# ILD Vertex Detector for the LoI

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## OUTLINE

- **Reminder on (conflicting ) requirements :**
  - *Physics goals*
  - *Running conditions*
- **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 very ambitious (realistic ?) goals :**
  - ◇ *excellent impact parameter resolution*
  - ◇ *distinguish impacts from close tracks (inside jets)*
  - ◇ *reconstruct soft tracks*
  - ◇ *minimal m.s.* $\mapsto$ *pattern confusions,* $\Delta$*p/p, part. flow, jet flavour content (*$e^-$ *vs* $\nu_e$*), ...*

- **Constraints mainly driven by** $\sigma_{ip}$ **= 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 ($\mu m$) | 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 tracking sub-detectors (SIT, low angle)**

# 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*

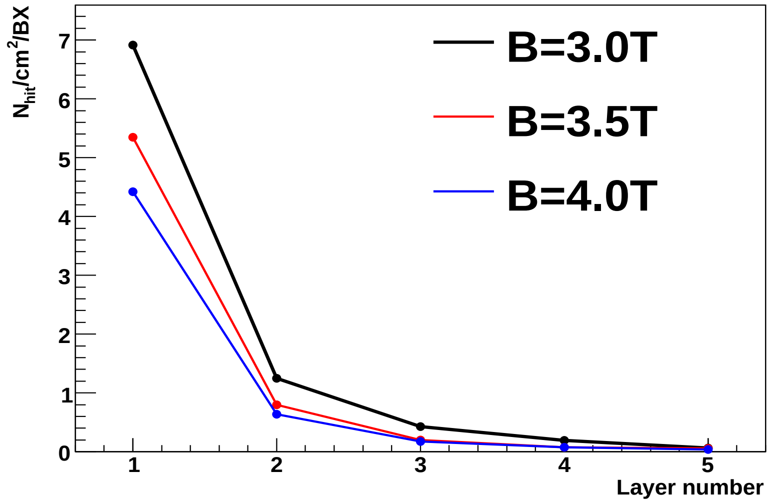
↦ *Final performances achievable with each variant not yet assessed*

⇛ **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)*

- **BG hit density in each layer being updated :**
  - *moderate $z$ dependence : maximal in inner layer (15–20 %)*
  - *substantial $\phi$ dependence suspected (factor $>$ 2)*
  - *varying B by $\pm$ 0.5 T changes hit rate by $\sim$ 20–30 %* $\longrightarrow$

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



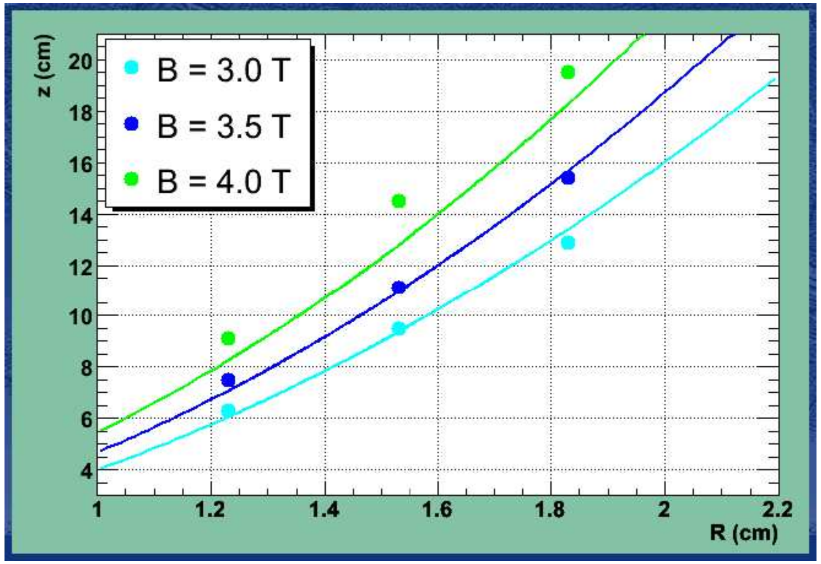

- **Concern for polar angle coverage :**
  - *cloud of defocussed $e^{\pm}_{BS}$ may hit ladder ends*
  - *corner position in $z$ vs B and R reevaluated* $\longrightarrow$

