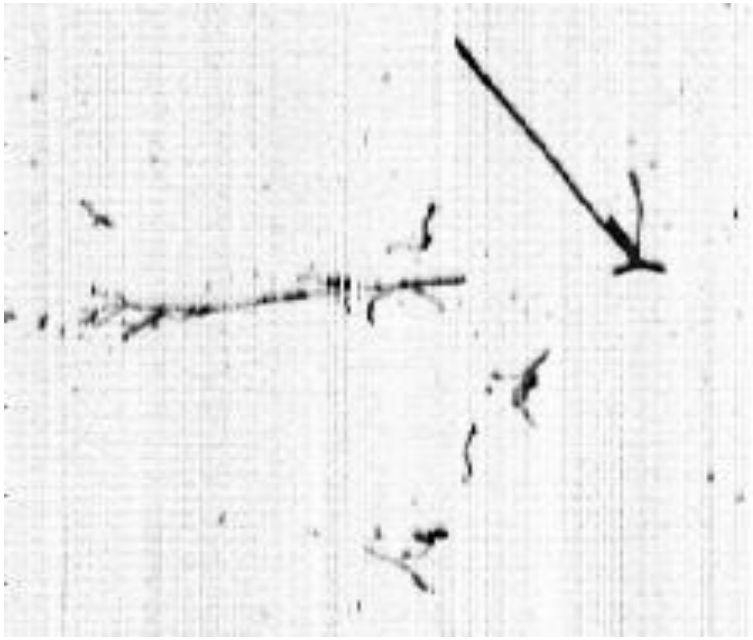


π^0 mass reconstruction in ICARUS

A. Menegolli

University and INFN Pavia (Italy)

Outline

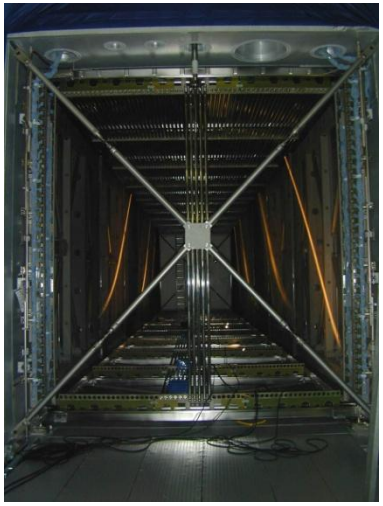
- The ICARUS surface run of 2001 in Pavia (Italy)
- Event selection for π^0 mass reconstruction
- Results
- π^0 mass reconstruction with LNGS data (2010-2013)
- Conclusions

π^0 event searches in LAr

- π^0 reconstruction from the invariant mass of the two photons from $\pi^0 \rightarrow \gamma\gamma$ decay is one of the handles we have to distinguish νeCC from νNC events in neutrino oscillation experiments.
- π^0 events are also a good way to test e.m. shower reconstruction tools also for calibration purposes.
- In ICARUS we have already performed analysis of π^0 events from the two past runs: at surface (cosmics - Pavia, 2001) and underground (CNGS - LNGS, 2010-2013).
- Here few results based on ICARUS past experience are shown.

The ICARUS surface run (2001 - Pavia)

- Very first run of large scale LAr-TPC: first of the two ICARUS T600 module exposed to cosmic rays at surface in July 2001 (Pavia, Italy).



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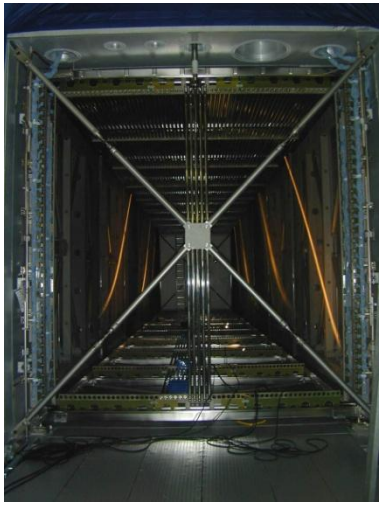


