Status of the automatization of the event reconstruction in the ICARUS T600 LAr TPC

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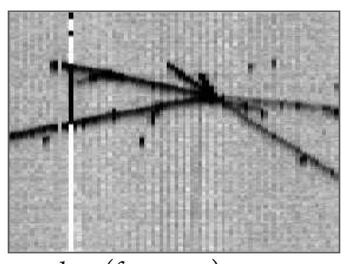
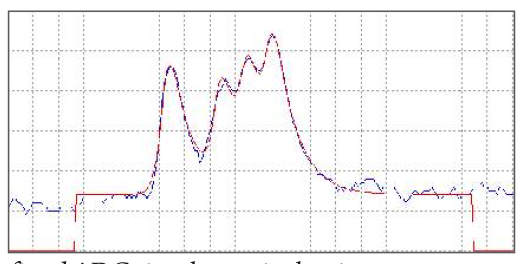
Liquid Argon Time Projection Chamber (LAr TPC) detectors offer charged particle imaging capability with remarkable spatial resolution accompanied with calorimetric measurement of particle energy losses. The technique is of interest for wide physics programs that require automatization of the reconstruction procedures suited for handling large amount of data. We present methods being prepared for the analysis of data collected with the ICARUS T600 detector, the largest LAr TPC ever built: the hit reconstruction, the two-dimensional event clustering with vertex finding, a novel three-dimensional track reconstruction approach, and finally stopping particle calorimetric reconstruction and identification. Performances and efficiencies of the algorithms are presented together with an example of the event reconstruction.

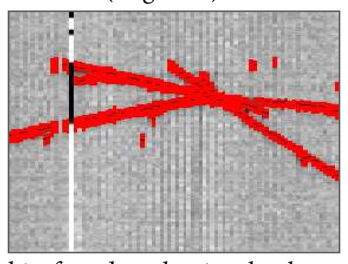
- wire noise reduction
- hit finding
  - rejection of fake hits
  - resolving overlapping hits
  - hit charge reconstruction



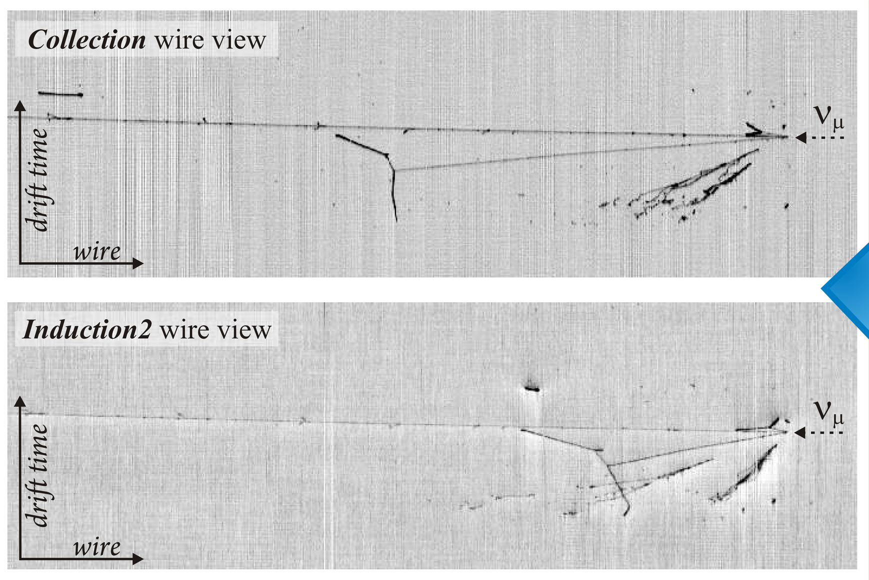
raw data (fragment)

