AURORA software framework

Daniil Zhadan
on behalf of the SCTau collaboration

Workshop on future Super c-tau factories 2021

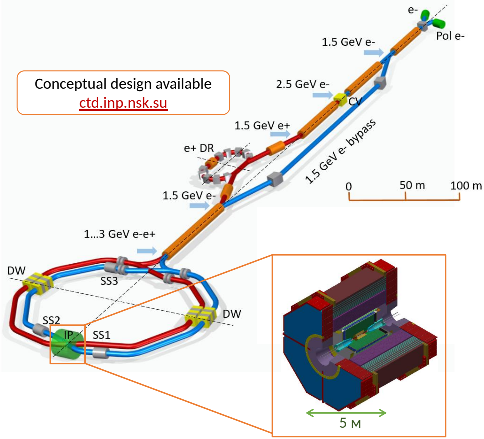
Budker Institute of Nuclear Physics, Novosibirsk, Russia

17 November 2021

BINP

SCT Experiment overview

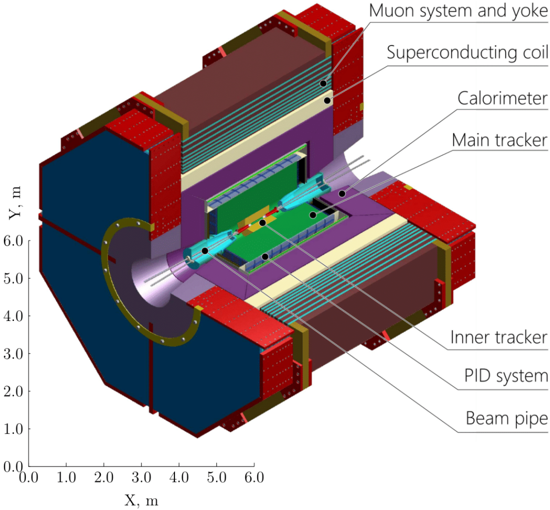
- Precision experiments with tau lepton and charmed hadrons, and search for BSM phenomena
- Electron-positron collider
  - Beam energy varying between 1.5 and 3.5 GeV
  - Luminosity $\mathcal{L} = 10^{35} cm^{-2} s^{-1}$ @ 2 GeV
  - Longitudinal polarization of the e^{-} beams
- Universal particle detector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



Software for the project

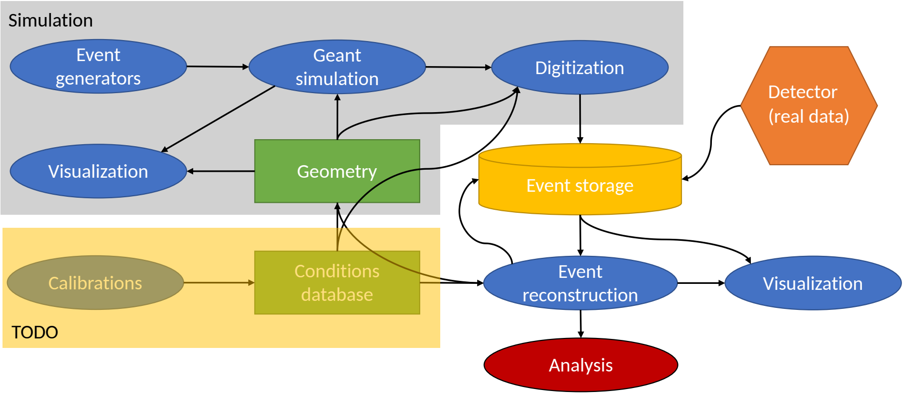
A HEP software framework

A typical HEP experiment requires complete stack of relevant software:

- event generators,
- parametric and full detector simulation,
- event reconstruction algorithms,
- online event interpretation for trigger decisions,
- 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.

