Performance of the 3x1x1 m^3 dual phase LAr TPC prototype

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March 9^{th}, 2018 / Zurich PhD seminar 2018

ETH zürich WA105 DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Outline

1. Dual Phase Liquid Argon Time Projection Chamber

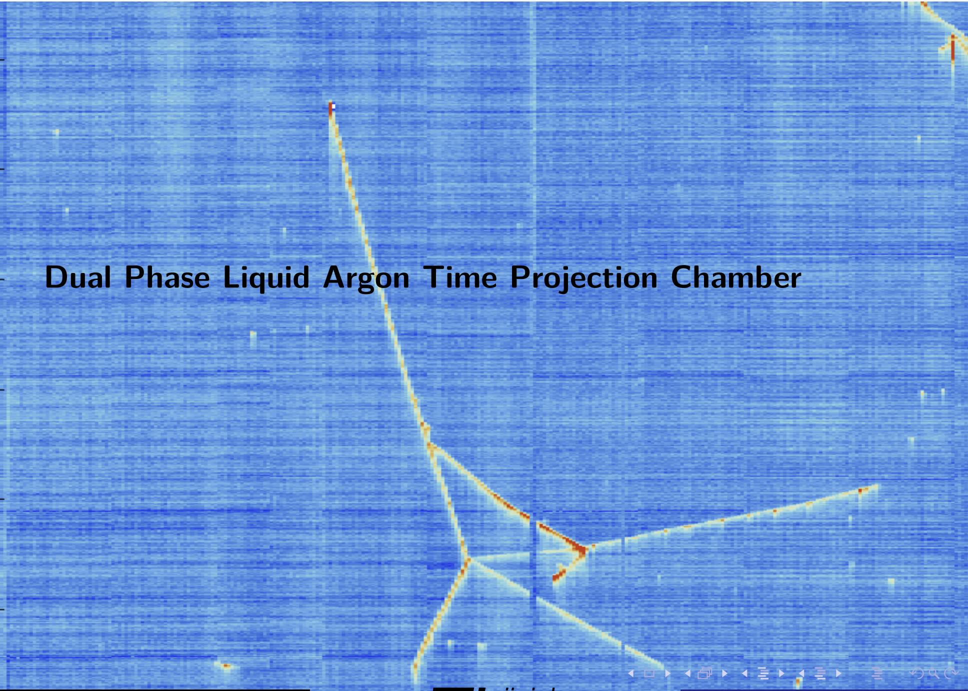
2. 3x1x1 m^3: installation, commissioning and operation

My work:

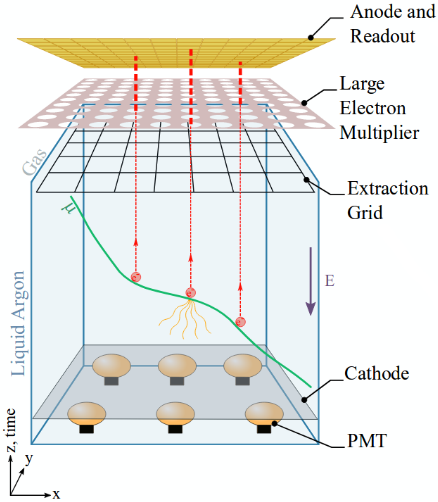
3. 3x1x1 m^3: data reconstruction

4. 3x1x1 m^3: data analysis
   - 4.1 Argon purity
   - 4.2 Charge readout uniformity
   - 4.3 Charge-light matching

Dual Phase Liquid Argon Time Projection Chamber



Dual Phase Liquid Argon Time Projection Chamber



- why argon?
1. noble gas → drift electrons over long distance
2. transparent to its own scintillation light
3. relatively cheap (atmosphere: 1 % argon)

- 2 perpendicular readout views + time info → 3D reconstruction
- high spatial and calorimetric resolution (channel pitch: 3 mm)
- scalable to large masses

Charge readout plane (CRP)

$\varepsilon_{collection}$= fraction of electrons transferred from LEM to anode (inefficiencies essentially due to electrons collected on top electrode of LEM)

G_{LEM}= multiplication factor of the electrons x transparency of its bottom electrode