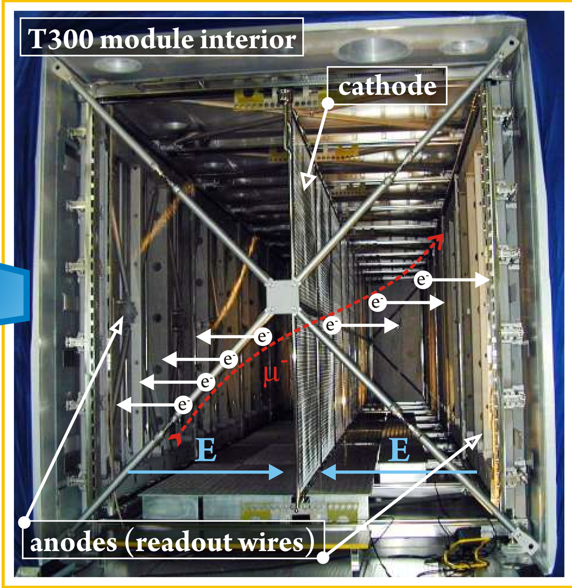


fitted ADC signal on a single wire



hits found on the signal pulses



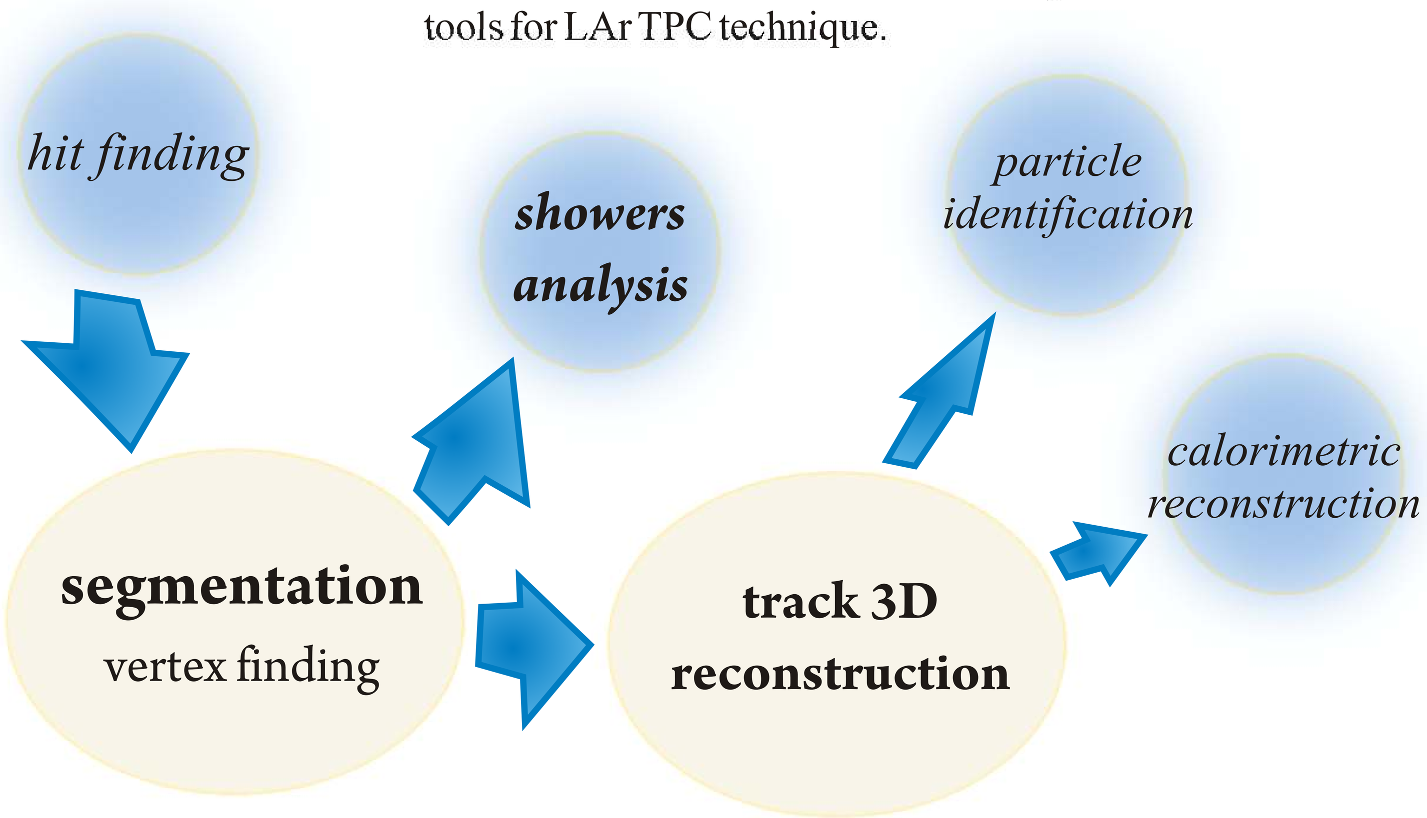


- Two T300 modules: 3.6x3.9x19.6m.
- Liquid Ar acts as *target* and *detector*.
- Liquid Ar active mass: ~476t.
- Drift length = 1.5m (1ms.).
- 3 readout planes: 0°, ±60° (54k wires).

