PERFORMANCE OF THE TIME PROJECTION CHAMBERS WITH RESISTIVE MICROMEGAS OF THE T2K NEAR DETECTOR UPGRADE

Sergey Suvorov
On-behalf of the T2K near detector upgrade team

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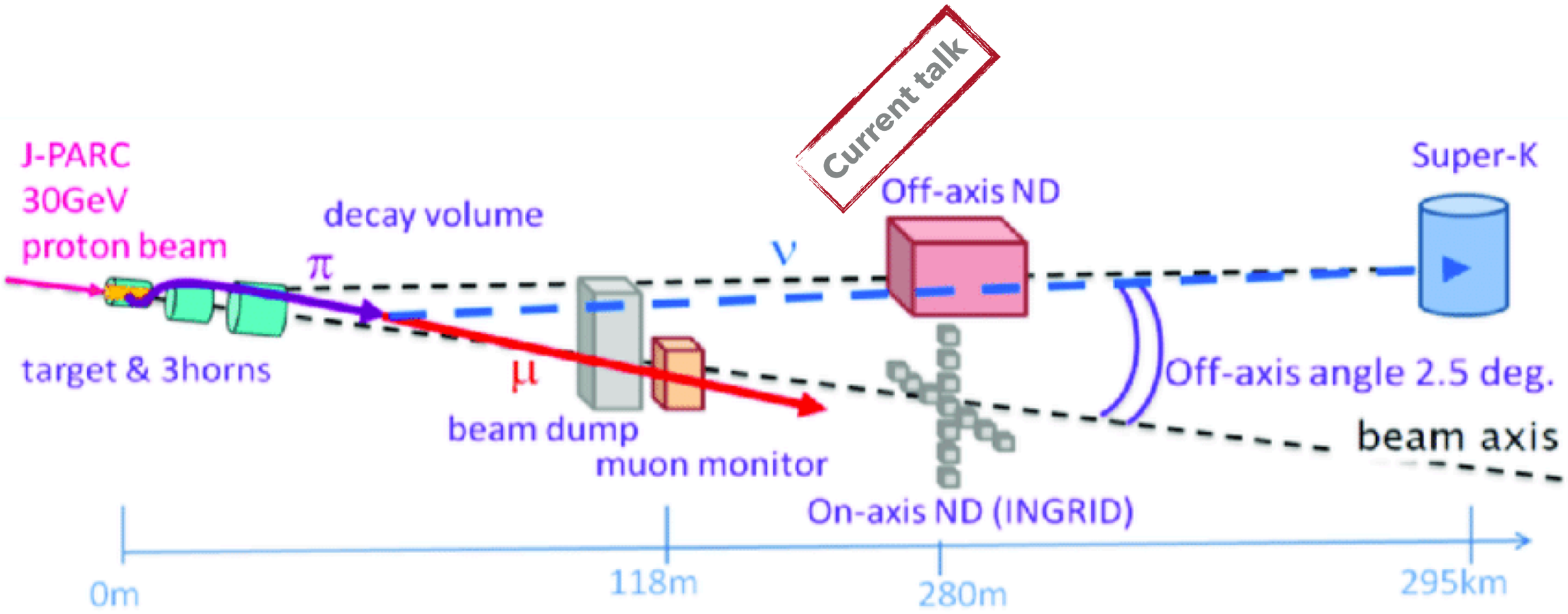
25.02.2020

T2K EXPERIMENT

- Accelerator experiment studies precisely neutrino oscillation
  - 30 GeV proton beam was used to produce ~600 MeV $\nu_\mu/\bar{\nu}_\mu$ beam



- T2K general talk
- T2K latest results
- T2K $\nu_\mu/\bar{\nu}_\mu$ disappearance

ND UPGRADE: GENERAL IDEA

- New detectors will be developed and installed in 2022:

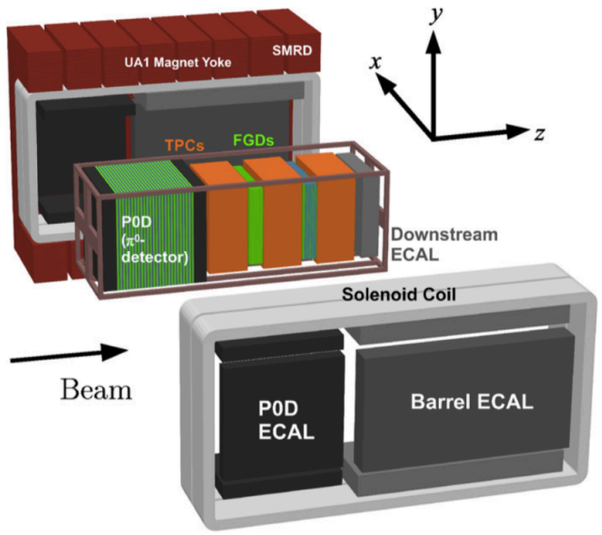
➡ Fully active 3D active target (SuperFGD)

Current talk

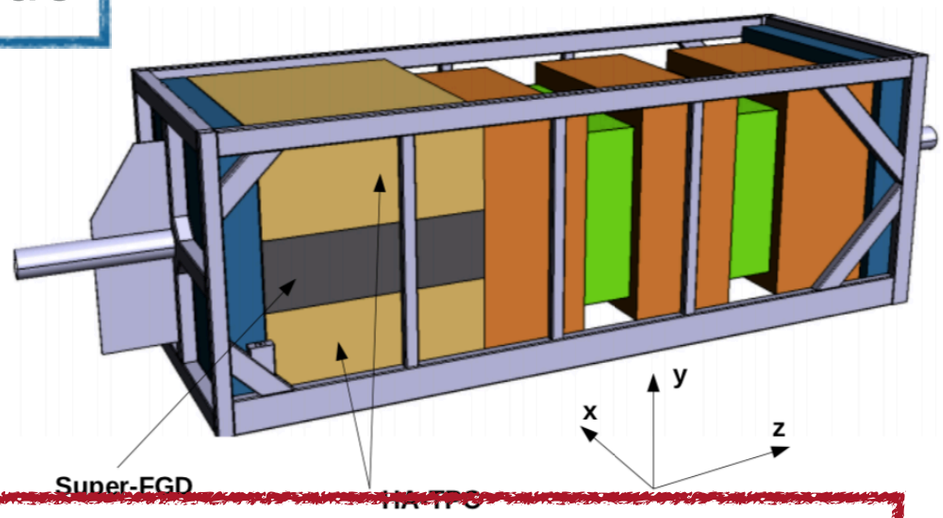
➡ 2 High angle TPCs

➡ Time of Flight detectors

Now



After upgrade

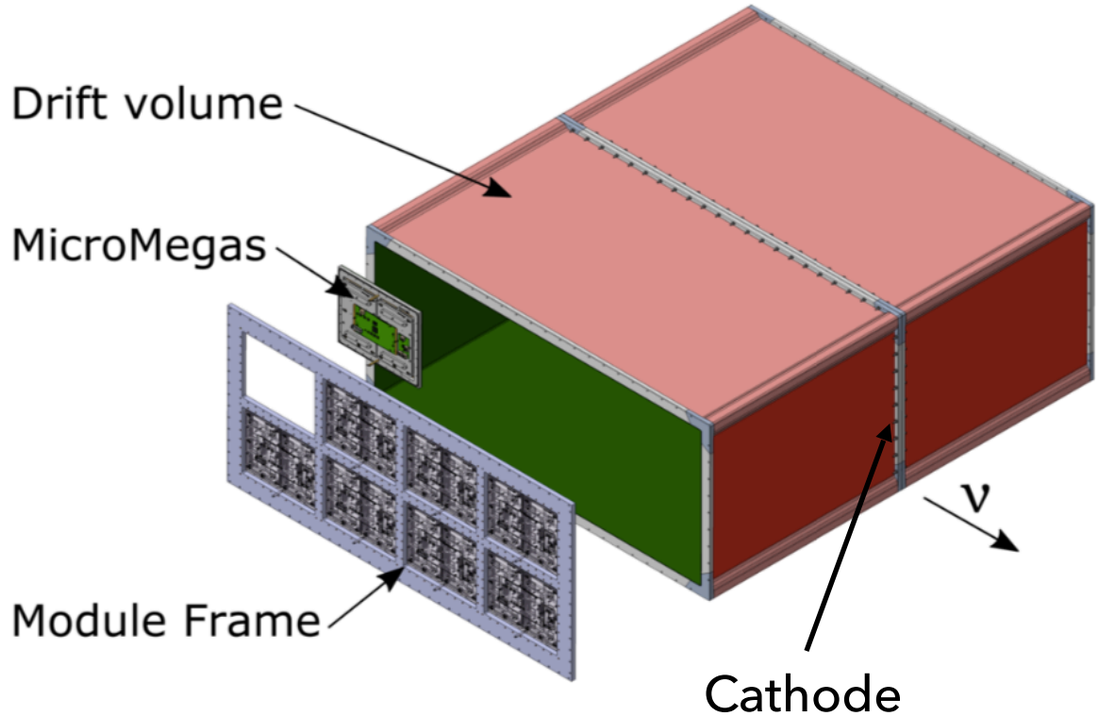


4π acceptance
low energy thresholds
TDR 2019: 1901.03750

–> improved sensitivity to CP violation in neutrino oscillations

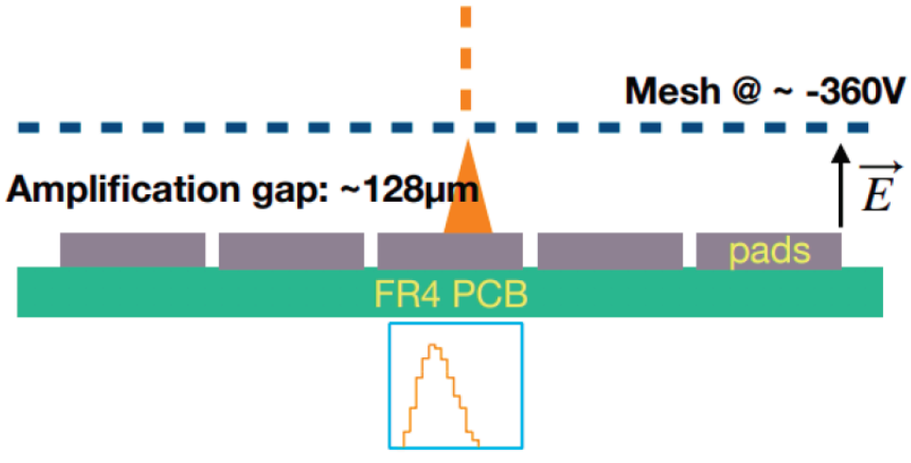
HORIZONTAL TPC

- New field cage with resistive micromegas
  - Made from composites
    –> minimum material budget
    –> minimum track distortions

