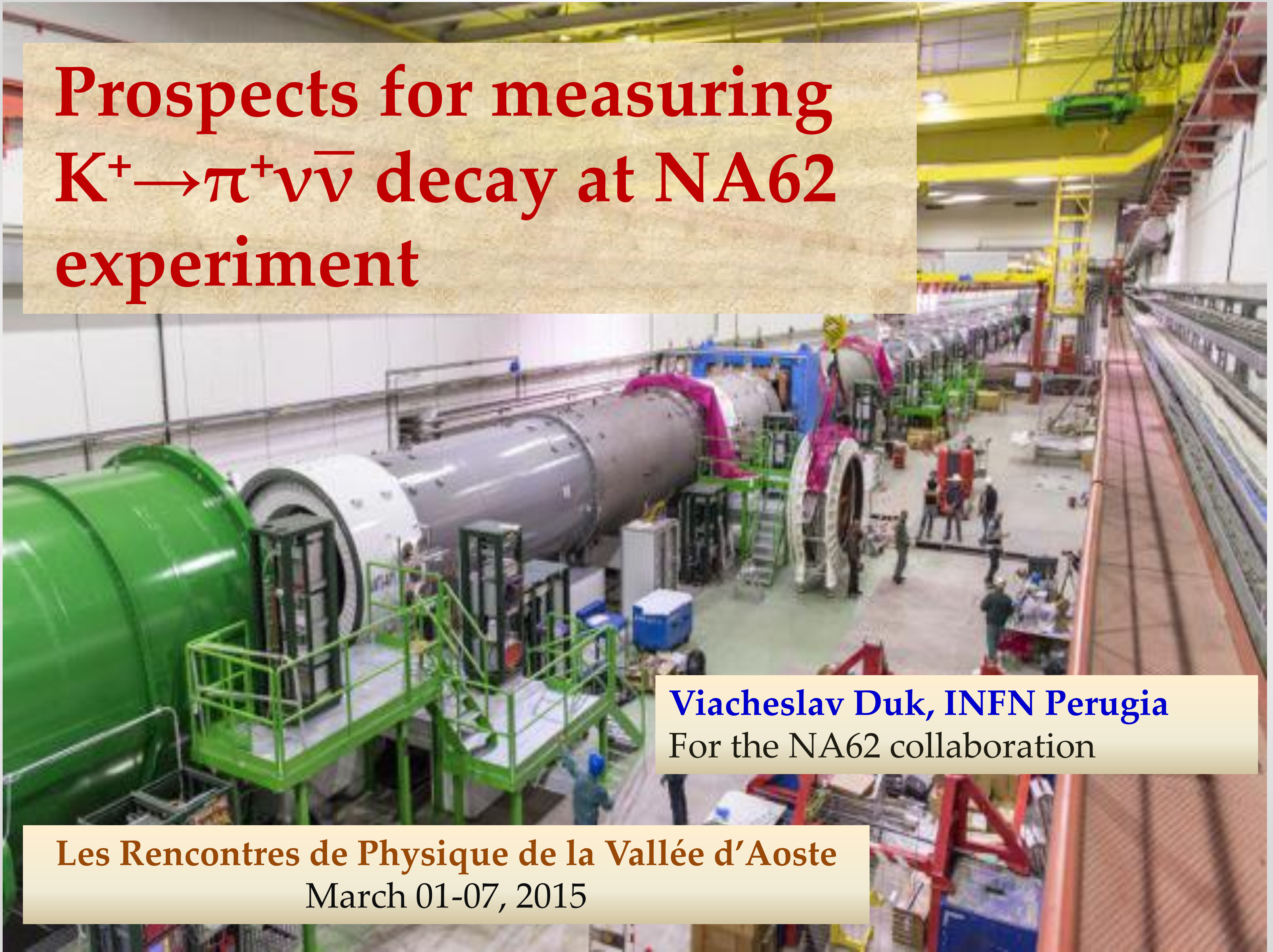


Prospects for measuring $K^+ \to \pi^+ \nu \bar{\nu}$ decay at NA62 experiment

Viacheslav Duk, INFN Perugia
For the NA62 collaboration

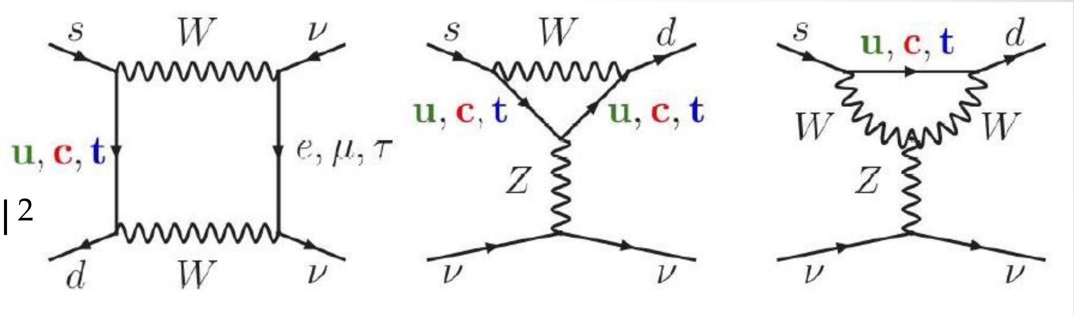
Les Rencontres de Physique de la Vallée d'Aoste
March 01-07, 2015

Outlook

1. Motivation
2. NA62 experiment
3. Event selection
4. NA62 detectors
5. NA62 sensitivity
6. Conclusions

$K \to \pi\nu\nu$ in SM

SM one-loop diagrams: box and penguins



2 modes: charged, neutral

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

Contributions to BR

- t-quark part (NLO QCD, 2-loop EW corrections): dominant
- c-quark part (NNLO QCD, NLO EW corrections): small
- LD correction
- Hadronic matrix element extracted from well-known decay $K^+ \to e^+ \nu \pi^0$

Uncertainties:

- Parametric (dominated by CKM, first error)
- Theoretical (dominated by LD corrections, second error)

$$BR(K^+ \to \pi^+ \nu\nu) = (7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$$
$$BR(K^0 \to \pi^0 \nu\nu) = (2.43 \pm 0.39 \pm 0.06) \times 10^{-11}$$

