acts for gaseous tracking detectors

Mainly about drift chambers

See Andreas Salzburger's talk for an overview of the project status

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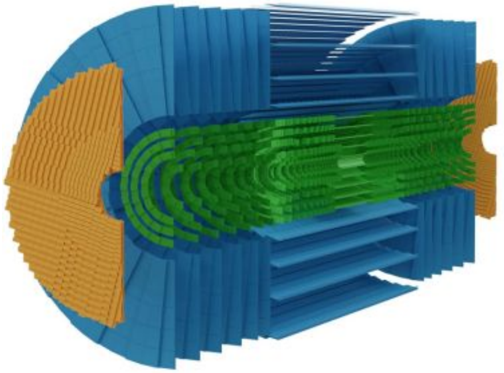
1. ZZU 2. USTC 3. SDU 4. IHEP, 5. CERN

FTCF 2024, Jan 17, 2024, USTC, Hefei

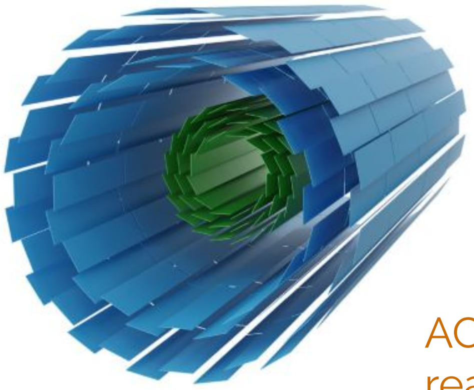
As a **Common** Tracking Software

- ACTS works well for solid state silicon trackers. Lots of users in the past three years:
  - ATLAS silicon and ITk, sPHENIX silicon, ALICE silicon, FASER, LDMX, ePIC …
    - These are mostly about track parameters/measurements represented on a planar surface

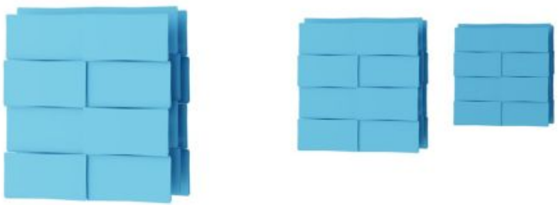
ATLAS ITk



sPHENIX silicon



FASER tracker

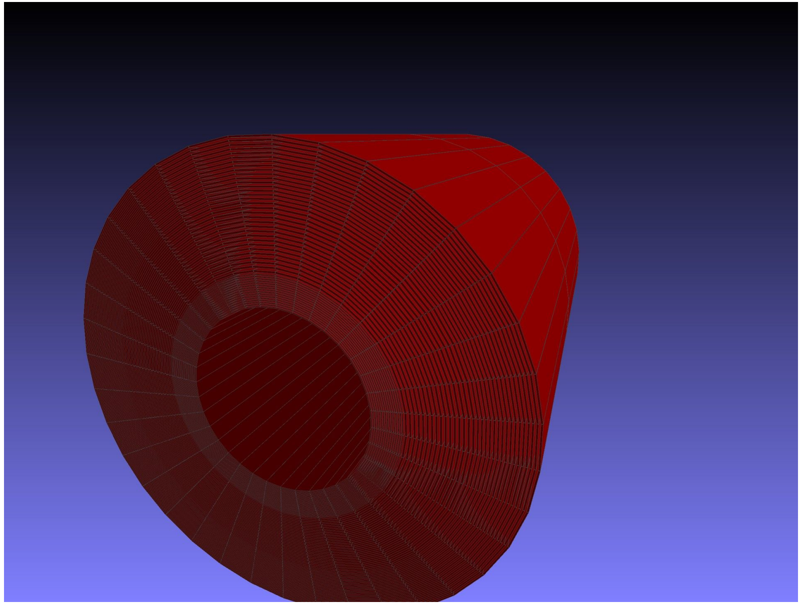


Figures from CSBS (2022) ***6,*** *8*

ACTS modules are already used for real data processing for ATLAS, sPHENIX, FASER!

As a **Common** Tracking Software

- ACTS is designed with the capability of working for gaseous tracking detectors
  - Time Projection Chamber (TPC) is represented with fake Planar detectors, e.g.
    - sPHNEIX TPC
    - CEPC v1 layout TPC (see Jin Zhang's slides in 2020)



sPHENIX TPC represented with fake planar surfaces (figure from Joseph Osborn)

How about drift wires/tubes?

Examples of drift chambers

- Ongoing experiments: Belle-II, BESIII

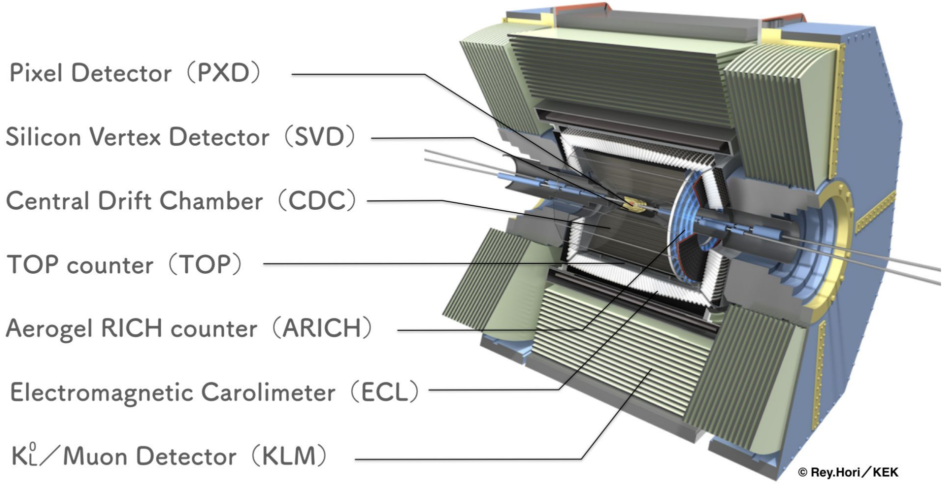


Figure from here. More about Belle-II CDC in Shoji Uno's talk

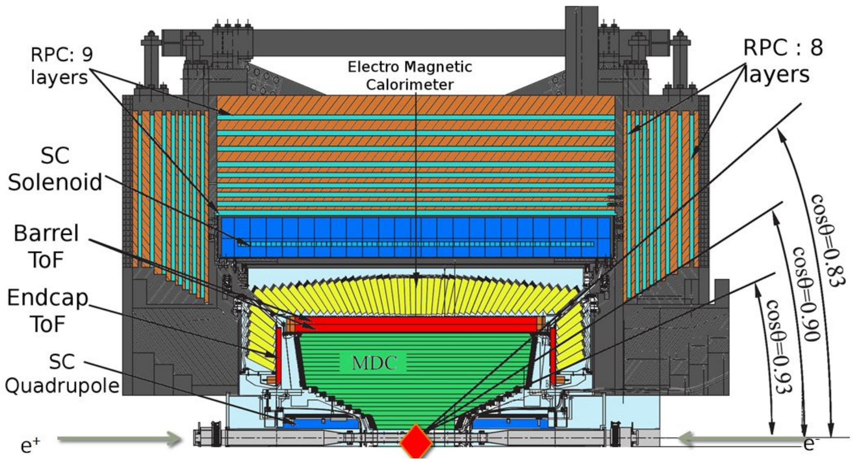


Figure from here.

Examples of drift chambers

- Ongoing experiments: Belle-II, BESIII
- Future programs:
  - Fcc-ee IDEA concept
  - **CEPC** IDEA and 4th concept
  - **STCF** (Super Tau-Charm Facility)

