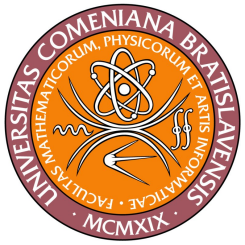




# Prospects for $K^+ \to \pi^+ \nu\bar{\nu}$ observation at CERN in NA62

Michal Kovaľ

*Comenius University Bratislava*

on behalf of the NA62 Collaboration

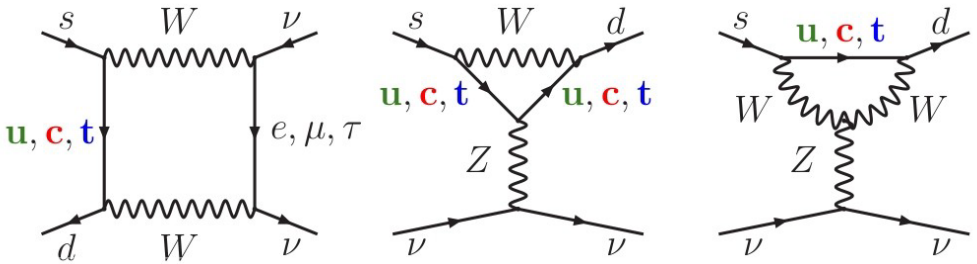
*XIIth International Conference on Heavy Quarks and Leptons*
*27. 8. 2014, Mainz, Germany*

# OUTLINE

- $K^+ \to \pi^+ \nu\bar{\nu}$ decay overview
  - Theoretical framework
  - Experimental status
  - New physics sensitivity
- NA62 experiment at CERN
  - Beamline
  - Signal signature, main backgrounds
  - The NA62 detector
  - Expected sensitivity
- Conclusions

# SM Theoretical Framework

- FCNC loop process, highly CKM suppressed, theoretically clean




- Dominated by short-distance contribution (BR $\sim |V_{ts}^* V_{td}|^2$)
- SM prediction:

$$\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$$

Brod, Gorbahn, Stamou: PRD83(2011) 034030

1. error: CKM parametric, dominated by $V_{cb}$
2. error: theoretical, mostly LD corrections

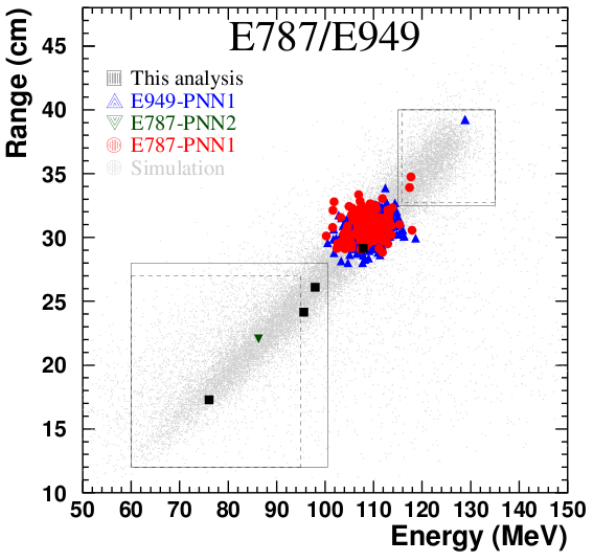
  - $t$ quark contribution computed at NLO QCD and 2-loop EW corrections
  - $c$ quark loop contribution computed at NNLO QCD and NLO EW corr.
  - Correction for LD contributions
  - Hadronic matrix element related to BR($K^+ \to \pi^0 e^+ \nu$)

# CURRENT STATUS AND NEW PHYSICS SENSITIVITY

**Current experimental result**:

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

BNL E787/E949: PRL101 (2008) 191802




- Based on 7 observed events
- Stopped kaon technique

**New Physics Sensitivity**:

- General Z' gauge boson model (FCNC at tree level)
  - Buras et al, JHEP 1302 (2013) 116
- Perfect probe of MSSM with non-Minimal Flavour Violation
  - Isidori et al, JHEP 0608 (2006) 064
- Still complementary to LHC searches

# NA62 Experiment

## Goal

- Branching ratio measurement of $K^+ \to \pi^+ \nu\bar{\nu}$
- 10 % measurement precision
- Collection of $O(100)$ events in 2-3 years of data taking

