# SiD Vertexing Report

**Su Dong**
**On behalf of the SiD Vertexing Group**

# SiD Vertexing Design Organization

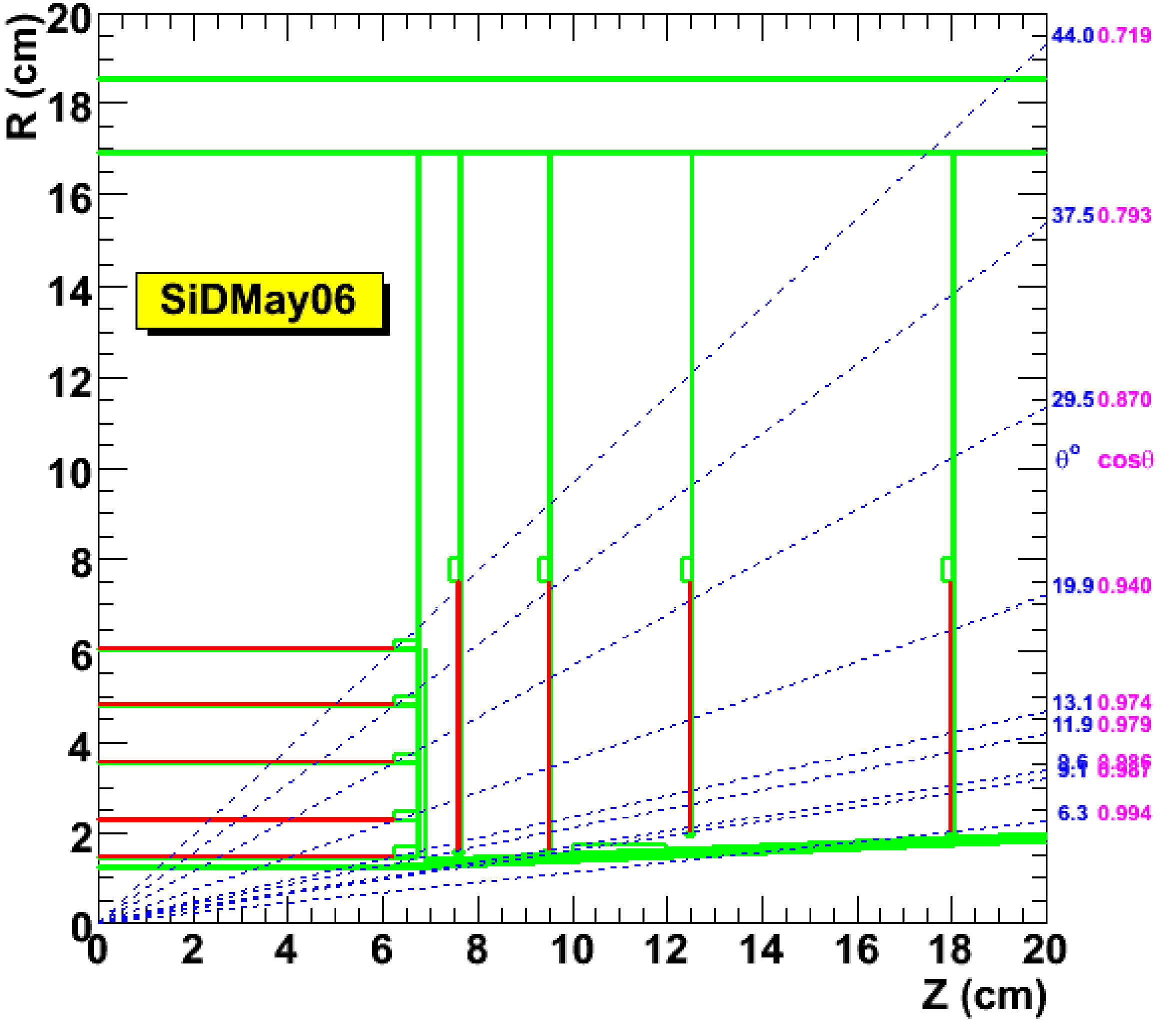
- Emphasis on the overall vertex detector system design for SiD tracking.
- Collaborating with many specific sensor R&D groups and considering broad spectrum of technologies.
- Detailed mechanical design effort in the context of the SiD tracking system, but also collaborating more broadly on common mechanical design R&D studies.
- Detector GEANT simulation and reconstruction studies primarily within the LCsim framework. Performance study and benchmark analyses also benefited from broader contributions.
- Coordinators: Ron Lipton, Bill Cooper, Su Dong

# SiD Vertexing Reports

- This report:
  - SiD VXD geometry and material model.
  - Simulation/reconstruction performance.
  - One sensor idea not covered by other review sessions
  - ILC beam background implications.
  - Sensor requirement considerations.
- Mechanical design (next talk): Bill Cooper for SiD and FNAL R&D collaboration.
- EMI Test Results from SLAC ESA (Thursday): Nick Sinev for joint SiD/Japan collaboration.