Imaging principle: charged particle traversing liquid Ar produces ionization electrons along its path. Ionization electrons are drifting in the uniform electric field toward anode. ADC(t) signals on the readout wires of the anode forms two-dimensional projection of the particle track.

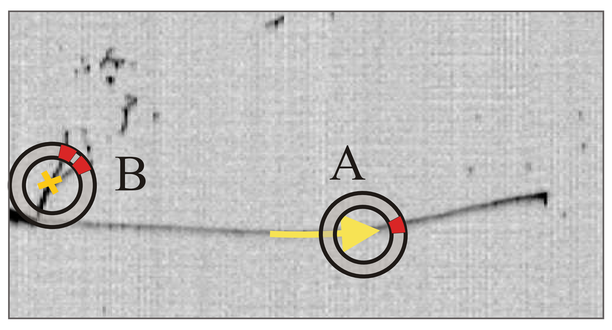
Reconstruction: association of projections obtained from wire planes (two induction-mode and one collection-mode, with different wire orientations) allows 3D spatial reconstruction; collection plane signal provides calorimetric information.

Key elements: excellent granularity of 2D images comes at the price of complex image recognition problem. 2D image segmentation and association of objects in complementary wire planes are now main efforts in the development of reconstruction algorithms. Significant progress in 3D track reconstruction, mature particle identification and calorimetric reconstruction algorithms complete the picture of the present state of analysis tools for LAr TPC technique.

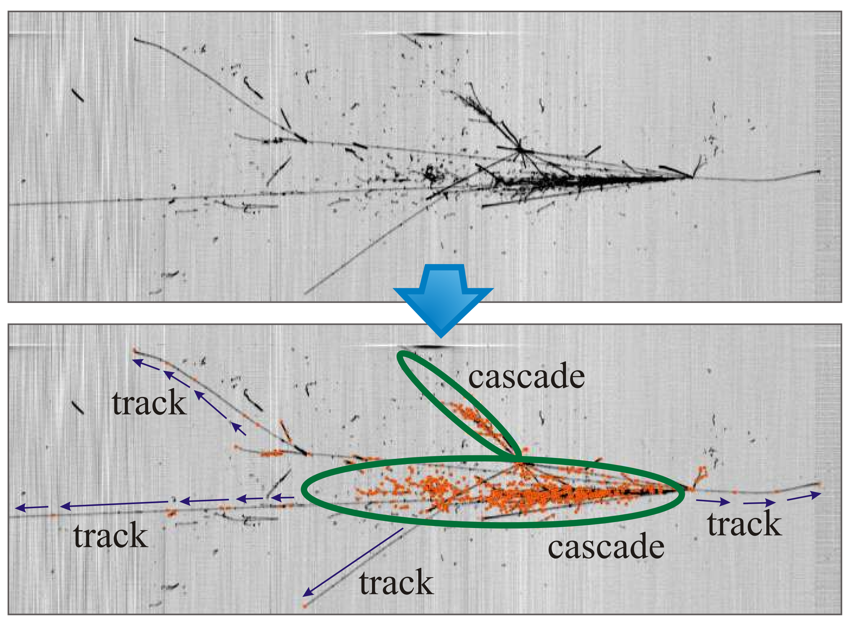


Segmentation algorithm idea:

- Follow the angular distribution of hits energy in rings (A).
- Vertex at branching and scattering points (B).



- Result: tree structure of hit clusters and vertices.
- Clean detection of tracks.
- High vertex density regions identified as cascades.

