Vertex Detector Requirements Governed by Machine Issues

M.Winter on behalf of Vertex Det. WG

PURPOSE

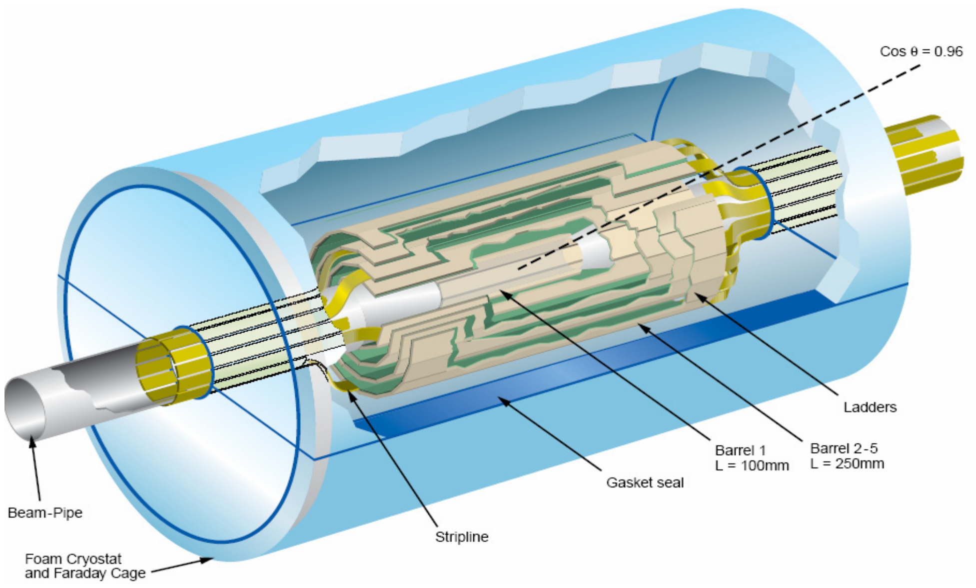
- Better understanding of background rates and doses
- Account of all sorts of uncertainties
- Role of Beam Pipe parameters (addressed by S.H.)
- Beam pick-up issues (cf previous meeting)
- Aim for minimal but regular/maintained exchange of information

