2x2 related LAr calibration: experience and thoughts

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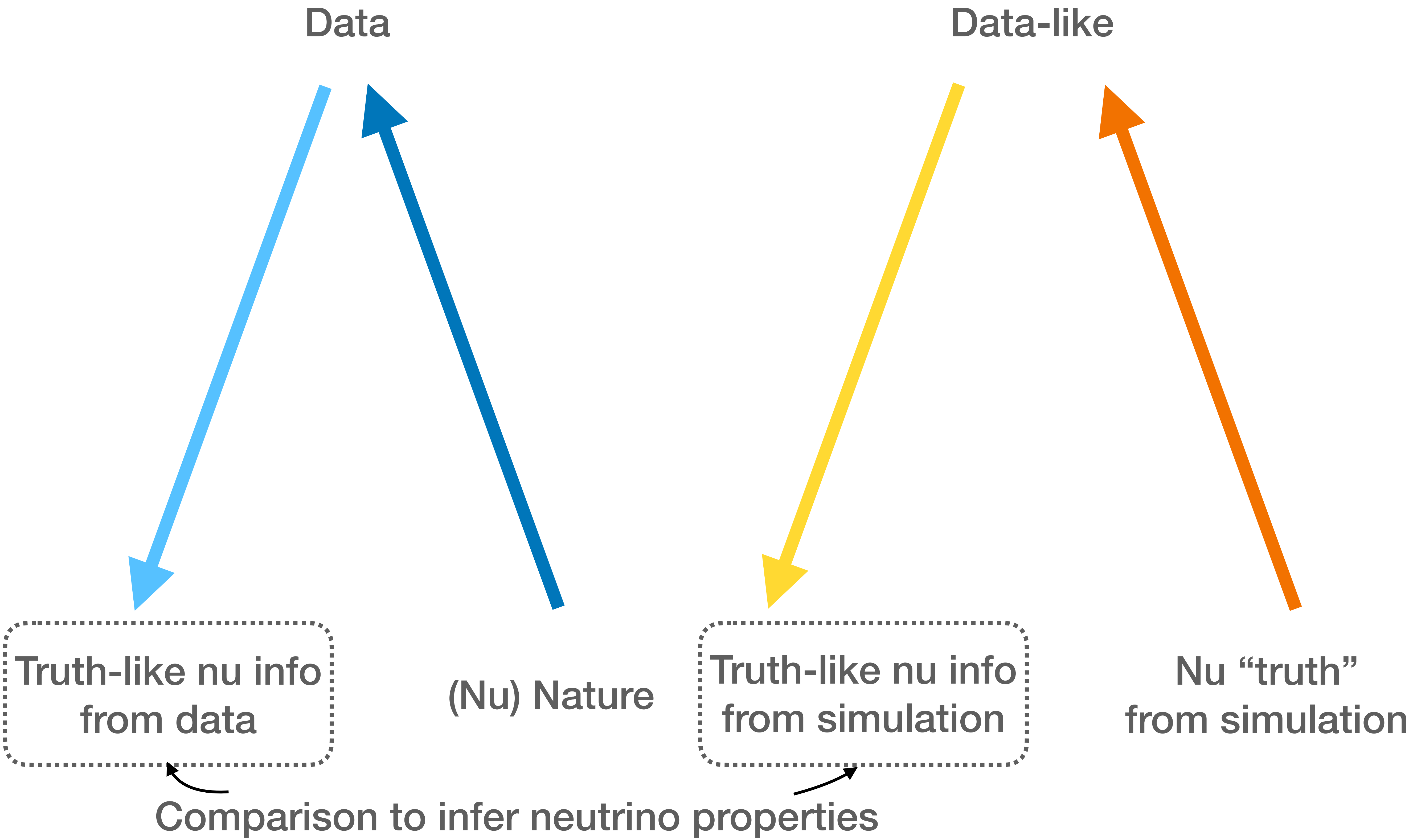
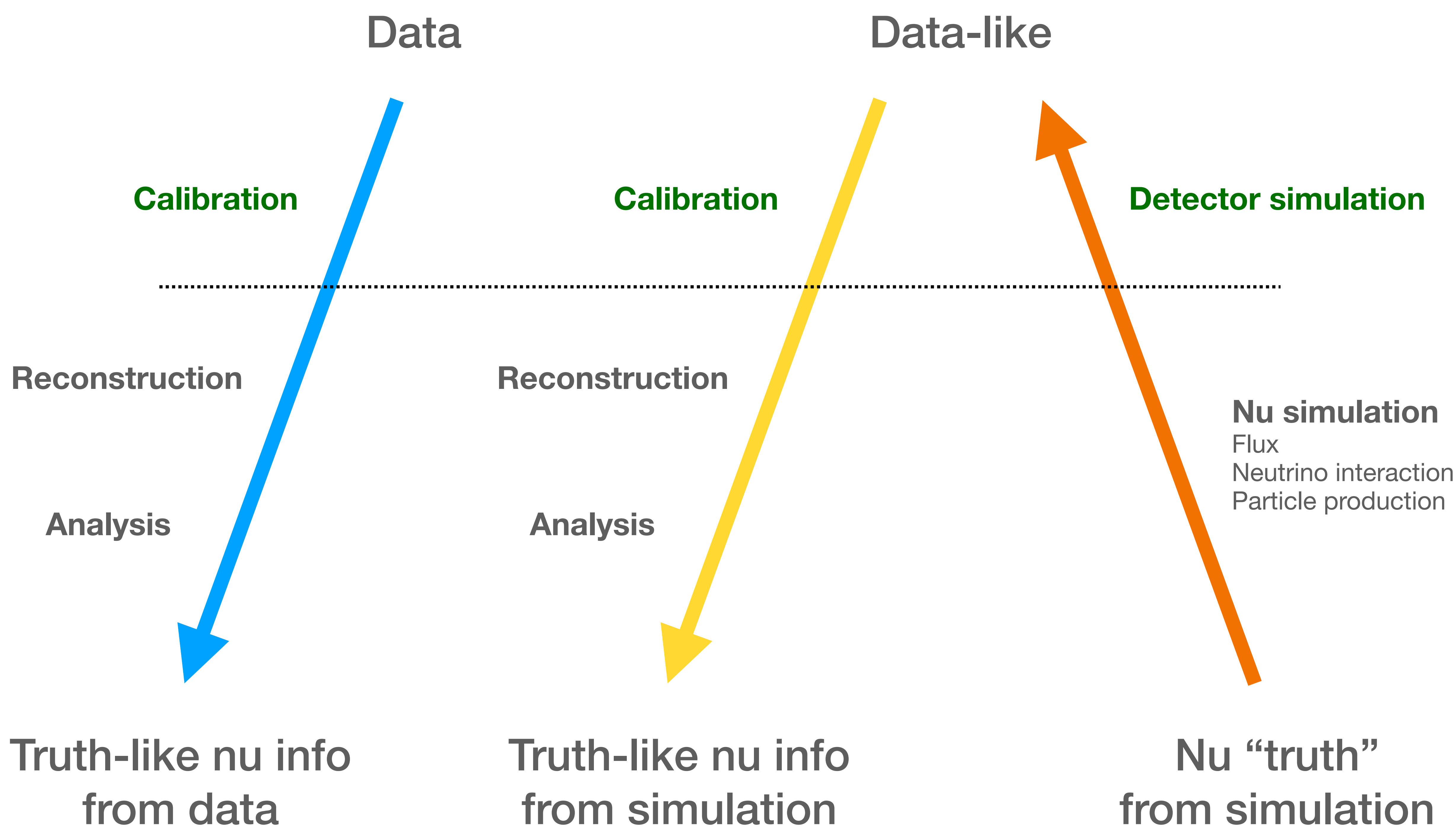
The obvious I



The obvious II



The obvious III

Data

Data-like

Calibration

Calibration

Detector simulation

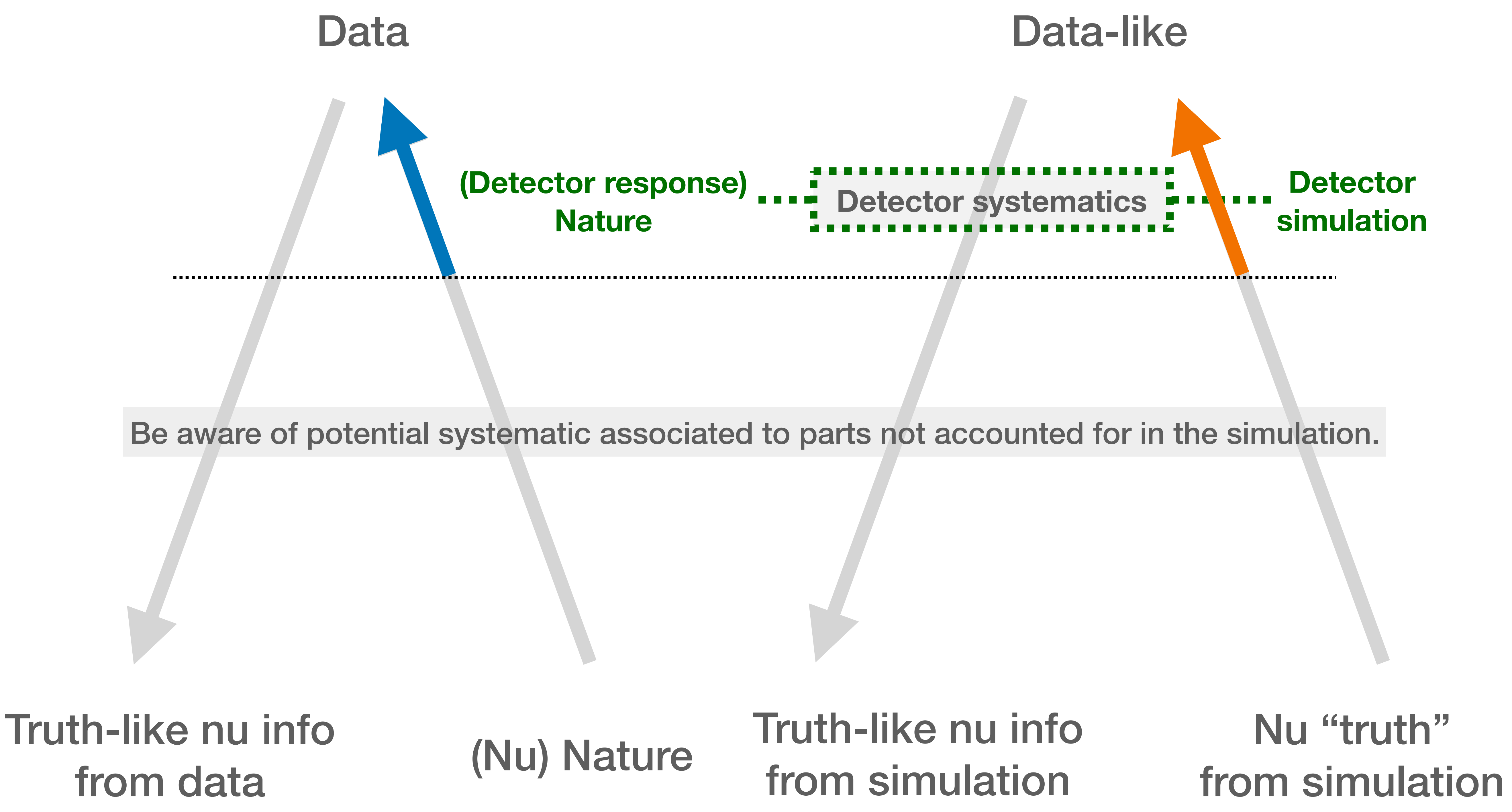
- Two types of calibration:
  1. Calibrating existing models — parameters, look-up tables, etc.
     a. Detector independent (e.g recombination in LAr)
     b. Run condition dependent (e.g electron lifetime)
  2. Calibrating not modeled effect ("must" be measured)
- Calibration for data and simulation should be consistent
- The detector simulation should correspond to the measurement from the calibration process.
  - Type 1a calibration may be extracted to improve fidelity of the simulation, but not directly applied on data (e.g charge diffusion)
  - Sometimes Type 2 calibration is not implemented in the simulation

