acts for gaseous tracking detectors

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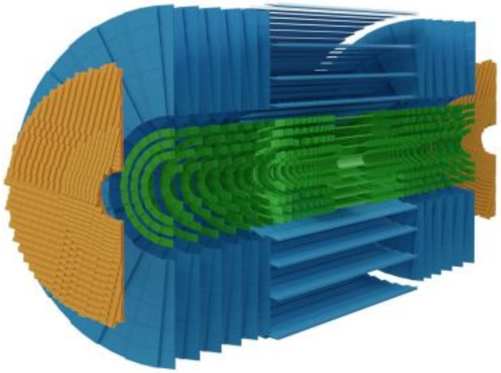
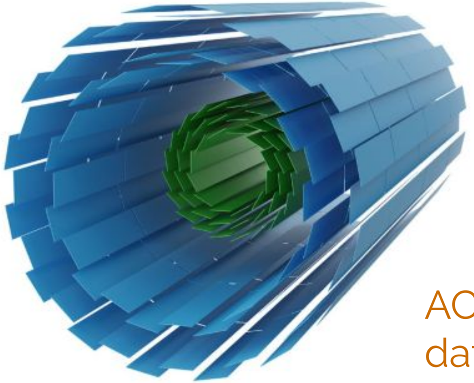
As a **Common** Tracking Software

- 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

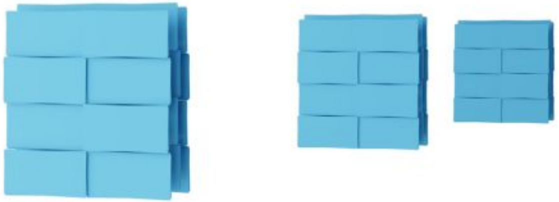
ATLAS ITk



sPHENIX silicon



FASER tracker

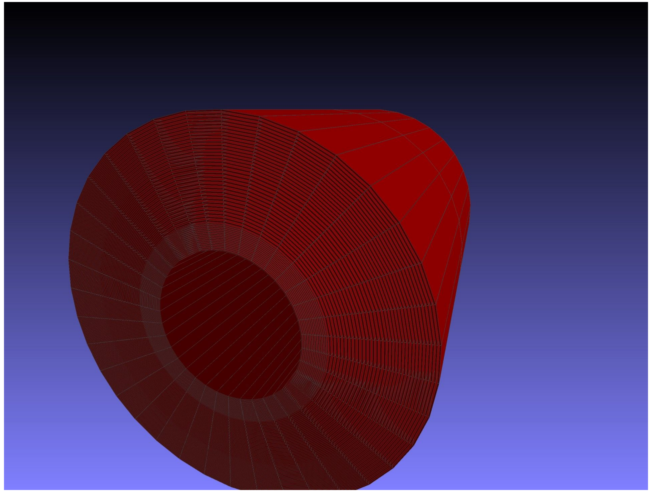


Figures from CSBS (2022) ***6,*** *8*

ACTS modules are already used for real data processing for ATLAS, sPHENIX, FASER (**See Ali Garabaglu 's talk**)!

As a **Common** Tracking Software

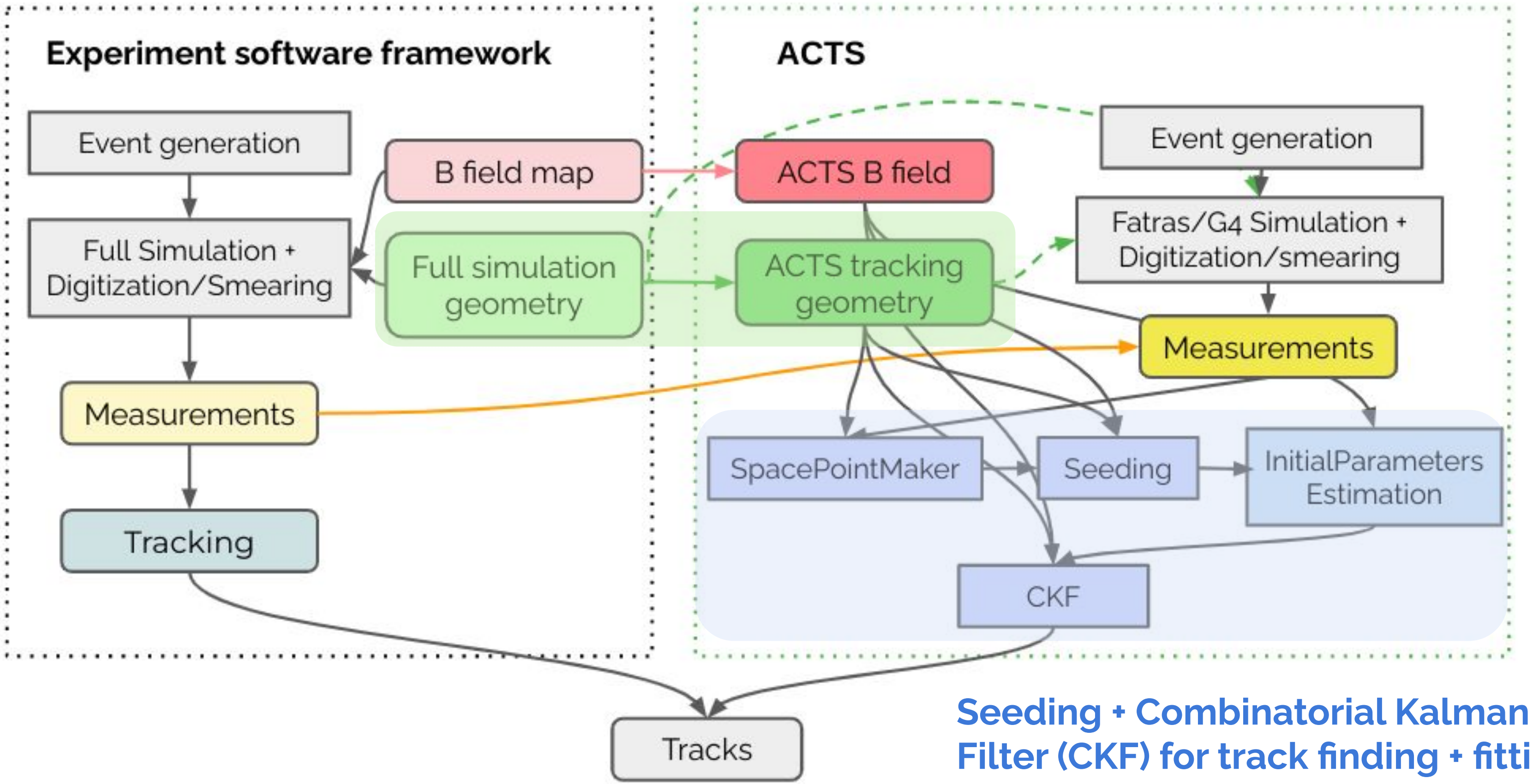
- ACTS is designed with the capability of working for gaseous tracking detectors
  - Time Projection Chamber (TPC) is represented with fake Planar detectors
    - e.g. sPHENIX TPC
  - Drift chamber and Transition Radiation Tracker is represented with N-layer drift wire/tubes, e.g.
    - Circular Electron-Positron Collider **(CEPC):** a factory of Higgs, W, Z...
    - Super Tau Charm Facility **(STCF):** a factory of hadrons, τ ...
    - ATLAS TRT (not covered in this talk)



