CEPC tracking performance with ACTS

Xiaocong Ai[1], Xingtao Huang[2], Mengyao Liu[2], Zuyin Qin[1]
[1] Zhengzhou University, [2] Shandong University

郑州大学 ZHENGZHOU UNIVERSITY

山东大学 SHANDONG UNIVERSITY

Connecting The Dots 2023, Toulouse, Oct 10, 2023

The CEPC Tracking system and tracking requirements

Circular Electron Positron Collider (CEPC) physics program

Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			240	91	160	360
Run time [years]			7	2	1	-
CDR (30 MW)		L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**3**	**32**	**10**	-
		$\int L\,dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	5
TDR (Latest)	30 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**5.0**	**115**	**16**	0.5
		$\int L\,dt$ [ab^{-1}, 2 IPs]	13	60	4.2	0.65
		Event yields [2 IPs]	2.6×10^6	2.5×10^{12}	1.3×10^8	4×10^5
	50 MW	L / IP [$\times10^{34}$ cm^{-2}s^{-1}]	**8.3**	**192**	**26.7**	**0.8**
		$\int L\,dt$ [ab^{-1}, 2 IPs]	21.6	100	6.9	1.0
		Event yields [2 IPs]	4.3×10^6	4.1×10^{12}	2.1×10^8	6×10^5

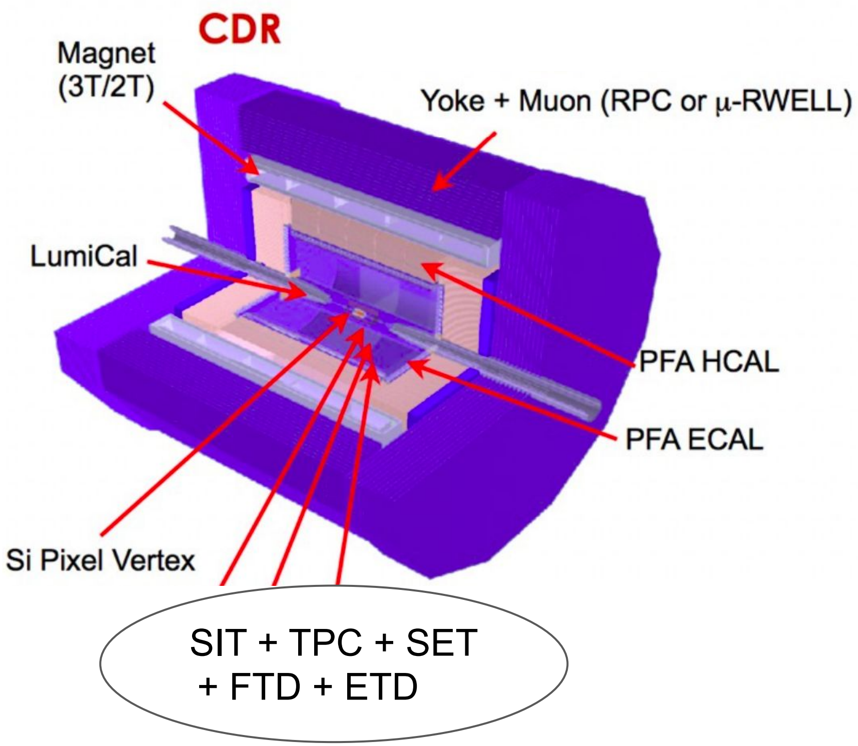
- Precision measurements of Higgs boson properties
- SM measurements: electroweak physics, QCD, flavor physics…
- Search for exotic decays of H, Z, B and τ, and BSM

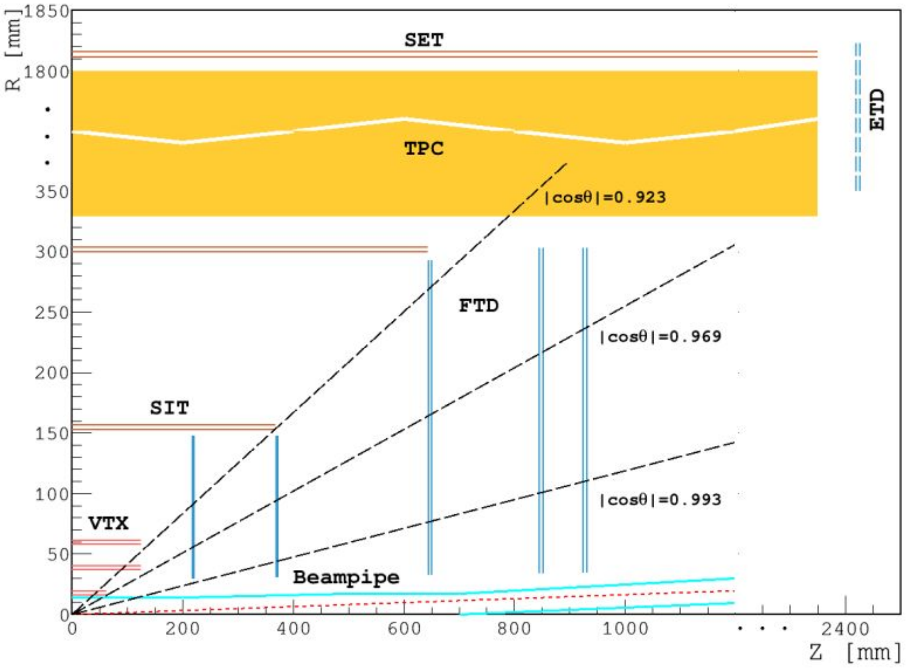
Far more than a Higgs factory !

From J. B. Liu's slides at CEPC workshop 2023, Oxford

CEPC Detector Conceptual Designs

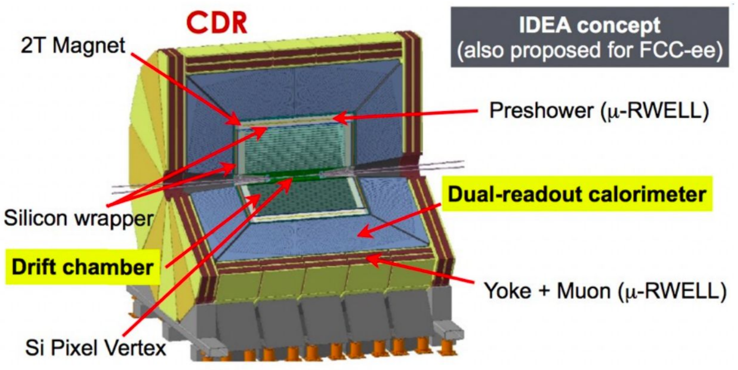
CEPC CDR Baseline Design (Particle Flow Approach)

