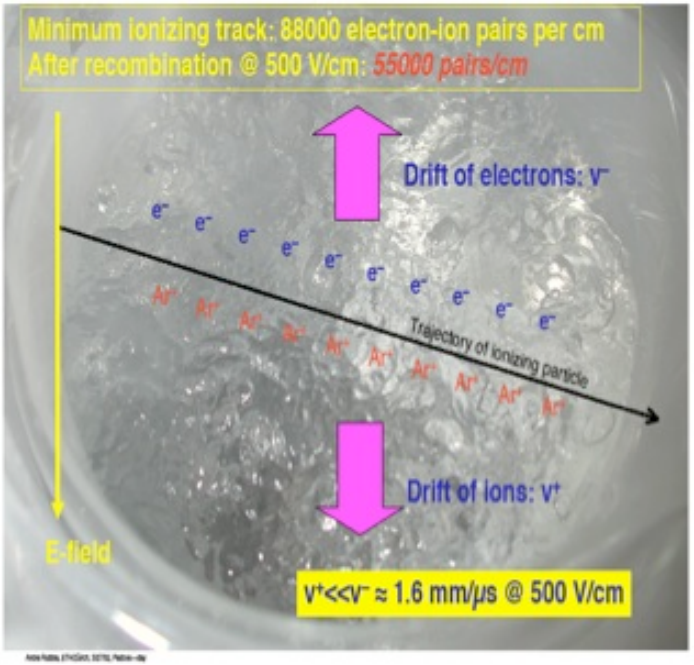
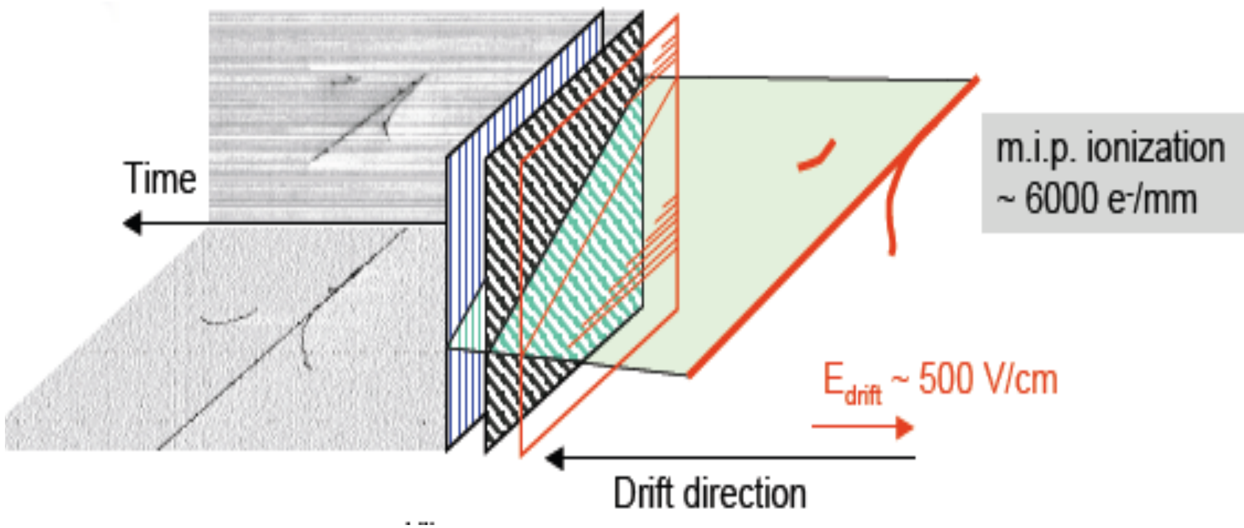
Event reconstruction in LAr TPC

The Liquid Argon TPC Working Principle

- A charged particle crossing LAr produces e^--Ar^+ pairs along its path.
- An Electric Field applied to the LAr volume makes ionization electrons to drift toward the TPC anode (made of 3 parallel wire planes: 1 grid and 2 read-out planes, wire pitch ~3-4mm)
- Electrons drift over very long distances if Argon is very pure (1 meter drift requires purity level at 0.1 ppb)
- e^--charges induce an electronic signal on the wires.
- Signals are acquired through low noise charge amplifiers and fast ADC waveform recording.
- Multiple non-destructing read-out wire signals can be assembled for 3D event reconstruction

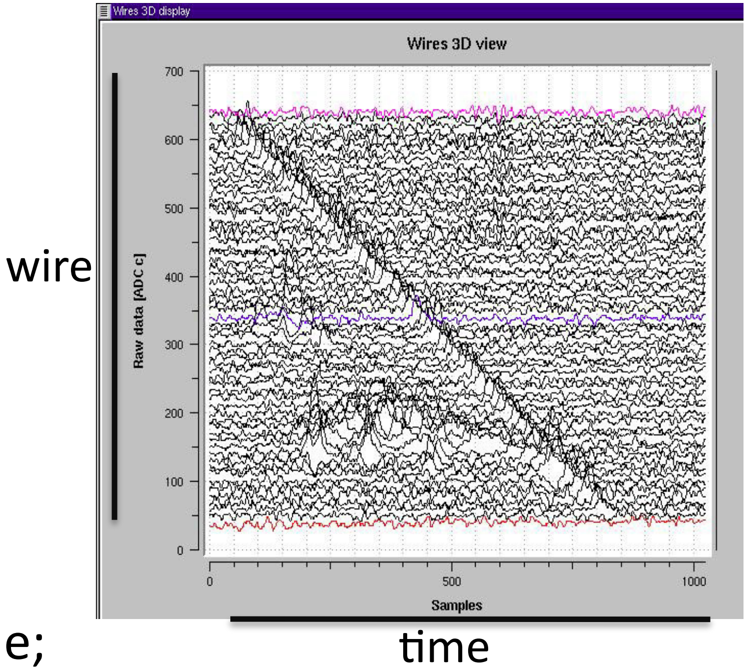




Event reconstruction procedure in LAr TPC (I)

The purpose of the reconstruction procedure is to extract physical information provided by the wire output signals (multiple non-destructing read-out planes), i.e. the energy deposited by the different particles and the space coordinates where such a deposition has occurred (HIT)

➔ to build a complete 3D (imaging) and calorimetric picture of the event



The offline reconstruction procedure consists of:

1. *hit identification*: the hits are independently searched for in every wire as signal regions of a certain width above the baseline;

2. *hit reconstruction*: the parameters defining the hit (position, height, area), which contain the physical information, are determined;

Event reconstruction procedure in LAr TPC (II)

3. *cluster reconstruction*: hits are grouped based on their position in the wire/drift coordinate plane (2D reconstruction);

4. *3D hit reconstruction*: the hit spatial coordinates are reconstructed by the association of hits from different views into common track segments;

5. *calorimetric reconstruction*: the determination of the energy release in LAr is performed in two steps:

- accounting for the charge loss due to the attachment by electro-negative impurities

$$Q_{corr} = Q\, e^{td/\tau_e}$$

- charge to energy conversion with correction for the quenching effect on the ionization charge in LAr (Birks law).

6. *Particle ID:* with dE/dx measurement vs. range

ICARUS T600 STATUS @ LNGS

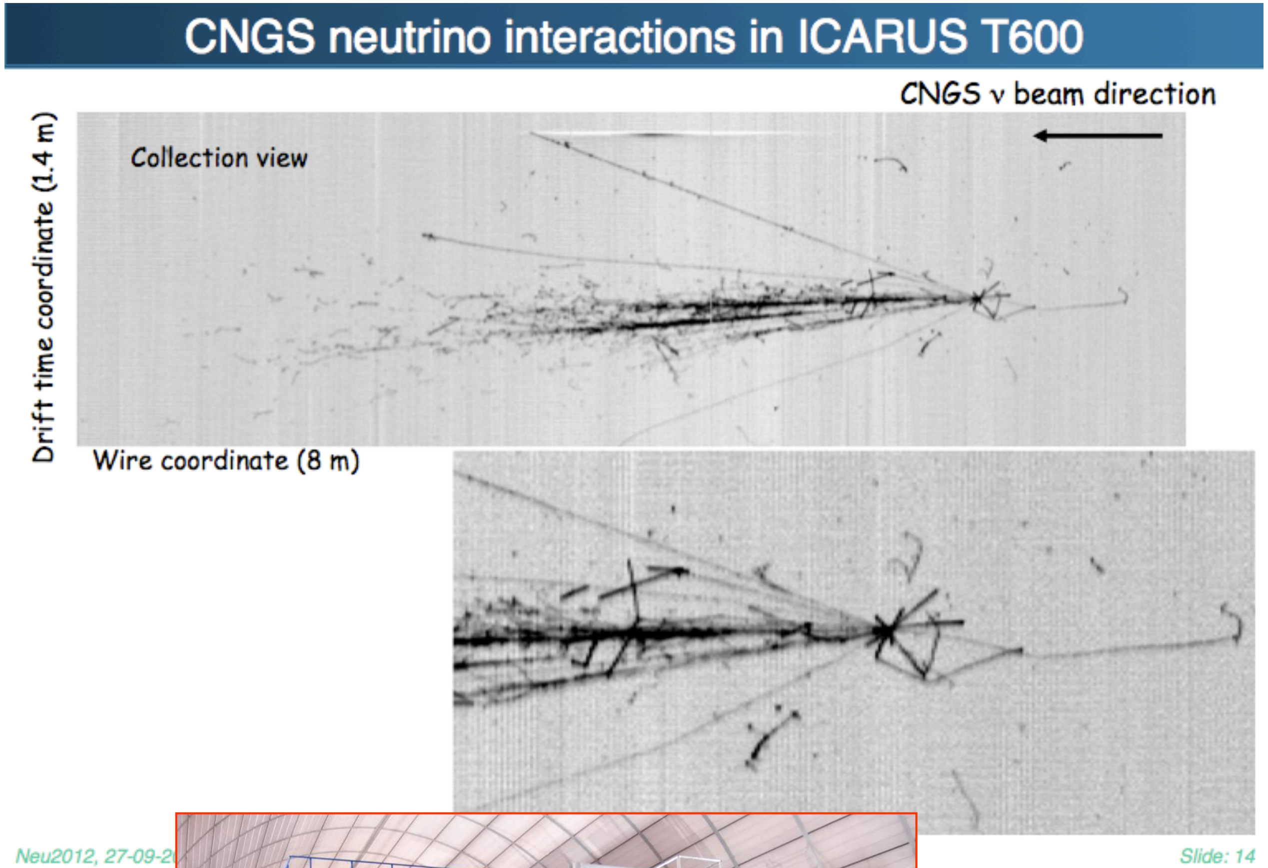
•Detector assembly completed by December 2009

•Cryogenic plant completed by March 2010

•On May 18thboth modules were completely full.

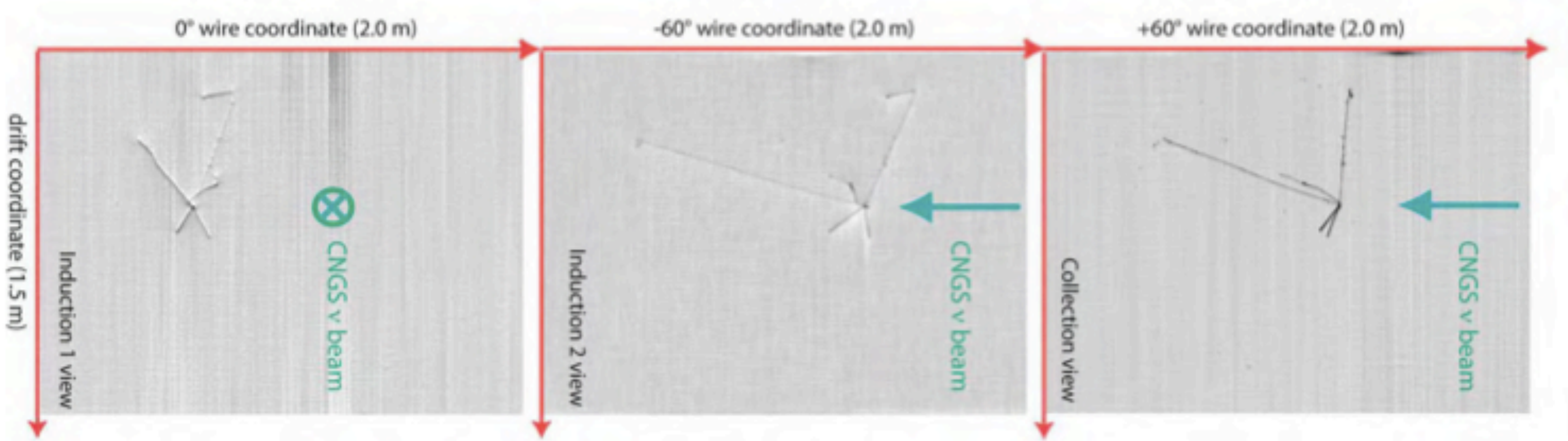
•On May 28that 19.54 the first CNGS neutrino interaction was observed.

• The T600 is presently taking data, smoothly reaching optimal working conditions. Neutrino interactions have been observed. Data analysis already on-going.

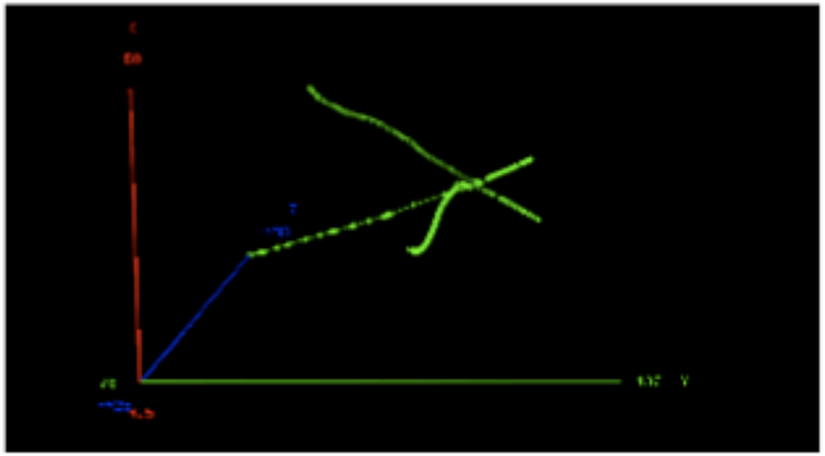


T600 in HALL B

Very low energy CNGS neutrino interaction



Total visible energy: 770 MeV (including quenching and electron lifetime corrections)

