Event reconstruction in LAr TPC
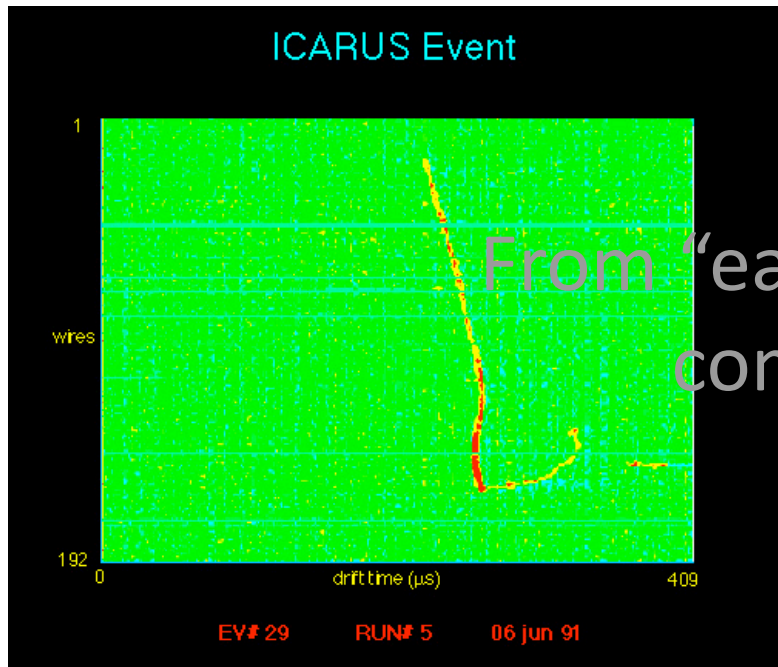

From "easy" to progressively more complicated topologies reconstruction

O. Palamara
Gran Sasso National Laboratory
(ITALY)

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
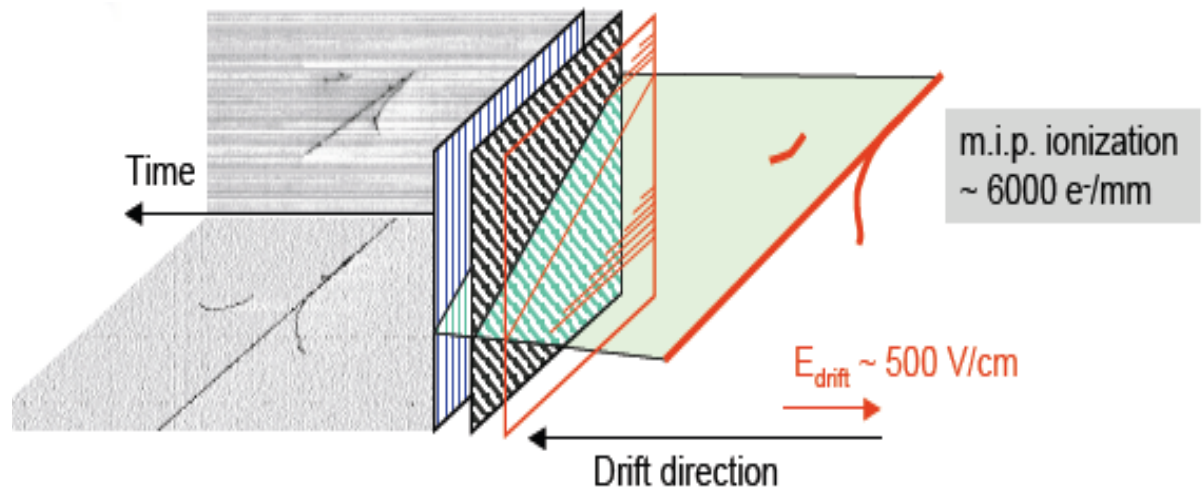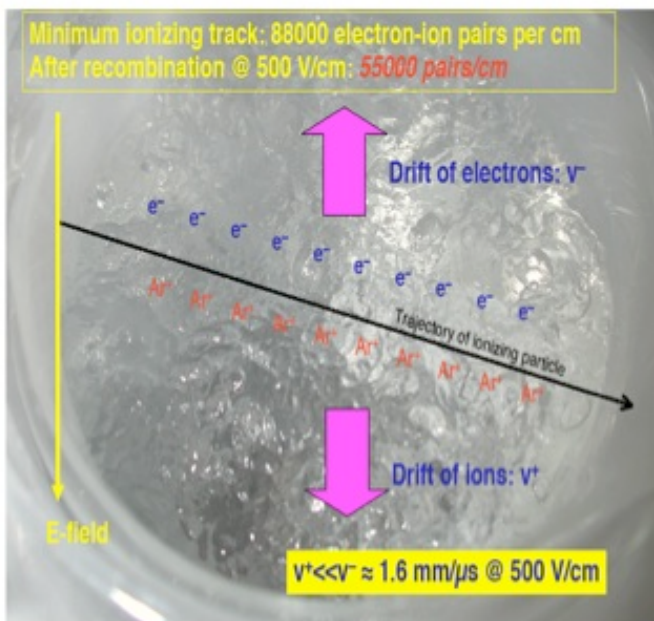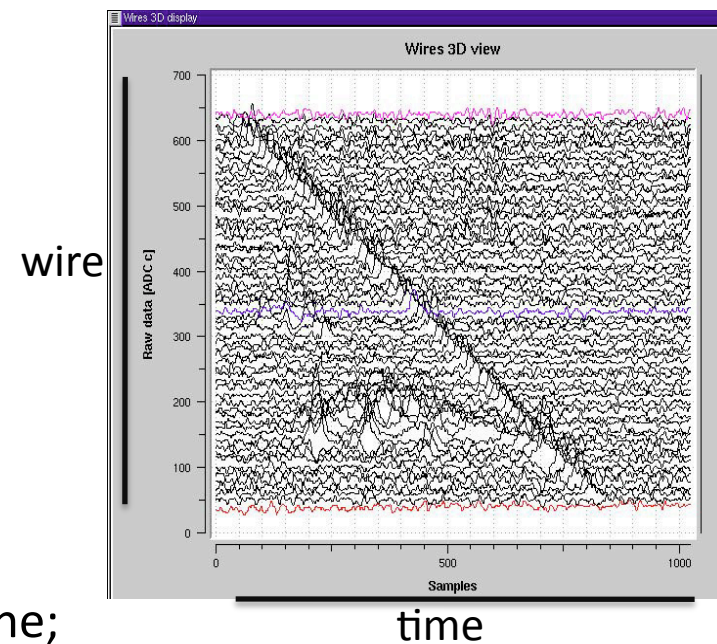
Event reconstruction procedure in LAr TPC (I)

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;

Wires 3D display

Wires 3D view

wire

time

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;
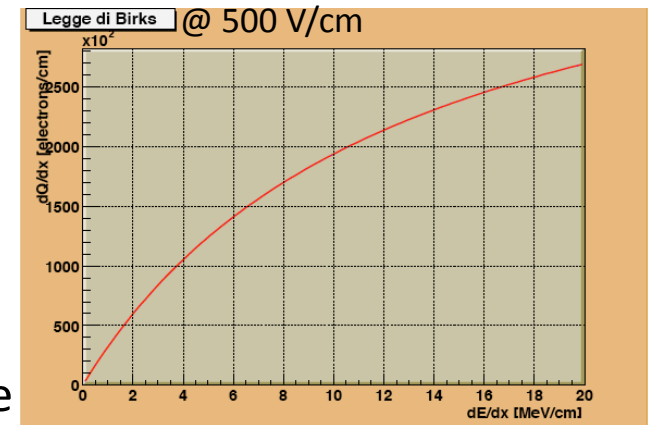
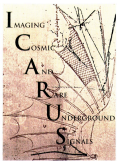5. *calorimetric reconstruction*: the determination of the energy release in LAr is performed in two steps:
   o accounting for the charge loss due to the attachment by electro-negative impurities

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

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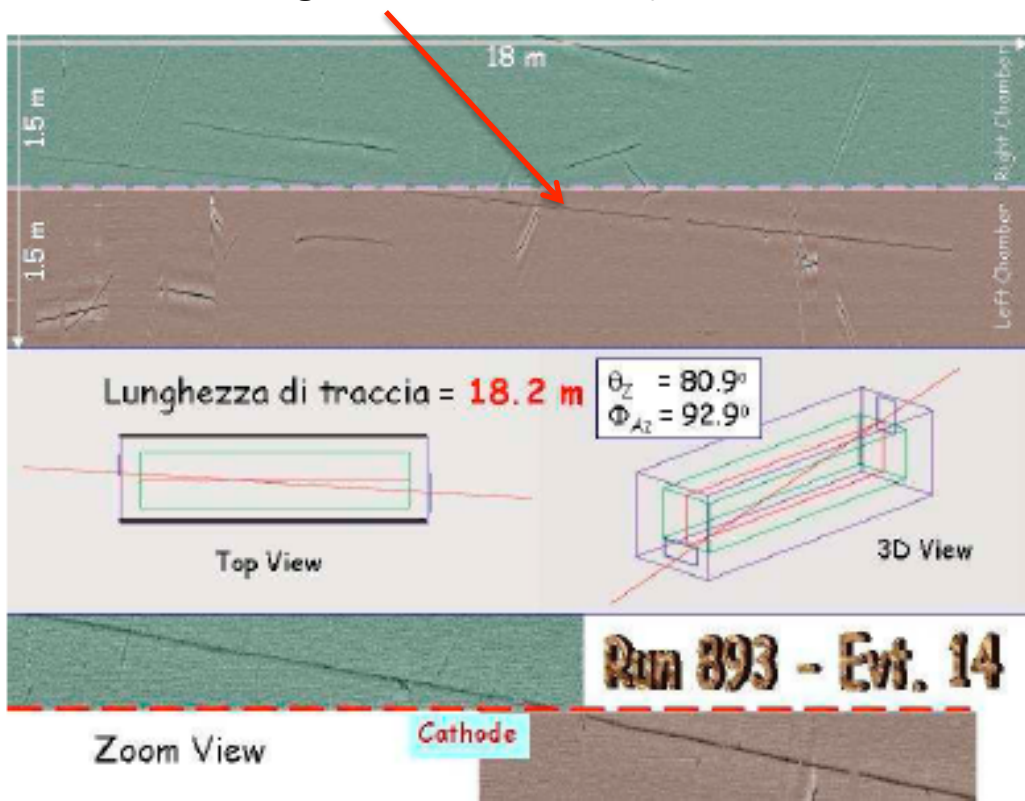

