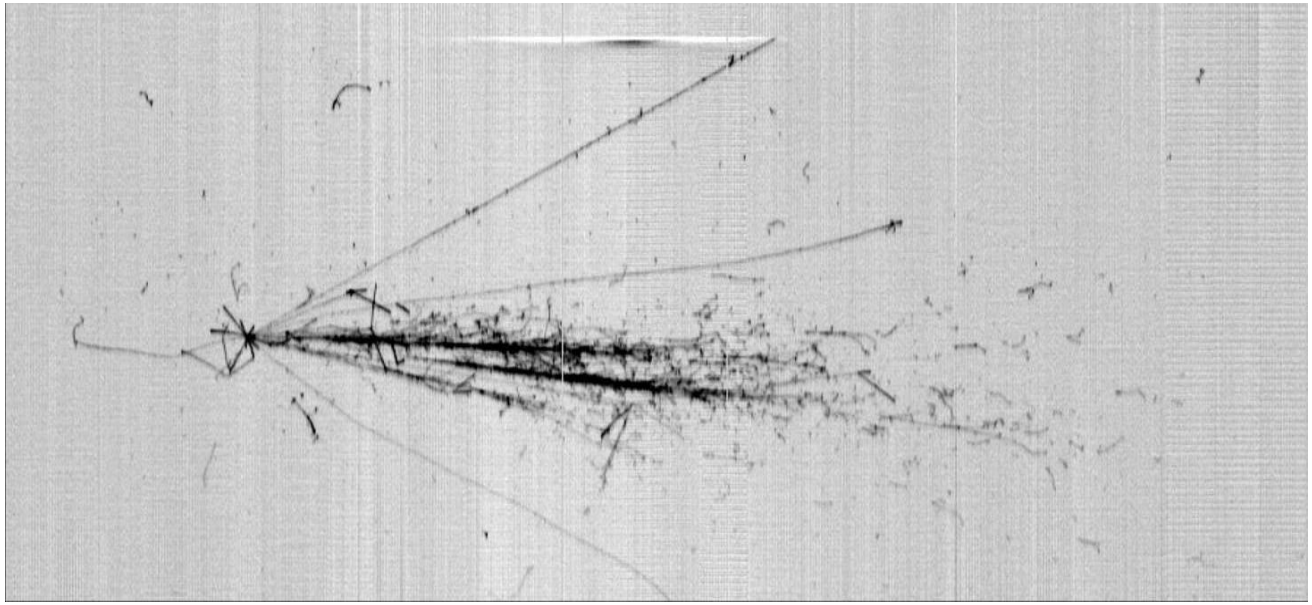
Calibration measurements from ICARUS

Christian Farnese (University of Padova)
and Filippo Varanini (INFN Padova)



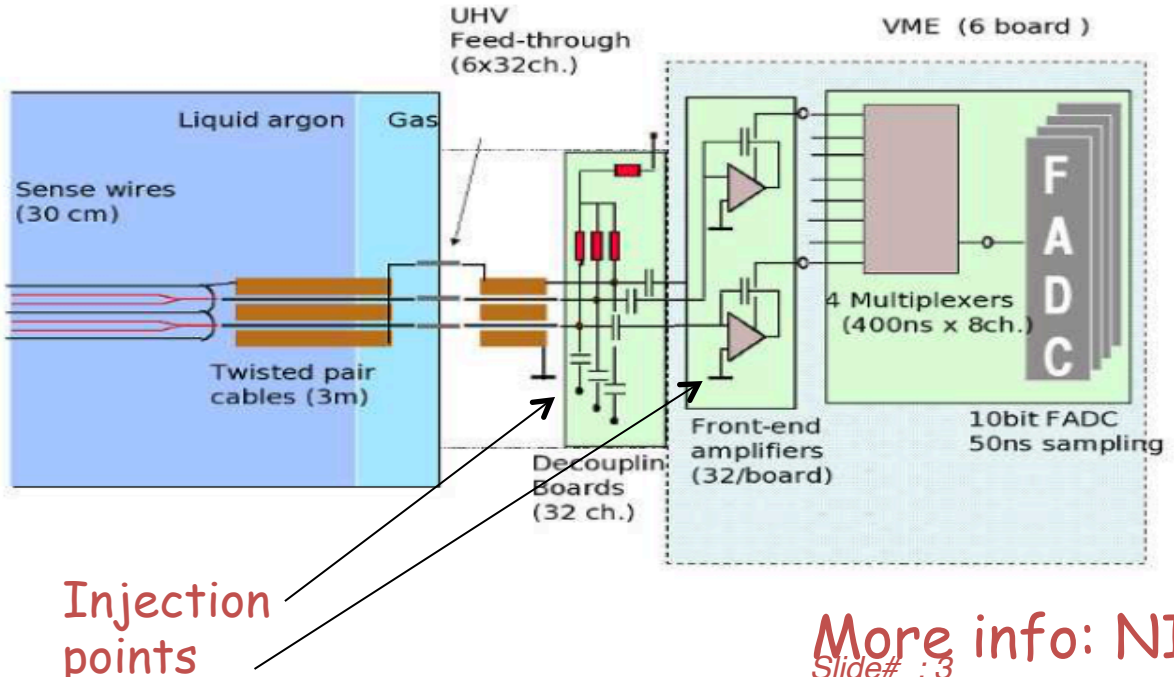
DUNE Calibration mini-workshop, July 26th, 2017

Outline

- Calibration algorithms for energy reconstruction are described:
  - Study of uniformity of front-end electronics response
  - Calibration with physical signals (stopping muons, p0)
  - Cross-check of global calorimetric reconstruction for neutrino events
- Estimation of liquid Argon purity and its uniformity
- Study of the effect of drift field disuniformities

Wire signal calibration

- The study of front end electronic response was performed injecting charge pulses (TP) into the individual channels through dedicated capacitors
  - Two independent injection points (at the decoupling board level and on the analogue board itself).
- The comparison of the two independent injection systems allows to address the uniformity of the response.



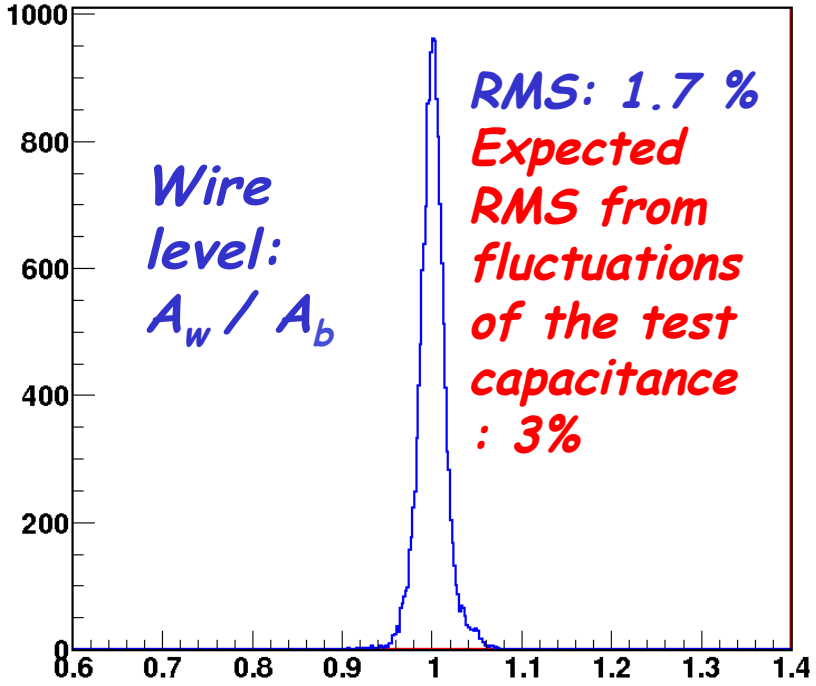
Very simplified scheme of the ICARUS electronics used during the Gran Sasso run

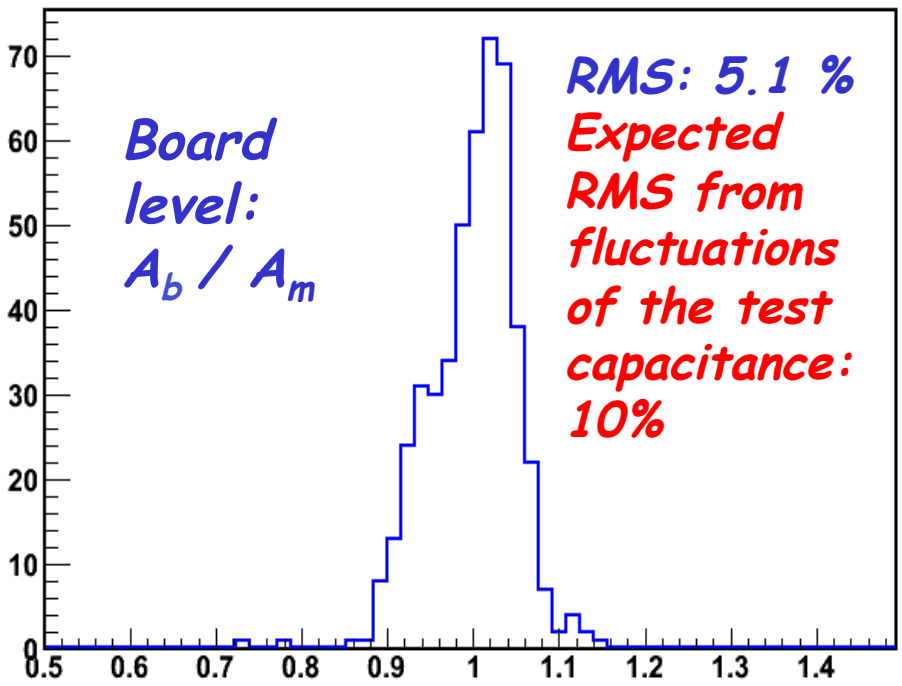
More info: NIM A 527 329-410 (2004)