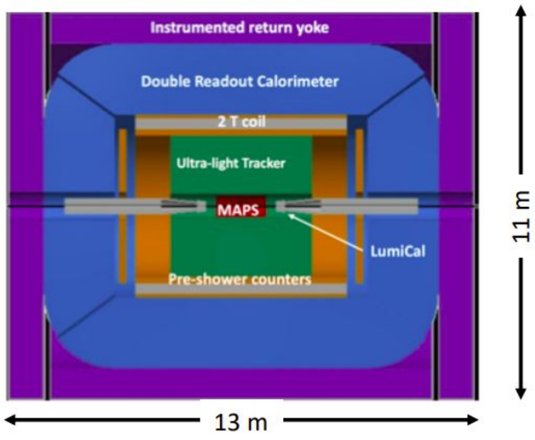


Figure from here

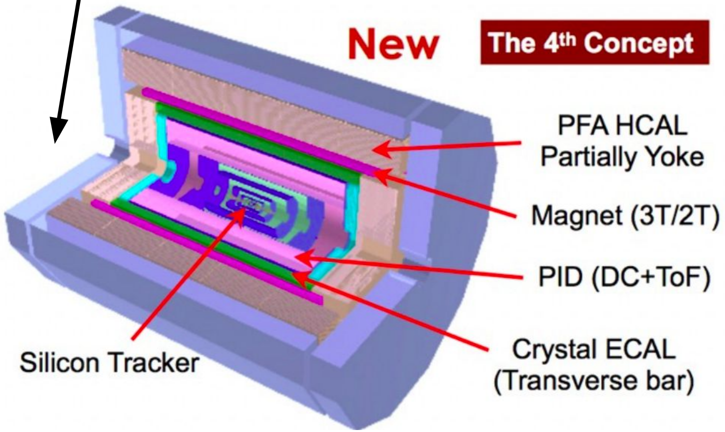
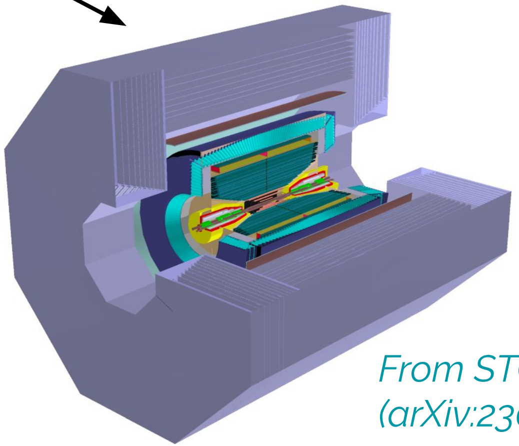
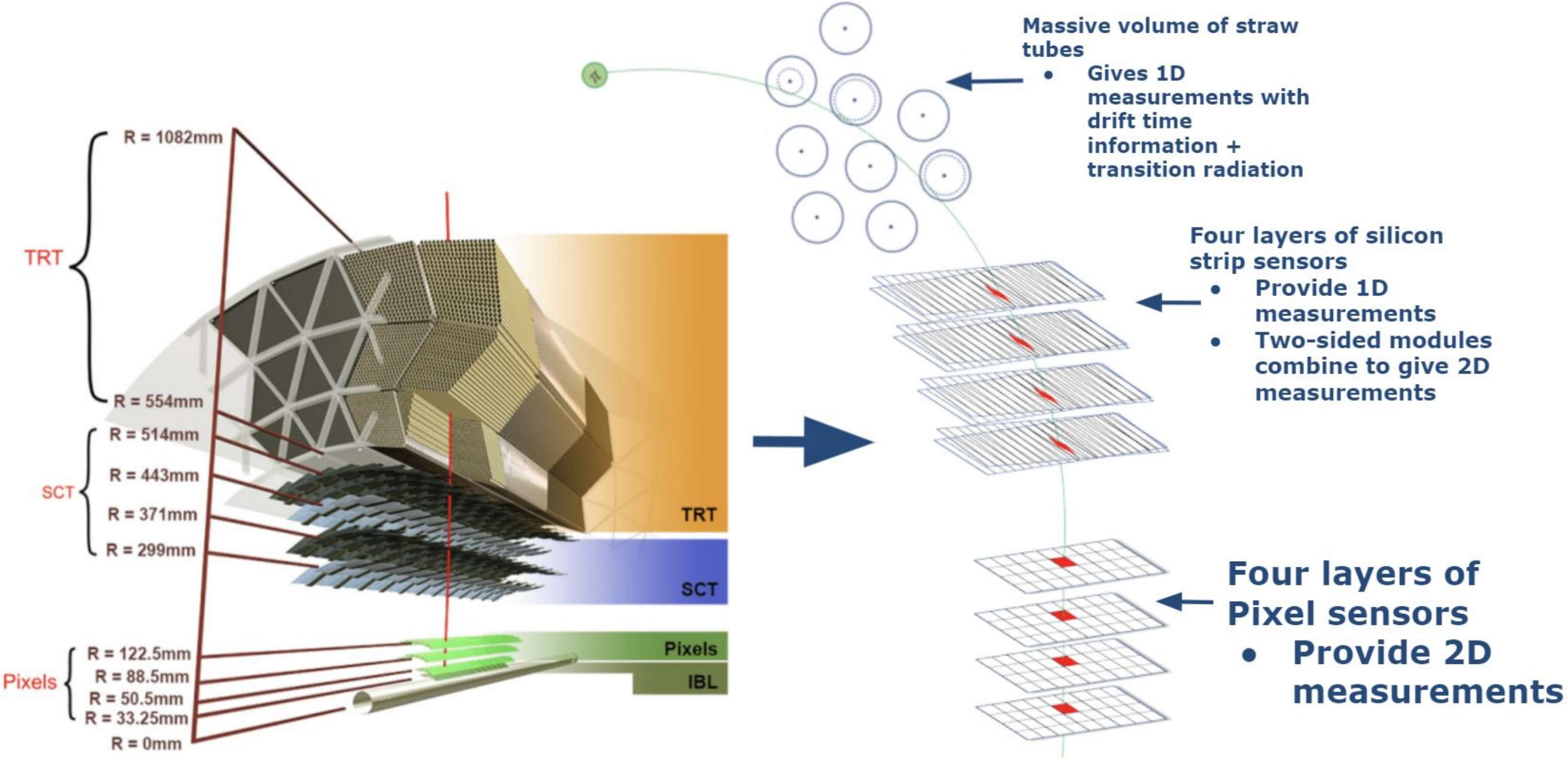


Figure from J. Liu's slides at CEPC workshop 2023



From STCF CDR (arXiv:2303.15790).

Example of Transition Radiation Tracker

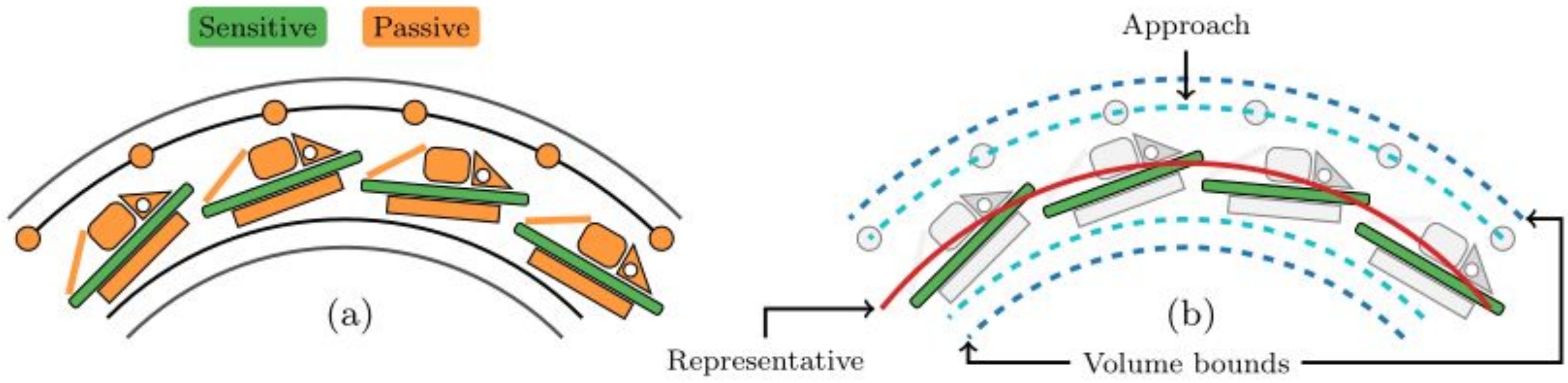


ATLAS Inner Detector: Pixels + SCT + TRT

The “common” geometry description

The ACTS tracking geometry

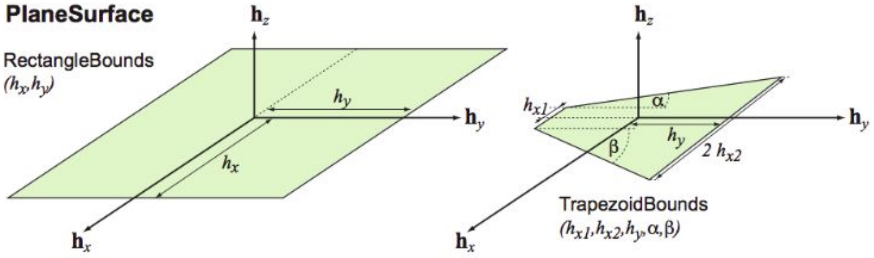
Figures from CSBS (2022) ***6*** *8*

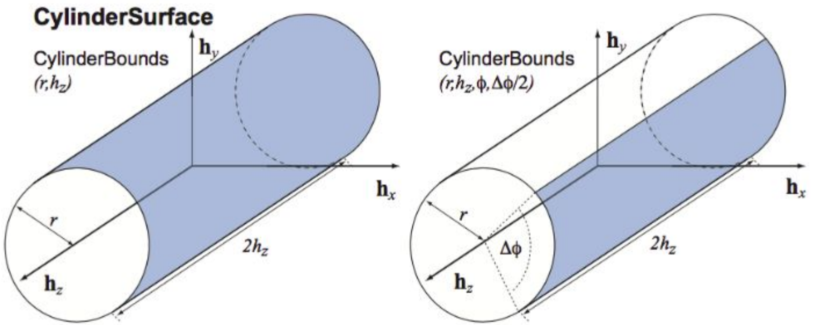


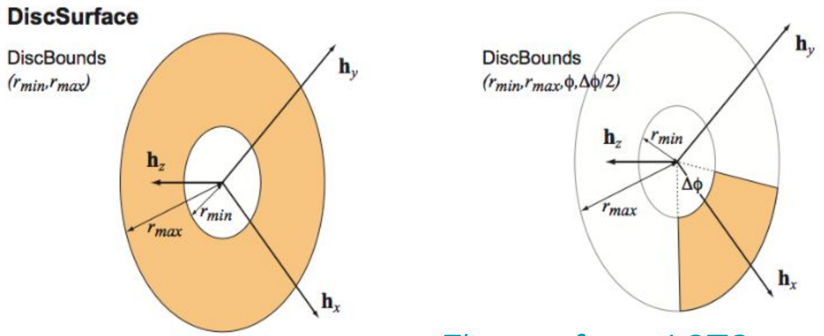
- Tracking geometry is simplified from detailed full simulation geometry for fast navigation (i.e. association of a position within detector), but with material effects well taken into account
- Navigation via hierarchical arrangement of the detector elements:
  - Legacy model: surfaces -> layers -> volumes
  - Layerless model: surfaces -> volumes (with grid indexed search)

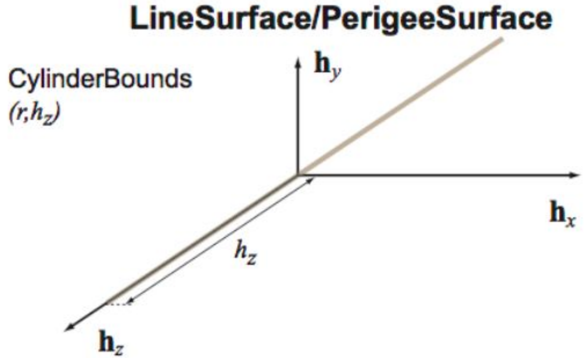
The building blocks of ACTS tracking geometry

- Different concrete surfaces types for various tracking detectors
  - A surface has shape, bounds, rotation+translation, local coordinates and its unique identifier…









Figures from ACTS [readthedocs]

