Introduction to Fun4All for CORE

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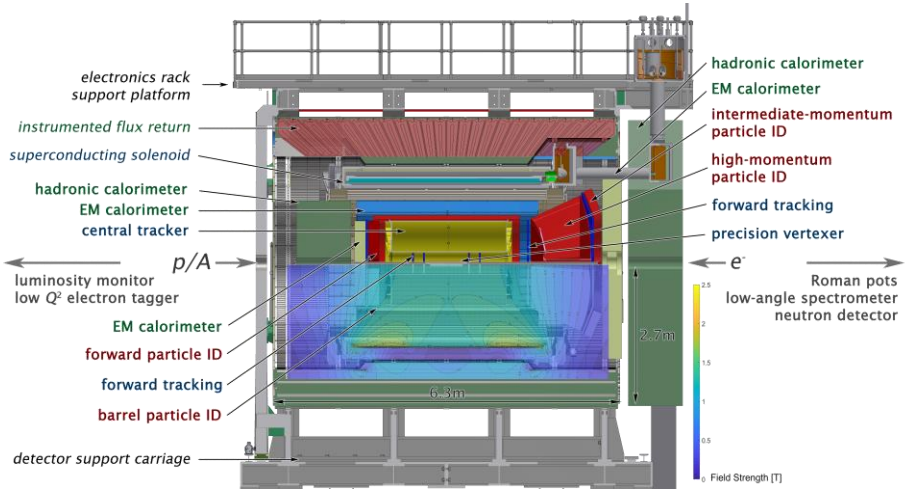
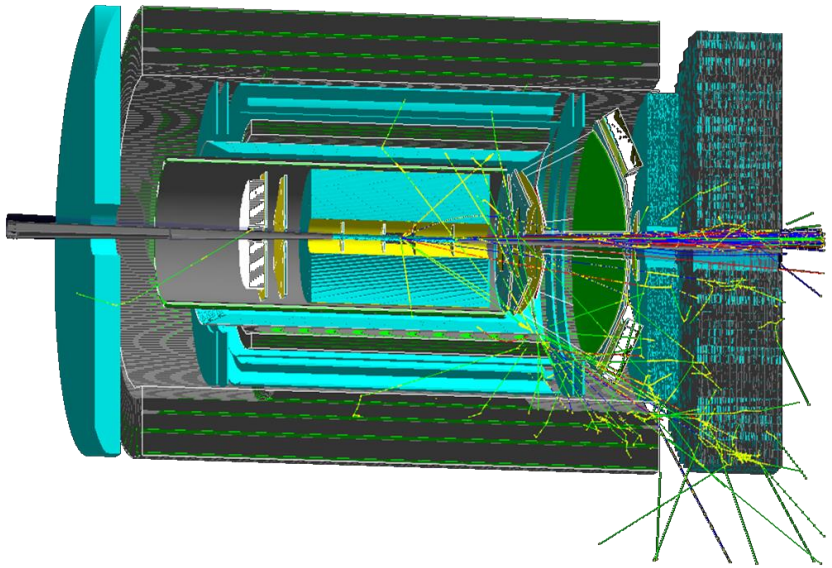
Fun4All EIC simulation and reconstruction

Concept from detector team
(an example with 1.5T magnet shown here)



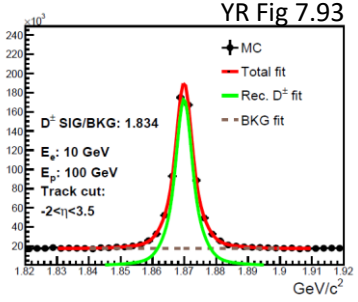
→ Fun4All sim. and reconstruction →

Yellow Report (YR) Fig 11.65

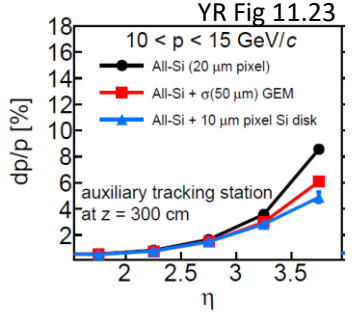


Validating performance

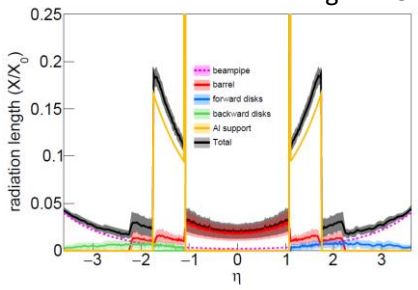
YR Fig 7.93



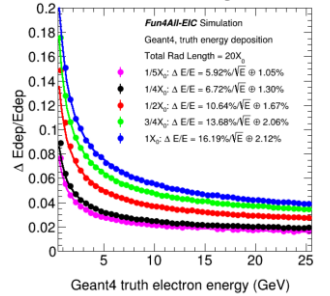
YR Fig 11.23



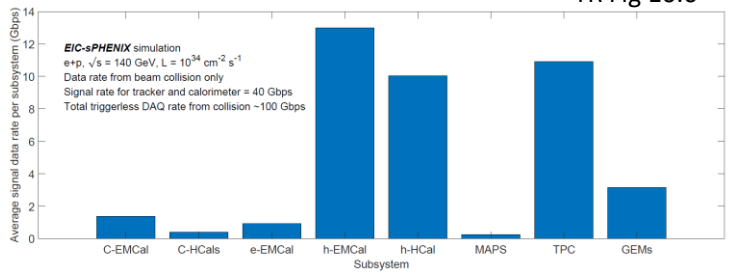
YR Fig 11.73



YR Fig 11.55



YR Fig 10.6



Note:

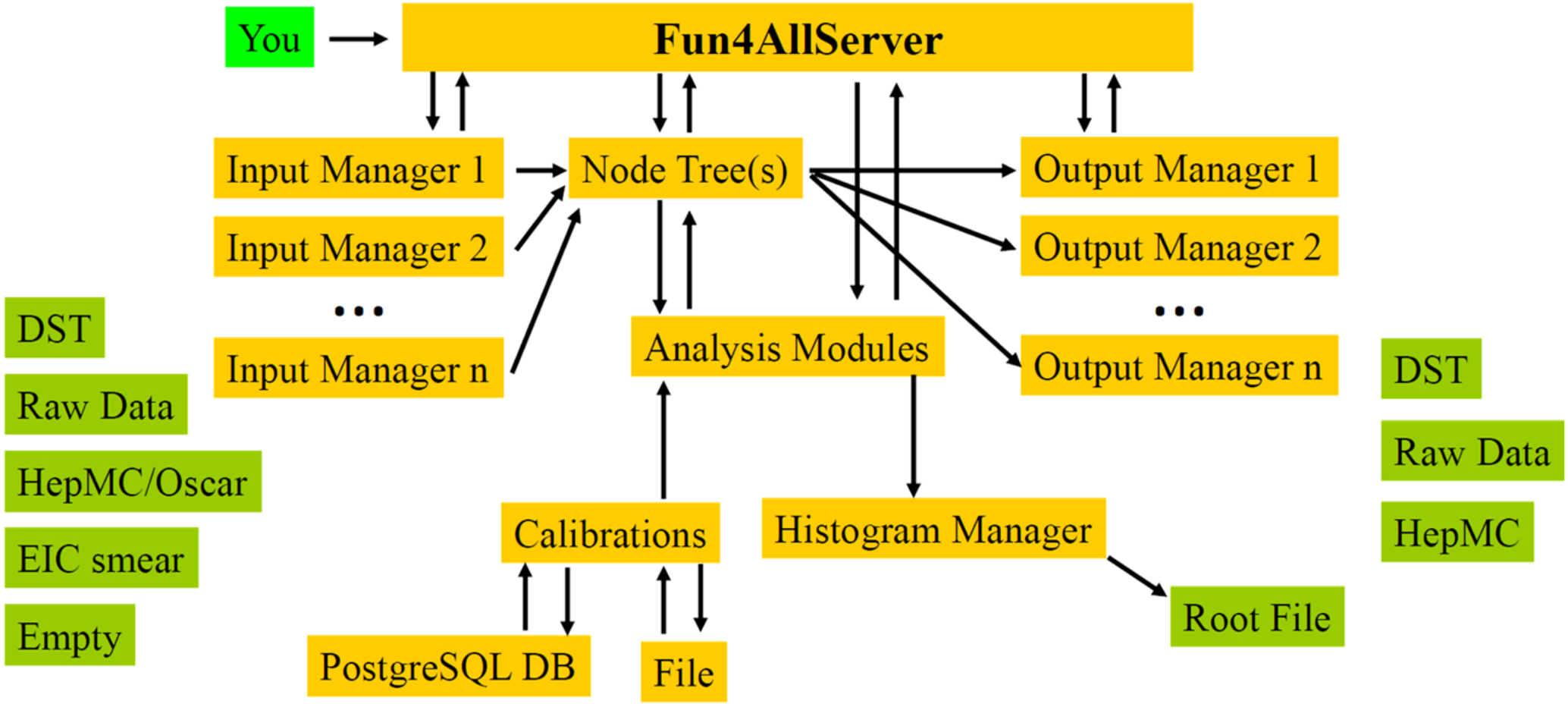
- Figures of a generic EIC detector are used for illustration purpose
- Non-collaboration specific yellow report figures shown
- Also used in sim+reco. in stages of proposal preparation for all three EIC proto-collaborations

Fun4All is …. the glue that binds them all

Fun4All is ….

