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The NA62 experiment at CERN

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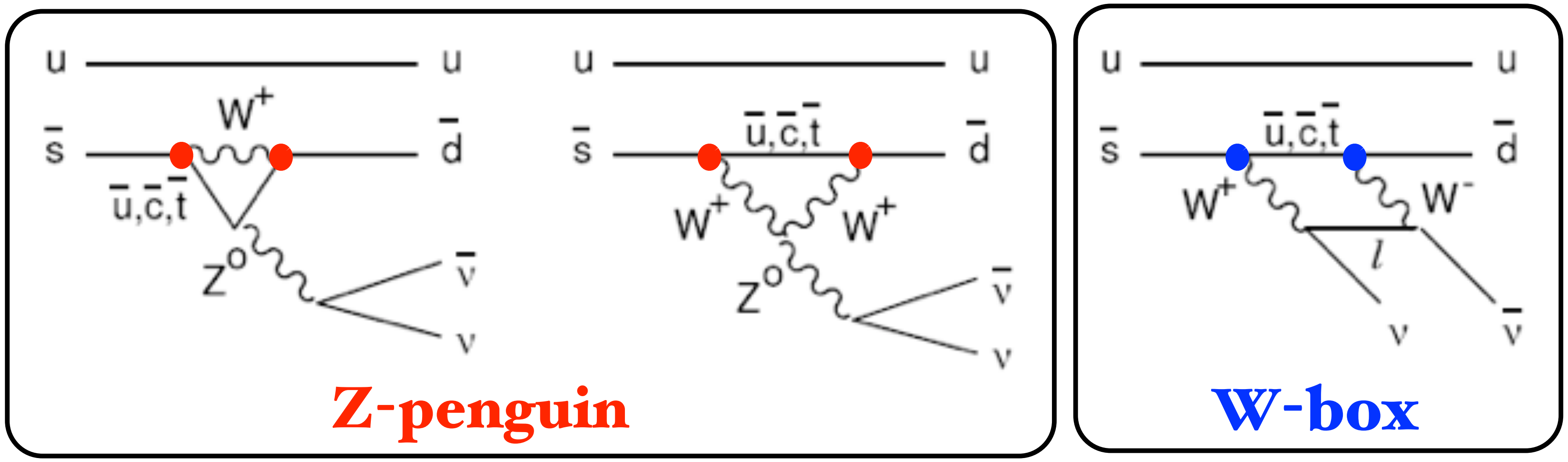
on behalf of the NA62 collaboration

Outline

- Theoretical introduction to the $K^+ \to \pi^+\nu\bar{\nu}$ rare decay
- NA62 experiment aim and strategy
- Detector overview
- First look at 2014 pilot run data

SM theoretical framework

The **$K^+ \rightarrow \pi^+\nu\bar{\nu}$** decay is extremely suppressed and is characterized by a theoretical cleanness in the SM prediction of the BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$)



Flavor-changing neutral current quark transition $s \rightarrow d\nu\nu$.

Forbidden at tree-level, dominated by short-distance dynamics (GIM mechanism)

SM prediction takes in to account:

✳ 1-loop contributions at the leading order.

✳ NLO QCD corrections to the top quark contributions

✳ NLO electroweak corrections to both top and charm contributions

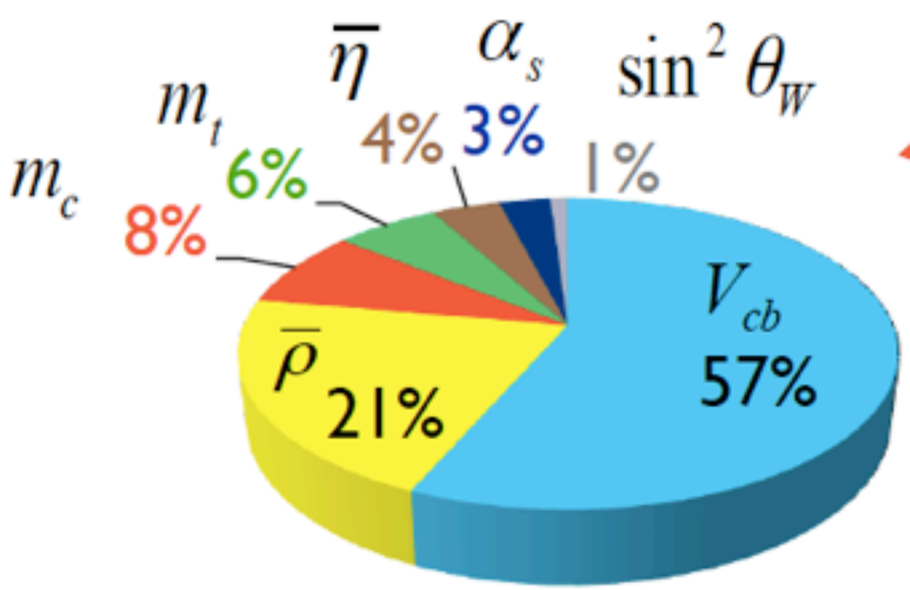
✳ NNLO QCD corrections to the charm contributions

✳ isospin breaking and non-perturbative effects

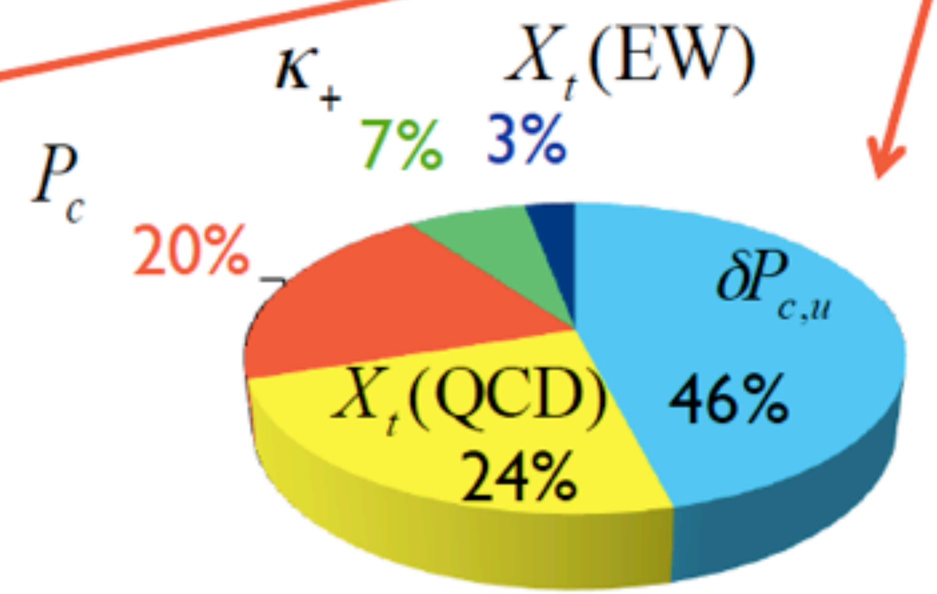
Stringent test of the SM and possible **evidence for New Physics**, complementary to LHC

Past measurement and prediction

Current theoretical prediction [1] [2] ▶ $\mathrm{BR}(K^+ \to \pi^+ \nu\bar{\nu}) = (7.81^{+0.80}_{-0.71} \pm 0.29) \times 10^{-11}$



Input parameters (10%)



Theoretical uncertainty (4%)

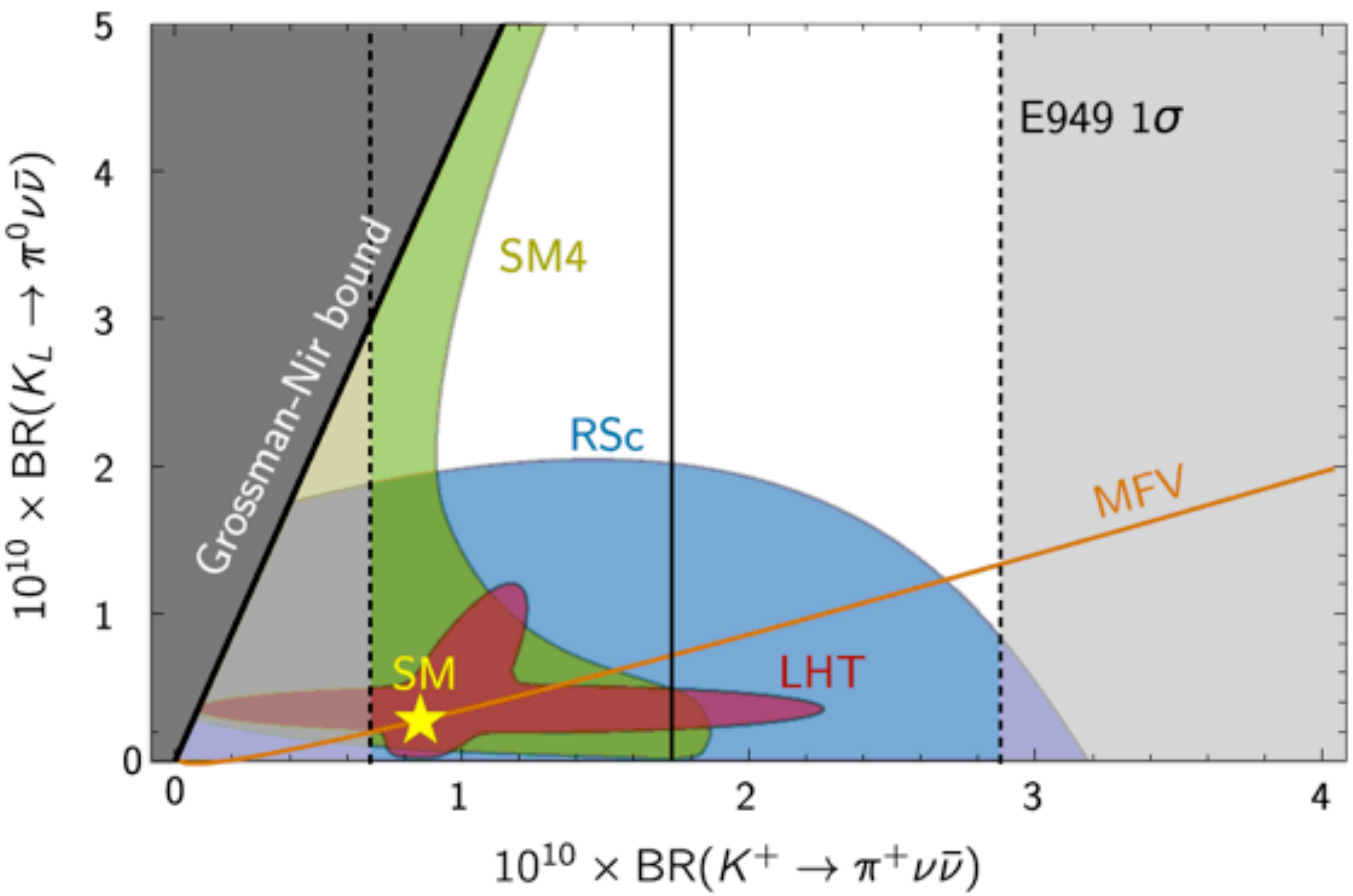
Experimental status: most precise results have been obtained by E787 and E949 experiments at BNL by studying stopped kaon decays [3]:

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

Gap between theoretical precision and large experimental error motivates a strong experimental effort. Significant new constraints can be obtained with a measurement of the BR at the level of 10% or better

New Physics from K→πνν decays

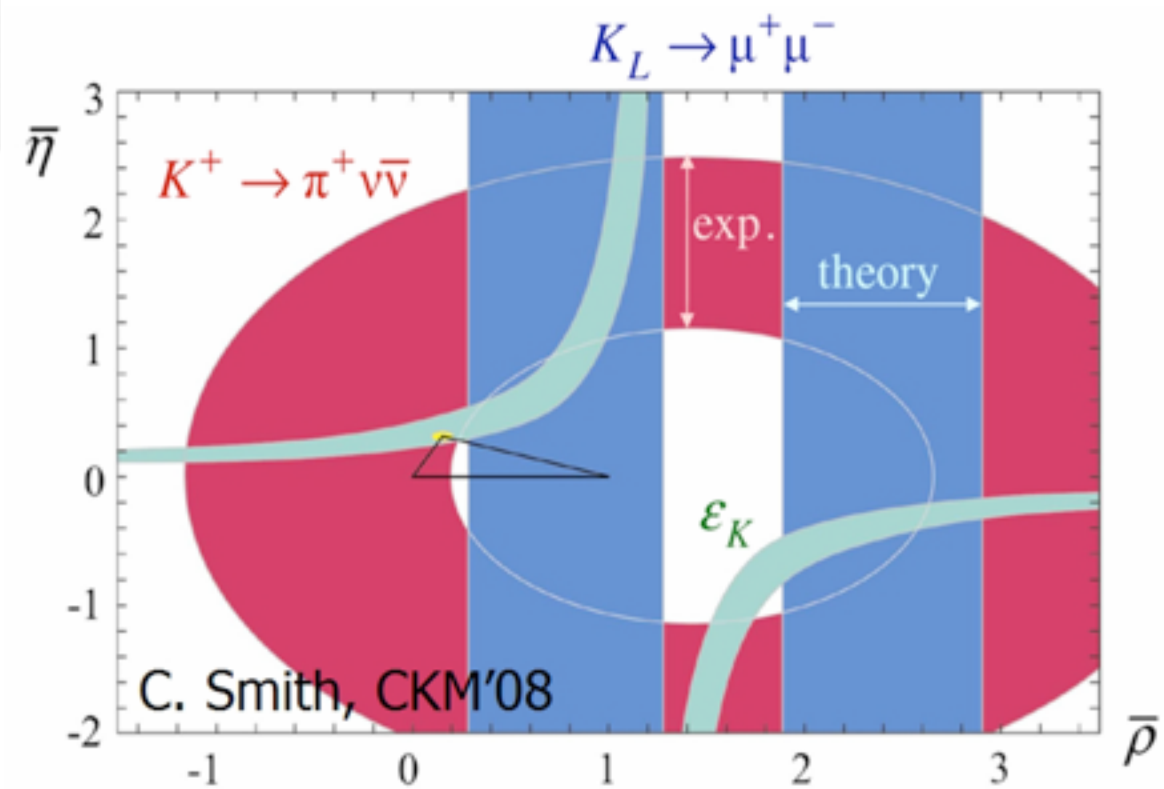
Measurement of charged ($K^+ \to \pi^+\nu\bar{\nu}$) and neutral ($K_L \to \pi^0\nu\bar{\nu}$) modes can discriminate different NP scenarios



SM4:
SM with 4th generation [4]
RSc:
Randall Sundrum mechanism [5]
LHT:
Littlest Higgs with T-parity [6]
MFV:
Minimal Flavor Violation [7]