One Line/Straw surface

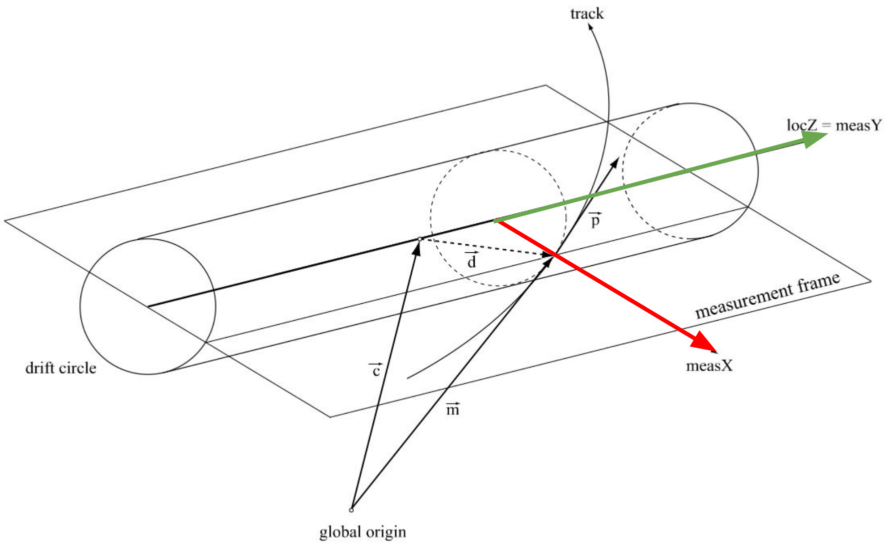


Figure from ATL-SOFT-PUB-2006-004

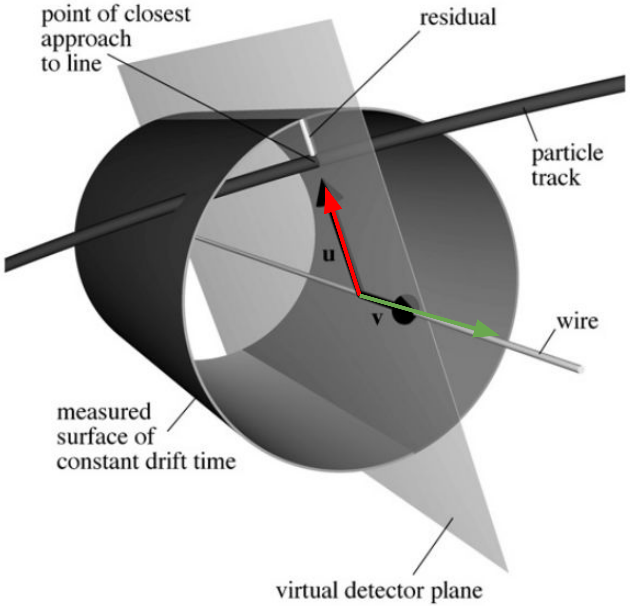
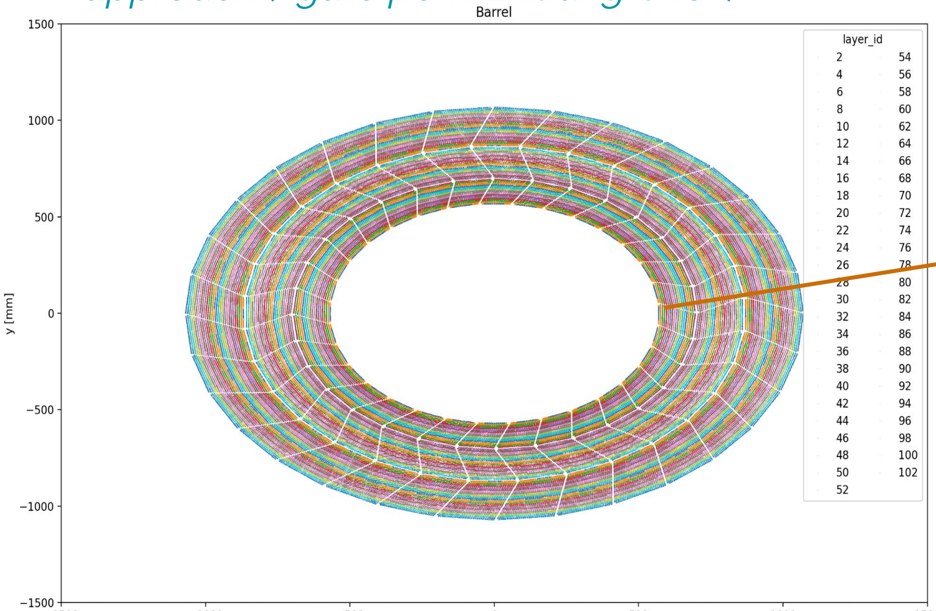


Figure from NIMA 620 (2010) 518

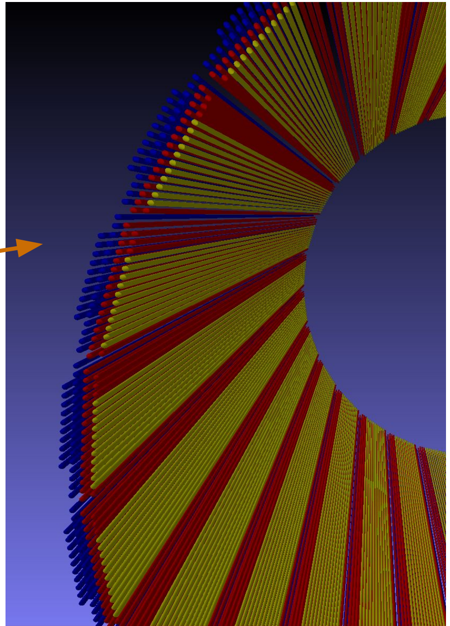
When there are many Line/Straw surfaces

- Currently, layer-based geometry model is used, i.e. wires/straws are associated to concentric Acts::Layer
- Suboptimal for navigation → try more intelligent navigation models

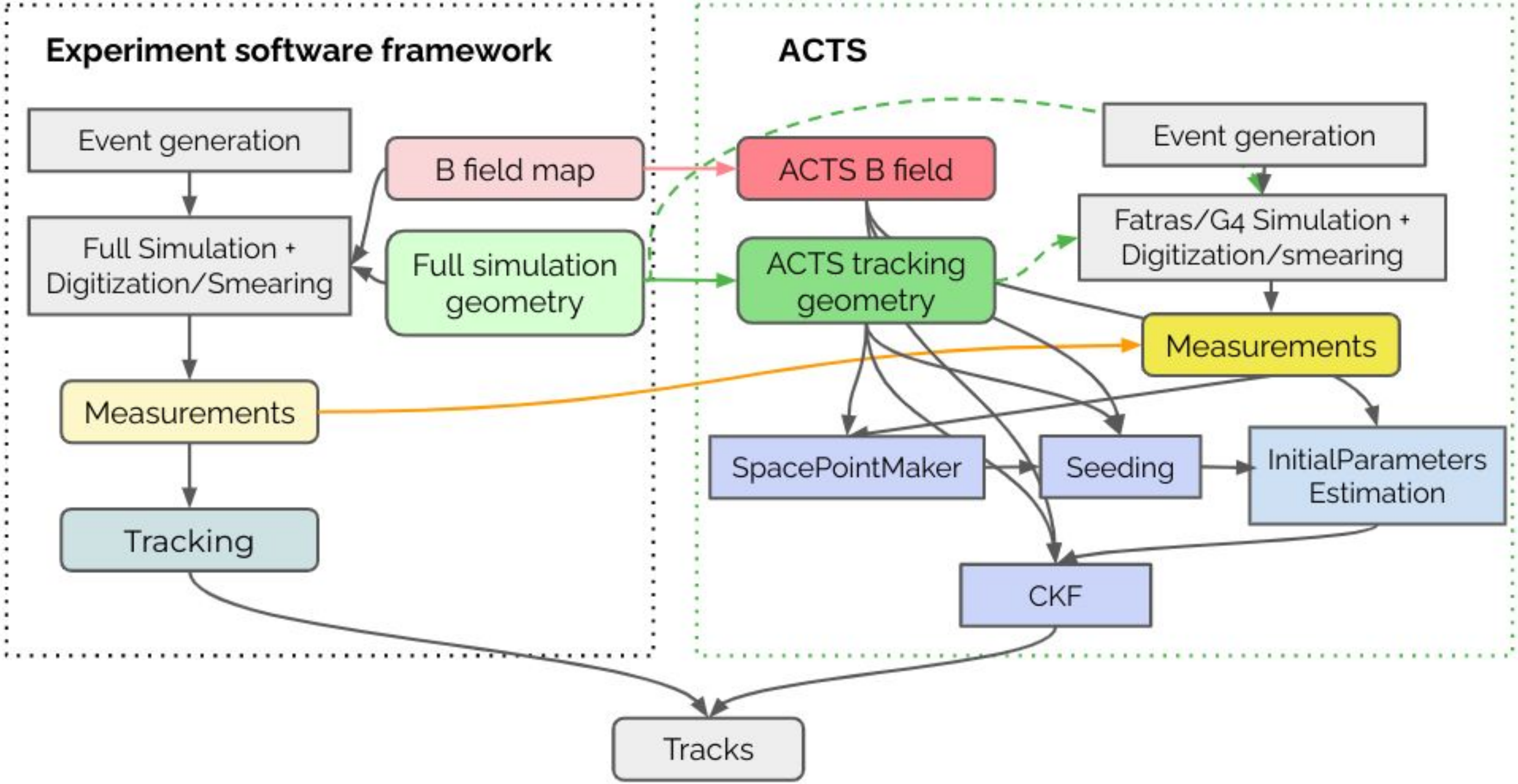
ATLAS TRT Barrel geometry with N-layers approach (figure from Zhiliang Chen)



