Overview of the ILD vertex detector layout

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OUTLINE

- **Reminder on requirements :**
  - *Physics goals* - *Running conditions*
- **Discussion on the limits imposed by beam background :**
  - *Occupancy ⟼ read-out speed* - *Radiation tolerance*
- **Vertex Detector geometries for the LoI :**
  - *5 layer geometry* - *3 layer-pairs geometry*
- **Questions addressed by LoI studies**
  - *Detector geometry* - *Sensor performances*
- **Summary**

Requirements : Ambitious and Conflicting

- **Aim for several goals :**
  - ◇ *excellent impact parameter resolution* ◇ *distinguish impacts from close tracks (inside jets)*
  - ◇ *reconstruct soft tracks* ◇ *minimal m.s. $\mapsto$ pattern confusions, Δp/p, part. flow, jet flavour content (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*

    $\hookrightarrow$ *Conflicts: high speed and low P$_{diss}$ call for low granularity and large inner radius ....*

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

How to meet the Best Compromise ?

▶ **Aim: ultra-light, very granular, poly-layer, swift, low power and rad. tol. Vertex Detector installed very close to the interaction point**

↪ *Aim of the studies driven by the LoI : find an optimal balance between*

Granularity,

Material budget,

Radiation tolerance,

Speed

and Power dissipation

(cost not expected to be a major issue)

▷ **Complications:**

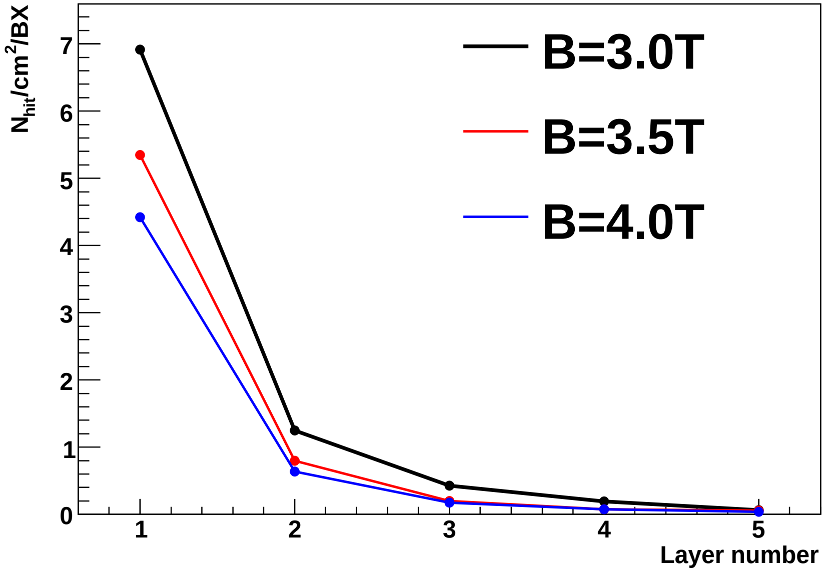
↦ *Several different detection technologies under development,*

↦ *Several read-out architectures under development*

↦ *Final performances achievable with each variant not yet assessed*

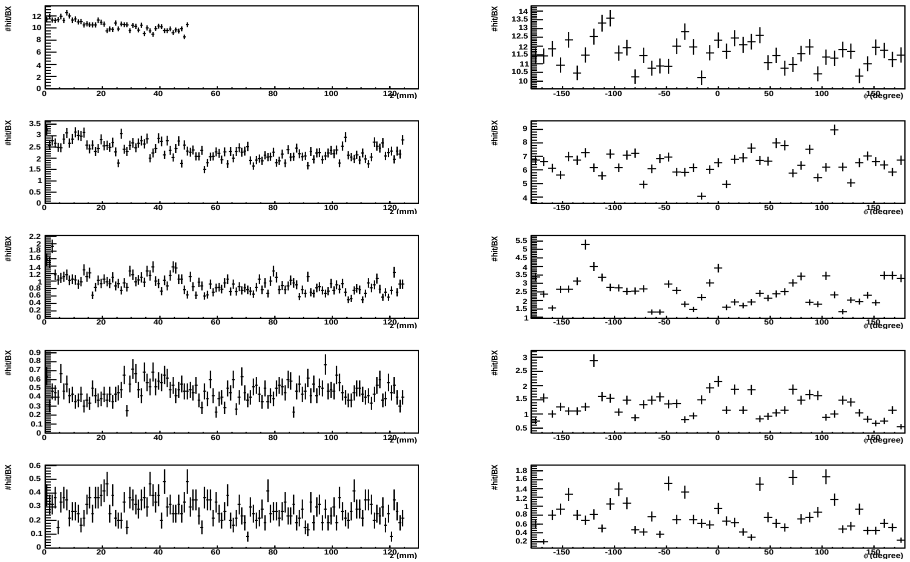
⇛ **Trade-off is technology dependent ↦ convergence within a few years (EDR) is a challenge**

- 14 mrad crossing angle $\rightarrowtail$ background simulation with Guinea-Pig *from K.Buesser (22.01.2008)*



- Average hit density /cm^2 /BX in each layer :
  - *inner most layer : $\sim$ 5 hits /cm^2 /BX for B = 3.5 T (R = 15 mm)*
  - *second layer : 6 times less*
  - *outer layers : 10–100 times less BG than in inner most layer*
  - *varying B by $\pm$ 0.5 T changes hit rate by $\sim$ 20–30 %*

    $\rightarrowtail$ *much less than uncertainty on hit rate itself*



- Uniformity in ϕ and z :
  - *moderate z dependence : maximal in inner layer (15–20 %)*
  - *ϕ dependence ???*