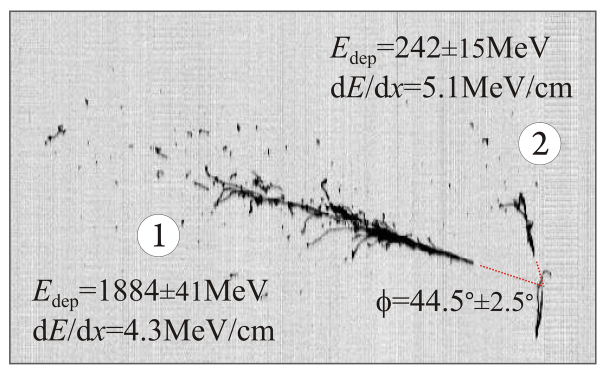


- Cascade energy: charge integration, averaged recombination correction.
- Separation of an electron from γ conversion: dE/dx of the initial part of cascade.

Example of η decay:
(seen in one of NC events)

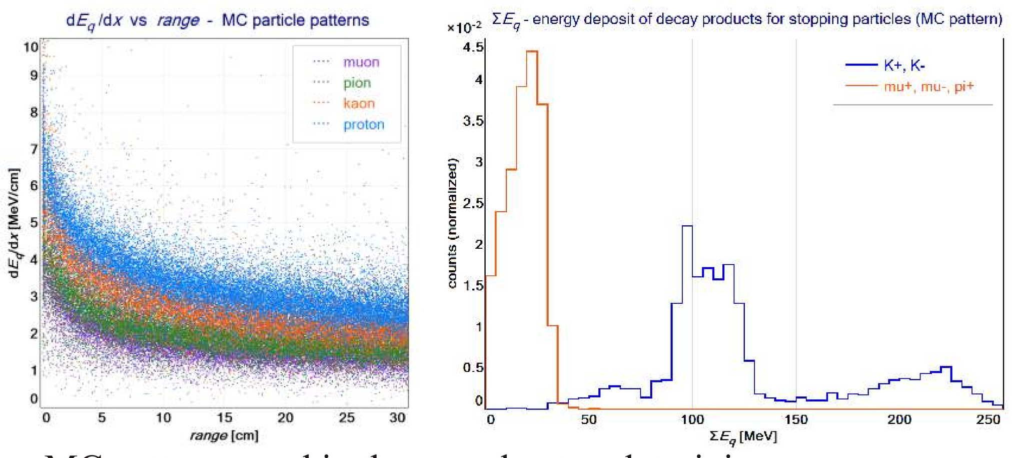
m_{inv} = 512±48MeV/c^2

(m_η = 547.9MeV/c^2)

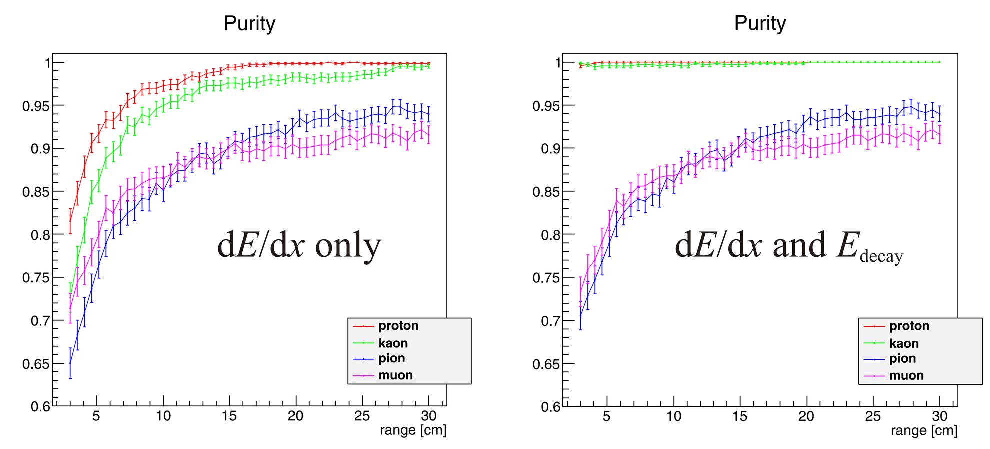


Neural Network based stopping particle identification.

- Level 1: sequence of dE_q/dx vs. track residual range
  - independent classification of each track segment;
  - NN outputs combined into single PID decision.
- Level 2: decay products energy - if available.
- Direct interpretation of the network outputs as the probability values.
- No need to assume model of the detector and reconstruction effects. But: relies on particle MC model.
- Statistically optimized network training and structure parameters; controlled network output uncertainties.

