Fine Pixel CCD R&D in Japan

Yasuhiro Sugimoto
KEK
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@Snowmass05

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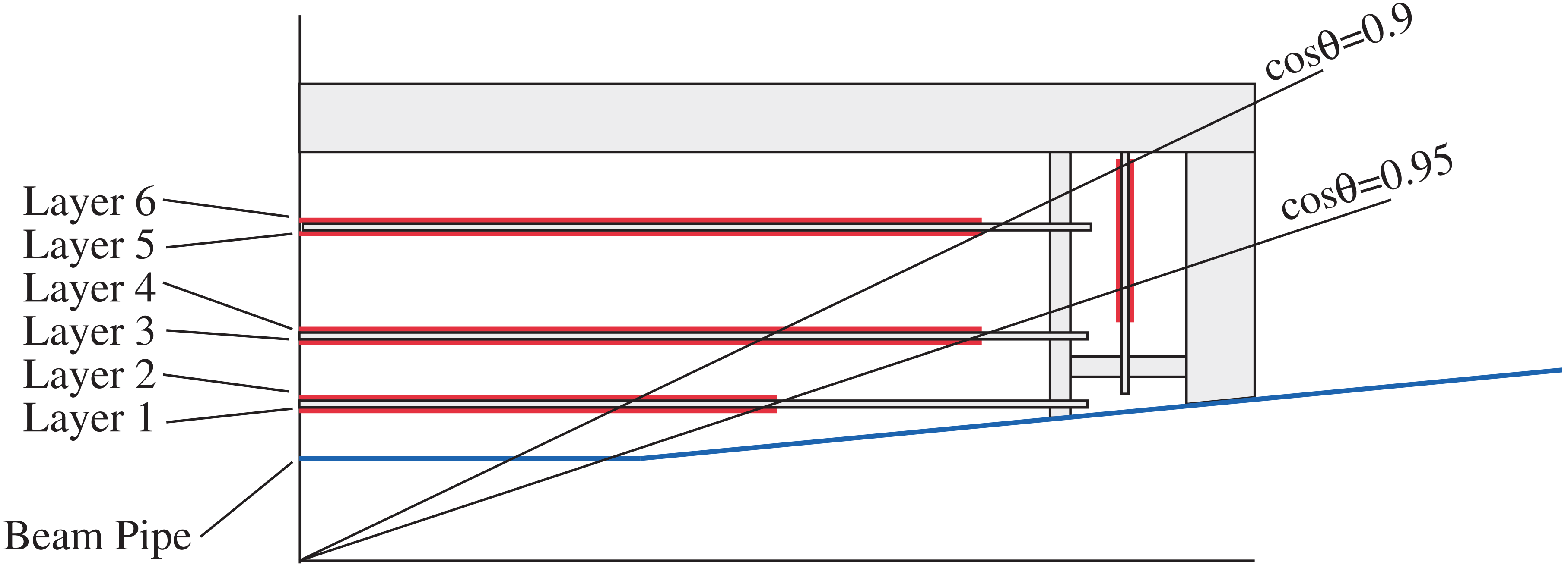
Introduction

