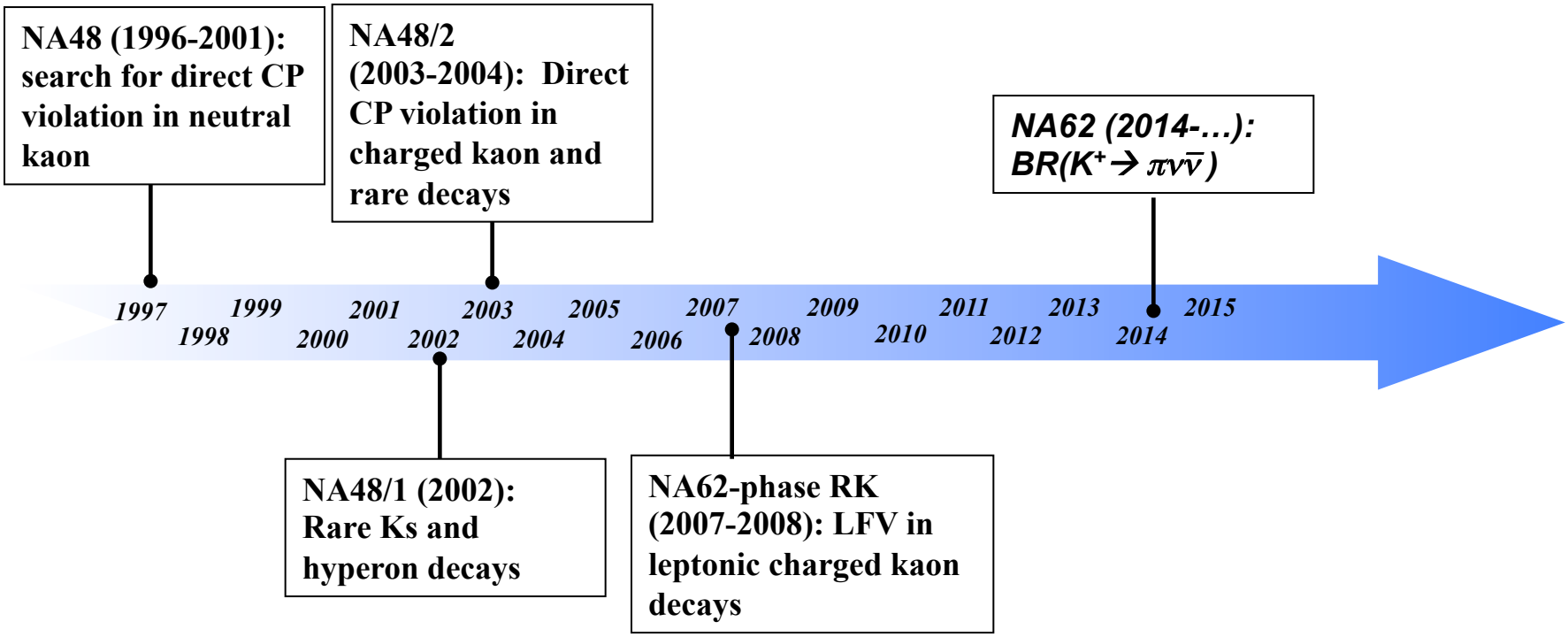
ICNFP2015 Conference
Kolympari, Chania, Crete (GR)
23 – 30 August 2015

The NA62 experiment at CERN

M. Piccini
CERN & INFN - sezione di Perugia
On behalf of the NA62 collaboration

Kaons at CERN - SPS



Kaons:

- **Theoretical cleanliness** unmatched
- The SM at E~M_K is remarkably **simple** (at least the EW part)
- Breaks of many symmetries: **C, P, CP, flavour**
- Extreme **hard-GIM SM-suppressed** FCNC decays

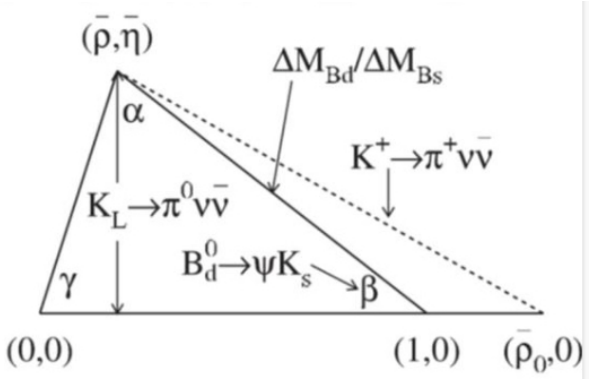
- Simple event topologies gives **clean experimental signature**
- **Few decay** channels
- Availability of **high intensity beams**

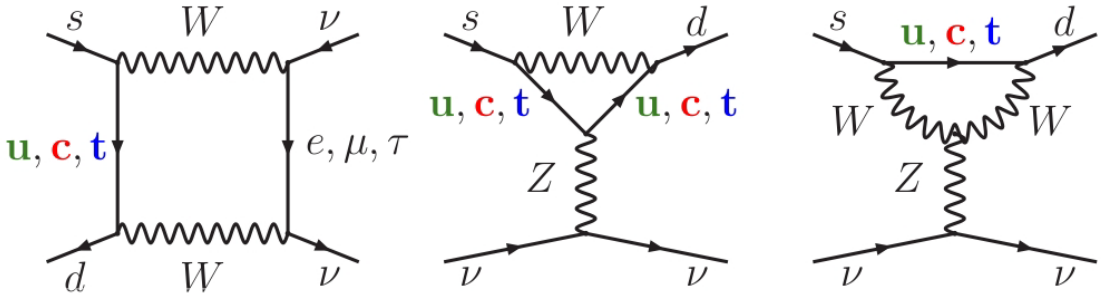
SM Theory for $K \to \pi^+ \nu\bar{\nu}$

- Very clean scenario
  - Short-distance contribution (top quark) dominance
  - No hadronic uncertanties
- SM suppression (proportionality to powers of $V_{ts}^* V_{td}$) allows high sensitivity to new physics

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

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



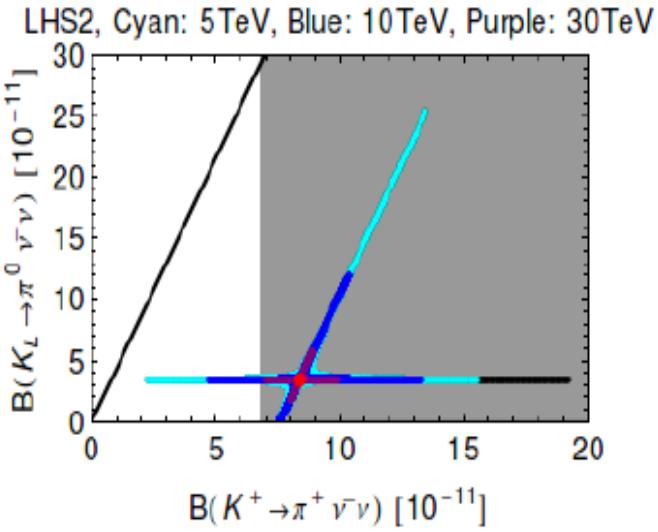


[A.J. Buras, D. Buttazzo, J. Girrbach-Noe and R.Knegjens, arXiv:1503.02693]

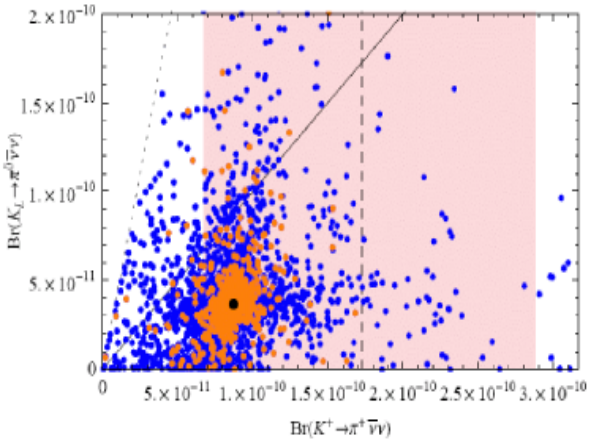
Beyond SM

- Z' gauge boson mediating FCNC at tree level
- *[A.J.Buras et al., JHEP 1302 (2013) 116; A.J.Buras et al. Eur. Phys. J. C74 (2014) 039]*
- Littlest Higgs with T-parity *[M. Blanke et al., Acta Phys. Polon. B 41 (2010) 657]*
- Custodial Randall-Sundrum *[M. Blanke et al.., JHEP 0903 (2009) 108]*
- Best probe of MSSM non-MFV (still not excluded by LHC) *[G. Isidori et al., JHEP 0608 (2006) 088]*

