Resistive Micromegas for TPCs in T2(H)K and DUNE near detectors

GDR neutrino

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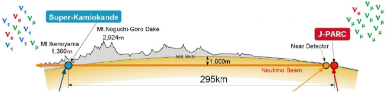
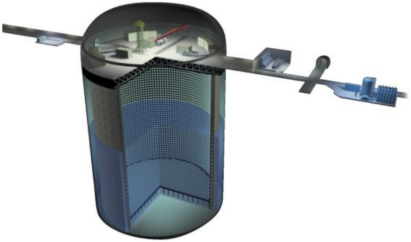
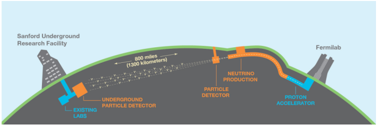
Long-baseline neutrino experiments



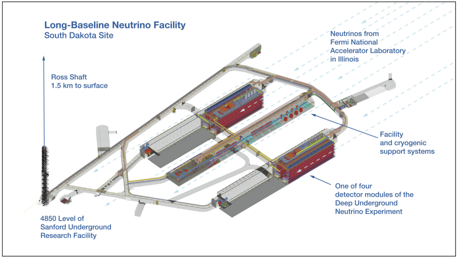
- T2K: Tokai-to-Kamioka
- Far detector: Water-Cherenkov Super-Kamiokande



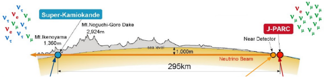
- Upgrade planned to T2HK, SK replaced by HK



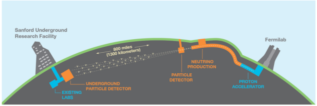
- DUNE: Deep Underground Neutrino Experiment
- Far detector: 4×17 kt LAr modules



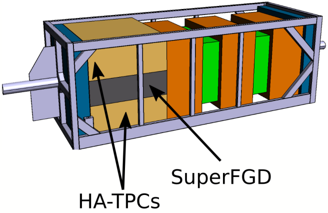
TPCs for the near detectors of DUNE/T2K

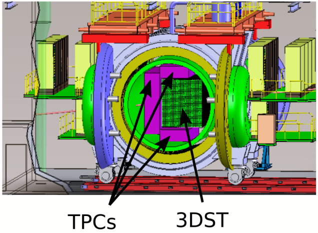


T2K: ND280-Upgrade



DUNE: SAND



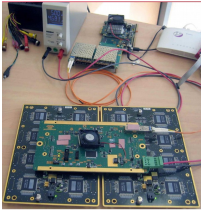


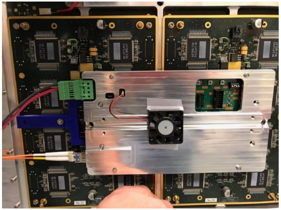
- 1998: TPC studies conducted for ILC with Micromegas R&D
- 2009: 3 TPCs with 72 Micromegas installed at ND280
- 2017: Encapsulated Resistive Anode bulk Micromegas (ERAM) proposed for T2K ND280-Upgrade
- 2022: Scheduled installation of ERAMs in T2K/ND-280
- 2026: Possible installation of ERAMs in DUNE/SAND

Characteristics of the TPCs

- Main TPC characteristics derived from ND280-Upgrade (e.g. gas, electric field, etc.)
- Readout for the Micromegas:
  - 1152 pads/Resistive Micromegas detector (assuming similar pad size ND280/SAND)
  - ND280: 32 detectors in 2 TPCs $\rightarrow$ 36864 channels
  - SAND: 44 detectors in 3 TPCs $\rightarrow$ 50688 channels
  - Resistive technology $\Rightarrow$ remove spark protection on FEC and reduces number of readout channel necessary

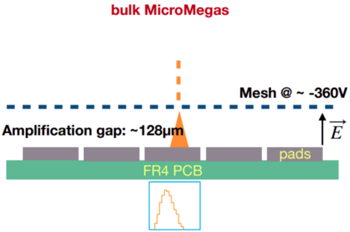
Parameter	Value (2x T2K/ HA-TPC)	2+1 DUNE SAND
Overall x × y × z (m)	2.0 × 0.8 × 1.8	1,41 x 0,57 x 3,3 0,77 x 3 x 3,3
Drift distance (cm)	90	
Magnetic Field (T)	0.2	
Electric field (V/cm)	275	
Gas Ar-CF_4-iC_4H_{10} (%)	95 - 3 - 2	
Drift Velocity $cm/\mu s$	7.8	
Transverse diffusion ($\mu m/\sqrt{cm}$)	265	
Micromegas gain	1000	
Micromegas dim. z×y (mm)	340x420 (32)	340x420 (44)
Pad z × y (mm)	10 × 11	10x11
N pads	36864	50688
el. noise (ENC)	800	
S/N	100	
Sampling frequency (MHz)	25	
N time samples	511	

