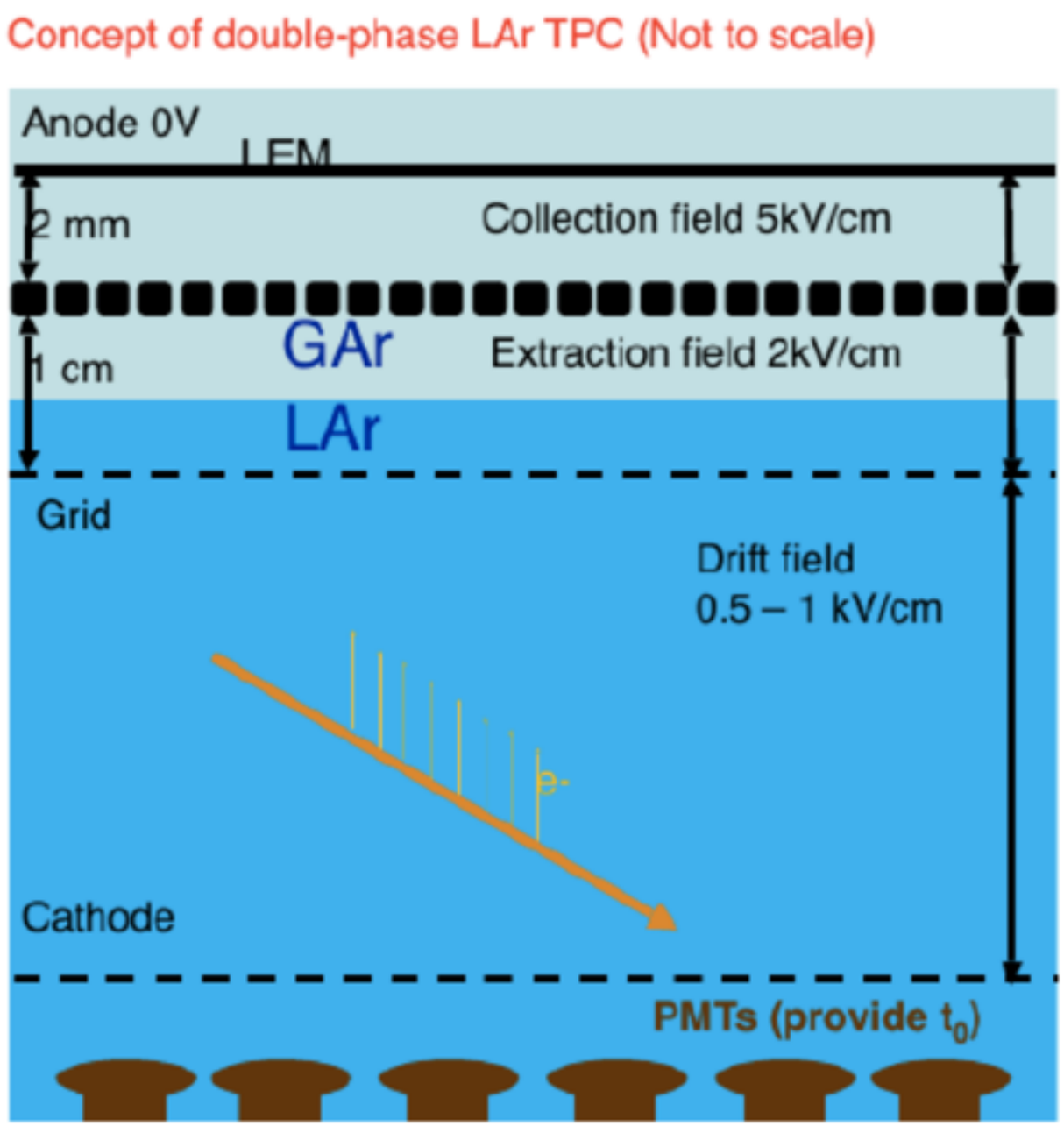
Dual Phase Considerations

- Conversation starter, not a complete set of slides.
- Keep DP in mind as we discuss topics
- A dedicated session on Dual Phase Friday morning

