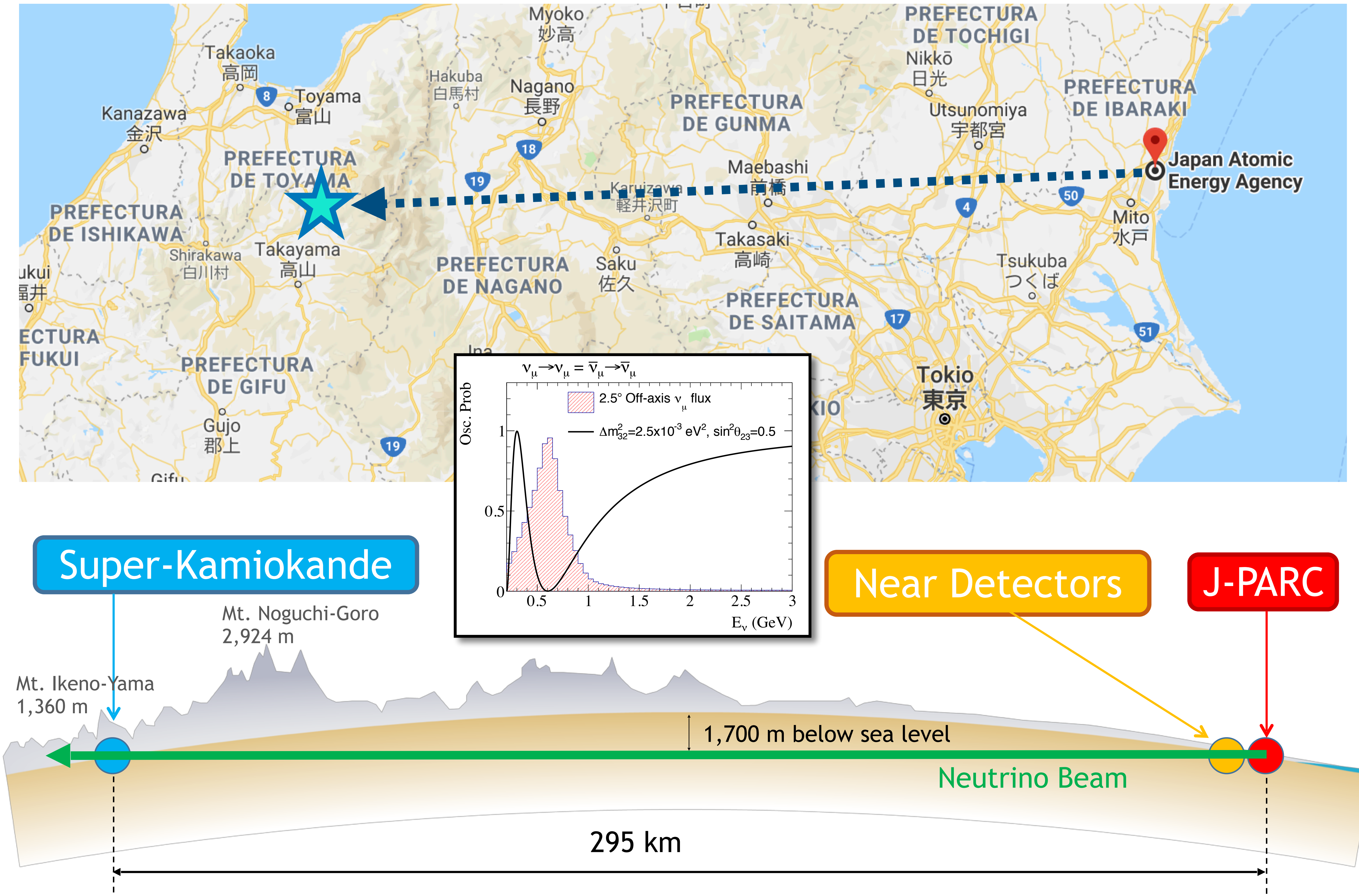
PIZZA SEMINAR

TPC beam test results for the ND280 upgrade

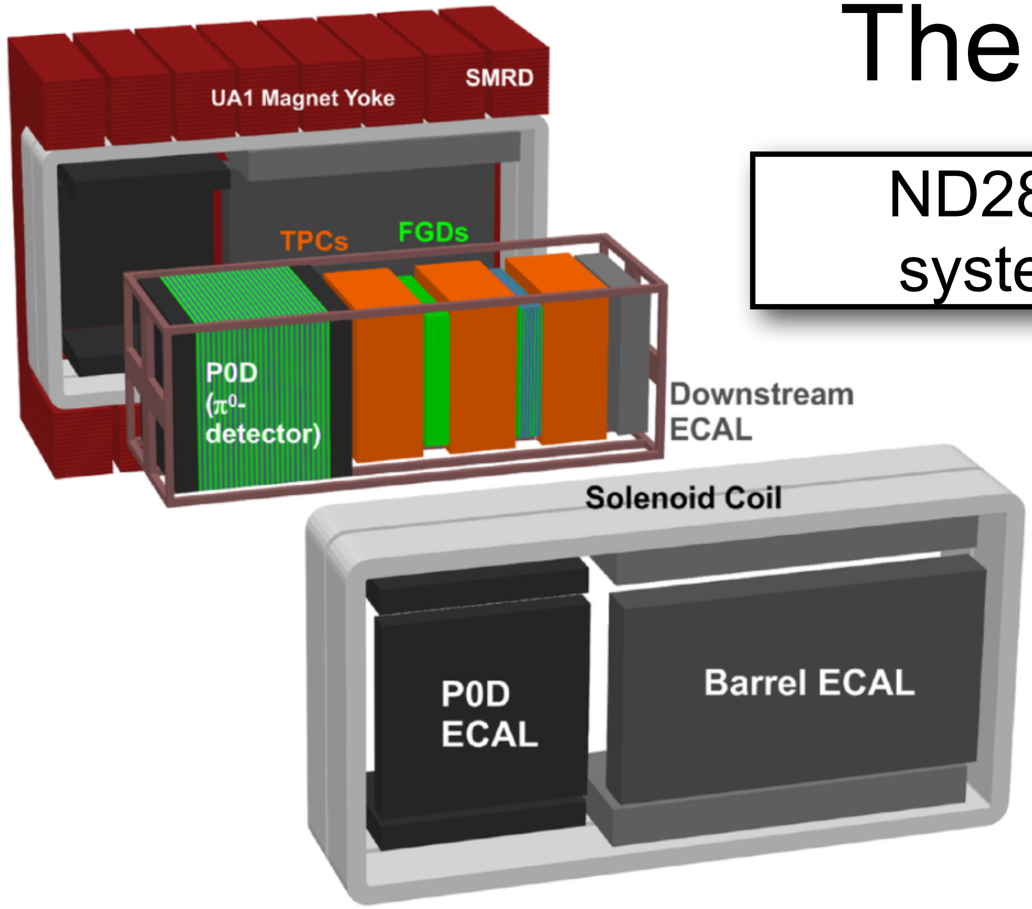
C. Jesús-Valls

T2K

The Tokai 2 Kamioka experiment



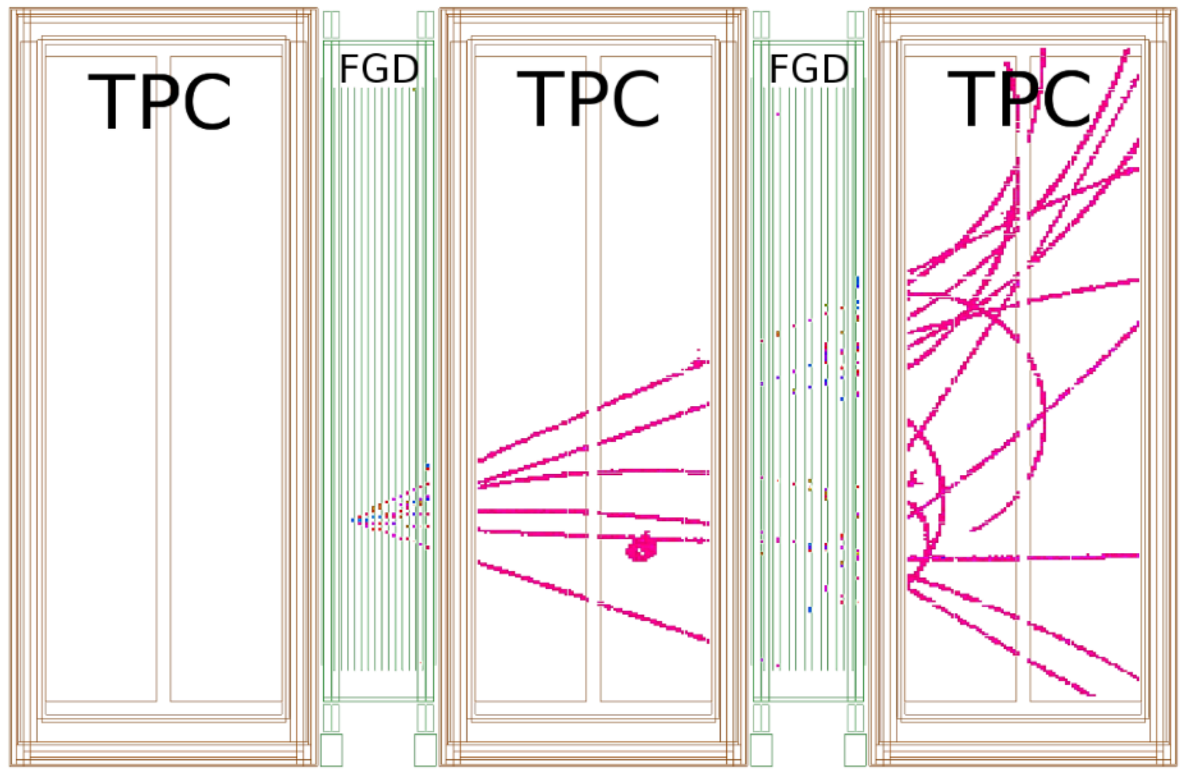
The current ND280



ND280 goal: Characterize neutrino flux, constrain systematics, learn about cross section modeling.

The basic idea of the detector is simple:

- Use FGDs as target.
- Measure tracks in TPC.
- Use magnet to curve tracks.
- Ignore extra stuff for this talk.



FGD (Fine grained detector)

- Bars of plastic (or water) with fibers that collect the light.
- Staggered in 2D.
- Limited tracking resolution.

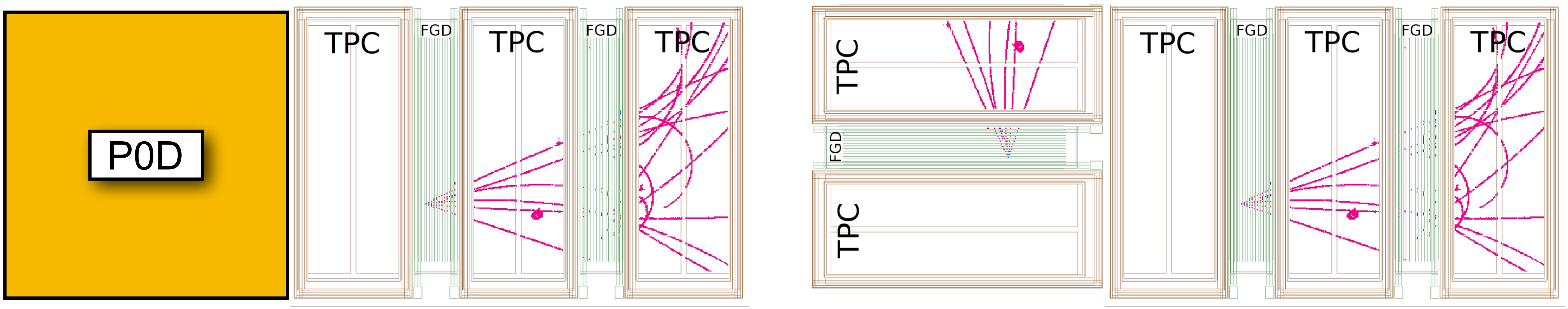
TPC (Time projection chambers)

- Gas volume boxes with electric field.
- Tracks are reconstructed on the anode.
- Good tracking resolution.

The upgraded ND280

ND280 Current: Very good for forward going tracks, limited for vertical tracks.

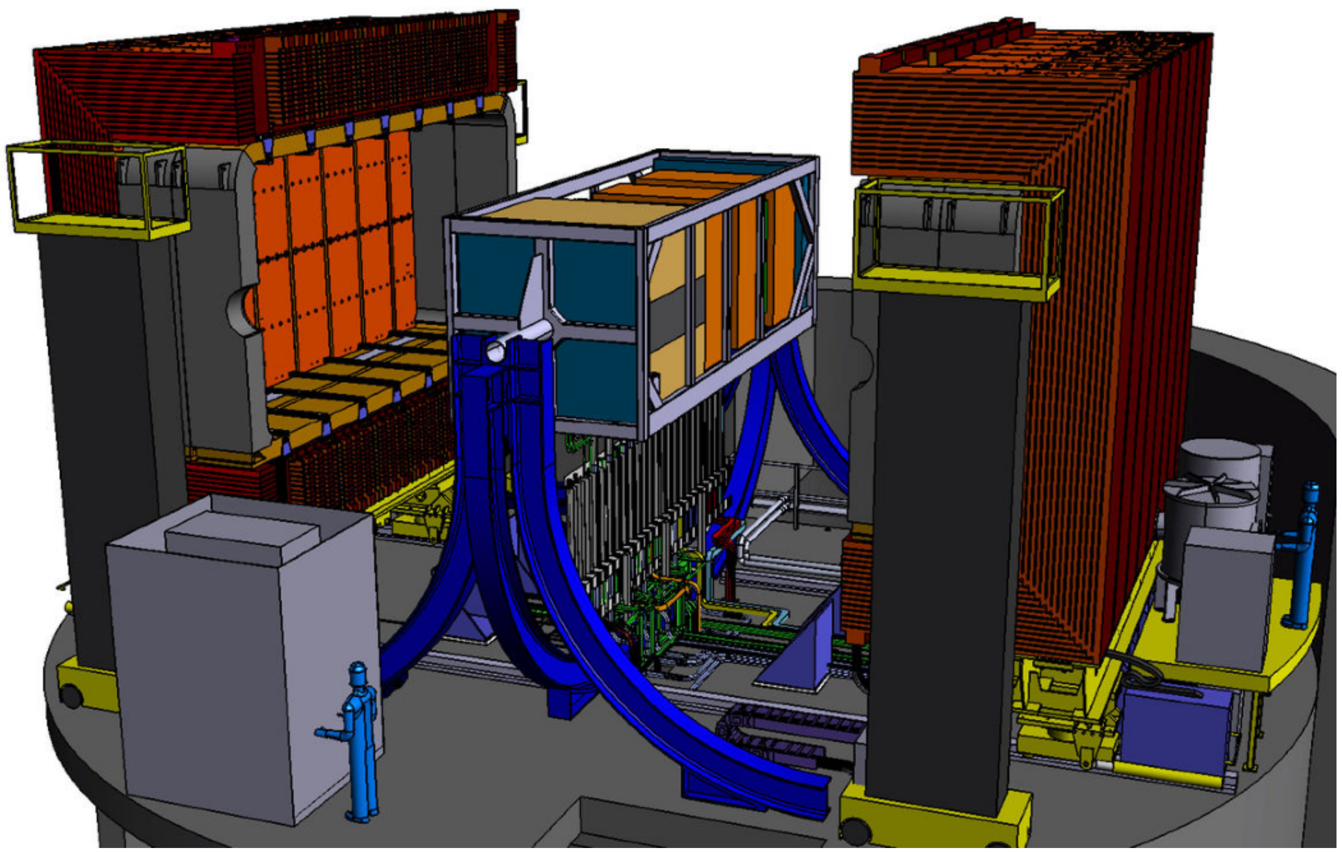
Solution: Remove P0D and copy the FGD + TPCs rotated 90º.



Let's try to do it better:

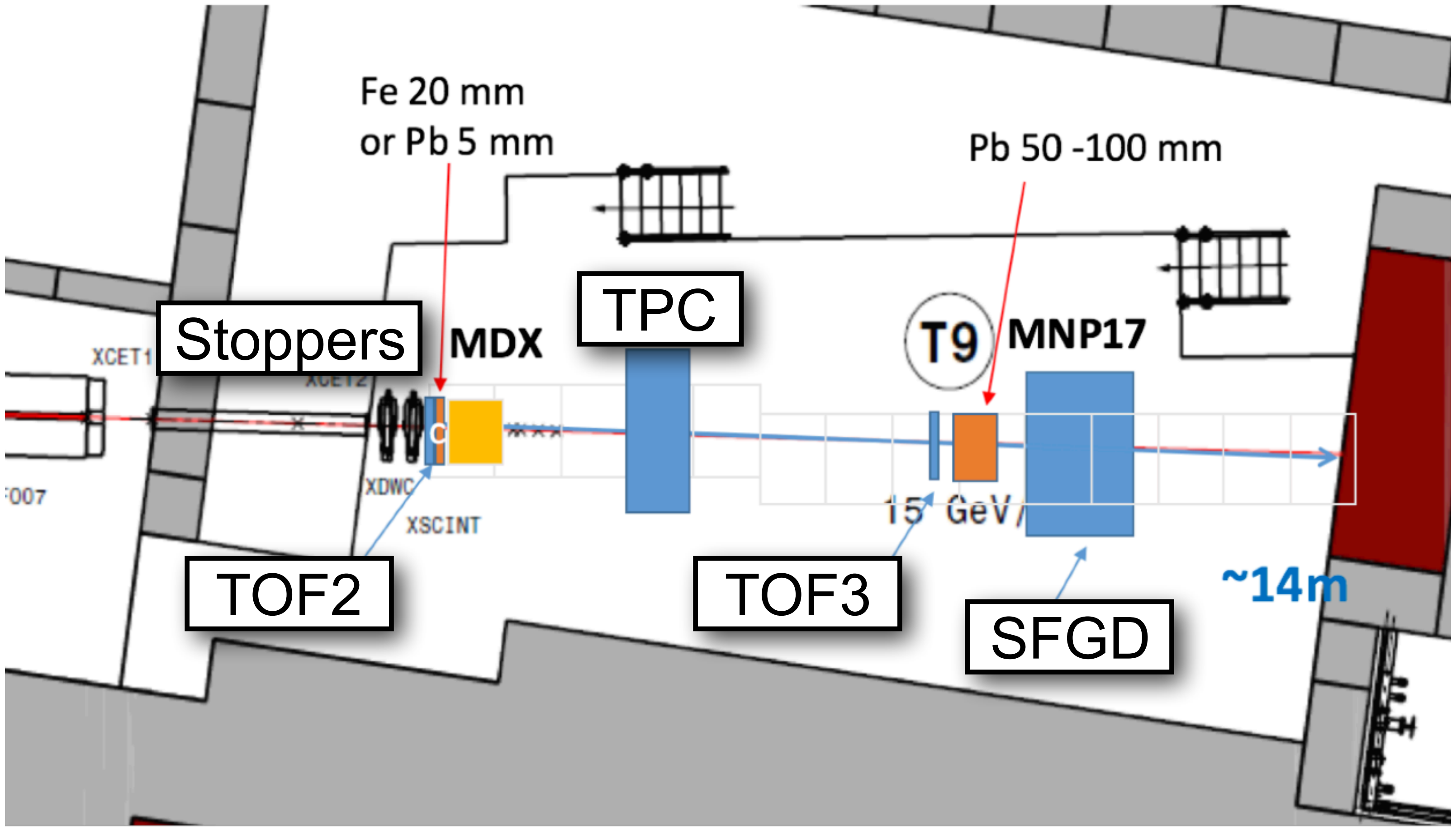
- Current FGD are 2D, let's do the new FGD 3D… and we will call it SFGD!
- Build TPCs with thinner field cage to maximize available sensitive volume.
- Improve read-out by testing new system: The resistive bulk MM.

All this talk is about.

