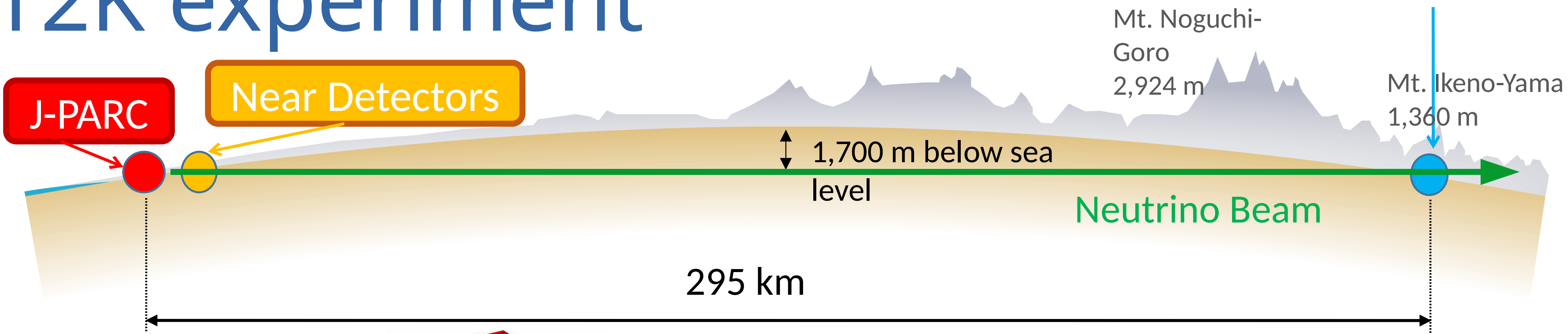
New TPCs for T2K near detector

David Henaff on behalf of ND280 Upgrade

IRN Neutrino meeting

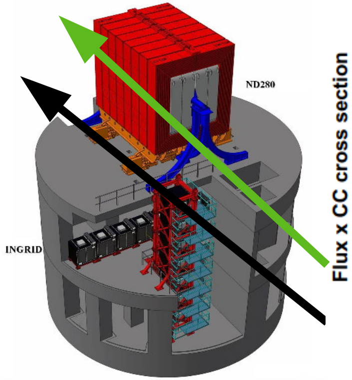
22/06/30

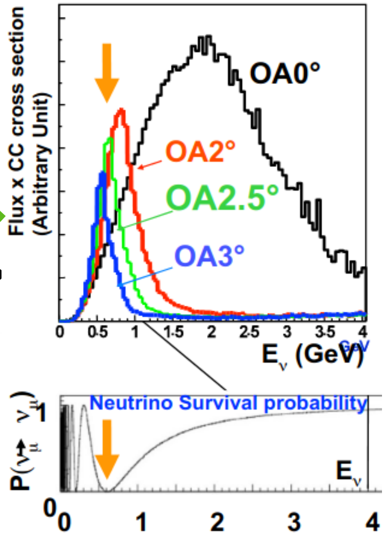
T2K experiment



J-PARC accelerator

- Protons @ 30 GeV
- Produced intense (anti) neutrino beams





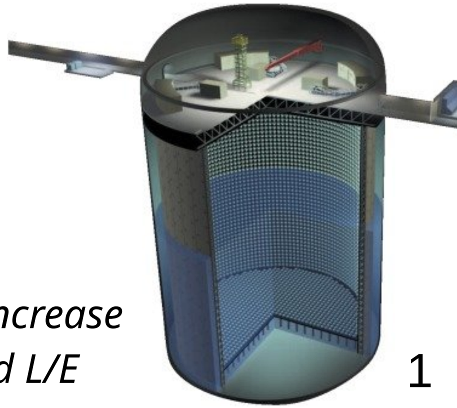
ND280

- 280 meters upstream beam target
- Perform measurement before oscillation of beam composition/flux
  → This talk

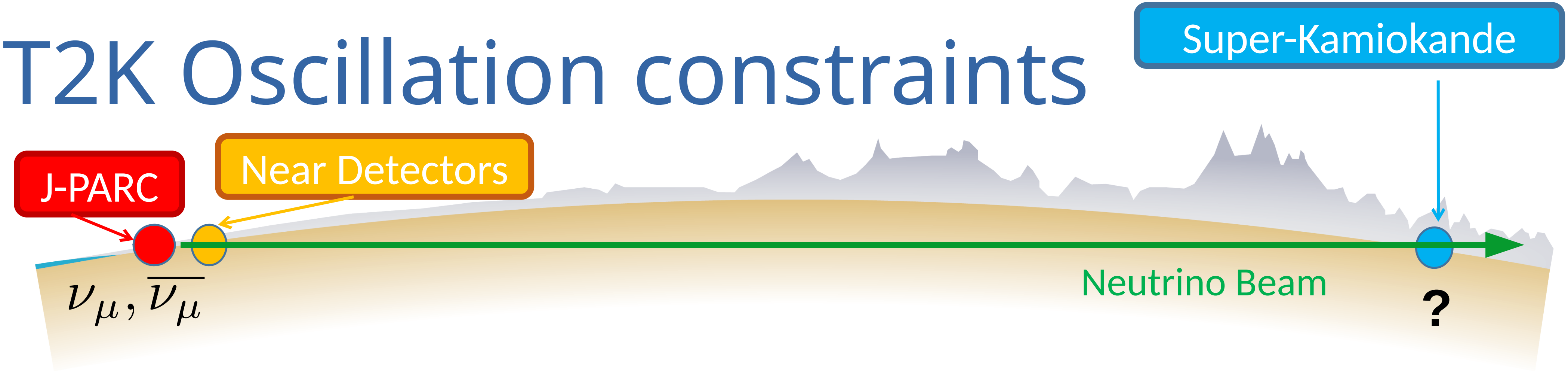
Super-Kamiokande

- 295 km away from J-Parc
- Measurement after oscillation
- 50kton water Cherenkov detector
- Reconstruction of:
  - Vertex position
  - Momentum
  - Muon vs electron

ND280 & SK off-axis to increase beam intensity at desired L/E



T2K Oscillation constraints



Appearance channel

$$P(\nu_\mu \longrightarrow \nu_e) \approx \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2 \frac{\Delta m^2_{23} L}{4E}$$

$$P(\nu_\mu \longrightarrow \nu_e) - P(\overline{\nu_\mu} \longrightarrow \overline{\nu_e}) \propto \sin \delta_{CP}$$

Disappearance channel

$$P(\nu_\mu \longrightarrow \nu_\mu) \approx 1 - \sin^2 2\theta_{23} \cos^4 \theta_{13} \sin^2 \frac{\Delta m^2_{23} L}{4E}$$

T2K physics goals

Long baseline experiments are sensivtive to several osc. parameters

- Precise measurements of theta23 and deltam32
- Nu oscillation open questions:
  - CP symmetry
  - Octant of theta23
  - Exotic scenarios (CPT violation, sterile, ...)