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

ACTS application strategies

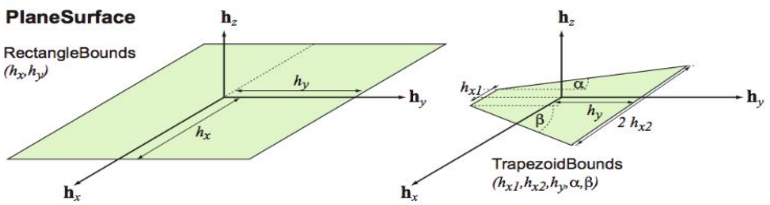
Geometry transformation is the first step

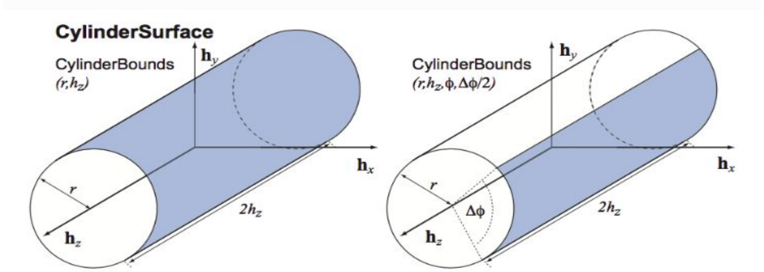


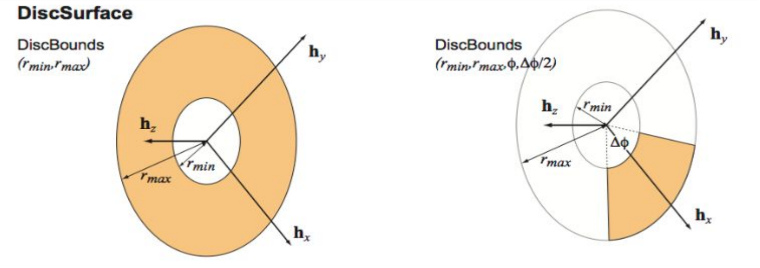
Seeding + Combinatorial Kalman Filter (CKF) for track finding + fitting

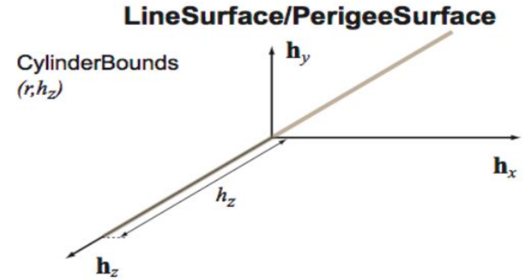
ACTS tracking geometry

- ACTS Tracking geometry is simplified from full simulation geometry for fast track propagation
- 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

Tracking geometry for drift chamber

- Currently, layer-based geometry model is used, i.e. drift wires are associated to concentric Acts::Layer (suboptimal for navigation. More intelligent model will be tried)

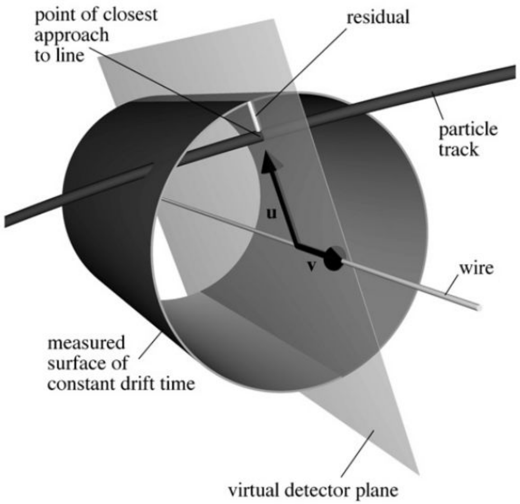
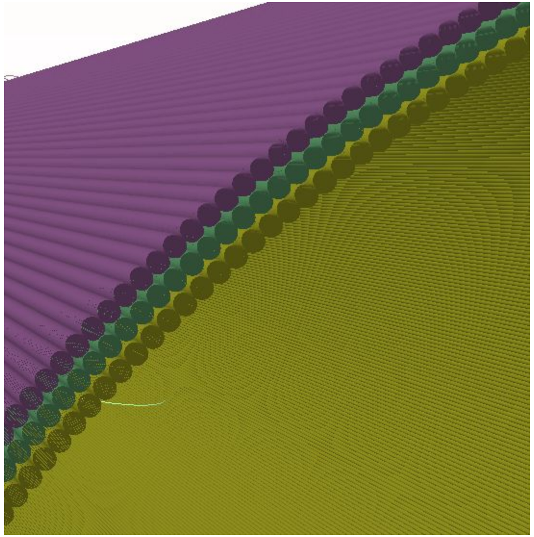


