Marlin Tracking Software in CEPCSW

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IHEP, CAS

Joint Workshop of the CEPC Physics, Software and New Detector Concept

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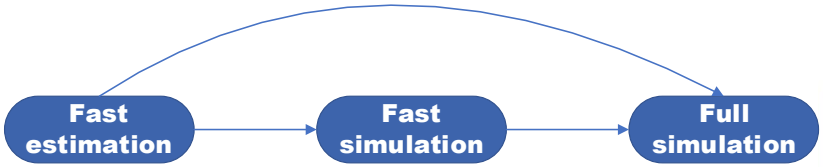
Outline

- Introduction
- Tracking software
  - Tracking tool
  - Tracking option
- Performance study
  - Particle gun
  - $H \rightarrow \mu\mu$
  - Vertex detector
  - Non-uniform field
  - Background
- Summary

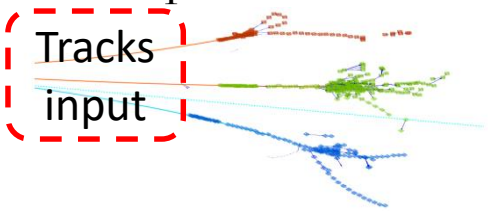
Introduction

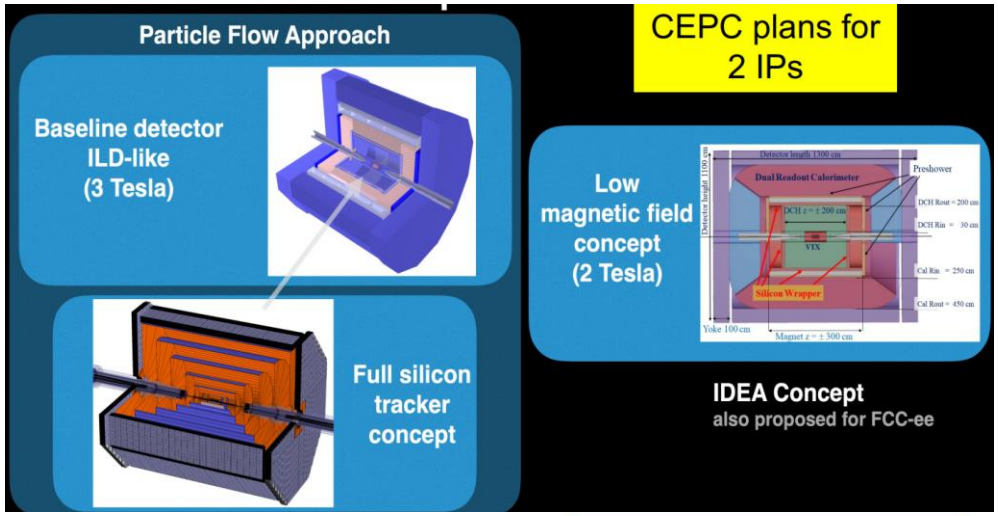
Physics process	Measurands	Requirement on tracker
ZH, $Z\to e^+e^-(\mu^+\mu^-)$, $H\to\mu^+\mu^-$	m_H, $\sigma(ZH)$, BR($H\to\mu^+\mu^-$)	$\Delta(1/p_T) = 2\times10^{-5} \oplus \frac{0.001}{p(GeV)\sin^{3/2}\theta}$

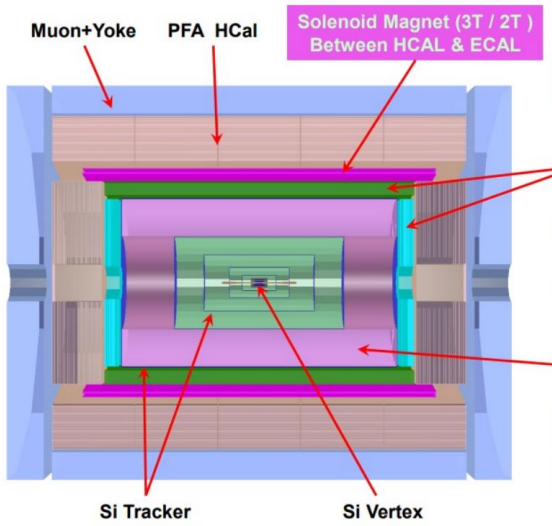
- CEPC being designed as Higgs&Z factory, has basic physics requirements, such as tracking resolution.
- Three detector concepts were designed at CDR stage, and the 4th conceptual detector design has been proposed since 2021.
- Track reconstruction for estimation on detector performance at post age of CDR, exactly as at CDR stage



- Tracker design: track performance estimation
- As PFA input







Advantage: the HCAL absorbers act as part of the magnet return yoke.
Challenges: thin enough not to affect the jet resolution (e.g. BMR); stability.

Transverse Crystal bar ECAL

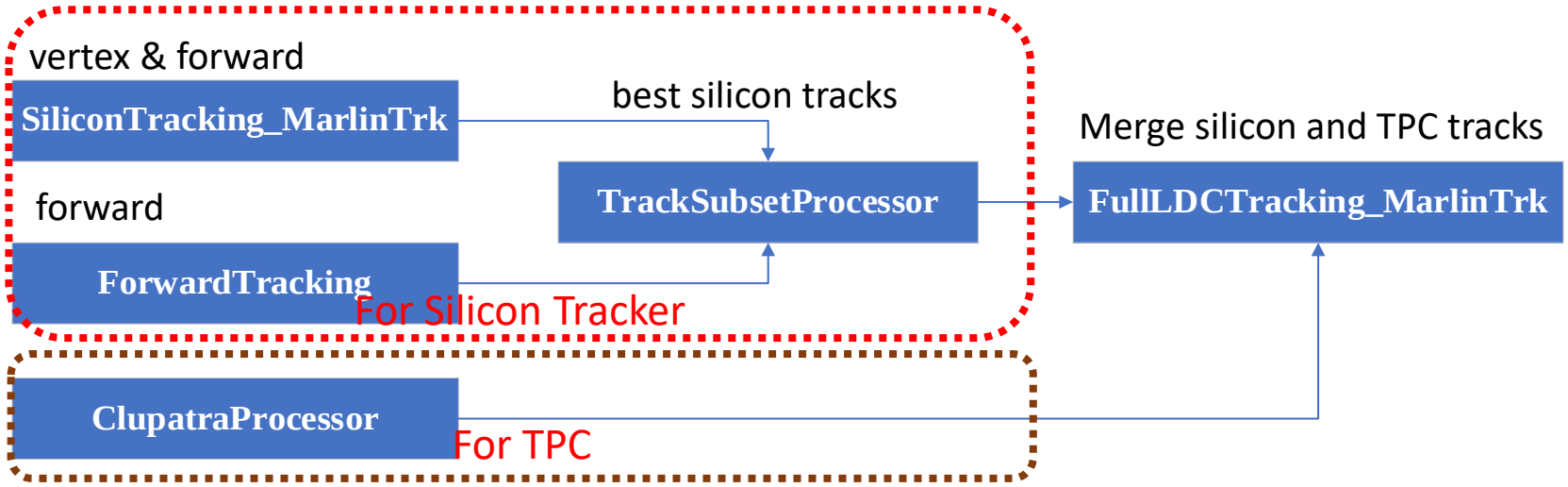
Advantage: better π^0/γ reconstruction.
Challenges: minimum number of readout channels; compatible with PFA calorimeter; maintain good jet resolution.

