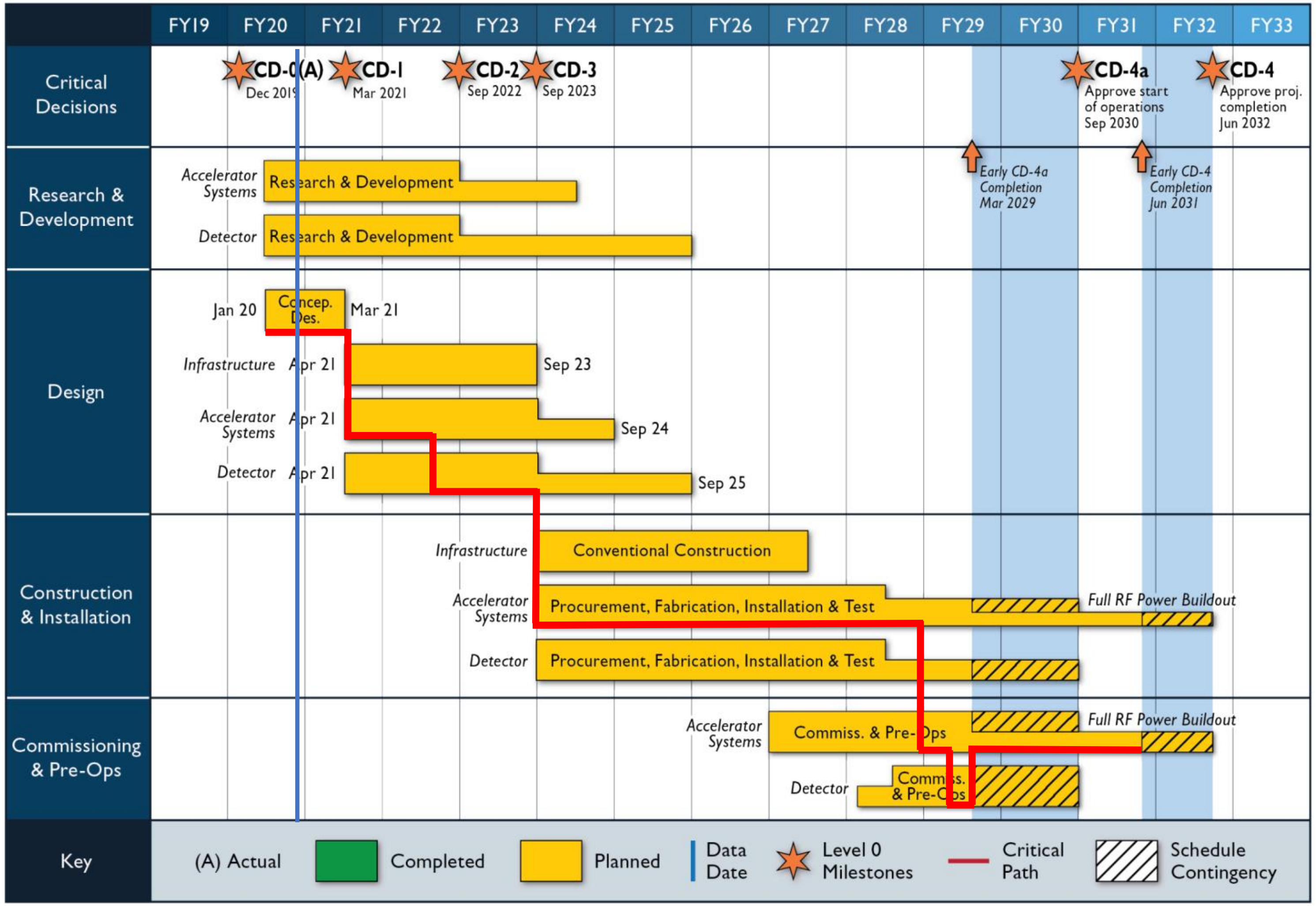
Simulation Tools for the EIC Detector Developments

Chris Pinkenburg BNL

EIC Schedule



End of Detector Design Sept 2025

In 5 years

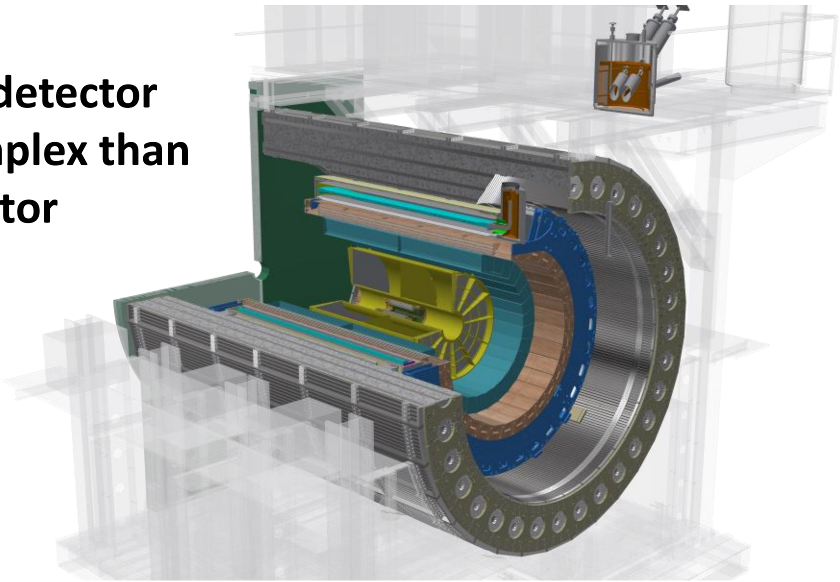
Start of Detector Construction Jan 2024

In 3 years

Jim Yeck, EIC Project Status and Next Steps
Sept 16, 2020

sPHENIX Timeline

Similar size detector but less complex than an EIC detector

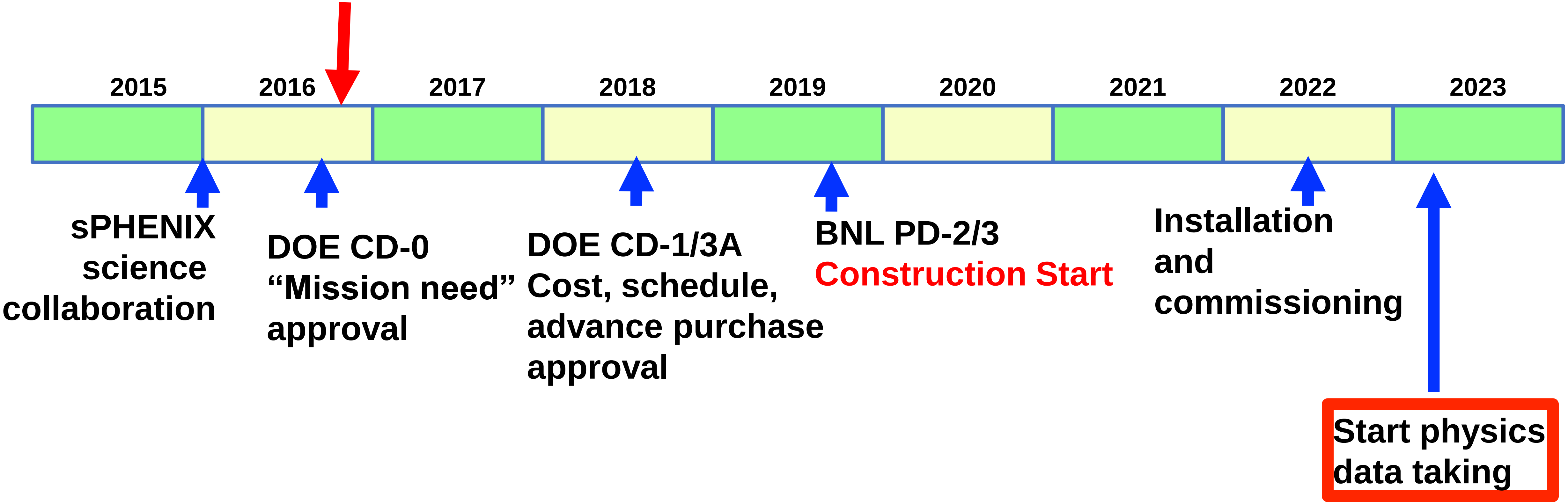


2015	2016	2017	2018	2019	2020	2021	2022	2023

- **sPHENIX science collaboration**
- **DOE CD-0 “Mission need” approval**
- **DOE CD-1/3A Cost, schedule, advance purchase approval**
- **BNL PD-2/3**
- **Installation and commissioning**
- **Start physics data taking**

sPHENIX Timeline

According to the schedule
the EIC detector is here,
3 years before construction start