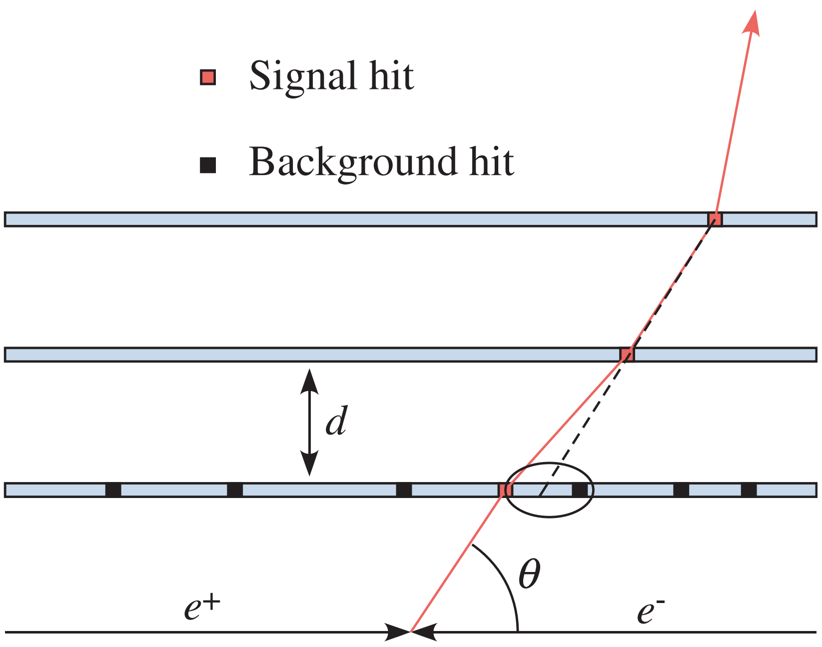
- FPCCD Vertex Detector
  - Accumulate hit signals for one train and read out between trains → Completely free from EMI
  - Fine pixel of ~5μm (x20 more pixels than “standard” pixels) to keep low pixel occupancy
  - Fully depleted epitaxial layer to minimize the number of hit pixels due to charge spread by diffusion
  - Two layers in proximity make a doublet (super layer) to minimize the wrong-tracking probability due to multiple scattering
  - Tracking capability with single layer using cluster shape can help background rejection
  - Three doublets (6 CCD layers) make the detector
  - Multi-port readout with moderate (~15MHz) speed
  - Operation at low temperature to keep dark current negligible (r.o. cycle=200ms)

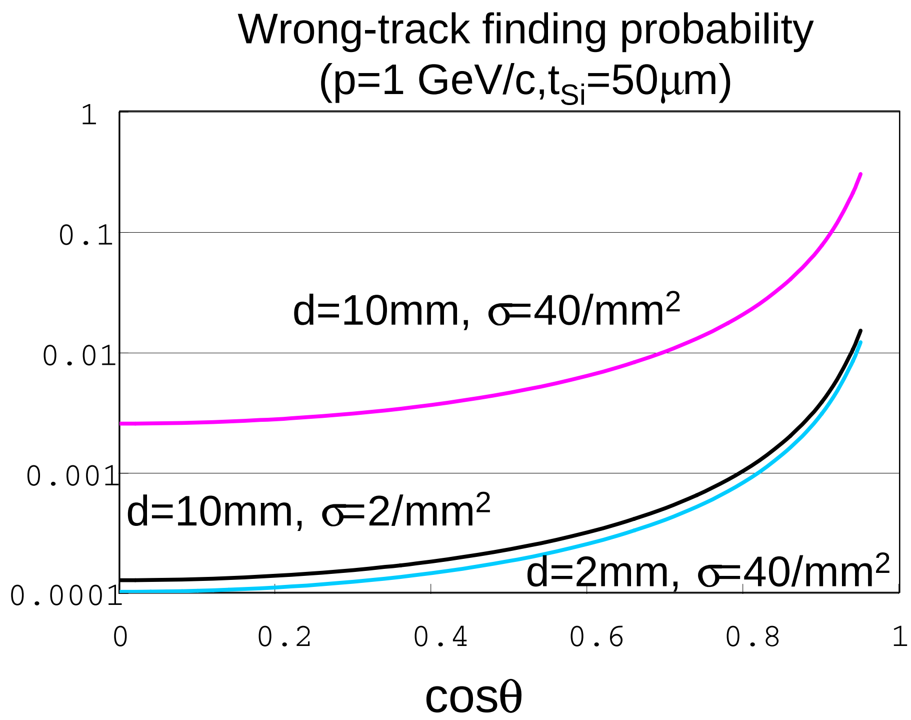
- Baseline design for GLD



Simulation study:
Background rejection by cluster shape

- Disadvantage of Fine Pixel option:
  - High hit density: ~40/mm^2/train at R=20mm, B=3T, nominal option at 500 GeV
  - Background hit can cause wrong-track finding
  - We need background rejection

