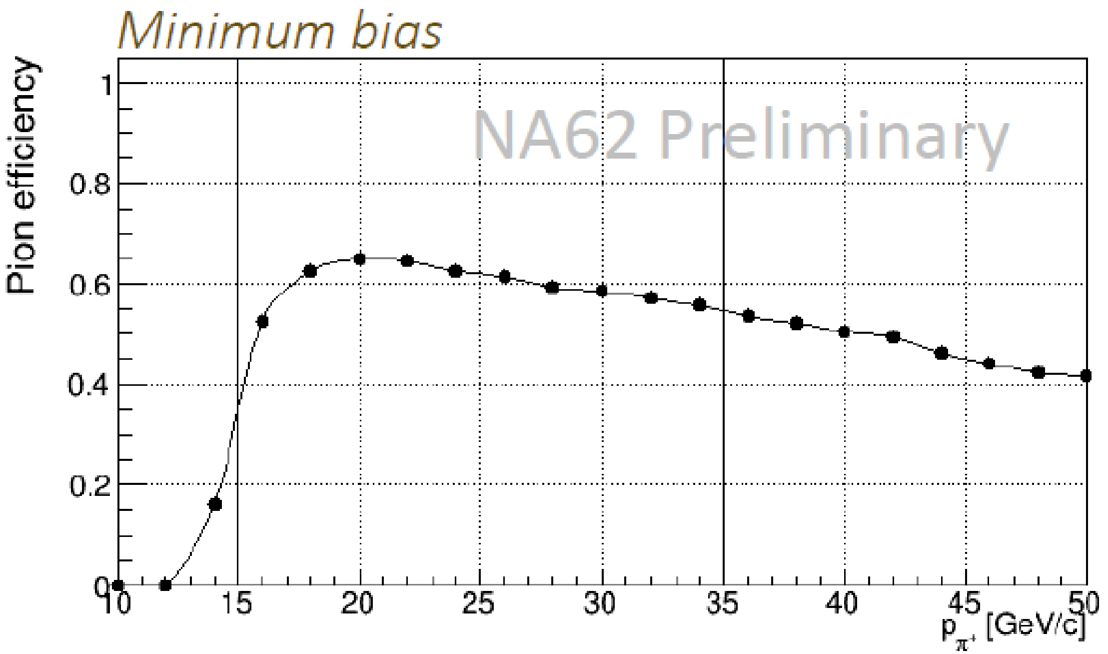
$\varepsilon_{ring}(\pi) \sim 90\%$ [depends on p_{π^+}]

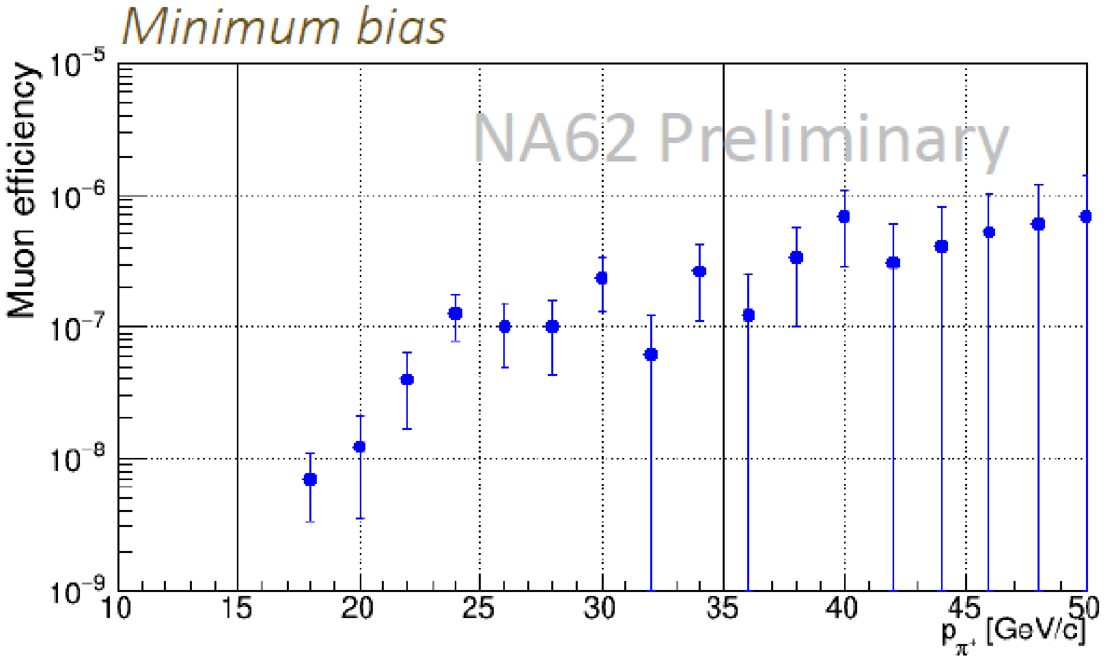
$\eta(\mu) \div \varepsilon_{ID}(\pi) \sim 10^{-2} \div 80\%$ [m]