Some reported studies also benefitted from many other collaborative effort (e.g. with LCFI).

# SiD VXD Geometry




Barrel+endcap geometry to avoid shallow angle track entrance

Trade-off for more demanding light weight support and service designs.

# SiD Geometry Implications

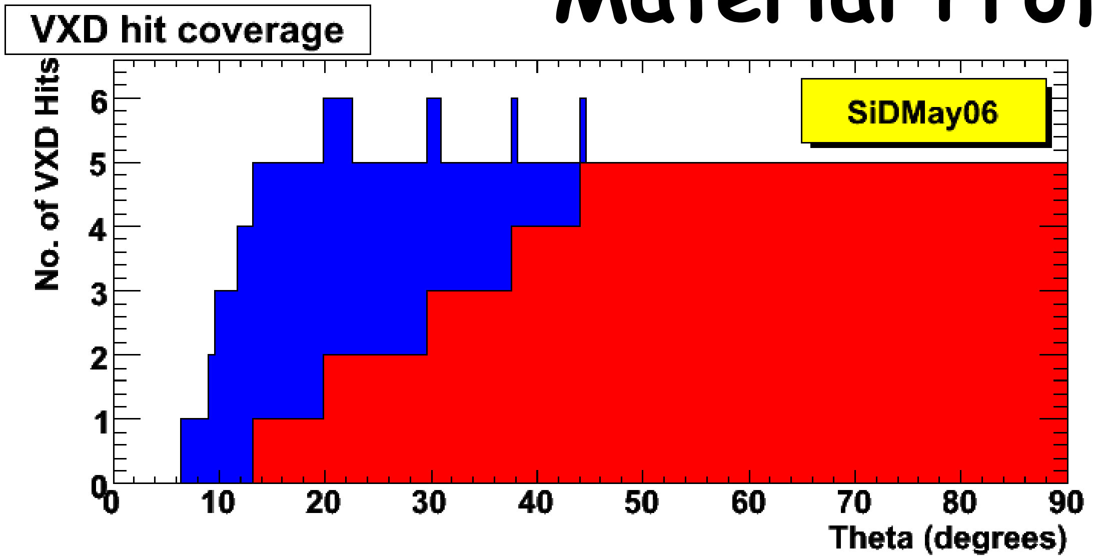
- No track at very shallow entrance angle. Full coverage of 5 VXD hits up to $|\cos\theta| \sim 0.98$.
  - Sensors has slightly thicker (e.g. 30μm) active region would not cause too much resolution degradation.
  - Less fear in barrel wafer shape issues when pushing for thin ladders with a shorter barrel.
  - Endcap sensors don't care much about Lorentz effect.
- Need to work harder on the barrel endplate service material.
  - *The R&D to achieve lightweight power delivery and signal communications are as important as the sensor technology and mechanical design !*

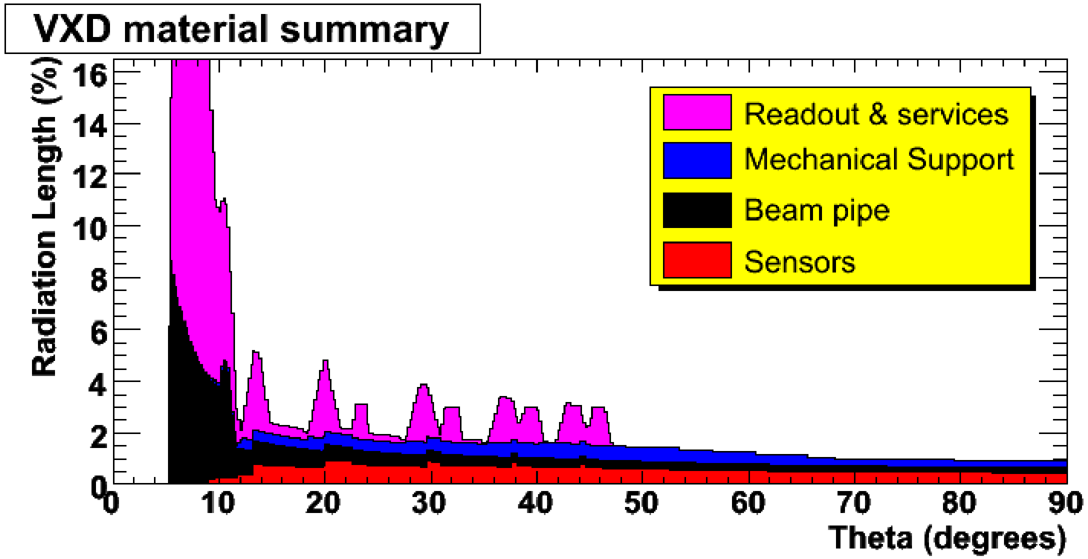
# Service Material Model

Due to the lack of a real design, this is unfortunately a very crude toy model in GEANT:

1) Readout/service connection at each barrel layer end is represented by a solid ring of G10 5mm wide in Z and 2mm high in radius.
2) The power and signal cables are represented by a 300μm diameter copper wire (leading to DC-DC on coned beam pipe) and 250μm diameter fiber at each end of a ladder. The cables all focus down to the beampipe to exit from there to be out of fiducial volume, but this causes a significant clumping of material at lower radius which may not work mechanically. It suffers Lorentz force at ~1 Newton at peak current in anyway. The eventual real design is more likely through serial power or local DC-DC.

