Full simulation status CLD/ILD

FCC Week 2024

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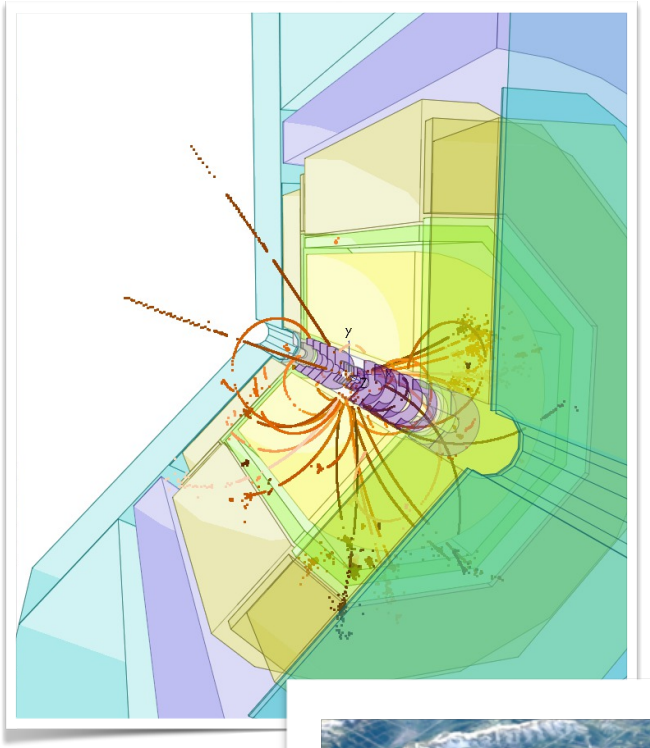
Frank Gaede, DESY

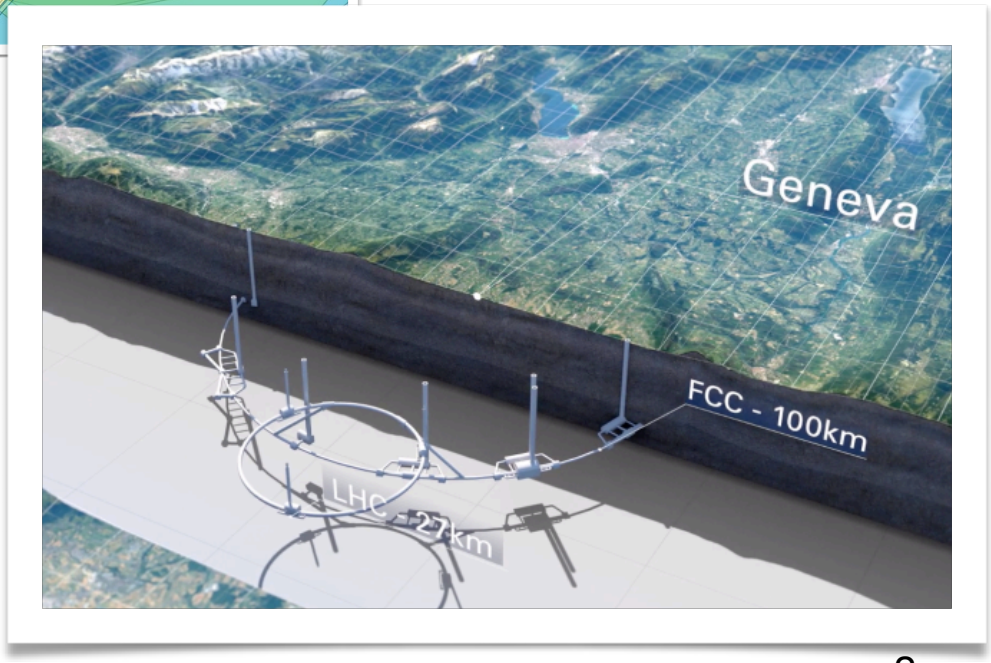
material and input from: A. Tolosa Delgado, D. Jeans, T. Madlener, L. Reichenbach, G. Sadowksi, A. Sailer, V. Schwan, ….

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

Outline

- Introduction :
- Key4hep and DD4hep detector models
- CLD/ILD detector variants for FCCee studies
- Recent results and ongoing work on
  - Simulation studies and Reconstruction
- Summary

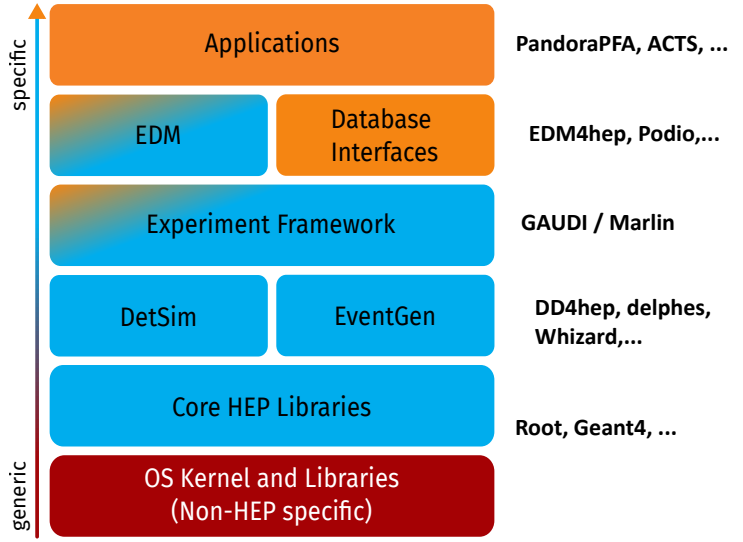


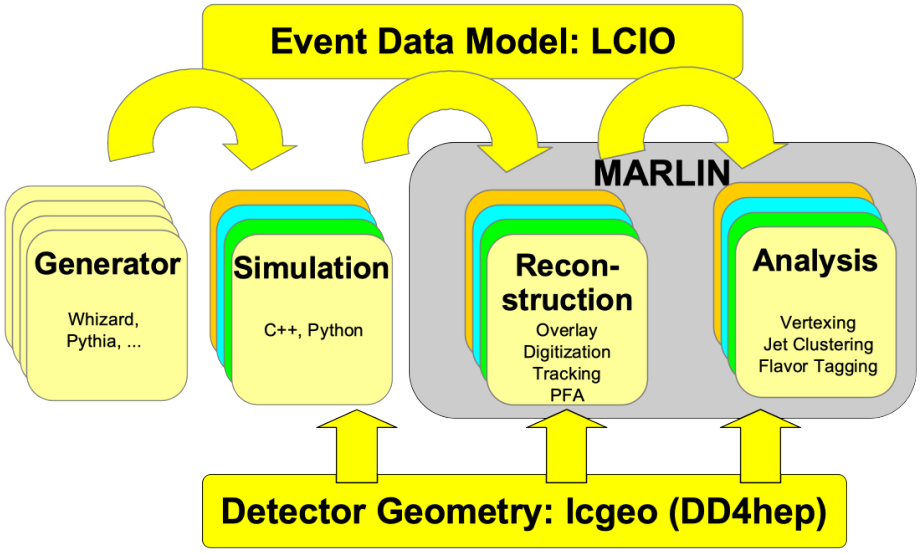


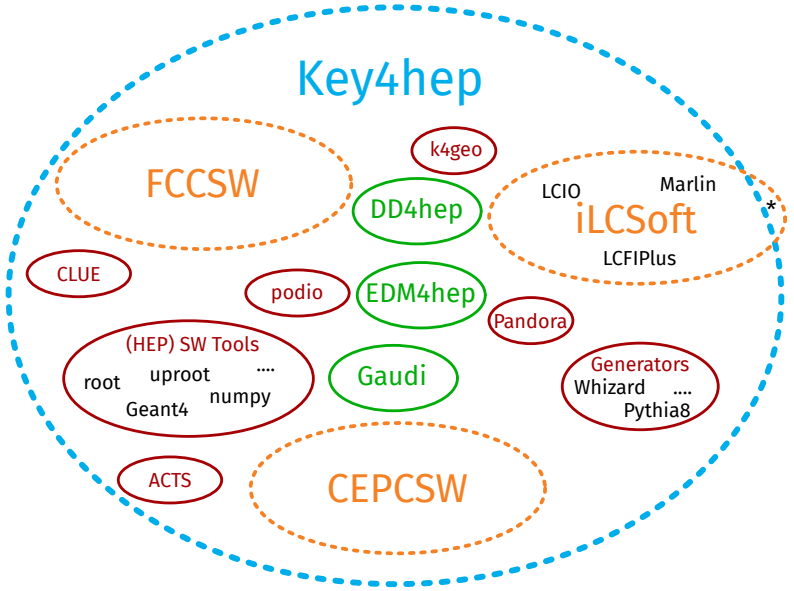
Key4hep

the turnkey software stack for FCC and all other future colliders

- HEP community decided 5 years ago to develop a **common turnkey software stack** – for future collider studies
- create a software ecosystem integrating in an o**ptimal way the best software components** to provide a **ready-to-use full-fledged solution** for data processing of (future collider) **HEP** experiments
- involved communities/contributors: CEPC, CLIC, EIC, FCCee, FCChh, ILC, LUXE, Muon Collider …







see talk by J.M. Carceller, Wed.

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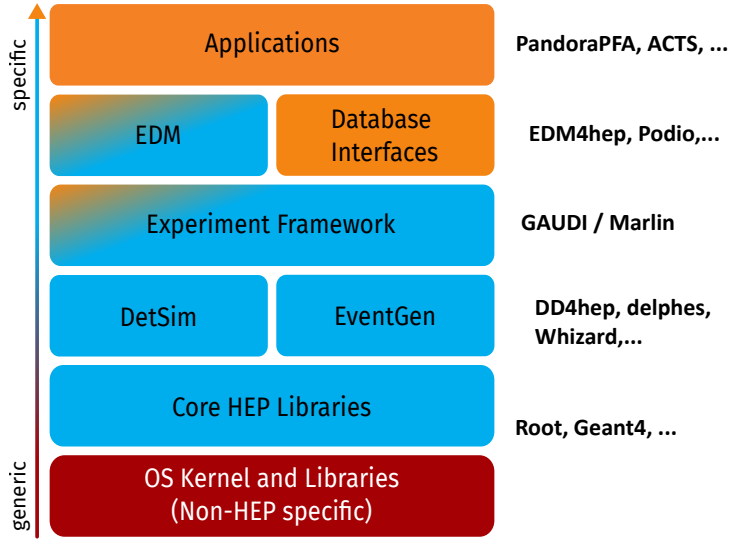

