Update on Tracking Distortions and Correction

sPHENIX Collaboration Meeting - December ‘23

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December 4, 2023

Outline

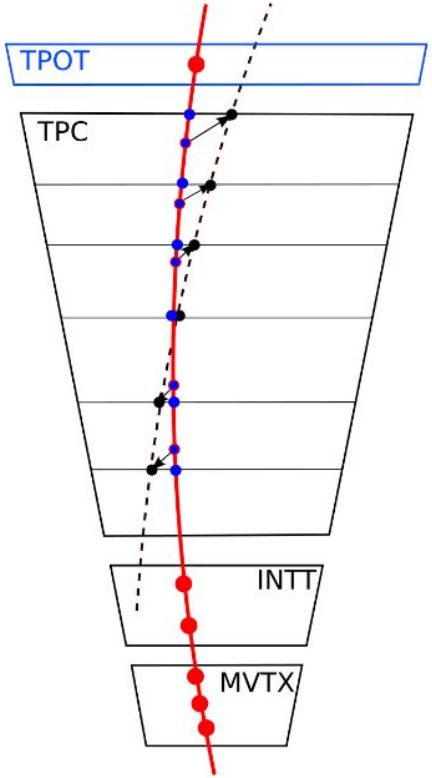
- Overview of Track Distortions
- Progress so Far
  - ExE Distortions
  - Average Distortions
  - Static Distortions
  - Digital Currents/Modeling
  - Using Machine Learning
- The Road Ahead

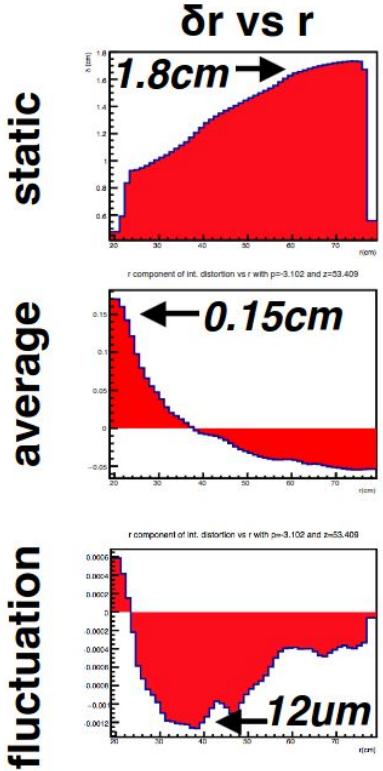
Distortions Overview

- **Static Distortions:**
  - ExB/non-uniform E,B fields
  - **Expected to be ~ O(1-2 cm)**
  - Changes slowly (ideally not at all)

- **Average Distortions:**
  - Average Space Charge
  - **Expected to be ~(0.1 - 0.2 cm)**
  - Changes slowly

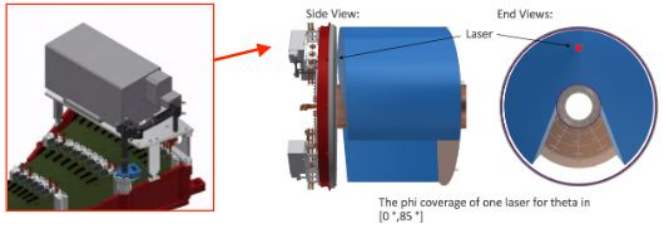
- **Fluctuation (ExE) Distortions:**
  - Fluctuations in Space Charge
  - **Expected to be ~O(< 100 μm)**
  - Changes Rapidly



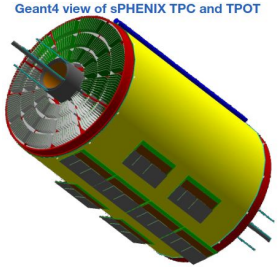


Distortions Overview - Tools

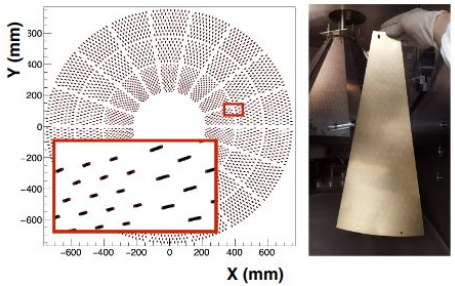
Static Distortions:
- TPC Direct Laser



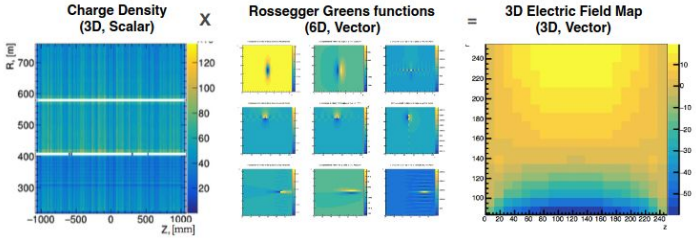
Average Distortions:
- TPOT



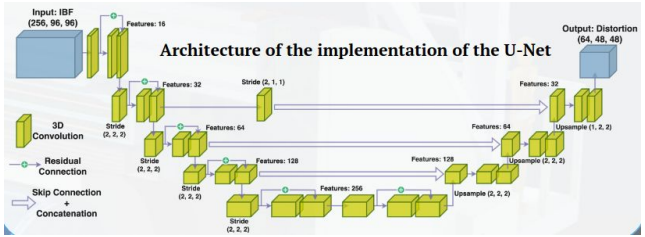
ExE Distortions:
- TPC Diffuse Laser



(All) Distortions:
- TPC Digital Currents/Modeling



(All) Distortions:
- Machine Learning



ExE Distortions

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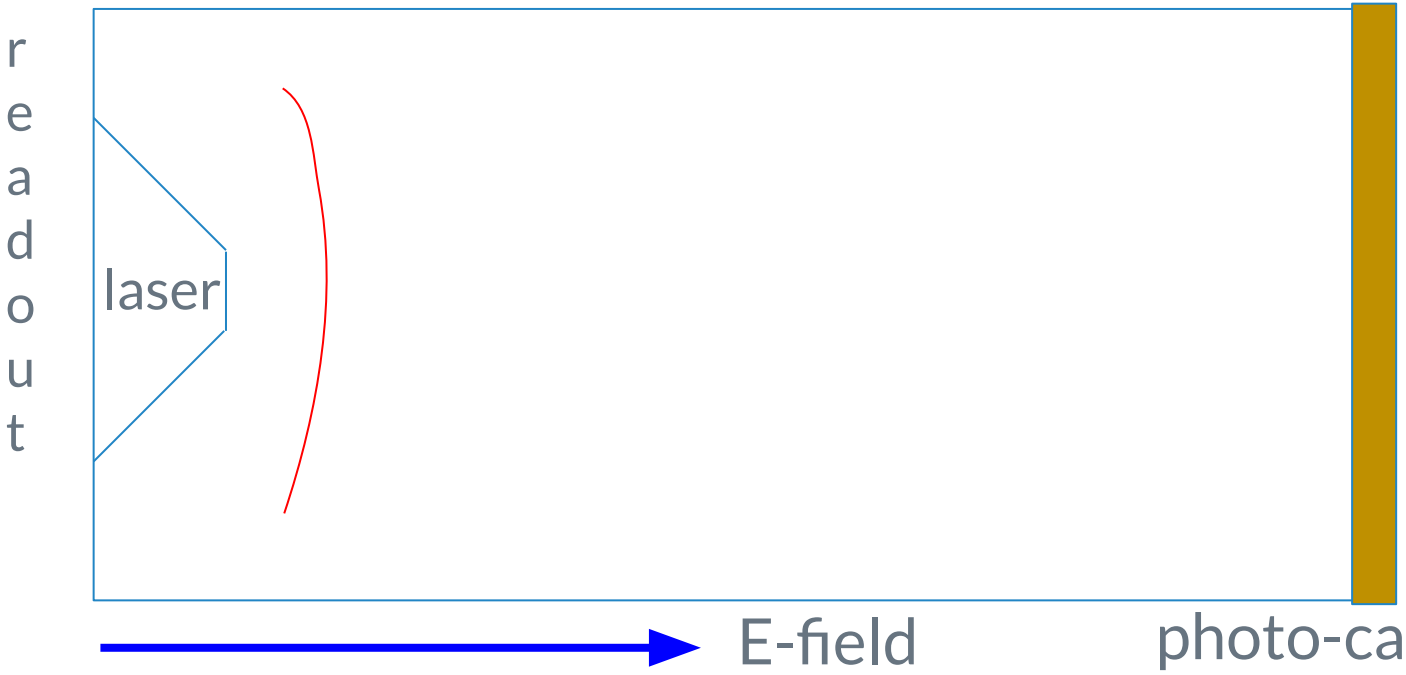
  - **4 lasers at each end cap send a diffuse beam towards segmented Al photo-cathode at CM**