$\varepsilon_{extraction}$= fraction of electrons which are extracted from the liquid (inefficiencies essentially due to transparency of grid)

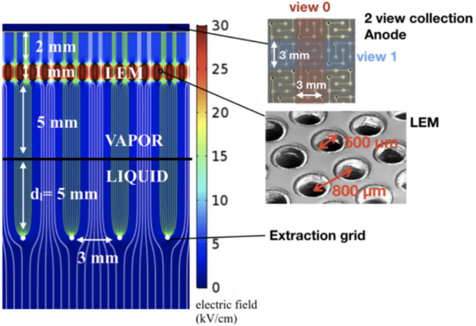
collection
5 kV/cm

amplification
33 kV/cm

extraction (vapor)
3 kV/cm

extraction (liquid)
2 kV/cm

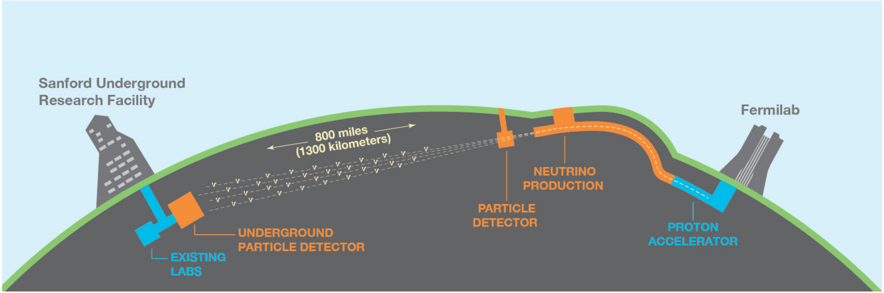
drift
0.5 kV/cm

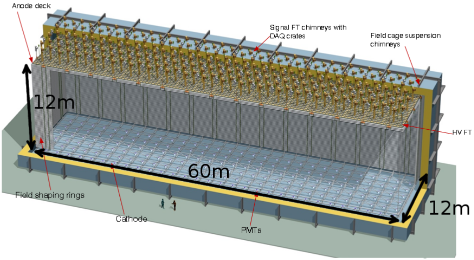


Effective Gain = Extraction Efficiency X LEM Amplification X Collection Efficiency

$$G_{eff} = \varepsilon_{extr} \times G_{LEM} \times E_{coll}$$

long term goal: DUNE (2028)





DUNE far detector:

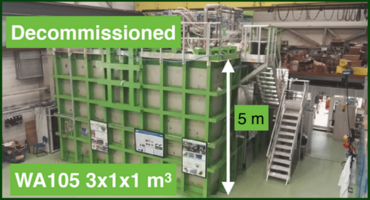
- 4 (DP) LAr TPC's
- 12 meter charge drift
- 10 kton fiducial mas
- accelerator ν's (δ_{CP}), nucleon decay, SN ν's

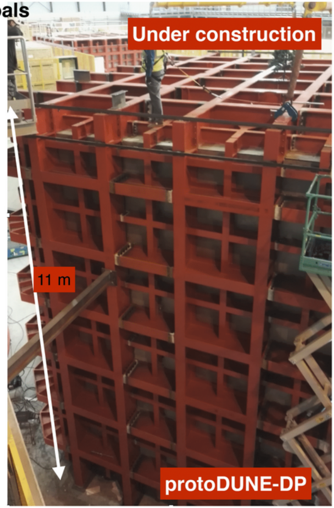
The two dual phase liquid argon TPC prototypes at CERN:

Same technology→different sizes→different goals

Common aspects

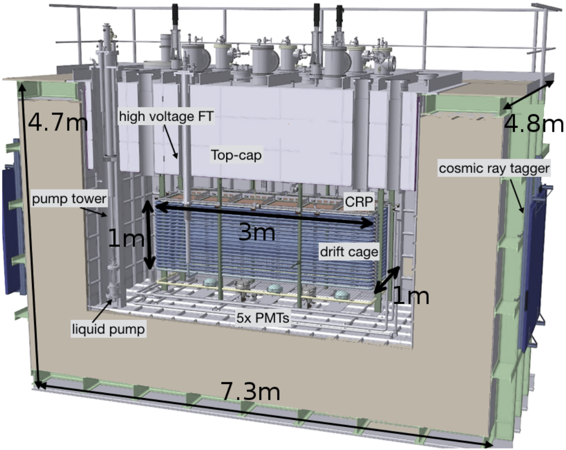
- ✓ LEMs and anode: design, purchase, cleaning and QA
- ✓ chimneys, FT and slow control sensors
- ✓ membrane tank technology
- ✓ Accessible cold front-end electronics and DAQ system
- ✓ amplification in pure Ar vapour on large areas





