FPCCD Vertex Detector for ILC

2007.2.6

@9th-ACFA, Beijing

Y. Sugimoto

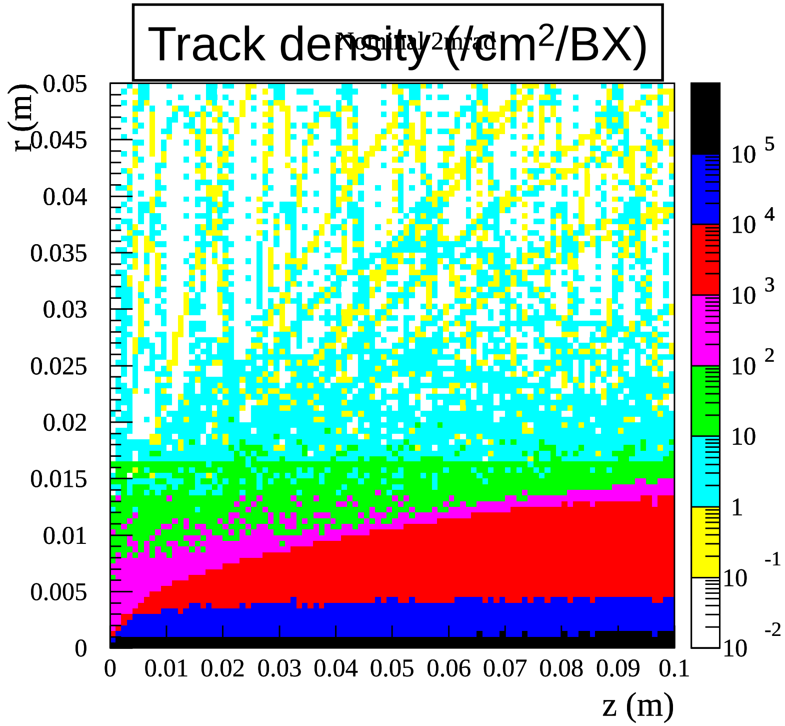
KEK

Challenge of ILC VTX

- To achieve the performance goal of $\sigma_{IP} = 5 \oplus 10/(p\beta \sin^{3/2}\theta)$ μm;
  - Material budget should be small: < 0.1% X_0 / layer
  - 1st layer should be put as close to the IP as possible
- Pair background at small R
  - ~2000 tracks/cm^2/train with B=3T and R=20mm
  - Pixel occupancy ~10% for 25μm pixel, if the signal of one bunch-train (2820 bunches) is accumulated
  - In order to keep the occupancy small (<1%),
    - read out 20 times per train (1ms), or
    - 20 times finer pixel

    is necessary

➔ FPCCD



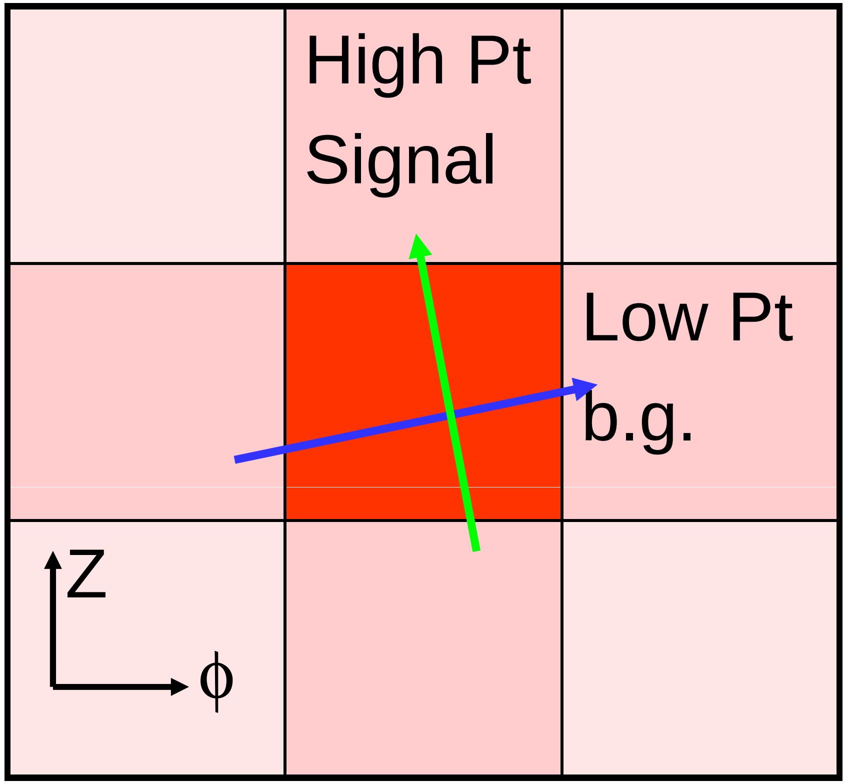
- Electro-magnetic interference (EMI) caused by short-bunch beam

