ProtoDUNE detector uncertainty brainstorming

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ProtoDUNE Analysis Workshop
Jan 26th, 2020

Apologies I could not attend and discuss in person.

Thank you for this chance to discuss these topics!

How do we approach systematic uncertainties?

1. *What are the expected physics effects in detector we need to develop systematic uncertainty estimates for?*
2. *What discrepancies do we see in ProtoDUNE data which may affect the analysis?*

How do we approach systematic uncertainties?

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Not this time: How we (technically) propagate effects

Today: Attempt to summarize what is known now. Please correct/add ideas!

What is our goal for the ProtoDUNE detector model (and uncertainties?)

MicroBooNE: estimate and correct for average effects (nice paper here: https://arxiv.org/abs/1907.11736)

Possible targets:

1. Develop tools to investigate individual effects?
2. Look for time dependant/spatial defendant issues
3. Closure test with charged particle beam

Explicitly not 'perfect' uncertainties for first paper but lay groundwork for improvements

Possible physics effects in LArTPCs

Charge & light response

- t0 offset
- t0 resolution
- light yield
- timing response
- Recombination
- Drift velocity
- Electron diffusion
- Electron lifetime
- Ionization energy
- E-field
- noise
- gain
- crosstalk
- Electronics transfer function
- ADC linearity (integral & differential)
- wire positions
- wire field response
- APA rotation
- APA displacement
- APA planarity
- CPA rotation
- CPA planarity
- CPA displacement

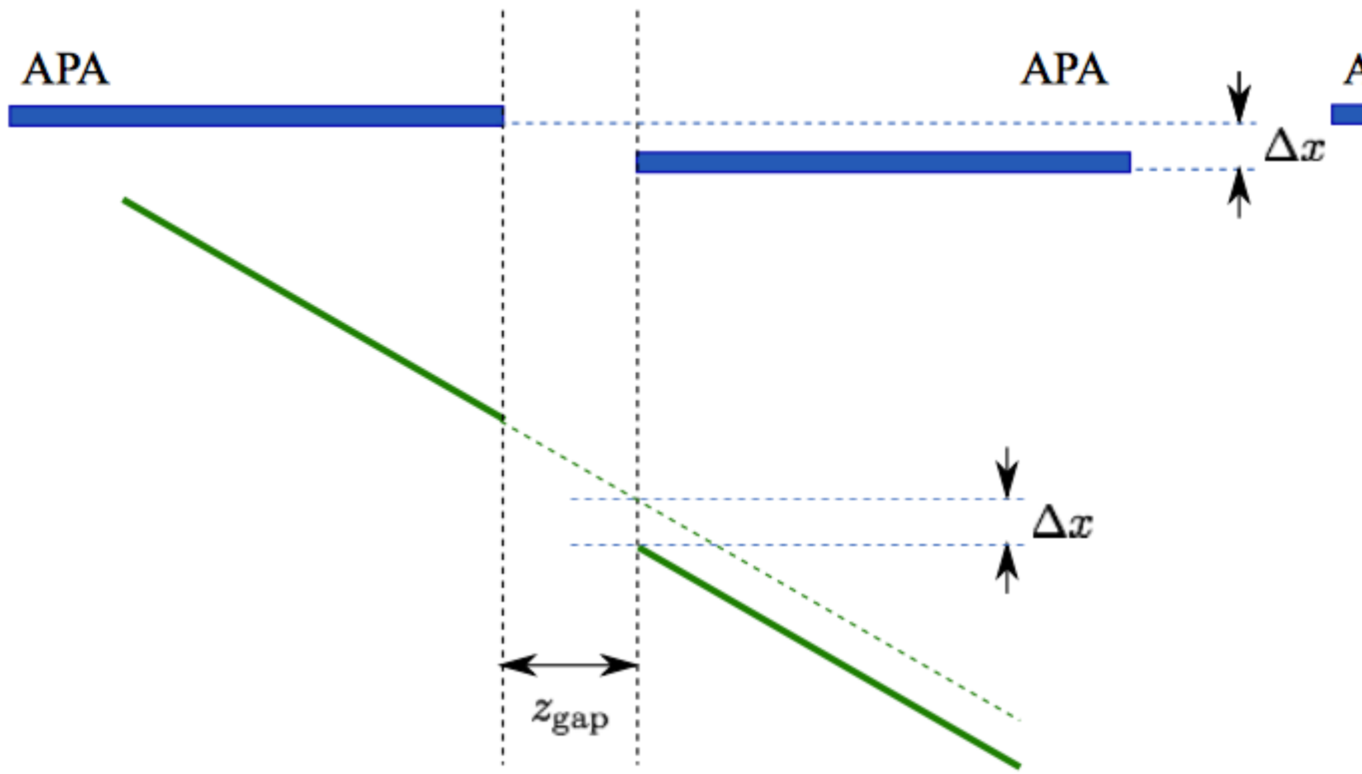
What are the size of mis-alignments?

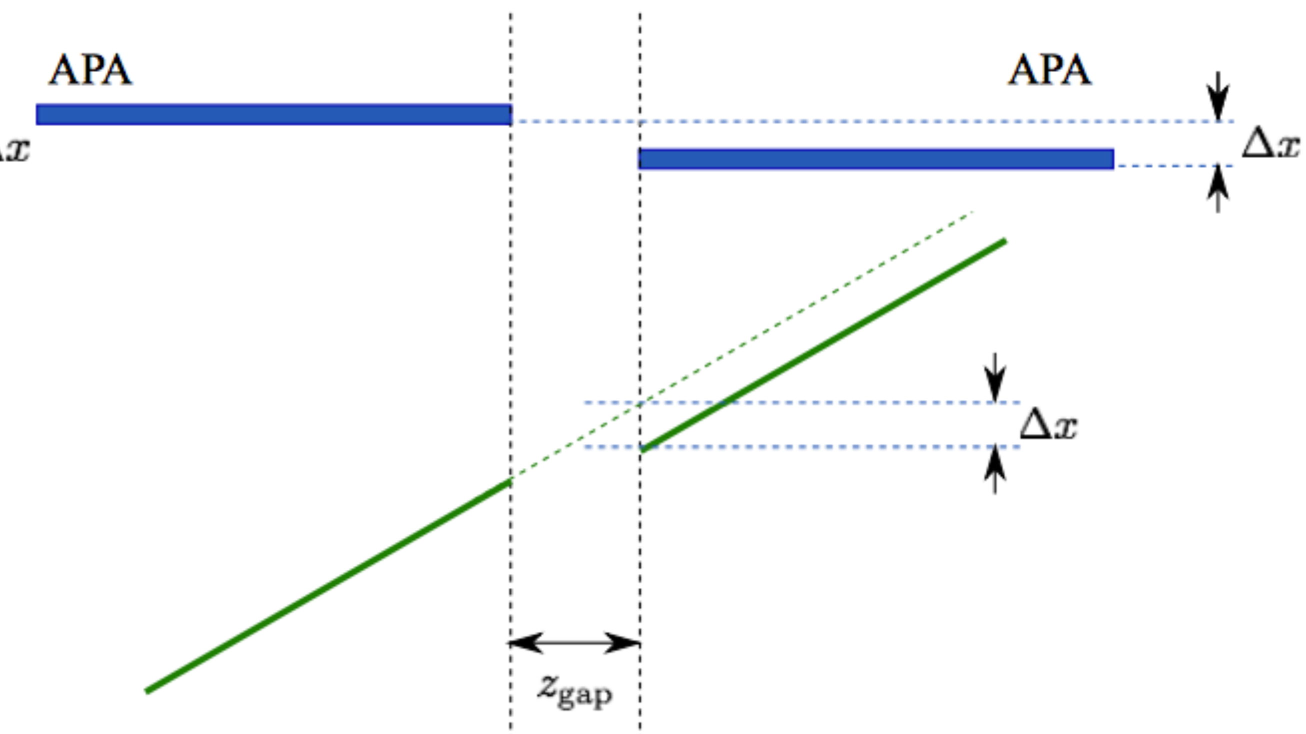
Predicted variations	Deflection
Tolerances as built (warm, x)	3mm base
Cool down in x	7mm
Cool down in y	**36mm**
Cool down in z	**180mm** over entire volume, may have uneven spacing between APA gaps (~6.5mm)
Bowing, deflection of CPA or APA structure	1cm tolerance for CPA

