Towards a vertex detector for FCCee:

Expression of Interest Status

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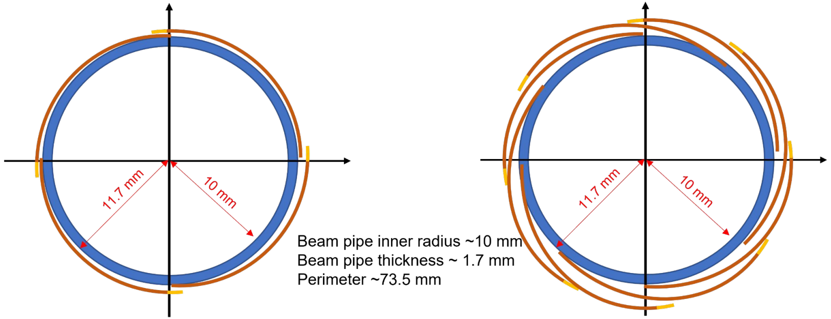
Introduction

- Discussion started in July 2024
    - (L. Vacavant, G. Bernardi, labs APC, IP2I, CPPM, IPHC, LPNHE, IRFU)
    - request: write a french EoI for a vertex detector at FCCee
        - 3 authors: Jeremy Andrea, Auguste Besson, Gaelle Boudoul
        - Supporting document has been written, prior to write the EoI,
    - Next steps to be defined (author list, extend/improve the document, diffusion outside France, etc.),
    - Target : ESPPU contribution.

- Content
    - Propose a global concept from the sensor design to the detector geometry,
    - List the challenges and the necessary R&D.

Key concepts



- Robust but ambitious vertex detector concept.
- New asynchronous sensor read-out architecture.
- Collected charge encoding on few bits + charge sharing => spatial resolution.
- Geometry based on bent sensor with full azimuthal acceptance.
- Simulation program to assess the concept and developped tools.

- Three “work packages” identified :
  - New sensor design, matching FCCee specifications,
  - Mechanics and integration (and cooling?): based on bent sensors,
  - Simulation: sensors responses, geometry, and software,

- Cover these aspects in a coherent way.

Vertex detector specifications

FCCee

$$\sigma_{d_0} = a \oplus \frac{b}{p \sin^{3/2}\theta}$$

$a \simeq 5\,\mu m; \quad b \simeq 15\,\mu m\,GeV$

$b \sim r_0 \sqrt{material}$

$a \sim \sqrt{r_0}$

- Data flux
  - Data flux significantly higher than ILC,
  - Higher radiations doses as well, for both ionising radiation and fluence.
- Beam pipe
  - Cooling mandatory as well as shielding,
  - Inner radius ~12 mm
- Strategy
  - Propose a robust but ambitious VTX concept,
  - Accounting for the chip design strategy, mechanics, cooling and integration altogether.
- Challenges
  - Lowest possible material budget,
  - Excellent spatial resolution (~3-5 microns),
  - Power: a key challenge,
  - Integration: working program dedicated to bend sensor,
  - Test and confirm choices with full simulations.

	thickness (mm)	Mat. Budget (X/X_0 %)
Beam pipe[1]		
Au	0.005	0.16%
AlBeMet162[2]	0.35	0.14%
Paraffin	1.0	0.18%
AlBeMet162[2]	0.35	0.14%
Total beam pipe	1.705	0.61%
Single layer		
Silicon sensor	0.050	0.05%
Cables, flex and support		$\simeq$ 0.10%
Material per layer		$\simeq$ 0.15%

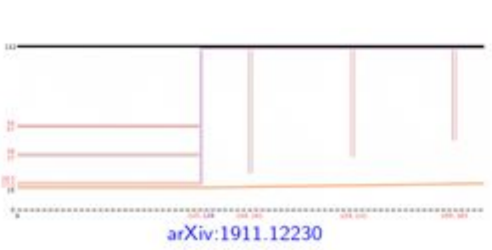
[1] described in [6]
[2] 62% Be and 38% Al alloy
[3] from [7]