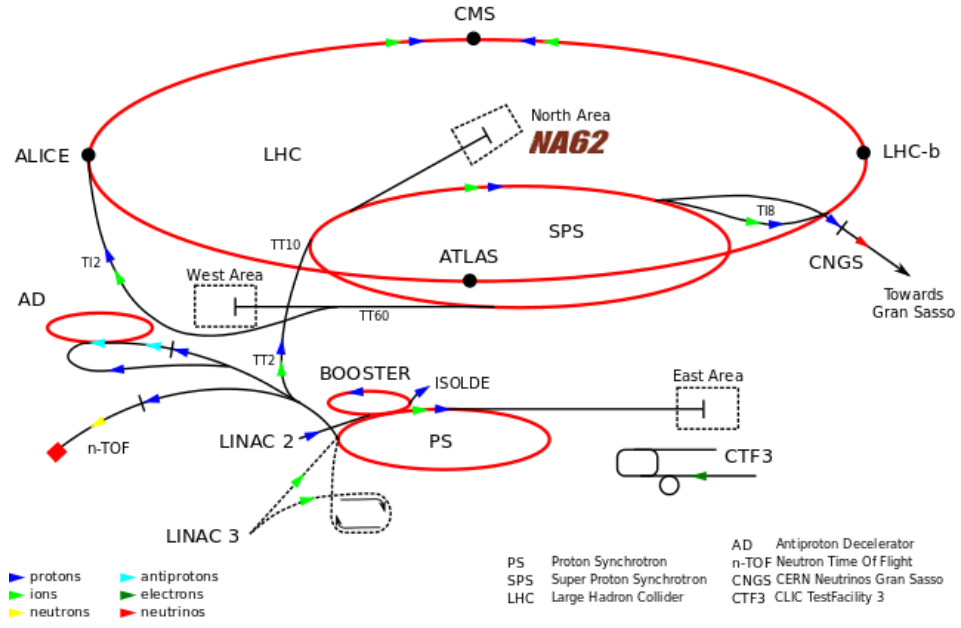
## Requirements

- Large statistics, at least $10^{13}$ $K^+$ decays
  - high intensity kaon beam
  - $\sim$ 10% signal acceptance
- Systematics control at % level
  - $10^{12}$ background rejection ($<$ 20% background)
  - at least 10% background measurement precision

## Technique

- High momentum $K^+$ beam (75 GeV/c) with kaon decay in flight
- Low momentum $\pi^+$ selection ($p_\pi < 35$ GeV/c) $\to$ large missing E

# NA62 Beamline

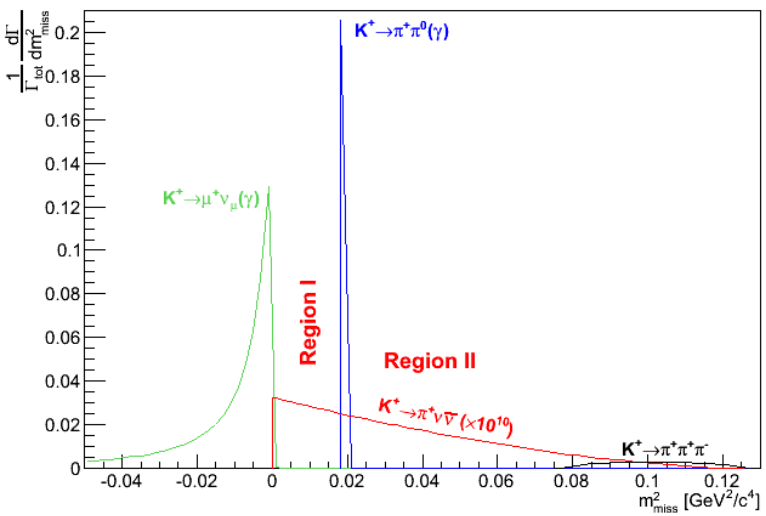



- Primary SPS protons (400 GeV/c)
- Protons on Be target: $3 \times 10^{12}$ / pulse
- Secondary hadronic beam, p = 75 GeV/c
  $\sim 6\%$ $K^+$ (others: $\pi^+$, protons)
- Total rate at beam tracker: 750 MHz
- Rate downstream: 10 MHz
- Simultaneous operation with LHC

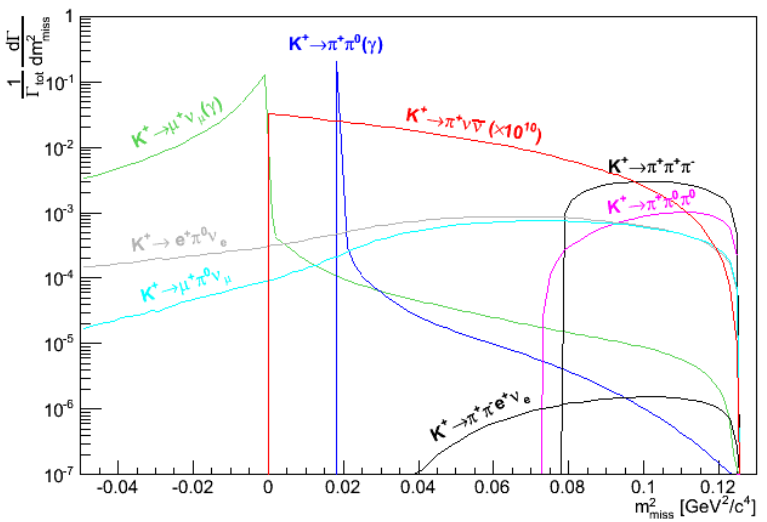
# Signal and Main Backgrounds

- Signal signature: one $K^+$ track, one $\pi^+$ track, **nothing else**
- Backgrounds:
  1. $K^+$ decay modes
  2. Accidental single track matched with a kaon like track
- Kinematic variable: $m^2_{miss} = (P_K - P_{\pi^+})^2$
  - Two $m^2_{miss}$ regions for event candidates are defined

