Prototyping for the DUNE ND-LAr Light Detection System

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New Perspectives

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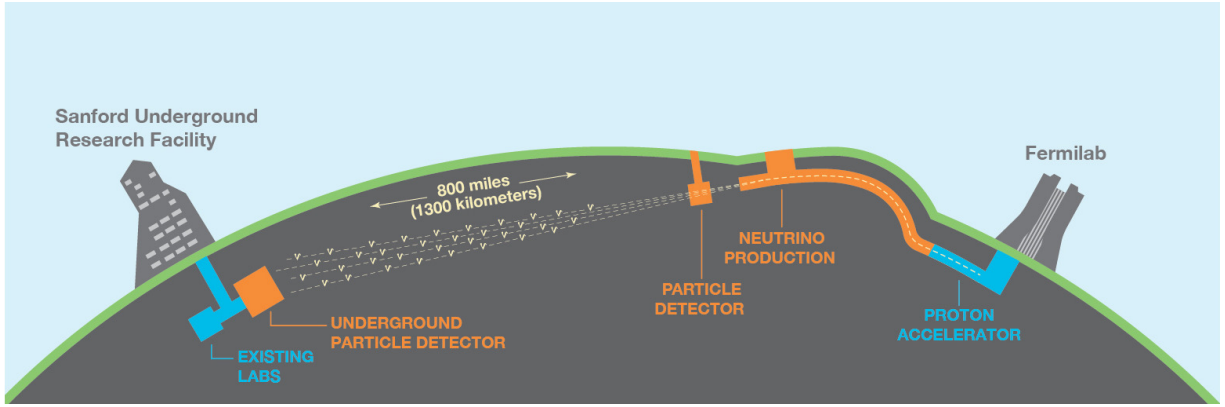
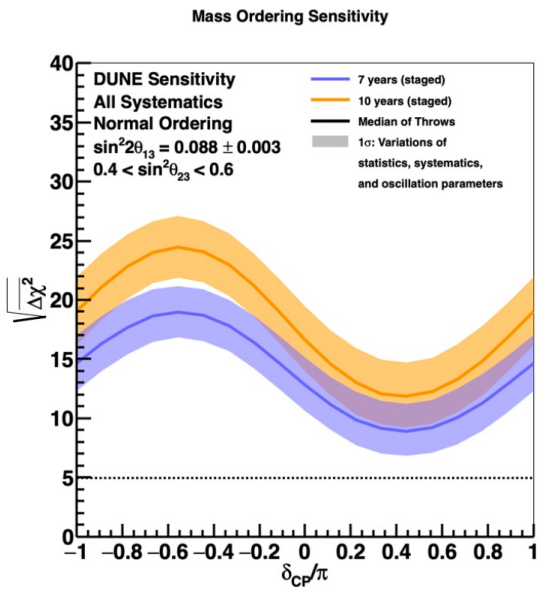
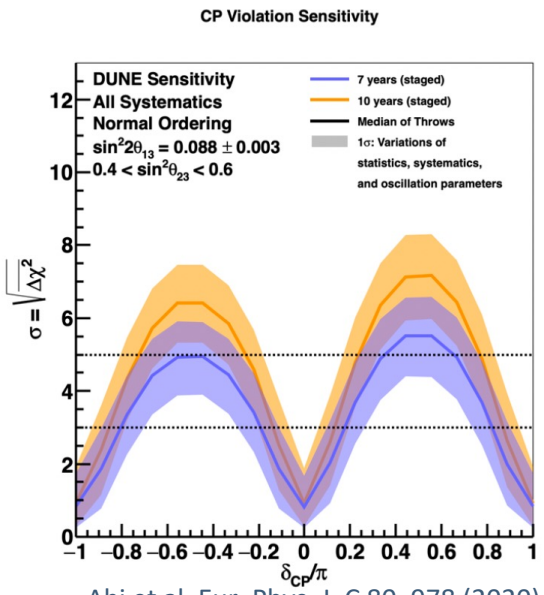
Deep Underground Neutrino Experiment (DUNE)

- Long baseline oscillation experiment (1300 km)
- Major goals:
  - δ_{CP}
  - Mass ordering
  - Non-beam physics (e.g. super nova ν)
- Overcome low ν cross section?
  - High intensity ν_μ ($\bar{\nu}_\mu$) beam (1.2 / 2.4 MW)
  - High detector mass (70kt FD / 50t ND)