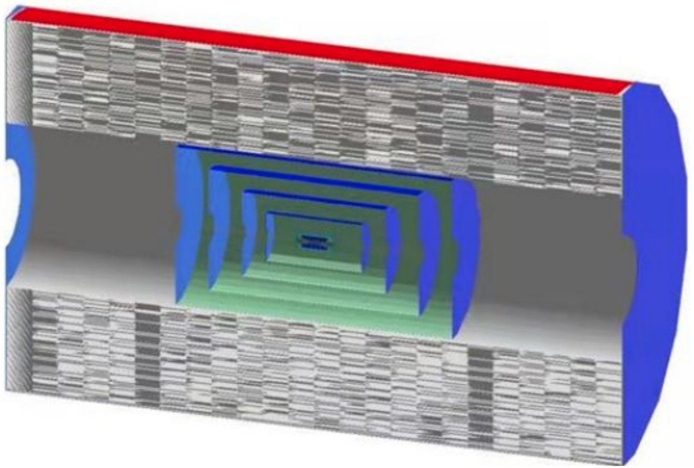
Figure from NIMA 620 (2010) 518



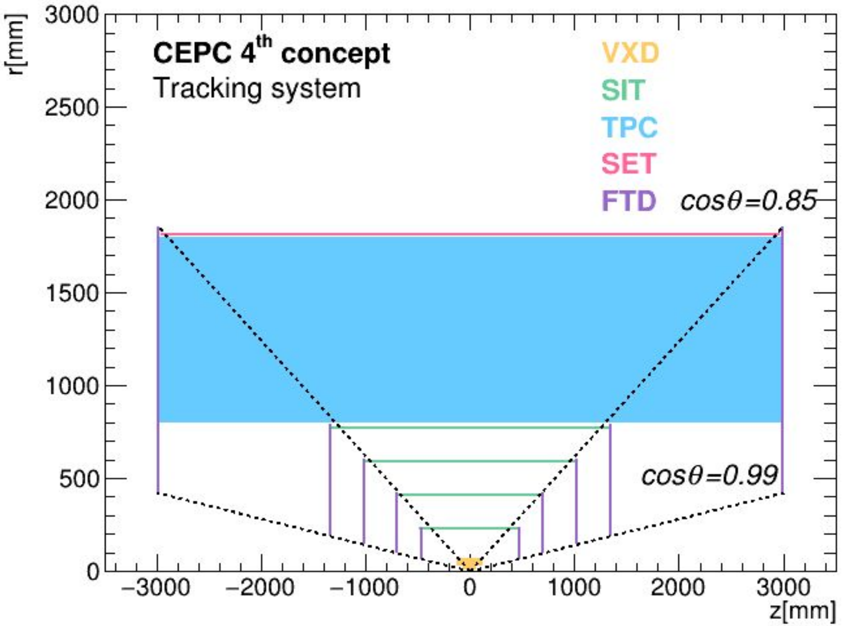
Example of three layers of drift wires

Application for CEPC and STCF

The CEPC tracking system



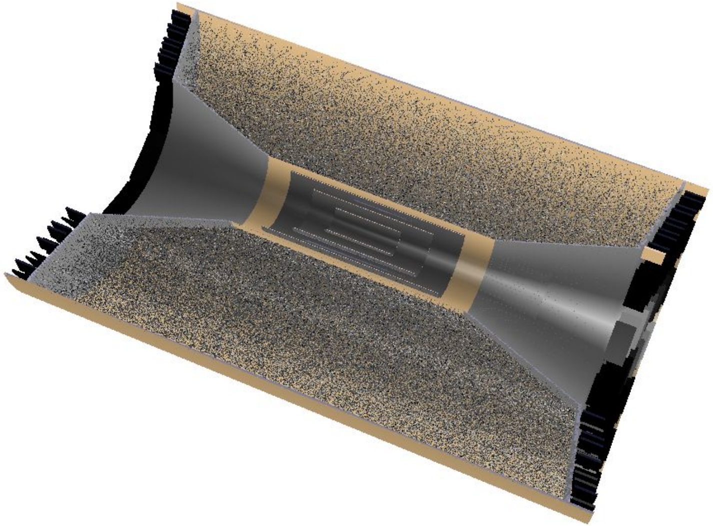
Silicon (VXD, SIT, SET, FTD) + Drift chamber

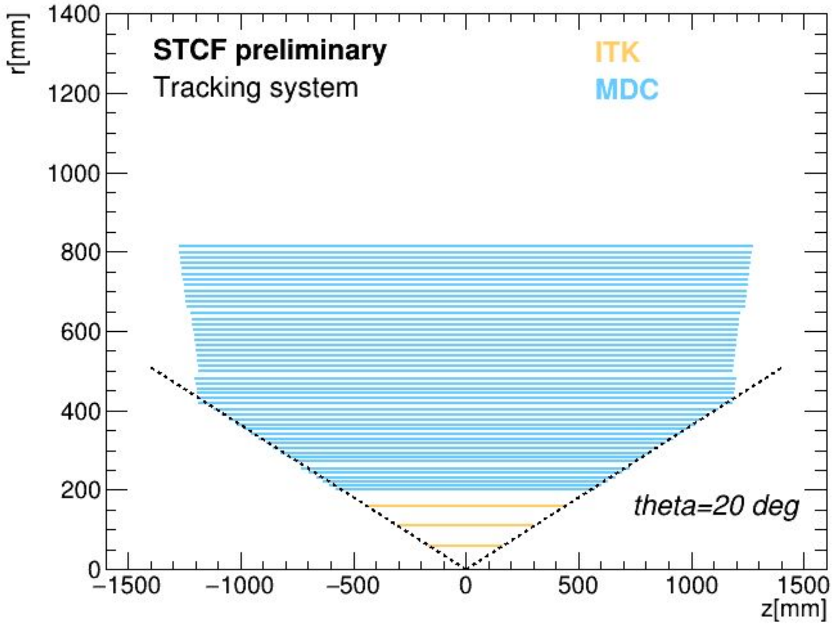


Tracker	Number of layers	Radius/ |z| (mm)	σ_x (μm)	σ_y (μm)	Technology
VXD	3 double layers	16-58	2.8/6/4/4/4/4	2.8/6/4/4/4/4	Silicon (pixel/strip)
SIT	4 layers	230-770	7.2	86	
SET	1 layer	1815	7.2	86	
FTD	5/7 layers at each endcap	467-2991	(2.8)/(2.8)/7.2/ 7.2/7.2/7.2/7.2	(7.2)/(7.2)/7.2/7. 2/7.2/7.2/7.2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

The STCF tracking system

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

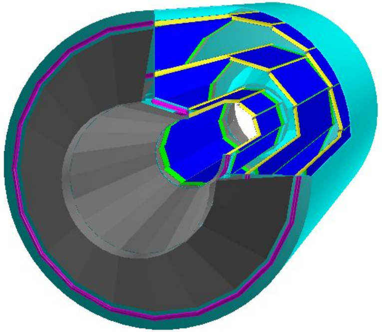




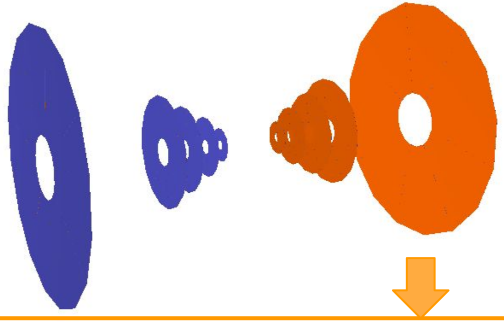
ITK: 3 layers, $\sigma_{r-\phi} \times \sigma_z \approx$ 100 um x 400 um
MDC: 48 layers, σdrift dist ≈ 120~130 um