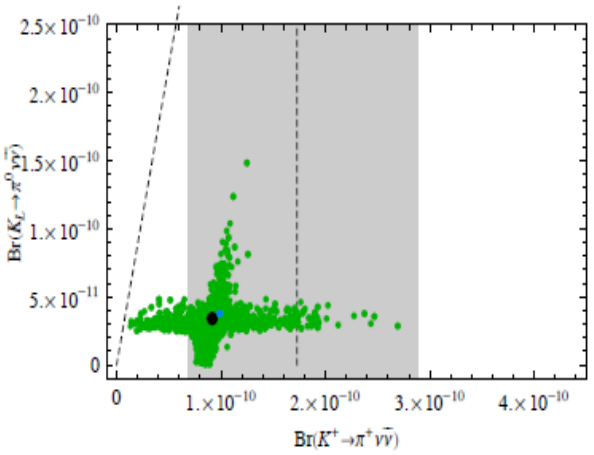
Z' model



Randall - Sundrum



Littlest Higgs



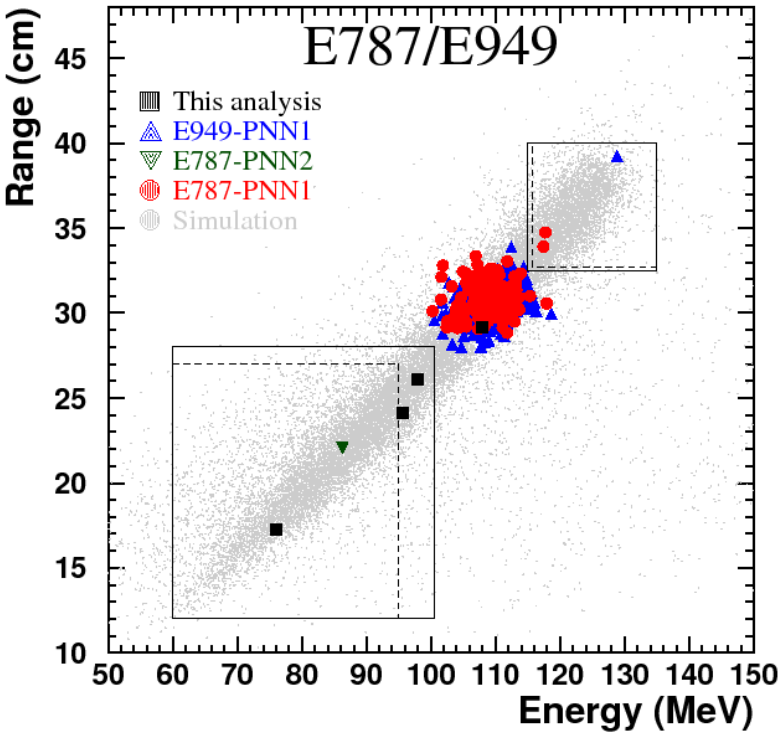
Experimental status

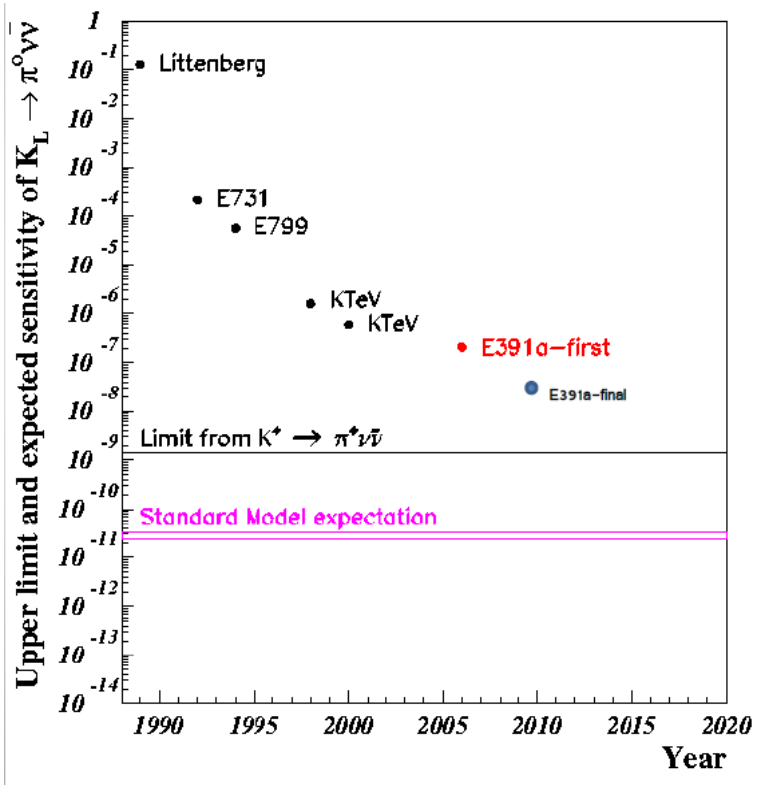
- $BR(K^+ \to \pi^+ \nu\nu) = (17.3^{+11.5}_{-10.5}) \times 10^{-10}$

  [E747/E949 collaborations, Phys. Rev. D 77, 052003 (2008), Phys. Rev. D 79, 092004 (2009)]

- $BR(K_L \to \pi^0 \nu\nu) < 2600 \times 10^{-11}$

  [E391a Collaboration , Phys. Rev. 100, 201802 (2008)]





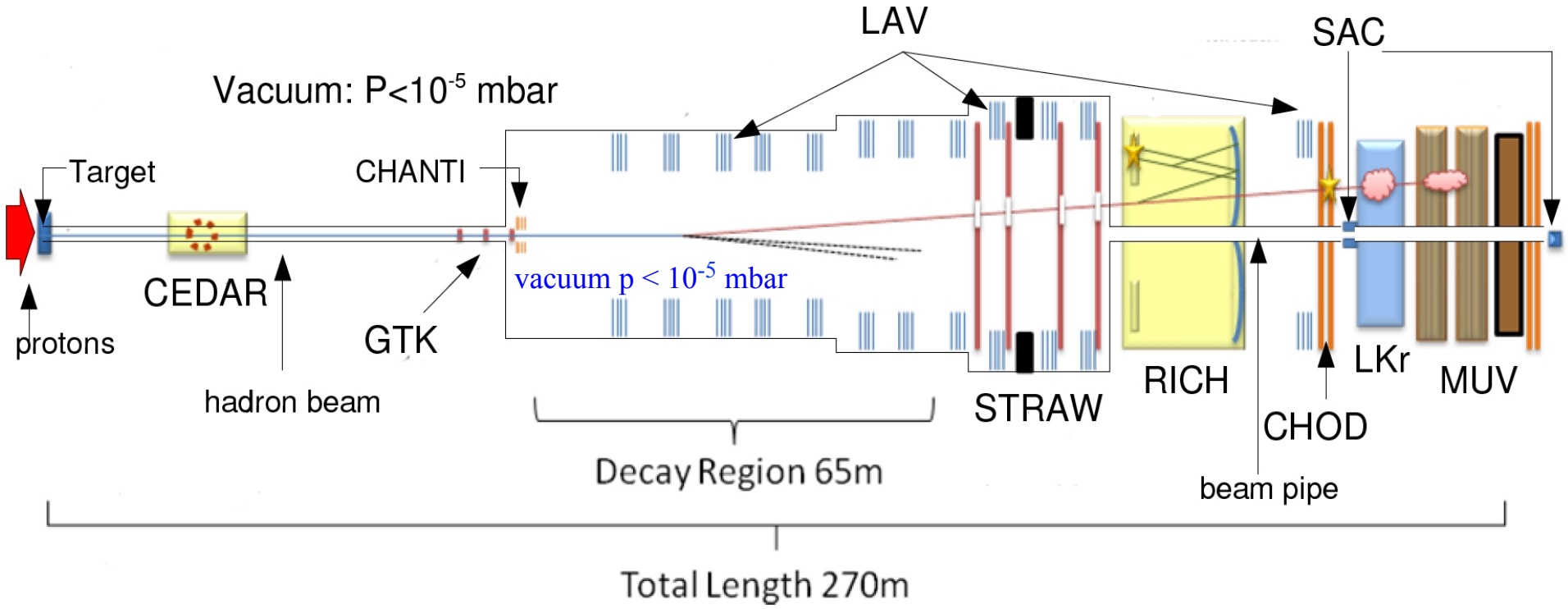
The NA62 experiment

2005	Proposal to measure the decay $K^+ \rightarrow \pi^+ \nu\bar{\nu}$
2009	Approved
2010	Technical design
2012	Technical run
2014	Pilot Run
2015-18	Physics Runs

Birmingham, BNL, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, LNF Frascati, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP) , Rome I, Rome II, San Luis Potosi, SLAC, Sofia, TRIUMF, Turin

Experiment layout

- 400 GeV/c SPS primary proton beam
- 75 GeV/c kaons unseparated hadron beam
- p, π^+,K^+ (~6%), $\Delta p/p$ ±1%
- 750 MHz → 50 MHz kaons→ 8 MHz decays
- 4.8 x 10^{12} K^+ decays/y on the 60 m long decay volume → SES ~ 10^{-12}



New approach: High momentum K^+ beam & decay-in-flight technique

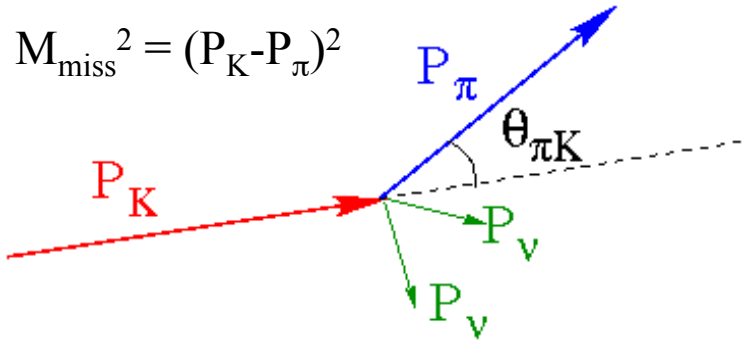
The analysis strategy

➔ Statistics
- BR(SM) ~ $(7.8\pm0.8)\times10^{-11}$
- Acceptance: 10%
- K decays: 10^{13}

