MECHANICAL INTEGRATION OF THE IDEA VERTEX DETECTOR IN THE FCC-EE INTERACTION REGION

Fabrizio Palla

Manuela Boscolo ², Filippo Bosi ¹, Francesco Fransesini ², Stefano Lauciani ²

¹INFN Sezione di Pisa, Italy
²INFN Laboratori Nazionali di Frascati (RM), Italy

FCC-Week
London, 5-9 June 2023
• Central tracking device:
  - light Drift CHamber

• **Silicon detectors for precision measurements**
  - vertex detector
  - silicon internal tracker
  - silicon wrapper

• Thin solenoid with 2T field (according to MDI limits)

• Dual readout calorimeter
  - supplemented by a pre-shower detector

• Muon chambers in the solenoid return yoke
Requirements

Interaction region detectors must be integrated with the beam pipe

- The vertex detector innermost radius should profit of the reduced beam pipe diameter (2 cm) and should cover $|\cos \theta| < 0.99$

- Must not interfere with the Luminosity Calorimeter (clearance of ~120 mrad)

- The mounting of the vertex and the outer tracker must be done inside the support tube

- Minimize the radiation lengths
Inner and outer vertex trackers

Inside the same volume of the support tube that holds also the LumiCal

- Inner vertex detector supported by the beam pipe
- Outer vertex detector (2 barrel and 6 disks) fixed to the support tube

Minimal number of detector module variants

- One module type only for the Vertex
- One module type only for the Outer barrel and disks

See talk by F. Francesini for the interaction region layout
**Inner Vertex detector:**

Modules of $25 \times 25 \, \mu m^2$ pixel size

- 3 barrel layers at - 13.7, 22.7 and 33 mm radius

**Outer vertex tracker:**

Modules of $50 \times 150 \, \mu m^2$ pixel size

- Intermediate barrel at 13 cm radius (improved reconstruction for $p_T > 40$ MeV tracks)
- Outer barrel at 31.5 cm radius
- 3 disks per side
Inner vertex detector modules

Based on ARCADIA INFN R&D

- Depleted Monolithic Active Pixel Detectors (DMAPS)
- Technology: LF11is 110 nm CMOS node, high-resistivity bulk
- Pixel size 25x25 µm², 50 µm 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 (to be demonstrated)

Modules composed of 2 sensors: total of 8.4 mm \((r - \phi) \times 32 \text{ mm} (z)\)

- Power budget: assume 50 mW/cm² - including power and readout buses


Breaking news from ARCADIA!

High rate capability (100 MHz/cm²) architecture on a scalable 512x512 pixel matrix (25µm pitch) MD3 Main Demonstrator chip: measured 30 mW/cm² at full-speed
Layer 1
15 overlapping staves of 6 modules each

Pinwheel geometry: all modules at the same (smallest) radius

Power budget ~12 W

Total weight ~22 grams

Total thickness 0.25% $X_0$

Silicon: 0.053% $X_0$

Power and readout bus: 0.056% $X_0$
Layer 2
24 overlapping staves of 10 modules each

Pinwheel geometry
Counter-rotated wrt layer 1 to mitigate charge-asymmetry effects in track reconstruction

Power budget
~32 W

Total weight ~63 grams

Total thickness 0.25% $X_0$
Layer 3
- 18 overlapping staves of double 16 modules each
- Lampshade geometry.
- Charge symmetric track reconstruction
- Total weight ~150 grams
- Total thickness 0.25% $X_0$
- Power budget
  ~77 W
Overall Inner Vertex layout

Total power ~120 W
Total weight ~230 grams
Air cooling studies have started!
Inner vertex detector supporting conical structures on elliptical chamber
~450 grams

Being engineered for air ducts and thermal isolation from the beam pipe during bakeout
Thermal simulation started

Start from a radial sector of layer 3 (relying on periodic symmetry) and import in ANSYS FEA. Then move to all other layers.

**FIRST STEPS**

- **Full model**
- **Extraction of a radial sector for layer 3**

**INFN Perugia**

G. Baldinelli, F. Bianchi, C. Turrioni

**Simplification of the solid domain**

**Definition of the fluid volume**
Outer vertex layers modules

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
Middle Vertex Barrel
At 13 cm radius

22 staves of 8 modules each.

Lightweight reticular support structure (ALICE/Belle-II like)

Readout chips either side

Power budget
~342 W

Total weight ~1 kg
Water cooled (2 pipes of 2 mm diameter)
Outer Vertex Tracker Barrel
At 31.5 cm radius

51 staves of 16 modules each

Lightweight reticular support structure (ALICE/Belle-II like)

Total weight ~3.7 kg
Readout chips either side

Power budget
~1400 W

Water cooled (2 pipes of 2 mm diameter)
Outer Vertex Tracker Disk 1

2 sides (front and back) each with 4 petals.