    $\Rrightarrow$ *confirms $\pm$ previous estimates :*

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

▷▷▷ *For R $\geq$ 15 mm : ladder half-length $\lesssim$ 8–9 cm*

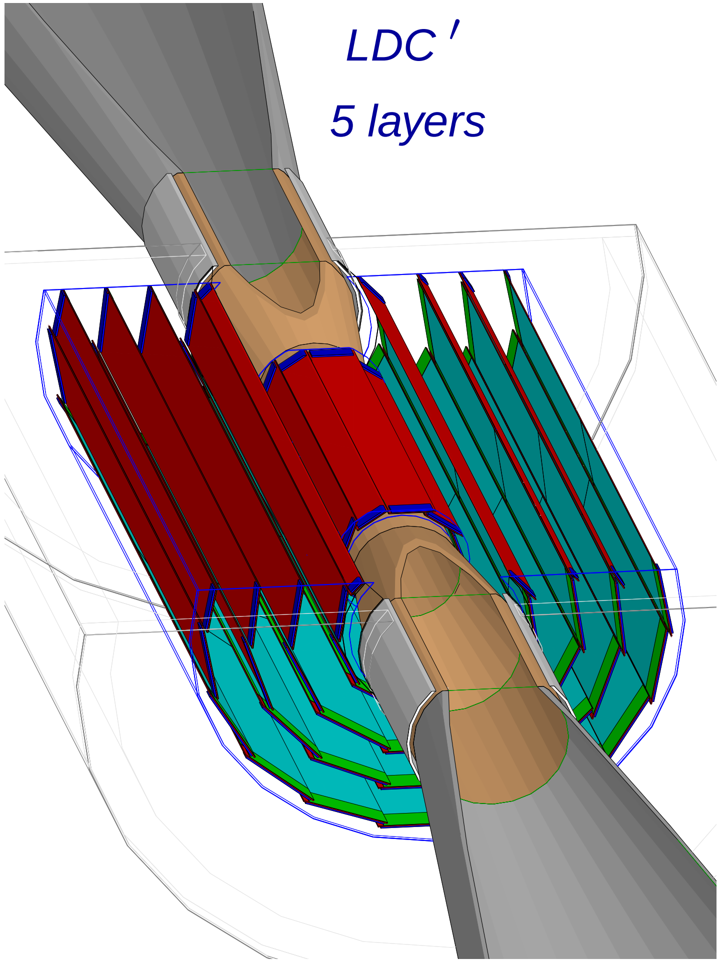
*free from defocussed cloud, even for B = 3 T*