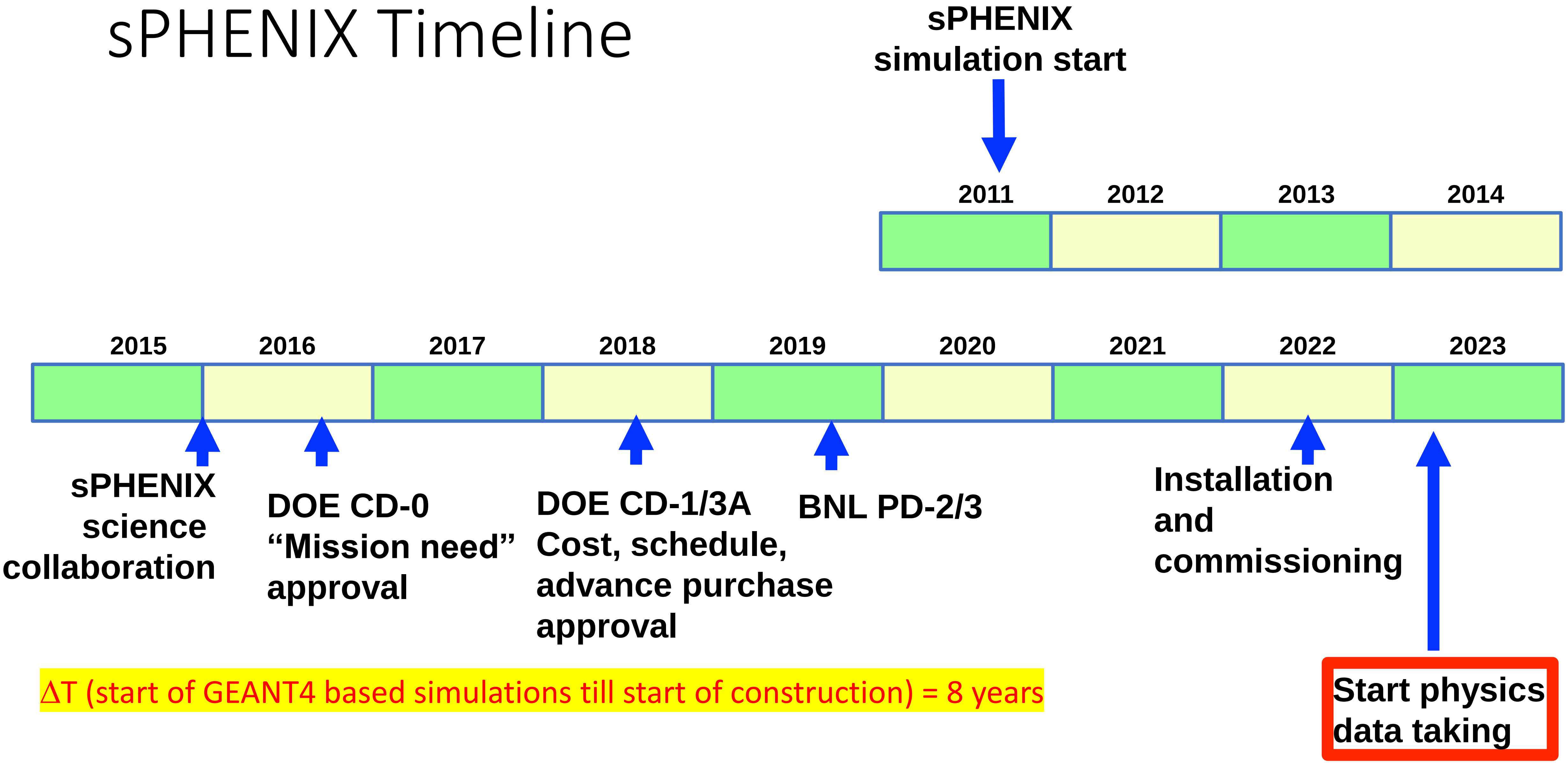


1st sPHENIX workfest, 2011 in Boulder

A week later

The first sPHENIX event display
(of a pythia event)

sPHENIX Timeline



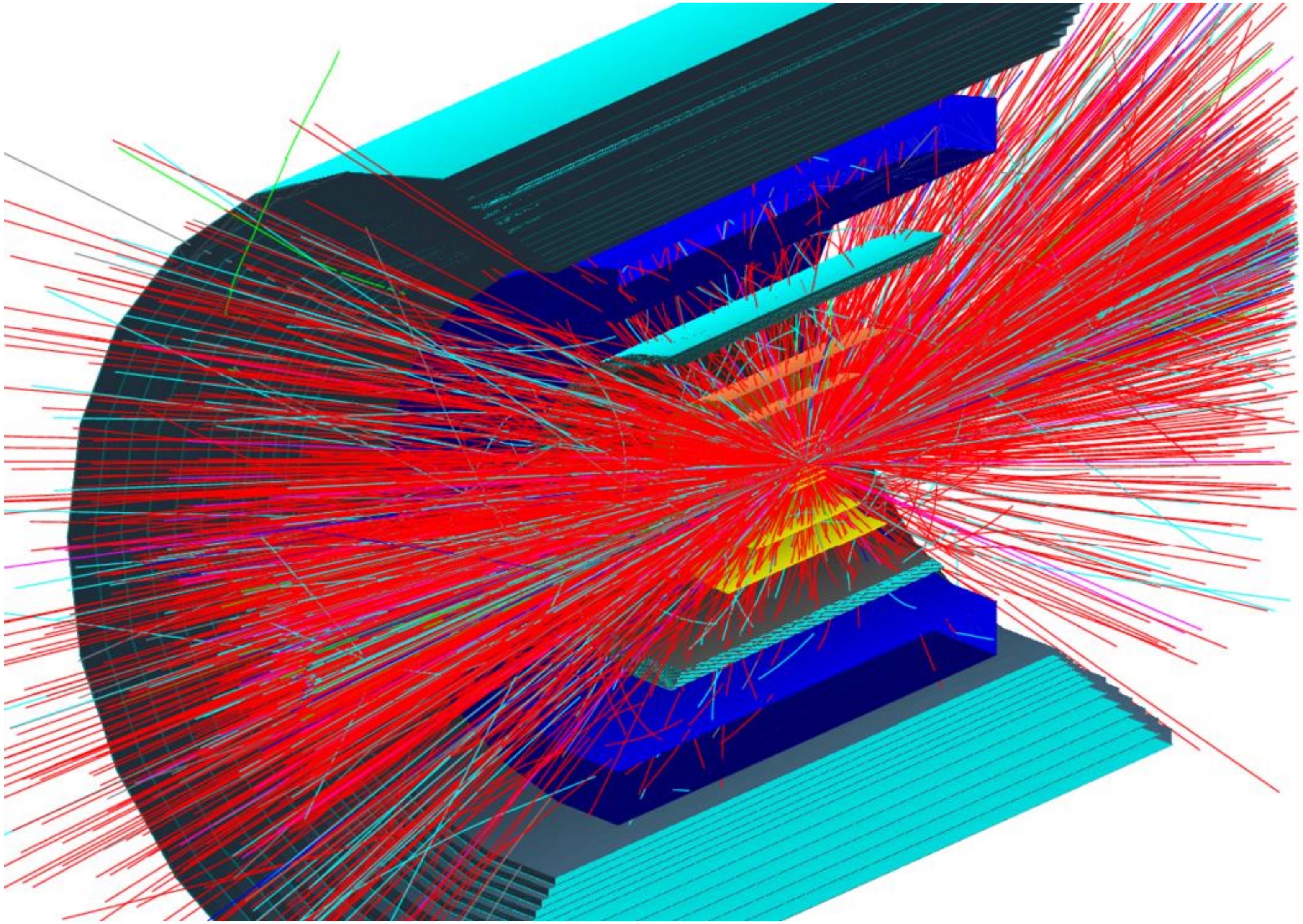
ΔT (start of GEANT4 based simulations till start of construction) = 8 years

GEANT Simulations, what do we actually get?

GEANT: GEometry ANd Tracking

- Tools to describe a detector geometry
- Tracking of particles in electric and magnetic fields
- Propagation of particles through material (including interactions)
- Event Displays

That's the "easy" part



How to create a splashy PR event display*:

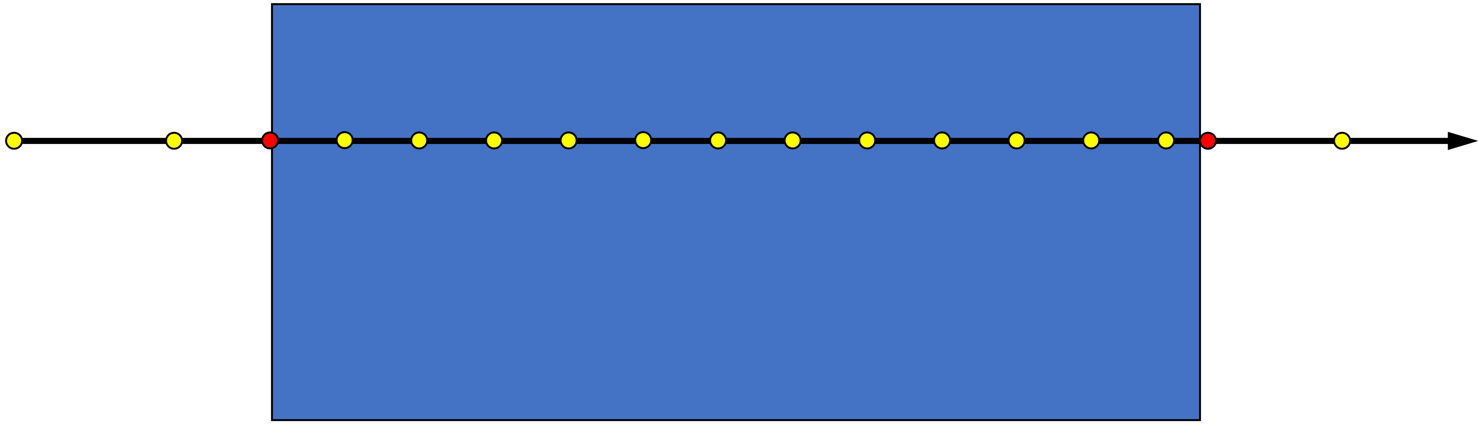
1. Make a detector from cylinders
2. Read in ASCII file from event generator
3. Run GEANT4
4. Spend the afternoon with cuts so the display looks reasonable

The real work starts after this
Any tool has to be able to do more than just running GEANT4

