Vertex Detector for GLD

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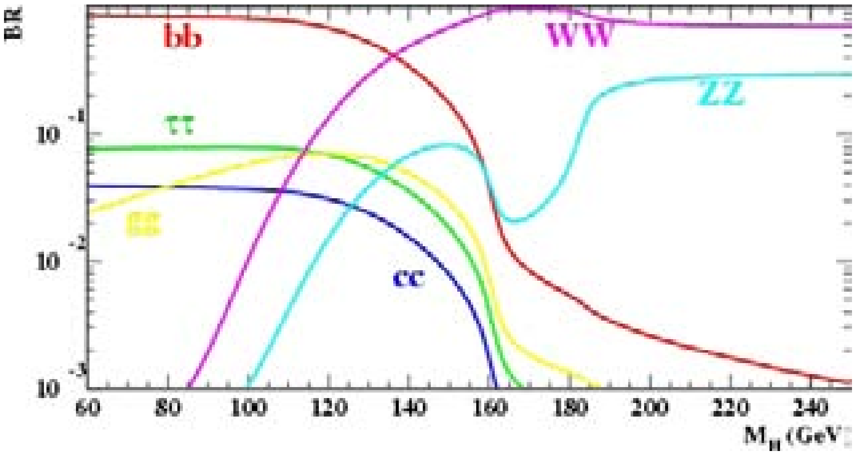
@Snowmass

Requirement for performance

- Role
  - Flavor tagging: τ, c, b

    → Important for many physics analyses: e.g. Higgs branching ratio measurement
  - Quark/anti-quark tagging (Vertex charge measurement)



- Performance goal: Impact parameter resolution of

$$\sigma = 5 \oplus \underbrace{10/(p\beta \sin^{3/2}\theta)}\ \mu\text{m}$$

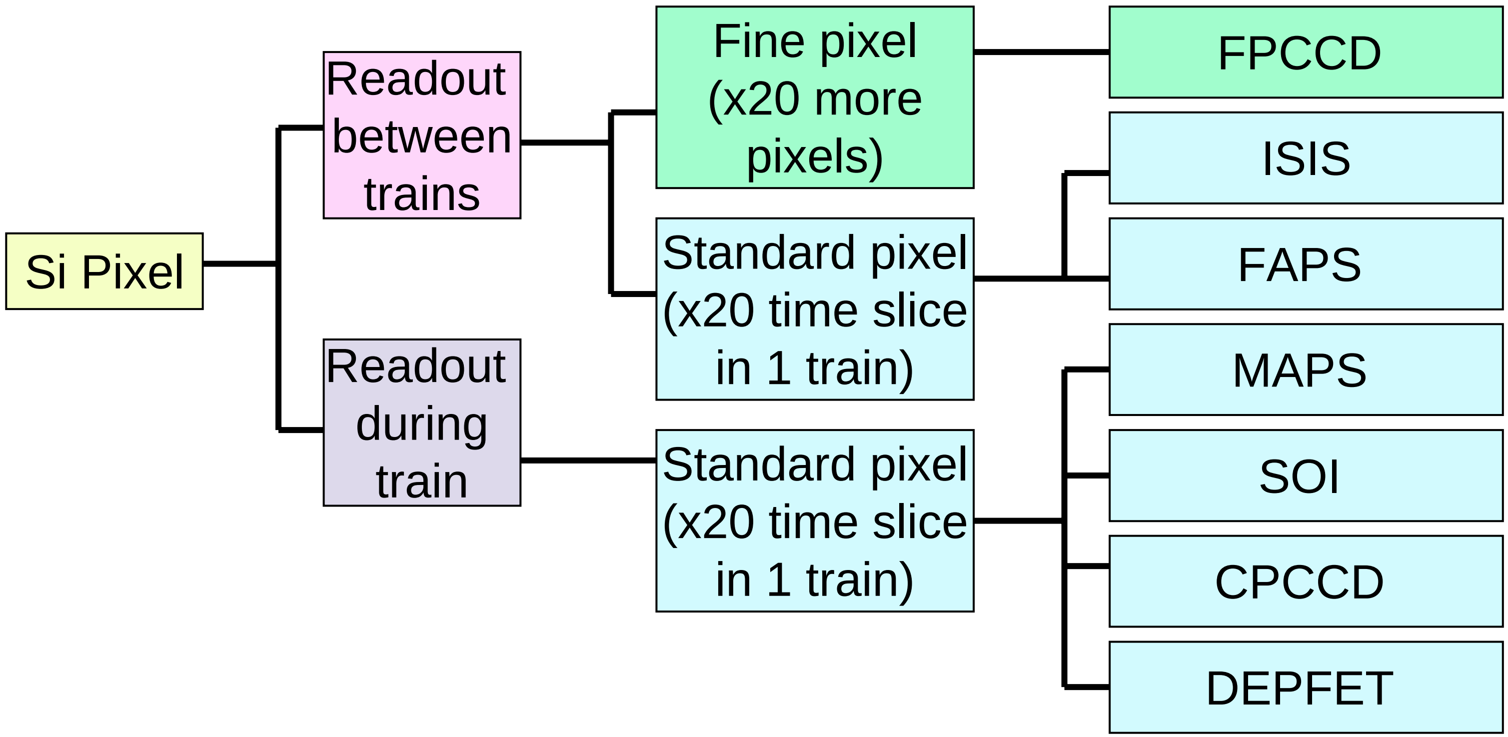
This M.S. term demands R&D efforts:
- Very thin wafer/beam-pipe and support structure
- Put 1st layer close to the interaction point (high b.g.)

Questions for optimization

- Sensor technology
- Inner / Outer radius
  - Background
  - Physics
- $\cos\theta$ coverage
  - Physics
  - Interface with FIT
- Support structure/Readout elec.
- Tracking efficiency v.s. background
- Effect of other PID devices (dE/dx, TOF etc.)
  - Flavor tag
  - Quark charge tag

Sensor technology

- A lot of sensor technologies are proposed but none of them has been demonstrated to work at ILC
- For the moment, we assume “Fine Pixel” option as the baseline design of GLD because it is unique (different configuration from standard pixel options which are assumed in SiD and LDC)



