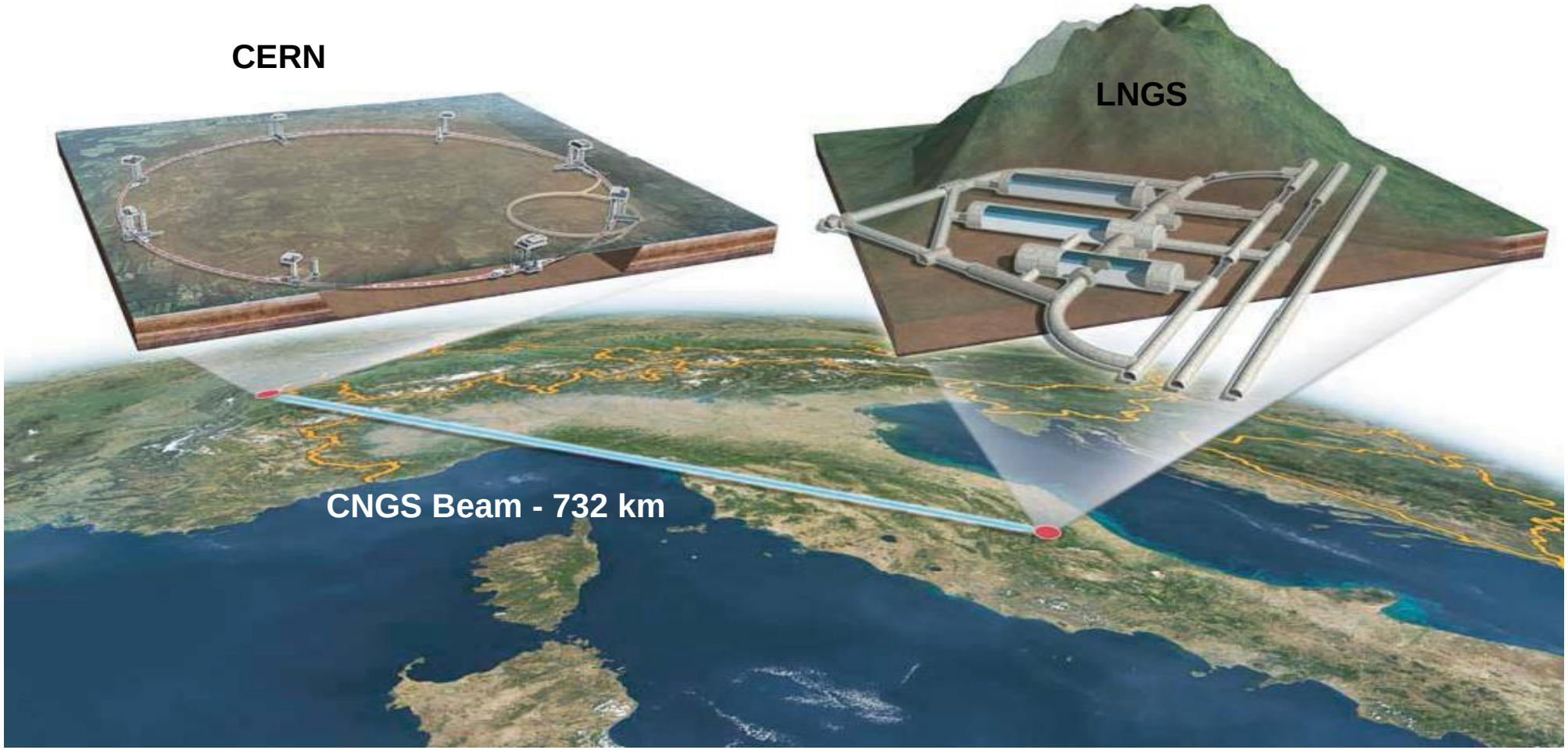
Study of muon neutrinos from the CNGS beam within ICARUS T600 experiment



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(on behalf of the ICARUS Collaboration)

The ICARUS Collaboration

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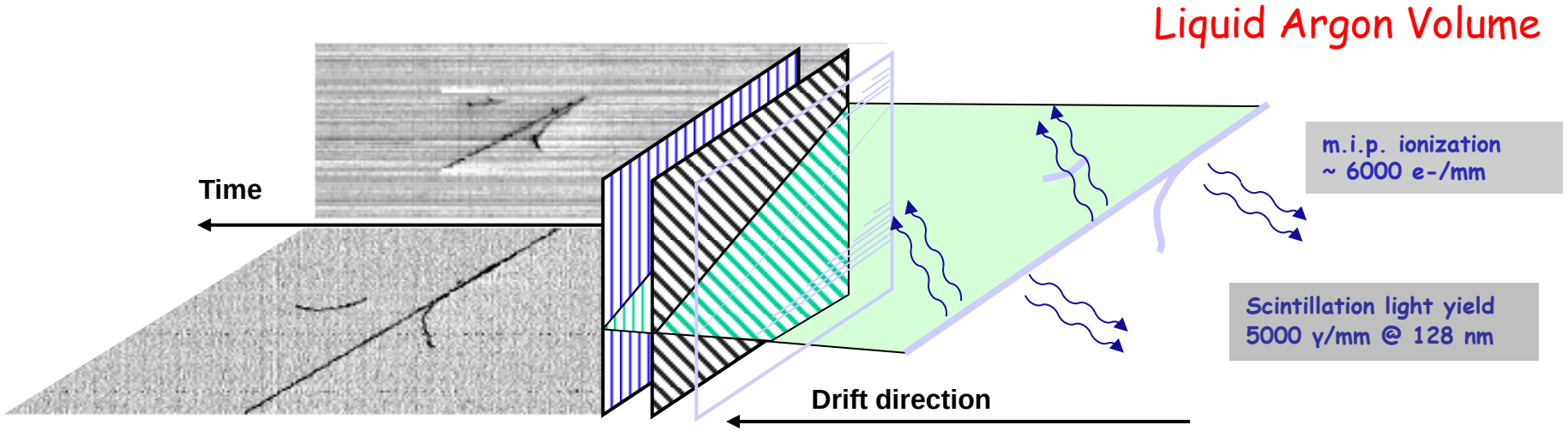
A powerful detection technique

The Liquid Argon Time Projection Chamber [C. Rubbia: CERN-EP/77-08 (1977)]

A 3D imaging of any ionizing event ("electronic bubble chamber"):

- continuously sensitive
- self triggering
- high granularity (~ 1 mm)
- excellent calorimetric properties
- particle identification (through dE/dx vs range)



Electrons from ionizing track are drifted in LAr by E_{drift}. They traverse two transparent wire arrays oriented in different directions where induction signals are recorded. Finally electron charge is collected by collection plane.

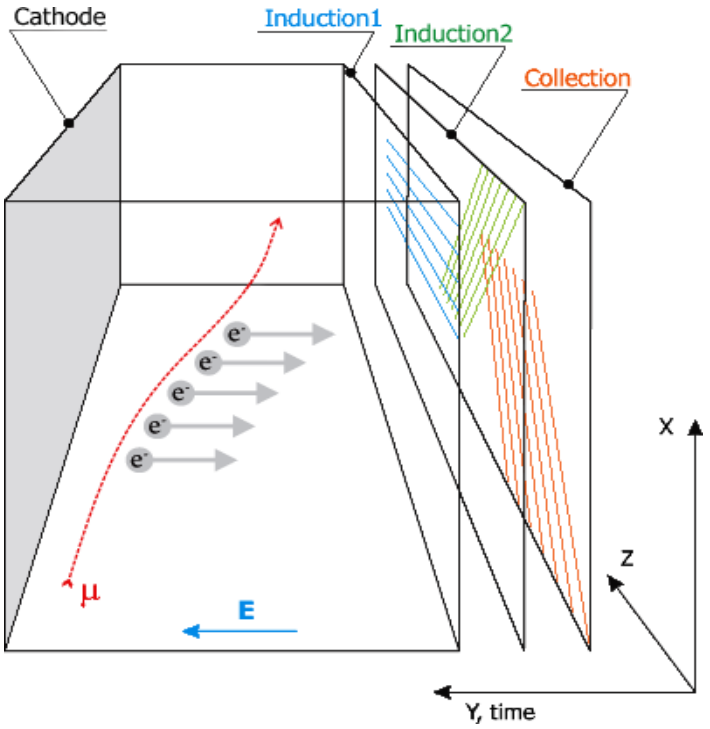
Key feature: LAr purity from electro-negative molecules (O_2, H_2O, CO_2)