- m: ring radius & p_{π^+} from STRAW
- p_{π^+}: ring radius assuming m_{π^+}

PID performance measurement:

- π and μ from $K^+ \to \pi^+\pi^0$ and $K^+ \to \mu^+\nu$ selected kinematically
- RICH, calorimeter independent

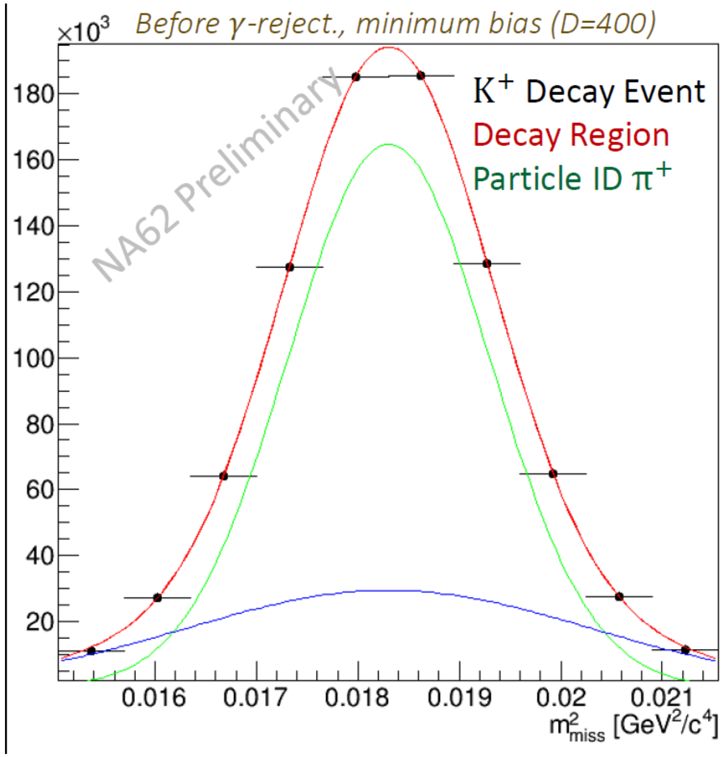


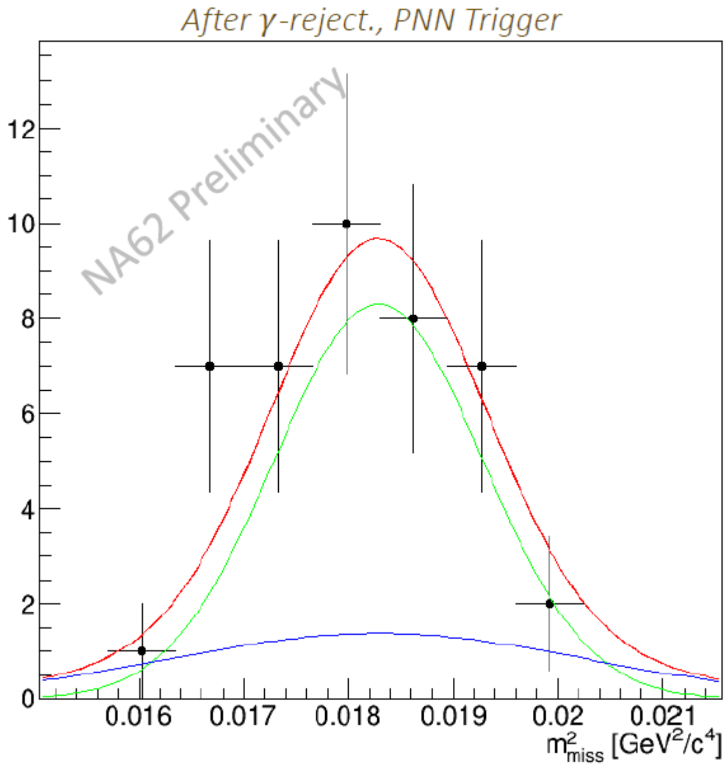


Photon rejection

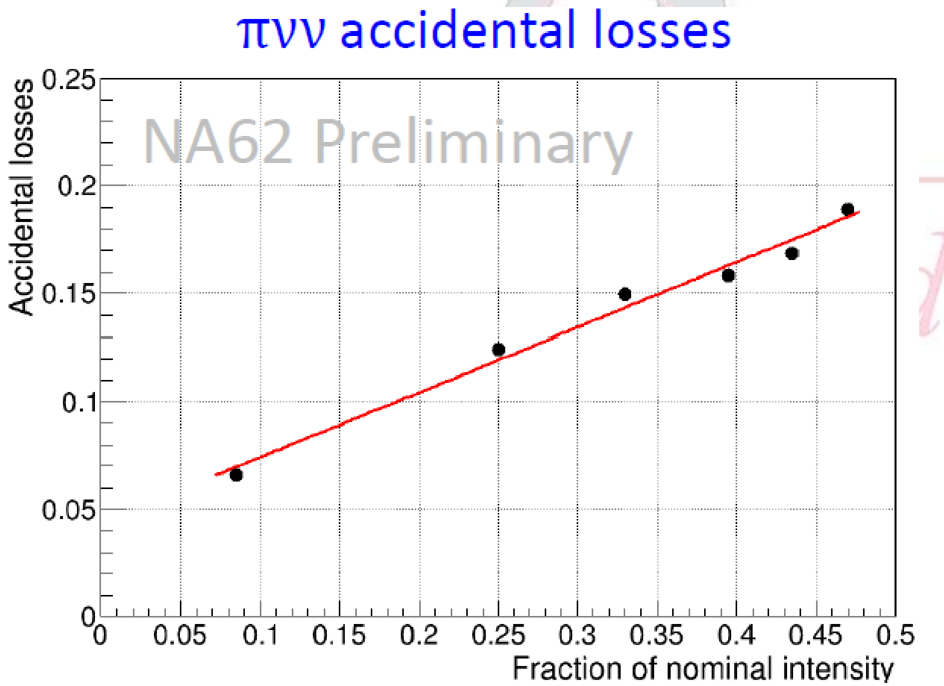
$\pi^+\pi^0$ suppression measurement:
events in $K^+ \rightarrow \pi^+\pi^0$ region

