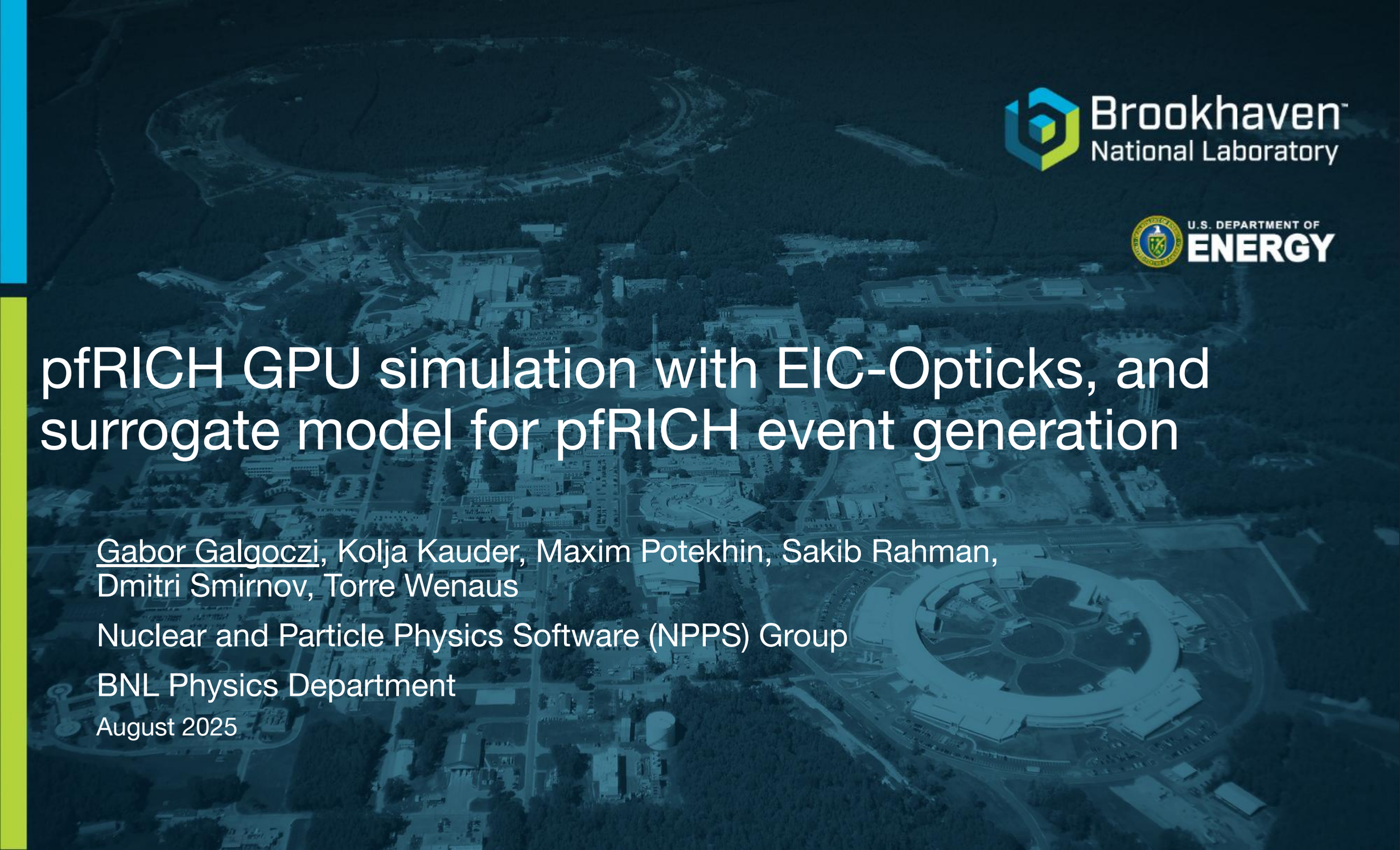

pfRICH GPU simulation with EIC-Opticks, and surrogate model for pfRICH event generation