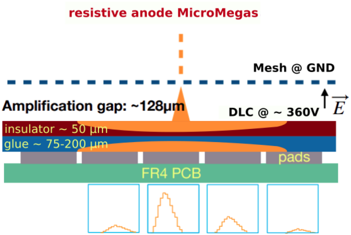




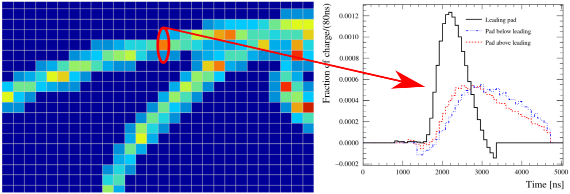
Encapsulated Resistive Anode bulk Micromegas (ERAM)

- Working principle: charge spreading over multiple pads on a bulk Micromegas (addition of resistive and insulating layers)
- Resistive material: Diamond-Like Carbon

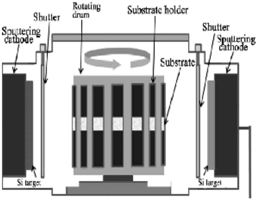


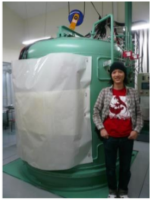


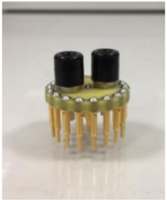
$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx \text{shaping time (few 100 ns)} \\ RC_{[ns/mm^2]} = \dfrac{180\, R_{[M\Omega/\blacksquare]}}{\frac{d_{[\mu m]}}{175}} \end{cases}$$

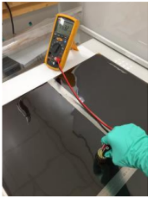


Diamond-like carbon as resistive layer





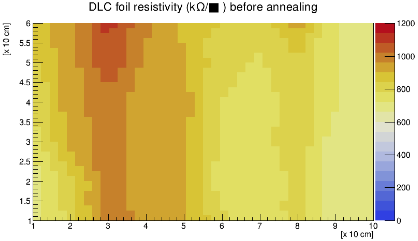


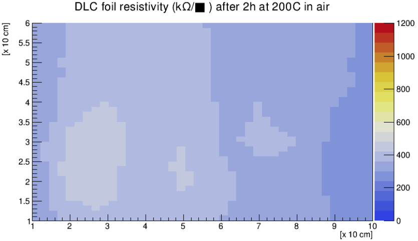


- Process by Be-Sputter company (Kyoto, Japan)
- Sputtering of DLC onto a 4 m^2 Apical foil
- Resistivity measured with custom sensor (Ω/square)
- Resistivity adjusted with annealing (e.g. reduced by 2.7 at 220° in air)

Current developments for ERAMs

- Differences between T2K and DUNE, e.g. beam energy
  $\rightarrow$ adapting charge spreading parameters
- Resistivity of the DLC foil mapped
- Results of resistivity measurements performed at CERN:

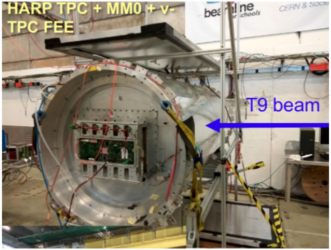


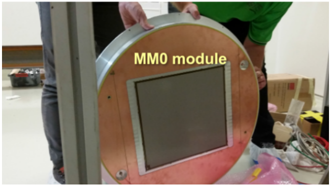


- Adjustment of the resistivity with annealing:
  factor $\sim$ 2 reduction after 2h at 200C
- Helps precise definition of the detector parameters

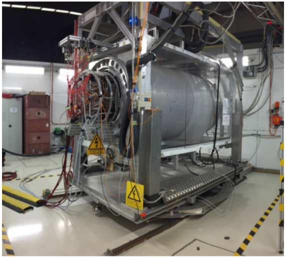
Prototyping for ND280-Upgrade

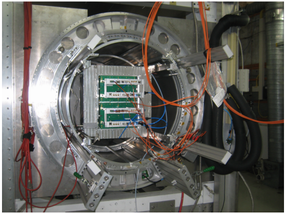
- Proof of principle at CERN (2018) in HARP TPC
- First prototype of resistive Micromegas





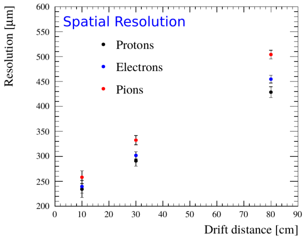
- Test beam at DESY in 2019 with 0.2 T (PCMAG)
- Full-scale optimized prototype