Measurement of $|V_{td}|$ complementary to those from B-B mixing

δ(BR)/BR = 10% would lead to
δ($|V_{td}|$)/$|V_{td}|$ = 7%



Experimental requirements

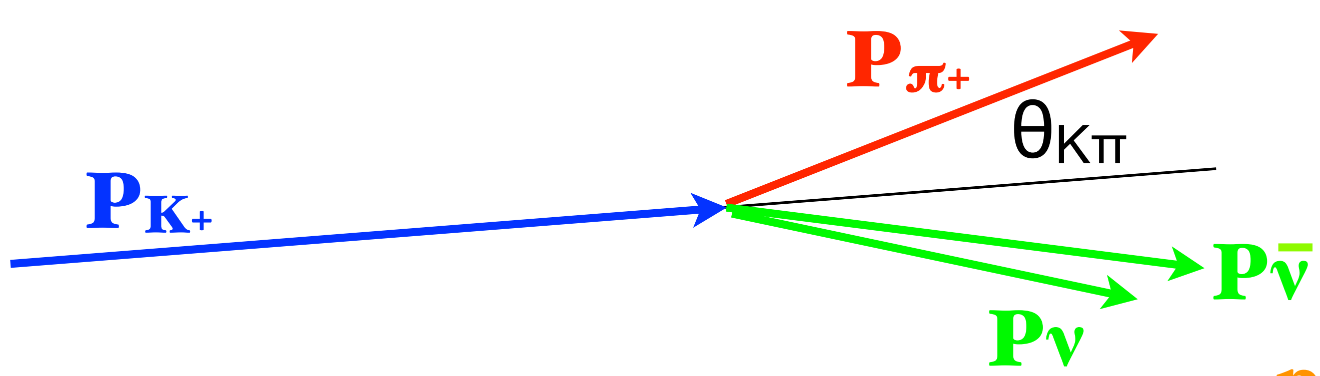
GOAL: measure BR($K^+ \rightarrow \pi^+\nu\bar{\nu}$) with 10% accuracy

O(100) SM events + systematics control at % level

- Assuming a 10% signal acceptance and a BR($K^+ \rightarrow \pi^+\nu\nu$) ~$10^{-10}$ at least 10^{13} K^+ decays are required
- Required a rejection factor for dominant kaon decays of the order of 10^{12} (<20% background)

NA62 design criteria: **kaon intensity, signal acceptance, background suppression**

Decay in flight technique, Kaon with high momentum



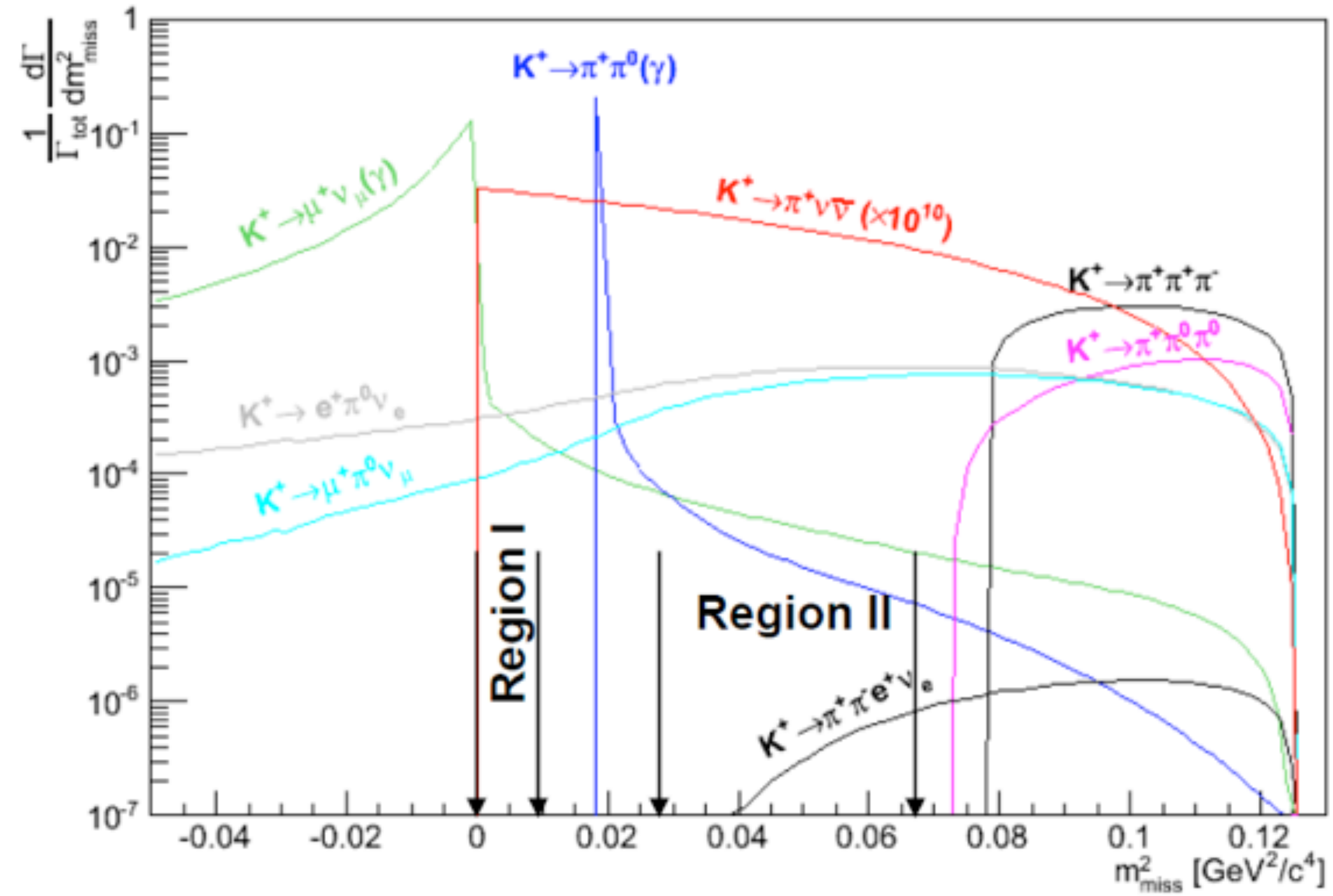
Signal signature:
one K^+ track & one π^+ track

Basic ingredients:
precise timing & kinematics cuts

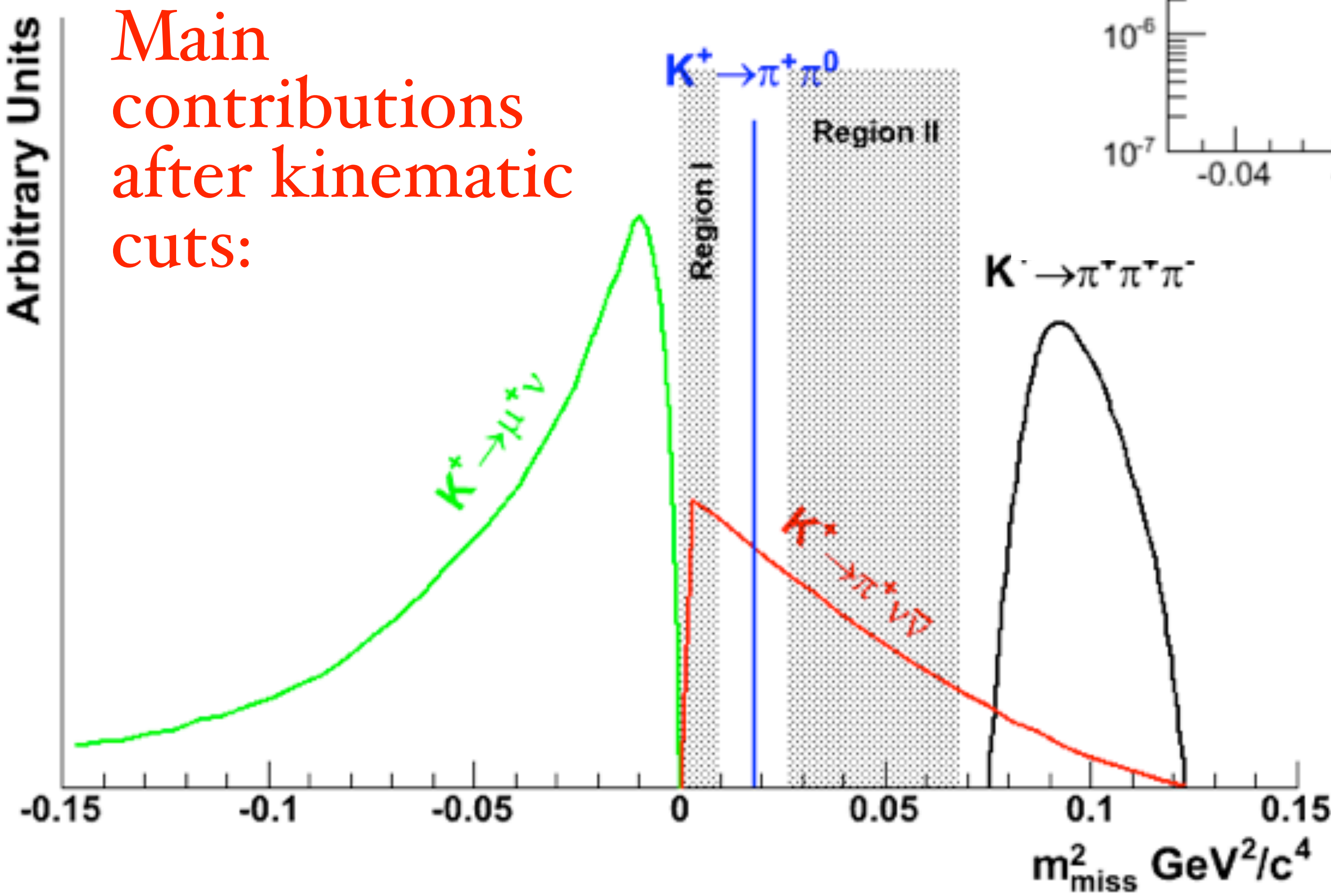
Analysis strategy

Most discriminating variable:
$m^2_{miss} = (P_{K+} - P_{\pi+})^2$

Where the daughter charged particle is assumed to be a pion



Main contributions after kinematic cuts:



2 signal regions, on each side of the $K^+\to\pi^+\pi^0$ peak, are chosen, where more than 90% of main K^+ decays are not contributing.

Background rejection

Background:

Decay	BR	Main Rejection Tools
$K^+ \to \mu^+\nu_\mu(\gamma)$	63%	μ-ID + kinematics
$K^+ \to \pi^+\pi^0(\gamma)$	21%	γ-veto + kinematics
$K^+ \to \pi^+\pi^+\pi^-$	6%	multi-track + kinematics
$K^+ \to \pi^+\pi^0\pi^0$	2%	γ-veto + kinematics
$K^+ \to \pi^0 e^+\nu_e$	5%	e-ID + γ-veto
$K^+ \to \pi^0\mu^+\nu_\mu$	3%	μ-ID + γ-veto

Subdetector requirements:

- Beam tracking system
- Photon veto system
- Muon veto system
- π/μ/e identification system

NA62 design sensitivity

Decay	Events/year
$K^+ \to \pi^+\nu\bar{\nu}$	45
$K^+ \to \pi^+\pi^0$	5
$K^+ \to \pi^+\pi^+\pi^-$	1
$K^+ \to \pi^+\pi^-e^+\nu_e$	< 1
$K^+ \to \pi^+\pi^0\gamma$	< 1
$K^+ \to \mu^+\nu_\mu\gamma$	1.5
other rare decays	0.5
Total backgrounds	< 10

Required background suppression:

Kinematics O(10^4-10^5)

Charged Particle ID O(10^7)

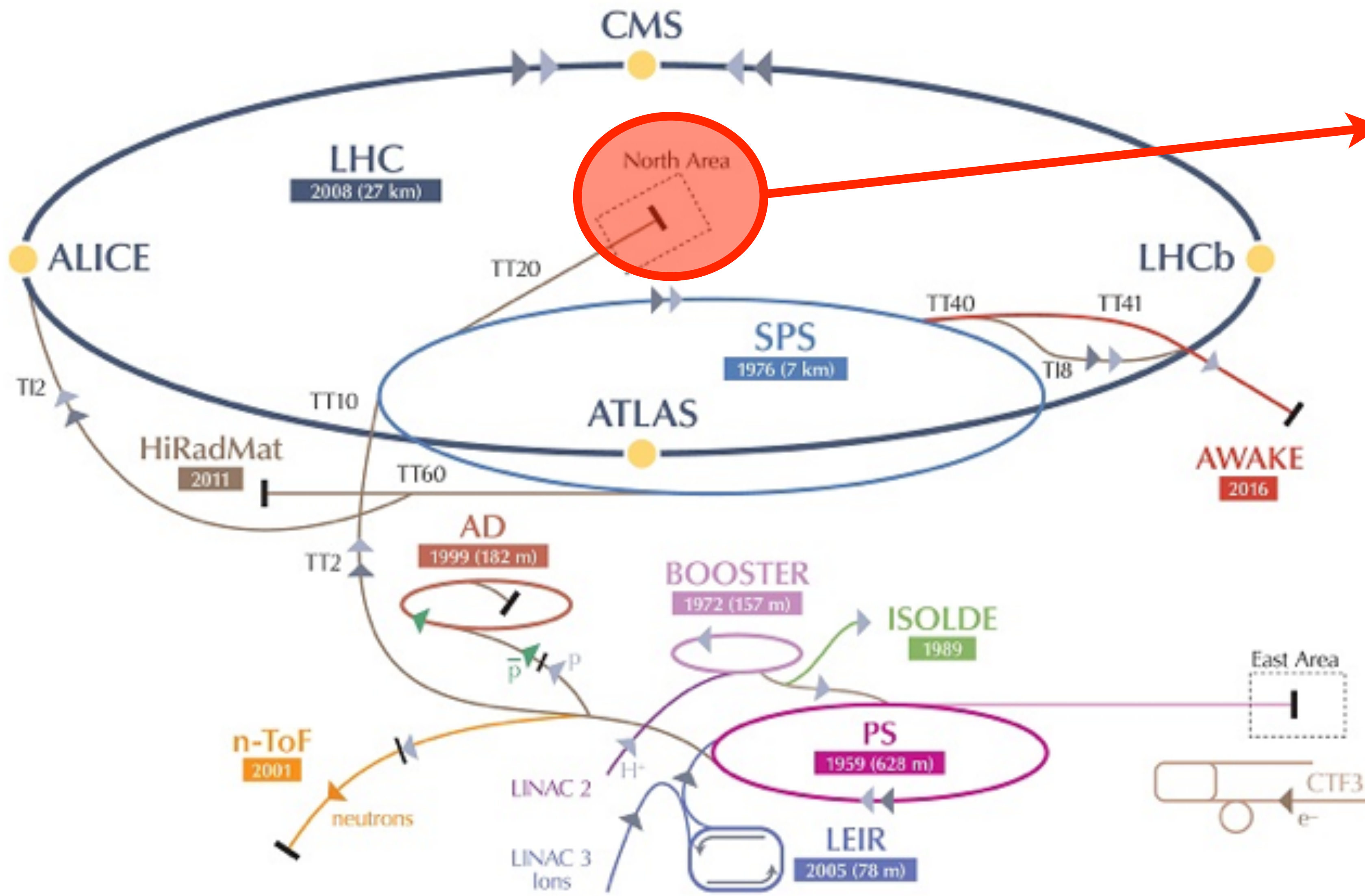
ɣ detection O(10^8)

($P_{\pi+}$<35 GeV to ensure $P_{\pi 0}$ > 40 GeV: such a large energy deposit can hardly be missed)

Timing O(10^2)

Kaon @ CERN - SPS

The **CERN-SPS** secondary beam line already used for the NA48 experiment can deliver the required K^+ intensity