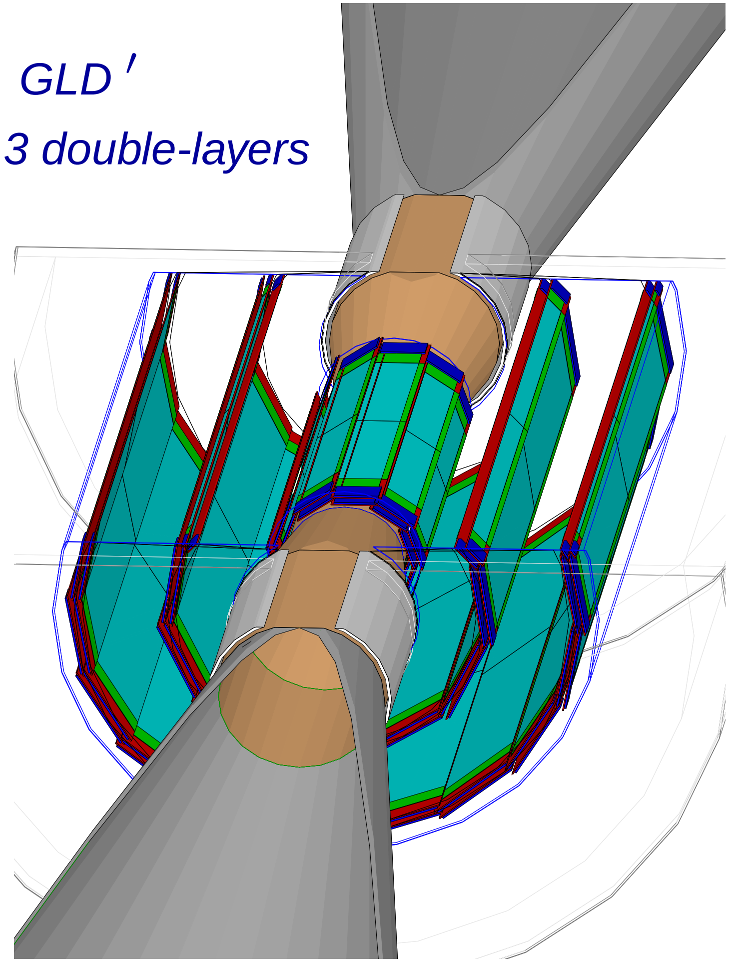



▷ **Direct & backscattered photons not yet (well) studied**

# Vertex Detectors Geometries Considered for the LoI

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

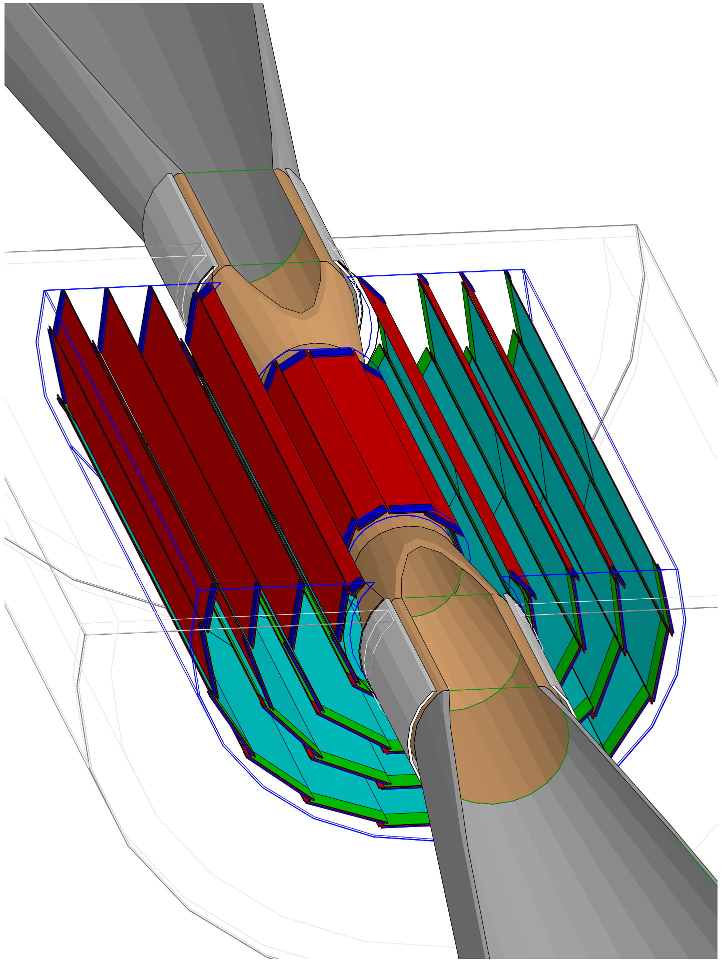



- **Two read-out modes considered :**
  - **continuous** *read-out*
  - *read-out* **delayed** *after bunch-train* $\longrightarrow$ *3 double layers expected to help*
    $\Rrightarrow$ *mini-vectors*

# 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 $\mu m$ thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner : 11 mm    - second : 15 mm    - outer : 22 mm*
  - *- 50 $\mu m$ thick silicon*