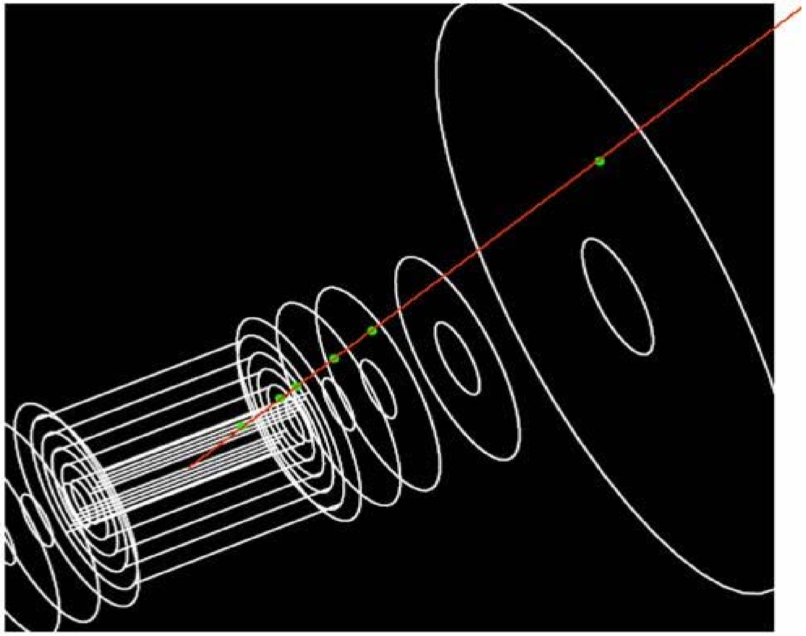
Machine Background

- Vertex Detector performances cannot be optimised simultaneously for granularity, material budget, speed, radiation tolerance and power dissipation
- We need to agree on common numbers governing the R$D goals (first years of collider operation)
- Occupancy due to Beamstrahlung electrons dictates read-out speed, smallest possible inner radius, and influences strongly integrated radiation dose (and granularity)
  - How well do we know the e_{BS} rate simulation ?
  - How much does the rate depend on ”yet moving” machine parameters: Crossing angle ? Collimators ? Other beam elements ? (High-)Luminosity ? Beam instabilities ?
  - How do we account for these unknowns ? Safety margin/factor ? x 3-5 ?
- Other electromagnetic backgrounds: photons (direct, back scattered) ?
- Neutron background may be embarrassing:
  - which fluence ? which uncertainty ? $\mapsto$ safety margin/factor (x 10 like LHC ?)
- Set-up regular direct communication between MDI and VD communities
  - Aim: 2 persons from VD community acting as contact with MDI WG
- A.O.B.

Pending Questions on Geometry

- Improve existing concepts $\mapsto$ make them more realistic and precise
- Try making most urgent questions emerge (hierarchy ?) $\mapsto$ concentrate efforts on answering them
- Come up with:
  - better defined questions on MDI issues
  - better defined questions & info related to surrounding sub-detectors
  - realistic needs of software tools $\mapsto$ strategy w.r.t. software evolution
  - set of Work Packages $\mapsto$ milestones