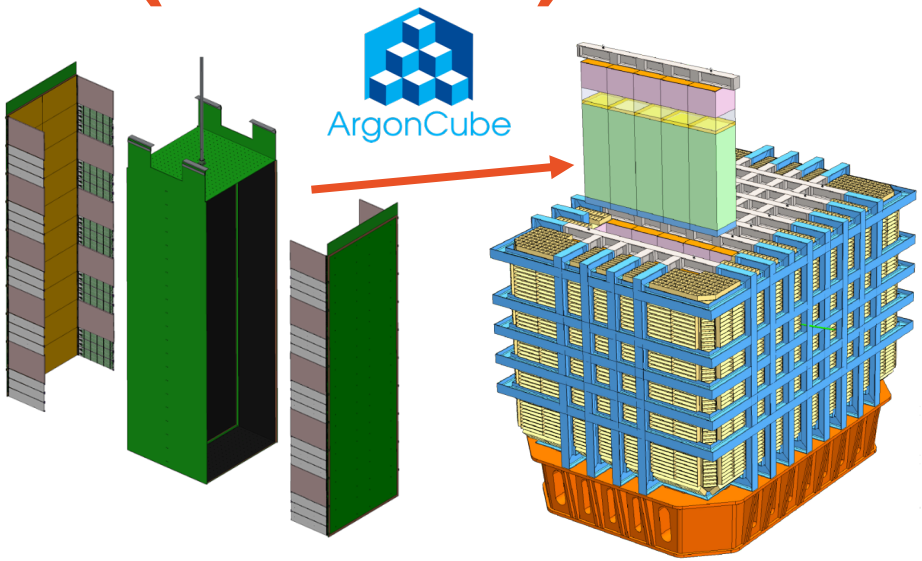


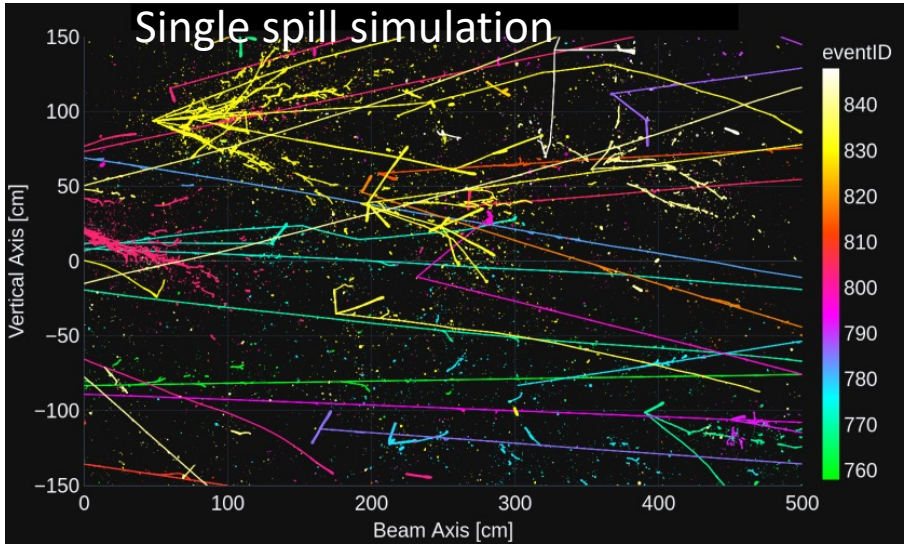
Abi et al, Eur. Phys. J. C 80, 978 (2020)

Liquid Argon Near Detector (ND-LAr)

- Use liquid argon as target and detection medium
- Time projection chamber detectors:
  - Ionisation (23.6 eV/pair) and long e^- lifetime (>1 ms)
  - Fast scintillation light ($O(1\ ns)$)

- DUNE ND-LAr: 7 x 5 x 3 m^3
- ~50 ν interactions per Spill (Phase I)
- Drift time at 0.5 kV/cm: >4 ms
- For Monolithic Design:
  PILEUP
  ⇒ **Segmentation!**

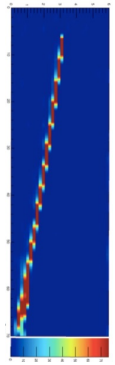




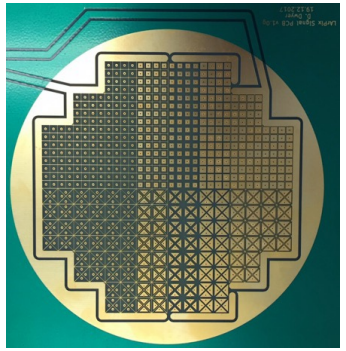
Prototyping campaign

Isolated tests of novel technologies (2018-2020)

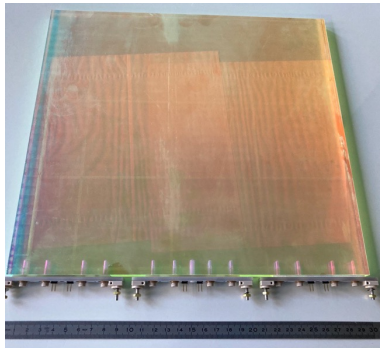
Resistive Shell



Charge readout

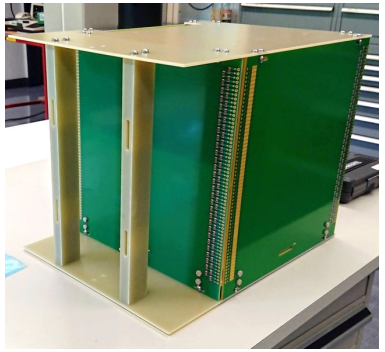


Light readout



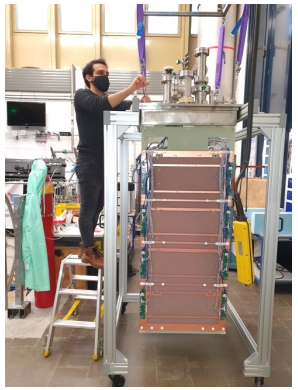
SingleCube (2020)

