T2K NEAR DETECTOR UPGRADE

PROTOTYPES BEAMTEST

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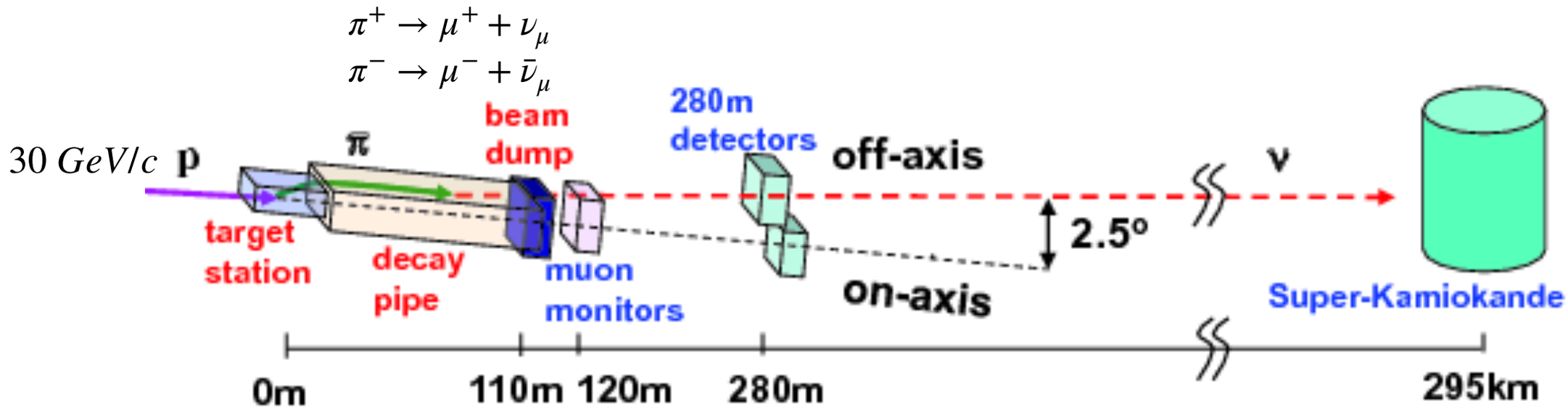
OUTLINE

- The T2K experiment
- The near detector upgrade project
  - Motivation
  - Main goals
- 3D scintillator neutrino detector
  - Concept of Super FGD
  - Beam test setup
  - First preliminary results
- TPC with resistive pads
  - Concept description
  - Beam test layout
  - Data analysis results

THE T2K EXPERIMENT

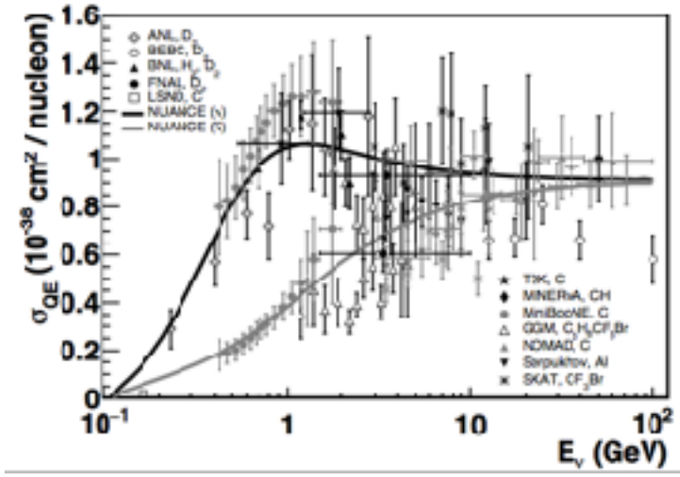
- The T2K is a long baseline neutrino oscillation experiment
- Pure muon neutrino beam from the J-PARC accelerator complex is tuned to the 1st oscillation maximum ~ 600 MeV



- Main goals:
  - Precise measurement of the neutrino oscillations parameters with:
    - $\overset{(-)}{\nu}_\mu$ *disappearance*
    - $\overset{(-)}{\nu}_e$ *appearance*
  - Probe of CP-phase measurements
  - Neutrino interactions studies:
    - *Cross-sections, nuclear models, etc.*

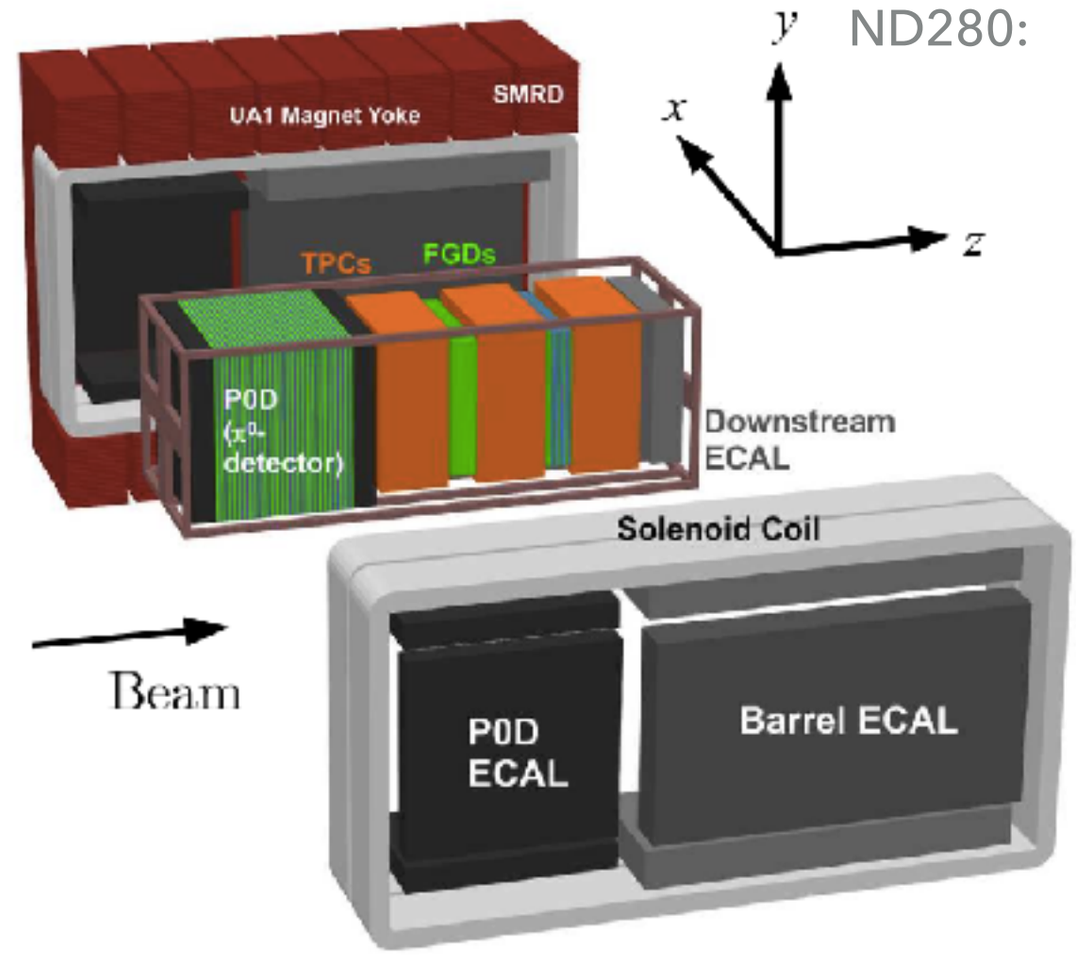
NEAR DETECTOR

- Off-axis near detector (ND280) is used for systematic uncertainties reductions with:
  - Flux fitting
  - Cross-section models fitting
- The effect is significant:
  - μ - like events: 12% –> 5%
  - e - like events: 12% –> 7%



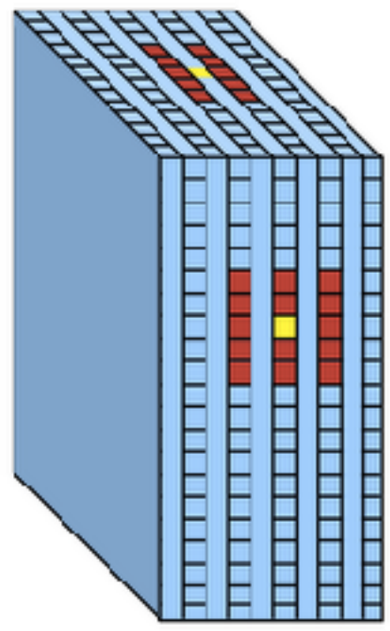
Neutrino cross sections at T2K energies from PDG 2016

ND280:



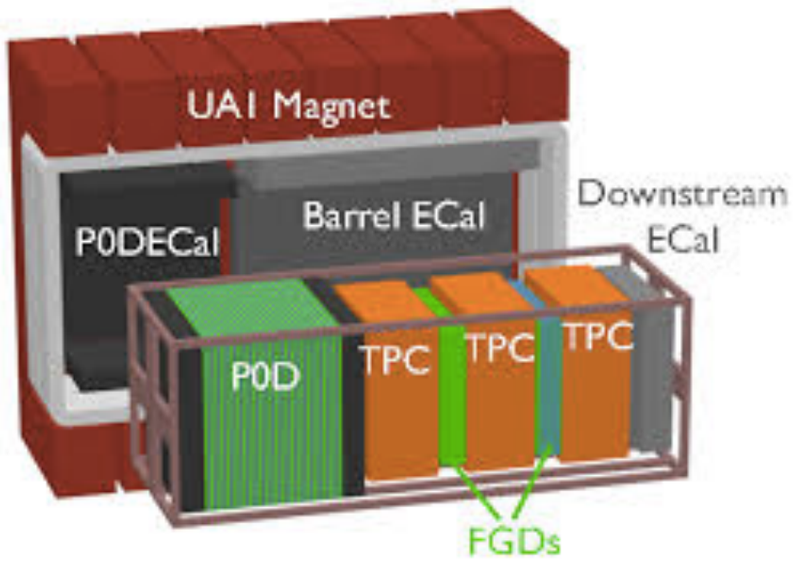
FGD:

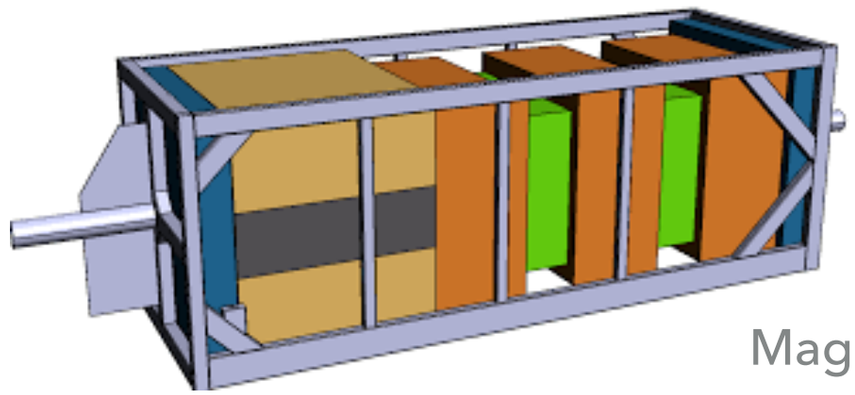
- Fine Grained Detectors (FGD) are used for the neutrino targets
- It is build with scintillator bars in X and Y directions organised in the sandwich structure
- The phase space is limited to forward-going particles



