FEDRA

Framework for Emulsion Data Reconstruction and Analysis

In the OPERA experiment

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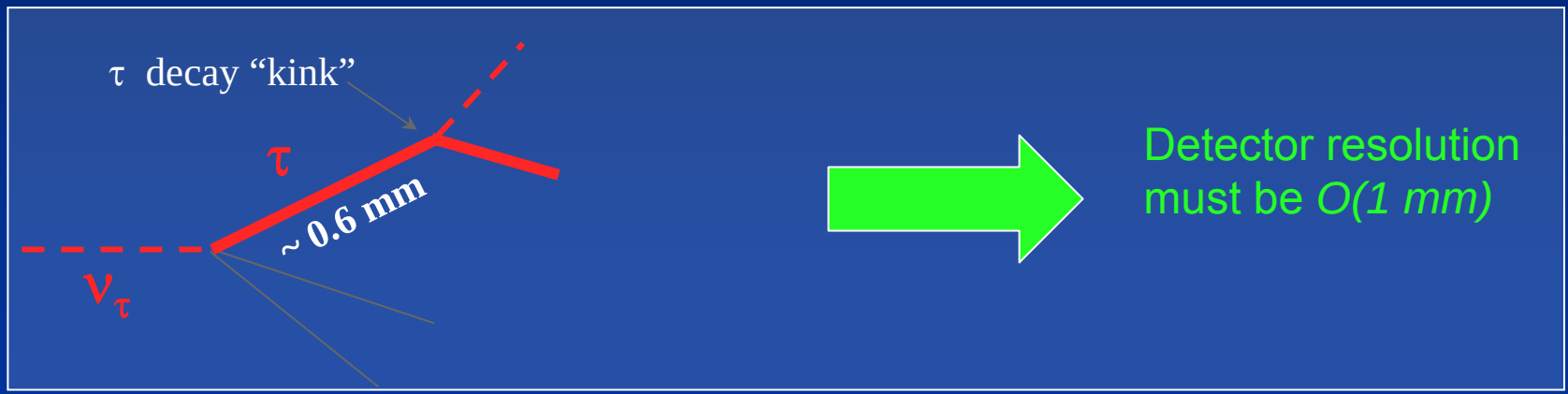
OPERA ≡ Oscillation Project with Emulsion tRacking Apparatus

Primary goal of OPERA:

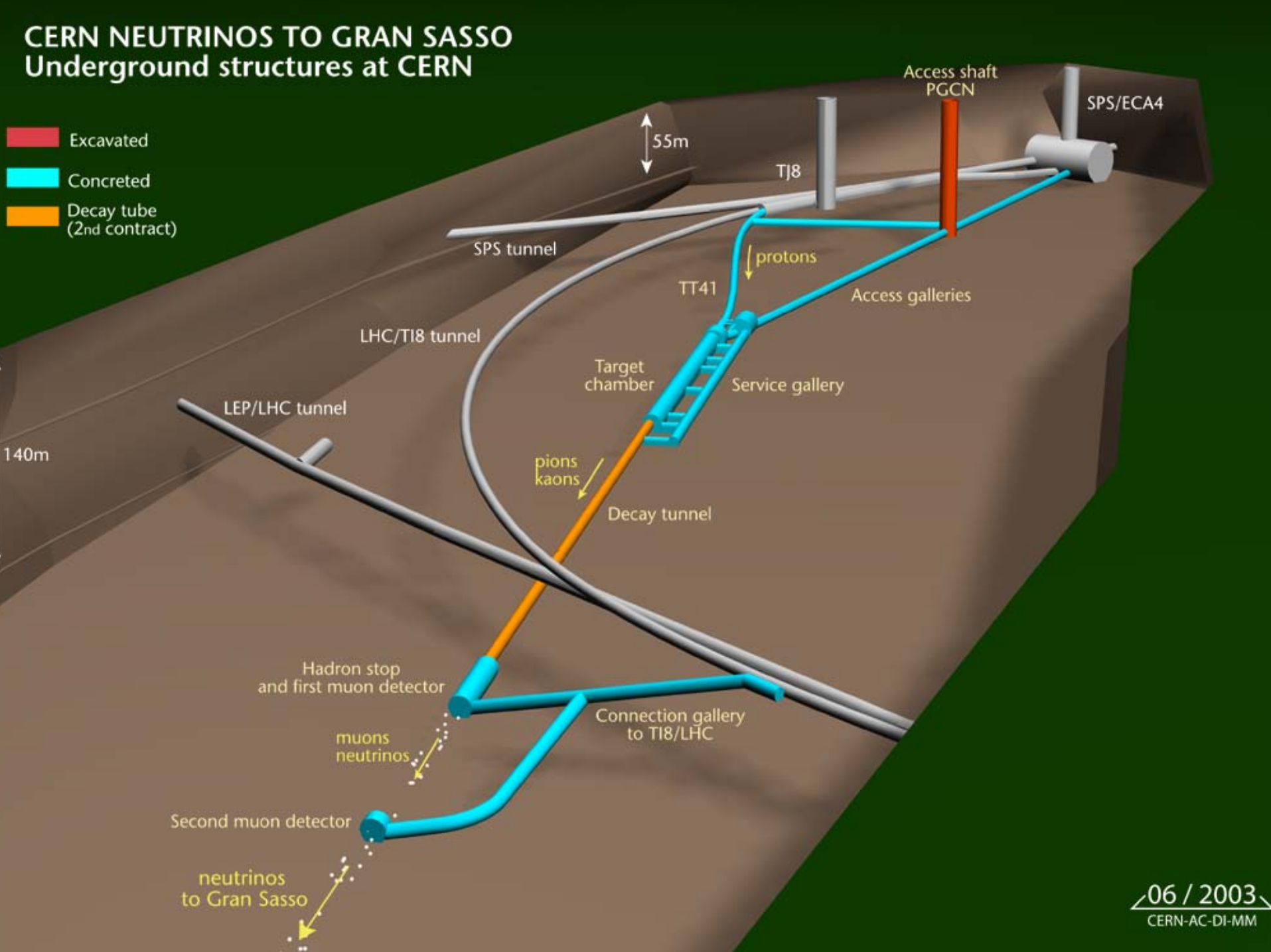
direct observation of τ leptons produced in ν_τ^{CC} interactions



$$N_\tau = N_A M_D \int \phi_{\nu_\mu}(E) P_{\nu_\mu \to \nu_\tau}(E, \Delta m^2) \sigma_{\nu_\tau}^{CC}(E) \varepsilon(E) dE$$

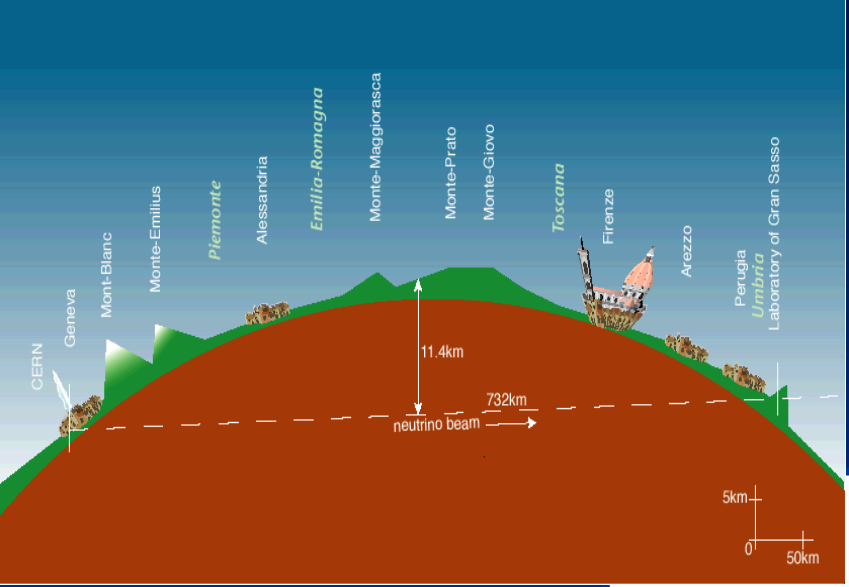
Target mass must be *O(1 kton)* for $\Delta m^2 = O(10^{-3}\ eV^2)$