CPA tilt (crumpled curtain) of 2cm in x is also possible

(Tom Junk)

Need Tracks With + and - Angles

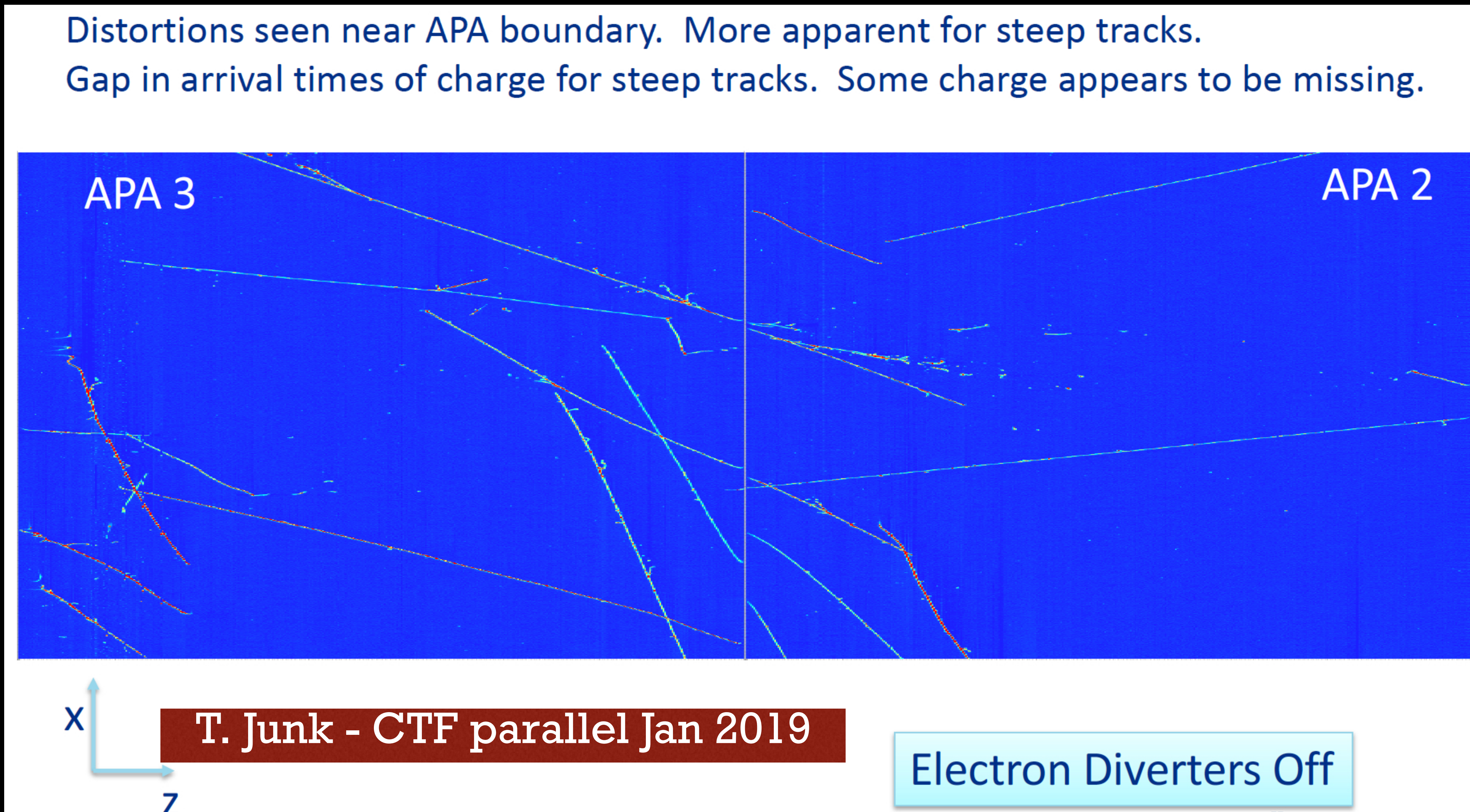




Need positive Δx or positive Δz to fix this track (really a combination)

Need positive Δx or negative Δz to fix this track (really a combination)