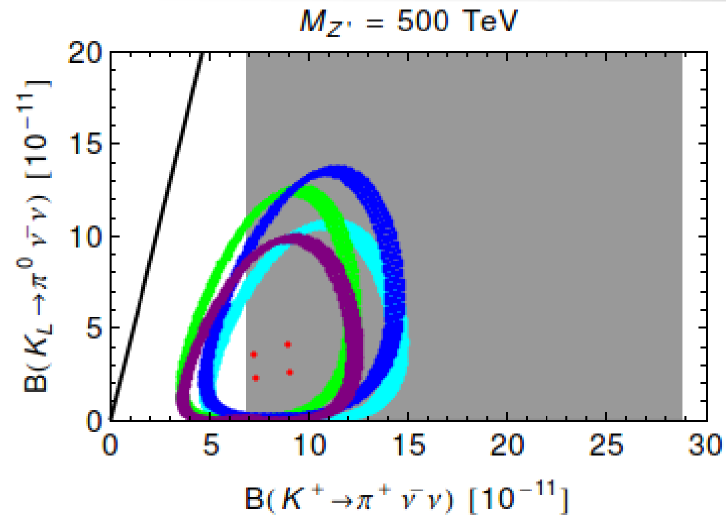
[Brod, Gorbahn, Stamou, Phys. Rev. D 83, 034030 (2011)]

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

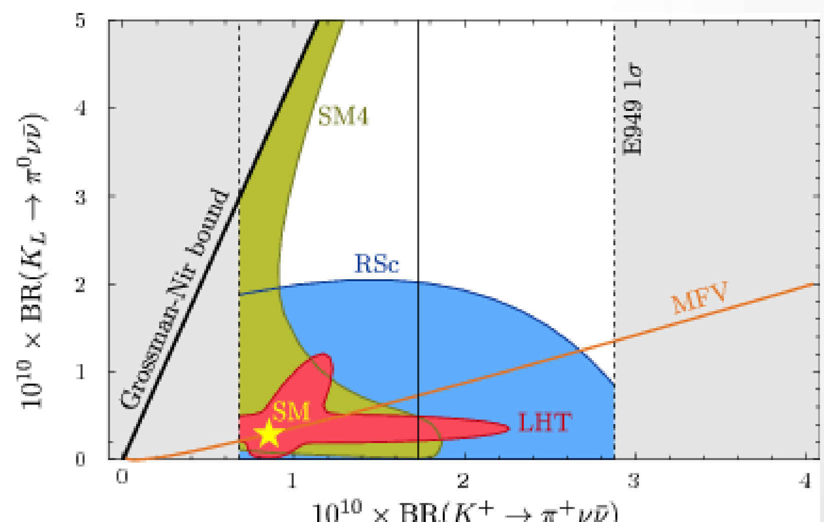
SM: Standard Model

SM4: SM with 4th generation

RSc: custodial Randall-Sundrum

LHT: littlest Higgs with T-parity

MFV: minimal flavor violation



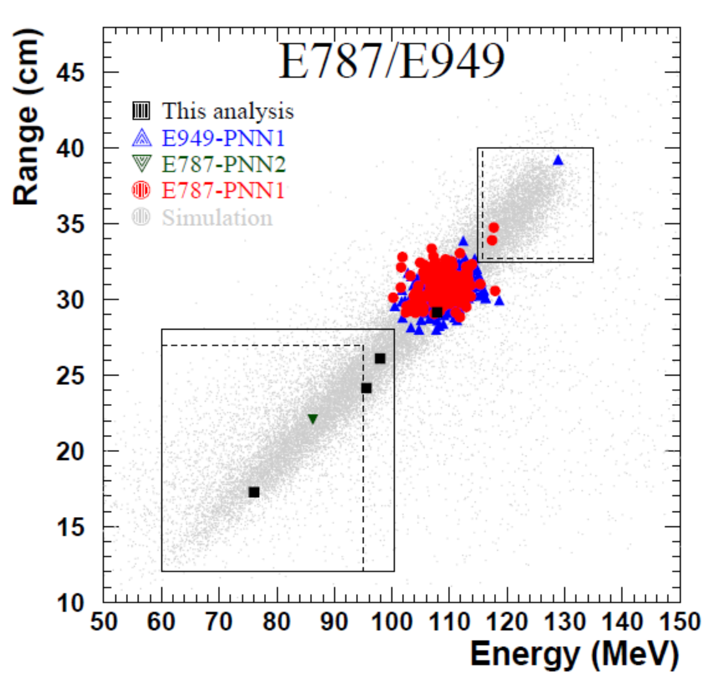
D. Straub @ CKM-2010
arXiv: 1012.3893

K→πνν in experimental physics

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

E787/E949 experiment @ BNL

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

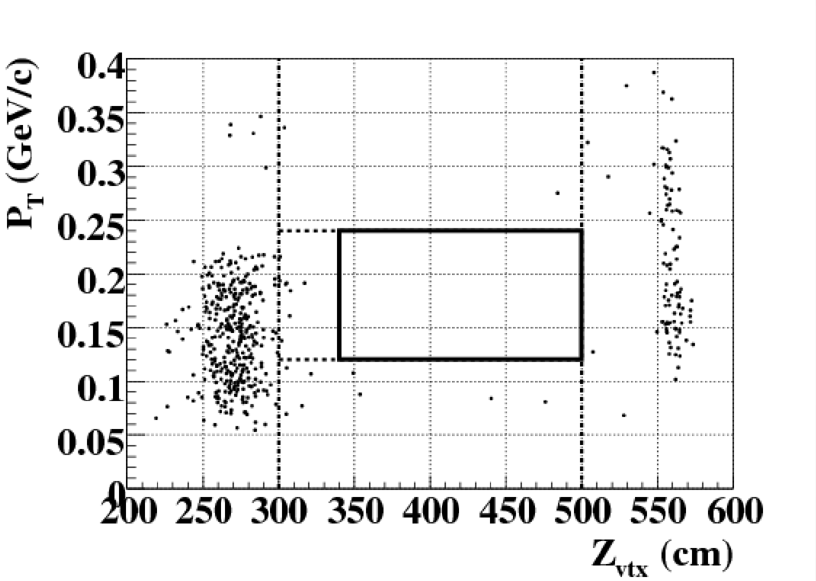


Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)

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

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 M. Raggi** for details)

NA62 @ SPS CERN

2007-2011: R&D

2011-2014: construction & installation

2012: Technical run (partial layout)

