$K^+ \to \pi^+ \nu \bar{\nu}$ at NA62

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on behalf of the NA62 collaboration

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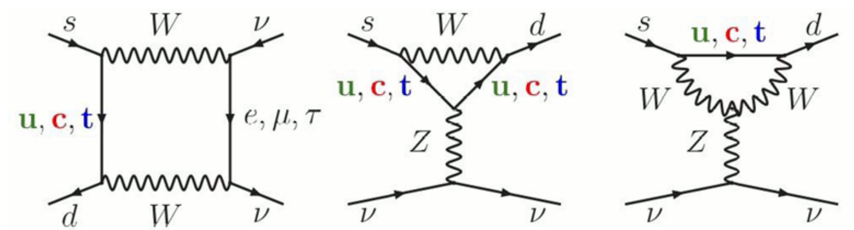
$K \to \pi \nu \bar{\nu}$ in the SM

Flavour Changing Neutral Current process forbidden at tree level in the SM



- Highest CKM suppression ⇒ very sensitive to New Physics
- High theoretical cleanness:
  - Dominated by short distance dynamics
  - In case of $K^+ \to \pi^+ \nu \bar{\nu}$ small effects of long distance contributions due to charm
  - Hadronic matrix element extracted from $K^+ \to \pi^0 e^+ \nu$
- SM predictions
  - $BR(K_L \to \pi^0 \nu \bar{\nu}) = (2.43 \pm 0.39 \pm 0.06) \times 10^{-11}$
  - $BR(K^+ \to \pi^+ \nu \bar{\nu}) = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$

  [Phys.Rev. D83 (2011) 034030]

Parametric error dominated by V_{cb} , ρ

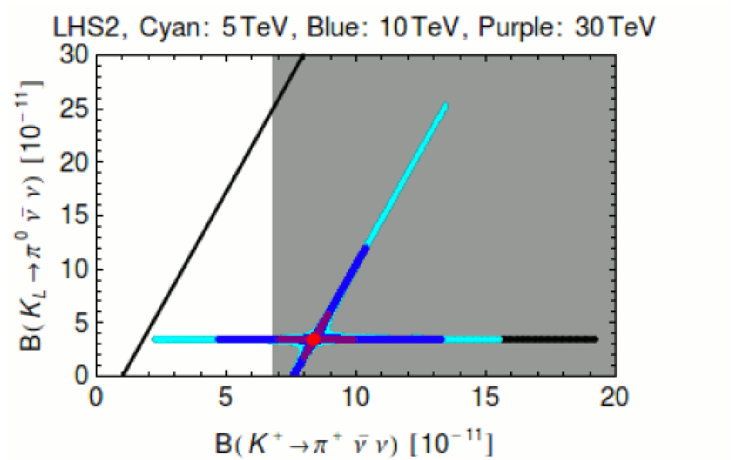
Pure theoretical error mostly LD contribution

- BR proportional to $|V^*_{ts} V_{td}|$ ⇒ theoretically clean V_{td} dependance

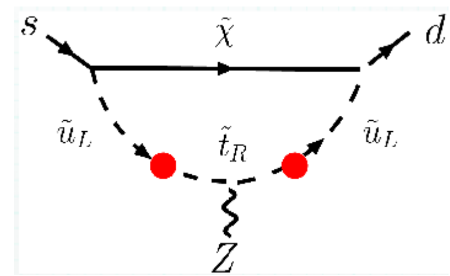
$K\to\pi\nu\bar{\nu}$ beyond the SM

Sensitive NP probe complementary to LHC

- In models with Z′ gauge boson mediating FCNC at tree level sensitive to mass scale beyond those explored by LHC ($M_{Z'} > 5$ TeV/c^2)
  [A. J. Buras, F. De Fazio and J. Girrbach JHEP 1302 (2013) 116]



- Best probe of MSSM non-MFV
  E.g. non MFV in up-squarks trilinear terms (still not excluded by the recent LHCb data) [JHEP 0608 (2006) 064]

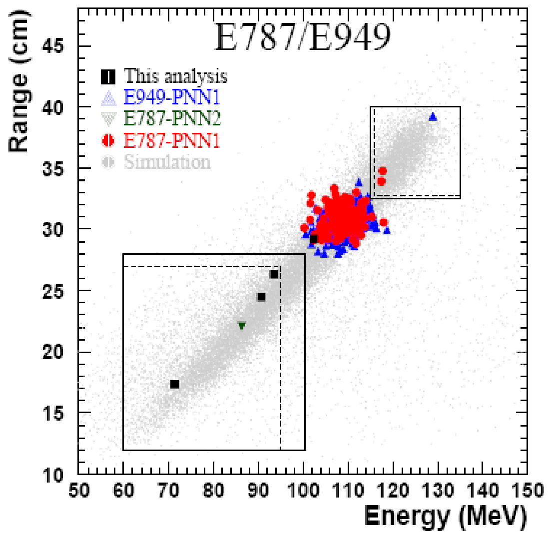


- More specific NP models

  Littlest Higgs with T-parity, Custodial Randall-Sundrum
  [Acta Phys. Polonica B41 (2010) 657, JHEP 0903 (2009) 108]

Status and Foreseen Experiments

- Present experimental results:
  - $BR(K^+ \to \pi^+ \nu\bar{\nu}) = (1.73\,^{+1.15}_{-1.05}) \times 10^{-10}$ [E787, E949]



7 candidates observed in the two allowed kinematics regions, stopped kaon technique

- Low energy separated K^+ beam
- PID: range
- Hermetic photon veto system

  - $BR(K_L \to \pi^0 \nu\bar{\nu}) < 2.6 \times 10^{-8}$ [E391a]