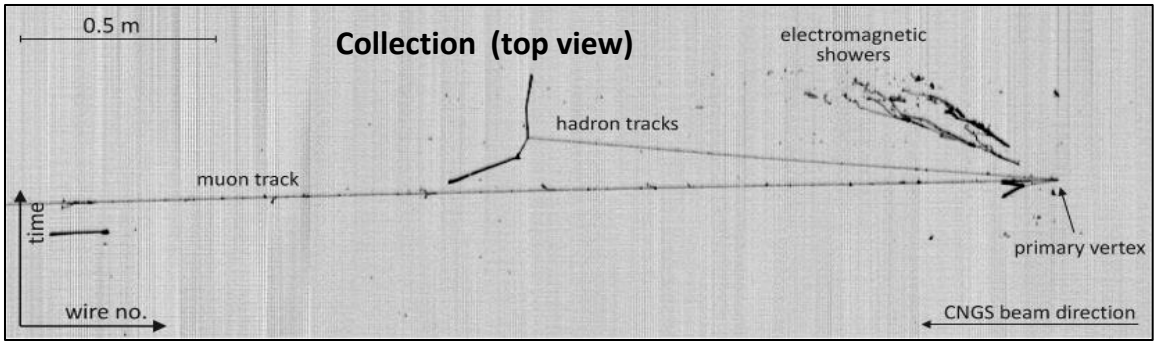
ICARUS T600: ~40 p.p.t. [O_2] eq → τ_{ele} > 7 ms; τ_{ele} = 1 ms @ 500 V/cm)

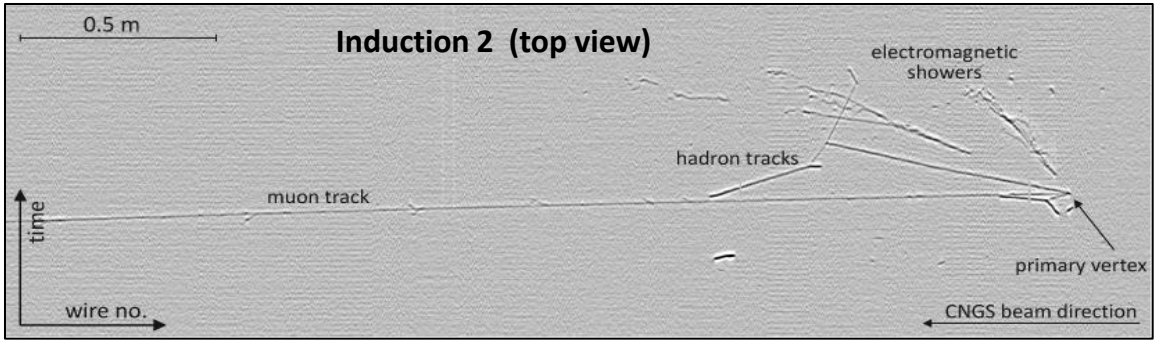
ICARUS LAr-TPC detection technique

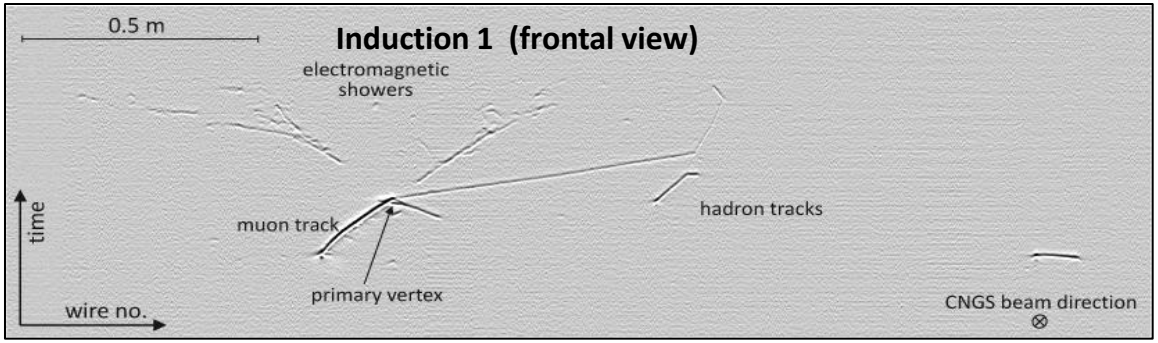
- 2D projection for each of 3 wire planes per TPC
- 3D spatial reconstruction from stereoscopic 2D projections
- charge measurement from Collection plane signals
- Absolute drift time from scintillation light collection