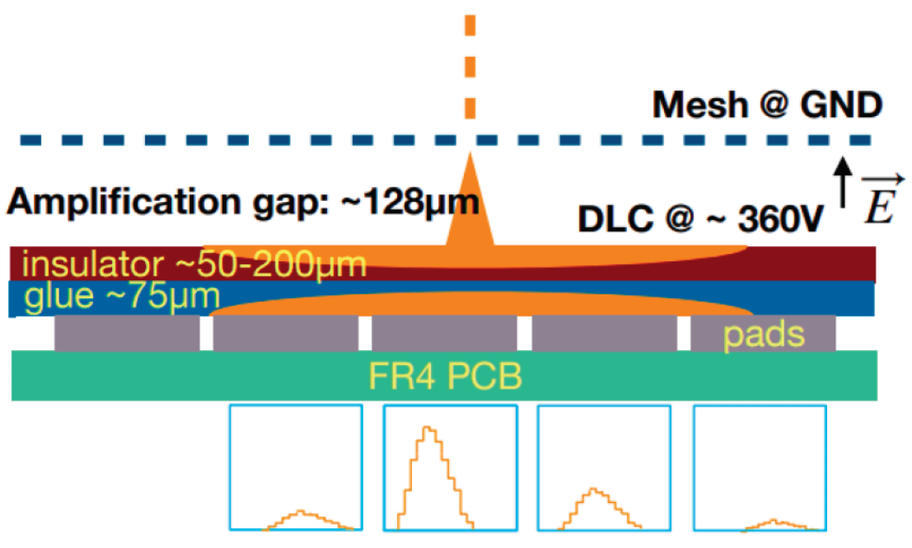


- Resistive micromegas detectors:
  - Share charge between pads –> precise position reconstruction

bulk MicroMegas



resistive anode MicroMegas

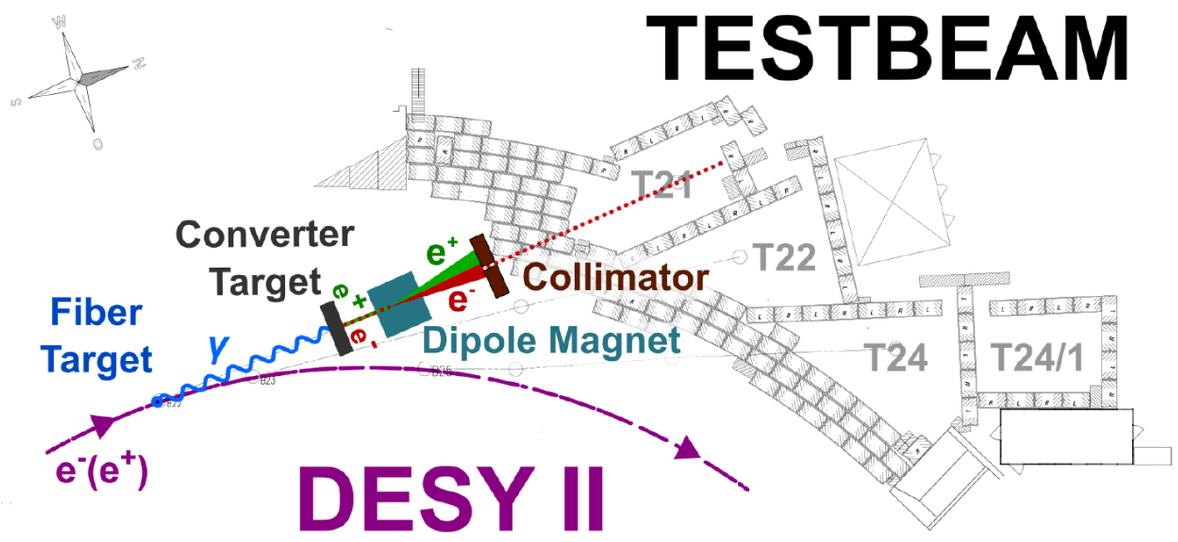


$$\rho(r,t) = \frac{RC}{2t} e^{-r^2 RC/(4t)}$$

- Better spatial resolution with the same number of pads –> better momentum resolution

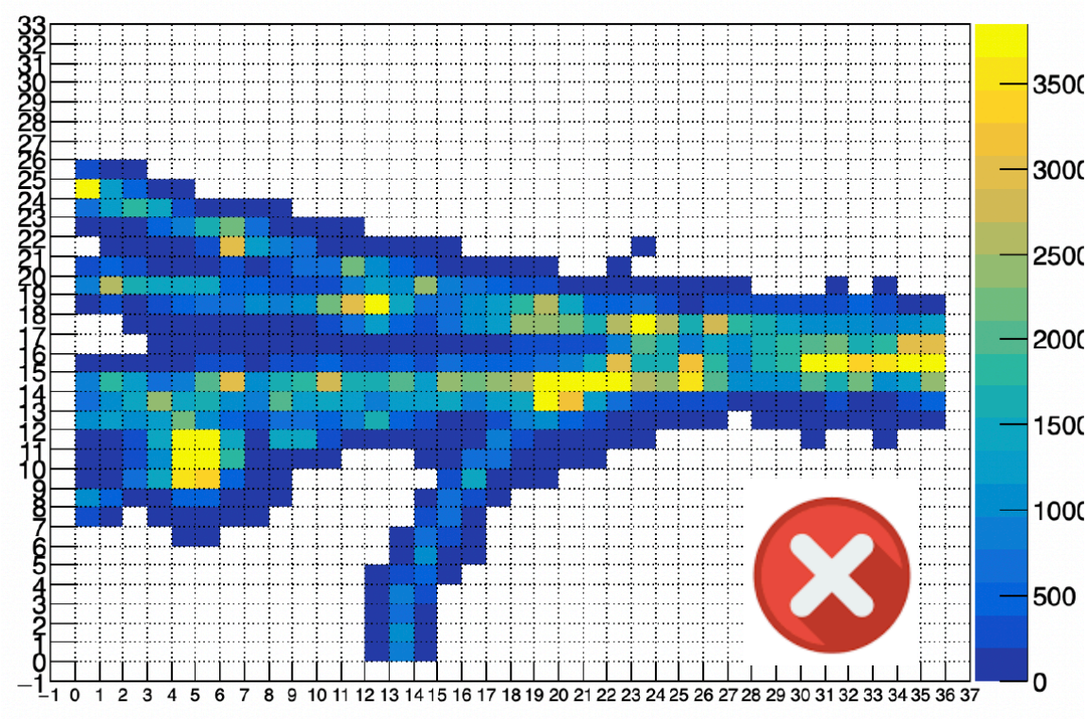
RESISTIVE TPC BEAMTEST

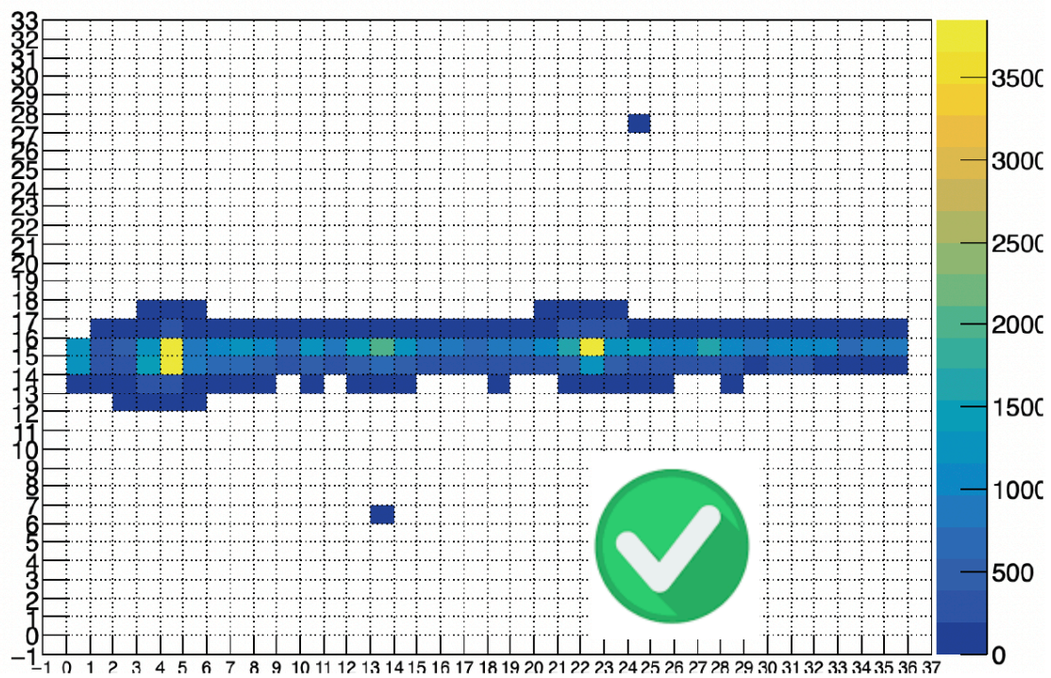
- 2018 test at CERN
  - 10% dE/dx resolution
  - 250 μm spatial resolution
- New prototype was build and tested in 2019 at DESY secondary beam
  - 1 - 5 GeV electron beam
  - TPC was put into magnet 0T and 0.2T was used (as in T2K)
  - Scan over:
    - Drift distance
    - Momentum
    - Track angle
    - Electronics shaping time
    - Micromegas voltage



