Prospects for $K^+ \to \pi^+ \nu \nu$ Observation at CERN in NA62

European Physical Society 2015, Wien

Vito Palladino - CERN

On Behalf of NA62 Collaboration

Outline

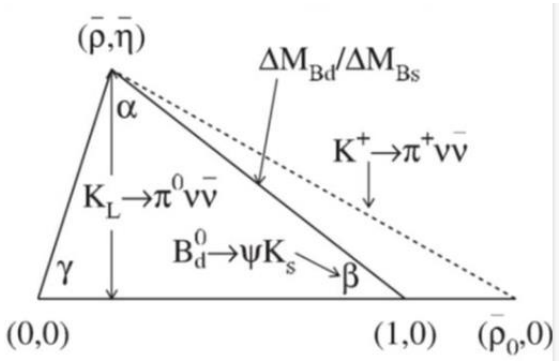
- Theoretical and experimental status
- The NA62 experiment
- Analysis strategy
- NA62 main detectors
- First look at 2014 data
- Conclusions

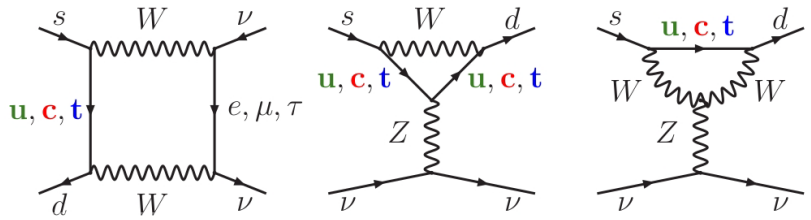
Theory

- 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]

New Physics Sensitivity

- 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]

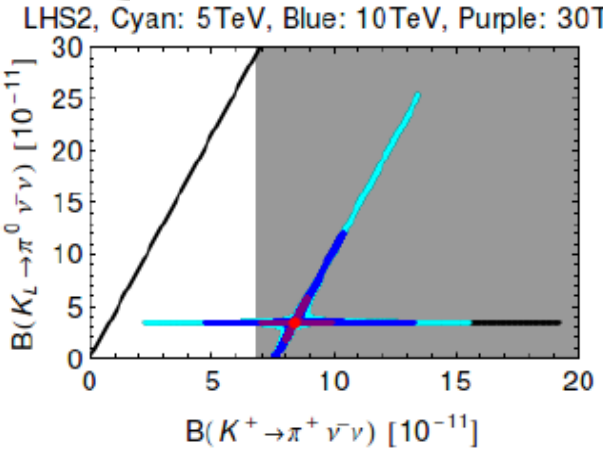
- Custodial Randall-Sundrum

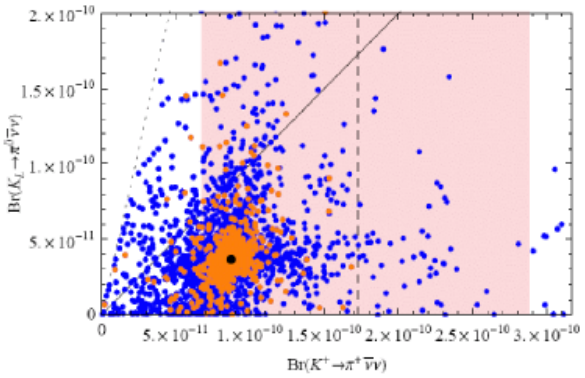
  [M. Blanke et al., JHEP 0903 (2009) 108]

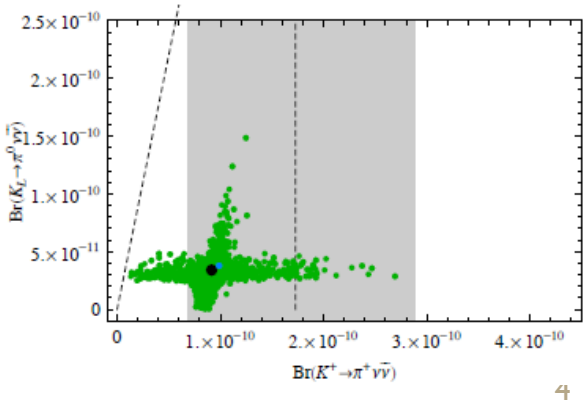
- Best probe of MSSM non-MFV (still not excluded by LHC)

  [G. Isidori et al., JHEP 0608 (2006) 088]

Z′ model *Randall - Sundrum* *Littlest Higgs*







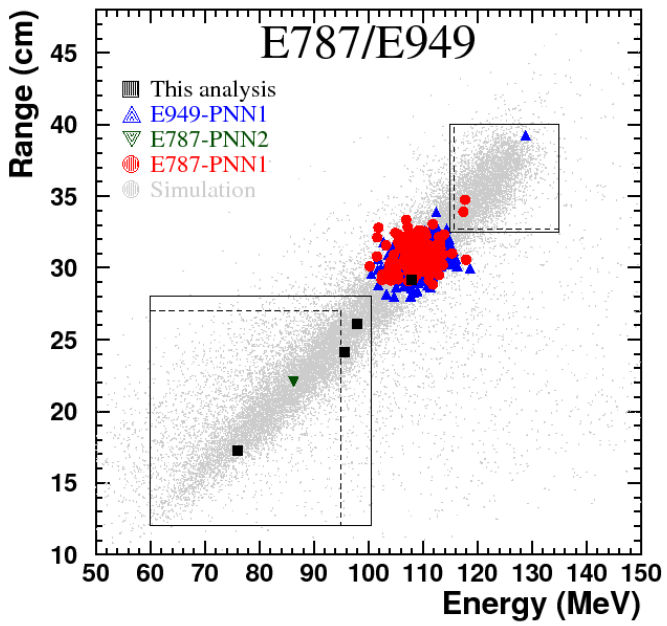
Experimental Status

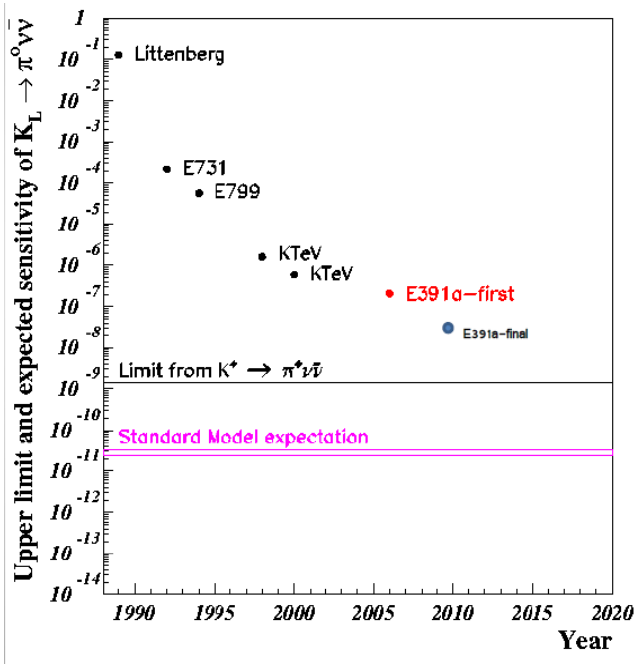
- $BP(K^+ \to \pi^+ \nu\nu) = (17.3^{+11.5}_{-10.5}) \times 10^{-11}$

[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
2009	Approved
2010	Technical design
2012	Technical run (partial layout)
2014	Pilot Run
2015-18	Physics Runs ←