- Built to handle 100PB real data and 1B event simulation annually
- C++1x-based framework and integrate many commonly used software packages, e.g. Pythia6/8, Geant4, ROOT, GenFit2, ACTS, FastJet, KFParticle
- The analysis is a continuous chain from the event generator/raw data up to analysis objects, e.g. jet reconstruction; steering flow of program using ROOT Cling macros
- Internal Node Tree our storage for data objects, support make snapshots at any state of the reconstruction/analysis
- Many IO formats, embedding, pileup, access to calibrations
- Continuously distributed over CVMFS and containerized

Fun4All framework: the glue that binds them all

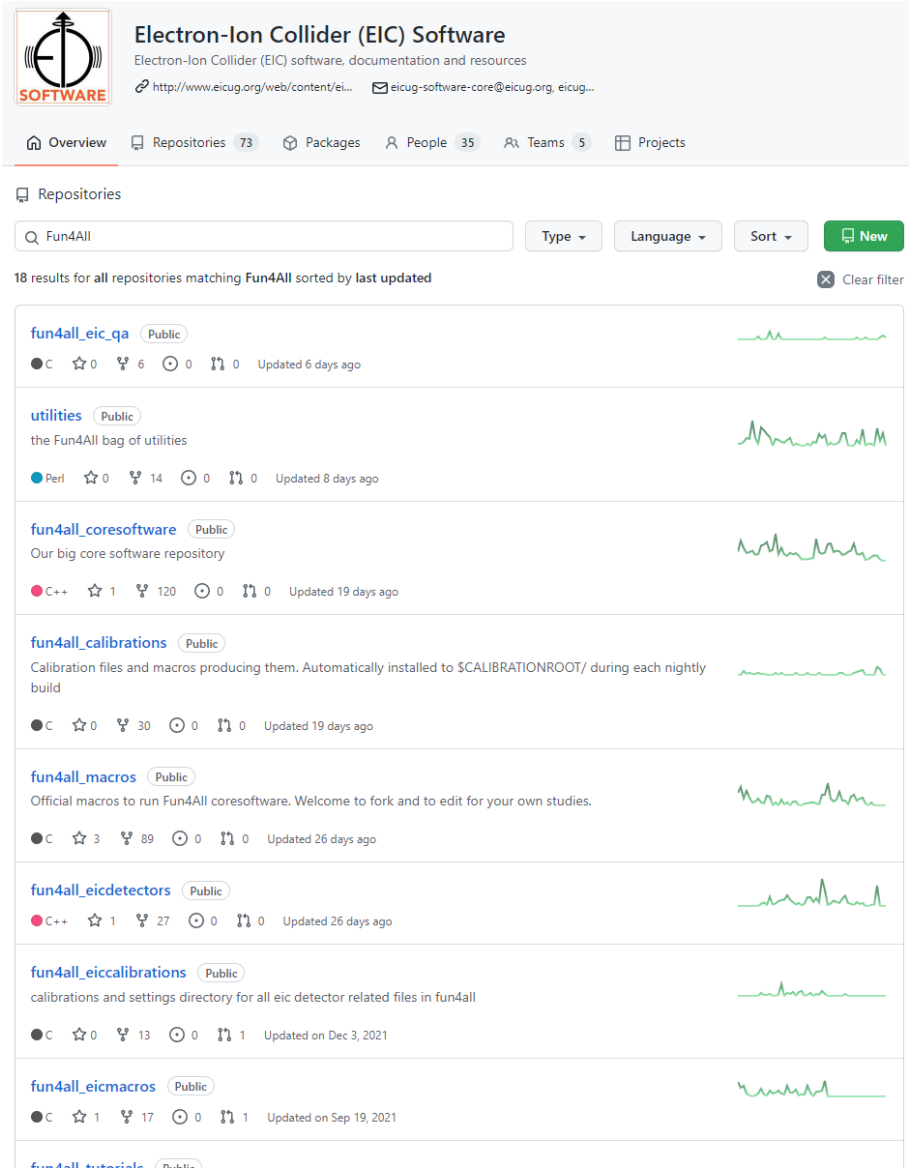


That's all there is to it, no backdoor communications – steered by ROOT macros

Fun4All-EIC Software Infrastructure

Repository organization

- EIC UG GitHub host a fork of Fun4All for EIC general use
  - Open-source software repository
  - Mirrored core-software from sPHENIX + EIC specific dev
  - Note: sPHENIX and ECCE use dedicated GitHub organization to have full control of repos
- EIC detectors built on top of Fun4All:
  - **fun4all_eicdetectors [daily build, require pull request]**: G4 detector description, reco. Module
  - **macros [daily build, require pull request]**: Detectors description and common macros
  - **fun4all_eiccalibrations [daily build, require pull request]**: calibration file, geometry descriptions



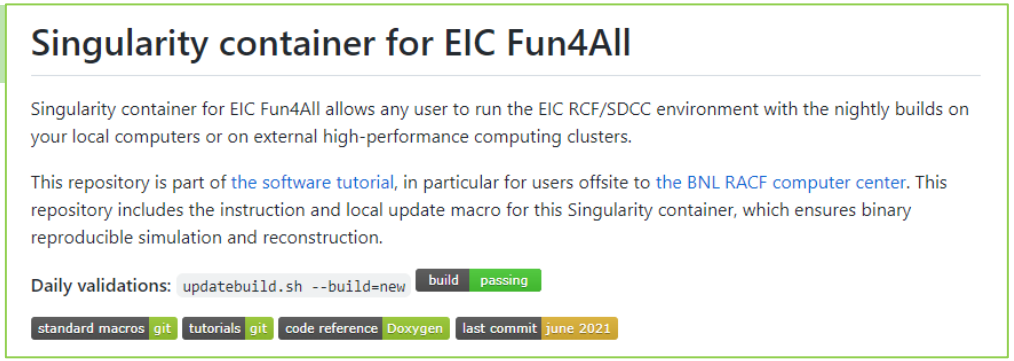
EIC build distribution

- Daily build and distribute via OpenScienceGrid CVMFS
- In place where sourced eic_setup.sh or sphenix_setup.sh:

```
singularity shell -B /cvmfs:/cvmfs /cvmfs/eic.opensciencegrid.org/singularity/rhic_sl7_ext.simg
source /cvmfs/eic.opensciencegrid.org/default/opt/fun4all/core/bin/eic_setup.sh -n
```

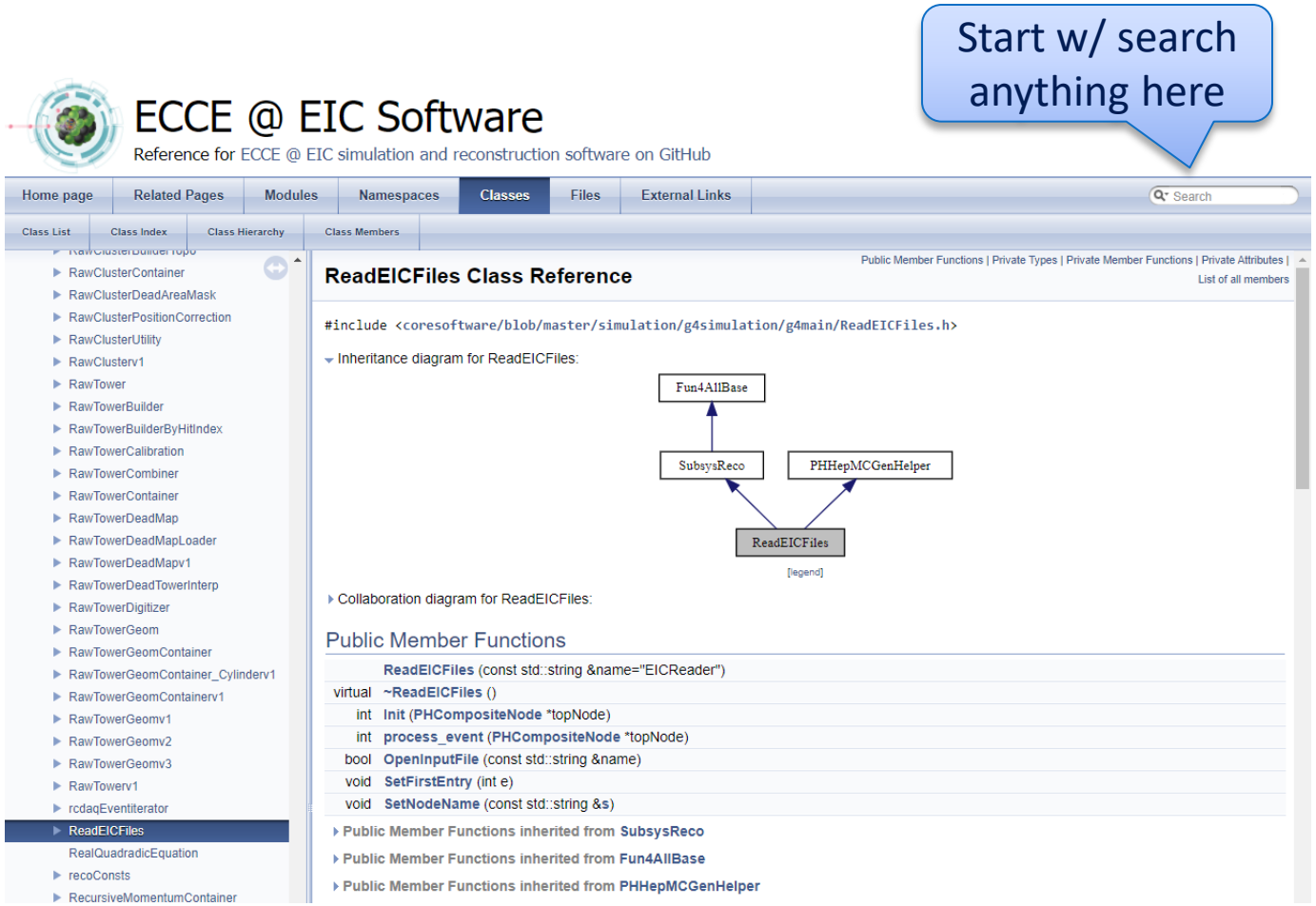
- Use out of box in major NP/HEP scientific computing centers
  - Example to use at Jlab: https://ecce-eic.github.io/tutorials_example2_JLab.html#run-the-simulation-in-batch-mode-in-example-2a
- Install in your institution Linux sever or laptop via Linux VM: https://github.com/EIC/Singularity
- Same container can be used for EIC-Smear fast simulation [e.g. EIC-Smear]

