Search for $K^+ \to \pi^+ \nu \bar{\nu}$ decay at NA62 experiment

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Marie Skłodowska-Curie Actions

Outlook

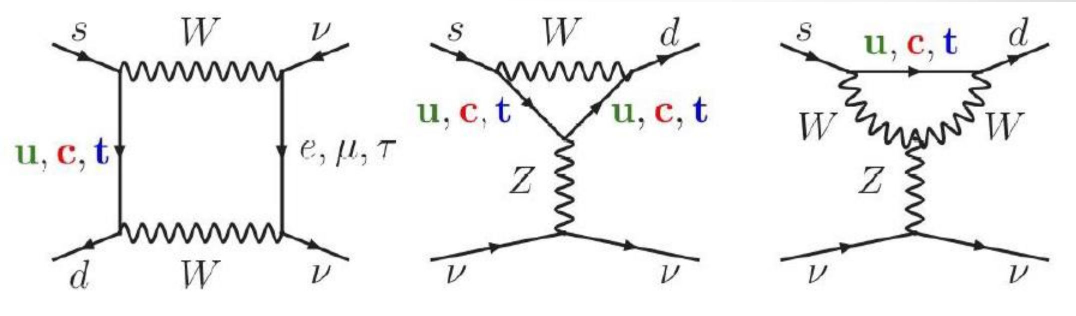
1. Motivation
2. NA62 experiment
3. Event selection
4. Analysis of the 2016 data
5. Conclusion

K→πνν in SM

2 modes: charged, neutral

- FCNC loop process
- Theoretically clean
- CKM suppression: BR ~ $|V^*_{ts}\ V_{td}|^2$

SM one-loop diagrams: box and penguins



Hadronic matrix element extracted from well-known decay $K^+ \to e^+ \nu \pi^0$

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

$$BR(K_L \to \pi^0 \nu\bar{\nu}) = \kappa_L \left(\frac{\mathrm{Im}\,\lambda_t}{\lambda^5} X(x_t) \right)^2$$

Top contribution (dominant)

charm contribution

EM radiative correction

$$\lambda = V_{us}$$
$$\lambda_c = V^*_{cs} V_{cd}$$
$$\lambda_t = V^*_{ts} V_{td}$$
$$x_q \equiv m_q^2 / m_W^2$$

[Buras et al. JHEP 1511 (2015) 33]

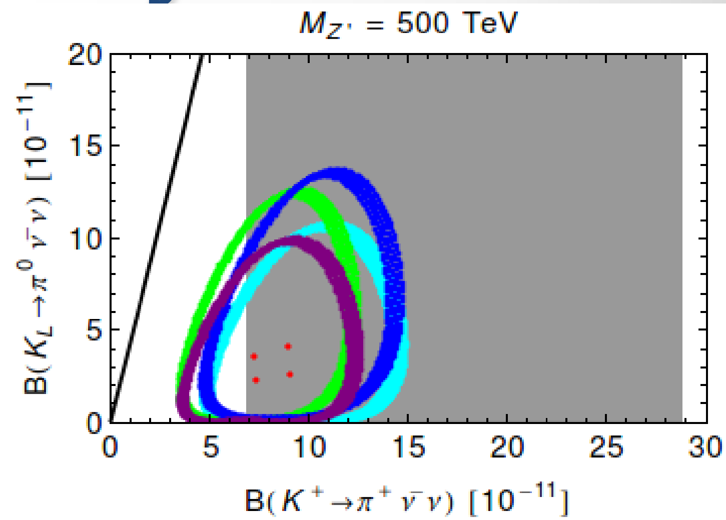
$BR(K^+ \to \pi^+ \nu\nu) = (8.4 \pm 1.0) \times 10^{-11}$

$BR(K^0 \to \pi^0 \nu\nu) = (3.4 \pm 0.6) \times 10^{-11}$

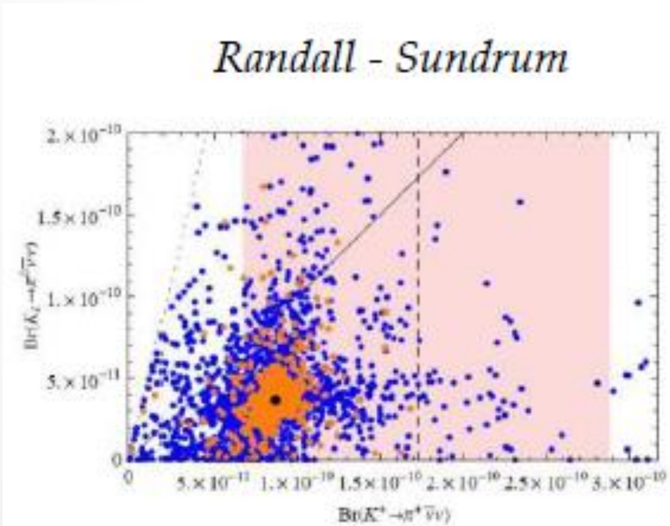
K→πνν in New Physics

Searches for NP in K→πνν:

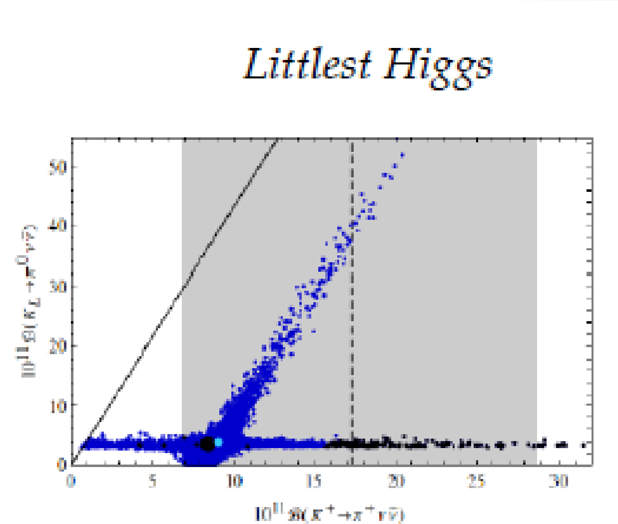
- Complementary to LHC
- Several scenarios possible
- Measurements of charged and neutral mode will allow to discriminate between NP scenarios