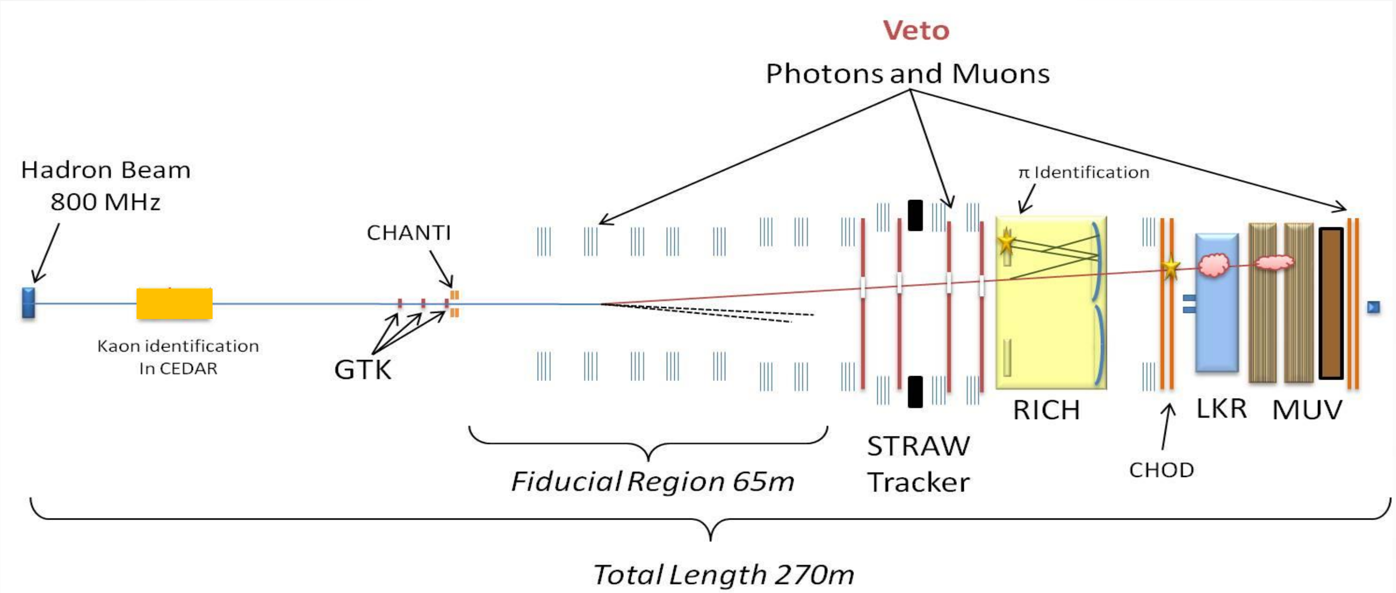
2014: Pilot physics run (full layout)

2015-2018: physics runs

NA62 collaboration:
Birmingham, Bratislava, Bristol, Bucharest, CERN, JINR Dubna, Fairfax, Ferrara, Florence, Frascati, Glasgow, IHEP Protvino, INR Moscow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Naples, Padua, Perugia, Pisa, Prague, Rome I, Rome II, San Luis Potosí, Sofia, Stanford, Turin

NA62 detector

NA62: kaon decays, decay-in-flight technique



From SPS to NA62:

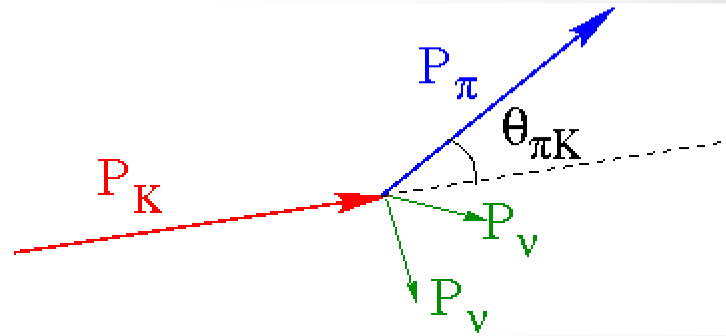
- ✓ SPS primary beam: 400 GeV/c, ~$1.1 \cdot 10^{12}$ protons/s on target
- ✓ Secondary hadron beam: 75 GeV/c, ~6% of K^+
- ✓ ~$4.8 \cdot 10^{12}$ kaon decays per year (~10MHz event rate downstream)
- ✓ ~10% signal efficiency
- ✓ ~50 signal events per year

Signal vs background

Main kinematical variable for the signal:

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

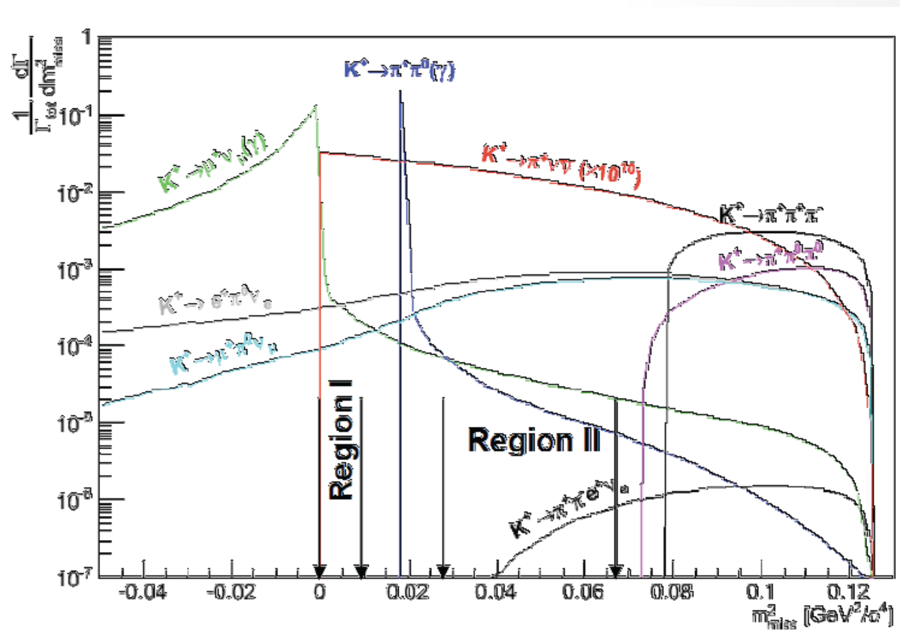
$$m^2_{miss} \cong m_K^2\left(1-\frac{|P_\pi|}{|P_K|}\right) + m_\pi^2\left(1-\frac{|P_K|}{|P_\pi|}\right) - |P_K||P_\pi|\theta^2_{\pi K}$$