TRACK RECONSTRUCTION

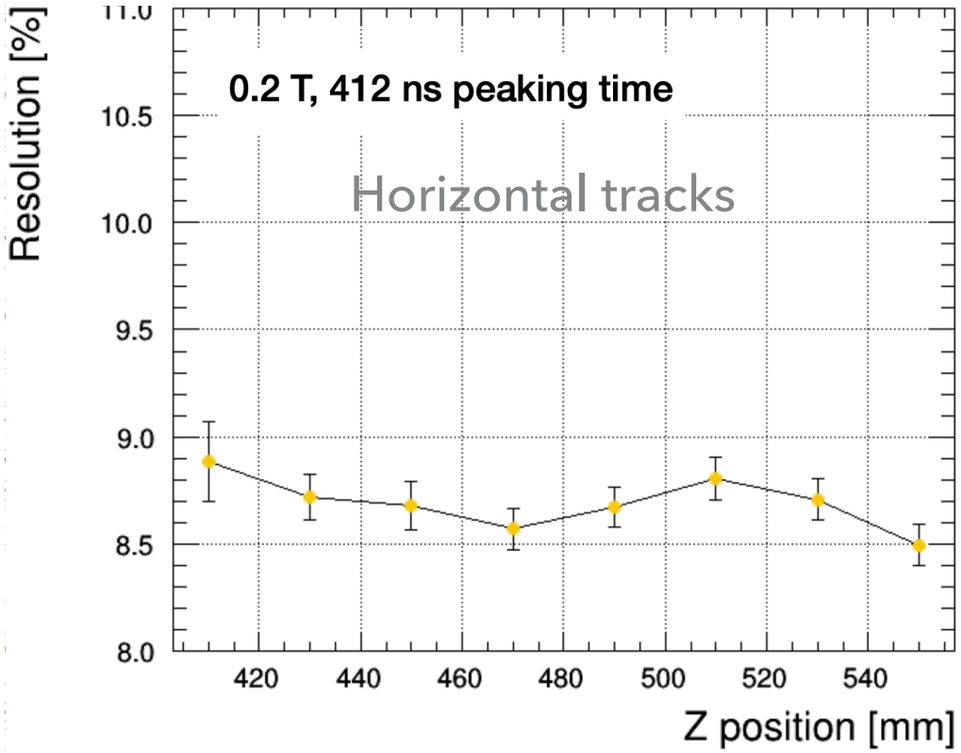
- Well-known DBSCAN clustering algorithm was used to find clear straight-forward tracks
- Only through-going straight tracks were accepted for the analysis
- Charge spreading feature is clearly visible by eye

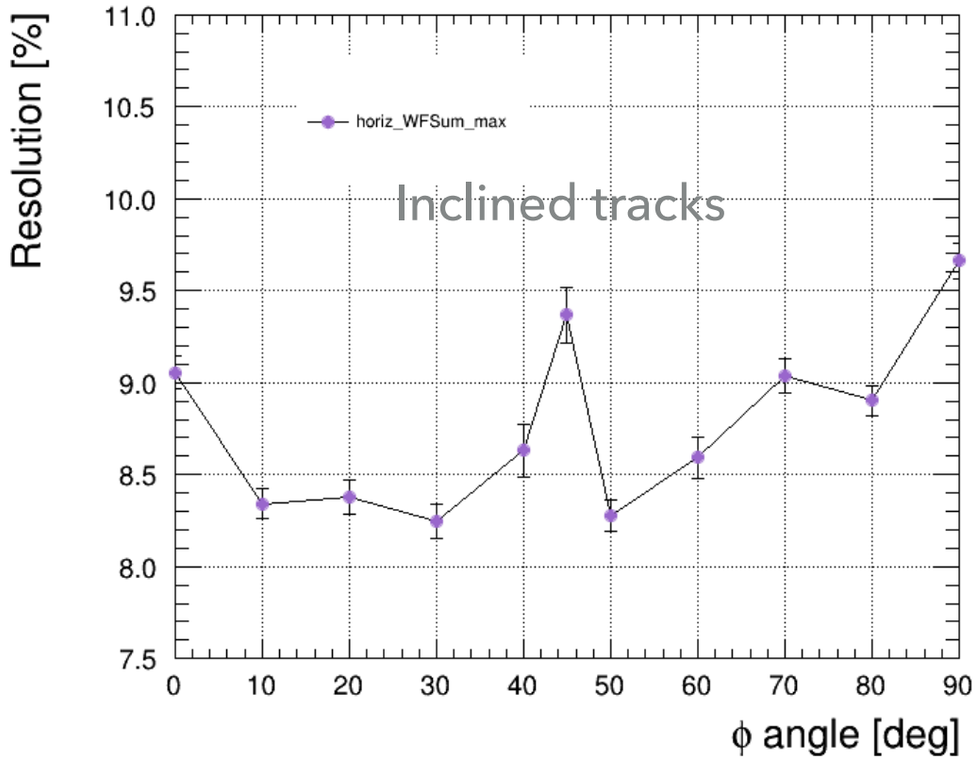




DE/DX RESOLUTION

- The standard “truncated mean” method was used to estimate dE/dx resolution

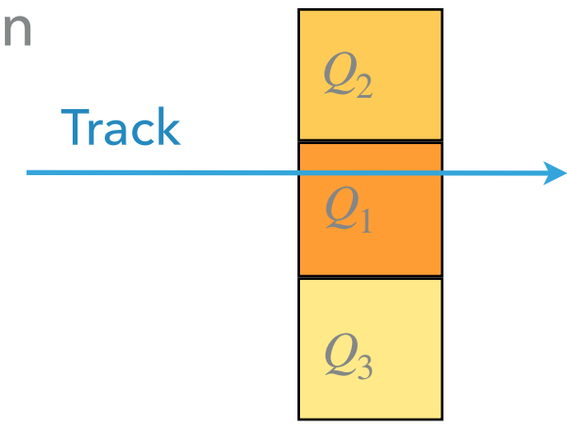




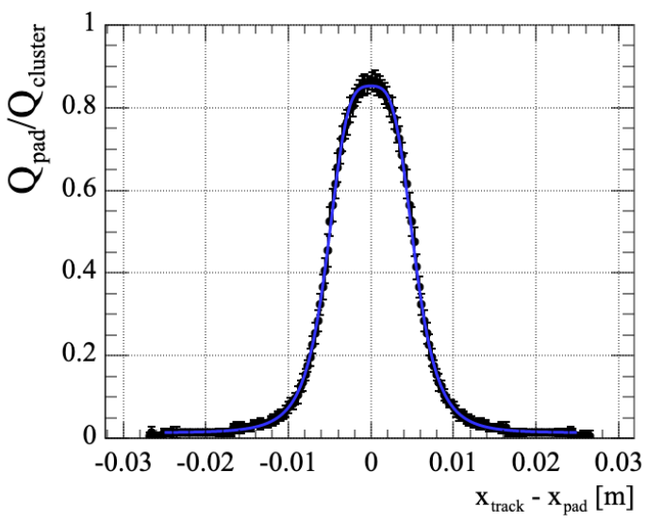
- dE/dx resolution was measured at ~9%
  - This is one module value –> for two modules we expect ~6%
  - Good performance at all track angles

SPATIAL RESOLUTION

Charge sharing in a cluster:



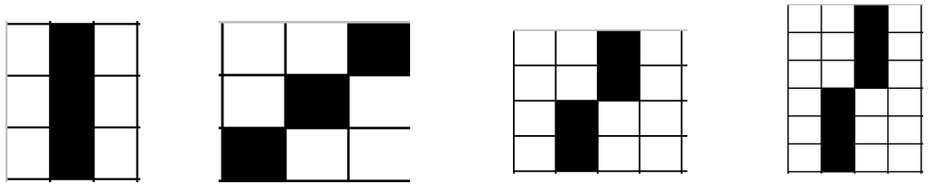
- Charge spreading provides promise knowledge about track position
- To extract position we parametrise charge ratios with Pad Response Function



