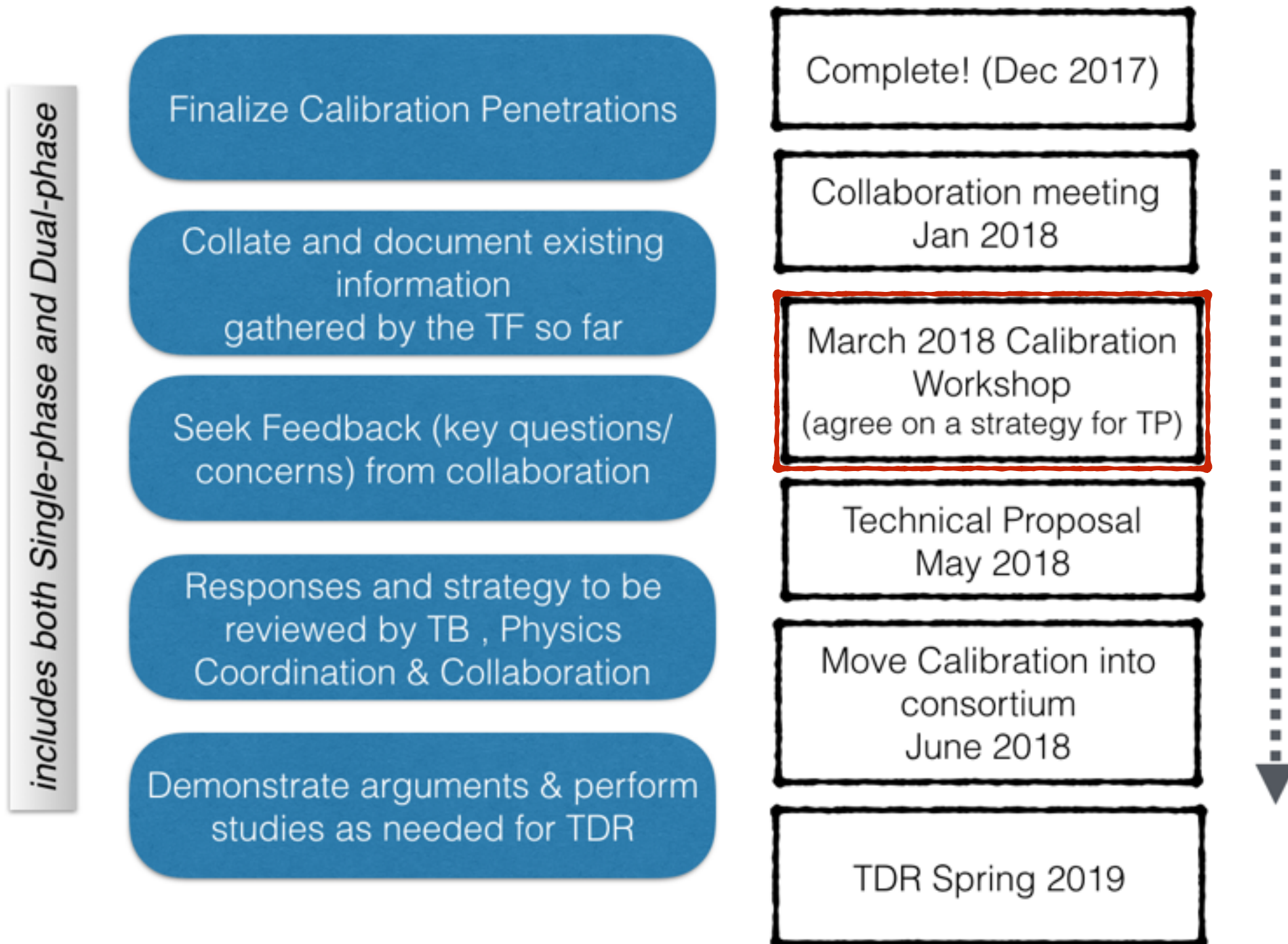


DUNE FD Calibration workshop: Summary, additional thoughts & Next steps

Sowjanya Gollapinni (UTK)
Kendall Mahn (MSU)

DUNE Calibration Workshop
March 16, 2018

Calibration Strategy: Collaboration Process Timeline



Workshop Goals/Format

(<https://indico.fnal.gov/event/16087/other-view?view=standard>)

- *Wednesday:*

- Summary of current status
- Existing calibration sources

- *Thursday:*

- External Systems: Motivation, physics benefits etc.
- Discuss Key Questions/Concerns received so far
 - <https://docs.dunescience.org/cgi-bin/private/ShowDocument?docid=7449>
- Note down possible studies for TDR

- *Friday:*

- Dedicated session on DP considerations
- Summary, Agree on external systems and what goes into TP

- ***Workshop focus:*** External calibration systems & Physics benefits

Attendance:
20 in-person
and 5-10 remote
(productive discussions!)

As we go through the slides,
comment on the following:

1.

2.

Existing Sources Discussion

- *Better categorization of sources*: Not all are calibration sources, some can only be used to test models
- *Emphasis that each source comes with unique challenge* (e.g. Michels, Pi0s) — strong argument for redundancy
- *Exchange rate of argon* through the purification system can impact estimates timescales for measurements, need to take it into account
- Would be good to understand what are the *measurements we need from ProtoDUNE* and also how we can use it to test things for DUNE (e.g. DUNE electronics test)
- New estimates for cosmic muons from the MUSUN Cosmic Simulation shown
- *Ar39*: good source but (noise) threshold dependent; lifetime critical
 - Need to understand *radiological background and requirements* for the detector. All consortia need to thinking about
- *Current monitors* as a source to diagnose resistor failures

Current Proposed Systems

External Calibration Systems (currently considered)

- Laser (e.g. MicroBooNE, SBND)
- Photo-electron (Laser) Calibration System (e.g. T2K)
- Radioactive source Calibration
- Portable (external) Neutron source
- Photon Detector Calibration system
- Cosmic Ray Tagger (CRT)
- Field response calibration devices — not discussed

- *New systems proposed/
considered/discussed*
 - Radioactive sources also attached to cathode; injecting sources into argon
 - T2K photo-calibration system — feasibility study planned
 - Re-use of PDS system as light emitter? — bench tests and protoDUNE for feasibility
- **Did we miss anything?**

Discussion on Laser

- T2K-style photoelectron laser calibration system: similar to pulsing the cathode, a nice wake-up system to know things are alive
- Safety associated to SBND-style laser system discussed
 - Laser head is plastic, but motor may have metal parts — need to understand
 - Laser will sit 40 cm (in X) from APAs, low field; will NOT penetrate ground plane
- *Post-workshop activity:* Laser vs Cosmics statistics arguments require updating with new simulation-based cosmic numbers from T. Junk & team.