Truth-like nu info from data

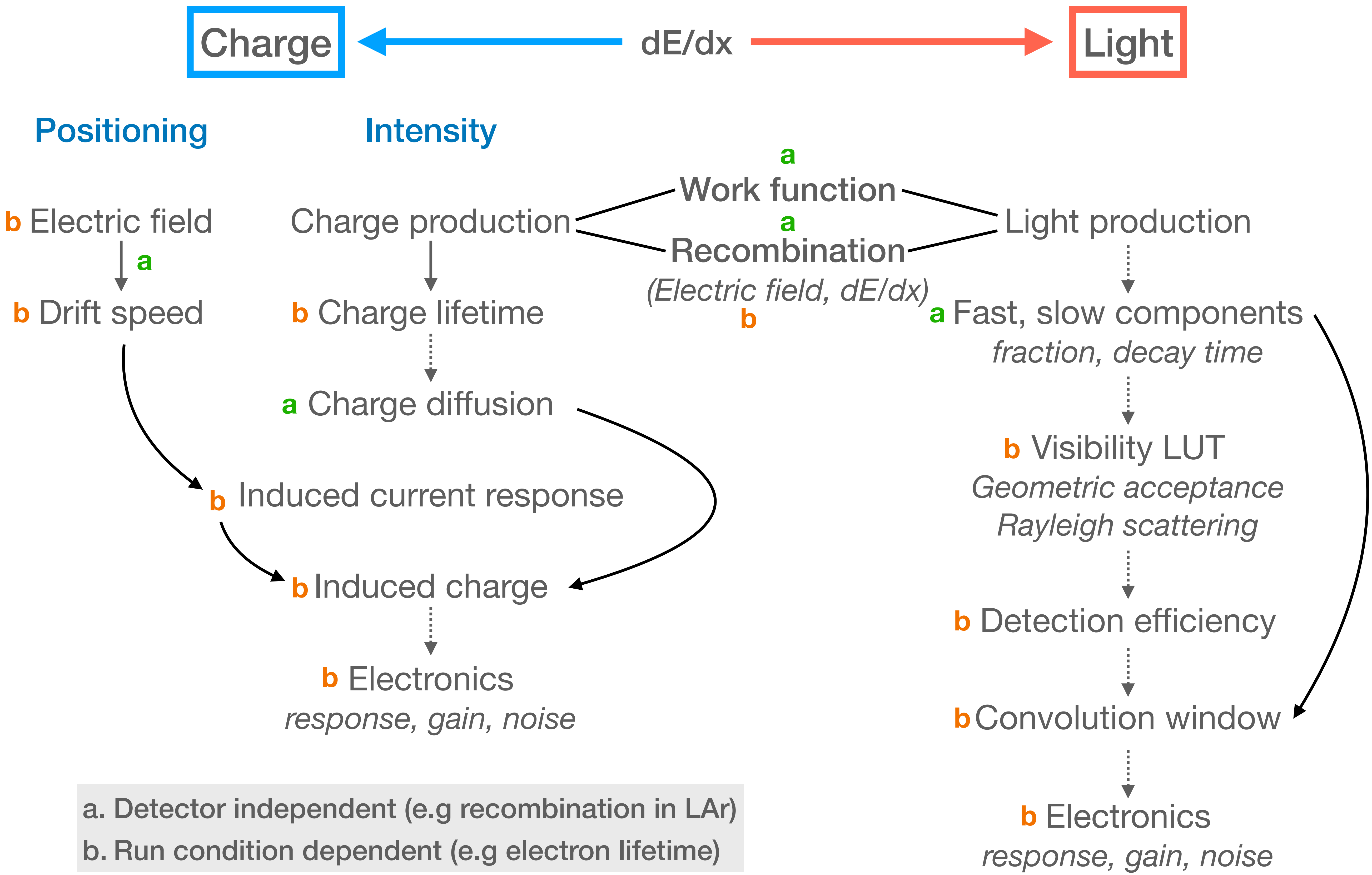
Truth-like nu info from simulation

Nu "truth" from simulation

The obvious IV



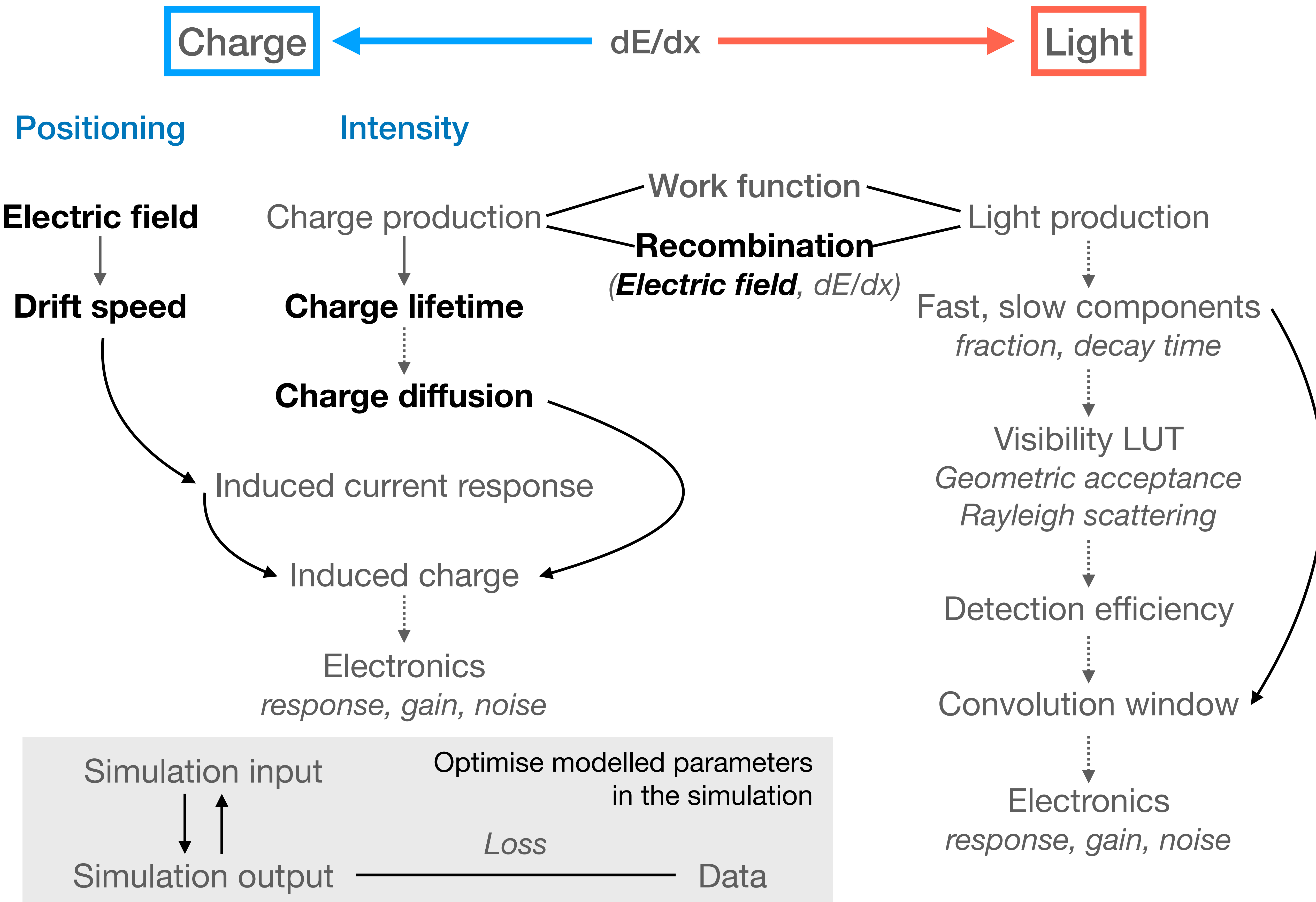
Type 1 calibration: modeled in the simulation



a. Detector independent (e.g recombination in LAr)

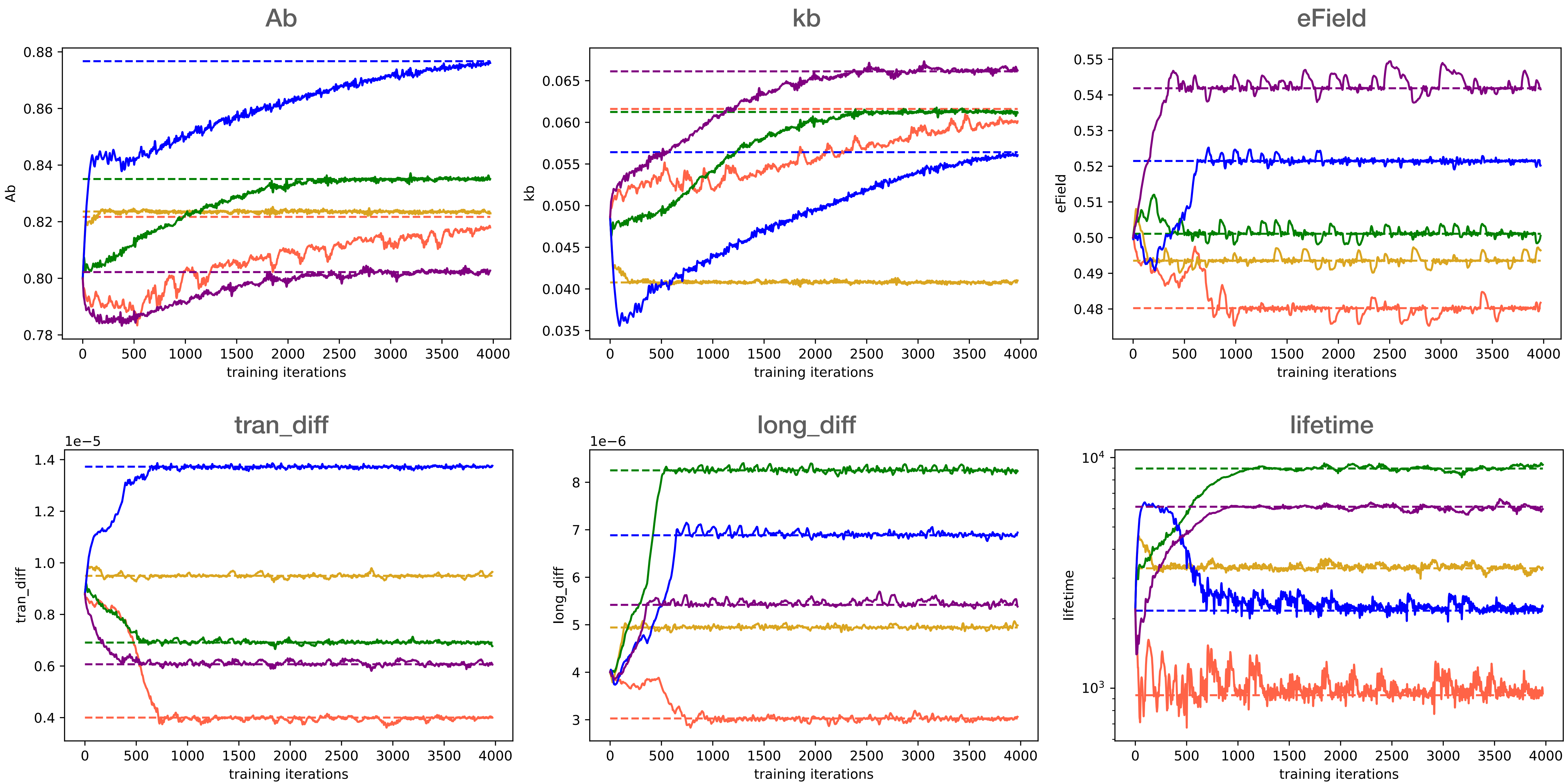
b. Run condition dependent (e.g electron lifetime)