*) displaying a complex "real world" detector can take hours

GEANT output: G4STEPs

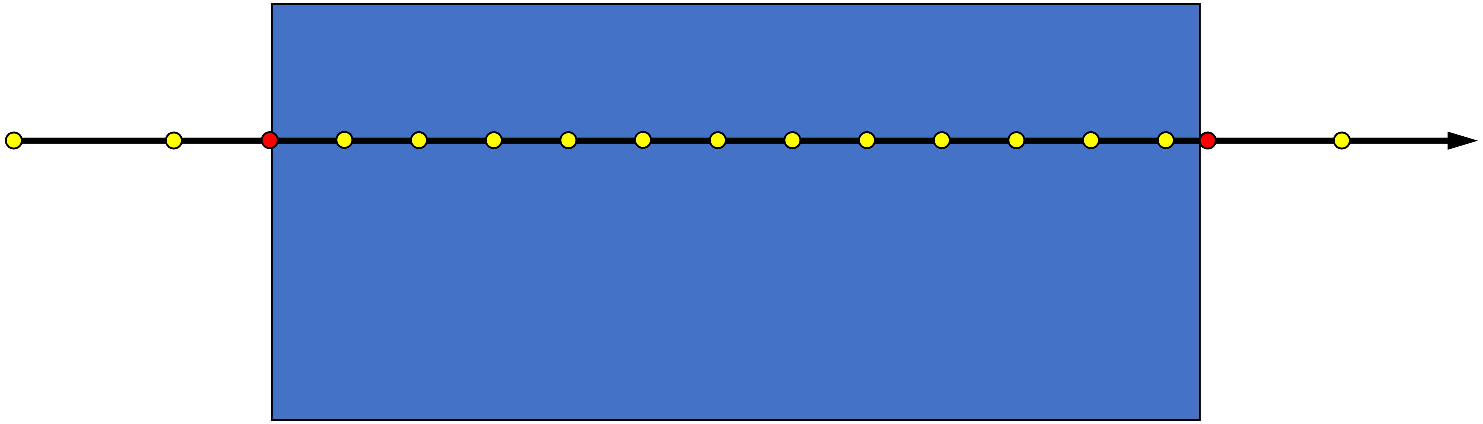
GEANT propagates particles one step at a time. The step size is determined by the physics processes associated with the current particle or when a boundary between volumes is crossed



After each step the user stepping method is called with a pointer to the current volume which has access to the full information (energy loss, particle momentum at beginning and end of step, …)

GEANT output: G4STEPs

GEANT propagates particles one step at a time. The step size is determined by the physics processes associated with the current particle or when a boundary between volumes is crossed



GEANT stops here – from now on it is up to you and your tools

What do we need from common EIC simulation tools?

The daydreams of cat herders

We are currently a very loose community with many different ideas at very different design stages

- Easily getting started with simple shapes – a cylinder gets you a long way in a collider detector
- Modularity – rather use building blocks than some monolithic thing
- Collaborative development but minimize interference between implementations
- Support standalone detectors as well as large setups
- We need higher level tools
  - Digitization
  - Clustering
  - Tracking
  - …

From sad experience – set everything up as a chain. Going through writing and reading back files will make you miserable

Connecting simulations to the real world

GEANT4 employs physics to model the particle transport we have a choice of physics lists

For EM physics this well under control

For Hadronic interactions which are much more complex it is a work in progress

Version 10.02:
Hadronic showers have changed in two aspects: increased visible energy in not heavy absorber materials (e.g. Fe and Cu); narrower lateral showers in heavy absorber materials (e.g. W and Pb).

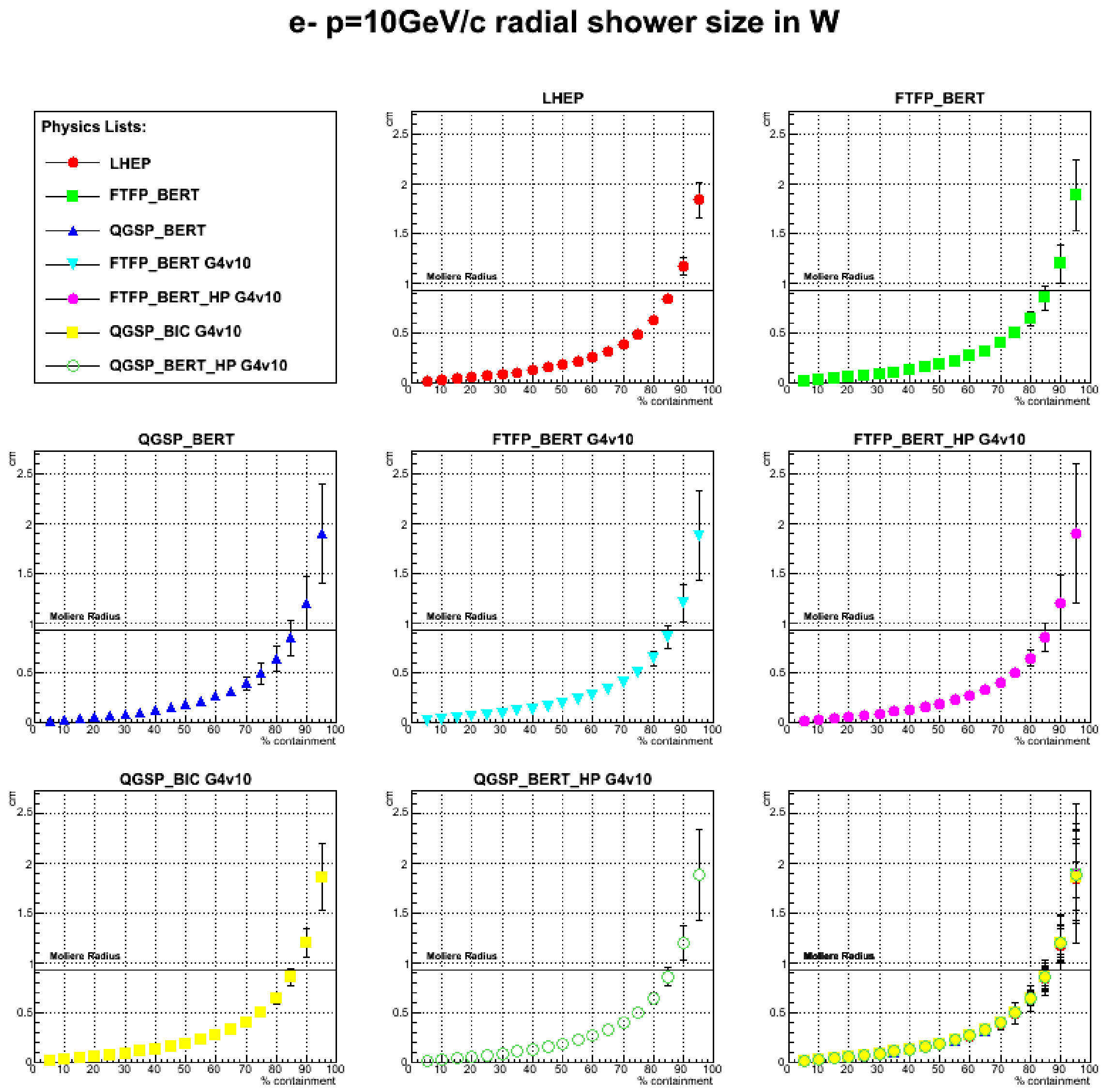
Version 10.03:
Based on tests performed on simplified calorimeters, hadronic showers are similar to those in version 10.1. Some differences - in particular wider hadronic showers and smoother behaviour as a function of the projectile energy, especially between 4 and 12 GeV - are due to the change of transition region between FTFP and BERT in the physics lists FTFP_BERT and FTFP_BERT_HP (now set to 3-12GeV

Version 10.04:
Hadronic showers remain very similar to those of version 10.3.

Version 10.05:
For the simulation of hadronic showers, both hadronic string models give higher energy response with respect to the previous versions, and consistently higher when compared with test-beam and collider data.

Version 10.06.p02 (latest version):
Changed transition region between hadronic string and intra-nuclear cascade models: now it is [3, 6] GeV consistently for all particle types (nucleons, pions, kaons, hyperons, ions and gammas; for anti-baryons, instead, FTFP is still used for all energies) Increased energy response and more compact hadronic showers mostly in the projectile energy range between 5 and 20 GeV, mainly due to the change in transition energy between FTFP and BERT

Physics Lists – EM Showers in W



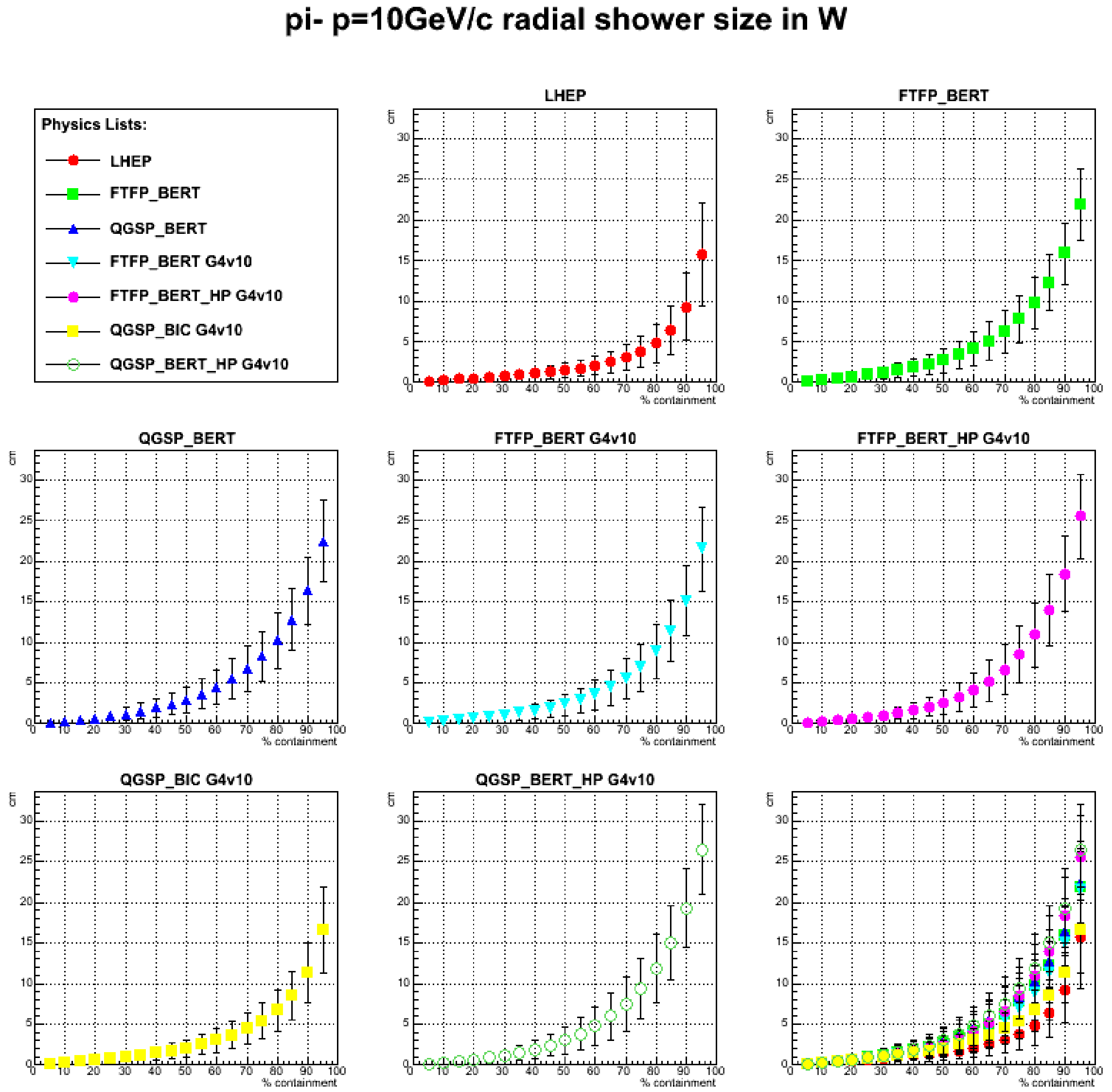
Comparison between physics lists in GEANT4 9.5 and 10.0

