The Large Angle Photon Veto System for the NA62 Experiment at CERN

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Sezione INFN Roma "La Sapienza"
On behalf of NA62 Collaboration

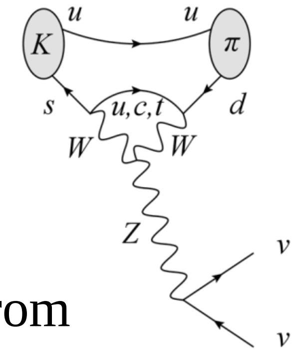
Chicago 9-6-2011

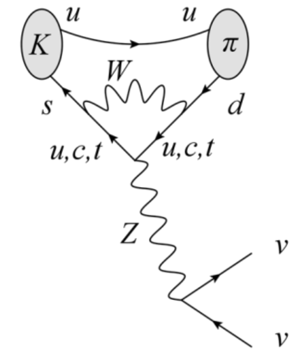
Overview

- NA62 Experiment
  - Motivation
  - Experimental strategy
  - Detector description

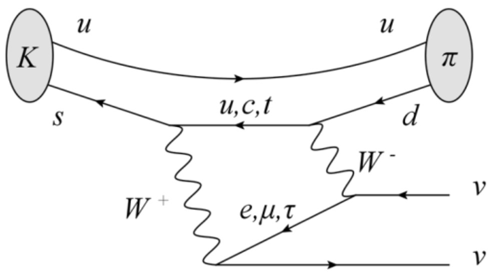
- Large Angle photon Veto (LAV):
  - Mechanical and readout description
  - Test beams.
  - MonteCarlo simulation.

Physic case





The NA62 experiment aims to detect New Physics effects from measurements of rare Kaon decays.



In particular, it aims to measure the Branching Ratio of the ultra-rare decay $K^+ \rightarrow \pi^+ \nu \nu$ with a 10% total uncertainty.

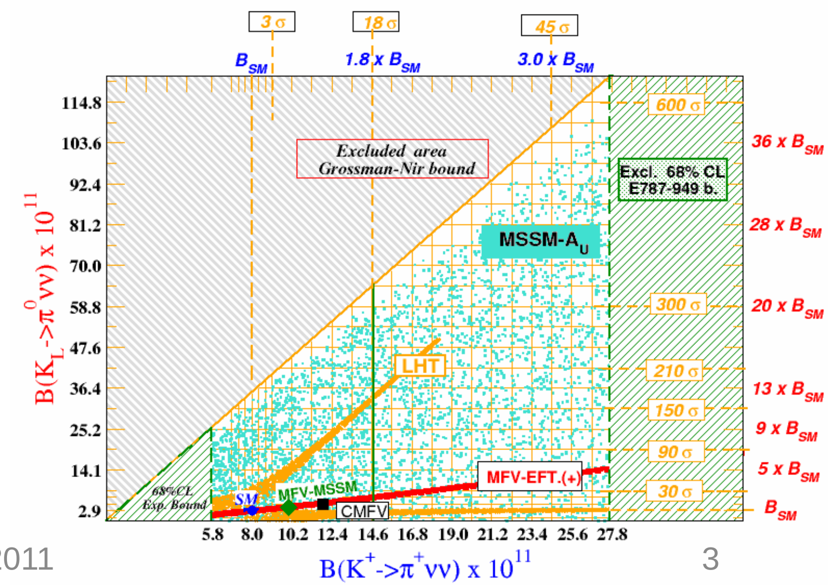
SM proceeds through loops, suppressed by GIM.

SM theoretical estimation: $BR=(7.81 \pm 0.75 \pm 0.29) \times 10^{-11}$

NP effects may induce ~O(10%) deviation.

Experimental status: 7 decays observed (E787/E949 at BNL) => $17.3\,_{-10.5}^{+11.5} \times 10^{-11}$

$BR(K^+ \rightarrow \pi^+ \nu \nu)$ will give the first direct determination of the CKM element V_{td}



Experimental Strategy

NA62 aims to measure the $K^+ \rightarrow \pi^+ \nu \nu$ Branching Fraction with a Signal/Background ratio of about 10

Intense beam needed to collect 100 signal events in 2 years of data taking, with a 10% selection efficiency

- $3x10^{12}$ protons on Be-target per pulse
- 4.8/16.8 s/s duty cycle
- 800 MHz, 75-GeV/c unseparated hadron beam with 6% K
- 40 MHz of K decay in a 60 m long fiducial region

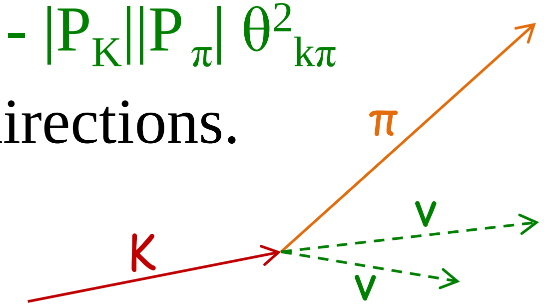
The main challenge: reaching a background rejection of 10^{-12} against main decay modes

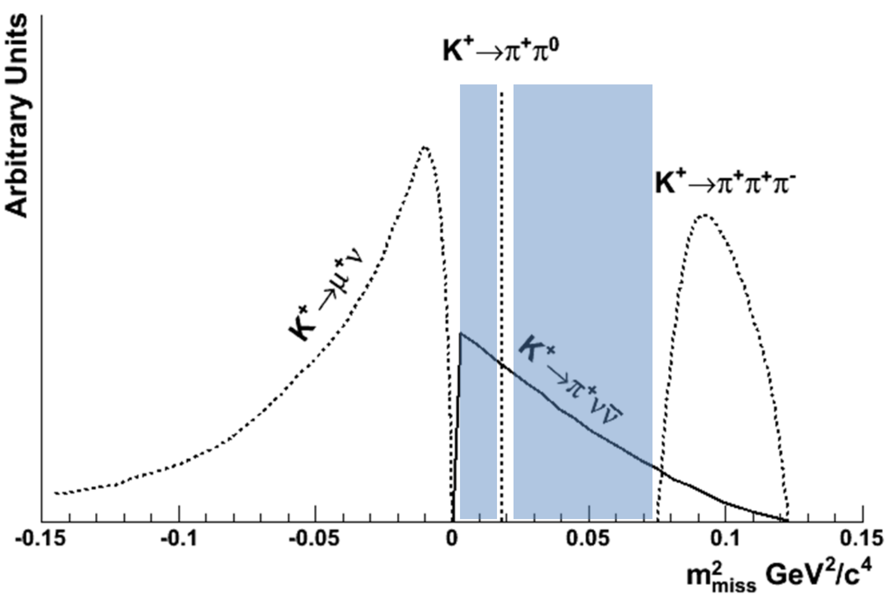
Experimental Strategy

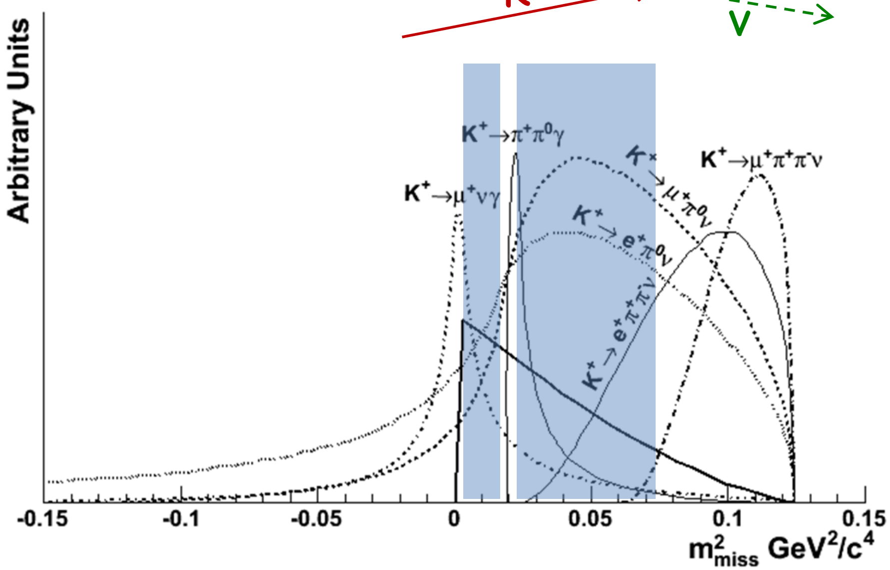
Kaon decays with only one charged particle in final state must be rejected.

$$m^2_{miss} \approx m^2_K (1-|P_\pi|/|P_K|) + m^2_\pi (1-|P_K|/|P_\pi|) - |P_K||P_\pi|\, \theta^2_{k\pi}$$

Must accurately measure K and π momenta and directions.





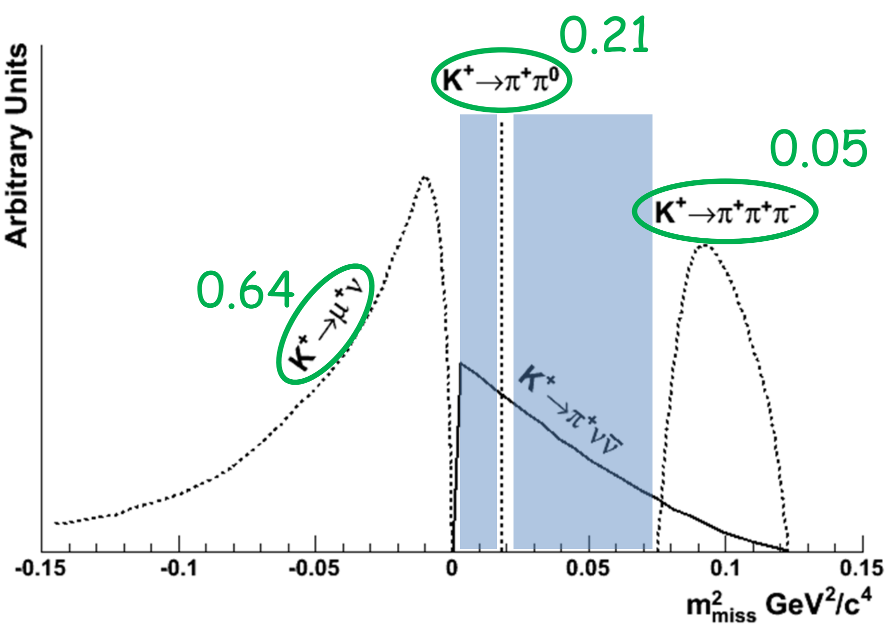


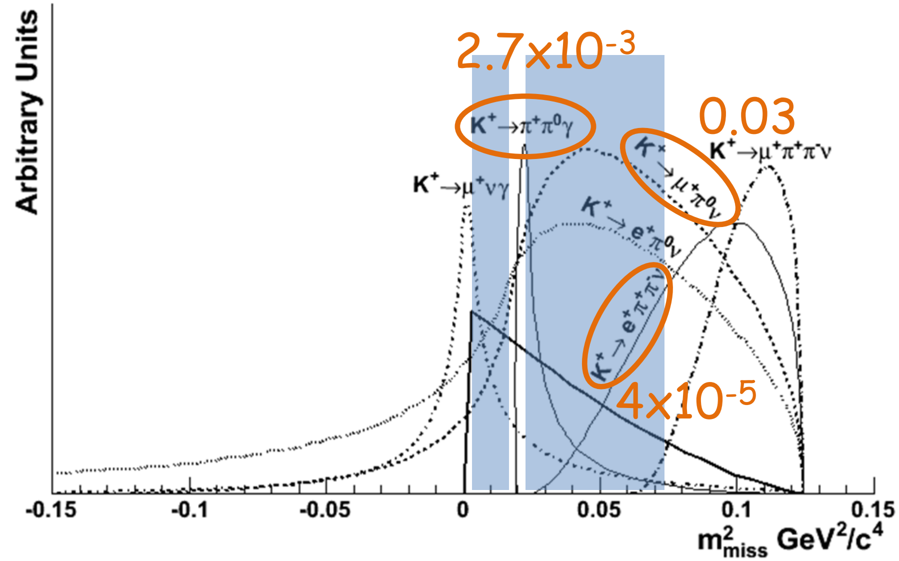
Experimental Strategy

Kaon decays with only one charged particle in final state must be rejected.

Kinematics rejection against main modes is ~10^4

Kinematics rejection against subleading modes of ~10^2





Experimental Strategy

Escaping neutrinos do not allow kinematic closure

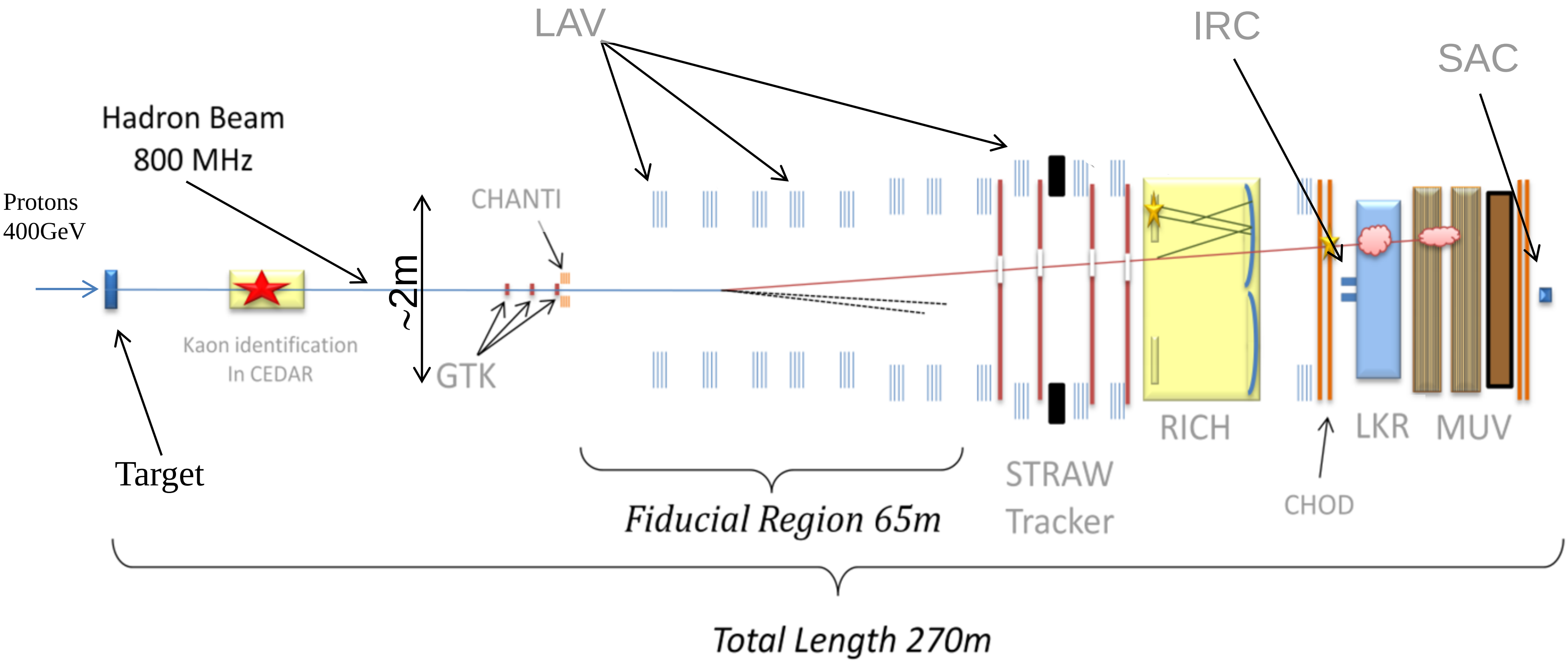
- Redundant Particle ID in order to reject decays not kinematically constrained
- High efficient and hermetic photon veto in order to reject decays with photons

Particle ID detectors: calorimeters, muon veto, Cherenkov

Photon veto detectors: composite calorimeter system

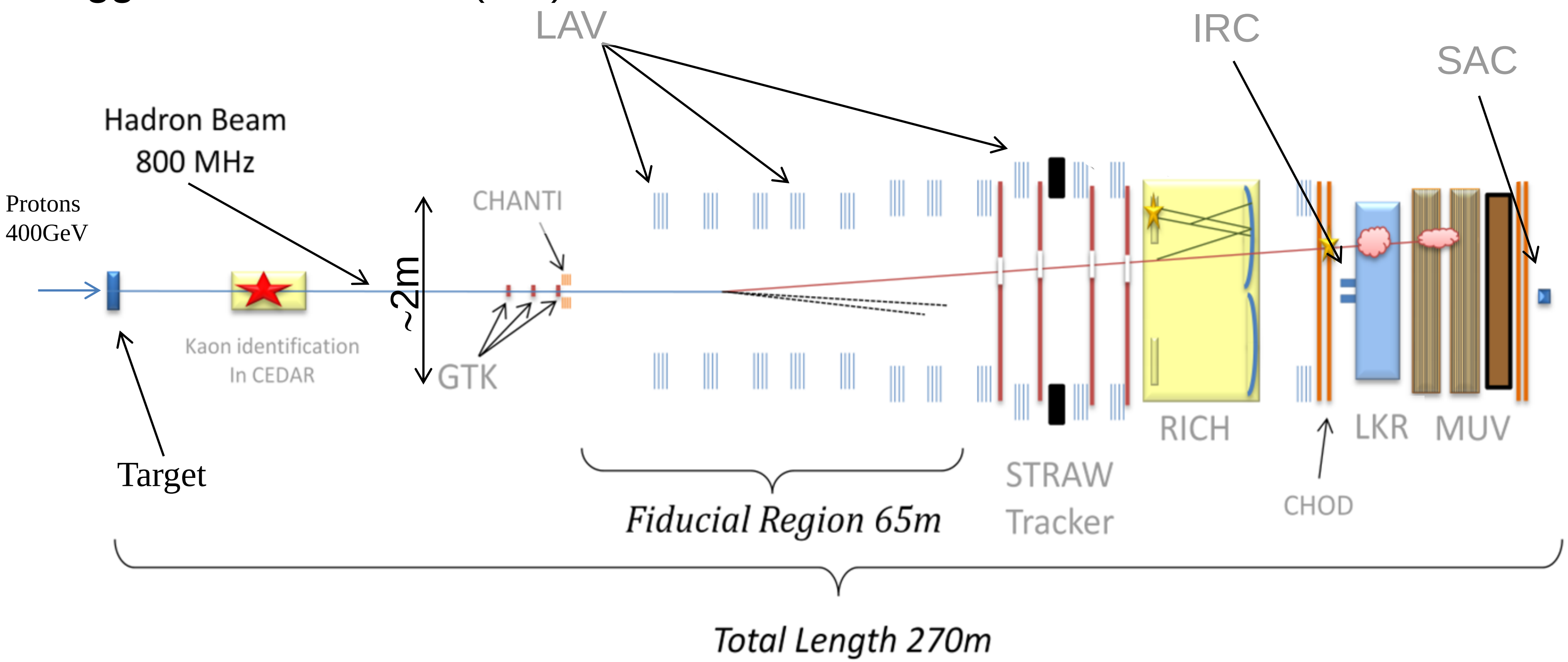
Common requirement: Excellent-timing (150ps) due to the high rate