- Upcoming Experiments:
  - NA62 at CERN ($K^+ \to \pi^+ \nu\bar{\nu}$)
  - KOTO at JPARK ($K_L \to \pi^0 \nu\bar{\nu}$)

The NA62 Experiment

- Goal
  - branching ratio measurement of $K^+ \to \pi^+ \nu\nu$ with 10% accuracy by collecting O(100) events over 2 years of data taking
- Requirements
  - Statistics: BR(SM) ~ 8×10^{-11}
    - K decays (2 years): 10^{13}
    - Acceptance: ~ 10%
  - Systematics:
    - > 10^{12} background rejection
    - < 10% precision background measurement
- Technique
  - High momentum K^+ beam

Kaon intensity
Signal efficiency

Signal Purity
Detector Redundancy

Decay in flight

Beam Line

- Primary SPS protons (400 GeV/c)
- Proton on target ~ 1.1×10^{12} /s
- Unseparated secondary hadronic beam (p = 75 GeV/c)
- Momentum bite 1%
- Composition: K^{+}= 6% (others: π^{+}, proton)
- Angular spread in X and Y < 100 μrad

Signal and Background

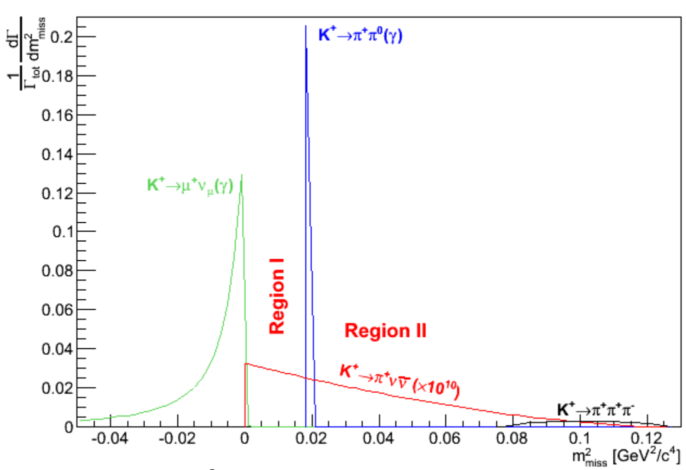
Signal signature:

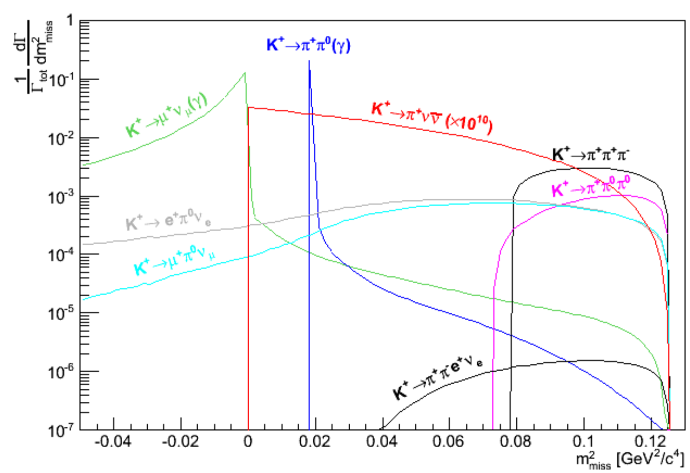
- Incoming high momentum (75 GeV/c) K^+
- Outgoing low momentum (<35 GeV/c) π^+ in time with the incoming K^+

Background:

- K^+ decay modes
- Accidental single track matched with a K-like track

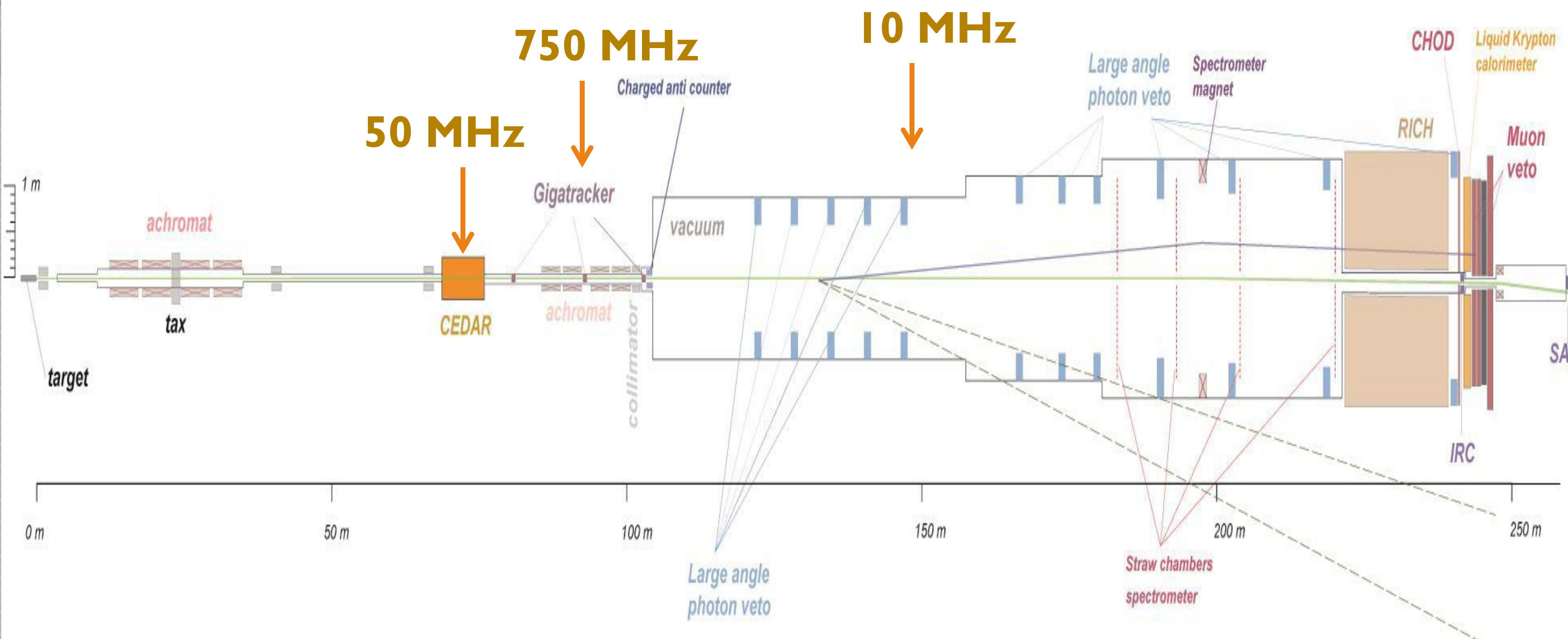
Kinematic variable: $m^2_{miss} = (P_K - P_\pi)^2$