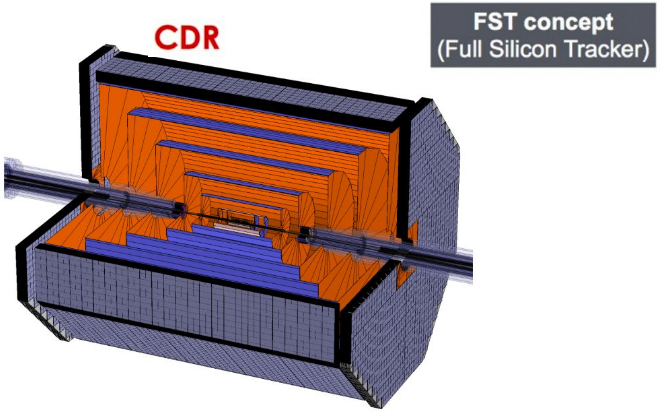


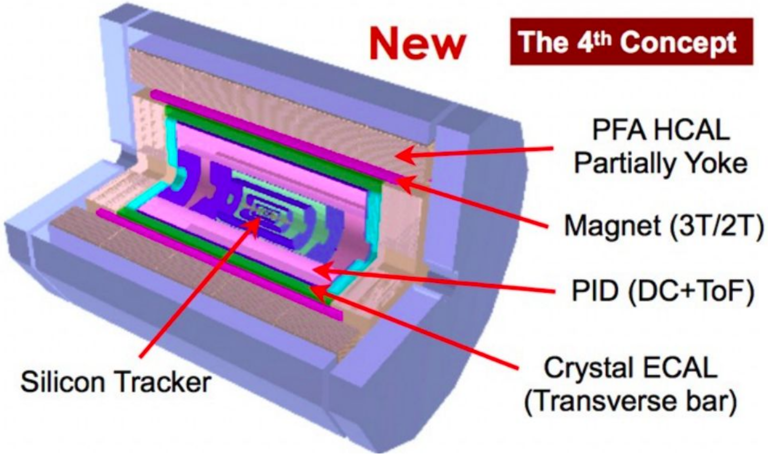


CEPC Detector Conceptual Designs

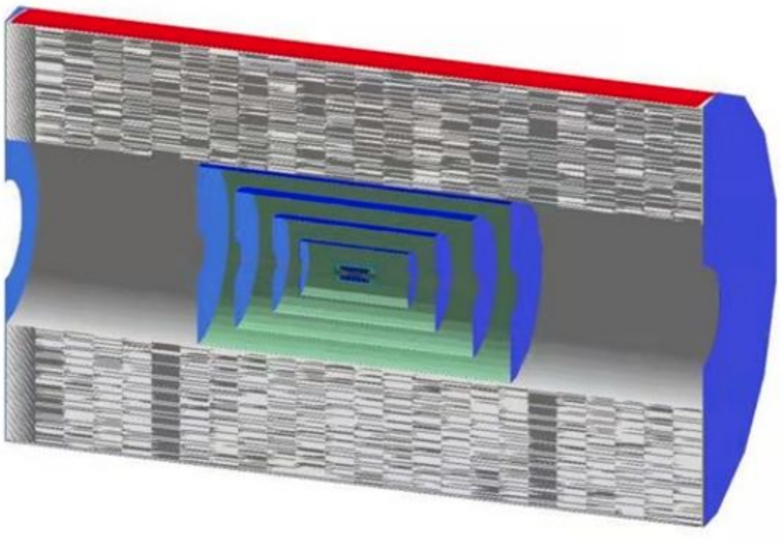
Alternative designs



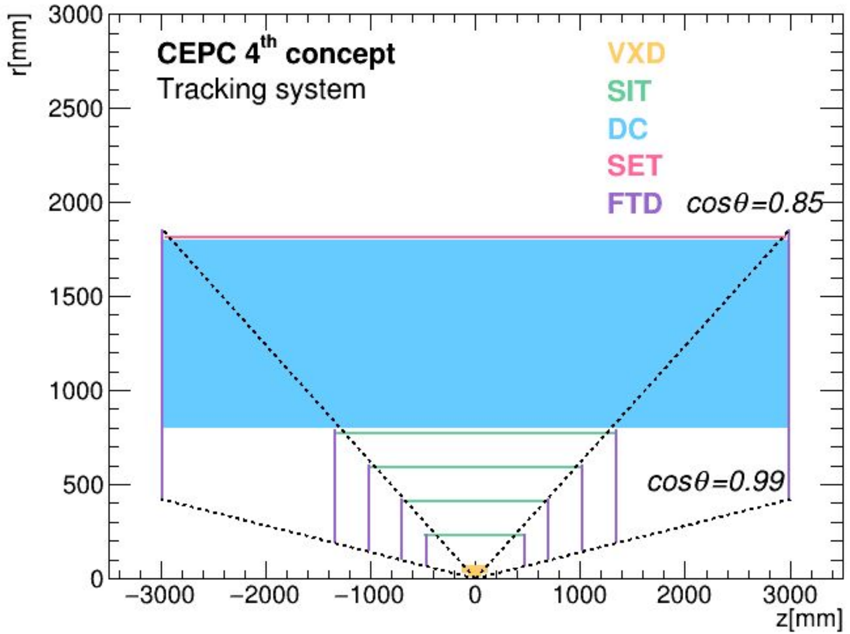




Tracking system of CEPC 4th concept



Silicon (VXD, SIT, SET, FTD) + Drift chamber
(optimized for particle identification)



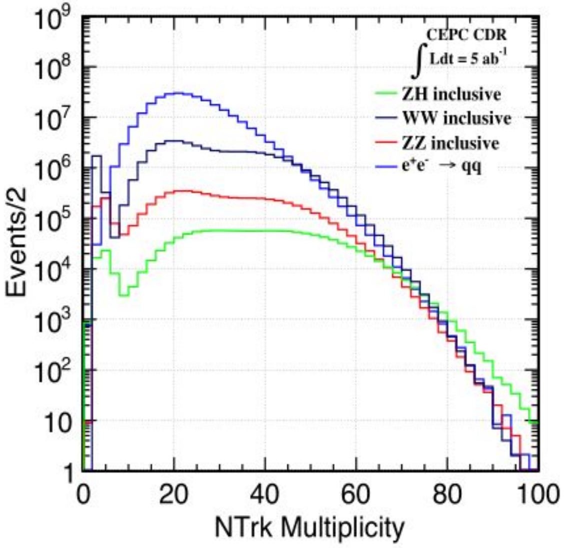
Coverage hermiticity down to | cosθ | < 0.992

Tracking detector design

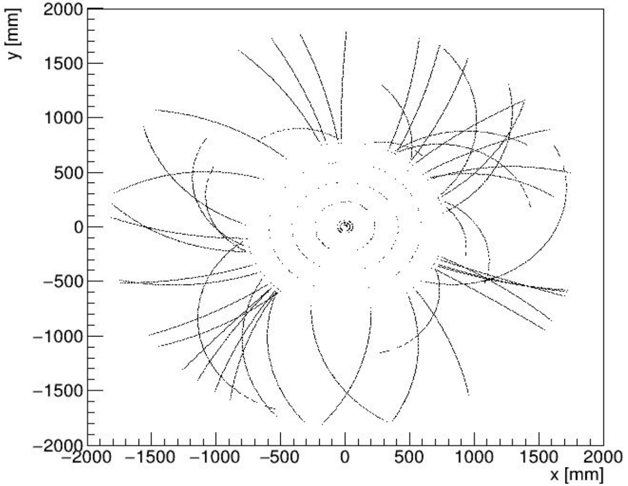
Tracker	Number of layers	Radius/ |z| (mm)	σ_x (µm)	σ_y (µm)	Technology
VXD	3 double layers	16-58	2.8/6/4/4/4/4	2.8/6/4/4/4/4	Silicon (pixel/strip)
SIT	4 layers	230-770	7.2	86	
SET	1 layer	1815	7.2	86	
FTD	5/7 layers at each endcap	467-2991	(2.8)/(2.8)/7.2/ 7.2/7.2/7.2/7.2	7.2/7.2/7.2/7.2 /7.2	
DC	100 layers	805-1795	110		Drift Chamber