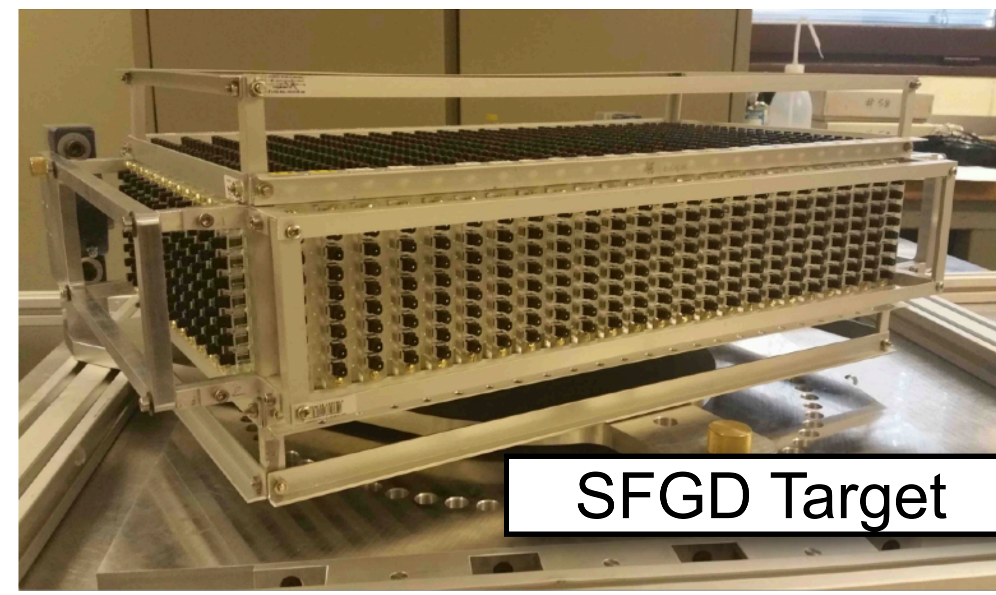


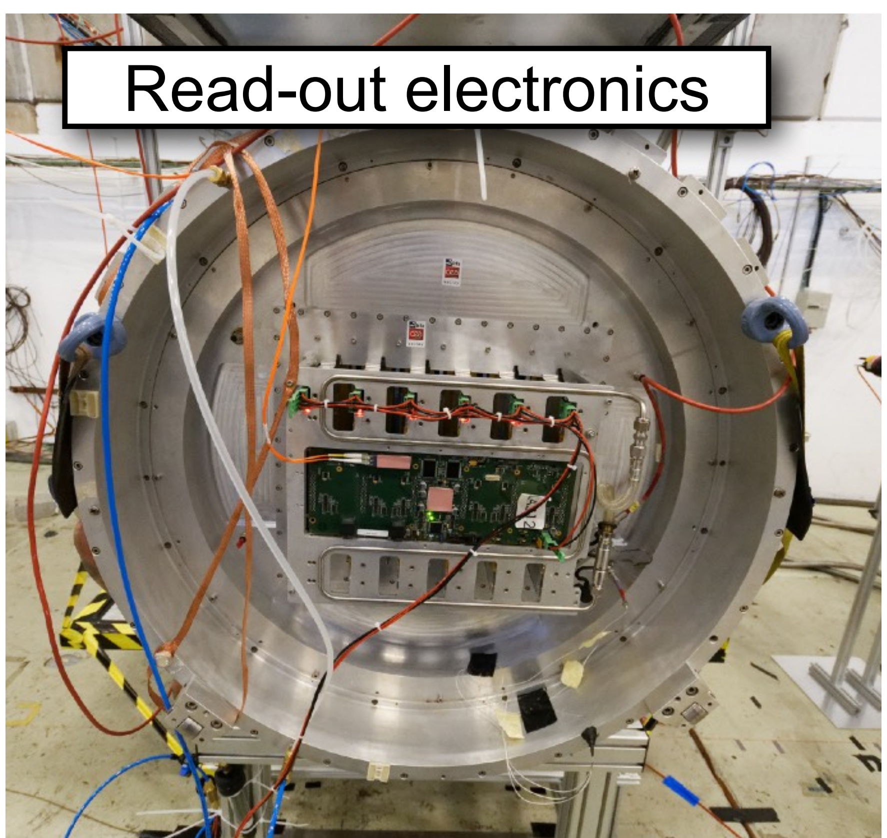
2018 BEAM TEST

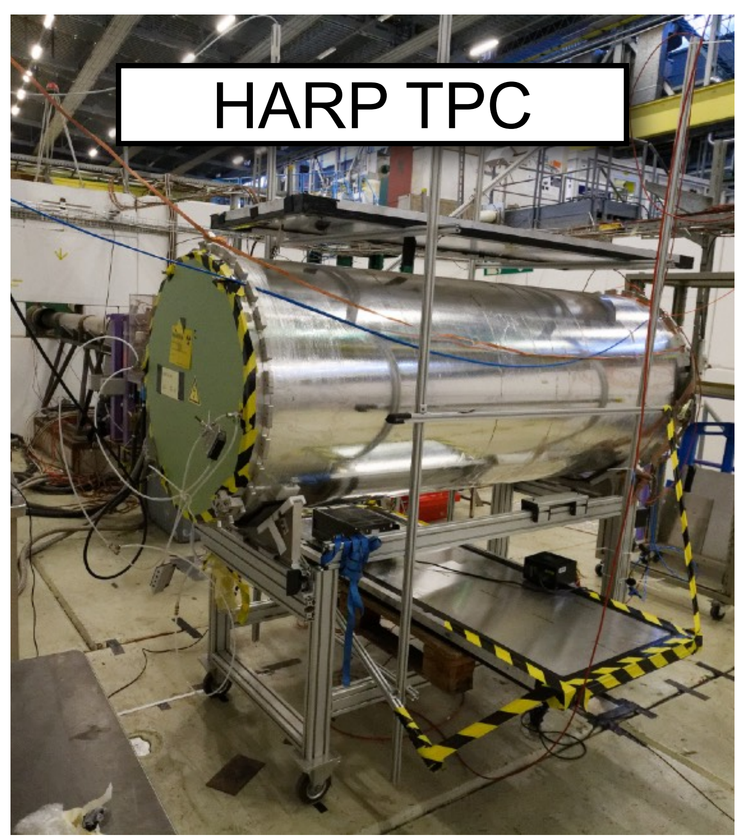
BEAM TEST AREA

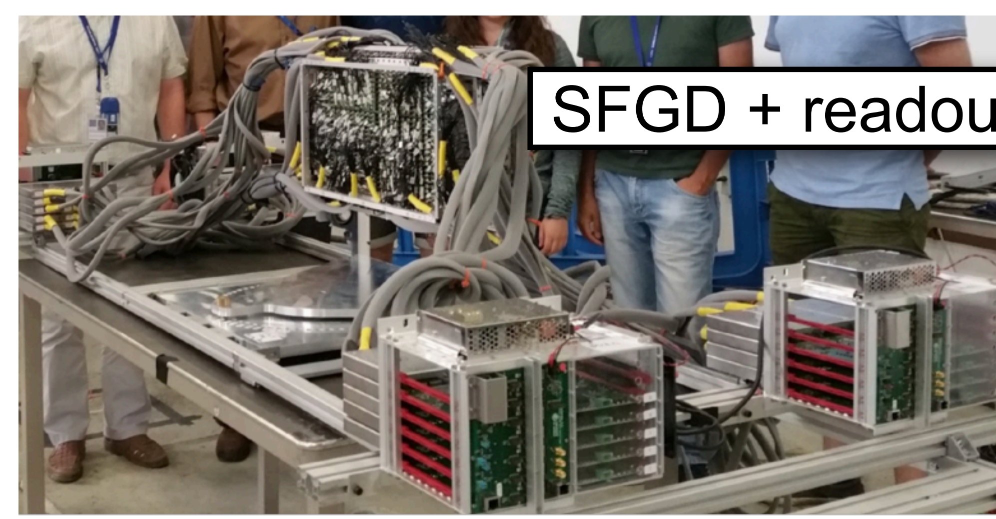


CERN T9



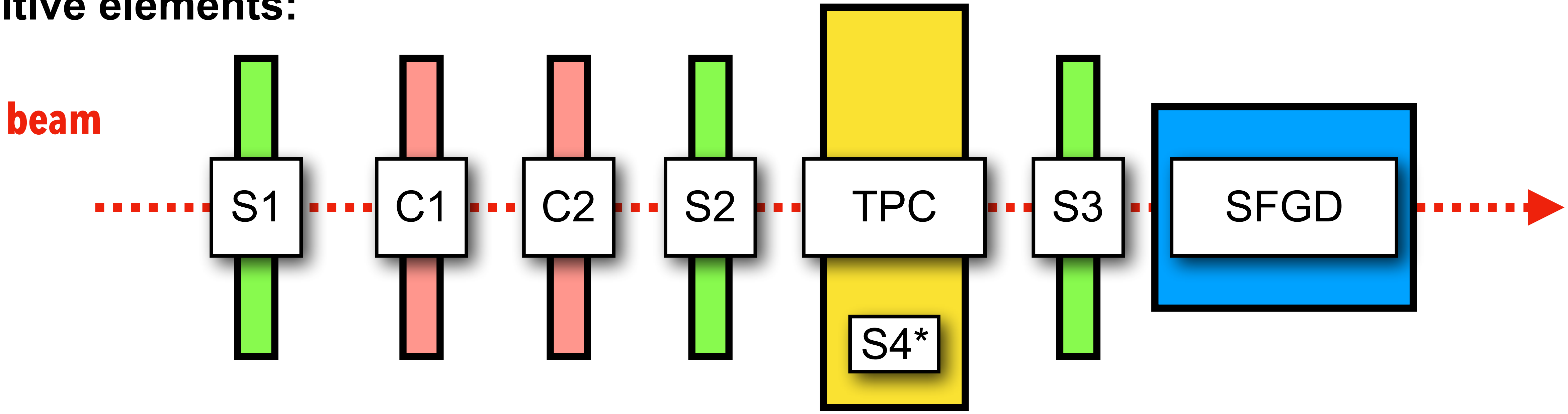




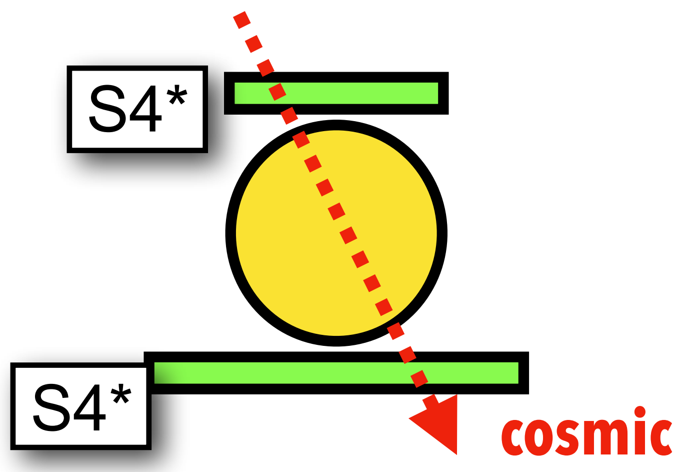


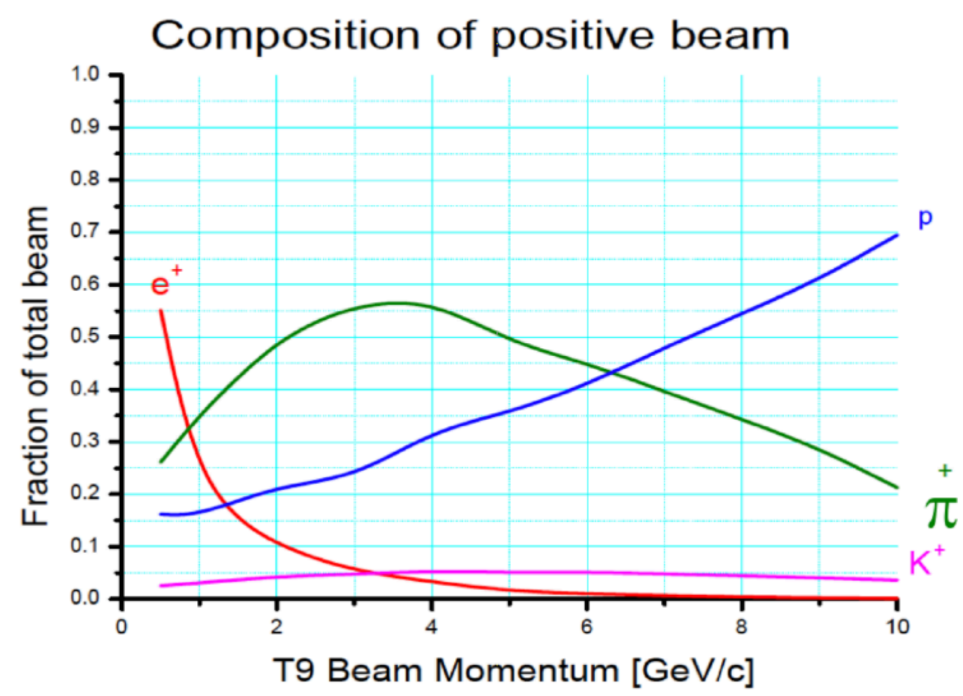
Trigger system and data sample

Sensitive elements:



Detail on cosmic trigger:



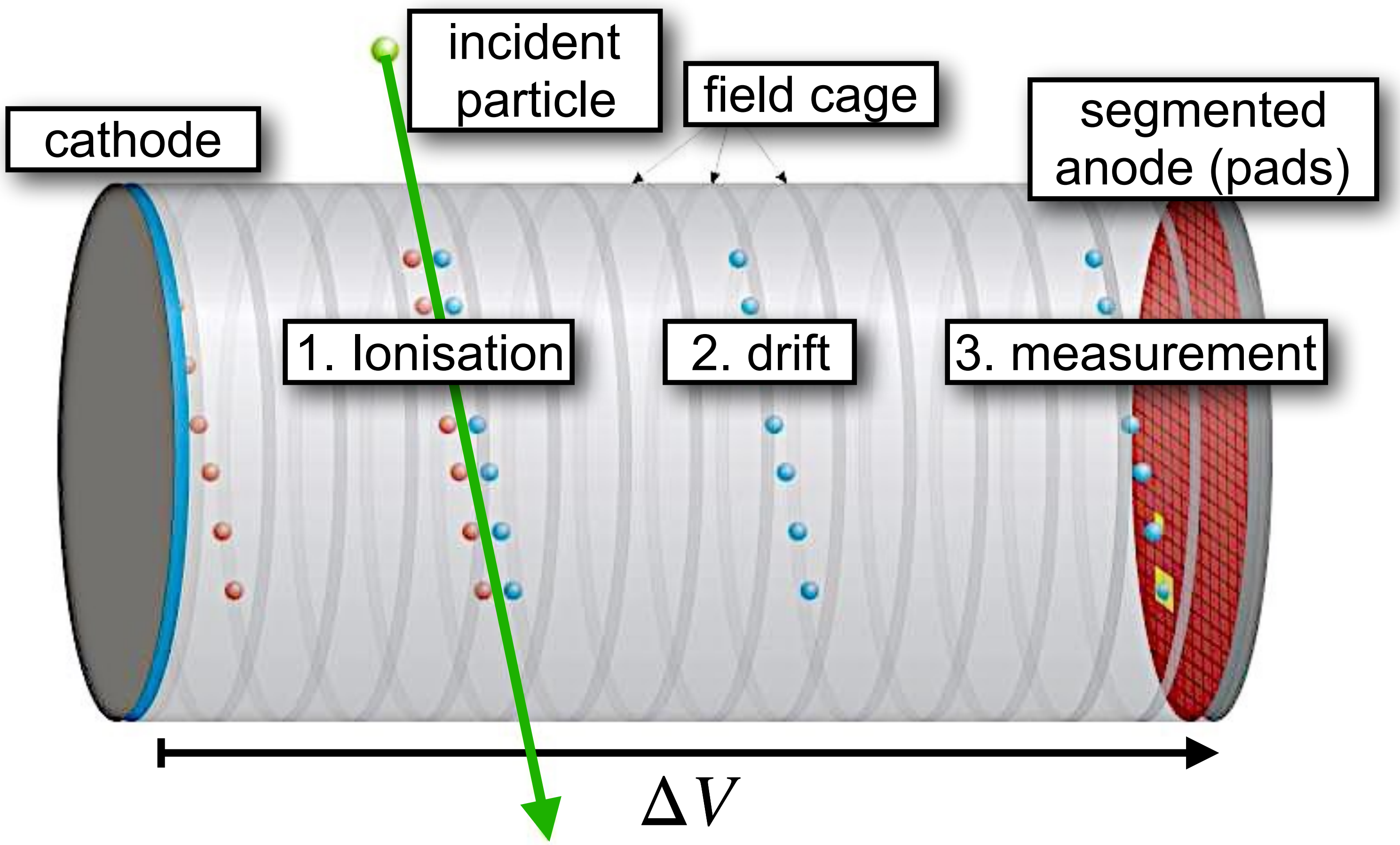


Which triggers:

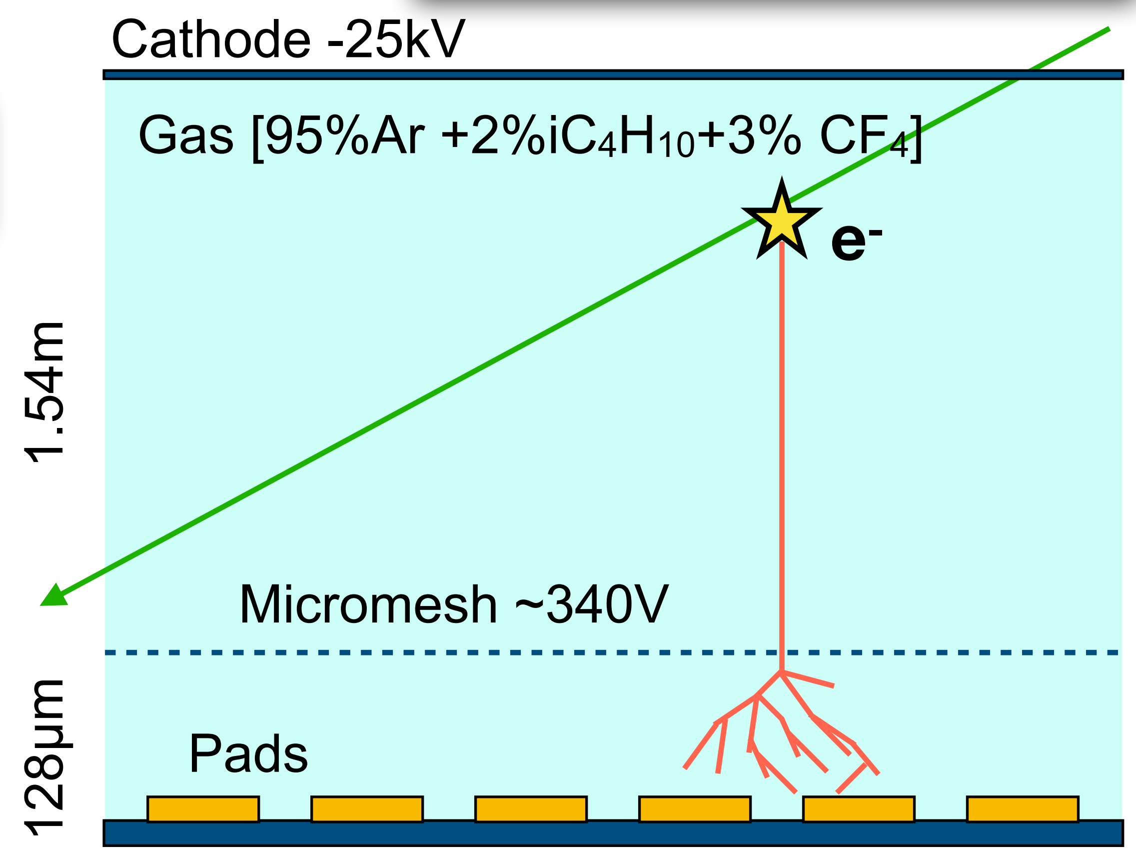
- **Positrons** = Scintillators +Cherenkov
- **Protons (+ kaons)** = S1_delayed + S2 (delay ~ proton TOF between S1 and S2)
- **Pions (+ muons)** = Scintillators + not_protons+ not_positrons
- **Cosmics** =S4* but only out of spill. Downscaled to have a balance beam:cosmic~1:7.

From tracks to analog signals

TPC working principle

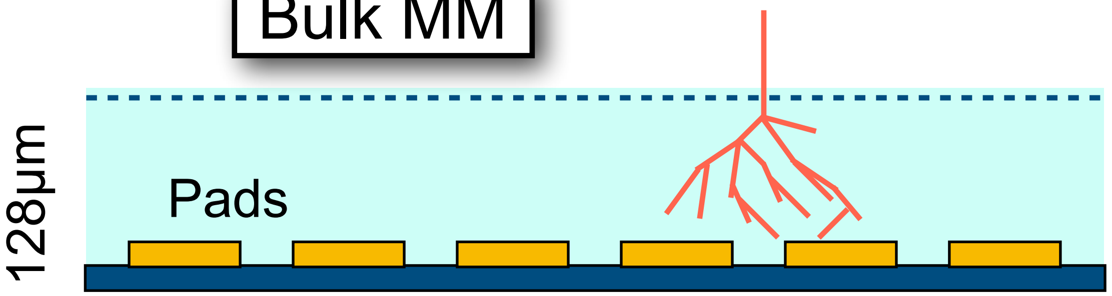


e⁻ drift and amplification



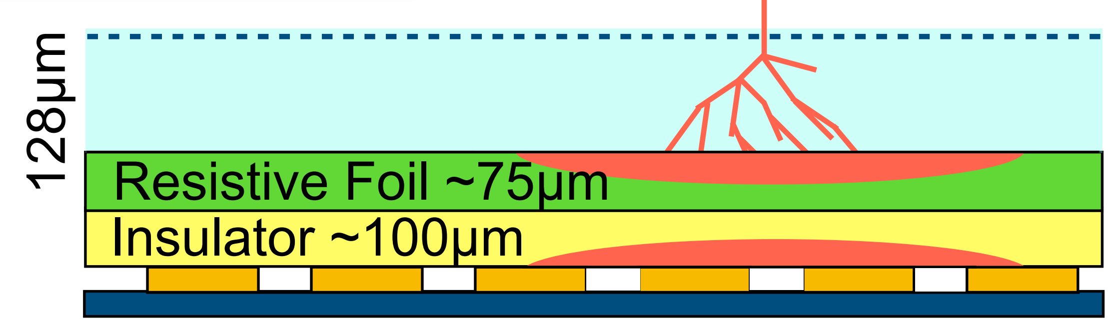
New MM concept:

Bulk MM

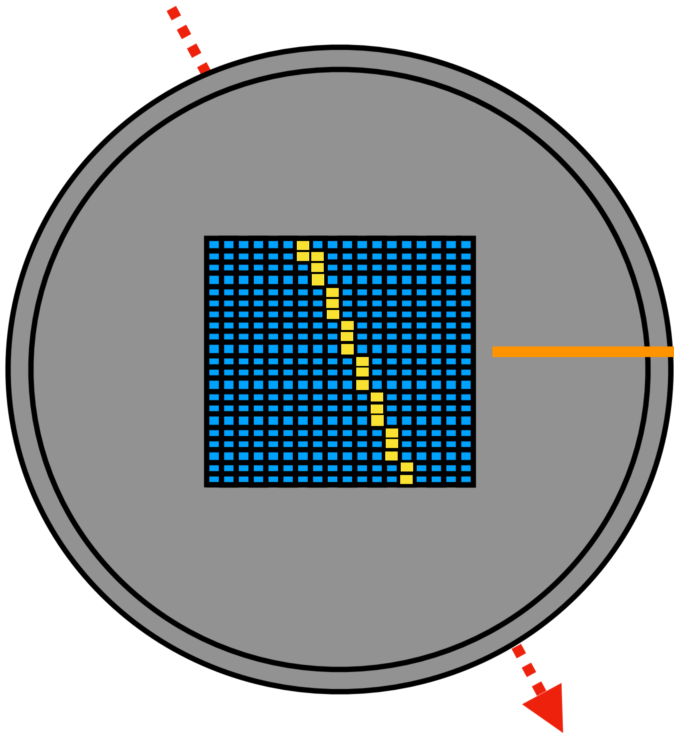


Resistive Bulk MM

$$\rho(r,t) = \frac{RC}{2t} e^{-r^2 RC/4t}$$



From analog signals to digital outputs



Tested (MM0)

MM size ~34x36cm^2

Resistivity: 2.5MΩ/square

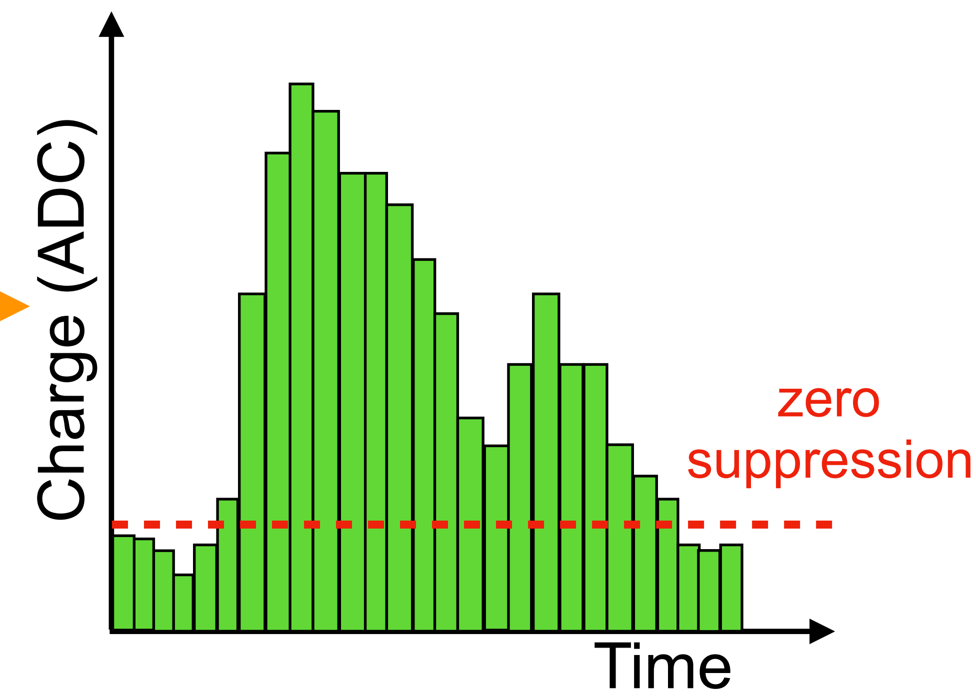
1728 pads of 7x9.8mm^2

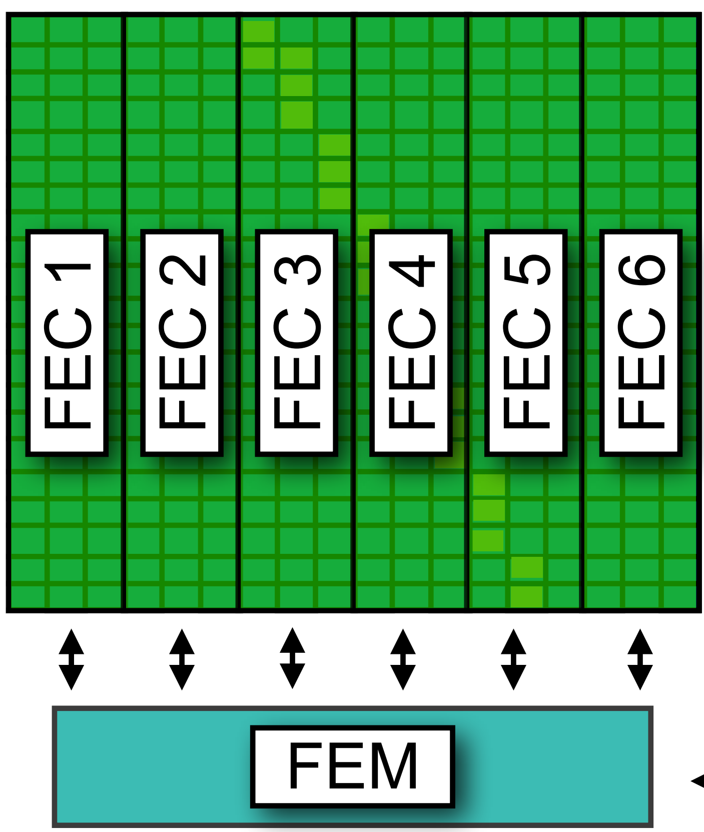
Final (MM1)

1728 pads of 1x1.1cm^2

MM size ~34x36cm^2

Resistivity: 0.4MΩ/square





FEC

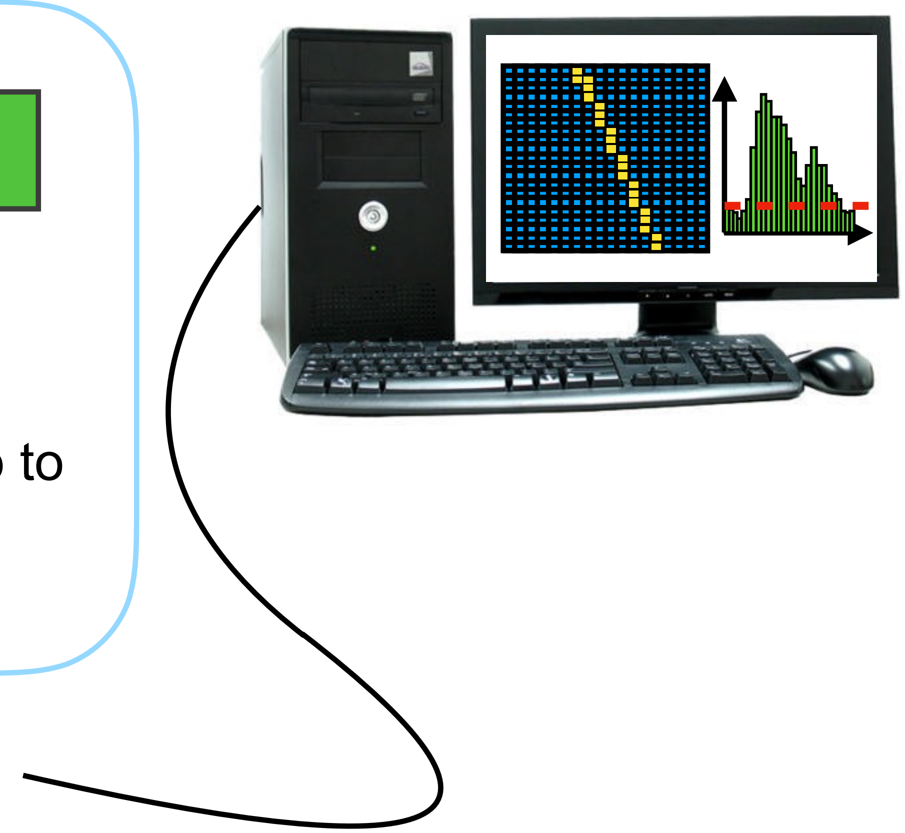
AFTER CHIP | AFTER CHIP | AFTER CHIP | AFTER CHIP

AFTER

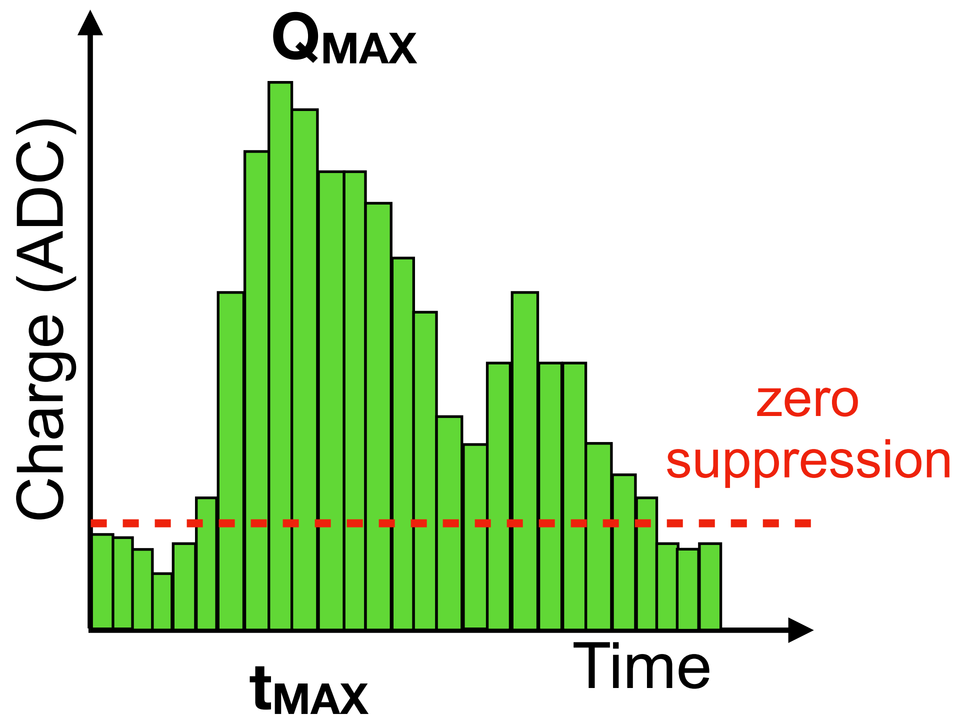
- 72 chanels
- 511-Bin Switch Capacitor Array.
- Variable sampling frequency (Up to 50MHz)
- 12 bit ADC

Optical link

DCC (FPGA)