Low energy relevant energy scales

K. Scholberg, E. Conley, J. Stock, J. Reichenbacher, R. Svoboda, B. Littlejohn

Gammas:

9 MeV

Electrons:

Muon decay (Michels)
endpoint ~50MeV

Neutrons:

6 MeV
(captures)

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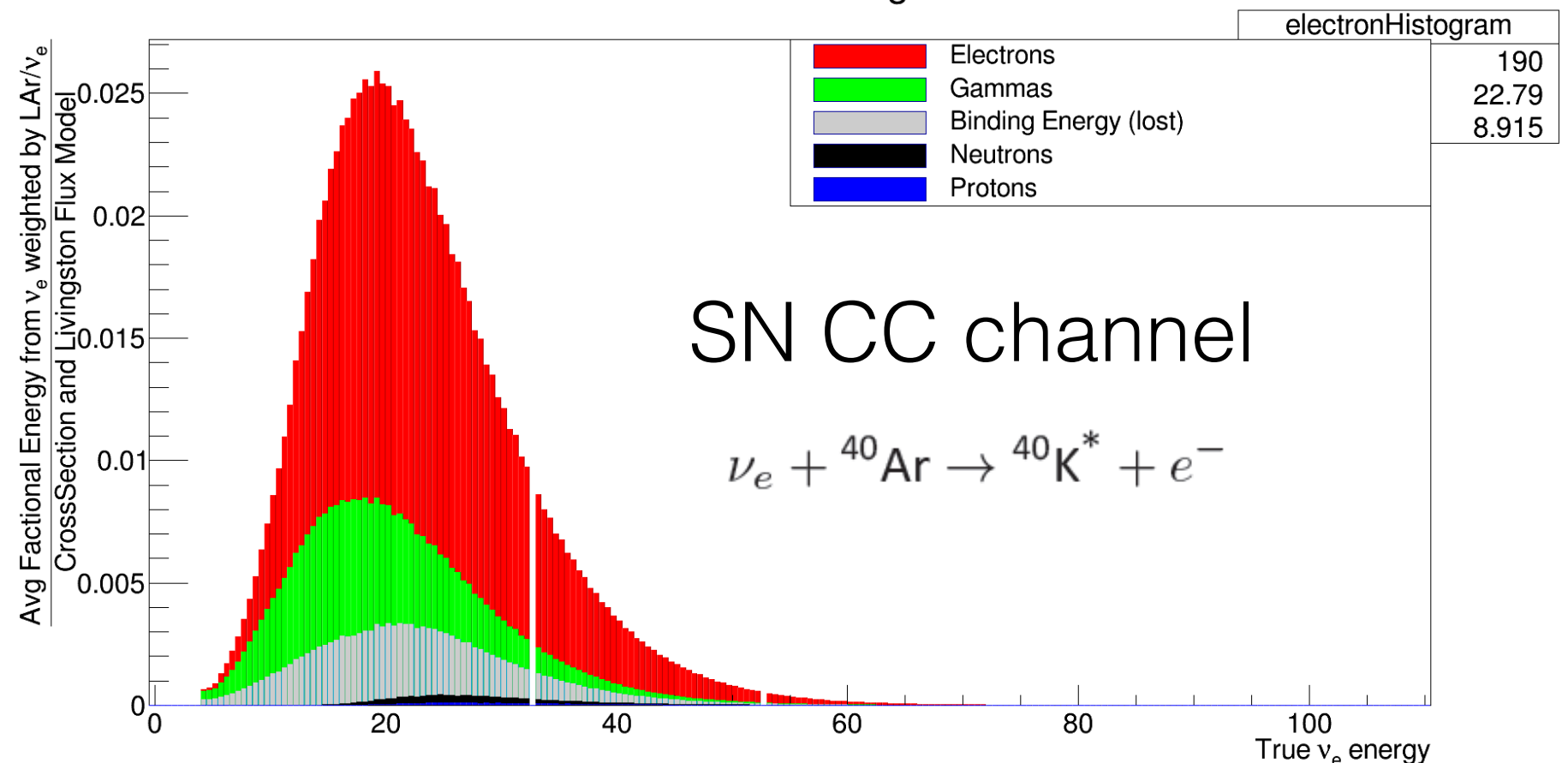
Muon decay (Michels)
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Neutrons:

6 MeV
(captures)

SN NC
channel
(10 MeV)

SN Neutrino Signal



Low energy EM response also relevant for LBL

K. Scholberg, E. Conley, J. Stock, J. Reichenbacher, R. Svoboda, B. Littlejohn

Gammas:

9 MeV

Electrons:

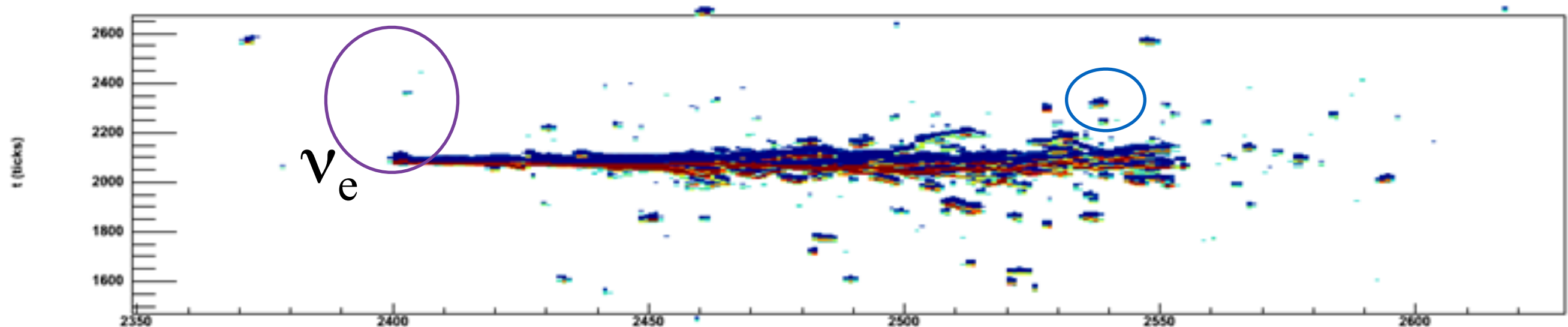
Muon decay (Michels)
endpoint ~50MeV

Neutrons:

6 MeV total
photon signal

Neutron capture

Low energy photons



EM shower outliers

Source Calibration

K. Scholberg, E. Conley, J. Stock, J. Reichenbacher, R. Svoboda, B. Littlejohn

- Sources serve as “standard candles”, direct test of efficiency of signal, background LE events with fixed position/energy/trigger
- Radiological sources:
 - Deployment on cathode, outside field cage, or in fluid
 - Some natural (Ar39) some not (Thoron, Nickel)
 - Range in gamma energy, ability to stage deployments
- Neutron generator:
 - Outside field cage, illuminates entire detector with capture events due to a anti-resonance
 - Characterizable capture spectrum (“bunch of standard candles”)