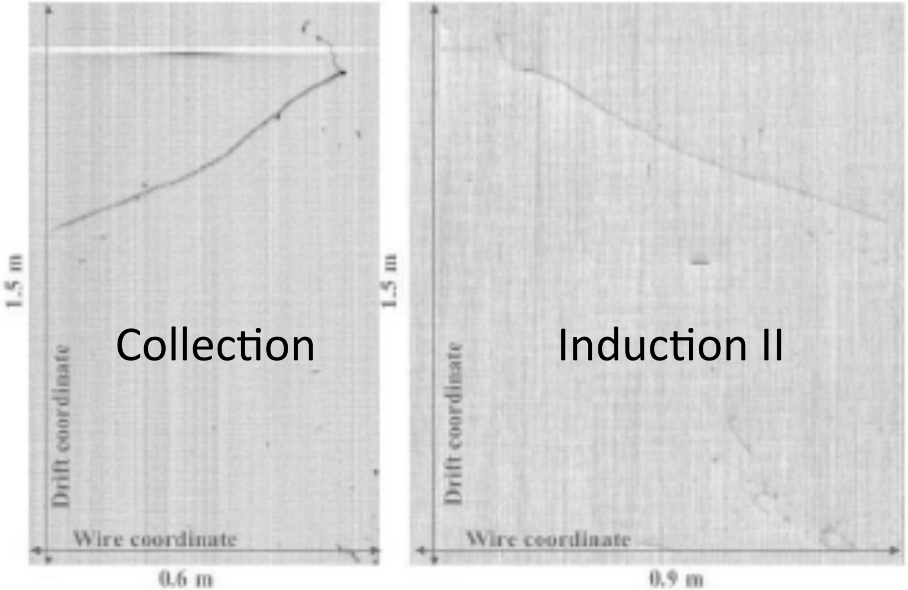


Neu2012, 27-09-2010

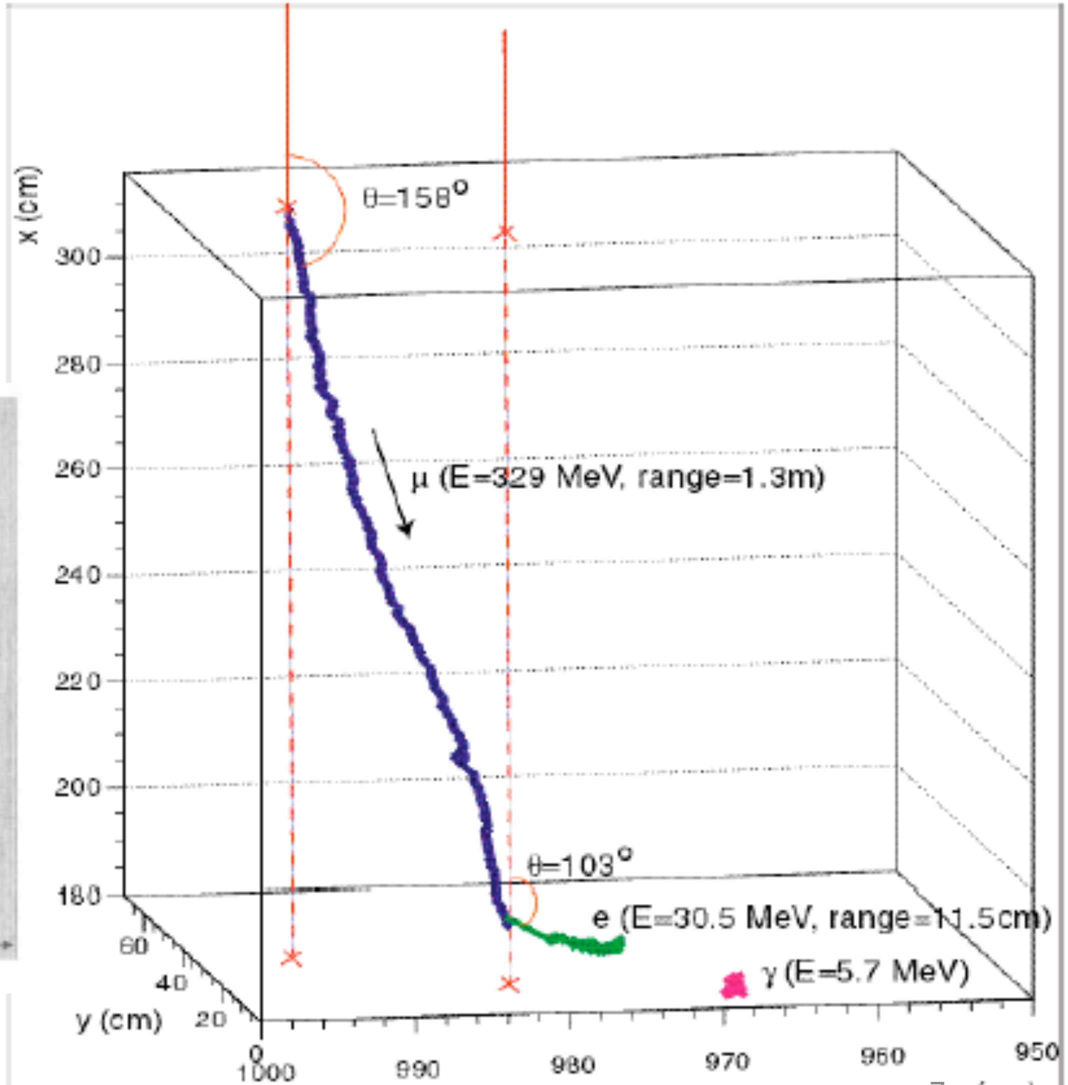
Slide: 16

Measurement of the μ decay spectrum with the ICARUS T600 LAr TPC (test on surface 2001)

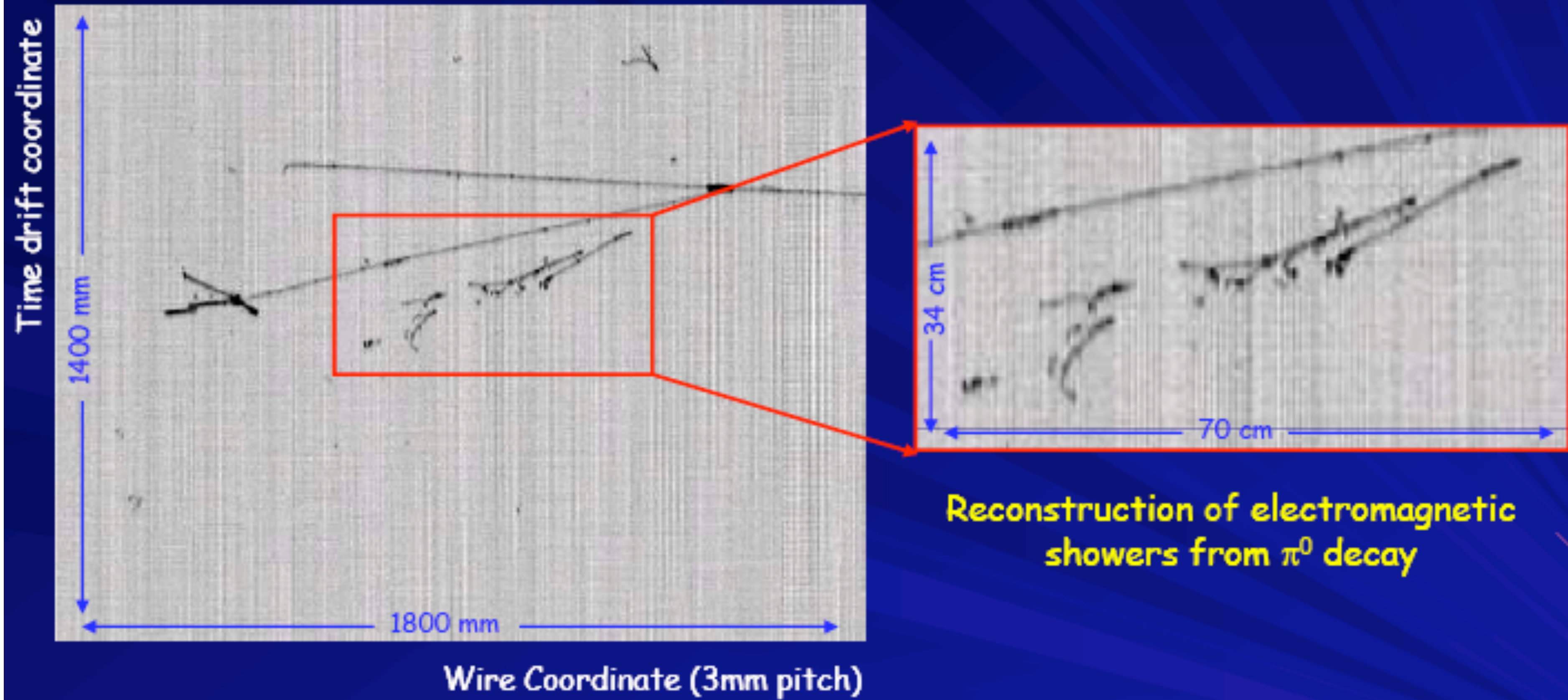
Right chamber:
muon decay event views (Collection and Induction II)



Fully reconstructed stopping muon event

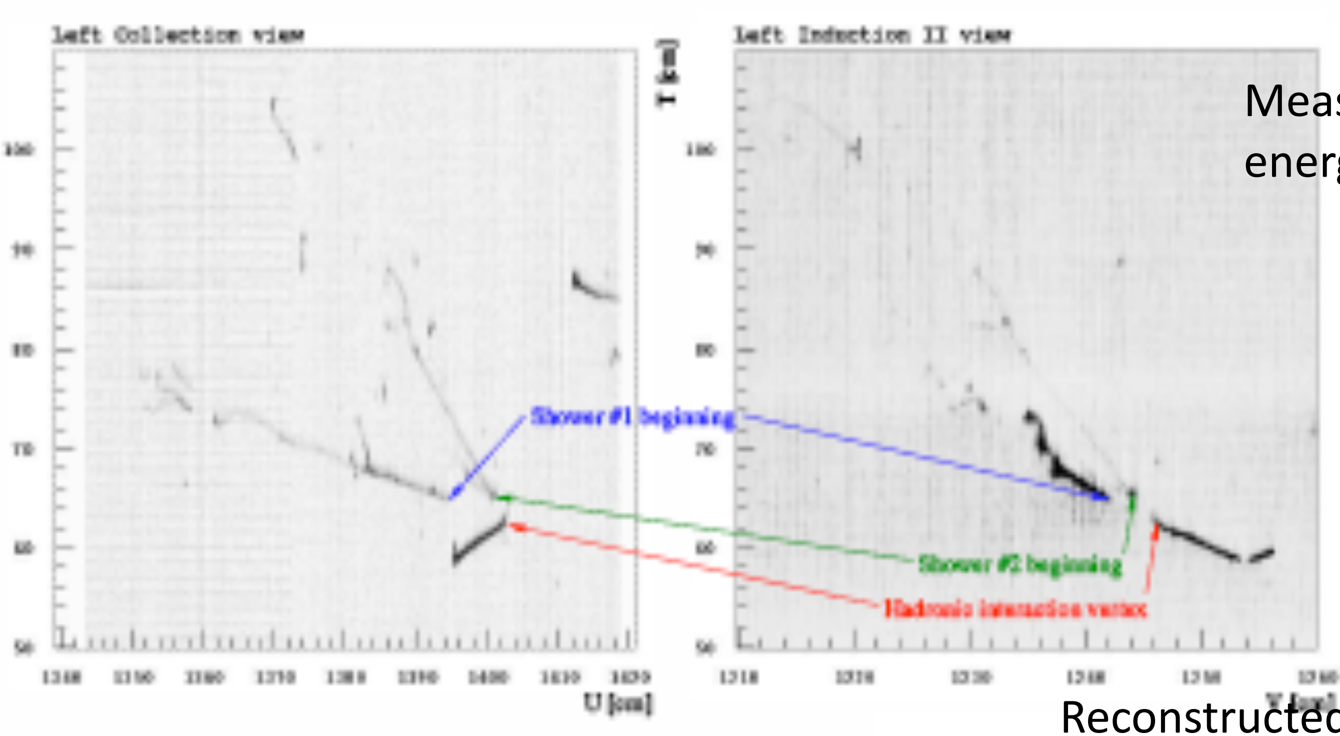


Energy reconstruction of e.m. showers from π^0 decays with the ICARUS T600 LAr TPC (test on surface 2001)

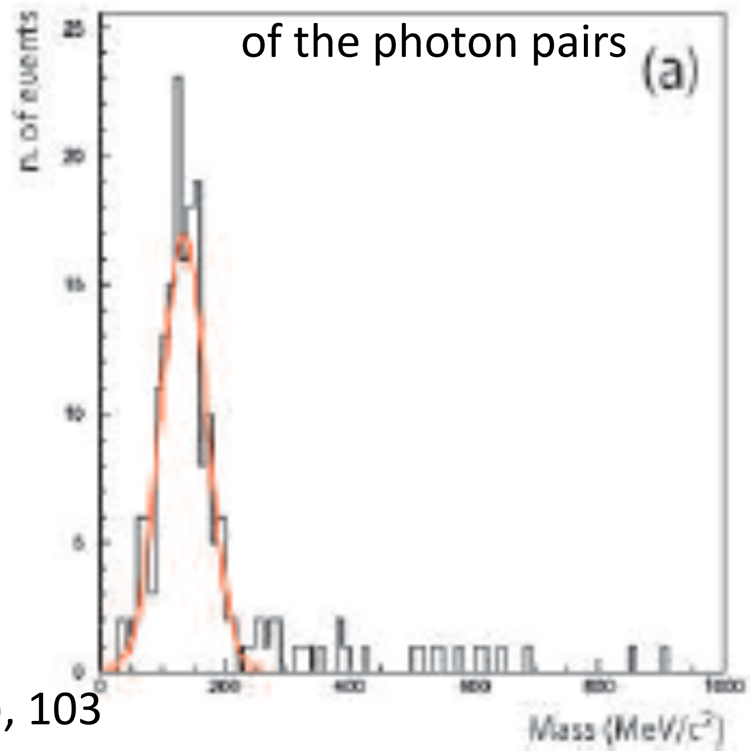


π^0 signature is given by the presence of two e.m. showers coming from the two photons of the $\pi^0 \rightarrow \gamma\gamma$ decay, pointing to the hadronic interaction vertex

Measurement of the shower energy and shower direction



Reconstructed invariant mass of the photon pairs



Selected sample
(after a fiducial volume cut):
196 π^0 candidates

Average mass:

$$m_{\gamma\gamma} = 134.4 \pm 3.0 MeV/c^2$$

+ a contribution of 7.1% from systematics

ICARUS Coll. Acta Phys. Pol. B 41 (2010), 103

Measurement of through-going particle momentum by means of multiple scattering with the ICARUS T600 TPC (test on surface 2001)

The momentum of partially contained events can not be measured by calorimetry

However multiple scattering based techniques can be applied to tracks (at least 1 meter long and with $E_{\mu} < 10\text{GeV}$) through two different techniques:

- Classical Method → energy losses not included, momentum resolution 25-30%

Scattering angle RMS →

$$\theta_{meas}^{RMS} = \sqrt{\left(\frac{13.6MeV}{\beta cp} z \sqrt{\frac{l}{X_0}}\left(1 + 0.038\ln\left(\frac{l}{X_0}\right)\right)\right)^2 + \left(C_1 \cdot l^{-3/2}\right)^2}$$

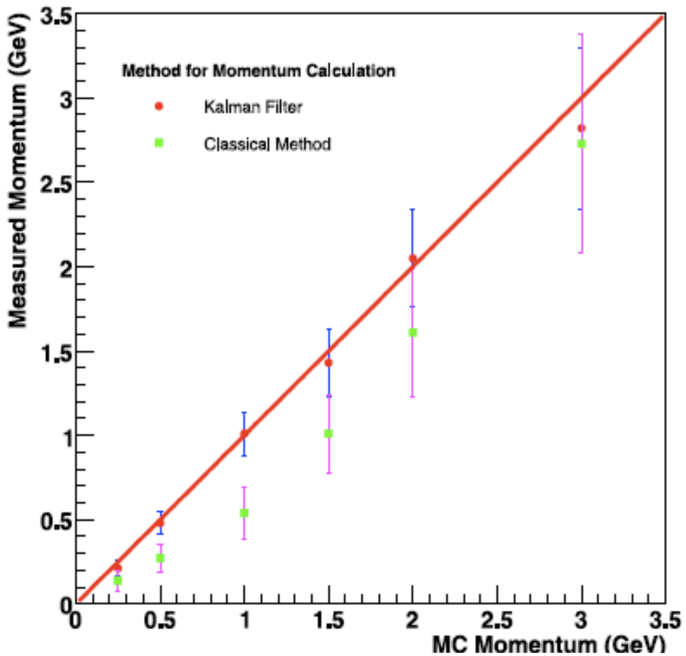
← Particle momentum (βcp)

