Status of the SCT detector software

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BINP

FTCF2024

USTC Hefei

A HEP software framework

A typical HEP experiment requires complete stack of relevant offline software:

- event generators,
- fast and full detector simulation,
- event reconstruction algorithms,
- event data model (EDM),
- I/O interface to conditions data base,
- I/O interface to data storage,
- offline data analysis algorithms,
- build system and release management software. . .

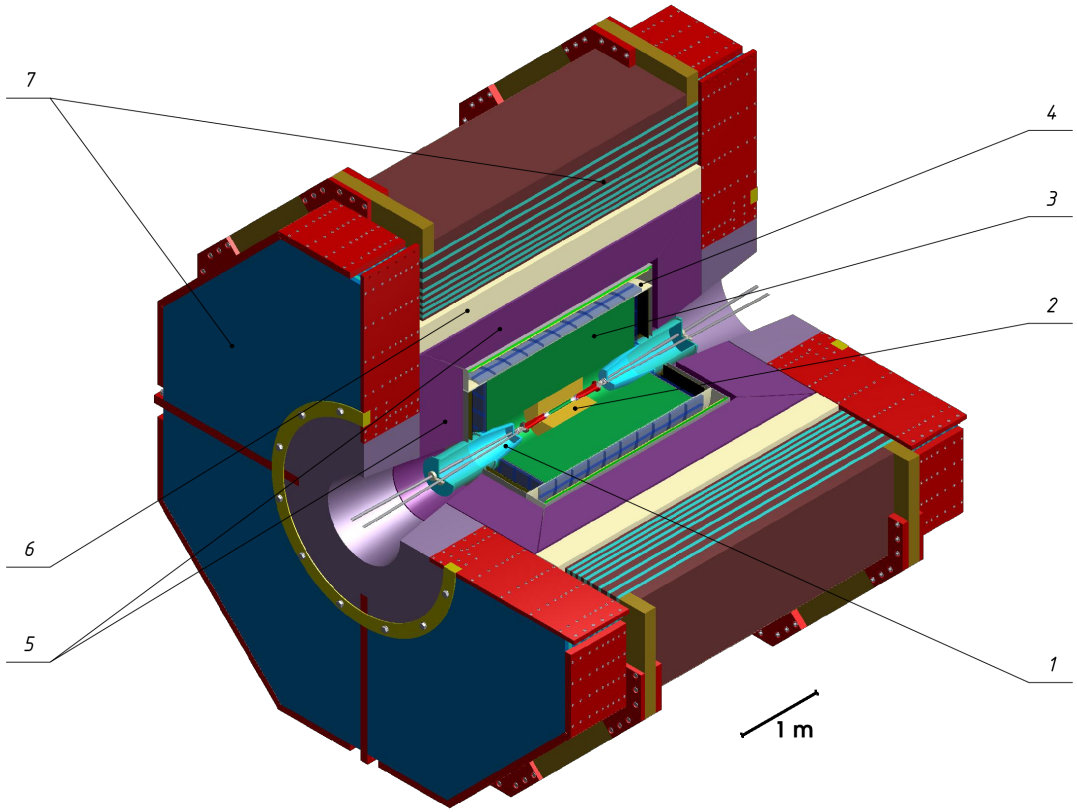
Also requires a well-defined computing environment.

Detector construction

SCT Detector overview

Requirements:

- Occupancy 350 kHz
- Good energy and momentum resolution
- High detection efficiency of soft tracks
- Best possible π/K and π/μ separations
- Minimal CP detection asymmetry



	subsystem	options		subsystem	options
1	Beam pipe	beryllium	**2**	Inner tracker	TPC, cGEM, Si-strip
3	Main tracker	drift chamber	**4**	PID system	FARICH, ASHIPH?, DI
5	Calorimeter	CsI, LYSO, LXe?	**6**	Magnet	thin coil?
7	Muon system	Scintillators, RPC?, ...			

Detector construction

General consderations of its implications on the software

- The SCT Detector construction is not finalized
- The detector structure is more or less typcal for its size
- Similar experiments of less scale are planned (VEPP-6)
- Similar detector KEDR operates in BINP

We are considering to develop the software in a generalized way

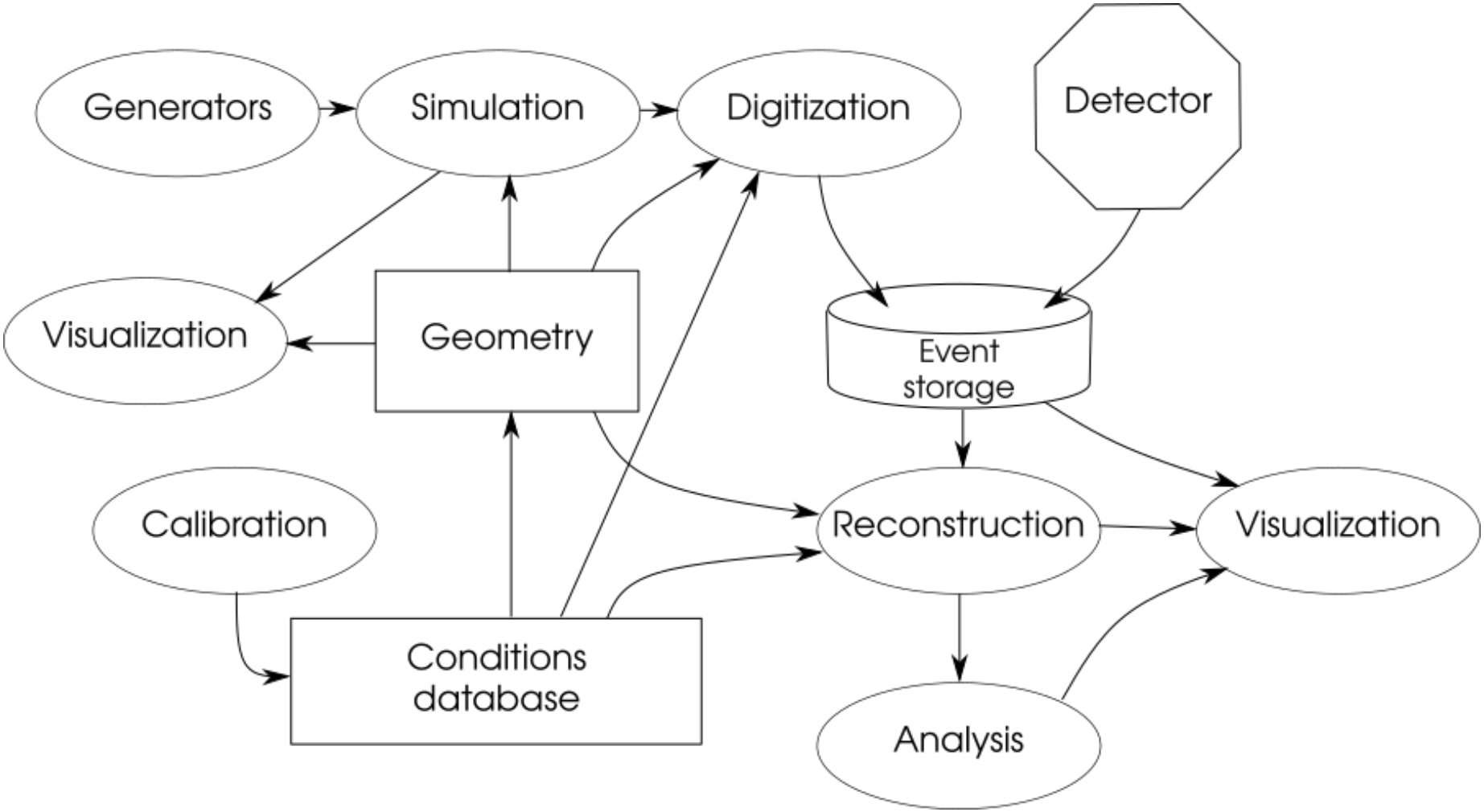
- Universal approach
- Tests on real data