92% background rejection by kinematic cuts



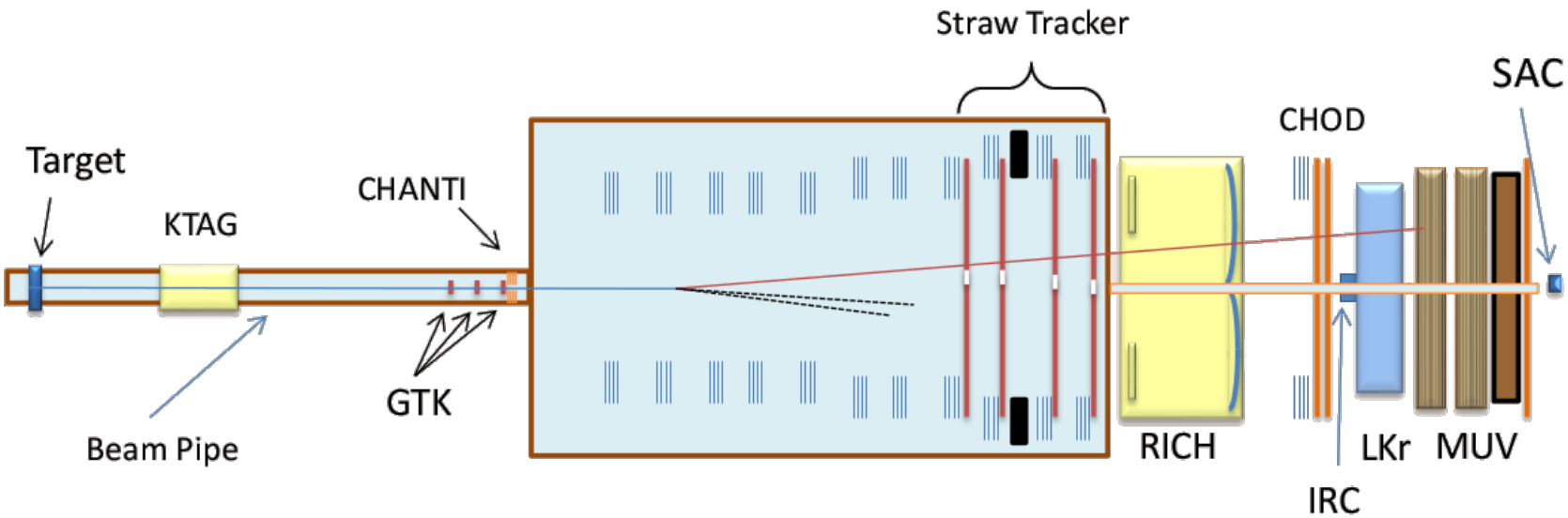

8% of background not separated by kinematics



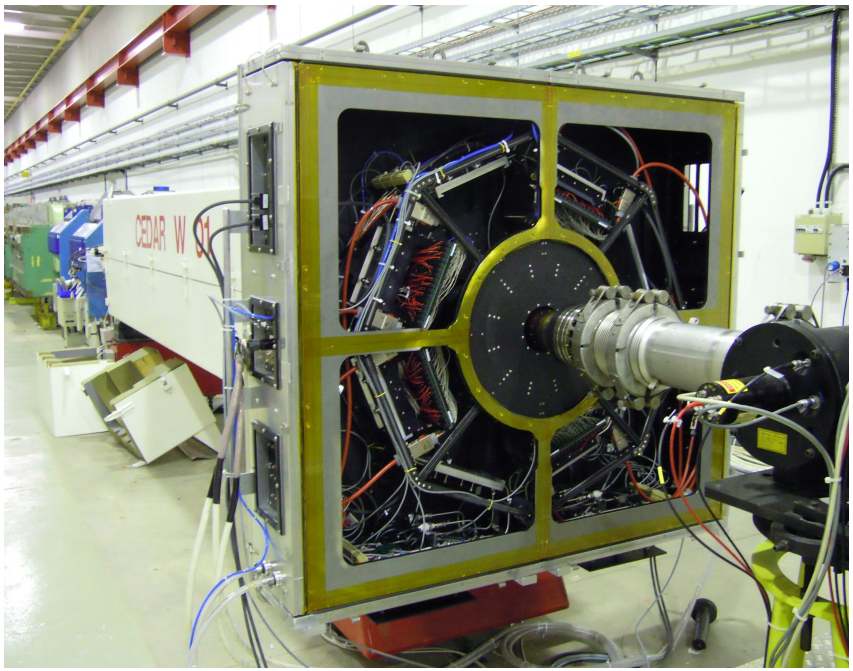

$\Rightarrow$ Need for efficient photon vetoes and particle ID

# GUIDING PRINCIPLES FOR THE NA62 DETECTORS

1. High intensity and precise timing (< 1 ns)
2. Good tracking detectors $\rightarrow$ $K^+$ and $\pi^+$ momentum vectors
3. Hermetic veto detectors $\rightarrow$ photons, muons
4. Particle identification $\rightarrow$ kaons in the beam, $\pi/\mu$ separation



# KTAG (CEDAR)

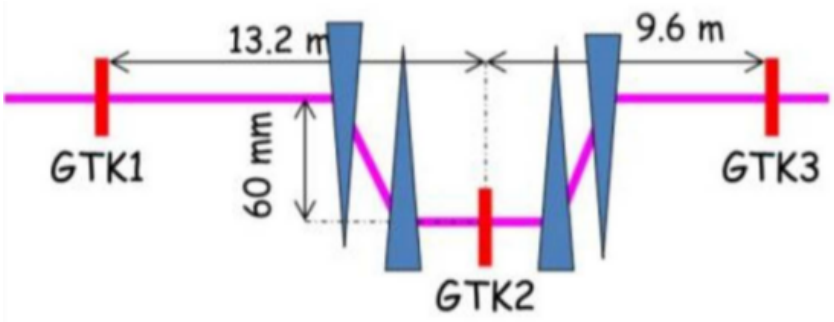



- Differential Cherenkov counter (CEDAR, from SPS)
