中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

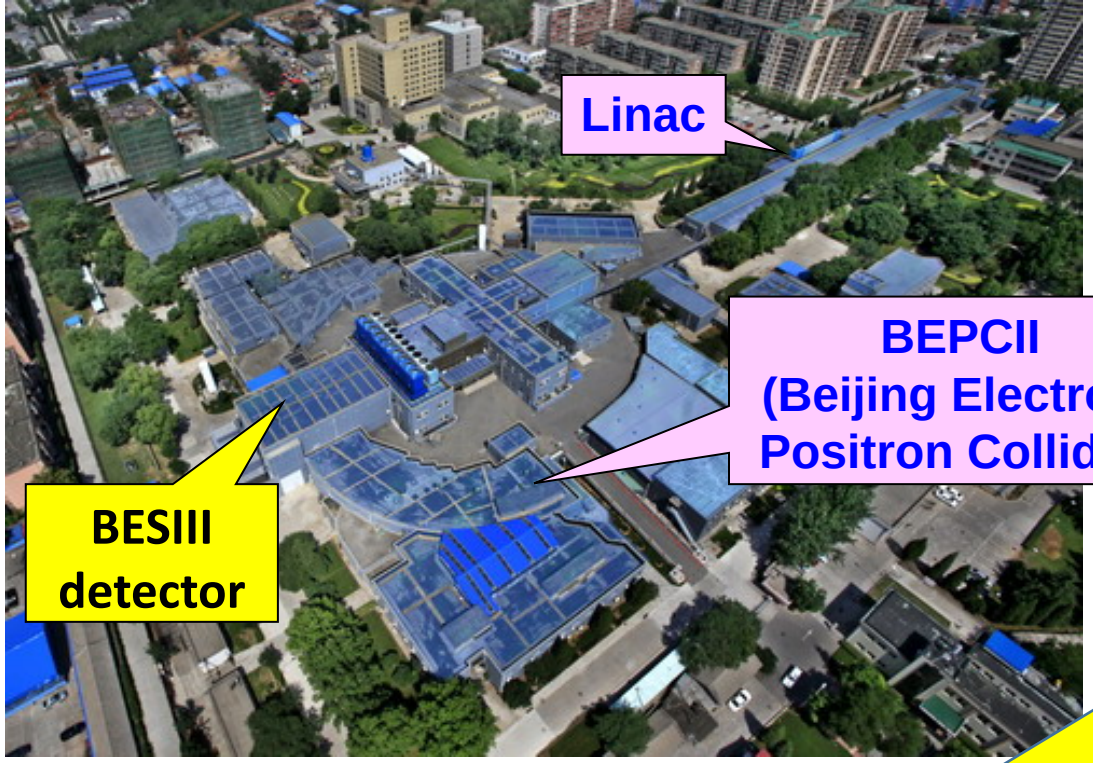
BESIII

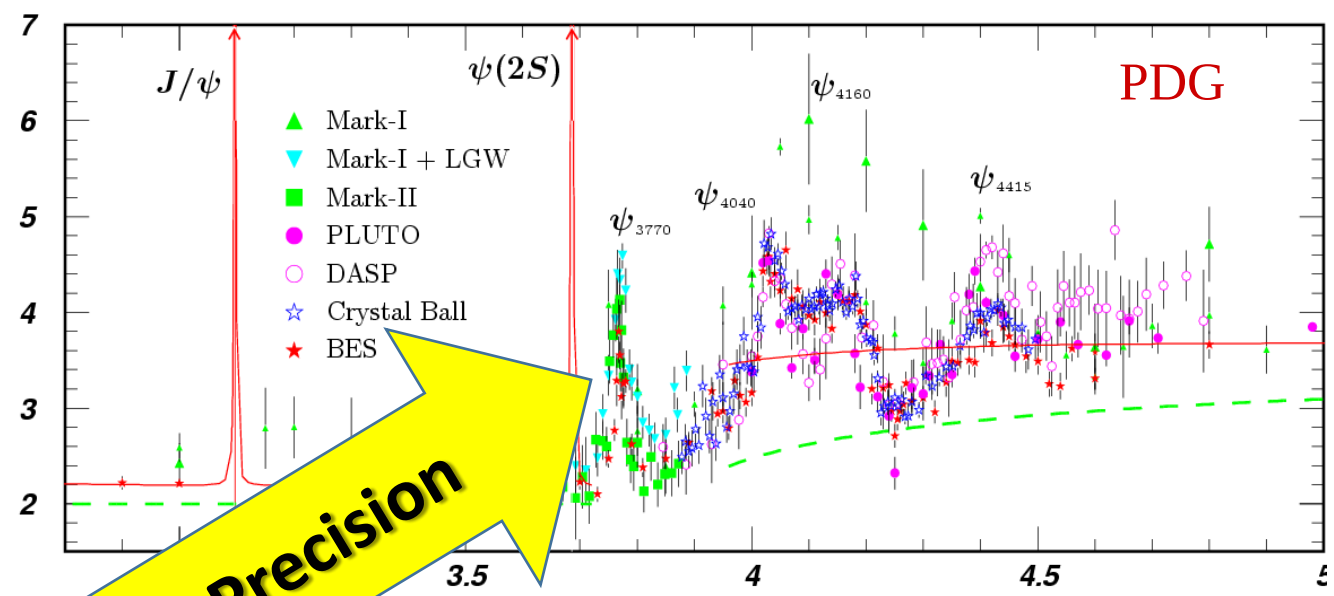
BESIII Software and Computing and Upgrade

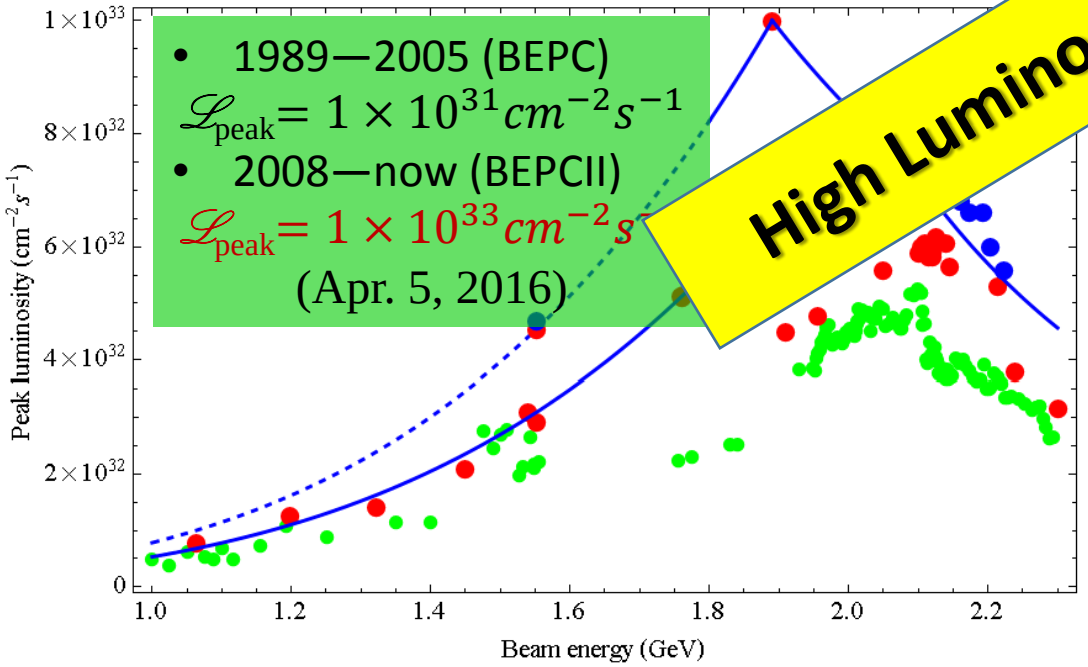
Sun Shengsen

Symposium on 30 years of BES Physics

Beijing, September 6, 2019



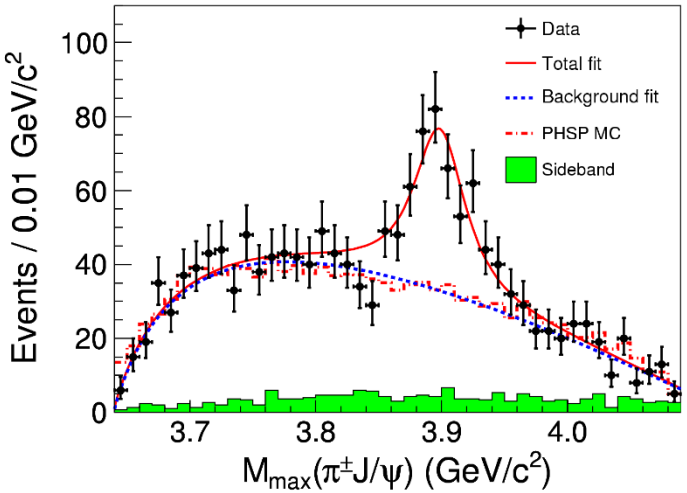


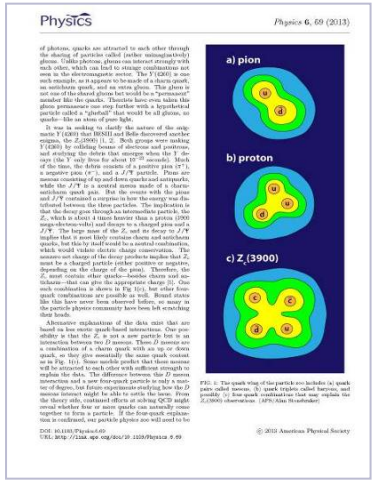


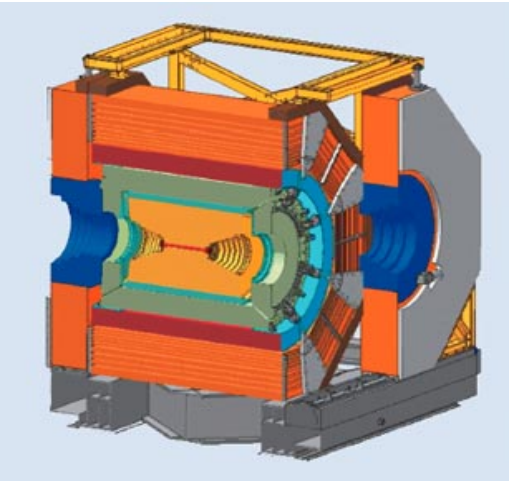
High Luminosity ➔ High Precision

- R…ances: charmonia and charmed mesons
- …old characteristics (pairs of τ, D, D_s, …)
- …ansition between smooth and resonances, perturbative and non-perturbative QCD
- Energy location of the new hadrons: glueballs, hybrids, multi-quark states

Big Data Challenges
BESIII Software and Computing



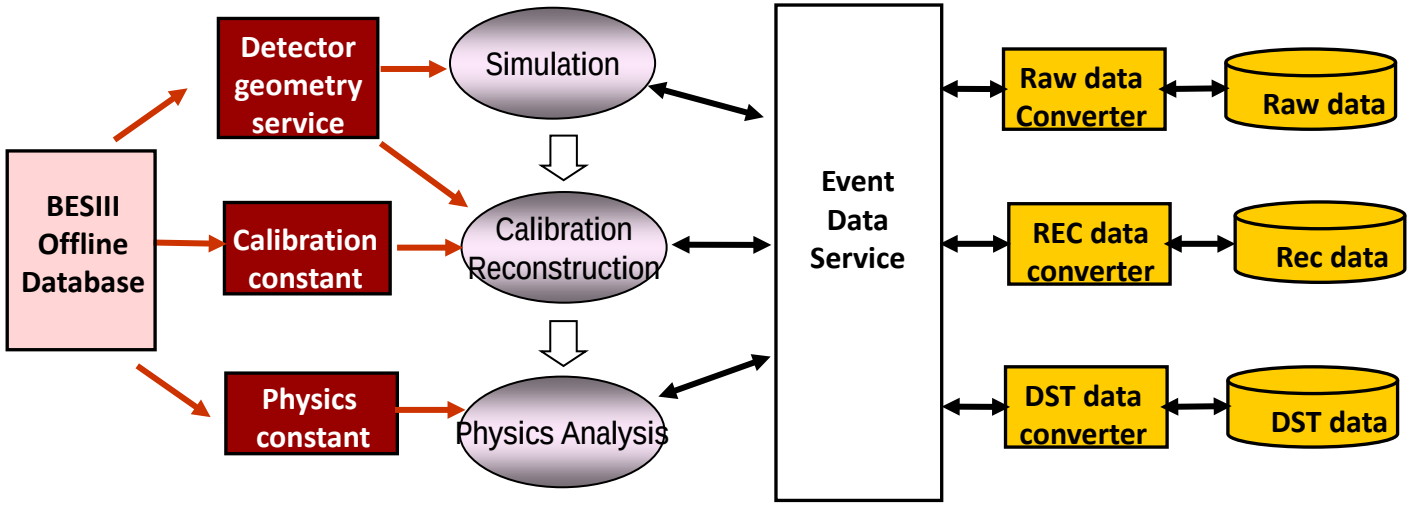




- Data-Flow Processing Framework
- Physics Generator
- Detector Simulation
- Event Reconstruction / Calibration
- Data Analysis Toolkit
- Visualisation
- Data Organization, Management and Access
- Facilities and Distributed Computing

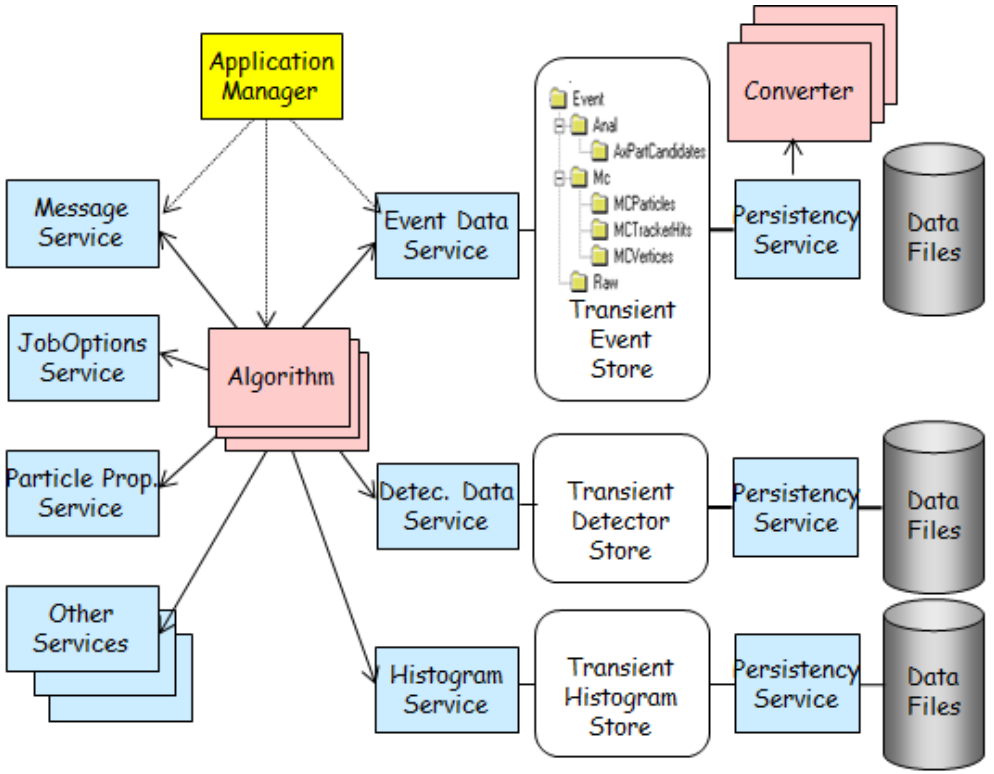
BESIII Offline Software System (BOSS)

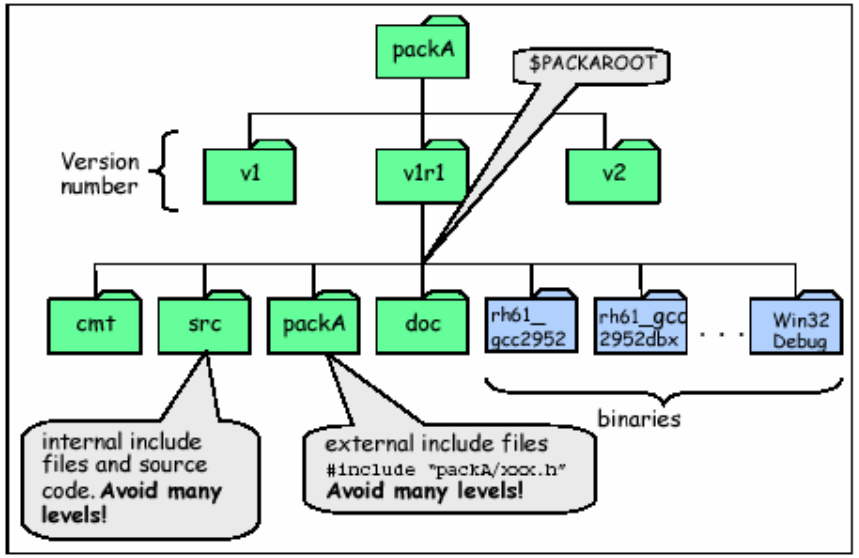
- BESIII offline software system (BOSS), is an offline data processing software system which is developed based on GAUDI framework.
- External Libs: Geant4, ROOT, GDML, MySQL, ……
- Operation System: Scientific Linux 6, GCC 4.6.3
- Simulation, reconstruction/calibration, and data analysis algorithms are core software for data processing and physics analysis, software framework provides event data service and constants data service



