Fine-grained tracker software; Super FGD - simulation, tests, reconstruction; status in Sofia and plans

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The Near Detector

Two quotes from our contract with EU Commission:

"The near detector… is needed to measure and monitor the neutrino beam flux and also, very importantly, to measure neutrino cross-sections in the energy range of interest as well as studying the different types of background and, thereby, to reduce significantly the systematic uncertainties in the measurements made with the far detector."

"This detector must have a water target like the far detector, in order to enable adequate measurements of the neutrino cross-sections … and to measure and monitor the neutrino flux. … Additional instrumentation surrounding the water target will be needed to measure the topology of the events and to distinguish between muons and electrons in order to properly identify the different neutrino interaction channels."

My point here:

In the next few years we should think about near detector as a unity which consists of two sub-detectors and not two detectors regardless of different physics processes they produce. Therefore a close cooperation between Ckov and tracker groups is a necessity.

The Near Detector Requirements

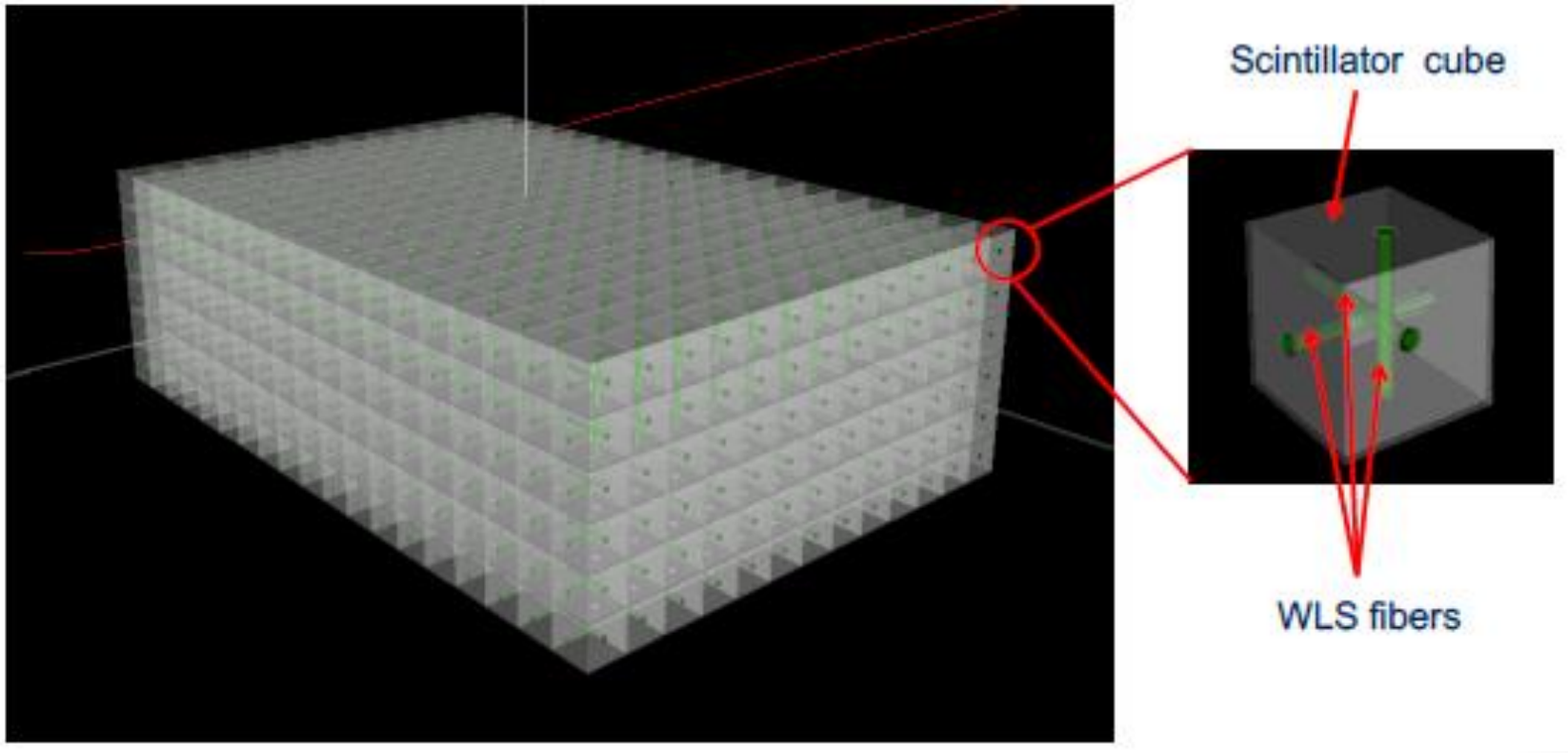
The detector will act as the target for the neutrino interaction and as detector to reconstruct the tracks around the interaction vertex. It needs to have:

- large mass to provide a sufficient number of neutrino interactions;
- acceptance for charged leptons (muons and electrons) in large scattering angle;
- capability to reconstruct and identify short tracks of low energy hadrons around the interaction vertex.

Sofia's standalone work so far…

- Our task within ESSnuSB is simulation, reconstruction and performance studies of an "additional instrumentation [which] will be needed to measure the topology of the events and to distinguish between muons and electrons".
- Current option under consideration is a high granularity scintillating tracker. Reasons for that:
  - Our group has an experience with study of a scintillating tracker for IDS NF project.
  - A much more advanced neutrino experiment is developing such detector: T2K ND280 upgrade effort made the choice of Super Fine Grained Detector (sFGD), based on scintillating cubes.
  - We can take advantages of:
    - Two prototypes already built and tested on beam to some level (with our participation too);
    - Some software for simulation and analysis of beam data exists;
    - We can follow closely the progress of sFGD.

SuperFGD design



Parameter	Cube edge: 1 cm
# of cubes	2.16M
# of channels	58.8k

Parameter	Value
Coating thickness	50 μm
Hole diameter	1.5 mm
WLS fiber diameter	1.0 mm

Simulation software

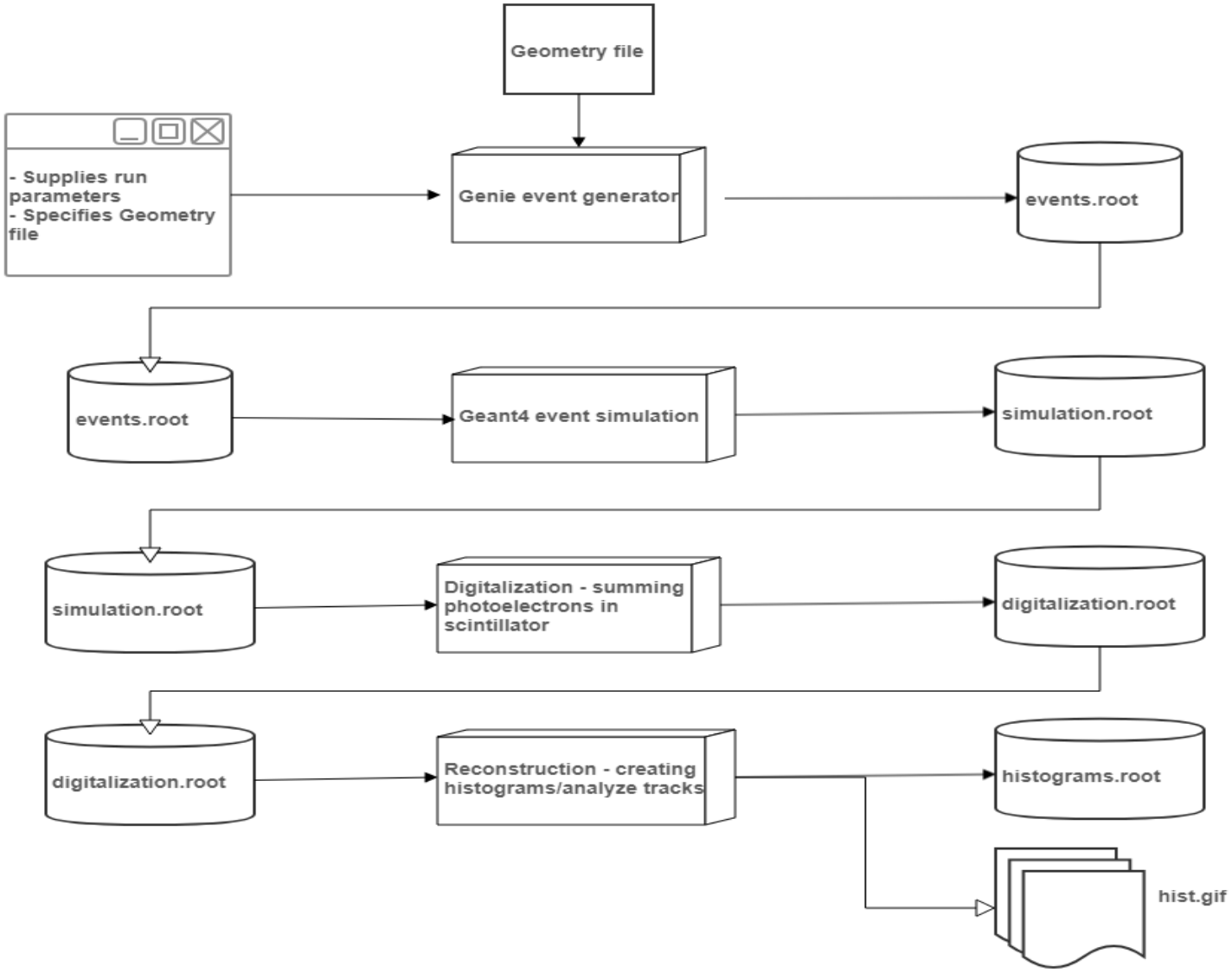
Firstly we looked at original sFGD simulation code and then rewrote simulation from scratch with completely different structure.