[Buras, Buttazzo,Knegjens, JHEP 1511 (2015) 166]



[Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]



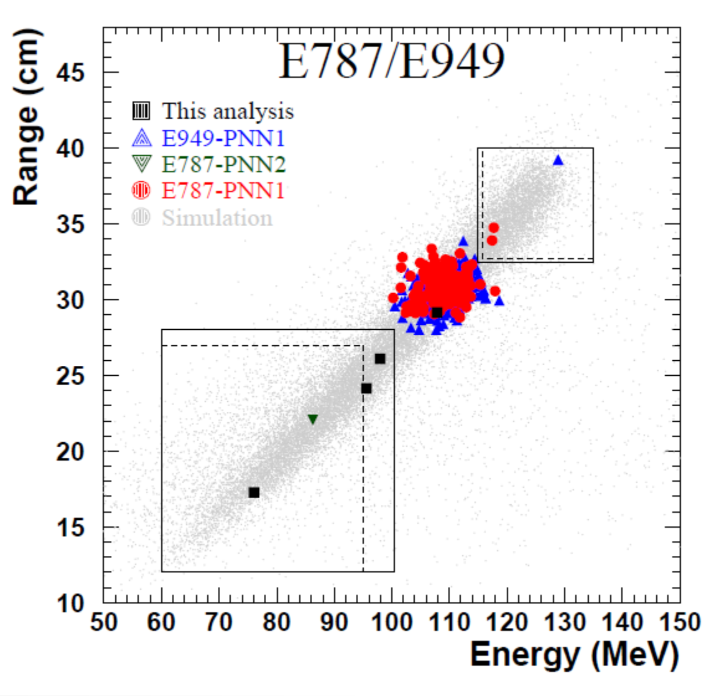
[Blanke, Buras, Recksiegel, EPJ C76 (2016) no.4 182]

$K \to \pi\nu\nu$ in experimental physics

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

E787/E949 experiment @ BNL

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

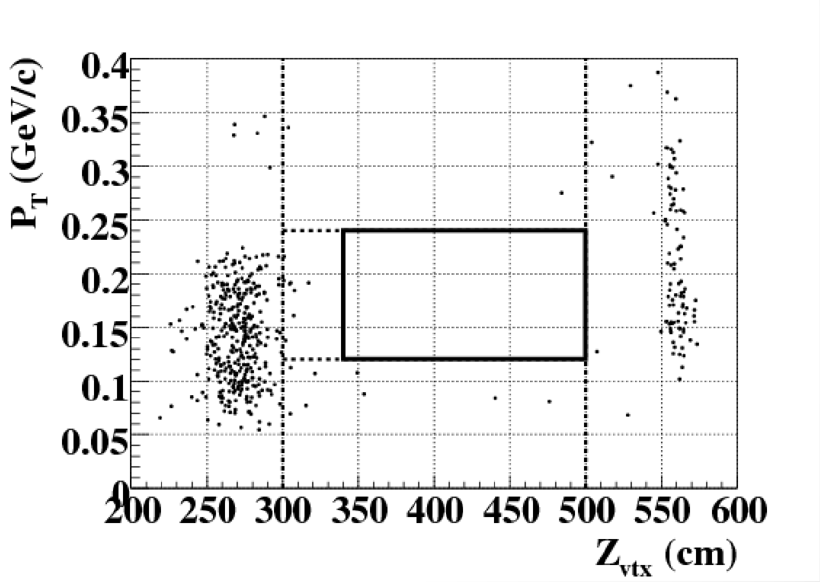


Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)

$K^0 \to \pi^0\nu\nu$

E391 experiment @ KEK

$$BR(K_L \to \pi^0 \nu\bar{\nu}) < 2.6 \times 10^{-8}$$



Phys. Rev. D 81, 072004 (2010)

NA62 goals

Main goal:

- Measure BR($K^+ \rightarrow \pi^+ \nu\nu$) with 10% precision

Requirements:

- O(100) events
- ~10^{13} kaon decays
- ~10% signal acceptance
- >10^{12} background suppression

Technique:

- Kaon decay-in-flight

Beyond the baseline:

- LFV/LNV decays in kaon decays
- Heavy neutral lepton searches
- π^0 decays
- Hidden sector particles searches

NA62 @ SPS CERN

NA62 prehistory:

- 1997-2001: NA48 (ε'/ε in K^0)
- 2002: NA48/1 (K_S rare decays)
- 2003-2004: NA48/2 ($K^\pm$ decays)
- 2007-2008: NA62-RK ($Ke2/K\mu2$)

NA62 history:

2006: Proposal

2007-2011: R&D

2011-2014: construction & installation

2012: Technical run (partial layout)

2014: Pilot run (full layout)