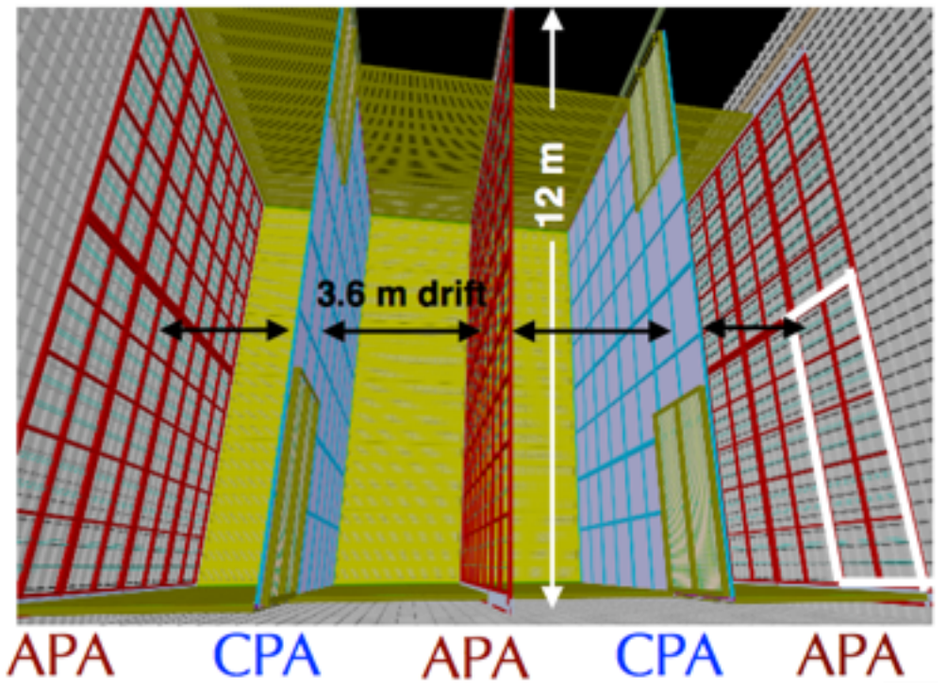
Dual Phase Technology



- Liquid and gas phase
- Ionization signals amplified and detected in the gaseous phase above liquid level