Discussion on Sources

- *External Neutron Source (Bob Svoboda)*

- Better estimates on size of the system: 2 x 2 m cylindrical tank; 3 systems (fixed) can span the detector
- Human safety needs to be taken into account
- Will need a hole in insulation as in Feedthroughs, need to do shielding studies and understand needs
- Proposal to understand argon capture gammas at the LANSCE facility, LANL as a test bench

- *Radioactive sources (Juergen/Jason)*

- Studies from Juergen/Jason on charge-light correlation using simulation of Ni Calibration Source in the DUNE FD
 - Developed MC cheating tools, geometry & photon library — huge effort ongoing

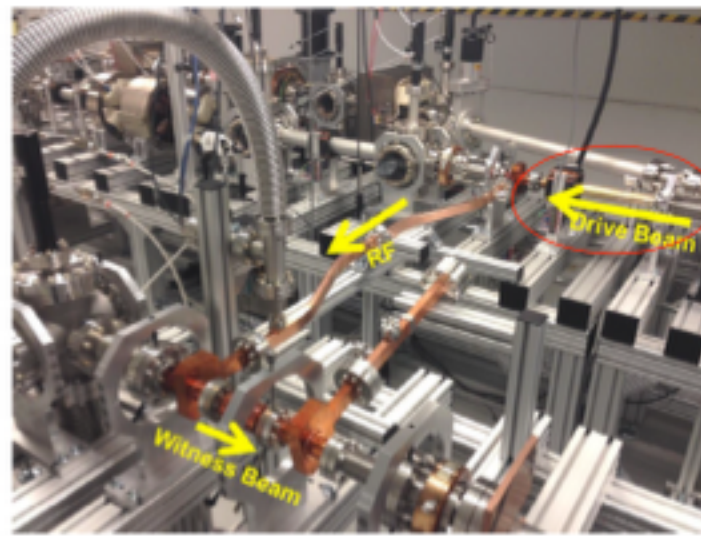
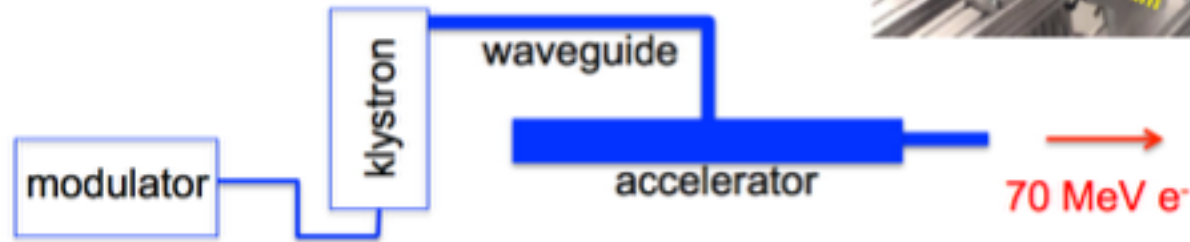
Photon Calibration System

(Zelimir Djurcic)

- *UV-light based Photon Calibration System*
 - verifies gain, timing resolution; monitors stability and response over time
 - light diffusers on cathode: safety discussed; some concern in how we route fibers safely
 - Interesting idea (Stephen Pordes): can one use a flash lamp and generate electrons off the mirror? much simpler system
 - Bench tests at ANL and an eventual test at ProtoDUNE as feasibility tests/studies
- Absolute Calibration (N_{photons} to ADC Charge)
 - Radioactive sources; cosmics — suggestion to think more about this
 - New idea: Electron Accelerator? (more general purpose than just PDS)

Electron Accelerator?

- ANL “hand-made” 70 MeV electron linac:
 - 50 kV HV Power Supply
 - Modulator (~250k M&S)
 - Klystron: L-Band 1.3 GHz (~\$275k)
 - Waveguide
 - Accelerator Structure (L-band -100k)



Electron Accelerator (Zelimir Djurcic)

- But all these components are commercially available: medical applications



Electron Accelerator Exploratory Study

- Is it “useful”?
 - What do we learn (low-E physics)?
 - Can the intensity dial-down to single electron?
- Interface with Cryostat/TPC
 - ProtoDUNE will bring the test-beam inside TPC, can we do the same with DUNE?
 - Beam pipe penetrations?
- Operational Requirements (power requirements, DAQ interface, cooling needs?)
- Noise issues?
- Space requirements?
- What else?

Cosmic Ray Tagger

(Josh Klein, Richard Diurba)

- Studies underway to better understand what such a system would provide
- Availability of space a consideration
- Growing agreement that a small portable system is more useful; smaller system also provides more simple/direct triggers
- In terms of motivation, some agreement that it is best served as an independent handle for t_0 and also as a reconstruction efficiency check

DAQ Needs for Calibration

(Matt Graham, Josh Klein, Kurt Biery)

