Status of STCF simulation and digitization

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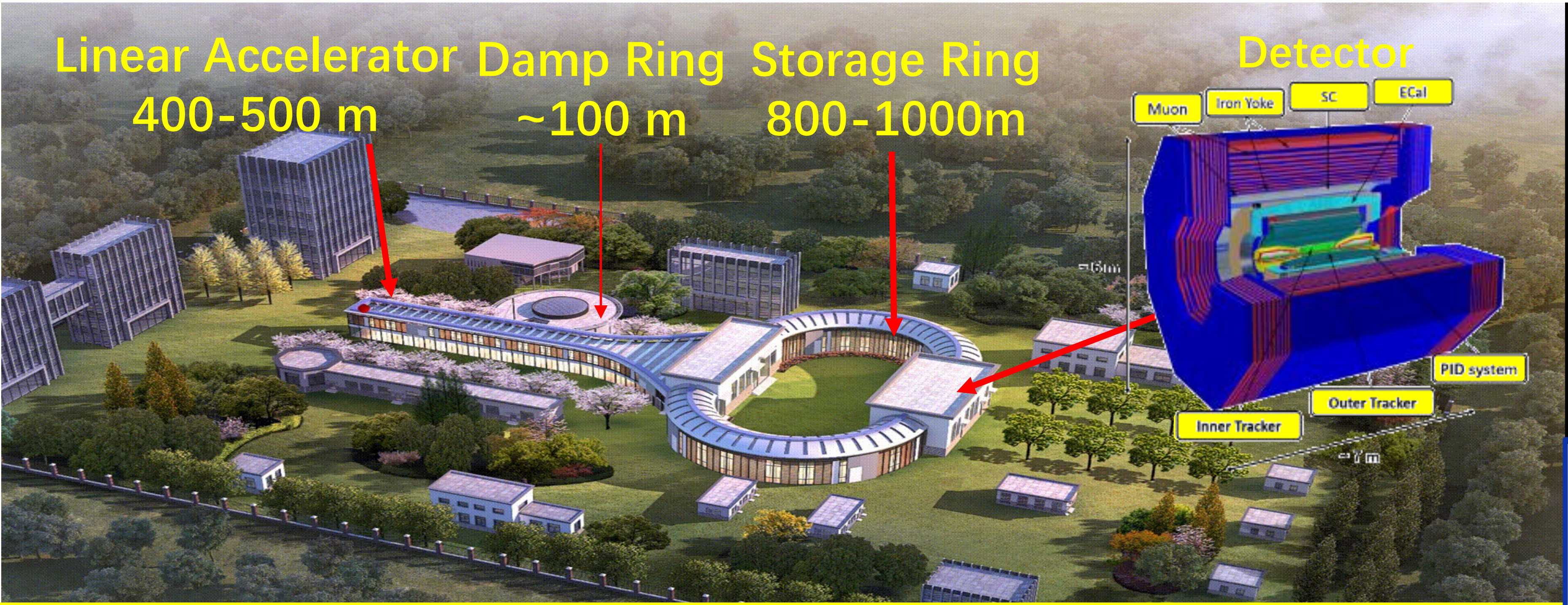
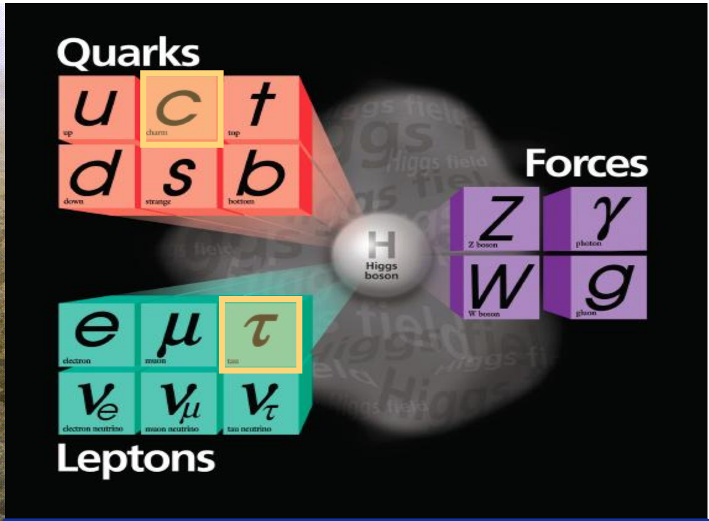
Super Tau Charm Facility (STCF)





Deliver a massive amount of tau-leptons and composed of charm quarks, to study the composition of particles, the deep structure of matter, as well as the basic interaction forces

- A future e^+-e^- collider in China
- E_{cm}= 2-7 GeV， $\mathcal{L} > 0.5\times10^{35}$ cm^{-2} s^{-1}
- Potential for upgrade to increase luminosity and realize polarized beam

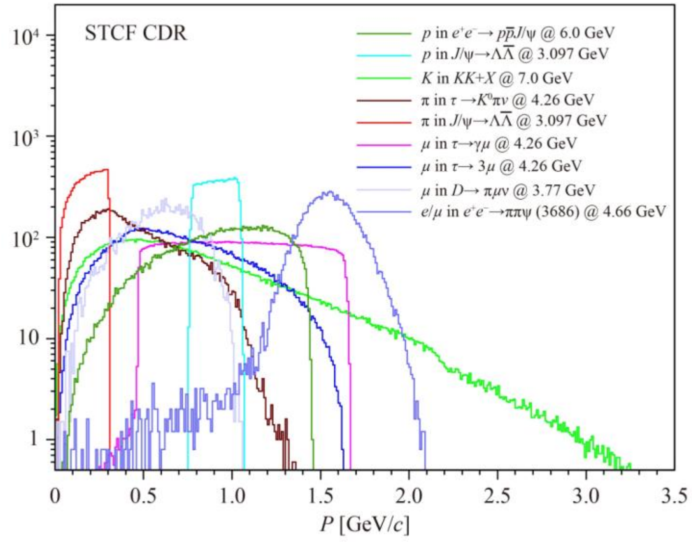
- 2021-2026： Conceptual design and R&D of Key technologies, 0.42 B CNY
- 2026-2031： Construction, 4.5 B CNY
- Operating for 15 years (may undergo upgrade).

STCF CDR (Volume 1): Physics & detector, 2024

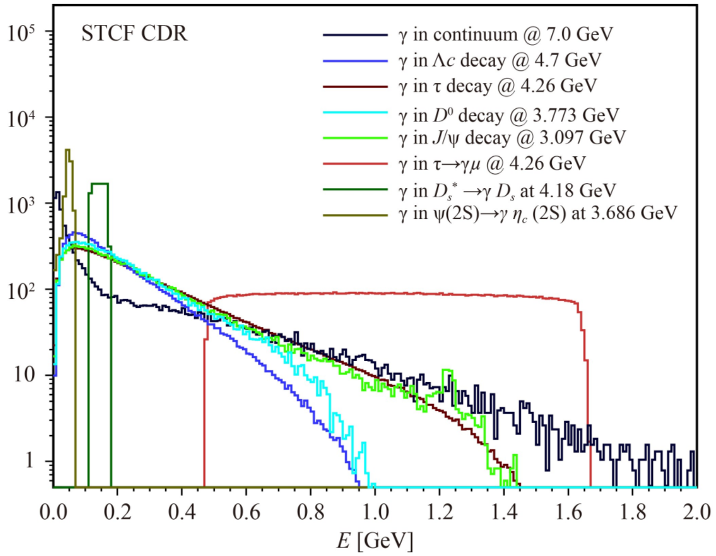
The Final State Particles of STCF

- Charged particles
  - e, μ, π, K, proton (p up to 3.5 GeV, most with p < 2 GeV, lots of particles with p < 400 MeV)
- Neutral particles
  - γ (energy coverage from 25 MeV to 3.5 GeV)
  - K_L, neutron (up to 1.6 GeV)

