Search for $\mathrm{K}^+ \to \pi^+\nu\bar{\nu}$ *at NA62*

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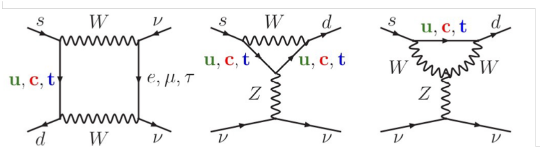
Outline

1. Theoretical motivation
2. NA62 setup
3. Event selection and analysis strategy
4. Analysis status/prospects

Theoretical motivation

- FCNC loop process: s→d coupling and highest CKM suppression



- Very clean theoretically: Short distance contribution and no hadronic uncertainties - Hadronic matrix element extracted from well-known decay $K^+ \to e^+\nu\pi^0$
- SM predictions: [Buras et al. arXiv:1503.02693], [Brod, Gorbahn, Stamou, Phys. Rev.D 83, 034030 (2011)]

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

$$BR(K_L^0 \to \pi^0\nu\bar{\nu}) = (3.36 \pm 0.05) \cdot 10^{-11} \left(\frac{|V_{ub}|}{0.00388}\right)^{2} \left(\frac{|V_{cb}|}{0.0407}\right)^{2} \left(\frac{\sin\gamma}{\sin 73.2}\right)^{2} = (3.4 \pm 0.6) \cdot 10^{-11}$$

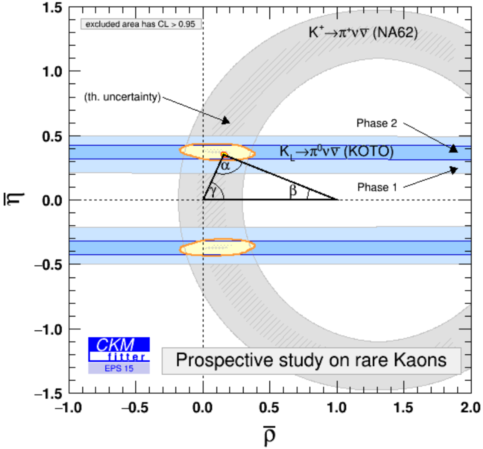
- Experiments:

$BR(K^+ \to \pi^+\nu\bar{\nu}) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$ Phys.Rev.D77, 052003(2008), Phys.Rev.D79, 092004(2009)

$BR(K_L^0 \to \pi^0\nu\bar{\nu}) < 2.6 \times 10^{-8}$ Phys.Rev.D81, 072004(2010)

Testing the Standard Model

- BR($K^+ \to \pi^+ \nu\bar{\nu}$) with 10% uncertainties allows to determine $|V_{td}|$ at 9% [Buras 0405132]
- With BR($K^+ \to \pi^+ \nu\bar{\nu}$), BR($K^0_L \to \pi^0 \nu\bar{\nu}$) the CKM unitarity triangle can be built independently from B observables:

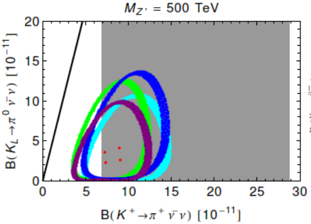


Going Beyond the Standard Model

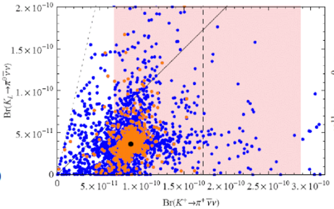
- Simplified Z, Z' models [Buras, Buttazzo,Knegjens, arXiv:1507.08672 (2015)]
- Littlest Higgs with T-parity [Blanke, Buras, Recksiegel, arXiv:1507.06316 (2015)]
- Custodial Randall-Sundrum [Blanke, Buras, Duling, Gemmler, Gori, JHEP 0903 (2009) 108]
- MSSM non-MFV [Blazek, Matak Int.J.Mod.Phys.A29 (2014) 1450162;
  Tanimoto, Yamamoto PTEP (2015) 053B07; Isidori et al. JHEP 0608 (2006) 064]

- Constraints from existing measurements (correlations model dependent):
  Kaon mixing and CPV, CKM fit, K,B rare meson decays,
  NP limits from direct searches

