ILD/CLD rationale and full-sim based studies

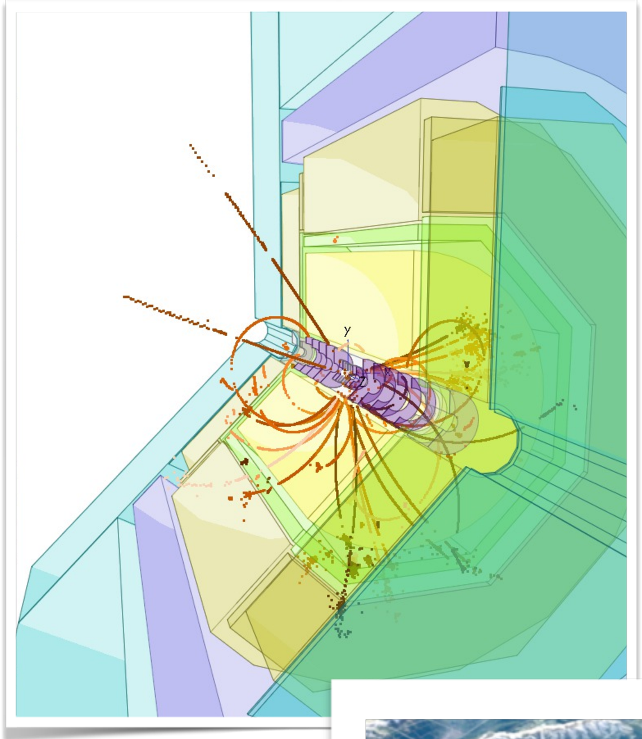
FCC Physics Workshop 2025

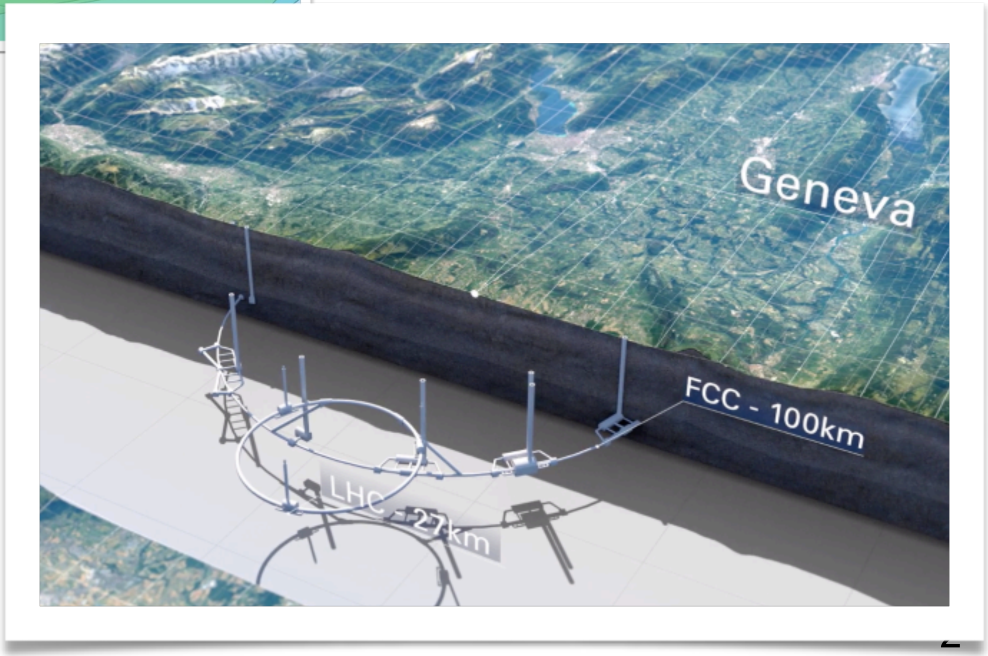
Jan 13-17, CERN

Frank Gaede, DESY

Outline

- Rationale of ILD (and CLD)
  - Relation ILD-CLD
- Key4hep and DD4hep detector models
- CLD/ILD detector variants for FCCee studies
- Some recent results and ongoing work on
  - Full Simulation studies and Reconstruction
- Summary



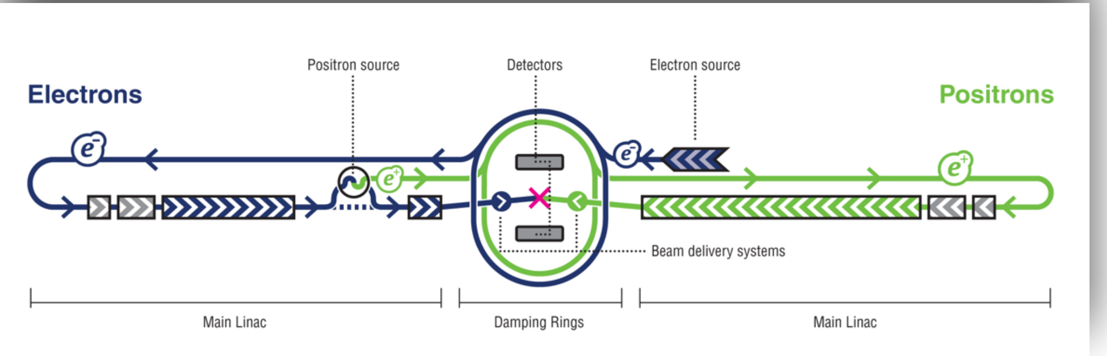


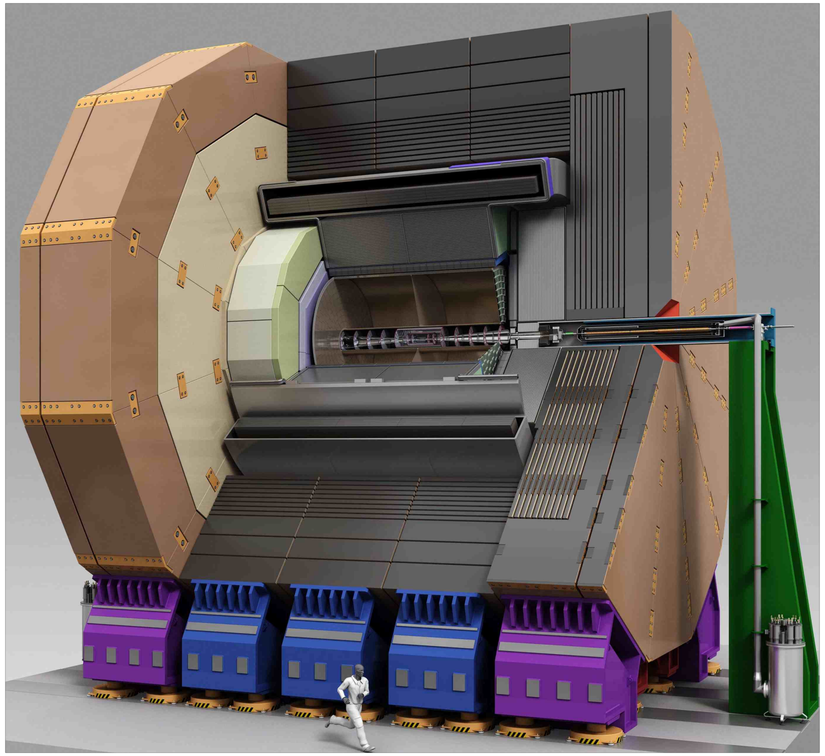
Rationale of the ILD detector

A fully optimised detector concept for the ILC

ILC

- a linear e+e- collider at **250-500 GeV** (up to 1 TeV) with super conduction RF technology
- was going to be build in Japan - now a potential candidate for 'plan B'





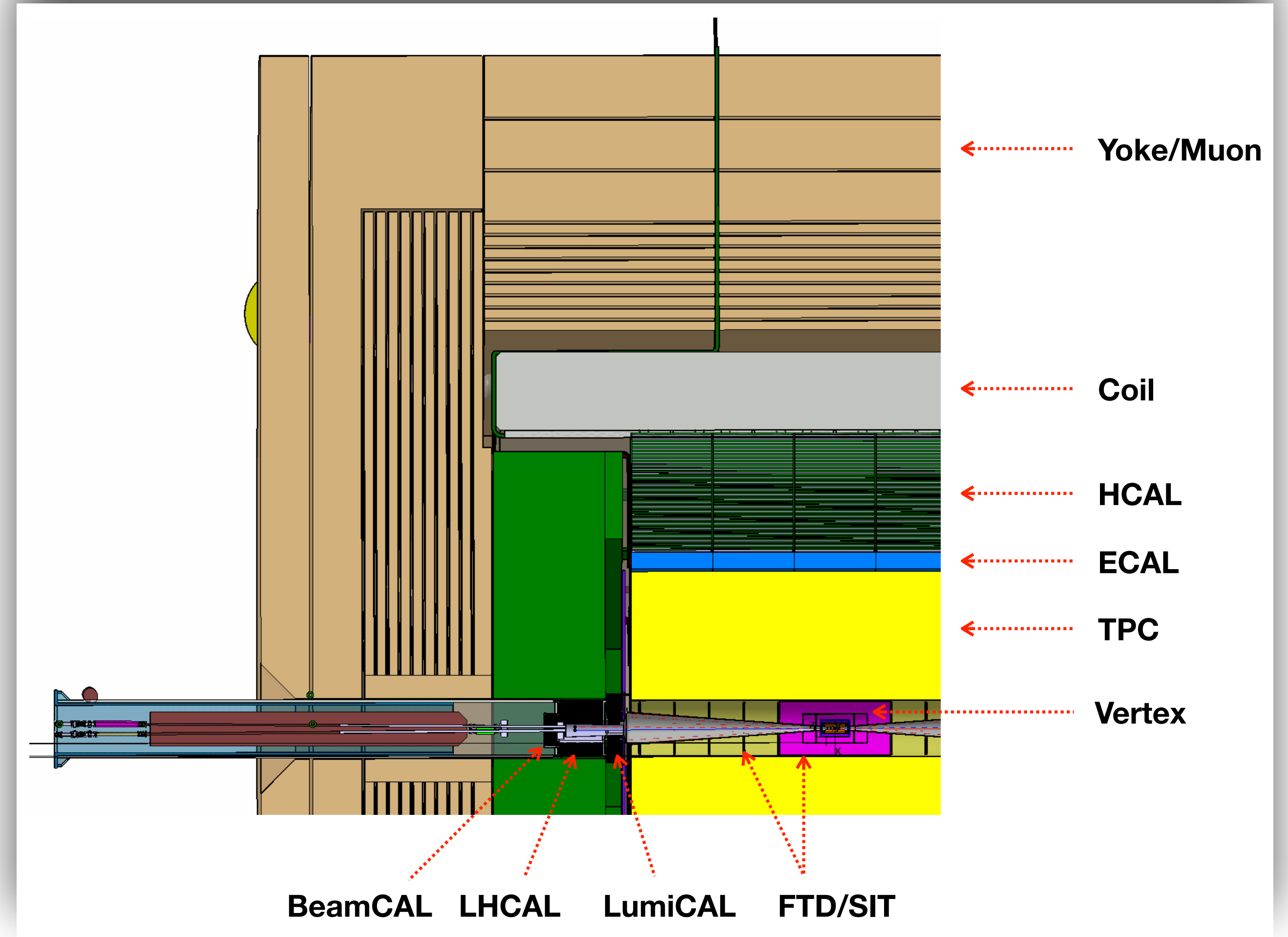
- **ILD** is one of two detector concepts for the ILC
- optimised for **PFA** at the ILC energies, w/
  - highly granular calorimeters
  - excellent tracking resolution
  - excellent vertex resolution
  - low material budget (in the trackers)