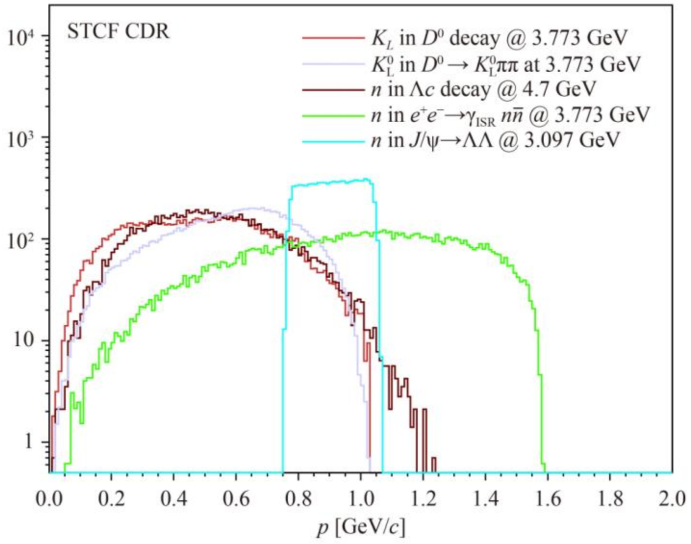
Charged particle momentum



Photon energy

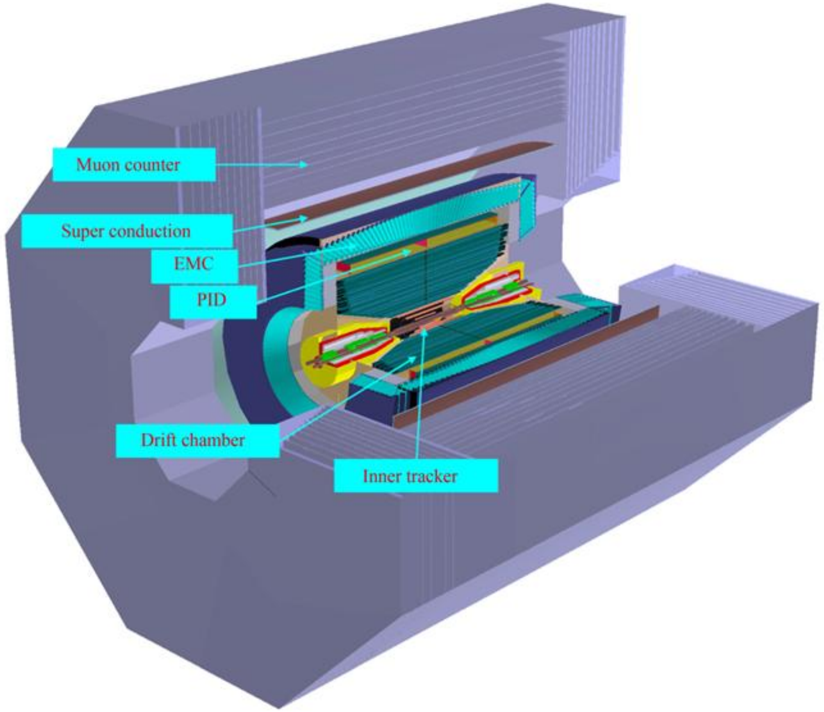


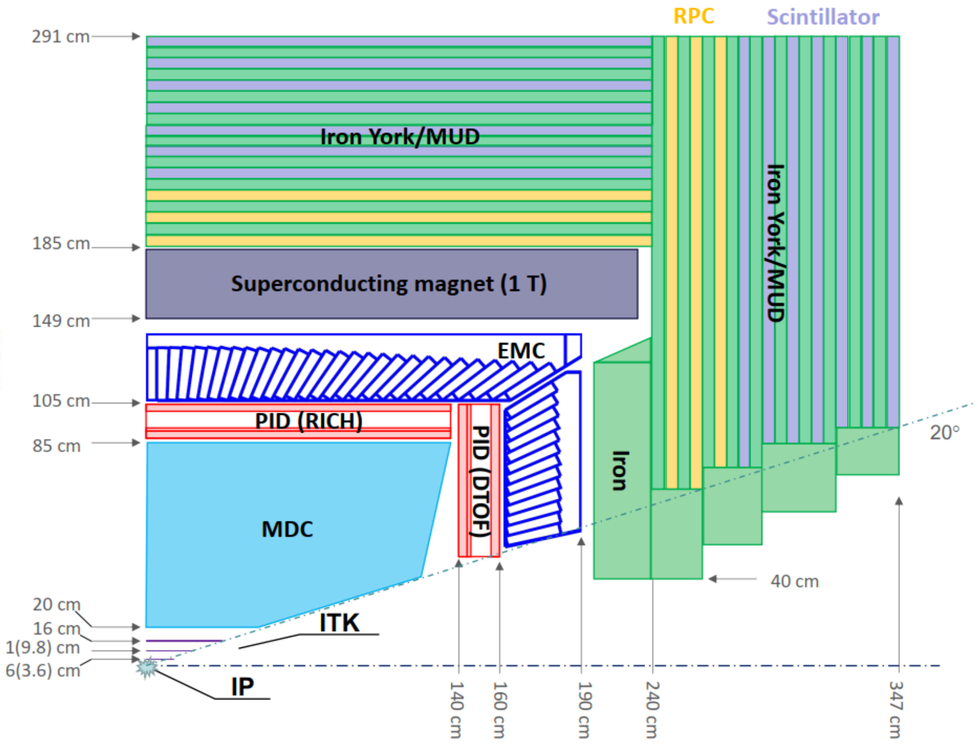
K_L and neutron



STCF Detector System

- To detect the final state particles (e, μ, π, K, p, γ, etc.) with high precision and efficiency in the whole dynamic space





MUD
- μ/π suppression power >30 at $p < 2$ GeV/c

EMC
- Energy range: 25 MeV - 3.5 GeV
- σ_E/E ~ 2.5% at E = 1 GeV
- σ_{pos} ~ 5 mm, σ_T ~ 300 ps at E = 1 GeV

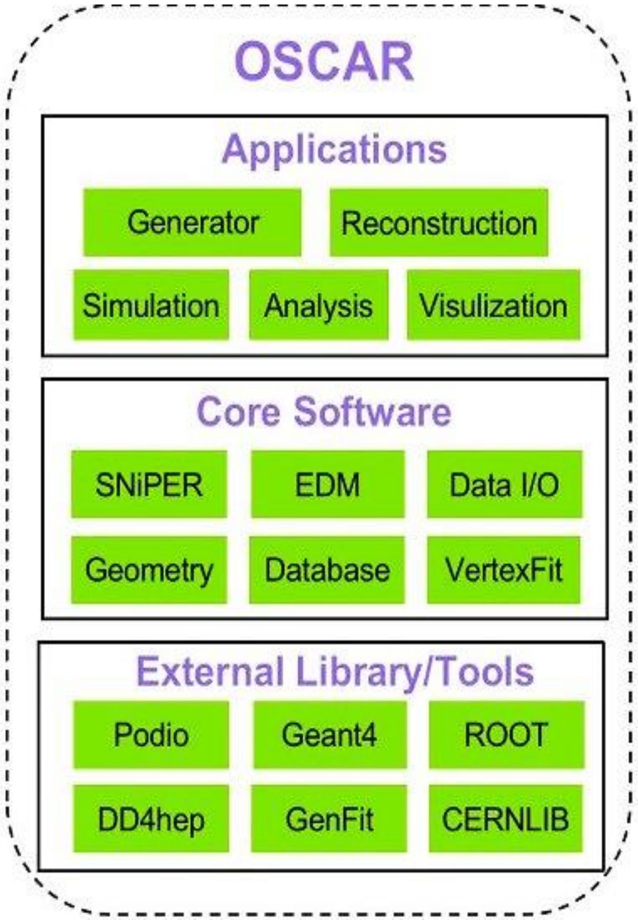
PID
- π/K (and K/p) 4σ separation power up to 2 GeV/c

