The NA62 Hadron Calorimeter

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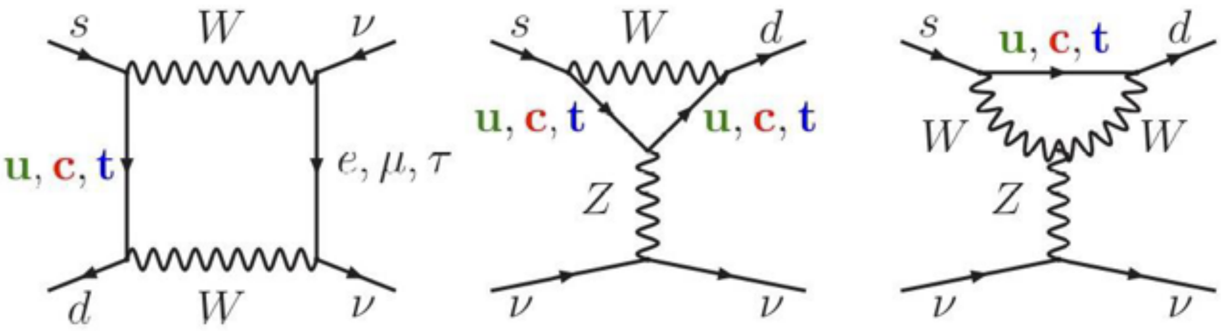
Bundesministerium
für Bildung
und Forschung

The NA62 Experiment

- Fixed Target Experiment
- Located at the North Area of CERN
- Main Goal: $Br(K^+ \rightarrow \pi^+ \nu\bar{\nu})$
  - 10% Precision
  - 100 Events in 2 Years
  - Background below 20%
- 75 GeV/c Secondary Hadron Beam
- Data Taking on going: 2014 (Pilot Run), 2015 – 2018 (Physics Data)

Theoretical Motivation

FCNC loop process, highly suppressed, theoretically very clean



Well calculated inside the Standard Model [A.J. Buras et al., JHEP 1511 (2015) 033]

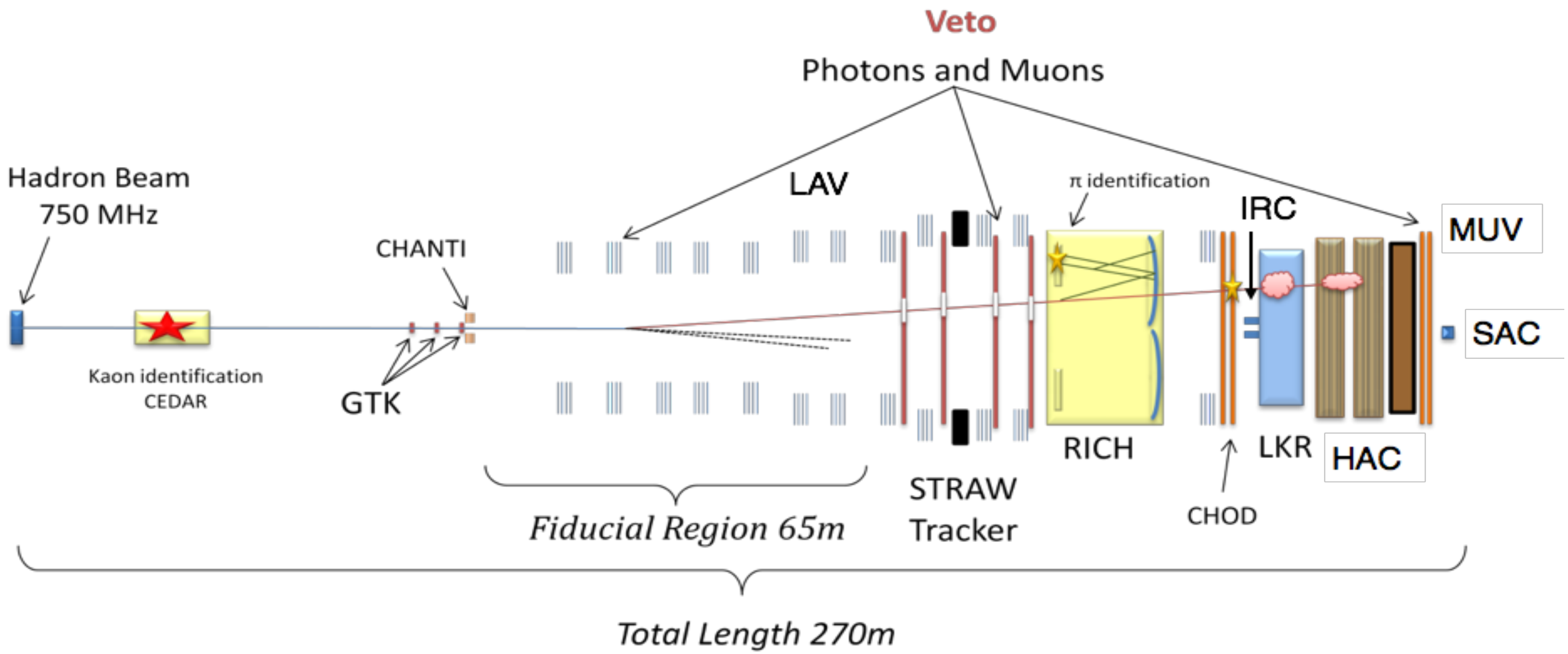
$$Br_{SM}(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = (9.11 \pm 0.72)\times 10^{-11}$$

Previous Measurement (only 7 events) [BNL E787/E949: PRL101 (2008) 191802]

$$Br_{Exp}(K^+ \to \pi^+ \upsilon\bar{\upsilon}) = \left(17.3 \pm^{11.5}_{10.5}\right)\times 10^{-11}$$

Any deviation from the SM prediction is a hint of new physics

The NA62 Strategy and Apparatus



SPS Protons

400 GeV

10^{12} protons/s

3.5 s spill

Beryllium Target

Secondary Beam

75 GeV,

$\Delta p/p \approx 1\%$

K (6%), p (23%), π (70%)

750 MHz

Kaon Decays

~5MHz

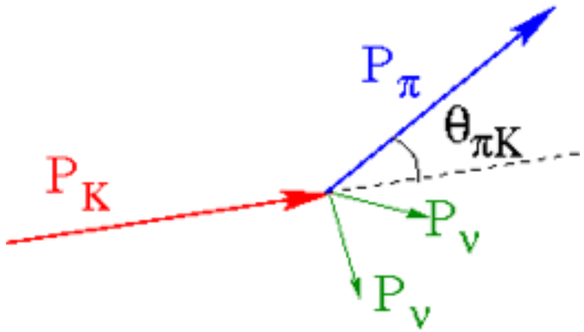
4.5 x 10^{12} per year

10^{-6} mbar vacuum

The NA62 Strategy and Apparatus

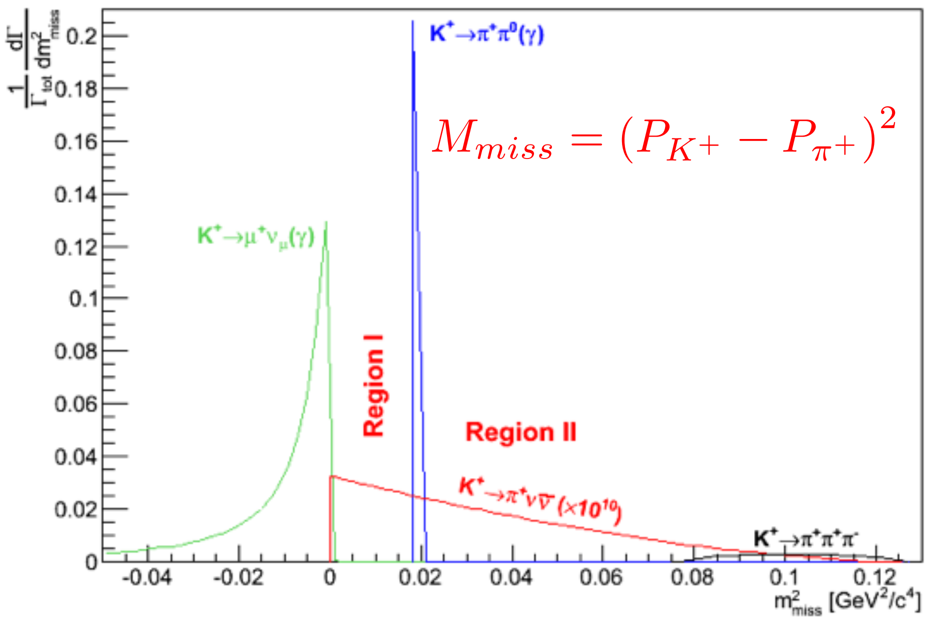
Signal:

- ✓ One beam K^+
- ✓ One π^+
- ✓ Nothing else



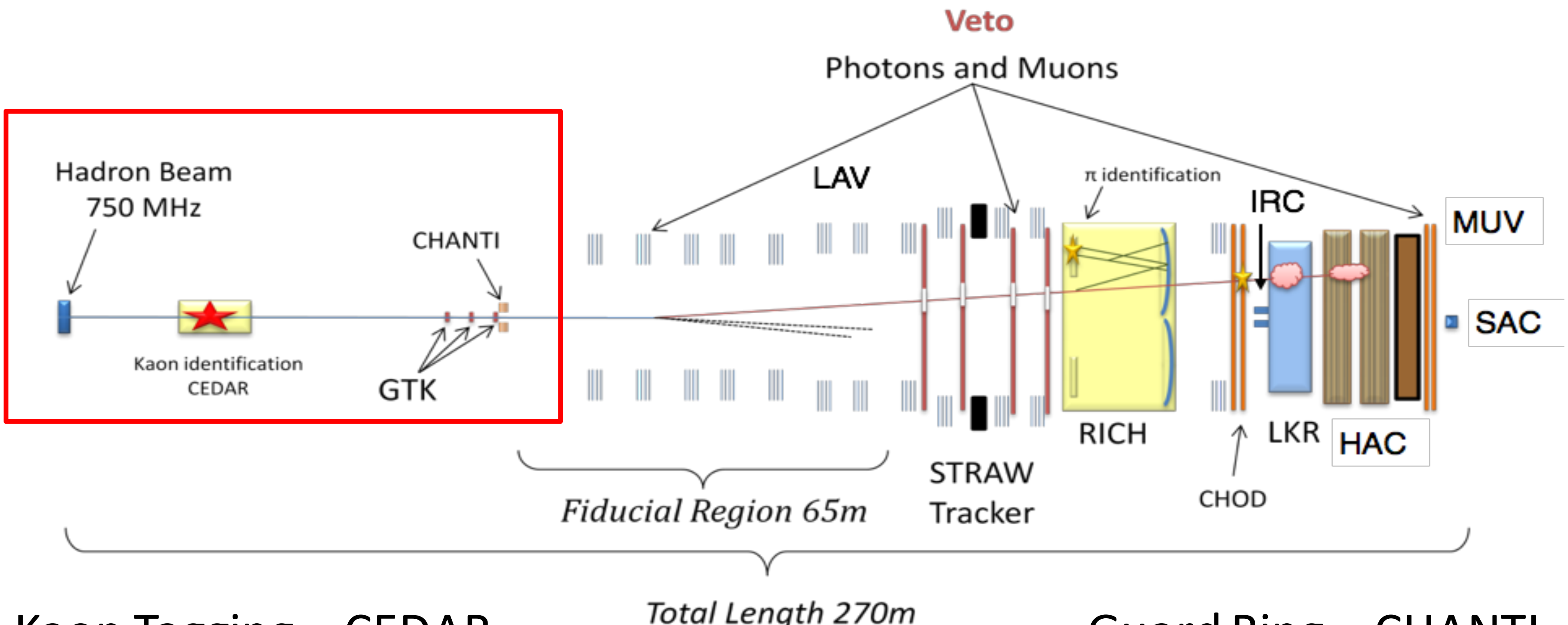
Background:

- x Beam activity
- x Other K^+ decays



- ➢ Precise kinematic reconstruction
- ➢ Hermetic Photon Detection
- ➢ Efficient PID for pion/muon discrimination

The NA62 Strategy and Apparatus



Kaon Tagging – CEDAR

45 MHz rate

time: 100 ps

Kaon Tracking – GTK

time: ≈ 200 ps

momentum: dp/p < 0.4%

direction : ≈ 0.016 mrad

Guard Ring – CHANTI

To detect beam interaction within the last GTK station

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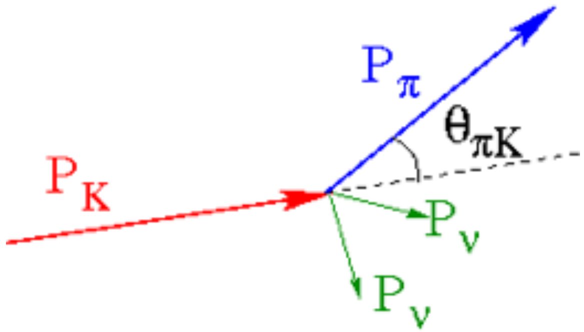

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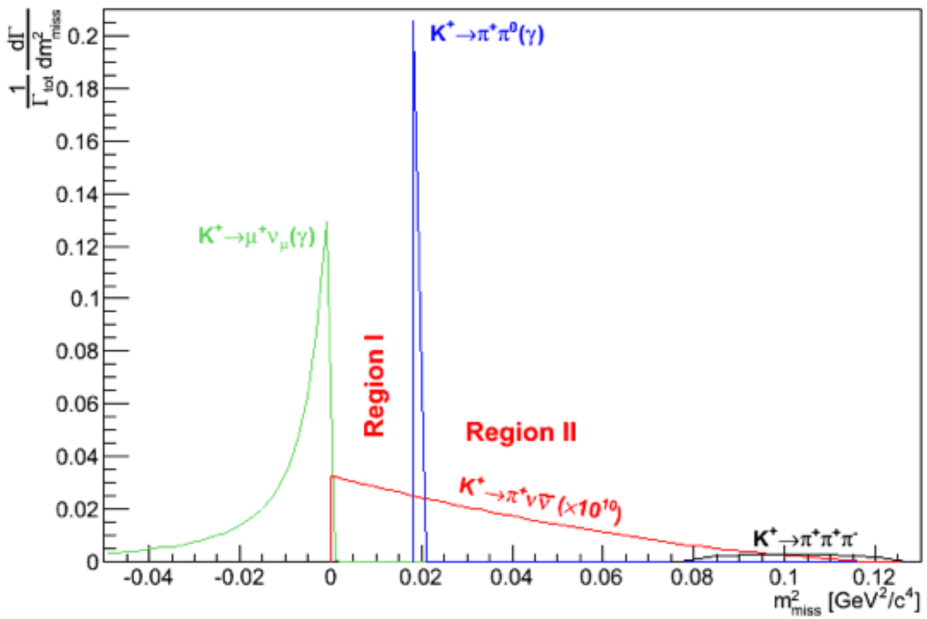

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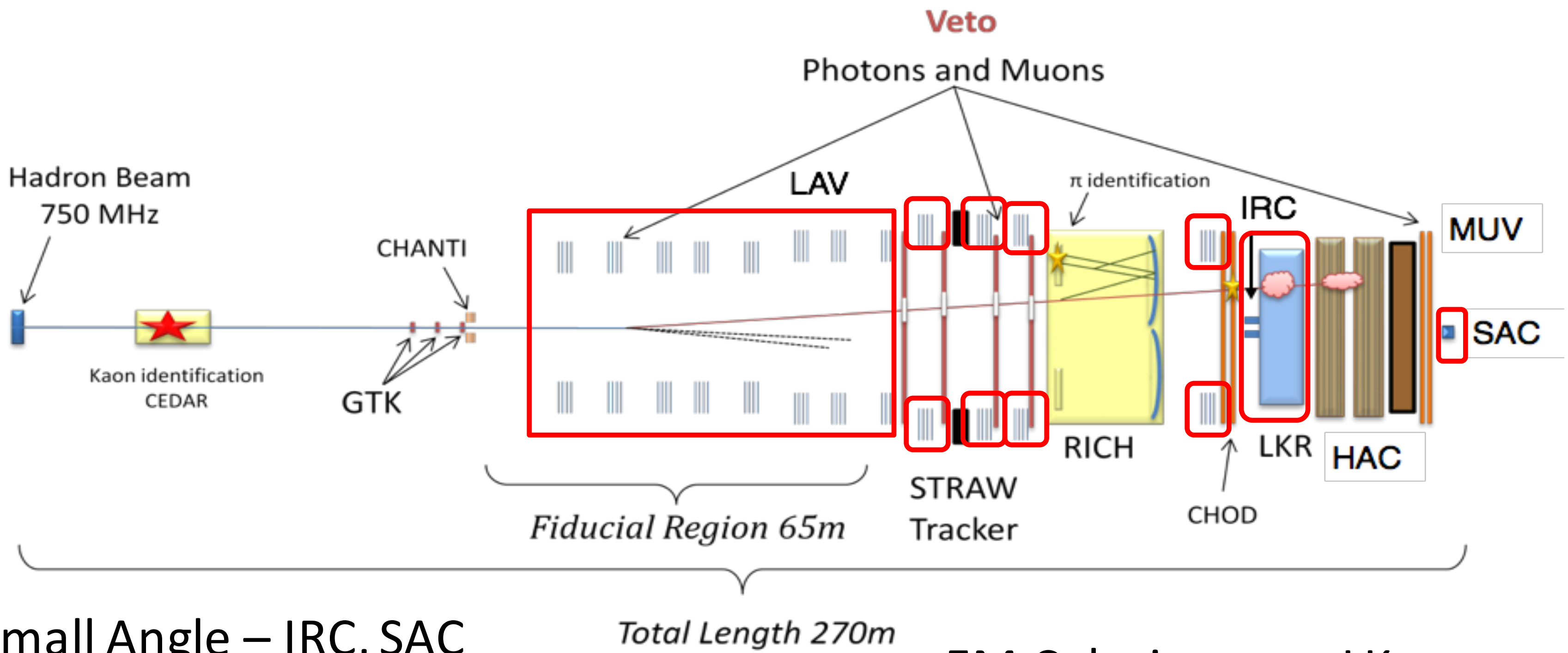
The NA62 Strategy and Apparatus