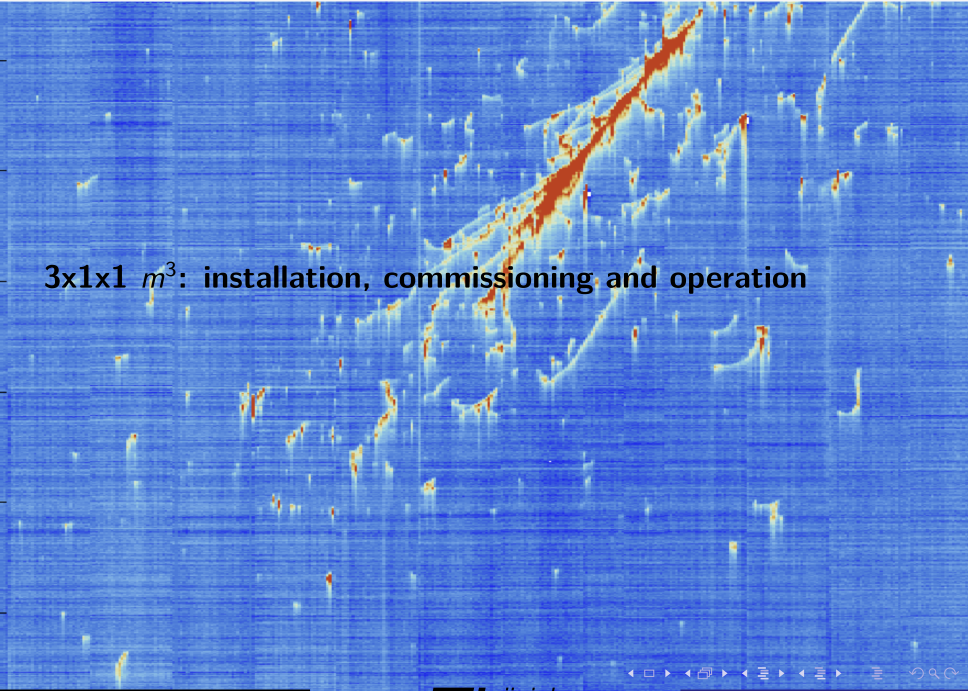
The 3x1x1 m^3 prototype at CERN

- Operation: June 2017 - December 2017
- Goal: demonstrate DP LAr TPC technology on large scale (cryostat, cryogenics, HV, charge readout and feedthroughs)



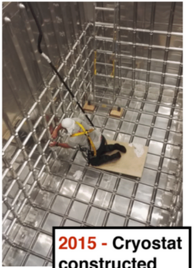
The next prototype: protoDUNE (6x6x6 m^3) at CERN

- Data taking: 2018 / 2019
- Main goals:
  - demonstrate electron drift over 6 meters
  - hadron beam: measure cross-sections and reconstruction efficiencies



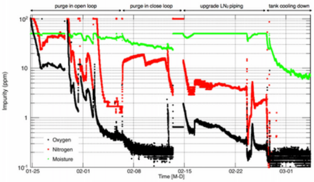
3x1x1 m^3: installation, commissioning and operation