$K^+\to\pi^+\pi^0$ splits the signal region in 2

The NA62 Detector



- Beam size at beam tracker: 5.5×2.2 cm^2
- Beam rate at beam tracker: 750 MHz
- Rate downstream 10 MHz (mainly K^+ decays)

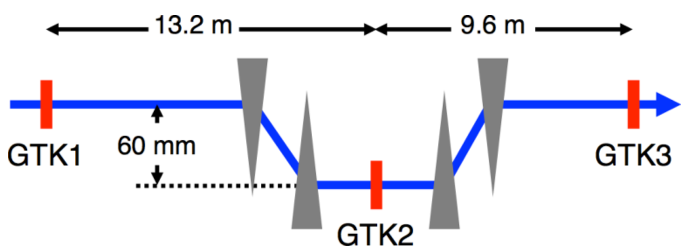
Reconstruction of the kaon beam

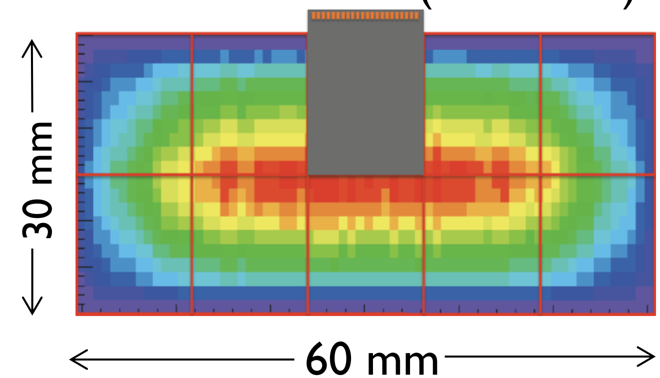
- Time measurement: Gigatracker, KTAG
- Track reconstruction: Gigatracker

Gigatracker

3 hybrid silicon pixel stations mounted around 4 achromat magnets

Inside the vacuum and subjet to high and non-uniform beam rate (750 GHz)

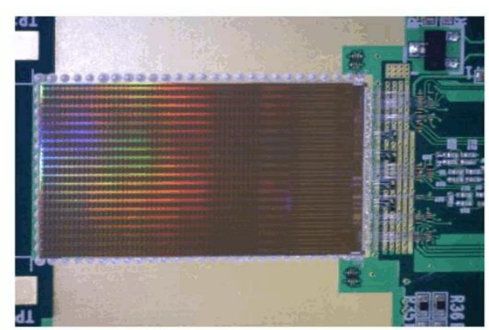




Provide precise

- momentum ($\sigma(p)/p \sim 0.2\%$),
- time ($\sigma_t \sim 175$ ps at 300V bias)
- and angular measurements ($\sigma_\vartheta \sim 16\ \mu$rad)