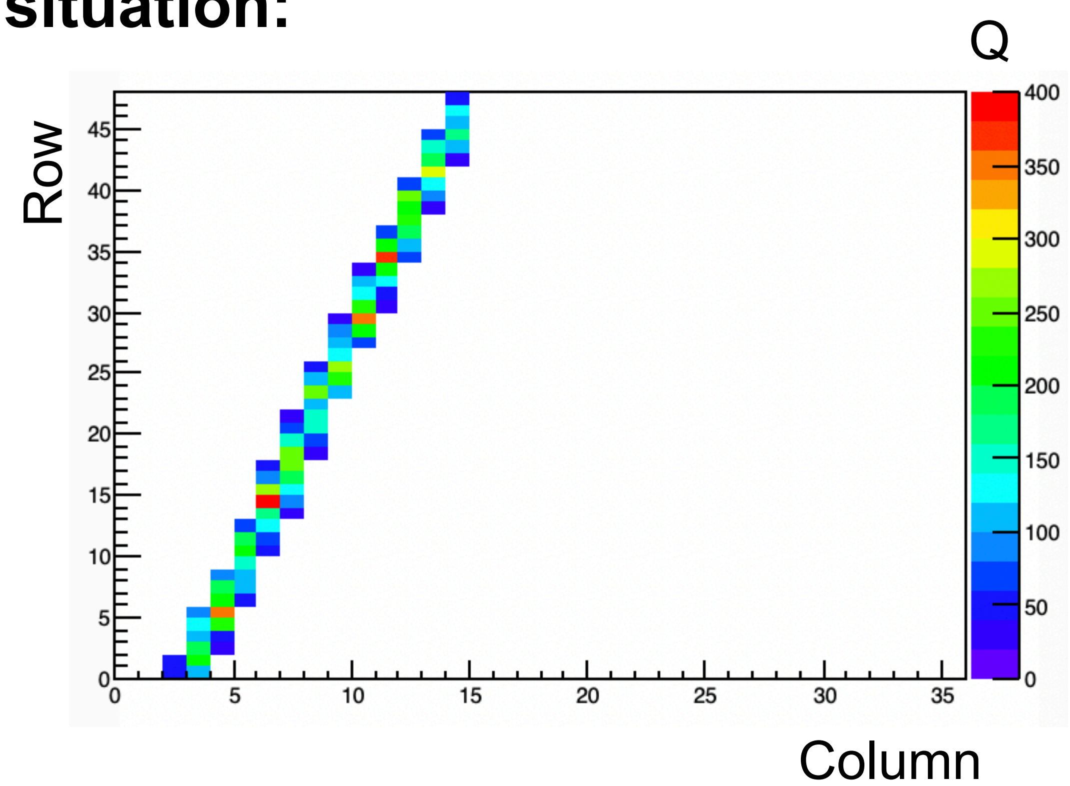
From pads to tracks (selection and reconstruction)

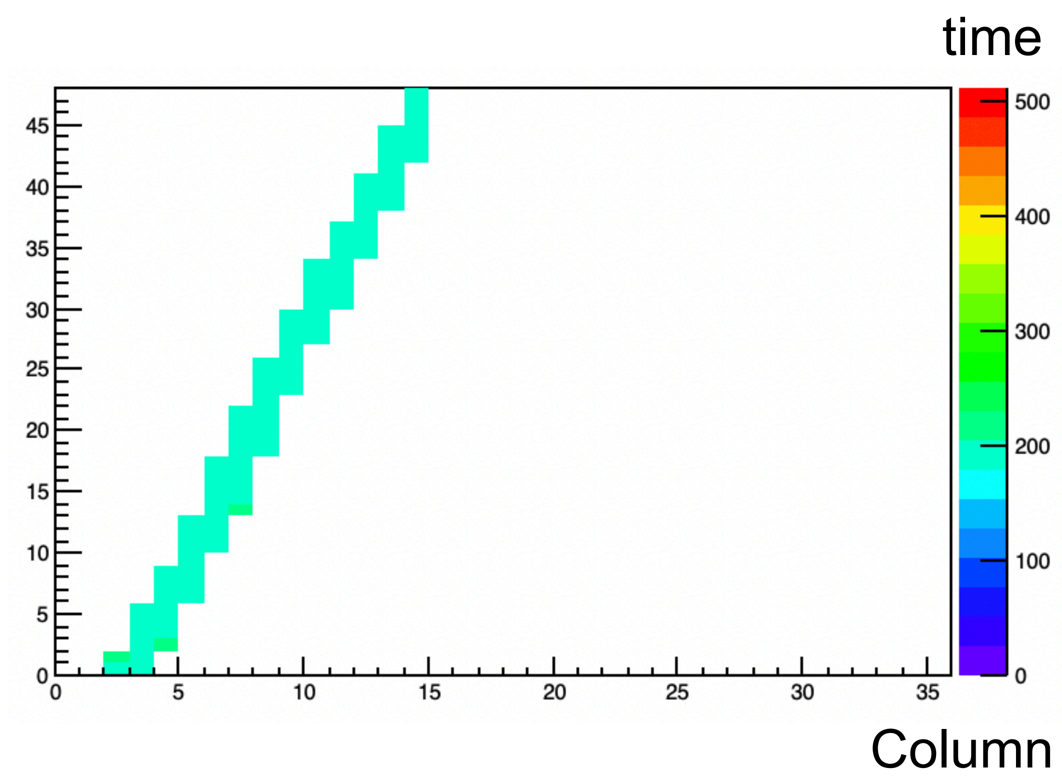


- Bin content is in reality integrated charge in a $t_{shaping}$ window.
- For most of the data samples $t_{shaping}$ = 600ns.

STRATEGY:
Find tracks in a 2D plane at $t=t_{max}$.
Assume all charge collected in $t_{shaping}$.

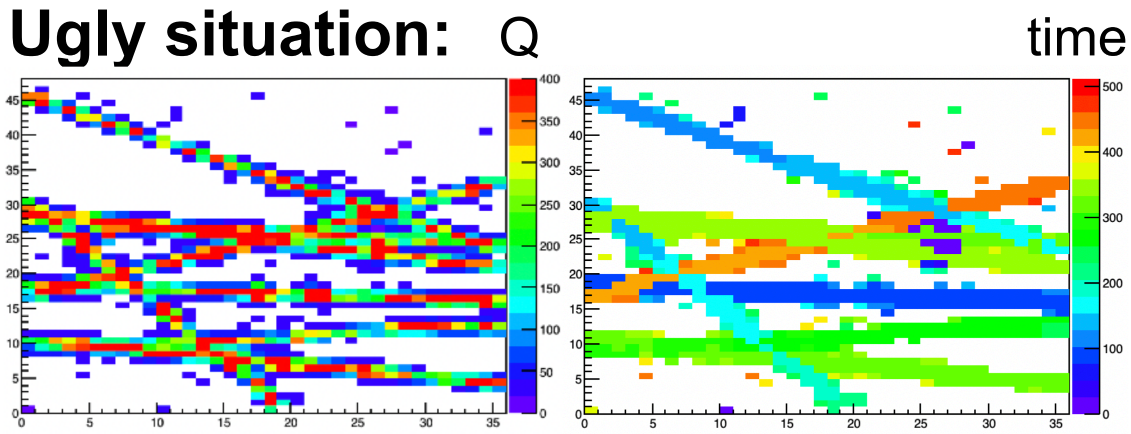
Ideal situation:



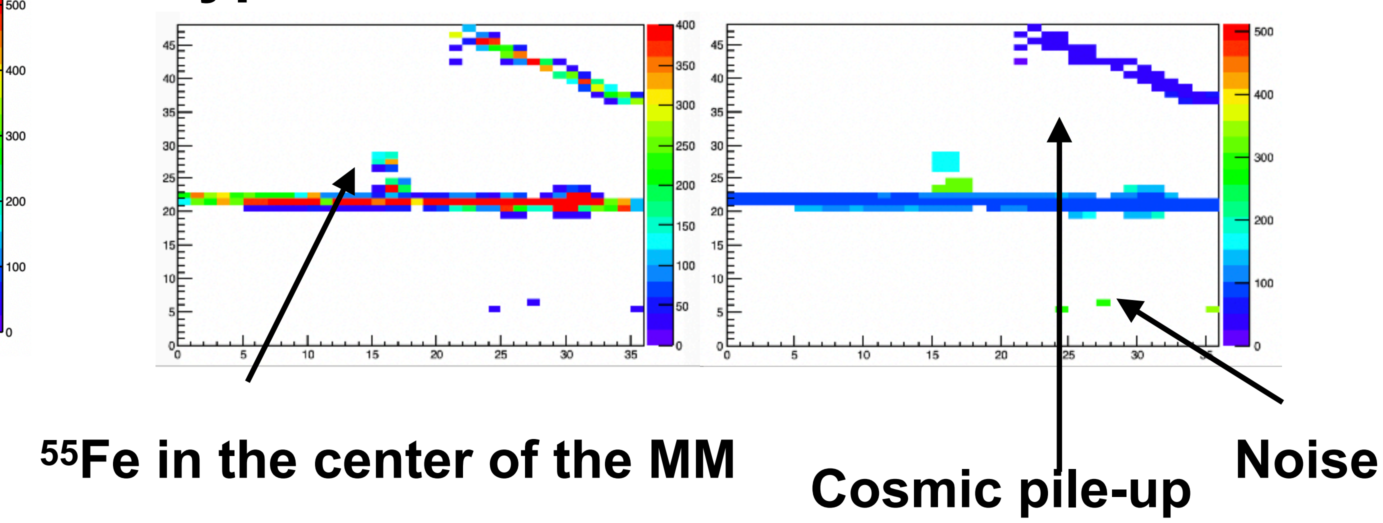


From pads to tracks (selection and reconstruction)

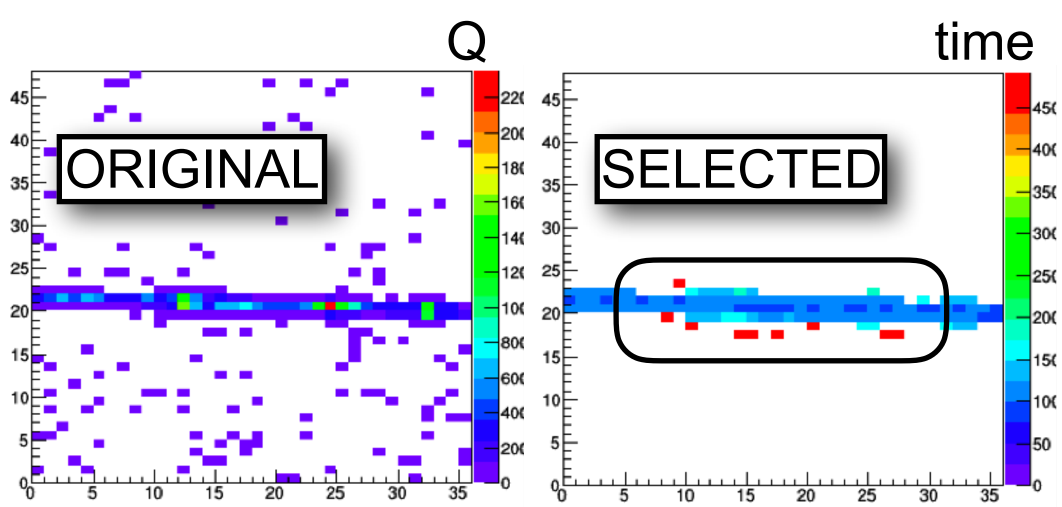
Ugly situation:

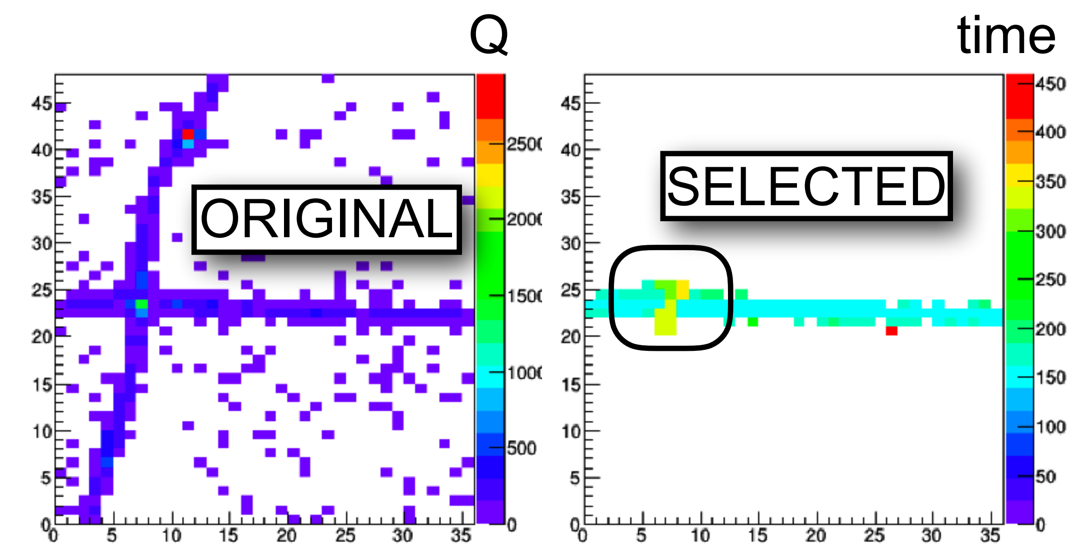


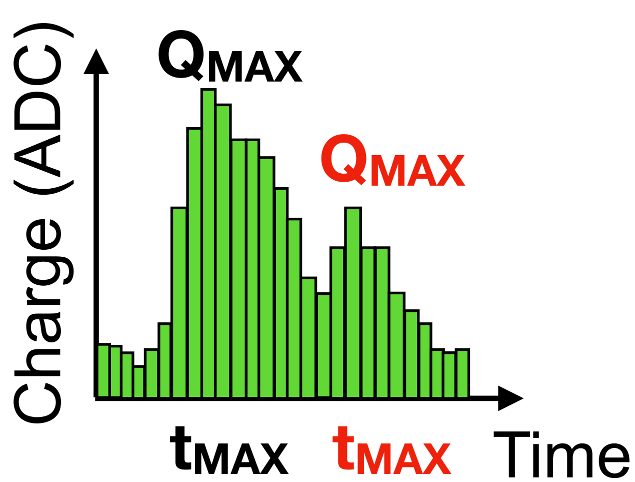
'Typical' event:



Potential problems:







When there is overlapping (usually) the selection has to be able to switch to a different Qmax or to not select the pad.

From pads to tracks (selection and reconstruction)

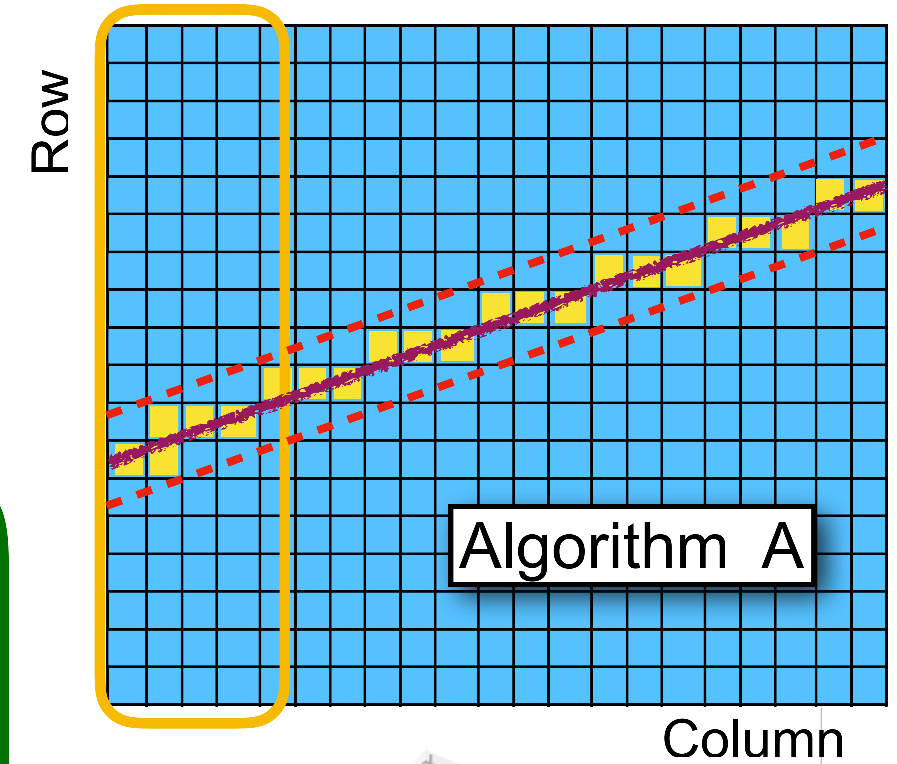
CLUSTERING :

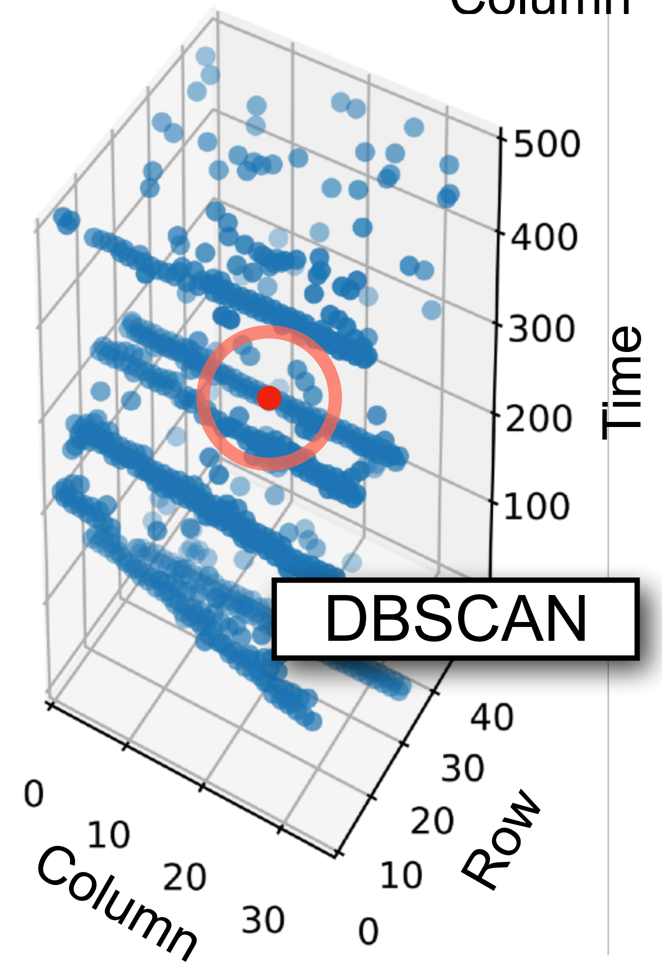
- Look for a cluster on first or last columns (rows).
- Linear fit.
- Pads around extrapolated fit.
- Fit quality.

Algorithm A

- 1: Take a candidate pad, search M pads closer than a distance D.
- If '1', add pad to cluster and add the pads closer than D ass cluster candidates.
- If any pad candidate is missing, end cluster and start a new one (random candidate without cluster)

Algorithm B: DBSCAN





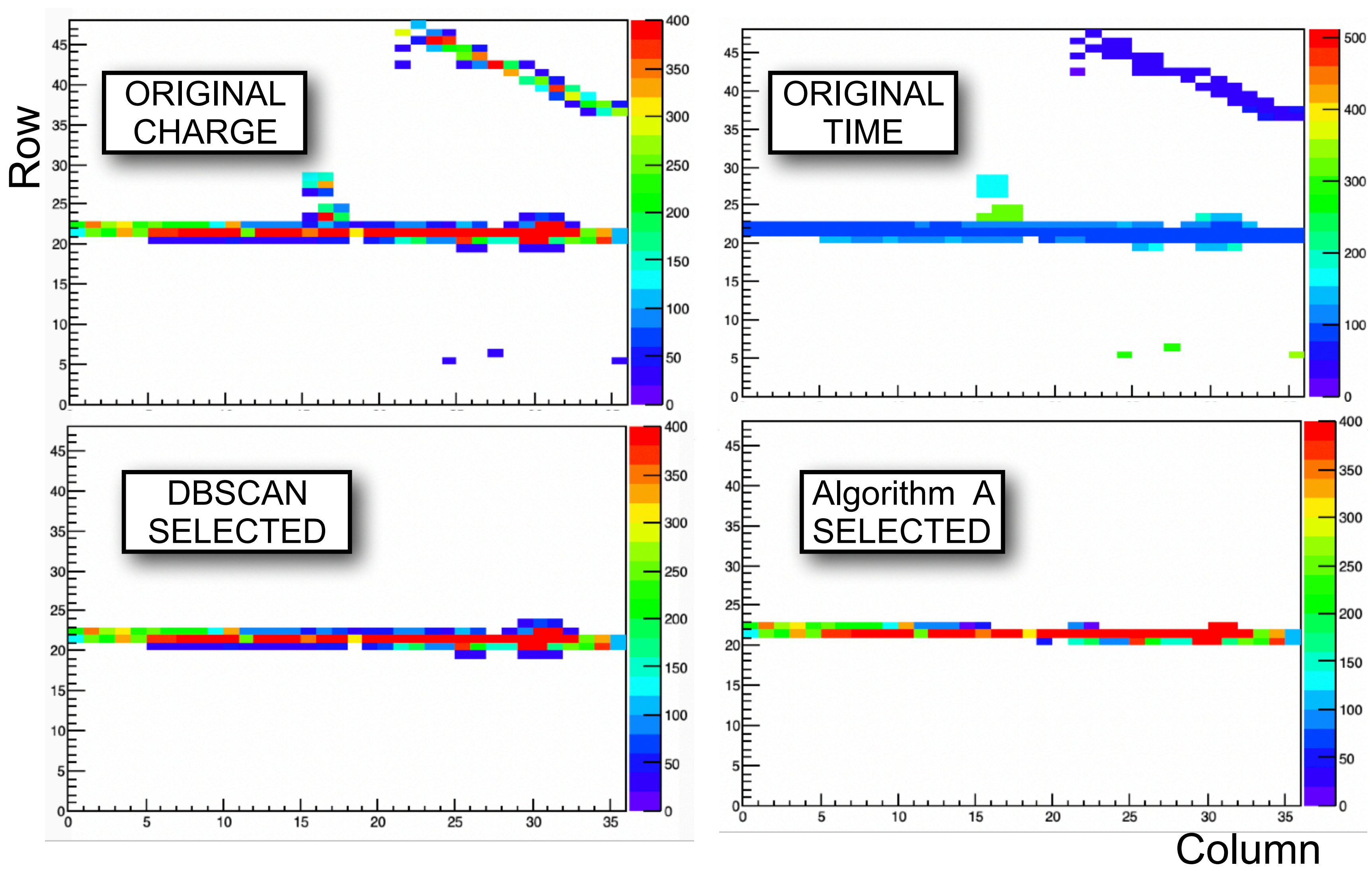
TIME FILTER & SAFETY:

Different for each Clustering

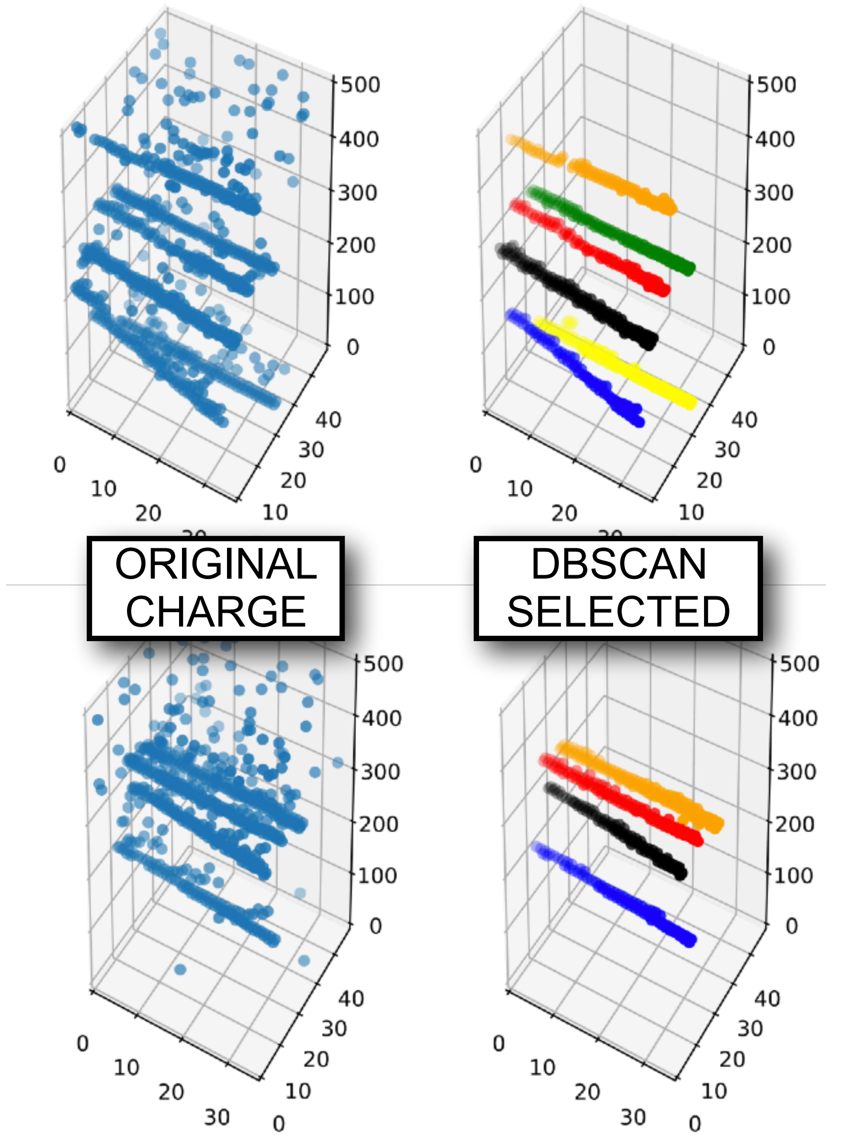
- Cuts on max & min number of selected pads
- Cuts on min number of columns (rows), to avoid holes.
- Check time of neighbor pads change to other t_{MAX} and Q_{MAX} under certain conditions.