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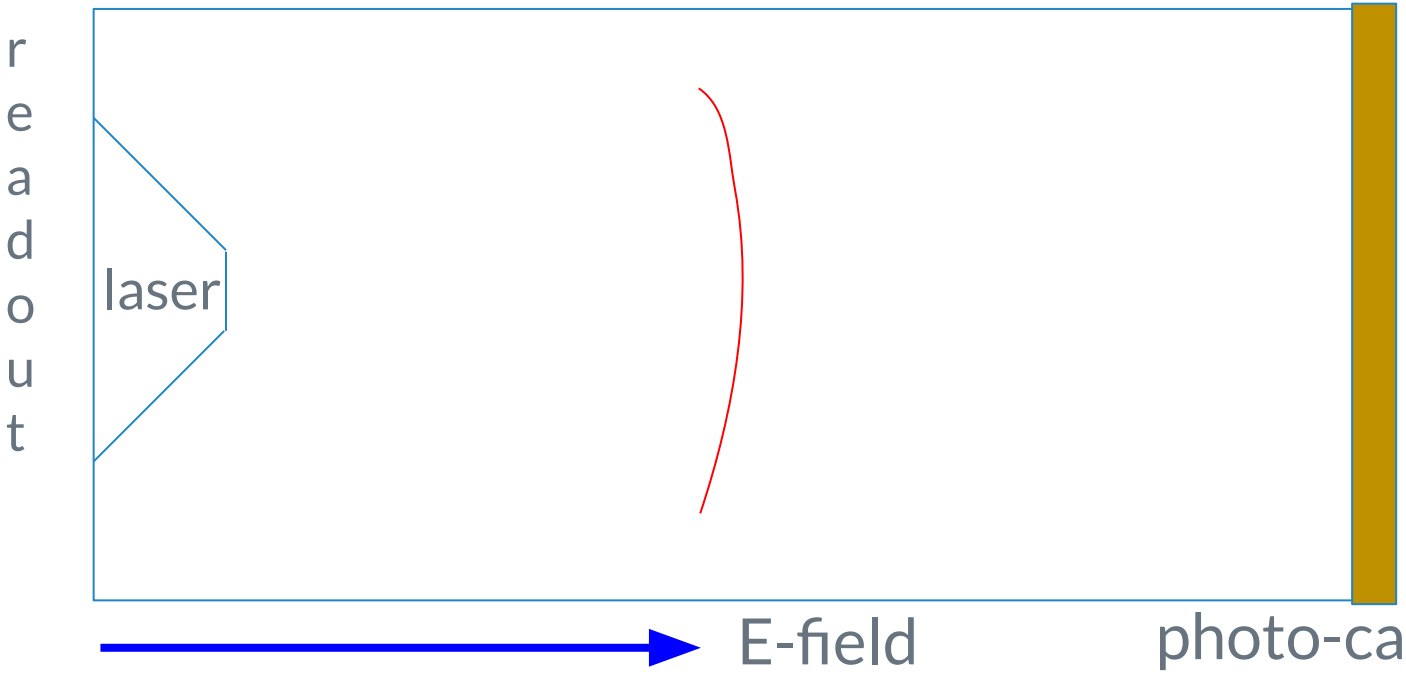

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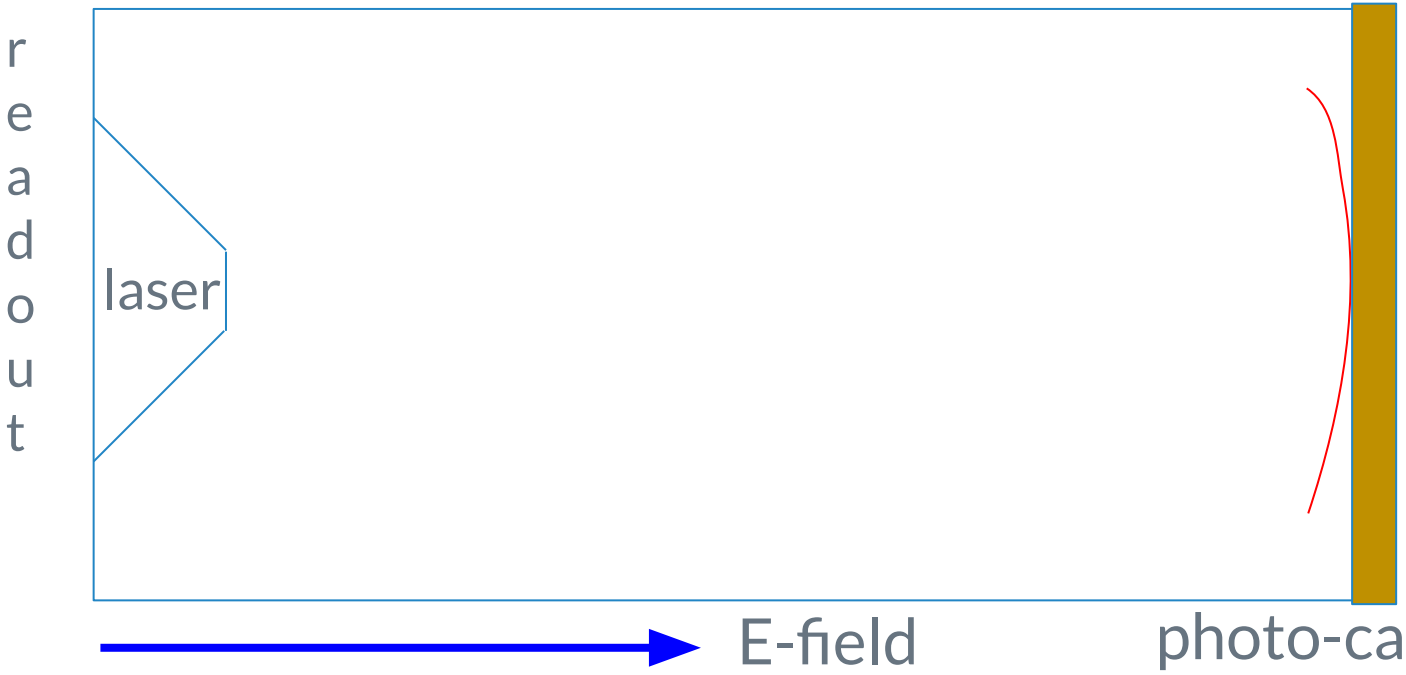