ND280 UPGRADE CONCEPT

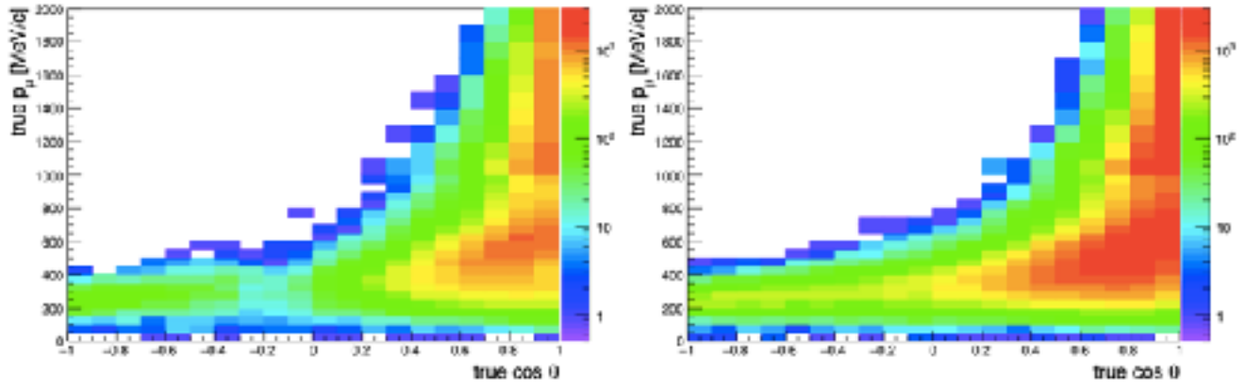
- For the further systematic reduction the full phase space coverage is necessary
- The ND upgrade project was proposed
- Aimed to replace P0D with horizontal target and 2 TPCs





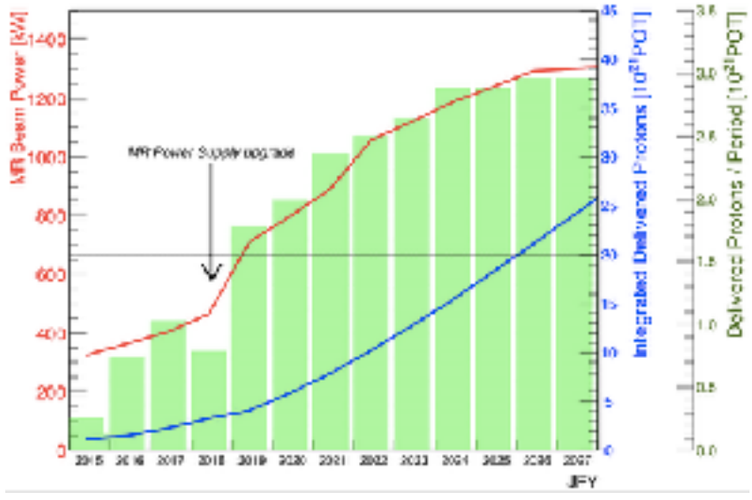
Magnet and ECal are not shown

- The phase space of the selected events is widen

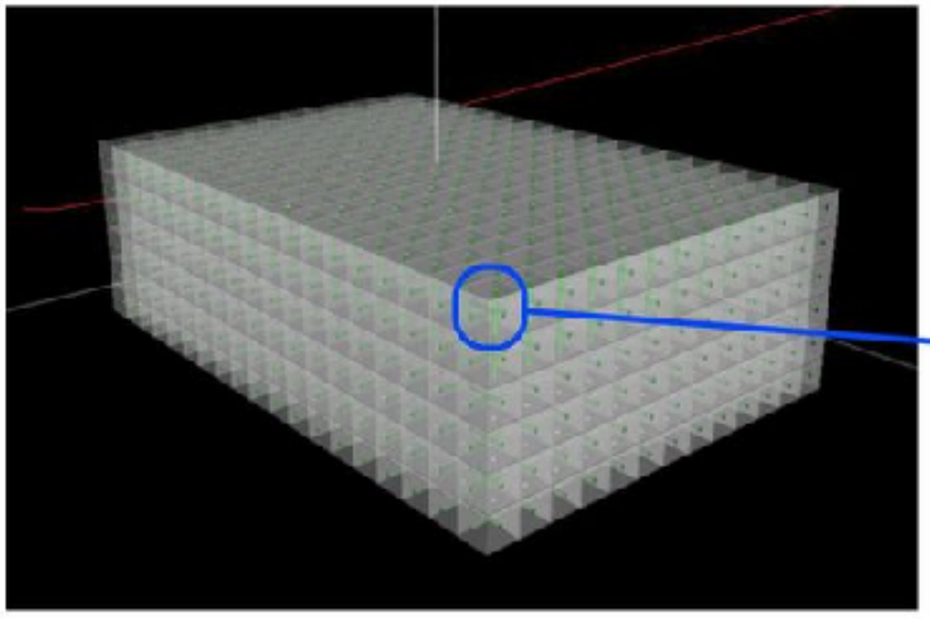


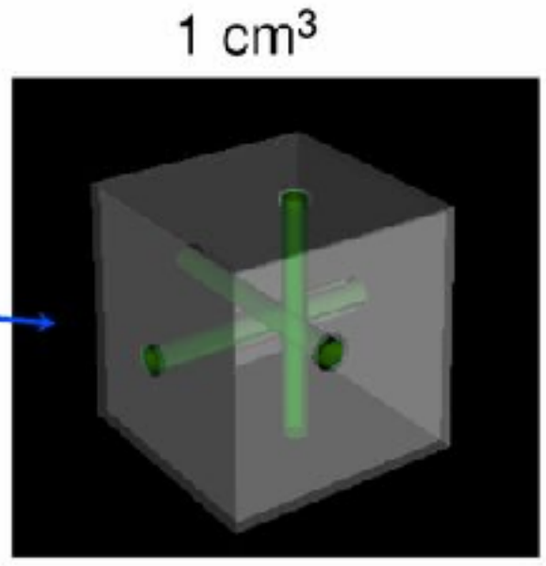
(simulation)

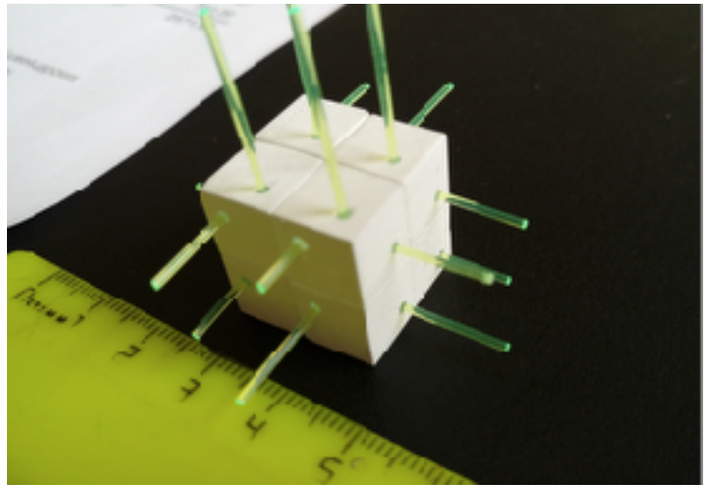
The T2K data taking plan:



SUPER FGD CONCEPT





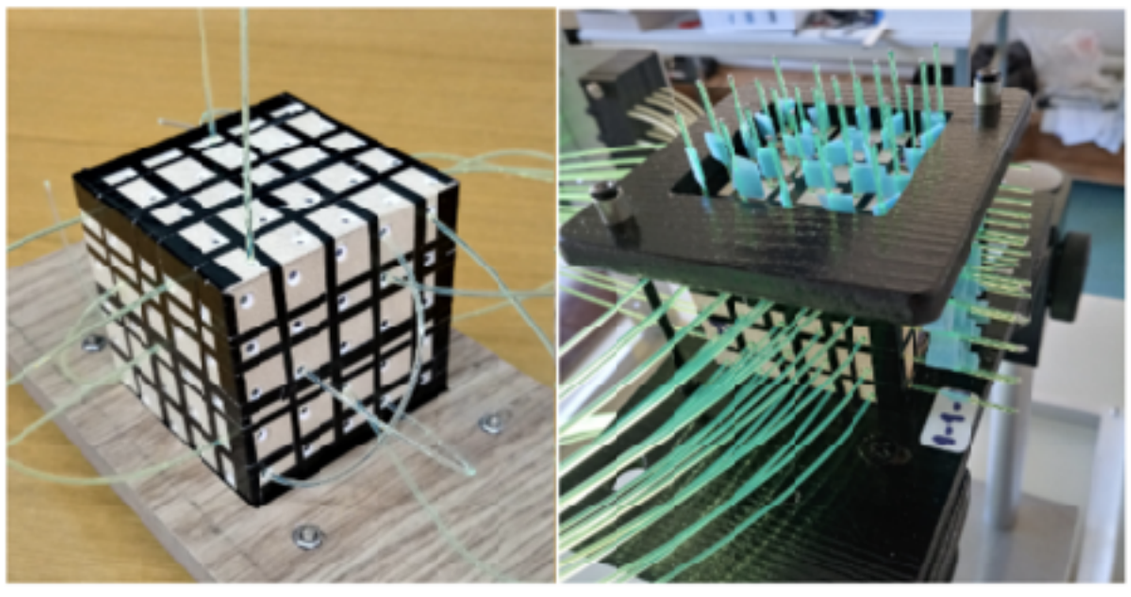


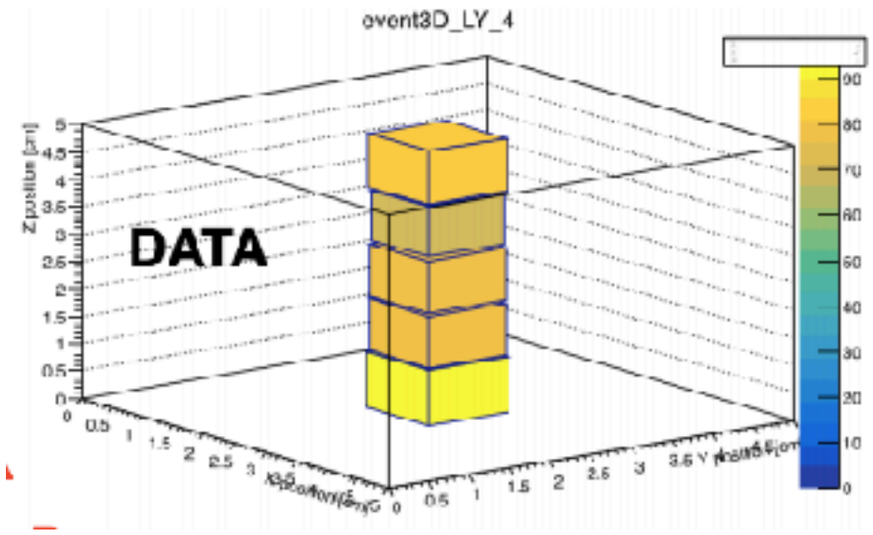
- Build the horizontal target with scintillator cubes (~2M cubes 2m x 2m x 60 cm)
- Three optical fibres go through each cube for light collection
- Signal readout with MPPC is performed from three planes

- With this concept the full phase space detection is possible
- Lot's of advantages are going to be probed:
  - Separation of gamma conversion from the electron track
  - Low energy proton, pion, muon tracks measurements
  - Possibility for neutron detection