# Material Profile



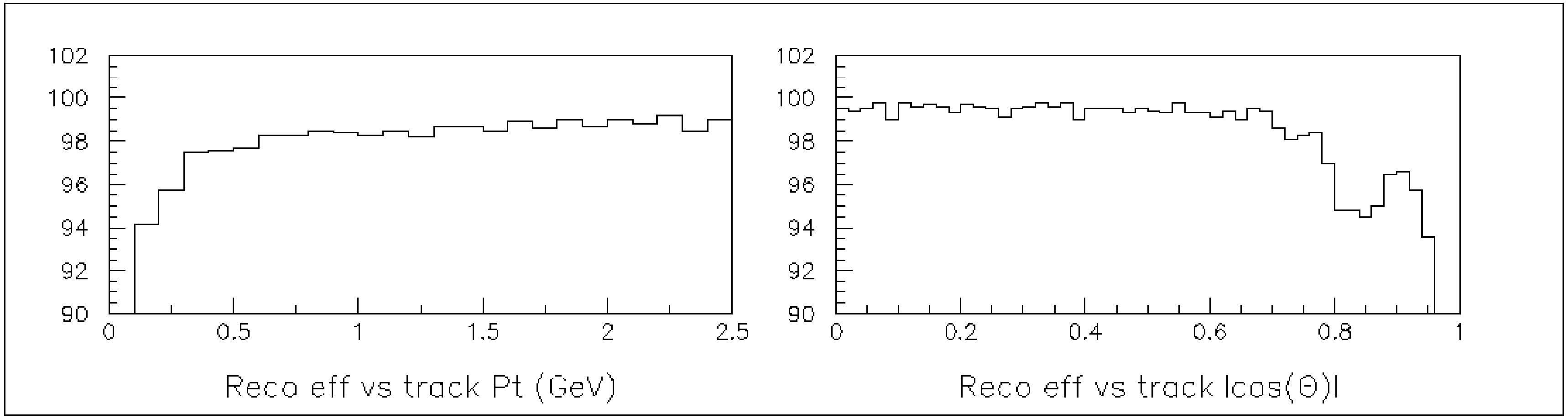

Real mechanical design but services are toy model

Not all material has same influence on impact parameter resolution.

# Simulation and Reconstruction

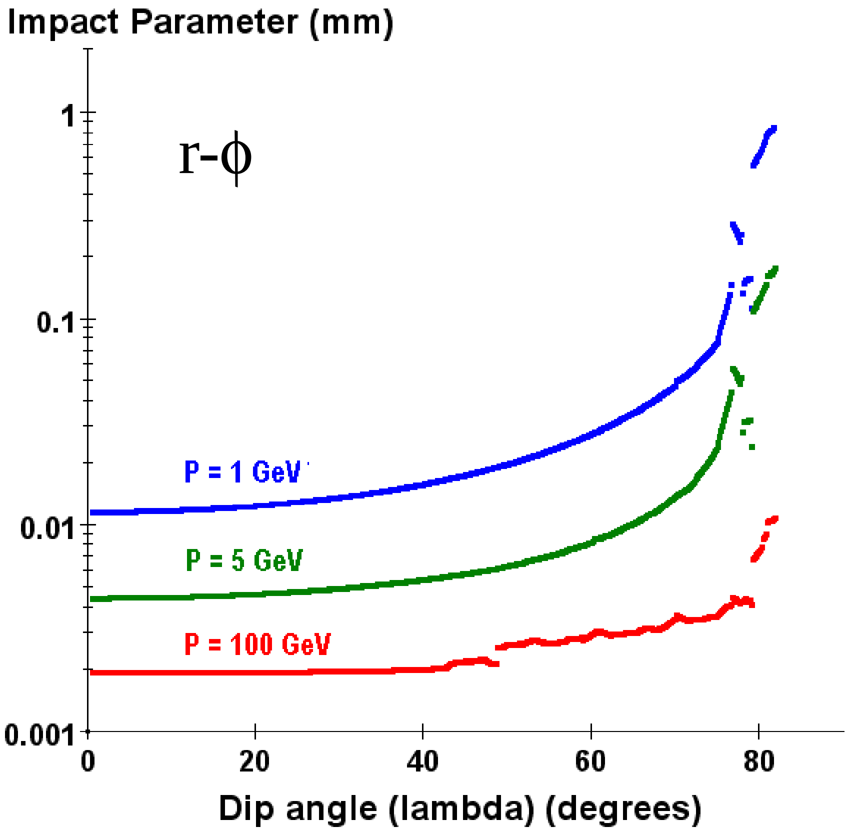
- GEANT simulation In LCsim framework
- Digitization model based on SLD VXD3 CCD data.
- Full tracking reconstruction starting from VXD alone tracking followed by matching to outer tracker.