CEPC tracker geometry in ACTS format

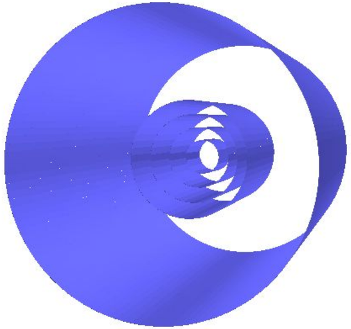
VXD



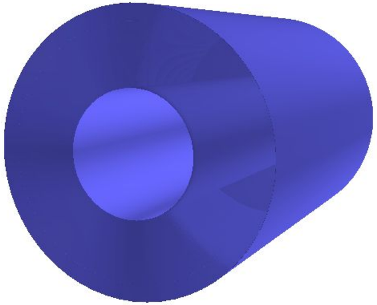
FTD



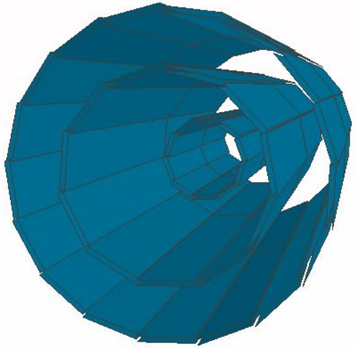
SIT + SET



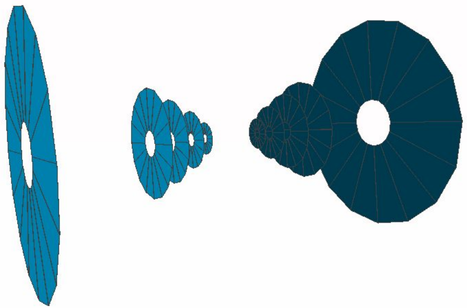
Drift Chamber



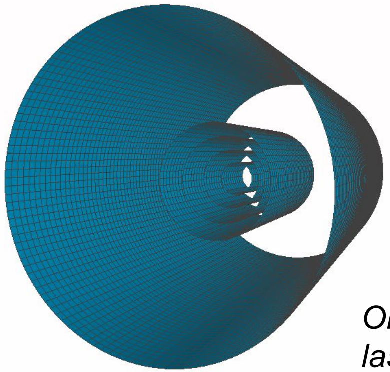
Acts::PlaneSurface



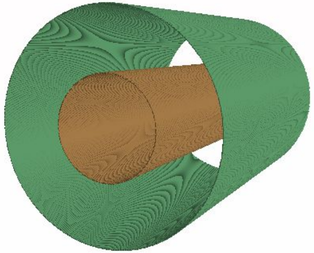
Acts::DiscSurface



Acts::PlaneSurface



Acts::LineSurface

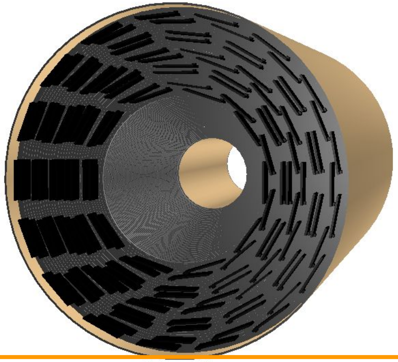


Only showing the first and last layer of line surfaces

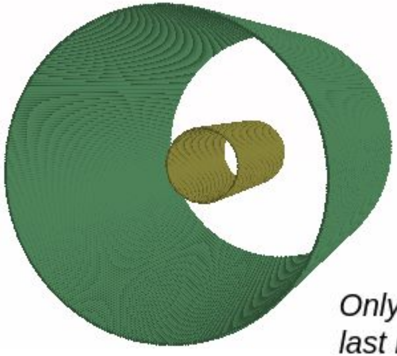
STCF tracker geometry in ACTS format

ITK

MDC



Acts::CylinderSurface

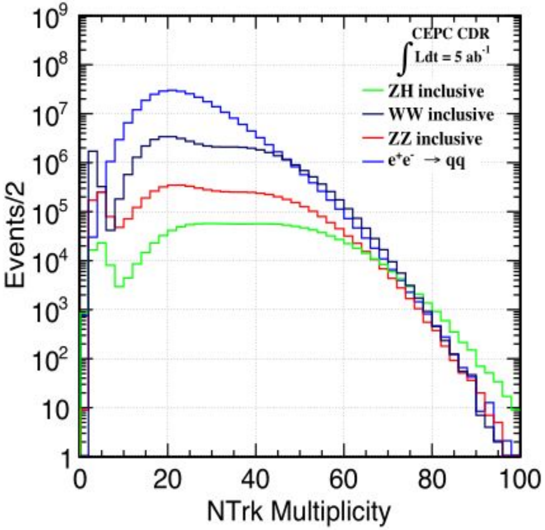


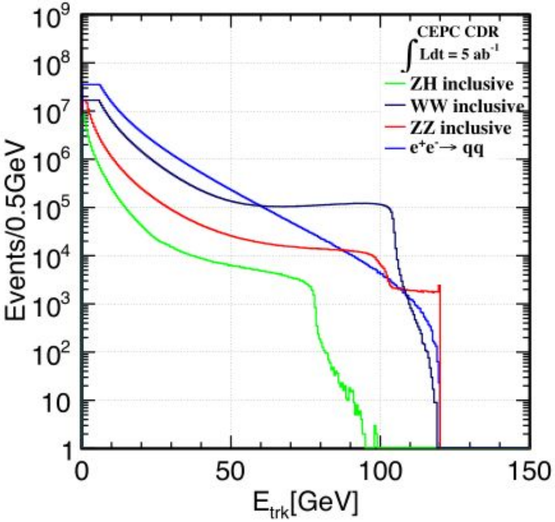
Acts::LineSurface

Only showing the first and last layer of line surfaces

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

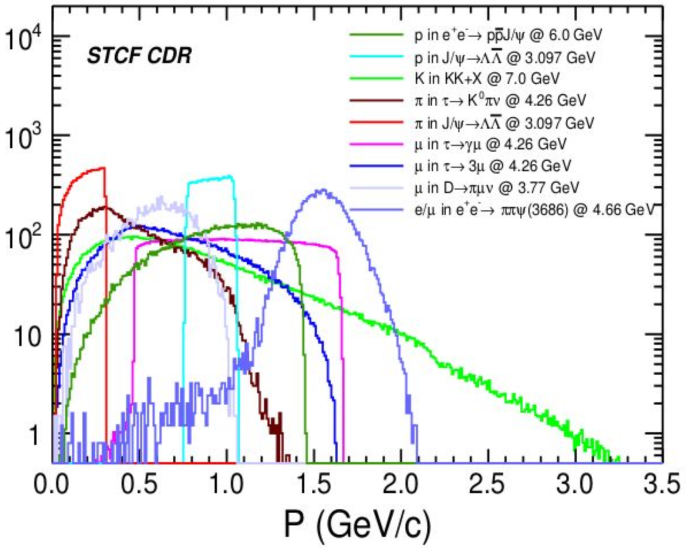




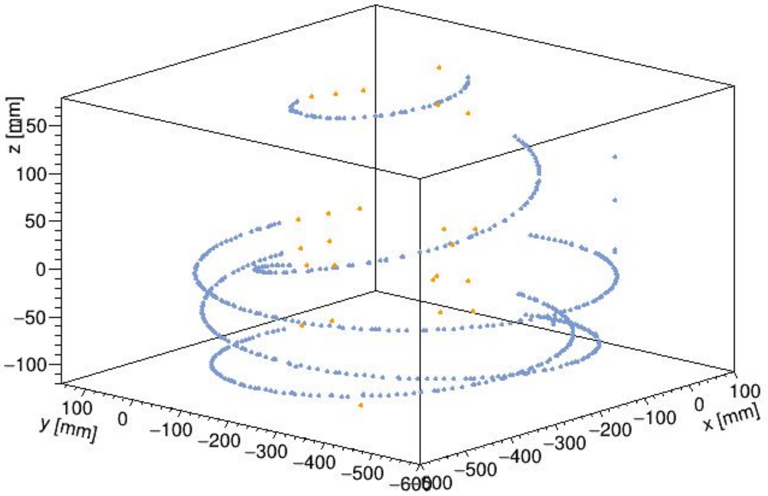
From CEPC CDR Physics&Detector (arXiv: 1811.10545)

STCF tracking requirements

- Low track multiplicity, but high background noise and **most tracks have p_T < 500 MeV**
  - σ(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)

