ILD Vertex Detector for the LoI

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OUTLINE

- **Introductory remarks :**
  - *VXD requirements*
  - *R&D questions related to the LoI*
- **Status of sensor and system integration R&D ▷ ”state-of-the-art” detector :**
  - *achieved performances ⟼ ”s.o.t.a.” VXD*
  - *continuation of the R&D*
- **The issue of alignment**
- **Accounting for beam background in LoI studies**
- **Towards the LoI :**
  - *which VXD parameters to vary*
  - *sharing of tasks*
- **Summary**

Introductory Remarks on Requirements

- **Aim for several very ambitious (realistic ?) goals :**
  - ◇ *excellent impact parameter resolution*
  - ◇ *distinguish impacts from close tracks (inside jets)*
  - ◇ *reconstruct soft tracks*
  - ◇ *minimal m.s.* $\mapsto$ *pattern confusions,* Δ*p/p, part.flow, jet flavour (*e^- *vs* ν_e*), ...*

- **Constraints mainly driven by** σ_{ip} **= a** $\oplus$ **b/p·sin**$^{3/2}\theta$

  small a $\mapsto$ *high granularity (pixels) and small* R_{in}

  small b $\mapsto$ *small* R_{in} *(b* $\sim R_{in}$*),*

  reduced mat. budget (b $\sim (X/X_0)^{1/2}$*)* $\mapsto$ *low* P_{diss}

Accelerator	a (μm)	b ($\mu m \cdot GeV$)
LEP	25	70
SLD	8	33
LHC	12	70
RHIC-II	13	19
ILC	$<$ 5	$<$ 10

- **Accommodate running conditions (e.g. event pile-up, background from** $e^{\pm}_{BS}$**, photon gas ?, etc.)**
  - ◇ *occupancy* $\mapsto$ *high r.o. speed (or extreme granularity)* $\mapsto$ *power dissipation*
  - ◇ *irradiation* $\mapsto$ *radiation tolerant detectors*

- **Accommodate requirements from other sub-detectors :**
  - ◇ *ex : relatively low B for PFA optimisation* $\Rrightarrow$ *occupancy in VXD* $\nearrow$

- **Accommodate & optimise VXD design consistently with neighbouring sub-det. (SIT, FW/BW trackers)**

R&D questions related to the LoI

- **How realistic is the vertex detector description used for the LoI physics studies ?**
  - ◇ *how far are we from achieving the LoI detector performance ?*
  - ◇ *what could actually be achieved within 2–3 years with the accumulated R&D experience and outcome ?*
  - ◇ *could these achievements already suit the least demanding part of the detector, i.e. the 3 outer layers ?*
  - ◇ *what is still needed to also satisfy the requirements of the two inner layers ?*
  - ◇ *meanwhile, could we imagine a* SAFE / CONSERVATIVE *version of the vertex detector allowing to assess the needs for further R&D and to spot where it is most necessary ?*

- **Beyond the LoI :**
  - ◇ *why do we need several R&D lines in parallel ?*
  - ◇ *how are sensor technologies and architectures connected to integration issues and detector geometry ?*
  - ◇ *what is the advantage of pursuing the LoI studies with 2 different (but complementary) VXD concepts ?*

- **How to optimise the goals of further R&D ?**

R&D questions related to the LoI

- **R&D groups expect guidance from detector performance studies in order to know :**
  - *how far each R&D direction should be pursued*
  - *which compromise between conflicting R&D directions is best suited to ILC physics goals*

    $\Rrightarrow$ *where to put most effort ?*

- **Physics studies need** ABSOLUTELY **to account for dominant backgrounds !!!**