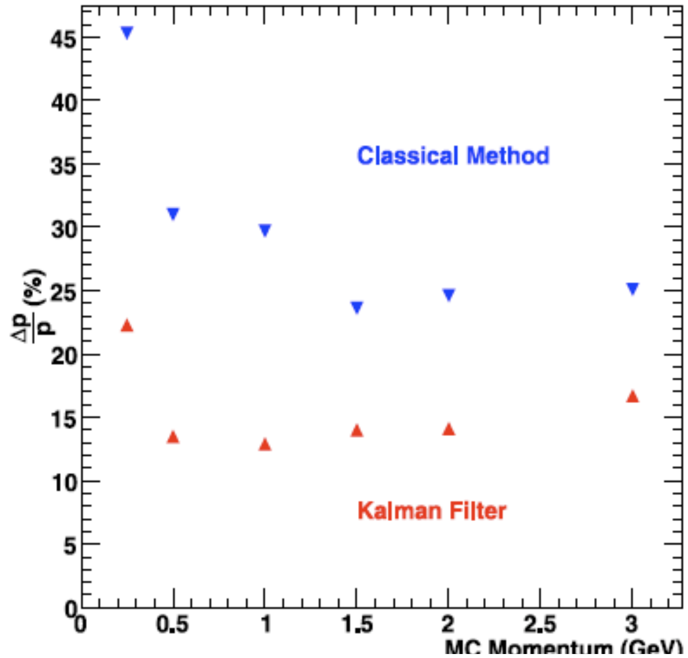
- Kalman Filter

The power of the method lies on the fact that all previous measurements are taken into account to predict the future dynamical behavior of the system

The Kalman filter does take correlations into account, in particular energy losses are automatically included → momentum measurement and its resolution improved (15%)

ICARUS Coll. Eur. Phys. J. C 48 (2006), 667

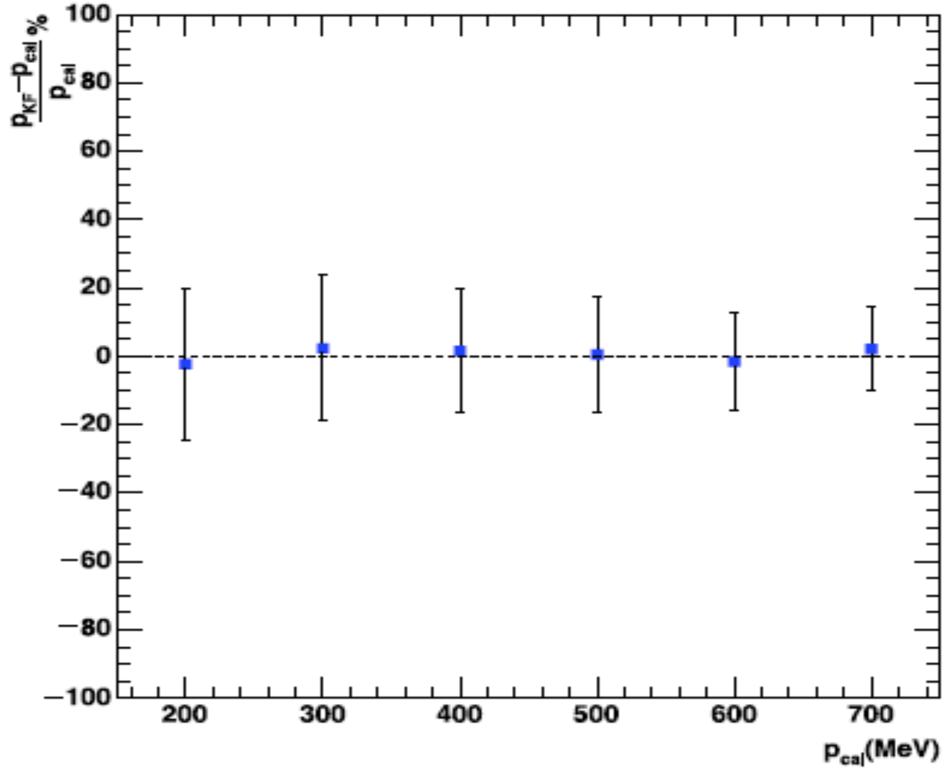




With the Kalman filter technique, for tracks > 1 meter (>250 MeV), the resolutions are around 15% for the whole range of studied momenta

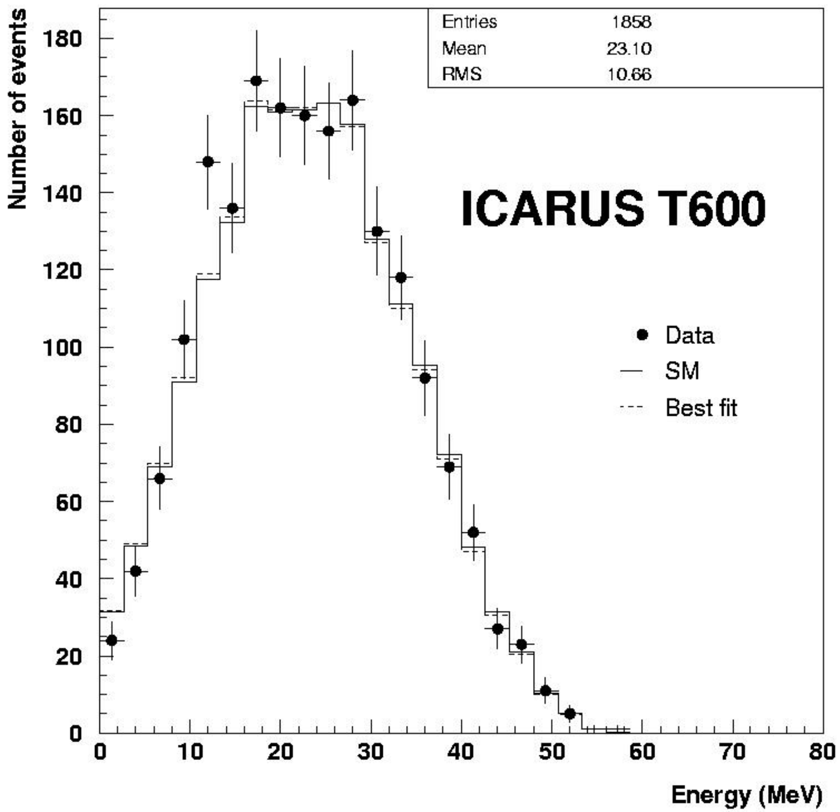
The Kalman filter gives a much better estimation with respect to classical method, since it takes into account energy losses

Dispersion of the Kalman filter measurements with respect to the momentum measured by calorimetry, pcal



Michel Electron Spectrum

From the calorimetric reconstruction: Energy spectrum of the electrons from muon decay



ICARUS Coll. Eur. Phys. J. C 33 (2004), 233

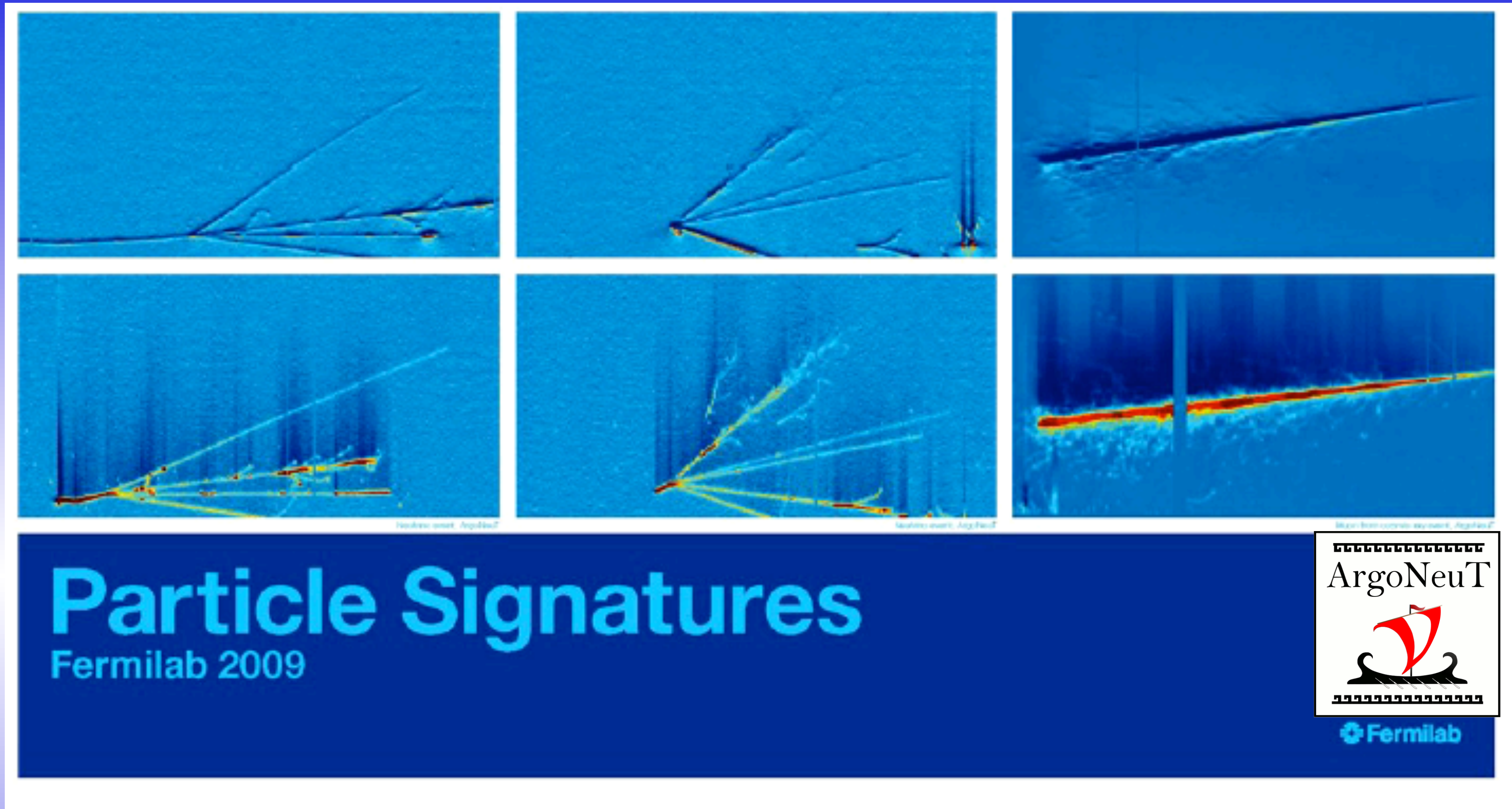
- Study of stopping muon sample
  - 3000 events analyzed and fully reconstructed in 3D
- ρ parameter measurement (from comparison with MC simulation)

$$\rho = 0.72 \pm 0.06\,(stat) \pm 0.08\,(sys)$$

➢ Standard Model ρ = 0.75

- Energy resolution for electrons below ~50 MeV

$$\frac{\sigma(E)}{E} = \frac{11\%}{\sqrt{E}} \oplus 2\%$$

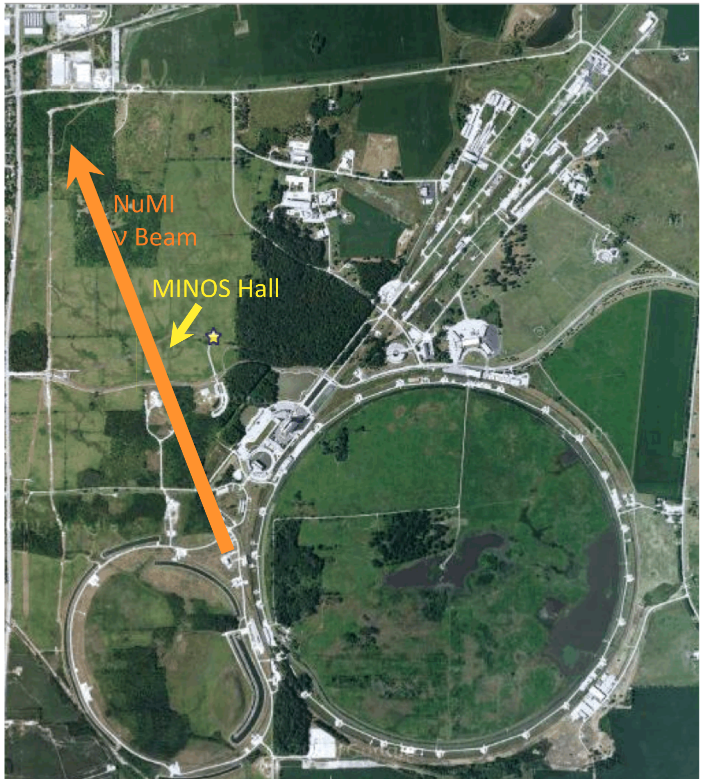


The ArgoNeuT LArTPC:

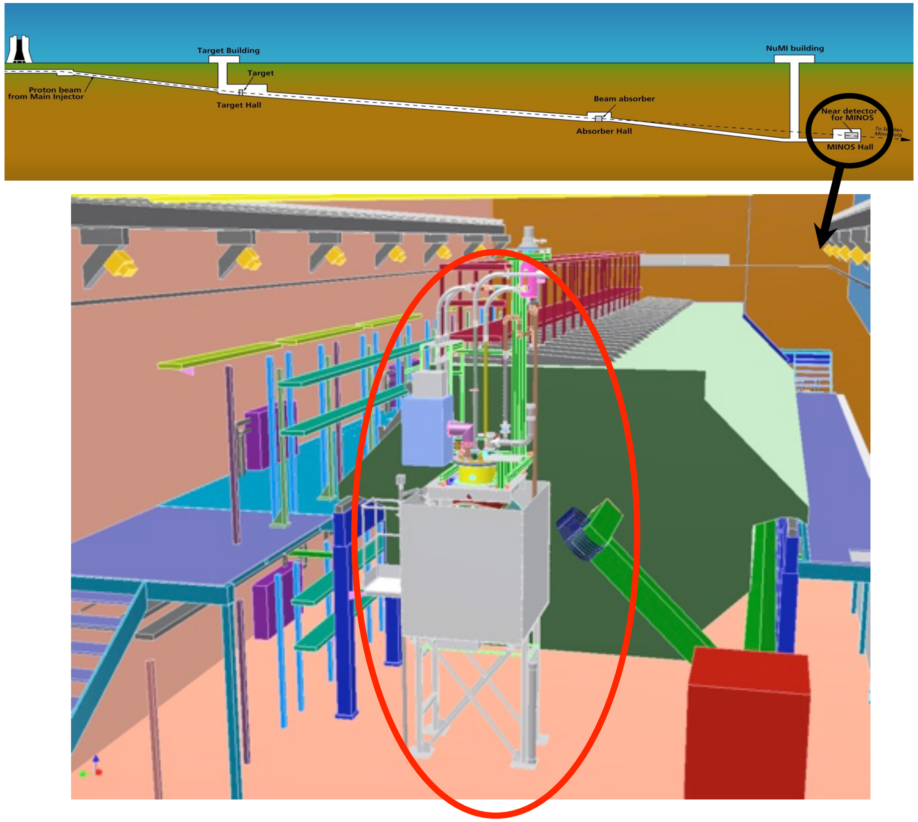
a dedicated Experiment for neutrino Cross Section measurement at FNAL

ArgoNeuT

- ✓ ArgoNeuT is a 175 liter (active) Liquid Argon Time Projection Chamber (LArTPC)
- ✓ Jointly funded by DOE/NSF
- ✓ Designed and assembled in 2007-08, first commissioned (on surface) at FNAL in Summer 2008
- ✓ Moved underground in $\nu/\bar{\nu}$ the *NuMI* beam at FNAL, in front of *MINOS Near Detector*, early 2009
- ✓ Phase I: Exposure to beam (*LE beam option*): June'09 ⊕ Sept'09-Feb.'10