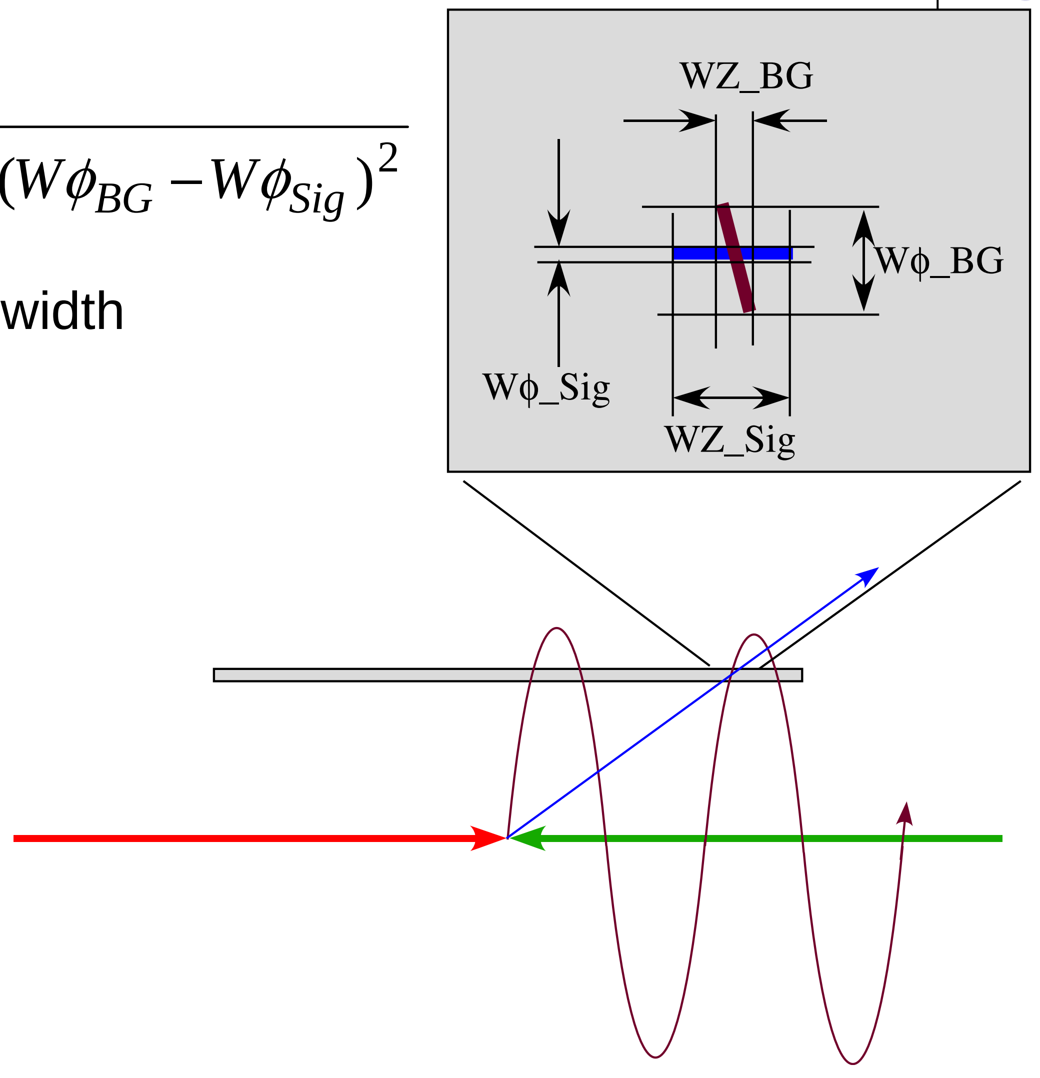




Background rejection by cluster shape

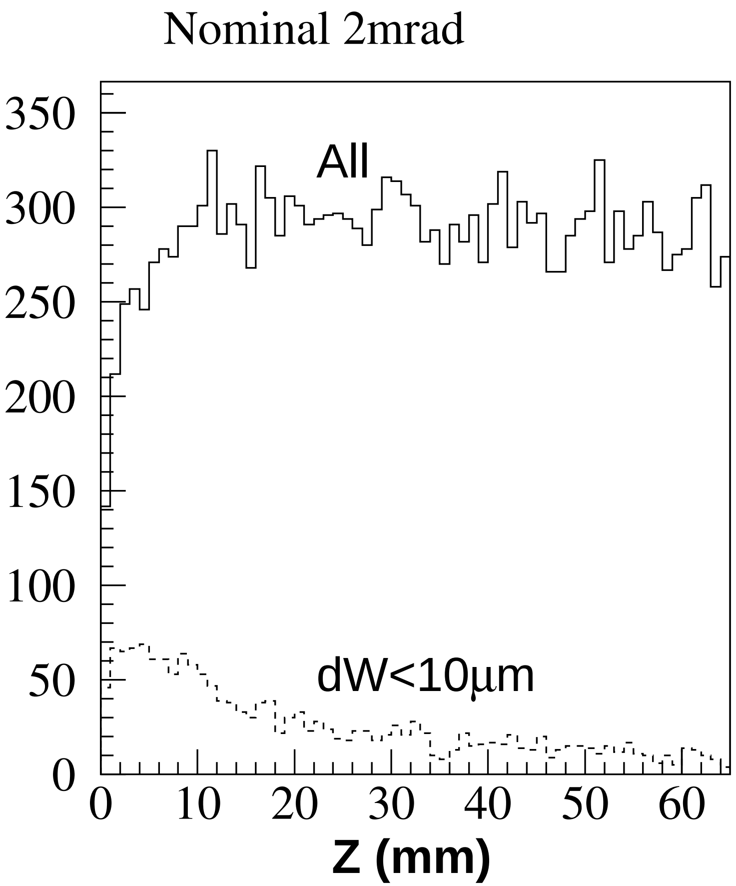
$$dW = \sqrt{(WZ_{BG} - WZ_{Sig})^2 + (W\phi_{BG} - W\phi_{Sig})^2}$$