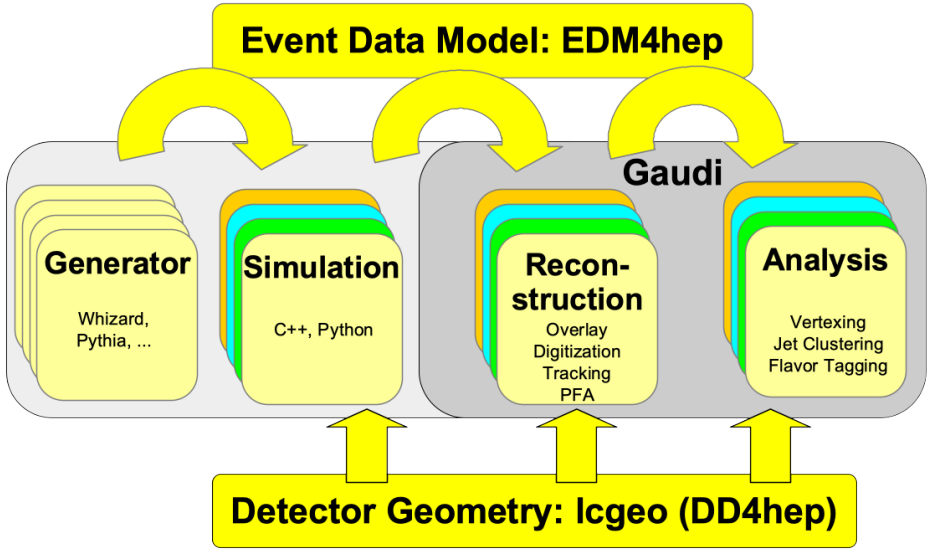

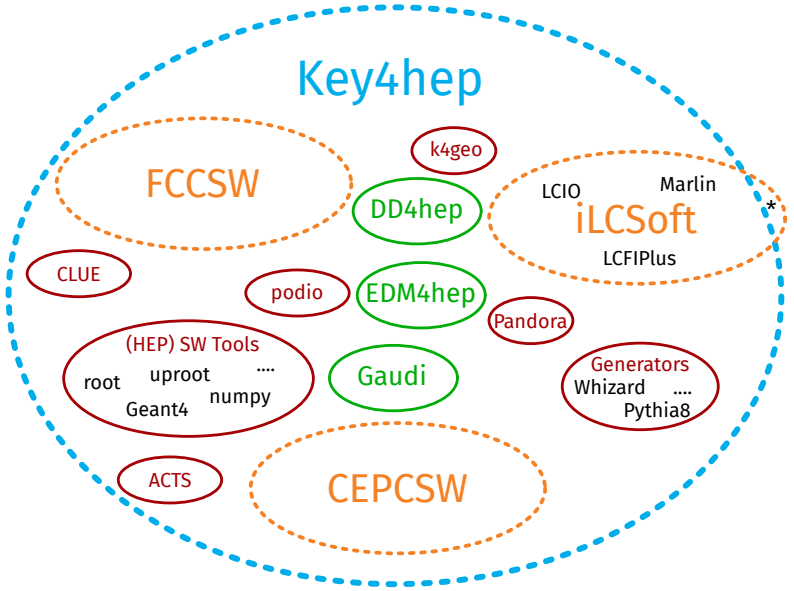

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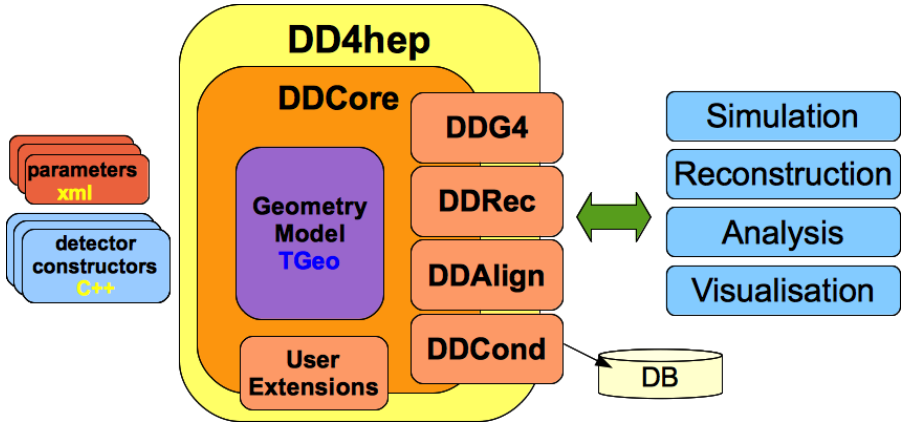
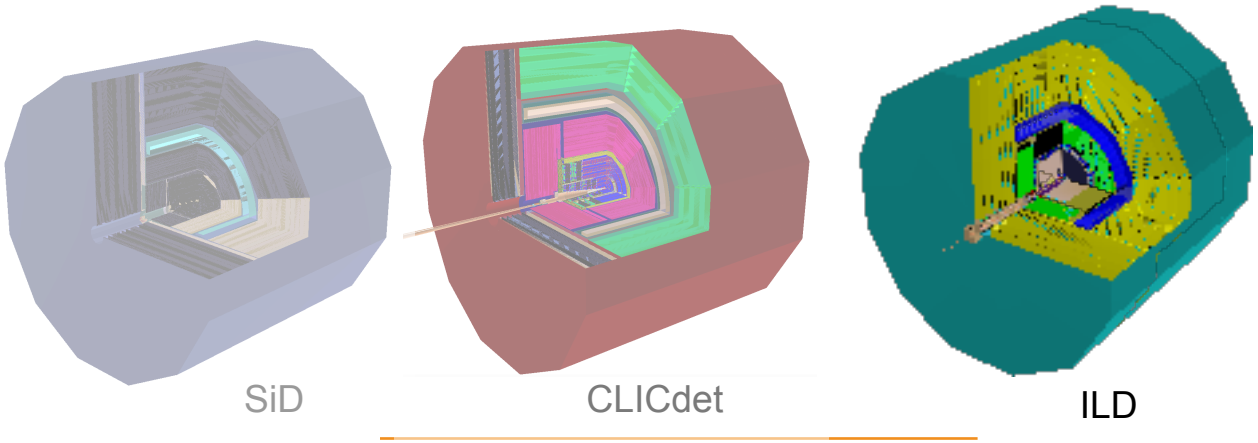
DD4hep geometry toolkit

defining the detector geometry and different views on it

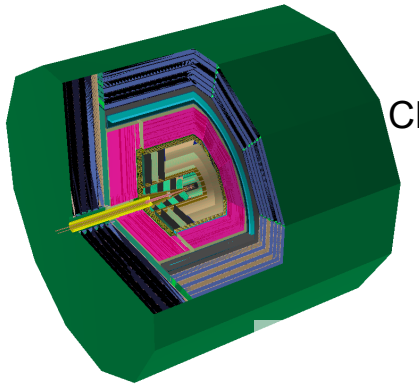
- supporting the full life cycle of the experiment
- **single source** of information for full **simulation, reconstruction, conditions, alignment, visualisation and analysis**
  - used by CEPC, CLIC, CMS, EIC, FCC, ILC, LHCb, …



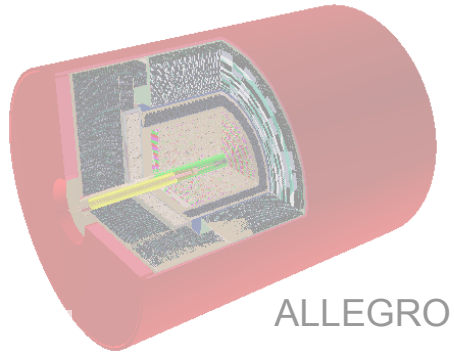
DD4hep: de facto industry standard



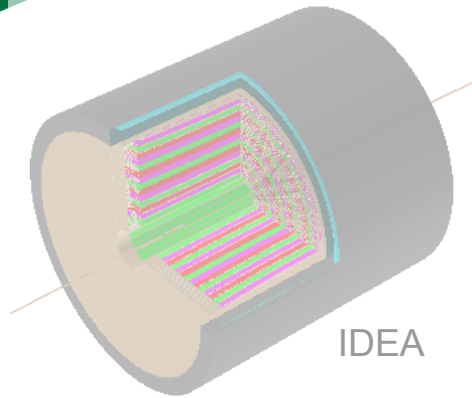
SiD CLICdet ILD



CLD



ALLEGRO



IDEA

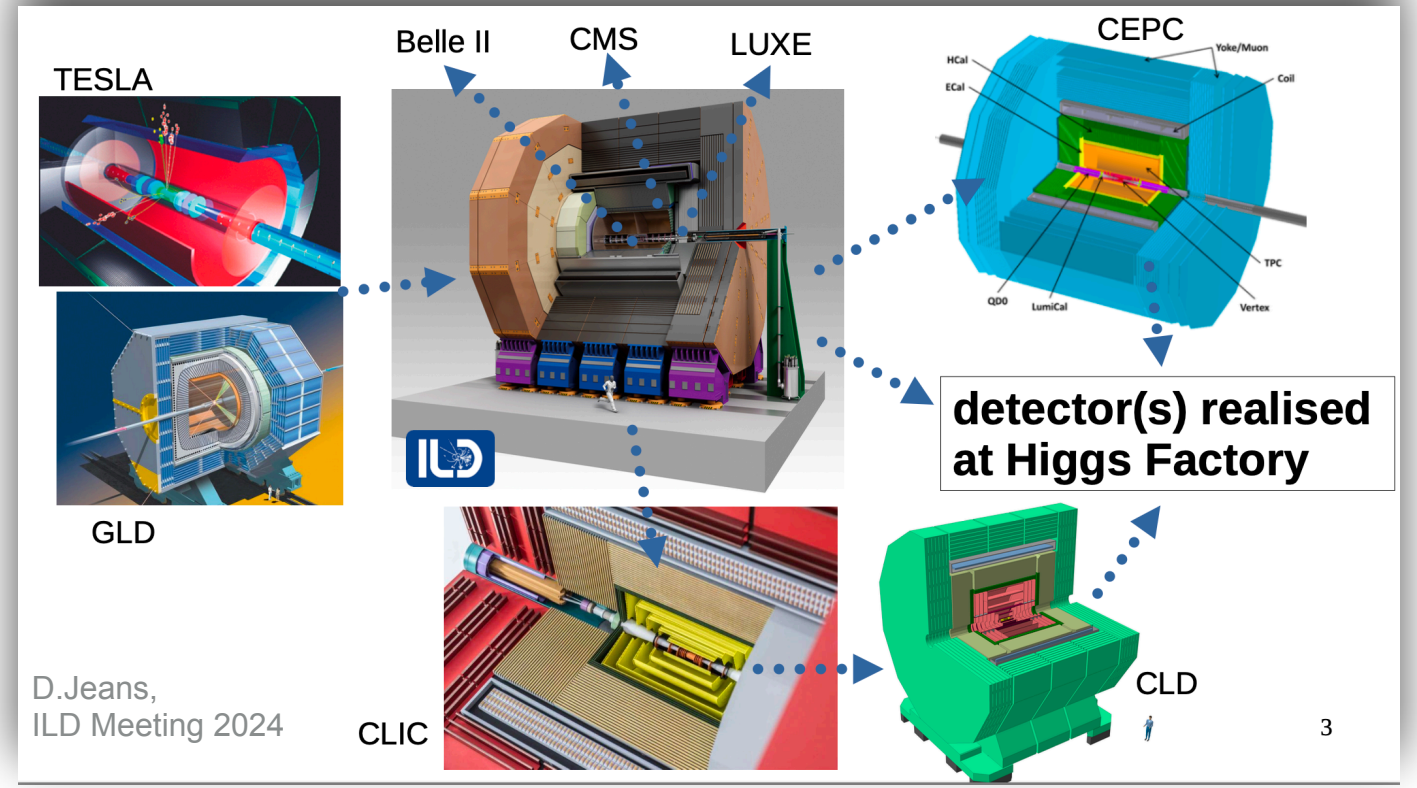
all future Higgs factory detector simulation models in **one package**
https://github.com/key4hep/k4geo

can use **plug-and-play** for sub detectors to study **detector variants**

CLD and ILD

closely related detector concepts

- both detectors are defined by their main CALICE **imaging calorimeters**:
  - ECal and HCal optimised for PFA with very high granularity
- major difference: large **Si-Tracker vs TPC**
  - and of course many differences in size, thickness, MDI, …