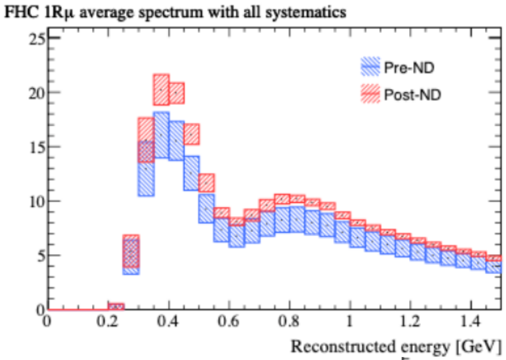
ND280 current design & limitation

Goals of near detector

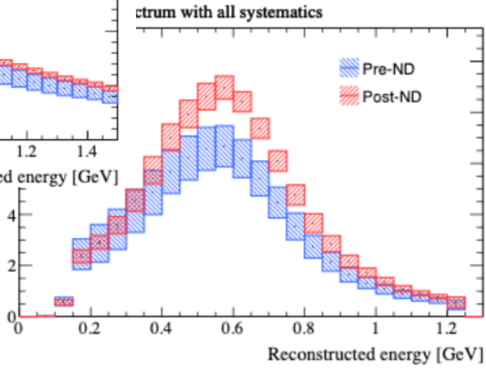
- Constrain neutrino flux and neutrino-nucleus interaction models
- Clear improvements of Far detector predictions with ND

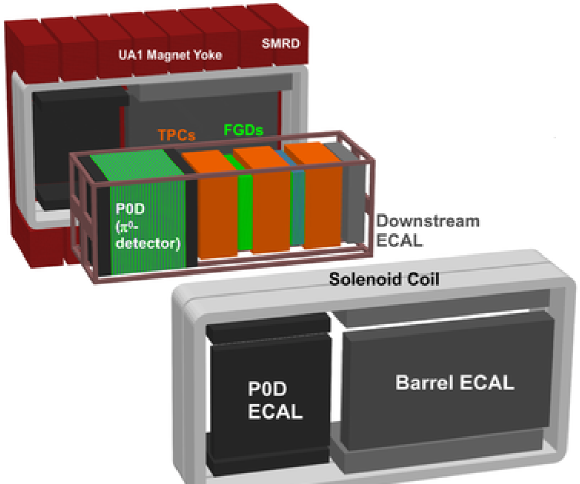
Current design

- **FGDs**: 2 fine grained detectors composed of plastic scintillator with layers of water
  - *Act as target for nu interaction*
- **TPCs**: 3 time projected chamber using Micromegas readout plane
  - *Characterisation of outgoing particle: Momentum + PID*
- **P0D**: Upstream detector optimised to tag neutral pion detection
- All detectors are surrounded by electromagnetic calorimeter and 0.2T magnet → needed for momentum reconstruction



Nu spectrum at FD

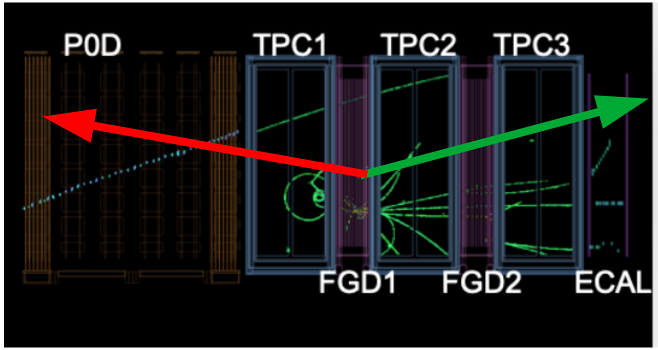


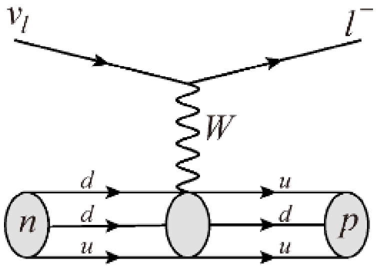


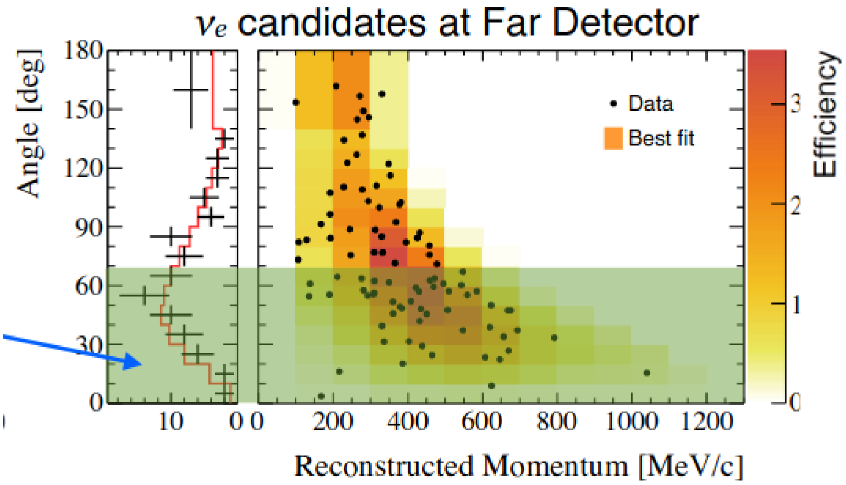
ND280 current design & limitation

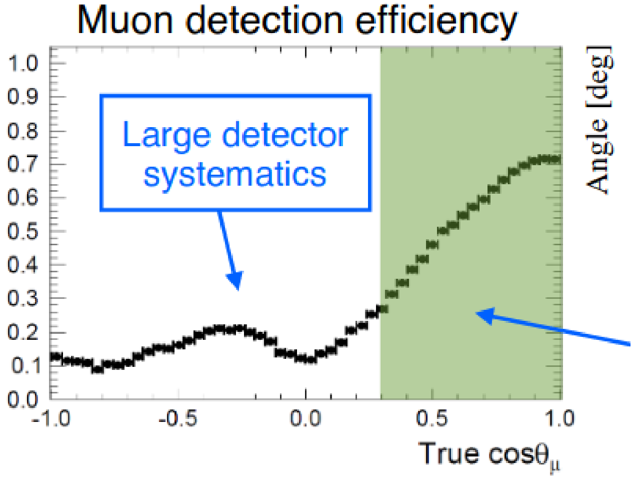
Limitations

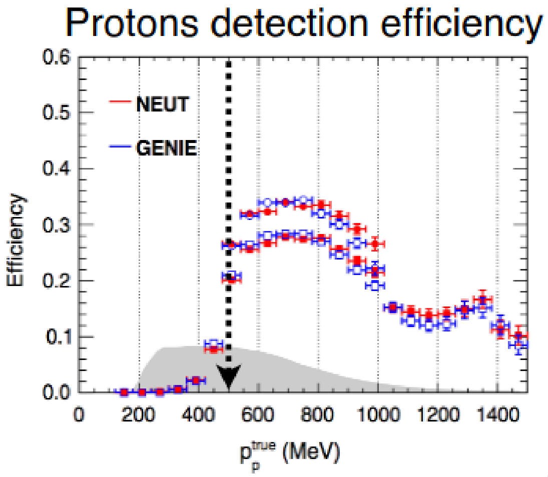
- Mainly a forward detector while SK is 4pi (backward track not well reconstructed)
- Hadronic part of interaction only partially reconstructed because of proton threshold and missing neutrons
  - Loss of information → need to rely on neutrino-nucleus model to reconstruct the neutrino energy from final state lepton