$$\epsilon_{\pi^0} = (1.2 \pm 0.2) \times 10^{-7}$$





$\pi\nu\nu$ accidental losses:
Measured on $K^+ \rightarrow \mu^+\nu$ region



Expected Signal and Background

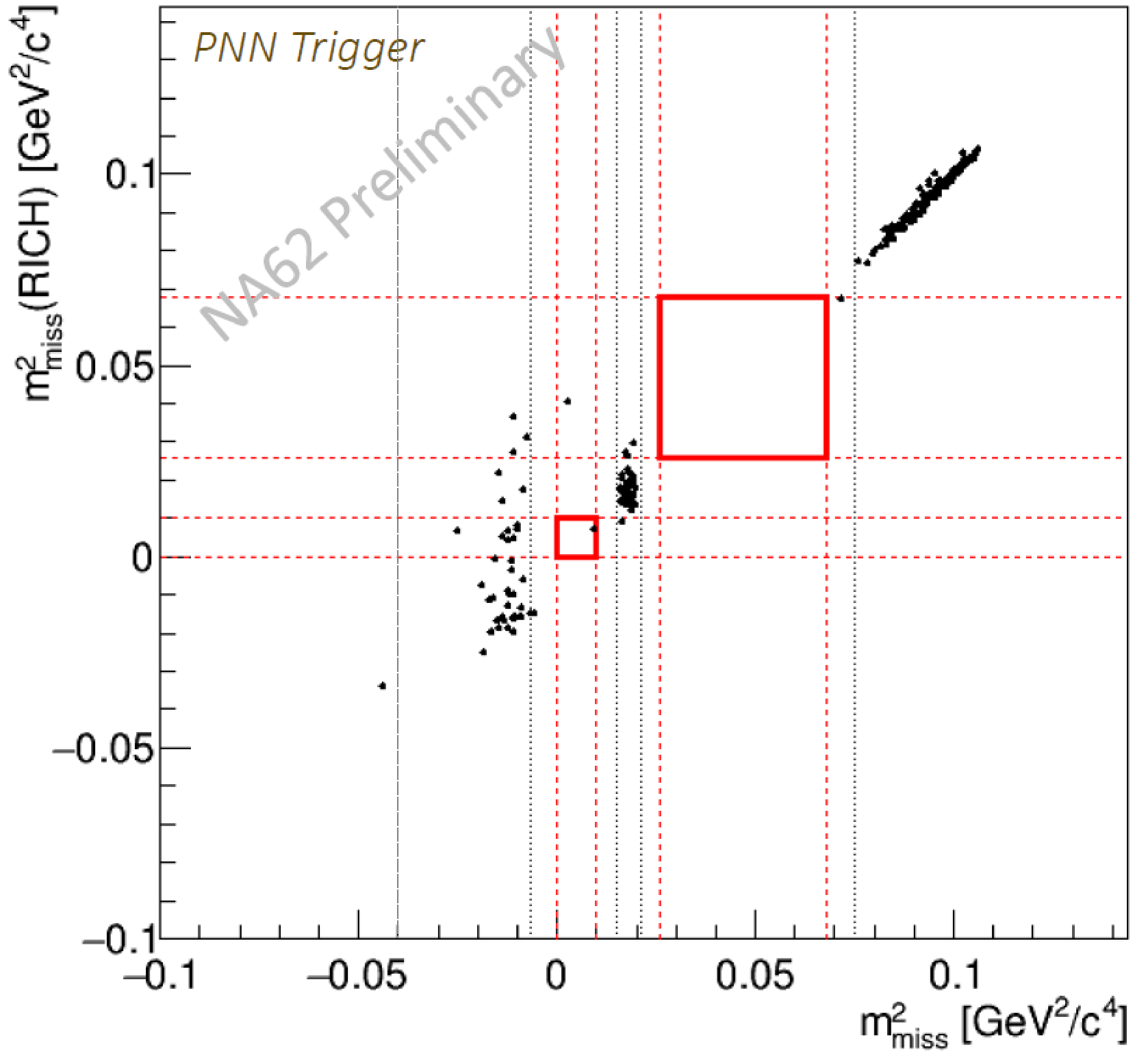
- **Normalization:** $K^+ \rightarrow \pi^+\pi^0$ in $\pi^+\pi^0$ region before γ-rejection from minimum bias
- **Acceptance:** ratio between signal and normalization, cancellations + MC
- **Photon veto random losses:** measured from data
- **Trigger efficiency:** measured from data
- **Branching ratios:** PDG (normalization), SM prediction (signal)