The Aurora framework

- Generally inspired by ATLAS Athena
- Based on Gaudi
- Conventional and recently emerged HEP software tools:
  - ROOT, Geant4
  - DD4Hep (Key4HEP), ...
  - misc. event generators
- Other experiments software
  - Belle II, ILC, FCCSW...
- Build & configuration system adopted from ATLAS
- `lcgcmake`-derived system to build external packages

Aurora

Framework elements and data flows



A conventional set of event generating tools available

- Exclusive decays of hadrons and tau lepton
  - EvtGen, Tauola, PHOTOS, Pythia
- Inclusive generators for $e^+e^- \to$ hadrons
  - preliminary solution based on Pythia
- Generators for luminosity measurements and calibrations
  - MCGPJ, BabaYaga, BBBREM, KKMC...

Important issues:

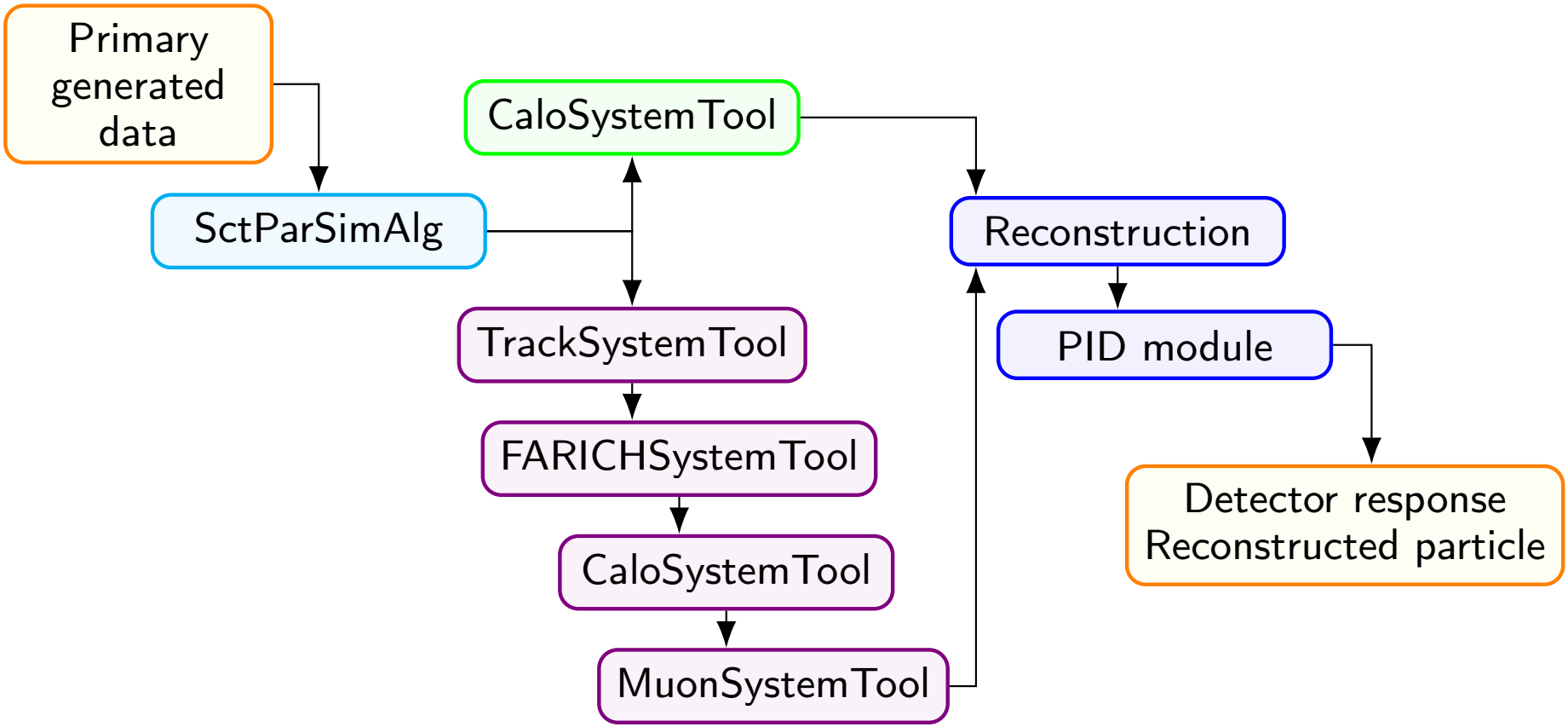
- correctly account for the beam(s) polarization
- need physics analysis people contribution

SCT Detector fast simulation

- Implemented as a set of Aurora packages
  - relies on Aurora MC generators and data flow
  - parameters controlled via Aurora mechanisms
  - about 150 times faster than full simulation
- Subsystems:
  - DC
    - ★ based on standalone simulations & BaBar experience
    - ★ expanded to cover the inner tracker region
    - ★ $\vec{p}$, L(h; p, $\mathrm{d}E/\mathrm{d}x$), L(h; p, $\mathrm{d}N_{\mathrm{cl}}/\mathrm{d}x$).
  - FARICH
    - ★ based on standalone simulations & test beams
    - ★ $N_{\mathrm{ph.e.}}$ and/or β, L(h; p, $N_{\mathrm{ph.e.}}$), L(h; p, β)
  - calorimeter
    - ★ based on standalone simulations & test beams
    - ★ energies of charged and neutral clusters
  - muon system
    - ★ based on full simulation in Aurora
    - ★ l and L(l; p, θ) for μ and π

