4th FCC / DRD France Workshop, Strasbourg (Nov.22-24/2023)

Status of the Key4hep Ecosystem

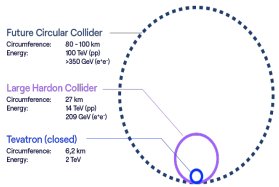
J.M. Carceller, 2nd ECFA Workshop 2023

A. Tolosa-Delgado, 2nd ECFA Workshop 2023

B. François, 2nd ECFA Workshop 2023

Ambitious physics studies

Physics Landscape @ FCCee



Detector requirement @ FCCee

Higgs
factory

m_H, σ, Γ_H
self-coupling
H→ bb, cc, ss, gg
H→inv
ee→H
H→bs, …

Top

m_{top}, Γ_{top}, ttZ, FCNCs

Flavor
"boosted" B/D/τ factory

CKM matrix
CP measurements
Charged LFV
Lepton Universality
τ properties (lifetime, BRs..)

$B_c \to \tau\, \nu$
$B_s \to D_s\, K$
$B_s \to K^* \tau\, \tau$
$B \to K^*\, \nu\, \nu$
$B_s \to \varphi\, \nu\, \nu$ …

QCD – EWK
most precise SM test

m_Z , Γ_Z , Γ_{inv}
$\sin^2\theta_W$, R^Z_ℓ , R_b, R_c
$A_{FB}^{b,c}$, τ pol.
α_S
m_W, Γ_W

BSM
feebly interacting particles

Heavy Neutral Leptons (HNL)
Dark Photons Z_D
Axion Like Particles (ALPs)
Exotic Higgs decays

Higgs
factory

track momentum resolution (low X_0)
IP/vertex resolution for flavor tagging
PID capabilities for flavor tagging
Hadron energy resolution (stochastic and noise) and PF

Flavor
"boosted" B/D/τ factory

track momentum resolution (low X_0)
IP/vertex resolution
PID capabilities
Photon resolution, pi0 reconstruction

QCD – EWK
most precise SM test

acceptance/alignment knowledge to 10 μm
magnetic field uniformity
lumiCal coverage down to 60 mrad

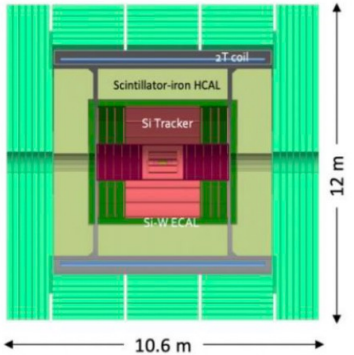
BSM
feebly interacting particles

Large decay volume
High radial segmentation
- tracker
- calorimetry
- muon
impact parameter resolution for large displacement
triggerless

M. Selvaggi, FCC Week 2023

Detector concepts

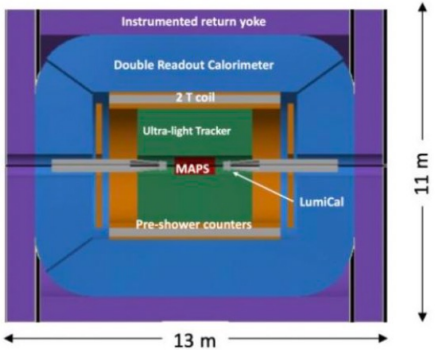
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker;
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?

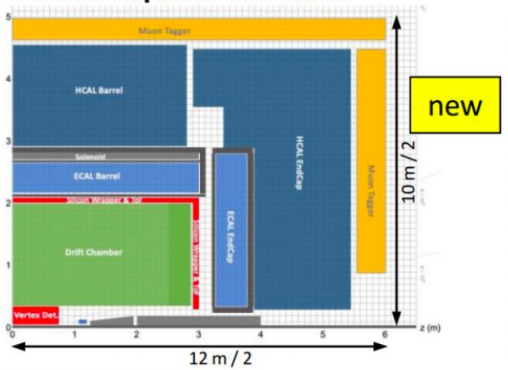
CDR

IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber w powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