Three layers

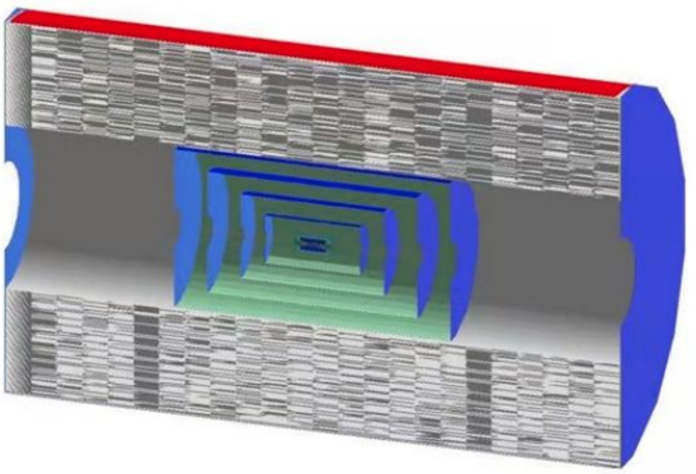


ACTS application strategies

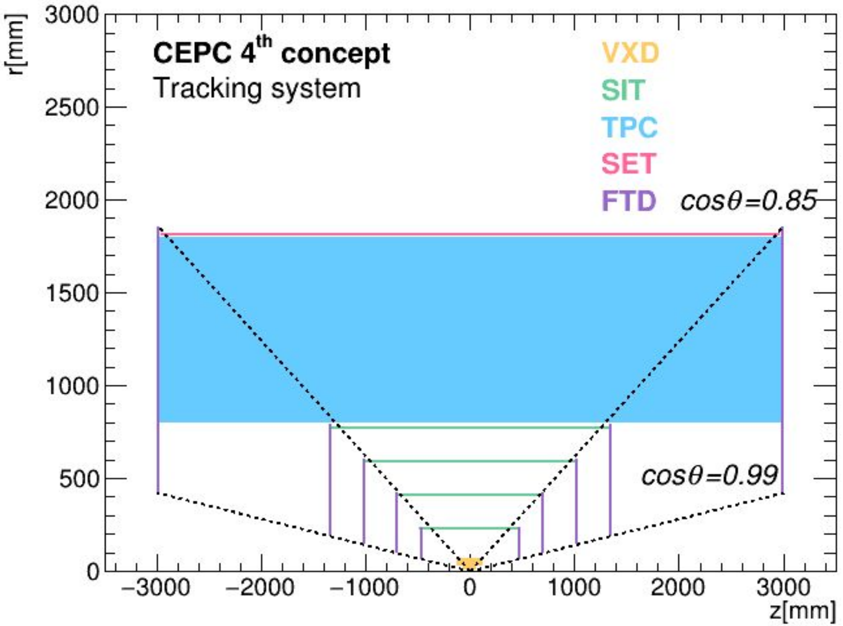


Application for CEPC and STCF

The CEPC tracking system



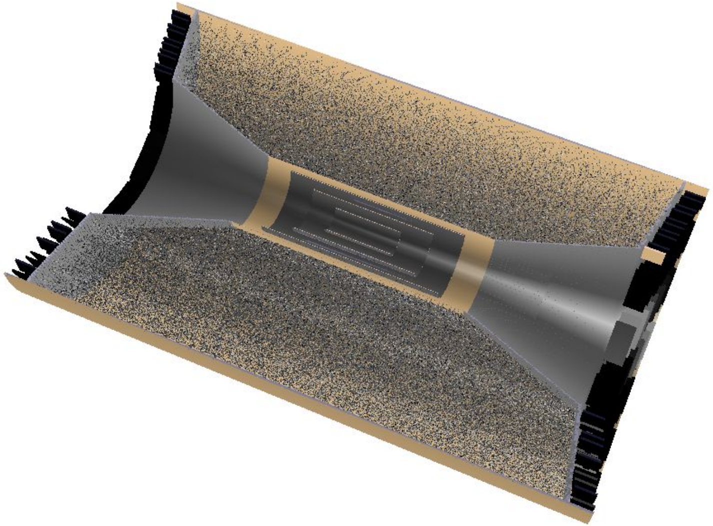
Silicon (VXD, SIT, SET, FTD) + Drift chamber

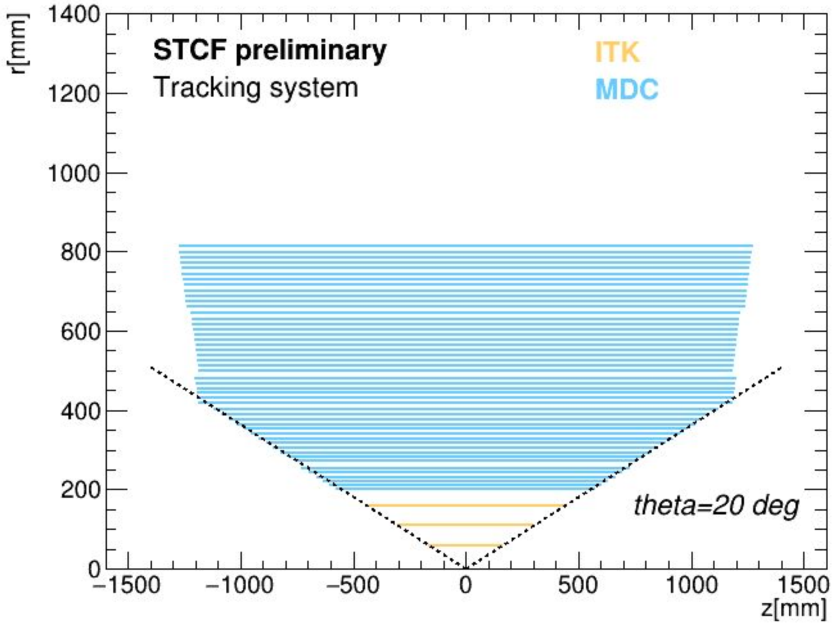


Tracker	Number of layers	Radius/ |z| (mm)	σ_x (μm)	σ_y (μm)	Technology
VXD	3 double layers	16-58	2.8/6/4/4/4/4	2.8/6/4/4/4/4	Silicon (pixel/strip)
SIT	4 layers	230-770	7.2	86	
SET	1 layer	1815	7.2	86	
FTD	5/7 layers at each endcap	467-2991	(2.8)/(2.8)/7.2/ 7.2/7.2/7.2/7.2	(7.2)/(7.2)/7.2/7. 2/7.2/7.2	
DC	100 layers	805-1795	110		Drift Chamber

The STCF tracking system

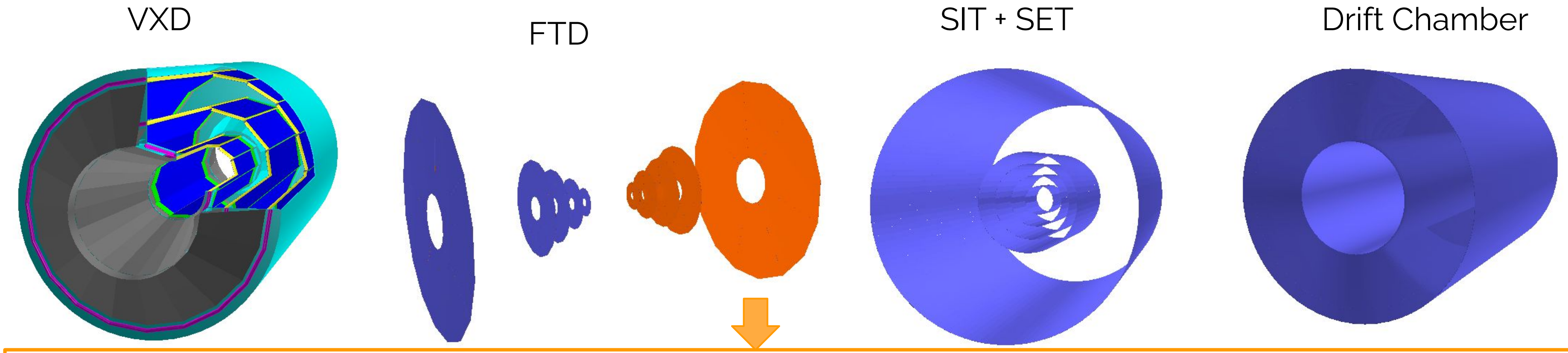
uRWell/MAPs-based Inner Tracker (ITK) + Drift chamber

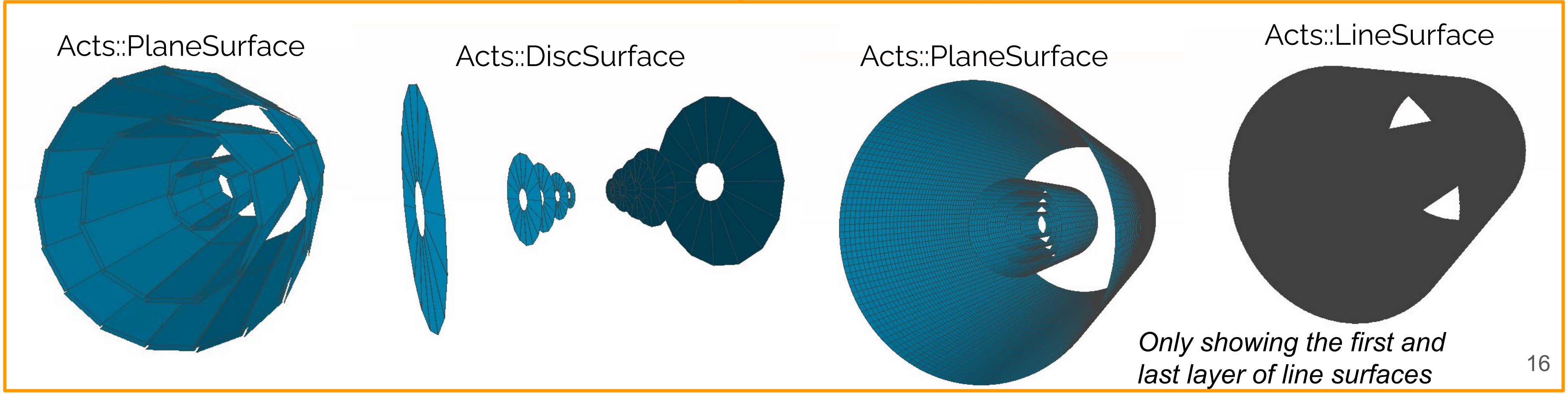




ITK: 3 layers, $\sigma_{r\text{-}\phi} \times \sigma_z \approx 100$ um x 400 um
MDC: 48 layers, σdrift dist ≈ 120~130 um