https://github.com/EIC/Singularity

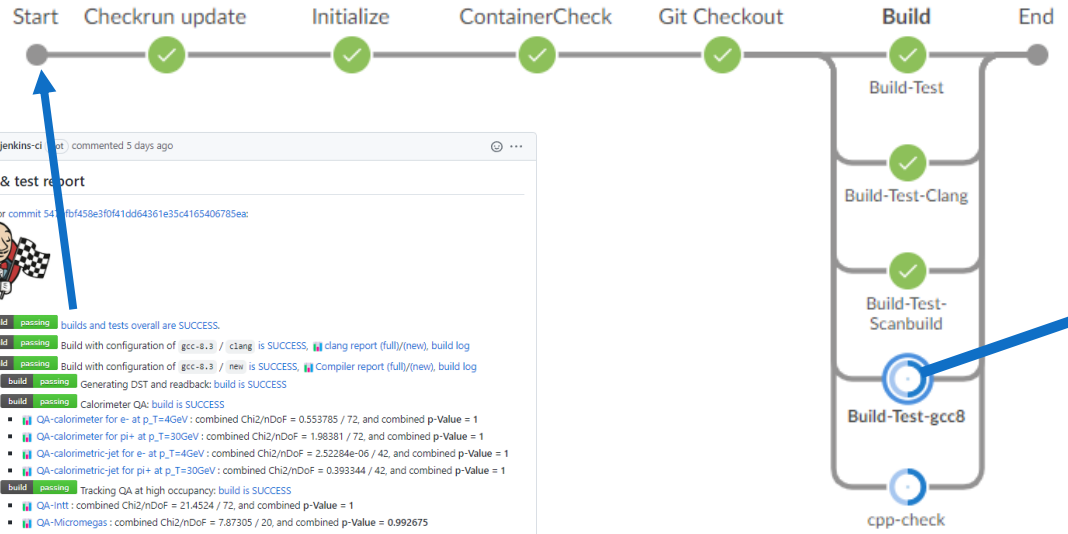


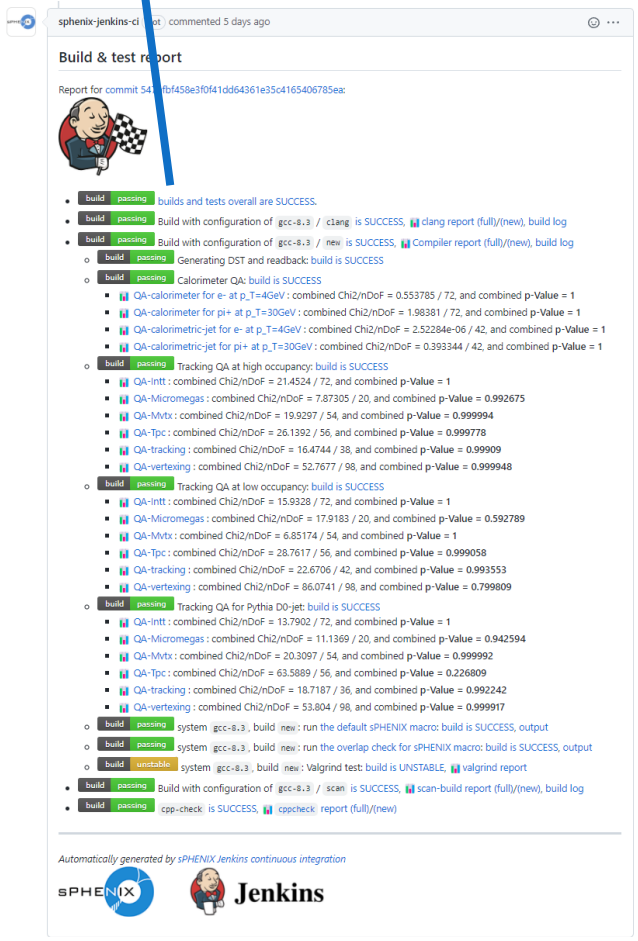
How do I navigate around all this mountain of code?

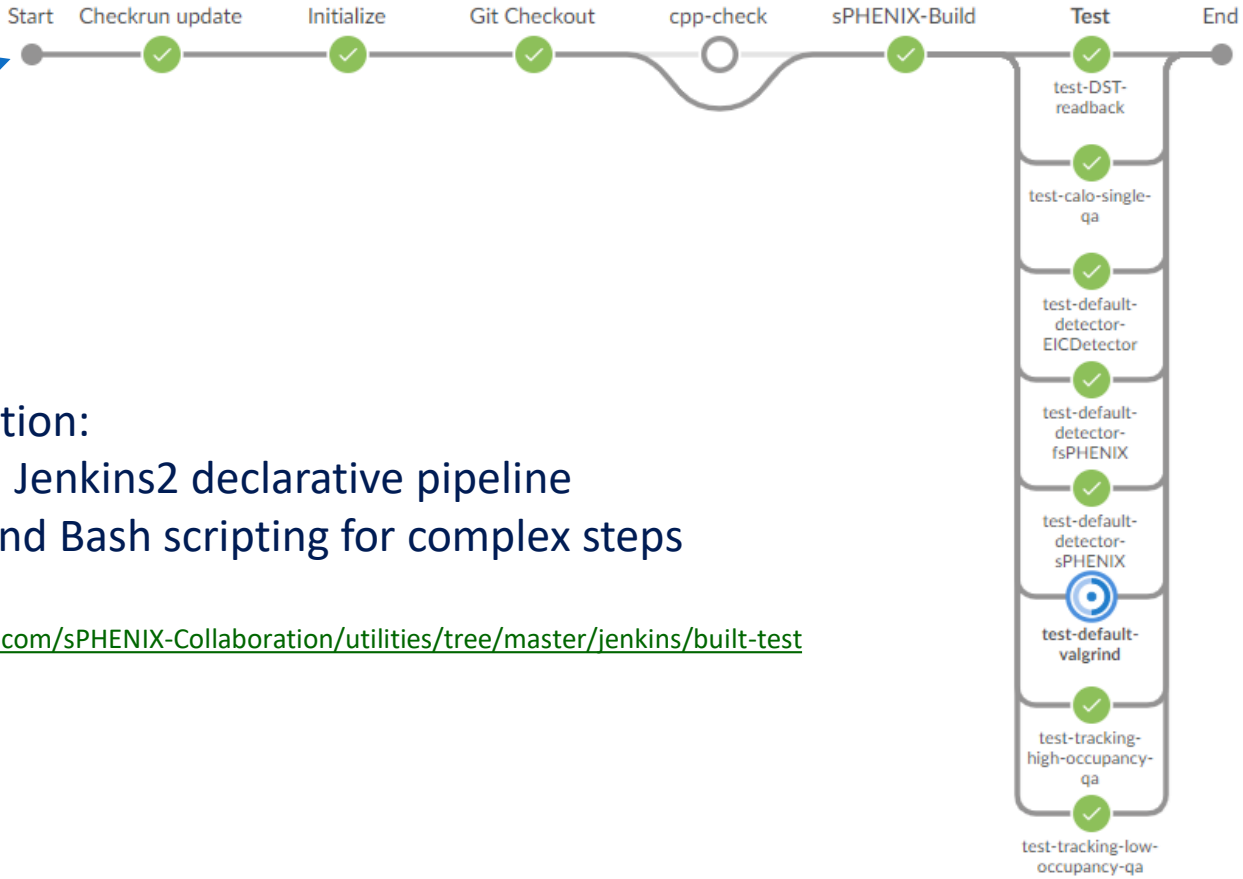
- eic.github.io/doxygen/
- All software on GitHub now digested in Doxygen via JenkinsCI
- Auto built at change of any repository
- Search anything in Doxygen site for EIC GitHub software



Fun4All Jenkins-CI Pipeline Workflow







- CI check in upstream sPHENIX-Fun4All repo

Implementation:

- Based on Jenkins2 declarative pipeline
- Python and Bash scripting for complex steps
- Git SCM:
  https://github.com/sPHENIX-Collaboration/utilities/tree/master/jenkins/built-test

https://github.com/sPHENIX-Collaboration/coresoftware/pull/1415#issuecomment-1036911557

Software modules

Event generators

- Running example given in sample EIC sim macro: https://github.com/ECCE-EIC/macros/blob/master/detectors/EICDetector/Fun4All_G4_EICDetector.C
- Arbitrary set-of-particle generators for testing
- Main event generator input format: HepMC files
- Built-in generators : PYTHIA8.3, PYTHIA6, SARTRE
- Reads events generated in EIC-Smear package [talk: Kolja]
  - Share the same Singularity image and CVMFS vol.
    Source different setup macros.
  - Allow comparison of same event sample processed by EIC-Smear and by the Fun4All simulation-reco.
- Support multiple background pile ups