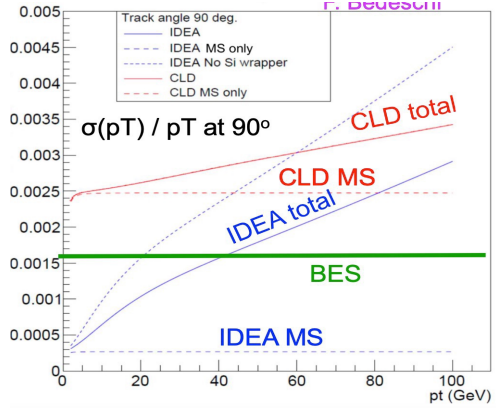
Noble Liquid ECAL based

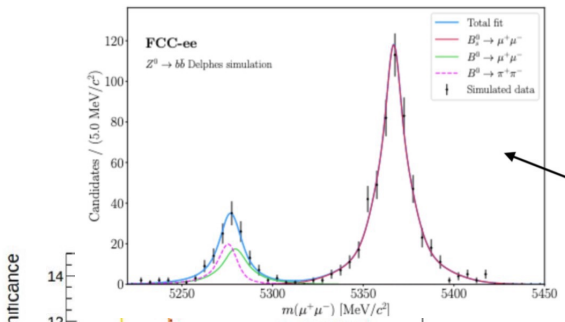


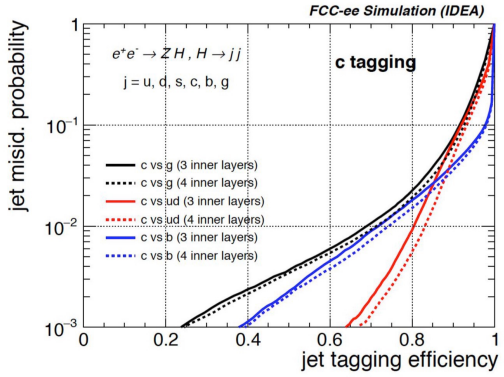
- A design in its infancy
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

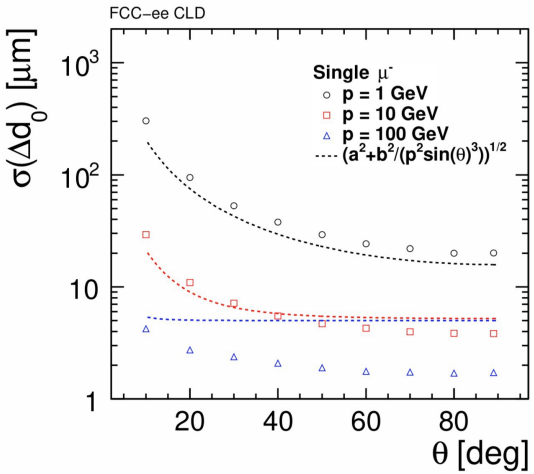
[FCC-ee CDR]

Exploring new physics…

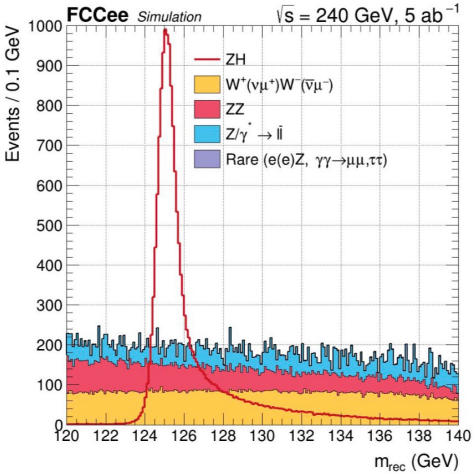








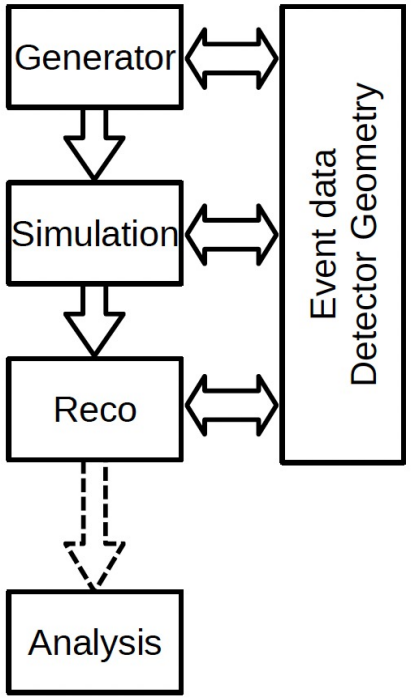
3-sigma separation for tracks with **p < 30GeV**



The key4HEP Software Ecosystem

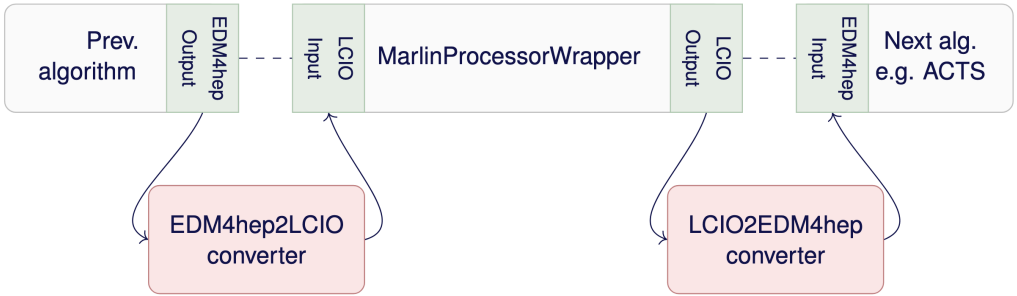
A. Tolosa-Delgado, 2nd ECFA Workshop 2023