Used packages:

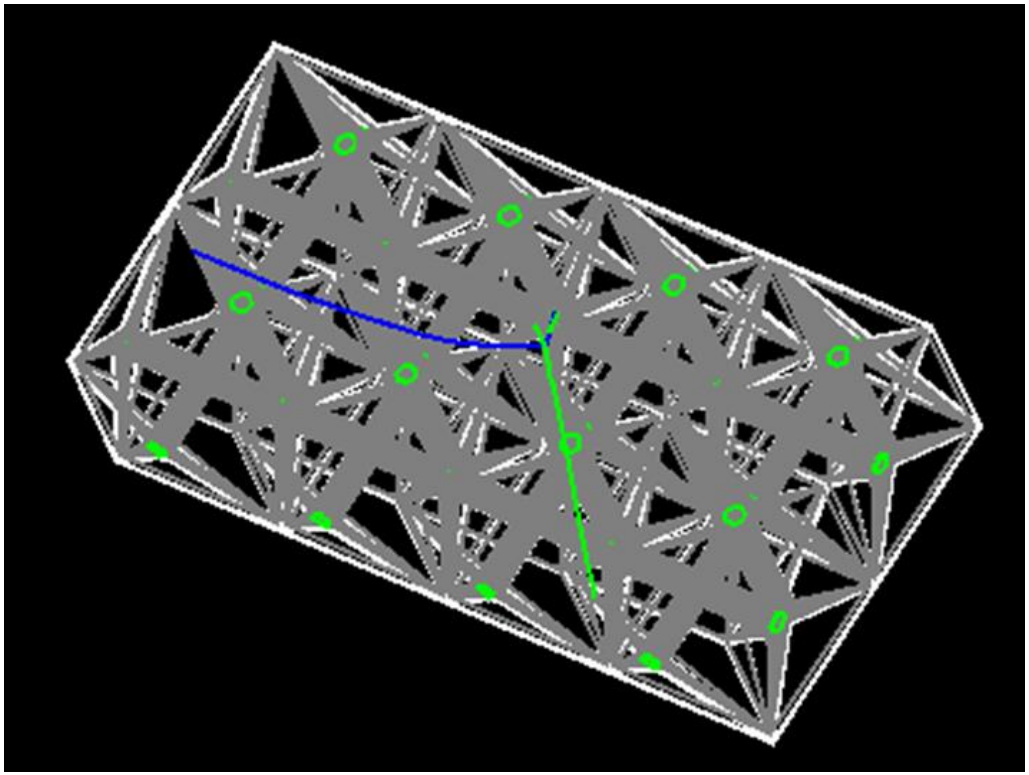
- Genie v2.12.6
- Geant4 v9.4
- CERN Root v6.10.02
- Pythia v6

This software is built and run under operating system Linux Mint 18.2 (or newer).

Data flow


Geometry file
- Supplies run parameters
- Specifies Geometry file
Genie event generator
events.root
events.root
Geant4 event simulation
simulation.root
simulation.root
Digitalization - summing photoelectrons in scintillator
digitalization.root
digitalization.root
Reconstruction - creating histograms/analyze tracks
histograms.root
hist.gif

Geometry creation
(Geant4)

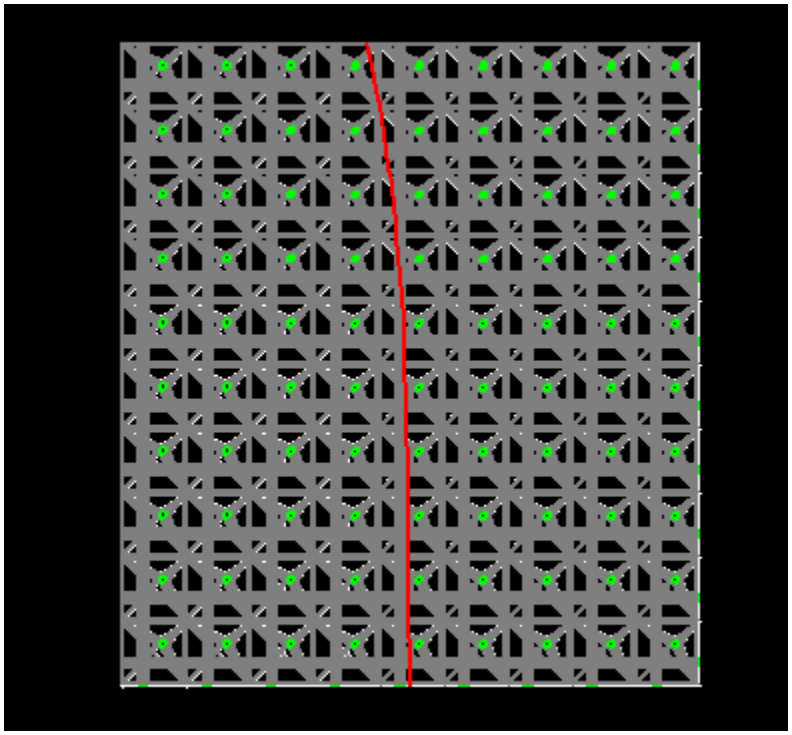


Here a small excerpt from full geometry simulation.

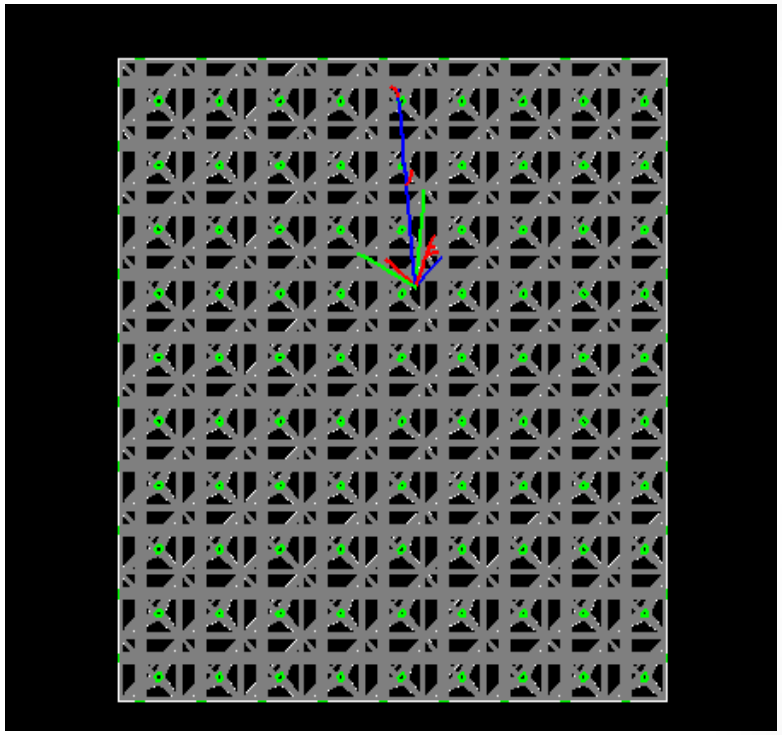
Including:

- Dimensions
- Materials of scintillating cubes and WLS fibers
- Magnetic field
- Optical photons on/off
- etc.

Simulation
(Genie + Geant4)



Muon,
E = 0.05 GeV, B = 0.5 T,
Output from Geant4



Muon neutrino,
E = 7.5 GeV, B = 0.5 T,
Output from Geant4

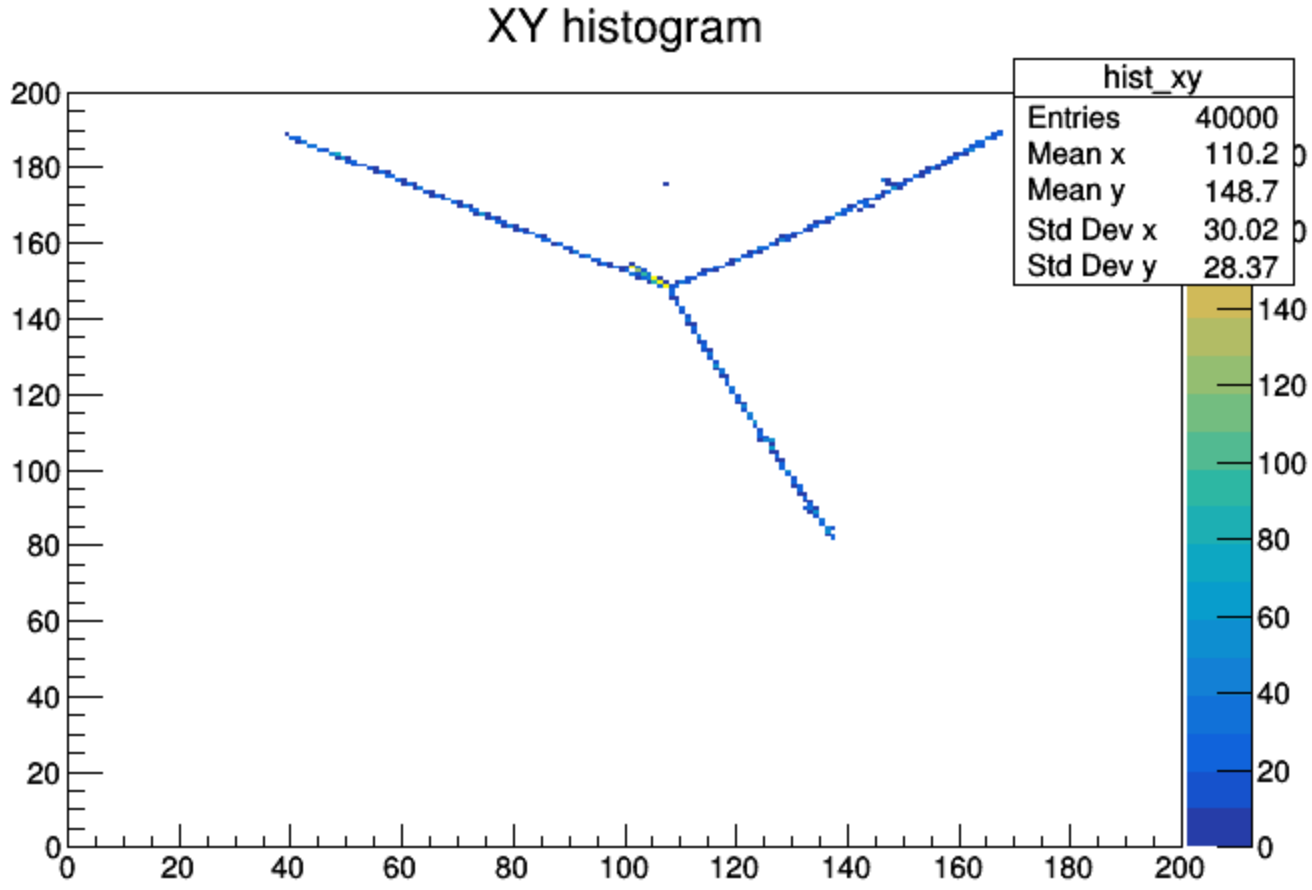
Digitization
(from dE/dx to photoelectrons)