➔ Systematics
- ≥10^{12} background rejection
- ≤10% precision on background measurement

Signal: single Pion in the final state matching a beam Kaon (timing and spatial association), the key variable is the squared missing mass:

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



Background suppression factors:

- **Kaon identification**
- **Kinematics rejection:** 5×10^3 $K^+\to\pi^+\pi^0$, 1.5×10^4 $K^+\to\mu^+\nu$
- **Photon veto:** 10^8 on $\pi^0\to\gamma\gamma$ (LAV, LKR, SAC, IRC)
- **Charged particle ID:** 10^7 (RICH, MUV)
- **Timing**

Target: O(100) SM events for $K^+ \to \pi^+\nu\bar{\nu}$

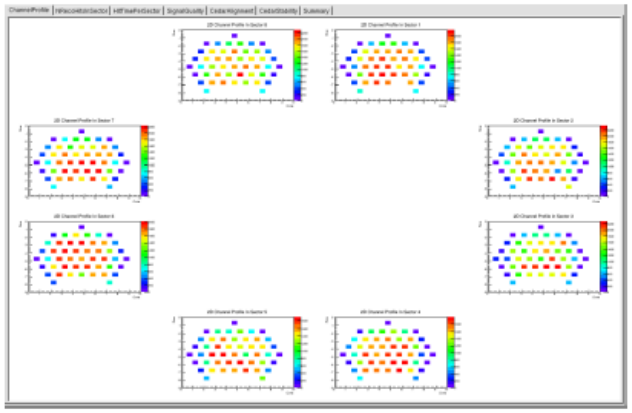
Analysis sensitivity (MC)

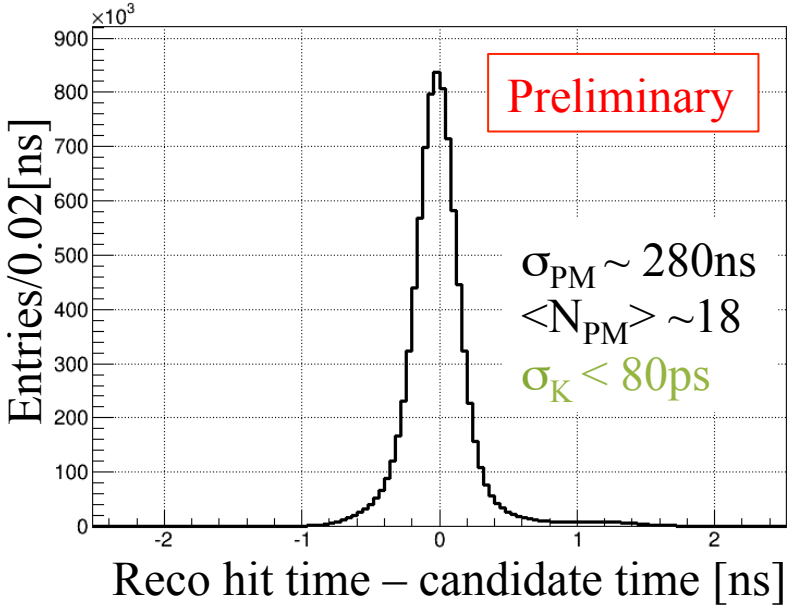
Decay	event/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12} K-decay/y)	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$ (IB)	1.5
$K^+ \to \mu^+ \nu \gamma$ (IB)	0.5
$K^+ \to \pi^0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

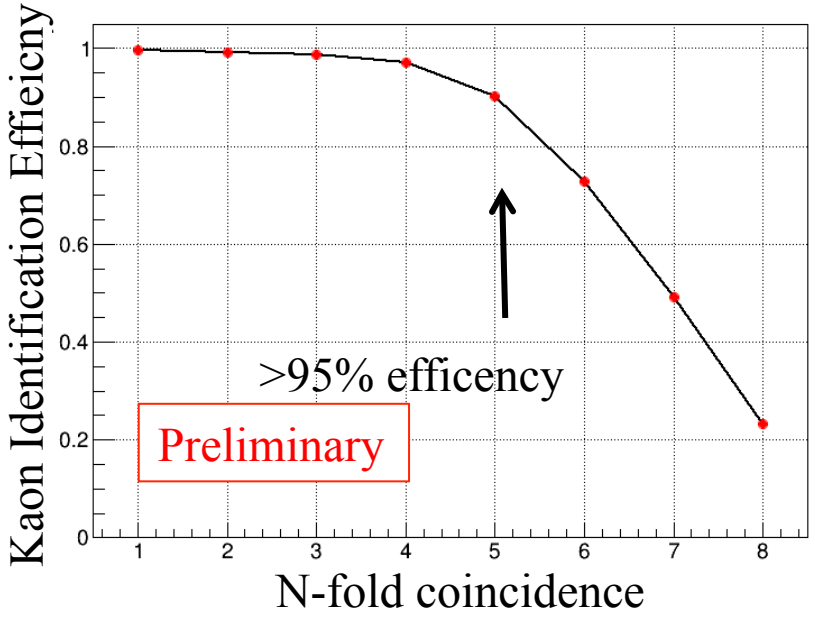
Detectors

KTAG: Kaon Identification

PMTs illumination



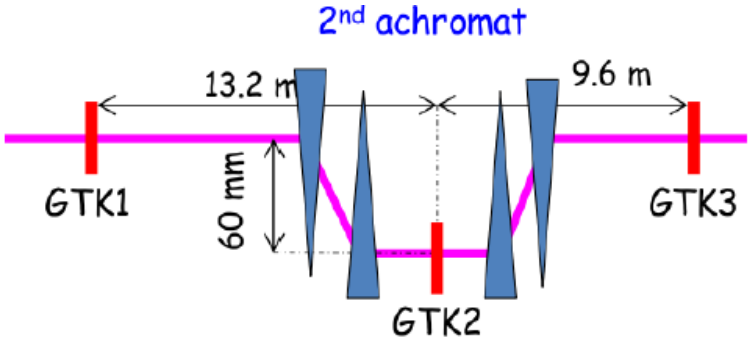


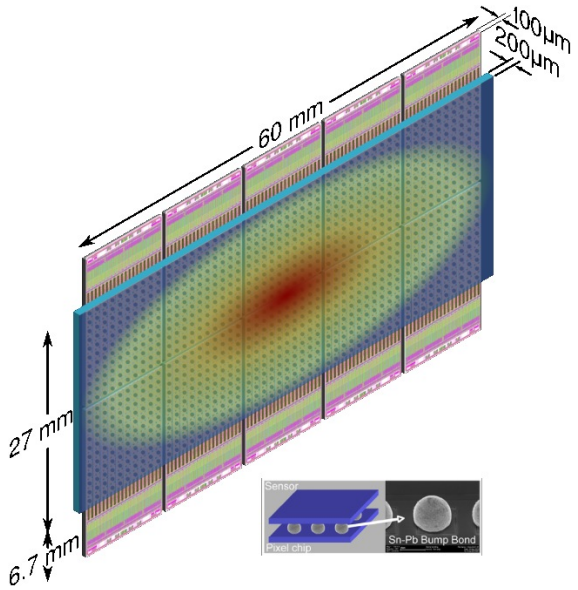


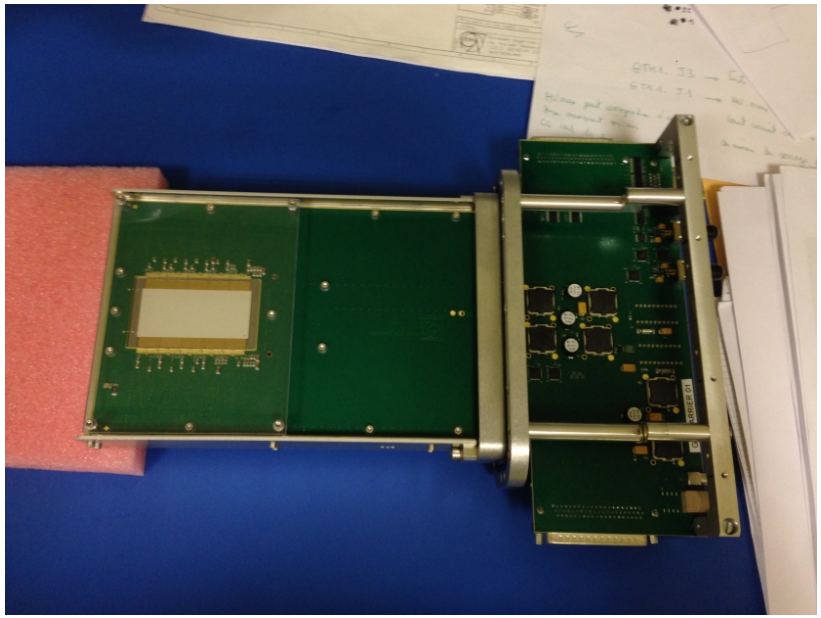
Beam tracking

The Gigatracker:

- 3 Si pixel stations on the beam
- 300 x 300 μm^2 pixels
- Cooled down using a microchannel technique
- On sensor TDC readout chip (~54000 pixels)
- Radiation length < 0.5% /station, δ(t)~200 ps
- Rate at full intensity ~750 MHz
- Partially commissioned in 2014