- Key4hep software stack aimed to be a common tool for e+e- colliders:
  - CLIC, FCC, ILC, C^3, CEPC.
- Data format is EDM4hep
- Detector Geometry built by DD4hep (Based on Geant4)
  - Central repository for geometry: k4geo
    (ALLEGRO, CLD, IDEA)
- Actions are a Gaudi service/tool/alg
  - Several repositories for reconstruction
- A dedicated framework for analysis

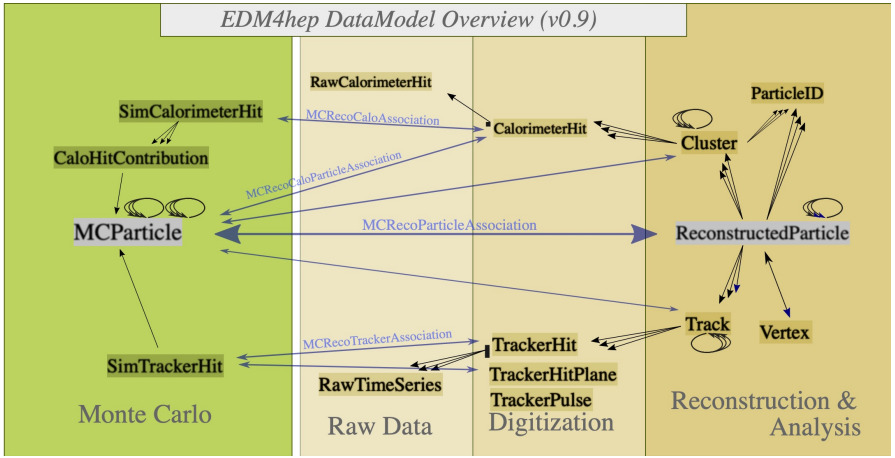


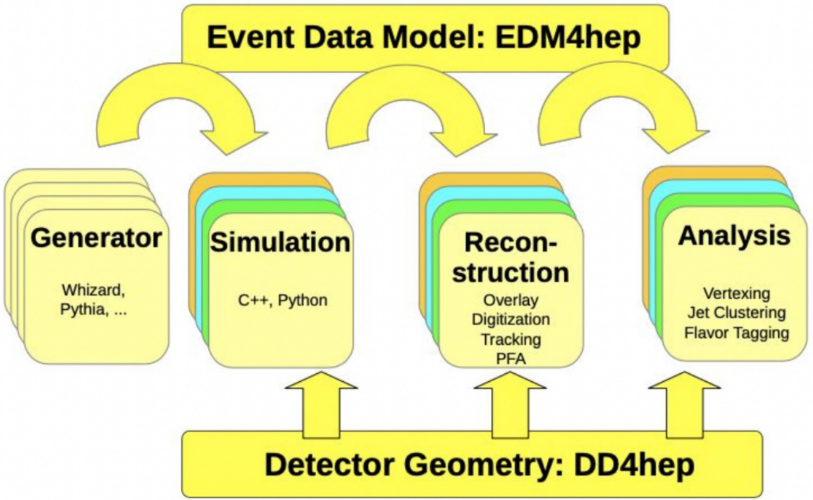
Inheritance from the ILCSoftware

- ILC community has a very advanced simulation toolkit and it has strongly influenced the central key4HEP components (*DD4hep and edm4hep).*
- Availability of MarlinWrapper and data format (LCIO ↔ EDM4hep) conversion were extremely valuable for the launching of key4hep.



EDM4hep Data Model





New functionalities

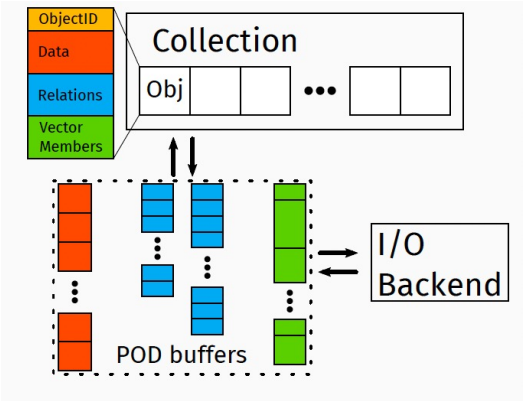
(definitely not an exhaustive overview)

Podio : a need for a versatile EDM

T. Madlener el al., vCHEP 2021

AIDASoft/podio

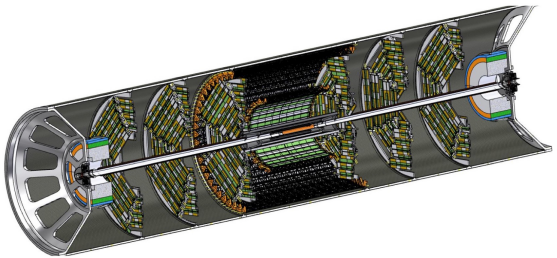
- Original HEP c++ EDMs are heavily Object Oriented
  - Deep inheritance structures
  - Thread-safety can be hard
  - Objects scattered in memory
- Data access can be slow with these approaches
- Use podio to generate thread-safe code starting from a high level description of the desired EDM
  - Users are isolated from implementation details
  - Target different I/O backends for persistence
  - Provide an easy-to-use interface to the users
- Users should not need to worry about resource management
- Python is used as first choice programming language