6. *Particle ID:* with dE/dx measurement vs. range

O. Palamara

Observation of long ionizing muon tracks with the ICARUS T600 LAr TPC (test on surface)
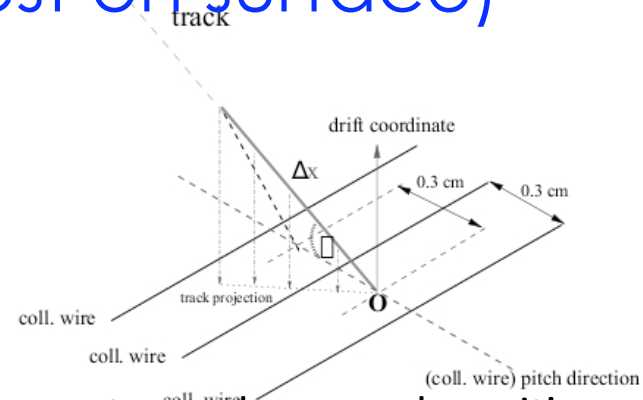
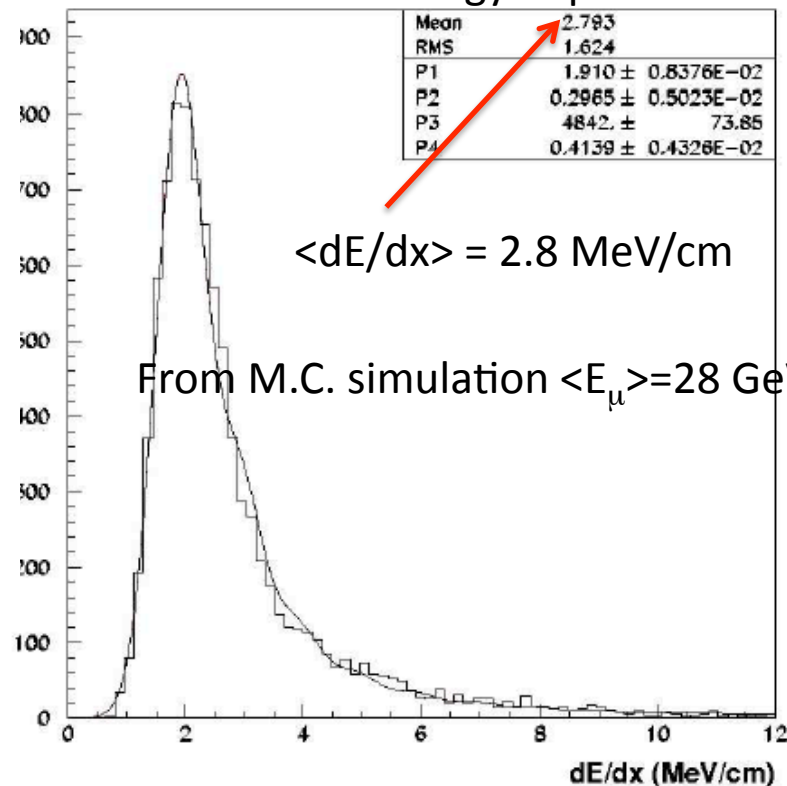About 18 m long c.r. muon tracks (~2000 collection wires)

Top View

$\theta_Z = 80.9^\circ$
$\Phi_{AZ} = 92.9^\circ$

Lunghezza di traccia = 18.2 m

3D View

Run 893 - Evt. 14

Cathode

Zoom View

Raw images from the Collection plane

ICARUS Coll. NIM A 508 (2003) 287

Reconstructed energy deposition

Mean	2.793
RMS	1.624
P1	1.910 ± 0.8376E−02
P2	0.2965 ± 0.5023E−02
P3	4842. ± 73.85
P4	0.4139 ± 0.4326E−02

<dE/dx> = 2.8 MeV/cm

From M.C. simulation $<E_\mu>$=28 GeV

dE/dx (MeV/cm)
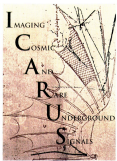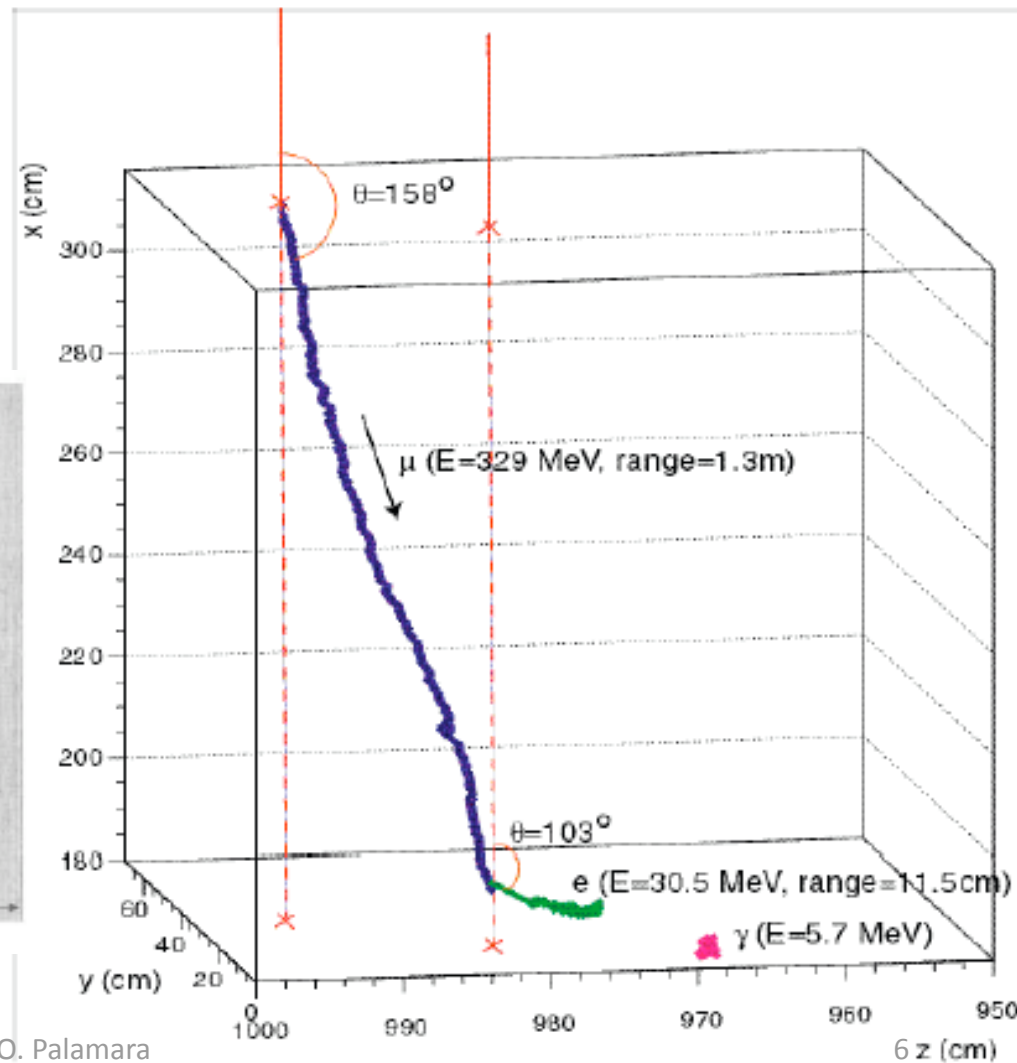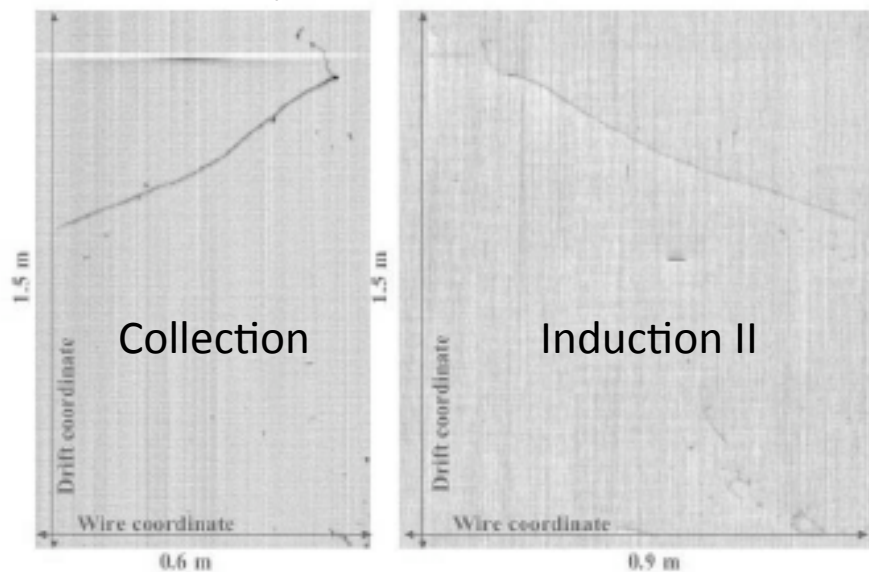
Measurement of the μ decay spectrum with the ICARUS T600 LAr TPC (test on surface)
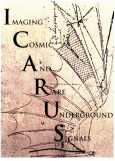
Fully reconstructed stopping muon event

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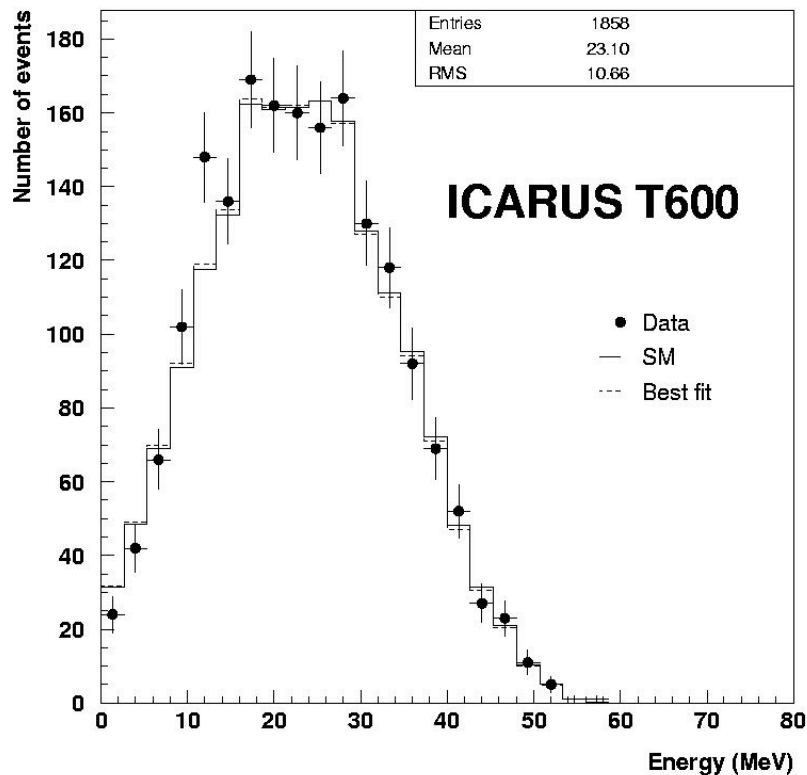muon decay event views (Collection and Induction II)

Collection

Induction II

θ=158°

μ (E=329 MeV, range=1.3m)

θ=103°

e (E=30.5 MeV, range=11.5cm)

γ (E=5.7 MeV)

O. Palamara

Michel Electron Spectrum

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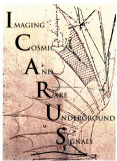

ICARUS Coll. Eur. Phys. J. C 33 (2004), 233

- Study of stopping muon sample
  - 3000 events analyzed and fully reconstructed in 3D

- ρ parameter measurement (from comparison with MC simulation)