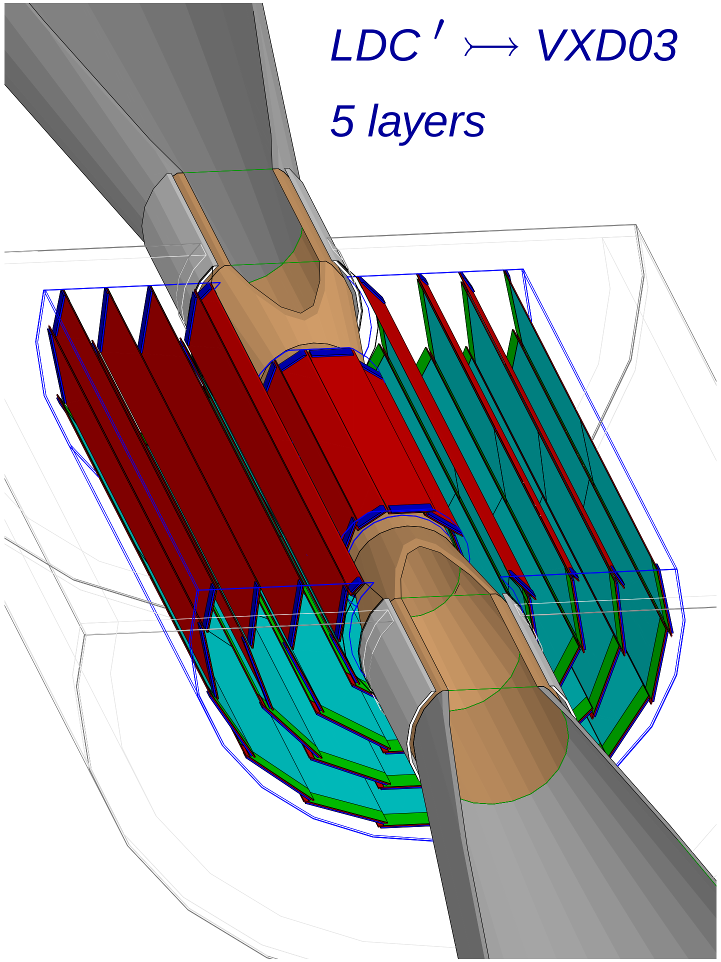
  (e.g. beamstrahlung $e^{\pm}$)