- **Electronics at ladder end :**
  - *- 10 mm long*
  - *- 100 $\mu m$ thick silicon*
- **Insensitive ladder edge :**
  - *- 1.5 mm wide*
  - *- 50 $\mu m$ 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 $\mu m$ thick)*
- **Ladder sensitive part width on each layer :**
  - *- inner : 11 mm     - outer : 22 mm*
  - *- 50 $\mu m$ thick silicon*
- **Electronics at ladder end :**
  - *- 10 mm long*
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- **Insensitive ladder edge :**
  - *- 0.5 mm wide*
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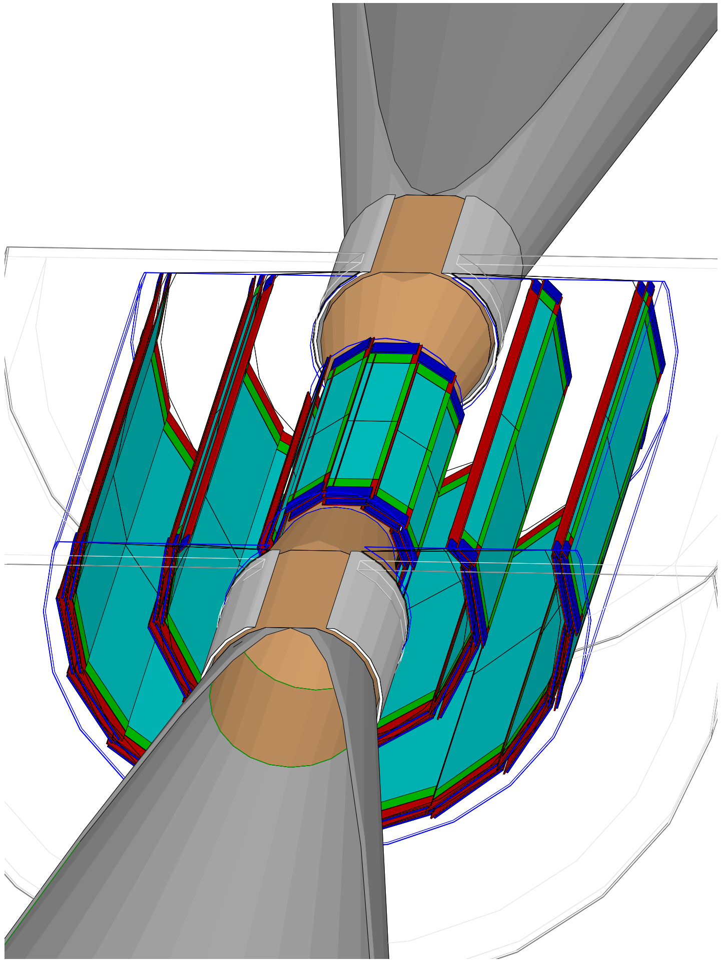
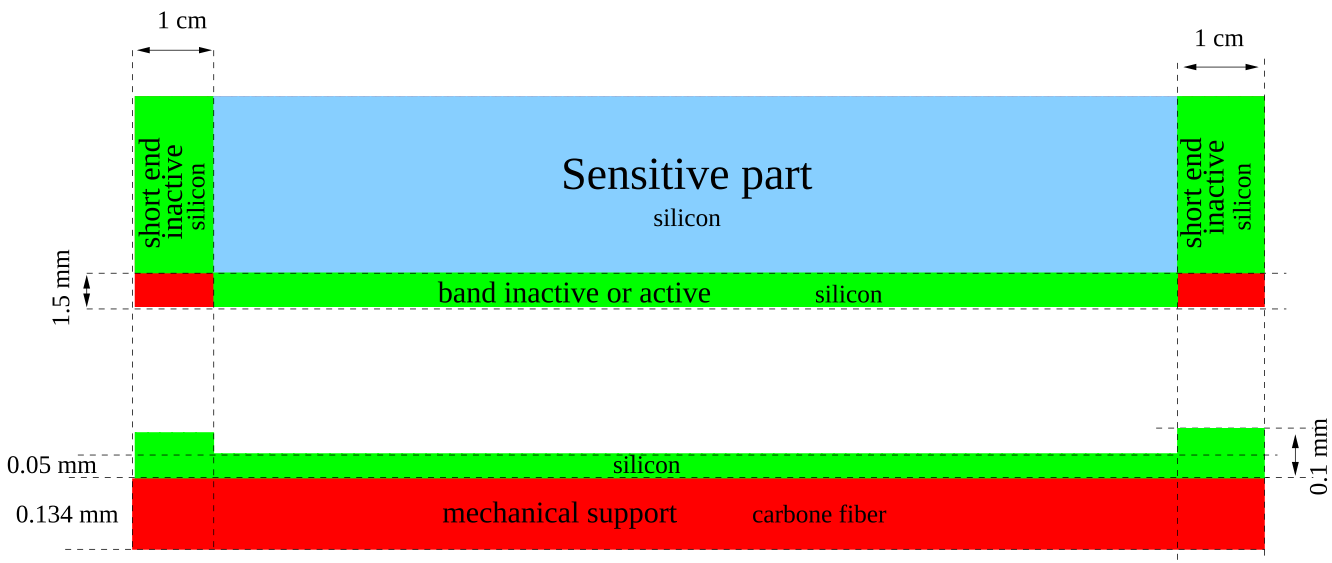
  - *- can be activated*