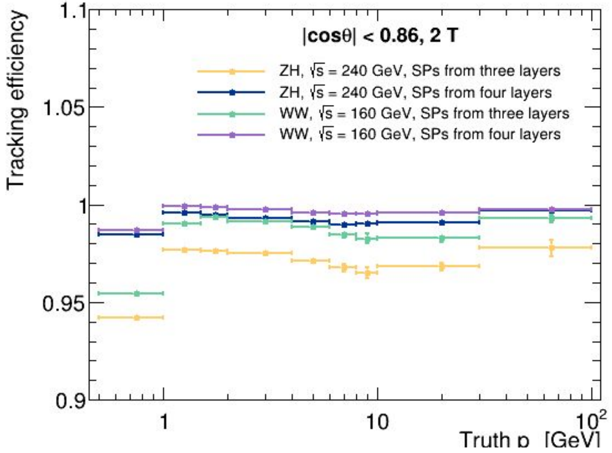


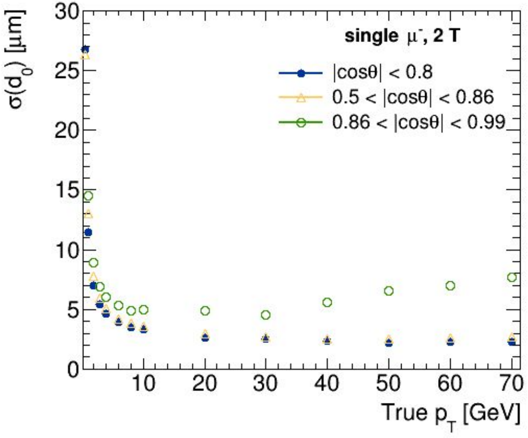
An example of muon trajectory (pT = 100 MeV, theta = 90 deg, 1 T B field)

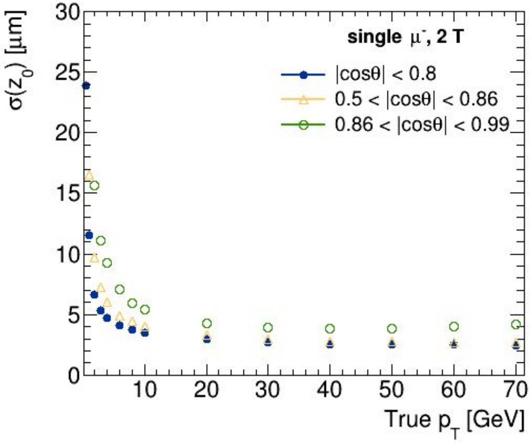
More in talk at CTD2023

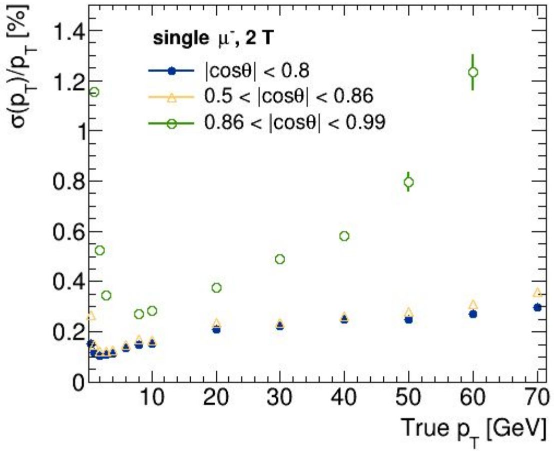
CEPC tracking performance (very preliminary)

- First look 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 (|cosθ|<0.8) :
  - $\sigma(d0)$ = 3 μm, $\sigma(z0)$ = 3.5 μm, $\sigma(p_T)/p_T$ = 0.16%





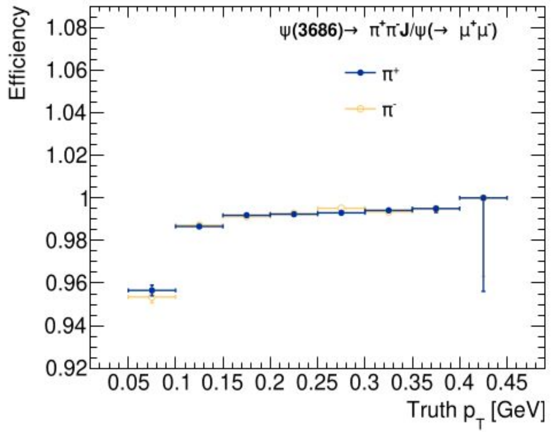


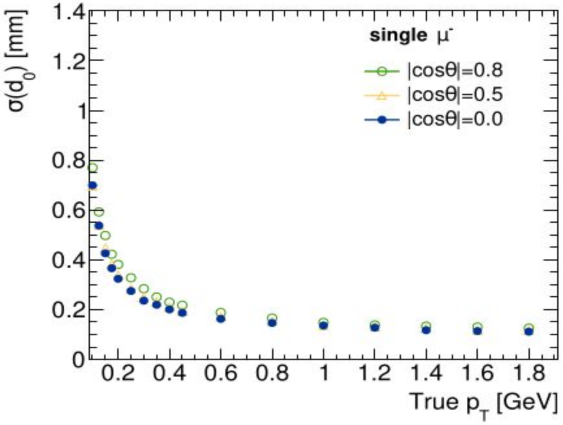


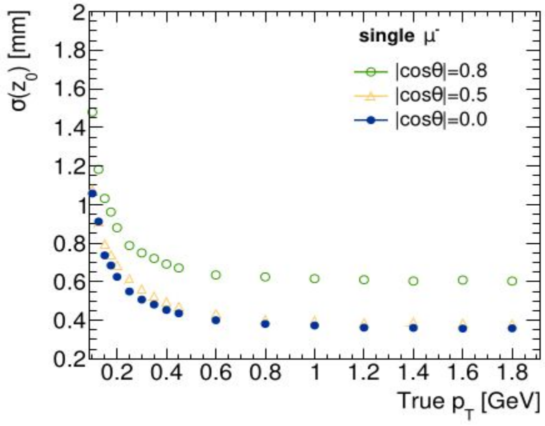
STCF tracking performance

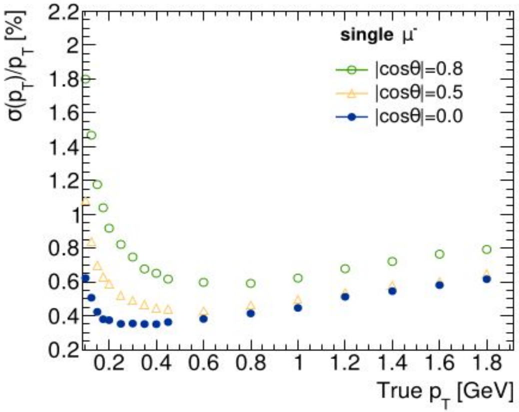
*More in [talk at CHEP2023](#) and JINST **18** P07026*