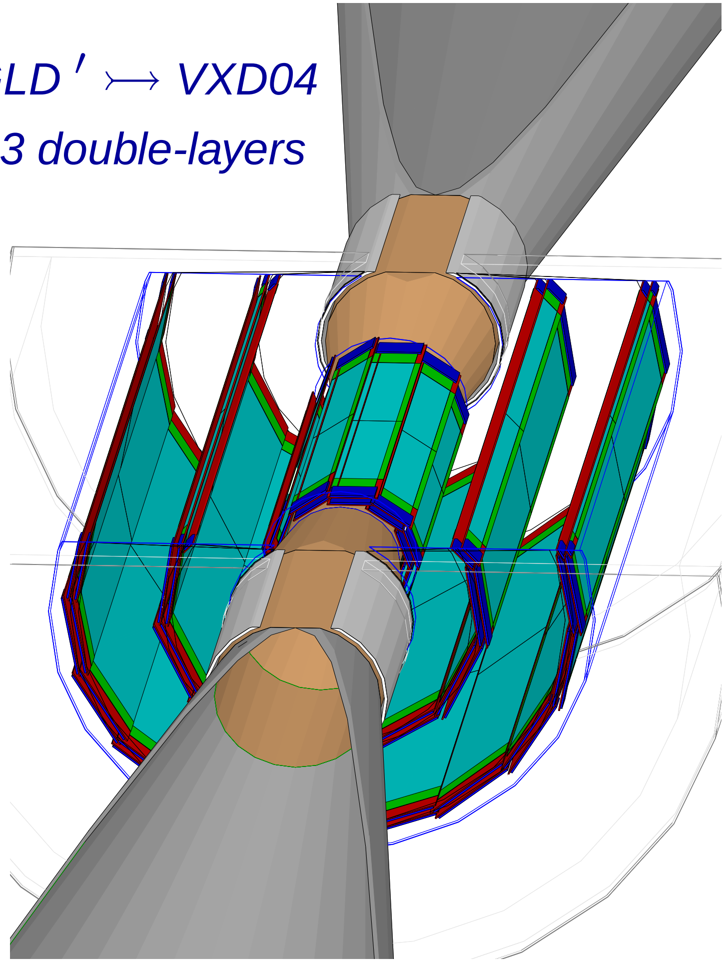
Current R&D Activities

- **Pixel sensors :**
  - ◇ *pixel technologies developed : CCD, CMOS sensors, DEPFETS, 3D-PS ($\supset$ SoI)*
  - ◇ *read-out architectures :* ≏ *continuous r.o. (during train) vs delayed r.o. (inbetween trains)*
    ≏ *various degrees of signal processing inside pixels (time stamping, discri., ...)*
  - ◇ *R&D goals : r.o. speed, power consumption (power cycling), radiation tolerance, EMI, material budget*
  - ◇ *CCD: UK (LCFI), Japan – DEPFET: Germany – CMOS: France, Italy, US ? – 3DPS: US, France, Italy*
- **Ladder design $\rightarrowtail$ mat. budget $\sim$ 0.1–0.2 % X_0 :**
  - ◇ *LCFI coll.: supports made of SiC foam*
  - ◇ *KEK: FPCCD sandwiching an RVC (+epoxy) support*
  - ◇ *DEPFET: monolithic Si slab incorporating sensors and mechanical support in a single piece*
  - ◇ *CMOS: extrapolate from STAR-HFT (0.3 % X_0)*
- **Global detector design $\rightarrowtail$ 2 approaches :**
  - ◇ *extrapolated from SLD vertex detector* ◇ *FNAL based studies (W.Cooper)*
  - ▷ ▷ ▷ *who cares about Be beam pipe near I.P.: 0.25 $\rightarrowtail$ 0.50 mm thickness ?*
- **Comprehensive reviews on http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=2564**
  (ILC Vertex Detector Workshop, Villa Vigoni, Menaggio, Italy, 21-24 April 2008)