Track multiplicity

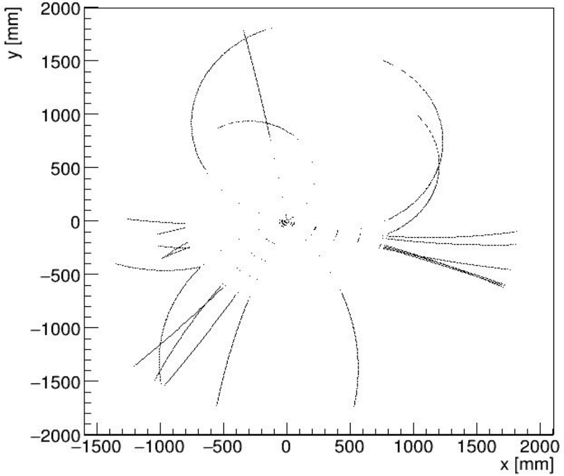
- Mostly >20 tracks per event
  - Up to 100 tracks per event



From CEPC CDR Physics&Detector (arXiv: 1811.10545)



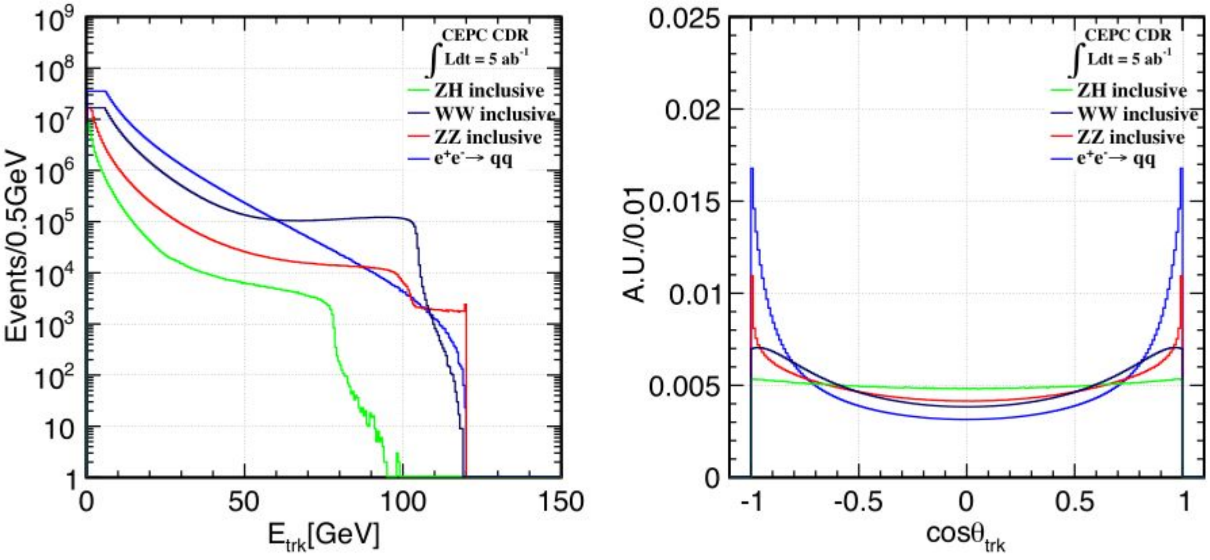
A ZH event with 56 particles in detector detection region



A ttbar event with 30 particles in detector detection region

Tracking requirements

- >99% tracking efficiency for p_T > 1 GeV
- Impact track parameter resolution at ~ 5 um
- Momentum resolution reaches per mille level in the range [10, 100] GeV



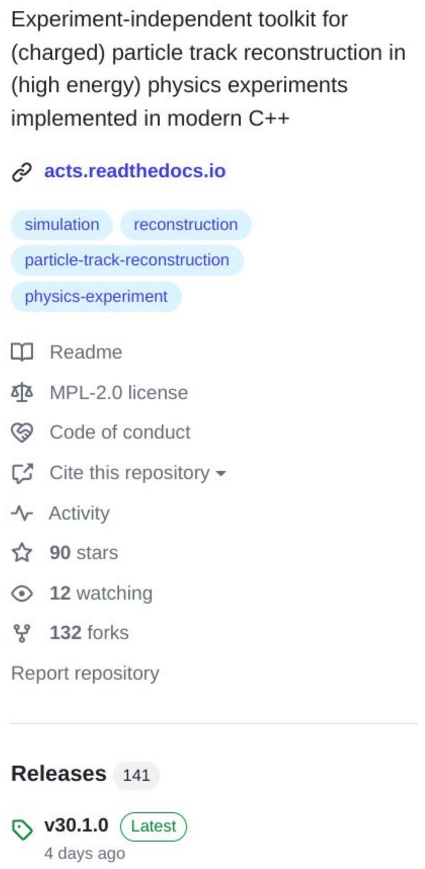
From CEPC CDR Physics&Detector (arXiv: 1811.10545)

