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

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Outlook

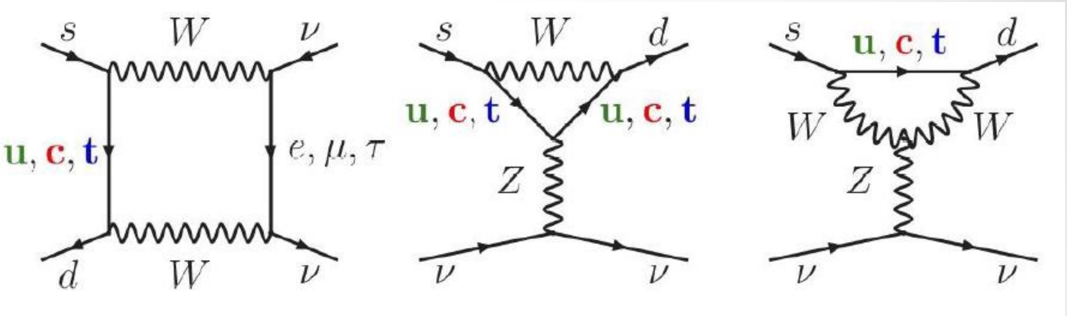
1. Motivation
2. NA62 experiment
3. Event selection
4. NA62 detectors
5. First look at the data
6. Conclusions

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

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

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

charm contribution

EM radiative correction

Top contribution (dominant)