GAUDI Framework & Software Configuration Management

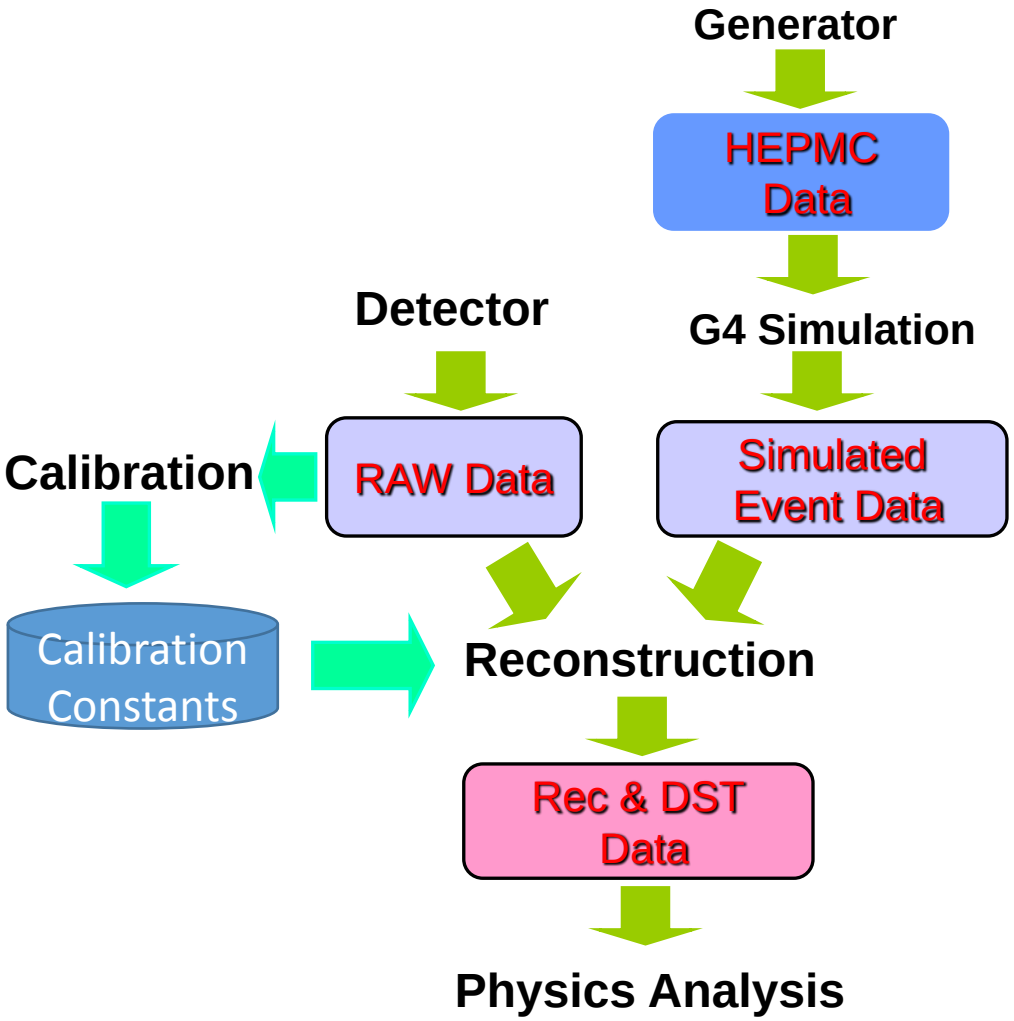
- GAUDI is adopted as the software framework — a skeleton of an application into which developers plug in their code and provides most of the common functionality.
- Clear separation between "algorithms" (key components) and "data" ("persistent data" and "transient data")





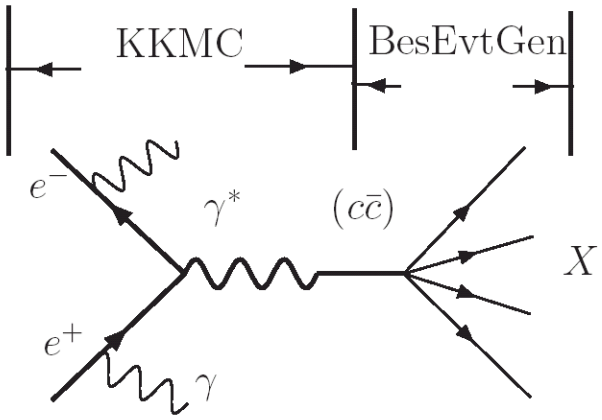
- CMT (Configuration Management Tool)
- Structure software development (concepts of areas, packages, versions, constituents)
- Operates the software production (management, build, import/export, etc…)

Offline Data Processing



- HEPMC Data: Kinematic information
- **RAW Data**
  - Delivered by DAQ
  - Byte stream format
- **Simulated Event Data**
  - Contain digits, hits and other MC truth information
  - Ascii file format
- **REC & DST Data**
  - Reconstructed data is event data
  - DST data is reduced event representation suitable for analysis
  - Both in ROOT format

Physics Generator

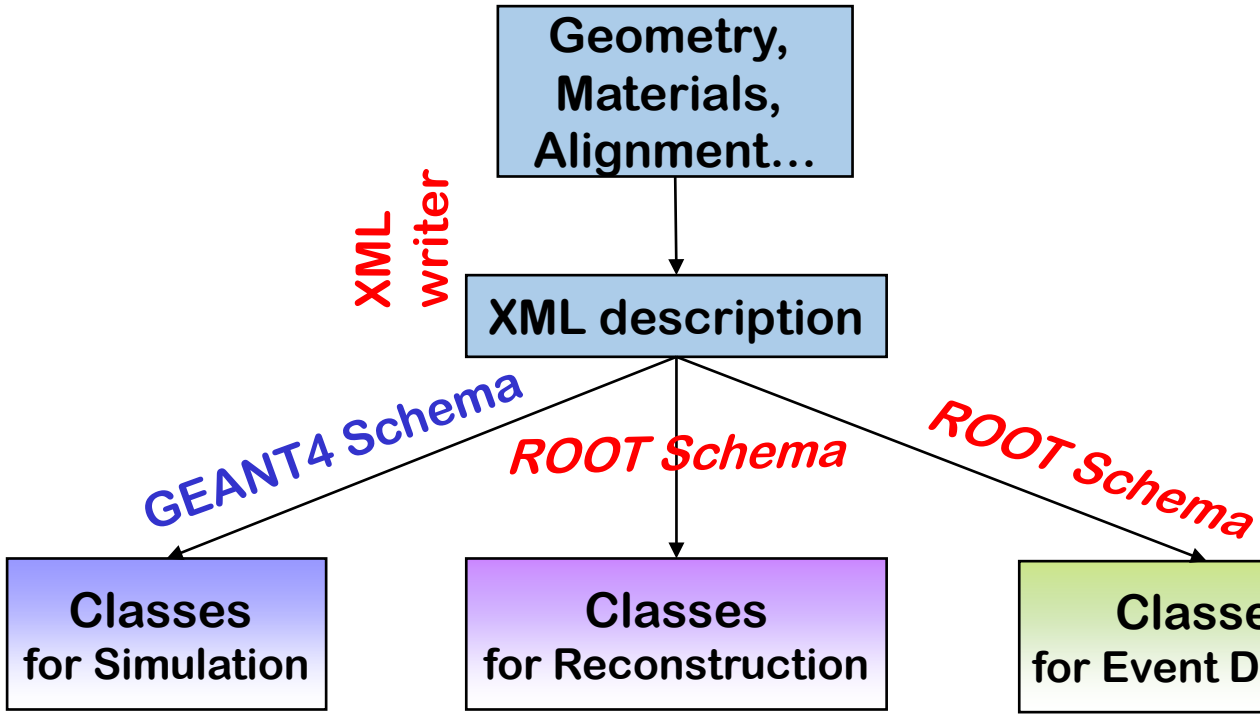


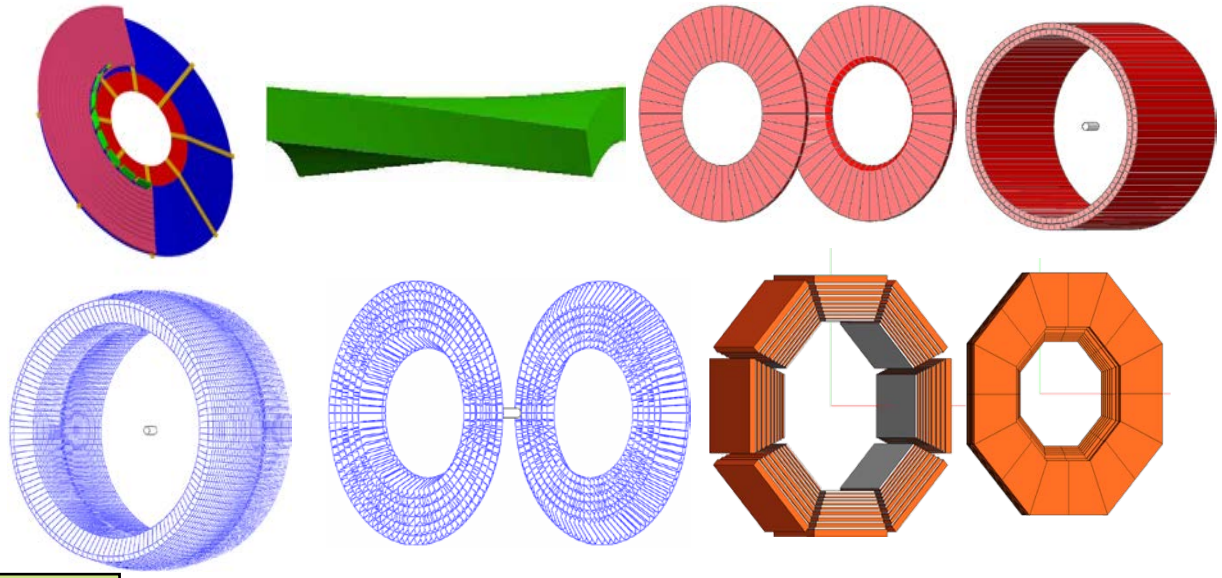
- Simulation = Physics Generator + Detector Simulation
- Charmonium decay process
  - KKMC+BesEvtGen: charmonium decay events
    - KKMC: e^+e^-annihilate, Initial state radiation process (ISR) and Beam energy spread
    - BesEvtGen: charmonium decays, final state radiation (FSR)
  - PYTHIA: Lundcharm — unknown decays
  - PHOTOS: estimate the size of the QED bremsstrahlung
- QED process
  - Bhlumi/Bhwide
  - Babayaga
  - Phokahara
  - Twogam
- Cosmic Ray

Detector Simulation

Detector Description

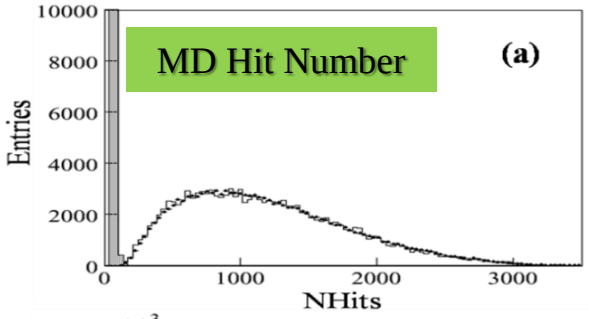
- Based GDML (Geometry Description Markup Language), a kind of XML developed by GEANT4 group.
- Accurate detector description of a series of irregular and complex structure is realized.
- A uniform geometric data service is developed based on GDML format.

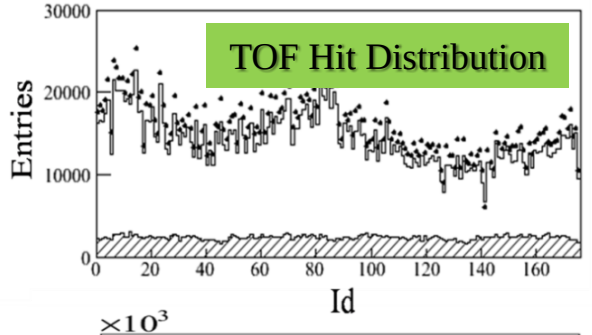


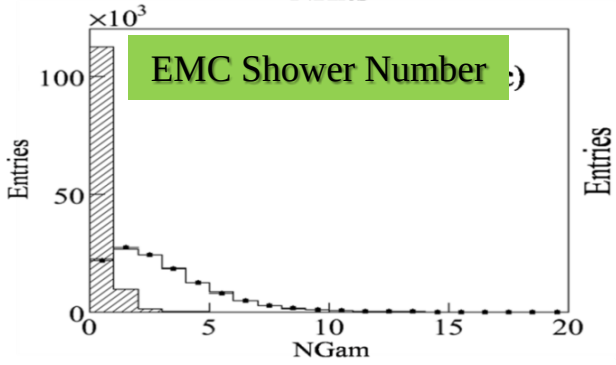


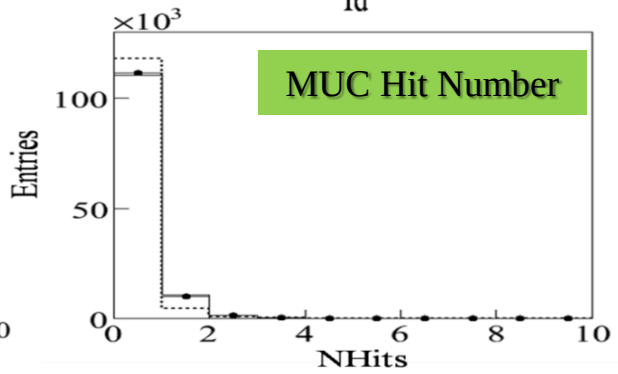
Detector Simulation

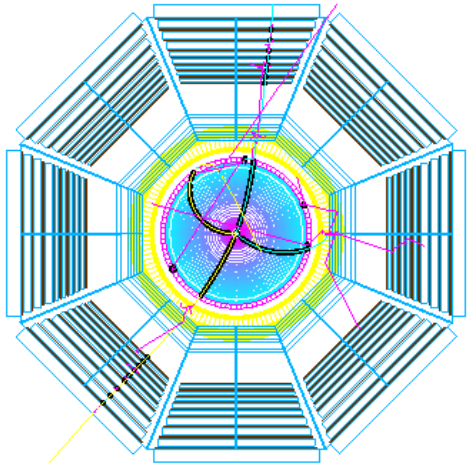
- BOOST (BESIII Objected Oriented Simulation Tool)
- Digitization
- Realization: mixing rangdon trigger
- MC Tuning