Vertex Detectors Geometries Considered for the LoI

- **Maintain 2 alternative long-barrel approaches :**



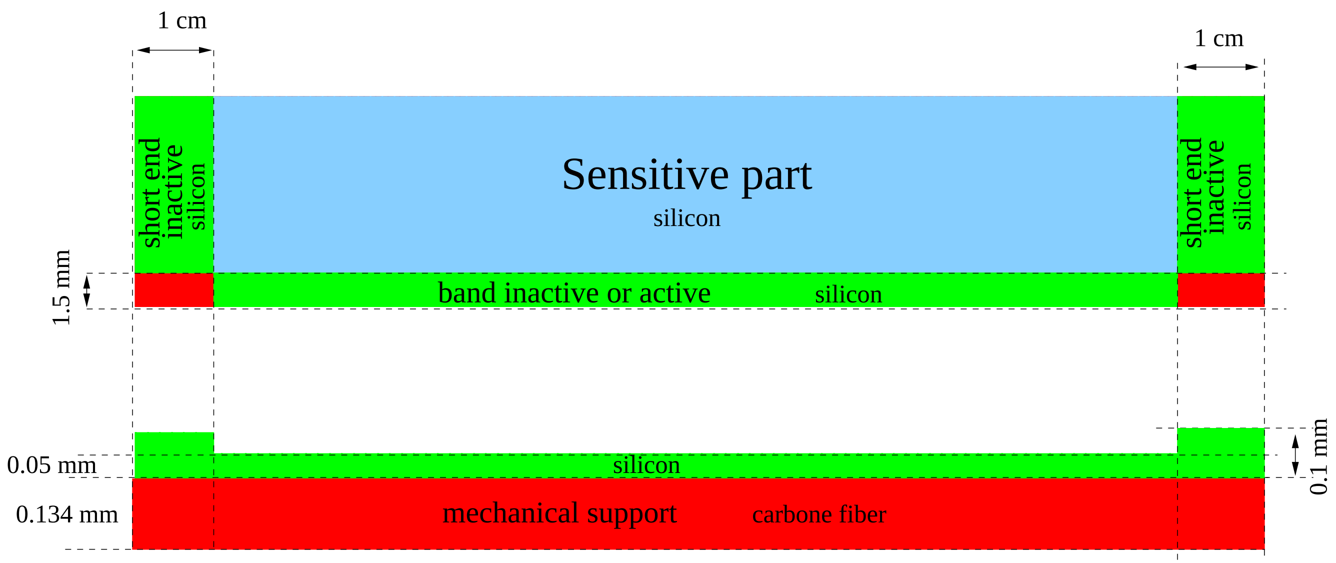


- **Two read-out modes considered :**
  - **continuous** *read-out*
  - *read-out* **delayed** *after bunch-train ⟼ 3 double layers expected to help*
    ⇛ mini-vectors

Ladder Geometry

- **Ladder geometry ⟼ accommodate simultaneously different sensor technologies :**
  - *Steering and r.o. electronics foreseen along the edges and at the ladder ends*
  - *Ladder material budget :* ⋇ *VXD03 : 0.11 %* X_0 ⋇ *VXD04 : 0.16 %* X_0

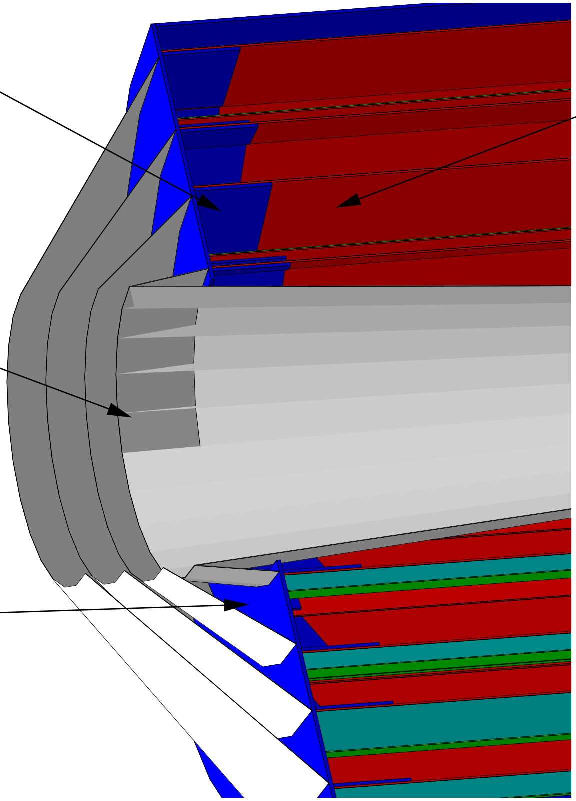
⇓

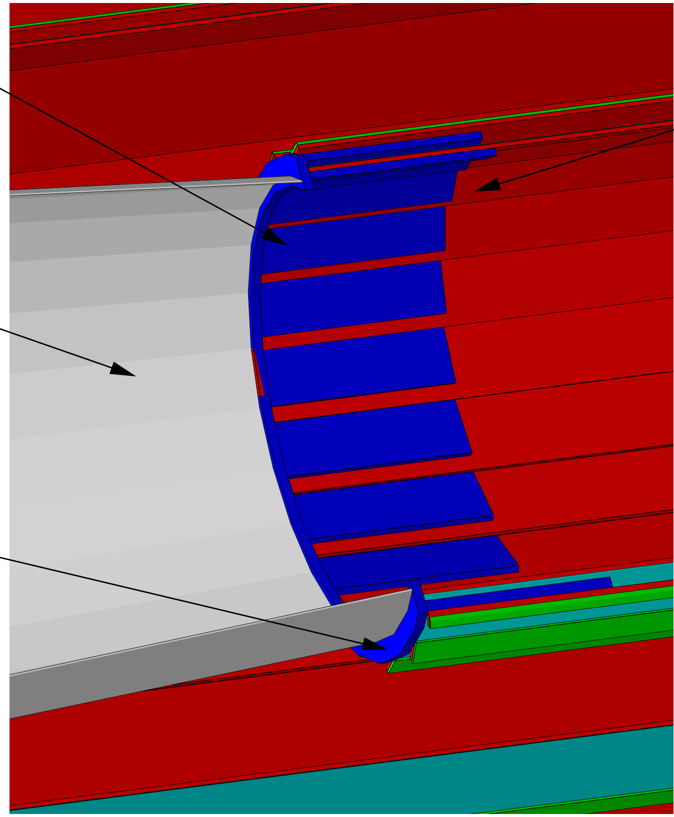


- **Will be studied extensively by VD groups working on diff. sensor technologies**