Wire signal calibration

- Two TP campaigns have been performed during the Gran Sasso data taking to verify the stability of the wire signals response: at the beginning of the run in 2010 and at the end of the run in 2013.
- In both campaigns the test pulse signals have been injected both in the analogue and in the decoupling boards in order to compare the results from these two different injection points.
- For each TP event collected, the test pulse signal on each wire was automatically identified and fitted in order to evaluate the test pulse height and the test pulse area A.
- Using 100 events, the average TP area is calculated:
  - for each wire: A_w
  - for each board (averaging over the 32 wires): A_b
  - for each module (averaging over the boards): A_m

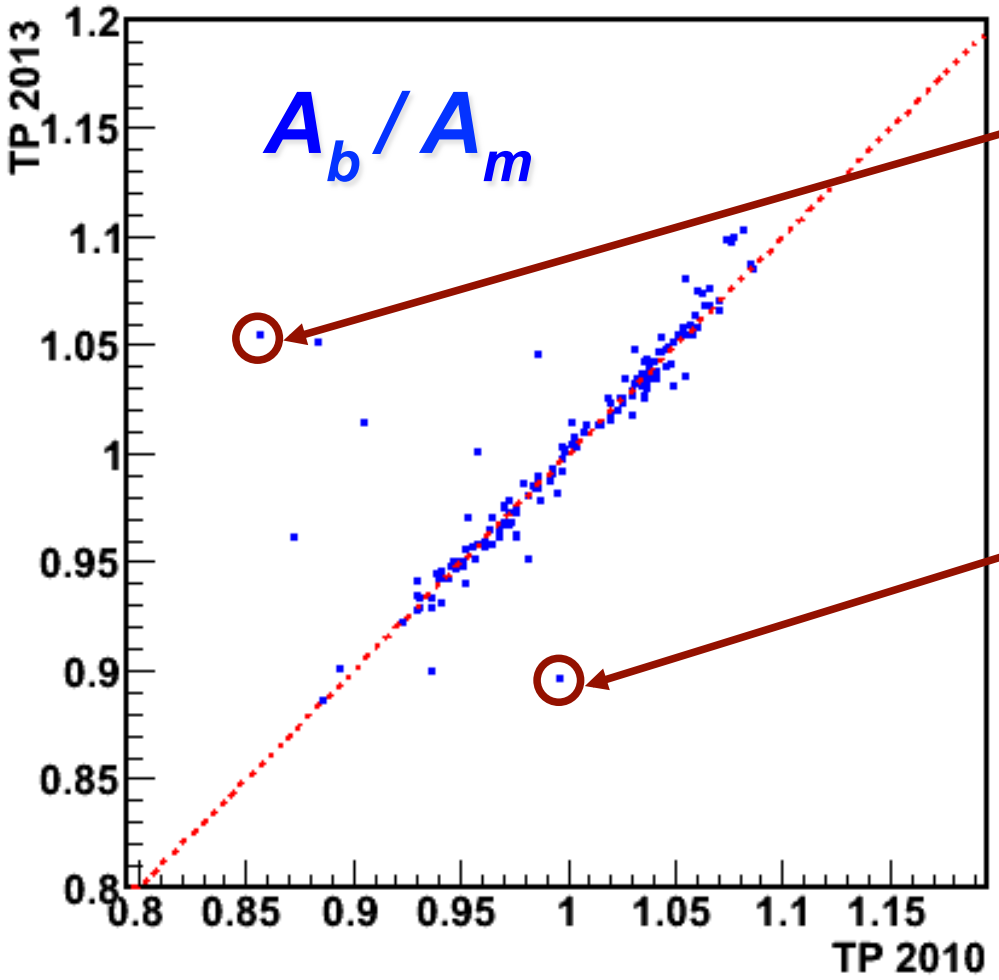
Wire Signal Calibration results





- The RMS of the distribution of the TP area turns out to be smaller than the theoretical tolerances of capacitances used to inject the TP;
- The comparison of the 2 independent injection channels ensures that:
  - the dispersion of the front end electronic response within a 32 channels card is $\lesssim 1$ %
  - the dispersion of the electronic response between different cards is $\lesssim 3$ %

Wire Signal Calibration Results: comparison 2010-2013 runs



Board changed! March 2011

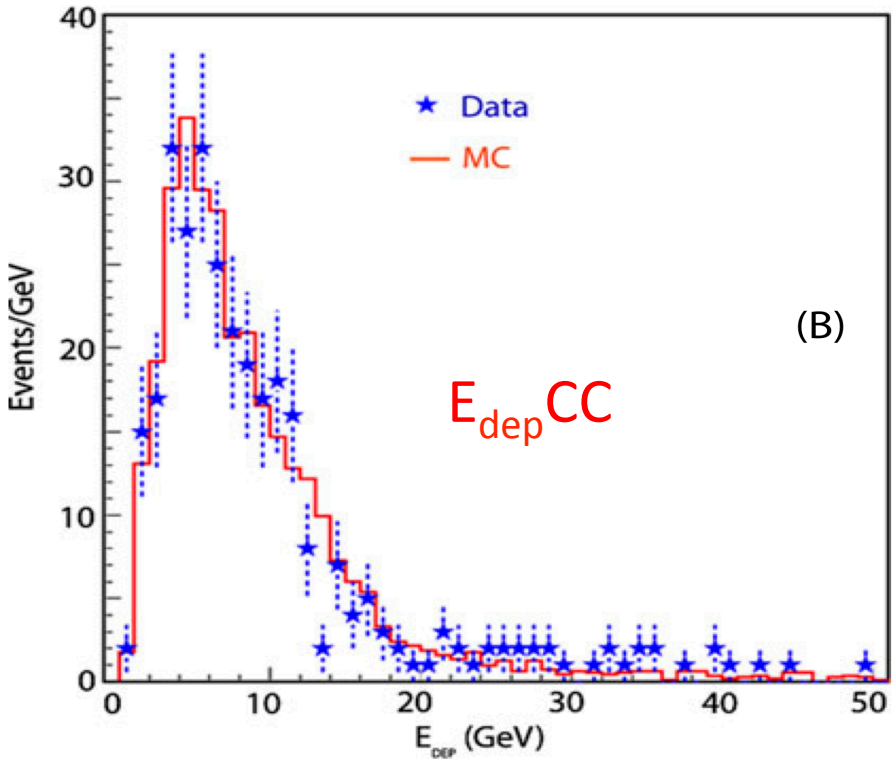
Board changed! October 2012

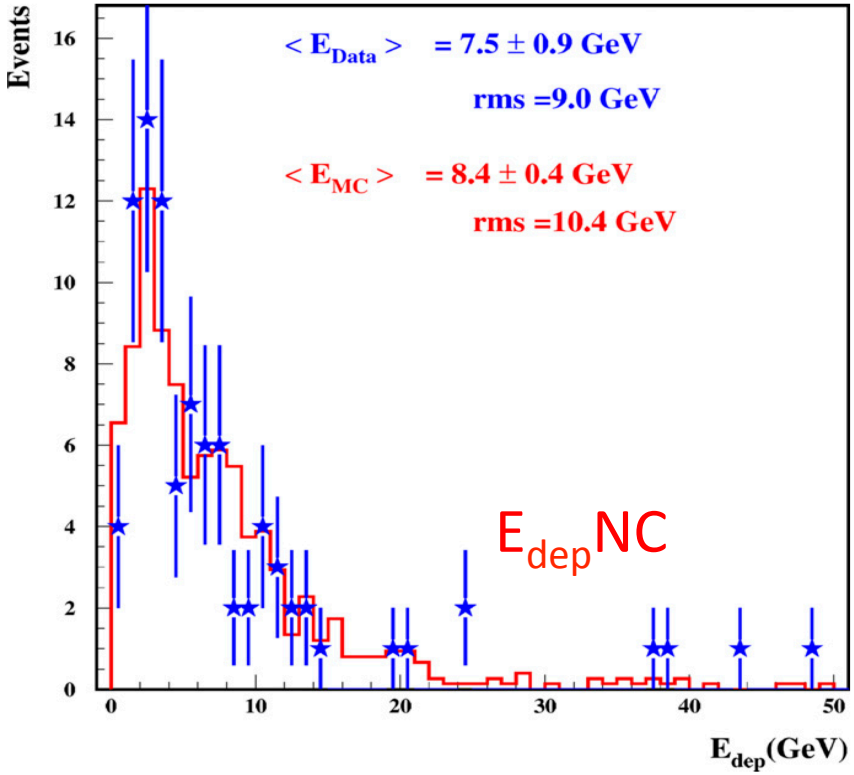
The outliers in this plot are identified as cards substituted for maintenance.