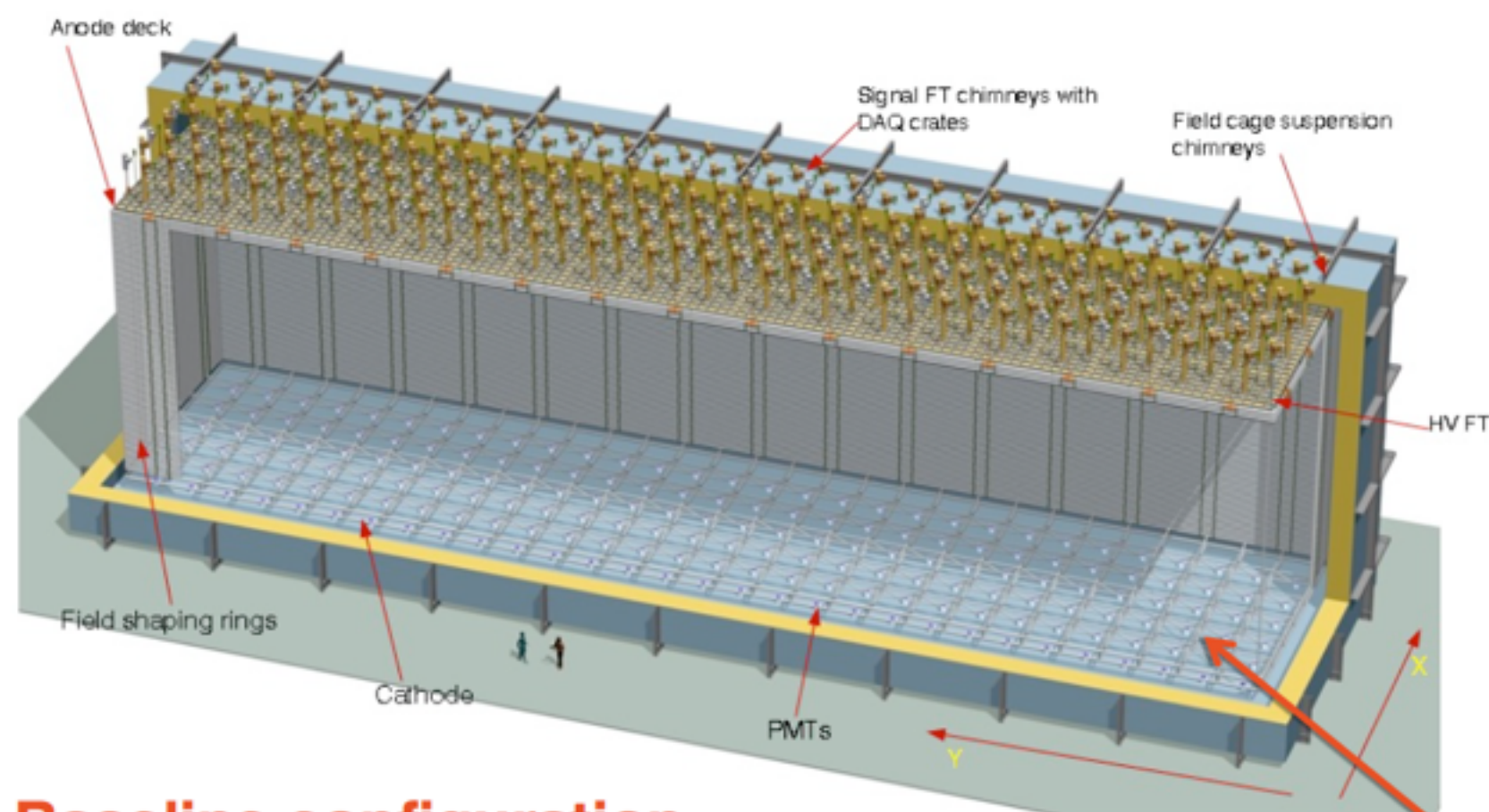
- Better understanding of limitations from the DAQ side
 - A total bandwidth of 30 PB/year for all 4 FD modules
 - Other than random triggers, it is anticipated that the TPC threshold will be >10 MeV for normal running
 - If event rate in detector is > 0.5 Hz, in existing paradigm event builder cannot keep up
 - All data from front-end is passed to a temporary buffer, without zero suppression (~ 10 Tb/s/10 kt)
 - If event rate in detector is $> 1.6 \times 10^6$ /year, you are dominant source of data for DUNE (unless events are zero-suppressed or geo-suppressed)

DAQ Needs for Calibration

- Some (very) rough initial estimates for annual data rates currently in TP (see backup)
 - Doesn't include some systems (e.g. Ar39, PDS)
 - Need to clarify and provide more realistic estimates in the coming weeks
- Mitigation strategies on the 0.5 Hz event rate and transfer rates from underground location to surface discussed; zero suppression schemes
- Didn't loop in offline computing folks into the discussion yet, there maybe challenges on that front that needs to be considered

1. DUNE FP DP Photon System

based on
ProtoDUNE-DP
design



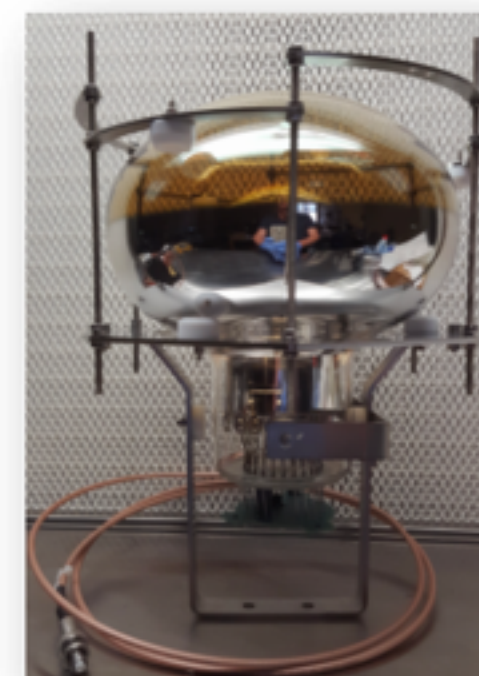
Goals

- t_0 for both beam and non-beam events
- Trigger for non-beam events

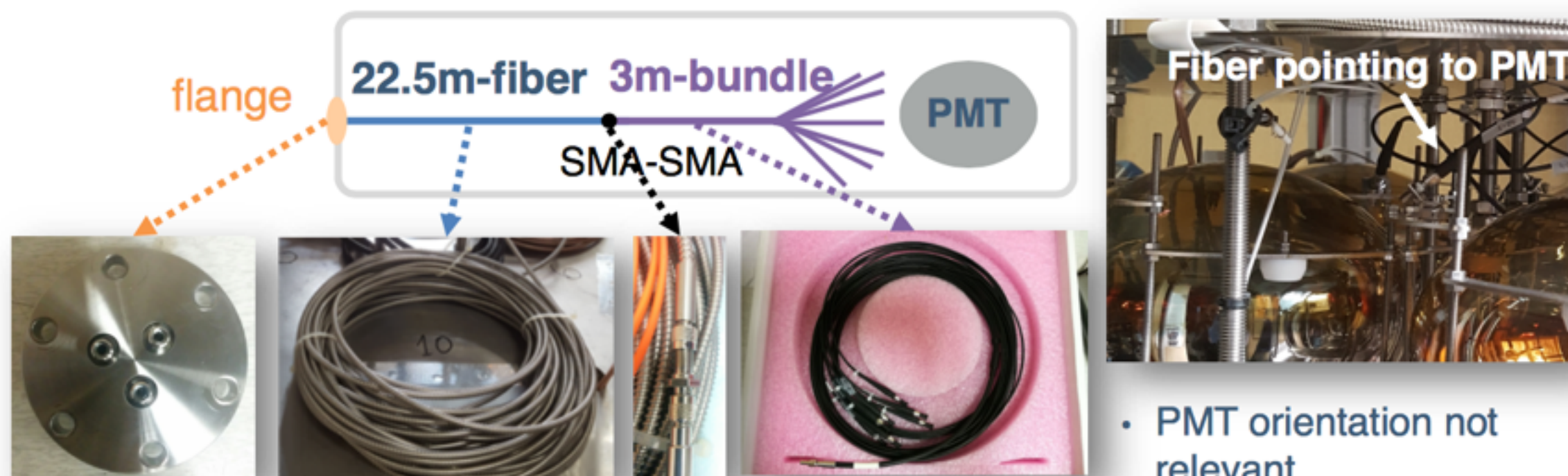
Baseline configuration

- **8" Hamamatsu R5912-02mod PMTs**
- 1 PMT/m² (720 total) fixed at the membrane floor
- Wavelength-shifter: TPB coating on PMT
- Voltage divider base + single HV-signal cable + splitter
- Light calibration system
- DAQ system (external)