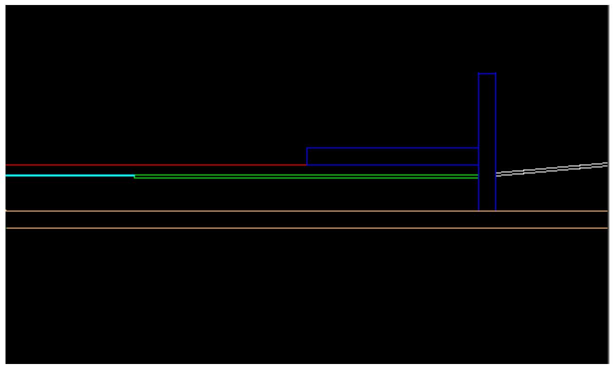
Ladder Support

- "Realistic" ladder fixture on "gasket" ⟶ combine with beam pipe geometry study

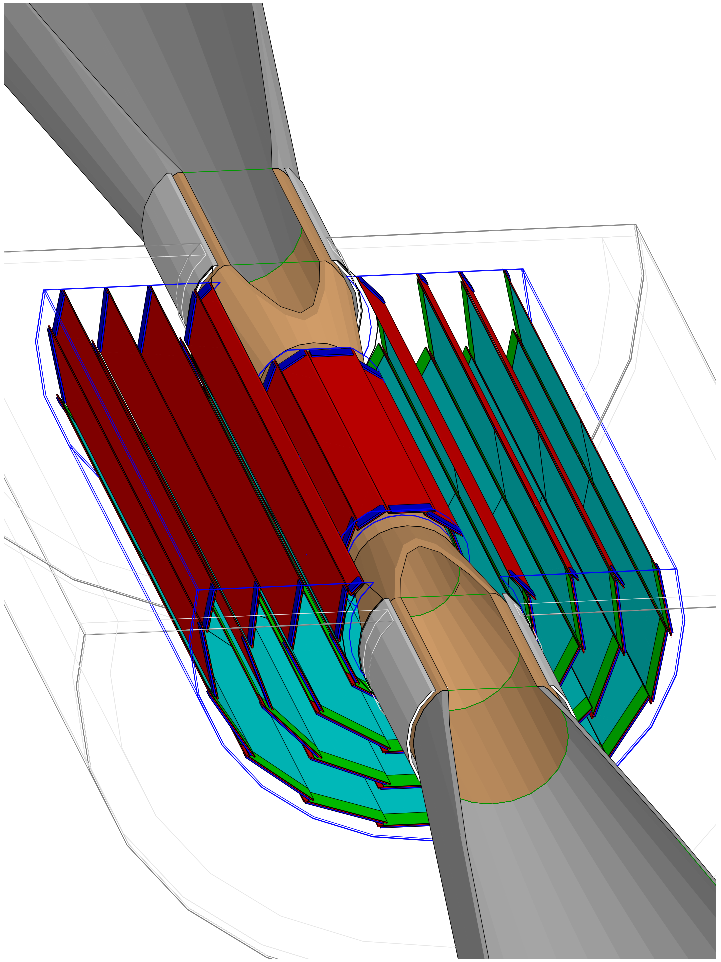




Ladder fixture ▷▷▷



- Vertex Detector parameters which seem achievable within short term, based on present R&D outcome :