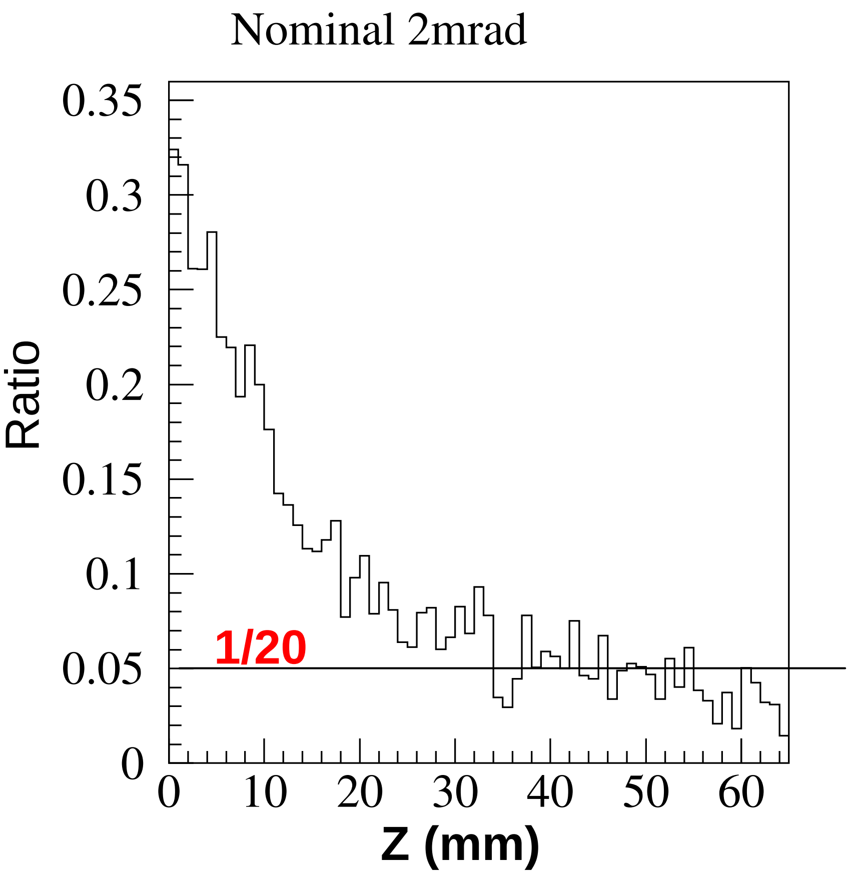
WZ_{Sig}, $W\phi_{Sig}$: Expected width



B.G. rejection by cluster shape

- R=20mm
- Cut at dW=10μm

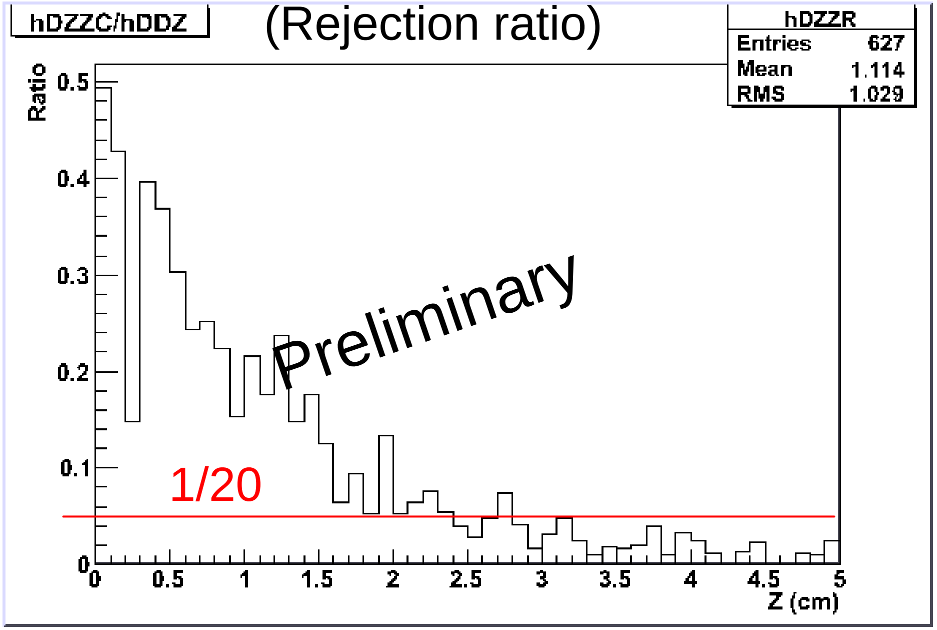