Differentiable larnd-sim



Differentiable larnd-sim status

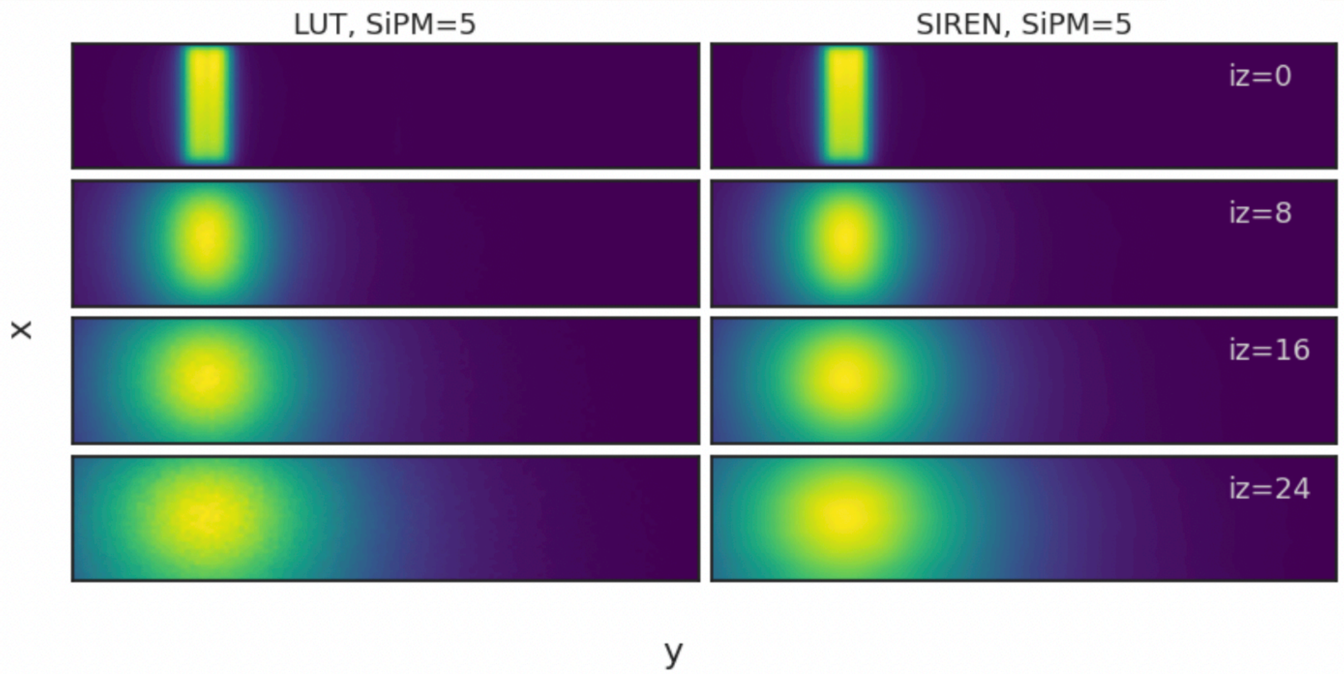
Simultaneously fit multiple parameters of the bulk LAr detector in the simulation from a noiseless closure test



Replacing visibility LUT with a SIREN model

Patrick Tsang: [Slides]

Model Visibility with SIREN



LUT (1 TPC of Module-0)
- 64 x 128 x 32 voxels
- ~10 mm voxel size
- 48 SiPMs
- ~12.5M parameters

SRIEN (f: $R^3 \rightarrow R^{48}$)
- a parameterized function mapping (x,y,z) to the visibility of 48 SiPMs
- 5 hidden layers + 32 hidden features
- ~7k parameters
- memory efficient + benefits from SIREN (e.g. smooth gradient) + optimizable (for calibration)

3

- Will improve the use in simulation and calibration
- Not yet implemented in larnd-sim

Light

Light production
dE/dx, Work function
Recombination
(Electric field, dE/dx)

Fast, slow components
fraction, decay time

Visibility model
Geometric acceptance
Rayleigh scattering

Detection efficiency

Convolution window

Electronics
response, gain, noise

Inclusive light calibration with SIREN model

Patrick Tsang: Slides

- Train a SIREN model from the LUT, and then calibrate it with data
- **Build a SIREN model directly from the data**

"effective light-yield" for 48 SiPMs (floating)

visibility by SIREN ~7k parameters (floating)

Prediction for SiPM-j $\text{pred}_j = \boxed{Y_j} \times \sum Q_i \boxed{\text{vis}_j(r_i)}$

measured charge of the track (fixed)

locations of charge deposition (fixed)

Charge data → Light prediction

Multi-parameter optimisation

Light data

Light

Visibility model

(Geometric acceptance, Rayleigh scattering)

Effective light yield

(Charge and light production — work function, recombination(E), Detection efficiency, Fast, slow components, Convolution window, Electronics response, gain, noise)

- Direct and inclusive (avoid propagating assumptions, a mix of Type 1 and 2 calibrations)
- Not to overcounting in systematics
- Used 6 days of anode-cathode crossing cosmic data (~680k tracks)
- In 2x2, calibration source: rock muons (topology)?
- How much data is reasonable?

Inspiration for induced current response

Charge ← dE/dx → Light

Positioning

Electric field

↓

Drift speed

Intensity

Charge production

↓

Charge lifetime

↓

Charge diffusion

Work function

Recombination

(Electric field, dE/dx)