1 sensor, 10 bump-bonded chips

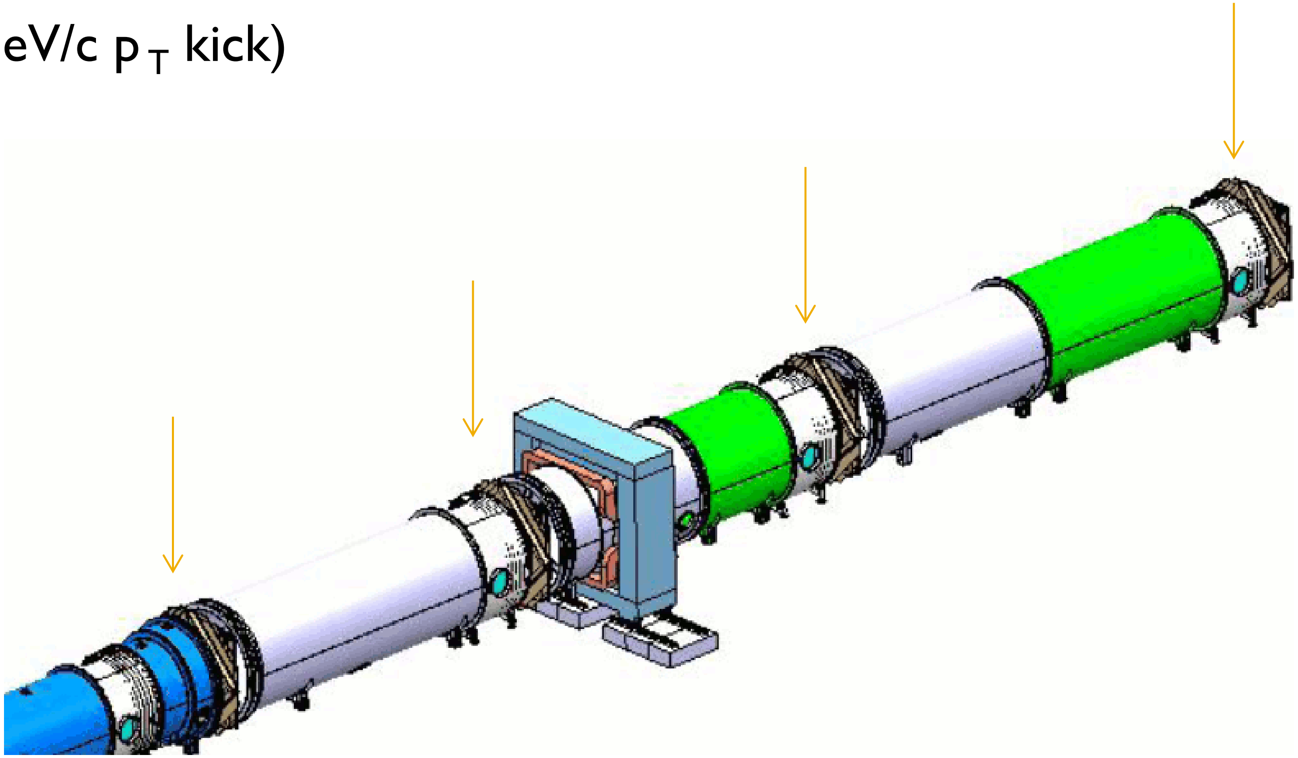


Reconstruction of charged pion

- Time measurement: RICH
- Track reconstruction: Straw spectrometer

Straw spectrometer

4 chambers located upstream and downstream of a dipole magnet (270 MeV/c p_T kick)



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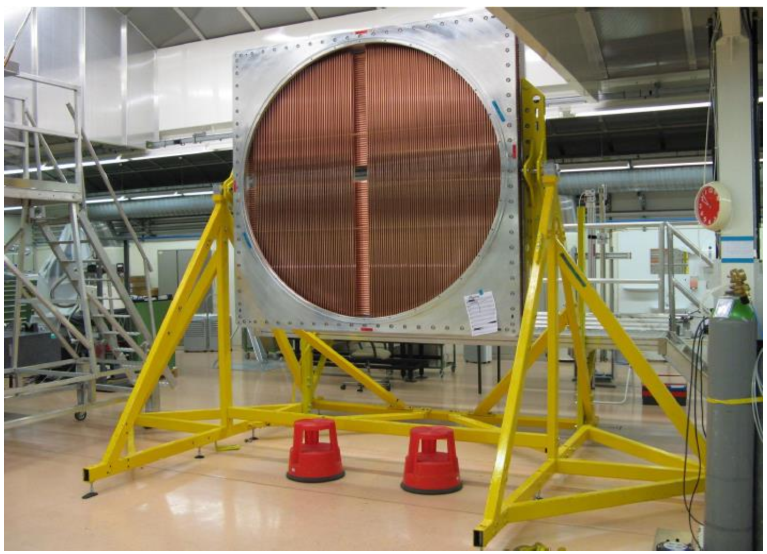


Each chamber equipped with ~1800 straw , positioned in 4 views (u-v,x-y)

To minimize multiple scattering:

- ultra-light material ($X/X_0 \sim 0.1\%$ per view → 2% total)
- integration in the vacuum tank

Measurement of

- coordinates (σ < 130 μm),
- and momentum ($\sigma(p)/p \sim 0.3\%$)

of charged particles from the decay

Kaon-pion matching

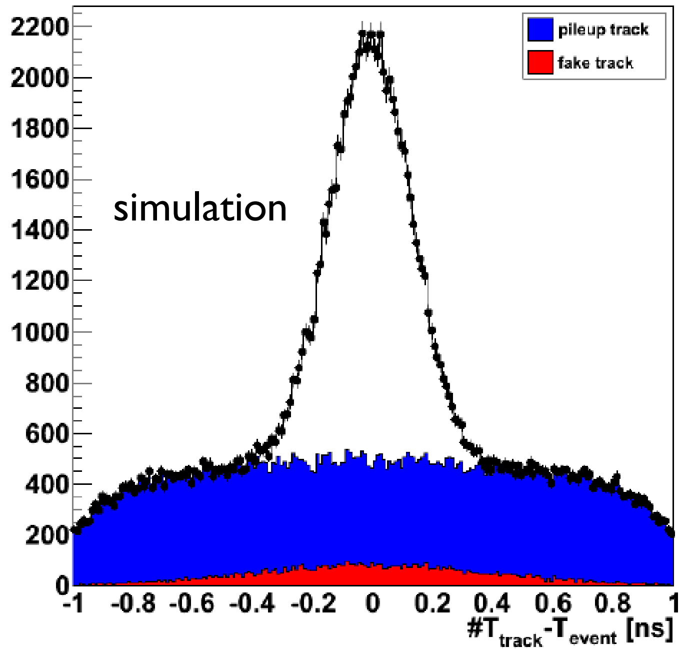
Different rate in Gigatracker (750 MHz) and downstream detectors (10 MHz)
Wrong kaon-pion assignment will spoil the kinematical reconstruction