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EIC-Opticks

- EIC-Opticks[1]: fork of Opticks, uses NVIDIA OptiX framework to simulate photons on GPU
- Works together with Geant4:
  - Hadronic, EM etc are done on CPU, only photons are offloaded to GPU
- Modifications:
  - Opticks can only simulate one G4Event in a GPU simulation
    - Very large overhead when simulating less than 1M photons in a GPU call
  - EIC-Opticks extended usability to cases with much fewer photons (as in most EIC applications)
    - Added G4Event ID to GPU simulated photons
    - Allows to aggregate photons across events and process on the GPU in bulk
  - Created a spack package
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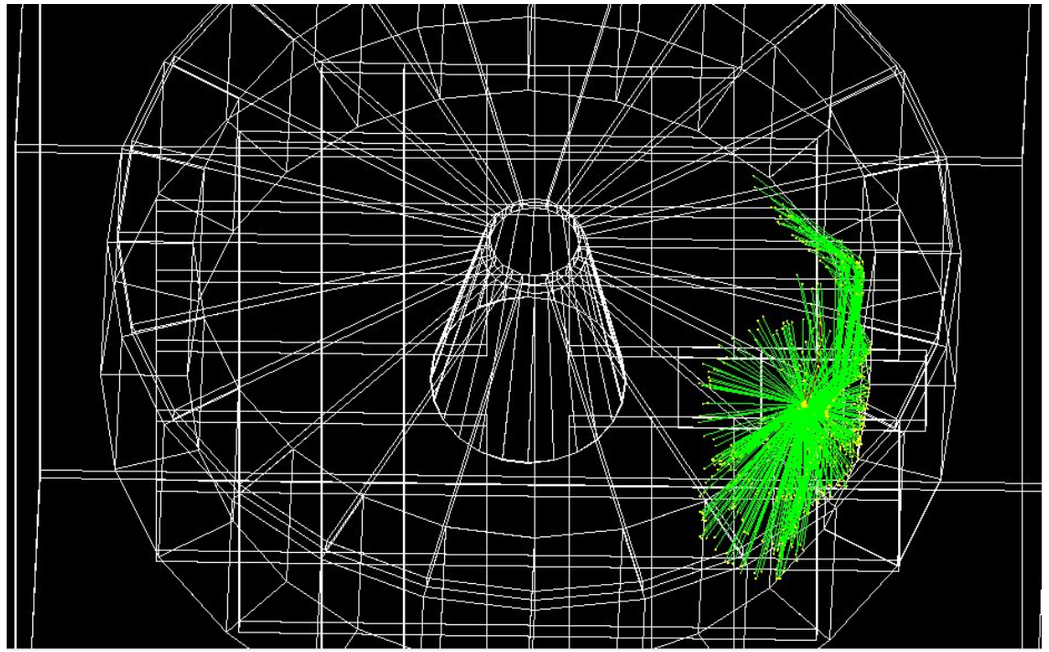
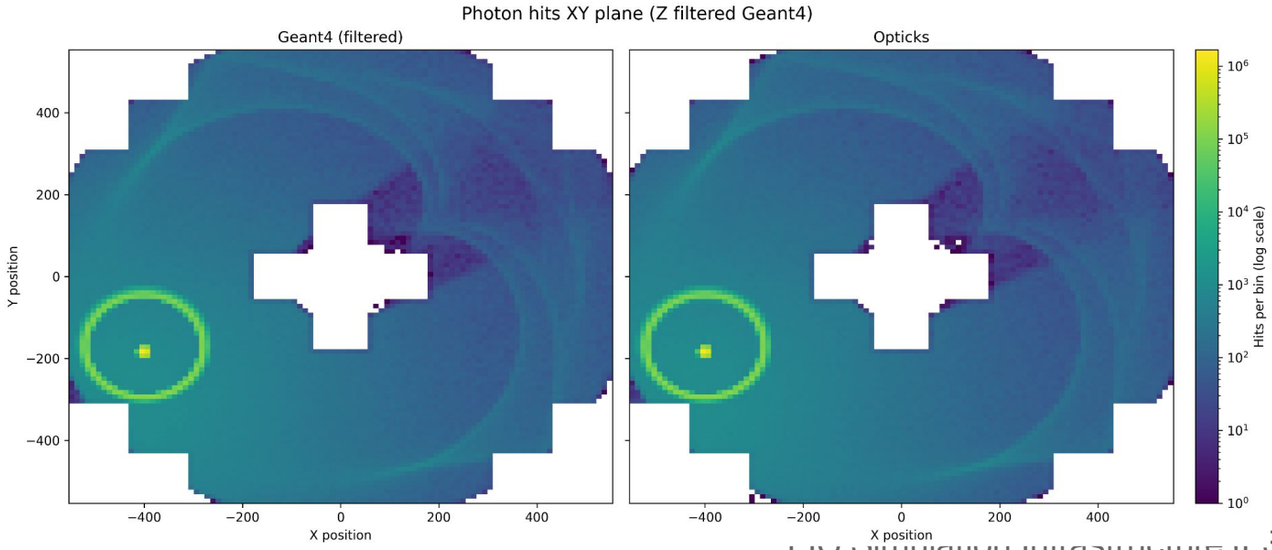
  - spack install eic-opticks ^optix-dev@7.9.0
  - EIC-Opticks is containerized, enabling seamless execution on any host with a modern GPU, without installation overhead
  - Testing is currently underway on NERSC Perlmutter
- Fixed some bugs, eg. rays were incorrectly blocked by transparent surfaces in certain volumes