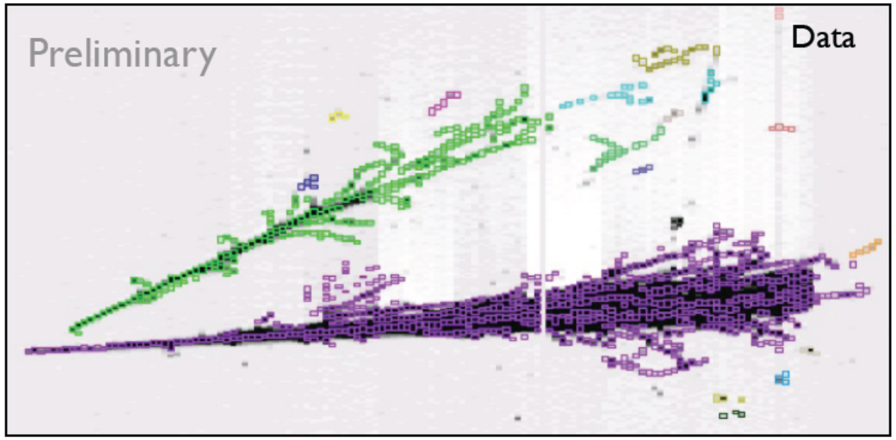


Fermilab, NuMI beam line

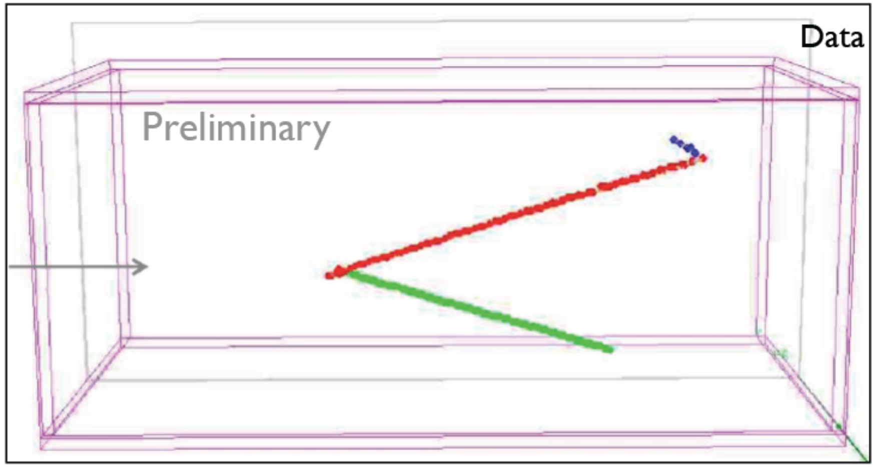


MINOS Hall: ArgoNeuT just upstream of the MINOS ND

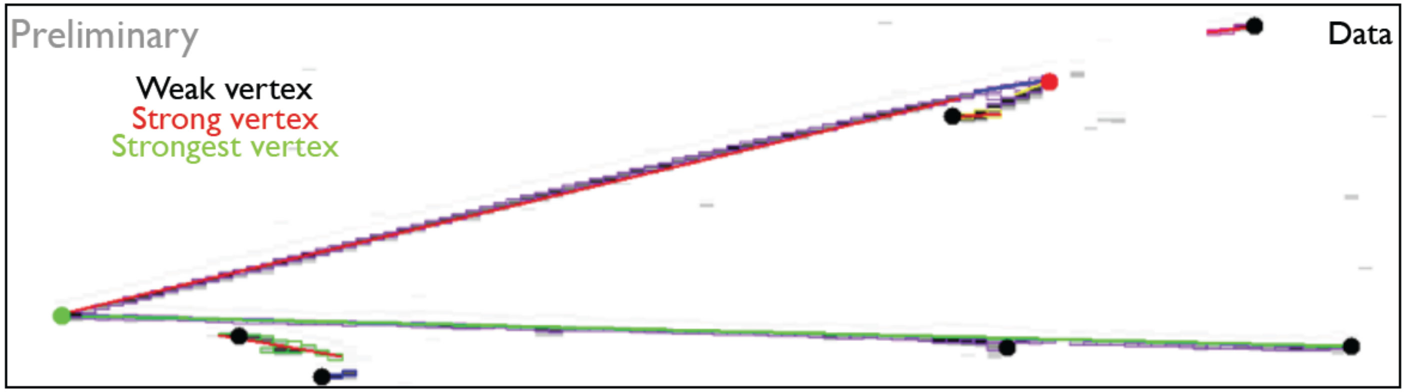
ν event 3D Reconstruction



Hit finding + density-based clustering.



3D reconstruction



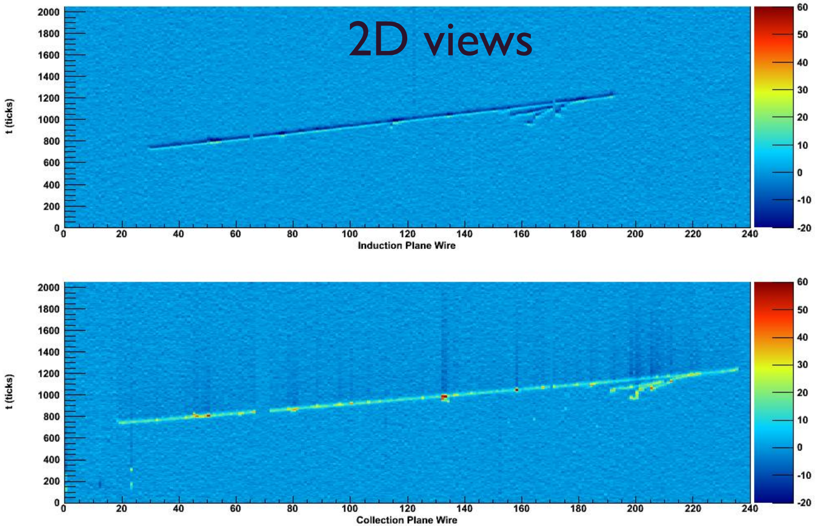
Track finding/fitting + vertex/endpoint finding

These plots from LArSoft – fully automated, detector independent simulation, reconstruction and analysis software

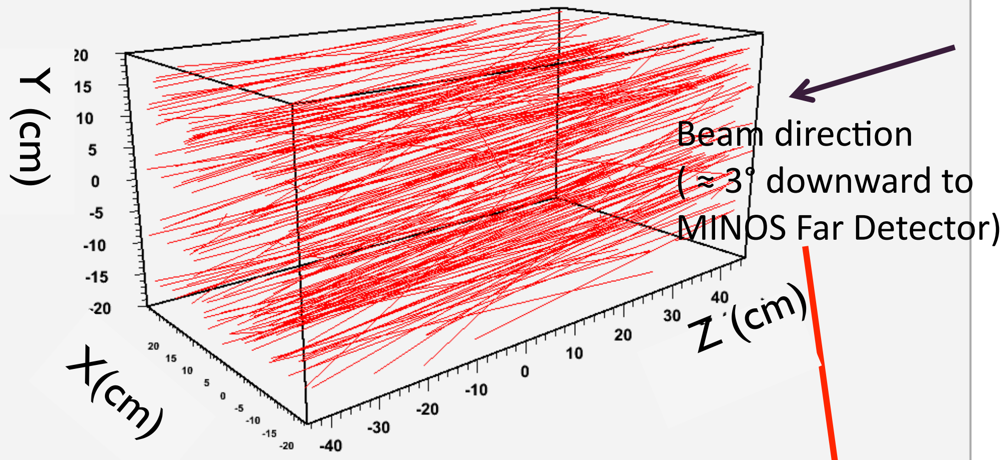
Used by ArgoNeuT, MicroBooNe, and LBNE

https://cdcvs.fnal.gov/redmine/projects/larsoftsvn

μ from upstream ν beam interaction

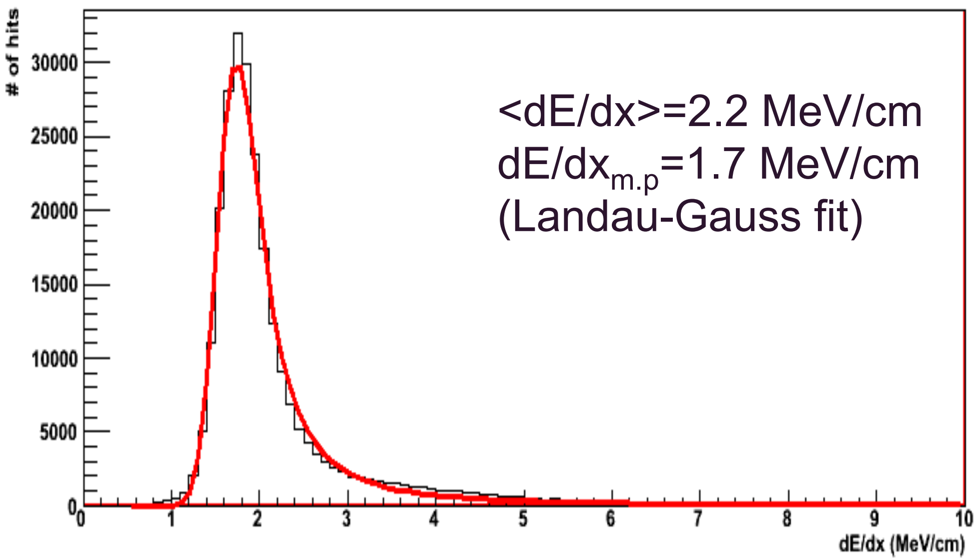


3D reconstruction

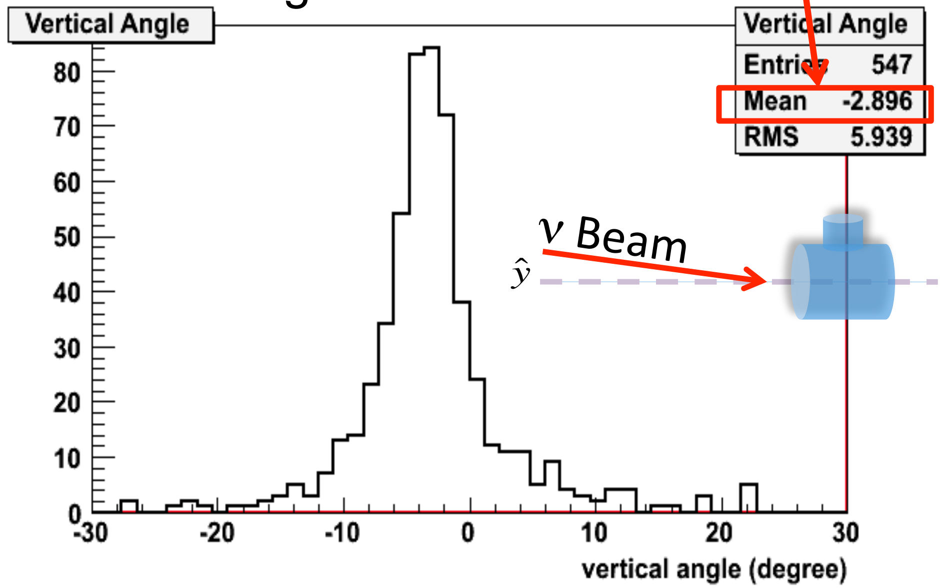


(**many**) crossing μ's superimposed in 3D view

Muon calorimetric reconstruction



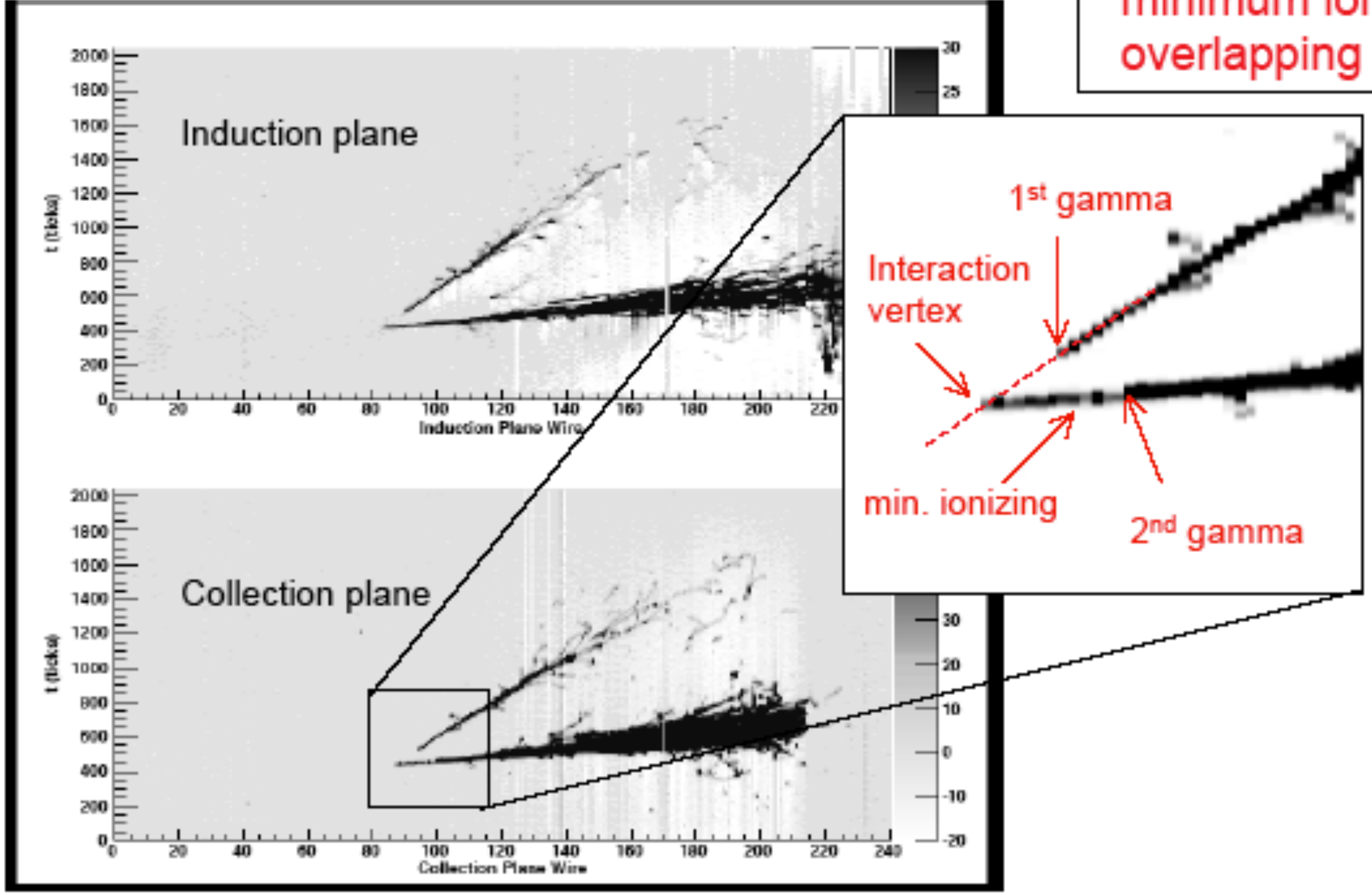
Muon angular distribution



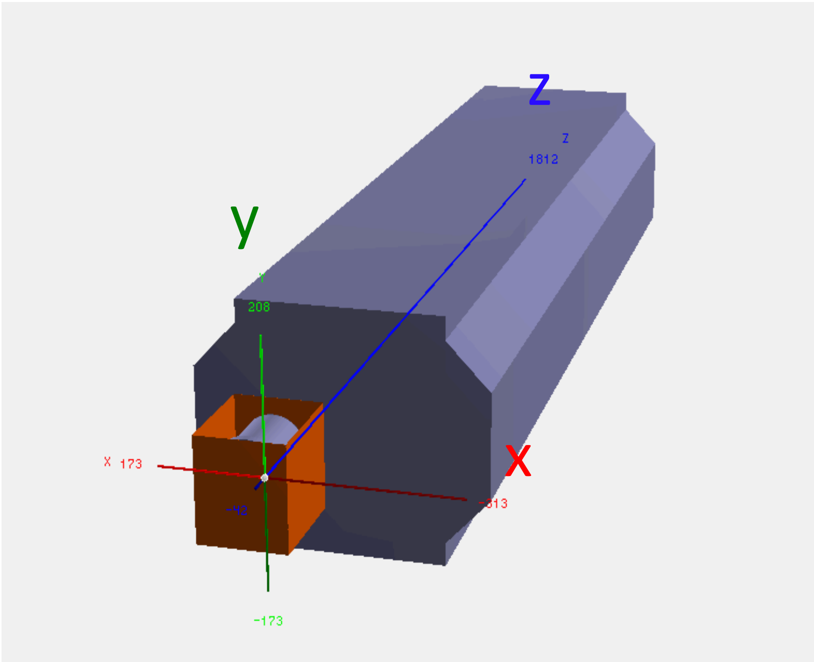
PID: e/γ separation study and optimization