- **CLD** is closely related (see later)

Rationale of the ILD detector

And its sub-detectors

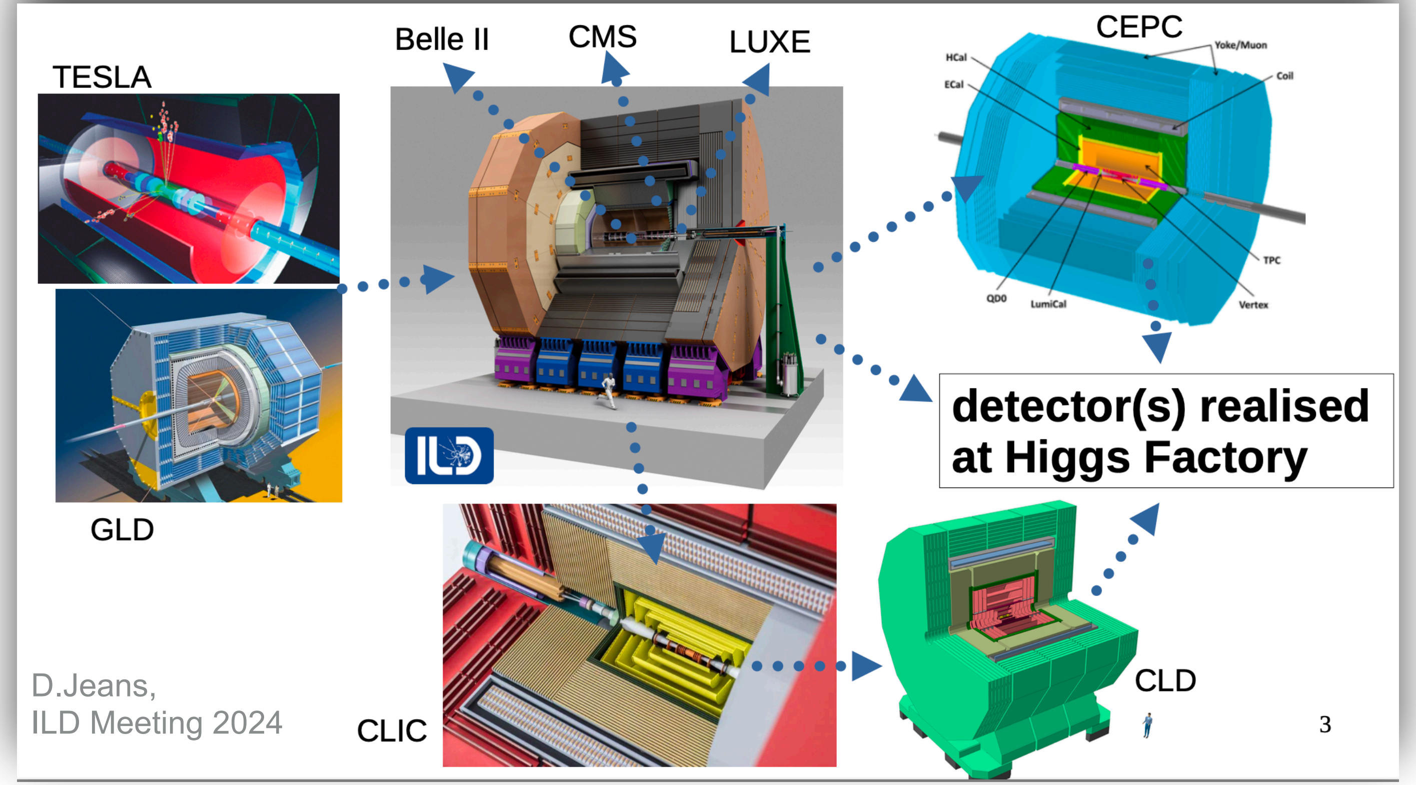
- high precision and low material tracking system
  - inner Si-tracking (VTX, SIT, FTD) - $\sigma_{point} = 3{,}5{,}7 \mu m$
  - TPC w/ 220 layers + SET $\sigma_{point} = 7 \mu m$
- highly granular calorimeters:
  - ECal, 20 layers, (SiW or SciW), $5 \times 5 mm^2$ $(5 \times 45 mm^2)$
  - HCal, 48 layers (SciFe or RPC-Fe) $3 \times 3 cm^2$ $(1 \times 1 cm^2)$
- inside 3.5 T B-field
- forward calorimeters
  - LumiCal, LHCal and BeamCal



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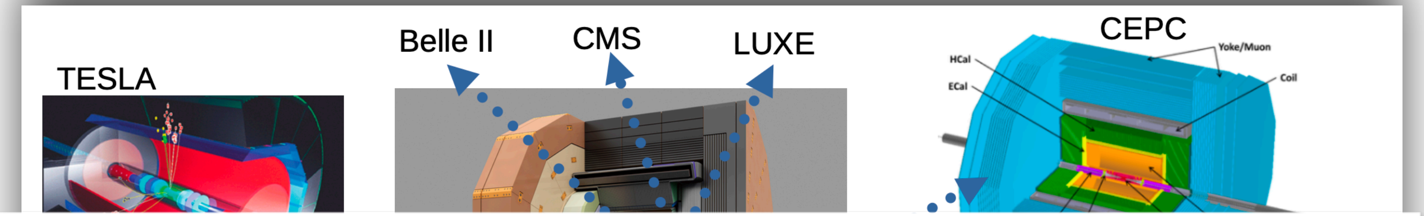
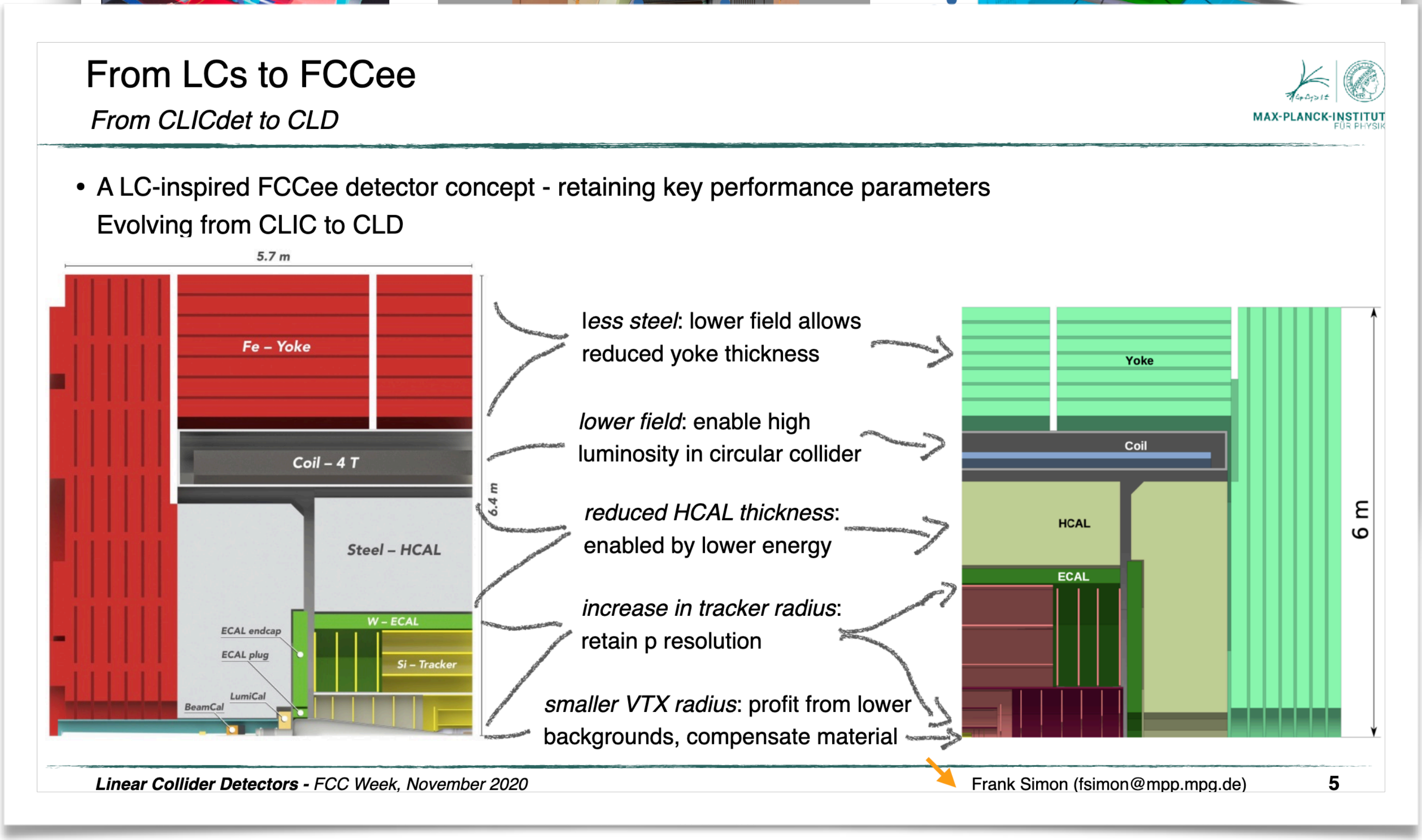
  - ECal and HCal optimised for PFA with very high granularity
- major difference: large **Si-Tracker vs TPC**
  - and of course many differences in size, thickness, MDI, …
- **CLD** is the well established **evolution of** CLICdp **optimised for FCCee**

- complete full simulation and **reconstruction software chain available in Key4hep for both**