Small Angle – IRC, SAC

coverage: < 1 mrad

Large Angle – LAV

coverage: 8.5 – 50 mrad

time: ≈ 1 ns

EM Calorimeter – LKr

coverage: 1 – 8.5 mrad

time: ≈300ps

resolution: $\frac{\sigma_E}{E}(20\ GeV) < 1\%$

The NA62 Strategy and Apparatus

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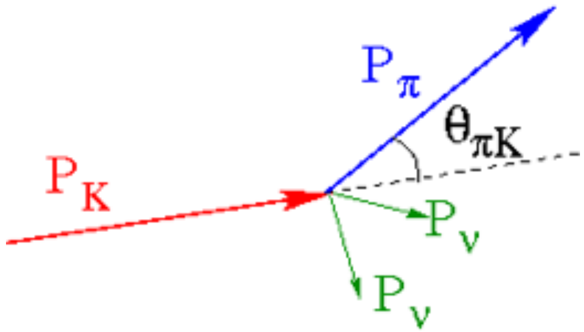
- ✓ One π^+
- ✓ Nothing else



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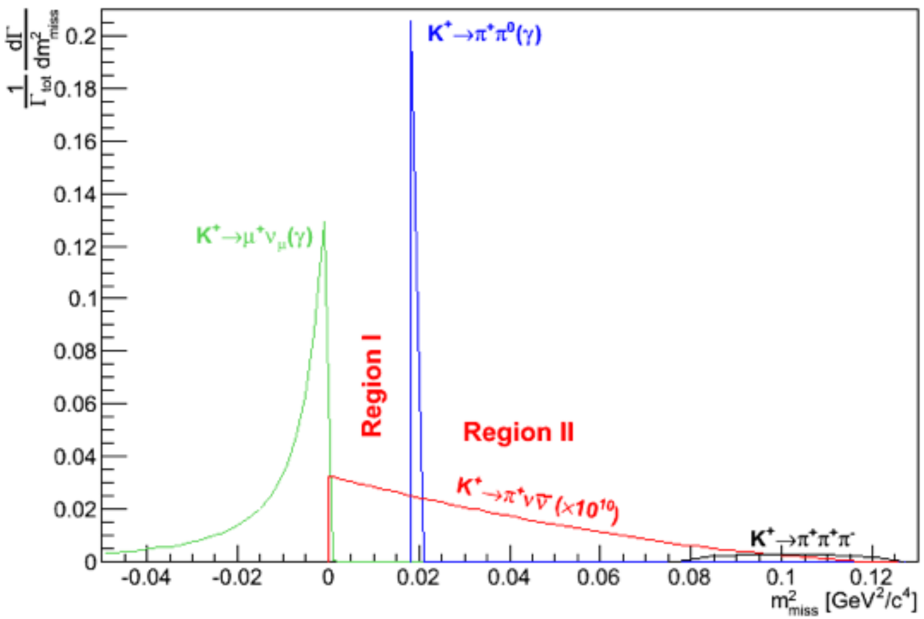

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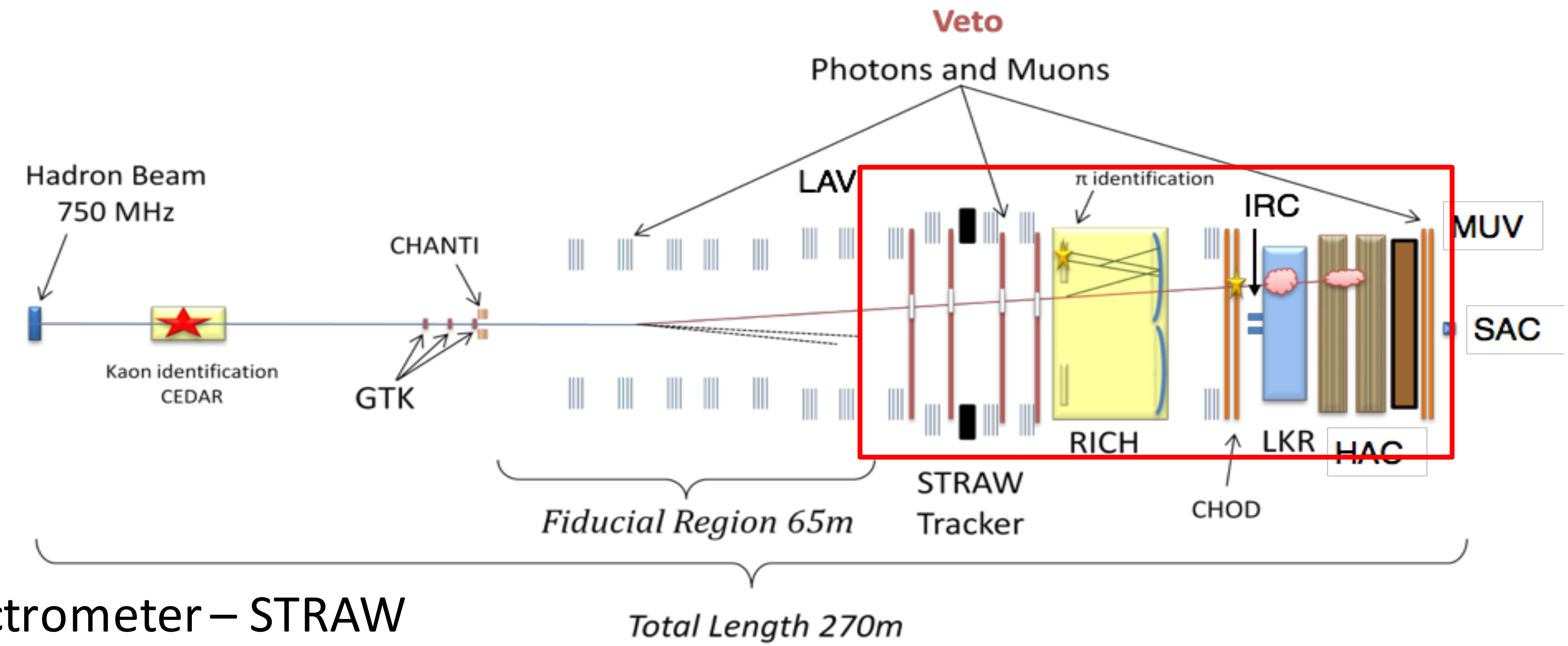
The NA62 Strategy and Apparatus