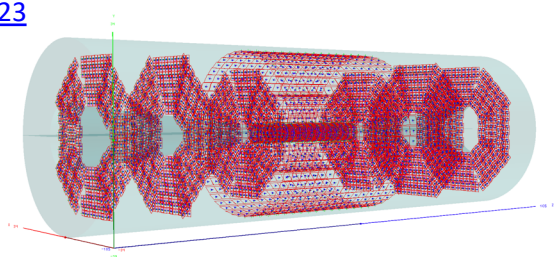
I/O Podio (flattening)

Geometry import from Computer Aided Design

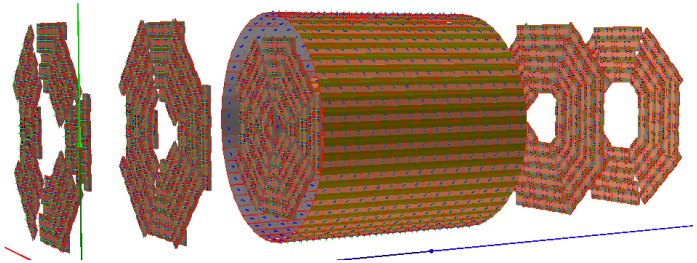
- IDEA:
  - Sensitive surfaces in IDEA vertex implementation in DD4hep
  - Vertex detector geometry based on Arcadia sensors imported from CAD

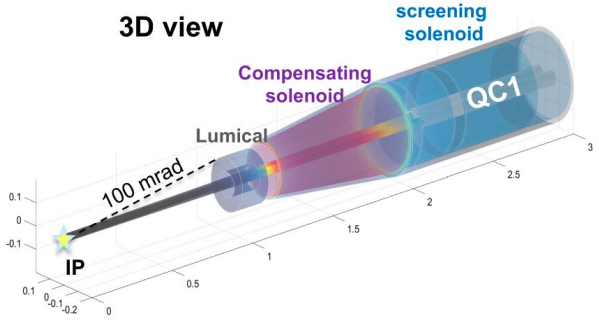


A. Ilg, FCC Week 2023



F. Palla, 2nd ECFA Workshop 2023





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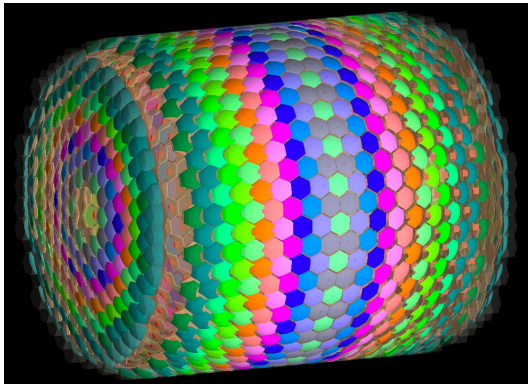
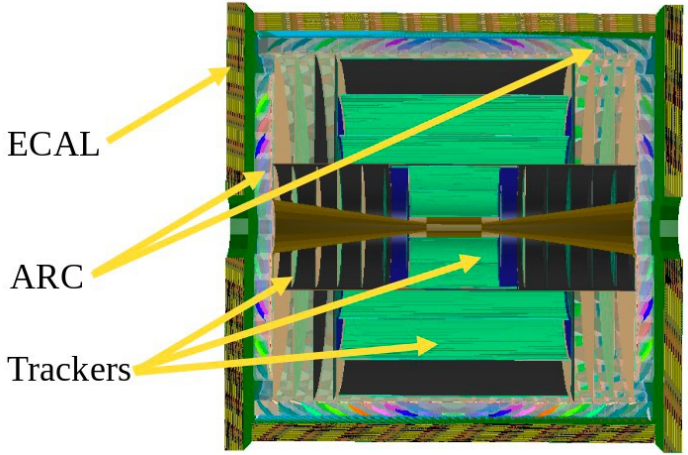
ARC Implementation in CLD

- New option of CLD to accommodate ARC (Array RICH Cells) subdetector Cerenkov-based detector
- RICH detectors are suitable for particle identification at high momentum
- Work in geometry optimization, digitization and reconstruction algorithms is ongoing





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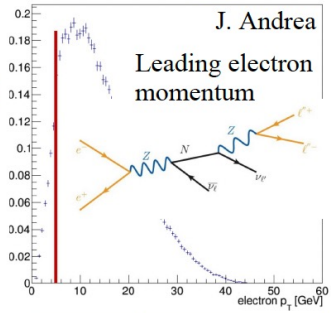
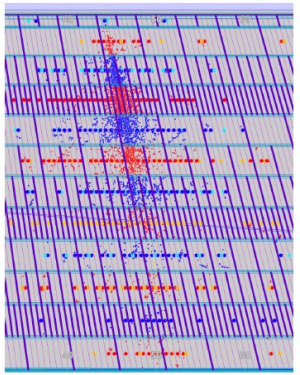
Highlights from FCC-ee