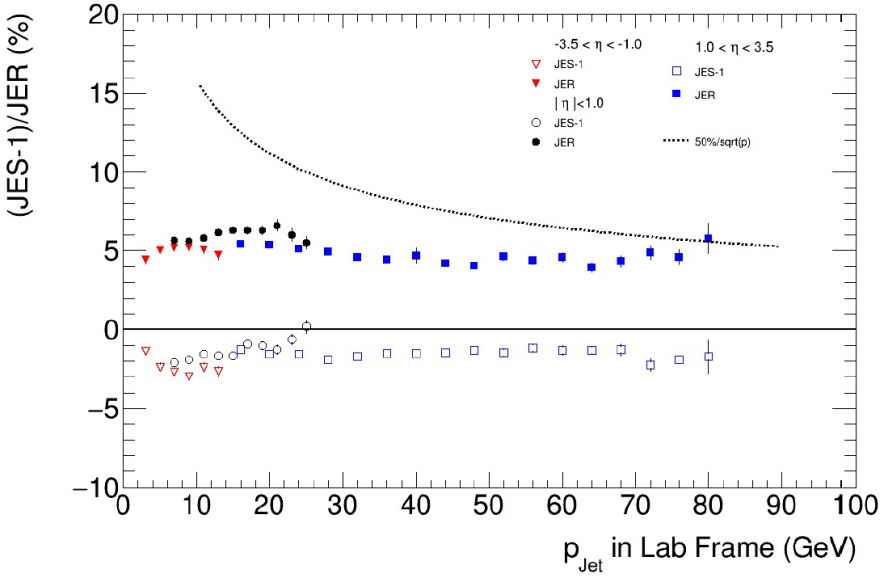
Note: All EIC full event generator has EIC beam parameters applied by default: see next section

https://eic.github.io/software/mcgen.html

Example Reconstruction Modules

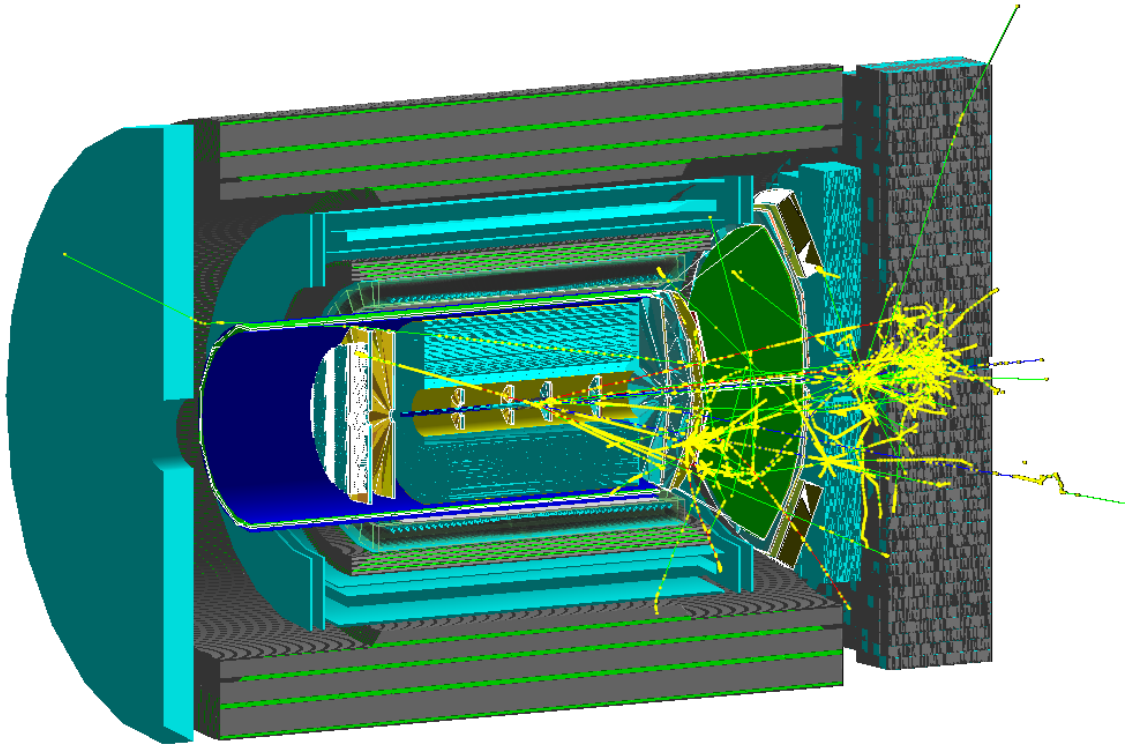
- Tracking:
  - Use GenFit2 for fast prototyping (PHG4TrackFastSim), widely used in YR tracking studies
  - ACTS comes built in and use by sPHENIX for speed gain. Not a real issue for EIC though
- Calo reco:
  - Many choices of clusterizers, FastJet, Particle flow jet via Centauro algorithm
- PID reco:
  - Loglikelihood-based PID interface : https://indico.bnl.gov/event/13060/contributions/54740/attachments/37240/61349/HadronPID.pdf
  - GenFit2 for TOF, e.g. track length and timing smearing
- Resonance search/HF reconstruction:
  - KFParticle , HF jet tagging
- Detailed truth tracing evaluation chain
  - e.g. what portion of reco jet is from a truth jet

Particle flow jet via Centauro algorithm [ECCE DPAP resp]