NA62 apparatus



NA62 apparatus

GTK => M. Fiorini (55) and G. Aglieri Rinella (369)
CHANTI => G. Saracino (389)
STRAW => A. Sergi (135)
RICH => M.Pepe (9)
Trigger => G. Lamanna (108)



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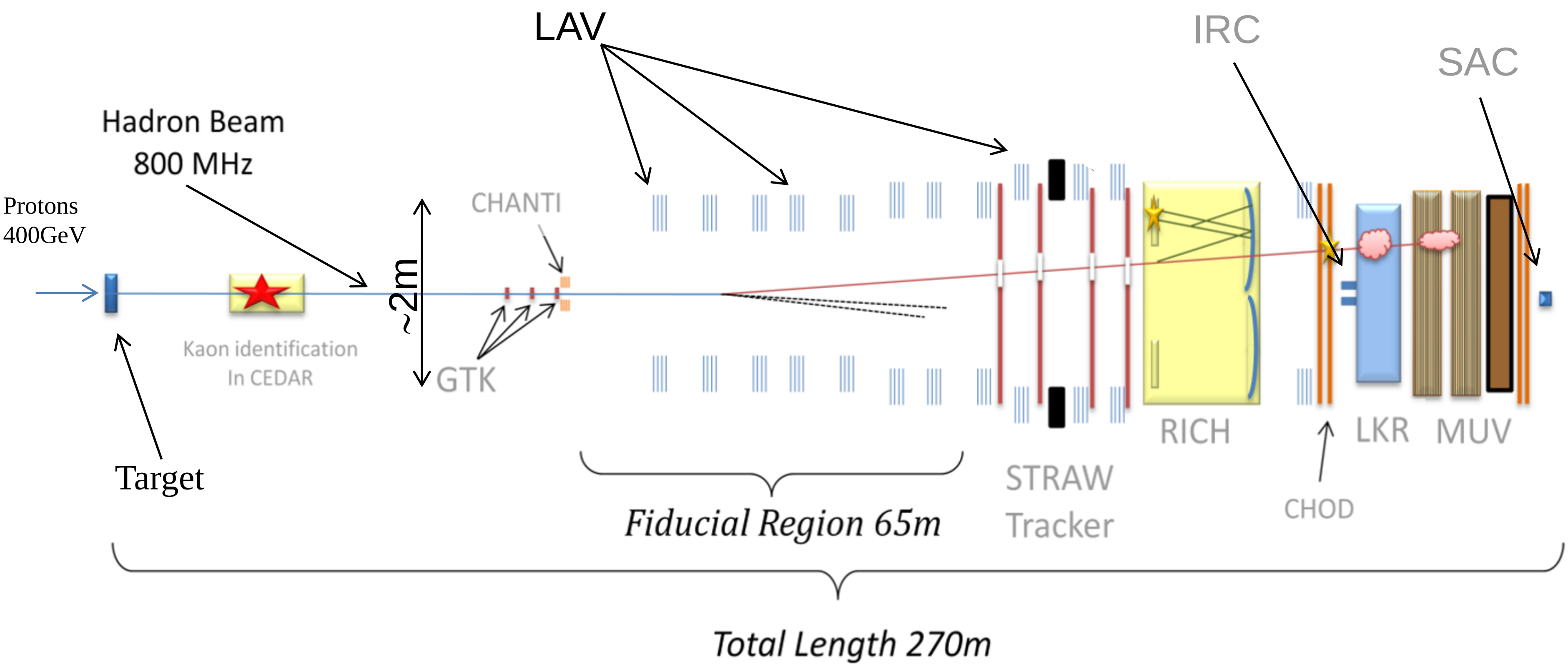
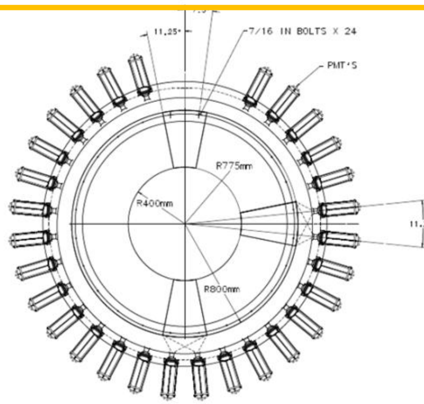
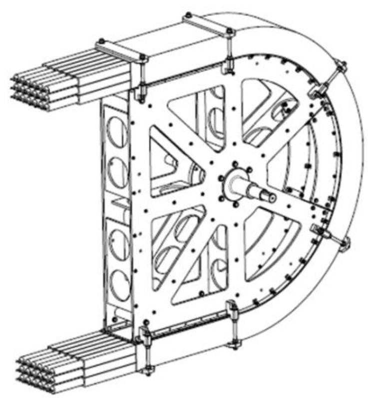
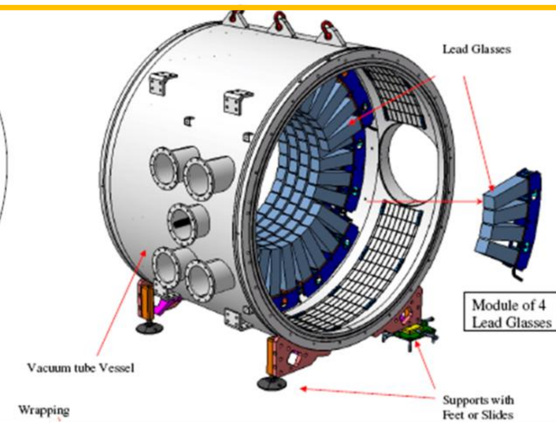


Large Angle photon Veto (LAV)

LARGE ANGLE VETOES REQUESTS:

Photon inefficiency:	10^{-4} for E down to O(100 MeV)
Energy Resolution:	10% at 1 GeV
Time Resolution:	better than 1ns
Angular region covered:	8→50 mrad
Main purpose:	$K^+ \rightarrow \pi^+\pi^0$ rejection at 10^8 level





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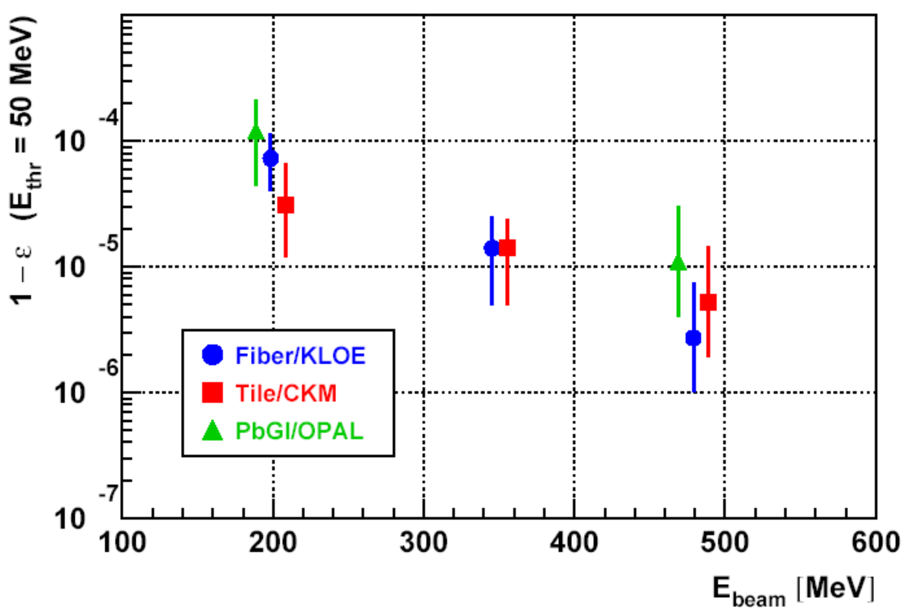
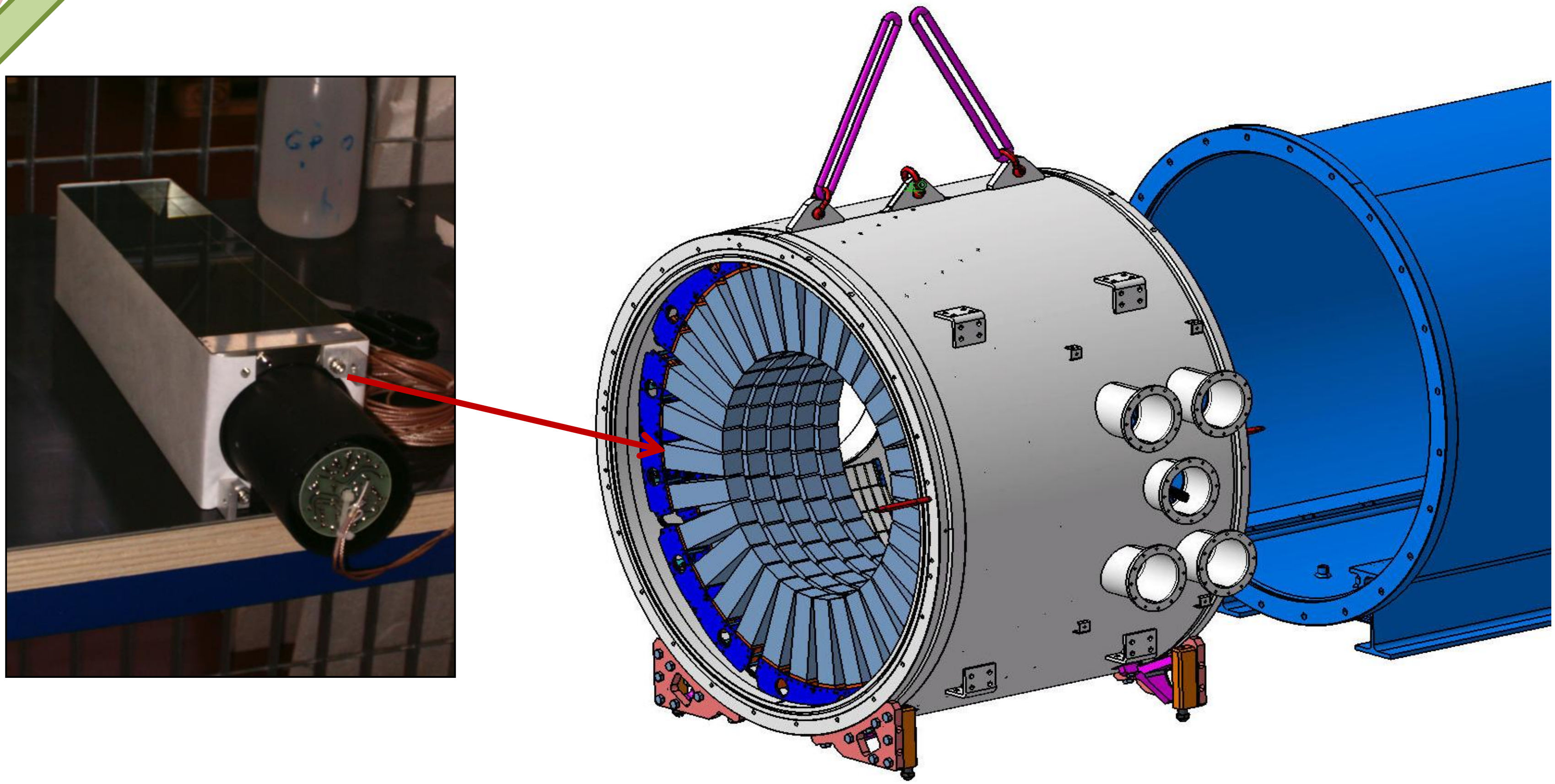


LAV



Our base line solution reuse the OPAL lead glass from the electromagnetic calorimeter (barrel). These are arranged in staggered layers (4 or 5 depending to the module position). The whole detector needs about 2500 blocks.

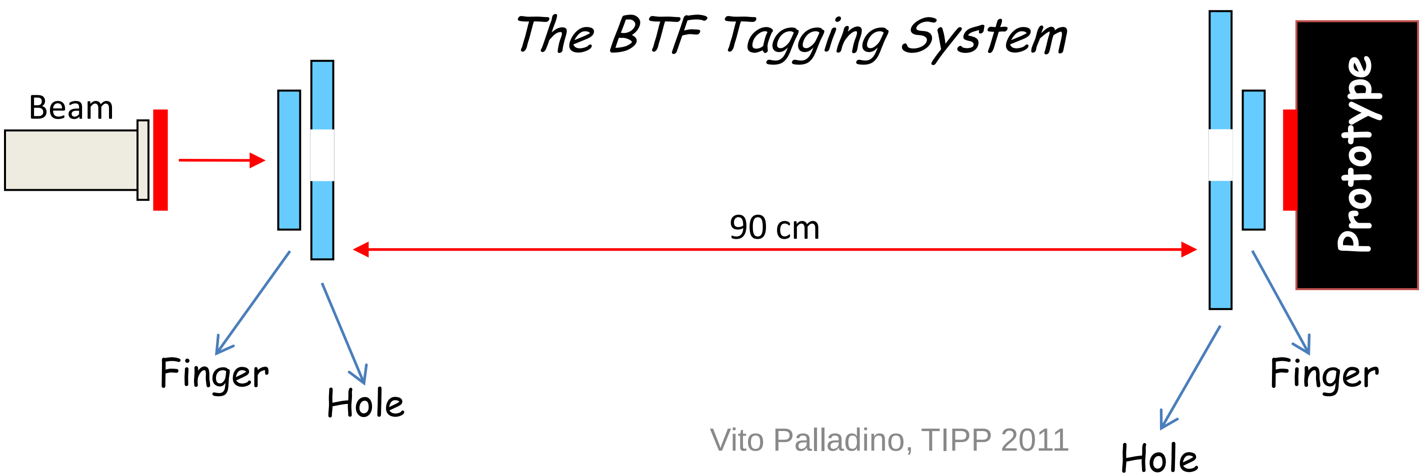
Inefficiency measurement

We have had only one opportunity to measure the inefficiency.

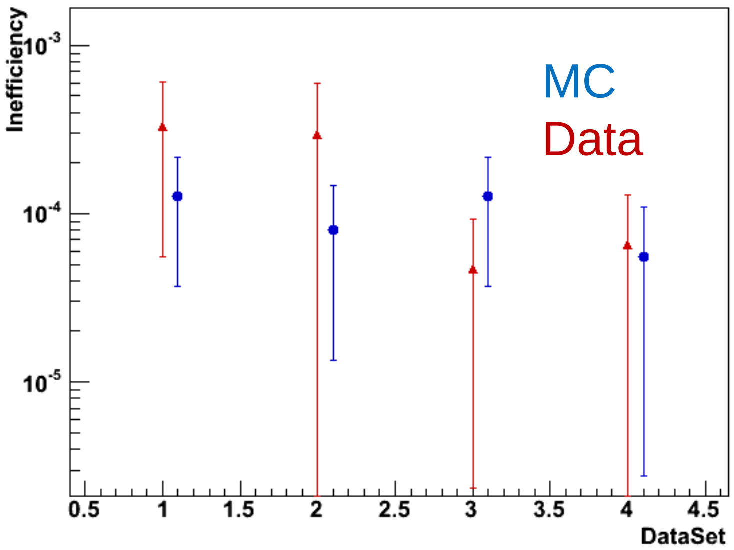
The test took place at Test Beam Facility (BTF) at Laboratori Nazionali di Frascati. The BTF provides an electrons beam with energy from 100 to 500 MeV.

A scintillating palettes/holes tagging system provides Single Electron events.

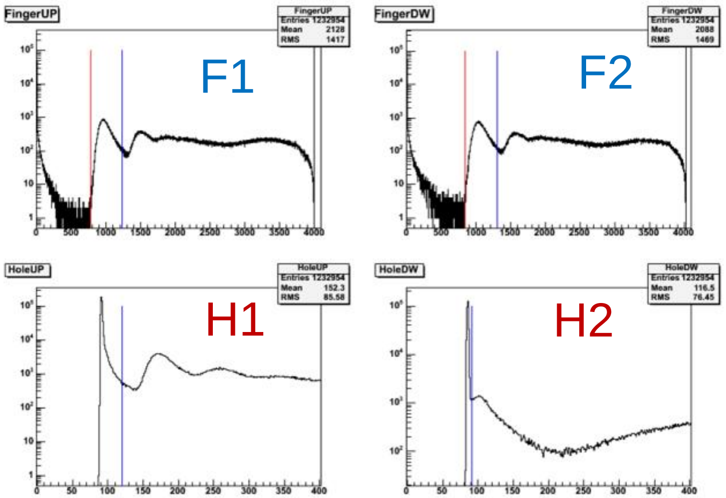
The BTF Tagging System



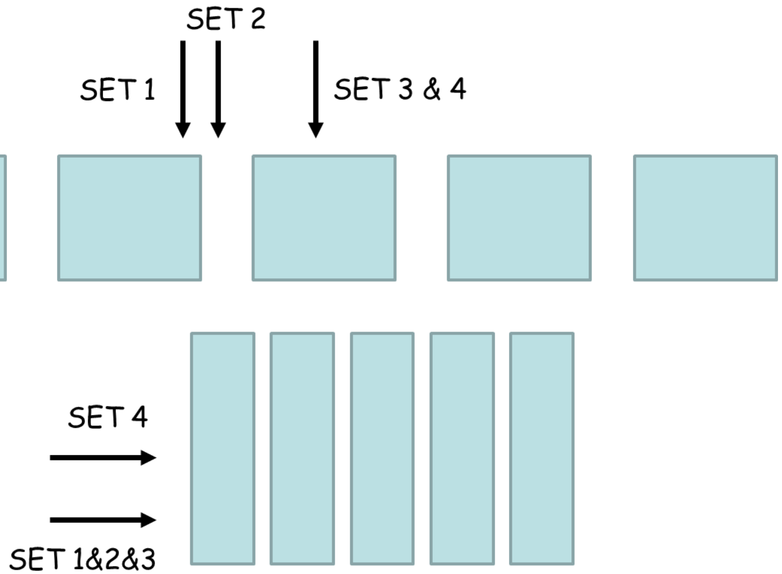
Inefficiency measurement



Single electron selection



Monocromatic electron beam of 471 MeV.