CNGS ν_μ charge current interaction, one of TPC's shown

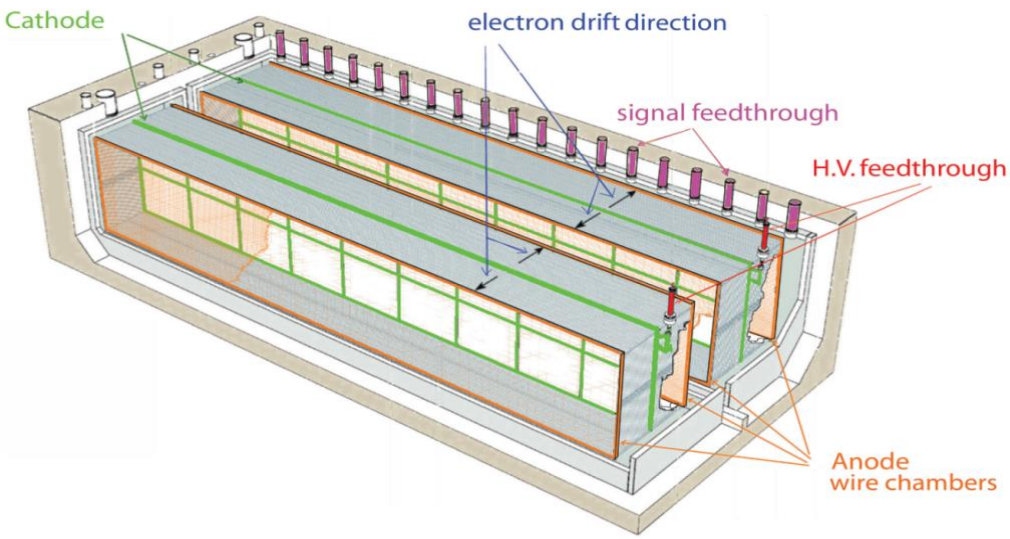


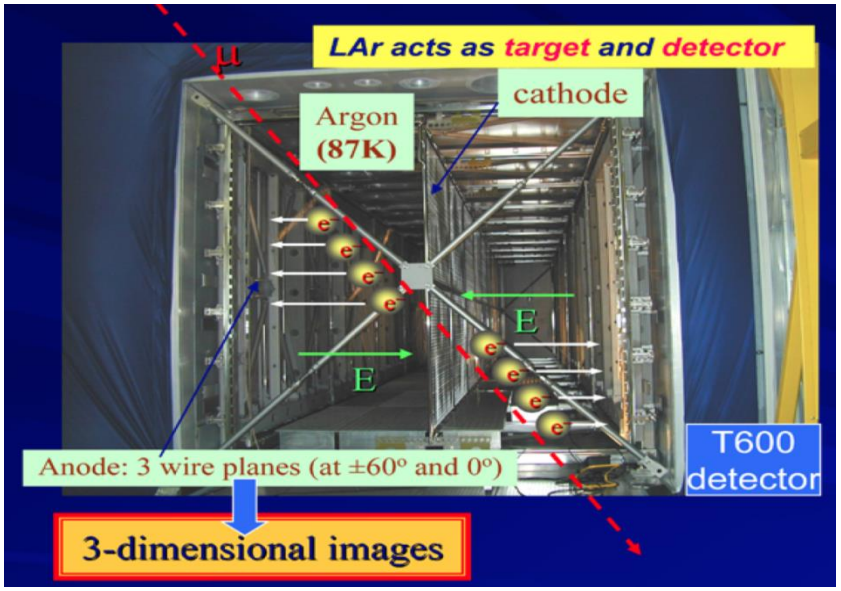






ICARUS T600: the largest LAr-TPC so far

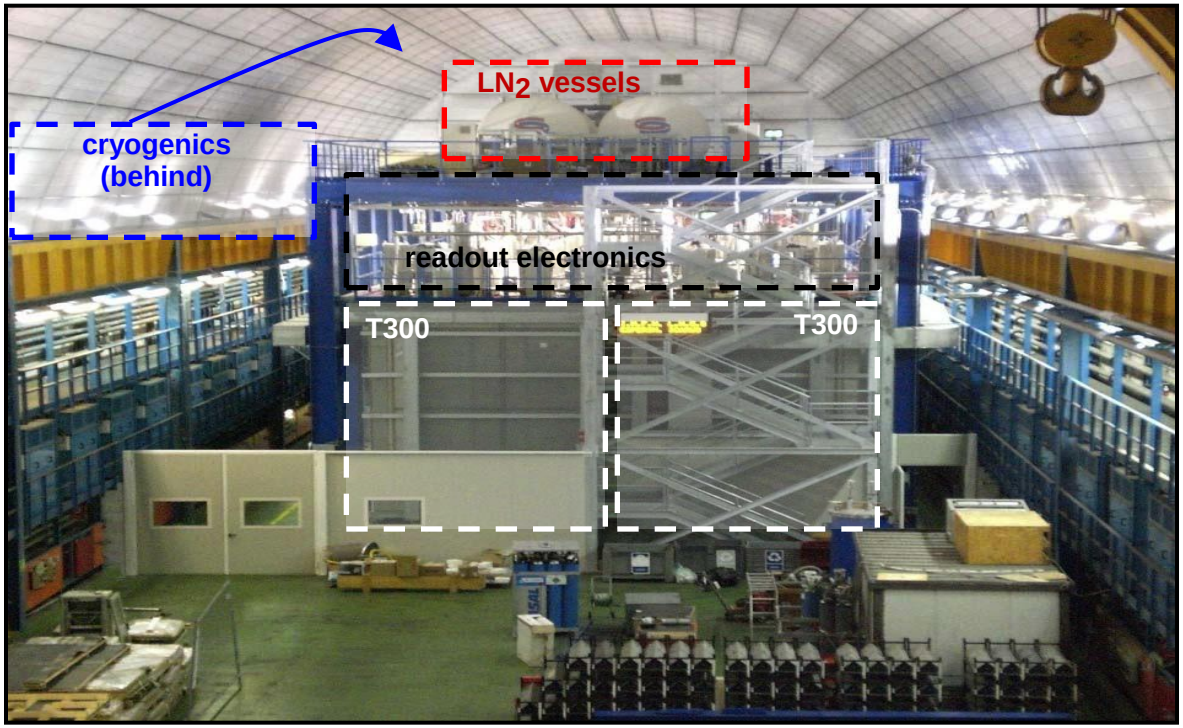


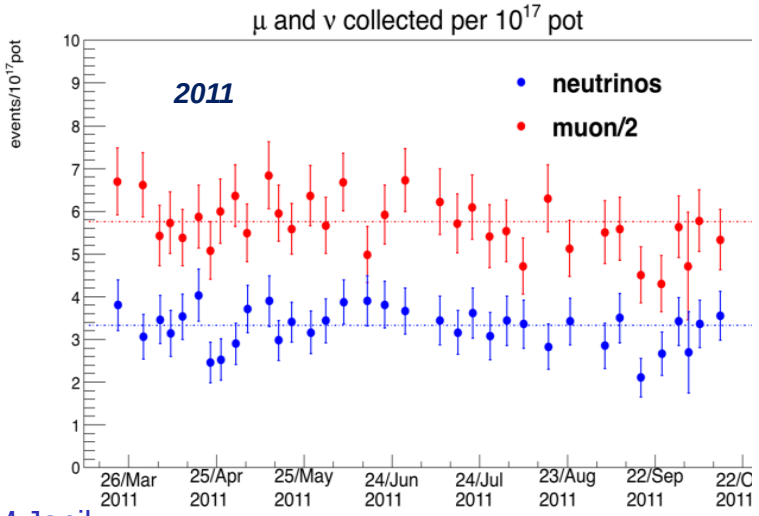


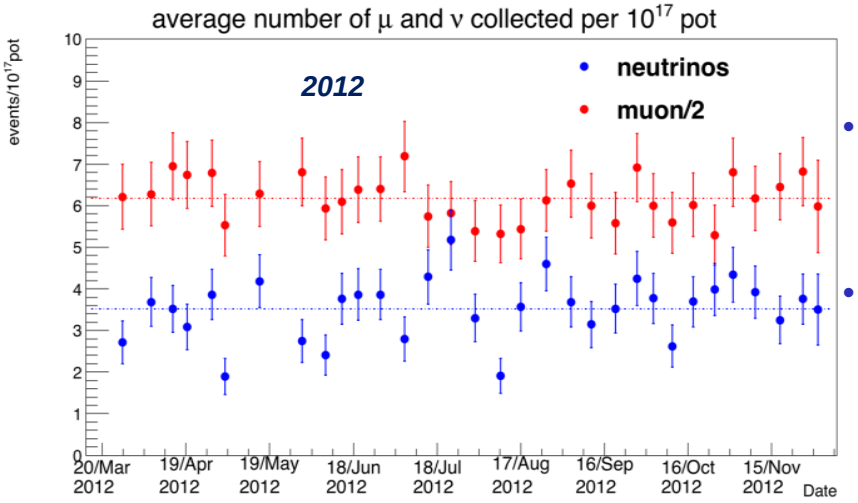
- Two identical modules
  - 3.6 x 3.9 x 19.6 ≈ 275 m3 each
  - Liquid Ar active mass: ≈ 476 t
  - Drift length = 1.5 m (1 ms)
  - HV = -75 kV E = 0.5 kV/cm
  - v-drift = 1.55 mm/μs
- 4 wire chambers:
  - 2 chambers per module
  - 3 readout wire planes per chamber, wires at 0°, ±60°
  - 53242 wires, 3 mm pitch, 3 mm plane spacing
- 20+54 PMTs , 8" Ø, for scintillation light:
  - VUV sensitive (128nm) with wave shifter (TPB)

ICARUS T600 in underground installation at INFN LNGS

- ICARUS T600, 0.47 kt LAr active mass, concluded in 2013 a very successful 3 years long run at CNGS ν beam collecting 8.6×10^{19} pot event statistic with a detector live time > 93%.
- At the same time ICARUS recorded cosmics for a total 0.73 kt/y exposure .







- 2650 CNGS ν events selected ~ 3.4 ν/10^{17} pot
- in agreement with expectations

ICARUS LAr-TPC preformance

Total energy reconstructed from charge integration

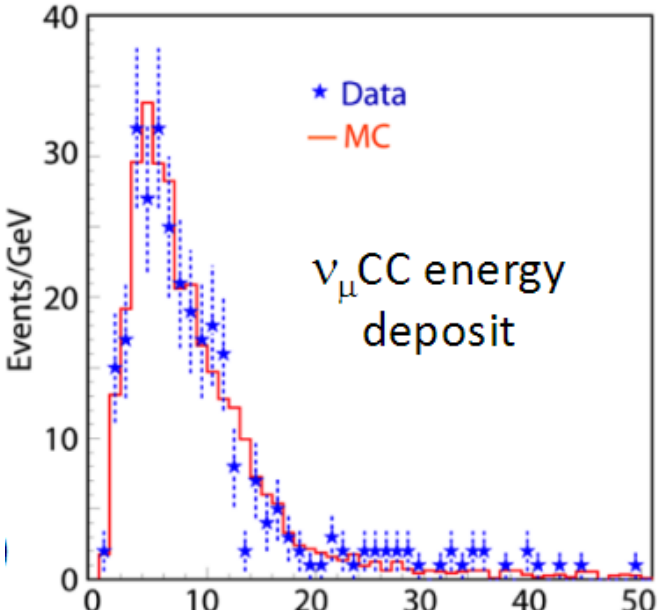
- Full sampling, homogeneous calorimeter with exellent accuracy for contained events

Tracking devices

- Precise 3D topology and accurate ionization
- Muon momentum via multiple scattering

Measurment of local energy deposited dE/dx

- e/γ remarkable separation (0.02 X_0 samples)
- - Particle identification by dE/dx vs range



Low energy electrons:

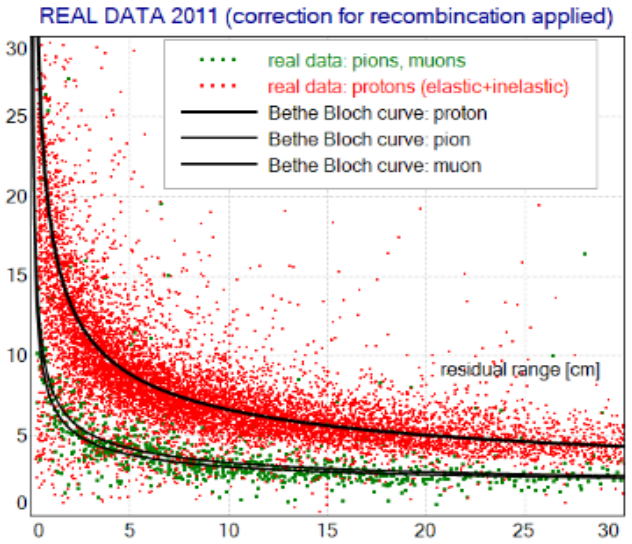
$\sigma(E)/E = 11\%/\sqrt{E(MeV)} + 2\%$