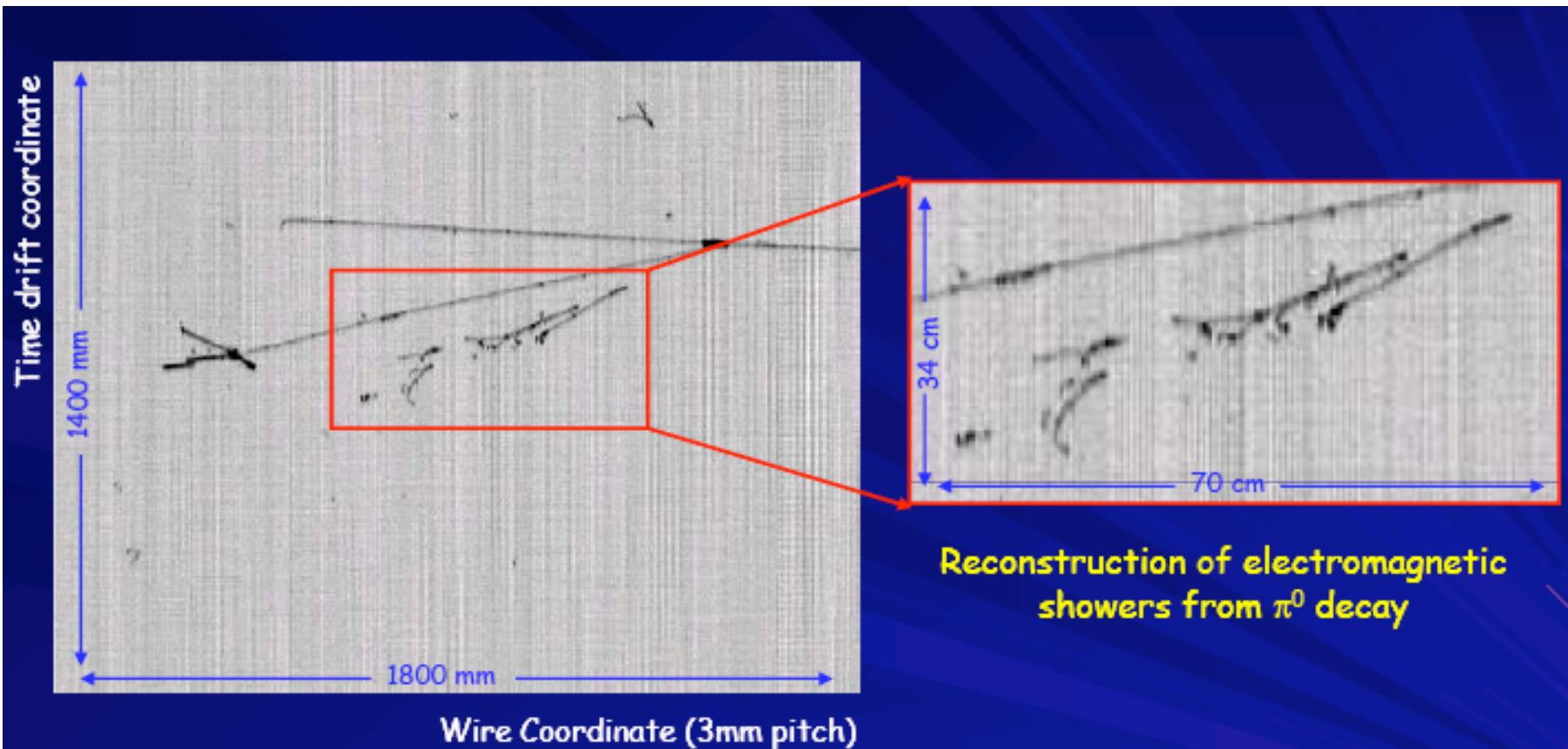$$\rho = 0.72 \pm 0.06\,(stat) \pm 0.08\,(sys)$$

➢ Standard Model $\rho = 0.75$

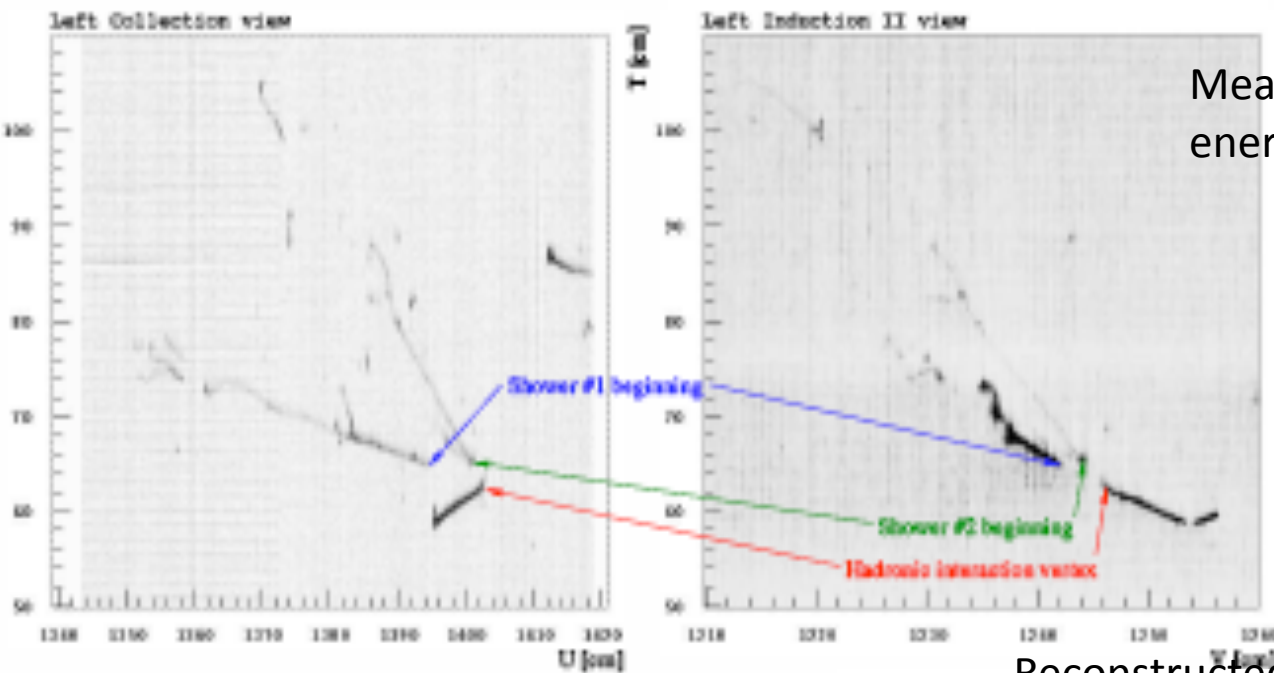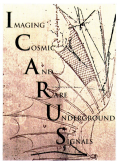- Energy resolution for electrons below ~50 MeV

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

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

Reconstruction of electromagnetic showers from π^0 decay

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

left Collection view — left Induction II view

Shower #1 beginning

Shower #2 beginning

Hadronic interaction vertex

Measurement of the shower energy and shower direction
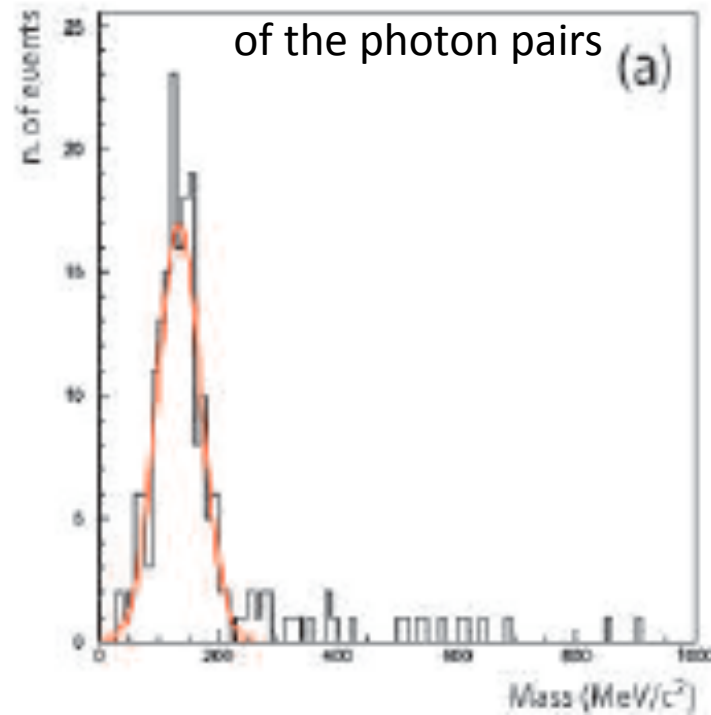
Reconstructed invariant mass of the photon pairs

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

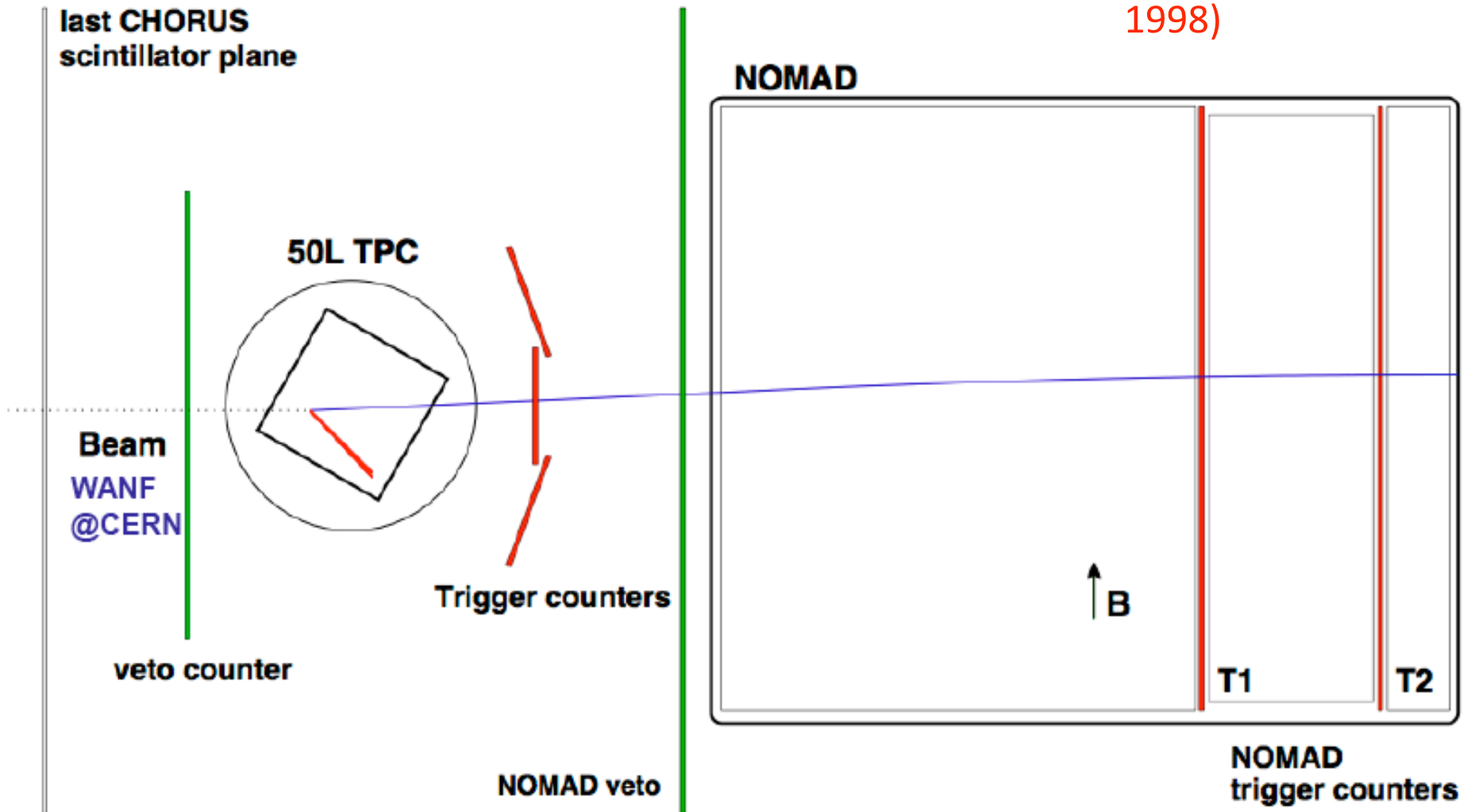Average mass:

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

+ a contribution of 7.1% from systematics

(a)

Mass (MeV/c²)

The ICARUS 50 lt Detector

last CHORUS scintillator plane

NOMAD

50L TPC

Beam

WANF @CERN

Trigger counters

veto counter

↑B

T1   **T2**

NOMAD veto

NOMAD trigger counters

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

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

Collection View

Induction View

Time (1300 samples: 47 cm)

Interaction vertex

Collection wires. (128 wires: 32 cm.)

Induction wires. (128 wires: 32 cm.)