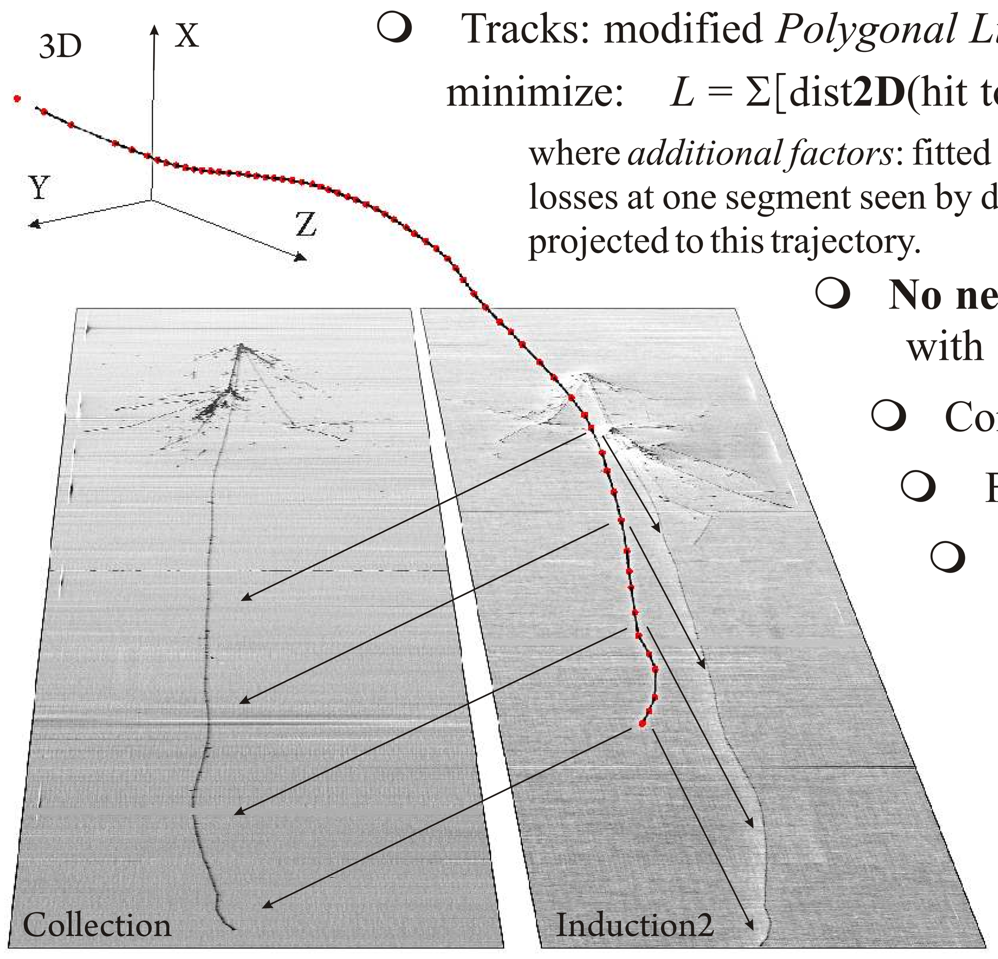


MC patterns used in the neural network training.



Classification results on the sample of MC tracks.

NOVEL, GENERAL APPROACH: build 3D object by optimizing its 2D projections to wire views.



- Tracks: modified *Polygonal Line*[*] fit to hits available in 2D wire views, including all additional information; minimize: $L = \Sigma[\text{dist}\mathbf{2D}(\text{hit to fit-2D-projection})^2] + \lambda\Sigma[\text{penalty}(\text{segment } \mathbf{3D} \text{ angle})] + \textit{additional factors},$

  where *additional factors*: fitted trajectory distance to peculiar points reconstructed in 3D space *(like: vertices, delta rays)*, energy losses at one segment seen by different 2D wire views. Fit results with the segmented 3D trajectory and the sequence of 2D hits projected to this trajectory.
- **No need to match 2D hits by their drift coordinate** (usual approach in LAr TPC, with significant disadvantages, like position quantization, see also further text).
- Common sequence of 2D hits from all wire views projected to 3D space.
- Full available information combined in one fit.
- Resistant to:
  - missing 2D information; • **tracks parallel to wire planes** (in case of usual hit-by-hit matching - constant hit drift time on track sections caused significant inefficiency of the reconstruction); • sophisticated trajectories (sharp track angles, difficult to resolve in 2D projections).