ND280 upgrade

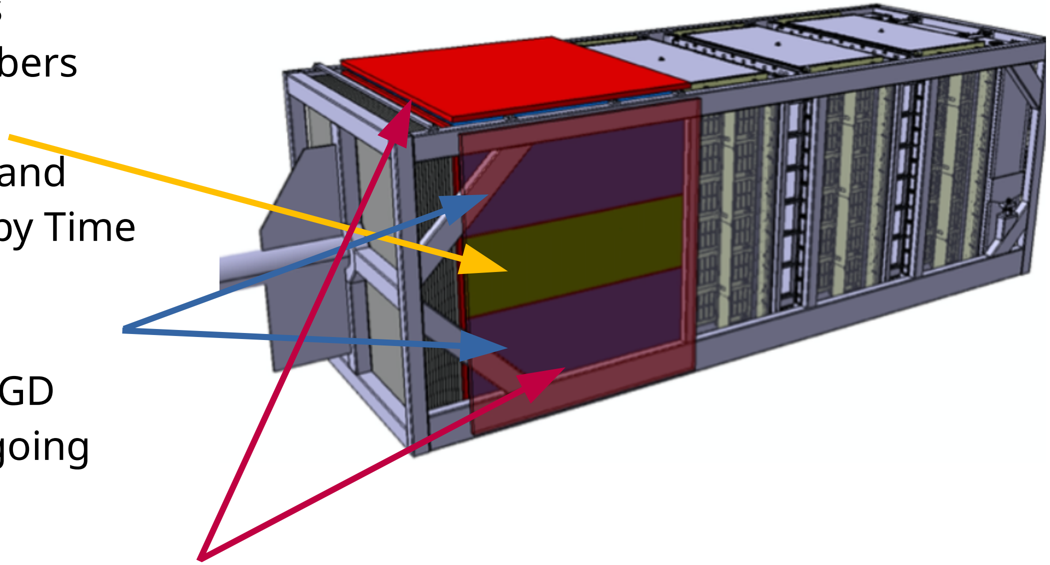
Limitations

- Mainly a forward detector while SK is 4pi (backward track not well reconstructed)
- Hadronic part of interaction only partially reconstructed because of proton threshold and missing neutrons

How to overcome this?

Remove the P0D and install new sub-detectors!

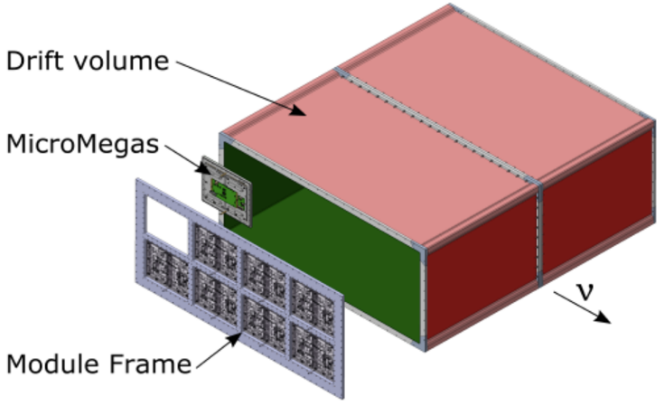
- **Super-FGD:** Highly segmented target (~2 millions scintillator cubes readout by a 3D network WLS fibers
  - Precise location of primary vertex
  - Lower threshold for reconstruction of protons and pions + neutron measurement event by event by Time of light



- **HA-TPC:** High Angle TPC on the top and below SFGD
  - Improving angular acceptance of charged outgoing particles

- **TOF:** Whole surrounded by plastic scintillator planes to tag external background and measure track direction.

Focus on HA-TPC

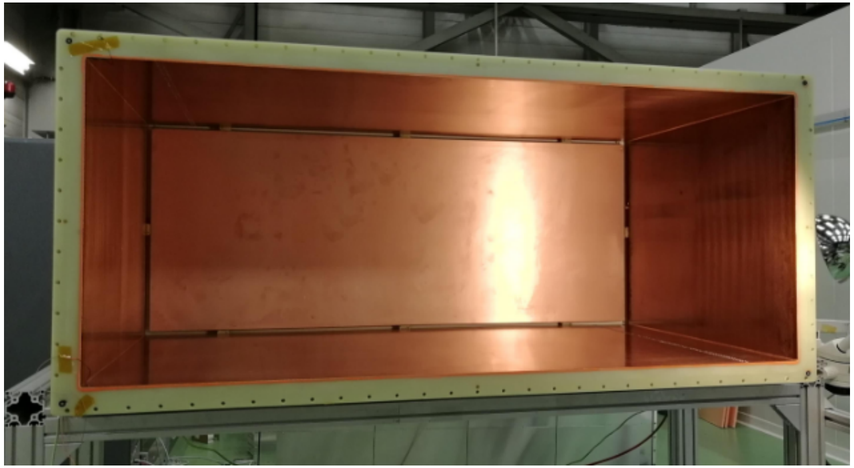


Requirements

- For the new TPC:
  - Best possible spatial separation, at least 600um as in previous TPC
  - dE/dX resolution of 10% with 1 module (8% for 2 modules)

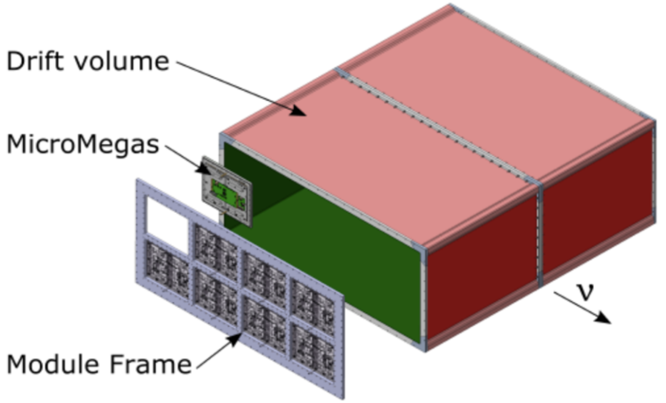
Field cage

- Composed of two half-TPCs with cathode in the middle (30kV)
- Field cage has thin composite walls (~39mm) to minimize multiple scattering
- Operated @ atmospheric pressure using Ar-CF4-C4H10 (95-3-2)



- ~ 400 strips
  - 200 are mirrored strip to obtain better field uniformity
- 30kV on the cathode shared by two half-TPCs

Focus on HA-TPC



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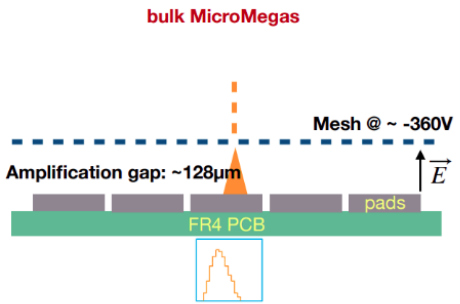
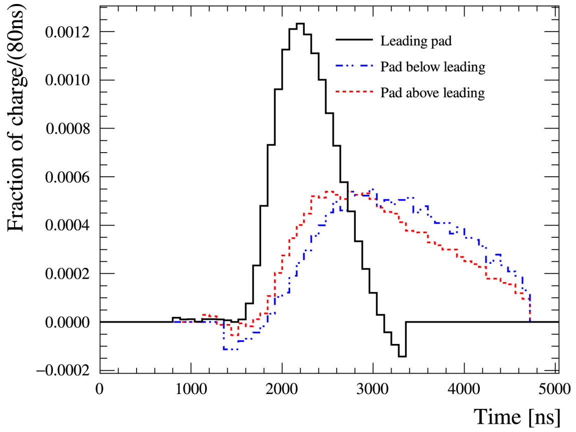
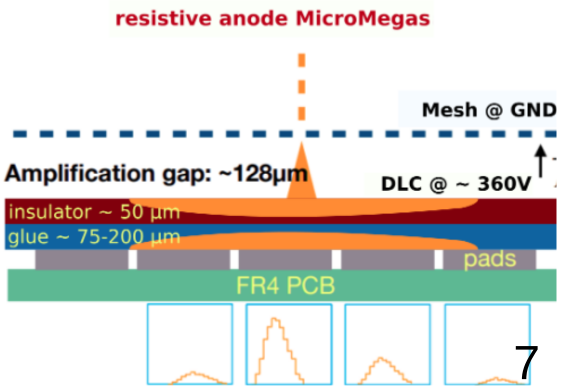


Encapsulated Resistive Anode Micromegas

- Benefits from ILC TPC & RD51 developments
- Classical bulk Micromegas + a resistive layer (DLC) allowing charge spreading on neighbouring pads
  - Gives a better spatial resolution with less pads (1728 to 1152)
  - Reduce spark rate
  - Mesh @ ground → Better E field homogeneity
- Equipped with water cooling to protect electronic and reduce electronic noise.





