Progress on the IDEA vertex detector implementation in Key4hep full simulation

Joint Software & Computing and Detector Concepts Meeting

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FUTURE CIRCULAR COLLIDER

IDEA vertex detector: Layout

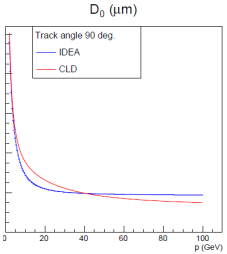
Refer to F. Palla's slides just before for full layout details

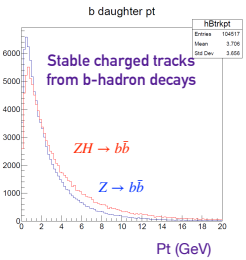
Vertex inner barrel

- Small beam pipe of 10 mm inner radius
- Three barrel layers to cover down to $\theta = 140$ mrad
- Consisting of staves of dual ARCADIA DMAPS, with pixels of $25 \times 25\,\mu\text{m}^2$ ($\sim 3\,\mu$m single point resolution)

Outer Vertex

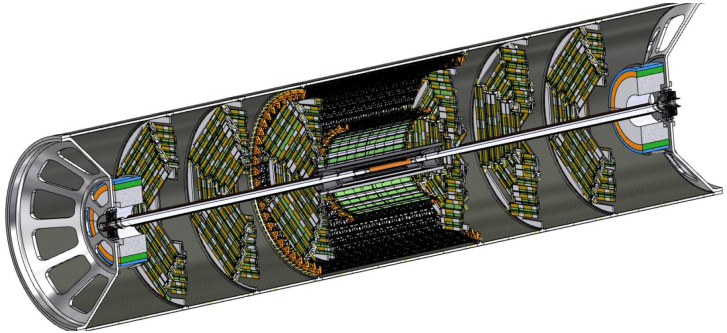
- Quad ATLASPix3 DMAPS with $150 \times 50\,\mu\text{m}^2$ pixels
- **Vertex outer barrel**
  - Intermediate layer at $r = 13$ cm, outer layer at $r = 31.5$ cm
- **Vertex disks**
  - Three disks per side
  - Disks of 8 petals with 4-6 staves going from small to large r

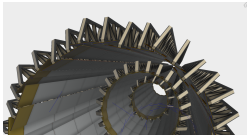




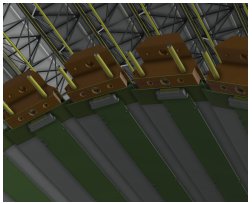
D_0 resolution in IDEA and CLD and p_T of b hadron tracks

IDEA vertex detector: Design

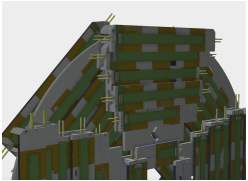




Vertex inner barrel



Vertex outer barrel



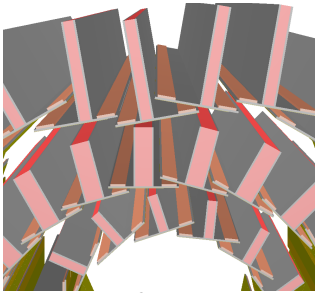
Vertex disks

- Vertex detector by F. Palla and F. Bosi (INFN- Pisa)
- Support tube done by F. Fransesini and M. Boscolo (INFN-LNF), see here. Holding:
  - Luminosity calorimeter
  - Vertex detector
  - Beam pipe ($R_{\text{inner}} = 1\,\text{cm}$)
- Rather advanced design, let's implement this in Key4hep full simulation!

