Software & Computing @BESIII

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Outline

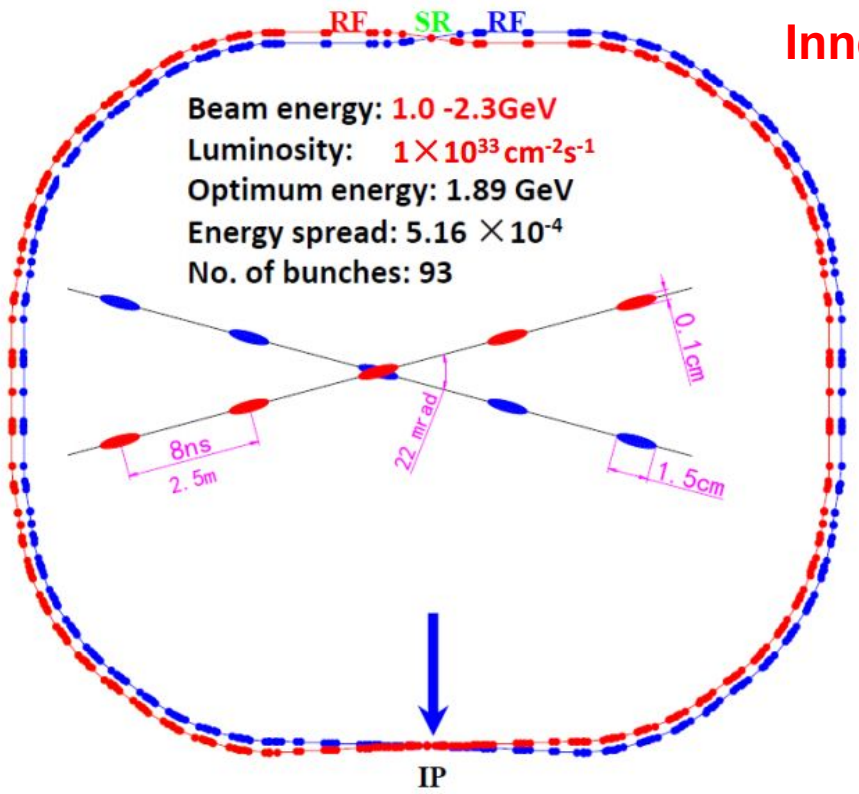
- The BESIII Experiment
- Recent software activities
  - MDC new tracking software
  - MRPC software
  - CGEM-IT software
- Computing
  - Central computing
  - Distributed computing
  - Tag-based analysis
- Summary

BEPCII and BESIII

Beijing Electron Positron Collider II

Energy plan: 1.0 - 2.45 GeV

Top-up mode:
beam injection during data taking
Int. luminosity increased > 20%



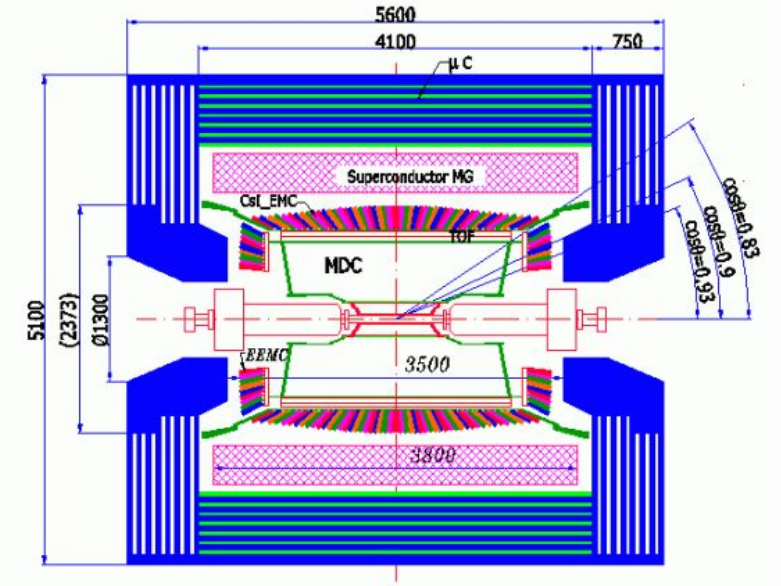
Top-up mode will be used in 2019 winter run

BESIII Detector

Inner tracker will be upgraded to CGEM

MDC: p 0.5%@ 1GeV/c
dE/dx: 6%

EMC: CsI (Tl) 2.5% (5.0%)
barrel (endcap) @ 1GeV



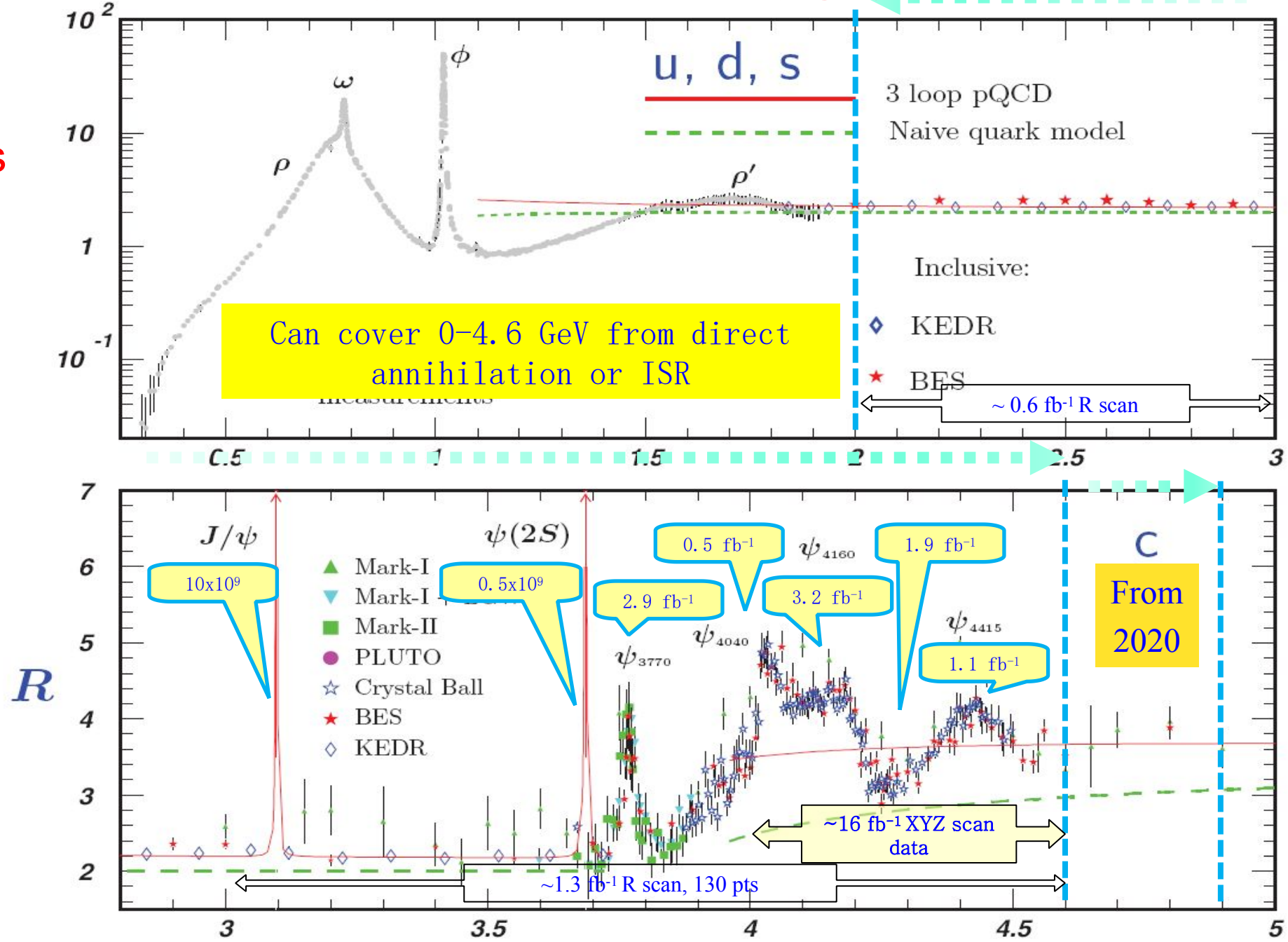
TOF: σT=80(70) ps
barrel (endcap)

MUC: RPC 9 (8) layers
barrel (endcap)

ETOF was upgraded to MRPC in 2015

e^+e^- annihilation at 2-5 GeV

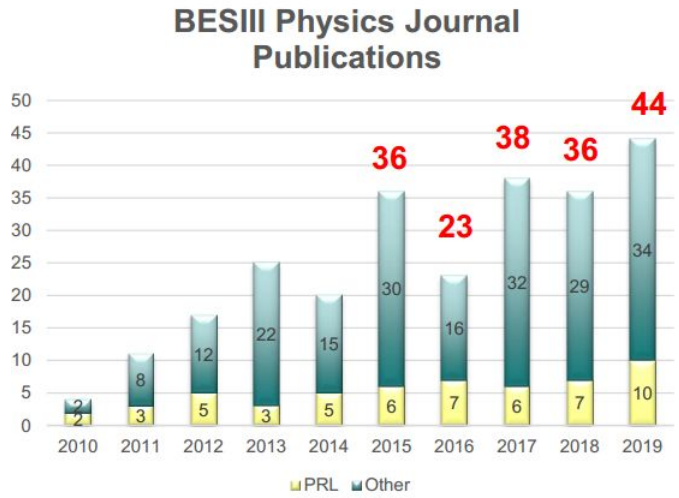
Data taken
In 11 years

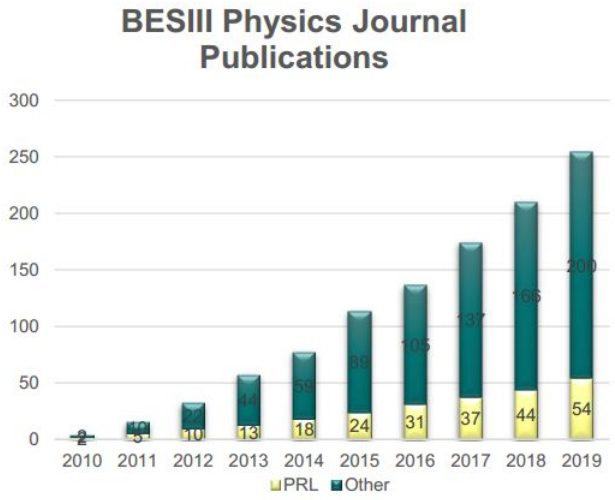


Milestones

- 2003/3 BEPCII/BESIII project got approval, construction started
- 2008/8 Commissioning run
- 2009/1 Physics Run, BESIII reached its designed goal
- 2015/9 BESIII/ETOF upgraded to MRPC
- 2016/4 BEPCII reached its designed luminosity
- 2019/3 BESIII accumulated 10 Billion J/Psi events
- 2020? BESIII/MDC-IT will be replaced by CGEM
- 202? Shutdown

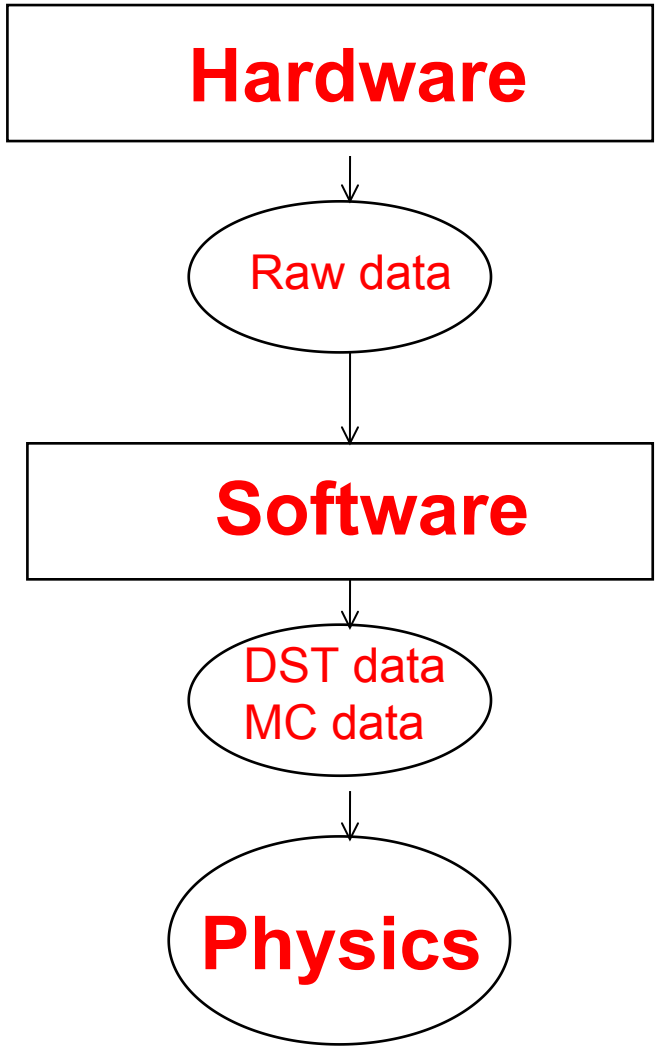
~11 years data-taking
~250 physics publications