Validation and performance

- Had to replace TRD, TRAP volumes in pfRICH GDML: pyramids are flat, single aerogel volume instead of tiles
- Validated EIC-Opticks vs pure Geant4 for a simplified pfRICH geometry
  - 50k 5 GeV e^- a:
    - Geant4 hits : 13840566
    - Opticks hits : 13840638
- Time measurement for EIC-Opticks included:
  - Data movement from CPU -> GPU
  - Ray tracing
  - Copying results from GPU -> CPU
- 160k 5 GeV e^- → ~ 100M photons
  - Single thread G4 CPU ~150 s
  - 20 threads MT G4 CPU ~10.5 s
  - EIC-Opticks (GPU): ~1.1 s

  ~ 137x speed-up wrt. single thread





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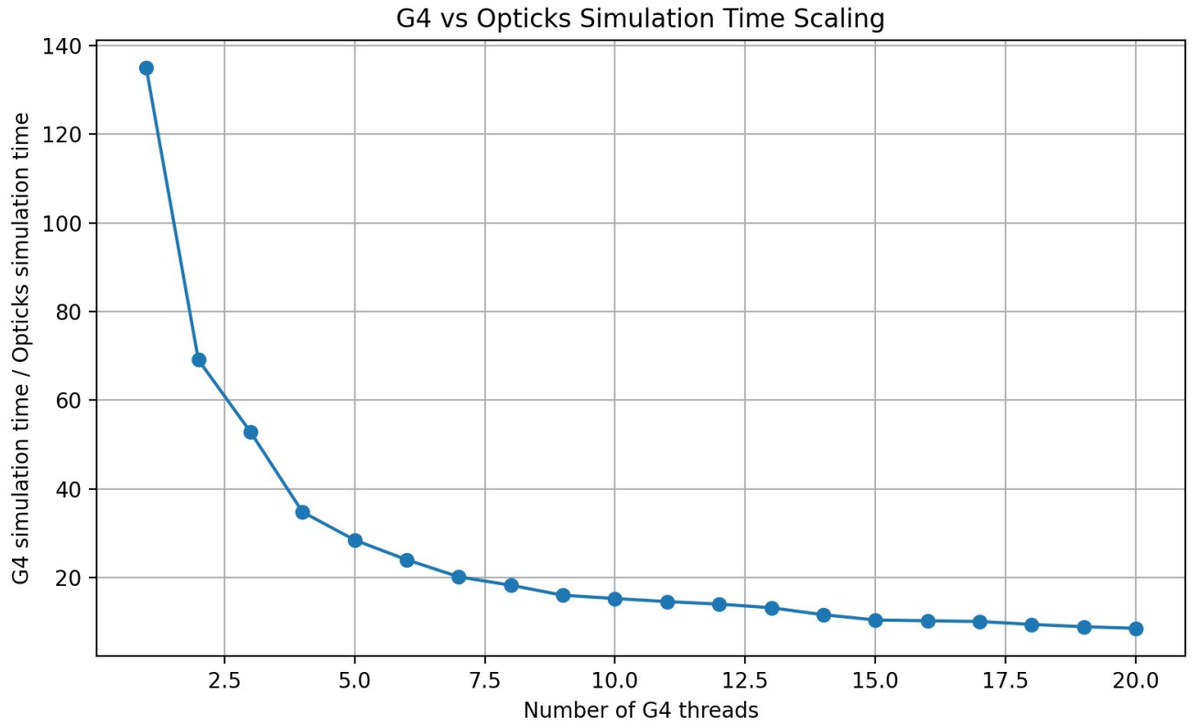