Background:

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

K^+ main decays	BR
$K^+ \to \mu^+\nu$	0.6355
$K^+ \to \pi^+\pi^0$	0.2066
$K^+ \to \pi^+\pi^+\pi^-$	0.0559
$K^+ \to \pi^+\pi^0\pi^0$	0.0176
$K^+ \to \pi^0 e^+\nu$	0.0507
$K^+ \to \pi^0\mu^+\nu$	0.0335
$K^+ \to \pi^+\pi^- e^+\nu$	4.257×10^{-5}



Event selection principles

Kaon detection

(track reconstruction, time, ID):

- K^+ track reconstruction (Gigatracker)
- K^+ time (Gigatracker, KTAG)
- $K/\pi/p$ separation (KTAG)

Pion detection

(track reconstruction, time, ID):

- π^+ track reconstruction (Straw spectrometer)
- π^+ time (RICH)
- $\pi/\mu/e$ separation (RICH)

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)

Trigger:

- 1 secondary charged track
- No muons among decay products
- "pion-like" energy deposition in calorimeters
- Signal in CHOD

background suppression:

- No signal in upstream veto (CHANTI)
- No signal in photon vetoes (LAV/IRC/SAC)
- No signal in muon vetoes (MUV)

Gigatracker

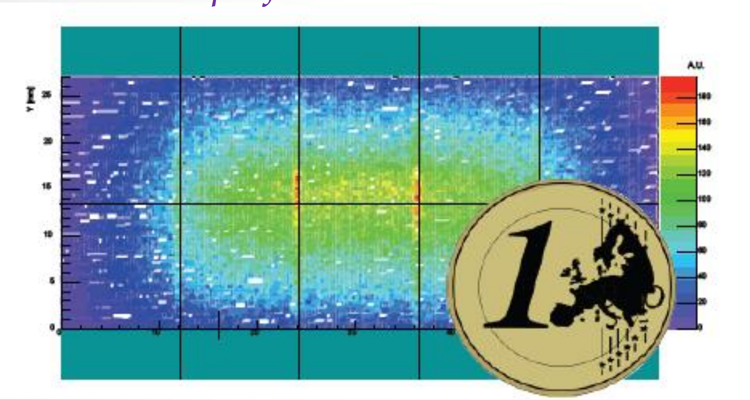
Si pixel detectors:

- 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

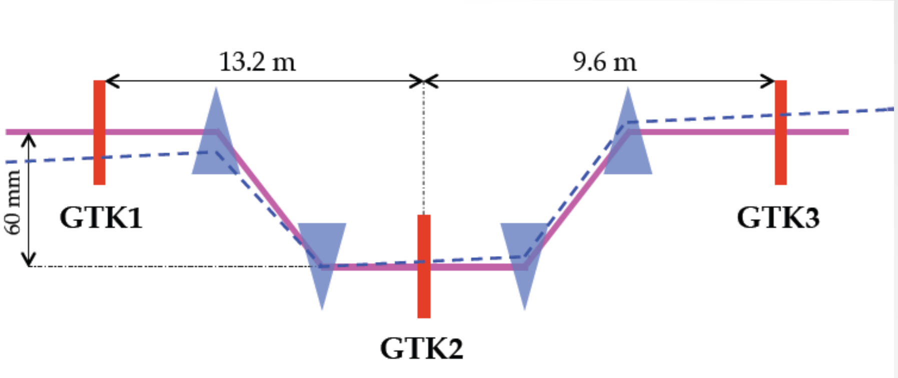
Resolutions:

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

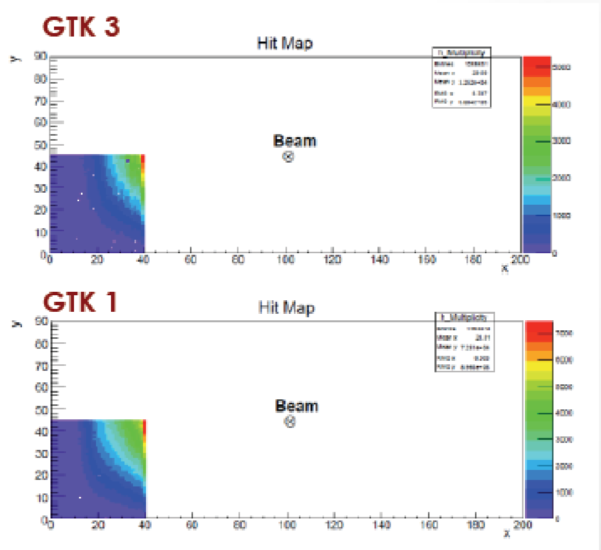
Beam profile (MC)



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

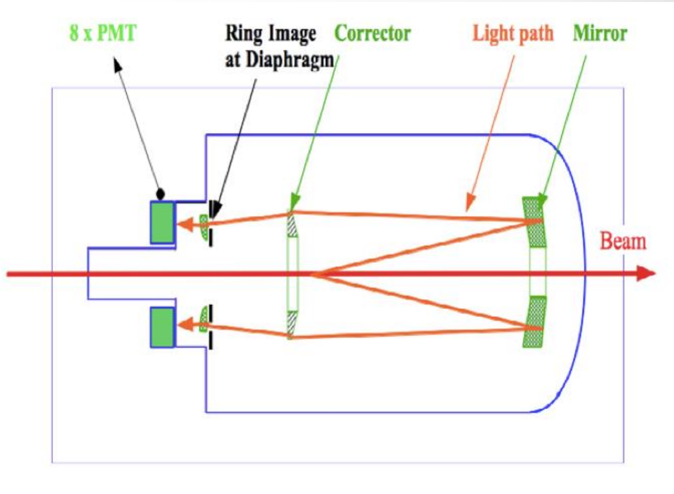


2014: partial readout (1 chip per station)