SCT Detector fast simulation

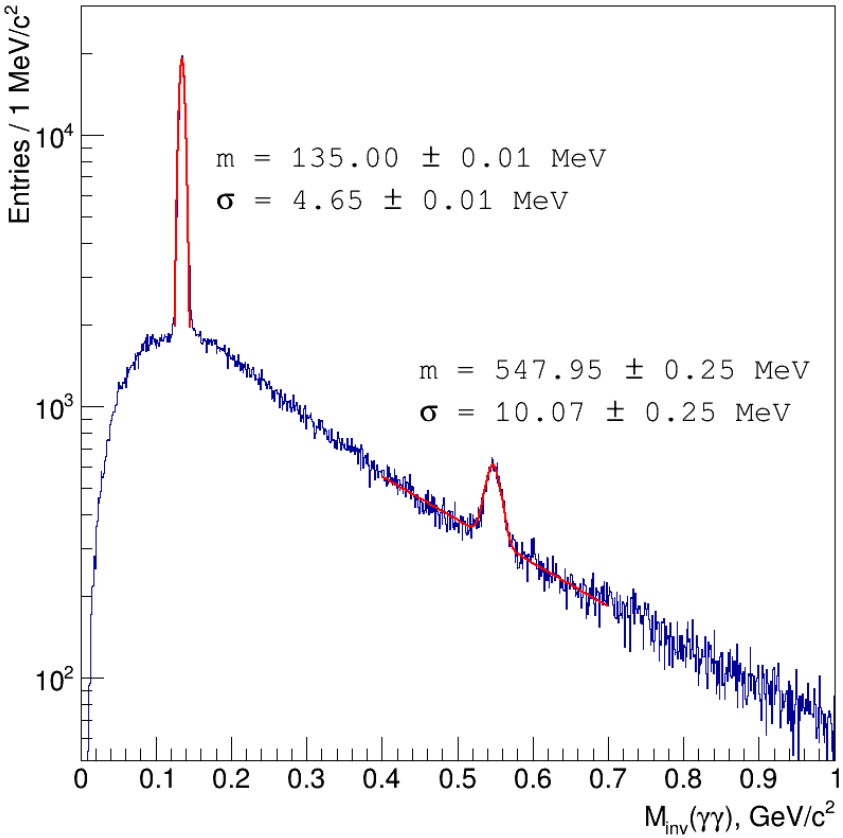
Fast simulation scheme



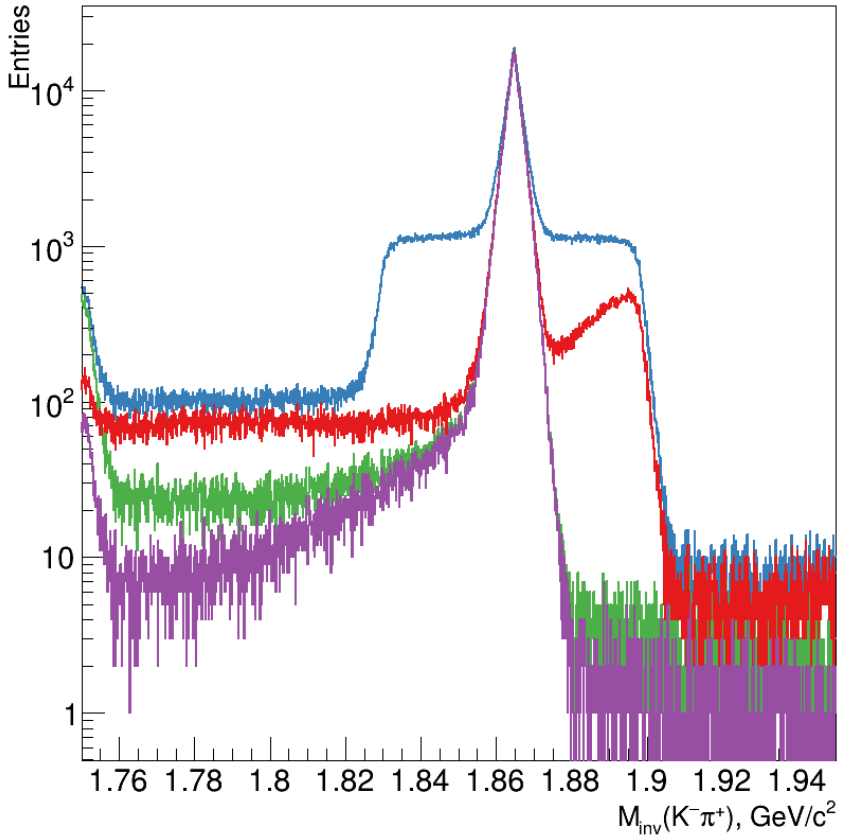
SCT Detector fast simulation

Some results

Invariant masses of two photons in decays of J/ψ



Reconstruction of $D^0 \to K^-\pi^+$ from inclusive decay of $\psi(3770)$



For the details please refer to the "Fast Simulation for the Super Charm-Tau Factory Detector" article (DOI: 10.1007/s41781-023-00108-7)

Aurora

Event Data Model

- ROOT-based
- PODIO to generate C++ classes using yaml file
- Not stable while active development is going on

  $\rightarrow$ Rebase to EDM4hep?

Aurora

Geometry

- Subsystems implemented at the moment:
  - Beam pipe & final focus magnets
  - Inner tracker (three options)
  - Advanced DC with StereoLayers
  - Particle ID
  - Crystal calorimeter
  - Simplified s/c coil
  - Muon system & yoke
- Geometry testing tools for CI

  (overlaps, material scans. . .)
- Simplified magnetic field inside

  the solenoid and yoke iron

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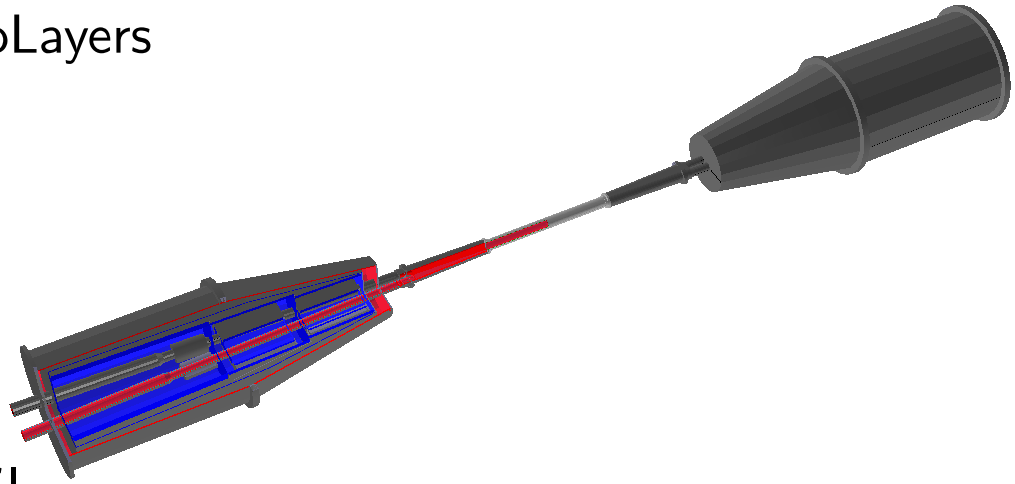

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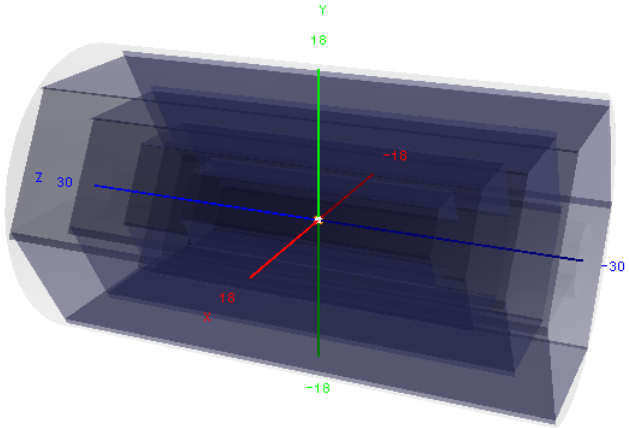