MDC
- σ_{pos} ~ 130 μm
- dE/dx ~ 6%, σ_p/p = 0.5% at 1 GeV/c
- Efficiency > 99% at p_T > 0.3 GeV/c and >90% at p_T = 0.1 GeV/c

ITK
- ~0.25% X_0/layer
- σ_{pos} ~ 100 μm for single hit

STCF Offline software System

- The Offline Software of Super Tau-Charm Facility （OSCAR） is designed for detector design, MC data production and physics analysis at STCF：
  - Applications: STCF specific application software
  - Core software: common platform for the offline software
  - External libraries and tools
- Core software are developed for common functionalities
  - Event loop control (sequentially and concurrently)
  - Detector data and event data management
  - Common tools for data analysis
  - To support efficient parallel and heterogeneous computing
- Some applications are ported from BESIII



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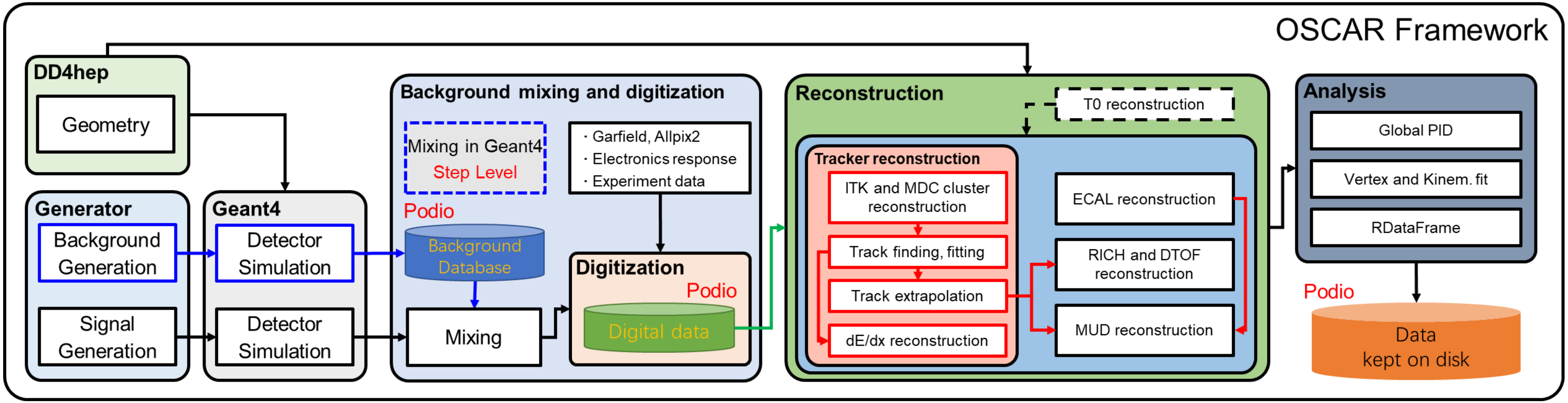
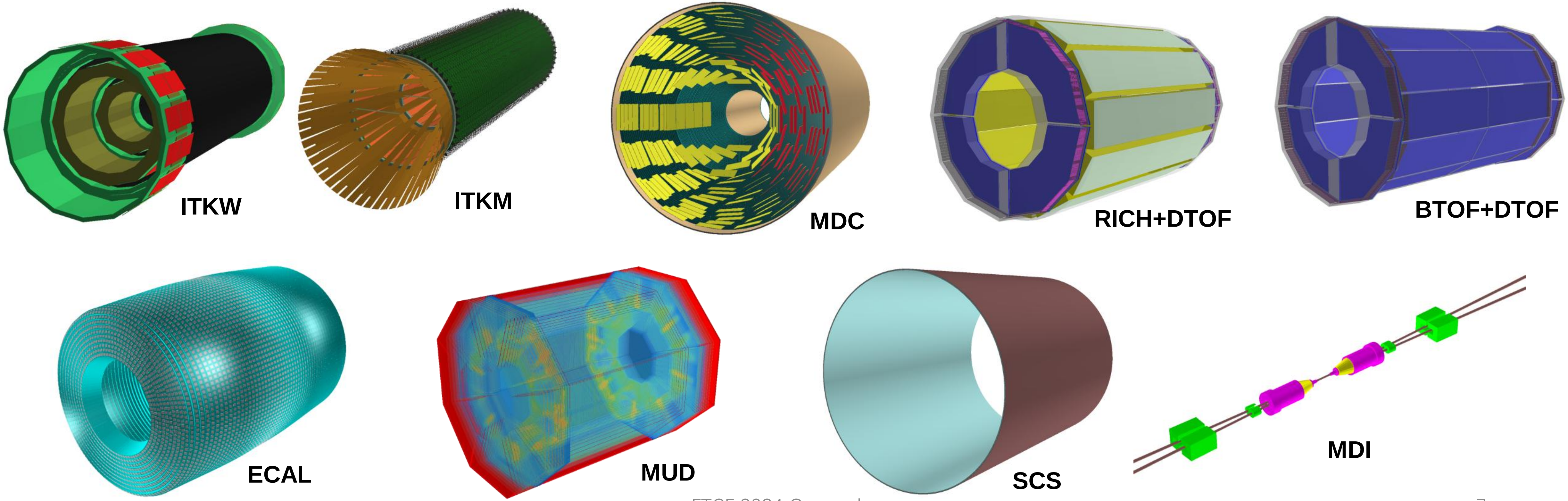
Status of STCF Offline Software

- Dedicated Core Software System including the underlying framework, DM system, GMS etc. are developed
- Full chain of detector simulation and physics object reconstruction has been built
- Physics analysis with full detector simulation and reconstructed objects is supported
- Parallelized simulation and reconstruction based on MT-SNiPER is developed



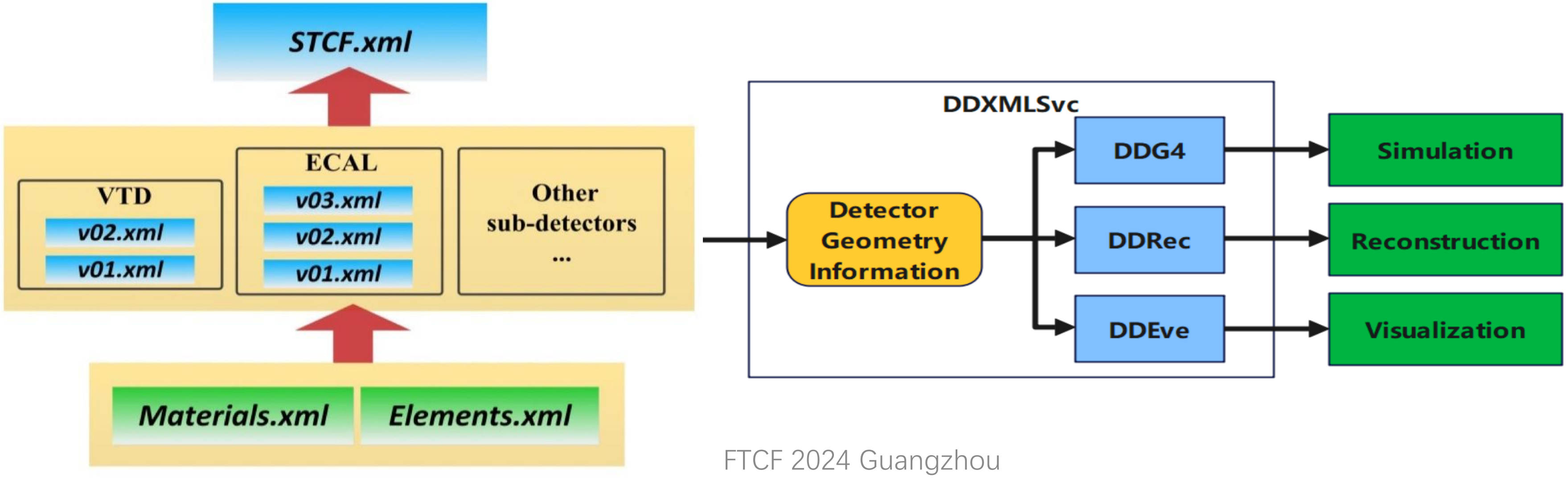
Detector Description

- The full STCF Detector is described with DD4hep
- Each sub-detector is implemented with a single compact file
- Very convenient to optimize detector geometry according to detector experts



