Vertex Detector for the LDC

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Outline

- LDC and pixels at the ILC
- Physics needs, detector implications
- Current state of development
- Next steps

What sort of Vertex Detector is needed?

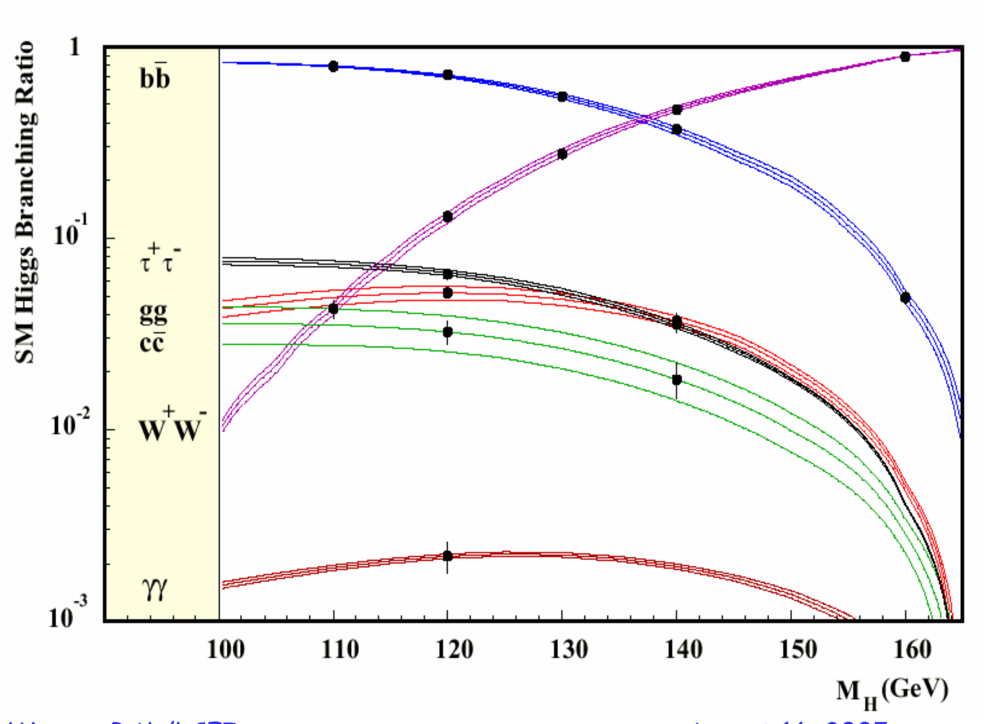
- Detector parameters driven by the physics needs
  - ILC is built for precision physics; reflected in detector
  - Must identify b, c, tau decays, also charge
  - Coverage to far forward, ultra-low mass
- Detector must fit the environment and construction constraints
  - How to get services in, cables and heat out
  - Detector operational environment must be better understood.
  - Can the beam structure can be exploited?
- The construction timescales
  - Vertex detectors always seem to be last to be installed– that's a good thing!
  - Detector TDR by 2008-2009, but detailed VTX design can come after this
  - Aim for VTX technology choice by ~2010

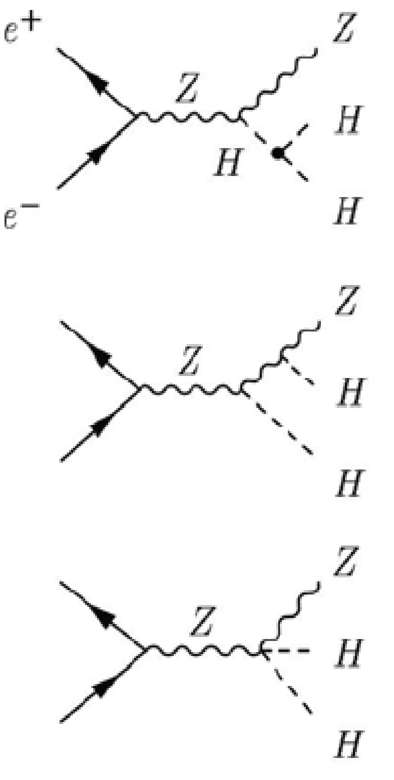
- See also talks by…
  - Marco Battaglia, general vertexing details/options
  - Sonja Hillert, vertex detector and beam pipe radius
  - Many more in Vertexing session, LGC, SiD, Tracking session, etc