- Direct & backscattered photons not yet (well) studied

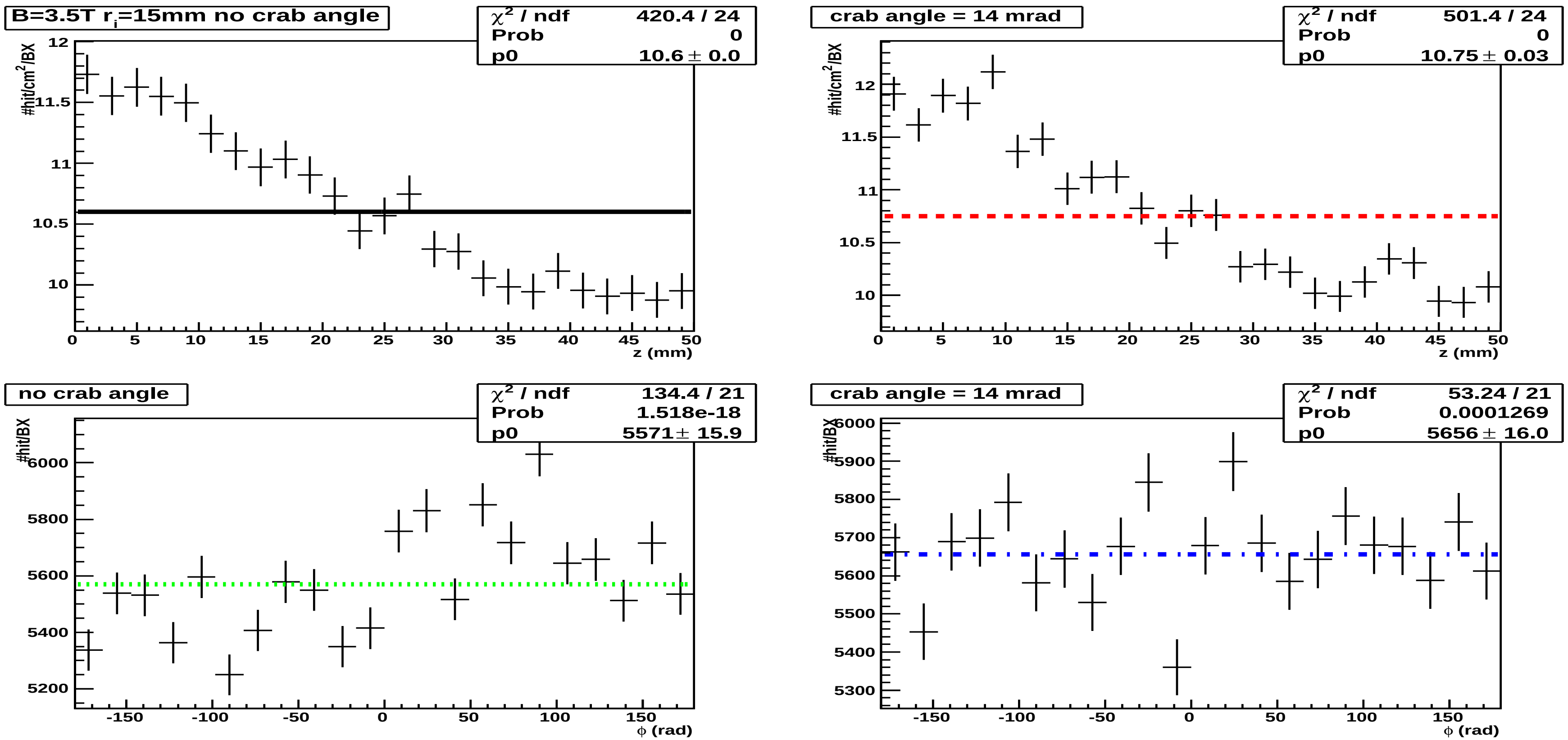
Beamstrahlung Background Characteristics