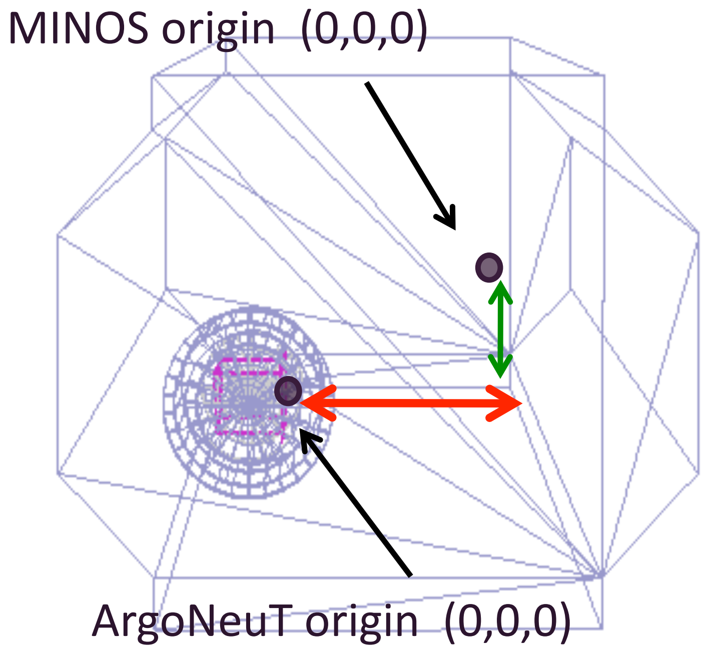
- Photon conversion background to ν_e interactions
  - Separation from primary vertex or by double ionization
  - γ-conversion over a minimum ionizing track requires excellent pair resolution

Careful inspection yields a minimum ionizing track with overlapping γ conversion



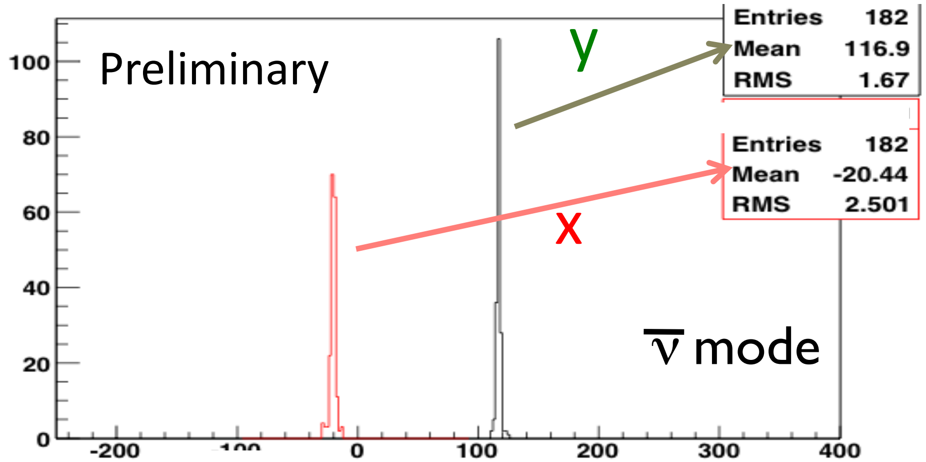
μ from upstream ν beam interaction: Matching with MINOS ND (I)





Tracks whose direction extrapolated from ArgoNeuT matches a MINOS track

Difference between horizontal coordinates and vertical coordinates of the "matched tracks"



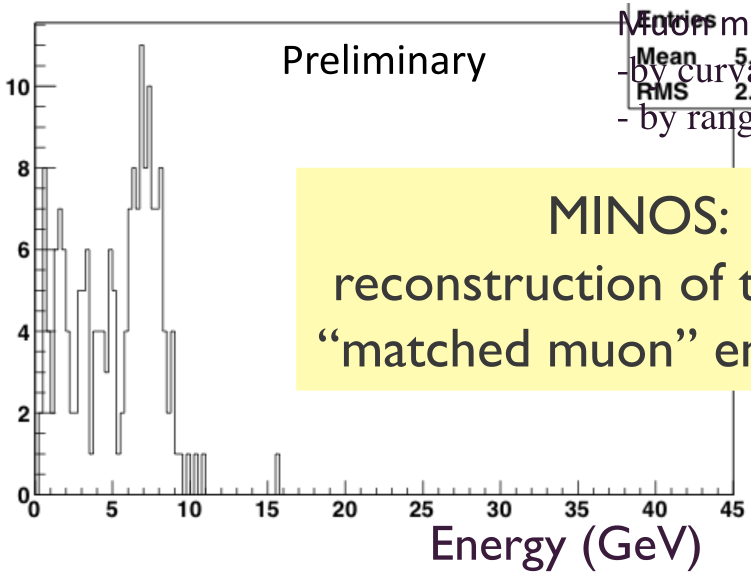
Conclusions

- Next-generation neutrino physics experiments require precision particle identification and fine grained 3D imaging. Liquid Argon (LAr) is recognized as an ideal detection medium, allowing the possibility of simultaneous ionization charge, scintillation and Cerenkov light signals collection in large volumes.
- The LAr TPC is a detector particularly suitable to study low energy neutrino interactions due to its high energy resolution and its robust particle identification capability down to the **"few GeV range"**.
- A big effort is under way to improve the event reconstruction procedures exploiting the full imaging and calorimetric capabilities of the LAr TPC technique.

Back-up slides

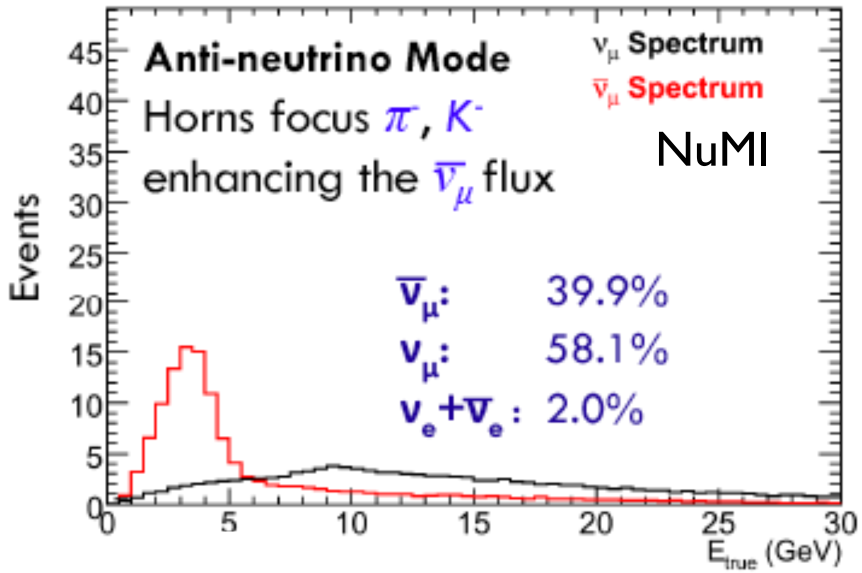
μ from upstream ν beam interaction: Matching with MINOS ND (II)

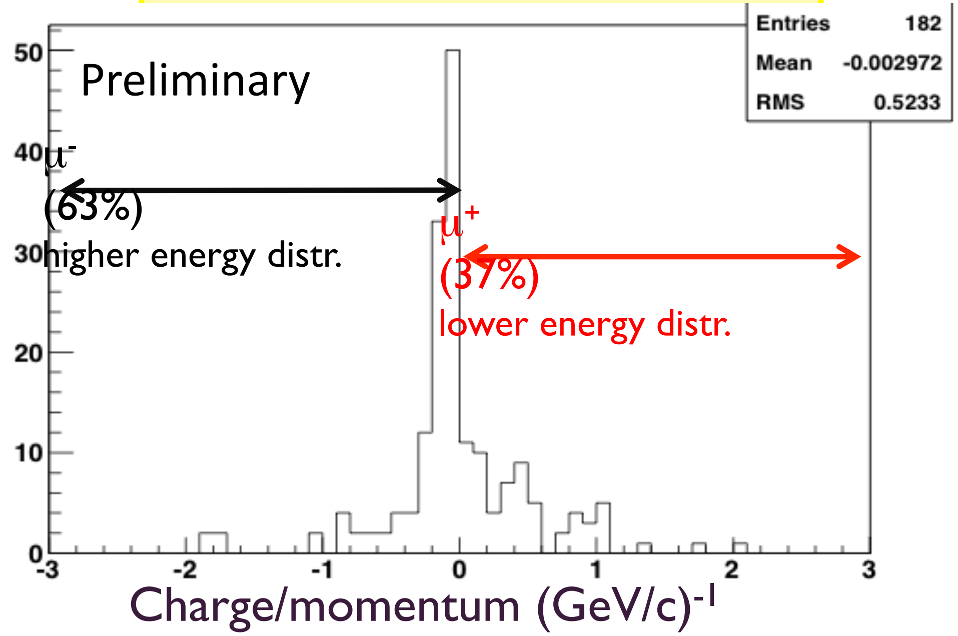
Muon momentum reconstruction from MINOS ND:
- by curvature in magn. field - 12% resolution for a 10 GeV muon
- by range for stopping muons ~6% resolution)



MINOS: reconstruction of the "matched muon" energy

MINOS: measurement of the "matched muon" sign





Understanding vertex activity

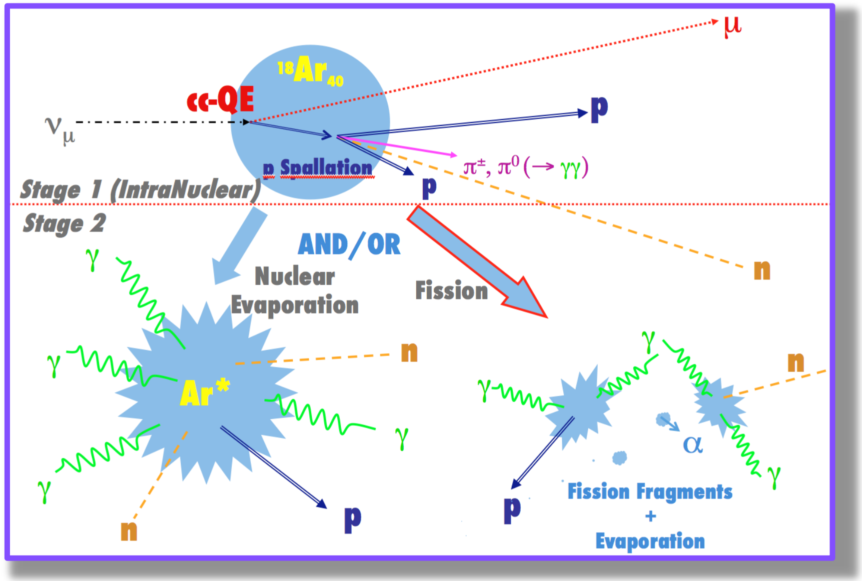
"Final State (re)-Interactions"- *the main source of uncertainty*:

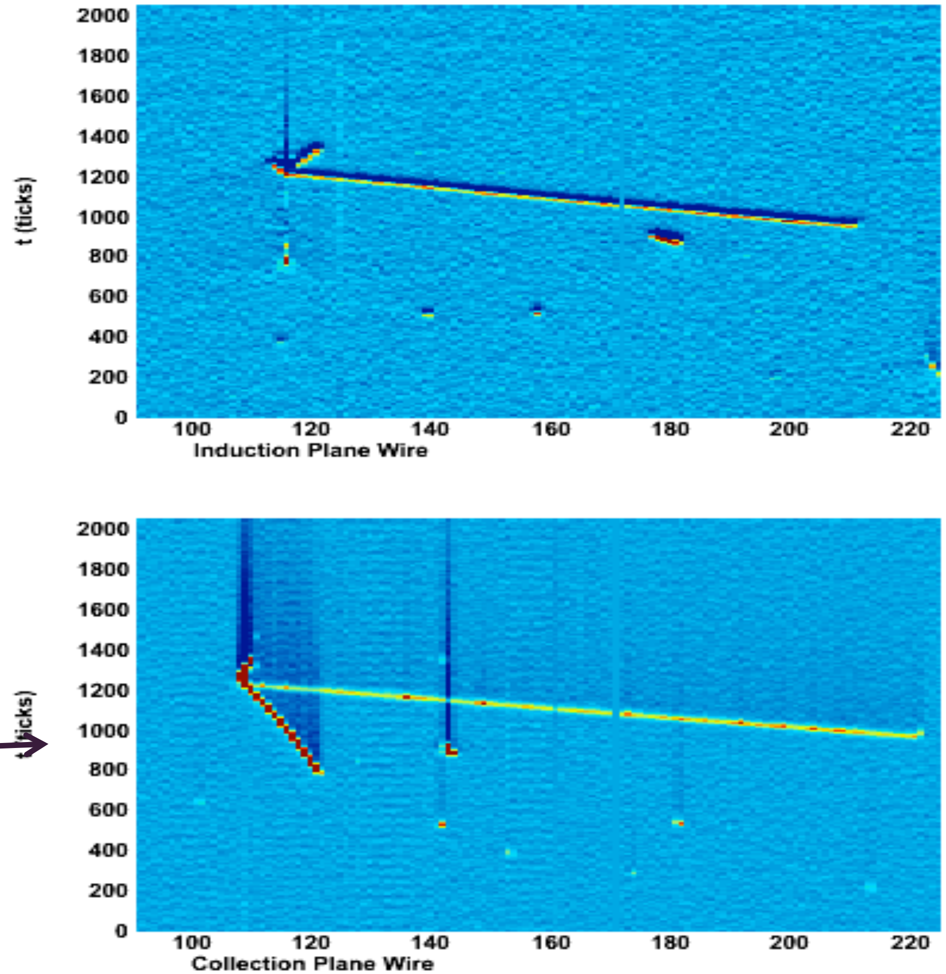
even the "easiest" topology (CC-QE) is not so simple

$\nu_\mu + n \rightarrow \mu^- + p$ (reaction on free nucleon)

$\nu_\mu + A(n) \rightarrow \mu^- + p + (A\text{-}1)^*$ (nucleon bound in the nuclear target)

FSI



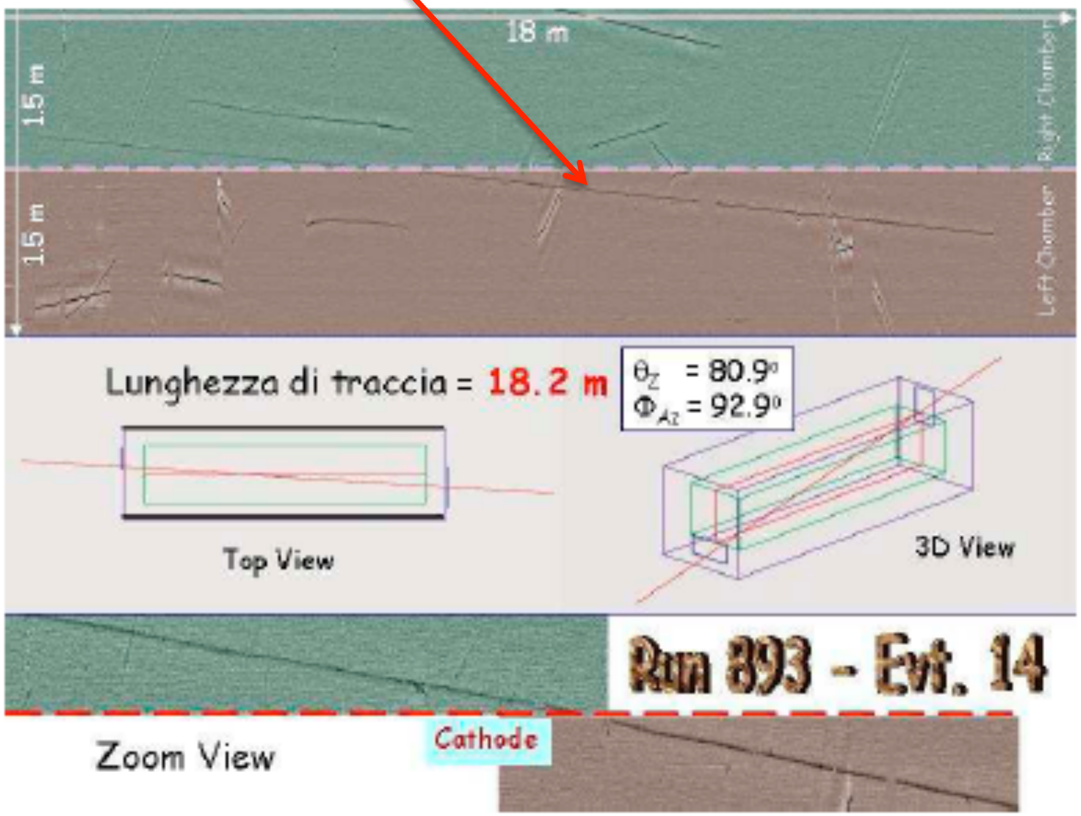


These products are usually neglected because not detectable, unless…
…. a high quality imaging detector is in use !!