Software for the project

Framework elements and data flows



All software for our detector is impemented in framework named Aurora

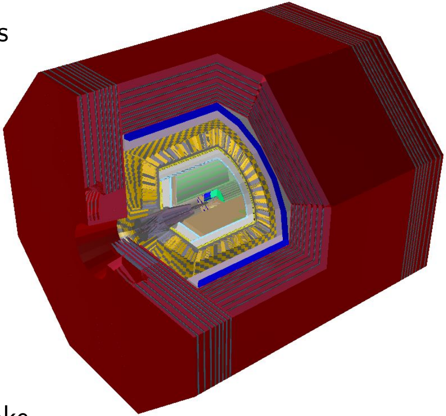
The Aurora framework

- Based on Gaudi
- Uses conventional and recently emerged HEP software tools:
  - ROOT, Geant4
  - DD4Hep
- When possible we reuse peaces of other experiments software
  - Belle II, ILC, FCCSW...
- Build & configuration system inspired by ATLAS Athena
- Functional modules are implemented as packages
- `lcgcmake` system to build external packages
- Nightly builds
- Current computing environment is Scientific Linux 7 x86_64, GCC9 + Python2&3

Status of the software

Geometry in Aurora

- Beam pipe & final focus magnets
- Inner tracker
- Advanced DC with StereoLayers
- Particle ID
- Crystal calorimeter
- Simplified s/c coil
- Muon system & yoke
- Magnetic field in solenoid and yoke

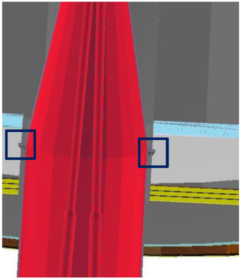


We have geometry for at least one option for each subsystem

Status of the software

Geometry testing tools

- Overlaps
- Material scans
- Geometry loading test
- Geometry hierarchy print



```
GeometryTools    INFO  Start test overlap
Info in <TGeoNodeMatrix::CheckOverlaps>: Checking overlaps for world_volume and daugh
ters within 0.01
TGeoMatrix::dtor:0: RuntimeWarning: Registered matrix Identity was removed
TGeoMatrix::dtor:0: RuntimeWarning: Registered matrix FarichEndcap_assembly_vol_place
ment was removed
TGeoMatrix::dtor:0: RuntimeWarning: Registered matrix Identity was removed
Check overlaps:      [==========]  764 [100.00 %]
Info in <TGeoNodeMatrix::CheckOverlaps>: Number of illegal overlaps/extrusions : 2

=== Overlaps for default ===
 = Overlap ov00000: world_volume/FarichEndcap_assembly_vol_1/FarichEndcap_1/layer_2_1
 overlapping world_volume/full_FinalFocus_assembly_vol_2/sub_FinalFocus_assembly_vol_
1/SteelFlange_2 ovlp=0.85
 = Overlap ov00001: world_volume/FarichEndcap_assembly_vol_1/FarichEndcap_0/layer_2_1
 overlapping world_volume/full_FinalFocus_assembly_vol_2/sub_FinalFocus_assembly_vol_
0/SteelFlange_2 ovlp=0.85
GeometryTools    INFO  End test overlap
```

+ Material scan between: x_0 = (0.00,   0.00,   0.00) [cm] and x_1 = (300.00,   0.00,   0.00) [cm] :