Induced current response

Induced charge

↓

Electronics

response, gain, noise

Light production

↓

Fast, slow components

fraction, decay time

↓

Visibility model

Geometric acceptance

Rayleigh scattering

↓

Detection efficiency

↓

Convolution window

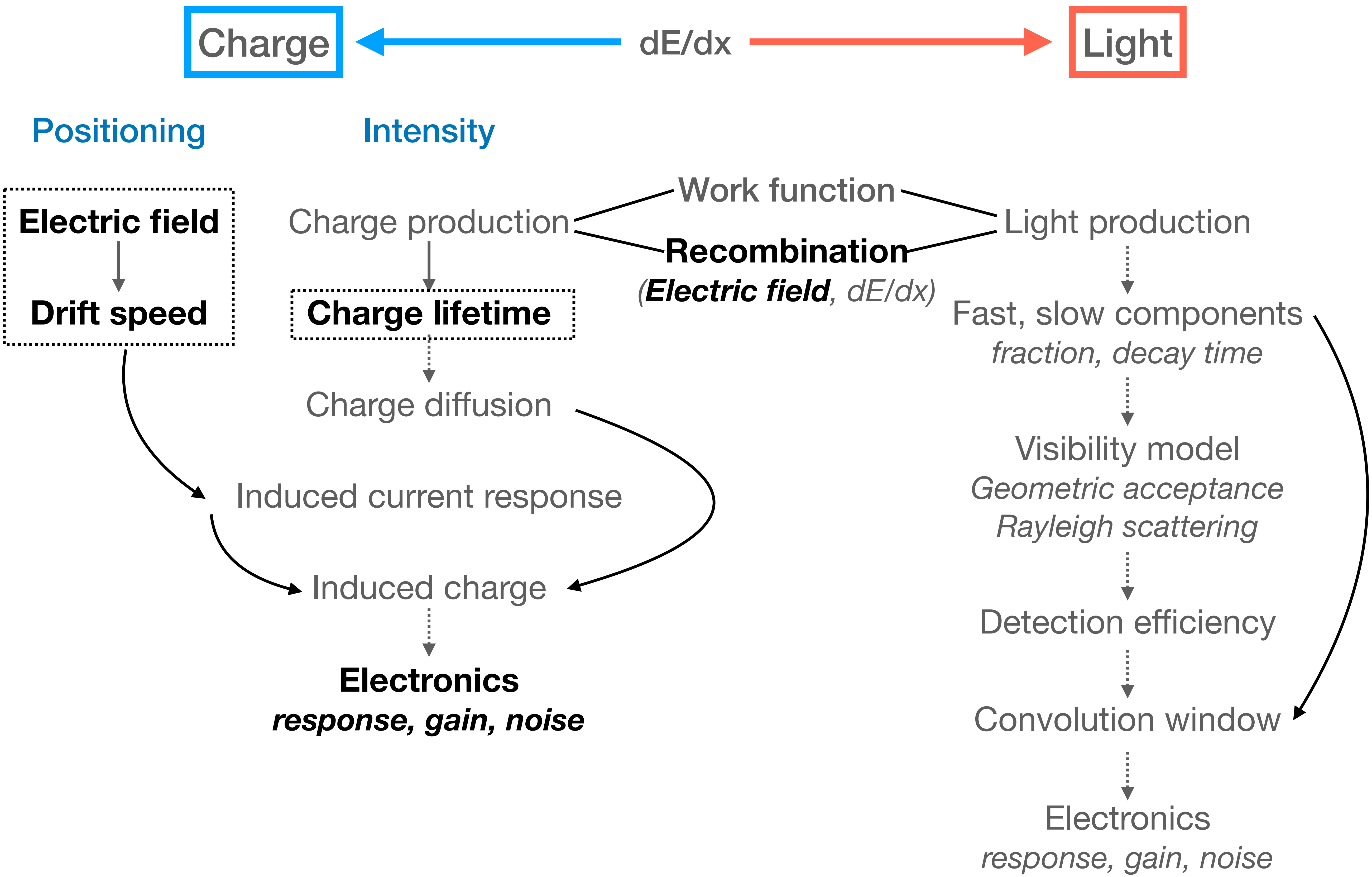
↓

Electronics

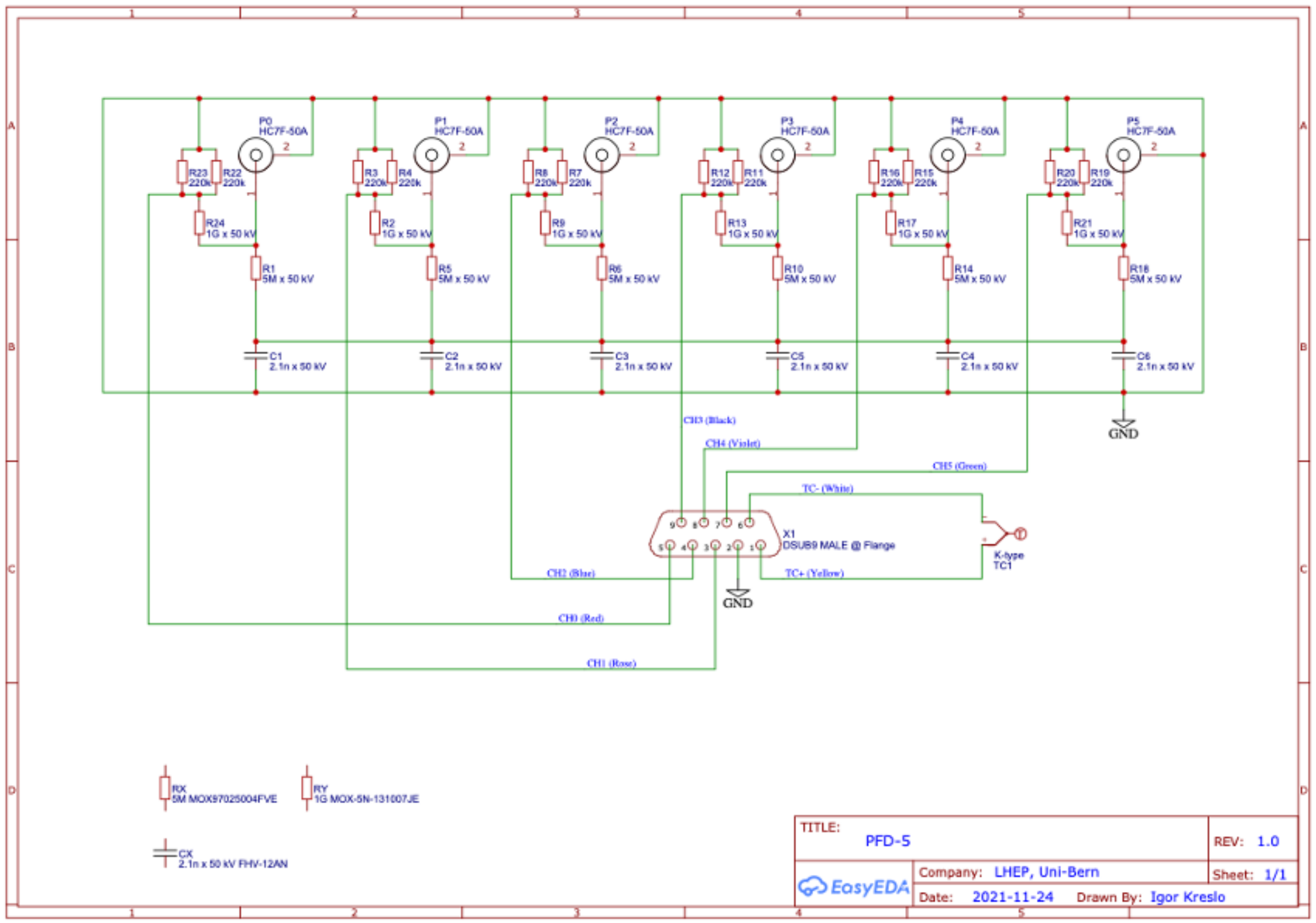
response, gain, noise

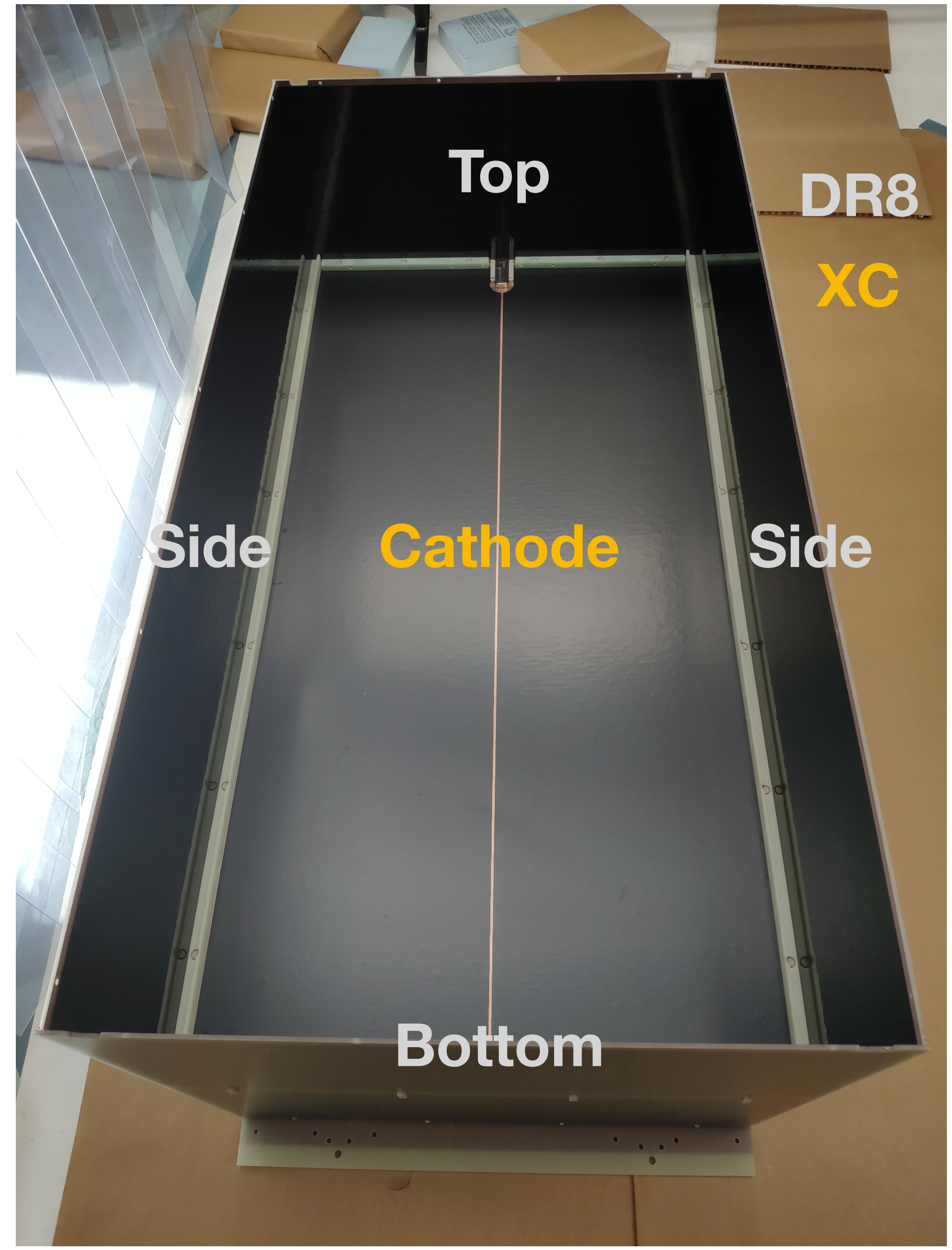
- [Simulation] Replace the induced current LUT with a SIREN-like model?
- [Calibration] include in the calibration scheme of differentiable larnd-sim? Otherwise, how to have a clean breakup from the inclusiveness