Predictions agree with each other between physics lists and versions

- No surprise for the physics lists, they tend to only differ in the hadronic physics

LHEP was a parametrization, dropped from GEANT4 version 10.0 on

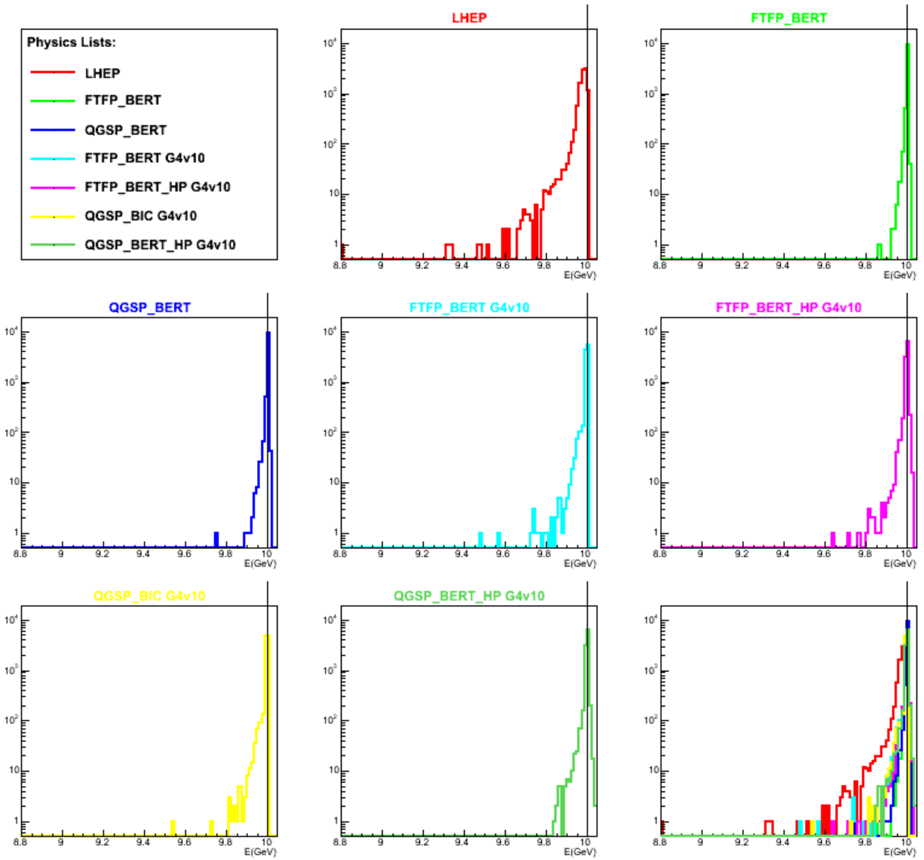
Physics Lists – Hadronic Showers in W



Comparison between physics lists in GEANT4 9.5 and 10.0
Large differences in shower sizes
High Precision Neutron (HP) physics needed for accurate description
LHEP was a parametrization, dropped from GEANT4 version 10.0 on