Test beams

- All aspects of detector production and performance tested during test beam:

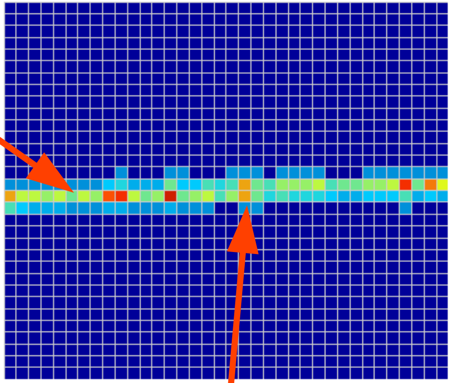
- <u>2018 @ CERN (*NIM A957 July 2019*)</u>
  → Proof of performance of charge spreading with large pad (70mm2 VS 20mm2 ILC)

- <u>2019 @ DESY (*NIM A1025 2022*)</u>
  → Procedure, performance with 110mm2 & 400k Ohm/Sq. but not final electronics

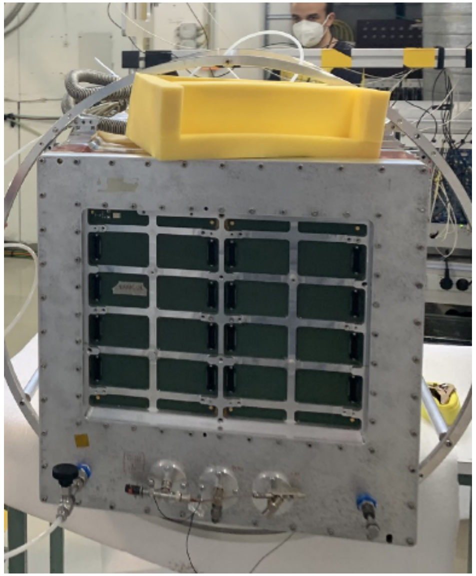
- <u>2020 & 2021 @ DESY</u>
  → Validation of performances with the final design and electronics
- Now: Production of 32 ERAM detectors

- Track reconstruction takes into account of **time and charge** seen in neighbouring pad

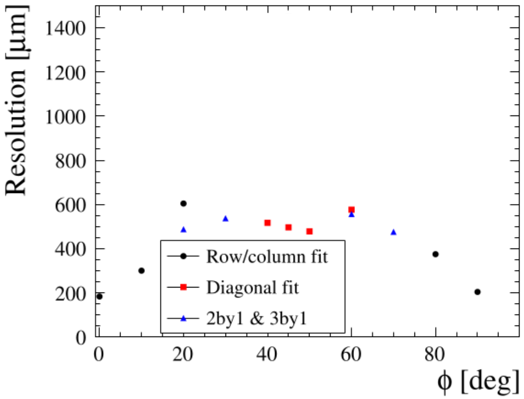
track



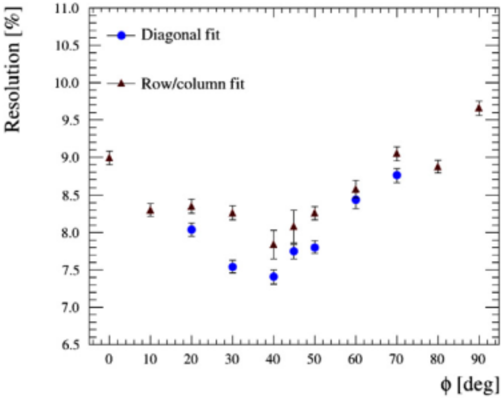
Charge spreading



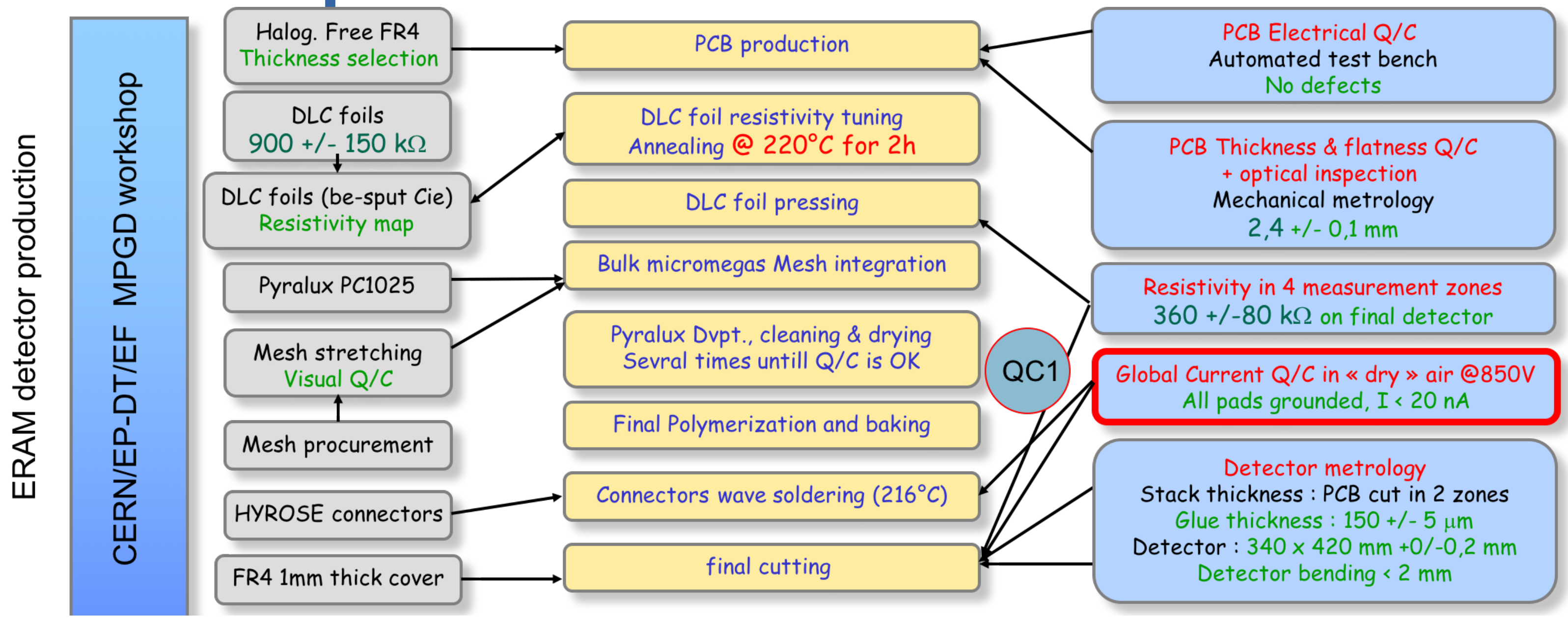
Spatial res.



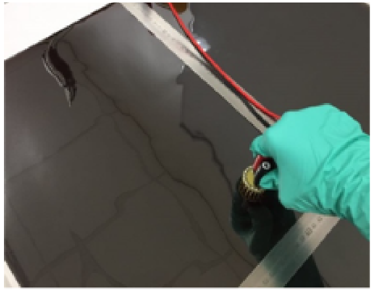
dE/dx res.