B. François, 2nd ECFA Workshop 2023

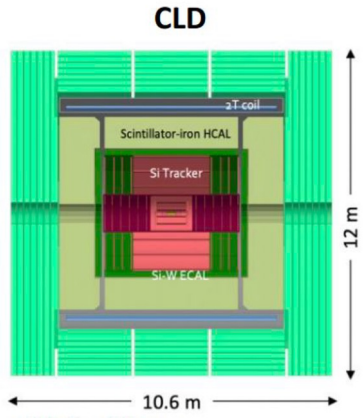
- 4 IP (baseline), 3 detector concepts (so far) under development/optimization
  - Detailed **beampipe**: **CAD drawing imported in DD4hep**, PR opened
    - Luminosity measurement studies starting
  - **CLD**: **fully available** in Key4hep (DD4hep, ddsim, ILCSoft reconstruction)
    - **First Full Sim physics analysis (HNL) starting!**
  - **IDEA**: many components were developed in standalone Geant4
    - Whole detector **being implemented in DD4hep/Key4hep**
    - Most sub-detectors are at the digitization/reconstruction step
  - **ALLEGRO**: new concept based on IDEA with different calorimeters
    - Started right away with Key4hep in mind
    - **ECAL and HCAL available**, will adapt the other IDEA sub-detectors
- Efficient **calorimeter granularity optimization** strategy
  - Time consuming Geant4 simulation with 'atomic' granularity
  - Multiple readout granularities defined at digitization step, from one simulation
  - Now possible to have different cell size per longitudinal layer
- Detector geometries ported in k4geo (already hosting ILC and CLIC detectors)

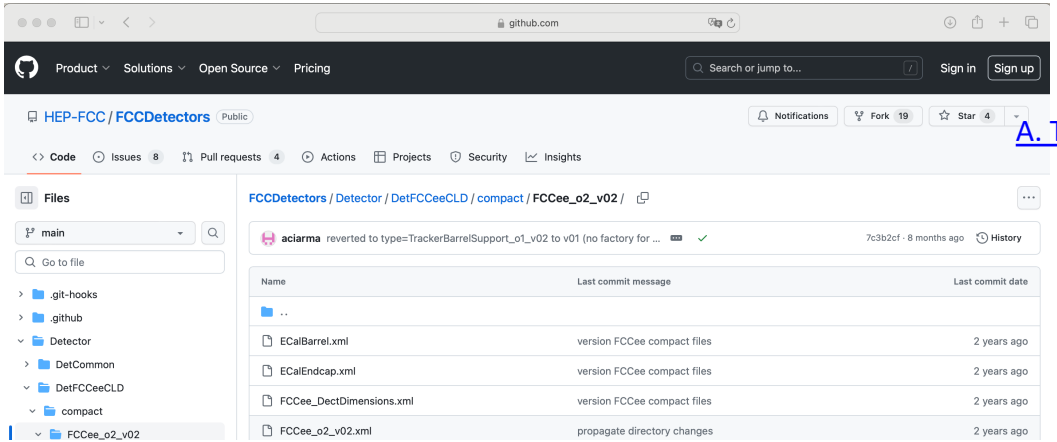




G. Marchiori

A common repository for detector description

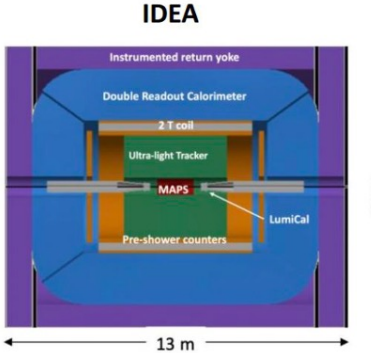


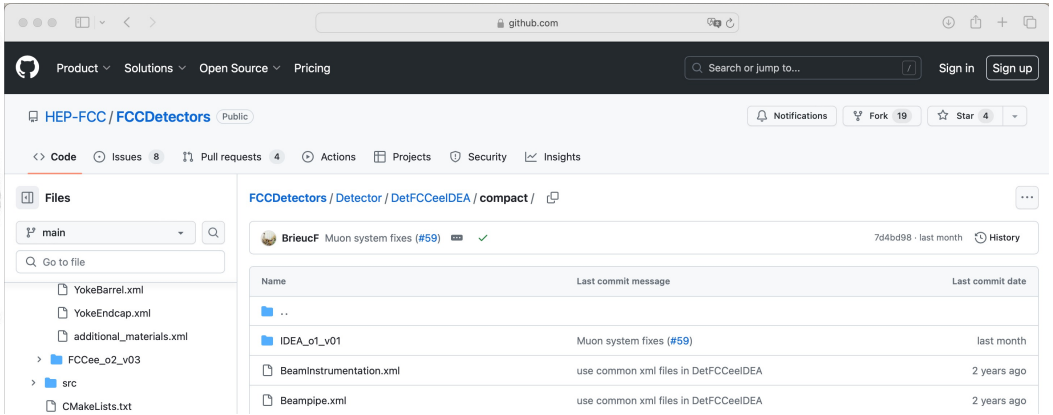


[A. T-Delgado, 2nd ECFA Workshop 2023]