- 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







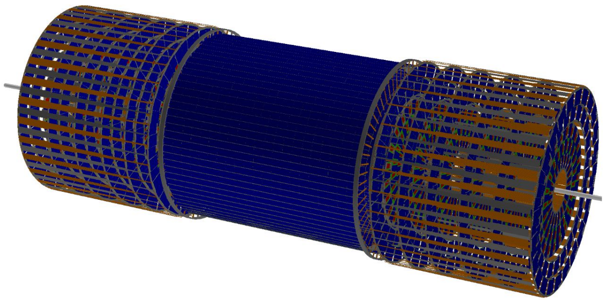


Towards an Open Drift Chamber

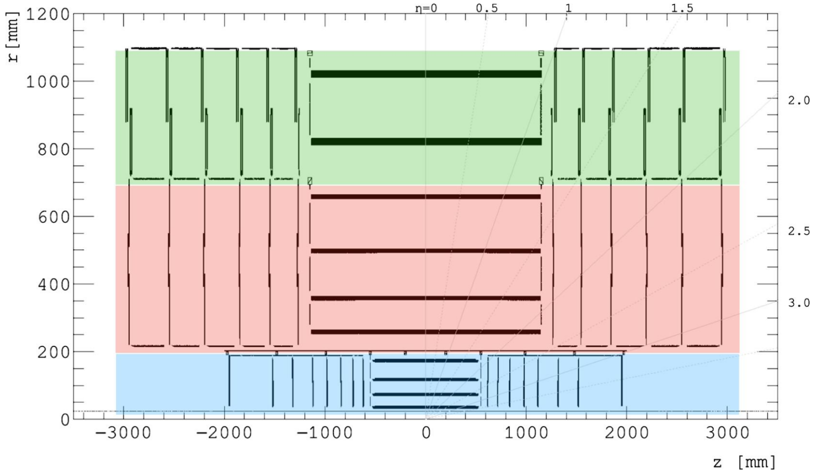
Open Data Detector in ACTS

- Open Data Detector (ODD) in ACTS is a full silicon tracker with realistic material description
- WIP to implement an Open Drift Chamber

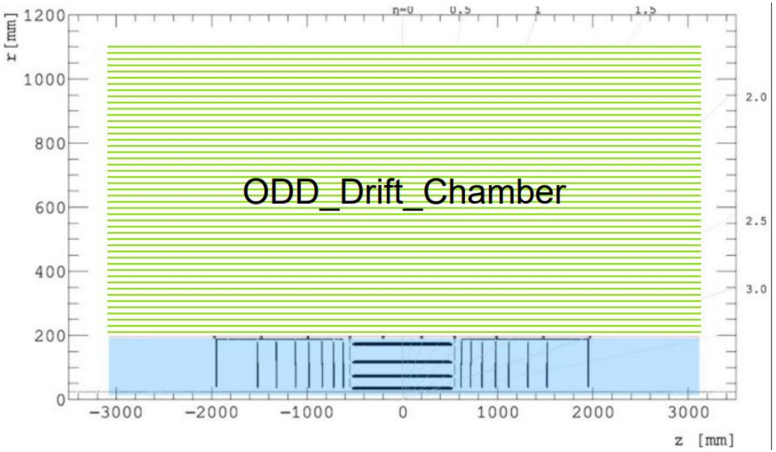
https://gitlab.cern.ch/acts/OpenDataDetector
More details here



ODD: Pixel + Short Strip + Long Strip

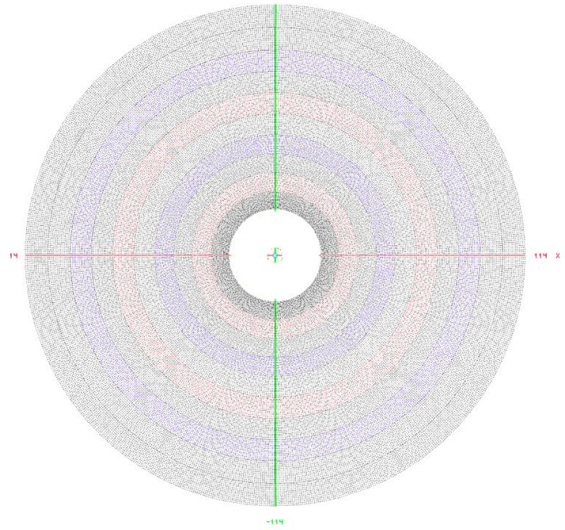


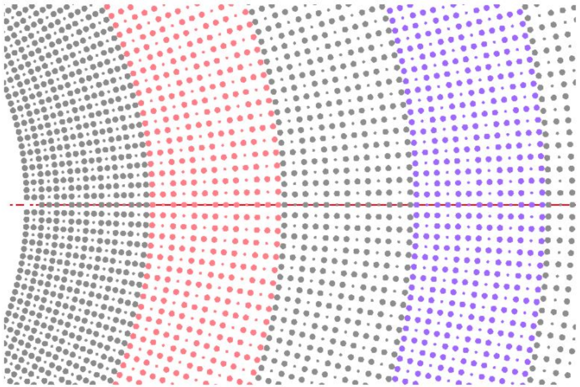
ODD: Pixel + Drift Chamber ?



The status

- A simple Belle-II drift chamber has been implemented using DD4hep
  - 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

More in my slides [here]()

Summary

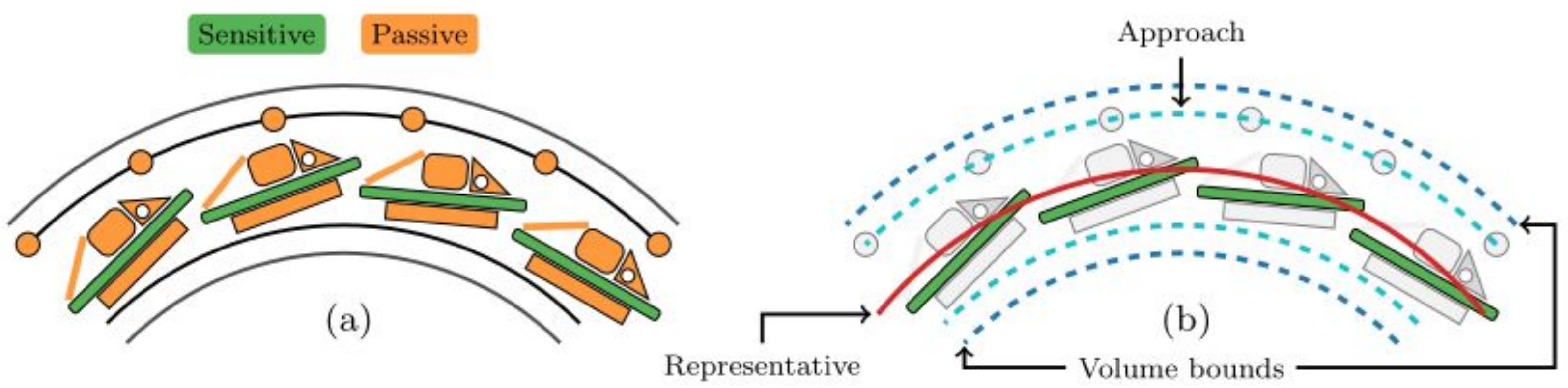
- ACTS has been working very well for silicon tracker
- For TPC, a planar representation turns out to be working well
- Recently has been successfully **implemented for tracking with drift chambers, e.g. STCF, CEPC and BESIII**
  - Very promising performance
  - Optimization, in particular geometry navigation,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

Thank you for your attention!