Spectrometer – STRAW

momentum: dp/p < 0.33%

direction : ≈10 mrad

extracted vertex: ≈1mm

Calorimeters – LKr, HAC

Hadronic Shower Reconstruction

muon rejection: 10^5

RICH

time: <100ps

muon rejection: 100

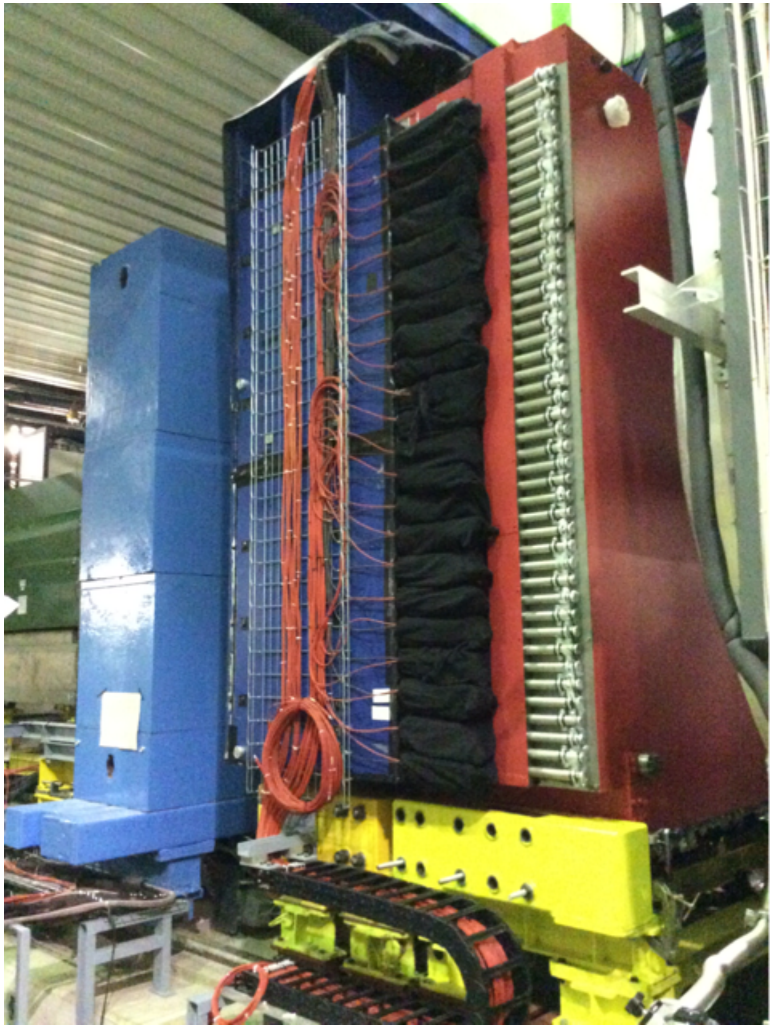
PID

Fast Muon Veto

time: ≈ 100ps

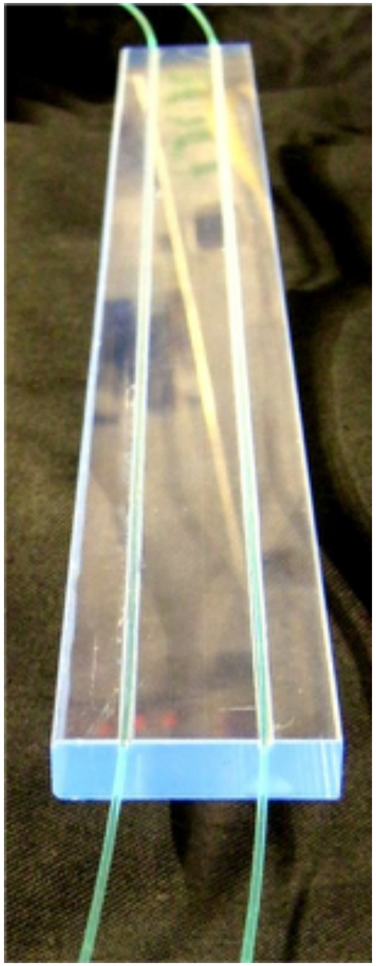
Hadron Calorimeter

- Part of the NA62 PID system
- Sampling Calorimeter, Alternated Iron – Scintillator planes
- 2 Modules:
  - Front (MUV1)
    - 176 Readout Channel
    - Readout with WLS fibers
  - Back (MUV2)
    - 88 Readout Channels
    - Direct readout via light guides
- More than 7 Interaction Lengths
- Flash ADC Readout common to both EM and HAC Calorimeters (40 MHz)



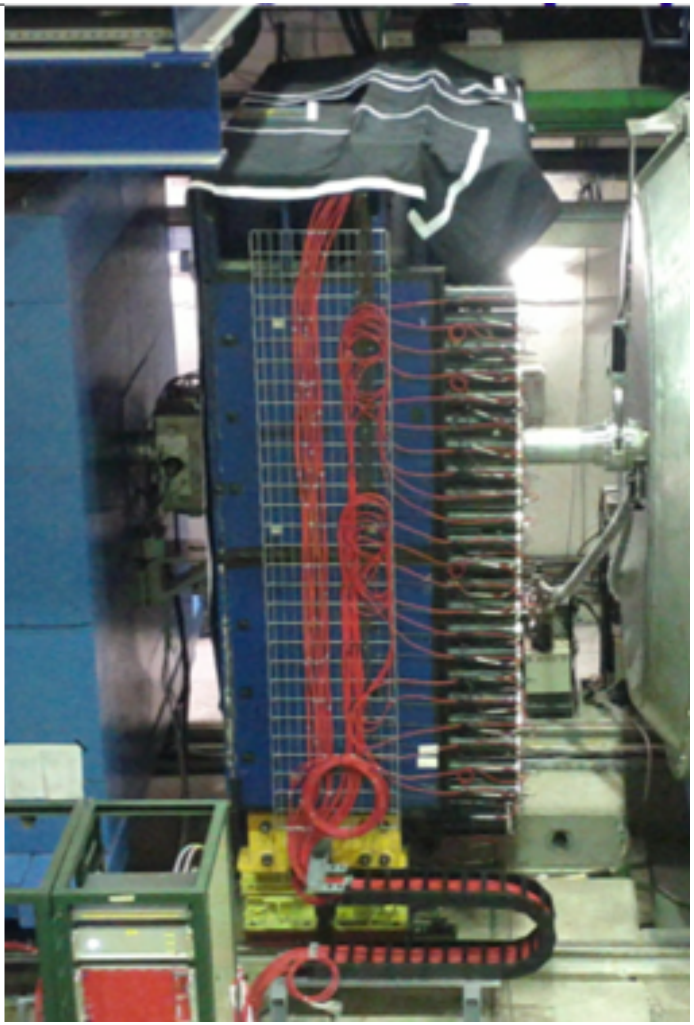
MUV1

- 1220 Scintillators in 23 Layers
- Thickness: 0.9 cm
- Maximum Length: 2.62 m
- Transversal Segmentation: 6 cm
- 2 Kuraray Y11 WLS fibers per scintillator
- Readout on both the fiber ends



MUV2

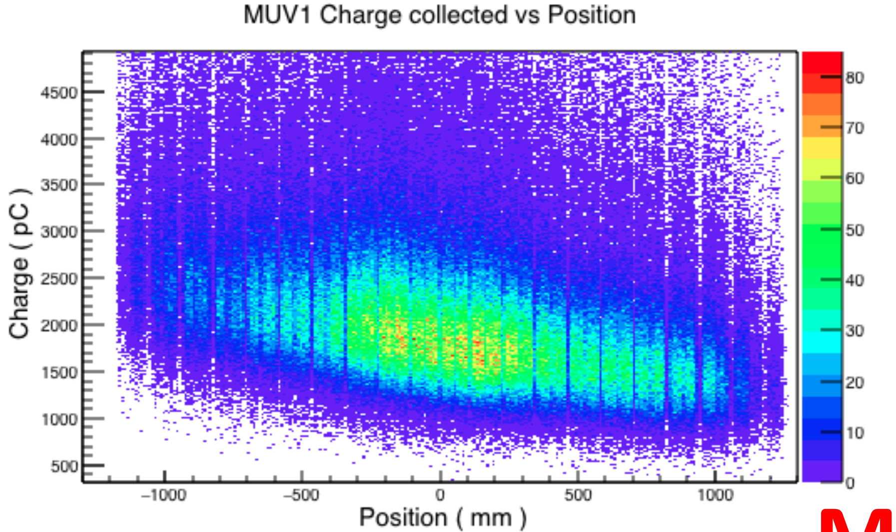
- NA48 HAC Front Module
- 1056 Scintillators in 24 Layers
- Thickness: 0.45 cm
- Maximum Length: 1.31 m
- Transversal Segmentation: 12 cm
- Direct Readout via Light Guides

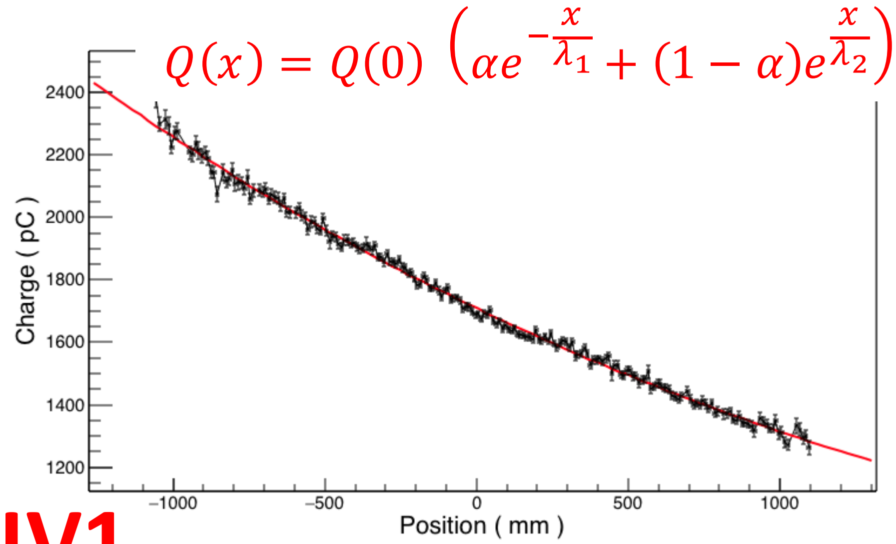


Channel Response Equalization

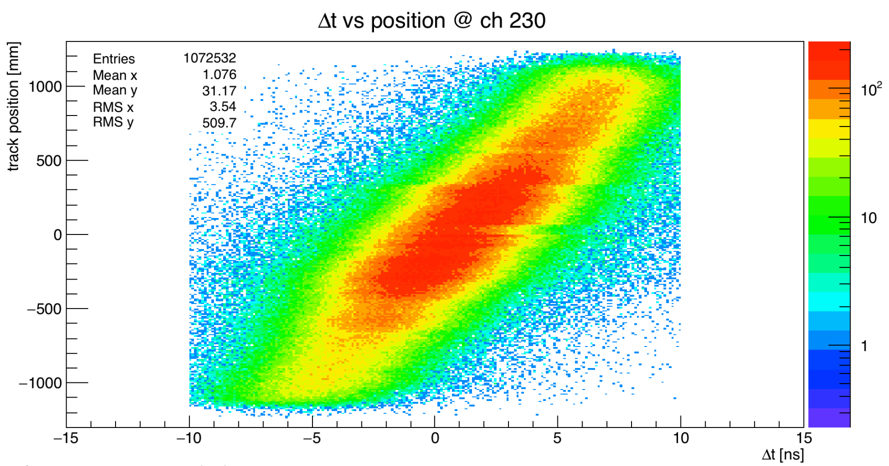
- Dedicated runs with muon beam
- First Equalization of Photomultipliers gain by changing the supply High Voltage
- Fine Equalization of single channel response applied offline
- Determination of Attenuation and Timing Corrections
- Cluster Energy Calibration