~200 participants from 30 institutions

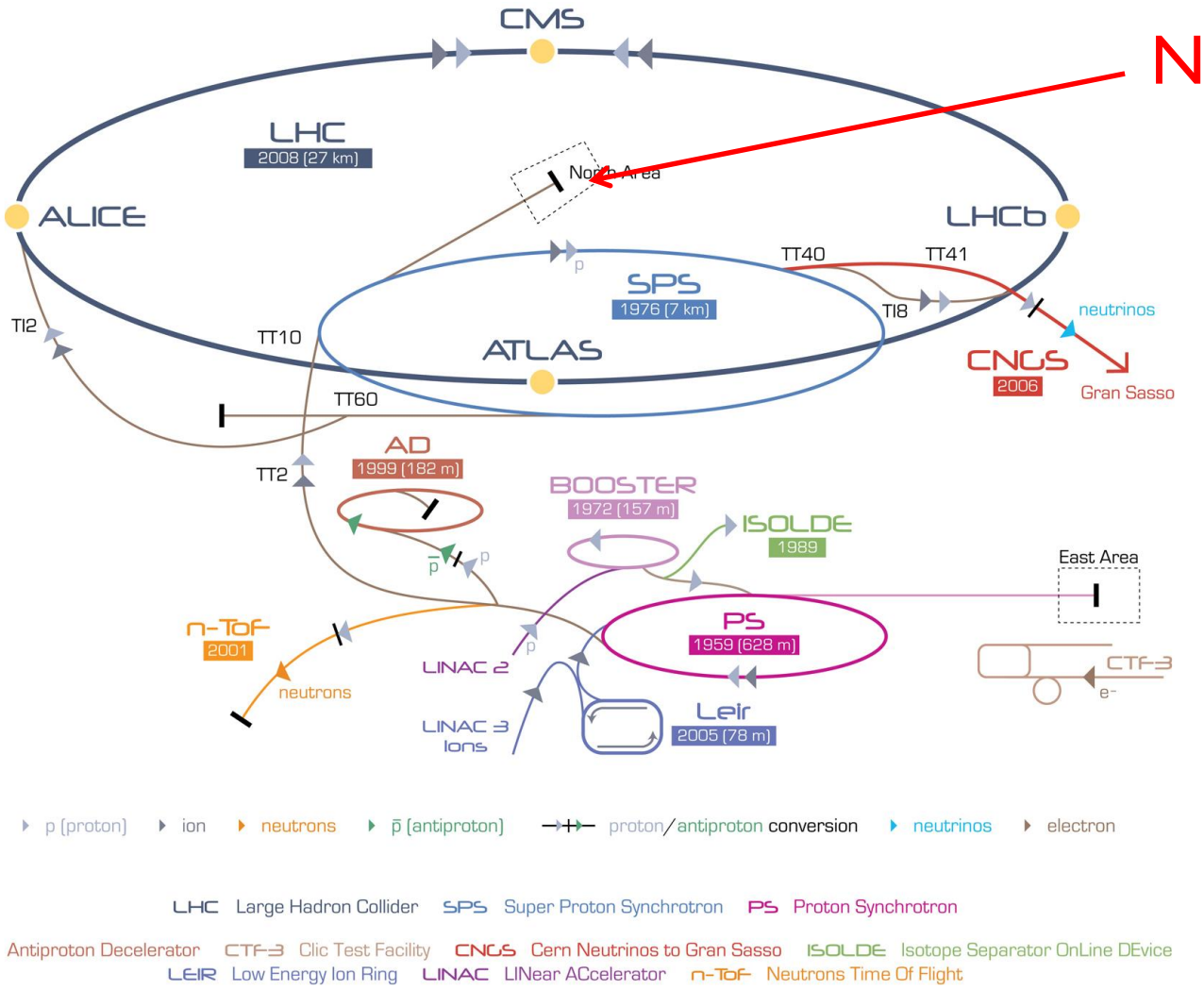
NA62 Goal

- The Experiment aims at
  - ~10% precision measurement of the BR($K^+ \to \pi^+ \nu\nu$) in 2 years of data taking

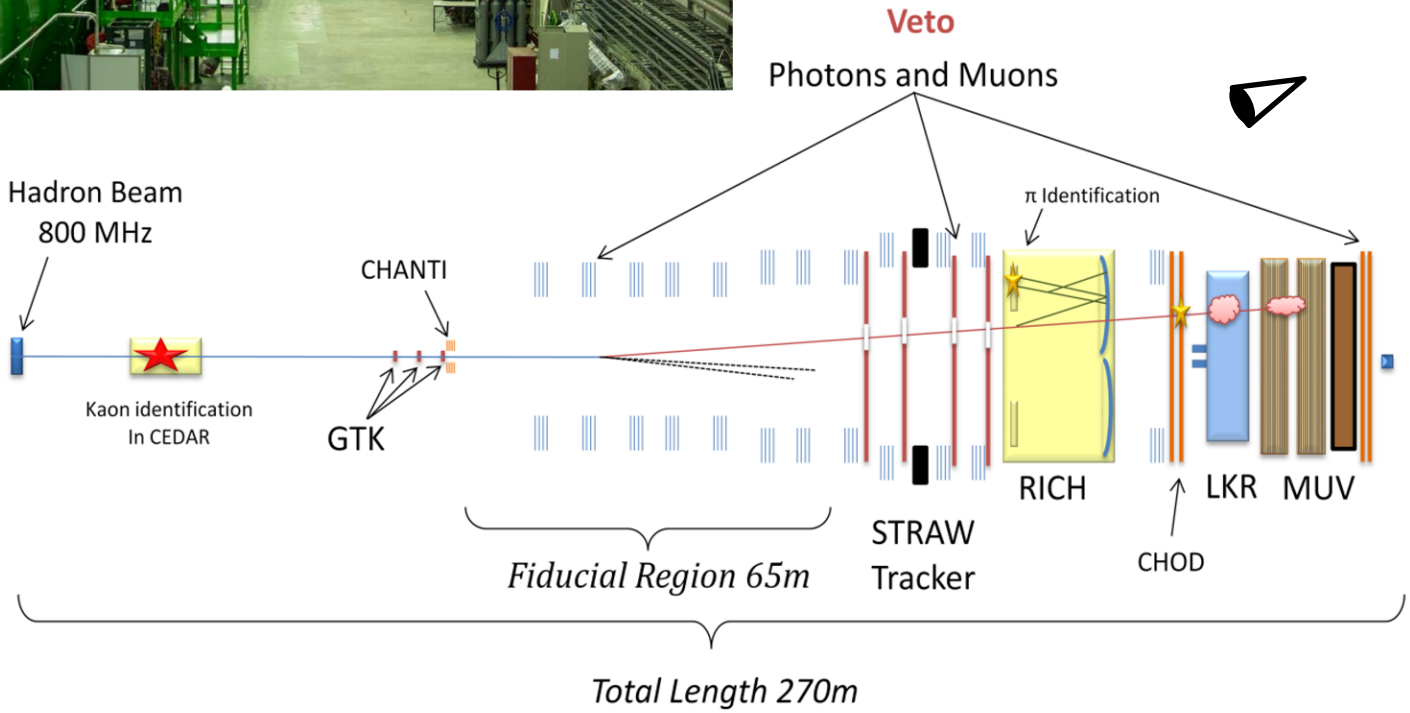
- Requirements:
  - Statistics: O(100) events
  - 10^{13} Kaon decays
  - Systematics: <10% precision background measurement
  - $>10^{12}$ background rejection