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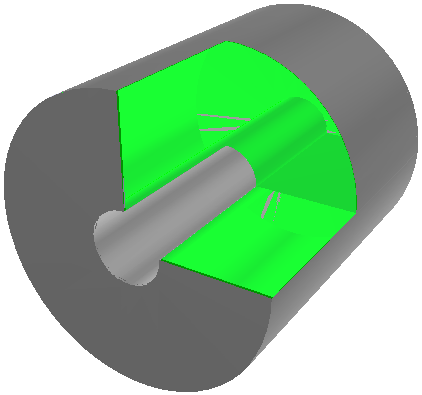

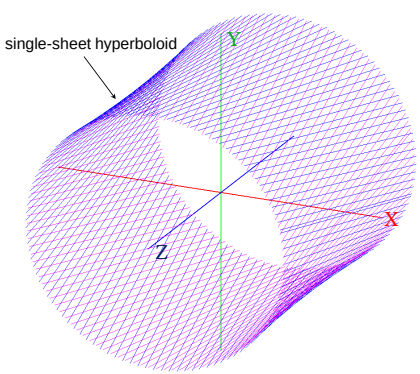

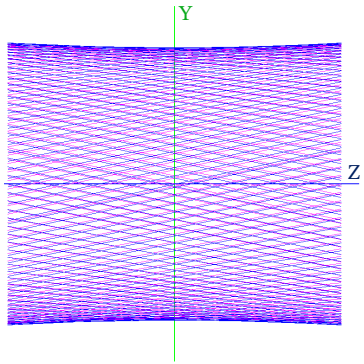

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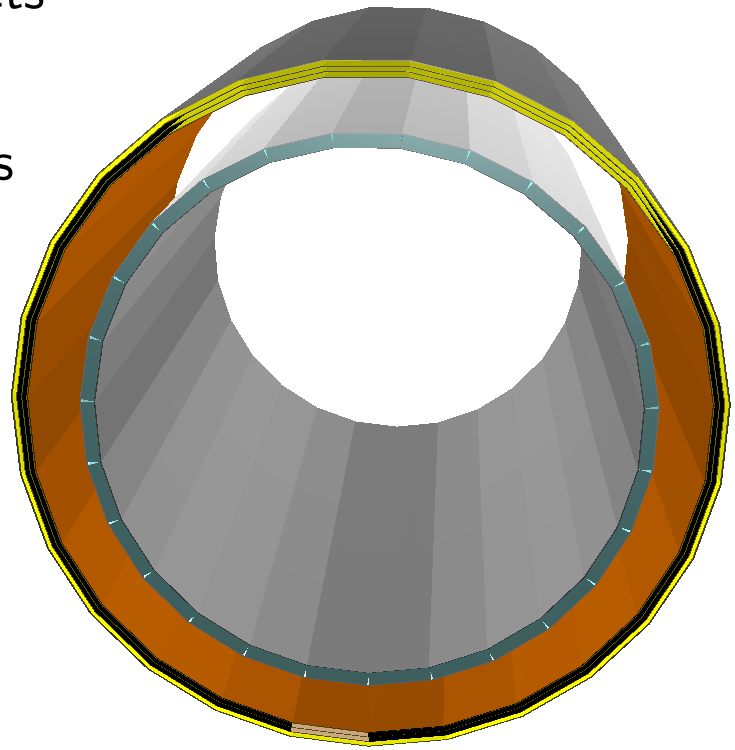

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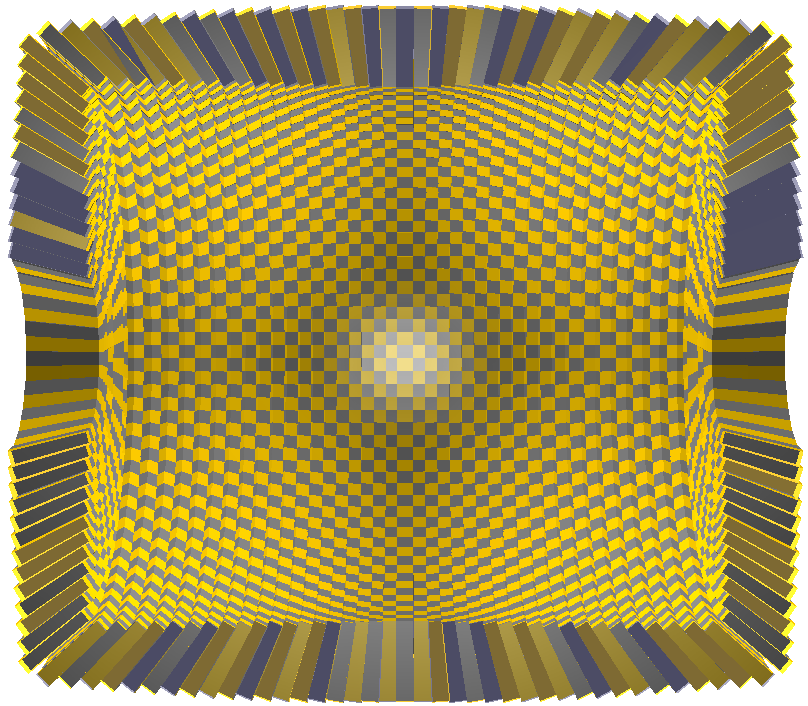

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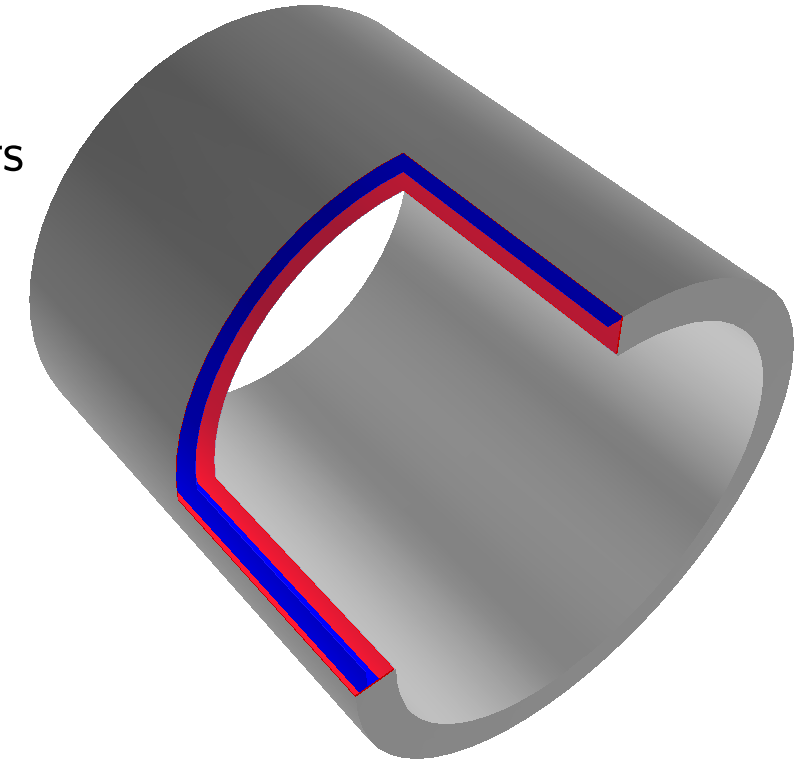