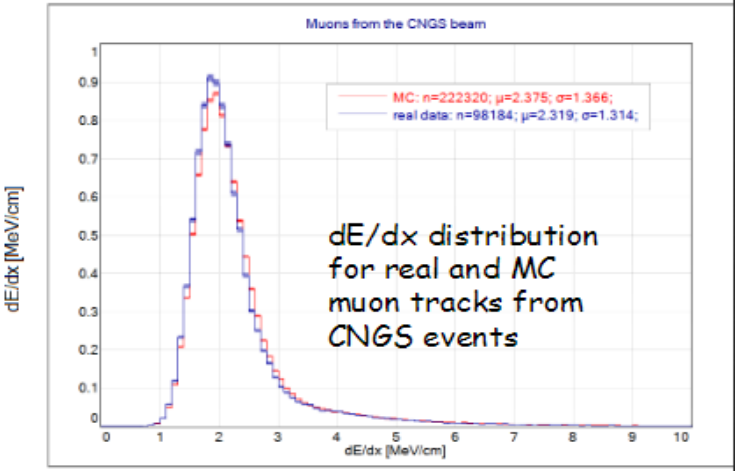
Electromagnetic showers:

$\sigma(E)/E = 3\%/\sqrt{E(GeV)}$

Hadron showers:

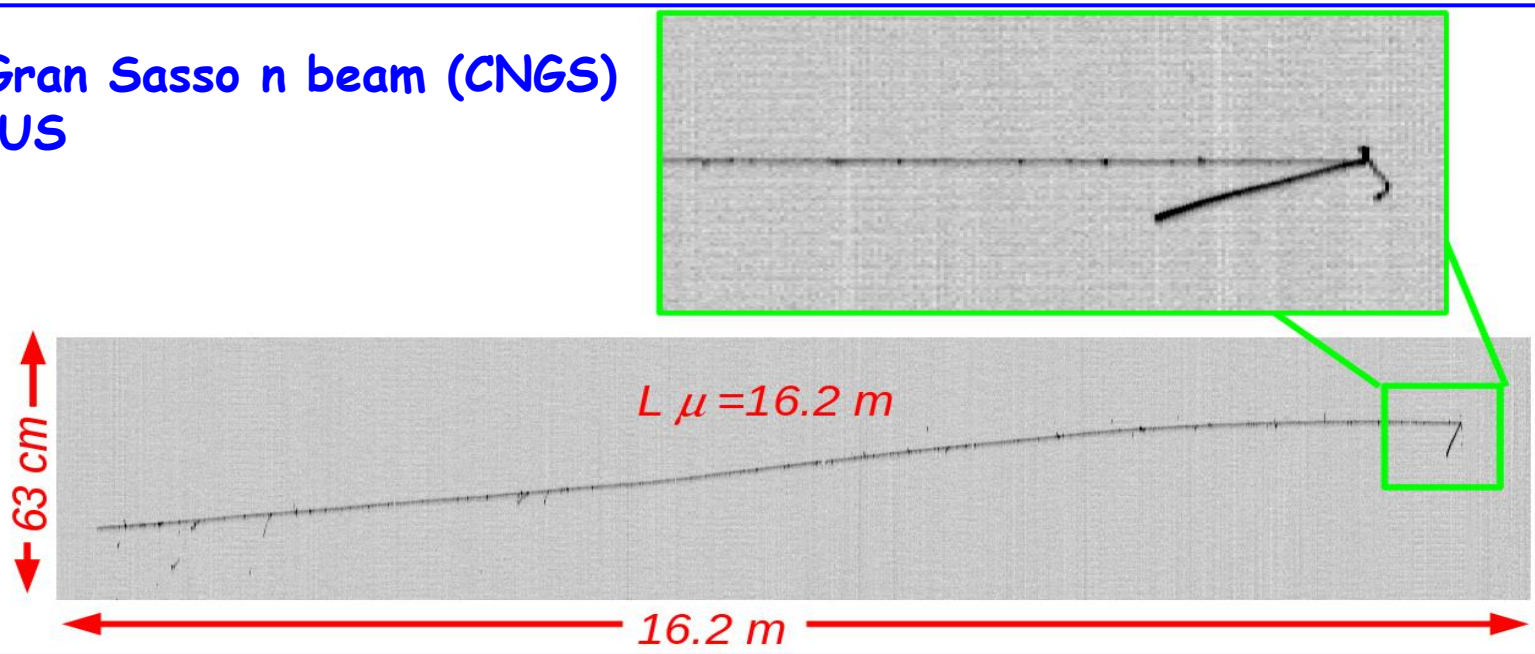
$\sigma(E)/E \approx 30\%/\sqrt{E(GeV)}$



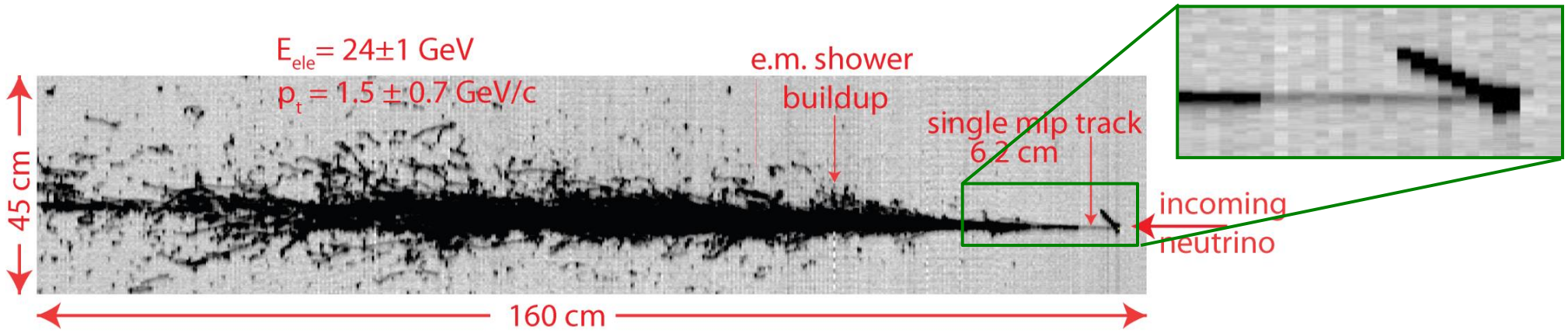


Muon and electron neutrino are really different!

a ν_μ from Cern to Gran Sasso n beam (CNGS) interacting in ICARUS



A ν_e from CNGS beam interacting in ICARUS



Analysis of CNGS ν_μ CC interactions (1)

The collected number of ν_μ CC events gives opportunity to study ν_μ disappearance for which we need to know:

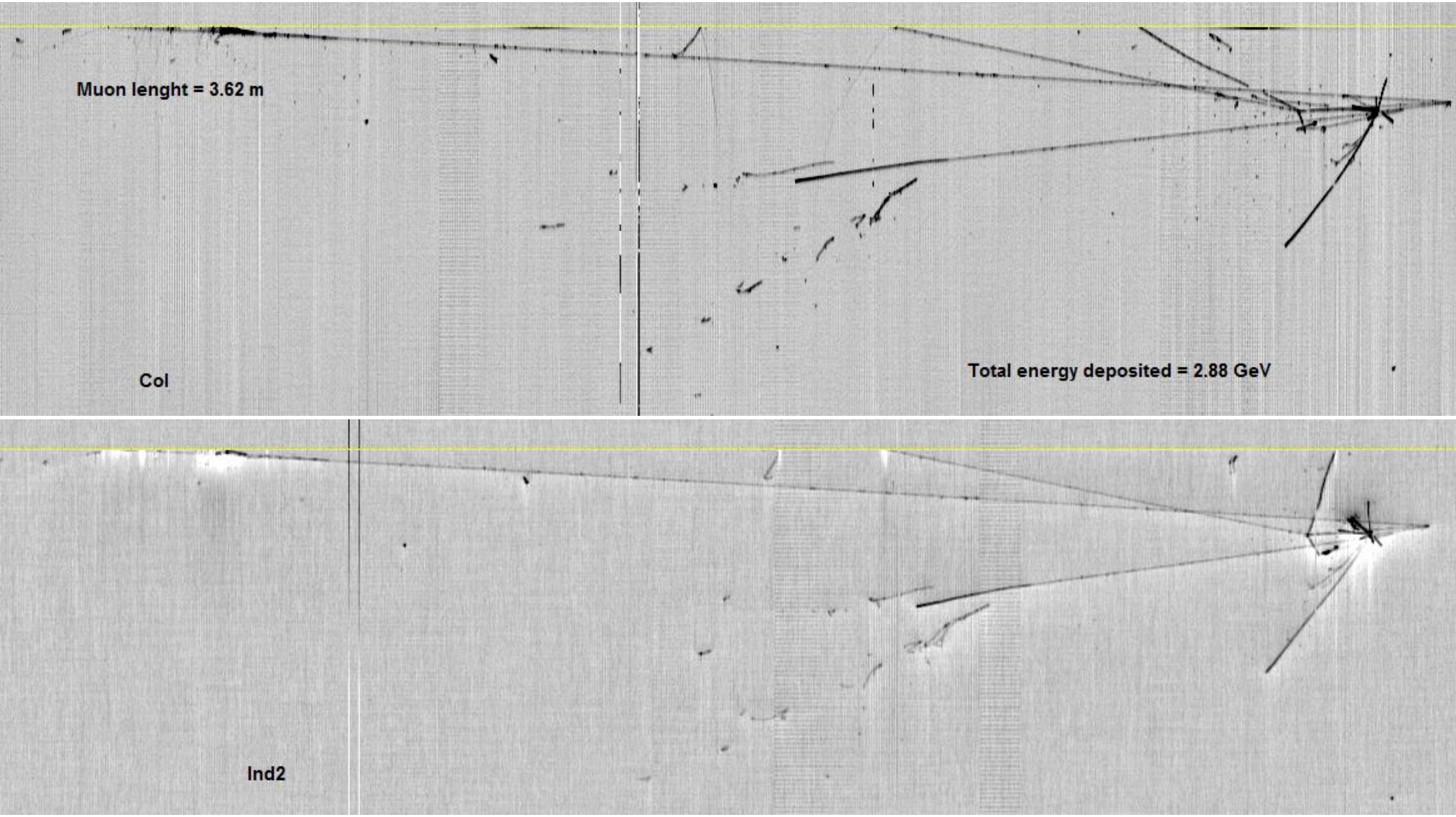
- the CNGS neutrino flux,
- neutrino interaction cross section,
- event reconstruction efficiency and uncertainties.

Direct comparison between the expected and observed ν_μ and anti-ν_μ charged current (CC) interactions was checked on the events selected requiring a minimal 2.5 m track length to identify a muon resulting in :

- ~70 % efficiency for genuine ν_μ CC,
- rejection of NC events by a factor ~60.

1285 ν_μ CC events satisfying this requirement were found, in the 2011 and 2012 runs (6.7×1019 pot)

CNGS ν_μ CC interaction – Run 10470 Event 449

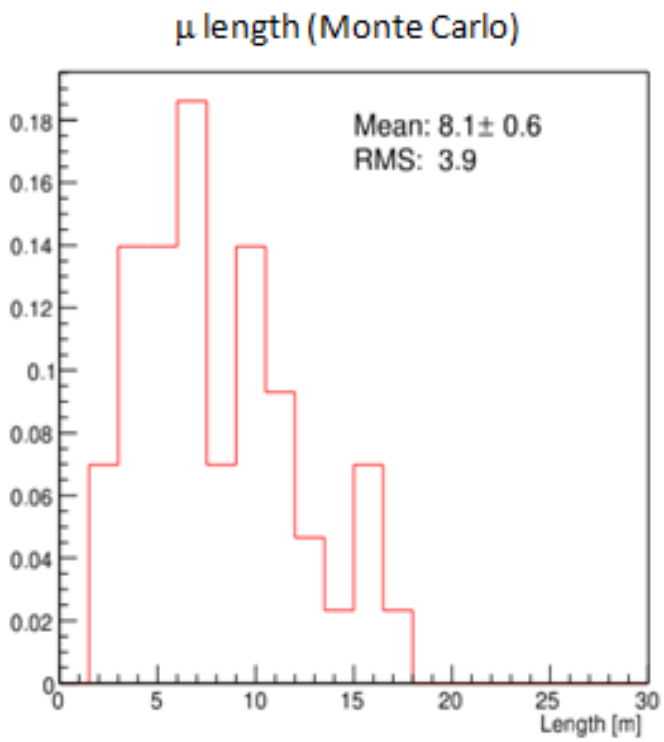


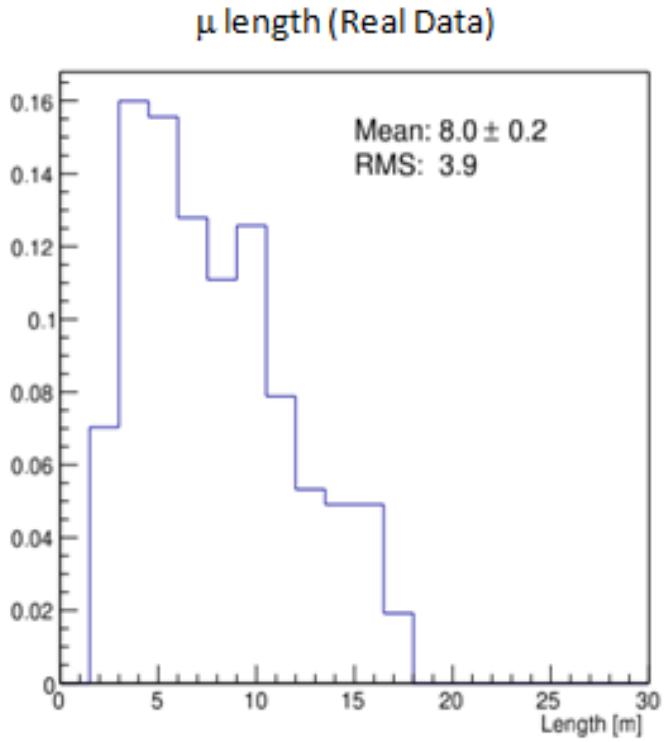
Analysis of CNGS ν_μ CC interactions (2)

So far, 493 out of 1285 events have been visually reconstructed (separately muon track and hadronic jet). Next steps:

- reconstruction of all events,
- estimation of muon momentum,
- and finally neutrino energy distribution.

Distribution of muon track length compared with Monte Carlo expectations





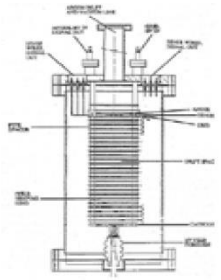
Conclusions

- The ICARUS T600 detector is the biggest LAr TPC built so far and represents the most important milestone for this technology.
- The ICARUS T600 detector was taking data at the LNGS underground laboratory, recording cosmic and CNGS neutrino events, in stable conditions since October 2010 till 2012. Data analysis is on-going.
- Such a long period of data taking allowed to: (1) study in details all technical aspects of the detection technique, (2) develop advanced reconstruction algorithms, and (3) obtain relevant physical results (new constraints on sterile neutrinos searches with CNGS neutrinos, measurement of neutrino velocity).
- ICARUS T600 was moved to CERN in 2014, to be upgraded (WA104 project). The detector will be transferred to FNAL at the beginning of 2017 for installation, commissioning and start of data taking with BNB beam (SBN project).
- In this talk only the results of the reconstruction of CNGS muon neutrino charge current interactions were presented.


Thank you !

Backup slides

The path to massive liquid Argon detectors



24 cm drift wires chamber

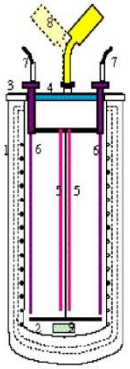
CERN

1

1987: First LAr TPC. Proof of principle. Measurements of TPC performances.

2

3 ton prototype



1991-1995: First demonstration of the LAr TPC on large masses. Measurement of the TPC performances. TMG doping.

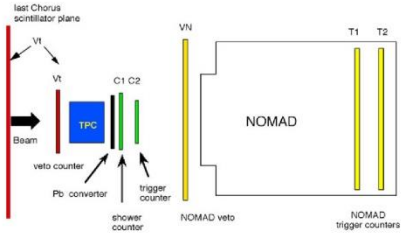
CERN

Laboratory work

50 litres prototype
1.4 m drift chamber

CERN

3



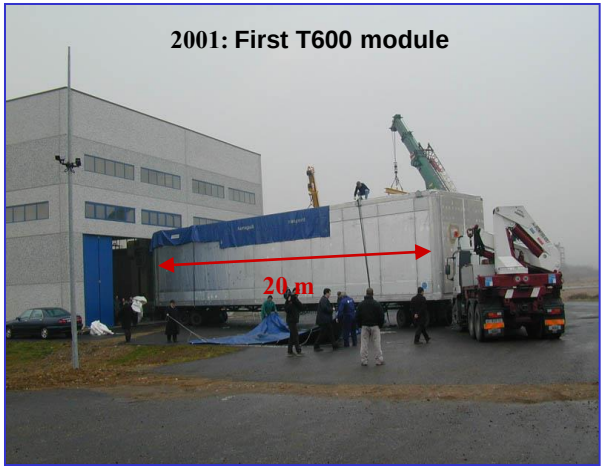
1997-1999: Neutrino beam events measurements. Readout electronics optimization. MLPB development and study. 1.4 m drift test.