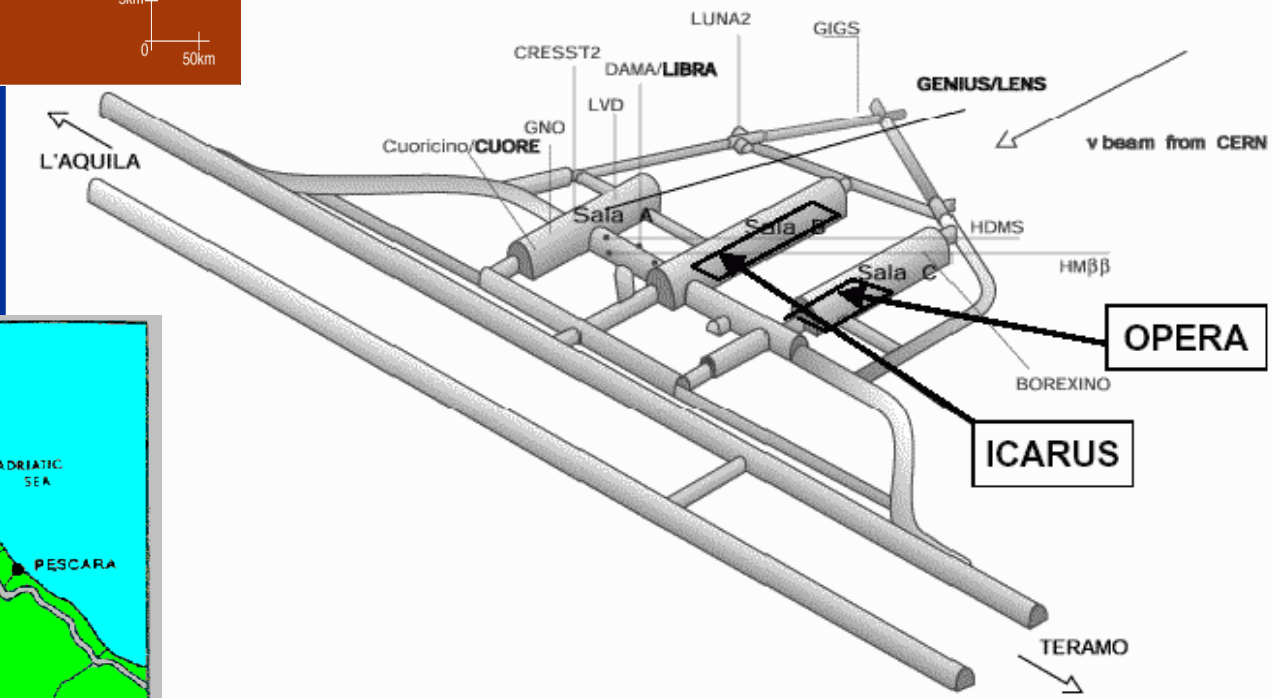
ECC concept adopted


CERN NEUTRINOS TO GRAN SASSO
Underground structures at CERN
Excavated
Concreted
Decay tube
(2nd contract)
55m
140m
Access shaft
PGCN
SPS/ECA4
TJ8
SPS tunnel
protons
TT41
Access galleries
LHC/TI8 tunnel
Target
chamber
Service gallery
LEP/LHC tunnel
pions
kaons
Decay tunnel
Hadron stop
and first muon detector
Connection gallery
to TI8/LHC
muons
neutrinos
Second muon detector
neutrinos
to Gran Sasso
06 / 2003
CERN-AC-DI-MM

Underground Lab:

1400 m of rock shielding: Cosmic Ray flux reduced by a factor 10^6 wrt surface; very reduced enviromental radioactivity.





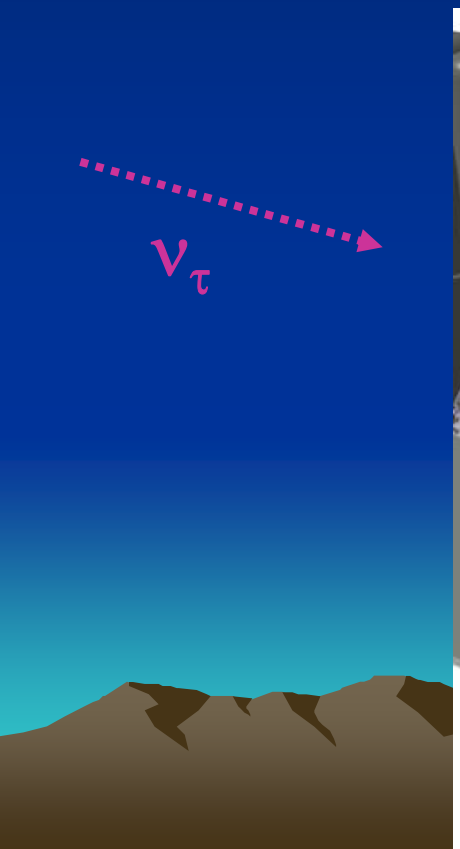
OPERA layout

Hybrid detector (electronic + emulsions) with a modular structure:

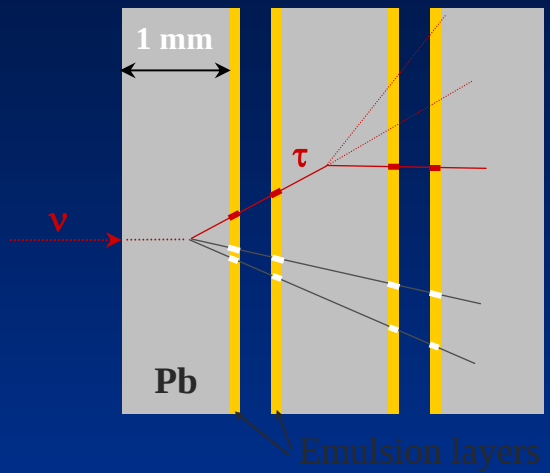
2 supermodules = 2*(31 walls + 1 spectrometer)

 31 walls = 31*(56*64 bricks + 1 scintillator tracker plane)

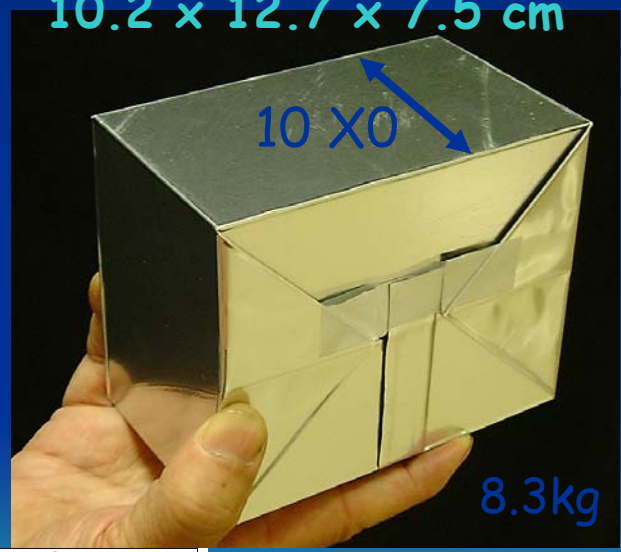
Total mass = 1766 tons, # of bricks = 206336



OPERA emulsion target



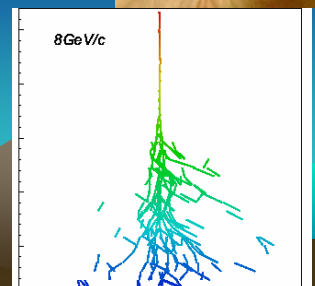
- Based on the concept of the Emulsion Cloud Chamber (**ECC**)
- **56 Pb sheets 1mm + 57 emulsion plates**
- Solves the problem of compatibility of large mass for neutrino interactions + high space resolution in a completely **modular** scheme



ECC are completely stand-alone detectors:

- Neutrino interaction vertex and kink **topology** reconstruction
- Measurement of the **momenta** of hadrons by multiple scattering
- **dE/dx** pion/muon separation at low energy
- **Electron identification** and measurement of the energy of the electrons and photons