Software/Computing in HEP

Accelerator



Detector

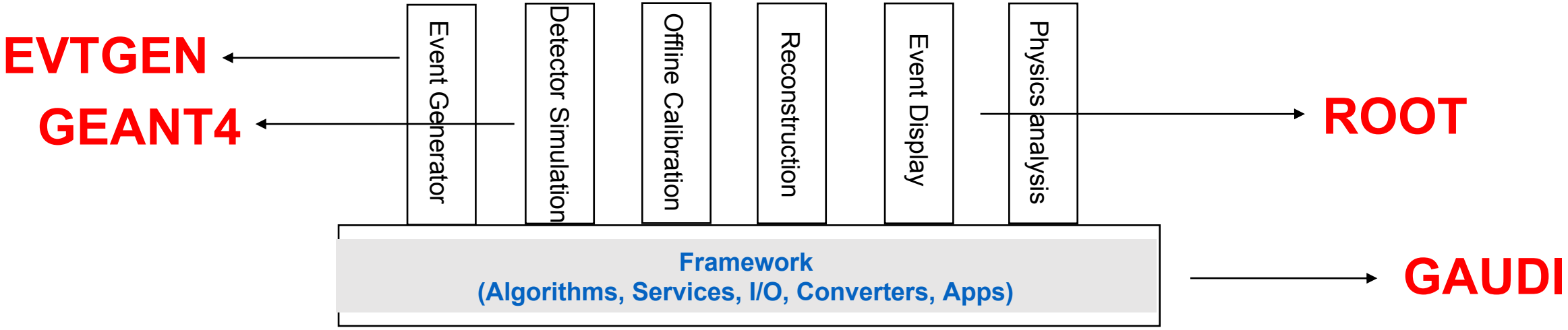
Data production
Physics analysis

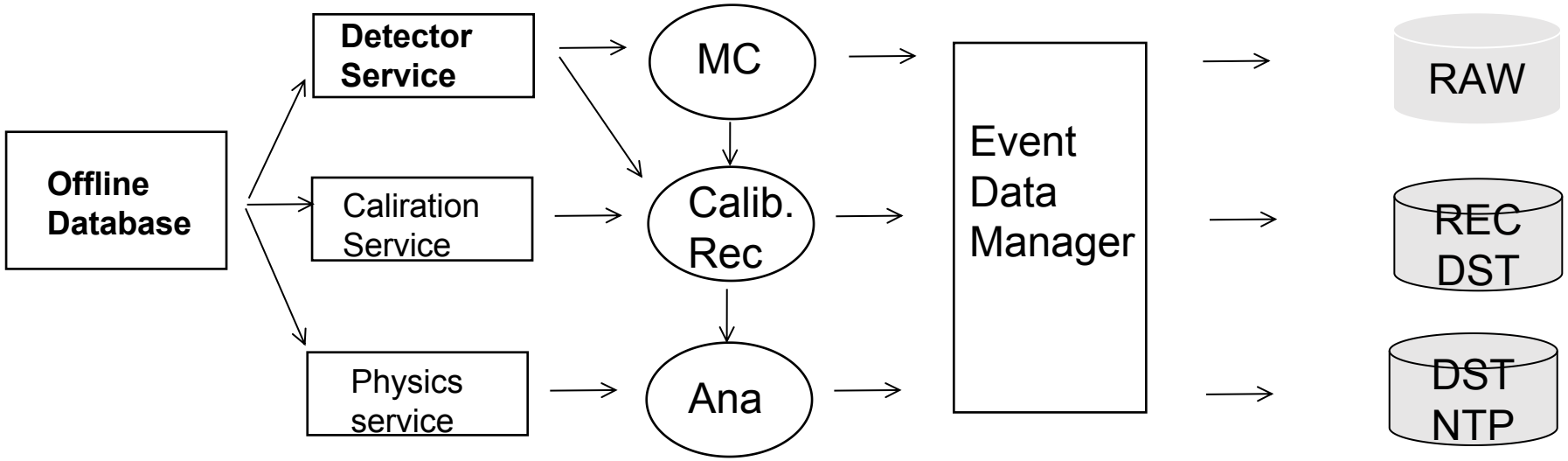
Event reconstruction
Monte Carlo Simulation

Statistical error
（Data quantity）

Systematic error
(Data quality)

BESIII Offline Software System (BOSS)





Developed from 2003

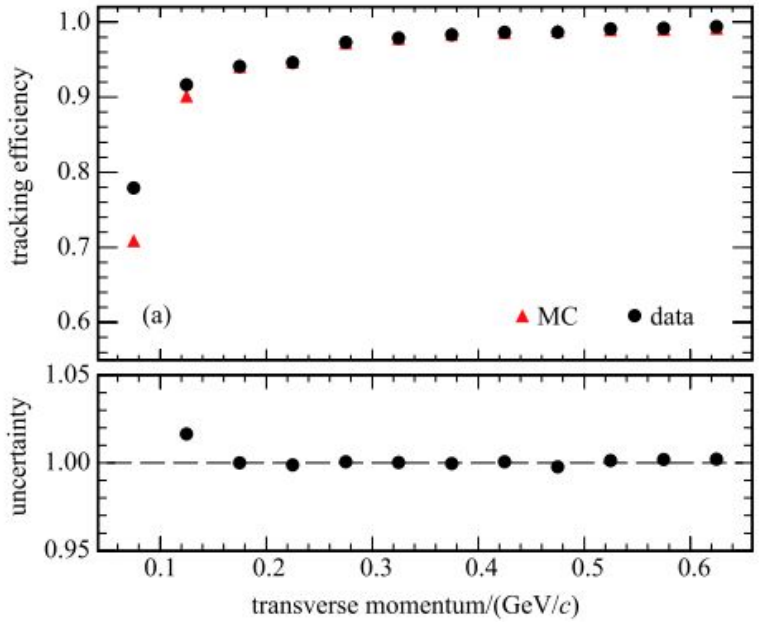
Latest release BOSS 7.0.5

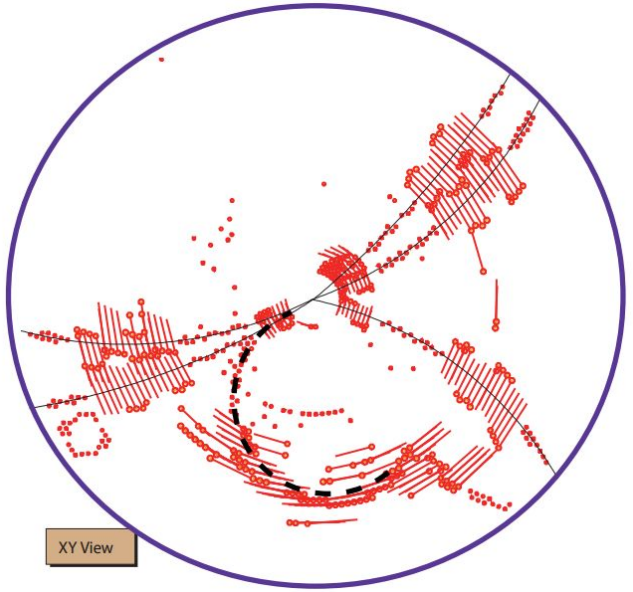
Offline Data process

Recent software activities

Problem in tracking at low Pt

***For p_T<120 MeV/c*, low tracking efficiency, large data/MC discrepancy**

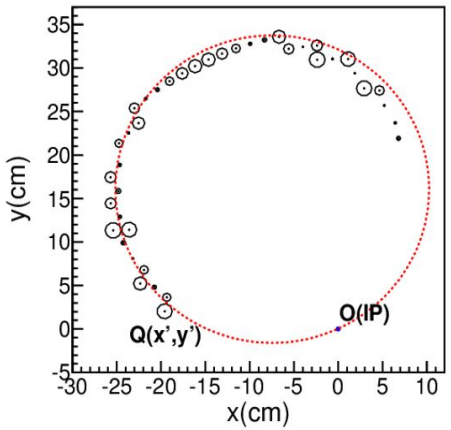


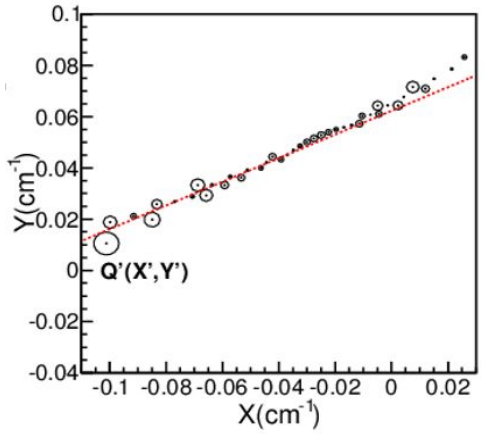


Current tracking packages PAT and TSF are local (search from seeded hit)
Hard to find curling/loop tracks at high noise level

Tracking based on Hough transform

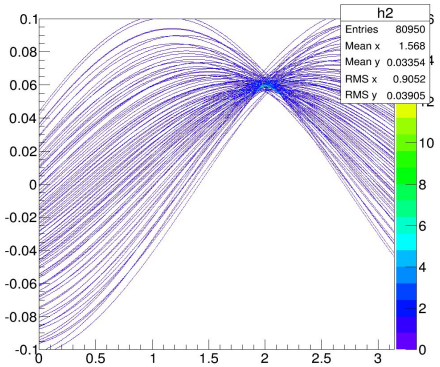
Conformal transform

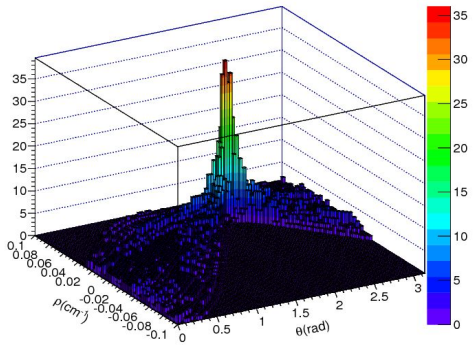




Hough：global tracking (using all hits)