T600 detector

4

10 m^3 industrial prototype

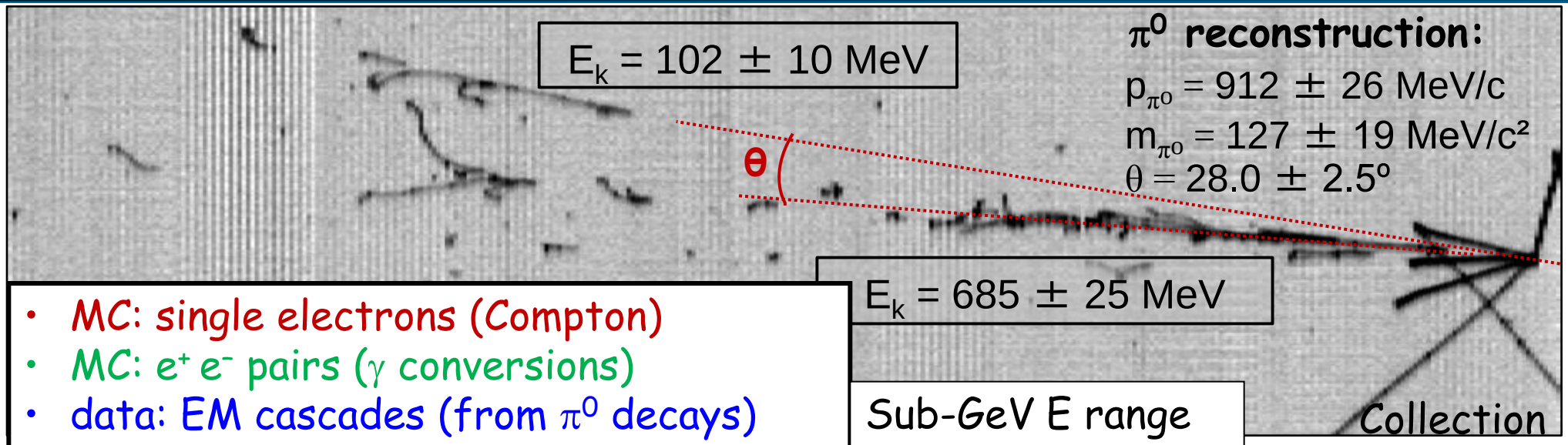
1999-2000: Test of final industrial solutions for the wire chamber mechanics and readout electronics.



5

Cooperation with industry

e/γ separation in Liquid Argon



π^0 reconstruction:

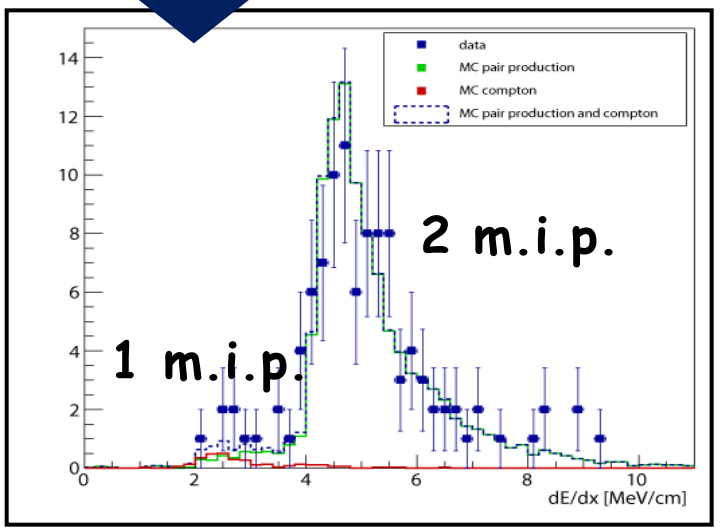
p_{π^0} = 912 ± 26 MeV/c

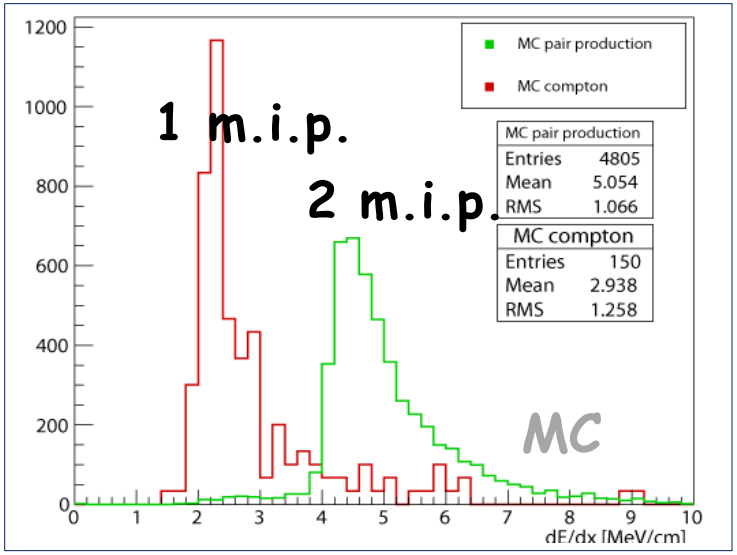
m_{π^0} = 127 ± 19 MeV/c²

θ = 28.0 ± 2.5°

- MC: single electrons (Compton)
- MC: $e^+ e^-$ pairs (γ conversions)
- data: EM cascades (from π^0 decays)