From pads to tracks (selection and reconstruction)

Selection on typical event:

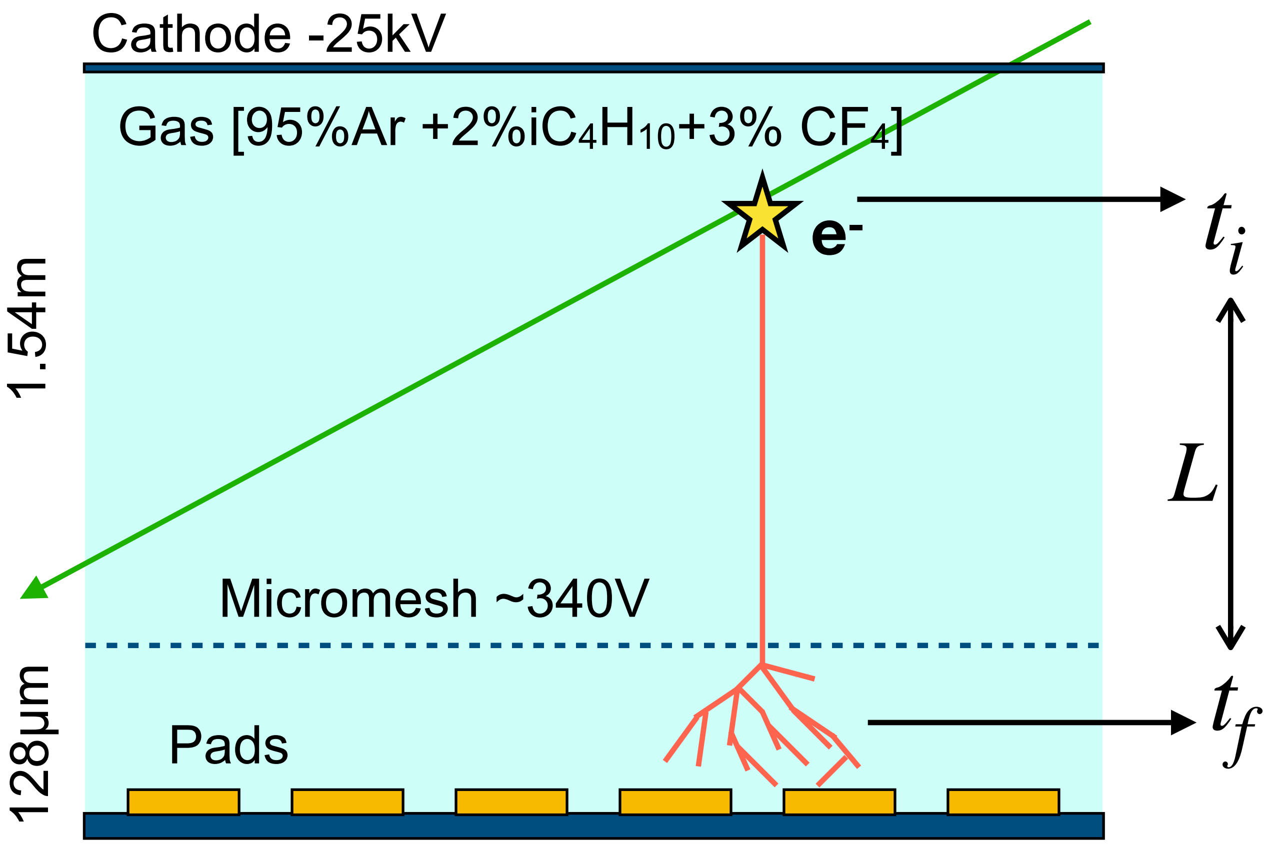


DBSCAN potential:



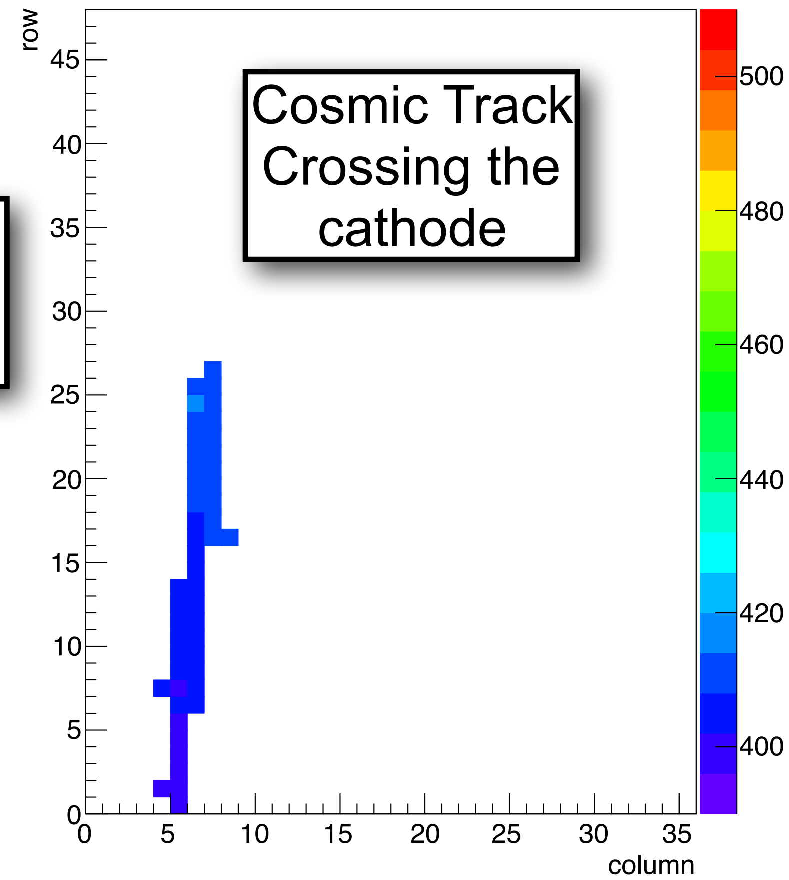
- Both selections have similar selection efficiency.
- Algorithm A is safer (DBSCAN is not physical and depends a lot on time-cuts and safety conditions).
- We decided to take the safest option, and develop it together with resolution studies.
- DBSCAN has proved to be very powerful and will be tested for future analysis.

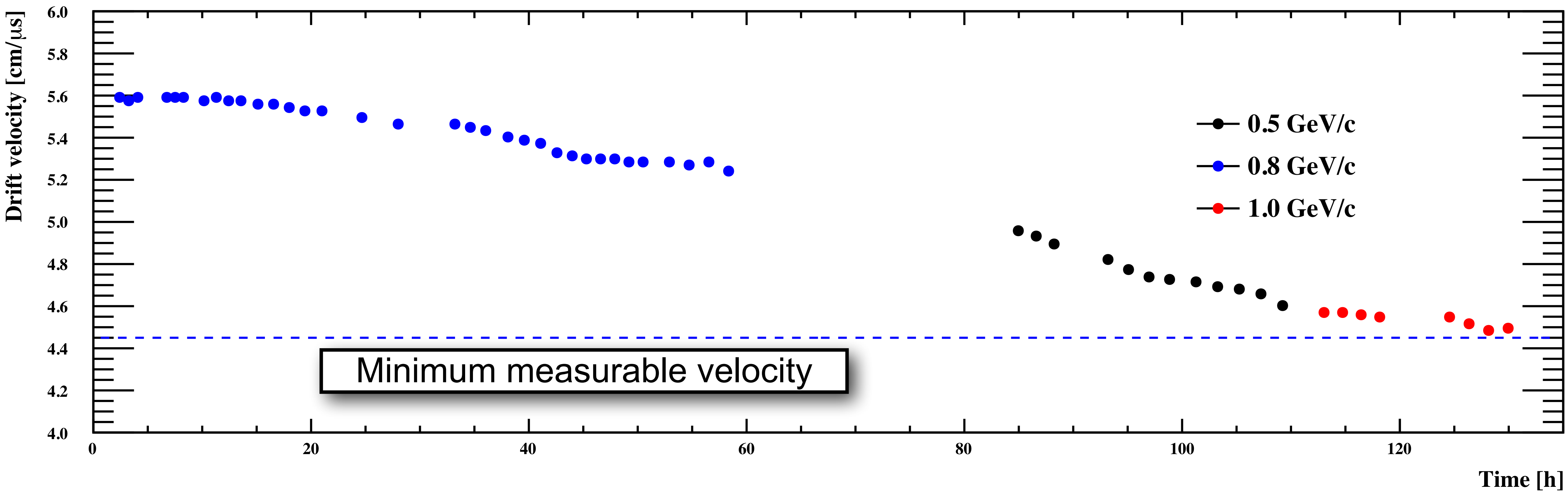
Experimental conditions (Drift velocity)



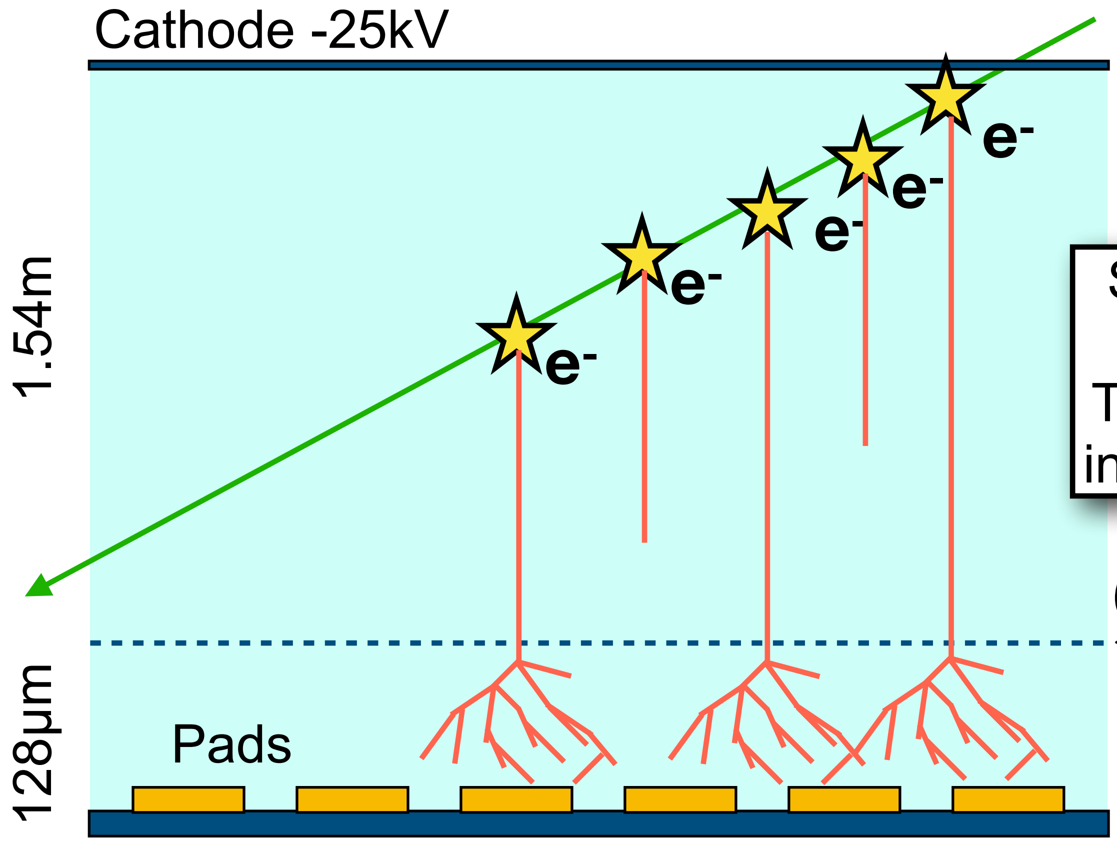
Can be computed from tracks crossing both ends of the chamber:

$$v_{drift} = \frac{L}{t_f - t_i}$$



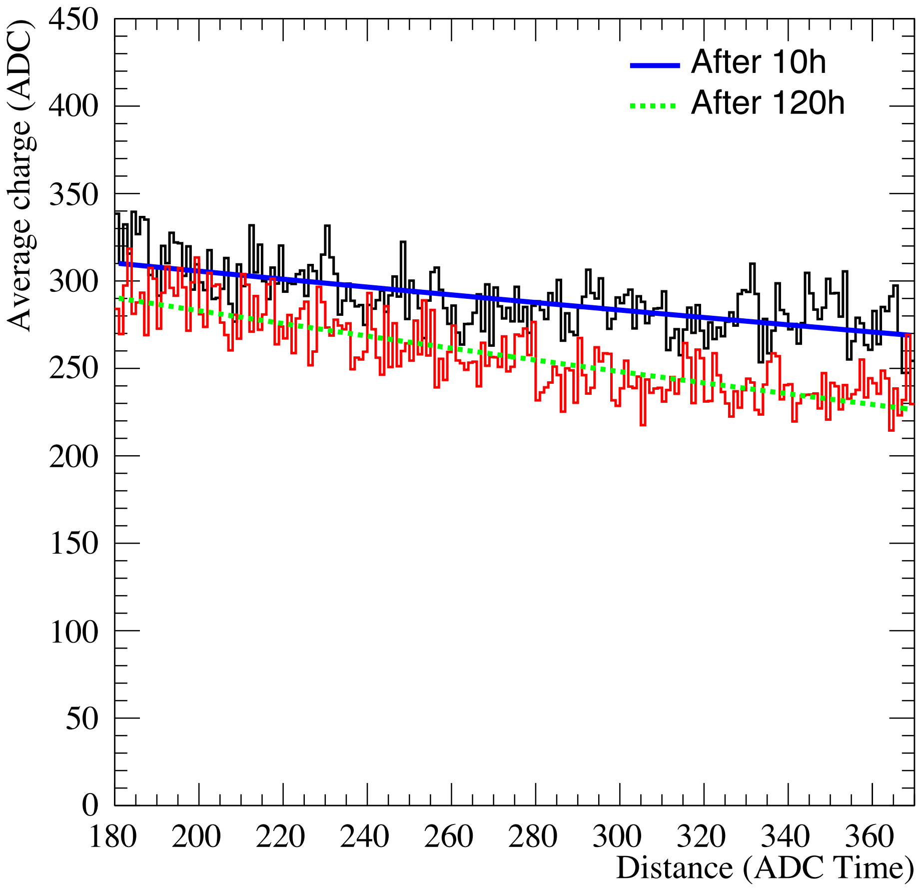


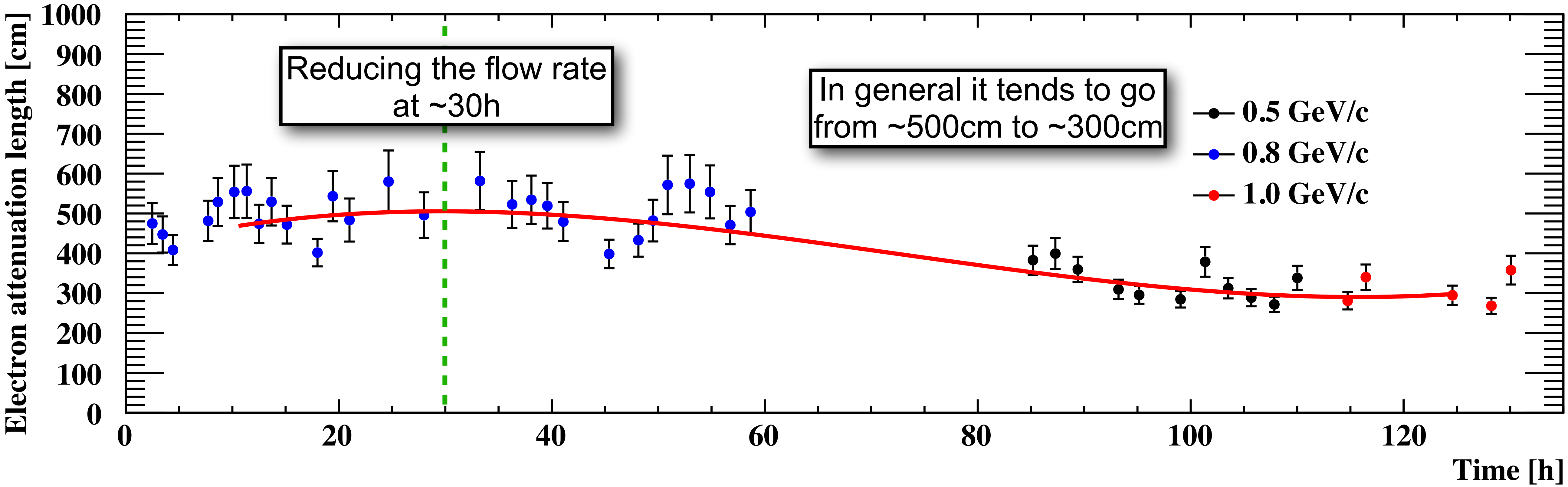
Experimental conditions (Charge attenuation)



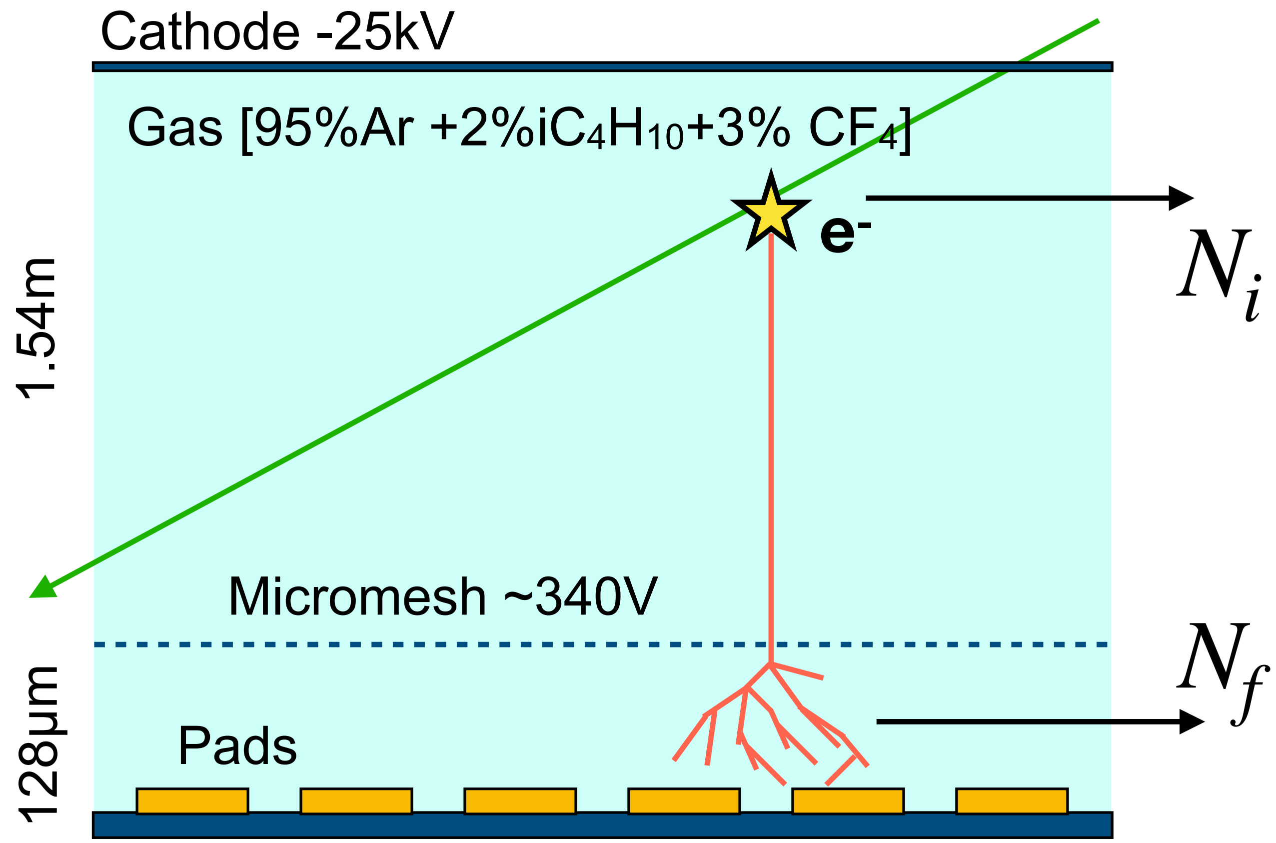
Some of the electrons are attached to O_2. The charge attenuation increases with distance.

$$Q = Q_0 e^{-x/\lambda}$$



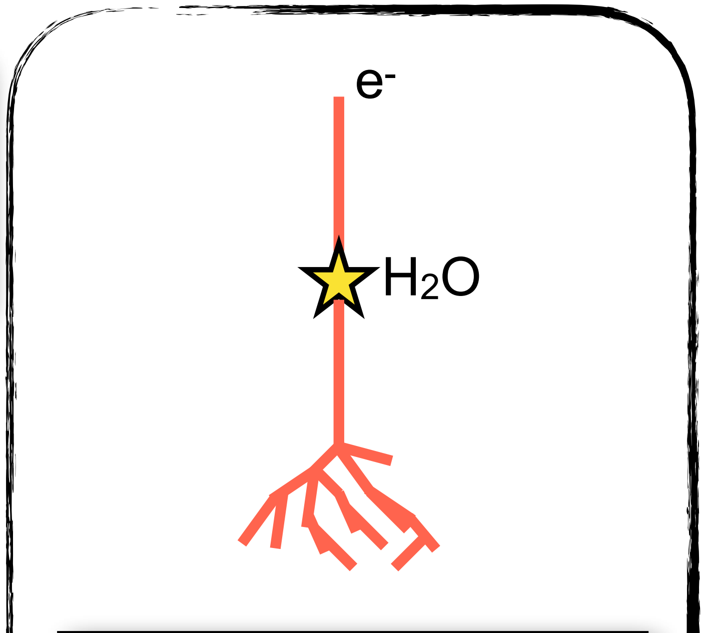


Experimental conditions (Absolute Gain)

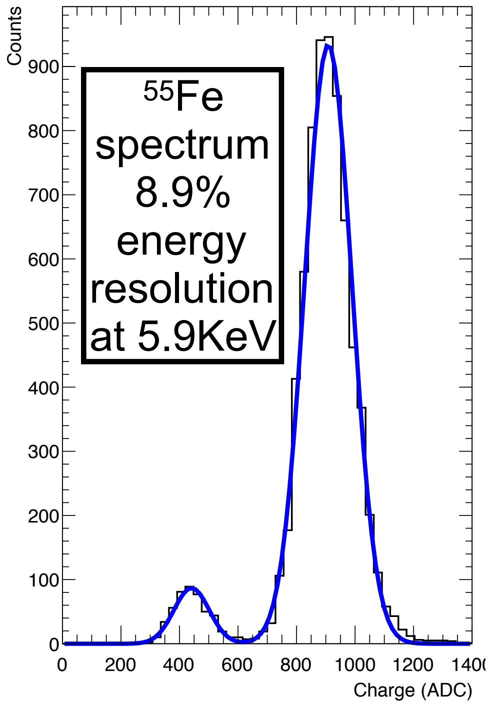


The initial number of electrons N_i generates N_f electrons after the avalanche.

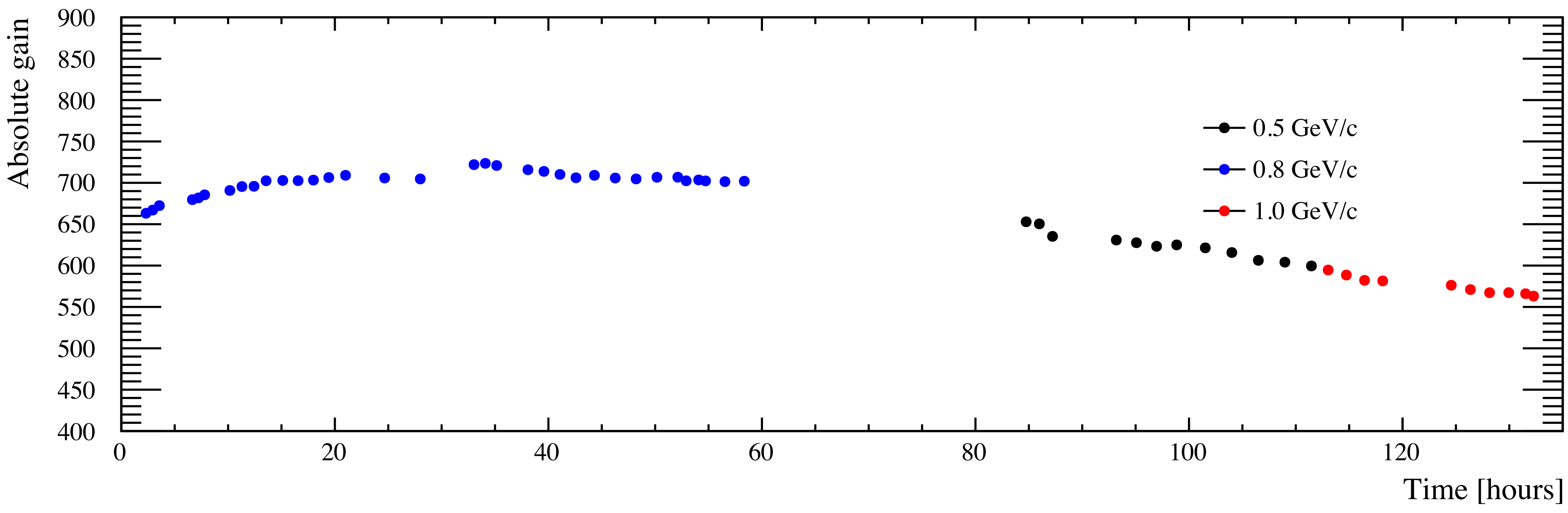
$$Gain = \frac{Nf}{Ni}$$



If there are contaminants in the gas, the gain drops!