ERAM production



- R&D first tests and validation procedure @ Saclay
  - During production all moved @ CERN
- DLC layer is produced in Japan
  - Able to produce large area with a controlled resistivity ~ 400 kOhm/Sq.
- Detector assembled @ EP/DT PCB workshop CERN
  - Allows a close following of the production and responsiveness



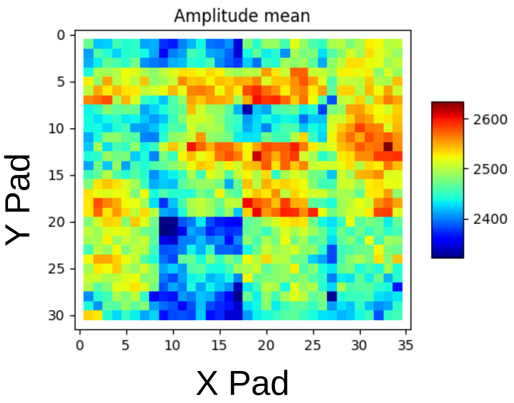
ERAM tests

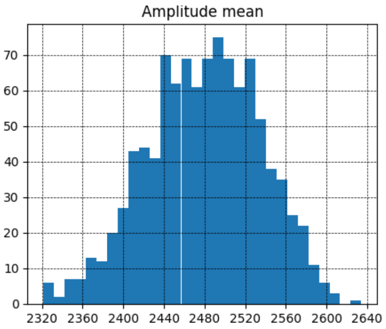
Mesh pulsing

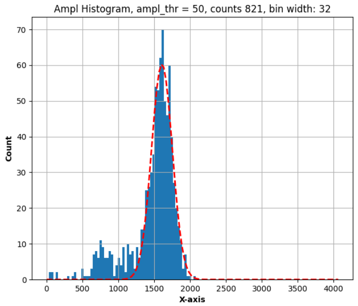
- After delivery the detector is checked with a mesh pulsing
- Inject signal on the mesh to detect defects affecting outgoing signal: electronic, resistivity, detector geometry
  → *Example: ERAM16, amplitude is dominated by electronic response (ASICs)*

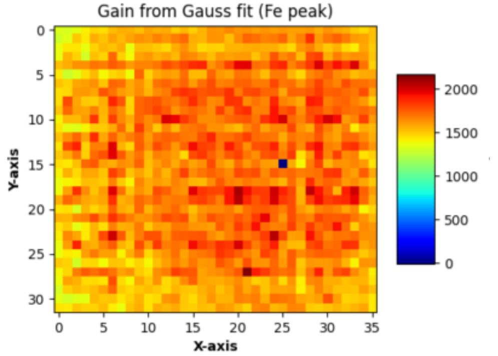
X-ray scan

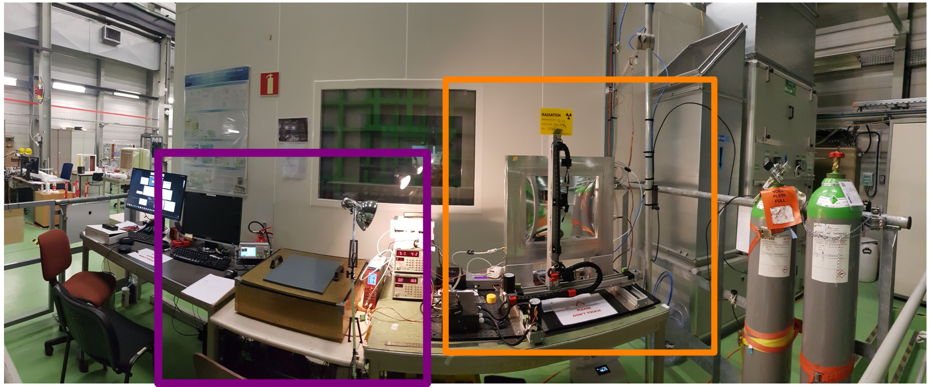
- Afterwards detector is scan with 55Fe source: Gain, resolution characterisation
- Automated robot controlled remotely allowing to position source in front of each pad
- Detectors are scanned with their own electronic cards
  - Besides to be a quality control it gives a fine calibration of each ERAM module
- Already 12 detectors fully qualified
  → *Example: ERAM01*



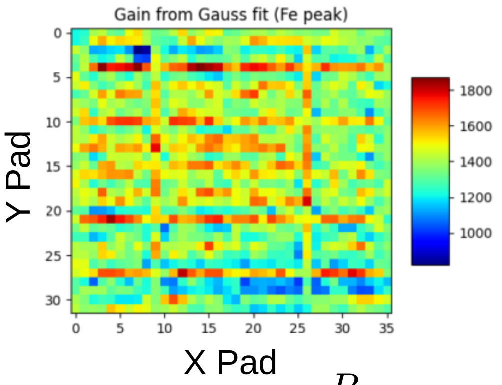


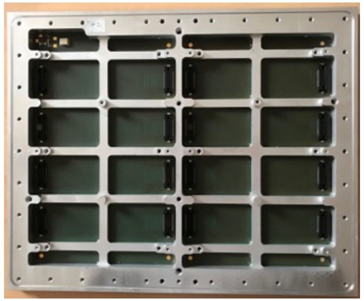






ERAM tests

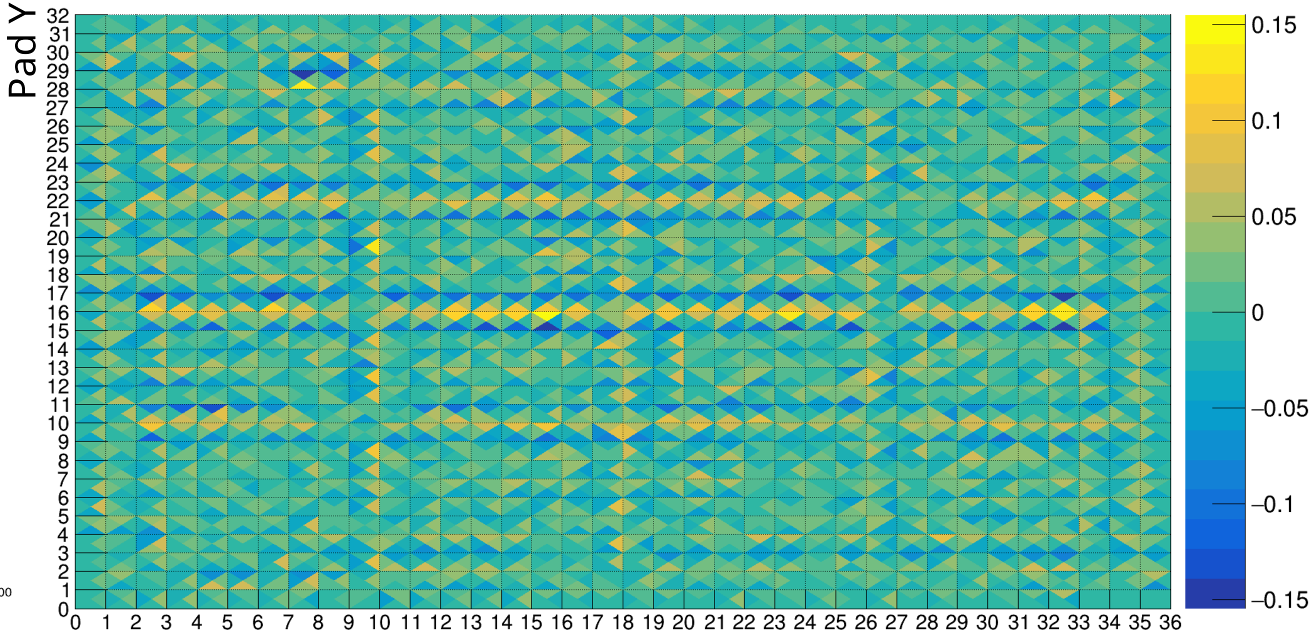




Difficulties

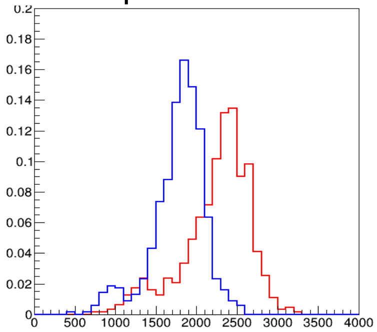
- During production pads with higher gain & resolution were observed on several detectors:
  - Pads position is correlated with mechanic ribs behind the detector