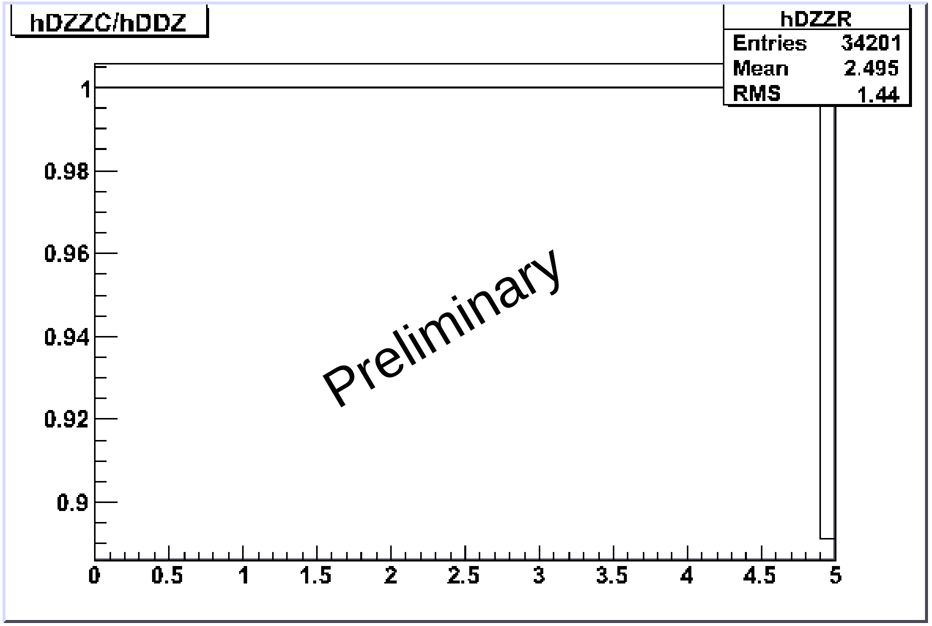
B.G. rejection by cluster shape

- Detector full simulation
  - $N_Z > Z(\mathrm{cm}) \times 1.2$, $N_x < 3$

Efficiency for pair b.g. (Rejection ratio)