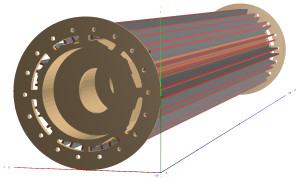
Today's talk

Today I will discuss the updates since FCC week.
Current status is documented in MDI note (not yet public), will also go into/be referenced in IDEA note.
PR in k4geo

Vertex inner barrel



Open



With vertex support

New constructor for vertex barrels

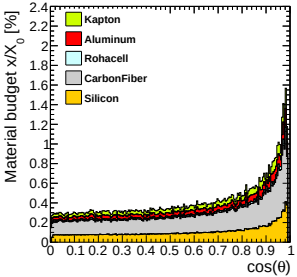
- Added proxy for lightweight truss structure consisting of Rohacell and carbon fiber (66% average density)
- DDCAD [1] to import conical vertex support

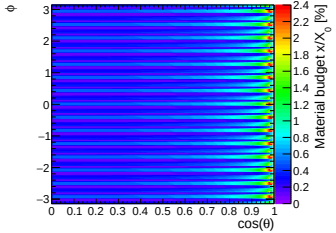
→ Overlap check is working and material budget evaluation with g4MaterialScan is okay, but not with k4SimGeant4 (so not included in material budget plots, but only relevant in very forward region)

Todo: Add end-of-stave structures and small layer of glue

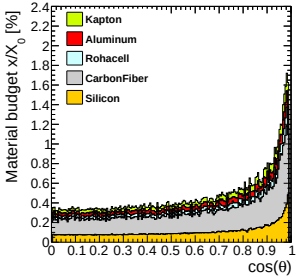
Material budget estimation: Vertex Inner Barrel per layer

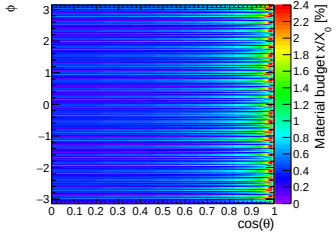
Layer 1



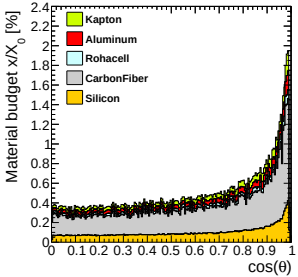


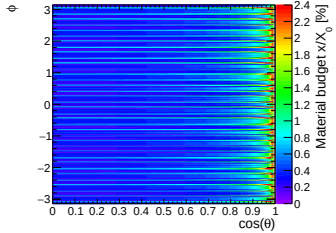
Layer 2



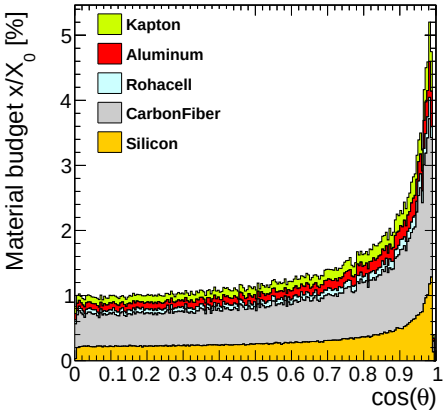


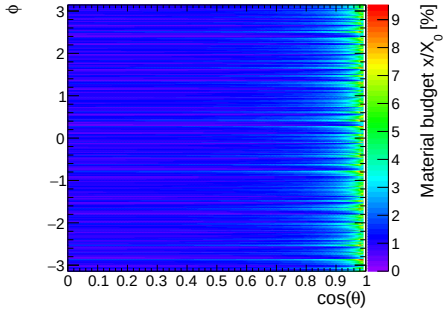
Layer 3





Material budget estimation: Vertex Inner Barrel





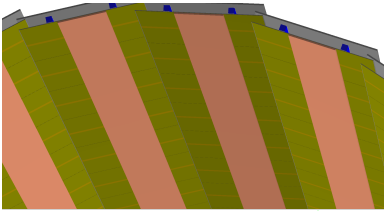
First material budget calculation (spreadsheet, F. Palla and F. Bosi) showed $\sim 0.25\% X/X_0$ per layer, so 0.75% for the whole vertex inner barrel at $cos(\theta) = 0$, not taking into account overlap between staves. Adding overlap adds a factor of $\sim 1.43 \rightarrow$ More in line with material budget simulation

