Software for future BINP HEP experiments

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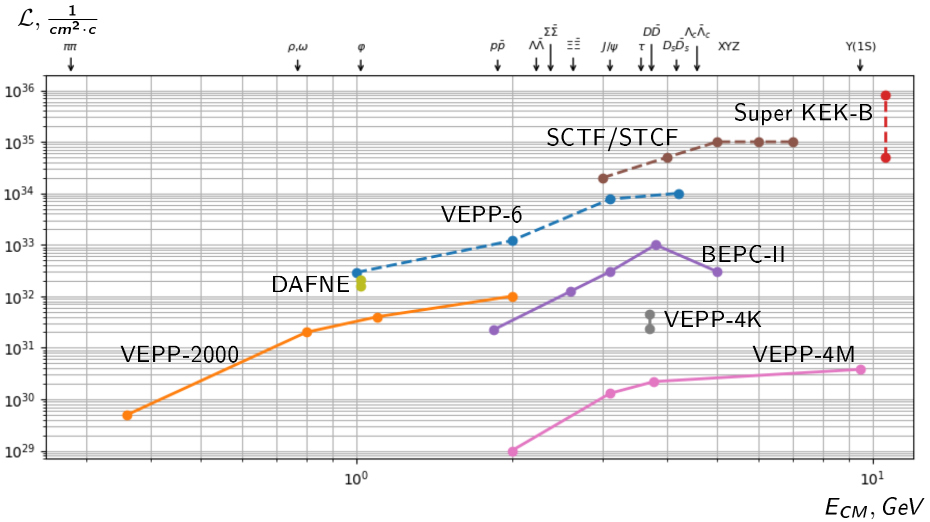
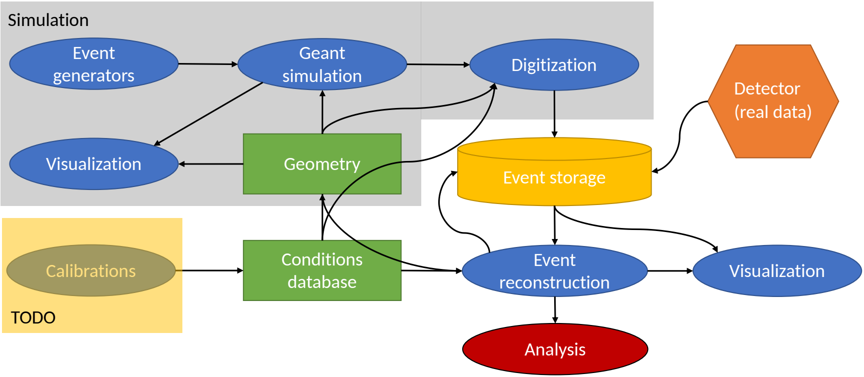
BINP

Electron-positron colliders world wide



Framework components and data flows



Framework also has:

- build & configuration system,
- release management software.

The Aurora framework features

Initially developped for SCTF project, now in a process of separation between framework itself and experiments specific parts.

- based on Gaudi with influence of FCCSW, Athena and BASF2,
- uses DD4Hep for detector geometry description,
- has its own Fast Simulation (DC, Calorimeter, PID, Mu),
- uses Geant4 for full simulation,
- data persistency based on ROOT and PODIO,
- single source of particle properties,
- random numbers generation infrastructure independent on algorithms execution order,
- conditions database prototype,
- powerful data analysis package.

The Aurora framework management

- build & configuration system inspired by ATLAS Athena,
- `lcgcmake` system to build external packages,
- current computing environment is AlmaLinux 8, gcc13 (C++17), Python3
- next probable computing environment is AlmaLinux 9, gcc14 (C++20), Python3
- software is partially distributed via CVMFS

Event Generators

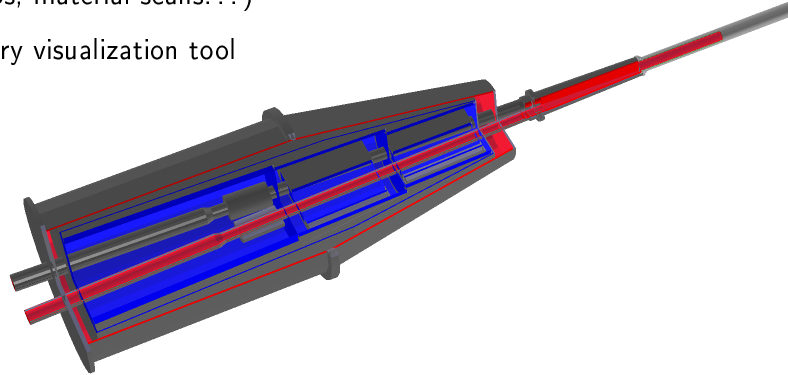
The conventional set of event generators available:

- Exclusive decays of hadrons and tau lepton
  - EvtGen, Tauola, PHOTOS, Pythia
- Inclusive generators for $e^+e^- \to$ hadrons *or* leptons
  - Solution based on KKMC, Pythia and EvtGen
- Technical generators
  - Particle gun, etc

List of generators is extended on demand

Geometry tools in Aurora

- DD4Hep stuff and some custom volumes implemented
- Enough to describe any complex detector
- Geometry testing tools for CI
  (overlaps, material scans. . .)
- Geometry visualization tool



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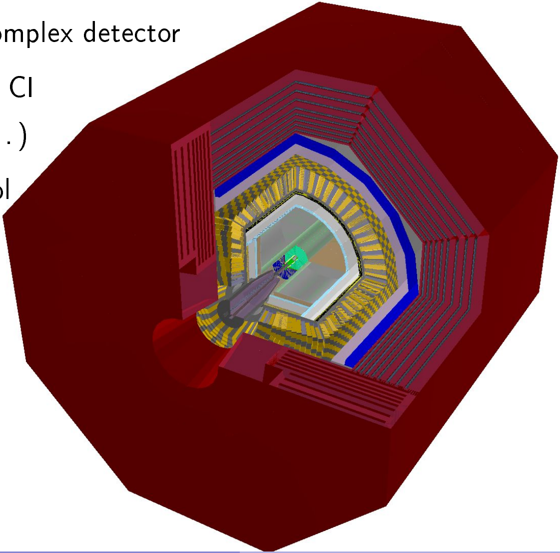
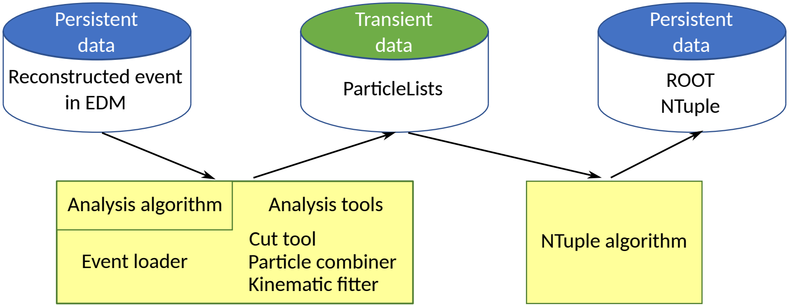


Data storage

- Based on ROOT and PODIO.
- Uses stable PODIO (since 1.0) storage container called `Frame`.
- `Frame` is an universal container capable store EDM and simple non-EDM data, also it is capable to contain another `Frame`.
- `Frame` container owns data stored into it, leads to conflicts with Gaudi storage (owns also), required additional step to resolve this.

Data Analysis package

- Following Belle II recipes and solutions for analysis



- final particles processing
- kinematic cuts
- reconstructuion of decayed particle

- kinematic parameters calculation
- particle selection
- kinematic fit

- save results

Data analysis usage example

Loading services

First of all it is necessary to configure data services:

```
# Particle data.
particle_data = ParticleDataService('ParticleDataService')

# Conditions database.
conditions = ConditionsService('ConditionsSvc',
    testingPayloadLocations=['local_database/database.txt',
                             AuroraConditions.databasePath()]
)
```

- ParticleDataService — is new unified service providing particle properties information based in EvtGen data format.
- ConditionsService — provides experimental environment: beam parameters and magnetic field.

Data analysis usage example

Input data, analysis algorithm

Creating analysis algorithm:

```
# Analysis algorithm.
analysis = AnalysisAlgorithm(
    'Analysis',
    eventLoader=event_loader,
    analysisTools=[cut1, combiner1, extrainfo1, fit1, combiner2, extrainfo2,
                   fit2]
)
```

Analysis algorithm sequentially calls analysis tools, event loader is called before all others.

Data analysis usage example

Event loading and selection

Event loader is configured by:

```
# Event loader.
event_loader = EventLoaderTool(
    'EventLoader',
    particleLists=['pi+', 'K+', 'gamma']
)
```

particleLists property defines lists of particles to be created (loaded). All particles including antiparticles created at this stage without any selection. Selection rules are applied by CutTool later.

```
# Apply selection criteria for kaons.
cut1 = CutTool(
    'Cut1',
    outputParticleList='K+:sel',
    inputParticleLists=['K+'],
    cut='pt␣>␣0.1'
)
```

New list K+:sel contains Kaons from original list K+, which satisfy condition $p_t > 0.1$ ГэВ$/c$.