- Extended external optics, new photo-detectors new electronics

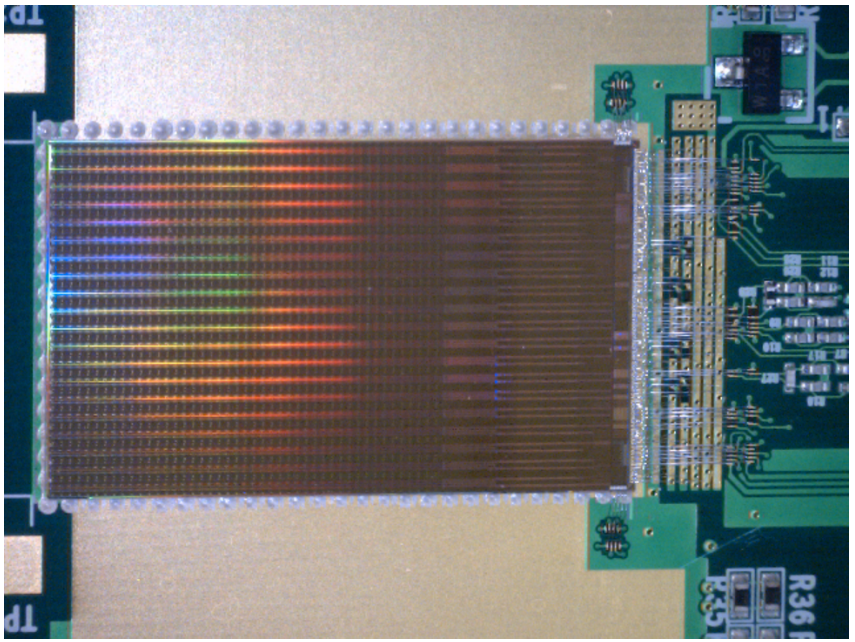
- Beam $K^+/\pi^+$ separation
- 50 MHz kaon rate
- Time resolution $\sigma_T < 100$ ps
- $<$ 1% pion mis-ID probability
- $>$ 95 % kaon tagging efficiency
- Suppression of background from *accidental tracks* $\leftarrow$ interactions of beam particles along the beam line

# GIGATRACKER

- Beam tracker for $K^+$ momentum and time measurement



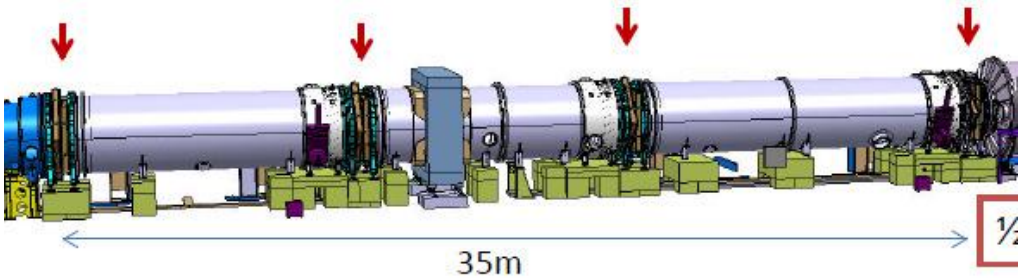

- Time resolution
  $\sigma_T \sim 200$ ps (per station)
- Momentum resolution
  $\sigma(P_K)/P_K = 0.2\%$
- Angular resolution
  $\sigma(\frac{dX,Y}{dZ}) = 15$ µrad