ACTS implementation

A Common Tracking Software

https://github.com/acts-project/acts

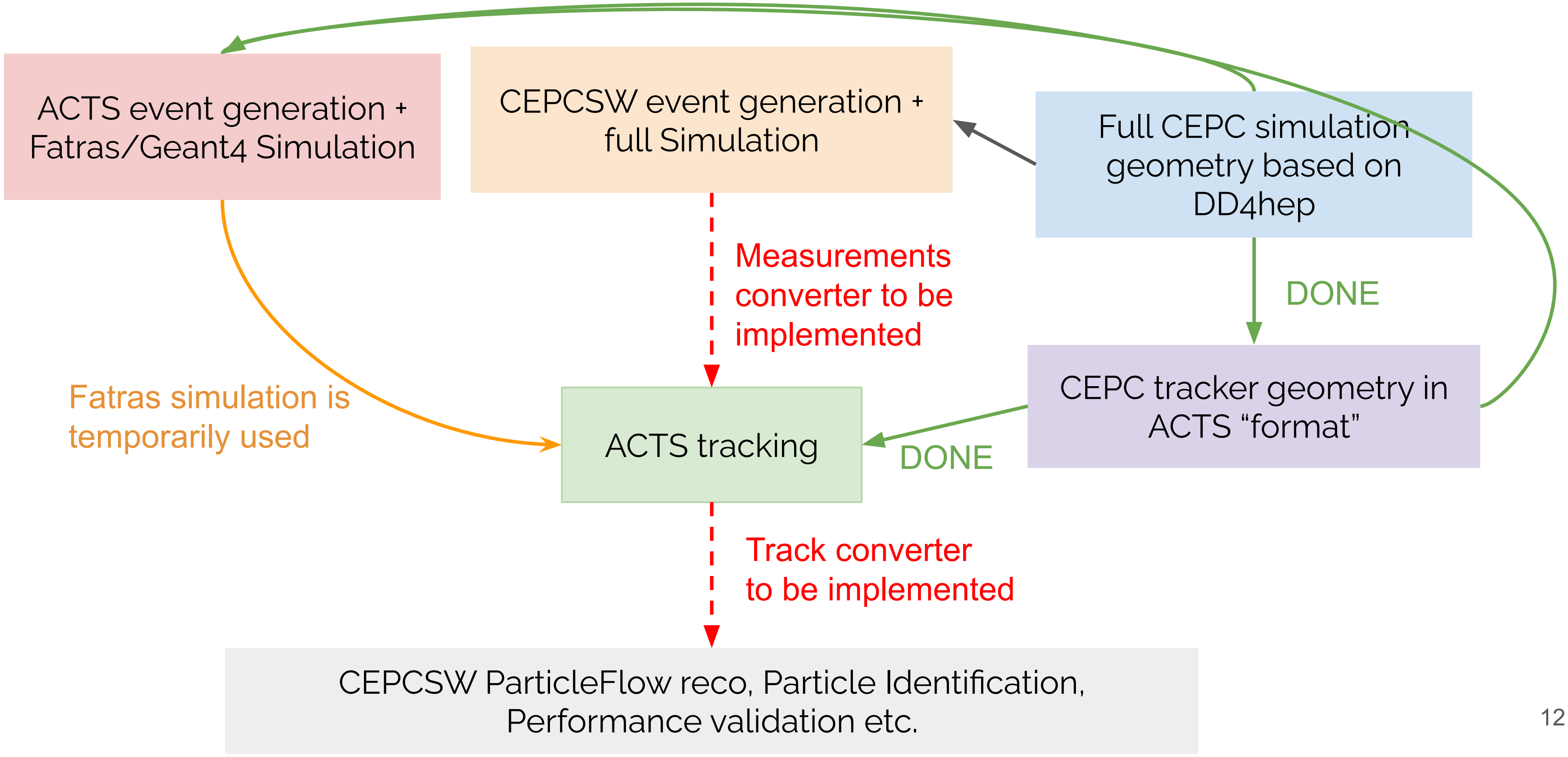
- A modern, open-source, common tracking reconstruction software for particle and nuclear physics experiments
  - Validated and being validated by various experiment applications
- And is going beyond a tracking software
  - Heterogeneous computing, ML…



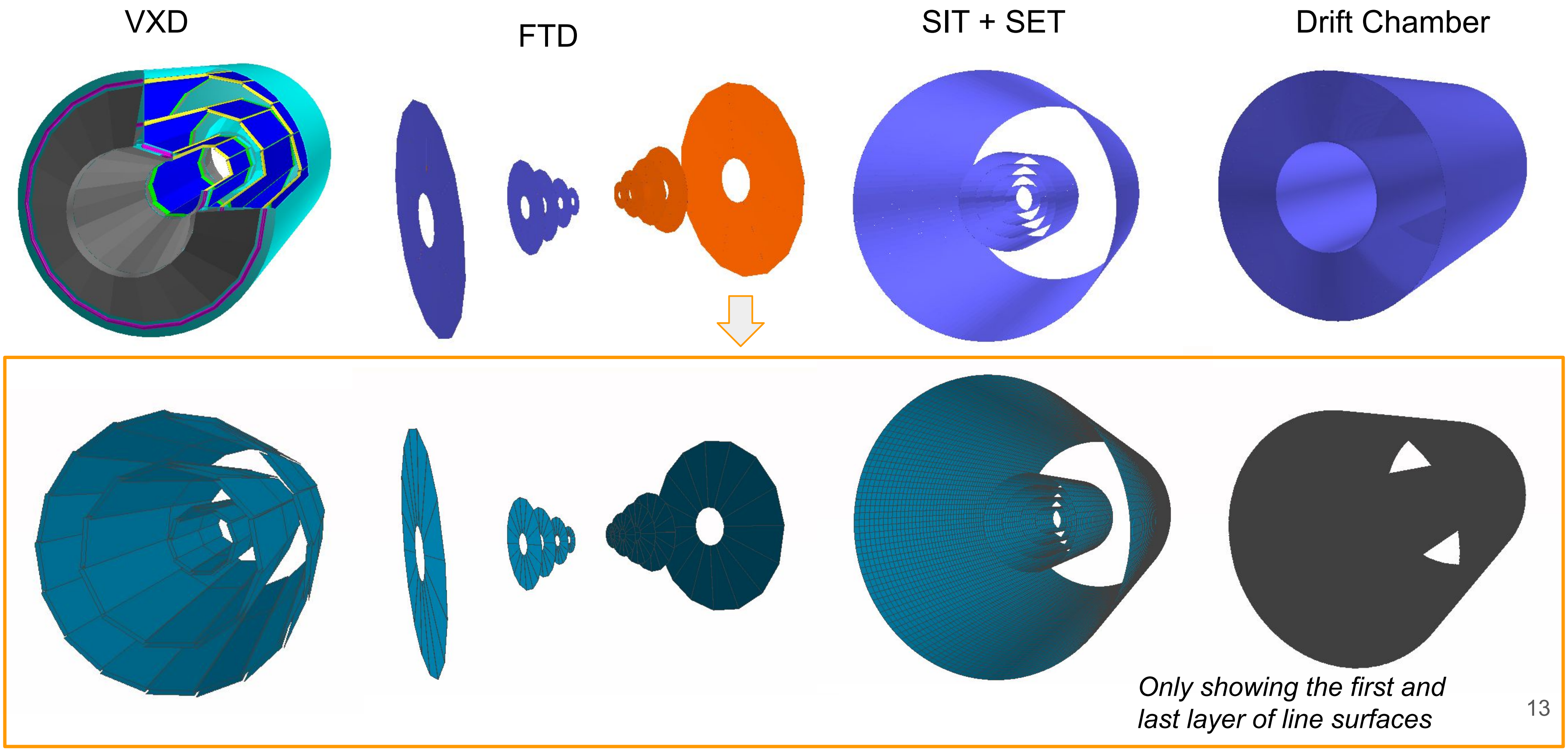
More about ACTS from talks:

→ J. Couthures: Flash Talk: Seeding with Machine Learning in ACTS
→ L-G Gagnon: On-the-fly measurement calibration with ACTS
→ A. Stefl: Reconstruction performance with ACTS and the Open Data Detector
→ L. Coelho: Seed finding in the Acts Software Package: Algorithms and Optimizations
→ L. AlSarayra: Studying a new Primary Vertex (PV) identification algorithm within ACTS framewo

ACTS application strategies



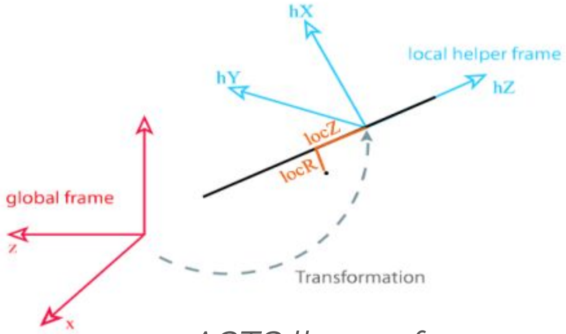
CEPC tracker geometry in ACTS format



CEPC drift chamber in ACTS

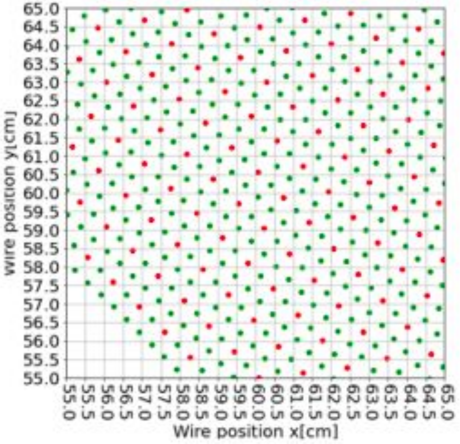
- A layer-based geometry model is implemented for the drift chamber so far
  - 100 layers, each layer with hundreds to thousands of Acts::LineSurface