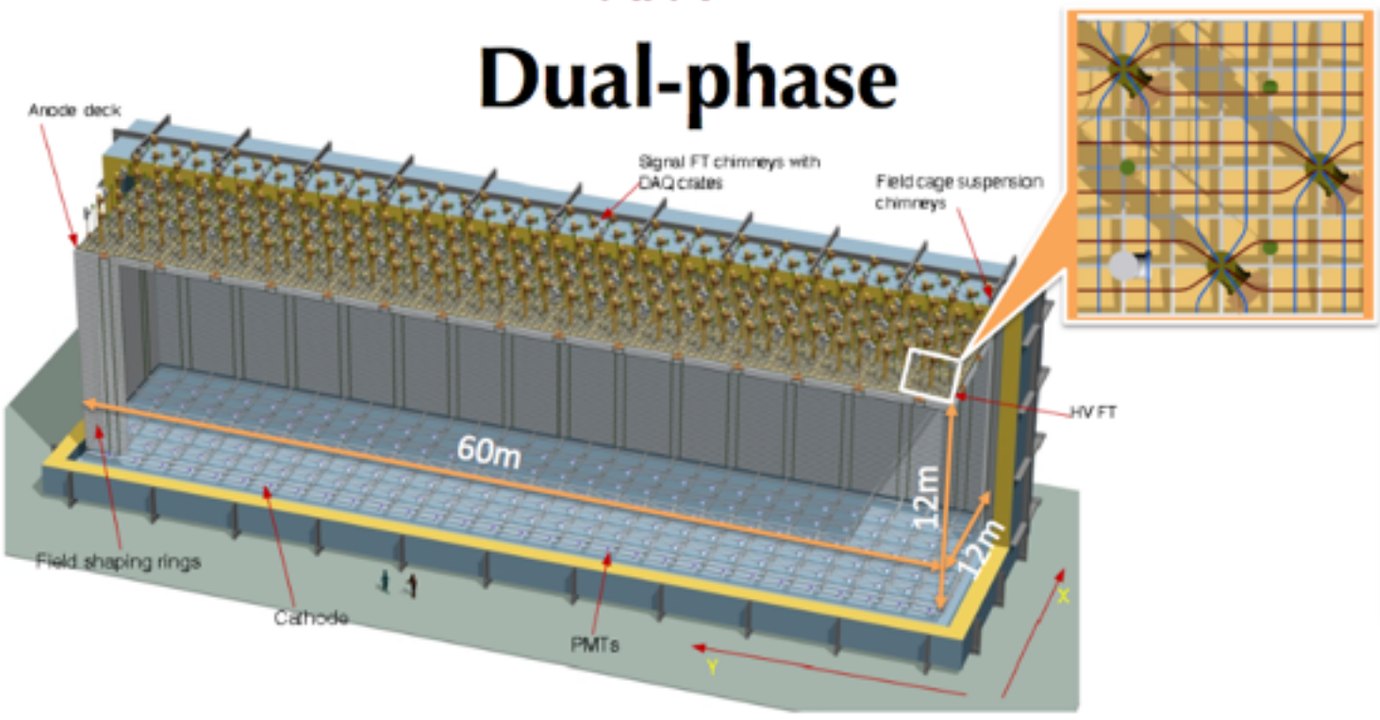
Two detector designs

Single-phase



- 150 Anode Plane Assemblies (APAs)
  - 6 m high x 2.3 m wide
  - embedded photon detection system
  - wrapped wires read out both sides
  - 1 collection & 2 induction wire planes (wire pitch 5 mm)
- 200 Cathode Plane Assemblies (CPAs)
  - 3 m high x 2.3 m wide
- Cathode at -180 kV for 3.6 m drift
- Cold electronics (384,000 channels)

Dual-phase



- 80 3 x 3 m^2 CRP modules at the gas-liquid interface (2D charge collection)
- Hanging field cage and cathode at 600 kV (12 m drift)
- Decoupled PD system (PMTs)
- Finer readout pitch (3 mm), high S/N ratio, lower energy threshold, better pattern recognition, fewer readout channels (153,600), absence of dead material

Ciemat

Two proposed technologies

Single-phase

reference design for the CDR

Table 1: Parameters of the DUNE Far Detector LArTPC.

Parameter	Value
Module height	12.0 m
Module width	14.5 m
Module length	58.0 m
channels per APA	2,560
APAs per module	150
Active height (APA)	6.0 m
Active width (APA)	2.3 m
Drift distance in Liquid Argon	3.6m
Drift velocity	1.6 mm/μs
Drift time	2.25 ms
# drifts/readout factor	2.4
readout time	5.4 ms
bytes/sample	1.5
sample rate	2.0 MHz
samples/readout	10,800
# of detector modules	4
Total # of channels	1,536,000

Dual-phase

alternative design for the CDR

Parameter	Value
Full length	60.0 m
Detectors	4.0
channel/CRP	1,920
CRP/detector	80
Active height	12.0 m
Active width	12.0 m
Drift distance	12.0 m
Drift velocity	1.6 mm/μs
Drift time	7.5 ms
bytes/sample	1.5
sample rate	2.5 MHz
# drifts/readout	1.0
Readout time	7.5 ms
Samples/readout	18,750
Total # of channels	614,400

2: Basic parameters of the alternative Far Detector design.

Expected detector capabilities

Parameter	Requirement	Achieved Elsewhere	Expected Performance
Signal/Noise Ratio[1]	9 : 1	10 : 1 [11, 12][2]	9 : 1
Electron Lifetime	3 ms	> 15 ms [12]	> 3 ms
Uncertainty on Charge Loss due to Lifetime	< 5%	< 1% [12]	< 1%
Dynamic Range of Hit Charge Measurement	15 MIP		15 MIP
Vertex Position Resolution[3]	(2.5,2.5,2.5) cm		(1.1,1.4,1.7) cm [13, 14]
$e-\gamma$ separation ϵ_e	> 0.9		0.9
$e-\gamma$ separation γ rejection	> 0.9		0.99
Multiple Scattering Resolution on muon momentum[4]	~ 18%	~ 18% [15, 16]	~ 18%
Electron Energy Scale Uncertainty	~ 5%	~ 2.2%[17]	From LArIAT and CERN Prototype
Electron Energy Resolution	$0.15/\sqrt{E(\mathrm{MeV})} \oplus 1\%$	$0.33/\sqrt{E(\mathrm{MeV})} + 1\%$ [17]	From LArIAT and CERN Prototype
Energy Resolution for Stopping Hadrons	< 10%		From LArIAT and CERN Prototype
Stub-Finding Efficiency[5]	> 90%		> 90%