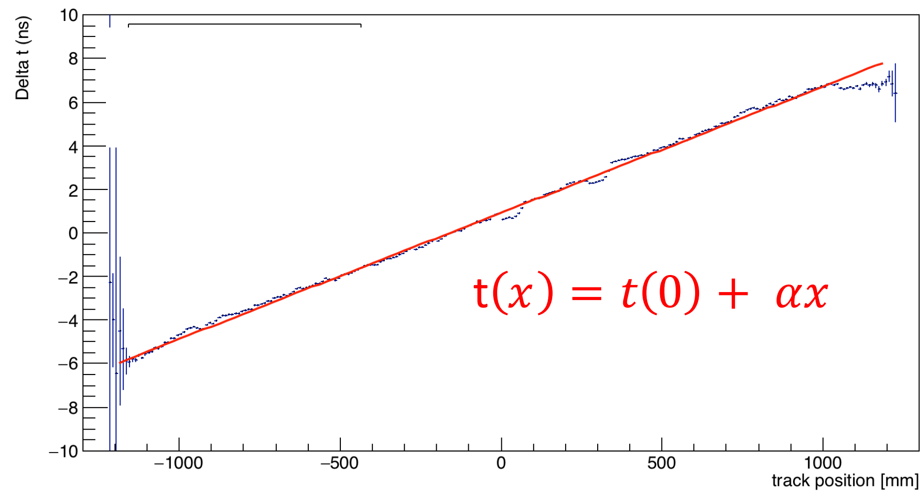
Channel Response Equalization



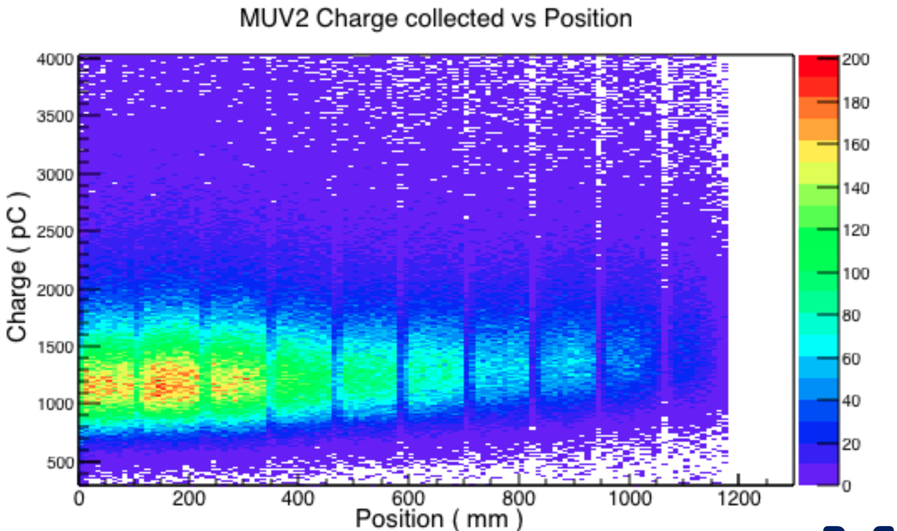


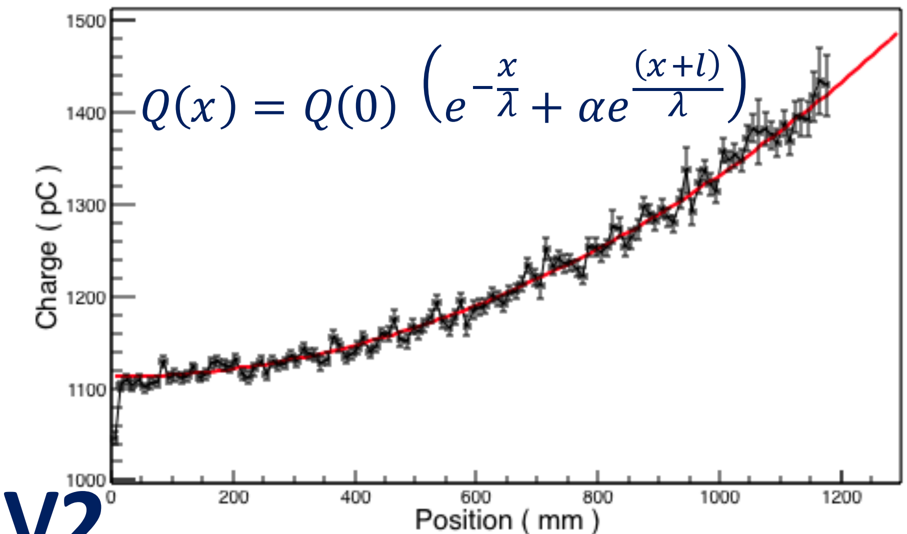
MUV1



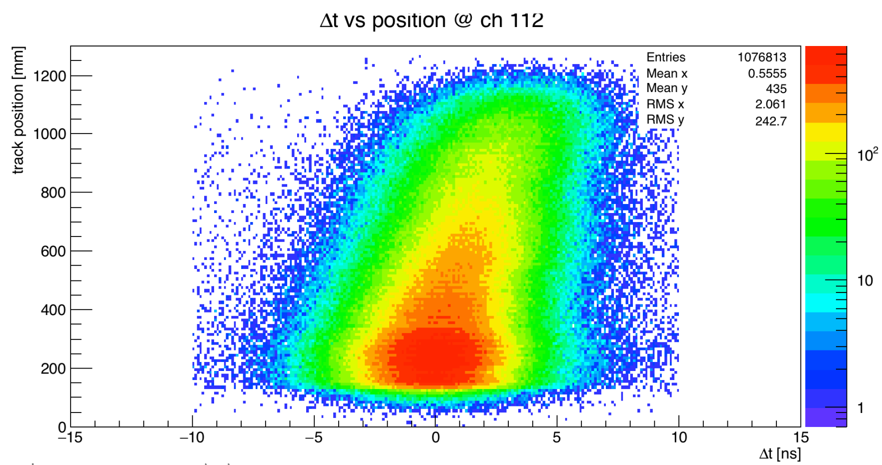


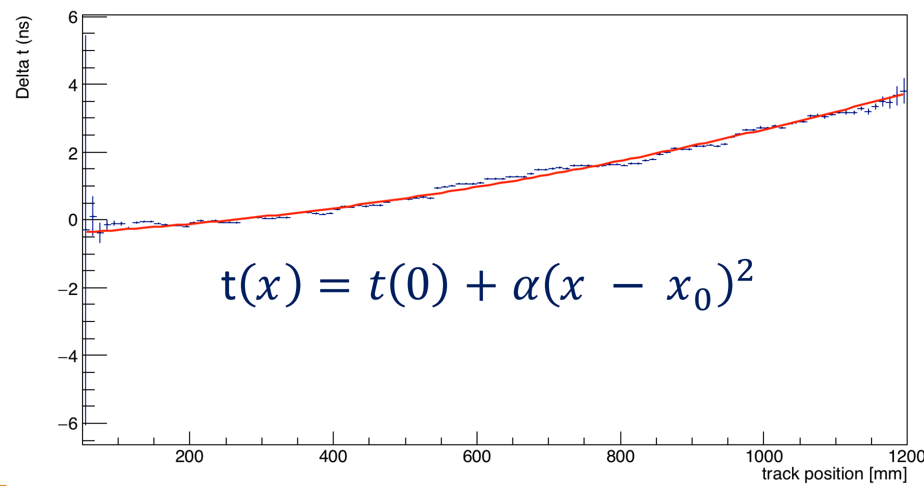
Channel Response Equalization



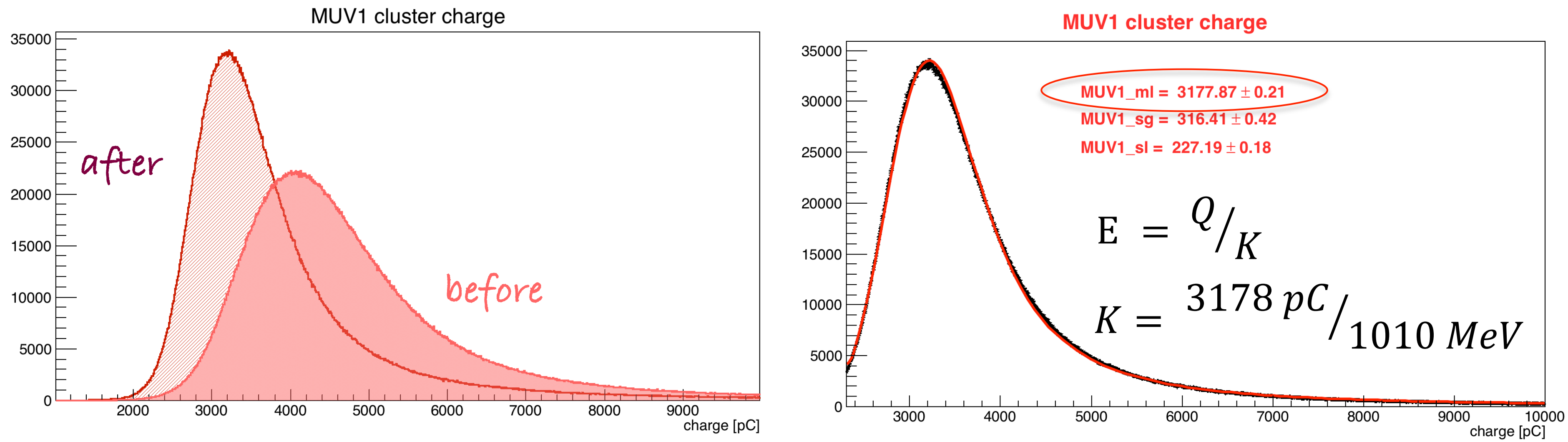


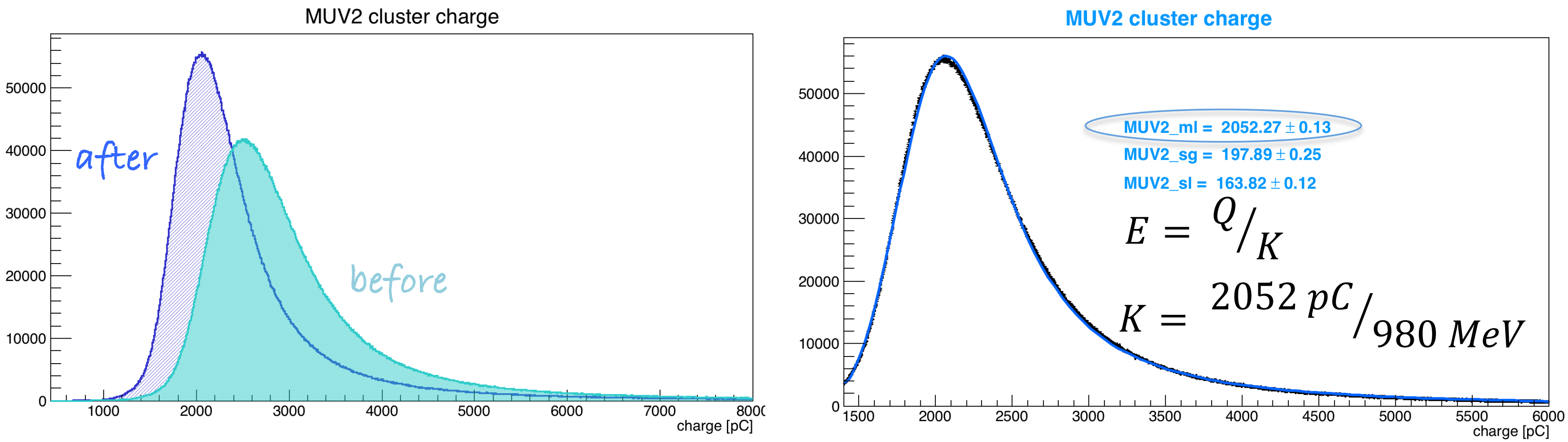
MUV2





Cluster Energy Calibration





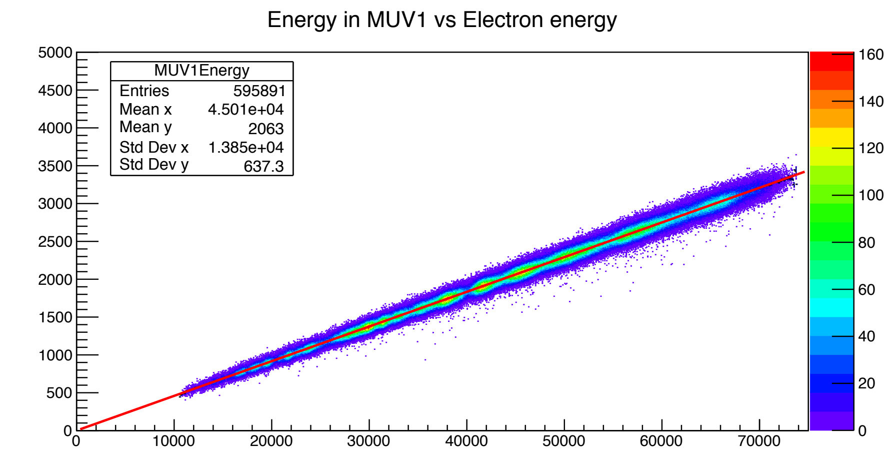
Pion Calibration

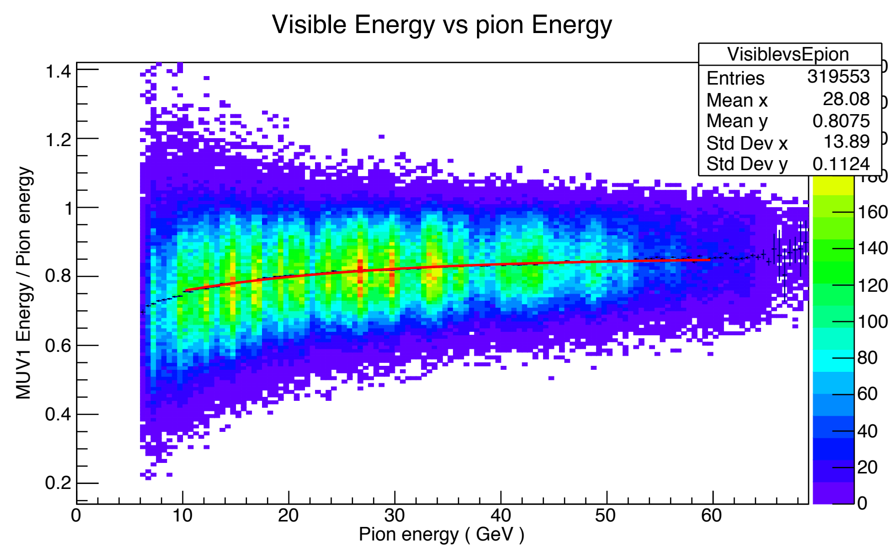
- Usually test beams to estimate the calibrations parameters and then test and optimization on data
- MUV1: No time for test beam before detector installation in 2015
- MUV2: Performed at beginning of NA48 ('94), before LKr installation, but information not anymore easily accessible