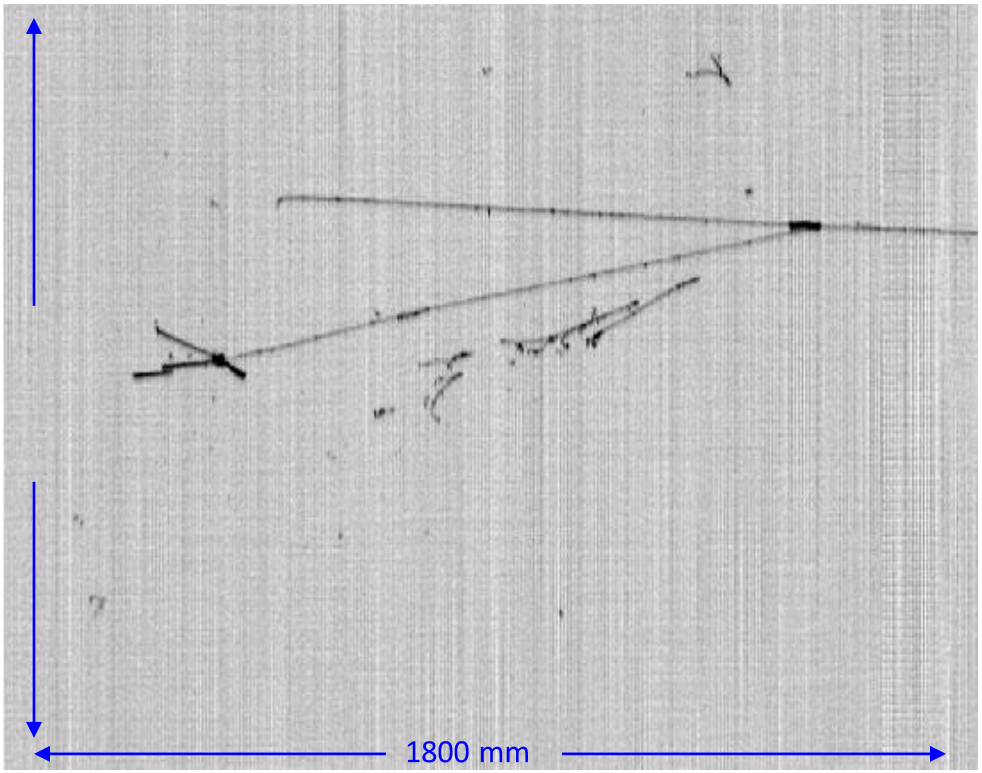
- Demo run in an environment crowded of tracks, but first results on many aspects of LAr-TPC technology (electron life-time, LAr purity, multiple scattering, Michel electrons, space charge, π^0 mass reconstruction).
- Several trigger conditions (external scintillators, random triggers, internal PMT trigger).
- Seminal paper for LAr technology: S. Amerio et al., «*Design, construction and tests of the ICARUS T600 detector*», Nucl. Instr. Meth A527 (2004) 329–410.

Event selection

- Automatic event selection tools not available at the time: visual scanning was a fundamental tool!
- π^0 interactions searched in the cosmic sample with a visual scanning for events with at least two e.m. showers pointing to the interaction vertex.

Event selection

- π^0 events mainly due to hadronic interactions of cosmic rays.
- Despite the surface run, many clear $\pi^0 \rightarrow \gamma\gamma$ were found.