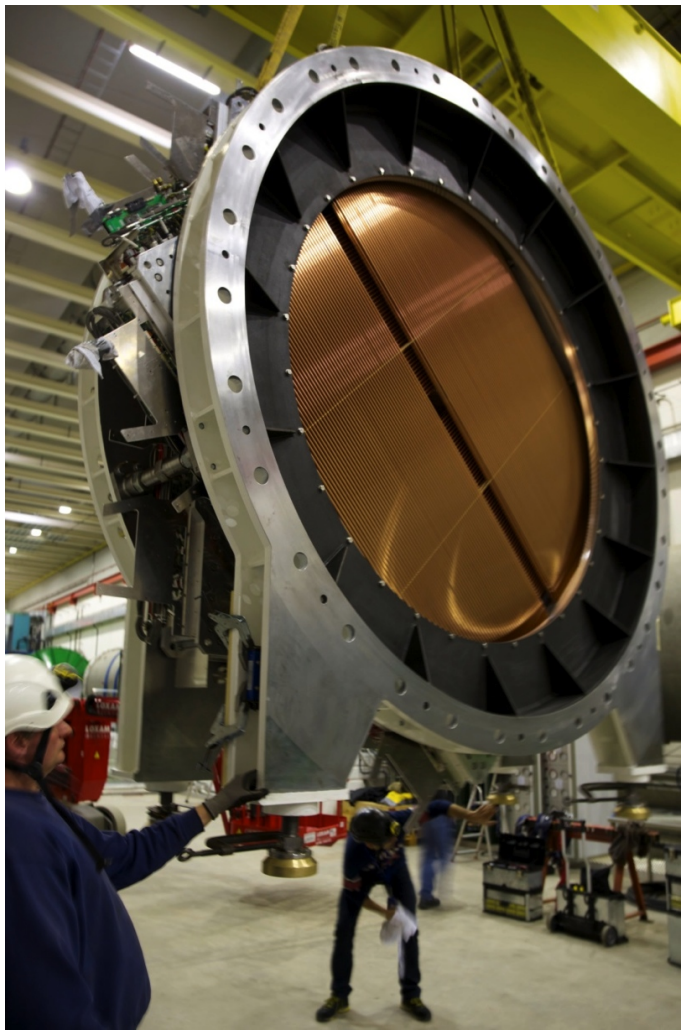
- 3 stations of Si pixel detectors
  ($300 \times 300\,\mu m^2$ pixel size)
- 18000 pixels per station
- $X/X0 < 0.5\%$ per station

# STRAW SPECTROMETER

- Charged tracks ($\pi^+$) reconstruction



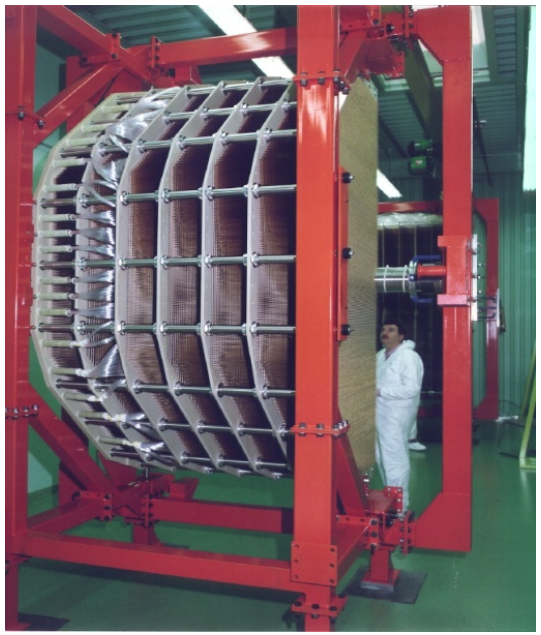

  - 4 straw chambers in vacuum
  - 4 views in a chamber
  - 4 planes of staggered tubes per view (9.6 mm radius mylar tubes, 2.1 m long)
  - Dipole magnet with 265 MeV/c $p_T$ kick
  - $X/X0$ : 0.1% per view (< 2% total)
- Resolution
  - $\sigma(P)/P = 0.32\% \oplus 0.008\,P\,[\text{GeV/c}]$
  - $\sigma(\frac{dX,Y}{dZ}) = 20 - 50\ \mu\text{rad}$