Measurements of alignment



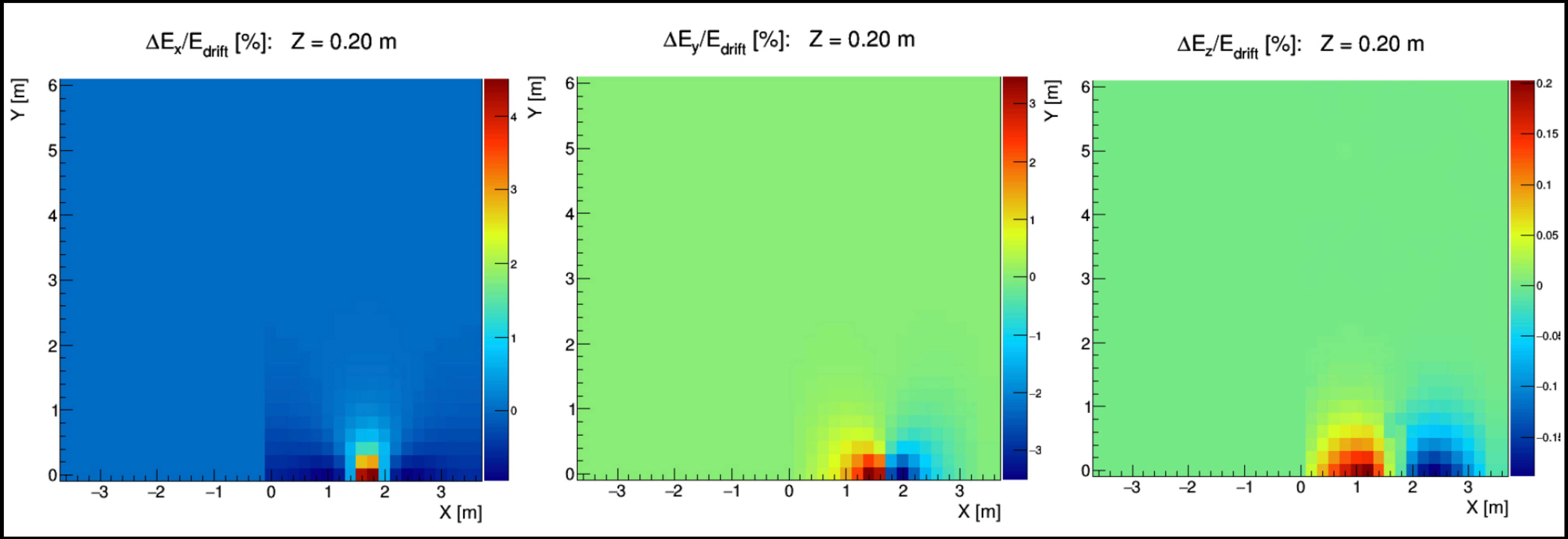
- Covariance: alignment of ‘straight’ tracks depends on E field and in-situ effects.

Alignment strategy for PD measurement

- Avoid boundaries for FV? - *look at statistics for measurement*
- Correct E field (maybe difficult except in fully charged state?)
- Update alignment to be further away from boundary (and accept increased uncertainties)

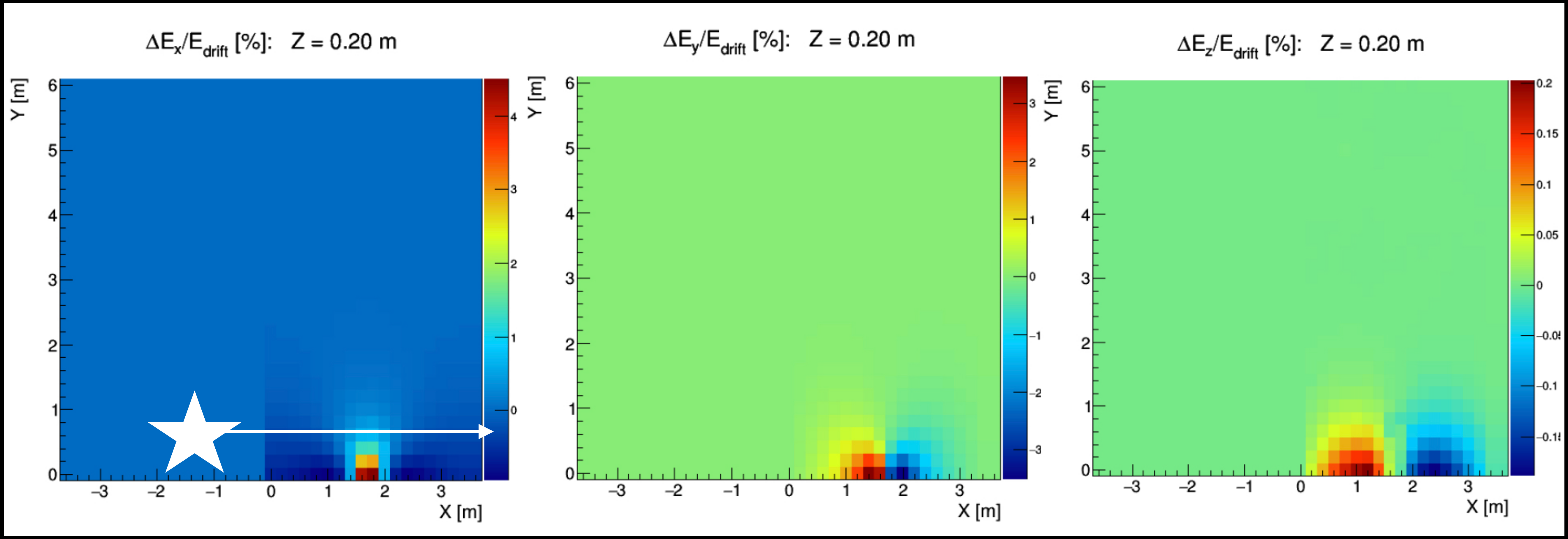
Ideas?

Example: E field variation impact on analysis



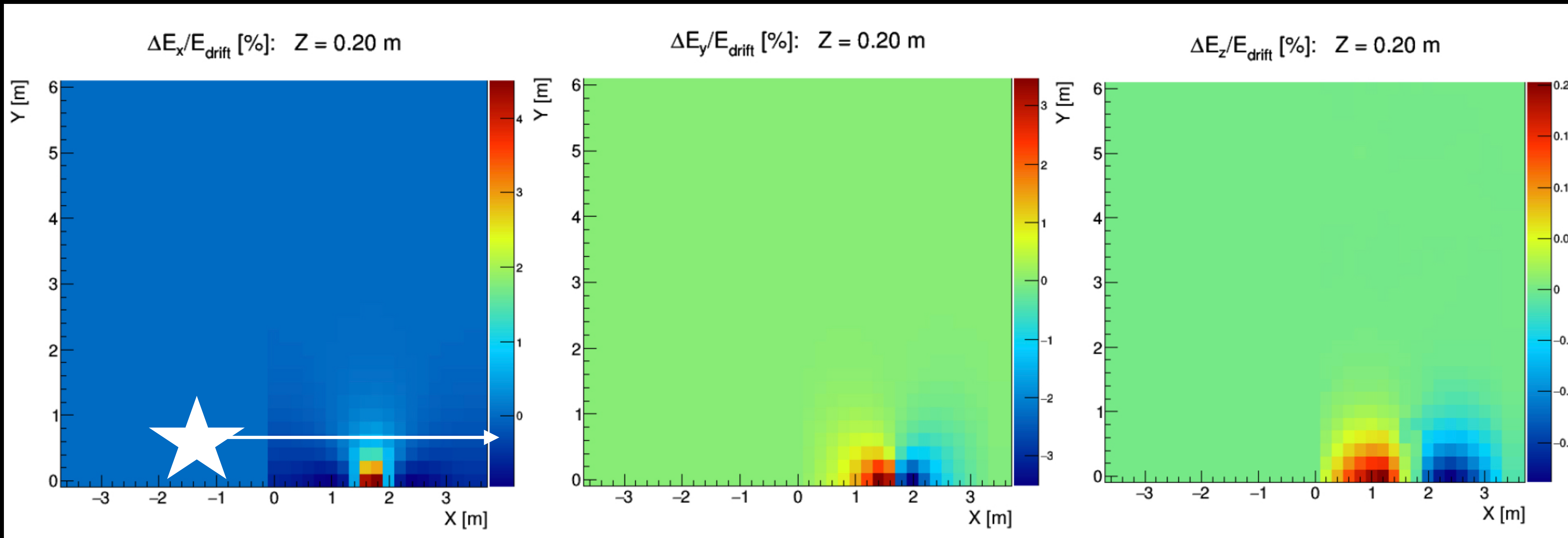
- A 4-5% E field distortion in a ~1m³ region (field cage resistor failure, not observed)