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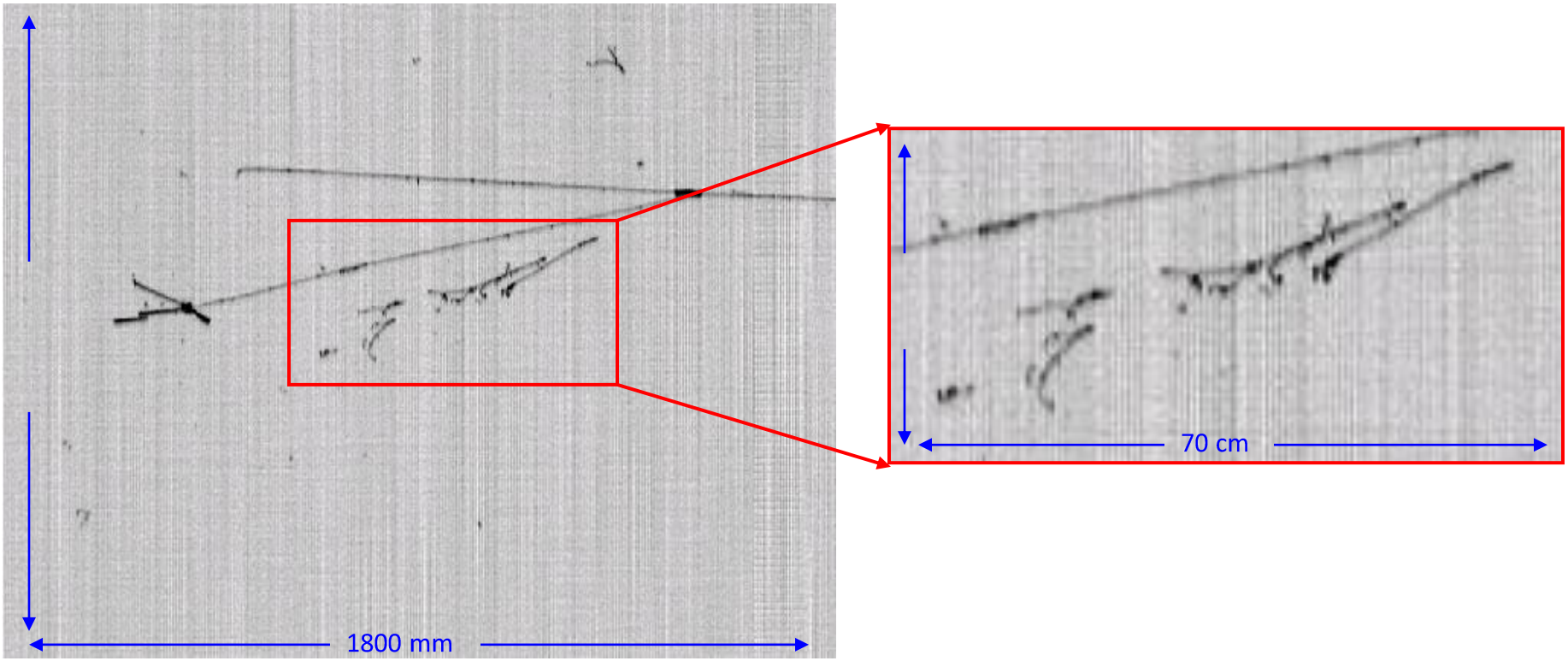