$\rho = X\cos\alpha + Y\sin\alpha$

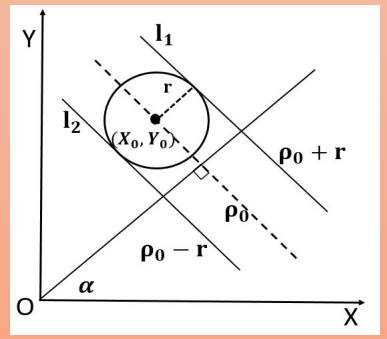


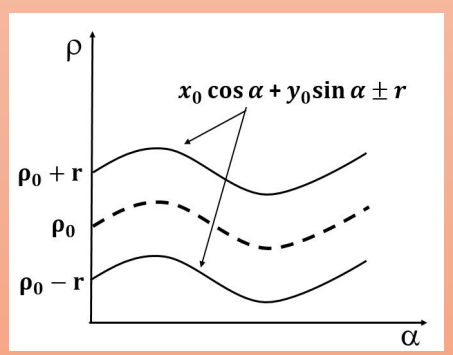


Peak finding in 2-d Hough plot

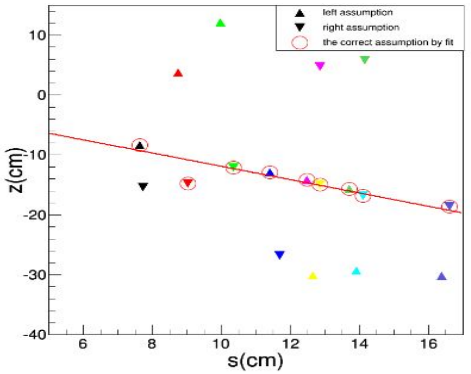
$$\rho = X\cos\alpha + Y\sin\alpha + r, (upper\ half\ circle)$$

$$\rho = X\cos\alpha + Y\sin\alpha - r, (lower\ half\ circle)$$

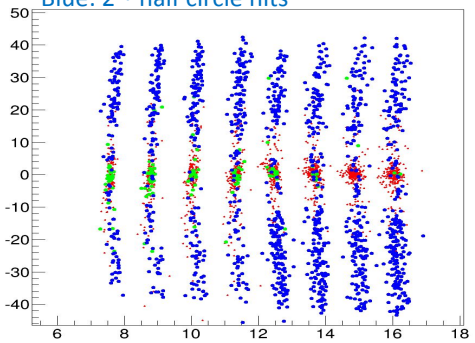




Hough transform using drift time



Red : 1st half circle hits
Green : noise hit
Blue: 2nd half circle hits

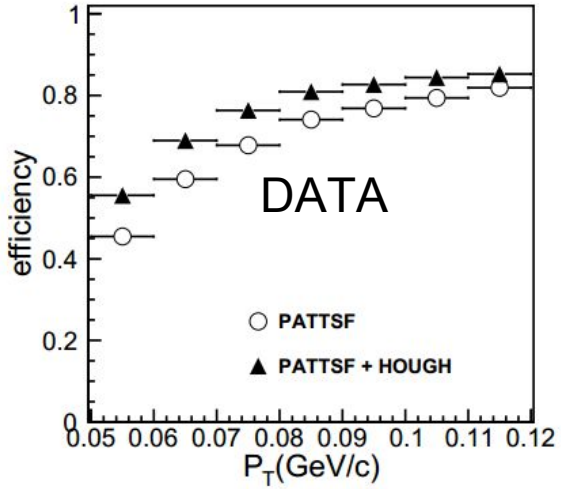


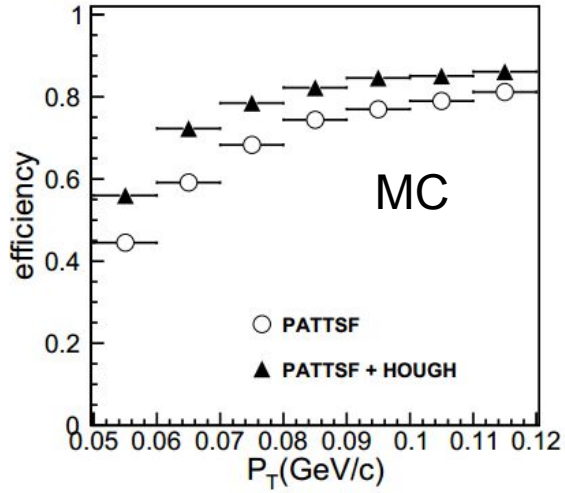
Tracking efficiency with Hough

p_T<120 MeV/*c*, the efficiency increased by ~7%

$J/\Psi \ -> p\bar{p}\pi^+\pi^-$

Momentum range：
50 MeV/c~120 MeV/c





Λ_c: Number of signals
703 – PATTSF+HOUGH
665p01 - PATTSF

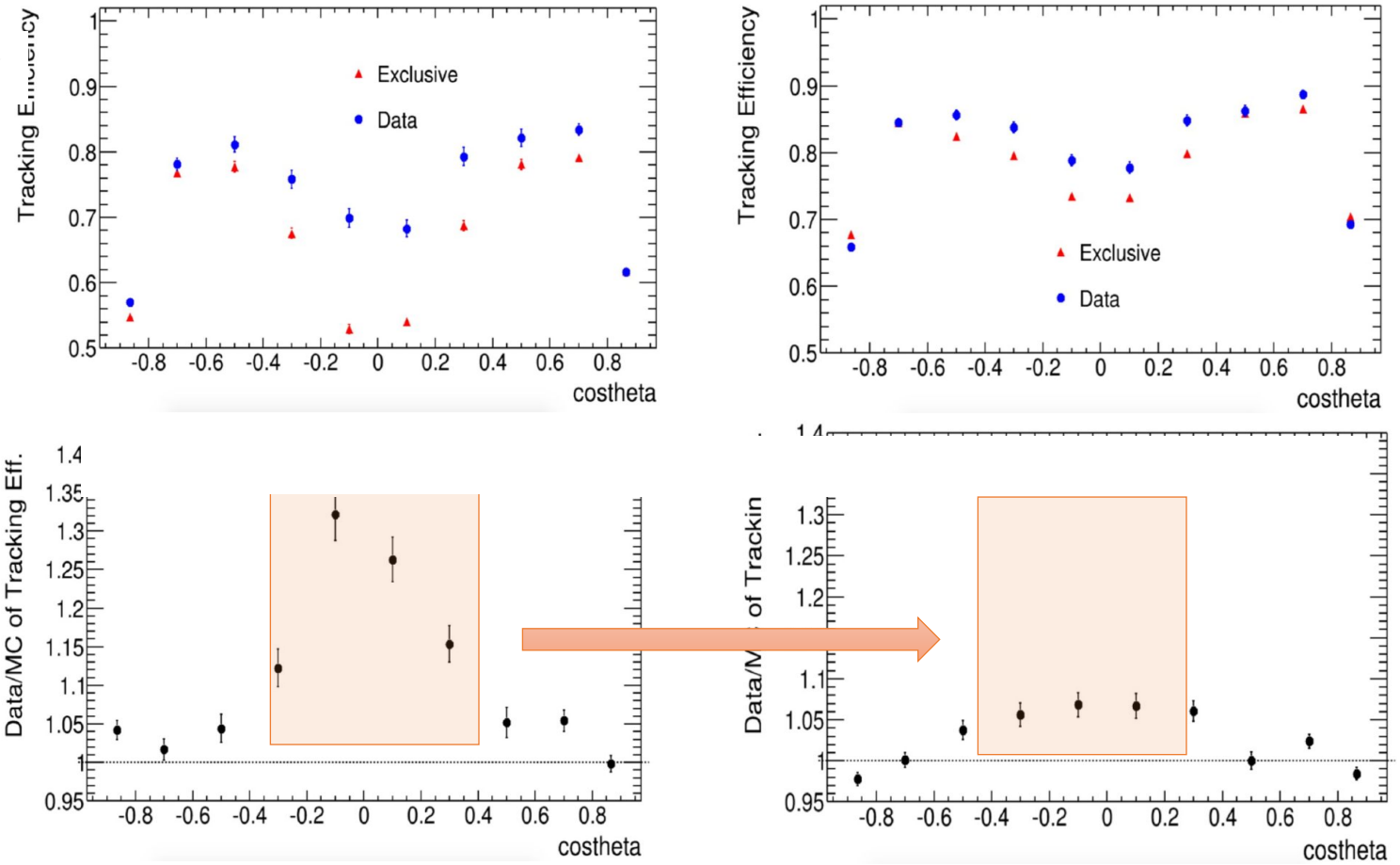
Modes	703	665p01
$\Lambda_c^+ \to p^+K_s$	1259 ± 39	1235 ± 39
$\Lambda_c^+ \to p^+K^-\pi^+$	6328 ± 89	6211 ± 88
$\Lambda_c^+ \to p^+K_s\pi^0$	532 ± 30	538 ± 30
$\Lambda_c^+ \to p^+K_s\pi^+\pi^-$	520 ± 29	469 ± 27
$\Lambda_c^+ \to p^+K^-\pi^+\pi^0$	1720± 60	1619 ± 57
$\Lambda_c^+ \to \Lambda\pi^+$	732 ± 28	723 ± 27
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	1516 ± 49	1401 ± 47
$\Lambda_c^+ \to \Lambda\pi^+\pi^-\pi^+$	682± 32	647 ± 31
$\Lambda_c^+ \to \Sigma^0\pi^+$	479 ± 25	469 ± 25
$\Lambda_c^+ \to \Sigma^+\pi^0$	282 ± 24	268 ± 25
$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	1093 ± 44	1042 ± 44
$\Lambda_c^+ \to \Sigma^+\omega$	151 ± 23	137 ± 18