For E_e < 50 MeV,
11%/√E(MeV) + 2%
ICARUS

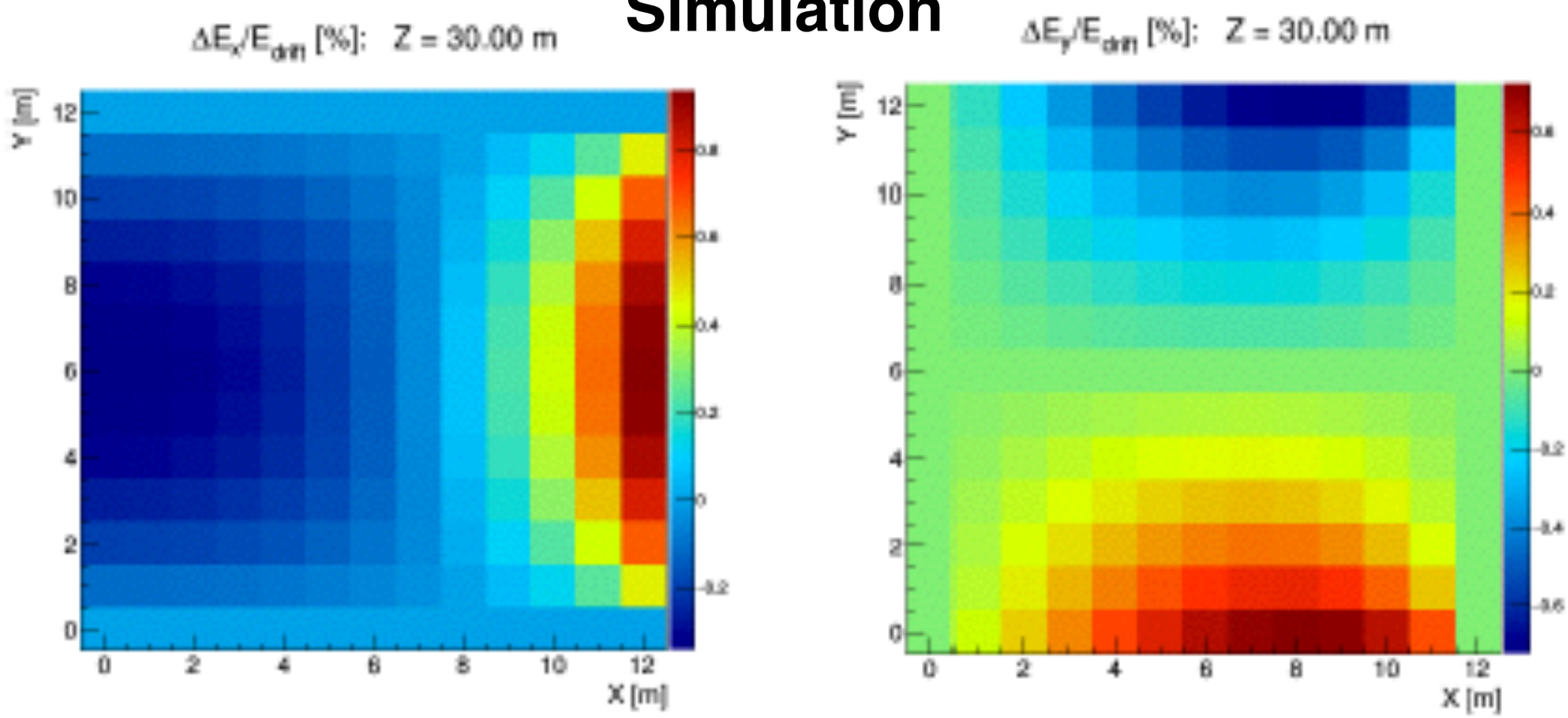
Table 5.1: Performance parameters specific to the dual-phase far detector design

Parameter	Requirement	Achieved Elsewhere	Expected Performance
Gas phase gain	20	200	20-100
Electron Lifetime	3 ms	> 3 ms 35-t prototype	> 5 ms
Minimal S/N after 12 m drift	9:1	> 100:1	12:1-60:1