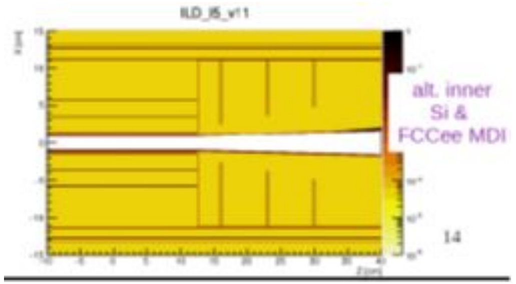
Spatial resolution per layer	$\simeq 3$	μm
Pixel pitch	14-20	μm [1]
read-out time	$\simeq 500$	ns [2]
Sensor thickness	$40 - 50$	μm [3]
Safety factor on particle rate	3	[4]
Maximum Hit rate	75 / 25	MHz/cm^2 [5]
Maximum Hit rate	22.5×10^{-3} / 7.5×10^{-3}	$hits/mm^2/BX$ [5]
Assumed cluster multiplicity	5	
Fired pixel rate	375 / 125	MHz/cm^2 [5]
Fired pixel rate	0.33 / 0.11	$fired\ pixels/mm^2/BX$ [5]
Occupancy/pixel/read-out	3.45×10^{-3} / 1.15×10^{-3}	$/pixel/readout$ [5]
Ionising radiation (1^{st} layer)	30 / 10	$MRad/year$ [5 6]
Corresponding Fluence	$\simeq 1.8 \times 10^{14}$ / 6×10^{13}	$n_{eq(1\ MeV)}/year$ [5 7]

[1] Depending on charge sharing/encoding
[2] Compromise between power dissipation and pile-up at $\sqrt{s} = 91\ GeV$
[3] To allow bending
[4] due to beam background uncertainties estimates
[5] With / without safety factor
[6] assuming beam running 180 days/year, and average incident angle of $\simeq 70^o$.
[7] assuming NIEL factor of 5×10^{-2}

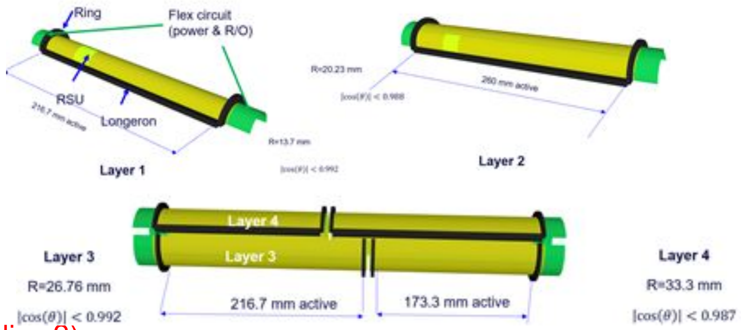
Possible design concepts

- À la CLD/ILD:
  - 3 double ladders + discs
  - Layer 1: $|z_{max}|$ ~ 12cm
  - R_{in} ~12 mm
  - Robust but not optimized for material budget

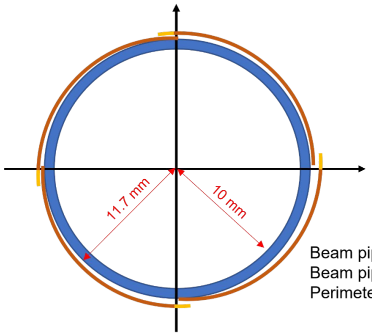




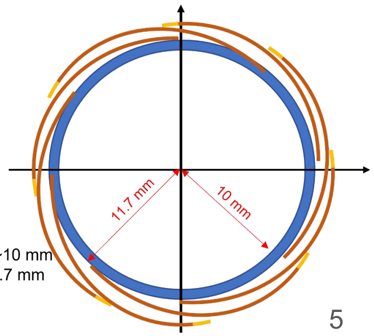
- À la ALICE ITS-3
  - 3/4 layers with stitched half cylinders
  - Fill factor not 100% per layer
  - Stitching mandatory
    - Pitch ? Power ? Yield ? Fill factor ? Bent radius ?
  - Very competitive for mat. budget but limitations (acceptance, resolution, radius ?)



- Concept Schnecke
  - Stitching or not stitching
  - Radius approaching constant value
  - Full acceptance in φ/ z
  - Double sided can be considered.
  - Number of layers = free parameter
  - Competitive for mat. Budget. AND full acceptance



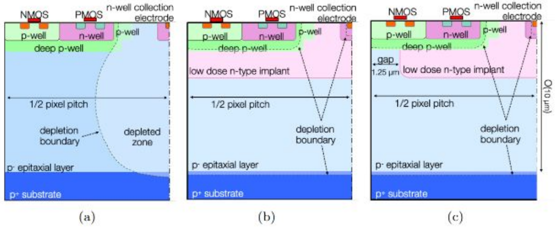
Beam pipe inner radius ~10 mm
Beam pipe thickness ~ 1.7 mm
Perimeter ~73.5 mm

