Progress on the IDEA vertex detector implementation in Key4hep full simulation
FCC Week 2023, London

Armin Ilg
University of Zürich

06.06.2023

Thanks to all the people who helped/are helping on the way!
Goal of the FCC feasibility study

A lot of work to be done for the feasibility study...

For the experiments:

- Requirements to the accelerator? (backgrounds, space constraints, etc.)
- Expected performance? What can we do with the particles we get?
- What next-gen detector technologies can benefit the FCC-ee physics program? Different detector concepts?
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**Goal: Establish feedback-loop**

Sensor perf. $\rightarrow$ detector $\rightarrow$ Subdetector perf. $\rightarrow$ sample analysis $\rightarrow$ physics perf. $\rightarrow$ theory input $\rightarrow$ sensor specification

Need to perform simulation and analysis of *realistic* detectors at FCC-ee! $\rightarrow$ **Full simulation of complete detectors, using particle flow**

Our software toolkit should be...
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Our software toolkit should be...
- deploying new software and detector technologies, ease adaption by current experiments
- efficient and easy to learn, use and develop (people with limited time on future colliders)
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
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- Standalone full simulation of IDEA in Geant4 available

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```
source /cvmfs/sw.hsf.org/Key4hep/setup.sh
```

Goal now: Full simulation in Key4hep/DD4hep!
IDEA vertex detector: Layout

Refer to F. Palla’s slides 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 $25 \times 25 \mu m^2$ ($\sim 3 \mu m$ single point resolution)

**Vertex outer barrel and vertex disks**
- Quad ATLASPix3 DMAPS with $150 \times 50 \mu m^2$ 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 $r$
IDEA vertex detector: Design

- Vertex detector by F. Palla and F. Bosi (INFN- Pisa)
- Support tube done by F. Fransesini and M. Boscolo (INFN-LNF), see next talk by F. Fransesini. Holding:
  - Luminosity calorimeter
  - Vertex detector
  - Outer tracker
  - Beam pipe
- Rather advanced design, let's implement this in Key4hep full simulation!
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Where to start?
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 \([1]\)
Existing (vertex) full simulation in CLD

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Access to all LC tools:

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

CLD vertex barrel

CLD endcap and vertex barrel

$D_0$ resolution in CLD [1]
IDEA vertex detector in DD4hep
Adapted **CLIC vertex barrel constructor** to enable...

- individual sensors along stave, can have insensitive area in $r - \phi$ or $z$
- ARCADIA duals implemented as 6.4 mm active + 2 mm periphery $(r - \phi) \times 32$ mm ($z$), with 0.2 mm distance between sensors in $z$
- multiple layers of support and include readout
- Support e.g consists of 20 $\mu$m of carbon fleece, 120 $\mu$m of carbon fiber and 25 $\mu$m of paper graphite
- Use DDCAD [2] to import conical vertex support
- Don’t get correct $X/X_0$ yet, overlap check fails (investigating...)

Todo: Add stave holder and end-of-stave structures
Vertex outer barrel

Same detector construction code as inner barrel

- Correct readout flex and stave support material stacks
- Simplified ATLASPix3 periphery (only implemented in $r - \phi$)
- Missing cooling pipes
- Missing lightweight reticular support structure

→ Import using DDCAD or adding simplified support
Vertex disks

Most complicated system to implement in DD4hep, based on CLIC vertex endcaps

Building the disks:
- Build quad sensors out of four sensitive and many insensitive rectangles
- Place quads along stave support structure, add readout
- Place staves with correct number of sensors to build a petal
- Place all petals to form a disk, repeat for all disks
  → Correct orientation and arrangement of all staves/petals

Still missing:
- Non-stave supports and cooling pipes
Sensitive surfaces in IDEA vertex implementation in DD4hep
Complete geometry in IDEA vertex implementation in DD4hep
Vertex detector: Overall system

Complete geometry in IDEA vertex implementation in DD4hep

Missing parts:
- Complex support structures and cooling (use DDCAD or simplified shape with equivalent material budget)
- Off-detector cabling (not designed yet)
Vertex detector: Overall system

Complete geometry in IDEA vertex implementation in DD4hep

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Such a detailed geometry description enables...
- Accurate material budget distribution in both $\theta$ and $\phi$
- Accurate description of angular coverage, #hits in vertex: Are there cracks in the coverage?

Pull request in k4geo
First look at performance...
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)

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**CLD full simulation**

**D**0 resolution in mm.

...inserting IDEA vertex

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Armin Ilg (UZH)

IDEA Vertex FullSim using Key4hep

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

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Preliminary (!) material budget estimation

Preliminary (!) estimation of the material budget of IDEA vertex in DD4hep

- Best-described detector: Vertex inner barrel
  → F. Palla’s slides: $3 \times 0.25\% \frac{X}{X_0}$ for complete vertex → Roughly agreeing

- Vertex outer barrel clearly underestimated, expect truss support structure and cooling to have largest $\frac{X}{X_0}$ contribution

Todo:

- Add missing components or appropriate placeholder
- Remake plot in $\theta$ and $\cos(\theta)$, compare with standalone Geant4 description and CLD
Summary

**Done**
- First implementation of the IDEA vertex detector in DD4hep → Can get vertex simHits for other studies
- Track+vertex reconstruction using iLCSoft with k4MarlinWrapper → It’s working!
- Preliminary material budget estimation

**Next steps**
- Complex services and support structures, reassess material budget
- Accurate sensor periphery description in barrels (done in disks already)
- Add digitisation inside Key4hep
- Implement silicon wrapper, aim to have complete IDEA description in DD4hep
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What else can we do?
Summary and outlook!

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R&D for better detectors

Should not close the eyes to new and unproven technologies.

→ Estimate possible performance gain of such new technologies using full simulation!

Example: DMAPS in 65 nm TPSCo process

- More logic per cm$^2$
- Lower power consumption
- Air cooling
- Enables 12" wafers
- → Wafer-scale bent sensors! See M. Mager's talk on Thursday!
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Material budget in ALICE ITS2 (left, [4]) and silicon only (M. Mager)

Layer assembly concept for ALICE ITS3 [3]

L. Freitag (BSc. thesis [5]) and A.I @ Krakow 2023

IDEA Delphes simulation

Particle gun muons

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Plan to do full simulation performance study of ALICE ITS3-like vertex detector for (parts of) the IDEA vertex detector

Layer 2
Layers 2+1
Layers 2+1+0

IDEA Delphes simulation

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Thanks!


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 $\mu$m$^2$, 50 $\mu$m thick
- Active area 640 pixel (16 mm) in $z$ and 256 pixels (6.4 mm) in $r-\phi$
- Chip periphery plus an inactive zone: total of 2 mm in $r-\phi$
- Chips are side-abuttable in $z$

**Composed of 2 pixelated parts: total of 8.4 mm $(r-\phi) \times 32$ mm (z)**

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

F. Palla, see talk at FCC US week at BNL
• Based on ATLASPIX3 R&D
  • DMAPS
  • 50 x 150 µm²
  • 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 mW/cm²