Relevant Type 1 calibration in 2x2



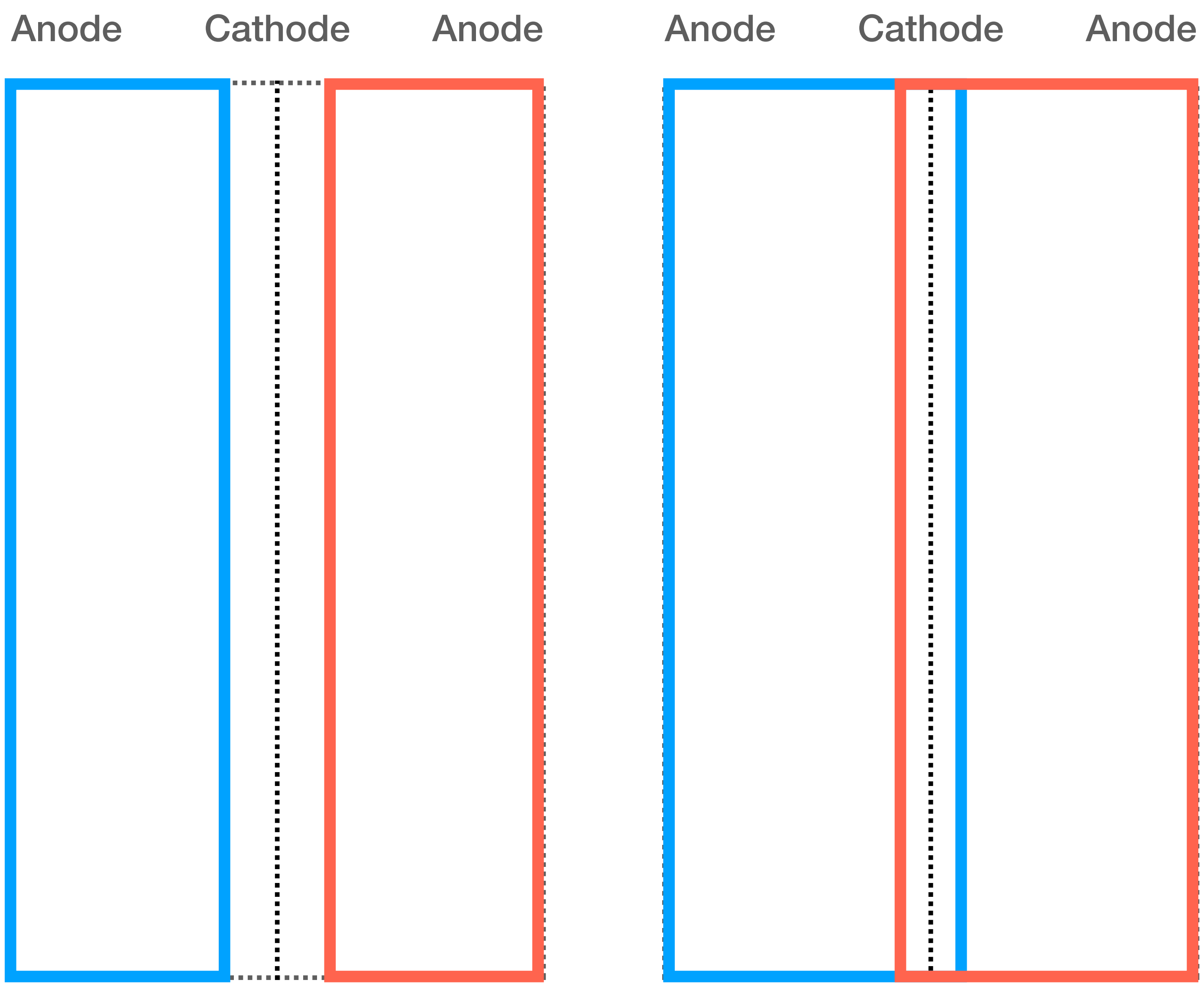
Electric field variation

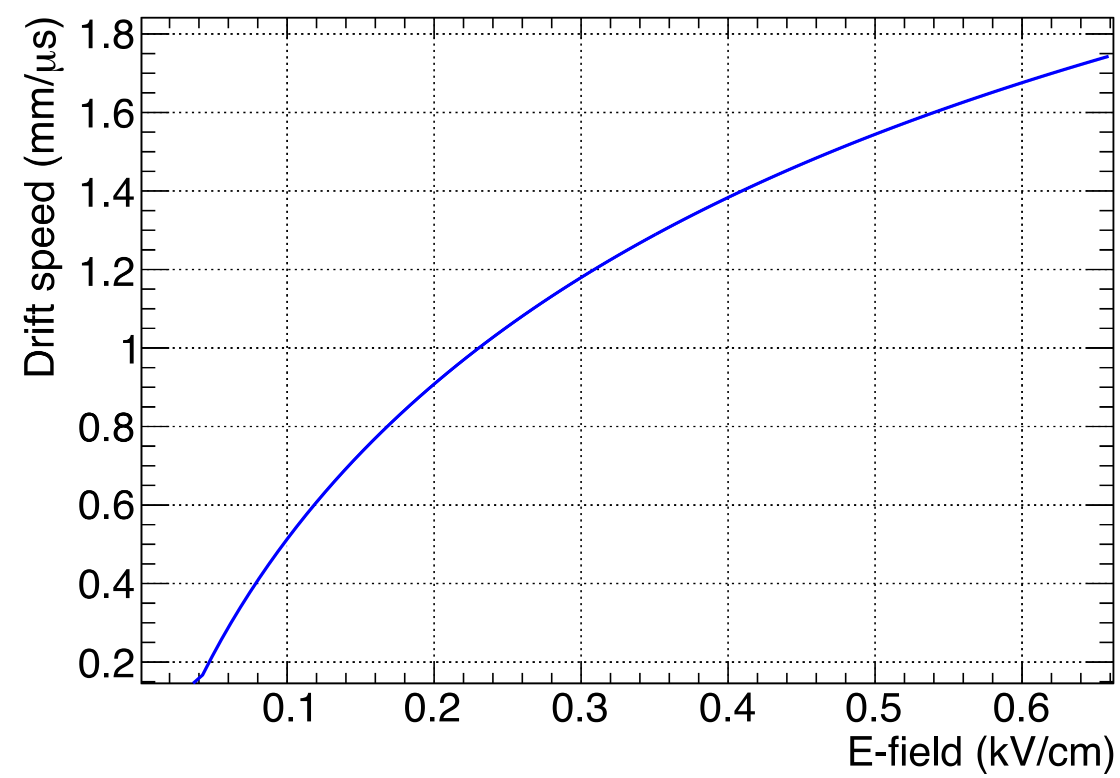




- Input HV is fixed all four modules
- This input HV shared by the filter resistor and field shell
- The sheet resistance of DR8 (field shell material) can vary ~100%
- This will lead to cathode voltage variation

Drift speed

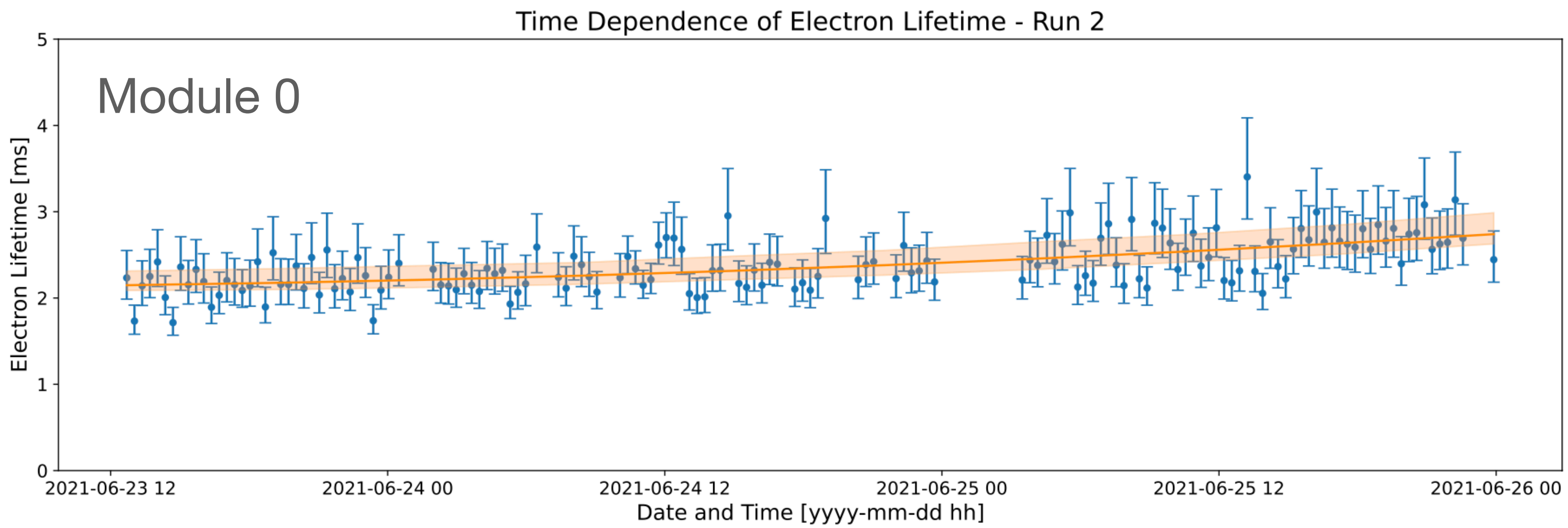


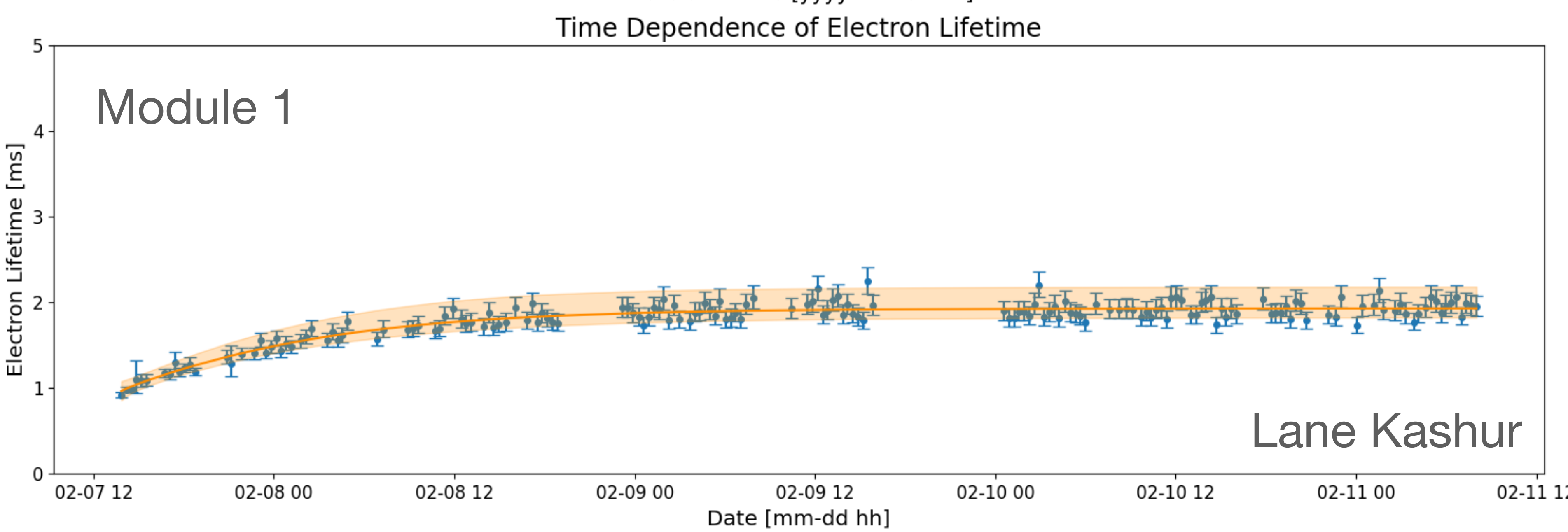


- If the drift speed is not calibrated according to the actual electric field, the readout TPC shape may distort in drift direction
- The drift speed modeled from the electric field and the measured maximum drift time is not constrained by the cathode position
  - Cold detector size
  - Electric field deformation

Charge lifetime

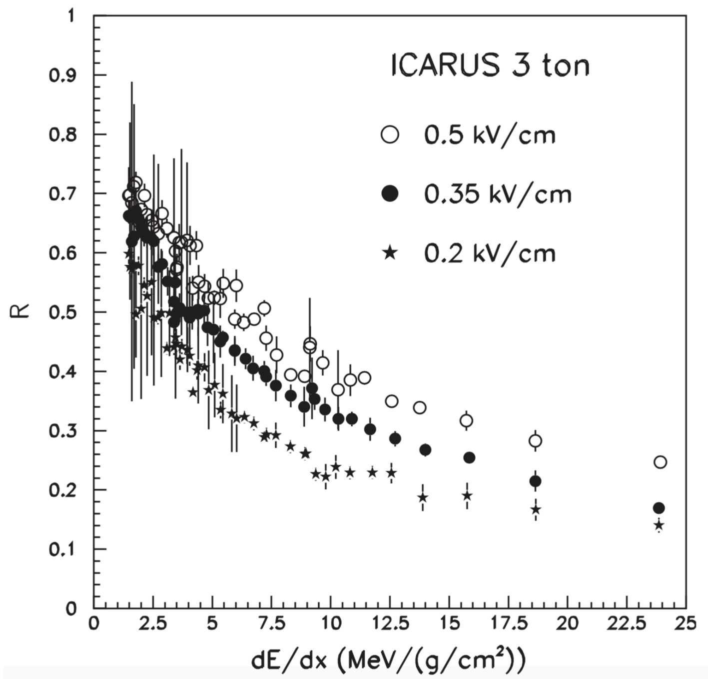
- Could be a noticeable effect of charge attenuation if not corrected
- Well defined procedure for charge deposition with known T0
- Verify the consistency between two TPCs in a module and between modules
- Calibration source in 2x2:
    - [charge-light matching] cosmic?
    - [beam] neutrino induced charge (rock muons, in-detector interactions)?
- Data size