Idea potentially applicable to shower and vertex precise 3D reconstruction.

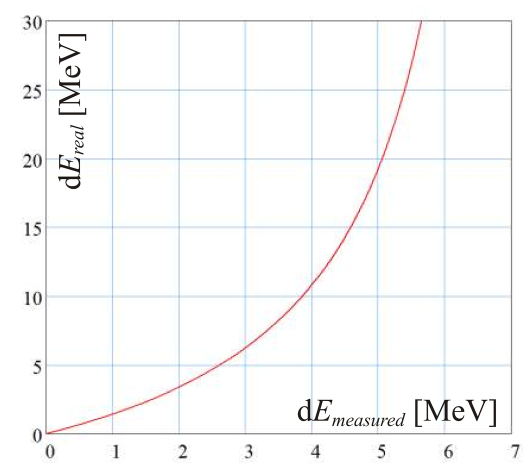
*B. Kegl et al., IEEE Transactions on Pattern Analysis and Machine Intelligence 22 no. 3 (2000), 281

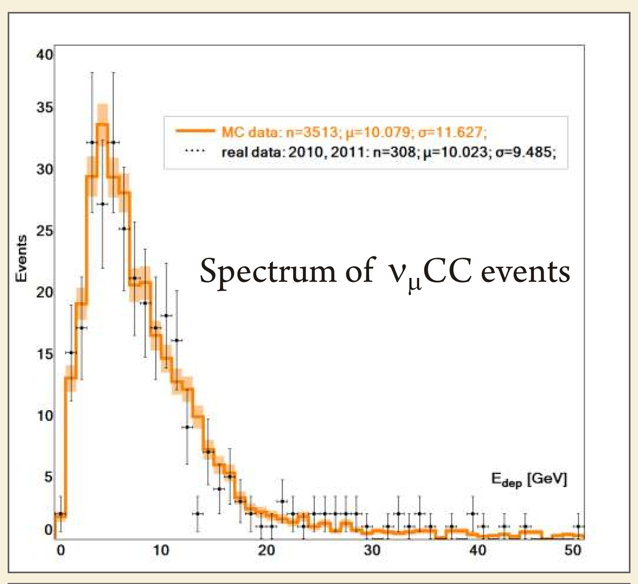
Calorimetric reconstruction of the particle energy.

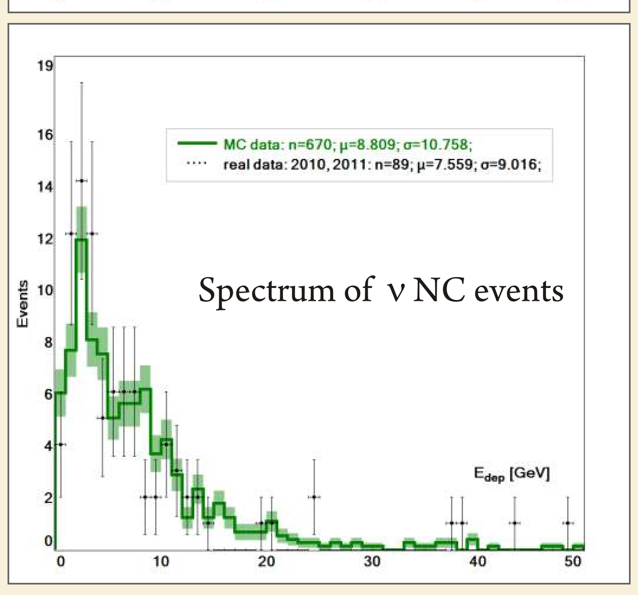
- Recombination in LAr affects measured charge.
- Correction is applied after 3D reconstruction, to the individual track segments, according to Birk's law:

$$dE_{real} = \frac{dE_{measured}}{A - \frac{k}{\varepsilon\rho} \cdot \frac{dE_{measured}}{dx}}$$