Energy Conservation/Recovery

e- p=10GeV/c total energy conservation in W

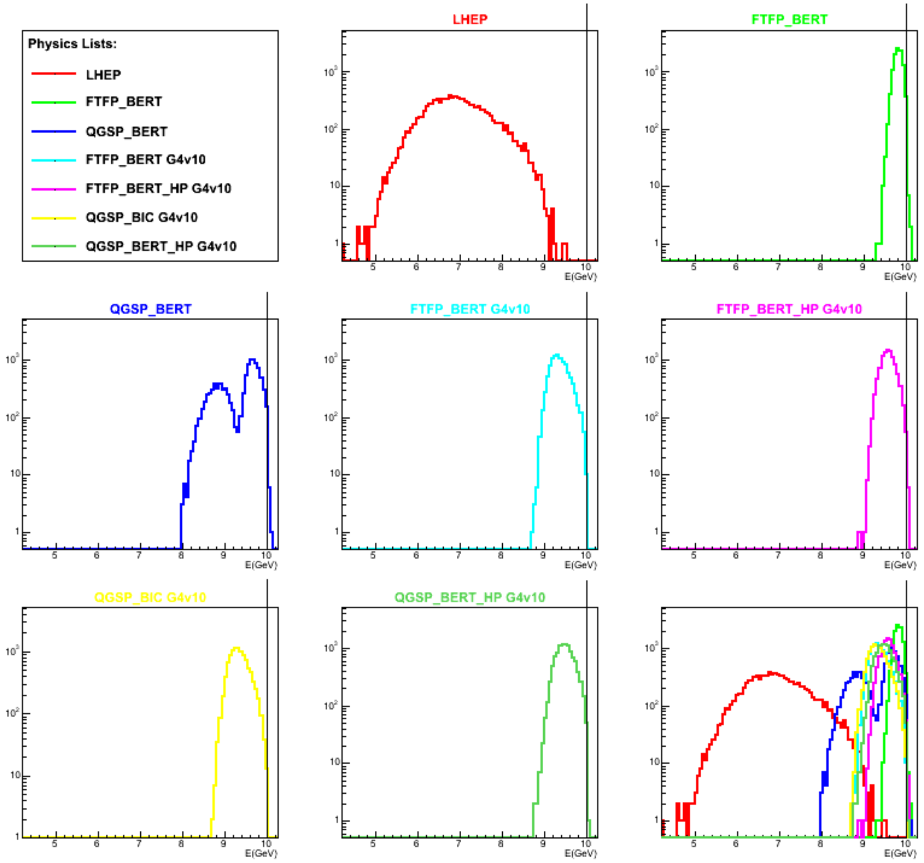


Energy is mostly conserved for em showers

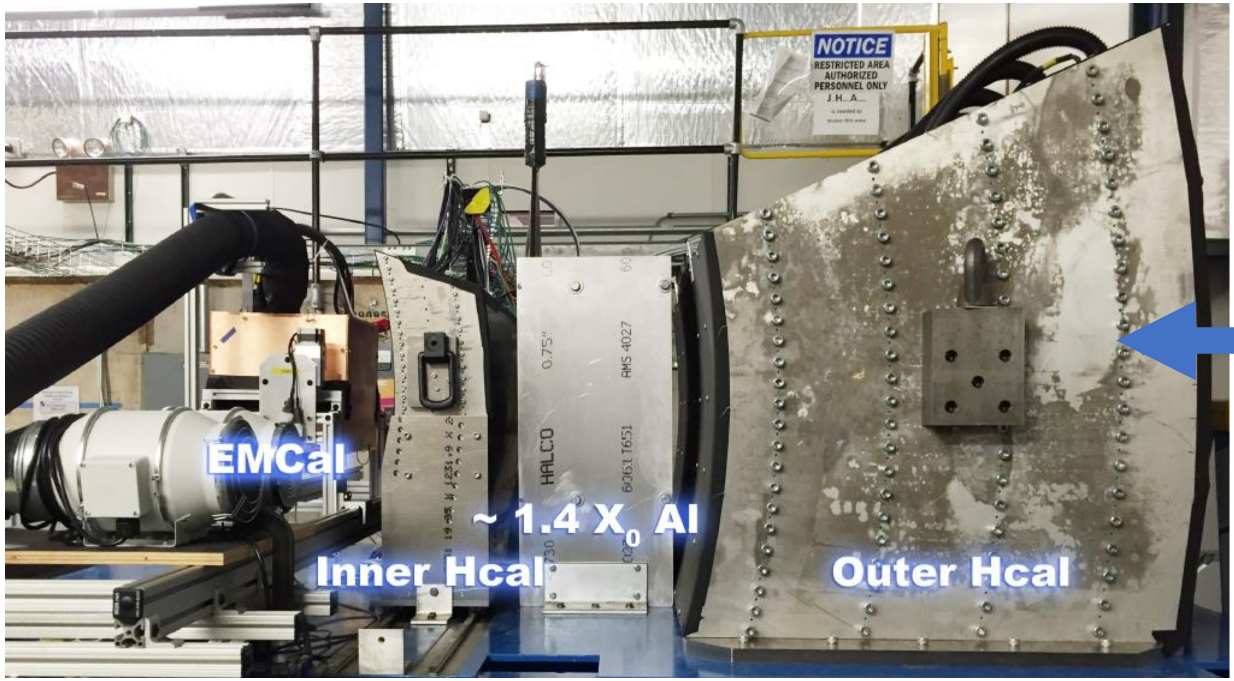
Hadronic showers typically loose energy

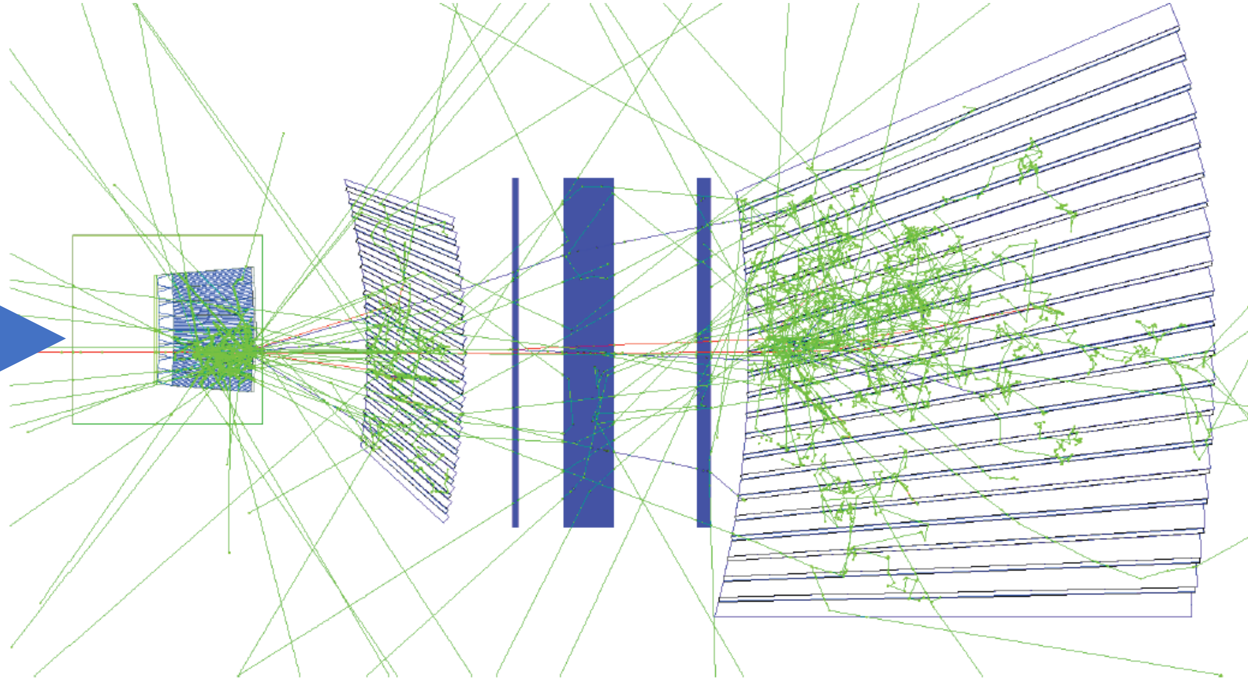
How can you trust your simulations????

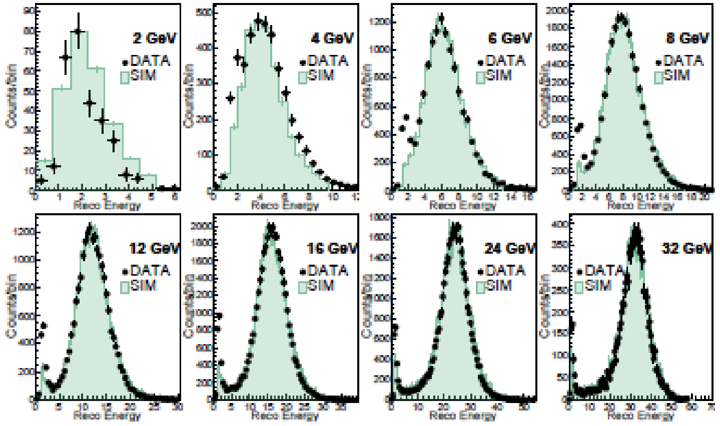
pi- p=10GeV/c total energy conservation in W



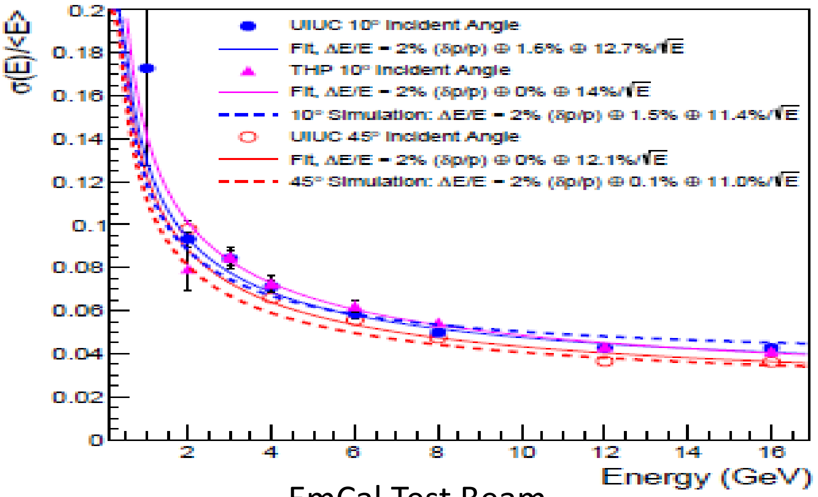
Combining data reconstruction and simulations







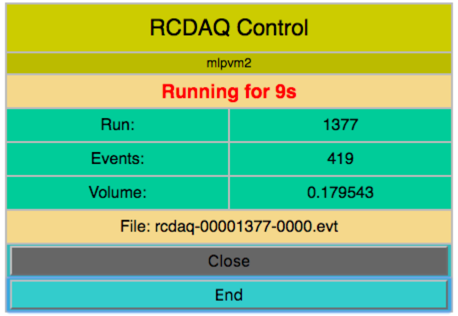
Hadronic Calorimeter Test Beam

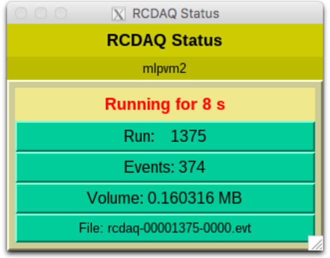


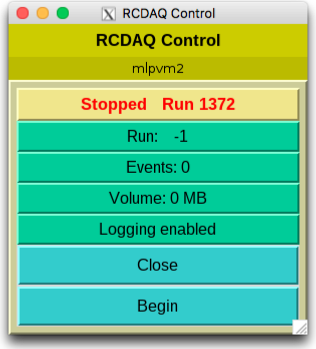
EmCal Test Beam

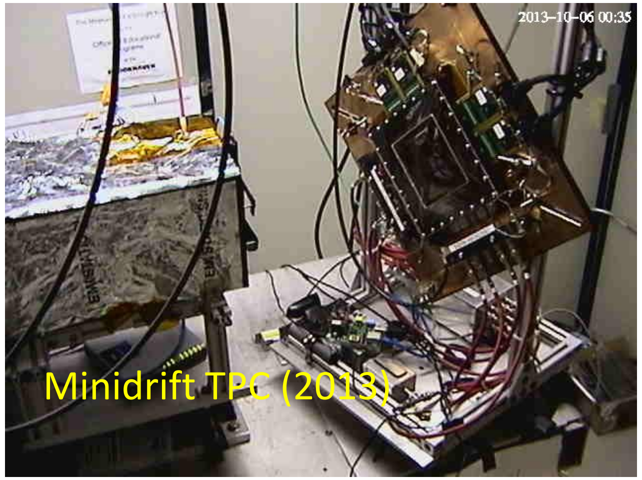
Simulation chain and reconstruction has been verified with real data.

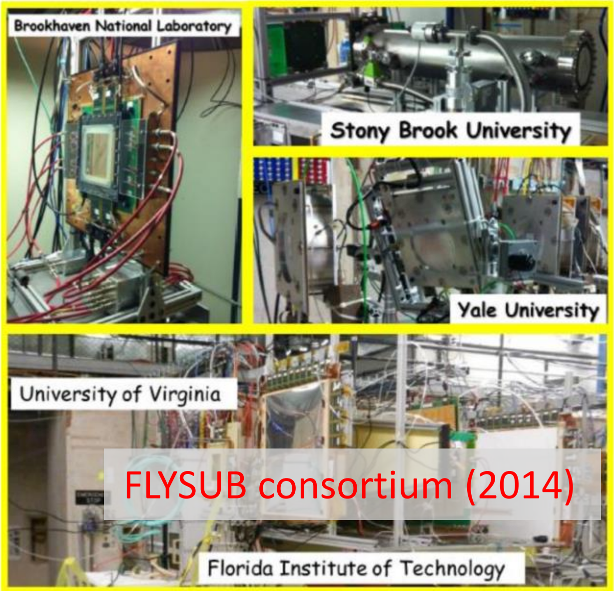
Many more EIC related test beam campaigns