- Measurements done in 2010 and in 2013 (3 years interval !!) demonstrate the exceptional stability of the front end electronic boards:
  - the board response is stable to better than ~1%:

Deposited energy distributions

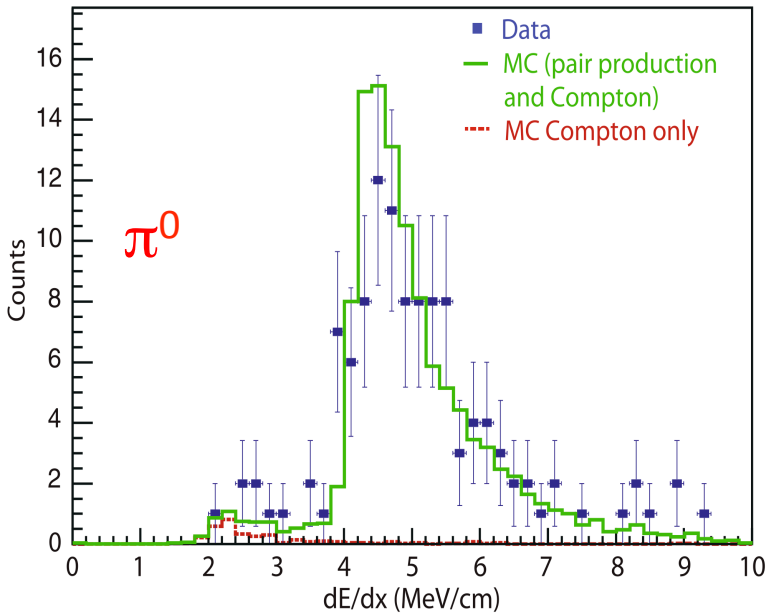
- Global distribution of deposited energy for both ν_μCC and νNC events can be compared with MC expectations
- Generally good agreement is found (average ~2% underestimation in all plots)

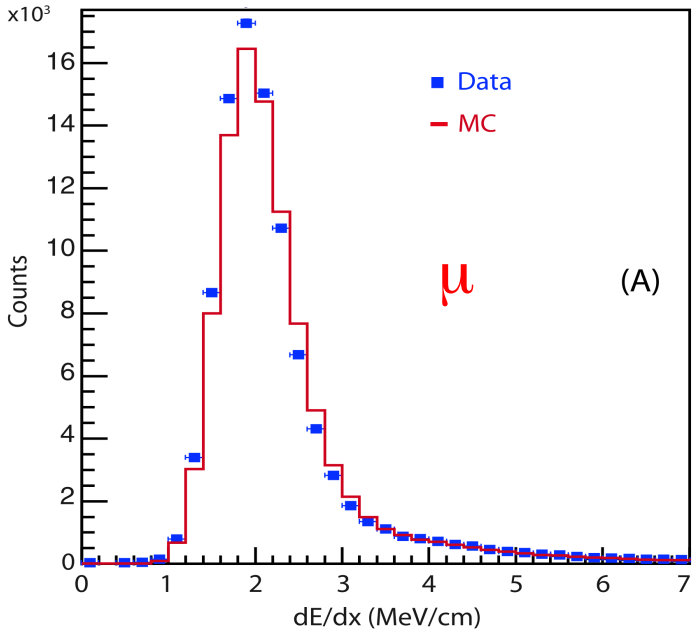




dE/dx comparison

- Ionization density distributions from different physical samples in CNGS data are compared with MC expectations:
  - Low energy showers from isolated secondary π^0 show good agreement
  - Stopping muons from ν_μCC interactions of CNGS neutrinos show a small (~2.5%) underestimation