3D View

50L TPC

Interaction vertex

ν_μ beam

Induction Plane

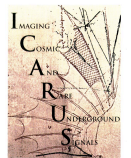Collection Plane

y

x

z
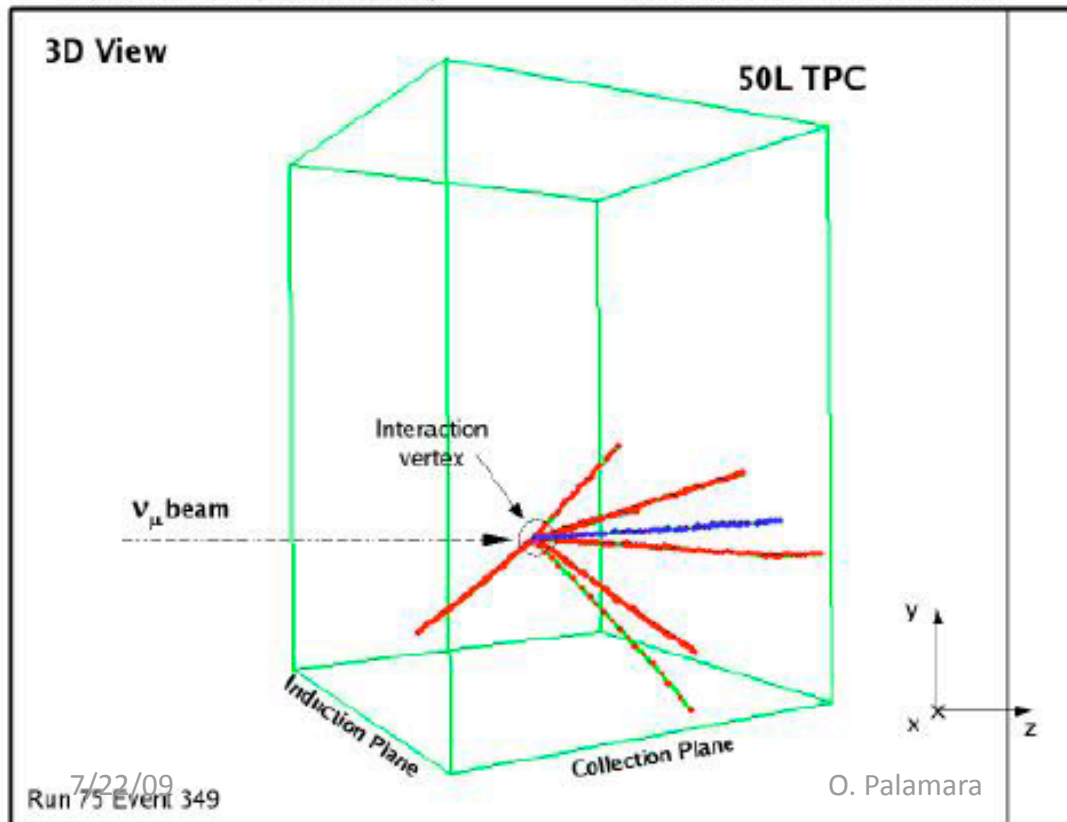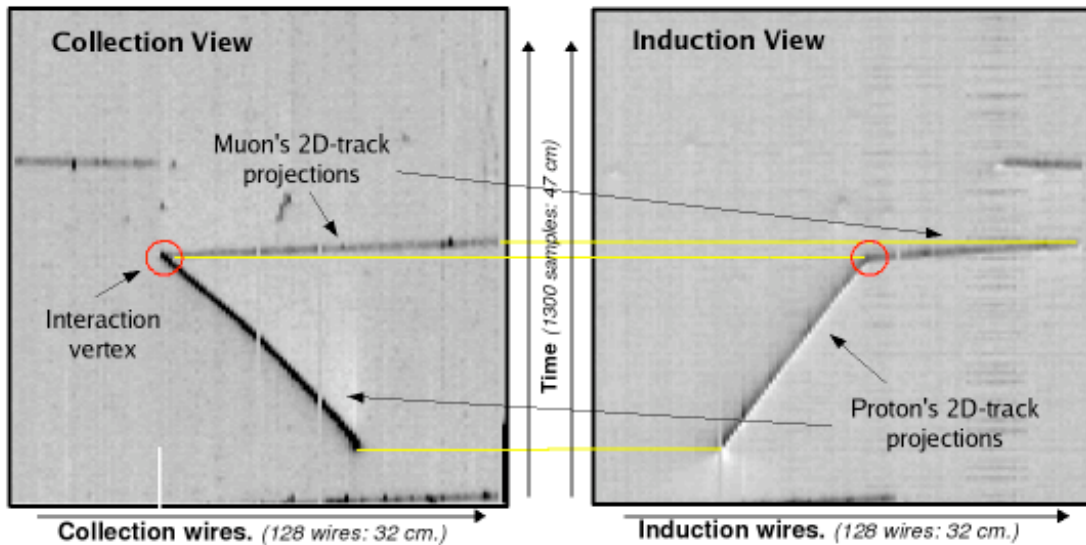
Run 75 Event 349

7/22/09

O. Palamara
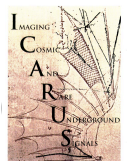
The ICARUS 50 lt Detector
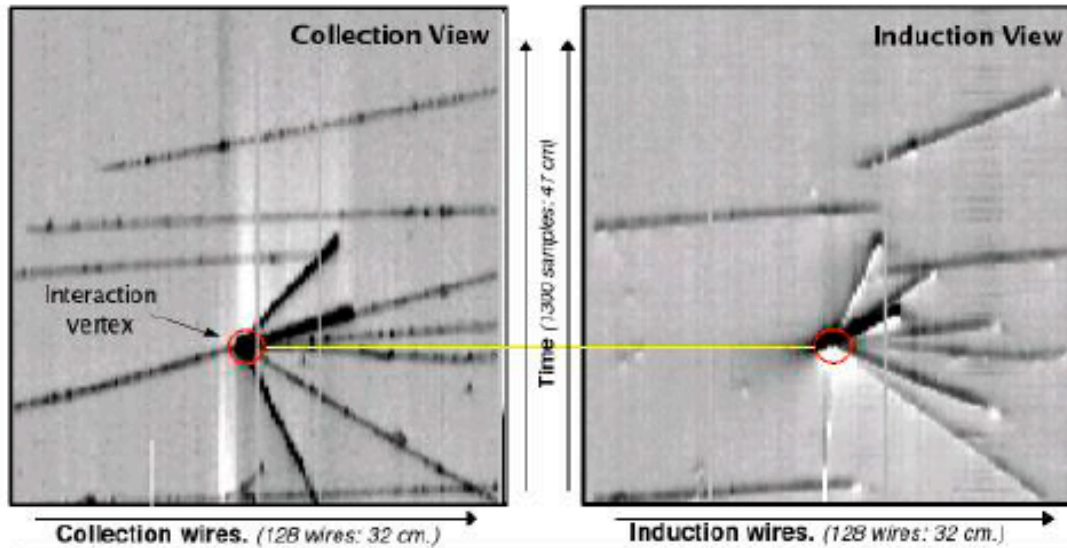
2D views and

3D reconstruction of DIS event

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1

Collection View

Muon's 2D-track projections

Interaction vertex

Collection wires. *(128 wires: 32 cm.)*

Time (1300 samples: 47 cm)

Induction View

Proton's 2D-track projections

Induction wires. *(128 wires: 32 cm.)*

3D View

NOMAD muon measurement

Muon track

Interaction vertex

Proton track

ν_μ beam

50L TPC
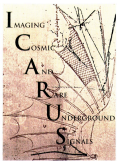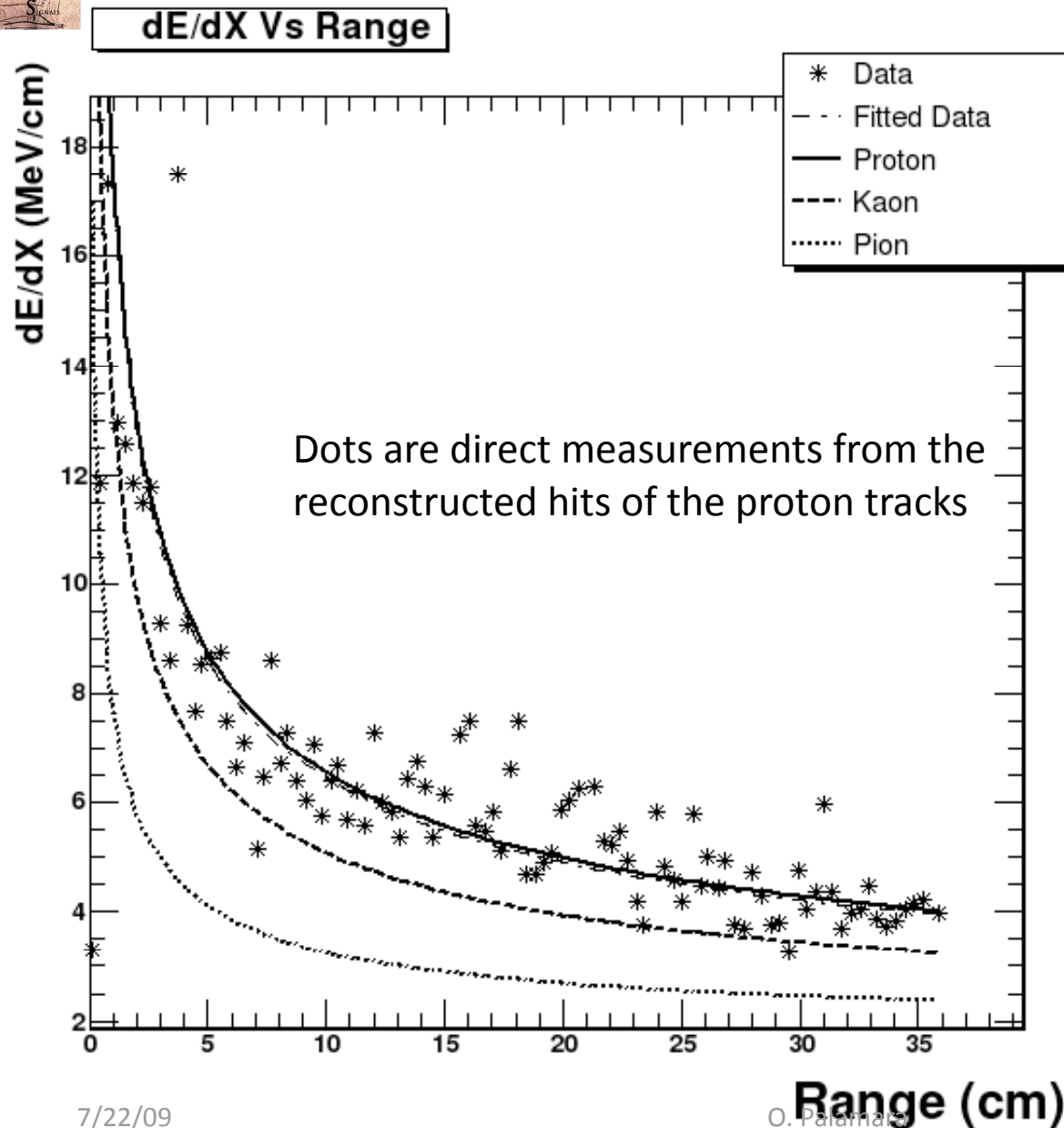
Run 103 Event 4142