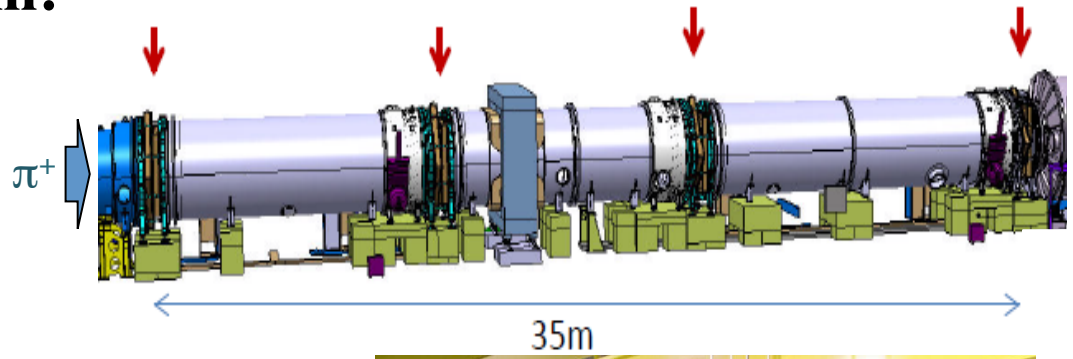




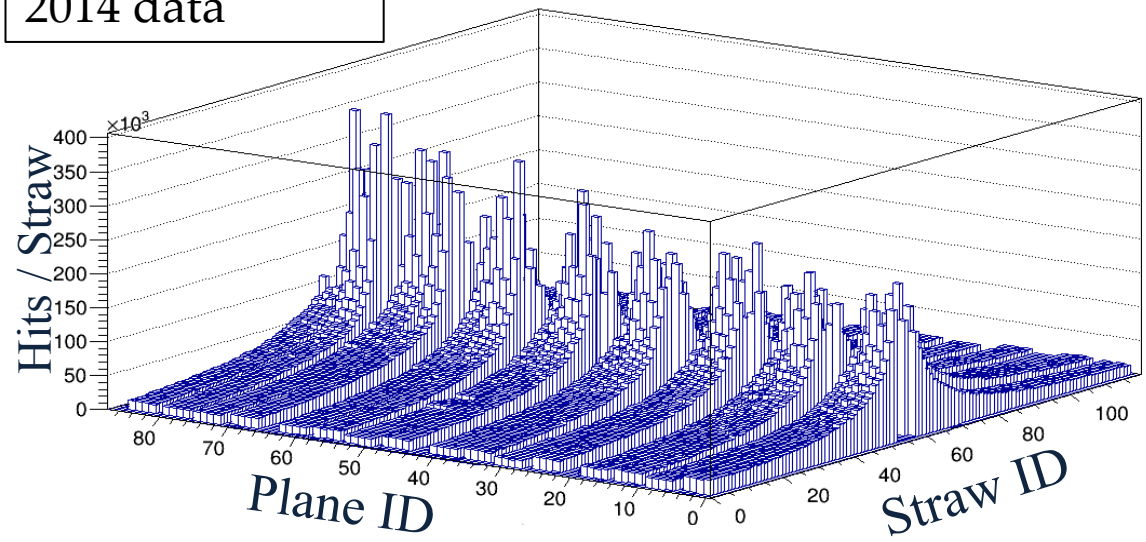
Pion tracking

Straw spectrometer in vacuum:

- 4 chambers; 1cm diameter straw
- Radiation length < 0.5% /chamber
- 0.5 Tm magnet (2x2 m aperture)
- TDC readout (~8000 channels)
- Rate at full intensity ~10 MHz
- Fully commissioned in 2014

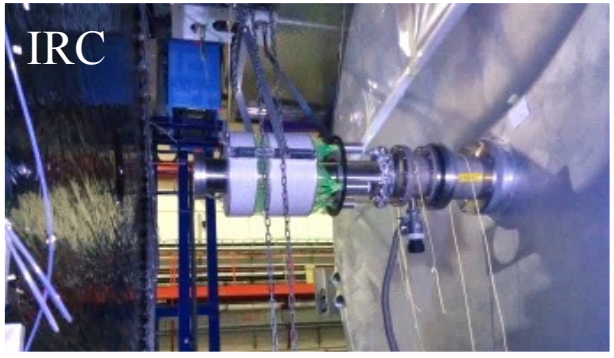


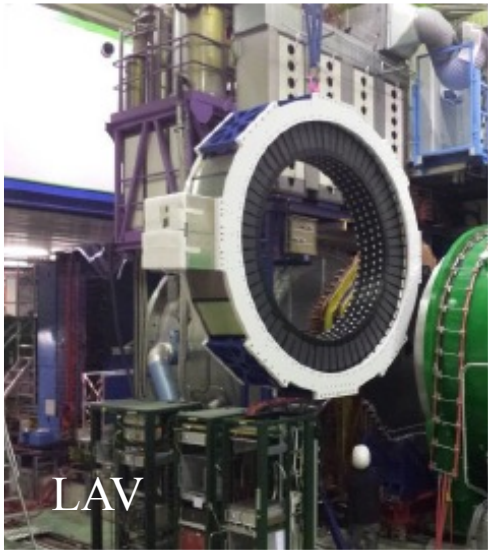
2014 data

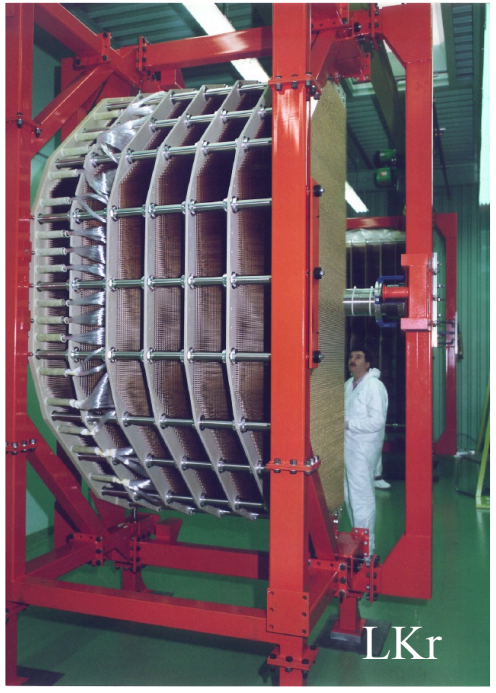


Photon rejection

- **Large Angle Veto (LAV, from 8.5 to 50 mRad) :**
  - 12 stations made of 4/5 leadglass detectors layers
  - $[10^{-3},10^{-4}]$ photon inefficiency down to 150 MeV
  - ~1ns time resolution
  - 1 MHz particle rate (full intensity)
- **Liquid Krypton calorimeter (LKr, from 1 to 8.5 mRad)**:
  - Quasi homogeneous calorimeter (former NA48 main calorimeter)
  - 10^{-5} inefficiency for $\gamma > 10$GeV
  - 10 MHz particle rate (full intensity)
- **IRC and SAC (< 1 mRad) :**
  - Shashlik technology
  - 10^{-4} inefficiency for $\gamma > 1$ GeV



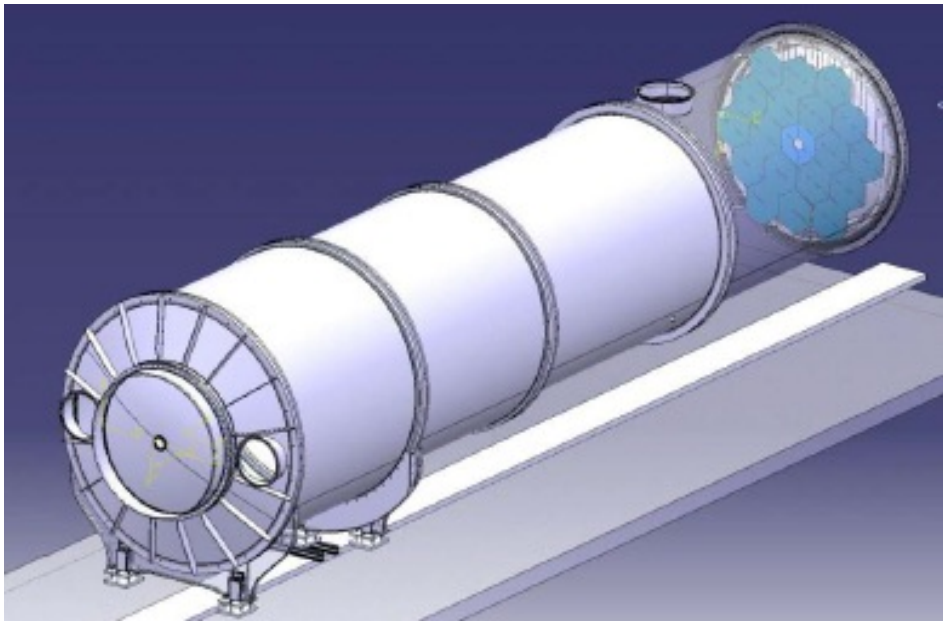


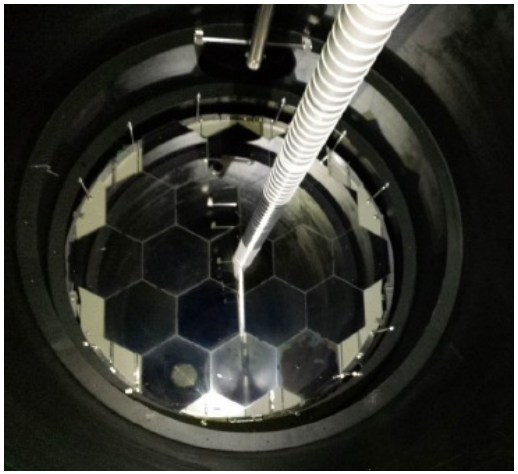


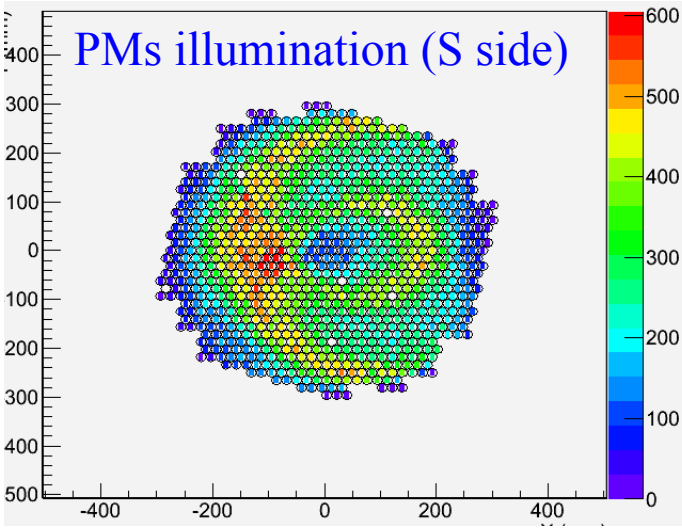
Particle ID: The RICH

RICH:

- 17 m, Ne at 1 atm, 20 mirrors
- PMT arrays separated in two spots
- TDC readout for PMs (~2000 channels)
- Track angle resolution < 100 μrad
- Time resolution < 100 ps
- μ/π separation >10^2 measured on a prototype
- Rate at full intensity 10 MHz
- Commissioned in 2014



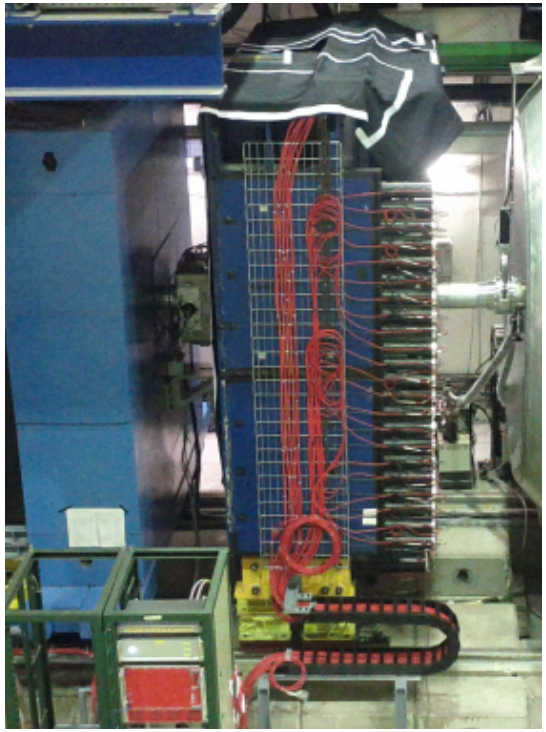




Particle ID: MUV1-2-3

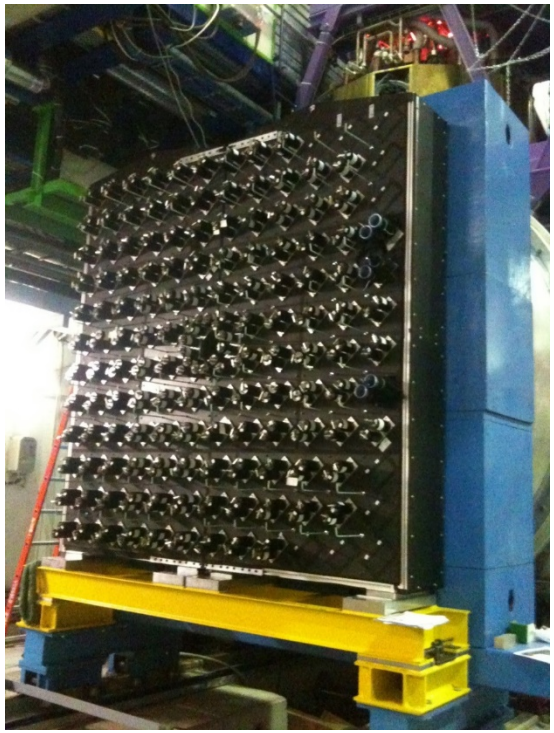
MUV1 & MUV2:

- Hadron calorimeter
- 2 modules of iron-scintillators planes (128+64 channels)
- FADC readout
- 1 module commissioned in2014



MUV3:

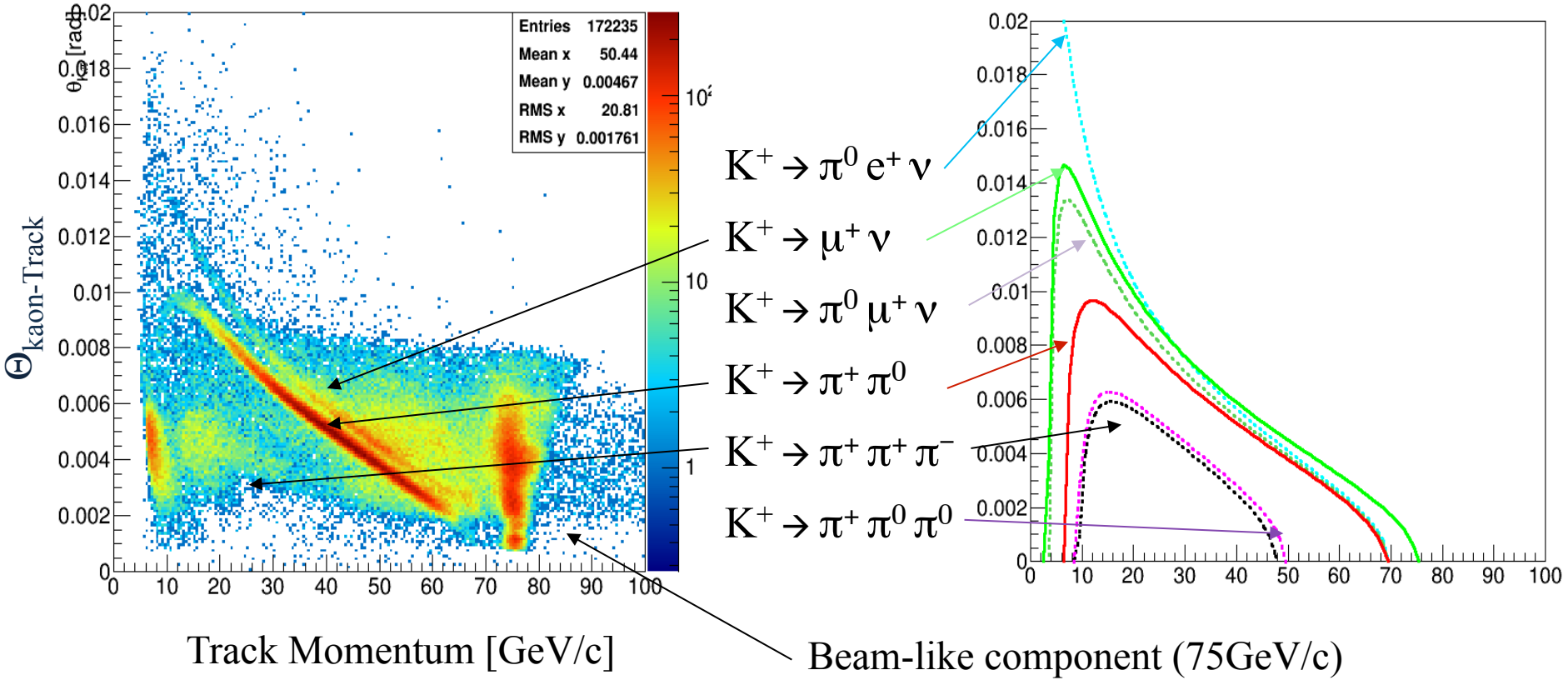
- Fast MUon Veto plane
- 2148 Scintillators tiles (2 PMs per tile)
- CFD+ TDC readout
- <500 ps time resolution
- Commissioned in 2014