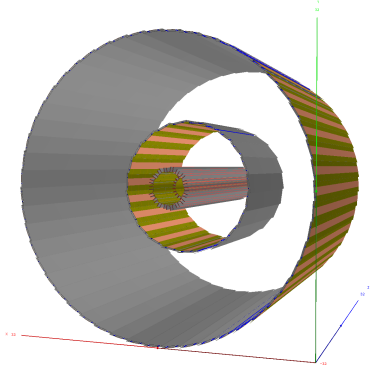
Vertex outer barrel

Same detector construction code as inner barrel

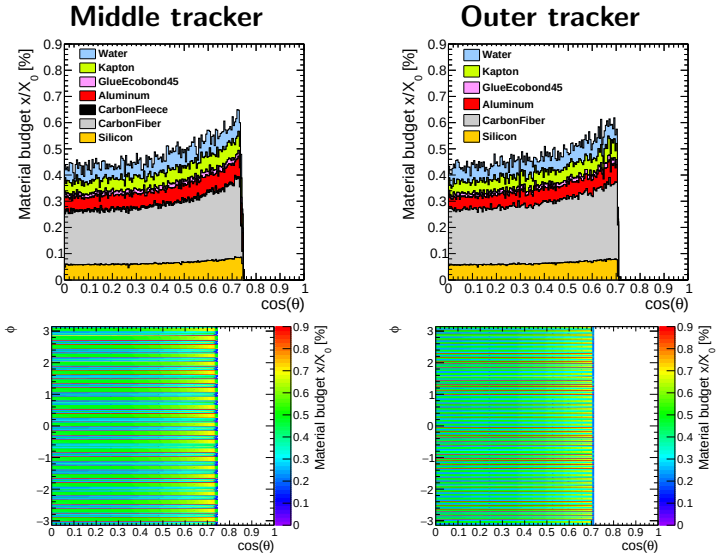
- ~~Simplified ATLASPix3 periphery (only implemented in $r - \phi$)~~ Actual ATLASPix3 geometry with four sensitive pieces and peripheries
- Added rectangular proxy for cooling pipe and water inside (see blue block in picture)
- Added proxy for truss structure (see box at larger r in picture)

Todo: Add missing parts of the cold plate and the hybrid circuit at the end of the staves ($\sim 1/3$ material budget increase)



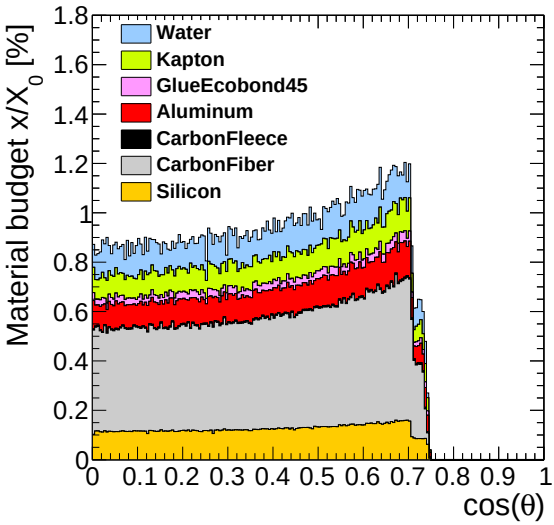


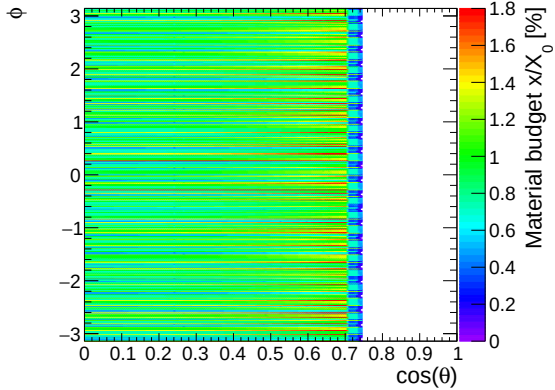
Material budget estimation: Vertex Outer Barrel per layer