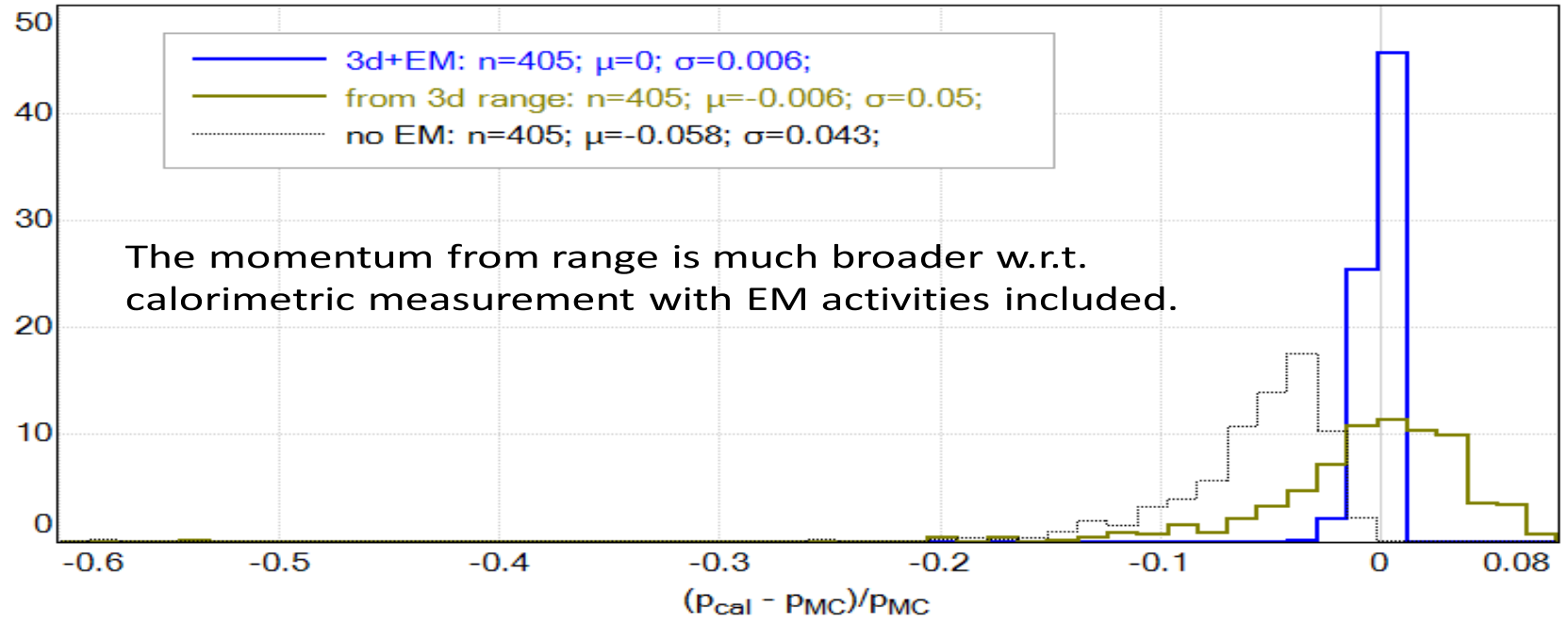




M. Antonello et al., Eur. Phys. J. C (2013) 73:2345

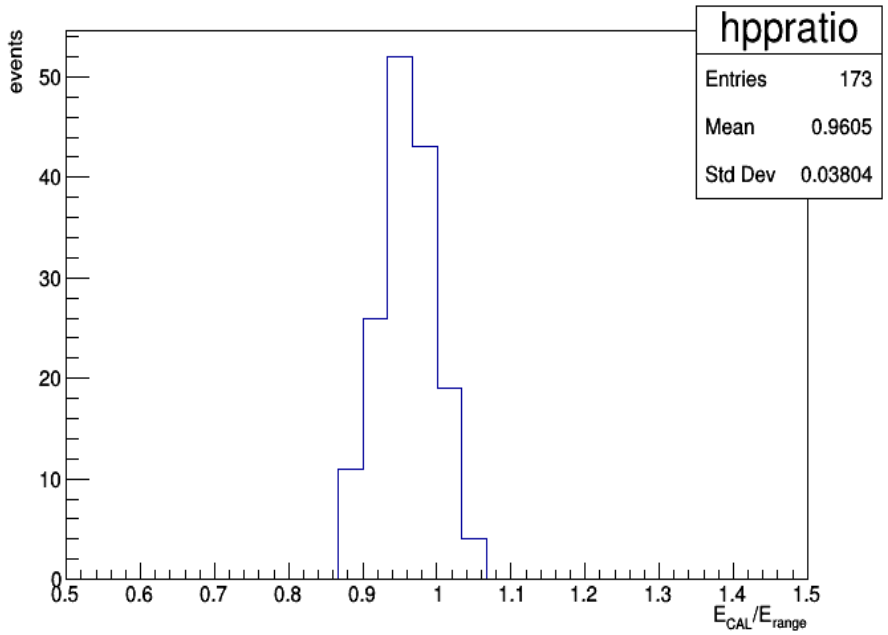
Calorimetric calibration through range

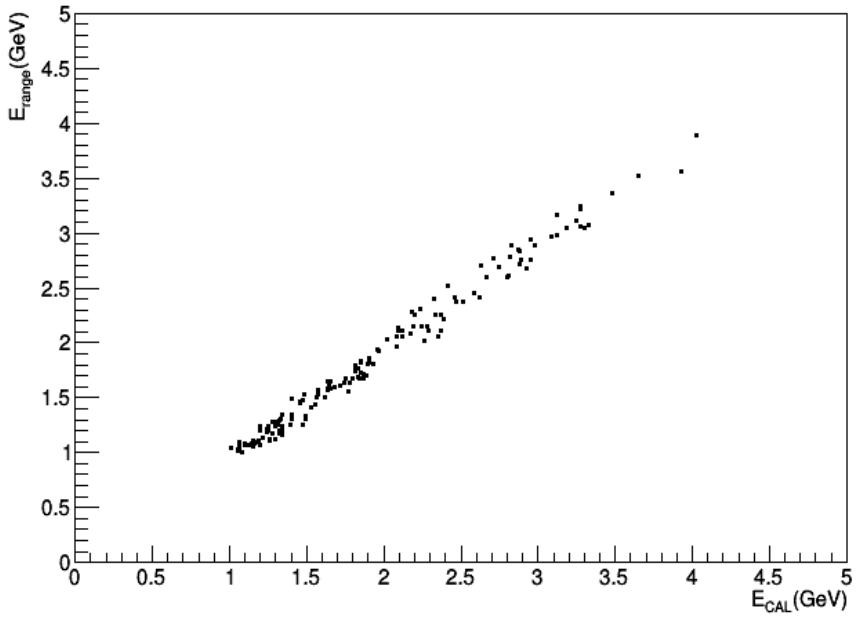
- Calorimetry is more precise (~1% resolution for stopping muons) but possibly affected by large systematics (electronic response, purity, quenching, delta rays…)
- Energy of contained particles can also be obtained by measured 3D range, by inverting Bethe-Bloch relation
- Range is a purely geometrical measurement: it has worse resolution (~5% on stopping muons, mainly due to intrinsical straggling) but is immune to calorimetric systematics



Calorimetric calibration through range

- Range measurement can be used to globally calibrate calorimetry: correction corresponding to average range/calorimetry ratio (typically few percent effect: ~4% in stopping muon case)
- On stopping muons, this improves calorimetric accuracy to <~1%
- It is also important for validation of MCS momentum measurement





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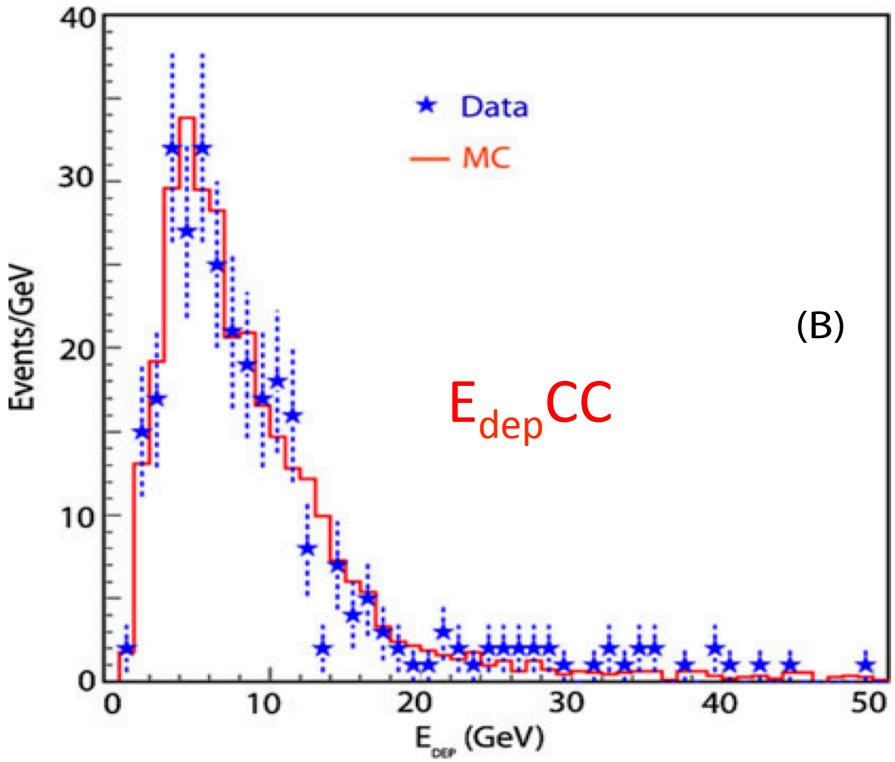

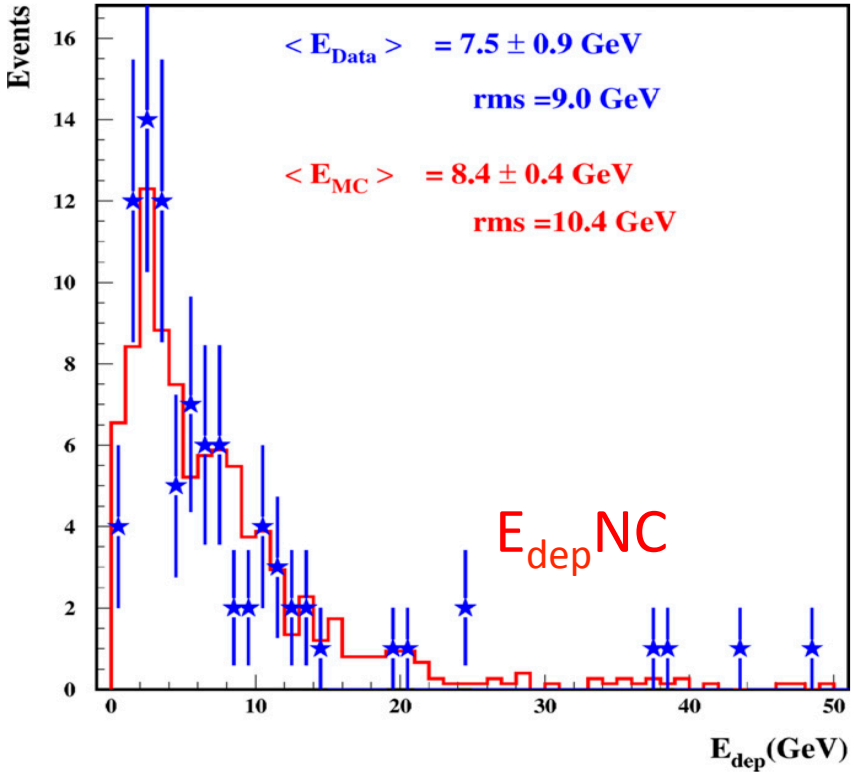

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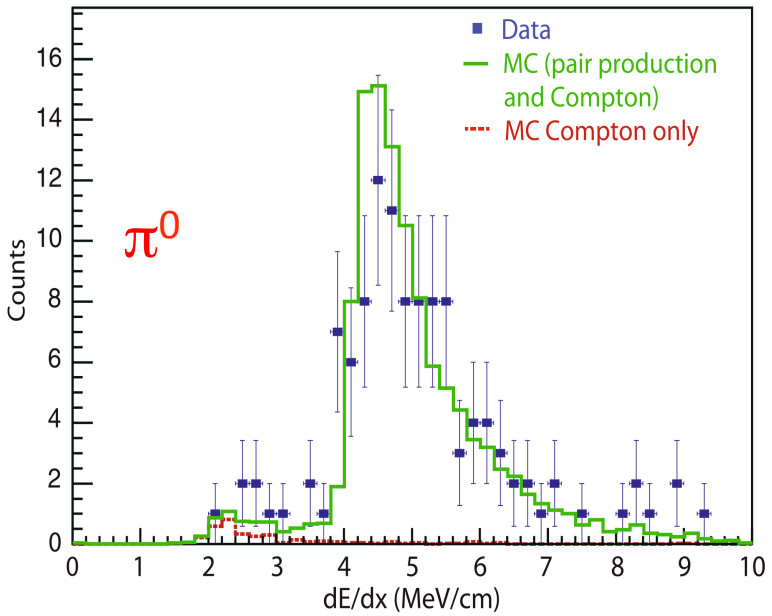