- MC Simulations to evaluate calibration and corrections
- Data to check results and optimize the corrections

Invisible Energy

- $K^+ \rightarrow e^+ \upsilon$ MC Simulation for precise sampling fraction estimation
- $K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}$ MC Simulation for Invisible Energy estimation
- No Invisible Energy in case of Pure EM showers
- Invisible Energy parametrized with the function:

$$\frac{E_{Vis}}{E_\pi} = \alpha\left(1 - e^{-\frac{(E_\pi+\beta)}{\gamma}}\right)$$





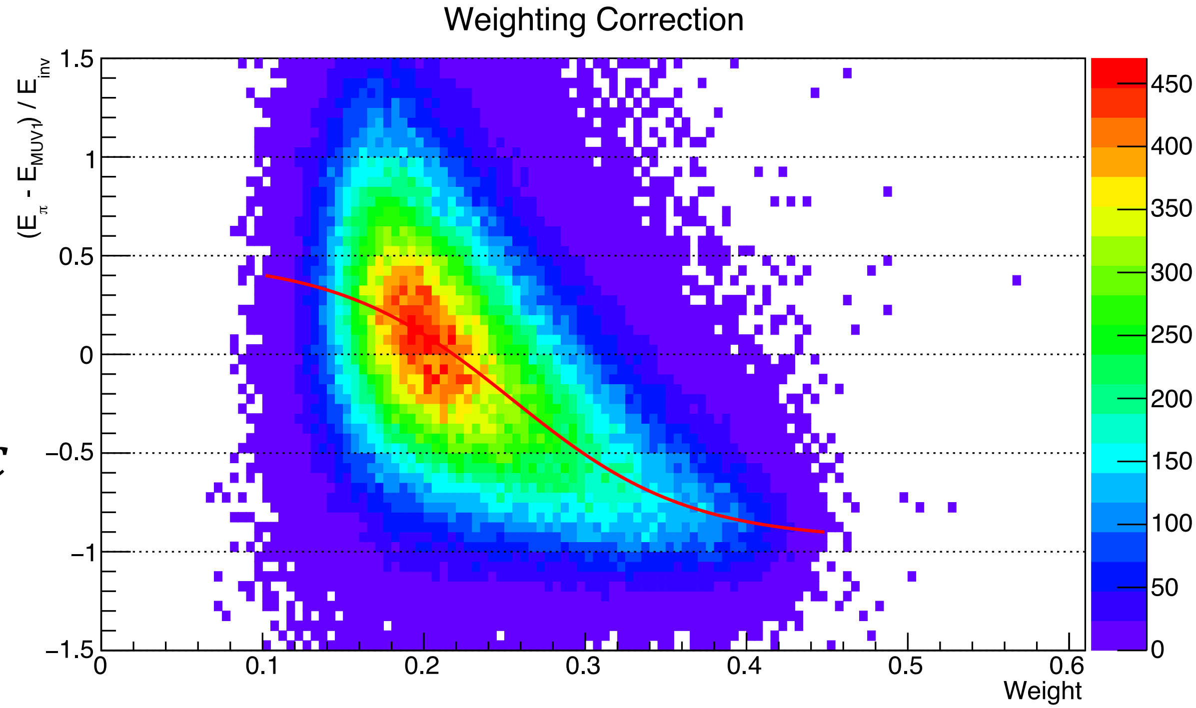
Shower Shape Weighting

In order to reach the best energy resolution it is necessary to take in account the different processes that characterize the pion showers