Sub-GeV E range



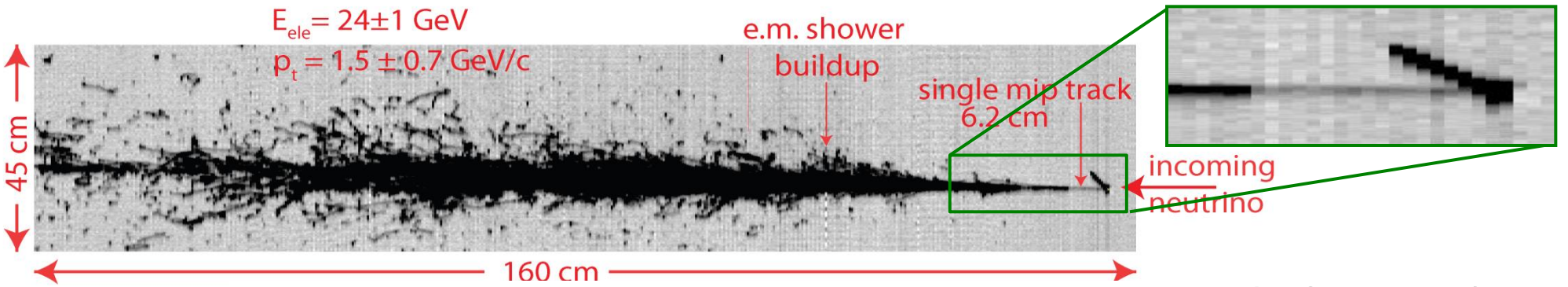


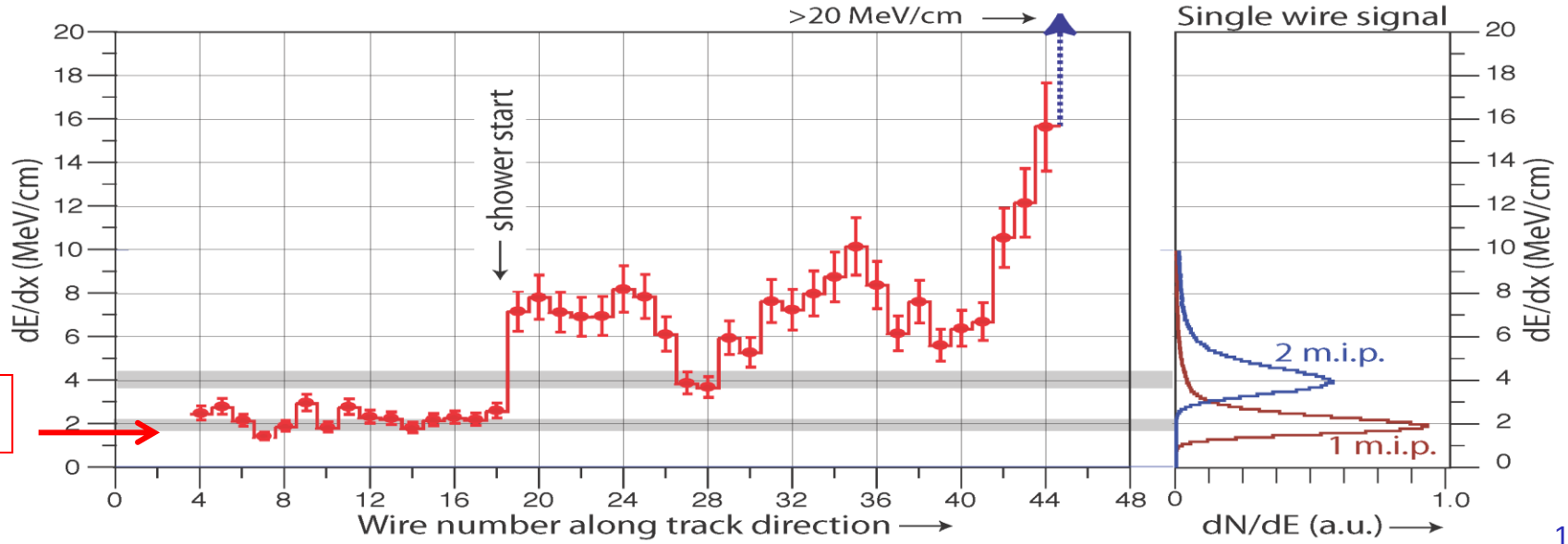
LAr unique features allow e/γ separation and π^0 reconstruction

-> Estimated bkg. from π^0 in NC and ν_μ **CC**: negligible

dE/dx evolution in ν_e CC events

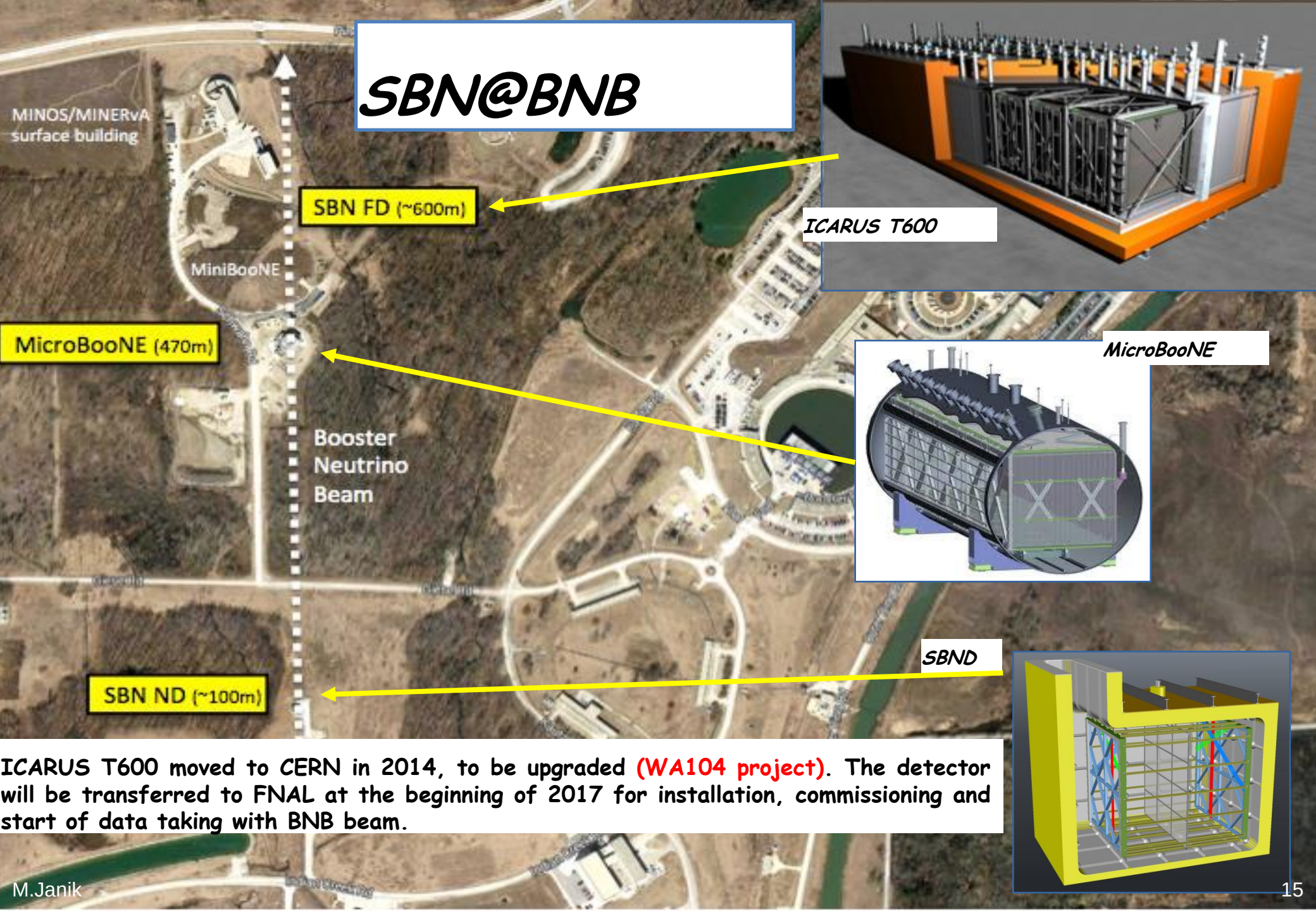
- Example of event with a clear electron signature found in the upgraded sample of 2450 ν interactions (7.23 x 10^{19} pot).
- The evolution of dE/dx from a single m.i.p. to an e.m. shower is clearly apparent from the depositions on individual wires.





Single M.I.P

SBN@BNB



ICARUS T600

MicroBooNE

SBND

ICARUS T600 moved to CERN in 2014, to be upgraded (WA104 project). The detector will be transferred to FNAL at the beginning of 2017 for installation, commissioning and start of data taking with BNB beam.

Towards SBN @ FNAL: the WA104 project

- The T600 was moved to CERN in 2014, to be upgraded introducing technology developments while maintaining the already achieved performance (WA104 project):
  - new cold vessels and new purely passive insulation;
  - refurbishing of the cryogenic and purification equipment;
  - new cathode with better planarity;
  - upgrade of the light collection system;
  - new faster, higher-performance read-out electronics.

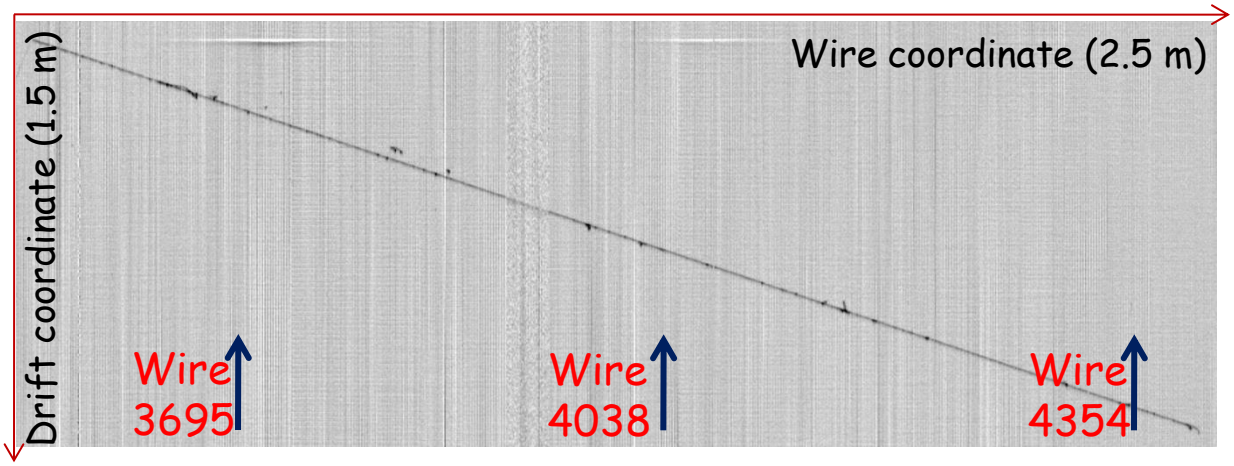
  In parallel, the muon tagging system will be designed and constructed.