Drift chamber
that is optimized for PID

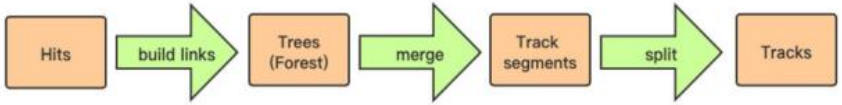
Advantage: Work at high luminosity Z runs
Challenges: sufficient PID power; thin enough not to affect the moment resolution.

History: Tracking for CDR in Marlin

- From ILCSoft
  - Use different tracking for different trackers, and then merge

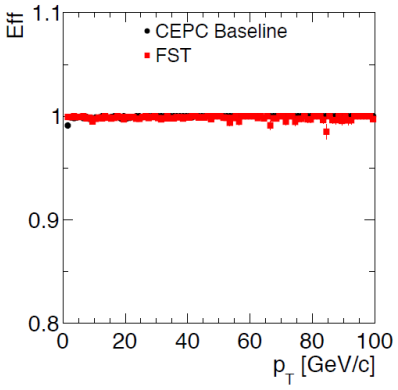


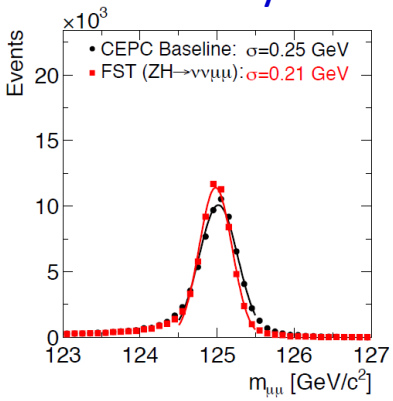
- Developed inspired by the idea of Arbor
  - ArborTracking algorithm



- Implement ConformalTracking
  - Test for the full silicon tracker (FST) concept

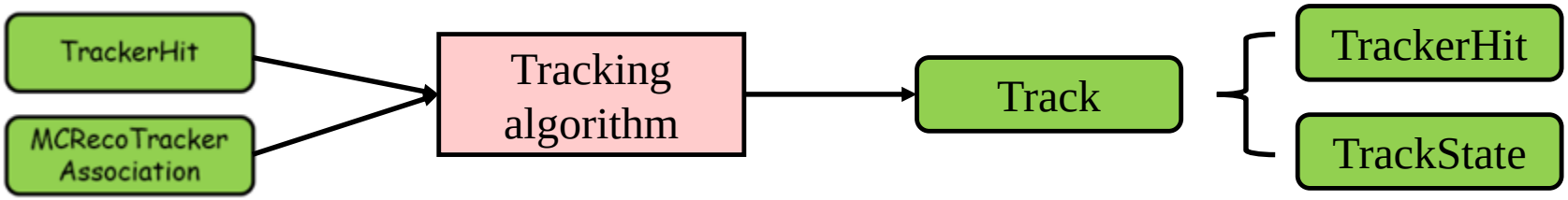
CDR full simulation study





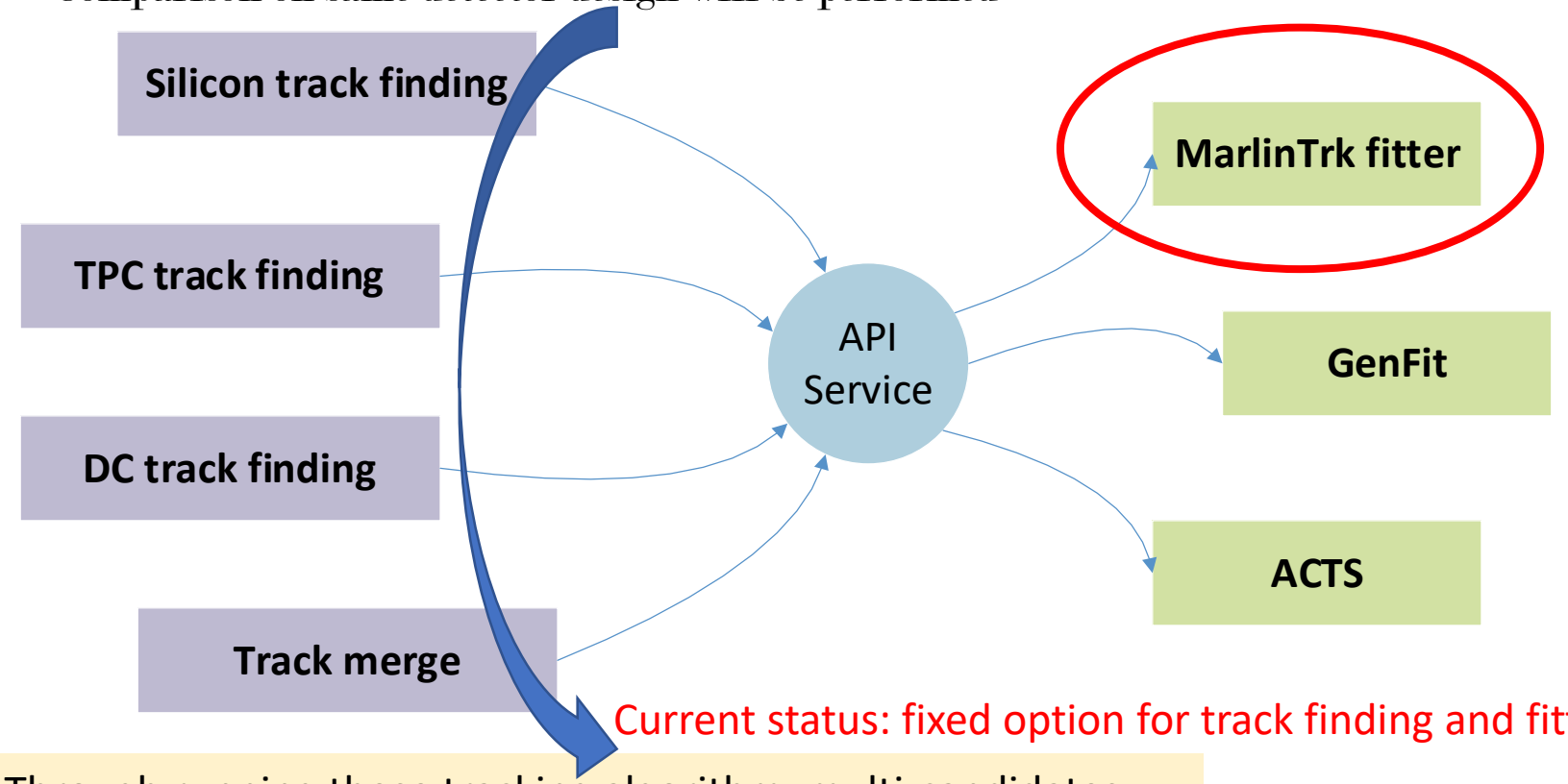
Tracking in CEPCSW

- CEPCSW
  - Core software, Applications, External libraries
  - EDM4hep and DD4hep are directly relative with tracking software development.
- Realize EDM4hep input and output
- A complete tracking chain same as CDR (Marlin)
- GaudiAlgorithm
  - initialize() to prepare parameters and services/tools
  - execute() to deal with input data (after digitization, edm4hep::TrackerHit)
    - ✓ Create auxiliary objects
    - ✓ Track finding → track candidates
    - ✓ Track fitting → edm4hep::Track (through call fitter interface)
  - finalize() to delete auxiliary objects