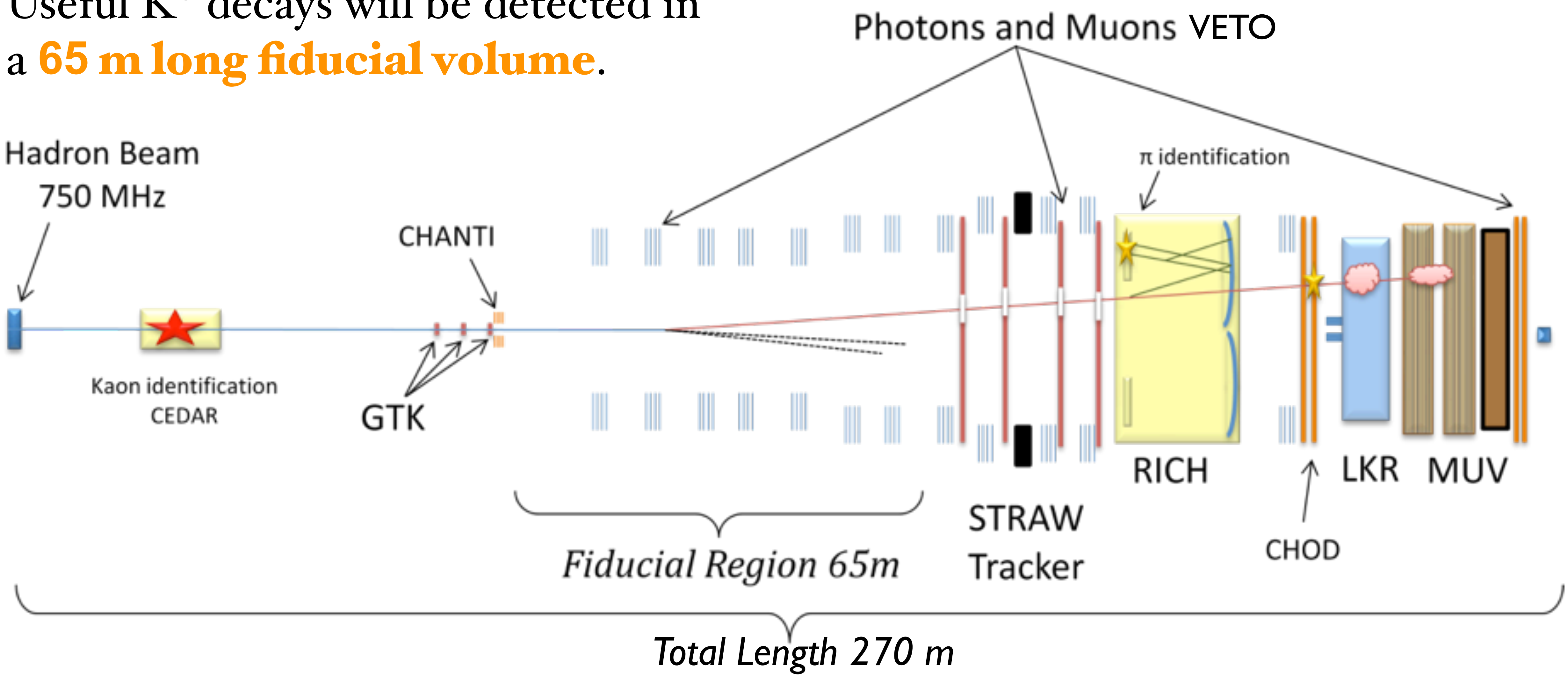
The NA62 is housed in the CERN North Area. A new beam line will provide a secondary charged hadron beam 50 times more intense than in the past, with only 30% more SPS protons on target

two years of data taking scheduled

Protons from the SPS at 400 GeV/c impinge on a beryllium target and produce a secondary charged beam. 6% are K^+ (mixed with π and protons).
Signal acceptance considerations drives the choice of a **75 GeV/c K^+** with a 1% momentum bite and a divergence ~ 100 μrad (in x and y)

NA62 Apparatus

The main elements for the detection of the K^+ decay products are spread along **a 270 m long** region starting about 100 m downstream of the beryllium target. Useful K^+ decays will be detected in a **65 m long fiducial volume**.



Approximately cylindrical shape around the beam axis for the main detectors. Diameter varies from 12 to 220 cm, in order to let the very intense flux of **undecayed beam particles passing through**.

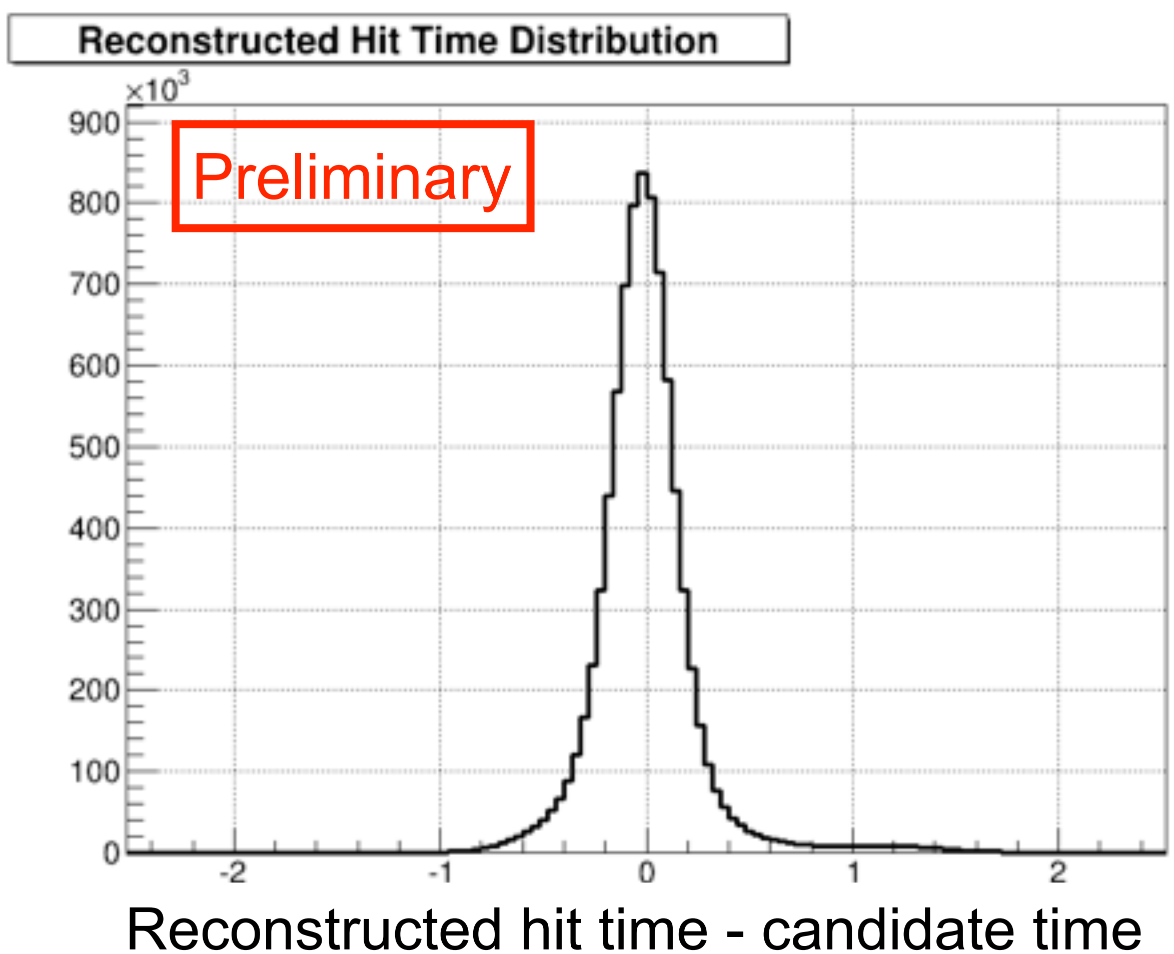
The overall rate integrated over these detectors is ~ 10 MHz

Kaon ID and timing: CEDAR & KTAG

K⁺ identification in the hadron beam

A ChErenkov Differential counter with Achromatic Ring focus operate to be blind to all particles but kaons of appropriate momentum (**75 GeV**).

Steel vessel, 4.5 m long and filled with compressed nitrogen.



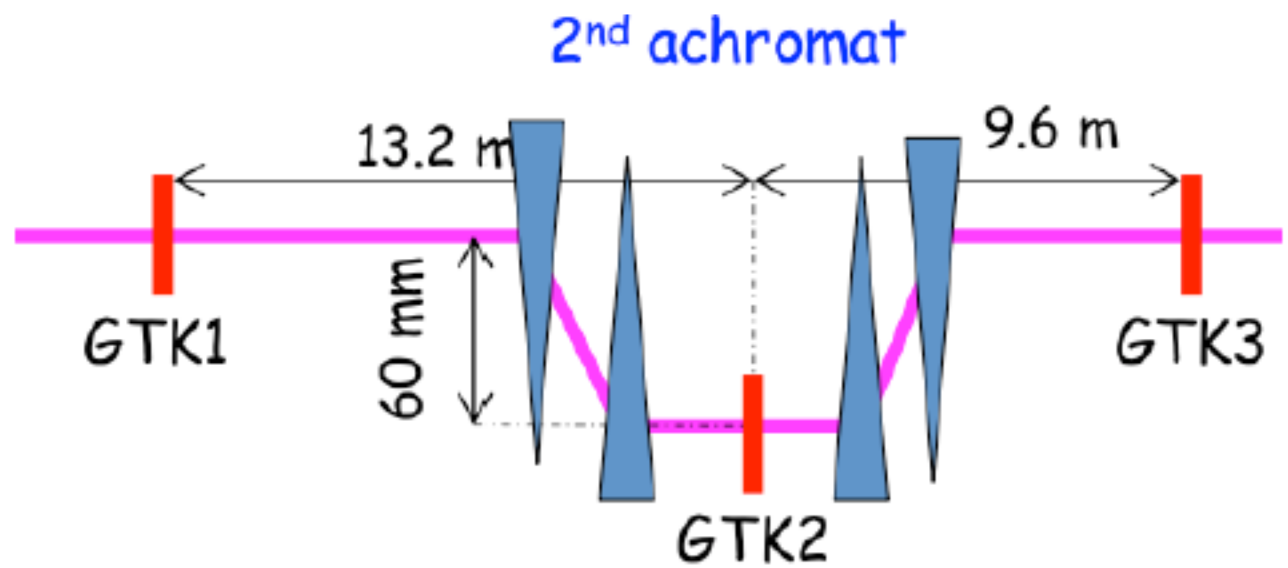
Given the high beam rate (750 MHz unseparated beam), a modified light collection system with a much higher granularity (KTAG) has been implemented to detect the Cherenkov photons emitted by the kaons

From 2014 commissioning run:
- overall time resolution ~ 66 ps
- K-ID efficiency > 95%, K mis-ID < 10^{-3}

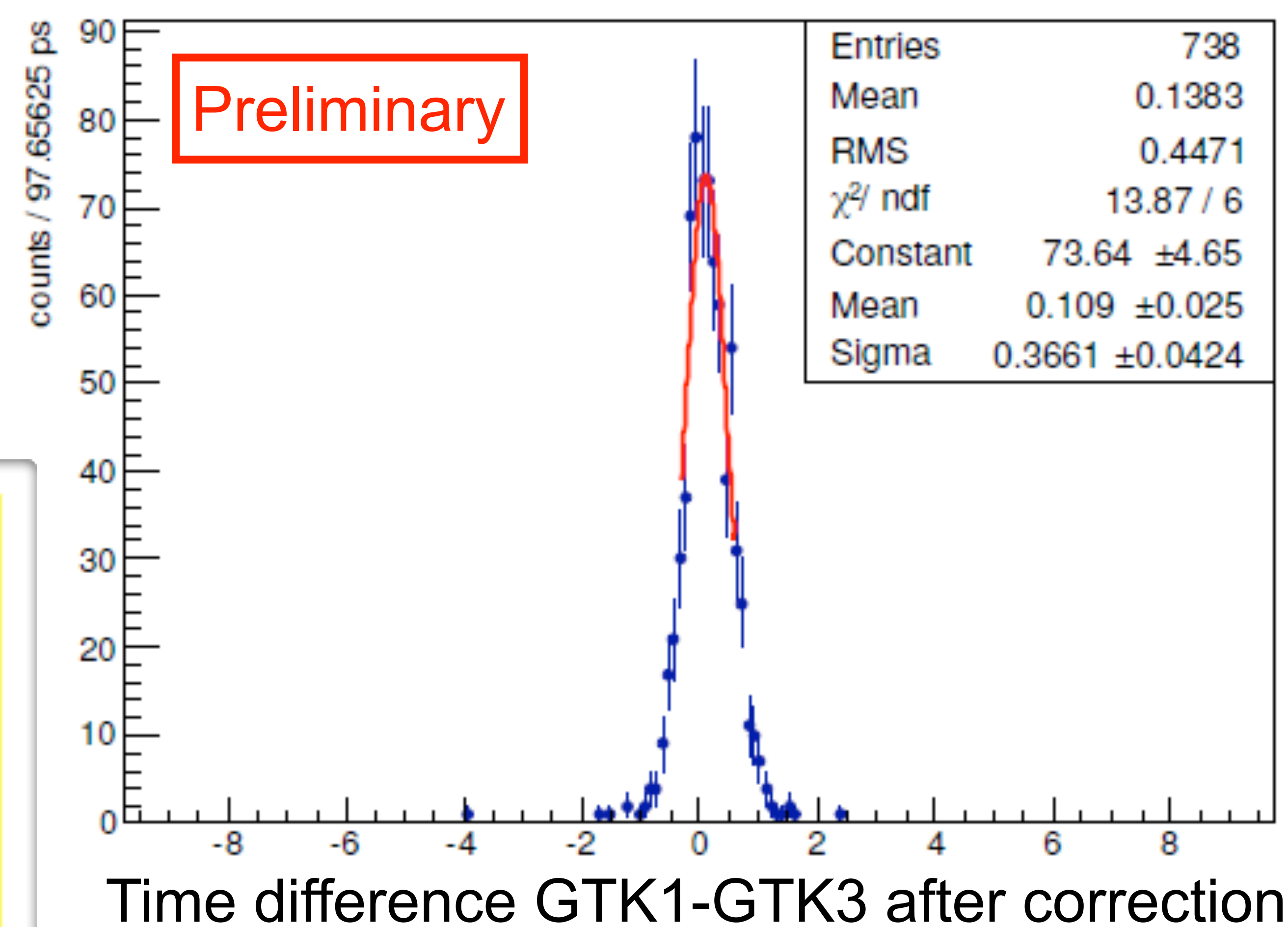
Tracking System: Beam Tracker (GTK)

<u>K^+ spectrometer for momentum and timing measurement</u>

GTK must provide, (in a 750 MHz beam environment) a precise timing of the kaon in coincidence with the particle from the decay detected in downstream detectors.