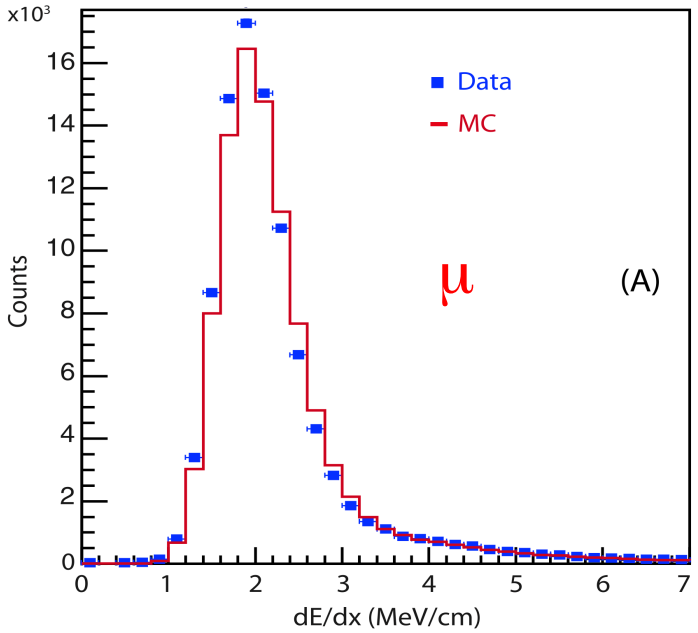

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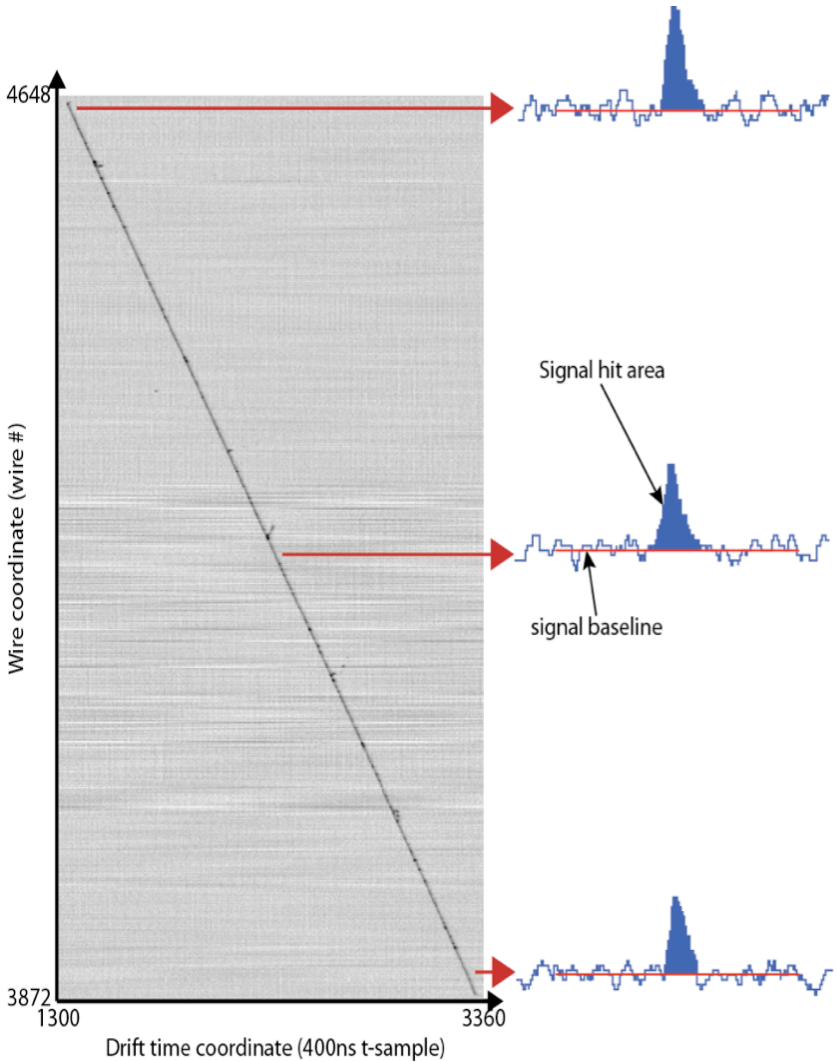
Purity measurement : method description - 1

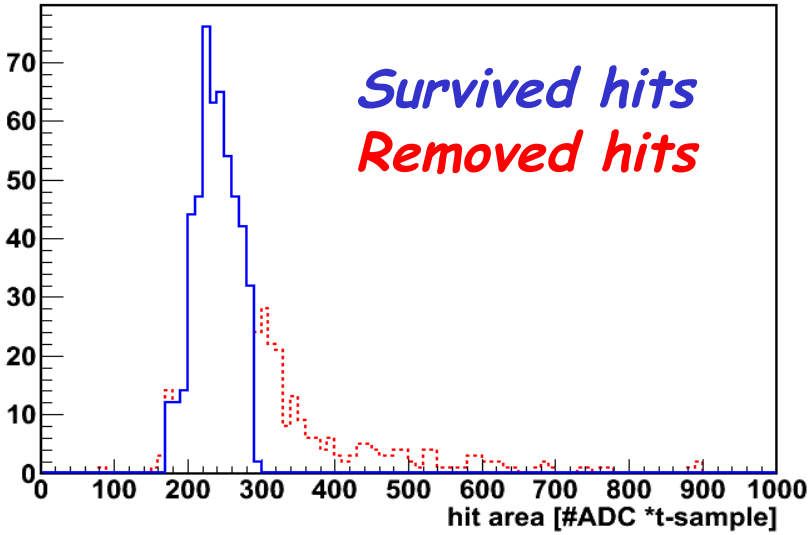
- A fully automatic procedure to monitor online the attenuation $\lambda = 1/\tau_{ele}$ has been prepared for the LNGS run:
  - Automatic selection of through-going cosmic-ray muons;

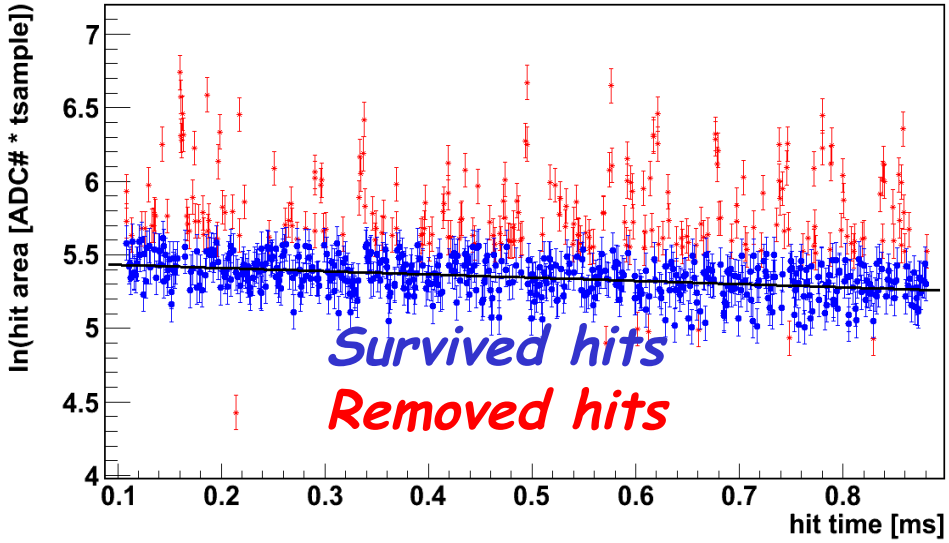


- The tracks is considered "good for purity measurement" if the cluster occupies at least 100 wires and 1450 t-samples (400 ns each) and if the track presents a reduced e.m. activity.
- Recursive rejection of hits at more than 3 mm distance from the track is applied: residual δ-rays along the track are removed

Purity measurement : method description -2

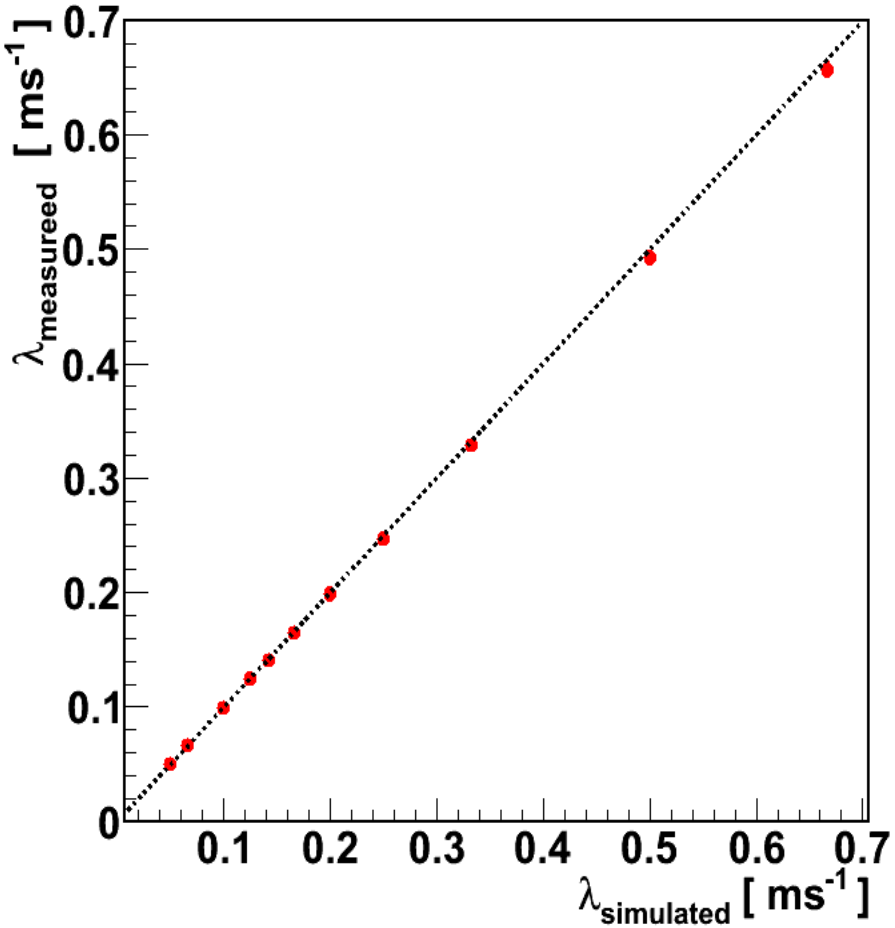
- $\lambda_{track} = 1/\tau_{ele}$ evaluation obtained by a fit of the charge attenuation along each survived tracks;
- The asymmetric Landau tail of the dE/dx distribution can introduce large non Gaussian fluctuations in the fit; a 2-step procedure is introduced *to remove the Landau tail and to exclude hits with lowest signals ➔ obtained signal distribution centered around the most probable dE/dx value*
- Final value of $\lambda = 1/\tau_{ele}$ estimated as the average of λ_{track} on 100 tracks collected during half a day