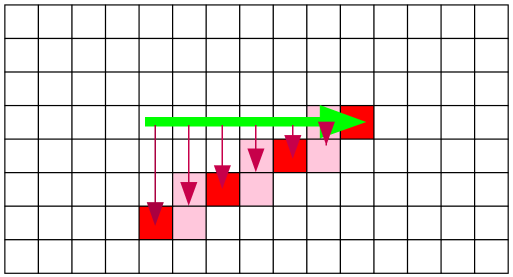


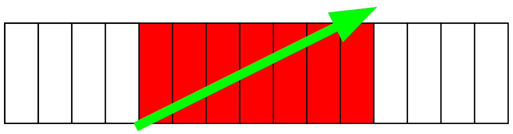
Efficiency for 1 GeV/c muon



T. Nagamine

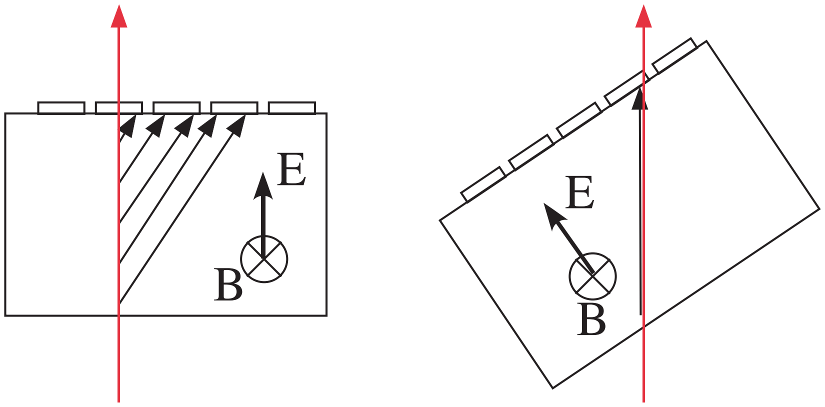
Lorentz angle in epi-layer





- Lorentz (Hall) angle in depleted-layer
  - $\tan\theta = \mu_n B$
    μ_n: electron mobility
  - Carrier velocity saturates at high E field:
    - $\mu_n = 0.07\ m^2/Vs$ @T=300K, $E = 1\times10^4 V/cm$
    - $\mu_n = 0.045\ m^2/Vs$ @T=300K, $E = 2\times10^4 V/cm$
  - Small angle can be cancelled by tilting the wafer
- May not be a serious problem
  - Number of hit pixels does not increase so much

	B=3T	B=5T
$E=1\times10^4 V/cm$	θ=12deg	θ=19deg
$E=2\times10^4 V/cm$	θ=7.7deg	θ=13deg