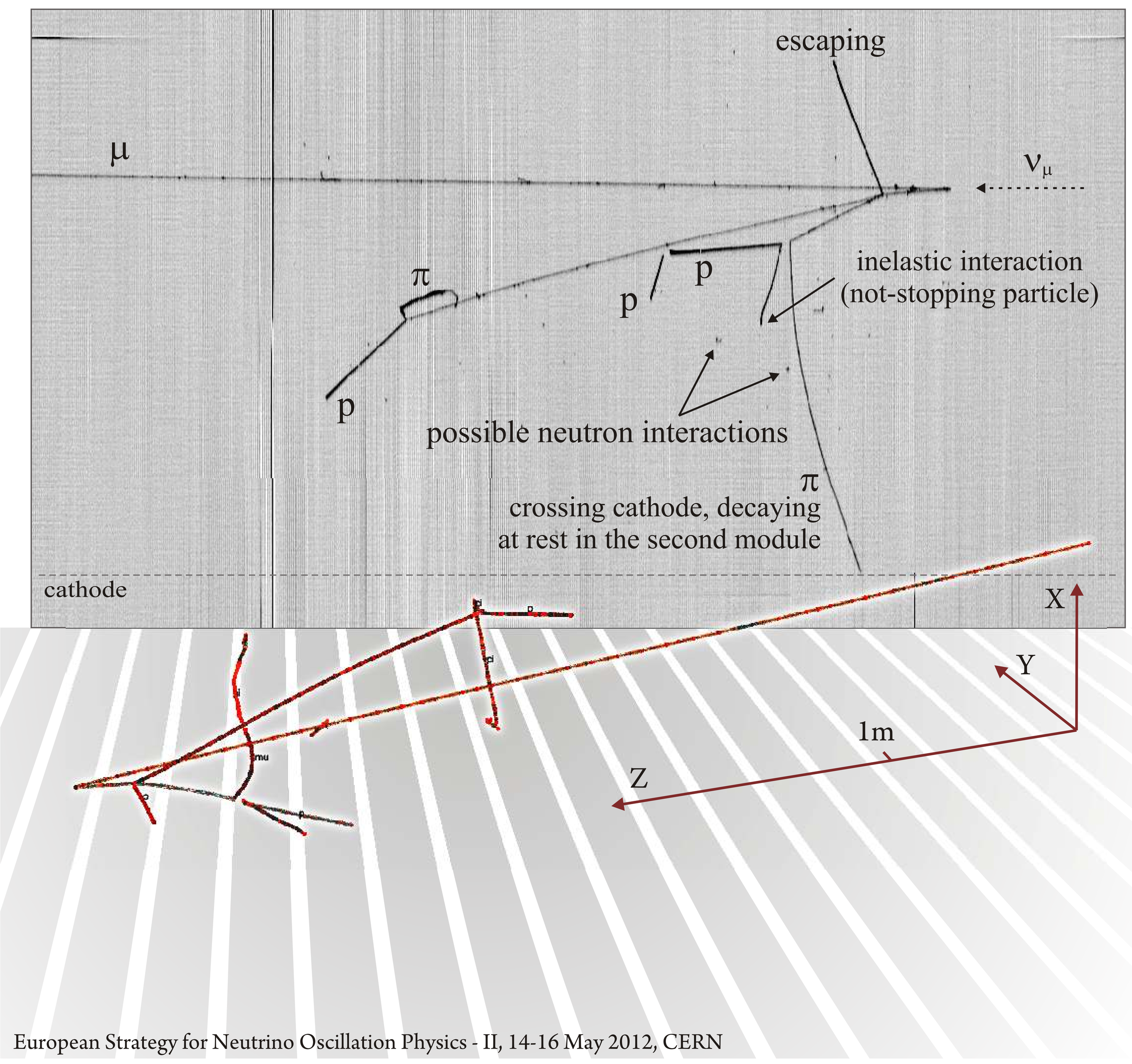
parameters measured during test run:
A = 0.81
k = 0.055 [(kV/cm)(g/cm²)/MeV]
ε = 0.5 [kV/cm]
ρ = 1.4 [g/cm³]