# 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 %* $X_0$

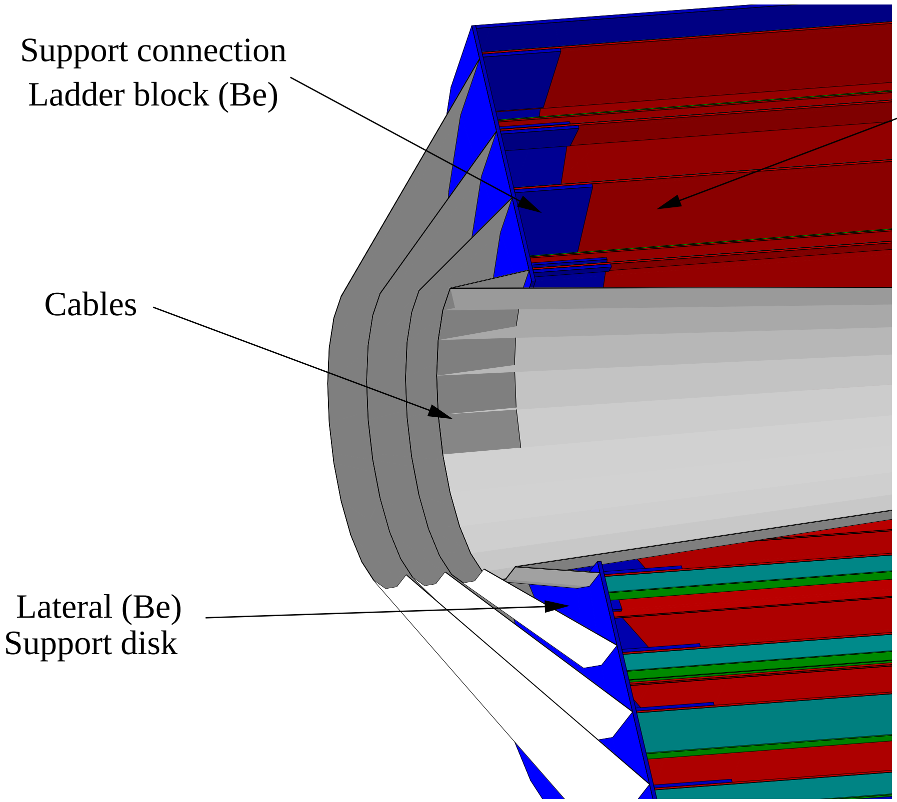
⇓

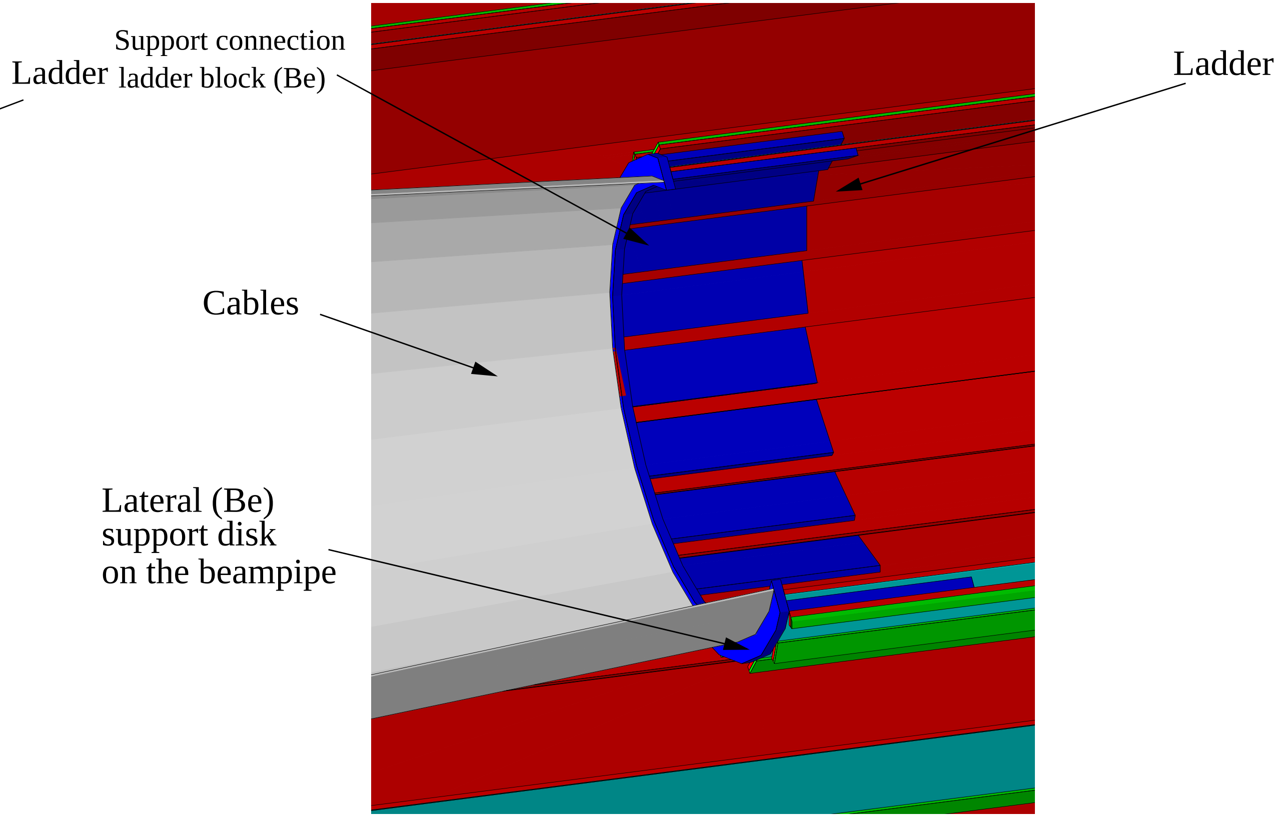



- **Will be studied extensively by VD groups working on diff. sensor technologies**