Data/MC consistency under Hough

Efficiency vs polar angle

$J/\Psi \rightarrow p\bar{p}\pi^+\pi^-$

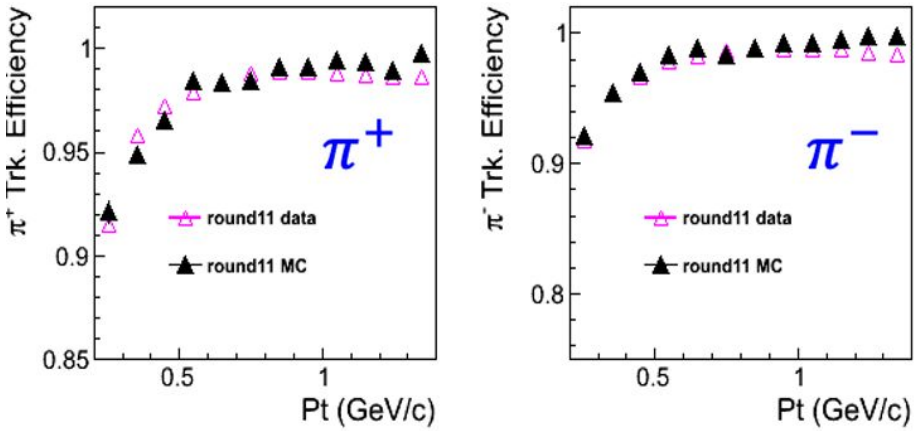
Momentum range：
50 MeV/c~120 MeV/c

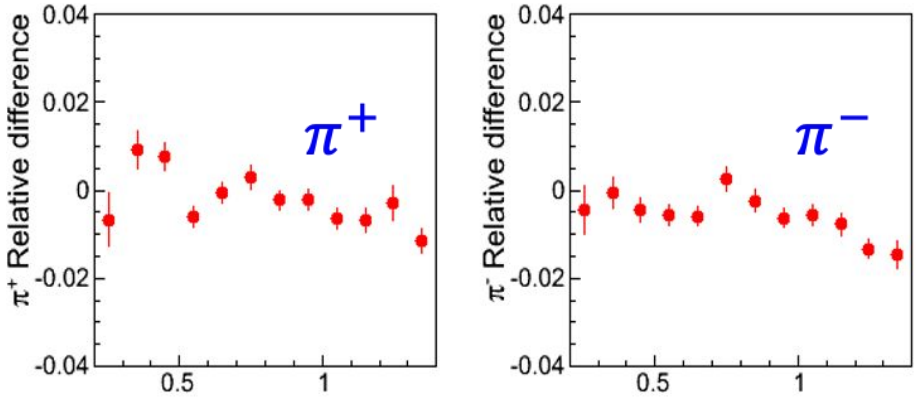


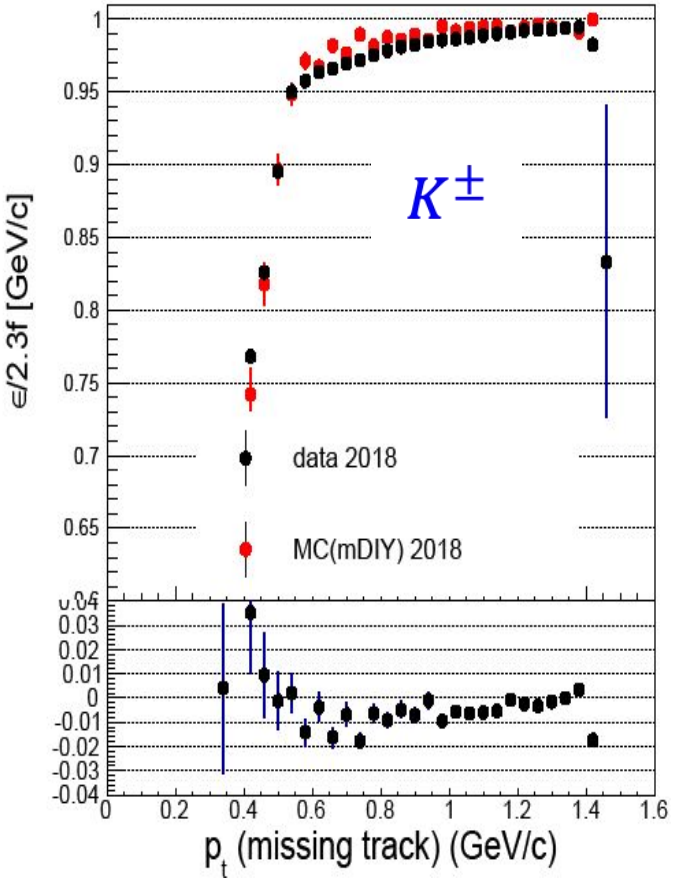
Obviously improved

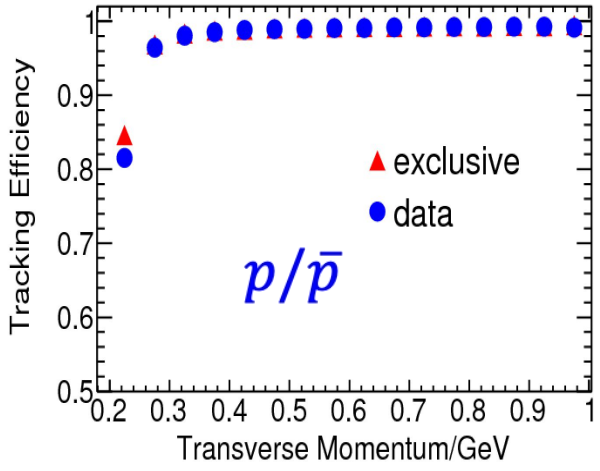
Tracking efficiency for hadrons

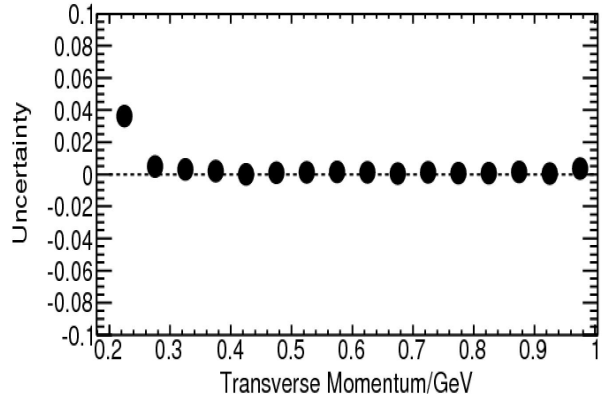
- Systematic error ~ 1%
- Protons at low P <200 MeV are extremely low due to large energy loss





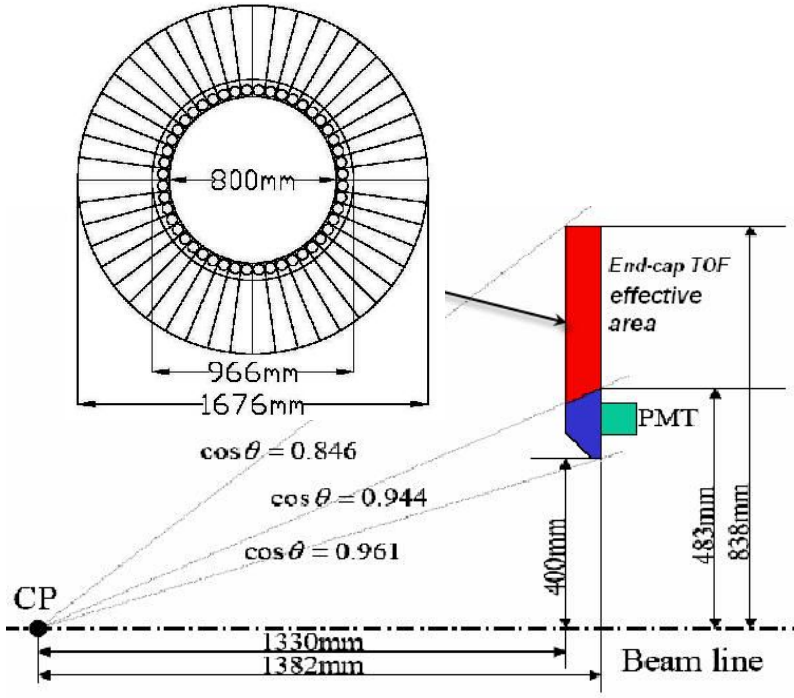






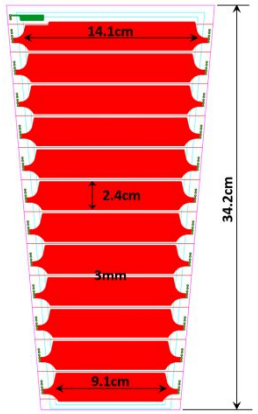
MRPC Software

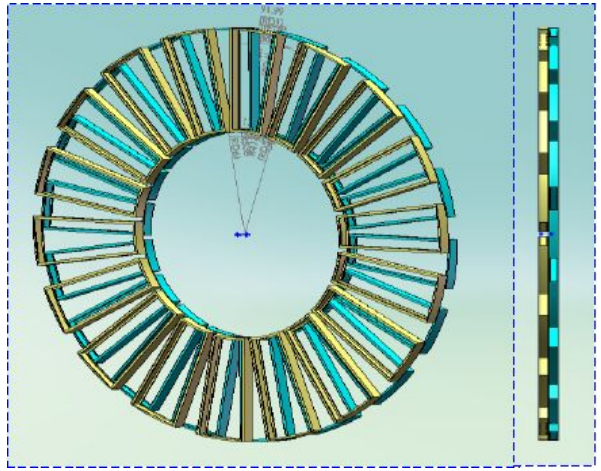
- TOF sintillators (barrel part and two end-caps)
- σ_b= 80 ps,σ_e= 140 ps, better PID power needed
- ETOF-MRPC developed by IHEP/USTC, installed in 2015



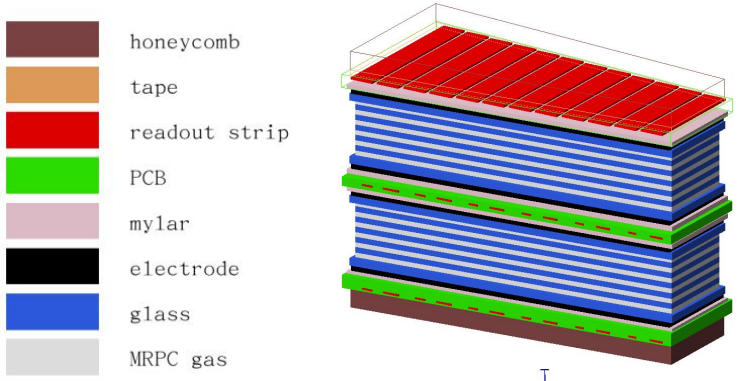
Soffware:

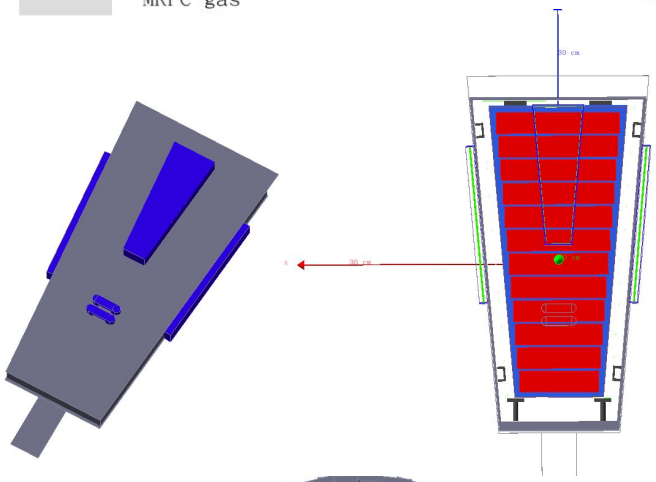
- Simulation
- Reconstruction
- Calibration/alignment
- New data model
- Backward compatibility

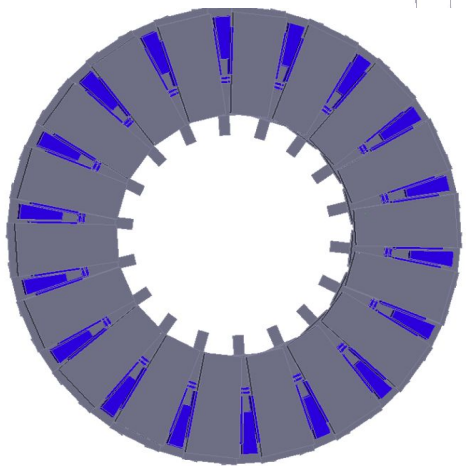




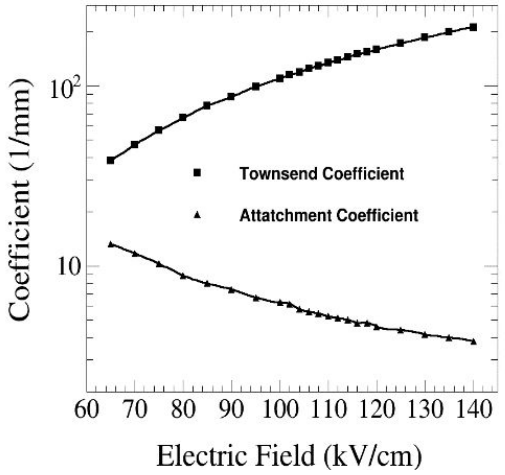
MC Simulation

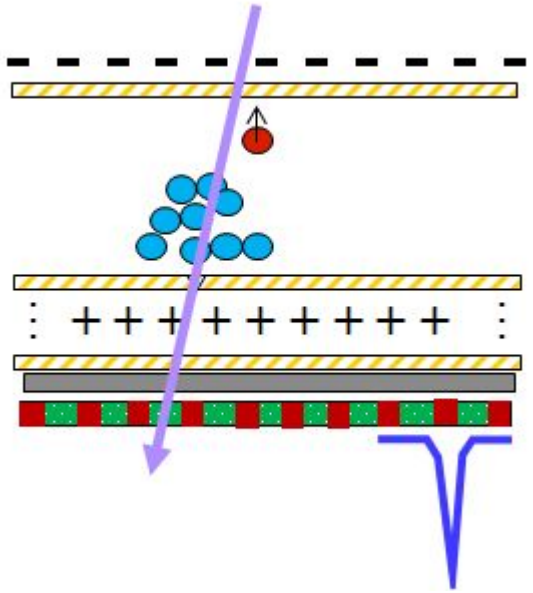


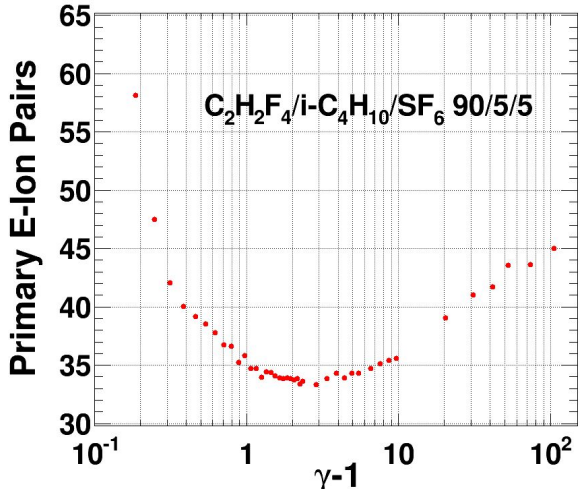




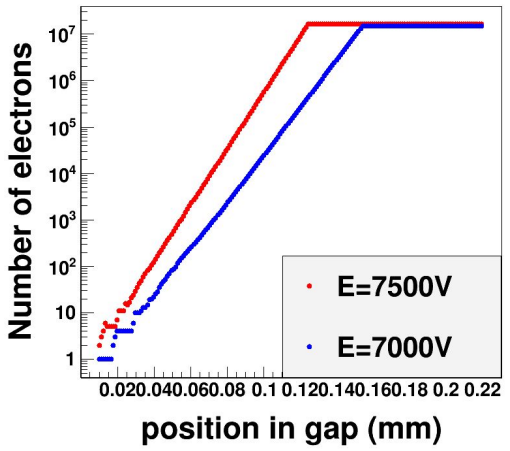
- Geometry and material bv GEANT4
- Digitization
  - primary ionizatio
  - multiplication
  - induced current