Propose of Tracking Chain

- Service to call the API of fitter according to option
- Possible to combine differently from track finding to fitting
  - For middle tracking, low CPU time
  - For final tracking, high performance
- Comparison on same detector design will be performed



Current status: fixed option for track finding and fitting

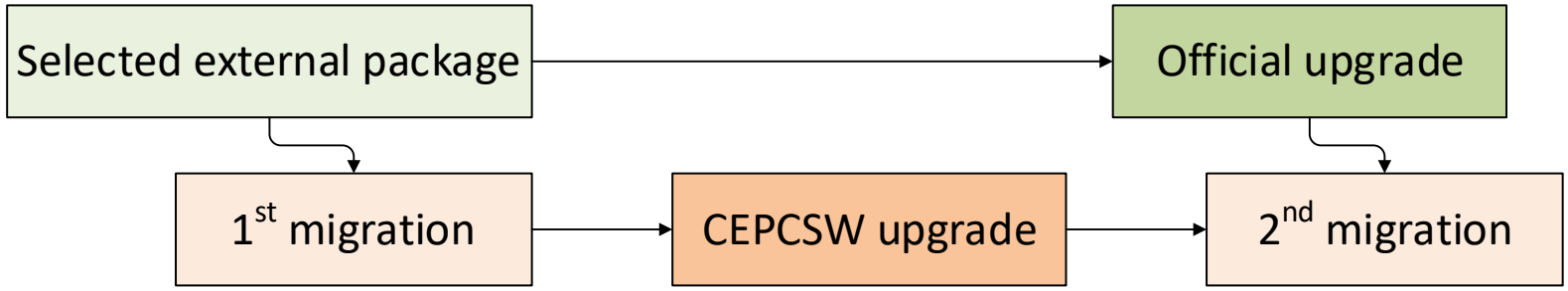
Through running these tracking algorithm, multi-candidates track with different measurement options will be obtained

Migration/Implementation

SiliconTracking → ForwardTracking → TrackSubset → Clupatra → FullLDCTracking

- Migrated full tracking chain from Marlin
  - Switch class to GaudiAlgorithm
  - Switch data model to EDM4hep (first realized)

Done and work!



extra merge not friendly

  - ConformalTracking migrated into CEPCSW, work well for single particle, more ongoing
- Another implement way is in considering, to test coversion cost
  - Create a GaudiAlgorithm to covert data model and call
    - ✓ EDM4hep→LCIO→call event loop function→LCIO→EDM4hep
- Key4hep (best) in plan
  - CallingAlg to call prepared API
  - event model support with same code is important

Frank Gaede, ECFA

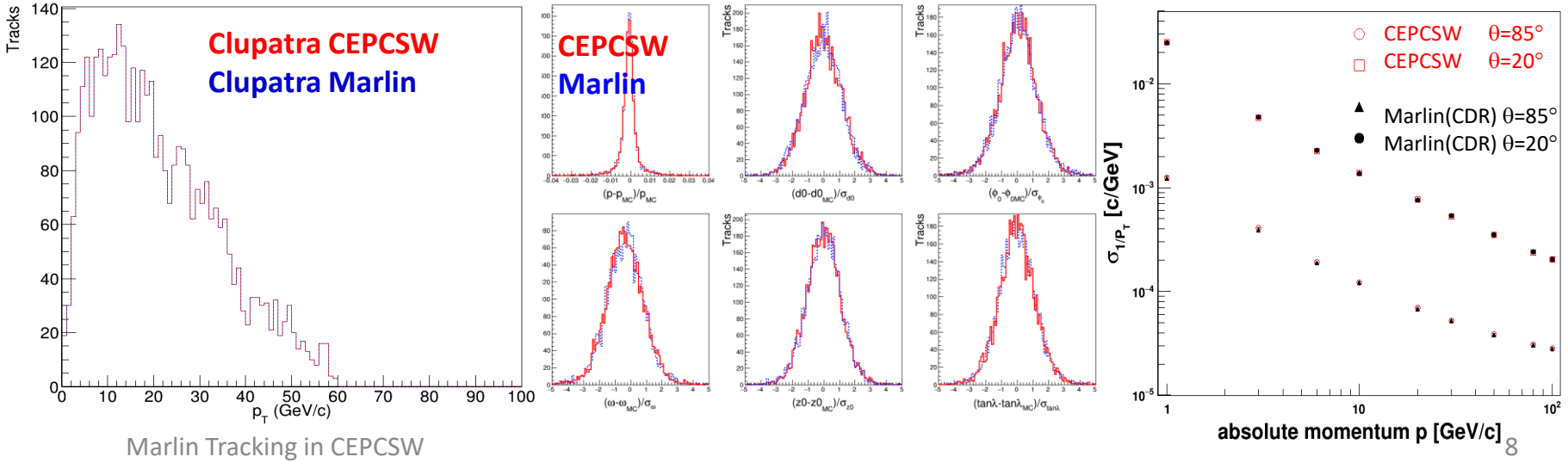
ILD also consider

- need to preserve existing pattern recognition tools in transition to Key4hep
- initially via MarlinWrapper - later via direct ports to Key4hep/EDM4hep