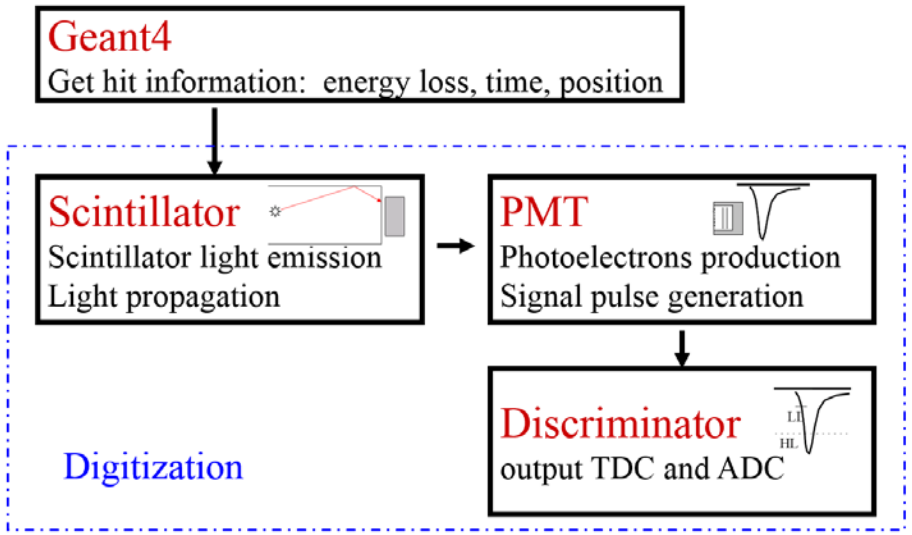






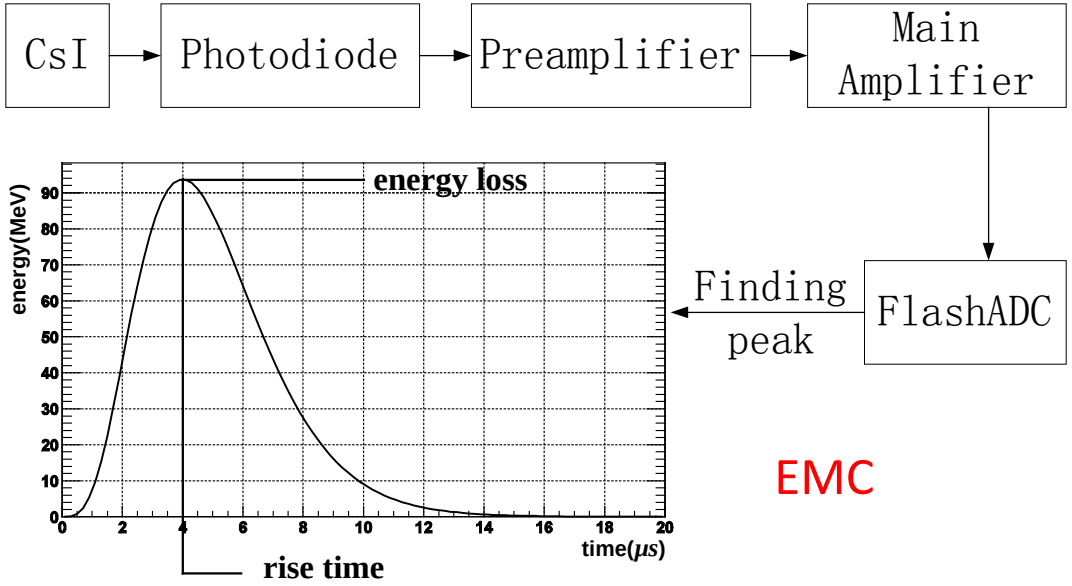


$\psi' \to \pi^+\pi^- J/\psi \to \pi^+\pi^-\mu^+\mu^-$



TOF

Developed parameterized fast simulation model



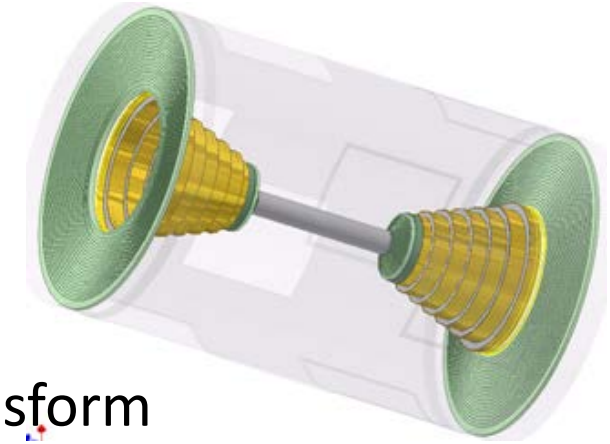
EMC

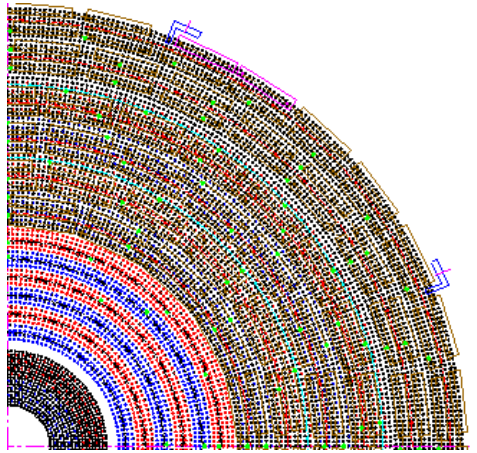
Readout electronics simulation for EMC

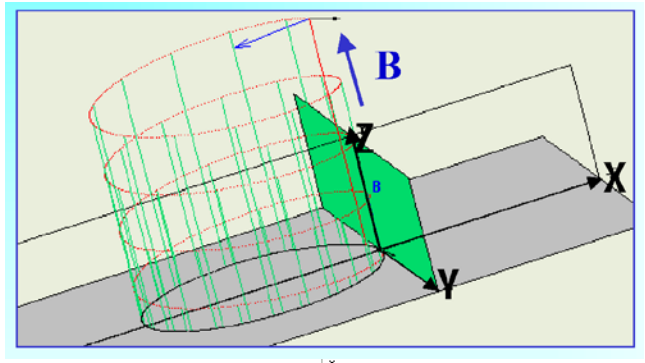
Event Reconstruction

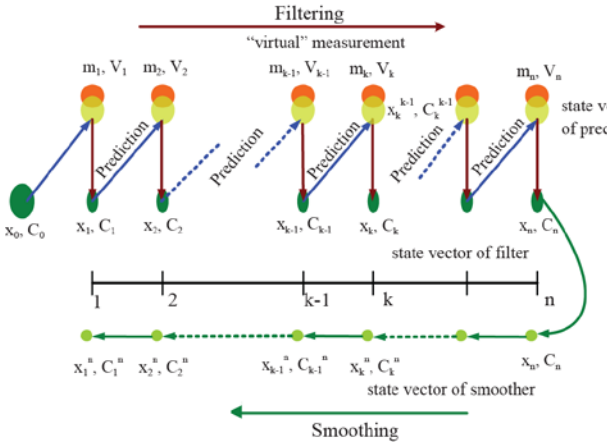
- MDC Reconstruction
- Track finding
  - TrkReco Segment Finding: Conformal Transform
  - MdcPatRec Segment Finding: Pattern matching
- Track fitting: least square method
- Kalman filter method

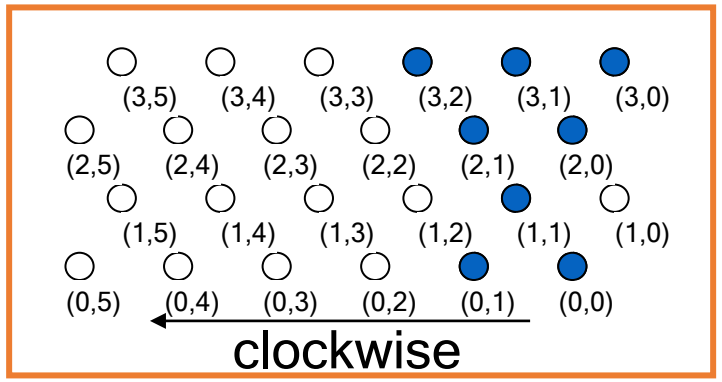
  Recursive least squares estimation

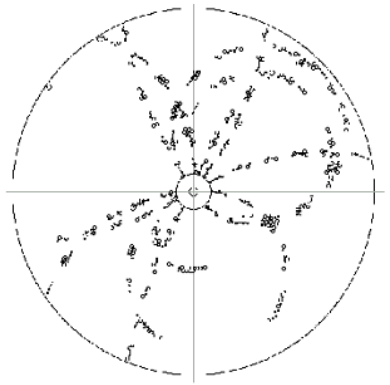


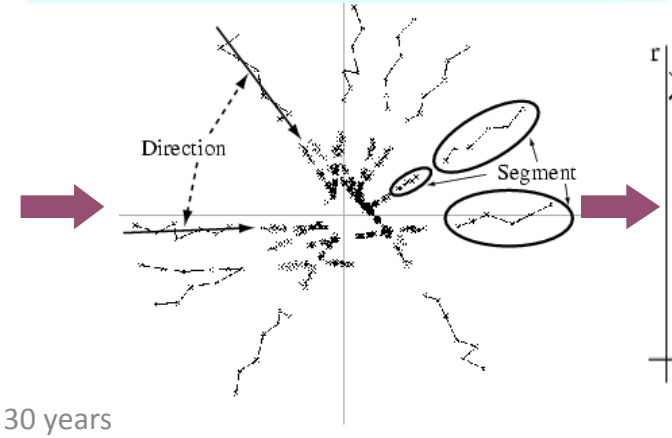


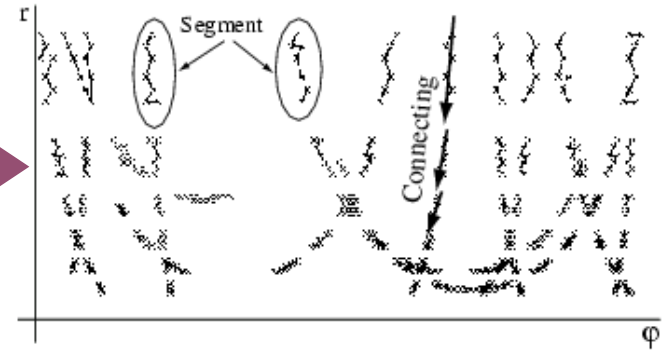






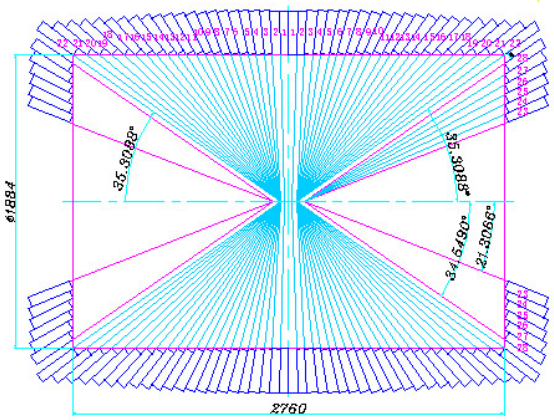


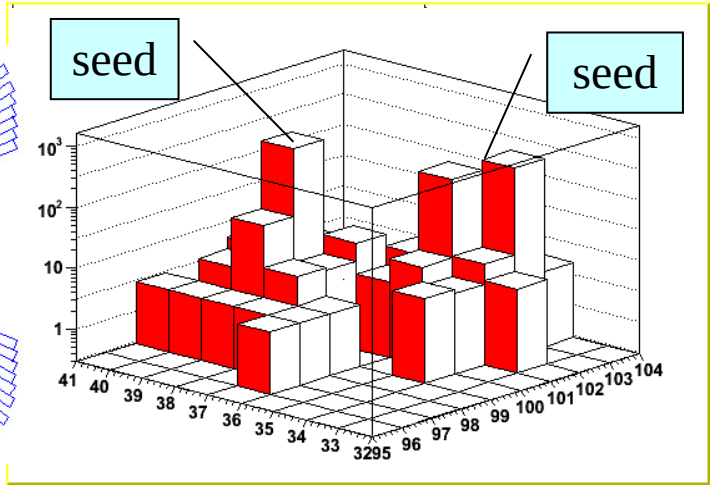


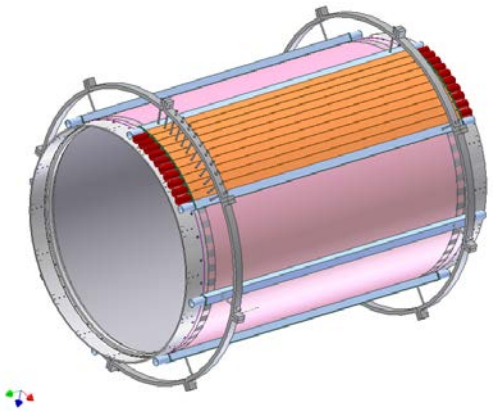


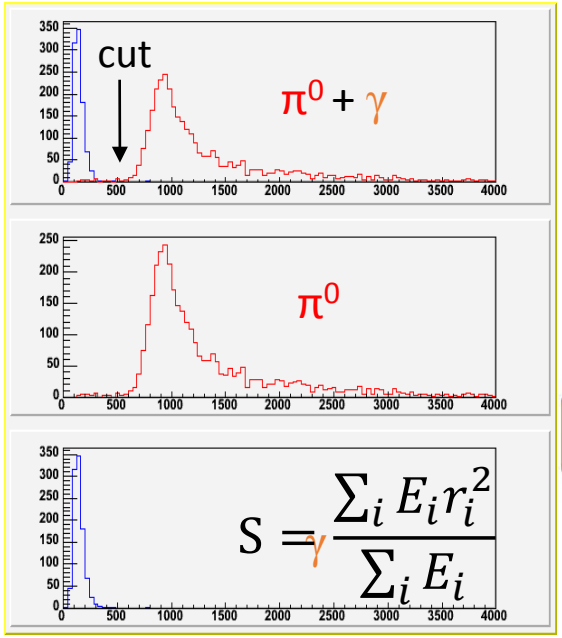
Event Reconstruction

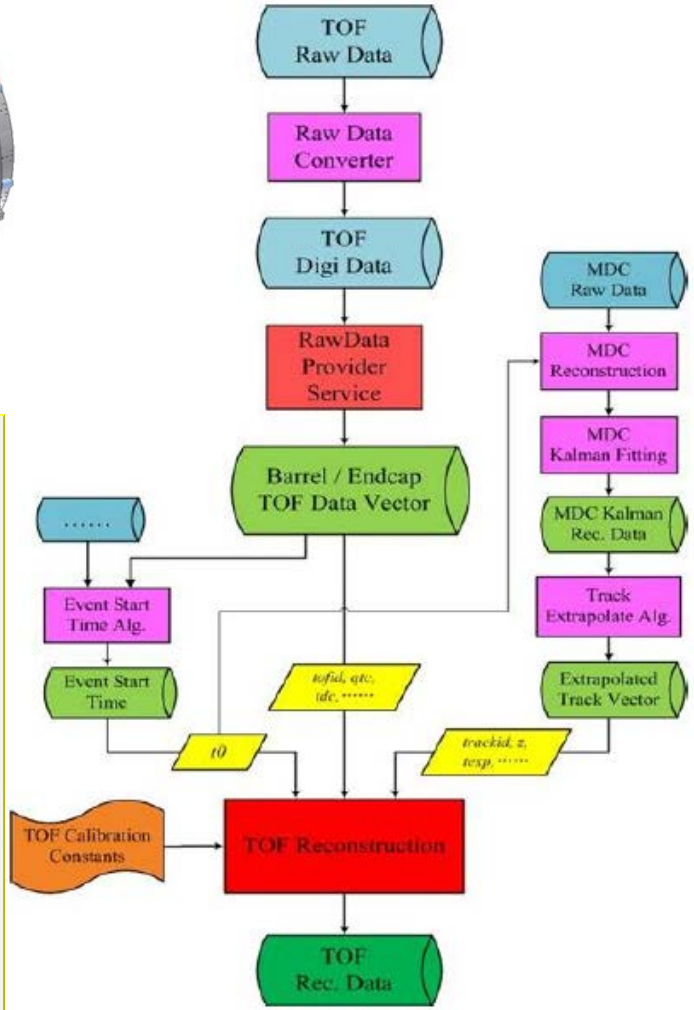
- TOF Reconstruction
  - T-Q match
  - Track-TOF signal match
- EMC Reconstruction
  - Cluster finding
  - Cluster splitting
- MUC Reconstruction