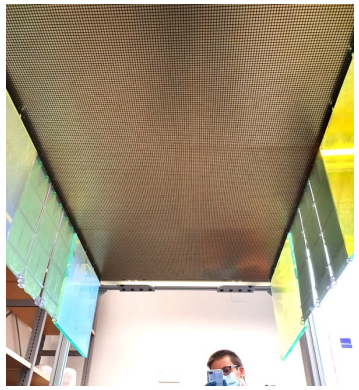
First combined charge and light test



SingleModule (2021)

First test of integration of all subsystems

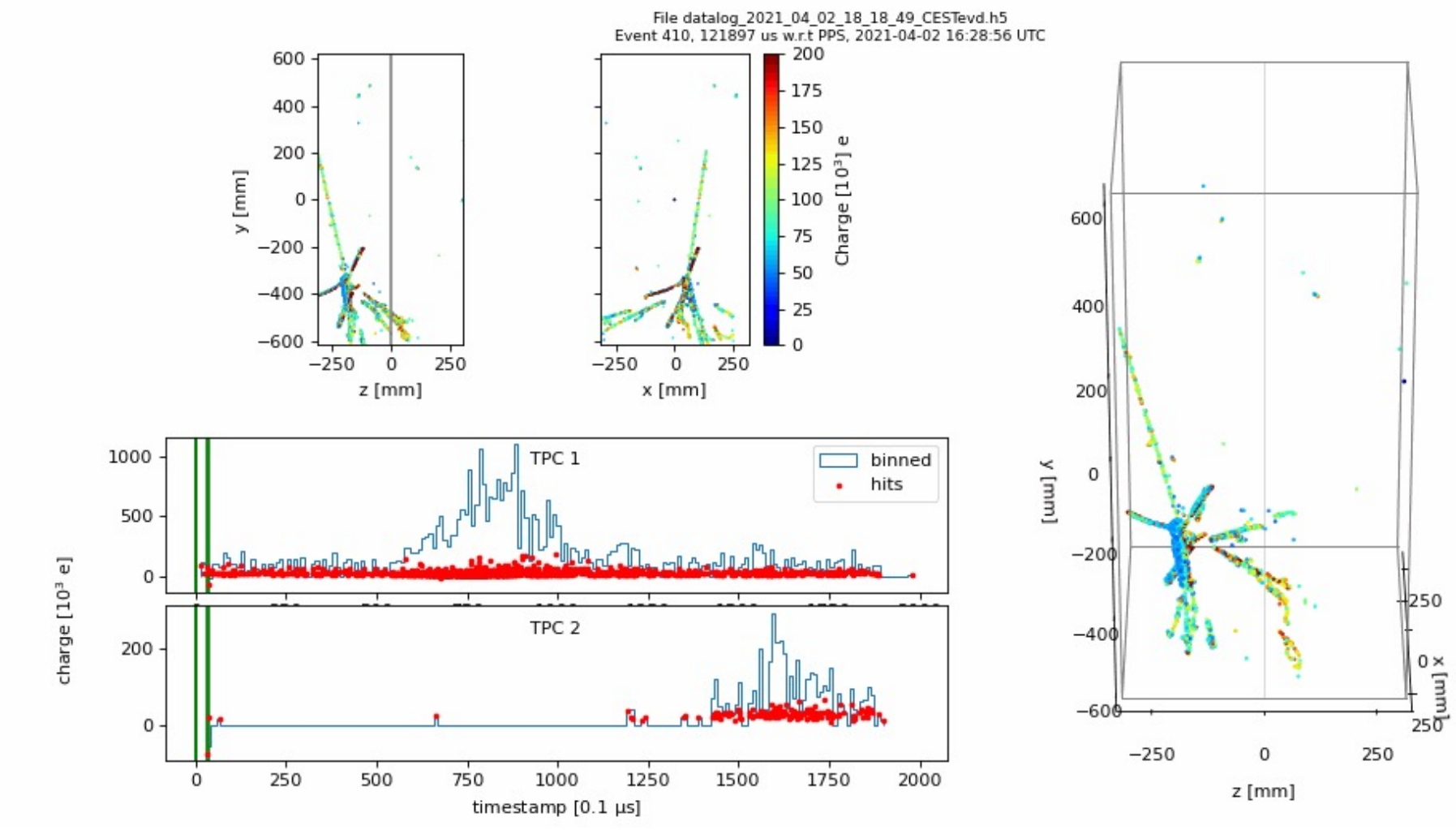




2x2 Demonstrator (2022-…)