2014 Data

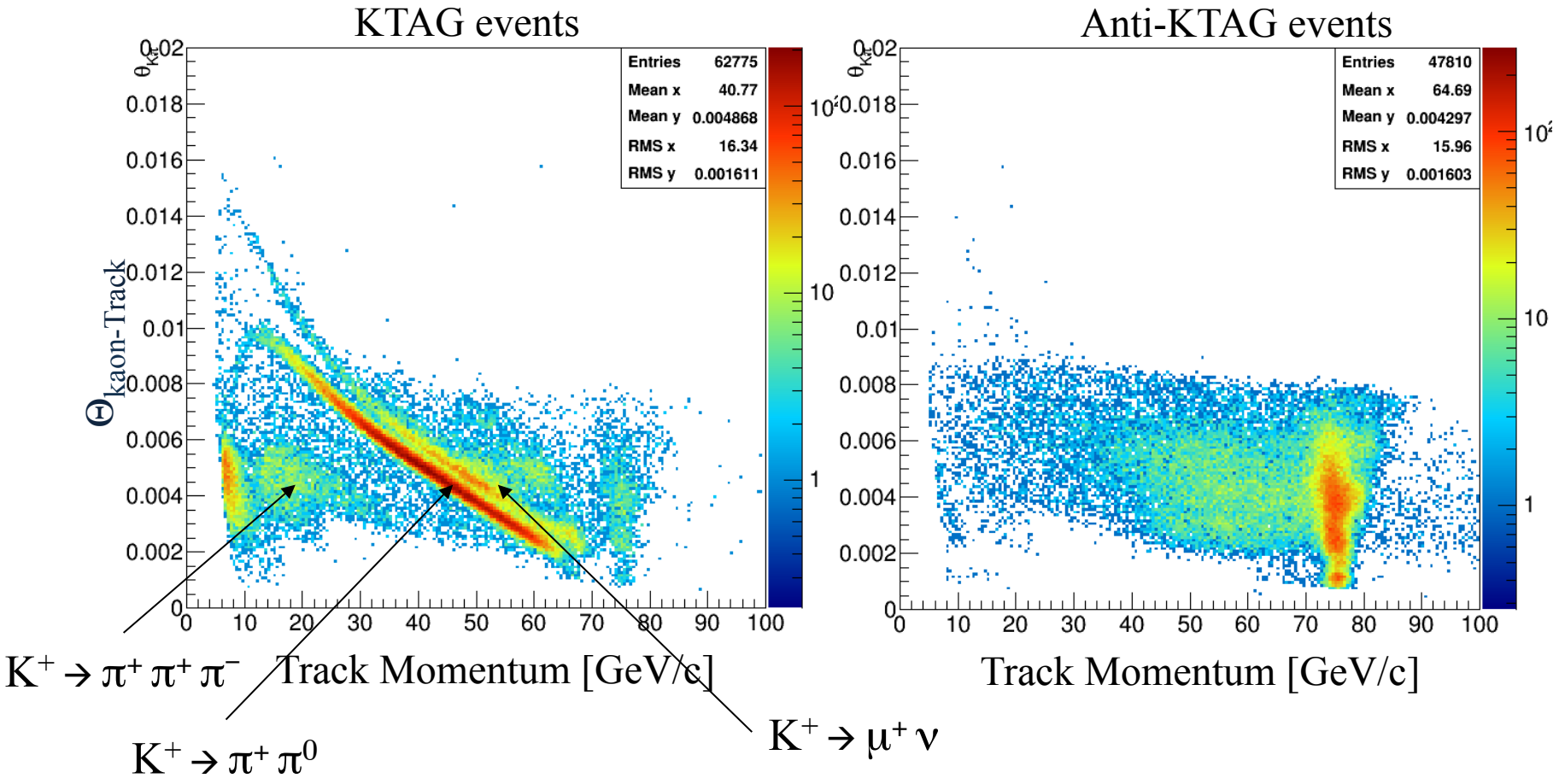
First look at 2014 data

- 1 track in the straw detector (window 40 ns)



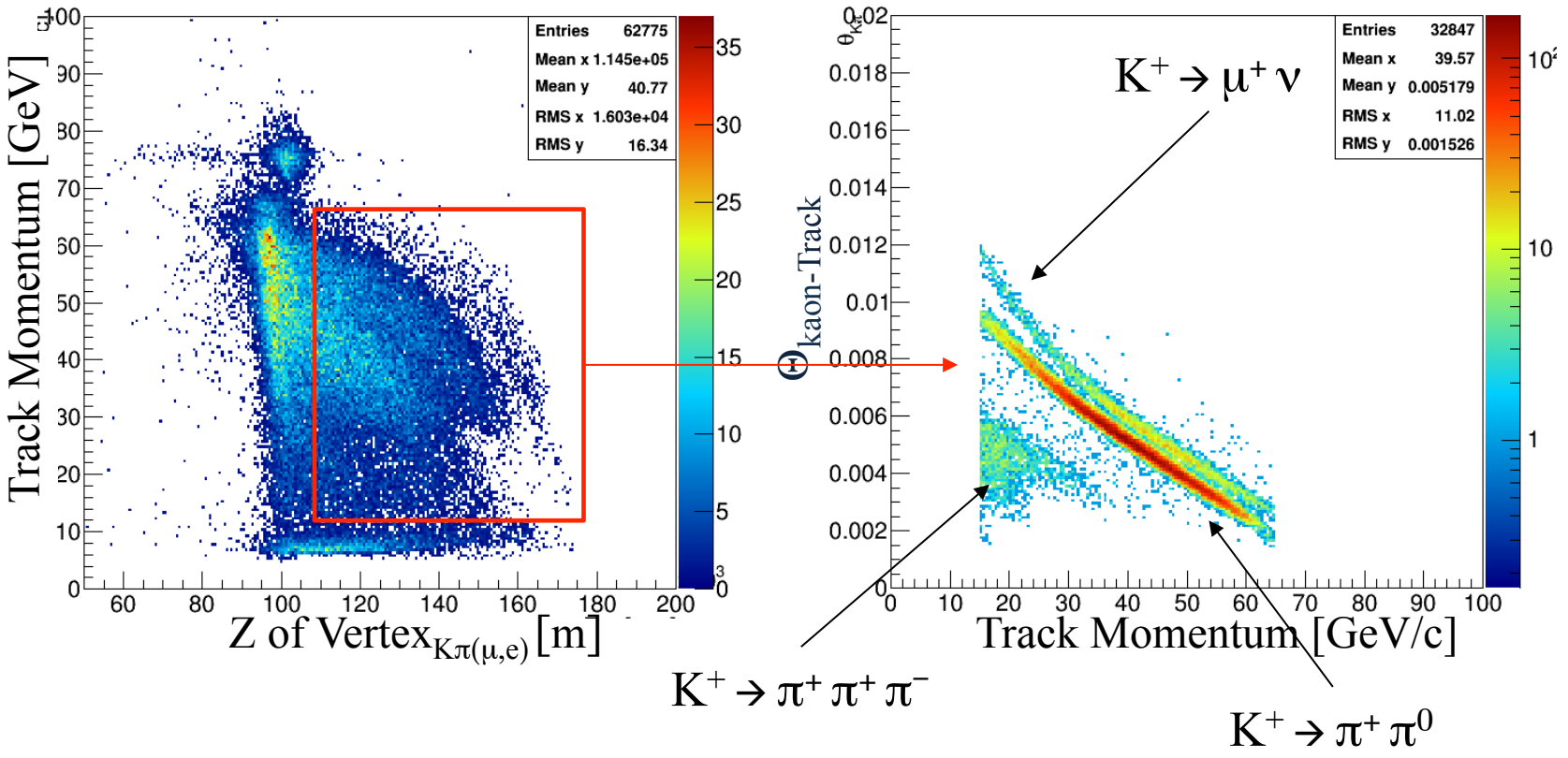
2014 data: kaon ID

- Apply Kaon identification (KTAG, more than 4 sectors)

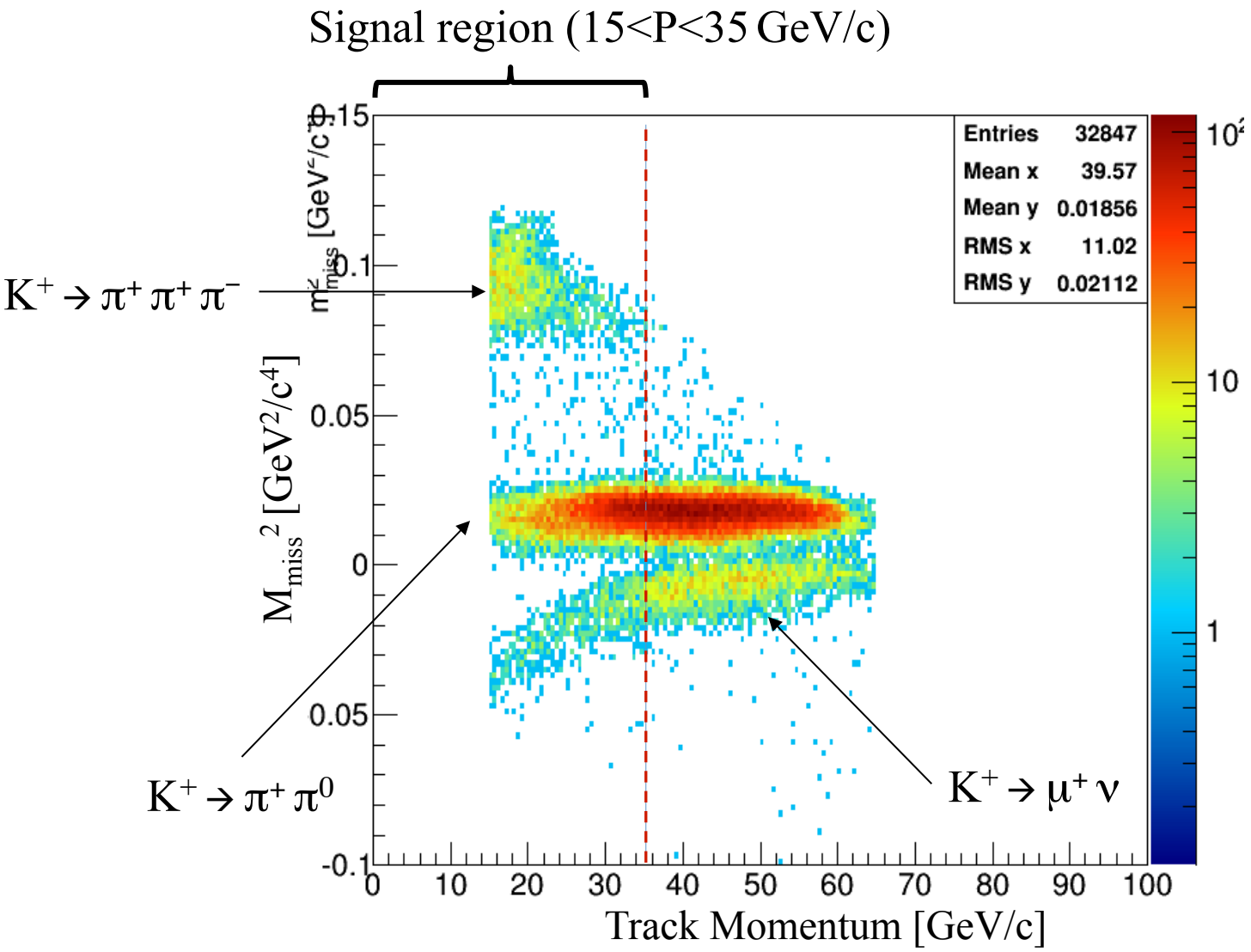


2014 data: charged vertex

- Vertex reconstructed to suppress background from Kaon interactions outside the decay volume. Used nominal beam direction (no GTK).