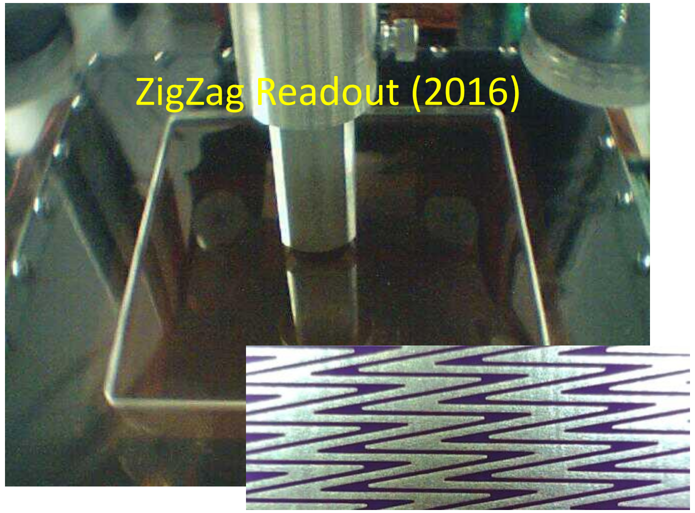


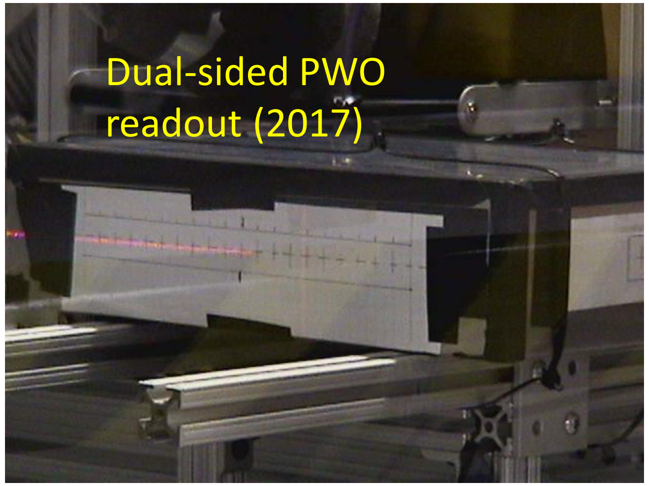


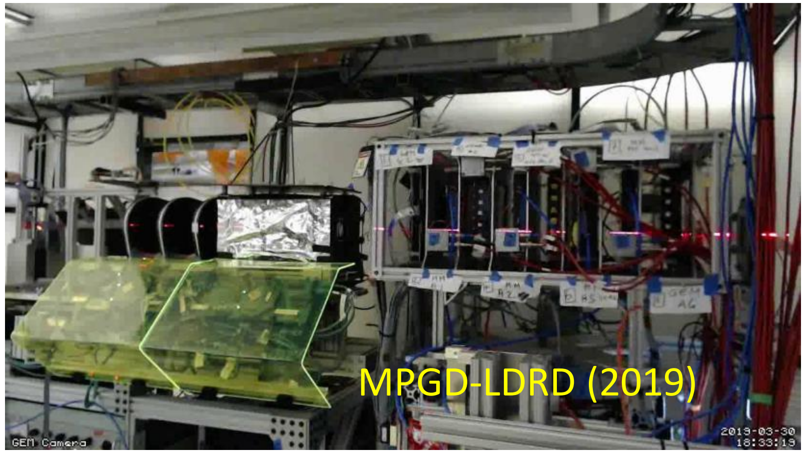












What do we need from common EIC ~~simulation~~ tools?

The daydreams of cat herders

Raw data reconstruction
by extension common geometry

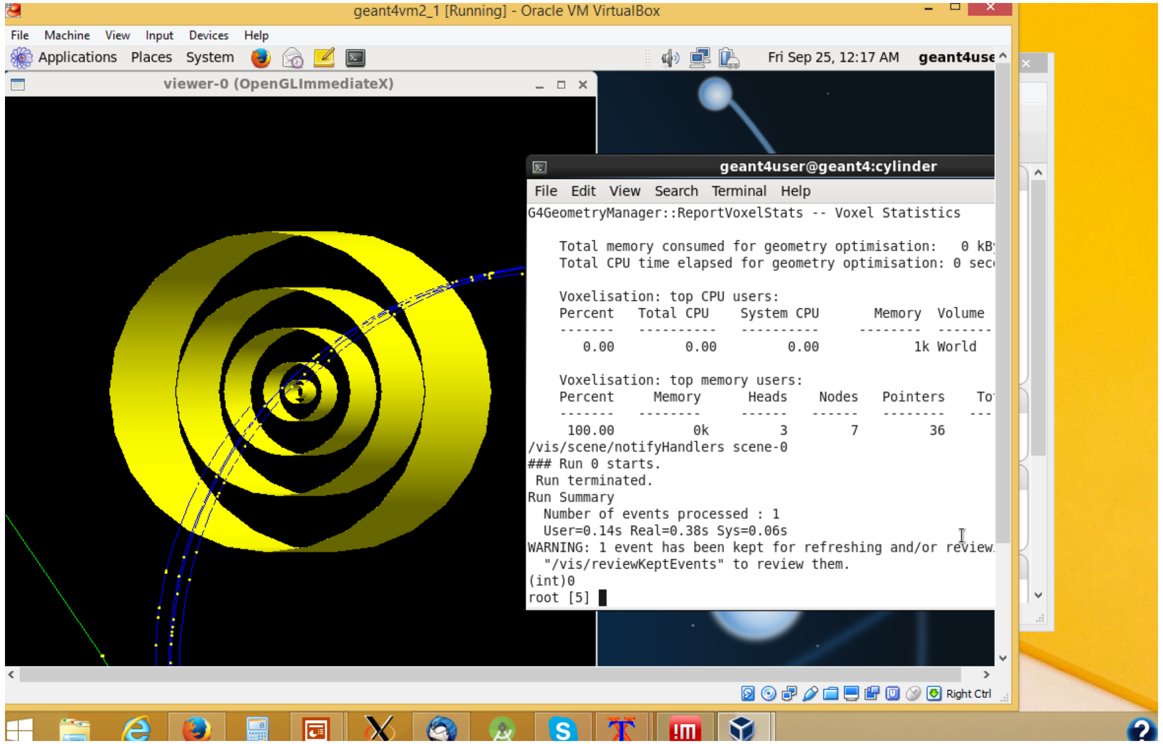
Since this looks empty otherwise some other important considerations which I left out previously:

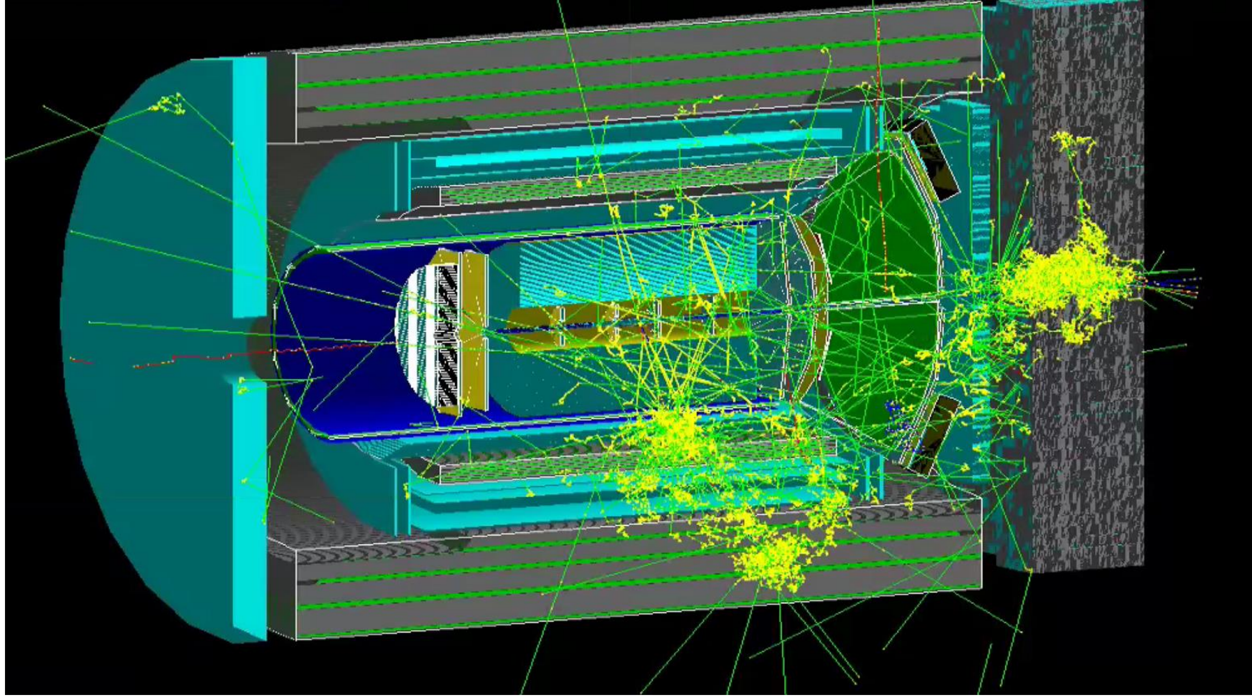
- Reproducibility – running twice achieving identical results (have your random number seeds under control)
- Geantinos for geometry verification (superior to muons)
- Easy import of purely GEANT4 based detectors

From sad experience – set everything up as a chain. Going through writing and reading back files will make you miserable