3 stations of silicon pixels matching the beam dimensions placed in vacuum.(18000 pixels per station, 10 read out chips)



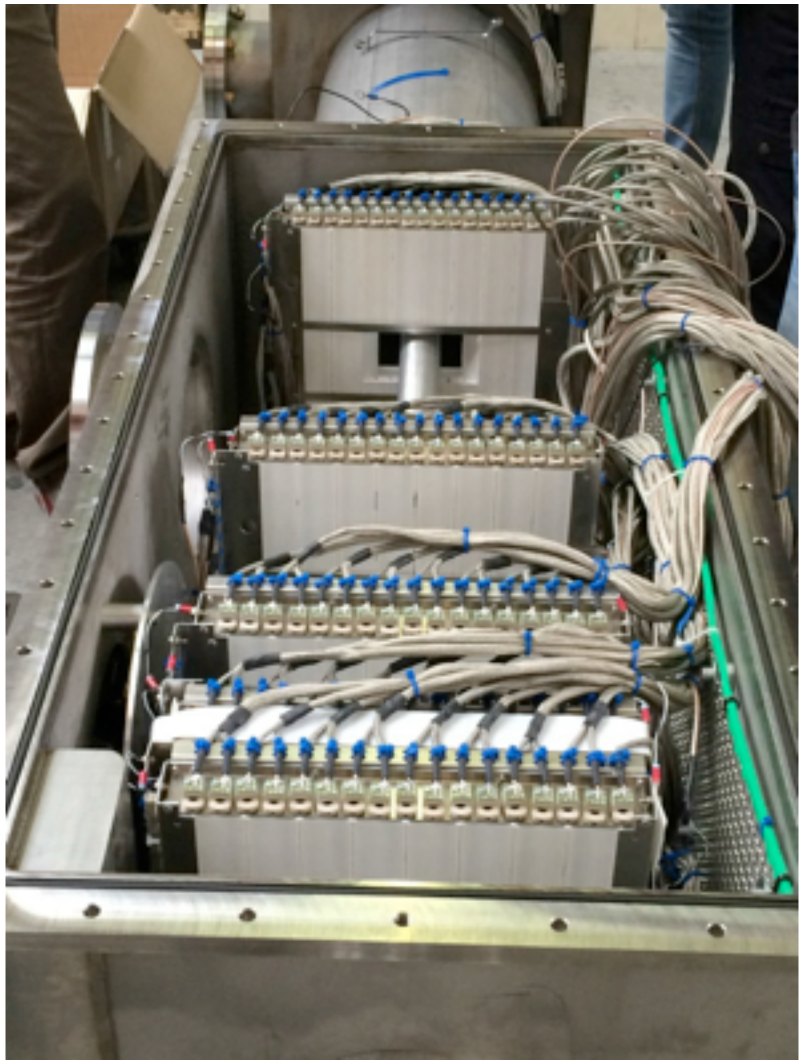
From 2014 run partial commissioning (1 chip per station):
- time resolution estimated to be 260±30 ps in agreement with nominal design
- direction resolution ~16 μrad

Guard-Ring detector: CHANTI

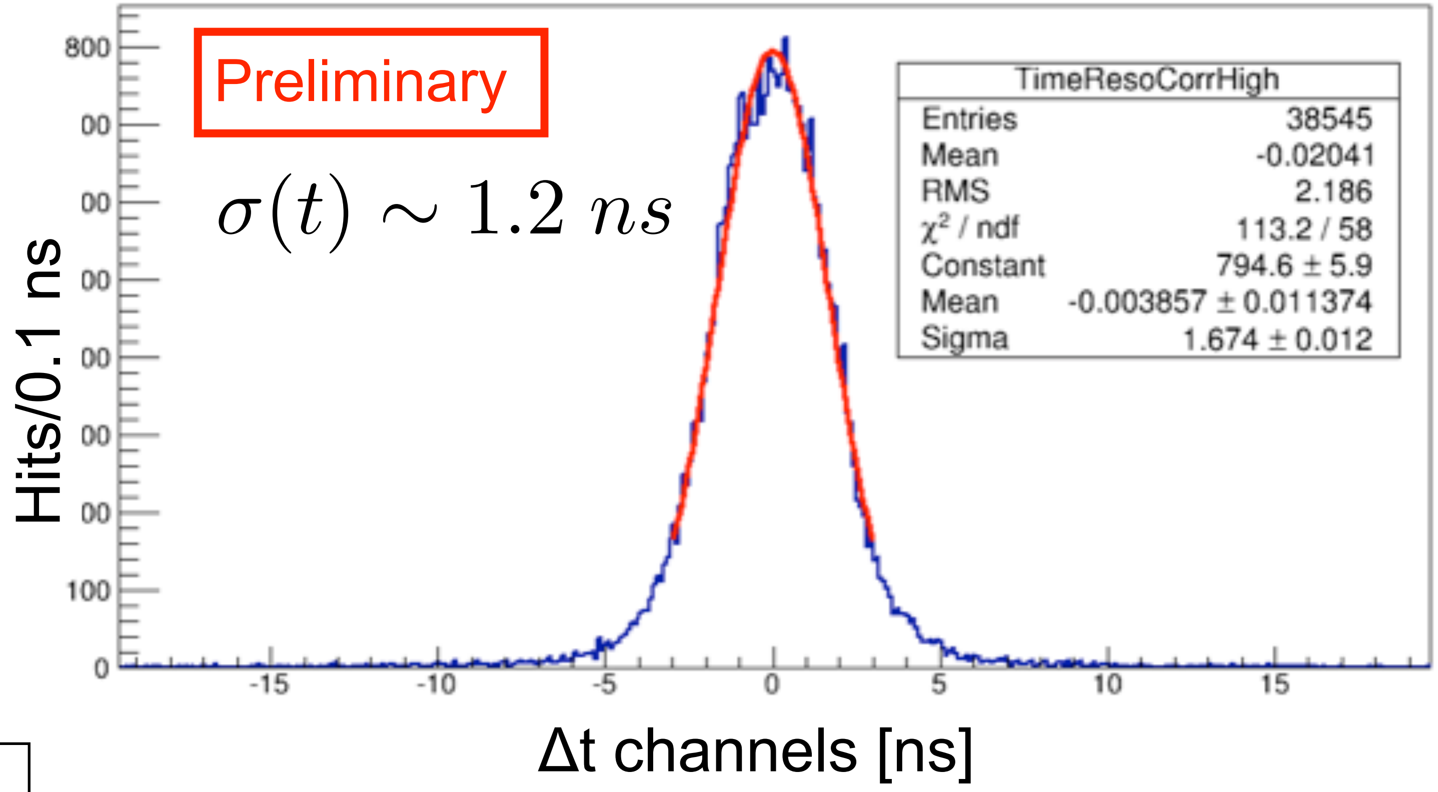
Veto for charged particles from inelastic scattering

The CHarged ANTIcounter detector aims at reducing the background induced by inelastic interactions of the beam with the last GTK station.

It detects the charged particles produced on GTK3 and emitted at relatively large angles



6 stations of X-Y plastic scintillator bars coupled with optical fibers



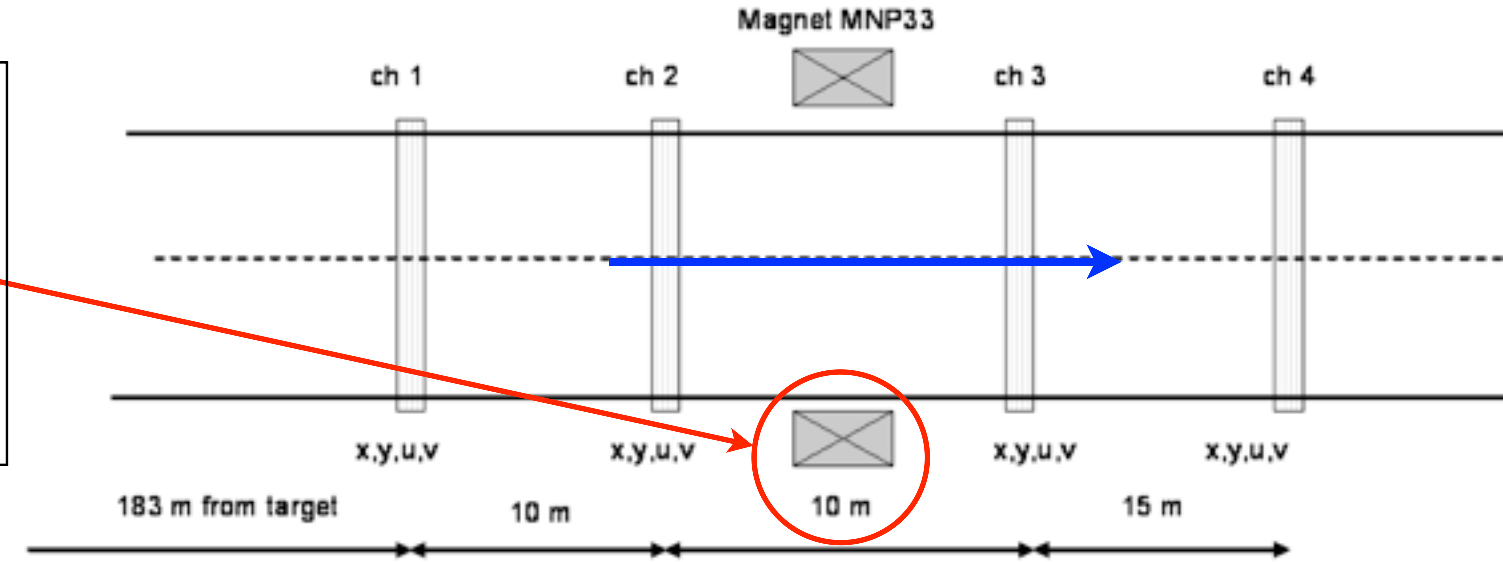
From 2014 run commissioning:

- the time resolution of few ns was reached: mandatory to reduce to a minimum level random vetoes while keeping a high level of efficiency in detecting K inelastic interactions

Tracking System: Pion spectrometer

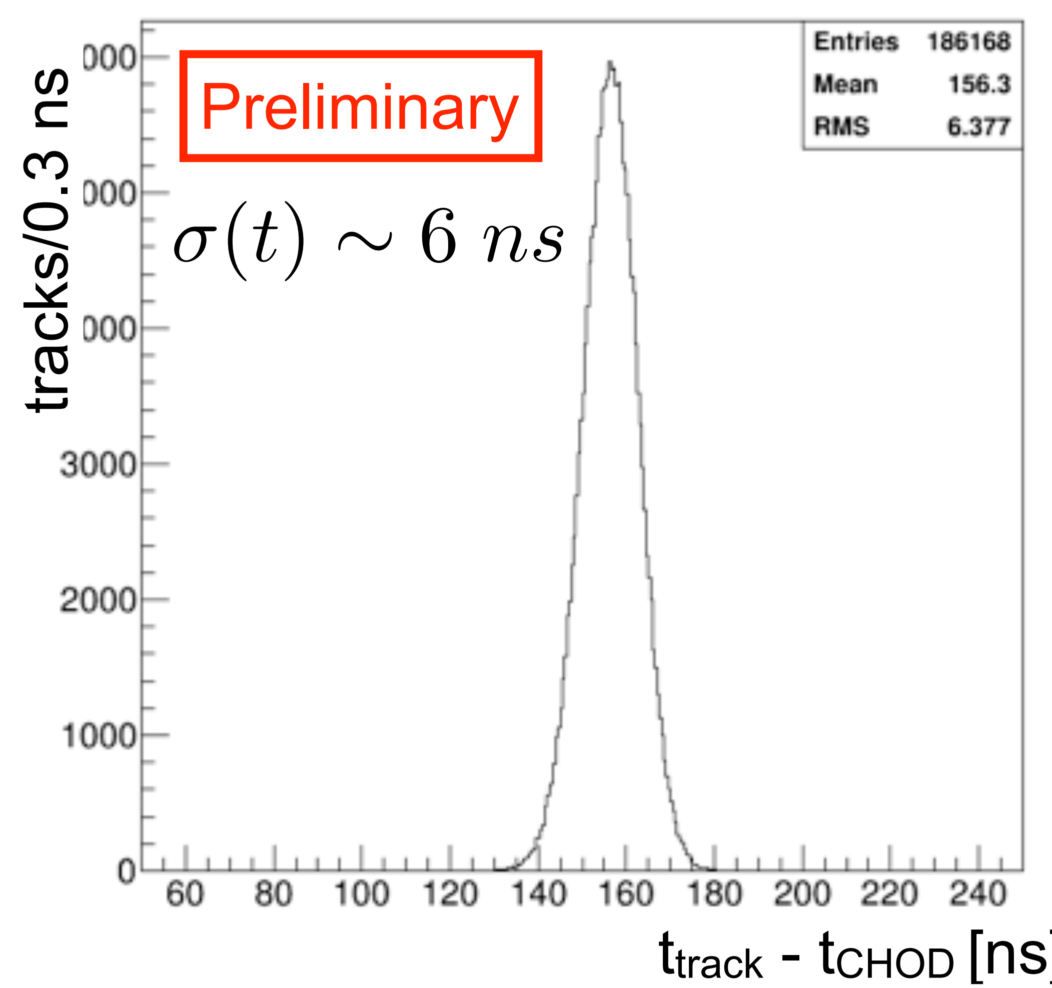
Momentum and direction of secondary charged particle measurement

4 chambers in vacuum, 7168 STRAW tubes with ⊘1cm, 4 layers per chamber (< 0.5 X0). Magnet after the 2nd STRAW chamber provides a 270 MeV/c momentum kick in the horizontal plane.



Expected performance:
σ(p)/p ~ 1%
and spatial resolution 130 μm

Detector fully commissioned in 2014 run



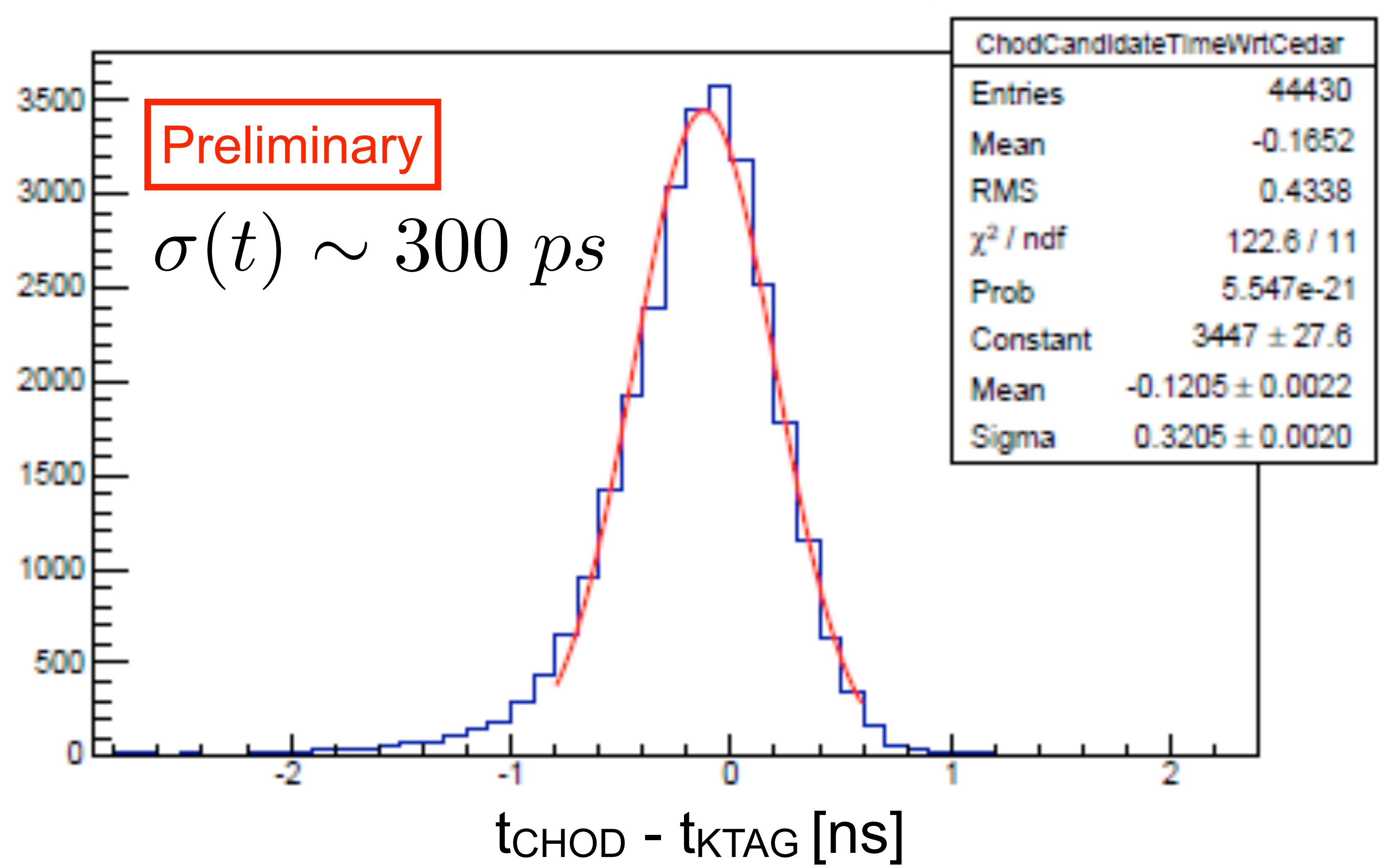
Pion Timing: CHOD

Secondary charged track fast detection and timing for trigger

Fast scintillator system covering the acceptance. Charged HODoscope to detect tracks with precise measurements of the arrival time and impact point, to provide a fast signal to drive the trigger and the data acquisition. Inherited from NA48

Array of horizontal and vertical scintillator slabs

From 2014 run commissioning : Preliminary time resolution measured for tracks has been found to be much better than 0.5 ns after corrections.