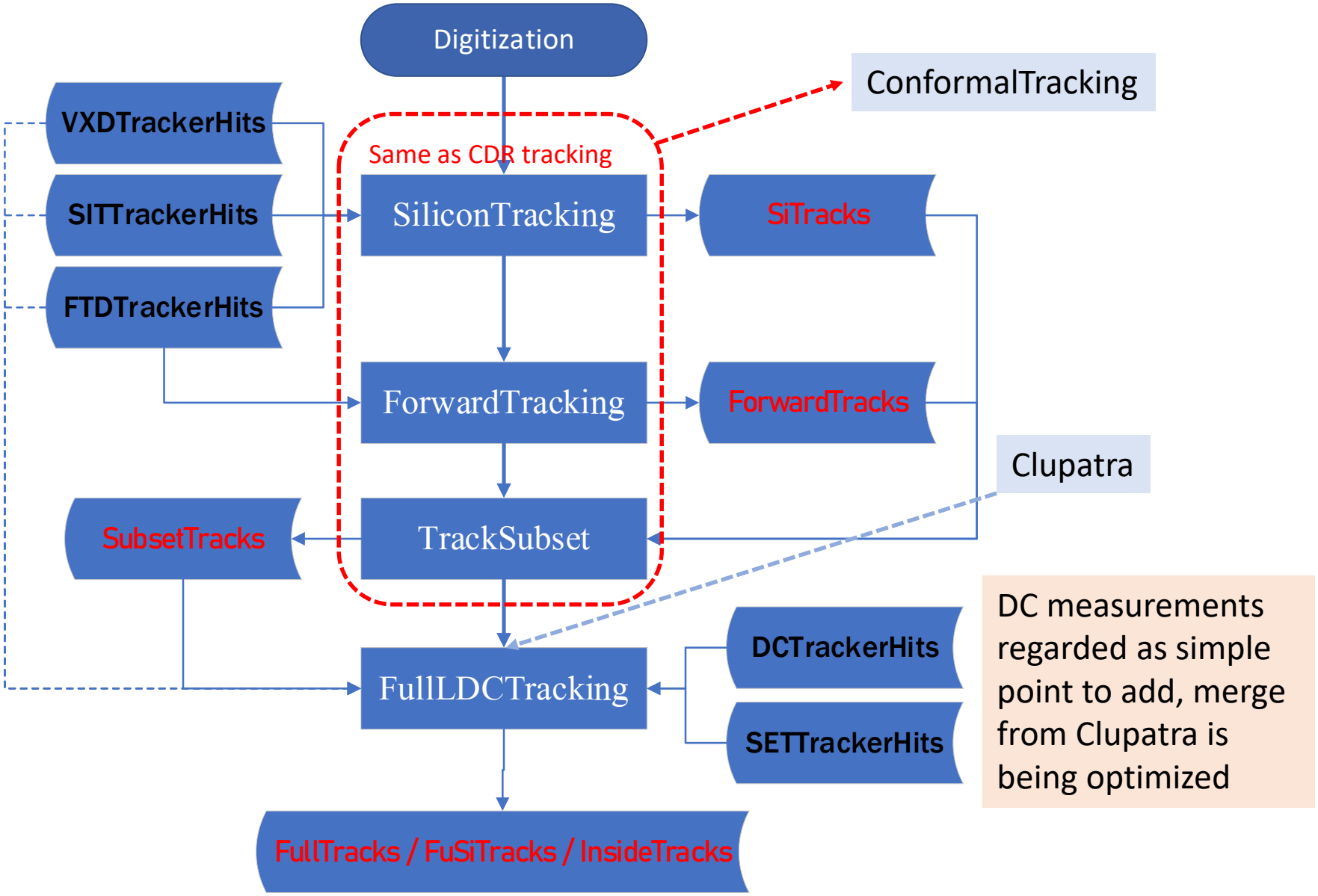
Migrated MarlinTrk

- Create service to convert DD4hep extension to Gear as KalTest geometry input
- Create service to create MarlinKalTest object, called by tracking algorithm
- Switch data model to EDM4hep
- After migration
  - Fully identical on same digitized input
  - consistent on different input (different random)
- Upgrade to DD4hep surface (DDKalTest) is in plan

Repeat complete CDR tracking chain in CEPCSW, therefore tracking study for the CDR baseline detector is possible to perform in CEPCSW now.



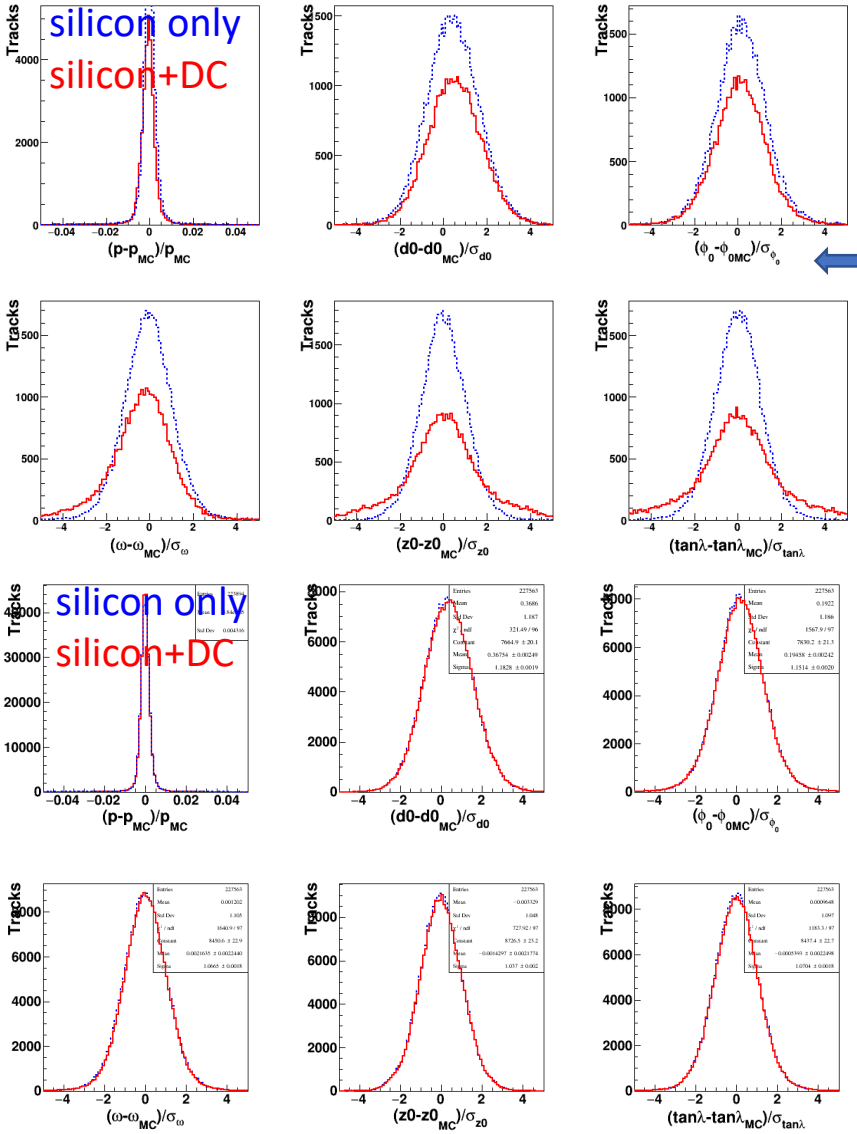
Option for the 4th Conceptual Detector

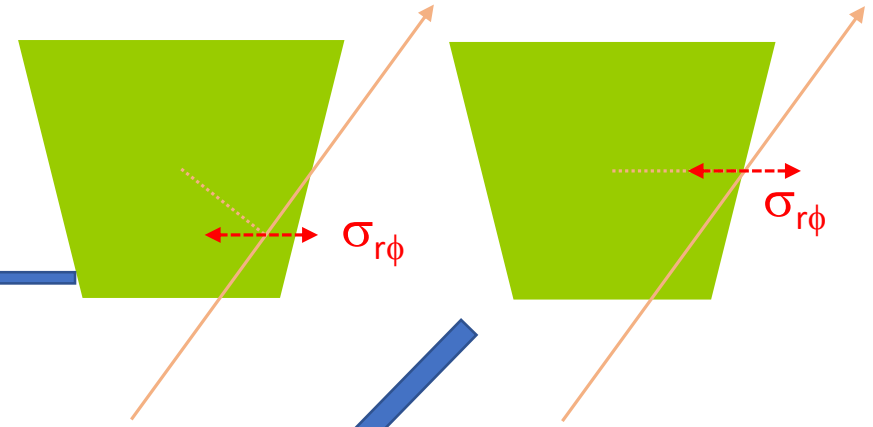


DC measurements regarded as simple point to add, merge from Clupatra is being optimized

