ePIC dRICH

Dual Ring Imaging Cherenkov Detector

Christopher Dilks

ePIC Collaboration Meeting

January 2023

Research supported by the

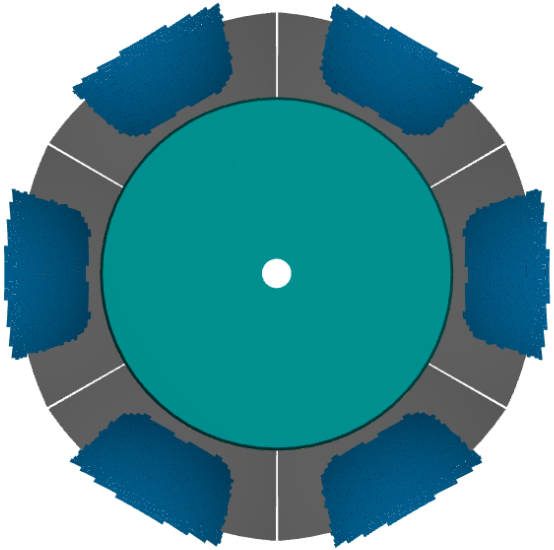
U.S. DEPARTMENT OF ENERGY | Office of Science

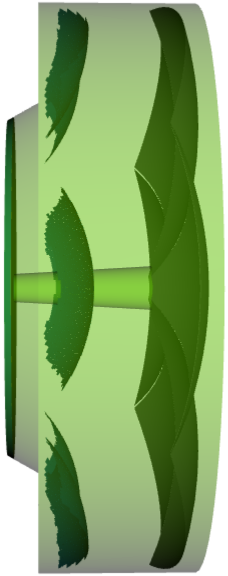
Duke UNIVERSITY

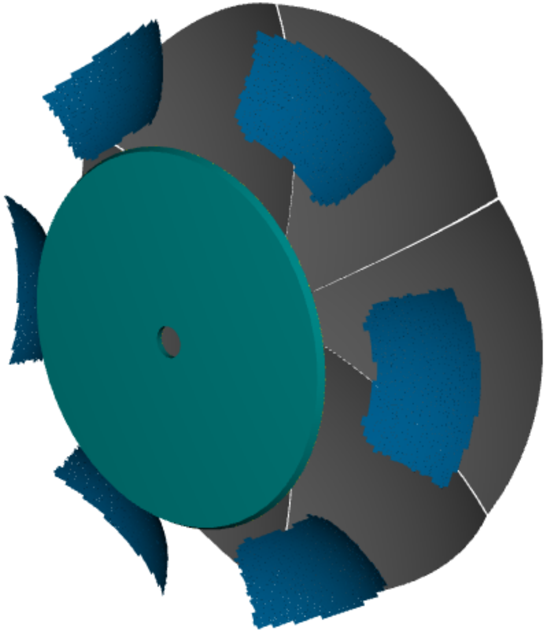
Outline

- **ePIC Simulation**
  - Geometry and Reconstruction
  - Performance studies
- **dRICH Prototype**
  - Beam tests
  - EIC-driven tests
  - Characterization

DD4hep Geometry







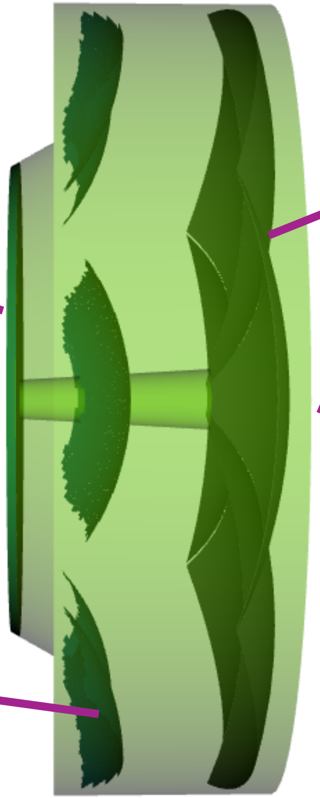
3D Interactive View!

https://eic.github.io/epic/geoviewer?file=artifacts/tgeo/drich_only.root&item=default;1&opt=zoom200;ROTY290;ROTZ350;trz0;trr0;ctrl;all

Geometry – Details

- **4 cm of aerogel**
- 0.01 mm air gap
- 0.3 mm acrylic filter

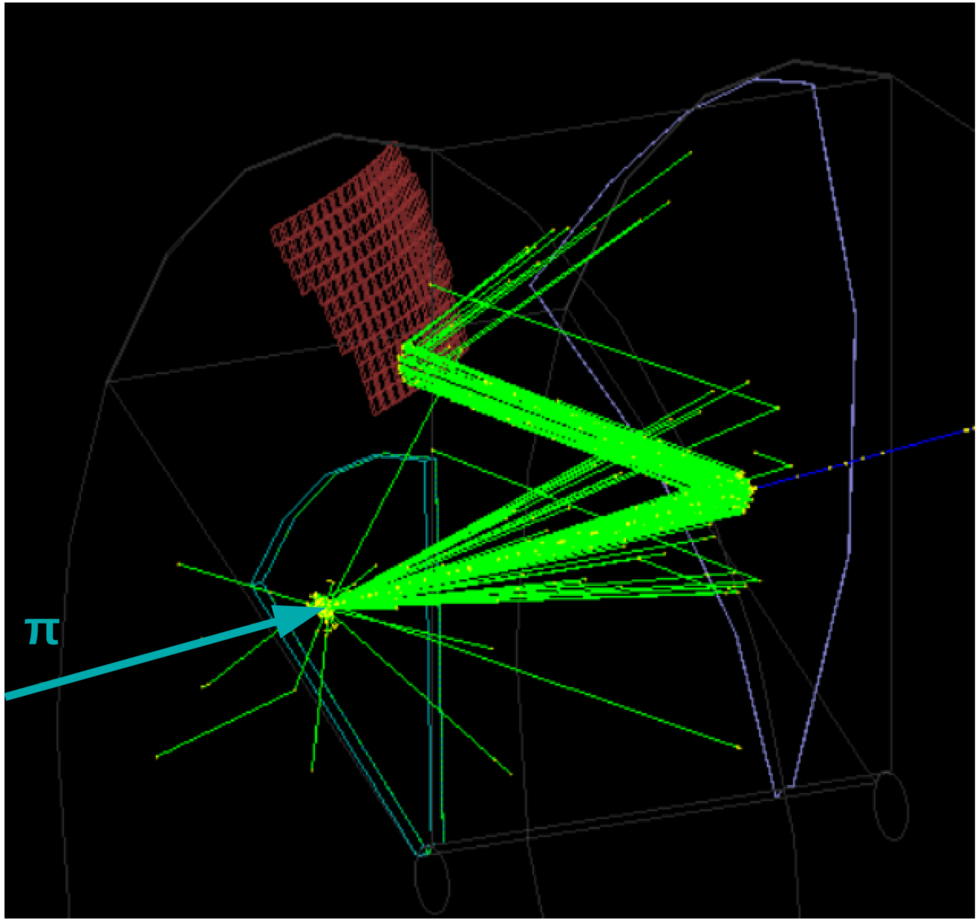
- Sensors tiled on **spheres**
- S13361-3050NE-08 SiPMs
- **8x8 pixels**

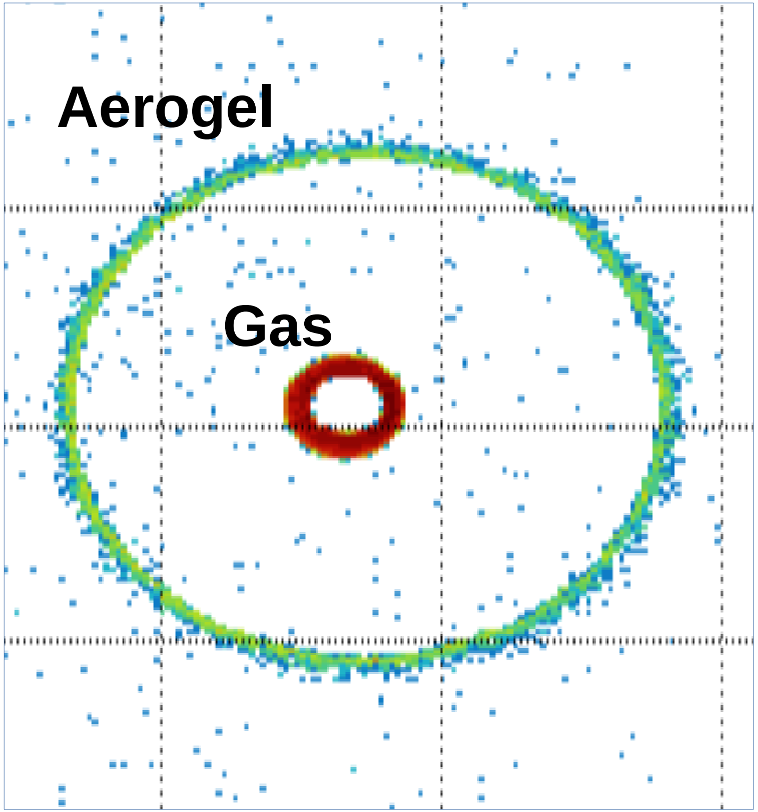


- **Spherical Mirrors**
- 6 Azimuthal Sectors

- **C_2F_6 Gas Volume**
- **120 cm (full) z-length**
- 185 cm outer radius
- Aerogel radius ~110 cm
- Tapered bore radius
- Aluminum vessel walls

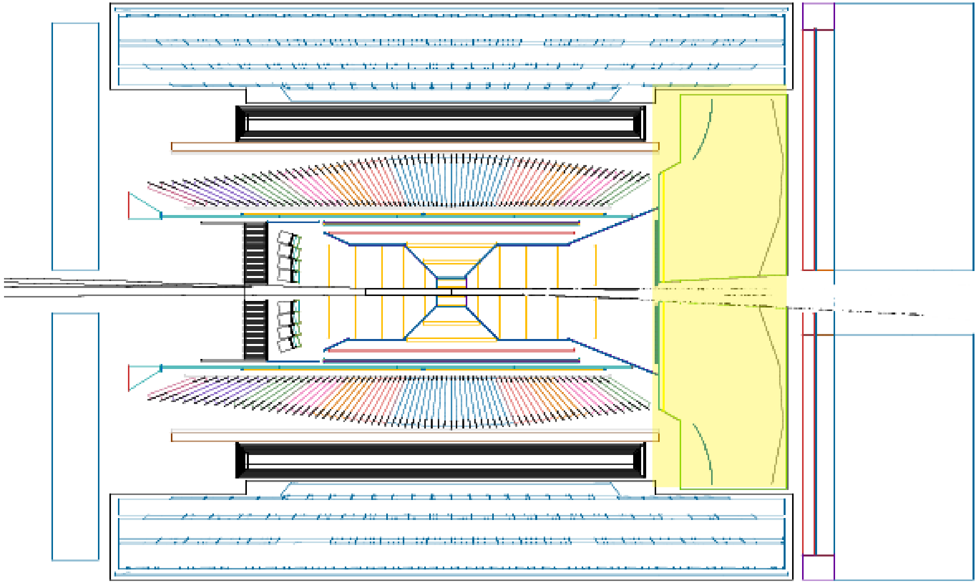
Example Event



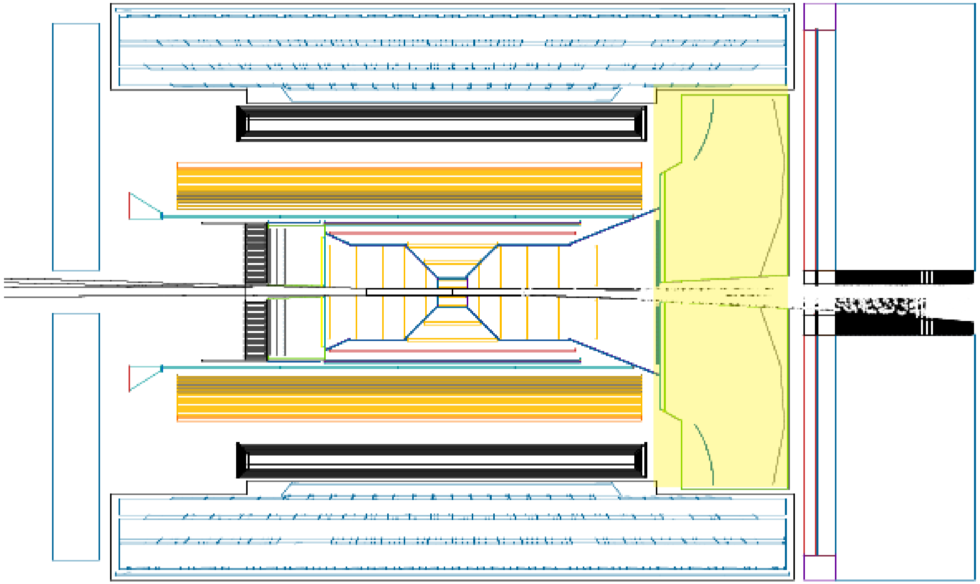


dRICH Integrated in Full ePIC Geometry

Arches

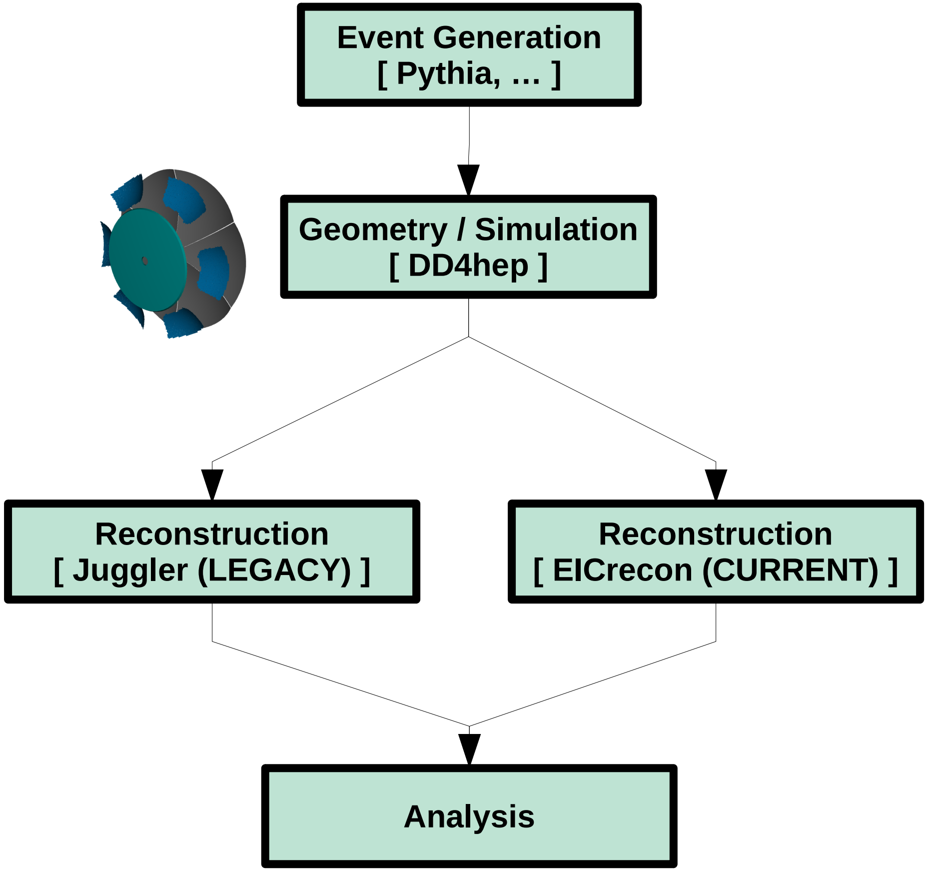


Bryce Canyon



- Includes effects from magnetic field, material in front (e.g., tracker support), and more