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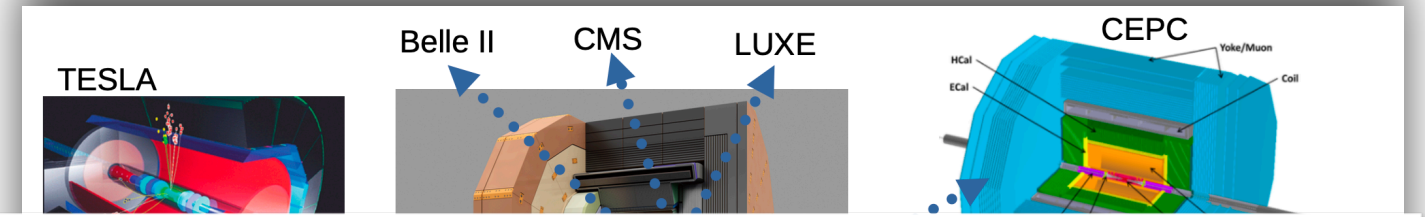
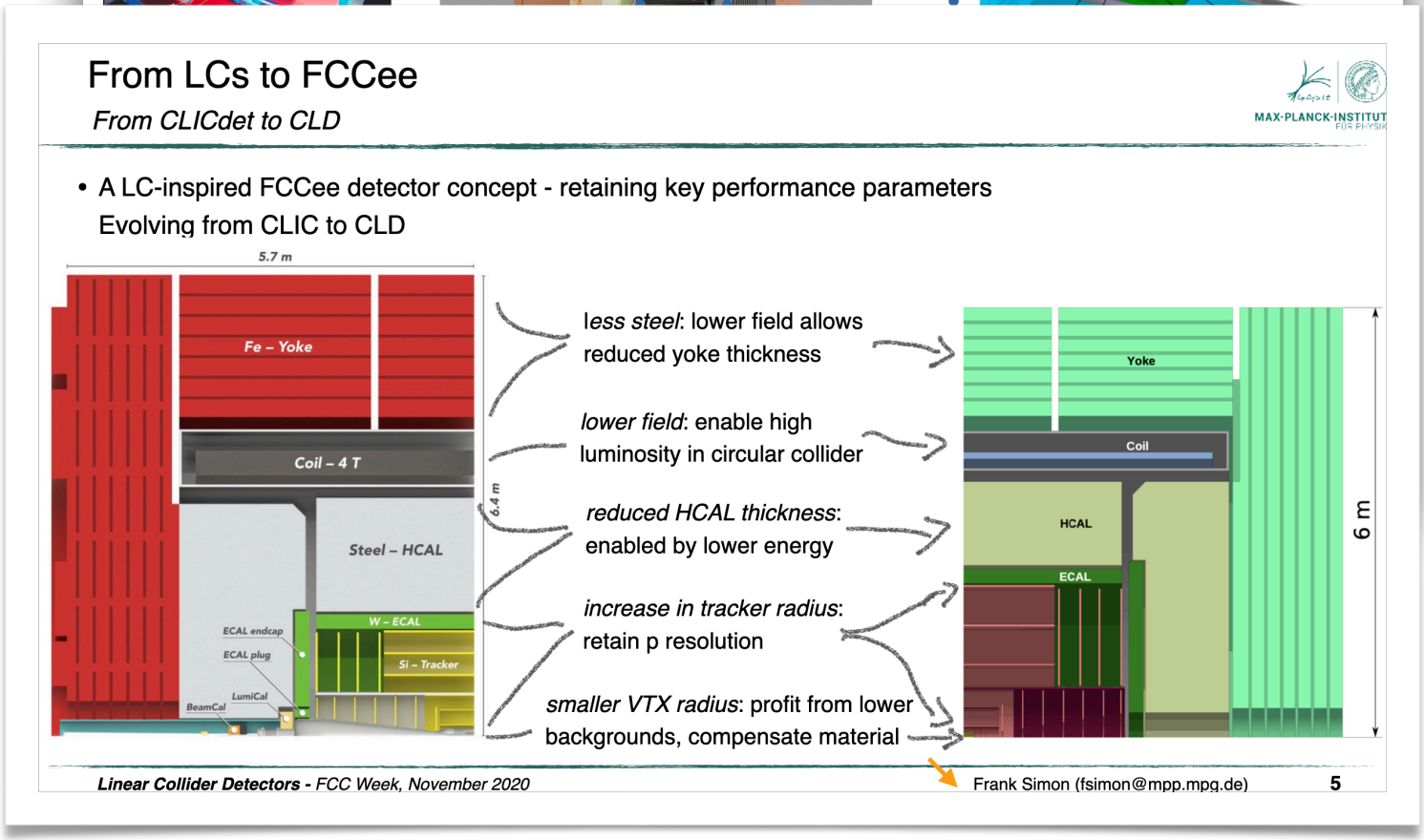
  - ECal and HCal optimised for PFA with very high granularity
- major difference: large **Si-Tracker vs TPC**
  - and of course many differences in size, thickness, MDI, …
- **CLD** is the well established **evolution of** CLICdp **optimised for FCCee**
- with the complete full simulation and **reconstruction software chain available in Key4hep**

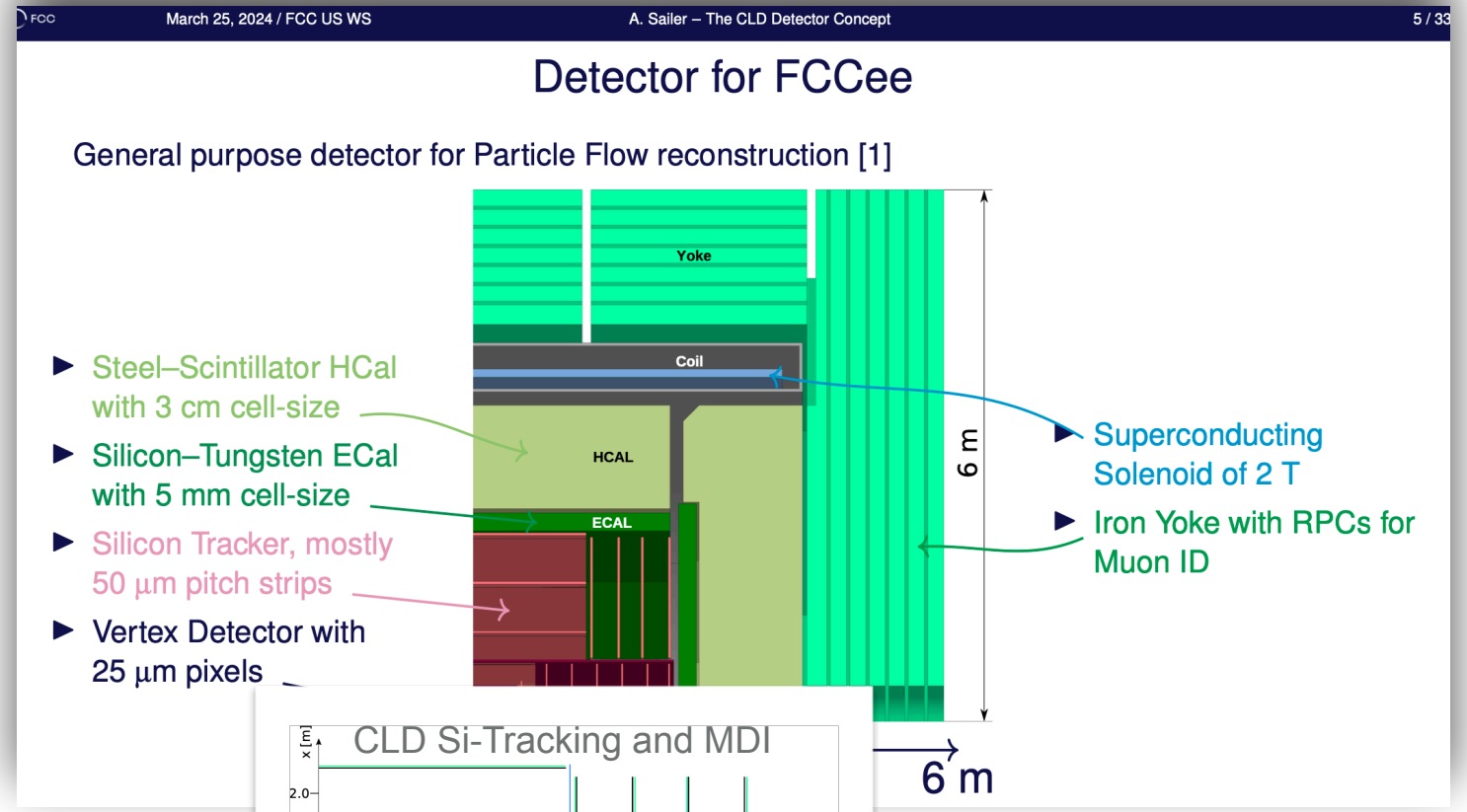


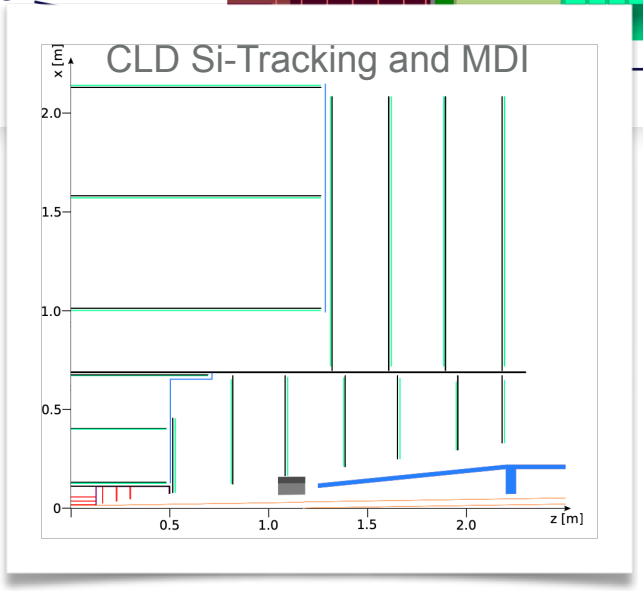


CLD and its variant(s)

studying options and develop algorithms

- the **standard CLD detector** model - with all Si-tracker and FCC specific MDI region, CLD_o2_v06