- **Single point resolution : 3.5 μm** *(LoI : 2.8 μm)*
  - $\hookrightarrow$ $\mathbf{a} \sim 5 - 6\ \mu m$
    - $\triangleright$ *LoI :* $\mathbf{a} < 5\ \mu m$
- **Ladder material budget : 0.25 – 0.3 %** *(LoI : 0.1 %)*
  - $\hookrightarrow$ $\mathbf{b} \sim 10 - 12\ \mu m \cdot GeV$
    - $\triangleright$ *LoI :* $\mathbf{b} < 10\ \mu m \cdot GeV$
- **Read-out speed :**

Layer	L1	L2	L3 – L5
LoI (μs)	$\leq$ 50	$\leq$ 100	$\leq$ 200
State-of-the-art (μs)	60	120	240

- **Power dissipation :** *(LoI : $<<$ 100 W in average)*
  - *- instantaneous : $\sim$ 1 kW*
  - *- average (1/50 duty cycle) : $\sim$ 20 W*

$\triangleright\triangleright\triangleright$ **Most decisive LoI assumptions for the VXD seem reachable**

Motivation for further R&D

- **Pixel sensors :**
  - ◇ *improve on read-out speed (as much as possible ...) and radiation tolerance*

    ↪ *magnitude of simulated beam background is a challenge, but reality may still be worse ...* ⇛ *account for it !*
  - ◇ *pursue R&D on delayed read-out architecture to avoid reading out during trains (EMI, consumption ?)*
  - ◇ *explore emerging technology variants offering better performances:*
    - ≏ *the best we have today may not be sufficient to face the real beam background*
    - ≏ *better performing technologies will be beneficial for higher* $\sqrt{s}$ *(luminosity, double hit separation)*

- **Detector design :**
  - ◇ *pursue ladder design studies in order to approach a global material budget of* $\sim$ *0.1 %*
  - ◇ *pursue detector design in order to prove realism of LoI detector geometry*
  - ◇ *investigate double sided ladder geometry*
  - ◇ *investigate alternative design based on short barrel with disks at small angle*

    ⇛ *manpower missing on system integration aspects*

▷▷▷ **The continuation of the R&D needs to be guided by physics simulations**

The Issue of Alignment

- **The critical issue is the** INTERNAL **alignment**
  - ▷ *need to control ladder (& sensor) position within a few μm (LHC experiments manage $\sim$ 10 μm)*

- **Alignment requirements will probably impact the vertex detector design (material budget ?) :**
  - ◇ *rigidity of gasket and ladder support*
  - ◇ *necessity to implement position sensors ?*
  - ◇ *effect of air flow and power cycling (Lorentz forces ...) ▷ effort to minimise it ?*
  - ◇ *make active areas of neighbouring ladders overlap sufficiently*
  - ◇ *squeeze σ_{sp} ($\mathbf{a}$ and $\mathbf{b}$!) in order to "leave room" for additionnal missalignment uncertainty*

- **Impact on/from neighbouring tracking detectors ?**

- **Running at Z^0 peak mandatory ($\gtrsim$ 1 week/yr ?)**

▷▷▷ **System study not yet started**

Accounting for Beam Background

- **Critical issue : beamstrahlung $e^{\pm}$ hitting the 2 inner layers**
  - *GuineaPig, "standard" optics, 14 mrad Xing, anti-DID, R_{in} = 15 mm, 3.5 T, 15 μm thick sensitive vol.,*
  - *inner layer rate $\gtrsim$ 5 $e^{\pm}_{BS}/cm^2/BX \rightarrowtail \gtrsim$ 800 $e^{\pm}_{BS}/cm^2/50\ \mu s \rightarrowtail \gtrsim$ 2000 "seed" pix/cm^2/50 μs*
    $\Rrightarrow$ 25 μm pitch $\rightarrowtail \gtrsim$ 1 % occupancy ($\cong$ 100 kRad & 10^{11} $n_{eq}/cm^2/yr$)
  - *2nd layer background (R = 26 mm) only 6–8 times less than innermost layer*
  - *not accounted for :*
    - *cluster size (only seed pixels)*
    - *thicker sensitive volume (e.g. 50 μm)*
    - *MC uncertainties (safety factor)*
    - *other backgrounds (photons, photon coll., ...)*
    - *ϕ-dependence (if any ?)*