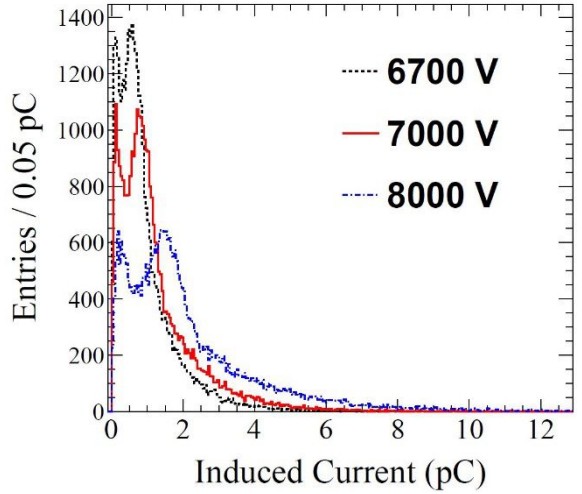




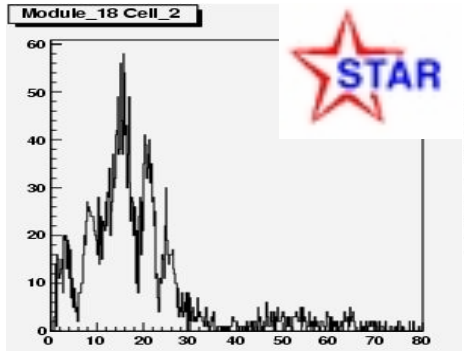


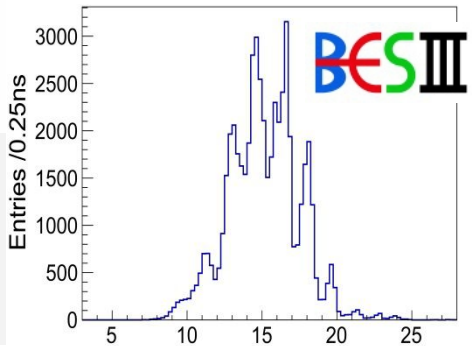
$N_{ion} \sim \gamma - 1$, GEANT4



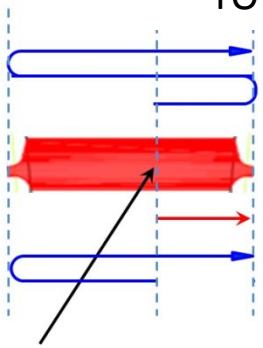


Offline Calibration





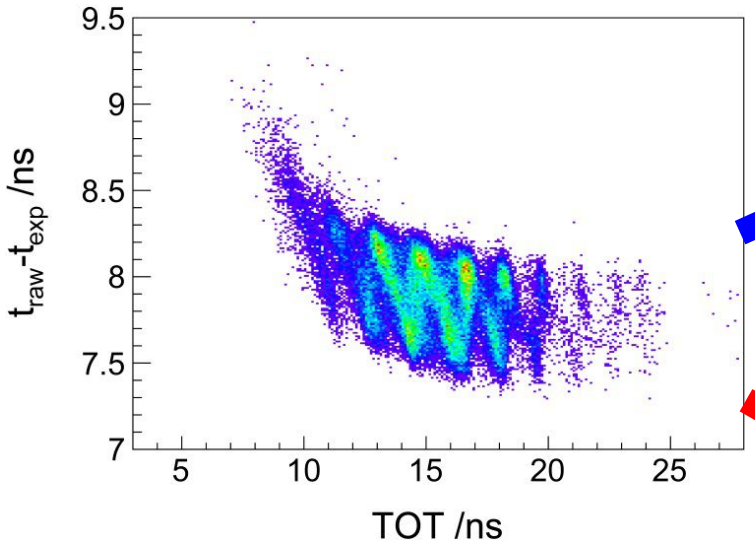
TOT **multi-peak structure**

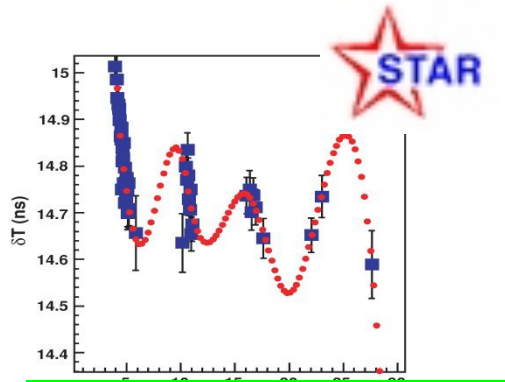


Near-end reflection

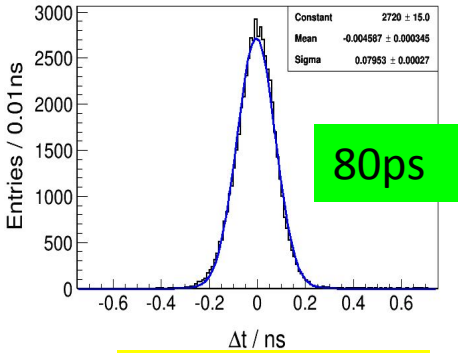
Far-end reflection

Bhabha events



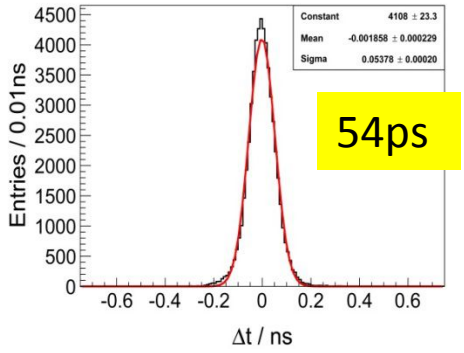


STAR: Simple interpolation



80ps

New calibration

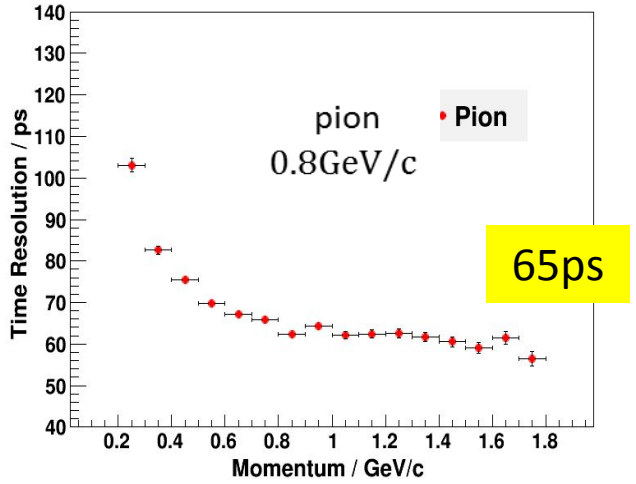


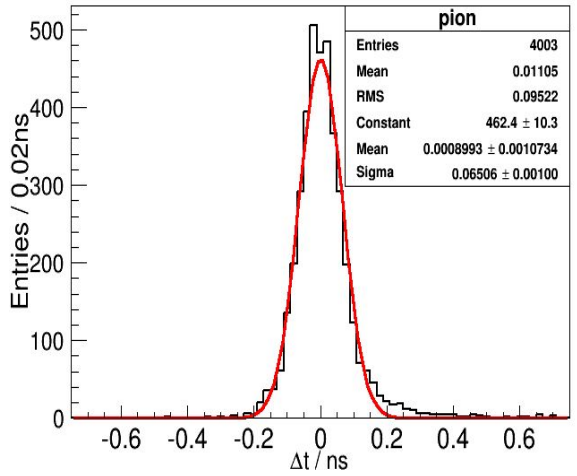
54ps

- **New calibration method**
- **Time-charge-position correlation**
- **Better resolution**

MRPC – time resolution of hadrons

Designed time resolution: 80~100 ps for pions at 800MeV

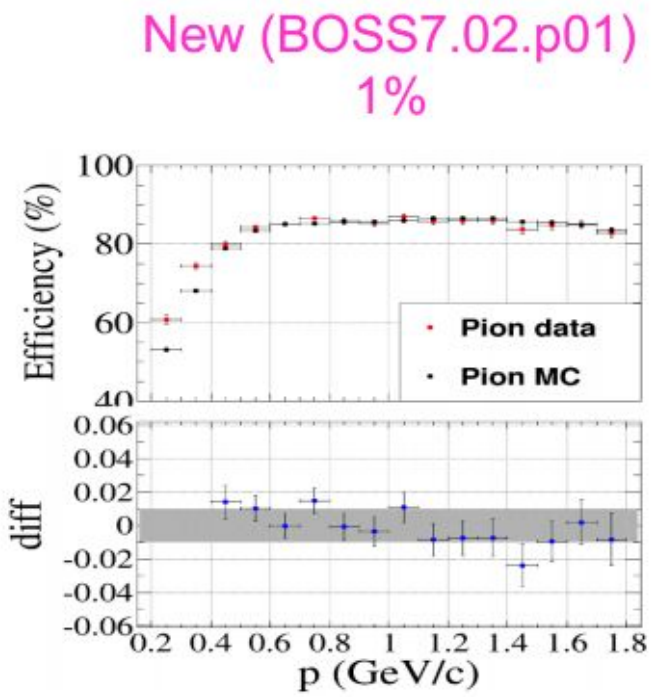




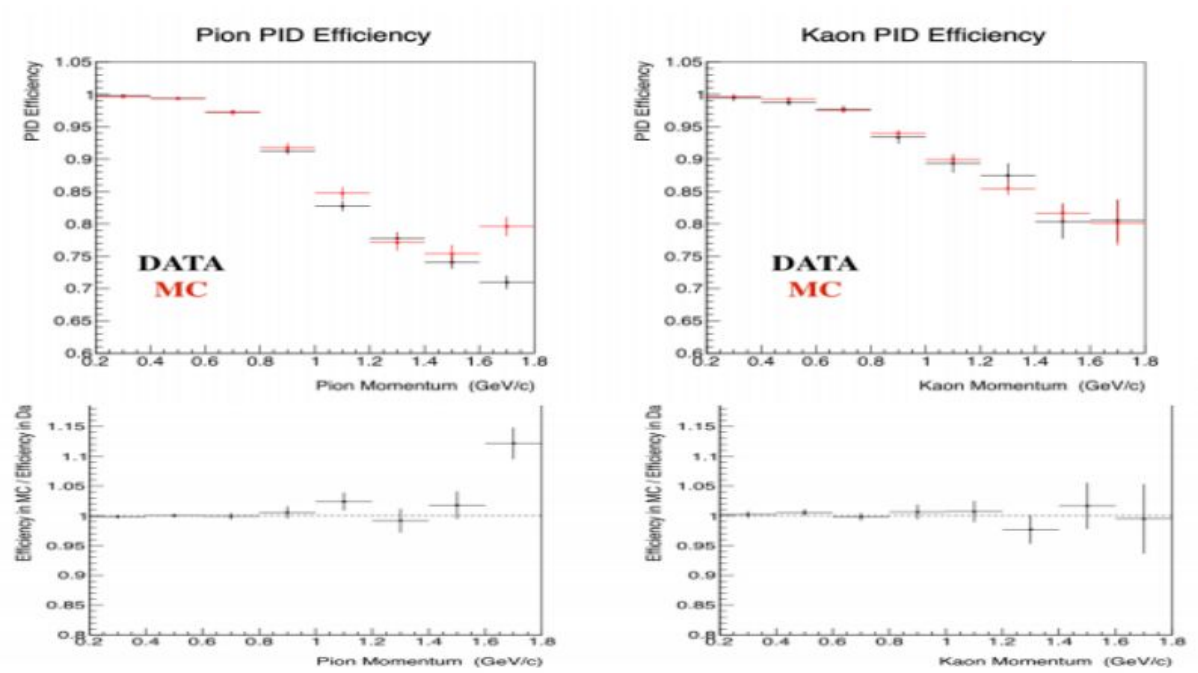
	Exp	Res.
RHIC	STAR	74~94ps
LHC	ALICE	86ps
BEPCII	BESIII	**65ps**

PID Efficiency (data/MC)

PID efficiency (MRPC-only)
Data: 4.180 GeV (2016)



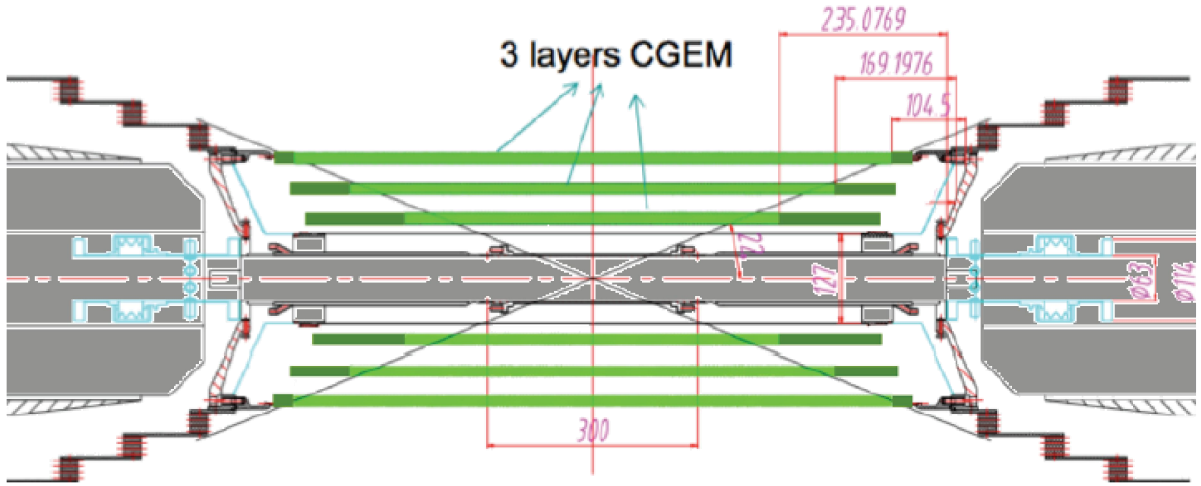
PID efficiency (TOF/MRPC+dE/dx)
Data: XYZ (2017)