N(expected $\pi\nu\nu$) ≈ 0.064
N(K decays) ~ 2.3×10^{10}
N(normalization) = 3.3×10^{8}
Acceptance normalization ~ 0.07
Acceptance $\pi\nu\nu$ ~ 0.033

Process	*Expected Events*	*Branching ratio*
$K^+ \rightarrow \pi^+\pi^0$	0.024	0.2066
$K^+ \rightarrow \mu^+\nu$	0.011	0.6356
$K^+ \rightarrow \pi^+\pi^+\pi^-$	0.017	0.0558
Early Decays	<0.05	

5% of 2016 Data only

Signal and Background Regions



No events in signal regions

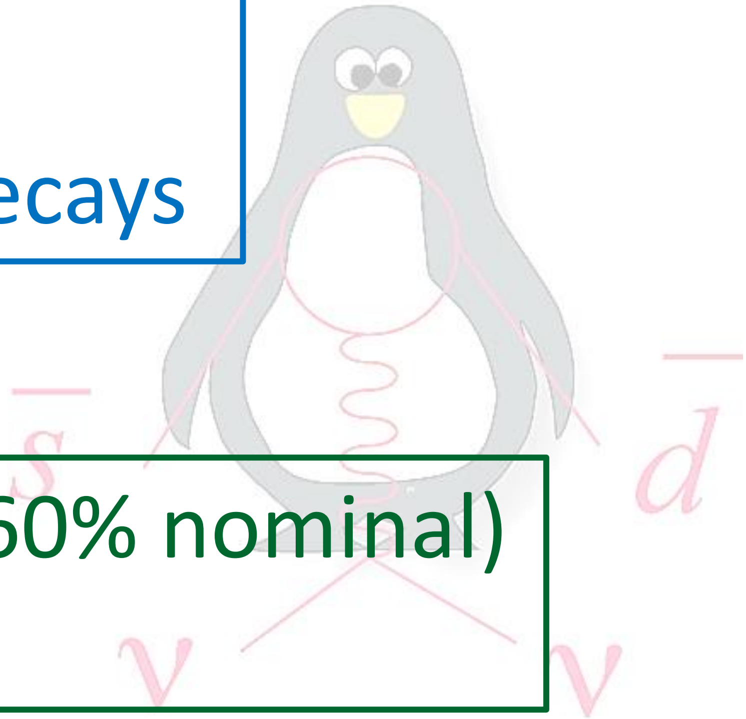
Event in box has m^2_{miss}(No GTK) outside the signal region