PMTs



3. ProtoDUNE-DP LCS: Inner System



All components available and tested at CIEMAT

Attenuation measurements

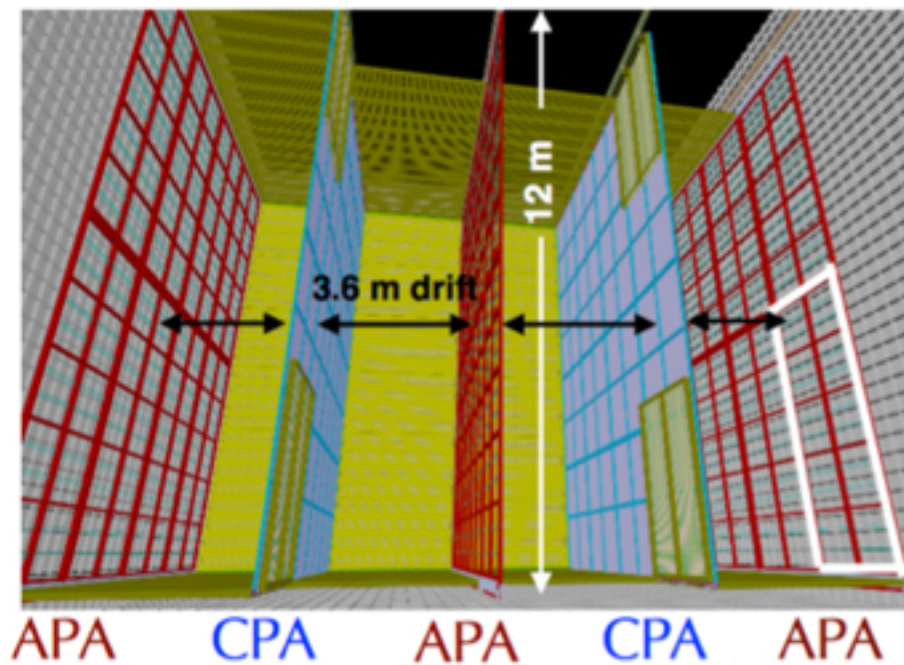
- **Source:** LED with Kaputsinsky driver, and laser
- **Sensor:** power meter and PMT
- Conditions: **RT and CT**

Expected and measured light attenuation of the inner system
~20 dB (~1% light transmission)

Full system to be tested at CIEMAT in April

Dual Phase Considerations

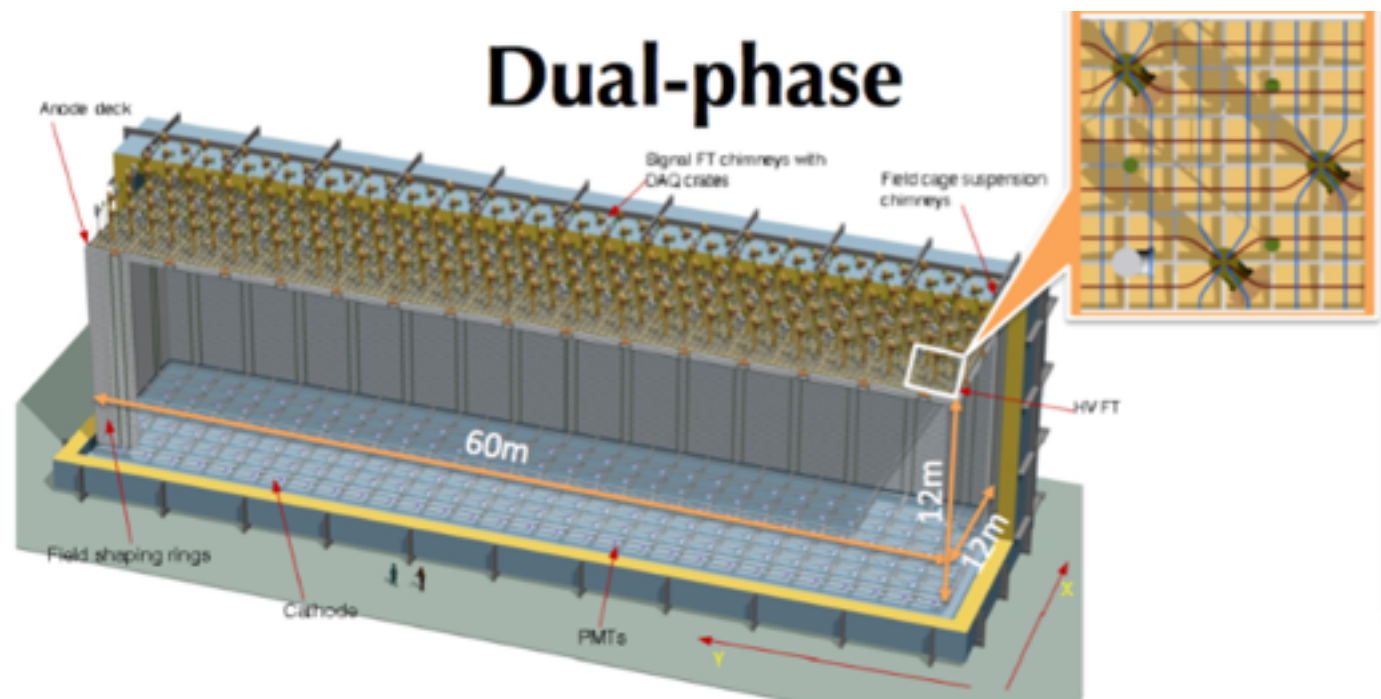
Single-phase



- *Dual Phase:*

- Liquid and gas phase
- Ionization signals amplified and detected in the gaseous phase above liquid level
- 12m vertical drift in liquid argon
- Benefit of vertical drift: Cosmics provide enormous number of APA-CPA crossers