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

$BR(K^+ \to \pi^+ \nu\nu) = (9.11 \pm 0.72) \times 10^{-11}$

$BR(K^0 \to \pi^0 \nu\nu) = (3.00 \pm 0.30) \times 10^{-11}$

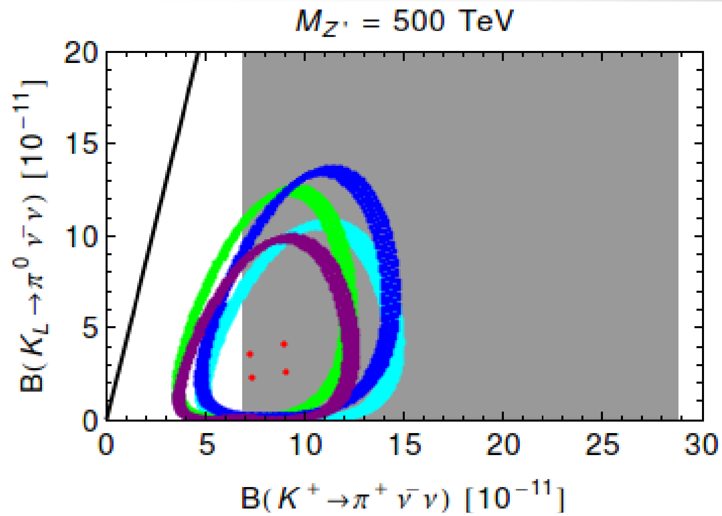
A.J. Buras et al, arXiv: 1503.02693

K→πνν in New Physics

A. Buras et al
arXiv: 1408.0728

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



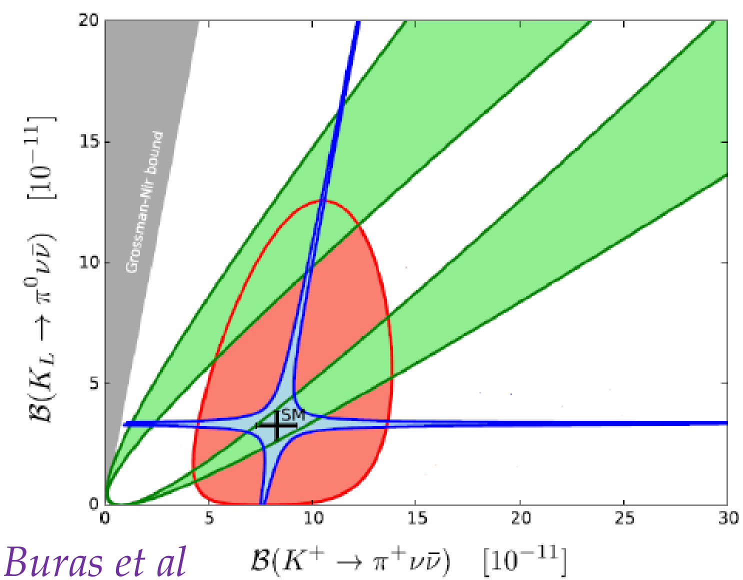
Grey: ruled out

SM: Standard Model

Red: custodial Randall-Sundrum

green: minimal flavor violation models

Blue: models with new flavour and CP-violating interactions



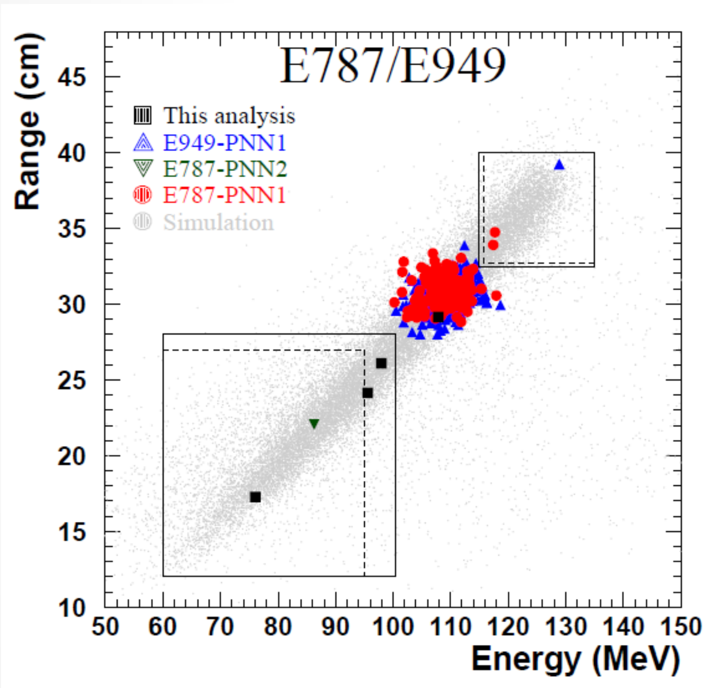
A. J. Buras et al
arXiv: 1507.08672

K→πνν in experimental physics

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

E787/E949 experiment @ BNL

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

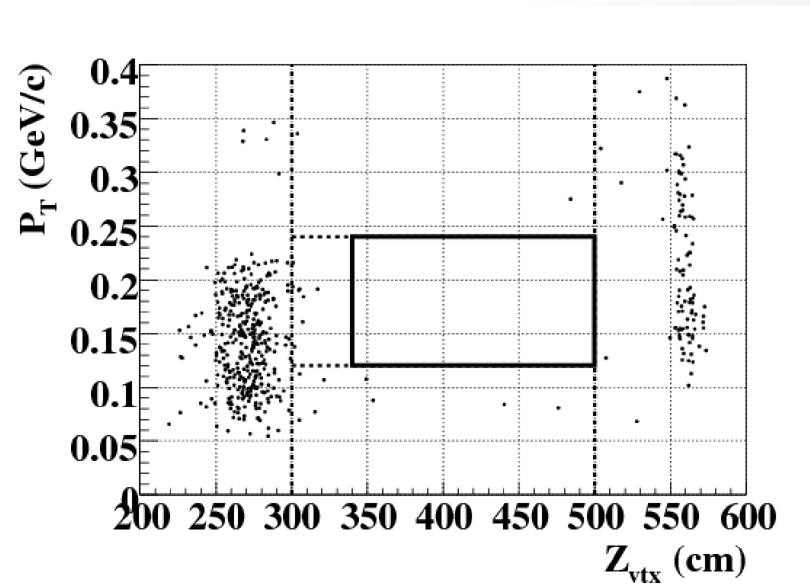


Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)

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

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:
- Collect O(100) signal events in 2 years
- Measure BR($K^+ \to \pi^+ \nu\nu$) with 10% precision

Further goals:
- Measure $|V_{td}|$ with ~10% accuracy
- Probe several NP scenarios in $K^+ \to \pi^+ \nu\nu$
- Probe NP in similar processes (e.g. $K^+ \to \pi^+ X$)

Beyond the baseline:
- LFV/LNV decays with 3 tracks in the final state
- Heavy neutrino searches
- π^0 decays
- Dark photon searches (see **talk by Evgueni Goudzovski** today)

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)

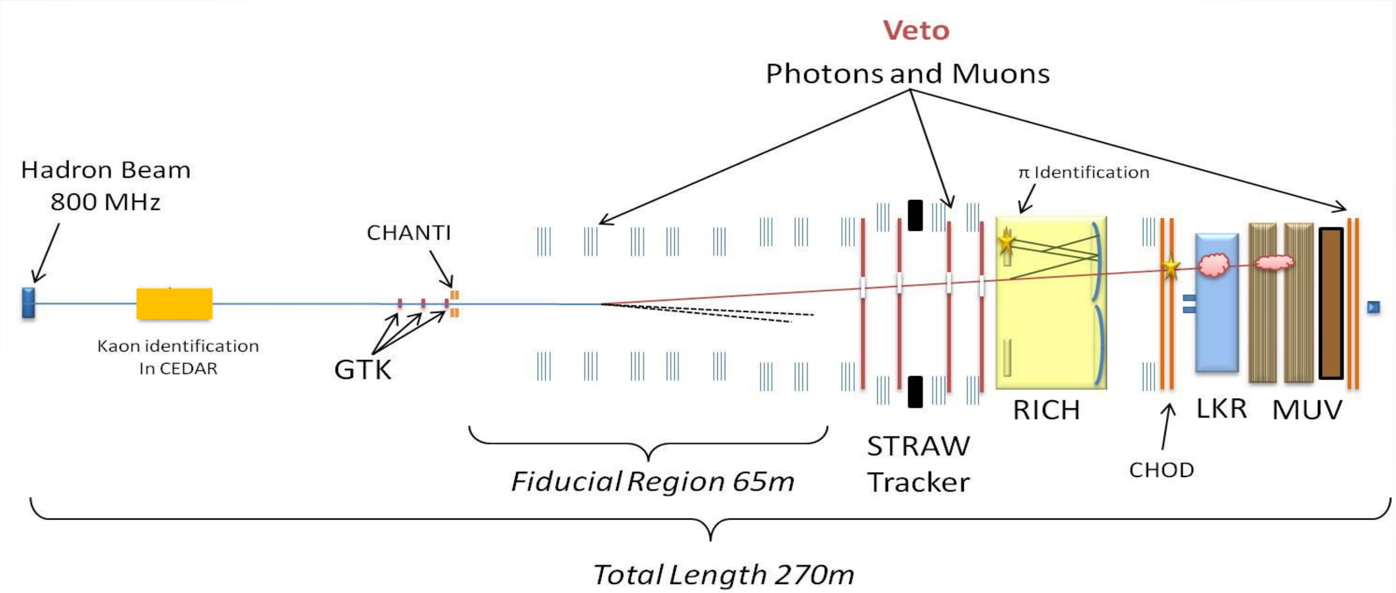
2014: Pilot physics run (full layout)

2015-2018: physics runs

NA62 collaboration:
Birmingham, Bratislava, Bristol, Bucharest, CERN, Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, Liverpool, Louvain, Mainz, Merced, Moscow, Naples, Perugia, Pisa, Prague, Protvino, Rome I, Rome II, San Luis Potosí, SLAC, Sofia, TRIUMF, Turin, Vancouver

NA62 detector

NA62: kaon decays, decay-in-flight technique



From SPS to NA62:

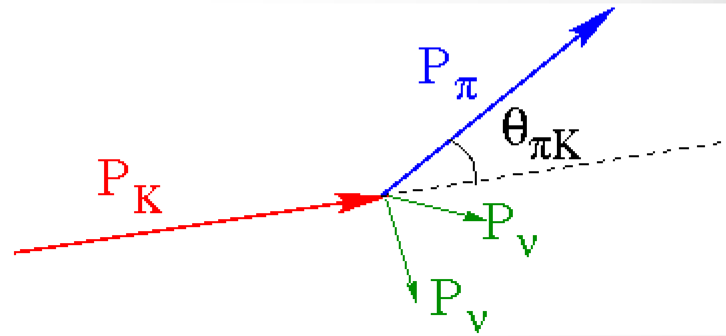
- ✓ SPS primary beam: 400 GeV/c, ~$1.1 \cdot 10^{12}$ protons/s on target
- ✓ Secondary hadron beam: 75 GeV/c, ~6% of K^+
- ✓ ~$4.8 \cdot 10^{12}$ kaon decays per year (~10 MHz event rate downstream)
- ✓ ~10% signal efficiency
- ✓ ~50 signal events per year

Signal vs background

Main kinematical variable for the signal:

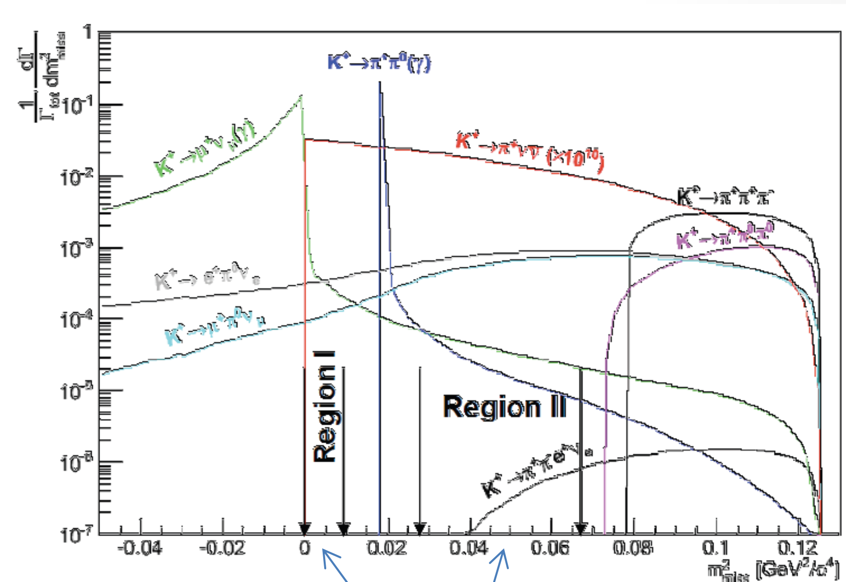
$m^2_{miss} = (P_K - P_\pi)^2$

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



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			✓	

veto:

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

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

Gigatracker

Si pixel detectors:

- 60 mm x 30mm sensitive area
- Si pixel detectors 300 x 300 μm^2
- 18000 pixels per station
- 10 readout chips
- $X/X_0 < 0.5\%$ per station

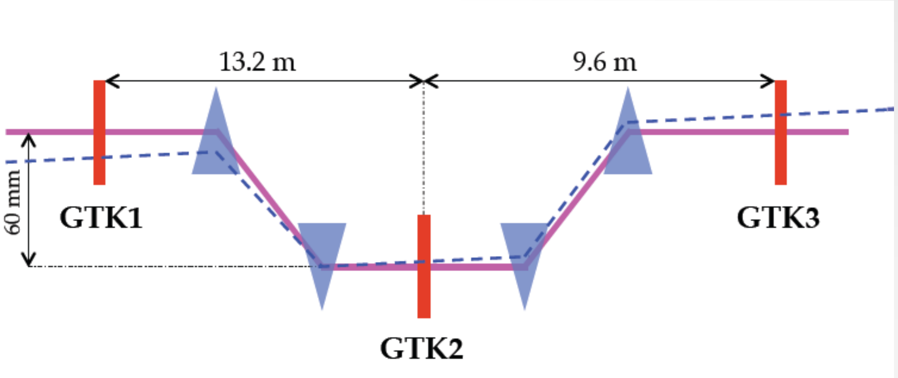
Performance:

- Time: ~200ps per station
- Direction: dx/dz ~ dy/dz ~ 16μrad
- Momentum: dP/P < 0.4%

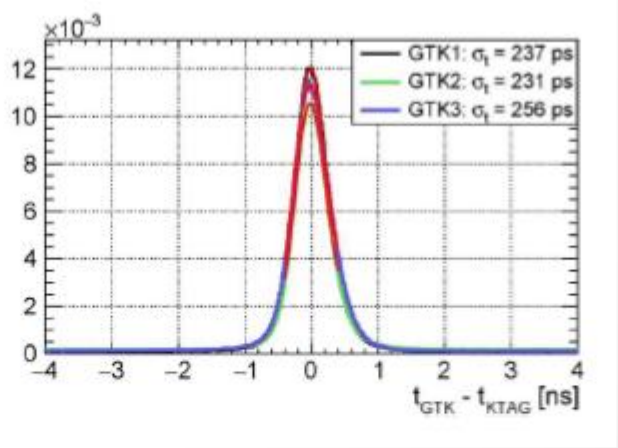
2015 results:

- Time: ~250ps per station
- Direction: dx/dz ~ dy/dz ~ 16μrad

3 stations and **4 achromat magnets** operating inside the beam pipe



2015 time resolution (partial readout)