Example: E field variation impact on analysis



- An electron starting at the star, will experience a distortion in measured position and/or charge

Example: E field variation impact on analysis

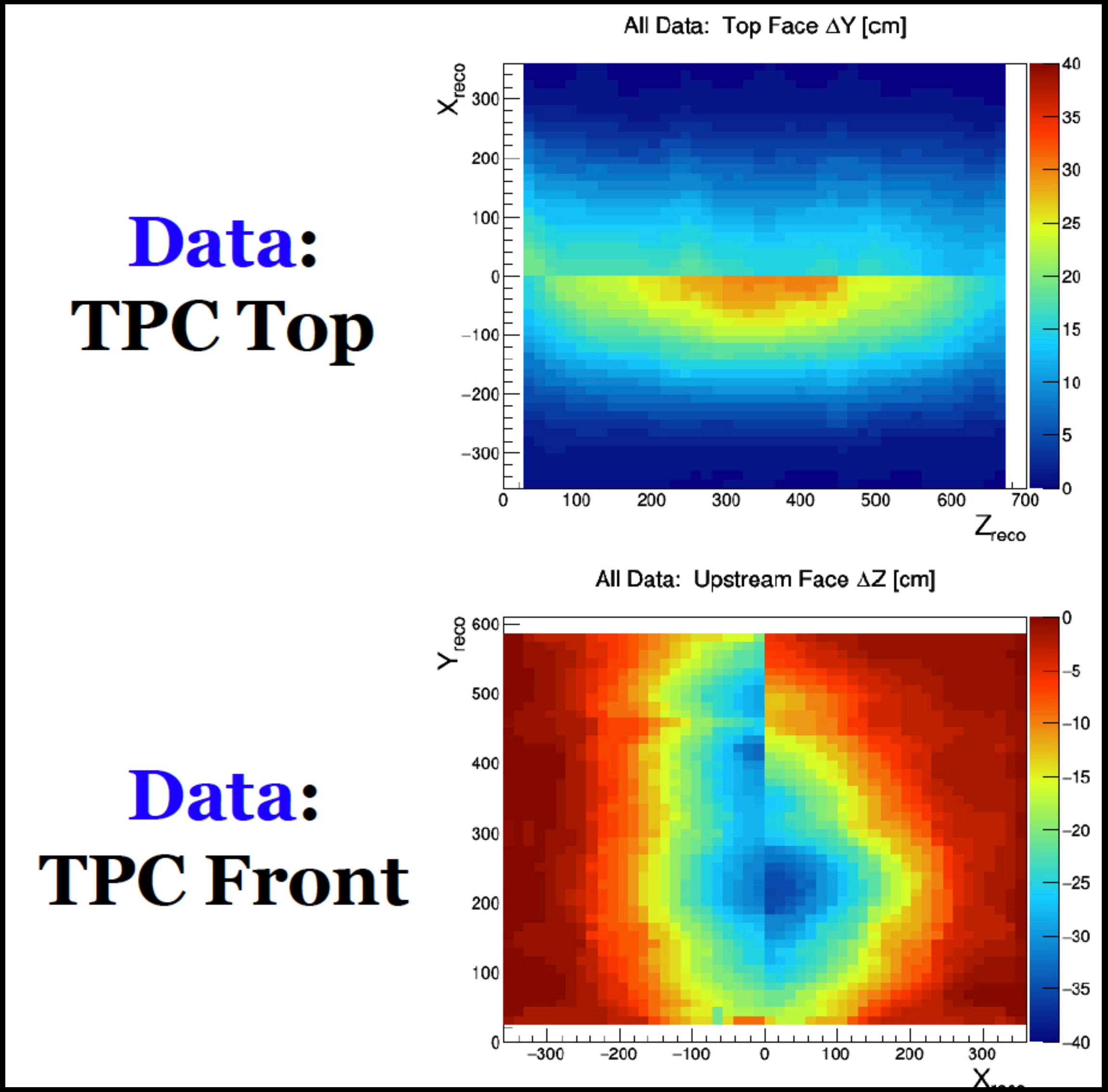


A 4-5% E field distortion creates:

- 1-2% bias in dQ (energy scale)
- and also a ~2cm effect in the position (dx, and FV)

How calibration? E field

- Space charge effect (SCE) map in ProtoDUNE using t0-tagged tracks - *once per hour*



Unknowns in Ar(39) induced space charge, fluid flow model, ion motility, and detector surface charging

M. Mooney- DUNE May 2019 collaboration meeting

How calibration? E field

- Comparison of 1 GeV/c stopping protons in data and MC with updated SCE maps:

	Data Set	Z [cm]
MC	**Prev. MCC12 SCE Cali.**	**3.8 (0.2)**
	***New* MCC12 after SCE Cali.**	**-0.1 (0.3)**
	New MCC12 before SCE Cali.	29.3 (0.6)
Data	**Prev. version of SCE Cali**	**6.7 (0.6)**
	***New* version after SCE Cali.**	**4.8 (0.6)**
	New version before SCE Cali.	33.0 (0.7)

H-Y. Liao, DRA July 10 2019

Residual 5cm offset; "Time dependance"?

E field strategy for PD measurement

- Can include size of discrepancy as an uncertainty, but helpful if we can understand what still could be incomplete

  - Additional checks for time dependance?

  - Document where at; what else in ‘chain’ needs to be reconsidered?

Ideas?