- Effect of 14 mrad crossing angle on hit uniformity *(B = 3.5 T – R = 15 mm)*

head-on collisions *14 mrad Xing angle*

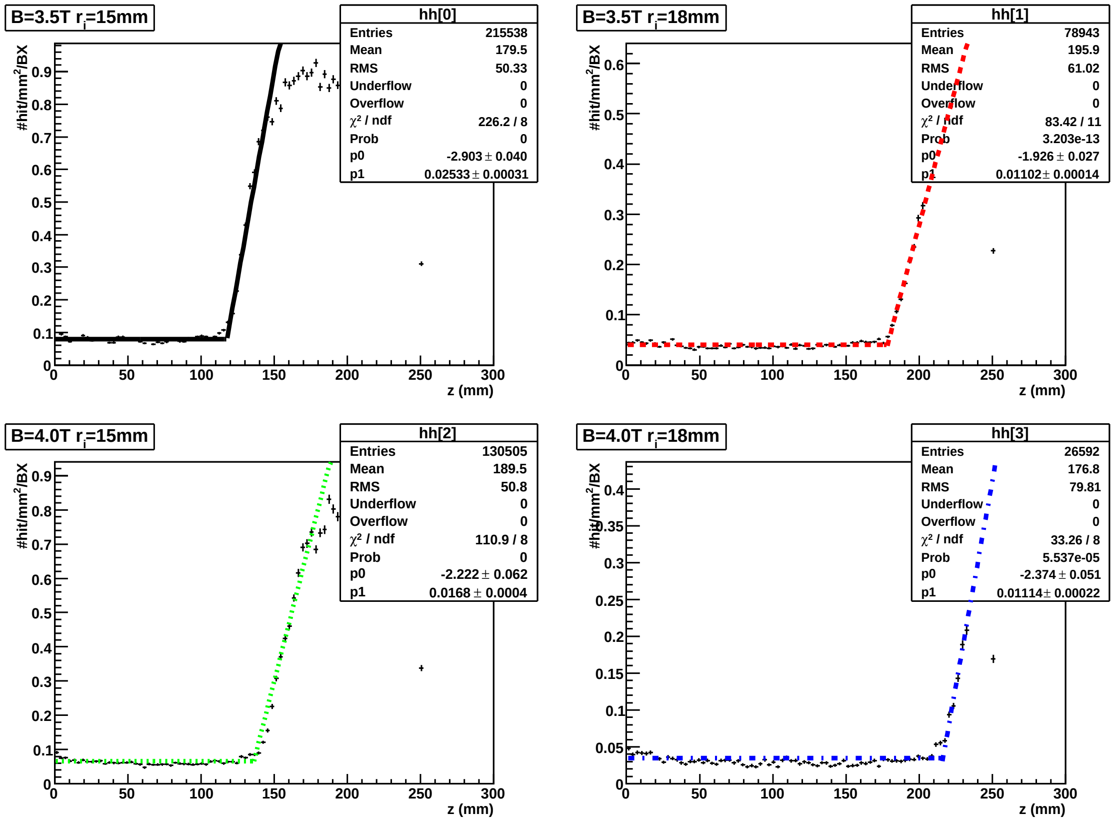
z

ϕ

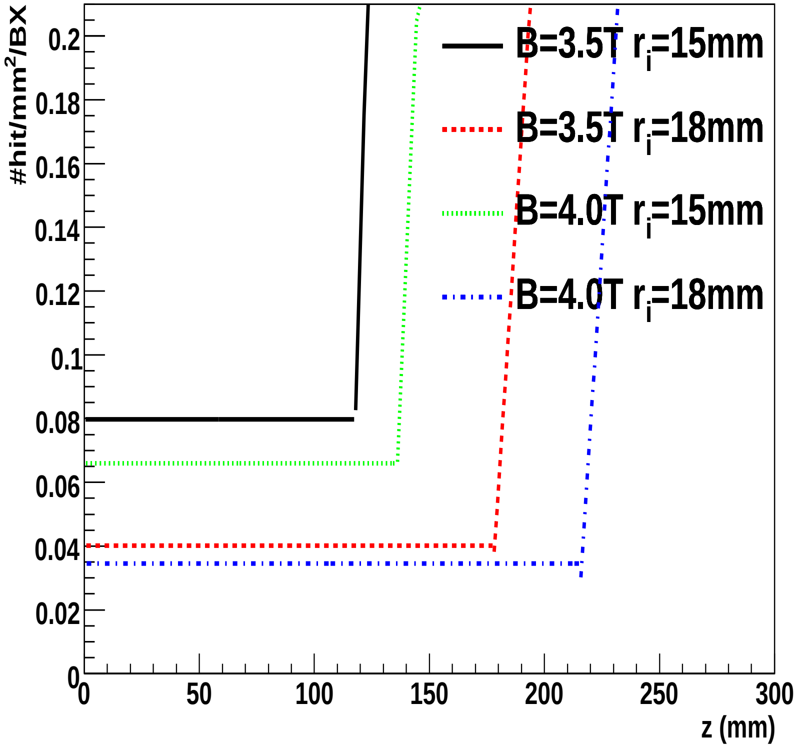


- Distributions in ϕ and z $\Rrightarrow$ *no significant change between head-on & 14 mrad Xing angle distributions*

- **Concern for polar angle coverage :** *cloud of defocussed* $e^{\pm}_{BS}$ *may hit ladder ends*
- **Spatial distribution of defocussed** $e^{\pm}_{BS}$ **studied with GuineaPig** *(vertical scales are arbitrary)*