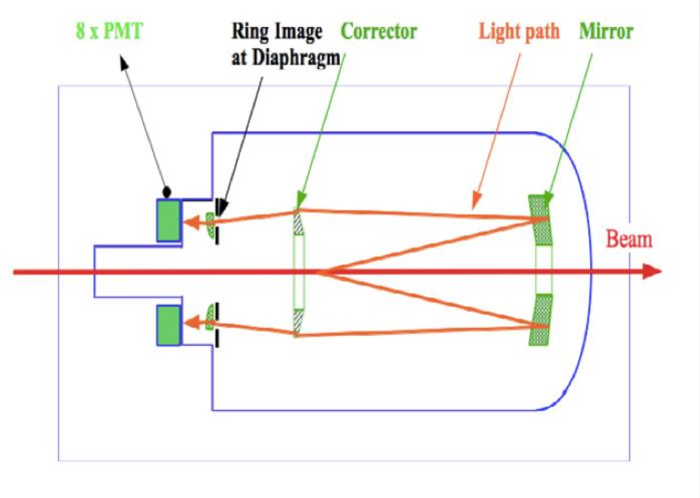
Status: partially commissioned

KTAG

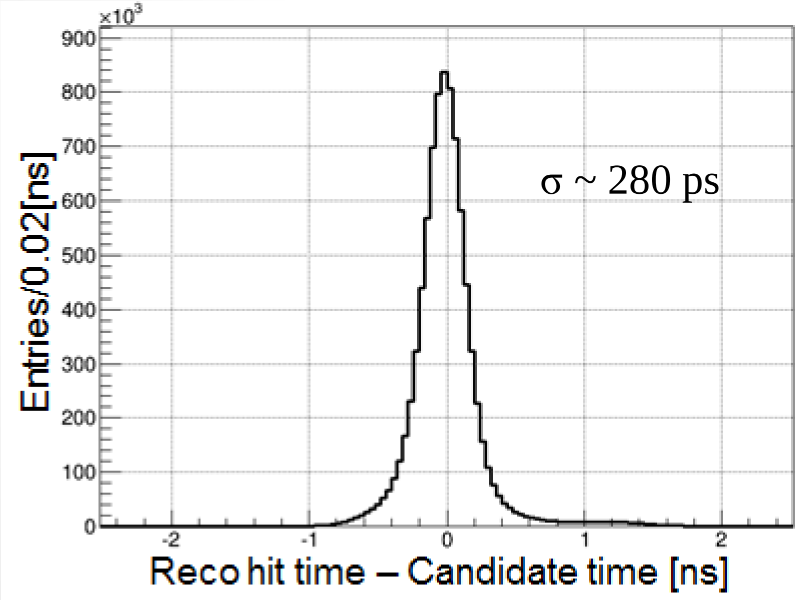
- Old: Cherenkov counter CEDAR
- N_2 or H_2 inside CEDAR
- New: external optics, PMs, front-end, readout
- 8 PM stations

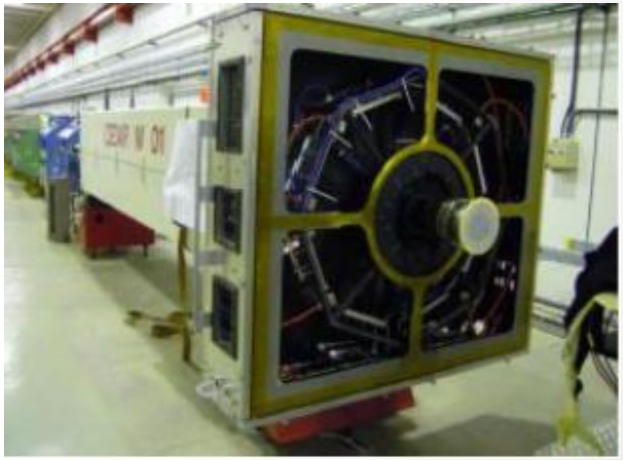
Performance:

- >95% K efficiency
- <1% pion mistagging
- Single hit time resolution σ_t ~ 280ps
- Event time resolution σ_t ~ 70ps



Single hit time resolution in 2015

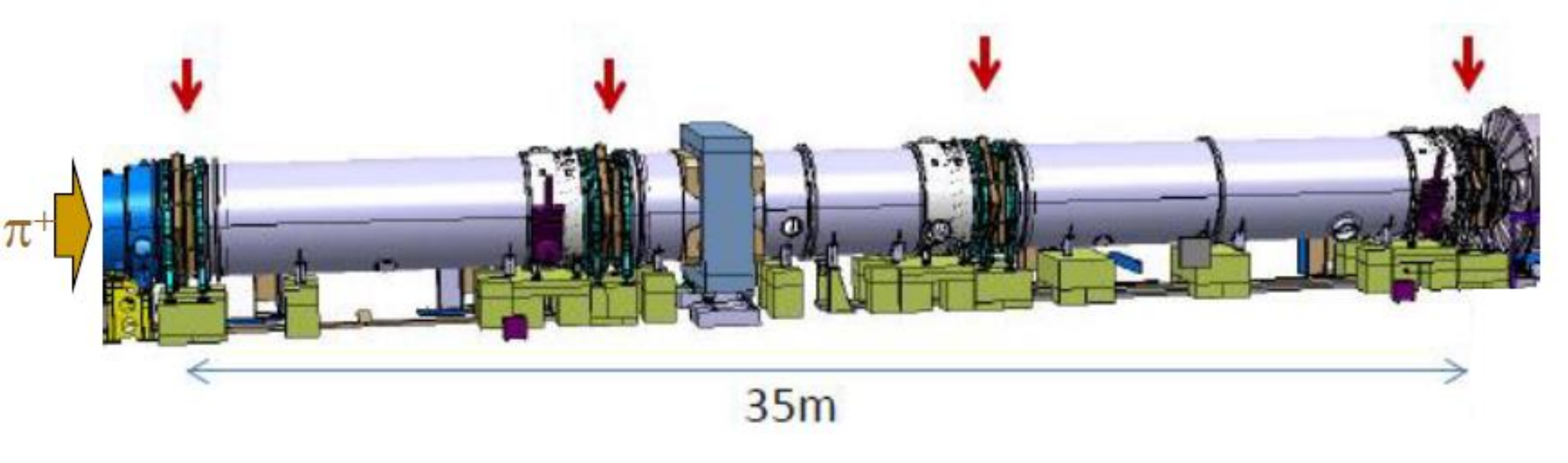




Status: fully commissioned

Straw spectrometer

4 straw chambers in vacuum + spectrometer magnet



Straw chamber:
- 4 views x 4 planes/view
- Mylar tubes: R=9.6mm, L=2.1m
- 112 mylar tubes per plane
- X/X_0 ~0.1% per view