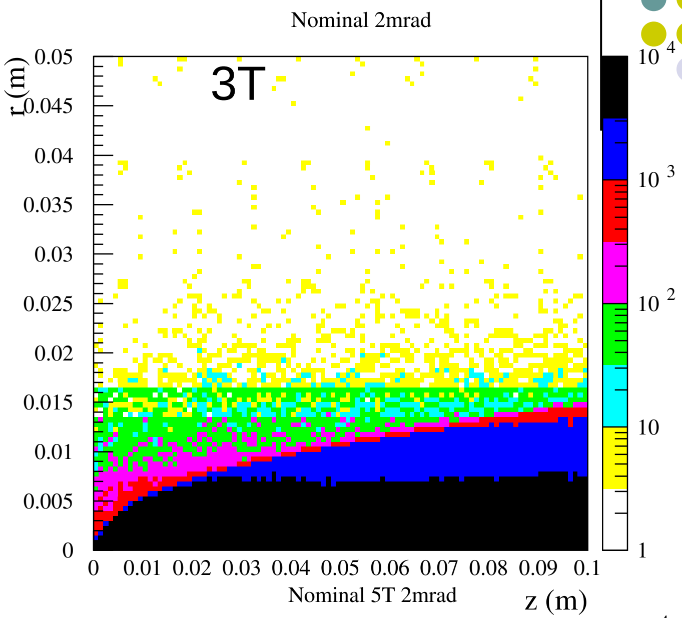
Inner radius: Background

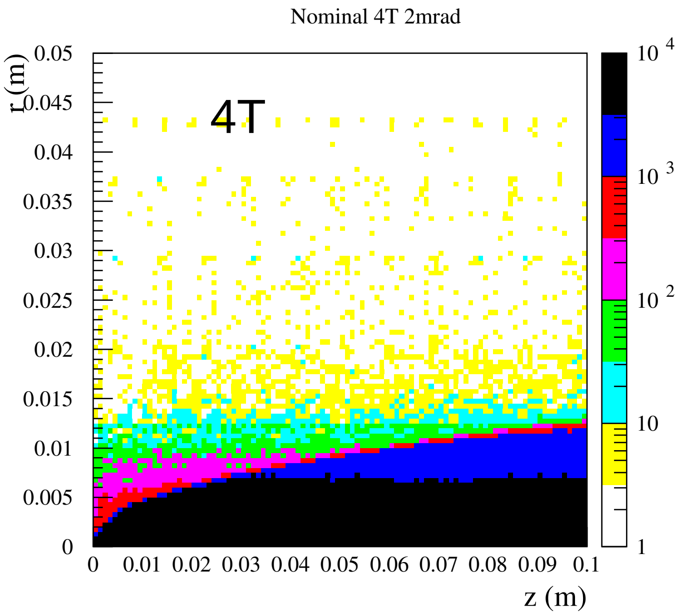
- Design criteria: Pair-background core should not hit the beam pipe
- B and Machine parameter dependence of R_{VTX} will be presented at the vertex sub-system working group session on 23ed and at the vertex session of GLD w.g. on 25th
- Baseline design should be compatible with the worst case

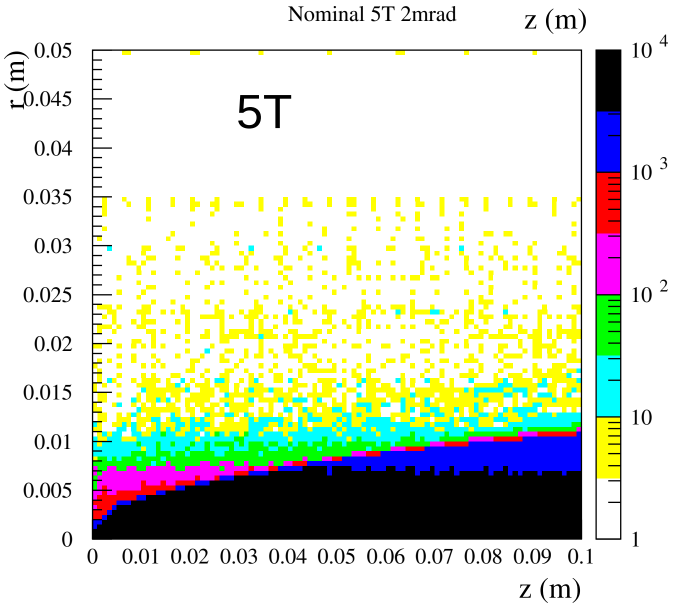
Inner radius: Pair background

- Simulation by CAIN
- B-dependence

(Track density: $1/cm^2/BX$)

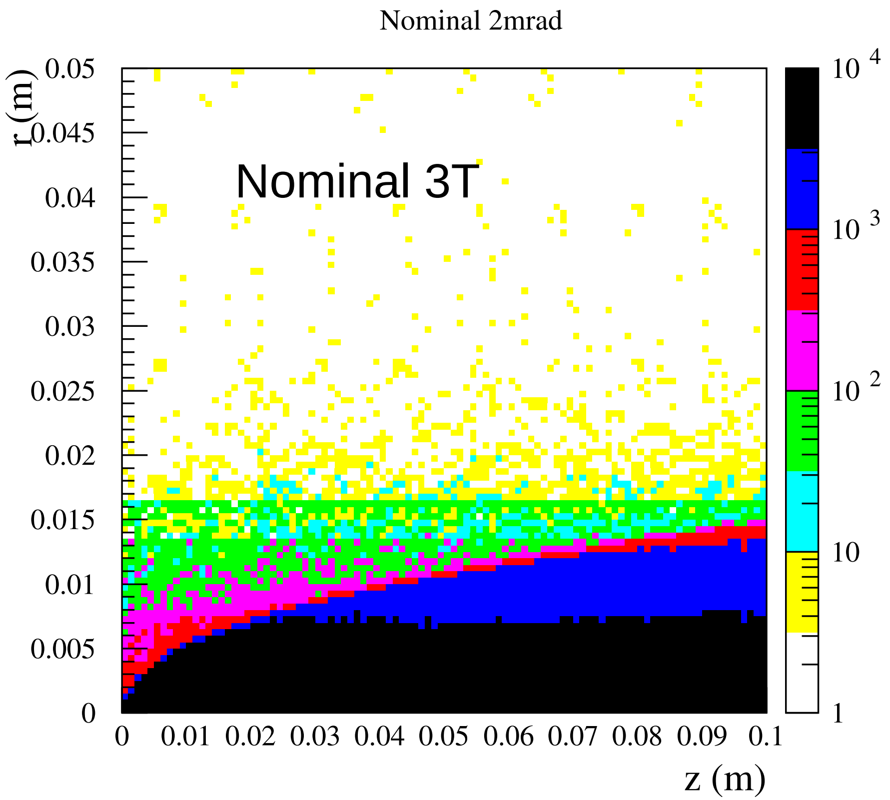


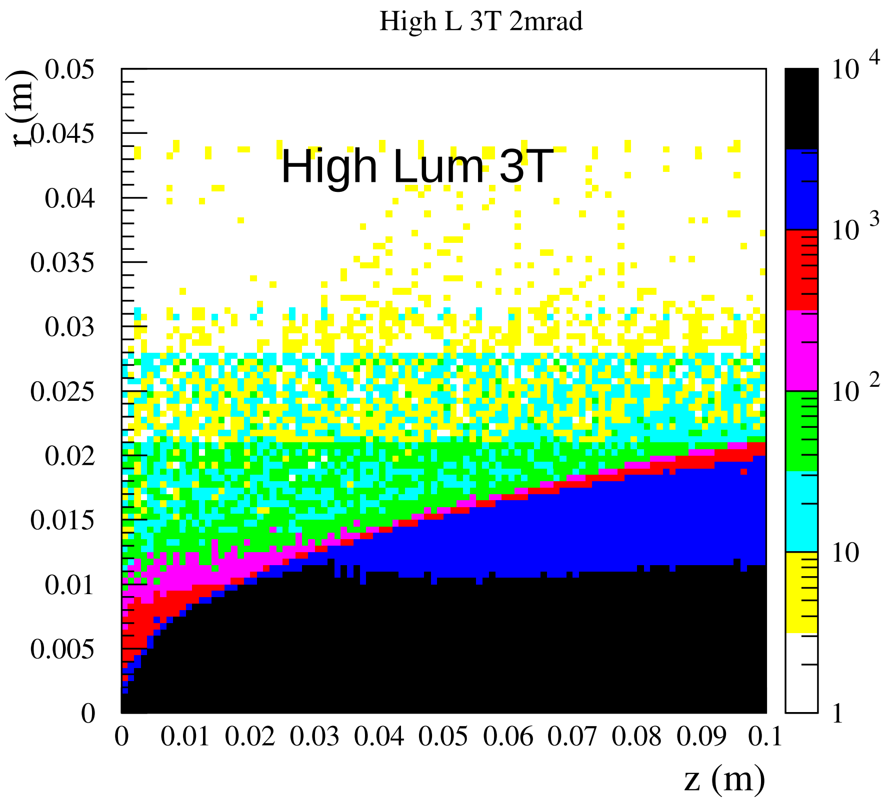




Inner radius: Pair background

- Machine-option dependence (1)