[A. Sailer, 2nd ECFA Workshop, 2023]

[CLD Detector Description]





[A. Ilg, FCC Week 2023]

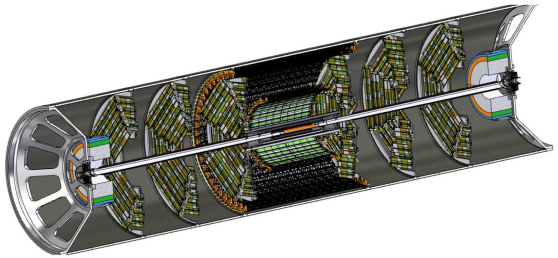
[F. M. Procacci, 2nd ECFA Workshop]

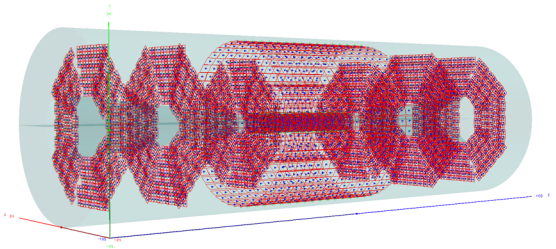
[IDEA Detector Description]

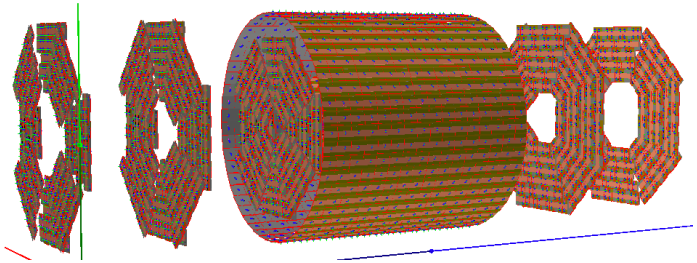
A case study: implementation of IDEA Vertex Detector with Key4HEP

Sensitive surfaces in IDEA vertex implementation in DD4hep
Vertex detector geometry based on Arcadia sensors imported from CAD

F. Palla, 2nd ECFA Workshop 2023







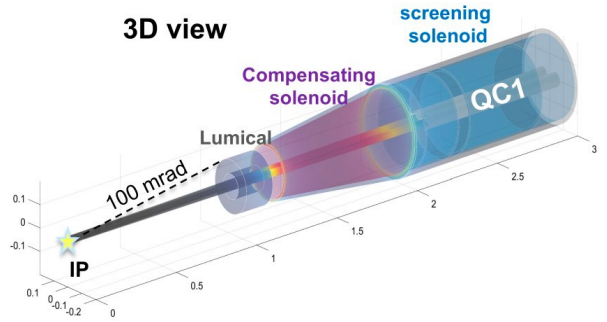
A. Ilg, FCC Week 2023

Run simulation on detector compact file (xml), using FCC steering file to generate EDM4hep output:

```
ddsim --compactFile k4geo/FCCee/compact/FCCee_IDEA_o01_v01.xml
--enableGun --gun.thetaMin 9.999 --gun.thetaMax 10.001
--gun.distribution uniform --gun.energy 10*GeV --gun.particle
mu- --steeringFile fcc_steer.py --numberOfEvents 1000
--outputFile ddsim_edm4hep.root
```

Run linear collider reconstruction (iLCSoft/CLICPerformance) using k4MarlinWrapper:

```
k4run fccRec_e4h_input.py --EventDataSvc.input
ddsim_edm4hep.root -n 1000
```



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A case study: implementation of IDEA Vertex Detector with Key4HEP

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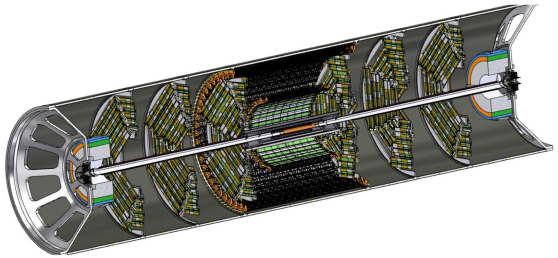
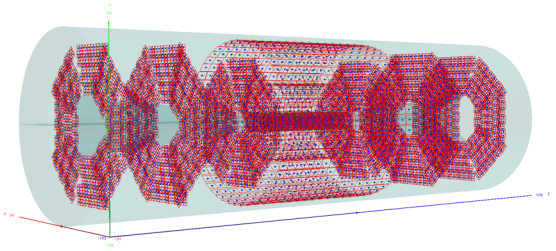
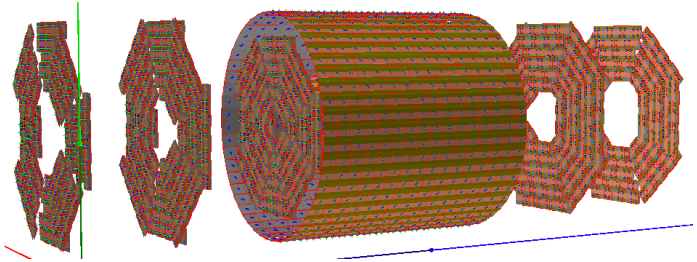
Vertex detector geometry based on Arcadia sensors imported from CAD

