Detector and Physics Simulation Updates

Kolja Kauder (presenter)
Brookhaven National Laboratory

Chao Peng (in Central Time)
Argonne National Laboratory

ePIC Collaboration Meeting, 07/27/2023

Priorities for 2023

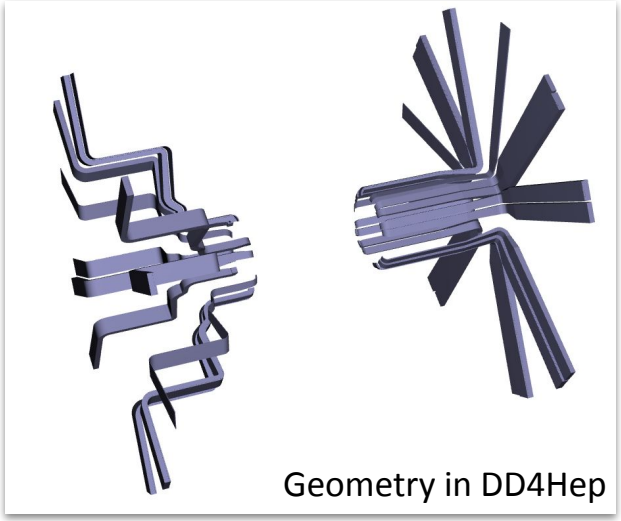
- Support the **detector design and integration with services.**
- Support the **needs for eA simulations.**
- Support the development of **background modeling** [...] with the BG Task Force**.**
- **Embrace modularity and separate the [...] digitization from the reconstruction.**
- **Embrace streaming readout** in simulation [...]

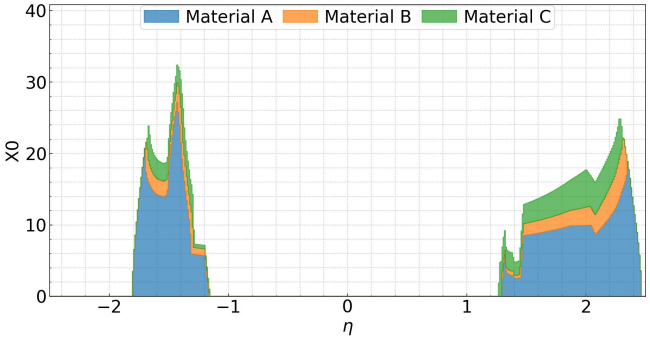
Service Structure

- **Implementation**
  - DD4Hep CAD conversion
    - *Direct conversion from CAD mesh file*
  - Ongoing work for proper materials info

- **Geometry**
  - Initial set of service structure for tracking detectors (received in May)
    - *mesh file: eic/epic-data/meshes (branch meshes)*
  - Obsolete, but good for testing
    - *Some overlaps with tracking detectors*
    - *Can be updated once new CAD files are ready*

- **Material Scan in DD4Hep**
  - Can be cross-checked with Geant4 scan
    - *Maxim Potekhin is working on it*


Geometry in DD4Hep



Issues and Plans

- **Simulation with converted geometry is very slow**
  - Problems, and therefore mitigations, similar to eA simulations, see below

- **Overlapping with existing subsystems**
  - Coordinate with engineers and detector subsystem collaborations
    - *Realistic dimensions in simulation*
  - May need effective models in simulation
    - *Validate effective models with material scan maps*