Distribution

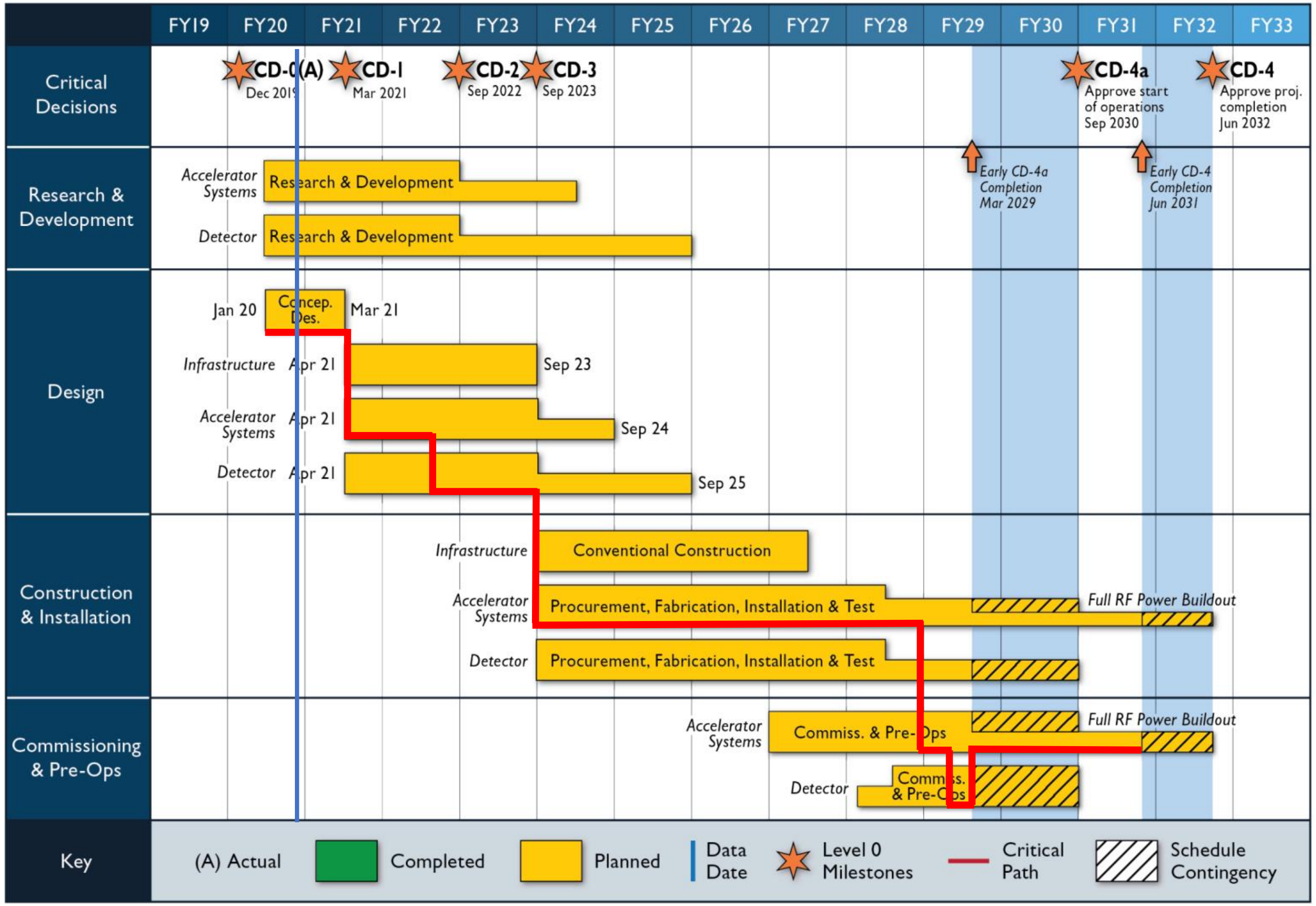
Containers are a solution for the problem to support many compilers and OS's guaranteeing identical outcomes. Can be run on the OSG as is as well as HPC





VM's on laptops do work for simple setups or fast eic-smear type simulations, but as soon as you do "real GEANT4 simulation runs" for detector designs running over 1000's (mio's) of events and have to deal with calorimeter showers that laptop approach reaches its limits quickly

Detector construction starts in 3 years

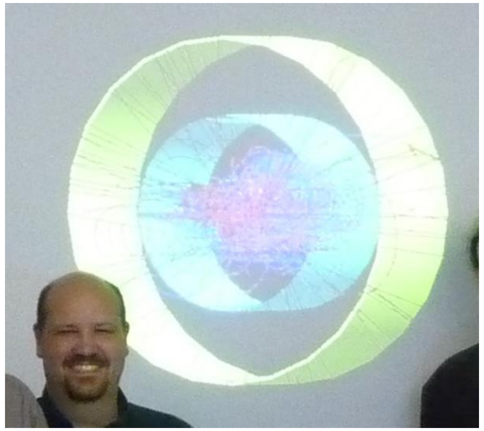


It is just too late to start creating tools from scratch for the EIC detector simulations if they should have any impact on the design

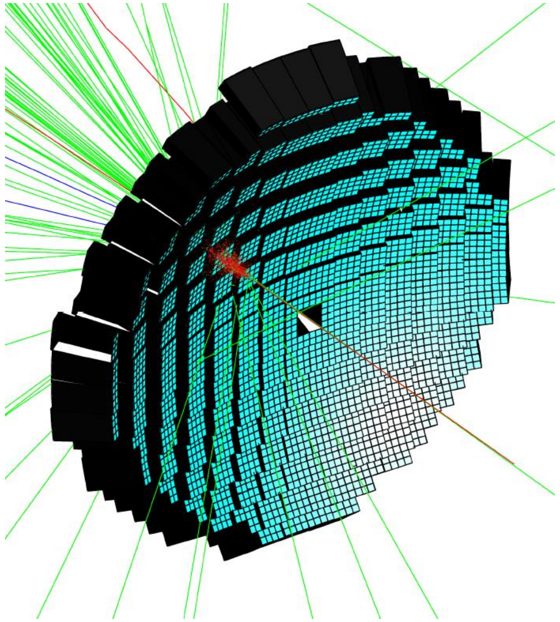
You will need a coherent GEANT4 simulation of the fully implemented detector you propose to build (two for two detectors) long before the construction starts

On the bright side

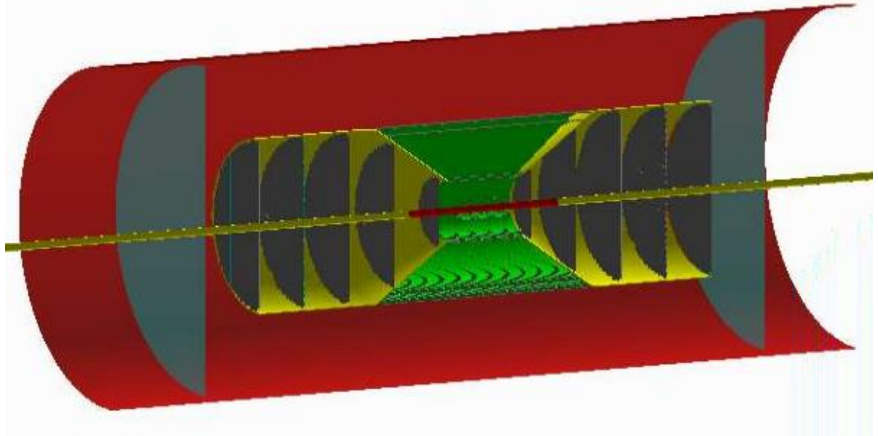
You do not start with this



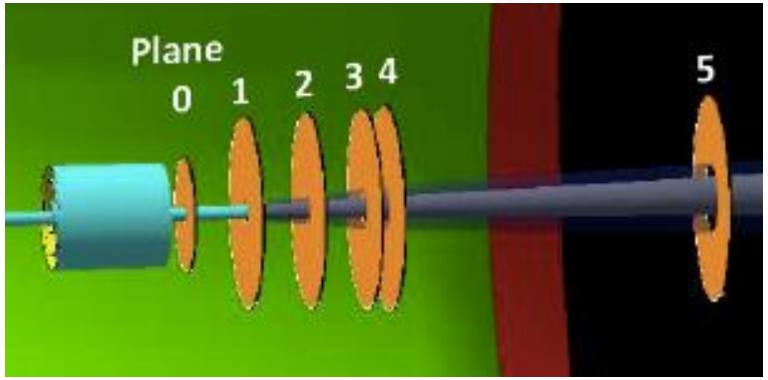
and this: Panda style e-going EMcal



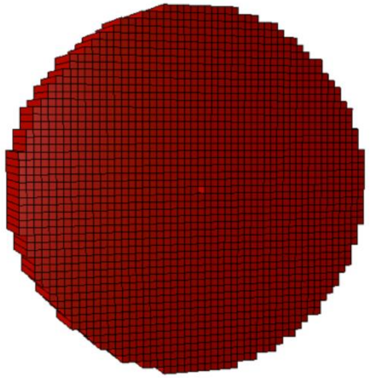
and this: All Silicon Vertex Tracker



and this: LANL FST



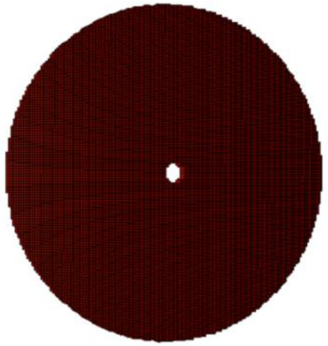
But this: h-going Hcal



2046 Tower

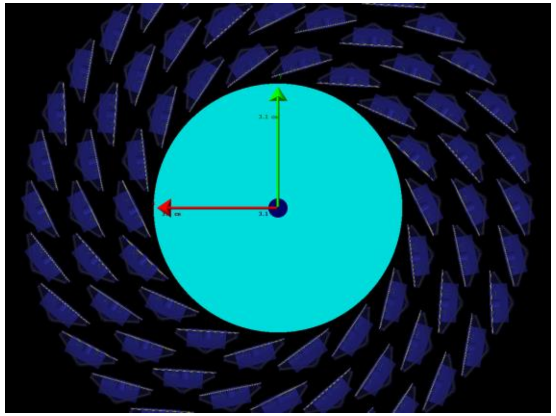
each tower:
$10 \times 10\ cm^2$ sampling
100 cm long
30 layers
4/5 iron
1/5 scintillator

and this: h-going EMcal



17350 Tower

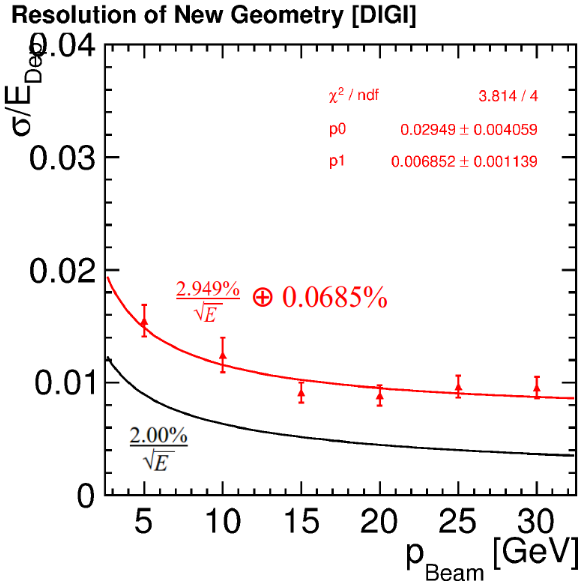
each tower:
$3 \times 3\ cm^2$ sampling
17 cm long
60 layers
2/3 lead
1/3 scintillator