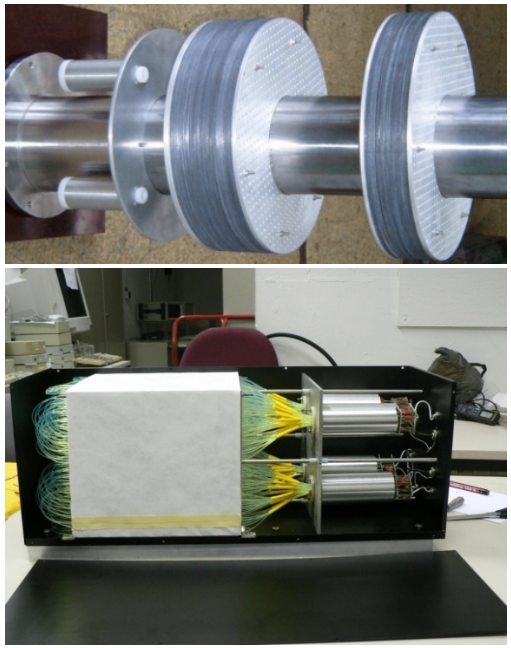
# PHOTON VETO SYSTEM

- $O(10^8)$ $\pi^0$ rejection from $K^+ \to \pi^+\pi^0$
- Selection of low energy charged pion $\to p_{\pi^0} > 40$ GeV/c
- Hermetic coverage up to 50 mrad, time resolution: $\sigma_T < 1$ ns


Large Angle Veto (LAV)
12 stations of lead-glass
(from OPAL)
8.5 mrad $\leq \theta \leq$ 50 mrad



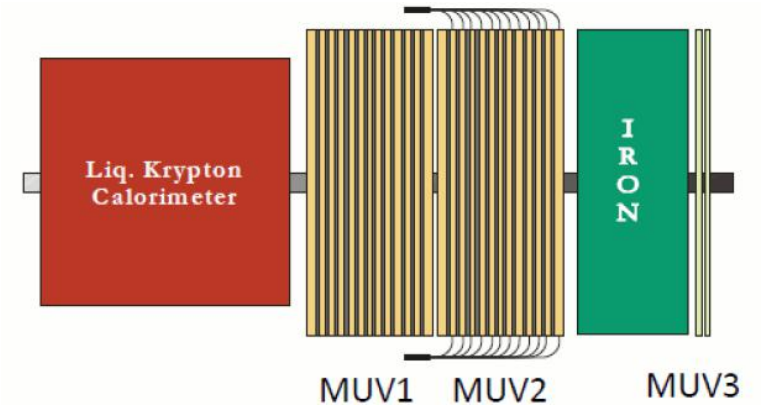
Liquid Krypton (LKr)
EM calorim. from NA48
1 mrad $\leq \theta \leq$ 8.5 mrad

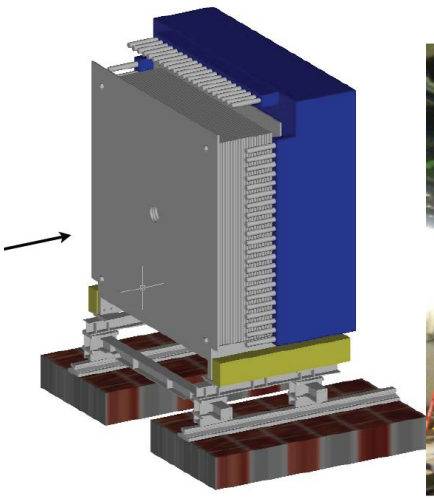


IRC - SAC calorimeters
Shashlyk technology
$\theta \leq 1$ mrad

# PARTICLE ID: CALORIMETERS

- $\pi/\mu/e$ separation
- $\mu$ rejection factor $\sim 10^5$
  - LKr: EM, hadronic, MIP cluster ID
  - MUV1,2: hadronic, MIP cluster ID
  - MUV3: $\mu$ fast counter