Data analysis usage example

Particles combinations

Compound particles are created by `ParticleCombinerTool` from earlier created lists of daughter partcles.

```
# Reconstruct pi0 -> gamma gamma.
combiner1 = ParticleCombinerTool(
    'Combiner1',
    decayString='pi0 -> gamma gamma',
    cut='0.120 < M < 0.150'
)
```

Created particles are subject to specified selection criteria.
J/ψ example:

```
# Reconstruct J/psi -> K+ K- pi0.
combiner2 = ParticleCombinerTool(
    'Combiner2',
    decayString='J/psi:channel1 -> K+:sel K-:sel pi0',
    cut='2.9 < M < 3.3 and p < 0.6'
)
```

Data analysis usage example

ExtraInfo and kinematic fits

ExtraInfoTool saves specified variables of particles list to extra info area, for example combined particle mass before fit could be saved.

```
# Save pi0 mass before fit.
extrainfo1 = ExtraInfoTool(
    'ExtraInfo1',
    particleList='pi0',
    extraInfo=[['M', 'M']]
)
```

First argument is ExtraInfo name, second is variable name.

KinematicFitterTool makes a fit of mass of particles from specified list.

```
# Perform mass fit for pi0.
fit1 = KinematicFitterTool(
    'Fit1',
    particleList='pi0'
)
```

Data analysis usage example

Save results

Particles after analysis stage could be saved to file by `NtupleAlg`. Variables to save for each particle could be specified.

```
# Define aliases.
aliases = [['M_before_fit', 'extraInfo(M)'],
           ['p_before_fit', 'extraInfo(p)']]

# Create ntuple.
ntuple1 = NtupleAlg('NtupleAlg1',
    listName='J/psi:channel1',
    fileName='scttuple/jpsi1',
    tupleTitle='',
    vars=[['M_before_fit', 'p_before_fit', 'M', ''],
          ['E', 'px', 'py', 'pz', 'px_mc', 'py_mc', 'pz_mc', 'pidkpi',
           'J/psi -> ^K+ ^K- pi0'],
          ['E', 'px', 'py', 'pz', 'M_before_fit', 'M', 'J/psi -> K+ K- ^pi0'],
          ['px', 'py', 'pz', 'px_mc', 'py_mc', 'pz_mc',
           'J/psi -> K+ K- [ pi0 -> ^gamma ^gamma ]']],
    aliases=aliases
)
NTupleSvc(Output = [
    "scttuple DATAFILE='jpsi_kpkmpiz_reconstructed.root' OPT='NEW' TYP='ROOT'"
])
```

It is possible to use several `NtupleAlgs` for different reconstructed particles.

Conclusions

The Aurora framework contains minimally required set of components for detector development:

- set of primary event generators,
- parameterized simulation,
- detector geometry description tools,
- full Geant4-based simulation,
- analysis and job configuration tools,
- test and service tools.

All described software is targeted to Aurora 3.0.0 release

Thank you for your attention

Backup

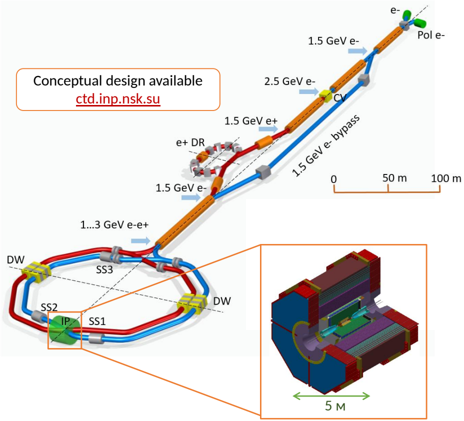
Further software development

The nearest goals for the software development are:

- implementation of digitization modules for all subsystems
- further reconstruction improvements, including adoption of some high-level tools, i. e. track finding,
- improvement of detector and event visualization tools. The underlying DDEve has been not actively developed recently, so this is an area of possible backward contribution to DD4Hep
- distribution of the software via CvmFS

SCT Experiment overview

- Precision experiments with tau lepton and charmed hadrons, and search for BSM phenomena
- Electron-positron collider
  - Beam energy varying between 1.5 and 3.5 GeV
  - Luminosity $\mathcal{L} = 10^{35} cm{-}2s{-}1$ @ 2 GeV
  - Longitudinal polarization of the e^- beams
- Universal particle detector
  - Tracking system
  - Crystal electromagnetic calorimeter
  - Particle identification system



Detector overview

Requirements:

- Trigger rate up to 300 kHz
- $10^4 cm^{-2}s^{-1}$ tracks at $R \leq 20$ cm
- $\sigma_p/p \leq 0.4\%$ at 1 GeV/c
- Good π^0/γ separation, $E_\gamma = 10 - 3000$ MeV, $\sigma_E \leq 1.8\%$ at 1 GeV
- Dedicated PID system
  - $\frac{dE}{dx} < 7\%$,
  - μ/π separation up to 1.5 GeV/c,
  - π/K separation up to 3.0 GeV/c.
- Minimal CP detection asymmetry