3x1x1 m^3 timeline: installation and commissioning



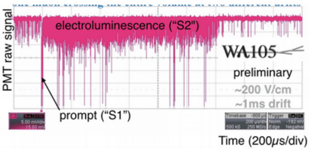
2015 - Cryostat constructed

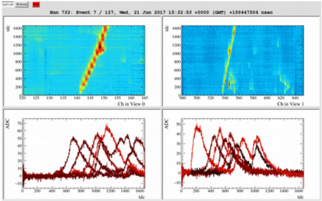
2016 - Detector installation completed



Jan 2017 - Commission started

Mar 2017 - Operation 'frozen' due to cryostat issues





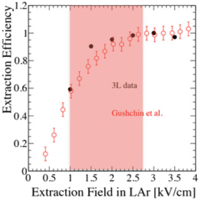
June 12th - Recirculation started → **June 15th - evidence of extraction from LAr to GAr** → **June 21st 2017 - First track seen!**

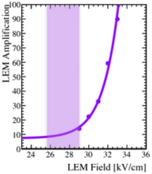
June July August September October November December

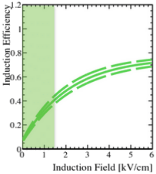
CRP alignment and HV trials

Period I: Data in different HV configurations

Extraction field scan

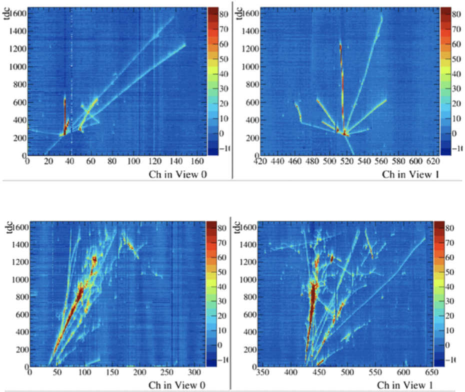




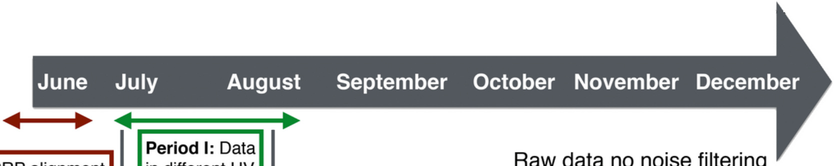


Amplification and collection field scan at a **fixed extraction field**

Raw data no noise filtering



3x1x1 m^3 timeline: operation



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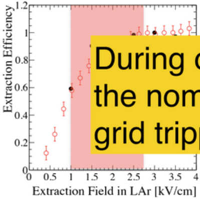
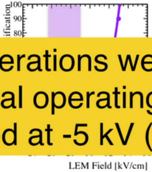
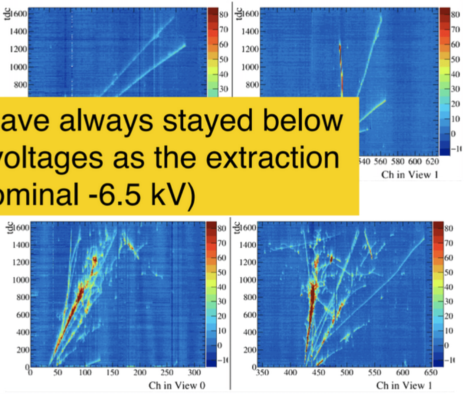


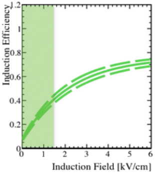


Raw data no noise filtering



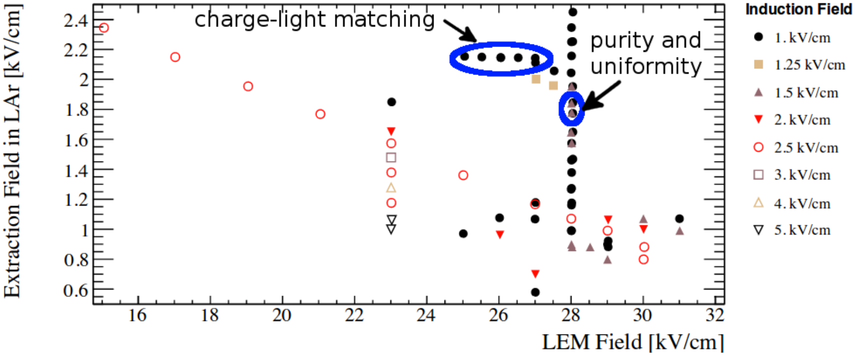
During operations we have always stayed below the nominal operating voltages as the extraction grid tripped at -5 kV (nominal -6.5 kV)