A zoomed-in view of a CCQE-like neutrino event with evidence of vertex activity

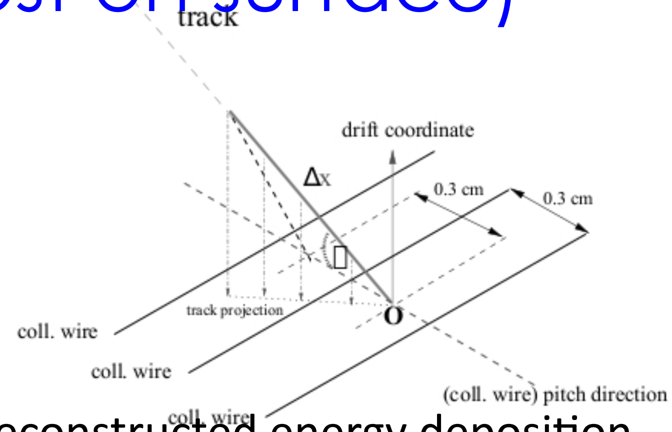
Observation of long ionizing muon tracks with the ICARUS T600 LAr TPC (test on surface)

About 18 m long c.r. muon tracks (~2000 collection wires)

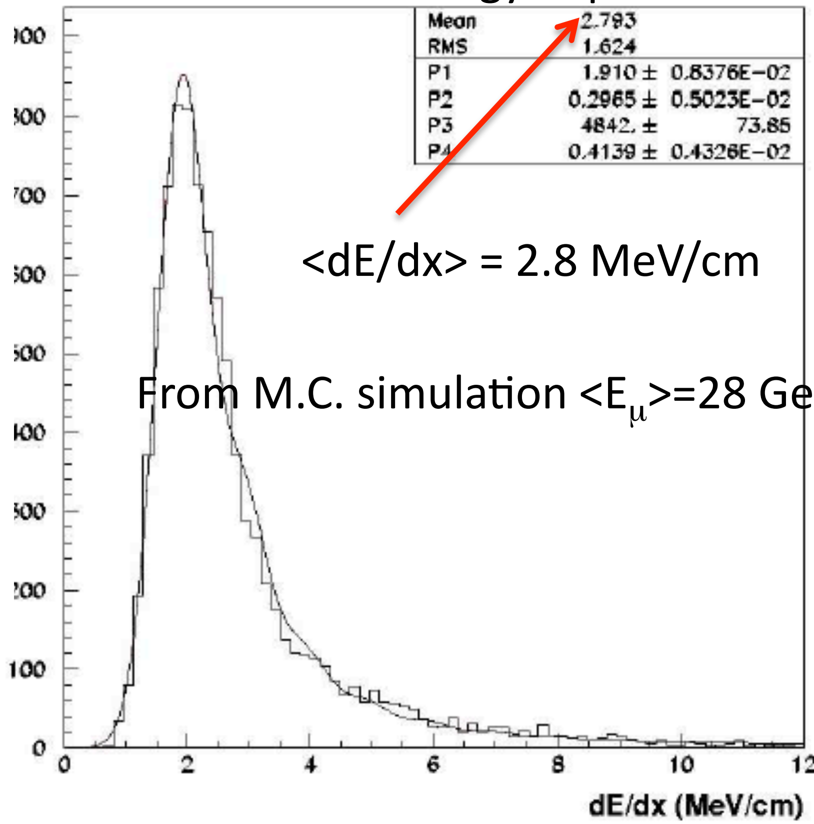


Raw images from the Collection plane

ICARUS Coll. NIM A 508 (2003) 287



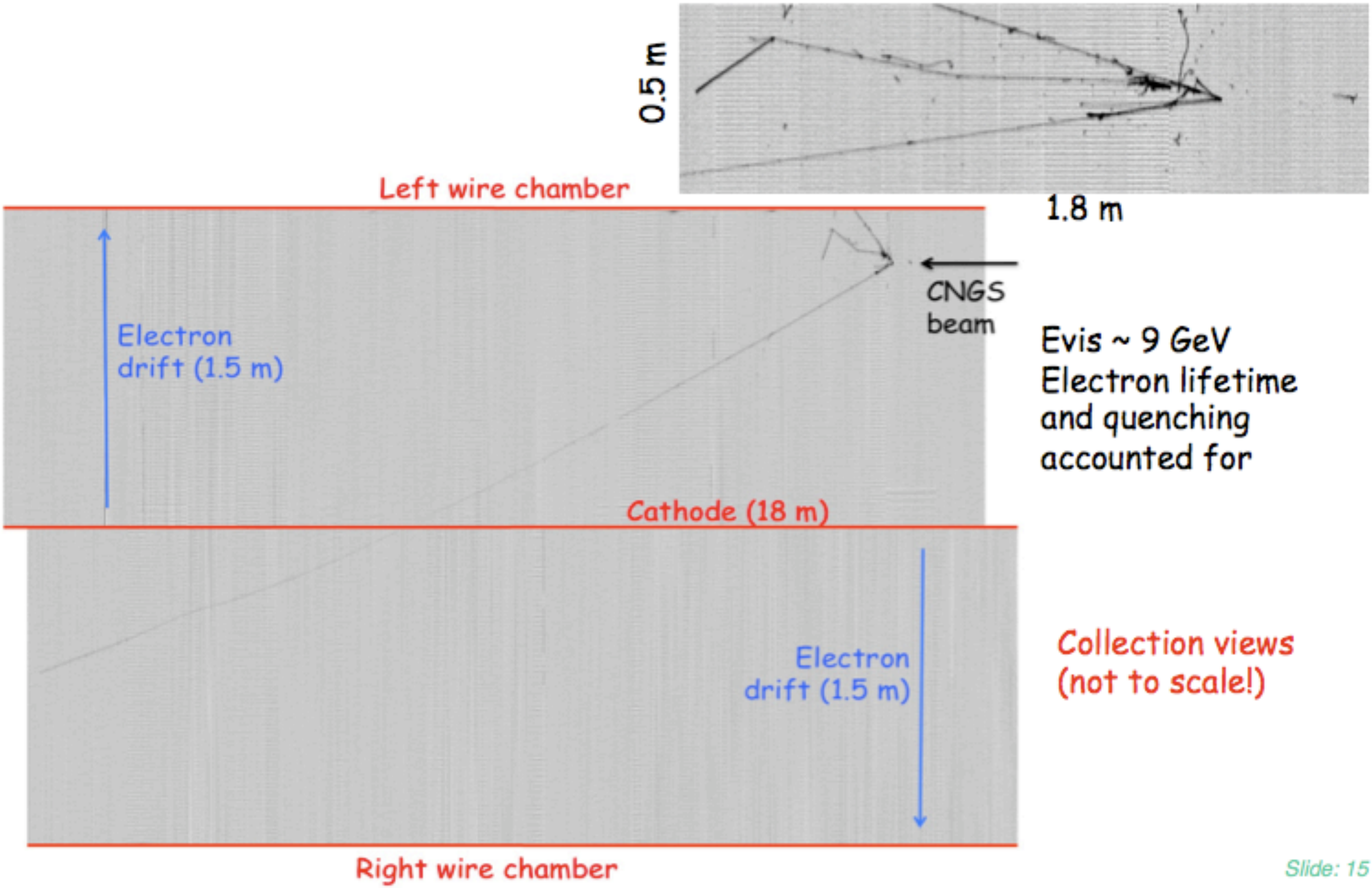
Reconstructed energy deposition



<dE/dx> = 2.8 MeV/cm

From M.C. simulation $\langle E_\mu \rangle$=28 GeV

Low energy CNGS neutrino interaction



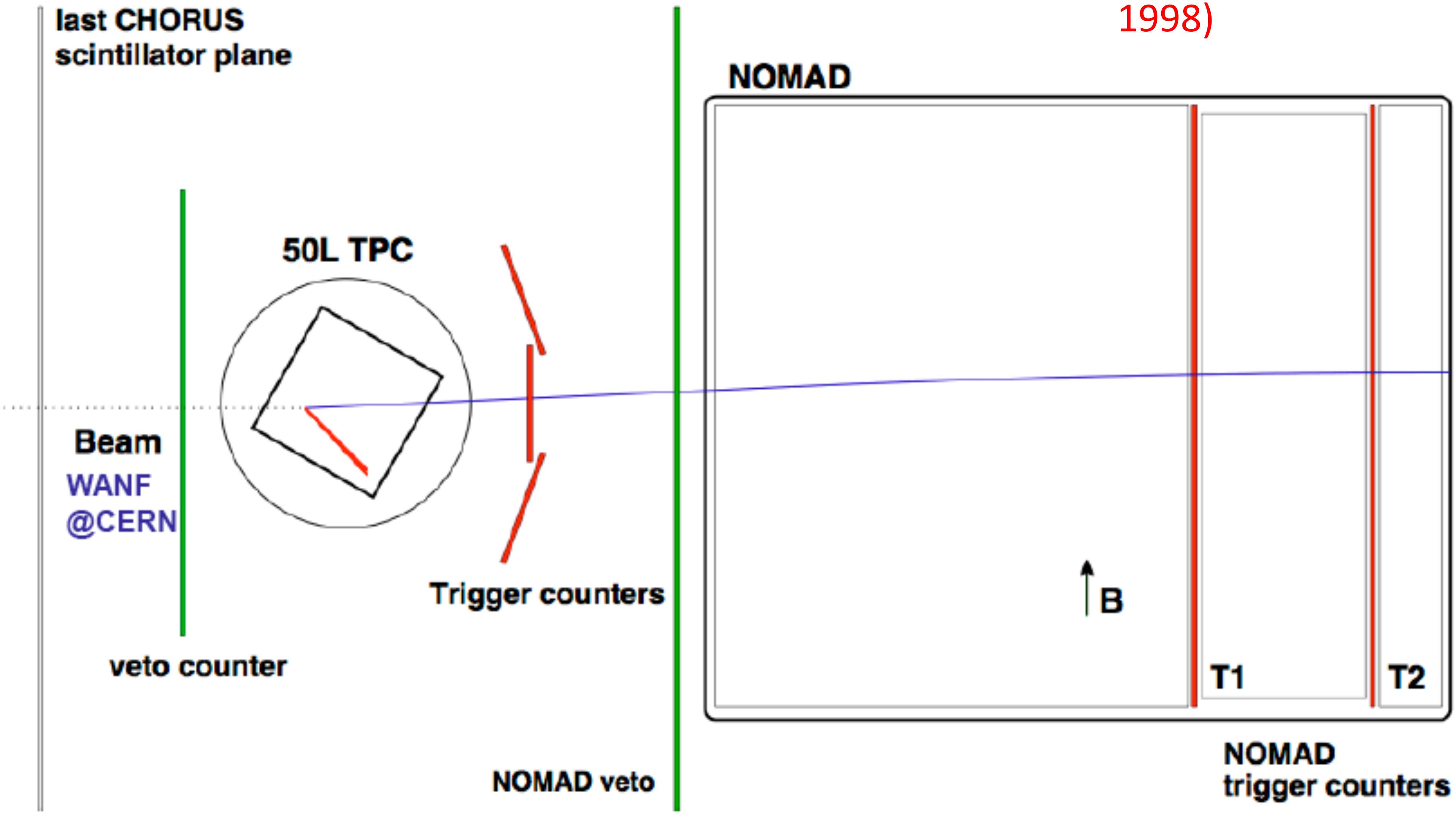
Evis ~ 9 GeV
Electron lifetime and quenching accounted for

Collection views (not to scale!)

Slide: 15

The ICARUS 50 lt Detector

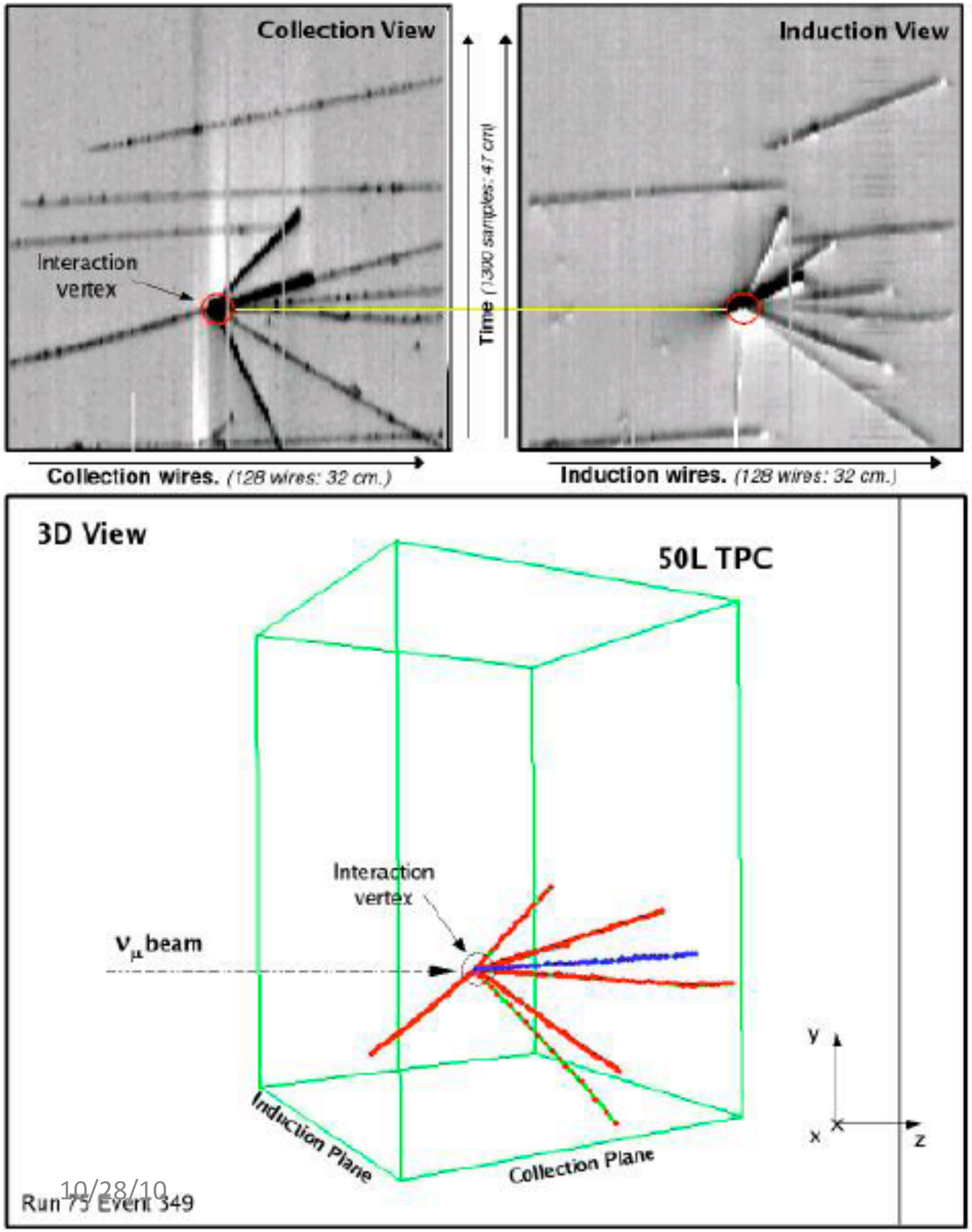
(1st exposure of a LAr TPC to a neutrino beam <E_ν>=28 GeV, 1998)