ePIC Software Stack Integration

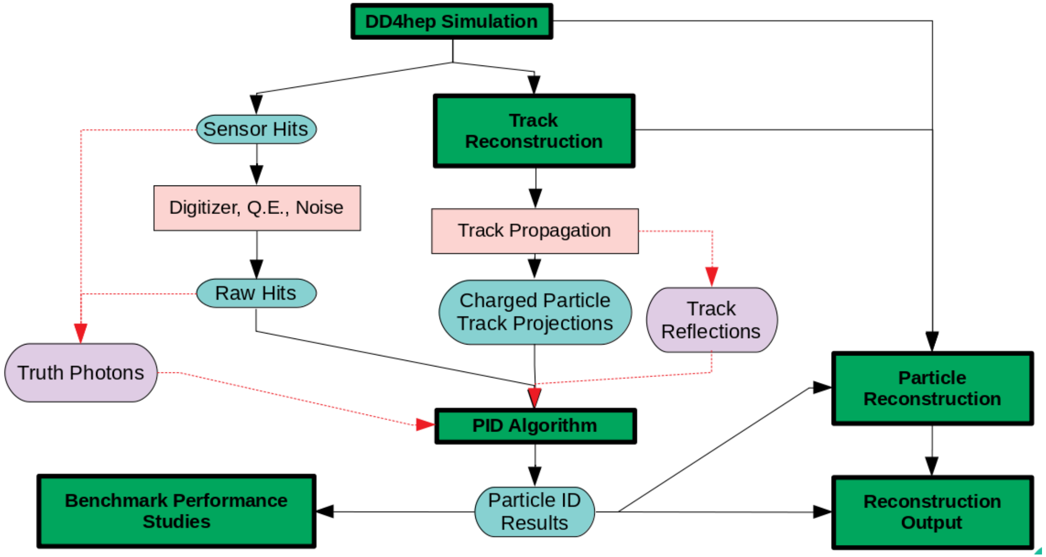


PID via IRT (Indirect Ray Tracing)

- Fully integrated with Juggler, used for present ePIC dRICH performance studies
- Integration into EICrecon mostly complete, but undergoing testing
- Standalone IRT library permits standalone performance studies too

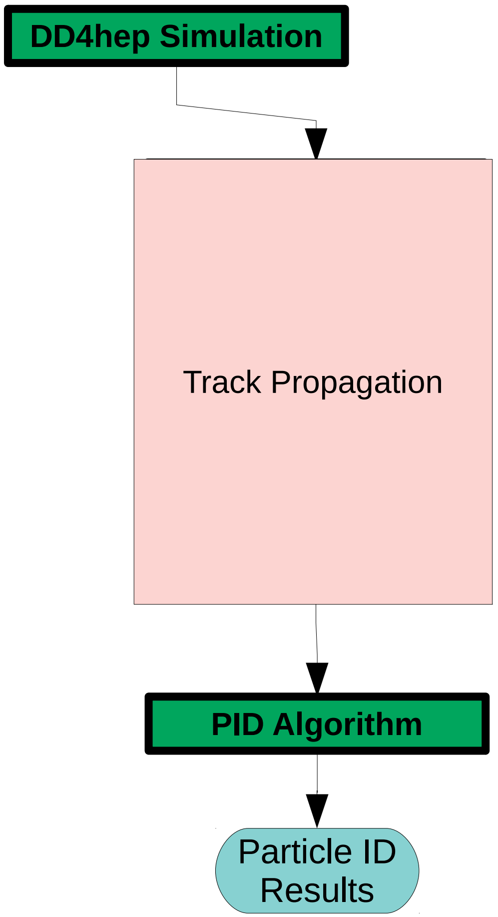
PID Integration: Modular Reconstruction Strategy

EICrecon Implementation



- Support PID in a modular, shareable, future-proof way
- Algorithms are small, focused, and generalized to support other PID subsystems
  - In some cases, other detectors (e.g. PMT digitizer)
- Keep algorithms independent of the reconstruction framework

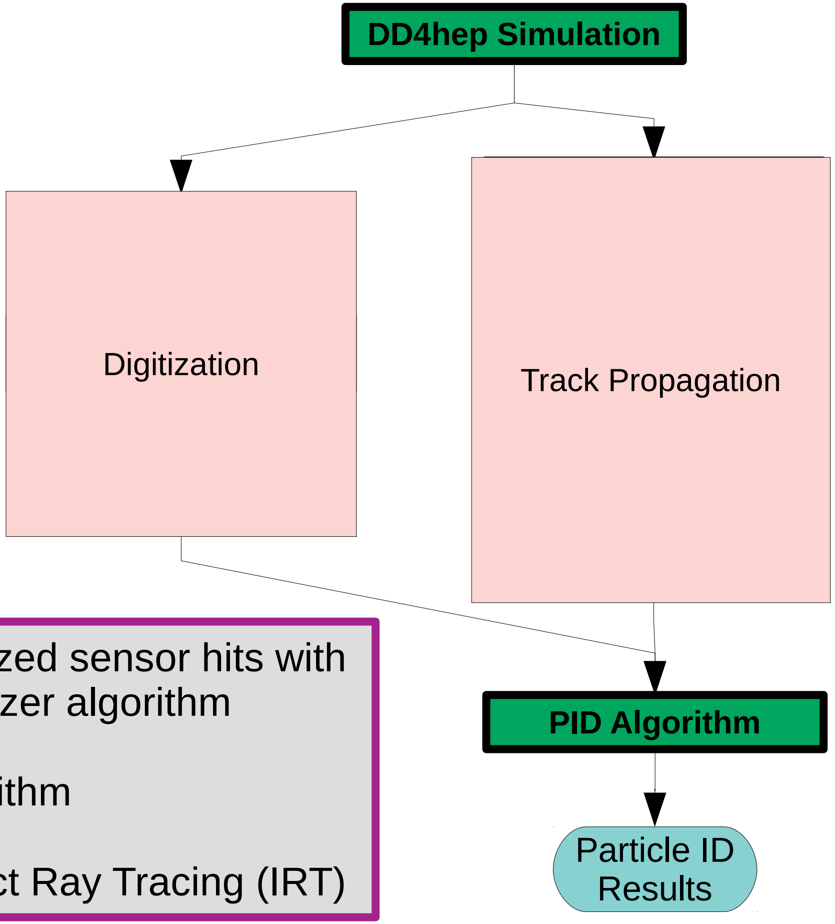
EICrecon Flowchart



- Goal: PID for each charged particle
- First, project reconstructed tracks to transverse planes of the dRICH

  → charged particle track points

EICrecon Flowchart



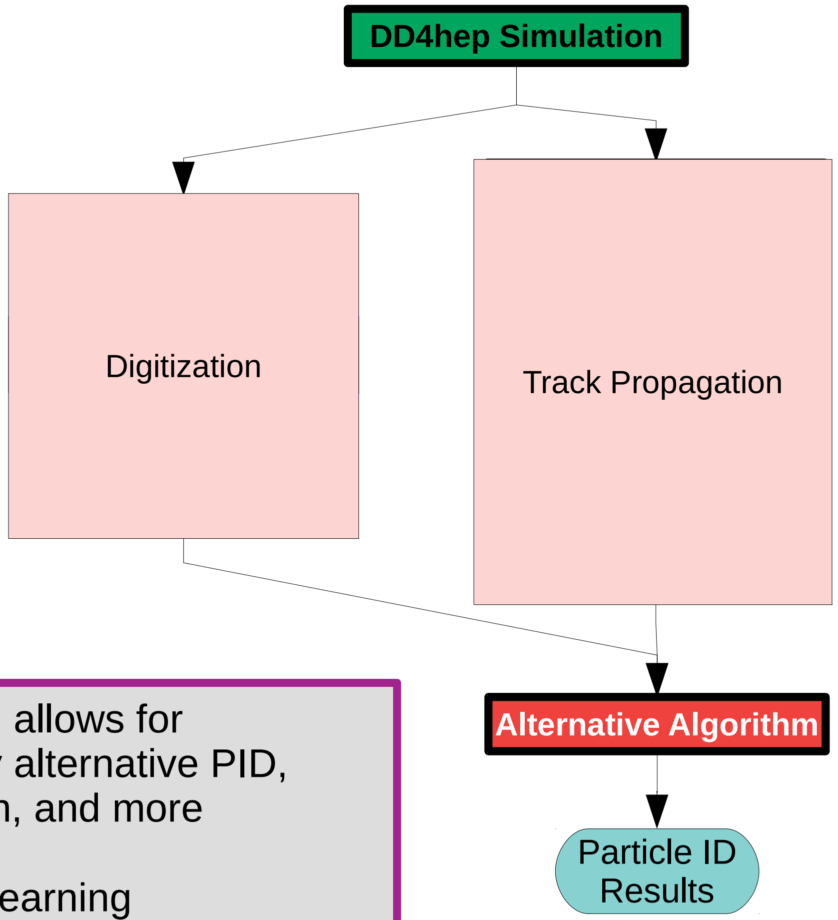
- Goal: PID for each charged particle
- First, project reconstructed tracks to transverse planes of the dRICH

  → charged particle track points

- Combine with digitized sensor hits with common PMT digitizer algorithm
- Then run PID algorithm

  Currently: Indirect Ray Tracing (IRT)

EICrecon Flowchart

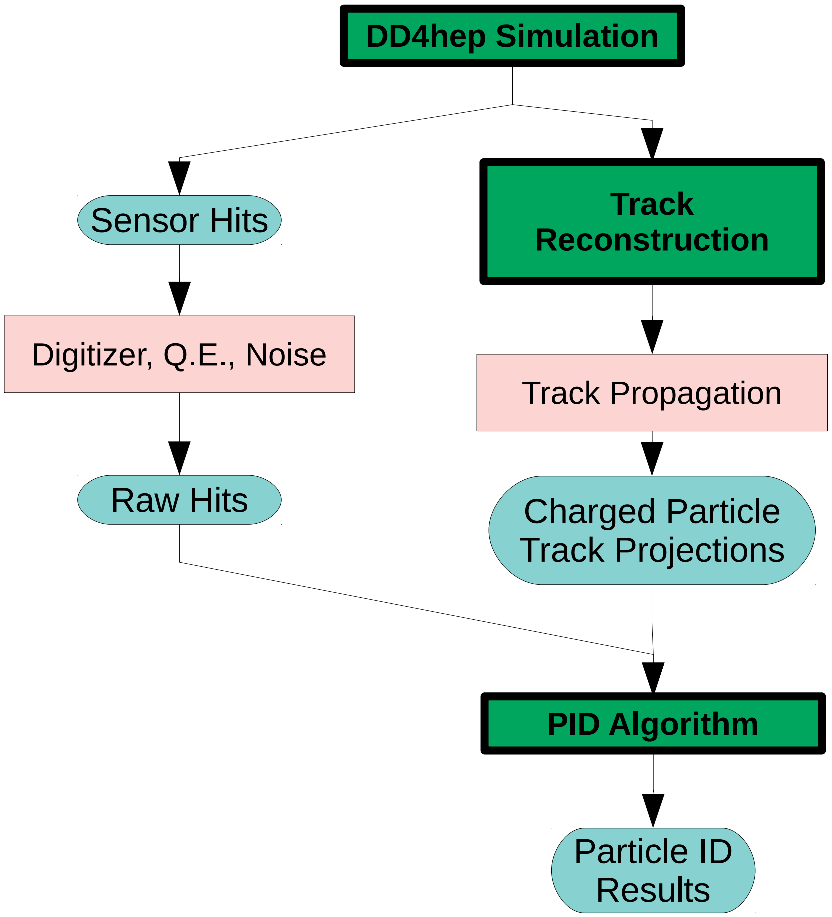


- Modular approach allows for substitution of any alternative PID, pattern recognition, and more

    e.g., Machine Learning

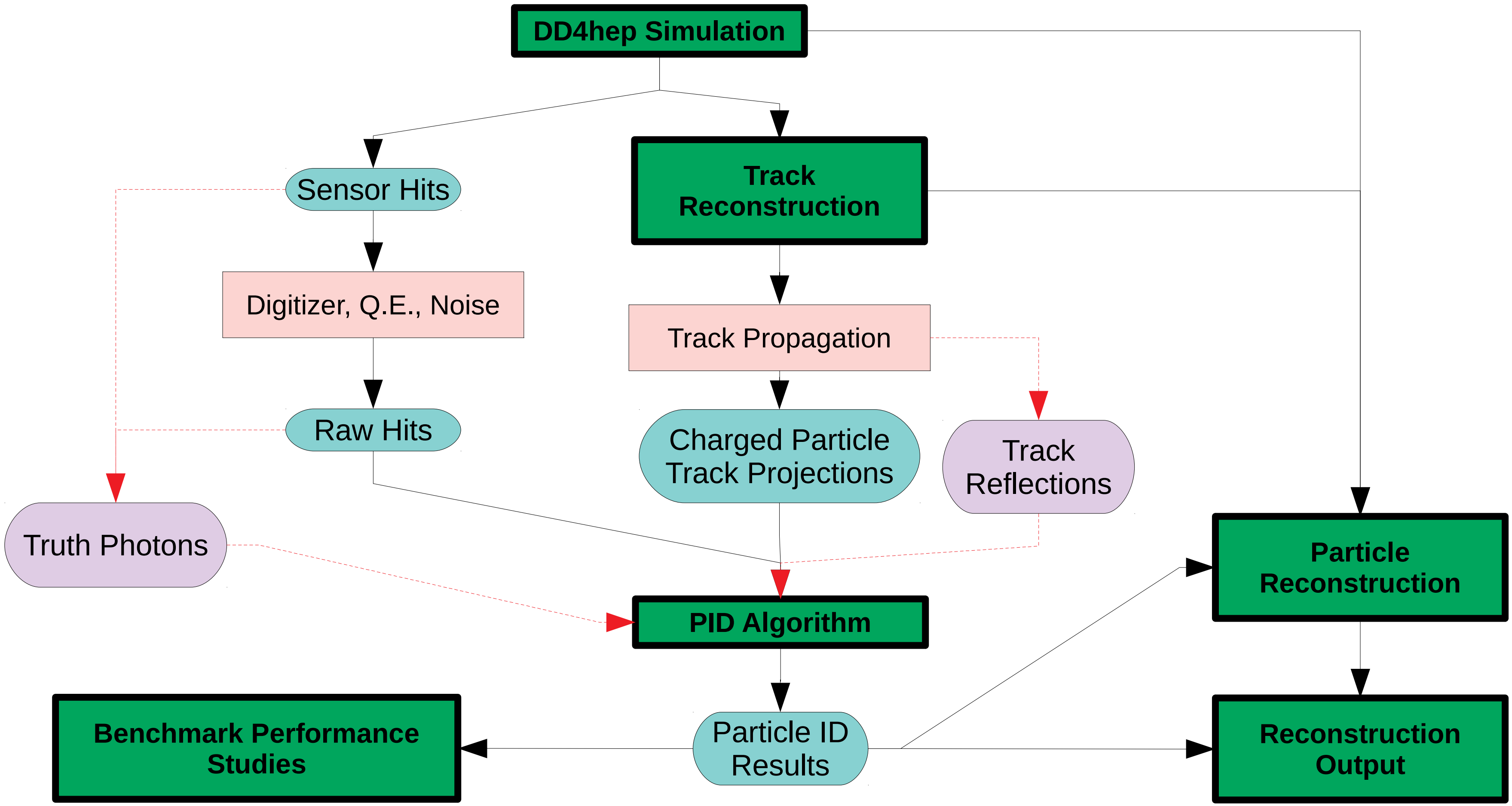
Algorithm Integration Welcome!