Data taken at an average intensity of 13×10^{11} ppp on T10 (40% nominal)

Plan for 2017

Stable data taking for Physics:

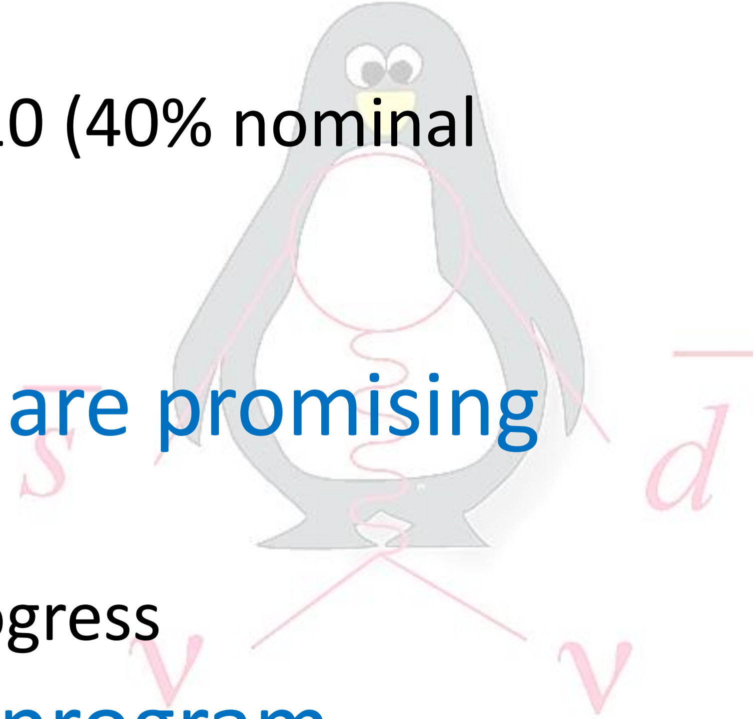
- $K^+ \rightarrow \pi^+ \nu \bar{\nu}$
- Exotics, Rare and Forbidden Decays



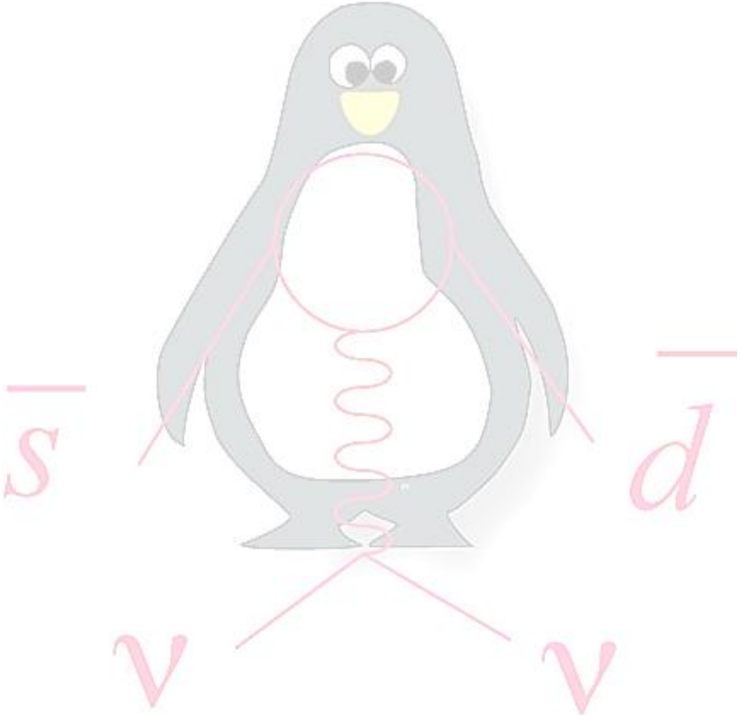
Optimal intensity around 20×10^{11} ppp (60% nominal)
Depending on spill quality

Conclusions

- NA62 fully working
- Good 2016 run:
  - Data for $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ at 13×10^{11} ppp average on T10 (40% nominal intensity)
  - Goal: test sensitivity down to 10^{-10}
- First preliminary results on πνν (5% data) are promising
  - Analysis of the full 2016 data set in progress
  - Optimization / Improvement of the analysis in progress
- Excellent prospects for a broader physics program