For every cube is performed following:

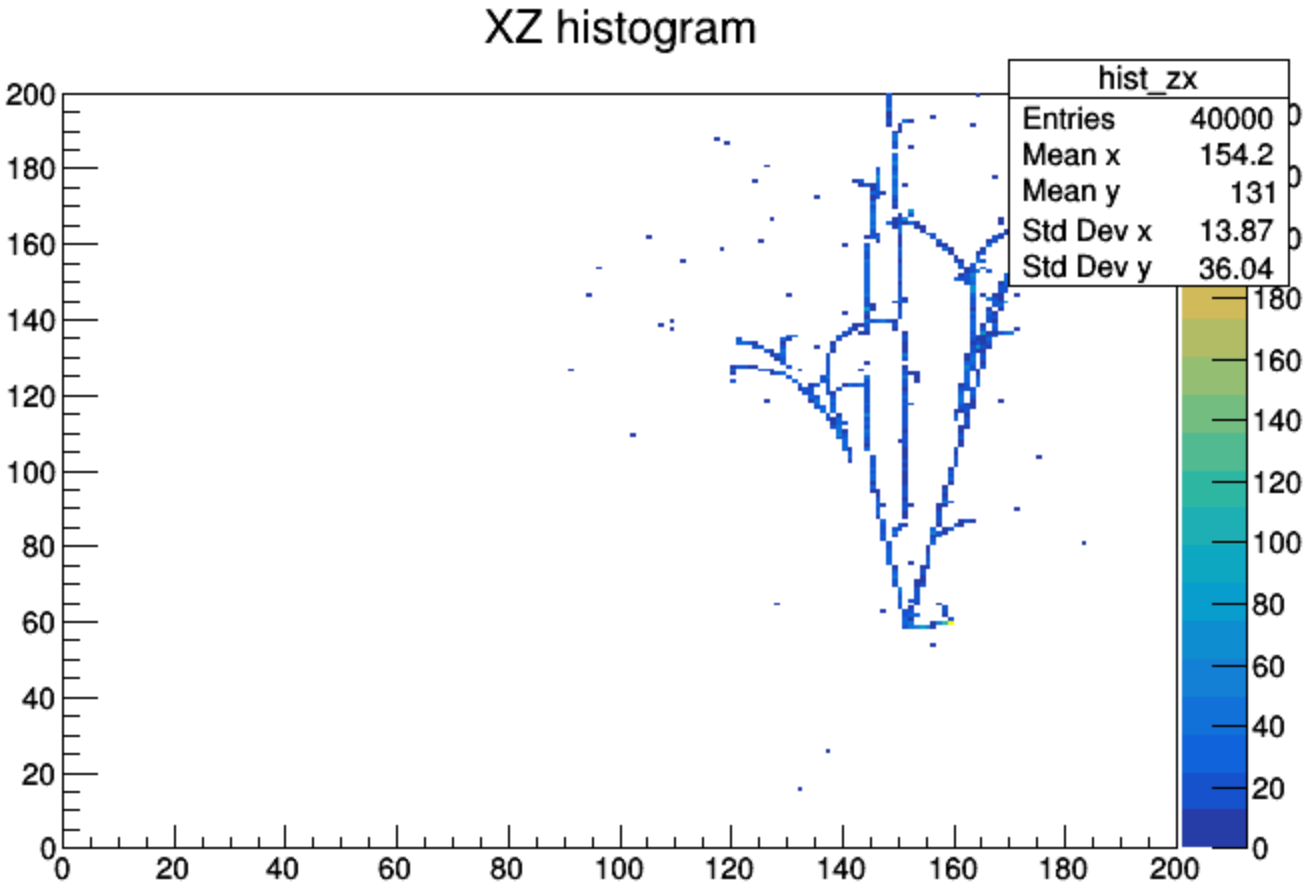
- Produced light yield via Birks' law.
- Conversion from photons to photoelectrons (from experimental data).
- Light attenuation in fibers.
- MPPC efficiency (from experimental data).

For every axis (X, Y, Z) is performed photon summation.

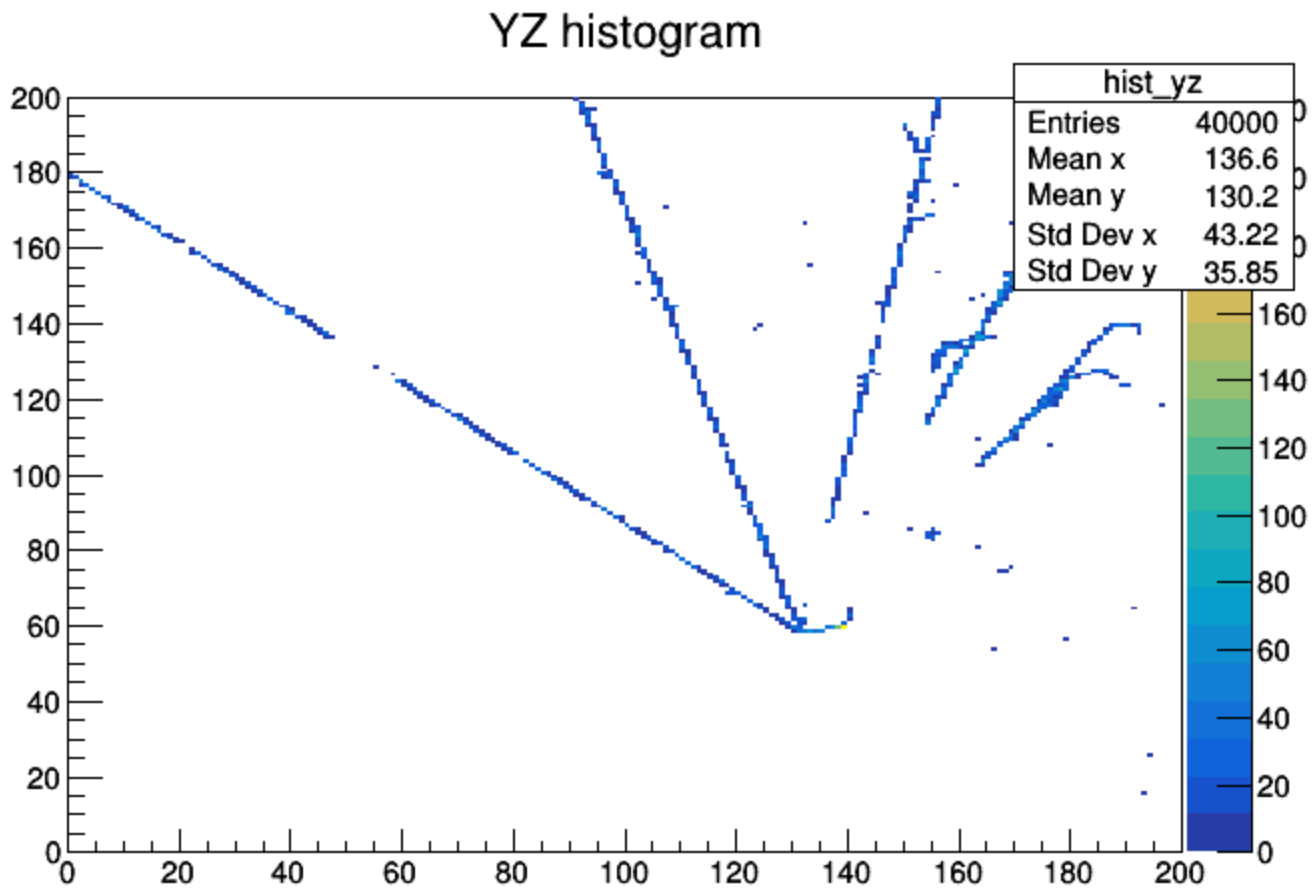
Digitization
(few neutrino interaction examples)



Digitization
(few neutrino interaction examples)



Digitization
(few neutrino interaction examples)



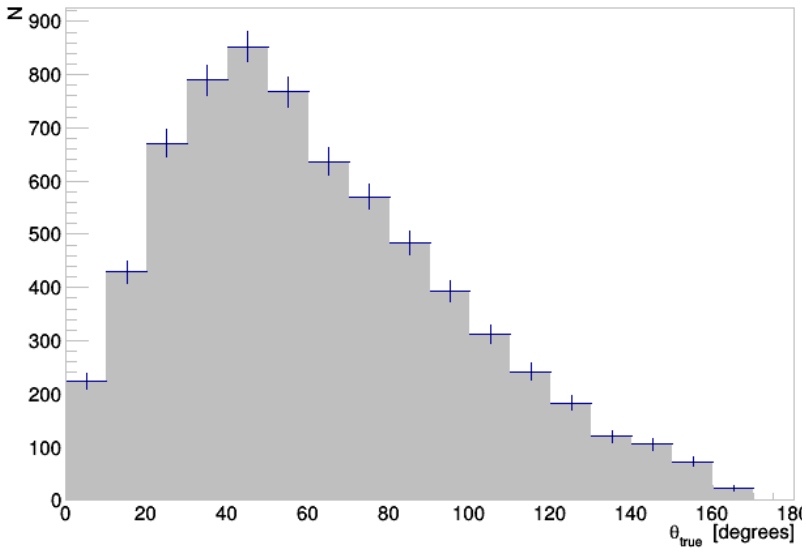
Track (proto)reconstruction

- Track reconstruction with pattern recognition is the most difficult task:
  - Event topology can be very complicated.
    - Confirmed by beam data.