x y z

2D views and
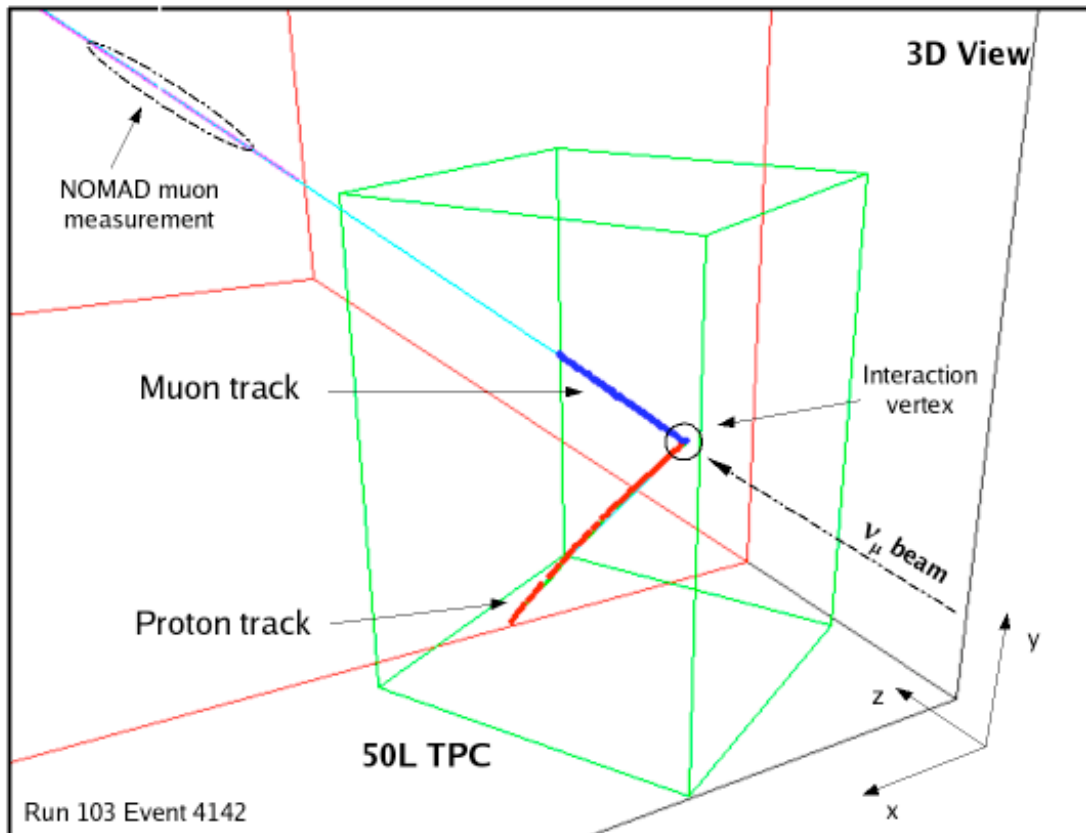
3D reconstruction of QE event

-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.

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dE/dX Vs Range

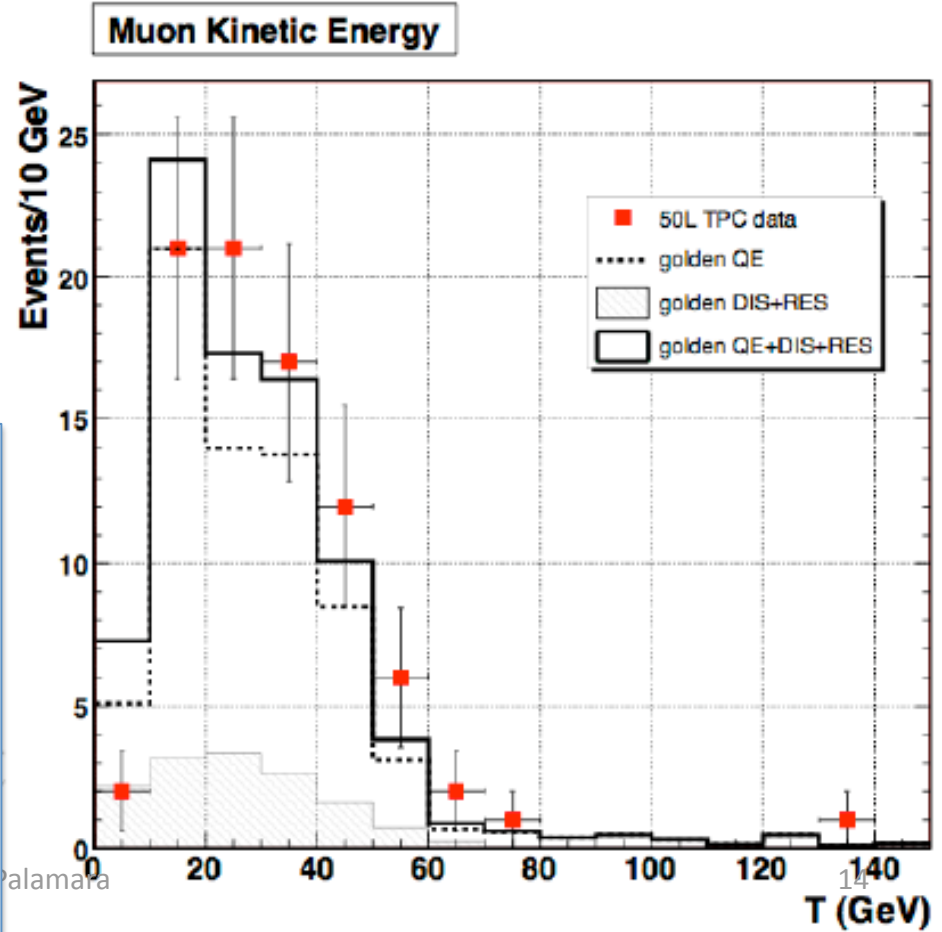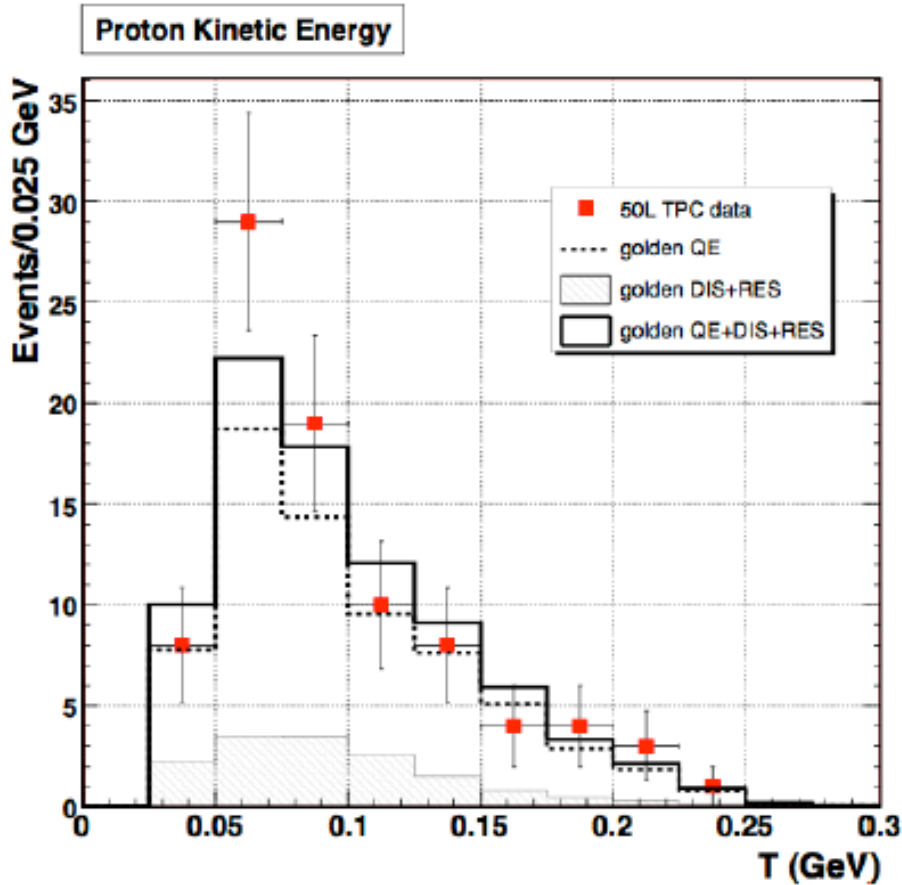
Legend:
* Data
- - Fitted Data
— Proton
--- Kaon
...... Pion

Dots are direct measurements from the reconstructed hits of the proton tracks

Ptcl. ID

Proton track recognition

Proton reconstruction and momentum measurement performed using only TPC information

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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

Legend:
- 50L TPC data
- golden QE
- golden DIS+RES
- golden QE+DIS+RES

Proton kinetic energy calculated from range

Muon Kinetic Energy

Legend:
- 50L TPC data
- golden QE
- golden DIS+RES
- golden QE+DIS+RES

Palamara

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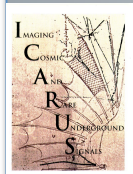
The ArgoNeuT Experiment

- ArgoNeuT is a 175 l (active) Liquid Argon TPC exposed to the NuMI low energy neutrino beam at FNAL   (Commissioning run: May-June 2009)

- ArgoNeuT detector is located between Minerva and the MINOS near detector at NuMI Tunnel – 100m underground. Muons escaping the TPC are reconstructed in MINOS ND.
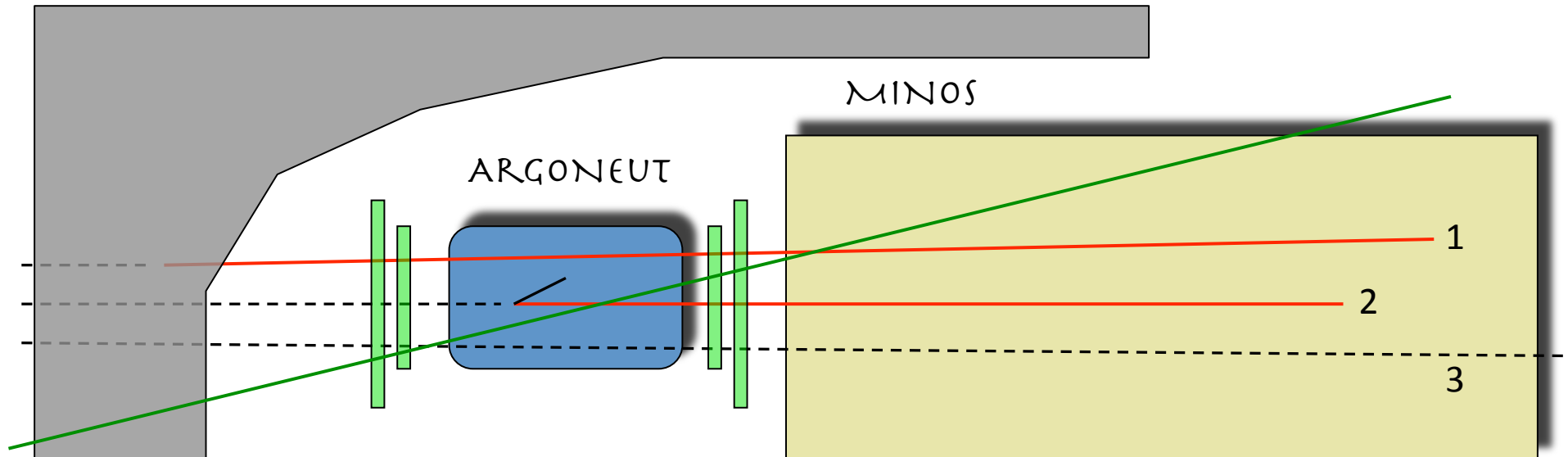