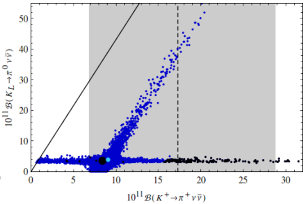
$Z'\,model$



$Randall - Sundrum$



$LittlestHiggs$

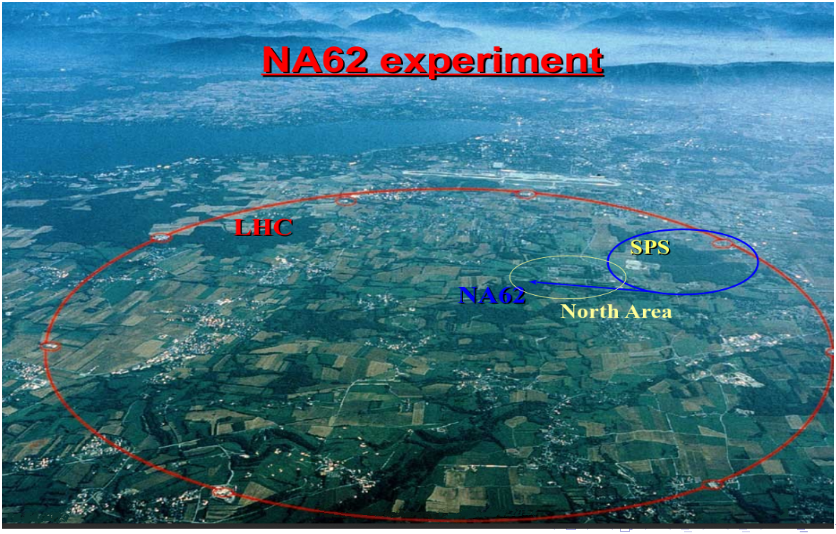


Physics programme of NA62 experiment

- Main goal:
  - Collect O(100) signal events in 2 years ⇒ 10^{13} Kaon decays
  - Measure BR($\mathrm{K}^+ \to \pi^+ \nu\bar{\nu}$) with 10% precision
  - Signal acceptance $\sim$ 10%
  - Systematics: $<$10% precision background measurement
  - $> 10^{12}$ background rejection ($<$ 20% background)
- Further goals:
  - Measure $|V_{td}|$ with $\sim$10% accuracy
  - Probe several NP scenarios in $\mathrm{K}^+ \to \pi^+ \nu\bar{\nu}$
  - Probe NP in similar processes (e.g. $\mathrm{K}^+ \to \pi^+ X$)
- Beyond the baseline:
  - LFV/LNV decays with 3 tracks in the final state
  - Heavy neutrino searches
  - π^0 decays
  - Dark photon searches

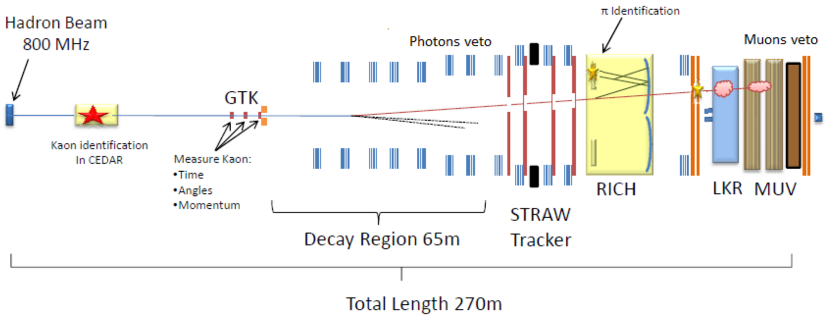
Experiment NA62 at CERN

1. SPS experiment NA62 - North Area experiment, Prèvessin
2. Extracting 74 GeV/c K^+ from 400 GeV/c proton beam



Detector layout

- $\sim$ 11MHz of K^+ decays



- High Intensity and fast Timing
- Low Mass Tracking
- Hermetic Vetoing for Photons and Muons
- Particle ID

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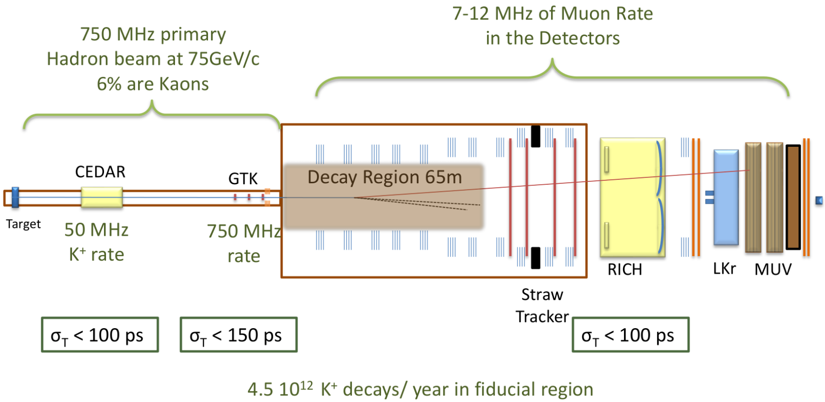