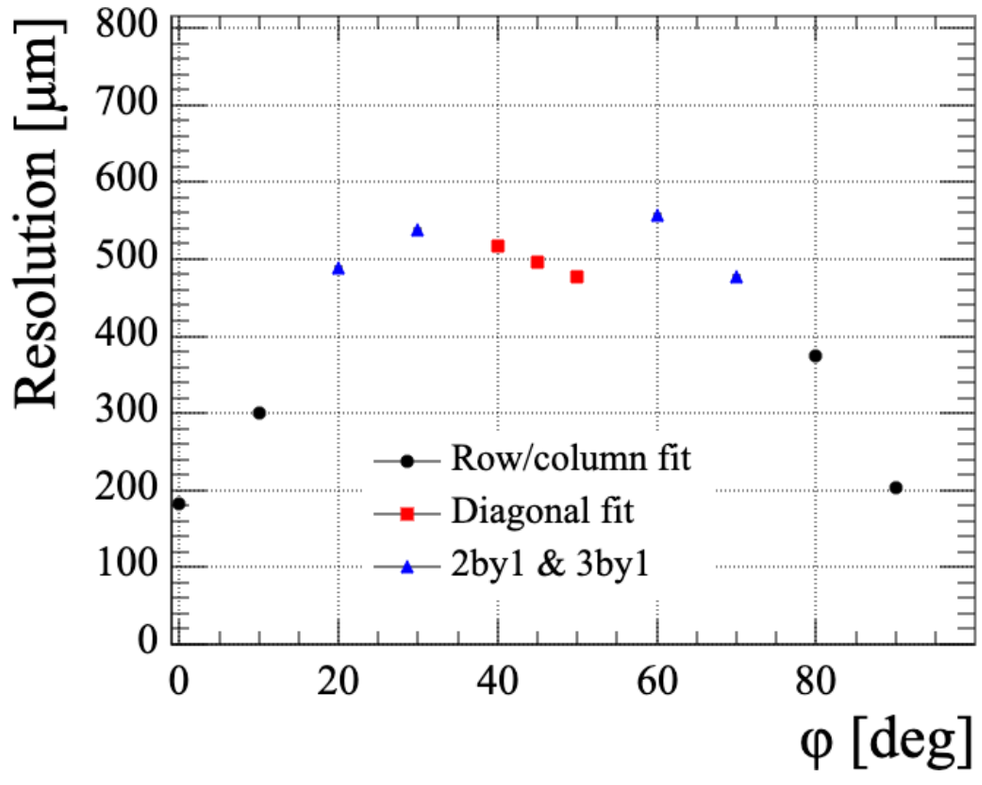
Known PRF is used in χ^2 fit:

$$\chi^2_{cluster} = \sum_{row} \left[\frac{Q_{pad}/Q_{cluster} - PRF\left(X_{pad} - X_{cluster}\right)}{\sigma_{Q_{pad}}} \right]^2$$

- For the sloped tracks we looked at "sloped clusters"



- Significant improvement was found w.r.t. existing TPCs



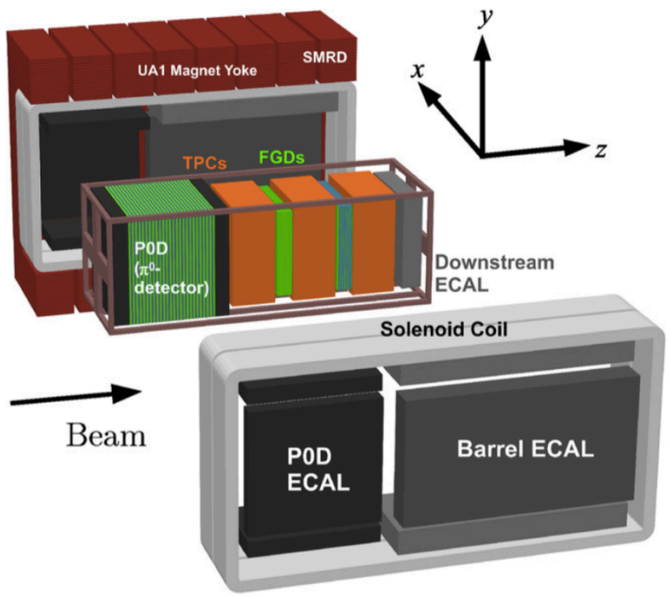
SUMMARY

- T2K near detector is going to be upgraded with **TPCs with resistive anode**
- Resistive technology is going to **improve TPC performance**
  keeping pad size the same

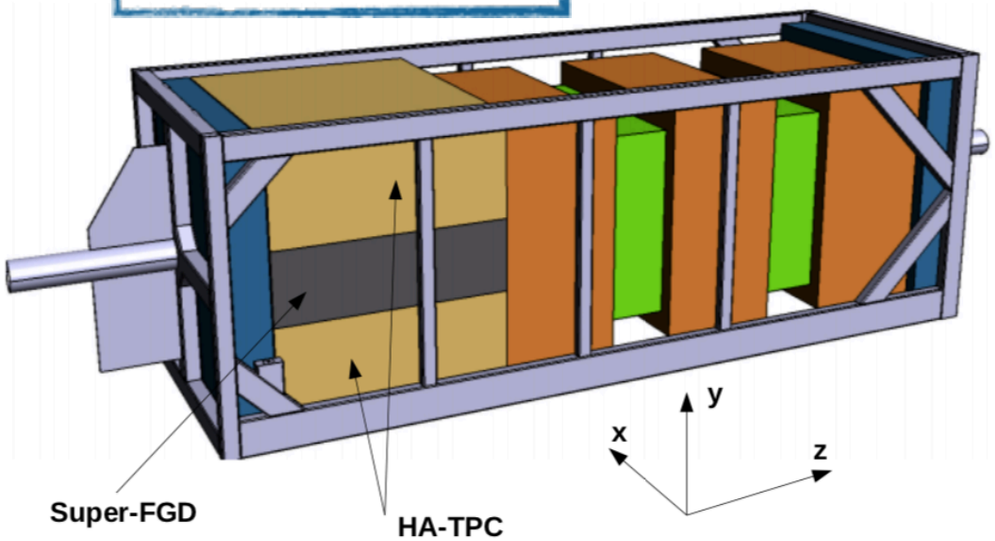
- Few beam tests were performed:
  - Prototypes were proved to operates successfully
  - dE/dx resolution was measured with similar values as in the existing TPCs
    - 9% for one module
  - Spatial resolution was measured at much better values to current TPCs
    - 200 μm vs 600 μm for 0°
    - 500 μm vs 1400 μm for 45°