Geometry Management System

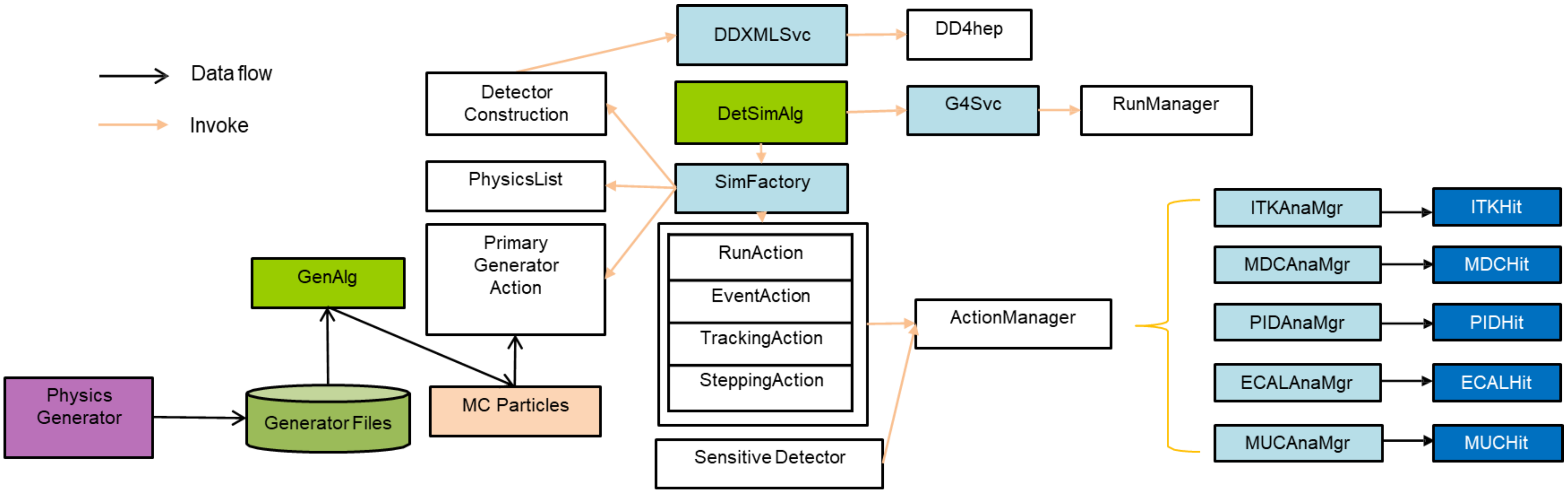
- Developed geometry management system for all applications
  - detector simulation, reconstruction and event display
  - The version number is used for different design options
- Ensure consistent detector information between different applications with a single source of detector description
  - DDG4 for delivering detector geometry to Geant4
  - DDRec for delivering detector geometry to reconstruction algorithms
  - DDXMLSvc: the unified interface to DD4hep, including DDG4 and DDRec



Detector Simulation Chain

❖ Full chain of detector simulation from generator to simulated information is built

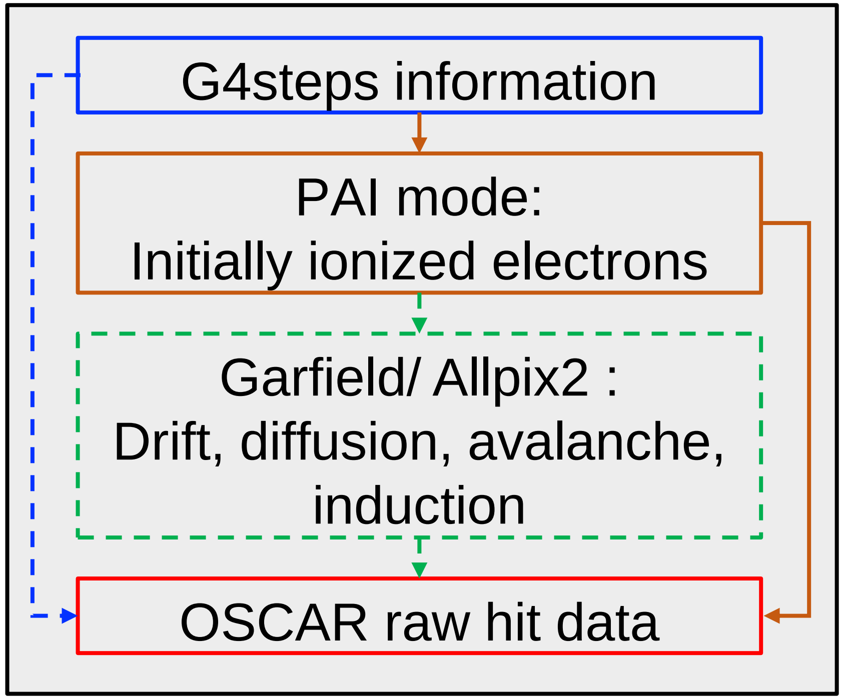
❖ Providing flexible configuration for different purposes of detector simulation
- Generator for different physics topics i.e. Babayaga, KKMC, Phokhara, DIAG36, BBBrem …
- Geometry for different detector design options
- User actions for recording MC truth information, G4Step level



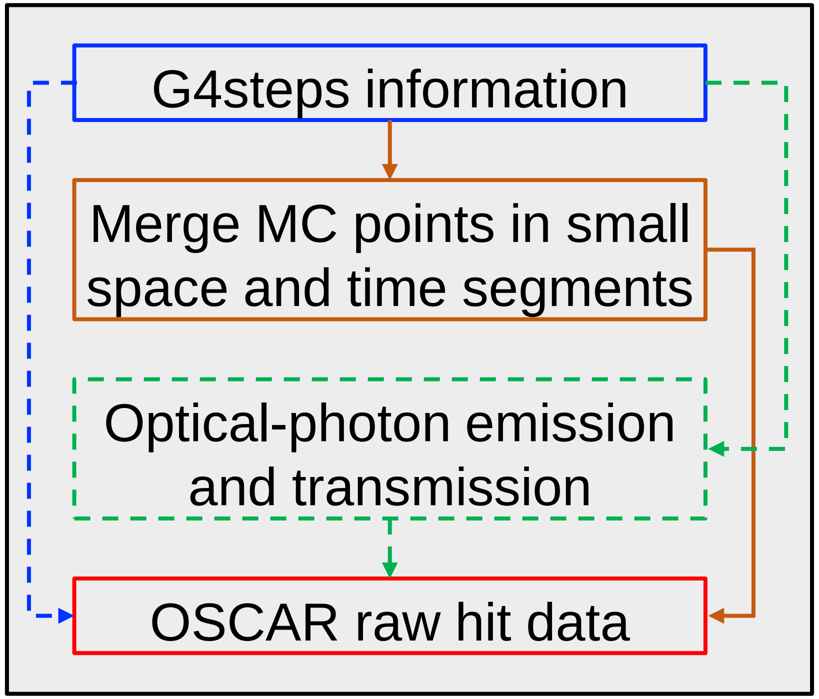
Flexible Simulation Configuration

- Configure simulation setups flexibly to balance accuracy and efficiency if need
- Some optimization setups to save the consumption of time the memory