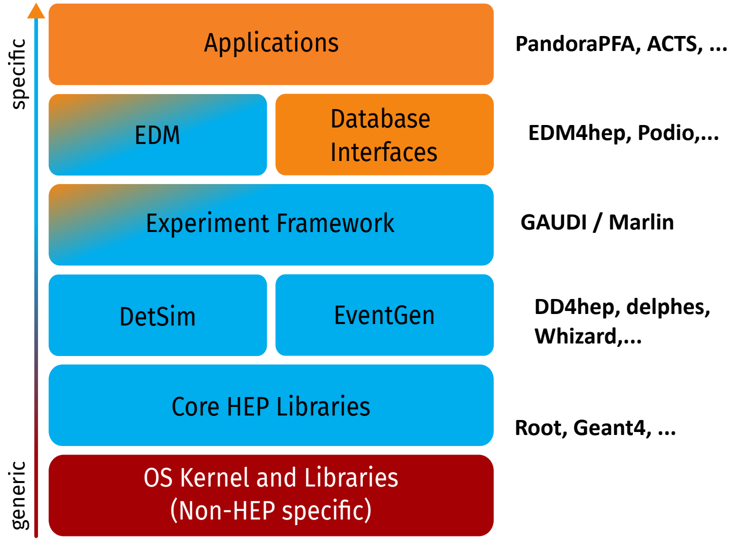


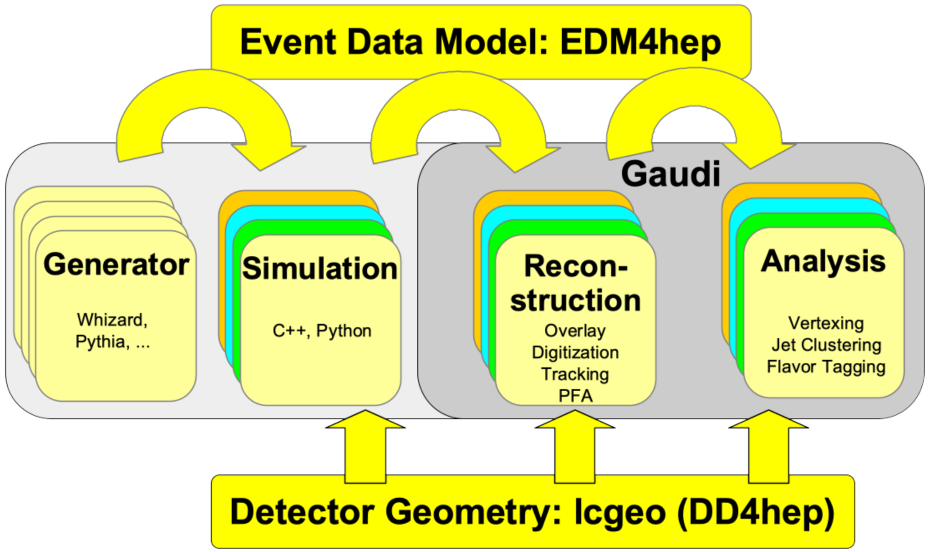


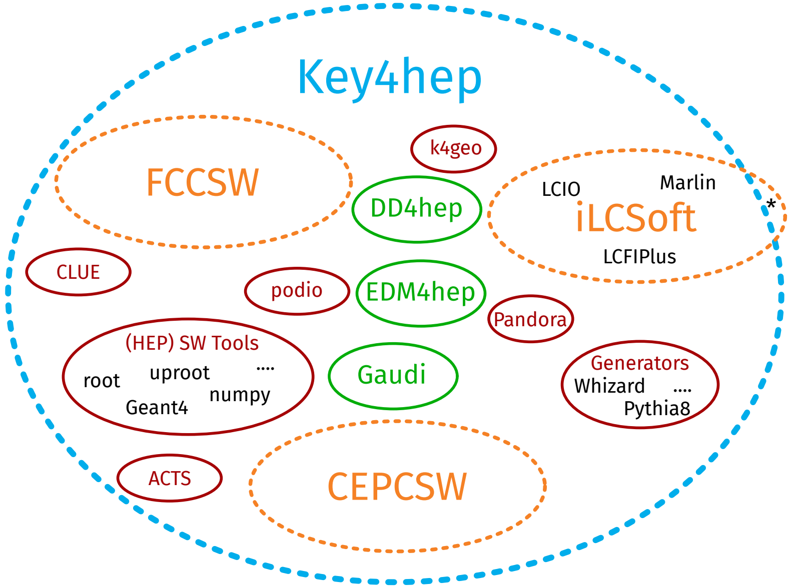
Key4hep

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 **optimal 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 …



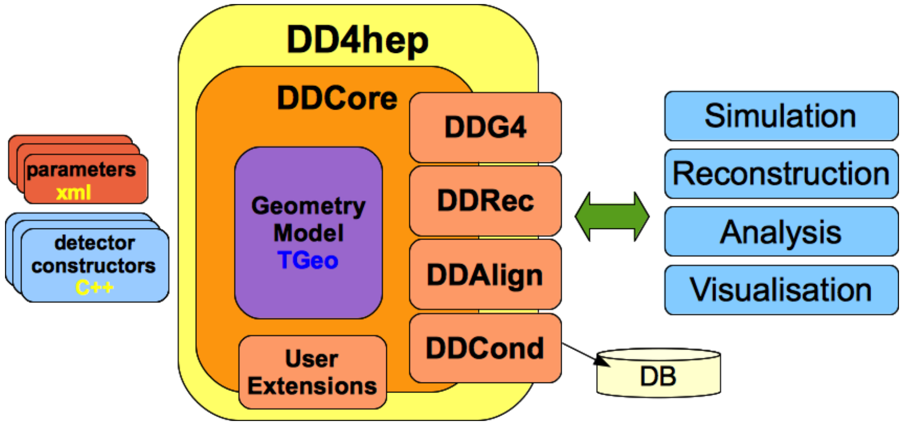




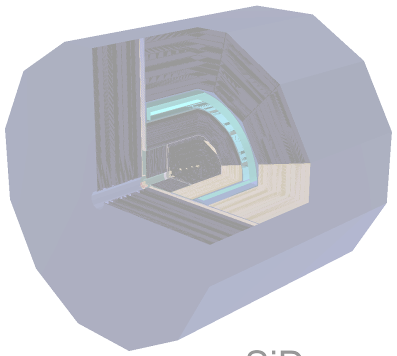
DD4hep geometry toolkit

defining the detector geometry and different views on it

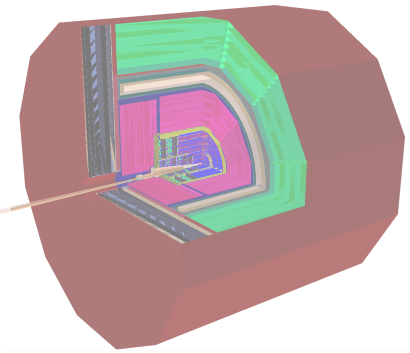
- supporting the full life cycle of the experiment
- **single source** of information for full **simulation, reconstruction, conditions, alignment, visualisation and analysis**
  - used by CEPC, CLIC, CMS, EIC, FCC, ILC, LHCb, …



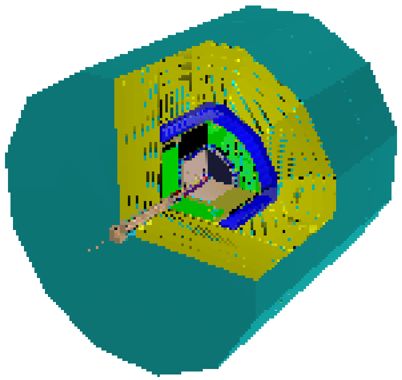
DD4hep: de facto industry standard



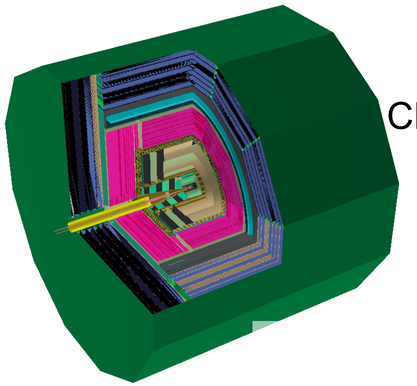
SiD



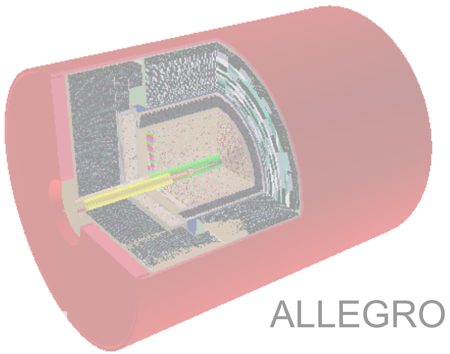
CLICdet



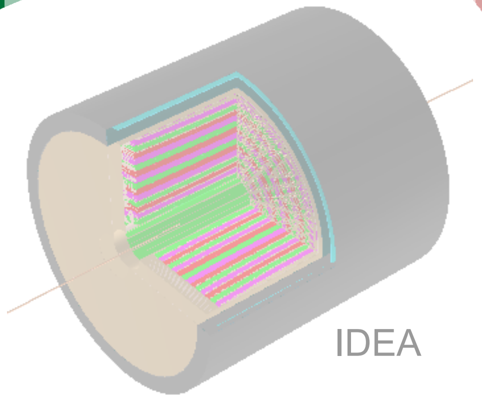
ILD



CLD



ALLEGRO



IDEA

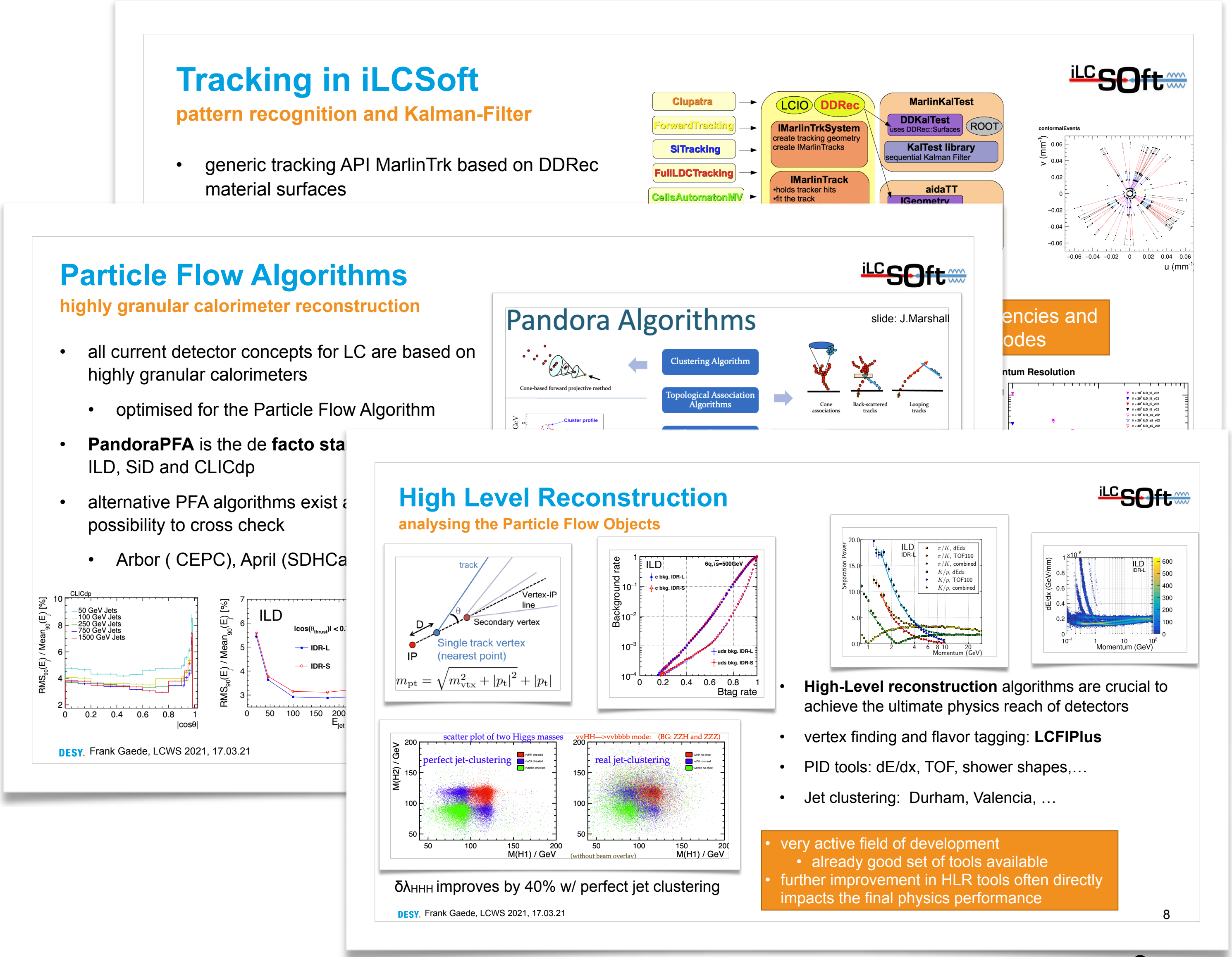
all future Higgs factory detector simulation models in **one package**
https://github.com/key4hep/k4geo