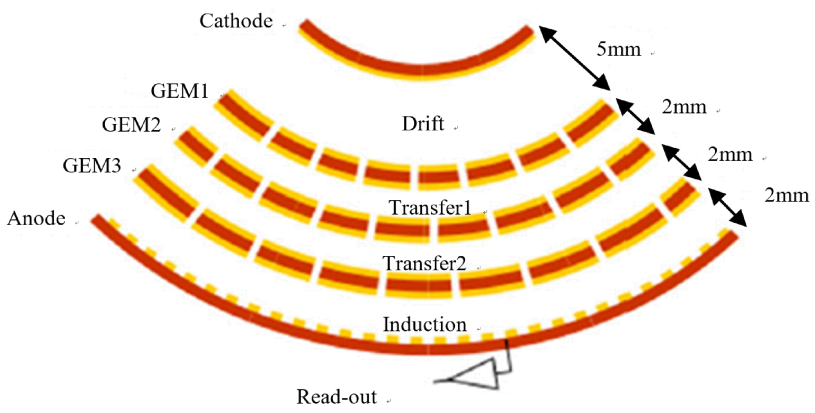
Data/MC difference: ~1% for p < 1.5 GeV/c

MDC-IT upgrade – CGEM-IT

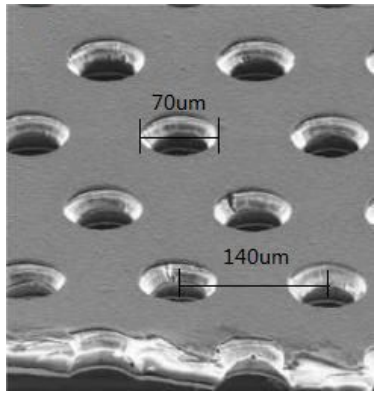
- Triple-layer Cylindrical GEM detector
  Acceptance 93%
  σ_{xy} ~ 130 μm
  σ_z < 1 mm
  Designed by Italian group



- Each CGEM layer：
  Cathode、3 layer GEM molar，anode
  2-d readout strips for time and charge



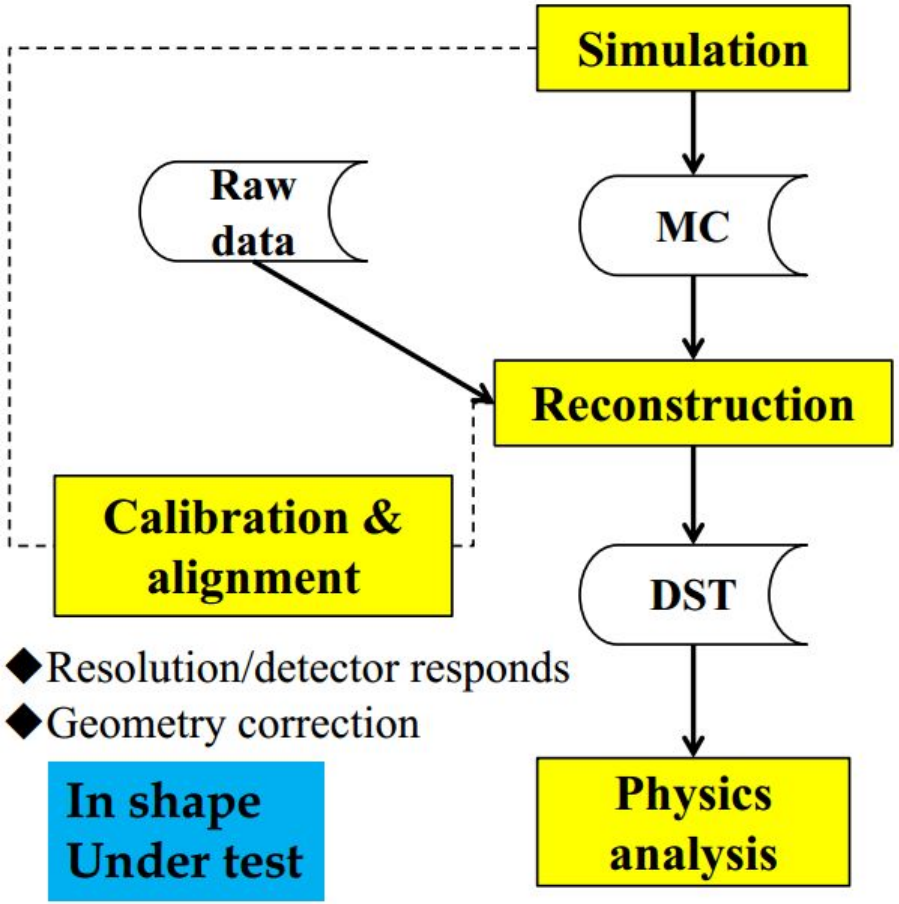
- Electron multiplication
  by electrical field in GEM



Complex structure / response
Challenge to software developers

CGEM offline software

part of the BESIII Offline Software System (BOSS)



- Detector description (Geometry/material)
- Digitization

All modules implemented in refinement and optimization

- Cluster reconstruction
- Track segment finding with CGEM
- Track matching
- Global track finding with Hough transform
- Track fitting

- Resolution/detector responds
- Geometry correction

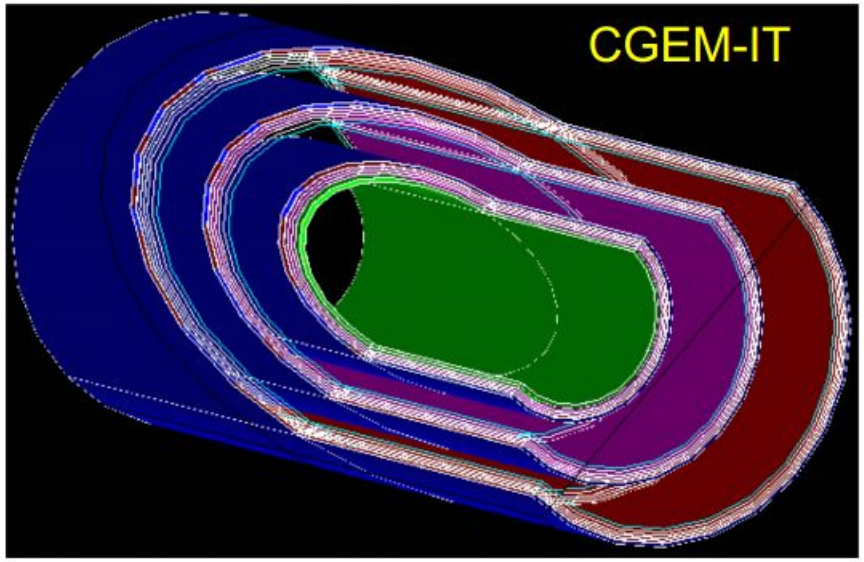
In shape Under test

- performance check (efficiency, resolution ...)

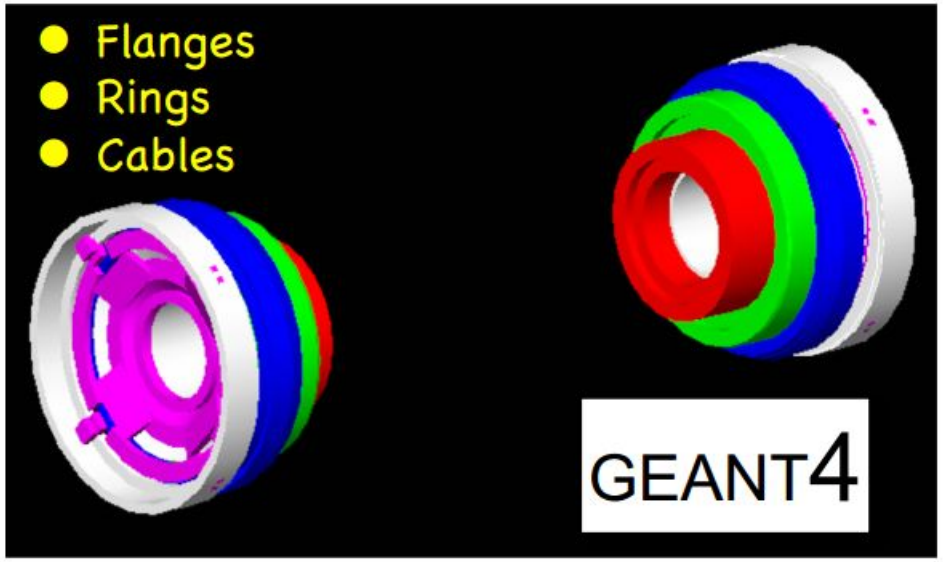
Many tests performed/prepared

GEANT4 description of CGEM

✓ CGEM-IT (sensitive part)



✓ Passive elements



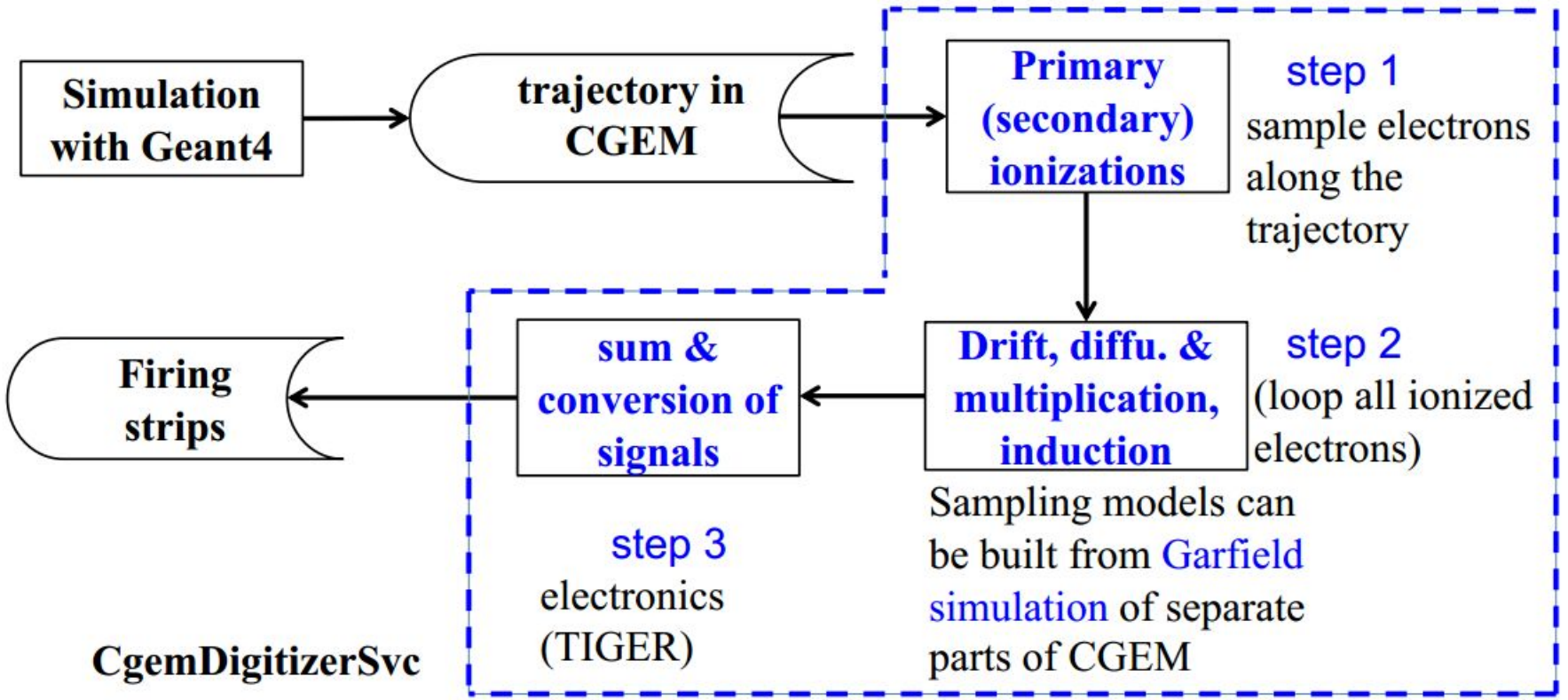
✓ Inner barrel of Outer-Drift-Chamber

✓ CGEM geometry service package (CgemGeomSvc)