$$R_{i=left,right,top,bottom} = \frac{Q^i_{lead} - \mu_{pad}}{\mu_{pad}}$$

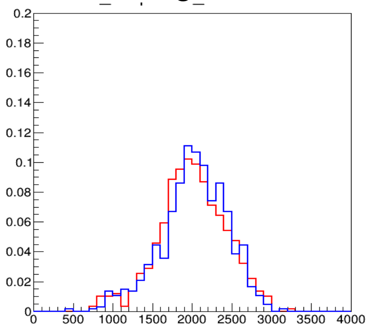


- Performed fine analysis of X-ray data
  - Can determine interaction position within a pad thanks to charge
  - spreading

Top-Bottom



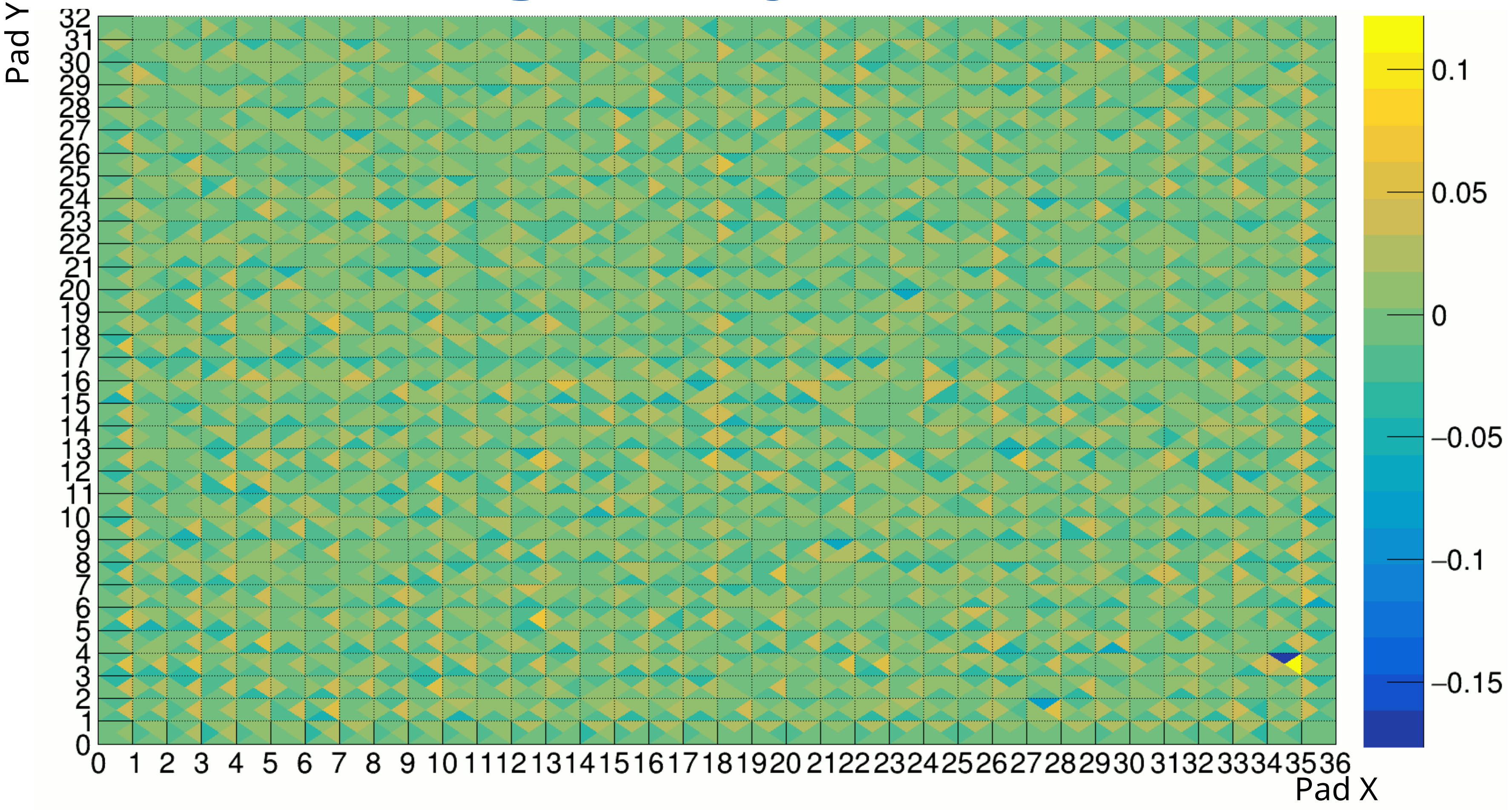
Left-Right



- Understood as an issue of PCB thickness after detector assembly.

Pad non-homogeneity Fixed

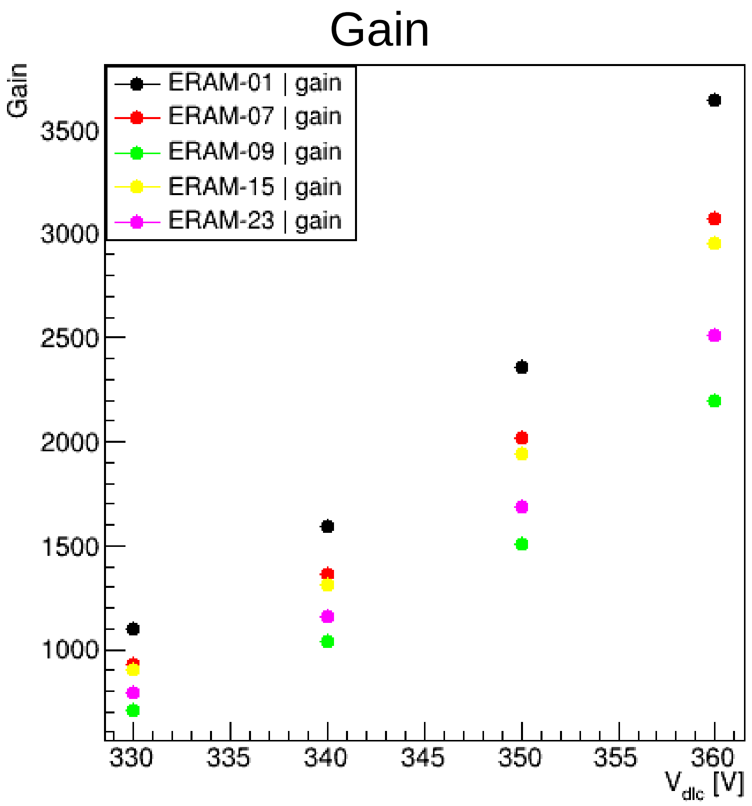
$$R_{i=left,right,top,bottom} = \frac{Q^i_{lead} - \mu_{pad}}{\mu_{pad}}$$