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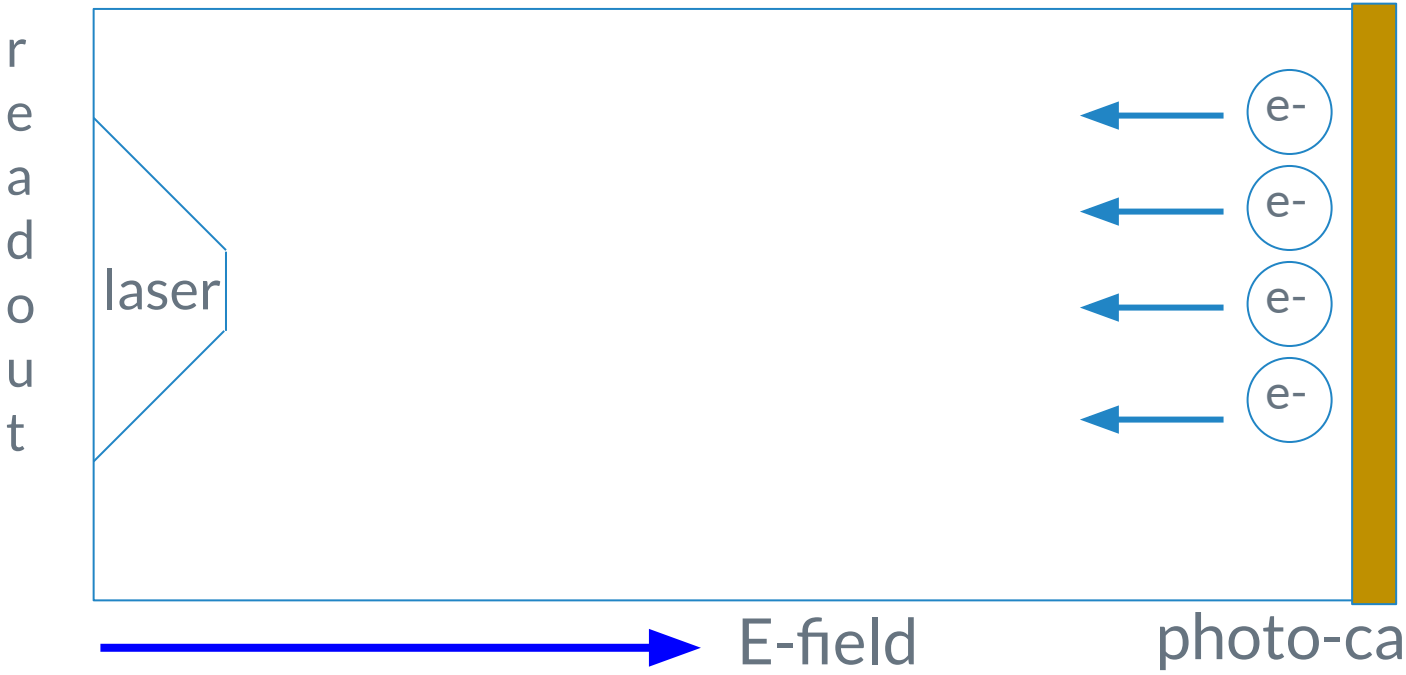

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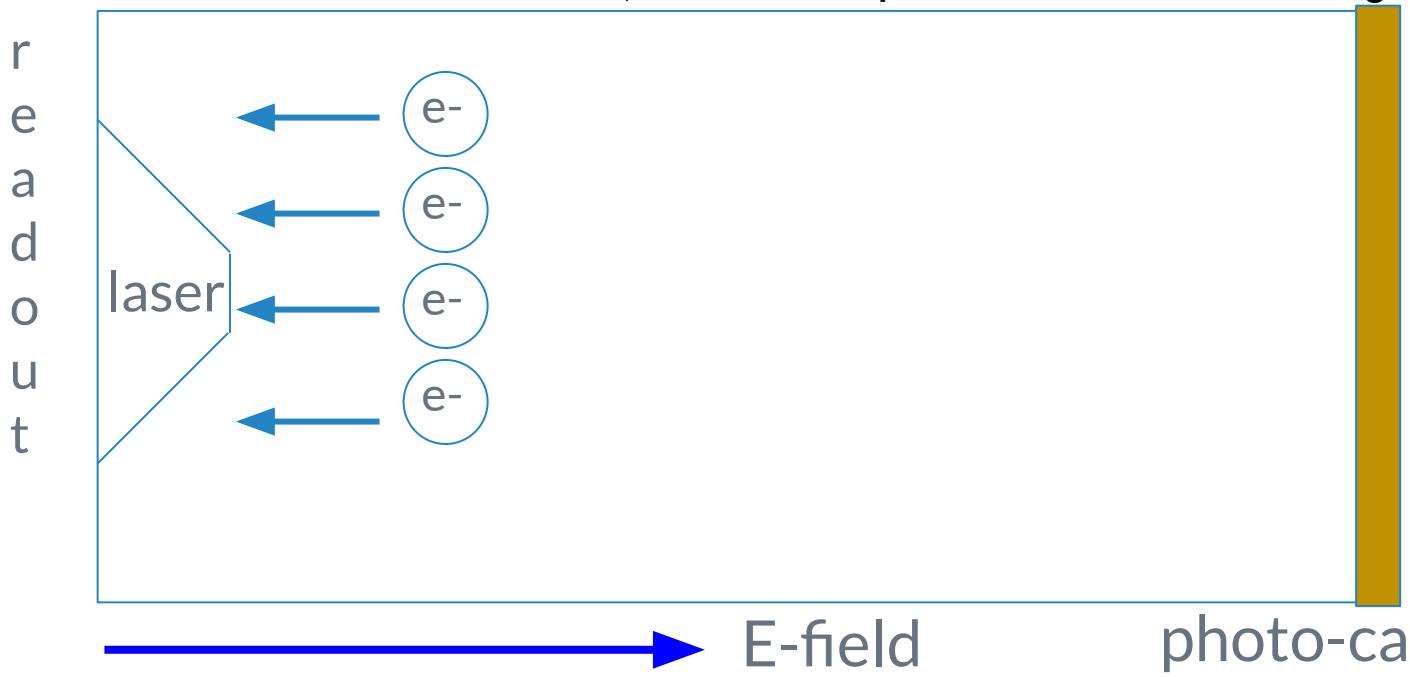

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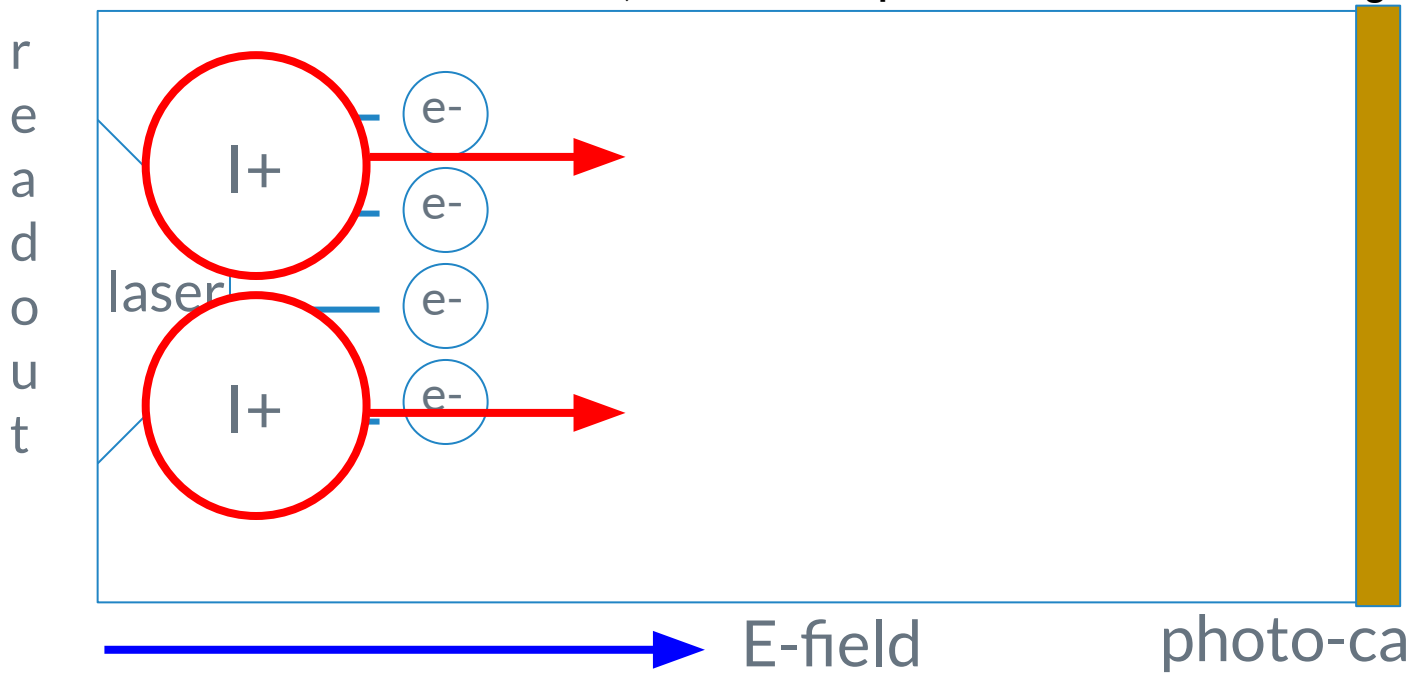