    -> Plan: indexed grid navigation model



ACTS line surface

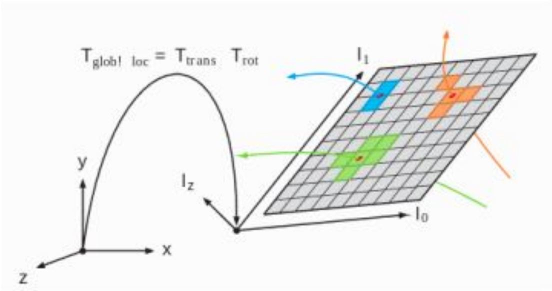
Half length	2980 *mm*
Inner and outer radius	800mm to 1800 *mm*
# of Layers	100/55
Cell size	~10mmx10mm/18mmx18mm
Gas	He:iC_4H_{10}=90:10
Single cell resolution	0.11 *mm*
Sense to field wire ratio	1:3
Total # of sense wire	81631/24931
Stereo angle	1.64~3.64 *deg*
Sense wire	Gold plated Tungsten ϕ=0.02*mm*
Field wire	Silver plated Aluminum ϕ=0.04*mm*
Walls	Carbon fiber 0.2 *mm*(inner) and 2.8 *mm*(outer)

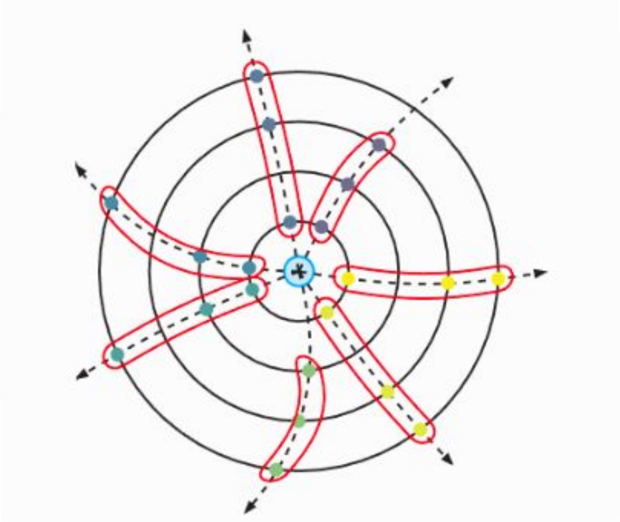


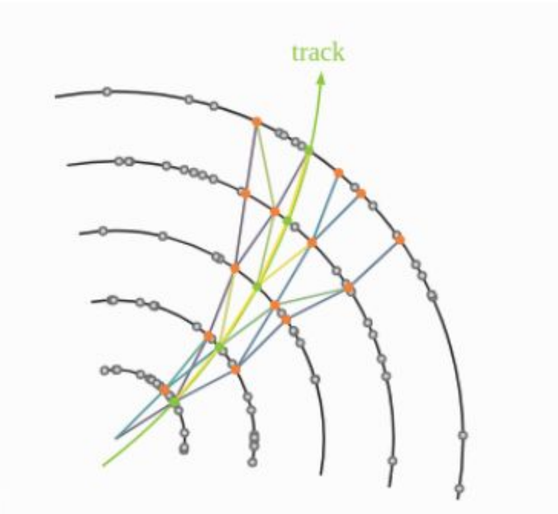
CEPC drift chamber cell structure

Tracking strategies with ACTS

- SpacePoint (SP) Creation + Seeding + Combinatorial Kalman Filter (CKF)
  - Seeding: using SPs from 1th, 3th, 5th layers of VXD and 1th, 2th, 3th layers of FTD (far from being optimized selection)
  - CKF for track following starting from track parameters from the seeds
  - No ambiguity resolving yet

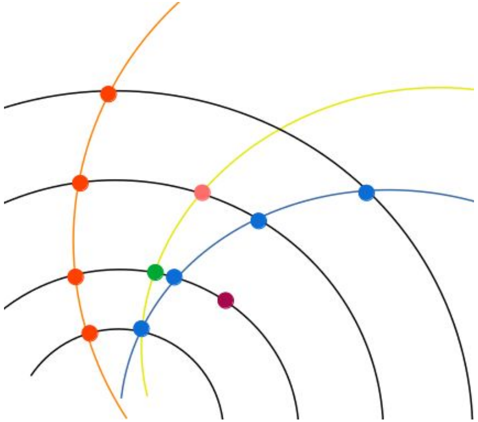






CKF for CEPC

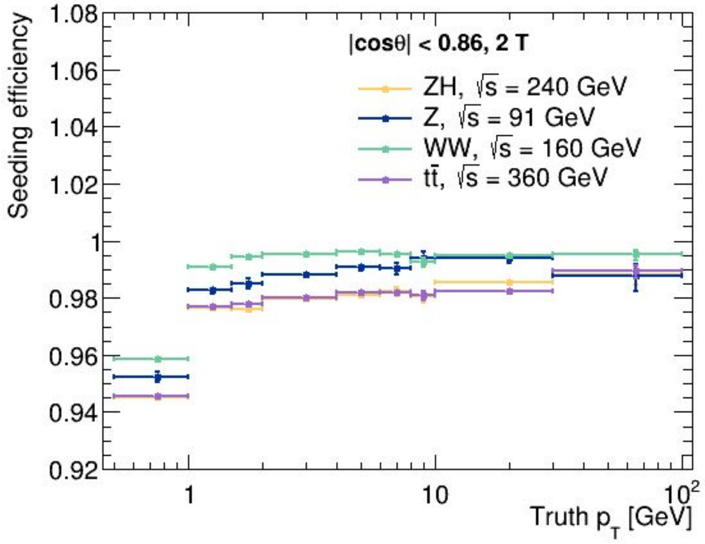
- Progressively associate compatible hits to tracks based on prediction $\chi2 : \chi2 = r^T (HCHT + V)^{-1} r$
  - r : residual
  - H: projection from track parameters to measurement
  - V: measurement covariance
- Currently, left/right sign of drift circle is taken to be the same as the predicted track parameters
  - Explosive combinatorics if considering two measurements with opposite signs for each drift distance
  - Plan: Implementation of ML-based predictor for the drift sign