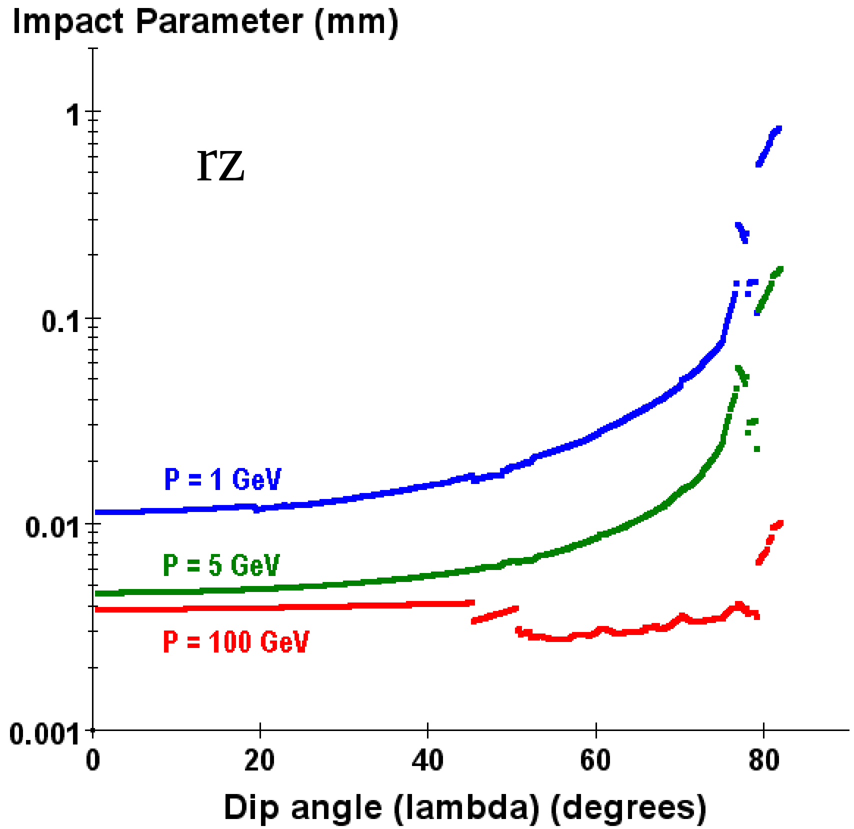
Nick Sinev



# Simulated Resolution Performance (I)

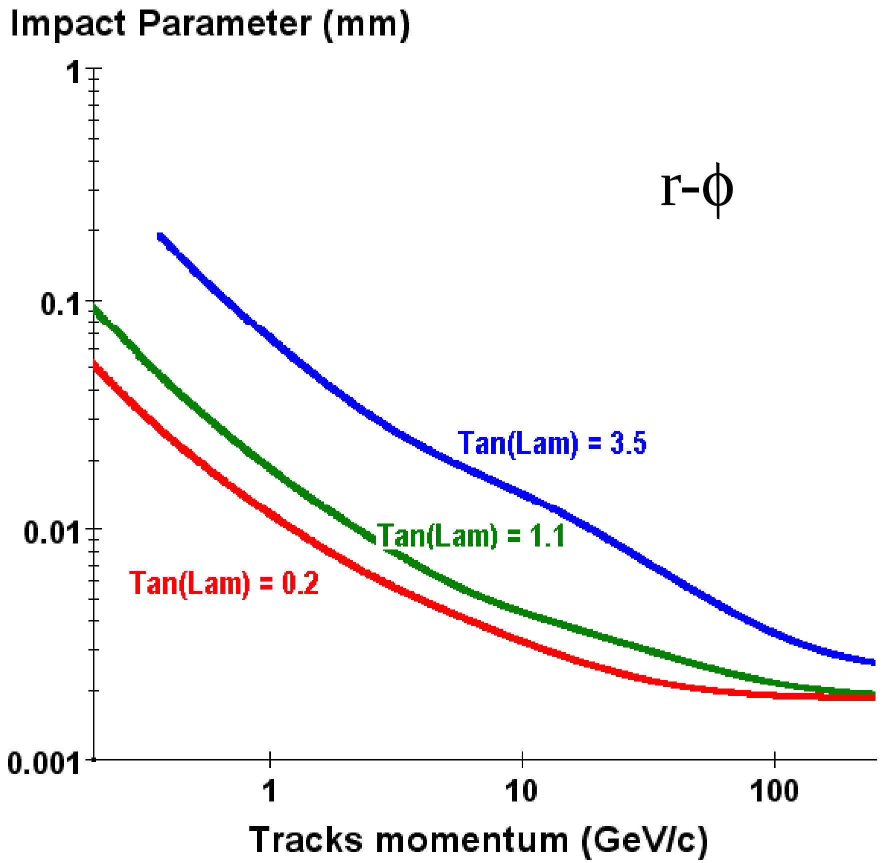
Nick Sinev

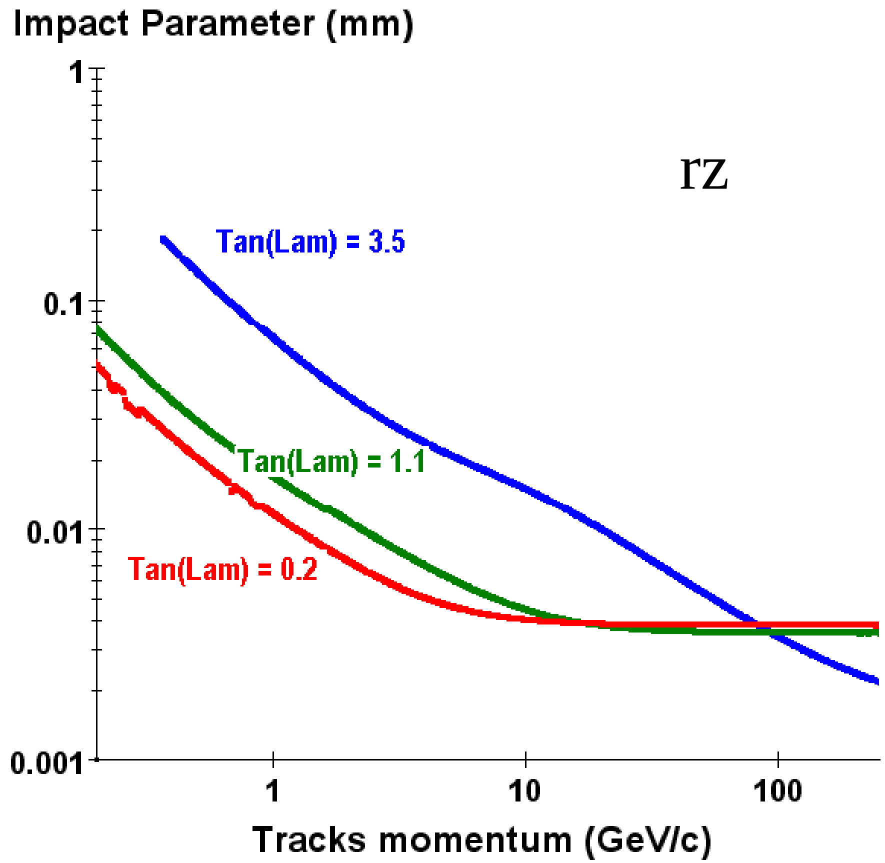


# Simulated Resolution Performance (II)

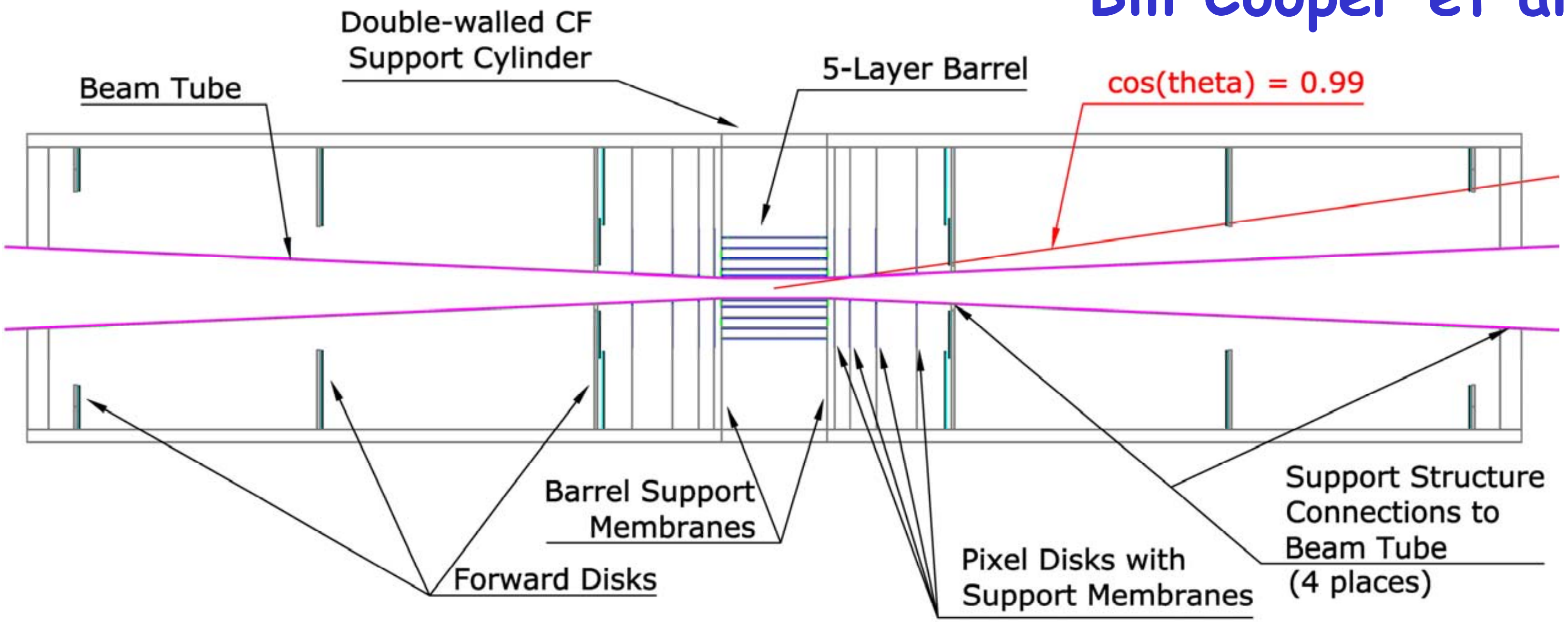