Electron lifetime (purity)

- Electron lifetime affects dE/dx

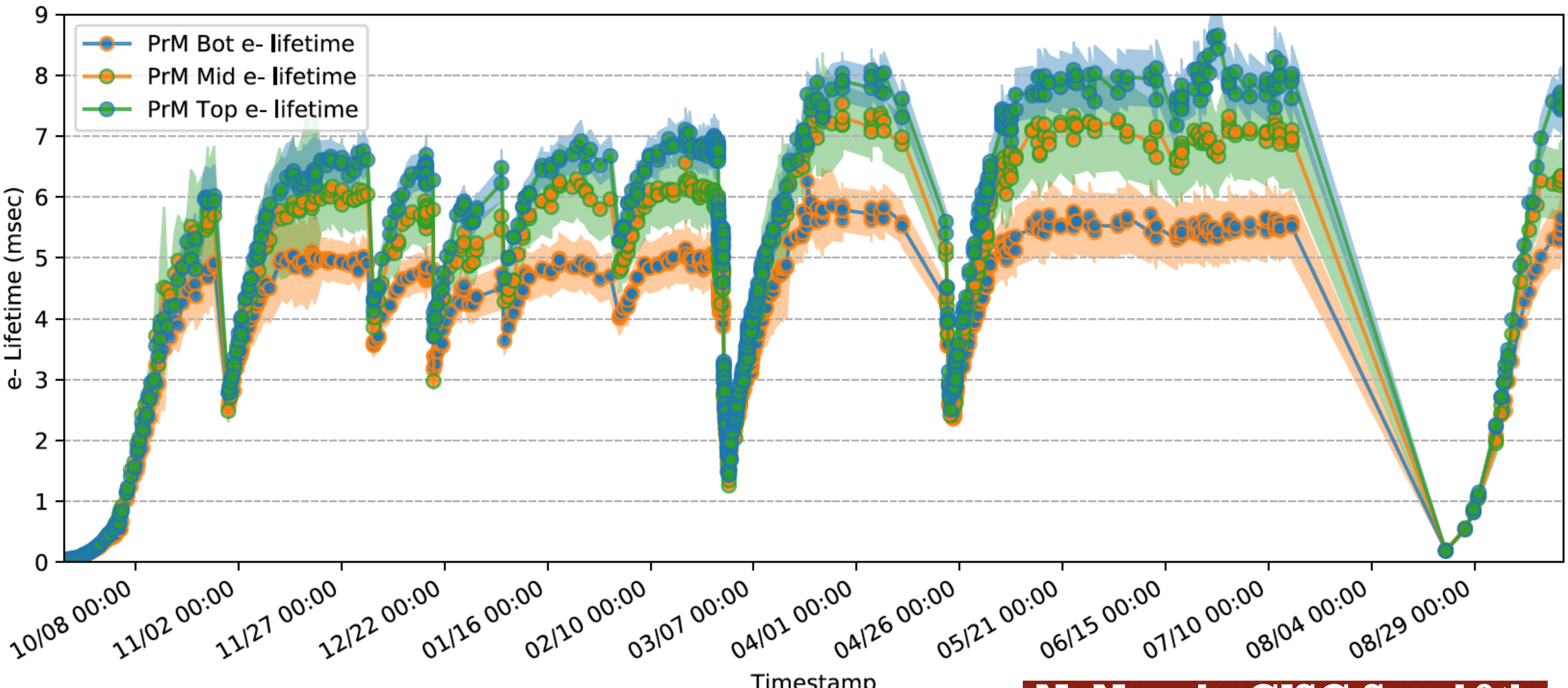
$$\frac{dE}{dx} = \frac{dQ}{dx} \times W \times R(\vec{E}) \times \exp^{t/\tau} \times D \times C$$

W=ionization energy in LAr (nb: probably depends on E)
R(E)=Recombination (explicit E dependence)
D=Diffusion
C="electronics calibration" (probably also includes other things)
$exp(t/\tau)$=lifetime correction

J. Klein, docdb 14926

Electron lifetime (purity)

- Purity monitors indicate different electron lifetime at different heights in detector



N. Nayak, CISC Sep 19th 2019; J. Bian June 2019 CISC scope review

- Not seen in TPC analysis but…

Electron lifetime (purity) strategy

- Purity monitors may need cross calibration (won't happen for this first PD result)
- TPC estimates of lifetime are sensitive to … SCE and other non-uniformities

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- **First: propagate this effect.** How much do we care for beam events in a (more limited region of the detector)?

- **Second, test some of the assumption.** PD can afford careful cosmic selections (e.g. OK to average over drift distance?) Iteration on TPC estimates?

Diffusion

- Consider both longitudinal and transverse diffusion

$$\frac{dE}{dx} = \frac{dQ}{dx} \times W \times R(\vec{E}) \times \exp^{t/\tau} \times D \times C$$

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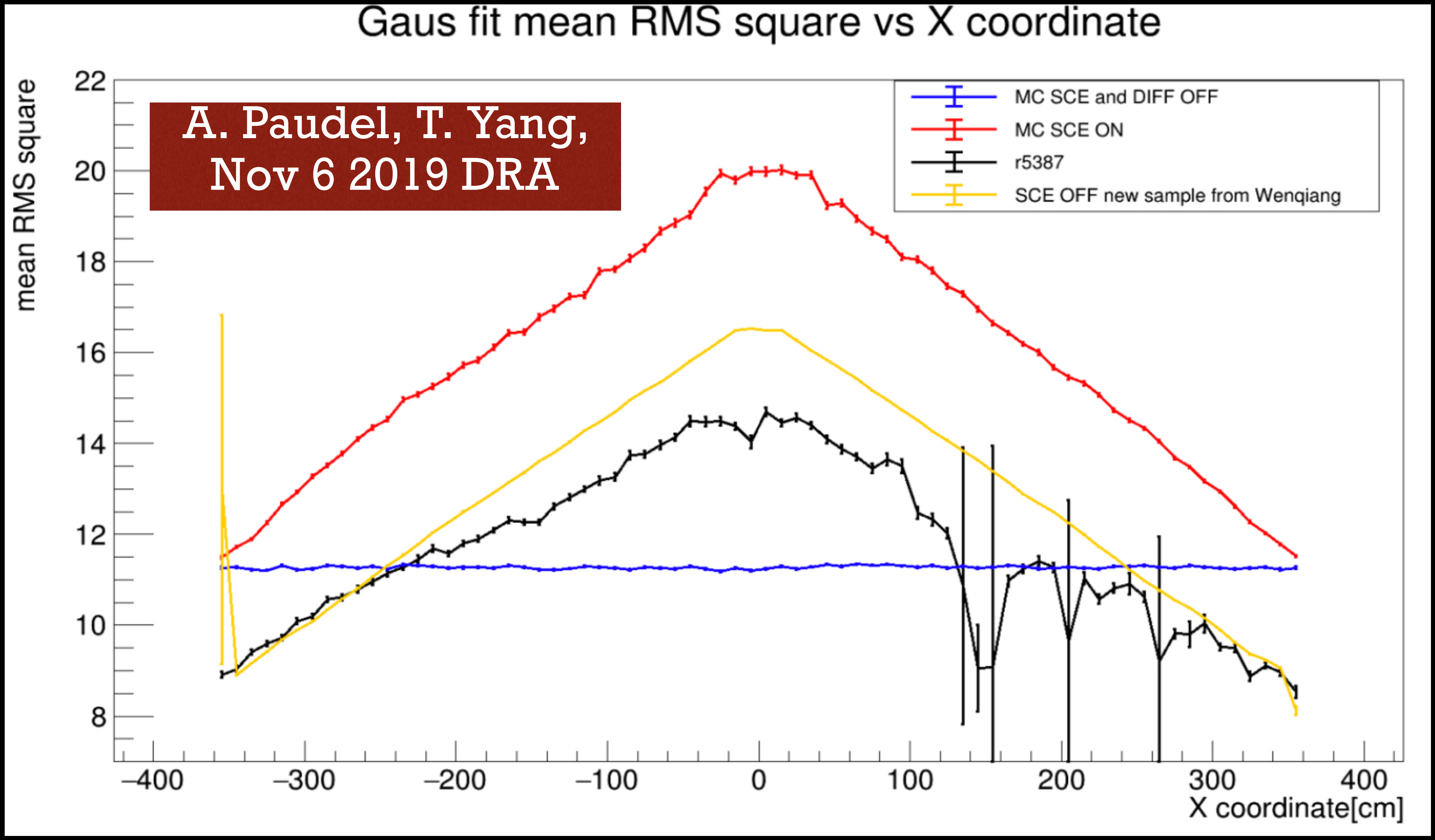
Diffusion