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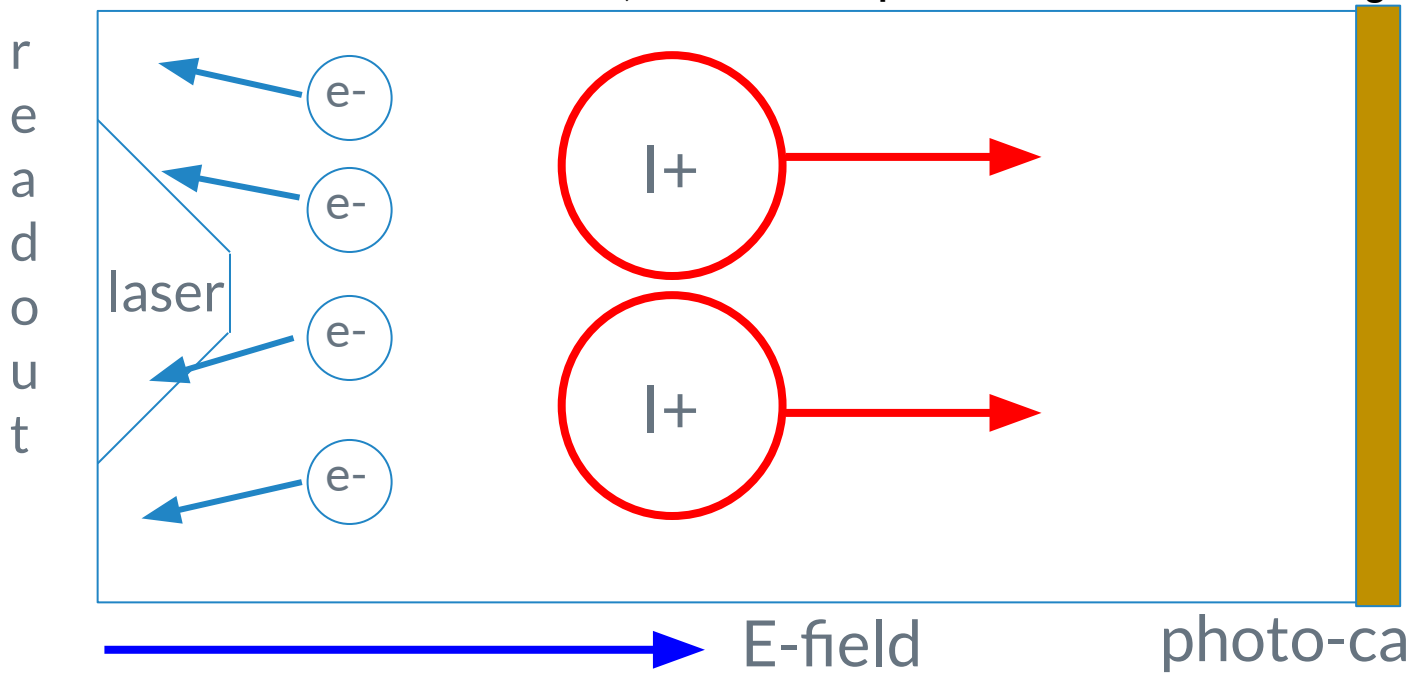
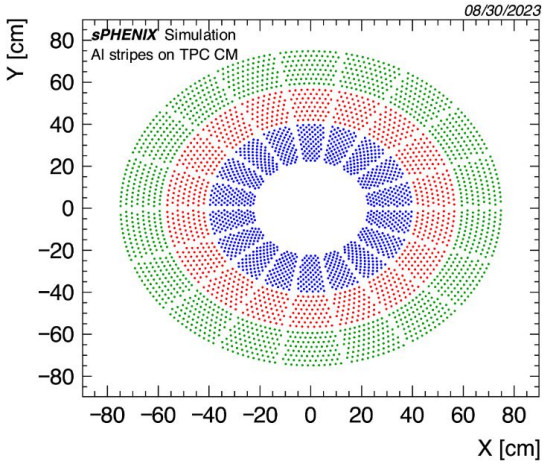
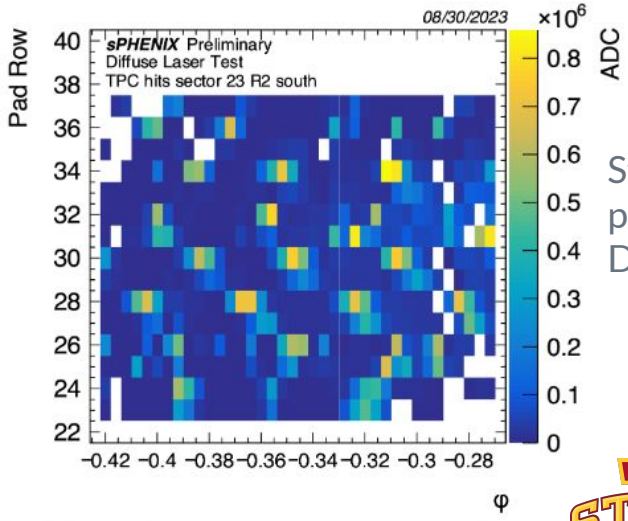


ExE Distortions

- Diffuse Laser:
  - Installed XXX?
  - First used (no collisions) - 06/15/23
  - Much testing throughout commissioning/Run ‘23
    - See Ben Kimmelman’s QM poster
    - Stripe pattern reconstructed
  - Not able to commission diffuse laser w/ beam
    - Hope to do soon into Run ‘24
  - Was able to us diffuse laser w/ cosmics
    - Laser fire fully integrated w/ cosmic trigger
    - Analyzing data now



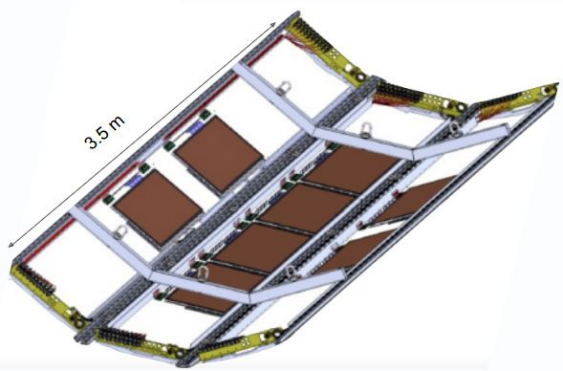
Stripe pattern in SIMULATION

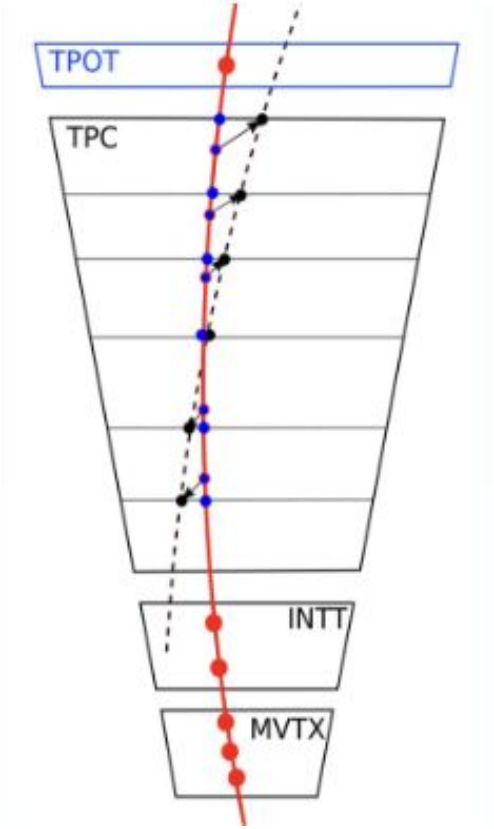


Stripe pattern in DATA

Average Distortions

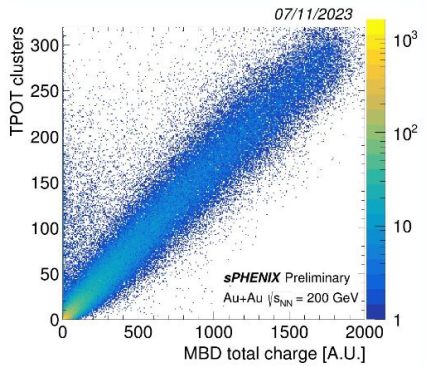
- **TPOT:**
  - **Tracks emerge from vertex**
  - **Tracks traverse TPC, are distorted**
  - **TPOT provides un-distorted reference point**
    - **In small volume of TPC**
  - **Can be used as a x-check for distortions correction**
    - **OR used to correct distortions***
    - ***** **in small volume of TPC**