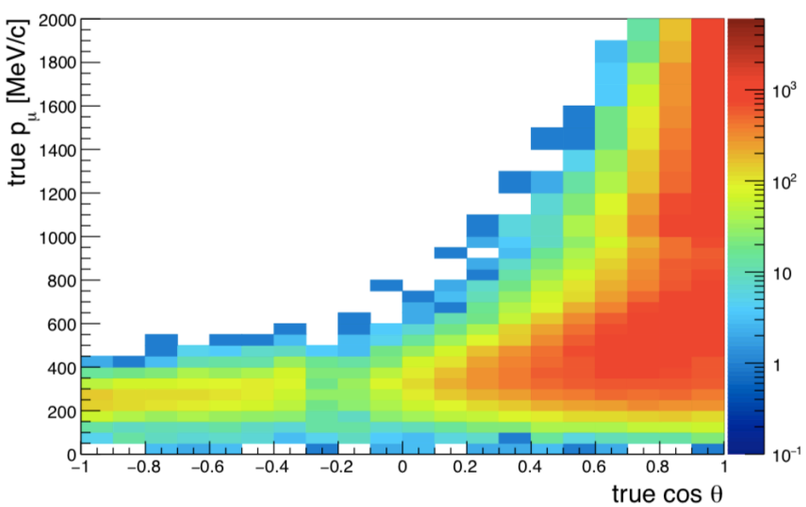
BACK UP

Now



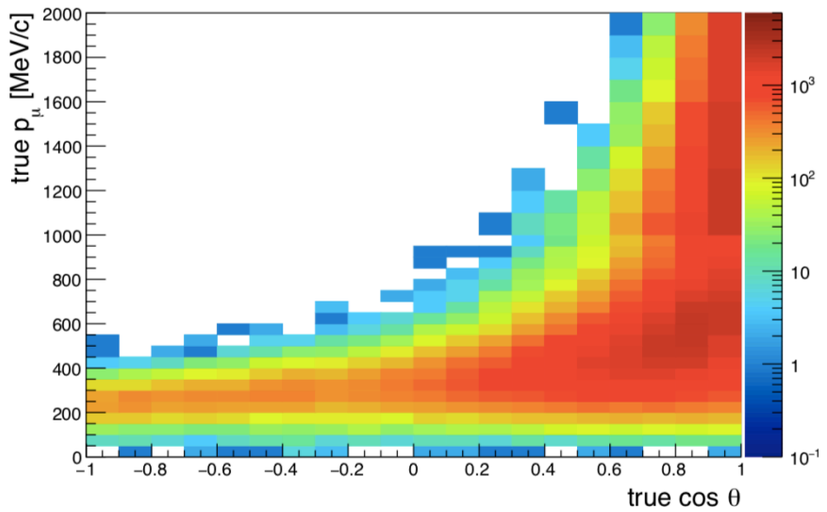
After upgrade

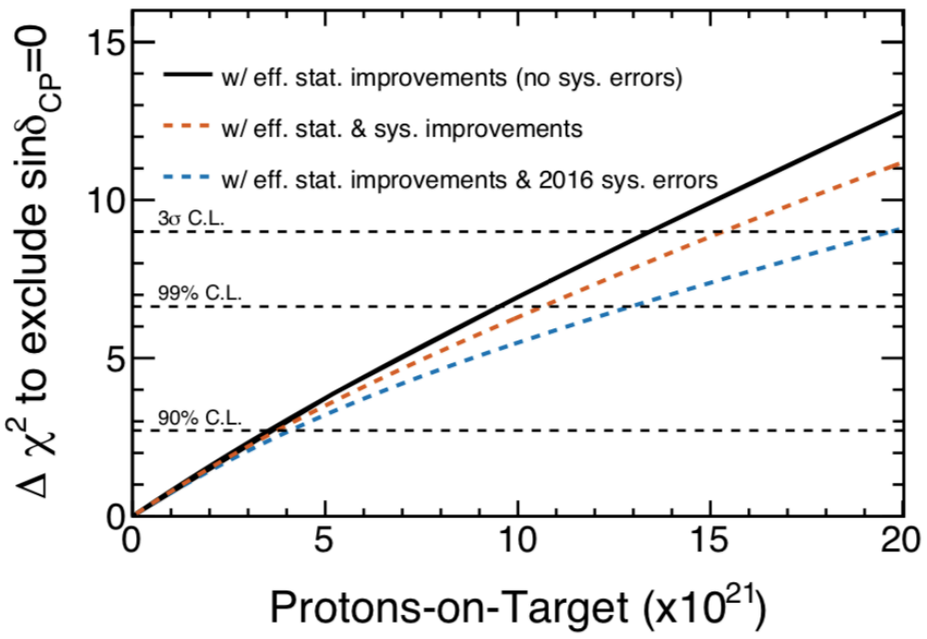


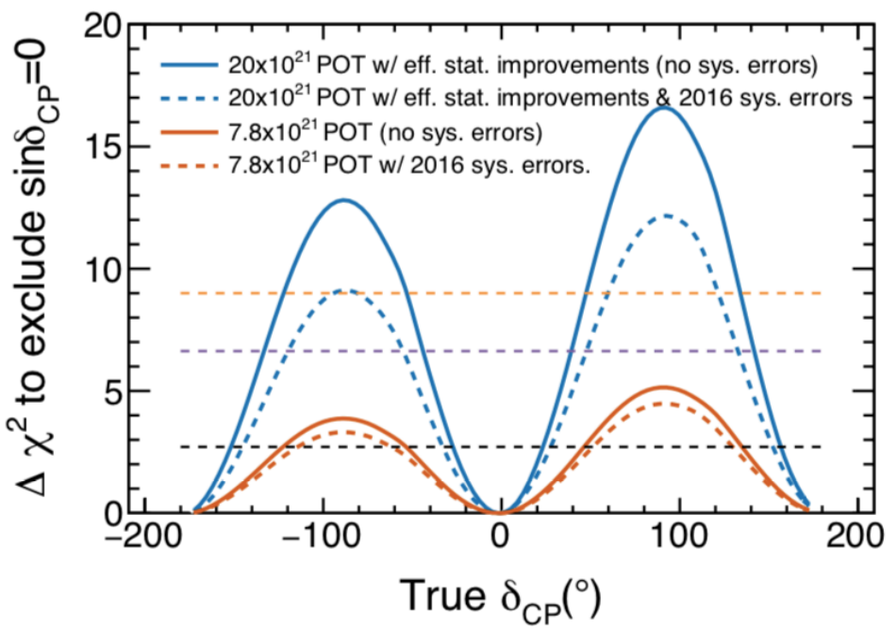


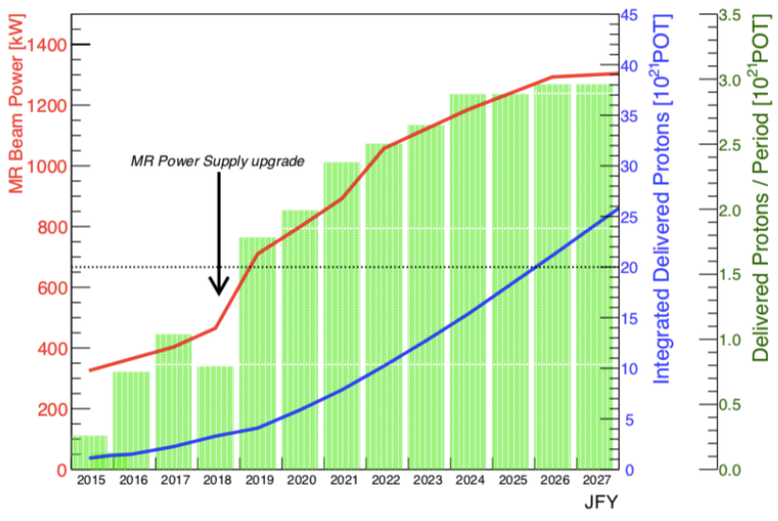
Selected $\nu_\mu CC$ events

NEUT simulations
same POT
statistics and efficiency gain are expected

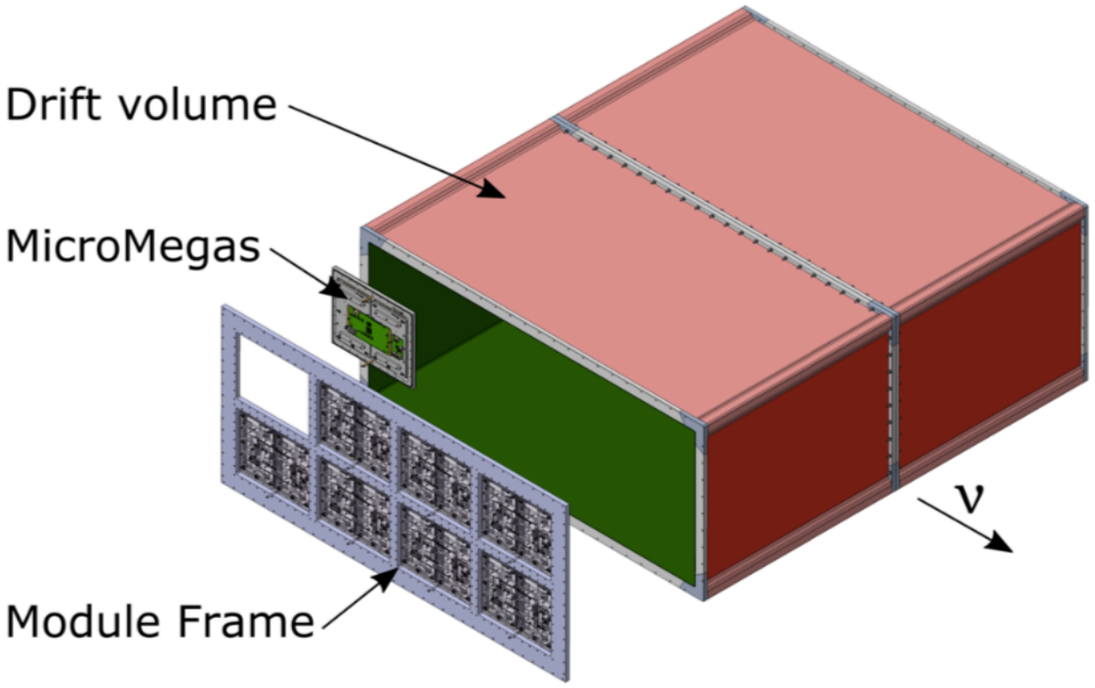



w/ eff. stat. improvements (no sys. errors)
w/ eff. stat. & sys. improvements
w/ eff. stat. improvements & 2016 sys. errors
3σ C.L.
99% C.L.
90% C.L.
Δ χ² to exclude sinδCP=0
Protons-on-Target (x10²¹)


20x10²¹ POT w/ eff. stat. improvements (no sys. errors)
20x10²¹ POT w/ eff. stat. improvements & 2016 sys. errors
7.8x10²¹ POT (no sys. errors)
7.8x10²¹ POT w/ 2016 sys. errors.
Δ χ² to exclude sinδCP=0
True δCP(°)


MR Beam Power [kW]
MR Power Supply upgrade
Integrated Delivered Protons [10²¹POT]
Delivered Protons / Period [10²¹POT]
JFY
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027

HIGH ANGLE TPC TECHNICAL DETAILS

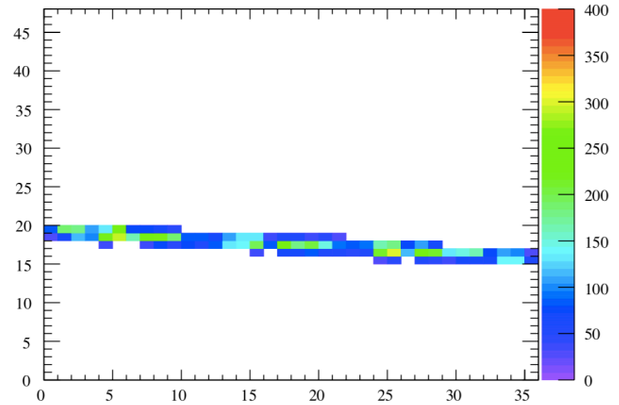


Parameter	Value
Overall x×y×z (m)	2.0×0.8×1.8
Drift distance (cm)	90
Magnetic Field (T)	0.2
Electric field (V/cm)	275
Gas Ar:CF_4:iC_4H_4 (%)	95-3-2
Drift Velocity cm/μs	7.8
Transverse diffusion (μm/$\sqrt{\text{cm}}$)	265
Micromegas gain	1000
Micromegas dim. z×y (mm)	340×410
Pad z×y (mm)	10×11
N pads	36864
el. noise (ENC)	800
S/N	100
Sampling frequency (MHz)	25
N time samples	511