Simplification of DC Measurement

- Work for CylinderMeasLayer

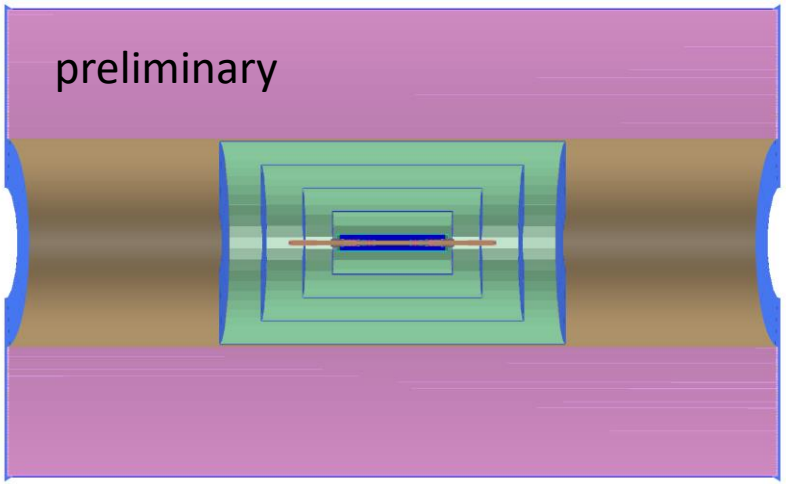


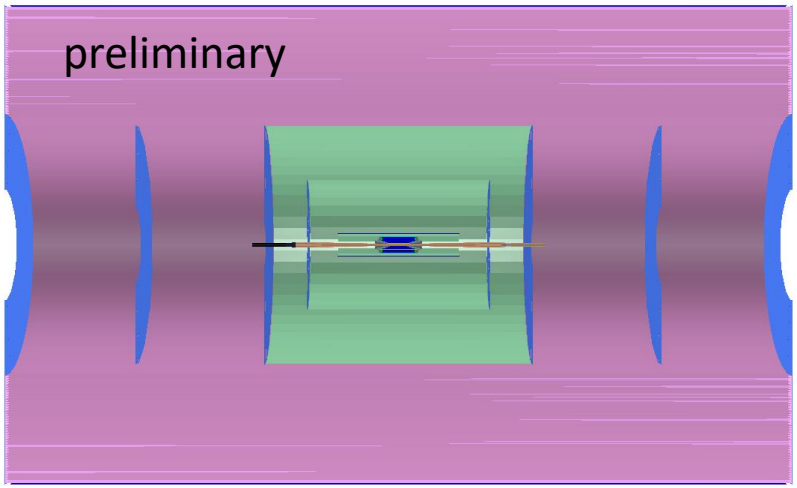


Ability to perform on bent CMOS sensor

Magnus Mager's talk

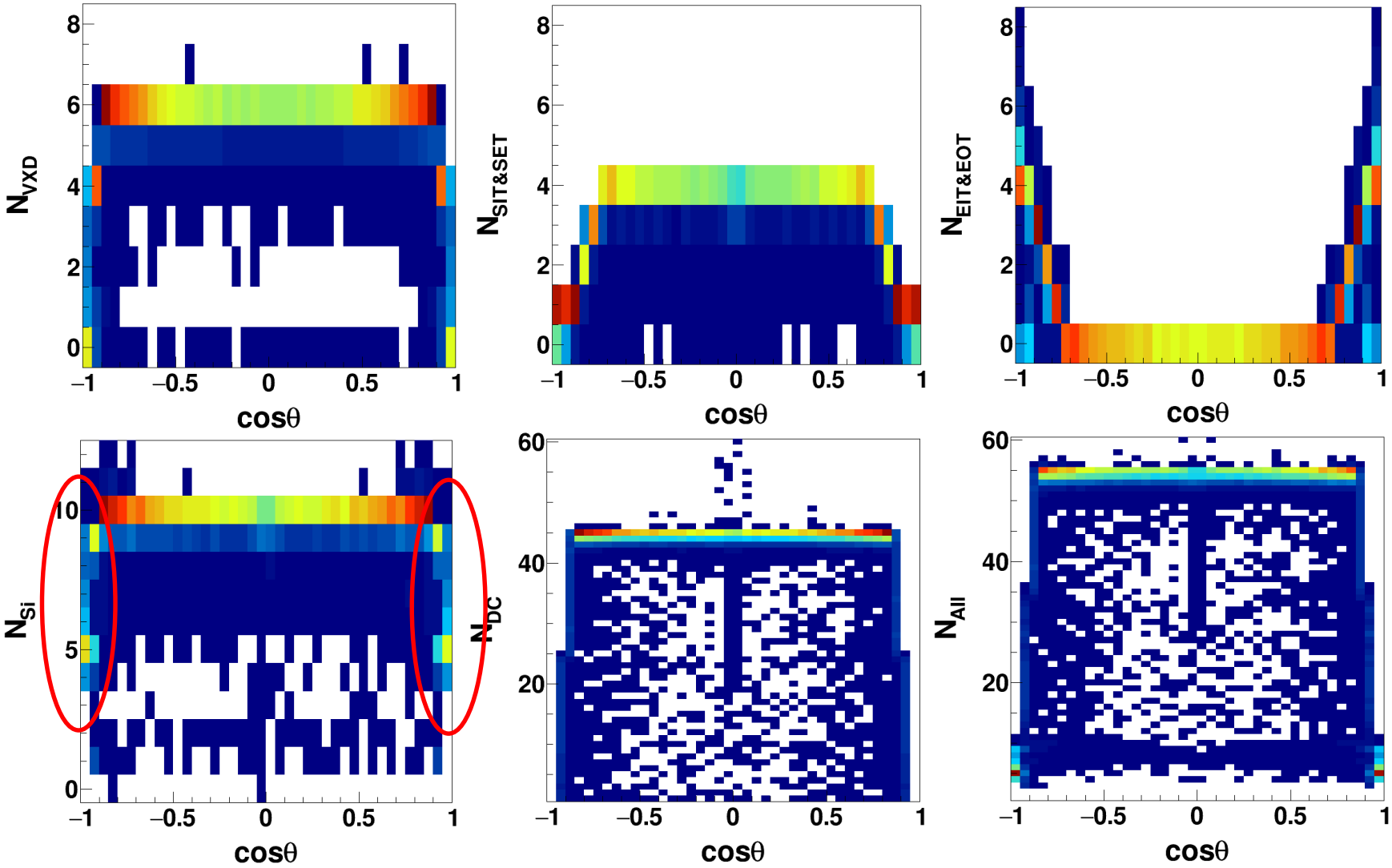
Track System





- Status: workable for optional detector concepts
- Vertex detector (VXD): 6 pixel layers
  - $\sigma_{rphi,z}$=2.8μm, 6μm, 4μm, 4μm, 4μm, 4μm
- Silicon inside/internal DC tracker (SIT): 4 or 3 pixel layers
  - σ_{rphi} =7.2μm, σ_z=86μm
- Silicon outside/external DC tracker (SOT/SET): 1 pixel layer
  - σ_{rphi} =7.2μm, σ_z=86μm
- Endcap tracker (EIT&EOT/FTD): 2 + 3 pixel layers
  - $\sigma_{x,y}$=3μm, 3μm, 7.2μm, 7.2μm, 7.2μm
- Drift chamber (DC): 18mm or 10 mm cell size
  - σ_{rphi} =100μm, σ_z=2.828mm

Hits Number in Fit

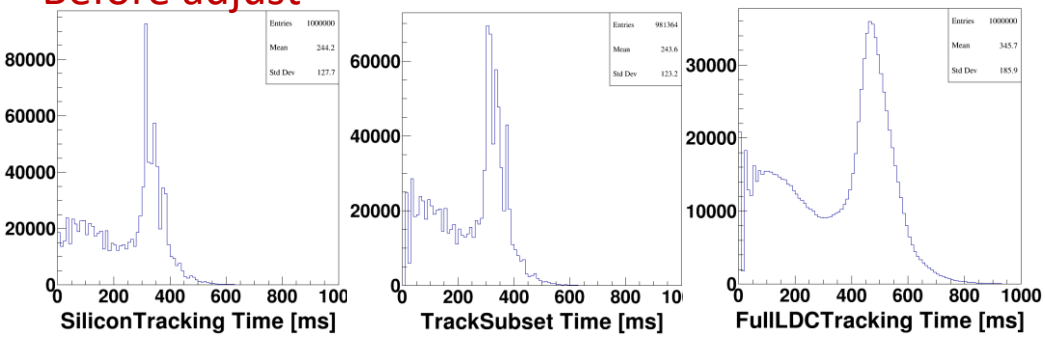


- **Barel**: ~10 silicon hits used in fit; **Endcap**: 10 or less, determined by vertex cover range