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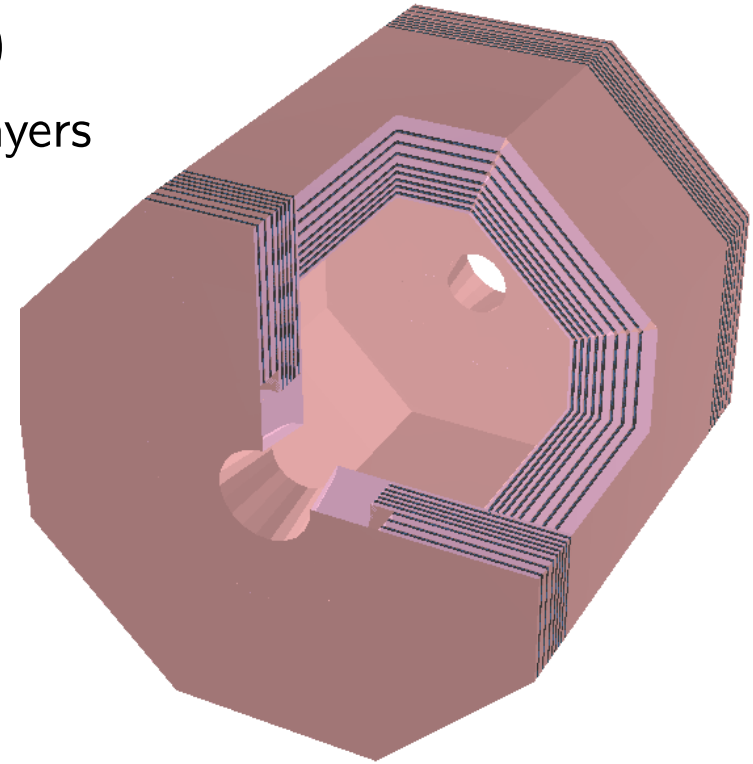

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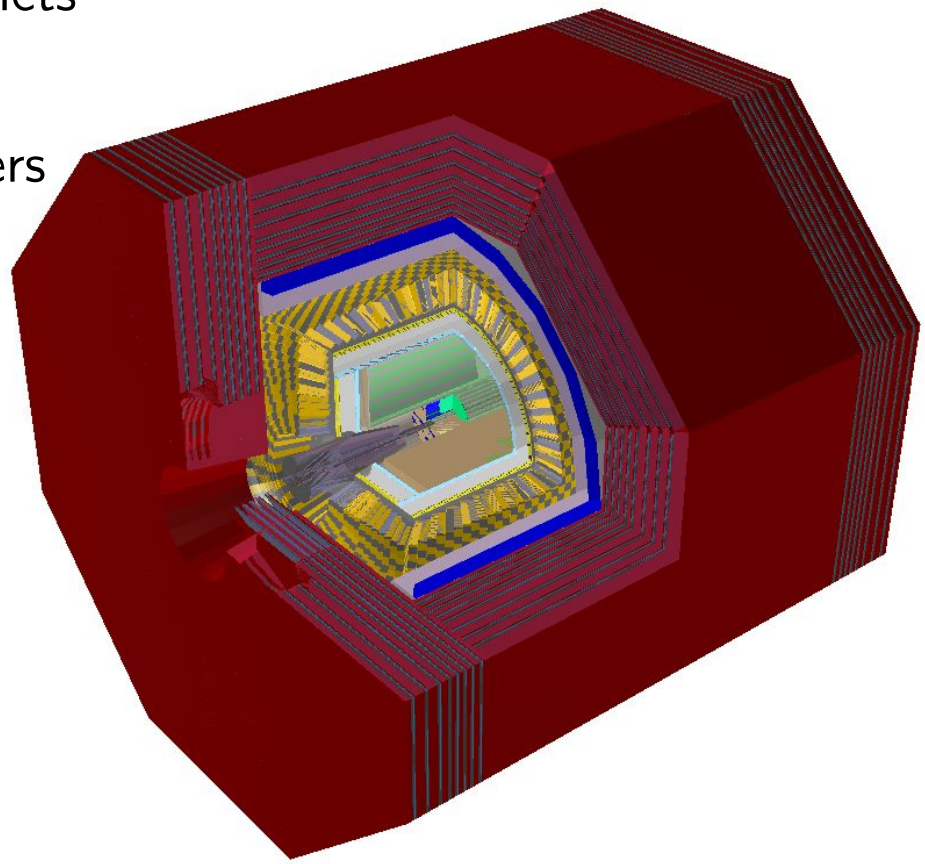


Aurora

Full simulation

- Set initial parameters via job options file:
  - generate primary particles / read pre-generated events
  - choose active subsystems and select variants
  - tools to save output collections
  - ...
- Geant4 is used for the particle propagation and hit generation
  - Optical photons activated for FARICH
  - G4Hit — information about hit, time, energy deposit, track ID and etc.
  - Special Gaudi tools to save G4Hit for each sensitive detector subsystem

Aurora

Digitization & Reconstruction

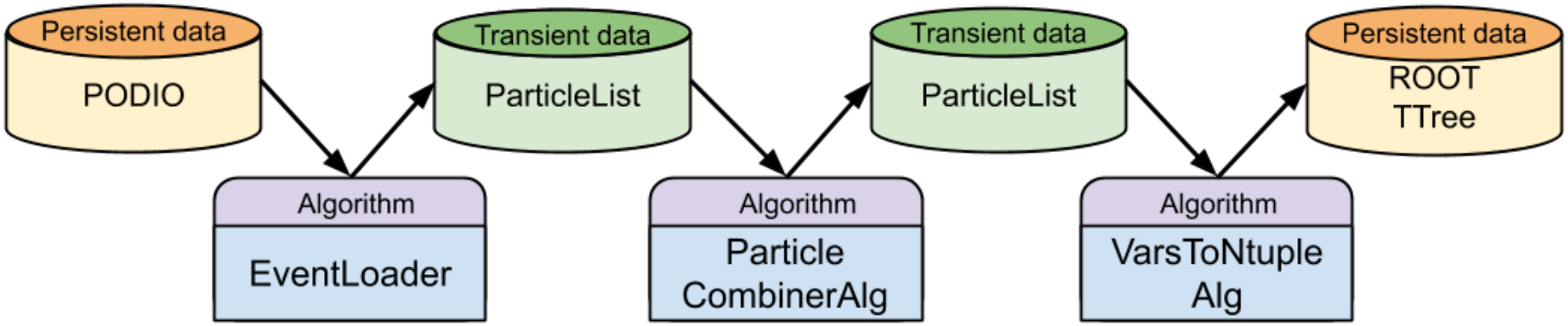
- most subsystems miss separate Digitization stage yet
  - integrated into reconstruction
  - based on standalone studies
  - modules prepared for Silicon Strip and Muon system
- 1st stage Reconstruction: individual subsystem level
  - in preparation by subsystem expert (need more activity)
  - MU is the most advanced at the moment
- 2st stage Reconstruction: combining subsystems, PID...