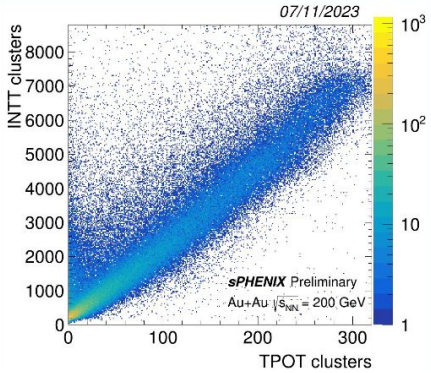


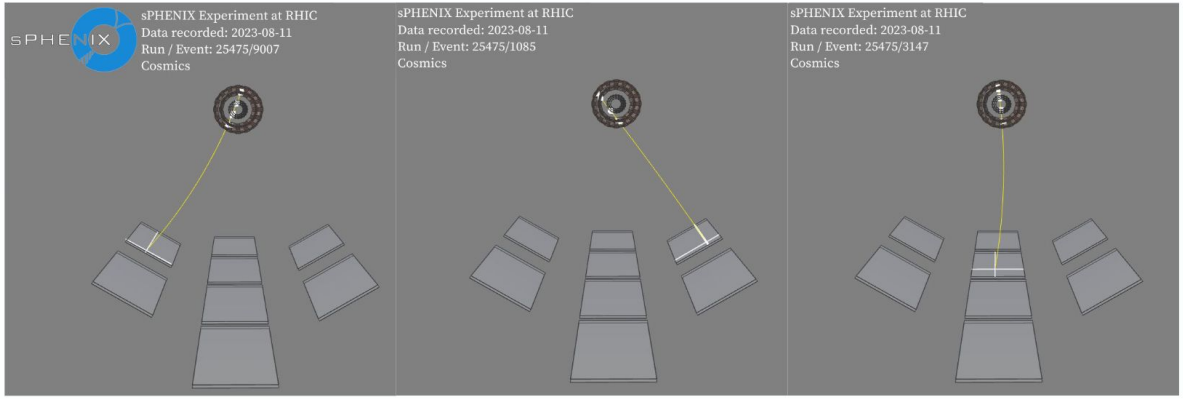


Average Distortions

- TPOT:
  - Installed 12/12/2022
  - Operating routinely since 05/23
    - No opportunity to exercise average distortion correction/x-check
    - Expect to do this in Run ‘24
  - Did take cosmic & collision data in Run’23
    - Cosmics w/ full tracking chain - analysis ongoing
    - Collision data demonstrate TPOT tracking functionality
    - See Bade Sayki’s Quark Matter Poster







Static Distortions

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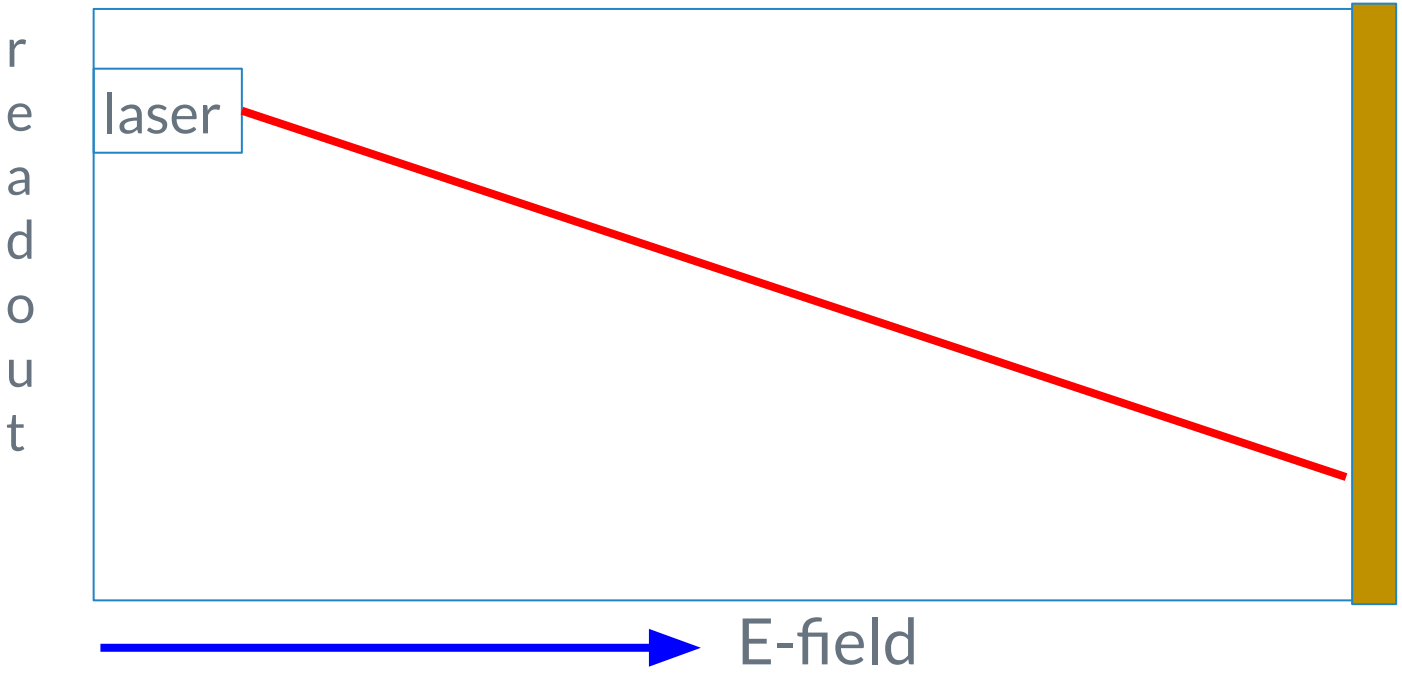
  - **4 steerable lasers at each end cap send a concentrated DUV beam into gas**