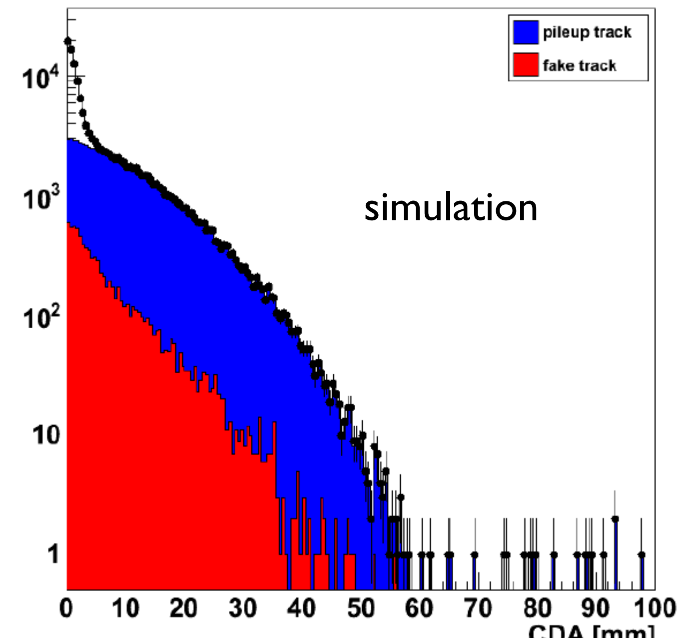
Precise timing between K^+ and π^+

- Gigatracker: σ_t = 200 ps /station
- KTAG: σ_t < 100 ps
- RICH: σ_t < 100 ps

Match in space between K^+ and π^+

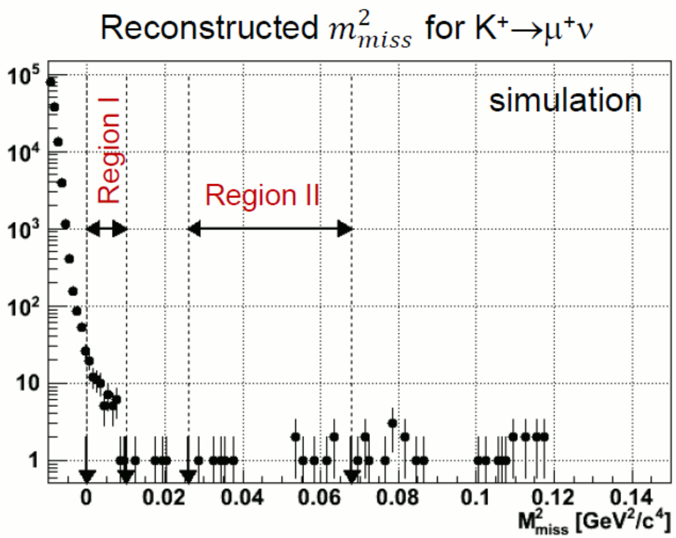
- Matching of GTK and STRAW tracks
- vertex defined at the CDA of both tracks



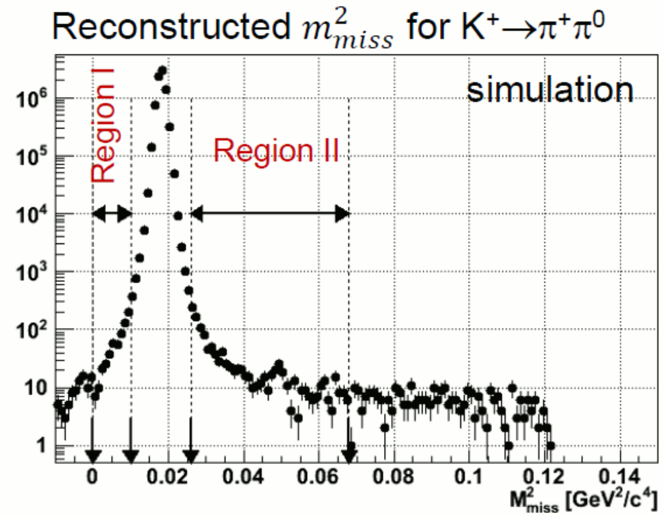


Background Kinematic Rejection

Main background sources: $K^+\rightarrow\mu^+\nu$ (BR~64%) and $K^+\rightarrow\pi^+\pi^0$ (BR~21%)



Rejection factor: 1.5×10^4



Rejection factor: 5×10^3

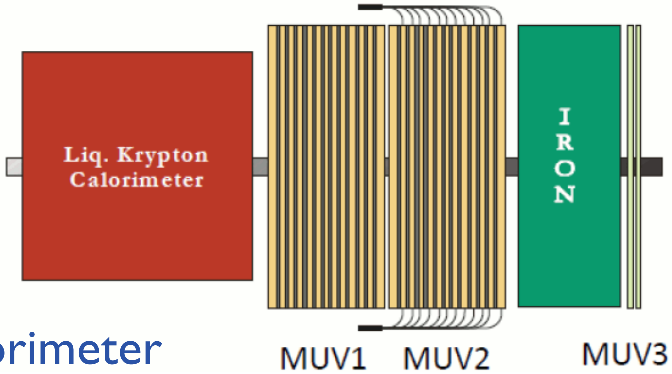
Source of inefficiency:

- Tails due to multiple scattering
- Pileup in the Gigatracker

In $K^+\rightarrow\mu^+\nu$ there is an analytical relation between m^2_{miss} and p_μ

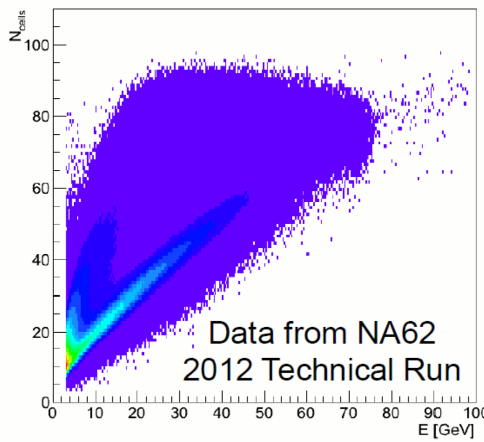
Particle Identification: Calorimeters

$\pi/\mu/e$ separation (global μ rejection factor $\approx 10^5$)