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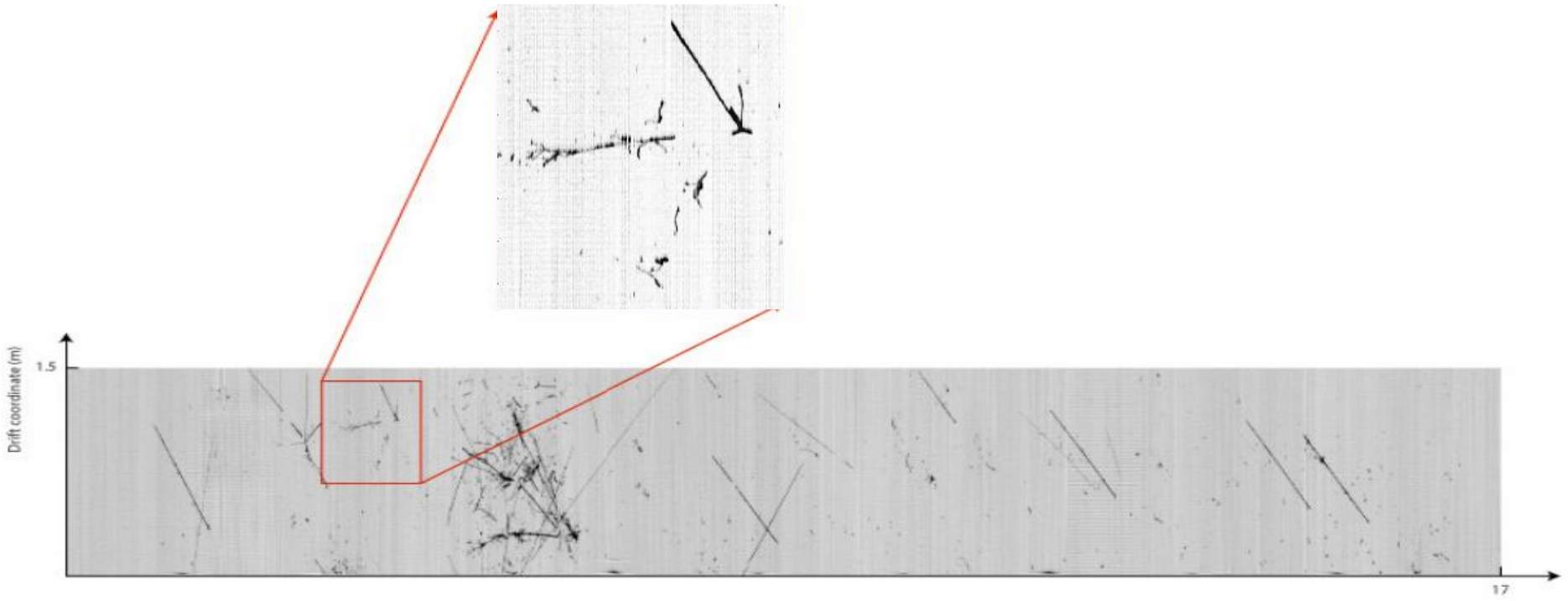

Event selection

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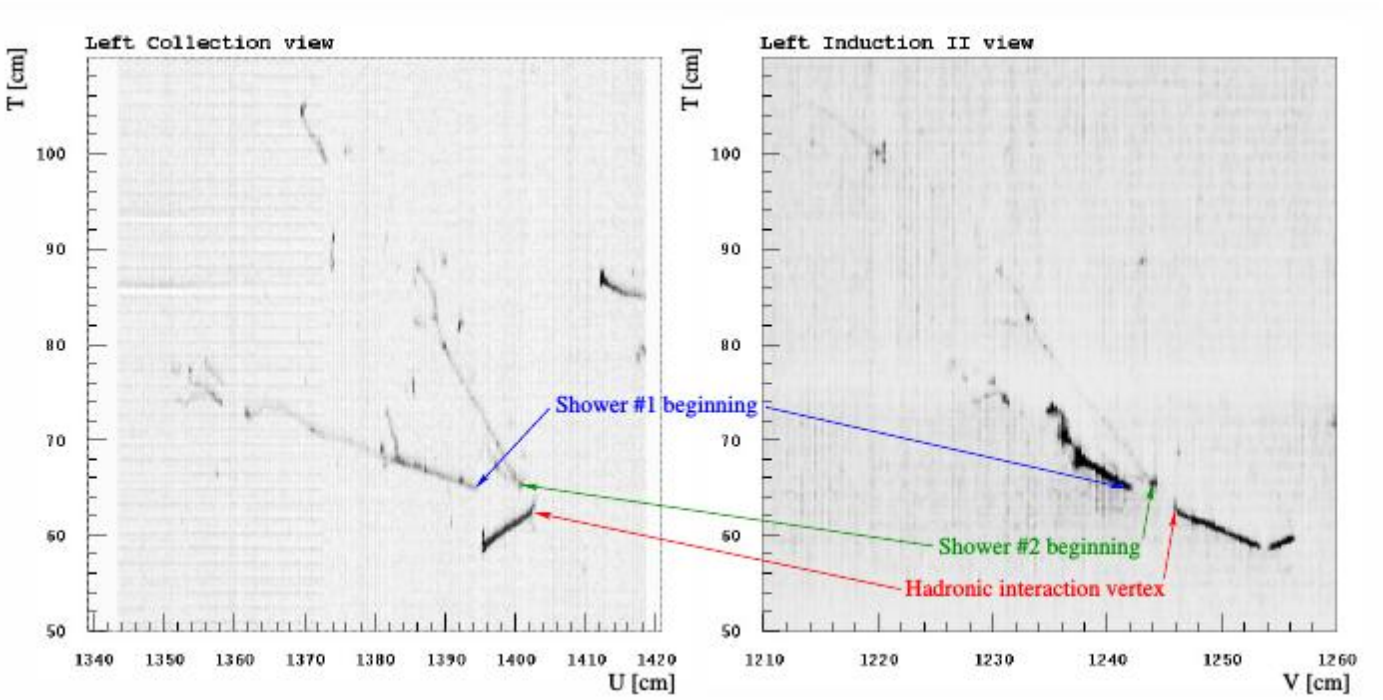
- π^0 interactions searched in the cosmic sample with a visual scanning for events with at least two e.m. showers pointing to the interaction vertex.
- Altogether, about 7500 images have been scanned by different groups. The majority of the events were collected with internal PMT triggers, rich in hadronic interactions.
- Selection rules adopted to cope with the crowded environment:
  - ✓ At least two, well separated electromagnetic showers originated by photons pointing to the interaction vertex in two views.
  - ✓ Unique t0 determination (note that at surface you can have many tracks out of trigger time).
  - ✓ Reject events with overlapping tracks from other cosmics.
  - ✓ Agreement between measurements performed by different groups.