- Technique:
  - In flight K-decay

The NA62 Apparatus

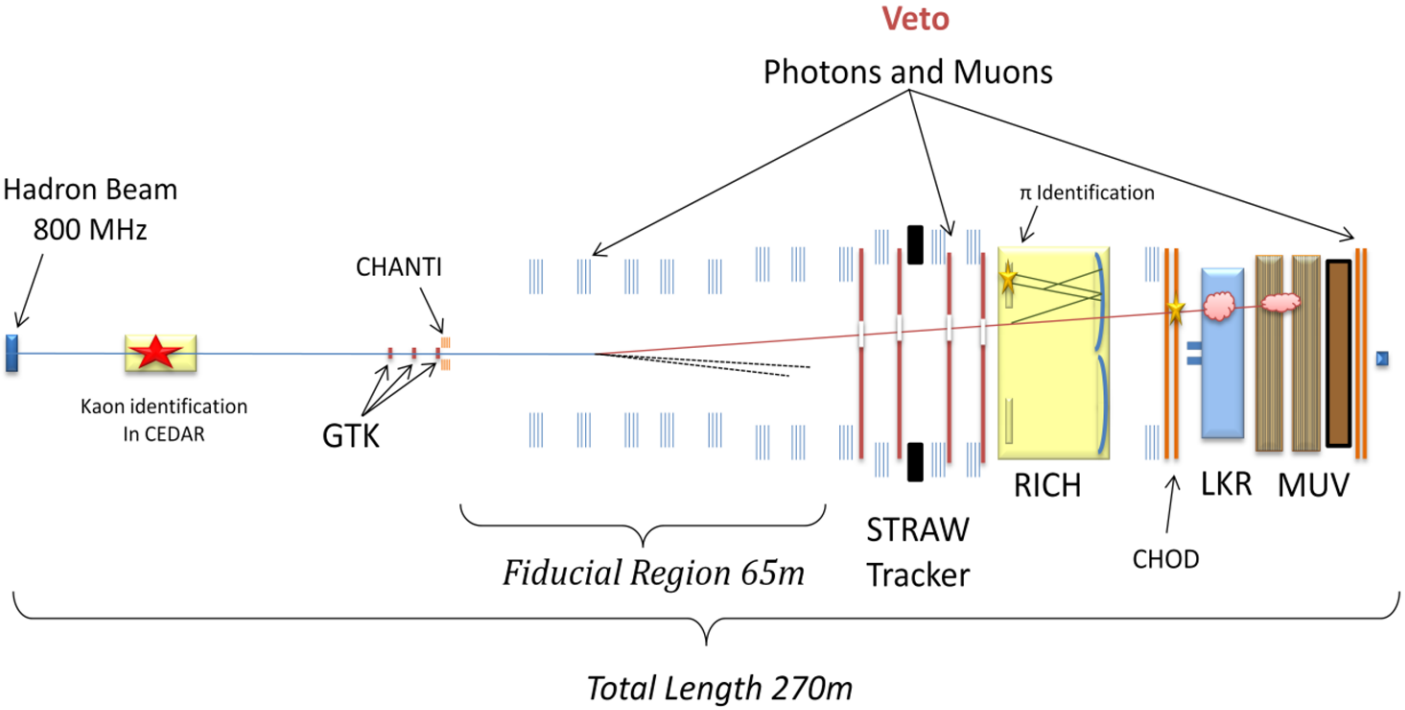


The NA62 Apparatus



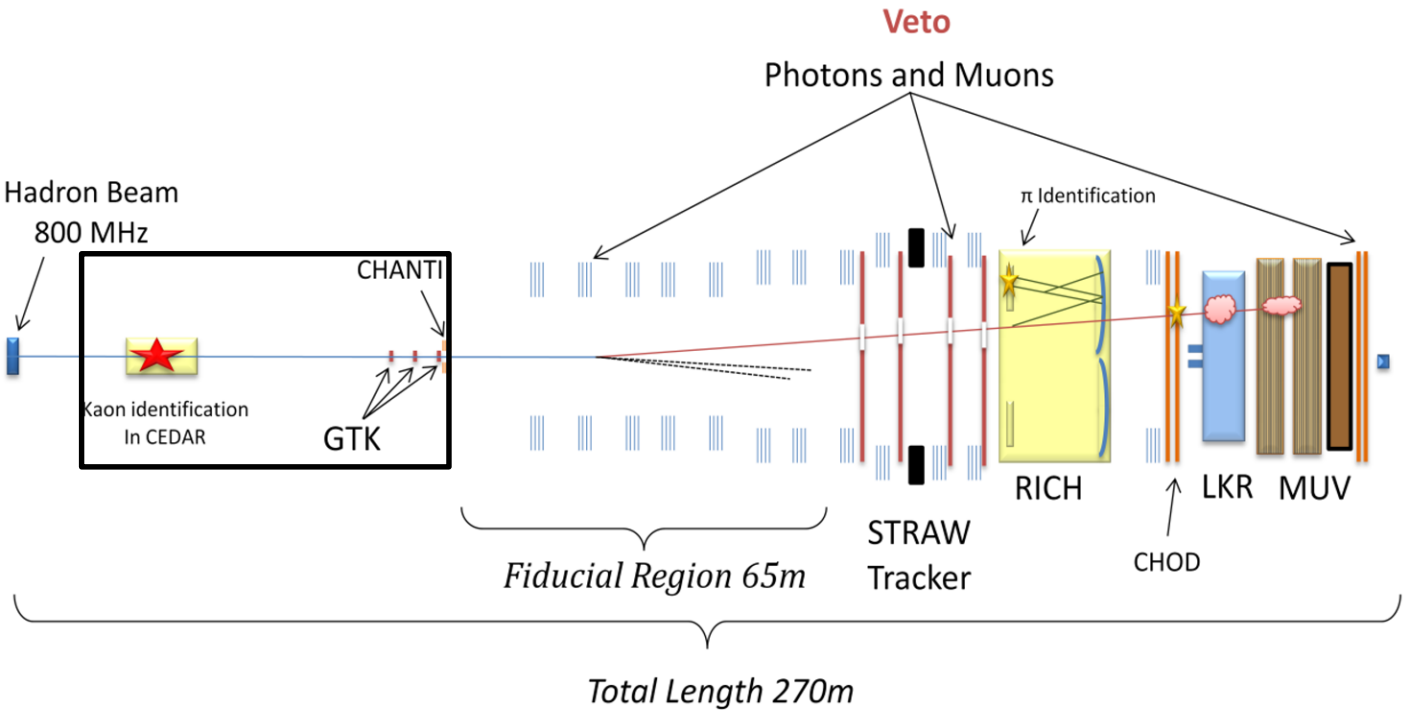
The Beam

- Positive unseparated hadron beam (6% of Kaons)
- 800MHz intensity
- 75(±1%)GeV Momentum
- ~5MHz Kaon decays within the Fiducial Region



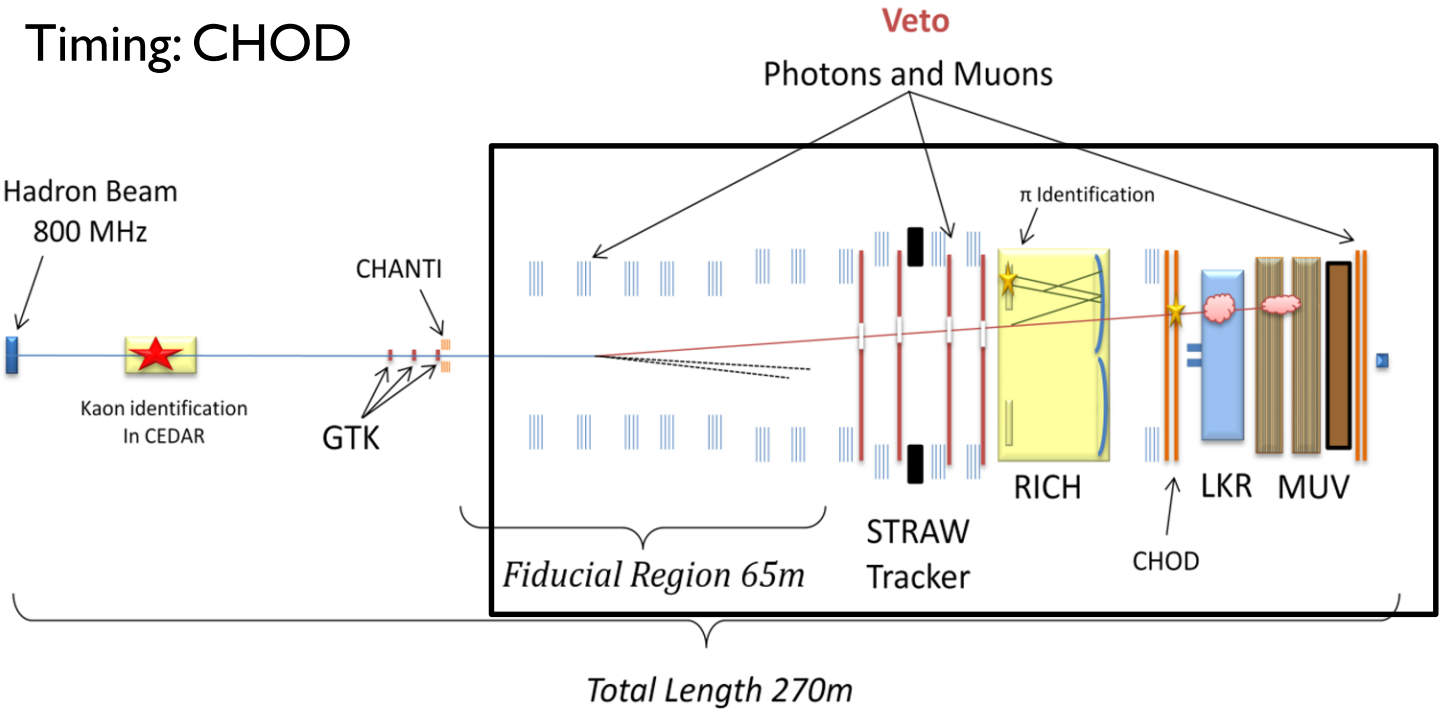
NA62 Detectors

- Beam Kaon oriented detectors: KTAG and GTK
  - Identification and 4-momentum measurement of the beam particles



NA62 Detectors

- Decay products oriented detectors (PID): Straw, RICH, LKr and MUVs
  - Identification and 4-momentum measurement of the decay products
- Photon veto systems: LAV, IRC and SAC
- Charged particles veto systems: CHANTI and CHOD
- Timing: CHOD

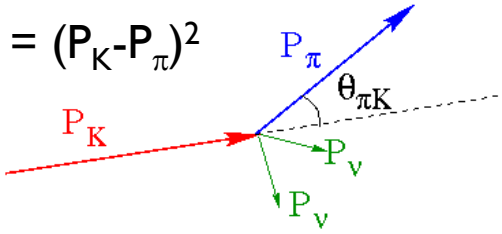


The Analysis Strategy

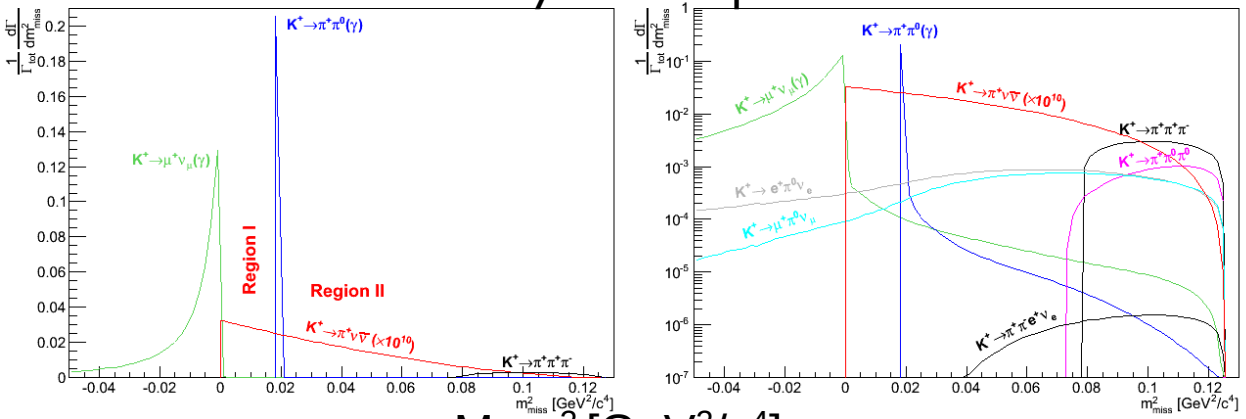
- Signal:
  - Single Pion in the final state matching a beam Kaon (timing and spatial association)