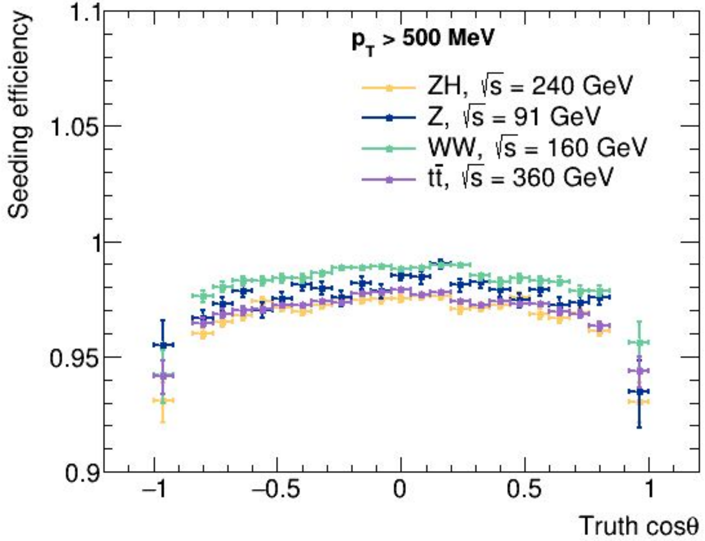


Tracking performance

Seeding performance

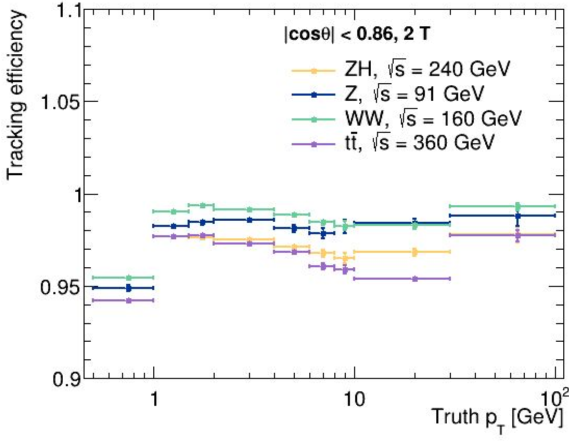
- >97% seeding efficiency for p_T > 1 GeV in benchmark physics processes
  - With 1% duplicate seeds

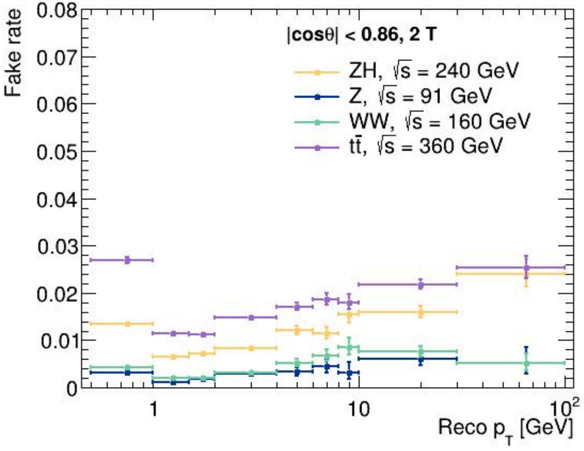


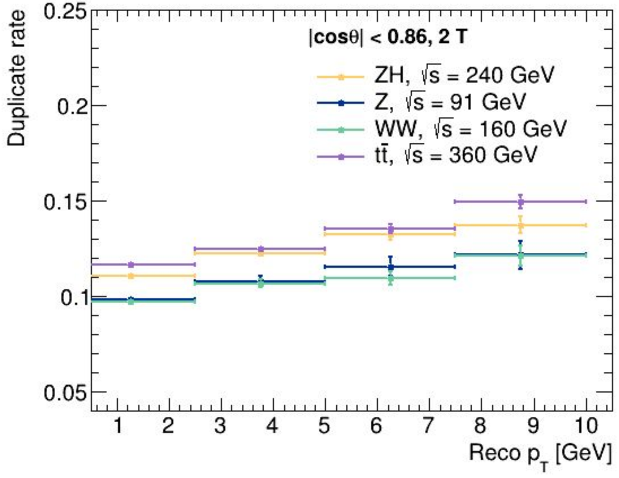


Tracking performance

- >=95% tracking efficiency for pT > 1 GeV in benchmark physics processes
  - With 1-2% fake tracks and 10% duplicate tracks

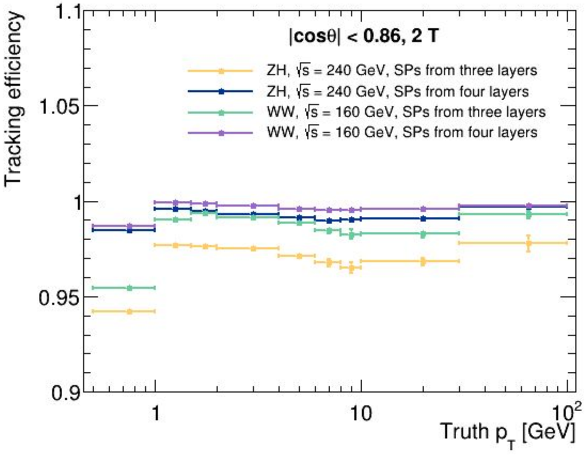


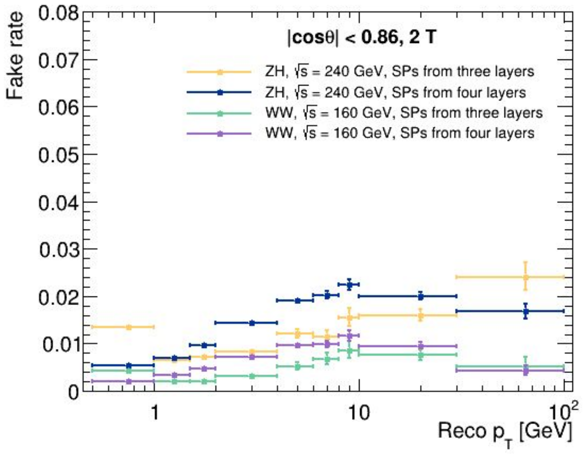


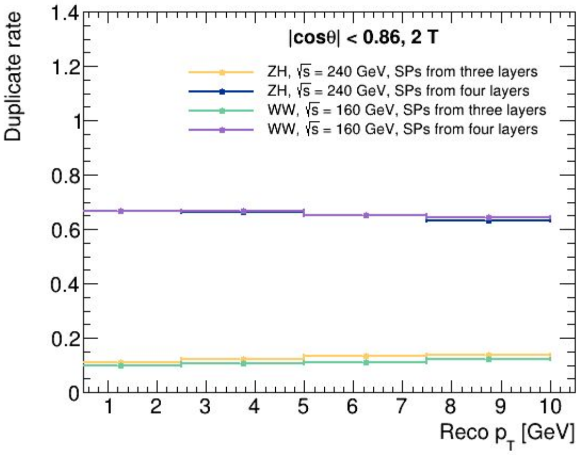


Tracking performance

- >99% tracking efficiency is achieved for $p_T > 1$ GeV, if more SPs from more pixel layers are used
  - Can introduce far more duplicate tracks (up to 70%)