Nick Sinev



# Mechanical Design

Bill Cooper et al



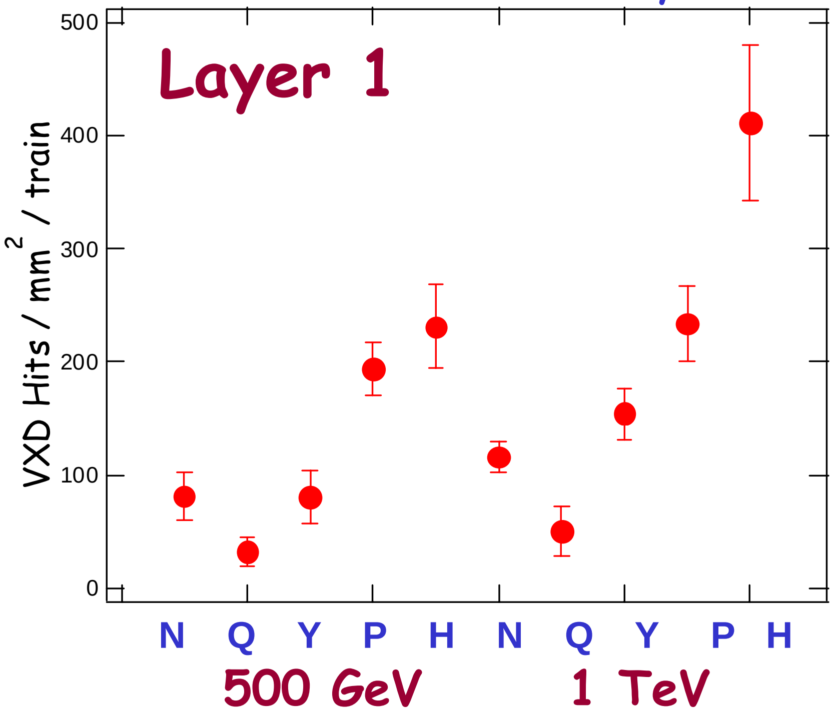

Assume sensor operating at > -10 C to enable light weight carbon-fiber support. Cooling with dry gas through the double wall of the outer support tube.

=> See Bill Cooper's report for mechanical design details.

# VXD Background Rate Variations

Takashi Maruyama

| Radius (cm) | Hit density/train/mm² (Mean/RMS) |
|---|---|
| 1.4 | 80.2 / 16.2 |
| 2.2 | 16.1 / 7.9 |
| 3.5 | 2.3 / 1.7 |
| 4.8 | 1.0 / 0.8 |
| 6.0 | 0.2 / 0.2 |