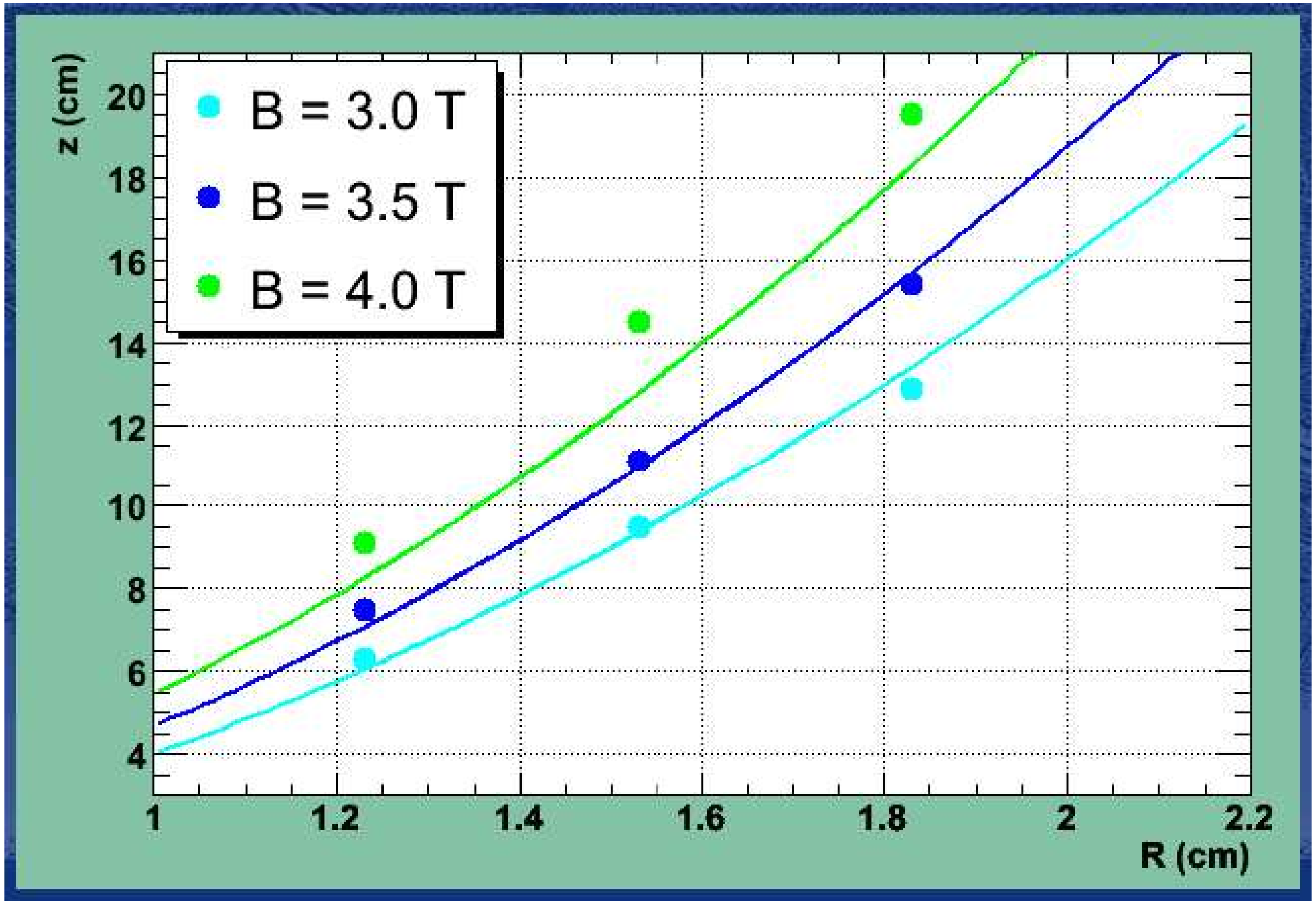


$\Rightarrow$



$\Rightarrow$ *Use the corner between direct and defocussed* $e^{\pm}_{BS}$ *to determine ladder lengths* $\longrightarrow$ *angular coverage*

- Corner position in z vs B and R :



Continuous lines :

$$z_C \simeq 8.3 \cdot R^2 \cdot B \cdot \sigma_z \cdot 10^{10}/N$$

M.Battaglia, V.Telnov,
Proc. 2nd Workshop on
backgrounds at MDI,
World Sci., 1998

Dots : *GuineaPig simulation*

▷▷▷ **GuineaPig simulation confirm empirical expression of z_C**

▷▷▷ **For R $\geq$ 15 mm : ladder half-length $\lesssim$ 8 cm free from defocussed cloud even for B = 3 T**

Beamstrahlung Background Induced Radiation

- **Required radiation tolerance because of beamstrahlung electrons :**

  5 $e^{\pm}_{BS}$ */cm*^{2} */BX* $\rightarrowtail$ *6·10*^{11} $e^{\pm}_{BS}$ */cm*^{2} */yr* $\rightarrowtail$ *safety factor (*$\gtrsim$ *3) : 2·10*^{12} $e^{\pm}_{BS}$ */cm*^{2} */yr*

- **Ionising radiation :**
  - *6·10*^{11} $e^{\pm}_{BS}$ */cm*^{2} */yr* $\rightarrowtail$ $\sim$ *20 kRad/yr* $\rightarrowtail$ $\sim$ *50 kRad/yr (inclined* $e^{\pm}_{BS}$ *trajectories)*
  - *safety factor (*$\sim$ *3)* $\rightarrowtail$ $\sim$ *150 kRad/yr*

    $\Rrightarrow$ **in 3 yrs : 150–500 kRad**

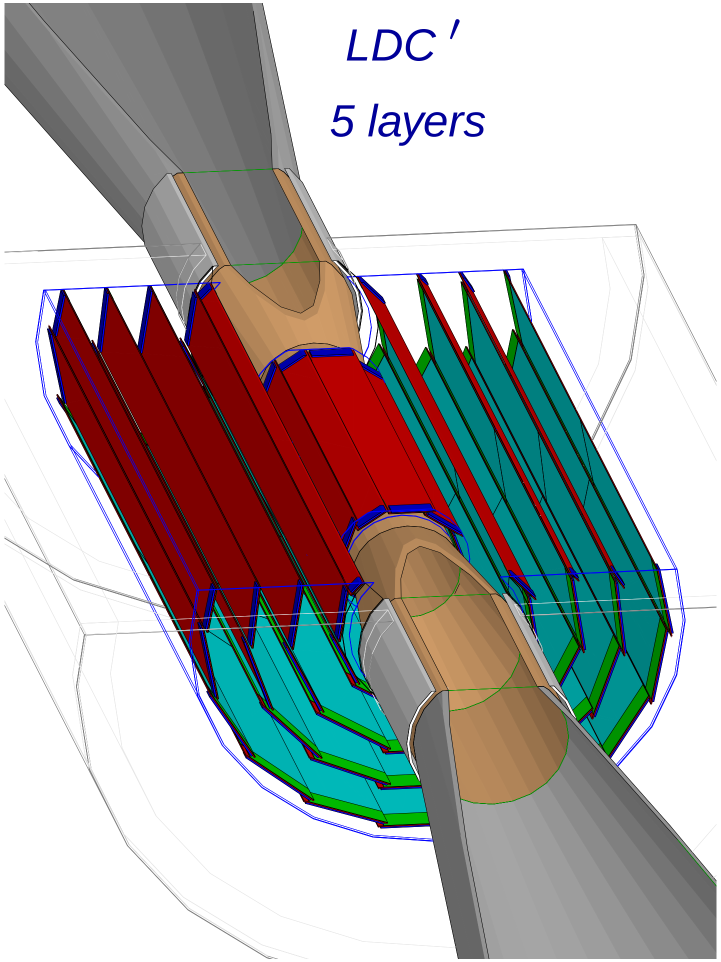
- **Non-Ionising radiation :**
  - $e^{\pm}_{BS}$ *(10 MeV) : NIEL factor* $\sim$ *1/30*
  - *6·10*^{11} $e^{\pm}_{BS}$ */cm*^{2} */yr* $\simeq$ *2·10*^{10} n_{eq} */cm*^{2} */yr* $\rightarrowtail$ *safety factor (*$\sim$ *3)* $\simeq$ *6·10*^{10} n_{eq} */cm*^{2} */yr*