Flavour Identification at the ILC

- Understanding the new physics will require identifying heavy quarks.
  - Higgs Branching ratios; are they as expected in the Standard Model?
  - Separation of b from $\bar{b}$, and c from $\bar{c}$ will be important.
  - High efficiency, purity to measure multi-b states, eg. $e^+e^- \rightarrow HHZ$, $t\bar{t}H$
  - Leads to reduced combinatorial background.

→ Excellent b, c (and tau) tagging crucial

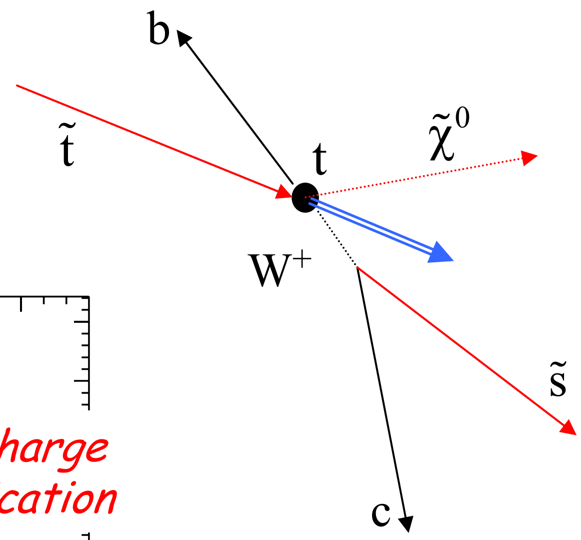


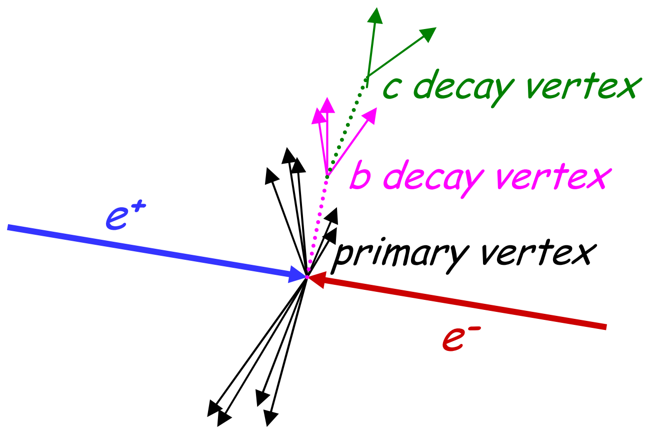


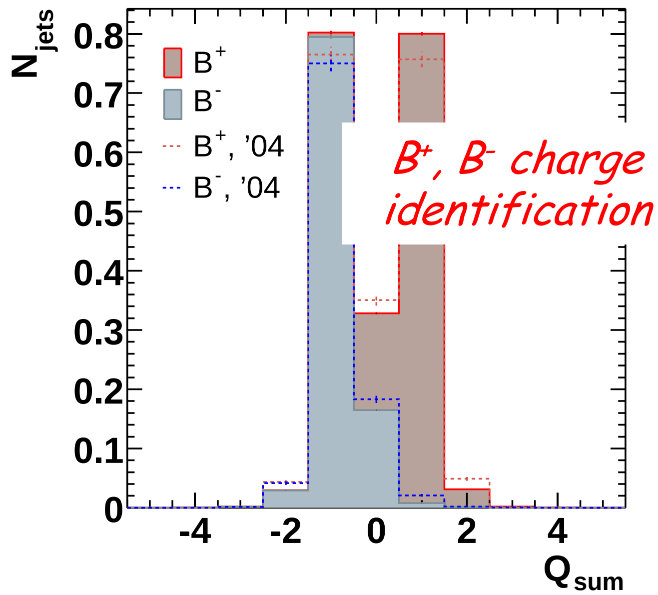
Quark Charge Identification

- Provides a new tool for physics studies
  - Helps sort out complicated multijet events, e.g. $e^+e^- \to t\bar{t}H \to$ jets
  - Allows study of polarisation in top decays, e.g. $t \to bW^+ \to b(cs)$
  - Determine $\tan\beta$ and tri-linear couplings A_t and A_b through measurements of top polarisation in sbottom and stop decays.

→ Quark charge identification also important







Vertex Detector Performance Goals

- Physics environment:
  - Average impact parameter, d_0, of B decay products ~ 300 μm, of charmed particles less than 100 μm.
  - d_0 resolution given by convolution of point precision, multiple scattering, lever arm, and mechanical stability.
  - Multiple scattering significant despite large √s, as charged track momenta extend down to ~ 1 GeV.
  - Resolve all tracks in dense jets.
  - Cover largest possible solid angle: forward/backward events are important.
  - Stand-alone reconstruction desirable.

- In terms of impact parameter, require resolution in Rϕ and z:

$$\sigma = \sqrt{a^2 + \left(\frac{b}{p\sin^{\frac{3}{2}}\theta}\right)^2}$$

$$a < 5\,\mu m \text{ (point precision)}$$

$$b < 10\,\mu m \text{ (multiple scattering).}$$

- Implies typically:
  - Pixels ~ 20 x 20 μm^2.
  - First measurement at r ~ 15 mm.
  - Five layers out to radius of about 60 mm, i.e. total ~ 10^9 pixels
  - Material ~ 0.1% X_0 per layer.
  - Detector covers |cos θ| < 0.96.

Physics Drives the Need for Precision Tracking

How precise will the tracking be? Why is such high precision needed?

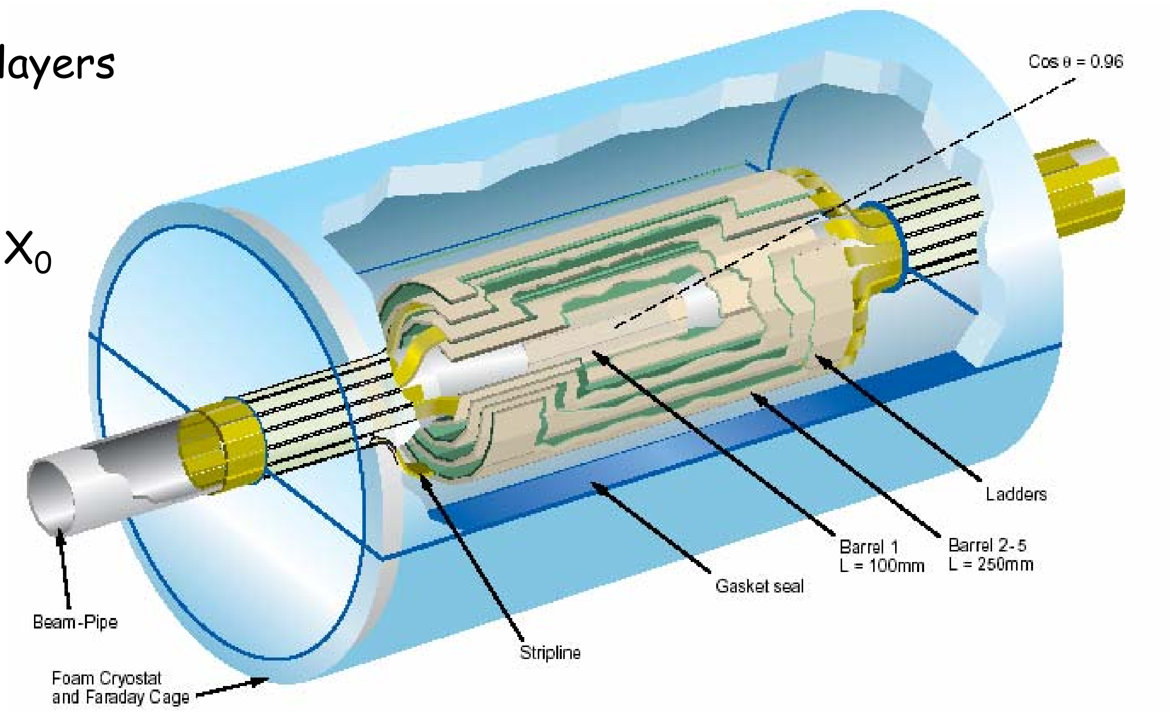
- In terms of momentum resolution:

Experiment	$\Delta(1/p_T)$ [GeV/c]$^{-1}$
CDF	0.15 %
ATLAS	0.3 %
ILC	0.005 %

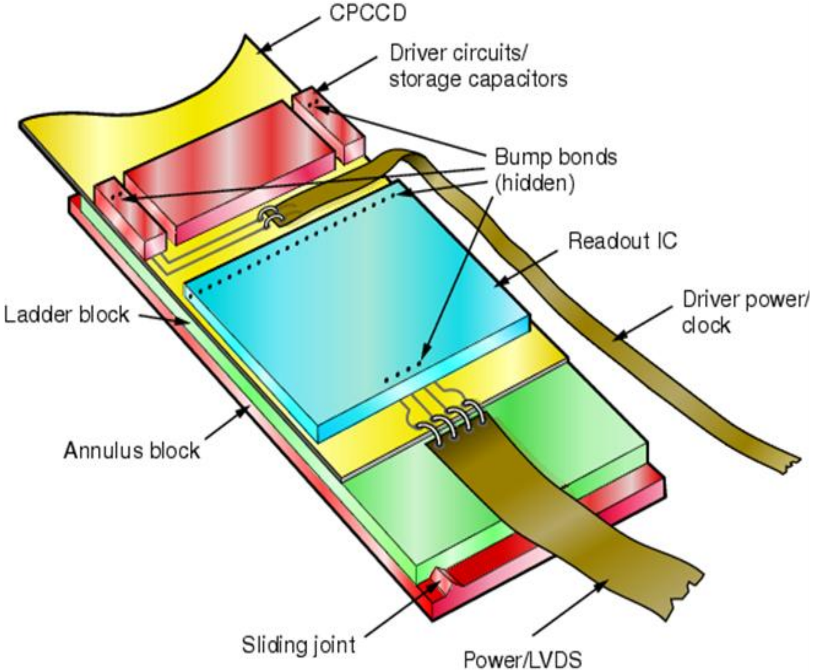
- Higgs physics is standard example: e+e- → HZ with Z → leptons
  - High precision tracking allows determination of mass of recoil
  - Study Higgs production independent of decay modes
  - Reduces combinatorics, drives high magnetic field, large volume tracking
  - More examples: charm and tau tagging, precision tracking for energy flow
- Need for precision tagging of b, c, tau implies
  - Small inner radius: ~15 mm
  - Excellent resolution in z, $R\varphi$: 5 μm pointing precision
  - Constraints on mass (multiple scattering): 0.1% X_0