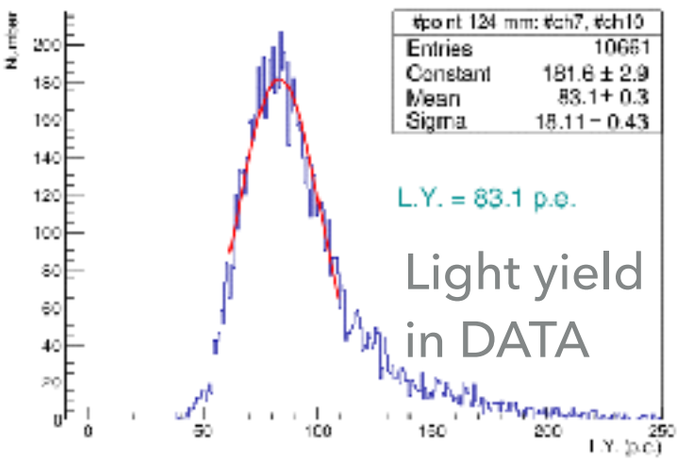
SUPER FGD FIRST LIGHT

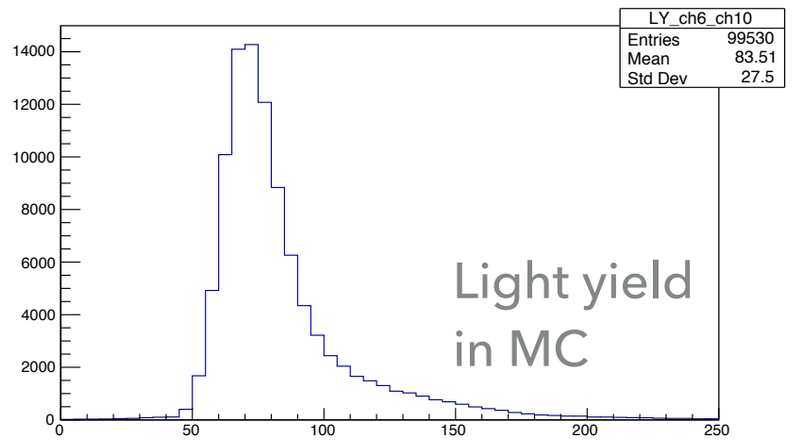
- The first tiny prototype 5x5x5 cubes was tested in October 2017 at CERN





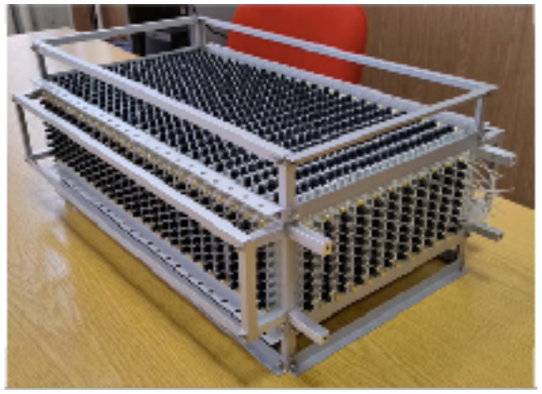
- It was the first proof of concept performance
- Also we obtained a clear result for the simulation calibration
  As it is very important for the new detector performance estimations





SUPER FGD SECOND PROTOTYPE

- The second prototype 48x24x8 cubes was built for the Summer 2018 beam test

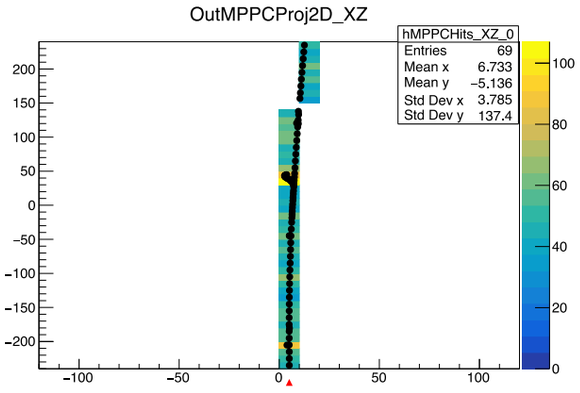


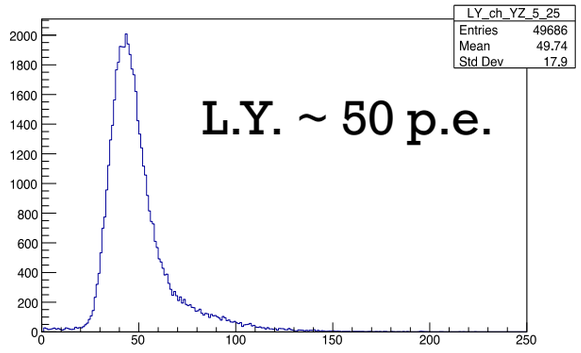
- The main aimes for this test were:
  - Electronics test. We used CITIROCK electronics adopted for the BabyMIND experiment (part of T2K near detector complex)
  - MIP track reconstruction
  - Stopping protons
  - Gamma conversion
    study the possibility of the gamma conversion / electron separation

SUPER FGD BEAM TEST

MC simulation

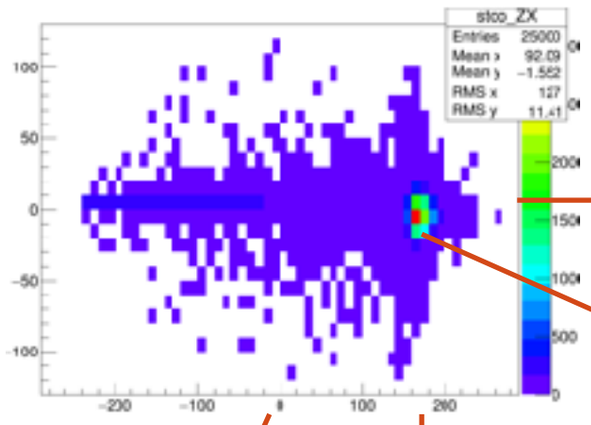
- With the calibrated simulation we estimated the beam test data accurately
- The MIP light yield:



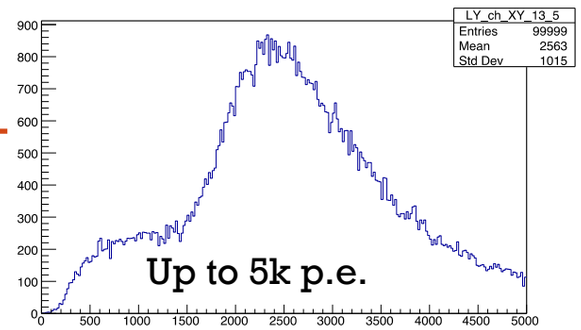


- The necessary energy and light yield from the stopping proton:

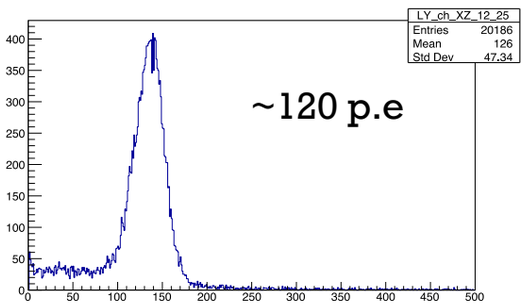
Stopping points 750 MeV/c:



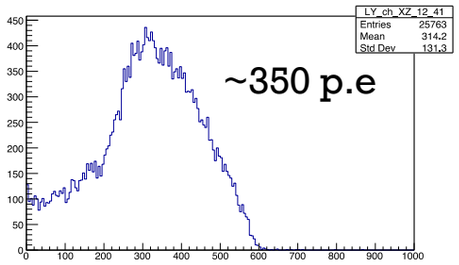
z fiber

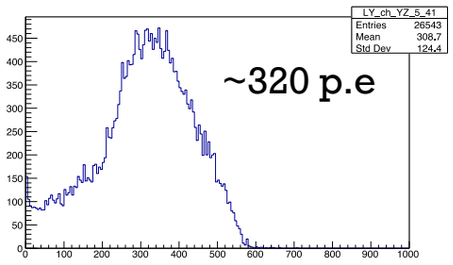


Y fiber in the middle

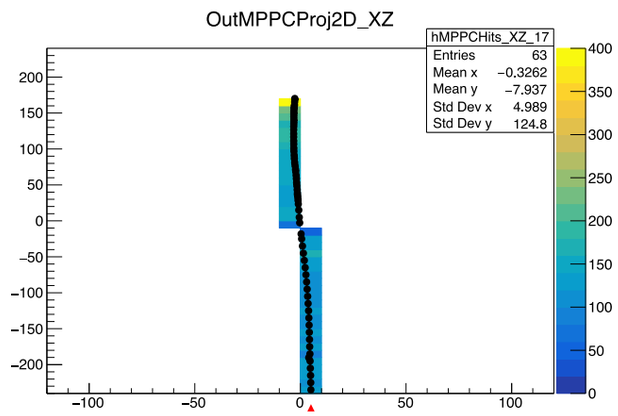


Y and X fiber at most probable stop cube





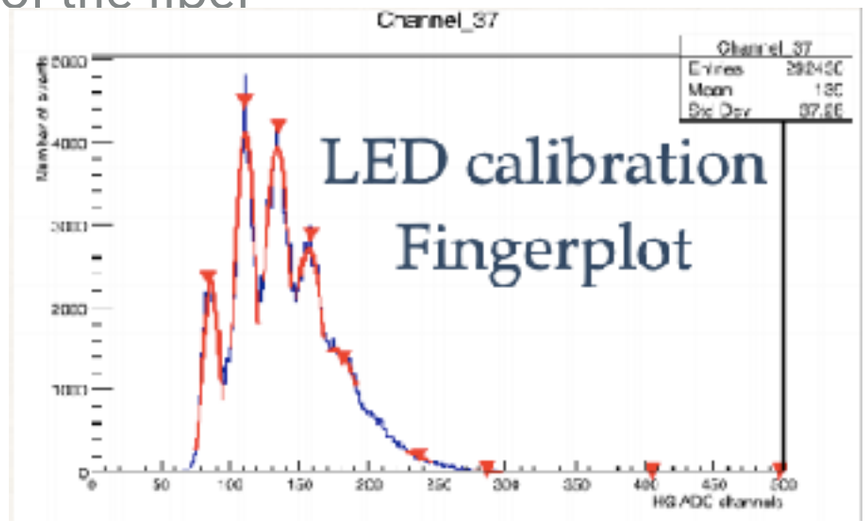
Event example:



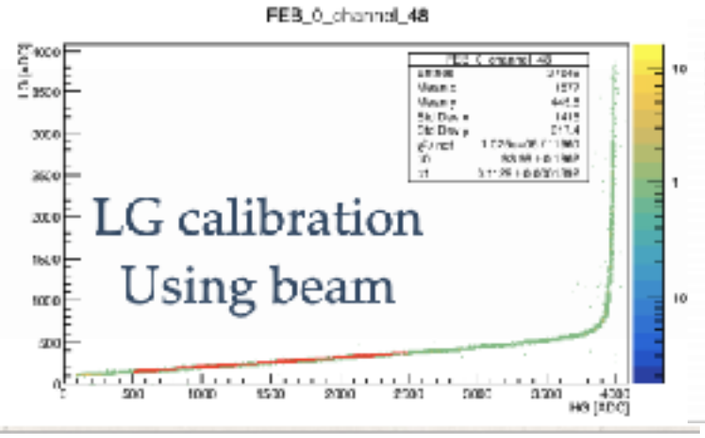
Necessary for the proper MPPC solution!