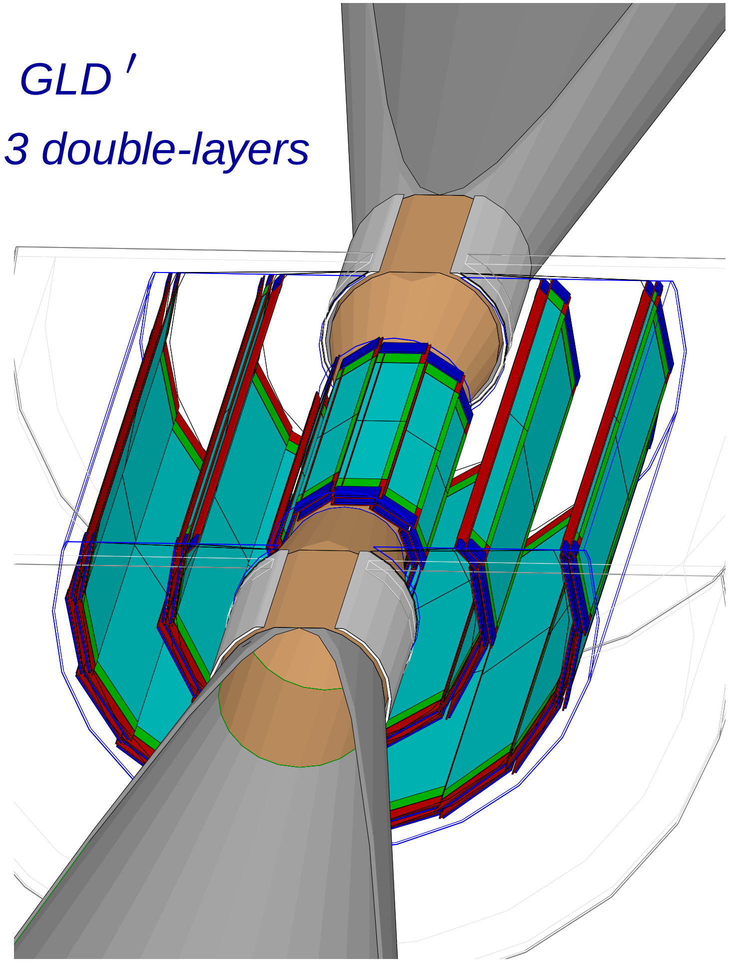
    $\Rrightarrow$ **in 3 yrs : 2·10**^{11} **n**$_{eq}$ **/cm**^{2} **(much more than neutron gas ...)**

- **Still to be studied :** **Photons**

Vertex Detectors Geometries Considered for the LoI

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

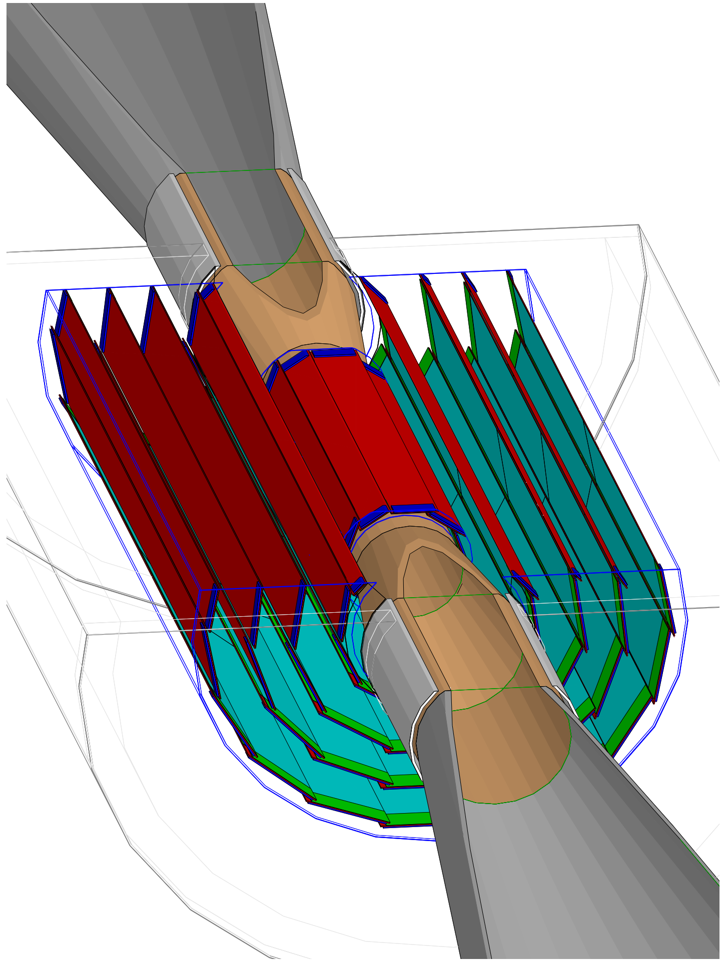




- **Two read-out modes considered :**
  - **continuous** *read-out*
  - *read-out* **delayed** *after bunch-train* ⟶ *3 double layers expected to help* ⇛ *mini-vectors*