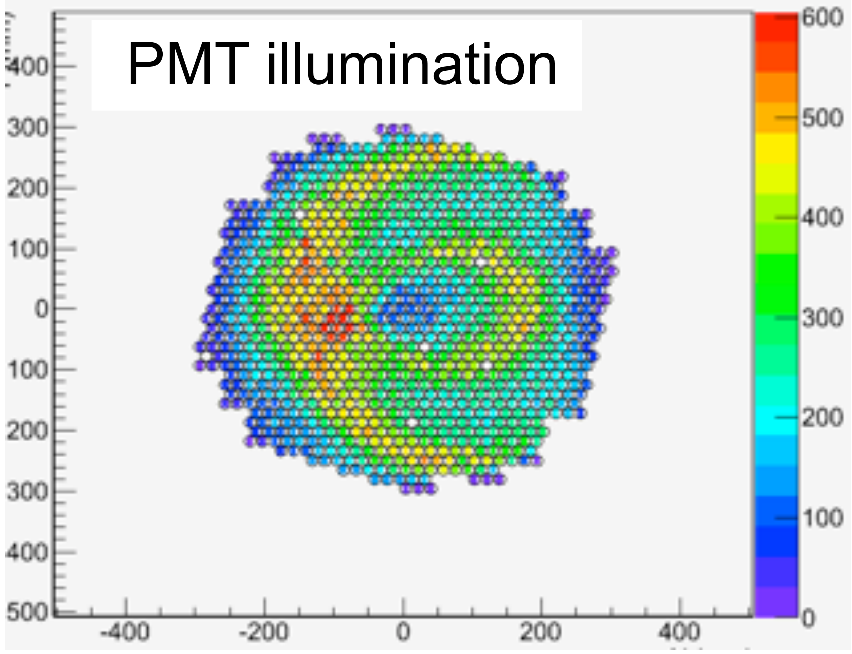


Particle ID detector: RICH

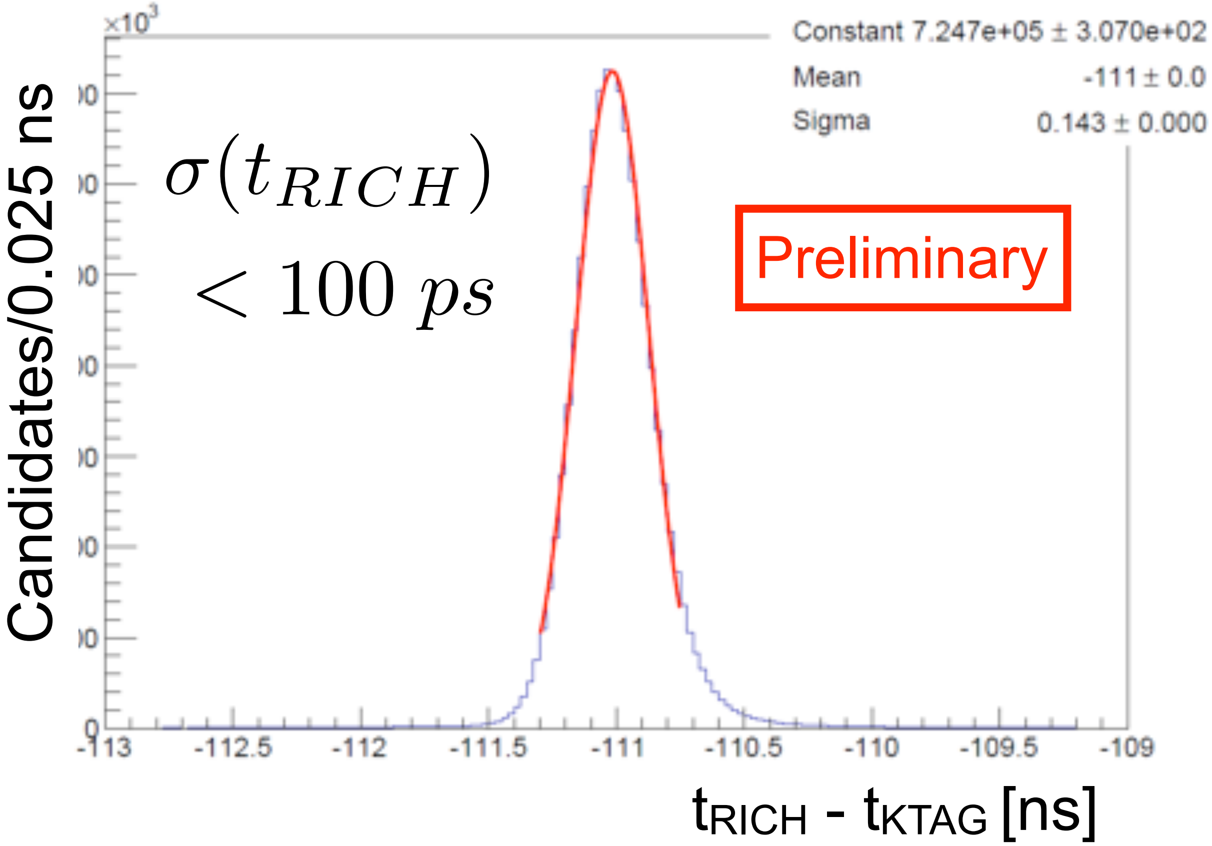
Secondary charged particle identification

The Ring Imaging CHerenkov detector is needed to suppress the μ+ and to measure the π+ crossing time.
Expected performance:
-μ/π separation at 15÷35 GeV ~ 10^{-2}
-particle crossing time resolution < 100 ps

17 m long tank filled with neon gas at atmospheric pressure. Downstream end: mosaic of 20 spherical mirrors. Upstream end: ~2000 PMTs. Internal Al beam pipe keep the beam particles in vacuum.



Fully commissioned: event time resolution ~70 ps

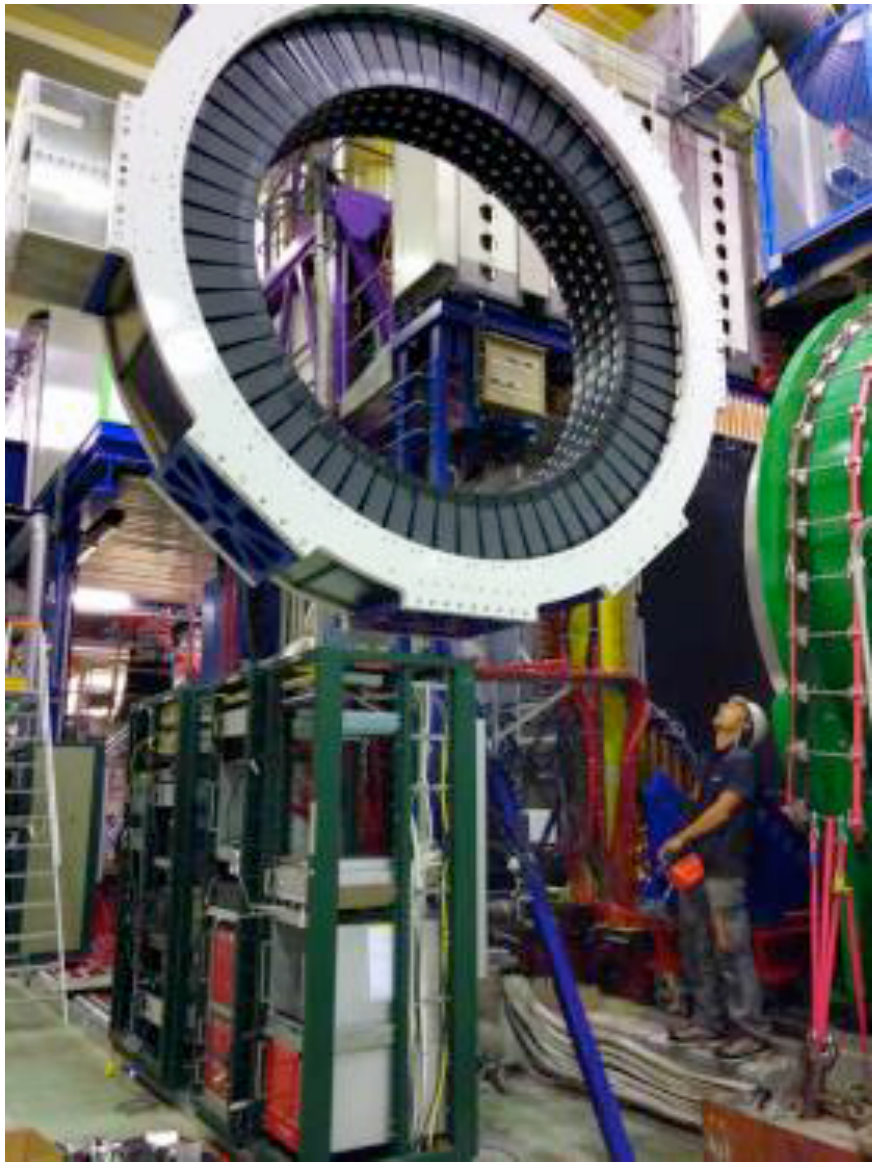


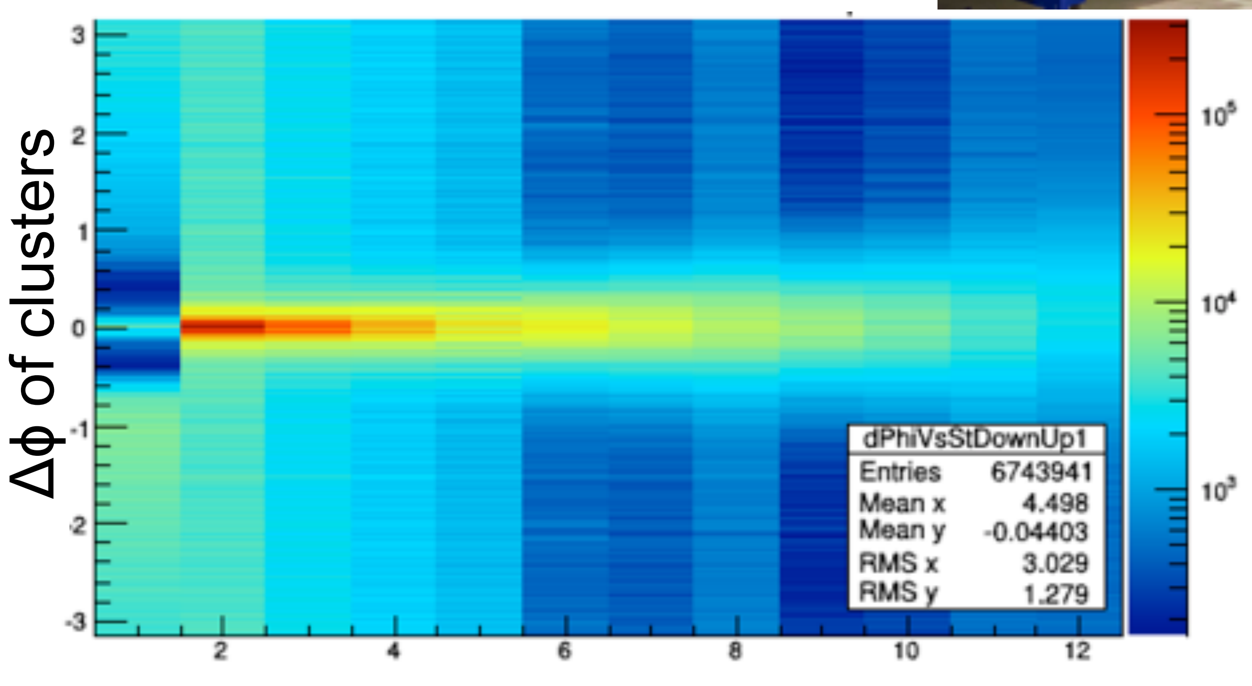
Large Angle Photon Vetoes: LAV

12 photon veto stations (11 in vacuum) covering 8.5 <θ <50 mrad

Lead glass crystals with attached PMTs. Each LAV station is made of 4 or 5 rings of crystals.