- manage geometry parameters (including misalignment effects)
- provide geometry information and calculation
- Same for simulation, reconstruction, calibration, and alignment

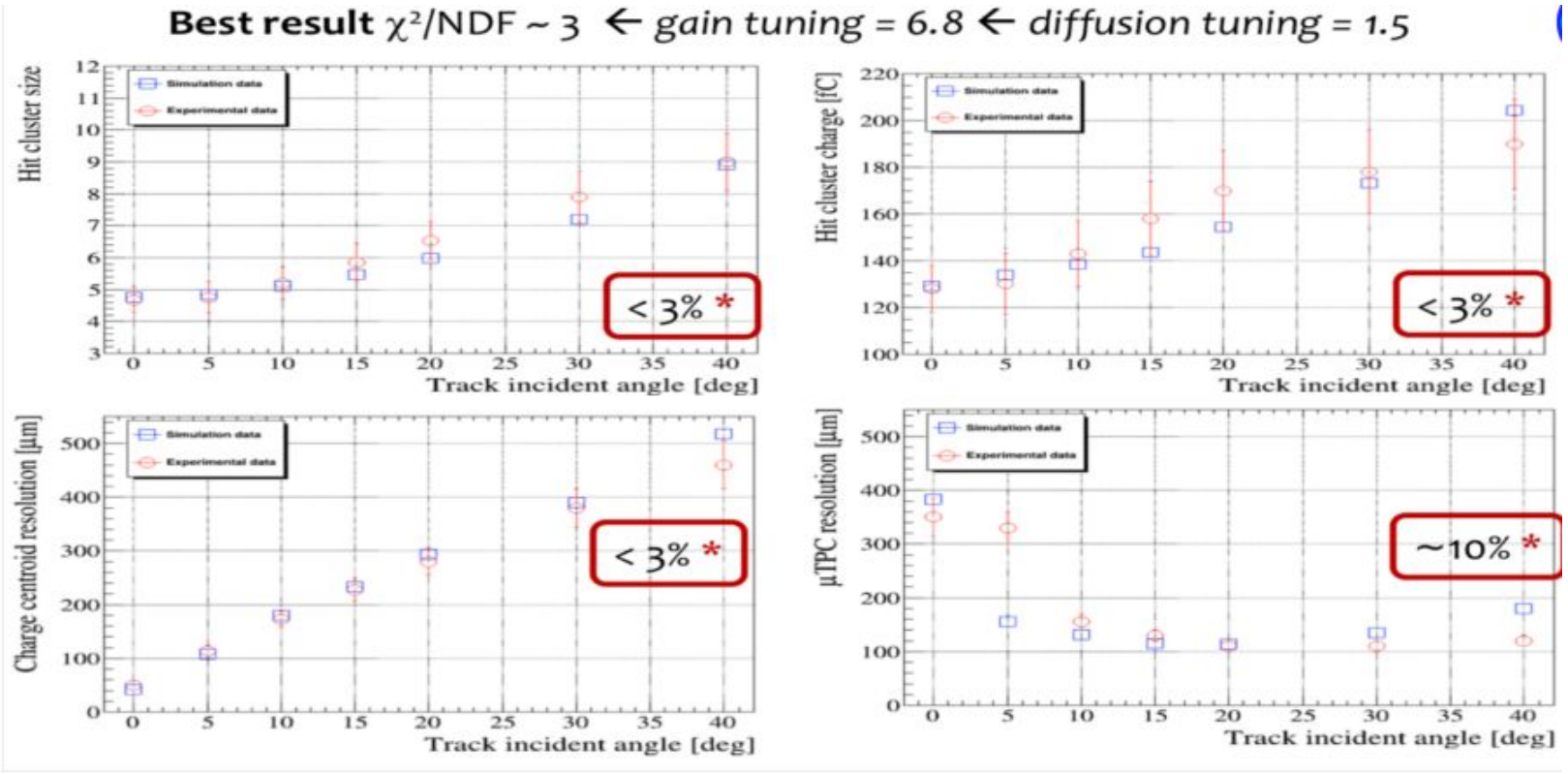
Full digitization

Most important part, the MC results from Garfield



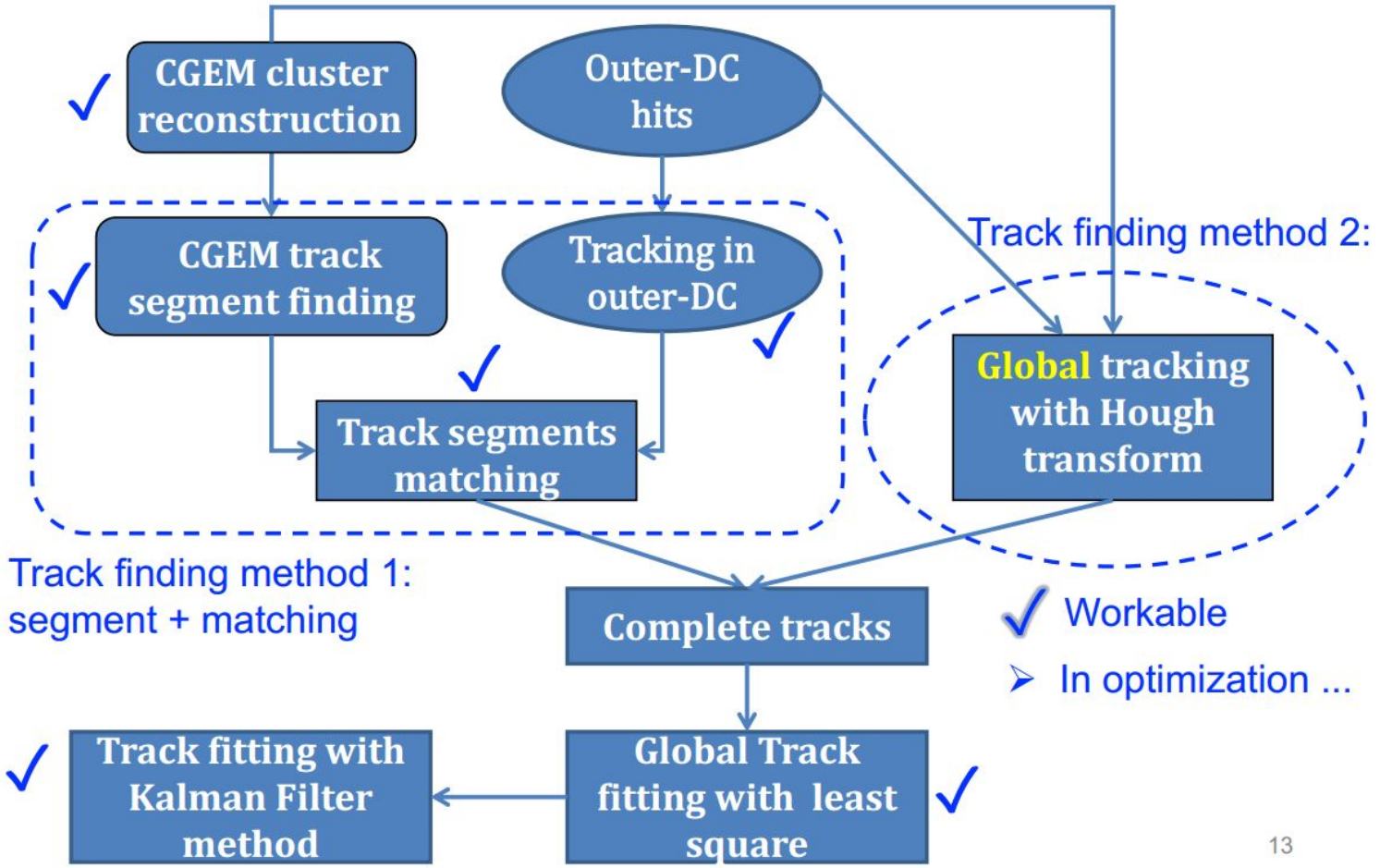
Comparison with test beam

Better agreement ~ 3% for planar GEM (from Lia)



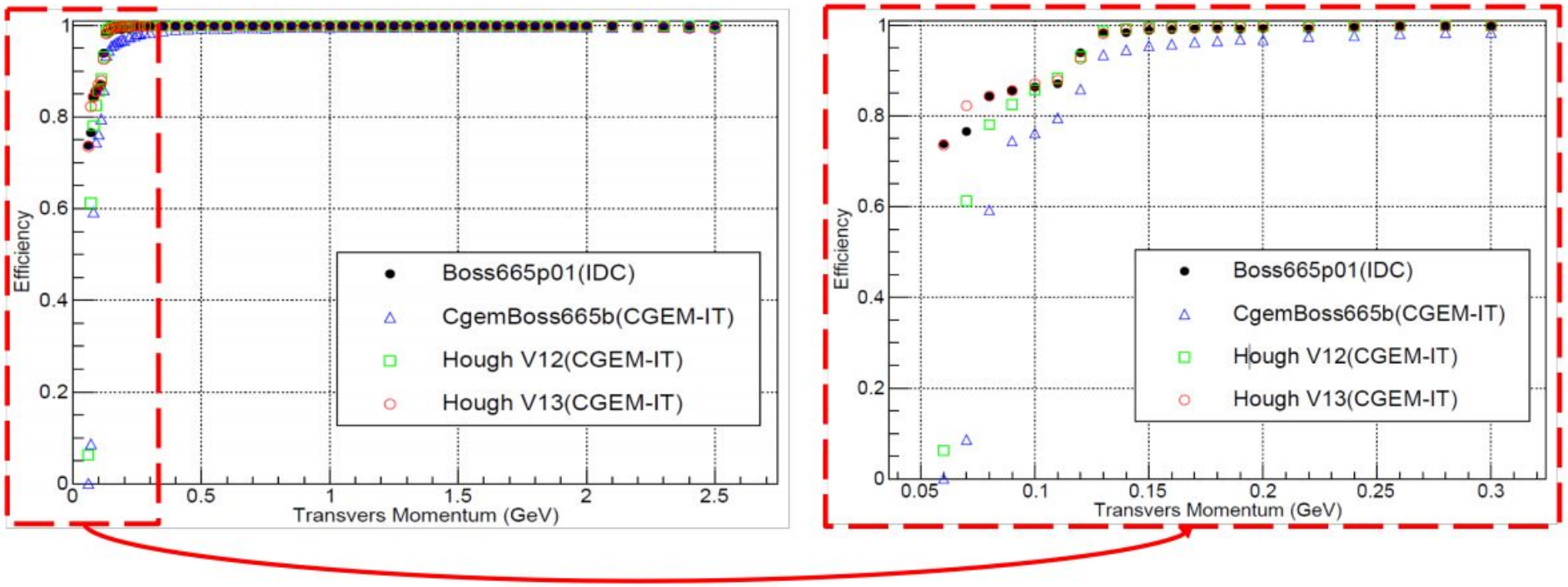
Track reconstruction (CGEM+ODC)

Global tracking with Hough transform



Track finding efficiency (CGEM+ODC)