FPCCD Vertex Detector

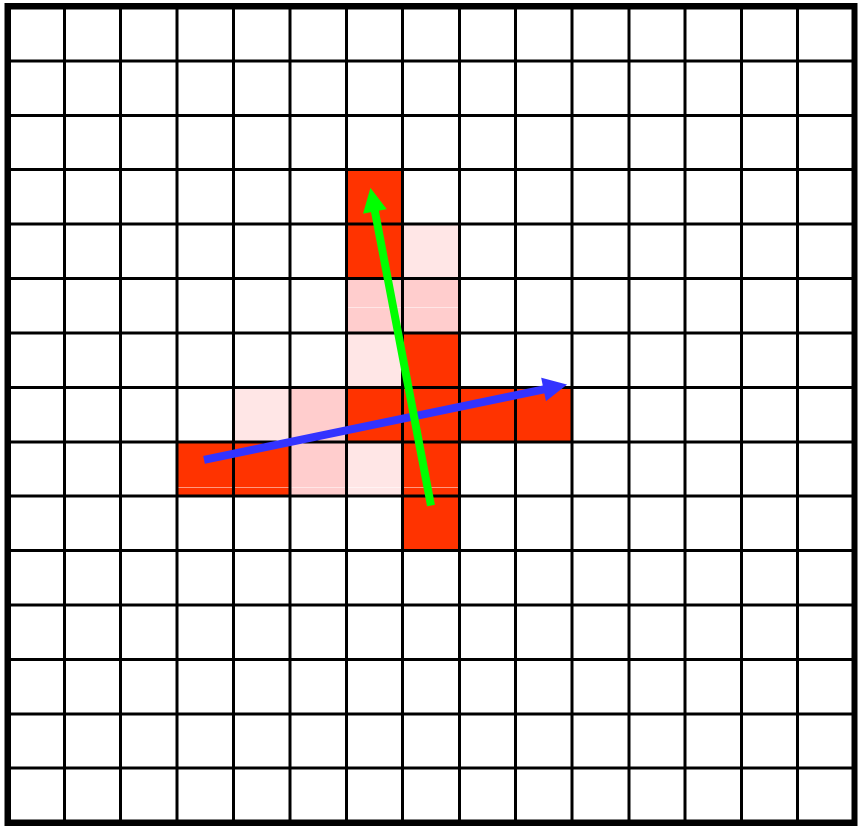
- Accumulate hit signals for one train (2840 BX) and read out between trains (200ms) → Completely free from EMI
- Fine pixel of ~5μm (x20 more pixels than "standard" pixels) to keep low pixel occupancy
  - Spatial resolution of ~1.5μm even with digital readout
  - Excellent two-track separation capability
- Fully depleted epitaxial layer to minimize the number of hit pixels due to charge spread by diffusion
- Two layers in proximity make a doublet (super layer) to minimize the wrong-tracking probability due to multiple scattering
- Three doublets (6 CCD layers) make the detector (in GLD DOD)
- Tracking capability with single layer using hit cluster shape can help background rejection
- Multi-port readout with moderate (~20MHz) speed (Very fast readout (>50MHz) not necessary)
- Simpler structure than FAPS or ISIS → Large area
- No heat source in the image area