Expected performance:
10^{-3} to 10^{-4} inefficiency on γ down to 150 MeV



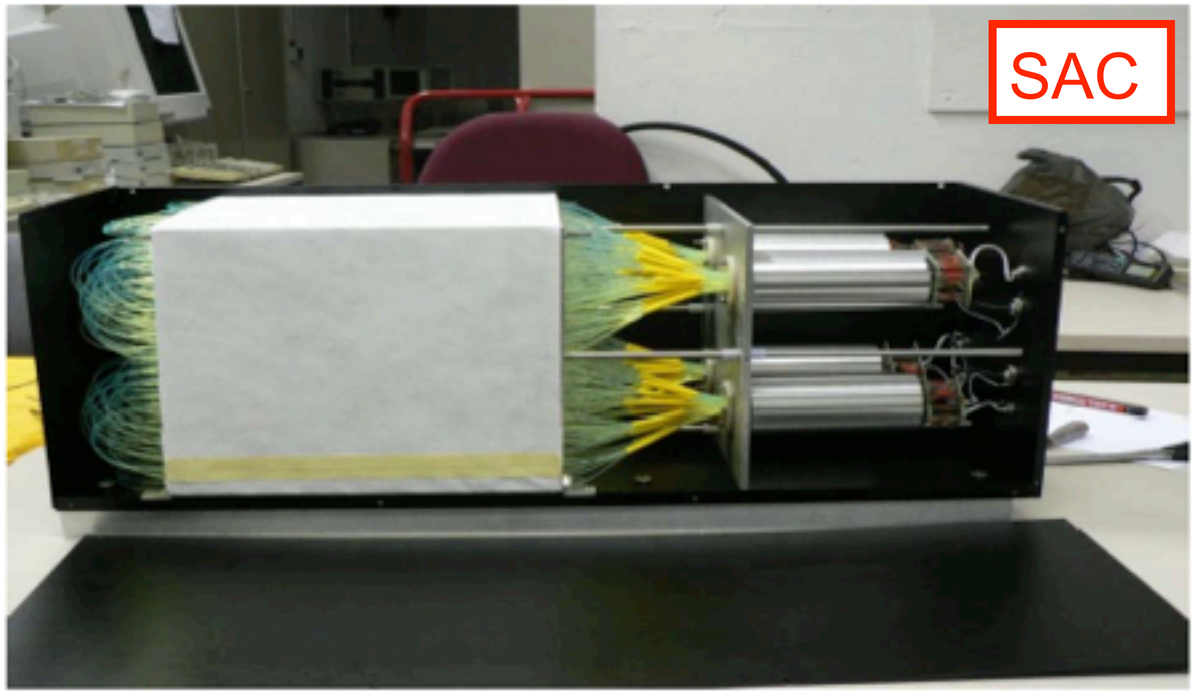


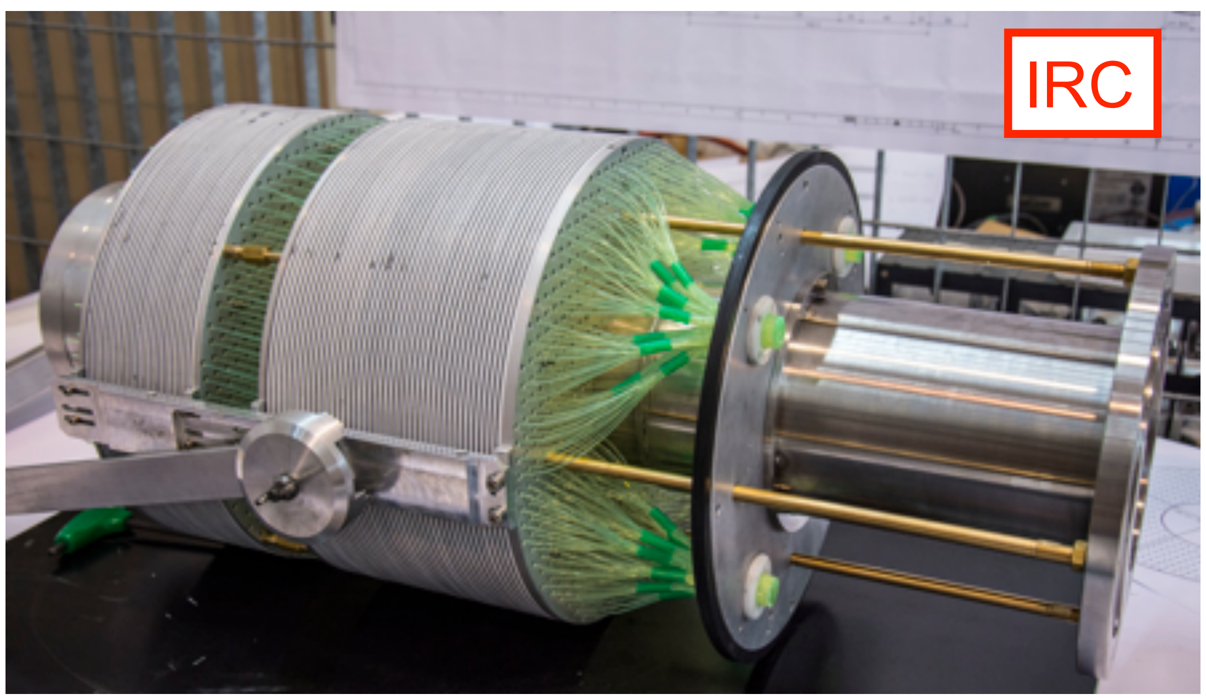
Tracks from halo muons crossing many stations

Fully commissioned:
- efficiency under evaluation
- time resolution ~ 1 ns

Small Angle Photon Vetoes: IRC & SAC

Vetoing photons emitted at angles less than 1 mrad.

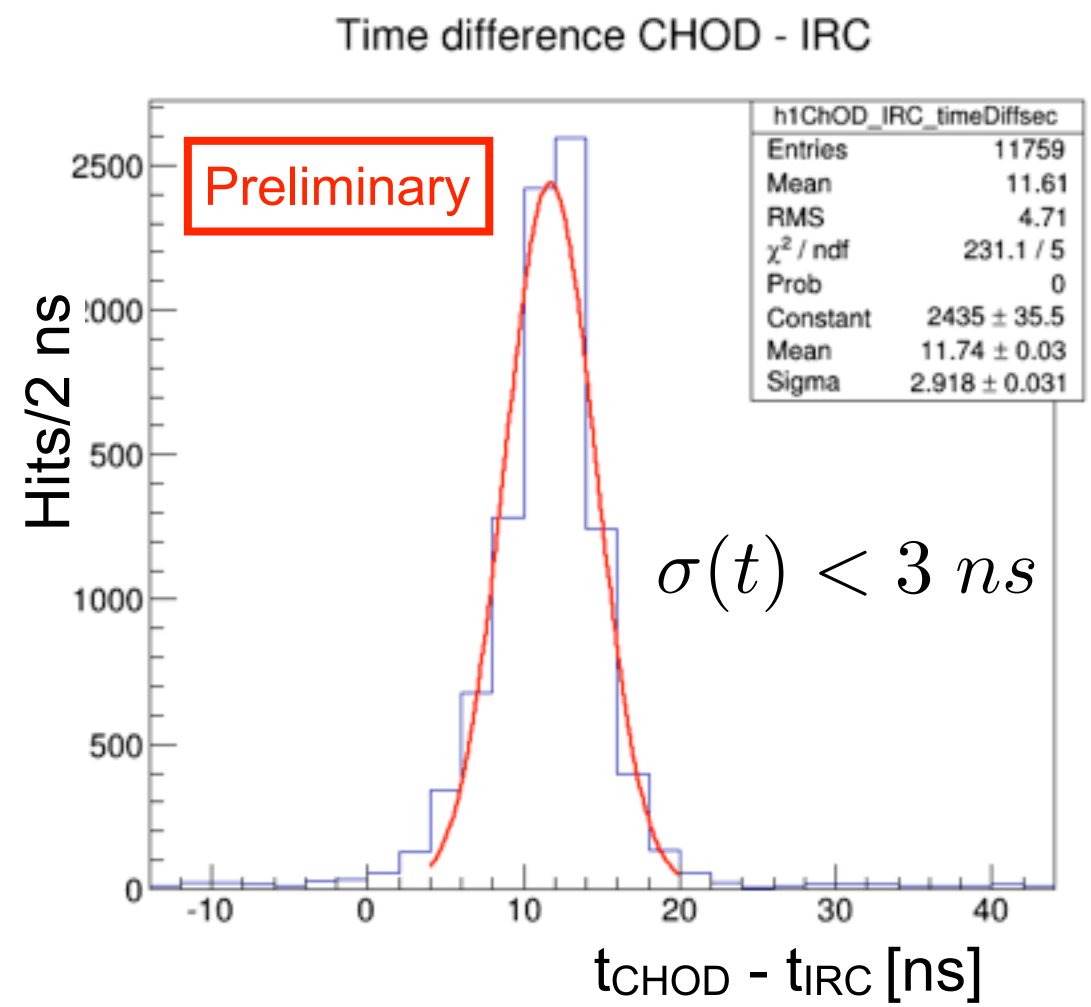




Both commissioned in 2014 run

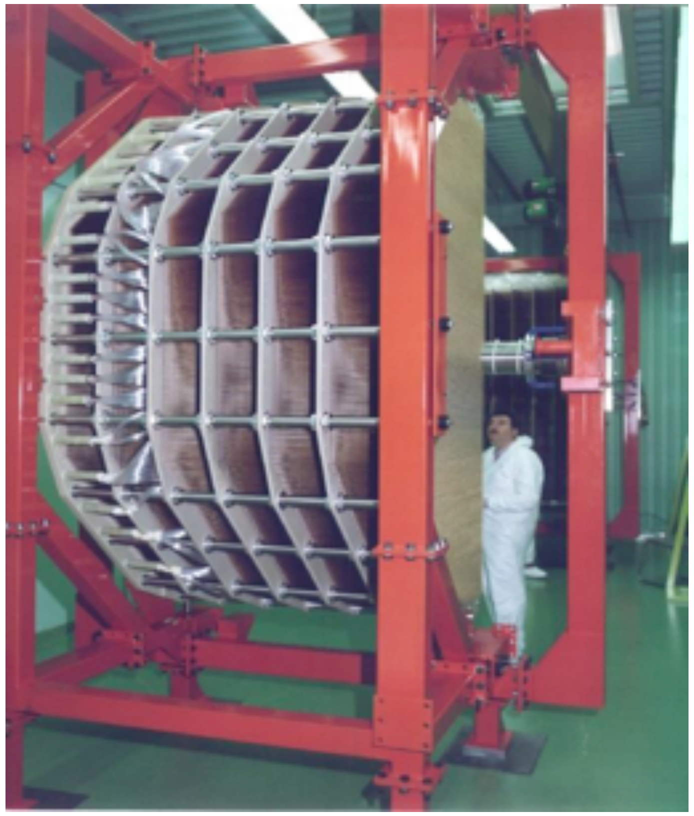
Inner Radius (IRC)
and Small Angle (SAC) calorimeters
- 10^{-4} inefficiency for > 1 GeV photons

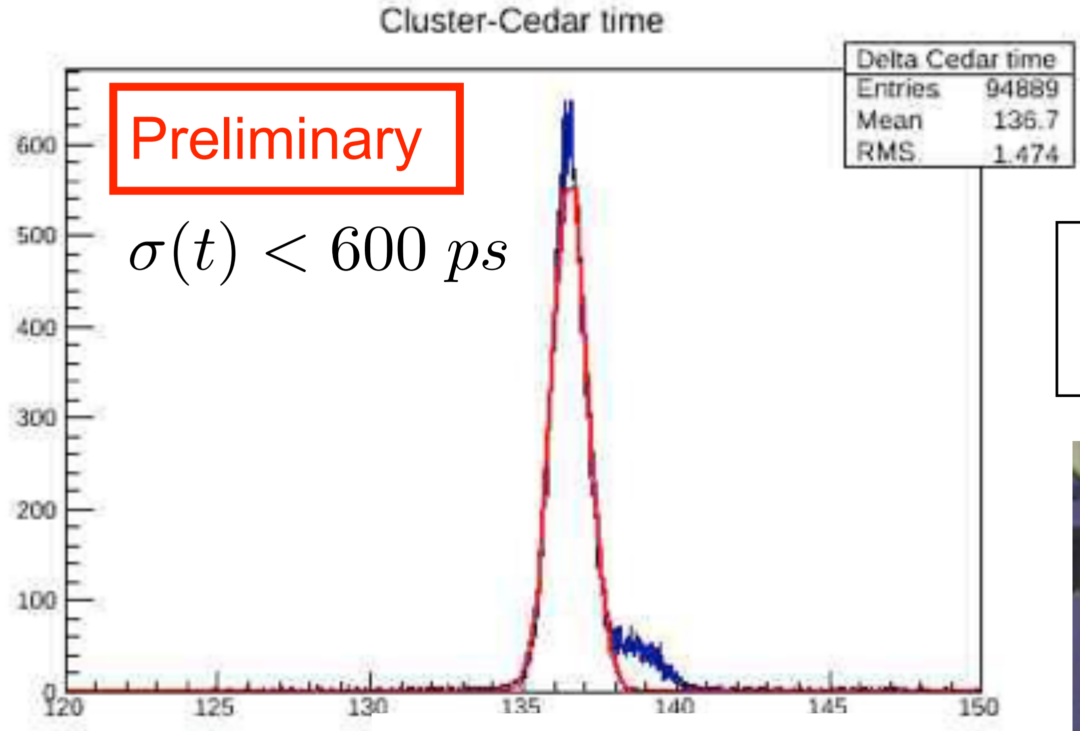
- Lead and plastic scintillator plates
- Electromagnetic showers detected through Shashlik calorimeters



Particle ID: LKr Calorimeter

Photon veto covering $1 < \theta < 8.5$ mrad

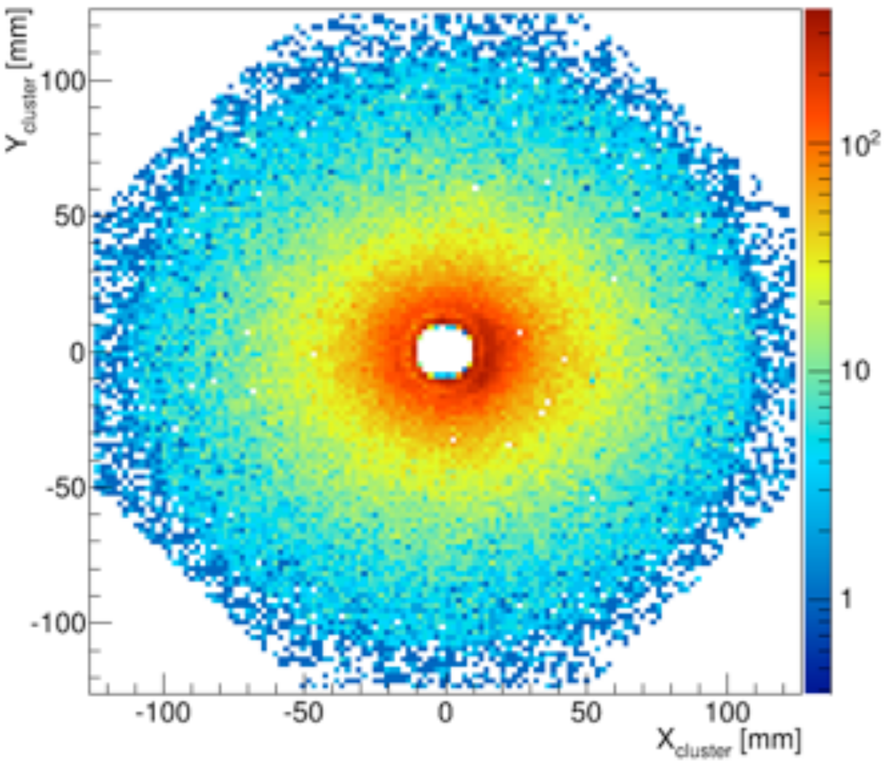




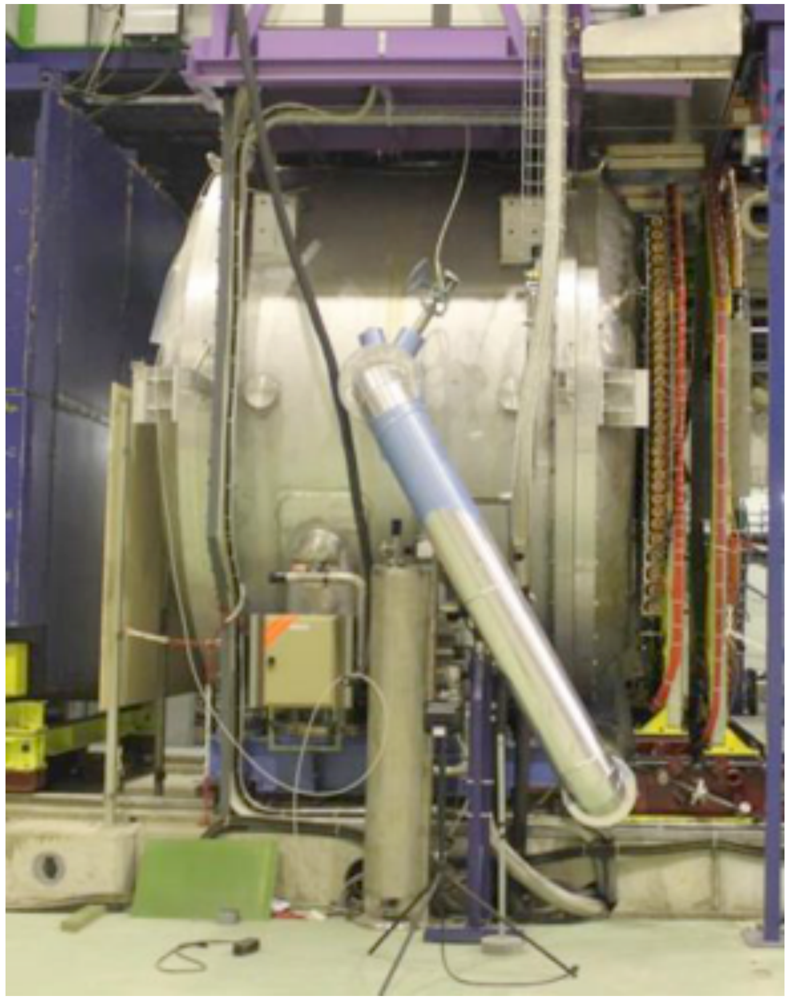
Inherited from NA48, and equipped with new readout electronics

Ionization chamber + liquid Krypton, 2x2 cm² cells.