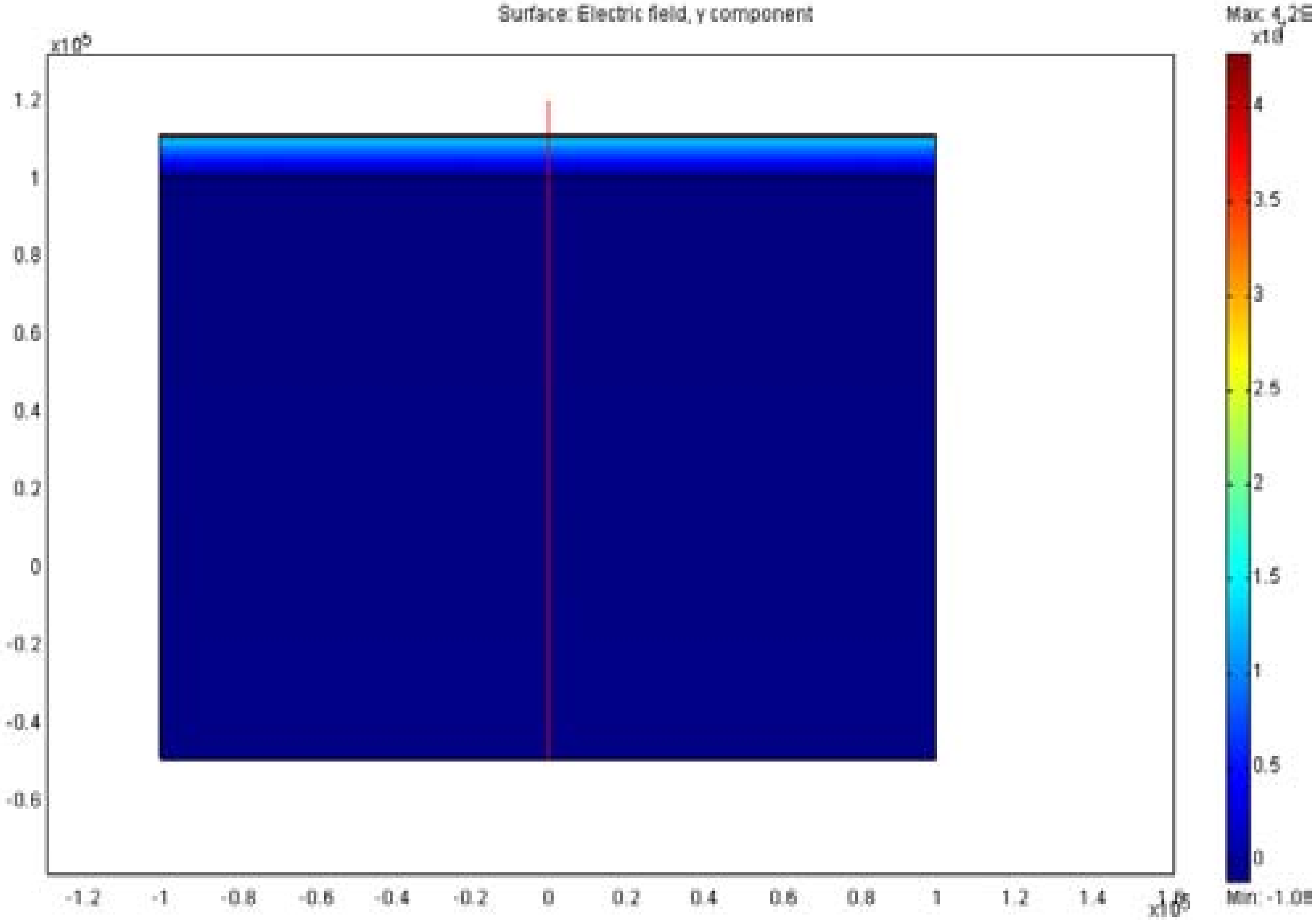


Lorentz angle

- Calculation of E-field in epi-layer
  - Tools
    - FEMLAB (COMSOL in Japan) 3.1
    - Solve Poisson equation by finite element analysis (FEA)
  - Parameters
    - Material is assumed fully depleted (No free charge)
    - n-layer: $N_D=1x10^{16}/cm^3=1.6x10^3$ C/m^3
    - Epi-layer: $N_A=1x10^{13}/cm^3=-1.6$ C/m^3
    - $V_G=4$ V
    - $t_{SiO2}=100$ nm
    - $t_n=1$ μm
    - $t_{epi}=15$ μm