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

ILD/CLD have very large reconstruction code base

Developed over >15 years for (linear) lepton colliders

- **track reconstruction**
  - generic API for fitting algorithms
  - large number of pattern recognition algorithms
- **particle flow algorithms**
  - PandoraPFA ans Arbor, AprilPFA
- **high level reconstruction**
  - jet finding, flavor tagging, PID, TOF,…



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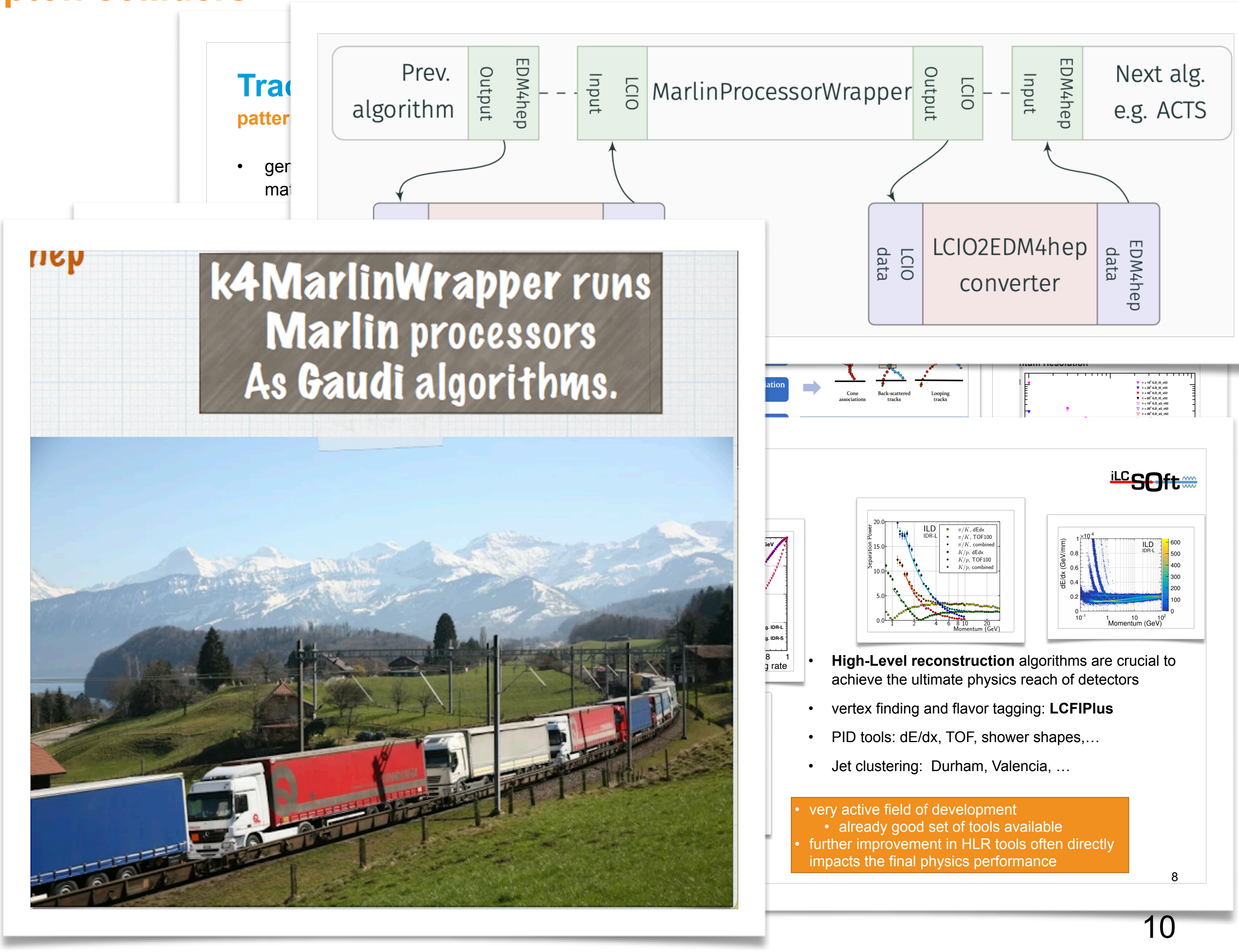
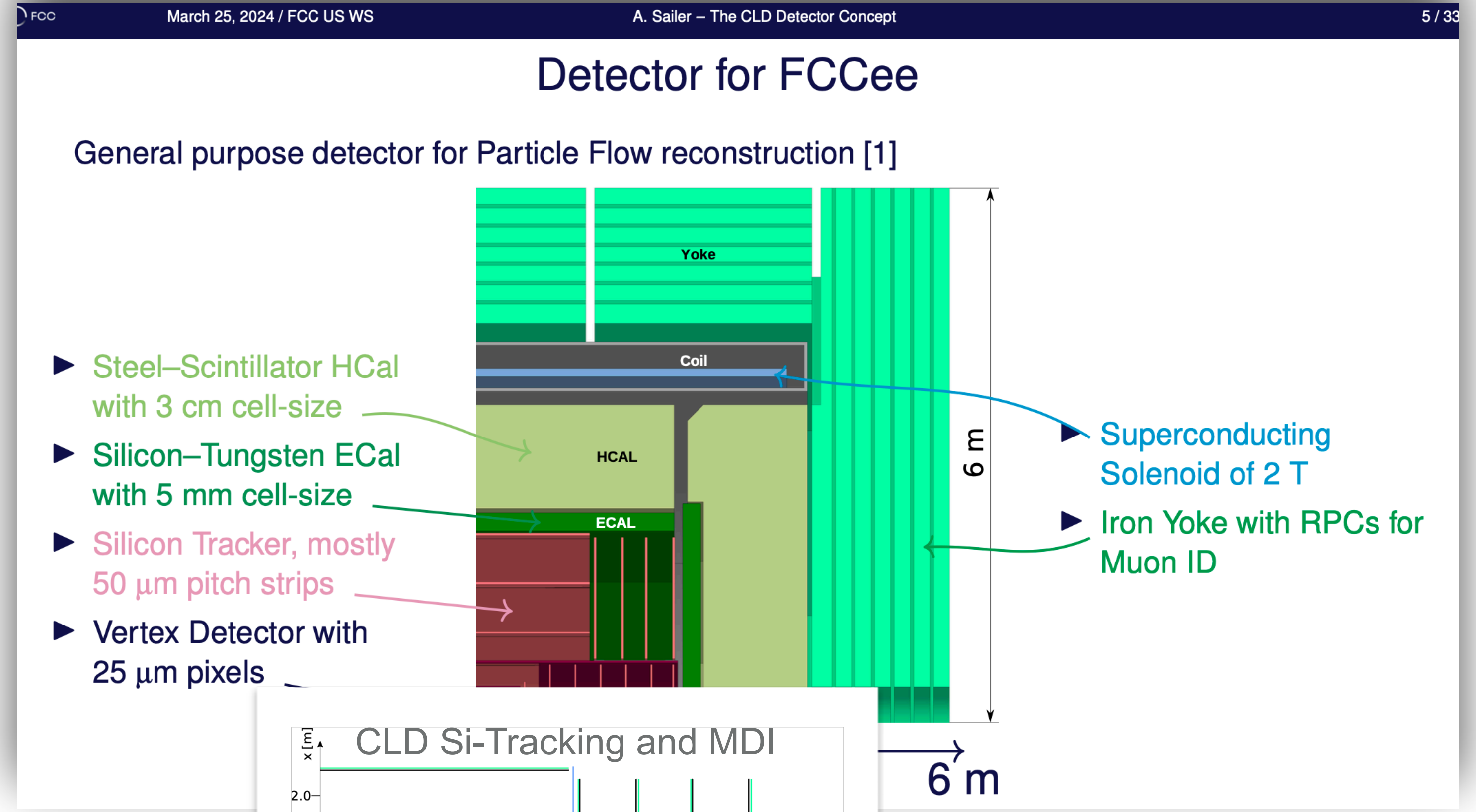
can re-use use these for FCCee detector variants in Key4hep via MarlinWrapper

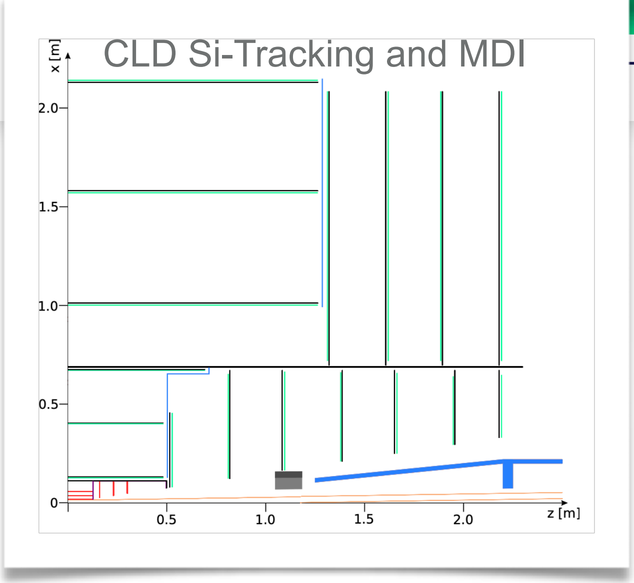


CLD and its variant(s)