Pending Questions on Geometry

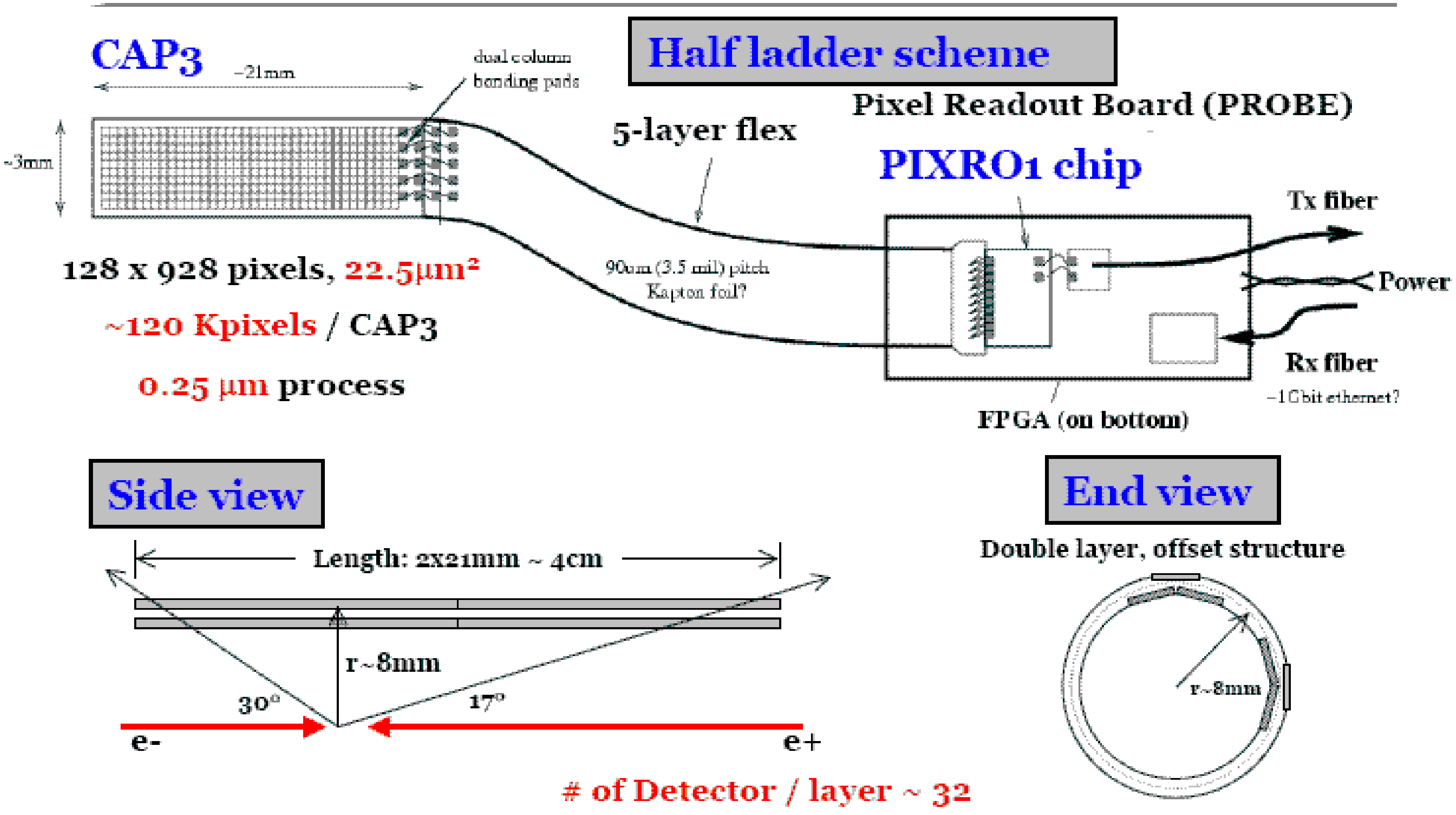
- **Cylindrical geometry:**
  - ◇ which cosθ range ? $\mapsto$ m.s. at low θ (layer thickness x 2-3) $\mapsto$ cone slices, disks in forward region ?
    - $\hookrightarrow$ link to surrounding sub-detectors $\mapsto$ delivering time stamp (BX tag) ?
  - ◇ how many layers ? R_{in} ? R_{out} ? double layer(s) ?
    - $\hookrightarrow$ study internal tracking ($\mapsto$ bg rejection) & low p tracking (with neighbouring sub-det.)
  - ◇ reconstruction studies $\mapsto$ based on geometry with ladders (instead of perfect cylindres)
    - $\hookrightarrow$ effects of mechanical support, ladder overlaps, FEE and signal transfer (e.g. small θ)
  - ◇ outer support ? (+ cryostat ? T_{op} ?)
  - ◇ reminder: beam pipe parameters
- **Granularity & speed:**
  - ◇ pixel pitch vs R, $t_{r.o.}$, P_{diss}, ...
  - ◇ $t_{r.o.}$: $\therefore$ short $t_{r.o.}$ for the TWO inner layers (robust against high beam induced background)
    - $\therefore$ short $t_{r.o.}$ for outer layer ladders exposed to back scattered particles (due to beam Xing angle)
- **Concept related parameters ?**
- **Technology related parameters ?** $>$ 1 technology equipping VD ?

Example of SuperBELLE

▶ CAP (Continuous Acquisition Pixel) for BELLE upgrade: short integration time ($\sim 10\ \mu s$)

◇ up to 10 memory cells in each pixel

◇ only cells (= time slots) selected by external trigger are read-out



Granularity

- Granularity is predominantly dictated by:
  - ◇ single point resolution (vs R)
  - ◇ track separation (vs R)
  - ◇ occupancy (vs R, $t_{r.o.}$)

- Relative importance of each parameter (s.p.r., t.s., o.) depends on technology $\mapsto$ how much ?