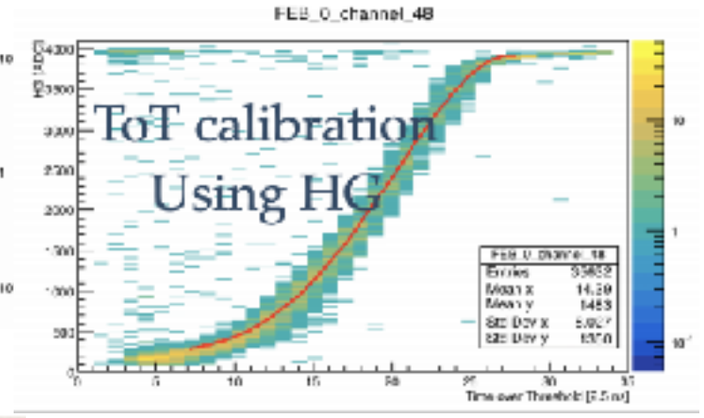
SUPER FGD PRELIMINARY RESULTS

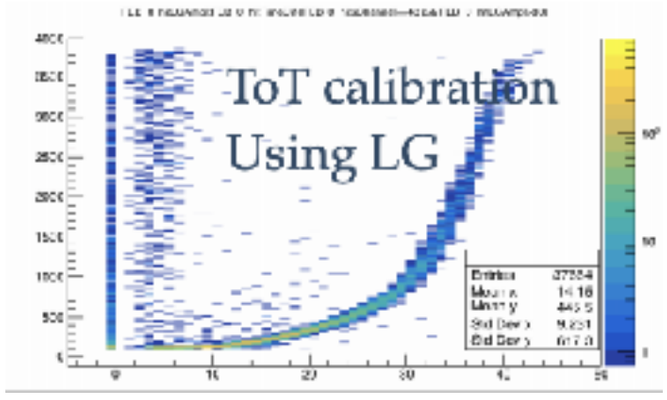
- The first and very important step is detector calibration
- It's painful as illumination of all channels is complicated
  - Cosmic? Need LOT of statistics
  - Use LED pulser and uncovered far end of the fiber

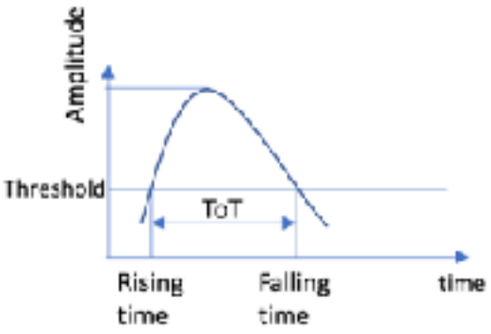


- The final calibration should match the following regimes of electronics:
  High Gain 1 - 150 p.e, Low Gain 1 - 700 p.e., Time Over Threshold





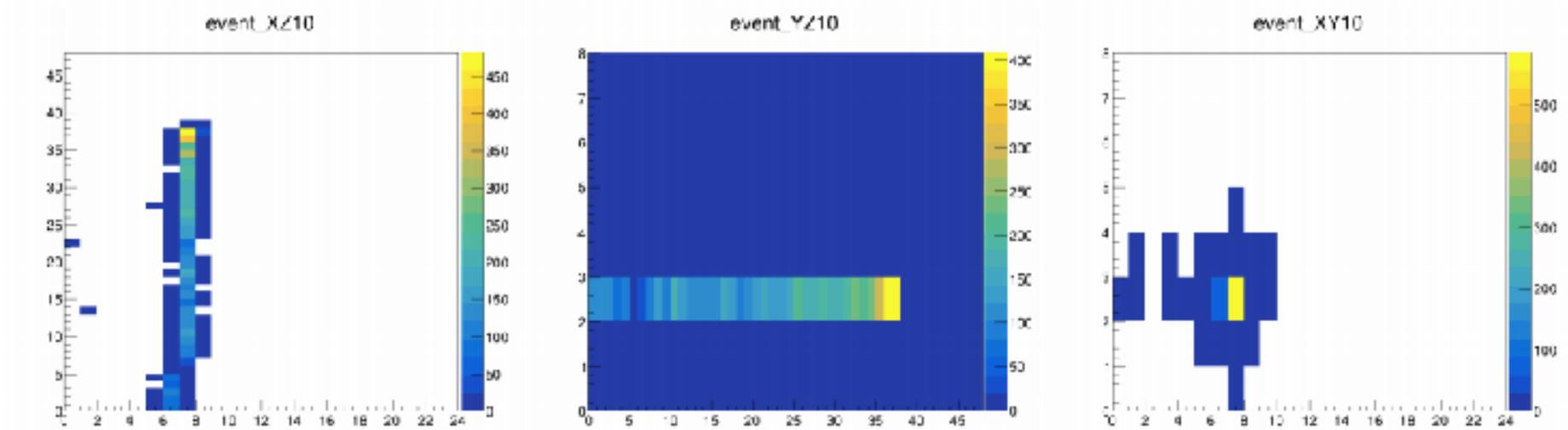




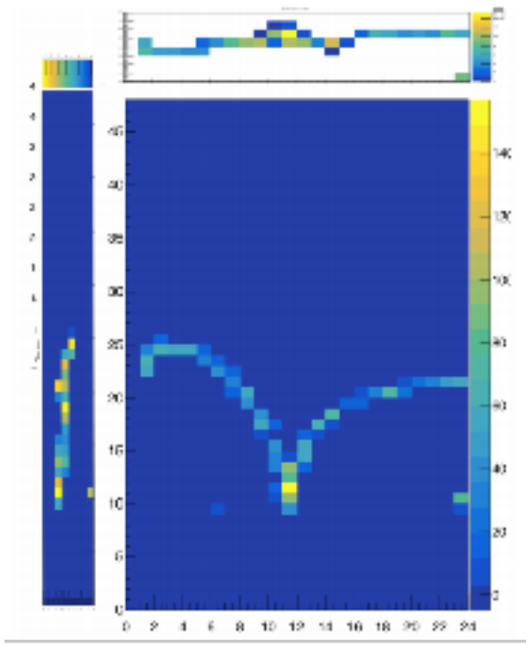
SUPER FGD PRELIMINARY RESULTS

Data

- At the moment the preliminary calibration is done
- The analysis went to the event recognition
  - Stopping proton event:

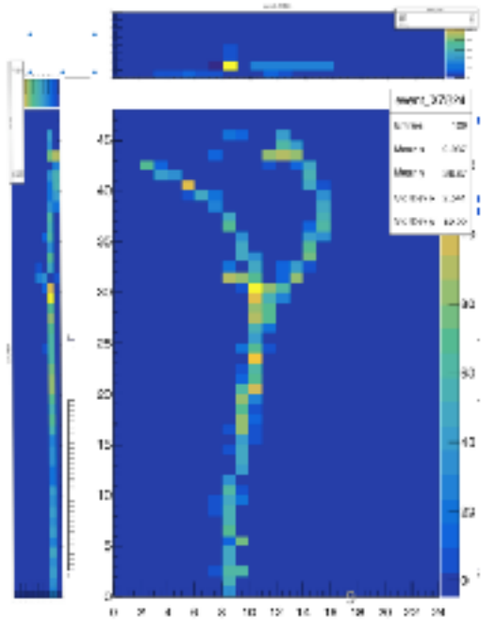


  - Gamma conversion:



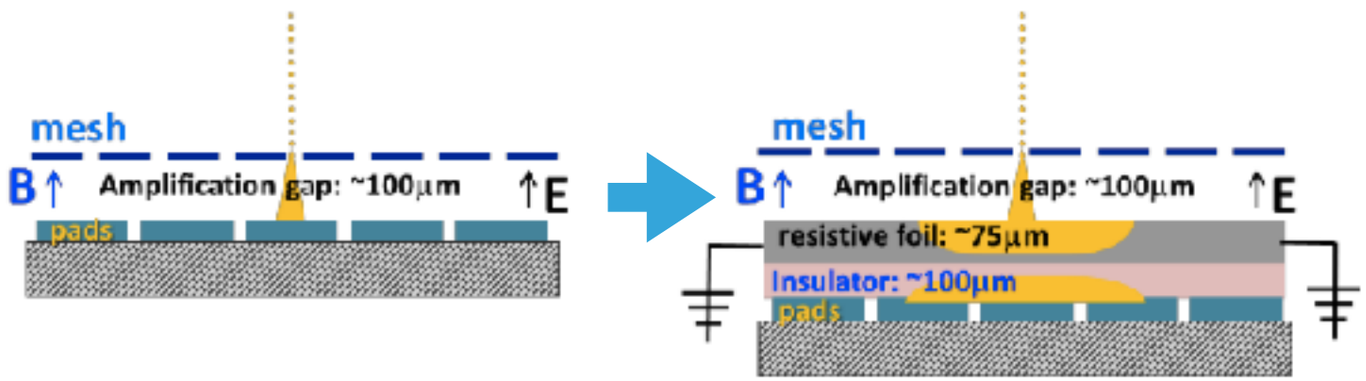
The data analysis are under severe development

Vertex:

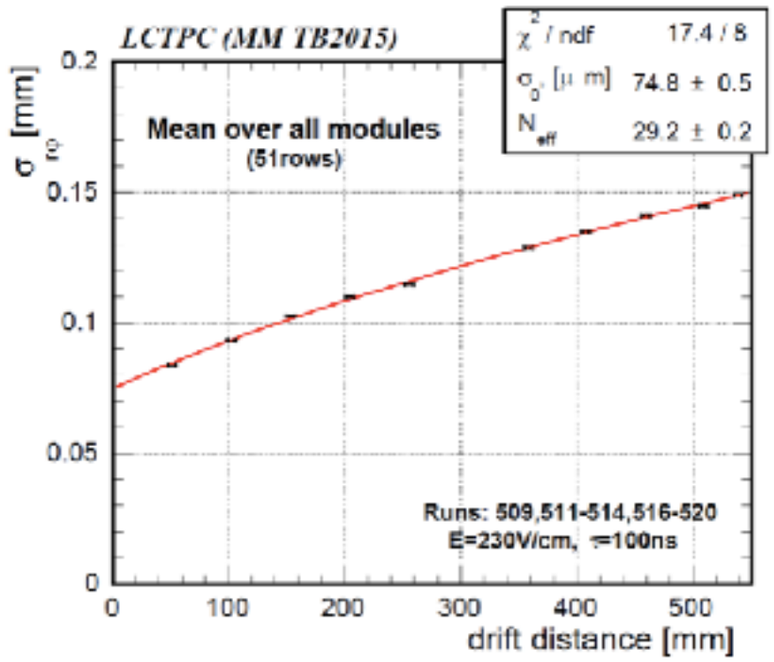


RESISTIVE TPC CONCEPT

- The concept: the resistive foil over the readout pads provides the charge spreading
- With more pads more accurate position reconstruction is reachable
- Better spacial resolution leads to more precise momentum measurements