Background embedding: beam gas interaction

- Built-in Pythia8 for beam gas interaction background generation

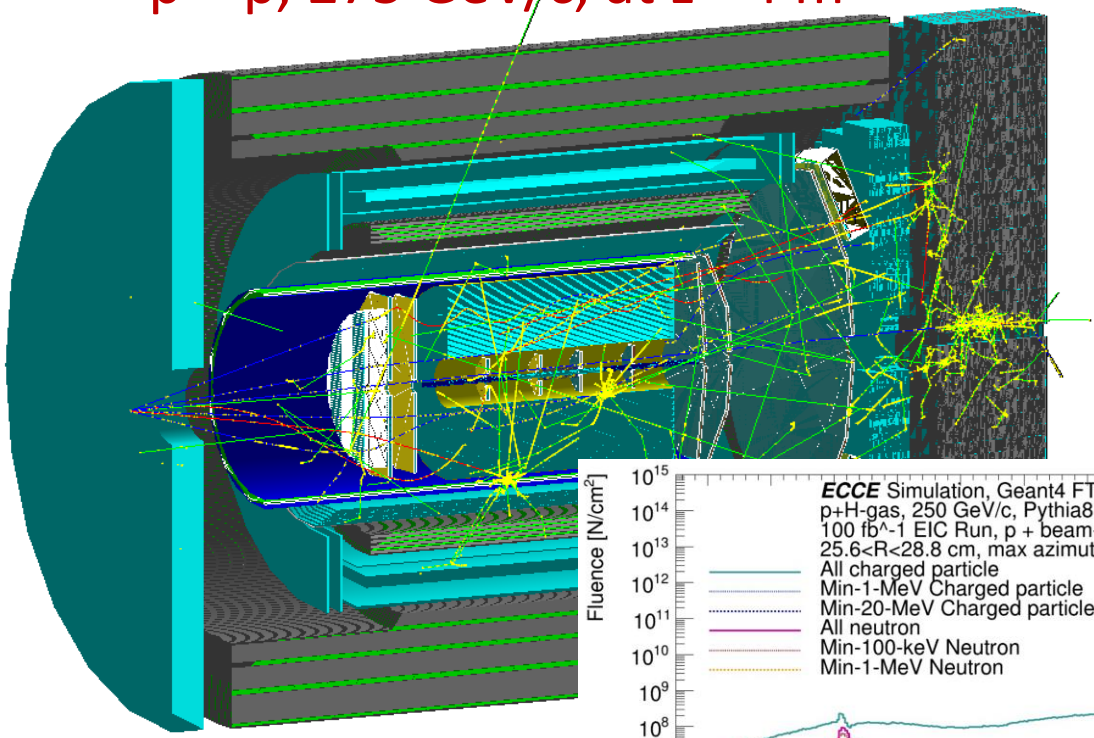


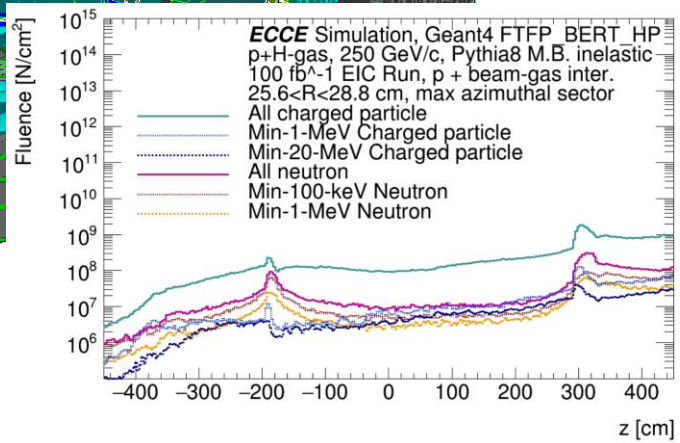
e+p DIS 18+275 GeV/c

$Q^2 \sim 100\ (GeV/c)^2$

Beam gas event

p + p, 275 GeV/c, at z=-4 m





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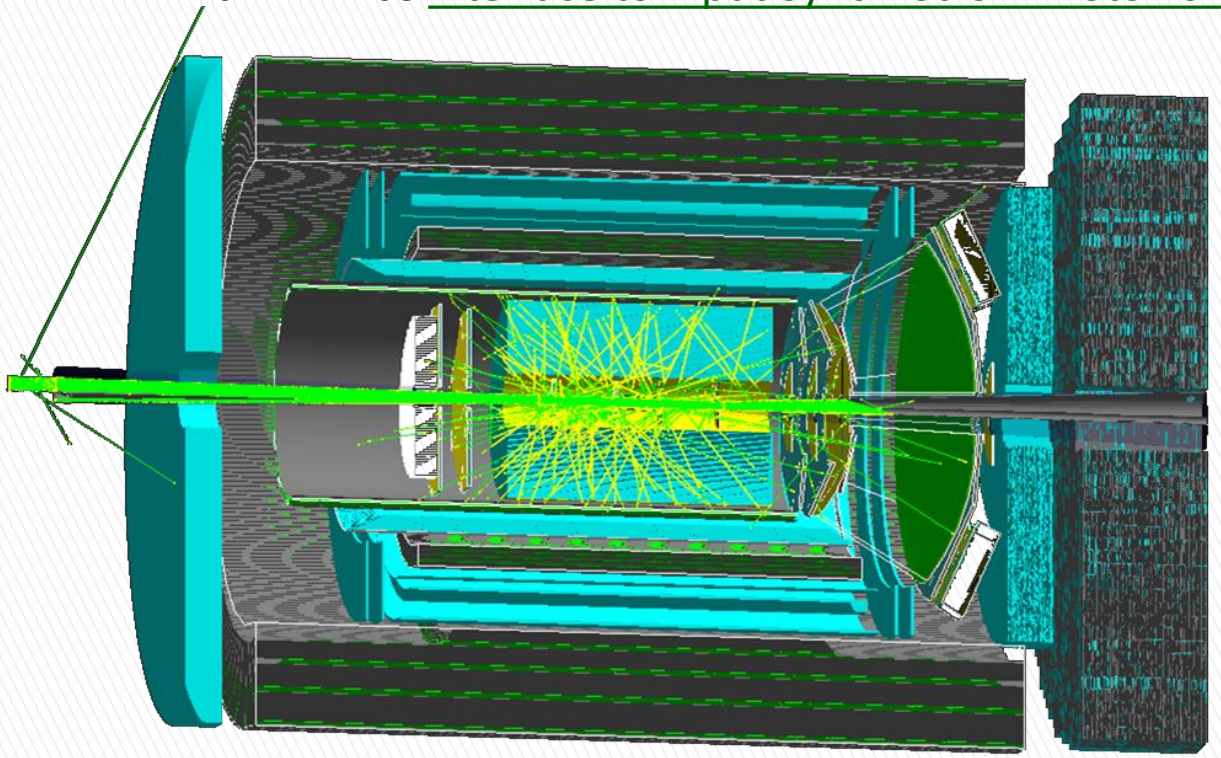
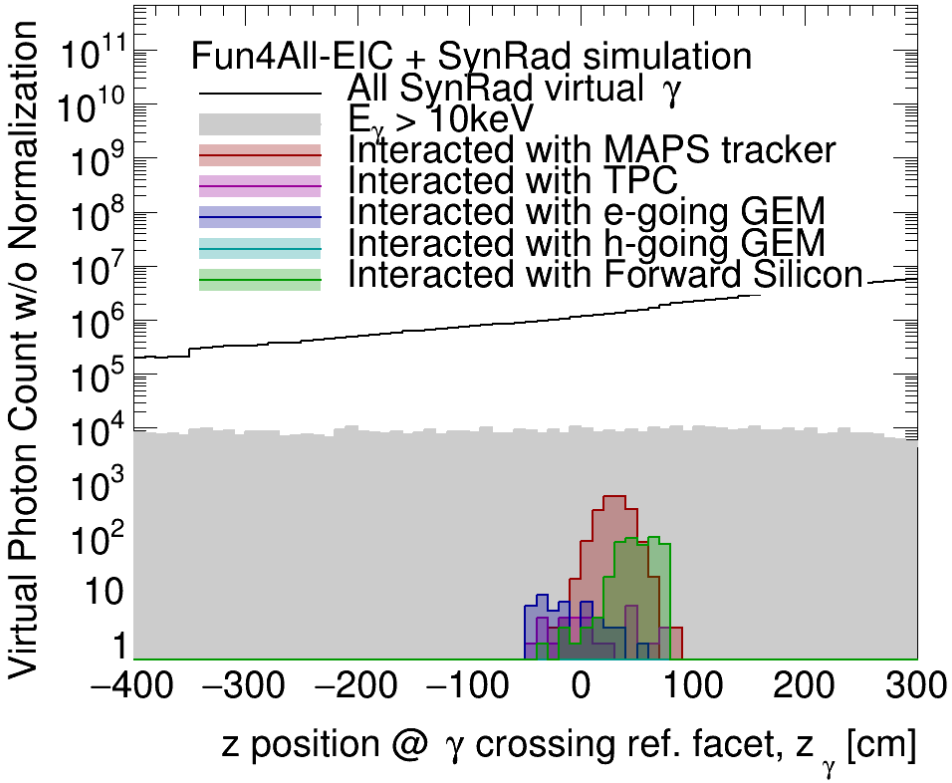
Background embedding : Synchrotron radiation

- Fun4All has interface to input Synchrotron Photon simulation, used in Synchrotron study leading to CD-1 review





100k Synchrotron photon in full detector simulation [YR Fig 10.12]

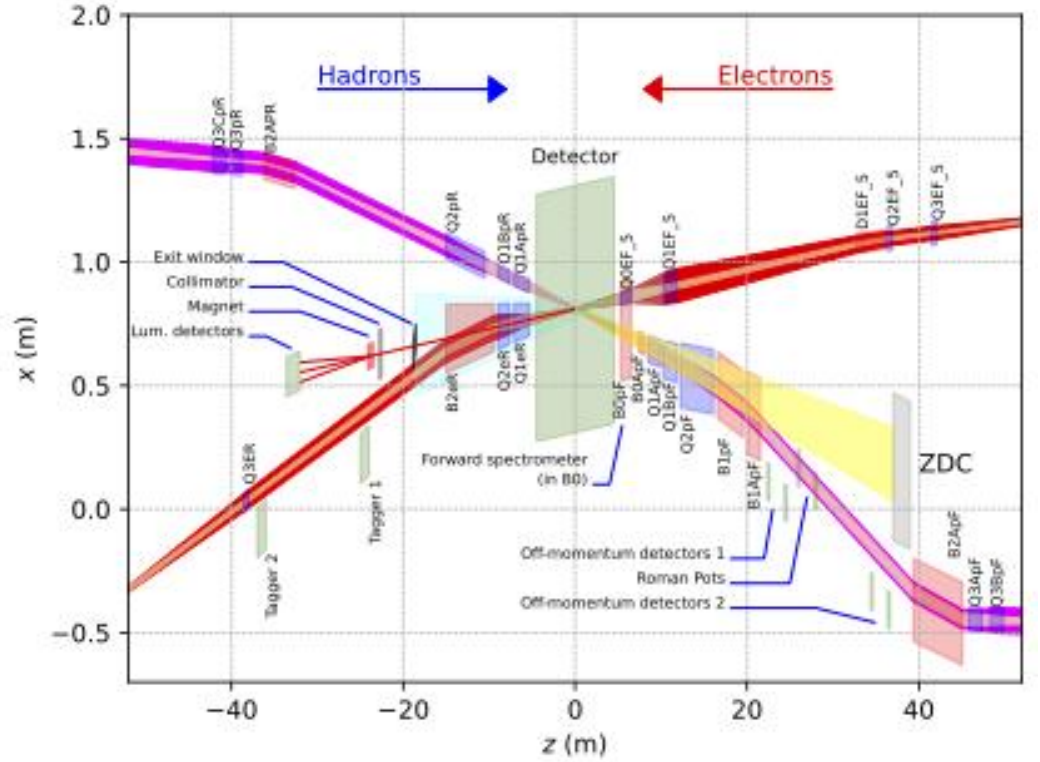
Detector background as function of beam-pipe exit-location

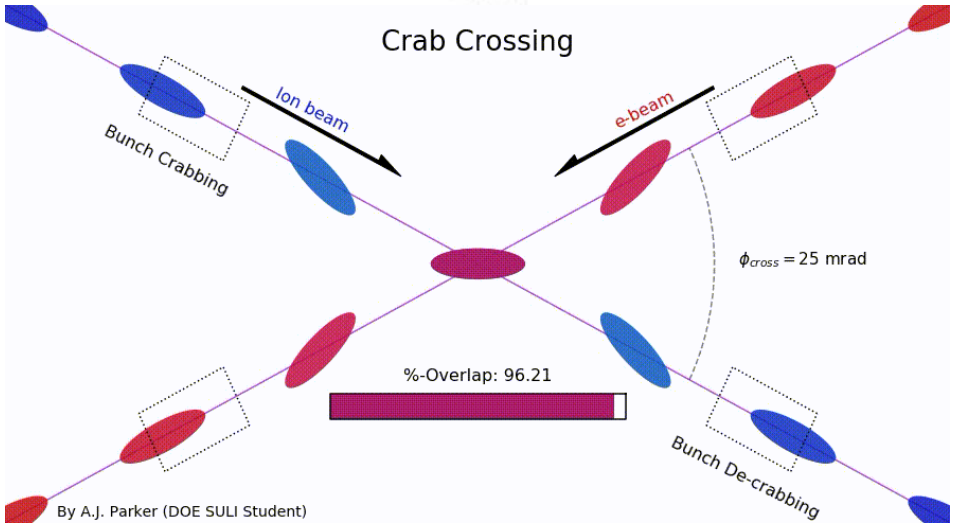
Note: all photons simulated for detector interaction, without cuts on z or energy. EIC/July-2020 lattice & chamber