KTAG

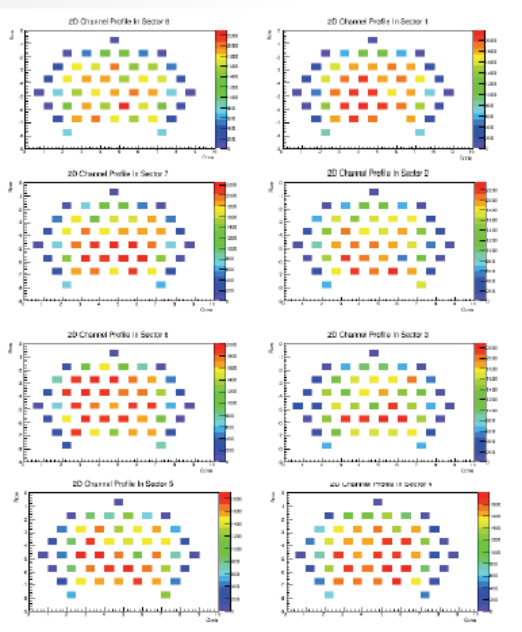
- Old: cerenkov counter CEDAR
- N_2 or H_2 inside CEDAR
- New: external optics, PMs, front-end, readout
- 8 PM stations



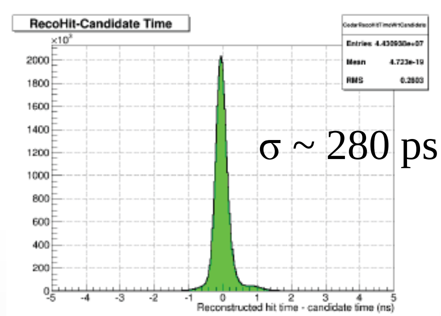
Performance:

- >95% K efficiency
- <1% pion mistagging
- Time resolution $\sigma_t < 100$ps

KTAG illumination in 2014



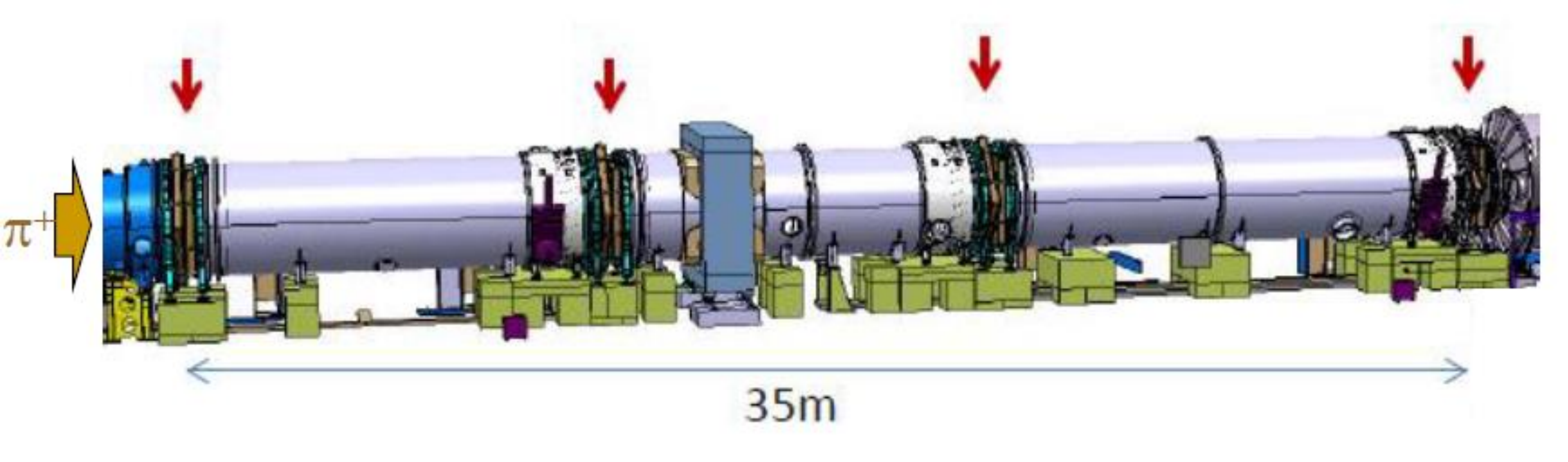
Single PM time resolution in 2014



KTAG

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

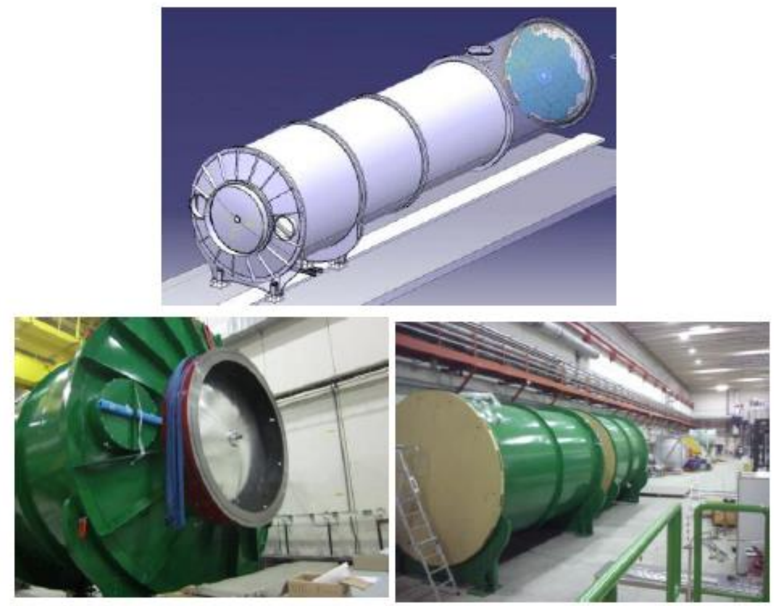
Performance:
- Spatial resolution < 130μm
- Momentum resolution dp/p ~ 0.32% + 0.008%*p

RICH

Detector:

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

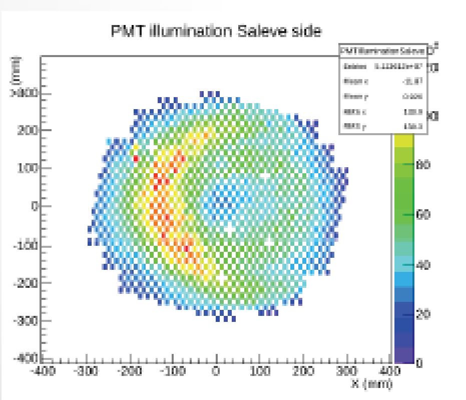
RICH vessel



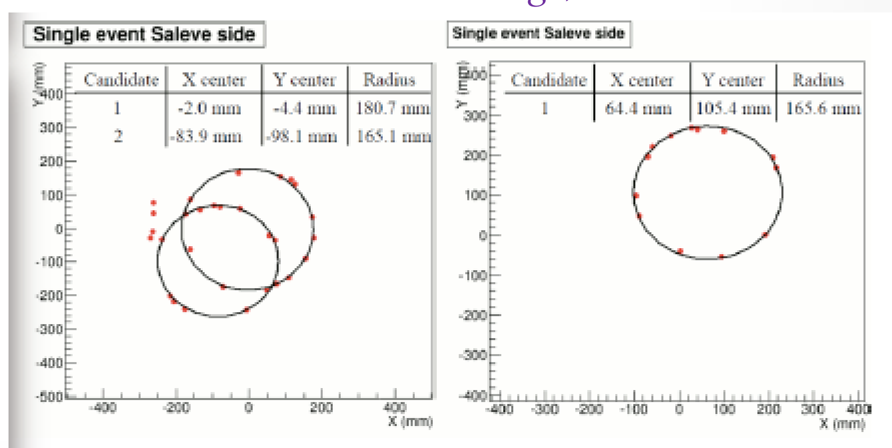
Performance:

- μ mistagging < 1%
- Time resolution ~70ps

RICH PM illumination in 2014

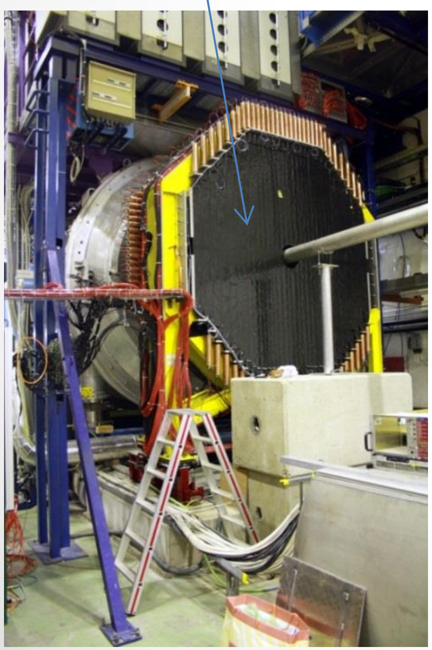


Reconstructed rings, 2014 run

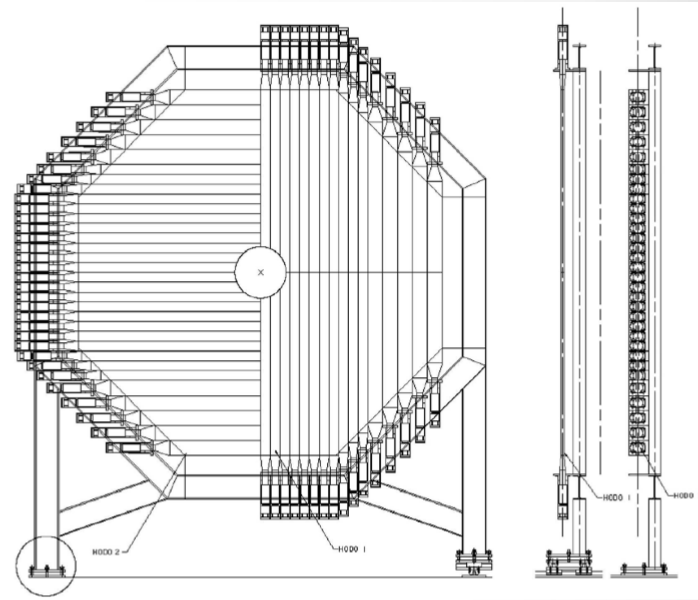


CHOD

CHOD vertical plane

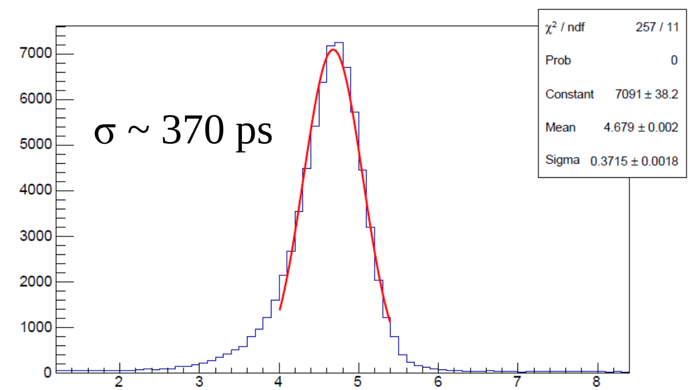


Detector:
- 2 planes with scintillator slabs
- 64 slabs per plane
- X/X_0 ~5% per plane



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

CHOD time resolution in 2014

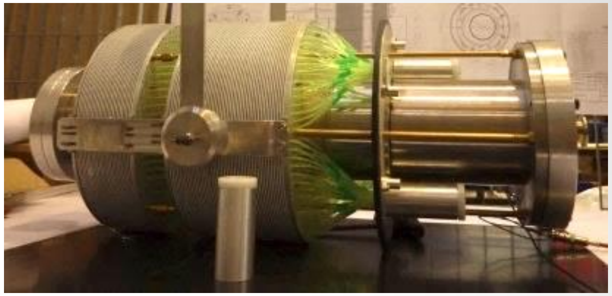


Photon veto: LAV/LKr/IRC/SAC

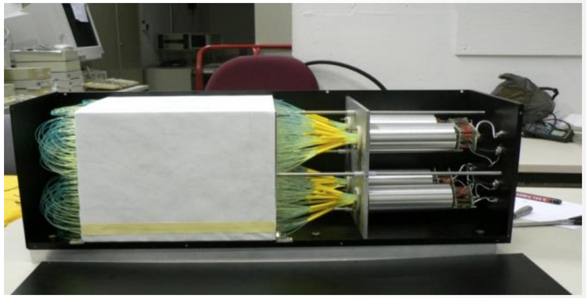
LAV station

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
- ✓ γ detection inefficiency for E>10 GeV: $(1-\varepsilon) < 8\times10^{-6}$
- ✓ 100ps time resolution

IRC & SAC:

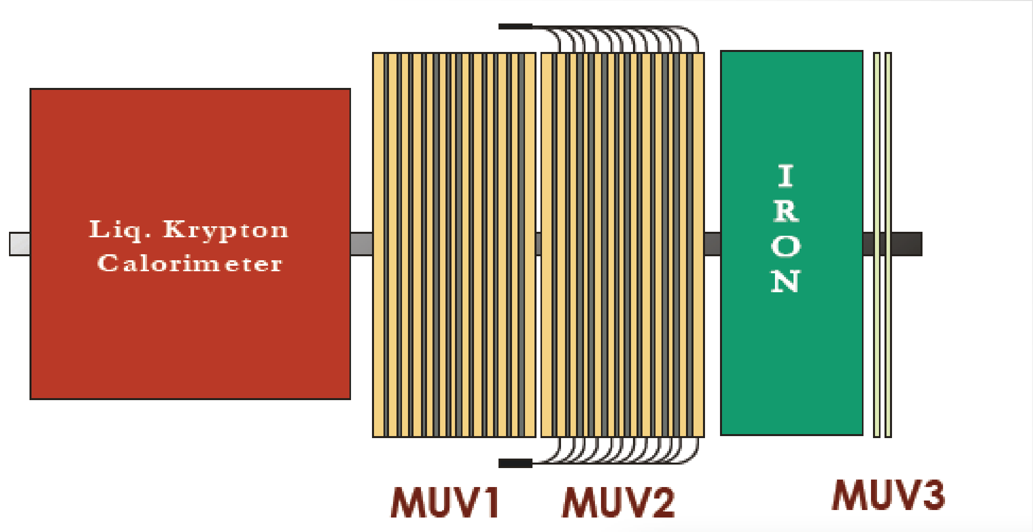
- ✓ Small angle calorimeters
- ✓ Cover <1 mrad

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

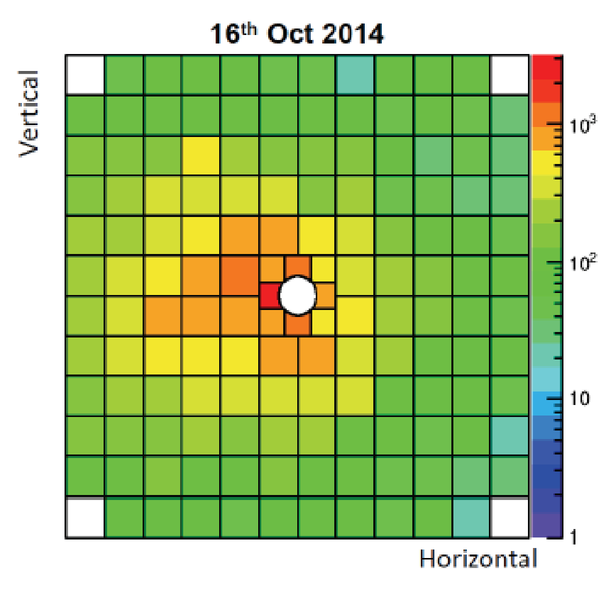
MUV

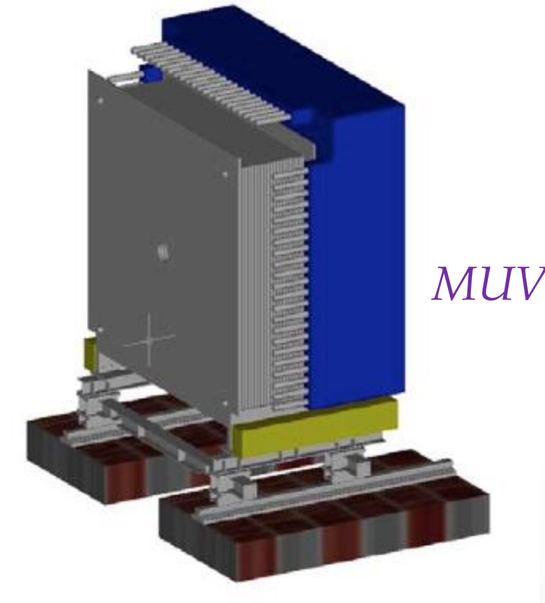
MUV1-2:
- Fe-scintillator calorimeter
- Hadronic/MIP cluster ID