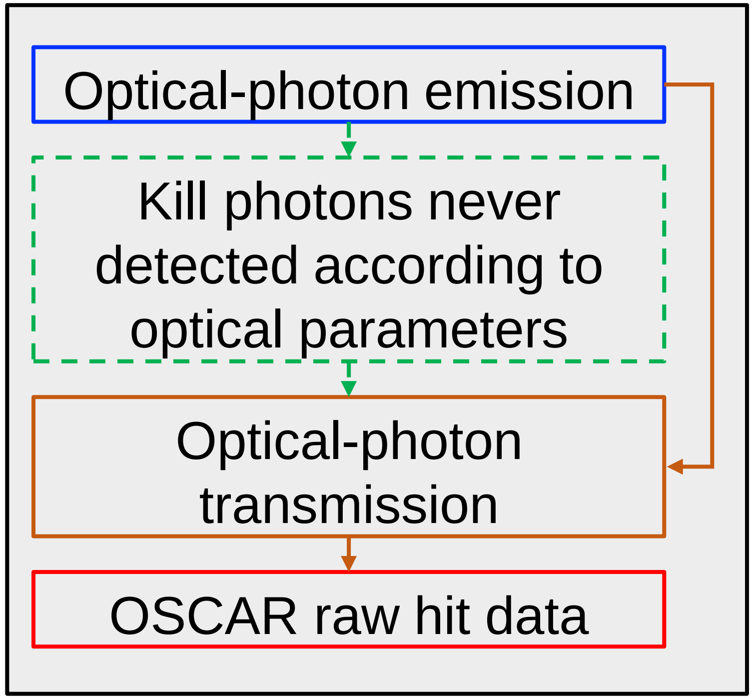
Gaseous/silicon detectors



Scintillator detectors

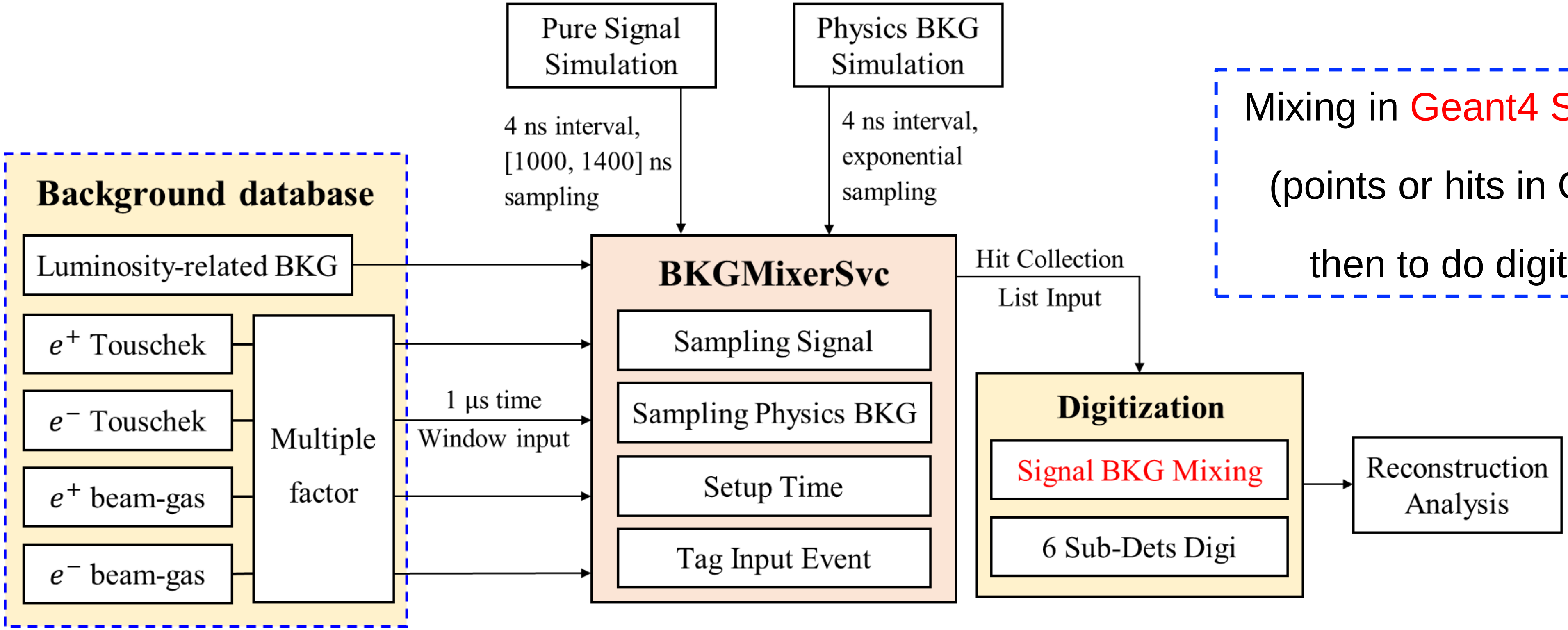


Cherenkov detectors



Moving to 'Realistic' Simulation

- Event mixing with background at the Geant4 step level
  - Simulated background particles as input, a unified algorithm applied to each sub-detector.
- Raw hit data digitized to be same as the detector measurement
  - Considering electronic response, noise and other effects, as input for reconstruction and analysis



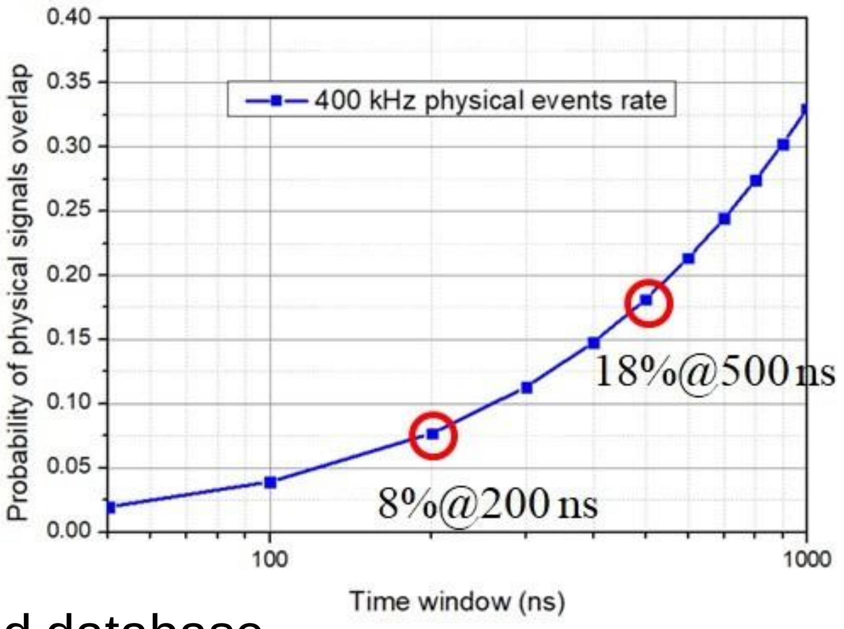
Mixing in Geant4 Step Level

(points or hits in OSCAR)