Beam crossing afterburner in Fun4All

Leading order beam effects

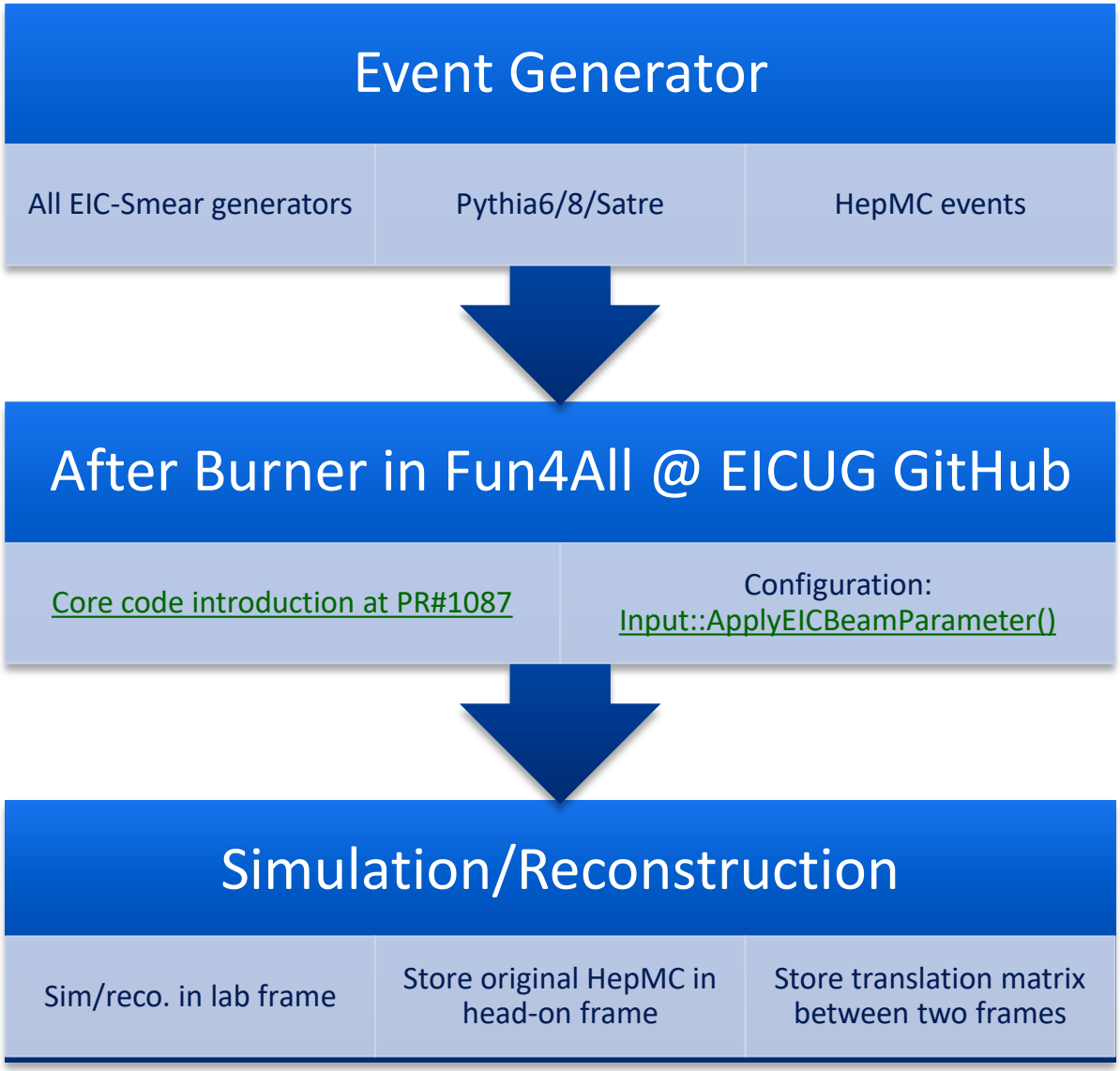
- At EIC unique accelerator with diverse beam effect [ref: CDR]
  - -25 to +35 mrad beam crossing angle, both supported in ECCE setup
  - Angular beam divergence: O(100urad)
  - Crab crossing (bunch-z dependent angle smear): O(<100urad)
  - Beam energy spread $O(10^{-4})$
  - Beam vertex spread from 10cm h-bunch collider with 1-cm e-bunch at finite crossing angle
- Interestingly, sPHENIX will run w/ 2mrad beam crossing angle at RHIC [ref: BUP]
  - Common interest in sim/reco./theory
  - Also use Fun4All simulation+reconstruction framework [link]





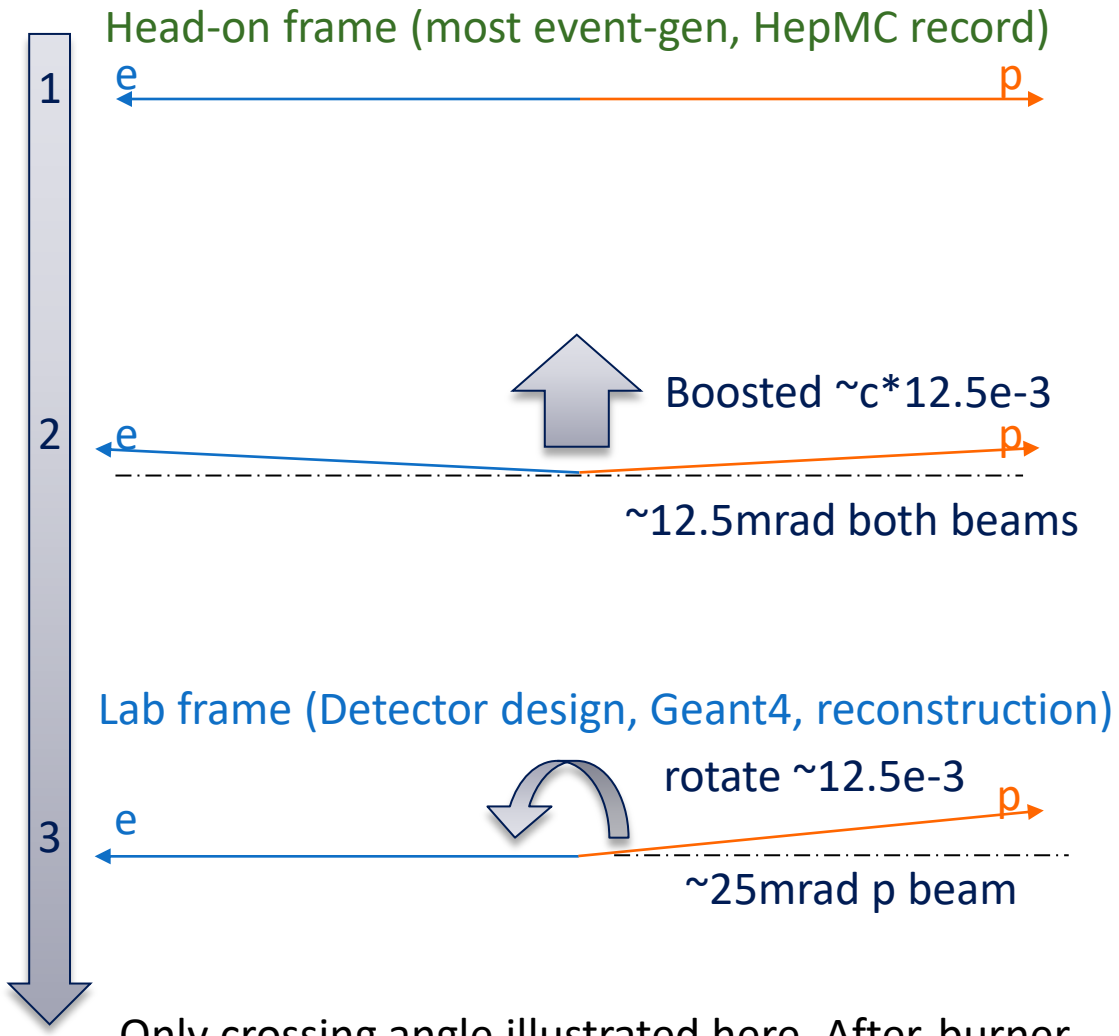
Beam effects in Fun4All sim.

- Not all event generator support beam effects while beam crossing and other effects are essential parts of EIC experiment
- After burner introduced to boost frame of any HepMC/EICSmear event of head-on collision to the lab frame with beam crossing, etc.
  - Note: $\sqrt{s_{eN}}$ is not changed in after-burner as it is boost invariant. Effect is small for most non-threshold measurement O(10^{-4})
- Book-keeping
  - Truth vertex, beam angle (variation event-by-event)
  - Truth and reco transformation matrix for reco objects → head-on frame