studying options and develop algorithms

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

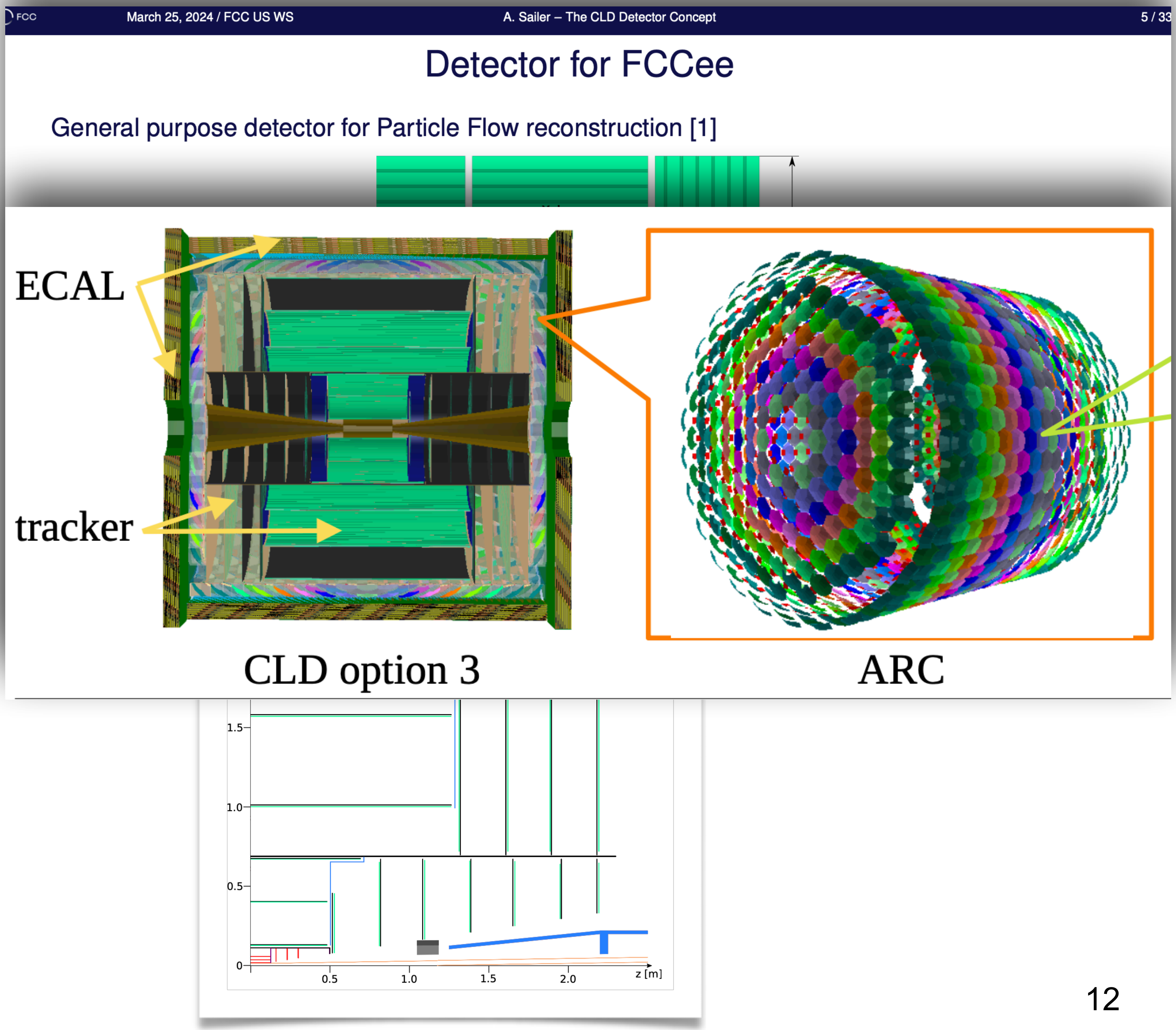




CLD and its variant(s)

studying options and develop algorithms

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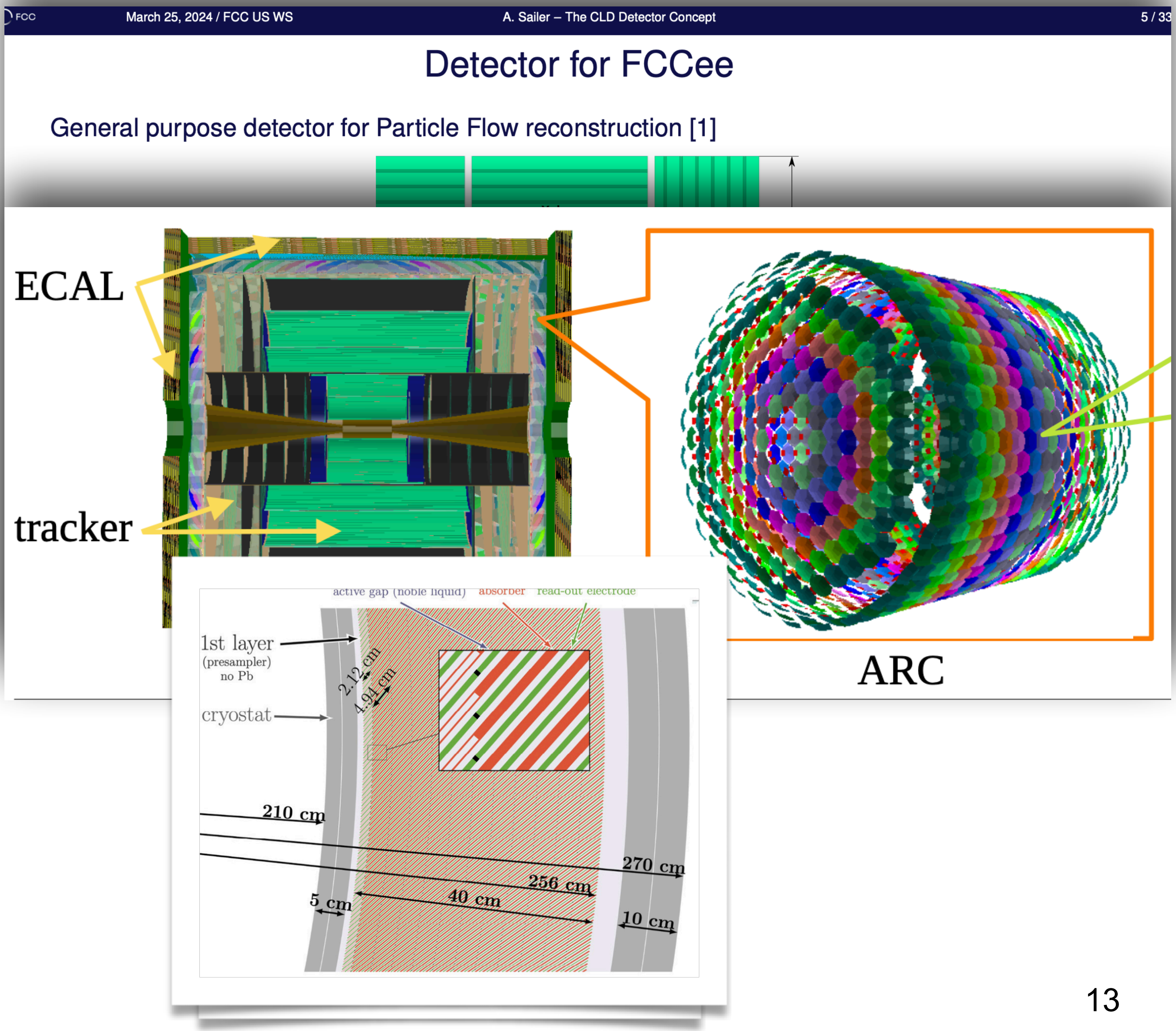
studying options and develop algorithms

- 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 …
- and also a **CLD-Alegro hybrid** with a LAr-Ecal in order to adapt **PandoraPFA** for the **LAr calorimeter**, *CLD_o4_v05* …

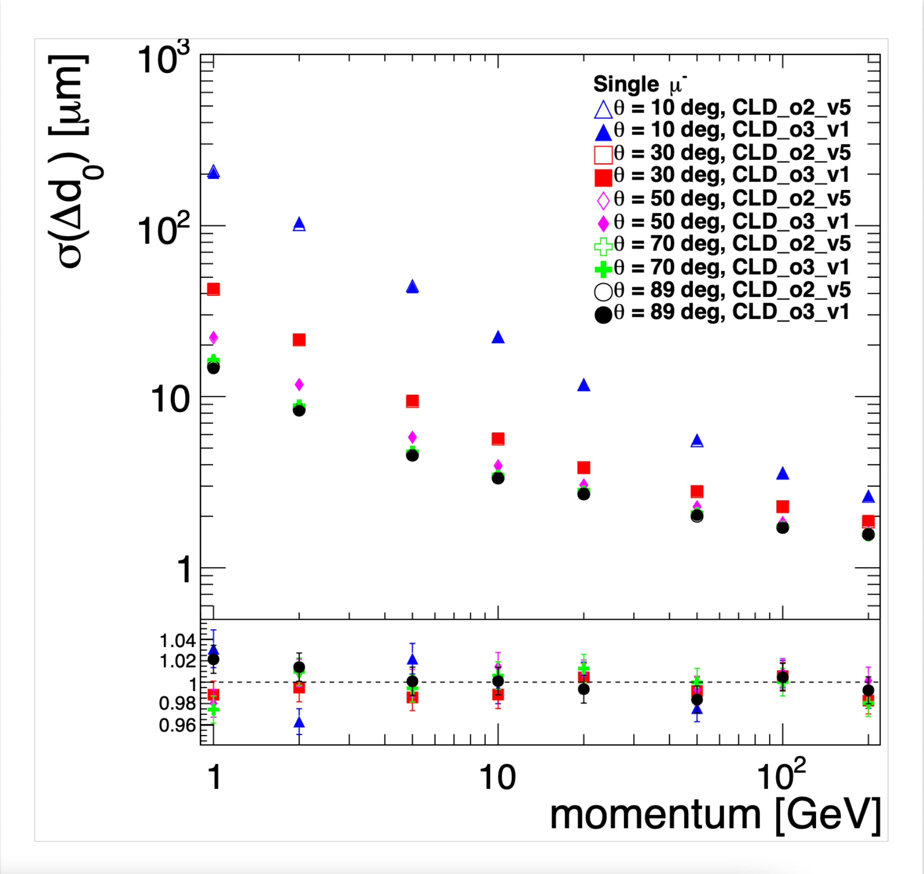


Studying tracking performance for CLD

G.Sadowski

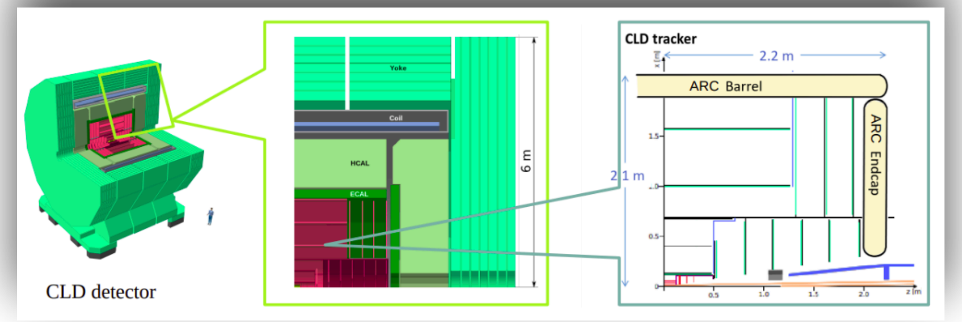
sub-detector variants

- 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)
- **reduced tracking volume** (ARC) results in
  - 10-15% **reduced momentum resolution** (lever arm)
  - ~unchanged **impact parameter resolution**