Backup

The ACTS tracking geometry

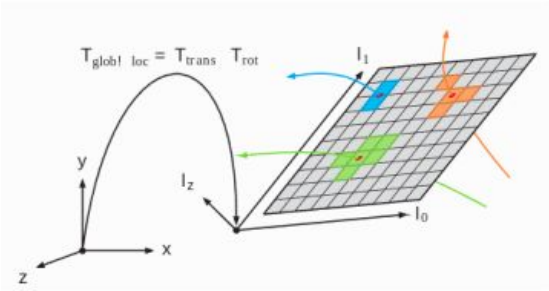
Figures from CSBS (2022) ***6*** *8*

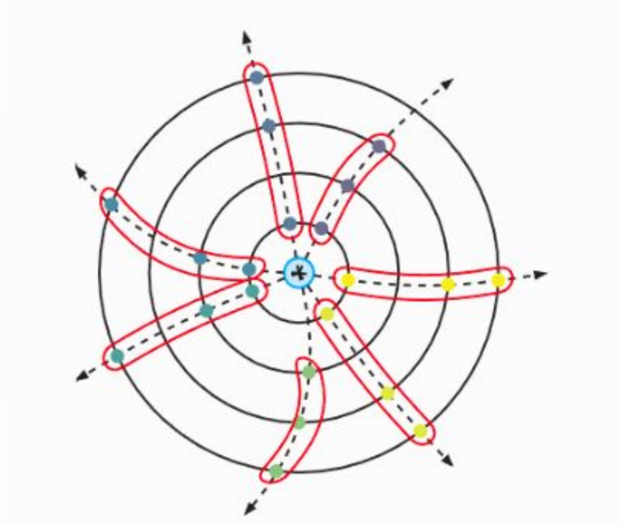


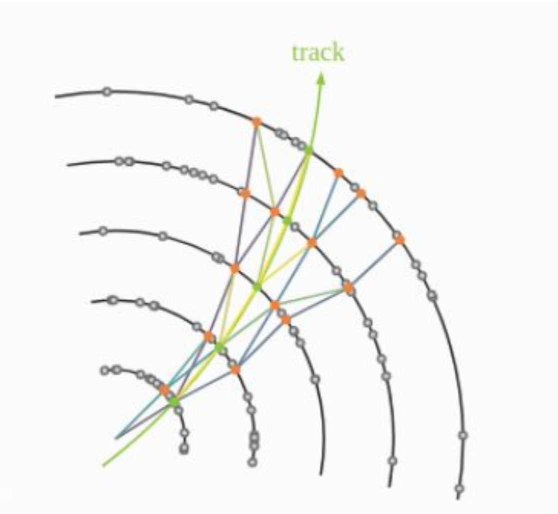
- Tracking geometry is simplified from detailed full simulation geometry for fast navigation, but with material effects well taken into account
- Navigation via hierarchical arrangement of the detector elements:
  - Legacy model: surfaces -> layers -> volumes
  - Layerless model: surfaces -> volumes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

Tracking strategies with ACTS

- SpacePoint (SP) Creation + Seeding + Combinatorial Kalman Filter (CKF)
  - Seeding: using SPs from vertex detector
  - CKF for track following starting from track parameters from the seeds
  - No ambiguity resolving yet

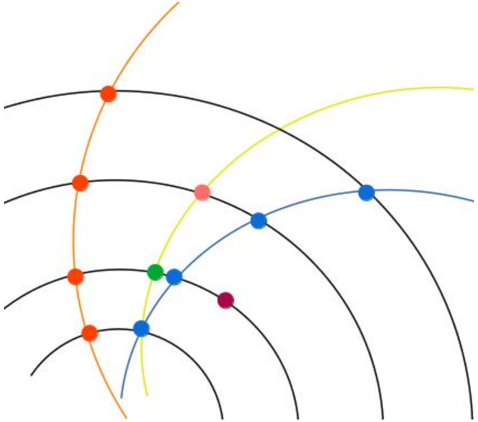






CKF for CEPC

- Progressingly 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



Circular Electron Positron Collider (CEPC) physics program

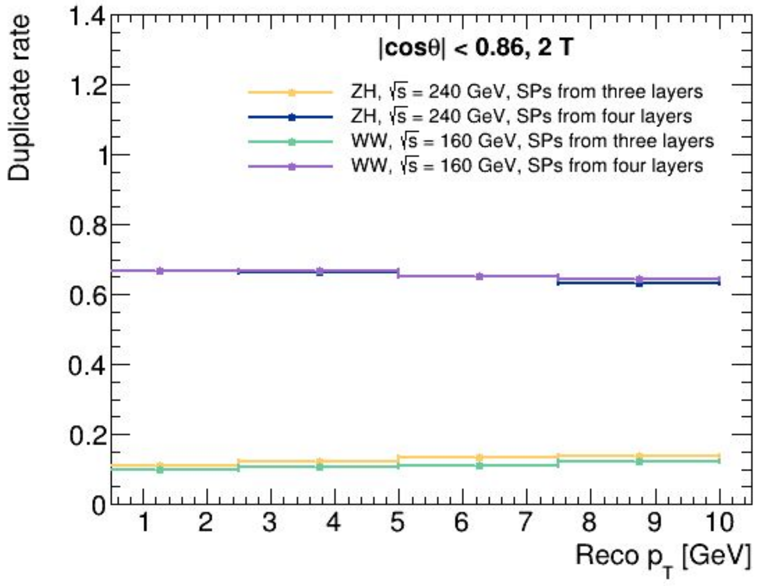
Operation mode			ZH	Z	W^+W^-	$t\bar{t}$
$\sqrt{s}$ [GeV]			240	91	160	360
Run time [years]			7	2	1	-
CDR (30 MW)		L / IP [$\times 10^{34}$ cm^{-2}s^{-1}]	**3**	**32**	**10**	-
		$\int L\, dt$ [ab^{-1}, 2 IPs]	5.6	16	2.6	-
		Event yields [2 IPs]	1×10^6	7×10^{11}	2×10^7	-
Run Time [years]			10	2	1	5
TDR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

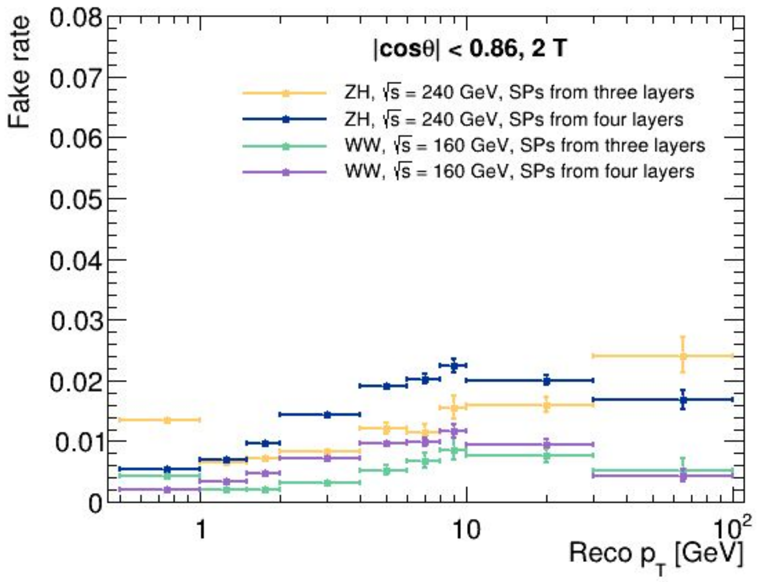
- Precision measurements of Higgs boson properties
- SM measurements: electroweak physics, QCD, flavor physics…
- Search for exotic decays of H, Z, B and τ, and BSM

Far more than a Higgs factory !