- Improved simulation is closer to shape

Diffusion

- Plan to use small angle CRT tagged tracks to measure longitudinal component
  - May need to iterate on SCE as well?
- Next step: propagate effect?

Ideas? *Comments?*

Additional effects

- **Wire response, gain, cross talk and electronics:** pulser + cosmics ala uB - a*nything of concern here to iterate on?*

- **t0, light yield, TPC-light response:** Beam signal is 'known' - *not so critical here?*

- **Recombination:** Model indicates some angular dependance - *propagate uncertainties and compare to other effects*

Ideas? *Missing big items?*

Aside on reconstruction

1. Run dedicated changes to detector model through reconstruction to test impact

2. Estimate entire impact with thoughtfully chosen data vs. MC comparisons

This talk: Discussing what effects to prepare (1)

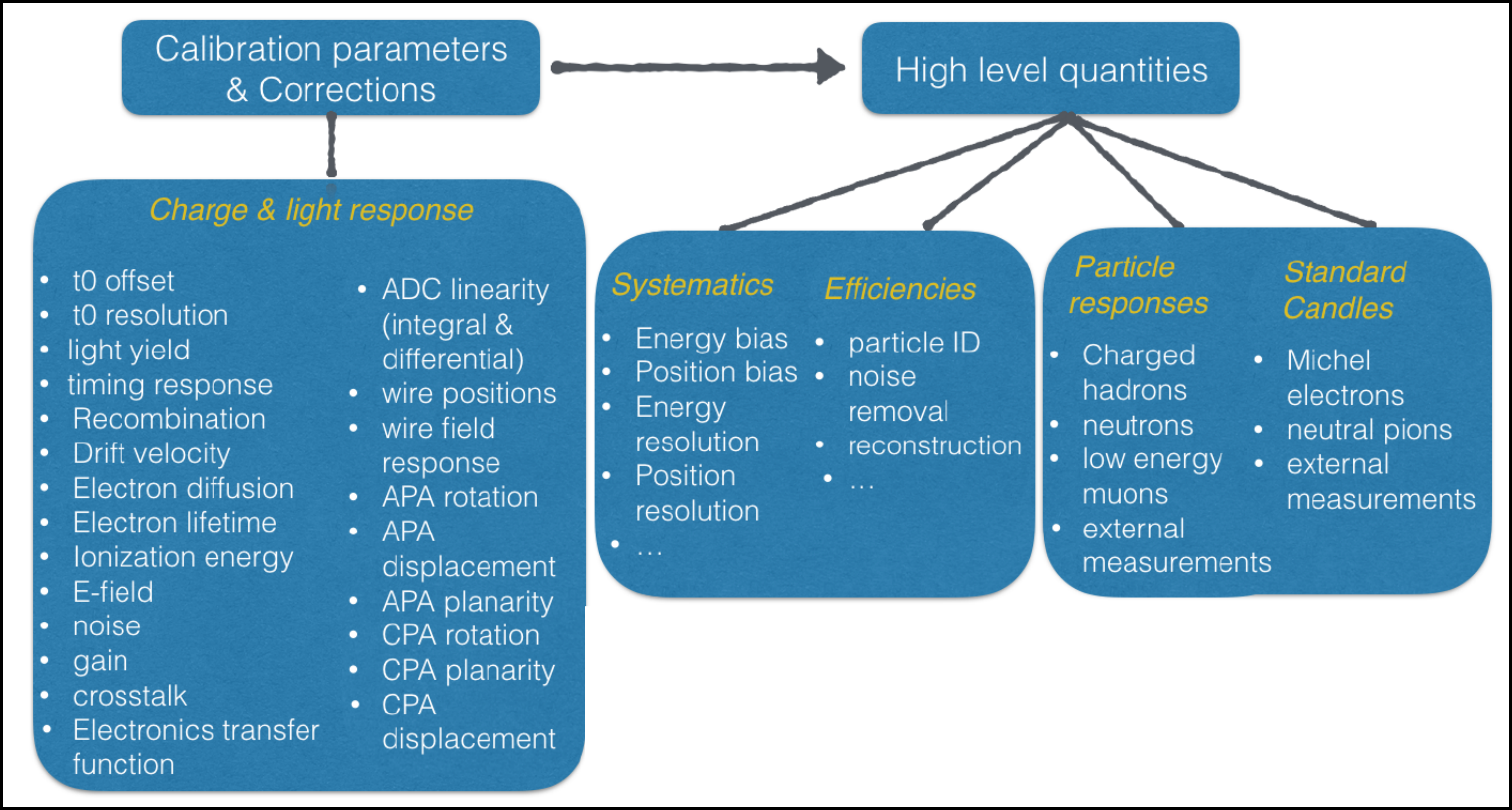
Actual plan in collaboration with reco groups