  — waiting for Rec. level 1 ready, need extra people

Aurora

Data Analysis

- Adopting Belle II recipes and solutions for analysis
- Base set of analysis algorithms ready:



- final particles processing
- kinematic cuts

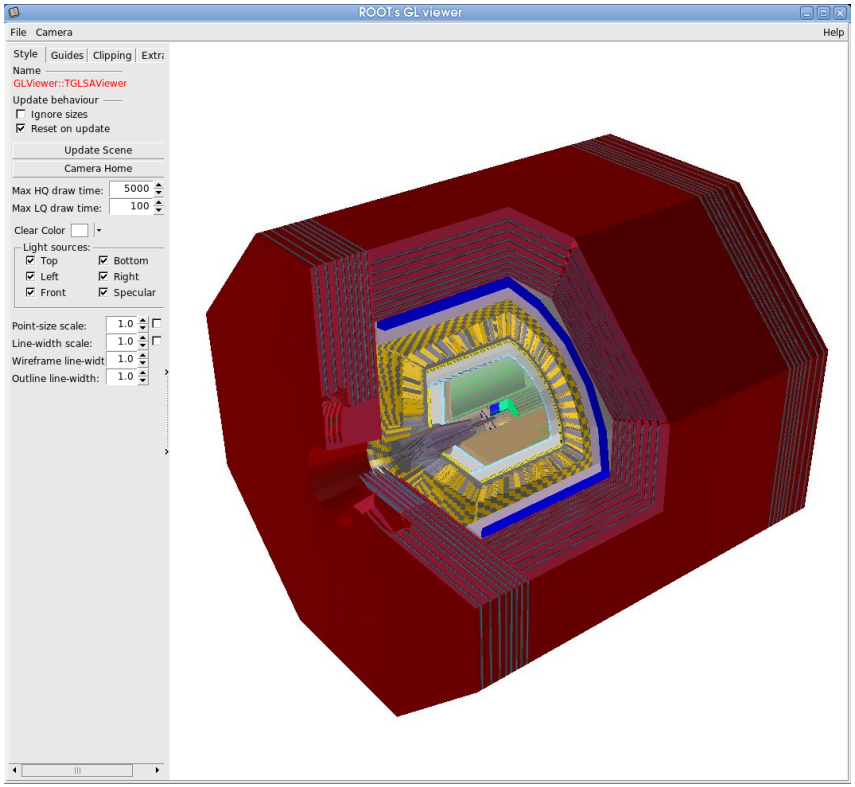
- reconstructuion of decayed particle
- kinematic cuts

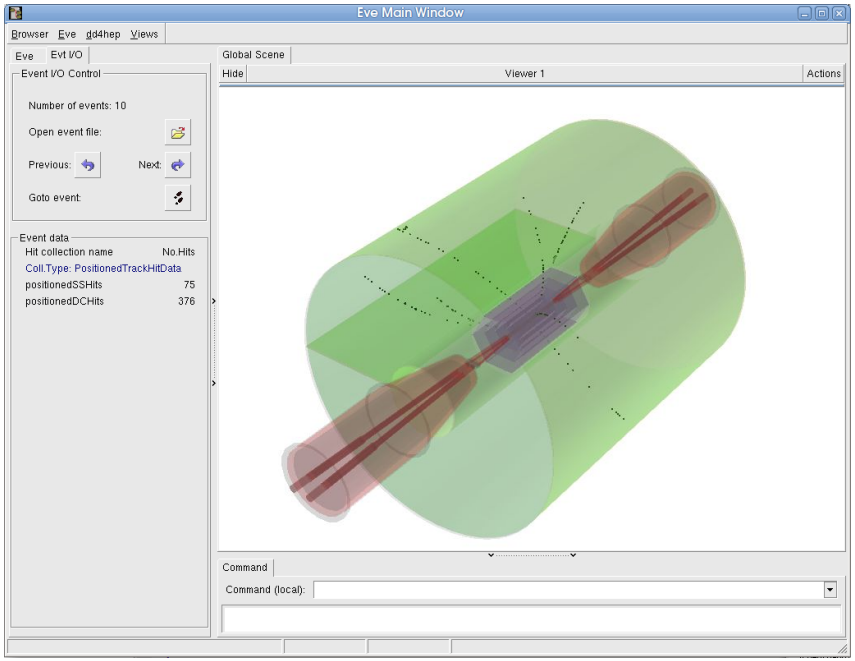
- kinematic parameters calculation
- particle selection