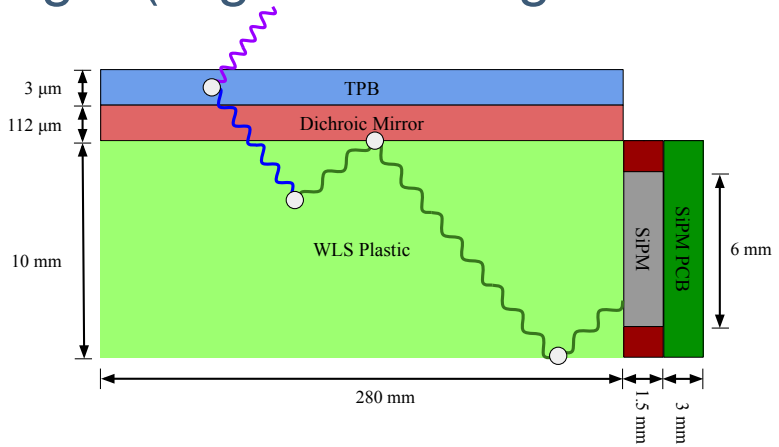
First combined test of multiple modules in a neutrino beam

Module-1 event

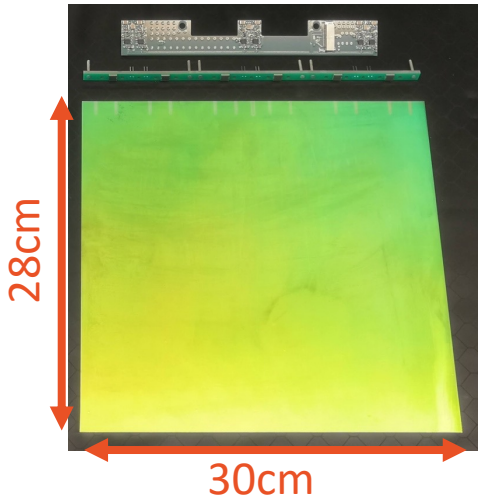


2x2 Light readout

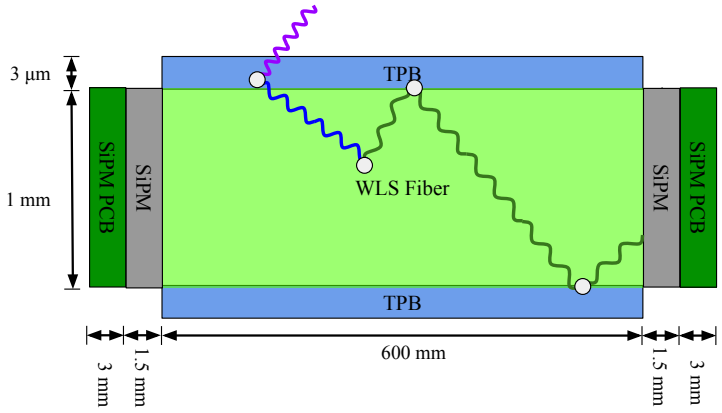
ArCLight (ArgonCube Light detector)



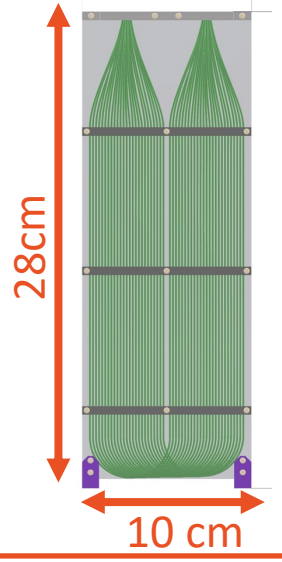
+ Large sensitive area
+ Large dynamic range
+ Good spatial resolution
- Lower efficiency



LCM (Light Collection Module)



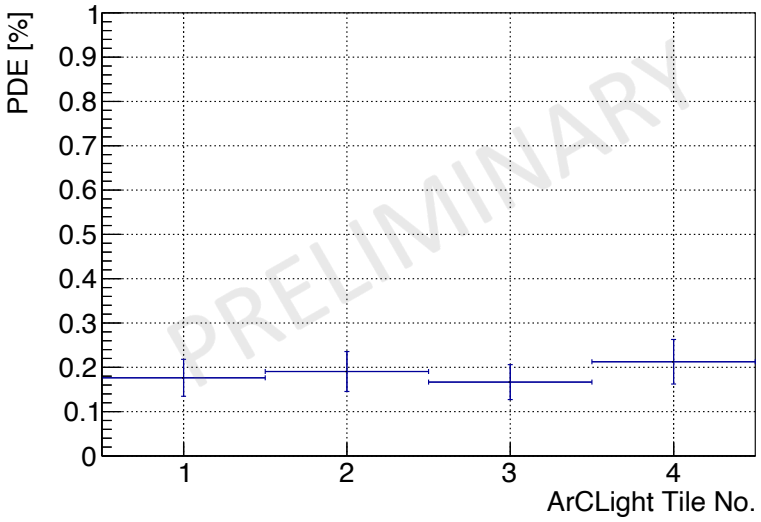
+ High efficiency
+ Easy to scale
- Spatial resolution ≃ Tile width (only one axis)