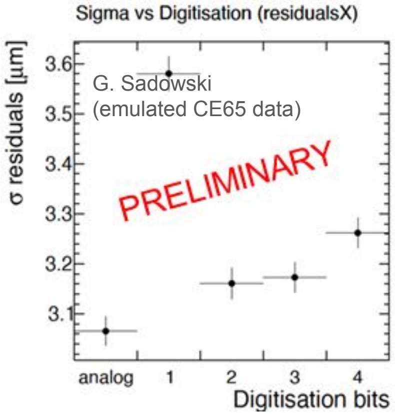


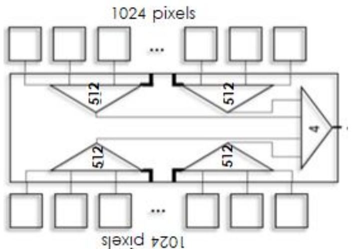
CMOS sensor: read-out architecture and charge collection

- Resolution challenge
  - Spatial resolution = 3 µm => pitch ~15 µm
  - Implementing an adapted read-out architecture (power, time) => pitch ~ 20-25 µm
  - Idea: decouple the relationship pitch - resolution with charge sharing AND charge encoding (few bits ADC)
    - Optimization of the sensing volume

- Read-out architecture challenge
  - Cope with the data flux while keeping Power < 50 mW/cm^2
  - Proposal: asynchronous read-out developed @ IPHC (C4PI)







Geometry: guarantee standalone tracking capabilities

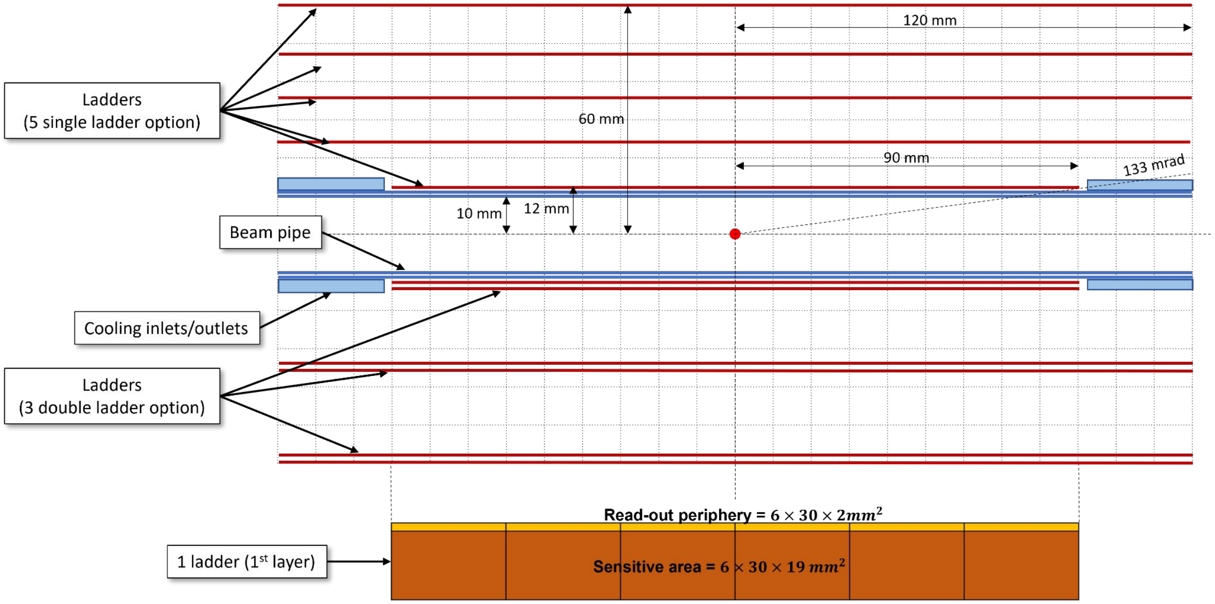


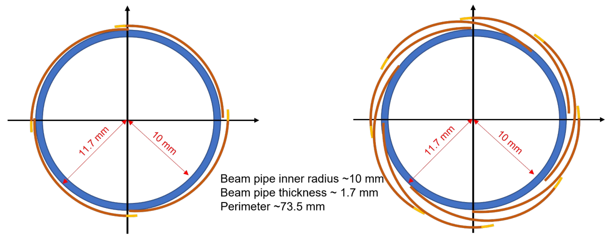
Table 3: Barrel dimensions (single and double sided option)

Layer	1	2	3	4	5
Radius (mm)	12-13	24	36	48	60
Zmax (mm)	90	120	120	120	120
Perimeter (mm)	75	151	226	302	377
# Chips per ladder	6	8	8	8	8
# ladders	4	8	12	16	20

Layer	1-2	3-4	5-6
Radius (mm)	12-13	35-36	59-60
Zmax (mm)	90	120	120
Max perimeter (mm)	82	226	377
# Chips per ladder	6	8	8
# ladders	4	12	20

Single chip dimension	$30 \times 22.2\ mm^2$
Sensitive area chip dimension	$30 \times 19.2\ mm^2$

Fig. 1: Central chamber in AlBeMet162 including cooling inlets and outlets, made in copper.