- Base on the ILC TPCs prototype tests the benefit is significant

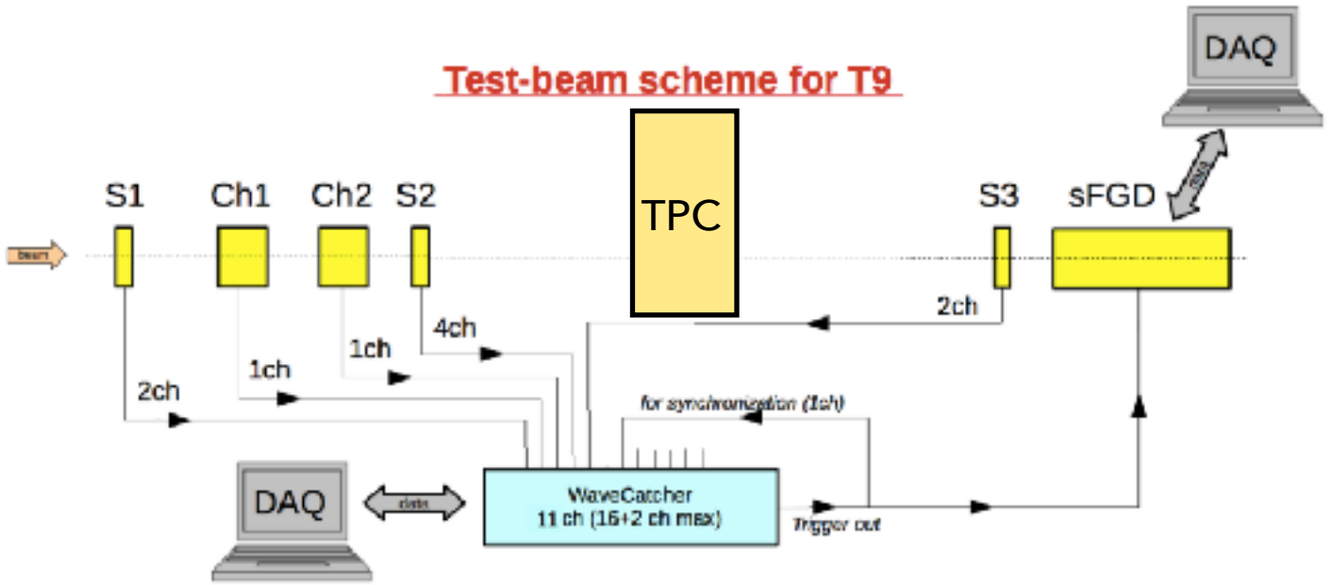


TPC BEAM TEST SETUP

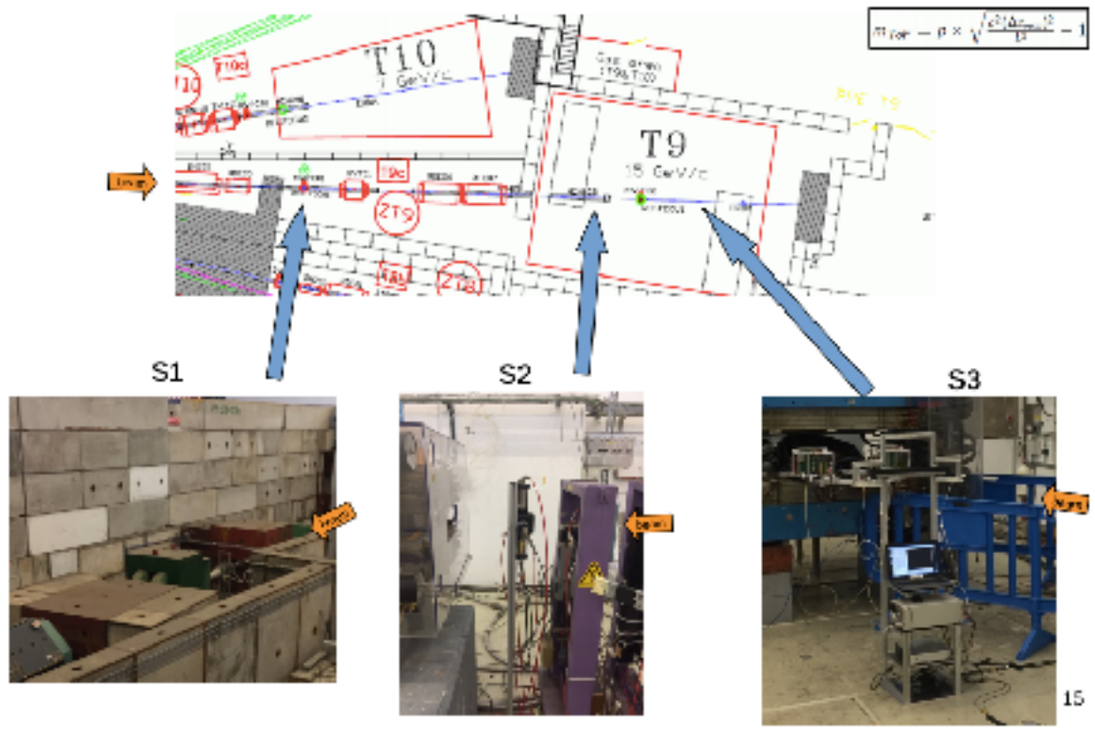
- Gas volume:
  - 1.5 m drift distance
  - Pre-mixtured Argon (95%) with CF4(3%) isobutane (2%)
- Detector:
  - MM with resistive foil
  - horiz. x vert. = 36 x 48 pads
  - each pad 0.98 x 0.7 cm
  - nominal MM voltage 340 V
  - Sampling time 80 ns (12.5 MHz)
  - nominal peaking time 600 ns
- Data sources:
  - cosmic
  - Fe55 source for 5.9 kEv X-rays
  - beam:
    - $0.5,\ \pm 0.8, 1, 2$ *GeV/c momentum*
    - π, e, p *triggers*

TPC BEAM TEST SETUP

- The trigger system was used to separate π, e, p samples

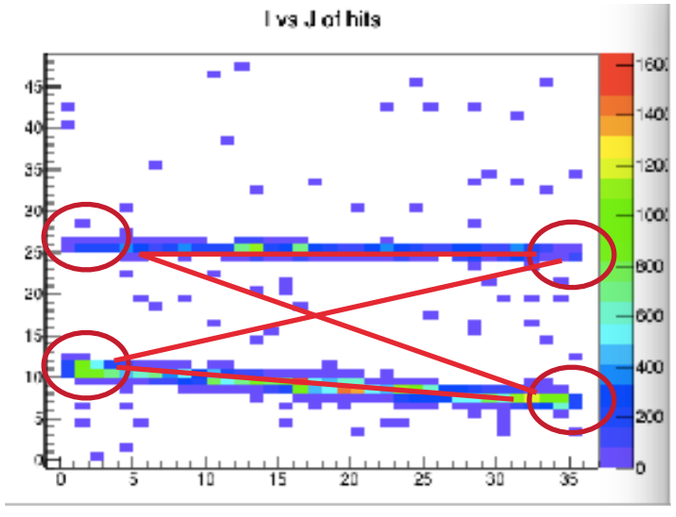


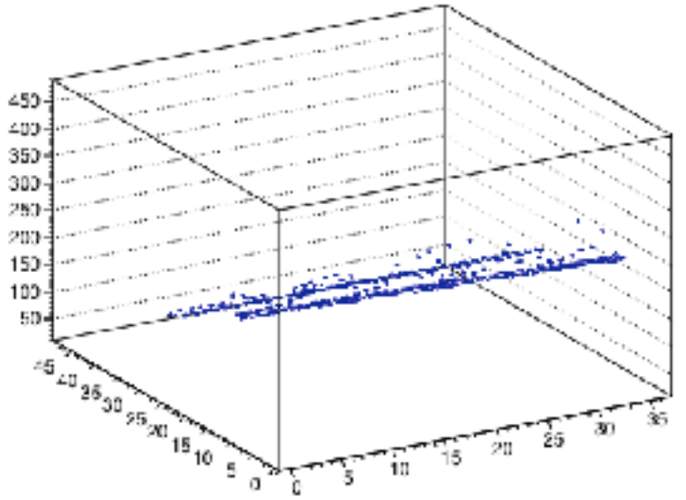
- Two Cherenkov and two scintillator detectors provides ‘almost’ clear particle samples



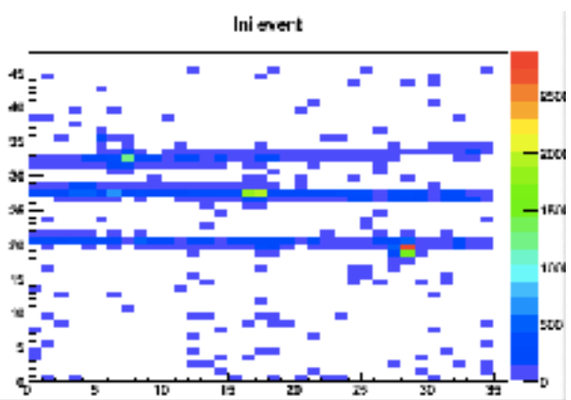
TPC DATA ANALYSIS

- Look for clusters at the left and right side of the detector
  clusters are selected with relatively high threshold to suppress noise
- Study all possible tracks from clusters combinations
- Define the box in 3D space: X, Y, T
- Take all the waveforms in pads inside this box
- Select the "good" tracks:
  - Enough number of pads and columns
- Main advantage:
  - Very simple!
  - Severe noise suppression
  - Possibility to select multiple tracks in the event

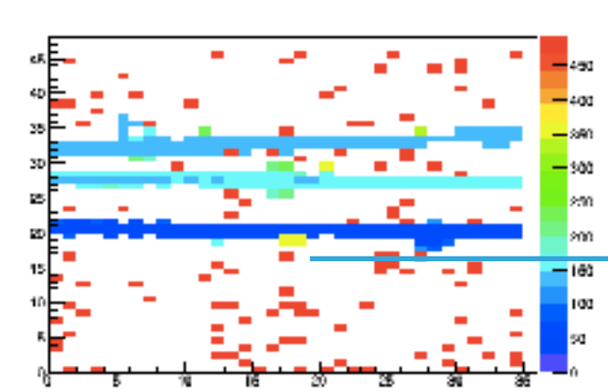




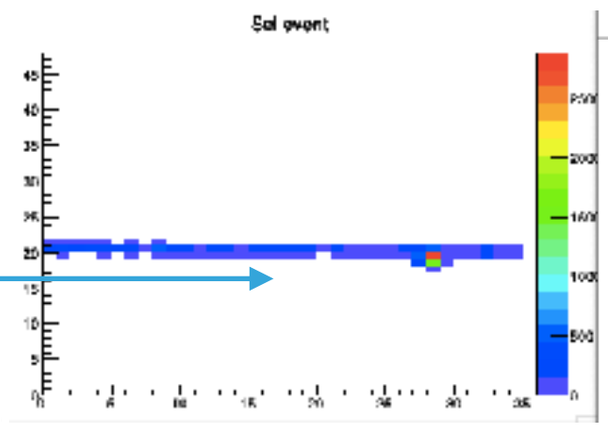
Display with charge:



Display with time:



Selected track:



TPC DATA ANALYSIS

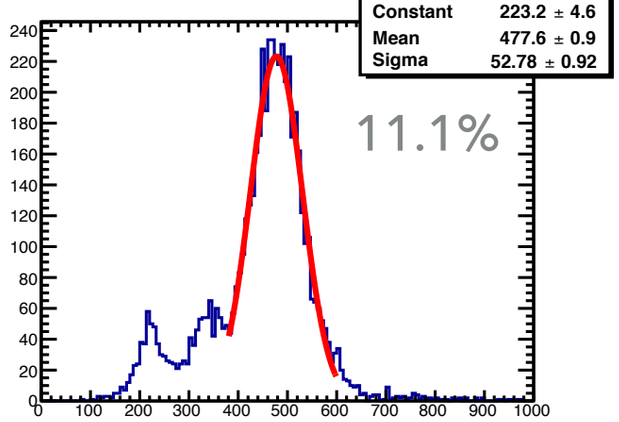
- The truncated mean energy deposition for different particles and distances:

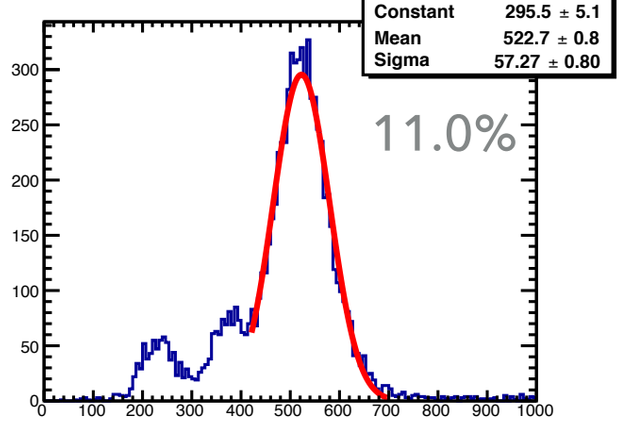
Drift distance: 80cm

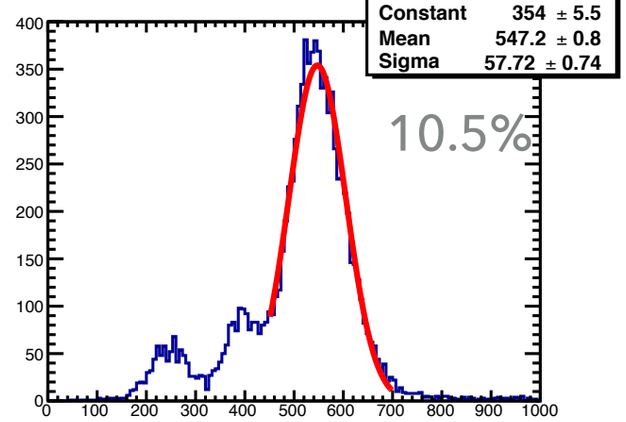
30cm

10cm

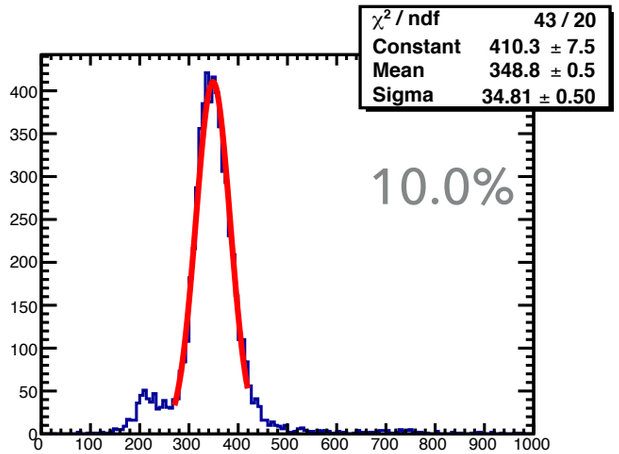
Proton

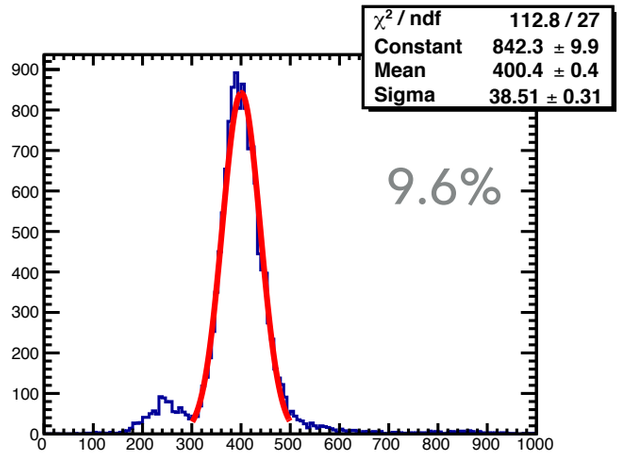


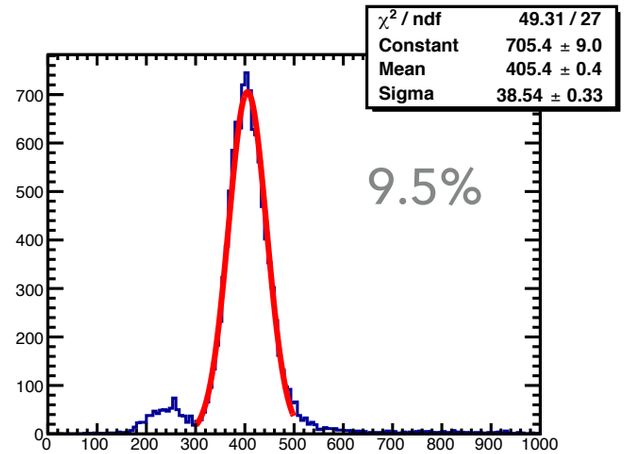




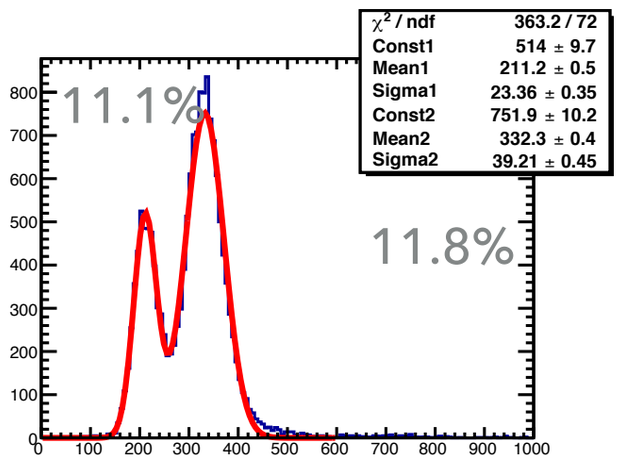
Electron

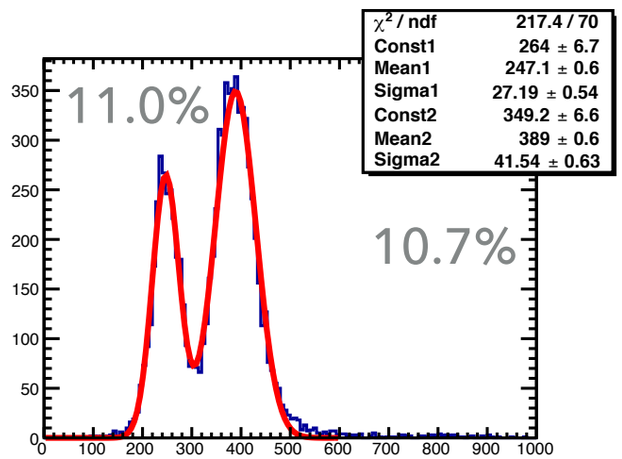


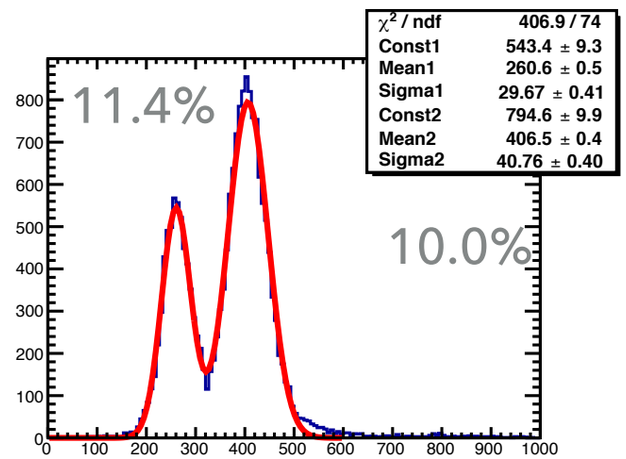




Pion



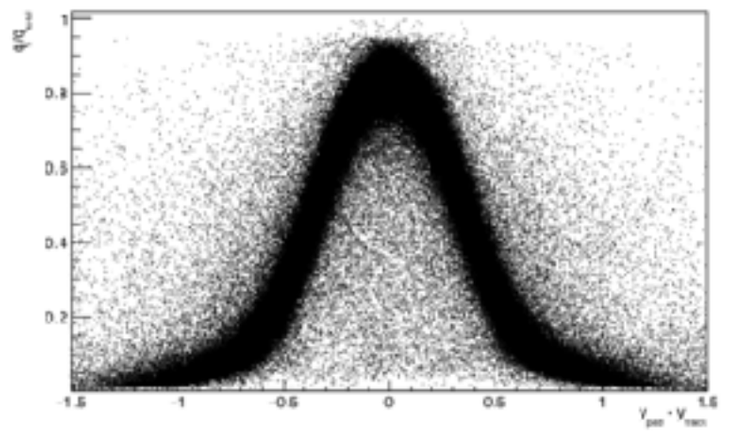


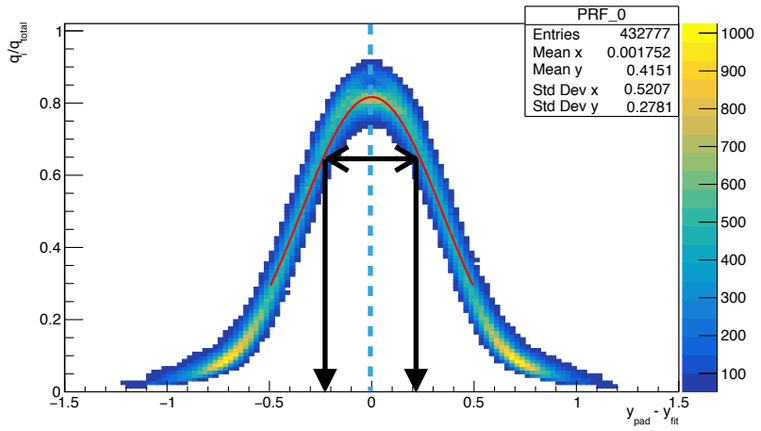


TPC DATA ANALYSIS

- Reconstruction of the track position with the Pad Response Function (PRF)
- Consider the PRF uniform for all the pads estimate it form:

PRF scatter plot:





$$PRF(x_{track} - x_{pad}) = \frac{q_{pad}}{q_{cluster}}$$

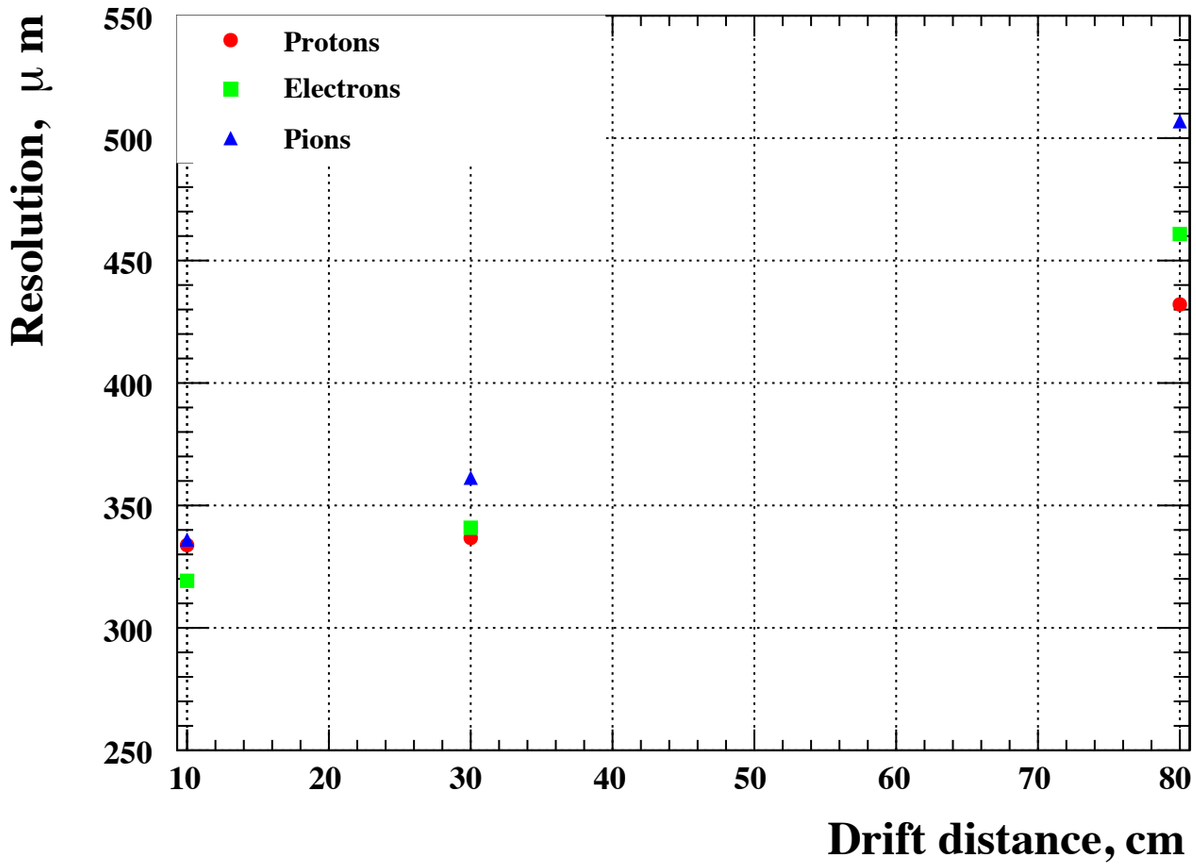
- Based on the measured charge ratio we reconstruct the track position with minimisation of

$$\chi^2 = \sum_{column} \left[\frac{a - PRF(y_{track} - y_{pad})}{\sigma_a} \right]^2 \qquad a = q_i / q_{total} \qquad \sigma_a = \sqrt{q_i} / q_{total}$$