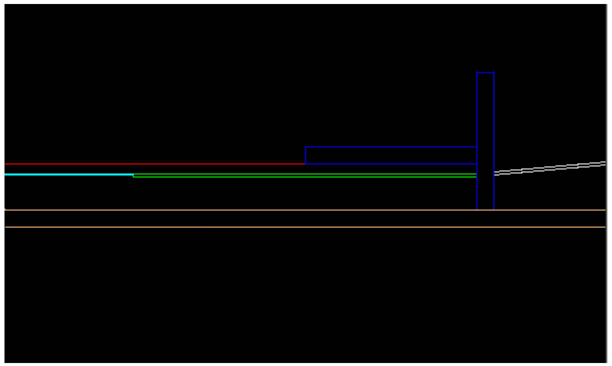
# Ladder Support

- ”Realistic” ladder fixture on ”gasket” ⟼ combine with beam pipe geometry study

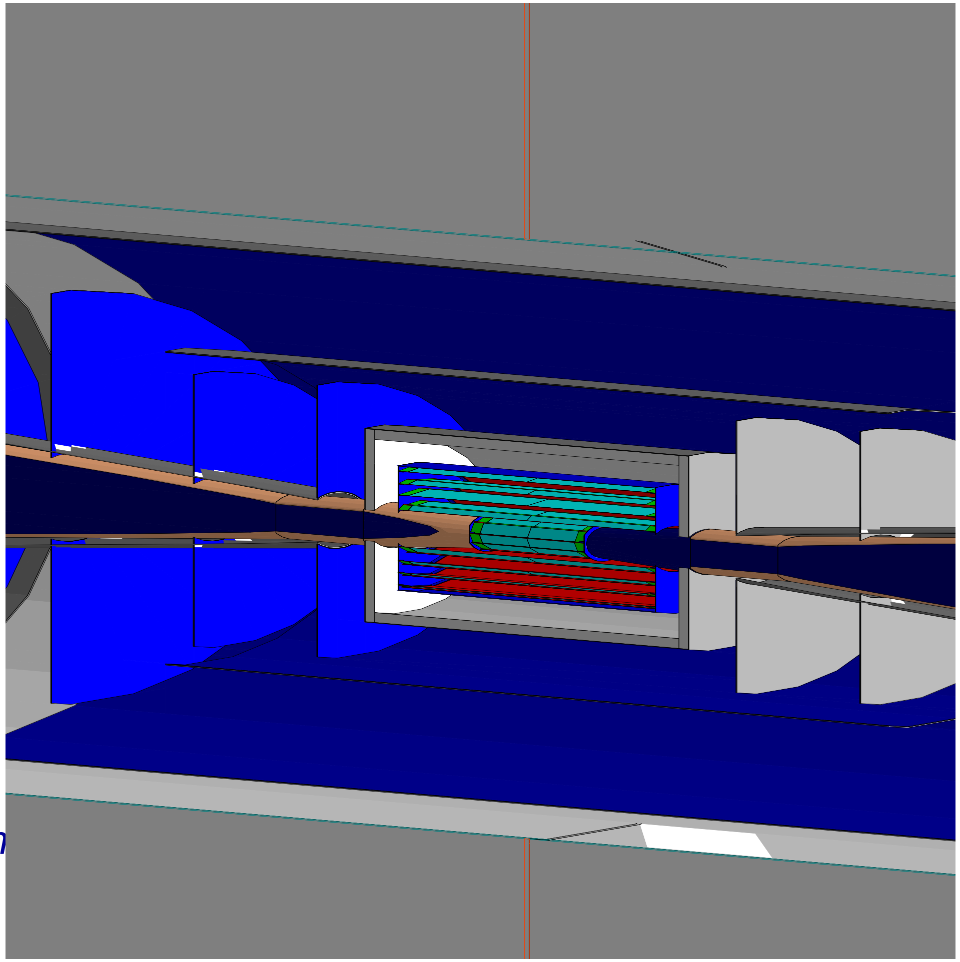



**Ladder fixture ▷▷▷**



- **"Gasket" : 0.74 % $X_0$ in barrel**
  - *Mechanical support (Be) :*
    - *R = 75 mm*
    - *thickness $\simeq$ 500 $\mu m$ : 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 ?*

# 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*

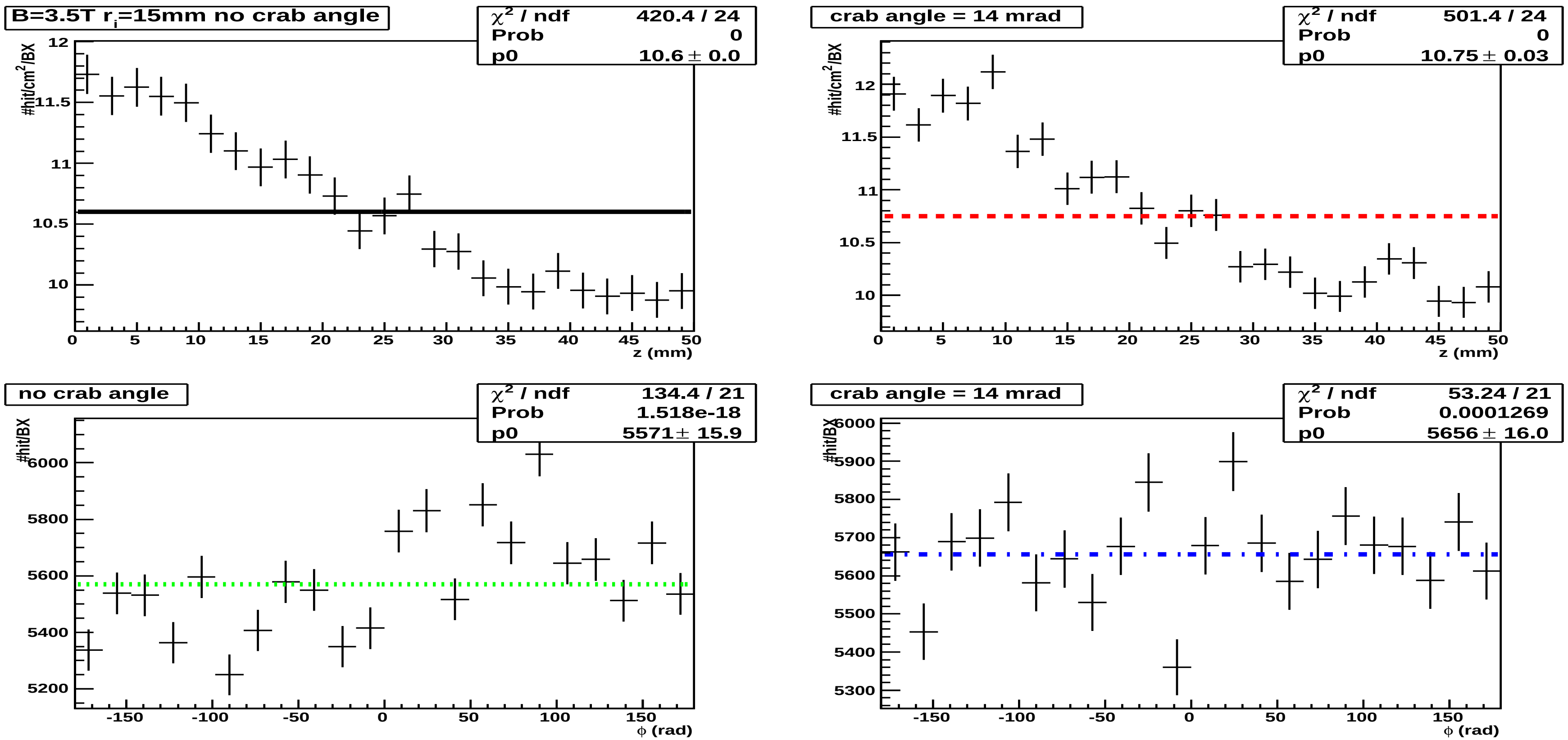
- **Difficulty: VXD optimisation needs to be organised in** $\geq$ **2 parallel ways**
  - *stand alone VXD optimisation*
  - *combined VXD optimisation accounting for (evolving ) neighbouring sub-detector parameters*