5 Layer Geometry : VXD03

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

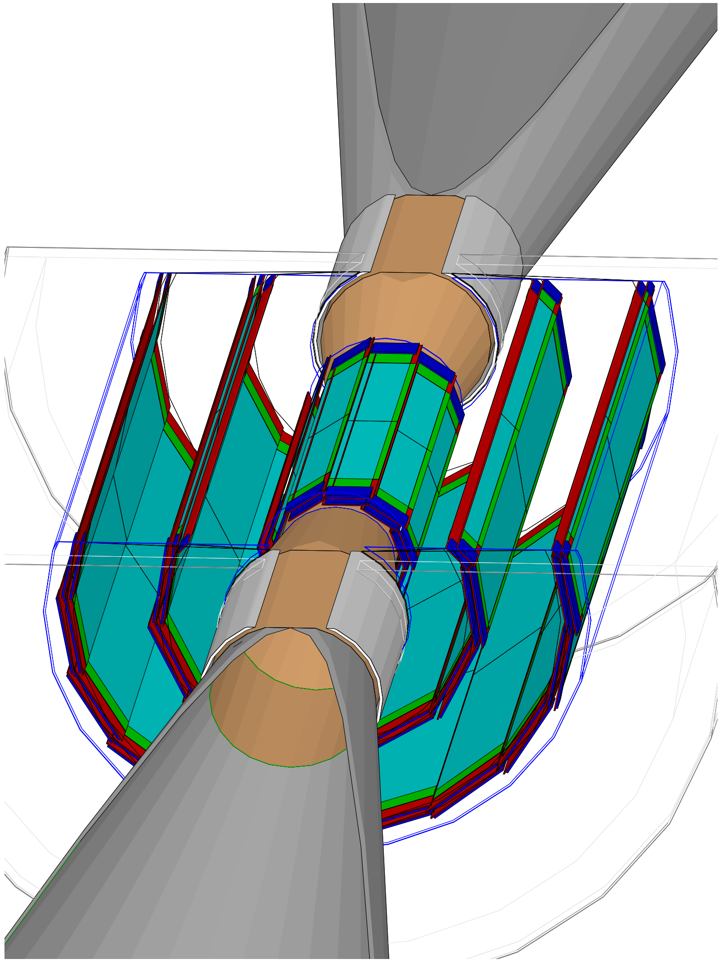


- **Layer radii :** *15, 26, 37, 48, 60 mm*
- **Nb of ladders per layer :** *10 (in) / 11 / 12 / 16 / 20 (out)*
- **Ladder lengths :** *125 mm (inner), 250 mm (outer)*
- **Ladder support structure :** *carbon fiber (100 μm thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner : 11 mm - 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 :**

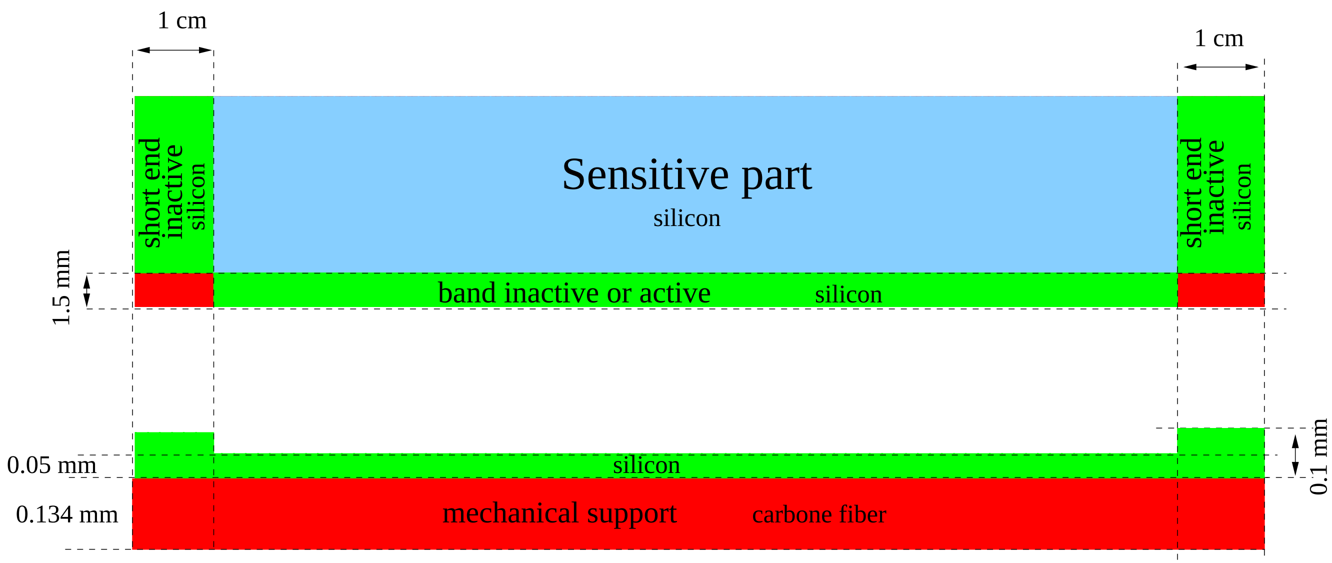
- **Double-layer radii (inner/outer) :** *16/18, 37/39, 58/60 mm*
- **Nb of ladders per layer :** *10 (in) / 12 / 20 (out)*
- **Ladder lengths :** *125 mm (inner), 250 mm (outer)*
- **Ladder support structure :** *carbon fiber (100 μm thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner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