Event reconstruction

- Dedicated (semi-automatic) tool developed to:
  - ✓ Mark the main hadronic interaction vertex and the two shower starting points directly on the Collection and Induction views.



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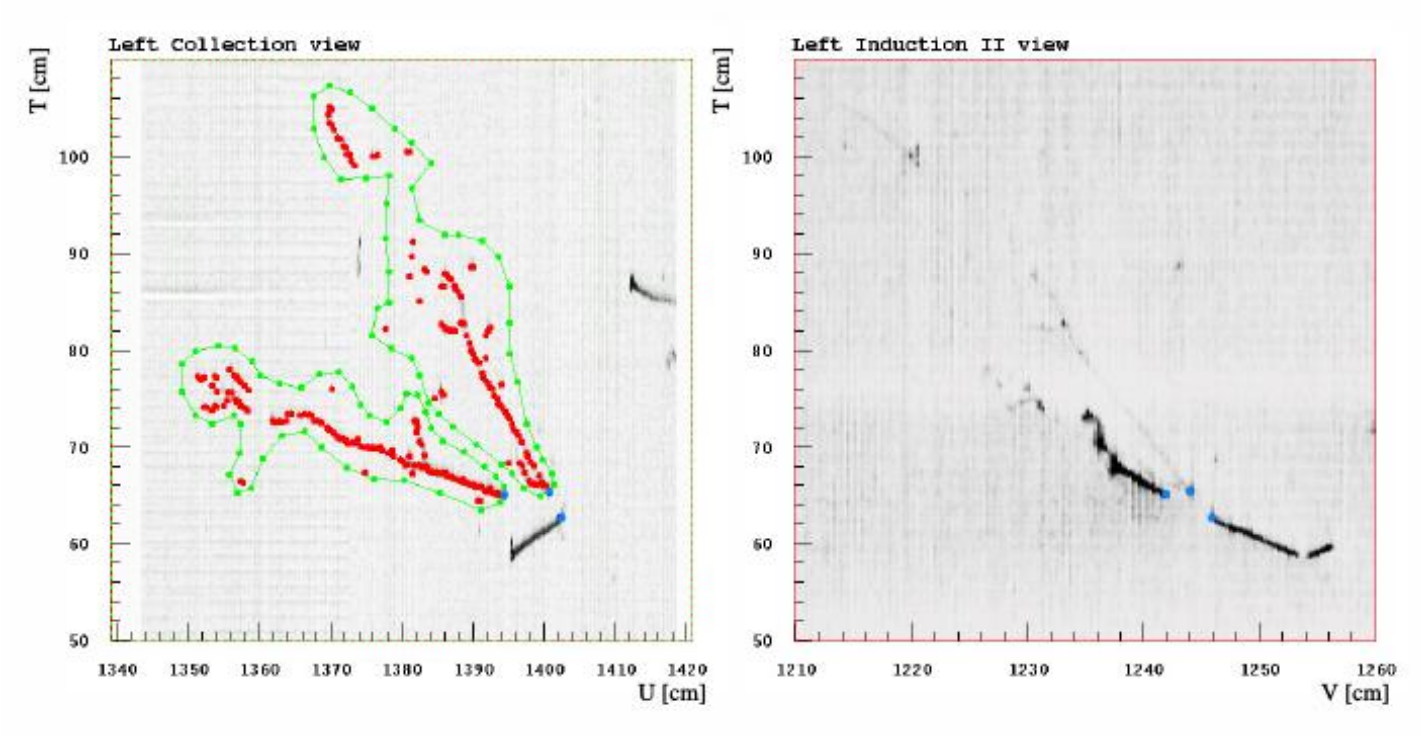