- Background suppression factors:
  - Kinematics $O(10^4\text{-}10^5)$
  - Charged Particle ID $O(10^7)$
  - γ detection $O(10^8)$
  - Timing $O(10^2)$

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



Analytical computation



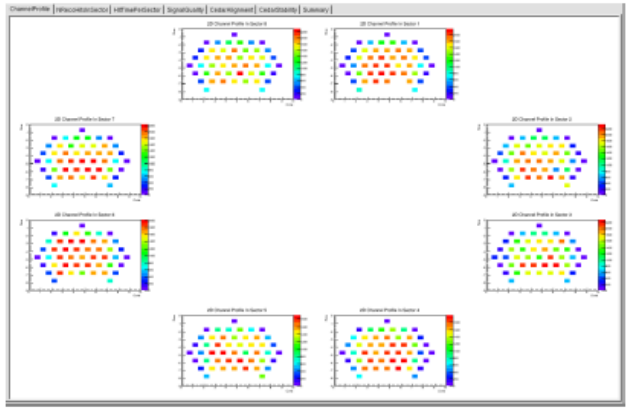
M_{miss}^2 [GeV^2/c^4]

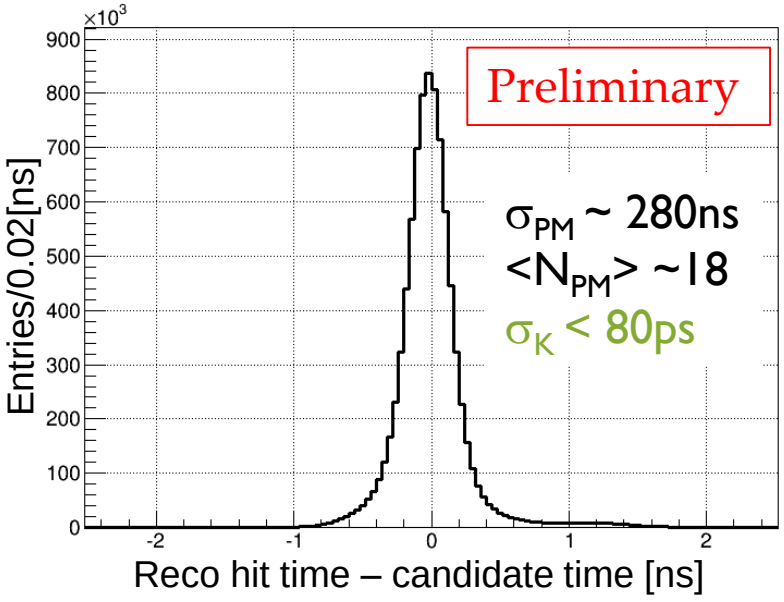
The Analysis Sensitivity (MC)

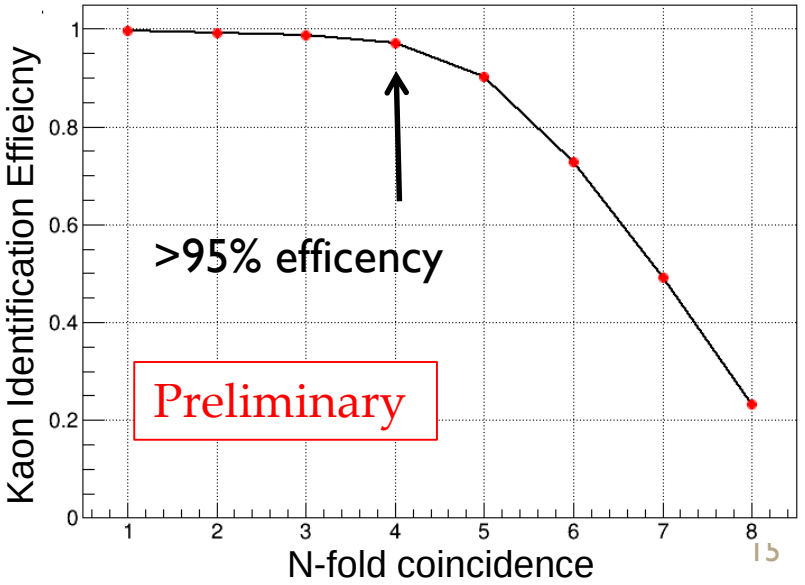
Decay	event/year
$K^+ \to \pi^+ \nu\nu$ [SM] (flux 4.5×10^{12} K-decay/y)	45
$K^+ \to \pi^+ \pi^0$	5
$K^+ \to \mu^+ \nu$	1
$K^+ \to \pi^+ \pi^+ \pi^-$	< 1
$K^+ \to \pi^+ \pi^- e^+ \nu$ + other 3 tracks decays	< 1
$K^+ \to \pi^+ \pi^0 \gamma$ (IB)	1.5
$K^+ \to \mu^+ \nu \gamma$ (IB)	0.5
$K^+ \to \pi^0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

Kaon Identification KTAG

PMTs illumination

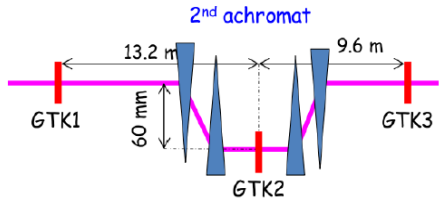


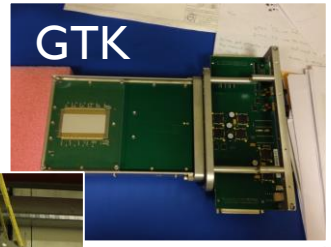


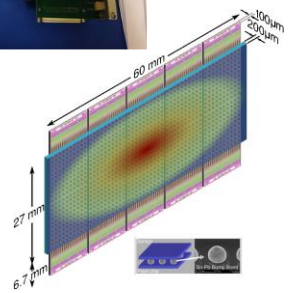


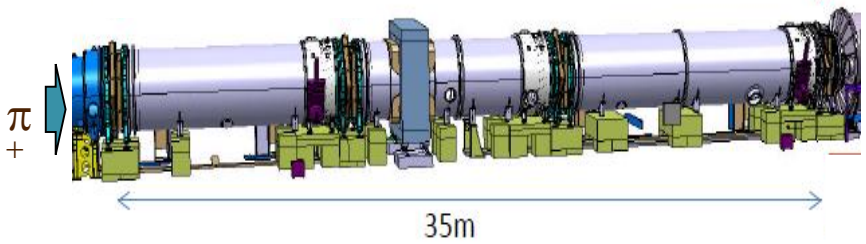
Kinematical Rejection: GTK and Straw

- Kinematical variable
  - $M_{miss}^2 = (P_K - P_\pi)^2$
- Requirements:
  - $\sigma(P_K)/P_K \leq 0.2\%$ and $\sigma(\Theta_K) \leq 20\mu rad$
  - $\sigma(P_\pi)/P_\pi \leq 1\%$ and $\sigma(\Theta_\pi) \leq 60\mu rad$