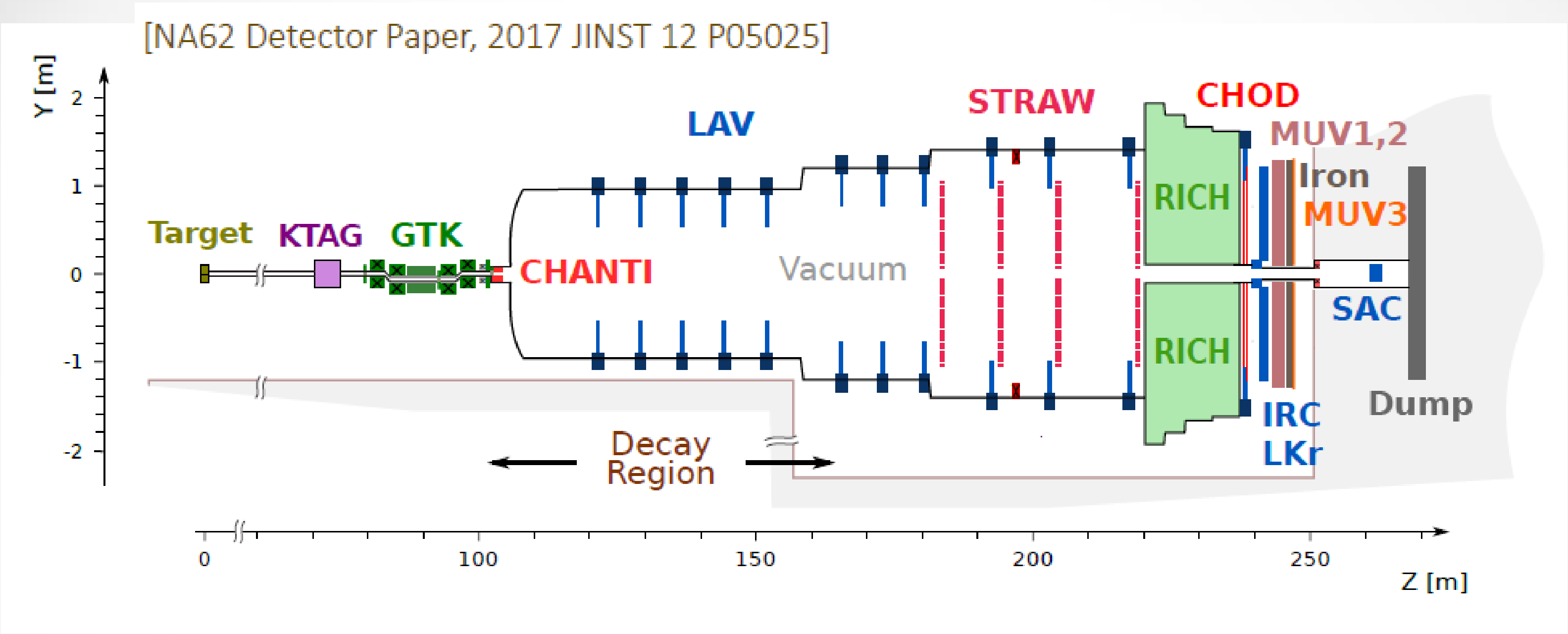
2015: Commissioning run

2016: Commissioning run + Physics run

NA62 collaboration:

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

NA62 detector



Beam:

- SPS primary beam: 400 GeV/c, ~33 $\cdot 10^{11}$ ppp on target (nominal intensity)
- Secondary hadron beam: 75 GeV/c, ~750 MHz @ GTK
- Beam composition: 6% K^+, 70% π^+, 24% p
- Beam geometry: 60 x 30 mm^2, 100 μrad divergency (RMS)

NA62:

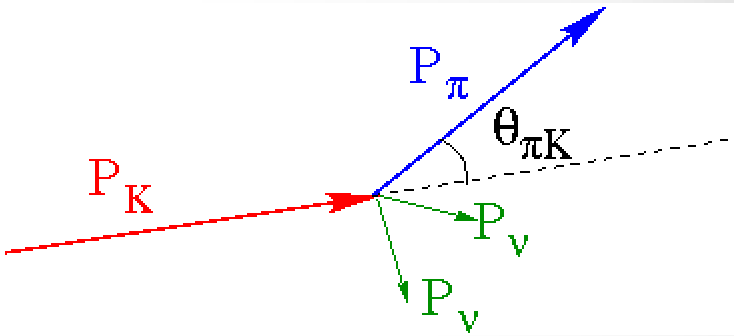
- ~5 MHz kaon decay rate
- ~10% signal efficiency
- 60 m fiducial volume
- Trackers (GTK for P_K, STRAW for P_π)
- Cherenkov counters for PID (KTAG for K, RICH for π)
- Hadron calorimeters for PID (MUV1,2)
- Photon veto system (LAV, LKr, IRC, SAC)

Signal vs background

Main kinematical variable for the signal:

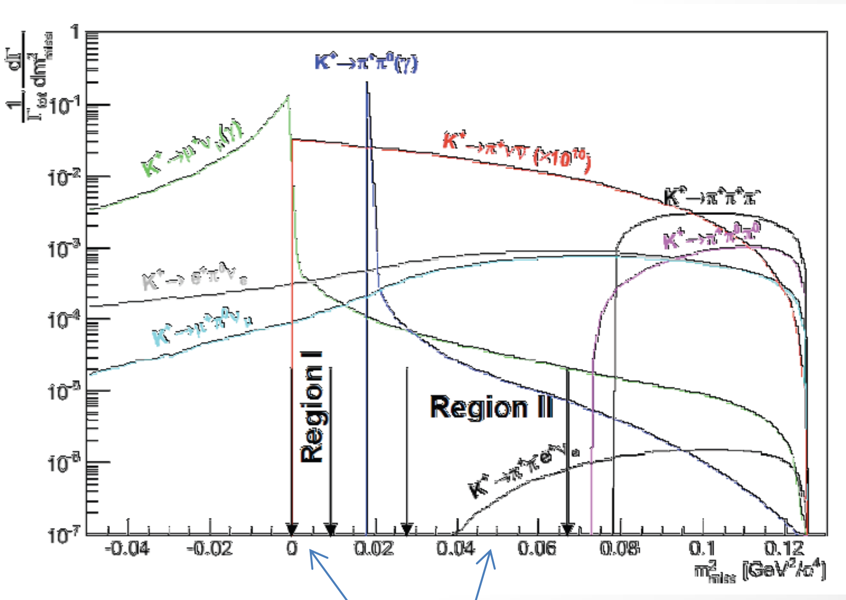
$m^2_{miss} = (P_K - P_\pi)^2$

$$m^2_{miss} \cong m^2_K\left(1-\frac{|P_\pi|}{|P_K|}\right) + m^2_\pi\left(1-\frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$