Questions

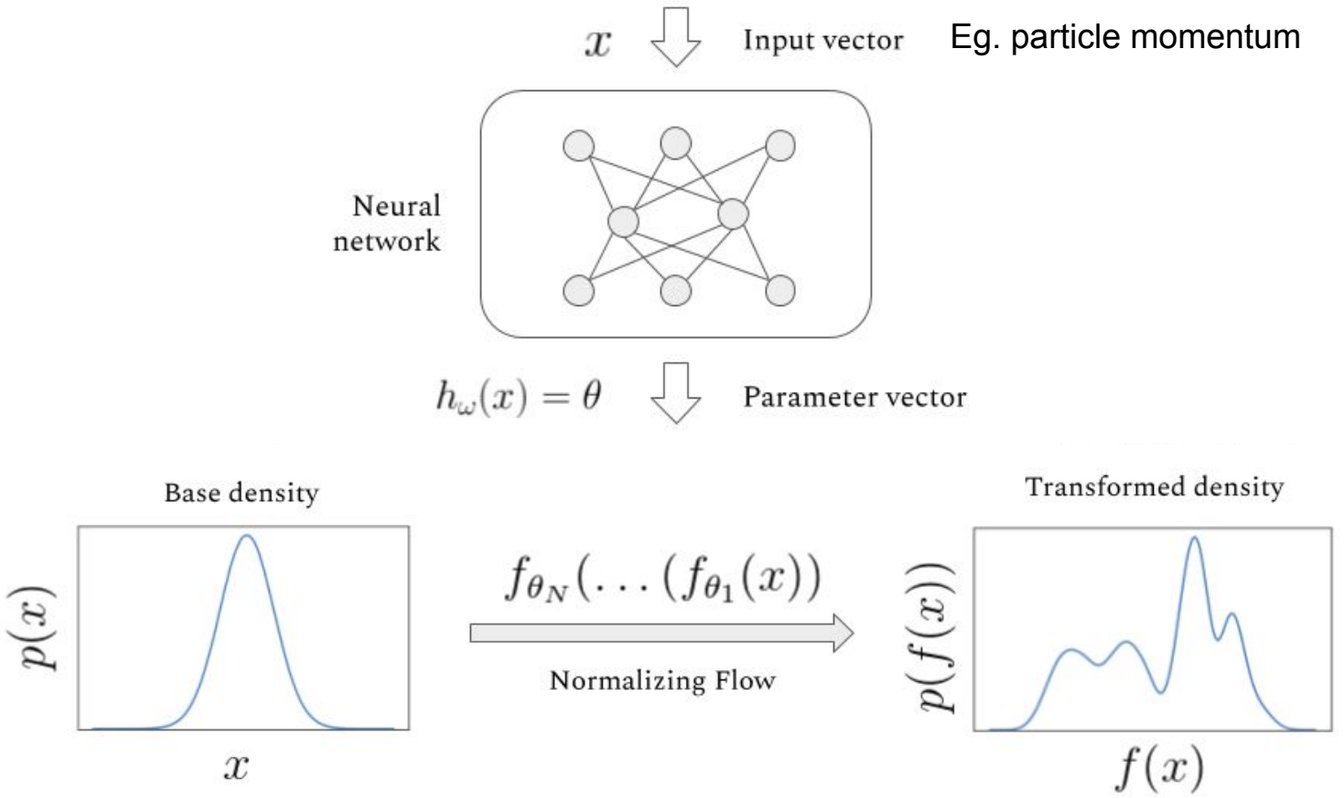
- How to make sure the geometry we are working does not affect the “physics” results?
  - Sakib is running same events with official EPIC code (IRT branch?)
- What particles to simulate?
  - What is most optical photon intensive?
- Anybody interested in trying out the code?