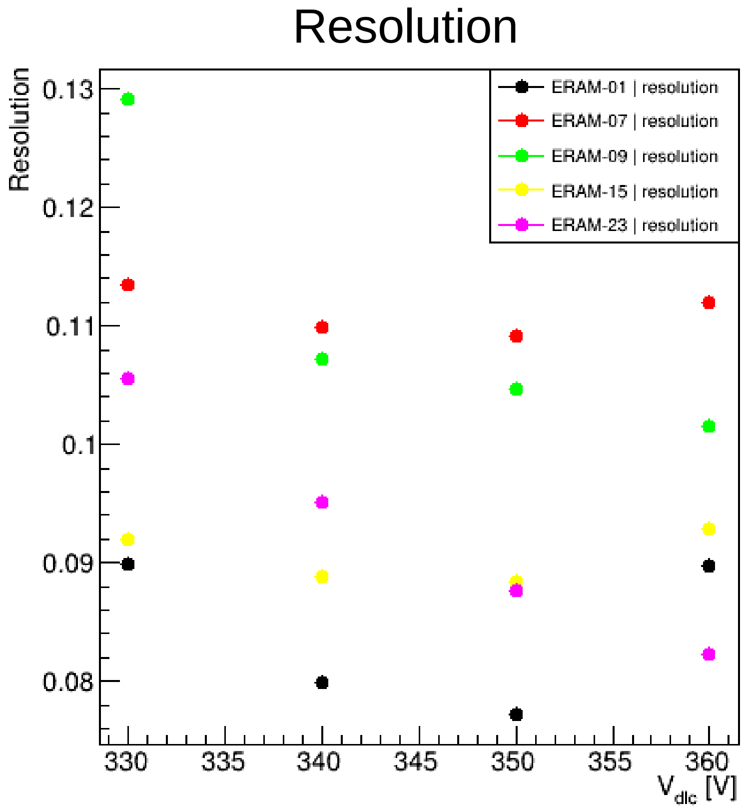


→ **Successful correction after change of PCB design, no more non-homogeneity**

Gain and resolution

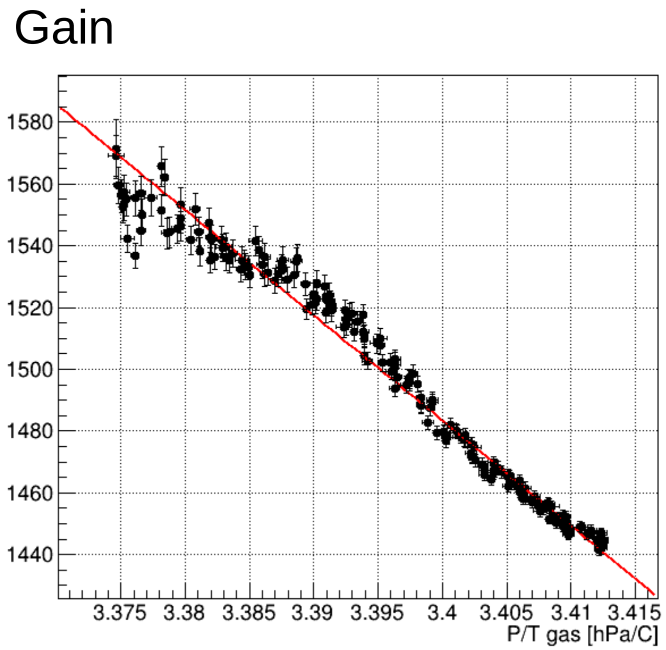
- We also preformed several measurements of Gain & Resolution at different DLC voltage:

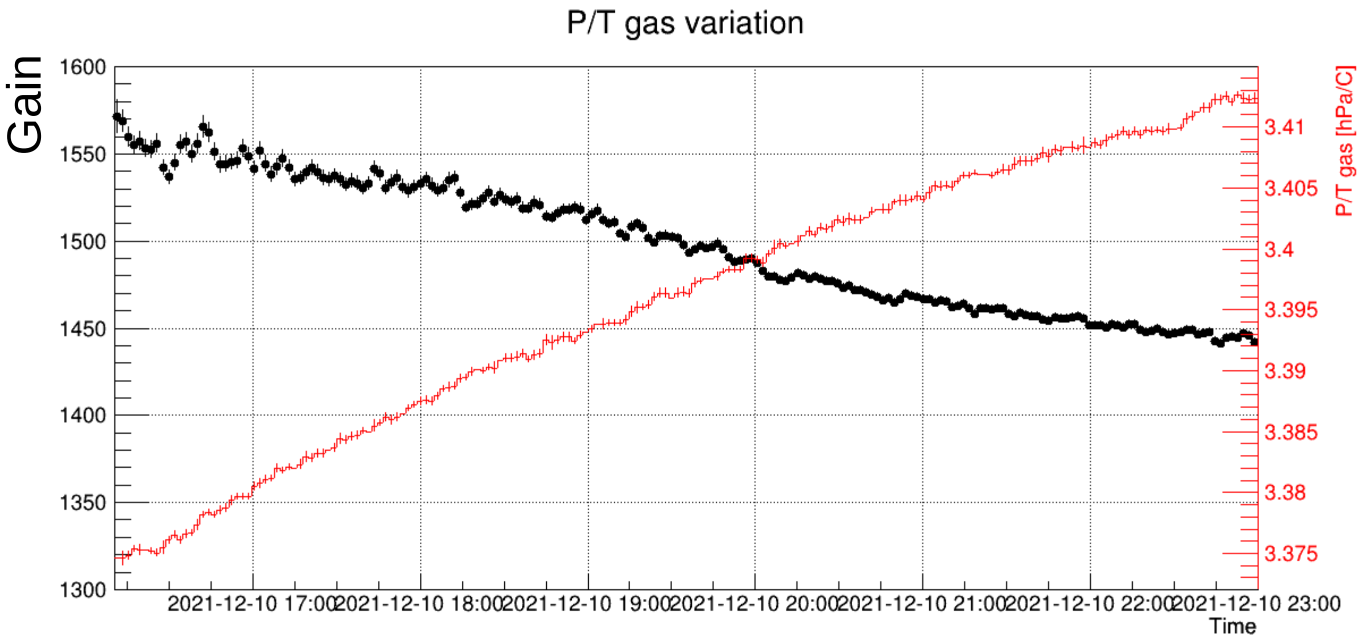




- The dispersion of measurement not proof, requires to correct for environmental conditions (gas composition, pressure & temperature, relative humidity)

Evolution of gain





- Example: Evolution of the gain as a function of the pressure over temperature

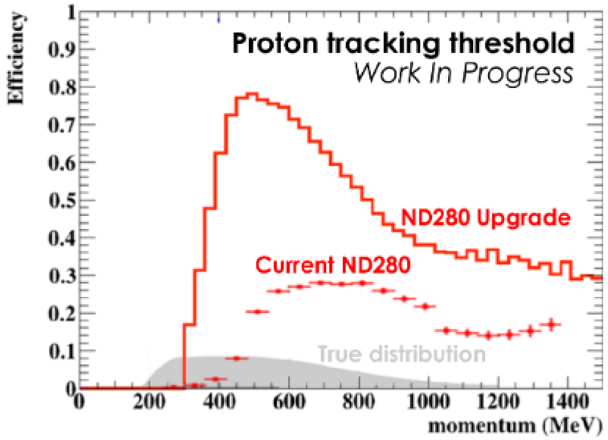
- We are currently trying to take into account for those variations.