2018 CERN BEAM TEST

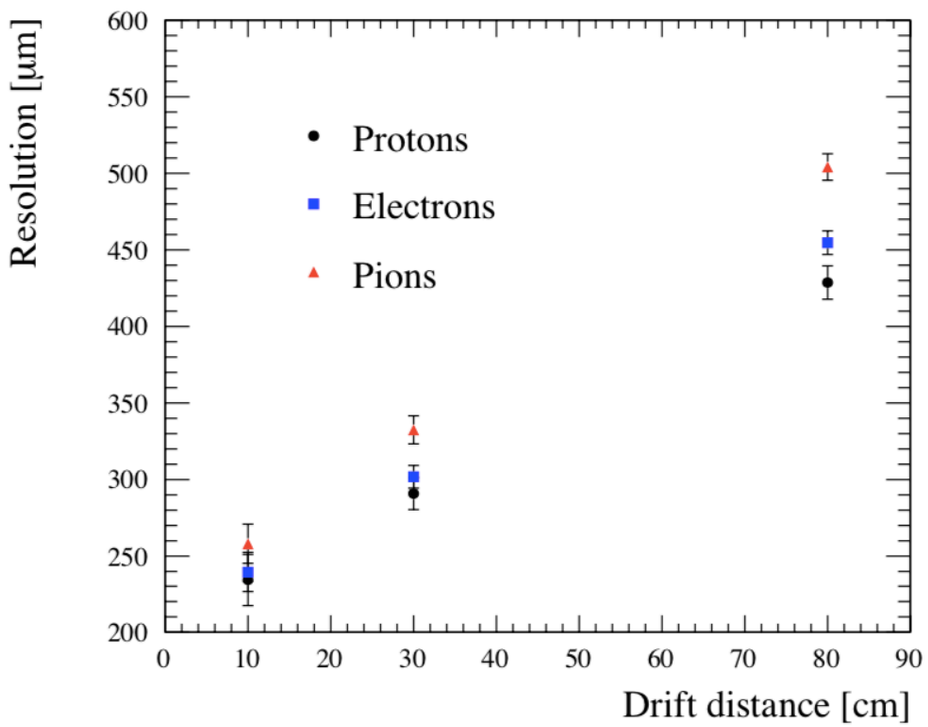
- TPC prototype with micromegas with resistive foil was tested at CERN beam (PS)
- e, π, p beams were used with the momentum ~1 GeV/c
- Very good performance was observed
  arXiv:1907.07060

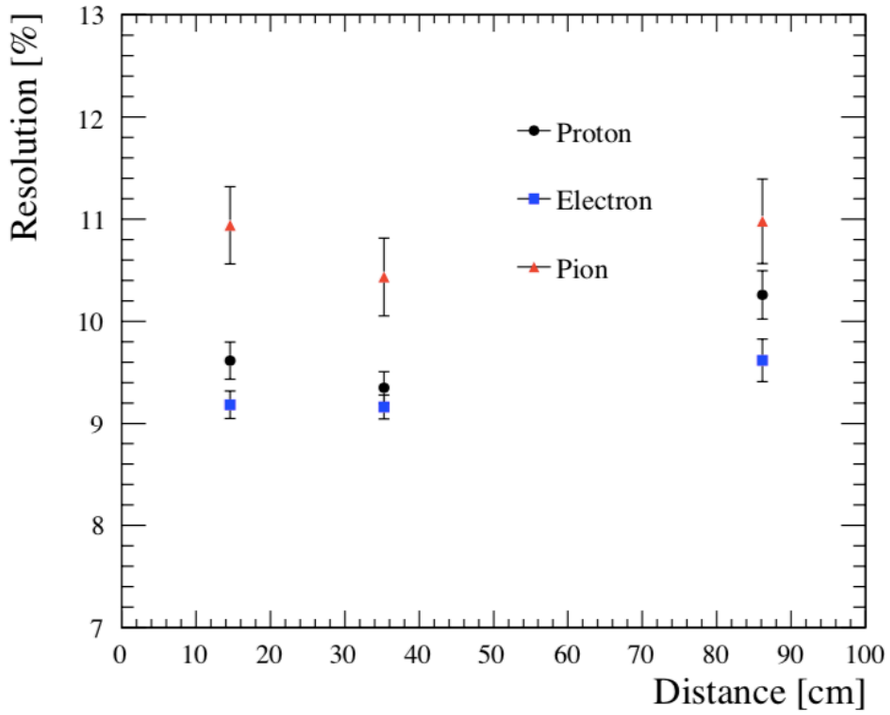
CERN Beam test event example with charge charing between pads



Spatial resolution from CERN test
T2K resolution ~0.6mm
With resistivity anode we reach 0.25 mm

dE/dx resolution from CERN test
~10% for 36 cm. tracks
similar to T2K performance

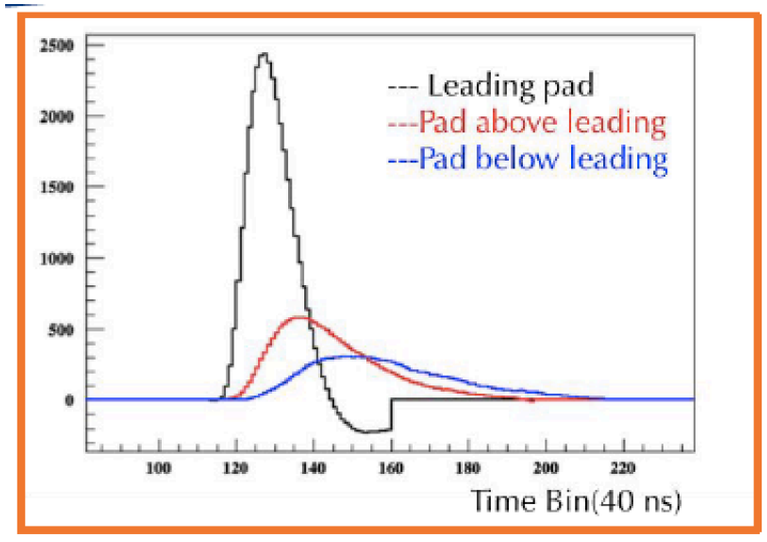


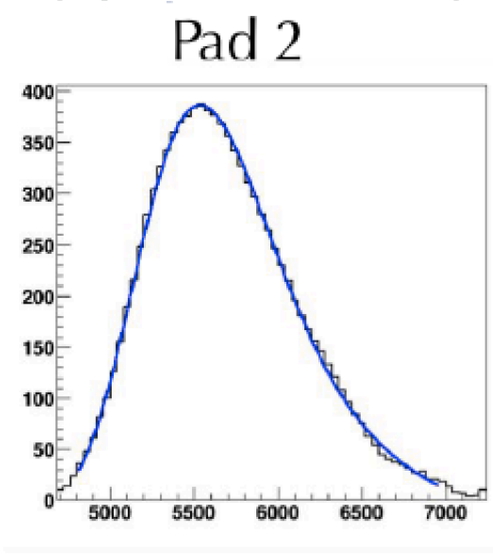


New beam test with optimised resistive MM was done in DESY in June 2019
Data analysis is in progress

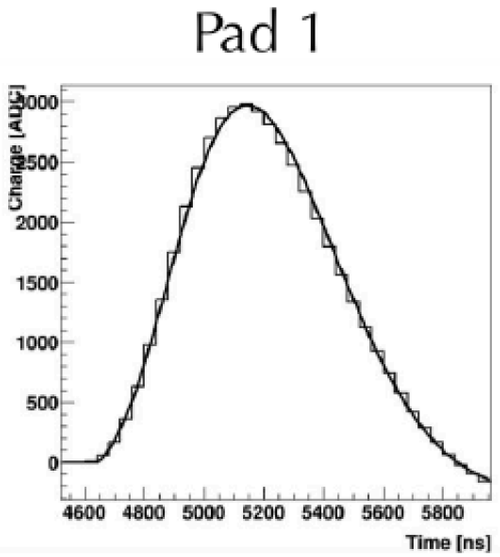
RC MAP

- By comparing signal in leading pad and neighbours the RC value was measured

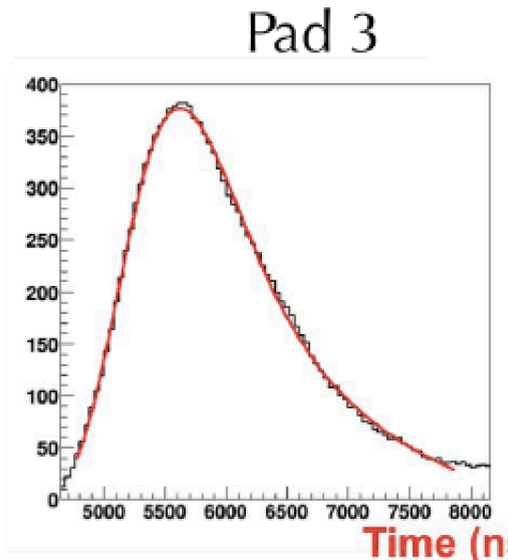




Fitted with A(t) x Q(t)



Fitted with A(t)