Spares



Expected Performances and Sensitivity

Required background suppression

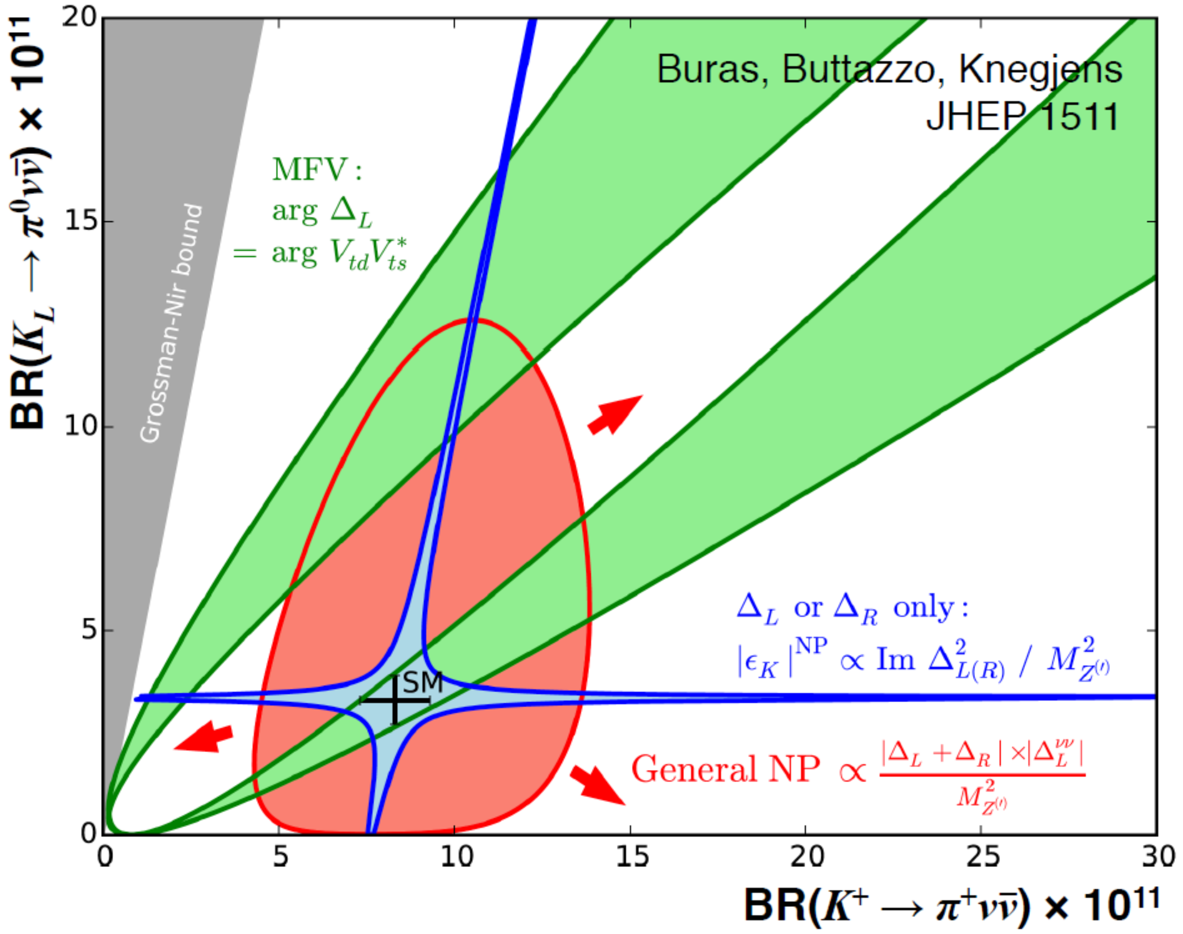
Kinematics	$O(10^4\text{-}10^5)$
Charged Particle ID	$O(10^7)$
γ detection	$O(10^8)$
Timing	$O(10^2)$

Sensitivity

Decay	ev/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$(IB)	1.5
$K^+ \to \mu^+ \nu \gamma$(IB)	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$, others	< 1
Total background	< 10