50 lt Detector backed by NOMAD exp. (magnetic spectrometer)

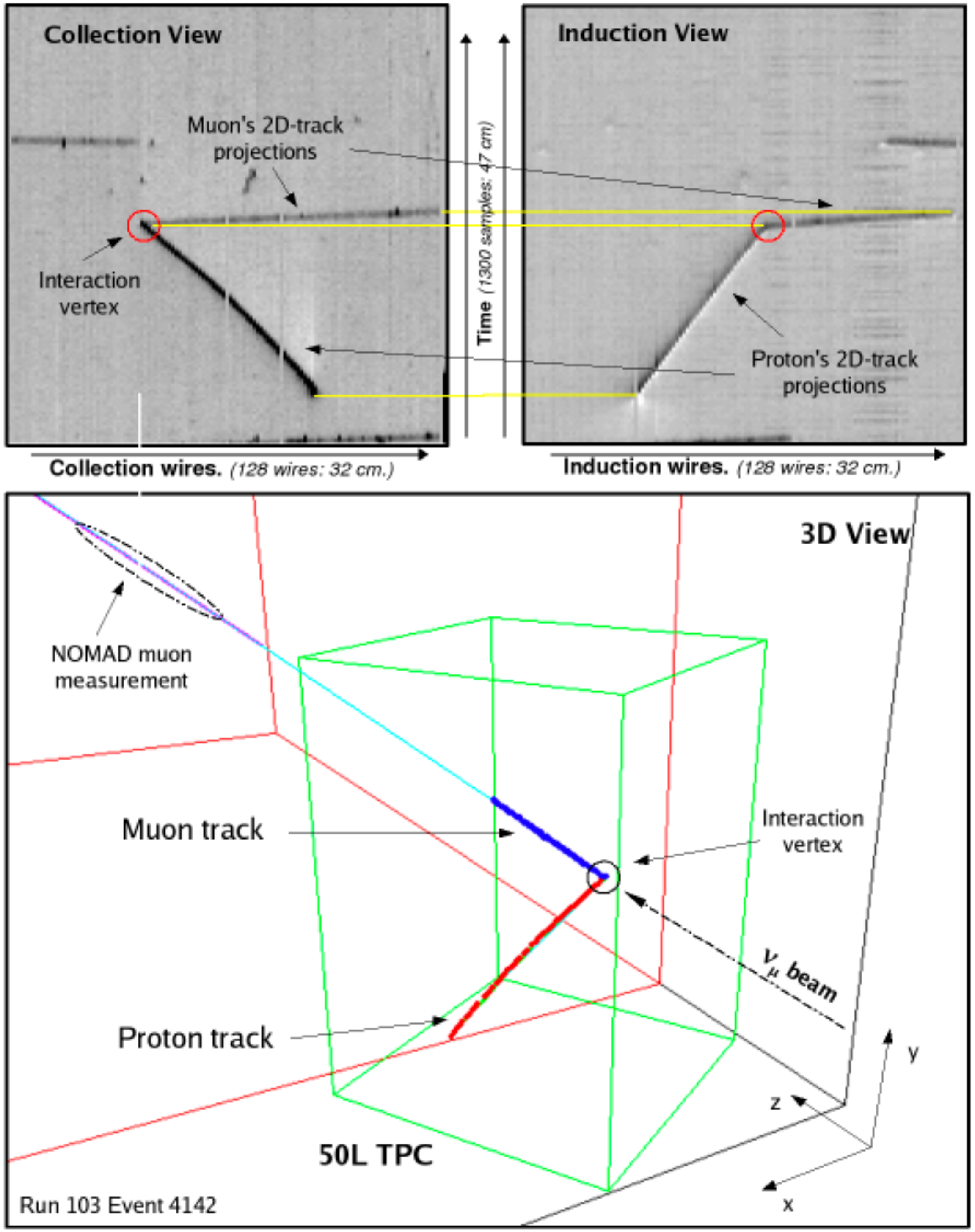
Trigger: (*SPS beam spill*.AND.*ScintCount*.AND.(*T1*+*T2*)).NOT.(*Chorus*.AND.*Veto*)

The ICARUS 50 lt Detector



2D views and

3D reconstruction of DIS event



2D views and

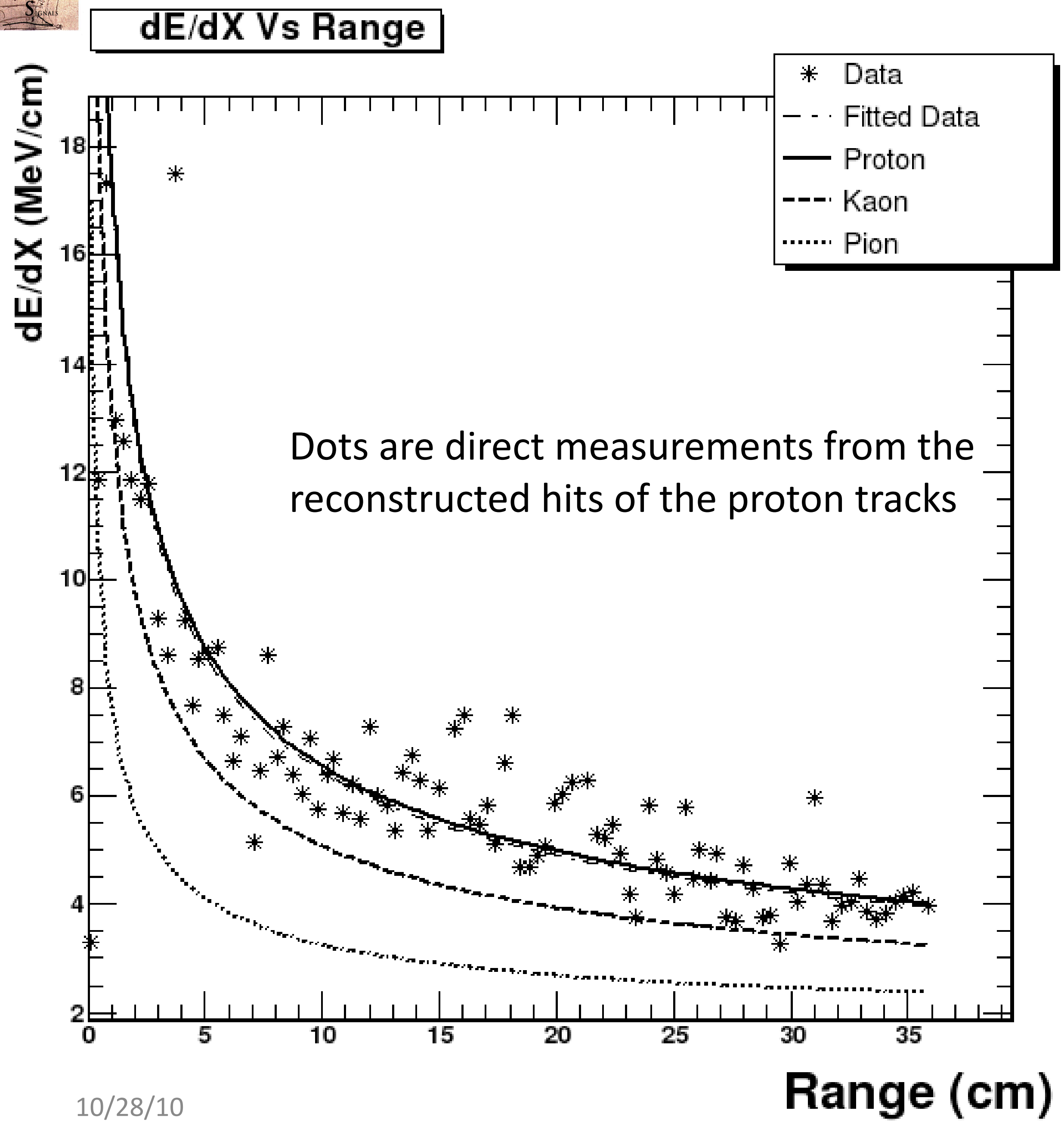
3D reconstruction of QE event

-Collection of around 10 000 *CC events*

-Selection of 86 ''golden sample'' events with:

an identified proton of kinetic energy >40 MeV fully contained in the TPC and one muon whose direction extrapolated from NOMAD matches the outgoing track in the TPC.

The ICARUS 50 lt Detector



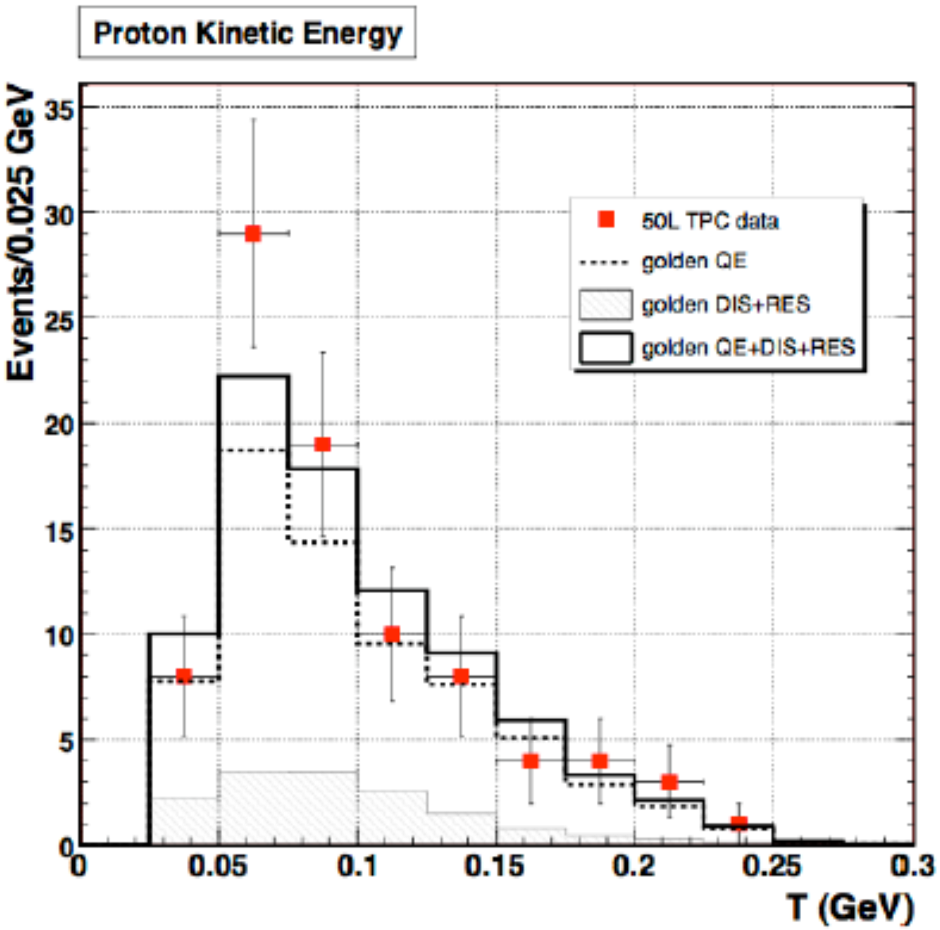
Ptcl. ID

Proton track recognition

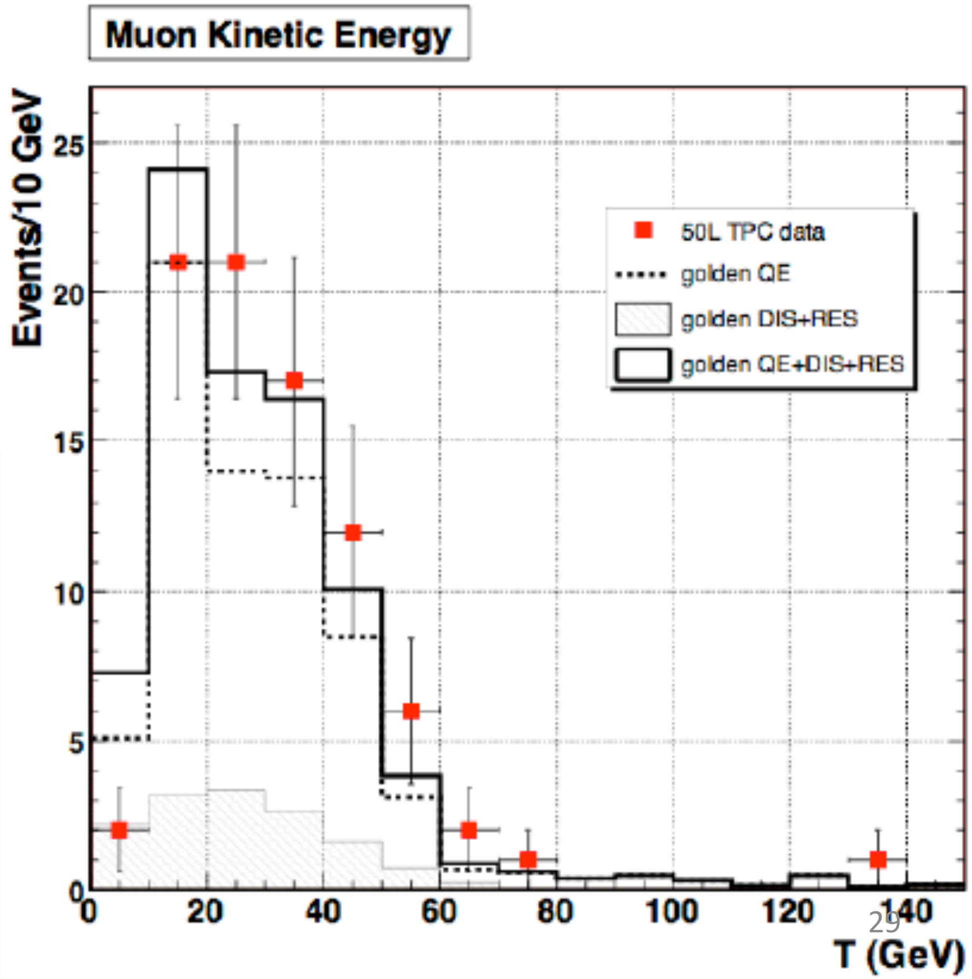
Proton reconstruction and momentum measurement performed using only TPC information

Energy Reconstruction for Muon and proton

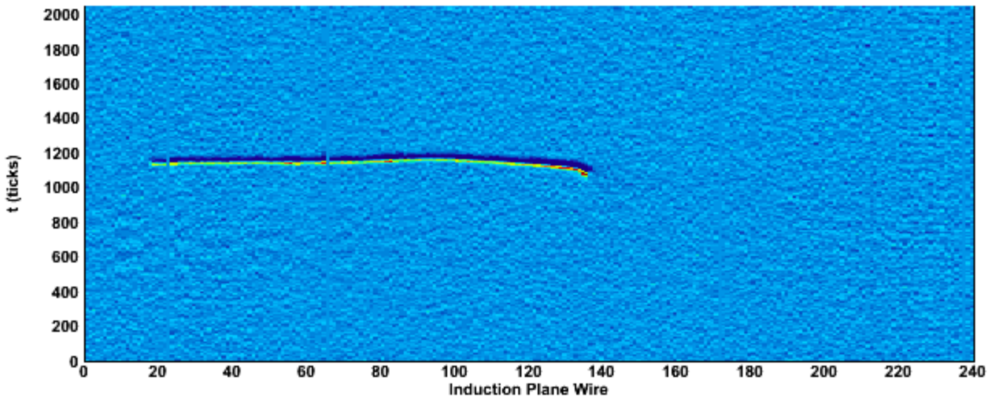
Kinematic reconstruction of the outgoing muon performed using the tracking capability of NOMAD and traced back to the TPC.