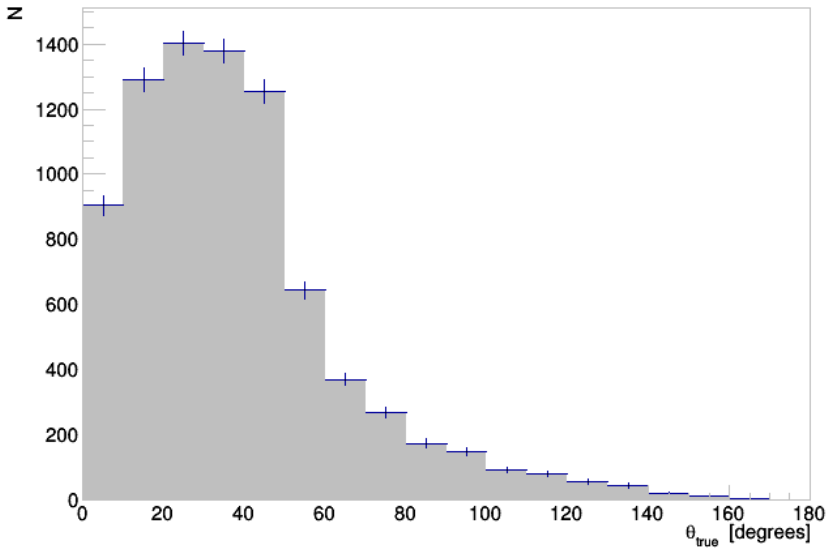
- Meanwhile we define a track if:
  - It has length at least three consecutive cubes.
  - There is at least one cube distance from other track in at least one projection.

Some angle distribution

(E_ν = 0.5 GeV)



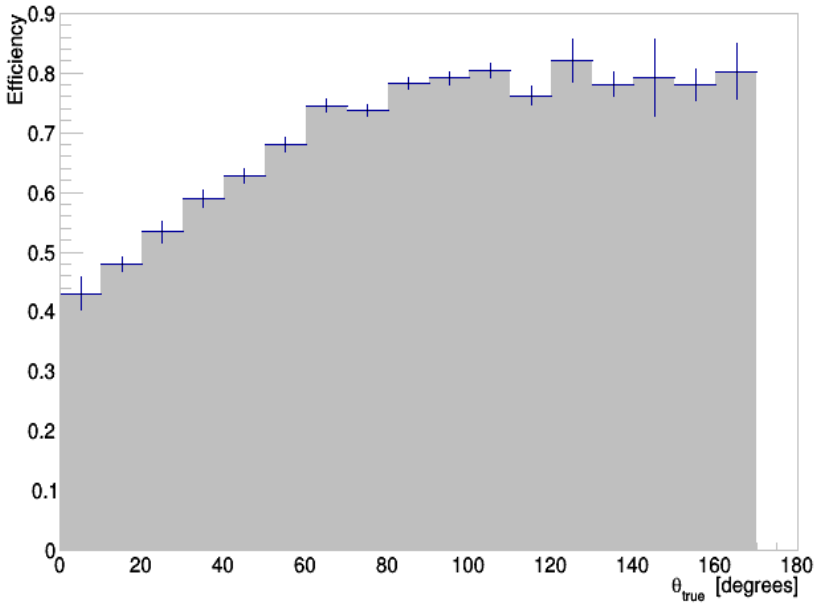
muons

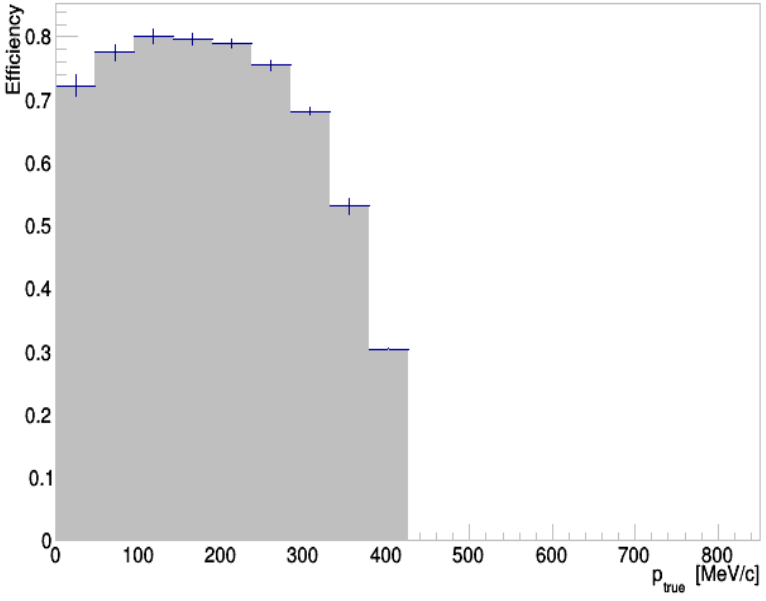


protons

Some efficiencies

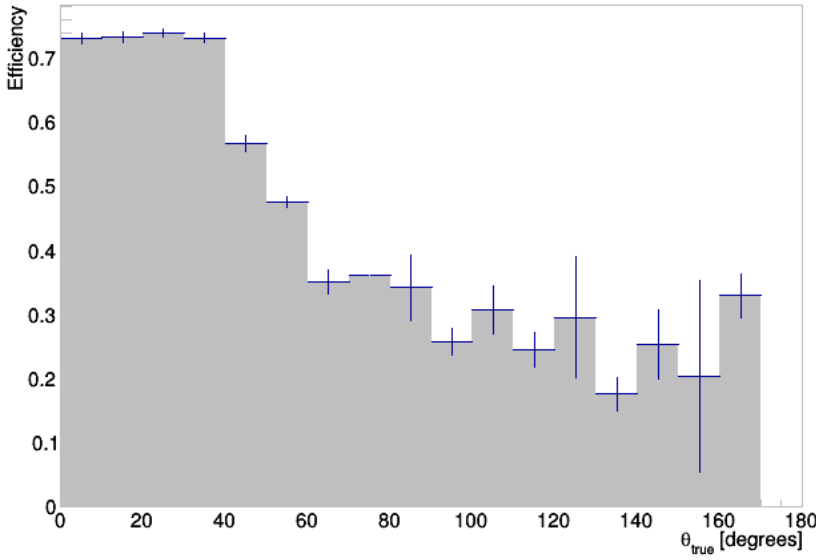
for muons (E_ν = 0.5 GeV)

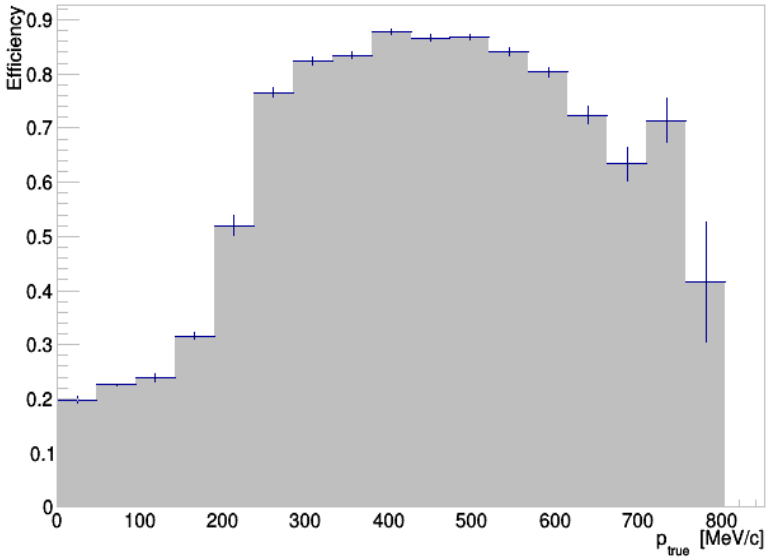




Some efficiencies

for protons (E_ν = 0.5 GeV)





HowTo


```
/data/G4EMLOW6.23
export G4LEVELGAMMADATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/PhotonEvaporation2.2
export G4NEUTRONHPDATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/G4NDL4.0
export G4NEUTRONXSDATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/G4NEUTRONXS1.1
export G4PIIDATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/G4PII1.3
export G4RADIOACTIVEDATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/RadioactiveDecay3.4
export G4REALSURFACEDATA=$OPT/geant4.9.5/share/Geant4-9.5.0
/data/RealSurface1.0

export PATH=$PATH:$OPT/geant4.9.5/bin
export LD_LIBRARY_PATH=$LD_LIBRARY_PATH:$OPT/geant4.9.5/lib64
```

g4py

==========

1. Build - envs for geant/4.9.5 clhep/2.1.2.0 required to be loaded
   $cd $BUILD/geant-4.9.5-src/environments/g4py
   $apt-get install libboost-all-dev
   $./configure linux64 –prefix=$OPT/g4py-4.9.5 –with-g4-incdir=
   $OPT/geant4.9.5/include/Geant4 –with-g4-libdir=$OPT/geant4.9.5/lib –with-clhep-incdir=
   $OPT/clhep2.1.2.0/include –with-clhep-libdir=$OPT/clhep2.1.2.0/lib –enable-openglxm –with-python-libdir=
   /usr/lib/python2.7 –with-boost-libdir=/usr/lib/x86_64-linux-gnu/ –with-xercesc-libdir=
   /usr/lib/x86_64-linux-gnu/
   $make
   $make install