$K \to \pi\nu\bar{\nu}$ and New Physics

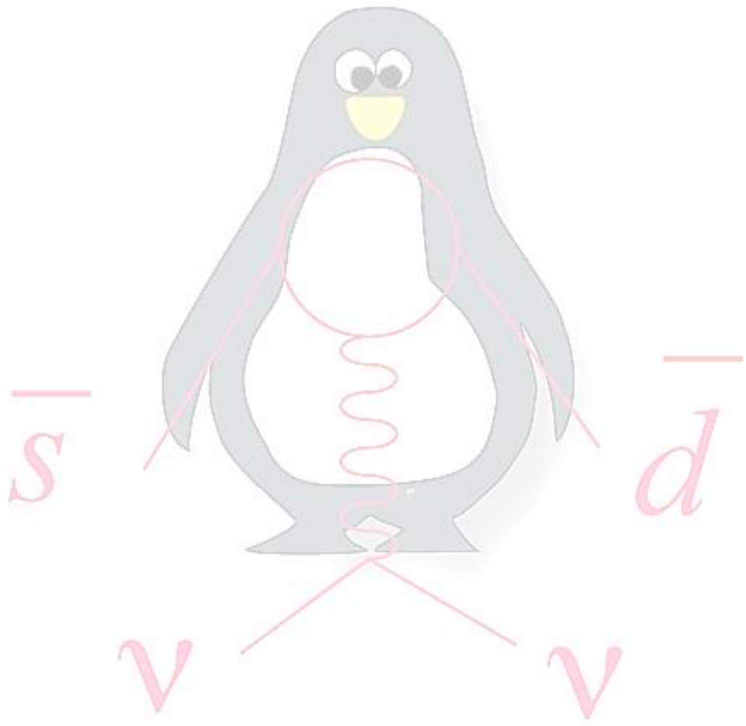
Measurement of charged ($K^+ \to \pi^+\nu\bar{\nu}$) and neutral ($K_L \to \pi^0\nu\bar{\nu}$) modes can **discriminate among different NP scenarios**



- Models with CKM-like flavor structure:
  - Models with MFV
- Models with new flavour-violating interactions in which either LH or RH currents dominate:
  - *Z/Z′* models with pure LH/RH couplings
  - Little Higgs with *T* parity
- Models without above constraints:
  - Randall-Sundrum

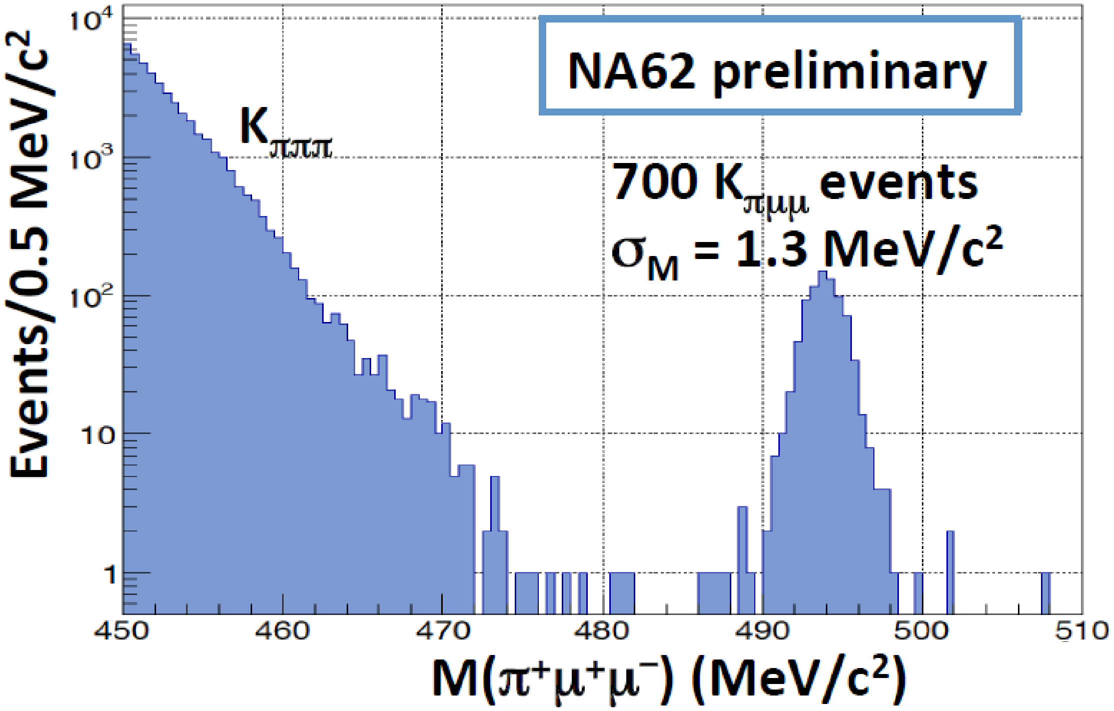
NA62 Physics beside $K^+ \rightarrow \pi^+ \nu \bar{\nu}$