How does it work: the transformation

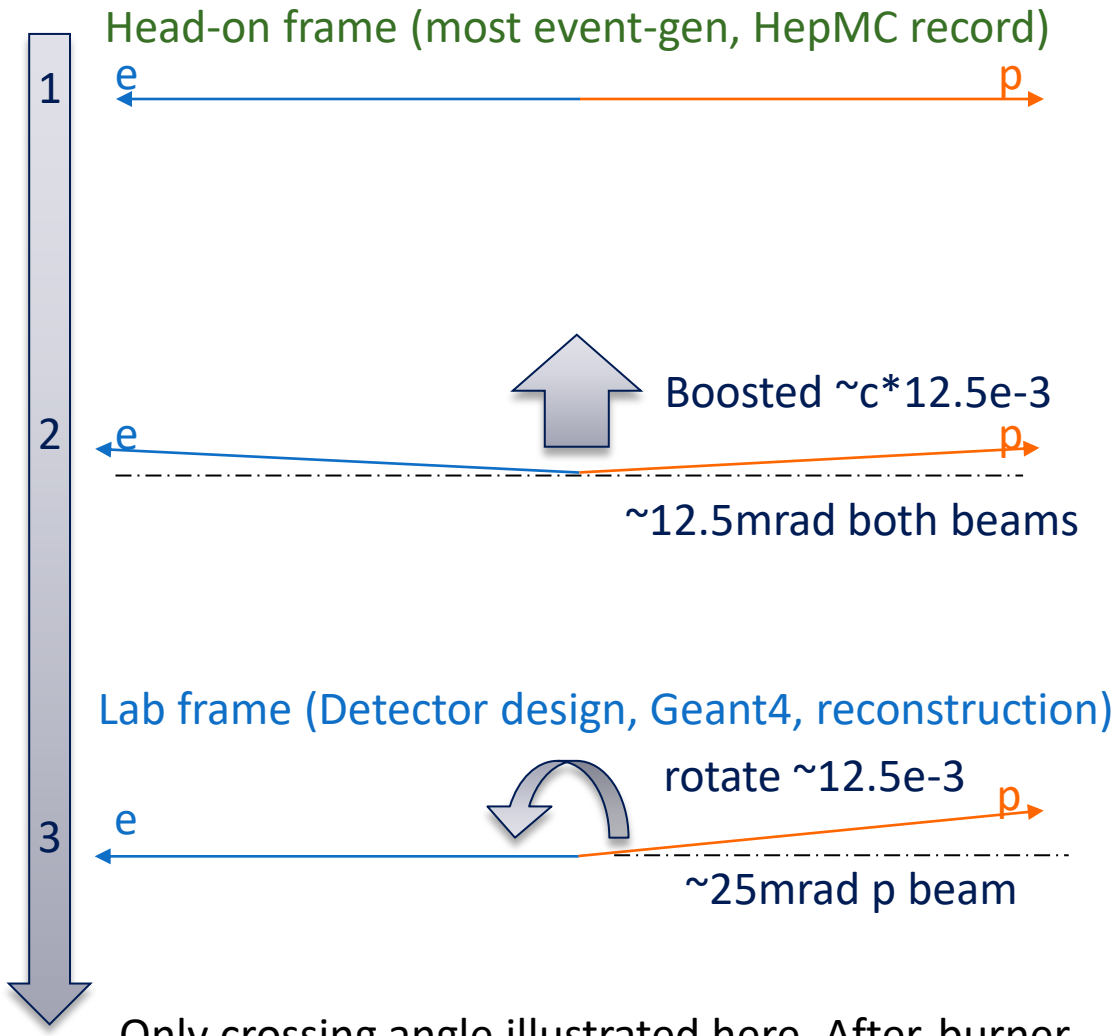
- Head-on → Lab transformation: one boost + one rotation
- Precise solution for relativistic beam
  - Minimal modification to beam energy, or RMS(Δp)
  - Significant simplify config management independent of beam specie and energy
  - Visual aid for interpretation of x-ing effects on EIC observables
- Non-relativistic beam correction
  - Correction At order $O(\theta_{Xing}\gamma_{Beam}^{-2})$ << beam divergence



Only crossing angle illustrated here. After-burner handles all beam effects [link]

How does it work: algorithm flow

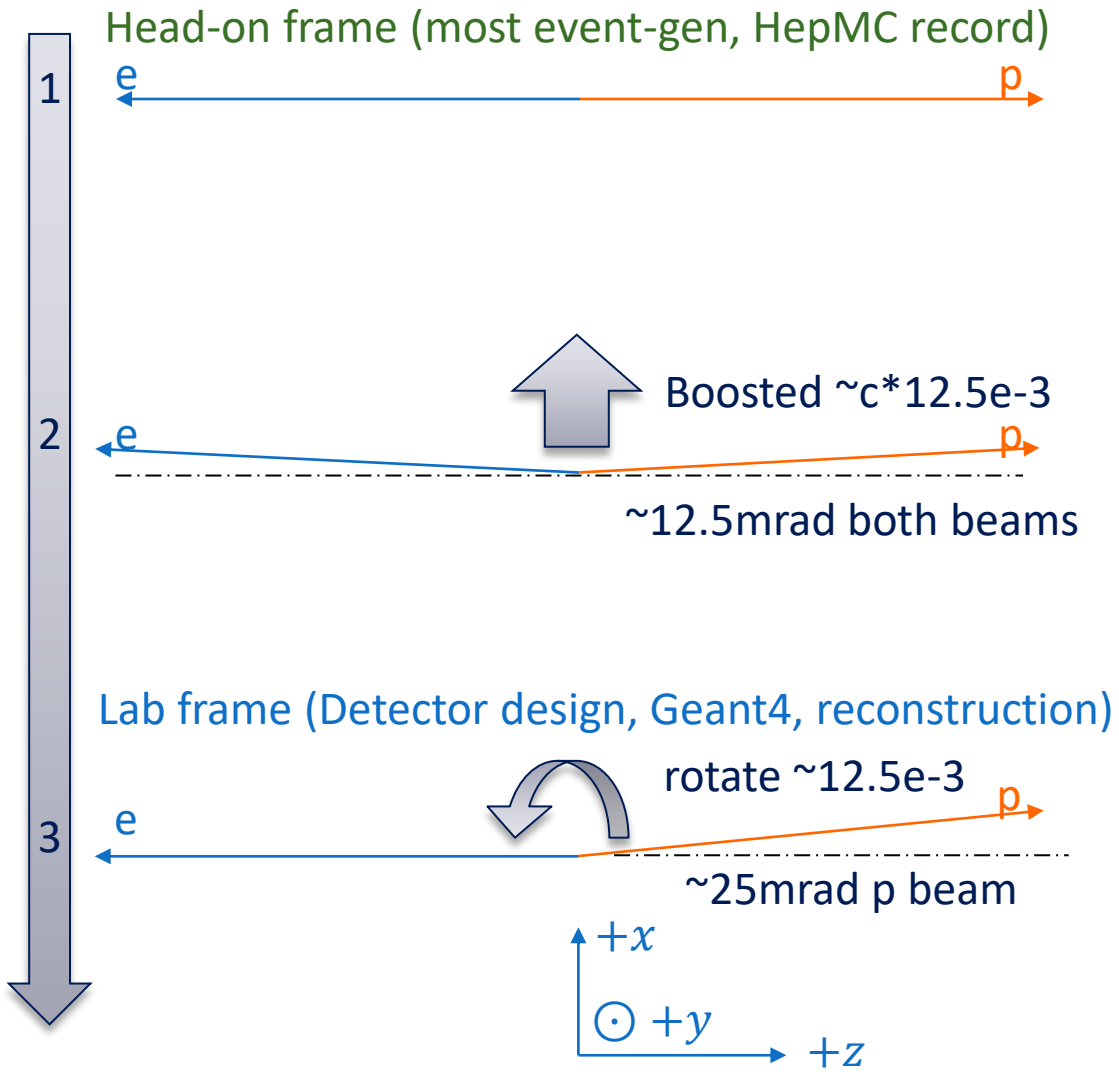
- Input via user macro [link] for beam angle, divergence, vertex shift in space time
- Calculate the boost-rotation-shift [link] that is used to translate a head-on-collision event generator's record to the lab frame and use in Geant4 simulation inputs
- Apply the boost-rotation-shift from event generator to G4 simulation input [link]
- Bookkeeping to allow analysis to reverse the transformation from lab observable to event generator frame



Only crossing angle illustrated here. After-burner handles all beam effects [link]

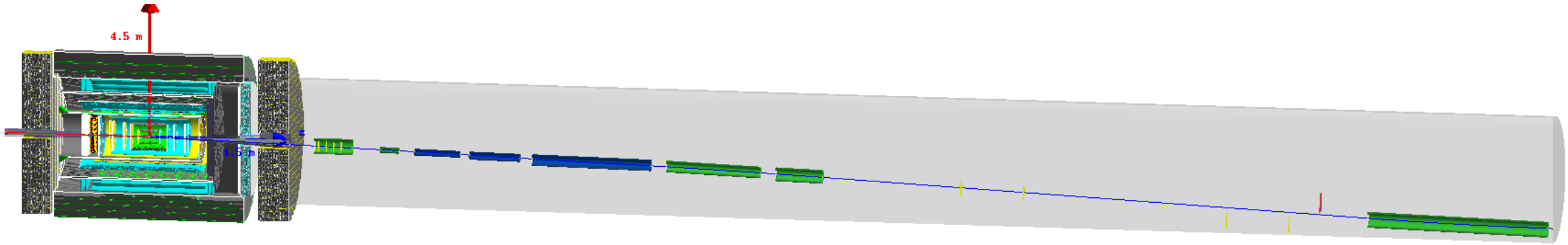
Coordinate system

- Head-on frame as used in most event generator and stored in HepMCEventMap is different from the Lab Frame as used in Detector design, Geant4 simulation and reconstruction
- In lab frame, electron is along –z axis, i.e. along symmetric axis of exp. and no B-bending
  - +z axis: inverse of electron beam direction
  - +y axis: up
  - +x axis: $y \times z$, towards center of RHIC ring
- Note: from head-on to lab frame, beam energy increase by
  $E_{Lab} = E_{HeadOn}/\cos(crossing\ angle/2)$



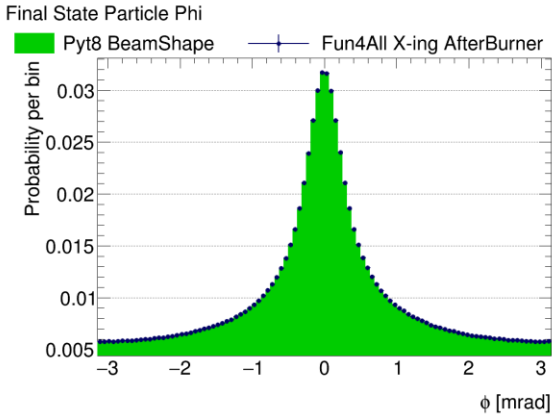
Beam transport checks

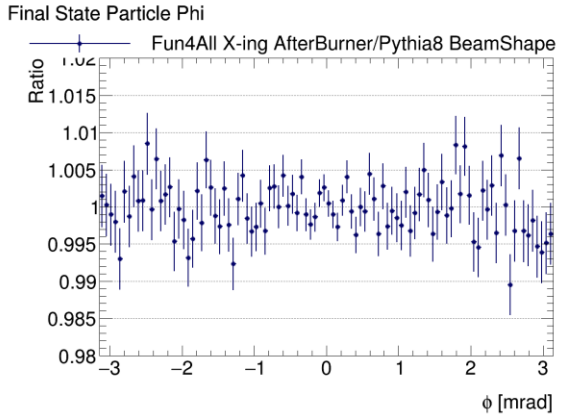
- Tested with proton and electron beam particle passing through each other in the head-on frame
- Boost-rotated to lab frame and validate the beam propagation through far-forward beamline
- Reference: https://github.com/ECCE-EIC/macros/pull/26 from Bill Lee