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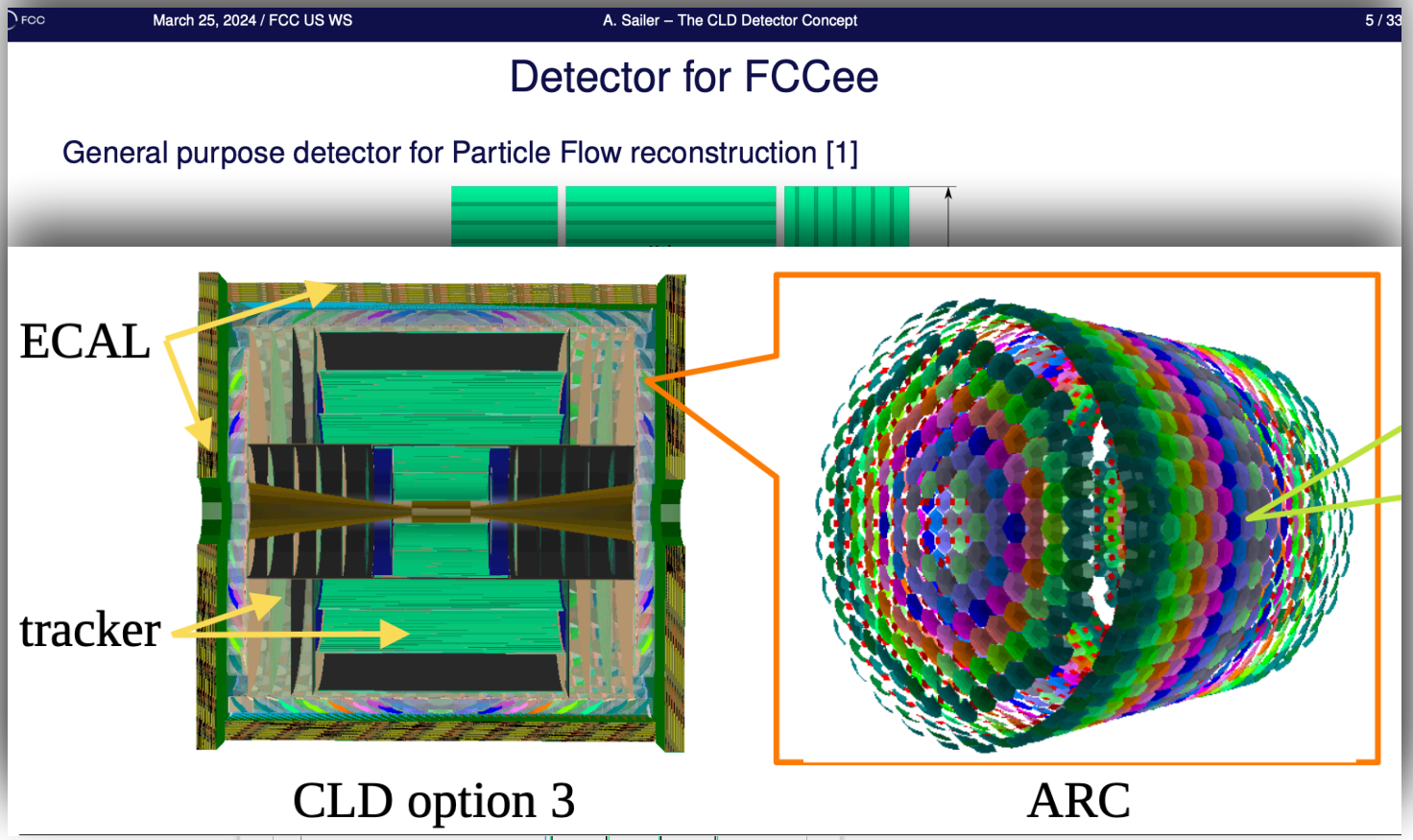
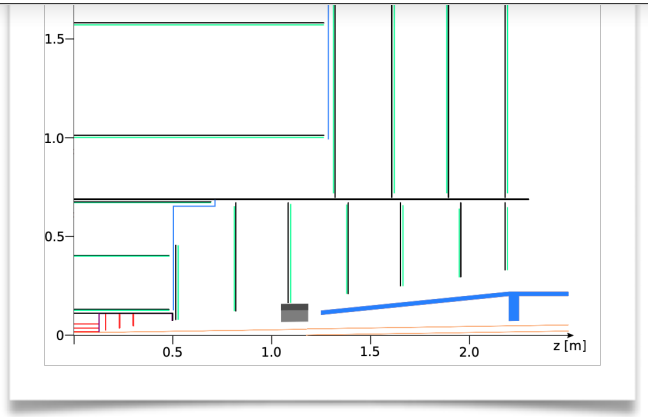
- the **standard CLD detector** model - with all Si-tracker and FCC specific MDI region, CLD_o2_v06

- a CLD variant with the **ARC and a slightly reduced tracking volume**, CLD_o3_v01
  - study excellent PID performance - and necessary trade-offs for tracking and PFA …





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- a CLD variant with the **ARC and a slightly reduced tracking volume**, *CLD_o3_v01*
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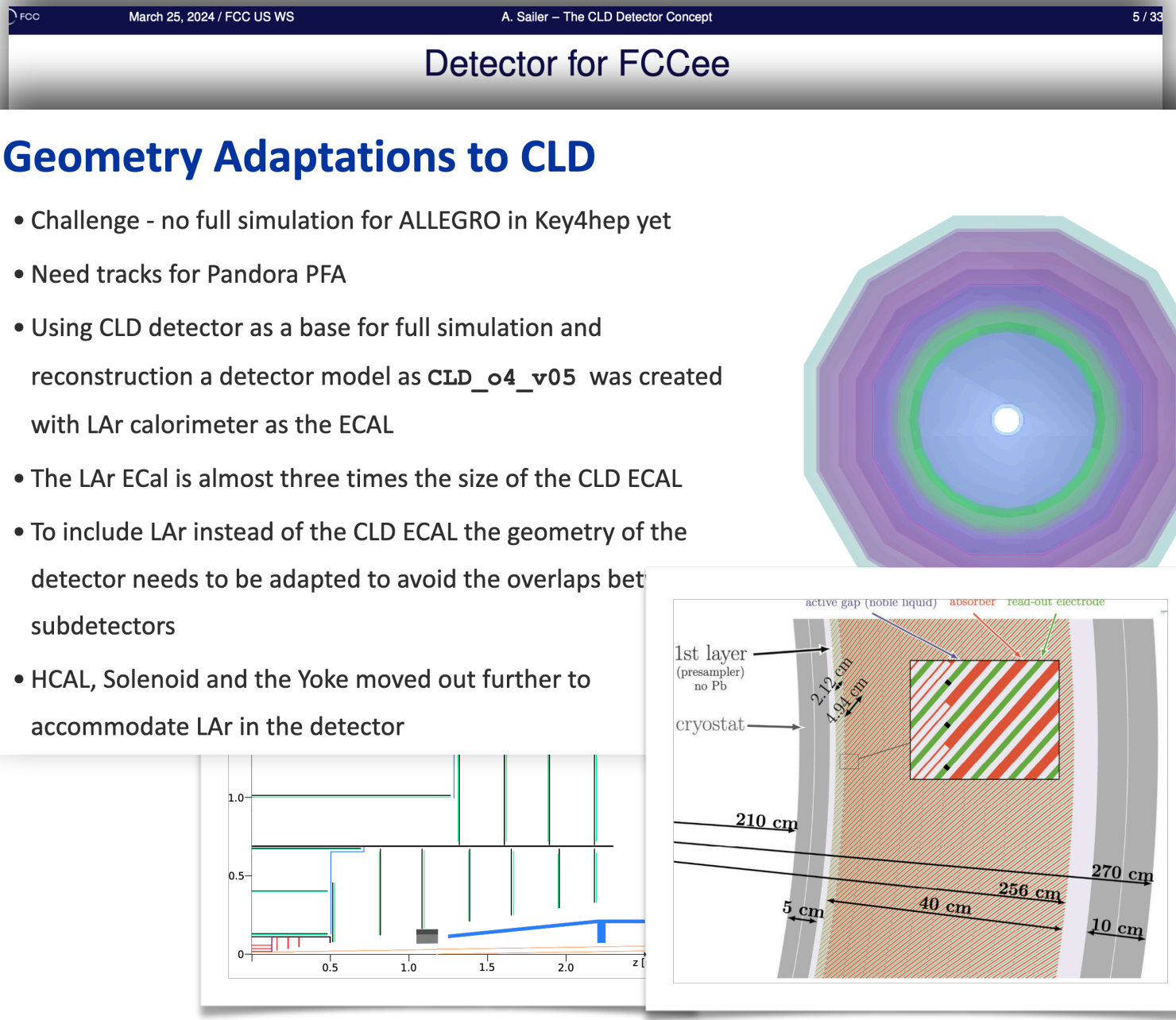
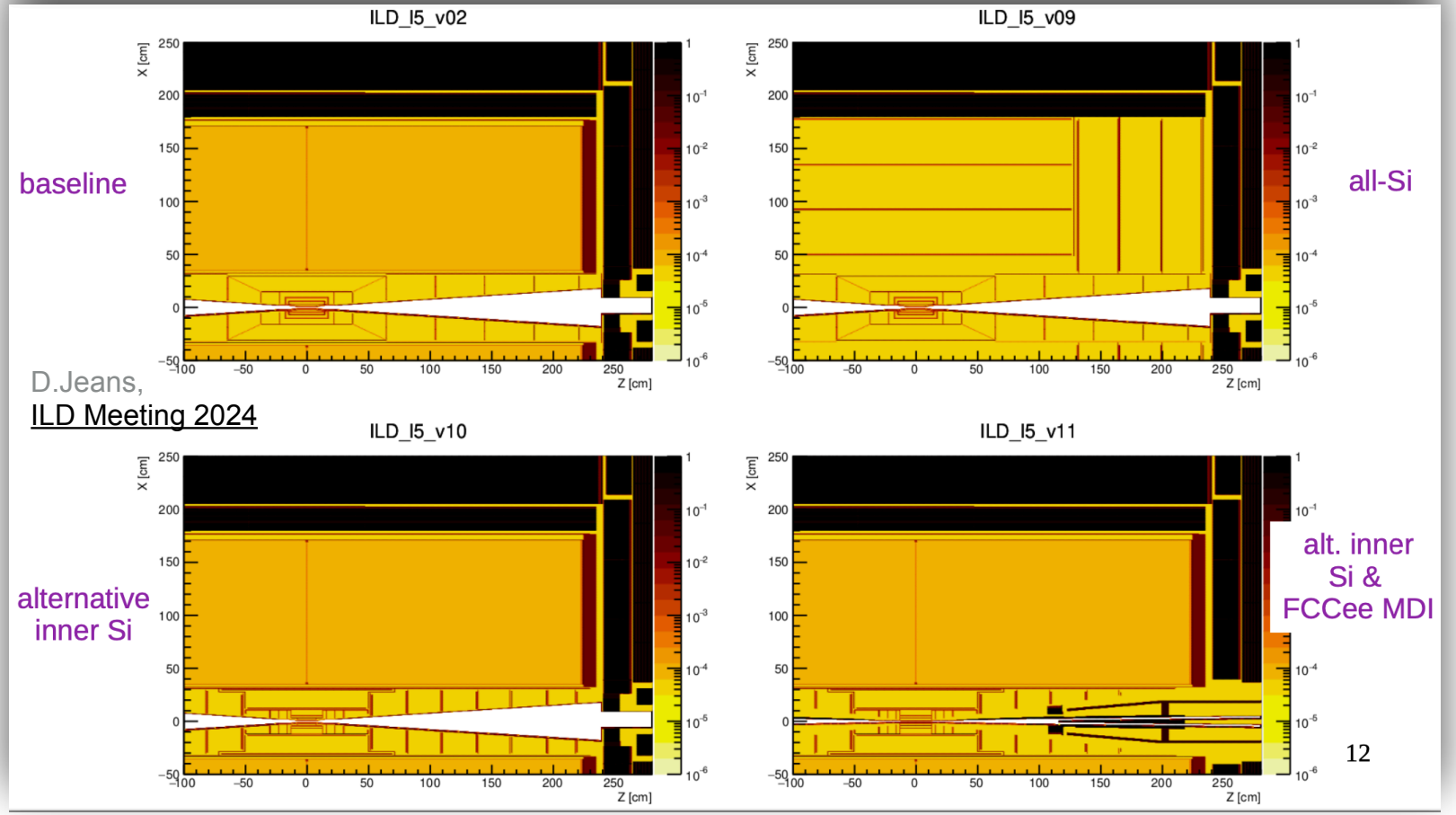
- a **CLD-Alegro hybrid** with a LAr-Ecal in order to adapt **PandoraPFA** for the **LAr calorimeter**, *CLD_o4_v05*
  - need tracker sim and rec from CLD