Static Distortions

- **Direct Laser:**
  - **4 steerable lasers at each end cap send a concentrated DUV beam into gas**
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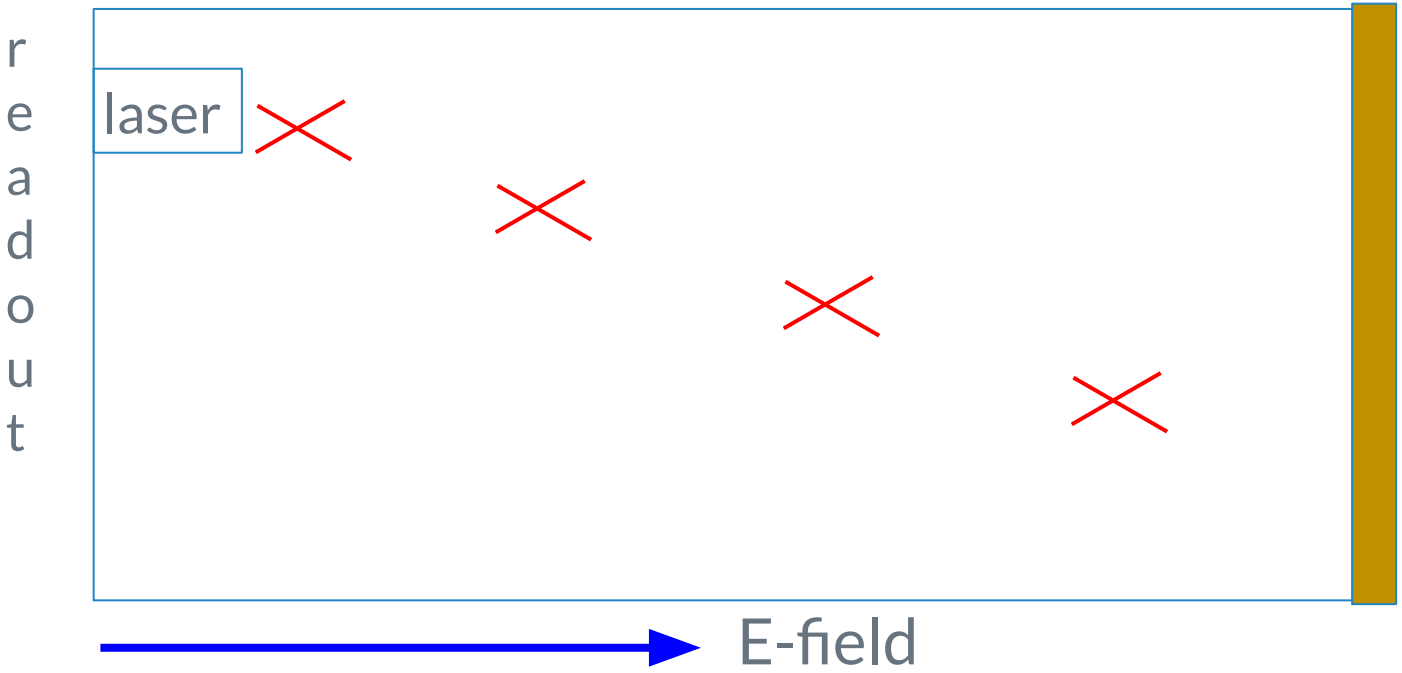
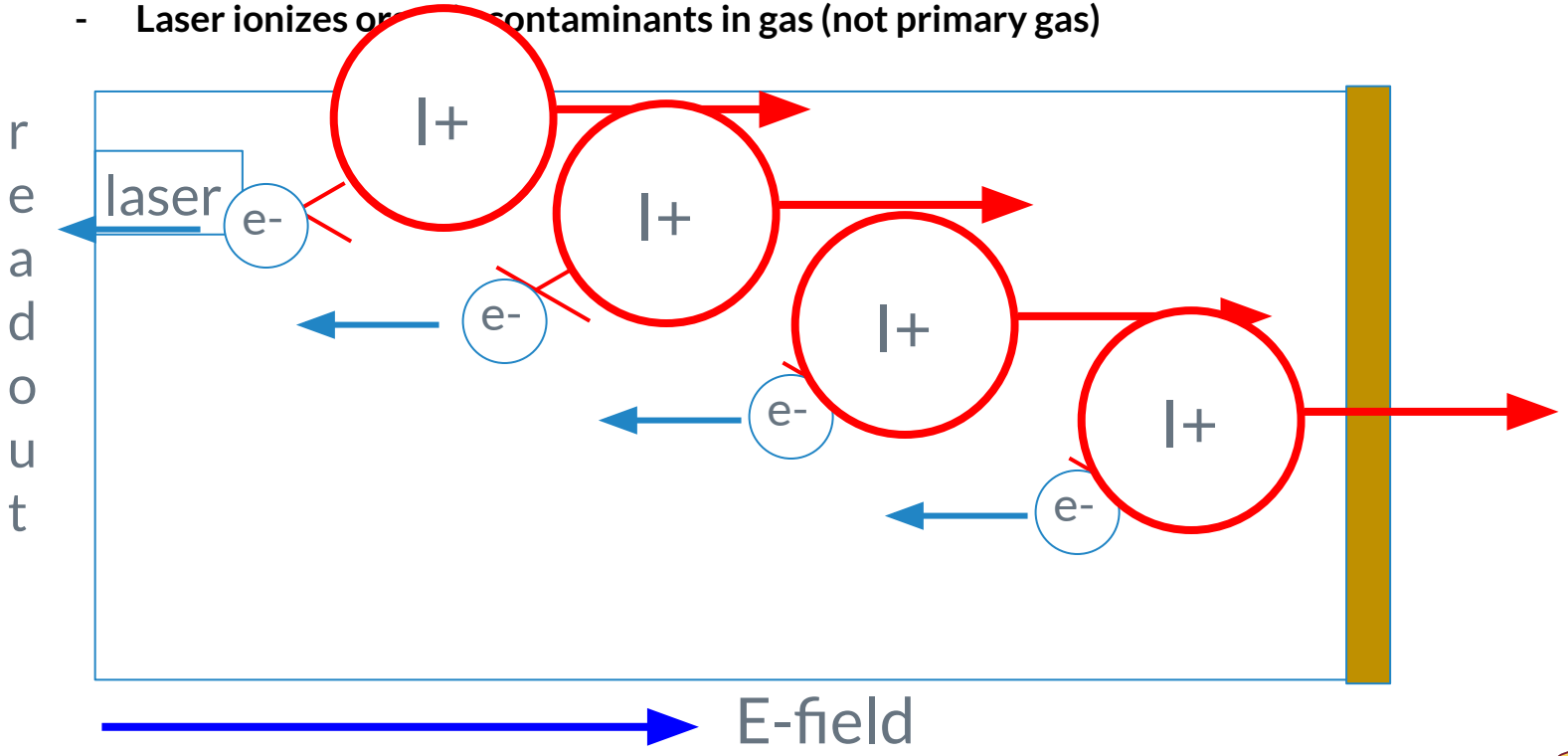


Static Distortions

- **Direct Laser:**
  - **Between runs, 4 steerable lasers at each end cap send a concentrated DUV beam into gas**
  - **Laser ionizes or[illegible]contaminants in gas (not primary gas)**



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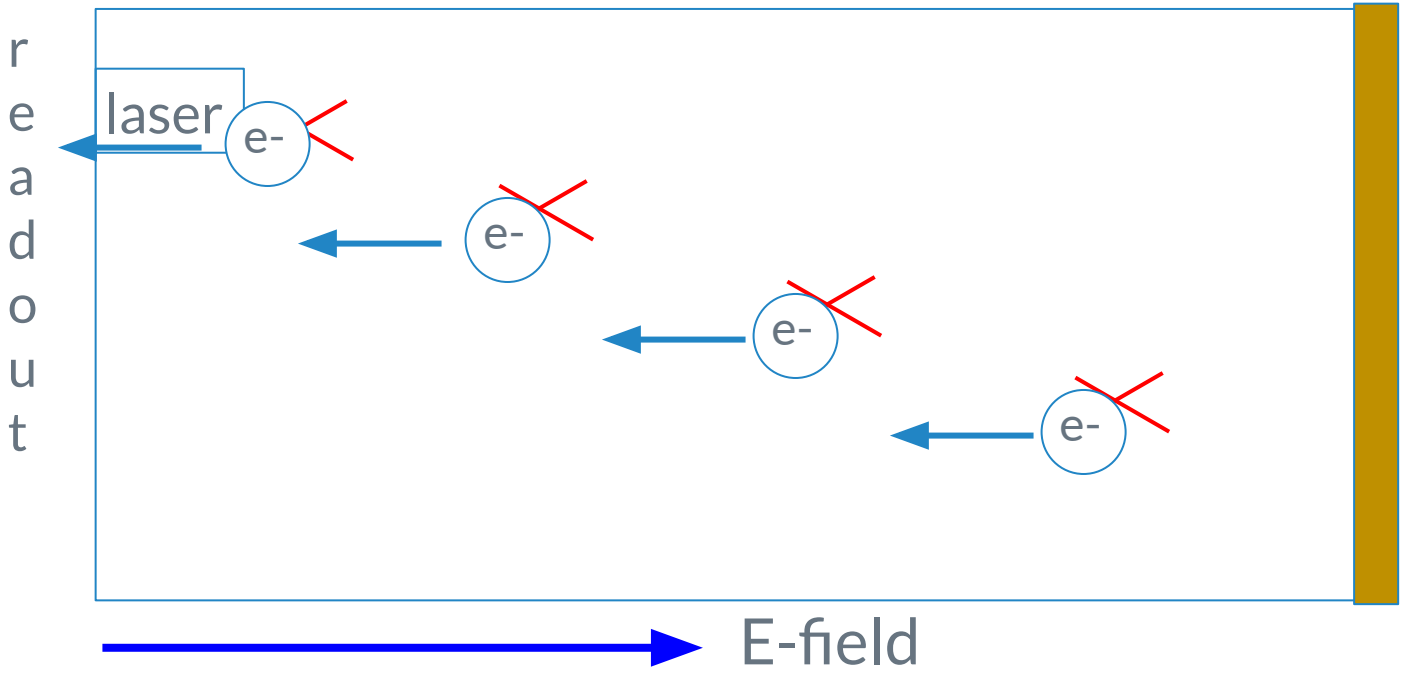