Mechanics, Integration and Cooling

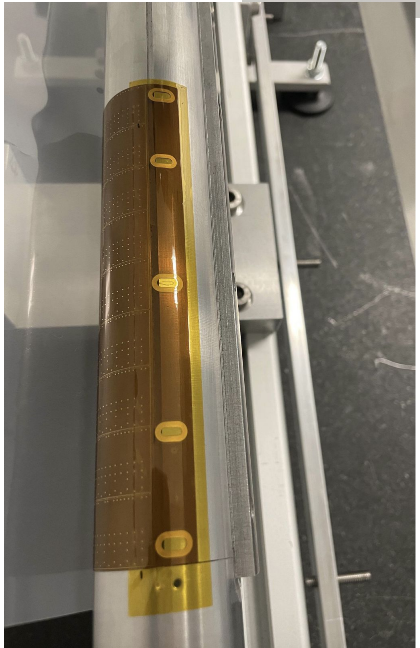
- Mechanics designed around curved sensors for the internal layers.

- Several challenges related to end sensor:
  - Thinning of sensors to few tenths of microns,
  - Perform mechanical curvature in a controlled way, using mandrill,
  - Integration aspects : connectivity, wire bonding, design of flex,
  - Design of mechanical structure, ease sensor installation and connections, light and good thermal properties.

- Pioneer work from Alice ITS3,
    - IPHC involved in super-Alpide,
    - Transfer of expertise and know-how, excellent basis for future developments.

Alice Super-Alpide Mock-up (Bari)

Bending setup At IPHC



Mechanics, Integration and Cooling

- Project being setup : toward a demonstrator of Layer 1 for a vertex detector for FCCee.

- Step-by-step approach:
  a. Curved single functional Mimosis : tests different sensor width and bending radius, study mechanics and connectivity, measure sensor characteristics.
  b. Super-Mimosis : same approach as Super-Alpide. Bending of a long wafer slices, related integration and mechanics, measure sensor characteristics.
  c. Layer one demonstrator based on FCCee-specific sensors.

- Activity at the cross-road between sensor design, integration and mechanics.

- Project being setup, under discussion at IPHC. Would involved micro-technique (C4PI) and mechanics (STM).

Full simulation development

- Nearly all HEP results are relying on simulations: Detector design, analysis optimization, background estimation, etc.
  - But nevertheless an underserved area – good place to make an impact

- **Interest from IP2I/IPHC to develop tracker software within the standard framework (FCCSW) developed and used by the HEP community in general, and FCC in particular**
  - Generic software development (reconstruction independent of the subtleties of the geometry description)

- Fully integrated in VTX detector design activities of the EOI
  - And essential in designing this detector

- The proposed work includes
  - Simulation and the propagation of the charge deposited by a charged particle in the sensors
  - Implementation of a cluster algorithm.
    - In link with detectors R&Ds proposed in the previous section.
    - Models of the charge propagation within the sensors developed within in2p3 community sed as input of the FCCSW development.
  - Built a representation of our detector: geometry and materials
  - Integration into common software efforts managed by the software group of the current PED structure at CERN.
  - Eventually : Tracking and flavor tagging performance should be assessed

- Competences :
  - Several years of expertise as convener and coordinator in several CMS software areas, including tracker software development, within a collaborative framework
  - However, some additional competence in evolving software techniques and optimization should be acquired via available courses or exchange of expertise among french (or not) developers

Status of the document and next steps

- Draft available here:

https://seafile.unistra.fr/d/73d4a7fb2903403a9f59/

- Comments, additional contributions, and signing authors are very welcome
  - E.g. cooling, sensor design, mechanics, etc.

Schnecke: Project for a Vertex detector for FCCee; supporting document for a Letter of Intent/Expression of Interest

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Abstract

One presents here a Letter of Intent to develop the concept of a vertex detector adapted to FCCee, using the CMOS Pixel Sensor technology in order to offer the best compromise between performances, acceptance, robustness and realism. The concept assumes a MDI region described in [1].

Nomenclature

FCCee electron positron Future Circular Collider
VTX Vertex detector

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