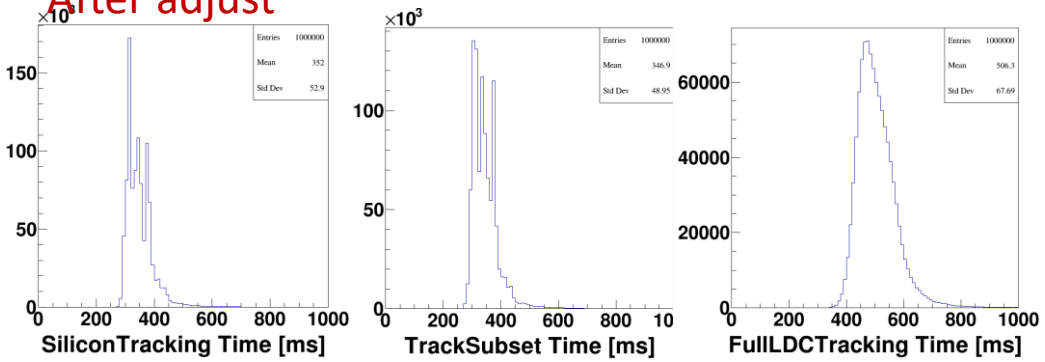
Efficiency VS Time Cost

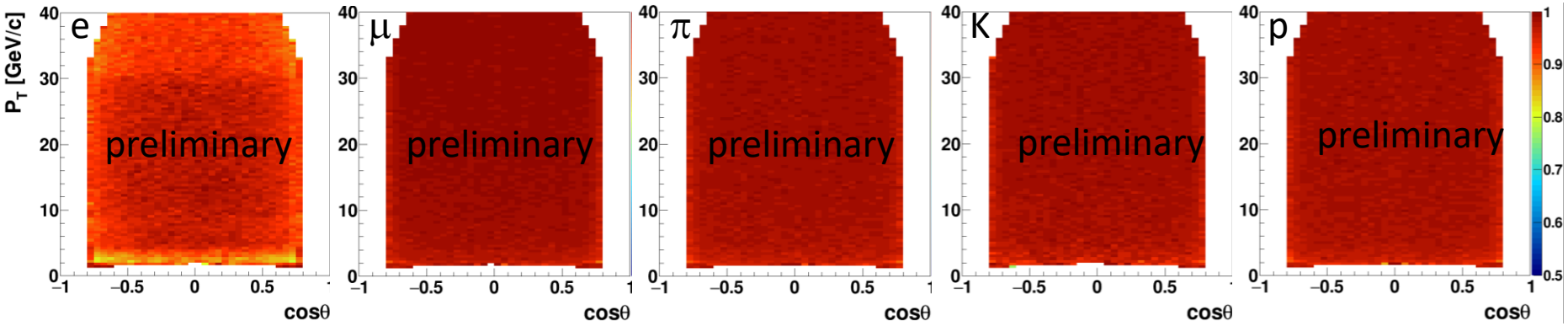
- 20 particle in each event
  - p∈[2,50] GeV/c
  - θ∈[40°,140°]
  - Independent: $(e^+,e^-,\mu^+,\mu^-,\pi^+,\pi^-,K^+,K^-,p^+,p^-)\times 2$
  - Vertex: (beam parameter @Higgs)
    - ✓ σx=15μm
    - ✓ σy=36nm
    - ✓ σz=3.9mm
- Tracking efficiency
  - Match: >50% of hits shares between MC truth and tracks
  - Improve through adjust pattern recognition