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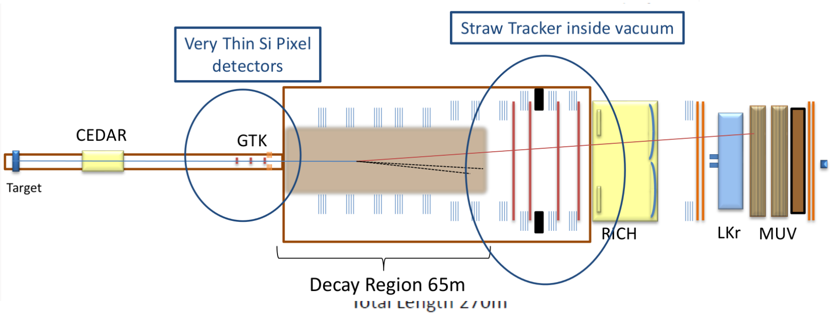

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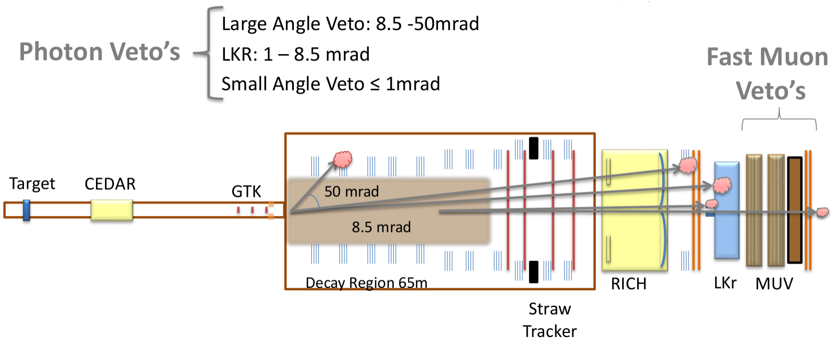

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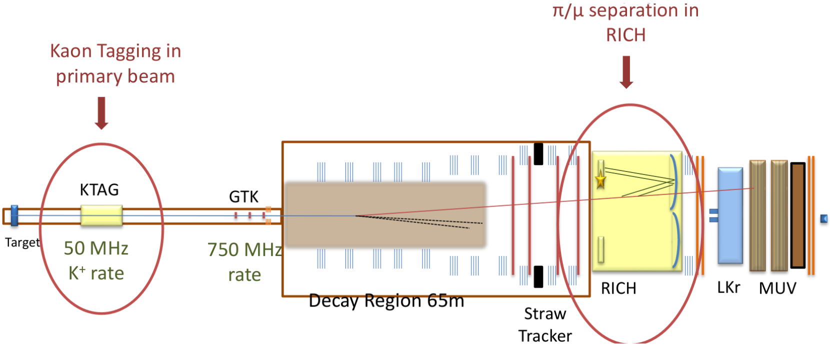

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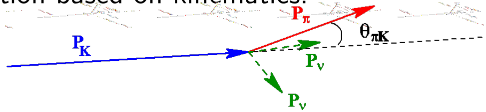
Experimental status

- NA62 took data in 2014 and 2015
- Beam commissioned up to nominal intensity Tracker:
  - Beam tracker (Gigatracker) partially commissioned
  - Straw spectrometer commissioned
- Cherenkov detectors:
  - Beam Kaon ID (KTAG) commissioned
  - RICH commissioned
- All the other detectors commissioned
- Trigger:
  - L0 commissioned; L1(2) partially commissioned
- Data samples for data quality study (mainly from 2015):
  - Low intensity data taken with a minimum bias trigger (this talk)
  - Samples at half and full intensity taken with a calorimeter trigger