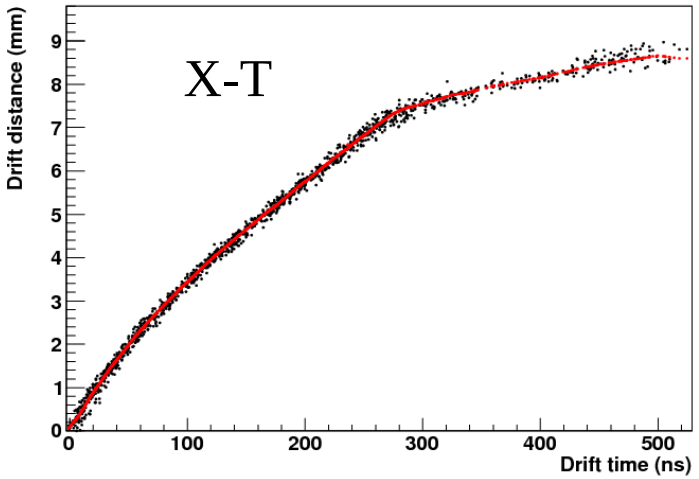


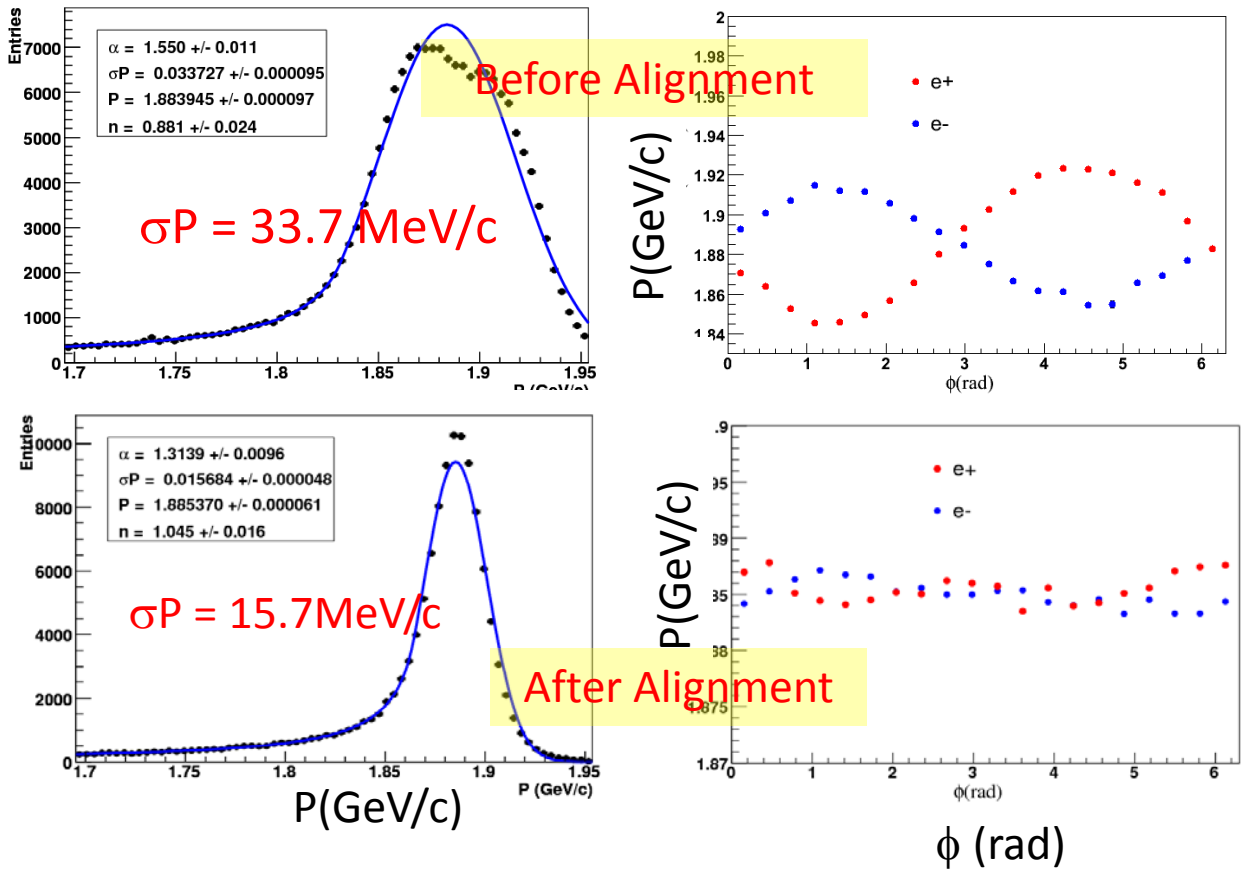




Calibration

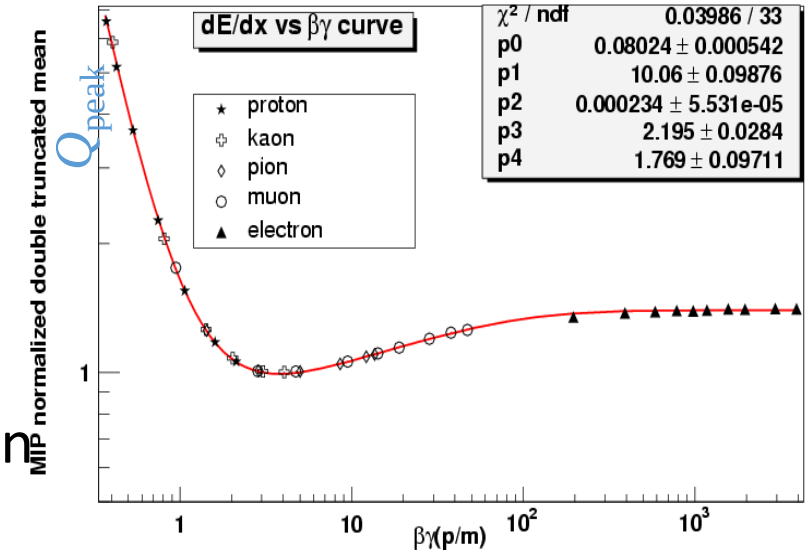
- MDC Calibration
  - Residual
  - Drift time and distant
  - Wire position, t0, propagation
  - Time walk effect
- Alignment





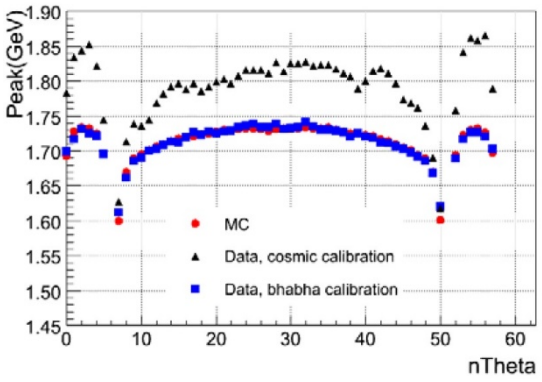
Calibration

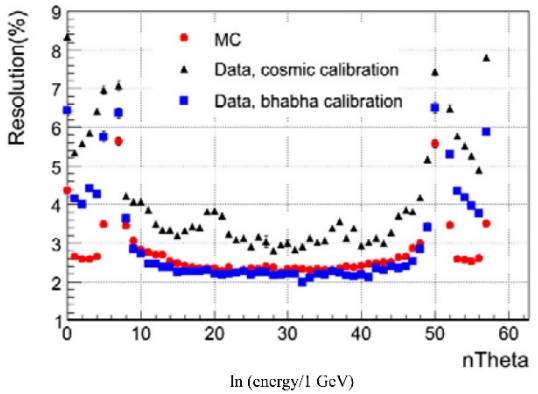
- dE/dx calibration
  - Track path length
  - Single wire gain and run/atmospheric pressure gain
  - Non-uniformity of charge collection
  - Space-charge effect
- TOF calibration
  - Time walk effect
- EMC calibration
  - Energy calibration of detection unit
  - Absolute photon energy calibration



$$t_{cor} = P_0 + \frac{P_1 + P_2 \times z}{\sqrt{Q}} + \frac{P_3}{Q} + P_4 \times z + P_5 \times z^2 + P_6 \times z^3$$

$$\chi^2 = \sum_{k=1}^{N} \frac{E_{exp}^{k} - \sum_i^{5\times5} g_i \cdot E_i^{elec}}{\sigma(\theta, \phi)}$$





BESIII Detector Performance

Exps.	MDC Spatial resolution	MDC dE/dx resolution	EMC Energy resolution
CLEOc	110 μm	5%	2.2-2.4 %
Babar	125 μm	7%	2.67 %
Belle	130 μm	5.6%	2.2 %
BESIII	115 μm	<5% (Bhabha)	2.4%

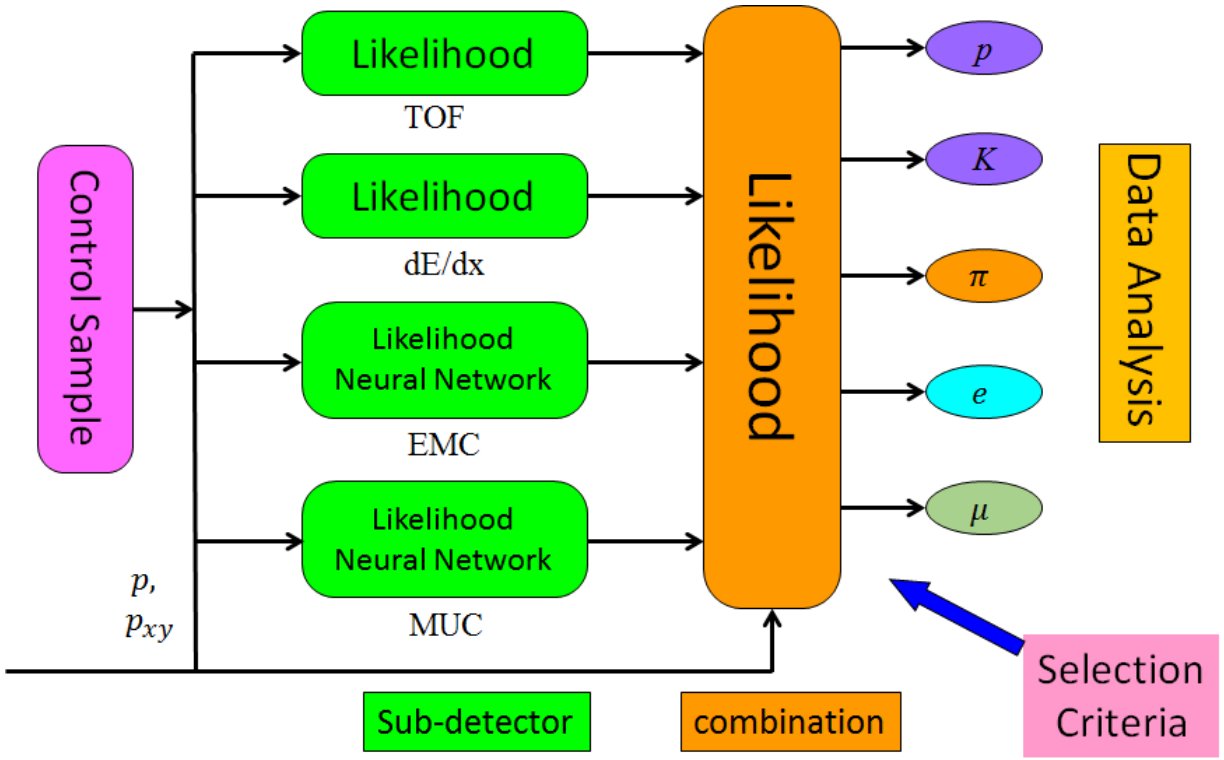
Exps.	TOF Time resolution
CDFII	100 ps
Belle	90 ps
BESIII	68 ps (BTOF) 60 ps (ETOF)

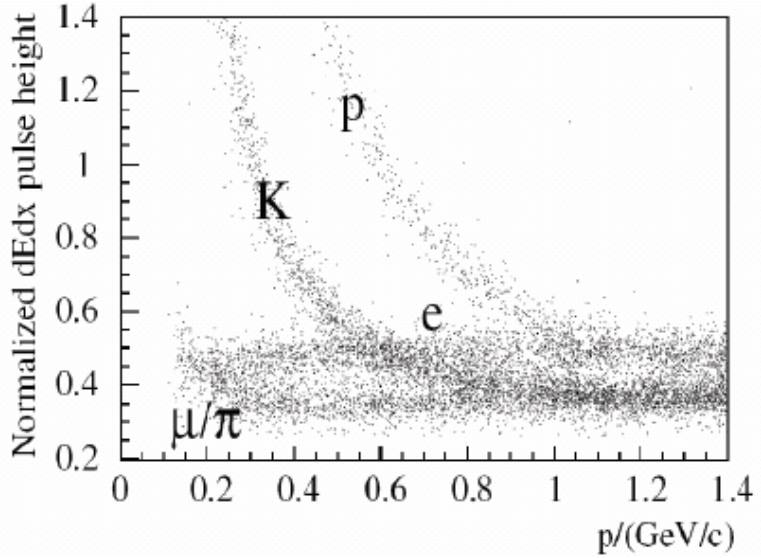
MUC: Efficiency ~ 96%

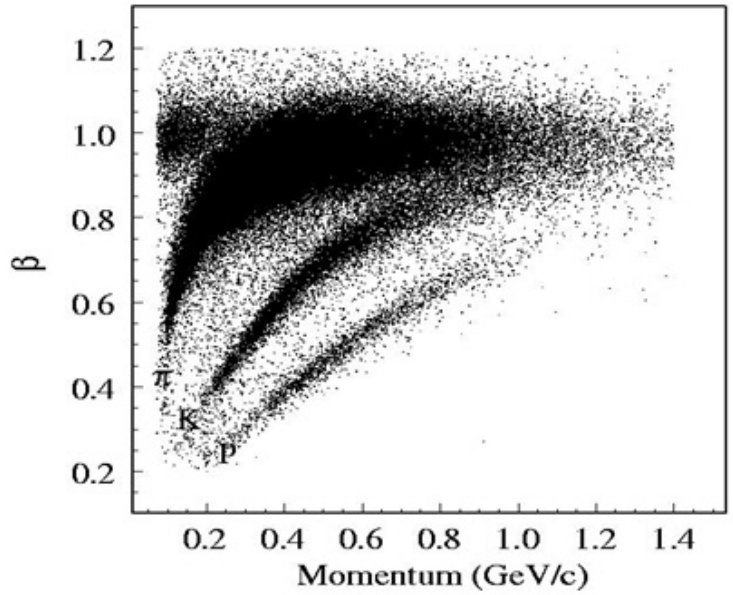
BG level: < 0.04 Hz/cm^2(B-MUC), < 0.1 Hz/cm^2(E-MUC)

Data Analysis Toolkit
Particle Identification

- Particle identification combine TOF information, dE/dx measurements, energy deposits in the EMC, and MUC information.

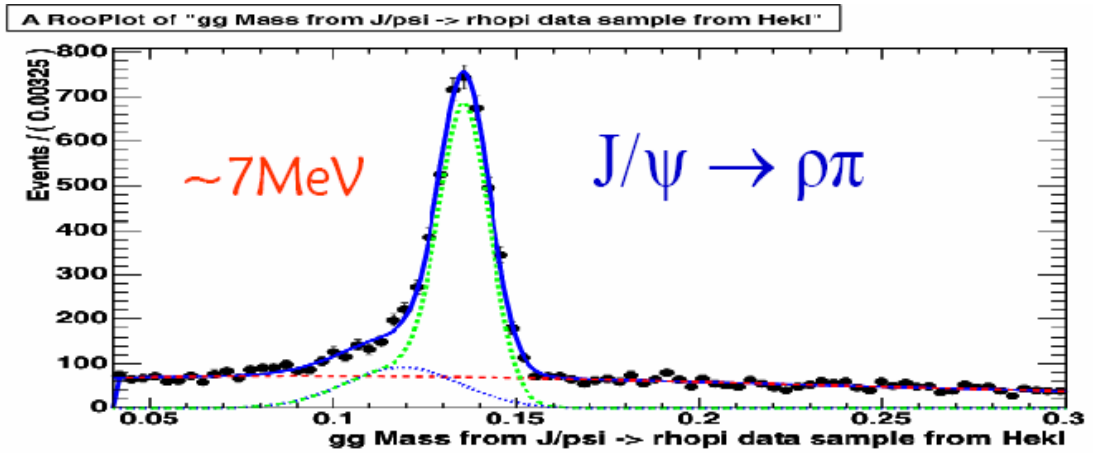


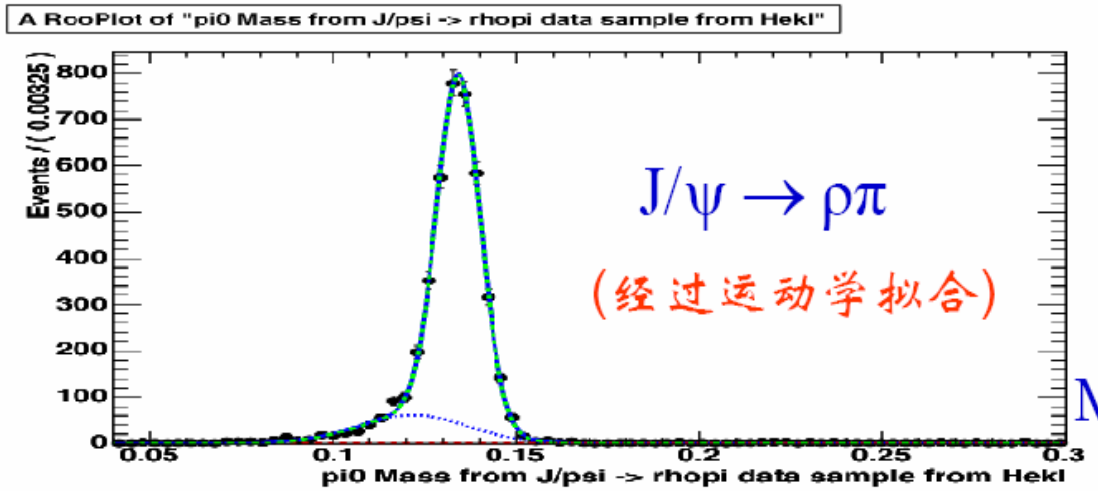




Data Analysis Toolkit
Kinematic Fit and Vertex Fit

- Physics laws are employed to constraint the interaction or decay process to improve the accuracy of measurements.
- Kinematic Fit: Lagrange multiplier method has been implemented.
- Vertex Fit: Kalman filter method and global least squares method, improve the precision and suppress the background.