ILD variants for FCCee

study individual evolution steps

- **baseline**: TPC, inner Si-Tracking, SET, SiW Ecal, SciFeHCal
- **all-Si**: replace TPCw/ CLIDdp Si-tracker
- **alternative inner Si**: use CLICdp inner tracking
- **alt.inner Si &FCCee MDI**: additionally replace fwd w/ FCCee MDI (mask in detector region)



- goal: study all changes individually in order to understand how to best define an **ILDlike** detector for **FCCee**

- models still in ILC dimensions - eventually need to adjust similar to what was done for CLD - or create a CLD variant w/ TPC …

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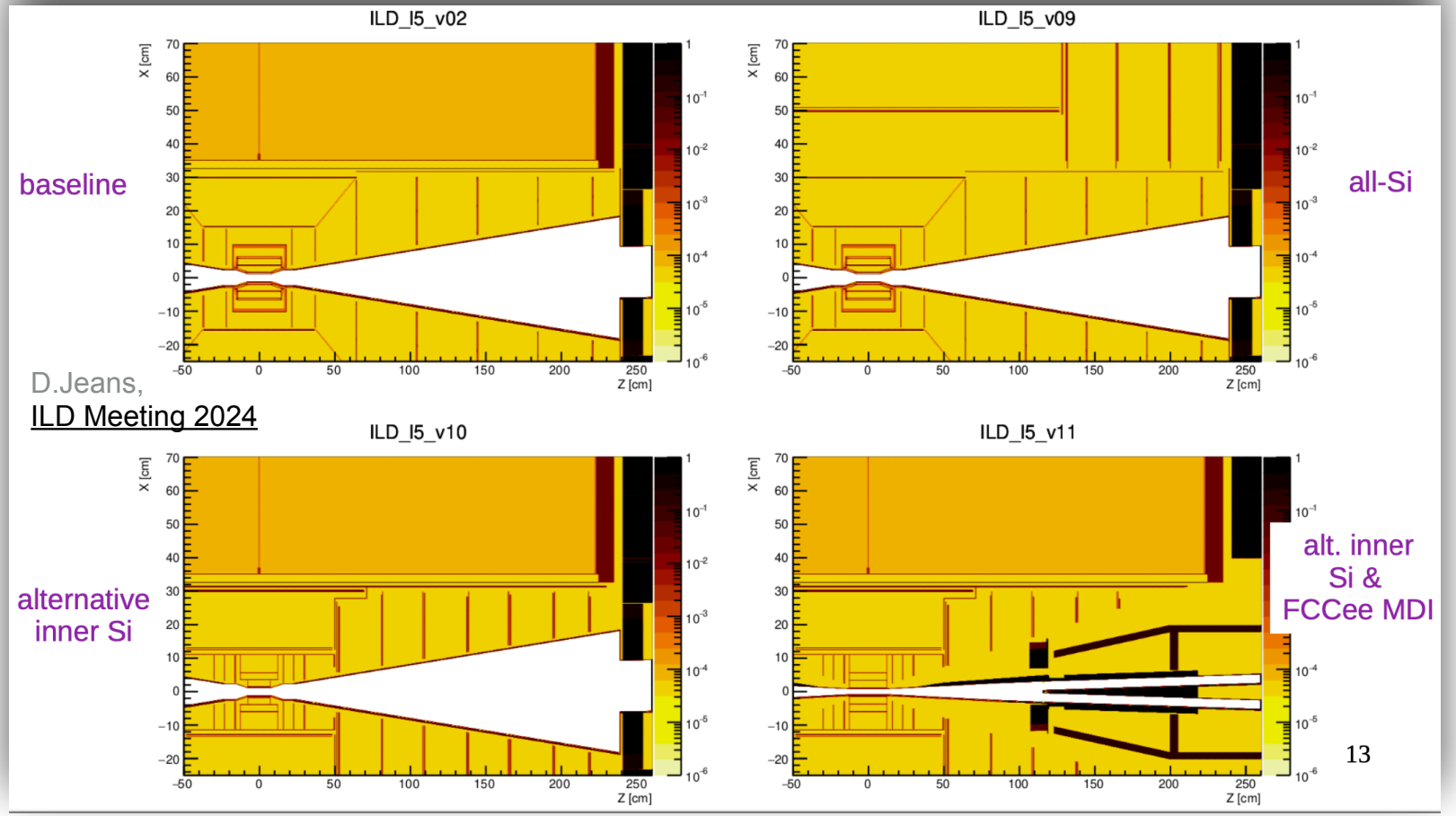

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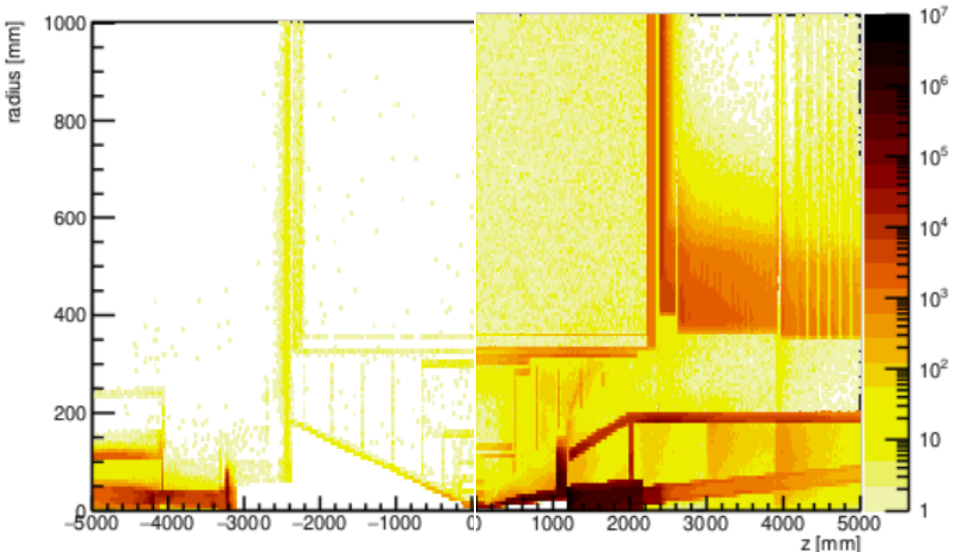
Can a TPC work at FCCee (91 GeV) ?

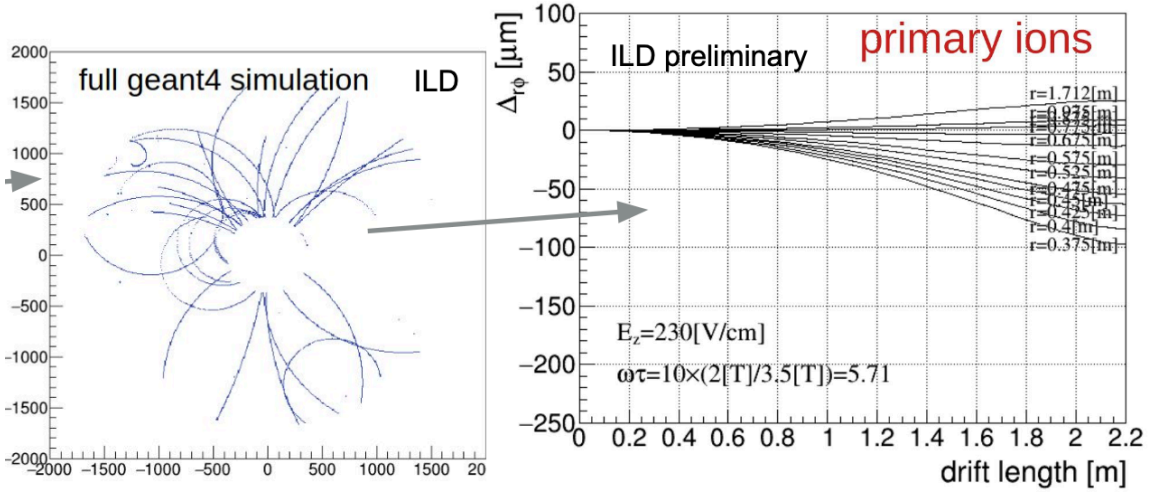
D.Jeans et al.