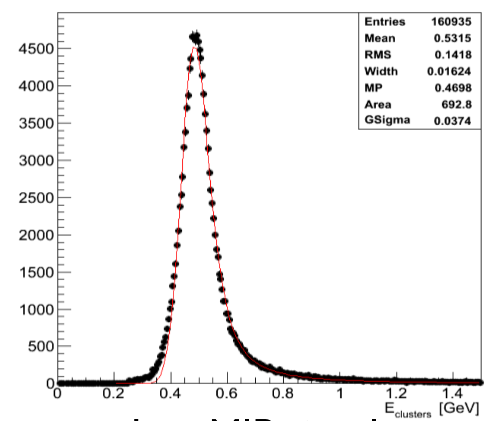


NA48 LKr calorimeter

- $10 m^3$ of liquid Kr, ~13000 cells, 2×2 cm^2, 27 X_0
- Used in L0 trigger



em/hadronic clusters distrimination



clear MIP signal

Particle Identification: Calorimeters

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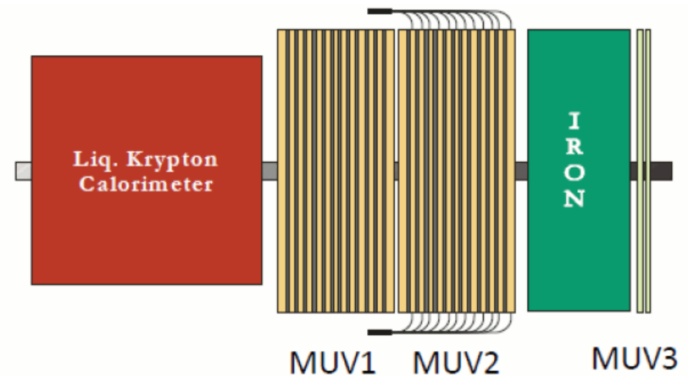
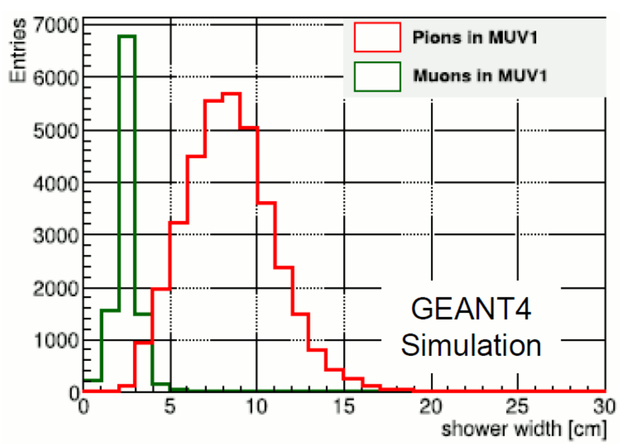


MUV1+ MUV2: μ/π discrimination

- 24 (MUV1) and 22 (MUV2) iron/scintillator layers

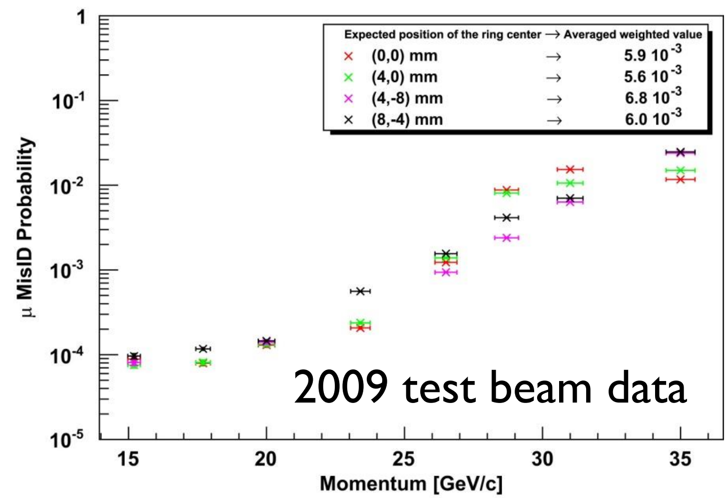


MUV3: μ counter

- Located behind an 80 cm thick iron wall consists of an array of scintillator tiles directly seen by 2 PMs.
- Used in the L0 trigger

Particle Identification: RICH

Additional π/μ separation (μ rejection factor > 10^2 up to 35 GeV/c)



RICH

- 17 m long vessel filled with Ne at 1 atm ($\approx$ 5% X_0)
- 14 GeV/c threshold for pions
- beam pipe ($\varnothing$ 157 mm) going through
- 20 mirror segments ($\approx$ 20% X_0)
- σ_t < 100 ps
- To be also used in the L0 trigger