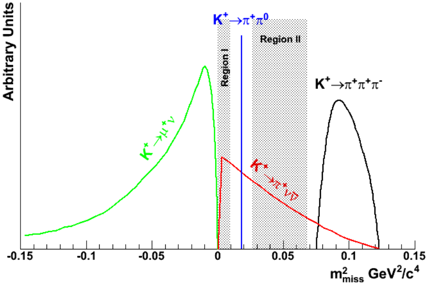
Scheme for $K^+ \to \pi^+\nu\bar{\nu}$

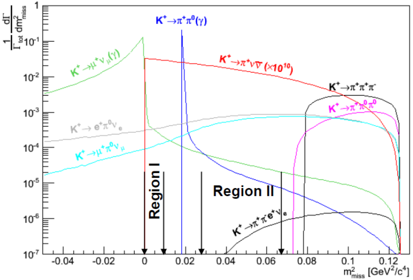
- Reconstruction based on kinematics:



$$m^2_{miss} = (P_K - P_\pi)^2 \approx m_k^2\left(1 - \frac{|P_\pi|}{|P_K|}\right) + m_\pi^2\left(1 - \frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\vartheta^2_{\pi K}$$

- 92% of Kaon decays are kinematically constrained





- Key analysis requirements:
  - 2 signal regions in m^2_{miss}
  - $15 < P_{\pi^+} < 35$ GeV/c
  - 65 m long decay region
- Expected 45 SM signal events/year with $\leq$ 10 background
- Main background sources:

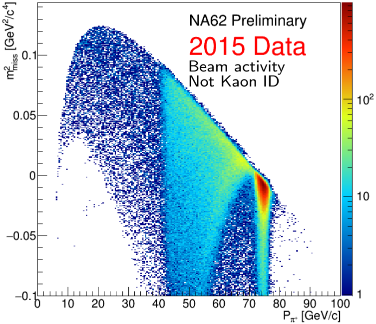
Decay mode	event/year
$K^+ \to \pi^+ \nu \bar{\nu}$ SM	45
Total Background	10
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 track decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma^{IB}$	1.5
$K^+ \to \mu^+ \nu \gamma^{IB}$	0.5
$K^+ \to \pi^0 e^+ (\mu^+) \nu$ + others	negligible

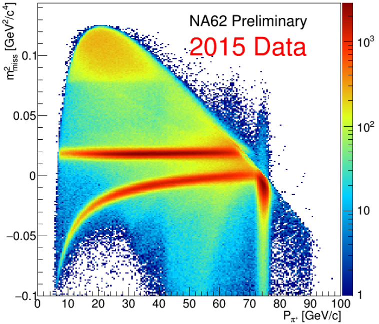
- Other possible background:
  - Accidental tracks in time with kaon tracks
  - Beam-gas and upstream interactions

Signal topology & kaon ID

One-track selection

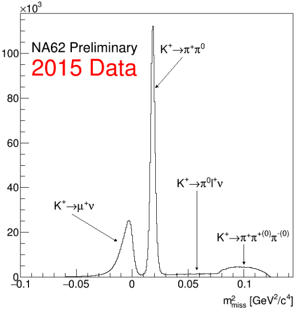
- Single downstream track topology
- Beam track matching the downstream track
- Beam track matching a K signal in Kaon ID
- Downstream track matching energy

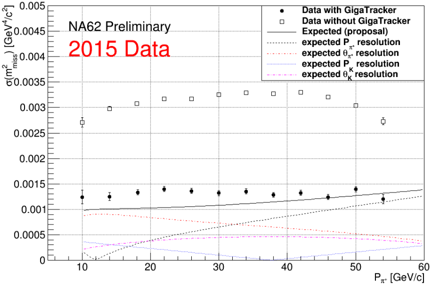




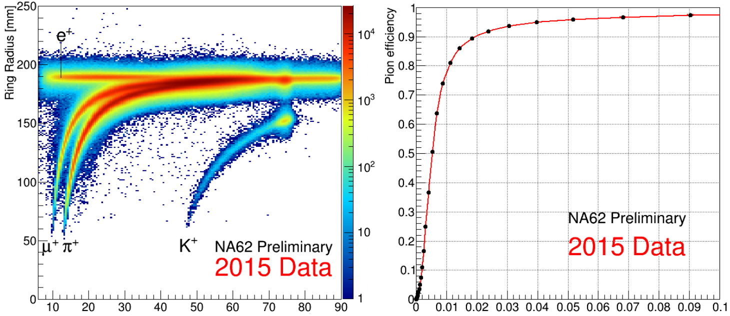
Time resolutions:

- Kaon ID < 100 ps
- Beam track < 200 ps
- Downstream track < 200 ps
- Calorimeters 1-2 ns