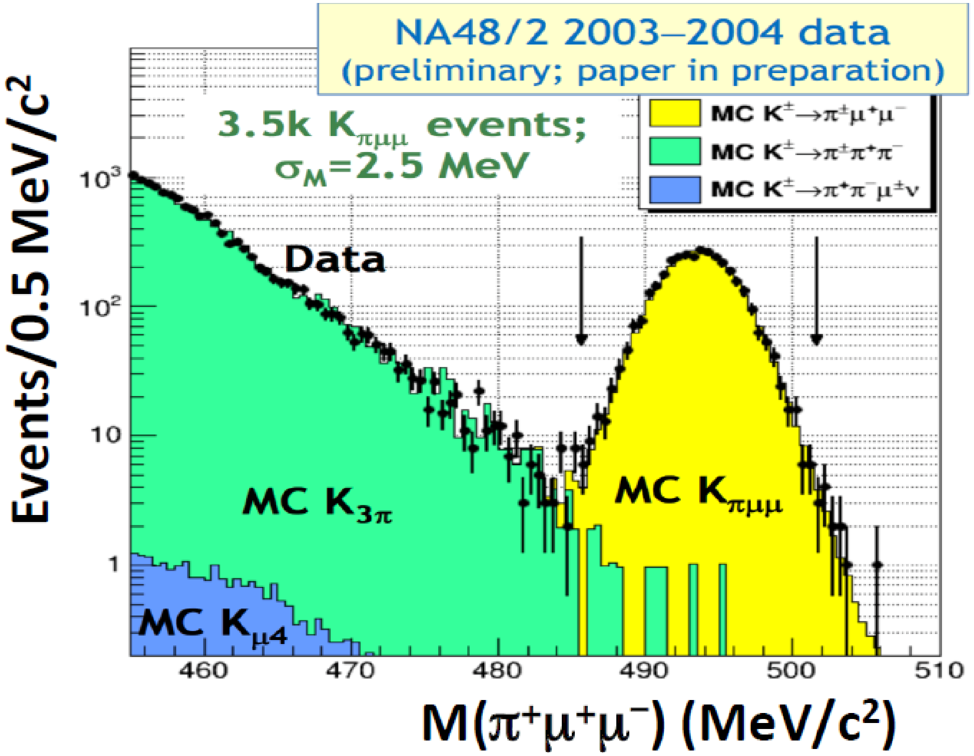
- Standard kaon physics:
  - ChPT studies: $K^+ \rightarrow \pi^+ \gamma\gamma$, $K^+ \rightarrow \pi^+ \pi^0 e^+ e^-$, $K^+ \rightarrow \pi^+ \ell^+ \ell^-$
- Searches for lepton-flavor or -number violating decays
  - $K^+ \rightarrow \pi^+ \mu^{\pm} e^{\mp}$, $K^+ \rightarrow \pi^- \mu^+ e^+$, $K^+ \rightarrow \pi^- \ell^+ \ell^+$
- Heavy neutral lepton production searches
  - $K^+ \rightarrow l^+ \nu_h$ (already under analysis with 2015 data)
  - ν_h from upstream K, D decays with $\nu_h \rightarrow \pi \ell$
- Searches for long-lived dark sector particles
  - Dark photon γ' produced in π/ρ decays in target, with $\gamma' \rightarrow \ell^+ \ell^-$
  - Axion-like particle A^0 produced in target/beam dump, with $A^0 \rightarrow \gamma\gamma$
- π^0 decays rare and forbidden/LFV, dark photon production:
  - $\pi^0 \rightarrow$ invisible, $\pi^0 \rightarrow 3/4\gamma$, $\pi^0 \rightarrow ee, eee$, $\pi^0 \rightarrow \mu e$, $\pi^0 \rightarrow \gamma' \gamma$



An Example: $K^+ \rightarrow \pi^+\mu^+\mu^-$

- A dedicated trigger in 2016 Run
- Sample from 2016 data: ~60k bursts (~2 week-equivalent) at ~18% intensity
- Improvements on NA48/2: mass resolution better by ~ a factor of 2
- BR is $O(10^{-7})$, expects improved sensitivity on hidden sector search, $K^+ \rightarrow \pi^+\chi, \chi \rightarrow \mu^+\mu^-$
- Basis for the search for LNV decay $K^+ \rightarrow \pi^-\mu^+\mu^+$





RICH Particle Identification