EICrecon Flowchart

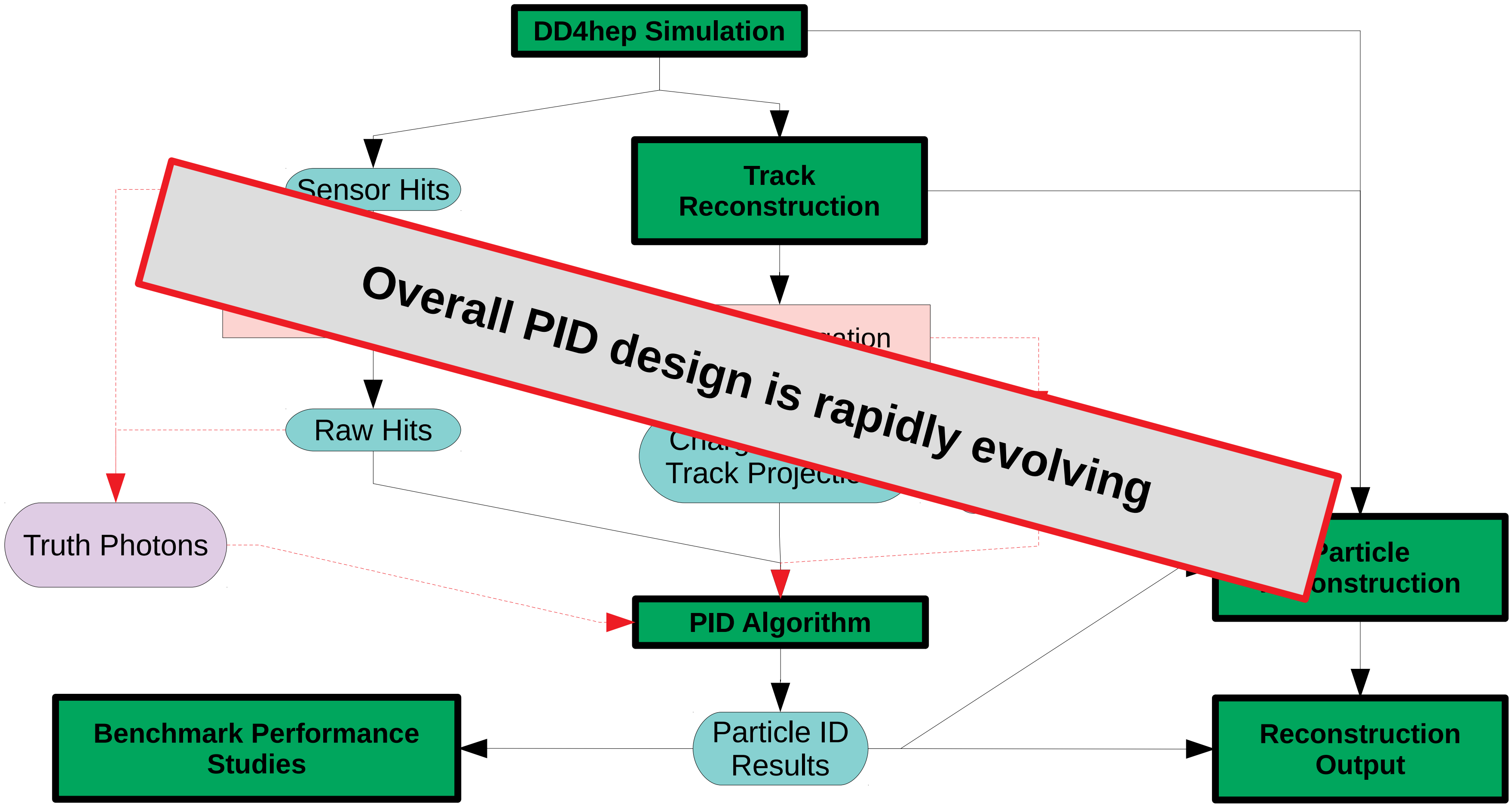


Under the hood…

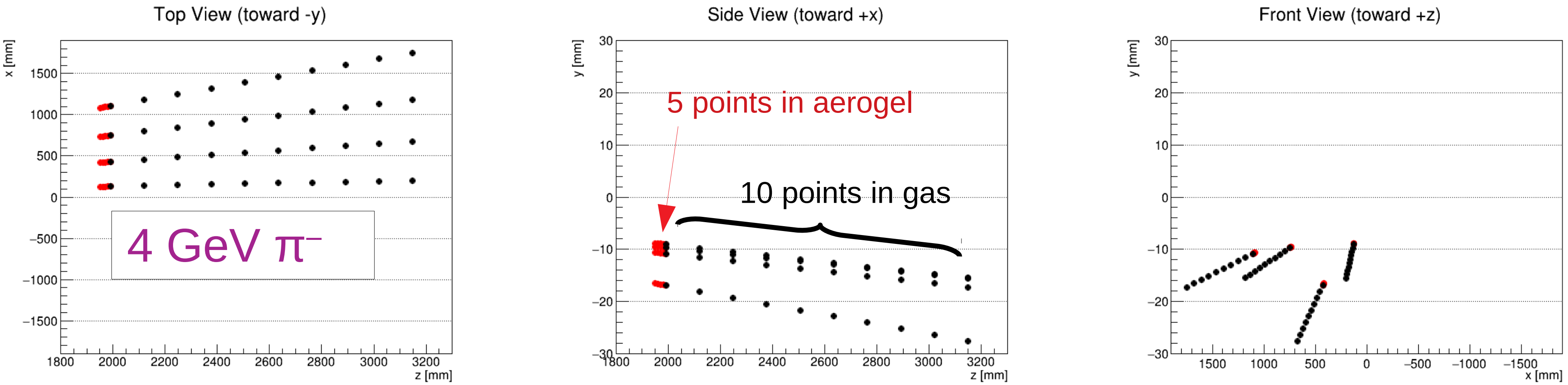
EICrecon Flowchart



EICrecon Flowchart



Charged Particle Track Projection



- Example: 4 GeV pions in horizontal y=0 plane
- **Reconstructed** track points in **Aerogel** and **Gas**

Digitization

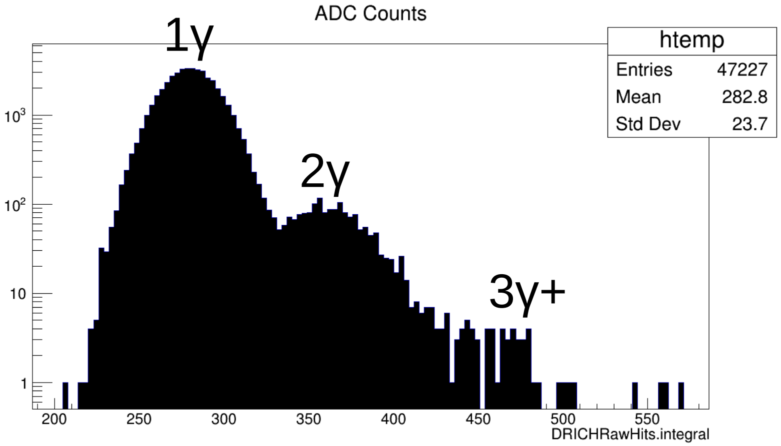
Common PMT Digitizer Algorithm

- Trigger parameters (gate, pedestal, etc.)
- Quantum Efficiency
- Empirical Safety Factor 70%
- Pixel Gap cuts (~88% survive)
- **TODO:**
  - noise injection (in progress, NISER)
  - Time over Threshold (ToT)
  - Streaming readout?

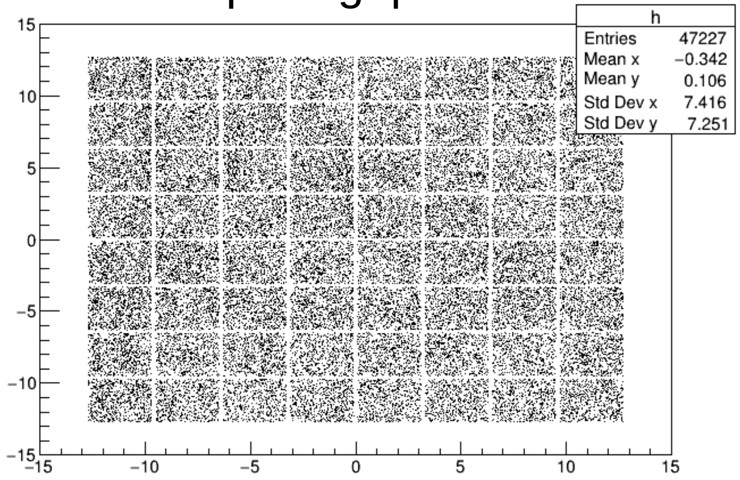
λ QE

```
{325*dd4hep::nm, 0.04},
{340*dd4hep::nm, 0.10},
{350*dd4hep::nm, 0.20},
{370*dd4hep::nm, 0.30},
{400*dd4hep::nm, 0.35},
{450*dd4hep::nm, 0.40},
{500*dd4hep::nm, 0.38},
{550*dd4hep::nm, 0.35},
{600*dd4hep::nm, 0.27},
{650*dd4hep::nm, 0.20},
{700*dd4hep::nm, 0.15},
{750*dd4hep::nm, 0.12},
{800*dd4hep::nm, 0.08},
{850*dd4hep::nm, 0.06},
{900*dd4hep::nm, 0.04}
```

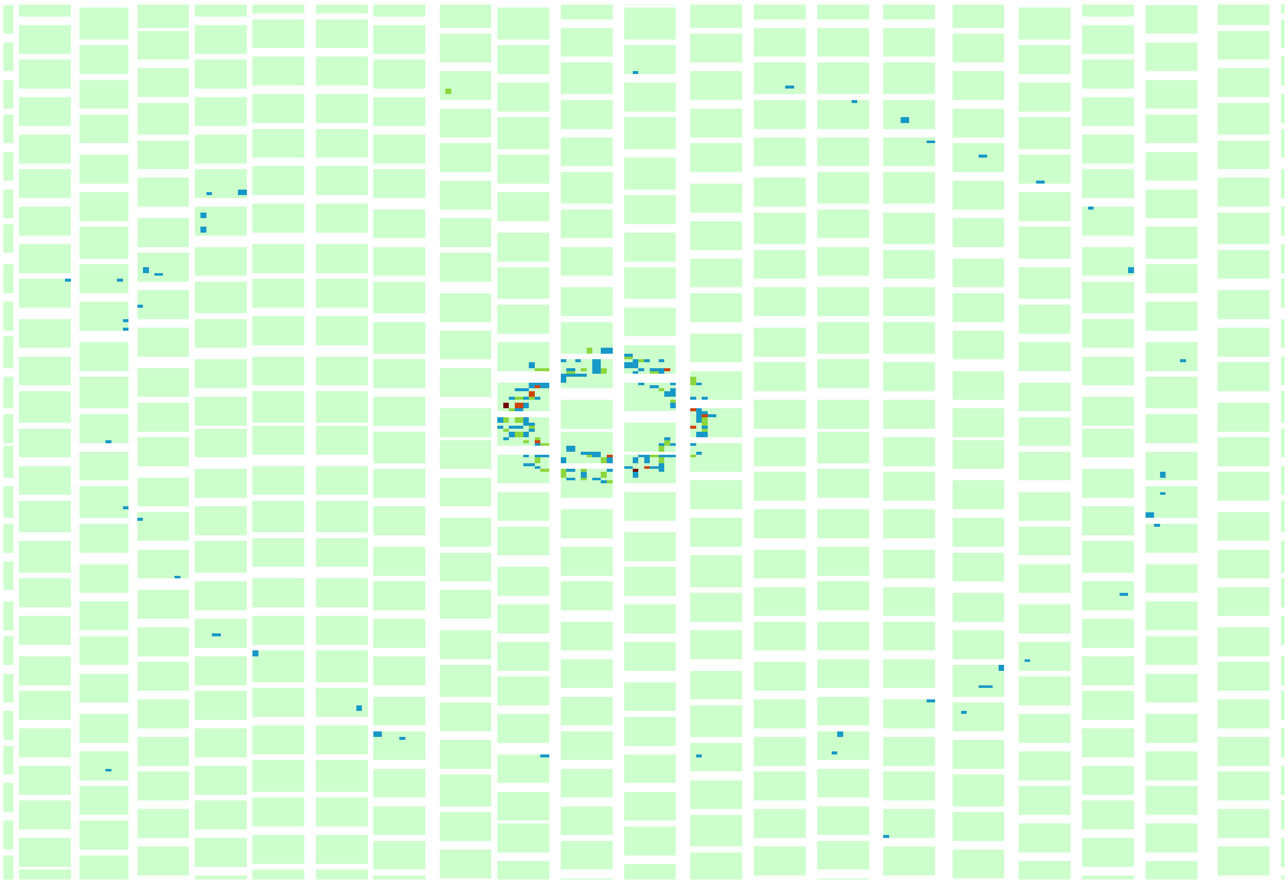
```
// triggering
double hitTimeWindow = 20.0*dd4hep::ns;
double timeStep      = 0.0625*dd4hep::ns;
double speMean       = 80.0;
double speError      = 16.0;
double pedMean       = 200.0;
double pedError      = 3.0;
```