Decay backgrounds

Mode		BR
$\mu^+\nu(\gamma)$	$K_{\mu 2}$	63.5%
$\pi^+\pi^0(\gamma)$	$K_{2\pi}$	20.7%
$\pi^+\pi^+\pi^-$	$K_{3\pi}$	5.6%
$\pi^0 e^+\nu$	K_{e3}	5.1%
$\pi^0\mu^+\nu$	$K_{\mu 3}$	3.3%
$\pi^+\pi^- e^+\nu$	$K_{e4}(+-)$	4.1×10^{-5}
$\pi^0\pi^0 e^+\nu$	$K_{e4}(00)$	2.2×10^{-5}
$\pi^+\pi^-\mu^+\nu$	$K_{\mu 4}$	1.4×10^{-5}
$e^+\nu(\gamma)$	K_{e2}	1.5×10^{-5}



2 signal regions defined

Other background:

- Accidental tracks in time with kaon tracks
- Beam-gas and upstream interactions

Event selection principles

Kaon detection	t_K	p_K	PID	K interactions
KTAG	✓		✓	
GTK	✓	✓		
CHANTI				✓

Pion detection	t_π	p_π	PID	π interactions
Spectrometer		✓		
RICH	✓		✓	
CHOD	✓			✓
MUV1,2			✓	

Keystones:

- $O(10^4)$ background suppression from kinematics
- O(100 ps) timing between detectors
- $>10^7$ muon suppression
- $>10^7$ π^0 suppression

Event reconstruction:

- 1 pion track
- K-π track matching (fast timing)
- Cuts on m^2_{miss} (Region I and II)
- Cut on P_π : $15 < P_\pi < 35$ GeV/c

(> 40GeV missing energy)

L0 trigger:

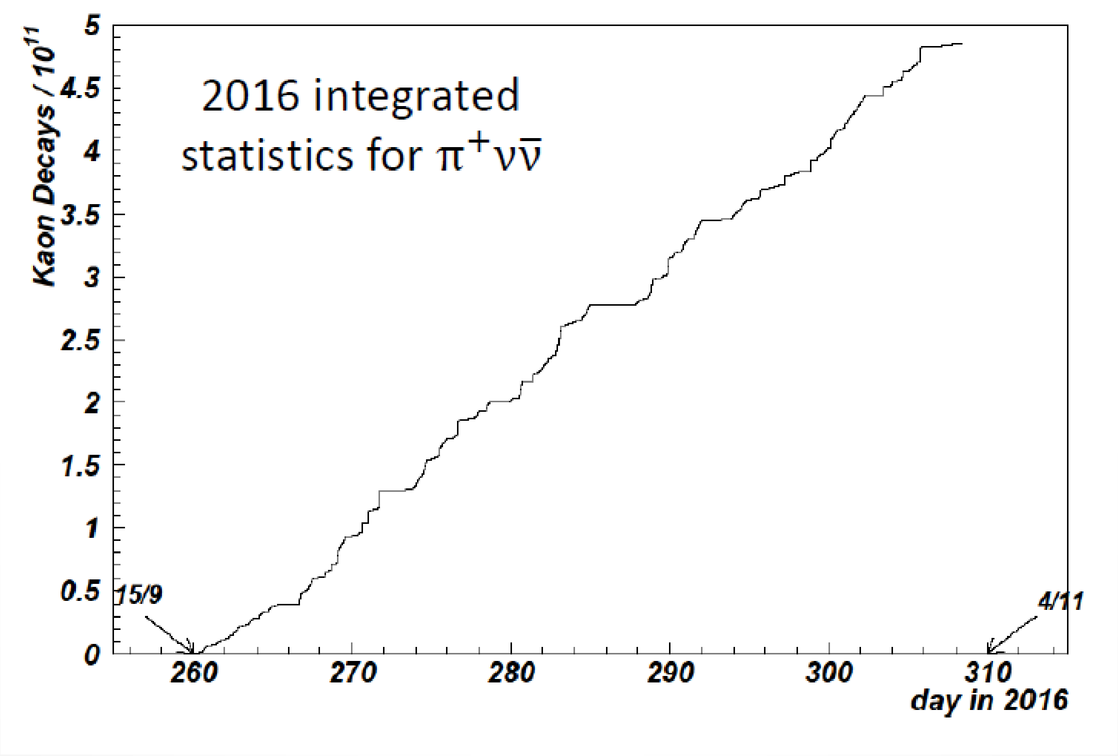
- 1 secondary charged track
- No muons among decay products
- "pion-like" energy deposition in calorimeters
- Precise time from RICH

veto:

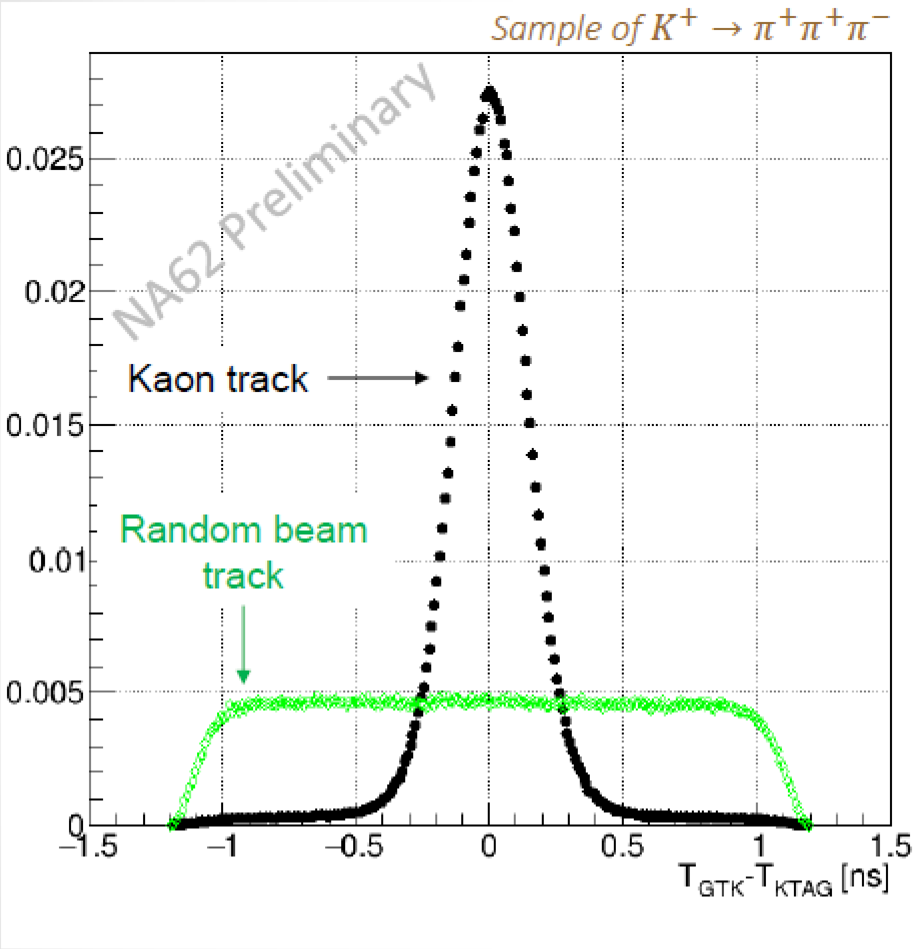
- upstream veto (CHANTI)
- photon vetoes (LAV/LKr/IRC/SAC)
- muon veto (MUV3)

2016 physics run

- ~4 x 10^{11} kaon decays collected in 2016
- This talk: analysis of ~5% (2.3*10^{10}) 2016 data
- Beam intensity: 13 x 10^{11} ppp (40% of the nominal)



Kaon-pion matching



Kaon time:

- KTAG: σ ~ 80 ps
- GTK: σ ~ 100 ps

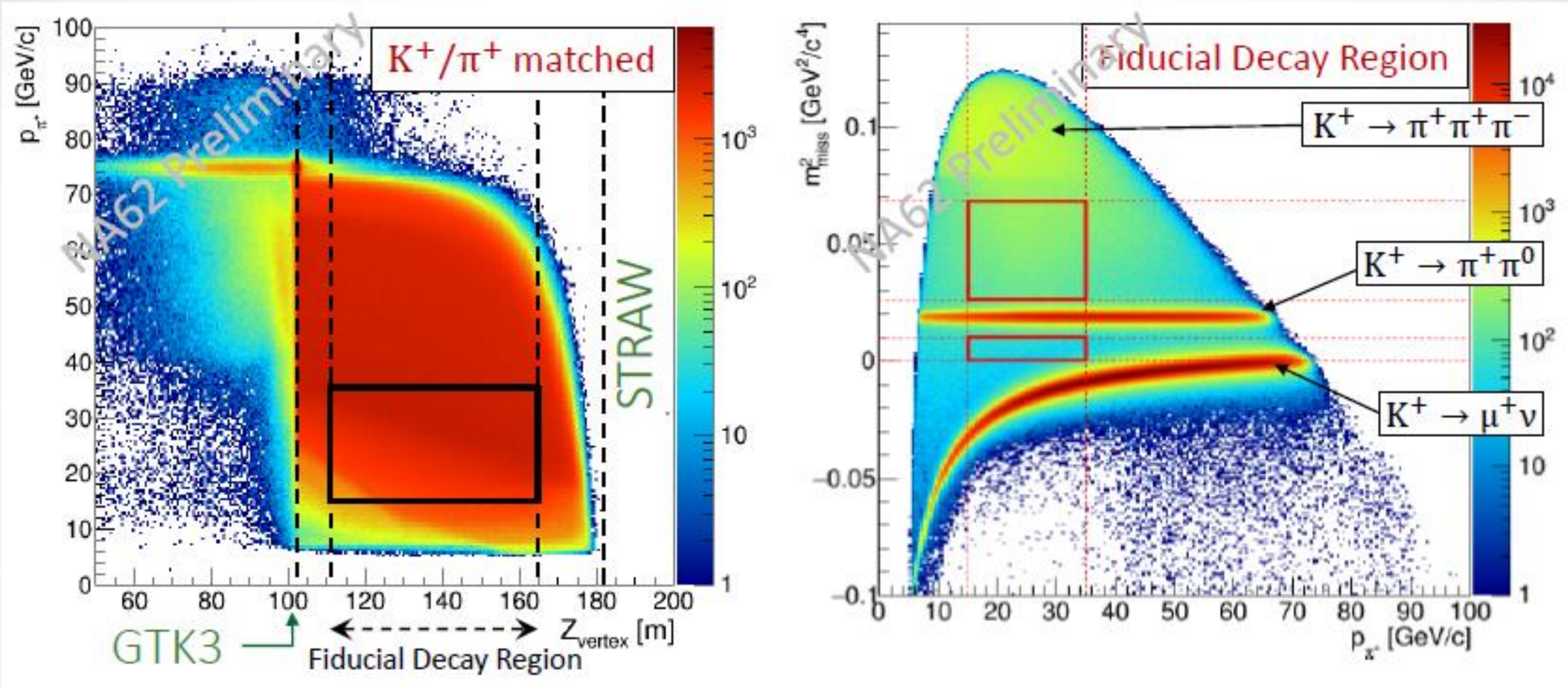
Pion time:

- CHOD: σ ~ 250 ps
- RICH: σ ~ 150 ps

K-π matching:

- Spatial track intersection: σ(CDA) ~ 1.5 mm
- Mistagging probability 1.7%
- Efficiency 75%

Signal regions



Signal region:

- Z_{vertex}
- P_{π}
- m^2_{miss}

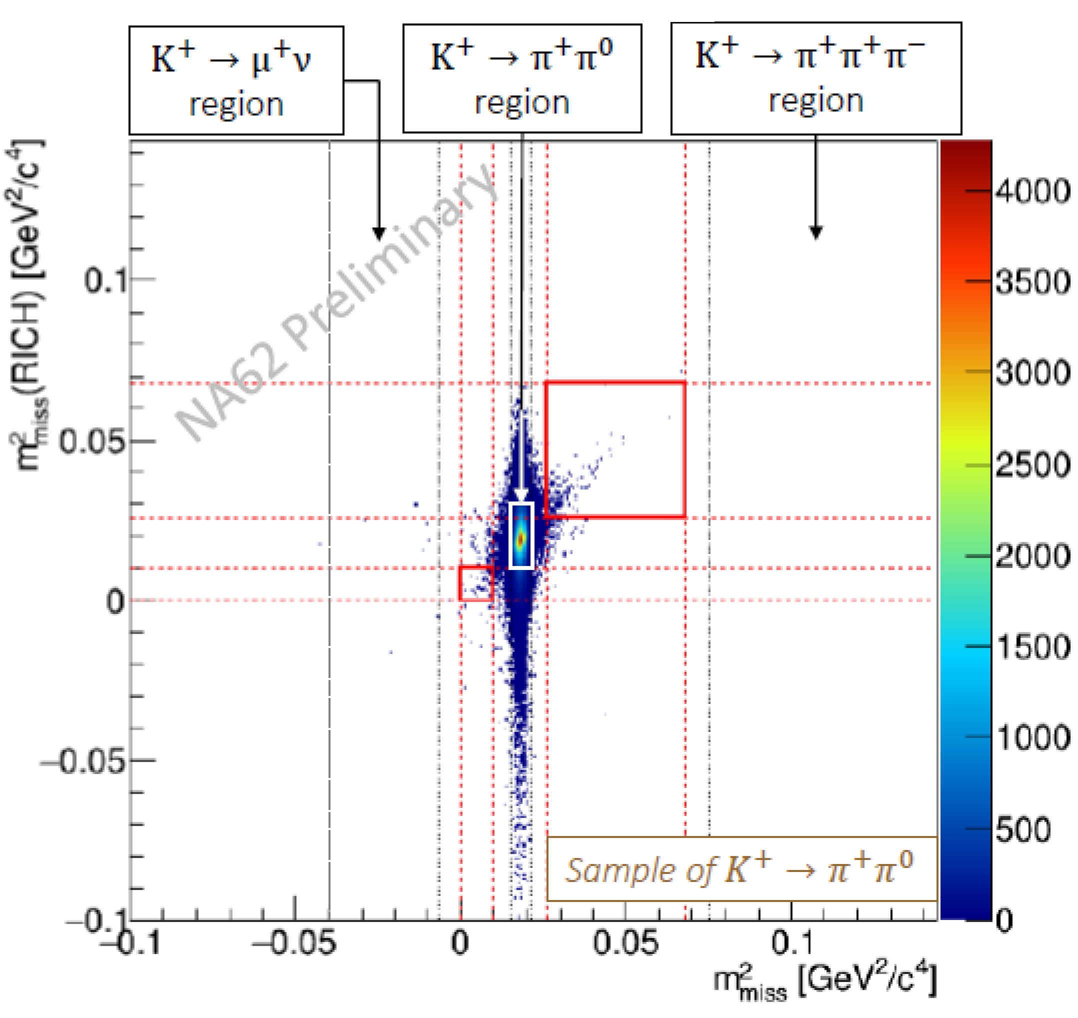
3 types of m^2_{miss} used:

- M^2_{miss} : P_K (GTK), P_{π} (STRAW)
- M^2_{miss} (RICH) : P_K (GTK), P_{π} (RICH)
- M^2_{miss} (No GTK): P_K (nominal), P_{π} (STRAW)

Kinematic regions and suppression

Suppression measurement procedure:

- data-driven
- $K^+ \to \pi^+ \pi^0$ and $K^+ \to \mu^+ \nu_\mu$ samples selected