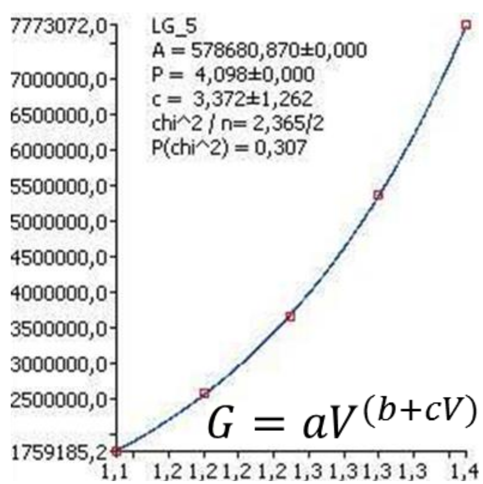


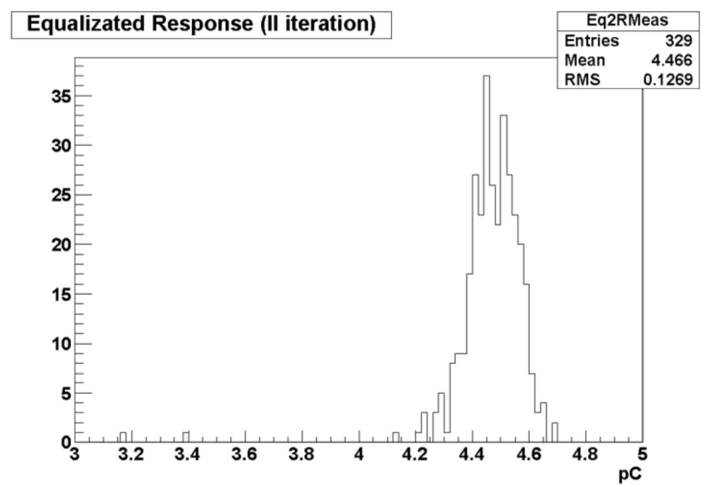
Top view

Block commissioning

All the blocks need to be characterized.
The test we developed is able to measure the gain versus voltage supply curve, using light from a temperature stabilized LED.

Equalization is then performed using Cosmic Rays.





The Large Angle Veto (LAV)

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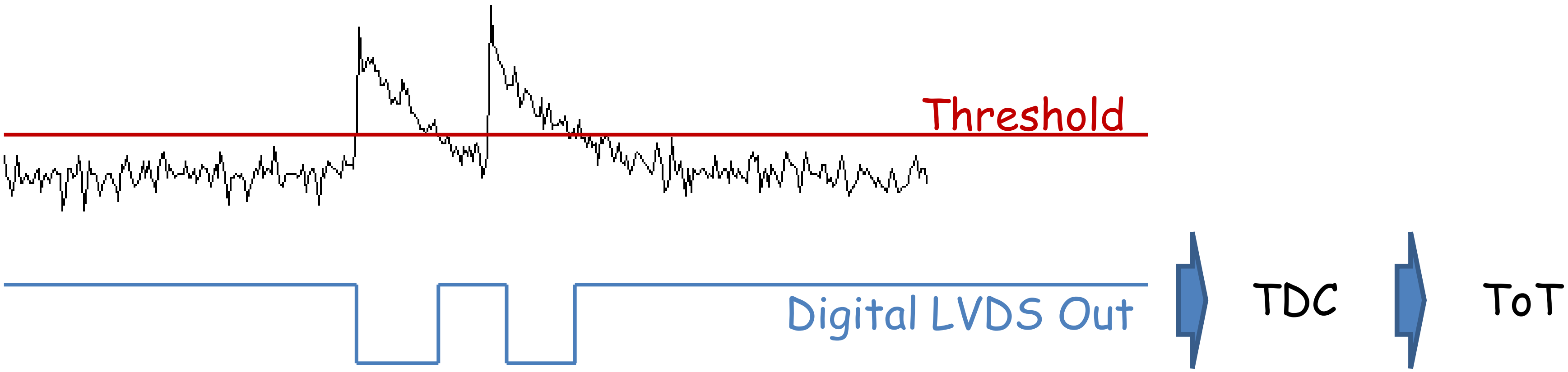
ANTI readout

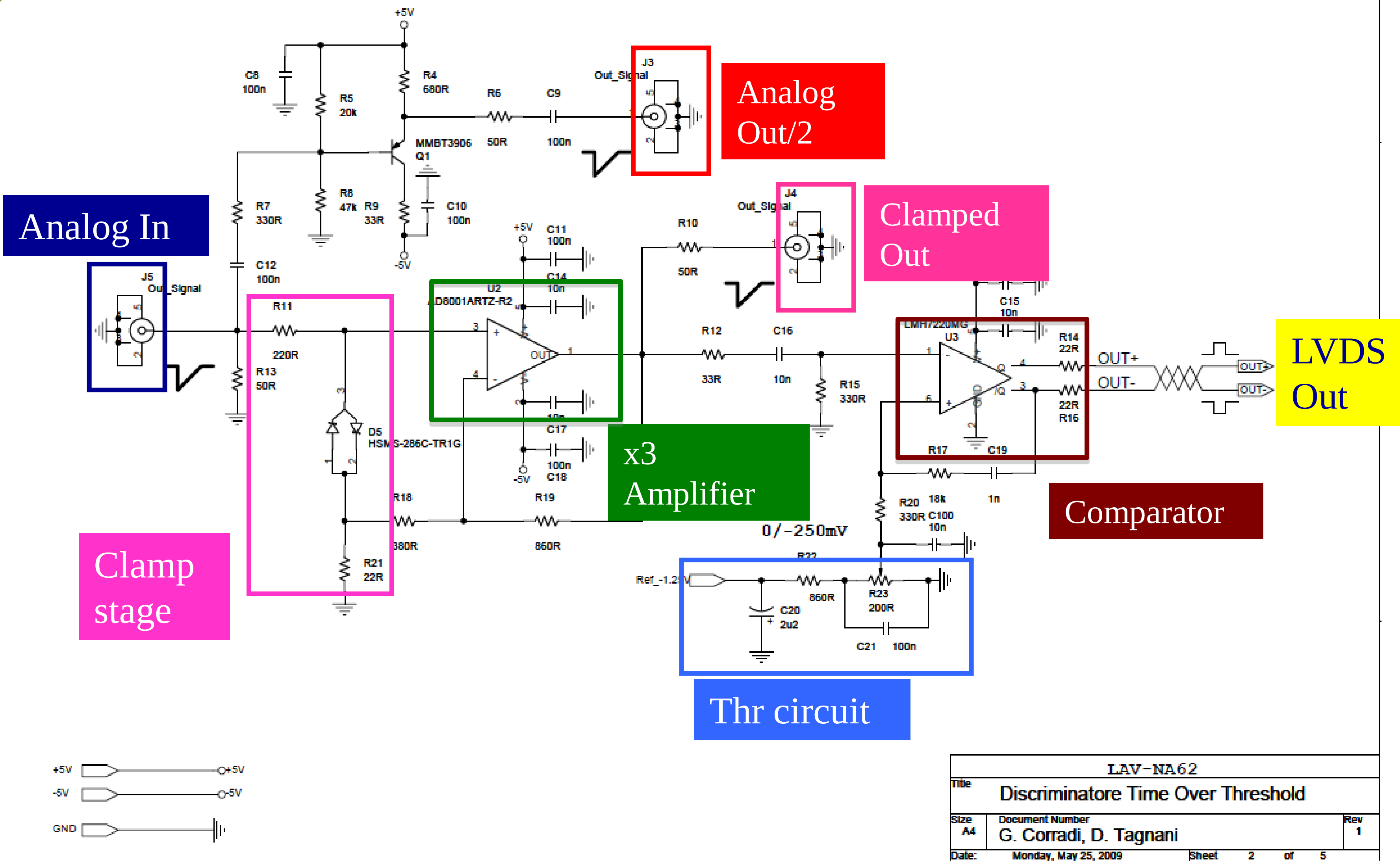
LAV readout electronics will use, in order to reduce costs, Time Over Threshold technique.

From the measured ToT, the signal charge can be evalauted.

Analog signals are discriminated and a digital output with a time width equal to ToT is produced.



Electronics



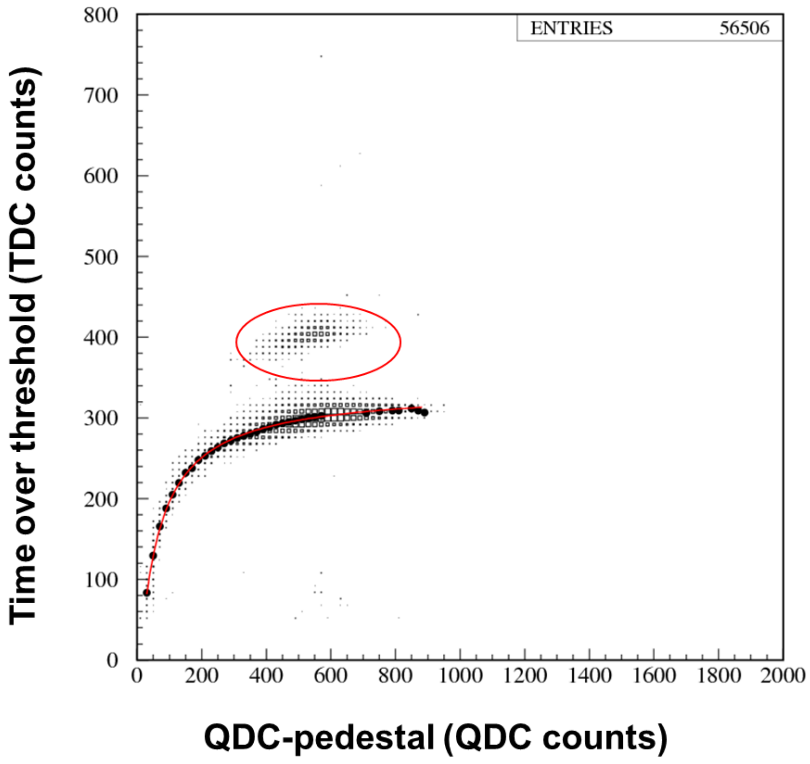
ANTI A1 Test

Module A1 has been sent to CERN. It was installed on K12 beam line where SPS provides different kind of beams (electrons and muons) and energies.

The test was able to check the correct blocks equalization and validate ToT technique.

ANTI A1 Test: results

ToT versus QDC plot showed a deviation from expected behavior.



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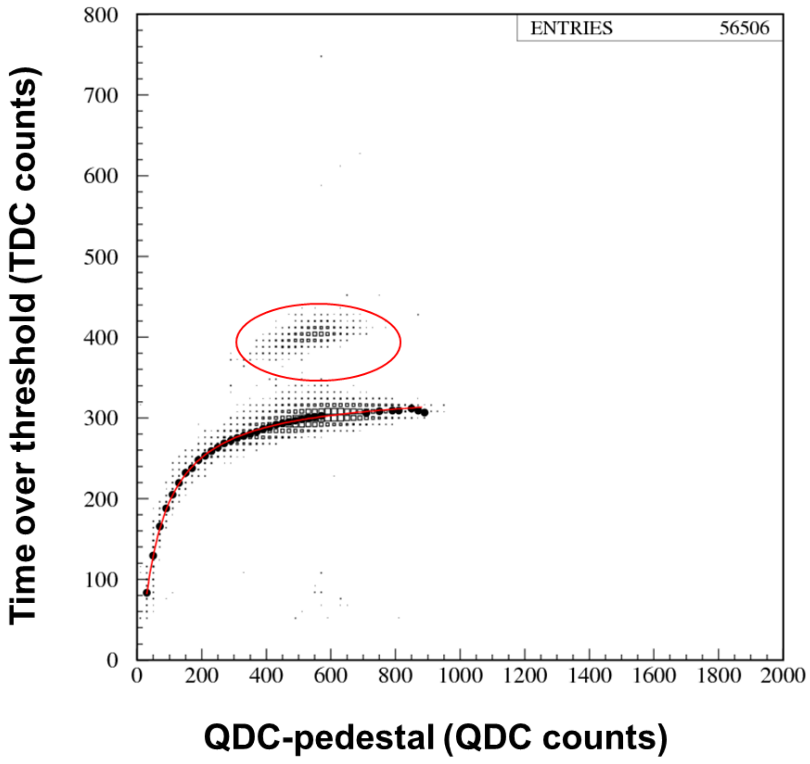
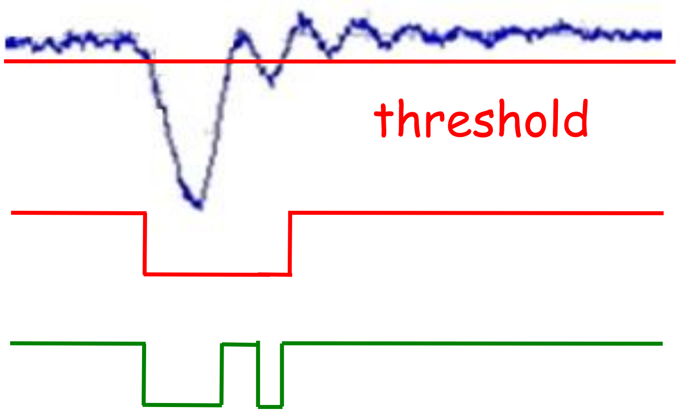


Explanation: observed ringing due to parasitic inductance. The TDC cannot distinguish two consecutive threshold crossings occurring within less than 5ns.



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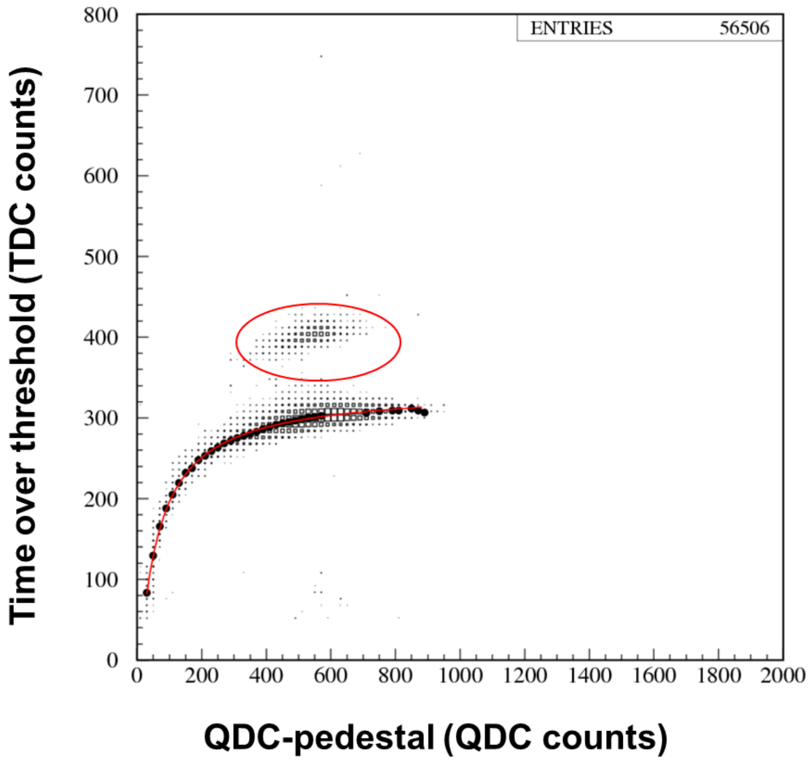
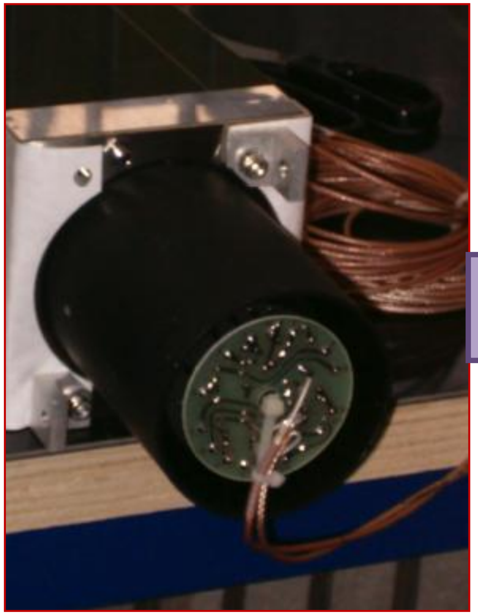
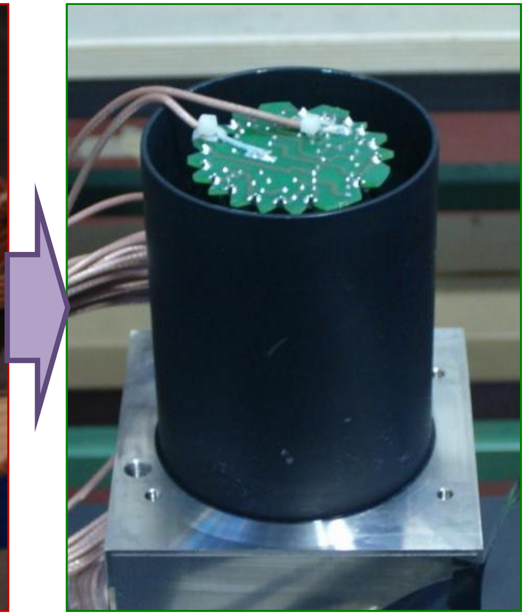


Solution: Effect can be mitigated by inserting a suited resistor => change HV dividers