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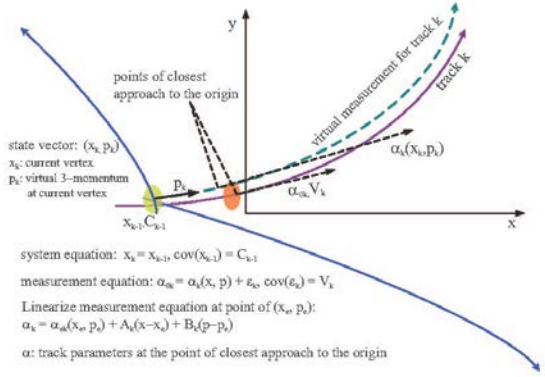
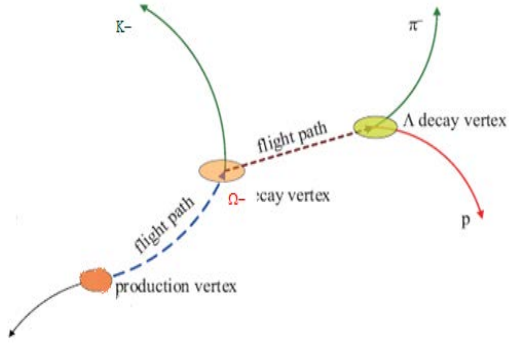
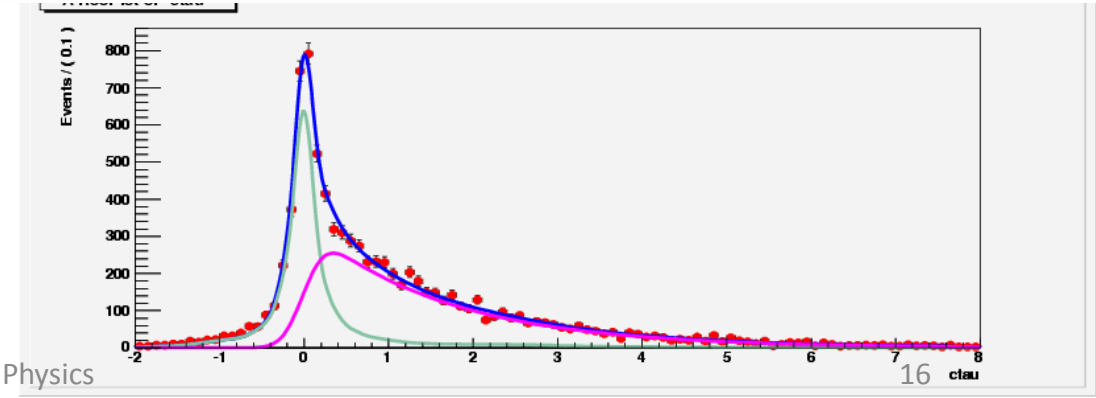
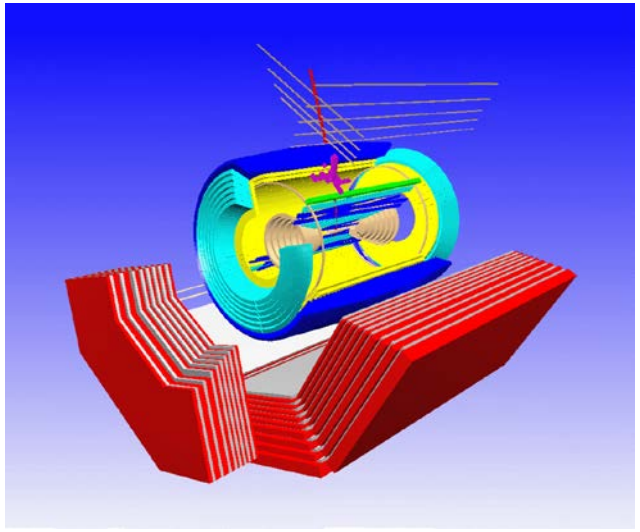
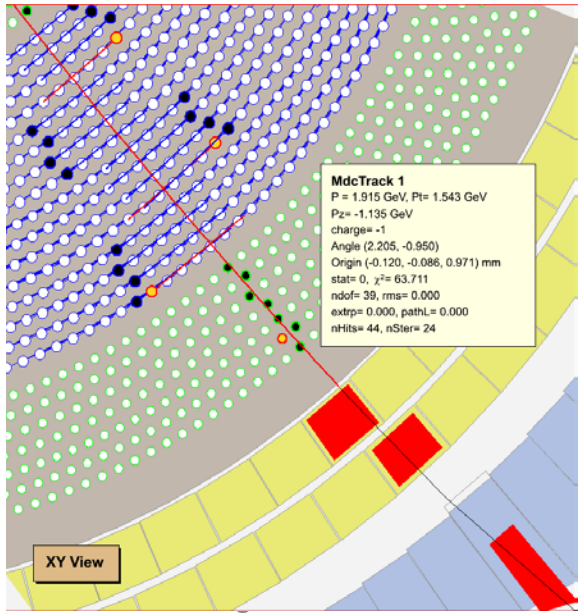


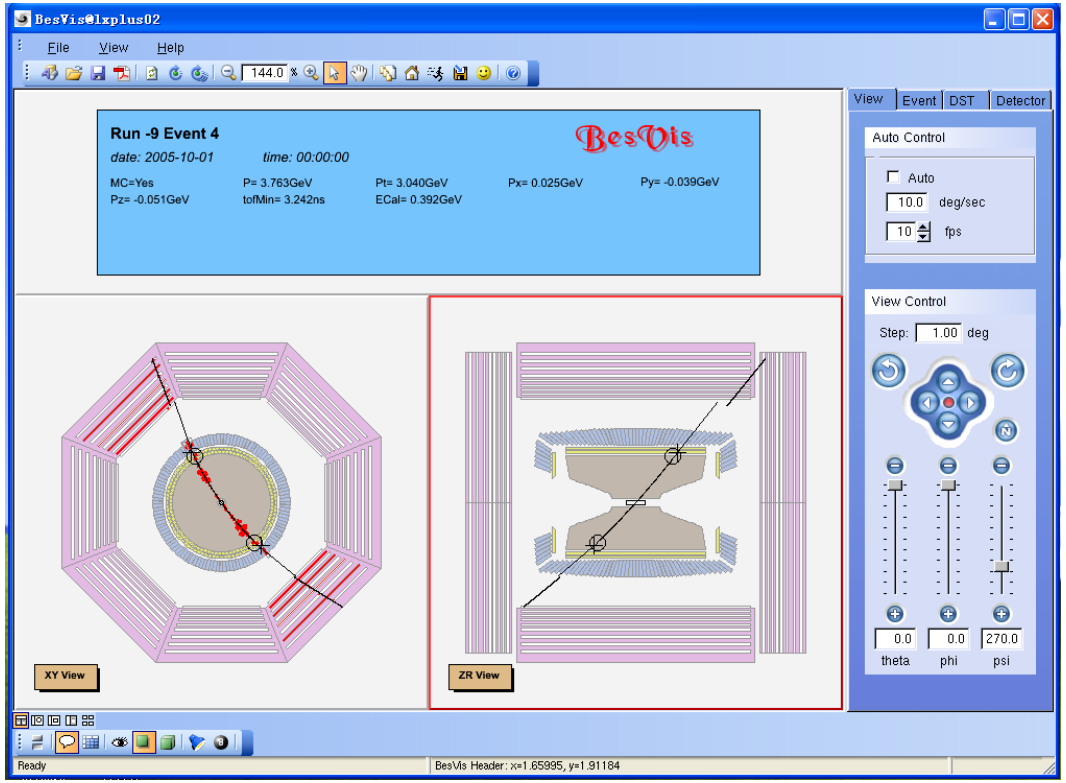


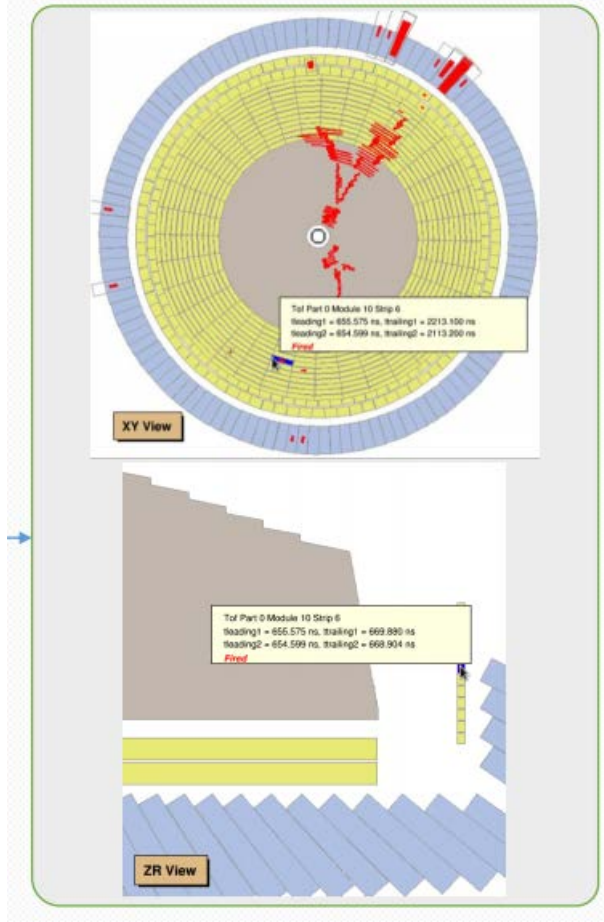


Visualisation









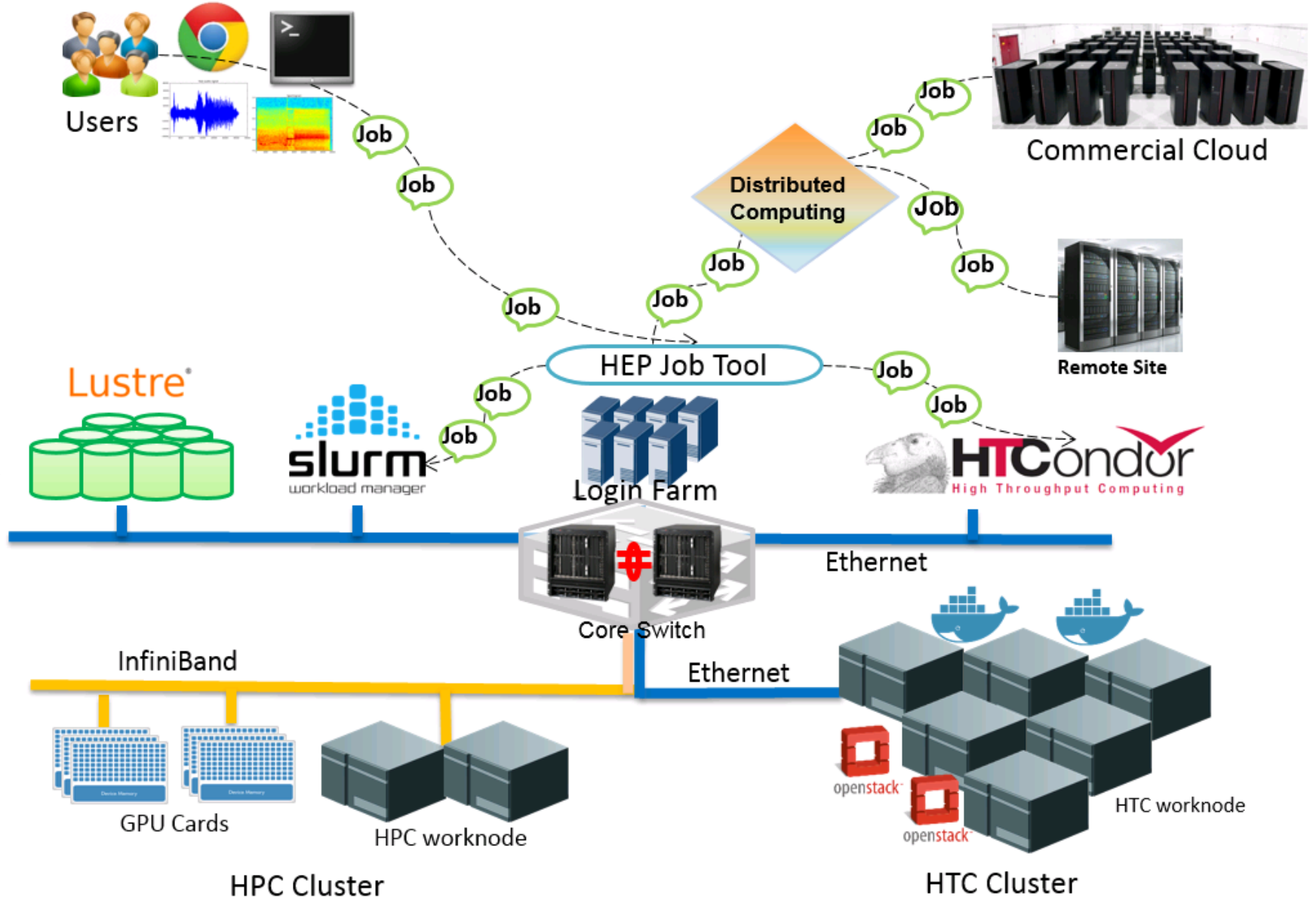
- Event displays are the main tool to explore experimental data at the event level and to visualize the detector.
- Detector development, monitoring, event generation, reconstruction, detector simulation, data analysis, as well as outreach and education.