Material budget from spreadsheet calculation (F. Palla, F. Bosi, corrected water X_0) is 0.8% for middle and 0.57% for outer layer at $cos(\theta) = 0$

Material budget estimation: Vertex Outer Barrel

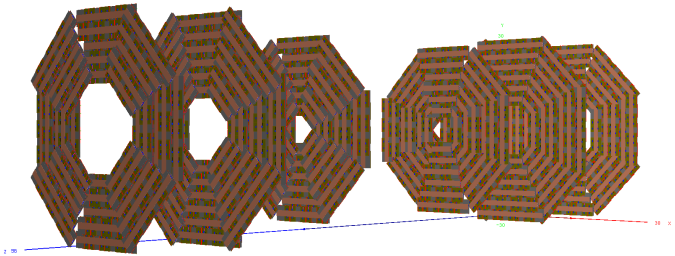


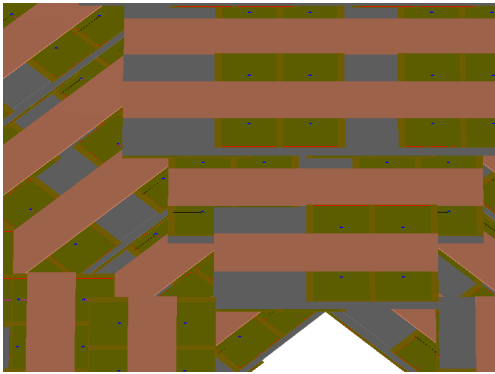


Vertex disks

- Added cooling pipes (same way as in vertex outer barrel)

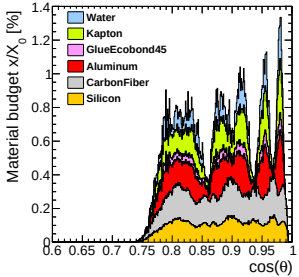
Todo: Non-stave supports (structure holding all staves in place), fix individual stave positioning in r

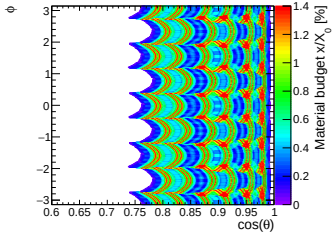




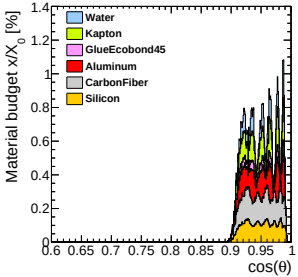
Material budget estimation: Vertex Disks per layer