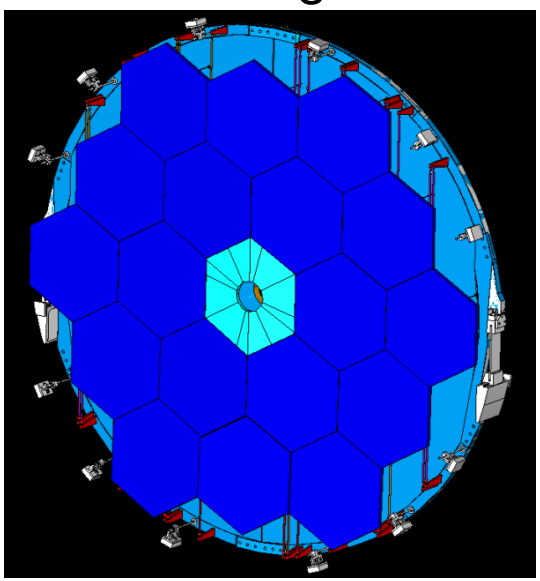
MUV1+MUV2

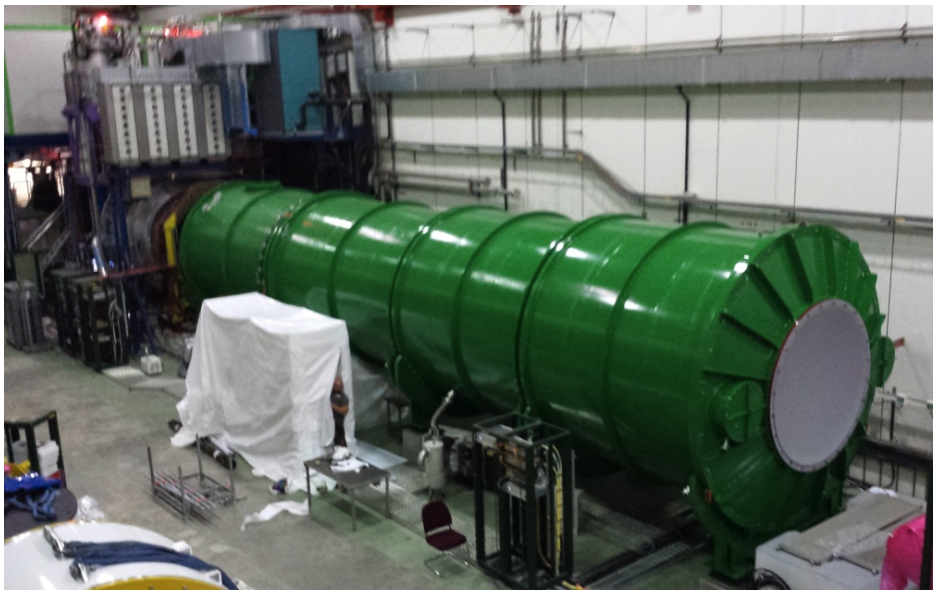
MUV3

- MUV1,2:
  - Iron/scintillator sampling calorimeters
- MUV3:
  - Array of scintillating pads with PMs read-out
  - Time resolution: $\sigma_T < 500$ ps
  - To be used at Level-0 trigger

# PARTICLE ID: RICH

- Additional $\pi/\mu$ separation
- $\mu$ rejection factor > $10^2$ (up to 35 GeV/c)
- 14 GeV/c threshold for $\pi^+$
- 17 m long vessel filled with Ne (1 Atm)
- 20 mirror segments

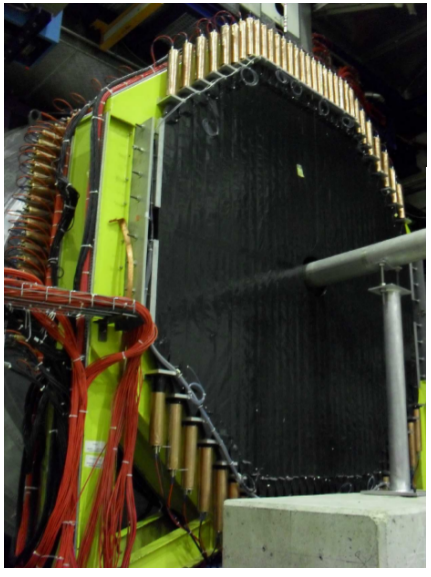


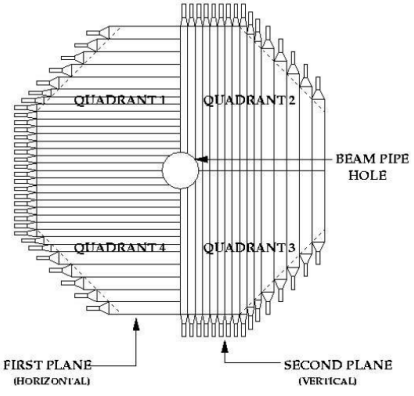


- $\pi^+$ crossing time measurement
- Time resolution: $\sigma_T < 100$ ps
- To be used both at L0 trigger and offline