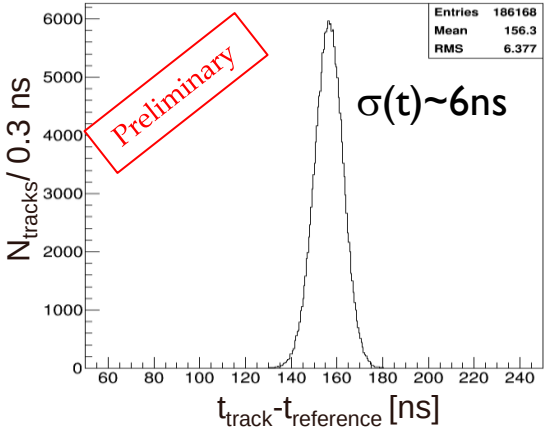




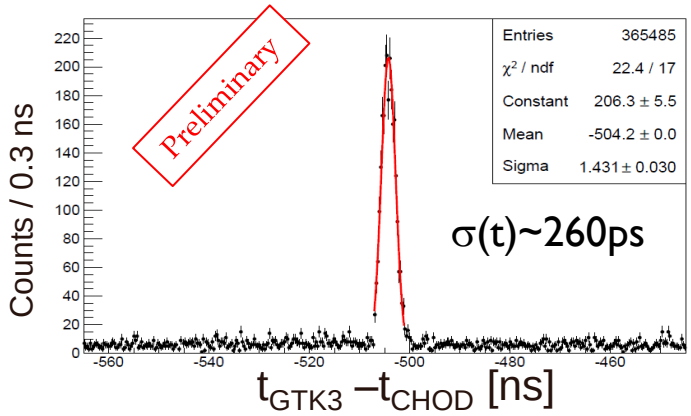




Straw Track time resolution

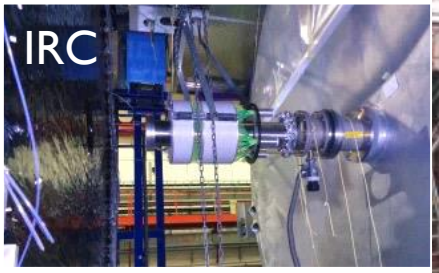


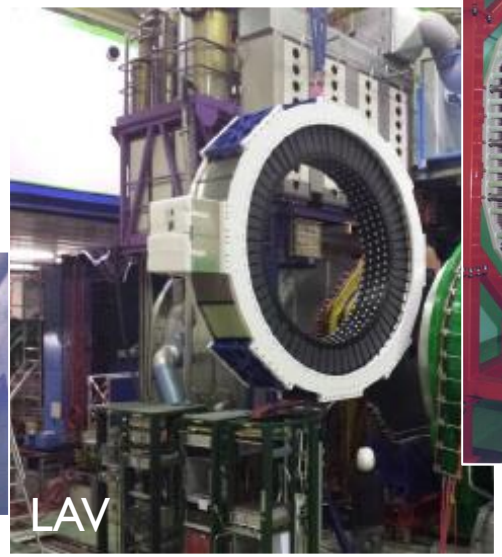
GTK time resolution



Photon Rejection: LAV, LKr, IRC and SAC

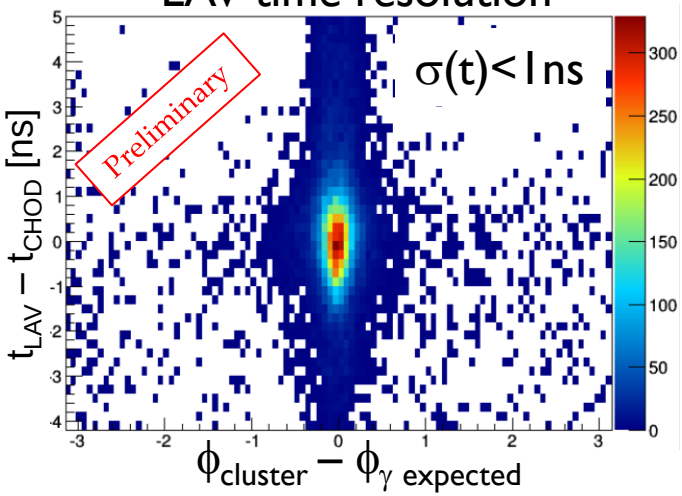
- LAV:
  - 12 stations made of 4/5 leadglass detectors layers
  - $[10^{-3}, 10^{-4}]$ photon inefficiency down to 150MeV
  - ~1ns time resolution
  - 1MHz particle rate (full intensity)
- Liquid Krypton calorimeter (LKr):
  - Quasi homogeneous calorimeter (former NA48 main calorimeter)
  - 10^{-5} inefficiency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



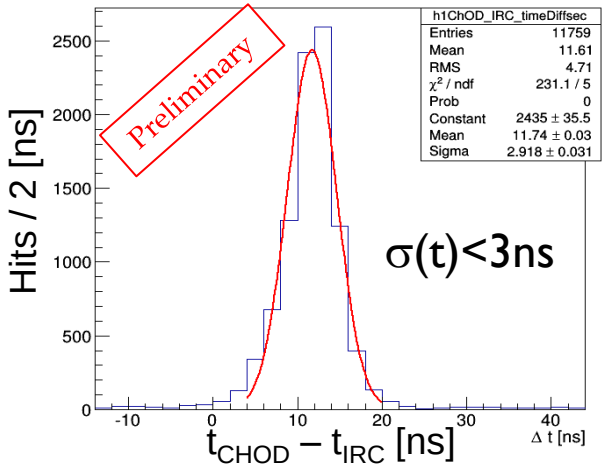


Photon Rejection: LAV, LKr, IRC and SAC

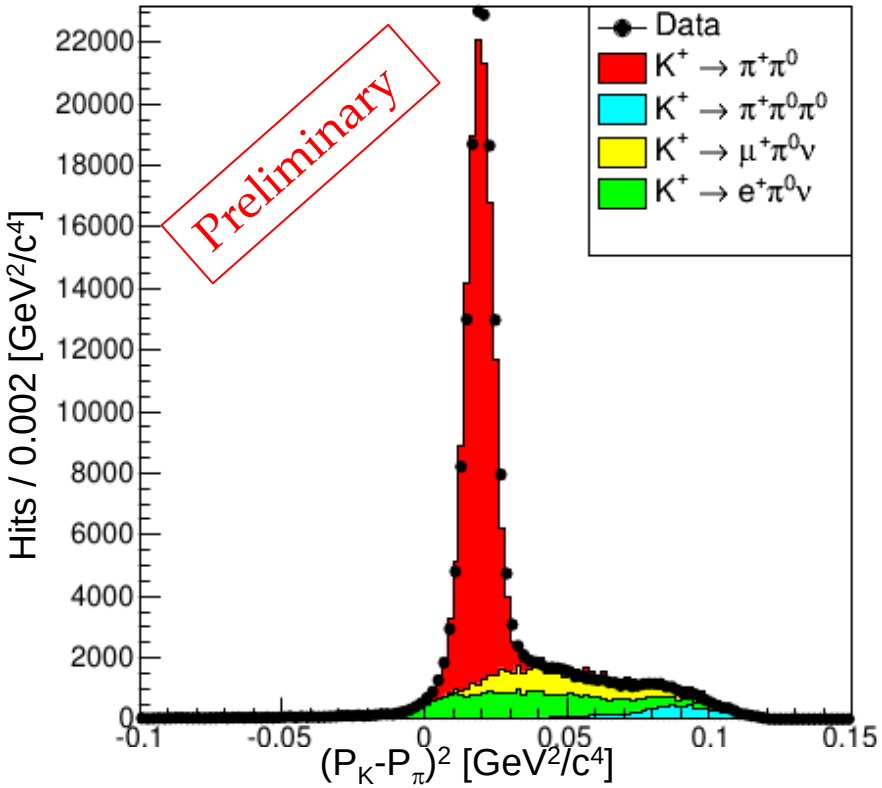
LAV time resolution



IRC time resolution

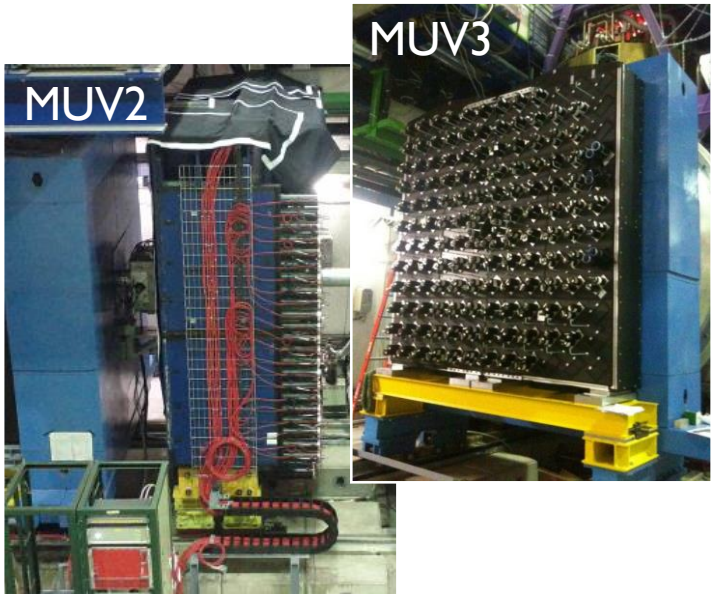


Krypton Calibration



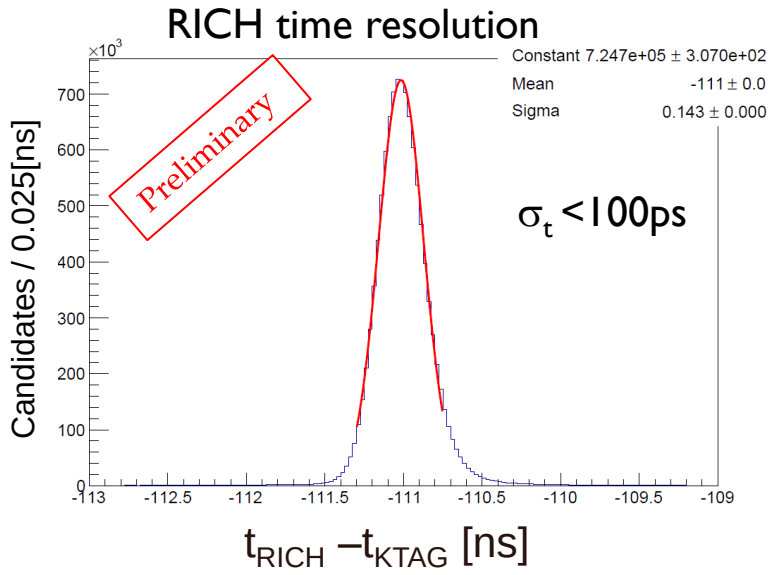
PID: MUV and RICH

- MUV1-2:
  - 2 hadron calorimeter modules (iron-scintillator plates+ PMT readout) for π/μ separation
- RICH:
  - 17m long vessel (Ne at 1 atm) for $\pi/\mu/e$ separation up to 35 GeV/c momentum
- MUV3:
  - scintillator tiles array, each readout by 2 PMT's for muon-ID (10MHz muon rate)