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- The π^0 is then reconstructed as: $M = \sqrt{2\ E_1 E_2 (1 - \cos\theta_{12})}$
  - ✓ E_1,E_2 are the two photon shower energies.
  - ✓ θ_{12} is the angle between the two showers, reconstructed from the directions evaluated from the marked points.

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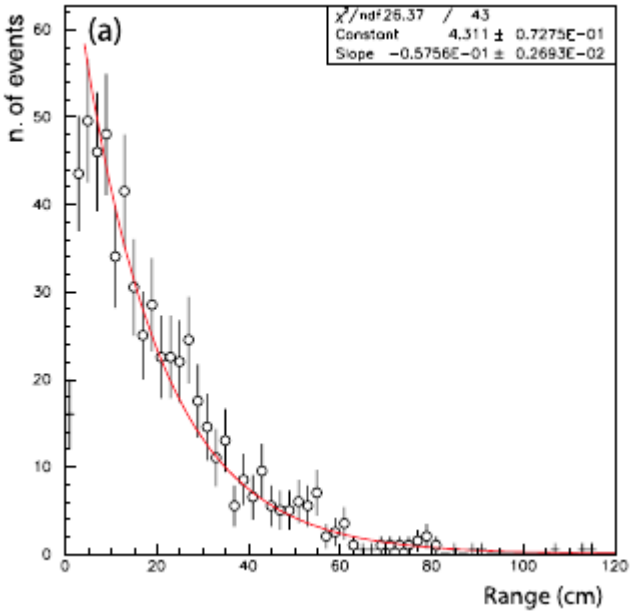

$X_\gamma = 17.4 \pm 0.8$ cm ($X_\gamma = 9/7\ X_0 = 18$ cm)

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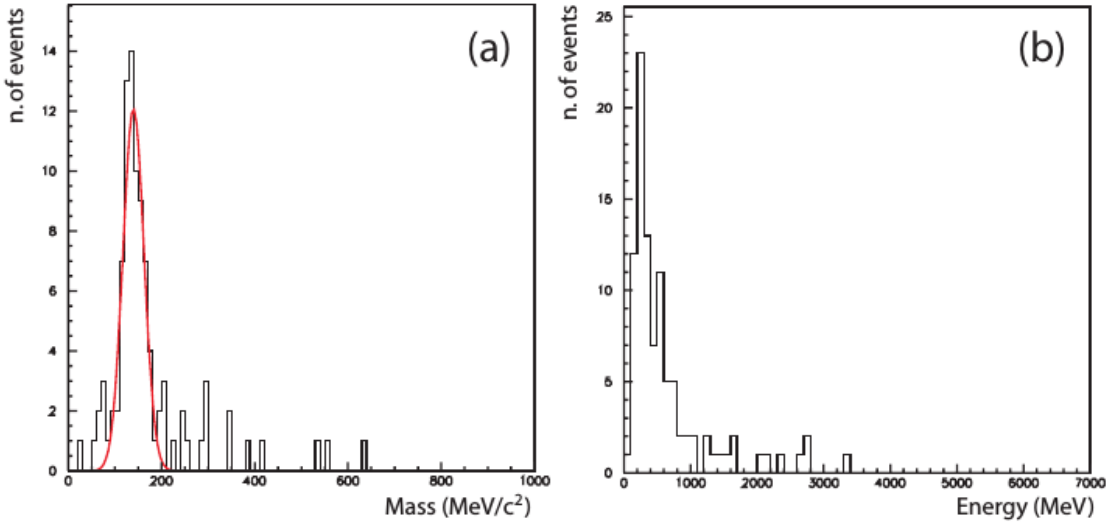
- $\gamma\gamma$ system total energy and invariant mass distribution:



- ✓ Average π^0 energy E ≈ 640MeV
- ✓ $m_{\gamma\gamma}$ = (139.9 ± 2.8 [stat] ± 9.9 [syst])MeV/c^2
- ✓ π^0 mass resolution ≈ 16% (RMS = 22.6 ± 2.9 MeV/c^2)

A. Ankowski et al., «*Energy reconstruction of electromagnetic showers from π^0 decays with the ICARUS T600 liquid argon TPC*», Acta Physics Polonica B Vol.41 (2010). http://www.actaphys.uj.edu.pl/fulltext?series=Reg&vol=41&page=103

LNGS data

- π^0 search and reconstruction was again performed with ICARUS T600 data from LNGS underground run with CNGS beam.
- Very much cleaner environment with respect to Pavia surface data → the sample used was the $\nu\mu$CC data from 2011 and 2012 runs.

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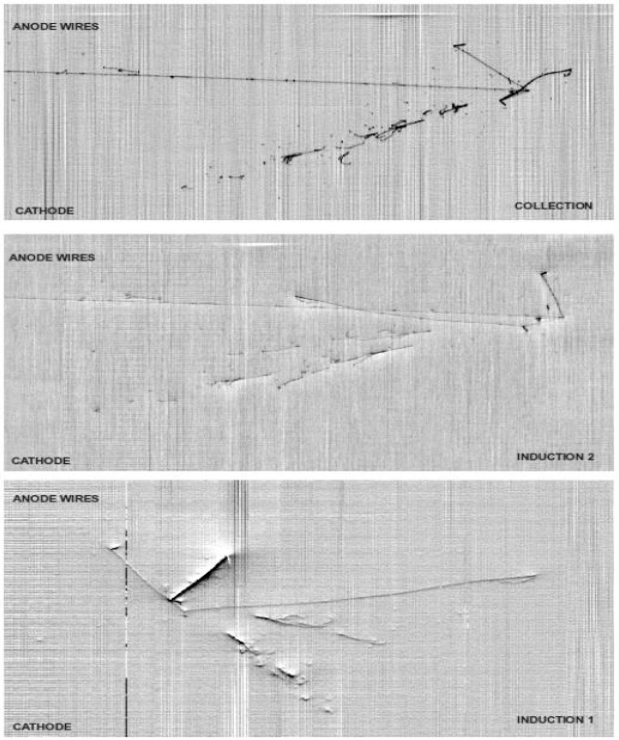
- All 1287 $\nu\mu$CC events were visually scanned to search for $\pi^0 \rightarrow \gamma\gamma$ decay events.
- $\nu\mu$CC MC sample with π^0 used to simulate:
  - ✓ energy resolution for the gamma shower
  - ✓ energy misidentification between the showers
  - ✓ resolution for the opening angle θ.