Before adjust

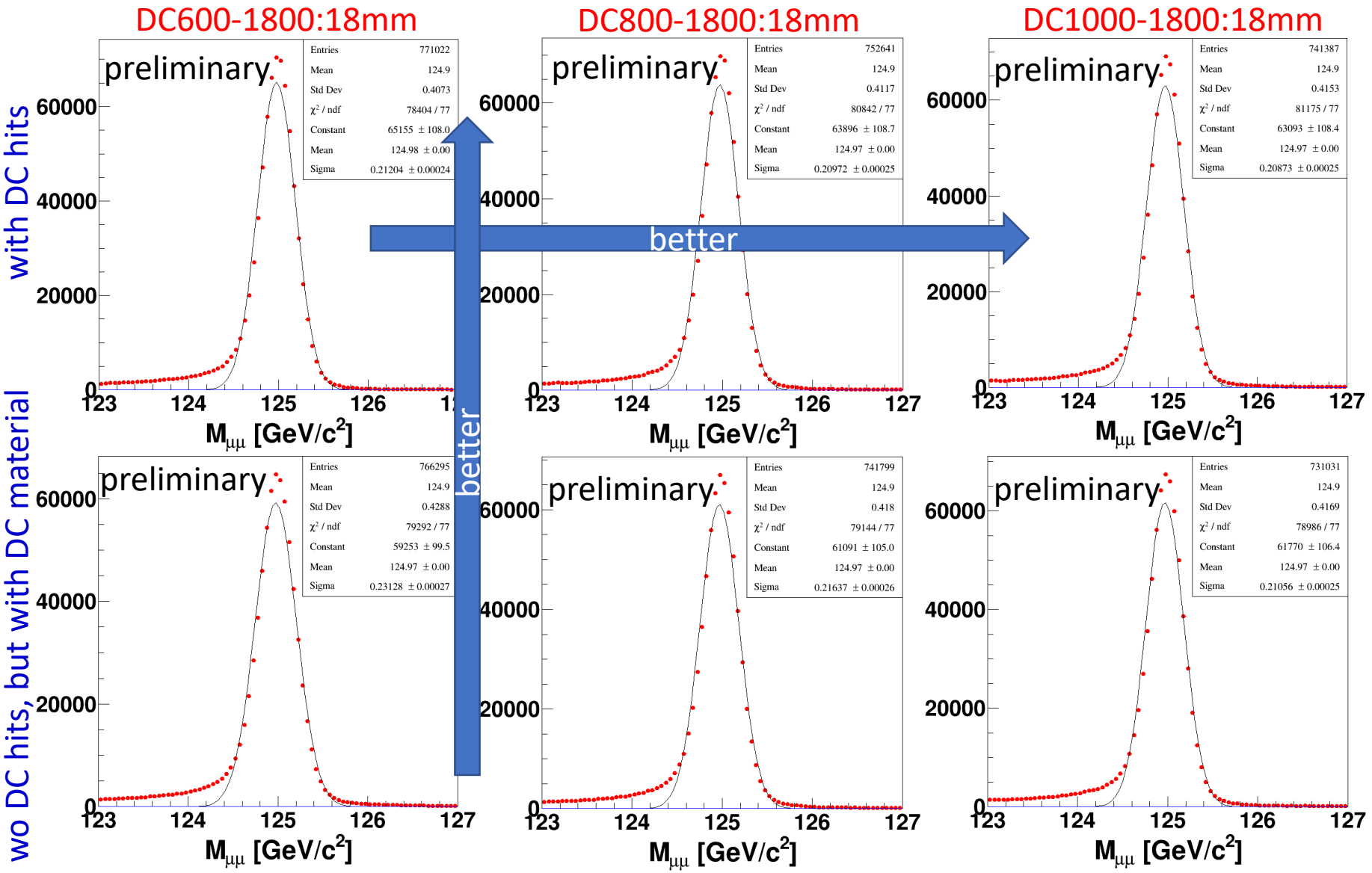


After adjust



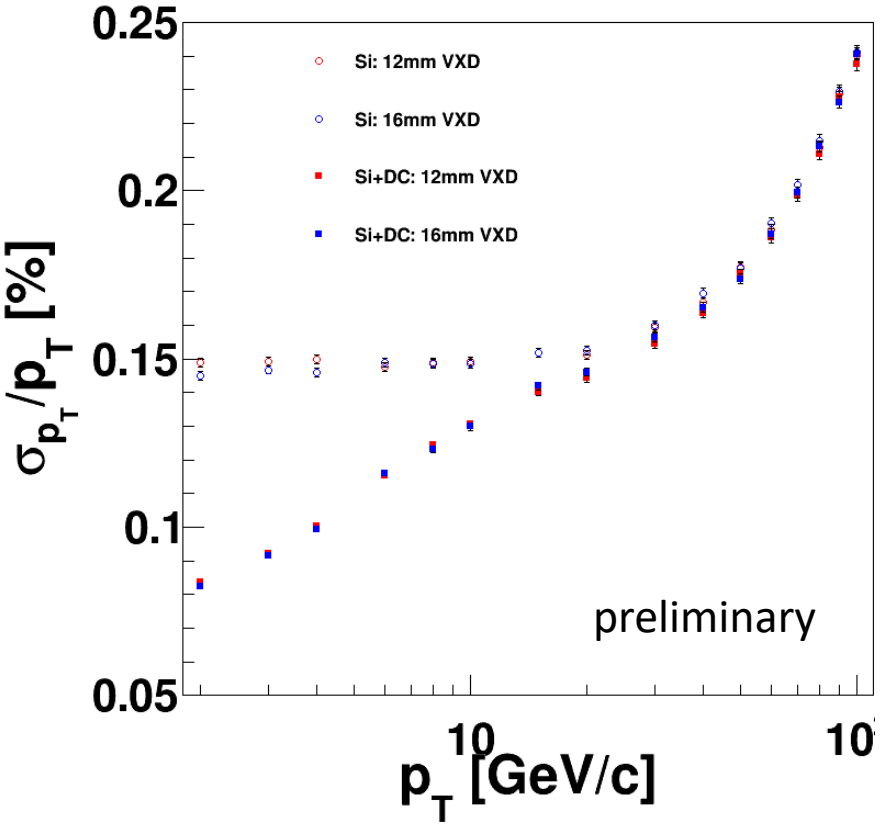


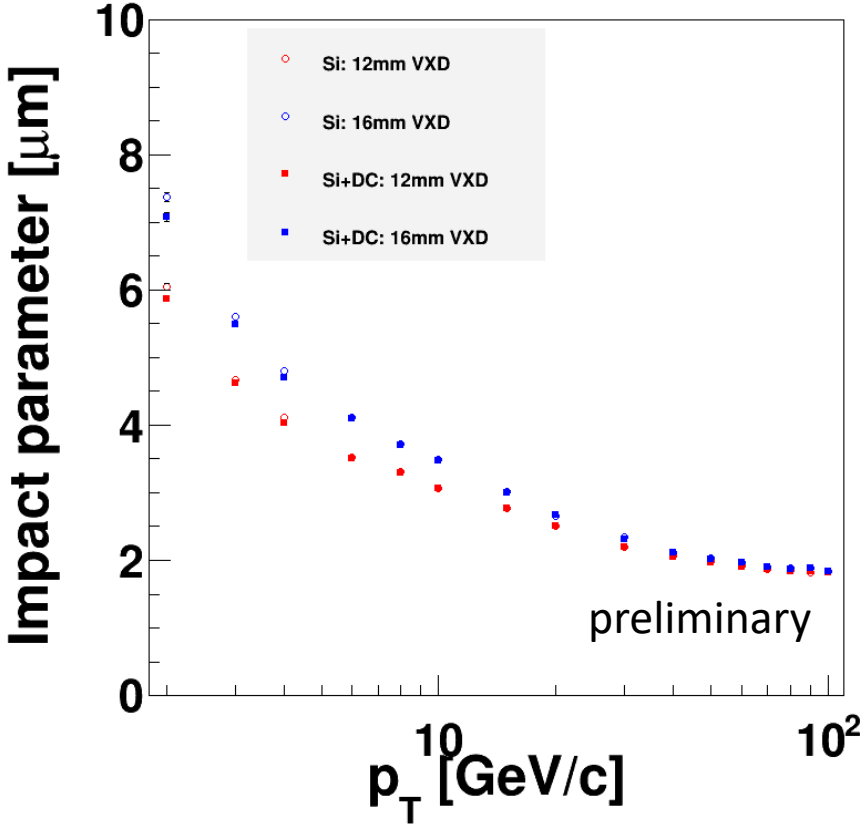
Resolution of Higgs Mass (H→μμ)



Effect of Inner Radius of Vertex

- CRD beam pipe
  - Inner radius: 14mm → Vertex: 16mm
- Newest beam pipe:
  - Inner radius: 10mm → Vertex: 12mm (keep layer5/6, and move layer3/4 2mm)