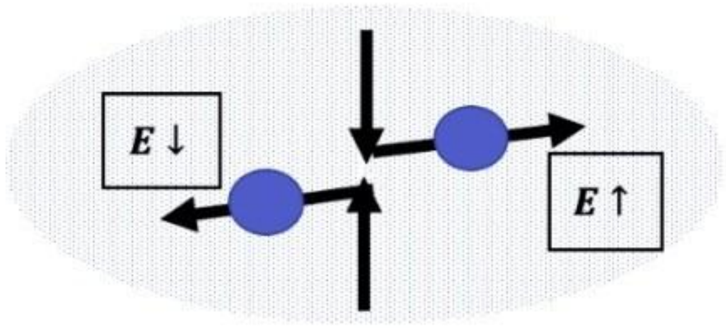
then to do digitization

Background Production

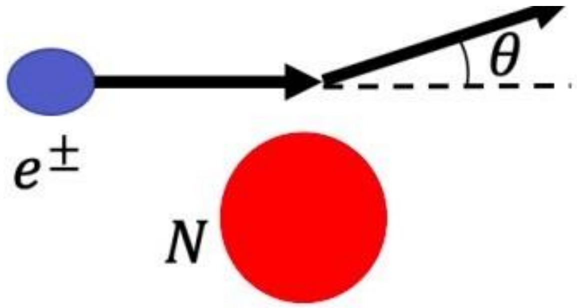
- ❖ Event pile-up: Physics Backgrounds
  - Multiple physics events can exist in one trigger window, i.e. pileup
  - Maximum event rate at STCF: 400kHz
  - Maximum time window in sub-detectors : 1 μs
  - Probability of events overlapping in1 μs: ~33%



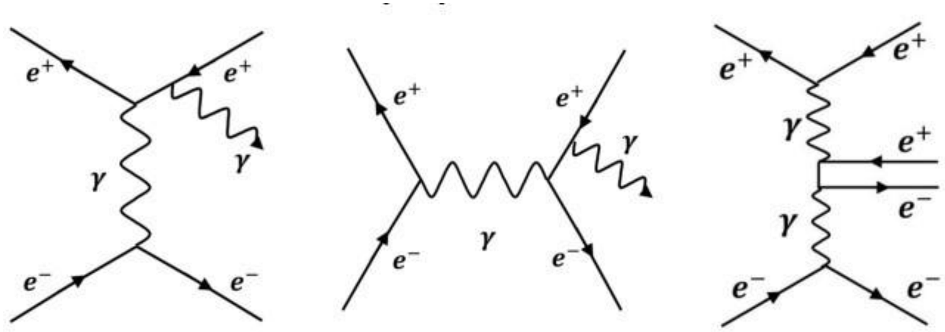
- ❖ Backgrounds: Touschek, beam-gas, luminosity-related
- ❖ Setup background simulation software and produced background database



Touschek



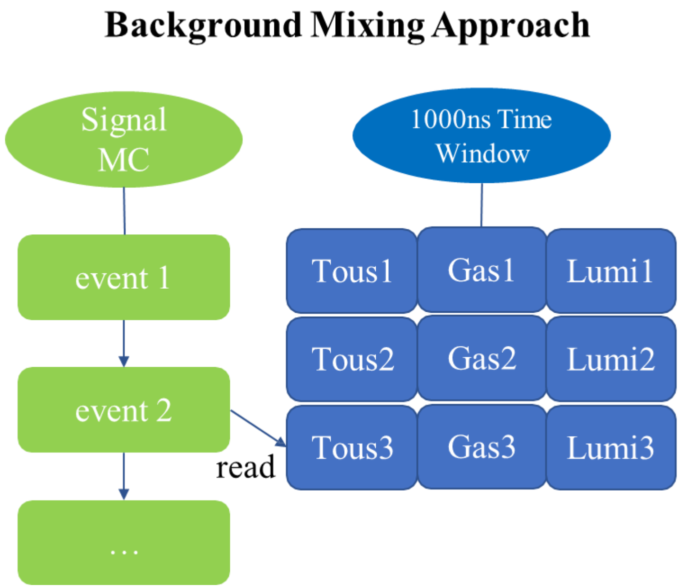
Beam-gas

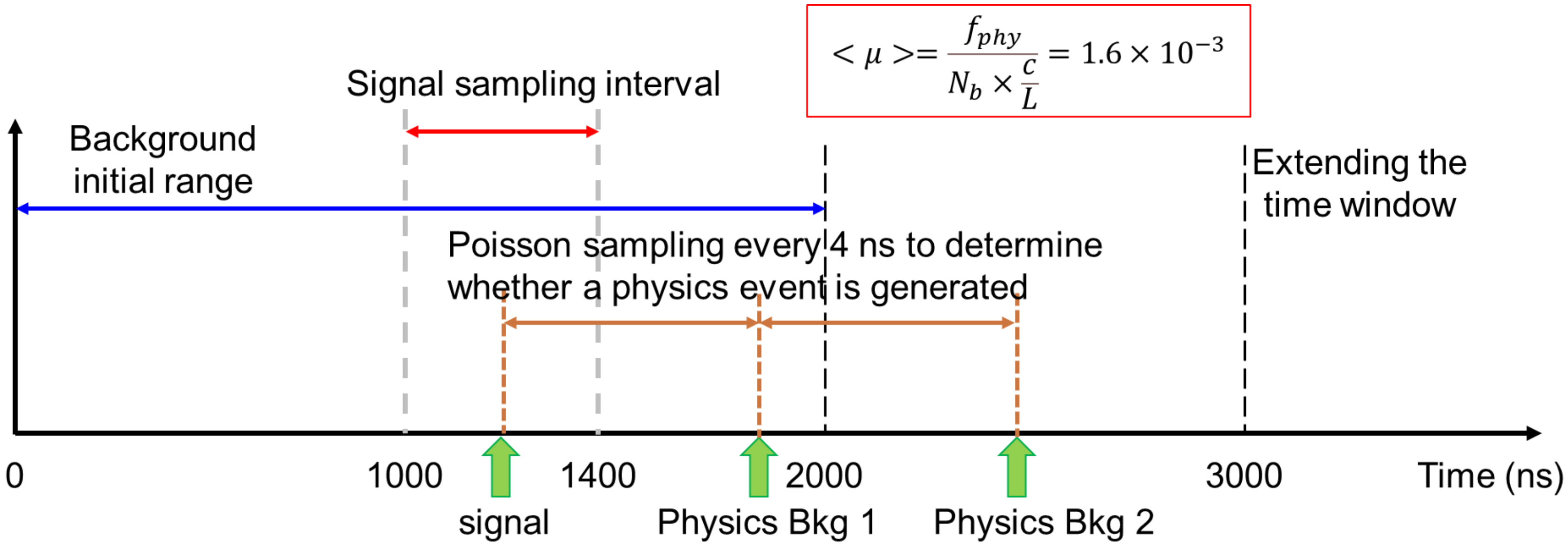


Luminosity-related

Event Mixing Algorithm

- Developed mixing algorithm based on multi-stream functions provided by OSCAR
- Providing flexible configuration for event mixing
  - Signal, e.g. $e^+e^- \to \pi^+\pi^- J/\psi(\to \mu^+\mu^-/e^+e^-)$
  - Backgrounds: Touschek, beam-gas, luminosity-related, reading from background database
  - Physics backgrounds: $e^+e^- \to anything$





Digitization

- Developed a unified digitization framework for all sub-detectors within OSCAR
- Each sub-detector implemented its digi. algorithms and produced the digi. information
- The reconstruction algorithms use the digi. information as their inputs

Gaseous/silicon detectors:

OSCAR raw hit data

↓

- Ionizing
- Electron drift & diffusion
- Avalanche
- Induced signal
- Electronics influence, transmission & noise

↓

OSCAR digi. data

Scintillator detectors:

OSCAR raw hit data

↓

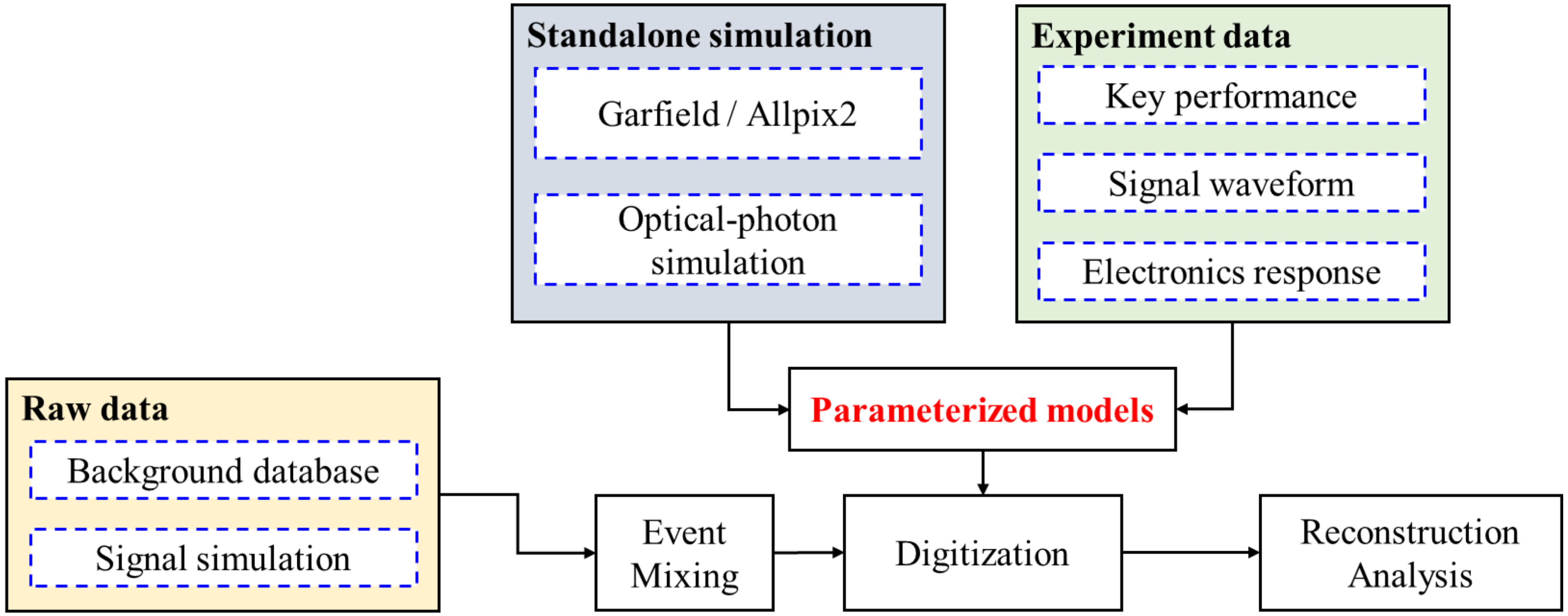
- Optical-photon emission and transmission
- Electronics effect
- Waveform generate & fitting
- Peak finding & T-Q reconstruction

↓

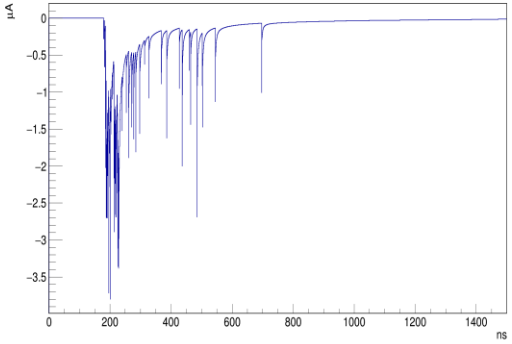
OSCAR digi. data

Parameterized Mode

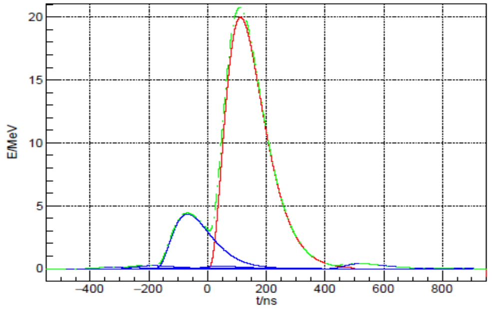
- The parameterized digi. modes for all sub-detectors are bult within OSCAR
- The digitization parameters are extracted from standalone simulation and experiment data
- Several different digi. Modes are developed, depending on the requirement of efficiency and accuracy



MDC current signal



ECAL pipeline fitting



Status of Event Mixing and Digitization

- All detectors are working, but still need improvement, keep in sync with detector R&D
- Very long time consumption (too many Bkg. hits), need optimization

Detector	Simulation	Mixing + Digitization	Reconstruction
ITKM	✓ (green)	✓ (green)	✓ (yellow)
ITKW	✓ (green)	✓ (yellow)	
MDC	✓ (green)	✓ (green)	
RICH	✓ (green)	✓ (green)	✓ (yellow)
BTOF	✓ (green)	✓ (green)	?
DTOF	✓ (green)	✓ (green)	✓ (green)
ECAL	✓ (green)	✓ (yellow)	✓ (green)
MUD	✓ (green)	✓ (yellow)	✓ (yellow)

✓ (green) Stable and Optimizable ✓ (yellow) Working, need optimization
? Developing or Not started

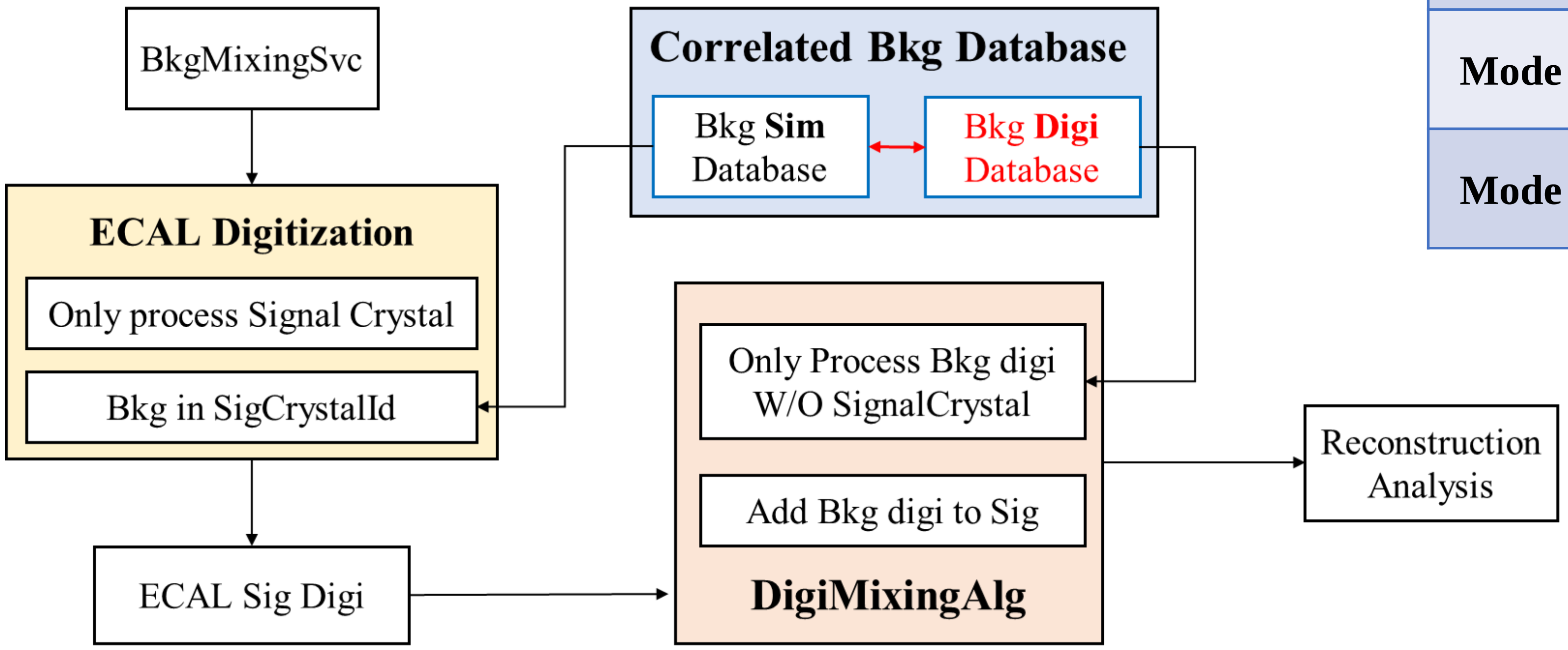
100 $\psi(2S) \to \pi^+\pi^- J/\psi(\to \mu^+\mu^-)$ events
Mixing and digitization time consumption