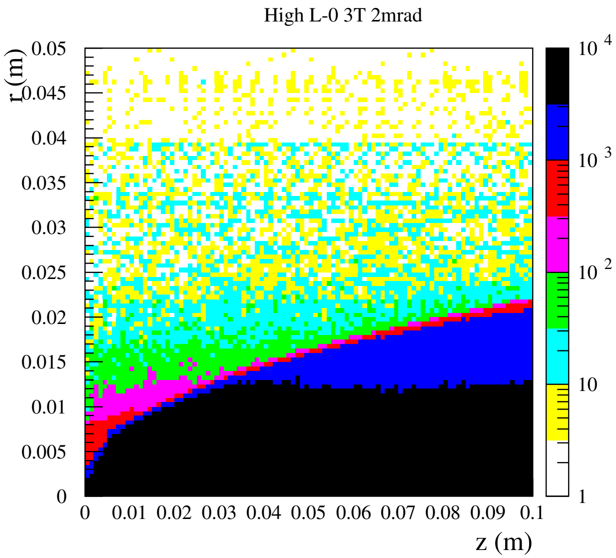




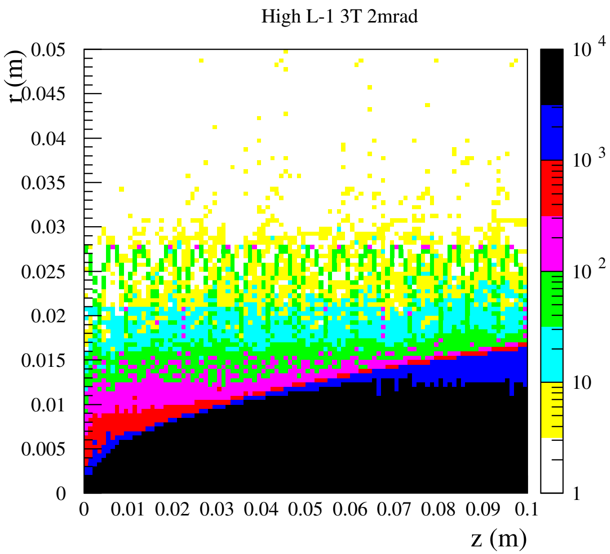
Inner radius: Pair background

- Machine-option dependence (2)
  - Comparison of Tor's parameter and Andrei's parameter at 1TeV

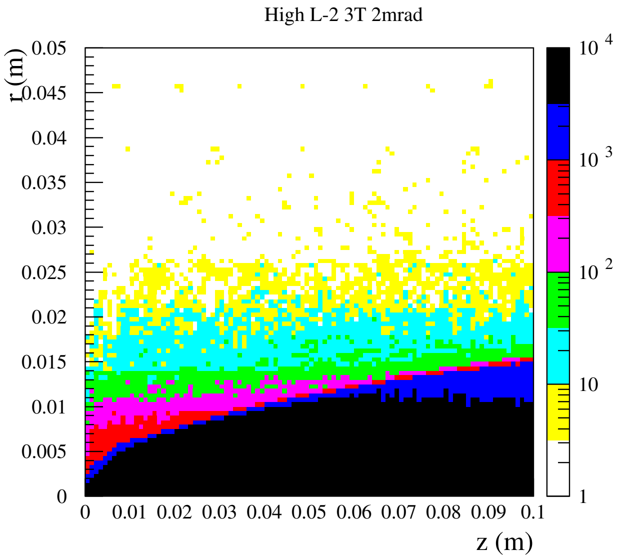
Tor, 1TeV 3T



Andrei – I, 1TeV 3T



Andrei – II, 1TeV 3T



Inner radius

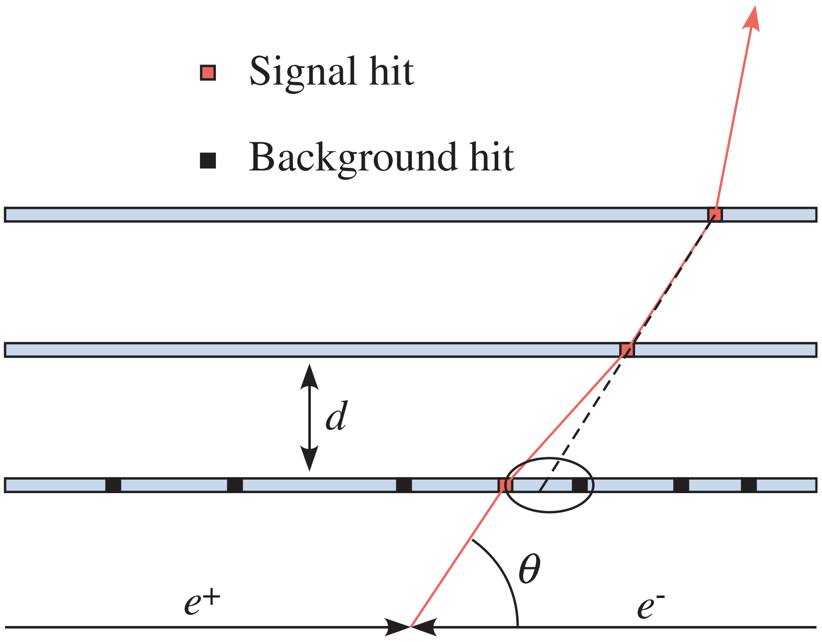
- More to be considered:
  - Synchrotron radiation
    - L*
    - Crossing angle
  - Back-scattering from BCAL
    - Hole size of low-Z mask
      - Synchrotron radiation
      - L*, Crossing angle
  - Physics

Outer radius

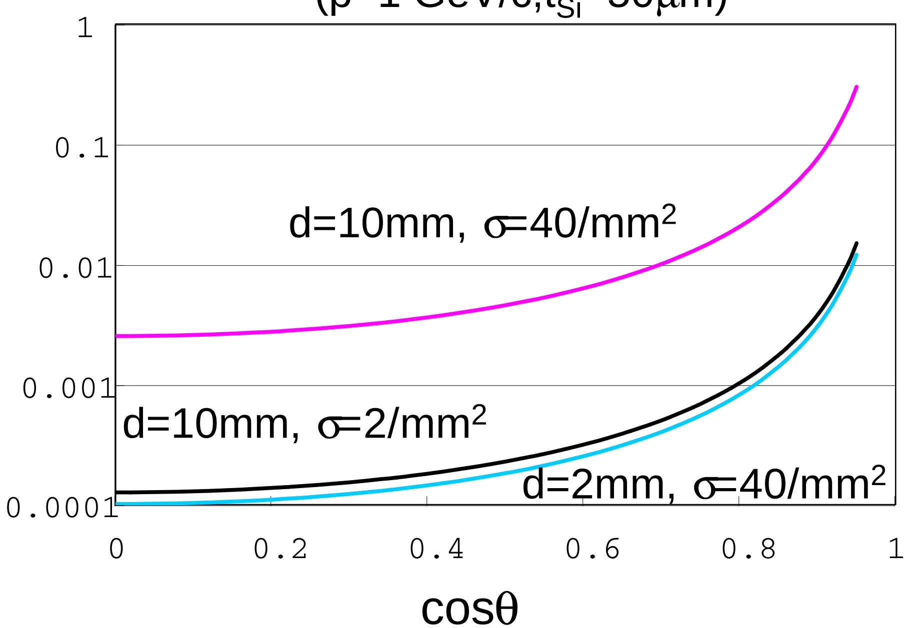
- In GLD, outer radius of VTX is not crucial for the impact parameter resolution of high momentum tracks
  - High precision outer trackers (TPC and IT) works as “outer layer” of the vertex detector
  - VTX layer configuration should be determined from the view point of;
    - Track finding under high background rate
    - Impact parameter resolution for low momentum tracks

Tracking efficiency v.s. B.G.