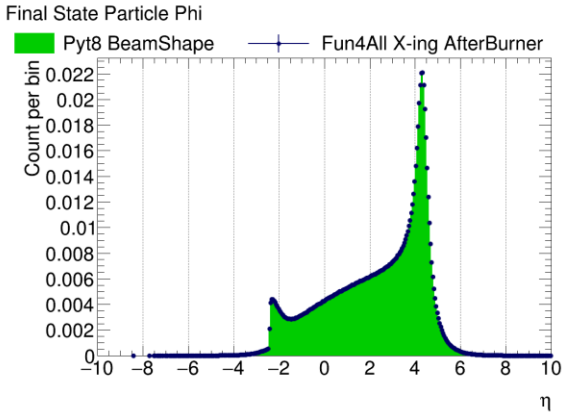


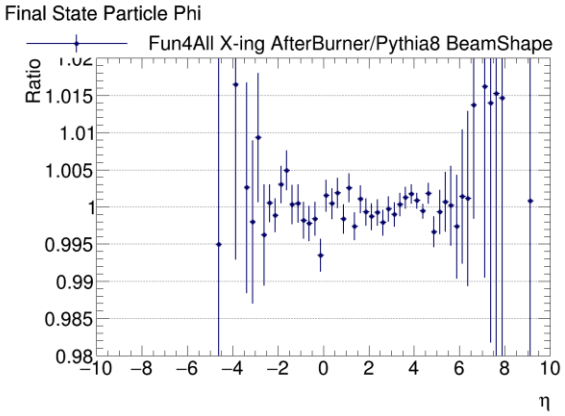
Direct comparison: Fun4all afterburner vs Pythia8

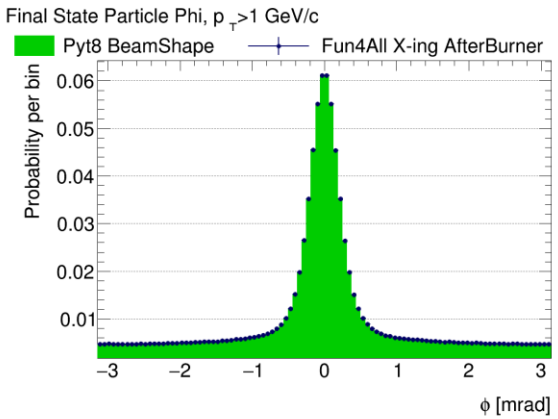
- 1M Pythia8 events -> Fun4All beam afterburner -> G4 ↔ compared to 1M Pythia8 BeamShape [link]. Also checked with IP6/8 and low-high beam configuration [link]
- Consistency well beyond the 1% stat. uncertainty provided by the test sample

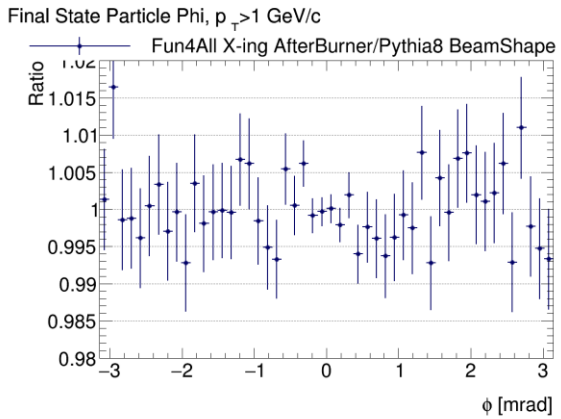


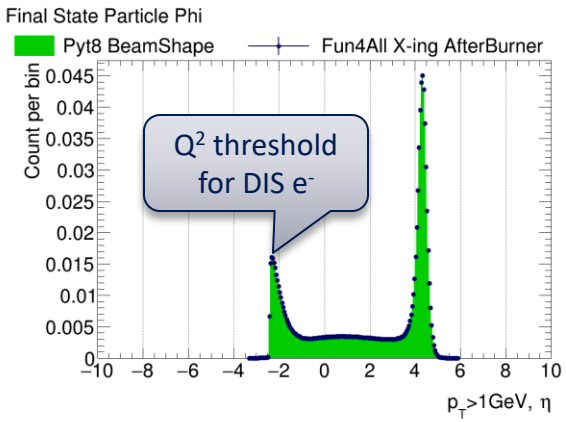


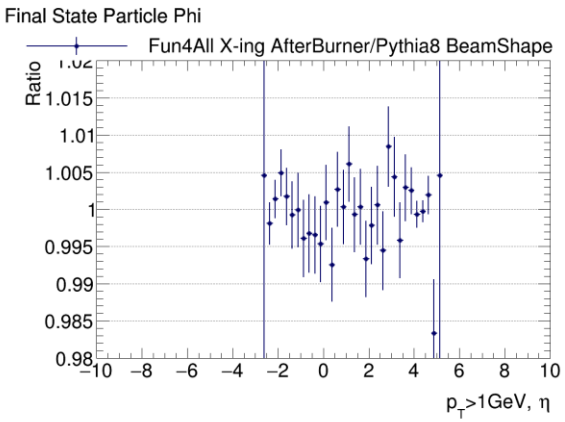












Summary

- Fun4All: C++1x-based framework and integrate many commonly used software packages, e.g. Pythia6/8, Geant4, ROOT, GenFit2, ACTS, FastJet, KFParticle
- Widely used in EIC YR, also used for sim+reco. in stages of proposal preparation for all three EIC proto-collaborations
- Built-in EIC beam effect afterburner
- Main code for EIC use at https://github.com/eic?q=Fun4All&type=all&language=&sort=
  - For CORE use, suggest at least CORE-controlled macros and calibration repositories

Extra information

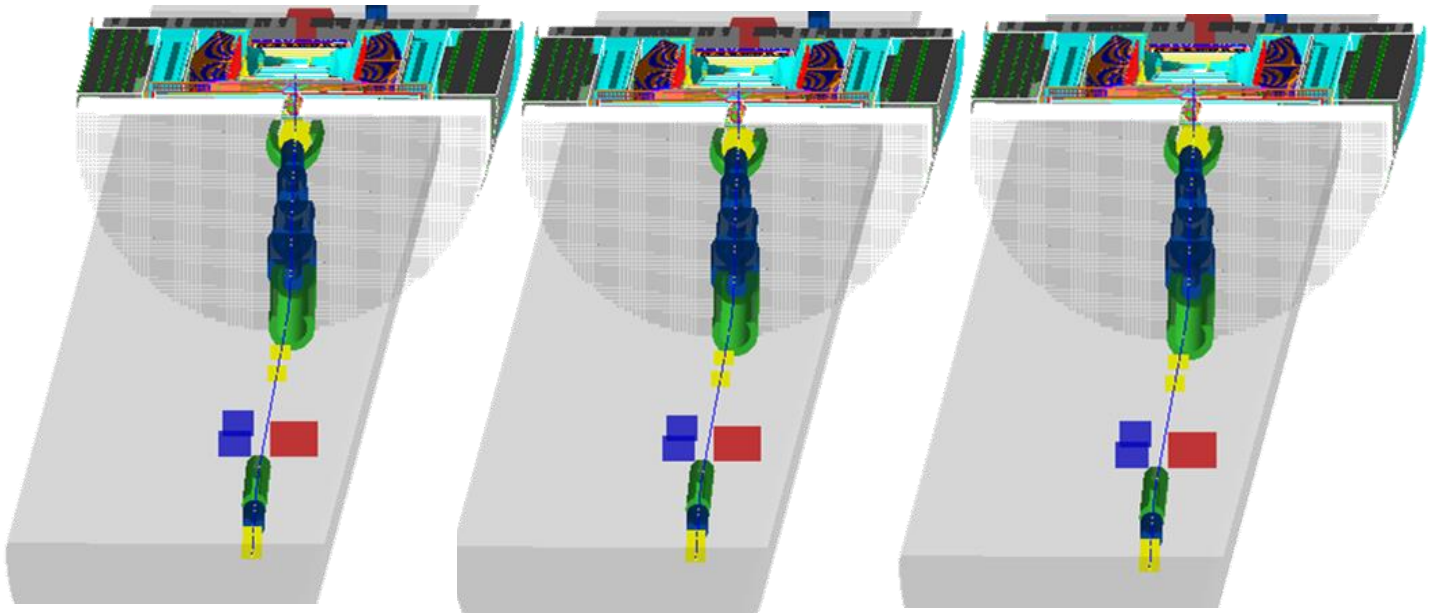
Beam steering at IP8, see also Bill's work

Work by Dhevan Gangadharan (University of Houston)

Fun4all support sanmoutanous study for IP6 and IP8 in ECCE

- Same event-gen file for both IPs
- Beam effect applied in Fun4All depending on the IP selection

Fun4all Beam Steering Capability



IP8 41GeV proton **IP8 100GeV proton** **IP8 275GeV proton**

Occupancy before and after 2nd focus