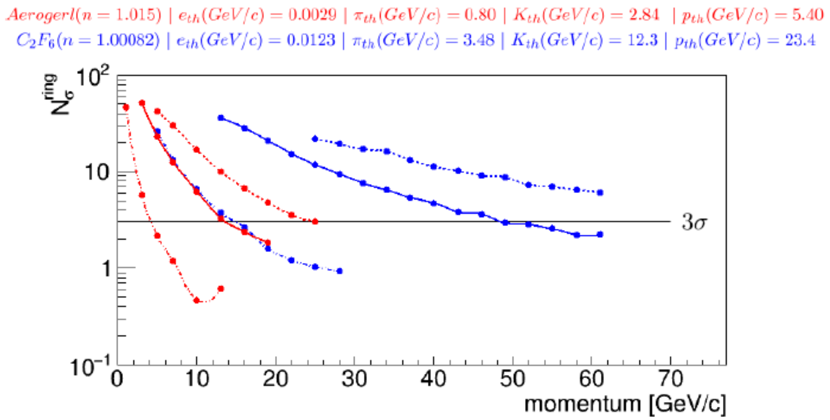
and this:
ALICE
maps
staves

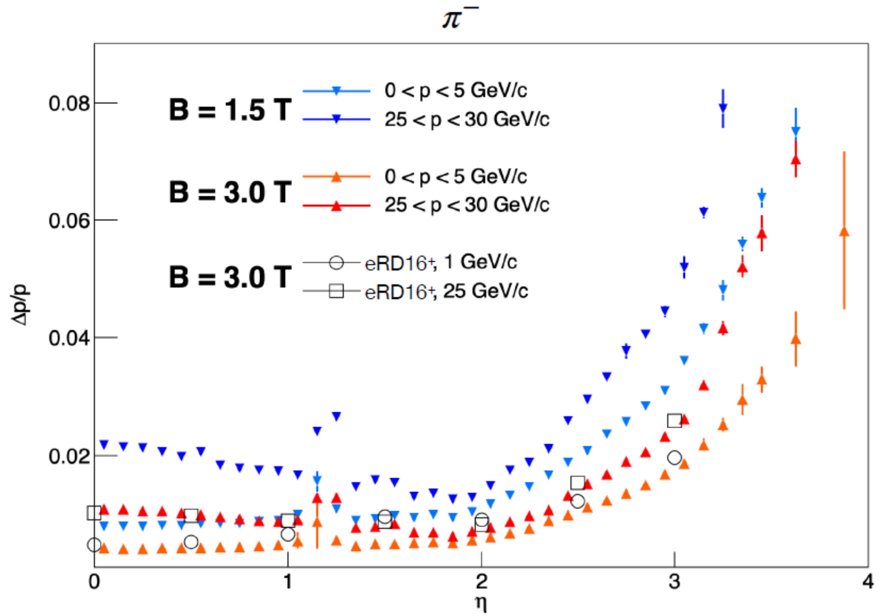
And many more

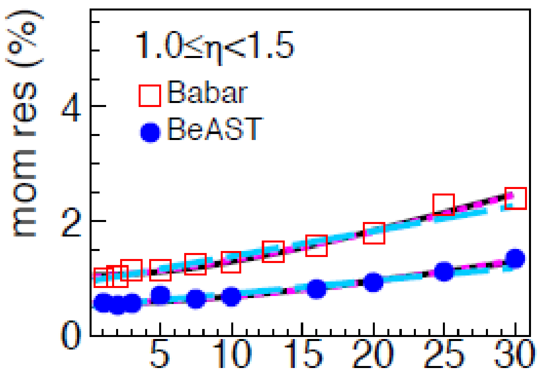
And not just the “easy” part



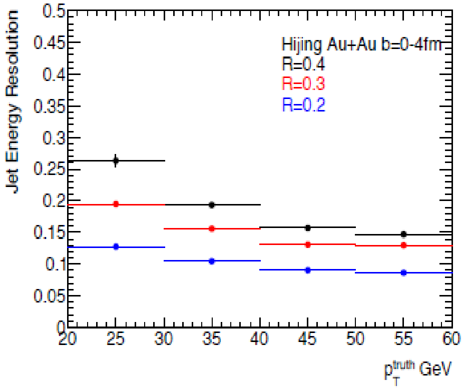
Rich PID



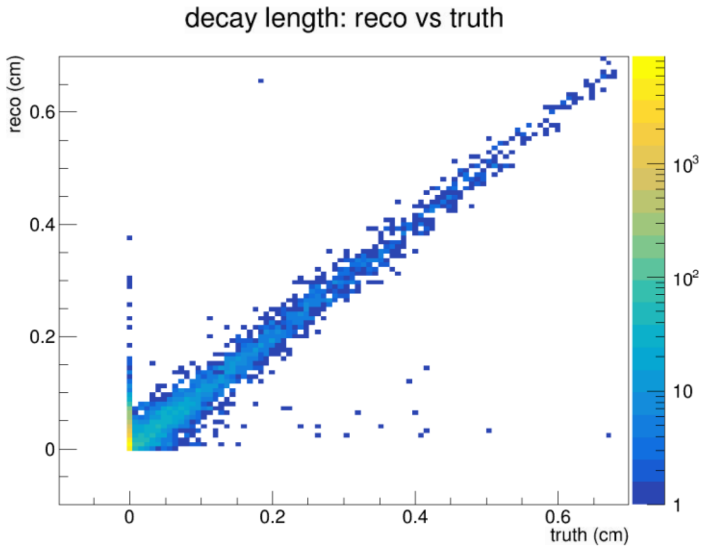




Central Barrel Jet Energy Resolution

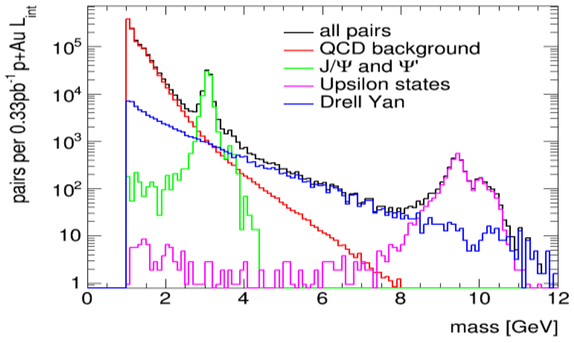


Reconstructed tau decay vertex



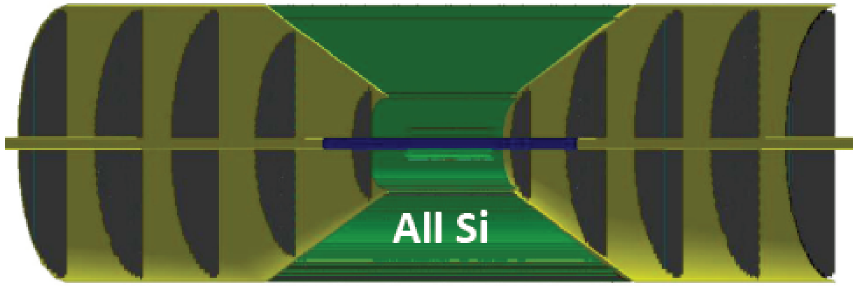
Truth tau decay vertex

Forward Quarkonia

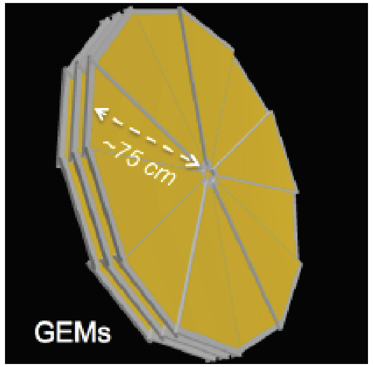


- **Integrated hybrid detector configurations are added to common simulation framework (Fun4All)**
  - TPC + Si disks + Si vertex
    - Including end cap material
  - MPGD barrel + Si vertex
  - Triple-GEM disks
    - Based on SBS GEMs
  - All Si detector
  - Ability to study various detector integrated configurations

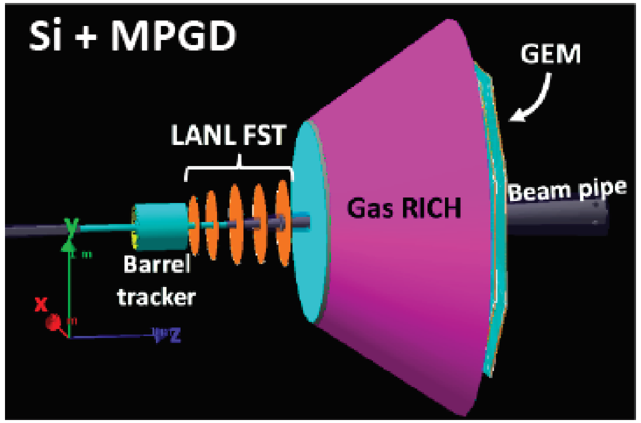
Rey Cruz-Torres et al: UCB



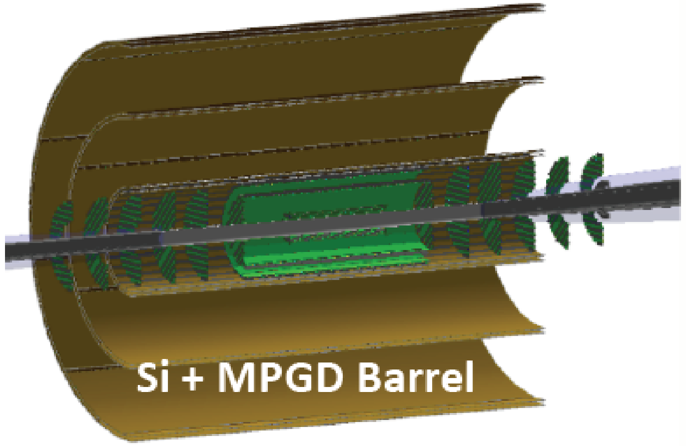
SBS GEMs



Cheuk-Ping Wong, et al: LANL



Qinhua Huang, et al , CEA Saclay



Hȧkan Wennlöf et al: UoB