- The detector will be transferred to FNAL at the beginning of 2017 for installation, commissioning and start of data taking with BNB beam.

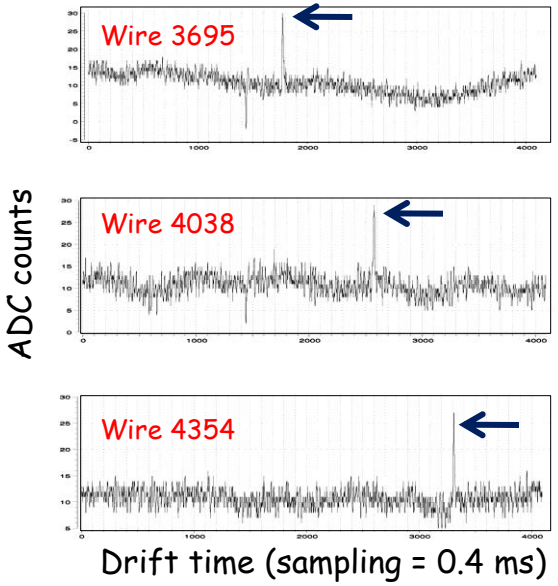
LAr Purification and measurement in T600

- The presence of electron trapping polar impurities attenuates the electron signal.
- Most of the contaminants freeze out spontaneously (87 K) . Residuals: O_2, H_2O, CO_2.
- Recirculation/purification of both, the gas phase and the liquid phase (4 m^3/h, full volume recirculation in 6 days) to reduce the initial impurities concentration (Hydrosorb/Oxysorb™ filters).

Charge attenuation along track allows event-by-event measurement of LAr purity
(Use of about 50 muon tracks without evident associated δ-rays and γ's, day-by-day)
(Pulse height for 3 mm m.i.p. ~ 15 ADC # (15000 electrons; noise r.m.s. 1500 electrons)



Run 10139 Event 8961 Collection view

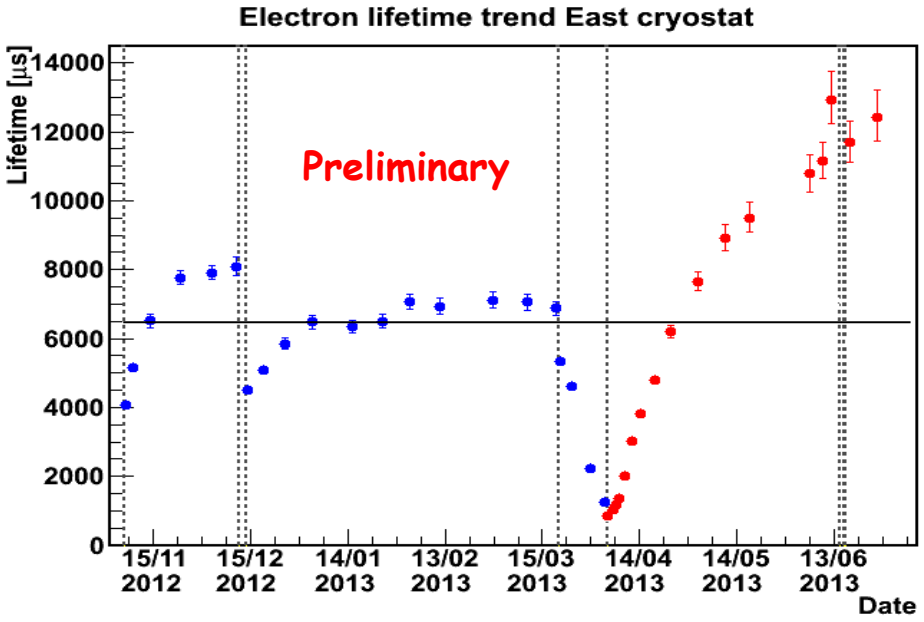


ICARUS T600 LAr purity offline analysis: new results

- The electron lifetime τele is a crucial parameter since LAr TPC performance strongly depends on the LAr purity.
- Operation of such large volumes (~ 1 kton LAr, ~ 1 ms drift time) requires to reach and maintain very high purity, which was achieved through use of commercial filters and liquid/gas recirculation

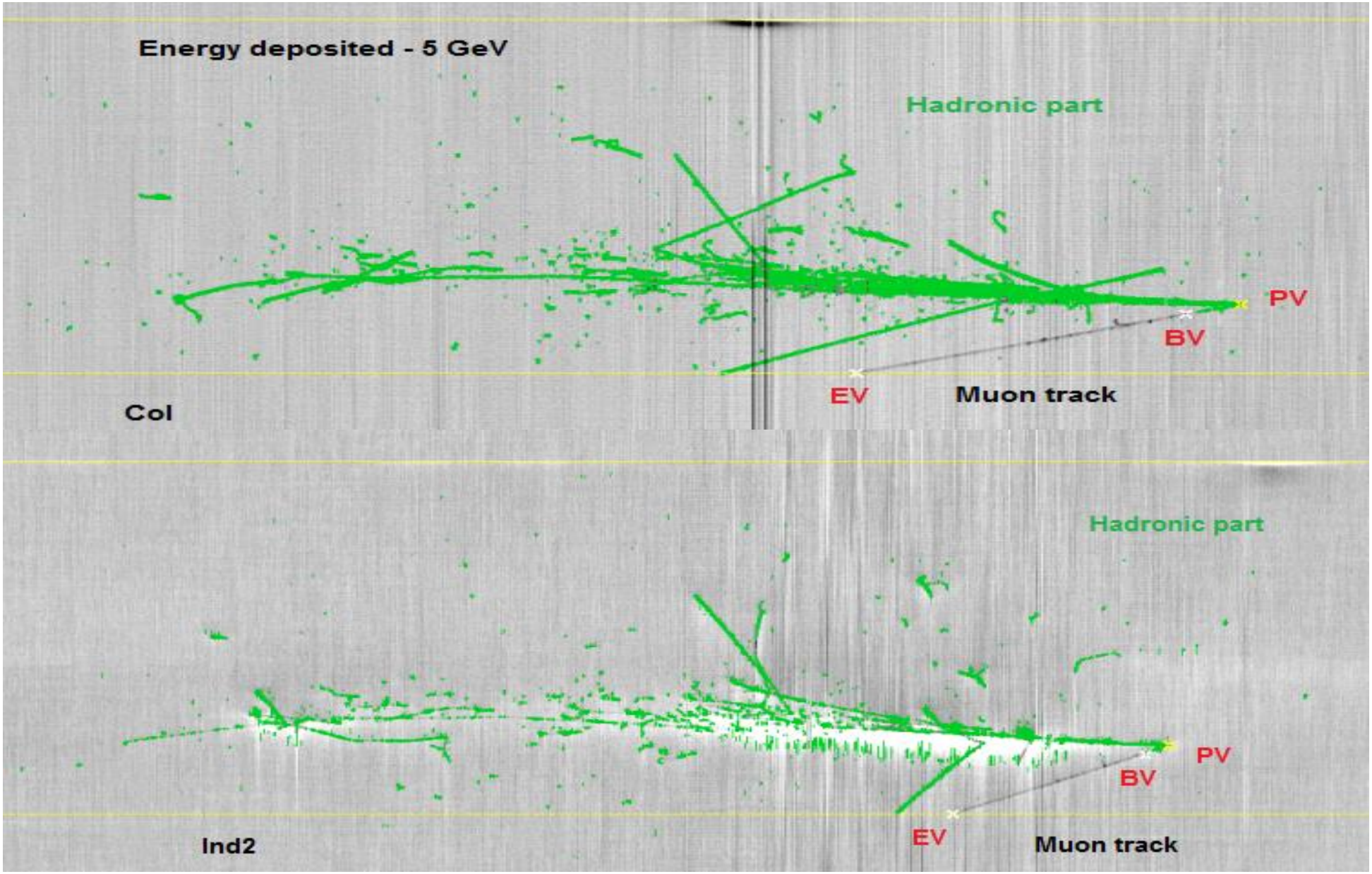
- **ICARUS has operated with tele > 7 ms (~ 40 p.p.t. [O2]eq) corresponding to a 12% maximum charge attenuation at longest drift distance**
- **New pump has been installed on east cryostat near run-end:**

tele exceeding 12 ms and still rising!



Comparable values were only reached so far in small prototypes (ICARINO, 21 ms). ICARUS has demonstrated the effectiveness of the single phase LAr-TPC technique, paving the way to huge detectors/~5 m drift as required for LBNE project

CNGS muon neutrino interaction in Qscan



CNGS NC interaction