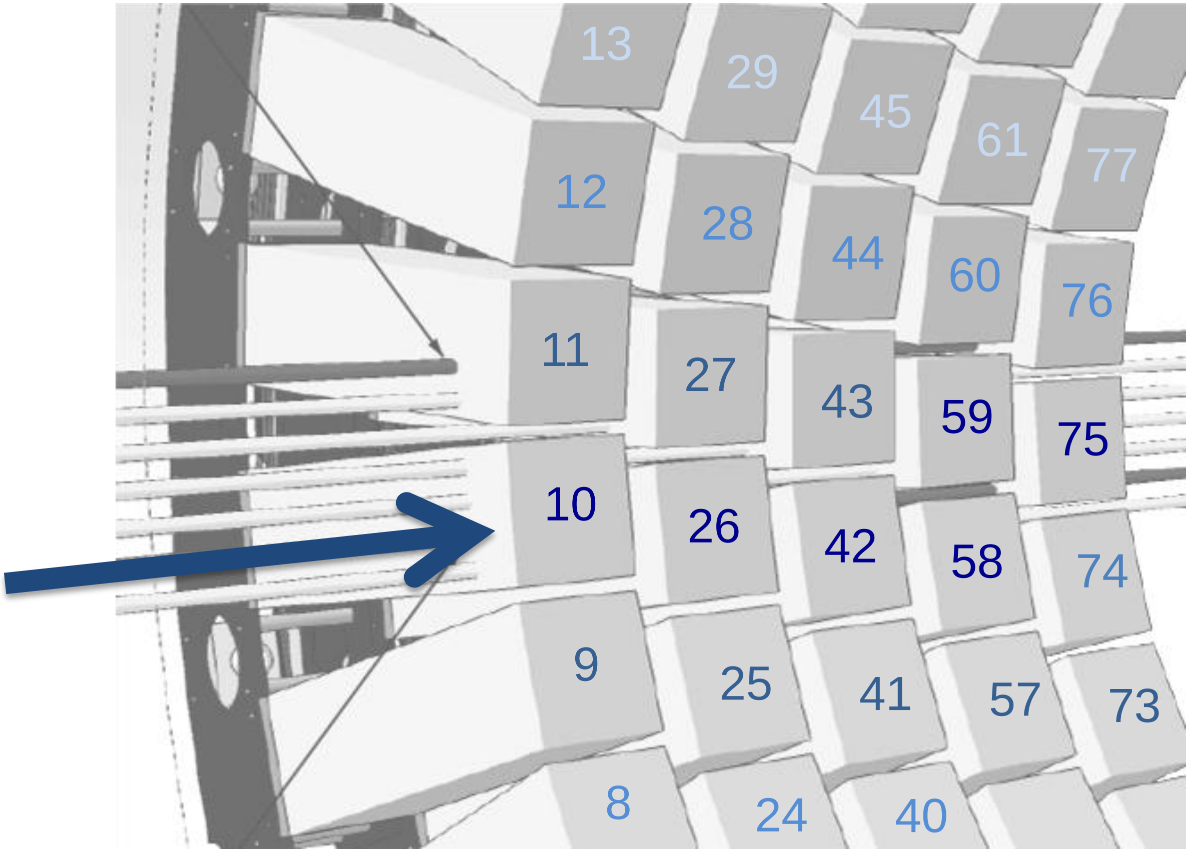


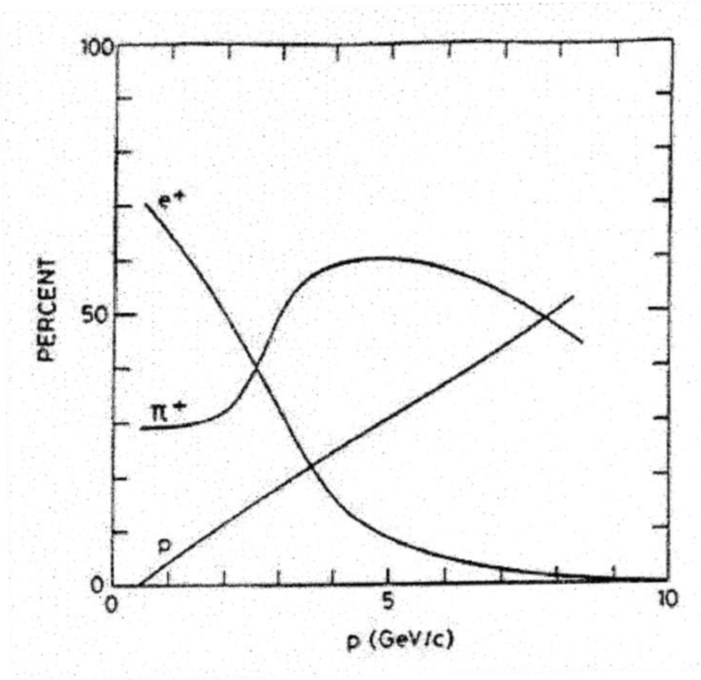


A2 test

A second module with updated dividers, has been constructed. A test has been done at CERN in August 2010.

The test took place at PS experimental area T9. Mixed e–π–μ beam energy is in range 0.3 to 10 GeV/c. Two Cherenkov detectors and a series of scintillating palettes were used to tag electrons.





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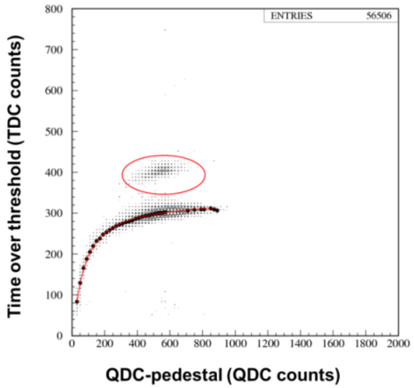
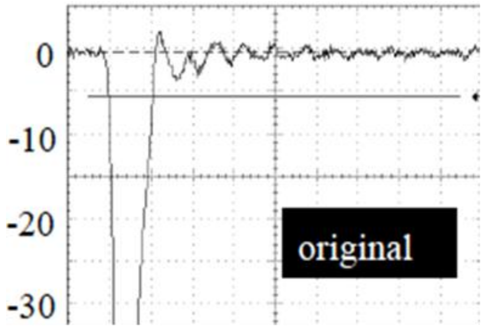
A second module with new dividers, has been constructed. A test has been done at CERN in August 2010.

It aims to validate new divider solution and to measure linearity of response, energy and time resolution.





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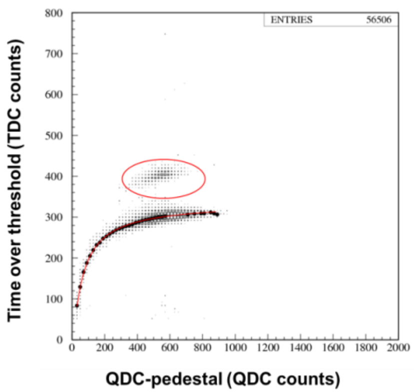
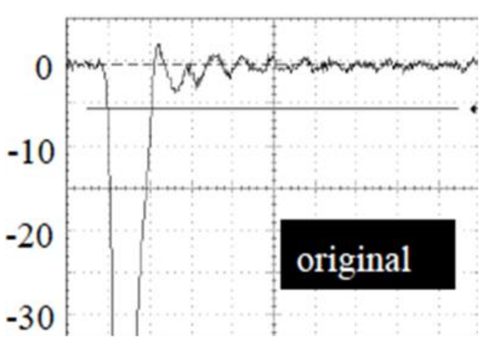
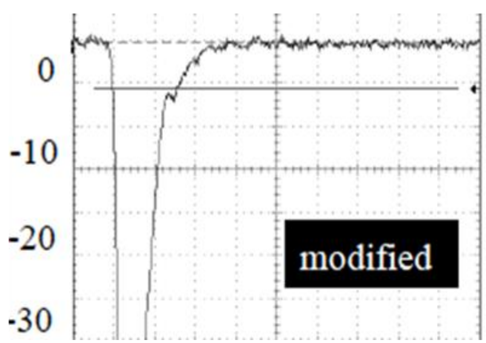
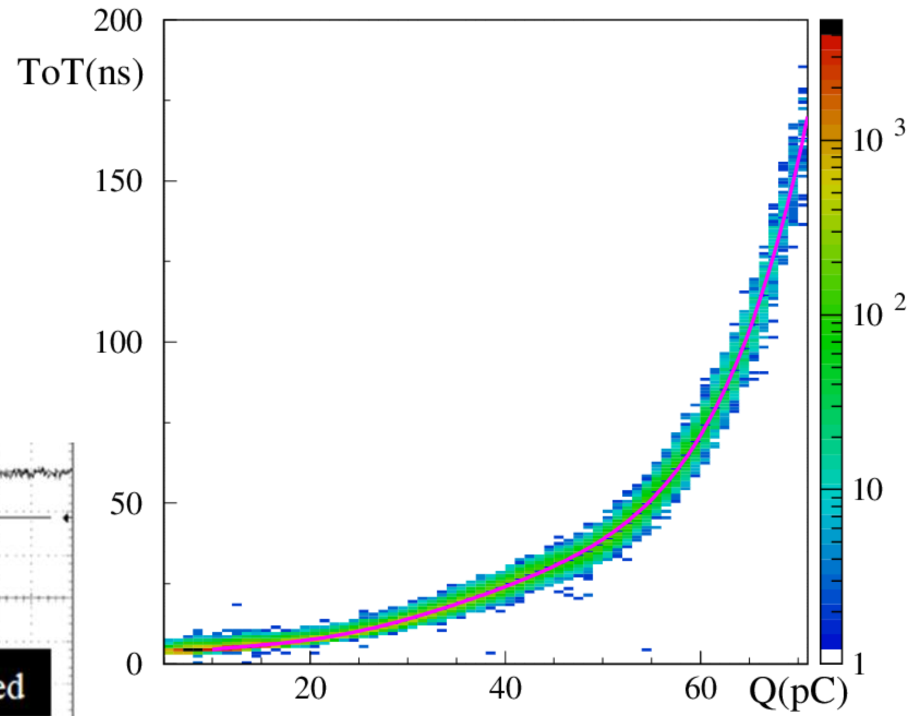




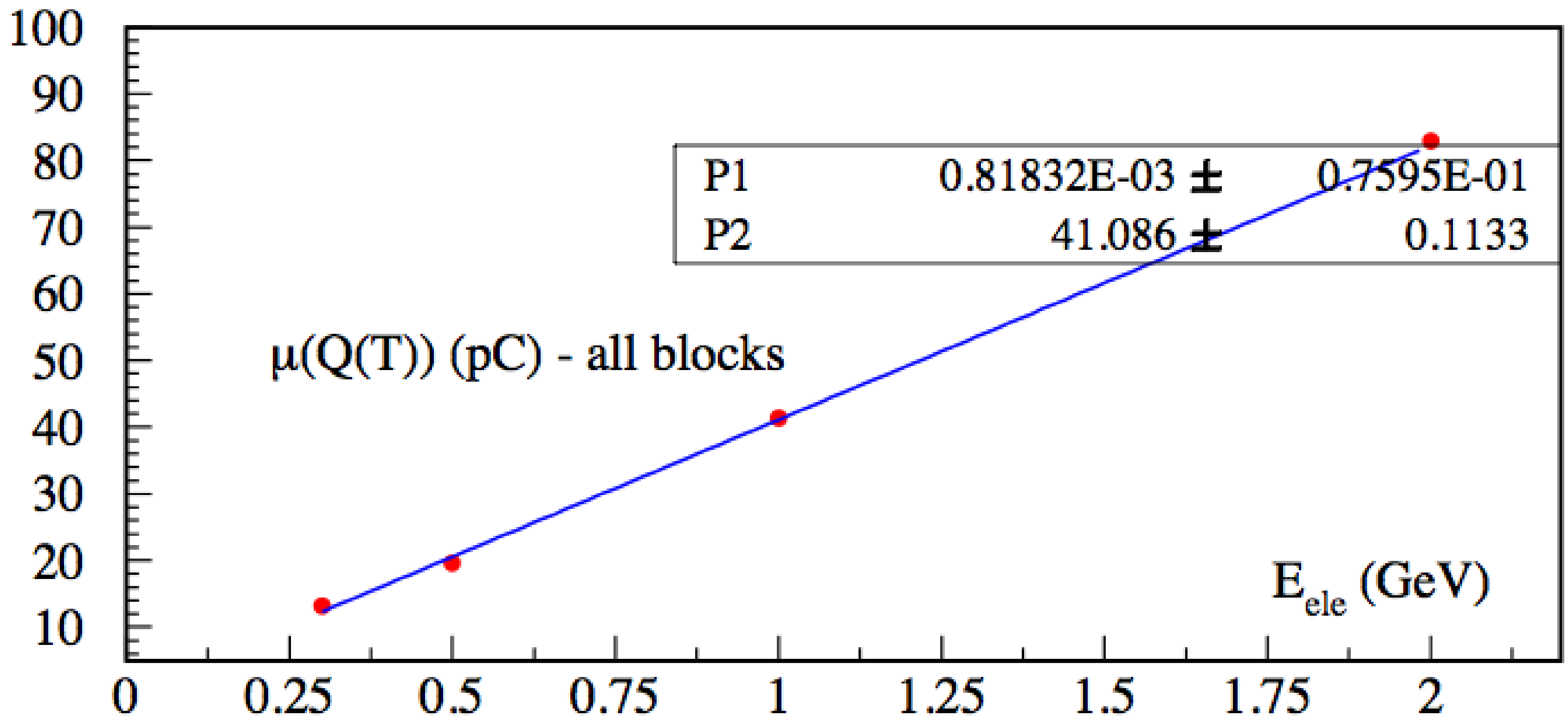




A2 test: linearity

Response linearity (electrons beam) has been proved in the range 0.3 up to 2 GeV/c, for both charge and ToT.

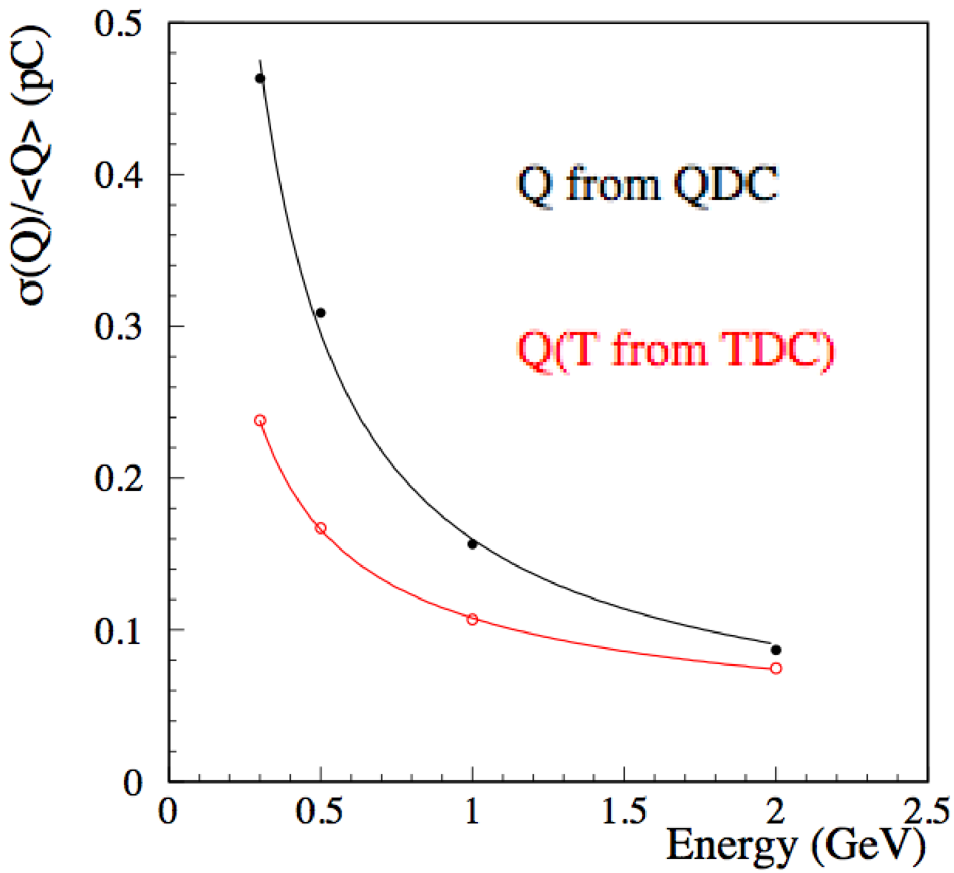
The threshold applied was 4mV, well above the observed noise level



A2 test: energy resolution

Energy resolution has been measured in the same range for 4mV threshold.
Both Q and ToT have been used.

Fitting function:
$A/\sqrt{E[GeV]} + B/E[GeV] + C$



$\sigma E/E = 0.086/\sqrt{E[GeV]} + 0.13/E[GeV]$

$\sigma E/E = 0.092/\sqrt{E[GeV]} + 0.05/E[GeV] + 0.025$

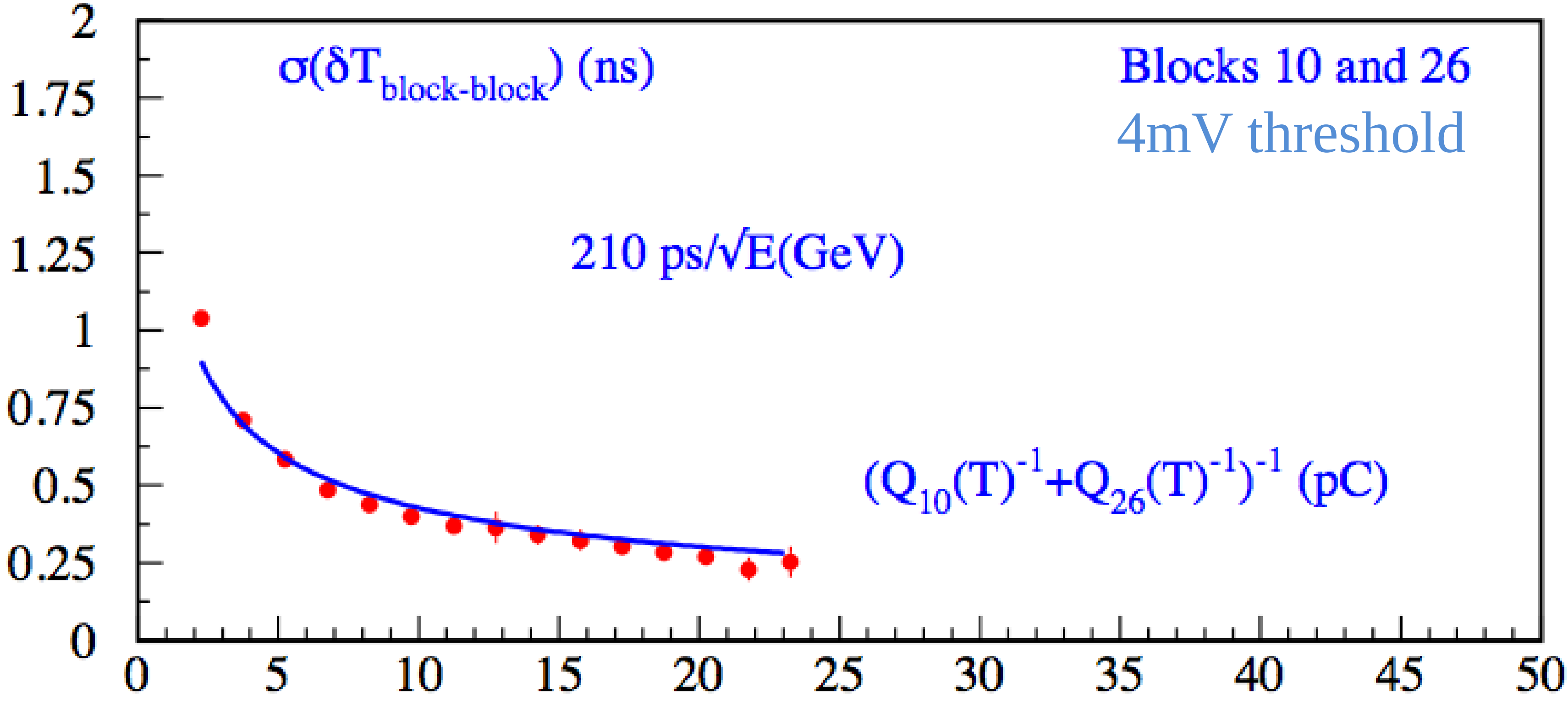
A2 test: time resolution

Time resolution has been measured using trigger time given by palettes used for tagging incoming particles and Cherenkov detectors .

Time slewing correction has been applied using the signal shape assumption:

$$V(t) \sim t^a e^{-bt}$$

In order to subtract the jitter induced by trigger we used the time difference of two consecutive blocks.