- 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

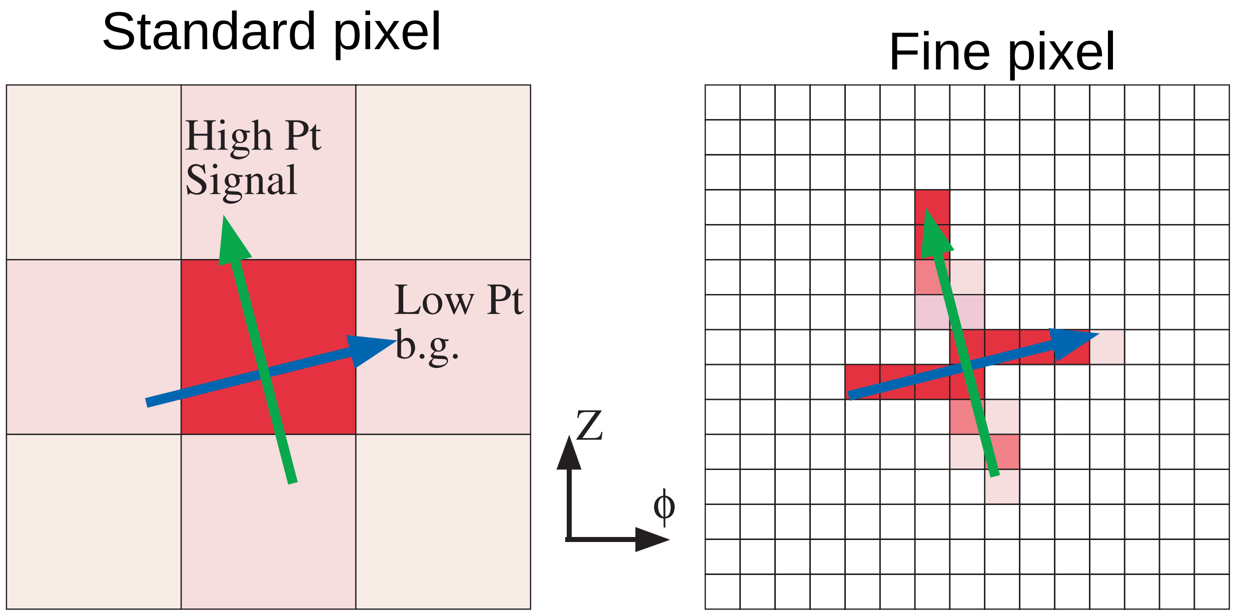


Wrong-track finding probability
(p=1 GeV/c,t_{Si}=50μm)



Tracking efficiency v.s. B.G.

- Advantage of Fine Pixel option
  - Fine segmentation enables background rejection using hit cluster shape



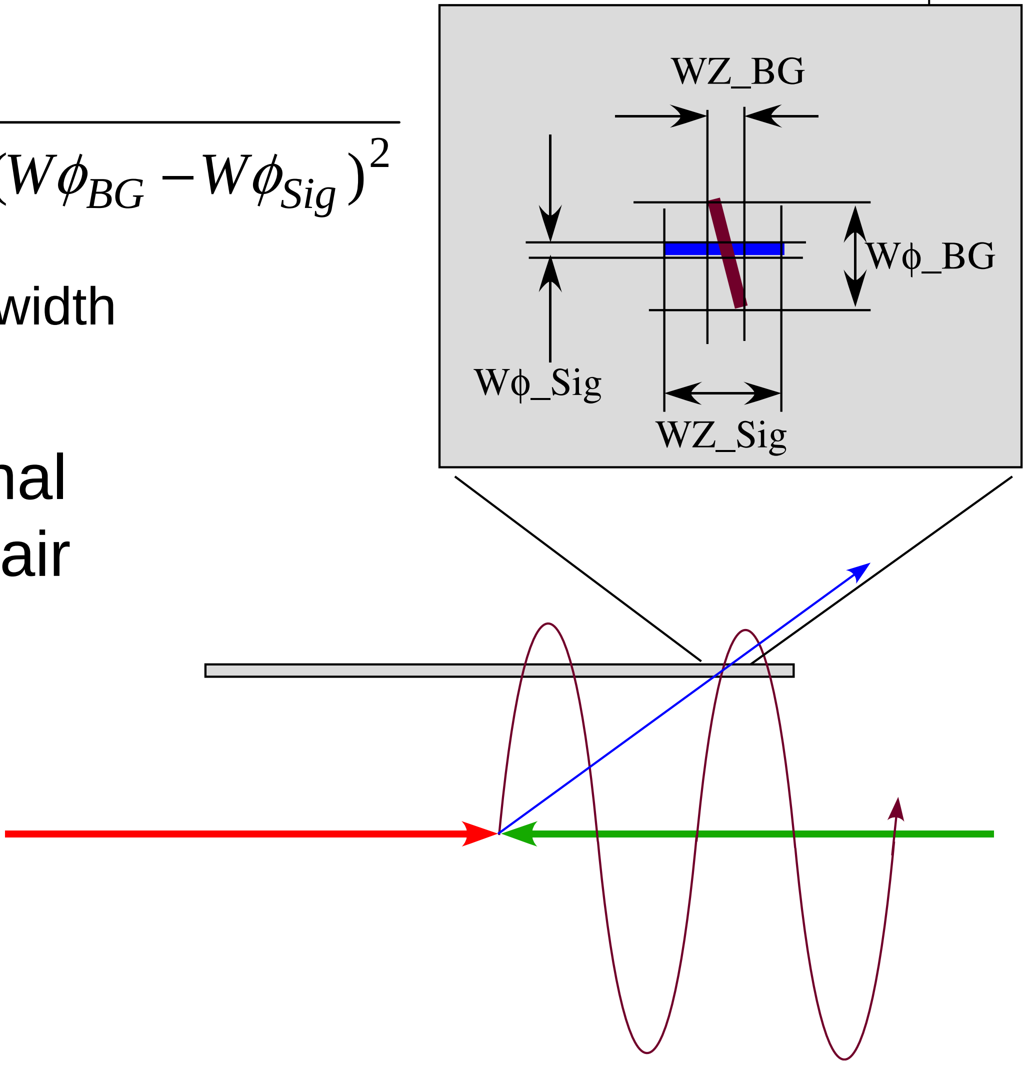
(tracking capability with single layer!)