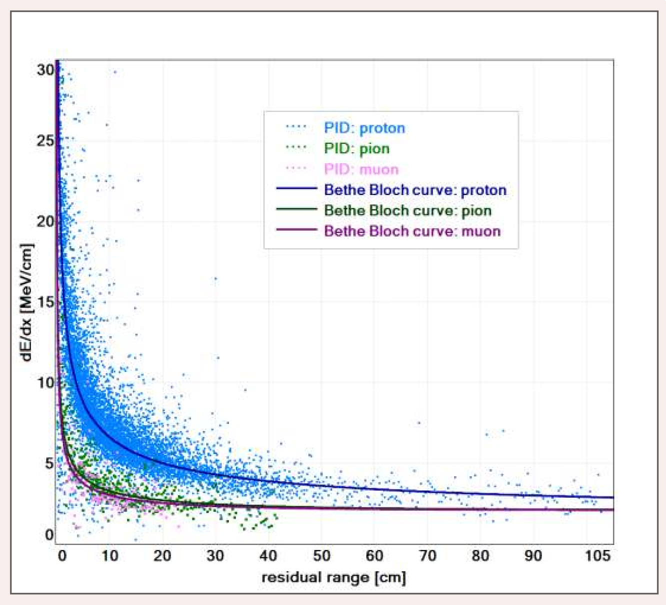


Hit energy deposit:
MC vs. real data comparison.



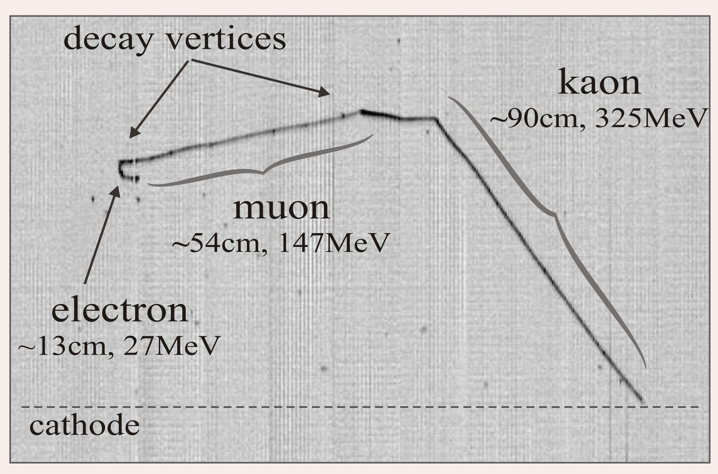
Calibration on stopping protons:

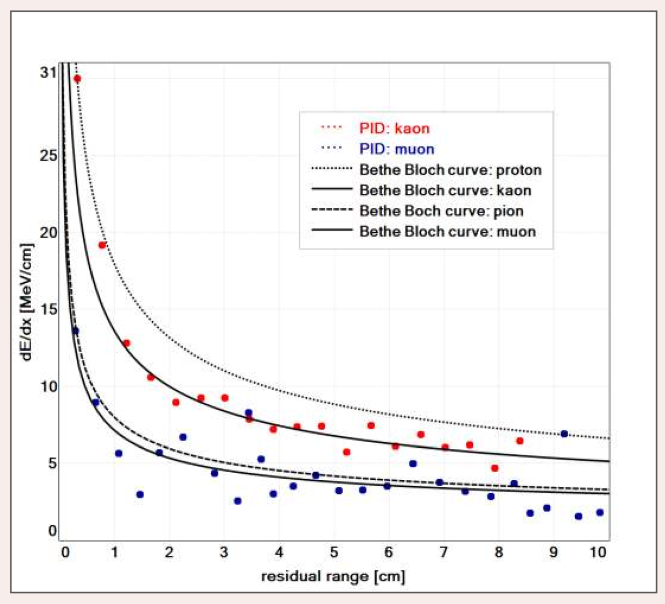
- Selected tracks with no visible decay products and high ionization at the stop point.
- Tracks reconstructed in 3D, identified with NN, dE/dx sequences corrected for recombination (right upper plot).
- Obtained very good agreement with Bethe-Bloch theoretical curves and particle simulation.
- Evident cases of π / μ in the selected sample (interacting at low energies with neutral products only).



Example of decaying kaon candidate:

- right bottom: dE/dx sequence for K and μ;
- below: raw data, *Collection* view.





European Strategy for Neutrino Oscillation Physics - II, 14-16 May 2012, CERN