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



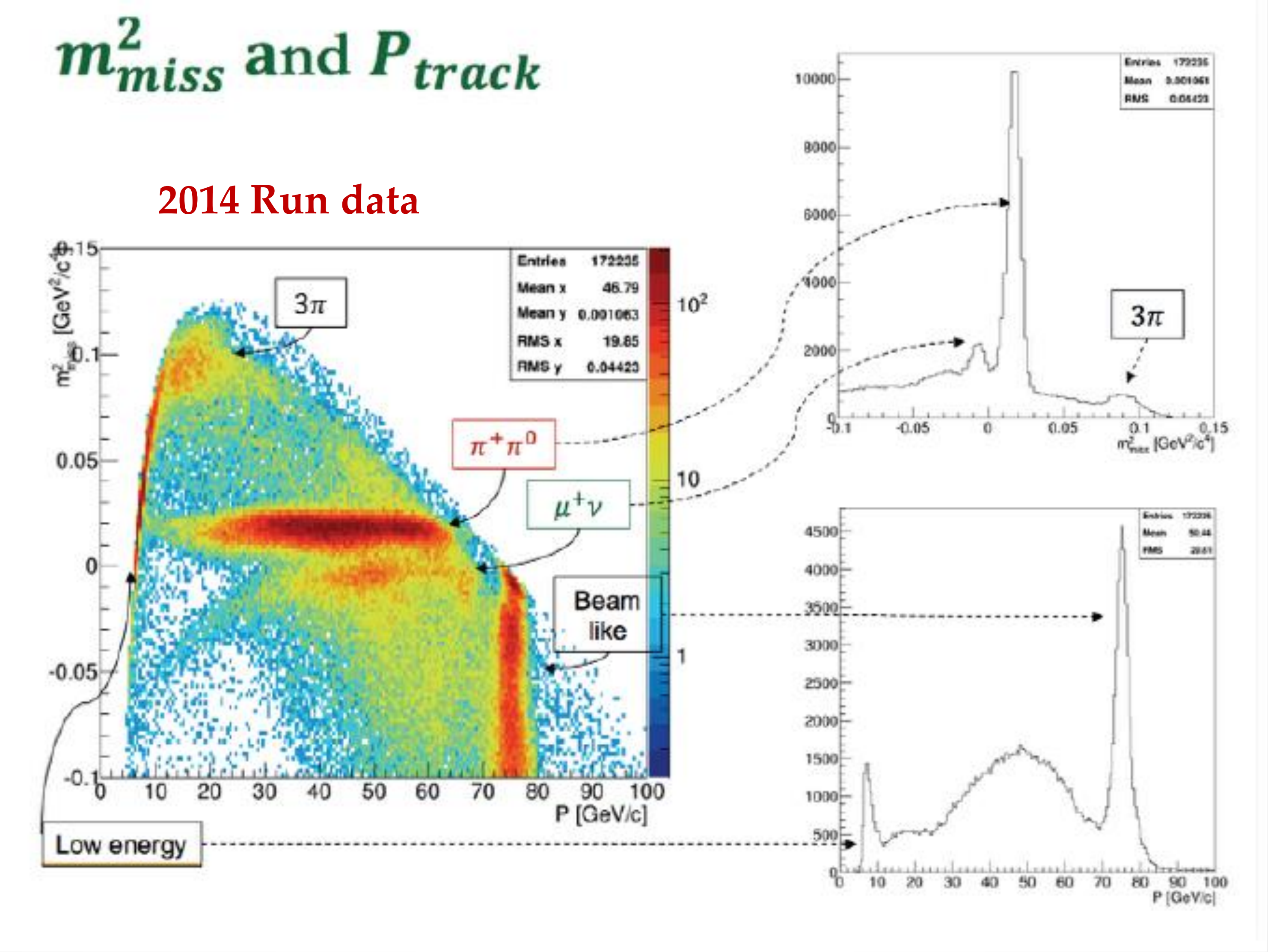
MUV3 illumination in 2014





MUV3

First look at the data



NA62 sensitivity

Decay	event/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12})	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks 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
Total background	< 10

Conclusions

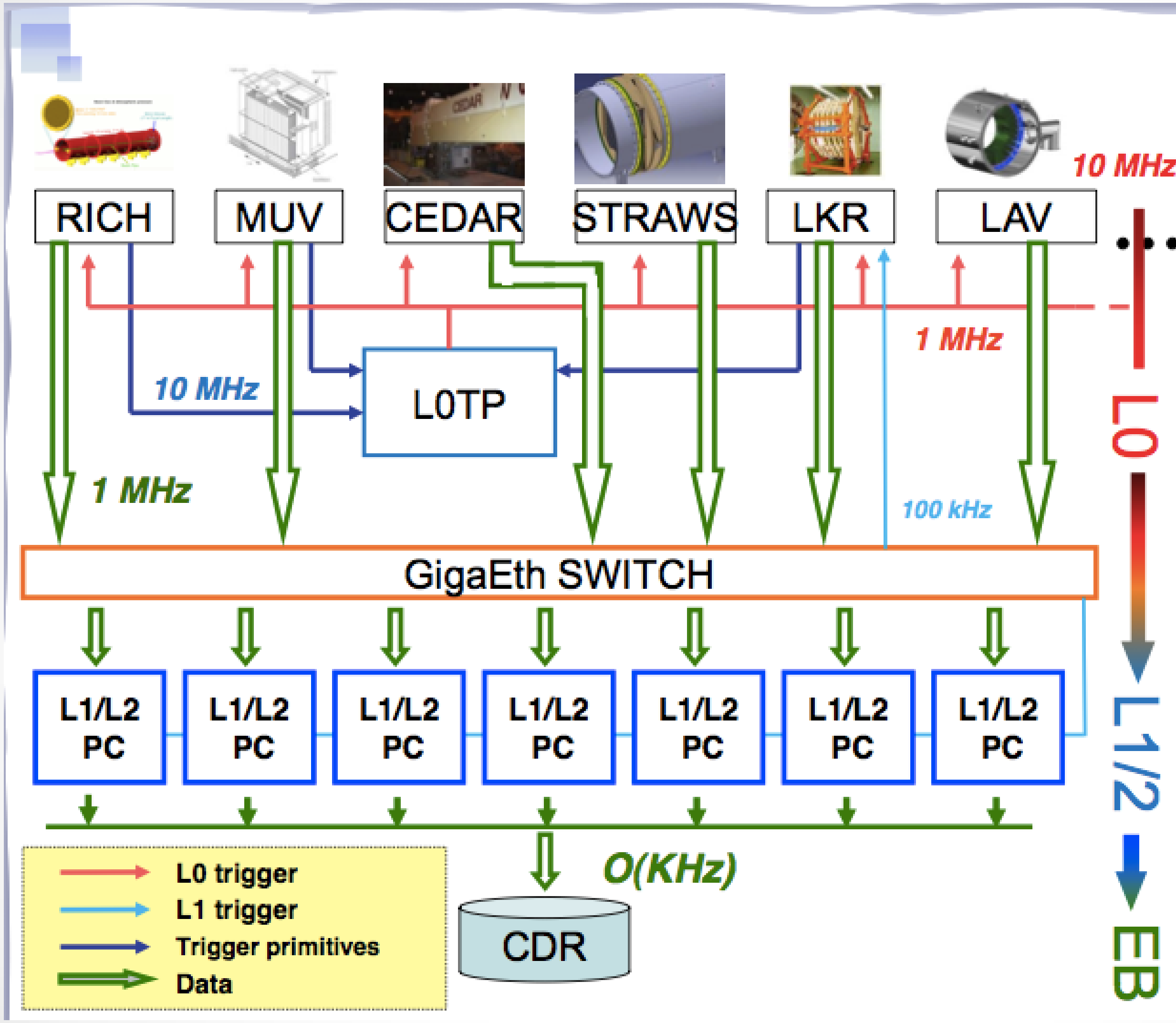
- The decay $K^+ \to \pi^+ \nu\nu$ provides unique opportunities for NP searches complementary to LHC
- The NA62 is aimed at measuring $BR(K^+ \to \pi^+ \nu\nu)$ with ~10% precision by collecting O(100) events in two years of data taking
- Most detectors were successfully commissioned during the pilot run in 2014
- NA62 is ready to take data in 2015-2018

spares

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	$5.9\times10^{-11}\ m_{X^0}=0$	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	$(2.488\pm0.010)\times10^{-5}$	>×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	-	$O(10^5)$

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.