SiPM pixel gaps

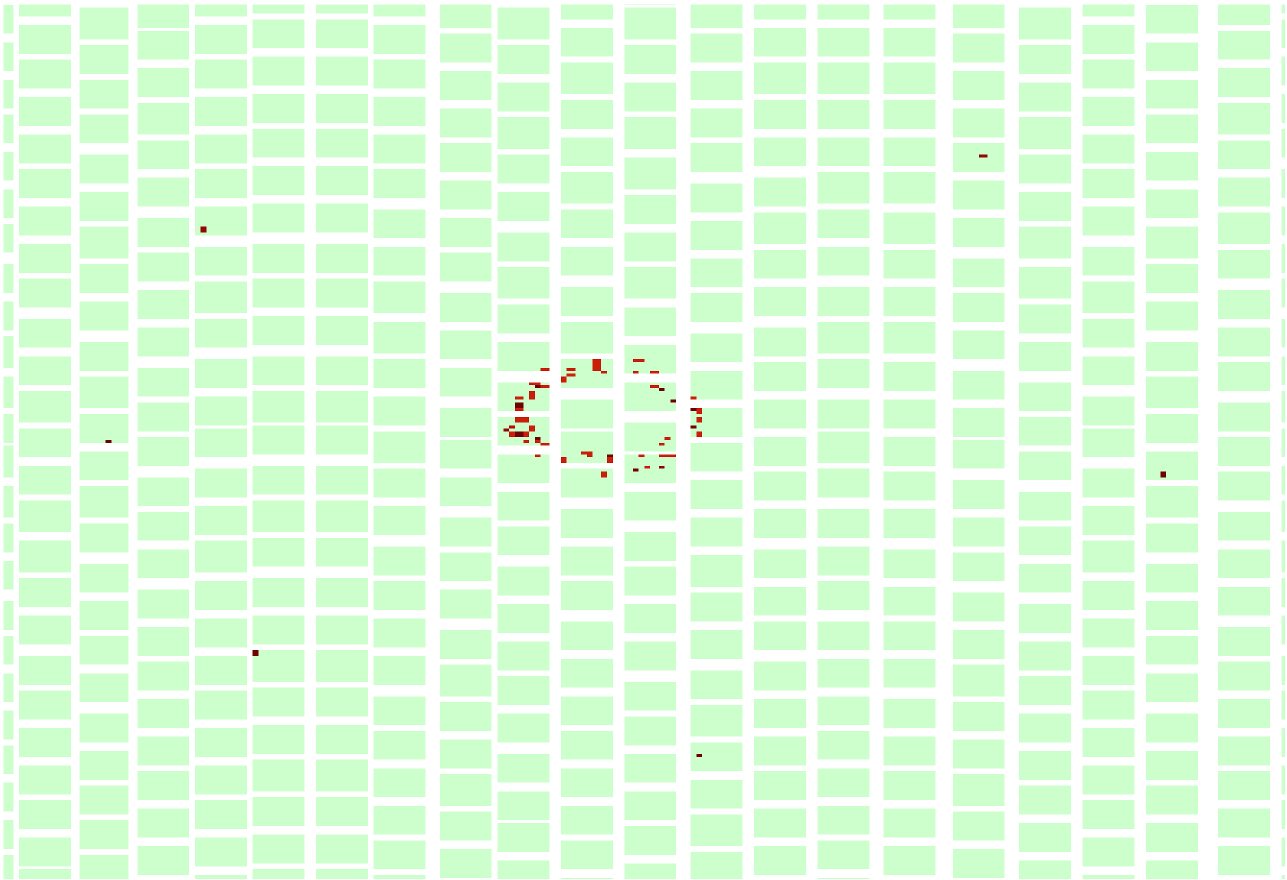


Event Display: all incident photons



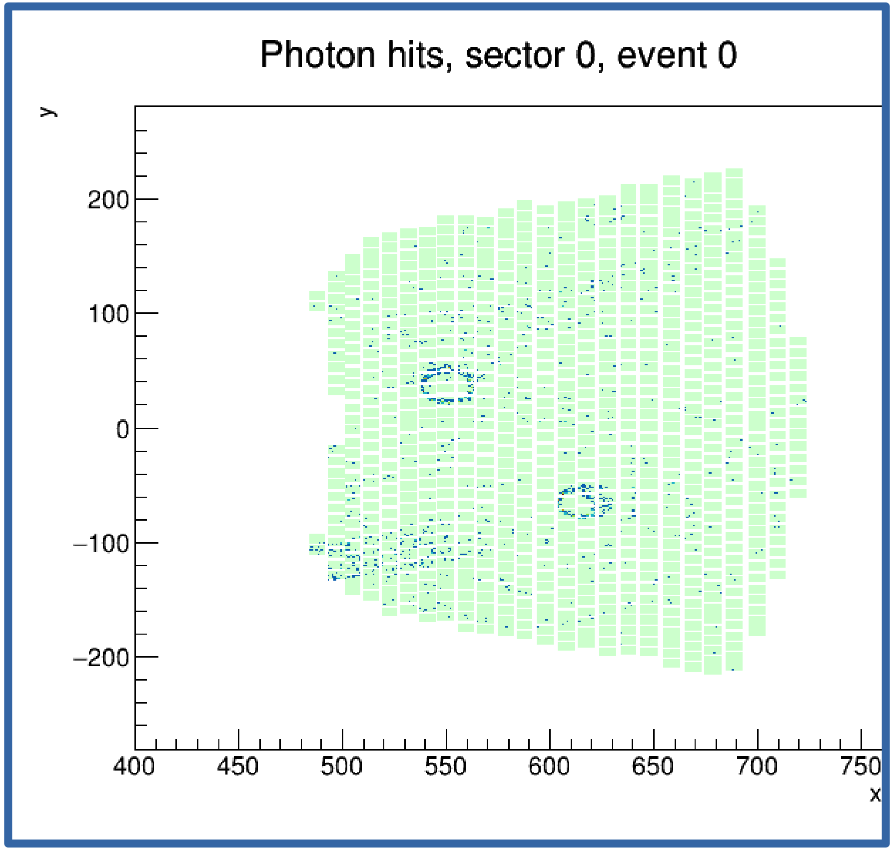
- Event display
  - Green boxes = SiPMs
  - 1 histogram bin = 1 pixel
- Rings from a single 40 GeV pion
- Shows **<u>all incident photons</u>** on the sensors (before Q.E.)

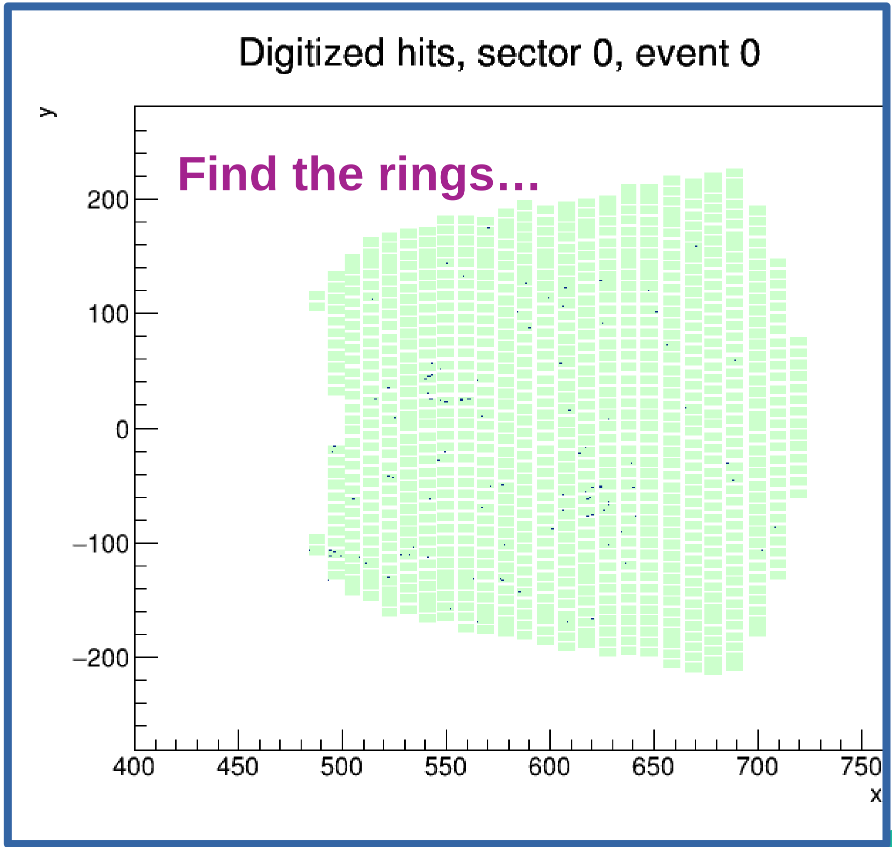
Event Display: digitized hits



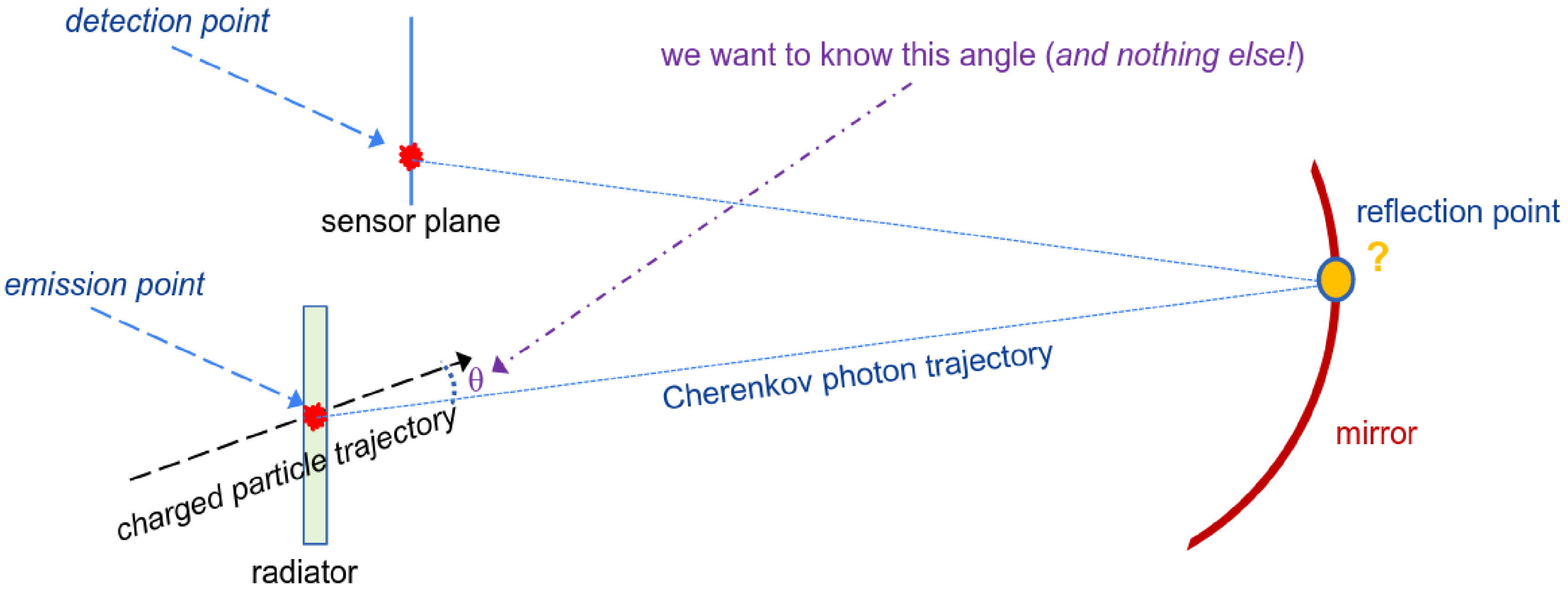
- Digitization:
  - Quantum Efficiency (20-40%)
  - Pixel gap cuts (88%)
  - Safety factor (70%)
- # hits << # photons
- Still does not include SiPM noise!

Reality will include multi-track events





Indirect Ray Tracing (IRT)



- Given sensor hits and optics, determine the photon emission angle, sampled along a charged particle trajectory
- Newton-Gauss iterative solver for optical path
- Compact, standalone library used for Geant4 and ATHENA

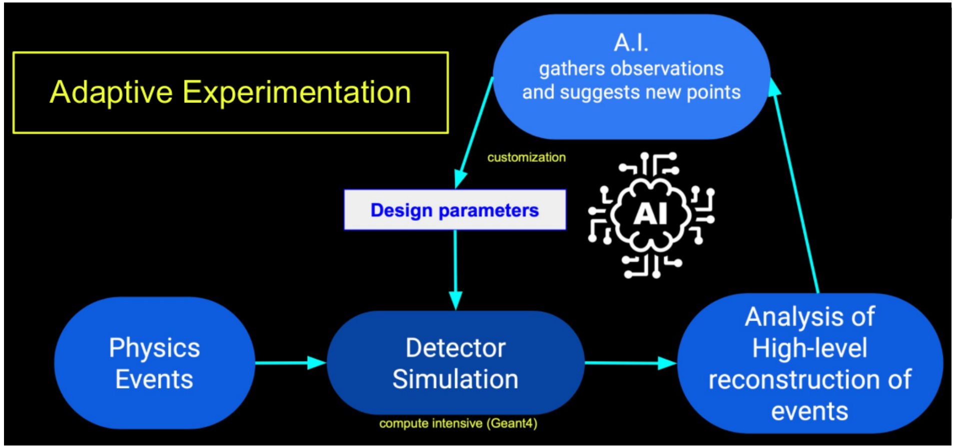
https://github.com/eic/irt

Figures from Alexander Kiselev, From meeting on RICH Pattern Recognition Challenges
https://agenda.infn.it/event/30966/

Machine Learning

For Particle Identification

- AI4EIC 2022 Hackathon: https://indico.bnl.gov/event/16586/page/435-hackathon
  - Challenge: use ML and these data to classify between pions and kaons
    - Charged particle momentum (p,θ,ϕ) + photon hit positions (x,y,z)
    - Involved varying momenta, noise hits, and B-field
- Future: Integrate these techniques into EICrecon (O. Hassan)



For Detector Design

- DD4hep software and geometry parameterizations are in general receptive to configuration changes
- Discussions are underway how to integrate detector design optimization with the ePIC stack
- See Cristiano Fanelli’s talk: AI/ML activities and next steps (Monday)

Performance Studies

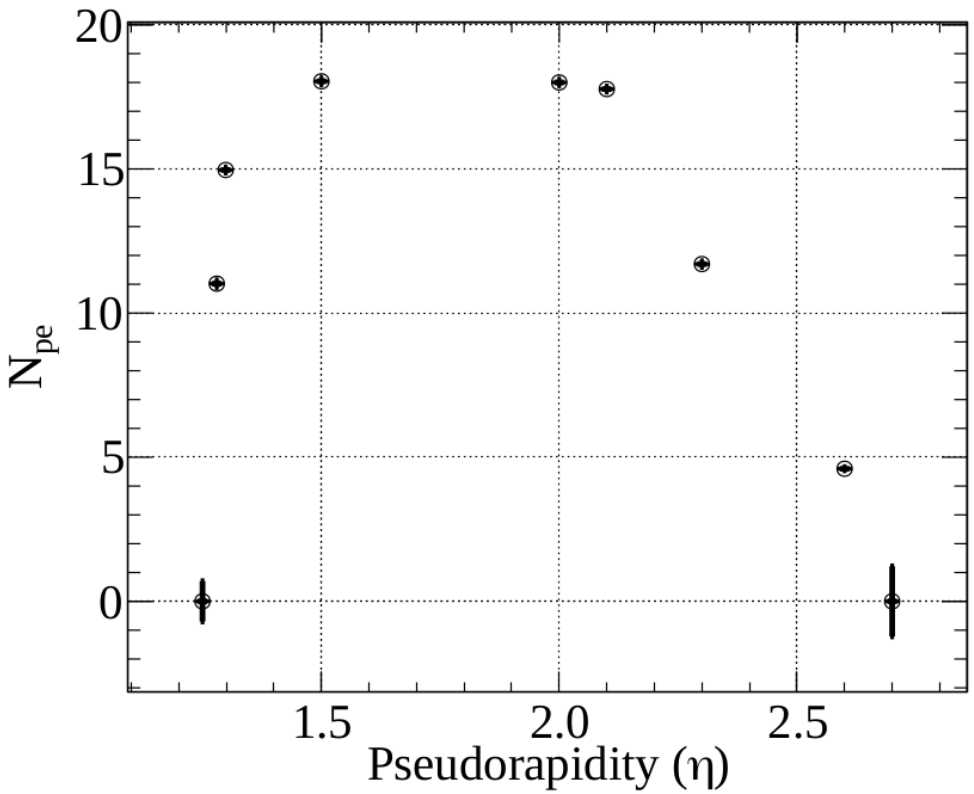
Acceptance

- 50 GeV pions
- Number of Photoelectrons (NPE) from gas radiator
- Acceptance limits:

  $1.3 < \eta < 2.3$

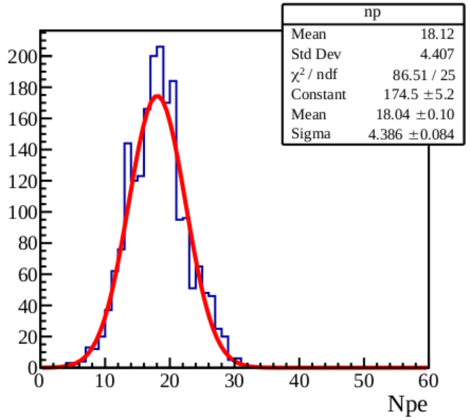
  $11.5° < \theta < 30°$

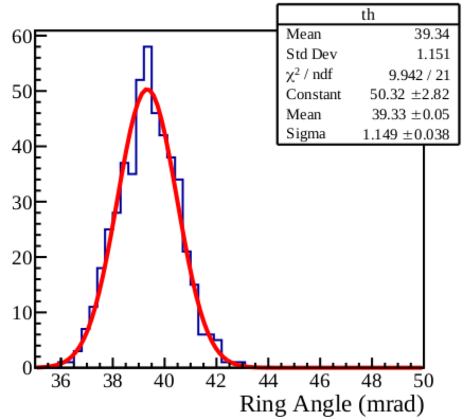
- Optics could be improved…

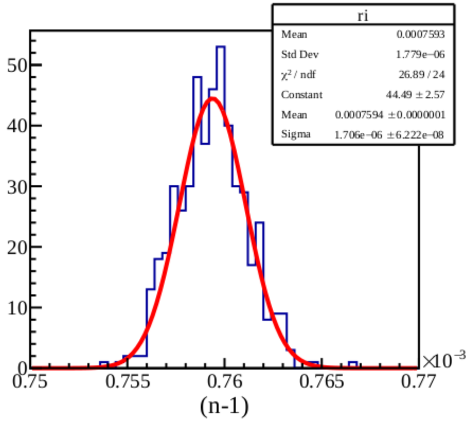


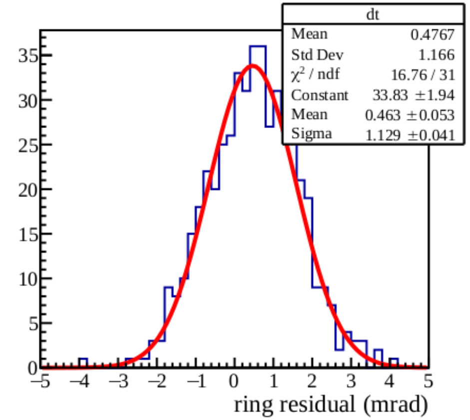
Study from C. Chatterjee

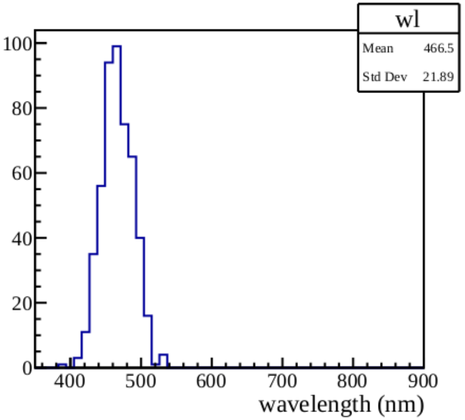
Performance Studies – Gas Radiator







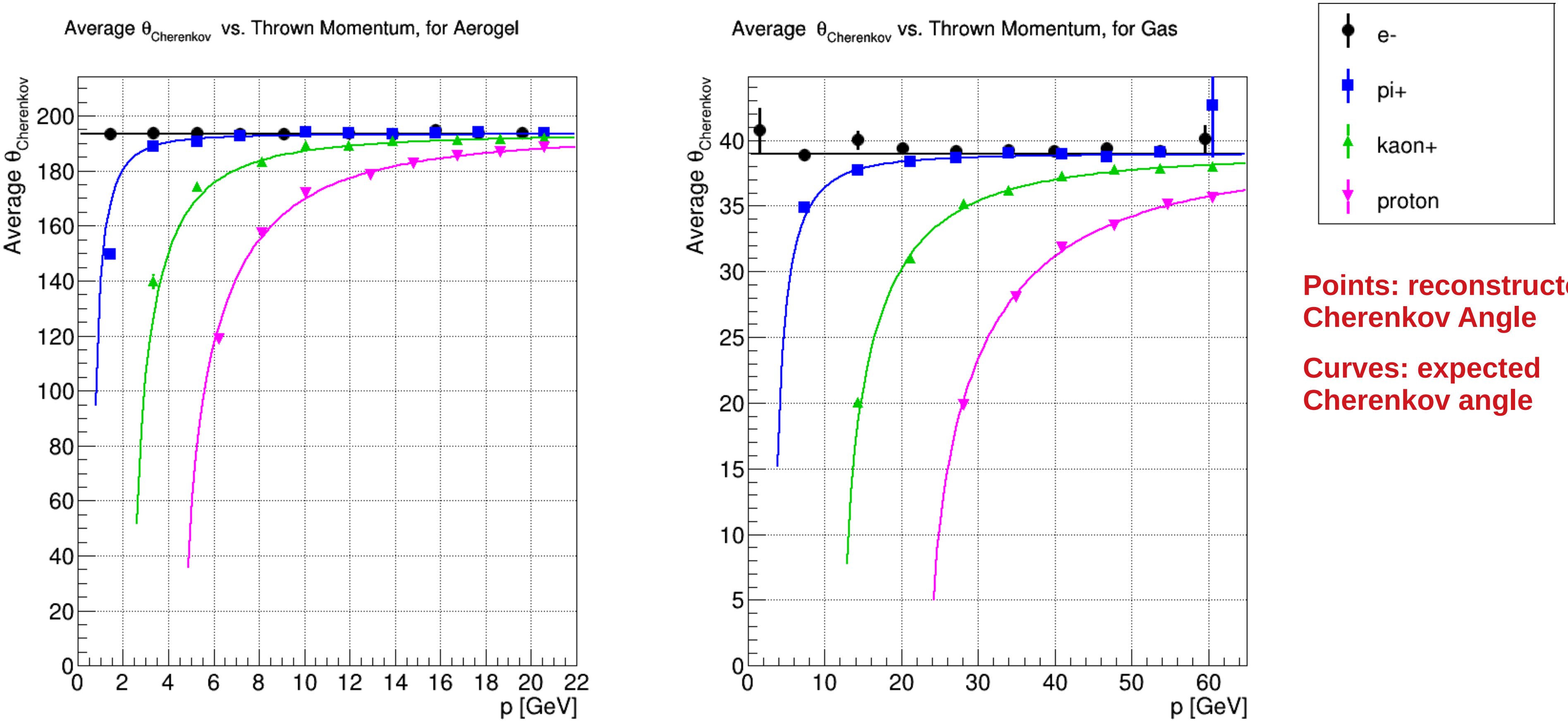




- Performance studies of ePIC dRICH well underway
- NPE, estimated ring angle, residual, …

Study from C. Chatterjee

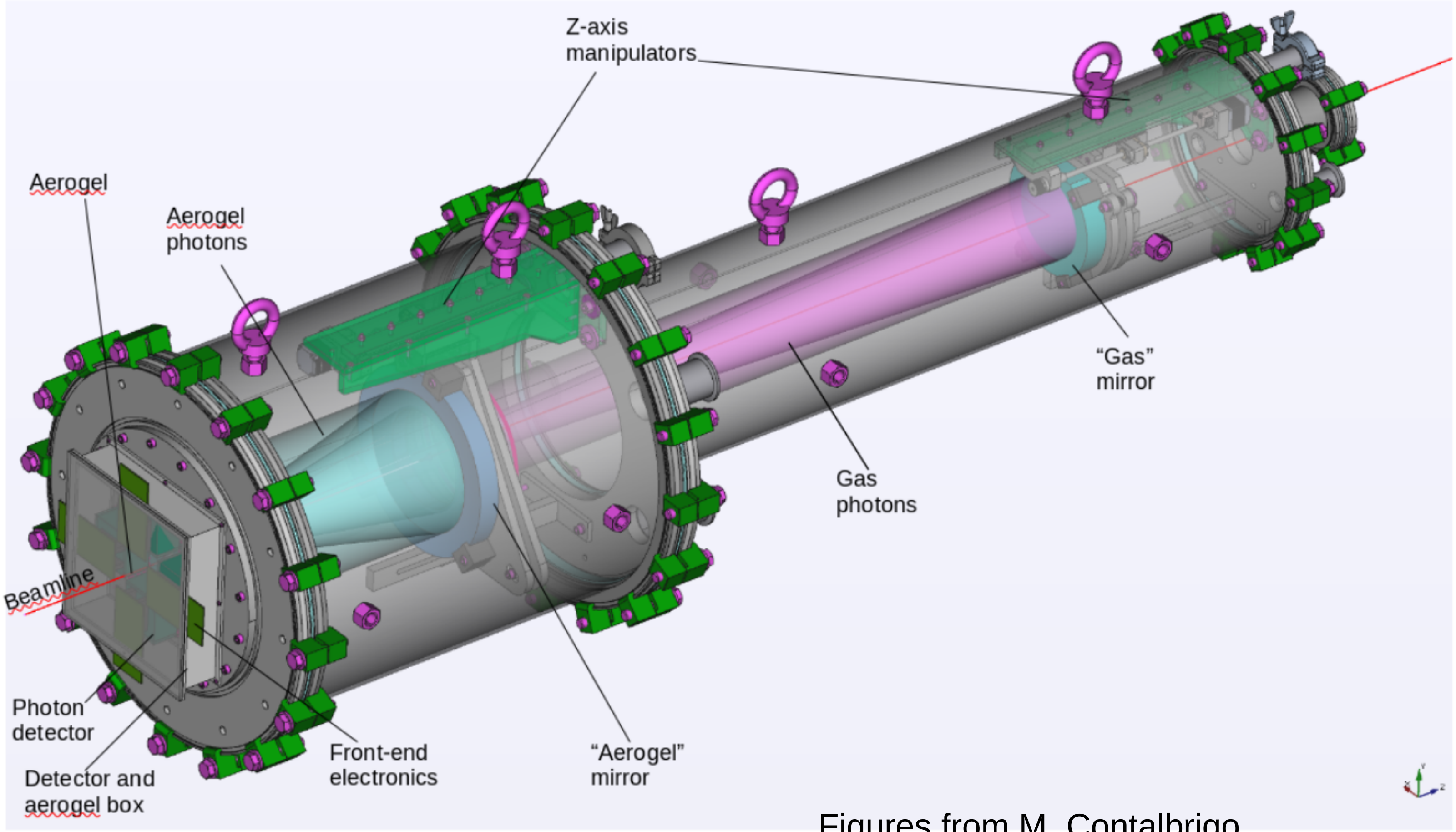
Reconstructed Cherenkov Angle vs. Momentum