For single track (MC), same level with BOSS 6.6.5p01

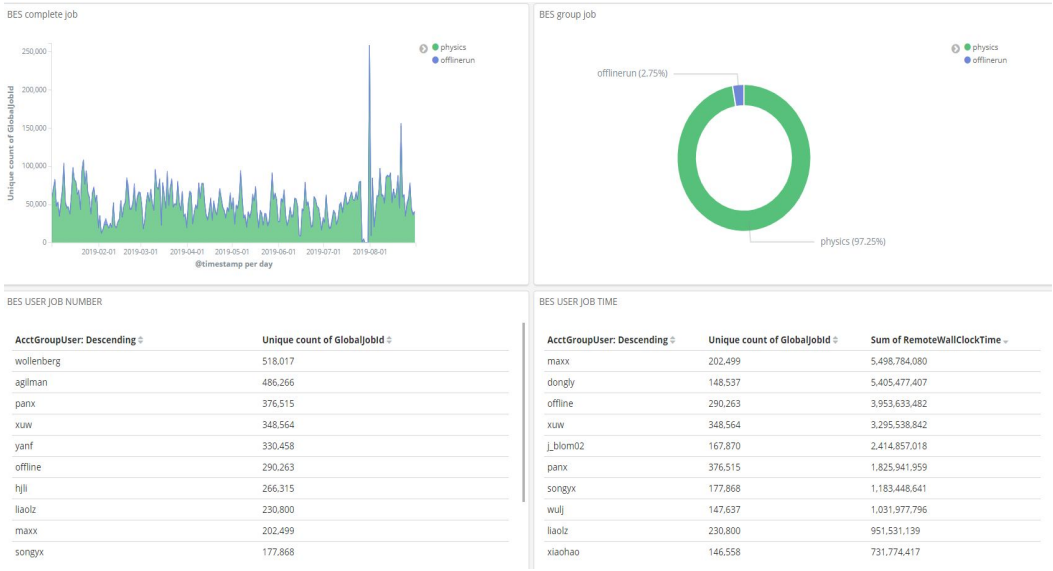


For track fitting, more work needed

Computing

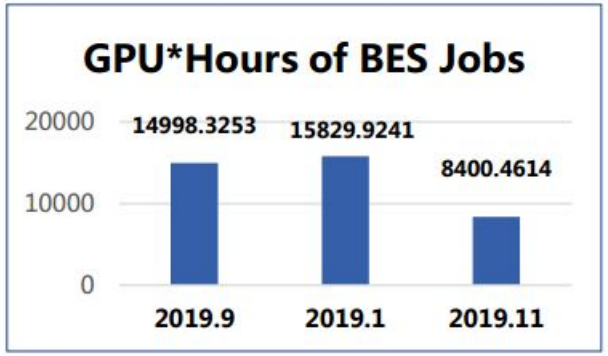
Central computing (IHEP)

- **HTCondor cluster**
  - CPU: ~8000 cores
  - Storage ~8.5 GB
  - Data production (Calib/Rec/MC)
  - Physics analysis (all collaboration members)



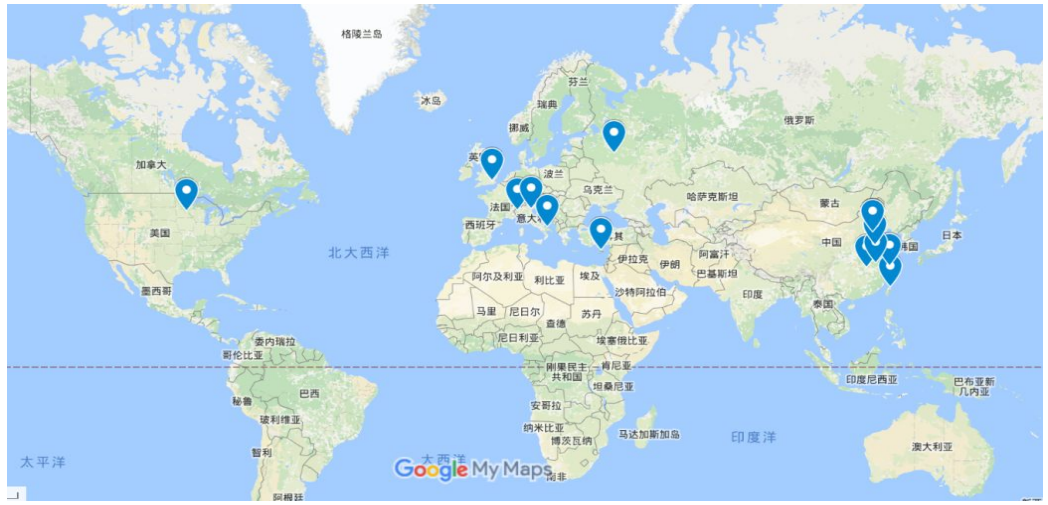
- **GPU cluster**
  - 1 control nodes , 2 login nodes
  - ~ 100 GPU cards (NVIDIA v100)
  - PWA (partial wave analysis)
  - ML (Machine learning)

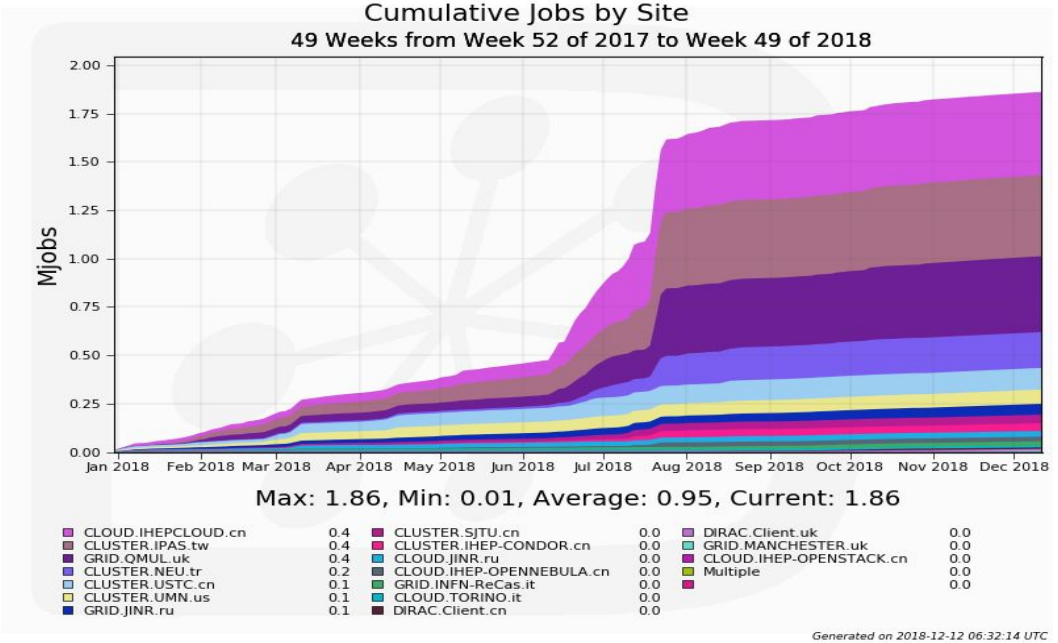
GPU hours of jobs: ~ 39,200
~ 35% of all occupied resources



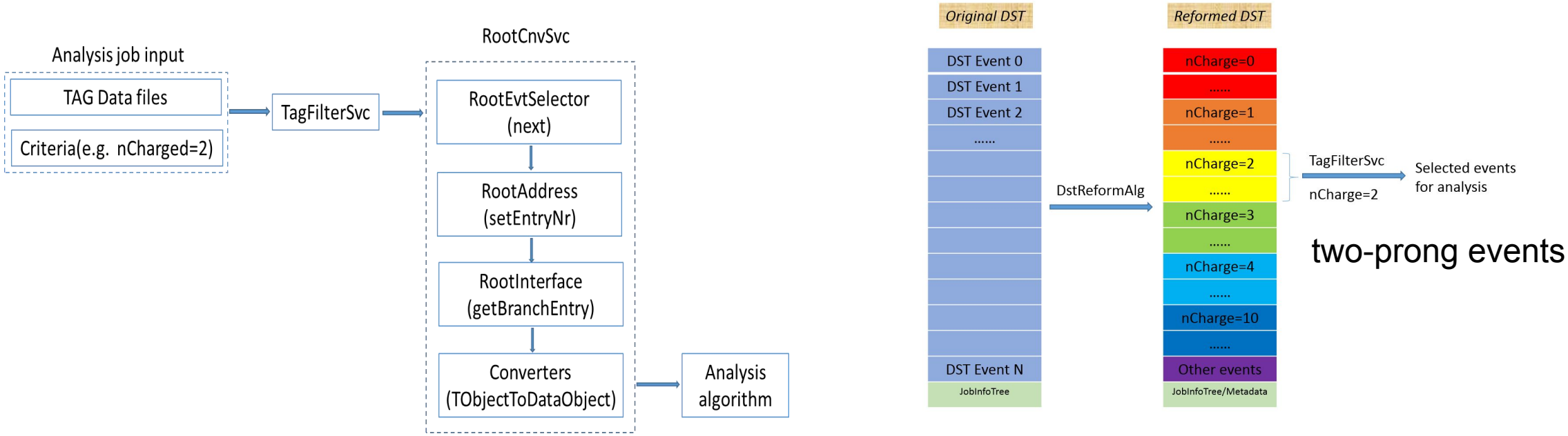
BESIII distributed computing

- 15 remote nodes: Russia, Italy, US, and Chinese universities
- CPU ~3000 cores，Storage ~500TB
- Mainly for MC production and physics analysis



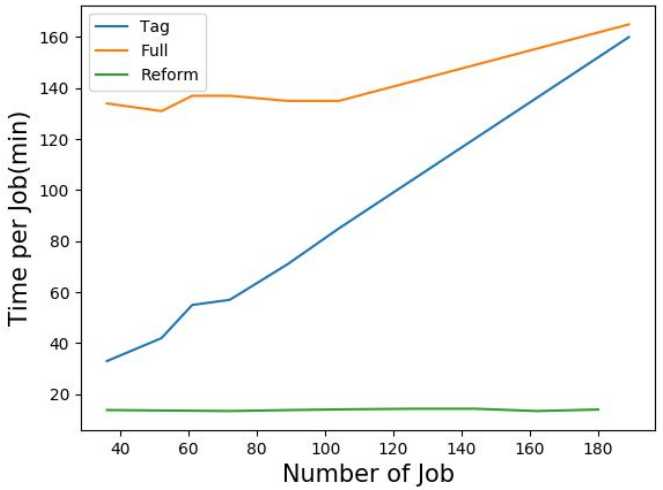


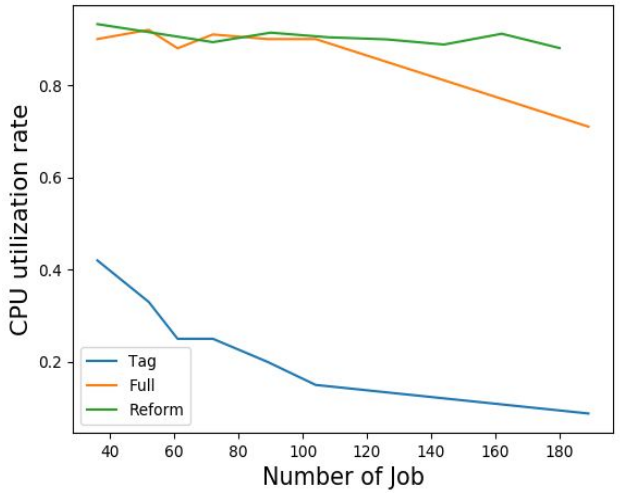
TAG based analysis

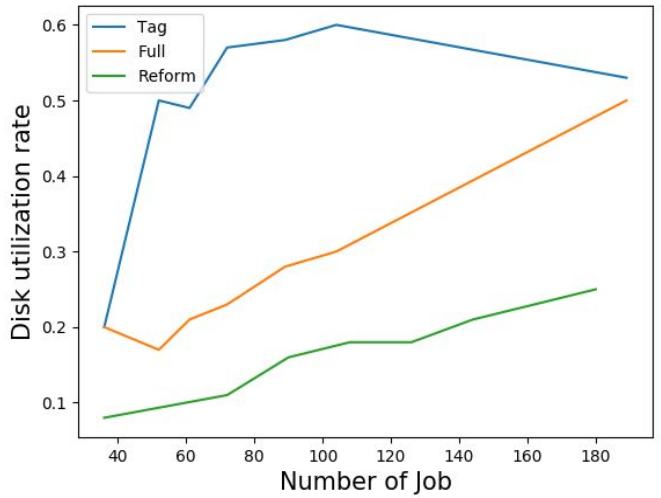


- Data I/O is the bottleneck in analysis: reading all events in a huge data sample
- TAG every event in DST, only the interested events are read into memory
- Non-consecutive event reading is still time-consuming, should be avoided
- Re-ordering the events by TAG information to save reading time
- New event ordering structure in DST, no information lost

Test of Tag based analysis







Tag
Full
Reform

- Performance at different number of jobs
- The speed of analysis jobs increases by 3-30 times
- Will be used in analysis - physics groups provide TAG info

Summary

- We are still working to improve offline software and data quality
- We are developing new software for the detector upgrade
- We are developing new method to speed up physics analysis
- BESIII has a powerful computing to face the future data challenge

Я люблю Россию
我 爱 俄 罗 斯

Спасибо
谢 谢