B.G. rejection by cluster shape

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

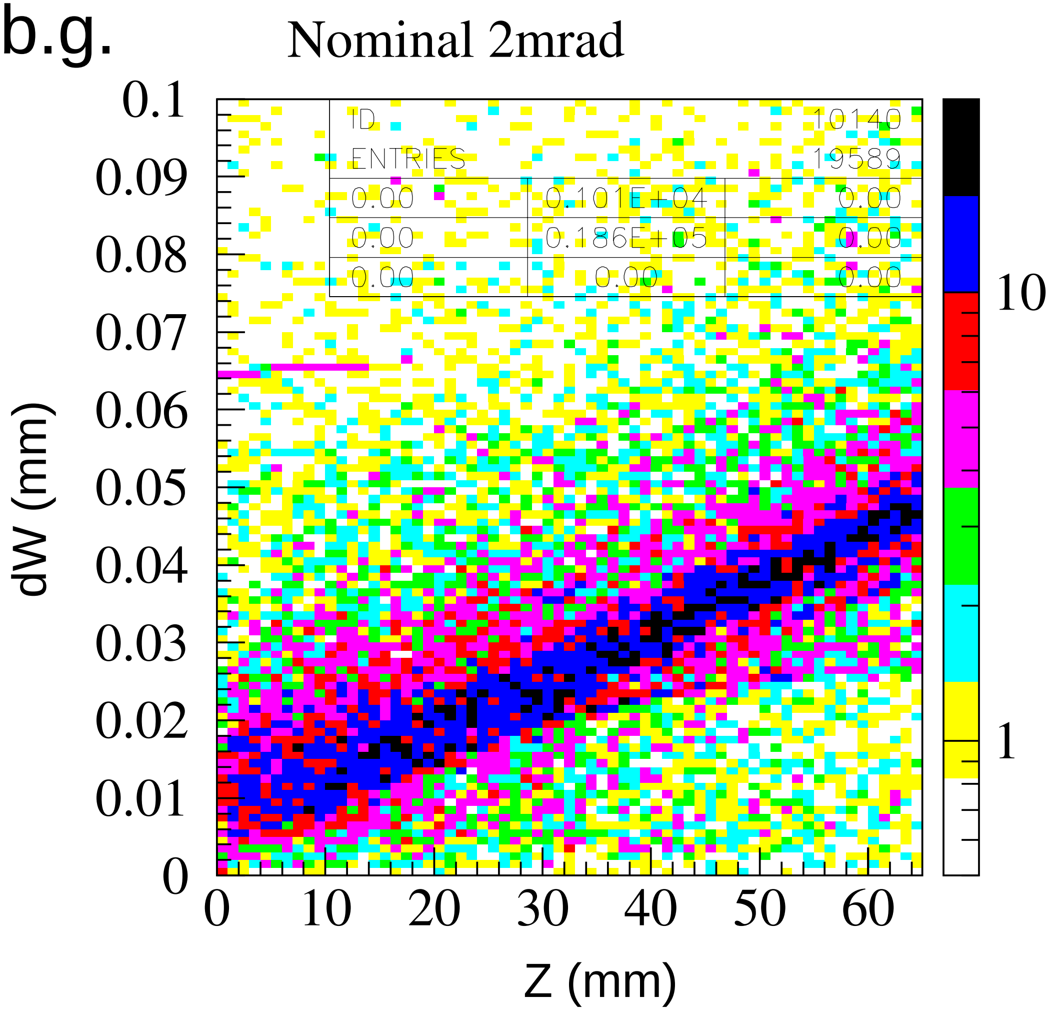
WZ_{Sig}, $W\phi_{Sig}$: Expected width

- dW~0 for high p_t signal tracks but large for pair background tracks



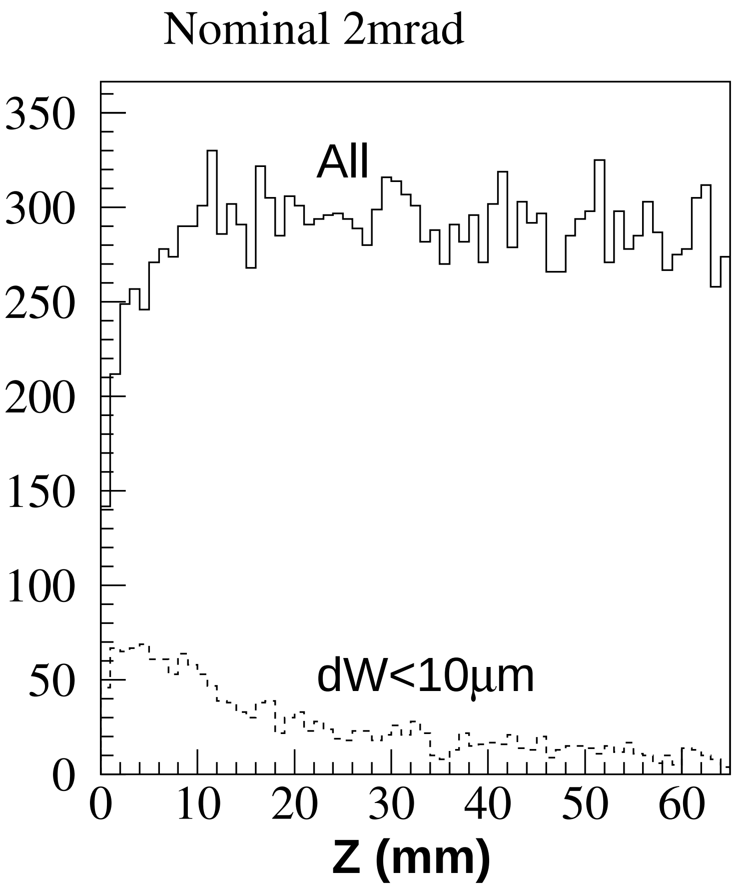
B.G. rejection by cluster shape

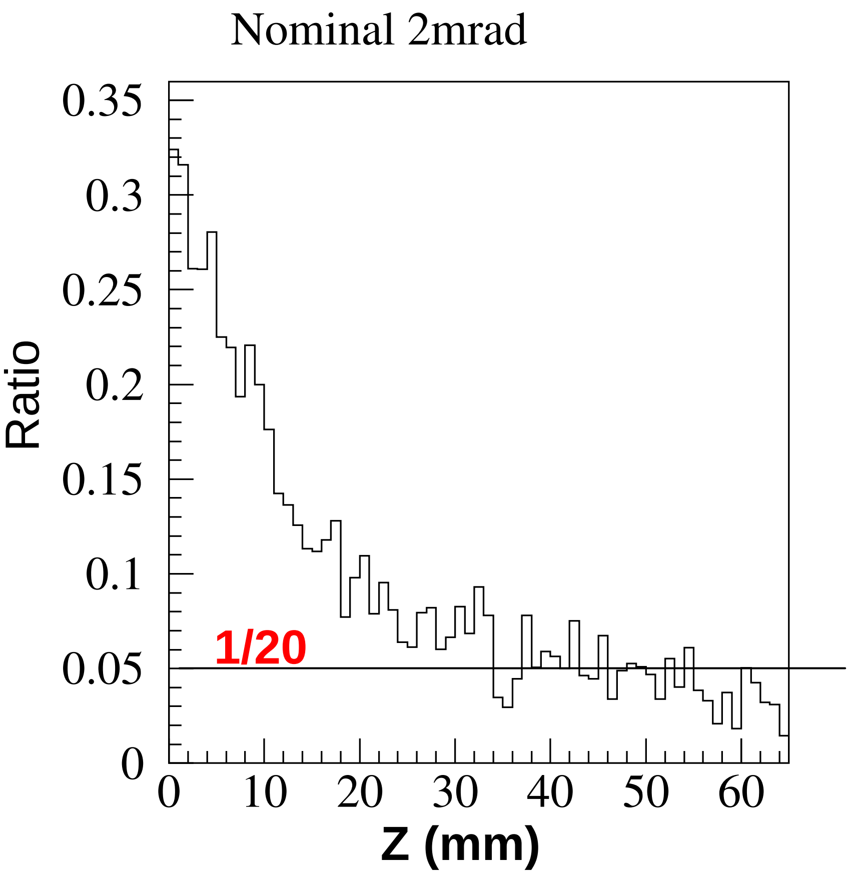
- dW v.s. z for pair b.g.
  - 500 GeV
  - 100 BX
  - R=20 mm