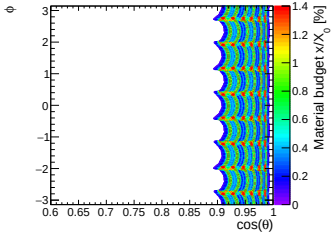
Layer 1



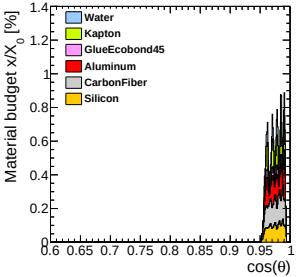


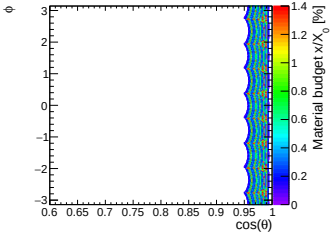
Layer 2



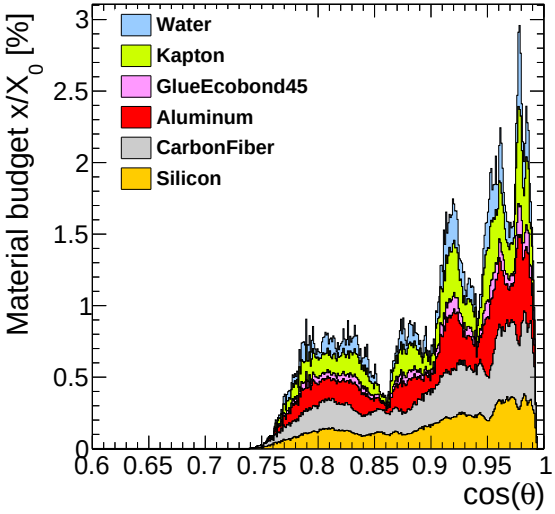


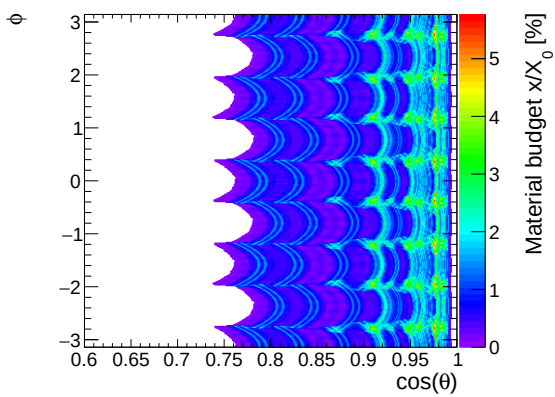
Layer 3





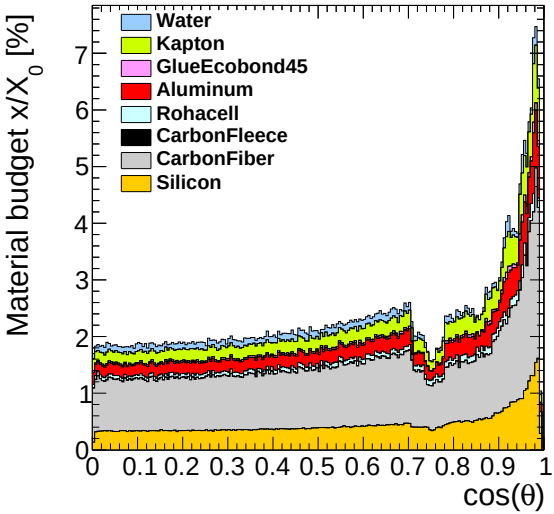
Material budget estimation: Vertex Disks



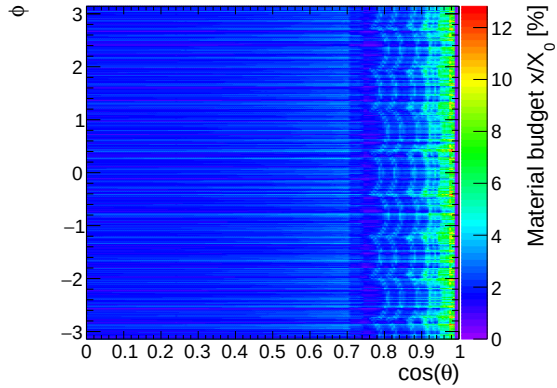


For vertex disks, no estimation of the material budget has been done before

Material budget estimation: Total vertex detector

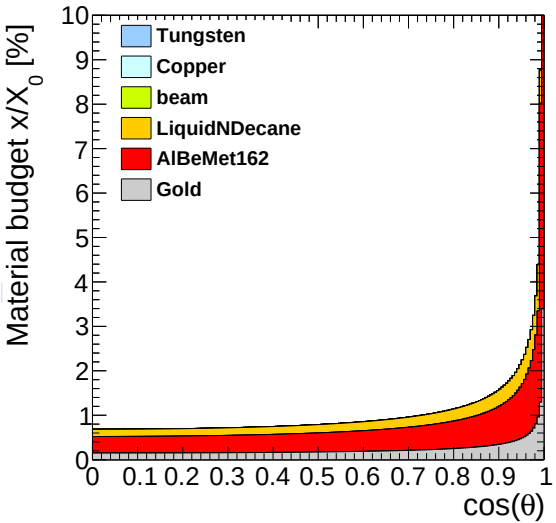


in $cos(\theta)$ vs. ϕ



Beam pipe

Took CLD beam pipe (low radius, but added paraffin):
Beampipe_o4_v04_noNotch_W_n02_smallBP.xml