Dual-phase

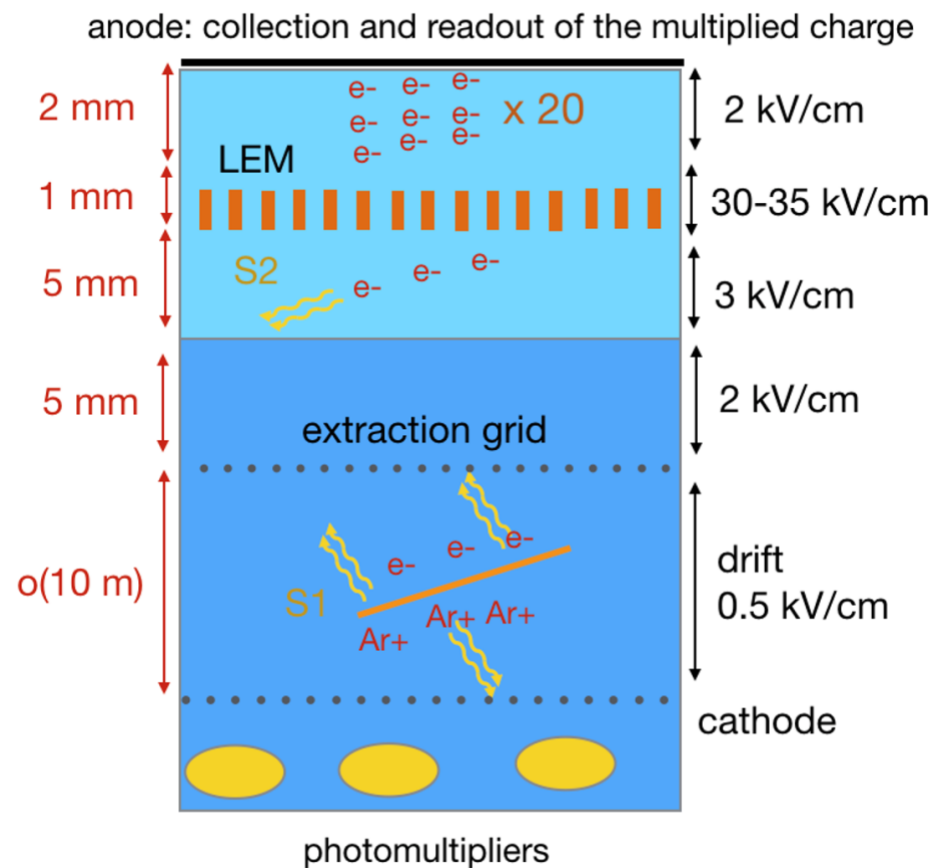


Dual Phase Considerations

- *E-field distortions*
 - Space charge from Ar-39 for DP: not small; E-field 1.0% ($dQ/dx < 0.3\%$); Spatial 5 cm (dQ/dx 2 – 3%) — *without taking into account ion accumulation*
 - plus E-field distortions from drift field deformations (cathode bowing, misalignment, APA flatness etc.) — more of an issue for SP than DP
 - Argon flow pattern (steady state or turbulent) can significantly impact this. Even more complicated for DP: +ve ions may collect above the liquid and create surface interface issues. *(Bo's talk)*
- *Does the gain vary with time?* charge up from cosmic rays, how long does it take to go away?
- Interplay b/n Electron lifetime (3 ms requirement) and gain; Lower lifetime risky
- Requirements (and the ability to measure things) will change if we cannot achieve our nominal drift field
- Do impurities from gas enter the liquid phase? Will that be an issue for lifetime? Temperature variations b/n gas and liquid phase can be an issue; flow pattern can also impact