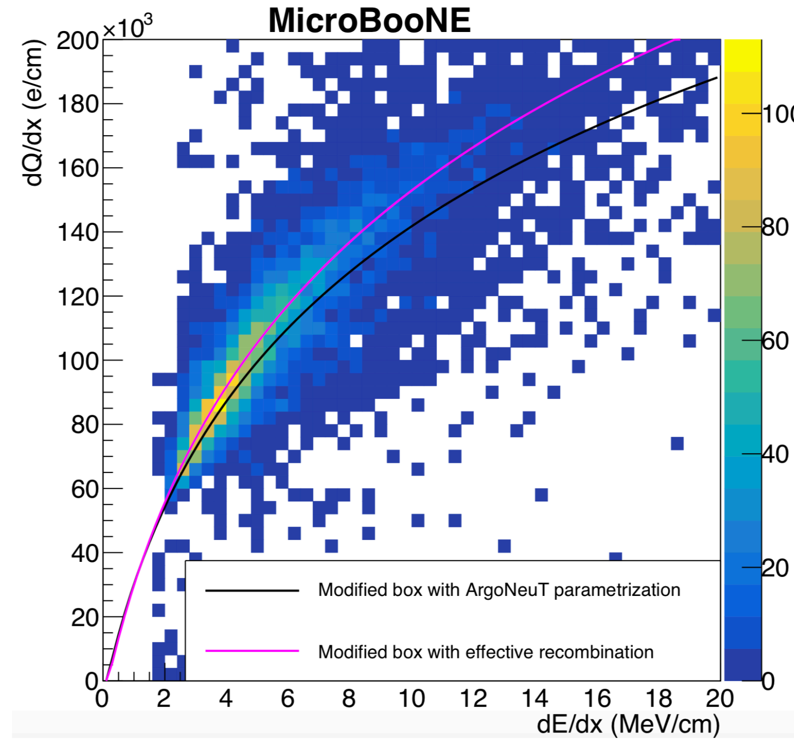


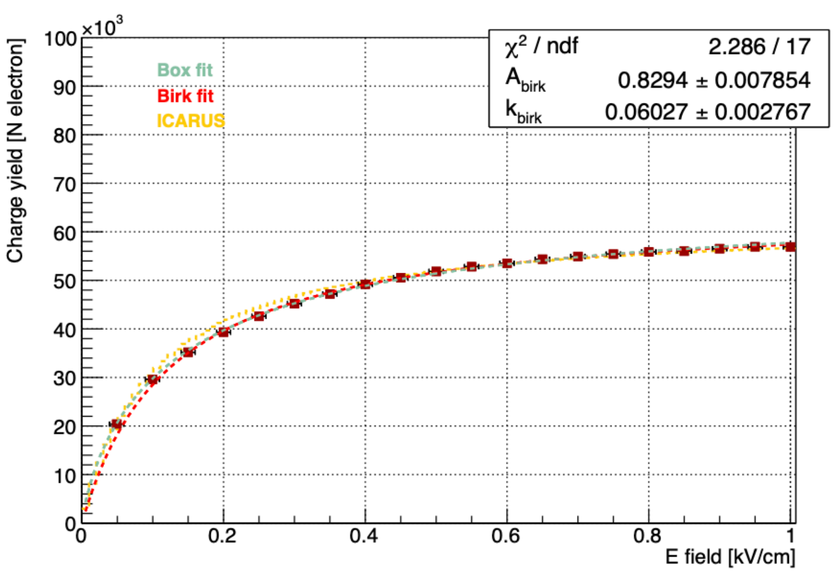


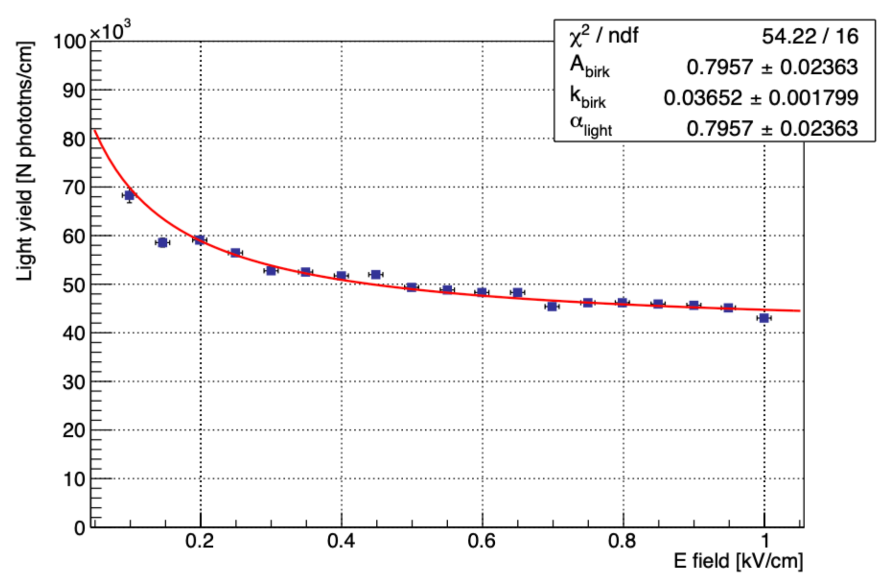
Recombination

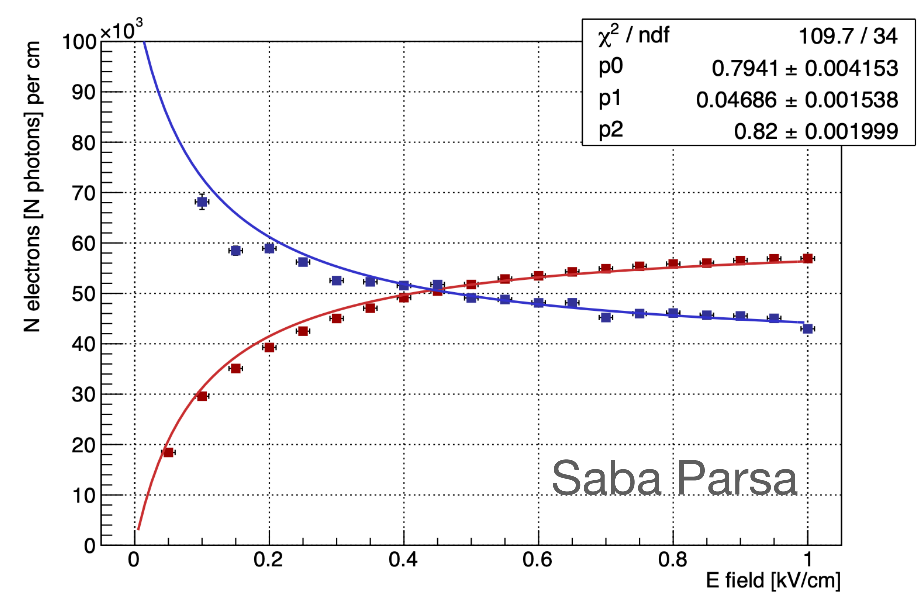
- Birks or Box: theoretically inspired phenomenologically recombination expression
- ICARUS 3t: muons and protons, 3 electric fields (0.2, 0.35, 0.5 kV/cm)
- ArgonNEUT: protons, 1 electric field (0.5 kV/cm), track angle dependence study
- MicroBooNE: protons, 1 electric field (0.5 kV/cm)
- Module 0: cosmic muons, detailed electric field scan between 0-1 kV/cm, fixed dE/dx











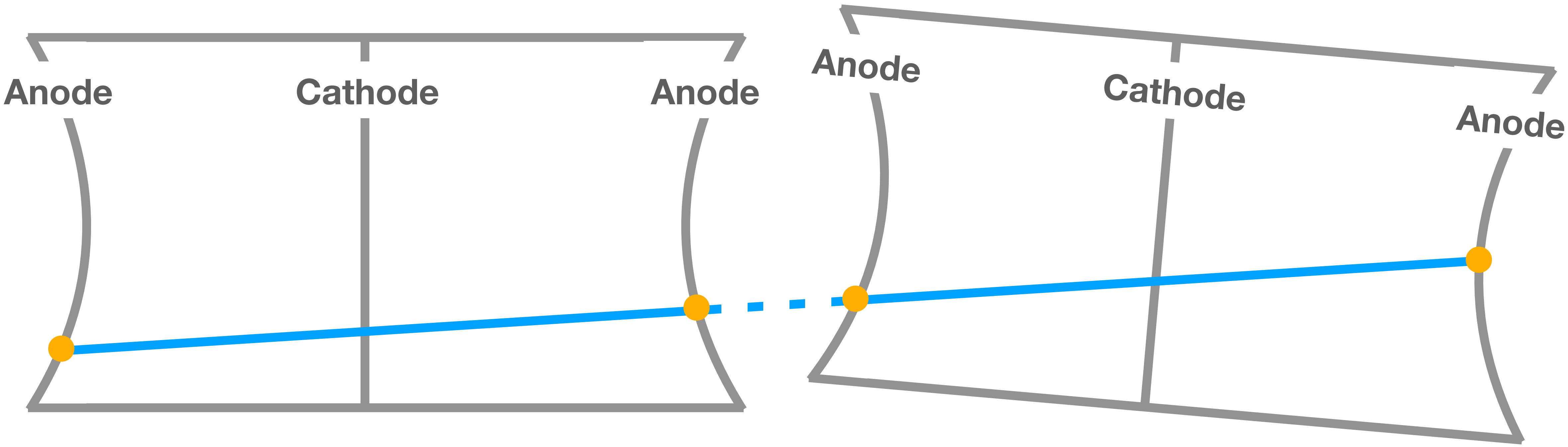
Saba Parsa

Type 2 calibration: not (yet) modeled effect

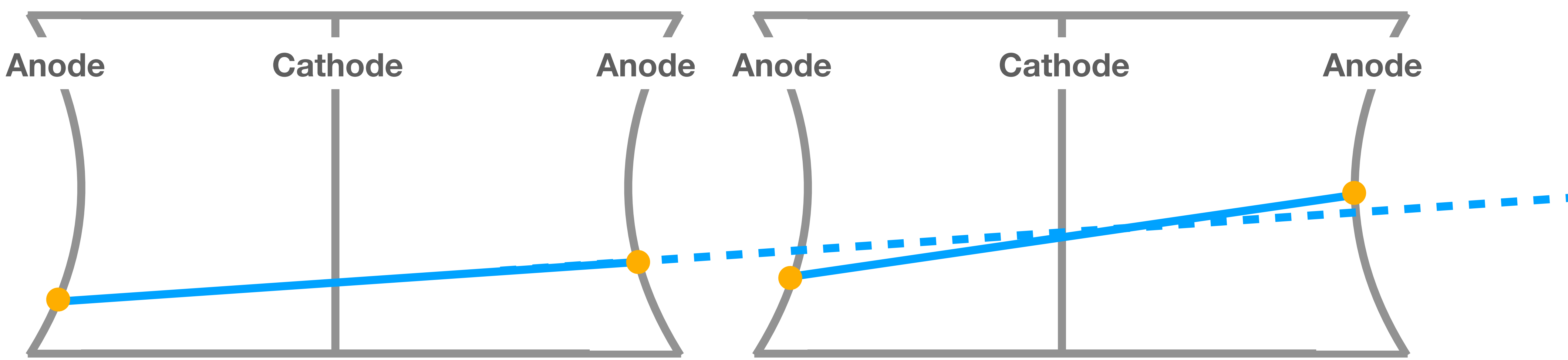
- Relative module positioning (ICARUS, protoDUNE) including MINERvA
- Detailed electric field mostly for charge positioning
- Fiducial volume uncertainty?
- Readout uniformity
- GPS time matching between systems (LAr-charge, LAr-light, MINERvA)
- Trigger efficiency in terms of position
- Trigger time (beam) 2x2 PACMAN implementation
  - Not in-time charge deposition
    - Coincident cosmics