Study w/ full simulation in ddsim (DDG4) and GunieaPig

- simulate events in TPC at FCCee (91 GeV) from
  - e+e- physics events: **~ 10^{10} ions -> 100 µm** distortions
  - beam induced background: **~ 2x10^{12} ions -> 20 mm** distortions (!)
- a TPC also at TeraZ **might be feasible - yet further studies needed**:
  - mitigation strategies for drift distortions (corrections, redesign MDI elements?, ...)
  - stability of distortions wrt time, operating conditions, ...



MCParticle endpoints at FCCee 91 GeV from beam bg in ILClike (left) and CLDlike (right) ILD



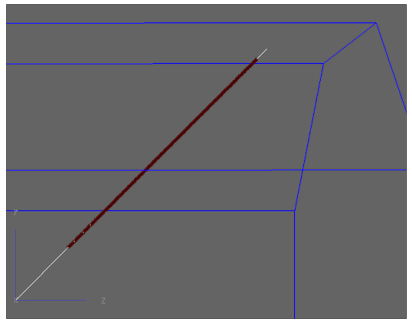
Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	1.8×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.8	0.54	0.0025

- primary ion density in TPC - compared to ILC-250:
  - 2500 (200) x higher at FCCee 91 GeV (240)
  - dominated by beam background

Physics performance of ILDlike detector at FCCee

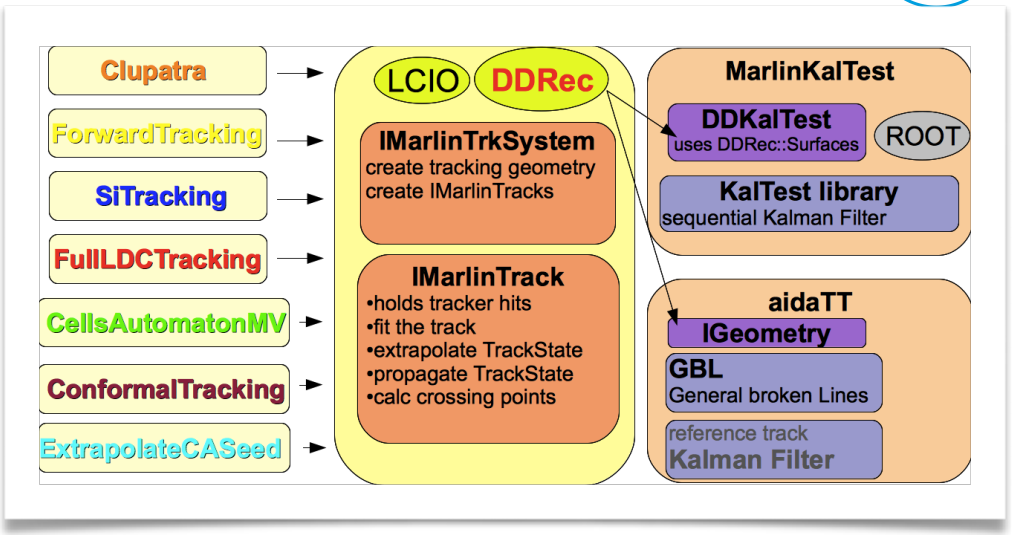
combining existing pattern recognition for tracking …

- to benchmark an ILDlike detector w/ TPC at FCCee **full reconstruction** code needed
- can re-use existing pattern recognition algorithms by combing: *Clupatra* (TPC), *ConformalTracking* (Si-tracking) and *FullLDCTracking* (Merging)
- work started recently w/ a PhD student
- single muon tracks work !

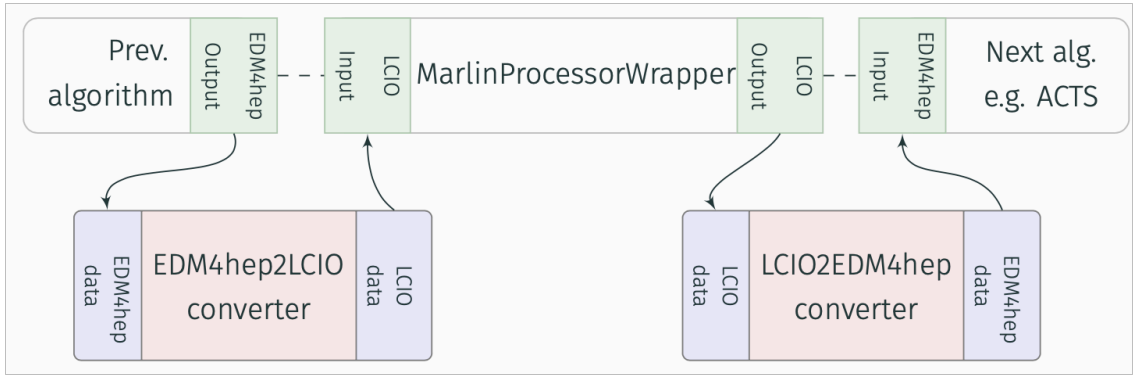


V.Schwan

- next step:
  - develop track performance tools in **k4DetectorPerformace** (w/ G.Swadowski et al)



MarlinTrk tracking toolkit w/ a variety of pattern recognition algorithms and Kalman Filter



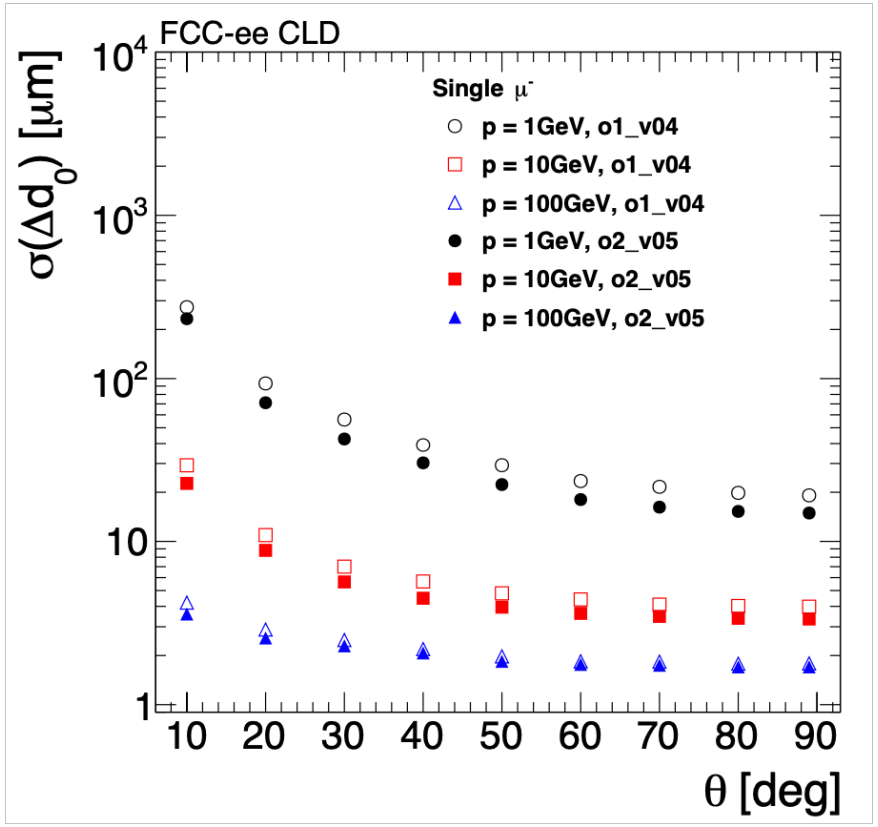
can run all MarlinTrk tracking algorithms with **MarlinWraper** in Gaudi

Studying tracking performance for CLD

sub-detector variants

G.Sadowski

- using full simulation (MarlinWraper) and tracking performance scripts (EDM4hep) to study and understand effects of
  - sub detector variants and modifications
- more **realistic** beam pipe w/ more material and smaller radius results in **better impact parameter resolution** (VXD r0 13/17.5)



CLD_o2_v05

- BeamPipe **radius**: 10 mm
- BeamPipe **material**: AlBeMet 0.35 mm + paraffin 1 mm + AlBeMet 0.35 mm
- BeamPipe **thickness**: 1.7 mm + 5 μm gold
- **X/X0** = 0.61 % ⇒ + 33 % material budget

CLD_o1_v04

- BeamPipe **radius**: 15 mm
- BeamPipe **material**: Beryllium
- BeamPipe **thickness**: 1.2 mm + 5 μm gold
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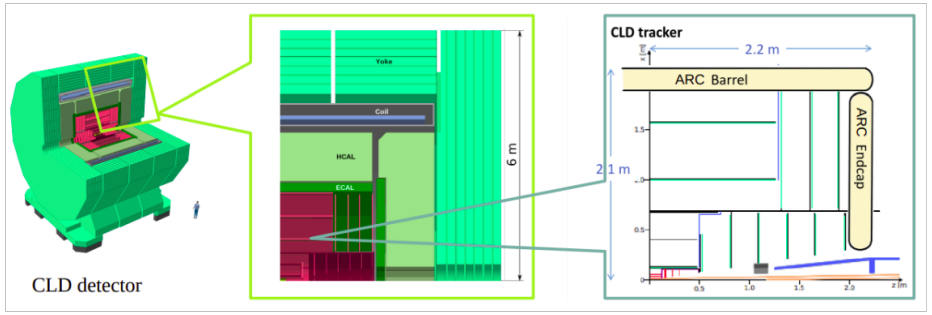

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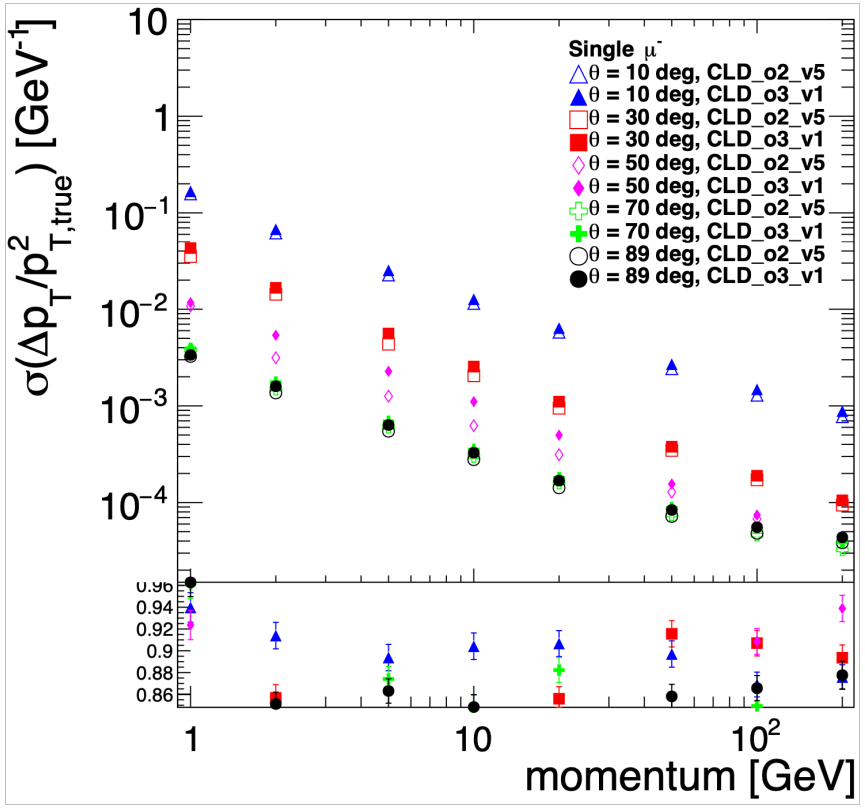