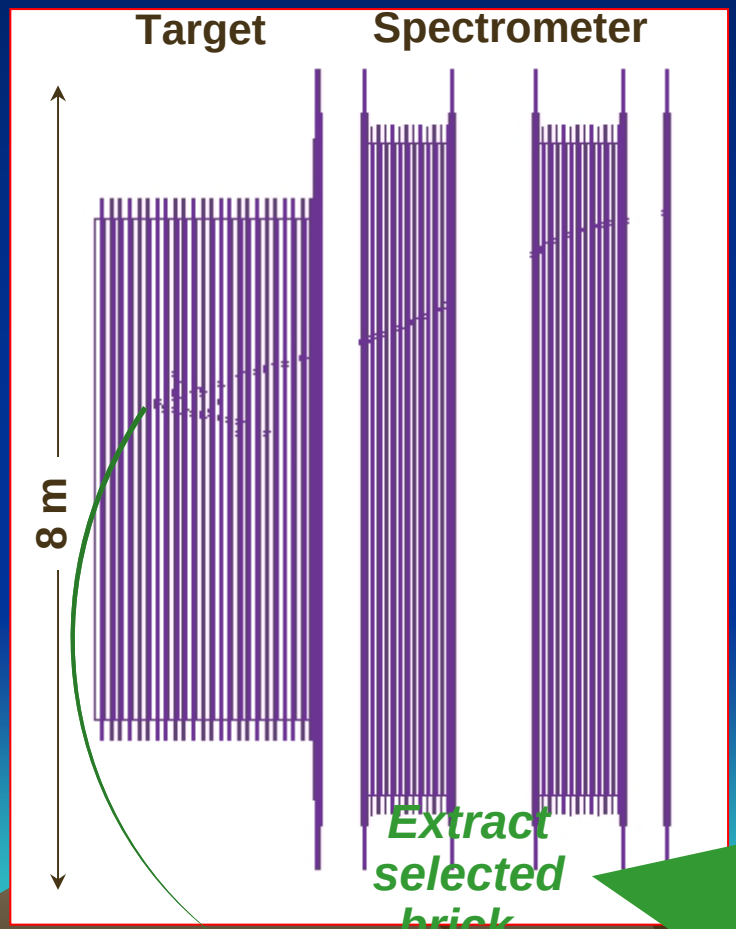
ECC Technique validated by the direct observation of $\mathbf{n_t}$:
DONUT 2000

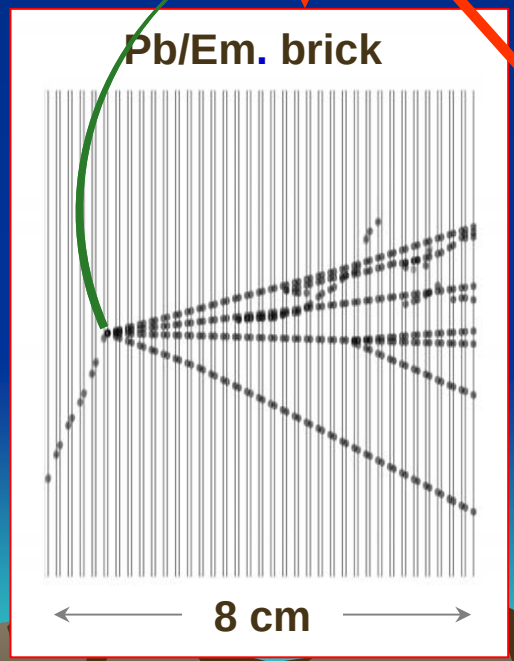


Target Tracker: trigger and localize the ν interaction

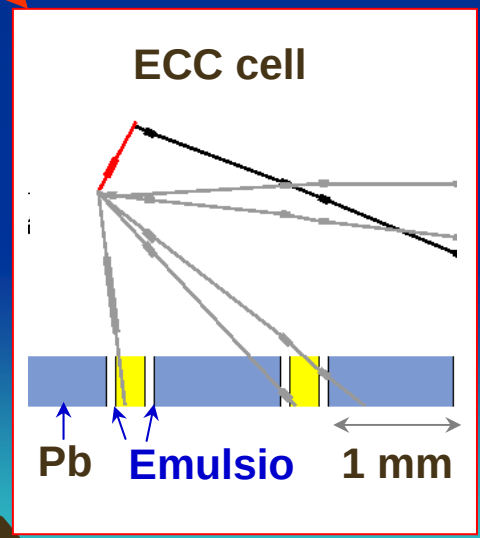
Spectrometer: measure μ ID, charge and momentum

ECC: measure kink, pID, momentum (via MCS), dE/dX, e/γ separation, general kinematic of the event