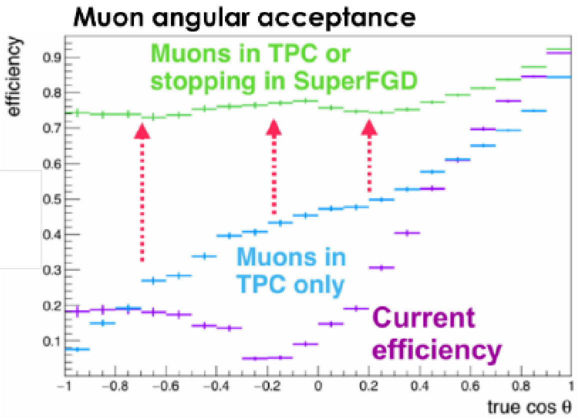
Picture of T2K with the upgrade

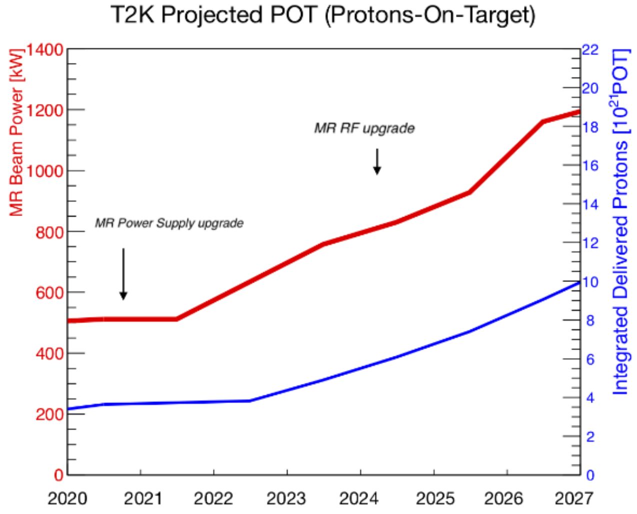
- With this upgrade Near detector will improve a lot!
  - Efficiency to reconstruct hadronic contribution
  - Angular acceptance

- T2K will not only benefit of detector upgrade but also of a beam upgrade
  - From 500kW to 750kW and then continuous improvement until >1MW in 2027 for Hyper-Kamiokande

- And in a few years Hyper-Kamiokande will come and ND280 will stay as Near Detector
  - See next talk by Mathieu Guigue!







Conclusion

- T2K has produced high quality results since 10 years and is leading measurement of atmospheric oscillation parameters
  - This performance is possible thanks to a near detector allowing to precisely constrain flux & interaction models
- With beam upgrade (and Hyper-Kamiokande), systematic uncertainties will become the limitations
- The ND280 upgrade has been designed to solve present ND280 limitations and be ready for large statistics
  - The new HA-TPCs allow to reach **larger angular acceptance**
  - ERAM modules have been characterized thanks to several prototypes and test beam campaigns
  - Desired performances are reached and ERAM modules are currently in production

Back-up

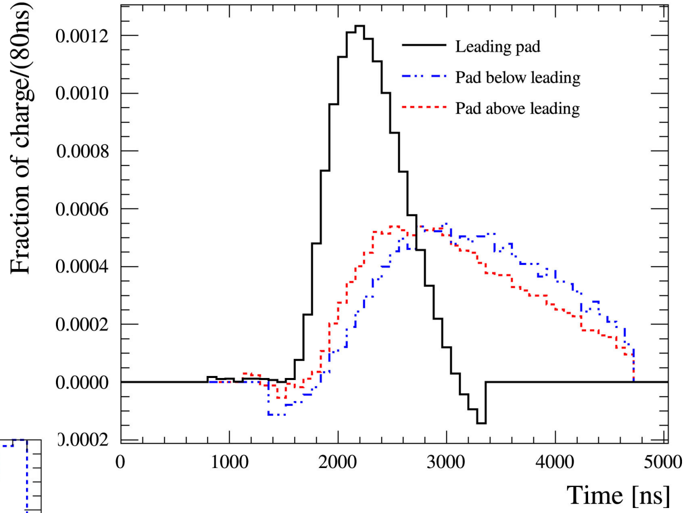
Pad response function

- Take advantage of it by looking at ratios:

$$\frac{Q_{pad}}{Q_{ratio}} = PRF(x_{track} - x_{pad})$$

- This function could be parametrised and used in a chi-square to find positions:

$$\chi^2 = \sum_{pads} \frac{\frac{Q_{pad}}{Q_{cluster}} - PRF(x_{track} - x_{pad})}{\sigma}$$



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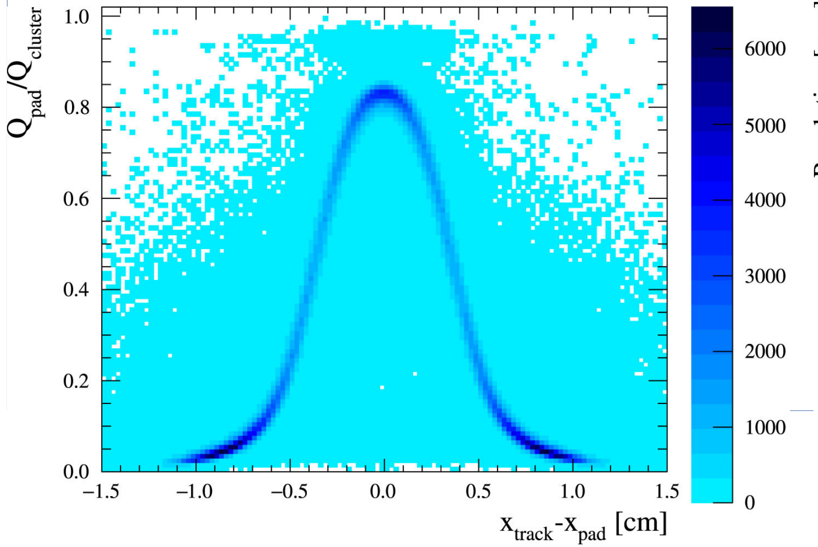

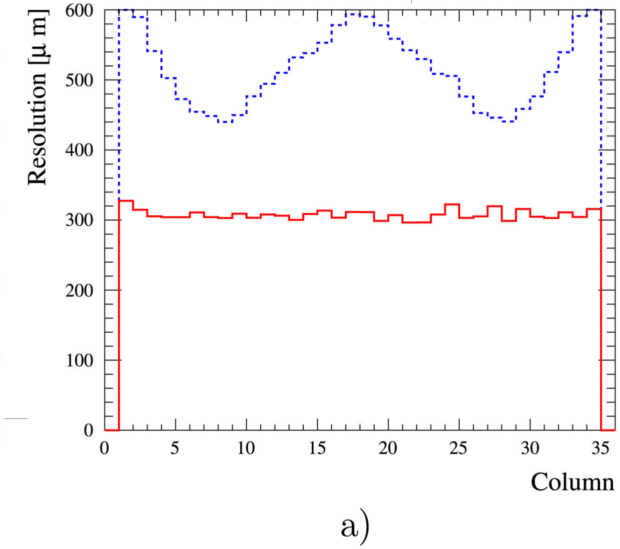

Great spatial resolution even w/ 33% less pads

New PCB design

- Stiffener gluing procedure was first suspect but no clear correlation found after several tests (change of gluing process)
- Assumption that non uniformity of PCB backside affects DLC side flatness and therefore amplification gap by a few microns after pressing DLC
  → PCB modification!
- ERAM up to 16
  - Those areas are also covered with green soldermask
- ERAM09-16
  - PCB produced by ELTOS Cie following industry IPC standard
  - Copper & soldermask is probably thicker than @ CERN
- ERAM17-24
  - Soldermask was removed
- ERAM23
  - Replaced copper pad by a copper mesh
    → More uniform PCB
    → More uniform Gain

ERAM top layer up to ERAM-23