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*

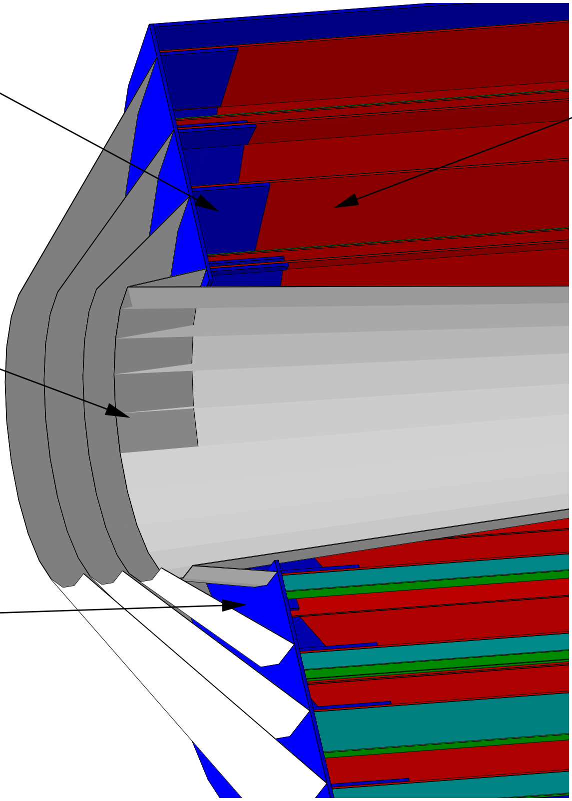
⇓

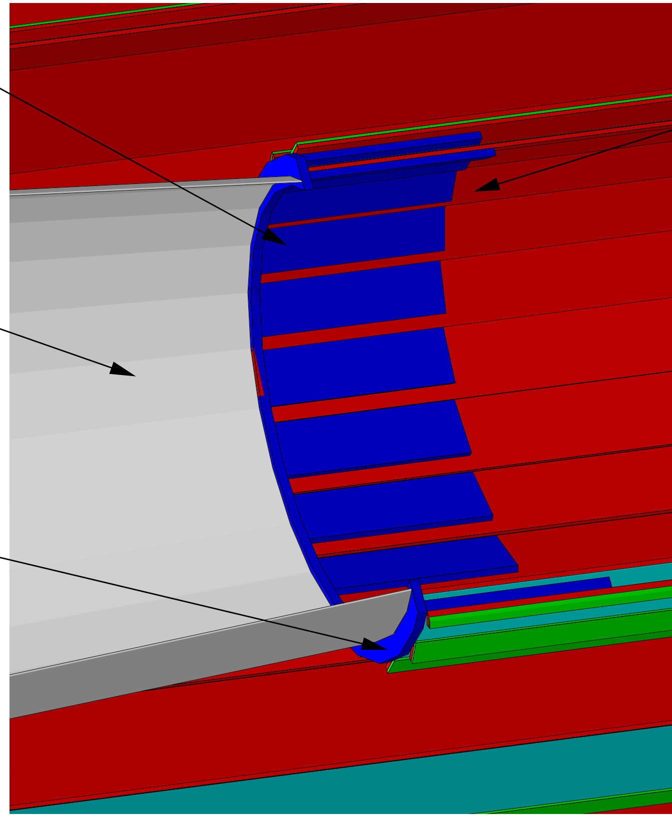


- **Will be studied extensively by VD groups working on diff. sensor technologies**

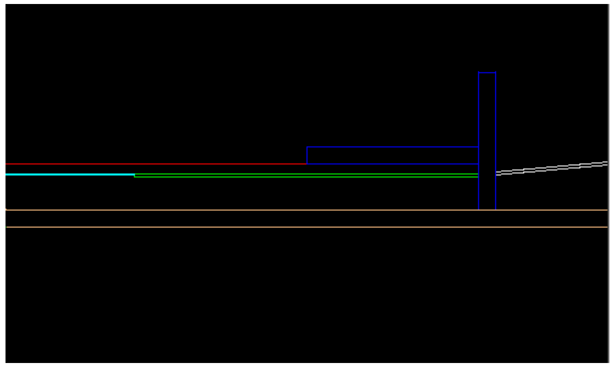
Ladder Support

- "Realistic" ladder fixture on "gasket"