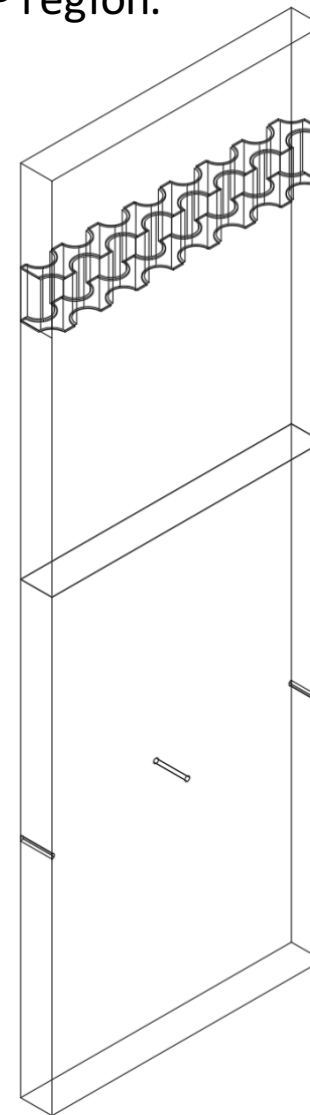
Field Lines Around the DP LEM

DP cross section view

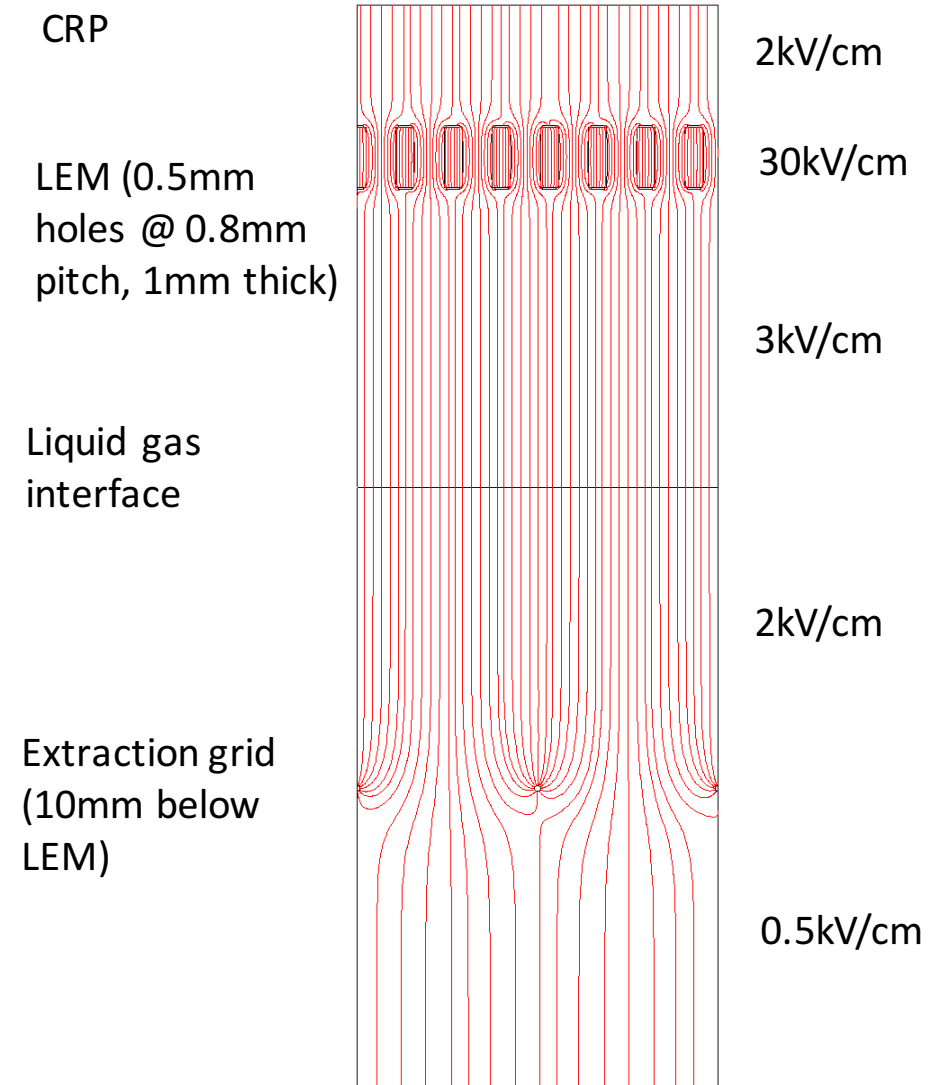


From S. Murphy

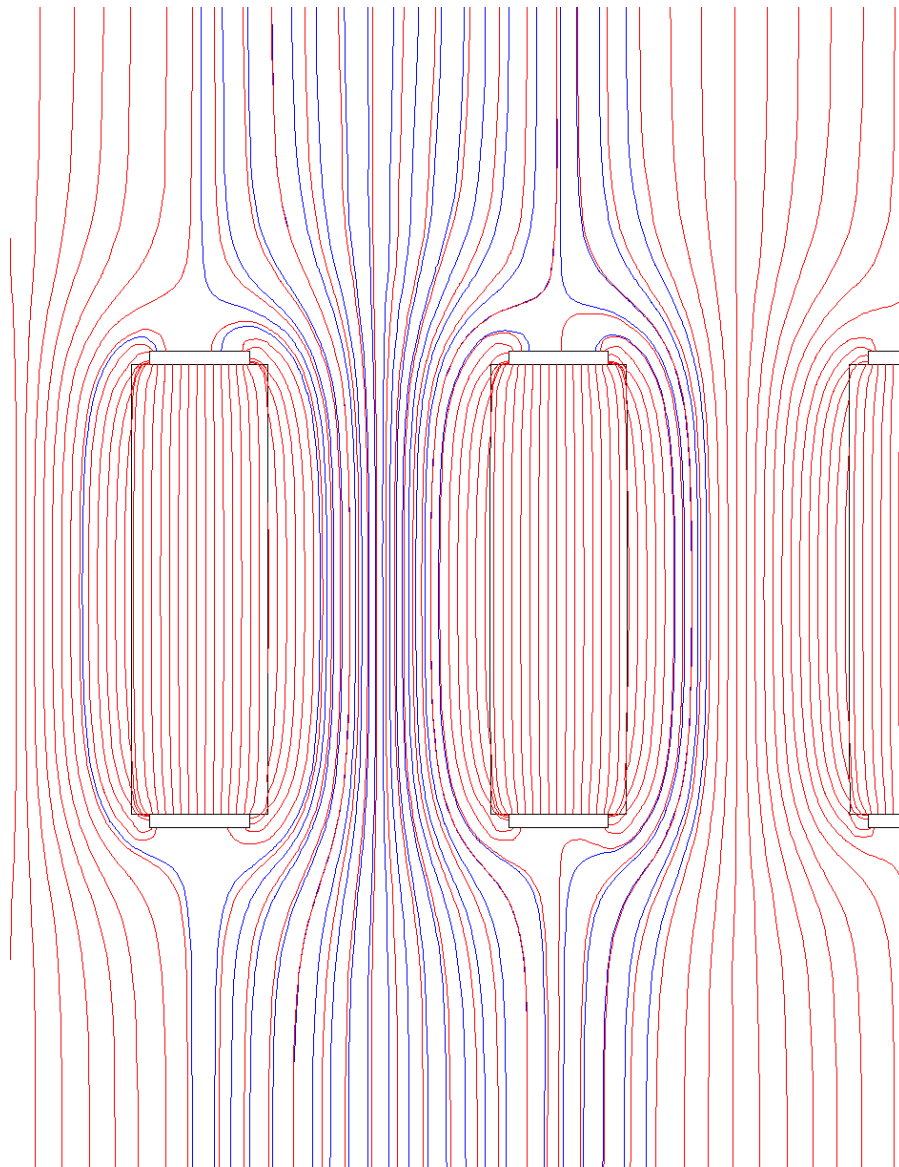
A 3D model of a small section of the drift, extraction, LEM, CRP region.



A 2D cut plane near the front face of the model is plotted in the following slides.



Field Lines Around the DP LEM



Due to the unfavorable collection to extraction field ratio (2:3), a fraction (1/3?) of the electrons lands on the upper surface of the LEM, therefore not contributing to the CRP signal.

Electron multiplication occurs mostly in the blue region. The positive ions created drift down following the same paths as the incoming electrons.

Diffusion of electrons and ions will alter their actual drift paths from these ideal lines (much less effective for ions).

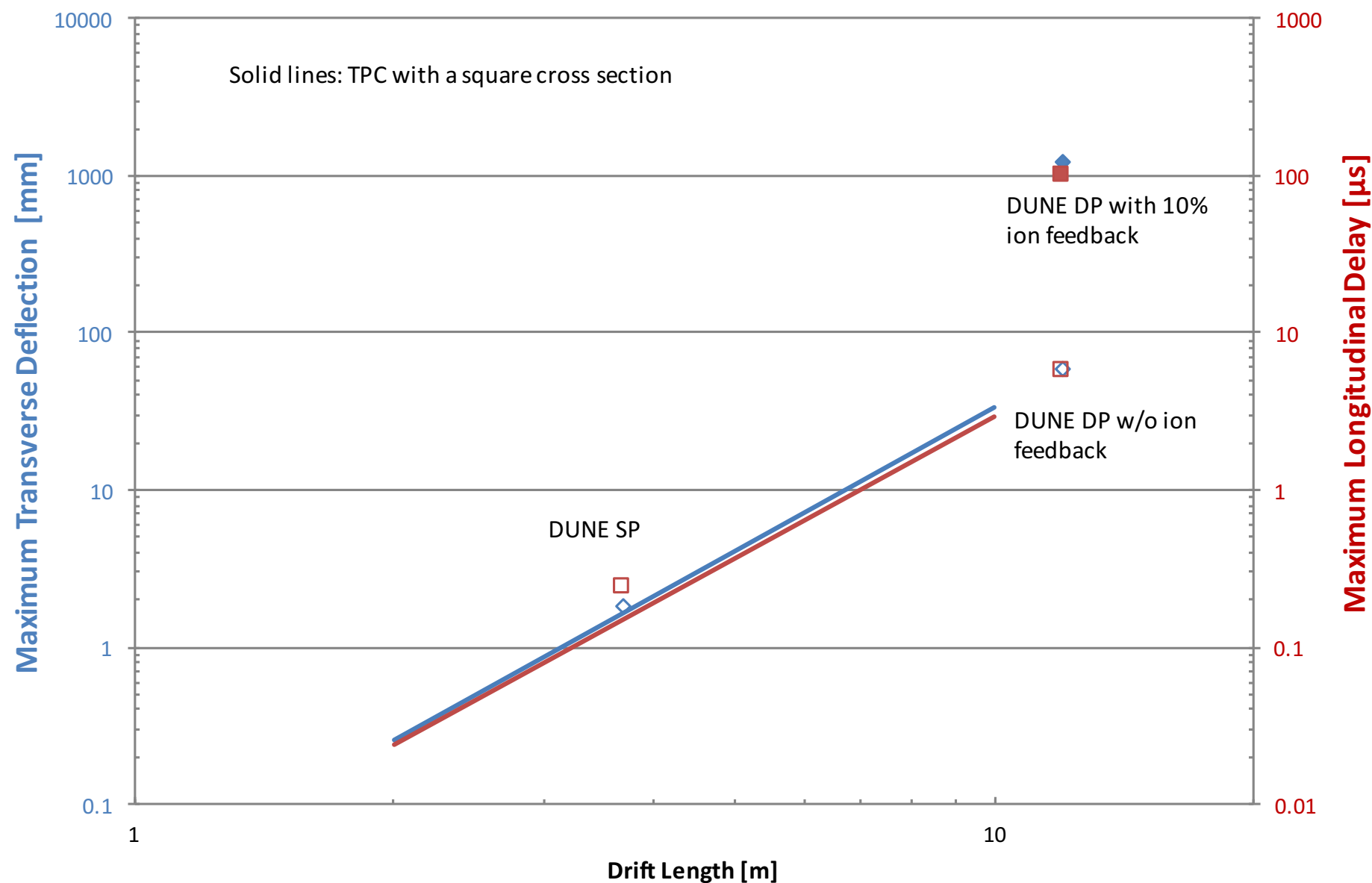
Assuming the gain of the LEM is defined by the collected electrons on the CRP, the ions created by these electrons are not near the outer layer of the “blue waist” inside the holes and they are most likely drift back to the cathode.