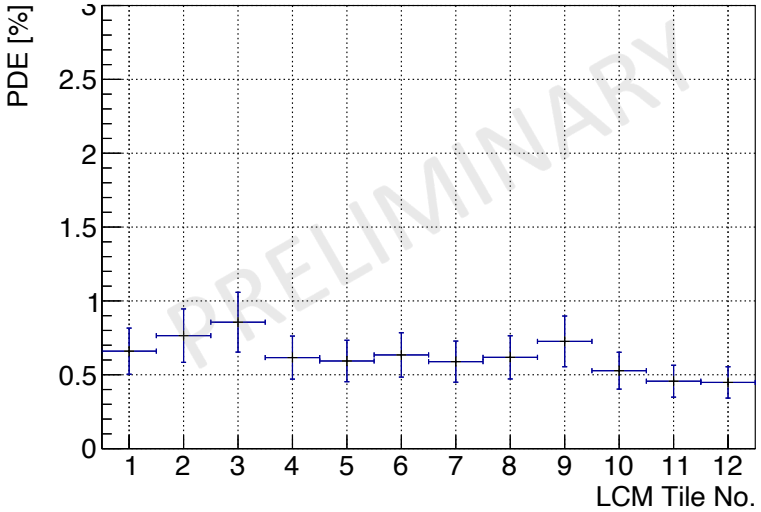


Photon detection efficiency (PDE)

- LAr: ~4.7k photons/mm for a MIP (@0.5V/cm)
- Goal: ≤ 5 MeV energy threshold for triggering
- Considering geometry and electronics response
- Required PDE: **~0.16%**

- How to measure PDE?
  - $PDE = \frac{\#\,measured\ photo\ electrons}{\#incoming\ photons}$
  - Using charge track information to simulate light yield
  - Compare number of measured photo electrons on SiPMs
- Current Results (Module 1):
  - ArCLigtht **0.187(22)%**
  - LCM **0.62(13)%**



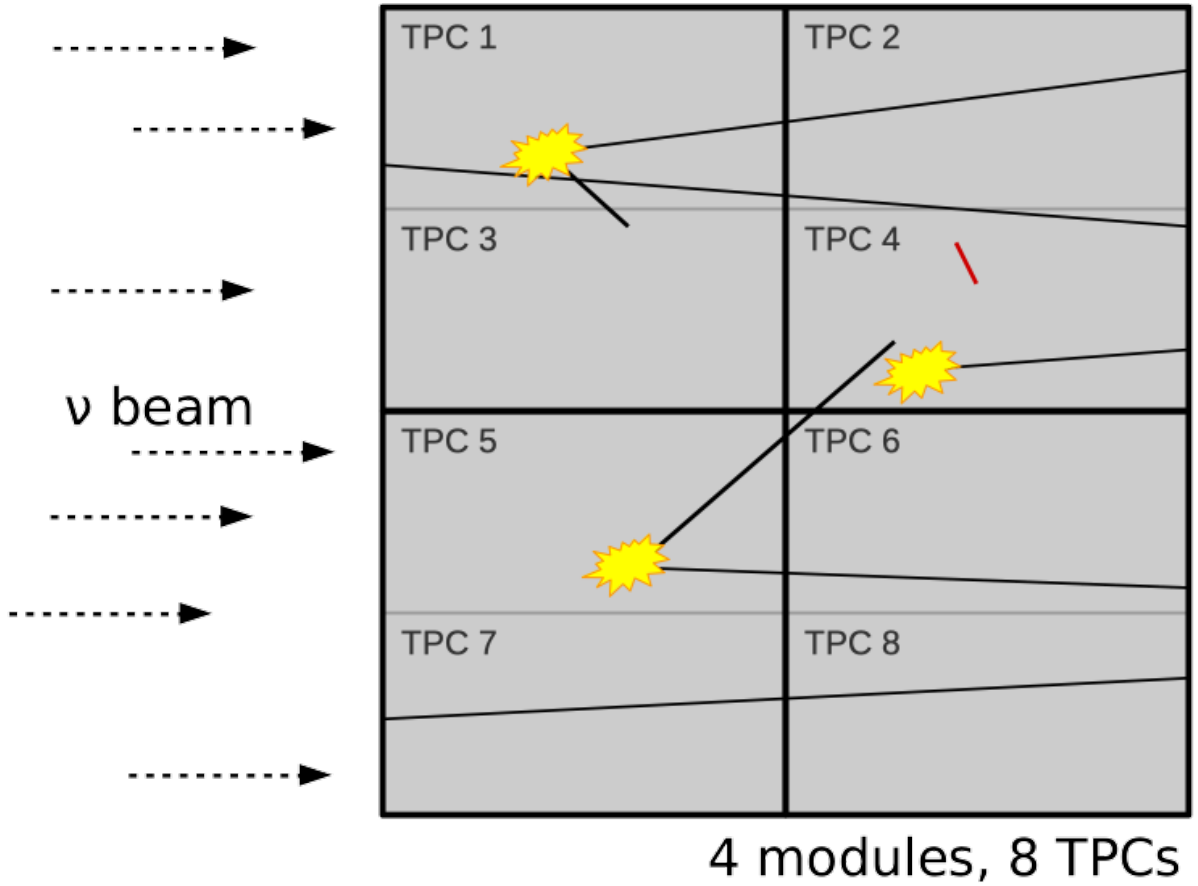


Detached energy deposits

- Missing energy in neutrino energy reconstruction due to “invisible” neutral particles
- Detached recoils (Ar or p^+)