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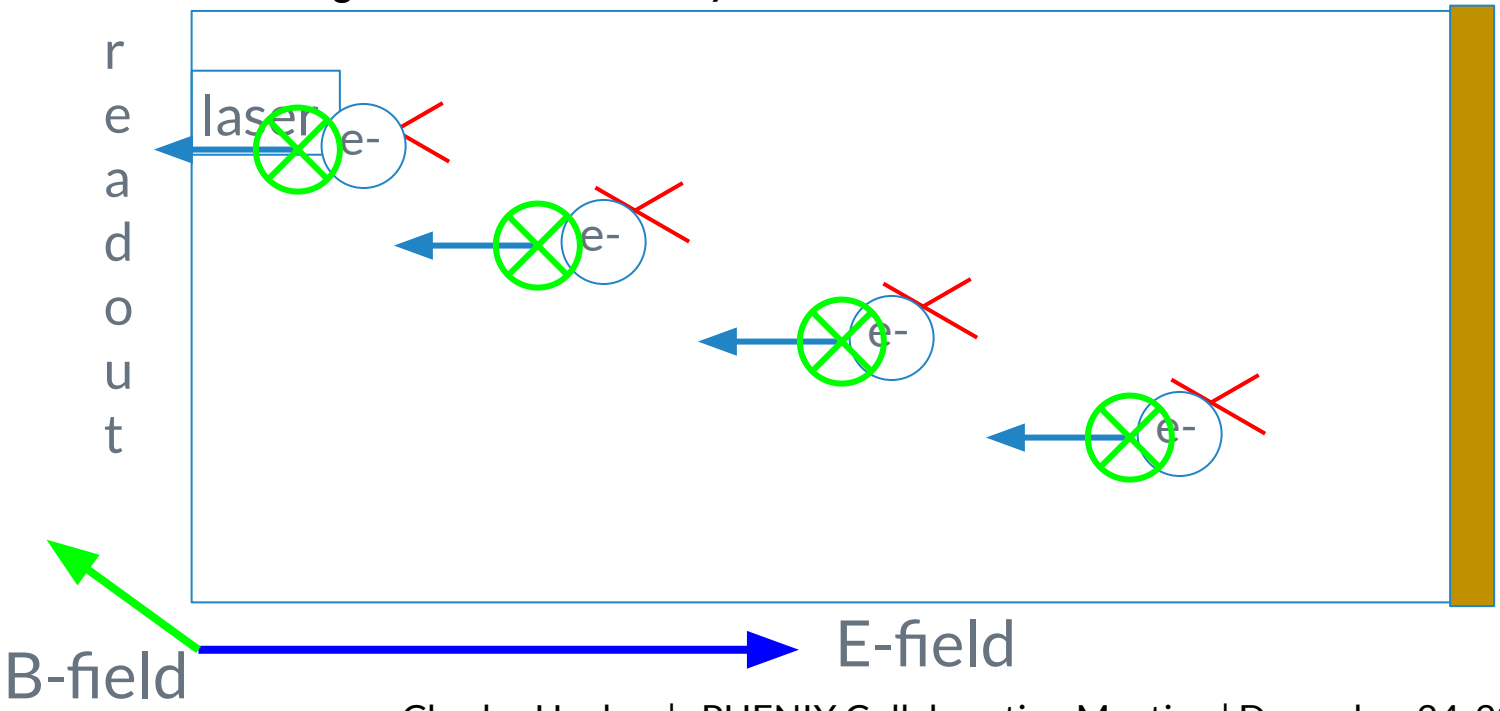

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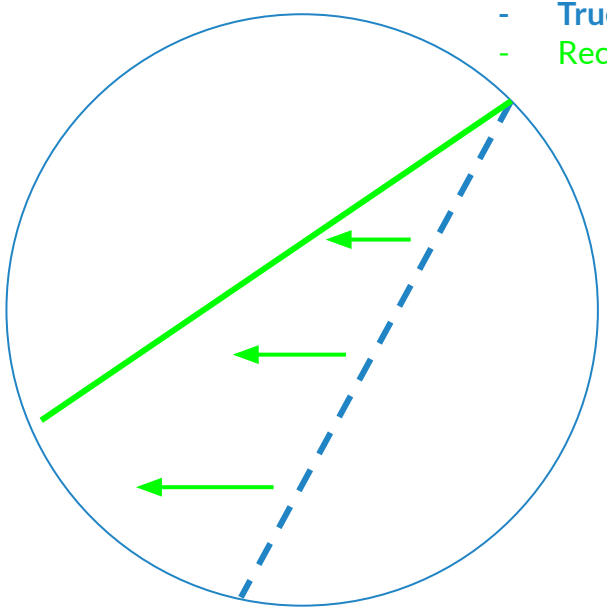
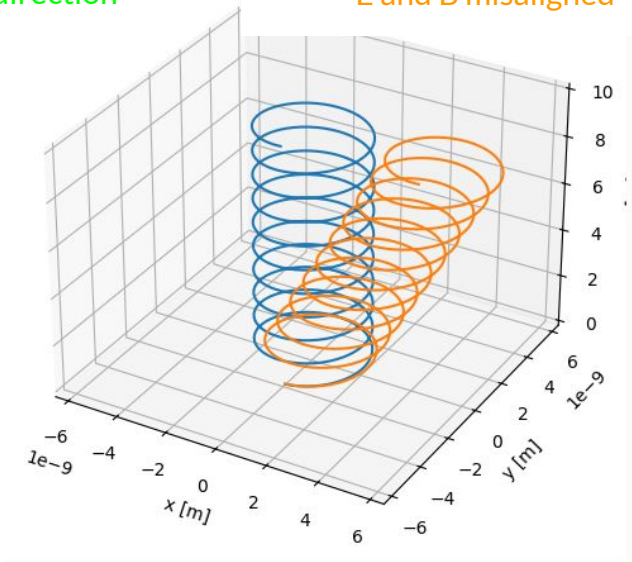