Purity measurement : test on MC events

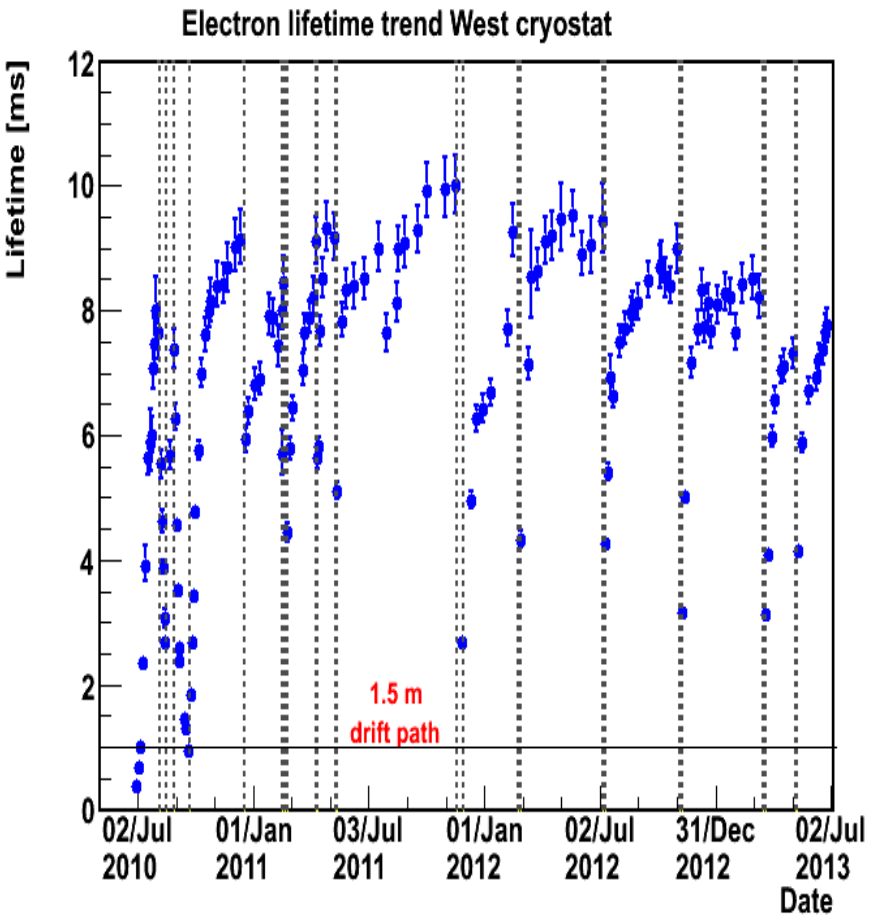
- The described method has been validated using a sample of simulated muon tracks with energy spectrum / angular distribution of cosmic rays as measured at LNGS

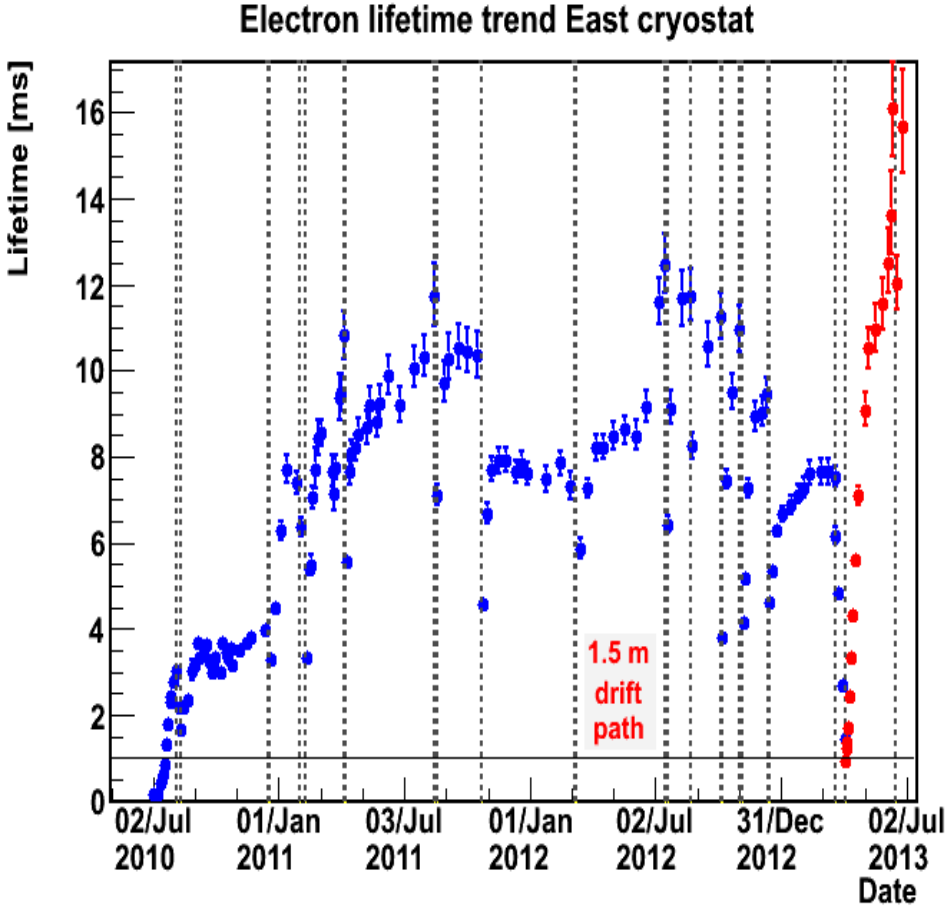


- Method tested for electron lifetime in the 1.5 - 20 ms range;
- The RMS of the $\delta\lambda = \lambda - \lambda_{track}$ distribution results ~ 0.06 ms^{-1}
- <1 % underestimation for τ_{ele} > 3 ms ➔ maximum effect on the energy measurement < 0.3 %
- 1.5 % underestimation for τ_{ele} < 3 ms ➔maximum effect on the energy measurement ~ 1 %

Purity measurements during the LNGS data taking

- During the LNGS run, electron lifetime measured in the 2 cryostats applying the described method on selected runs, taking into account of the stops and restarts of the liquid recirculation system.

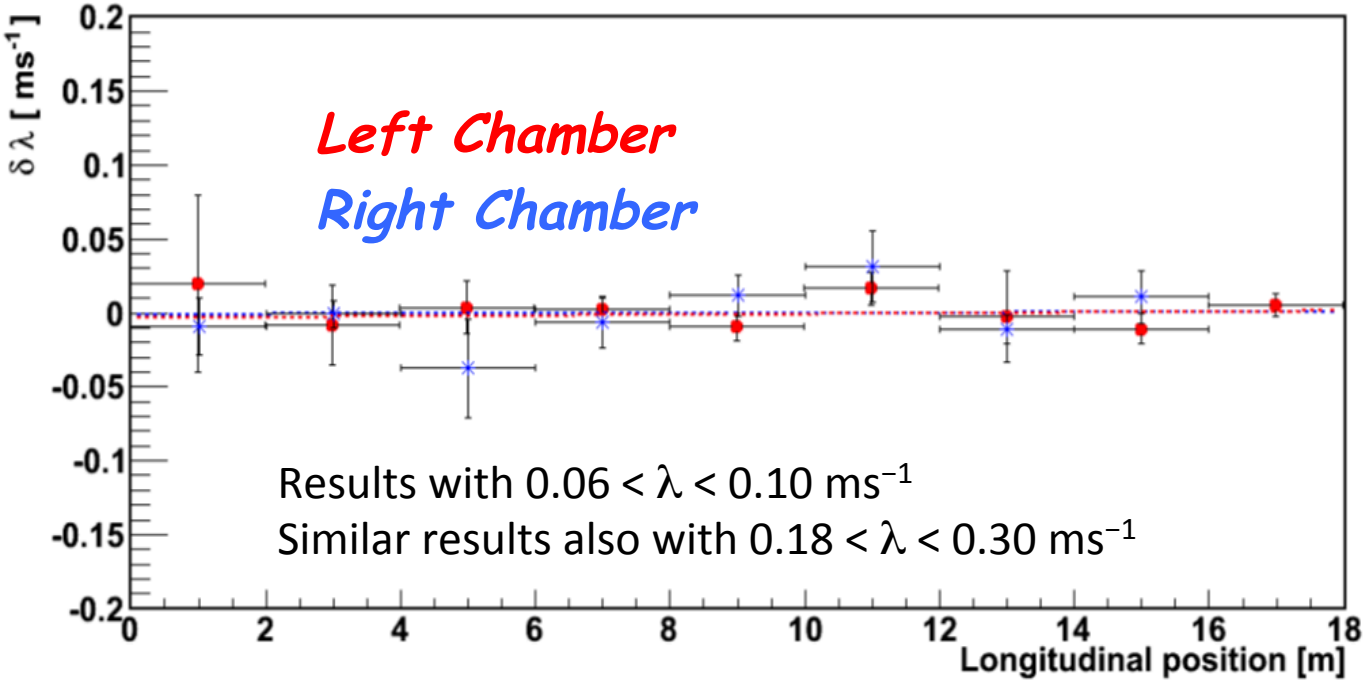




- Detailed description of the method in JINST 9 P12006 (2014);