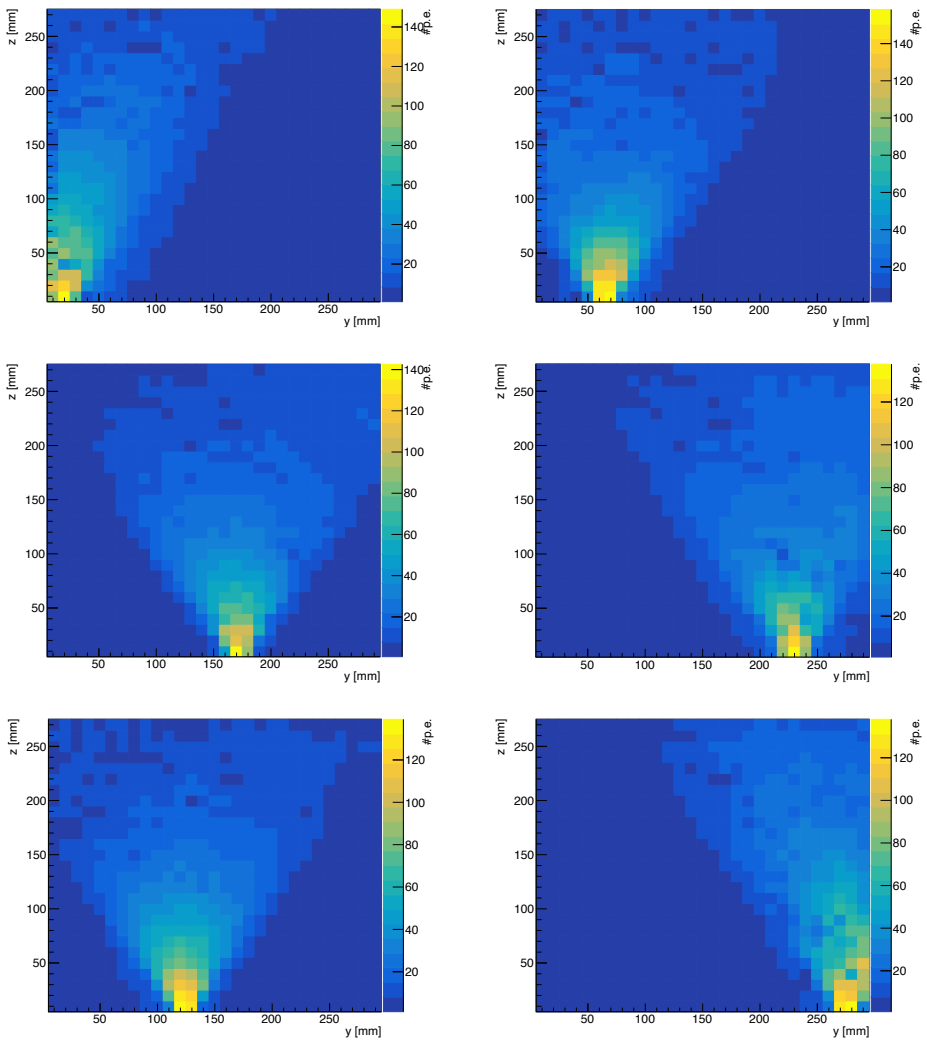
⇒ Need fast light information (and spatial resolution) for matching original vertex or decoupling from overlapping events

Graphic: P. Koller



ArCLight spatial resolution

- Individual sensitive area for each SiPM
- Specific distribution of light intensity across all SiPMs
- First approach for y axis:
  - $\delta_y = y_{reco} - y_{true}$
  - y_{reco} = center of gravity of measured photo electrons
  - y_{true} = center of track
  - $\sigma_y \simeq 50$ mm
- High potential for improvement!



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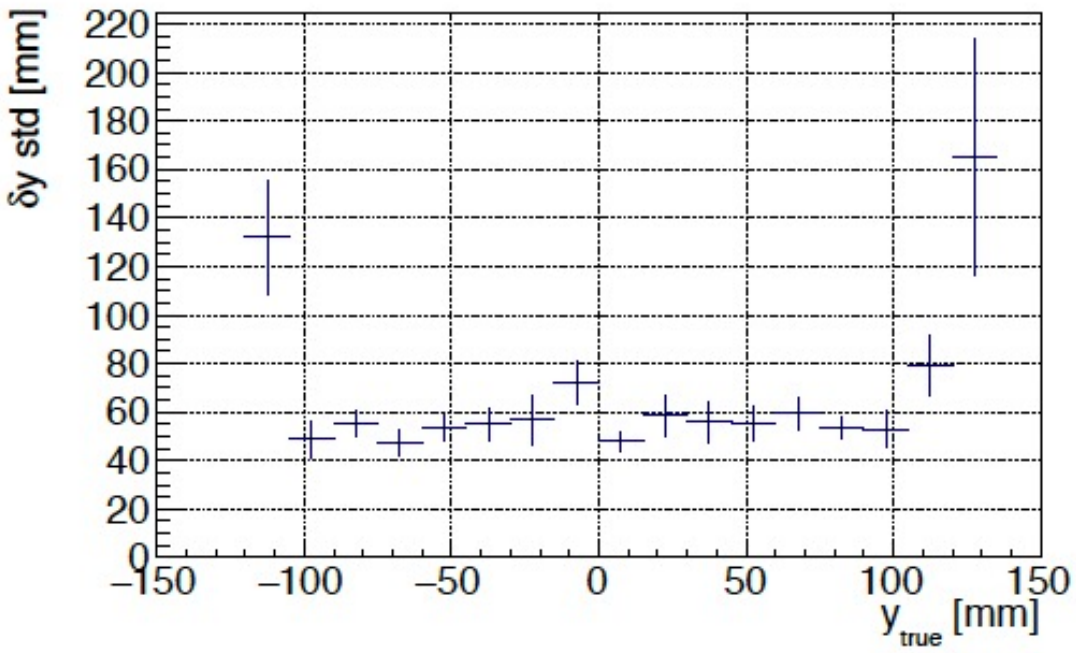
Spatial resolution in y axis (SingleCube data)