One petal is made of different staves of overlapping modules

Total modules per disk: 196
Total weight ~850 grams
Power budget ~ 336 W

Cooling using 1 water pipe (2 mm diameter)

Similar geometry for the other two disks
Overall layout and dimensions
Support cylinder

All elements in the interaction region (Vertex and LumiCal) are mounted rigidly on a support cylinder that guarantees mechanical stability and alignment

- Once the structure is assembled it is slided inside the rest of the detector
- Studies on-going where to anchor it (most likely to the Calorimeter)

See F. Fransesini talk
LumiCal integration

Currently under study the possibility to include LumiCal as a single object

The main modification consists into the creation of an annulus:
• 18 mm along z (a multiple of 3.5 mm W (1X0) + 1.0 mm gap for Si pads)
• 20 mm along the radius of the LumiCal
Assembly procedure – I

1) Outer vertx tracker, middle vertex tracker and disks 1 are installed as a rigid structure inside the support tube

2) Disks 2 and 3 are installed inside the support tube
Assembly procedure – II

3) LumiCal is installed in centered position, then beam pipe with inner vertex detector is inserted with a dedicated tool inside disks and outer vertex tracker, then fixed to both endcaps

4) LumiCal can be aligned in the correct position on the outgoing beams

5) Support tube can be closed
General integration

M. Boscolo, F. Palla, F. Francesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ+ Techn. and Instr.
Conclusions

A layout of the interaction region with LumiCal and vertex trackers of the IDEA detector has been engineered

- Feasibility studies of integration successfully done including mounting sequence
- Documented in (accepted for publication)
  - M. Boscolo, F. Palla, F. Fransesini, F. Bosi and S. Lauciani, Mechanical model for the FCC-ee MDI, EPJ+ Techn. and Instr.

Next/ongoing steps:
- Inner Vertex detector
  - Dimensioning the air-cooling system has started
  - Study thermal isolation from the beampipe bakeout in progress
  - Study the routing of the services (readout and power cables) in progress
- Outer Vertex Tracker
  - Study the routing of the services (readout and power cables, cooling manifolds) in progress
- Lumical
  - Engineering and assembly to be done

Engineering layout imported in the simulation (see next talk by A. Ilg)
Thank you for your attention.
Backup
Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

Fully Depleted Monolithic Active Pixel CMOS sensor technology platform allowing for:

- Active sensor thickness in the range 50 µm to 500 µm or more;
- Operation in full depletion with fast charge collection by drift, small collecting electrode for optimal signal-to-noise ratio;
- Scalable readout architecture with ultra-low power capability (O(10 mW/cm²));
- Compatibility with standard CMOS fabrication processes;
- Technology: LF11s 110nm CMOS node (quad-well, both PMOS and NMOS), high-resistivity bulk;
- Custom patterned backside, patented process developed in collaboration with LFoundry.

Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

- Sensor R&D and Technology, CMOS IP Design and Chip Integration, Data Acquisition and Characterisation
- 3 engineering runs with full-scale FD-DMAPS and sensor R&D (monolithic FD-strips and readout, fast sensors with gain layer)
- High rate capability (100 MHz/cm²) architecture on a scalable 512x512 pixel matrix (25um pitch) MD3 Main Demonstrator chip:
  - measured 30 mW/cm² at full-speed (16 data Tx active) and 10 mW/cm² on low-rate mode (1 data Tx active)

Cosmic ray data

Main Demonstrator MD3 Matrix: 1.28 x 1.28 cm²

ARCADIA INFN CSNS Call Project
Half-ladder layout – layer 1

Layer 1 ladders are placed at 13.7 mm radius
Half-ladder layout – layer 2

Layer 2 ladders are placed at 23.7 mm radius
Half ladder layout – layer 3

Layer 3 ladders are placed between 30.5 and 35.55 mm radius

Overlapping in \( r - \phi \): 2 parallel ladders separated by 500 µm - see engineering drawings later

Passive parts on the sides
Layer 1 stave detail

Reticular lightweight support to provide stiffness

- Thin carbon fiber walls interleaved with Rohacell
- 2 buses (data and power) 1.8 mm wide and 250 µm thick (50 µm Al, 200 µm kapton) per side

Sensors facing interaction point w/o any other material in front

Readout chips either sides

Air cooled
Vertex on the beam-pipe
Air cooling for Belle-II upgrade

Thin multi-CMOS-chip Silicon structures for Belle 2 upgrade
Thermo-mechanical demonstrator submitted to IZM by Valencia and Bonn, thermal simulations in IJCLab Paris
CF water-jet cut (by WatAJet Company)
OUTER TRACKER
MIDDLE TRACKER
Stave detail
DISK 2

Diagram of DISK 2 with technical specifications and part list.