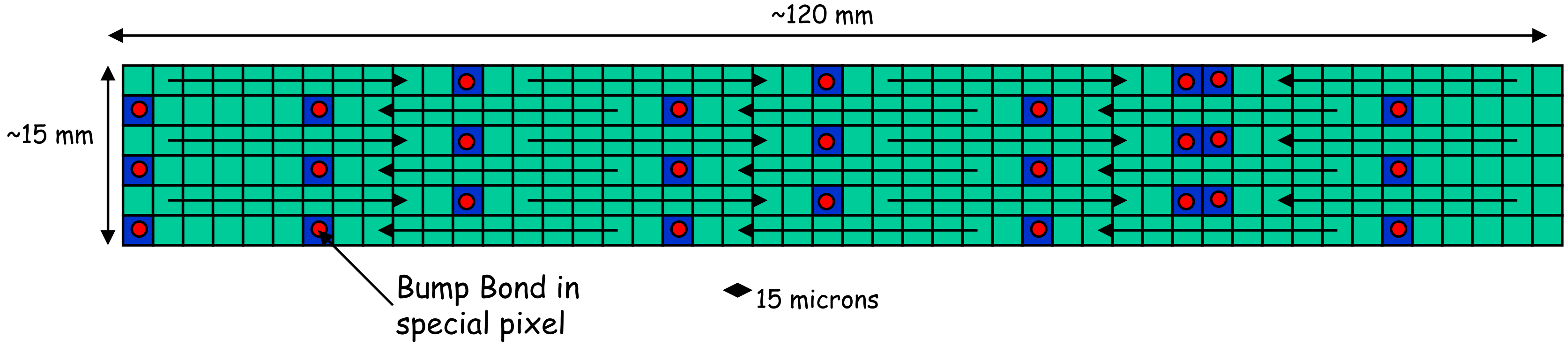

Layer 1's problem is in its own league (Revised estimated based on new RDR design).

Need to be able to deal with ~200 hits/mm$^2$/train –

*Tracking studies by Nick Sinev for NLC and by Richard Hawkings for TESLA both point to performance problem at Layer 1 density of ~1-2 hits/mm$^2$. Can only get there with time stamping !*

# Another sensor idea: Short Column CCD's
## (Marty Breidenbach, Dieter Freitag)

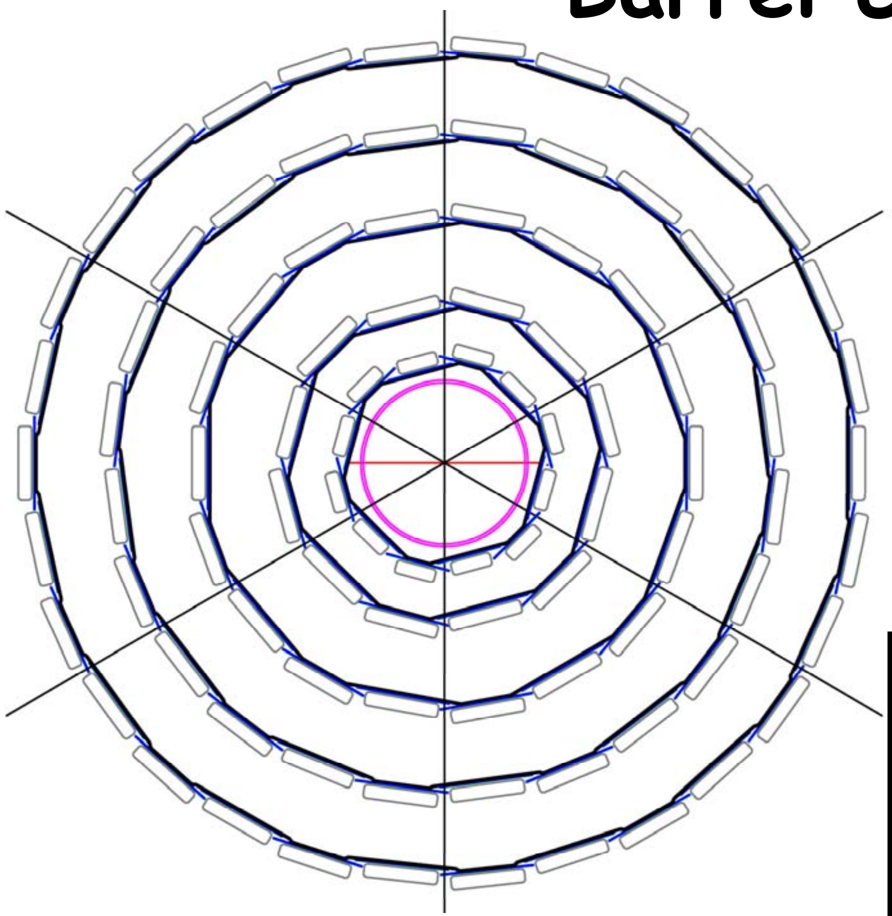
- Make CCD's with short columns ~512 pixels and no rows.
- Design CCD so charge sharing likely across columns.
- Design CCD so adjacent columns move in opposite directions.
- Bump bond to a readout layer of KPiX like CMOS.
- 15 micron pixels, 3 clocks/bunch (~10 MHz) , and ~500 pixels in a row have satisfactory background rejection.




Study from Nick Sinev: Adjusting column width, sensor thickness, pixel threshold, readout speed can find operable phase space for high efficiency time stamp reconstruction.