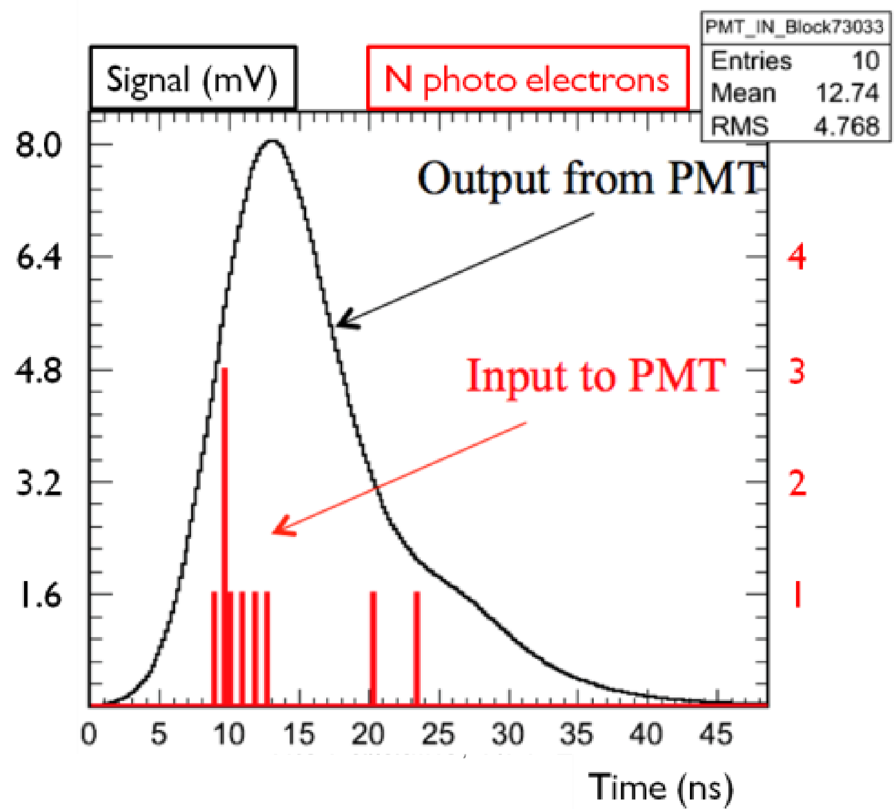


MonteCarlo simulation

A detailed MC simulation has been implemented in order to study in the LAV apparatus response and its inefficiency.

Starting from the single photons incident on photocathode MC is able to reproduce the signal shape of the PMT and evaluate the TOT.

A preliminary data/MC comparison has been done using the data collected during A2 test.



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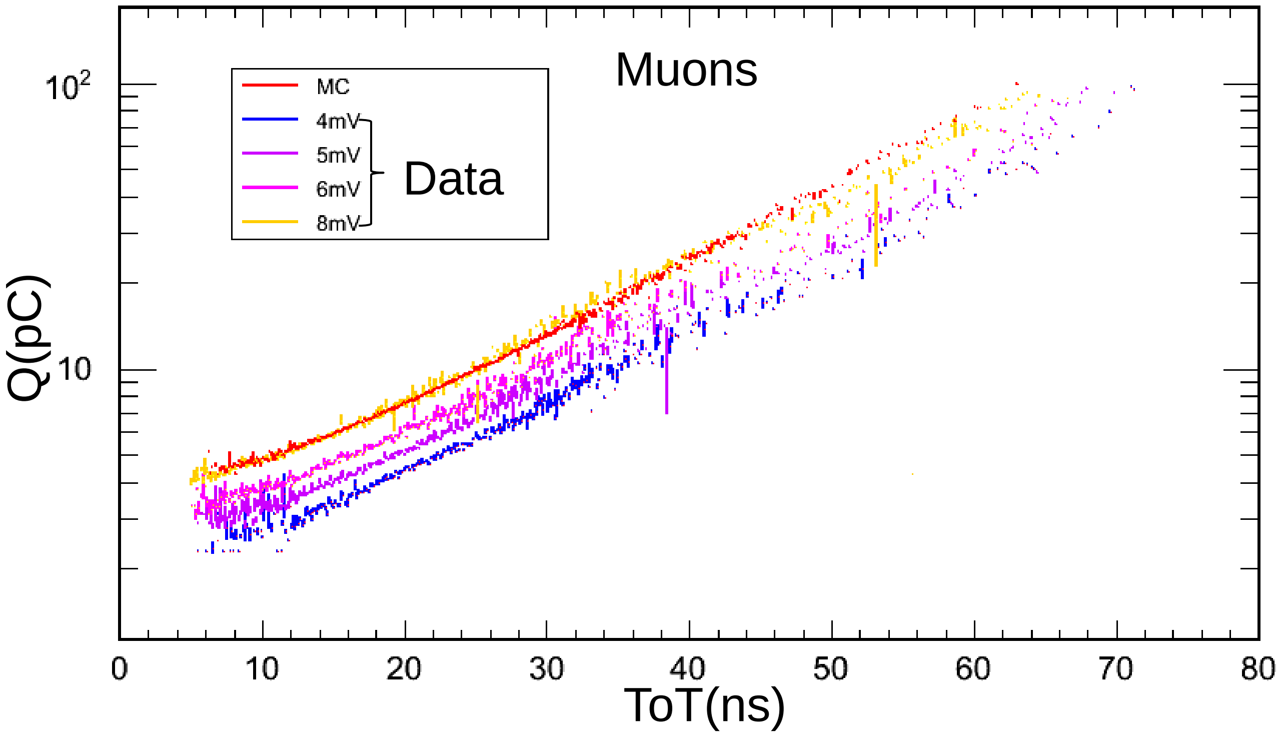

Conclusions

Large angle vetoes thorough and intense R&D phase completed. Efficiency validated. Time, energy resolution and linearity fulfill requirements in the energy range [0.3, 2]GeV/c

Massive production started, up to now five out of twelve stations are ready. These stations will be installed in July 2011. All stations will be ready for late 2012.

Accurate MC studies on going for precise geometrical and photonuclear efficiency assessment.

Thanks

Spares

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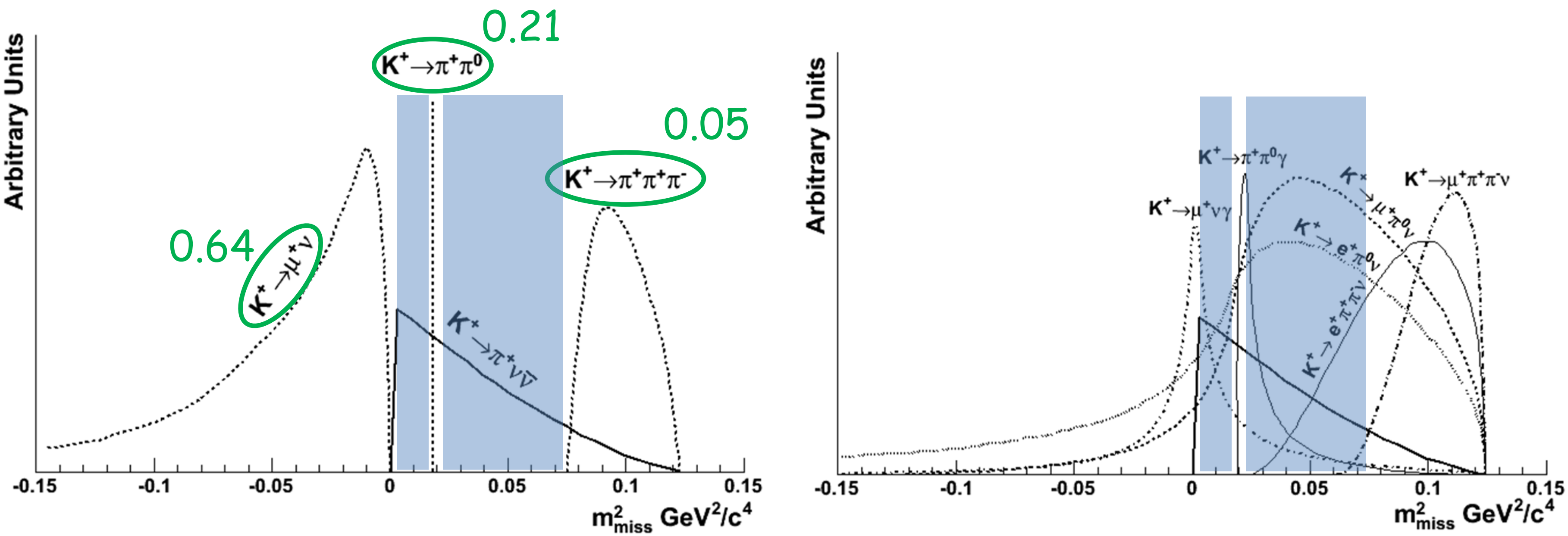

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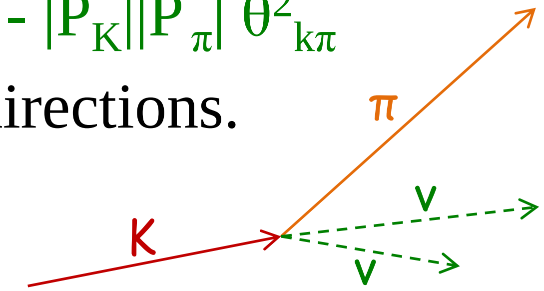
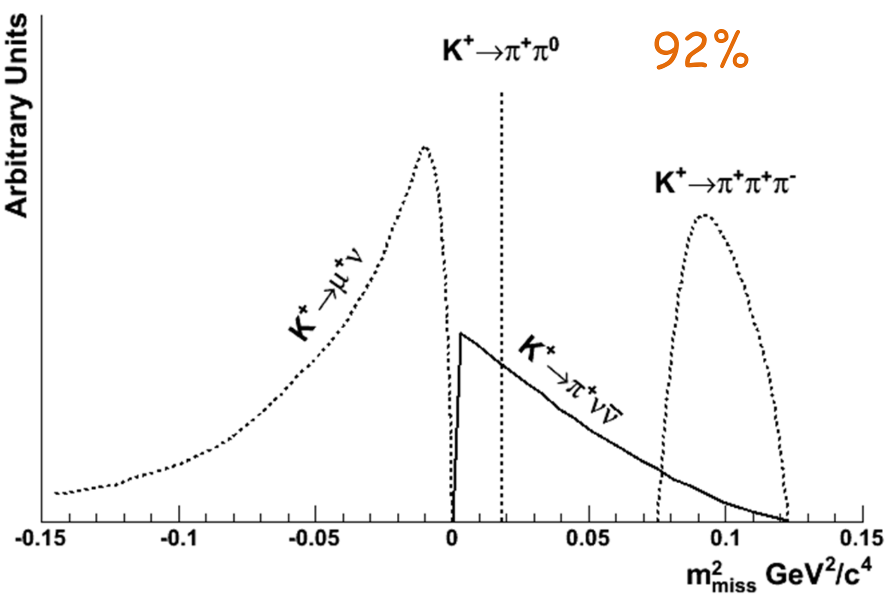
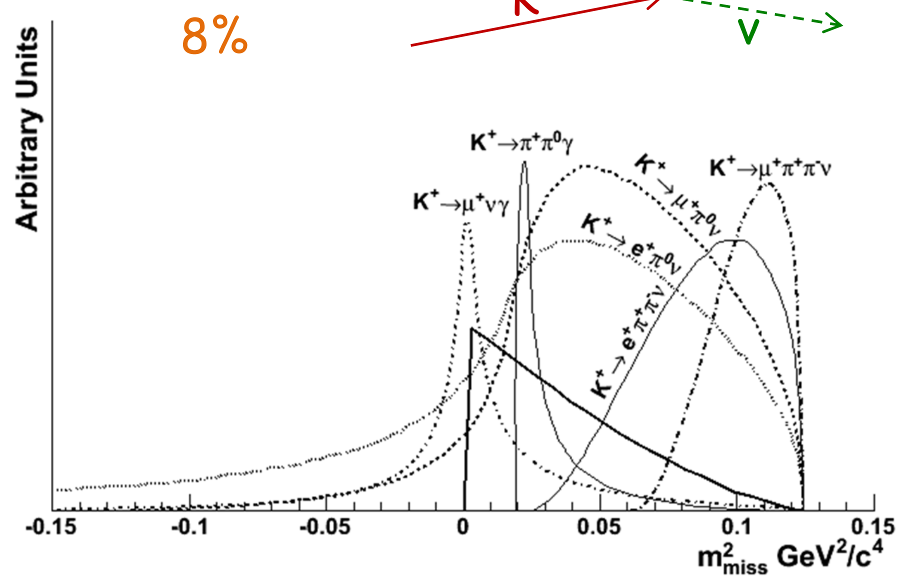
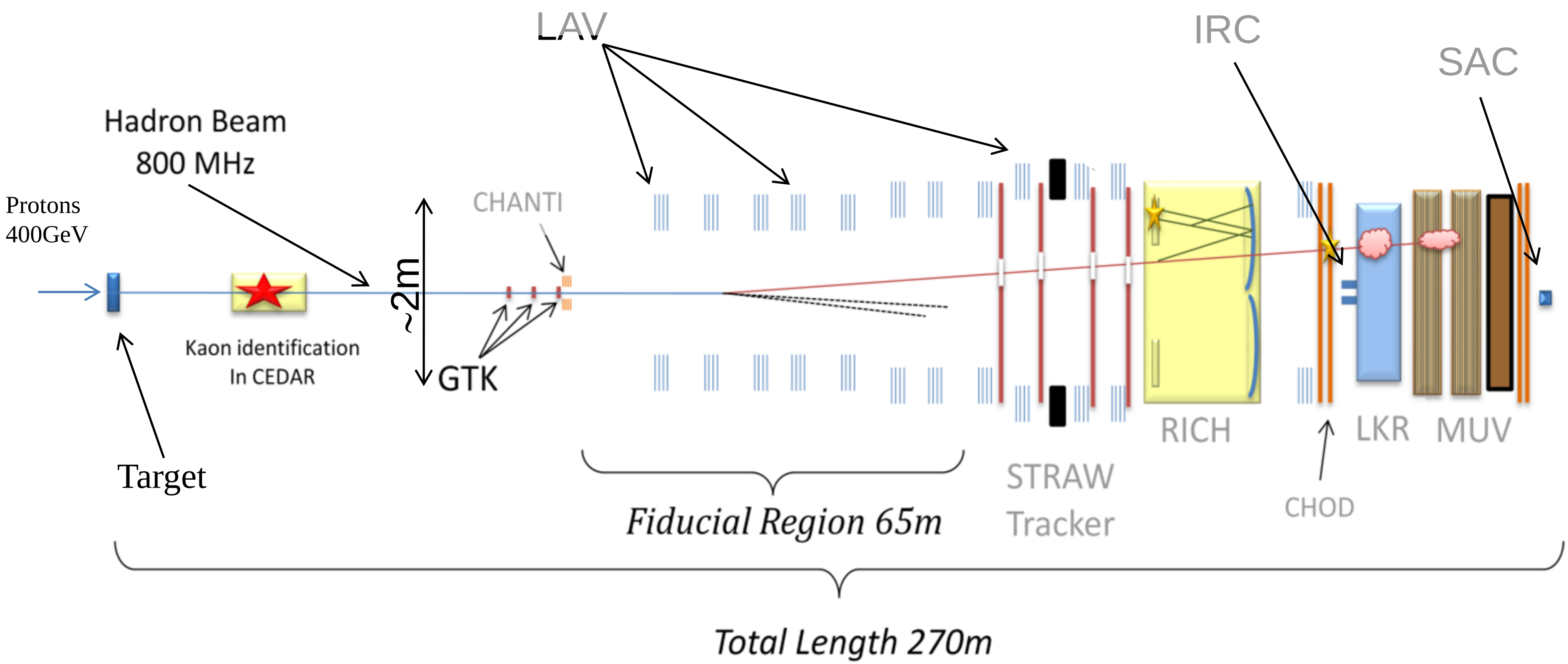






NA62 apparatus



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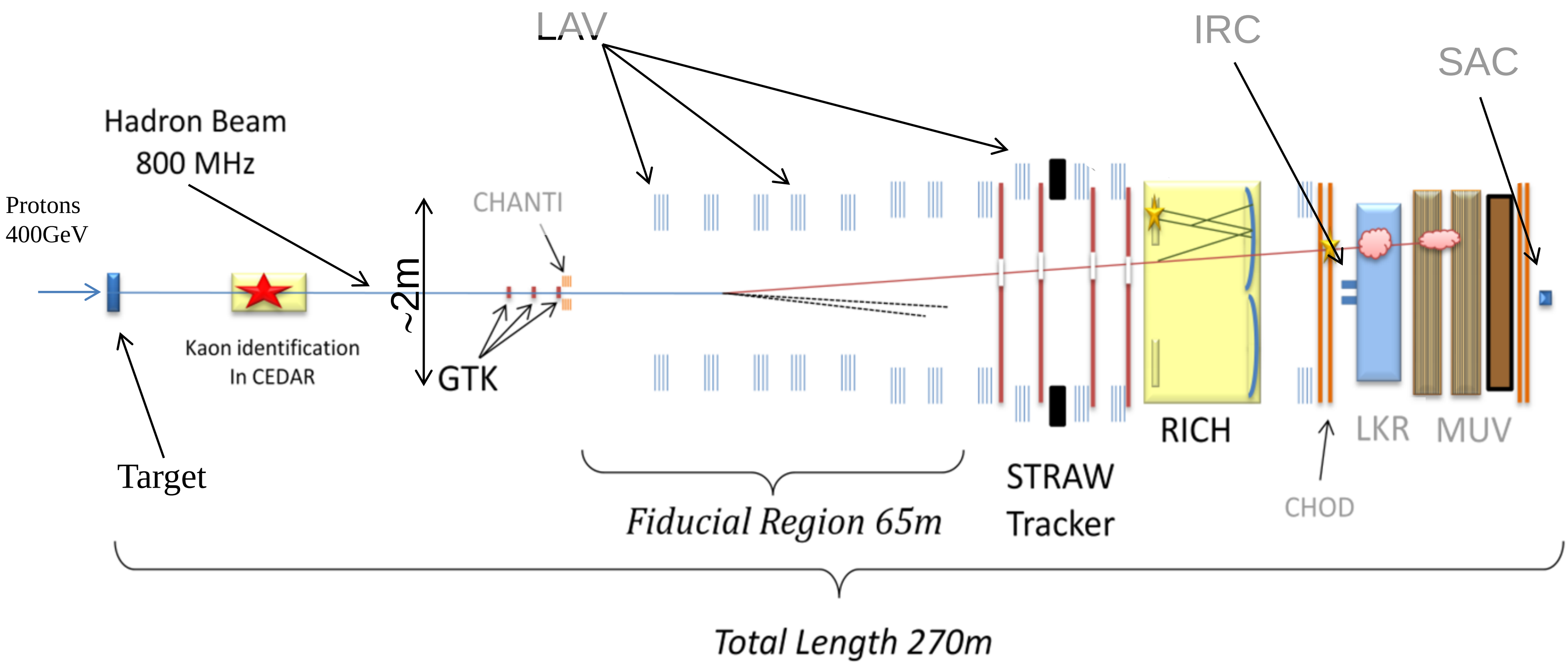