Surrogate model to generate pfRICH events

- https://github.com/BNLNPPS/esi-fastlight
- Idea: use ML to create pfRICH events on the fly without the need of Geant4, EIC-Opticks or any MC code
- Anybody on any computer can create huge dataset
  - For testing PID / tracking
  - Pretraining ML models
- A single python code that generates realistic pfRICH events for given momentum, particle type, direction and position
  - All you need to download an ML model, 100 kB now
  - Have python ML tools installed
  - Can create pfRICH hitmaps
- Only few weeks old project
- For now can create electrons with 5 GeV momentum, single direction and position

Conditional Normalizing Flow

- Sounds fancy but basically a neural network + an assumed (priori) probability density function
- Neural network is used to map (tweak, distort, transform) the a priori distribution
- 1 dimensional example:

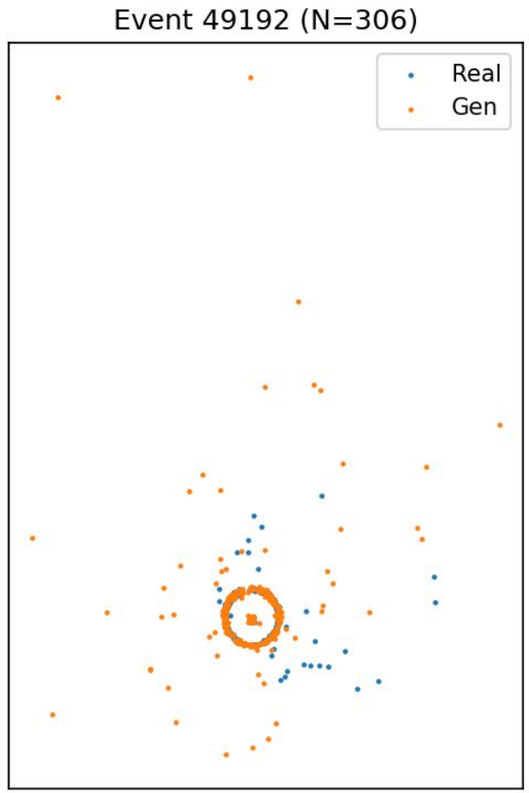


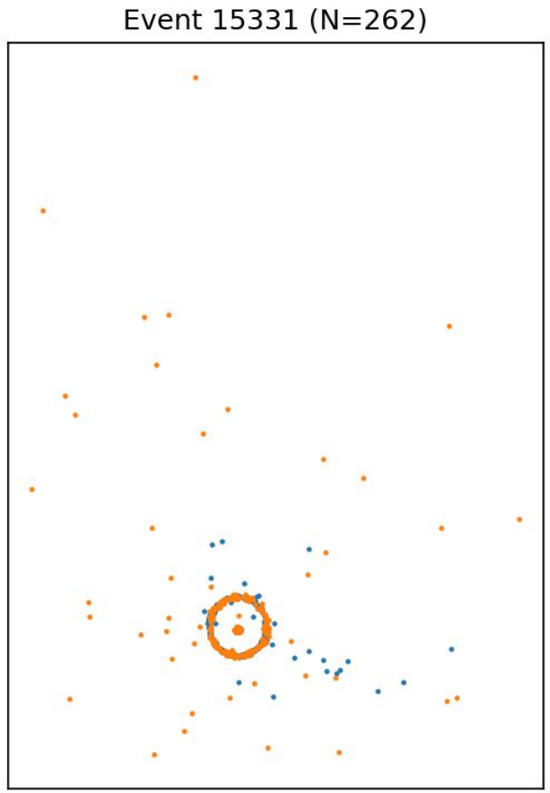
Conditional Normalizing Flow

- We want to do “Physics aware” machine learning:
- Do not give a 2D Gaussian as priori PDF
- We gave the CNF a 3-component mixture prior:
  - A ring PDF
  - A 2D Gaussian PDF for the center
  - A 2D Gaussian PDF for the scattered photon hits
- The neural network “fits” this priori to the training events
- 50k 5 GeV electron hitmaps used for training
- NN has ~100k hyperparameters