▷▷▷ **Physics studies ought to include beamstrahlung effects**

- *we need to know which occupancy is acceptable for (which ?) physics*
- *potential impact on VXD design (radius and read-out speed of inner layers, technology, ...)*
- *potential impact on neighbouring tracker design*

▷▷▷ **How should we proceed ?**

Aiming for the Optimal Detector Geometry (1/2)

- **Strategy : studies based on central production with baseline geometry**

  $\rightarrowtail$ *outcome will be used by VD groups for refined studies*

- **Basic VXD parameters to vary in order to evaluate impact on physics performance :**
  - *innermost layer radius : 14 mm* $\lesssim R_{in} \lesssim$ *20 mm*
  - *single point resolution :* $2\ \mu m \lesssim \sigma_{sp} \lesssim 3\ \mu m$
  - *ladder material budget :* $0.1\ \%\ X_0 \lesssim t \lesssim 0.2\ \%\ X_0$
  - *magnetic field strength :* $3\ T \leq B \leq 4\ T$

- **How to deal with the beam background vs VXD read-out frequency ?**
  - *depends on layer : 5* $\rightarrowtail$ *40 frames / train*
  - *depends on read-out architecture : continuous read-out vs delayed read-out*

Aiming for the Optimal Detector Geometry (2/2)

- **Several specific aspects of the VXD will be studied by vertex detector community :**
  - *optimal pixel pitch and read-out time for each layer*
  - *mini-vector efficiency for BG rejection (layer-pair geometry)*
  - *optimal number of ladders per layer, etc.*
  - *influence of electronics on ladder edge and ends (mat. budget)*
  - *consequence of low P optics : shorter innermost layer*
  - *influence of SIT : track matching $\rightarrowtail$ time stamping , low P reconstruction, ...*
  - *track matching (& time stamping) with fw/bw trackers $\rightarrowtail$ how long should the barrel be ?*
    - ▷ *for which fw/bw material budget does a geometry based on short barrel + end-cap disks start to be more attractive than long barrel ?*
  - *effect of Be beam pipe material budget (0.25 ... 0.50 mm thick)*

- **Work organisation ▷ Connecting VXD community studies with Global physics performance studies :**
  - *consider* $\mathbf{a}$ *and* $\mathbf{b}$ *in* σ_{ip} = $\mathbf{a} \oplus \mathbf{b}$/p·sin$^{3/2}\theta$ *as the reference indicators of the benefits or disadvantages of variants of the VXD geometries used in the central detector performance studies*
  - *input from central detector performance studies towards VXD groups :*
    - ≏ *values of* $\mathbf{a}$ *and* $\mathbf{b}$ *corresponding to nominal detector studies*
    - ≏ *correspondance between* $\sigma_{\mathbf{ip}}(\mathbf{a}, \mathbf{b})$ *and flavour tagging efficiency⋆purity*

SUMMARY

- **VXD geometry in LoI :**
  - *VXD geometry in MOKKA expected to be detailed enough for LoI*
  - *present R&D achievements support the realism of LoI VXD descriptions*
  - *guidance expected from detector performance group to orient next R&D steps*

- **Alignment :**
  - *internal alignment is a serious challenge : few μm precision required*
  - *may impact VXD requirements (σ_{sp}), geometry and operation (power cycling, cooling)*
  - *need substantial running time at Z^0 (how much ?)*

- **Organisation of VXD related studies for the LoI :**
  - *connection between detector performance group & VXD community could consist in evaluating impact of VXD variations on parameter $\mathbf{a}$ and $\mathbf{b}$ entering $\sigma_{\mathbf{ip}}$ (relation with efficiency⋆purity ?)*
  - *define sharing of VXD related studies between detector performance group & VXD community*