Magnet:
- B ~ 0.36T
- p_T = 270 MeV/c

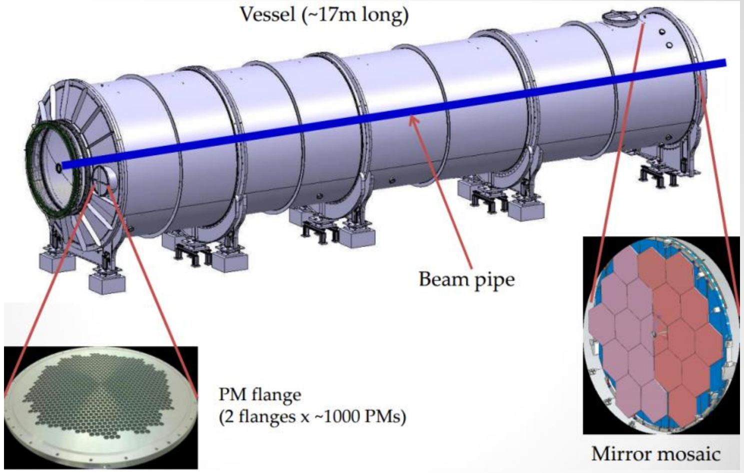
Performance:
- Spatial resolution < 130μm (1 view)
- Angular resolution < 60 μrad
- Momentum resolution dp/p < 1%

Status: fully commissioned

RICH

Detector:

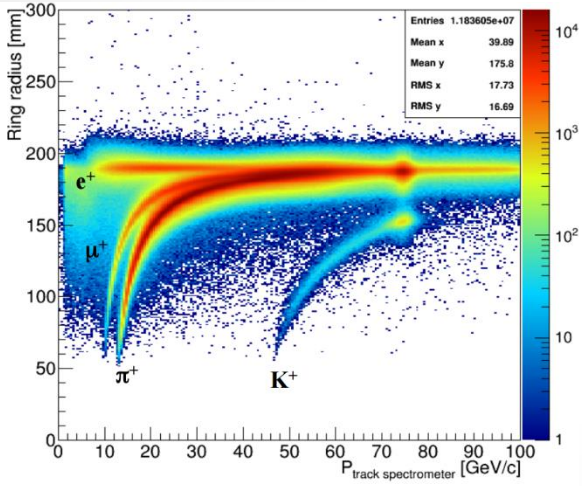
- 17m long vessel filled with Ne at atmospheric pressure
- Array of 20 mirrors
- 2 PM flanges
- 976 PMs per flange

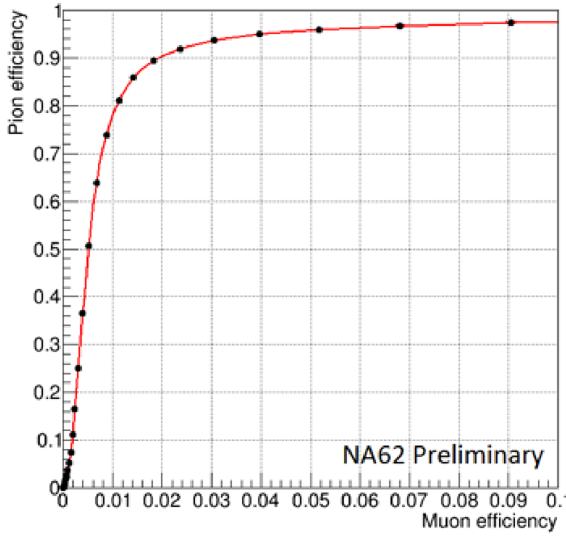


Performance:

- μ mistagging ~1% for 15 < P < 35 GeV/c
- Event time resolution ~70ps

RICH PID in 2015



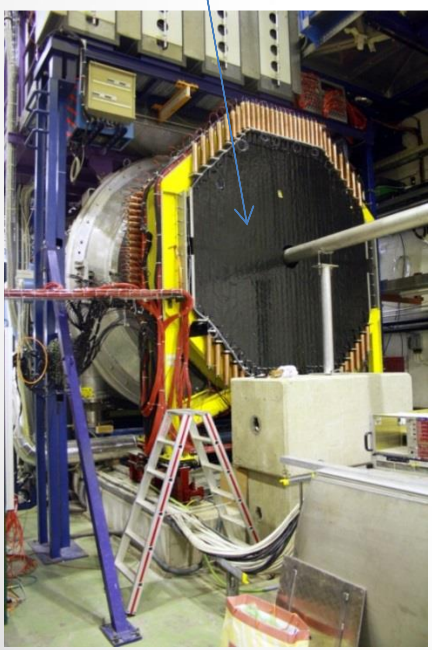


RICH vessel

Status: fully commissioned

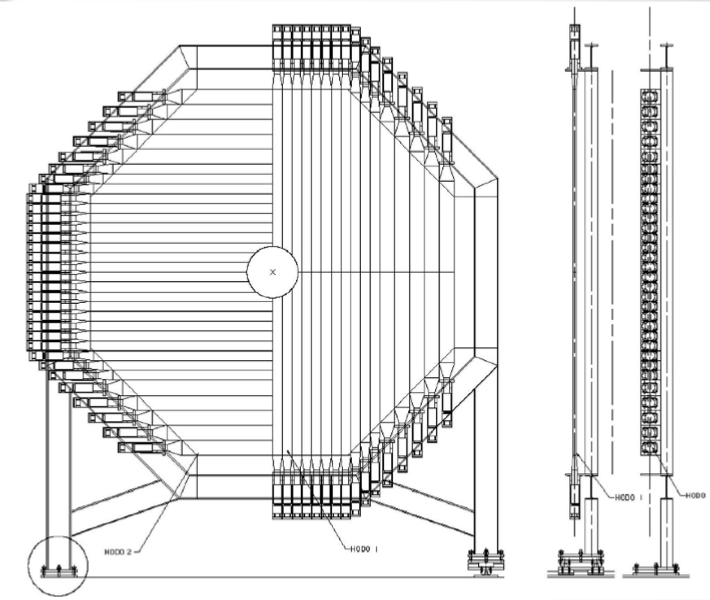
CHOD

CHOD vertical plane



Detector:

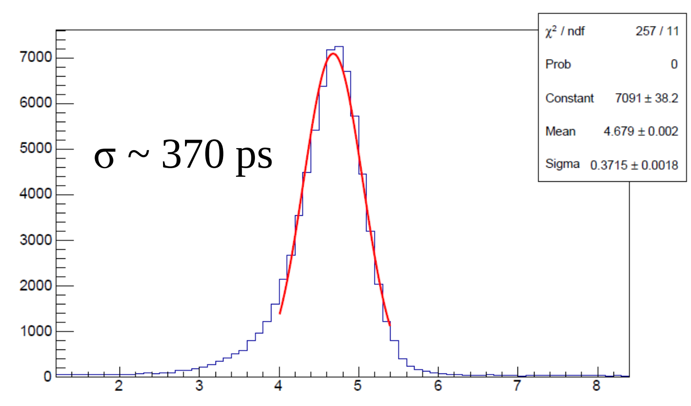
- 2 planes with scintillator slabs
- 64 slabs per plane
- X/X_0 ~5% per plane



Performance:

- Time resolution with impact point correction $\sigma_t < 400$ps

CHOD time resolution in 2014



Status: fully commissioned

Photon veto: LAV/LKr/IRC/SAC

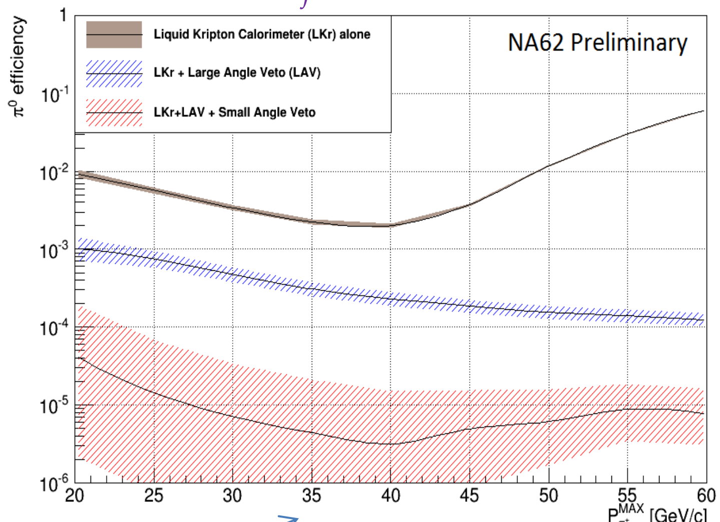
LAV:
- ✓ 12 stations in vacuum
- ✓ **Cover 8.5 to 50 mrad**
- ✓ OPAL lead glass read by PMs
- ✓ ~18.6 X_0

LKr:
- ✓ NA48/2 em calorimeter
- ✓ **Cover 1 to 8.5 mrad**
- ✓ ~27 X_0
- ✓ 100ps time resolution

IRC & SAC:
- ✓ Small angle calorimeters
- ✓ **Cover <1 mrad**

LAV+LKr+IRC+SAC:
~10^8 rejection of $\pi^0 \to \gamma\gamma$

π^0 rejection in 2015



LAV station

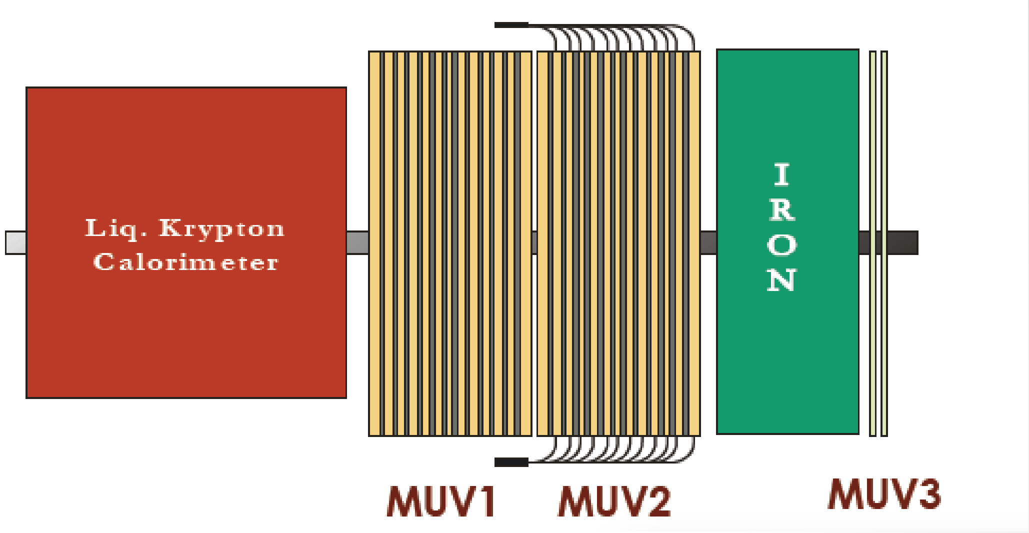
Performance:
- ➢ LAV σ_t ~ 1 ns
- ➢ LKr γ detection inefficiency for E>10 GeV: $(1-\varepsilon) < 10^{-5}$
- ➢ LKr σ_t ~ 500ps
- ➢ IRC, SAC σ_t ~ 1 ns
- ➢ O(10^6) π^0rejection already obtained in 2015