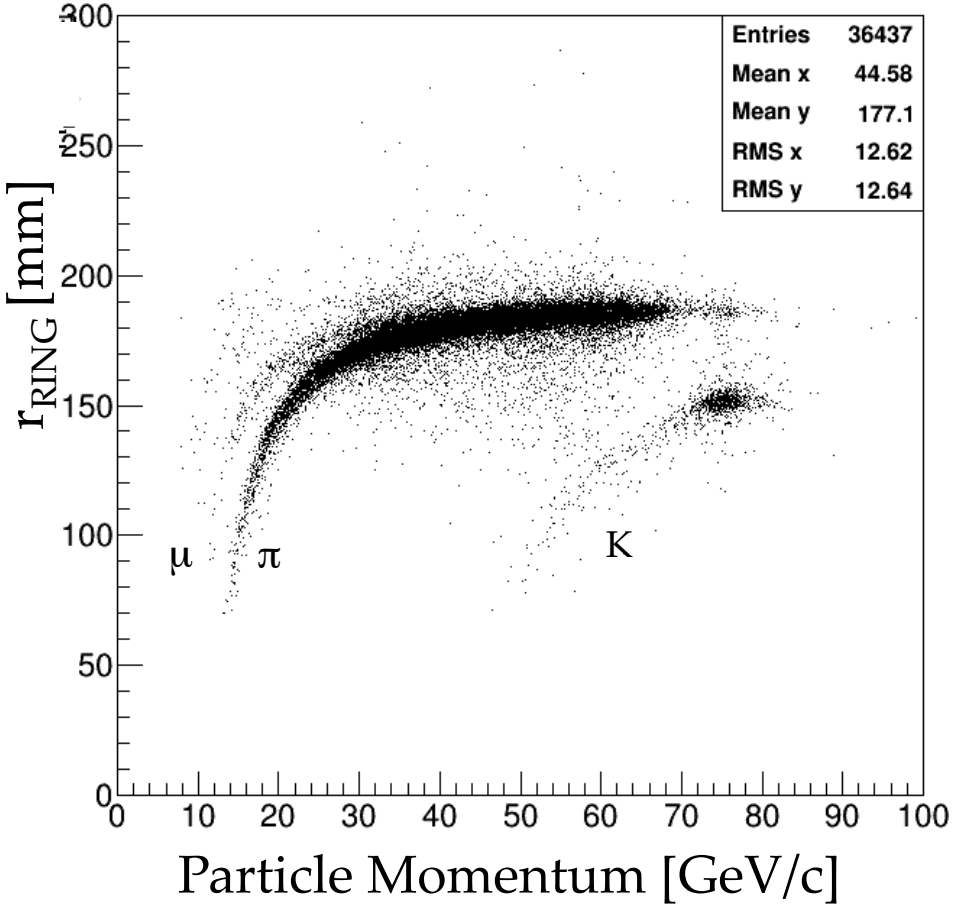


2014 data: single track

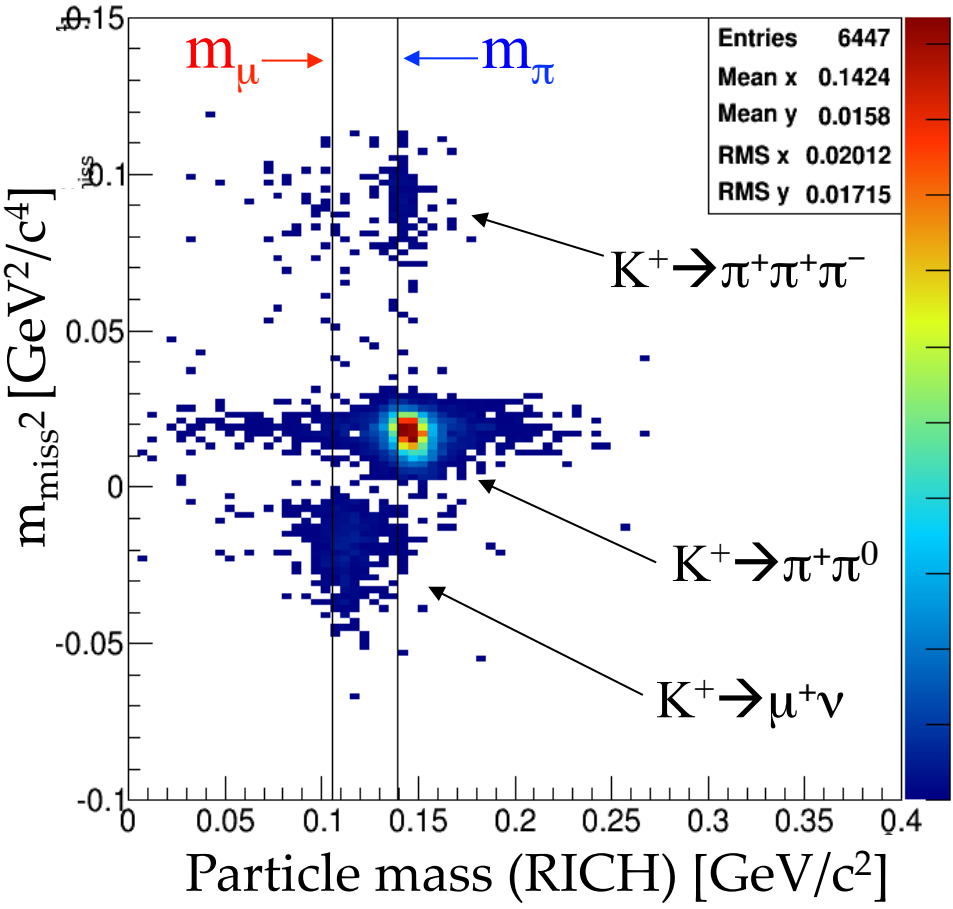


2014 data: particle ID

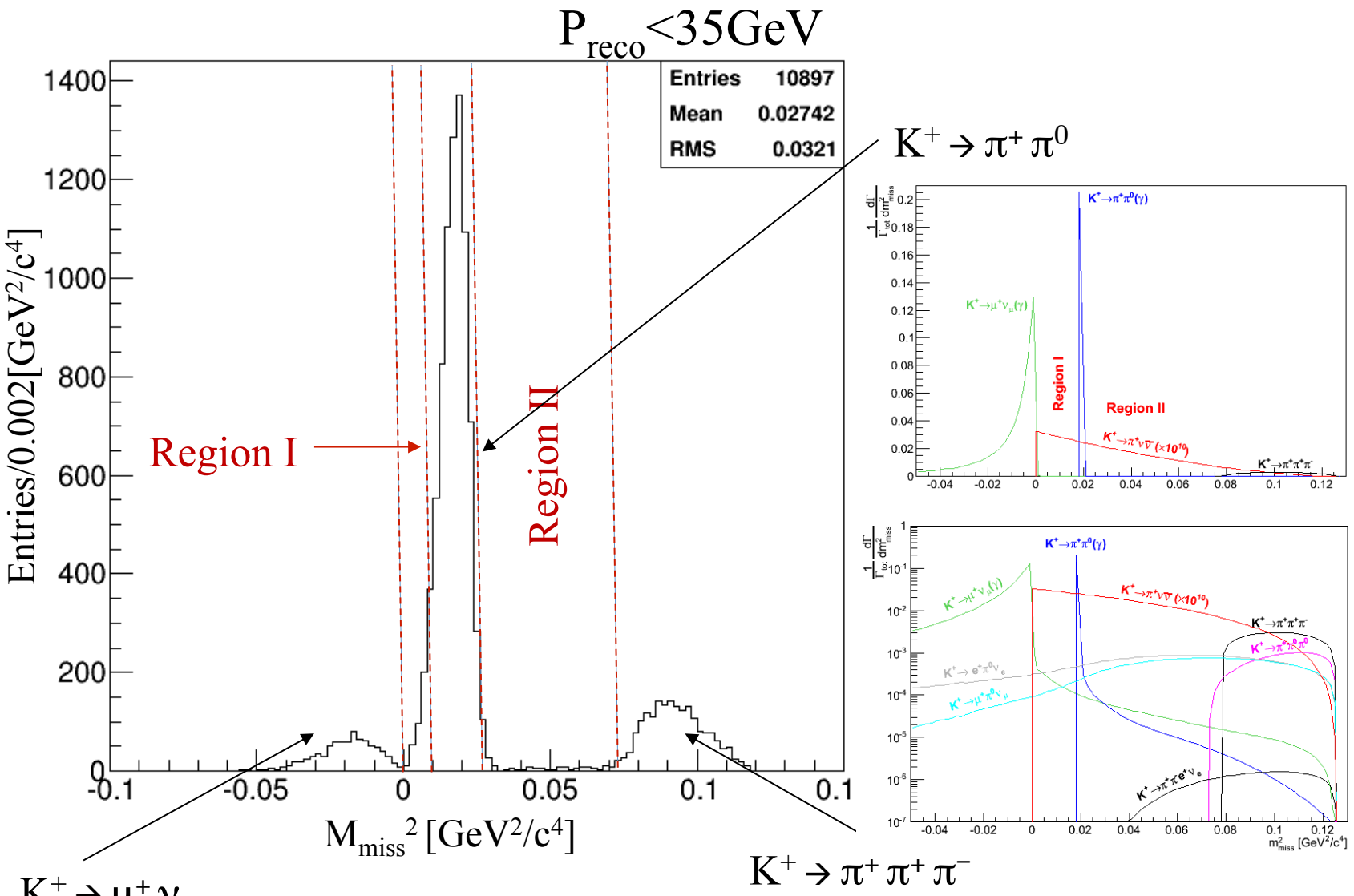
- Matching between track and RICH ring to study the particle content
- Positrons suppressed by the trigger