CEPC tracker geometry in ACTS format

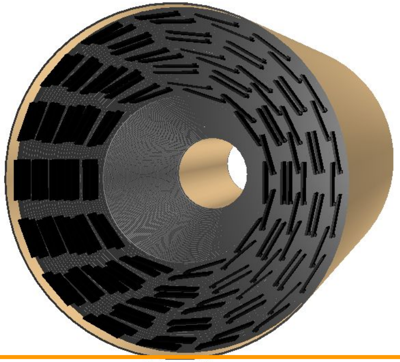




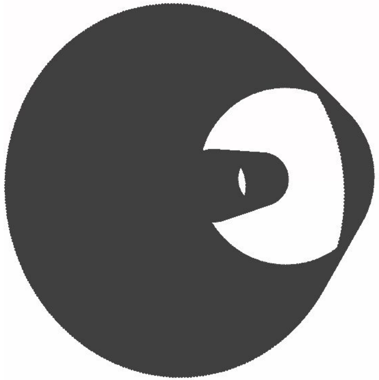
STCF tracker geometry in ACTS format

ITK

MDC



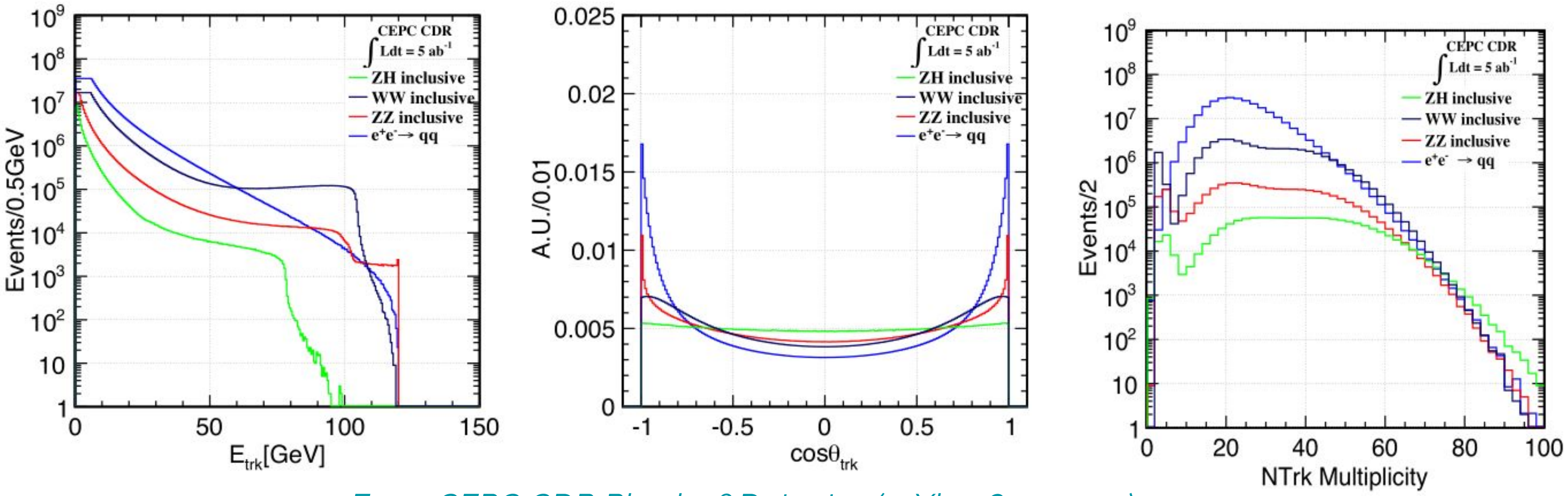
Acts::CylinderSurface



Acts::LineSurface

CEPC tracking requirements

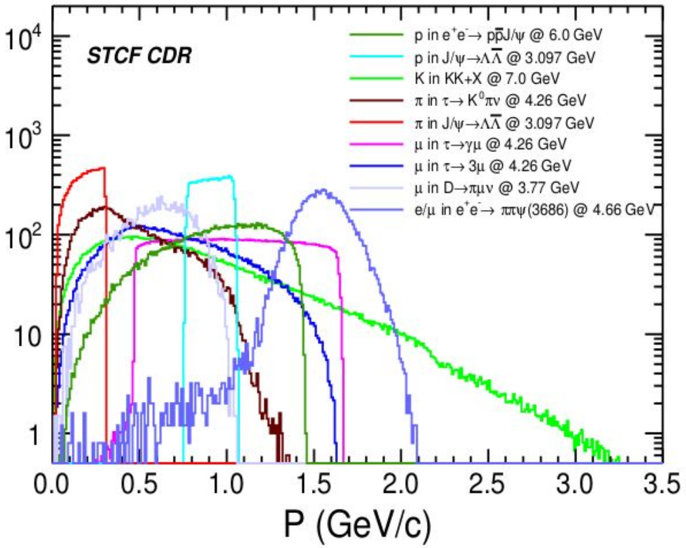
- Mostly >20 tracks per event (up to 100 tracks per event)
  - >99% tracking efficiency for p_T > 1 GeV
  - Impact track parameter resolution at ~ 5 um
  - Momentum resolution reaches per mille level in the range [10, 100] GeV



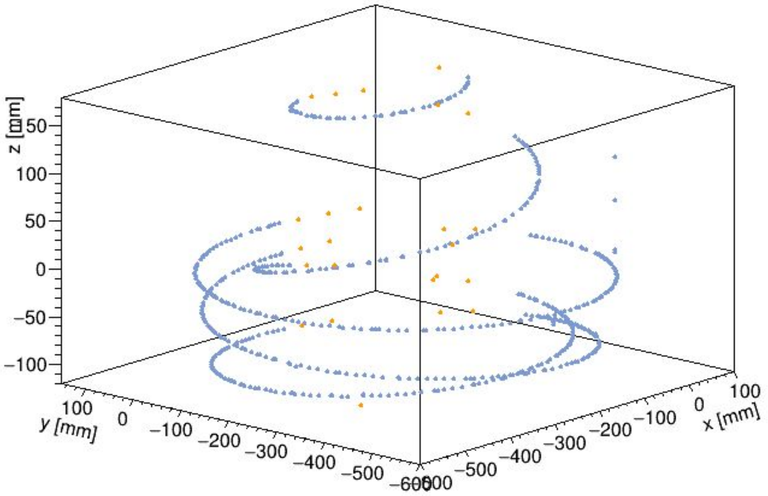
From CEPC CDR Physics&Detector (arXiv: 1811.10545)

STCF tracking requirements

- Low track multiplicity, but high background noise and **most tracks have p_T < 500 MeV**
  - $\sigma(p)/p$ = 0.5% with p = 1 GeV
  - Tracking eff. > 50/90/99 % with p_T > **50**/100/300 MeV



From STCF CDR (arXiv:2303.15790v2)

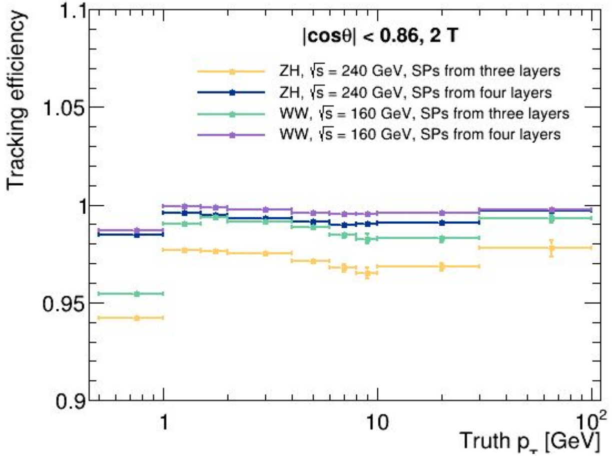


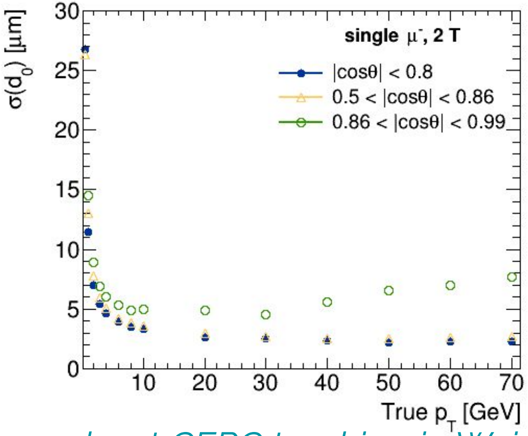
An example of muon trajectory (pT = 100 MeV, theta = 90 deg, 1 T B field)

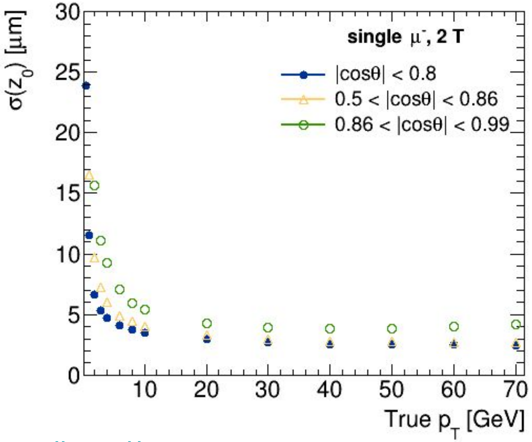
CEPC tracking performance (very preliminary)

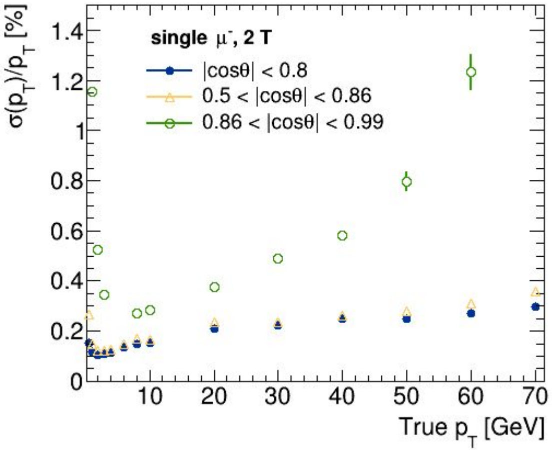
More in talk at CTD2023

- ACTS with CEPC full simulation is not working yet. Currently using ACTS Fatras simulation.
- >=95% tracking efficiency for $p_T > 1$ GeV in benchmark physics processes
  - 1-2% fake tracks and 10% duplicate tracks
- 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%