Amplification and collection field scan at a fixed extraction field



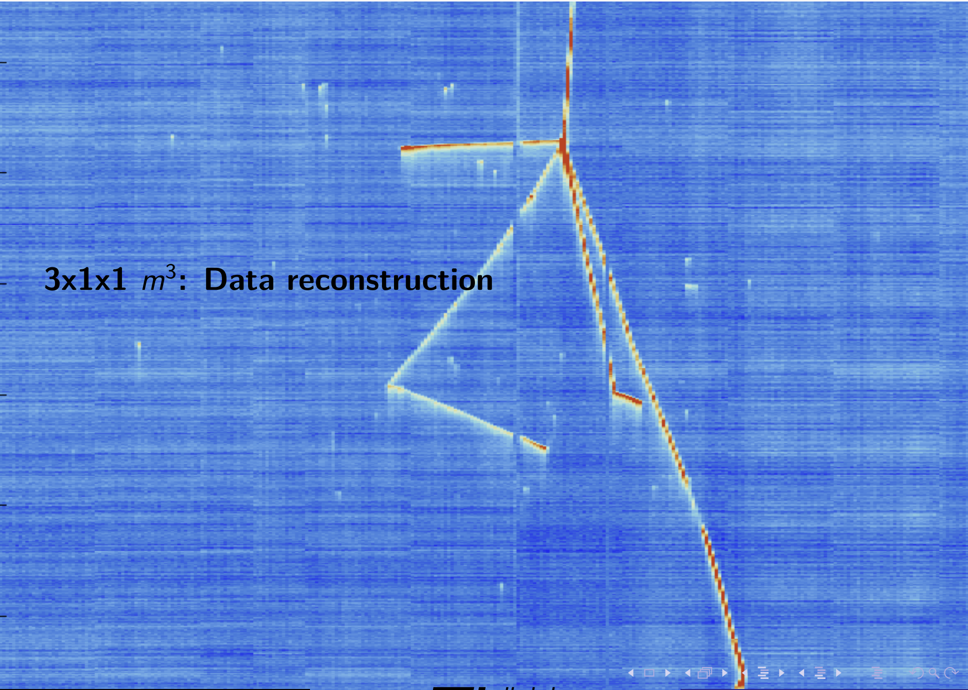
Data set

400 000 events in more than 100 different HV configurations:

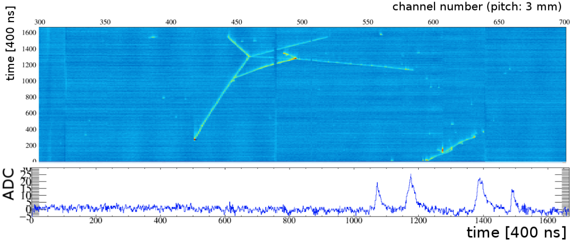


- purity and uniformity analysis: 38 000 events with PMT trigger
- charge-light matching: 45 000 events with CRT trigger

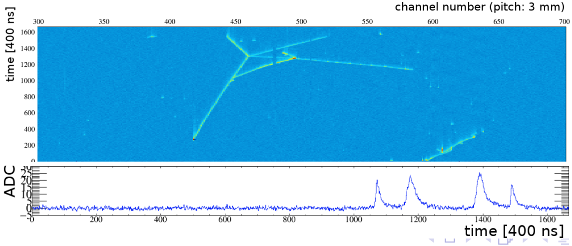
3x1x1 m^3: Data reconstruction



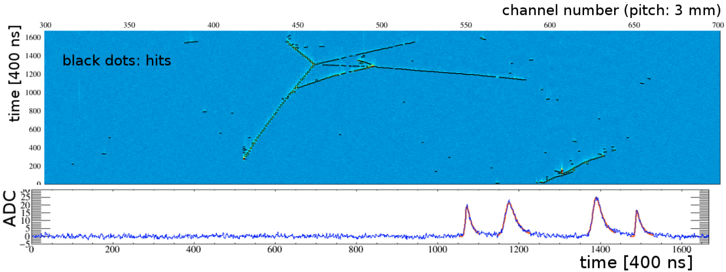
Raw data: slow baseline fluctuations and coherent noise