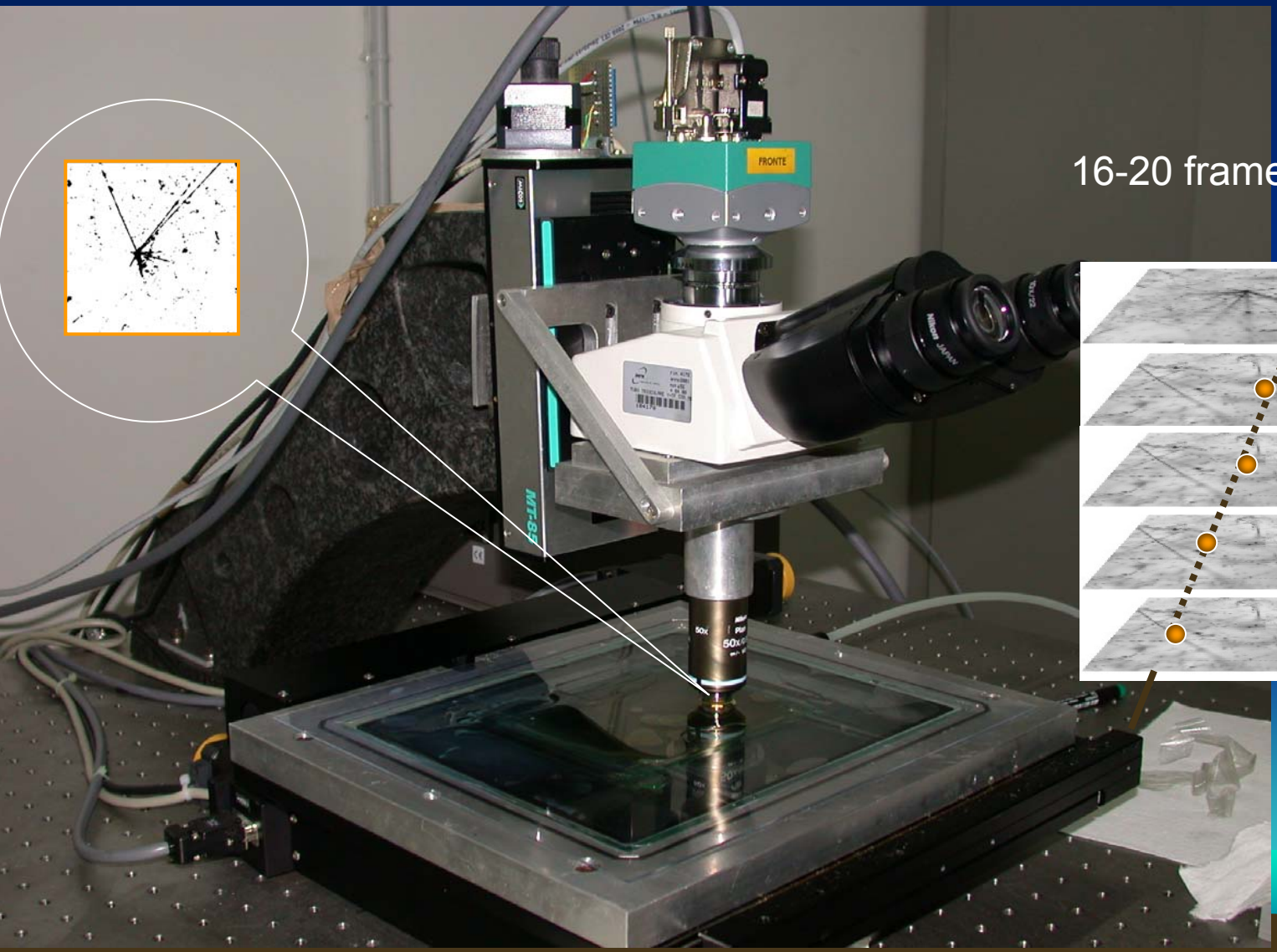




Vertex Location

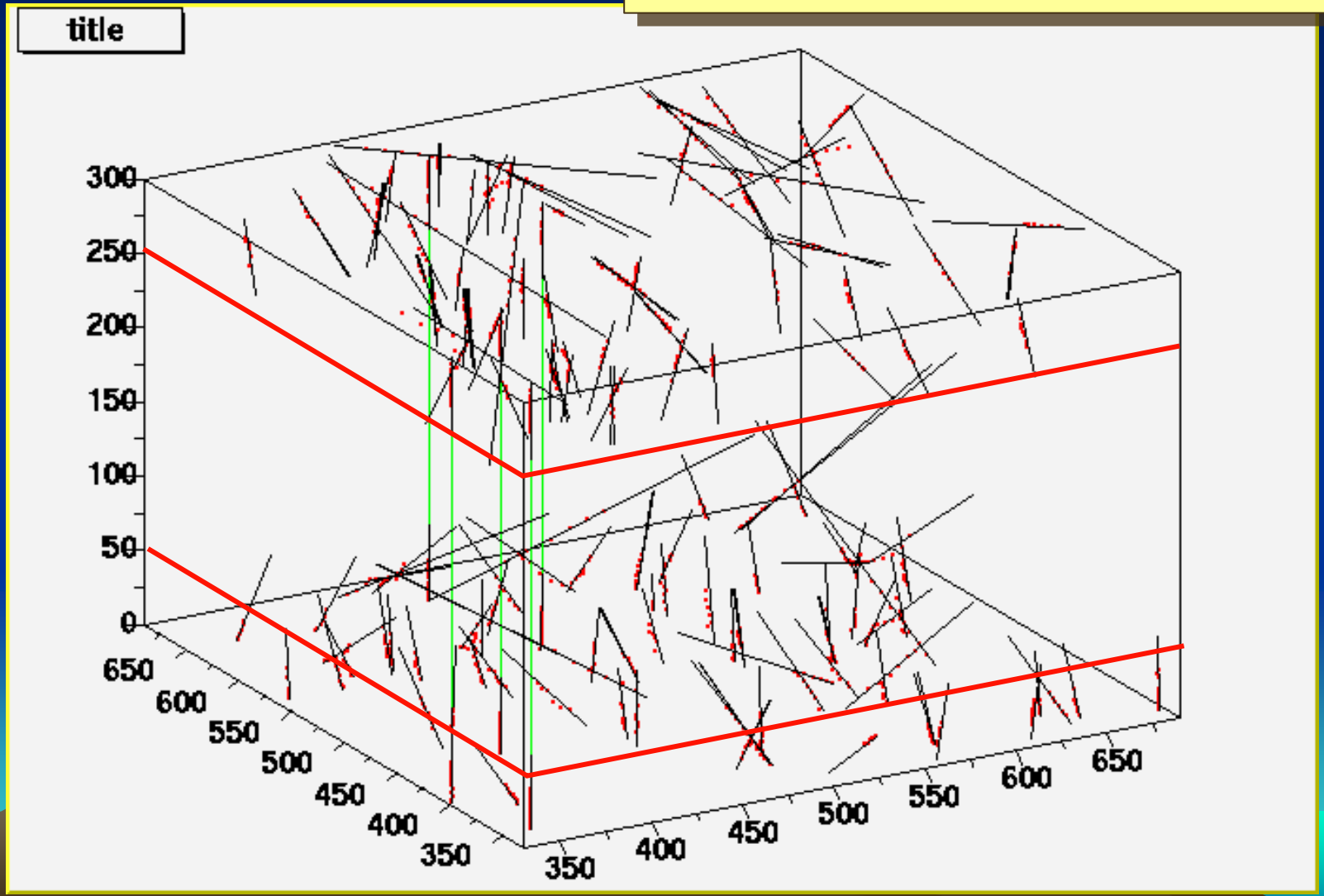


The automatic emulsion scanning



16-20 frames/45 microns

3D view of track segments reconstructed on both emulsion layers



Emulsion data processing

Basic FEDRA modules

libraries of C++ classes based on ROOT structures

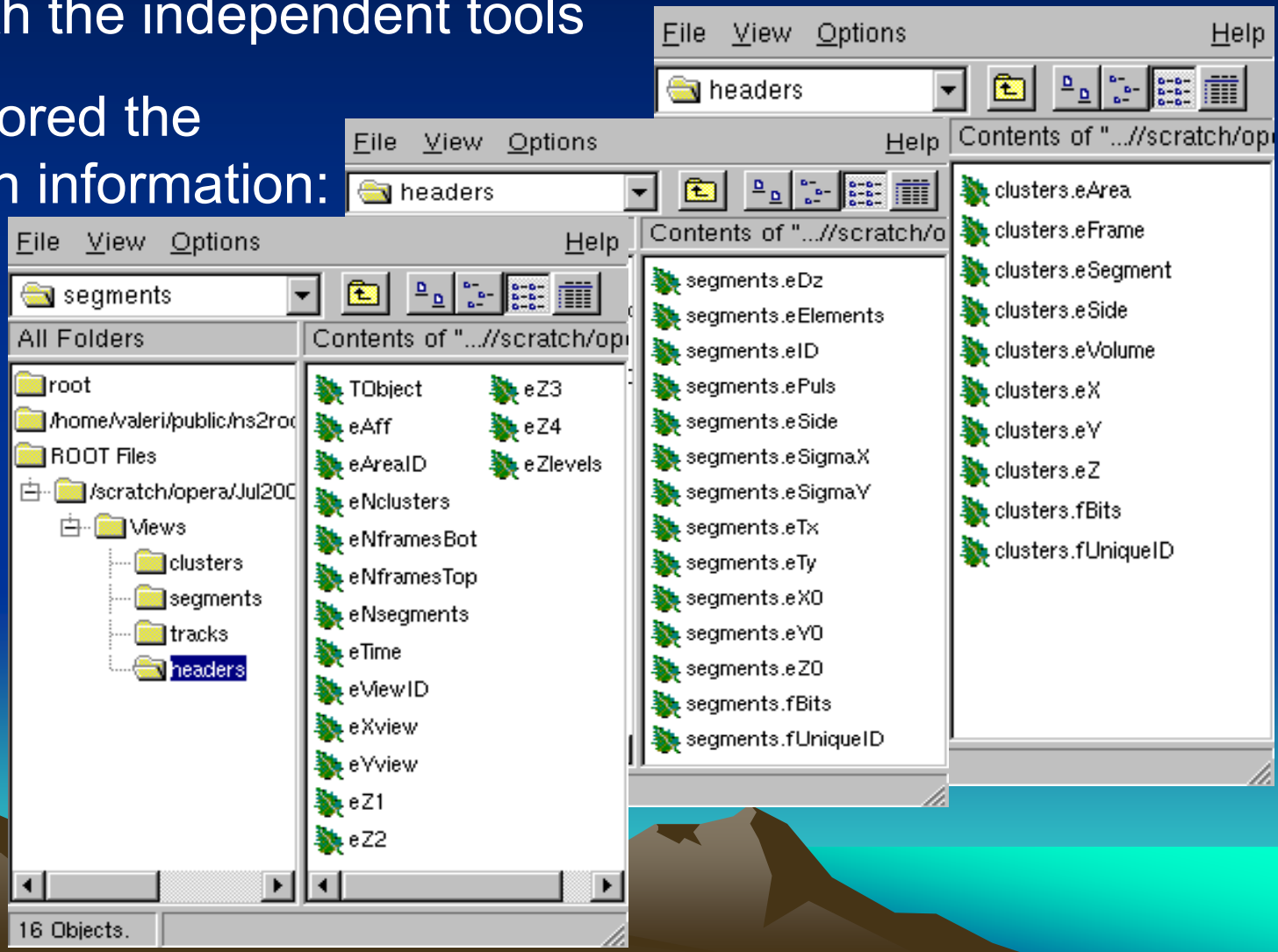
- libEmath, libEphys – some tools specific for emulsion processing
- libVt++ - vertex fit library with KF technique (Hera-b)
- libEdb – raw emulsion data storage classes
- libEIO – input output and control classes
- libEdr – tracks and vertex core reconstruction (pattern recognition)
- libEMC – internal Monte-Carlo
- libEGA – images and grains analysis classes
- libEdd – Emulsion Event Display