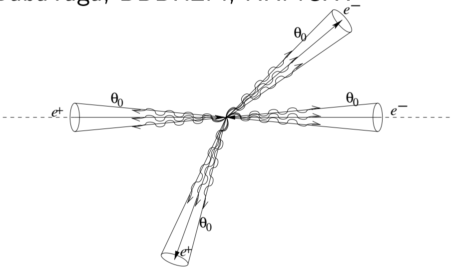
Num. Layer	Material Name	Atomic Number/Z	Mass/A [g/mole]	Density [g/cm3]	Radiation Length [cm]	Interaction Length [cm]	Thickness [cm]	Path Length [cm]	Integrated X0 [cm]	Integrated Lambda [cm]	Material Endpoint (cm,	cm,	cm)
1	Air	7	14.801	0.0012	30513.3509	71309.4666	81.137	81.14	0.002659	0.001138	(81.14,	0.00,	0.00)
2	Aluminum	13	26.982	2.6990	8.8963	38.8767	0.100	81.24	0.013919	0.003714	(81.24,	0.00,	0.00)
3	Aerogel_n1050	8	15.250	0.2320	153.0922	371.8424	4.007	85.24	0.040091	0.014490	(85.24,	0.00,	0.00)
4	Plexiglass	6	12.399	1.1900	34.0748	62.7757	0.301	85.54	0.048910	0.019277	(85.54,	0.00,	0.00)
5	Air	7	14.801	0.0012	30513.3509	71309.4666	15.626	101.17	0.049422	0.019496	(101.17,	0.00,	0.00)
6	Silicon	14	28.085	2.3300	9.3661	45.7533	0.020	101.19	0.051561	0.019934	(101.19,	0.00,	0.00)
7	G10	10	20.536	1.7000	16.2003	54.3032	0.250	101.44	0.067019	0.024545	(101.44,	0.00,	0.00)
8	Copper	29	63.546	8.9600	1.4356	15.5142	0.011	101.45	0.074346	0.025223	(101.45,	0.00,	0.00)
9	Air	7	14.801	0.0012	30513.3509	71309.4666	1.277	102.73	0.074388	0.025241	(102.73,	0.00,	0.00)
10	G10	10	20.536	1.7000	16.2003	54.3032	0.250	102.98	0.089846	0.029853	(102.98,	0.00,	0.00)
11	Copper	29	63.546	8.9600	1.4356	15.5142	0.011	102.99	0.097172	0.030531	(102.99,	0.00,	0.00)
12	Air	7	14.801	0.0012	30513.3509	71309.4666	1.277	104.27	0.097214	0.030549	(104.27,	0.00,	0.00)
13	G10	10	20.536	1.7000	16.2003	54.3032	0.250	104.52	0.112672	0.035160	(104.52,	0.00,	0.00)
14	Copper	29	63.546	8.9600	1.4356	15.5142	0.011	104.53	0.119998	0.035838	(104.53,	0.00,	0.00)
15	Air	7	14.801	0.0012	30513.3509	71309.4666	1.277	105.81	0.120040	0.035856	(105.81,	0.00,	0.00)
16	Carbon	6	12.011	2.0000	21.3485	40.1007	0.200	106.01	0.129424	0.040852	(106.01,	0.00,	0.00)
17	Aluminum	13	26.982	2.6990	8.8963	38.8767	0.100	106.11	0.140684	0.043429	(106.11,	0.00,	0.00)
18	Air	7	14.801	0.0012	30513.3509	71309.4666	193.894	300.00	0.147038	0.046148	(300.00,	0.00,	0.00)
0	Average Material	9	17.795	0.0140	2040.2821	6500.8543	300.000	300.00	0.147038	0.046148	(300.00,	0.00,	0.00)

Status of the software

Event Generators

A conventional set of event generators 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...

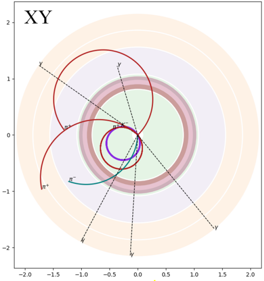


arXiv:hep-ph/0504233

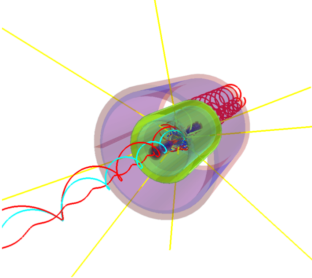
Status of the software

Simulation

- Parametric simulation is a tool for quick estimations of the detector performance.
  Details are presented in the poster "Parametric simulation of the SCT detector" by Maria Belozyorova.



- Full Geant4-based simulation with implemented detector geometry



Status of the software

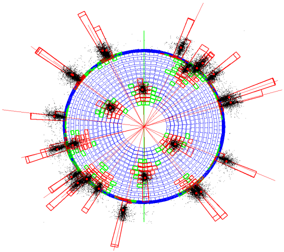
Digitization

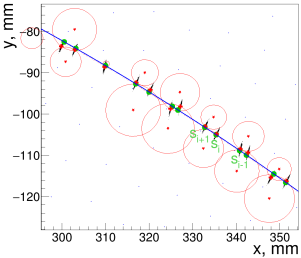
- Unified output data for reconstruction: G4Hit $\rightarrow$ RawHit
- To be implemented by subsystem experts
- Common part of algorithms implemented as a parent class
- Initial versions are ready for several subsystems:
  Silicon Strip, Calorimeter, Moun system and TPC