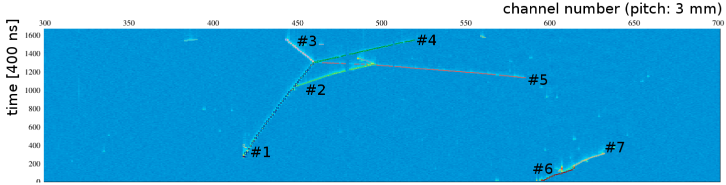
After baseline flattening and coherent noise removal:



Hit finding: peaks are fitted and filled into a 2D histogram



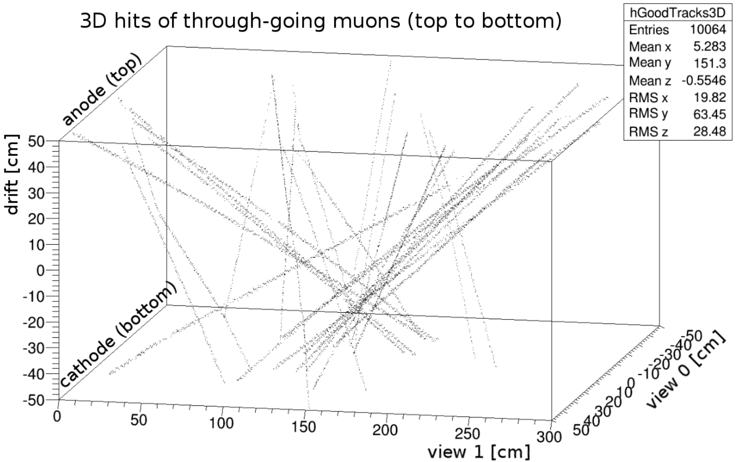
2D pattern recognition: group of hits = "cluster"



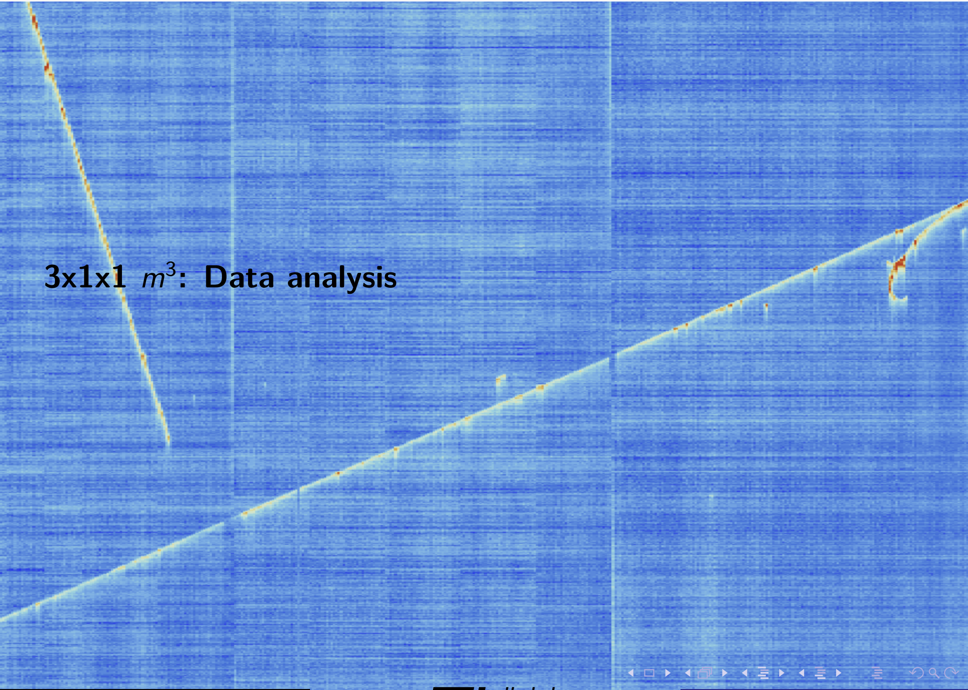
- 3D reco matches two clusters from the two readout views