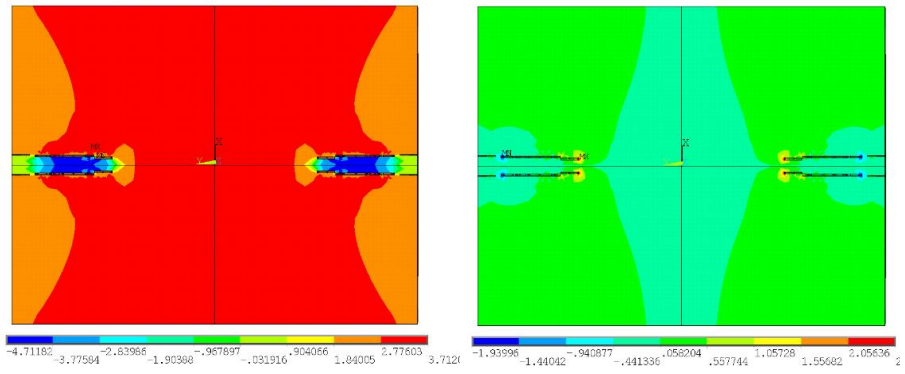




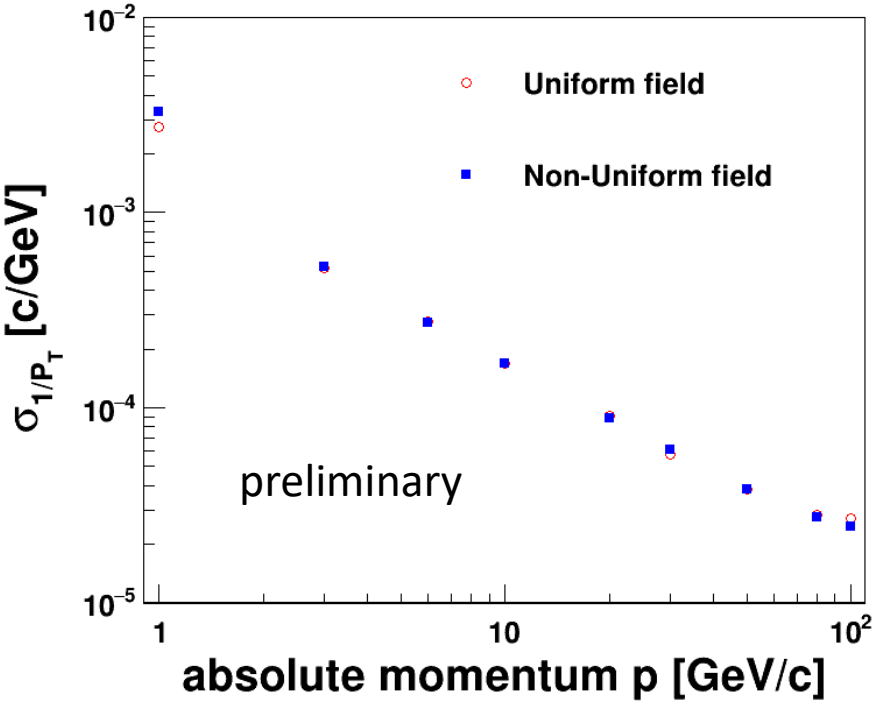
Non-uniform Field Test on MarlinTrk

- Include non-uniform field by map files through GenericBFieldMapBrBz in simulation
- Keep to use field value at (0,0,0) in reconstruction
  - Resolution changes very small: $(\sigma_{Pt}-\sigma_{Pt,non})/\sigma_{Pt}$ ~4%@100GeV
  - momentum departure from MC truth, to correct through average past field

~5%



Bz Br



Background

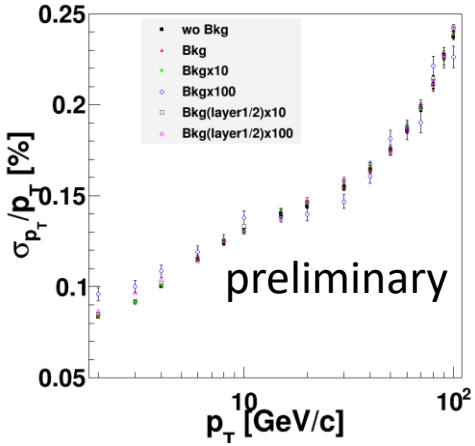
- As known, more close to beam line, more background from beam
- According to Haoyu's talk on 2021 Workshop

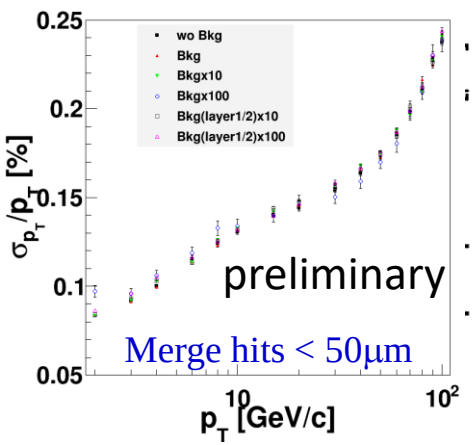
Name	Position	Hit/cm^2/BX	Hit/cm^2/s
VTX	15 mm	~2.3	~3.33e7
SIT	15 cm	~0.01	~14507
TPC	50 cm	~0.005	~7253
Ecal	200 cm	~1e-4	~145
Hcal	220 cm	~2e-6	~2.9

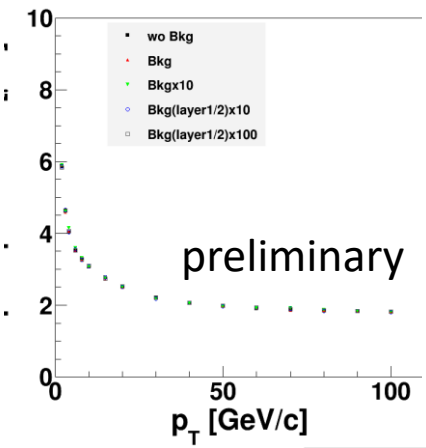
  - Assume ~$e^{-r/c}$
  - For VTX ($r_{1st\ layer}$=12mm), Hit/cm^2/BX
    - ✓ 2.6, 2.4, 1.0, 0.96, 0.41, 0.38 as baseline
    - ✓ × 10 for all layers
    - ✓ × 100 for all layers
    - ✓ × 10 for 1st/2nd layers
    - ✓ × 100 for 1st/2nd layers
- Background mixing (simply) with single muon (θ=85°)
  - Random hits at silicon sensors
  - Optional merge for distance less than 50μm
    - ✓ Center of merged hits as new position
- More reliable estimation needs beam simulation to generate beam background

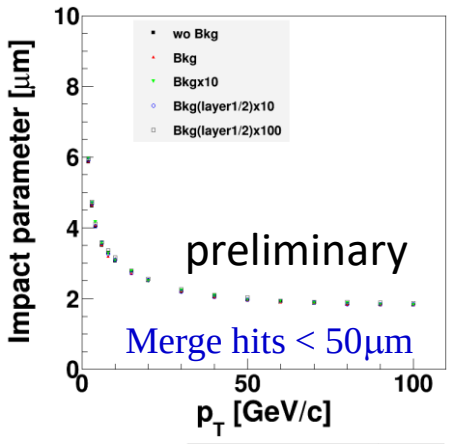
Effect of Background

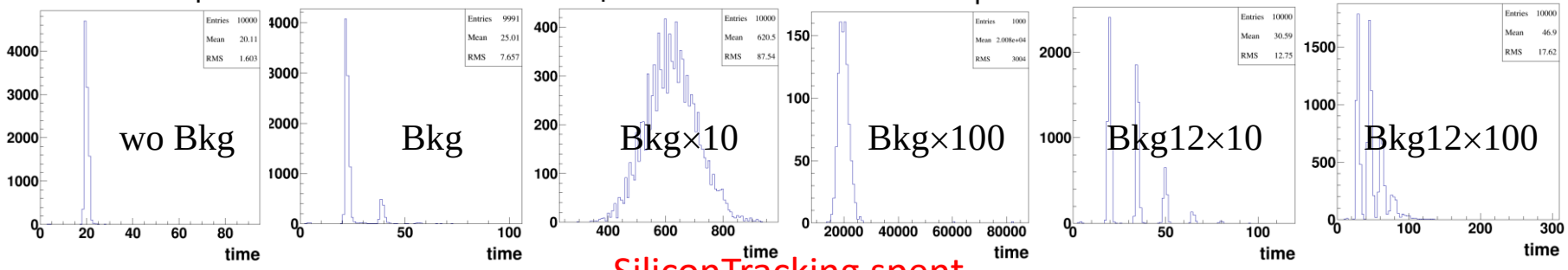
- Background cause fake tracks, extremely, fake tracks will even exceed real tracks much more.
- Increase CPU time
  - More hits, more track finding time
  - More fake tracks, more track fitting time
- If serveral Hits/cm^2/BX, background's effect will be small











SiliconTracking spent

Summary

- Tracking algorithm and Kalman filter tool have been migrated from Marlin into CEPCSW, work well for the CDR detector.
- Tracking option from digitization to track finding to track fitting has been defined.
- Performance study shows reasonable tracking efficiency, resolution, CPU time.
- But tracking parameter set still has improving capacity. Genrally, tracking efficiency is competition of CPU time.
- Non-uniform field and background are considered in preliminary, showing small effect on resolution. Further study is still needed.

Thanks very much for your attention!