F. Palla, 2nd ECFA Workshop 2023







A. Ilg, FCC Week 2023

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--gun.distribution uniform --gun.energy 10*GeV --gun.particle
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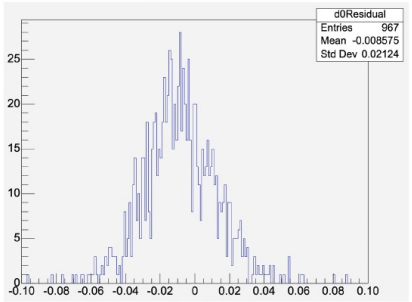
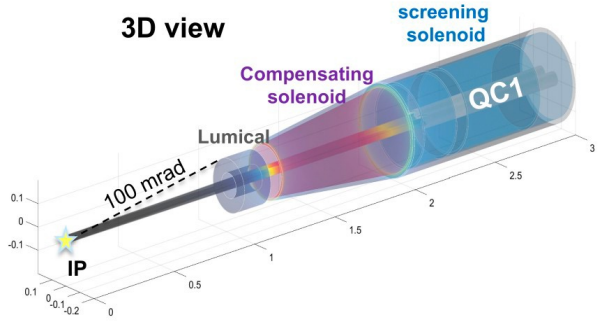
Run linear collider reconstruction (iLCSoft/CLICPerformance) using k4MarlinWrapper:

```
k4run fccRec_e4h_input.py --EventDataSvc.input
ddsim_edm4hep.root -n 1000
```

...inserting IDEA vertex



D_0 resolution in mm.



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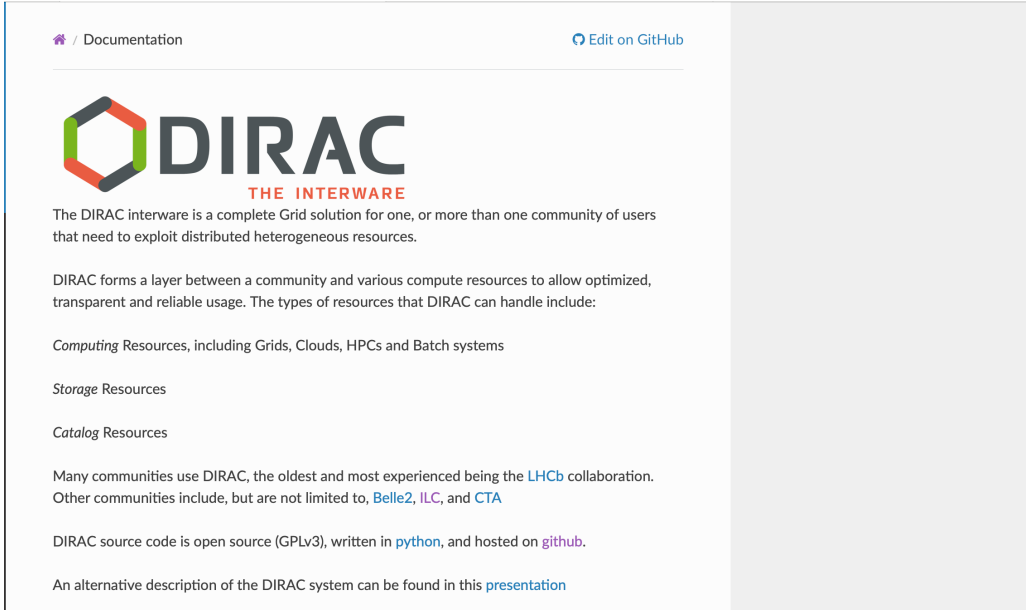
Need for massive production



Documentation

Edit on GitHub

DIRAC

THE INTERWARE

The DIRAC interware is a complete Grid solution for one, or more than one community of users that need to exploit distributed heterogeneous resources.

DIRAC forms a layer between a community and various compute resources to allow optimized, transparent and reliable usage. The types of resources that DIRAC can handle include:

Computing Resources, including Grids, Clouds, HPCs and Batch systems

Storage Resources

Catalog Resources

Many communities use DIRAC, the oldest and most experienced being the LHCb collaboration. Other communities include, but are not limited to, Belle2, ILC, and CTA

DIRAC source code is open source (GPLv3), written in python, and hosted on github.