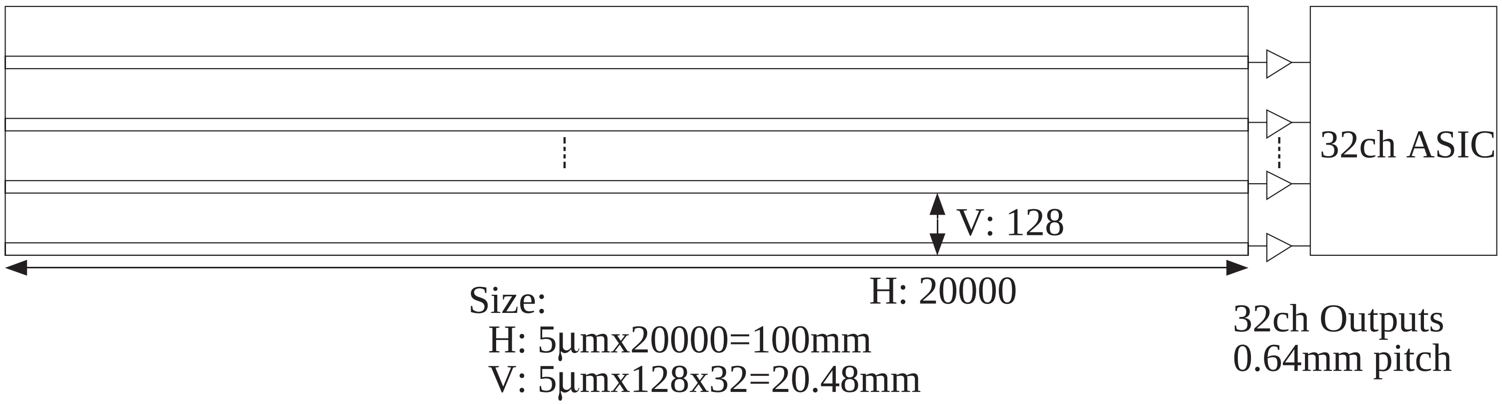
- B.G. rejection by hit cluster shape
  (tracking capability with single layer!)
  ➔ B.G. suppression factor of 2 (cosθ~0) – 20 (cosθ~0.9) is expected