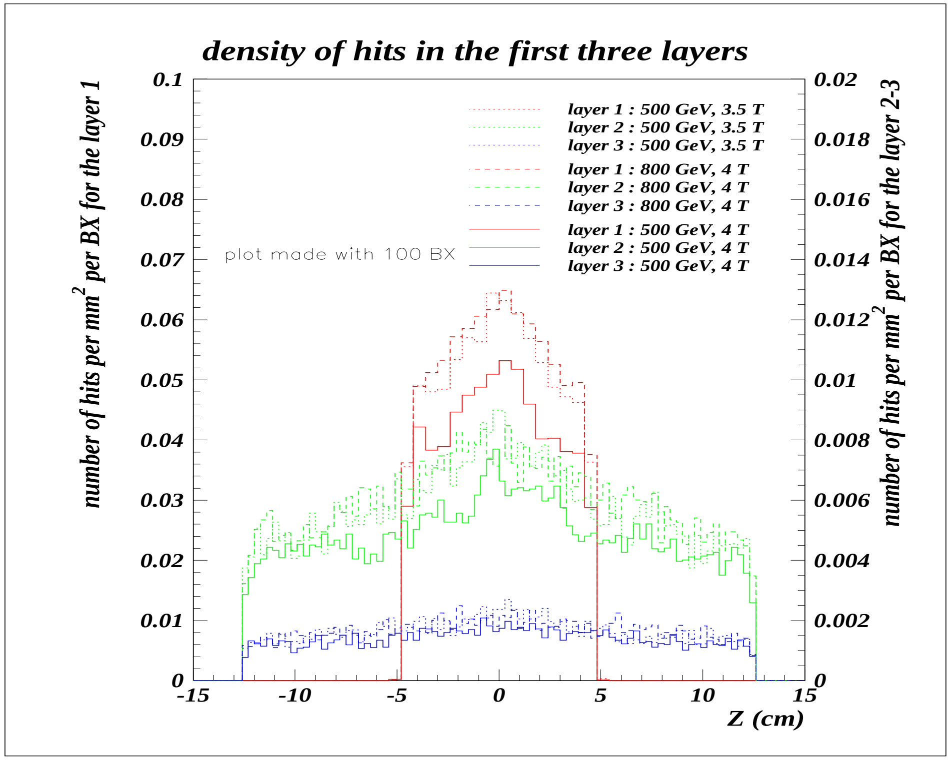
- Same pixel pitch in all layers ?

  $\hookrightarrow$ larger pitch for outer layers relaxes constraint on speed and reduces P_{diss}

- Occupancy driven by beamstrahlung $e^{\pm}$ $\mapsto$ how well can we determine their rate ?

- **Characteristics (from Monte-Carlo !!!)**

  $\hookrightarrow$ **detector requirements should account for safety margin w.r.t. raw MC output !**



- $\lesssim$ **5 hits/cm^2/BX at 90° (R_0=15 mm, 4T)**

  1) Impact on read-out speed:

  - **0.15 % hit occupancy in 25 μs**
  - **cluster mult. (5-10), uncertainties (MC x 3, etc.)**

    $\hookrightarrow$ **occupancy $\lesssim$ 5 %**

    $\hookrightarrow$ $\lesssim$ **25 μs needed in L0 and $\sim$ 50 μs (?) in L1 ($R_1 \sim$ 25 mm)**

  2) Impact on radiation tolerance w.r.t. non-ionising damage:

  $\hookrightarrow$ **6$\cdot$10^{11} e_{BS}/cm^2/yr $\mapsto$ 2$\cdot$10^{10} n_{eq}/cm^2/yr (NIEL factor $\sim$ 1/30)**

  $\hookrightarrow$ **uncertainties (MC, NIEL, etc.): $\lesssim$ 1$\cdot$10^{11} n_{eq}/cm^2/yr**

  $\mapsto$ **Ionising damage: $\lesssim$ 50 kRad/yr**

Constraints from Other Backgrounds

- Neutron gas: expected to amount $\sim 10^9 n_{eq}/cm^2/yr$
  - ◇ Still poorly simulated ?
  - ◇ Which safety margin w.r.t. M.C. predictions ? (ex. LHC takes factor 10)
  - ◇ If rate is problematic $\longmapsto$ how well can we shield the VD from it ?
  - ◇ Any need of cooling ?