→ two clusters need to have similar start and end times

- each hit inside a 3D "track" is given a 3D coordinate (x,y,z)



3x1x1 m^3: Data analysis

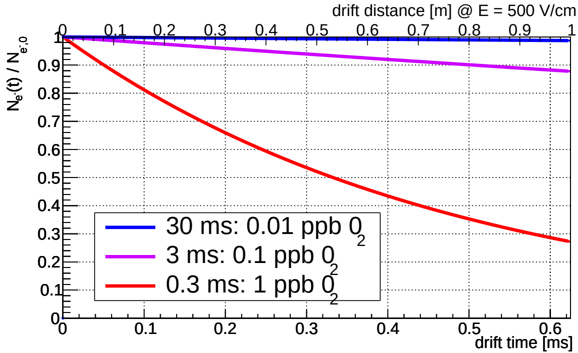


Argon purity: why is it important?

- impurities in LAr such as O_2 and H_2O capture electrons

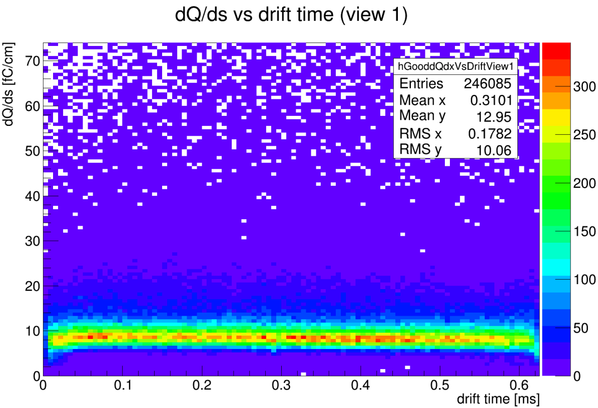
$$N_{e^-}(t) = N_{e^-,0} \cdot e^{-t/\tau_{e^-}}$$

$$\tau_{e^-} \approx \frac{300\ \mu s}{\rho_{O_2}[ppb]} , \qquad 1\,\mathrm{ppb}\text{ of } H_2O = 17\,\mathrm{ppb}\text{ of } O_2$$



→ high argon puritiy essential for long drift distances (DUNE: 3 *ms*)

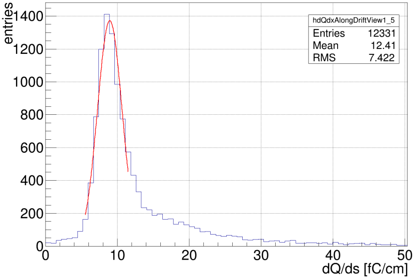
- select through-going tracks (top to bottom)
- from 3D reco: calculate dQ/ds for each hit of the track:



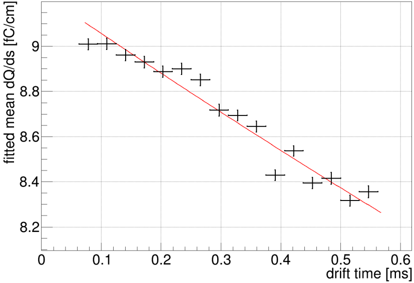
- divide drift time into 20 bins, exclude first and last two bins

Argon purity: analysis

dQ/ds for one drift time bin



Fitted mean vs. drift time



- fit dQ/ds distribution for each drift time bin with Gaussian

$\rightarrow$ plot fitted mean of each drift time bin vs. drift time

$\rightarrow$ fit with $f(t) = A \cdot e^{-t/\tau}$

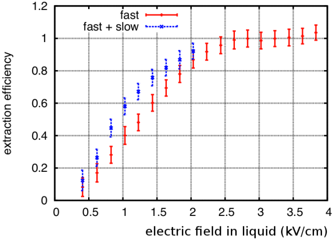
- measured electron lifetime: $\tau = (5.1 \pm 0.2)\ ms$

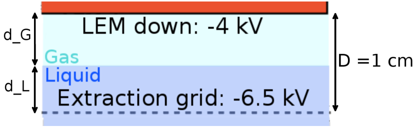
Charge readout uniformity: why is it important?