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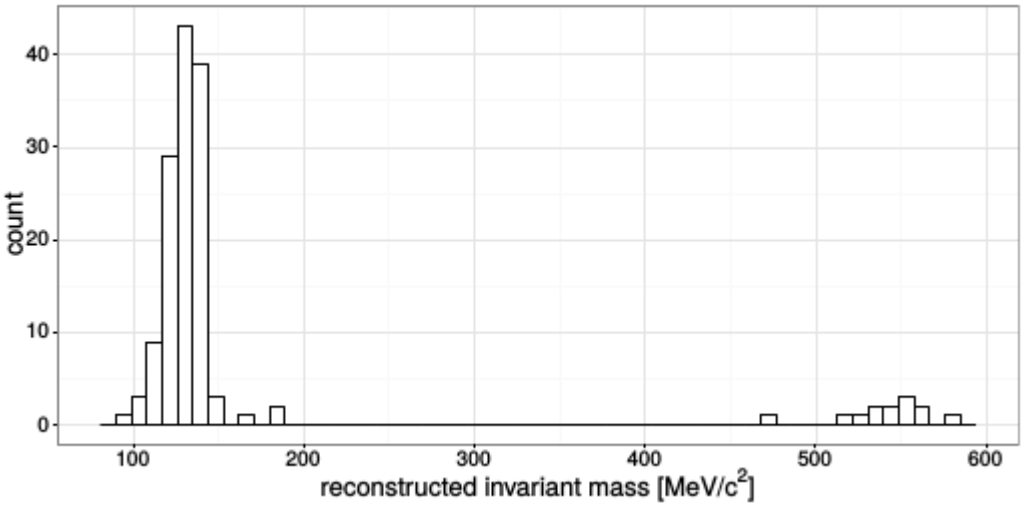

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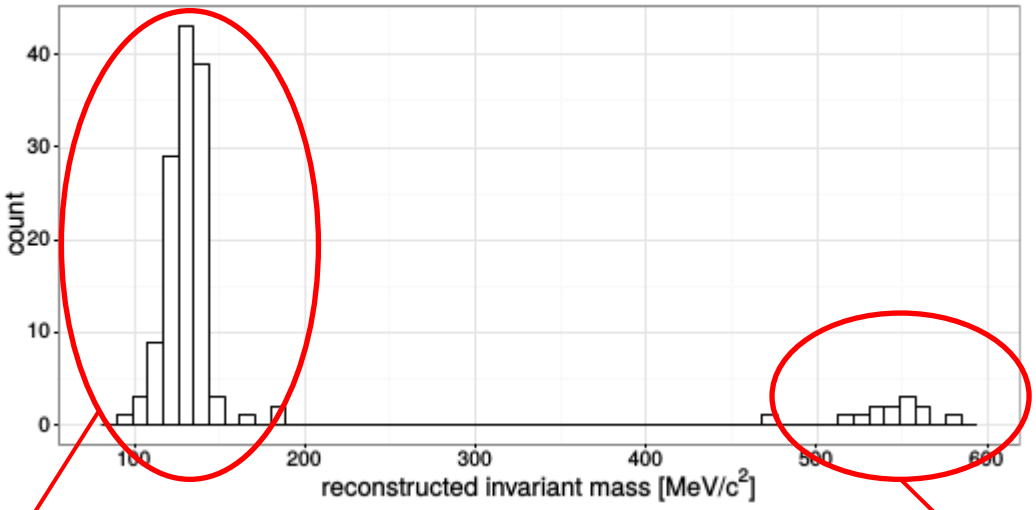

- ✓ $m_{\gamma\gamma}$ = (134.5 ± 1.5 [stat] ± 4.2 [syst])MeV/c^2
- ✓ π^0 mass res. ≈ 9.5% (RMS = 12.8 ± 0.8 MeV/c^2)

- ✓ $m_{\gamma\gamma}$ = (558 ± 23) MeV/c^2
- ✓ 13 events of $\eta^0 \rightarrow \gamma\gamma$!

I. Kochanek, «*Analysis of neutral pions from νμ CC CNGS interactions inthe ICARUS detector*», PhD Thesis (2015). https://sbc.org.pl/dlibra/publication/220536/edition/208391

Conclusions

- $\pi^0 \rightarrow \gamma\gamma$ decay is one of the handles we have to distinguish νeCC from νNC events and it is a invaluable tool for LAr data calibration.
- ICARUS T600 performed the analysis of π^0 events twice, either at surface and in undeground environment.
- Despite the difficult conditions, already at surface it was possible to measure the π^0 mass from a sample of events coming from cosmic interactions in LAr (RMS ≈ 16%).
- The cleaner LNGS environment allowed to measure π^0 mass with a better resolution (RMS ≈ 10%) with CNGS $\nu\mu$CC events.
- In ICARUS-SBN, the 3m concrete overburden should give a LAr environment clean enough to have π^0 mass reconstructed with quality similar to LNGS.


Thank you !