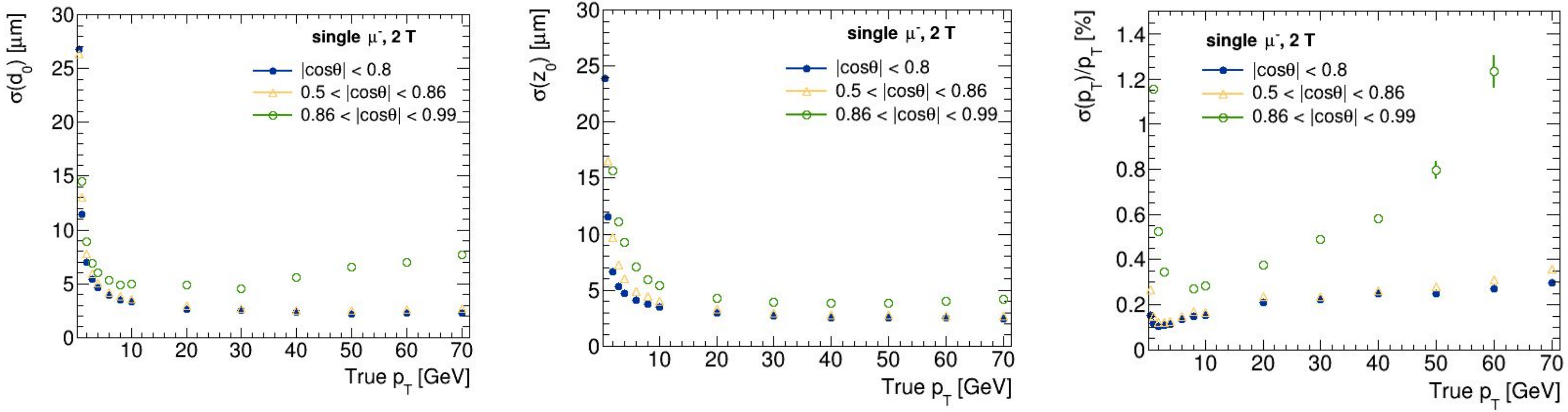






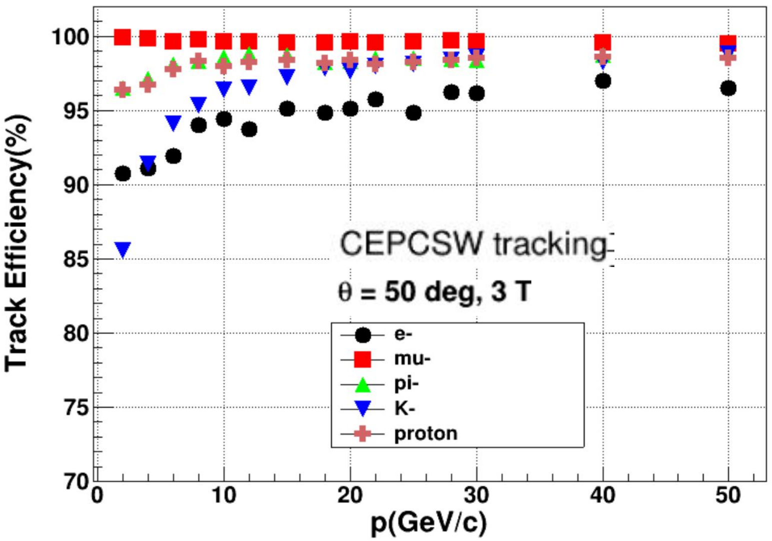
Tracking resolution

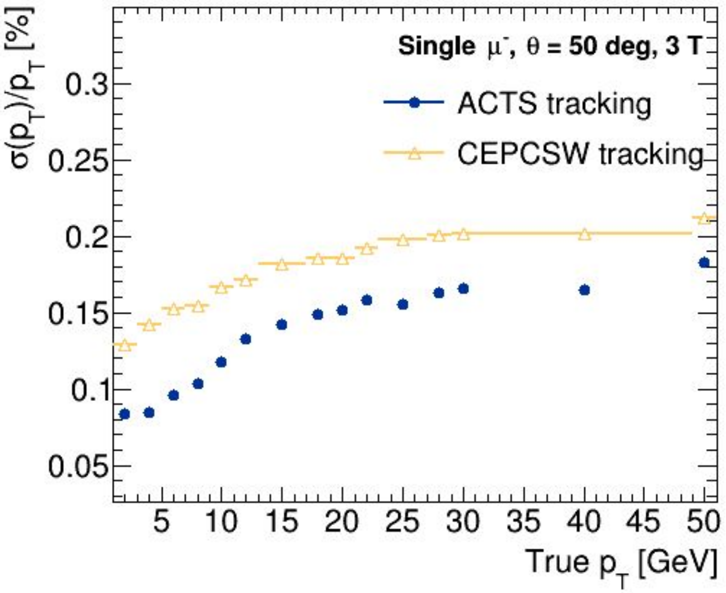
- Fitted track parameters are obtained from CKF and compared with truth track parameters
- At p_T = 10 GeV, central region ($|\cos\theta|<0.8$) :
  - $\sigma(d0)$ = 3 μm, $\sigma(z0)$ = 3.5 μm, $\sigma(p_T)/p_T$ = 0.16%



Preliminary comparison with CEPCSW tracking performance

- CKF-based tracking finding + GenFit track fitting transcribed from Belle-II tracking software are available in CEPCSW
  - >95% tracking efficiency for single particle with p > 10 GeV based on full simulation (~100% with ACTS based on Fatras simulation and much looser track quality requirements)





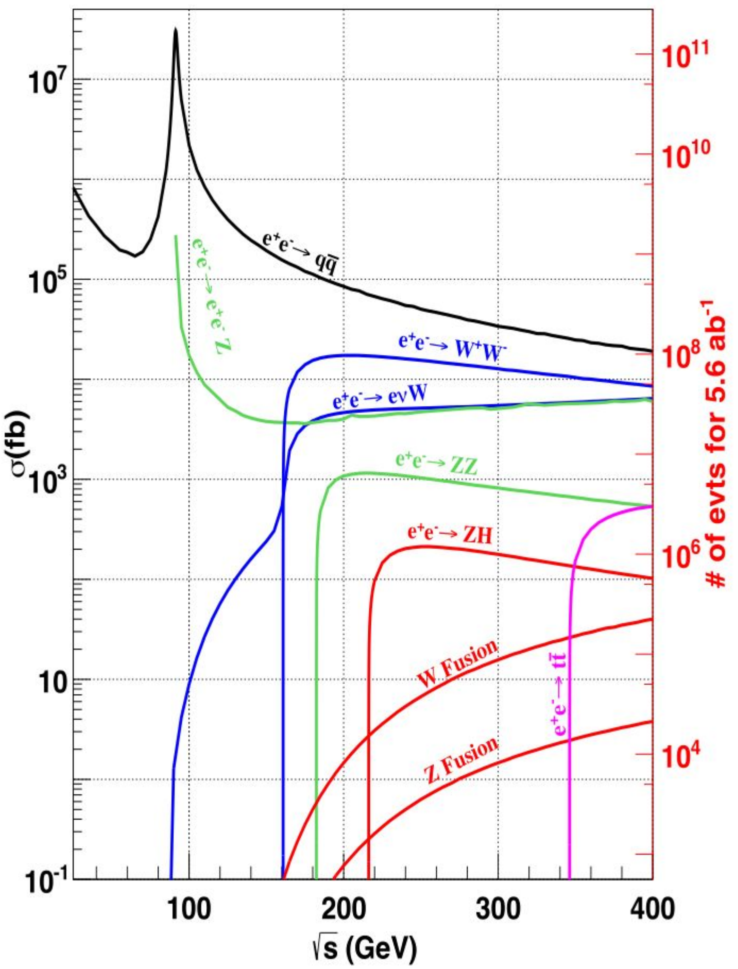
Summary

- ACTS is preliminarily implemented for tracking at CEPC
  - CEPC 4th concept tracker geometry (silicon + drift chamber) has been successfully implemented with ACTS
  - Connection with CEPCSW simulation is still not available
- Promising tracking performance is achieved
  - >99% tracking efficiency achieved for benchmark processes e.g. HZ, Z, WW, but with bunches of duplicate tracks
- Much remains to be optimized
  - Try ACTS ML ambiguity resolver to remove fake/duplicate tracks
  - Performance validation with CEPC full simulation (W/ beam backgrounds)
  - More solid comparison with other tracking strategies for CEPC