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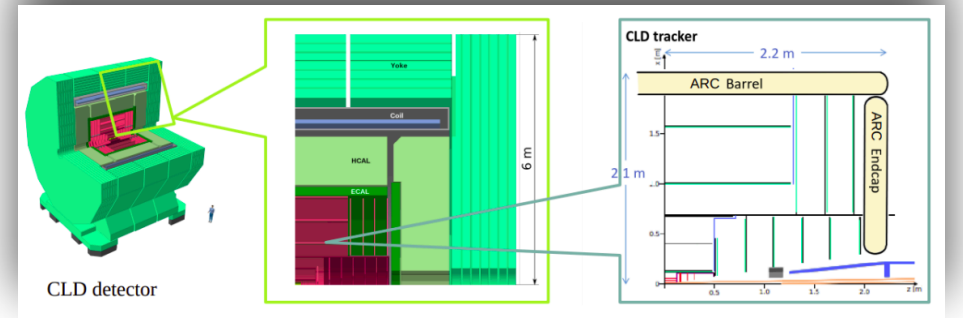

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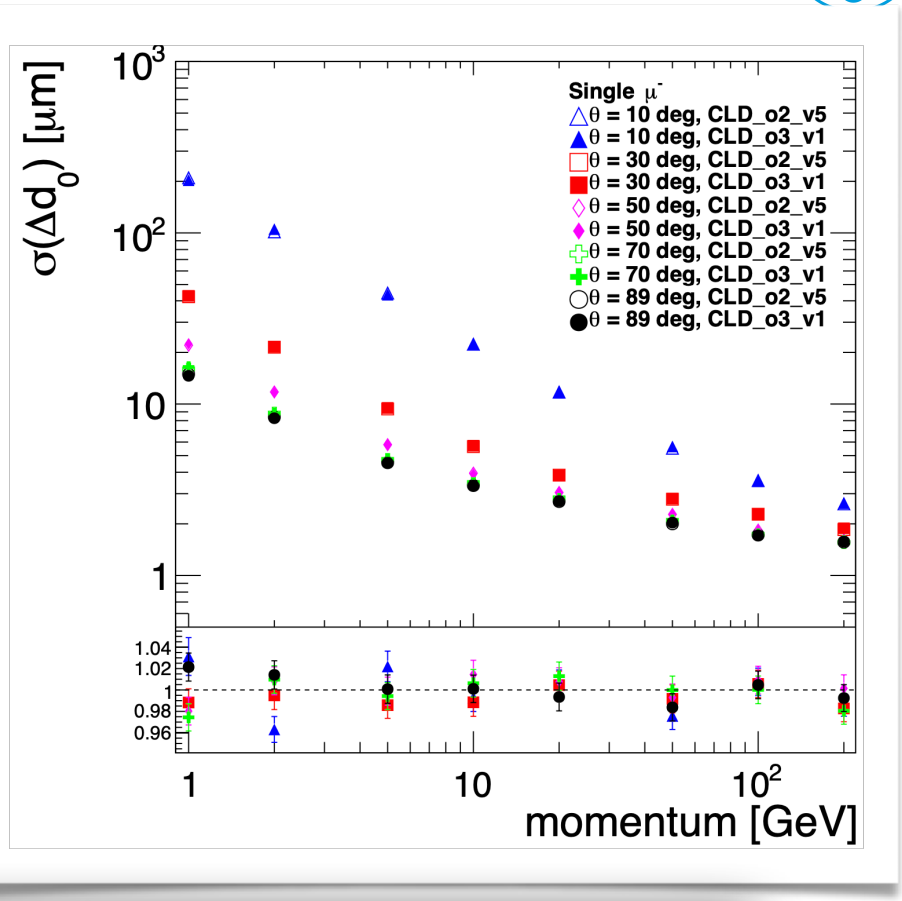
  - ~unchanged **impact parameter resolution**



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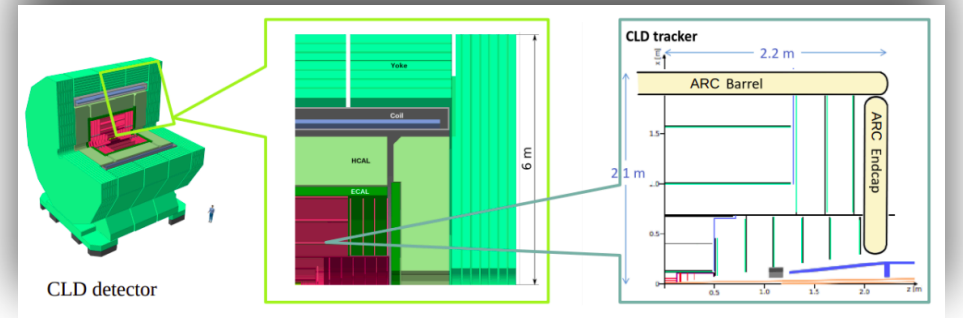
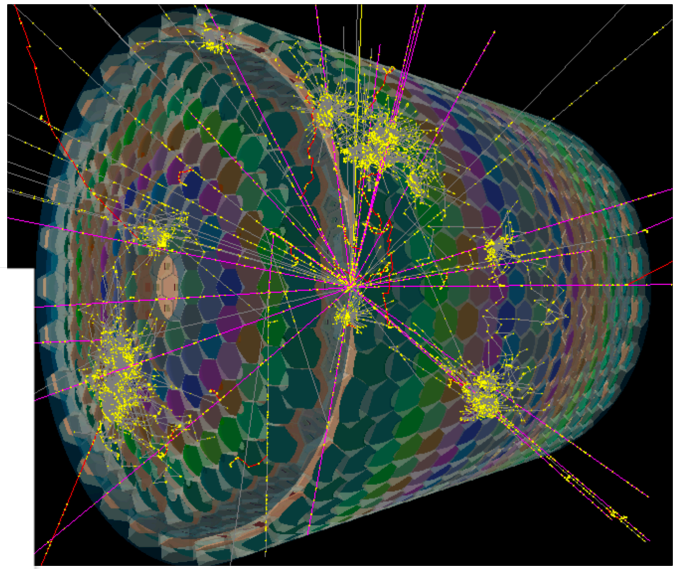


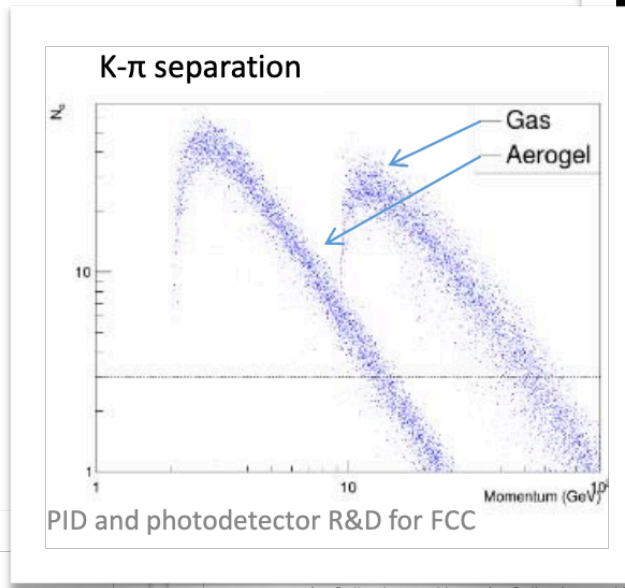
ParticleID performance with the ARC

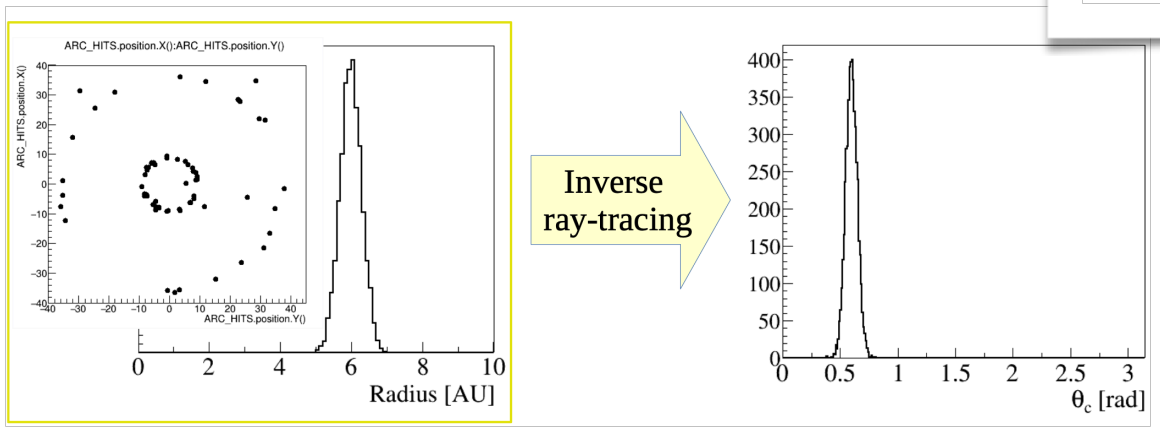
a novel GAUDI algorithm in Key4hep

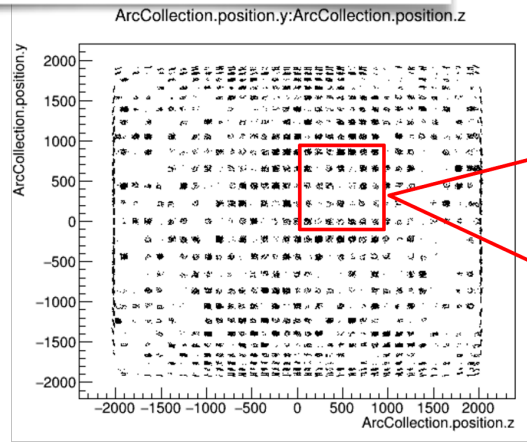
A. Tolosa Delgado

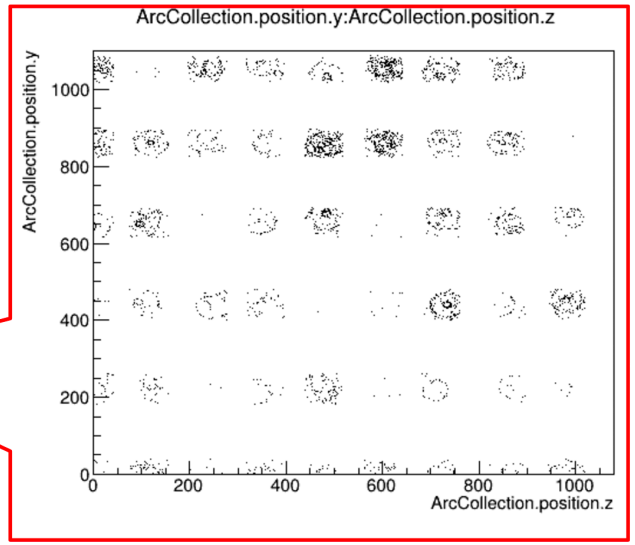
- can simulate full events in CLD w/ ARC with dddim (DD4hep)
- standalone reconstruction w/ inverse ray-tracing exists for single cell
  - should provide excellent K-pi separation from 2-50 GeV
- ongoing work: full ARC reconstruction in Gaudi - aim for end of summer