100m
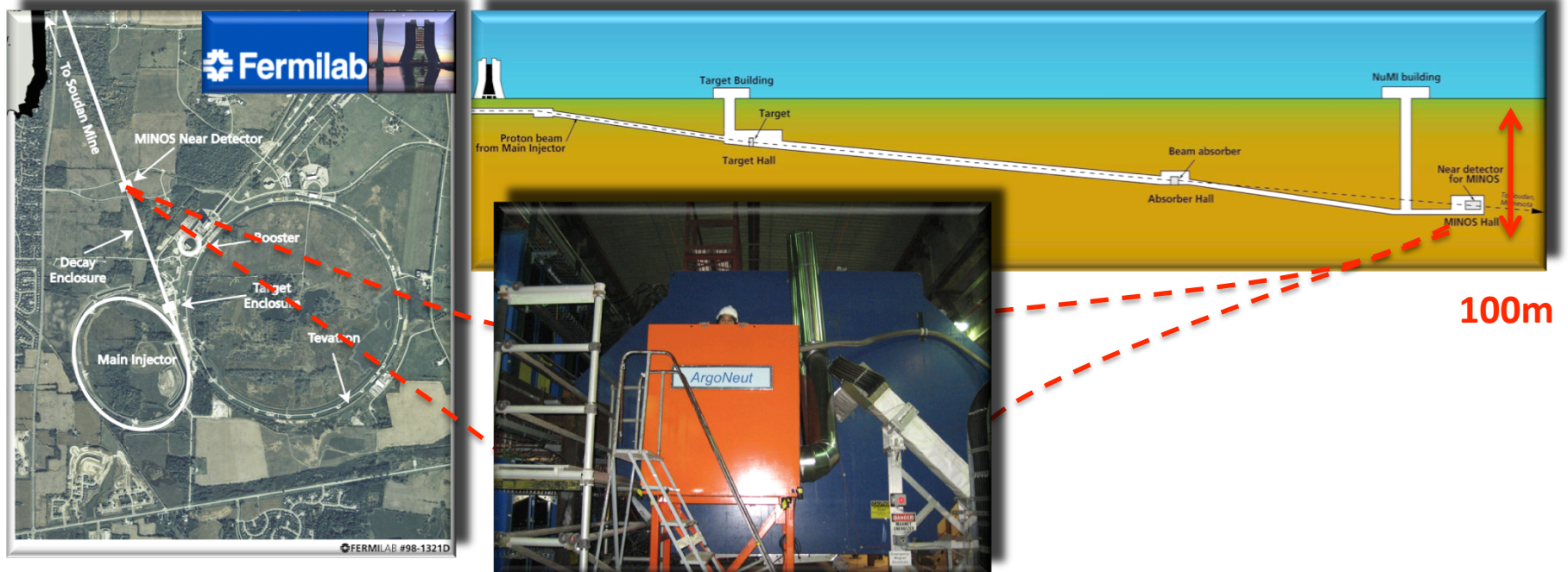
- Collecting events in the 0.1 to 10 GeV range, ArgoNeuT is producing the first ever data for low energy neutrino interactions within a LArTPC.

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External Trigger
for ν -beam operation or horizontal c.r. muons

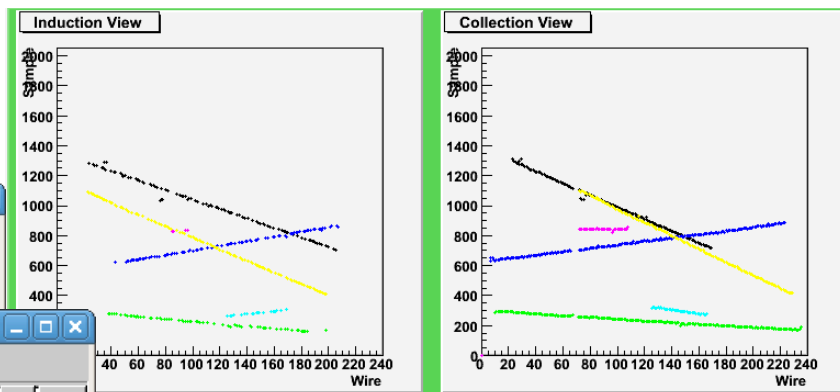*Three main ν-beam topologies:*
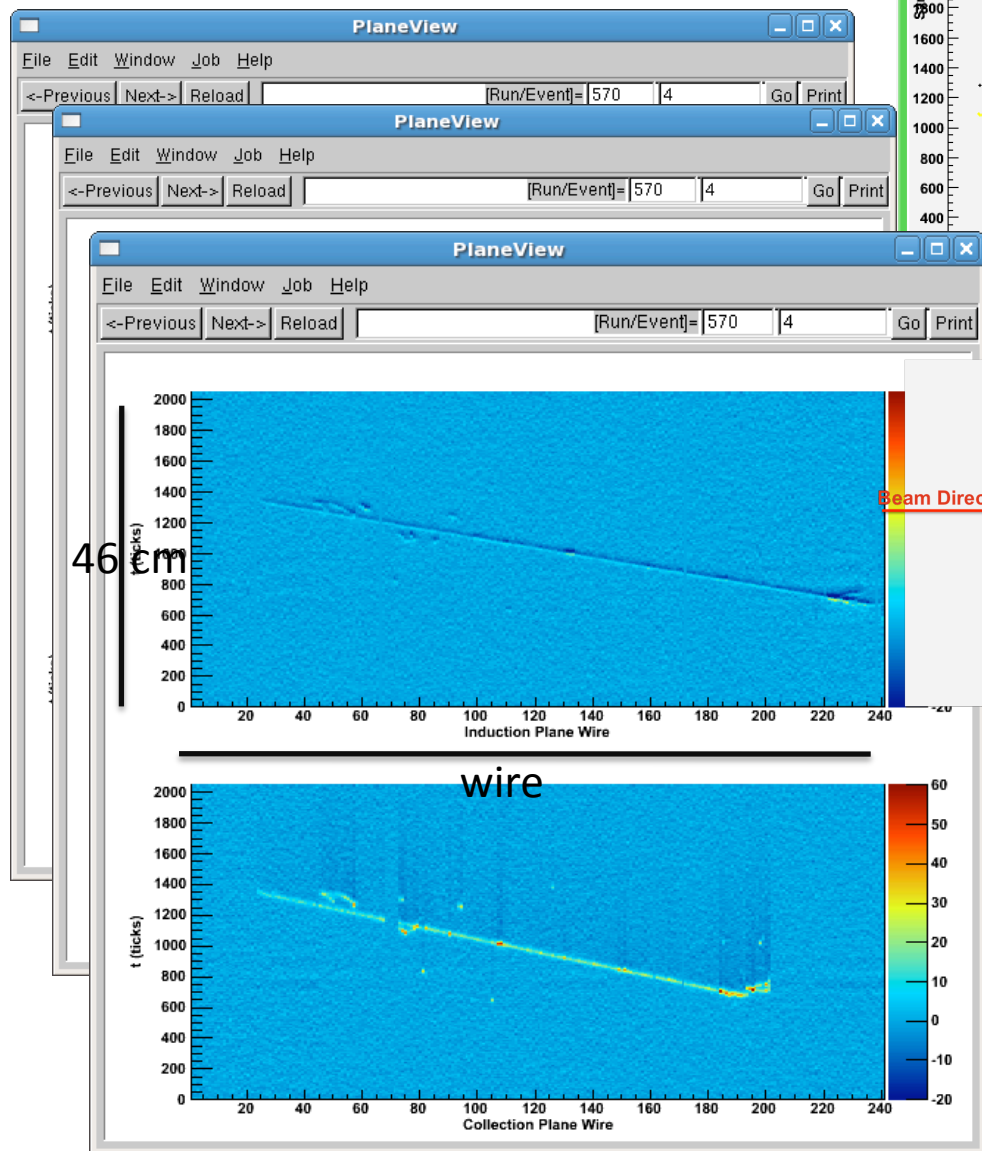
1. through-going μ from ν-int. in the rock upstream
2. ν-int in LAr (good event to be selected)
3. Empty event: No interaction in coincidence with beam spill
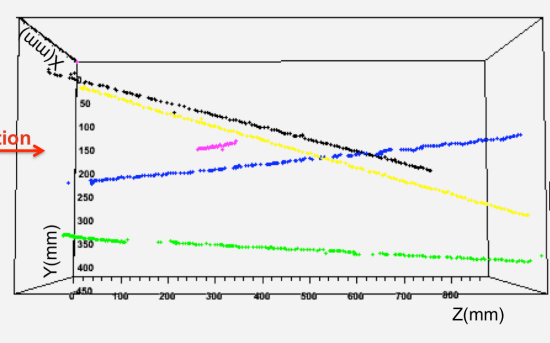
   or

1. Horizontal c.r. muons
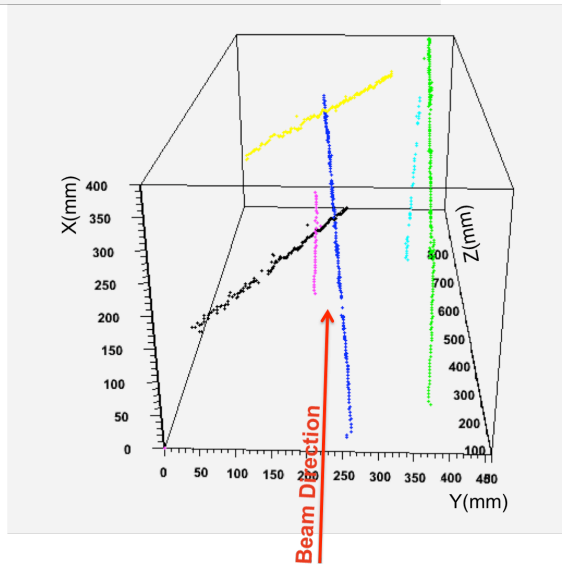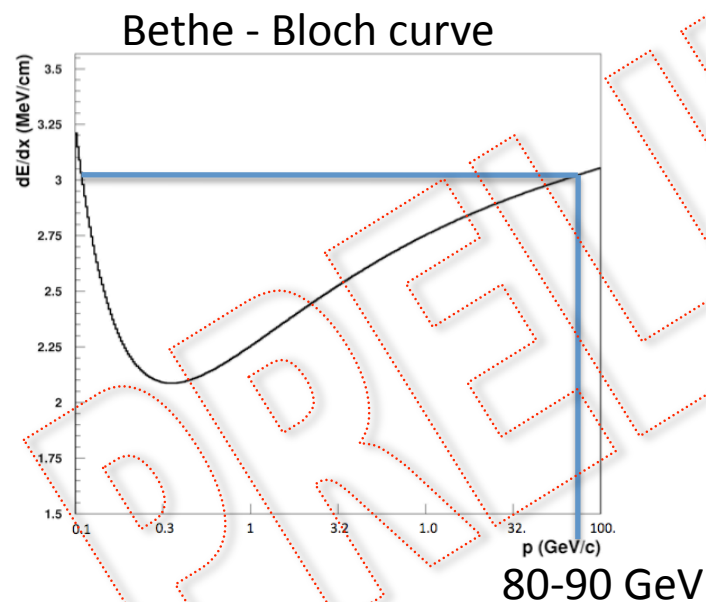
3D reconstruction of a sample of cosmic muons

2D and 3D reconstruction

46 cm

wire

TOP VIEW

Beam Direction

Calorimetric reconstruction of cosmic muons:
detector performance validation test