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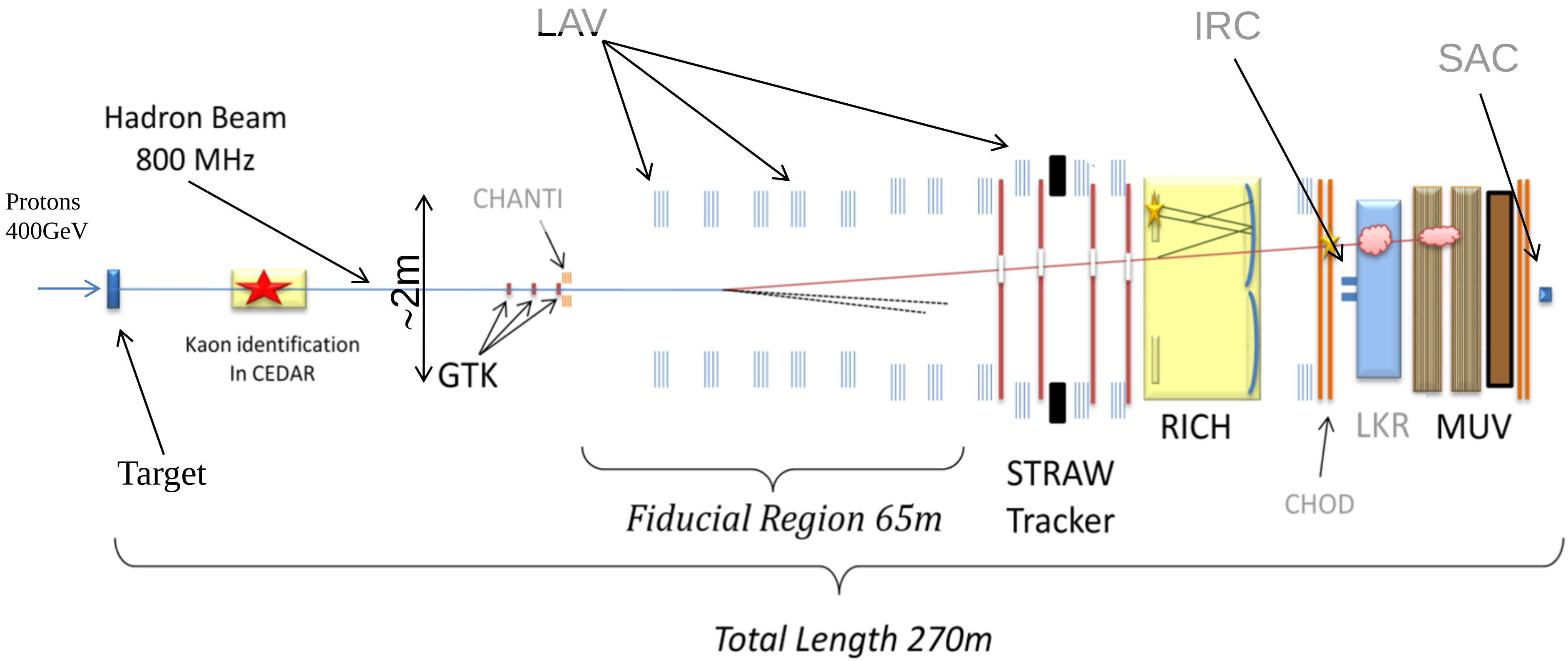

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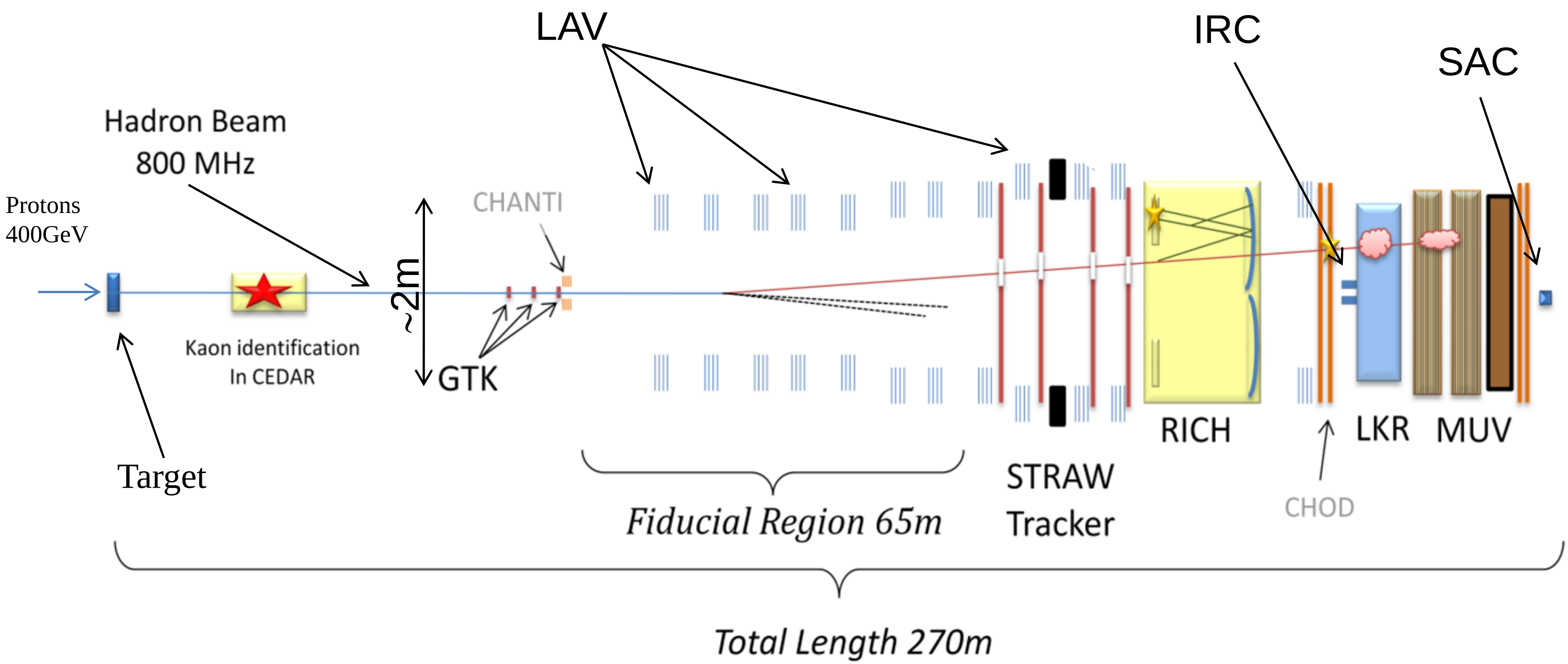

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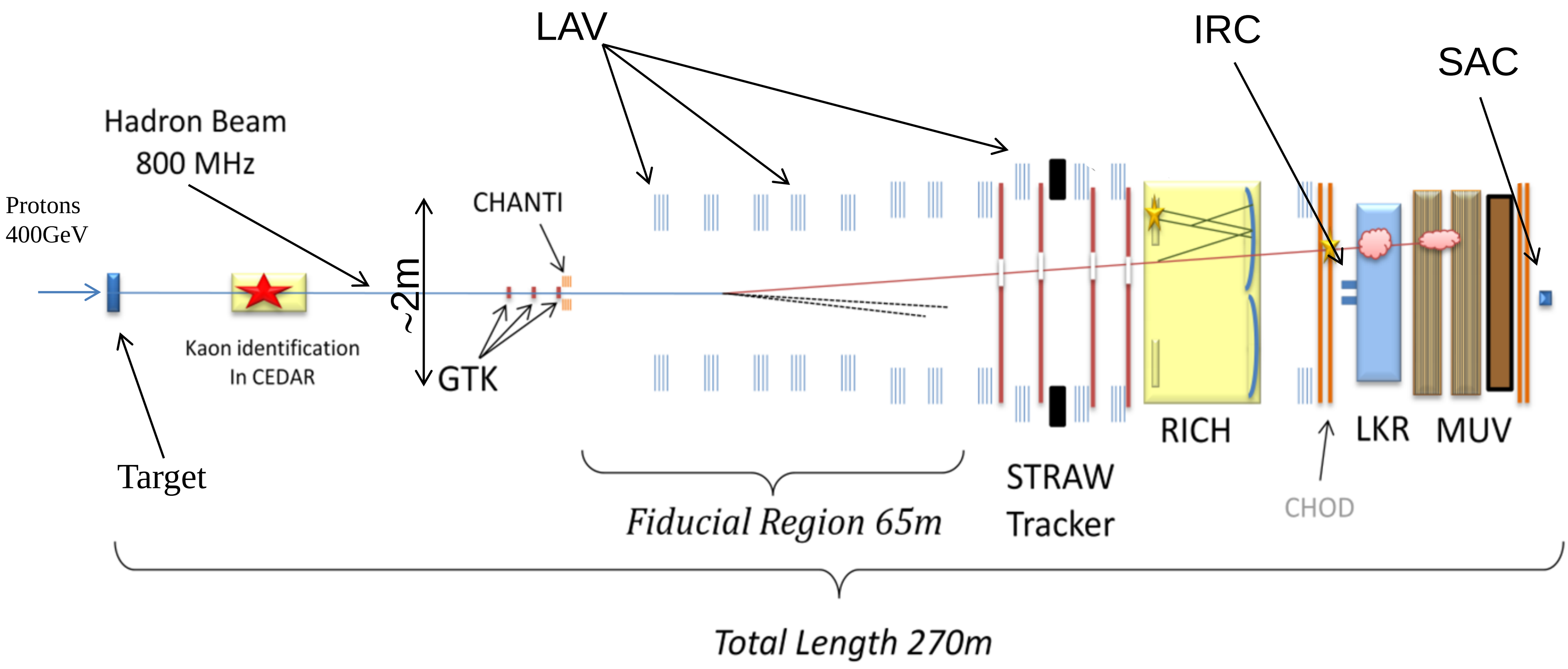
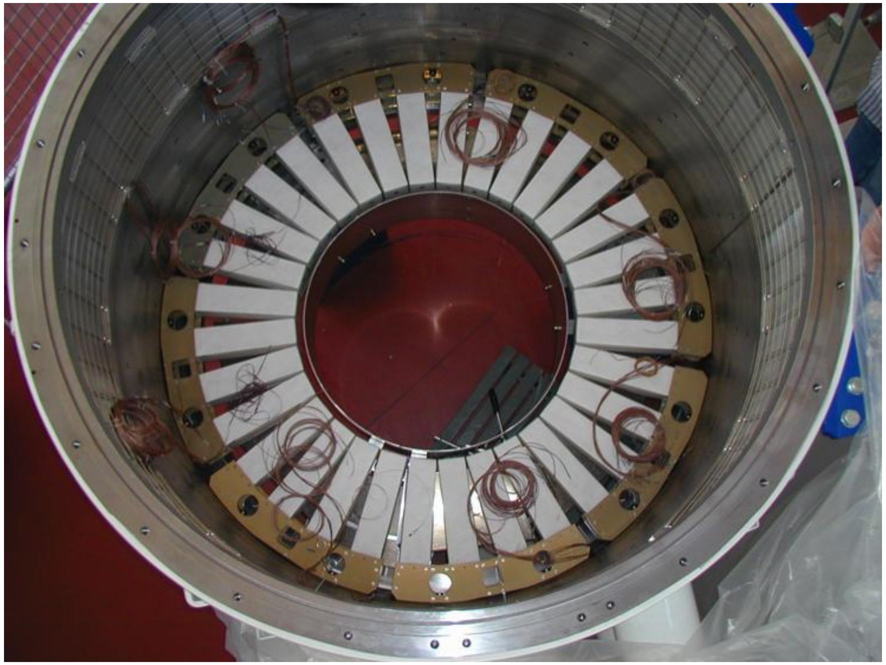
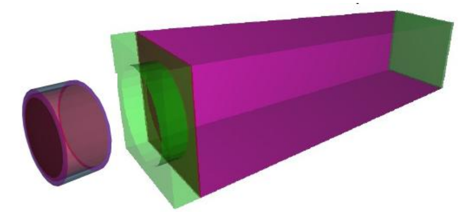


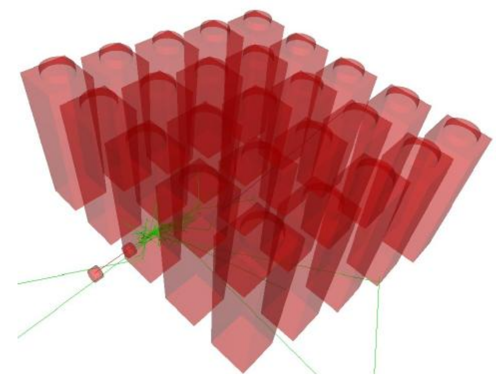
The Large Angle Veto (LAV)

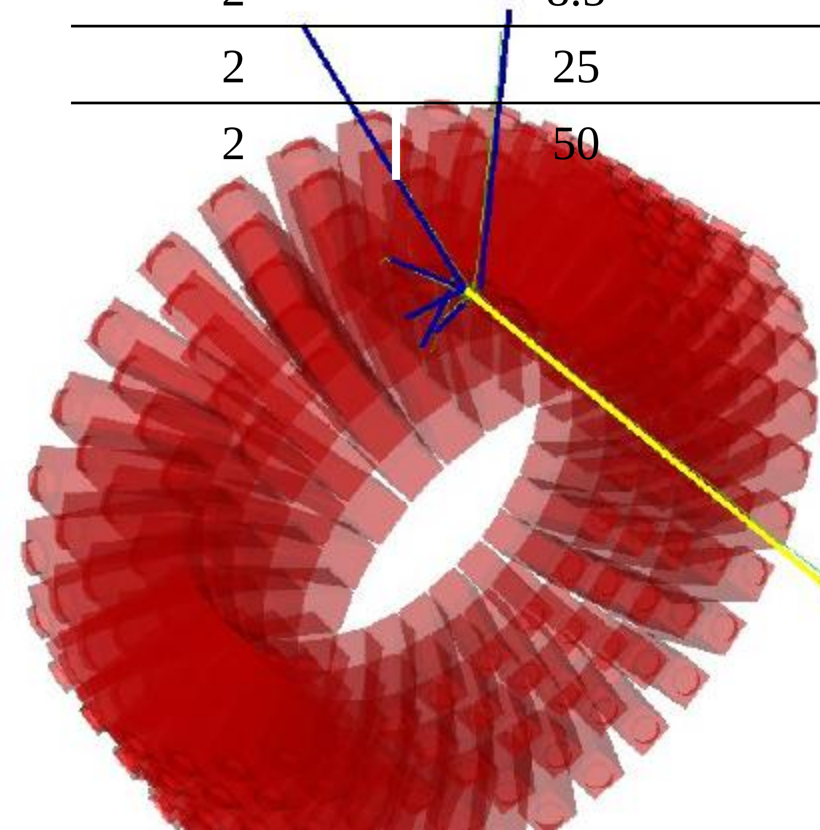


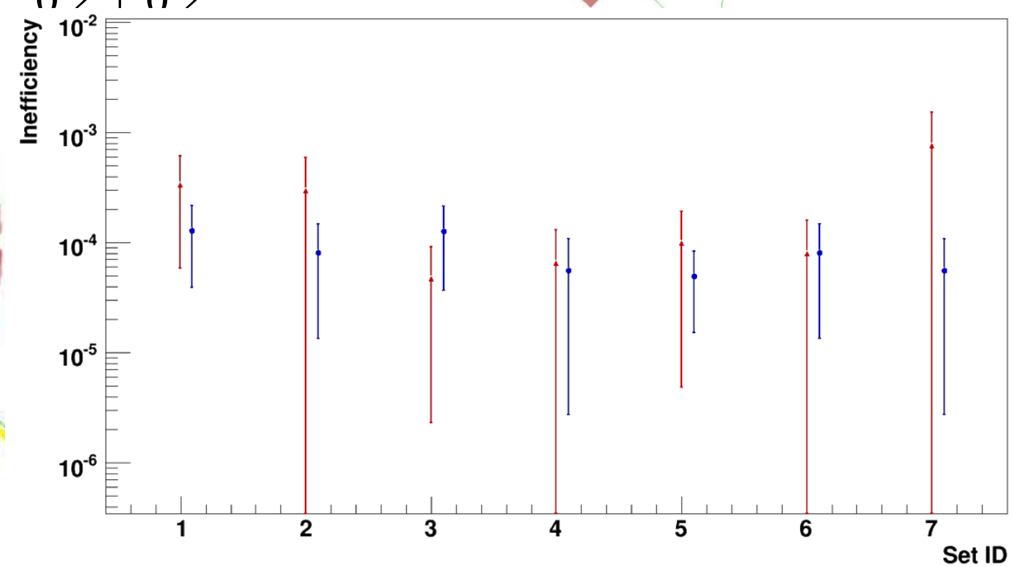
Simulations

Energy (GeV)	Angle(mrad)	Ineff (10^{-4})
0.2	8.5	10 ± 2
0.2	25	17 ± 2
0.2	50	14 ± 2
2	8.5	<0.488
2	25	0.2 ± 0.2
2	50	0.2 ± 0.2



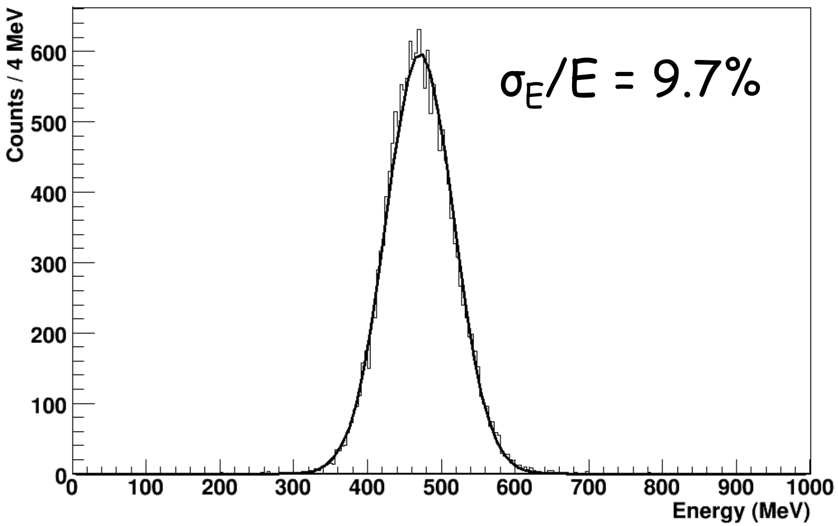






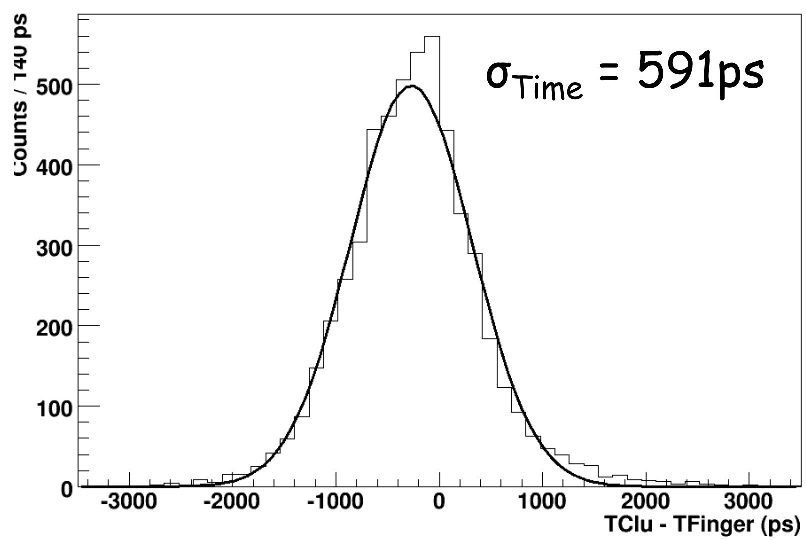
Time and Energy Resolution

Energy Resolution



Energy Resolution will be computed using data from other energies.