Summary

- Challenges of DUNE required the development of new technology
- Intensive prototyping with first neutrino interaction data from 2x2 demonstrator
- Two complementary light detectors using the same readout electronics

  -ArCLight: Spatial resolution

  -LCM: Photon detection efficiency
- Measured PDE fulfils requirements for both ArCLight and LCM
- Spatial resolution needed for efficient charge-light matching of deteched tracks

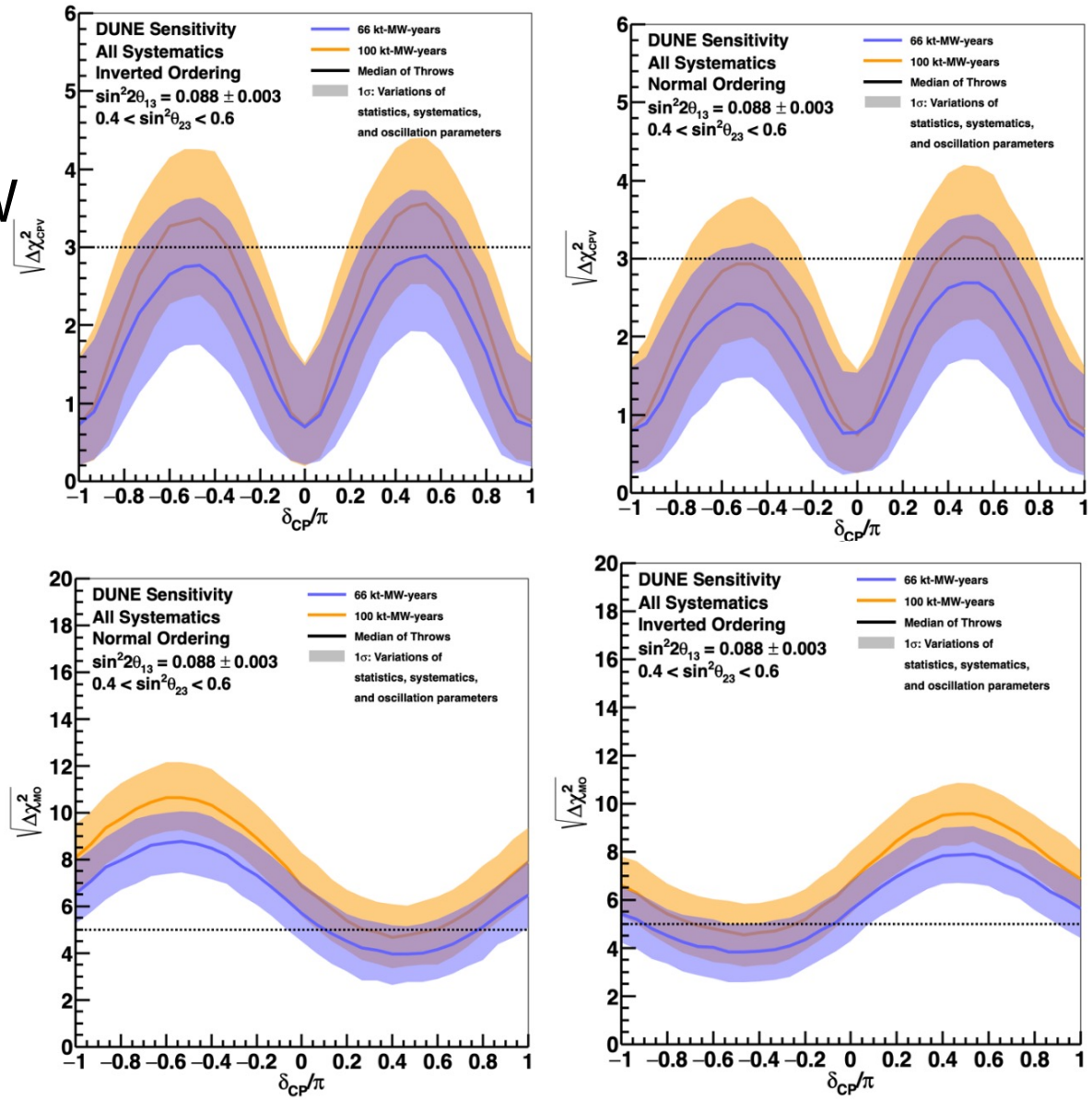
Backup

Sensitivity

- Nomial beam power: 1.2 (2.4) MW
- ~70kT FD with all 4 modules
- With full configuration:

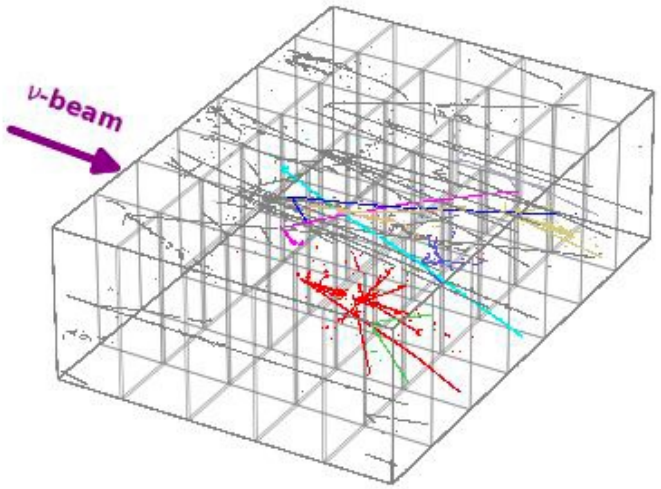
  ~84 kT-MW-year

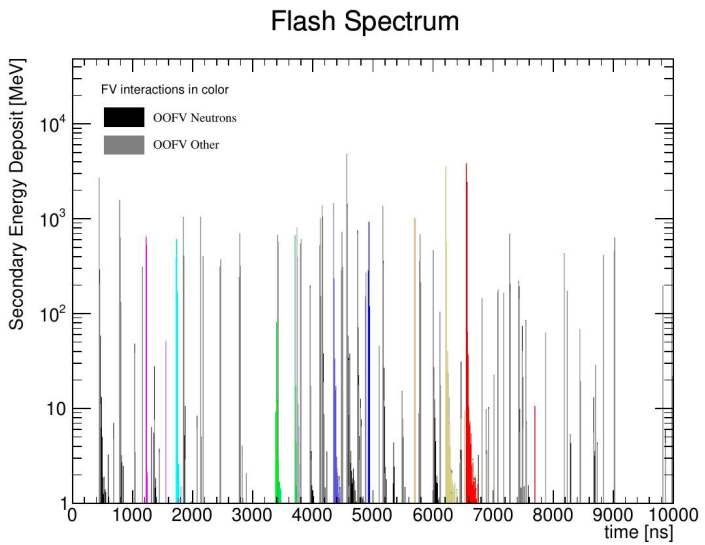
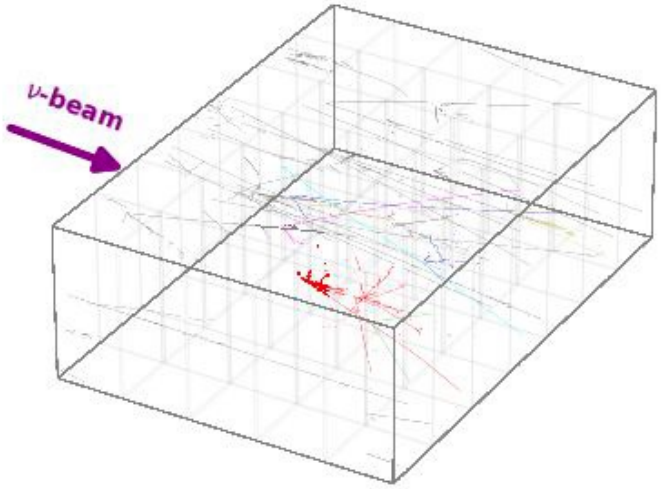
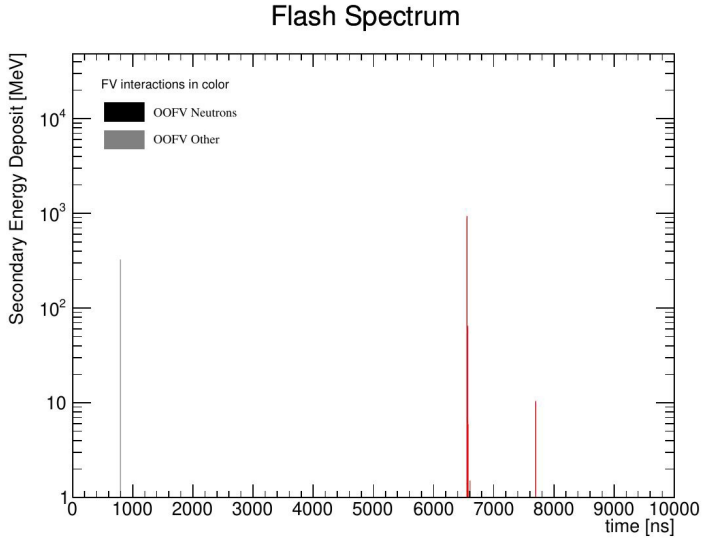
- ~35kT Day-1 configuration
- ~42kT-MW-year



Modularity

Monolithic





70 TPCs