Particle Identification: KTAG

K/π separation in the beam

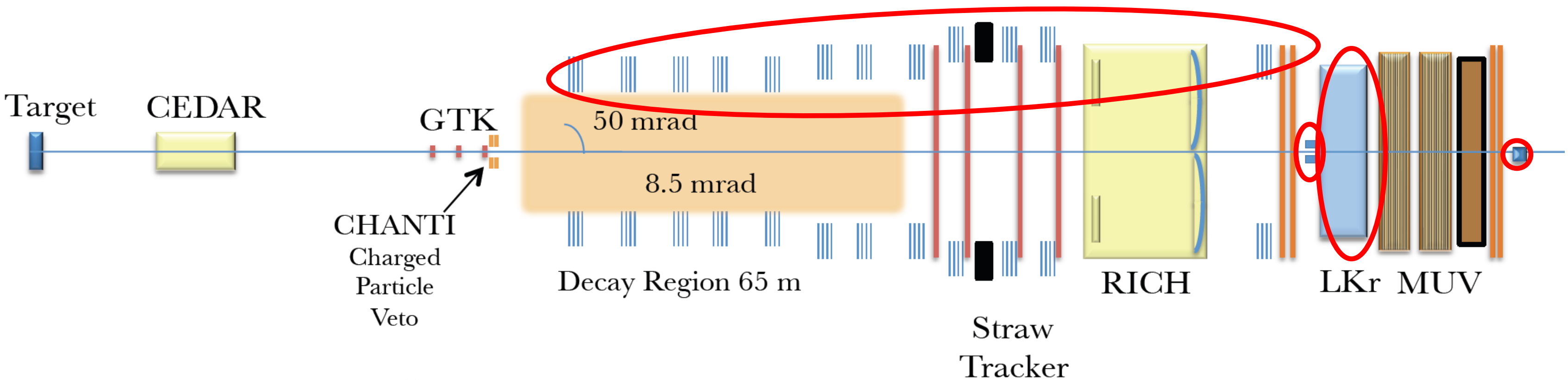
KTAG

- Differential Cherenkov counter (CEDAR from SPS)
- Filled with H_2 or N_2
- New external optics, PMs and readout able to sustain the 50 MHz K rate
- $\sigma_t < 100$ ps
- Sub-percent π mis-tagging for K efficiency > 95%

Photon Veto System

To suppress the dominant decay $K^+ \to \pi^+ \pi^0$ (BR ~21%):

- π^0 rejection inefficiency at 10^{-8} level ($\to \gamma$ detection inefficiency at 10^{-4})
- Hermetic γ coverage up to 50 mrad



3 different detectors to cover 3 different angular regions

- Large Angle Vetoes (LAV): 8.5 – 50 mrad
- The NA48 Liquid krypton calorimeter (LKr): 1 – 8.5 mrad
- Small Angle Vetoes (IRC+SAC): $\leq$ 1 mrad

Photon Veto System

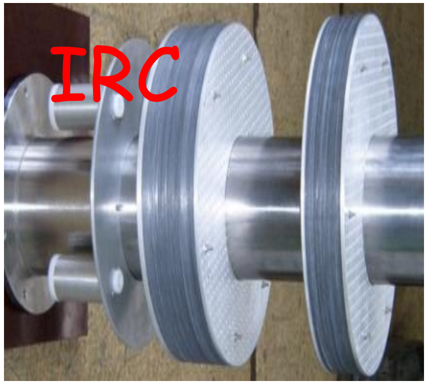
LAV

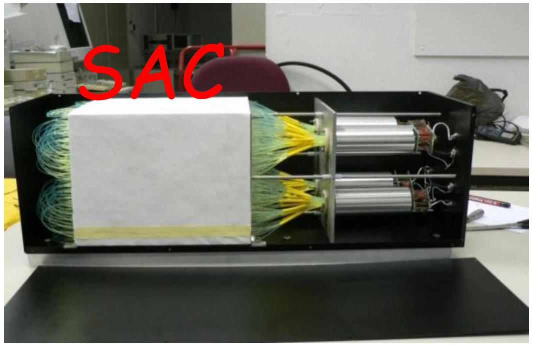
- 12 stations (11 in vaccum) formed by 4 to 5 overlapping in azimuthal angle rings of OPAL lead glass blocks
- Inefficiency < 10^{-4}

  for 100 MeV < E_{γ} < 35 GeV
- Used in L0 trigger

IRC + SAC

- Consecutive lead and plastic scintillator plates with WLS fibres passing through via holes in the plates (Shashlyk)
- Used in L0 trigger



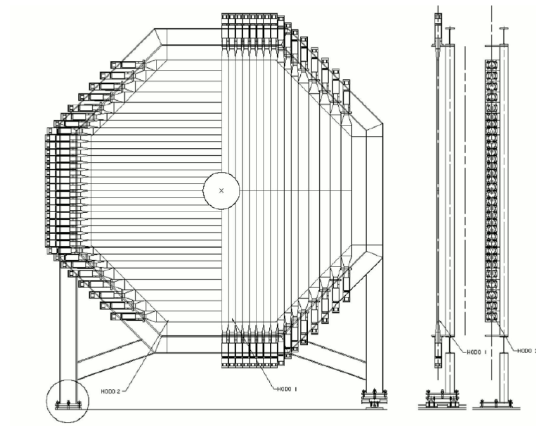


Charged Tracks Veto System

Need to detect photonuclear interactions in the RICH (CHOD) and veto inelastic interactions in the GTK3 (CHANTI)

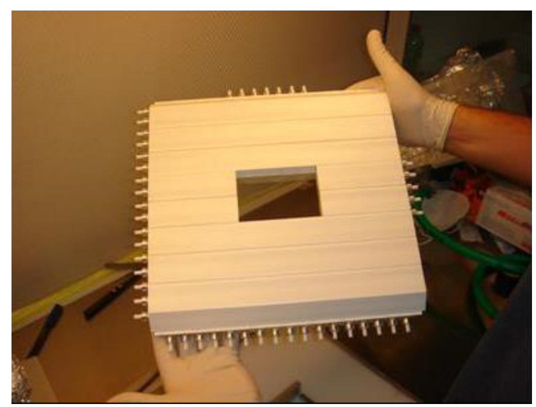
CHOD

- NA48 charged hodoscope
- 2 planes of horizontal and vertical plastic scintillator counters
- σ_t = 200 ps



CHANTI

- 6 stations inside vacuum, each made of 2 planes (x,y)
- Composed of staggered triangular scintillator bars
- Light collected by WLS fibers and readout by SiPMs



NA62 Sensitivity

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

Cut and count analysis without any optimization

LFV/LNV modes

High fluxes and PID/veto capabilities of NA62 are well suited to look for Lepton Flavor/ Lepton Number Violation both in kaon and pion decays
See talk by V. Duk tomorrow morning