Summary

- First simulation of realistic vertex detector for FCC-ee, with cooling pipes, flexes, various layers of support, overlapping staves, etc.
- Vertex inner barrel is described in most detail, $X/X_0 \sim$ matching expectation from spreadsheet calculation
- Material budget quite irregular in ϕ, due to overlapping staves in barrels and petal geometry in disks $\rightarrow$ Will be extremely interesting to see impact on case studies!

Next steps:

- Fix positioning of individual staves in disks, add missing detector elements or add proxies for them
- Off-detector cabling (not designed yet)
- Add digitisation inside Key4hep (started last week)
- Implement silicon wrapper, aim to have complete IDEA in DD4hep
- Accurate description of angular coverage, #hits in vertex: Are there cracks in the coverage?

Thanks and have a nice summer!

References I

[1] M. Frank, F. Gaede, M. Petrič, and A. Sailer, *CAD support and new developments in DD4hep*, in *EPJ Web of Conferences*, p. , 03015, EDP Sciences. 2021.

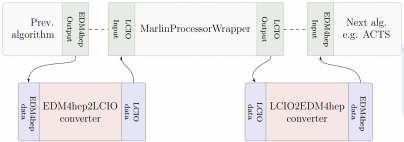
[2] N. Bacchetta, et al., *CLD – A Detector Concept for the FCC-ee*, arXiv:1911.12230 [physics.ins-det].

[3] FCC Collaboration, *FCC-ee: The Lepton Collider*, The European Physical Journal Special Topics **228** (2019) 261–623.

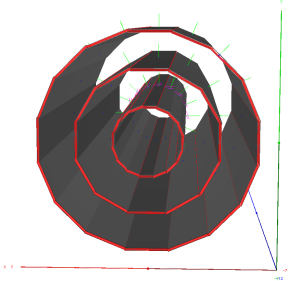
Existing (vertex) full simulation in CLD

Detector model in k4geo/FCCDetectors (smaller beam pipe)

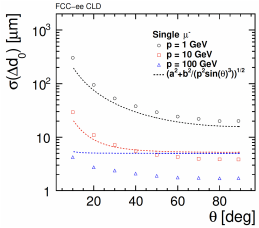
- Linear collider reconstruction (iLCSoft/CLICPerformance)
- Can generate EDM4hep output using k4MarlinWrapper



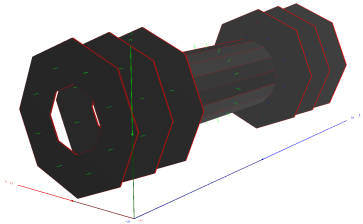
Access to all LC tools: PandoraPFA, LCFI+, etc.



CLD vertex barrel



D_0 resolution in CLD [2]



CLD endcap and vertex barrel

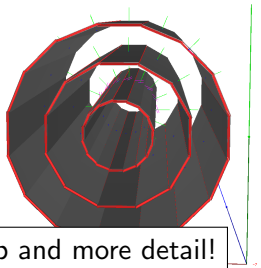
Existing (vertex) full simulation in CLD

Detector model in k4geo/FCCDetectors (smaller beam pipe)

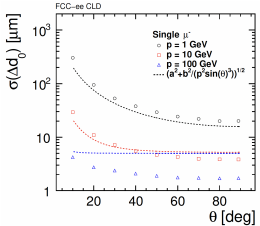
- Linear collider reconstruction (iLCSoft/CLICPerformance)
- Can generate EDM4hep output using k4MarlinWrapper

Access to all LC tools:

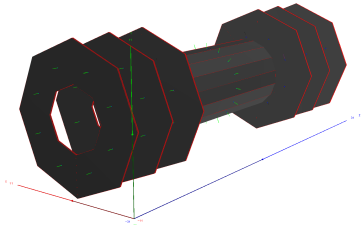
Want full simulation for IDEA, but using native Key4hep/DD4hep and more detail!