2. add to load.sh
   export PYTHONPATH=$PYTHONPATH:$OPT/g4py-4.9.5/lib

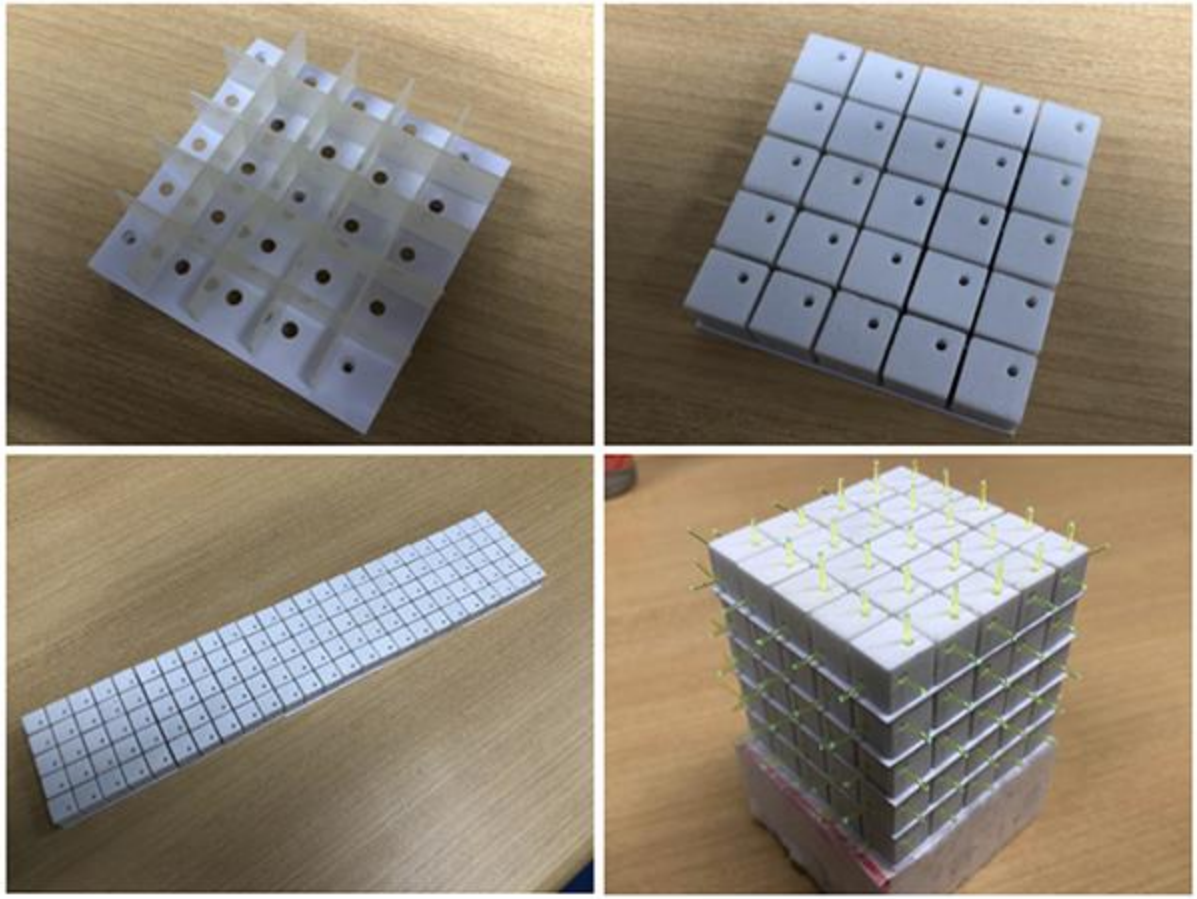
SuperFGD beam test at CERN PS T9 line

June/July/August/September 2018

At INR (before CERN)

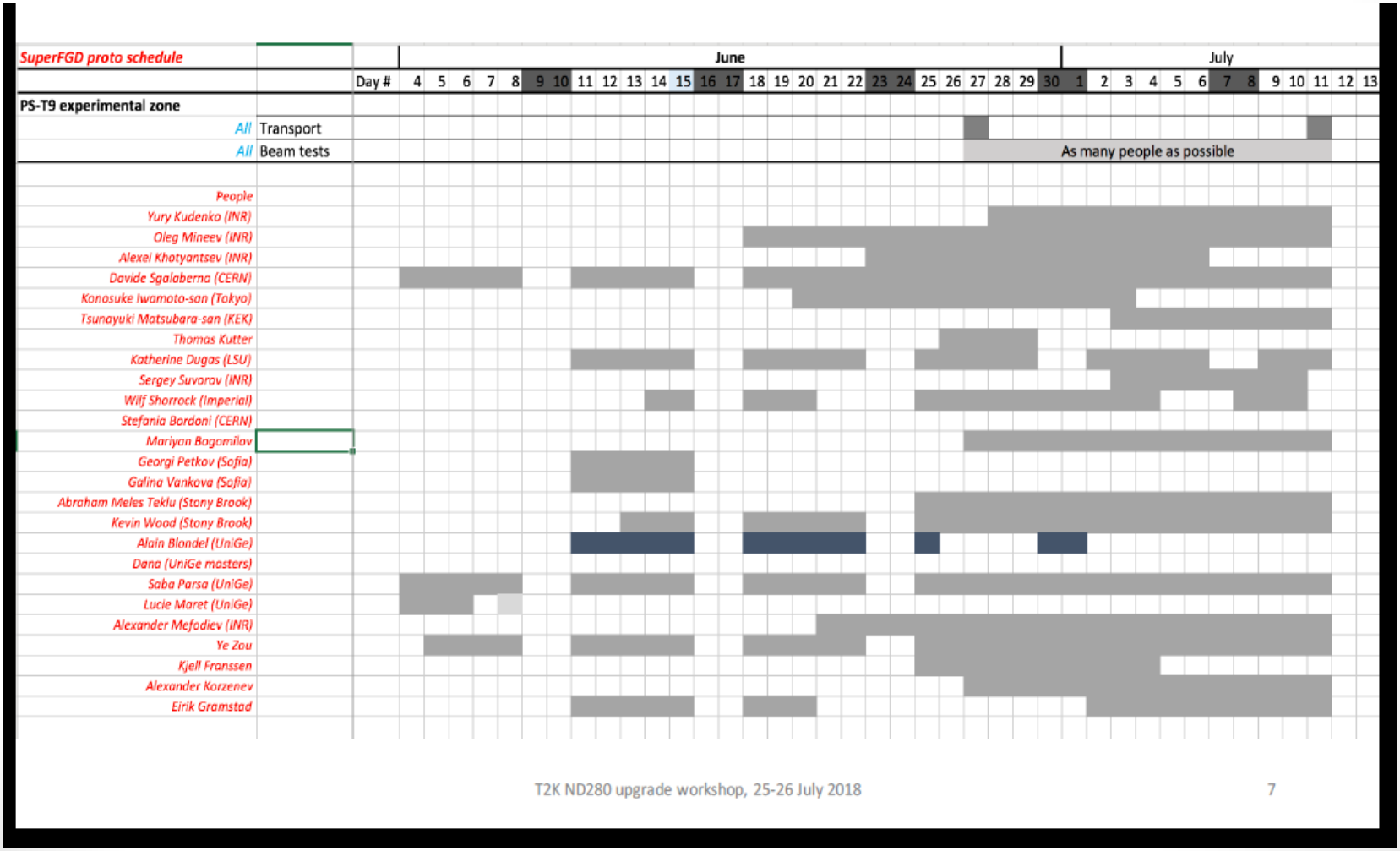
Detector construction at INR

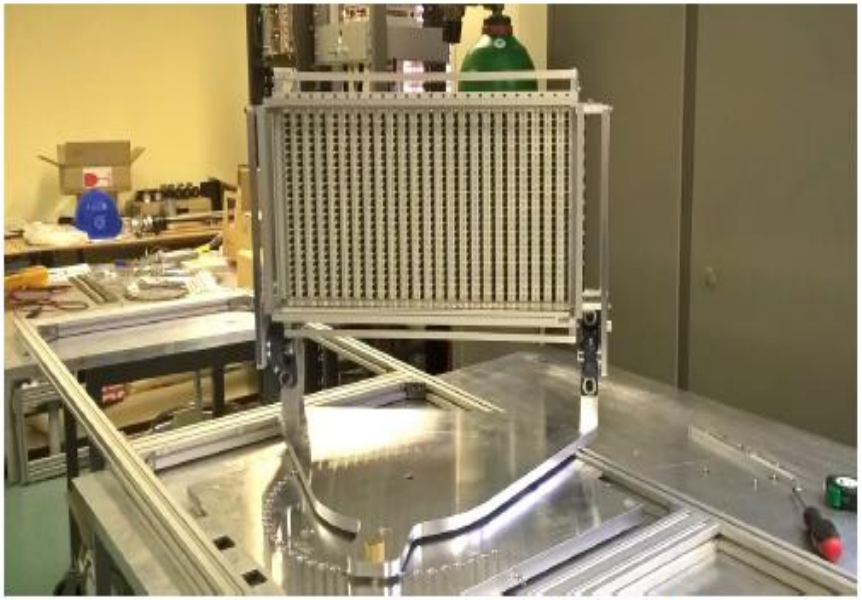
At INR (before CERN)