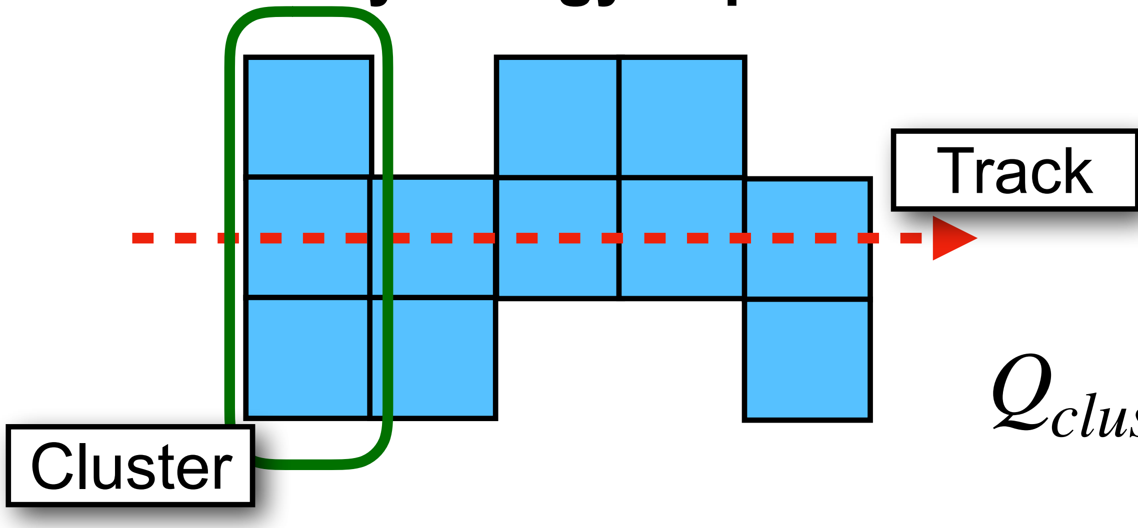


^{55}Fe spectrum 8.9% energy resolution at 5.9KeV

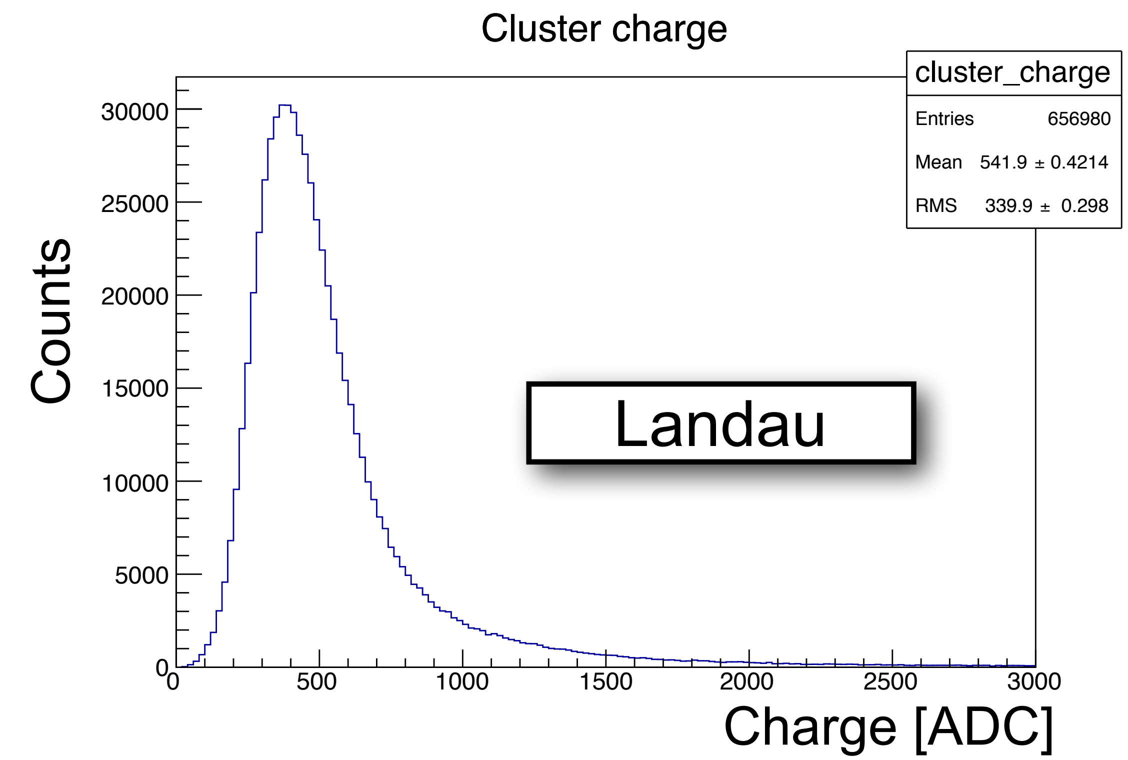


dE/dx studies

To study energy deposition:



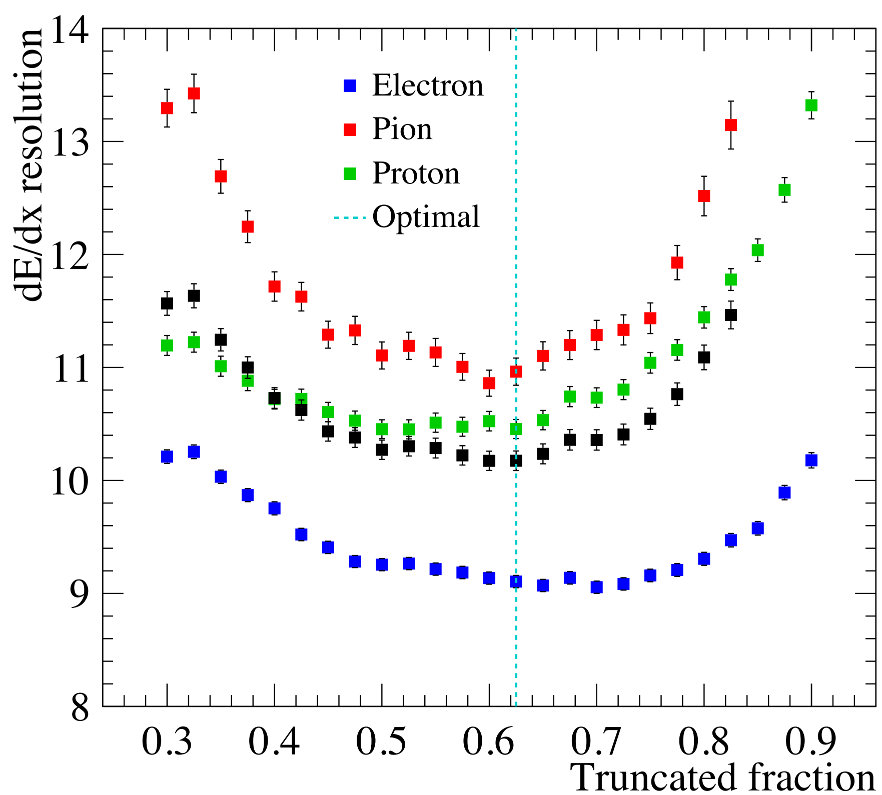
$$Q_{cluster} = \Sigma Q_{pad_i}$$

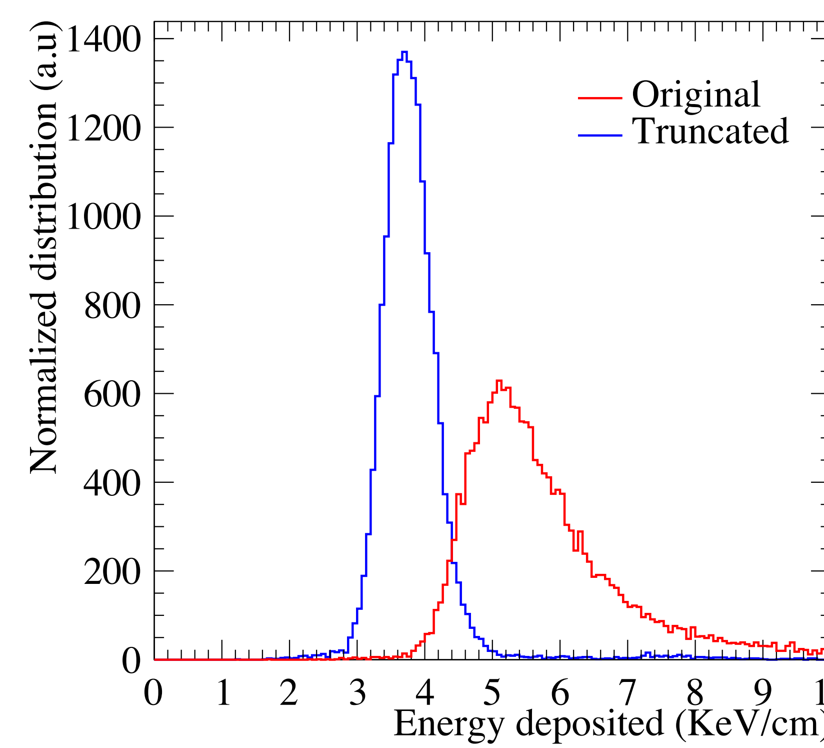


$$dE/dx = Q_{cluster_i}/L_{track}$$

Large fluctuations due to long landau tail!

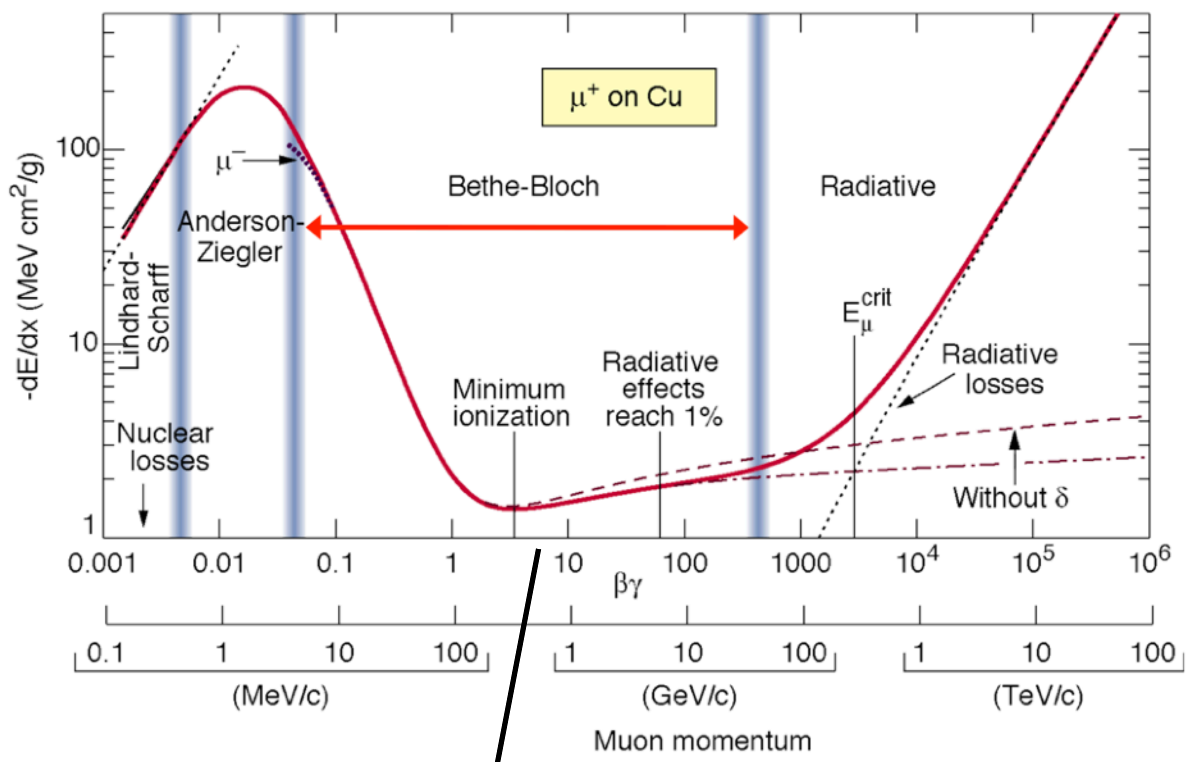
We work with the truncated mean: Only use the N clusters with the lower 62.5% charge.

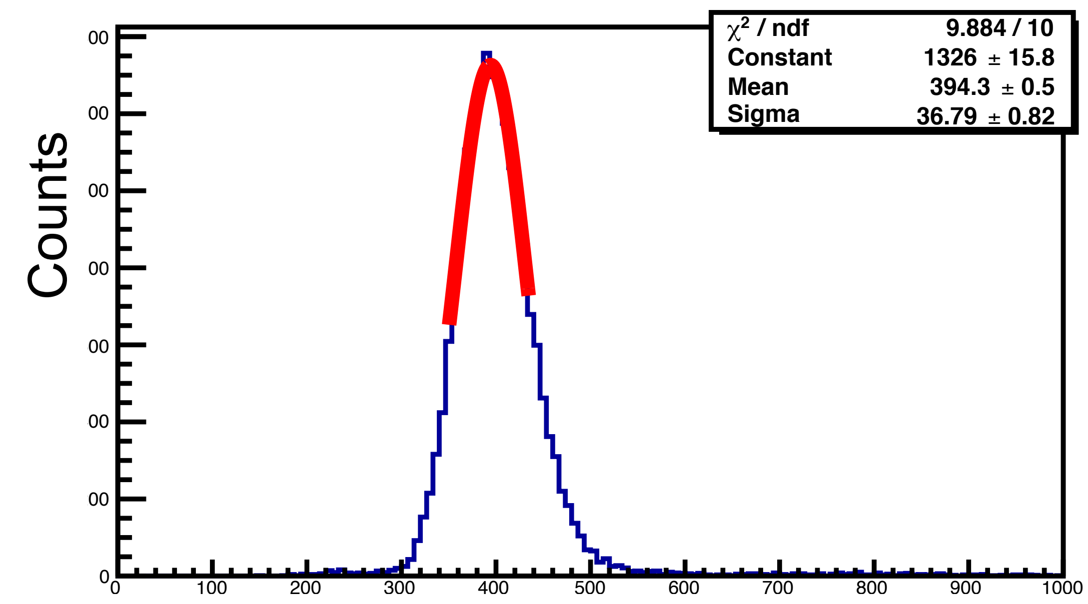




Particle ID fundamentals (characteristic dE/dx)

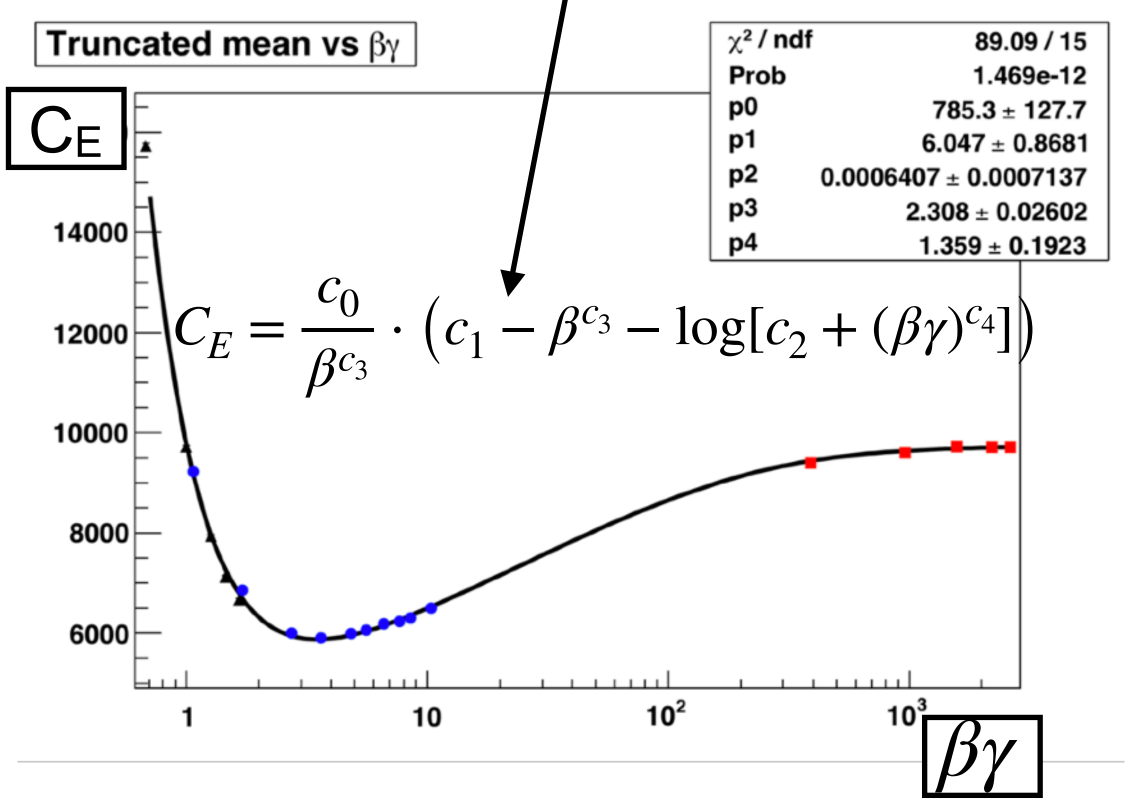
Energy deposit





Mean = C_T

$$\sigma_T = \sigma_{MIP}\sqrt{\frac{C_E}{C_E(MIP)}}$$



$$C_E = \frac{c_0}{\beta^{c_3}} \cdot \left(c_1 - \beta^{c_3} - \log[c_2 + (\beta\gamma)^{c_4}]\right)$$

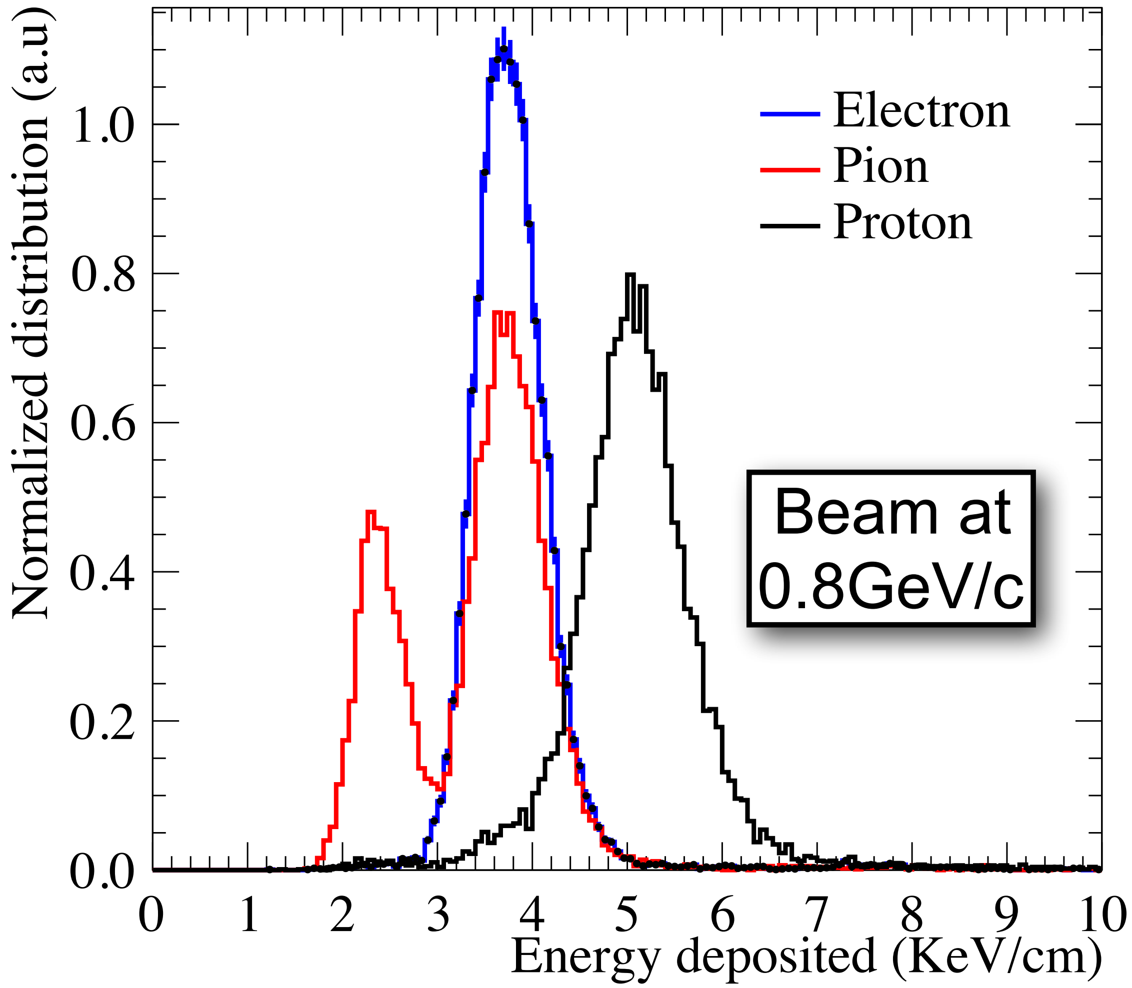
Pull for the *i-th* hypothesis:

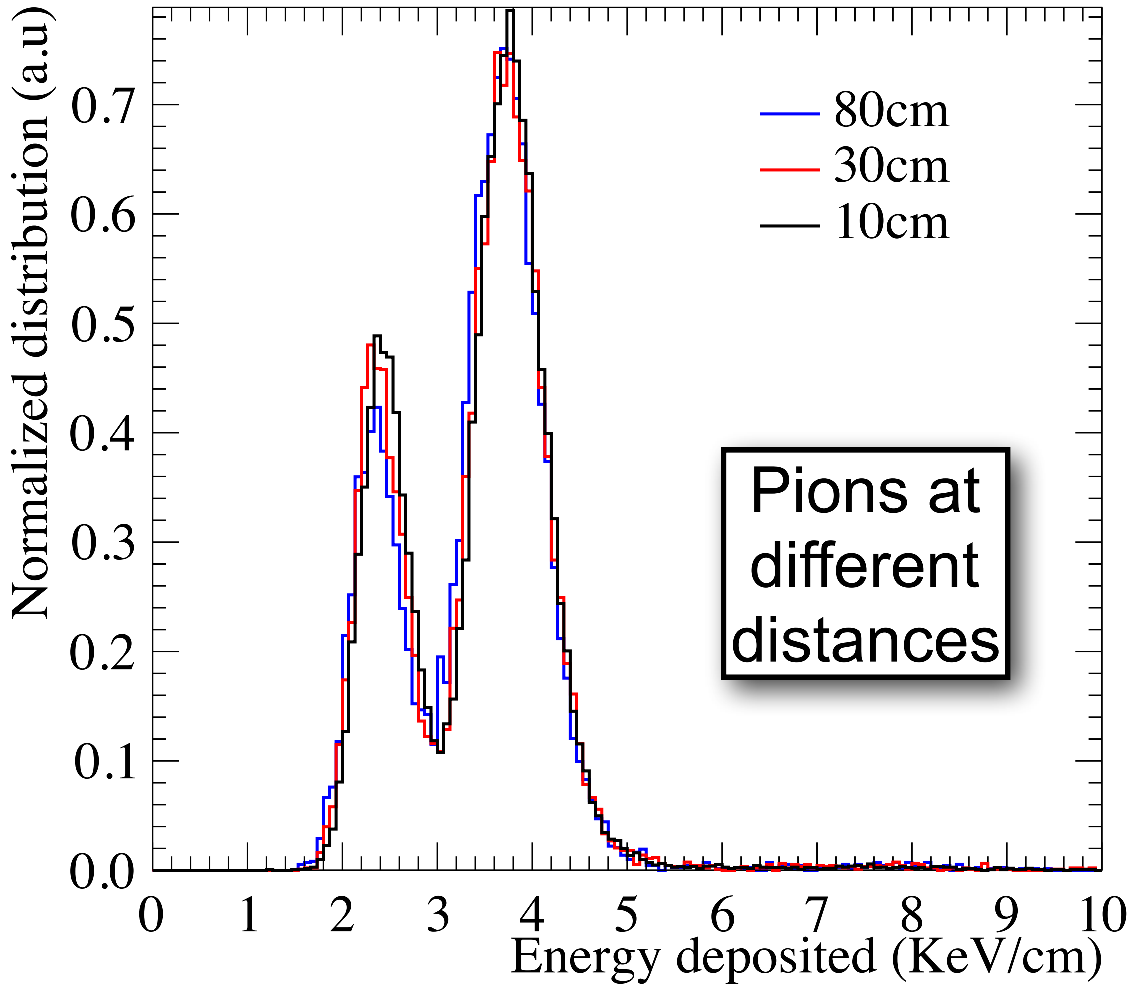
$$\delta_E = \frac{C_T - C_E(i)}{\sigma_T(i) + (dC_E/dp)\sigma_p}$$

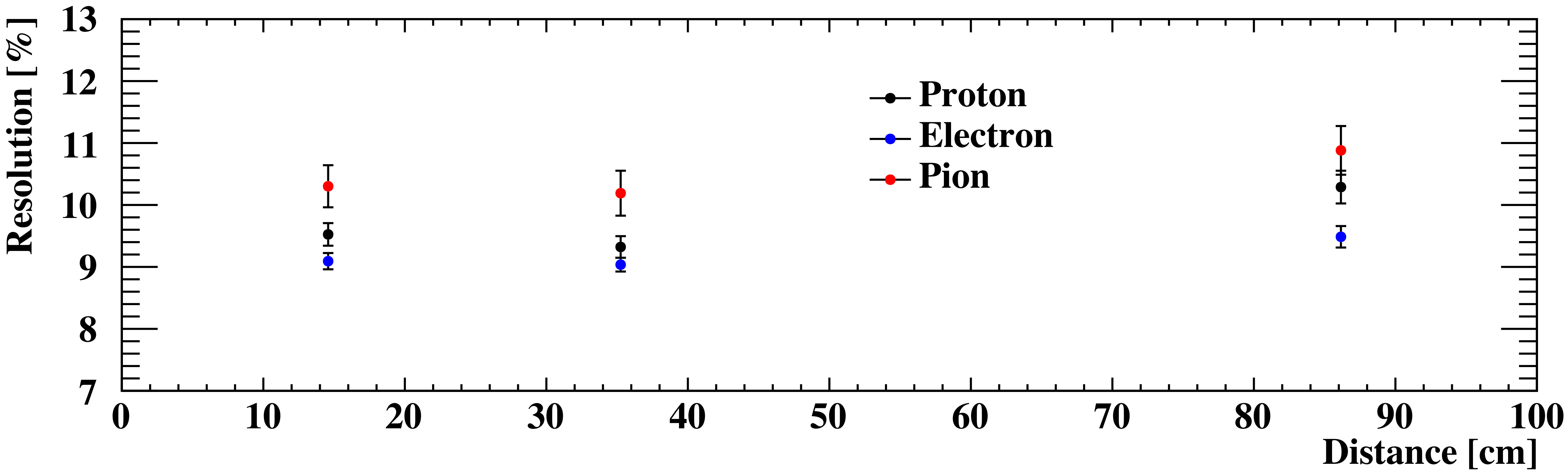
Likelihood of each hypothesis:

$$L_i = \frac{e^{-(\delta_E(i))^2}}{\sum e^{-(\delta_E(i))^2}}$$

dE/dx studies

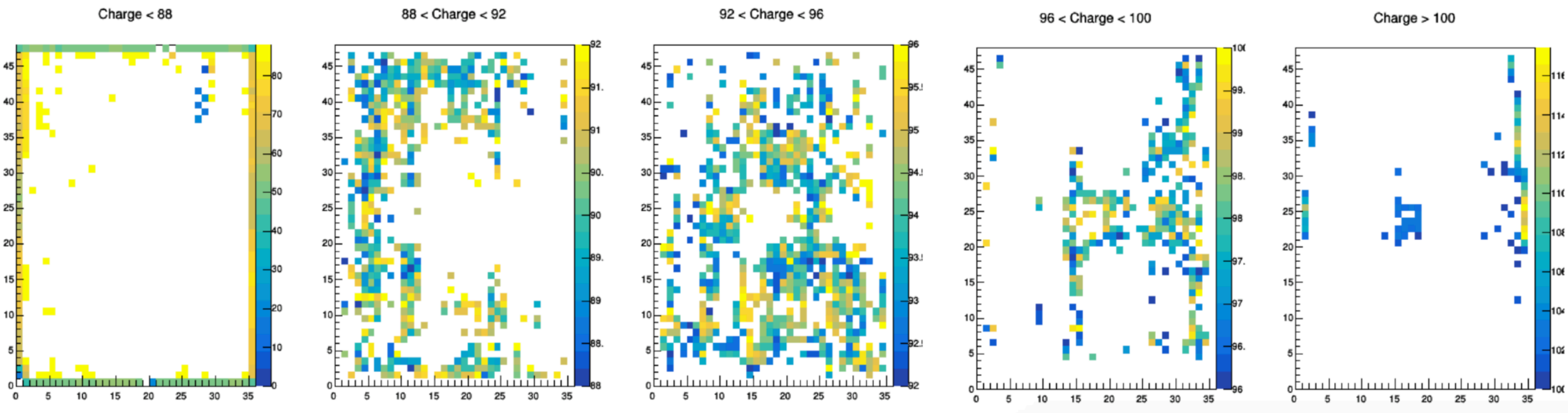


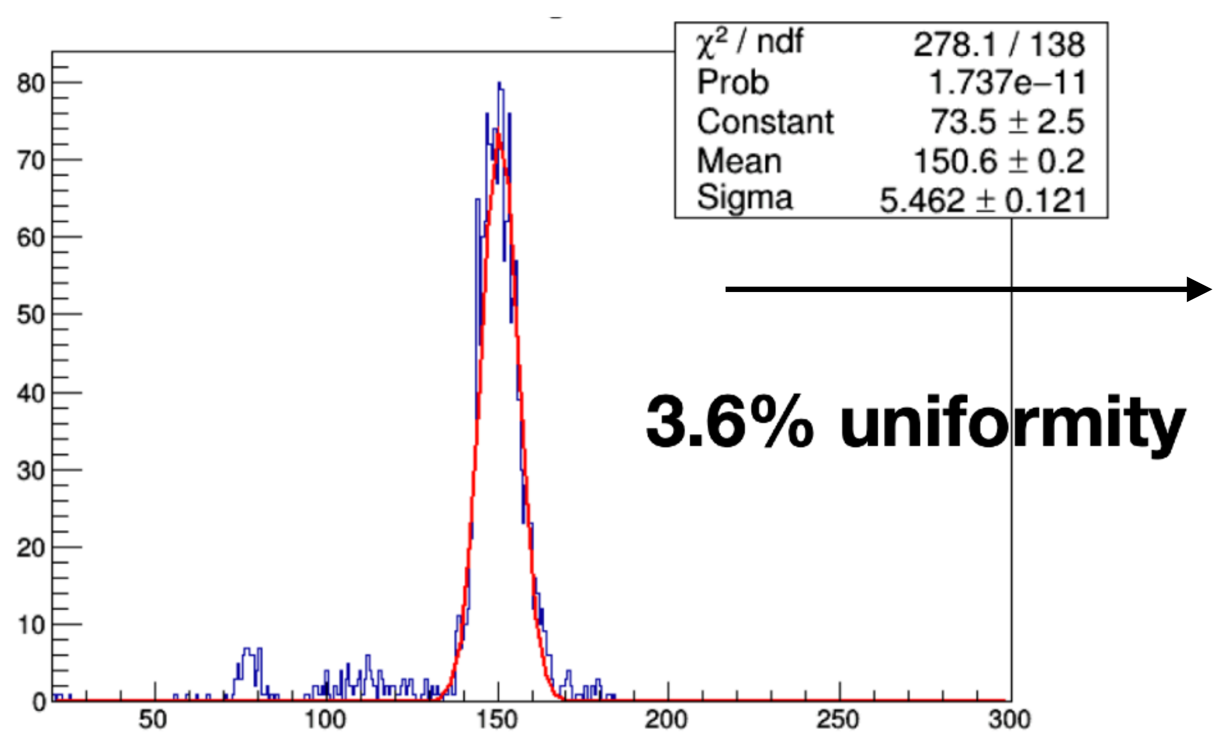




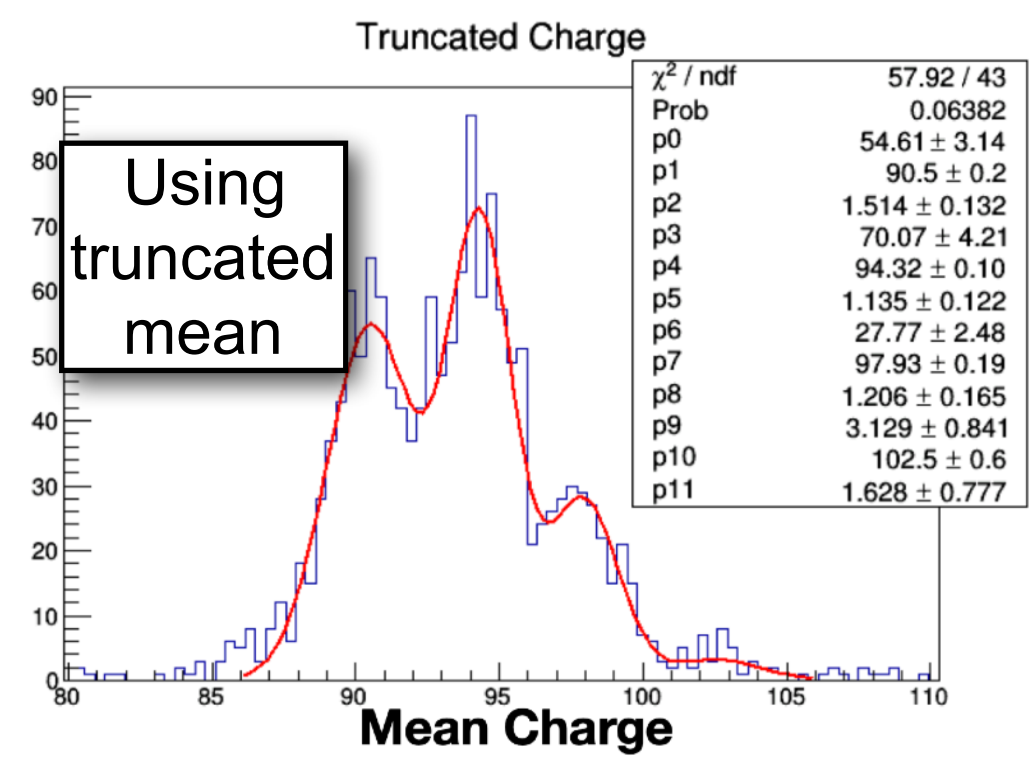
Gain stability and MM uniformity

Take cosmic tracks, and compute average charge in each pad with large statistics.





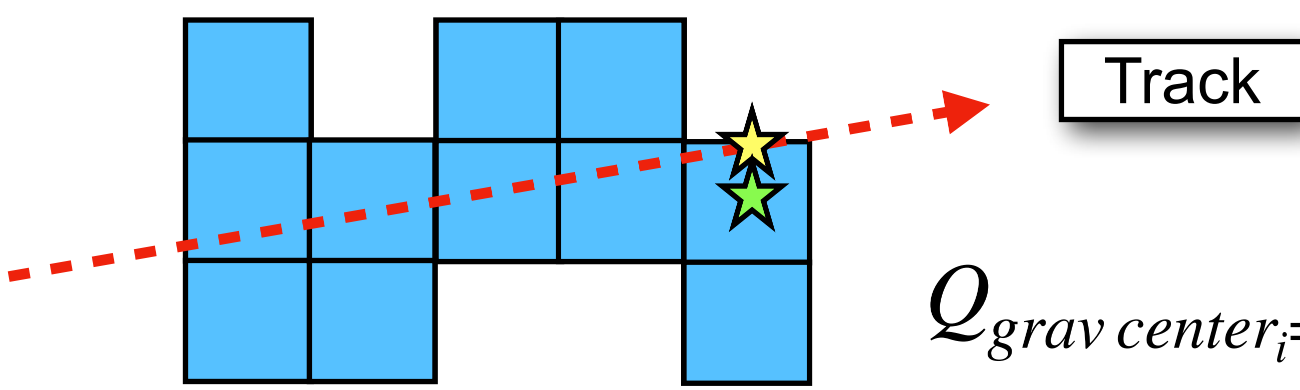
3.6% uniformity



Point resolution σ_{xy}

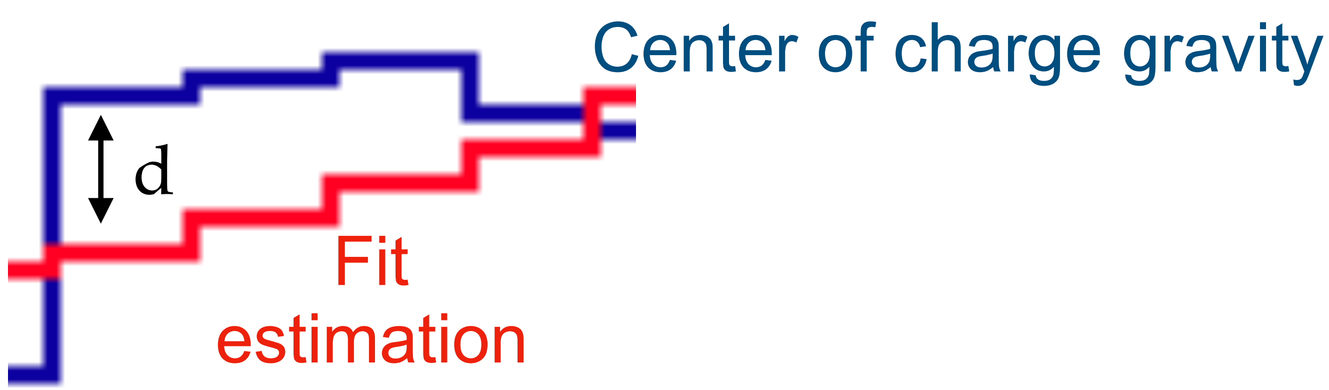
What is the real trajectory of the track? How sure we are?

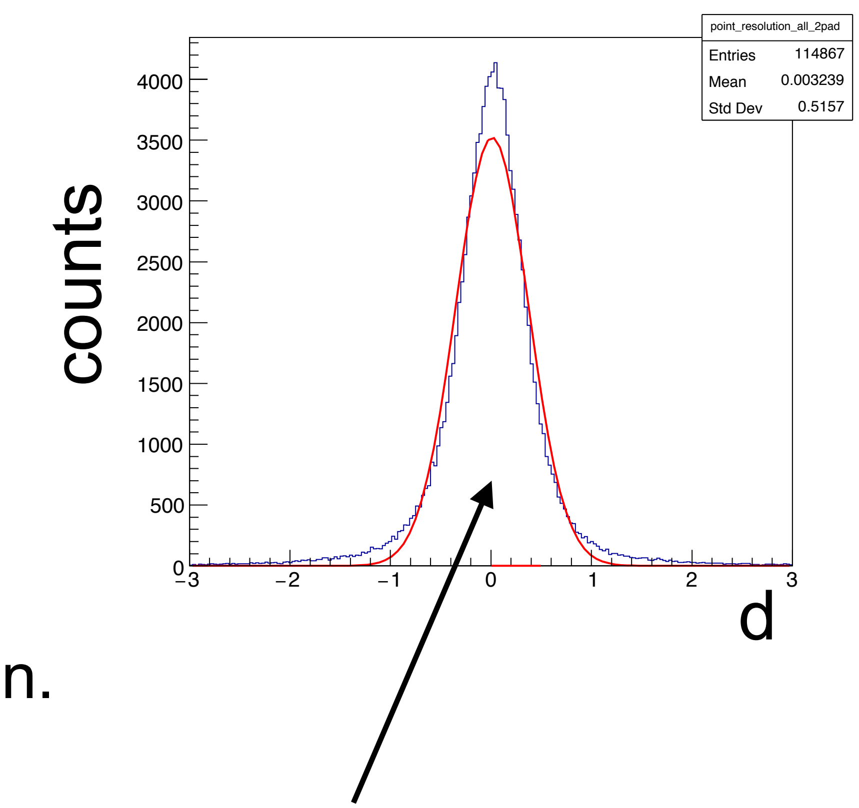
A. Apply your selection.
B. Do a linear fit. (B = 0 during test beam).



☆ = Fit estimation
☆ = charge center of gravity

$$Q_{grav\ center_i} = \Sigma(Q_i x_i)/\Sigma Q_i$$

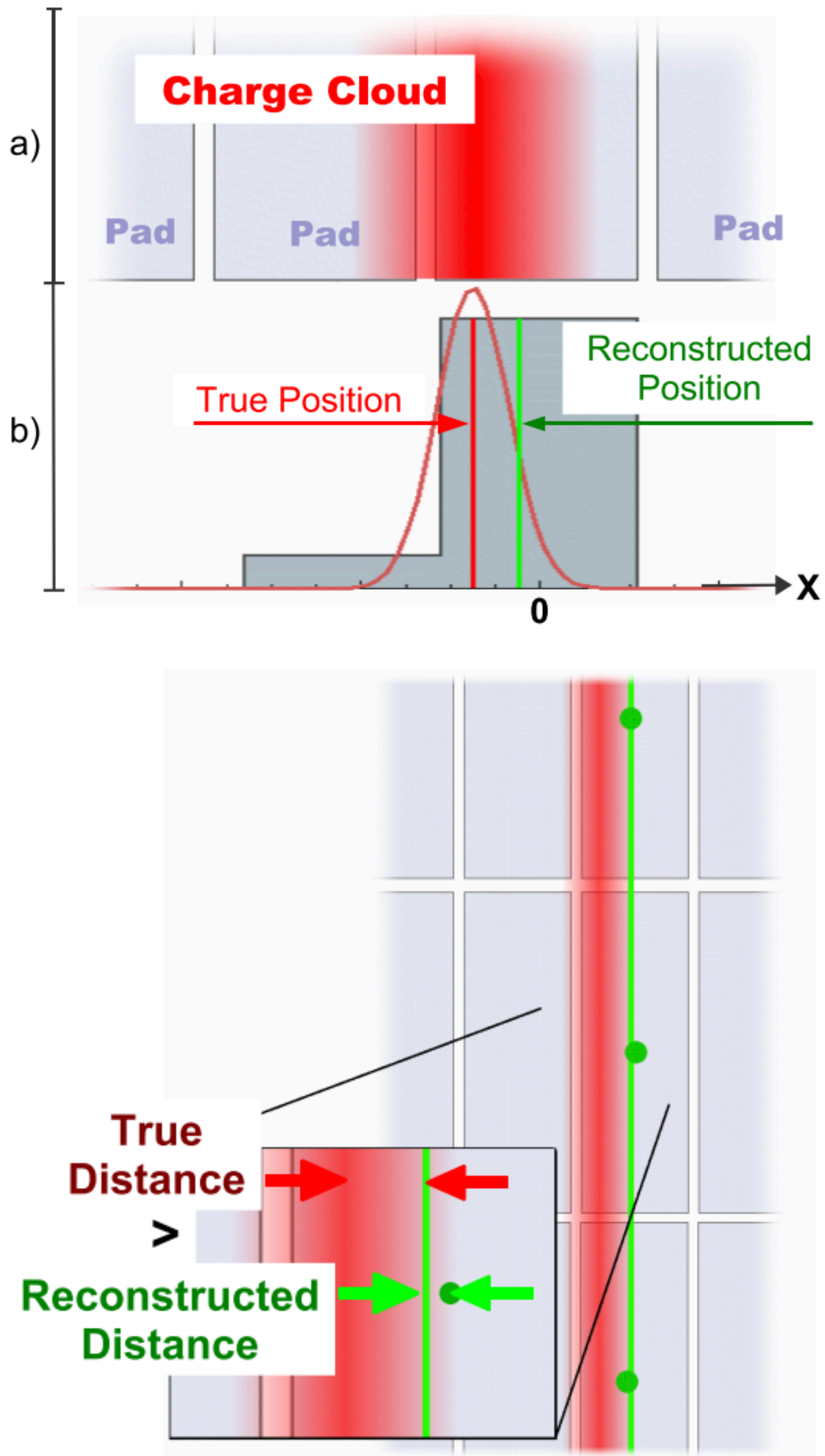




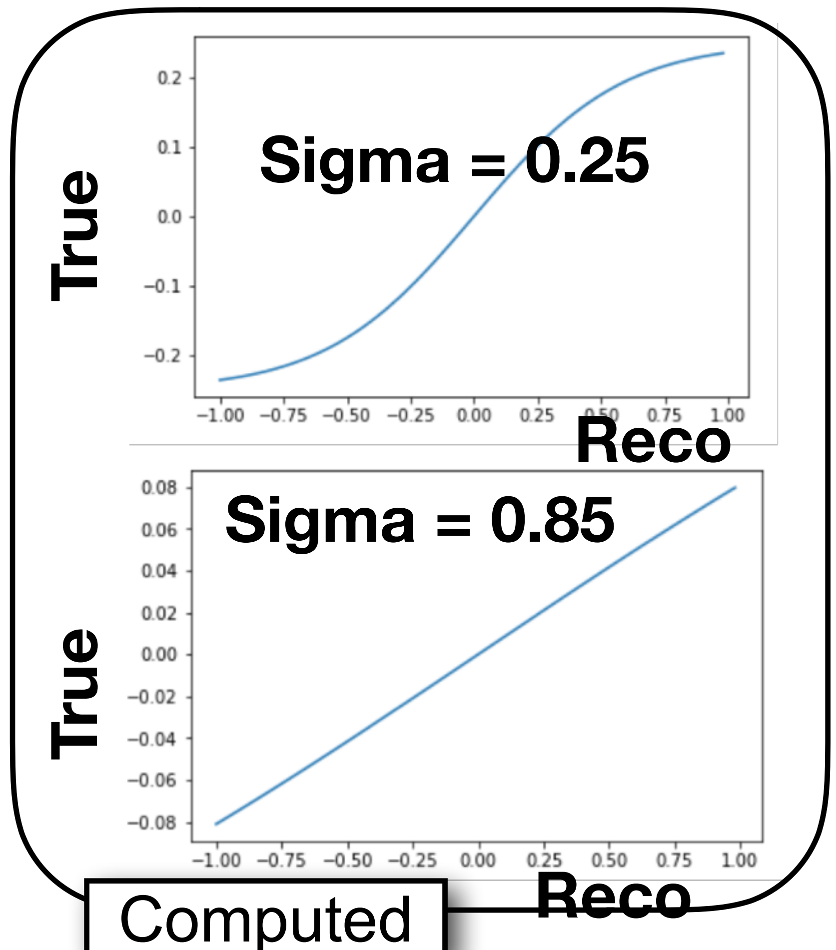
The point resolution is the sigma of the **distance** distribution.

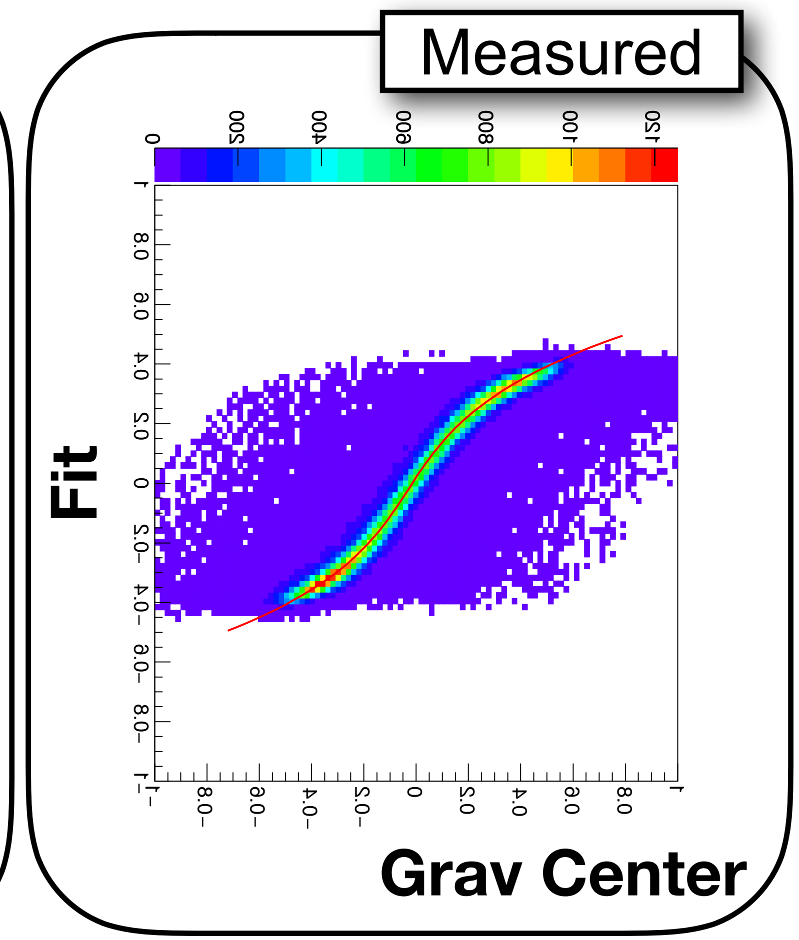
actually the distribution is Gaussian Lorentzian: $PRF(x,r,w) = \dfrac{\exp[-4\ln 2(1-r)x^2/w^2]}{1+4rx^2/w^2}$

PRF (Pad Response function)



Pads bigger than the typical spreading naturally bias the gravity center of the distribution.

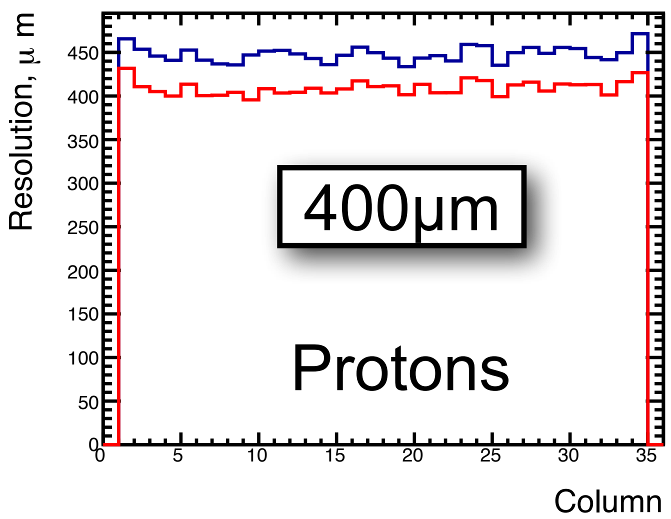


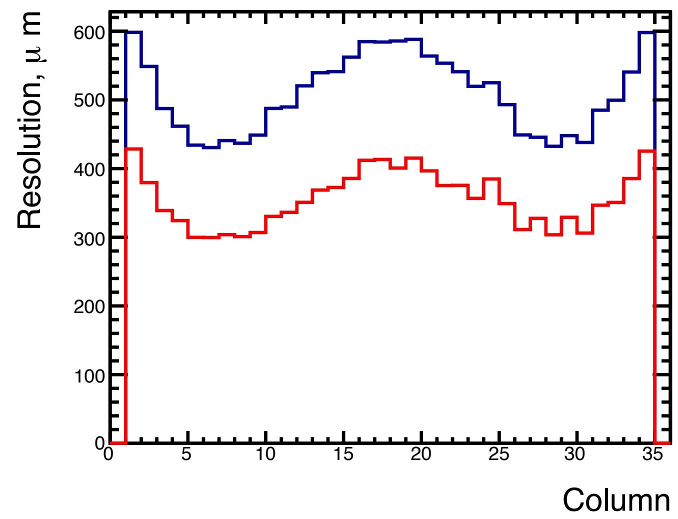


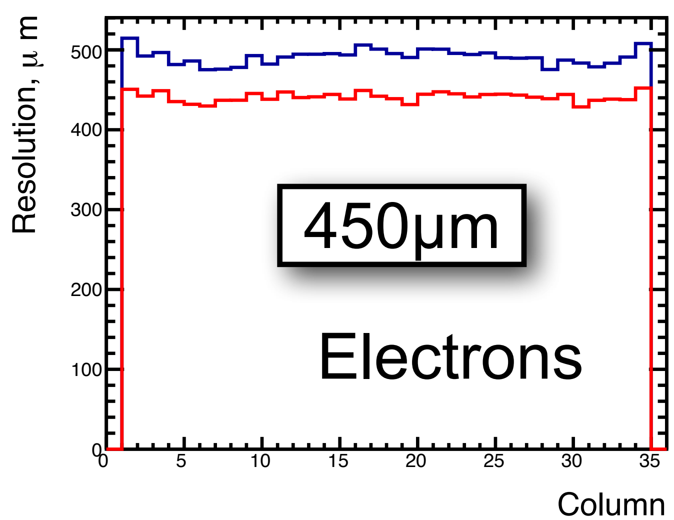
We can use the info from the fit to unfold the distribution.

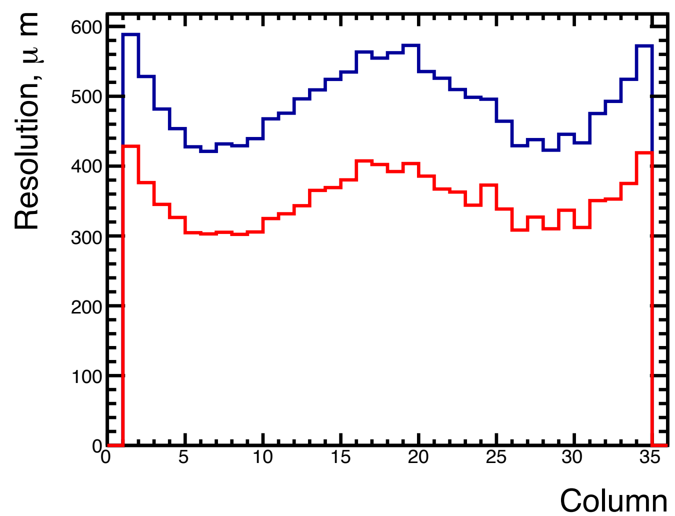
Point resolution σ_{xy}

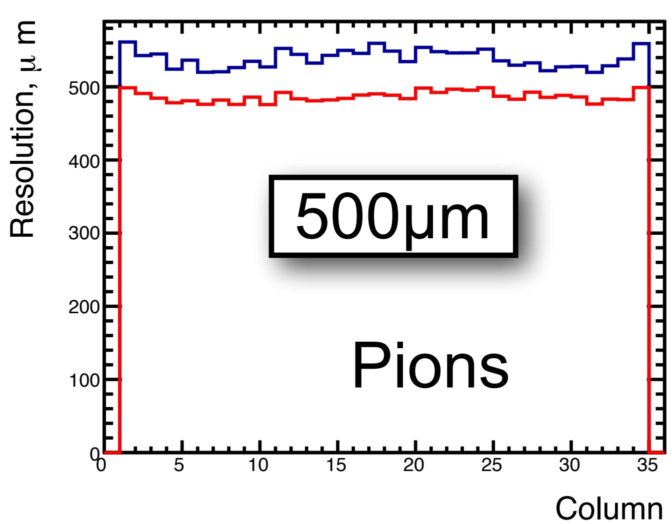
At 80cm | **At 10cm**

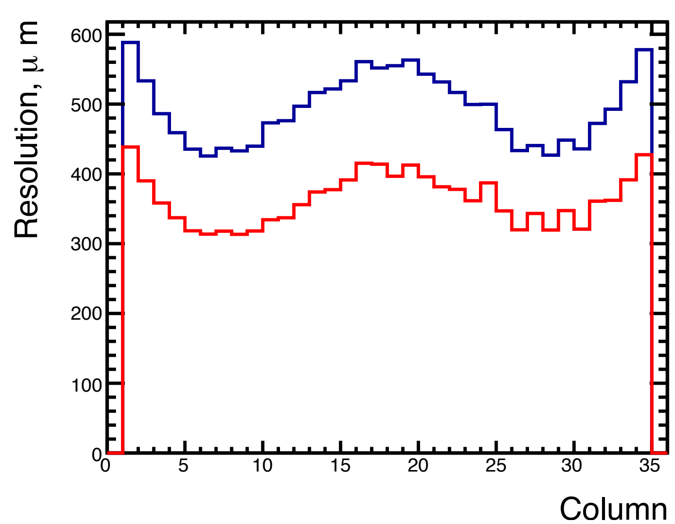








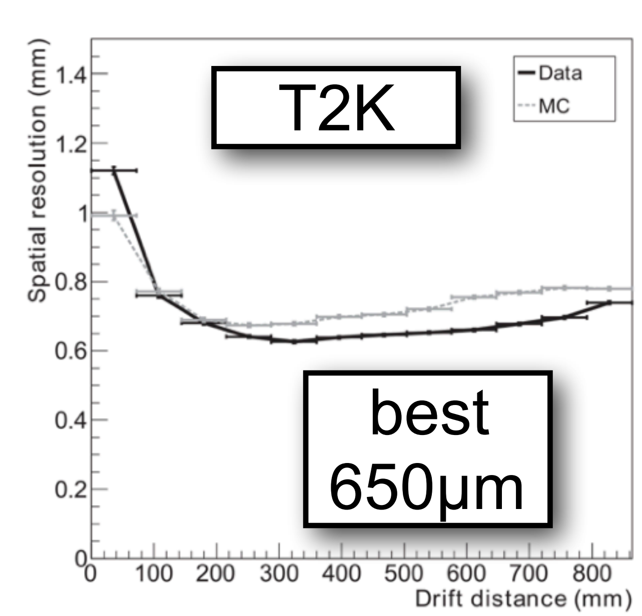




When the track is closer some extra effect enters into play!