CLD vertex barrel



D_0 resolution in CLD [2]



CLD endcap and vertex barrel

Vertex detector module

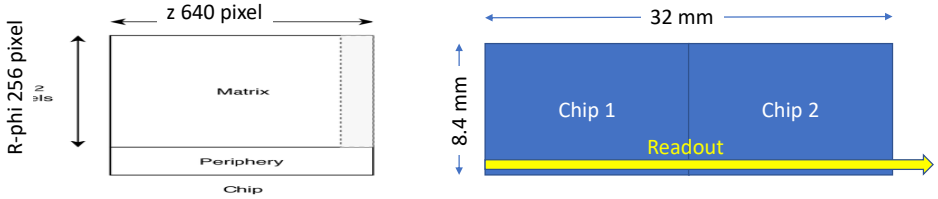
Istituto Nazionale di Fisica Nucleare

Module concept inspired by ARCADIA INFN R&D

- Depleted Monolithic Active Pixel Detectors (DMAPS) sensor and back-side processing already tested on silicon
- Pixel size 25x25 μm^2 , 50 µm thick
- Active area 640 pixel (16 mm) in z and 256 pixels (6.4 mm) in $r - \varphi$
- Chip periphery plus an inactive zone: total of 2 mm in $r - \varphi$
- Chips are side-abuttable in z

Composed of 2 pixelated parts: total of 8.4 mm $(r - \varphi)$ × 32 mm (z)

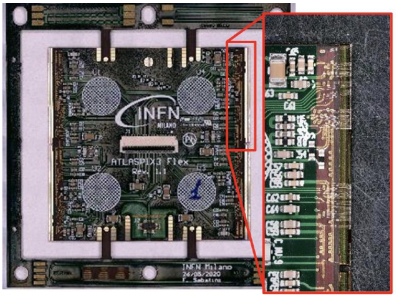
- Power budget not established yet: assume (reasonably) $50\ mW/cm^2$

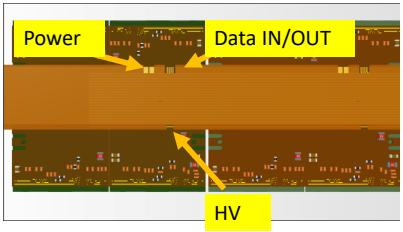


F. Palla , see talk at FCC US week at BNL

Outer tracker module

- Based on ATLASPIX3 R&D
  - DMAPS
  - 50 x 150 μm^2
  - Up to 1.28 Gb/s downlink
  - TSI 180 nm process
  - 132 columns of 372 pixels
  - Active (total) length (r-phi x z)
    - 18.6 (21) mm x 19.8 (20.2) mm
  - Module is made of 2x2 chips – total length:
    - size 42.2 mm x 40.6 mm
  - Power budget not established yet:
    assume $100\ \mathrm{mW/cm^2}$





F. Palla , see talk at FCC US week at BNL

IDEA vertex detector: First results in DD4hep (preliminary!)