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
- X/X0 = 0.45 %



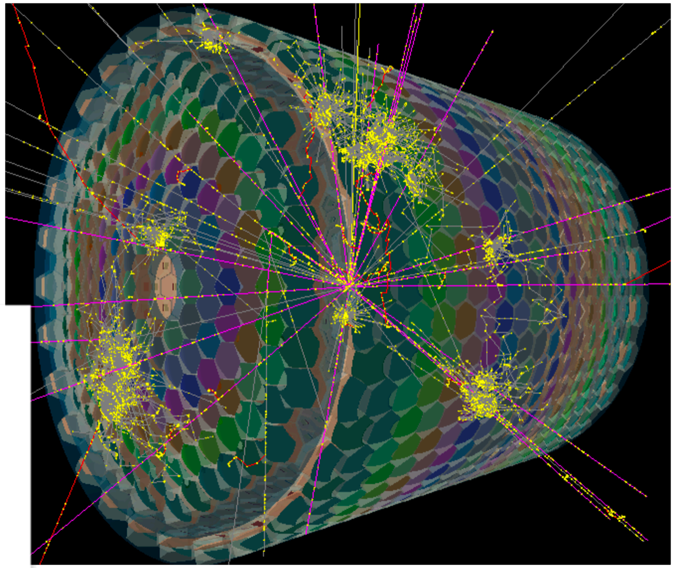
ParticleID performance with the ARC

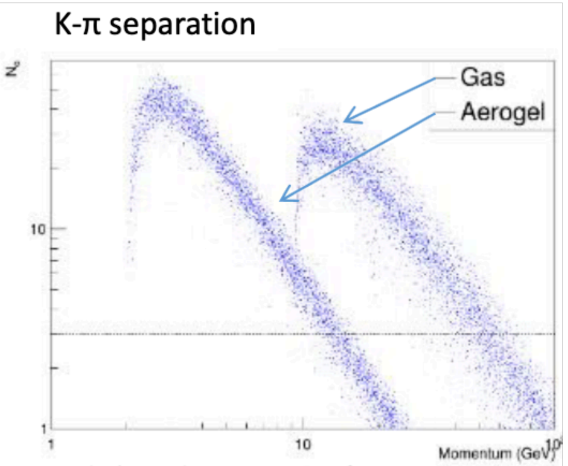
a novel GAUDI algorithm in Key4hep

A. Tolosa Delgado et al.

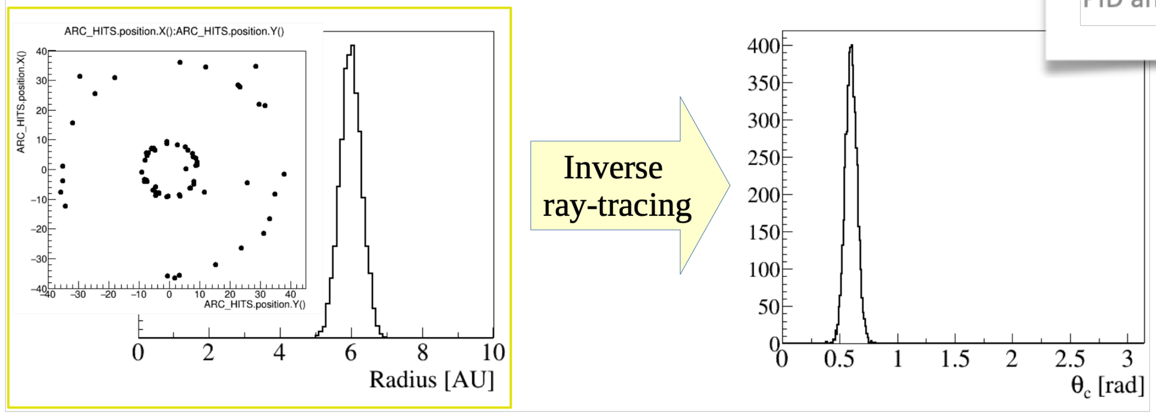
- can simulate full events in CLD w/ ARC with dddim (DD4hep)
- standalone reconstruction w/ inverse ray-tracing exists for single cell
  - should provide excellent K-pi separation from 2-50 GeV
- work in progress …

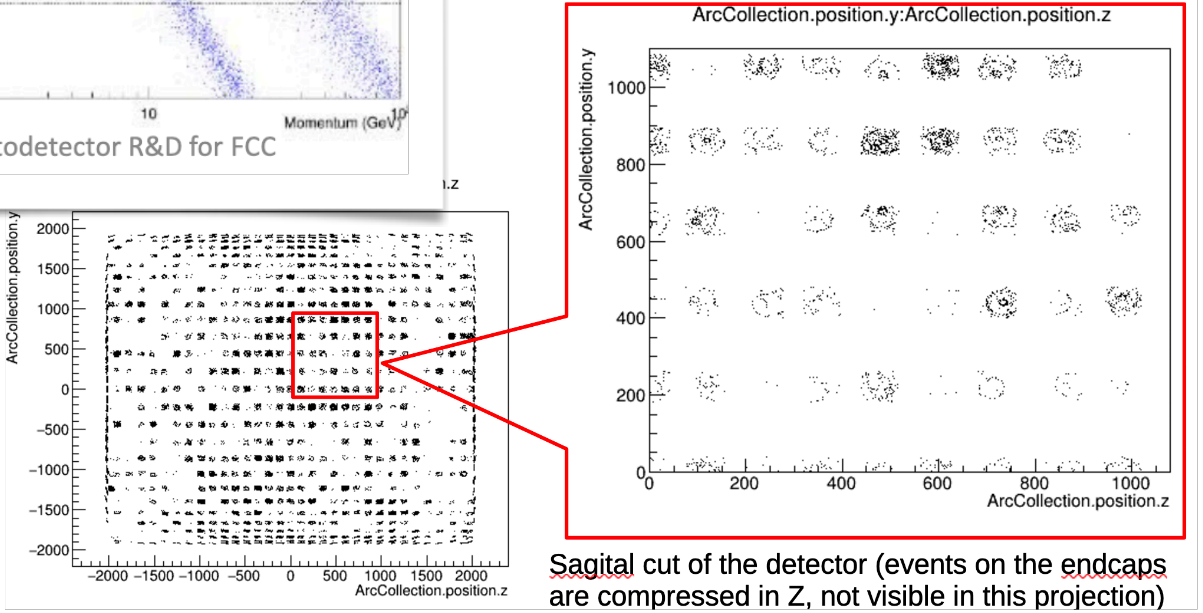
see talk by Serena Pezzulo tomorrow





PID and photodetector R&D for FCC



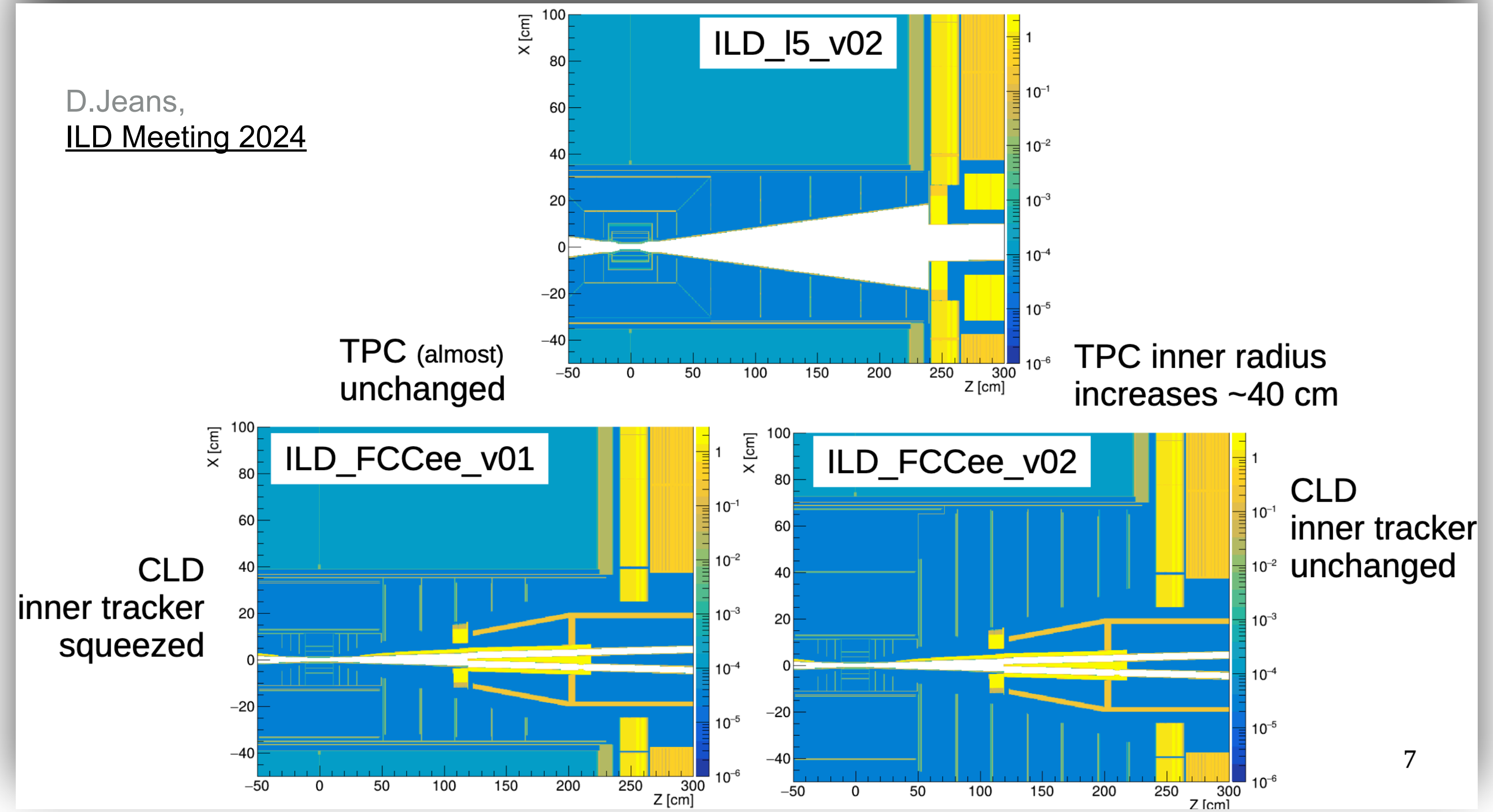


Sagital cut of the detector (events on the endcaps are compressed in Z, not visible in this projection)

ILD variants for FCCee

study individual evolution steps

- **ILC baseline of ILD**: TPC, inner Si-Tracking, SET, SiW Ecal, SciFeHCal
- **ILD for FCCee - v01**: TPC, inner and fwd tracking from CLD (squeezed), standard FCC-MDI region
- **ILD for FCCee - v02**: TPC - larger inner_r , inner and fwd tracking from CLD, standard FCC-MDI region



can use these models to study:

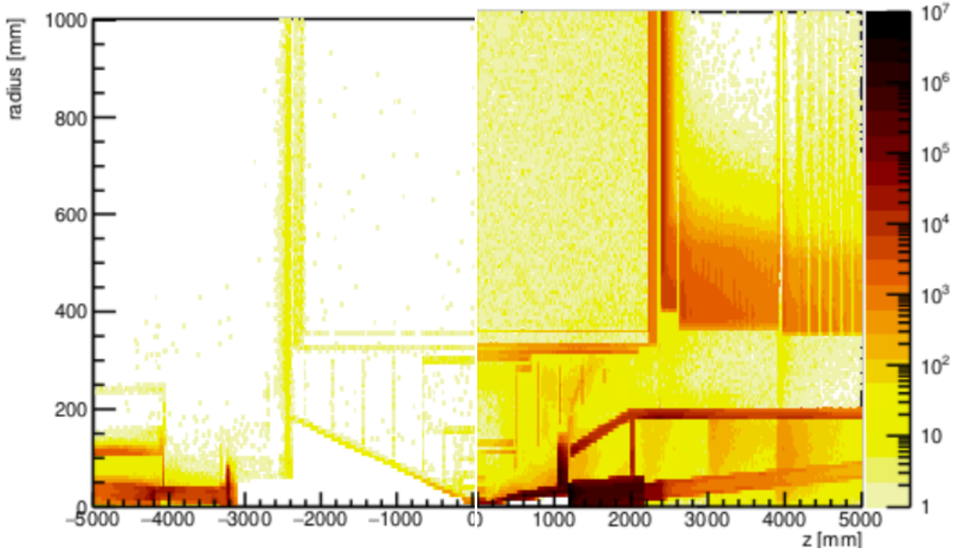
- background at FCC
- tradeoff between larger/smaller TPC
- does a TPC work in principle
- …

Can a TPC work at FCCee (91 GeV) ?

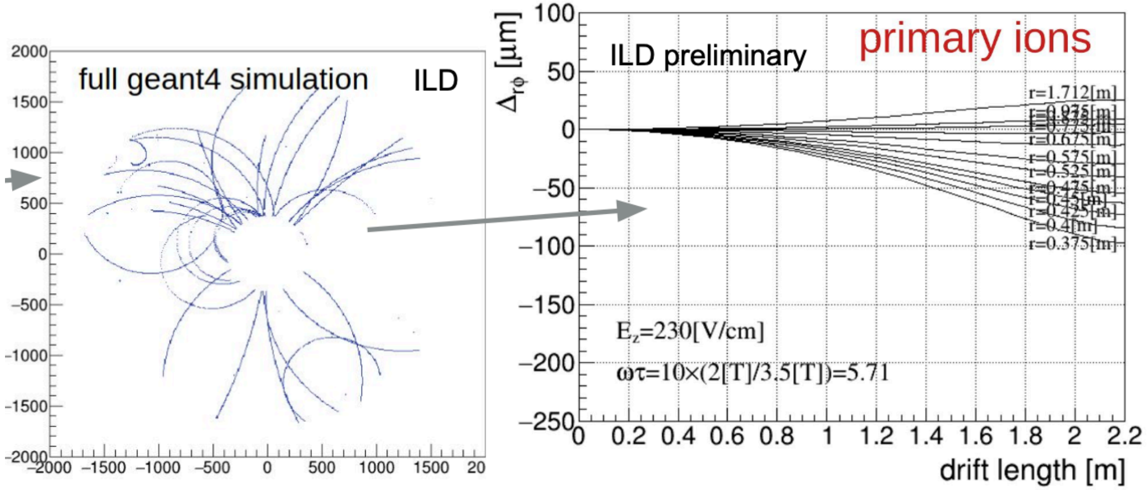
D.Jeans et al.

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: ~ **2×10^{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



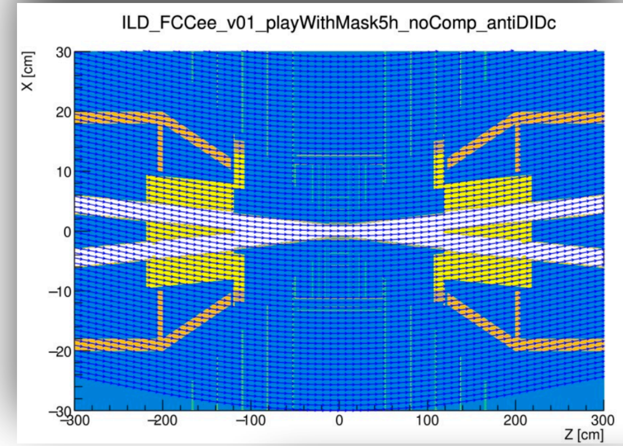
Collider	FCCee-91	FCCee-240	ILC-250
Detector model	ILD_l5_v11γ	ILD_l5_v11γ	ILD_l5_v05
average BX frequency	30 MHz	800 kHz	6.6 kHz
primary ions / BX	270 k	800 k	450 k
primary ions in TPC at any time	1.8×10^{12}	1.4×10^{11}	6.5×10^{8}
average primary ion charge density nC/m^3	6.8	0.54	0.0025

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

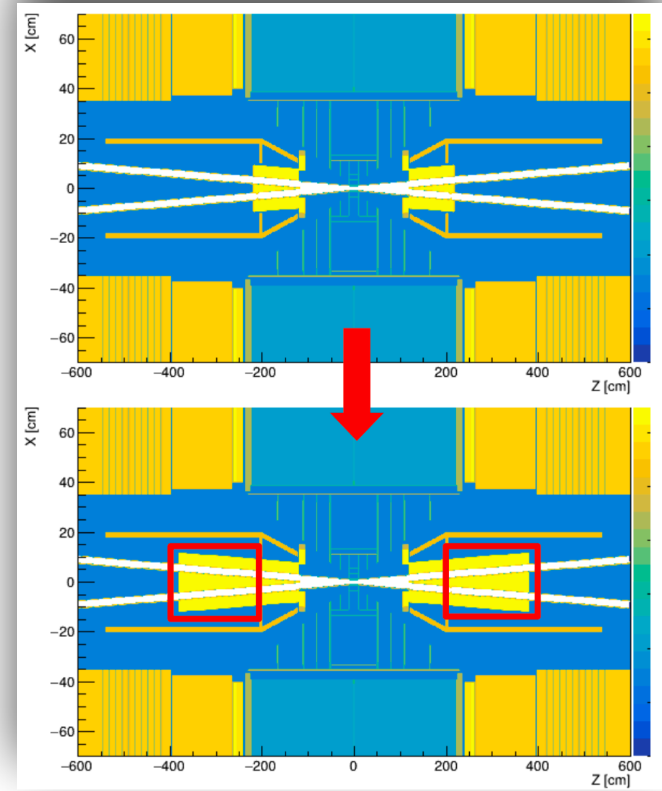
TPC background can be mitigated

By up to an order of magnitude

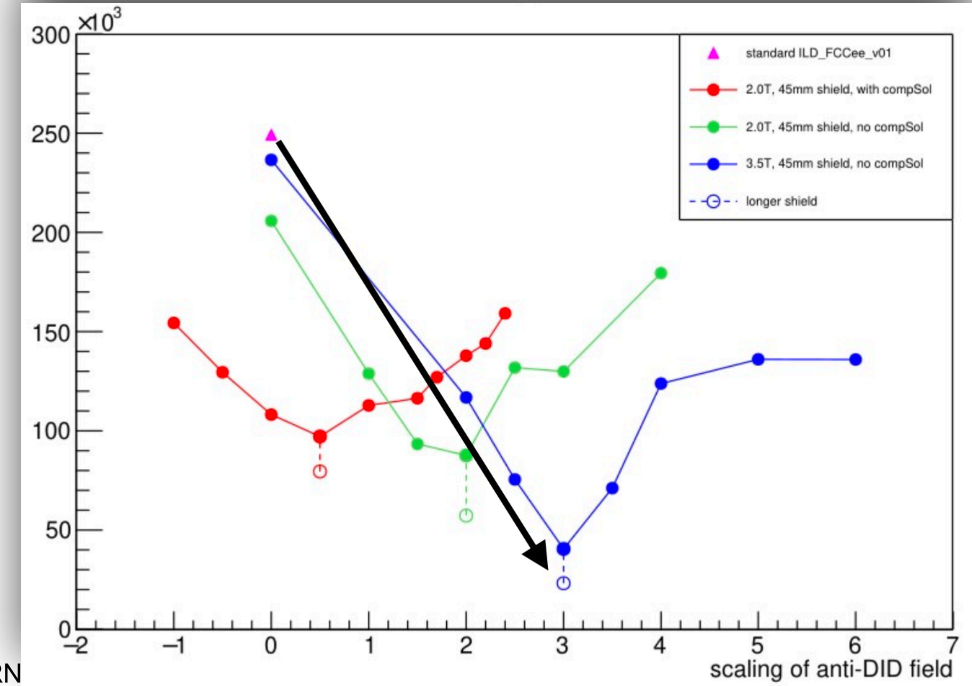
- additional anti-DID field
- thicker and longer shield after lumi cal
- larger 3.5 T magnetic field
  - engineering design/verification pending



see talk be V.Schwan this morning



- potentially yet better numbers with v02, i.e. larger inner radius of TPC
  - to be studied …
- engineering level details in inner forward region are important to be simulated

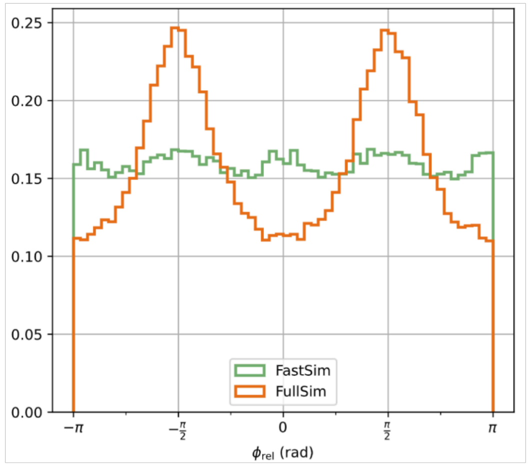


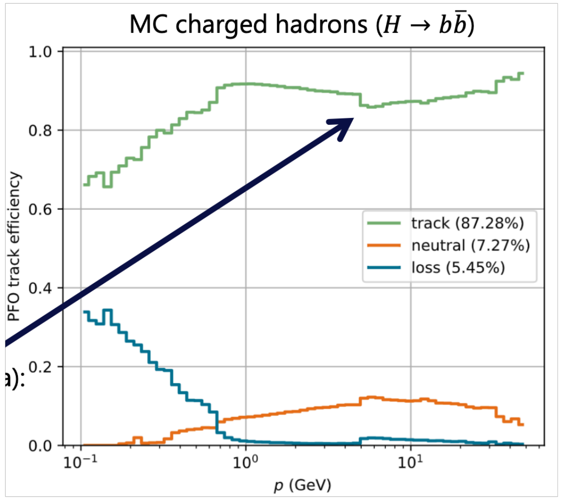
Full simulation is important

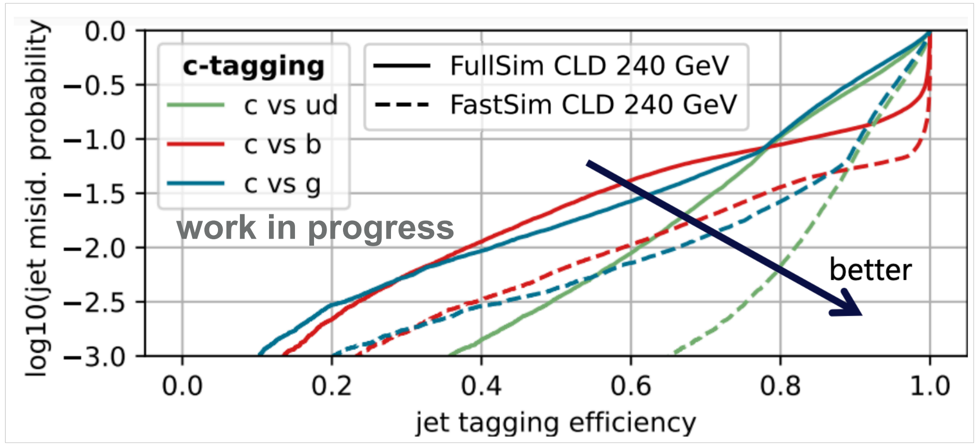
demonstrated here for flavour tagging with CLD