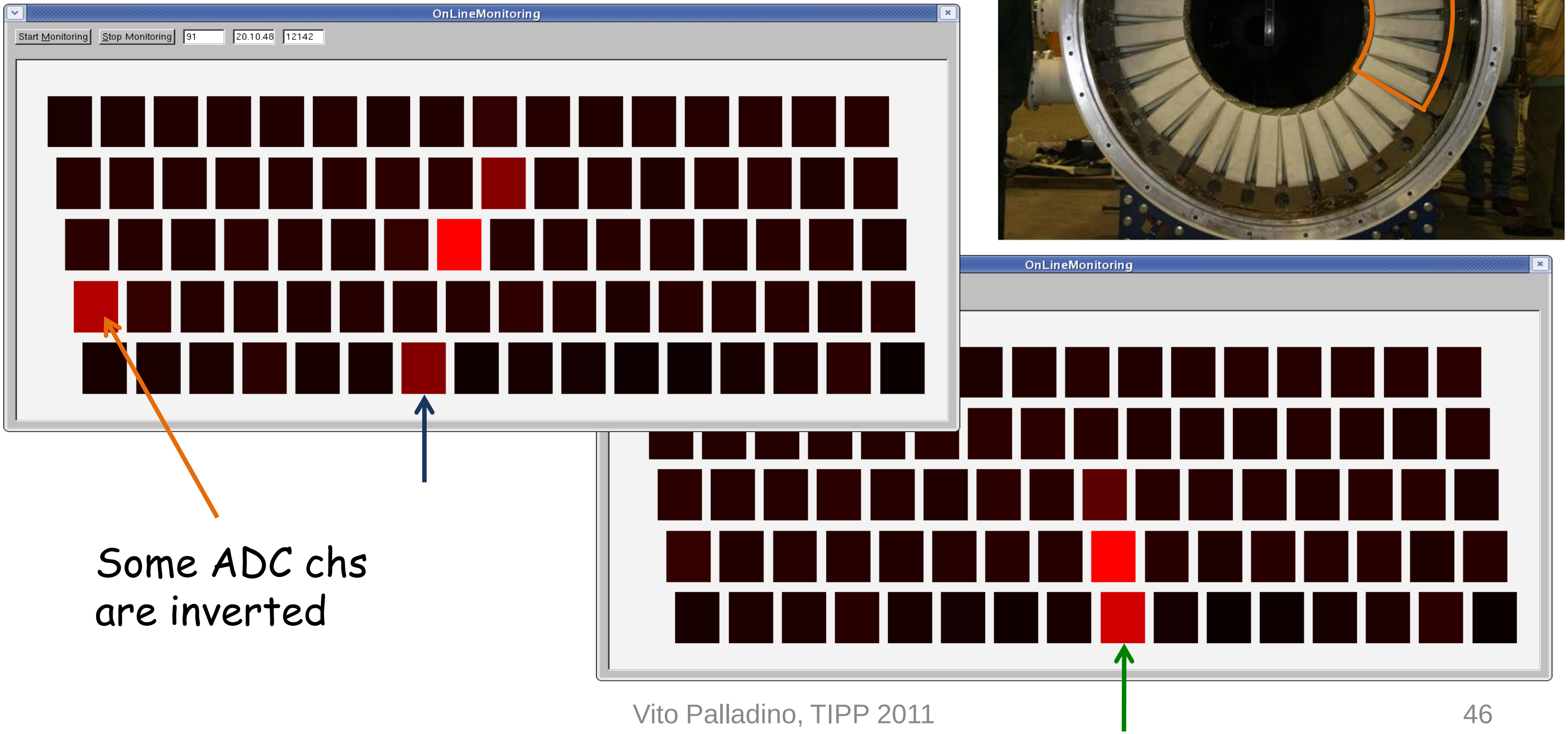
Time Resolution



Time Resolution will be subtracted by the fingers one (174ns).

ANTI A1 Test

In this test we are used commercial ADCs to validate and calibrate the ToT technique.



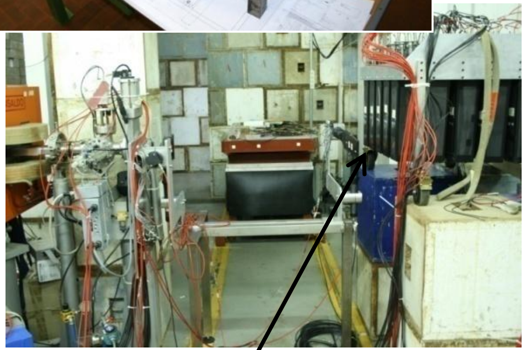
Some ADC chs are inverted

Large Angle Veto Tests

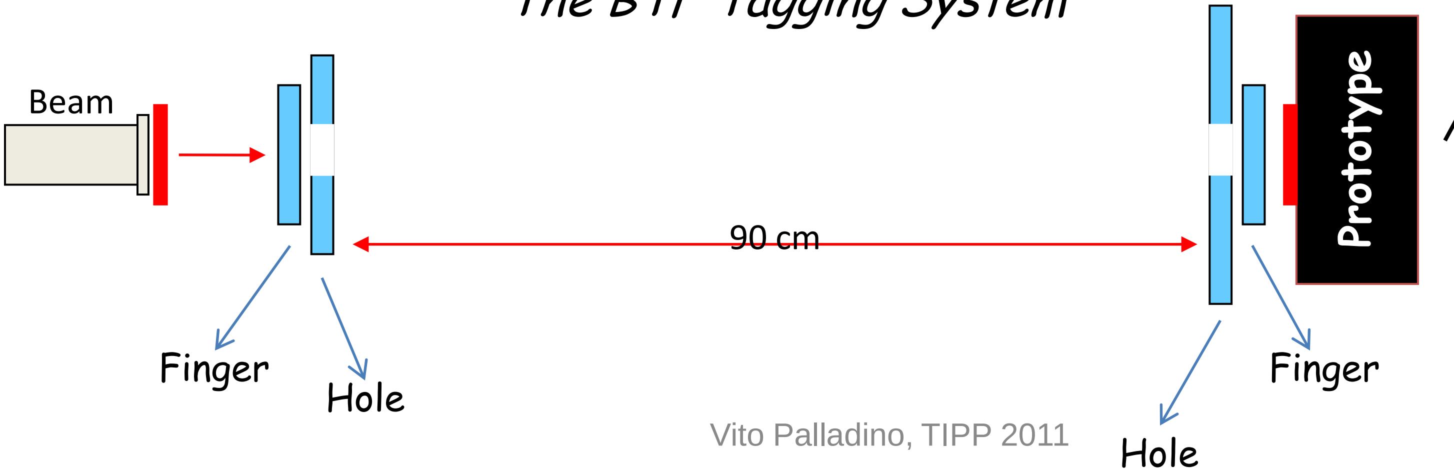
Up to now we have only one opportunity to measure the inefficiency.

The tests location was the Test Beam Facility (BTF) at Laboratori Nazionali di Frascati, that provide a beam of electrons with energy from 100 to 500 MeV.

The BTF has a tagging system that provide to define events of Single Electron, this is a mandatory request for the efficiency measurement.

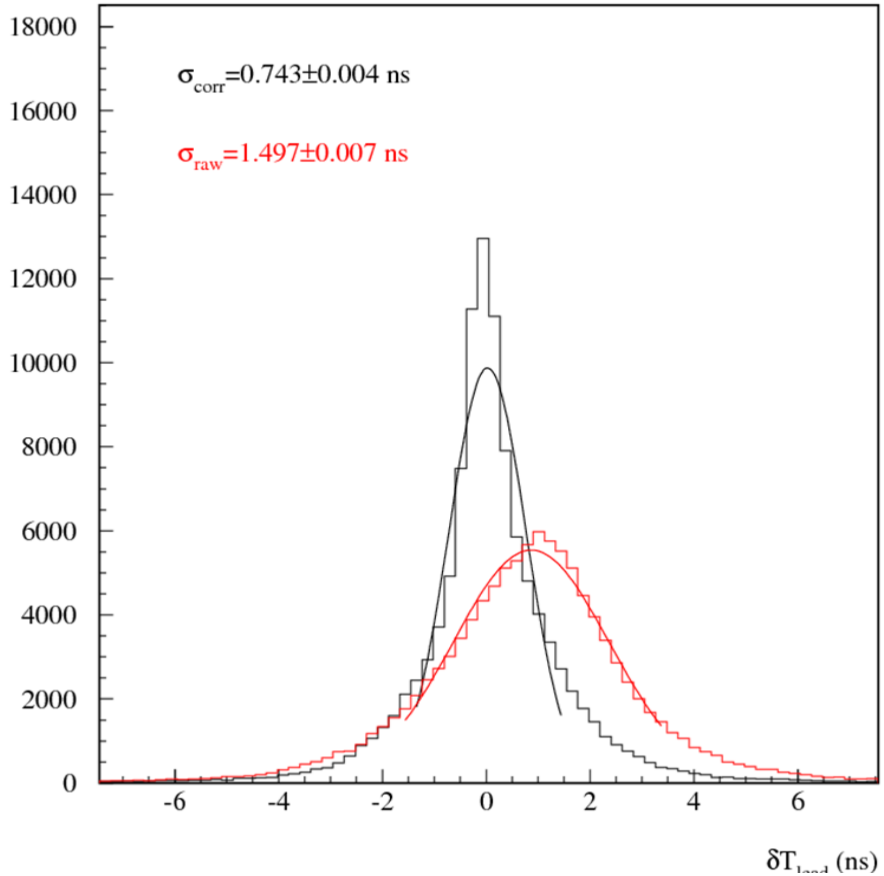


The BTF Tagging System



ANTI A1 Time Resolution

Also time resolution preliminary measurements has been done, the black line takes into account time slewing corrections:



The Large Angle Veto (LAV)

The LAV system will be composed of 12 stations.

During an intense R&D period 3 different technologies were tested:

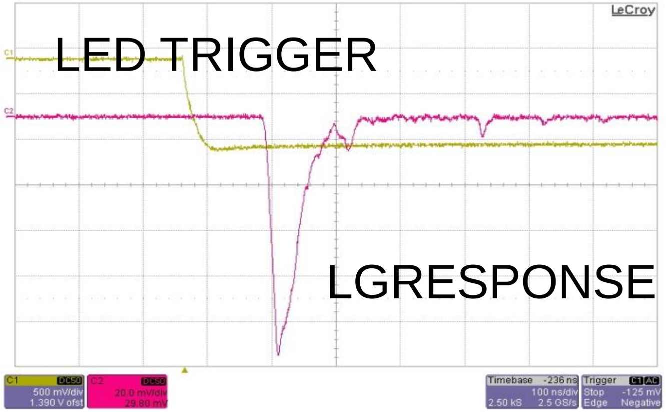
- Lead + Scintillating Fibers (constructed from scratch)
- Lead + Scintillating Tiles (FNAL loan)
- Lead Glass (OPAL gift)

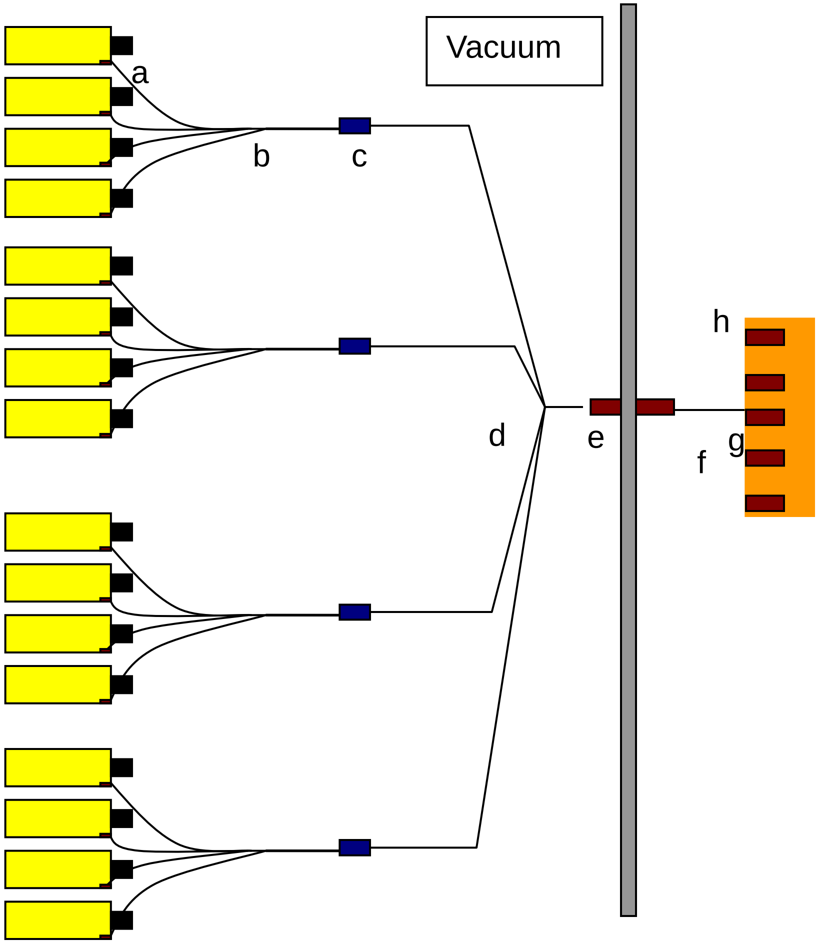
All our tests shown that the prototypes characteristics were at level our specifications. Due to the availability of a large amount of Lead Glass blocks originally used by OPAL, we choose this as our baseline solution.

Monitoring System

Each station will be equipped with a monitoring system made using optical fibers and a set of temperature stabilized LEDs with adjustable light pulse intensity. One LED pulses 16 blocks.

This system will provide us the monitoring of the gain for each block.



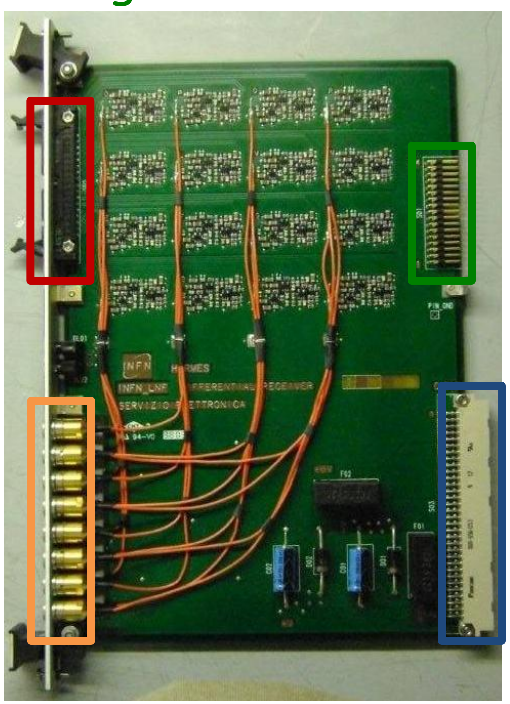


Front End Electronics

The front end electronics for LAV system requirements are:

- Energy resolution ≈ 10%/√E(GeV)
- Time resolution < 500 ps
- Max rate ≈ MHz x ch (probably lower)
- Measure energy in 20 MeV – 20 GeV range
- Signals range: from few mV to 10V

Our solution is to use the time over threshold (ToT) and a clamping stage in order to have reasonable signals without compromise the TOT.



16 ch analog in 34 pin connector
16 ch lemo analog out x1
16 ch LVDS out

4 threshold adjust (4ch each)
16 ch Low voltage suply

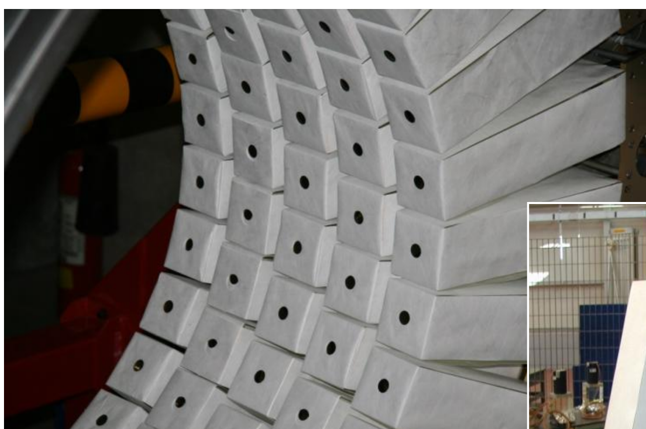
ANTI Construction

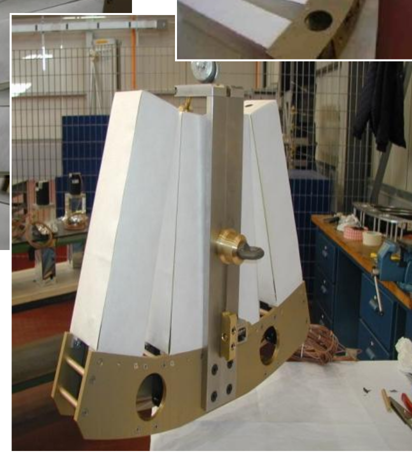
LAV modules are been assembling at LNF (Laboratori Nazionali di Frascati).