Still under study…

Nevertheless the resolution of the resistive micromegas supersedes the one in the current T2K TPCs!



Conclusions & Future studies

- After the first test, 13 years ago, a new team (with some experienced members) has started the testing of prototypes for the new T2K upgrade.

- We had no software, so we had problems monitoring the gas conditions, but…
  - A new software stand-alone platform has been developed from scratch.
  - Nice training for students learnt quite a lot about how to deal with the detector at the basic lvl. We have ~3years of tests ahead.

- We found that the resistive bulk xq works nicely (even if it is not final version):
  - Larger pad multiplicity than in the past. (Back up)
  - Good uniformity from pad to pad. (3.6%)
  - 9-10.5% energy resolution.
  - 400-500μm point resolution.

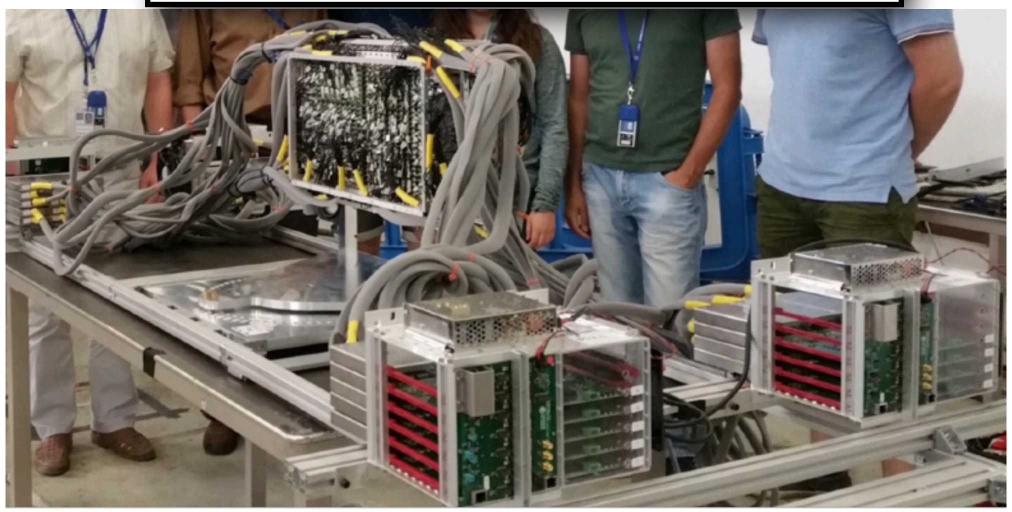
Future:

- Test final MM with new PCB (based on same AFTER chip). Different #pads, pad size, resistivity… ⟶ Test beam this summer… Using also prototype field cage.
- **Work on SFGD prototype!**

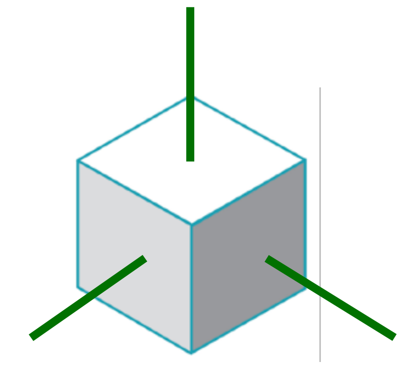
BONUS, SFGD

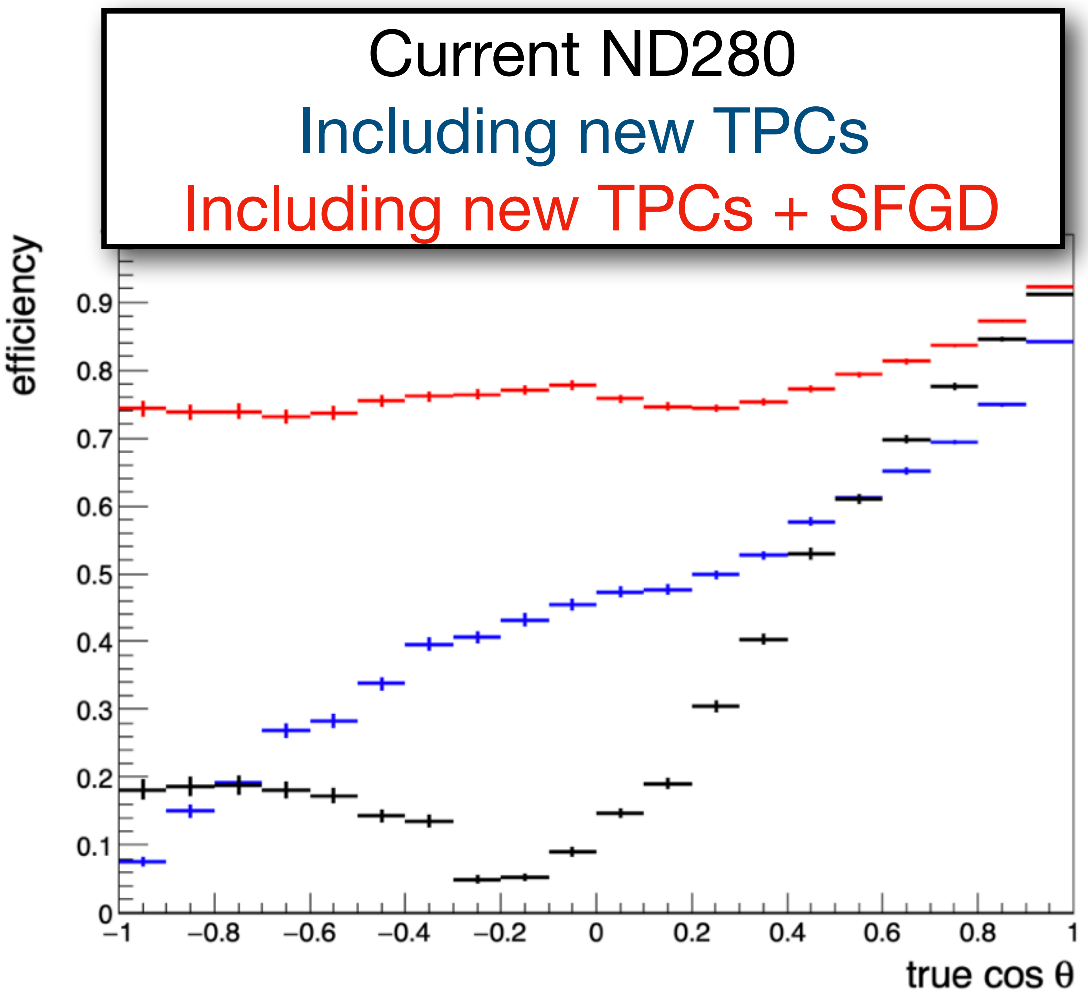
Since I had so much fun with TPC… we decided to expand my PhD and also join SFGD:

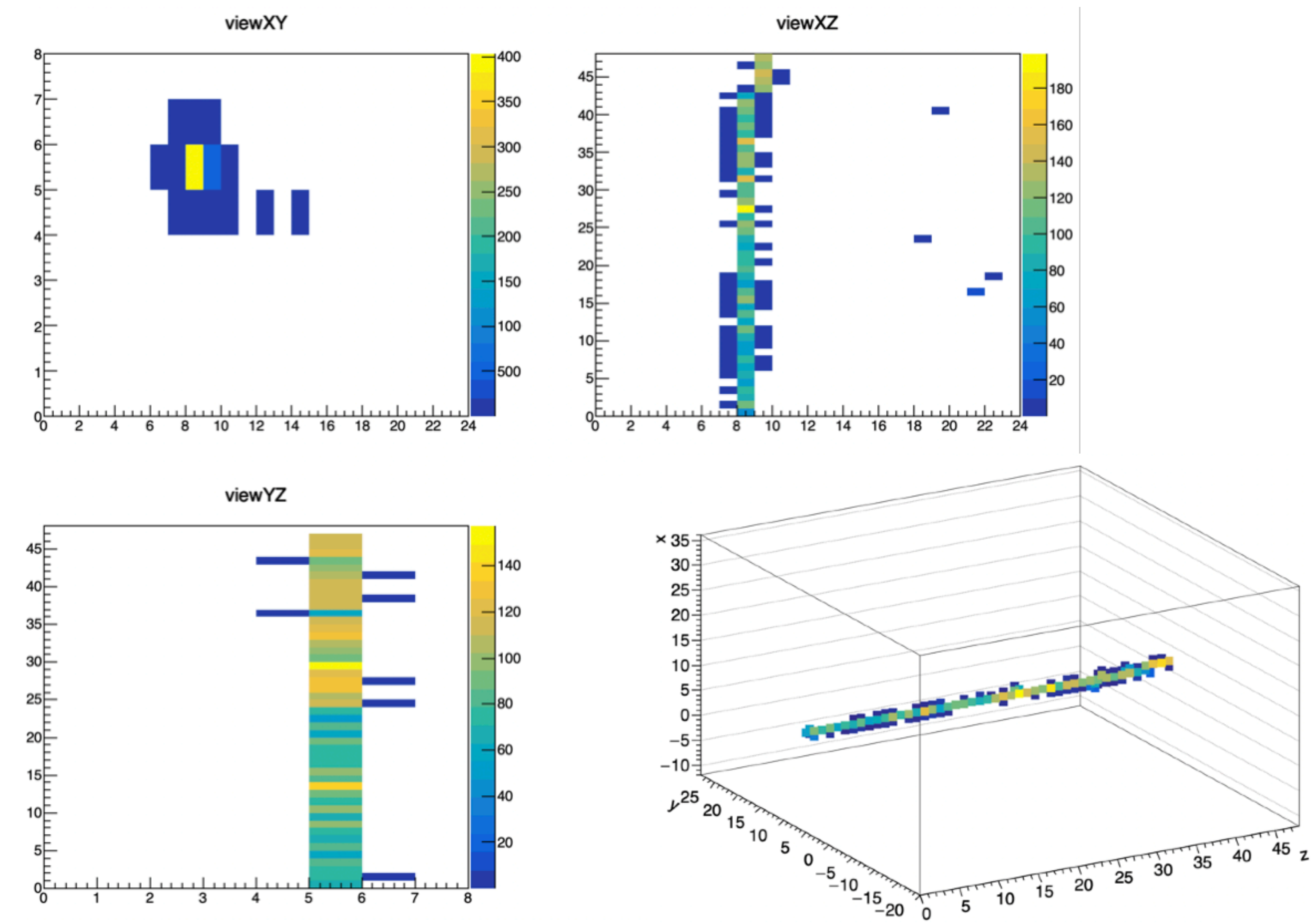
BeamTest with 10k cubes



- 2M scintillator cubes of $1x1x1cm^3$.
- 3 fibers cross each cube.
- Needs a completed new software and reconstruction system.
- It is a new technology that could boost the efficiency and sensitivity of T2K.



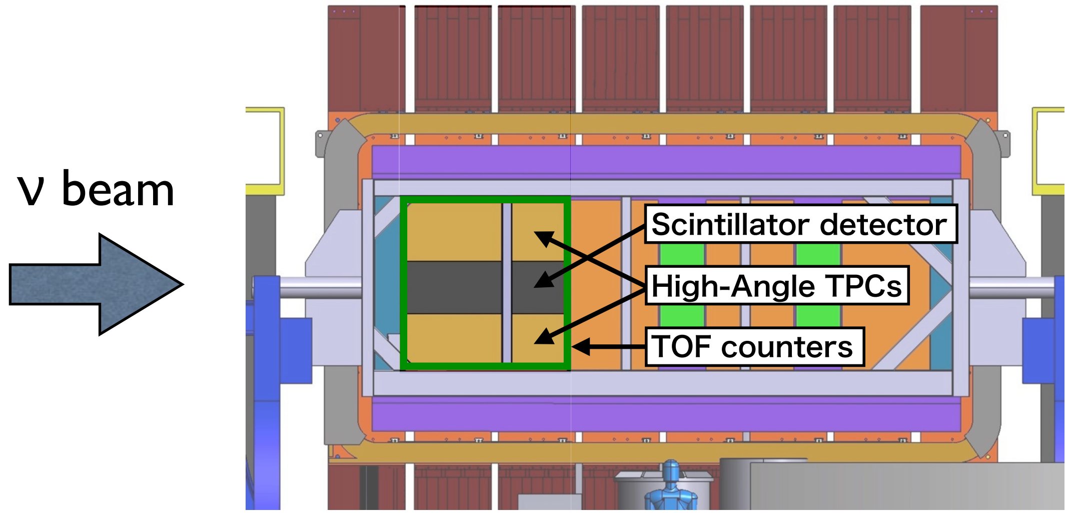




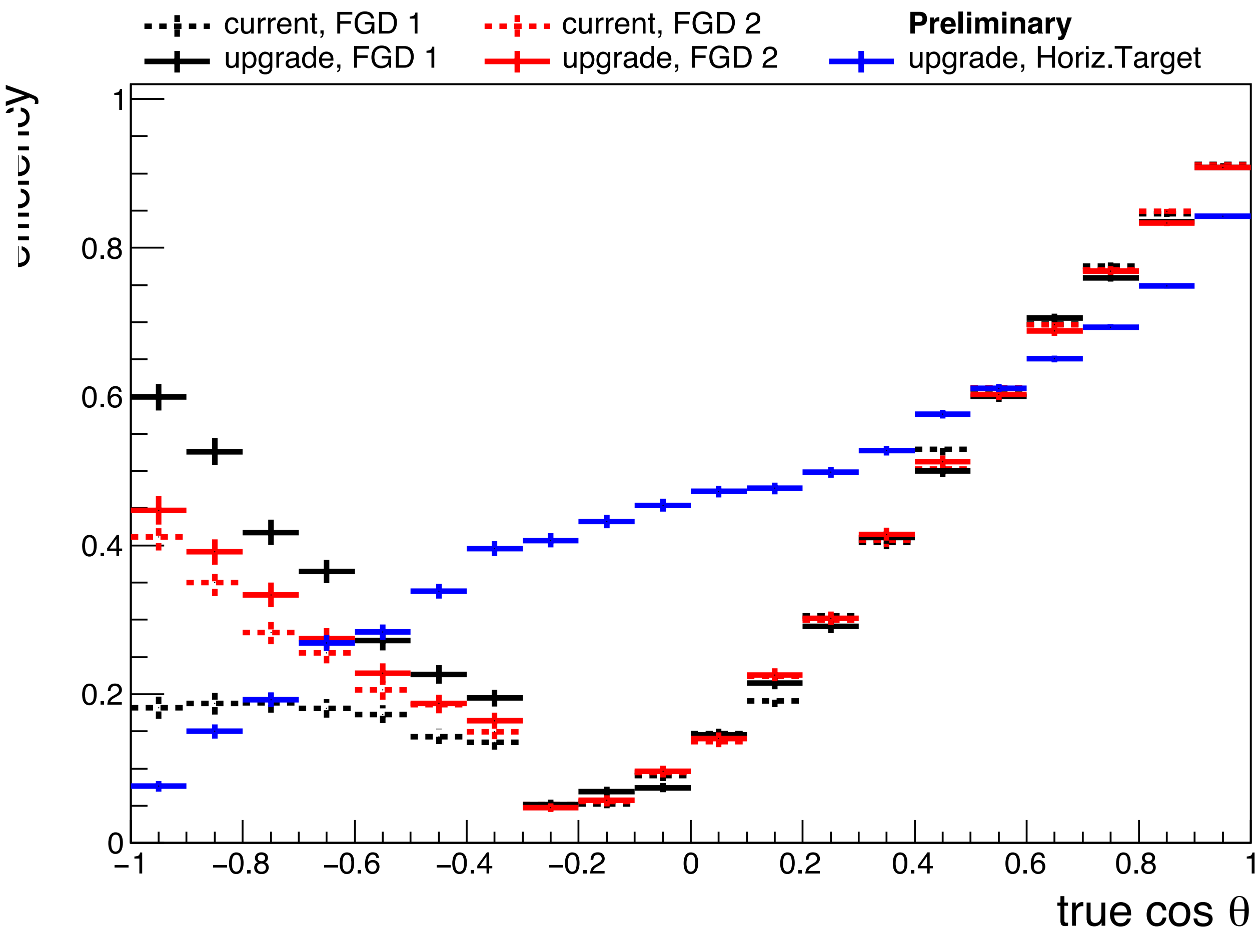
THANKSSSS!!!

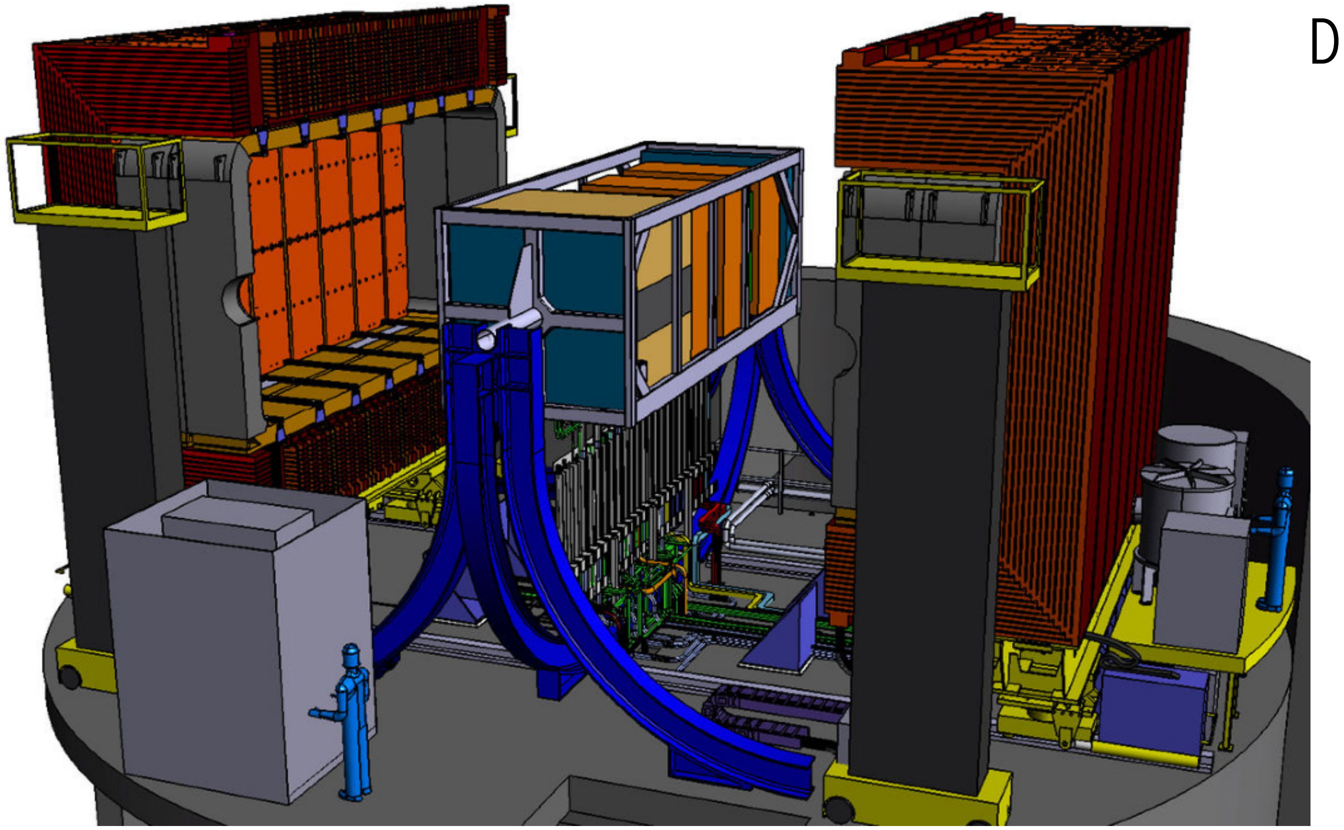
BACK UP

The ND280 upgrade

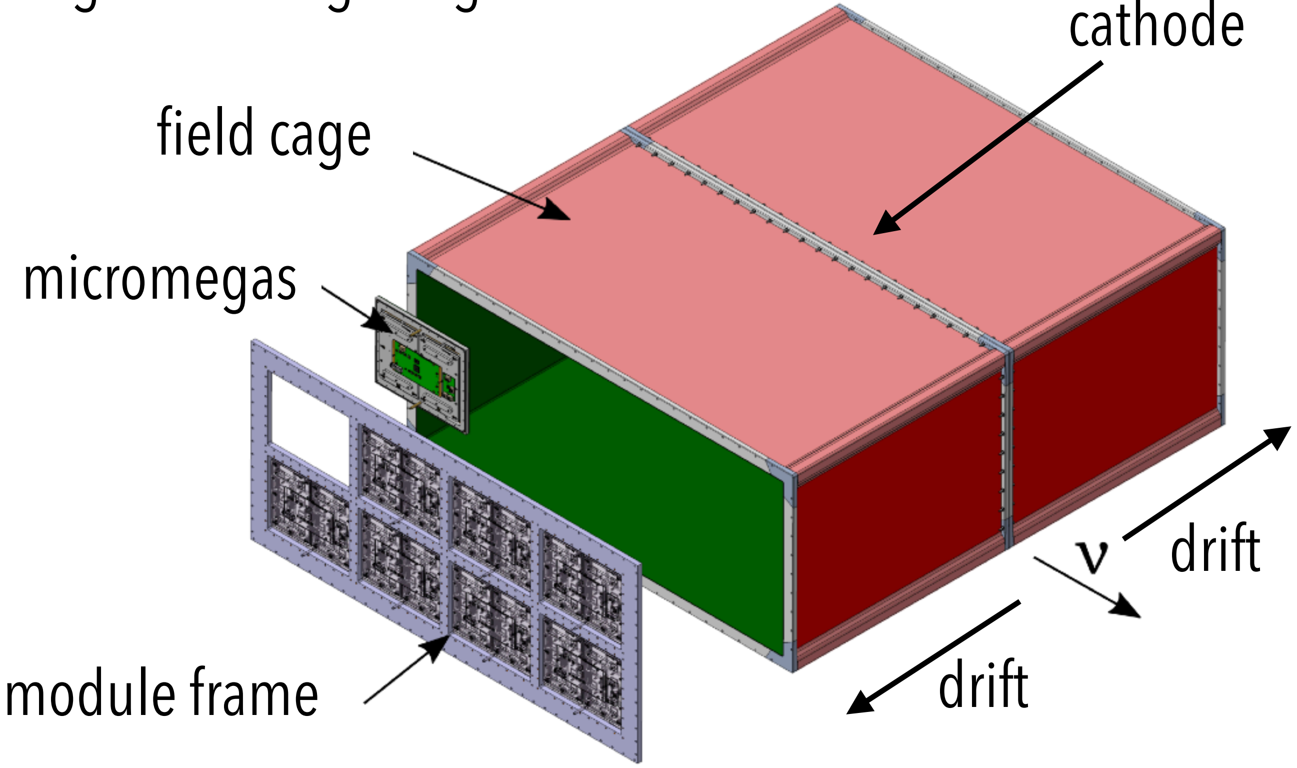


- Replace (most of) P0D with **Scintillator Detector** + **2 High-Angle TPCs** + **TOF**
  - Improve acceptance for large angle tracks
- Keep current "tracker" [2 FGDs + 3 TPCs] (& upstream part of P0D) as well as ECal, magnet & SMRD
  - For keeping continuity and forward acceptance



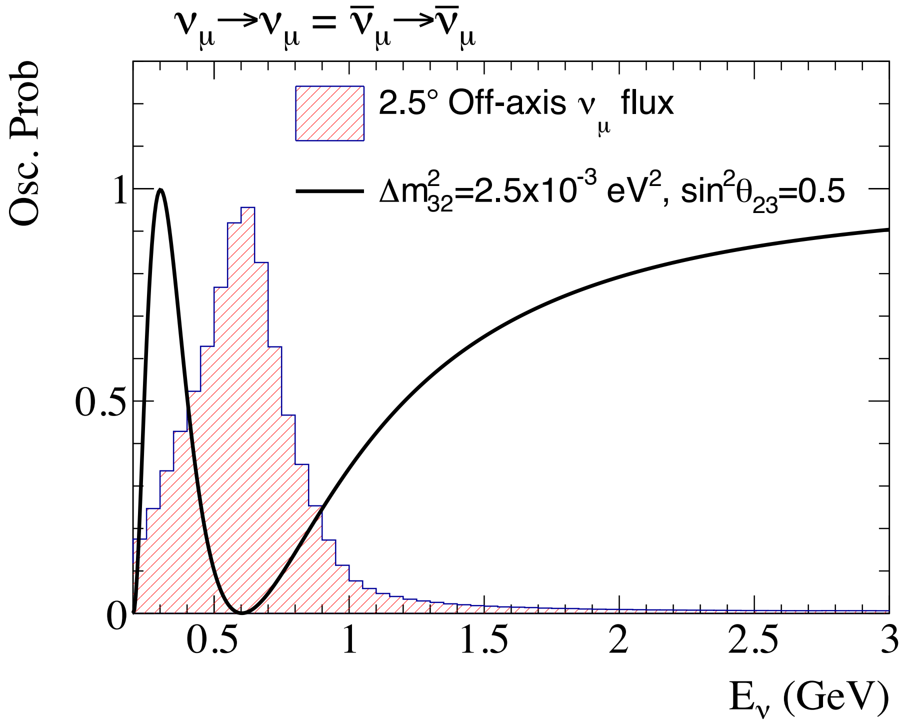


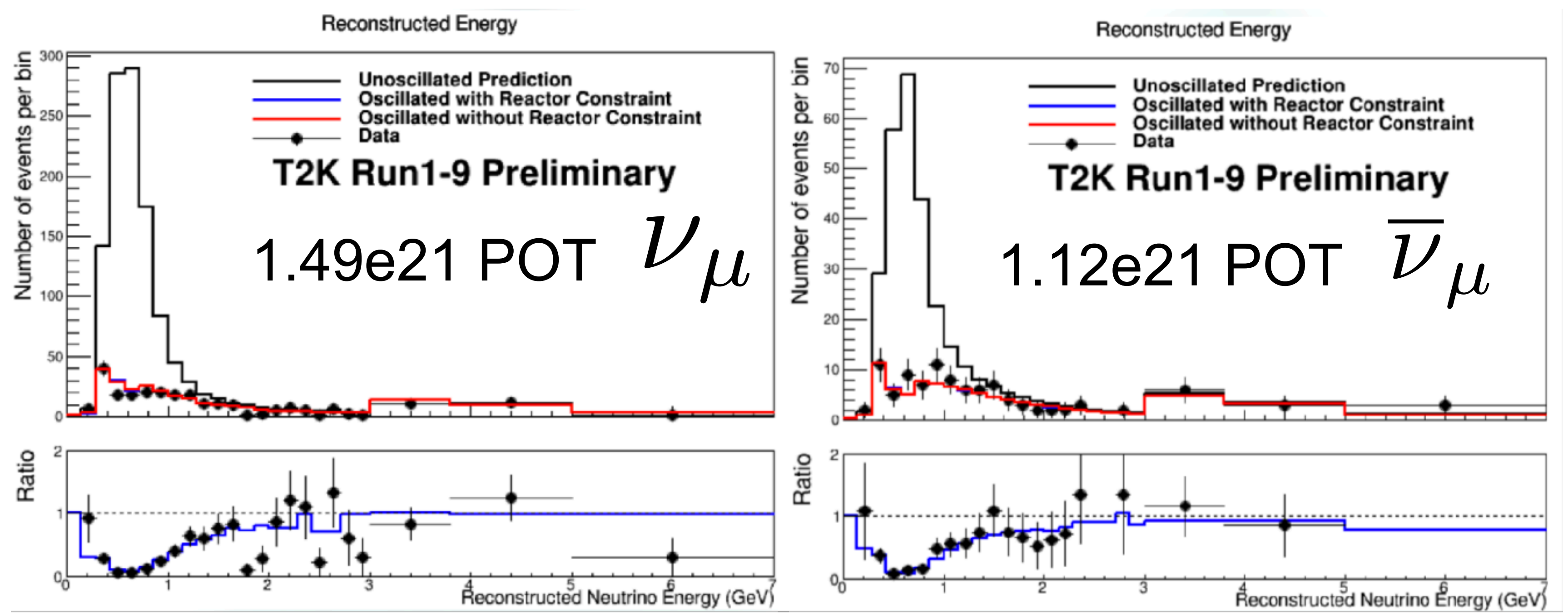
Desing of final high angle TPCs:



Goal: measure oscillation parameters

Example:



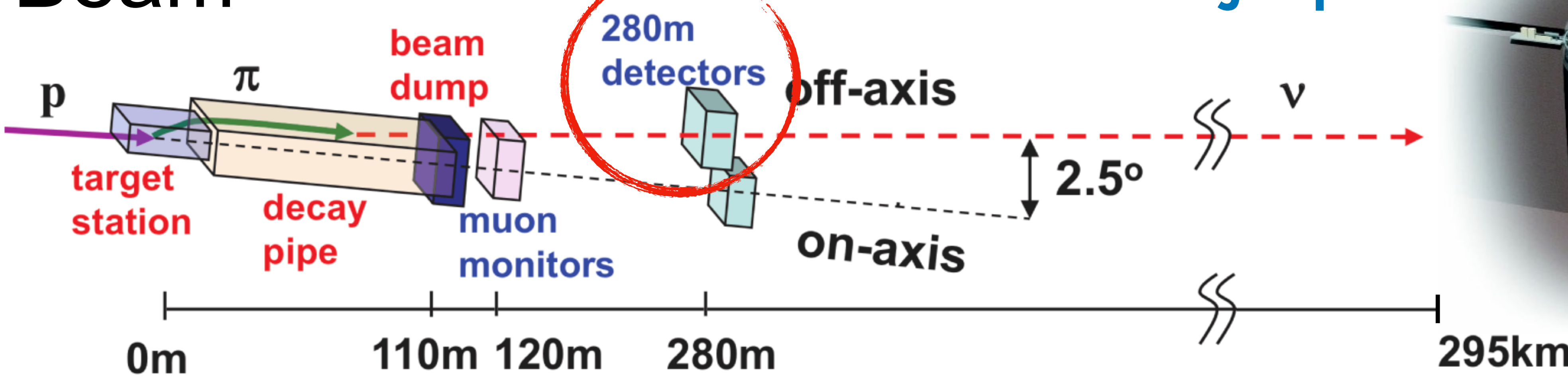


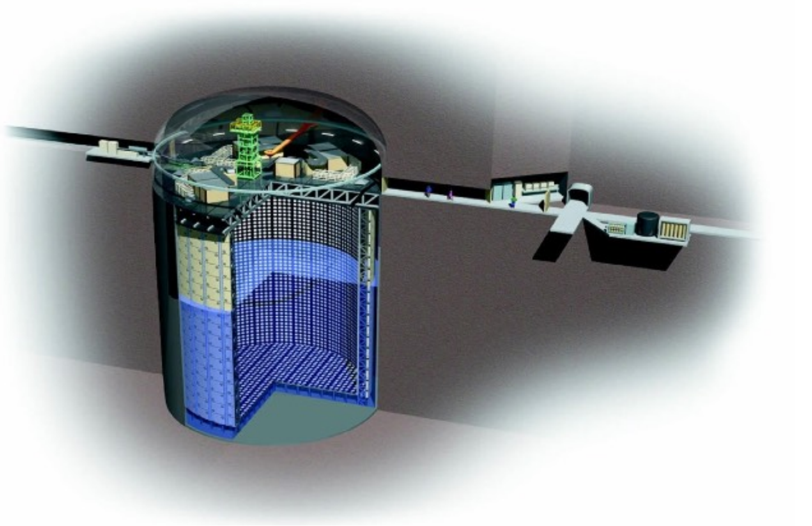
We compare expected vs observed neutrino vs antineutrino samples.

We test oscillation hypothesis and look for best oscillation parameters.

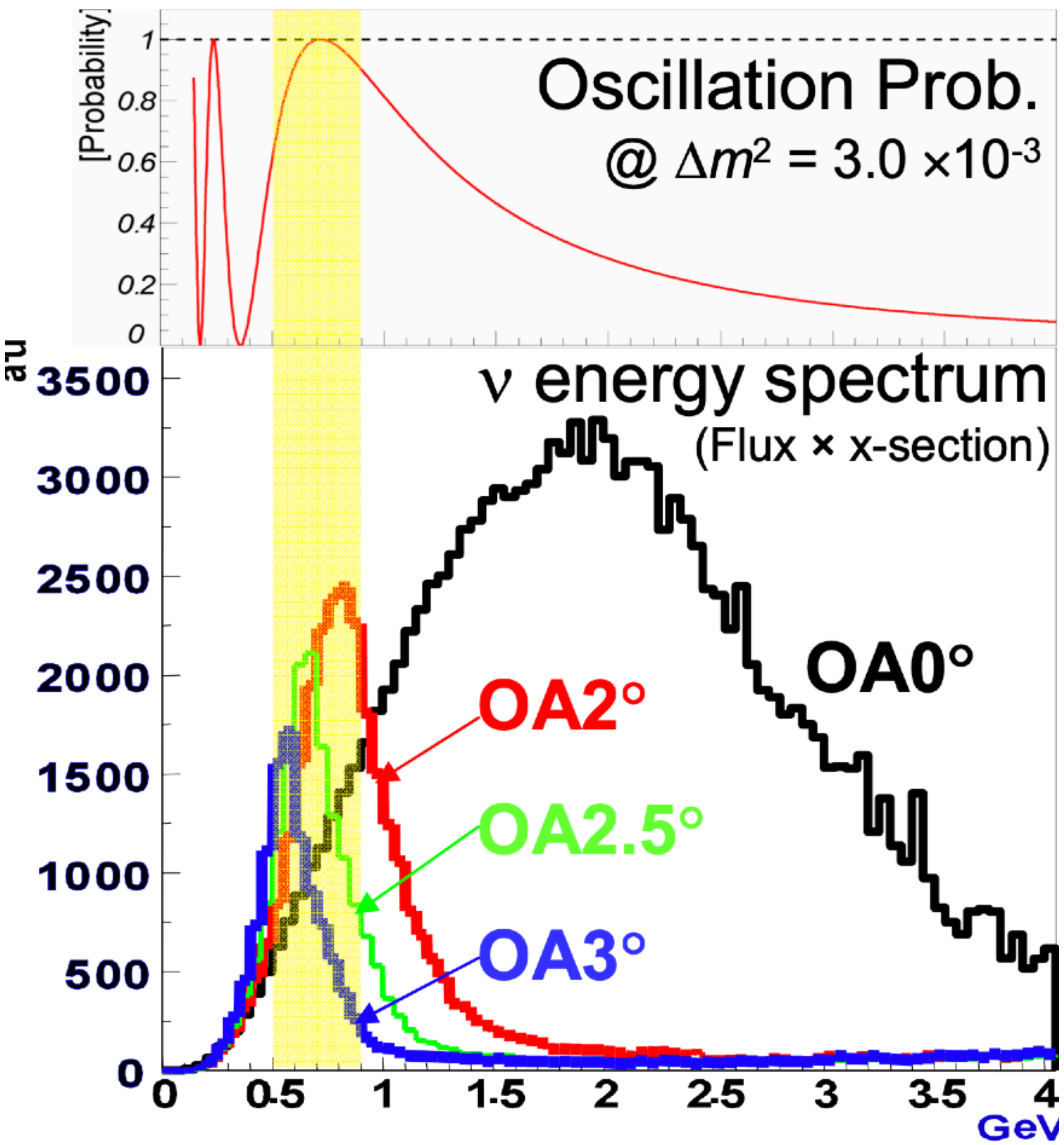
Beam

IFAE's neutrino group

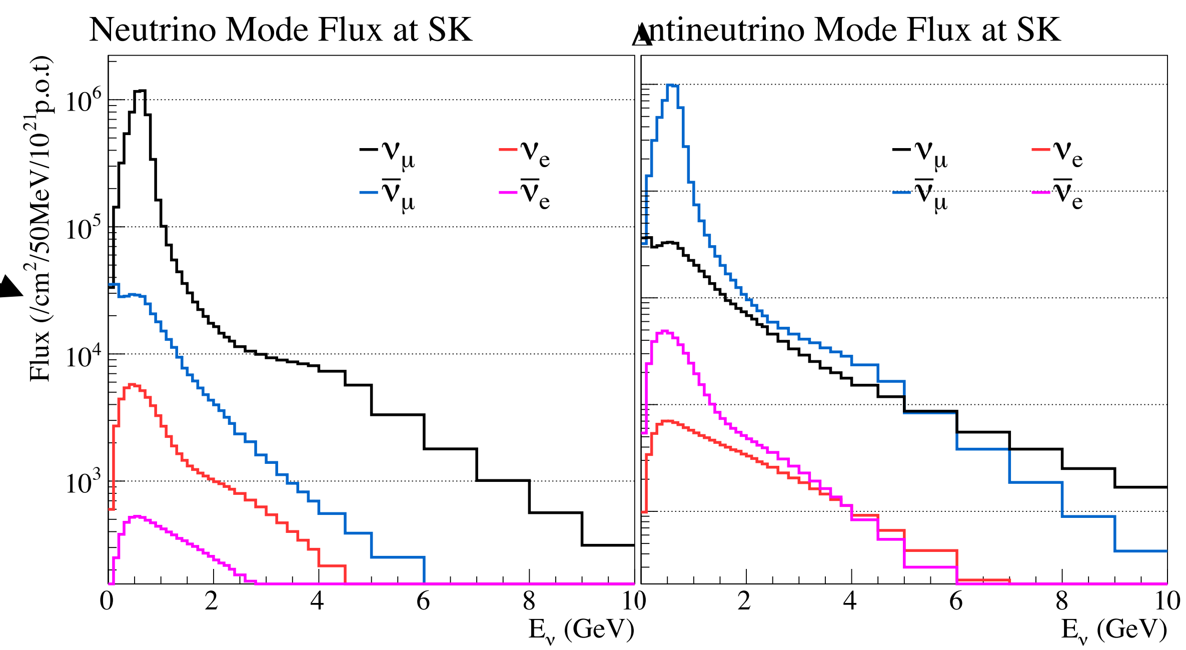




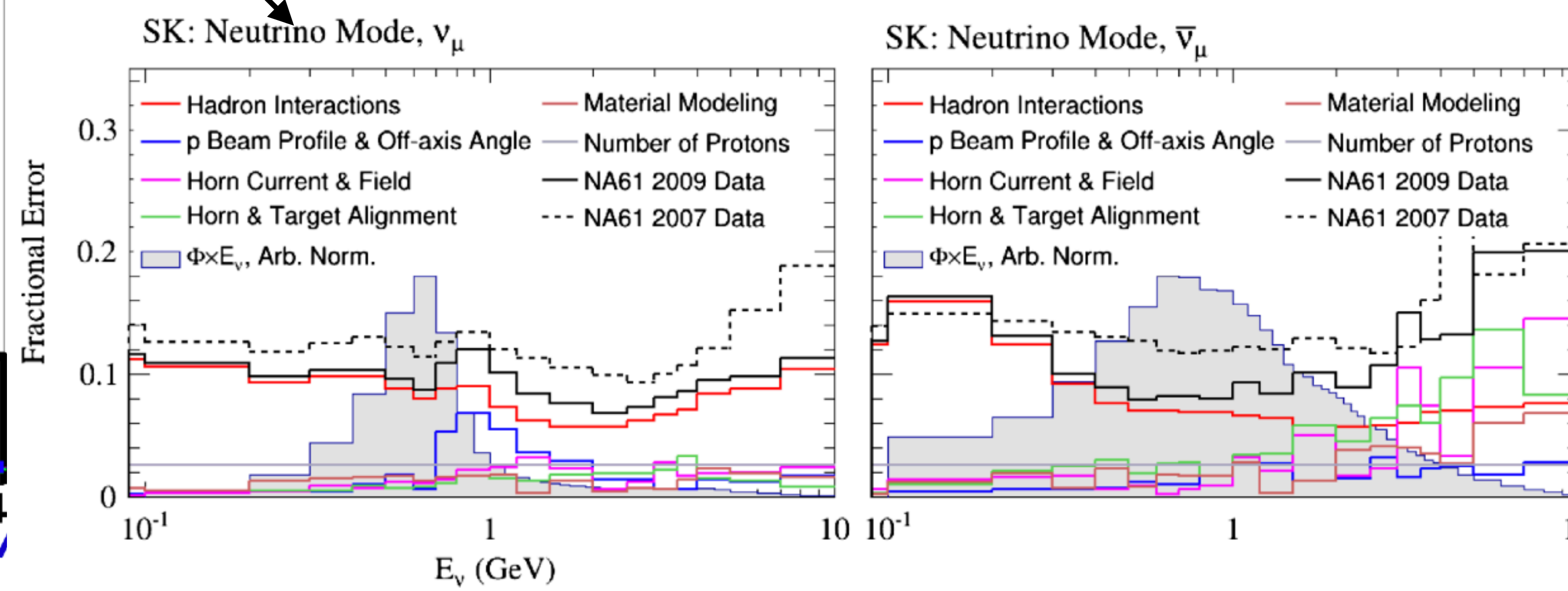
Super-Kamiokande



Flux

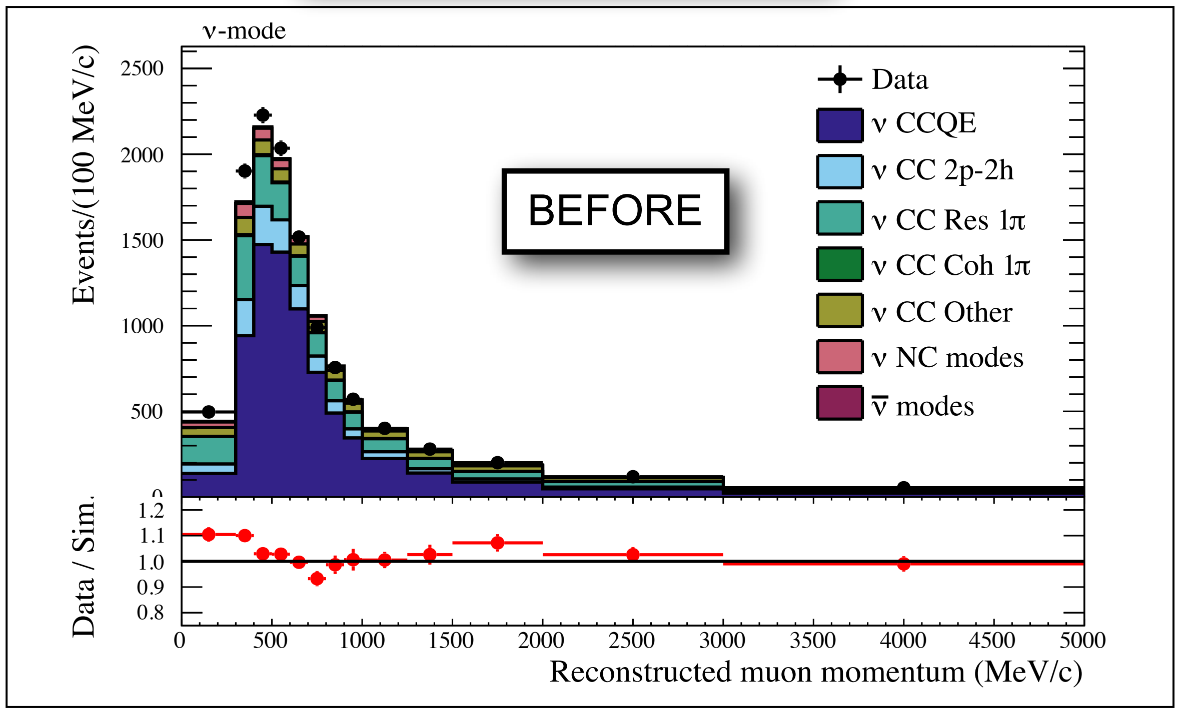


Flux Error ~10%

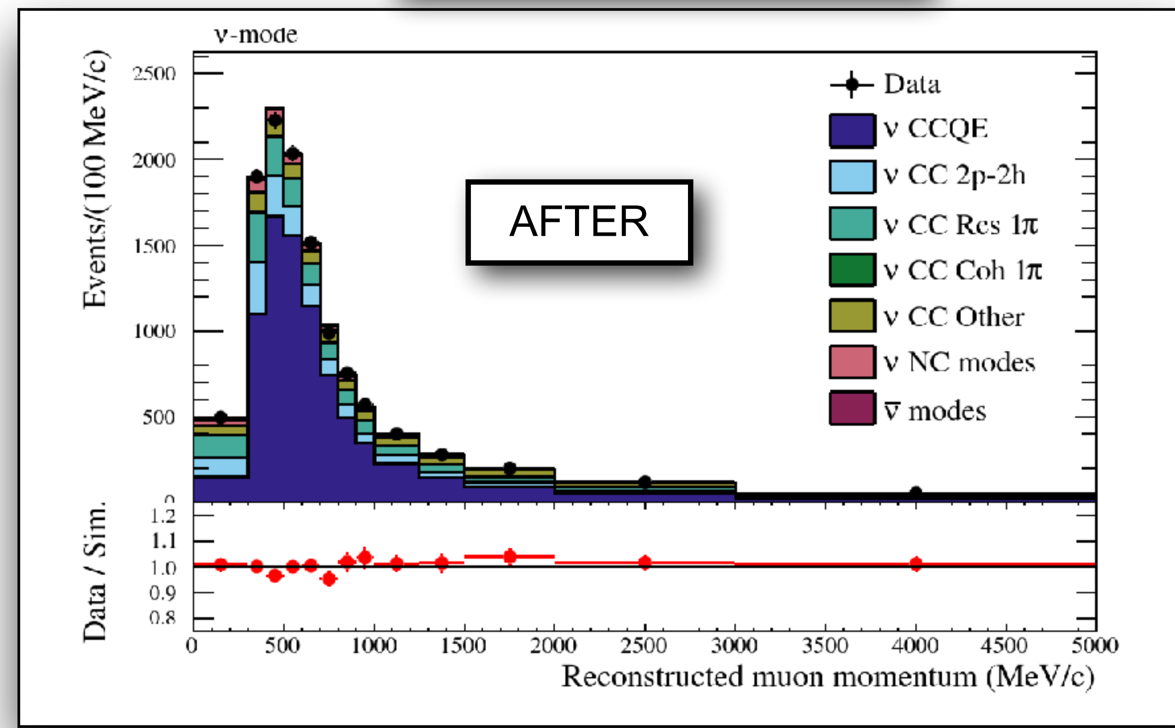


ND280 Role

PREDICTION AT ND280



PREDICTION AT ND280



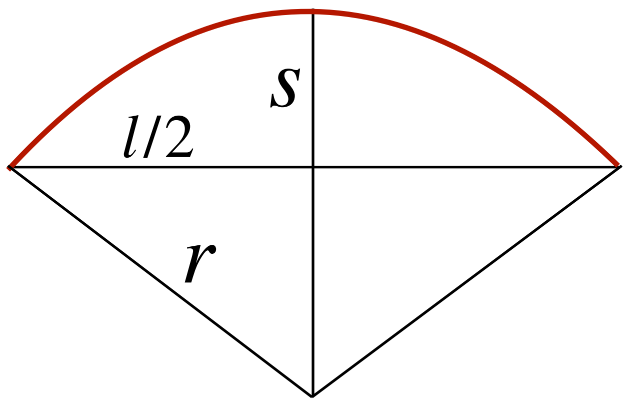
Before oscillation Error in Flux is ~%10. After using ND280 constrain overall (Flux, cross section, SK) uncertainty is ~5% for muons, ~10% for electrons.

There are lots of topologies not used since the modeling is not good enough… !

Particle ID fundamentals (momentum reconstruction)

B = 0.2 T in ND280

Momentum reconstruction:



If $s \ll l$

$$p_t = erB = \frac{eBl^2}{8s}$$

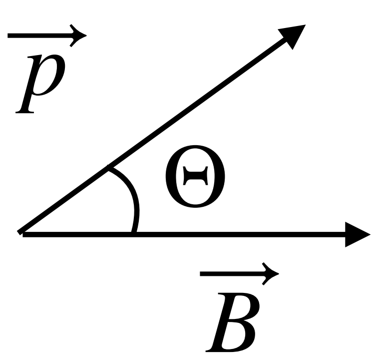
Momentum resolution:

$$\frac{\sigma_{pt}}{p_t} = \frac{\sigma_s}{s} = \sigma_{xy}\frac{p_t}{eBl^2}\sqrt{\frac{720}{N_p + 4}}$$

σ_{xy} = point resolution XY plane

N_p = number of points

Polar angle reconstruction:



$$p = \frac{p_t}{sin\Theta}$$

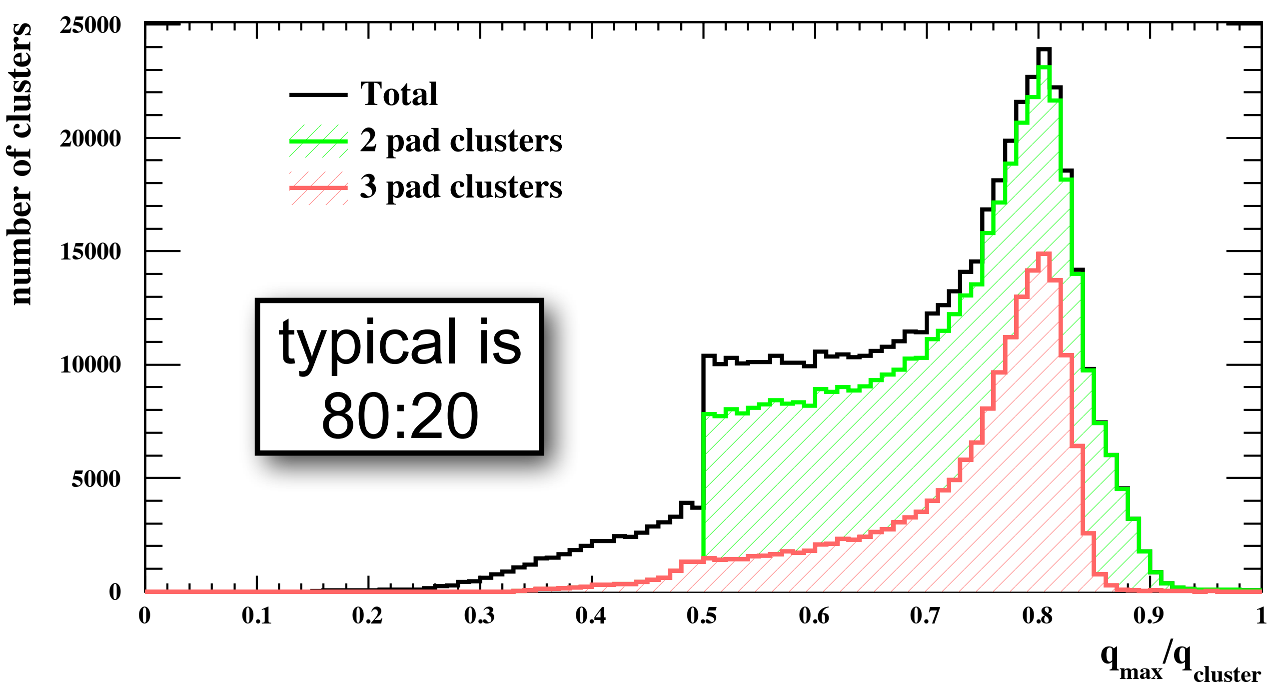
Polar angle resolution:

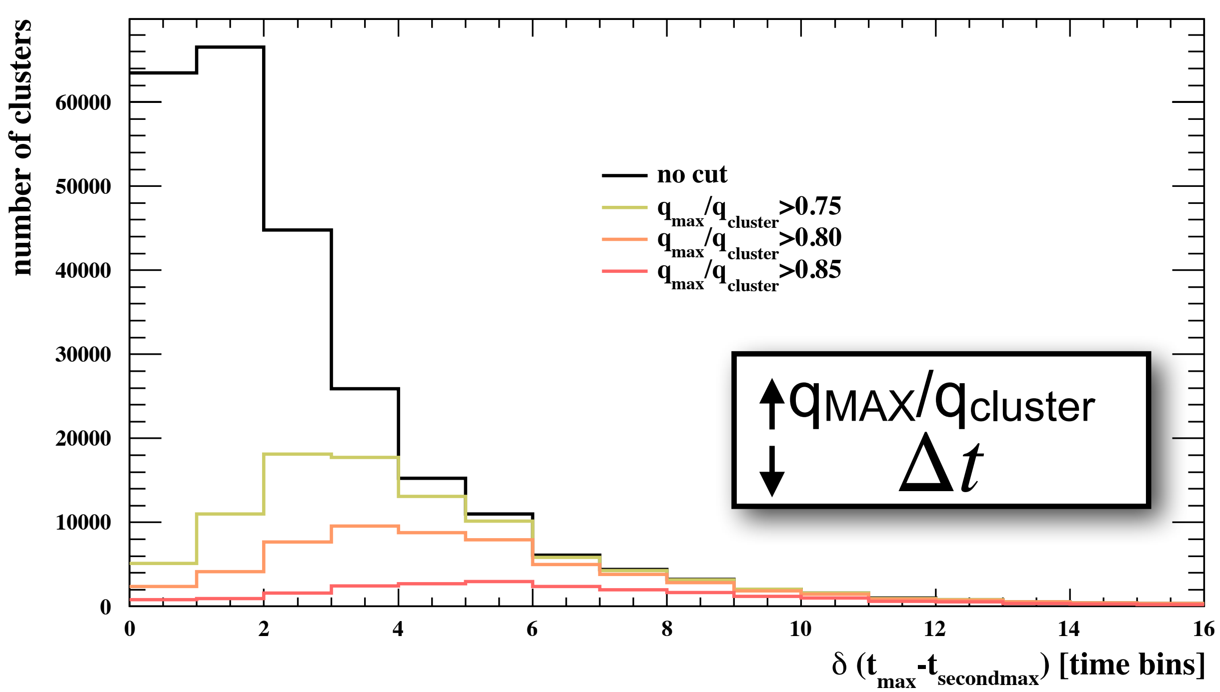
$$\frac{\sigma_\Theta}{\Theta} = \sqrt{\frac{12(N_p - 1)}{N_p + 1}}$$

Charge spreading in the resistive foil

Assume $Q_2 >> Q_1 >> Q_3$

How the signal spreading affects the measurement?





Majority of 2 and 3 pads