LKr cells illumination:

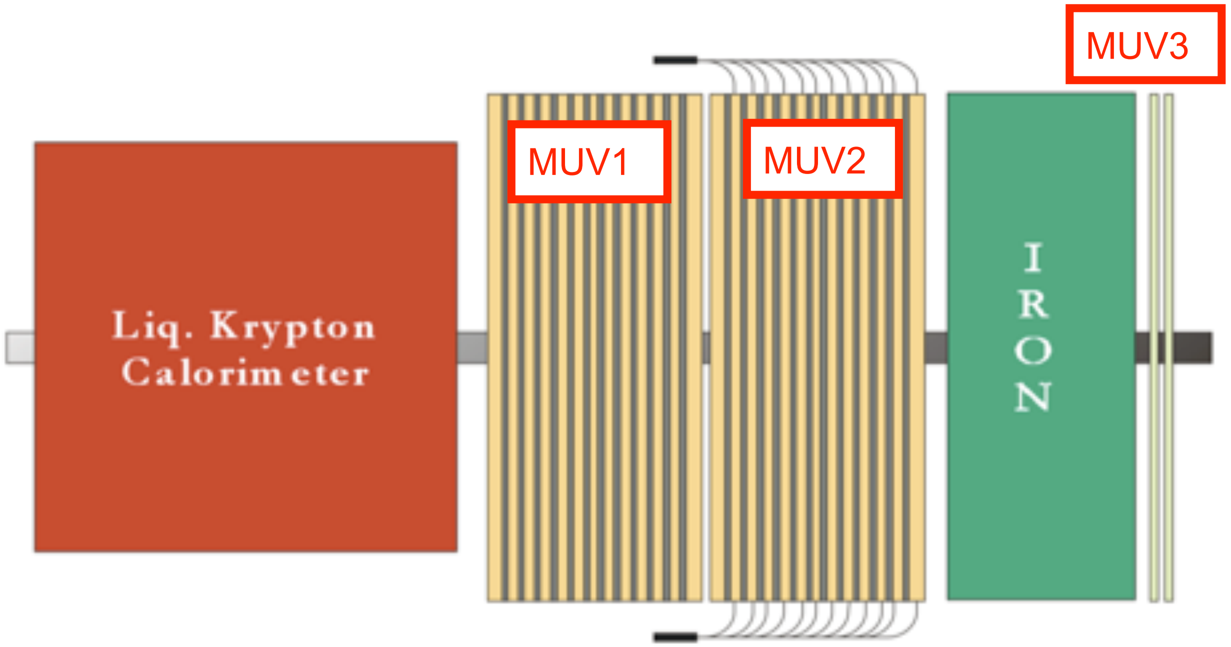


- Shower time resolution ~500ps
- Space resolution 1mm
- inefficiency < 10^{-5} for photon energies > 10 GeV



Particle ID detector: Muon Veto (MUV)

MUon Veto detector is essential to suppress muons from kaon decays



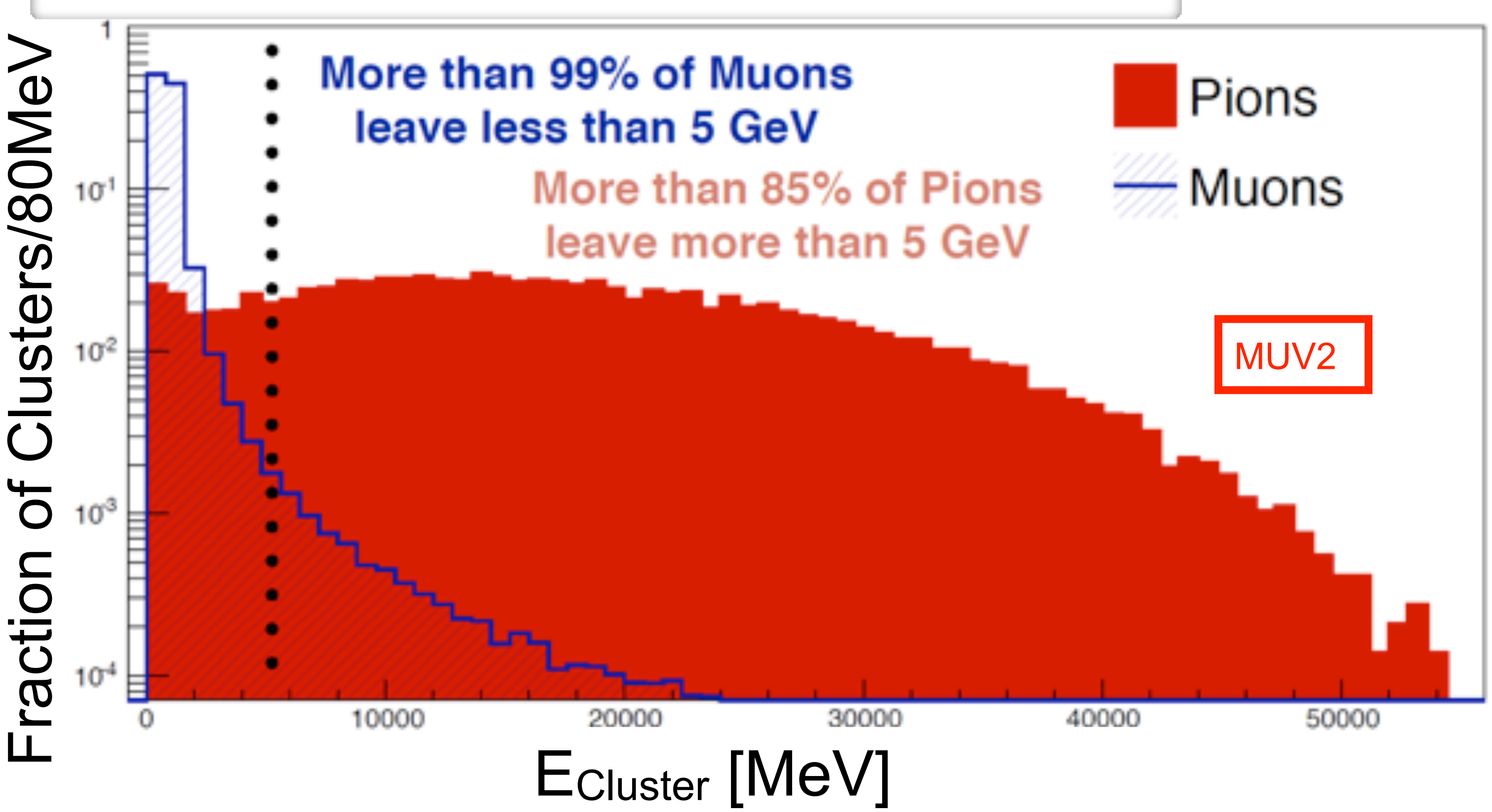
MUV1 and MUV2: hadron calorimeters

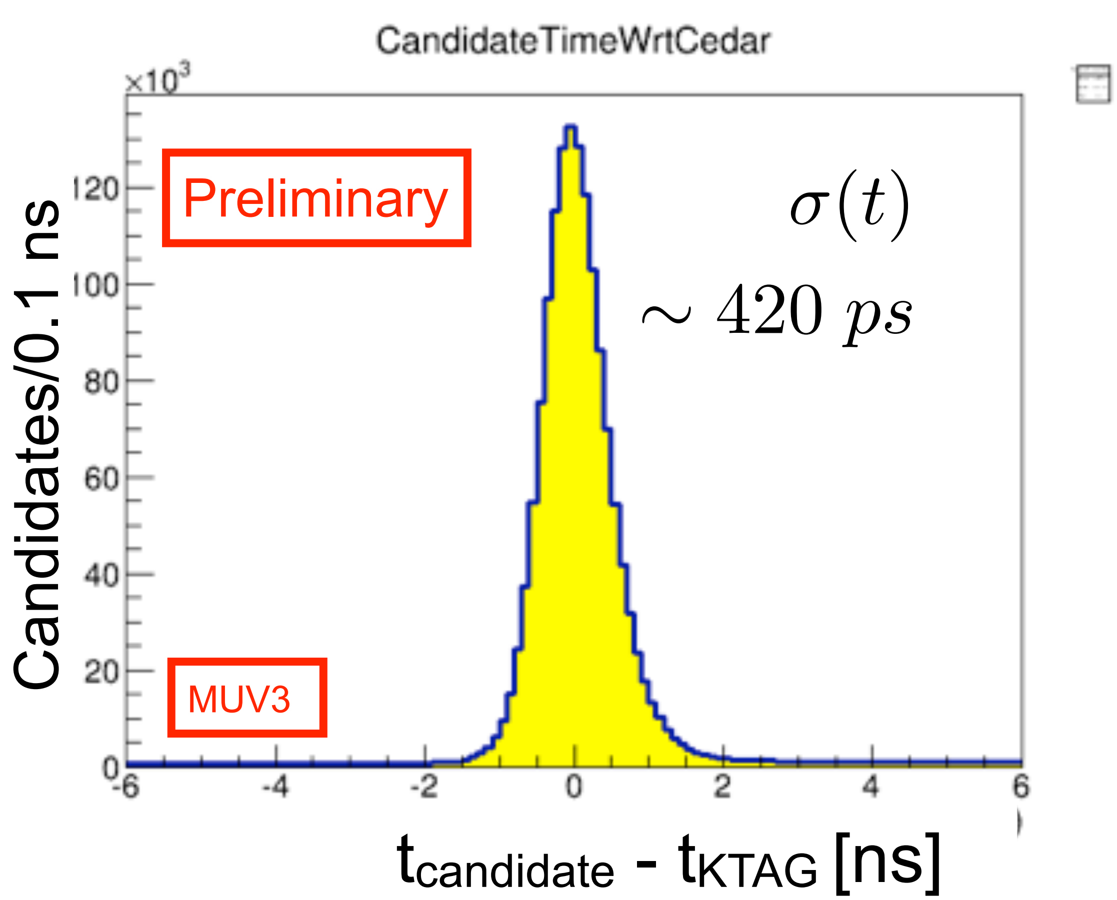
2 modules of iron-scintillator plate sandwiches

MUV3: fast μ-veto, efficient non-showering μ detection used in the hardware trigger level

1 plane of 148 5cm thick scintillator tiles, each readout by 2 PMTs

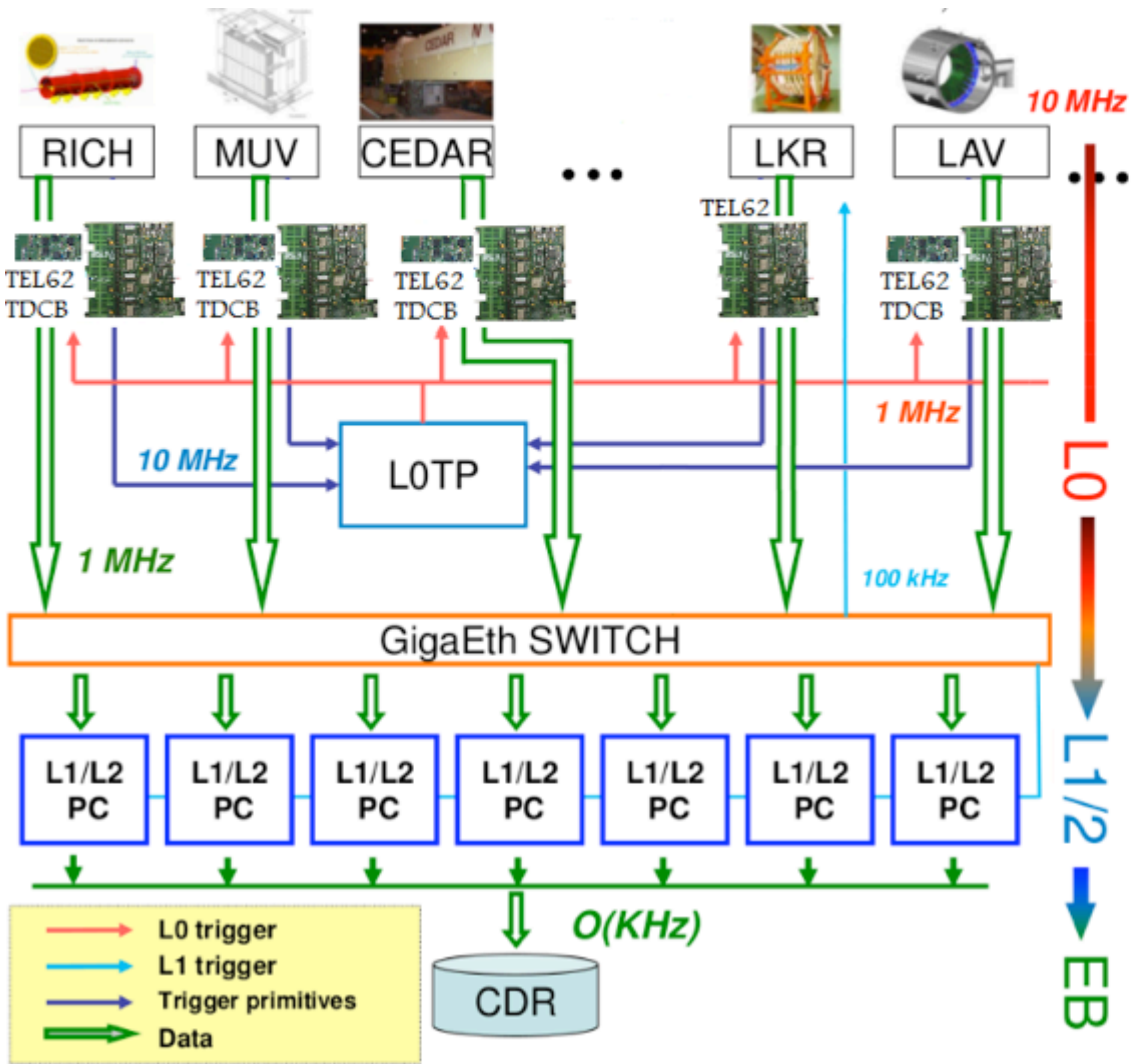
Preliminary cluster reconstruction





Trigger and Data acquisition

Na62 trigger is broken into 3 stages: L0, L1, L2



L0:

RICH & CHOD & $\overline{\text{MUV}}$ & $\overline{\text{LKr}}$ & $\overline{\text{LAV}}$

Implemented in **hardware** (FPGA)

Rate reduction from 10 to ~ **1 MHz**

L1 & L2:

Software based: programs running on a dedicated PCfarm.

Rate reduction to **~10 kHz**

First look at 2014 Data

About 2 weeks of data has been taken in stable conditions at about 5% of the nominal intensity.