Module-to-Module Positioning

Using "straight" muon tracks

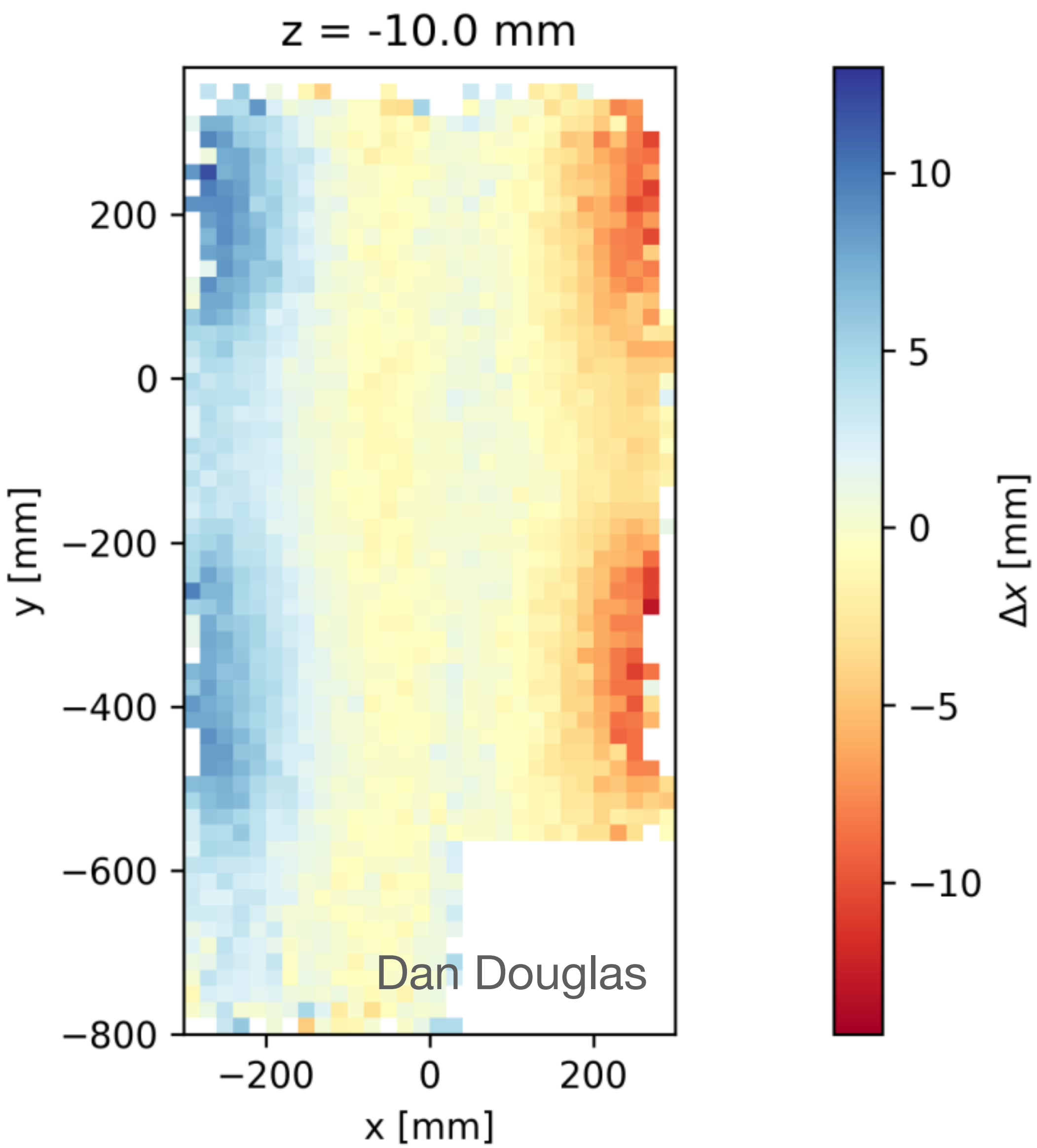


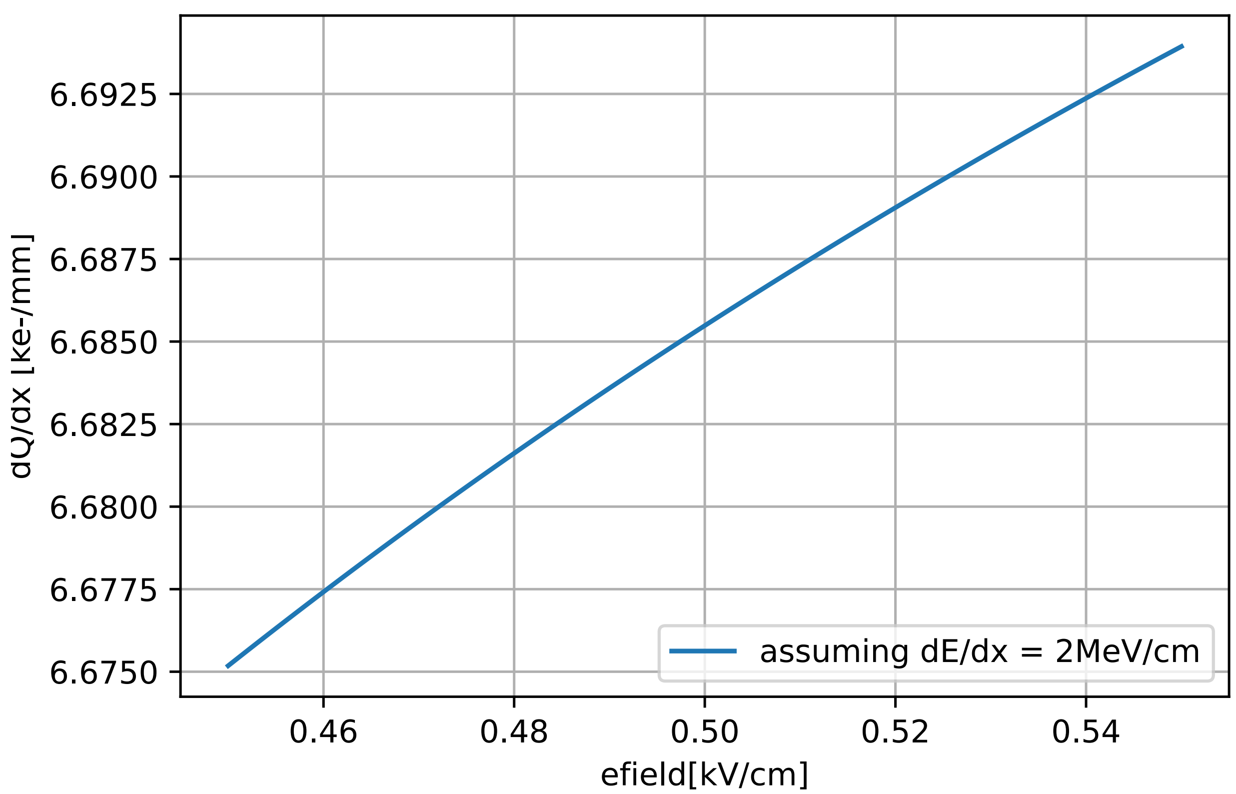
Correct modules to a common reference frame



Detailed electric field

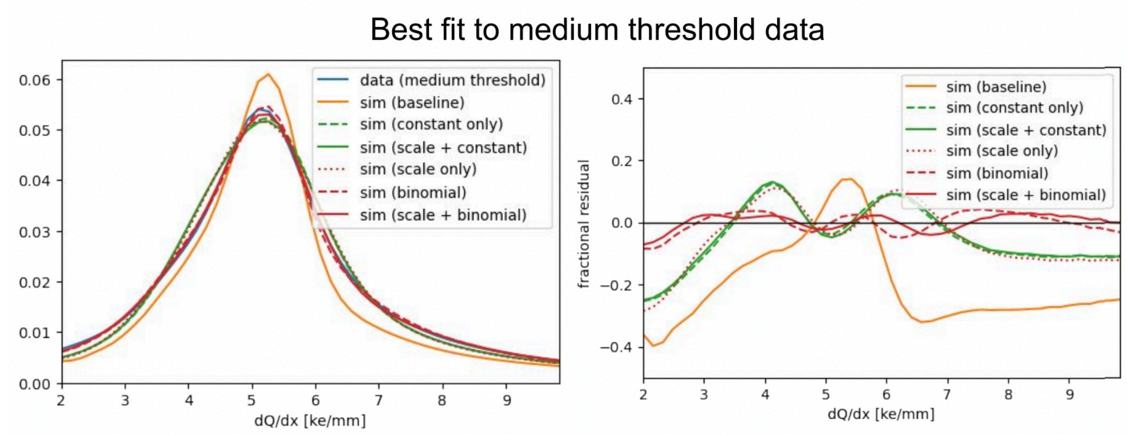
- Observed maximum position displacement ~1 cm
  - Close to the light detectors
  - Close to the cathode
- To be investigated: TPC to TPC variation
- Would it be the same in 2x2?
- Time stability (beam dependent?) and data size
- Trivial impact on recombination, and therefore the calorimetric output





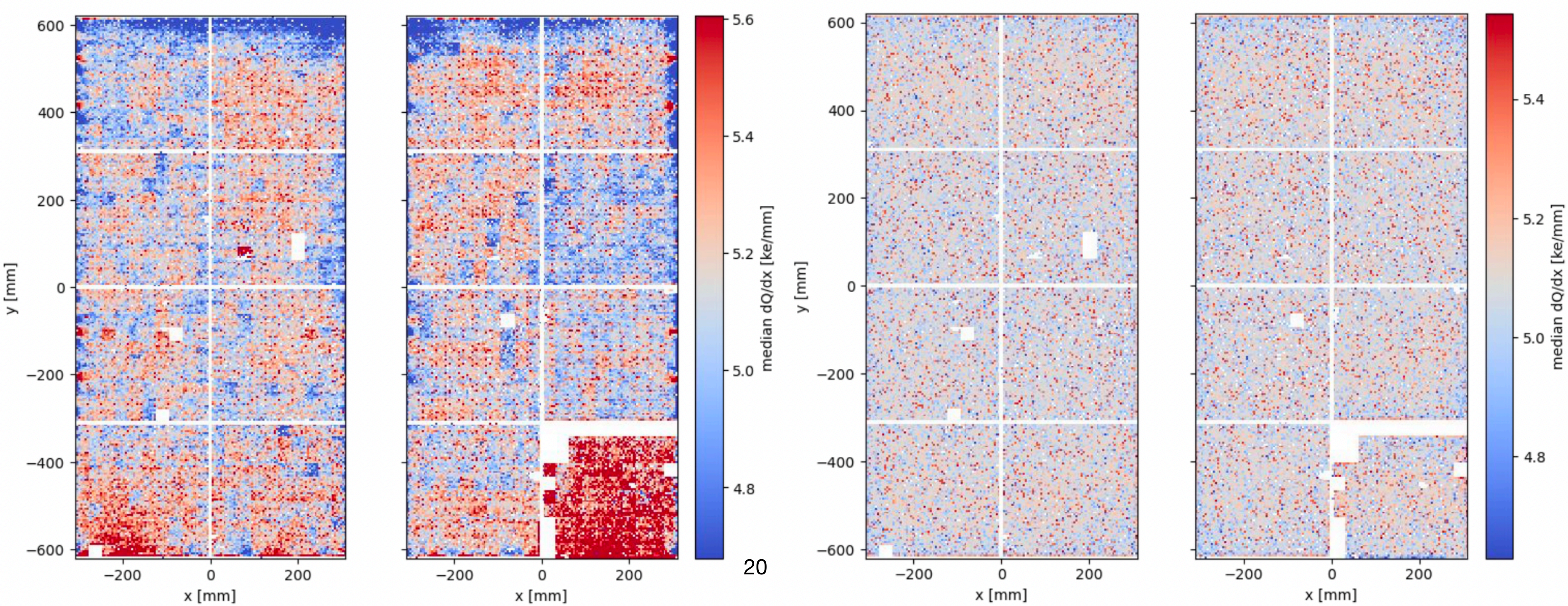
Readout performance and uniformity

- Readout performance: data-simulation
- Readout uniformity (x, y, z)
  - Inclusive uniformity map?
- To-be investigated (quoting Peter's slides)
  - Channel-to-channel gain variation (~5%)
  - Digital-analog cross talk (dQ/dx distribution in the tail)
- Alternative noise modeling improved readout dQ/dx performance