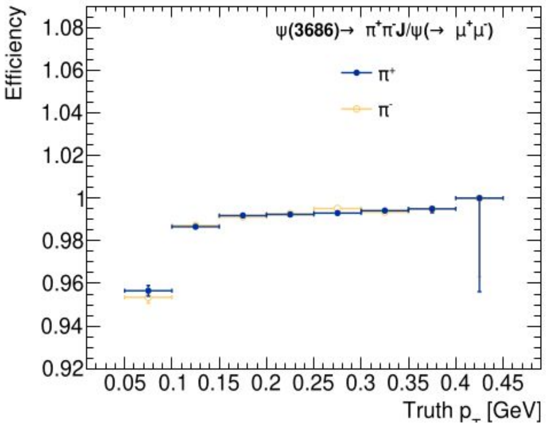


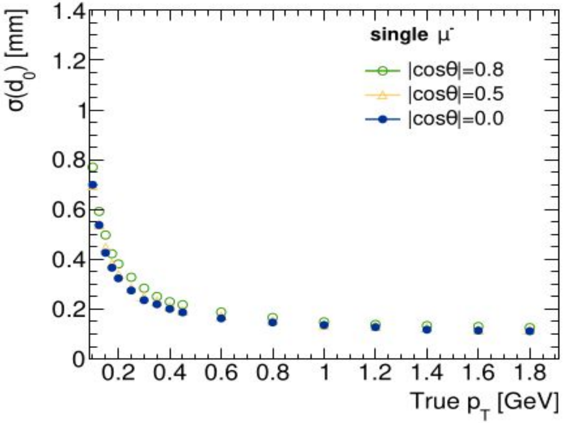
More about CEPC tracking in Weidong Li's talk

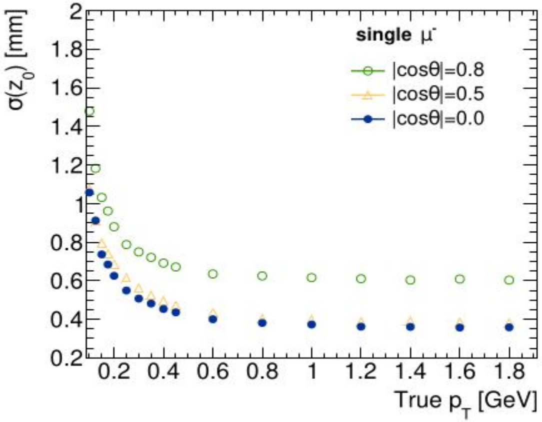
STCF tracking performance

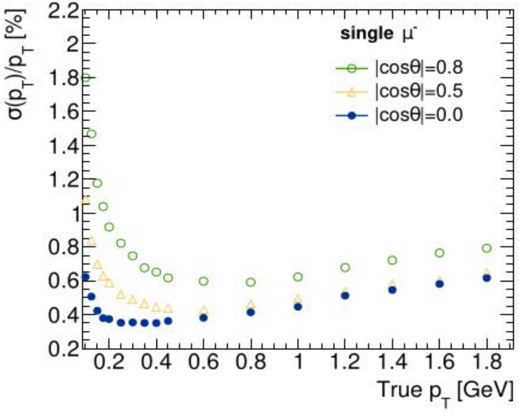
*More in [talk at CHEP2023](#) and JINST **18** P07026*

- 94% tracking efficiency with p_T in [50, 100] MeV
- Negligible fake rate (<0.01%)
- <0.5% duplicate tracks for p_T < 130 MeV due to duplicate seeds for looping tracks
- $\sigma(p_T)/p_T$ < 0.5% with p_T = 1 GeV, θ = 90° is achieved







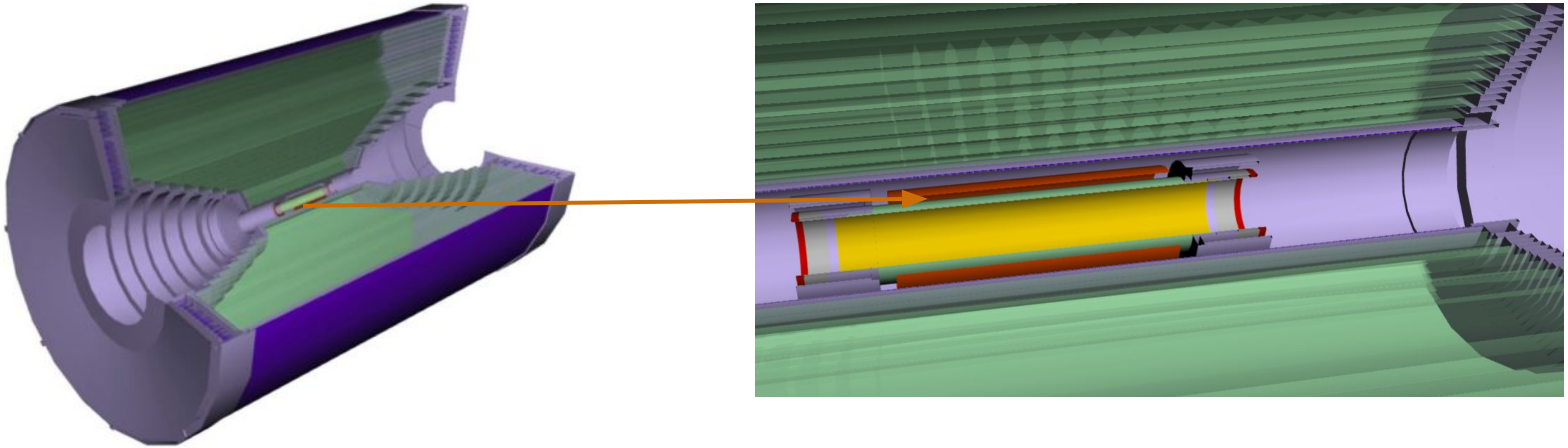


More about STCF tracking in Hang Zhou's talk

Application for BESIII

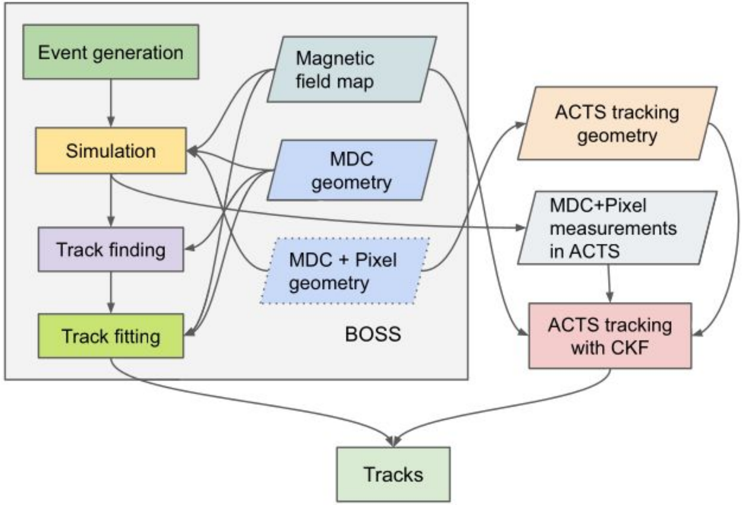
BESIII tracking system

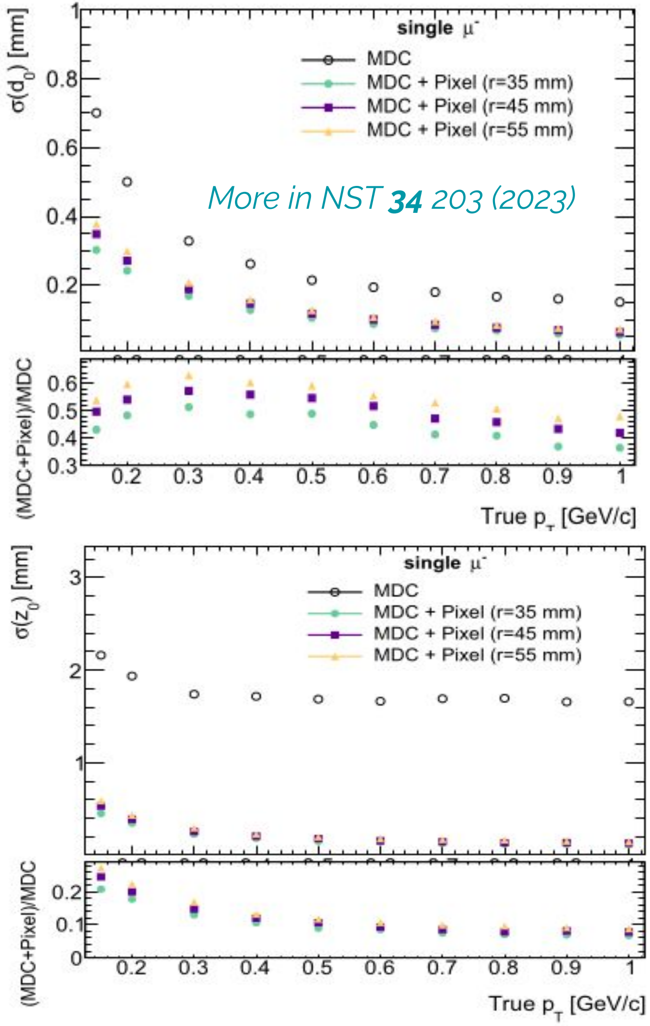
- BESIII drift chamber is suffering from aging after operation for > 15 years
- Proposals for preserving and enhancing the tracking performance:
  - New inner drift chamber
  - Replacement of inner DC with cylindrical gas electron multiplier (CGEM)
  - Or a very thin (50 um) **stitched CMOS sensor** between beam pipe and drift chamber to **minimize the material budget** (the key impacting factor for performance of low pT tracks)?