- Other sources of background to worry about ?
  - ◇ Beamstrahlung, synchrotron, backscattered photons ?
  - ◇ Effect of beam crossing angle ?
  - ◇ Others ?

▷ We need to agree on:

- updated & realistic M.C. predictions for beam backgrounds
- "safety factors" w.r.t. these MC predictions

  $\therefore$ factor 3 or 5 on e_{BS} ? $\therefore$ factor 10 on neutron gas ? $\therefore$ others (e.g. γ) ?

  $\hookrightarrow$ Discussion with MDI

▷ Which rate of n_{eq}/cm^2, e(10 MeV)/cm^2, 10 – 10^3 keV γ can each device/technology stand ?

Material Budget

- Effect of VD material on ILC physics not yet well known $\mapsto$ fears more than documented opinions ...

- Considerations influencing the material budget:
  - ◇ thickness of beam pipe (account for beam pick-up)
  - ◇ read-out speed (mainly inner most layer)
  - ◇ thinning of sensors (vs rigidity of mechanical support)
  - ◇ cooling $\mapsto$ operating temperature, rad. tolerance, speed, P_{diss}
  - ◇ material (FEE, signal transfer) at small θ ($\gtrsim 5^\circ$) vs forward tracking & part. flow

- Pressing questions:
  - ◇ Do we have the tools to assess how much material we can afford ?
  - ◇ Should the baseline geometry really assume a set of concentric cylinders ?
    $\hookrightarrow$ are ladders with overlaps not closer to a "baseline" ?
  - ◇ How much material will go into the "small θ corner" ?
  - ◇ Can we define an intervalle in which the mechanical support budget is likely to end up ?
  - ◇ Can we converge on the beam pipe thickness $\mapsto$ global task ?
  - ◇ How much additional material does "light" cooling bring into the fiducial volume ?

- R&D on mechanical supports and cooling systems is relatively technology transparent
  $\hookrightarrow$ set up a global – $\sim$ technology decoupled – effort ?

SUMMARY

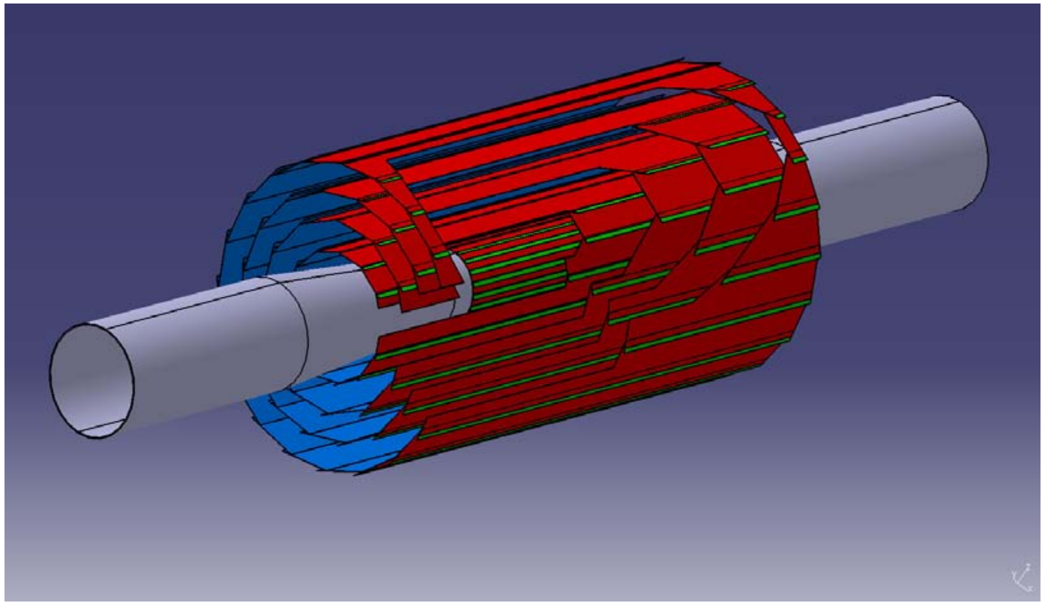
- Pressing need $\mapsto$ improved assessment of vertex detector requirements:
  - w.r.t. running conditions:
    - $\therefore$ background rates (e$_{BS}$, n, ...) $\oplus$ agreed safety margins $\therefore$ beam pipe radius & thickness (pick-up)
  - w.r.t. physics issues, e.g.:
    - $\therefore$ importance of material budget vs θ $\therefore$ R$_{in}$, R$_{out}$, lever arm, nb of layers, ...
    - $\therefore$ role of VD in tracking: link to neighbour detectors $\therefore$ time stamping vs pile-up
- Need discussing background types, characteristics, rates and uncertainties with MDI
- Need discussing issues related to surrounding sub-detectors with groups in charge of the latter
- Need setting up tasks $\mapsto$ define work packages (instrumental & software studies):
  - need to hierarchise the WP (in time)
  - identify & distinguish WP (essentially) independent of detection technology:

    ex = mechanical support geometry, materials, ...
- Given the time constraints, we need to refocus from ultimate performances to those achievable within $\sim$ 3-4 years (?)
- We should try organising a combined effort task force $\mapsto$ document

CMOS Sensor based ILC Vertex Detector

- Geometry: 5 cylindrical layers (R=15 – 60 mm), $\|cos\theta\| \leq$ 0.90 – 0.96
- $\sigma_{\mathbf{IP}} = \mathbf{a} \oplus \mathbf{b}/\mathbf{p} \cdot \sin^{3/2}\theta$, with a $<$ 5 μm and b $<$ 10 μm
- Read-out time: ¶ 25 μs in L0 ¶ 50 μs in L1 $\therefore$ $\lesssim$ 200 μs in L2, L3, L4

Layer	Radius (mm)	Pitch (μm)	$t_{r.o.}$ (μs)	N_{lad}	N_{pix} (10^6)	P^{inst}_{diss} (W)	P^{mean}_{diss} (W)
L0	15	20	25	20	25	$<$100	$<$5
L1	25	25	50	26	65	$<$130	$<$7
L2	37	30	$<$200	24	75	$<$100	$<$5
L3	48	35	$<$200	32	70	$<$110	$<$6
L4	60	40	$<$200	40	70	$<$125	$<$6
Total				142	305	$<$565	$<$29



- Ultra thin layers: $\lesssim$ 0.1 % X_0/layer ?
- Very low P^{mean}_{diss}: $<<$ 100W ($\mapsto$ minimise cooling)
- Rad. tolerance (3 yrs): $\lesssim 3 \cdot 10^{10} n_{eq}/cm^2$ – $\lesssim 6 \cdot 10^{12} e_{10MeV}/cm^2$ (150 kRad, $2 \cdot 10^{11} n_{eq}/cm^2$)

Compromise Illustration: speed vs material

- $e^{\pm}_{BS}$ rate is $\sim$ twice less at R=18 mm than at R=15 mm
  Is it worth reducing the read-out time by a factor of two
  if additional material is introduced in the fiducial volume ?

  - Occupancy at R=15 mm with $t_{r.o.}$=25 μs is the same as at R=18 mm with $t_{r.o.}$=50 μs
  - Twice shorter r.o. time introduces $\lesssim$ 10 % additional material $\mapsto$ b increases by $\lesssim$ 5 %
  - Reducing R_{in} from 18 to 15 mm reduces b by $>$ 15 %

- Ccl: doubling the read-out speed (and thus adding material in the fiducial vol.) improves b by $>$ 10 %