An alternative description of the DIRAC system can be found in this presentation

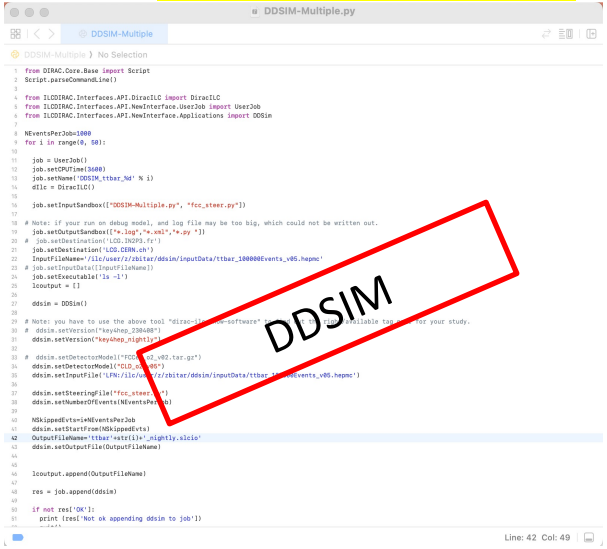
Mastering the workflow for Dirac

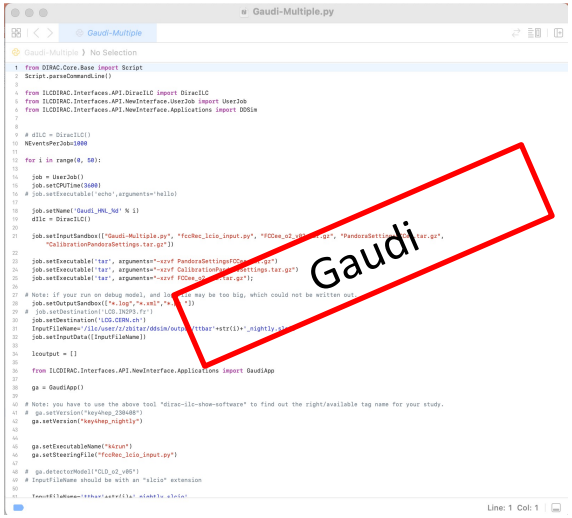
Generation : MadGraph, Pythia (data format:hepMC)

Simulation: ddsim

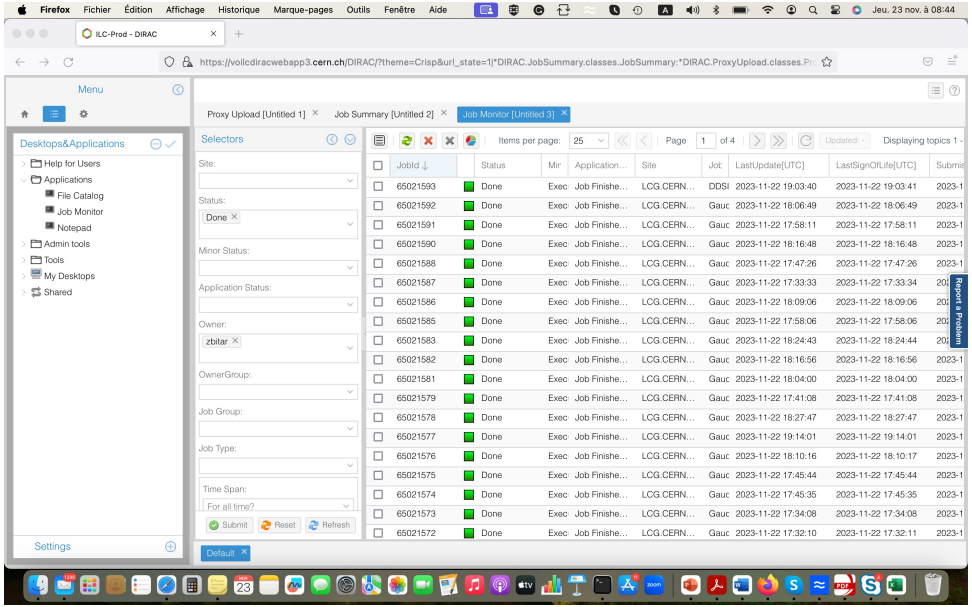
Reconstruction and Analysis

Translate into Dirac …





Dirac web portal for jobs monitoring



Dirac script manages Data so that it is directly written to a Storage Element

```
-rwxrwxr-x 1 zbitar ilc_user 2754289690 2023-11-22 18:08:33 ttbar_rec_0_nightly_edm4hep.root
-rwxrwxr-x 1 zbitar ilc_user 2743137725 2023-11-22 17:29:39 ttbar_rec_10_nightly_edm4hep.root
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```

Conclusion

- Many ongoing developments and improvements in the Key4hep Ecosystem: detector description (CAD, RICH), data format, and calculation.
- Full simulation studies on the impact of the geometry on tracking and vertexing are on going for interesting physics cases (see J. Andrea and G. Sadowski talks).
- Massive production is available also on DIRAC (need a grid certificate, could be ilc or fcc user).
- Regular meeting and dynamic community : FCC-PED-SoftwareAndComputing-Full-Simulation

Thank you