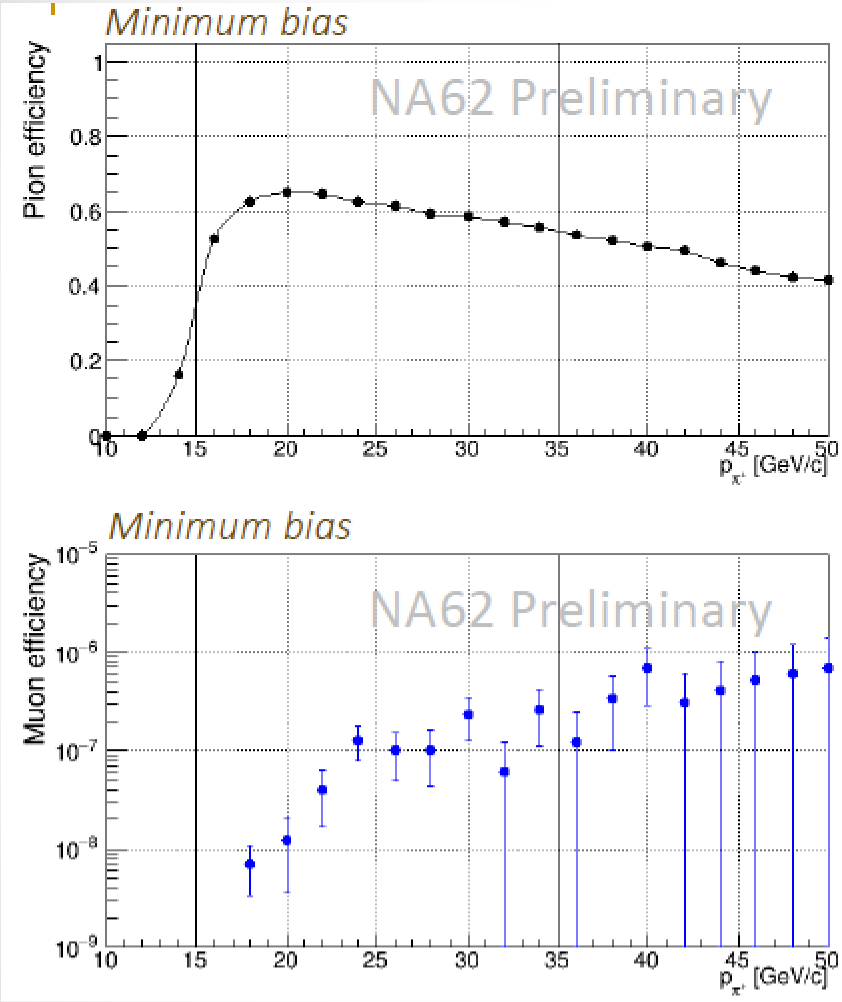


Kinematic suppression:

$K^+ \to \pi^+ \pi^0$ ~ 6 x 10^{-4}

$K^+ \to \mu^+ \nu_\mu$ ~ 3 x 10^{-4}

Pion ID



Calorimeters:

$\varepsilon(\mu) \sim 10^{-5}$

$\varepsilon(\pi) \sim 80\%$

RICH:

$\varepsilon(\mu) \sim 10^{-2}$

$\varepsilon(\pi) \sim 90\%$[ring reco] x 80% [PID]

RICH + calorimeters:

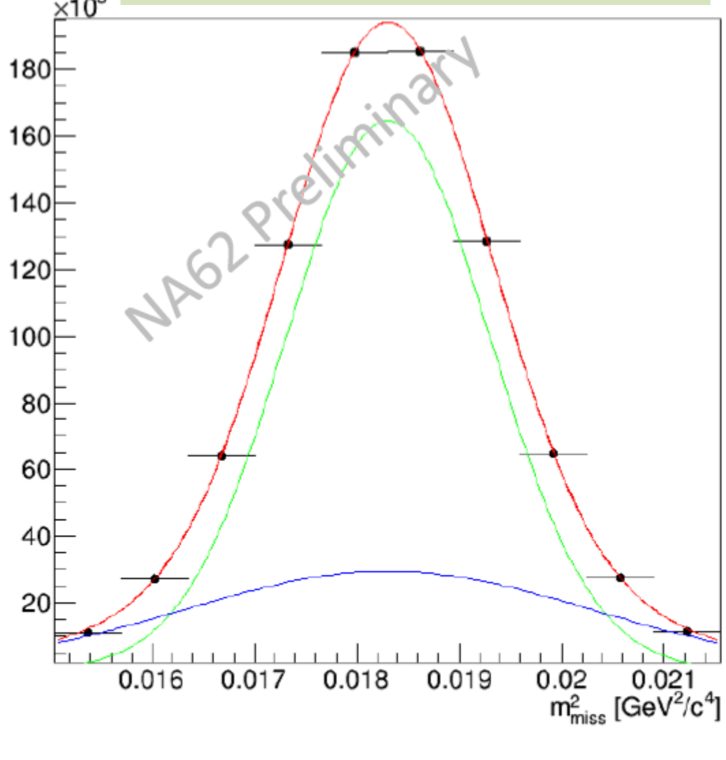
$\varepsilon(\mu) \sim 10^{-7}$

$\varepsilon(\pi) \sim 60\%$ (momentum dependant)