Advantage for low energy measurement

SCE for DUNE DP FD

Simulation

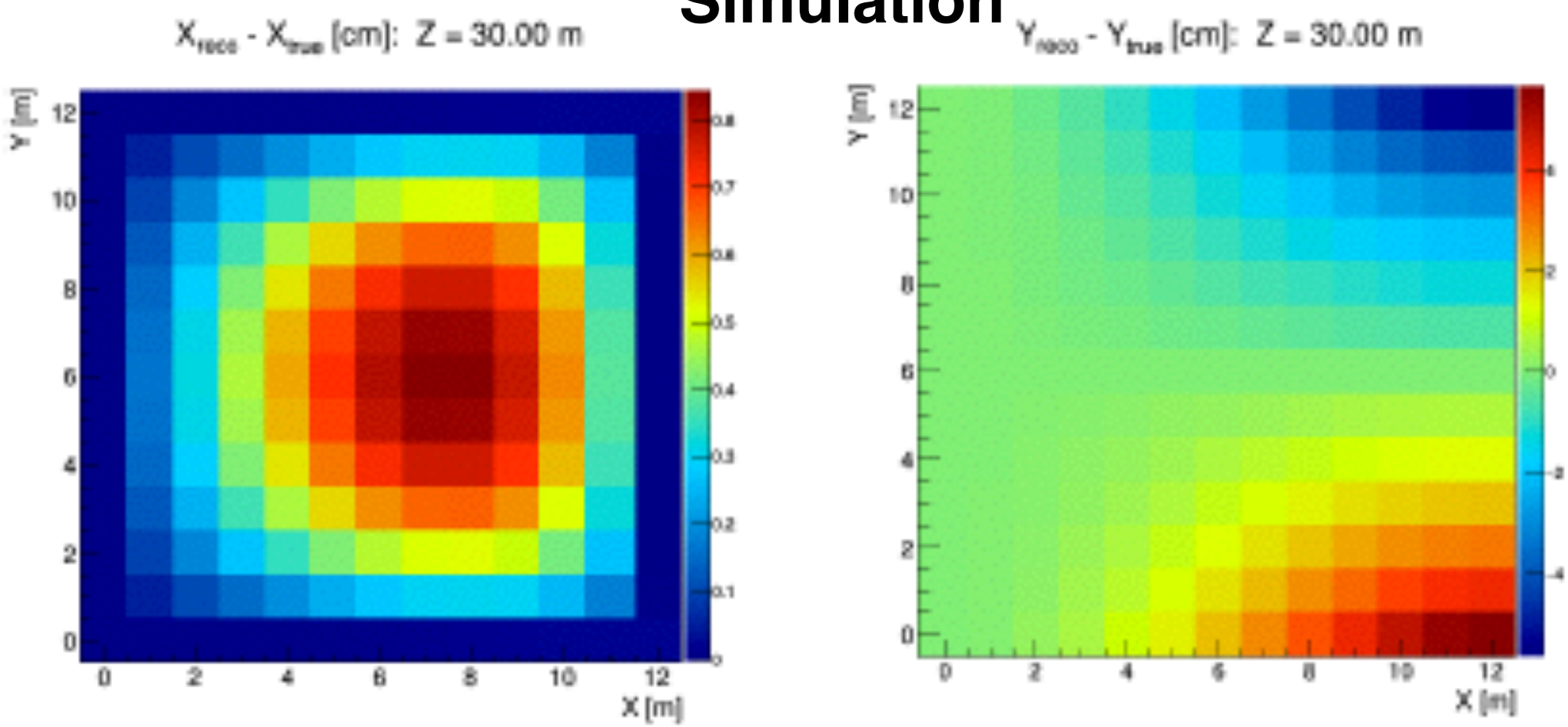


- DUNE DP FD – looking at full detector, central Z slice
  - Ionization **drift is to the left** (anode on left, cathode on right)
- E field distortions on order of **1%** – larger than for SP case
  - Impact on dQ/dx from recombination ~ **0.3%**

M. Mooney

SCE for DUNE DP FD

Simulation



- DUNE DP FD – looking at full detector, central Z slice
  - Ionization **drift is to the left** (anode on left, cathode on right)
- Spatial distortions on order of **5 cm** – not negligible!
  - Total impact on dQ/dx (including recomb.) ~ **2-3%**

M. Mooney[7]

DP Challenges

- *E-field distortions — biggest concern?*
  - Ionization sources (e.g. Ar39)
  - Drift field deformations (misalignments, resistor failures etc.)
  - Argon flow pattern (steady state or turbulent) can significantly impact this, for both SP and DP
  - Even more complicated for DP, positive ions may collect above the liquid and create surface interface issues. Negative ions may also accumulate on surface.
- *The 12 m vertical drift can pose challenges*
  - Electron lifetime?
  - Diffusion?
  - Recombination? — impacted by E-field

Other Challenges/Considerations?

What can be learnt from Prototypes?