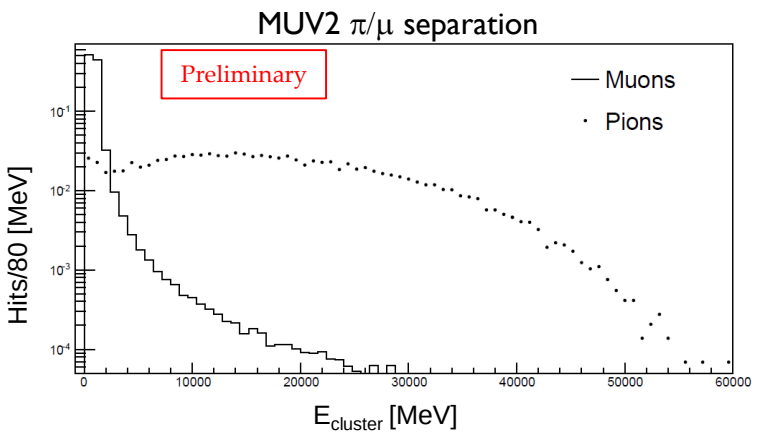
PID: MUV and RICH

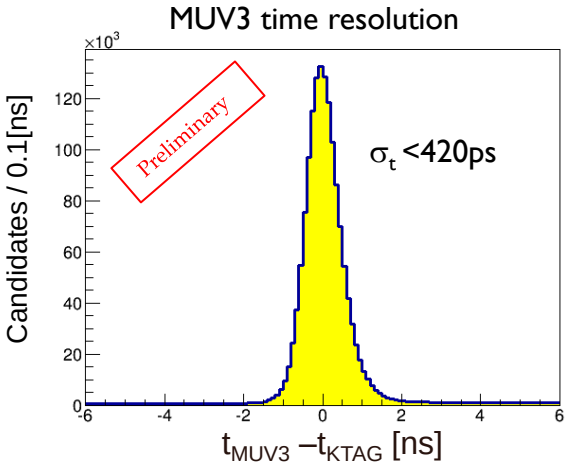
- MUV1-2:
  - 2 hadron calorimeter modules (iron-scintillator plates+ PMT readout) for p/m separation
- RICH:
  - 17m long vessel (Ne at 1 atm) for $\pi/\mu/e$ separation up to 35 GeV/c momentum
- MUV3:
  - scintillator tiles array, each readout by 2 PMT's for muon-ID (10MHz muon rate)



PID: MUV and RICH

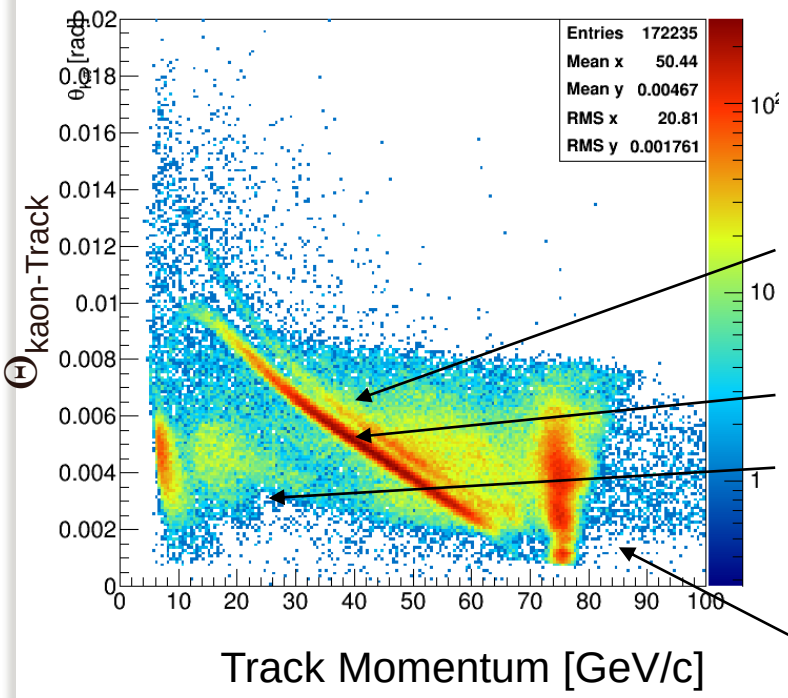
- MUV1-2:
  - 2 hadron calorimeter modules (iron-scintillator plates+ PMT readout) for p/m separation
- RICH:
  - 17m long vessel (Ne at 1 atm) for $\pi/\mu/e$ separation up to 35 GeV/c momentum
- MUV3:
  - scintillator tiles array, each readout by 2 PMT's for muon-ID (10MHz muon rate)





First Look at 2014 Data

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



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

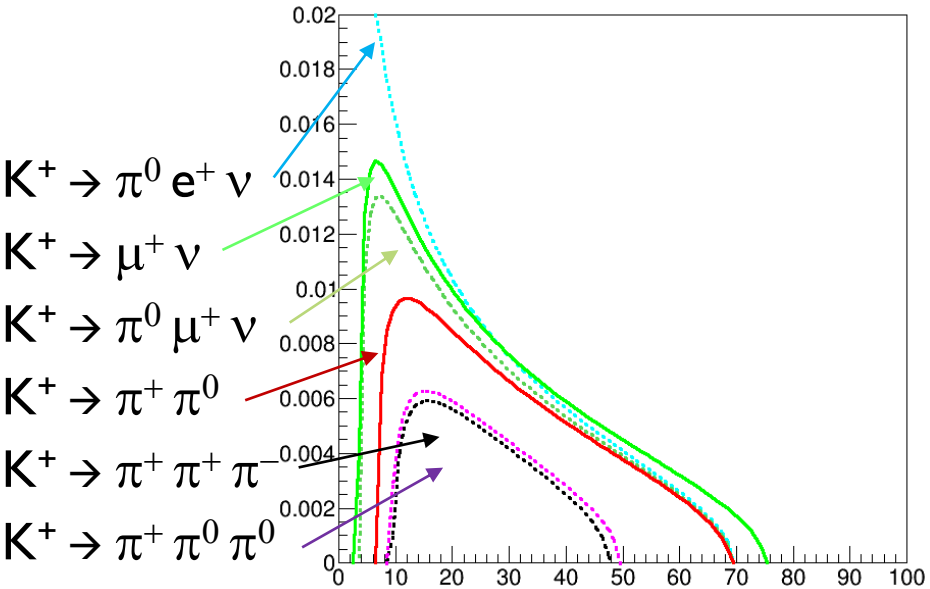
$K^+ \to \mu^+ \nu$

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

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

$K^+ \to \pi^+ \pi^+ \pi^-$

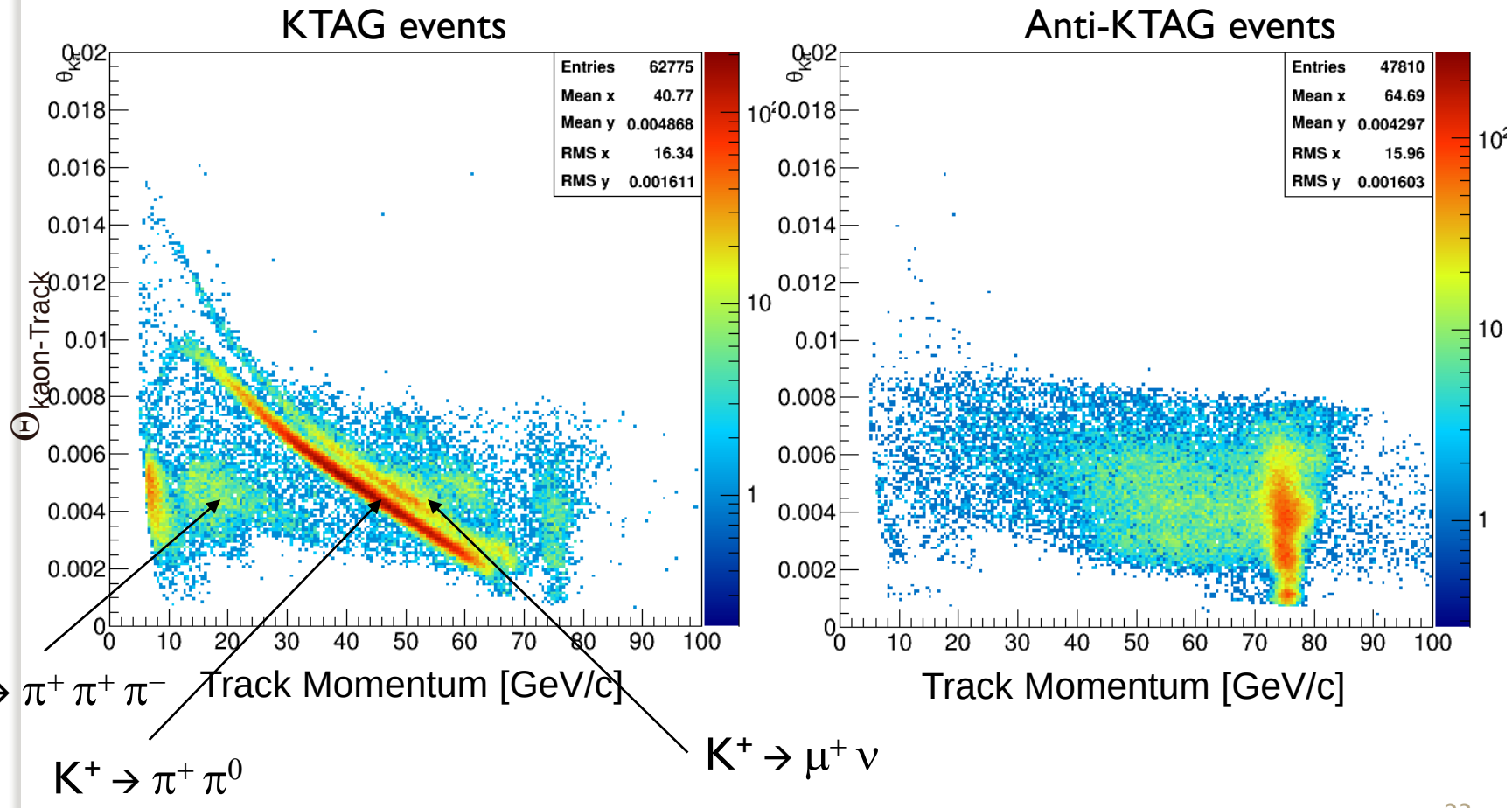
$K^+ \to \pi^+ \pi^0 \pi^0$



Beam-like component (75GeV/c)