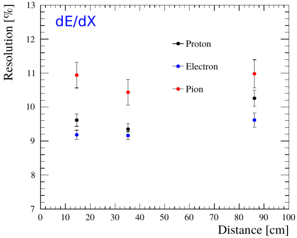




Performances

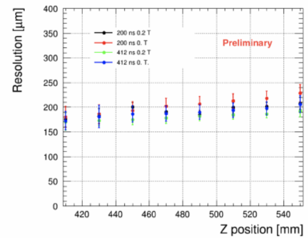
- CERN 2018: 0.7×1.0 cm^2 pads, 2.5 MΩ/sq + 200 μm glue (RC$\sim$300 ns/mm^2)

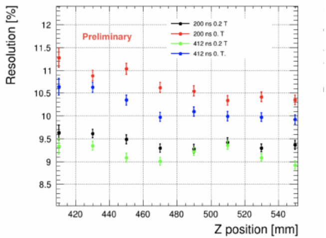




Nucl.Instrum.Meth.A 957 (2020) 163286

- DESY 2019: 1.0×1.1 cm^2 pads, 0.2 MΩ/sq + 75 μm glue (RC$\sim$50 ns/mm^2)

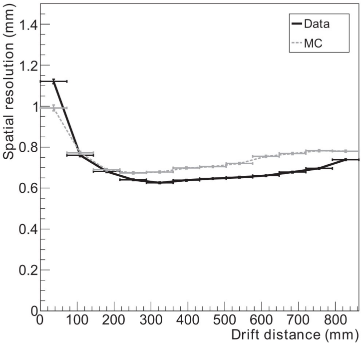




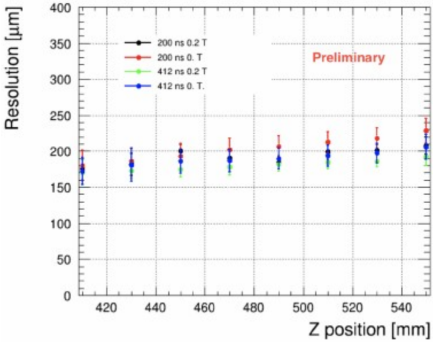
arXiv:2005.05695

Improvements from T2K-ND280 to SAND

- Spatial resolution for current ND280 TPCs



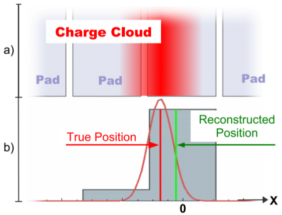
- Spatial resolution for MM1 design in ND280-Upgrade



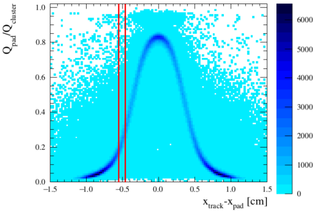
- Preliminary spatial resolution $\sim 3\times$ better than current ND280 vertical TPCs
- SAND magnetic field $3\times$ larger than ND280 ($0.2 \rightarrow 0.6$ T) $\Rightarrow$ Improved momentum resolution

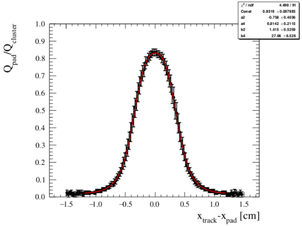
Pad Response Function (track position in clusters)

Center of Charge method



Pad Response Function Method

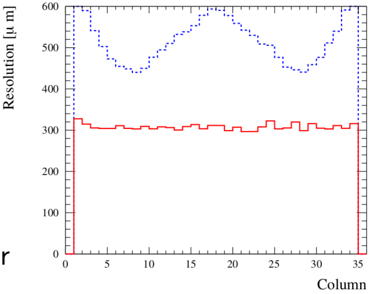




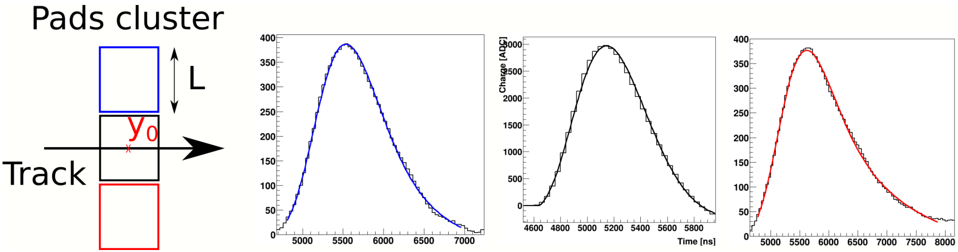
- **PRF(x_{track} - x_{pad}) = $Q_{pad}/Q_{cluster}$**
- Analytical function for the PRF:

$$PRF(x_{track} - x_{pad}) = \frac{1 + a_2 x^2 + a_4 x^4}{1 + b_2 x^2 + b_4 x^4}$$