Points: reconstructed Cherenkov Angle

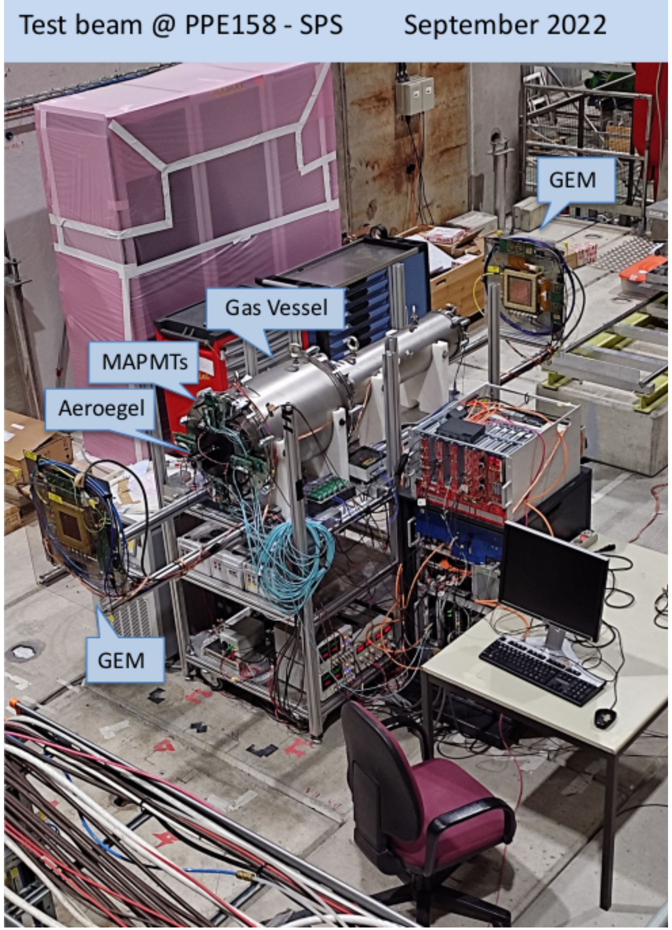
Curves: expected Cherenkov angle

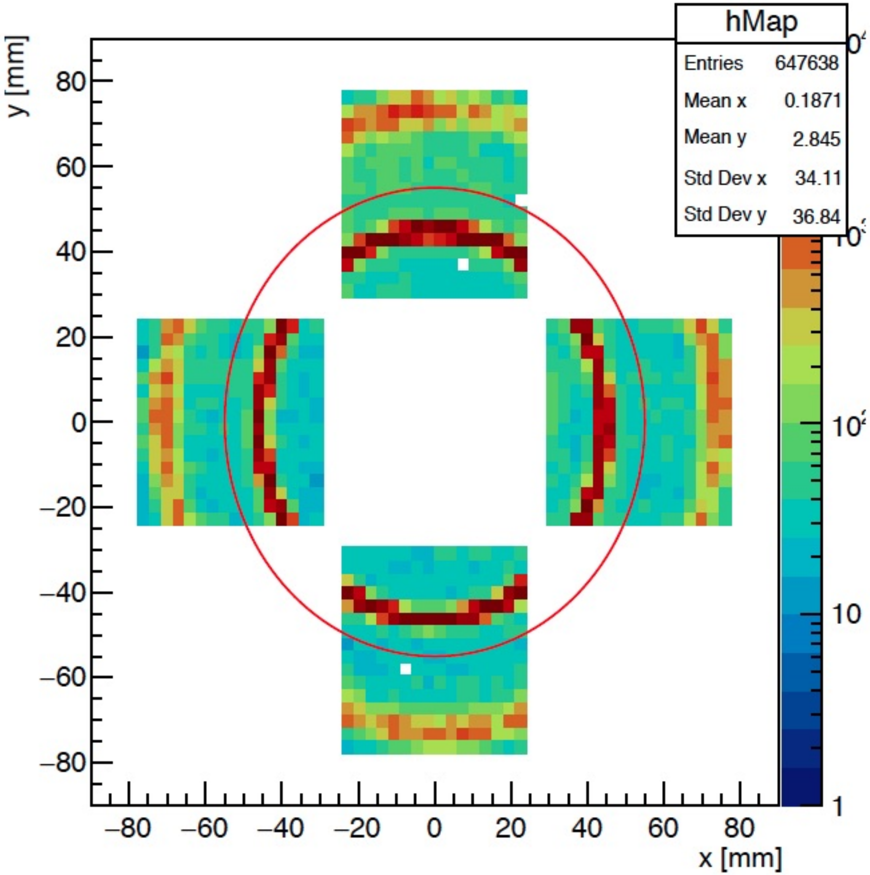
dRICH Prototype



Figures from M. Contalbrigo

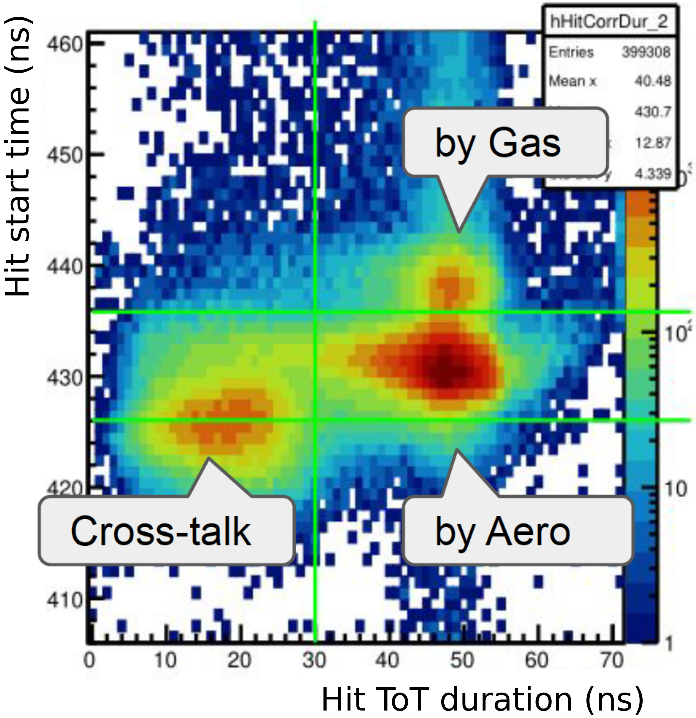
dRICH Prototype Tests

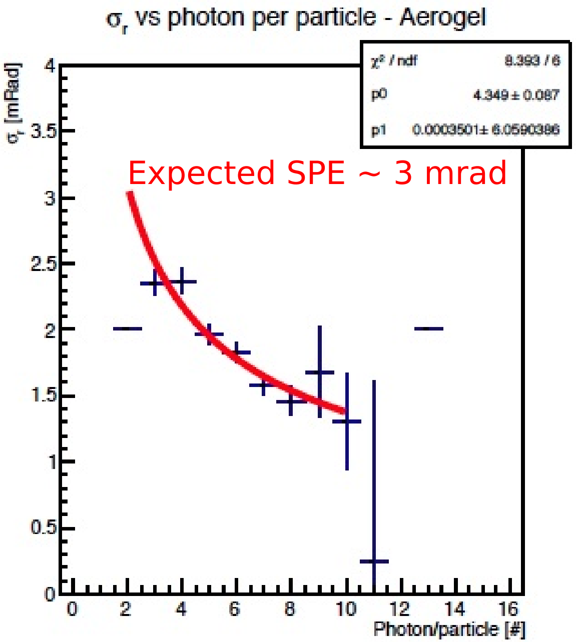


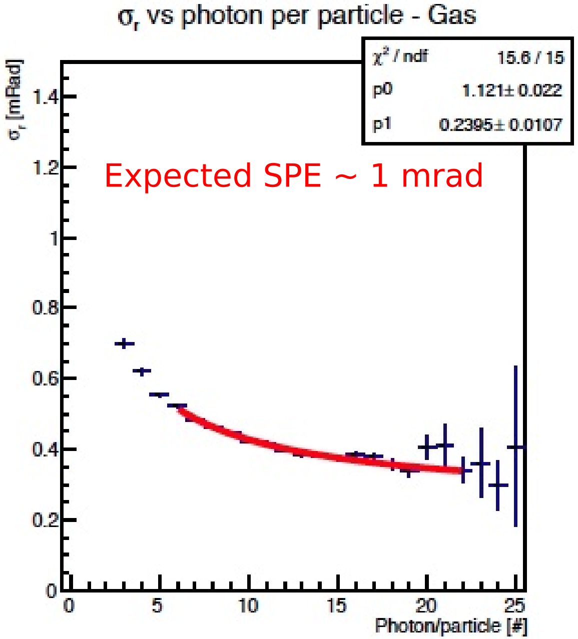


Figures from M. Contalbrigo

dRICH Prototype Tests



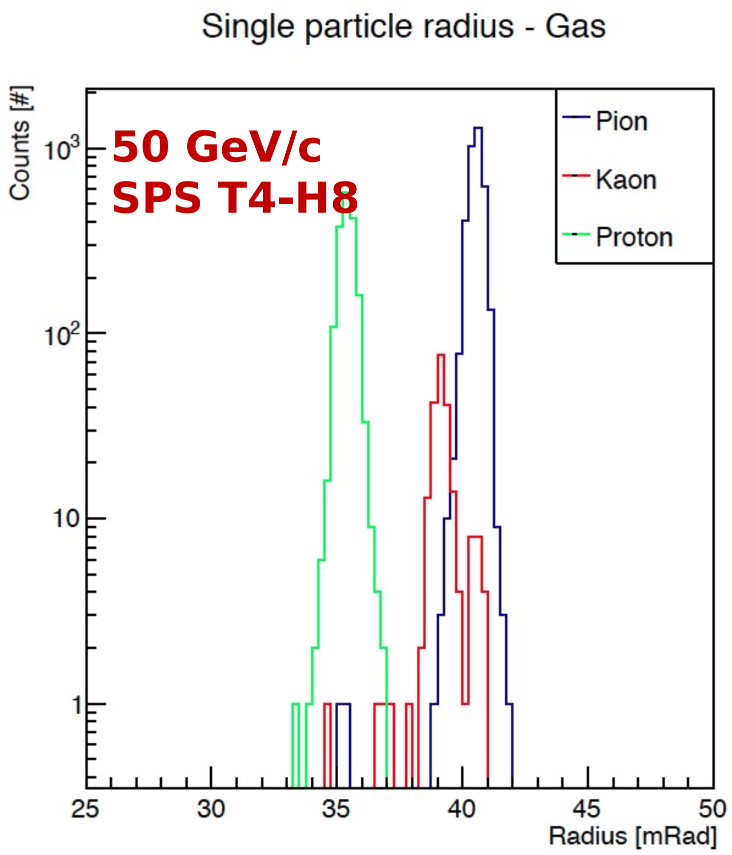


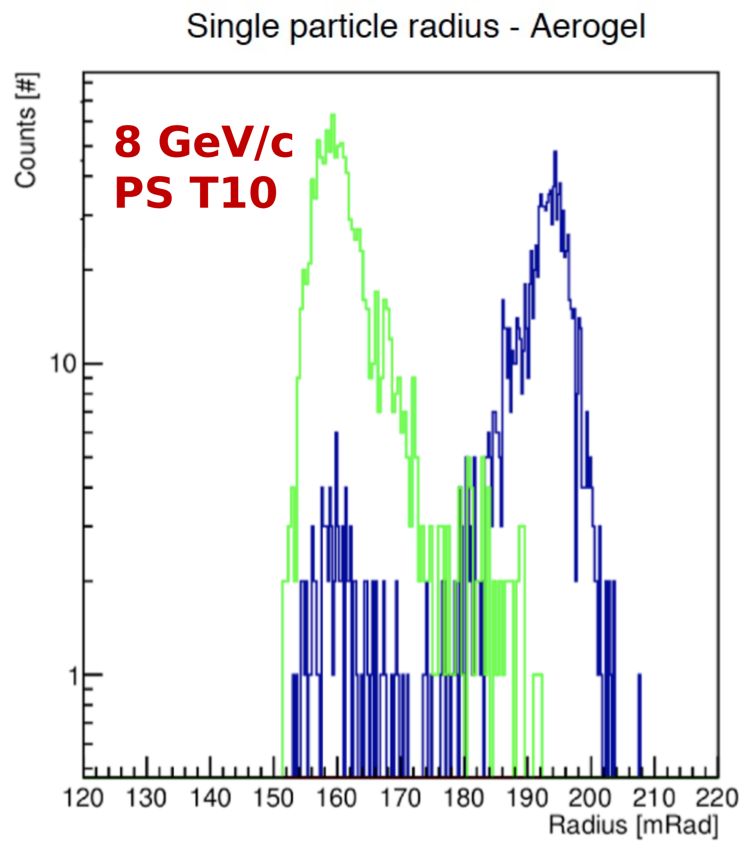


Figures from M. Contalbrigo

dRICH Prototype Tests – Radiator Interplay

Test at 50 GeV mixed hadron beam with tagging by beam instrumentation (3x gas Cherenkov)

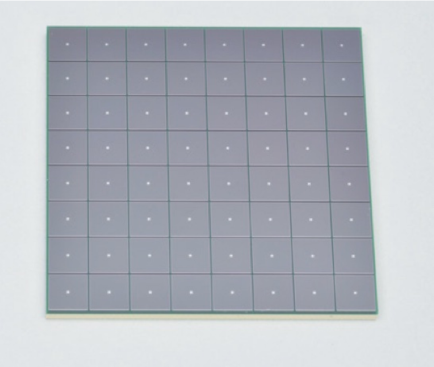




Figures from M. Contalbrigo

EIC-driven SiPMs and Readout

Hamamatsu S13361-3050

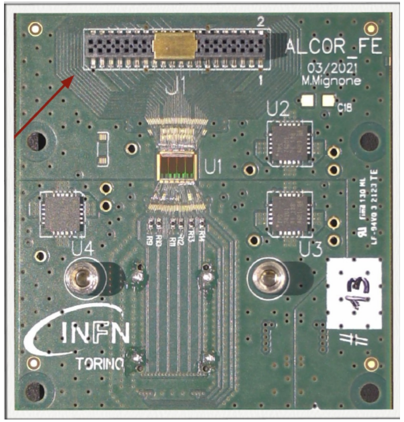


MPPC arrays procurement ongoing
Front-end design being finalized
ALCOR v2 (better dynamic range and rate)
ready for production (INFN in-kind)

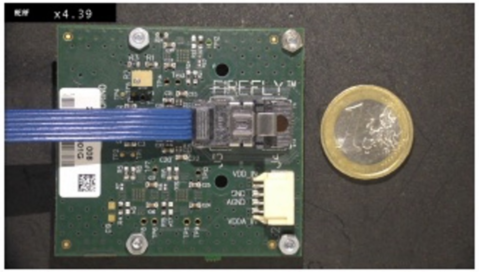
ALCOR chip (high-rate ToT architecture)
in streaming mode

- 50 ps time bin
- 500 kHz rate per channel
- cryogenic compatible

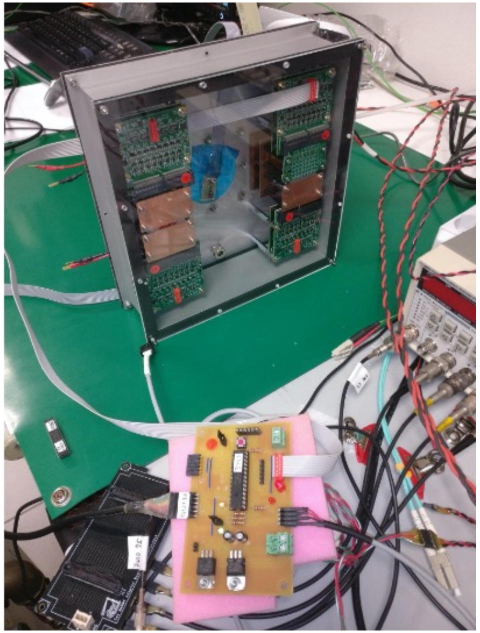
ALCOR chip



Streaming readout



Integrated Cooling,
In-situ annealing

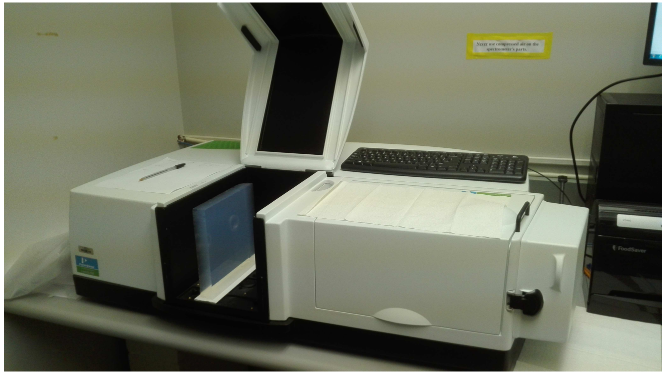


Figures from M. Contalbrigo

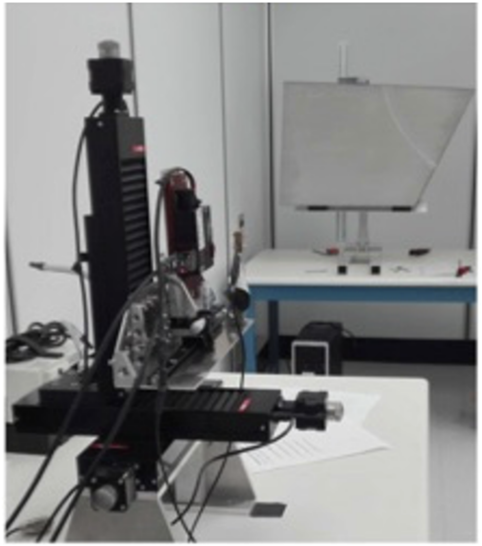
Optical Characterization

Laboratory characterization of optical properties

Radiators: refractive index, transmittance, surface planarity, forward scattering