June/July shift schedule

Similar one in Aug/Sep

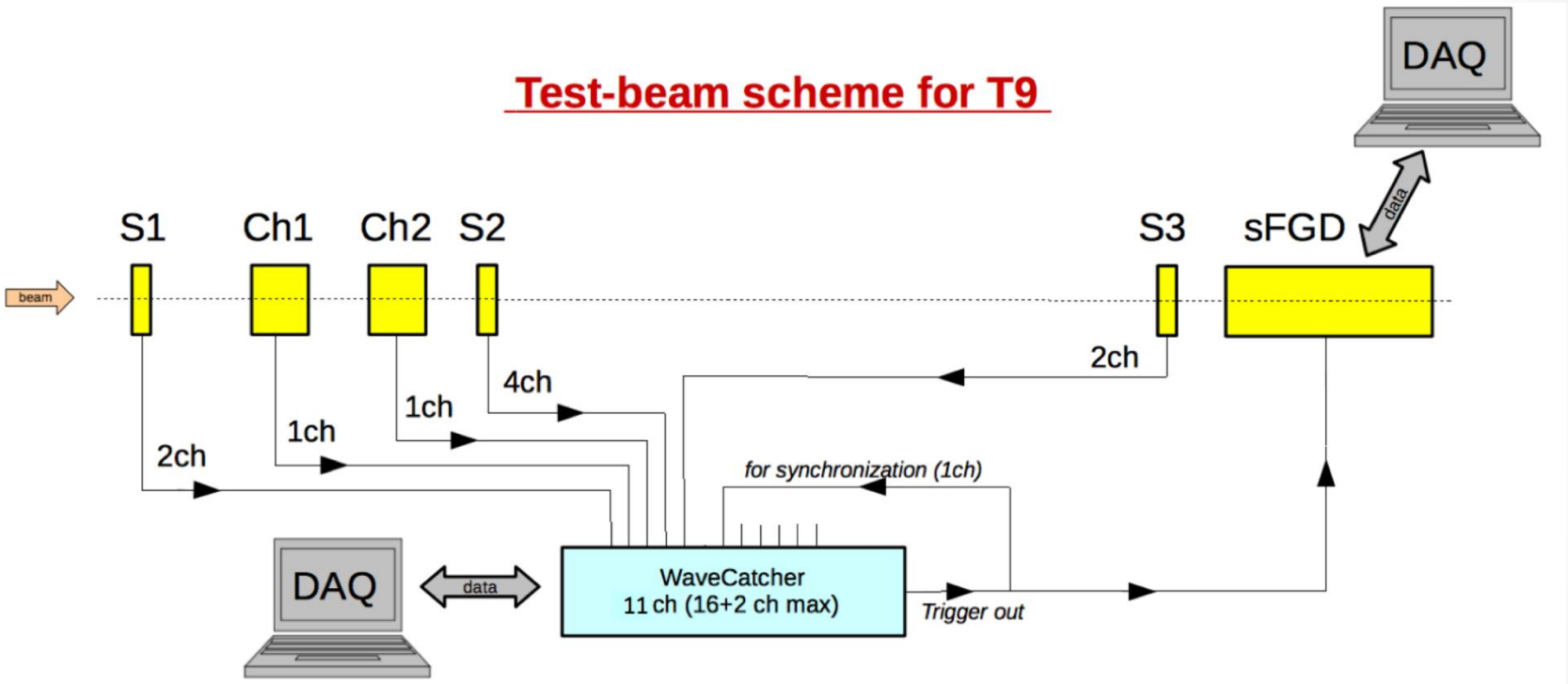




Mechanical frame provides tilting and rotation

At T9

At T9


Test-beam scheme for T9
DAQ
data
S1
Ch1
Ch2
S2
S3
sFGD
beam
2ch
1ch
1ch
4ch
2ch
for synchronization (1ch)
DAQ
data
WaveCatcher
11 ch (16+2 ch max)
Trigger out

Data taken in June/July

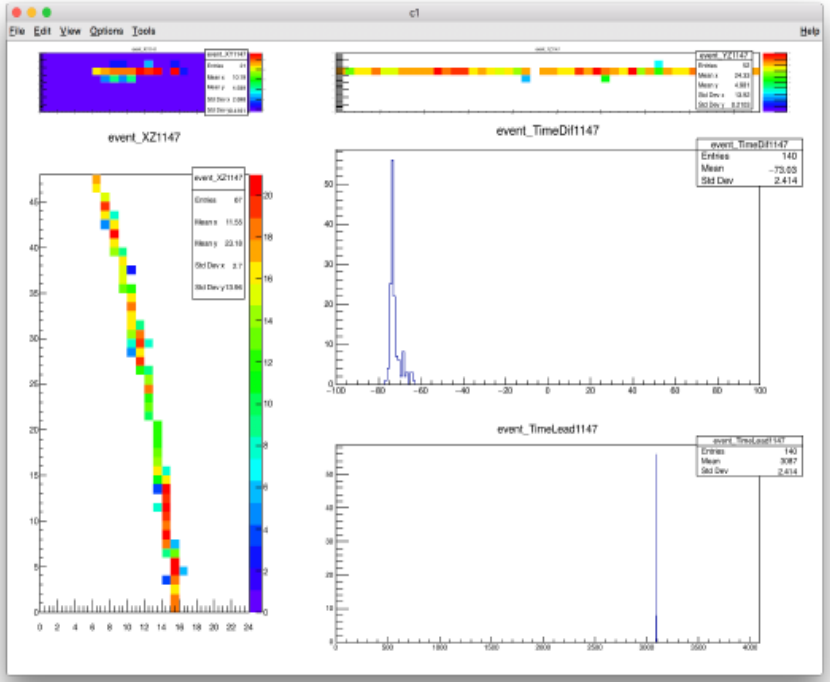
Data is on CERN server EOS : ~ 1150 GB

Detector orientation	Magnet MNP 17	Beam type	Momentum
45 degree	0.2	muon	0.5, 0.7, 1, 1.5 , 2, 5, -5, -0.5,
45 degree	0.2	pion	0.7, 0.8, 1, -1
45 degree	0.2 + Degrader	muon	0.5, -0.5
45 degree	0.7 + Degrader	muon	0.5, -0.5
0 degree	0.2	pion	0.4, 0.5, 0.6, 0.7, 0.8, 1, -0.5, -0.7, -1
0 degree	0.7	pion	0.5, 0.6, 0.7, 0.8, 1 , -0.5, -0.7, -1
0 degree	0.2 + MDX	pion	0.5, 0.8, -0.5, -0.8
0 degree	0.35 + MDX	pion	0.5, 0.8 , -0.5, -0.8
0 degree	0.2 + Degrader	pion	0.3, -0.3

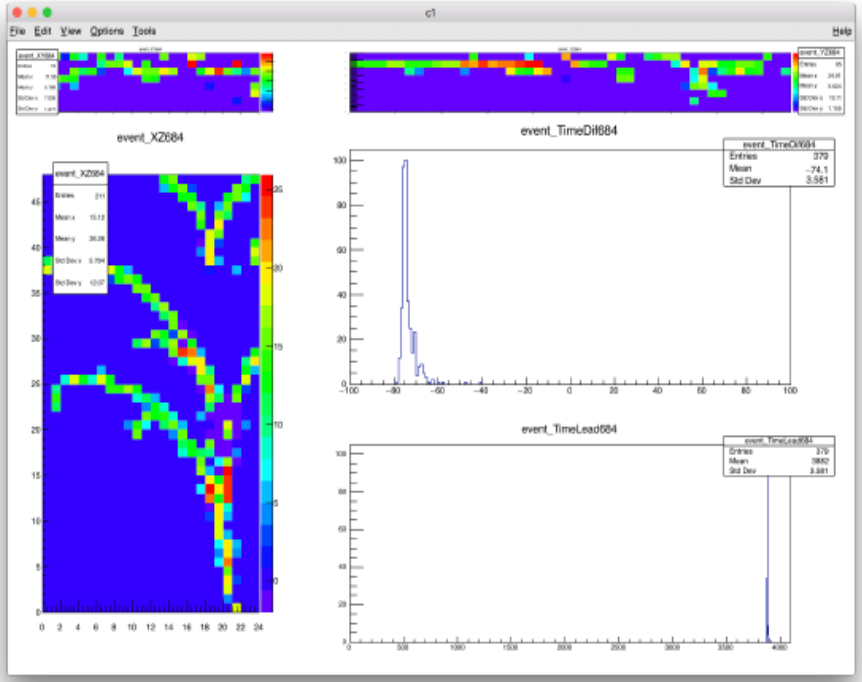
In Aug/Sep more data taken:

- in parasitic mode behind T2K TPC <- high priority
- detector rotated to 30° also
- more muon, photon and hadron data

Event displays (pion beam -0.5 GeV/c : 2300 events triggered by TOF)