Results

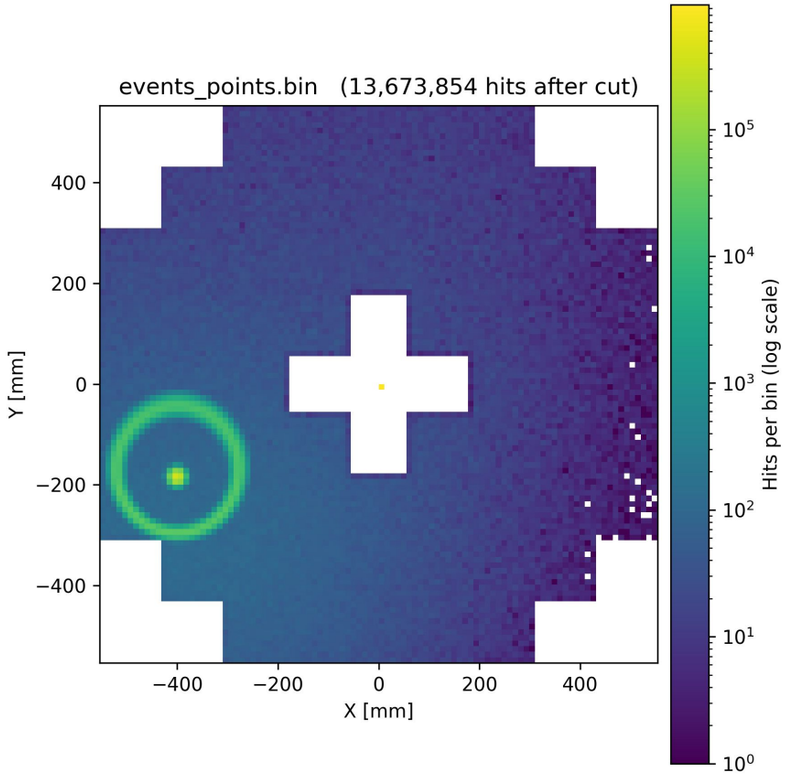
- Comparing Monte Carlo (“real”) and events generated by CNF model
- Center, ring well modelled
- The scattered photon hits do not yet match up
- Multiplicity matches





Results

- 50k events generated by CNF ML model
- Took 0.7 seconds on my PC GPU (even faster than EIC-Opticks simulation!)
- Obviously ML can not understand caustics and complicated reflection patterns
- However for tracking testing etc. they are not needed
- ML understood that on the opposite side there should be less hits