B.G. rejection by cluster shape

- R=20mm
- Cut at dW=10μm

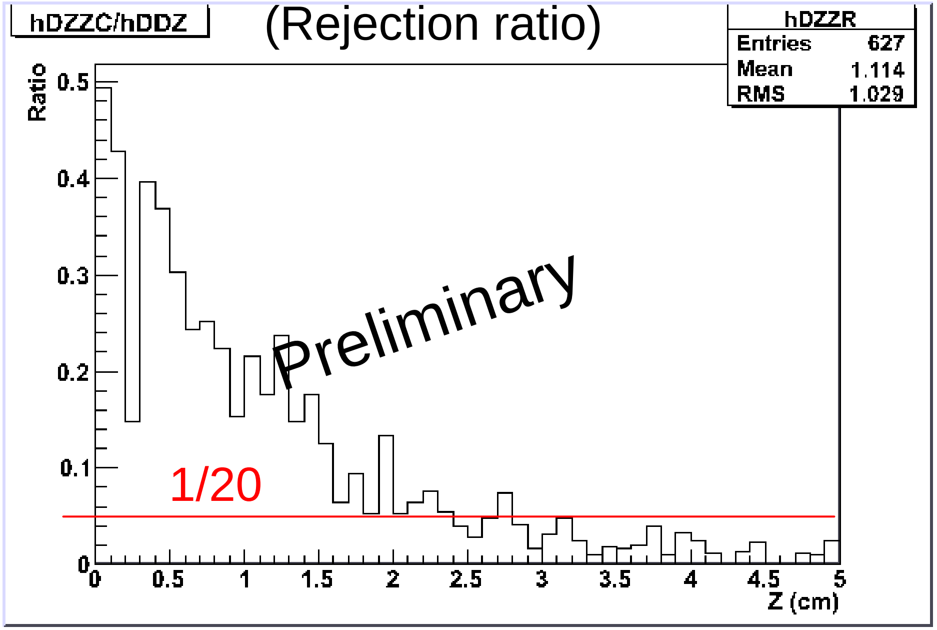




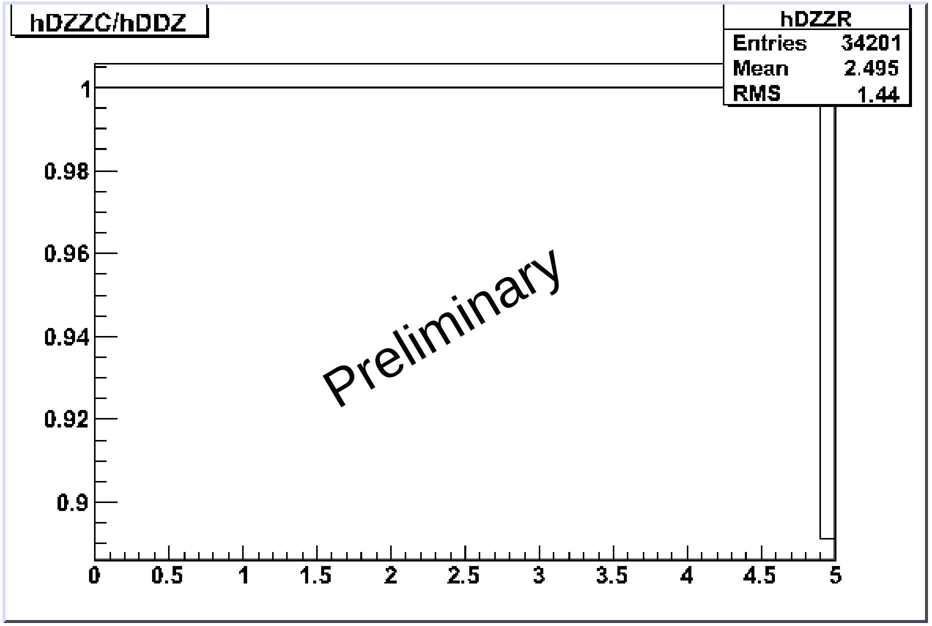
B.G. rejection by cluster shape

- Detector full simulation
  - $N_Z > Z(cm) x1.2$, $N_x < 3$

Efficiency for pair b.g.
(Rejection ratio)

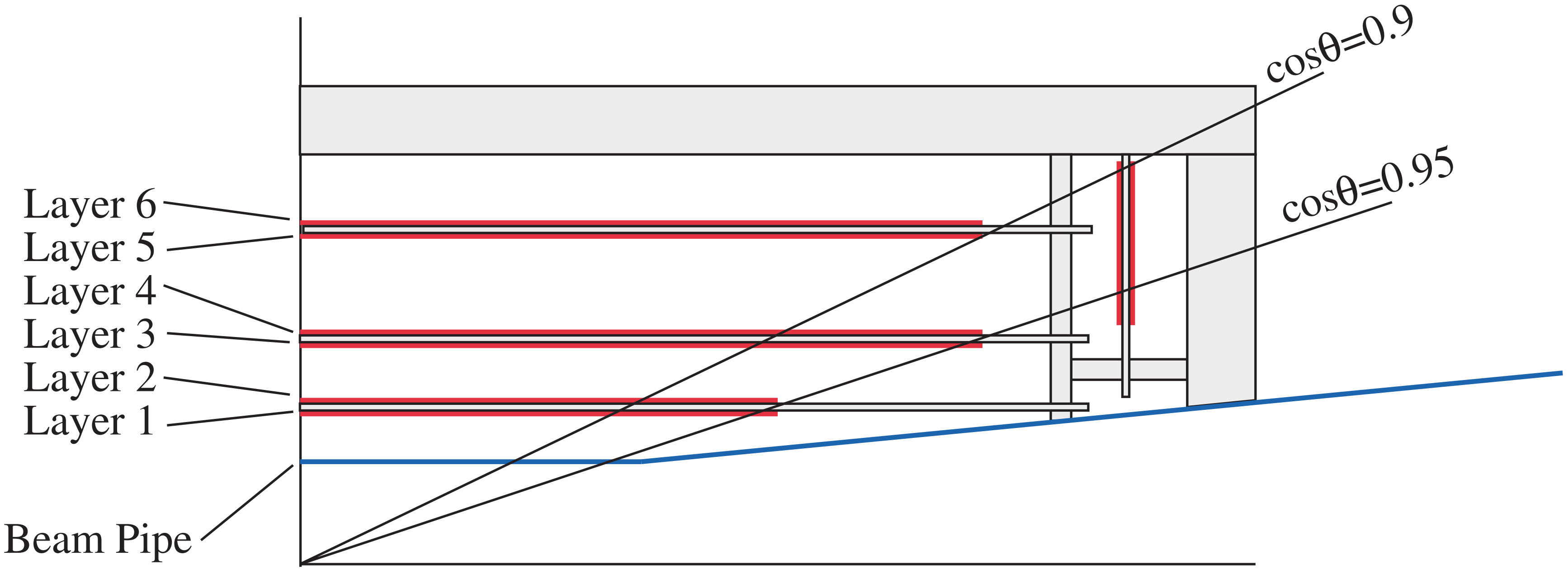


Efficiency for 1 GeV/c muon



T. Nagamine

Tentative baseline design



Summary

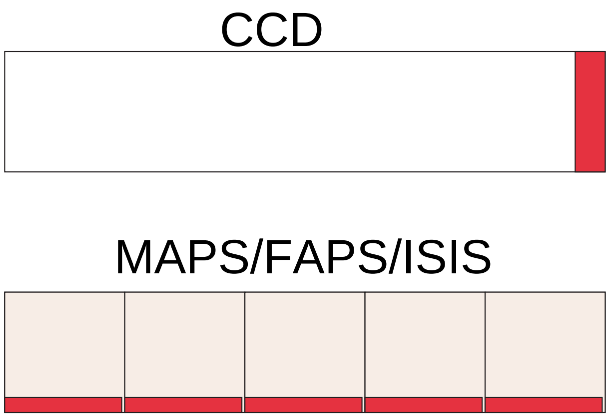
- We assume Fine Pixel option as the baseline design for the GLD vertex detector
- Inner radius depends on the pair background. The distribution of the pair background has a large dependence on the machine parameter
- The high hit density of Fine Pixel option can be overcome by background rejection using cluster shape
- More optimization study is necessary based on
  - New high luminosity parameter at 500 GeV
  - Synchrotron radiation
  - Backscattering from BCAL
  - Interface with FIT
  - Physics