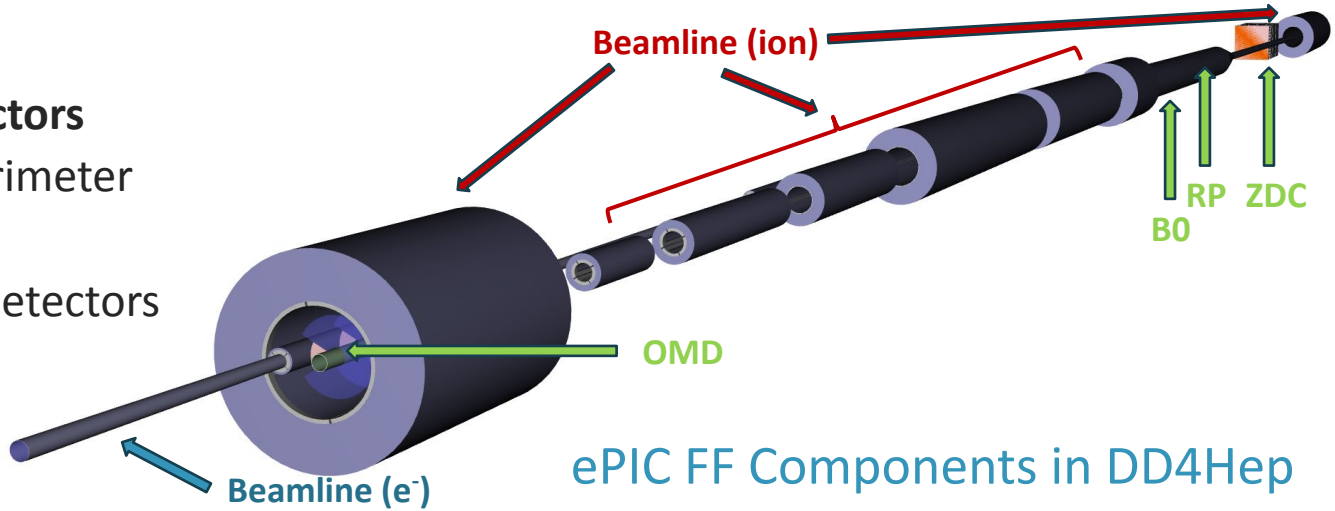
- **Setup machinery for implementing the service structure in simulation**
  - Accelerate and automate the process
    - *Convert CAD model, cross-checking with Geant4 conversion (GDML)*
    - *Test the overlaps with existing detector components*
    - *Benchmark the effects from the service structure (in detector and physics)*
    - *Benchmark the simulation performance*

eA Simulation

- **eA simulation is challenging**
  - Far-forward side: many secondaries from the collision
  - Need good performance to accumulate statistics
    - ***Ideally << 1 sec/event***

- **Far-forward subdetectors**
  - Zero Degree Calorimeter
  - Roman Pots
  - Off-Momentum Detectors
  - B0 Sensors

- **Beamlines**



ePIC FF Components in DD4Hep

Issues and Solutions

- **Simulation is too slow**

  ~10 seconds for proton, much slower for nuclei

- **Investigate and Improve the simulation performance**
  - Identify the bottleneck of the eA simulations

    Develop tools to evaluate the performance of each FF component
  - Tune Geant4 limits for the bottleneck components

    Discard low-energy secondary particles, less number of steps, …
  - Try different physics lists (current: FTFP_BERT)

    LHEP (fast), QGSP_BERT, …

- **Geometry needs updates**

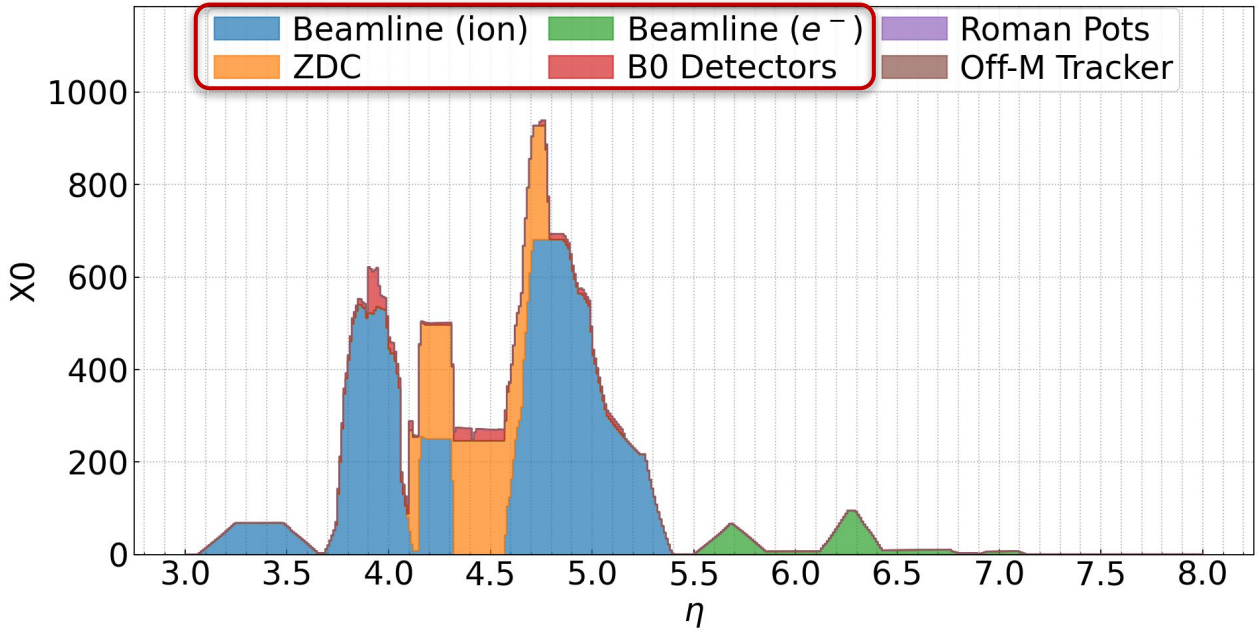
  ZDC: Far-forward DSC is working on it (*Alex Jentsch*)