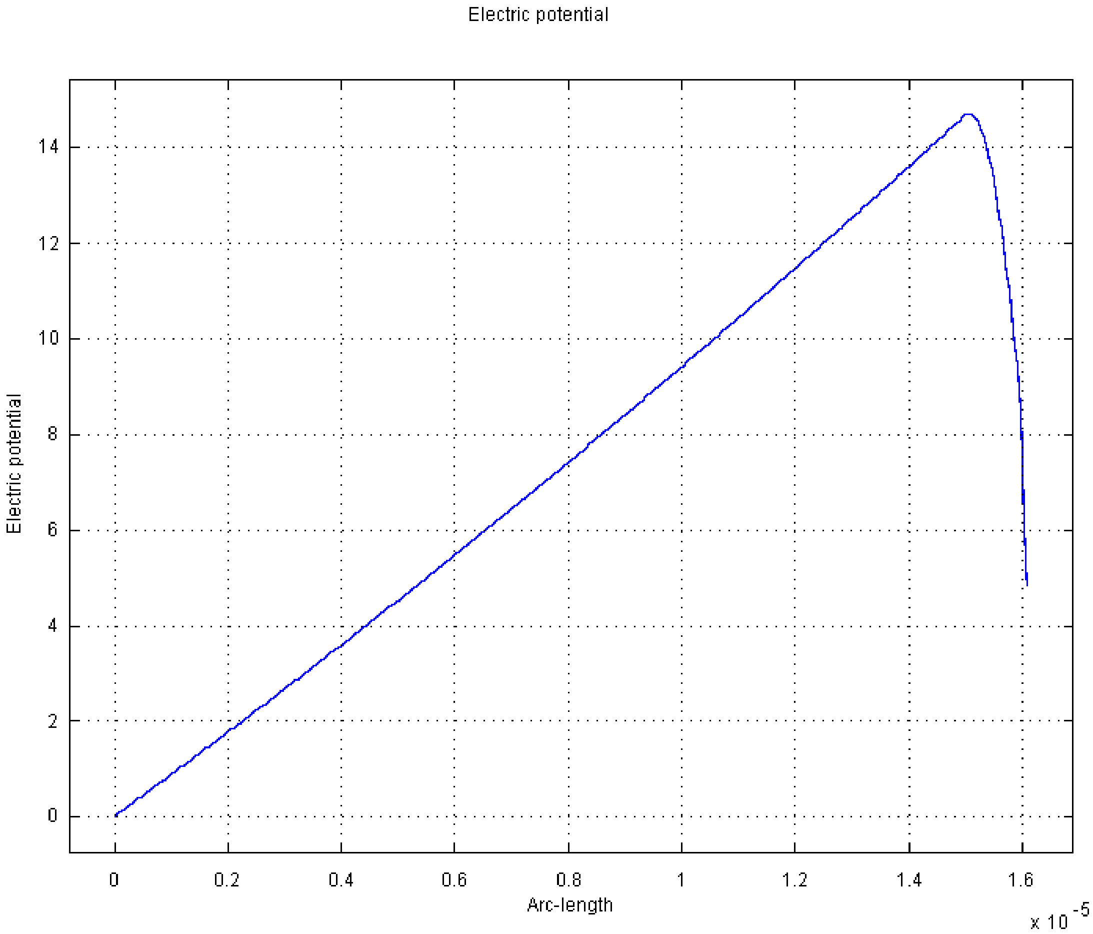
Lorentz angle

- Result of E-field calculation



Lorentz angle

- Result of E-field calculation – Potential



Lorentz angle

- Result of E-field calculation – Summary
  - Almost constant E-field of ~10^4V/cm in epi-layer can be achieved
  - E-field in epi-layer depends on gate voltage
    - Higher (positive) gate voltage gives higher E-field
    - Positive gate voltage should be applied during train crossing in order to get saturated carrier velocity and less Lorentz angle (Inverted (MPP) mode can be maintained for ~1ms at low temperature)
  - The Lorentz angle of 12 degrees is expected at B=3T

Status of sensor R&D

- Fully depleted CCD for astrophysics by Hamamatsu
  - 24 μm, 12 μm pixel size:
    - Available now
    - We will test them in this FY
  - 5 – 9 μm pixel size:
    - Under development
    - Will be available in 0.5 – 1 year
- Custom fully depleted FPCCD for VTX
  - High speed (~15MHz)
  - Multi-port readout
  - We wish to start in 2006

Summary

- We propose FPCCD option for the ILC vertex detector
  - Fully depleted fine pixel (~5μm) CCD
  - Accumulate hits of 1 train and read out between trains
- FPCCD has several advantages
  - Completely free from EMI
  - Moderate readout speed
  - CCD is established technology
  - No heat source in the image area
- Disadvantage of FPCCD – high background hit density – can be overcome by background rejection using hit cluster shape
- Estimated Lorentz angle in the depleted layer is small (~12 degrees) at 3T
- Fully depleted CCD is already available
- FPCCD for astrophysics is being developed by Hamamatsu
- We would like to start development of custom FPCCD for ILC from 2006
- Wafer thinning is essential for FPCCD option. We need R&D