Ion feedback in DP

(also need to consider liquid flow effects into this)

- Bo's numbers agree with Mike's space charge numbers without including ion feedback

Ar39 Positive Ion Space Charge Distortion vs. Drift Length

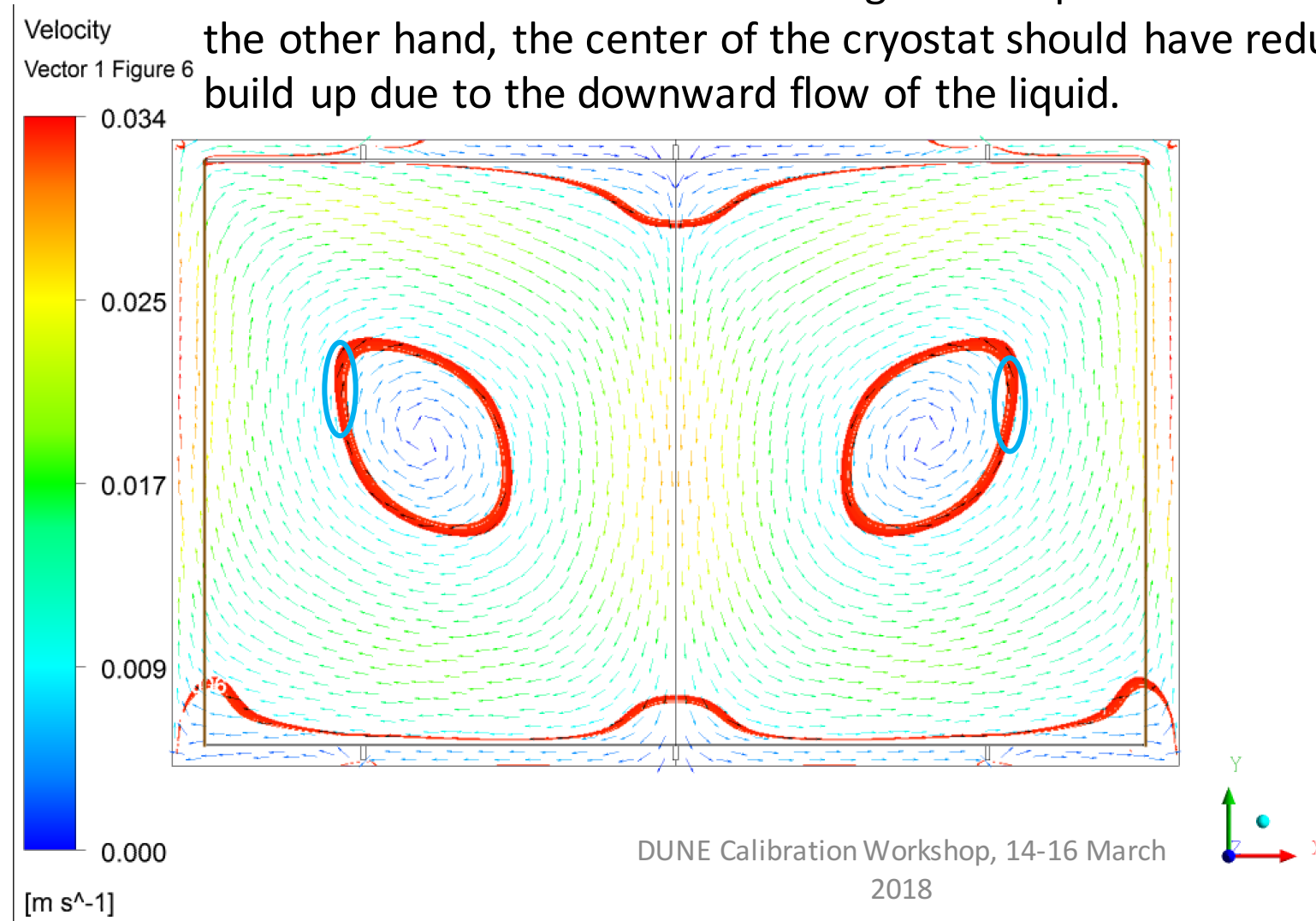


The maximum $E_{\text{(transverse)}}$ is 14% of drift field

The maximum $E_{\text{(longitudinal)}}$ is 15% of drift field

Space Charge and Liquid Flow

I have not seen a CFD of the DP FD cryostat. The closest study I can find is this plot from Erik Voirin on a LBNE 33kt design, in which the cathodes are wire mesh with little impact on the liquid flow. The red bands represents regions where the liquid flow velocity is close to 8mm/s, the ion drift velocity @ 500V/cm field. The two blue circles indicate the region with possible stalled ion movement. On the other hand, the center of the cryostat should have reduced space charge build up due to the downward flow of the liquid.



Need to understand this more

Other calibration issues for DP

- Negative ions in DP?
 - Impurities in the LAr capture a fraction of the primary electrons. Electron lifetime will make this worse.
 - But can the negative ions be extracted into the gas phase by the 3kV/cm extraction field? Or can the electron be striped off the ion and pulled into the gas by the extraction field?
- A gain map of the entire LEM surface is needed. And if the gain drifts with time, periodic re-mapping of the gain may be needed.

TP & Post Workshop Goals

- A document summarizing current status is already in works
- The immediate goal after the workshop is to incorporate workshop discussions/considerations into the summary document with responses to key questions/concerns
- This document will form basis for the calibration section in Technical Proposal (2 to 3 page long?)
- Technical Proposal text due in April — *we don't have a lot of time*
 - *Need to understand how much of calibration related discussions will be included in individual consortium chapters?*
 - *Coordination between TF conveners and Consortium leaders, TP main editors — we will follow up*

Next Talk

Open items, primary vs non-primary calibration sources/systems, how to converge to a strategy, any missing items