- We perform several iterations of “estimation PRF –> track position extraction” until the track fit quality stops improving

TPC DATA ANALYSIS

- Based on the track position obtained with the described method the spacial resolution was estimated for different particle types and drift distances:



- Below 500 um result was obtained

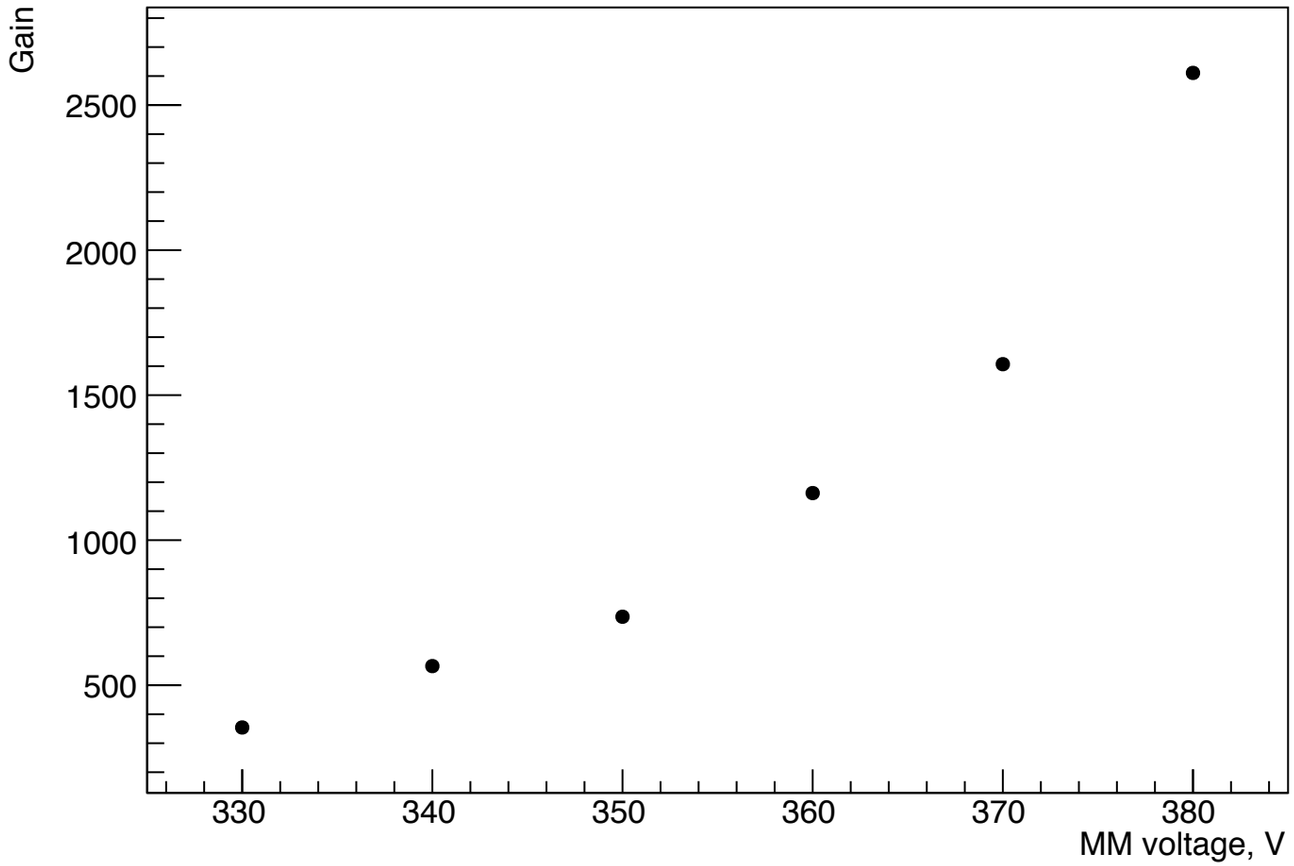
SUMMARY

- The T2K experiment will continue taking data until 2027
- The ND280 upgrade project is aimed to implement new subdetectors
  - The significant systematic reduction for oscillation analysis is expected
  - Better sensitivity for neutrino interaction studies
- New detector concepts were developed:
  - 3D scintillator detector with cubes (Super FGD)
    - *First light was seen by baby-prototype in October 2017*
    - *Larger prototype was tested in the Summer 2018 at CERN*
    - *Preliminary results*
  - TPC with resistive pads
    - *The prototype was tested with cosmics in Saclay and with beam at CERN*
    - *The test shows the detector performance at a good level*
      dE/dx resolution is near the current ND280 TPCs values
      Spacial resolution is at level of 500 um
- All the studies of the beam tests data are ongoing and the results are preliminary!
  - Hope to have more robust and complete results soon
  - The TDR is now preparing

BU

TPC MM GAIN

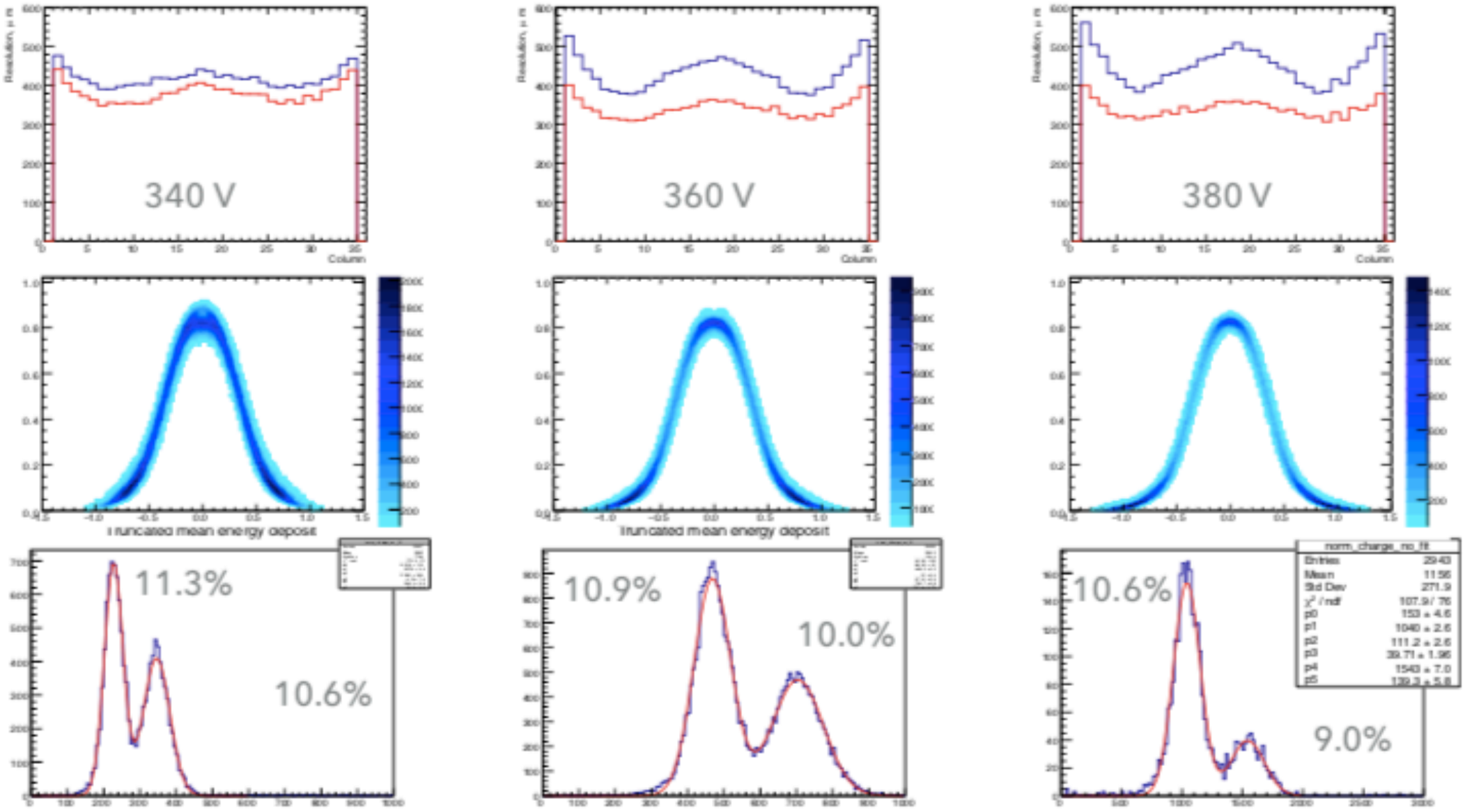
- MM gain versus high voltage measured with the Fe55 radioactive source



SPACIAL RESOLUTION

1 GeV/c pions
30 cm

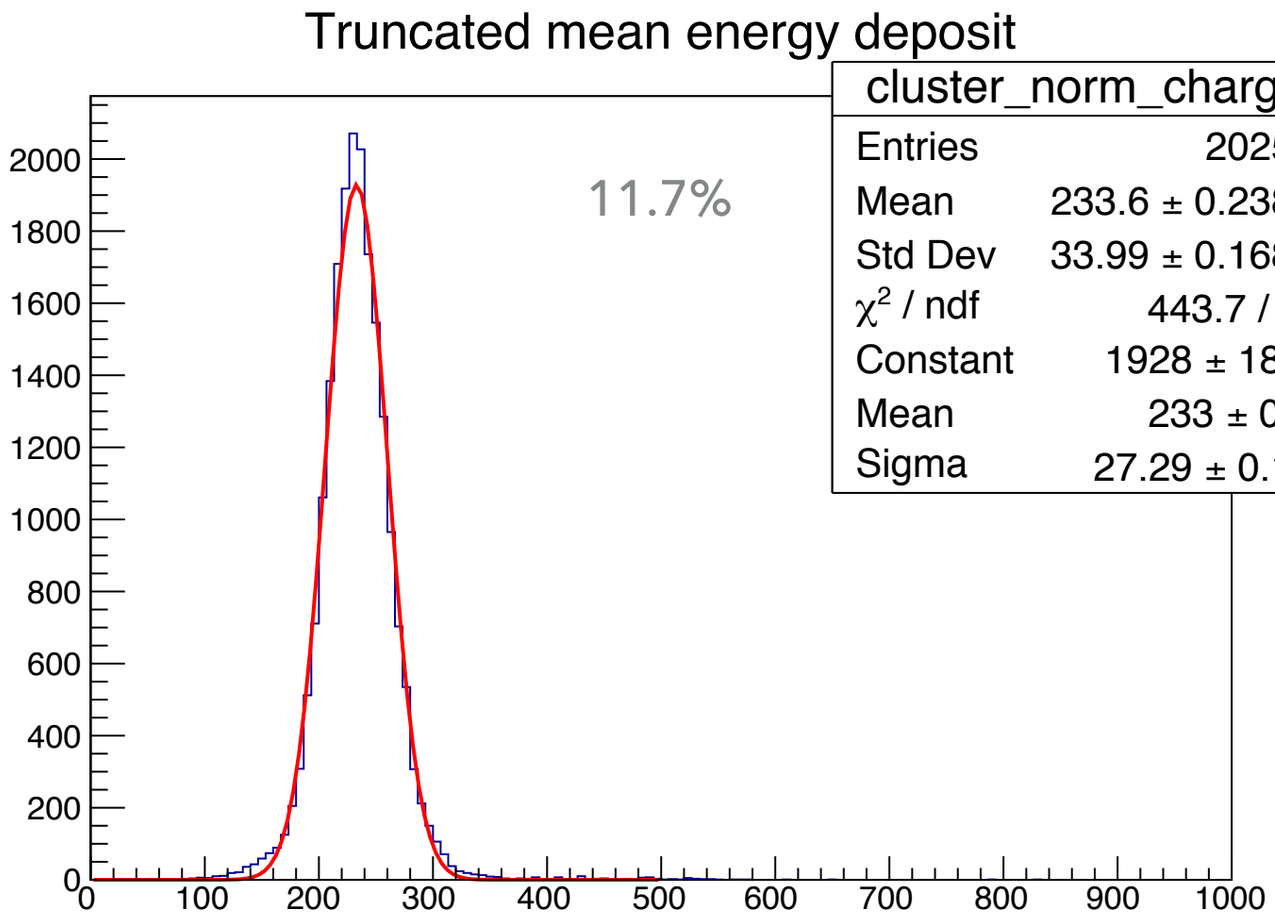
- With the higher MM voltage the signal is much more clear
- Have a chance to get rid of small noise, whatever