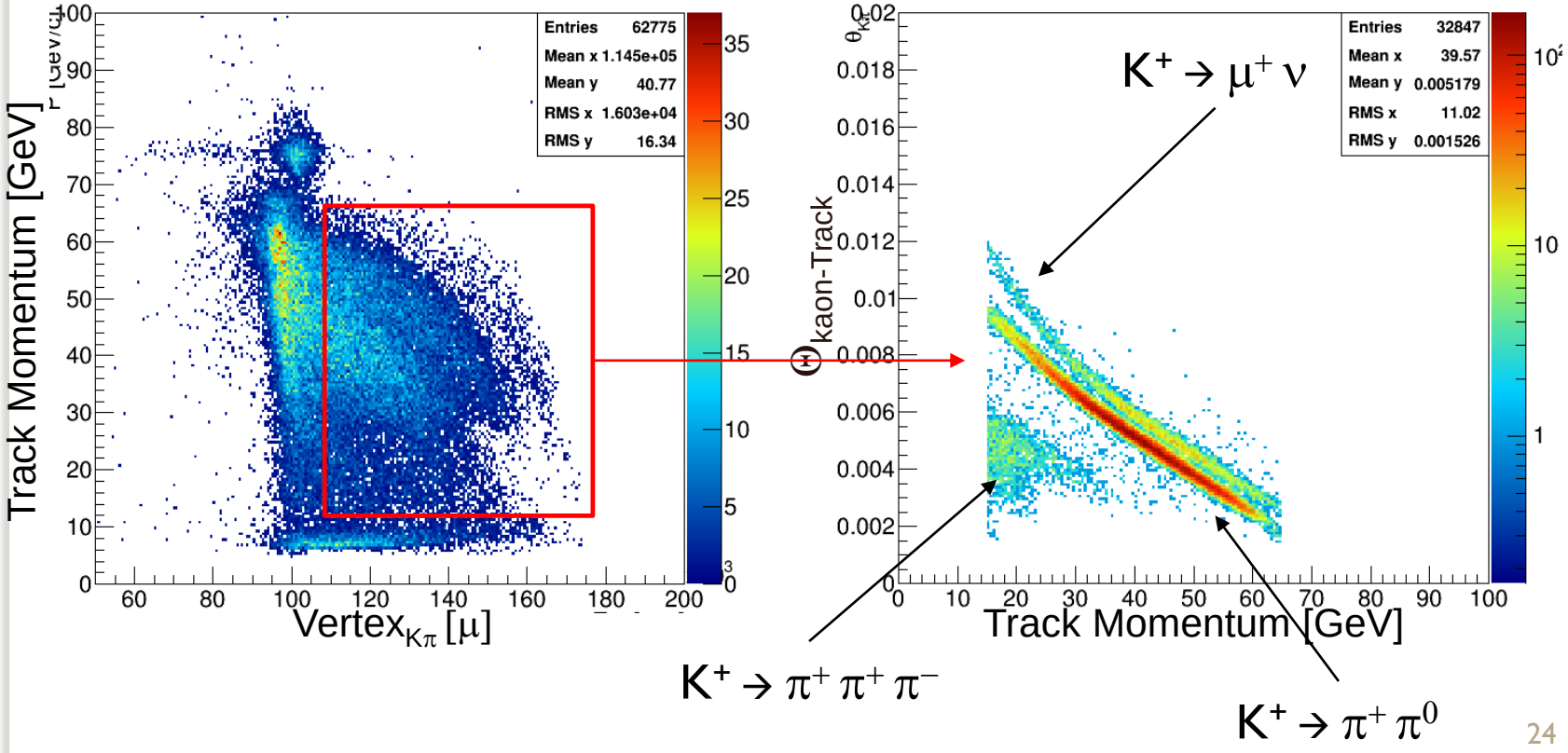
First Look at 2014 Data

- Apply Kaon identification (KTAG)