# Barrel Geometry

**Bill Cooper**



Sensors:
IR_A = 14, 22, 35, 47.6, 60 mm
IR_B = 15.15, 23.13, 35.89, 48.41, 60.77 mm
Active widths: 9.1, 13.3 mm
Cut widths: 9.6, 13.8 mm
Beam pipe IR: 12 mm
Beam pipe OR: 12.4 mm
March 3, 2006

Oblong boxes are openings in end rings and end membranes for cables, optical fibers, and air flow.

| Layer | Ladder | Area ($cm^2$) |
|---|---|---|
| 1 | 12 | 144 |
| 2 | 12 | 207 |
| 3 | 18 | 311 |
| 4 | 24 | 414 |
| 5 | 30 | 518 |

**Layer 1 sensor has a narrower width**

**Layer 1 area is 9% of barrel total**

# A Different View at the Sensor Requirements

So far no `ideal' technology performs best in all categories. In particular, attempts to reduce hit density via faster readout or time stamping seemed to be invariably associated with more power.

Have we dug a hole for ourselves by having the one size shoe fit all requirements ?

We have seen that the problems at inner and outer barrels and the endcap are different in some important aspects.

If we can tolerate the loss of elegance, is it so bad to consider the option of a mixed sensor technology ? Life may get significantly easier if the sensor only need to meet the requirement for a specific region of the detector.

# Innermost Barrel

The first layer carries a huge weight in determining the ultimate impact parameter resolution and is in the most hostile environment of highest hit density. So one might desire:

- Small, thin pixels with low noise to gain the ultimate spatial resolution of <3μm (or even 2?)
- Time stamping or other means of tagging bunch crossings to bring the effective hit density down to <1 hits/mm$^2$.
- Yes it needs more power but we may afford that:
  - The end service section is falling out of fiducial so that a bit more service material may be OK.
  - Power lines still axial along beamline – no Lorentz force.
  - Layer 1 is only 9% of the total barrel area.
  - There is also a possibility of some liquid cooling around the beampipe region out of the fiducial.

# Outer Barrels

- Many more sensors. Services will suffer Lorentz force and in fiducial region. It is therefore highly preferable to be a low power technology.
- In exchange, do not have to work as hard for the readout hit density.
- Still cares about Lorentz angle.
- If service light enough, routing them radially outwards outside the endcap may not be paying too much penalty on material ? This will reduce clutter around beampipe and reduce multiple scattering problem at low angles.

# Endcap

- The access to power is in less critical fiducial regions so that there are more sensor options to choose from.
- Tracks are more perpendicular so that thicker sensors may be OK.
- Don't care about Lorentz angle.
- Cooling delivery is also somewhat easier.

We still need to settle the endcap sensor segmentation. Inner ring and outer ring configuration also naturally permit separate technologies.

# Remarks on Mixed Sensors

Once lowered the elegance requirement on a single technology, one suddenly has some interesting freedom to consider more options to better optimize for the different regions.

Question/Issues:

- Shared operating temperature for the two sensor types
- Asynchronized readout of mixed technology may interfere ?
- Separate spatial resolution requirements for outer barrel ?

Hopefully a useful starting point for discussions and further thoughts to exploit the extra freedom.

# Summary

- The SiD VXD system design effort yielded interesting perspective on sensor technology requirements:
  - Specific detector geometry layout has different emphasis of sensor requirements for different regions of the detector.
  - Depending on the deployed region, some requirements can be dropped or relaxed to allow more focused R&D on more relevant requirements.
- For the overall system design, detailed engineering solutions for power and data transmission are equally important and R&D must be encouraged.

# Backups

# Old Sensor Requirements

As of the DOD writeup, we have defined the following requirements:

1) Spatial resolution <5μm in all dimension for track entrance angles $15^0$-$90^0$.
2) Two track resolution <40μm.
3) < ~0.1% X0 material per layer.
4) ~30W+30W total power in barrel+endcap. Gas cooled.
5) Operable at 5T with little resolution loss.
6) <5 hits/mm$^2$ at Layer 1; <1 hit/mm$^2$ in outer layers.
7) Low noise to allow threshold for >99% hit efficiency and readout noise <30% of all hit data.
8) EMI immunity.
9) Can withstand: >20Krad/year; >$10^9$/cm$^2$/yr 1 MeV Neutrons.

# Comments on Sensor Requirements

- The 5μm resolution is very generous and one ought to be able to do better. One should still give extra credit for significantly better resolution (which may need the combination of thin EPI, low noise and perhaps not fully depleted).
- The power requirement is not only bound by the need for gas cooling. The necessary copper to deliver the instantaneous current is also an important factor.
- The hit density requirement has some uncertainties. We have not fully explored the tracking robustness at these limiting densities. Given the pivoting role of VXD in SiD tracking, capability for lower density could be important insurance to leave necessary margin to accommodate significant machine background variations.