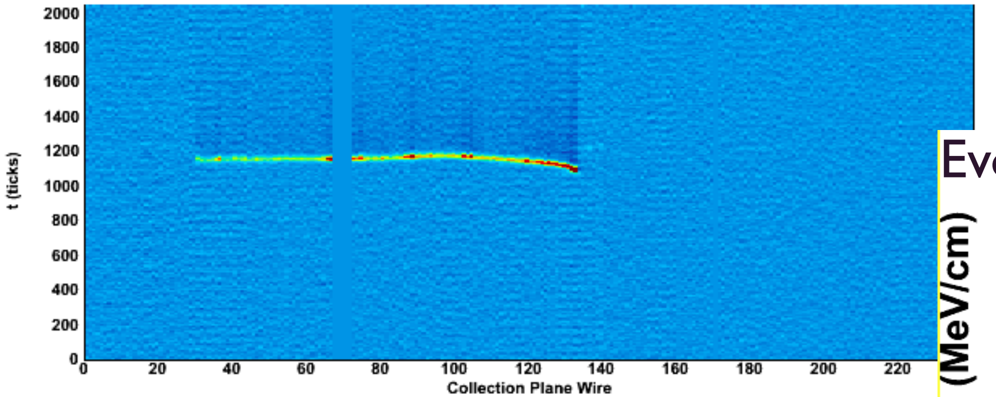


Proton kinetic energy calculated from range



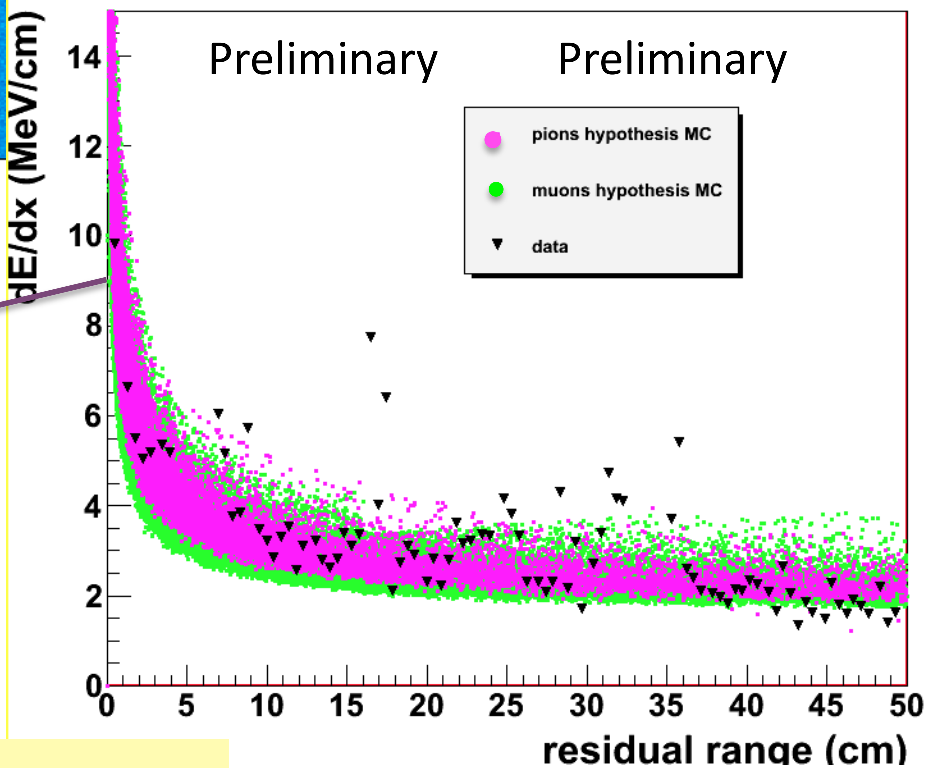
Particle ID





Penetrating particle
(from upstream interaction)
stopping in LAr volume

Evolution of the ionization along the track



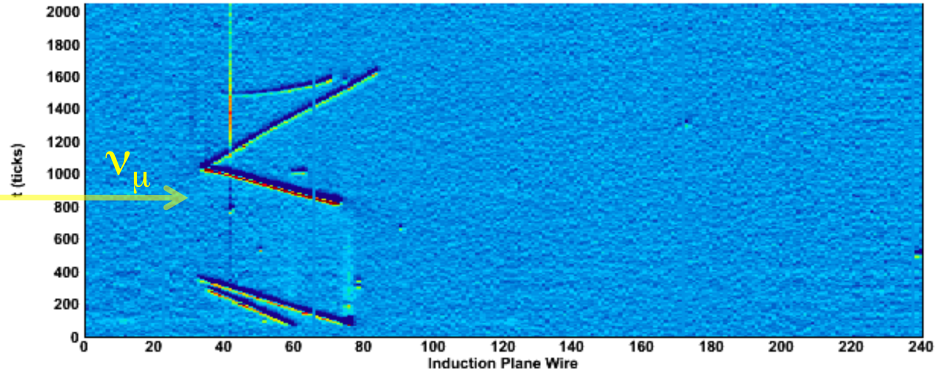
Minimum ionizing ptcl:

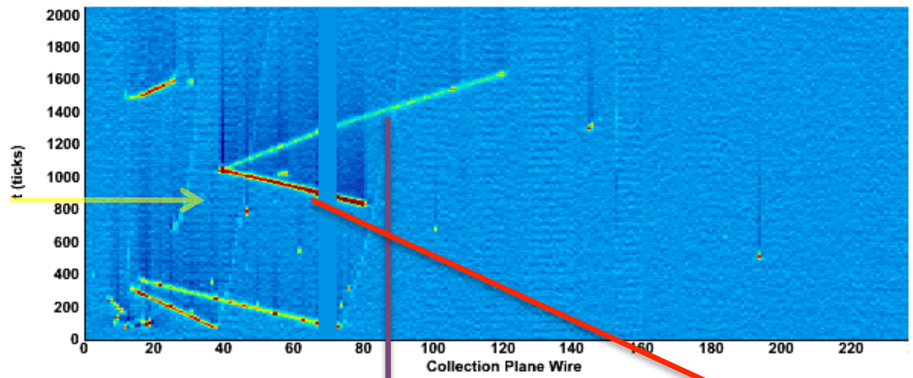
muon or pion

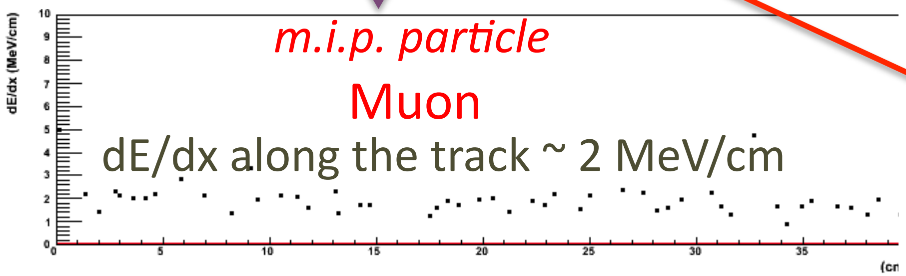
Track lenght= 52 cm
Kinetic Energy=160 MeV
(in agreement with expectations GEANT)

Muon-Pion separation possible only in same cases

ν_μ CC QE event reconstruction







m.i.p. particle

Muon

dE/dx along the track ~ 2 MeV/cm

ν Interaction in LAr volume

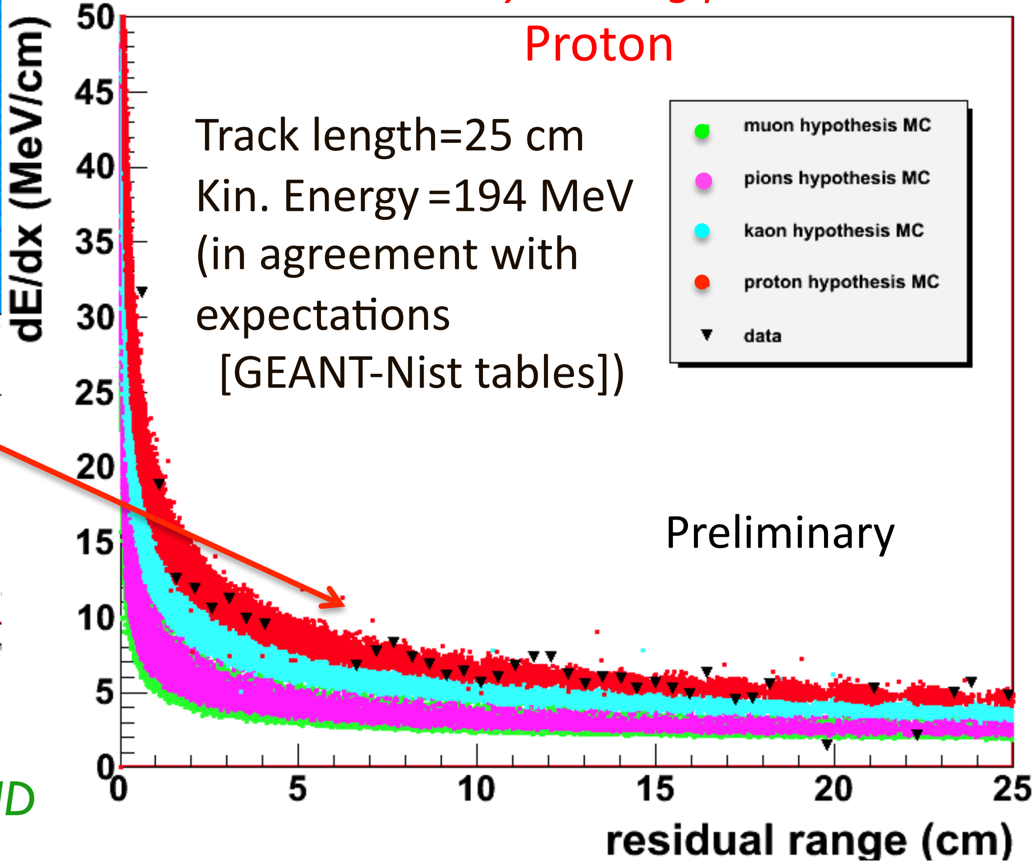
μ+p (ν_μ CC QE event)

+

uncorrelated tracks from upstream neutrino interaction

Heavy ionizing ptcl.

Proton

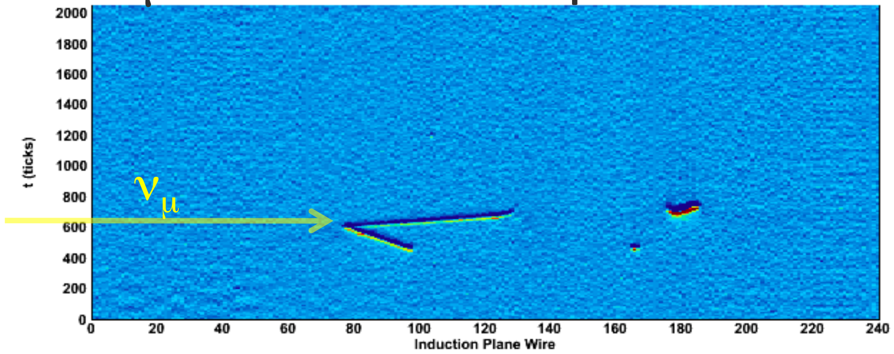


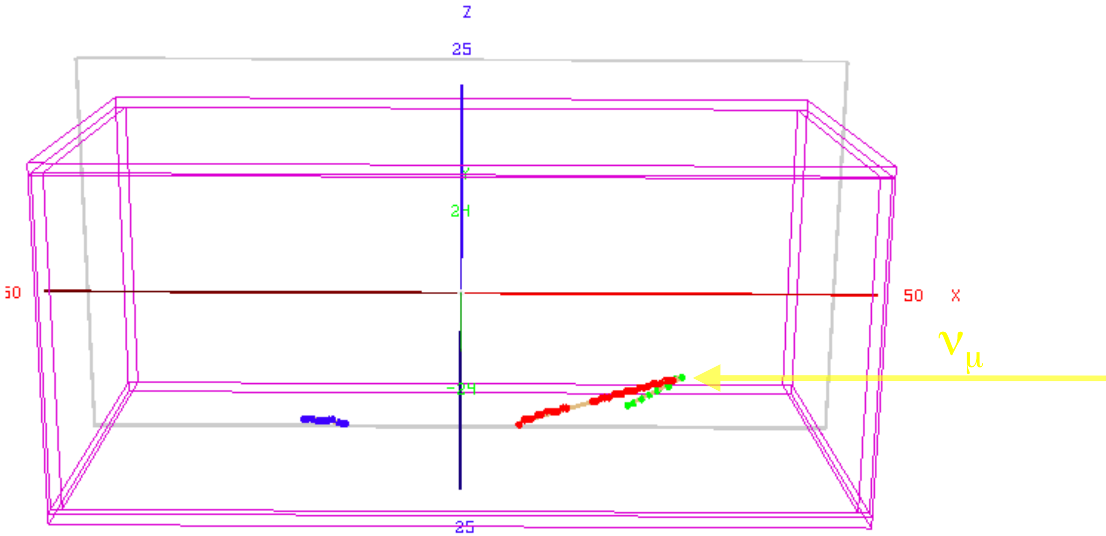
Track length=25 cm
Kin. Energy =194 MeV
(in agreement with expectations [GEANT-Nist tables])

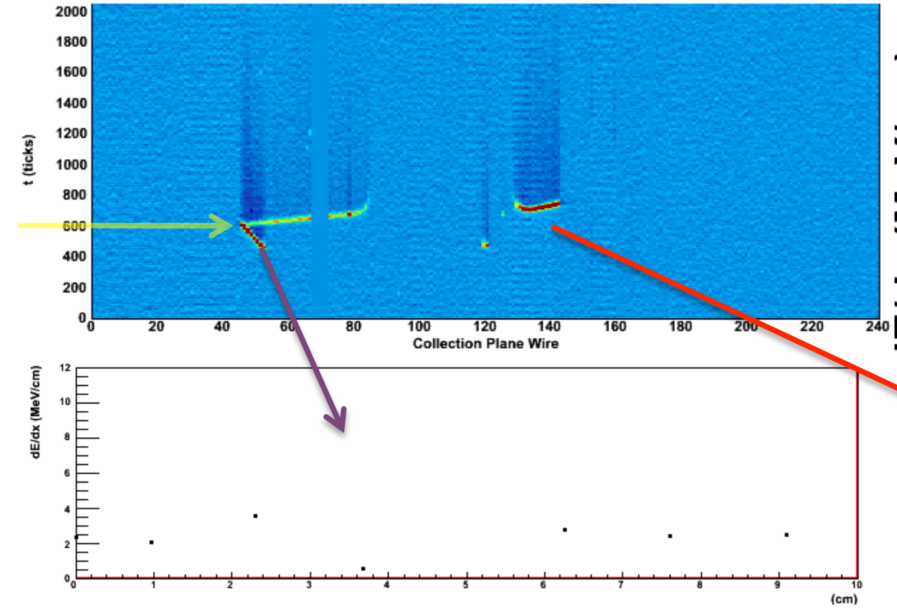
Long escaping muon momentum and sign reconstructed exploiting downstream MINOS ND

ν interaction in LAr

$\mu + \pi$ event + proton track







2 m.i.p. particles ($\mu + \pi$) at vtx

[*faking a QEL signature (μ + p)*]

+

proton track (far from vtx.)