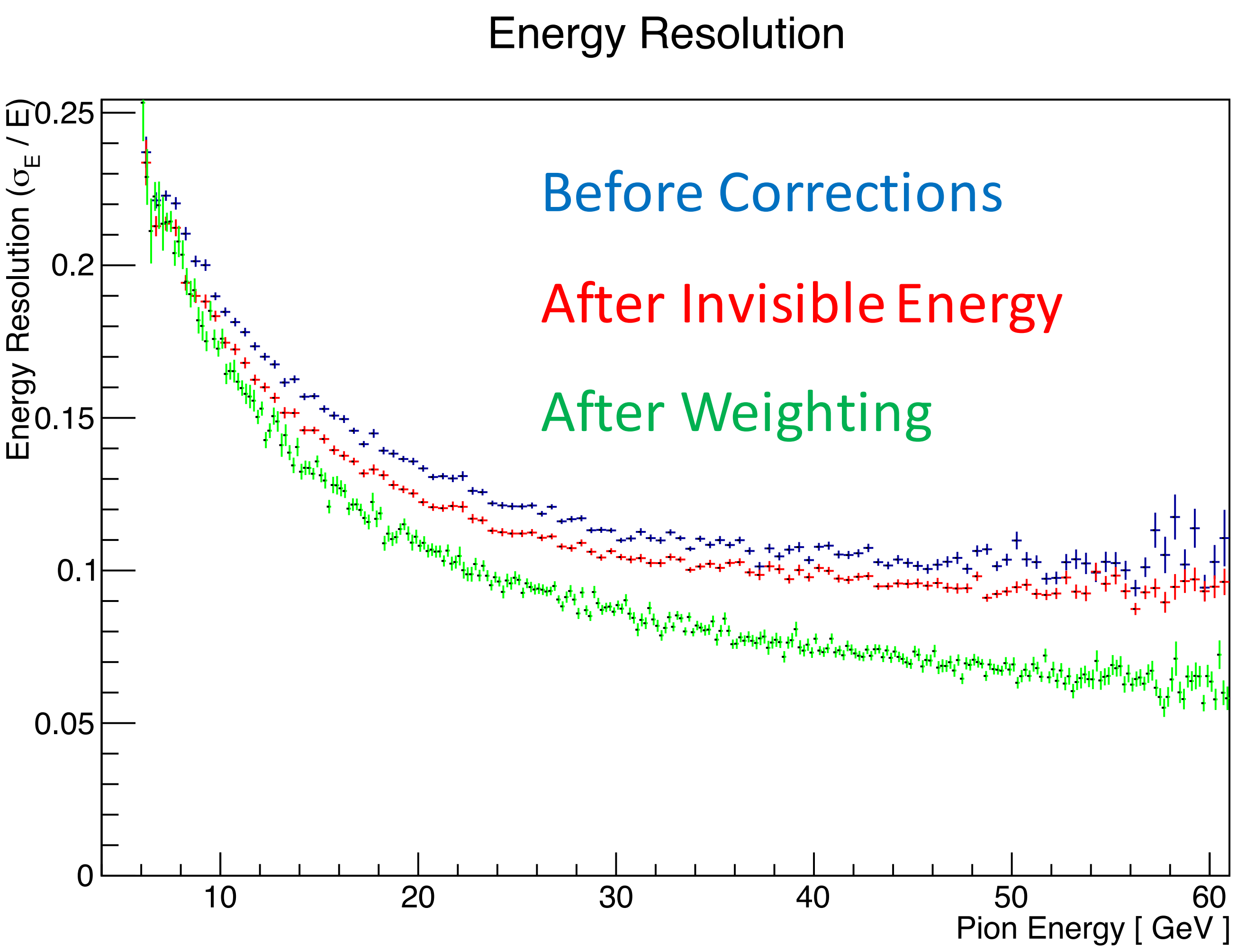
$$E = E_{Detected} + E_{Invisible} \times \left(1 + F(W)\right)$$

$$W = \sum_i \frac{E_i^2}{E_{Tot}^2}$$

$$F(W) = Fermi\ Dirac$$



Test Corrections on MC

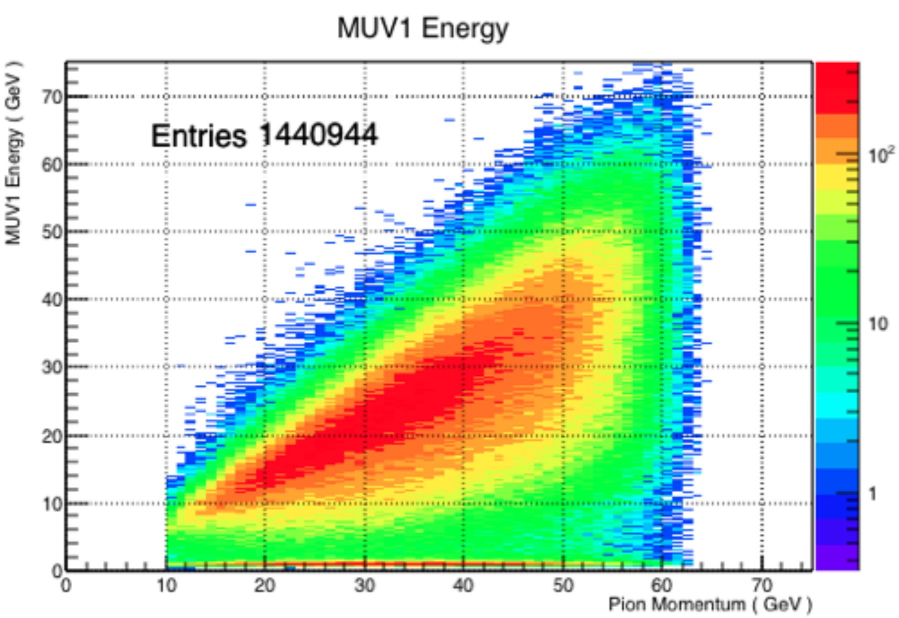


Data

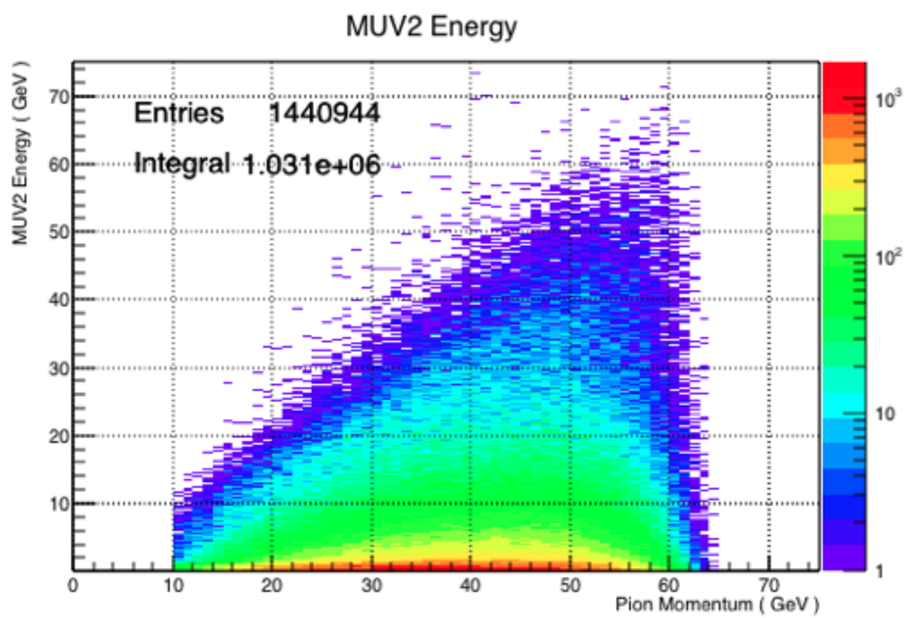
Selecting pure Pion Samples with no Interaction in the EM Calorimeter (LKr)