- Joining kinematics and particle ID



2014 data: missing mass



Next step: 2015 run

- NA62 Run I started end of June until mid of November
- Improvement on missing mass resolution expected from:
  - GTK Kaon spectrometer information
    (instead of nominal beam momentum/direction)
  - Fine STRAW spectrometer alignment/calibration
  - Detailed B field map (instead of simple Pt kick)
- Background rejection improvements expected from:
  - RICH particle identification ($\pi/\mu/e$)
  - Photon rejection (LKr, LAV, IRC and SAC)
  - Muon rejection (commissioning of MUV1)
- Beam intensity will be increased up to the nominal intensity, at the same time trigger and read-out systems will be fully commissioned

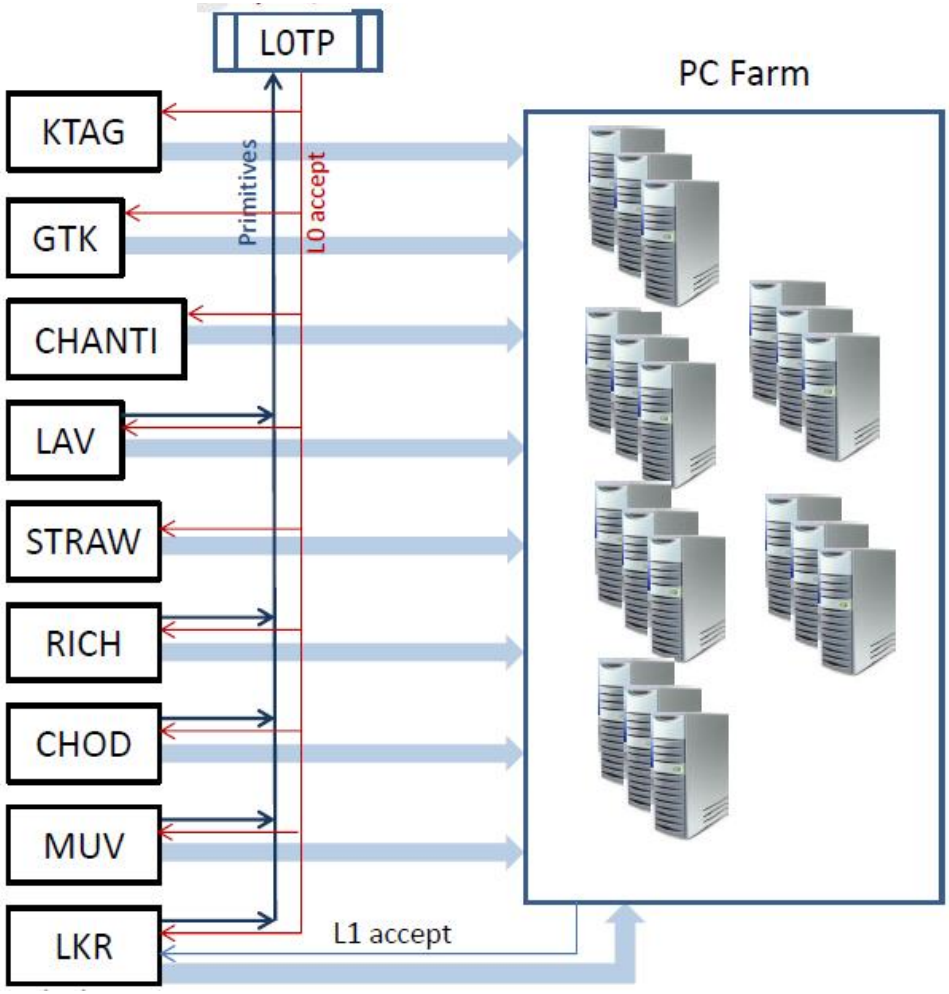
CONCLUSIONS

- The successful 2014 Pilot run has officially started the NA62 experiment physics program
- Almost all the detectors have been fully commissioned
- Detectors performances measurement are ongoing, preliminary results within expectation
- Analysis technique has be exercised on the a small dataset from (preliminary results shown here)
- New NA62 Run started end of June 2015, to measure in the next few years the BR of the $K^+ \rightarrow \pi^+ \nu\nu$ and to pursue a rich phȳsics program

(i.e. talk by R. Piandani at this conference on the search of dark photons)

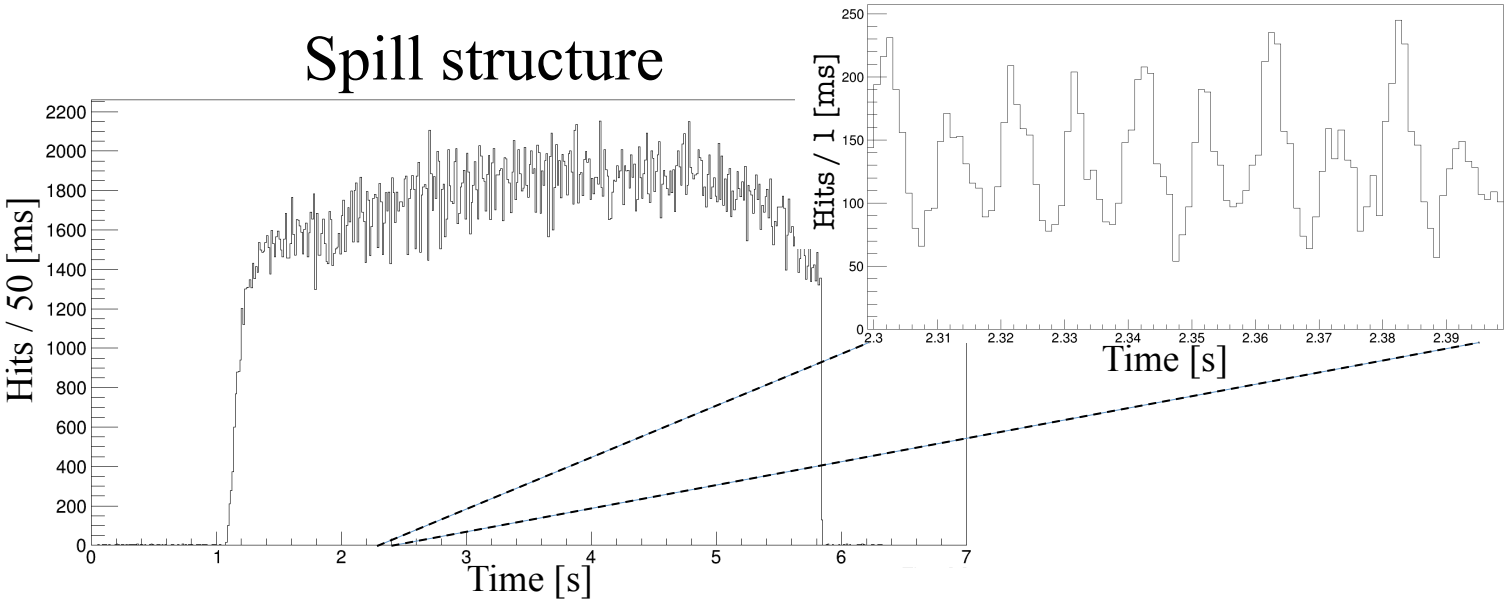
SPARES

Trigger and DAQ systems



- Trigger:
  - L0 (hardware): 10 → 1 MHz
  - L1/L2 (software): 1 MHz → 20 KHz
- DAQ: 20 KHz
- L0 trigger for $K^+ \to \pi^+ \nu\bar{\nu}$:
  - Single charged particle topology
  - Energy in hadron calorimeter / no muons
  - No photons
- L0 Trigger partially commissioned in 2014 (no photon trigger).
- DAQ commissioned in 2014 at 5% of nominal intensity.

2014 pilot run



- Duty cycle: 4.8/16.8 s spill
- 5% nominal beam intensity (0.025MHz K-decays)
- 2 weeks dedicated to physics studies

K physics program

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	$5.9 \times 10^{-11}\ m_{X^0} = 0$	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)