Status: fully commissioned

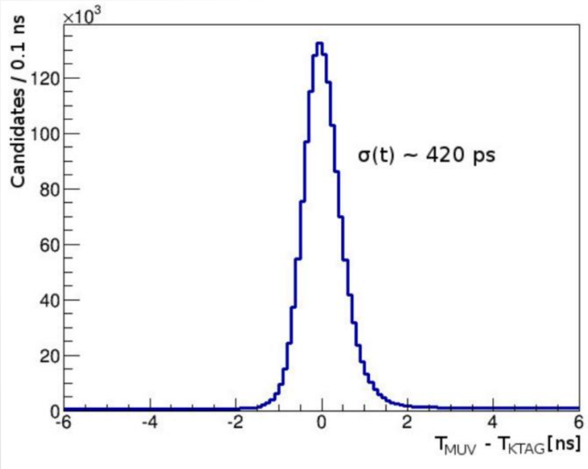
MUV

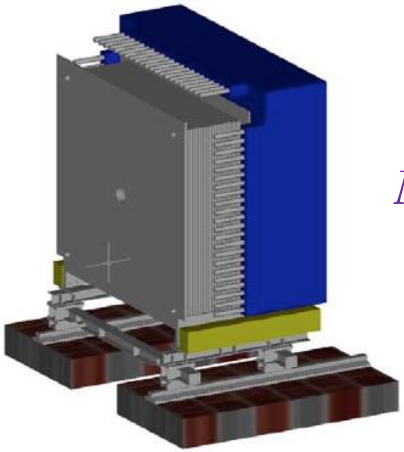
MUV1-2:
- Fe-scintillator calorimeter
- Hadronic/MIP cluster ID