Emulsion raw data structure: the data acquired by the automatic scanning system are stored in the root files with the following processing can be done by FEDRA or with the independent tools

libEdb

In one tree is stored the full scanning run information:

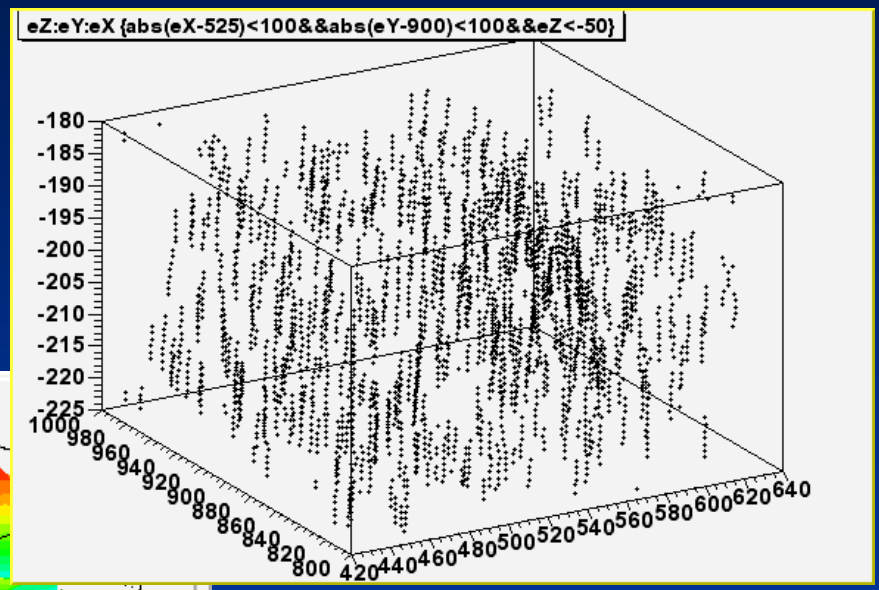
- View header
- Microtracks […]
- Clusters […]
- Frames […]
- Images (opt)

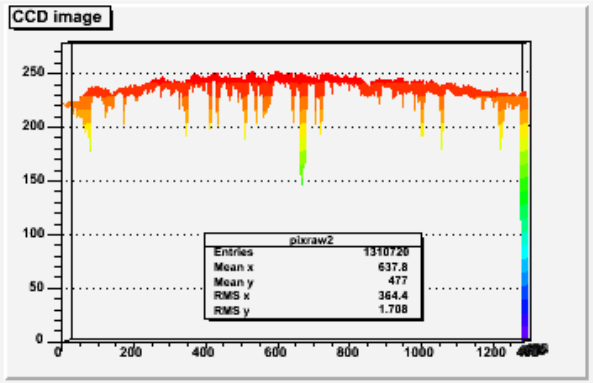


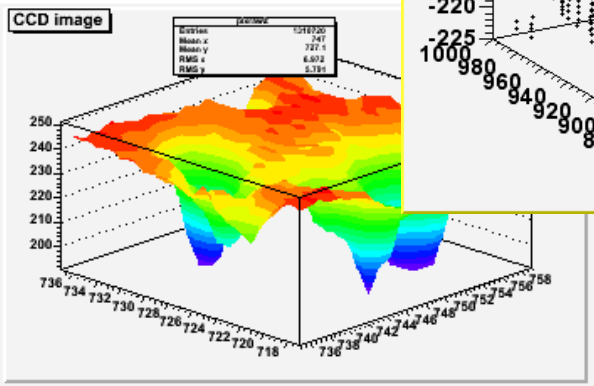
Images and grains processing module

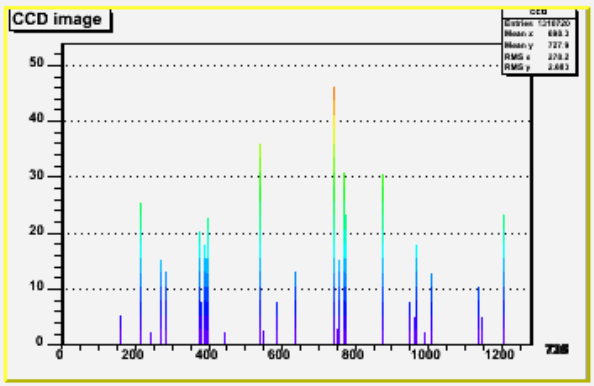
libEGA

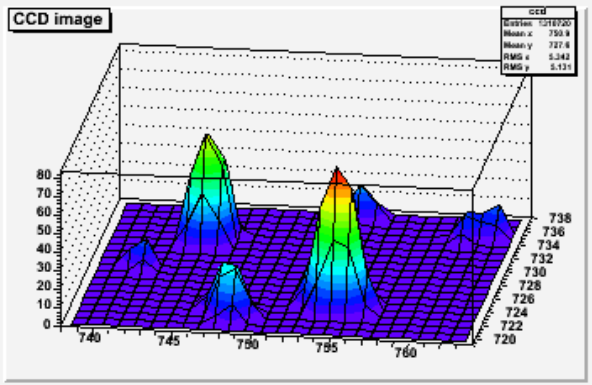
FIR filtering, surface analysis,
Clustering,
3-D grains reconstruction from the tomographic images











While most of these tasks on regime performing by the on-line scanning system, off-line processing is useful for the algorithms tuning and special cases study

Data volume estimations in OPERA:

- 1 event approximately corresponds to 100 cmxcm scanned
- with the expected data density it means:
  - about 1Gb of raw data/event
  - about 30 Mb of pre-processed data (segments)/event
- Expected the 30000 – 40000 events to be processed during the lifetime of the OPERA give us 30 Terabytes of raw data to be acquired in more then10 scanning laboratories located in Italy, Japan, France and Switzerland

Reconstruction in FEDRA

- Microtracks linking to form the basetracks
- Plate-to-plate alignment using the basetracks patterns matching
- Track finding: recognition of the long volume tracks formed by basetracks segments
- Vertex finding and fitting using the KF
- Event analysis with use of the 3-D Event Display and user customized scripts in the interactive ROOT session

Plates (patterns) alignment

Plate to plate patterns matching is one of the most important reconstruction operations necessary to pass from the reference systems of the individual plates to the global one.

In case of emulsions intercalibration is the routine operation has to be done for each scanned plate

This procedure calculate the affine transformations between the adjacent patterns (shift , rotation and expansion) and apply it in a way to have all (56) patterns in the same RS.

Plates (patterns) alignment

Based on the hypothesis that tracks passed through the assembled ECC are nearly straight, the corresponding patterns may be found. This permit us to pass from the mechanical accuracy of plate positioning (~100 microns) to the intrinsic accuracy of the emulsion (0.1-.5 microns)

This operation is formalized in FEDRA and could be applied to any kind of patterns in any-dimensional phase-space (for segments we use the 4-dimensional one). Operation is speed-optimized for combinatory reduction: the patterns of 100000 x 100000 elements could be processed in a few minutes.