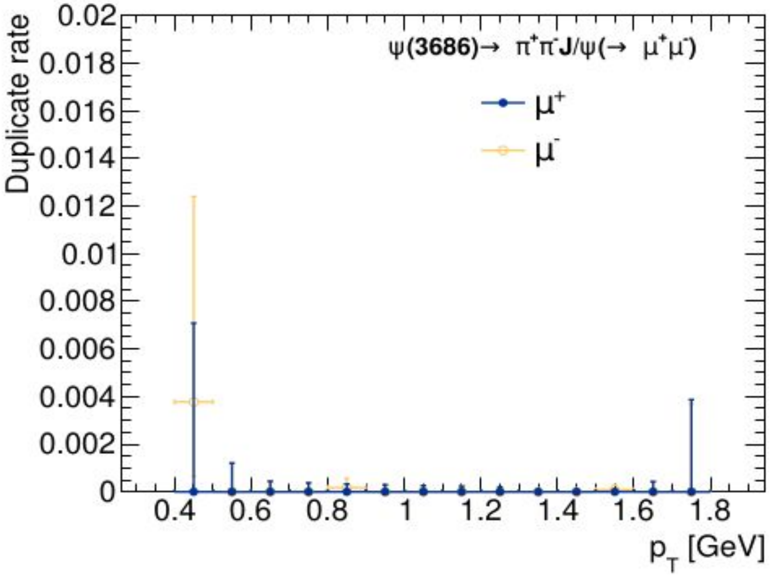
From J. Liu's slides at CEPC workshop 2023, Oxford

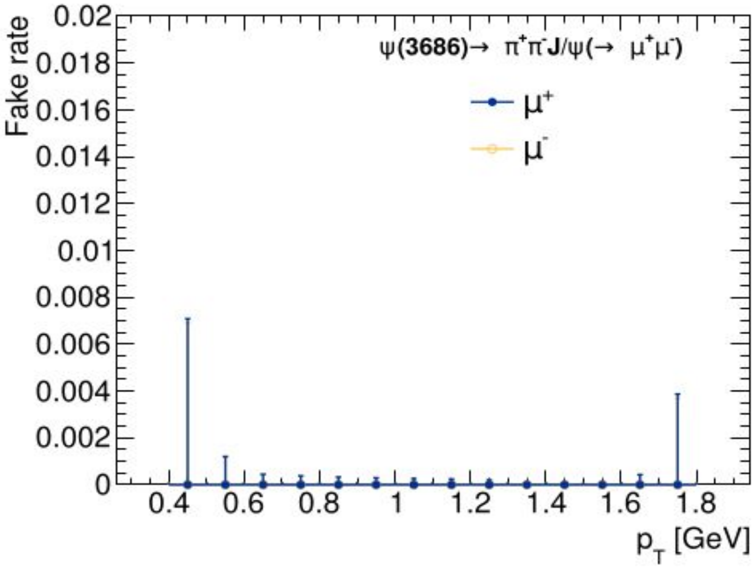
CEPC tracking



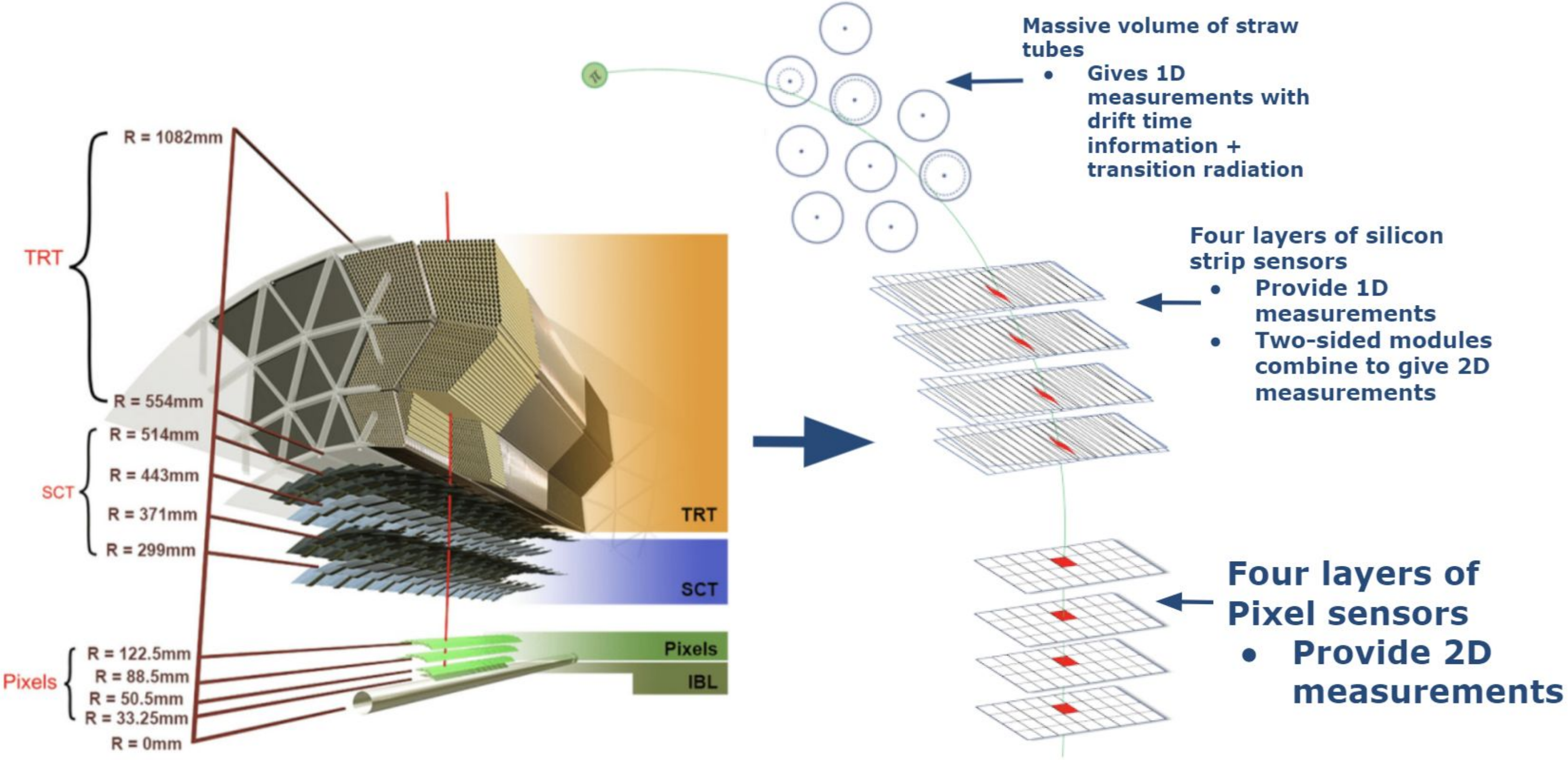


STCF tracking





Example of Transition Radiation Tracker



ATLAS Inner Detector: Pixels + SCT + TRT

CEPC Detector Conceptual Designs

CEPC CDR Baseline Design (Particle Flow Approach)