Bethe - Bloch curve

80-90 GeV

Reasonable median cosmic ray muon energy in the NuMI underground location

<dE/dx> = 3.0 MeV/cm

dQdx_e	
Entries	810
Mean	8.075e+04
Weight	3977
MPV	6.372e+04
Area	5.33e+06
sigma	1.619e+04

dEdx	
Entries	810
Mean	2.991
Weight	0.2165
MPV	2.073
Area	160
sigma	0.491

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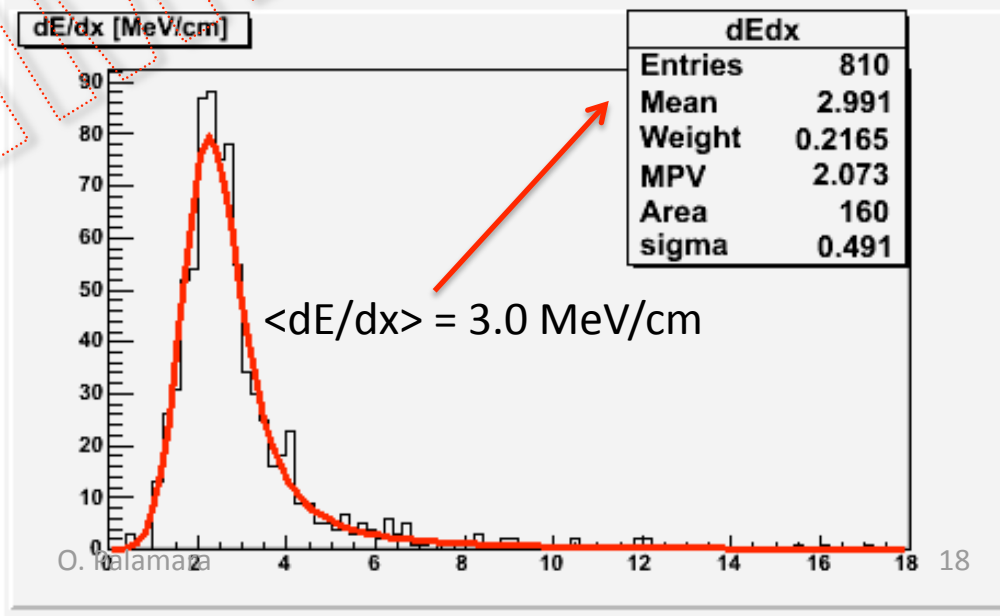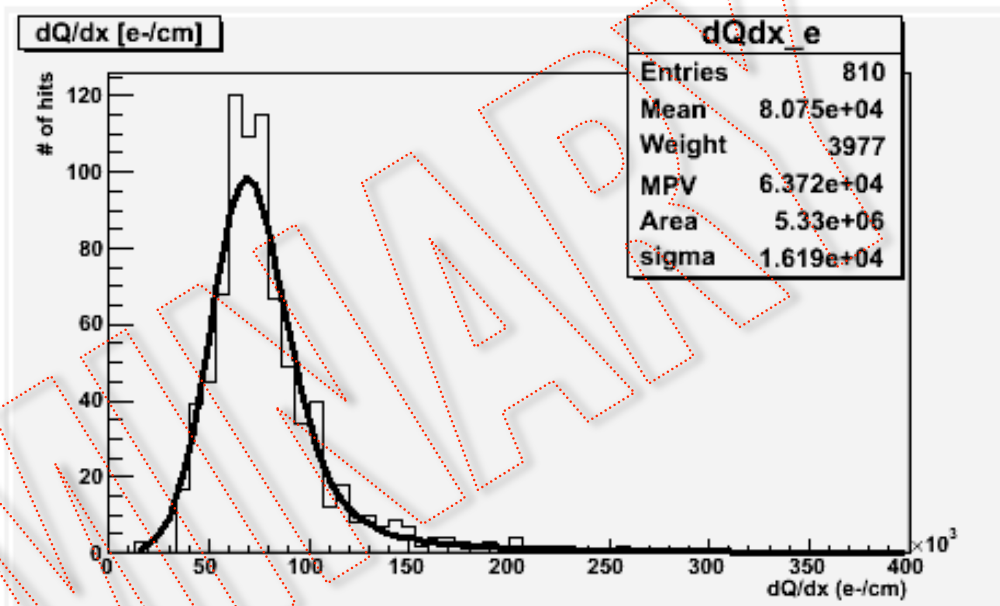
Reconstruction of neutrino CC interactions

ArgoNeuT expected rate at NuMi :

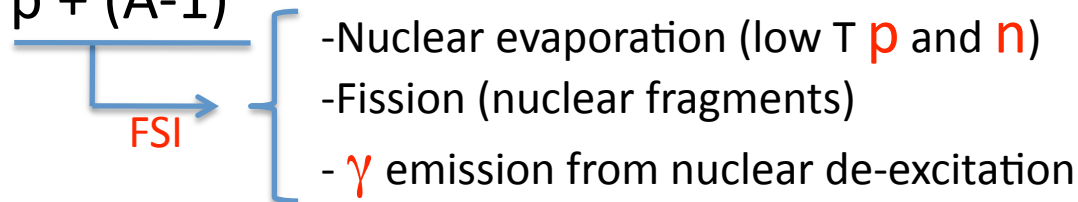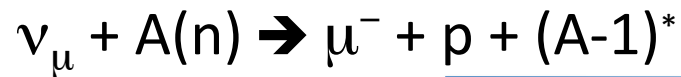~ 19 QE events/day + ~ 15 RES events/day + ~ 83 DIS events/day

Main aim of the experiment: QE cross section measurement with Ar target
in the few GeV energy range.

QE process:

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

when nucleon bound in the nuclear target nuclear effects must be taken into account:

$\nu_\mu + A(n) \rightarrow \mu^- + p + (A-1)^*$

FSI

- Nuclear evaporation (low T p and n)
- Fission (nuclear fragments)
- γ emission from nuclear de-excitation

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

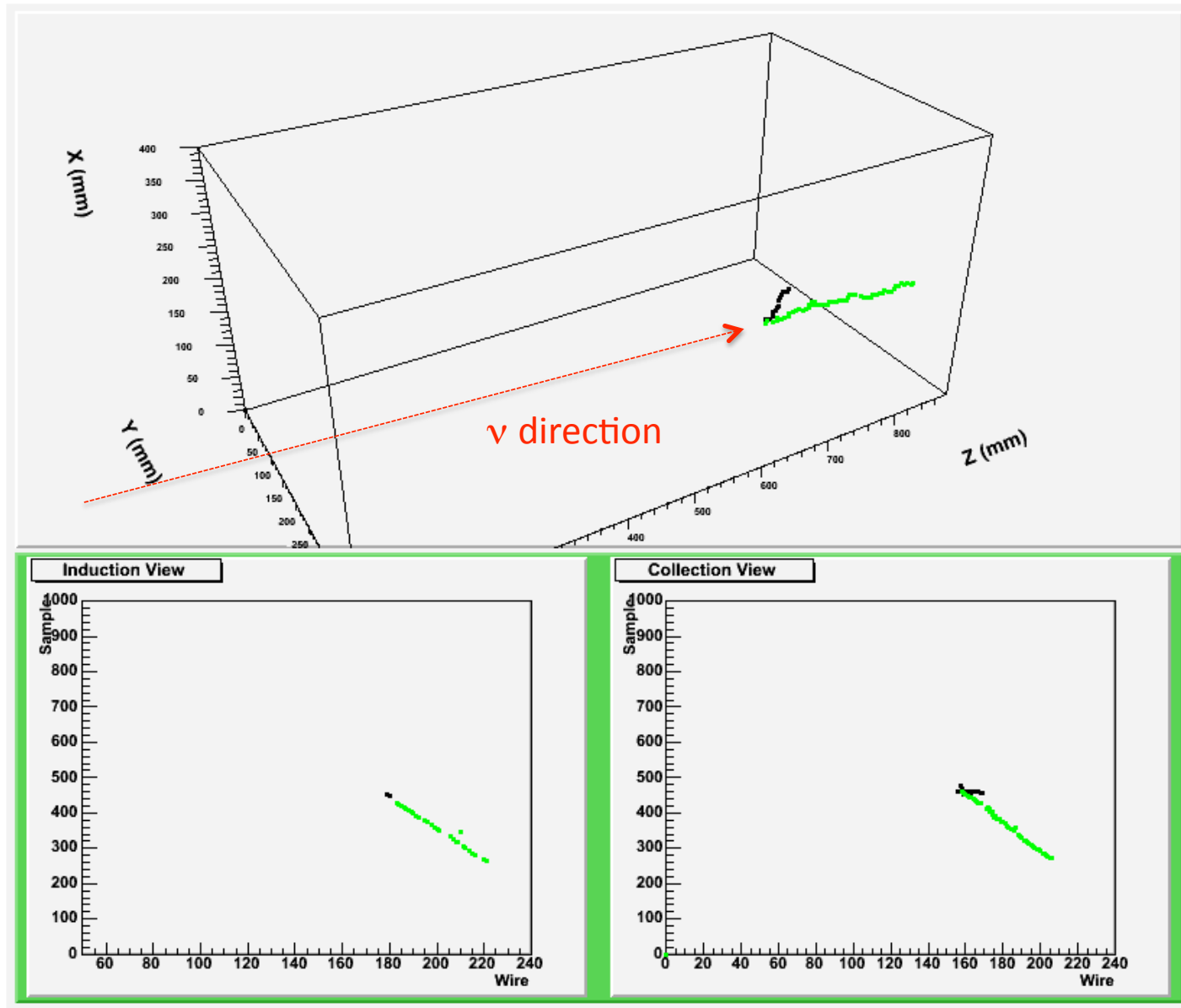Reconstruction procedure (proton and muon) as for the ICARUS 50 lt

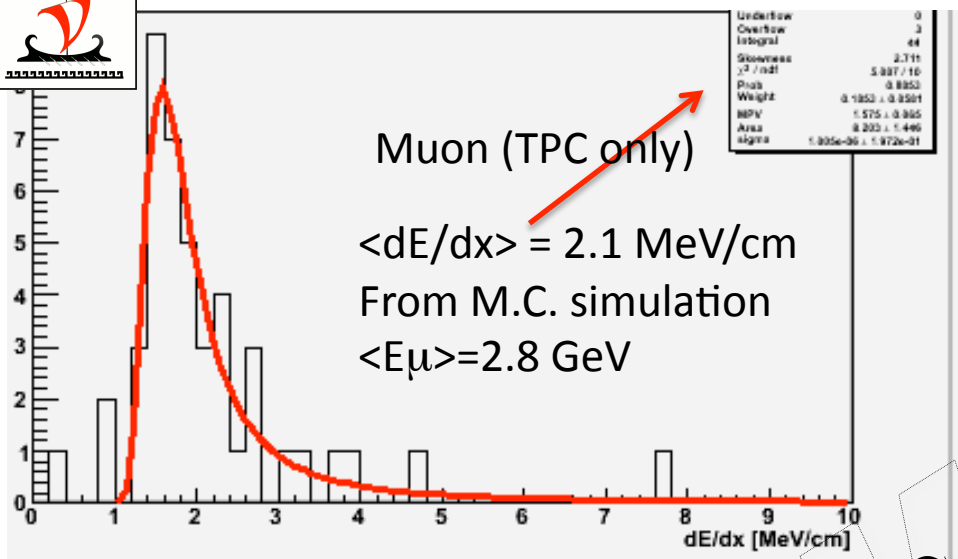Sensitivity to nuclear effects: as an example, a particularly interesting event