Investigation

- **Material scan of the FF components**

  Focus on far-forward side (the likely cause as learned from eA study group)

  High material thickness from beamlines, ZDC, and B0 ECal (with $\phi = \pi$)

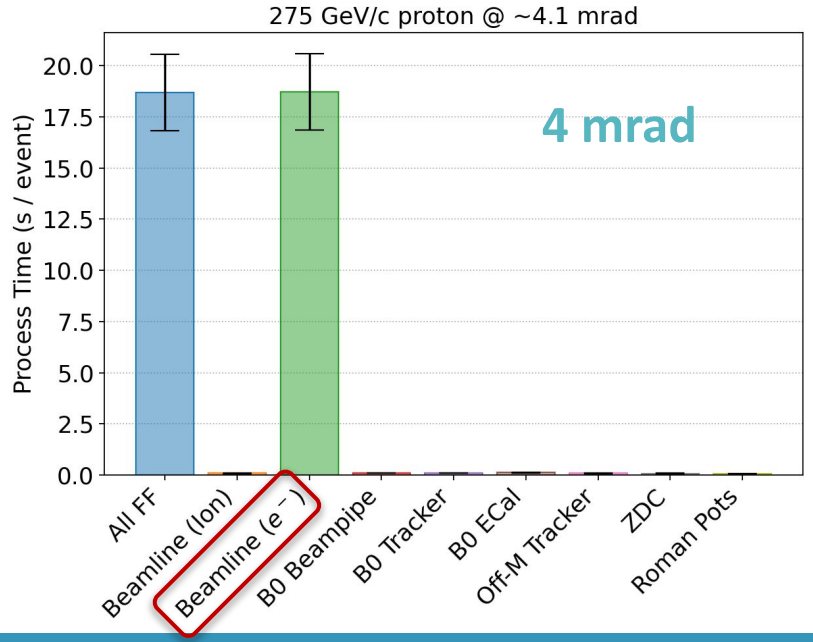


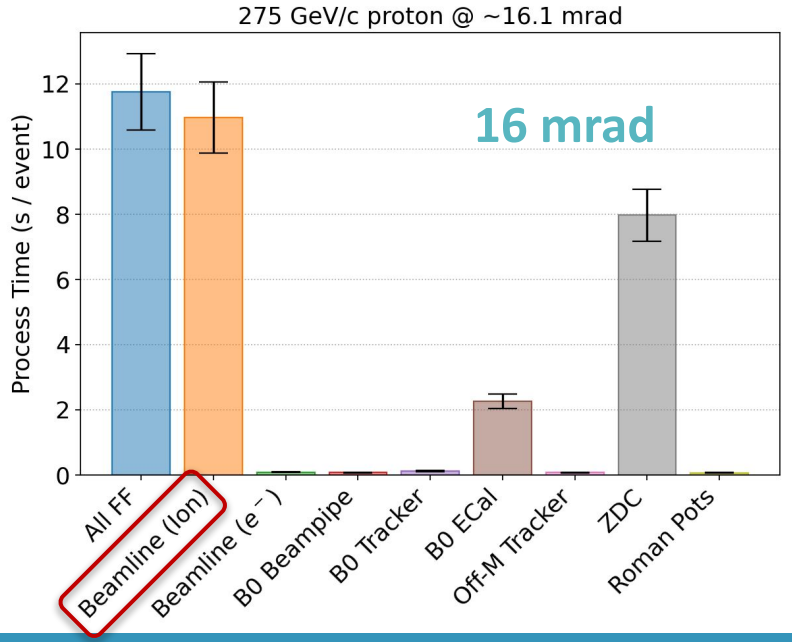
Benchmarks

- **Beampipes are likely the cause of unsatisfying performance**

  Single particle simulations with protons: ~ 10 seconds per event

  eA is much worse: up to a few minutes per event (*Kong Tu*)