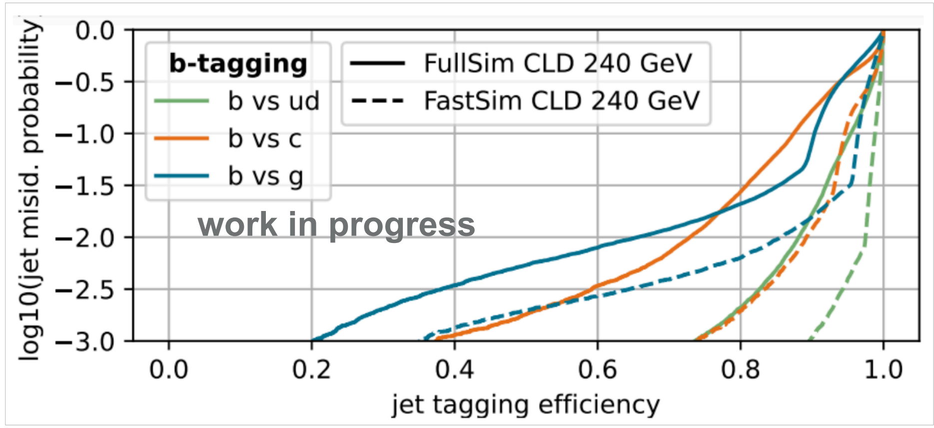
S.Aumiller

- training a PartTransformer for CLD w/
  - Delphes and Fullsim samples
- observe differences in extra neutrals due to
  - split clusters in real algorithm and due to tracks intentionally dropped as no cluster found
- leads to significant differences in tagging









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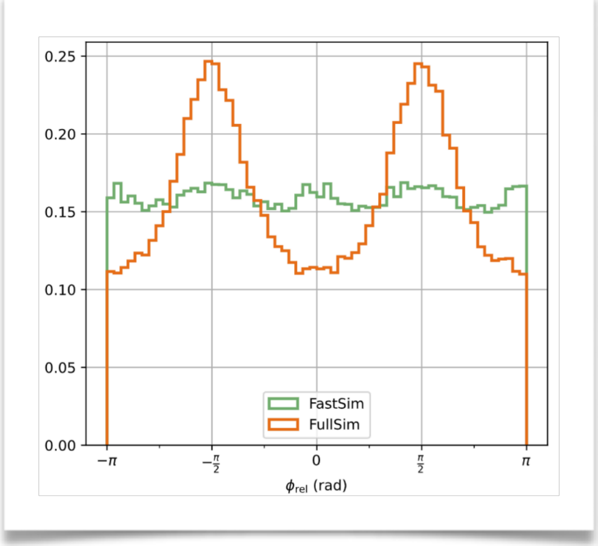
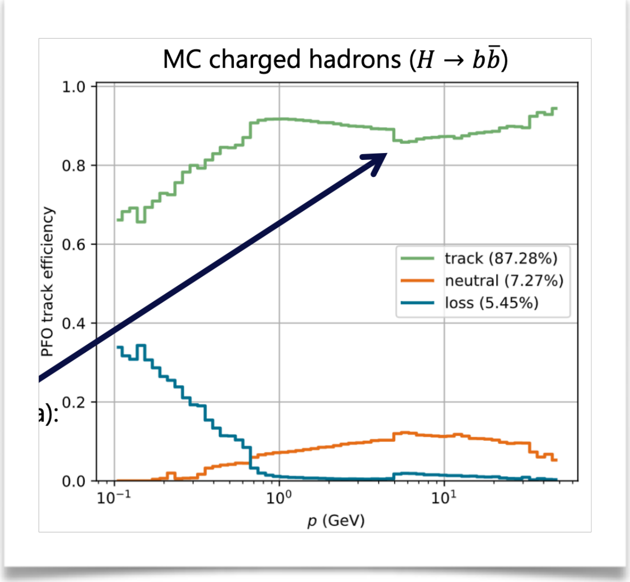
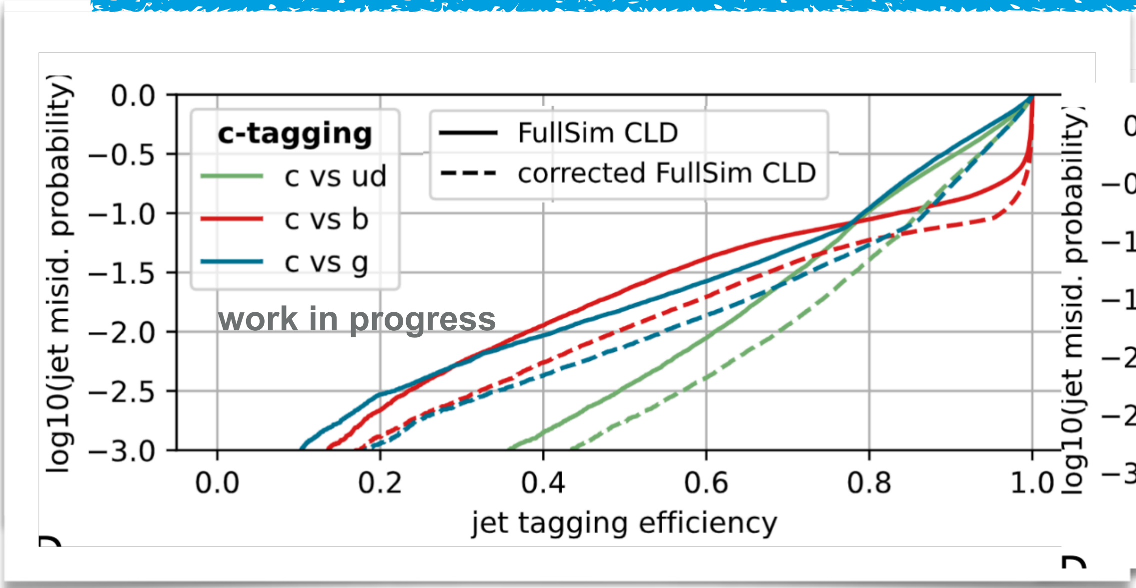
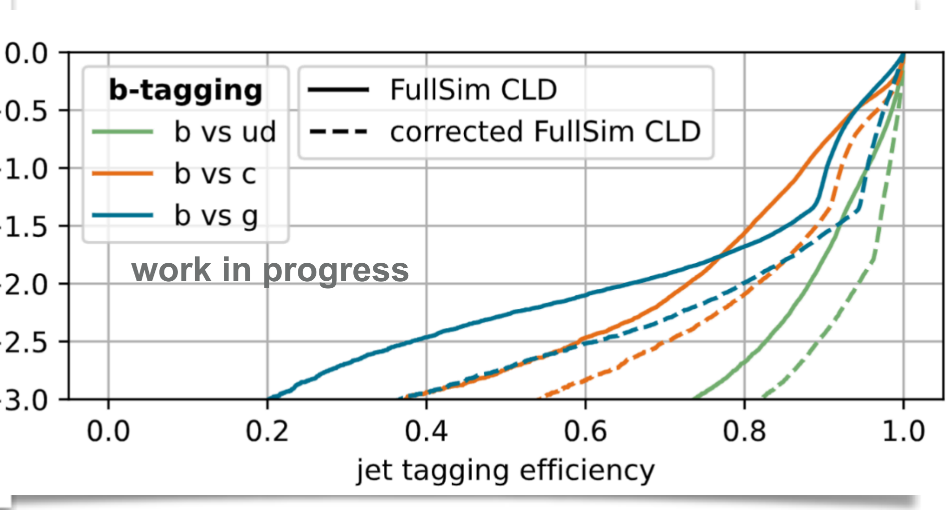




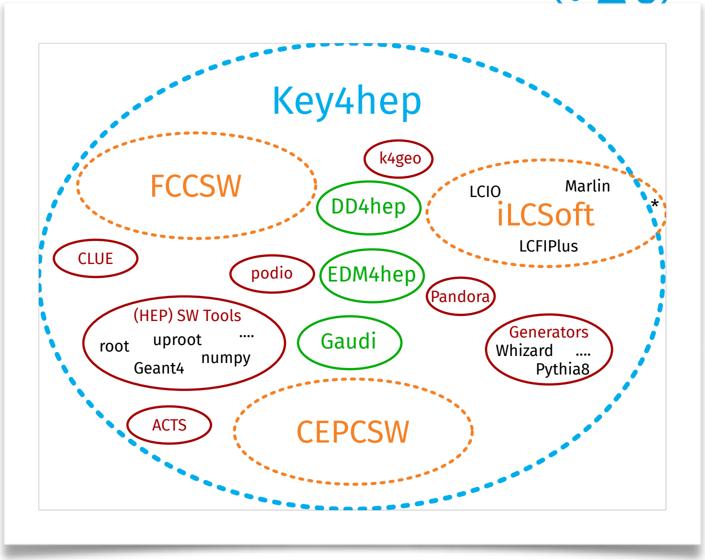
- can recuperate some of the flavour tag performance with better reconstruction
  - here cheating w/ MCTruth for demonstration





Summary

- ILD and CLD are closely related detector concepts, with **highly granular calorimeters**, partly common inner Si-tracking and either all-Si large tracker or a TPC
- complete reconstruction code for both is available in **Key4hep**
- flexibility of DD4hep allows to have a number of variants, e.g.
    - CLD w/ ARC or a CLD w/ LAr calorimeter
    - ILD w/ CLD inner tracking and TPC
- reconstruction code for new sub detectors under development
- **CLD/ILD ideal platform to study potential detectors for FCCee**
- for ILD ongoing work to establish wether and how a TPC can be operated at the FCCee (Z-Pole running)
    - recent studies show room for improvement wrt. backgrounds



CLD/ILD’