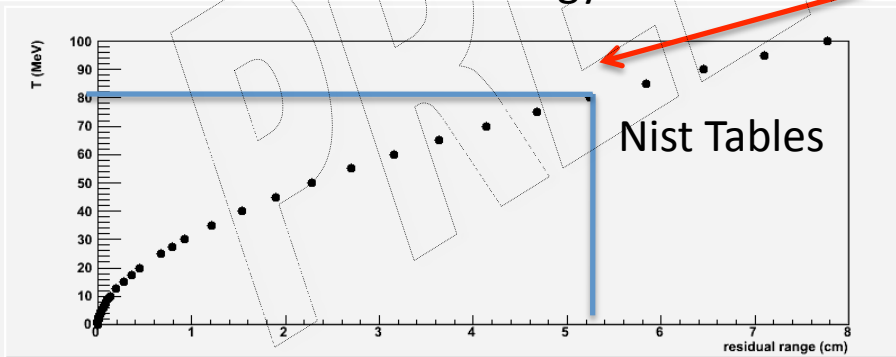O. Palamara

2D and 3D reconstruction of the event

ν direction

Induction View

Collection View
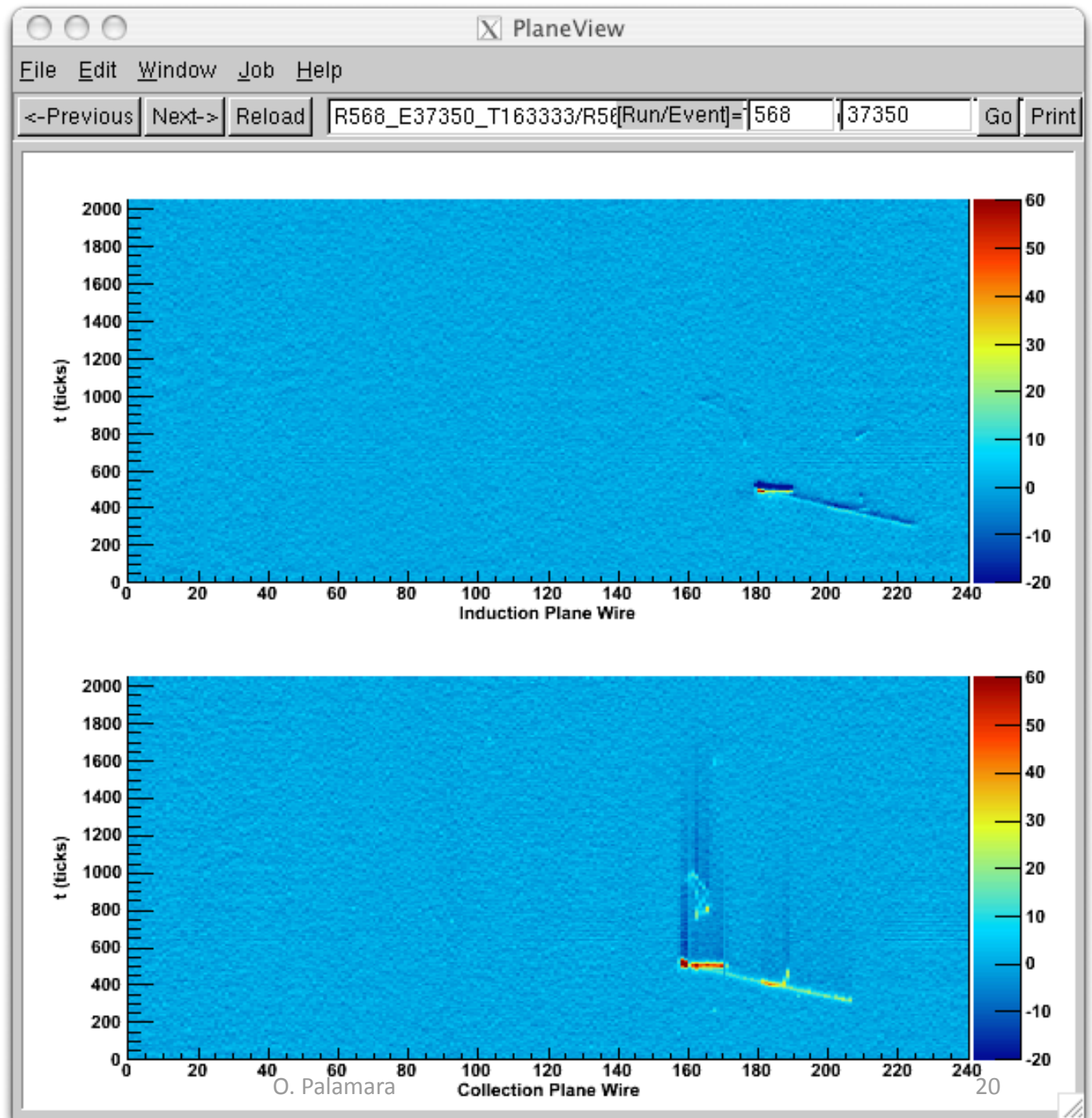
Final State Muon and Proton reconstruction

Muon (TPC only)

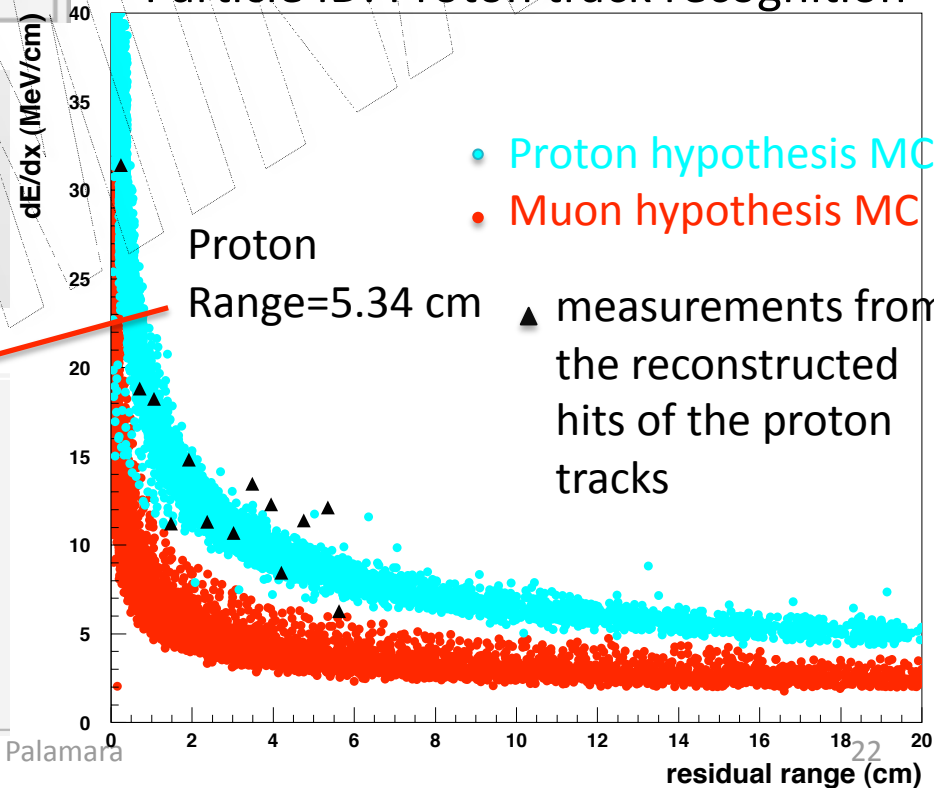<dE/dx> = 2.1 MeV/cm
From M.C. simulation
<Eµ>=2.8 GeV

Proton reconstruction and momentum meas. performed using only TPC information. Kinetic energy calculated from range.

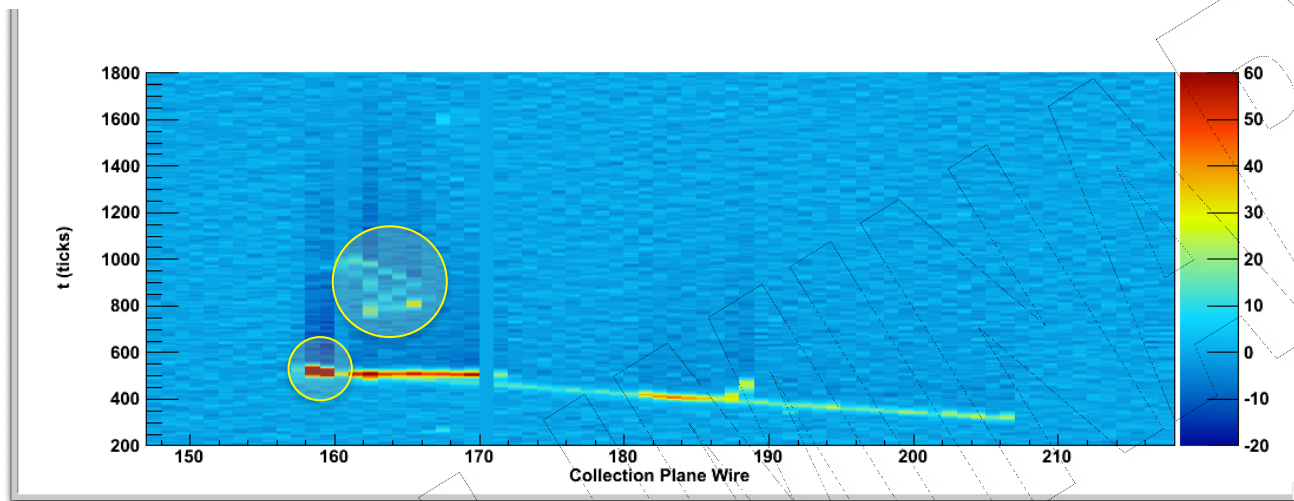Proton kinetic energy = 80 MeV

Nist Tables

Particle ID: Proton track recognition

- Proton hypothesis MC
- Muon hypothesis MC

Proton
Range=5.34 cm

▲ measurements from the reconstructed hits of the proton tracks

A closer inspection of the event topology (thanks to the imaging capabilities of the LAr TPC) shows:
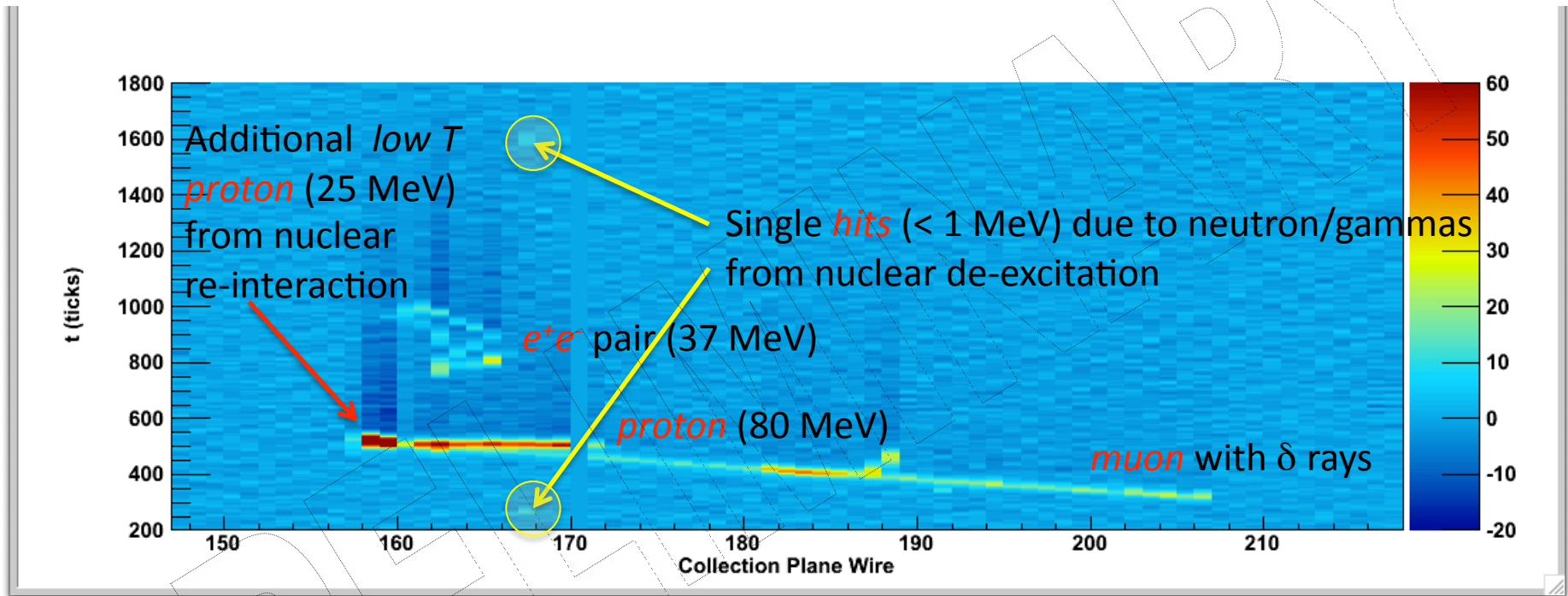

1) **large activity near the vertex**

   μ^- + p + X (X = additional "short track" [2 wires] associated with high energy density deposition)

   X compatible with a second 25 MeV p track
   from nuclear evaporation (FSI in nucleus) or pion re-absorption

2) **an extra energy deposition** (37 MeV) possibly associated with the event
(e^+e^- *pair*), induced by a neutral particle.

This event reconstruction is still preliminary.
A full and detailed MC simulation including nuclear effects is required for validation.
A preliminary FLUKA MC simulation support the possibility to detect
such nuclear effects in LAr TPC.

Conclusions

- Next-generation neutrino physics experiments require precision particle identification and fine grained 3D imaging. Liquid Argon (LAr) is recognised as an ideal detection medium, allowing the possibility of simultaneous ionisation 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.