- True laser direction
- Reconstructed direction

- E and B aligned
- E and B misaligned

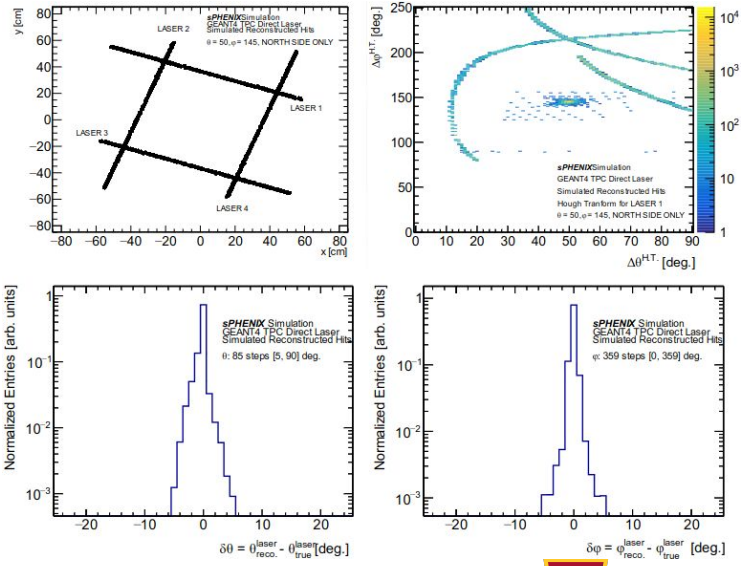


Static Distortions

- Direct Laser:
  - Installed 02/23-03/23
  - Uninstalled 11/23

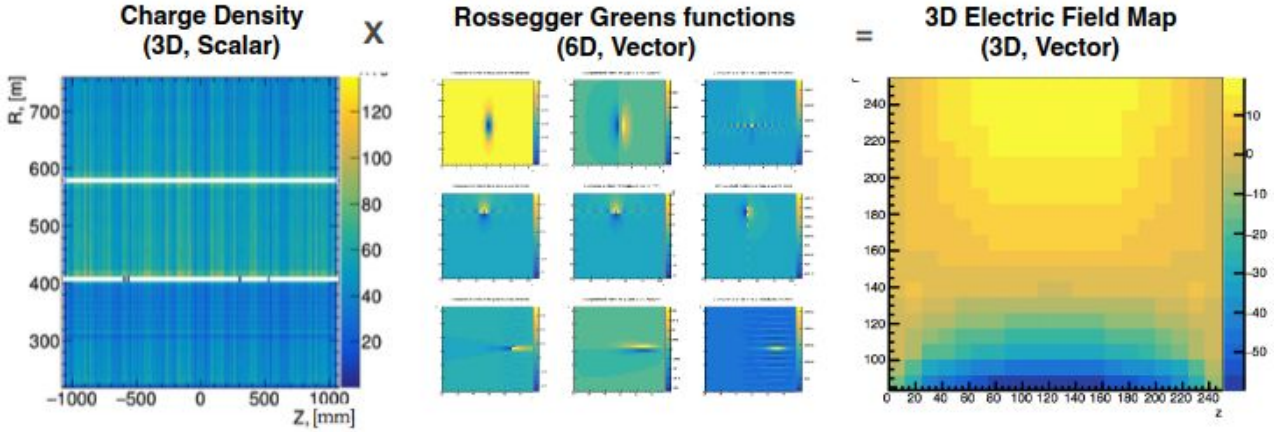
  - Not used during ‘23
    - Lack of controller hardware
    - BUT have controller hardware now
    - Test between now and March ‘24
    - Re-install before March ‘24

  - Meantime, understanding reconstruction in simulation
    - See Charles Hughes’ QM Poster
    - Un-biased way to find reference direction



Distortions Modeling/Digital Currents

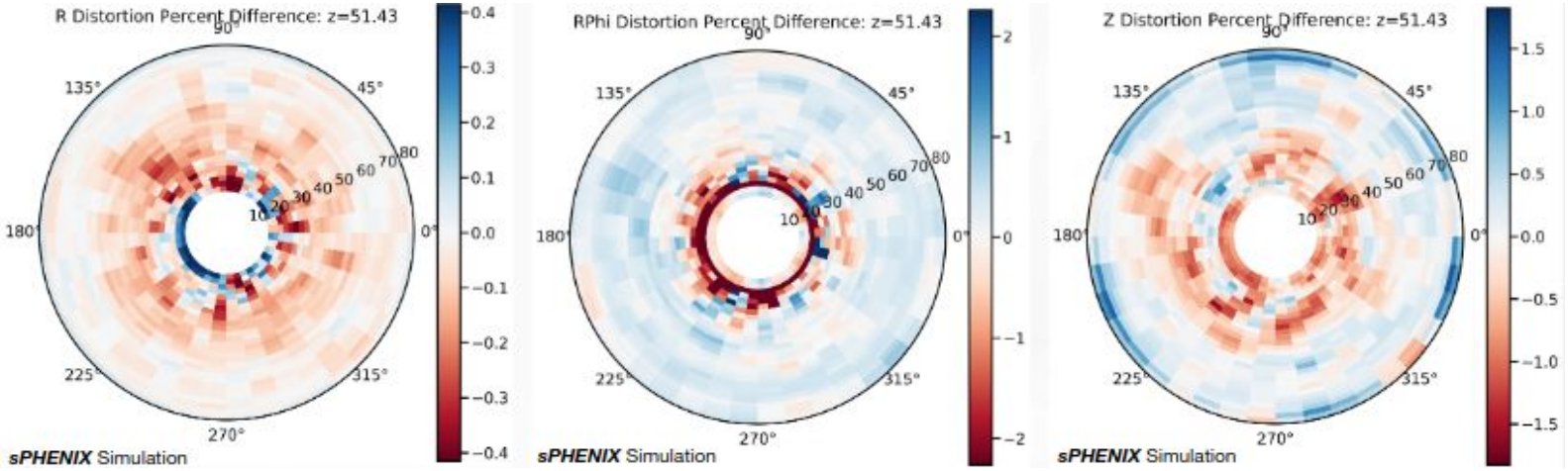
- Ion Back Flow for each module characterized on bench
- Scale integrated digital charge by IBF to get digital current density
- Combine with model estimate of primary charge -> space charge map
- Use space charge map + E and B field simulation to “swim” test particles to readout -> get distortions



Distortions ML

- Use digital current density map (previous slide) to estimate distortions with ML
  - Map 3D image of digital current to 3D image of distortions
  - Use U-net architecture
  - Reduces computational cost compared to “swimming particles” model

- Good results with simulations so far:
  - See [Dhanush Hangal’s Quark Matter Poster]



The Road Ahead

- We want to be able to tackle track distortions from multiple angles
  - Direct & Diffuse Lasers, TPOT, Modeling, ML
  - Making good progress in doing this - simulations & data

- The limitations of Run ‘23 prevented us from commissioning full distortions correction chain
  - TPC commissioning (see Tom’s update)
  - Loss of cryo in August (no beam/detector magnet)
  - Lack of hardware (direct laser)
  - Commissioning of Event Pooling/Reconstruction (see Chris’ update)

- We will not wait until Run ‘24 to start learning about distortions in the TPC
  - **In the meantime, we must make the best use of the data we do have**

The Road Ahead - Contd.

- In the meantime, we must make the best use of the data (and capabilities) we do have

- So the road ahead passes through the following:
  - Cosmics
  - Data Processing on Distortions
  - Readiness for real data (including pp) in Run ‘24

The Road Ahead - Cosmics

- Can take cosmics data independent of beam/magnet status
  - Have already done this many times (see Tom's talk)
  - Now have ability to reconstruct full events automatically (see Chris' talk)
  - Tracks in absence of B-field should be perfectly straight
    - Any deviation must be alignment and intrinsic TPC performance
    - We will work to understand this
  - Study of cluster shapes/ion tails in cosmics
  - Verification of channel mapping (in conjunction with use of Diffuse Laser flash)

The Road Ahead - Data Processing

- **Prepare to set up the tool chain which measures distortions from data and applies corrections**

-

The Road Ahead - Readiness for Data

- Work on track matching between TPC/INTT/MVTX to do track-based distortions
  - Can do this with the cosmics data we have now
  - Need to learn how without a distortions map OR
- Get a static distortion map without the lasers?
  - Diffuse laser flash + modeling/interpolation
- Set up analysis framework for track residual and Central Membrane based performance studies.

Conclusions

- A lot of good work has been done/is being done despite challenges of ‘Run 23
- Much work remains to get to a state of readiness distortions corrections in ‘Run 24
- A road map exists for this work:
  - Direct laser hardware tests
  - Cosmics/Diffuse Laser data taking/analysis
  - Code/Infrastructure
- It is important to keep in mind a couple things:
  - The TPC HV system is undergoing extensive modifications - these take priority
  - The distortions group could use some help…

Backup

- **Backup**