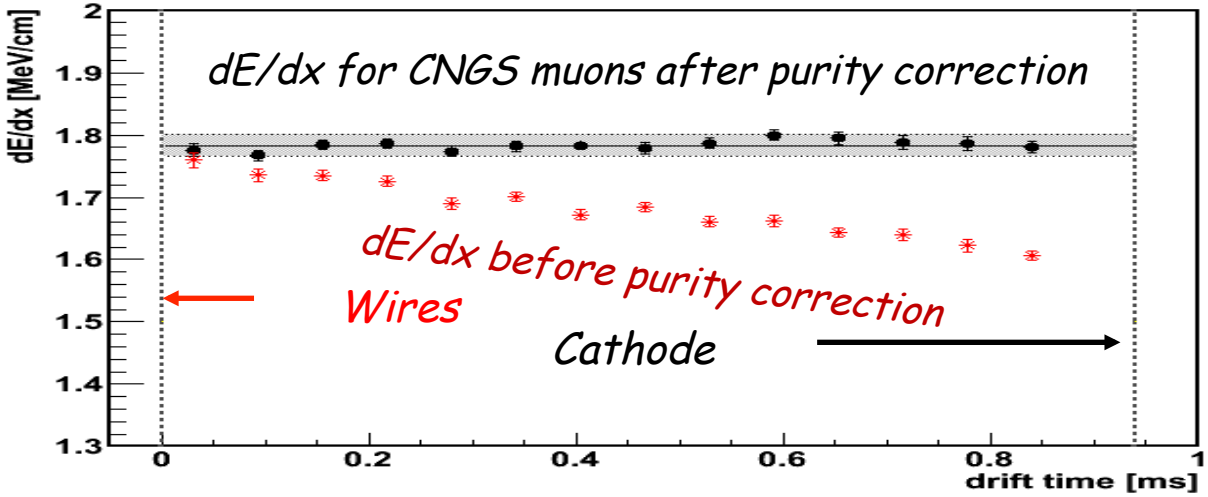
Uniformity of the electron lifetime along the longitudinal direction

- A sample of 1000 almost vertical cosmic muons in the East cryostat have been selected to investigate the uniformity of the lifetime along the detector.
  - Tracks automatically reconstructed in 3D to define their position along the detector longitudinal direction.
  - For each track $\delta\lambda = \lambda - \lambda_{track}$ evaluated
  - $\delta\lambda$ distribution studied in different regions of the detector



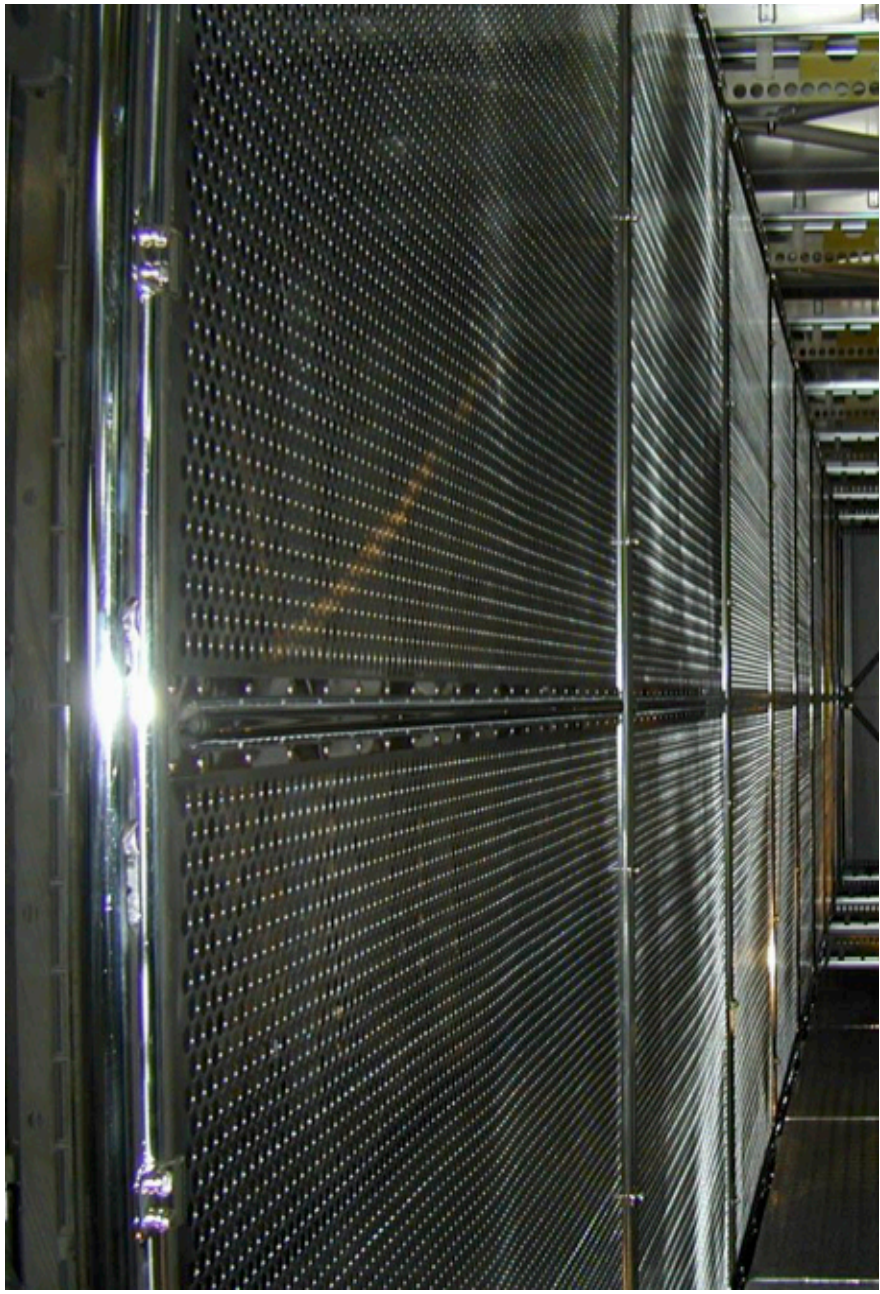
Uniformity of the dE/dx along the drift direction

- The electron lifetime measurements have been verified studying 254 muons from CNGS ν interacting in the upstream rock entering the T600 module and travelling almost parallel to the wire planes
  - dE/dx and drift position associated to each hit estimated;
  - Drift path split into 15 bins of 10 cm each (last bin discarded due to small electric fields distortions in the cathode region)
  - For each event and bin, the most probable dE/dx is extracted. Then for each bin the dE/dx value is extracted averaging over the selected events (statistical precision better than 1%).
- A similar check was started along beam coordinate



The ICARUS-T600 cathode

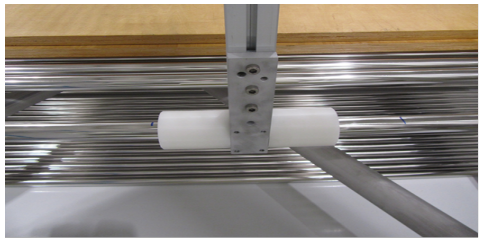
- Cathode is composed of panels of punched stainless steel
- Each panel ~2m long (along beam), ~3.2 m high. Reinforcing bar at half height
- No measurement of possible non-planarity performed before T600 data-taking at LNGS
- Cathode non-planarity produces disuniformities in the electric field and drift velocity -> apparent track distortions
- MCS muon momentum measurement can be significantly affected, especially at higher momentum