Computing Platform for BESIII Data Process

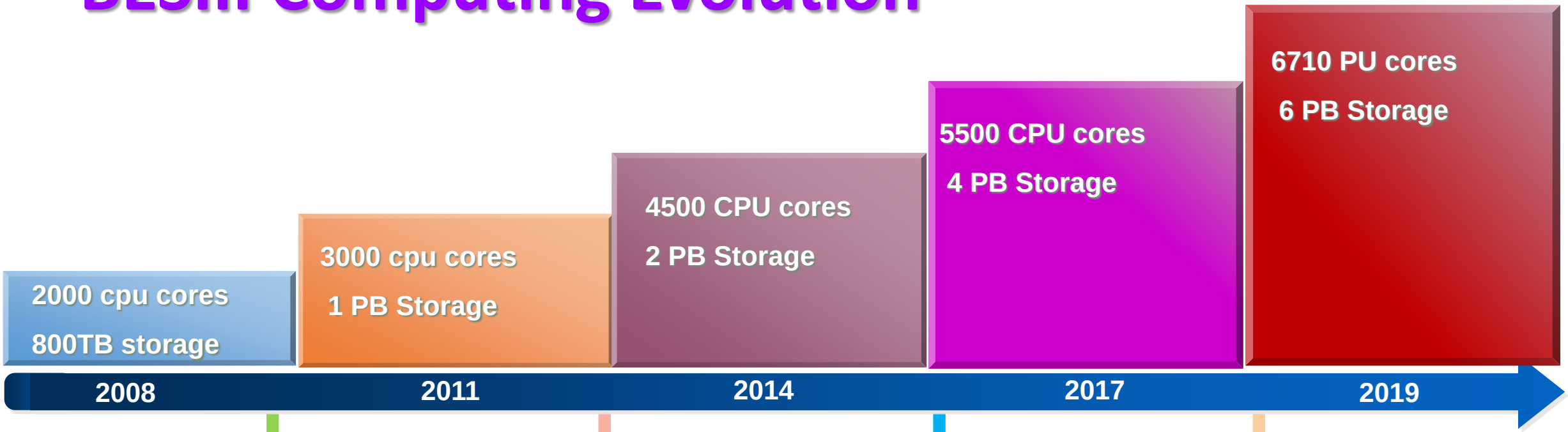
Computing

Storage

Network



BESIII Computing Evolution



Network

10Gb Ethernet for computing network
1Gb for internet

Distributed Computing

Distributed Computing for BESIII created. 18 sites with 3500 cpu cores

Virtual Computing

Virtual Platform Published with 2000 cpu cores

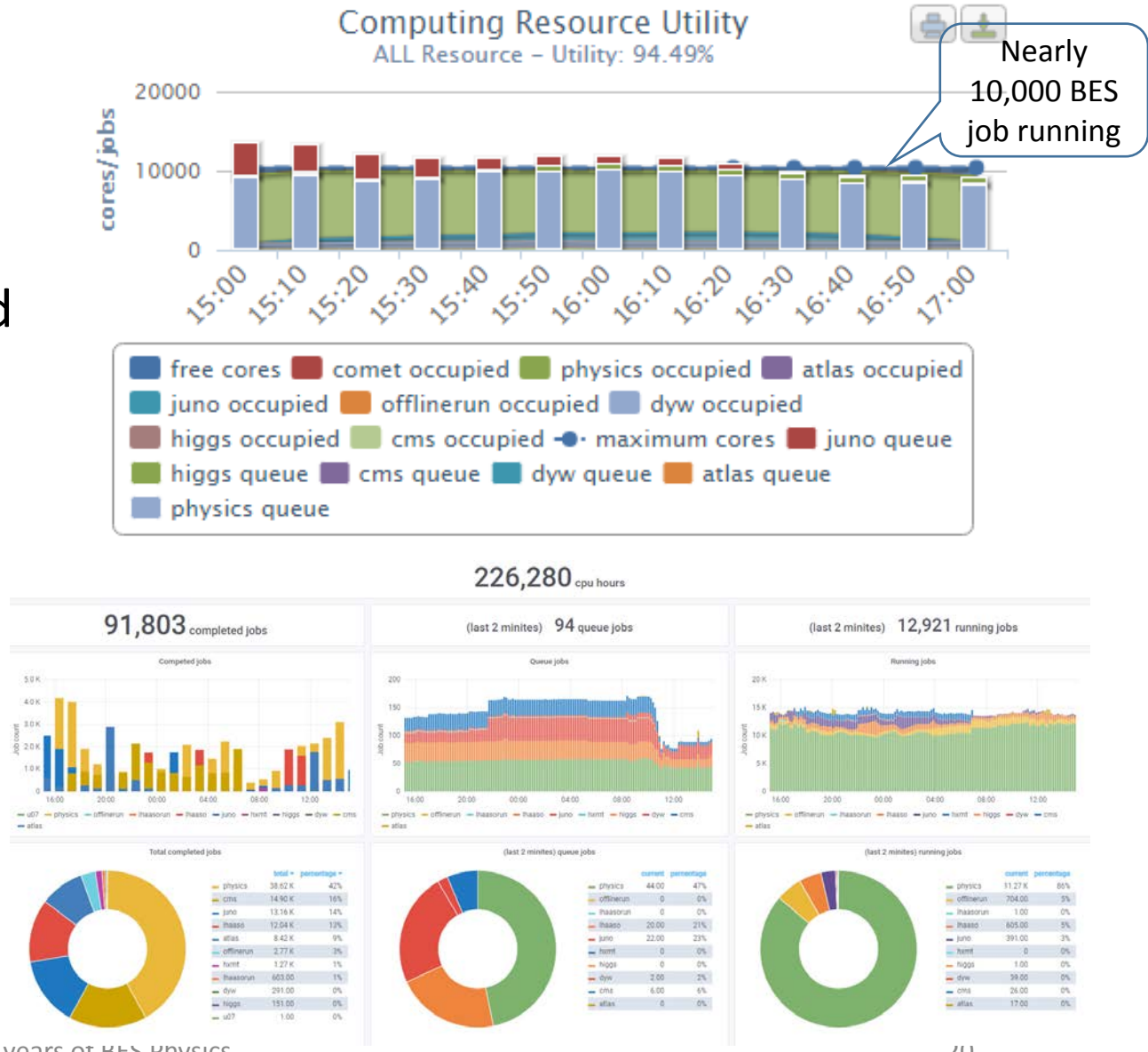
Security

Security Maintenance center established

Based on Open Source and NO Commercial Software

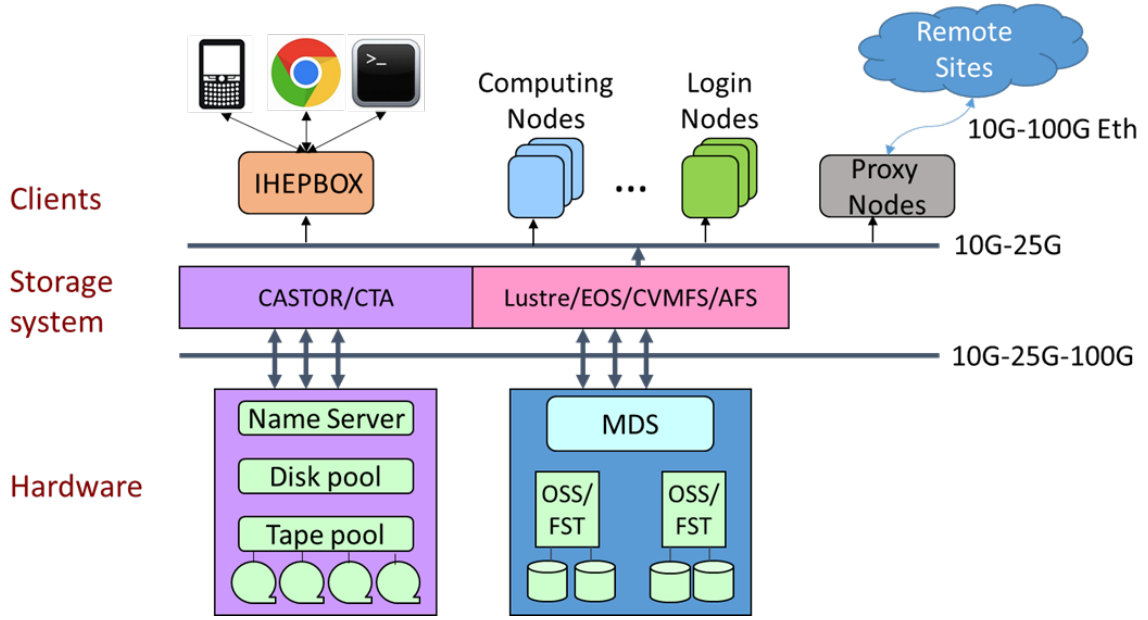
BESIII CLUSTER Computing

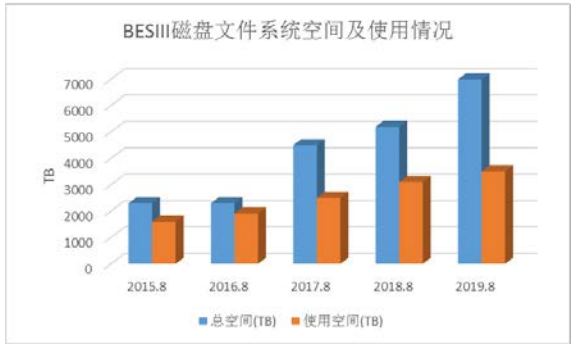
- Main Computing resources support 1000+ BESIII physicists
- 2008: Torque Maui cluster
  - Several job queues
- 2012： Dynamic job scheduling policy applied
  - BESIII job slots utilization reach to nearly 100%
- 2016: Migrated to HTCondor cluster
  - Fast job scheduling
  - More than 10,000 job slots
- 2017: Fair share resource pool policy applied
  - Run BESIII job on the free job slots from other experiments
- 2018: HPC Cluster established focusing on partial wave analysis & machine learning
- 2019: Virtual Computing applied to BESIII cluster



Massive Hierarchical Storage System

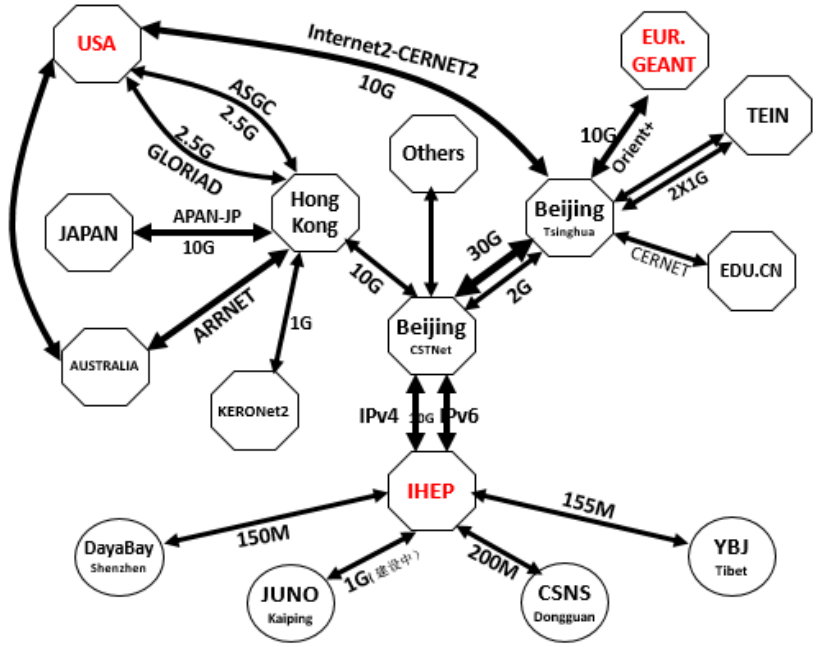
- BESIII Disk File system is based on Lustre
  - Capacity: 6.6 PB， Bandwidth: ~24GB/s
  - 200,000,000 files
  - Self developed monitor & diagnosis tool :
- BESIII Tape management based on CASTOR
  - Capacity: ~5PB with replica
  - 2 GB/s access bandwidth
- Cloud storage and data agency supported
  - Singe data view

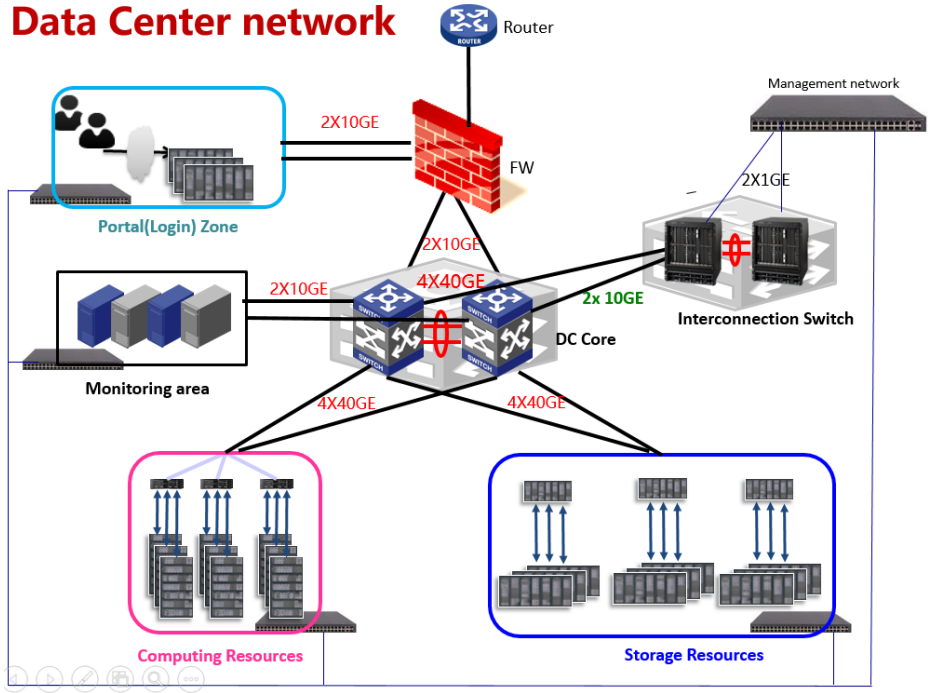




Network development for BESIII

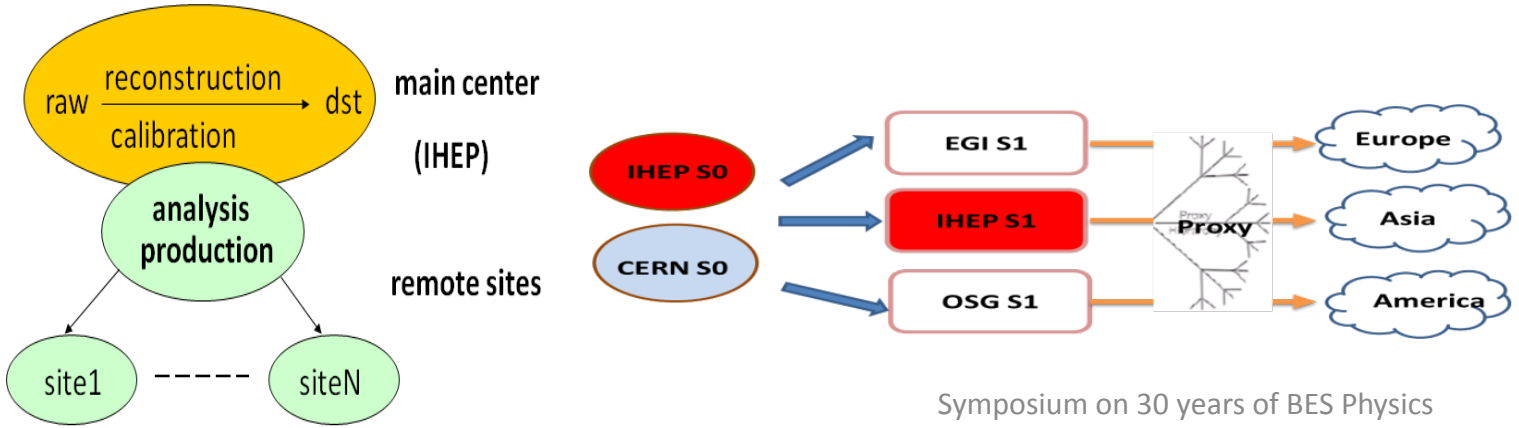
- 2008： 10Gb/s Ethernet for Computing Network, and 1Gbps internet connection
- 2011： 40Gb/s Ethernet for Computing Network, and 10Gbps internet connection
  IPv4/IPv6 dual-stack supported
- 2012： WIFI supported for campus network
- 2015： eduroam supported for campus network
- 2016： 160Gb/s Ethernet for Computing Network
  2X10Gbps internet connections
- 2018： LHCONE member
  4X10Gbps internet connections

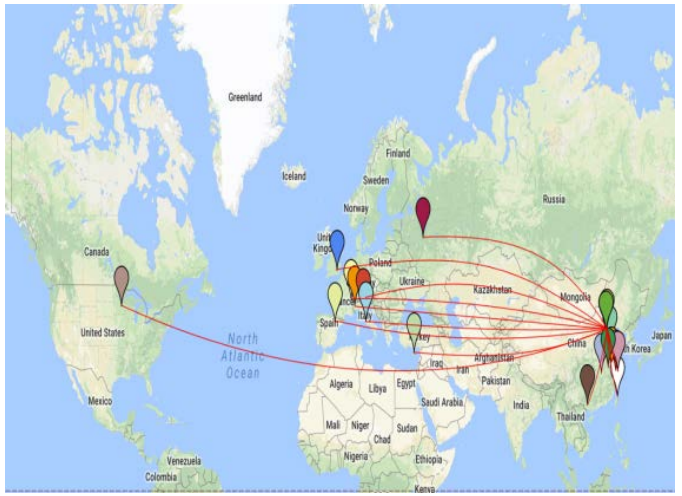




BESIII Distributed Computing

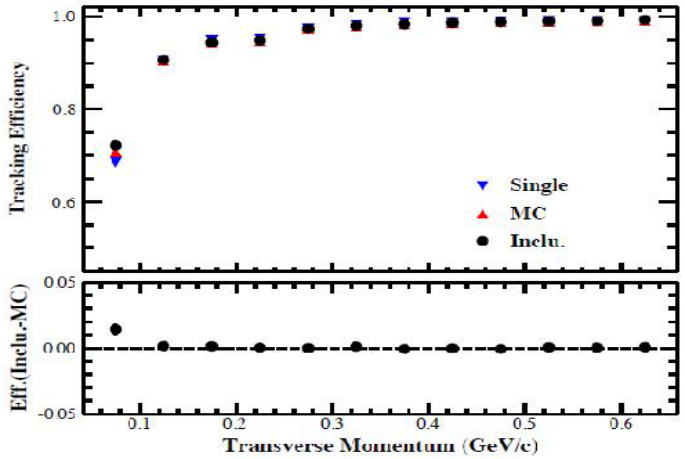
- In 2013, a distributed computing system was built based on DIRAC, which realized the integration of cluster, grid and cloud resources
  - The resource volume exceeded 3500 cores, and 18 domestic and foreign sites joined
  - Network bandwidth between IHEP and European, American and domestic universities is 10Gb/s
  - Realize reasonable and effective allocation of resources, that is, make full use of idle time of resources without affecting local users
  - It provides a unified platform, so that experimental users can easily use distributed heterogeneous computing resources without geographical restrictions
- The grid storage system and data transmission system are established to realize the high-speed data sharing among the cooperative units of the experiment
  - The total storage capacity reaches ~500TB, and the transmission speed exceeds 1Gb/s
- Since 2014, distributed computing has contributed about 6 million CPU hours to the experiment, and the data transmission volume between experimental cooperative units has exceeded 800TB



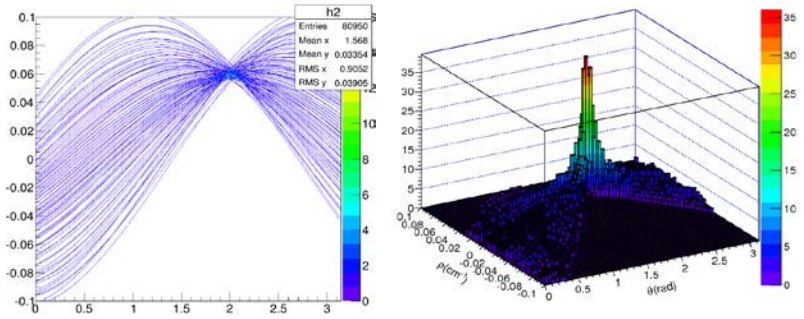


BESIII Software Upgrade
Tracking based on Hough Transform

Track efficiency of π^- vs P_T



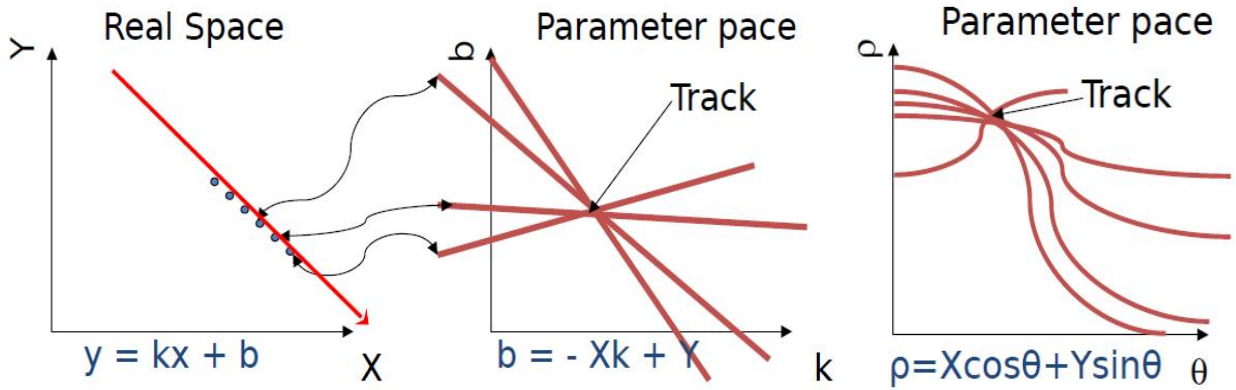
Low efficiency for low transvers momentum particle