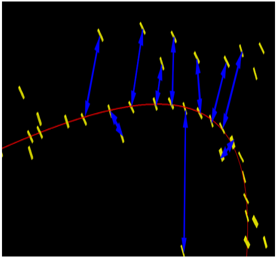
Status of the software

Reconstruction

- Reconstruction developed at individual subsystem level
  - Calorimeter and DC most advanced at the moment
- Common part of algorithms implemented as a parent class



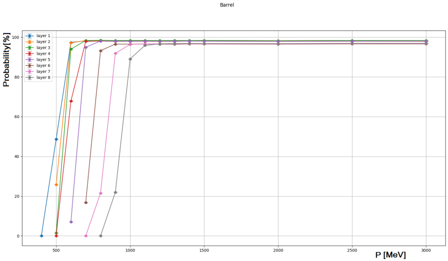




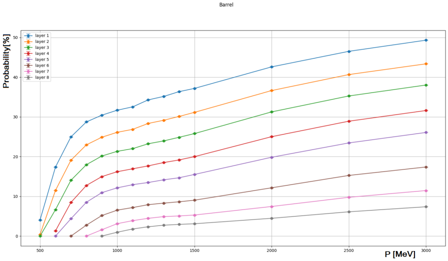
Status of the software

Reconstruction: Example

Probabilities to reach Muon System layers:



Muons

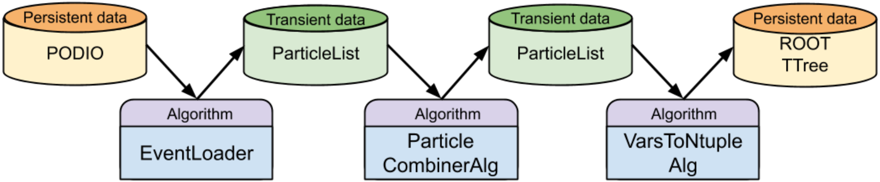


Pions

Status of the software

Data Analysis

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



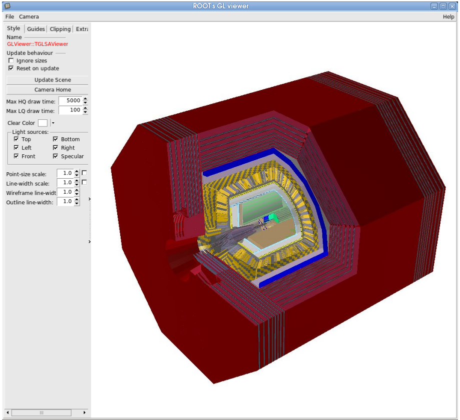
- final particles processing
- kinematic cuts

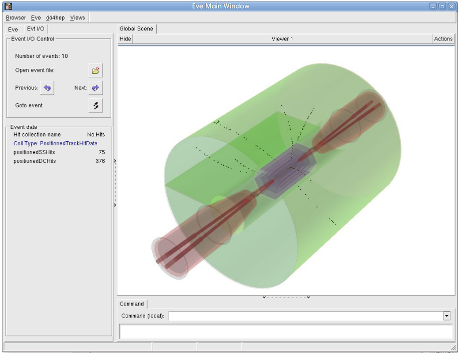
- reconstructuion of decayed particle
- kinematic cuts