- Need contributing users

Aurora: detector & event visualization

Standard DD4hep tools

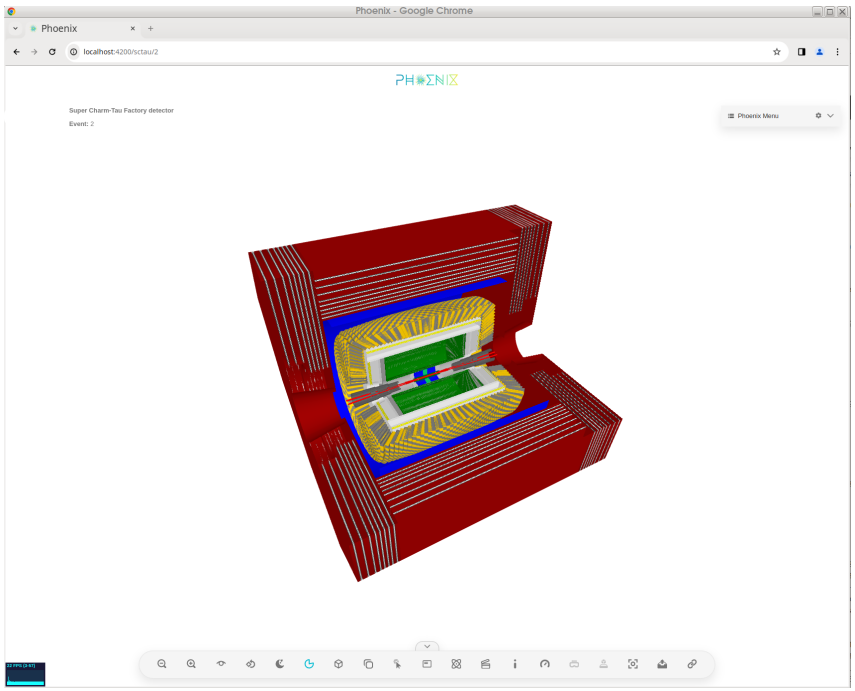


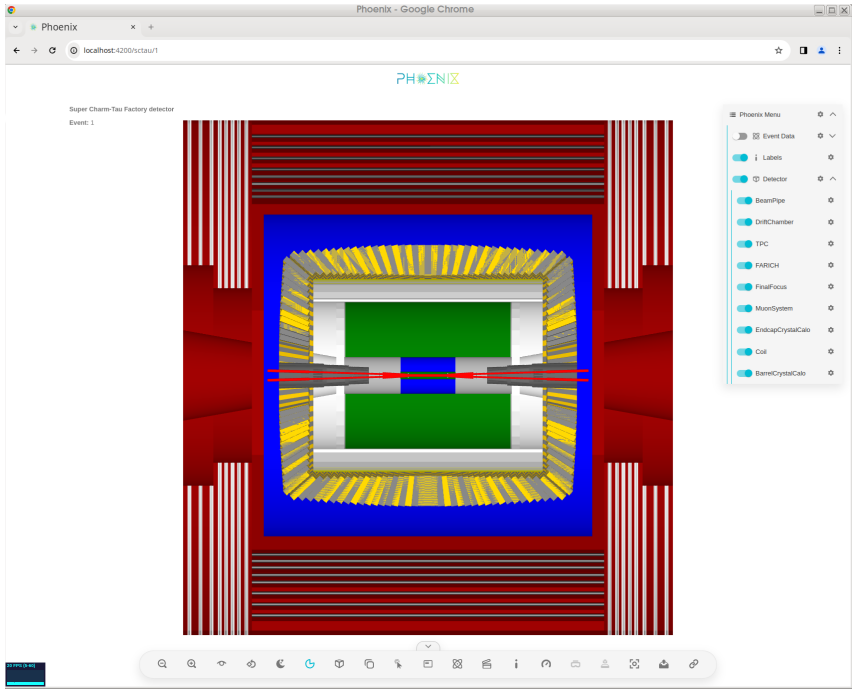


- Geometry Display tool is ready
- Event Display (DDEve-based) available, lots of things to improve

Aurora: detector & event visualization

Web-based Detector/Event Display





- based on the Phoenix project
- supports VR
- still lots to be done. . .

Aurora: detector & event visualization

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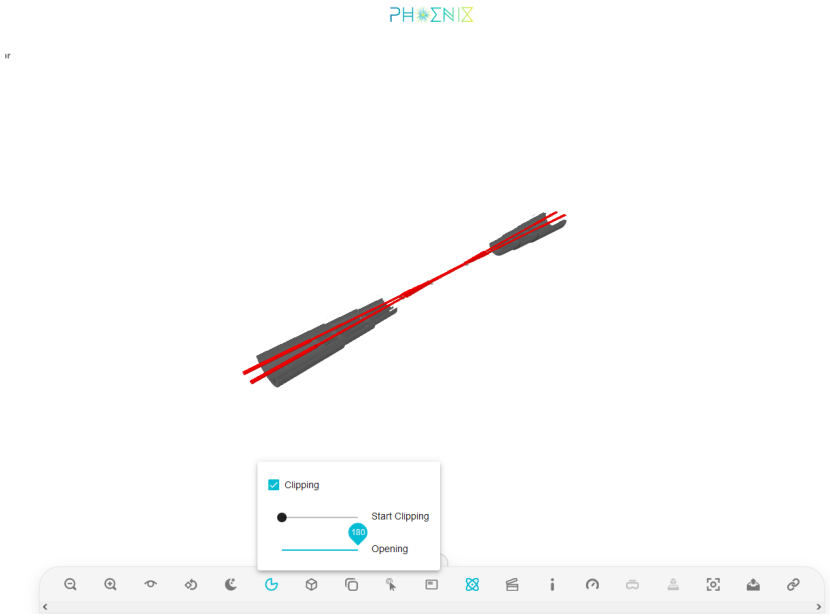

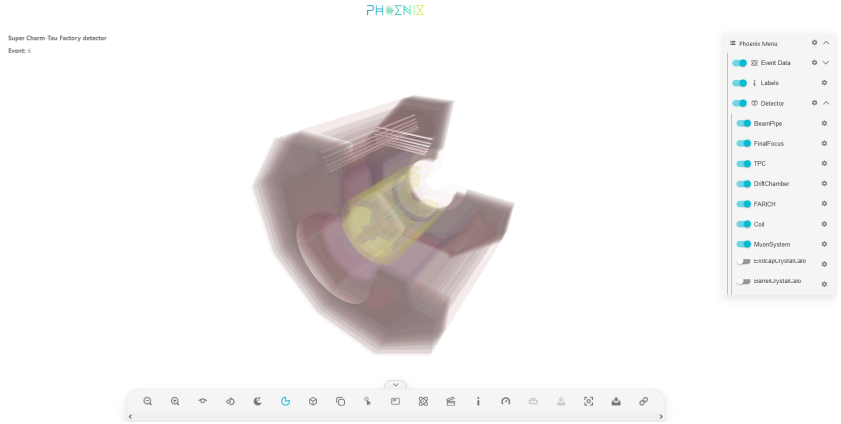

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Aurora

The software distribution

User's options to access the software are:

- Be registered at BINP/GCF cluster and use the "master" installation
- Download VirtualBox and QEMU/KVM VM images and run the VM locally
  - a Linux system image (currently SL7)
  - a specific Aurora release image (e.g. `rel_2.1.0.qcow2`)
  - an empty expandable `/home` image (optional)

  This variant completely emulates the BINP/GCF Aurora environment for a given release
- (Hopefully in the nearest future) worldwide directly via CVMFS