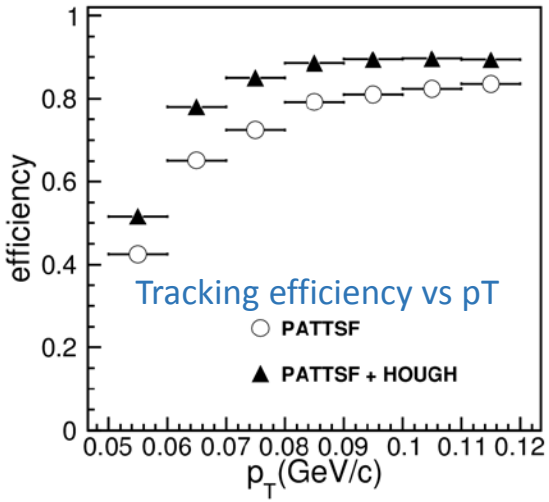


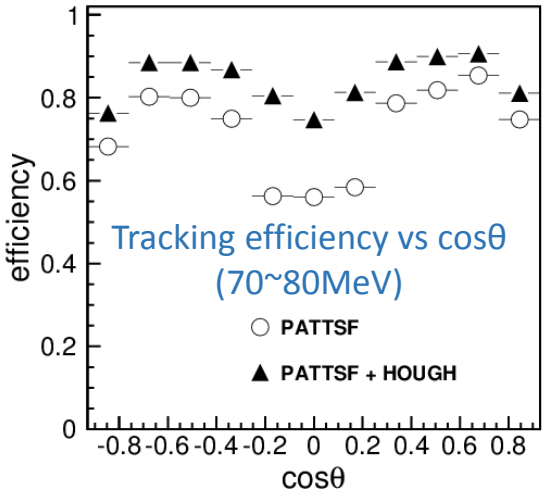
Sun Shengsen

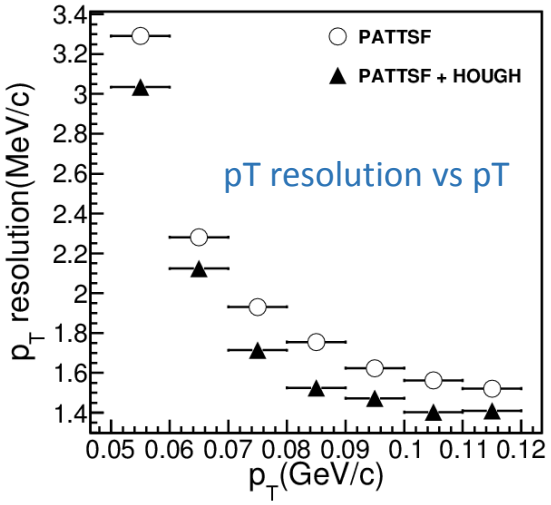
A track in real space ➔lines or curve in parameter space

Tracking ➔ Peaking

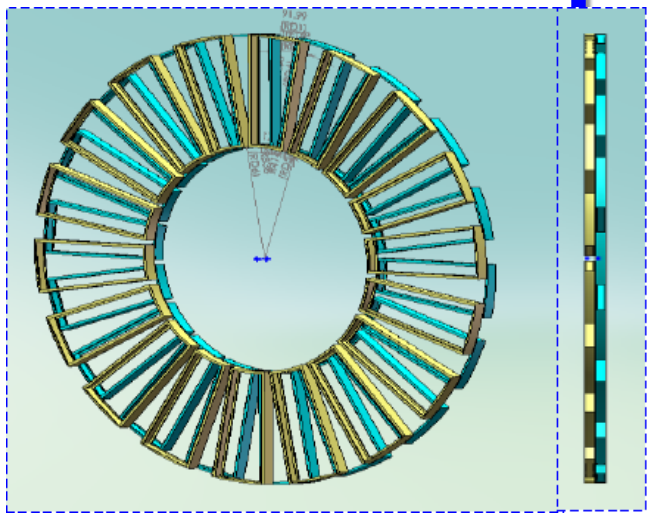




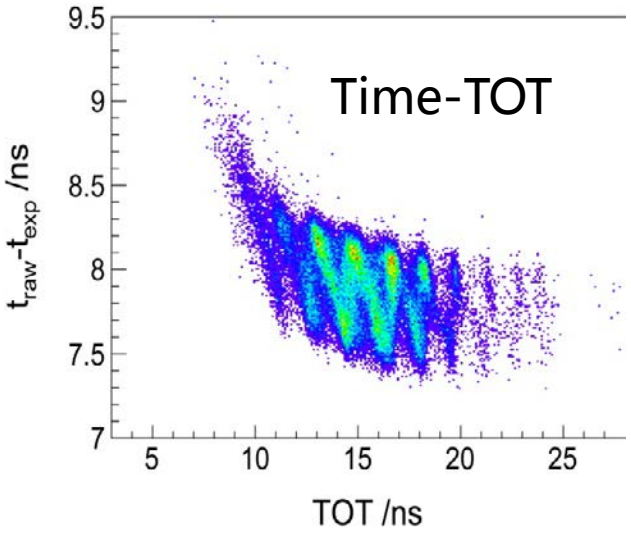




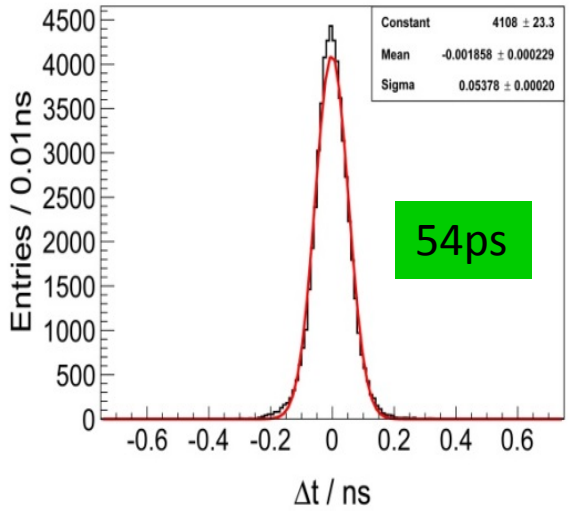
BESIII Software Upgrade
MRPC Endcap TOF Software



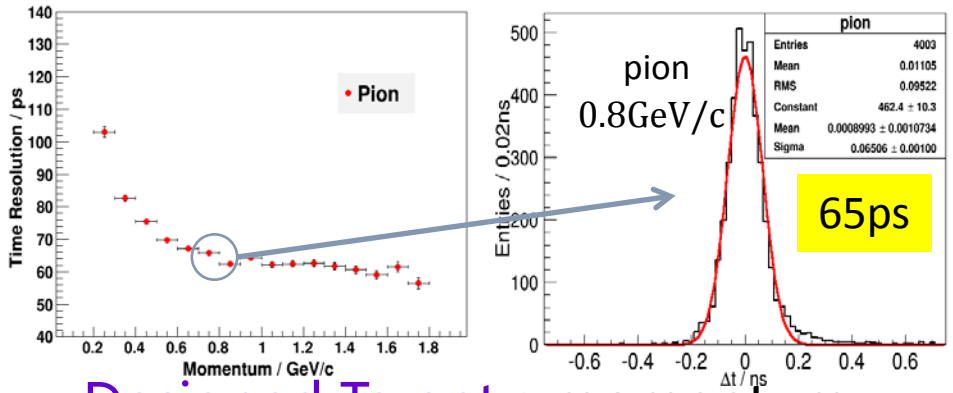
Endcap TOF upgrade in Oct2015



Multi-peak structure



Time difference with calibration



Designed Target : momentum 0.8GeV/c π meson overall 80~100ps

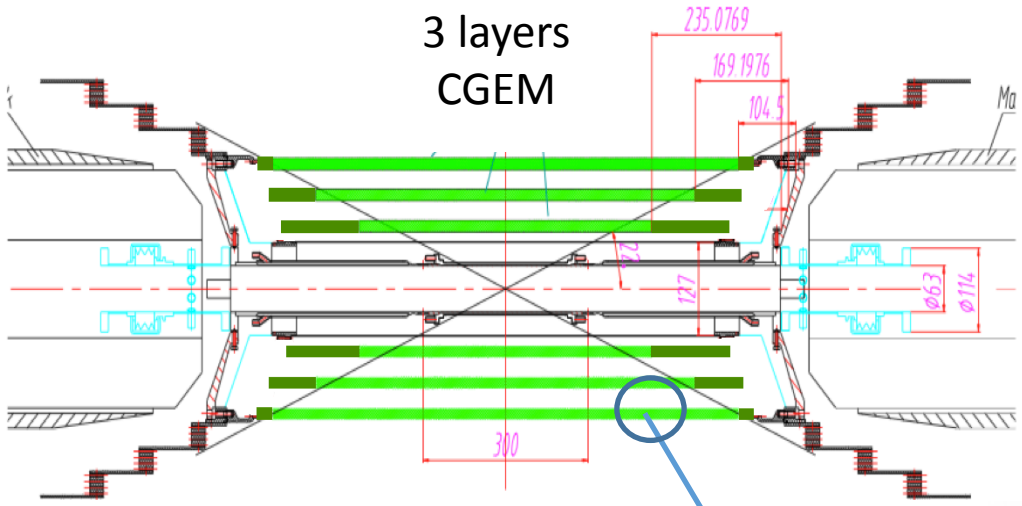
Comparison with International experiments

Acceleratro	Detector	Time resolution (π meson)
RHIC	STAR	74−94ps
LHC	ALICE	86ps
BEPCII	BESIII	**65ps**

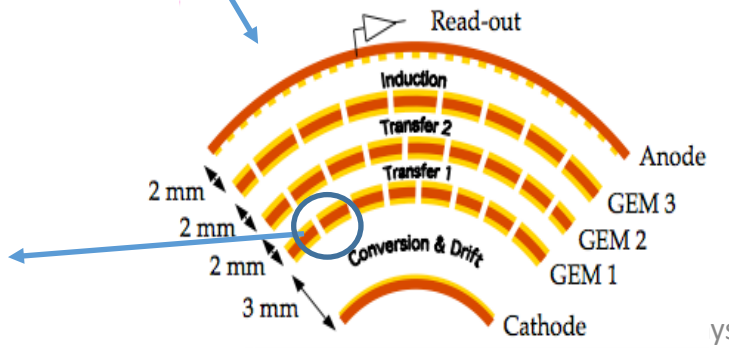
BESIII Software Upgrade
Cylindrical GEM Inner Tracker

BESIII is building a cylindrical GEM detector (CGEM-IT) to replace the BESIII Inner MDC to recover some efficiency loss due to aging and to improve the secondary vertex resolution.

3 layers CGEM



Each layer composed by a triple cylindrical GEM

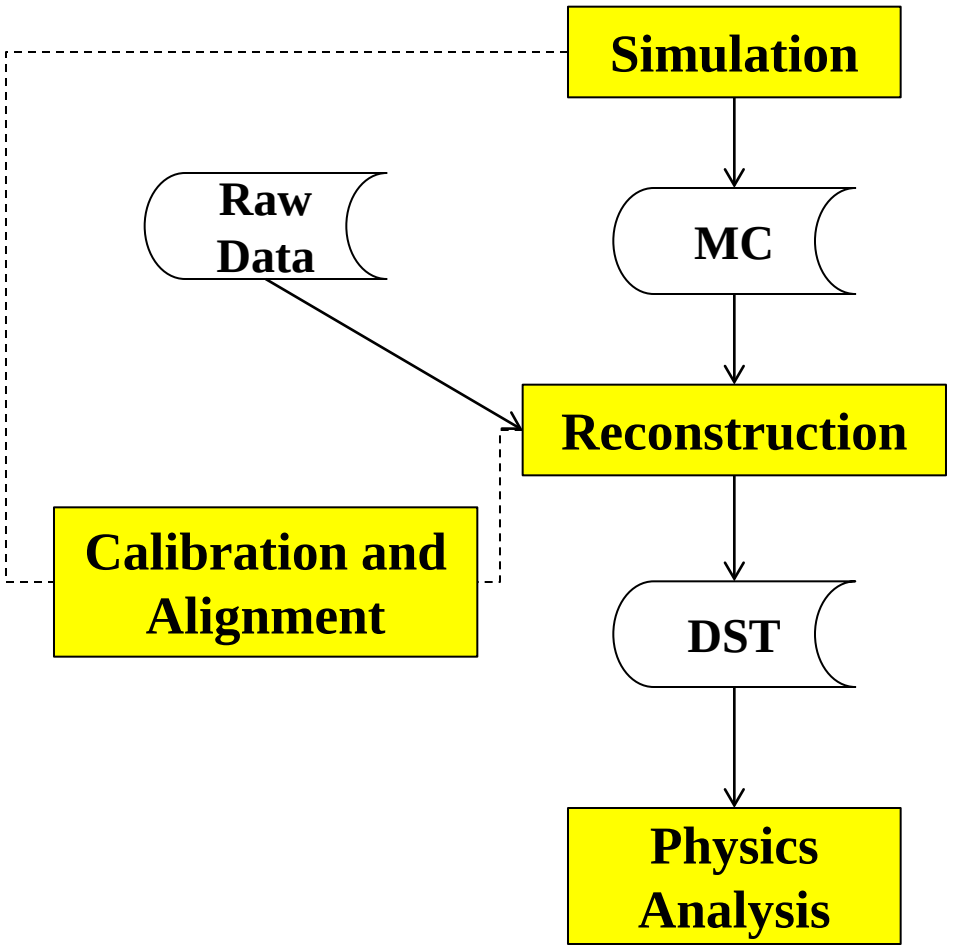


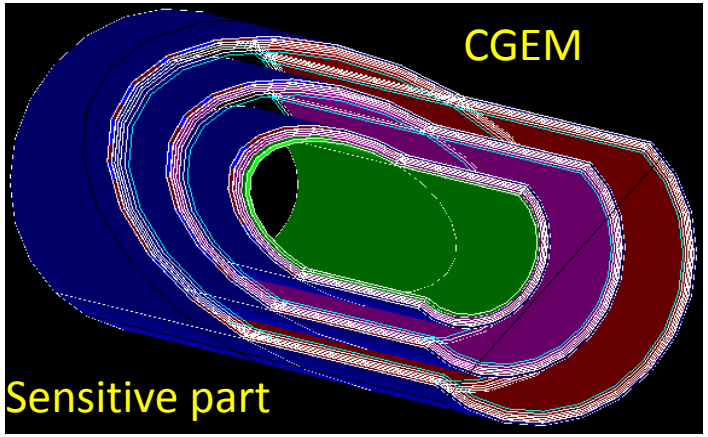
- **Low Material budget ≤ 1.5% of X_0 for all layers**
- **High Rate capability: ~10^4 Hz/cm^2**
- **Coverage: 93%**
- **Spatial resolution $\sigma_{r\phi}$ ~130 μm in 1 T magnetic filed**
- **Operation duration at least 5 years**

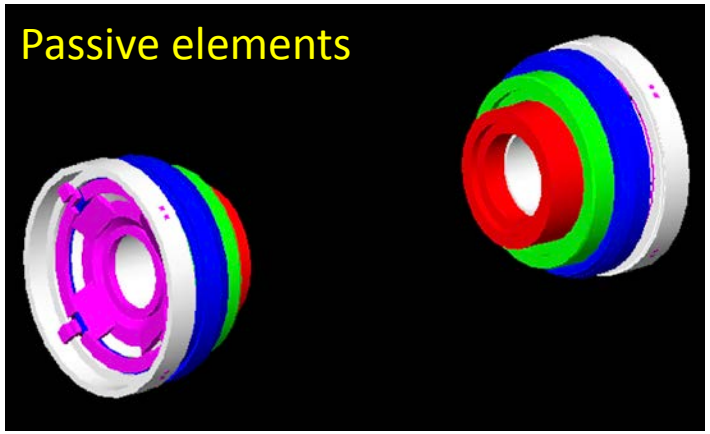
The CGEM is co-funded by the European Commission Research and Innovation Staff Exchange (RISE) project 2015-2018.

Formation of a consortium: IHEP, INFN (Ferrara, Frascati, Perugia and Torino), Mainz, Uppsala.