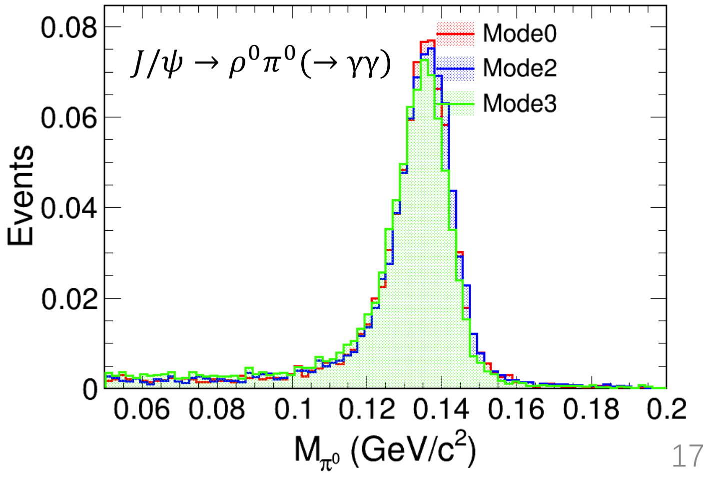
Detector	Time w/o Bkg (s)	Time With Bkg (s)
ITKM	~3	59
ITKW	~1	6
MDC	~2	35
RICH	<1	~1
DTOF	<1	~1
ECAL	23	1475
MUD	<1	~1
All Detector	24	1488

Another Mixing Framework

- Some or all hits mixing in digi. hit level, pre-digitize the Bkg raw hit to produce a Bkg digi. Database
- One order of magnitude time savings, with no significant performance degradation
- The mixing algorithms in digi. hit level is developing, need balance precision and efficiency

Mode 0	• Mixing + digi.
Mode 1	• Sig. and Bkg just add digi. hit
Mode 2	• Crystals with Sig, Mixing + digi. • Bkg. just add digi. hit
Mode 3	• Crystals with Sig, Mixing + digi. • Bkg, mixing in digi. hit level





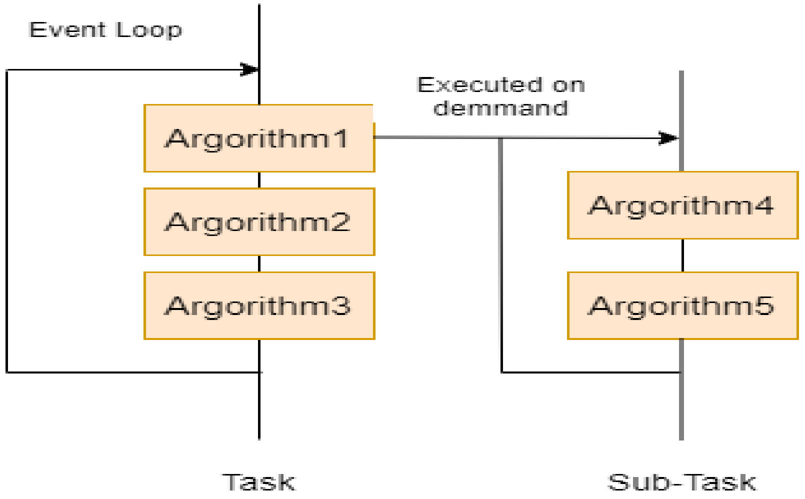
Summary

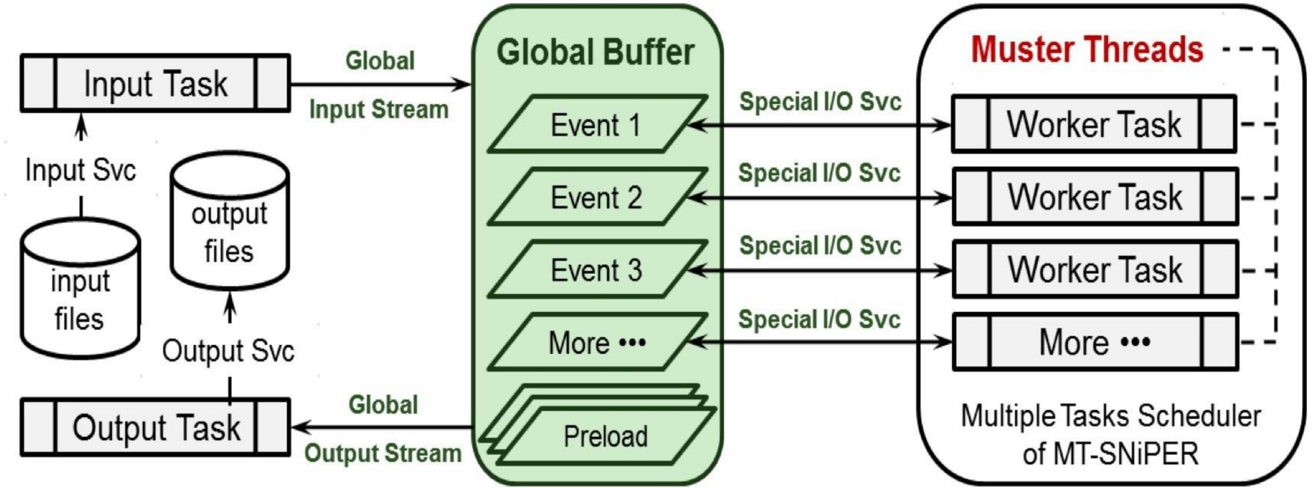
- STCF is an important and unique platform for probing physics at τ-charm sector
- Full chain of detector simulation and digitization has been built within the STCF offline software system (OSCAR)
  - The framework of simulation, event mixing and digitization is built, and all detectors are working now
  - Digitization information after event mixing has been as inputs for recon. Algorithms
  - We are developing the Mixing framework in digi. hit level to balance precision and efficiency
- Future plan
  - Optimization of digi. parameters and algorithms, keep in sync with detector R&D
  - Focusing on improving OSCAR's computing performance to meet high luminosity requirements

BACKUP

Underlying framework: SNiPER

- Developed since 2012, very lightweight and flexible, supporting both non-collider experiments and collider experiments
- Providing basic functions of event loop control, application interface, job configuration, logging etc.
- Providing simple interfaces for building multi-threaded applications, thus supporting both serial and parallel event processing with extension of SNiPER, Muster
- Adopted by JUNO (neutrino), LHAASO (cosmic ray), nEXO (neutrinoless double beta decay) and HERD (dark matter)





Event Data Model (EDM) and Serial Event Data Management

- Very crucial and taking significant effect on performance of the event processing
- Developed STCF EDM based on podio, which is also adopted by EDM4hep
  - Define event data and relationship between data object in YAML file
  - Re-use MCParticle and ReconstructedParticle from EDM4hep as the core index
  - Good support for multithreading
- Extended SNiPER data management system based on podio