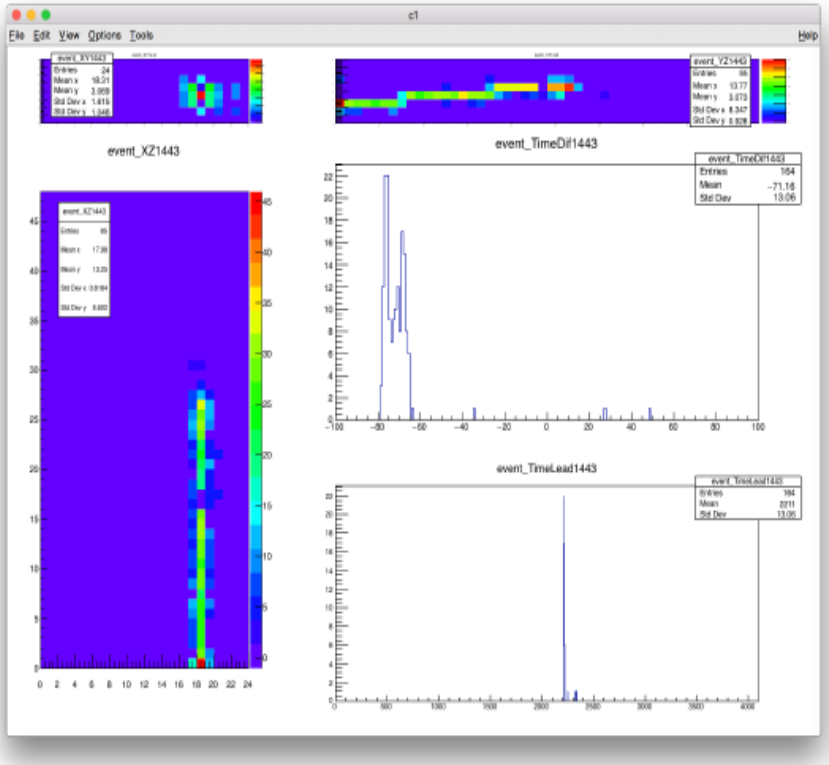


Single track event (1420/2300)

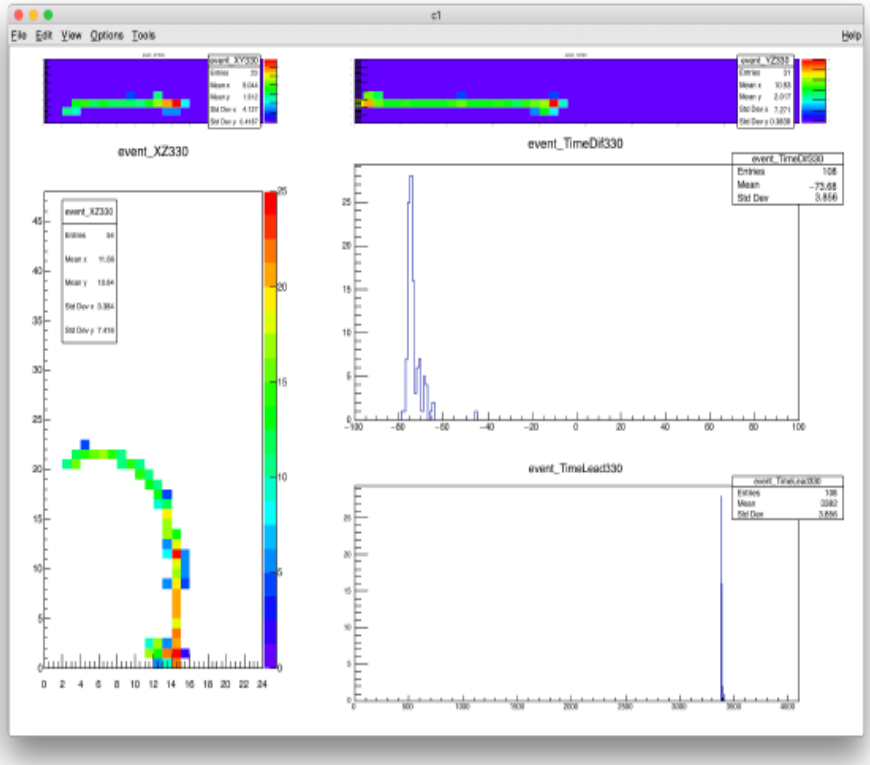


Multi track event (840/2300)

Event displays (Stopping events)

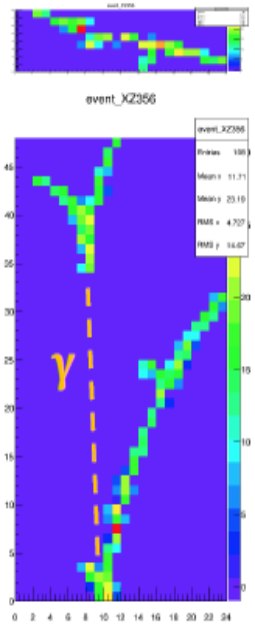


Stopping proton (very few)

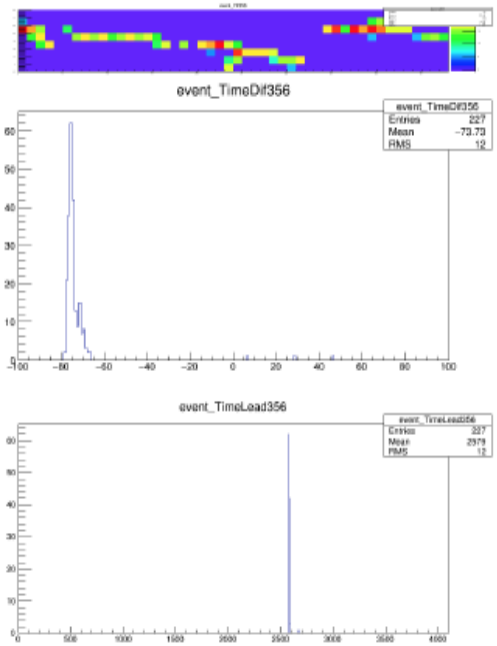


Stopping electron (a dozen)

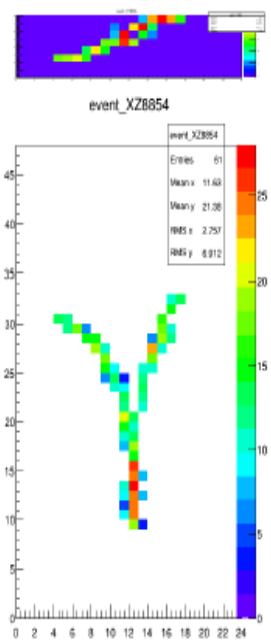
Event displays (γ signature)

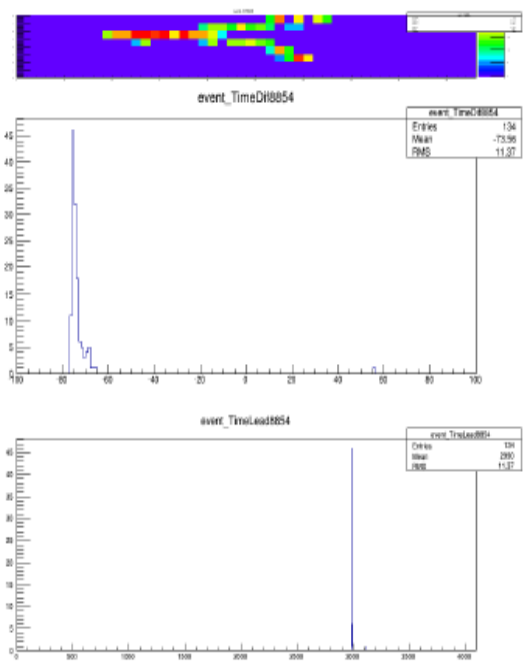


Possible to reconstruct energy of the gamma



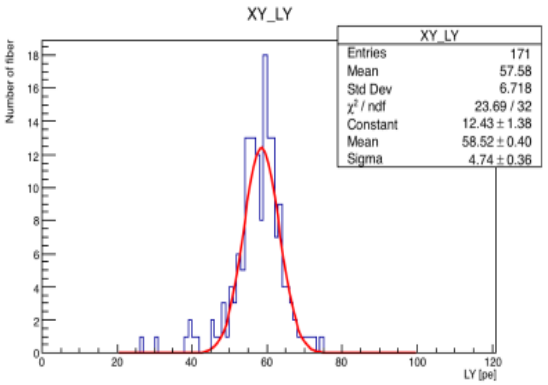
Pion beam +0.6 GeV/c

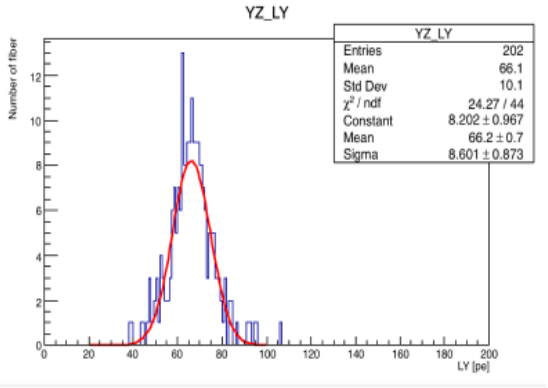


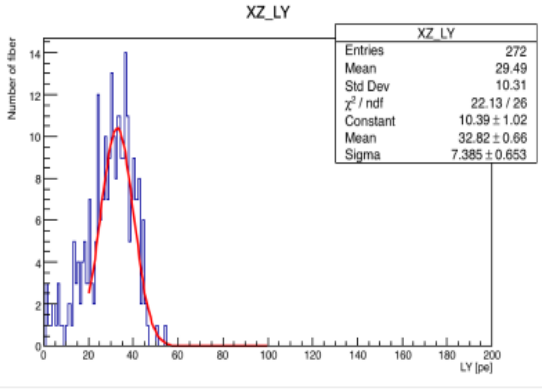


Photon beam +0.7 GeV/c

Light Yield for fibers results

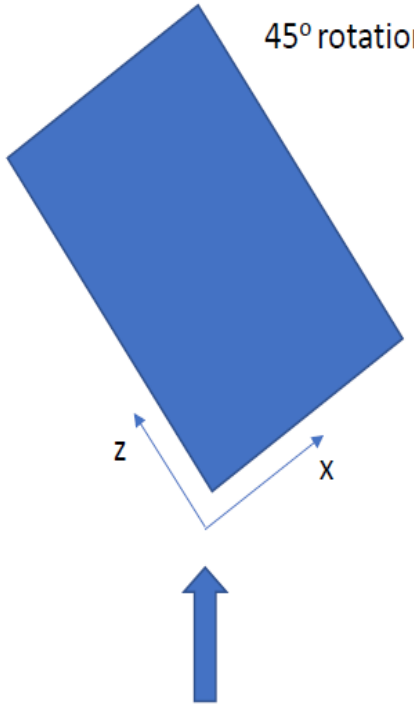






Each entry is fiber LY in p.e.