Triggers:
1) $K^+ \rightarrow \pi^+\nu\bar{\nu}$ without photon rejection
2) Minimum bias

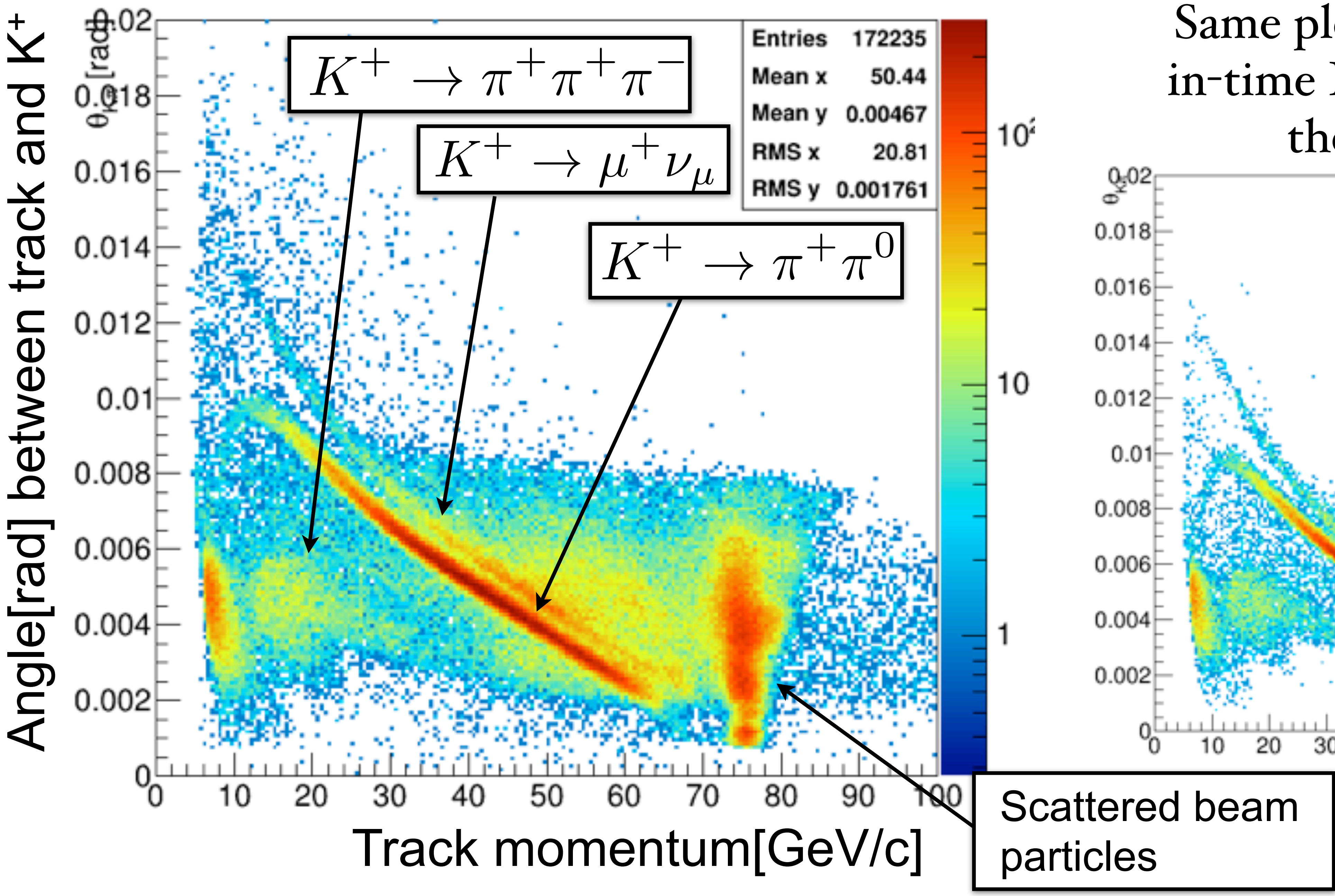
Preliminary conditions:

- No Gigatracker: the K^+ nominal momentum and direction have been assumed
- Pion Spectrometer: 3 of 4 chambers used, very preliminary fitting code to obtain the momentum of the secondary track candidates (no detailed field map yet)
- K identification (KTAG): preliminary time alignment
- LKr Calorimeter: preliminary calibration
- RICH: no offline mirror alignment
- Photon veto not yet applied
- Muon veto applied online by triggering on hadronic energy (inefficiency 1%)

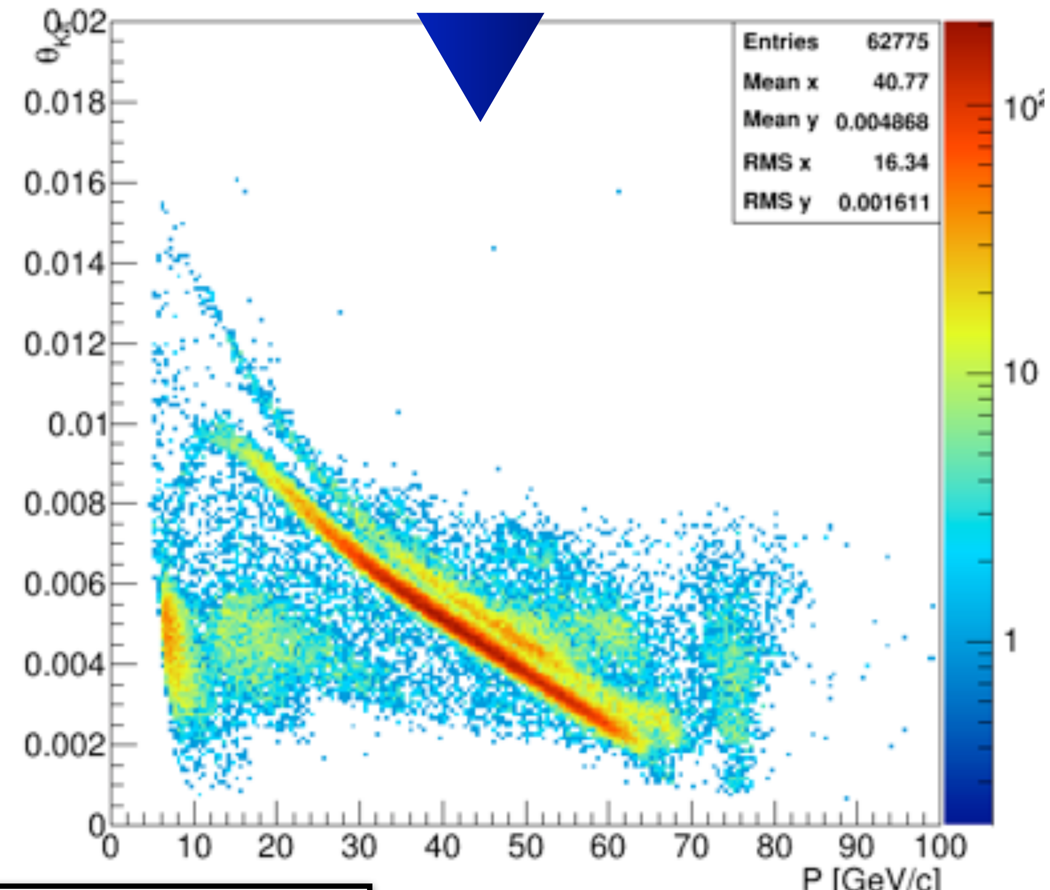
Single track analysis

< 1% of the total data with $K^+ \rightarrow \pi^+\nu\bar{\nu}$ trigger is shown here

Events with exactly 1 track reconstructed in the Pion spectrometer



Same plot for events with an in-time Kaon candidate from the KTAG: ±2 ns



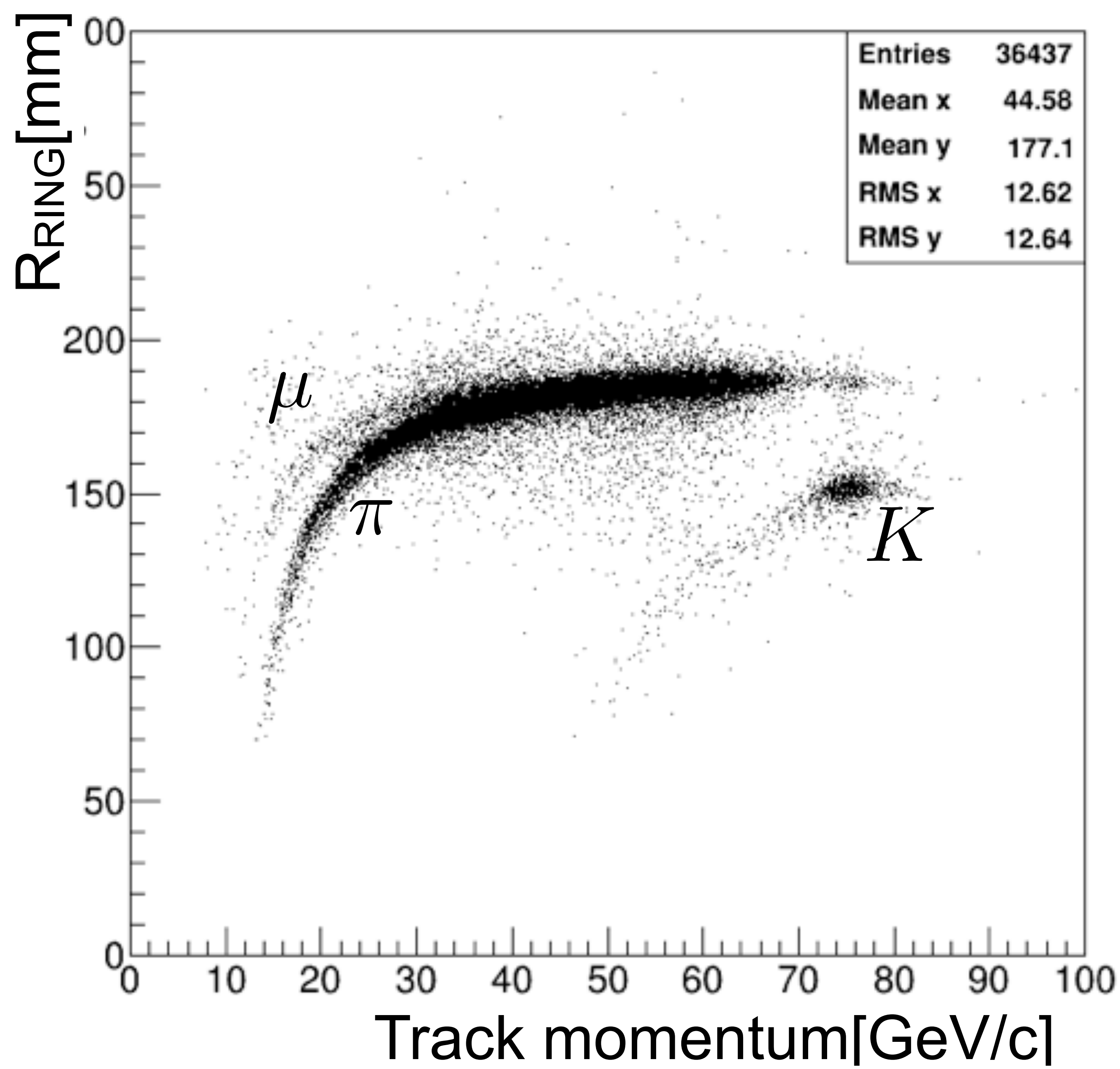
RICH ring matching

The nature of the selected track can be investigated using the RICH

98% of events had at least 1 ring reconstructed

Ring center position provides a measurement of the track slope independent of the spectrometer.

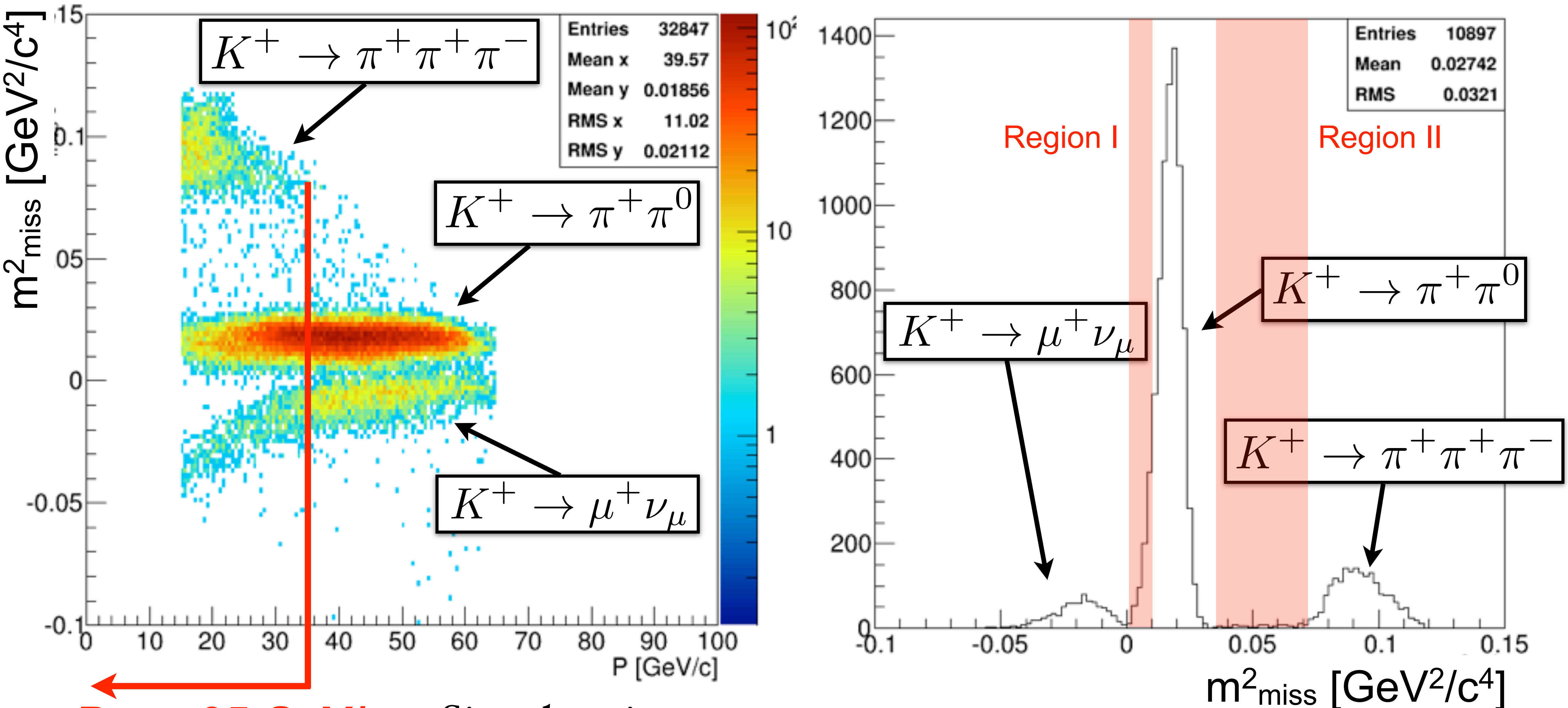
Ring radius Vs particle momentum for events with exactly **one ring matched to a track**



- π and μ can be separated up to 30 GeV/c
- scattered K^+ component from the beam is also present
- positrons hardly seen as suppressed at trigger level (no e.m. energy)

Kinematic variable $m^2_{miss} = (P_k - P_{\pi+})^2$

Distribution of the missing mass as a function of the particle momentum, where $P_{\pi+}$ is the momentum of the particle under the π+ hypothesis.



$P_{\pi+}$ < 35 GeV/c = Signal region
+ Fiducial Volume cut:
105 < Z_{vtx} < 165 m

A factor 4 improvement in the resolution is expected after adding the GTK information

Conclusion

- Kaon Physics is partner of LHC in the search for NP
- The NA62 apparatus is almost completely commissioned
- After 9 years from the proposal,
  NA62 collected data in a first pilot run at the end of 2014
- We are working and ready to do physics
  (2015 run scheduled from July till November) .....and thank you for the attention!!

NA62 COLLABORATION:
Birmingham, BNL, Bratislava, Bristol, Bucharest, CERN, Dubna (JINR), Fairfax, Ferrara, Florence, Frascati, George Mason, Glasgow, Liverpool, Louvain-la-Neuve, Mainz, Merced, Moscow (INR), Naples, Perugia, Pisa, Prague, Protvino (IHEP), Rome I, Rome II, San Luis Potosi, Stanford, Sofia, TRIUMF, Turin, UBC

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