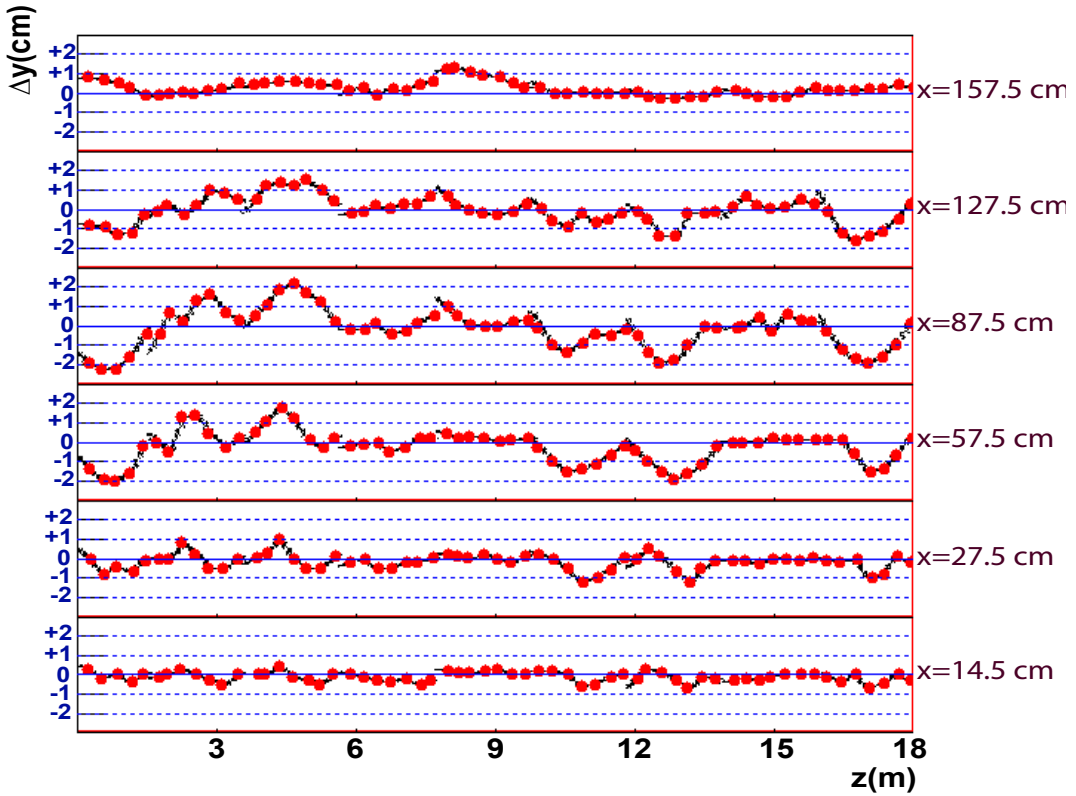


M. Antonello et al., J. Inst., 12 P04010 (2017)

Direct measurement of cathode distortions

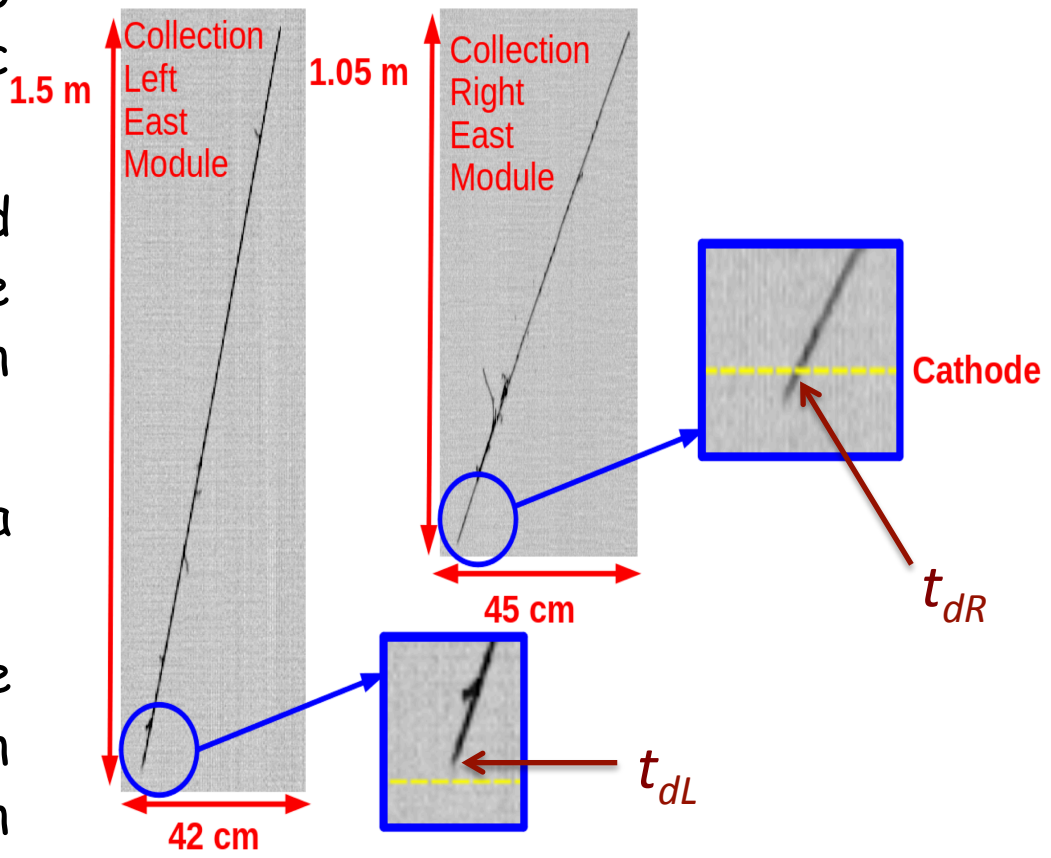
- Performed during the T600 refurbishing at CERN (2015-17) on an empty and warm detector
- Laser-meter could be moved both longitudinally and vertically. Resolution ~2.5 mm
- Measurements performed on a grid of ~30 cm mesh (red points) and interpolated
- Deviations from planarity extend up to ~2.5 cm
- Only East module fully analyzed: lower half is shown here





Indirect measurement of cathode distortions

- Cathode non-planarity can also be measured from data: cosmic μs crossing the cathode plane
- Measurement can be performed during run but takes a long time *underground* (results shown here refer to ~6 months)
- This measurement refers to a full and cold TPC
- The apparent drift coordinate of the point where the muon crosses the cathode plane in both TPC is considered
- The difference $\Delta t_d = t_{dR} - t_{dL}$ is approximately proportional to the cathode distortion Δy in that point:

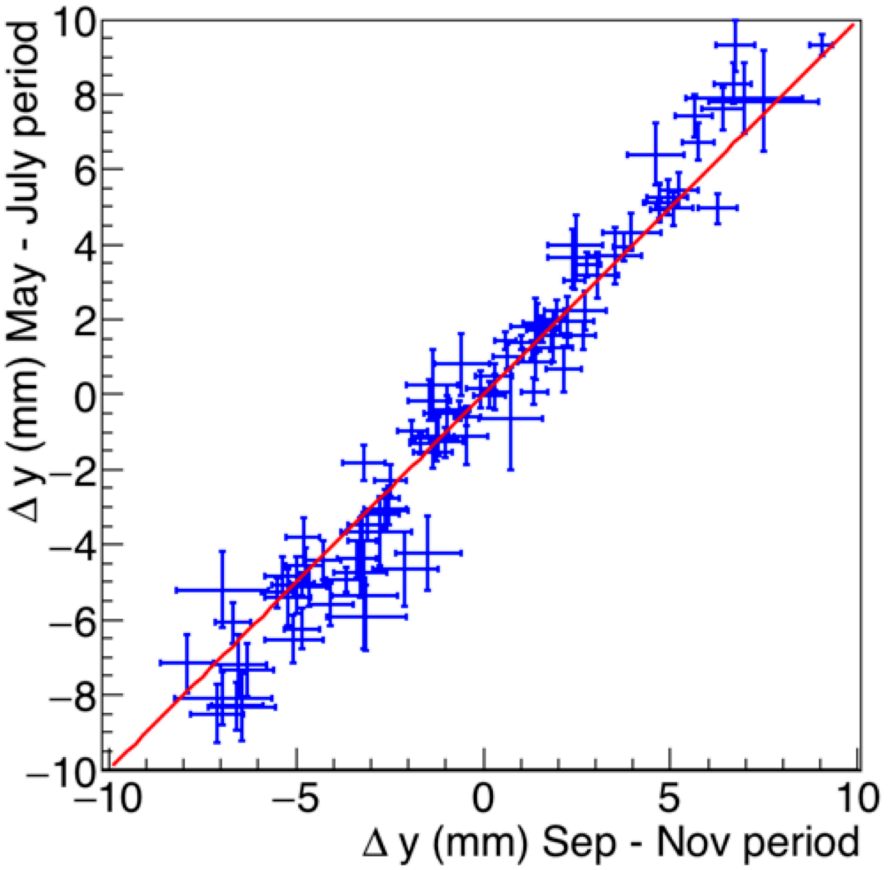


Yellow line marks nominal cathode position(Δy=0)

$$\Delta y \approx 1/3\, v_d \Delta t_d \qquad \sigma_{\Delta y} \sim 2mm$$

Time stability of cathode distortions

- Stability of the cathode distortions during run has been checked by the indirect method with cosmic muons
- The considered data-taking time has been subdivided in 2 equal periods (~3 months)
- No evidence of any change in local cathode distortions is found



Comparison of direct/indirect measurements

- Results from the two measurements of cathode distortion are largely well correlated
- A few exceptions, localized in 1/2 panels. show no correlation or even anticorrelation. Might be related to mechanical "flipping" of panels