Particle gun to shoot 10 GeV muons, $\theta = 10^\circ$

Get Key4hep stack (latest has issues currently):

```
source /cvmfs/sw.hsf.org/spackages6/Key4hep-stack/2022-12-14/
x86_64-centos7-gcc11.2.0-opt/zkjui/setup.sh
```

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

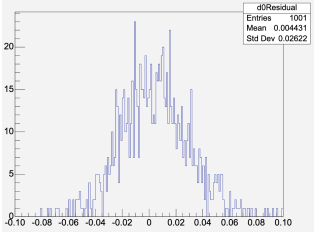
```
ddsim --compactFile k4geo/FCCee/compact/FCCee_IDEA_o01_v01.xml
--enableGun --gun.thetaMin 9.999 --gun.thetaMax 10.001
--gun.distribution uniform --gun.energy 10*GeV --gun.particle
mu- --steeringFile fcc_steer.py --numberOfEvents 1000
--outputFile ddsim_edm4hep.root
```

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

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

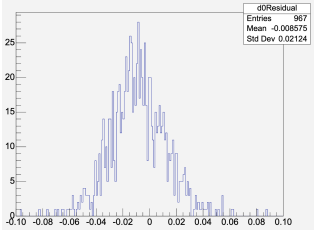
It runs! Performance to be assessed properly... (need IDEA drift chamber)

CLD full simulation



D_0 resolution in mm.

...inserting IDEA vertex

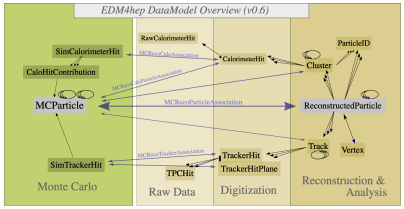


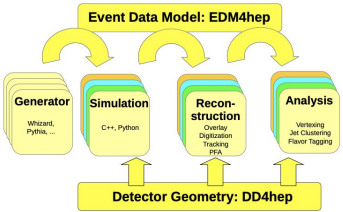
D_0 resolution in mm.

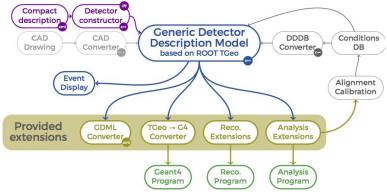
The common software vision: Key4hep

Key4hep is a huge ecosystem of software packages adopted by all future collider projects, complete workflow from generator to analysis, see also PE&D: Software and Computing / Detectors session

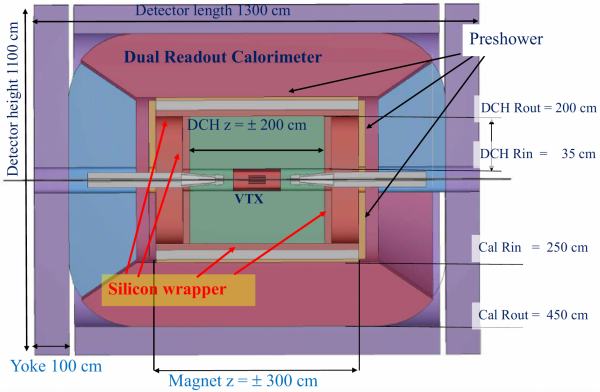
- Event data model: EDM4hep for exchange among framework components
  - Podio as underlying tool, for different collision environments
  - Including truth information
- Data processing framework: Gaudi
- Geometry description: DD4hep, ability to include CAD files
- Package manager: Spack: `source /cvmfs/sw.hsf.org/Key4hep/setup.sh`







IDEA: Innovative Det. for e^+e^- Accelerators



Schematic layout of the IDEA detector concept for FCC-ee [3]

Status of simulation: Full simulation in Geant4
Goal now: Full simulation in native Key4hep!

- Vertex detector adopting DMAPS (depleted monolithic active pixel sensor) to minimise material budget
- Tracker consisting of light-weight drift chamber ($\mathrm{d}N_{\mathrm{ionisation}}/\mathrm{d}x$) and silicon wrapper with timing information (time-of-flight)
- Dual-readout calorimeter with preshower
- Low-mass 2 T solenoid coil inside calorimeter system
- Muon system composed of μRWell in the return yoke

More: P. Azzi @ FCC US Workshop