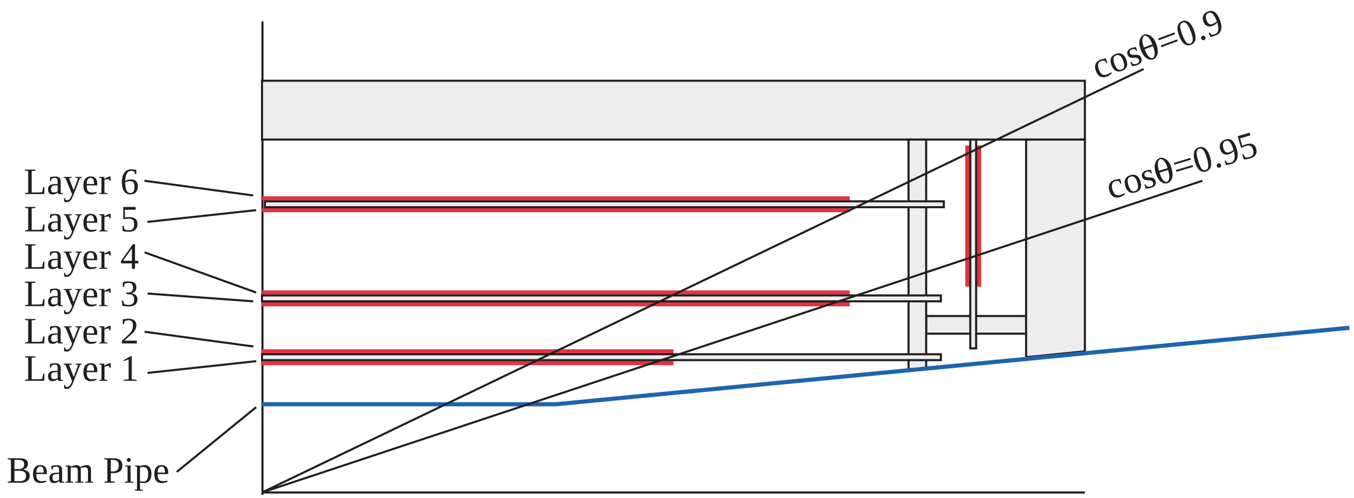
- Standard CCD



- Fine Pixel CCD







Layer	R (mm)
1	20
2	22
3	32
4	34
5	48
6	50

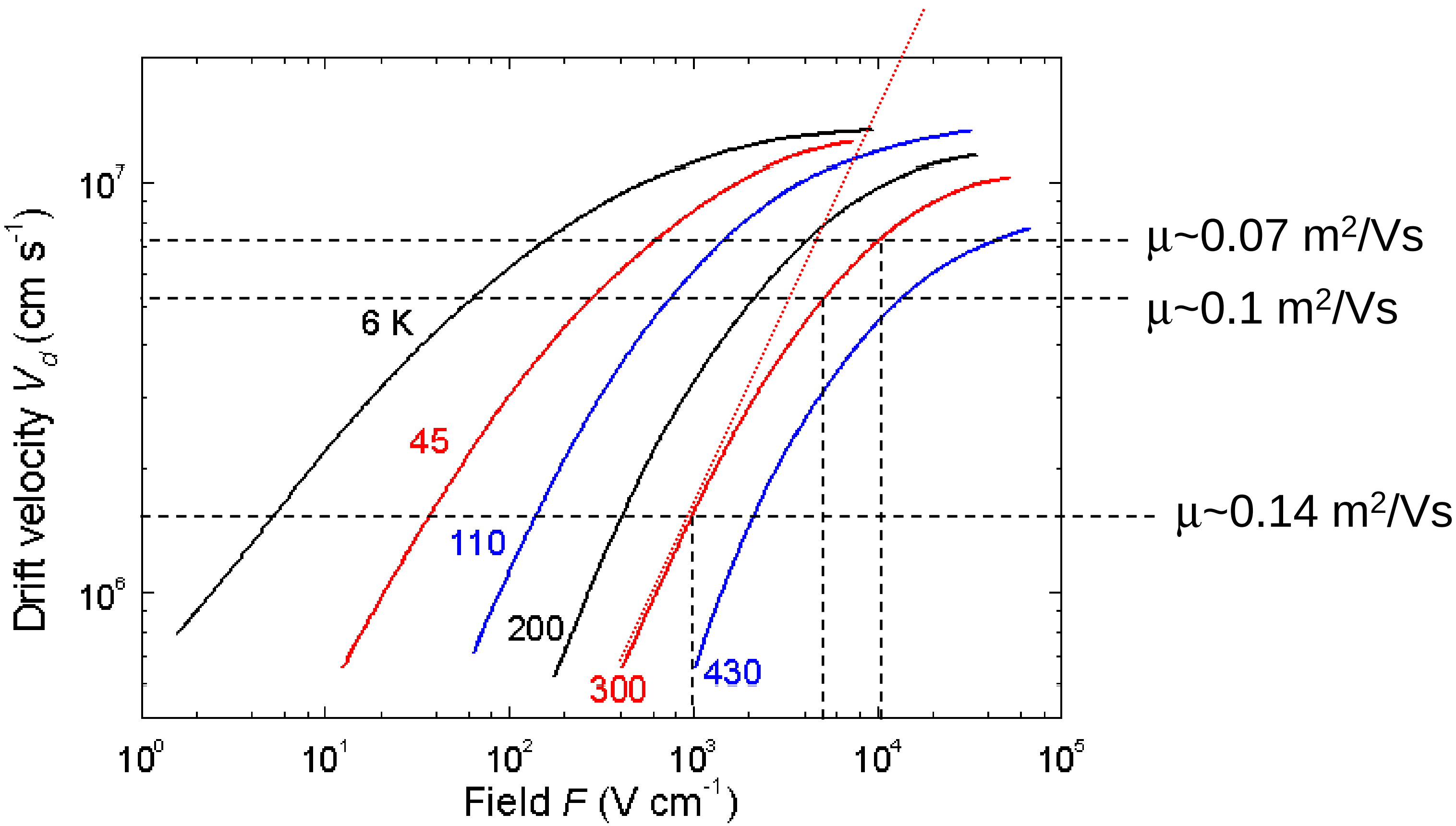
Challenge of FPCCD

- Fully depleted – charge spread
- Lorentz angle
  - $\tan\theta = r_H \mu B$, r_H: Hall coefficient~1, μ: mobility (m^2/Vs), B: Magnetic field (T)
  - Stronger E-field in dep. layer (>10^4V/cm = 1V/μm) gives saturation of carrier velocity and smaller μ