- LEM thickness can vary

→ different LEM gains across the CRP

- Extraction process depends on the extraction field in liquid:





$$E_{liquid} = \frac{\Delta V}{d_L\left(1 - \frac{\epsilon_L}{\epsilon_G}\right) + D\frac{\epsilon_L}{\epsilon_G}}$$

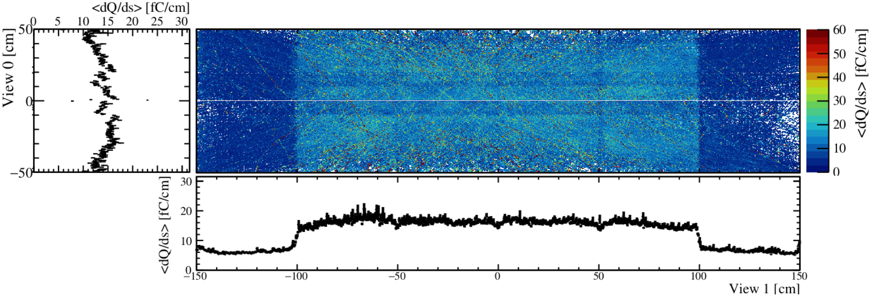
- charge readout plane (CRP) can be tilted w.r.t. liquid level

→ different extraction fields and efficiencies across the CRP

- other possible scenarios

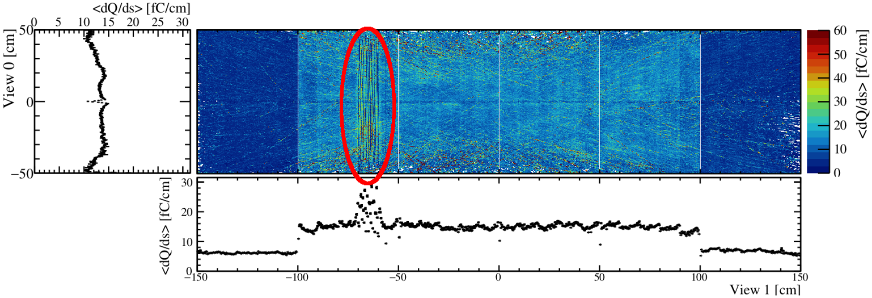
Charge readout uniformity: analysis

- from 3D reco: calculate dQ/ds for each hit in **view 0**:



- corner LEM's were at lower amplification field for this run
- dead areas between LEM's clearly visible (each 50 cm)
- uniform charge response

- from 3D reco: calculate dQ/ds for each hit in **view 1**:



- after opening the detector we found a loose screw

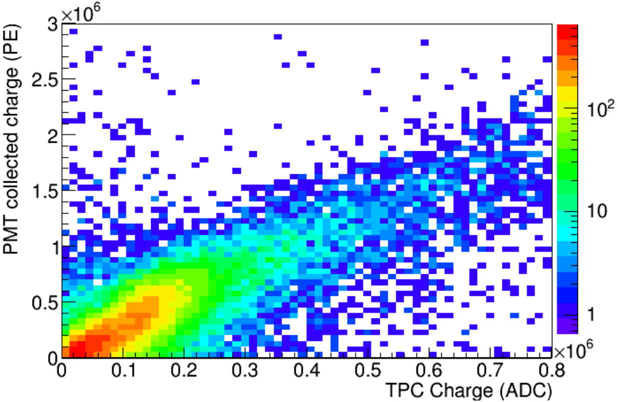
→ less tension on extraction wires in highlighted area

→ charge focussing disturbed

- comparison with view 0: equal charge sharing between readout views

Charge-light matching

- for tracks recorded with cosmic ray tagger (travelling along 3 meter side), we have matched the charge and light signal
- PMT charge: sum of S1 and S2 over all PMT's
- TPC charge: hit integral of all reconstructed hit



Summary

1. First large scale DP LAr TPC was successfully operated
2. We have learned valuable lessons from the 3x1x1 m^3 for protoDUNE and DUNE
3. Good argon purity will allow charge drift over several 10m
4. No problems with charge readout uniformity and charge sharing
5. Technical paper will be published soon
6. Analysis paper will follow later this year

Thank you!