Summary

- Measurements using charged particle beam will need an estimate of detector model uncertainties
- Challege: detector model is highly convolved, will need to separate effects and test model in entirety
- One big contribution ProtoDUNE can make is to quantify disagreements (and test specific hypotheses)
  - Enabled by charged particle beam
  - Indications of some effects which have spatial and/or temporal effects

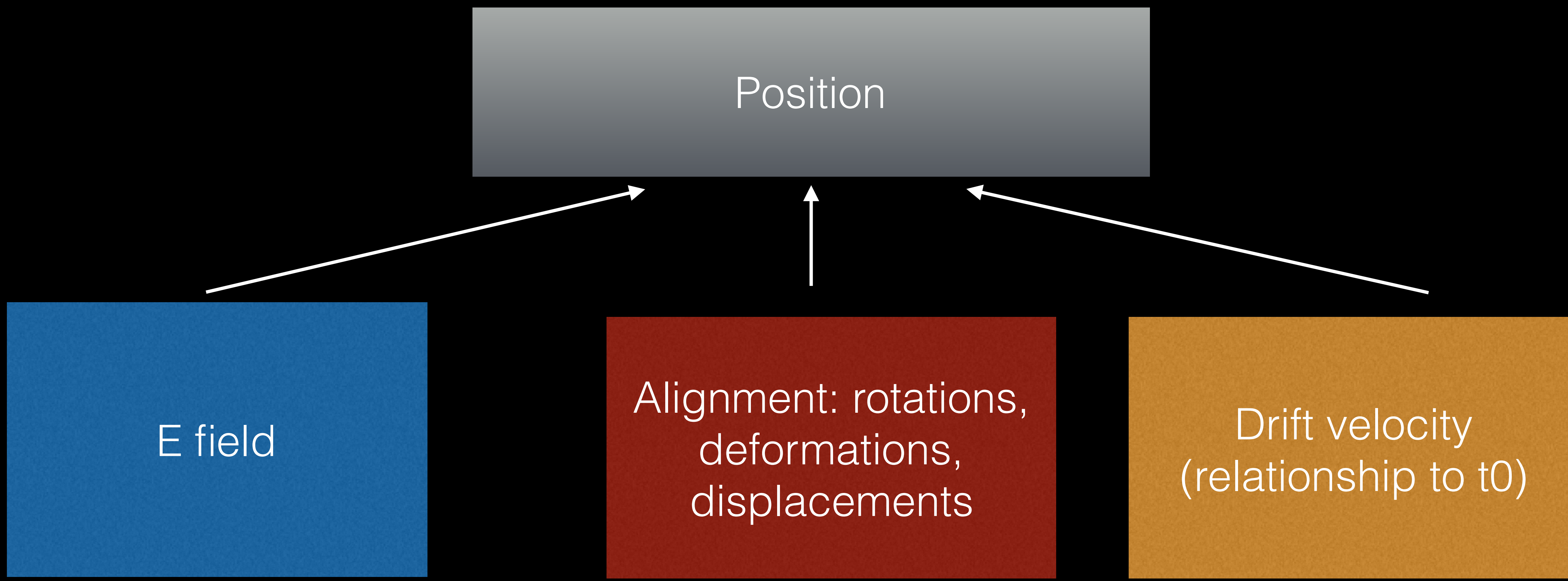
Backup slides

Calibration strategy



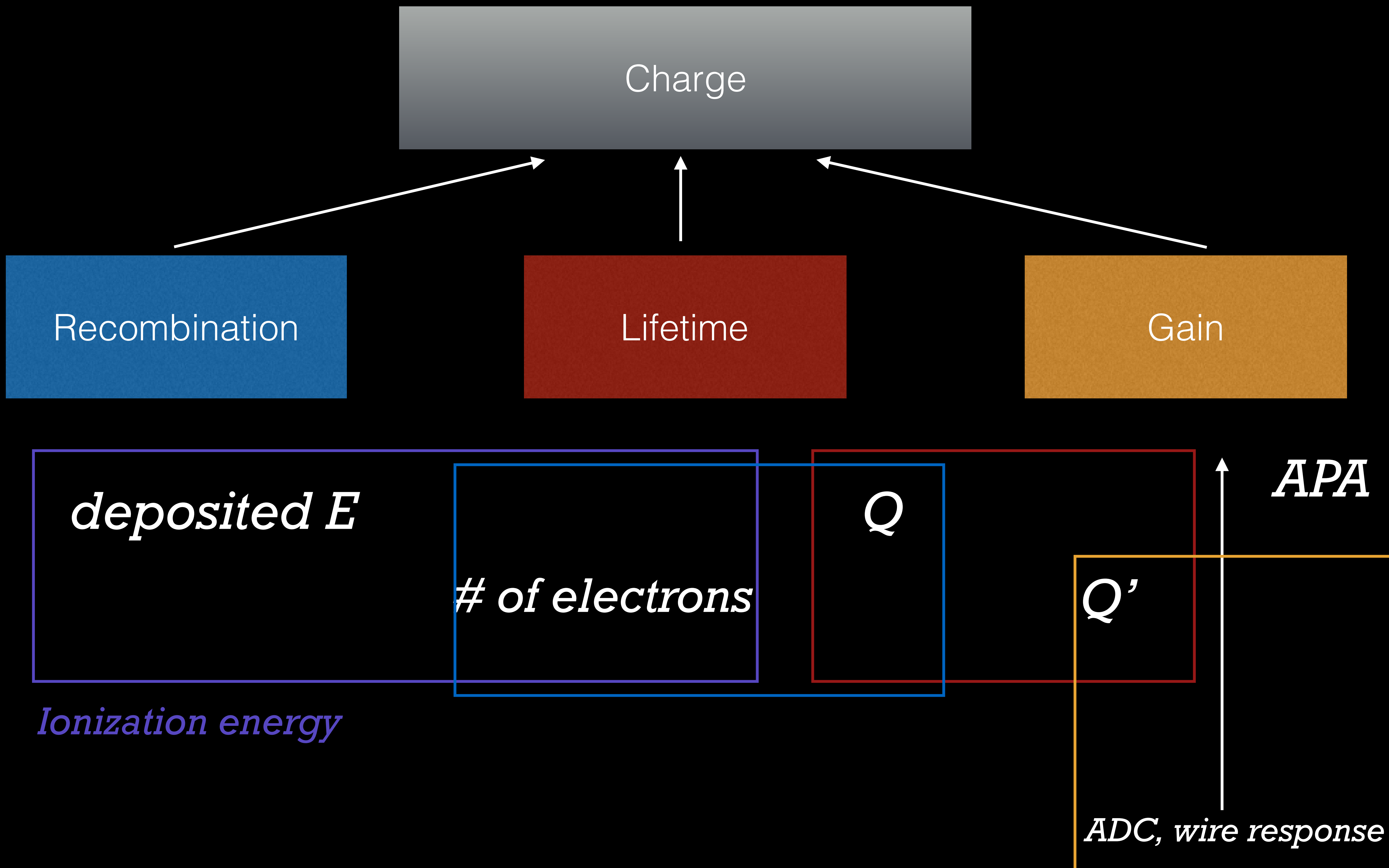
System	Primary Usage
Existing Sources	**Broad range of measurements**
μ, predominantly from cosmic ray	Position (partial), angle (partial), electron lifetime, wire response, dE/dx calibration etc.
Decay electrons, π^0 from beam, cosmic, atm ν	Test of electromagnetic response model
^{39}Ar beta decays	electron lifetime (x,y,z,t), diffusion, wire response
External Measurements	**Tests of detector model, techniques and systems**
ArgoNeuT [27], ICARUS [28, 58, 59], MicroBooNE	Model parameters (e.g., recombination, diffusion)
DUNE 35 ton prototype [60]	Alignment and *t0* techniques
ArgonTUBE [61], MicroBooNE [62], SBND, ICARUS [63], ProtoDUNE [64]	Test of systems (e.g., Laser)
ArgoNeuT [65], MicroBooNE [66, 67, 68, 57, 69, 27], ICARUS [70, 71, 72], ProtoDUNE	Test of calibration techniques and detector model (e.g., electron lifetime, Michel electrons, ^{39}Ar beta decays)
ProtoDUNE, LArIAT [73], CAPTAIN [74]	Test of particle response models and fluid flow models
LArTPC test stands [75, 76, 77, 29]	Light and LAr properties; signal processing techniques
Monitoring Systems	**Operation, Commissioning and Monitoring**
Purity monitors	Electron lifetime
Photon detection monitoring System	photon detection system (PDS) response
Thermometers	Temperature, velocity; test of fluid flow model
Charge injection	Electronics response