  ➔ Epi layer of ~15μm would be OK
- Radiation tolerance
- Small pixel （~5 μm)
- Fast readout speed （~20Mpix/s）
- Multi-port readout
  - H-Register in image area
- Low noise:
  - <50 e (total) → < 30 e (CCD)
- Low power consumption
  - Metal layer
  - Low drive pulse voltage
  - Output circuit
- Large area:10x65mm^2（in）/20x100mm^2（out）
- Thin ladder （<0.1%X_0/layer)
  - Essential for FPCCD option (high hit density)
- Full well capacity
  - >10^4 e is OK
- Readout ASIC
  - Necessary for proto-type ladder

Lorentz angle

- $\tan\theta = r_H \mu B \sim \mu B$ (μ:m^2/Vs, B:T), $\mu = v/E$



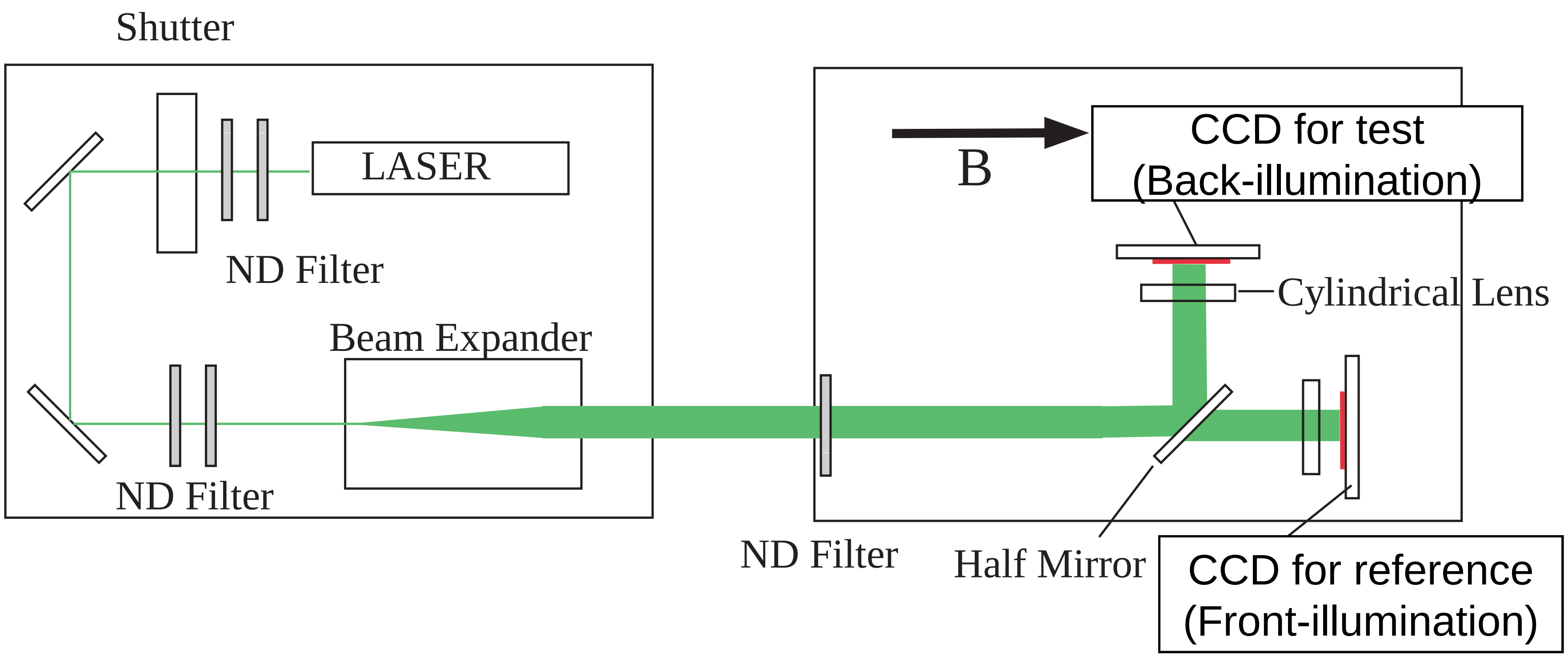
R&D for FPCCD

- Study of fully depleted CCD
  - Charge spread
  - Lorentz angle
  - Radiation damage
- Development of FPCCD
  - 3 rounds expected
  - Prototype ladder in 5 years
  - Collaboration with Hamamatsu
- Minimization of material budget
  - Wafer thinning
  - Si-RVC-Si sandwich structure
- Development of readout ASIC