# CHOD AND CHANTI

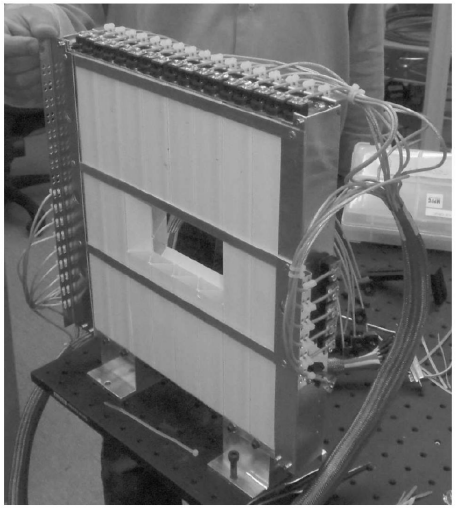
## CHOD





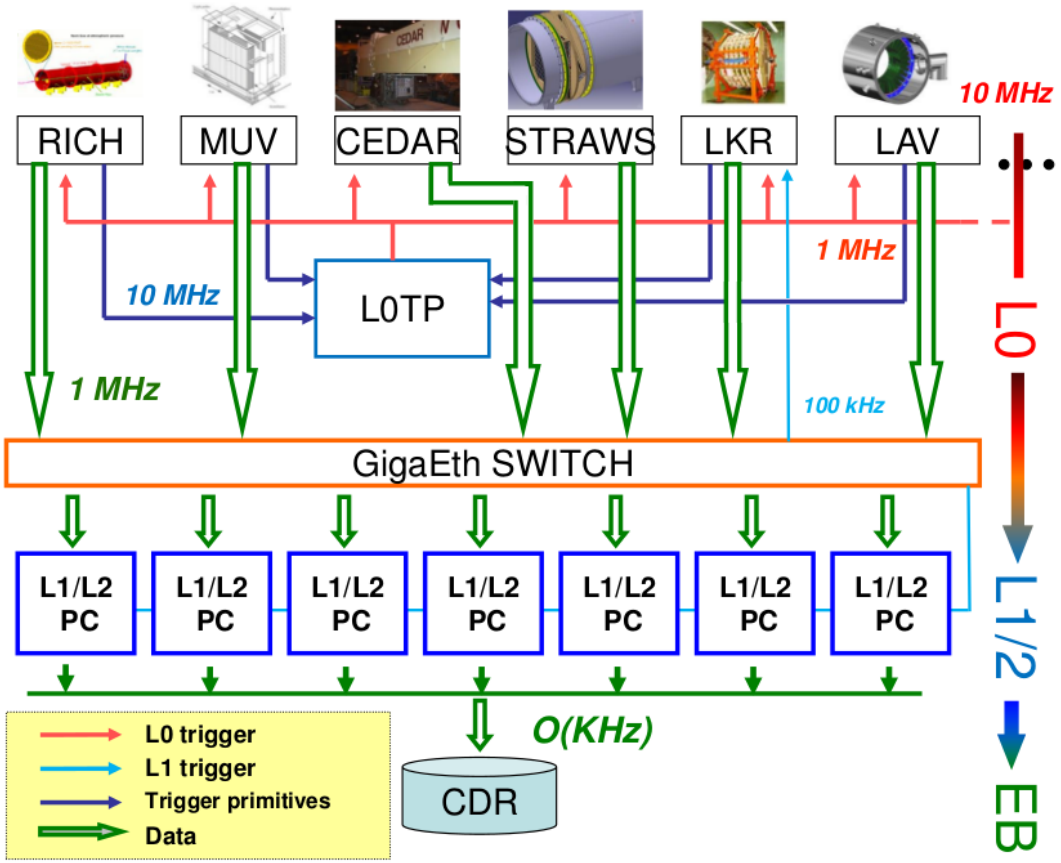

- NA48 hodoscope
- Provides fast trigger signals (charged particles) $\sigma_T < 1$ ns
- 2 planes (horizontal + vertical) of 64 plastic scintillator strips

## CHANTI (one station)



- Veto for charged particles produced by inelastic interactions in GTK3
- 6 scintillator stations in vacuum, each made of 2 planes (x,y)

# TRIGGER AND DATA ACQUISITION




Reduction of 10 MHz $K^+$ decay rate to 10 KHz

**Multilevel Trigger System**

1. FPGA based Level-0
   - synchronous signals to sub-detectors
   - decision based on digital primitives from fast detectors
   - latency: < 1 ms
2. PC based Level-1/2
   - asynchronous processing in the PC farm
   - L1: single detector information, lat. < 1 s
   - L2: all detector information, lat. < 30 s

# NA62 SENSITIVITY

| Decay | events / year |
|---|---|
| $K^+ \to \pi^+ \nu\bar{\nu}$ [SM] | 45 |
| $K^+ \to \pi^+ \pi^0$ | 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 |
| $K^+ \to \mu^+ (e^+) \pi^0 \nu$, others | negligible |
| Total background | < 10 |

Nominal intensity: $4.5 \times 10^{12}$ $K^+$ decays in the fiducial region / year

Cut and count analysis without any optimization

# CONCLUSIONS

- NA62 detector construction is almost complete
- 1st physics run starts on 6 October 2014 (lower beam intensity)
  - 2 months of data taking
  - Detector commissioning
  - Aiming to reach SM sensitivity
- Full intensity beam in 2015, 2016, 2017
- Many other rare kaon decays will be studied (see next talk)