Roadmap: calibrating dx



- Measurements of alignment are sensitive to E field (T. Junk talk)
- Laser system measures displacement maps (E field and drift velocity (T))

Roadmap: calibrating dE



Roadmap: calibrating dE

Charge

ADC to charge, gain and noise from charge injection, random triggers

Gain

deposited E

# of electrons

Q

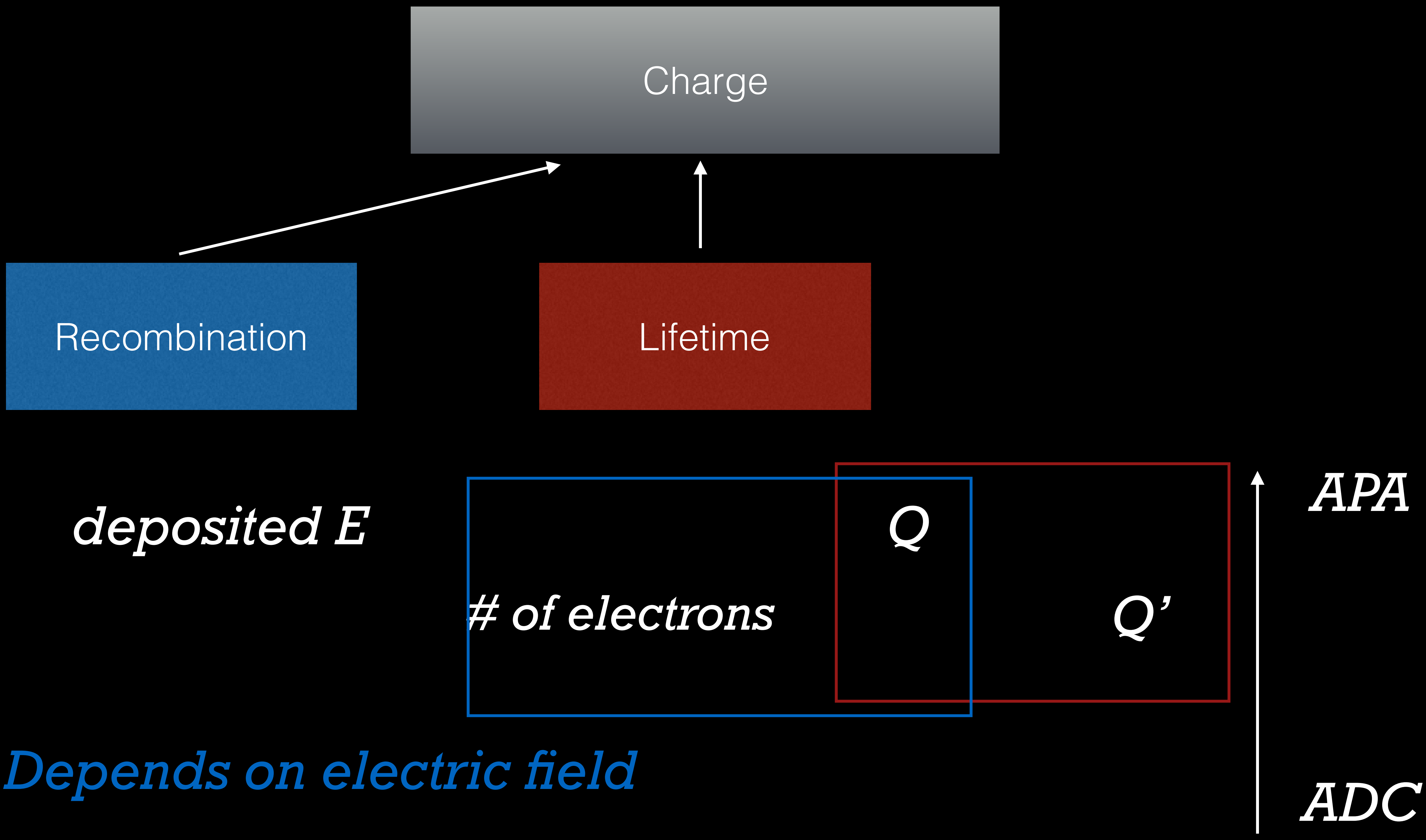
APA

Q'

ADC

Ionization energy from dedicated measurements of Ar

Roadmap: calibrating dE



What are the size of E field effect?

Systematic	E field distortion	uncertainty on distortion
field cage resistor failure	4-5% (dQ and dx)	known
Ar(39) SP	0.1%	other radiological, fluid model
Ar(39) DP	1%	other radiological, fluid model, ion feedback
CPA tilt (crumple mode), 1-2cm deflection in x, (Also CPA/APA bowing)	1-2%	known assuming deflection

Goal: measure E field to 1% (confirm no non-uniformities at 1% level, or correct them)