Instructions in the SCT Detector wiki

Aurora

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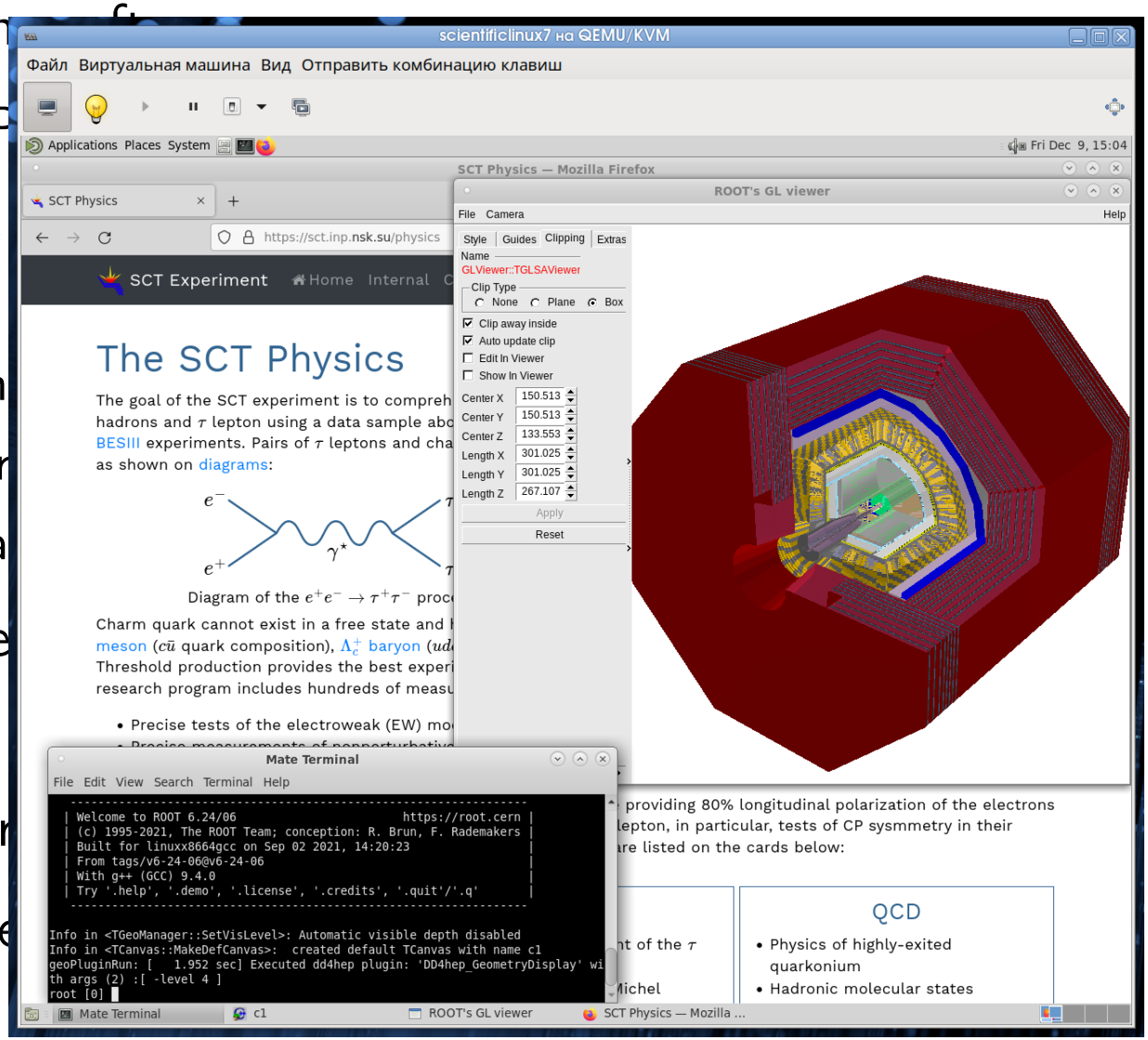

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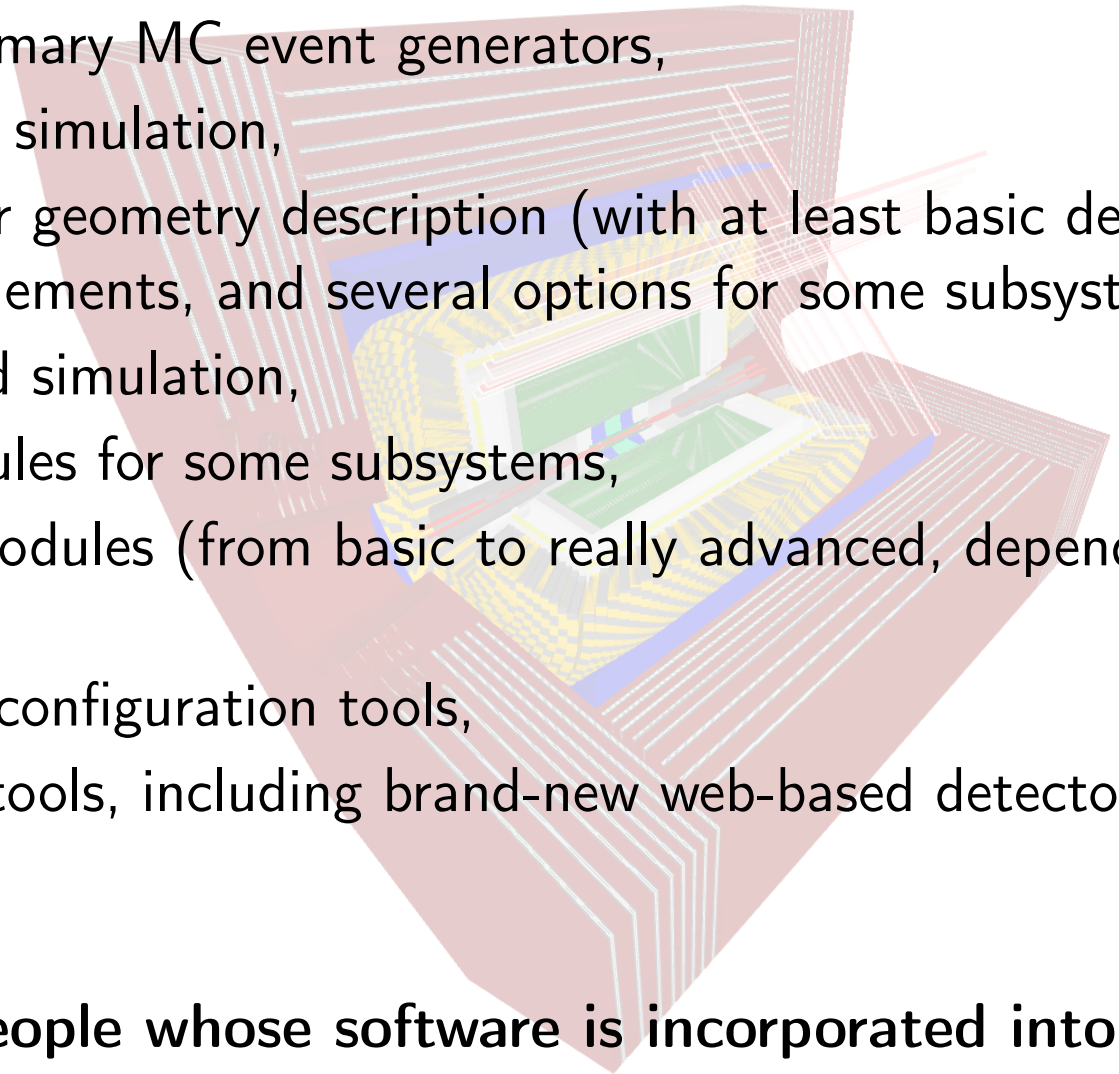
Instructions in the SCT Detector wiki

Conclusions

Aurora 2.1.0 released last year, featuring

- a basic set of primary MC event generators,
- ready-to-use fast simulation,
- common detector geometry description (with at least basic description for all detector elements, and several options for some subsystems),
- full Geant4-based simulation,
- digitization modules for some subsystems,
- reconstruction modules (from basic to really advanced, depending on subsystem),
- analysis and job configuration tools,
- test and service tools, including brand-new web-based detector display utility.



We thank all the people whose software is incorporated into or used by Aurora

Conclusions

Aurora 2.1.0 is available at BINP/GCF, via VM images, and (soon) via CVMFS.

Further development:

- framework “generalization”,
- digitization & reconstruction modules (need experts participation),
- generators & analysis tools (need physics people participation),
- visualization improvements,
- computing environment & software stack upgrade,
- . . . and lots more.

Thank you for attention