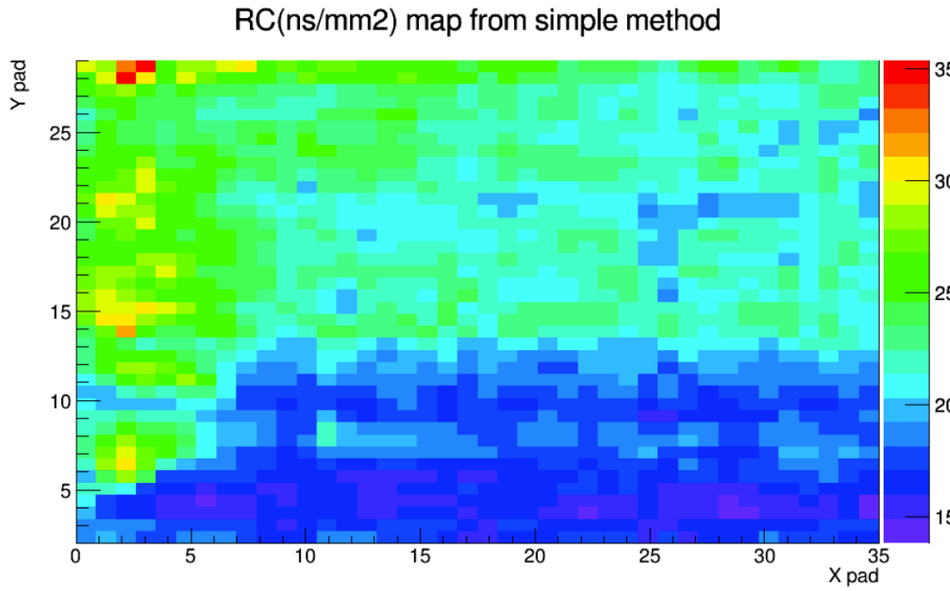


Fitted with A(t) x Q(t)

$$A(t) = A_{peak} \times \exp\left(-\exp\left(t - t_{peak} - a\right)/\tau_1\right)) \times \exp\left((t - t_{peak})/\tau_1\right) \times \sin\left((t - t_{peak})/\tau_2\right)$$

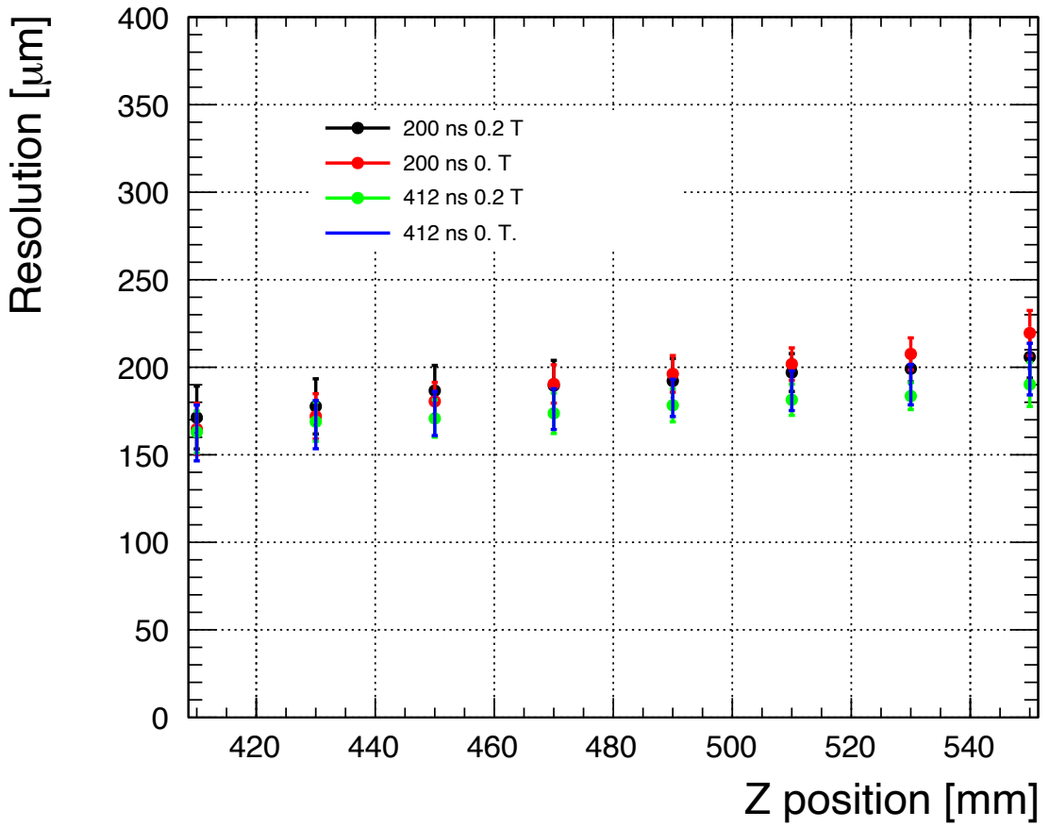
$$Q_{pad}(t) = \frac{Q}{4}\left[erf\left(\frac{x_{high} - x_0}{2\sigma(t)}\right) - erf\left(\frac{x_{low} - x_0}{2\sigma(t)}\right)\right]\left[erf\left(\frac{y_{high} - y_0}{2\sigma(t)}\right) - erf\left(\frac{y_{low} - y_0}{2\sigma(t)}\right)\right] \qquad \sigma(t) = \sqrt{\frac{2t}{RC}}$$

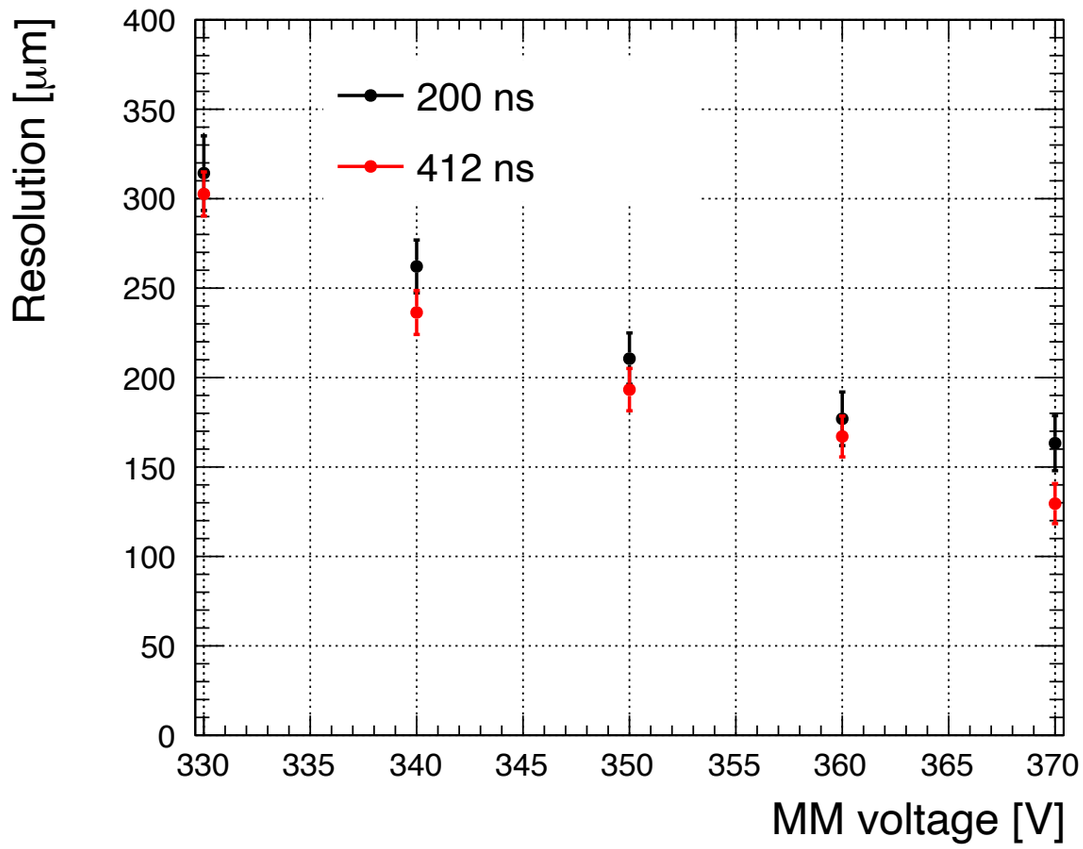
- Leading pad affected only by electronics $A(t)$
- Neighbours convolutes charge spreading with electronics $Q_{pad} \times A(t)$
- RC map was obtained from fit the equations above
  - y_0 was obtained with Pad Response Function (PRF)