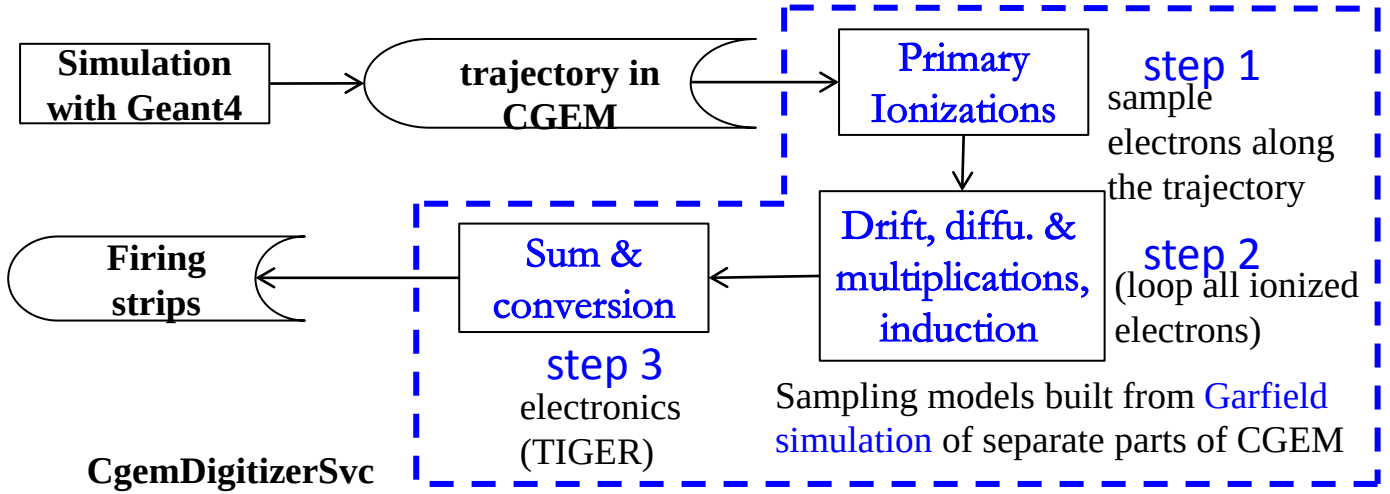
BESIII Software Upgrade
CGEM Software: Simulation





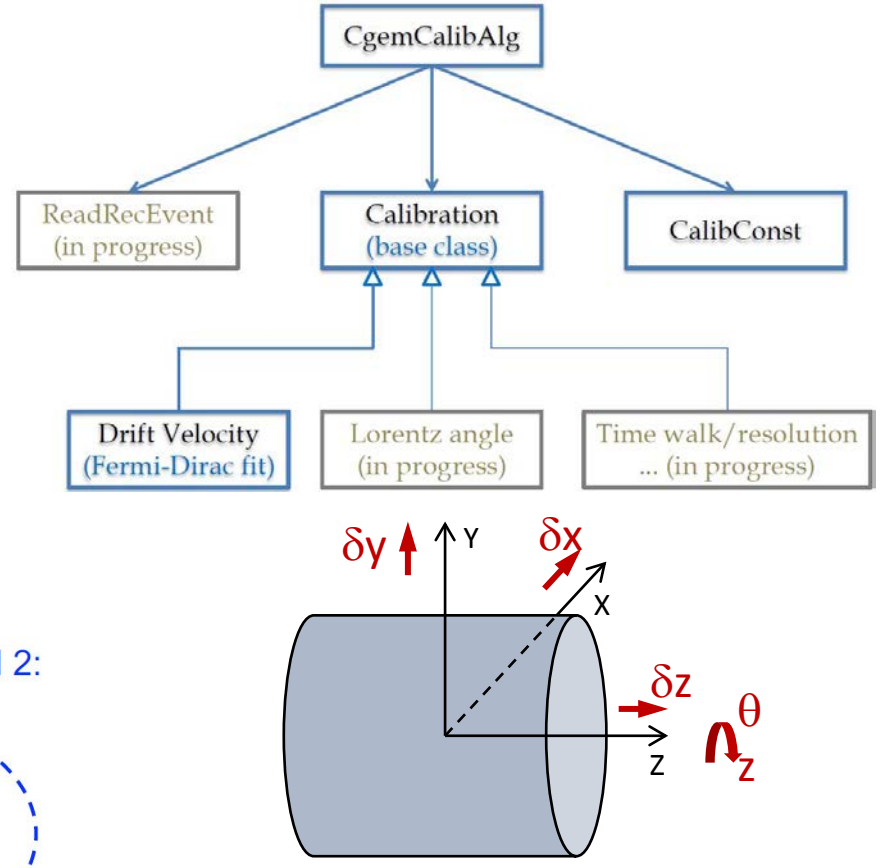


Detector Description

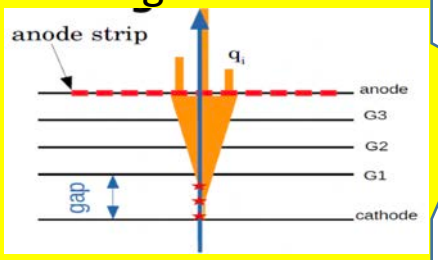


Full Digitization (simulation of detector response)

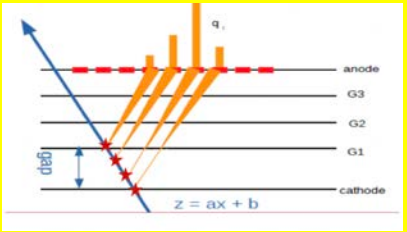
BESIII Software Upgrade
CGEM Software: Reconstruction, Calibration and Alignment

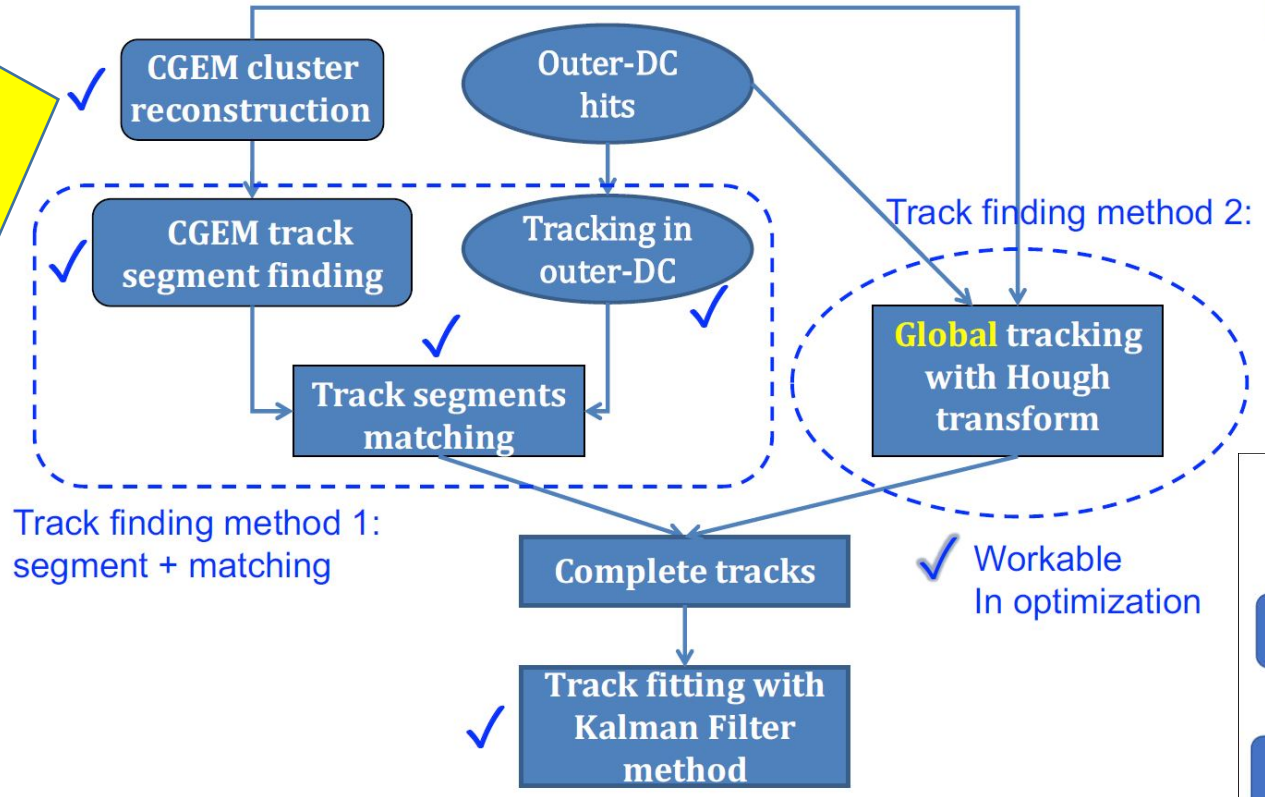


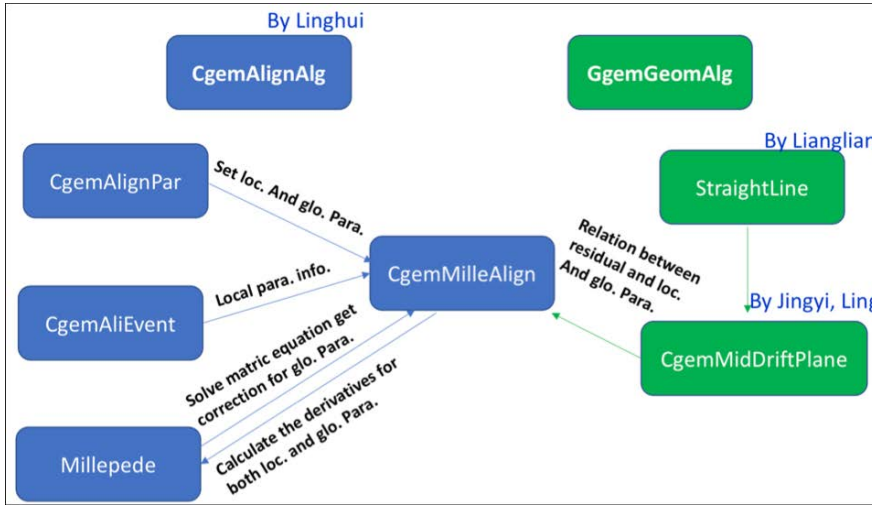
Charge centroid



microTPC

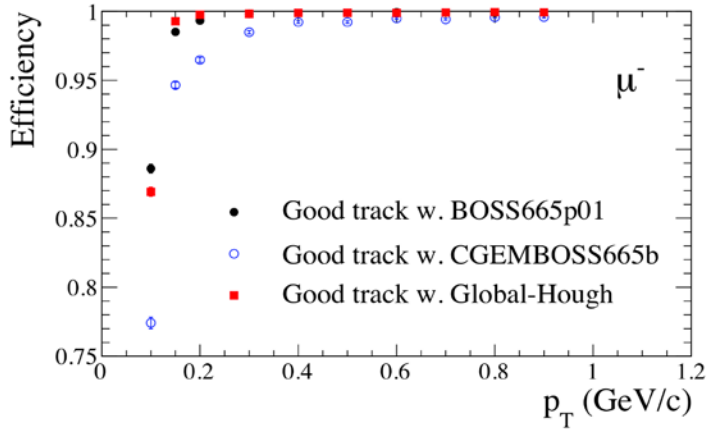


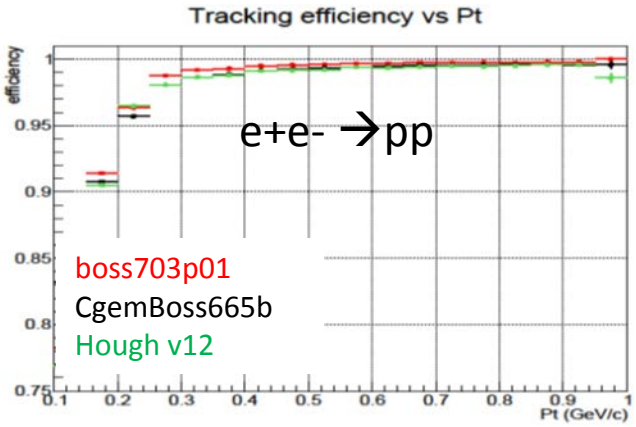


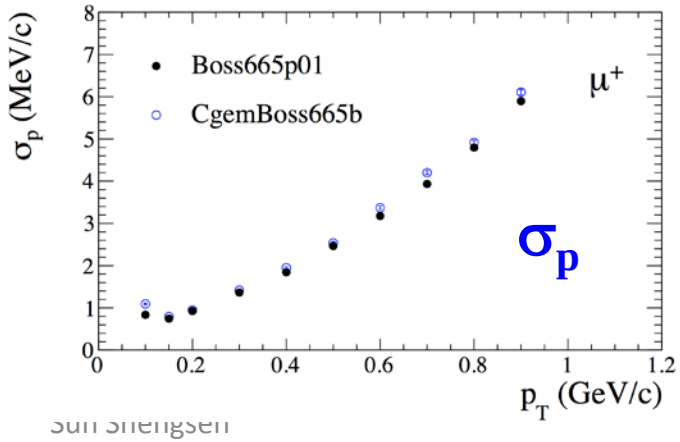


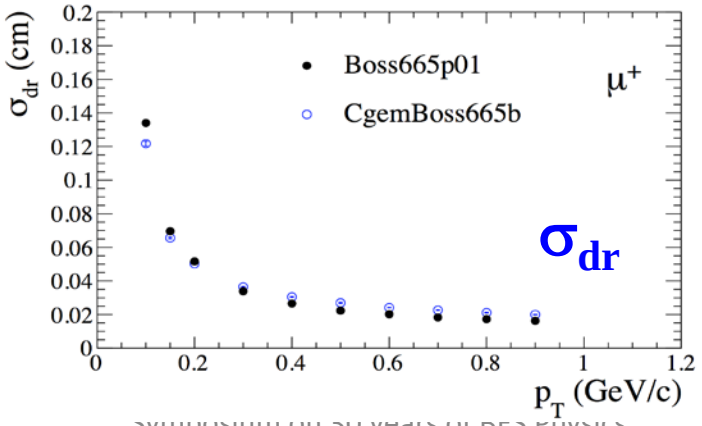
BESIII Software Upgrade
CGEM Software Performance

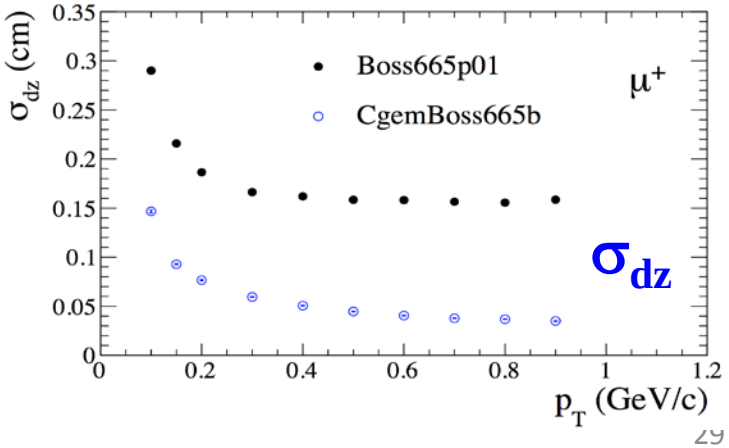
- Software version: CGEMBOSS665b, CGEMBOSS665c
- Validation
- Tracking efficiency
- Spatial resolution









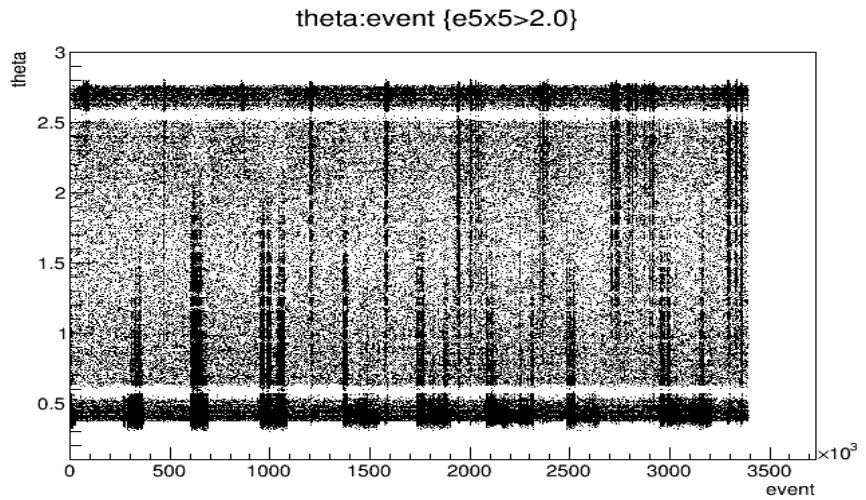


BESIII Software Upgrade
Constant-Current Pattern of Accelerator

- A nearly constant beam current results in a high integrated luminosity
- Data quality is satisfied for physics analysis?
- Solve the confliction between long-time run and precise detector calibration.

BossRelease	DataType	CalibConst	RunFrom	RunTo	BossVer	eventFrom	eventTo
7.0.5	dE/dx	File1	8093	9025	7.0.0	—	—
7.0.5	dE/dx	……	……				
7.0.5	dE/dx	File1	80000	80000	7.0.5	0	10000
7.0.5	dE/dx	File2	80000	80000	7.0.5	10001	20000
7.0.5	dE/dx	File3	80000	80000	7.0.5	20001	30000
7.0.5	dE/dx	File1	80001	80001	7.0.5	0	12345
7.0.5	dE/dx	File2	80001	80001	7.0.5	12346	54321
7.0.5	Mdc	File1	80000	82000	7.0.5	—	—

Event Time Stamp



Thanks all BESIII Colleagues for Contributions to BESIII Software and Computing!

I must apologize for missing many important achievements and outstanding contributions in this slides!