- **Face A**: N.24 stave = 124 pixel detector
- **Face B**: N.24 stave = 124 pixel detector
- **Power dissipated by a single pixel detector** = 100 mW cm²
- **Surface** = 4.06x4.22 cm² = 17.13 cm²
- **Power dissipated by a single detector** = 1.713W
- **Power dissipated Face A** = 124 x 1.713 = 212.412 W
- **Power dissipated Face B** = 124 x 1.713 W = 212.412 W
- **Total Power dissipated** = 424.824 W

**Part List**

<table>
<thead>
<tr>
<th>ELEMENTO/QTA</th>
<th>NUMERO PARTE</th>
<th>DESCRIZIONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Assieme supporto modulo 5 disco 2</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
<td>Assieme supporto modulo 4 disco 2</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>Assieme supporto modulo 4 bis disco 2</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>Assieme supporto modulo 3 disco 2</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>Assieme supporto modulo 2 disco 2</td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Assieme supporto modulo 1 disco 2</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>Assieme disco completo 2_1</td>
</tr>
</tbody>
</table>

Instituto Nazionale di Fisica Nucleare - Sezione di Pisa
IDEA-Disk 2

Date: 03/01/2023
Disk 3:
- Face A = N.20 stave = 108 pixel detector
- Face B = N.20 stave = 108 pixel detector
- Power dissipated by a single pixel detector = 100 mW cm² / Surface 4.06x4.22 cm² = 17.13 cm²
- Power dissipated by a single detector = 1.73 W
- Power dissipated Face A = 108x1.713 = 185 W
- Power dissipated Face B = 108 x 1.713 W = 185 W
- Total Power dissipated = 370 W

<table>
<thead>
<tr>
<th>ELEMENTO</th>
<th>QTA</th>
<th>NUMERO PARTE</th>
<th>DESCRIZIONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Assieme supporto modulo 4 bis disco 3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Layout disco 3</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>Assieme supporto modulo 5 disco 3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Assieme supporto cpl/plate disco 1 modulo 3 recente</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>Assieme supporto cpl/plate disco 3 modulo 3 update</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>8</td>
<td>Assieme supporto modulo 3 disco 3</td>
<td></td>
</tr>
</tbody>
</table>

Istituto Nazionale di Fisica Nucleare- Sezione di Pisa
IDEA-Disk 3

Editore 1 / 1
Typical disk module stave

- Electrical bus
- Cooling pipes
- Carbon fibre spacers
- Upper modules
- Lower modules
- Front
- Back
- Carbon fibre spacers
Effective Moliere radius of W-Si sandwich: ~15 mm
Stay 1 Moliere radius away from both inner radius and somewhat more at outer radius
  - To be optimised

Wide acceptance: 62 – 88 mrad
Slightly smaller narrow acceptance: 64 – 86 mrad
  - Bhabha cross section: 14 nb
  - Compared to 30 nb multihadronic Z decays at peak

Geometrical tolerances for shift in acceptance of 10^{-4}:
  - Inner border: $\delta \Theta_{\text{min}} = \pm 1.3 \mu\text{rad}$; $\delta R_{\text{min}} = \pm 1.5 \mu\text{m}$
  - Outer border: $\delta \Theta_{\text{max}} = \pm 3.0 \mu\text{rad}$; $\delta R_{\text{max}} = \pm 3.3 \mu\text{m}$
  - Half distance between two calorimeters: $\delta Z = \pm 55 \mu\text{m}$
Design considerations:

- Need to control geometry to a precision of $O(1 \mu m)$
  - Keep geometry as simple as at all possible

Multilayer barrels where all layers have identical circular geometry

- 25 layer SiW sandwich
  - 3.5 mm W (1 $X_0$) + 1.0 mm gap for Si pads

- Physical dimensions
  - Sensitive region: $r = 54$-$115$ mm
  - Region for "services": $115$-$145$ mm
  - Calorimeter face at $x = 1074$ mm

- Proposed segmentation
  - 32x32 pads/layer (1.9 x 10-22 mm² pads)
  - 25,600 channels per LumiCal

- Weight
  - About 65 kg per LumiCal