Tracks finding and fitting

- Find all couples of adjacent basetracks
- Form the chains of couples having the common segment
- Use these chains as a triggers to start the KF procedure for track fitting and following
- The final result of the procedure is the long track consisting of the array of segments accompanied by the “fit function”
- The main criteria for tracks/segment acceptance is the probability given by KF

Vertex finding and fitting

- Find all 2-track vertexes using the impact parameter and geometric criteria
- Starting from them form the n-tracks vertexes using the Kalman Filtering technique

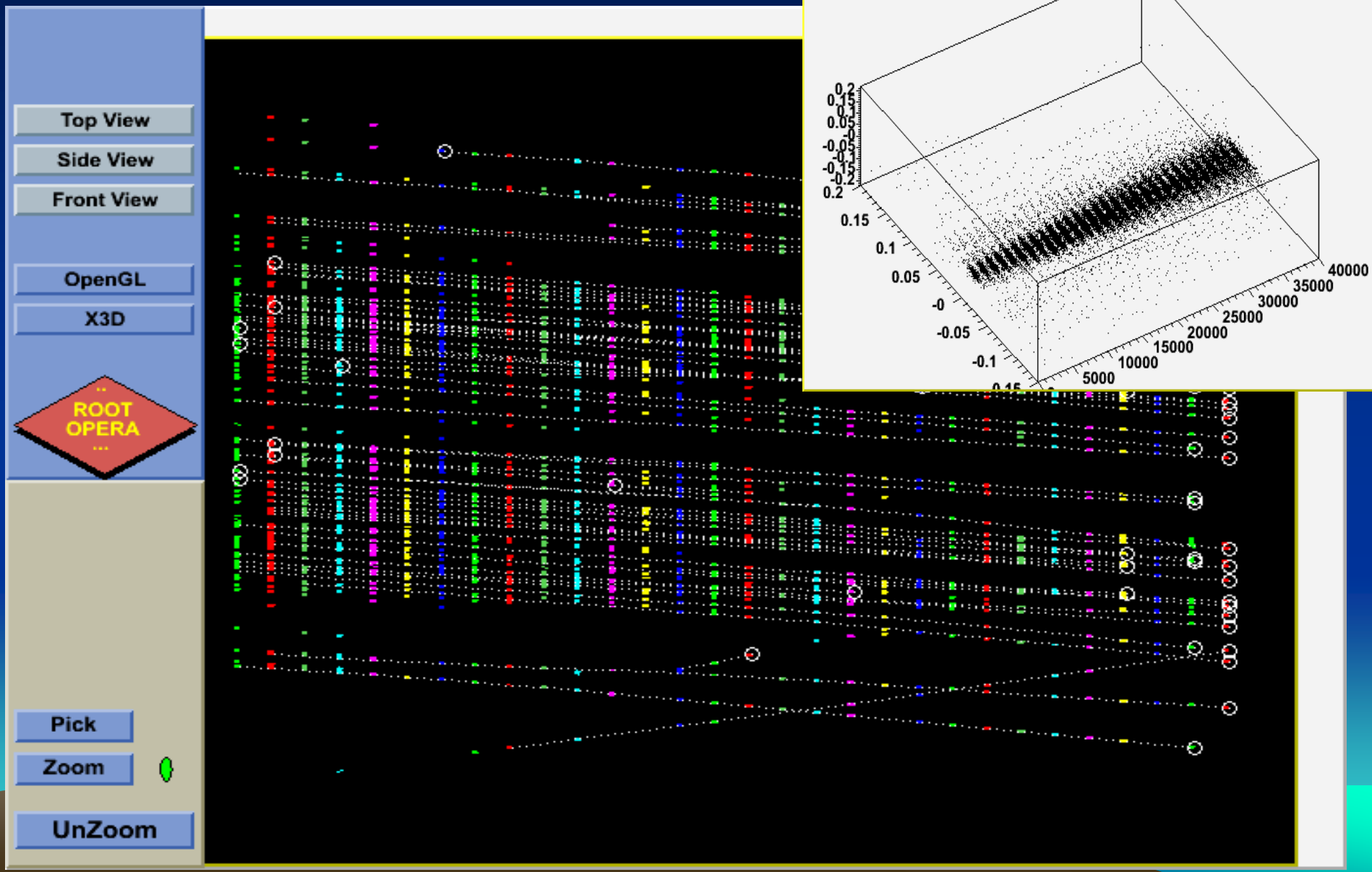
Internal Monte-Carlo classes for fast algorithms testing

- Vertex, tracks and background generation with the following effects taken into account:
  - Multiple scattering
  - Energy loss by the particles passing throw the ECC matter
  - N-body decay kinematics for vertex reconstruction tests
  - various apparatus resolution and smearing effects
- The exact knowledge of the reconstructed effects is essential for the algorithms tuning

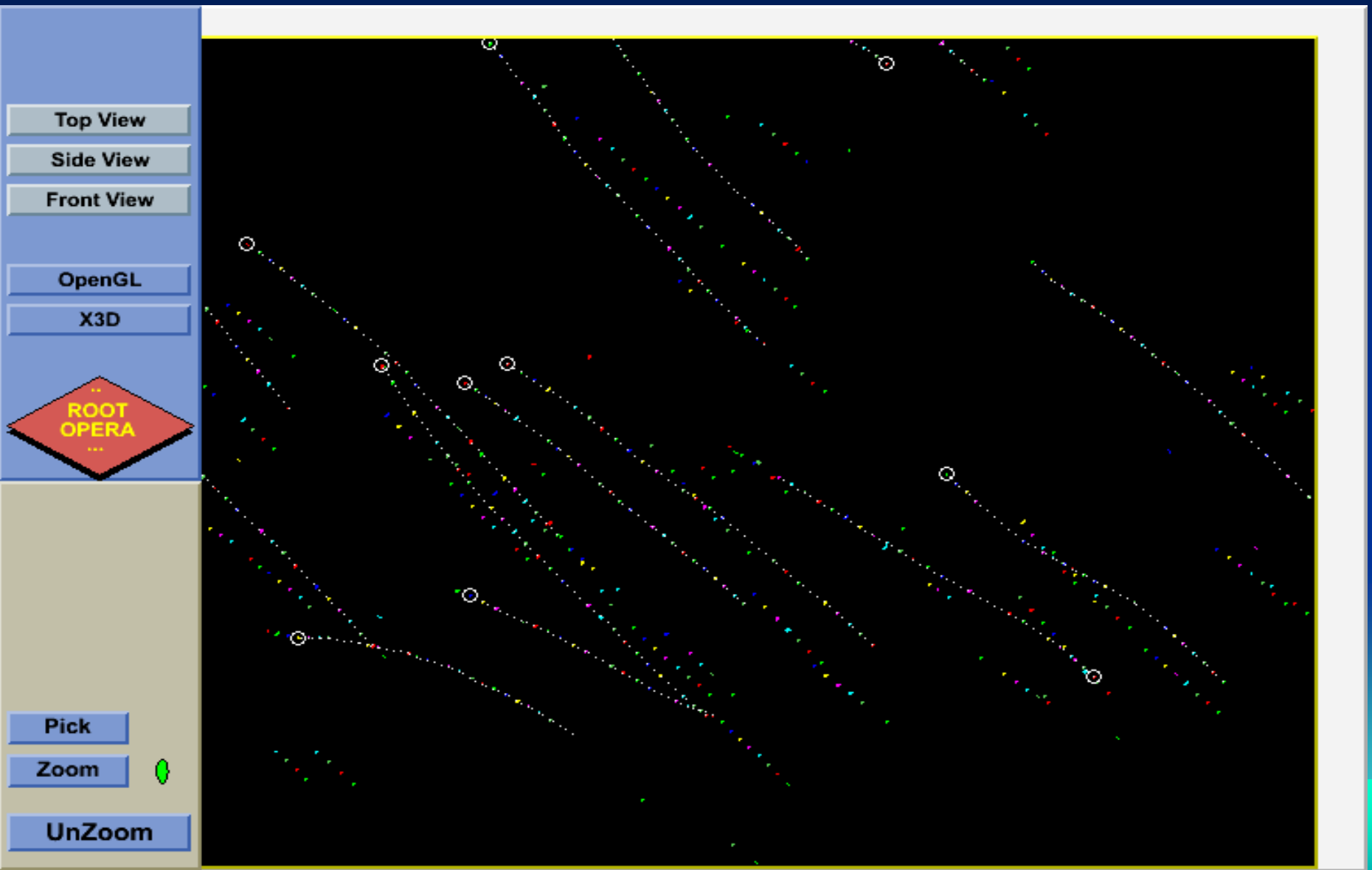
Physics event analysis

- The main scope of FEDRA is to provide for physicists the environment for the final event analysis
- The algorithms developed by end-users first as a scripts or C++ classes may be integrated into FEDRA as a standard libraries
- Currently available ones:
  - Momentum definition by Multiple Scattering method
  - Shower analysis and e/pi separation with NN use
  - Pi/mu separation (coming)