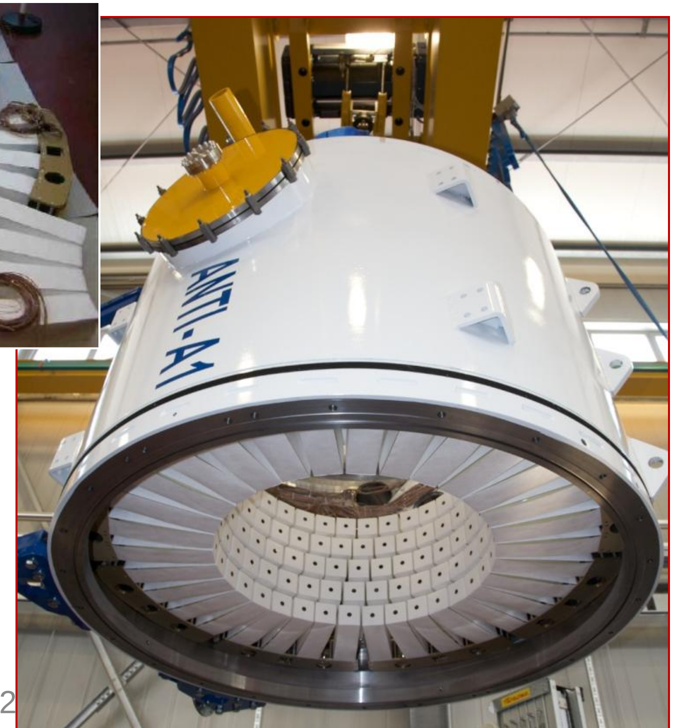
The OPAL lead glass blocks, has been arranged in elementary “Bananas”.

Our request on the efficiency is reached rearranging the LGs in 5 staggered layers configuration, in order to have at least three modules involved in detection.

The number three is in order to have at least 20 X_0 needed for the inefficiency requests.



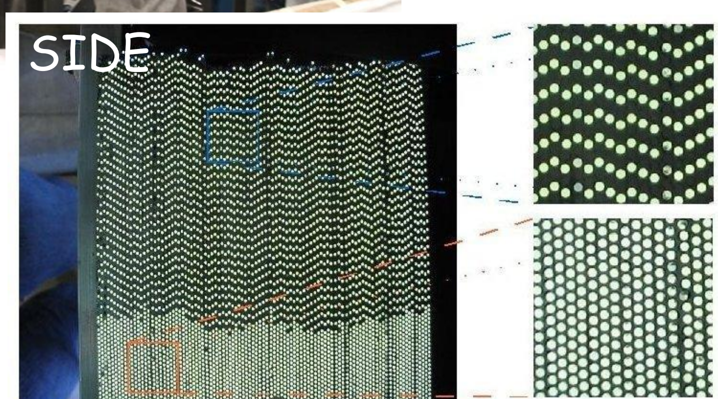


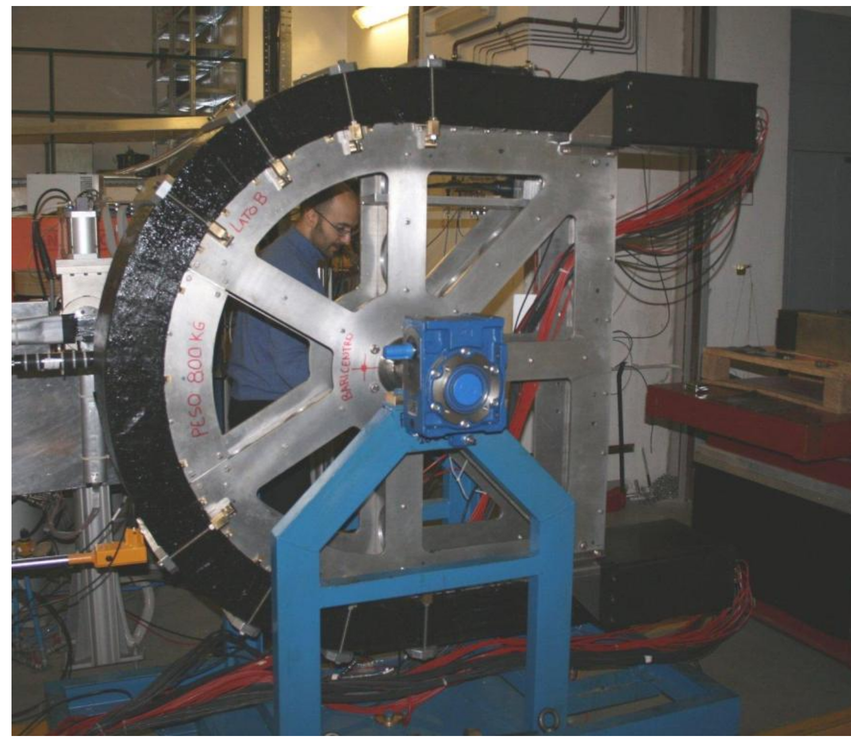


Lead + ScFibers Solution

This solution is based on the realization of a sampling detector whose active material is a matrix of scintillating fibers (1mm Ø) glued between thin (0.5 mm thickness) lead layers.

The ring may be made by superimposing two U shaped modules.





Lead Glass Results (Preliminary)

First test

Beam Energy[MeV]	*Tagged Events*	*Event with E<50MeV*	*1-ε(Inefficiency)*
203	65 069	3	$1.2^{+0.9}_{-0.8} \times 10^{-4}$
483	91 511	1	$1.1^{+1.9}_{-0.7} \times 10^{-5}$

Second Test

Central Incidence

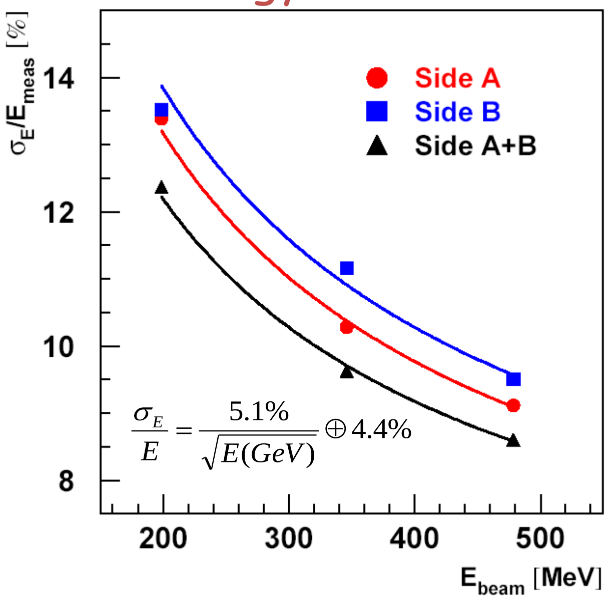
Beam Energy[MeV]	*Tagged Events*	*Event with E<50MeV*	*1-ε(Inefficiency)*
471	22 703	1	$4.4^{+7.6}_{-2.8} \times 10^{-5}$

On edge Incidence

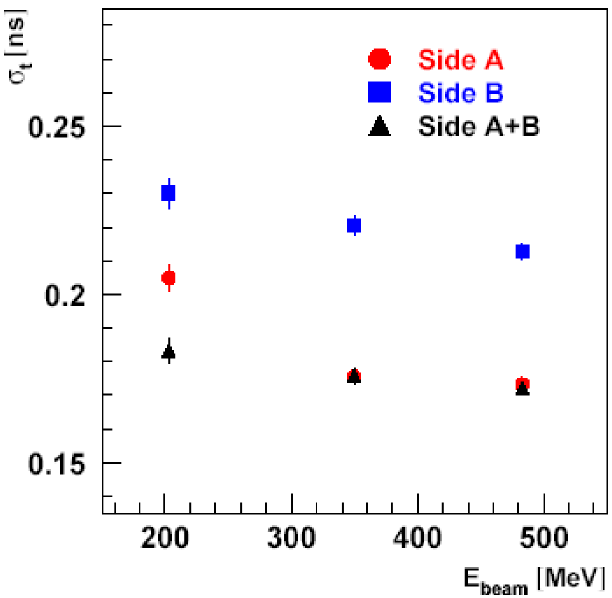
Beam Energy[MeV]	*Tagged Events*	*Event with E<50MeV*	*1-ε(Inefficiency)*
471	9 711	1	$1.03^{+1.75}_{-0.65} \times 10^{-4}$

Lead+ScFibers Test Beam

Energy Resolution



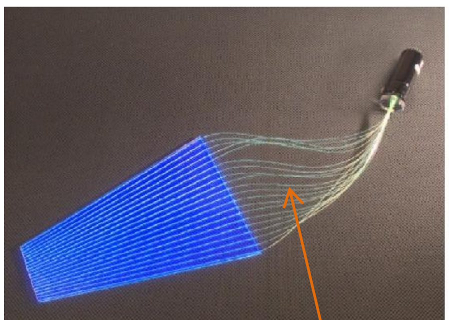
Time Resolution



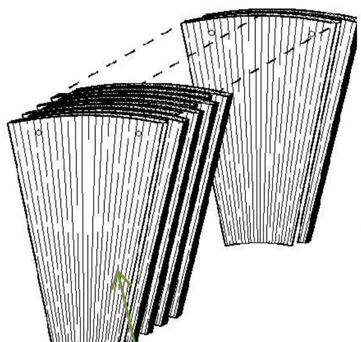
Beam Energy[MeV]	Tagged Events	Event with E<50MeV	1-ε(Inefficiency)
203	68 829	5	$7.3^{+4.1}_{-3.3} \times 10^{-5}$
350	207 385	3	$1.4^{+1.1}_{-0.9} \times 10^{-5}$
483	371 633	1	$2.7^{+4.7}_{-1.7} \times 10^{-6}$

Lead + ScTiles Solution

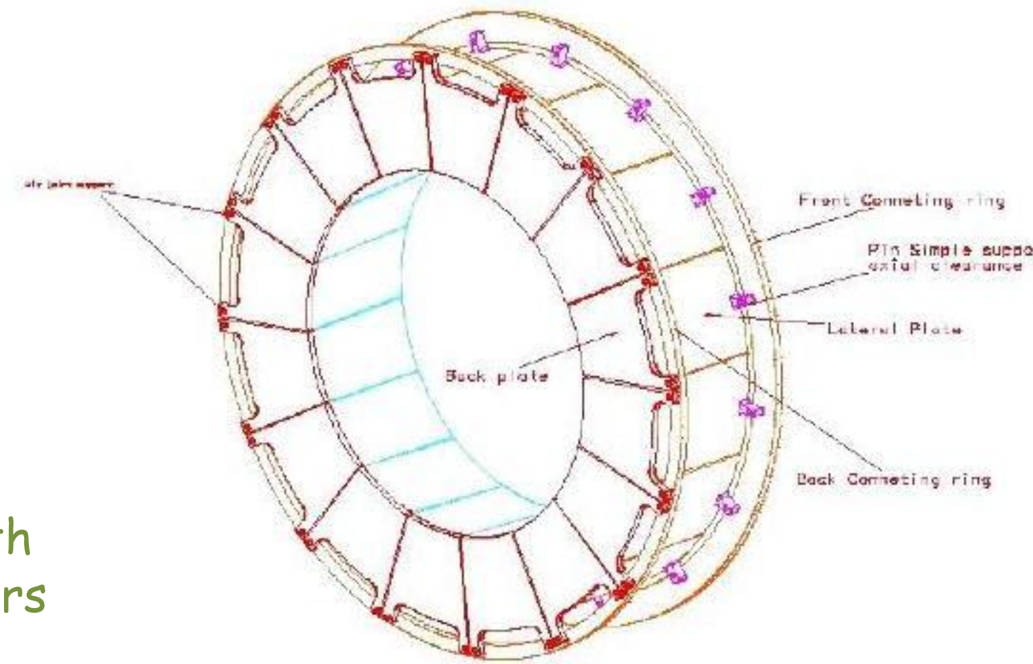
This solutions was designed by CKM Collaboration (FNAL). It consist of a sampling calorimeter that alternate lead (1mm) and scintillator (5mm) tiles. The ring was 16 X_0 long, and was made by 16 sectors. The scintillating layers was read by Wave Length Shifters Fibers.



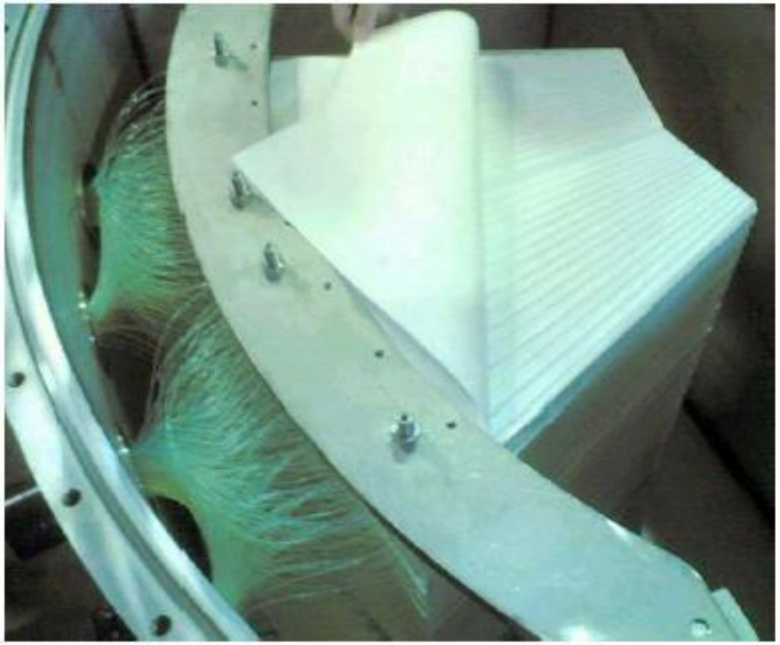
WLS



One sector with staggered layers



Lead+ScTiles Test Beam Results (Preliminary)

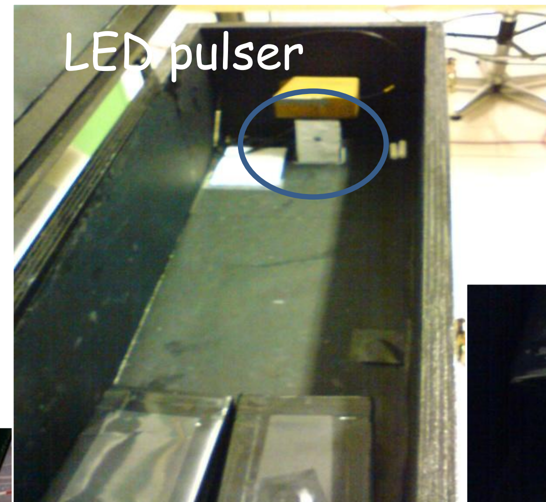


Beam Energy[MeV]	*Tagged Events*	*Event with E<50MeV*	*1-ε(Inefficiency)*
203	65 165	2	$3.1^{+3.5}_{-1.9} \times 10^{-5}$
350	221 162	3	$1.4^{+1.0}_{-0.9} \times 10^{-5}$
483	192 412	1	$5.2^{+9.1}_{-3.3} \times 10^{-6}$

Block commissioning

LAVs need about 2500 blocks.
All of them need to be characterized.

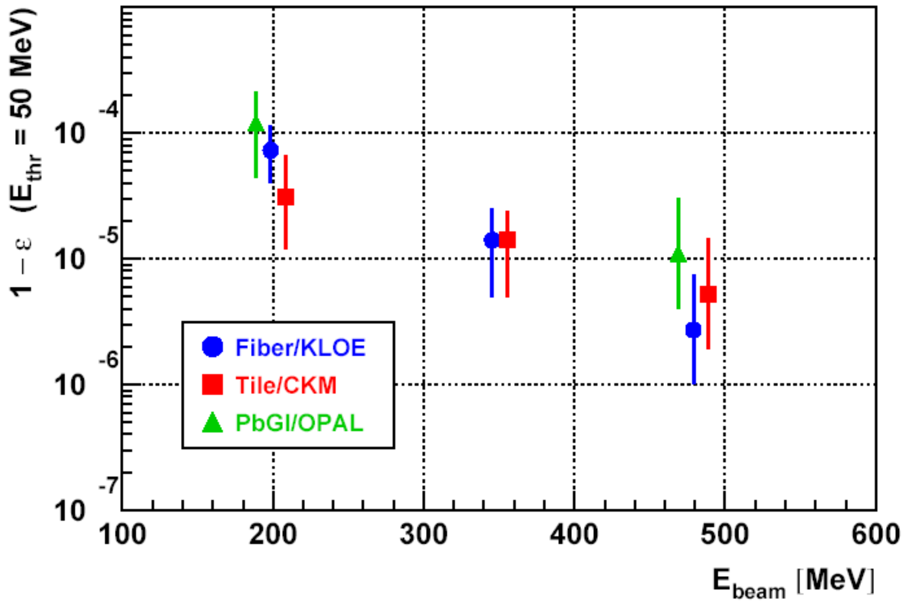
μ



Test with cosmics was able to equalize "a priori" all the blocks response.

A preliminary test wih LED was able to measure the PM quantum efficiency and made a first quality selection.

Conclusions



All our tests have shown that the prototypes characteristics were at level (and beyond !) our specifications for the inefficiency on low energy electrons.
Due to the availability of a large amount of Lead Glass blocks originally used by OPAL, we choose this as our baseline solution for the realization of the LAV system.

Future Plans

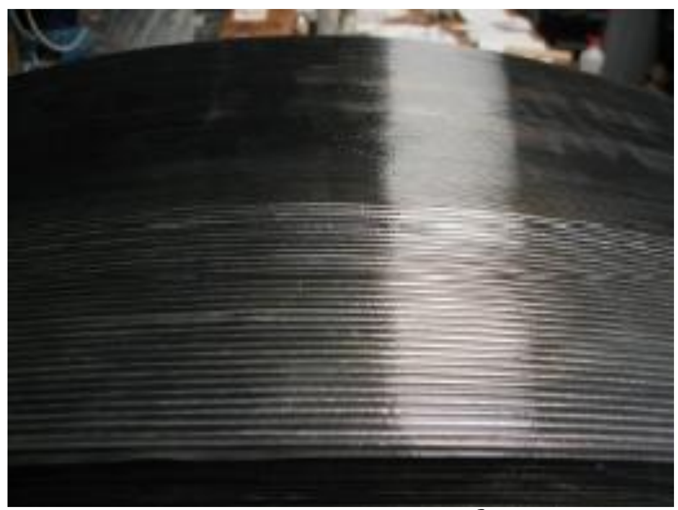
Next months will be full of events:

- After some problems with the storage of the LGs (the storage area has been flooded), we are working for defining a procedure for cleaning and test half of the LGs needed for the whole project (~1000).

- Starting from September is scheduled a test of a sector of a ring at CERN on a K^+ beam to evaluate the performance of the device for photons and investigate the effects of the muon halo .

- In the same period of the test we will start the realization of the first prototype (Module 0) of the whole ring. This prototype will be used as one of the LAV station of the apparatus.

Lead+ScFibers Construction



Layer aspect after fiber and cables positioning

Lead+ScFibers Construction