Plans

- **Continue the test of ep/eA simulations**
  - Develop tools for an automated benchmarking
    - *eic/epic PR:* ep/eA Performance Test Scripts #486
  - DD4Hep geometry validation with FF DSC
    - *Test with the updated geometries (ZDC, …)*
  - More ep/eA simulations including physics event generators

- **Apply mitigations to improve the performance**
  - Try different physics Lists
    - *LHEP (fastest, good for shower simulation), QGSP_BERT, …*
    - *Register different physics models for different regions*
  - Tune the region limits
    - *Step size, energy threshold, …*
    - *Balance between precision and performance*

Overarching - Background Work

Ties together:

- **Background modeling - HepMC input, sources, rates**
- **Digitization - sub-system integration time, propagation to ACTS**
- **Streaming readout model - "Events" → Time slices with time-stamped hits**

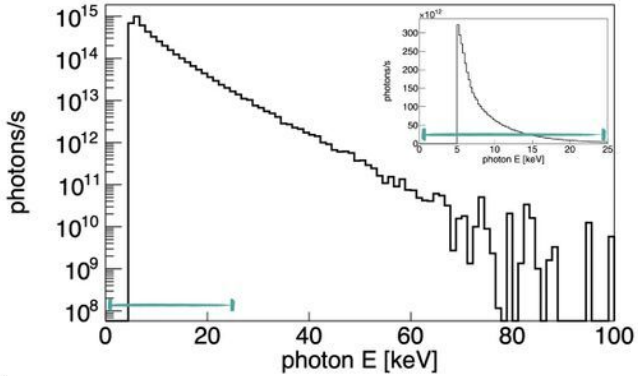
Strong connection to and cooperation with the track reconstruction group

Note: Also ties back to MCEG development and maintenance - FF: DPMJet ≫ Pythia

Background Modeling

Sources:

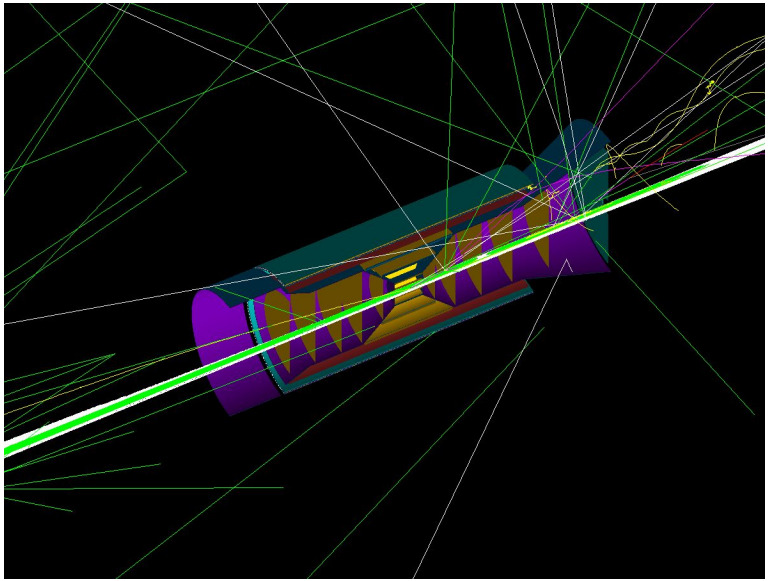
- **e+gas, h+gas:** "Fixed target" events
- **Synchrotron Radiation:** 1.8M photons from SynRad:
- NB: No "MB events" background for now



- **Input files, rates, etc.:** Zhengqiao Zhang, Jarda Adam, Benjamen Sterwerf, Rey Cruz Torres - Background Wiki