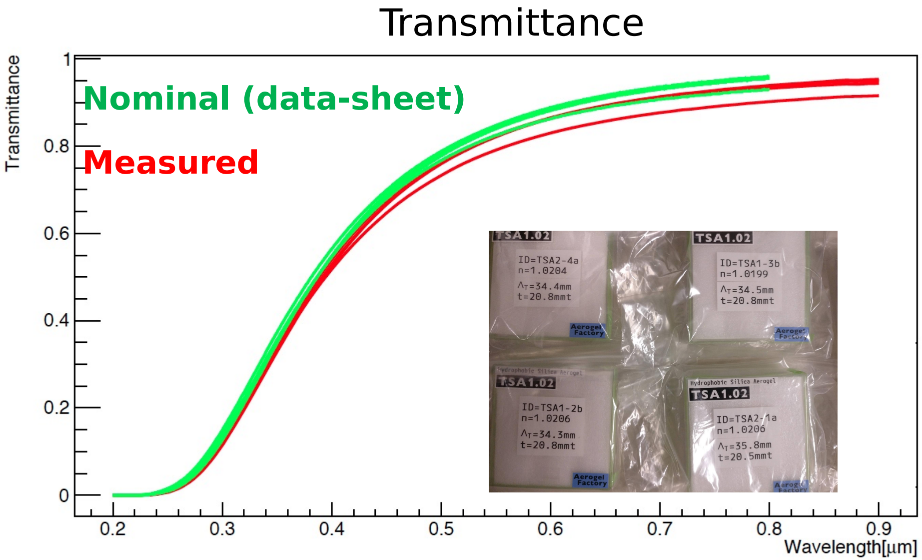
Mirrors: pointlike image, shape accuracy, surface rms

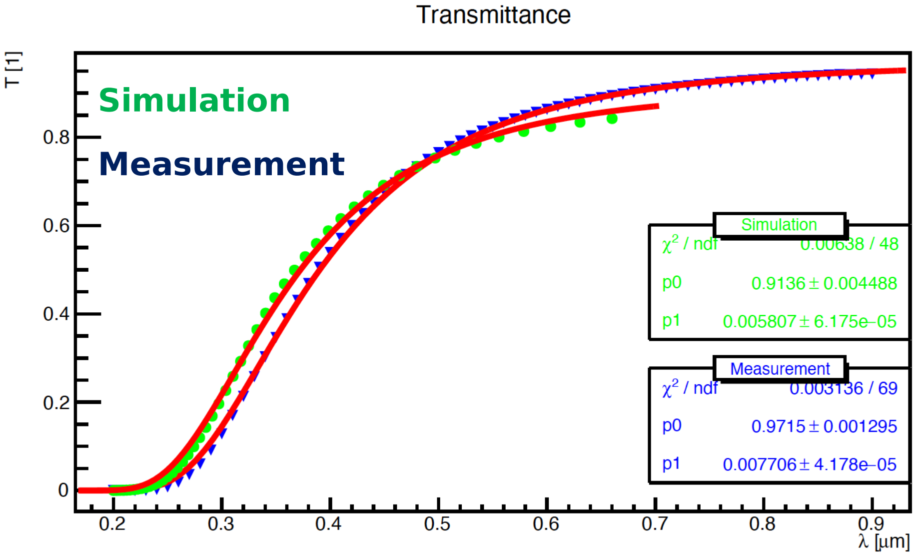


Figures from M. Contalbrigo

Optical Characterization

Samples from Aerogel Factory (Japan)

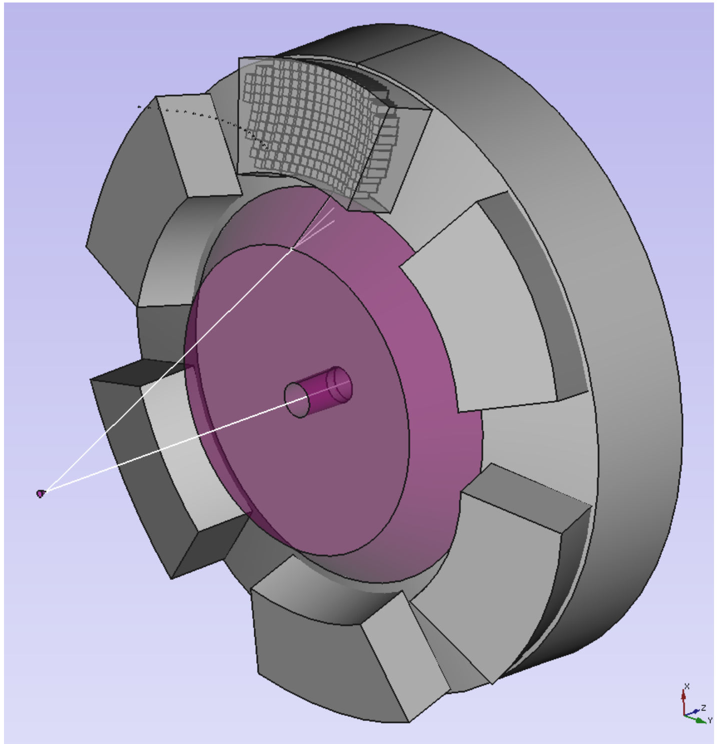




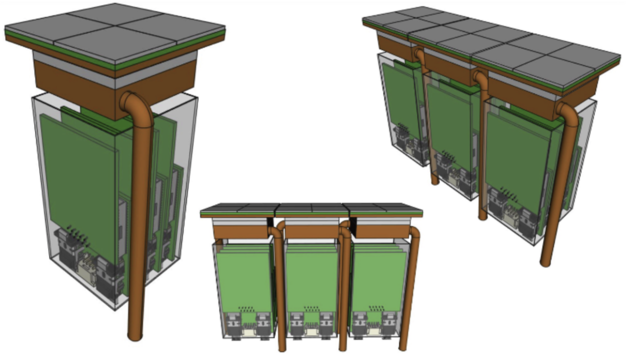
Figures from M. Contalbrigo

dRICH Mechanics and Integration

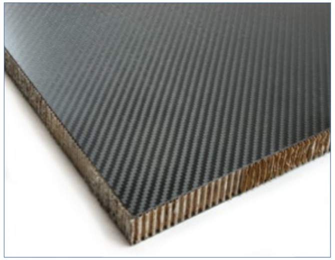
Global layout and tolerances

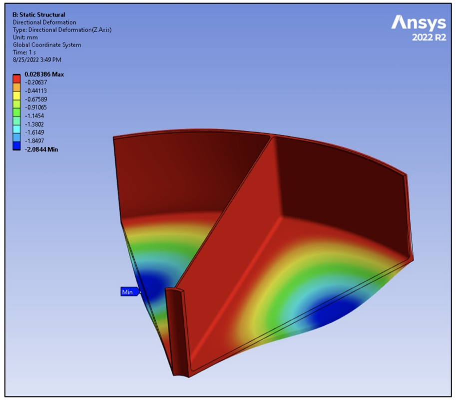


Readout modular unit and services



Composite materials and structural study
(also for the over-pressure version)





$\Delta_{Z\text{-}dir}$ = +0 / - 0.21 cm

Figures from M. Contalbrigo

Summary

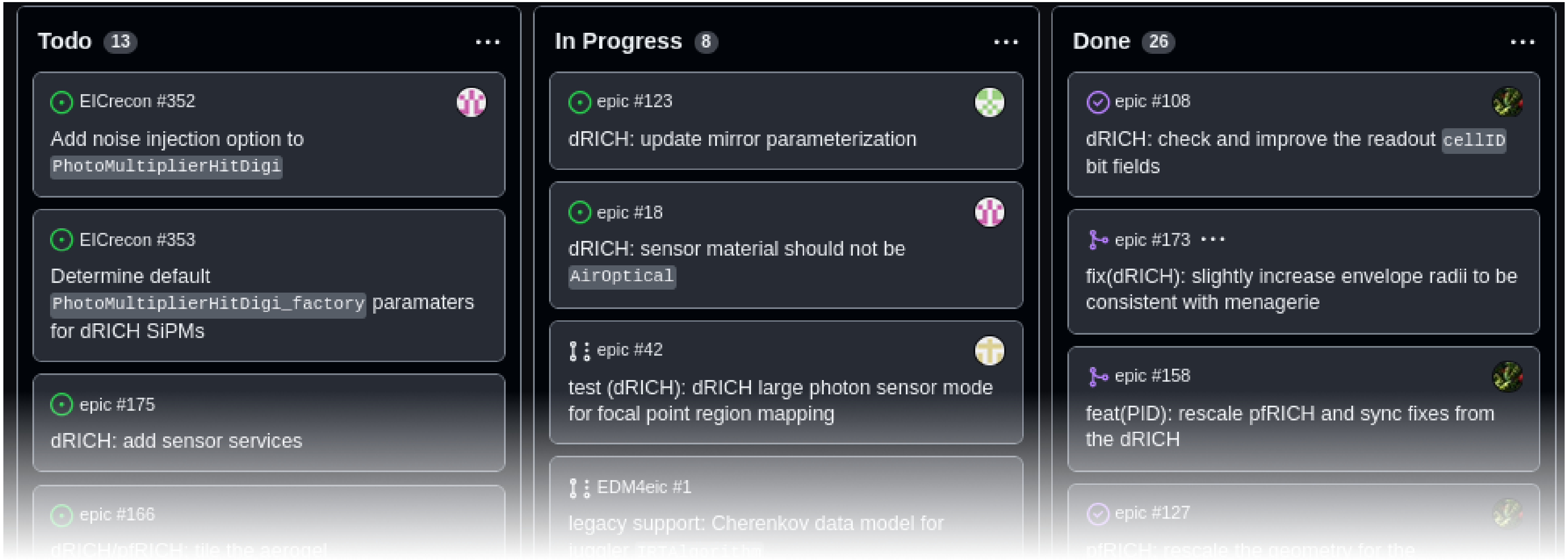
- **Simulation and Reconstruction**
  - Geometry implemented in DD4hep
  - Reconstruction (PID) in Juggler, migrating to EICrecon as standalone algorithms
  - Performance studies well underway
- **Prototype**
  - Recent beam test shows promising results
  - Moving toward EIC-driven prototyping
  - Optical characterization and testing

Backup

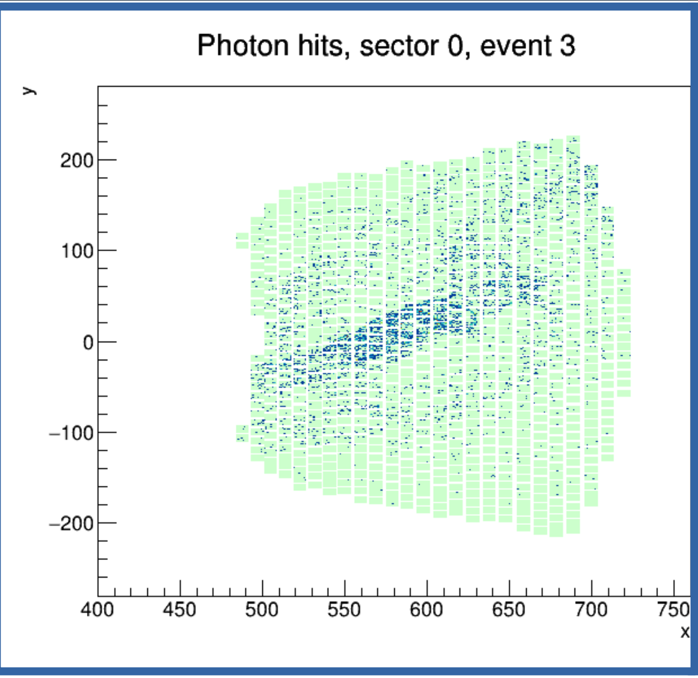
ePIC dRICH Software Project Page

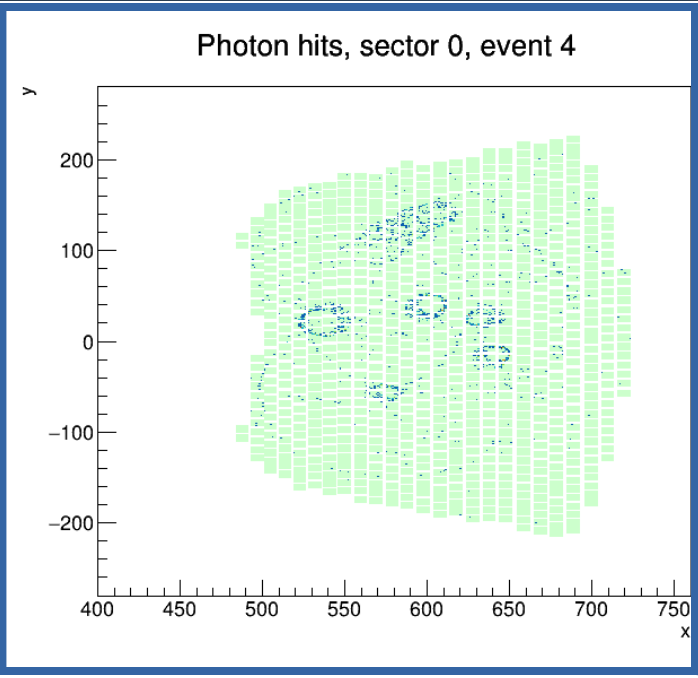
- Tracks GitHub Issues and Pull Requests from all repositories
- Help Wanted on Open Issues!
- More Issues (TODOs) welcome