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

*head-on collisions* *14 mrad Xing angle*

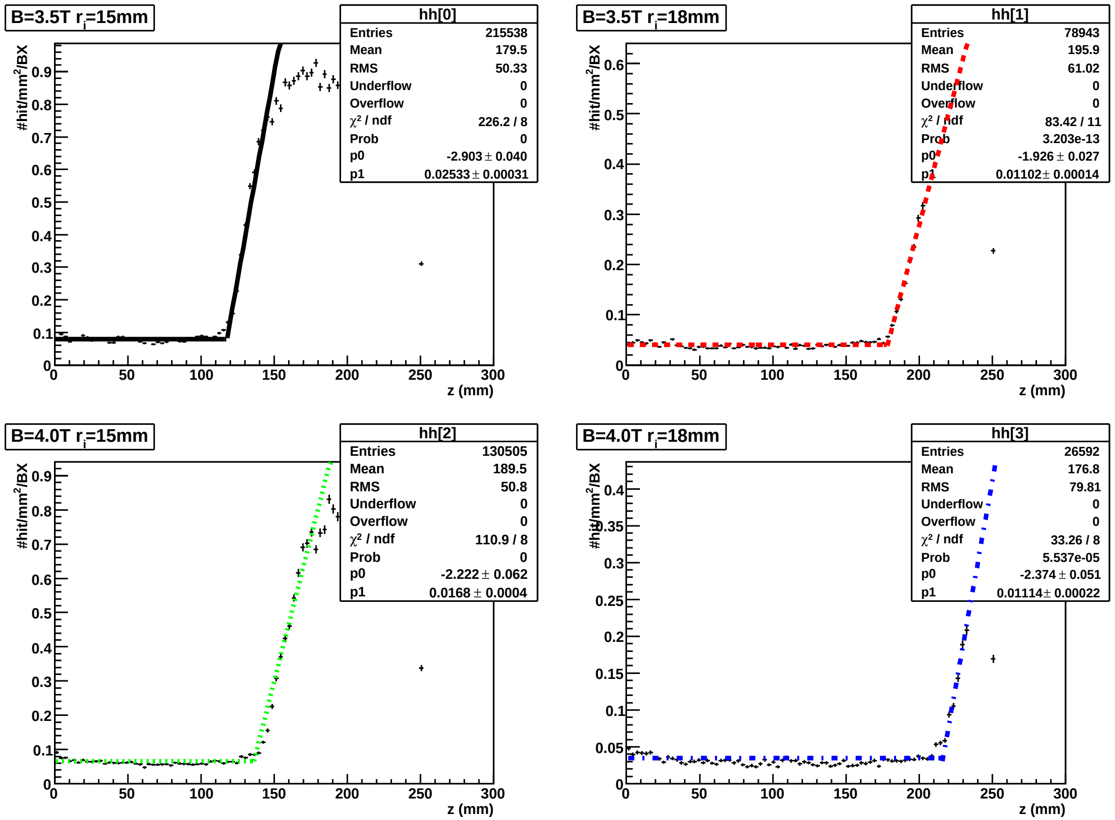
$z$

$\phi$

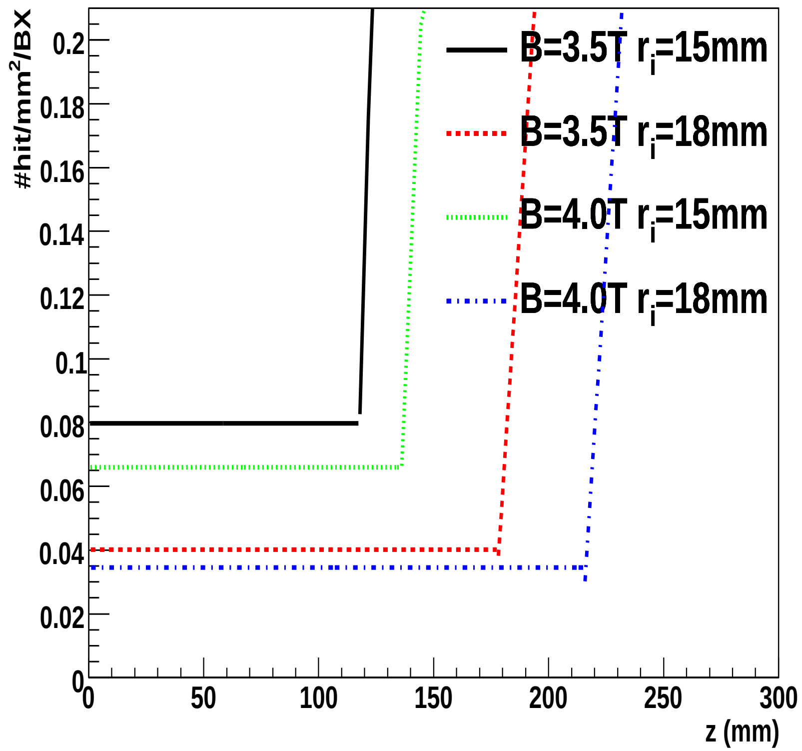



- **Distributions in $\phi$ and $z$** $\Rightarrow$ *no significant change between head-on & 14 mrad Xing angle distributions*