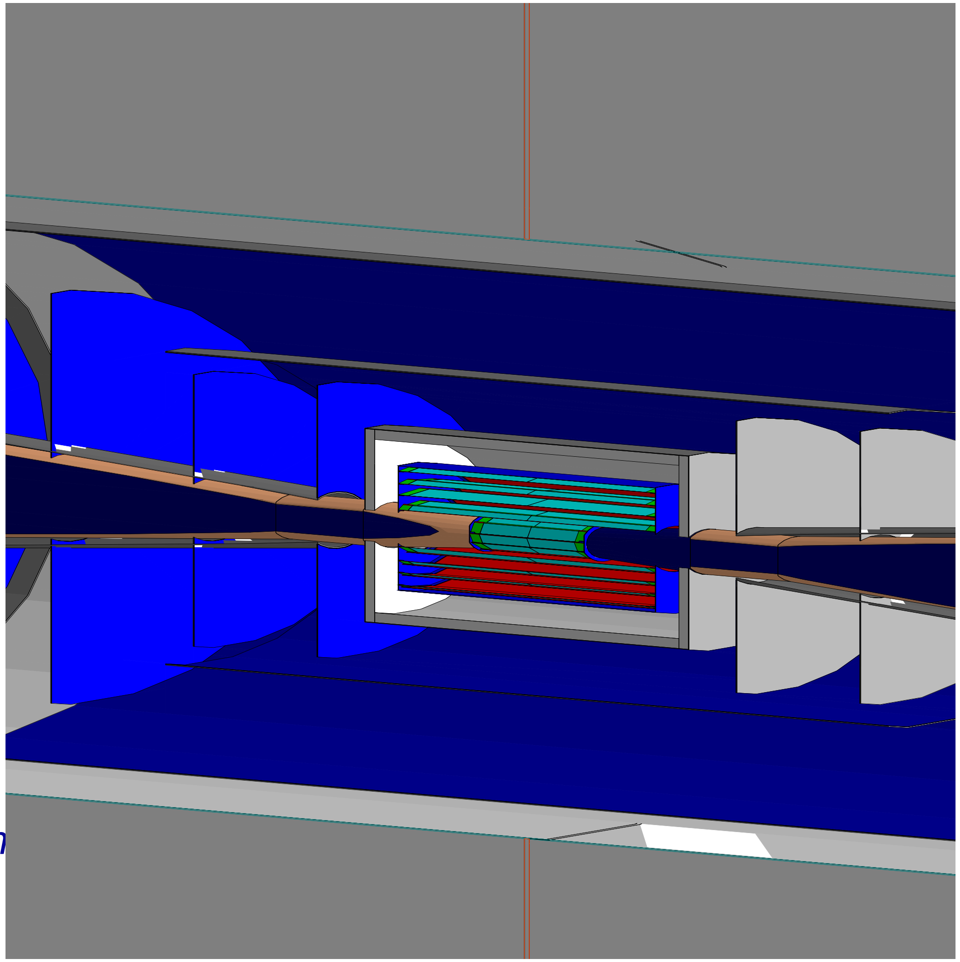




Ladder fixture ▷▷▷



- **"Gasket" : 0.74 % X_0 in barrel**
  - *Mechanical support (Be) :*
    - *R = 75 mm*
    - *thickness $\simeq$ 500 μm : 0.14 % X_0*
  - *Cryostat :*
    - *R = 90/100 mm*
    - *styropor (10 mm) : 0.05 % X_0*
    - *Al skin (0.5 mm) : 0.55 % X_0*
- **Neighbouring trackers :**
  - *Barrel :*
    - *2 layers of Si strips (R = 160 & 270 mm*
  - *End-caps (provisionnal) :*
    - *3 disks of hybrid pixels*
    - *4 disks of Si strips*



Objectives of the Study : Optimal Detector Geometry

- **Studies based on central massive production of signal and background events with baseline geometry**

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

- **Vary basic parameters :**
  - *innermost layer radius : 14 mm* $\lesssim R_{in} \lesssim$ *20 mm*
  - *ladder material budget : 0.1 %* $X_0 \lesssim t \lesssim$ *0.2 %* X_0
  - *magnetic field strength : 3 T* $\leq B \leq$ *4 T*

- **Specific questions :**
  - *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)*
  - *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 ?*

Objectives of the study : Sensor Technology

Read-out architecture : continuous vs delayed r.o.

Continuous read-out :

- *Several draw-backs : data throughput, power dissipation, EMI risk, etc.*
- *5 hits /cm^2 /BX $\Rrightarrow$ 0.3 % hit occupancy in 50 μs (20 μm pitch)*
  $\Rrightarrow$ $\lesssim$ *1 % pixel occupancy (3 seed pixels /hit due to inclined tracks)*
- *in case of 15 hits /cm^2 /BX $\Rrightarrow$ several % pixel occupancy*
  $\Rrightarrow$ *read-out may be too long $\Rrightarrow$ risk alleviated with fast read-out in 2nd layer*

Delayed read-out :

- *how small should the pixel be ?*

Upper limit M on double hit /pixel $\rightarrowtail$ pixel pitch

limit M	(3; 3)	(3; 6)	(15; 3)	(15; 6)
0.3 %	17.7μm	12.5μm	7.9μm	5.6μm
0.1 %	13.5μm	9.5μm	6.0μm	4.2μm
0.03 %	10.0μm	7.0μm	4.5μm	3.1μm

$\Rrightarrow$ $<$ *10 μm pitch mandatory !*

Prob ($\geq$ 2 hits/pixel) for 3/15 hits/cm^2/BX & 3/6 pixels/hit

pitch	(3 ; 3)	(3 ; 6)	(15 ; 3)	(15 ; 6)
20 μm	0.48 %	1.80 %	9.25 %	27.4 %
18 μm	0.32 %	1.21 %	6.46 %	19.9 %
16 μm	0.20 %	0.77 %	4.26 %	13.9 %
14 μm	0.12 %	0.46 %	2.63 %	8.94 %
12 μm	0.07 %	0.25 %	1.48 %	5.25 %
10 μm	0.03 %	0.12 %	0.74 %	2.72 %
8 μm	–	0.05 %	0.31 %	1.18 %
6 μm	–	0.02 %	0.10 %	0.39 %
4 μm	–	–	0.03 %	0.08 %

SUMMARY

- **ILD baseline geometry :**
  - *vertex detector made of long cylinders (down to* $||\cos\theta|| \simeq$ *0.97)*
  - *B = 3.5 T (intermediate between GLD and LDC fields)*

- **Two alternative geometries studied (inheritated from GLD & LDC) :**
  - *VXD-03 : 5 layers (R =15 – 60 mm)*
  - *VXD-04 : 3 double layers (R =16 – 60 mm)*
    - $\Rrightarrow$ *continuous and delayed read-out*

- **Emphasis on low material budget :**
  - *all layers* $\simeq$ *0.48 – 0.54 %* X_0
  - *Be mecha. support, surrounded by cryostat (styropor) & field cage (Al)* $\rightarrowtail \Sigma$ *= 0.74 %* X_0

▷▷ **Alternative geometry to study :** *short barrel with end-cap disks*