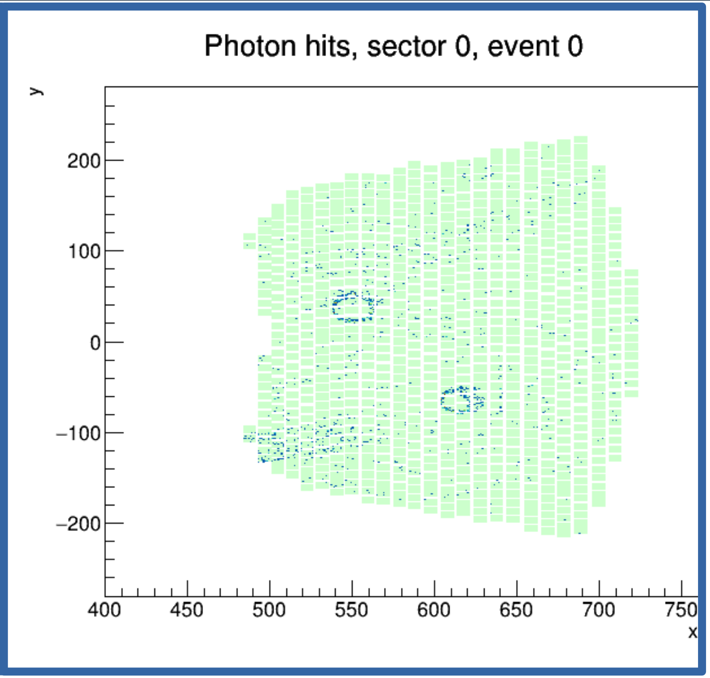
https://github.com/orgs/eic/projects/4/



Pions at 21.9°

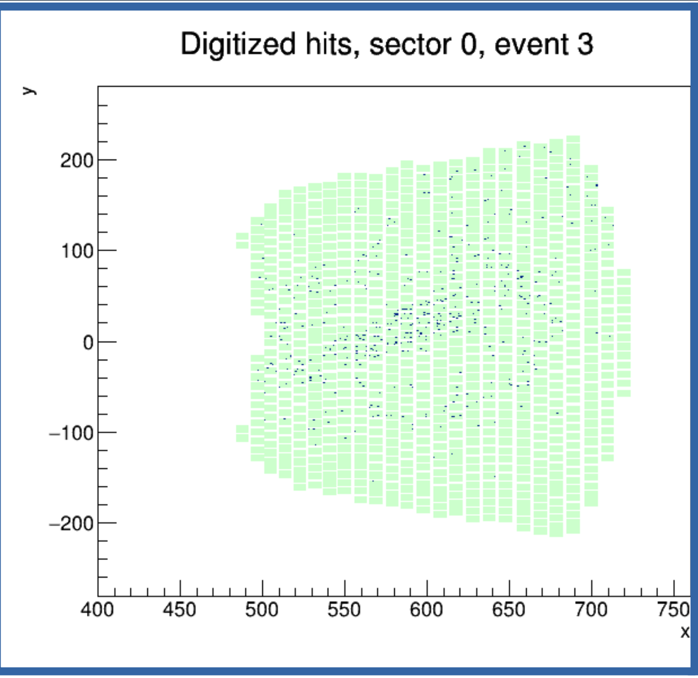


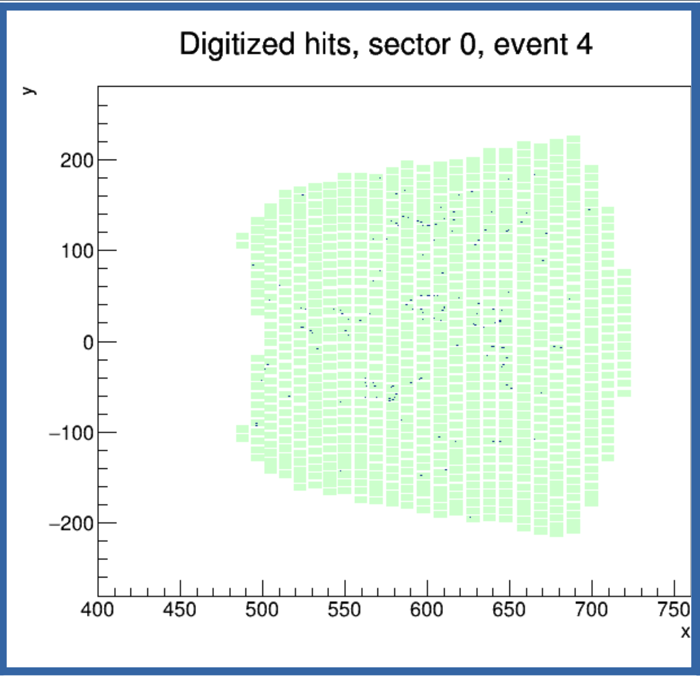


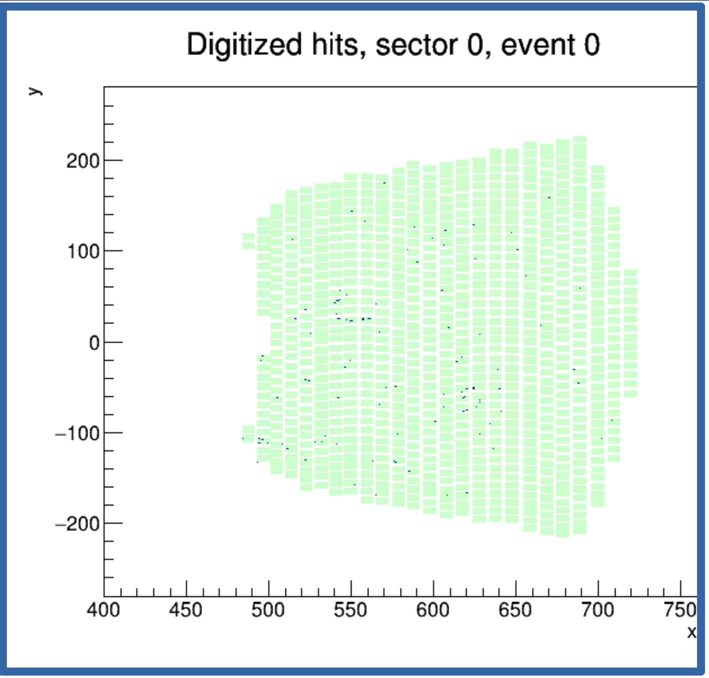


- 40 GeV pions thrown at θ = 21.9°
- Something is causing multiple scattering, all other θ regions behave as expected
- Example multi-track events

Pions at 21.9°



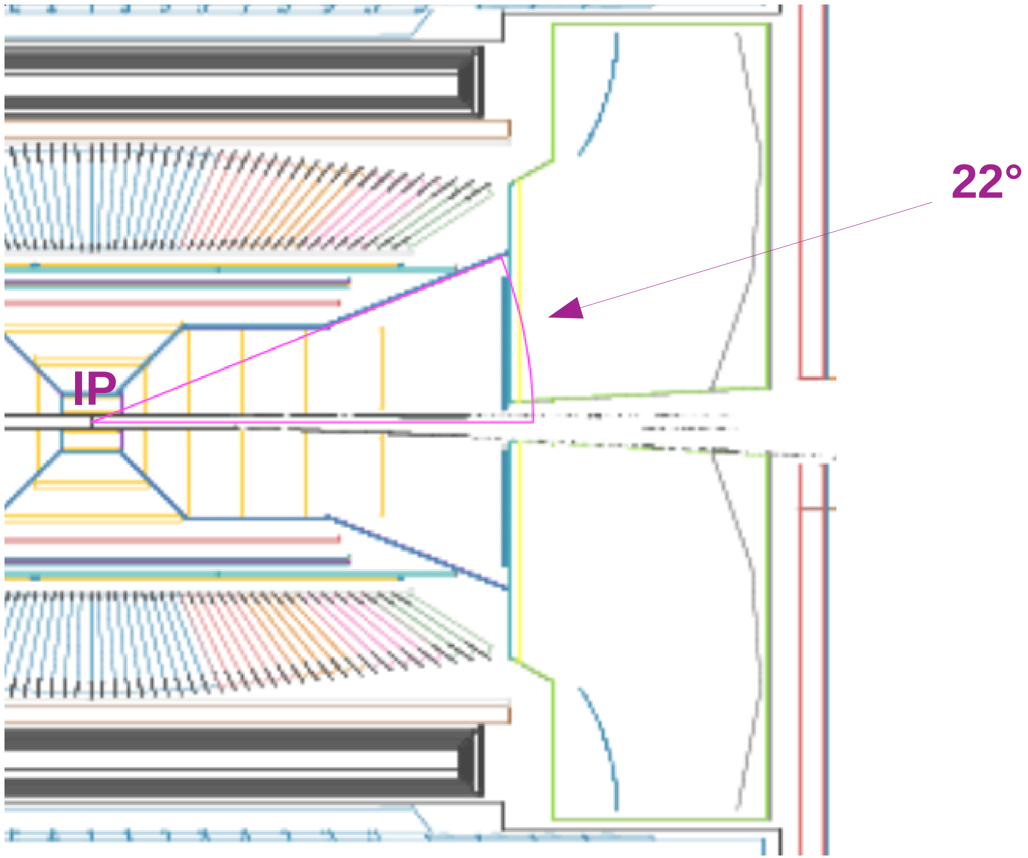




- After Digitization

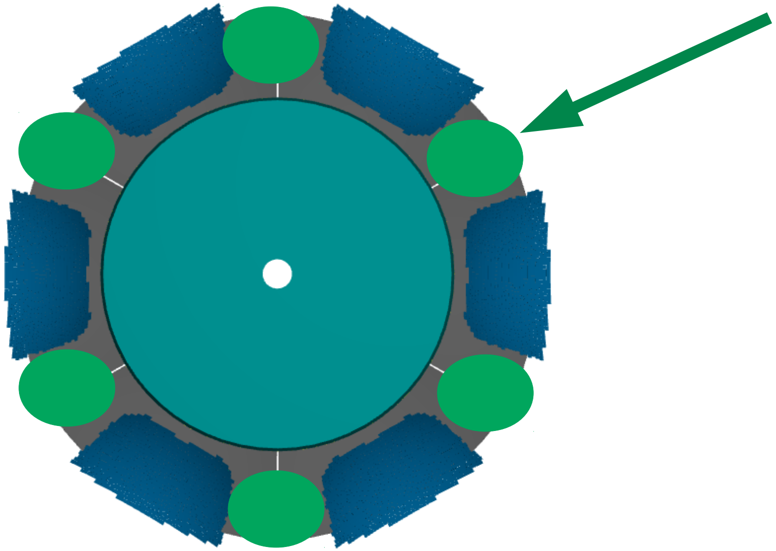
Pions at 21.9°

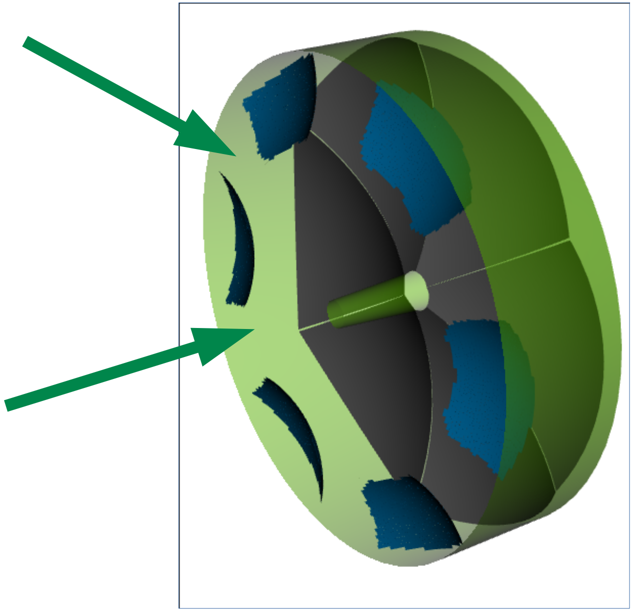
The cause: tracker support



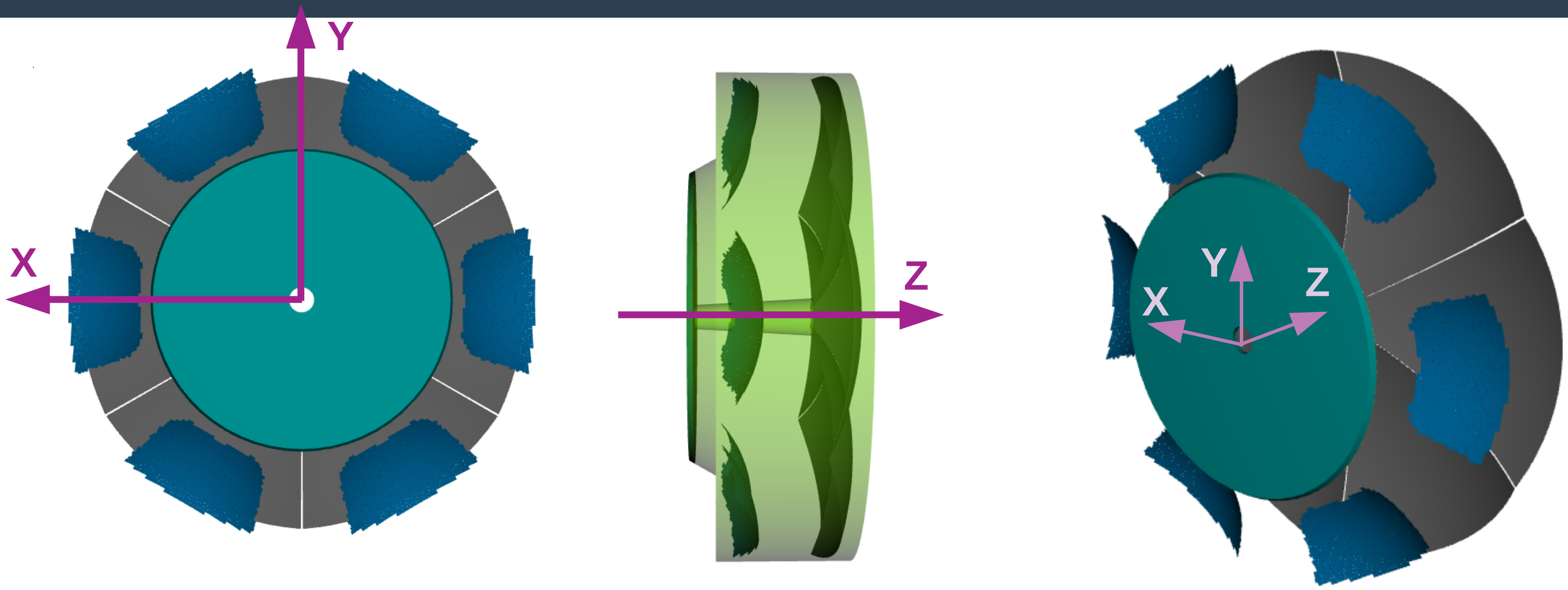
Services

- Use empty azimuthal space between sensors
- Expect no reflected photons in these regions





DD4hep Geometry



3D Interactive View!

https://eic.github.io/epic/geoviewer?file=artifacts/tgeo/drich_only.root&item=default;1&opt=zoom200;ROTY290;ROTZ350;trz0;trr0;ctrl;all

Modular Reconstruction Strategy

- **Generic algorithms**
  - Modular: each algorithm focuses on one thing, e.g.:
    - Digitization
    - Track Projection
    - Running IRT
  - Each algorithm has 2 components:
    - Framework-independent algorithm (only depends on data model)
    - Framework boilerplate algorithm runner (EICrecon factories and processors)
  - Multiple input collections, one output collection

- **Algorithms are generalized to support other PID detectors:** pfRICH, mRICH, DIRC, …
  - And in some cases, other subsystems (e.g., PMT digitization)

To Do: PID Performance Parameterization

- Parameterization generator code:
  - Efficiency in bins of (η,p), for pairs in {π,K,p}
  - Produces configuration for Delphes fast simulation (screenshot)
  - Plan to make usable by full simulations
    - (until PID is integrated in full production)

```
add EfficiencyFormula {211} {321} {
  (eta<  1.20 || eta>=  3.60 || pt * cosh(eta) <    0.90 || pt * cosh(eta) >=   27.00) * ( 0.00 ) +
  (  1.20 <= eta && eta <   1.60) * (   0.90 <= pt * cosh(eta) && pt * cosh(eta) <    1.40) * (0.000000) +
  (  1.20 <= eta && eta <   1.60) * (   1.40 <= pt * cosh(eta) && pt * cosh(eta) <    2.90) * (0.000000) +
  (  1.20 <= eta && eta <   1.60) * (   2.90 <= pt * cosh(eta) && pt * cosh(eta) <    4.20) * (0.000000) +
  (  1.20 <= eta && eta <   1.60) * (   4.20 <= pt * cosh(eta) && pt * cosh(eta) <    5.50) * (0.000000) +
  (  1.20 <= eta && eta <   1.60) * (   5.50 <= pt * cosh(eta) && pt * cosh(eta) <   10.00) * (0.000000) +
  (  1.20 <= eta && eta <   1.60) * (  10.00 <= pt * cosh(eta) && pt * cosh(eta) <   15.00) * (0.000381) +
  (  1.20 <= eta && eta <   1.60) * (  15.00 <= pt * cosh(eta) && pt * cosh(eta) <   20.00) * (0.026793) +
  (  1.20 <= eta && eta <   1.60) * (  20.00 <= pt * cosh(eta) && pt * cosh(eta) <   27.00) * (0.140689) +
  (  1.60 <= eta && eta <   2.00) * (   0.90 <= pt * cosh(eta) && pt * cosh(eta) <    1.40) * (0.000000) +
```