- **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)*




$\Rrightarrow$




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

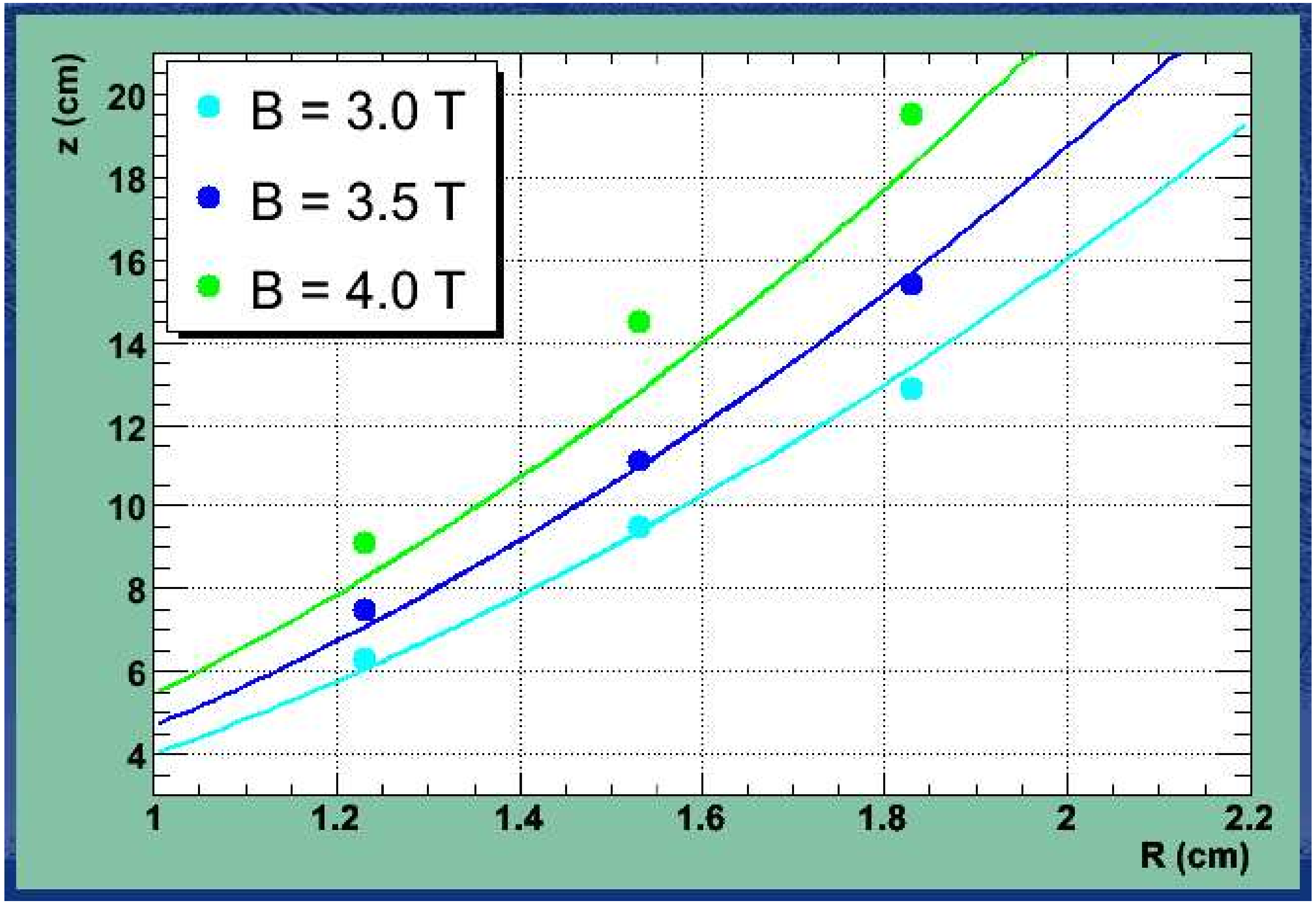
- Corner position in $z$ vs B and R :

**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**

- **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**

# 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 $\mu s$ (20 $\mu m$ 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 $\longrightarrow$ pixel pitch**

| limit M | (3; 3) | (3; 6) | (15; 3) | (15; 6) |
|---|---|---|---|---|
| 0.3 % | 17.7$\mu m$ | 12.5$\mu m$ | 7.9$\mu m$ | 5.6$\mu m$ |
| 0.1 % | 13.5$\mu m$ | 9.5$\mu m$ | 6.0$\mu m$ | 4.2$\mu m$ |
| 0.03 % | 10.0$\mu m$ | 7.0$\mu m$ | 4.5$\mu m$ | 3.1$\mu m$ |

$\Rrightarrow$ $<$ *10 $\mu m$ 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 $\mu m$ | 0.48 % | 1.80 % | 9.25 % | 27.4 % |
| 18 $\mu m$ | 0.32 % | 1.21 % | 6.46 % | 19.9 % |
| 16 $\mu m$ | 0.20 % | 0.77 % | 4.26 % | 13.9 % |
| 14 $\mu m$ | 0.12 % | 0.46 % | 2.63 % | 8.94 % |
| 12 $\mu m$ | 0.07 % | 0.25 % | 1.48 % | 5.25 % |
| 10 $\mu m$ | 0.03 % | 0.12 % | 0.74 % | 2.72 % |
| 8 $\mu m$ | – | 0.05 % | 0.31 % | 1.18 % |
| 6 $\mu m$ | – | 0.02 % | 0.10 % | 0.39 % |
| 4 $\mu m$ | – | – | 0.03 % | 0.08 % |