Partially funded

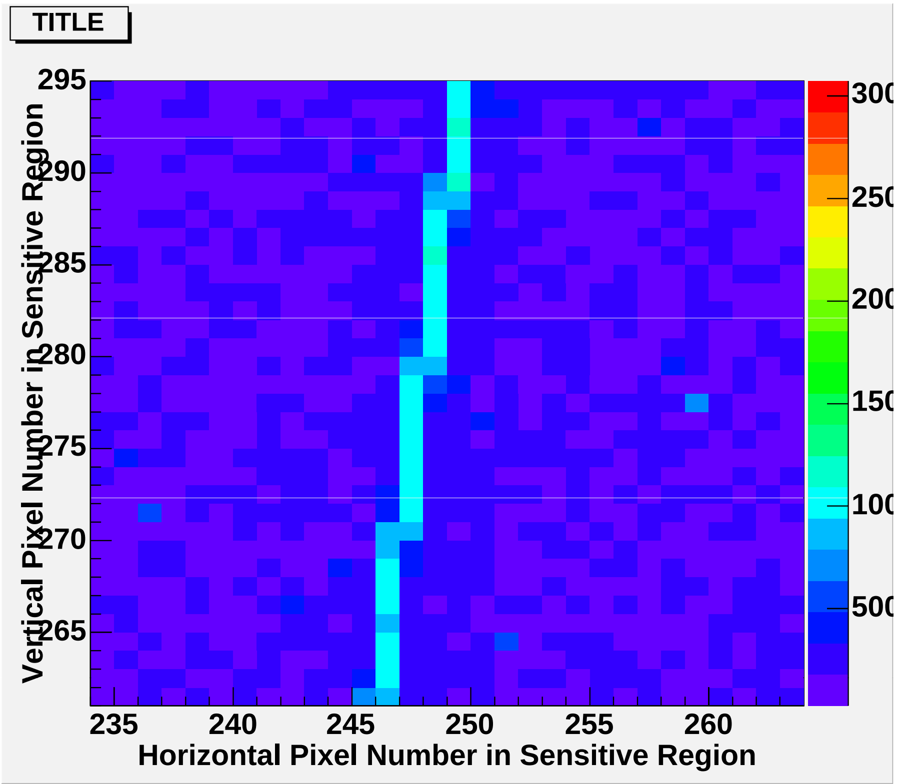
Study of charge spread

- Apparatus

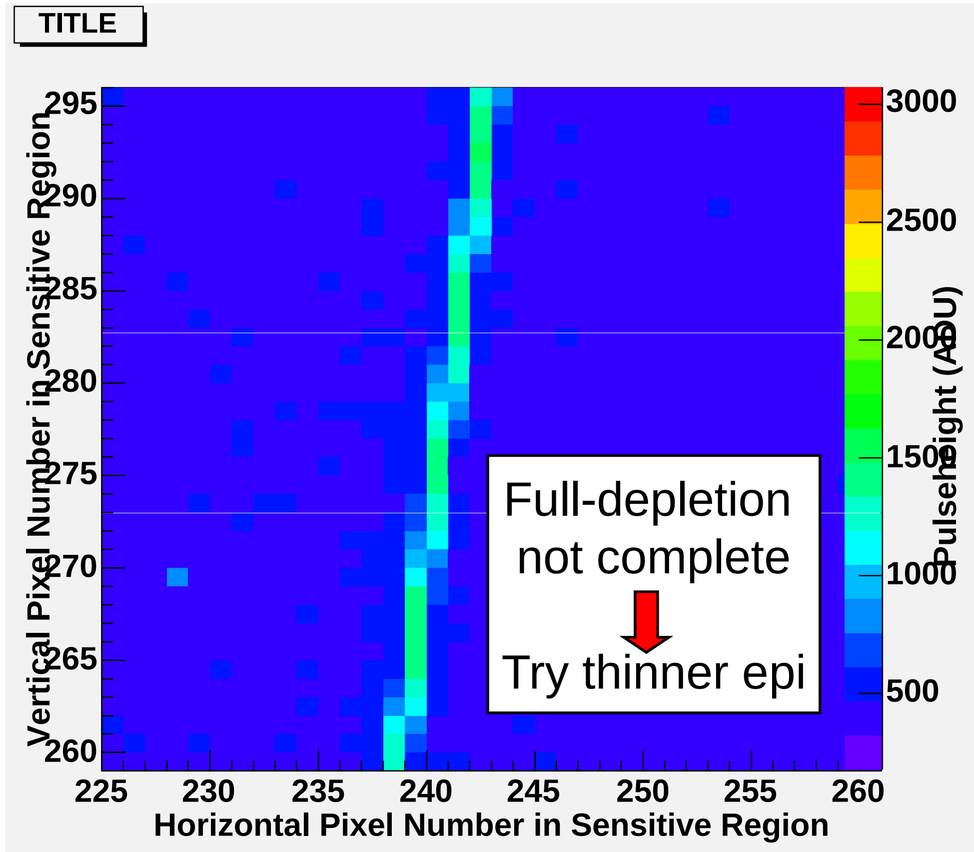


Charge spread

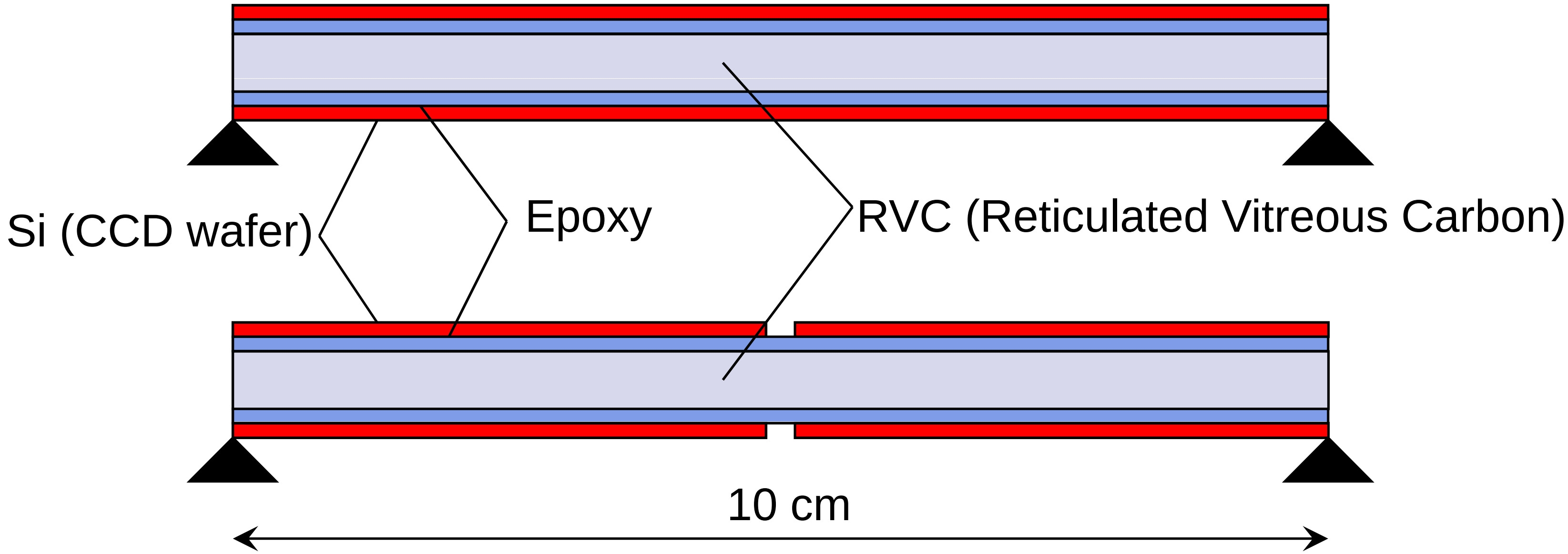
- Front illumination
- Standard



- Back illumination
- Deep2 (30µm epi)



FEA of Ladders



Deformation by self-weight is calculated by FEA program COMSOL

FEA of Ladders

- Parameters (assumption)

	Density (g/cm^3)	X0 (g/cm^2)	E (GPa)
Si	2.33	21.8	110
Epoxy	1.15	40.9	3
RVC	0.05	42.7	0.031