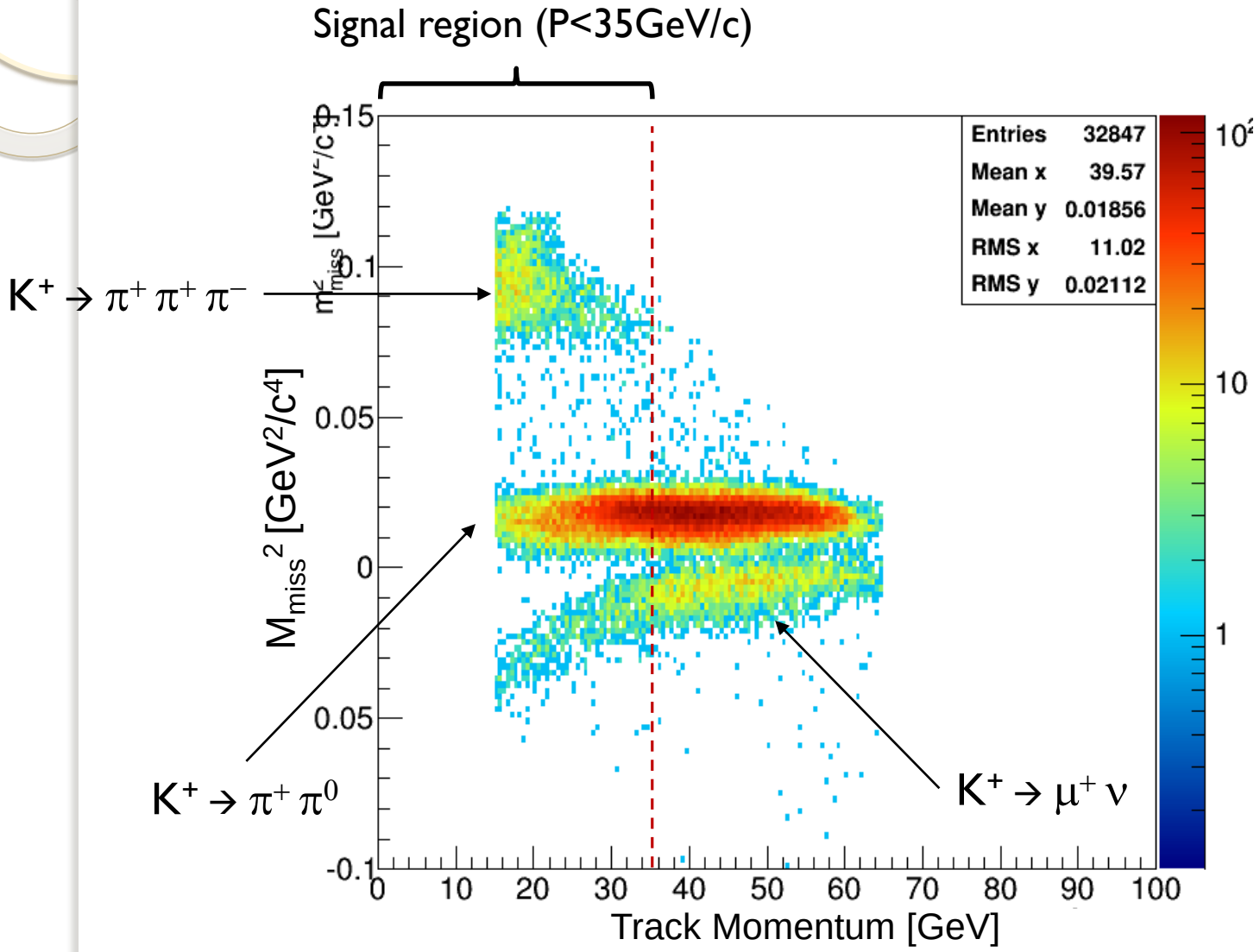


First Look at 2014 Data

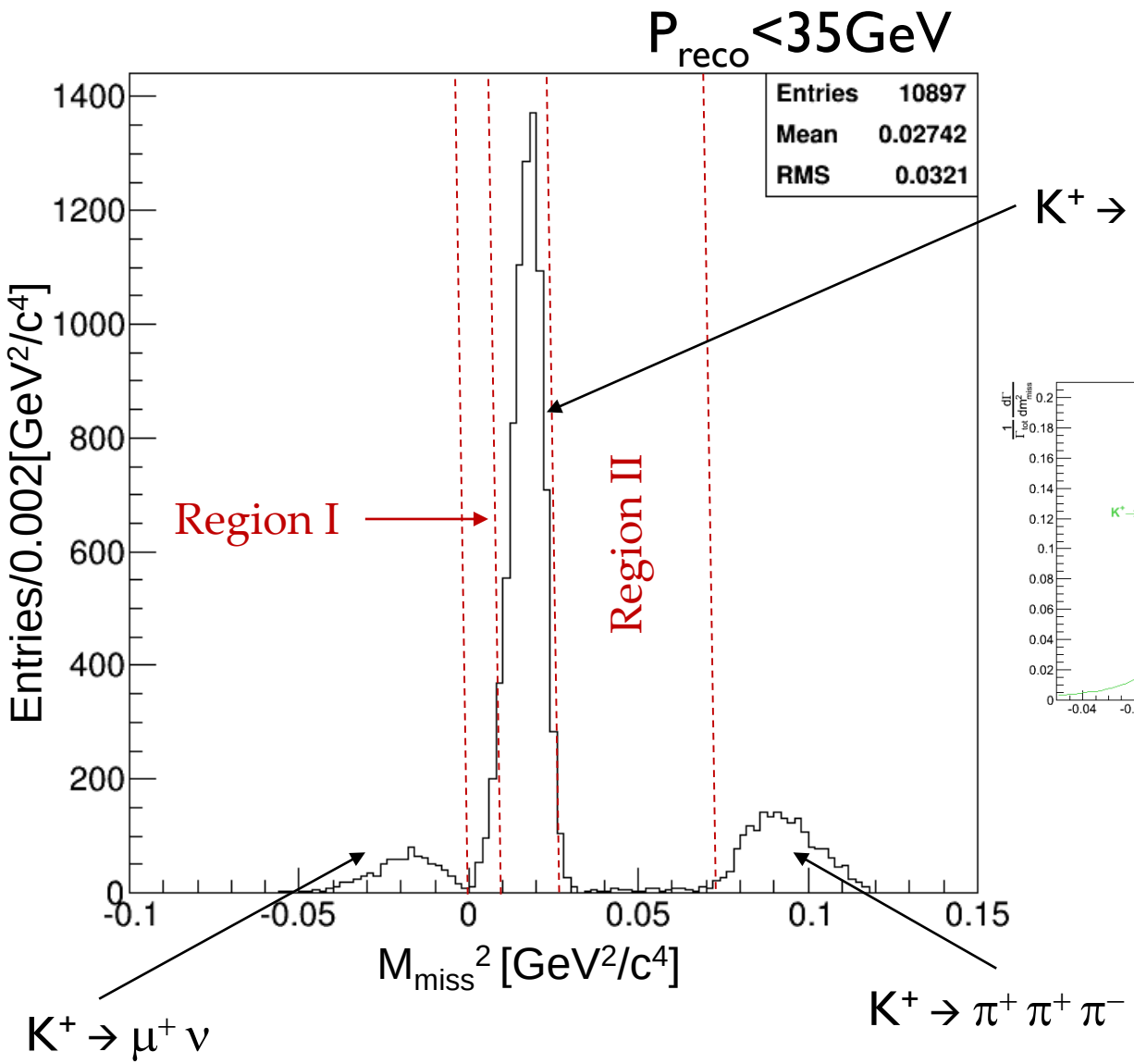
- Vertex reconstructed to suppress background from Kaon interactions outside the decay volume. Used nominal beam direction (no GTK).

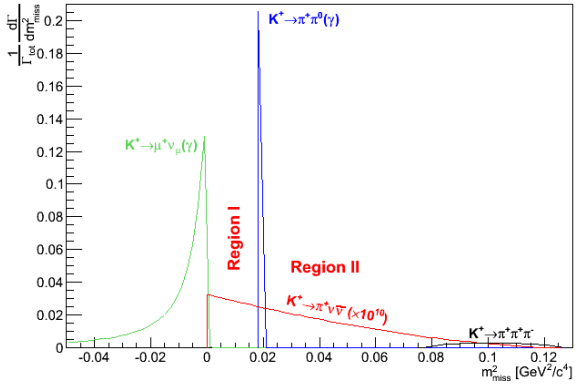


First Look at 2014 Data



Missing Mass





Next Steps

- Resolution improvement expected from:
  - GTK Kaon spectrometer information (instead of nominal beam momentum/direction)
  - Fine STRAW spectrometer alignment/calibration
  - Detailed B field map (instead of simple P_t kick)

- Background rejection improvements from:
  - RICH particle identification ($\pi/\mu/e$)
  - Photon rejection (LKr, LAV, IRC and SAC)
  - Muon rejection (MUVs)

Conclusions

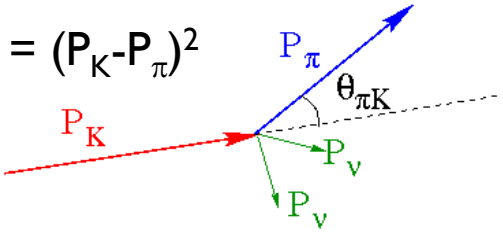
- The successful Pilot run has officially started the NA62 experiment physics program
- Almost all the detectors have been fully commissioned
- Detectors performances measurement are ongoing, preliminary results within expectation
- Analysis technique has be exercised on the a small dataset

- NA62 Run1 started end of June…

The Analysis Strategy

- Signal:
  - Single Pion in the final state

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



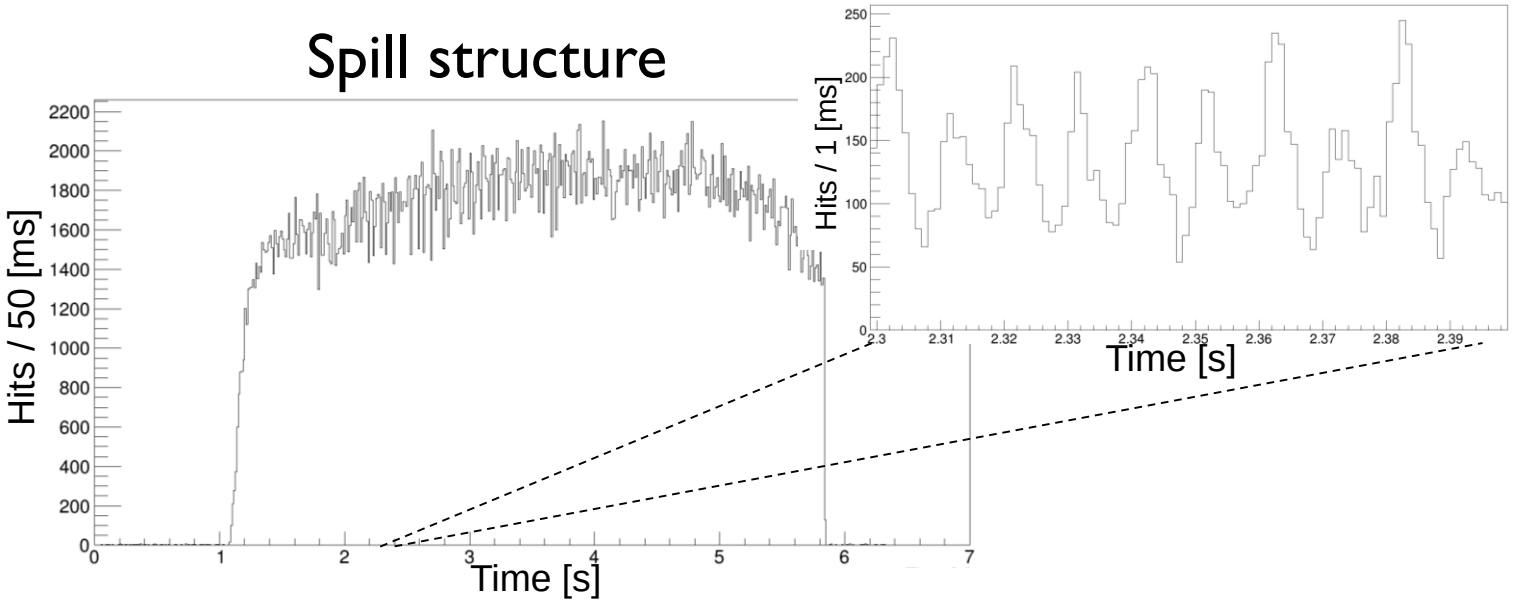
- Main requirements:
  - Kaon-Pion timing and spatal matching
  - $P_\pi < 35$ GeV/c

- Background suppression factors:
  - Kinematics $O(10^4\text{-}10^5)$
  - Charged Particle ID $O(10^7)$
  - γ detection $O(10^8)$
  - Timing $O(10^2)$

K decay background	*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
$K^+ \to \pi^+ \pi^- \varepsilon^+ \nu$	4.257×10^{-5}

~92% ~8%

Pilot Run Conditions



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