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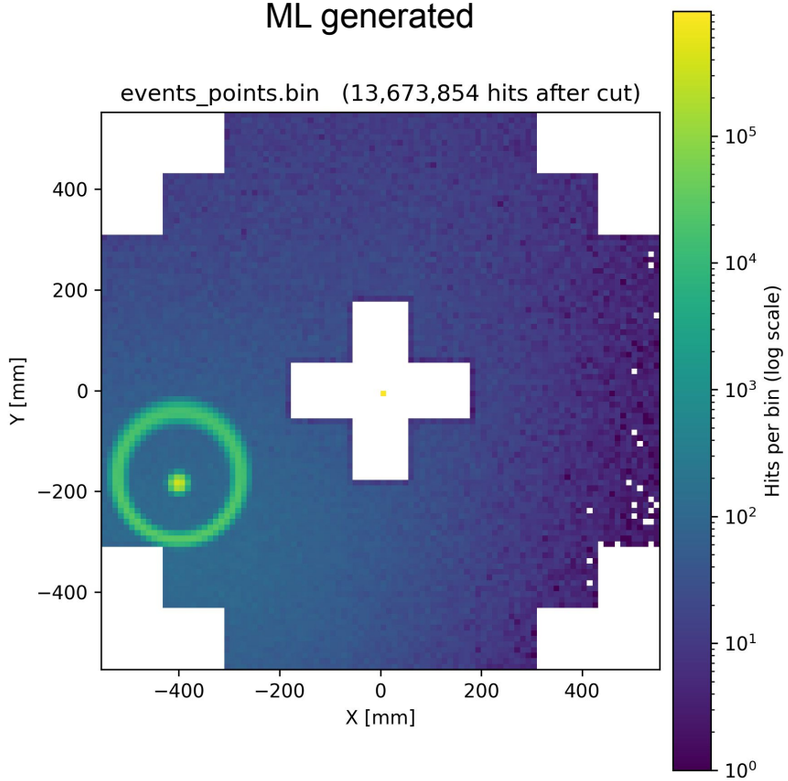
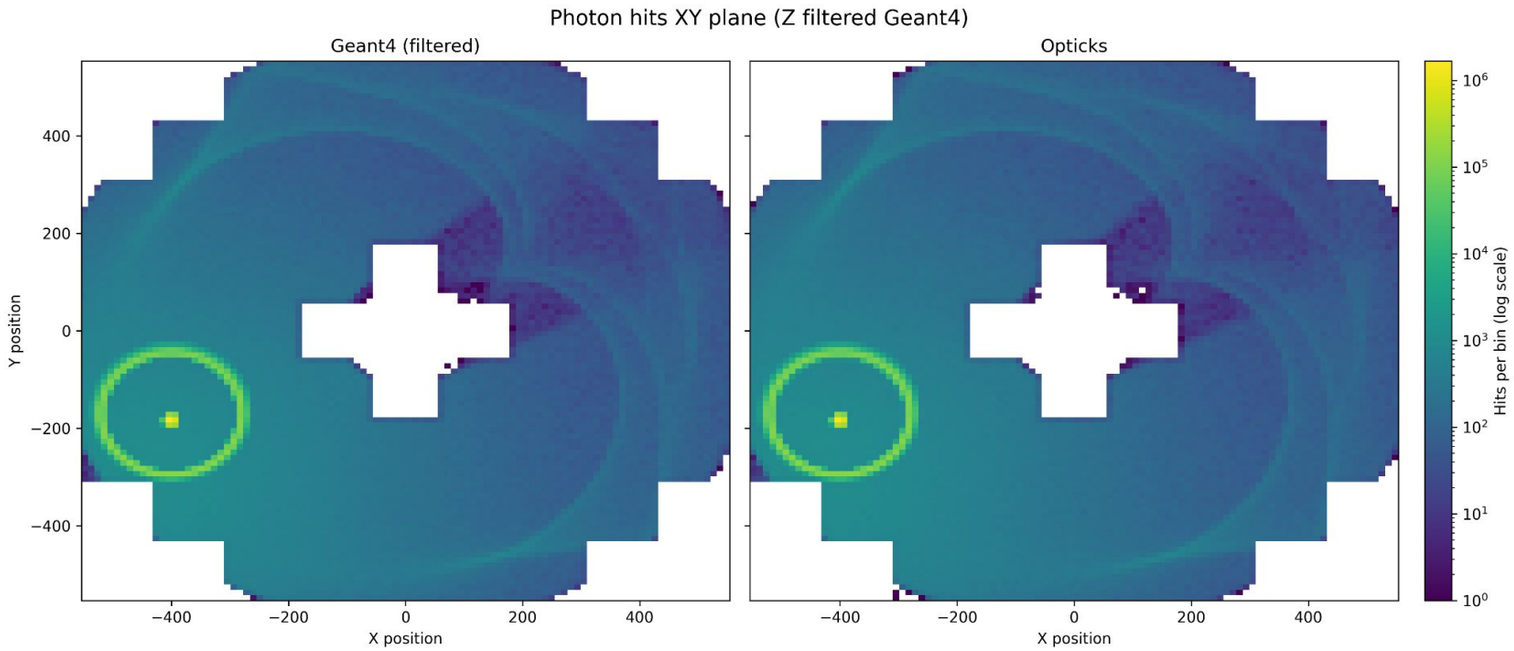
ML generated



Geant4 generated

EIC-Opticks (GPU) generated



Next steps + Questions

- Will add the following options / features / inputs:
  - Momentum
  - Particle type
  - Position
  - Direction

- Should time be generated too, not only positions?
- What particles are relevant?
- What are ranges of interest in momentum, direction, position?
- Looking for testers
- Any idea on the background priori?