MUV3:
- Scintillator tiles
- PM readout
- Used in L_0 trigger



MUV3 time resolution in 2015

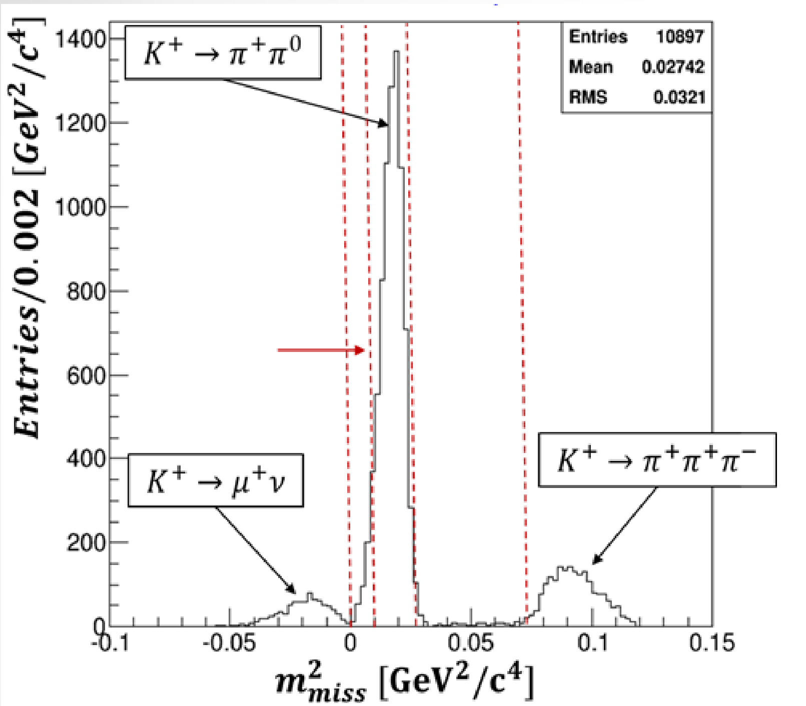


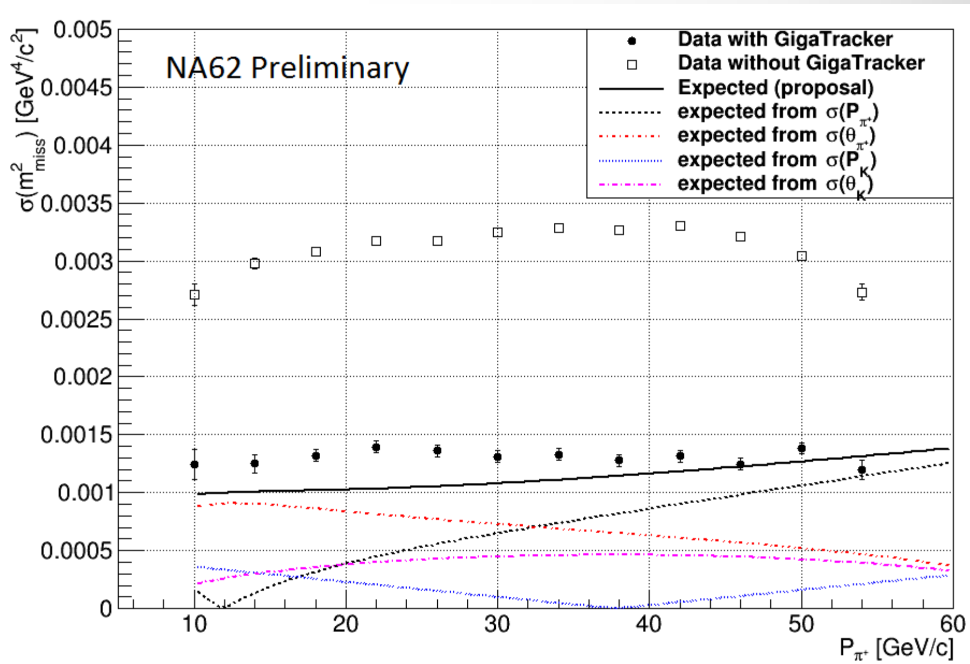


MUV3

Status: fully commissioned

First look at 2015 data





Resolution on m^2_{miss} close to the design

O(10^3) kinematic suppression factor in 2015

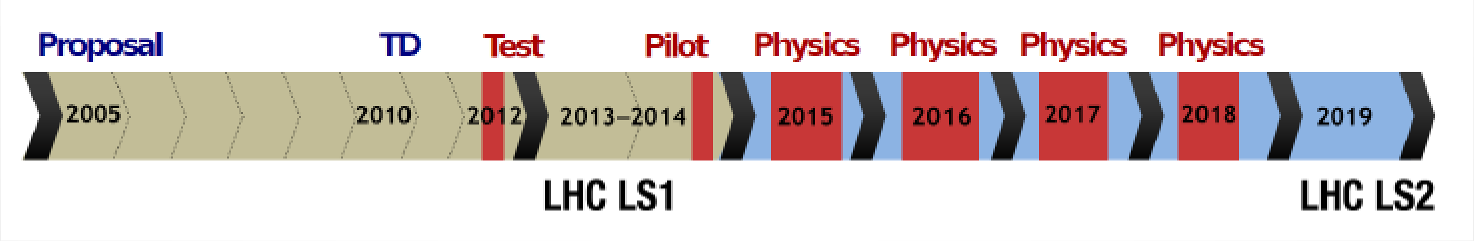
Goal: 10^4 - 10^5 kinematic suppression

Rooms for improvement:

- GTK full commissioning
- Fine STRAW alignment with detailed B field map
- RICH fine mirror alignment
- Photon and muon rejection

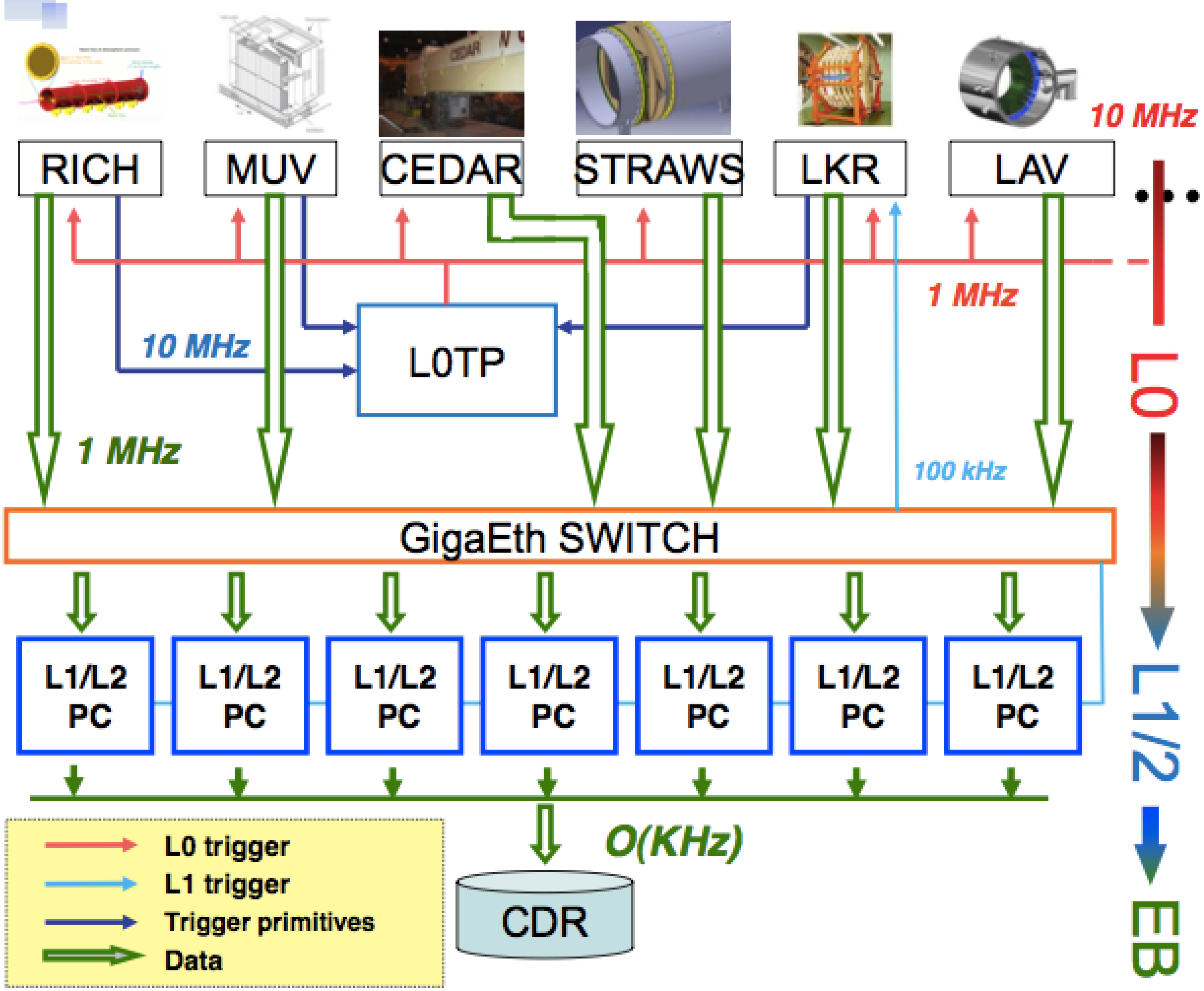
Conclusions

- 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 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



spares

NA62 TDAQ



L0: Hardware synchronous level. 10 MHz to 1 MHz. Max latency 1 ms.

L1: Software level. "Single detector". 1 MHz to 100 kHz

L2: Software level. "Complete information level". 100 kHz to few kHz.

NA62: beyond the baseline

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	-	$O(10^5)$