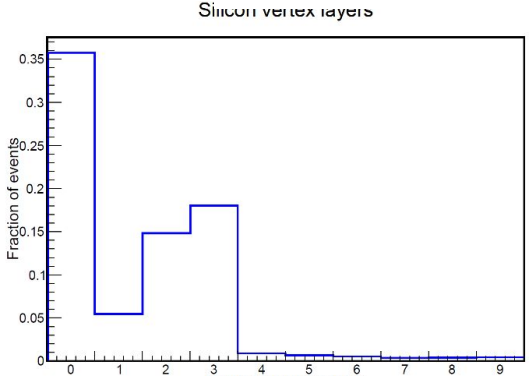
- **Merge** with a given signal (DIS, particle gun):
  1. Select a time slice width, e.g. 2μs for MAPS integration time
  2. Place signal event(s) at random point(s) in the slice
  3. Select **how many** background events to add from Poisson distribution
  4. Draw random events, or SR photons from weighted distribution
  5. Place at **uniformly random times**

First Look after Geant4

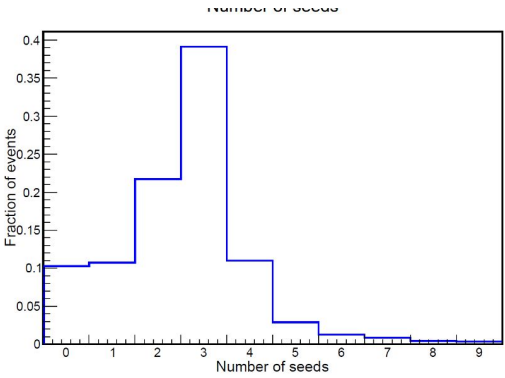


DIS+BG event (Shyam)

Digitized hits



Seed multiplicity



WORK IN PROGRESS - Encouraging but DO NOT RELY ON OR USE

Single muons + background (Barak)

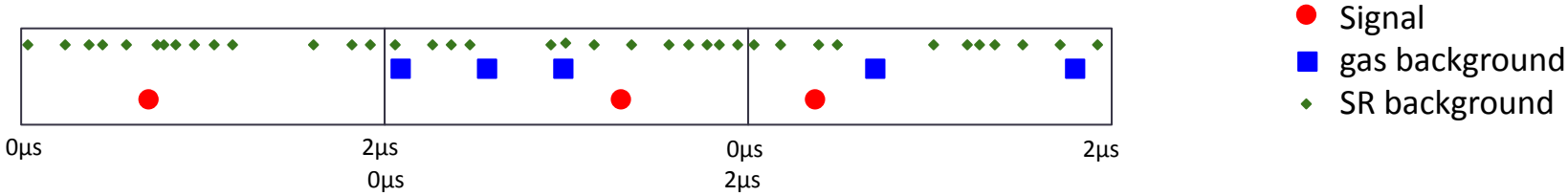
Source files and merged files under S3/eictest/EPIC/EVGEN/BACKGROUNDS/

Digitization

- **Time information is currently only propagated through Geant4**
  - Does **not** reach ACTS
  - Does not contain/use/propagate time resolution of detectors
  - On-going work on seeding and tracking currently assumes:
    - either full integration over the window for all detecors
    - or (worse) only the last hit in a given cell is counted
- While merged files can now be used for initial studies and thresholds by the track reconstruction group, we will focus on:
  - **Untangling digitization** from reconstruction → by the time reconstruction starts, simulation should be indistinguishable from data
    - Extra truth information for QA can be discussed
  - **Improving digitization:** Realistic tim**e integration, covariance matrix**
- Note: Not the first priority, but this is the natural, and simple, place for **noise**

Streaming data format

- Merged files fully embrace the concept of **time slices** instead of events:



- … but slice width, and one-event-per-slice, are just defaults and can be changed

- Other details, such as what triggers a slow detector, can be adjusted according to the DAQ / Streaming Readout groups' specifications

Summary

- **Service Structure**
  - Implemented DD4Hep CAD conversion and material scan
    - *Issues: performance, overlaps → May need effective geometry models*
  - Developing automatic conversion/evaluation tools
- **ep/eA simulation**
  - Performance is an issue → found the likely bottleneck
  - Developed benchmarking tools and will continue the development
  - Plan to explore various methods to improve performance

- **Background:**
  - Mixed signal+background files exist and are being used for reco development
  - Current priority: Improved digitization and hit time forwarding to ACTS
  - Throughout, the data embraces a streaming "time slice" format

This work is supported in part by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357.

Backup