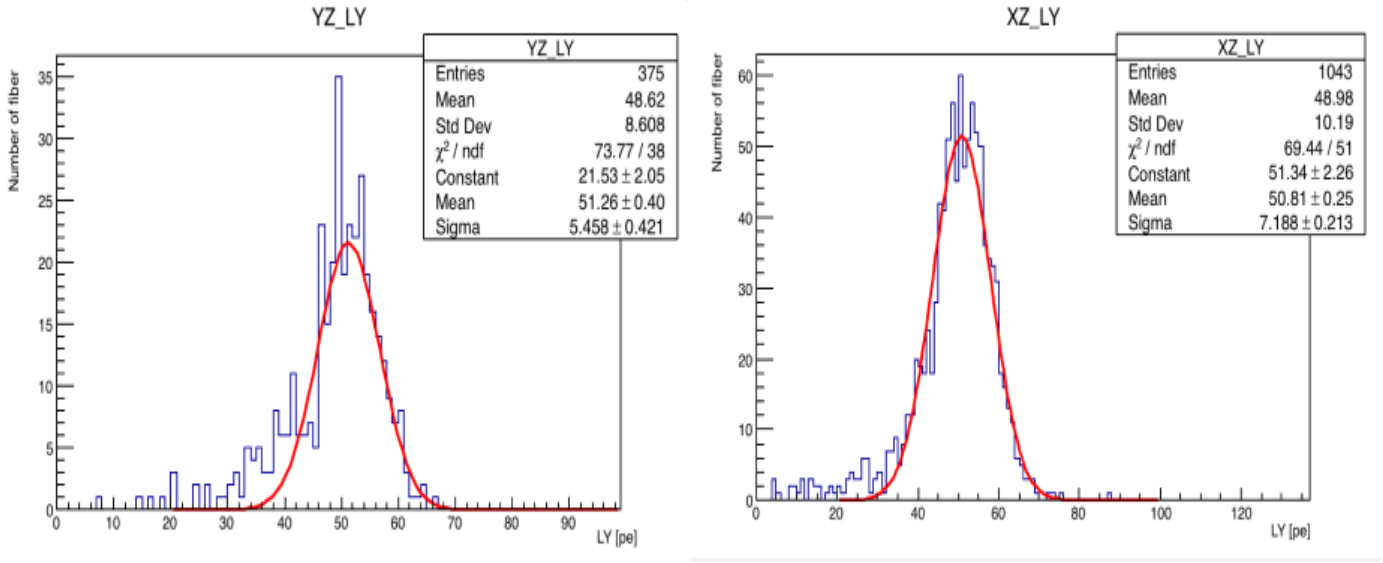
Using LED calibration results



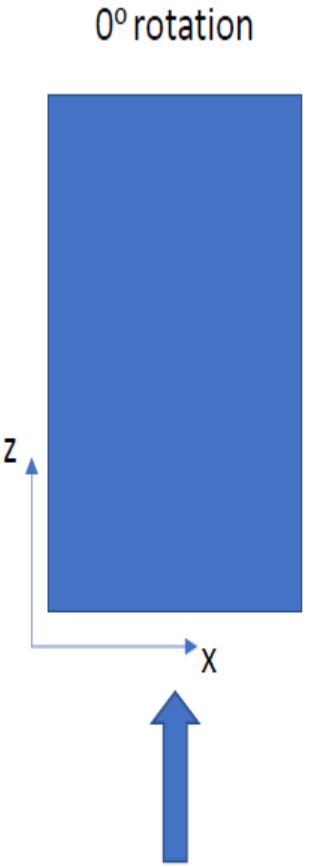
-5GeV muons

All events synchronized with ToF

Light Yield for fibers results



Each entry is fiber LY in p.e.



1GeV hadrons

All events synchronized with ToF

Using LED calibration results

ESSnuSB was well represented.

sFGD Analysis status

- On simulation:
  - We did froze our work for few reasons:
    - Graduation of our student (Georgi);
    - Fix software framework – avoid doing same job double and triple times;
    - Find a full-time postdoc.
- On prototype beam data:
  - Analysis is ongoing by a group of people (mainly Geneva Uni and INR).
    - We are not involved, lack of man power.
  - We don’t follow the progress since summer both in MC and data analysis (not good).

SFGD Beam Data Analysis

- Two rounds of test beams:
  - June-July: Time Of Flight integrated in CITIROC readout, but rate was low (~100Hz).
    - Calibration not optimised.
  - August-September: TPC trigger system information integrated in CITIROC readout, no limitation on rate - up to 10 kHz.
    - Calibration done much more carefully.
    - Data used for further analysis

Data Analysis

The data collected during summer 2018 is believed to be sufficient to provide relevant feedback for the design of the SuperFGD to be installed in 2021 at the T2K ND280.

Three levels of data analysis:

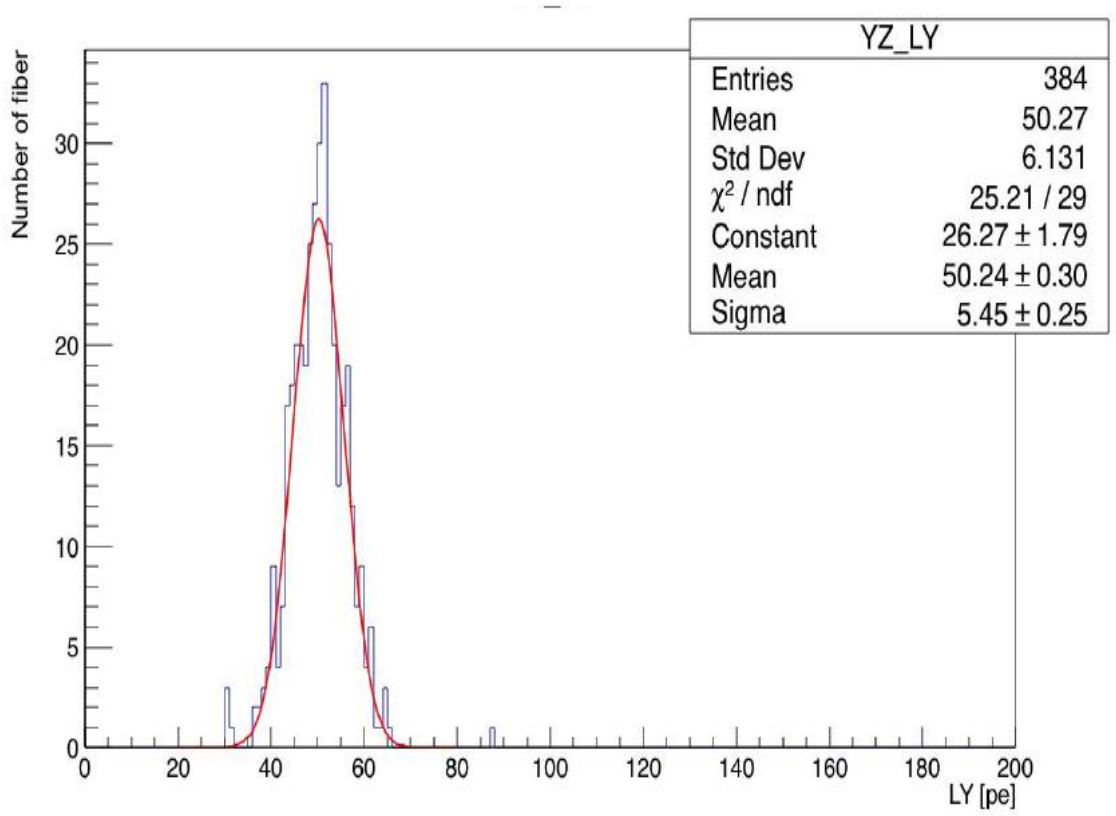
1. Basic detector performance: what we can study in terms of digitisation parameters and system limitations (understanding parameters, providing relevant digitisation parameters for simulations to convert raw energy deposition into hits based on plastic scintillator/WLS fiber/MPPC/electronics response).
2. Basic track reconstruction: capacity to identify tracks, and determine what type of particle produces each track based on simple cuts.
3. Pattern recognition: pattern recognition will require more advanced algorithms to sort different event types.

Level 1 Analysis status

Not yet started
Ongoing
Done

- **Calibration in photoelectrons** (HG, LG, ToT)
- **Channel uniformity**
- **Hit energy resolution of ToT** (resolve pi->mu->e decay from mu->e decay)
- **Data quality**
  - new firmware has been developed since beam tests to solve some issues, seems to be working well.
- **Hit efficiency per cube**
- **Time resolution**
- **Crosstalk**
- **Afterpulsing**
- **Saturation effects**
- **Stopping protons**
- **Event displays**

MIP Signal



Retrieved by selecting events synchronized with the trigger

Thoughts and plans

- To set up final near detector software framework.
  - No change until the end of the project.
- Integration with Ckov within common framework allowing track extrapolation and matching from one detector to other.
  - Synchronized efforts between teams.
- Stronger synergy with T2K sFGD upgrade
  - Our weakest point so far. We can benefit a lot.
  - Some efforts to participate in analysis of prototype data taken summer'18 ?
  - No man power in our group. Some volunteer?
- Consider another detector geometry: shifted cubes, scintillating slabs, WAGASCI-type?
  - Again man-power

- Manpower:
  - up to now ½ postdoc (Georgi Petkov)
  - to hire (and actually we're searching for) another full-time postdoc.

Thoughts and plans

- Set-up a detector project working platform or communication and sharing similar to Slack?
  - Available for Windows, Linux, via web browser.