BACKUP

	Higgs	W	Z (3T)	Z (2T)
Number of IPs	2			
Beam energy (GeV)	120	80	45.5	
Circumference (km)	100			
Synchrotron radiation loss/turn (GeV)	1.73	0.34	0.036	
Crossing angle at IP (mrad)	16.5 × 2			
Piwinski angle	3.48	7	23.8	
Bunch number	242	1524	12000 (10% gap)	
Bunch spacing (ns)	680	210	25	
No. of particles/bunch $N_e (10^{10})$	15	12	8	
Beam current (mA)	17.4	87.9	461	
Synch. radiation power (MW)	30	30	16.5	
Bending radius (km)	10.7			
β function at IP: β_x^* (m)	0.36	0.36	0.2	0.2
β_y^* (m)	0.0015	0.0015	0.0015	0.001
Emittance: x (nm)	1.21	0.54	0.18	0.18
y (nm)	0.0024	0.0016	0.004	0.0016
Beam size at IP: σ_x (µm)	20.9	13.9	6.0	6.0
σ_y (µm)	0.06	0.049	0.078	0.04
Beam-beam parameters: ξ_x	0.018	0.013	0.004	0.004
ξ_y	0.109	0.123	0.06	0.079
RF voltage V_{RF} (GV)	2.17	0.47	0.1	
RF frequency f_{RF} (MHz)	650			
Natural bunch length σ_z (mm)	2.72	2.98	2.42	
Bunch length σ_z (mm)	4.4	5.9	8.5	
Natural energy spread (%)	0.1	0.066	0.038	
Energy spread (%)	0.134	0.098	0.08	
Photon number due to beamstrahlung	0.082	0.05	0.023	
Lifetime (hour)	0.43	1.4	4.6	2.5
F (hour glass)	0.89	0.94	0.99	
Luminosity/IP (10^{34} cm^{-2}s^{-1})	3	10	17	32

Table 3.1: Main beam parameters for the CEPC operation at three center-of-mass energies. The detector solenoid magnetic field affects the beam quality in the Z-factory operation mode. The last two columns compare the beam parameters for the case of a 2 or 3 Tesla detector solenoid.



Concept	ILD	CEPC baseline	IDEA
Tracker	TPC/Silicon	TPC/Silicon or FST	Drift Chamber/Silicon
Solenoid B-Field (T)	3.5	3	2
Solenoid Inner Radius (m)	3.4	3.2	2.1
Solenoid Length (m)	8.0	7.8	6.0
L* (m)	3.5	2.2	2.2
VTX Inner Radius (mm)	16	16	16
Tracker Outer Radius (m)	1.81	1.81	2.05
Calorimeter	PFA	PFA	Dual readout
Calorimeter λ_I	6.6	5.6	7.5
ECAL Cell Size (mm)	5	10	-
ECAL Time resolution (ps)	-	200	-
ECAL X_0	24	24	-
HCAL Layer Number	48	40	-
HCAL Absorber	Fe	Fe	-
HCAL λ_I	5.9	4.9	-
DRCAL Cell Size (mm)	-	-	6.0
DRCAL Time resolution (ps)	-	-	100
DRCAL Absorber	-	-	Pb or Cu or Fe
Overall Height (m)	14.0	14.5	11.0
Overall Length (m)	13.2	14.0	13.0

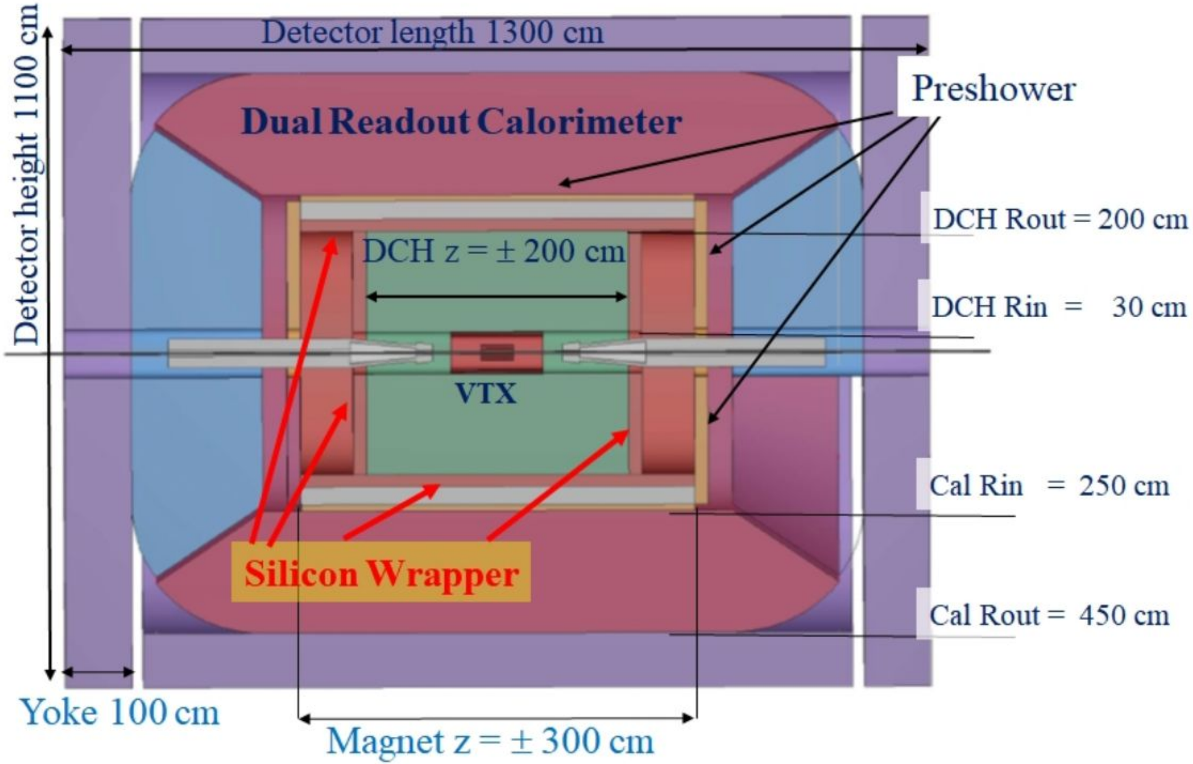


Figure 3.10: Schematic layout of the IDEA detector.