▷ ▷ ▷ **Studies ought to incorporate dominant beam background !**

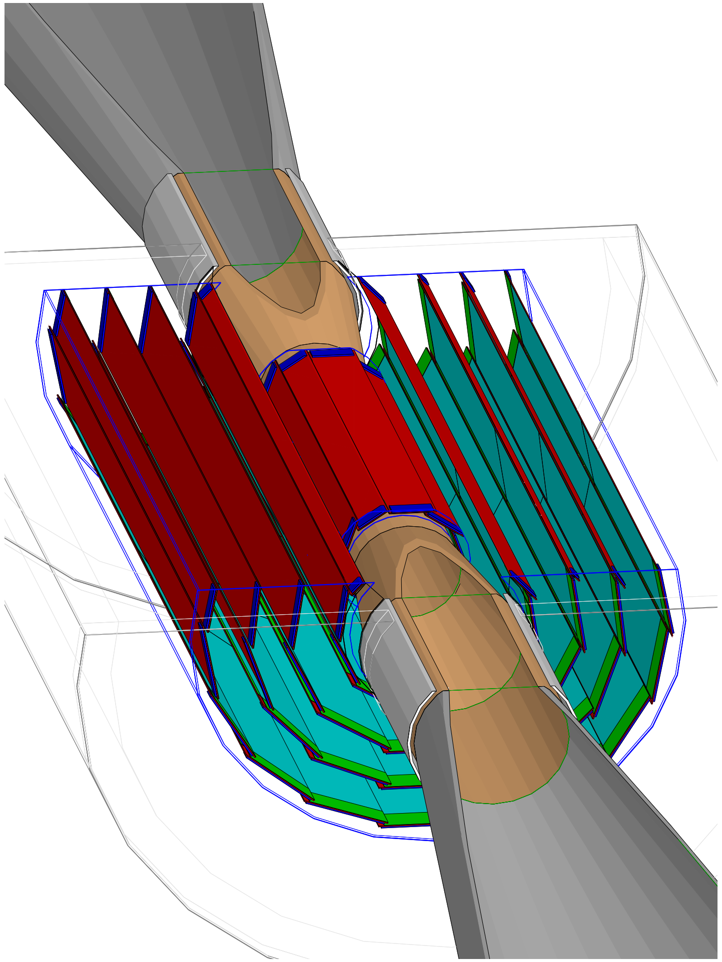
▷ ▷ ▷ *mailing list for discussions on ILD vertex detector:* **ild-subsystem-vtx@desy.de**
people interested may subscribe to the mailing list from https://lists.desy.de/sympa/info/ild-subsystem-vtx

BACK-UP SLIDES

5 Layer Geometry : VXD03

5 layers intercepting angles down to $||\cos\theta|| \simeq$ 0.97 :

- **Layer radii :** *15, 26, 37, 48, 60 mm*
- **Nb of ladders per layer :** *10 (in) / 11 / 12 / 16 / 20 (out)*
- **Ladder lengths :** *125 mm (inner), 250 mm (outer)*
- **Ladder support structure :** *carbon fiber (100 μm thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner : 11 mm - second : 15 mm - outer : 22 mm*
  - *- 50 μm thick silicon*
- **Electronics at ladder end :**
  - *- 10 mm long*
  - *- 100 μm thick silicon*
- **Insensitive ladder edge :**
  - *- 1.5 mm wide*
  - *- 50 μm thick silicon*
  - *- can be activated*



3 Layer-Pairs Geometry : VXD04

3 pairs of layers intercepting angles down to $\|\cos\theta\| \simeq$ 0.97 :

- **Double-layer radii (inner/outer) :** *16/18, 37/39, 58/60 mm*
- **Nb of ladders per layer :** *10 (in) / 12 / 20 (out)*
- **Ladder lengths :** *125 mm (inner), 250 mm (outer)*
- **Ladder support structure :** *carbon fiber (100 μm thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner : 11 mm - outer : 22 mm*
  - *- 50 μm thick silicon*
- **Electronics at ladder end :**
  - *- 10 mm long*
  - *- 100 μm thick silicon*
- **Insensitive ladder edge :**
  - *- 0.5 mm wide*
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  - *- can be activated*