- kinematic parameters calculation
- particle selection

Status of the software

Detector/Event Display



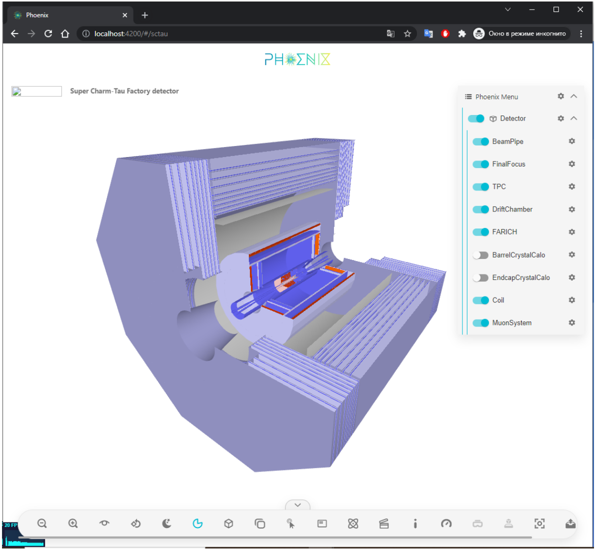


$\psi(4040) \to$ hadrons

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

Phoenix

Web event display



Further steps

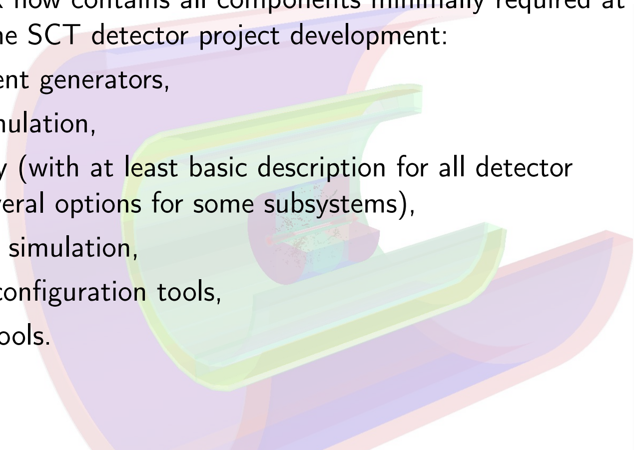
The nearest goals for the software development are:

- 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.
- Distribution of the software via CvmFS
- External software stack upgrade

Conclusions

The Aurora framework now contains all components minimally required at the present stage of the SCT detector project development:

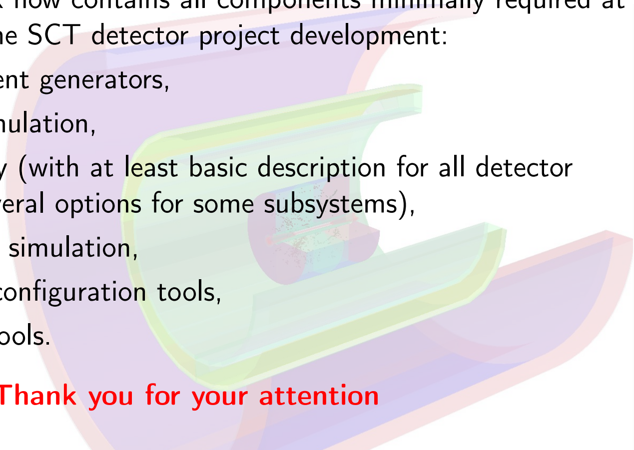
- set of primary event generators,
- parameterized simulation,
- detector geometry (with at least basic description for all detector elements, and several options for some subsystems),
- full Geant4-based simulation,
- analysis and job configuration tools,
- test and service tools.



Conclusions

The Aurora framework now contains all components minimally required at the present stage of the SCT detector project development:

- set of primary event generators,
- parameterized simulation,
- detector geometry (with at least basic description for all detector elements, and several options for some subsystems),
- full Geant4-based simulation,
- analysis and job configuration tools,
- test and service tools.



Thank you for your attention

Backup

Computing infrastructure for the project

- The immediate goal is to design the detector
  - need the simulation
  - need hardware to run it
- The existing BINP/General Computing Facility is available
  - local computing farm of about 2k CPU cores
  - various storage systems
  - service VM servers (about 100 CPU cores)
  - IB/10GbE/40GbE local interconnects
  - access to remote resources

. . . also shared with other groups

Backup

Resources available via BINP/GCF

- Computing resources of the Novosibirsk Scientific Center
  - NUSC & SSCC supercomputers
    - mostly GPU, but still several thousands of CPUs
  - ICT SB RAS storage
    - $>$ 500 TB
  - connected with isolated 10GbE network (NSC/SCN)
- Dedicated network link to Moscow (KIAE)
  - 2 Gbps presently
  - direct access to LHCone network

Backup

Resources available via BINP/GCF

- Computing resources of the Novosibirsk Scientific Center
  - NUSC & SSCC supercomputers
    - mostly GPU, but still several thousands of CPUs
  - ICT SB RAS storage
    - > 500 TB
  - connected with isolated 10GbE network (NSC/SCN)
- Dedicated network link to Moscow (KIAE)
  - 2 Gbps presently
  - direct access to LHCone network

We have enough computing resources for the present stage of the detector project