Test-beams data reconstruction

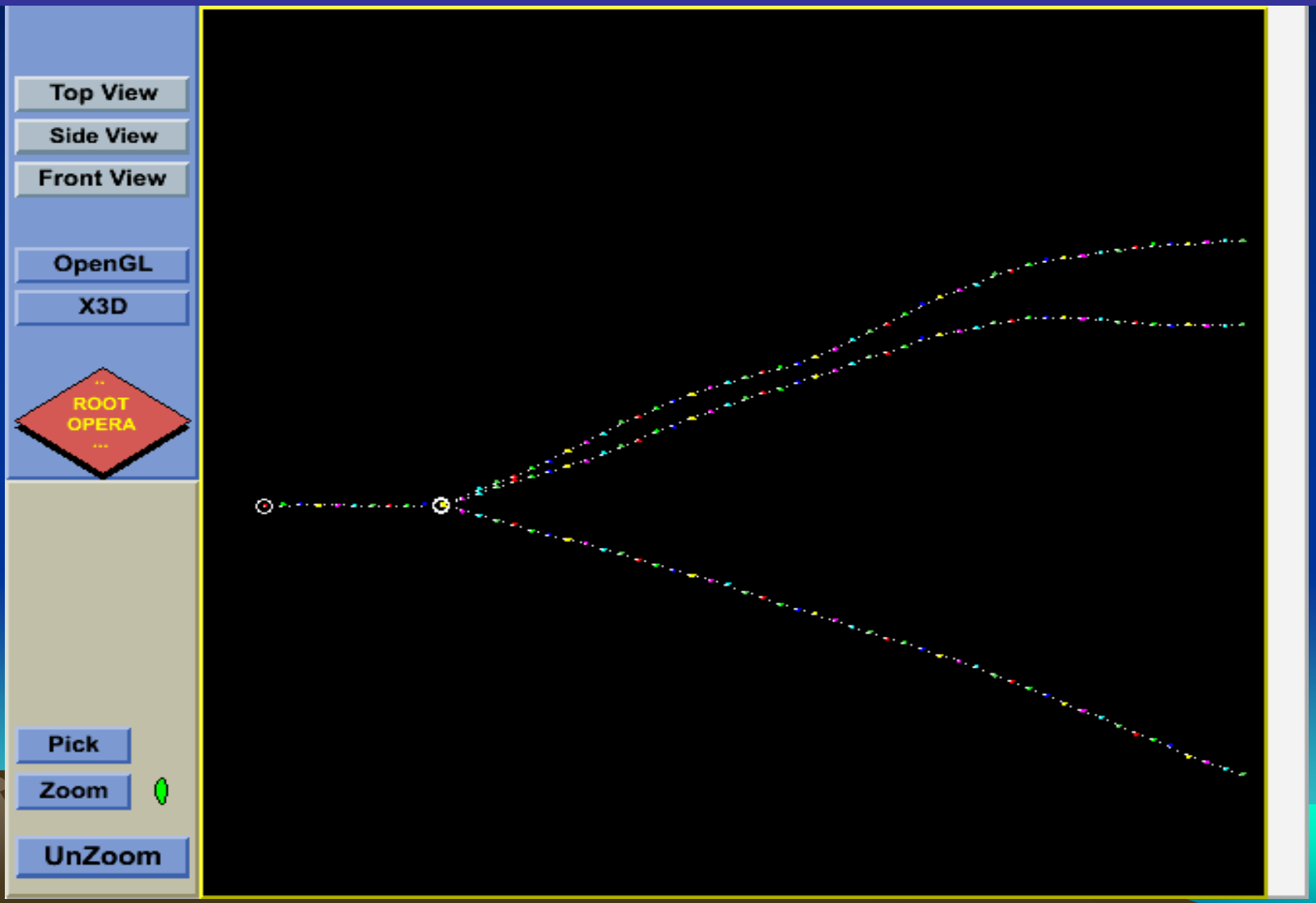


Test-beams data reconstruction



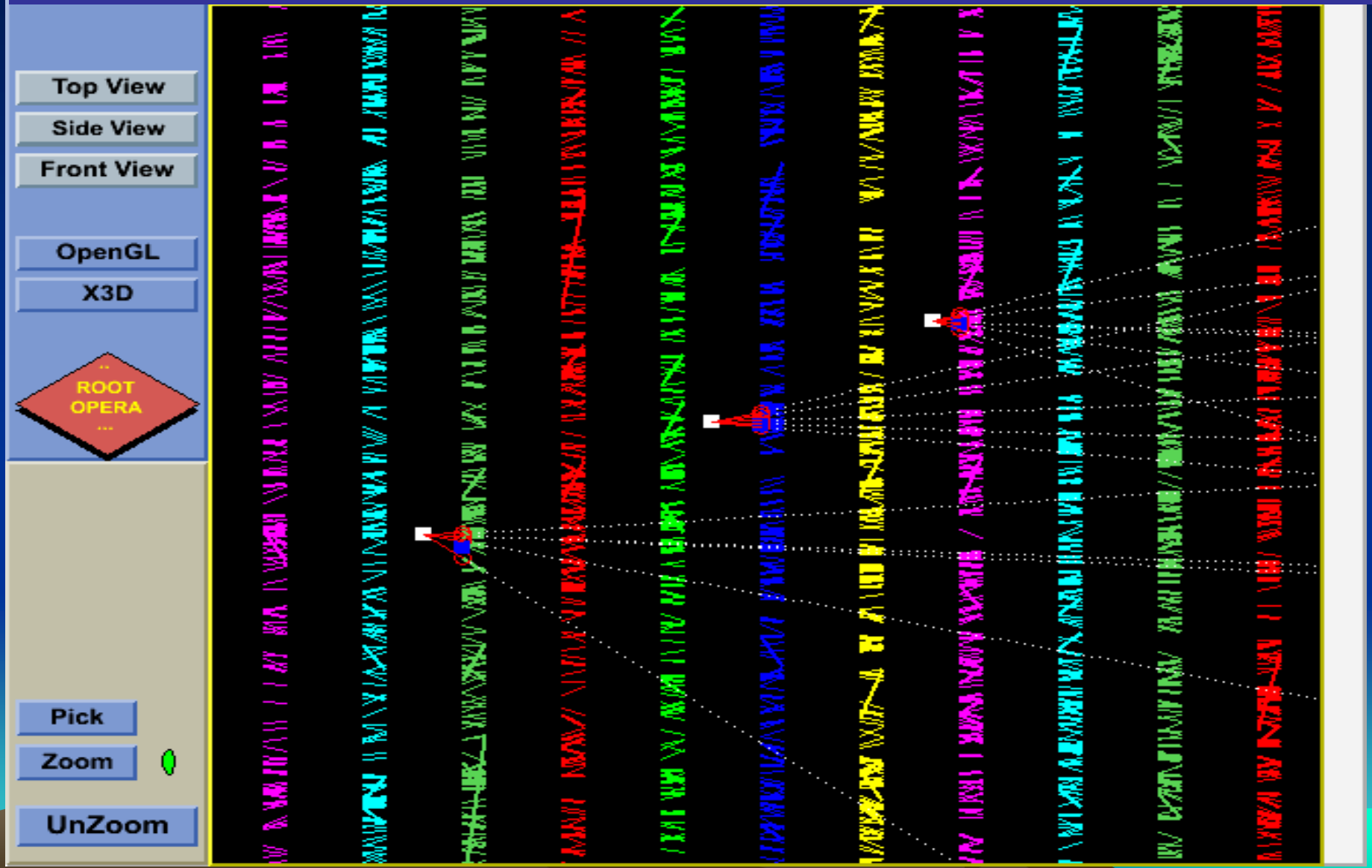
K->3Pi decay

fast simulation with EMC to test vertex fitting quality

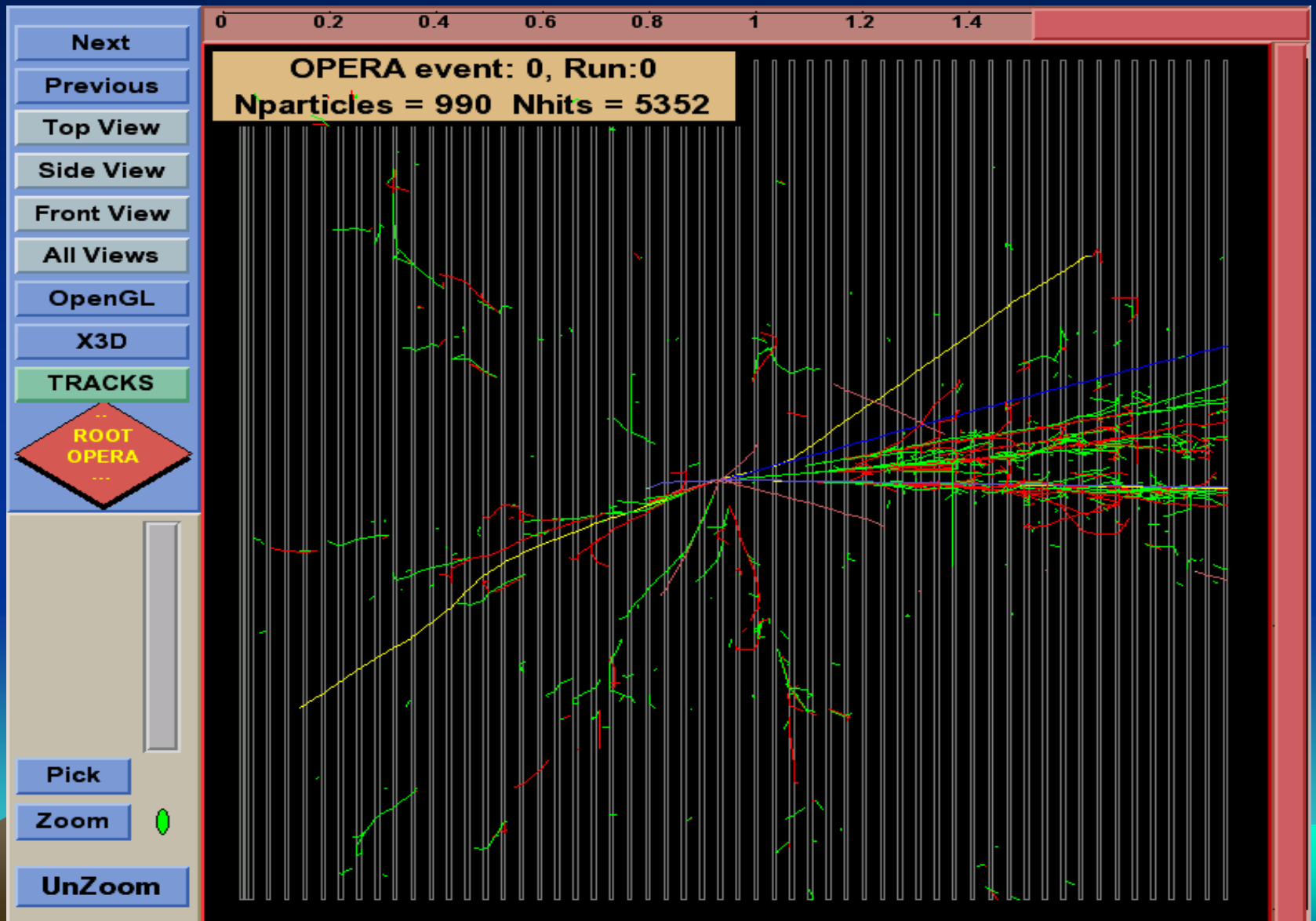


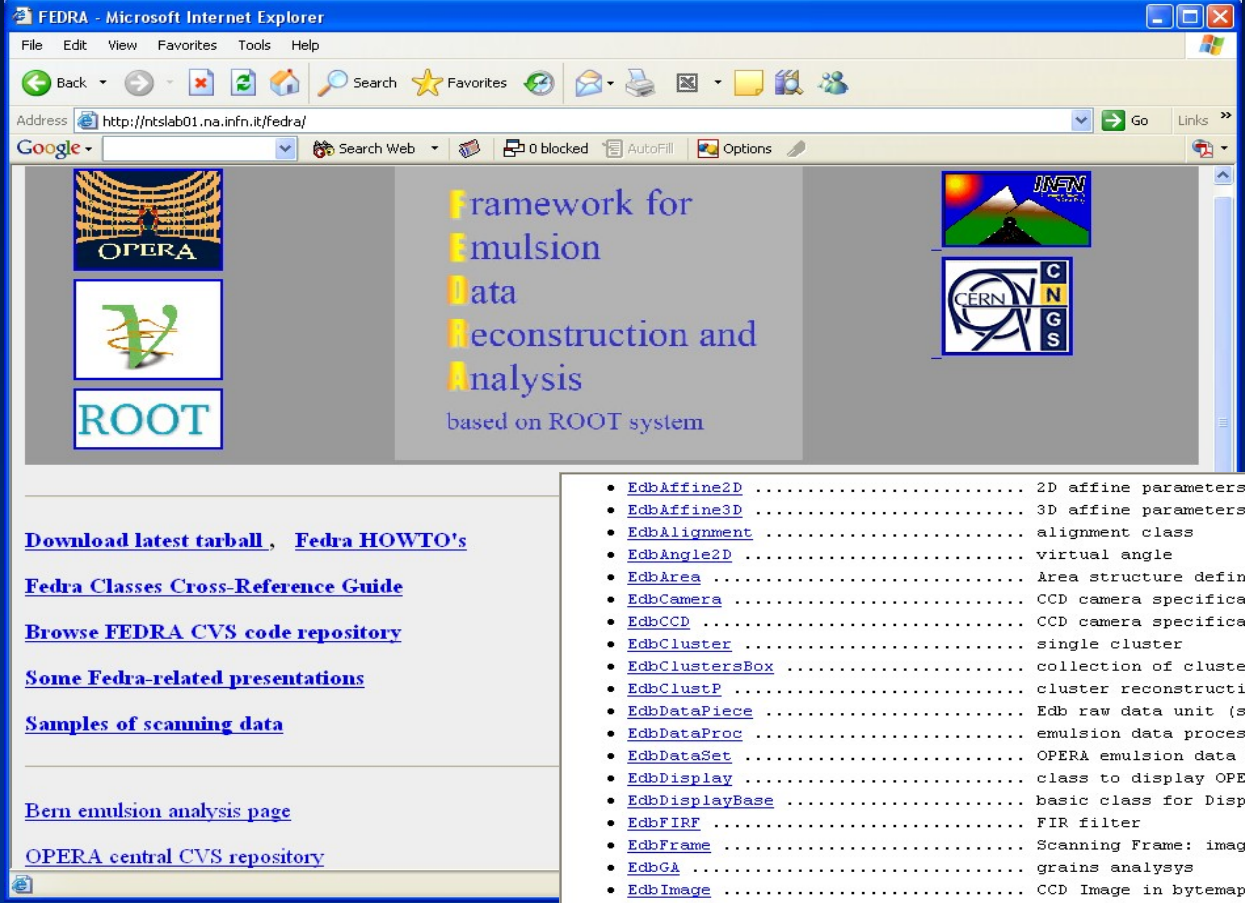
Neutrino vertexes with background

fast simulation with EMC to test vertex finding and fitting



tau event simulated by GEANT in the ECC brick and reconstructed with FEDRA





FEDRA web-page contains the code, classes cross-reference guide, instructions of usage and many examples of applying fedra tools for the data analysis.

Conclusion

In the OPERA – massive lead-emulsion hybrid experiment the major part of physics data is provided by the automatic emulsion scanning systems with the computer-driven microscopes.

The amount of medium and high level emulsion data is of the order of Gb/event. Storage, calibration, reconstruction, analysis and visualization of this data is the purpose of FEDRA system written in C++ and based on the ROOT framework. The system is now actively used for the processing of test-beams and simulation data.

The emulsion data specifics droved us to find several interesting algorithmic solutions permitting to make very efficient code for the pattern recognition.

The substantial part of the project is finished and already in use