- Also very nice result that shows PRF method stability
  While Center of Charge method shows big result variation

TPC BEAM TEST ANALYSIS

- 2 GeV/c muon sample at 30 cm drift distance



SUPER FGD ASSEMBLY STABILITY TESTS

- The assembly of the 2m long detector were tested

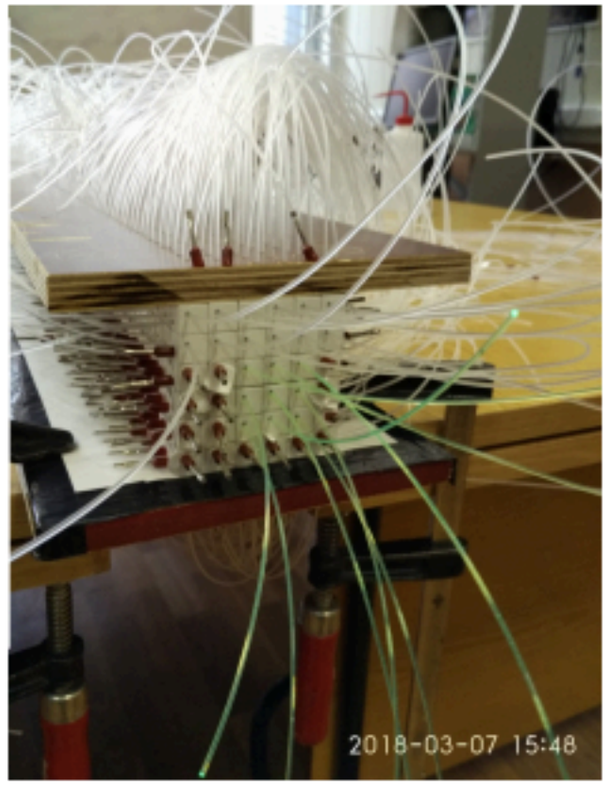
Array of 7200 extruded cubes: 200 x 6 x 6 cm³

10k cubes were manufactured from long 1 cm thick extruded scintillator slabs. These cubes were used for different mock-ups and prototypes. **The prototypes tested in beam were made from these cubes.**

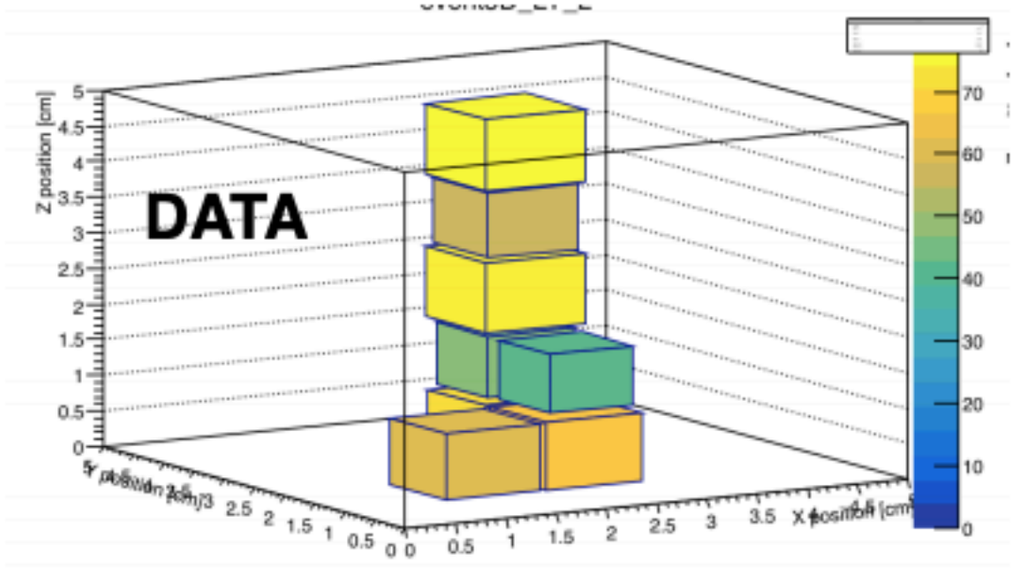
Mock-up shown in the photo was assembled to study how to insert 2 m long WLS fibers through the cubes.

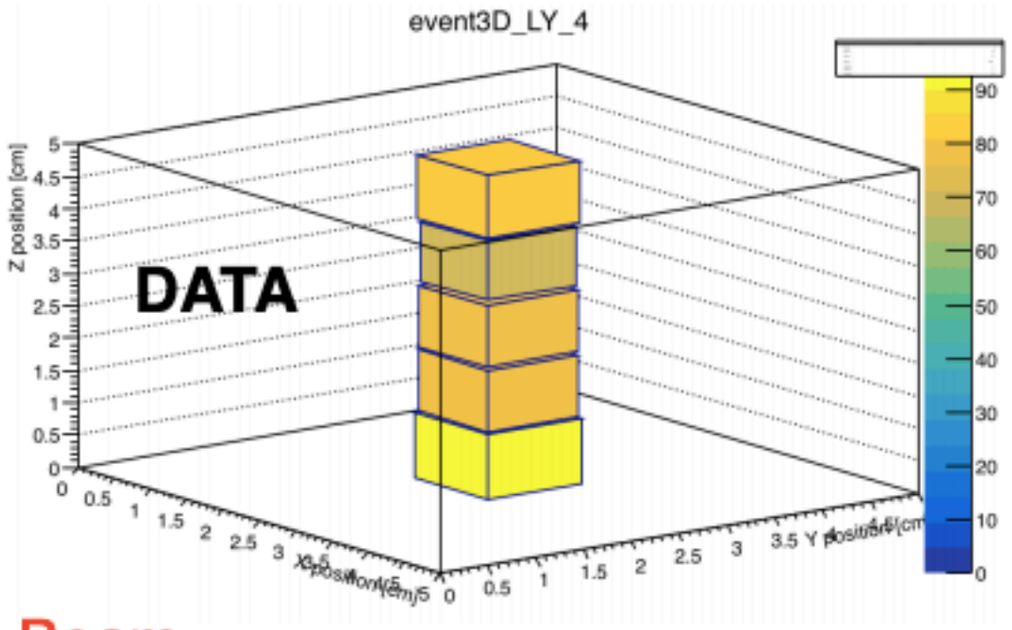
We have succeded to draw the fibers through 2 m long array even though the extruded cubes were not perfect in shape and have variable size with

σ_x=100 μm per side width.

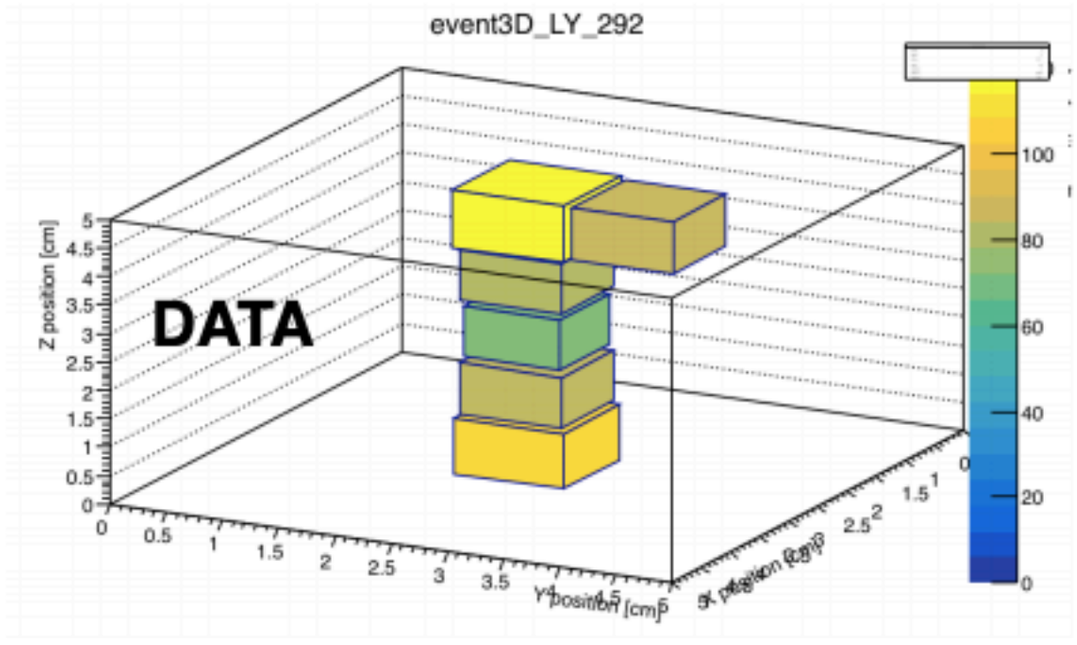


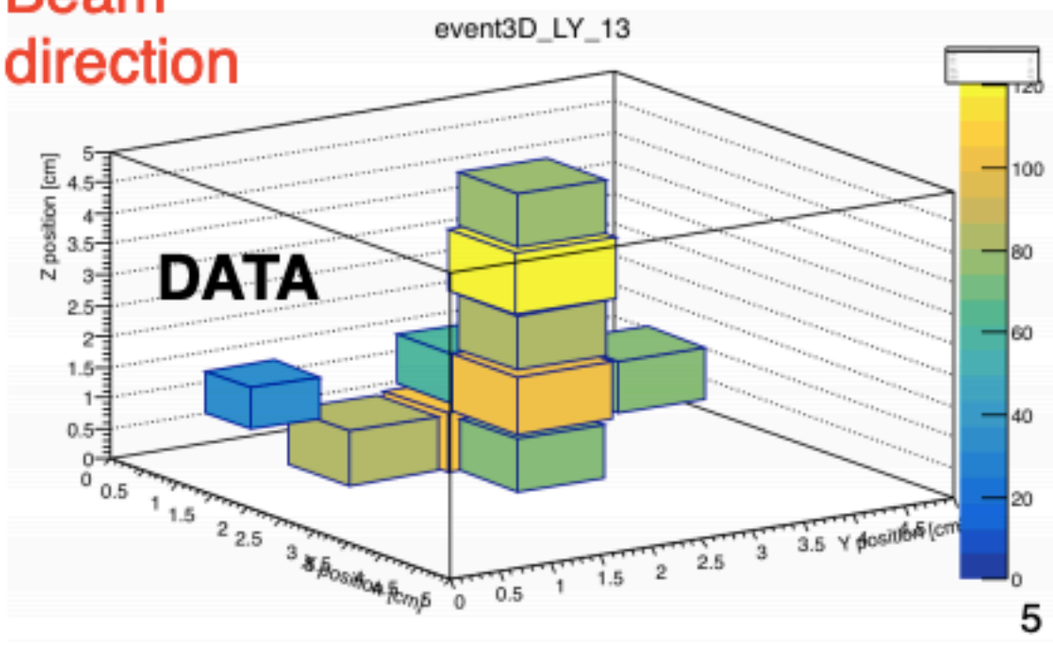
SFGD OCTOBER 2017 EVENT DISPLAYS





Beam direction





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