Simulation studies with ACTS

- Obvious tracking resolution/efficiency improvement with one more layer of stiched pixel studied using ACTS compared to current drift chamber





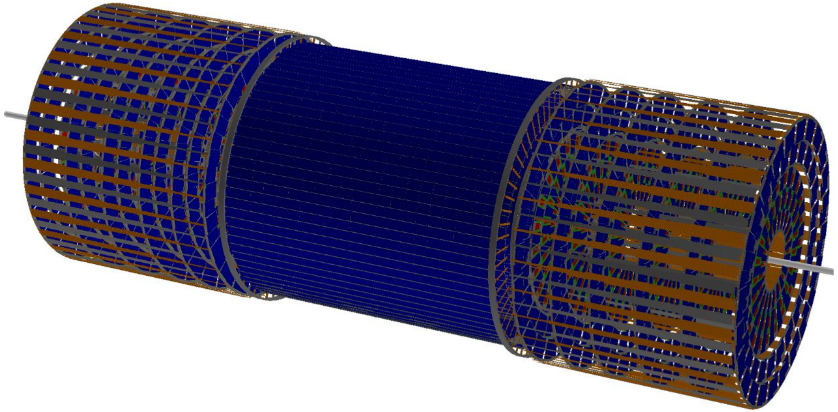
*More in NST **34** 203 (2023)*

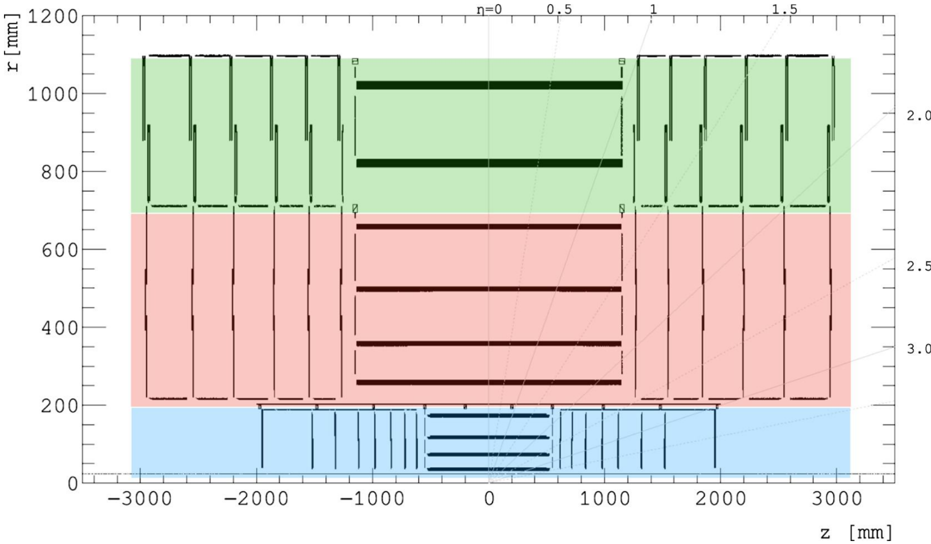
More about BESIII tracking in Jin Zhang's talk

Towards an Open Drift Chamber

Open Data Detector in ACTS

- A full silicon tracker with realistic material description
  - Very useful for tracking algorithms development&validation
- Configurable replacement of Strip with Drift Chamber?





https://gitlab.cern.ch/acts/OpenDataDetector

More details here

A very naive drift chamber

e.g. a brainstorm BelleII-like drift chamber
with 10 Super Layers, 62 layers in total

#Super Layer	Type	nLayers	rMin [mm]	rMax [mm]	Cell size	halfZ [mm]
0	A	8	~209	~290	~10	~3000
1	U	6	~290	~375	~14	~3000
2	A	6	~375	~460	~14	~3000
3	V	6	~460	~545	~14	~3000
4	A	6	~545	~641	~16	~3000
5	U	6	~641	~737	~16	~3000
6	A	6	~737	~833	~16	~3000
7	V	6	~833	~930	~16	~3000
8	A	6	~930	~1032	~17	~3000
9	A	6	~1032	~1135	~17	~3000

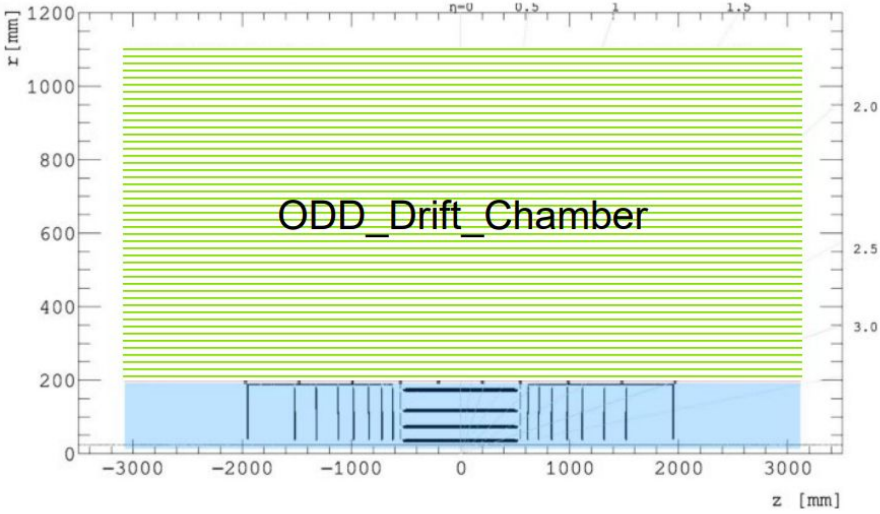
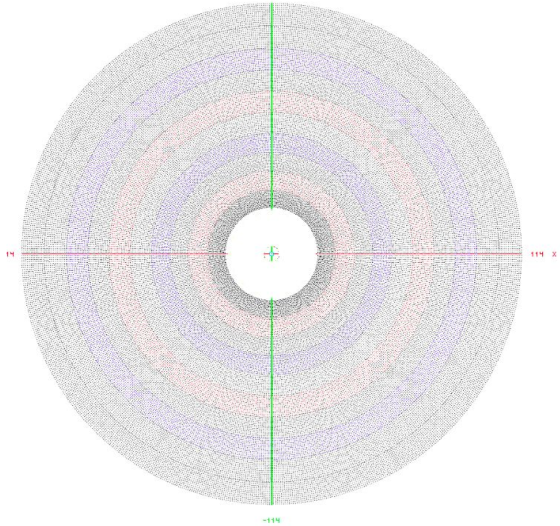
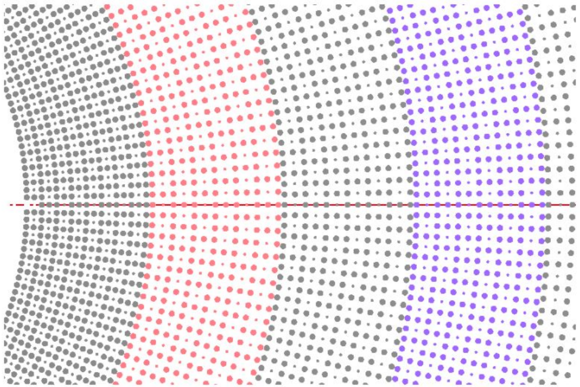


Figure from Tao Lin.
More in his slides here

The status

- A simple geometry of drift chamber has been implemented
  - Superlayers and layers are configurable in the compact files. Only axial wires are implemented for the moment
  - Also needs dedicated simulation+digitization for drift chambers





A: grey; U: red; V: blue

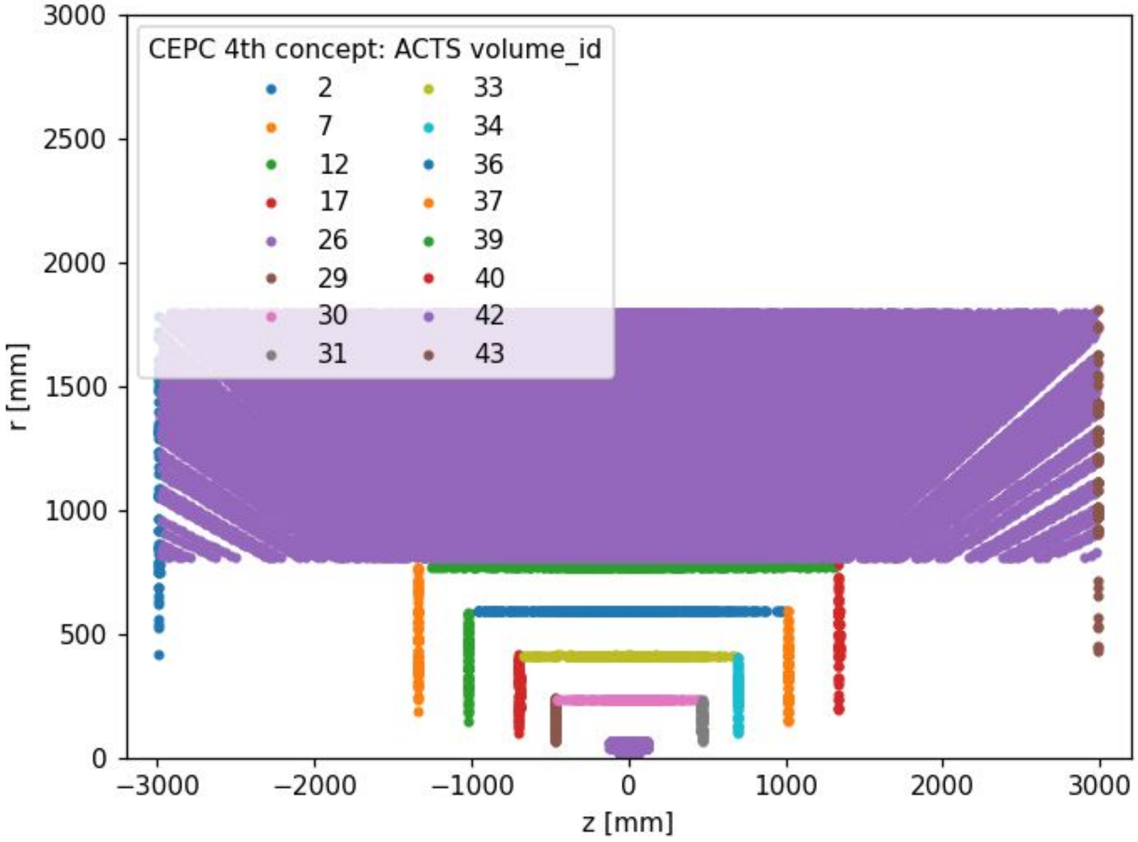
Figure from Tao Lin.
More in his slides here

Summary

- ACTS has been working very well for silicon tracker
- For TPC, a planar representation turns out to be working well
- Recently has been successfully **implemented for tracking with drift chambers, e.g. STCF, CEPC and BESIII**
  - Very promising performance
  - Optimization, in particular geometry navigation, yet remains to be done
- For more independent development and validation, we have started the efforts on **implementing an Open Drift Chamber in ACTS**

- Join us if you are interested
  - ACTS Developers Meeting recently started a CERN Morning Slot (once per month, Tuesday 4 pm Beijing time)
  - China zone bi-weekly discussion about ACTS for tracking (Friday 11 am Beijing time)

Backup


CEPC 4th concept: ACTS volume_id
2
7
12
17
26
29
30
31
33
34
36
37
39
40
42
43
3000
2500
2000
1500
1000
500
0
r [mm]
−3000
−2000
−1000
0
1000
2000
3000
z [mm]