Keeping in the sample small amount of Muons as Control Sample

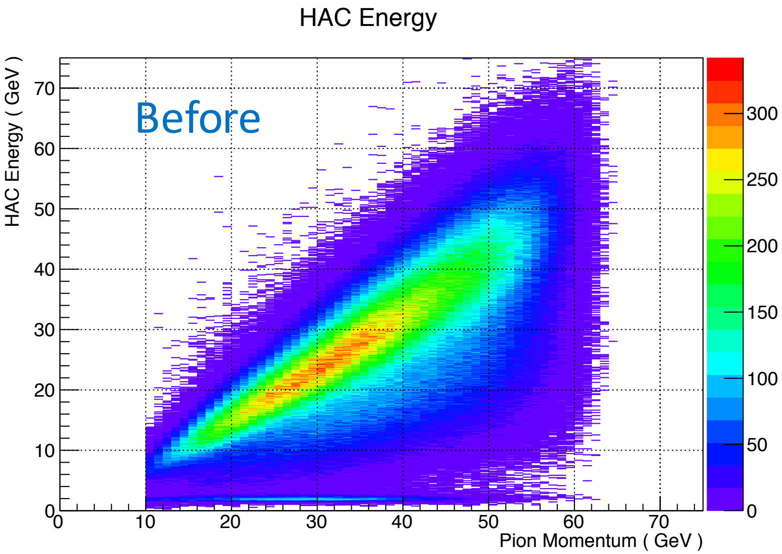
MUV1

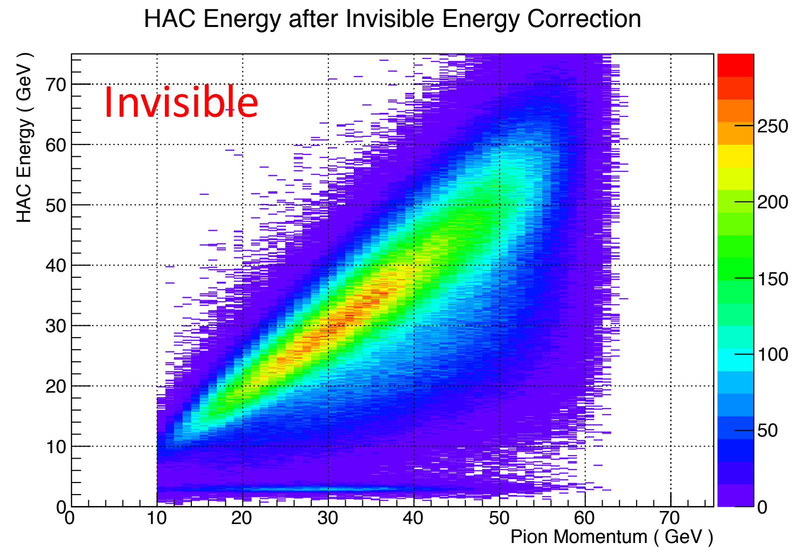


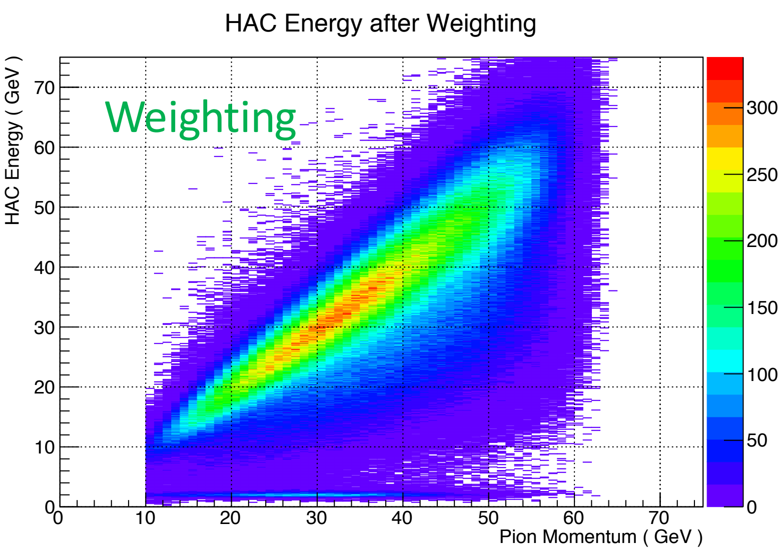
MUV2

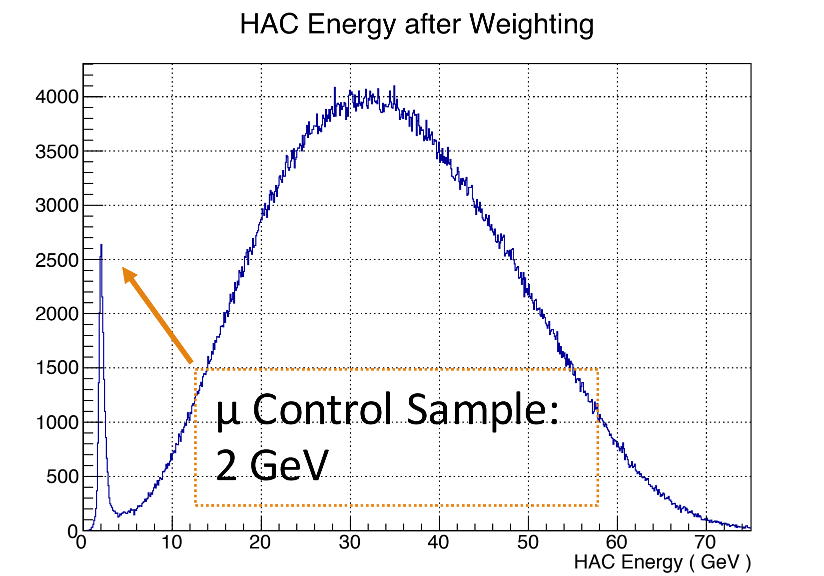


Data


HAC Energy
Before
HAC Energy (GeV)
Pion Momentum (GeV)

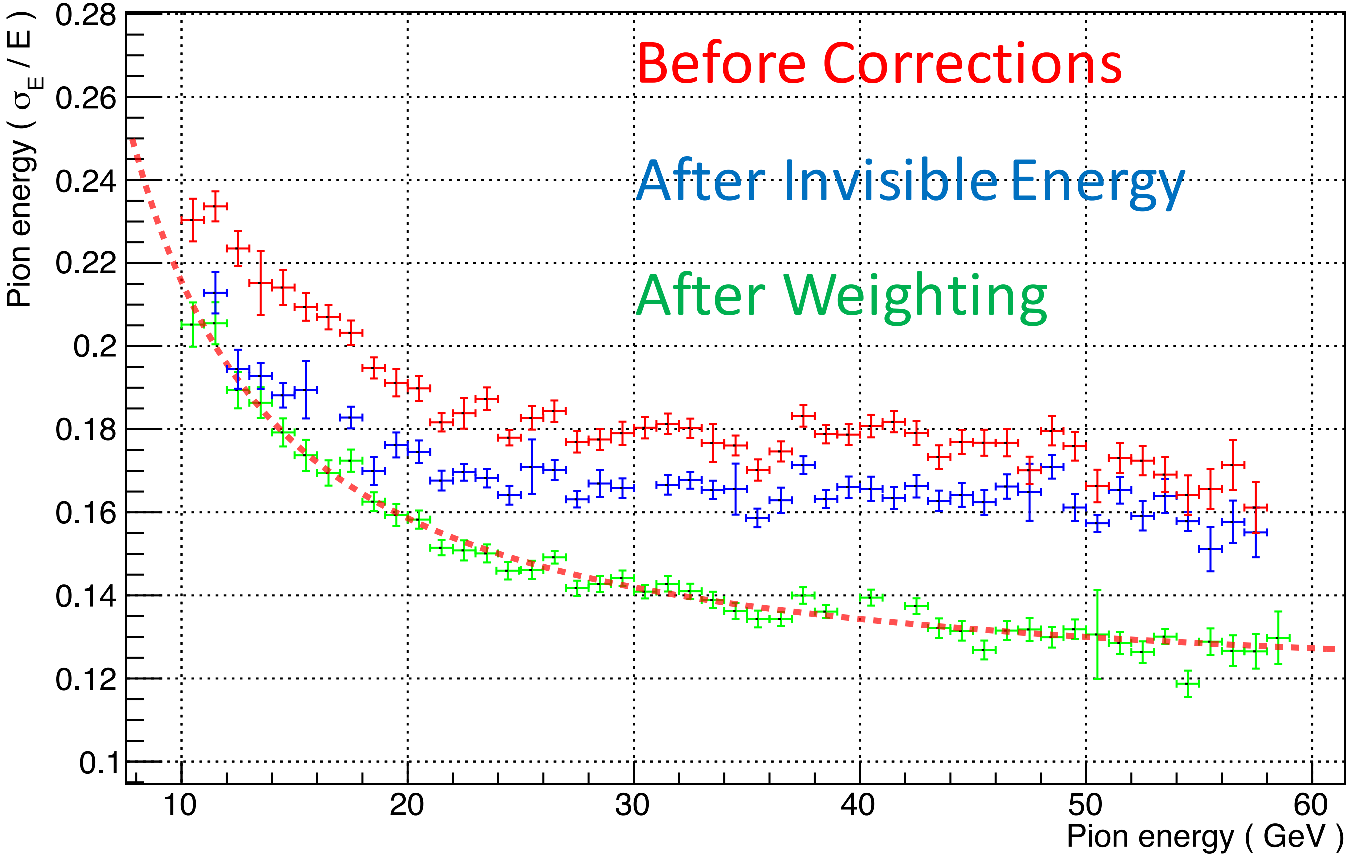

HAC Energy after Invisible Energy Correction
Invisible
HAC Energy (GeV)
Pion Momentum (GeV)


HAC Energy after Weighting
Weighting
HAC Energy (GeV)
Pion Momentum (GeV)


HAC Energy after Weighting
μ Control Sample:
2 GeV
HAC Energy (GeV)

HAC Resolution

$$\frac{\sigma_E}{E} = (0.115 \pm 0.003) \oplus \frac{0.38 \pm 0.05}{\sqrt{E[GeV]}} \oplus \frac{1.37 \pm 0.17}{E[GeV]}$$



Conclusion

- NA62 aims to measure: $Br(K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon})$ with 10% precision
- Very tiny theoretical $Br_{SM}(K^+ \rightarrow \pi^+ \upsilon\bar{\upsilon}) = (9.11 \pm 0.72)\times 10^{-11}$
- Very efficient PID system required
- The Calorimetry System plays a major role in the PID
- The Hadronic Calorimeter is composed by two modules
- More than 7 Interaction Lengths
- Slightly different structure between the modules
  - To be treated separately in calibration phase
- Calibration performed
- Energy Resolution: $\frac{\sigma_E}{E} = 0.115 \oplus \frac{0.38}{\sqrt{E}} \oplus \frac{1.37}{E}$