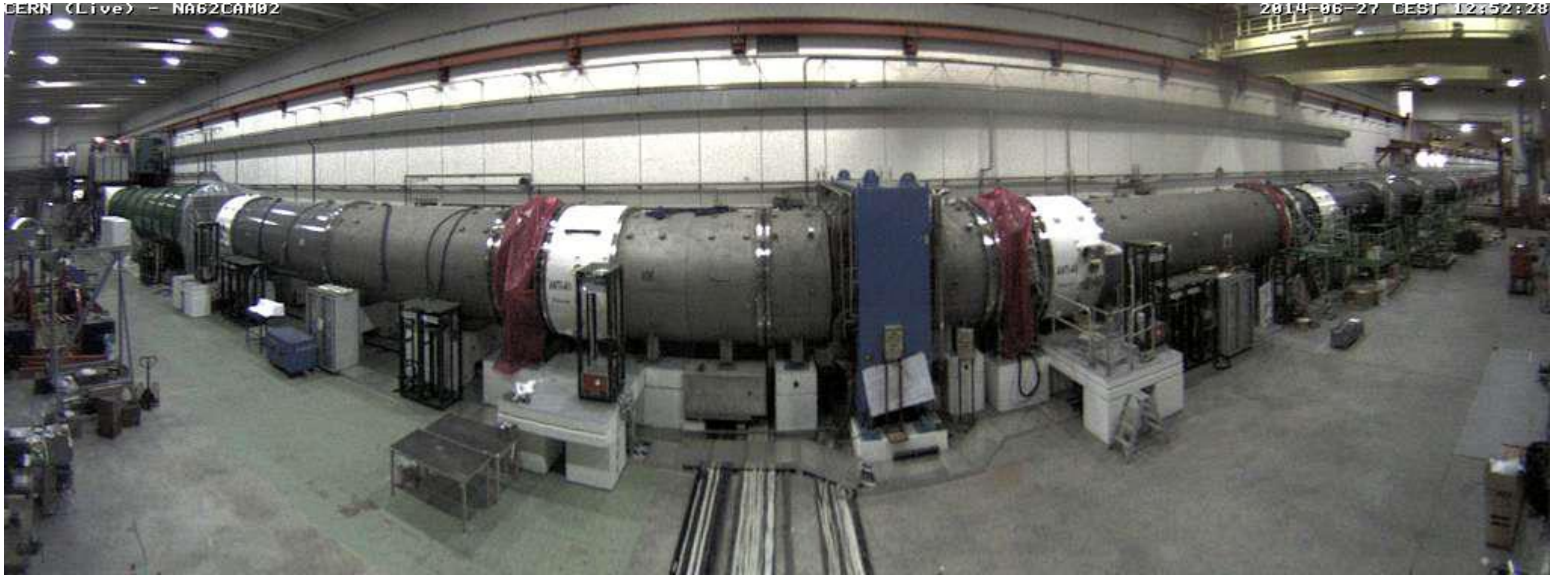
Expected decays in Fiducial Volume in 2 years of data taking:
1.2×10^{13} K^+ decays, 2.5×10^{12} π^0 decays

Decay	Physics	Present UL at 90% CL
$K^+\to\pi^+\mu^+e^-$	LFV	1.3×10^{-11}
$K^+\to\pi^+\mu^-e^+$	LFV	5.2×10^{-10}
$K^+\to\pi^-\mu^+e^+$	LNV	5.0×10^{-10}
$K^+\to\pi^-e^+e^+$	LNV	6.4×10^{-10}
$K^+\to\pi^-\mu^+\mu^+$	LNV	1.1×10^{-9}
$K^+\to\mu^-\nu e^+e^+$	LNV/LFV	2.0×10^{-8}
$K^+\to e^-\nu\mu^+\mu^+$	LNV	no data
$\pi^0\to\mu^+e^-$	LNV	3.8×10^{-10}
$\pi^0\to\mu^-e^+$	LNV	3.4×10^{-9}

Further Kaon Physics Opportunities

Decay	Physics	Present result
$K^+ \to \pi^+ \chi^0$	New particle	$< 5.9 \times 10^{-11}$, $M\chi^0 = 0$
$K^+ \to \pi^+ \chi\chi$	New particle	no data
$K^+ \to \pi^+ \pi^+ e^- \nu_e$	$\Delta S \neq \Delta Q$	$< 1.2 \times 10^{-8}$
$K^+ \to \pi^+ \pi^+ \mu^- \nu_\mu$	$\Delta S \neq \Delta Q$	$< 3 \times 10^{-6}$
$K^+ \to \pi^+ \gamma$	Angular momentum	$< 2.3 \times 10^{-6}$
$K^+ \to \mu^+ \nu_h, \nu_h \to \nu\gamma$	Heavy neutrino	Limits up to $m_{\nu h}$= 350 MeV
R_K	LU and NP	$(2.488 \pm 0.010) \times 10^{-5}$
$K^+ \to \pi^+ \gamma\gamma$	ChPT	<500 events
$K^+ \to \pi^0 \pi^0 e^+ \nu$	ChPT	66000 events
$K^+ \to \pi^0 \pi^0 \mu^+ \nu$	ChPT	-

Status of the installation



Conclusions

- The NA62 experiment will start its data taking on the 6th of October. The unprecedented statistics and the powerful detector features will allow to explore ultra rare (and forbidden) kaon decays opening a new chapter of tests for the SM.
- During the first physics run (2 months):
  - Complete the commissioning
  - Lower Intensity
  - Likely to reach the SM sensitivity
- Nominal beam intensity in 2015, 2016, 2017