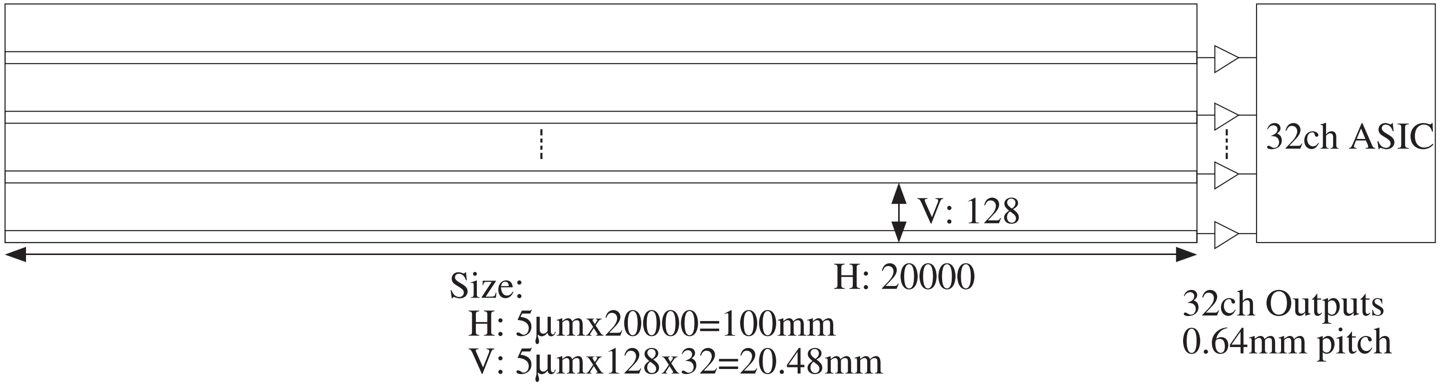
as much as possible in this workshop

Backup slides

Advantages of FPCCD

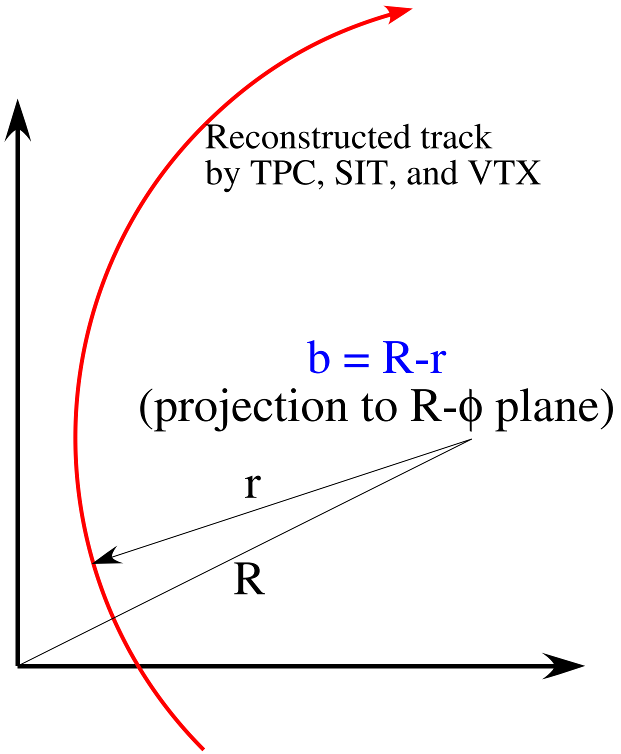
- Free from beam-induced RF noise
- σ_x~1.4μm even with digital readout
- Simple structure : advantageous for large size
- Active circuit on one edge : easy to control temperature
- Readout speed: 15MHz is enough (128(V)x20000(H)/200ms=12.8MHz)



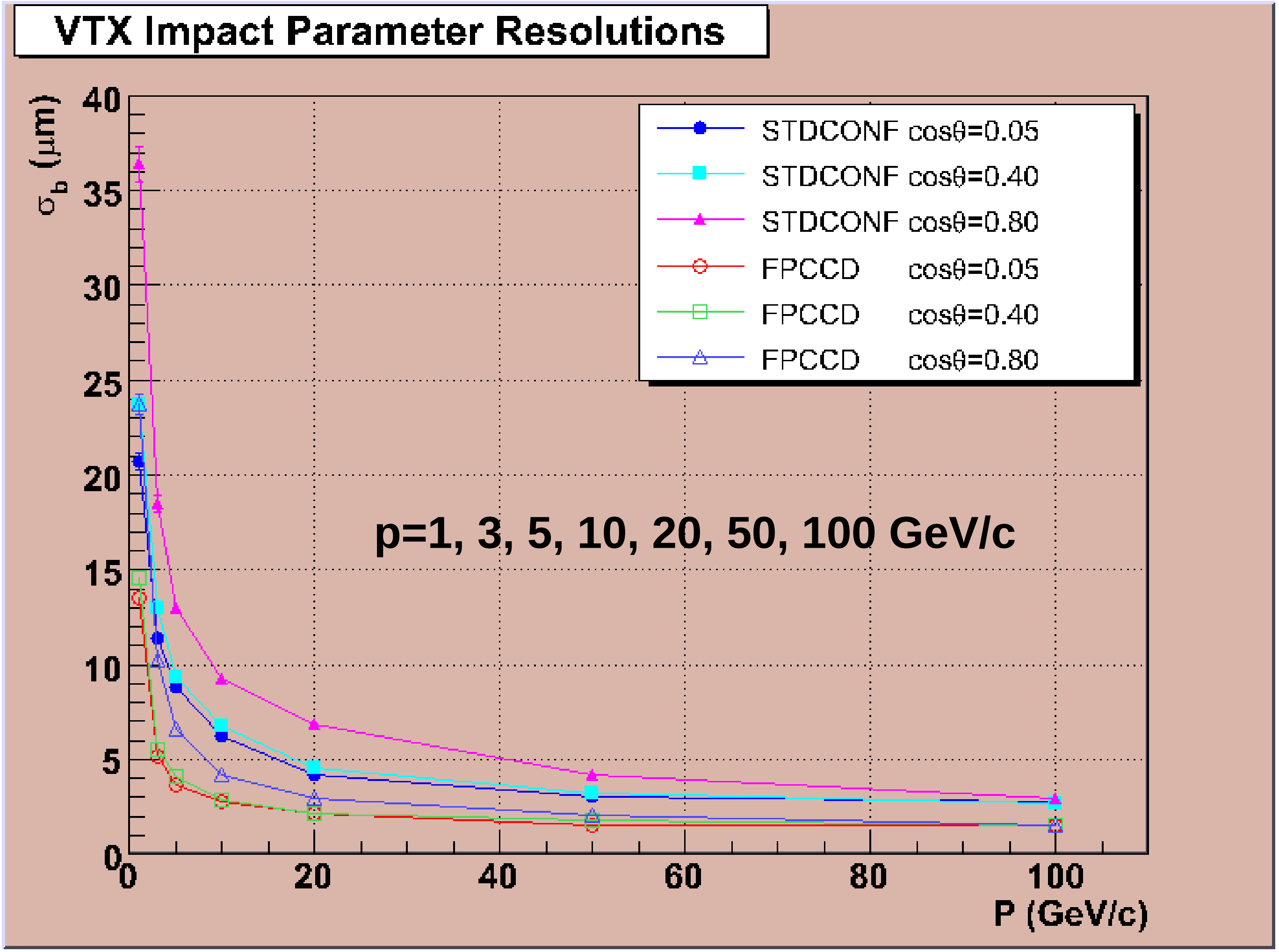


Impact parameter resolution

- Full simulation study by Jupiter
- Parameters:
  - Old standard option:
    - R=24, 36, 48, 60 mm
    - t = 330 μm/layer
    - σ = 4 μm
  - FPCCD option:
    - R=20, 22, 39, 41, 58, 60 mm
    - t = 80 μm/layer
    - σ = 2 μm
  - Be beam pipe (common):
    - R=18 mm
    - t = 500 μm