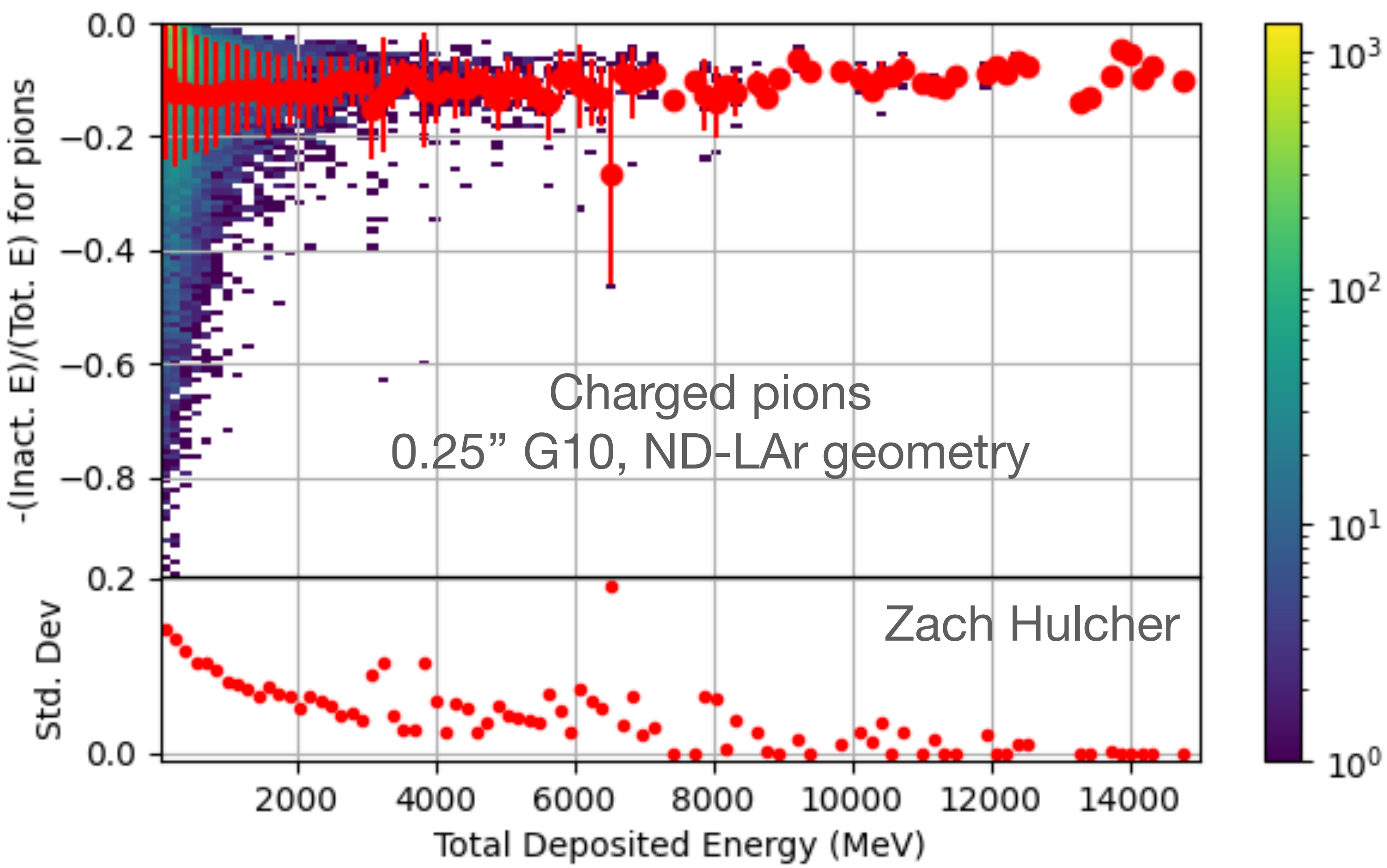
Peter Madigan: [Slides]

Medium threshold



Energy Calibration/Correction

- To account for particle energy loss in TPC gaps (known source)
- “Smearing matrix” all inclusive flattened response
- Position, angle, energy dependent for particles of interest
- Reconstruction and particle identification required
- Do we need all these dimensions?
    - Might be statistics dependent (analysis dependent)
- Intrinsic fluctuation in energy deposition

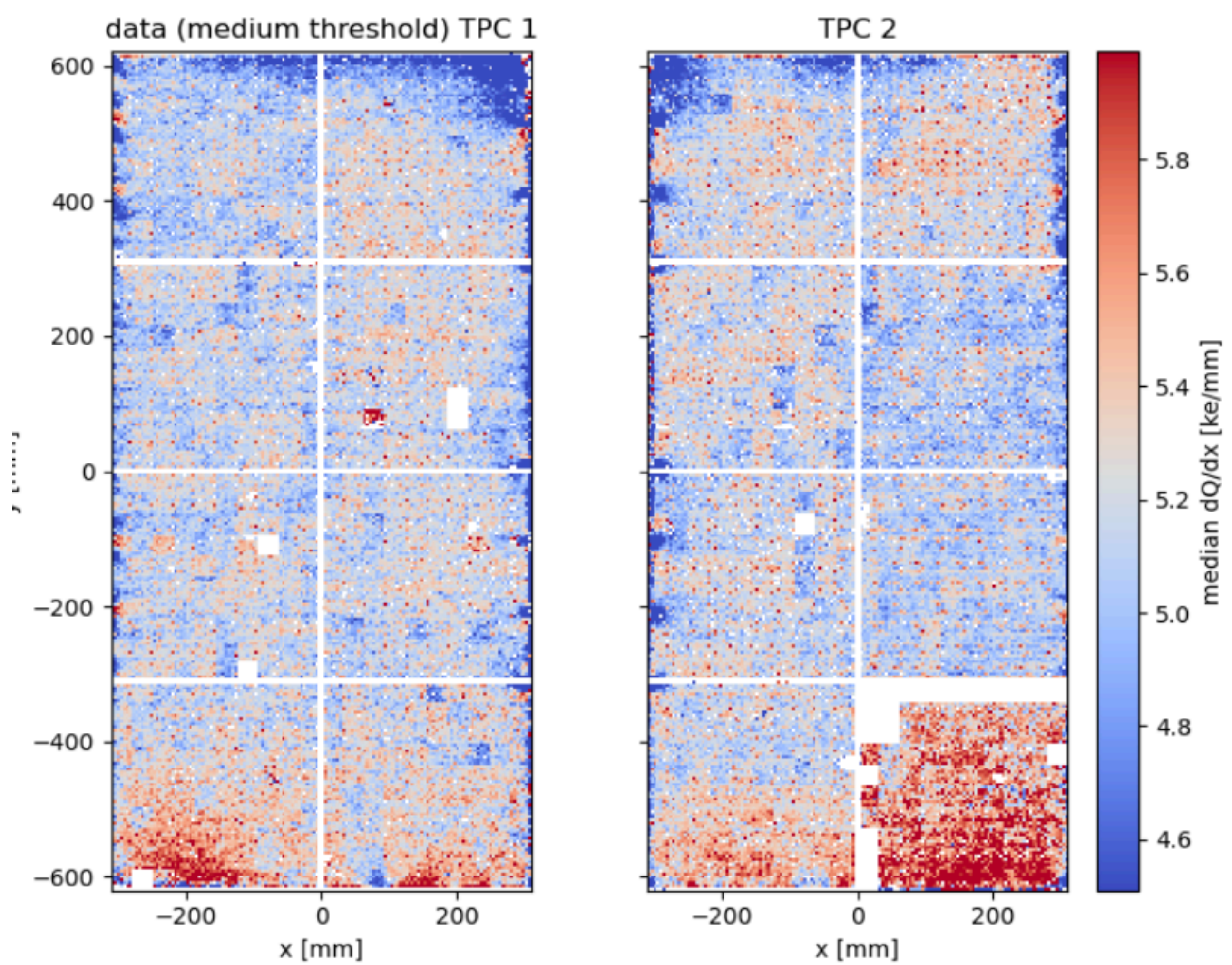


Do not introduce a calibration
that you cannot improve upon the prior resolution or systematics

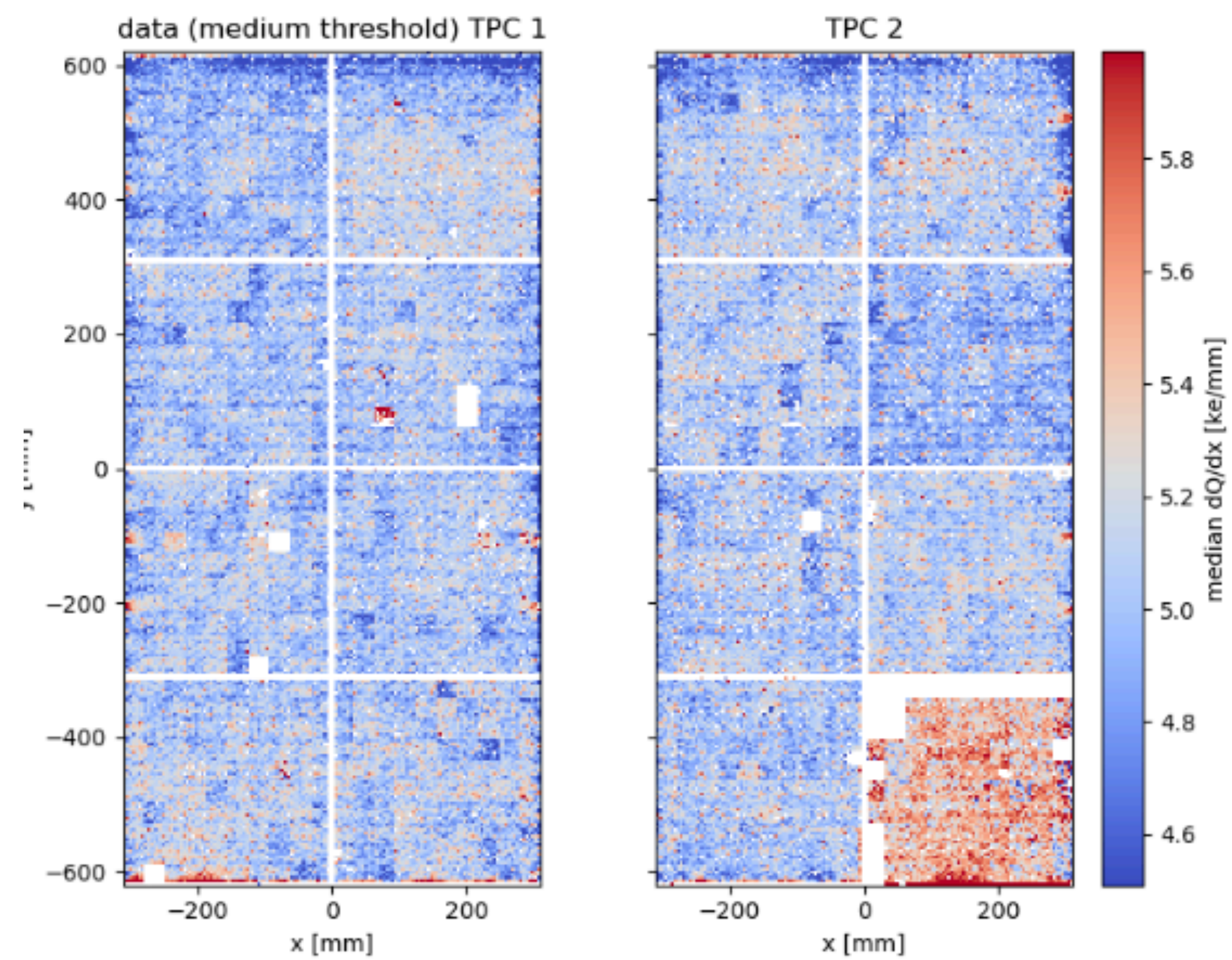
Readout uniformity

Single pixel dQ/dx uniformity

10 cm near the cathode



10 cm near the anode



Peter Madigan

High voltage filter