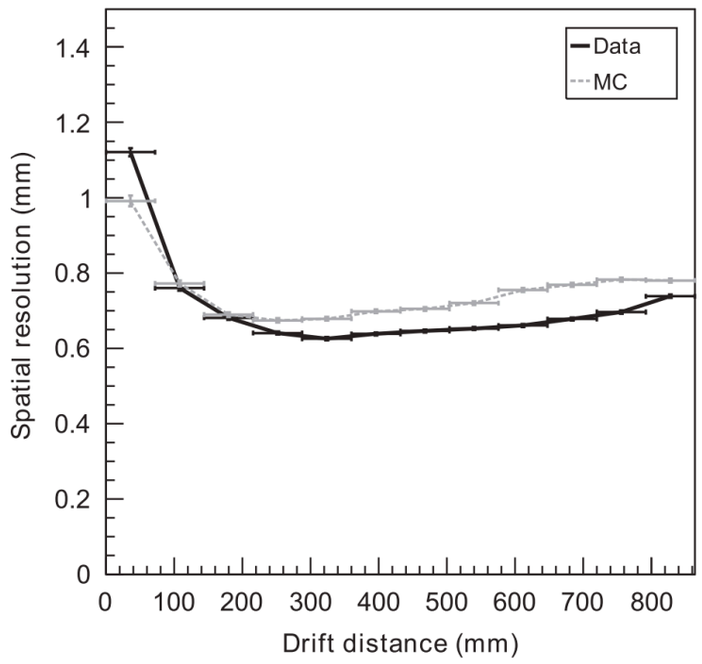
SPATIAL RESOLUTION

- With PRF the resolution at the level of 200 um was obtained



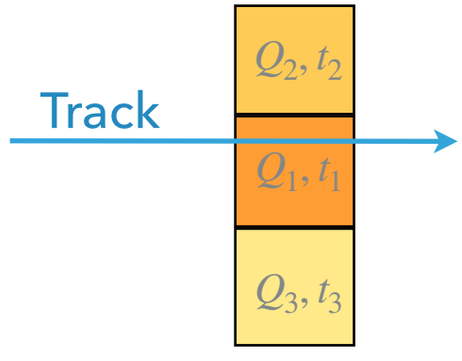


- ND280 Vertical TPCs:

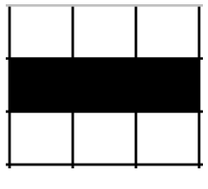


INCLINED TRACKS

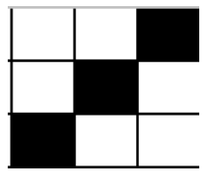
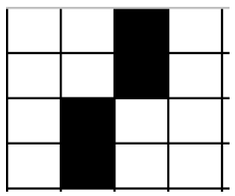
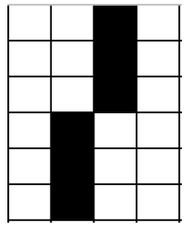
Charge sharing



- Prototype was rotated to measure inclined tracks
- PRF method is designed to work with transversal spreading
  –> works with inclined tracks but new patterns have to be defined

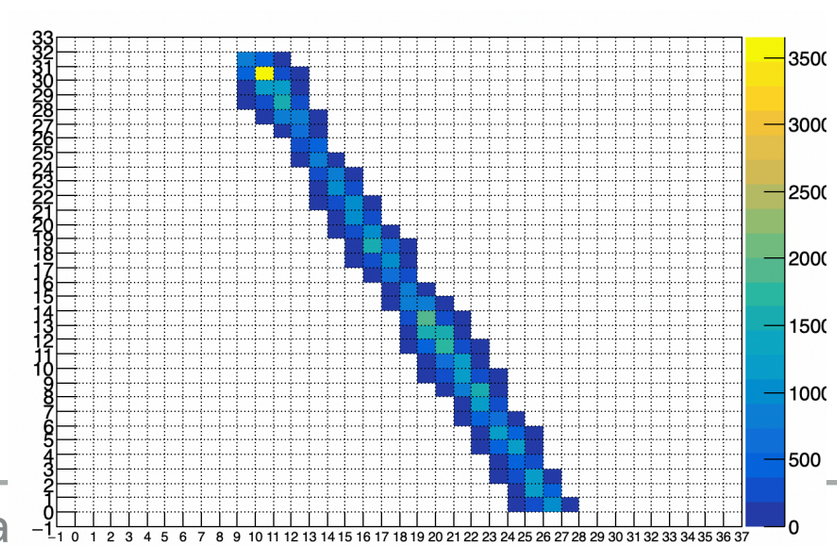
-  Works well for 0° and 90°

- To deal with sloped tracks more complicated “clusters” were used

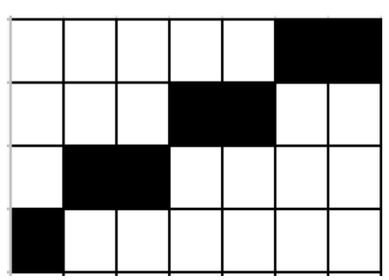




- Example:

60° track

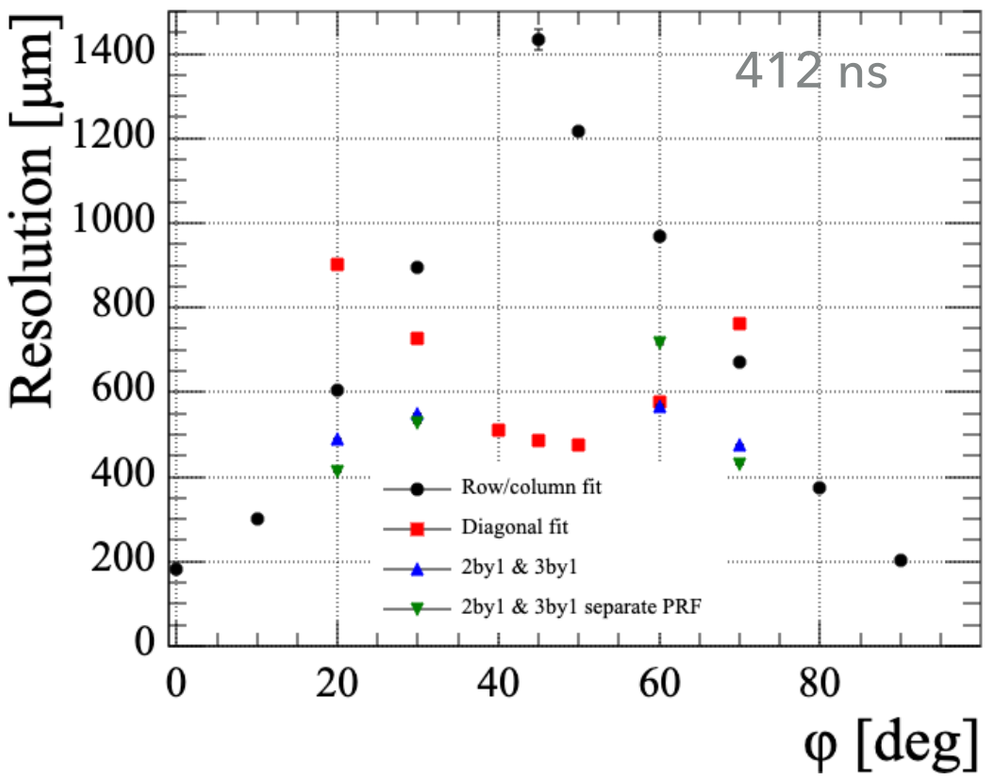


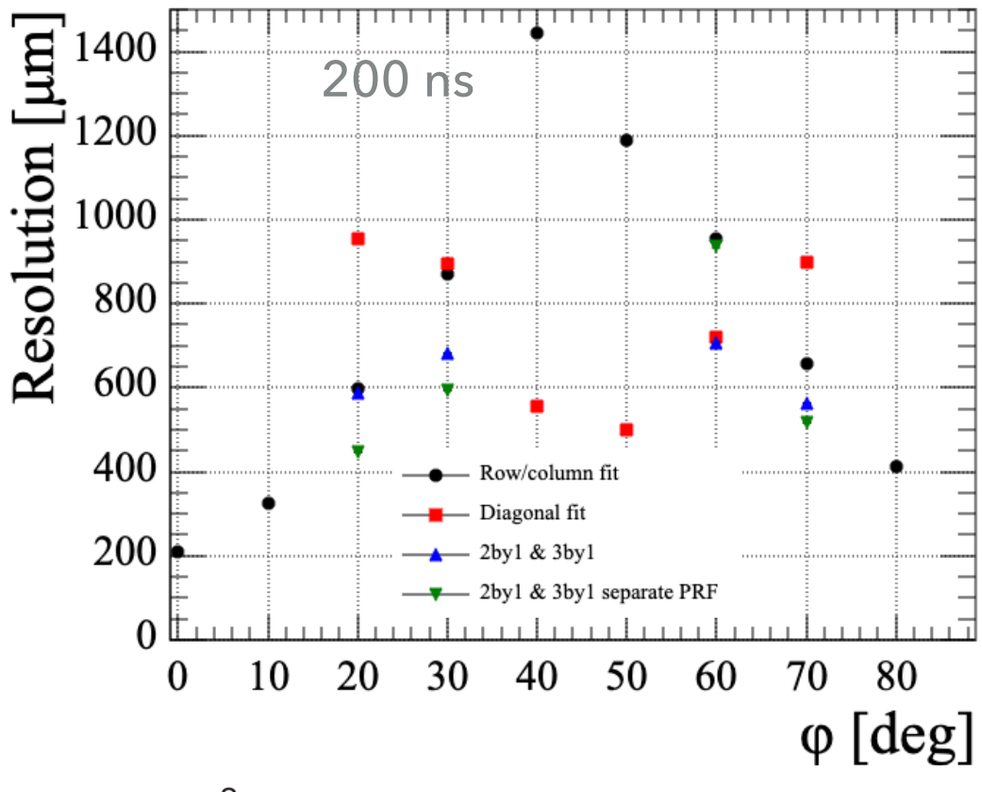
Appropriate cluster
to look at transversal spreading



INCLINED TRACKS

- The final results for different shaping time:





- With choice of the “right pattern” for each track resolution < 600 um is obtained for all the angles