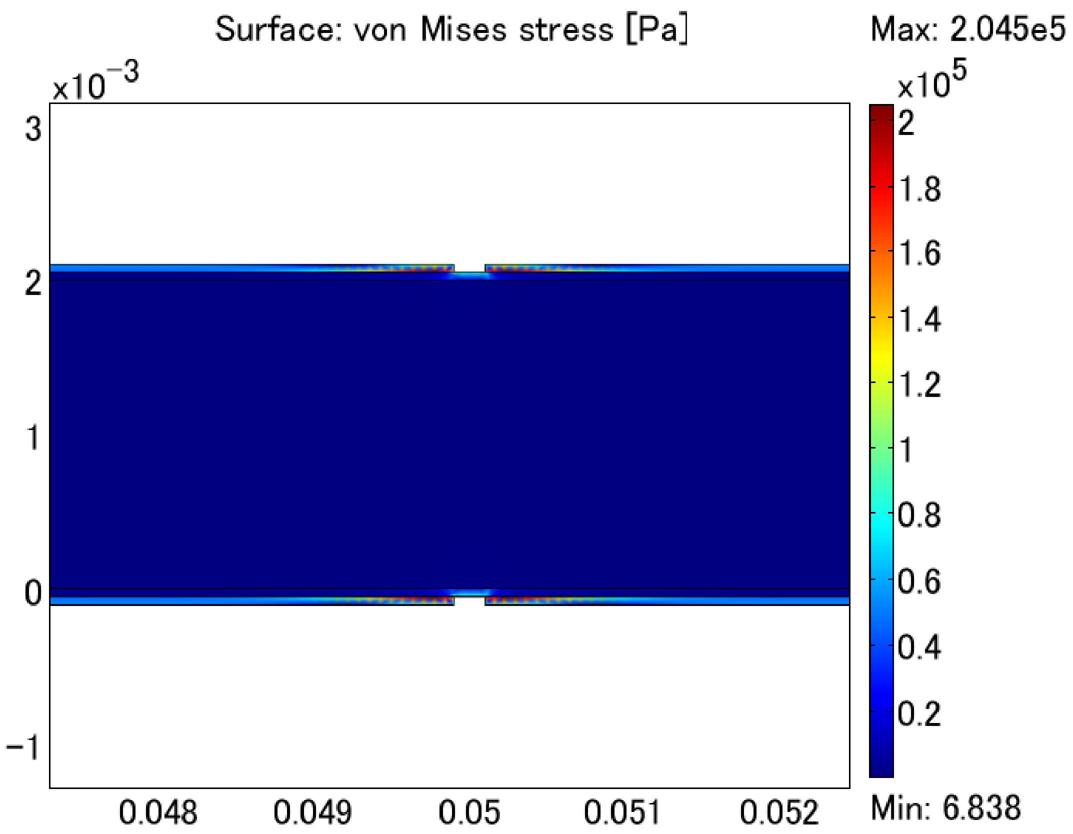
- Geometry

	Thickness	Weight	Radiation length
Si	50 μm	0.01165 g/cm^2	0.0534%X_0
Epoxy	50 μm	0.00573 g/cm^2	0.014%X_0
RVC	2 mm	0.0084 g/cm^2	0.0234%X_0
Epoxy	50 μm	0.00573 g/cm^2	0.014%X_0
Si	50 μm	0.01165 g/cm^2	0.0534%X_0
Sum		**0.04316 g/cm^2**	**0.1582%X_0**

0.08%X_0/layer

FEA of Ladders

- Results
  - Maximum deformation:
    - Without gap : v_{max}=0.536 μm
    - With 0.2mm gap : v_{max}=0.723 μm
  - For longer ladders
    - $v_{max} \sim l^4$ ➔ ~8.6 μm for 20cm ladder without gap



Summary

- We have started R&D of FPCCD for ILC vertex detector
- Study of fully depleted CCD is on going in FY2006, and will be continued to FY2007
  - CCD sample with 30μm epi seems not fully depleted
  - We will try to measure 15μm epi sample soon
  - Lorentz angle measurement and radiation damage test are planned
- Finite element analysis was done for a ladder of Si-RVC-Si sandwich structure
  - 0.08% radiation length per layer with [50μm Si]x2 + [50μm epoxi]x2 + [2mm RVC]
  - Deformation by self weight is less than 10μm for 20cm long ladder
- The 1st test sample of FPCCD is expected to be made by Hamamatsu in FY2007
- We wish to construct and test prototype ladders of FPCCD in 4years, but the budget (for r.o. ASIC and support structure) is not enough to complete that goal