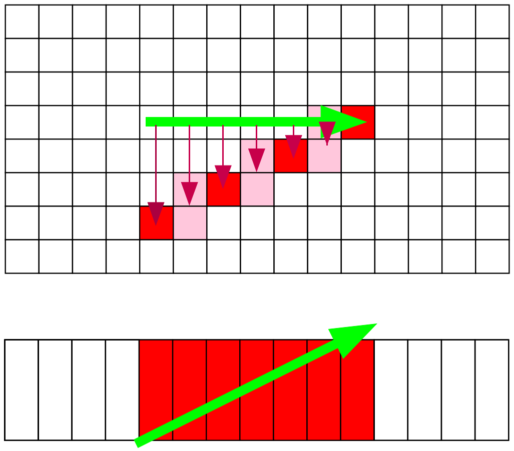
Impact parameter resolution



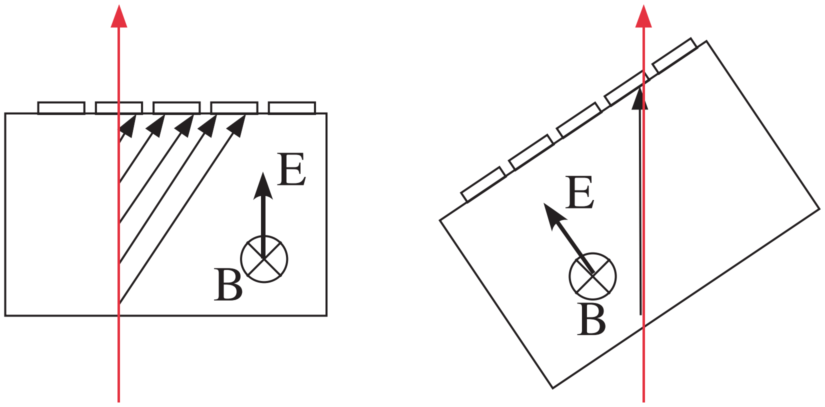
T. Nagamine

Lorentz angle

- Lorentz 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

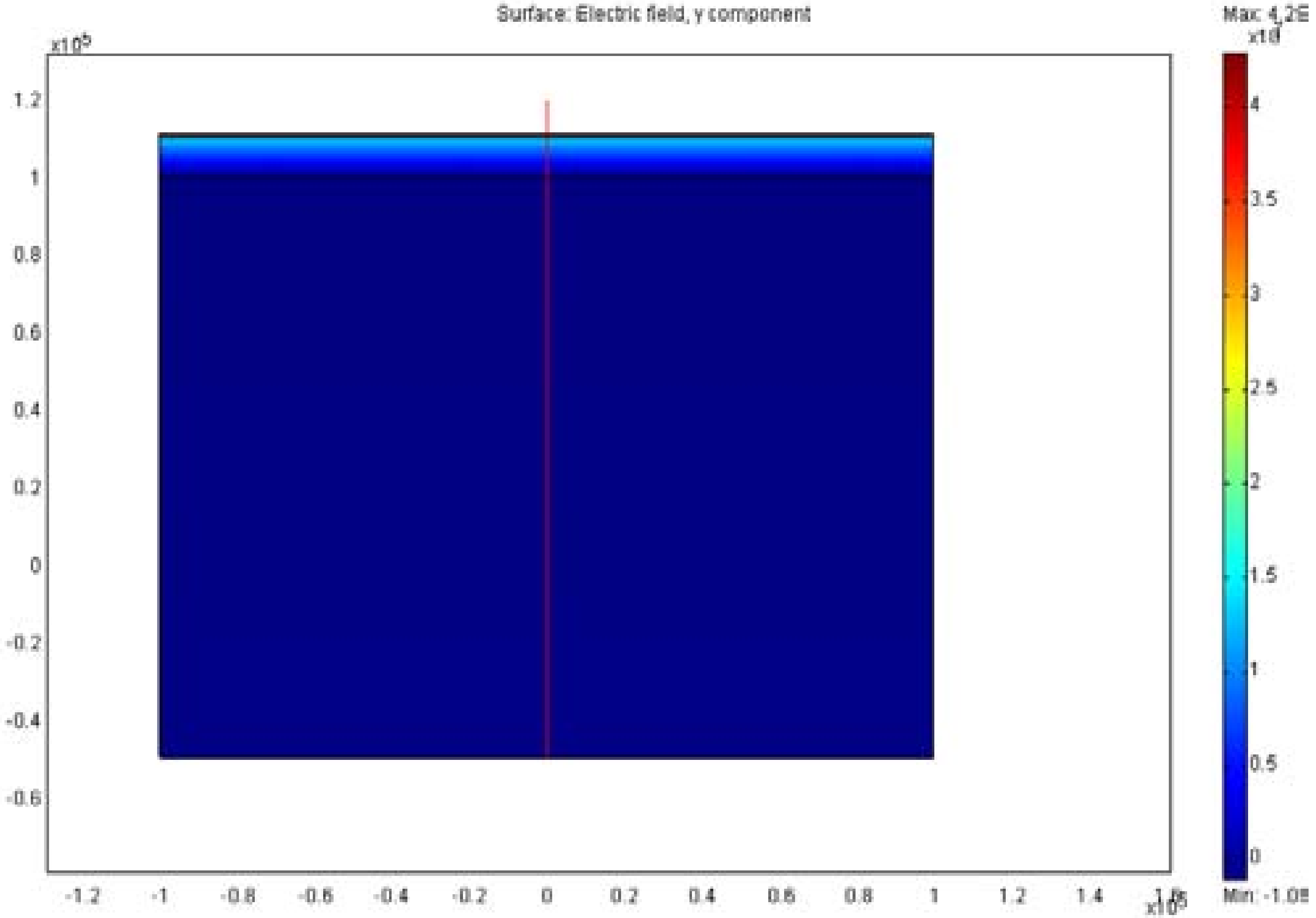


Lorentz angle

- 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

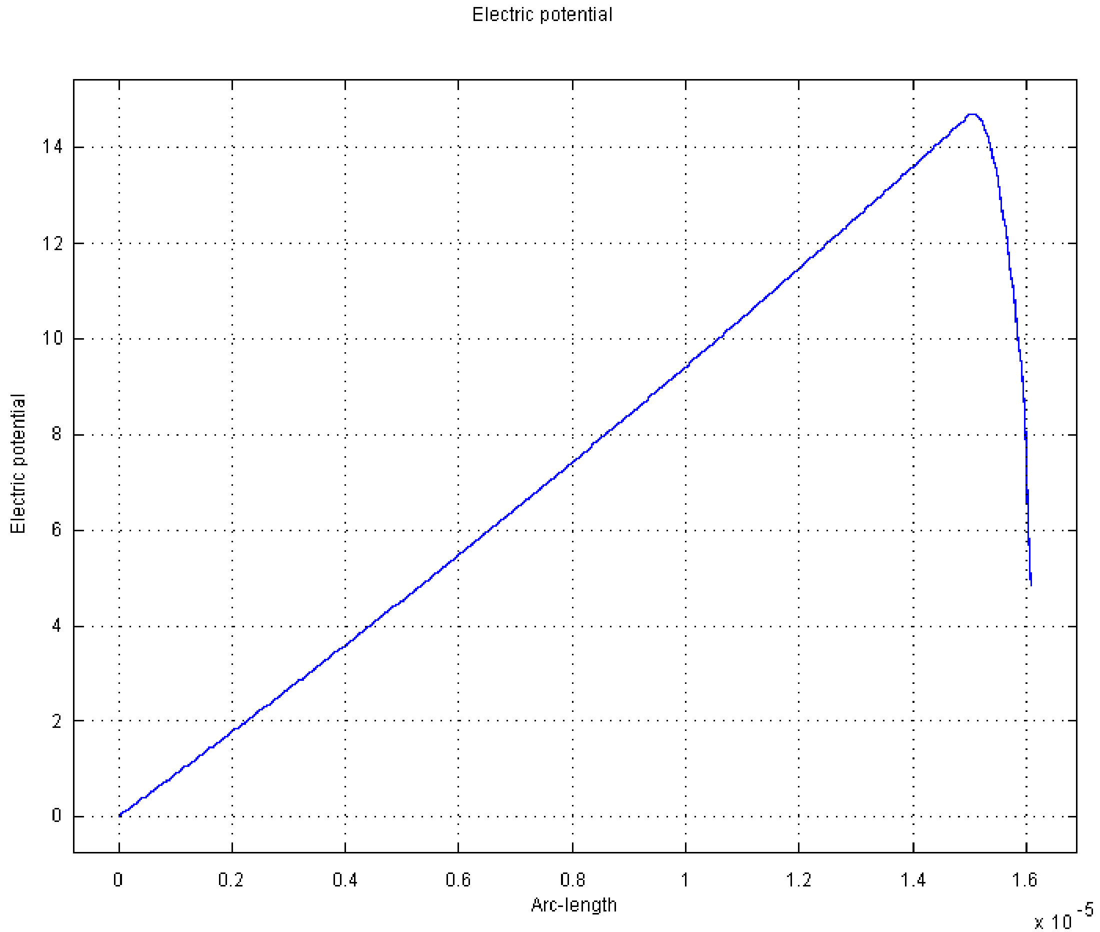
Lorentz angle

- 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)
  - The Lorentz angle of 12 degrees is expected at B=3T