- Spatial resolution significantly improved with PRF compared to CoC
- χ^2 estimate of best track position in cluster
- PRF iteratively applied until χ^2 is stable

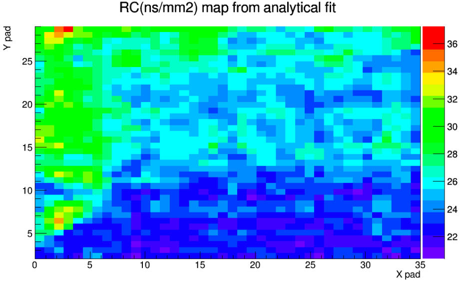


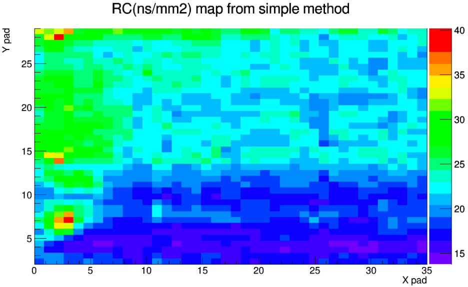
Charge spreading principle in clusters



- Leading pad fit accounting for electronics response (no charge spreading)
- Subleading pads fitted accounting for both electronics response and charge spreading
- Charge spreading modelled with 2D Telegraph equation

RC measurements

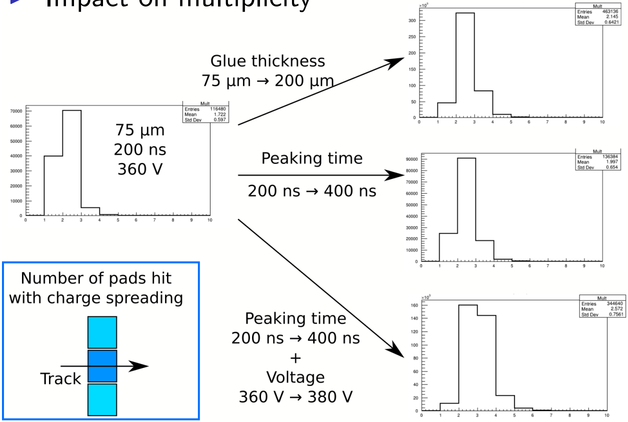




- Analytical fit: based on the Telegraph equation to account for charge spreading
- Simple method: Use time difference between subleading pads to extract RC
- Methods show compatible results
- $\sim$ 30% non-uniformity measured, consistent with DLC resistivity measurement of the DLC
- Effect on track reconstruction under study

Current developments for ERAMs

- Study of charge spreading parameters (resistivity/glue thickness), pad size and electronic shaping time/gain
- Impact on multiplicity



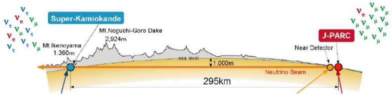
- Prototypes tested on cosmic test bench in Saclay

Summary

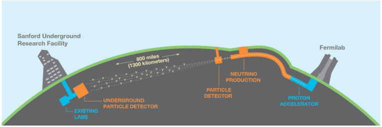
- Need to reduce systematics for T2(H)K and DUNE
- Recently developed technology to be deployed in LBL near detector TPCs
- PRF yields significant improvement to spatial resolution
- Tracks reconstruction using both time and charge under development
- Reconstruction of non-horizontal/vertical tracks being studied
- SAND detector to be constructed (2026) benefitting from experience gained with ND-280 Upgrade

Collaborators more than welcome to join us!

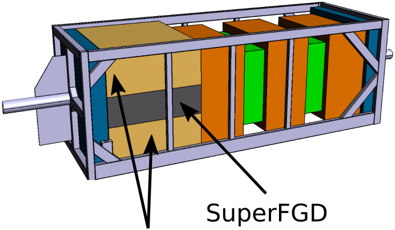
Thank you for your attention!



T2K: ND280-Upgrade

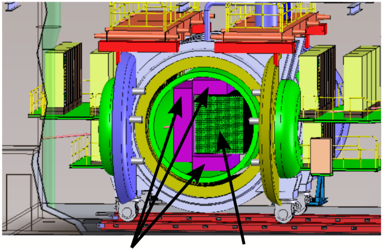


DUNE: SAND



SuperFGD

HA-TPCs



TPCs

3DST