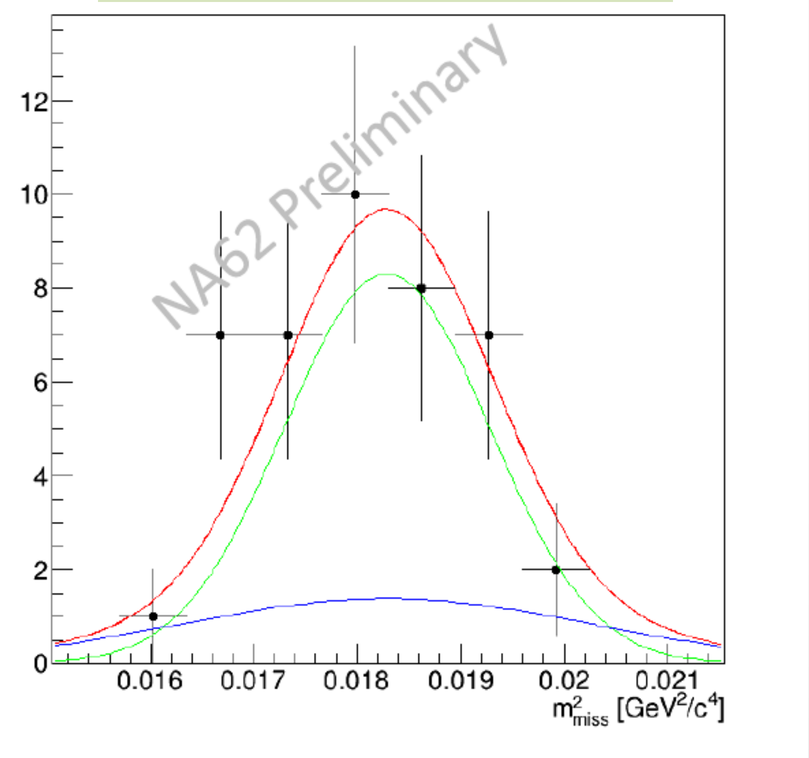
Photon rejection

- Photon veto detectors: LAV, LKr, IRC, SAC
- Kinematic region for the rejection estimate: $K^+ \to \pi^+ \pi^0$ region
- $K^+ \to \pi^+ \pi^0$ suppression: **$\varepsilon = (1.2 \pm 0.2) * 10^{-7}$**
- Accidental losses: 15-16% (at 40% of the nominal intensity)

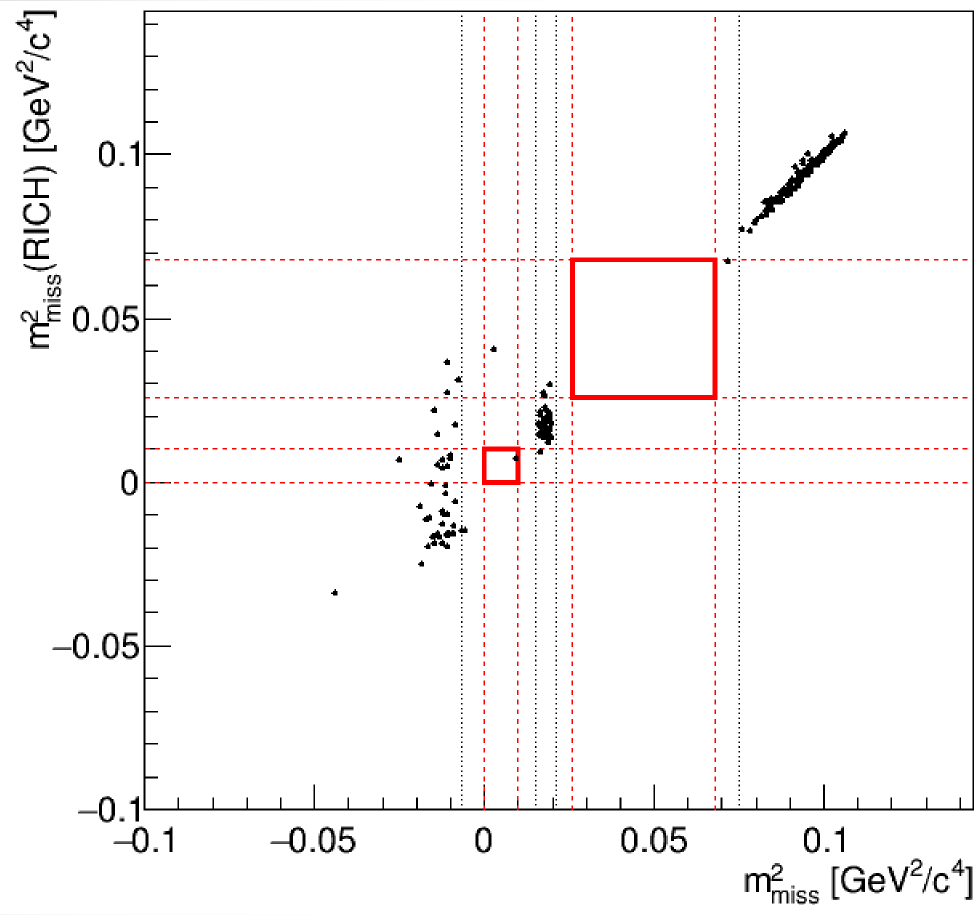
Minimum bias trigger (D=400)
Before γ rejection



Physics trigger for $K^+ \to \pi^+ \nu \nu$
After γ rejection



Preliminary result



- **0 events observed**

  1 event in the box: m^2_{miss} (no GTK) outside the signal region

- **Expected signal: 0.064**

  Acceptance: 0.033
  Normalization: $K^+ \to \pi^+\pi^0$

- **Expected background: <0.057**

  Bkg data-driven estimates:

$K^+ \to \pi^+\pi^0$	**0.024**
$K^+ \to \pi^+\pi^+\pi^-$	0.017
$K^+ \to \mu^+\nu_\mu$	0.011
Beam-induced	<0.005
Total bkg	**<0.057**

Analysis optimization in progress

Prospects

- Analysis of 2016 data: reach SM sensitivity
- 2017 physics run: 4 months, beam intensity ~55-60% of the nominal one
- 2018: 4 months run scheduled
- 2019-2020: LS2
- 2021-2023: more $K^+ \to \pi^+ \nu\nu$ runs (and/or LFV/LNV, beam dump)

Conclusion

- The decay $K^+ \to \pi^+ \nu\nu$ provides unique opportunities for NP searches complementary to LHC
- The NA62 is aimed at measuring $BR(K^+ \to \pi^+ \nu\nu)$ with ~10% precision by collecting O(100) events
- NA62 is running; detector performance within expectations
- SM sensitivity to be reached soon, data analysis ongoing
- BR measurement: in few years

Thank you!