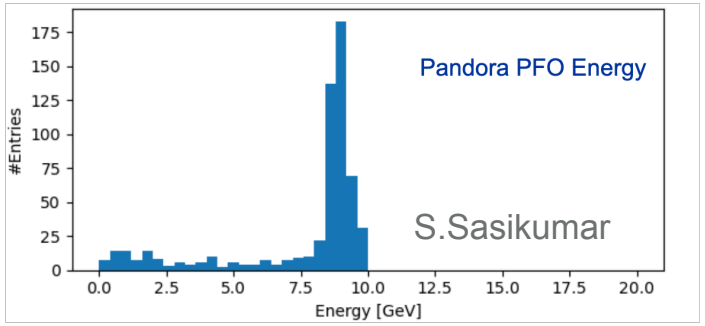


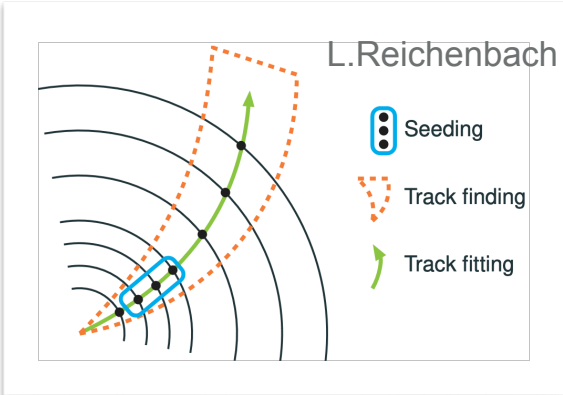
Sagital cut of the detector (events on the endcaps are compressed in Z, not visible in this projection)

Reconstruction in Key4hep

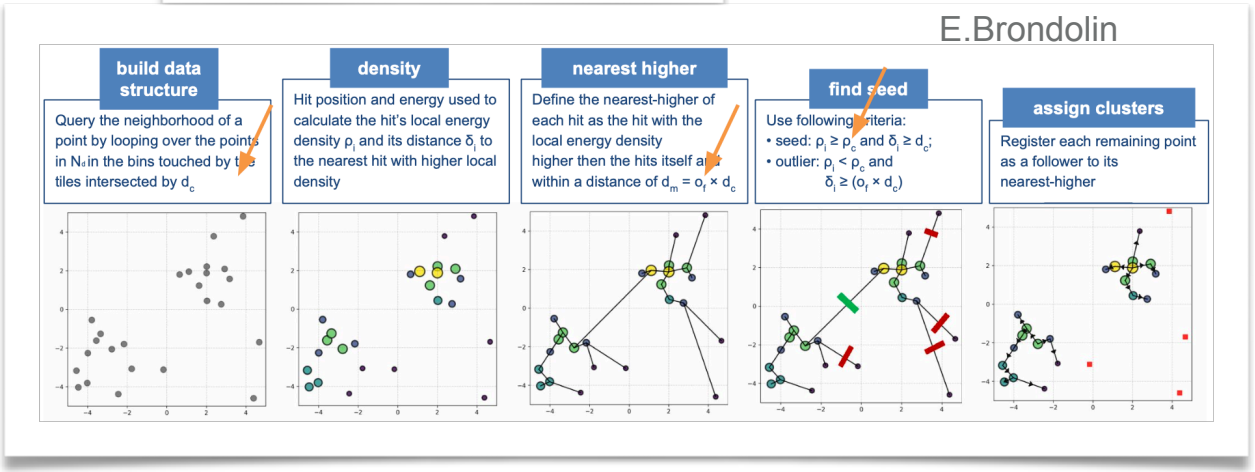
developing novel full reconstruction algorithms in Gaudi

- detector optimisation is only possible with full simulation - DD4hep models for ALLEGRO and IDEA exist - **and reconstruction**
- active development now started to create reconstruction algorithms for ALLEGRO and IDEA CLD detector variants, e.g.
- PandoraPFA for LAr cało (ALLEGRO) w/ ***k4Pandora***
- TruthTracking with ACTS in Key4hep in ***k4ACTSTracking***
- clustering (a la CMS HGCal) for highly granular calorimeters in ***k4Clue***



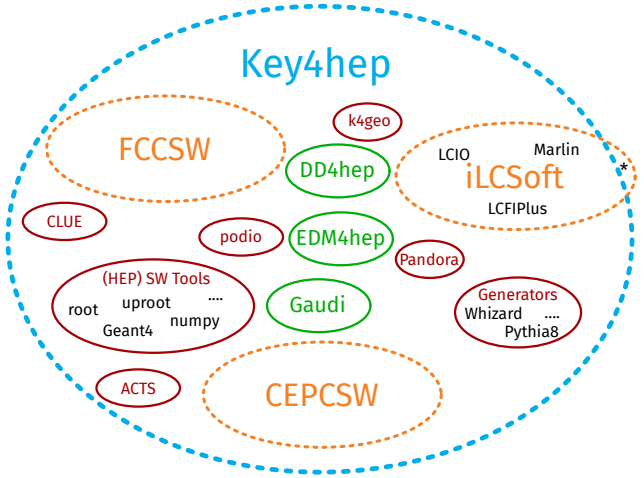


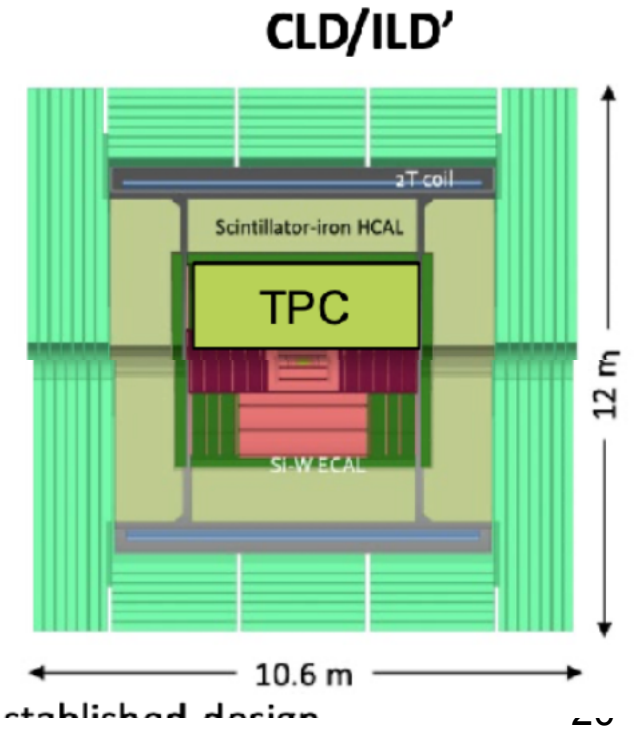

```
INFO Hello from event: 1
INFO track fit ok :)
INFO track momentum: 1.00842
INFO Hello from event: 2
INFO track fit ok :)
INFO track momentum: 0.947415
INFO Hello from event: 3
INFO track fit ok :)
INFO track momentum: 1.02946
```



Summary

- **CLD** well established detector model for **FCCee** studies with **highly granular calorimeter** and complete reconstruction code available in **Key4hep**
- now a number of variants developed to
  - study detector optimisation and develop reconstruction code
  - CLD w/ ARC RICH and CLD w/ LAr calorimeter
- closely related **ILD** detector model brings **TPC study** as potential central tracker at FCCee
- significant progress and new developments since last FCC week
- first genuine **Key4hep**/EDM4hep/Gaudi **reconstruction algorithms** start to become available (k4Clue, k4ACTS, k4Pandora,….)

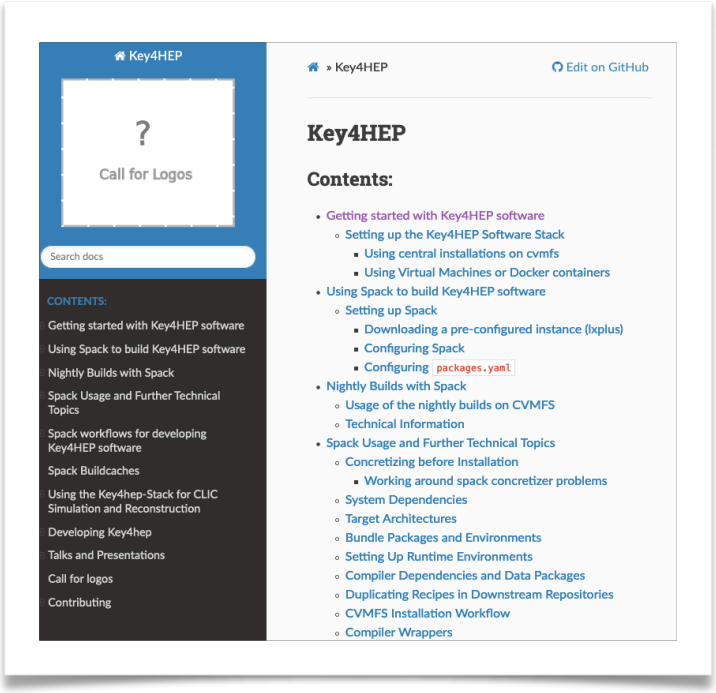




pointers to documentation

entry points to Key4hep et al

- Key4hep GitHub Project
  - https://github.com/key4hep
- Key4hep main documentation page
  - https://key4hep.github.io/key4hep-doc/
- k4geo project (all FC detector models)
  - https://github.com/key4hep/k4geo
- Doxygen available., e.g. for EDM4hep
  - https://edm4hep.web.cern.ch/



- Key4hep Tutorials
  - https://github.com/key4hep/key4hep-tutorials
- FCC Tutorials:
  - https://hep-fcc.github.io/fcc-tutorials/main/index.html