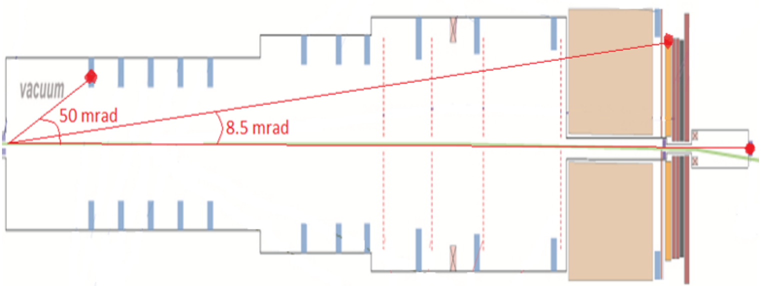


- Technique: Si-pixel tracker; Straw tube tracker in vacuum
- Goal: $O(10^4 \div 10^5)$ suppression factor of the main kaon decay modes
- $P_{\pi^+} < 35$ GeV$/c$: best $K^+ \to \mu^+\nu$ suppression
- Kinematics studied on $K^+ \to \pi^+\pi^0$ selected using LKr calorimeter. Resolutions close to the design. $O(10^3)$ kinematic suppression factor in 2015.

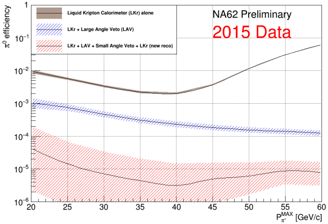


- Technique: RICH and calorimeters
- Goal: $O(10^7)$ μ/π separation to suppress mainly $K^+ \to \mu^+\nu$
  $15 < P_{\pi^+} < 35$ GeV/c: best μ/π separation in RICH
- Pure samples of pions and muons selected using kinematics
- RICH: $O(10^2)$ μ/π separation, 80% π^+ efficiency in 2015
- Calorimeters: $10^4 \div 10^6$ μ^+ suppression, $90\% \div 40\%$ π^+ efficiency in 2015 using a cut analysis. Room for improvements.

Photon rejection



- Technique: EM calorimeters exploiting correlations between γs' from π^0
- Goal: $O(10^8)$ rejection π^0 from $K^+ \to \pi^+\pi^0$
- $P_{\pi^+} < 35$ GeV$/c \Rightarrow E_{\pi^0} > 40$GeV
- Measured on data using $K^+ \to \pi^+\pi^0$ selected kinematically
- 2015 measurement statistically limited



Conlusions

- The decay $K^+ \to \pi^+ \nu \bar{\nu}$ provides unique opportunities for NP searches complementary to LHC
- The NA62 is aimed at measuring BR($K^+ \to \pi^+ \nu \bar{\nu}$) with $\sim$10% precision by collecting O(100) events in two years of data taking
- Most detectors were successfully commissioned during the 2014-2015 runs; detector performance within expectations
- NA62 is taking data in 2016-2018

Further NA62 physics programme

Decay	Physics	Present limit (90% C.L.) / Result	NA62
$\pi^+\mu^+e^-$	LFV	1.3×10^{-11}	0.7×10^{-12}
$\pi^+\mu^-e^+$	LFV	5.2×10^{-10}	0.7×10^{-12}
$\pi^-\mu^+e^+$	LNV	5.0×10^{-10}	0.7×10^{-12}
$\pi^-e^+e^+$	LNV	6.4×10^{-10}	2×10^{-12}
$\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}	0.4×10^{-12}
$\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}	4×10^{-12}
$e^-\nu\mu^+\mu^+$	LNV	No data	10^{-12}
π^+X^0	New Particle	5.9×10^{-11} $m_{X^0} = 0$	10^{-12}
$\pi^+\chi\chi$	New Particle	–	10^{-12}
$\pi^+\pi^+e^-\nu$	$\Delta S \neq \Delta Q$	1.2×10^{-8}	10^{-11}
$\pi^+\pi^+\mu^-\nu$	$\Delta S \neq \Delta Q$	3.0×10^{-6}	10^{-11}
$\pi^+\gamma$	Angular Mom.	2.3×10^{-9}	10^{-12}
$\mu^+\nu_h, \nu_h \to \nu\gamma$	Heavy neutrino	Limits up to $m_{\nu_h} = 350\ MeV$	
R_K	LU	$(2.488 \pm 0.010) \times 10^{-5}$	>×2 better
$\pi^+\gamma\gamma$	χPT	< 500 events	10^5 events
$\pi^0\pi^0e^+\nu$	χPT	66000 events	$O(10^6)$
$\pi^0\pi^0\mu^+\nu$	χPT	-	$O(10^5)$