Circular Electron Positron Collider (CEPC) physics program

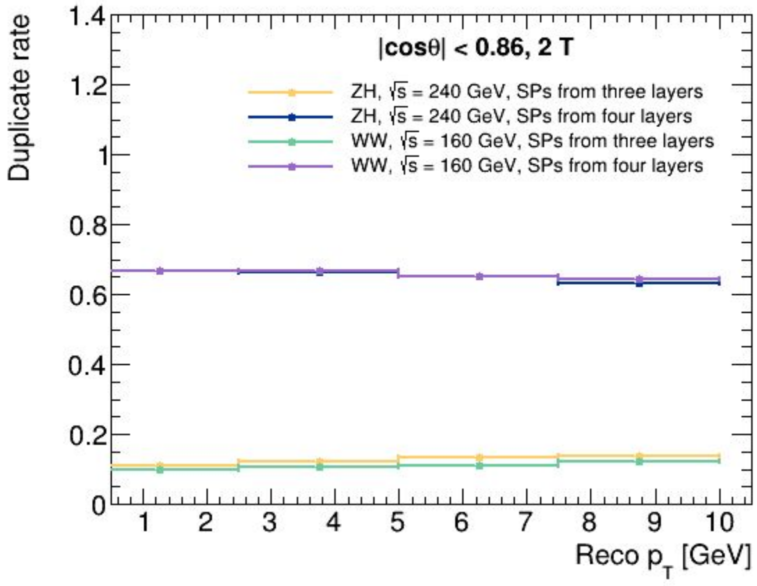
Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			240	91	160	360
Run time [years]			7	2	1	-
CDR (30 MW)		L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**3**	**32**	**10**	-
		$\int L\, dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	5
TDR (Latest)	30 MW	L / IP [$\times 10^{34}$ 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 [$\times 10^{34}$ 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

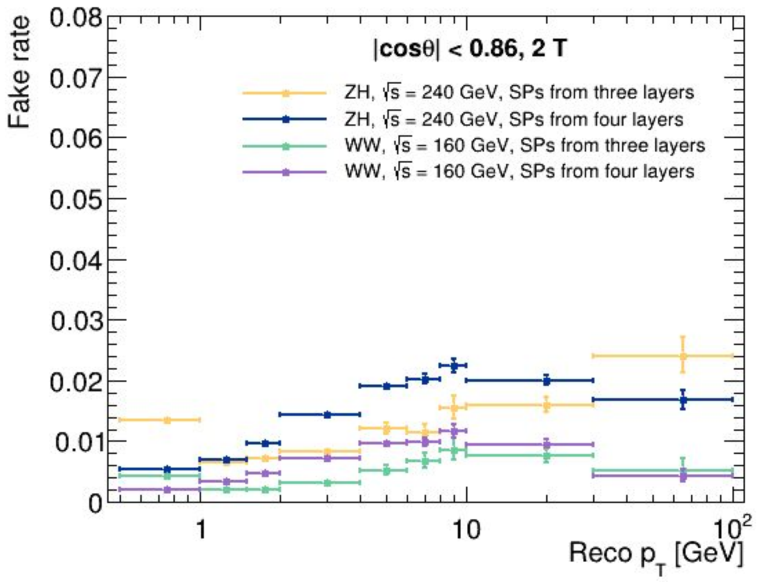
- Precision measurements of Higgs boson properties
- SM measurements: electroweak physics, QCD, flavor physics…
- Search for exotic decays of H, Z, B and τ, and BSM

Far more than a Higgs factory !

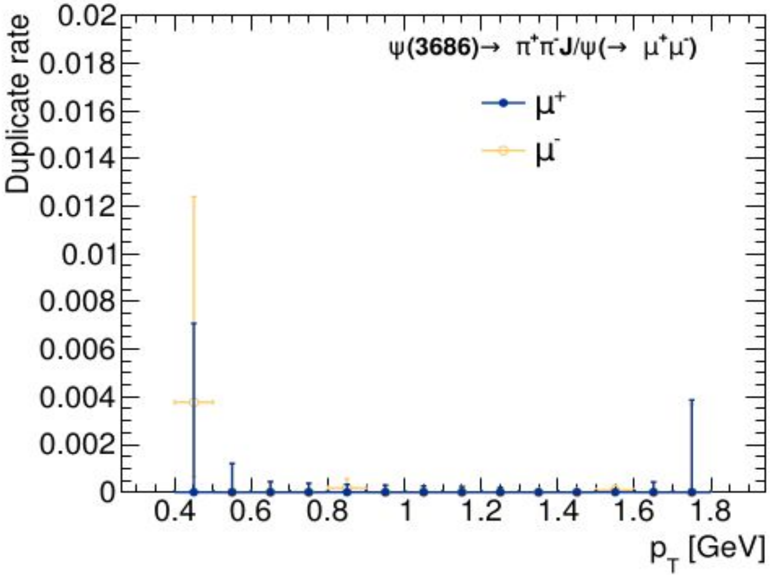
From J. Liu's slides at CEPC workshop 2023, Oxford

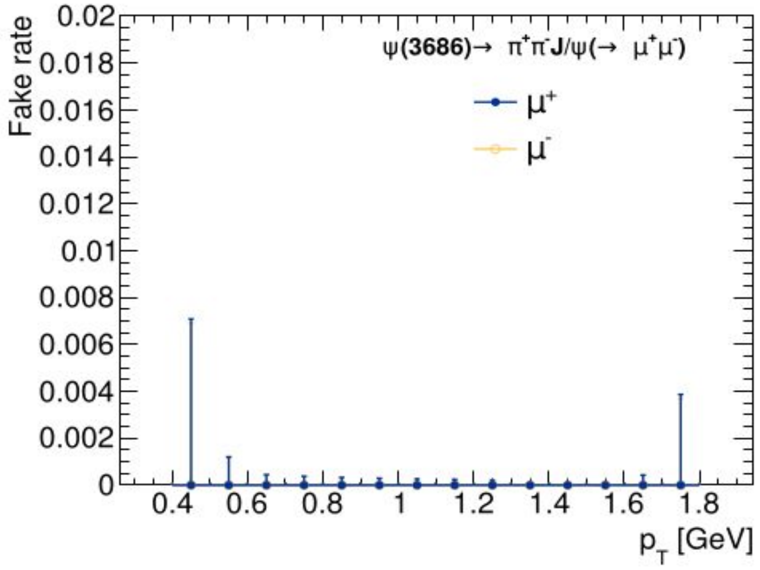
CEPC tracking





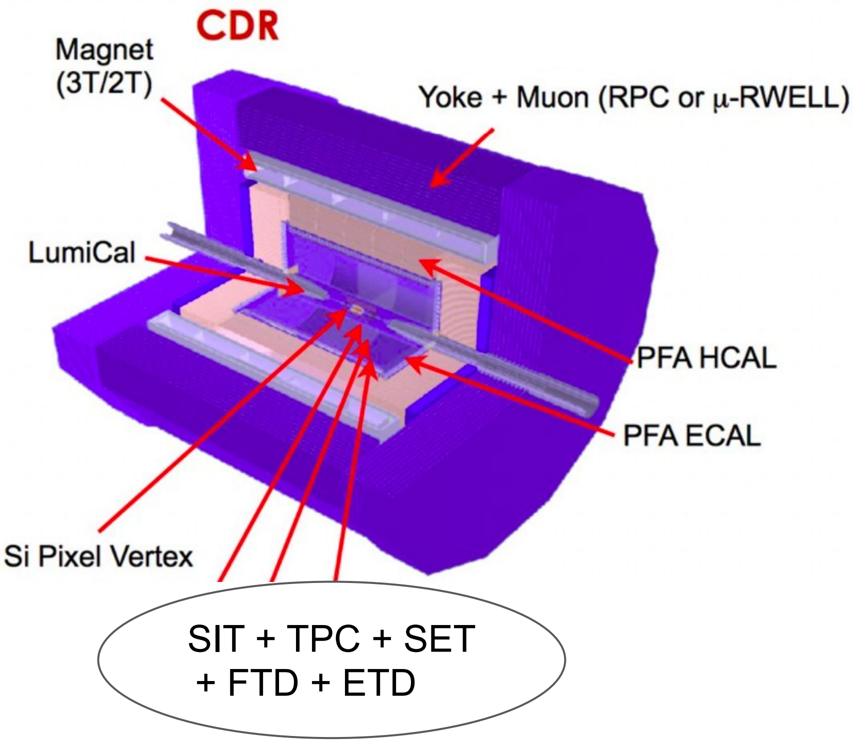
STCF tracking

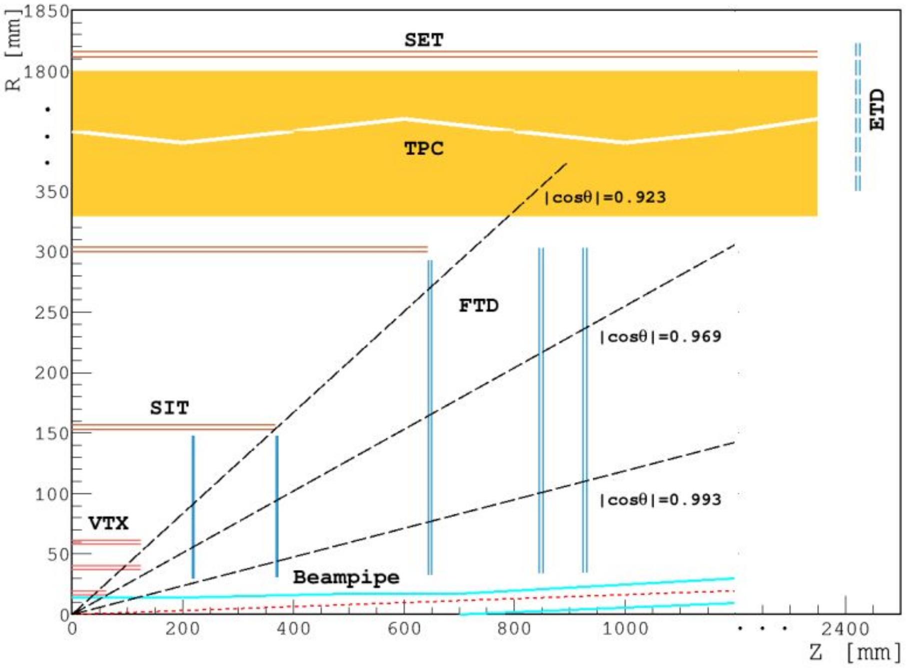




CEPC Detector Conceptual Designs

CEPC CDR Baseline Design (Particle Flow Approach)





CEPC Detector Conceptual Designs

Alternative designs