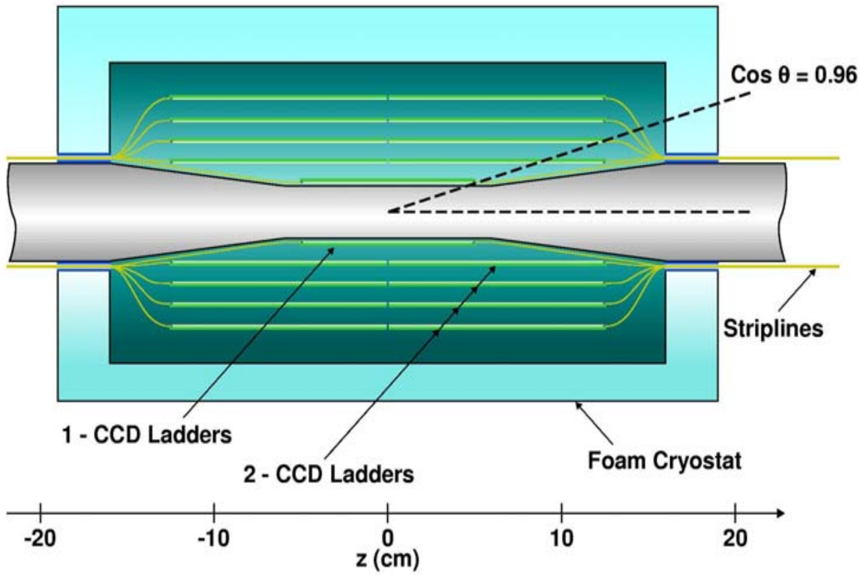
LDC Vertex Detector

- Detector not yet final; sensor technology not chosen yet
  - Many options from TESLA TDR; CCDs, CMOS pixels, hybrid pixels
  - Many new ideas being developed
  - It is too early to choose (no need to yet)
- Fast (column-parallel readout) CCDs used as default technology in TDR
  - Most developed sensor+layout
  - 800 million channels
  - 20 x 20 μm pixels in 5 layers
  - Inner radius 1.5 cm
  - Readout time 50 μs
  - Ladder thickness 0.1% X_0



Vertex Detector Layout



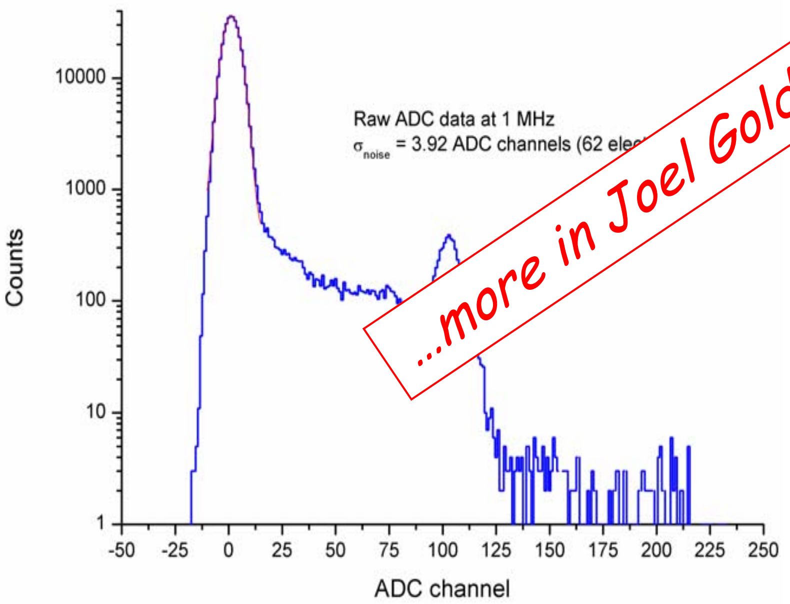


Layer	Radius [mm]	L x W [mm^2]	CCD size [Mpix]	Ladders	Clock [MHz]	Background [hits/mm^2, khits/train]	
1	15	100 x 13	3.3	8	50	4.3	761
2	26	125 x 22	6.9	8	25	2.4	367
3	37	125 x 22	6.9	12	25	0.6	141
4	48	125 x 22	6.9	16	25	0.1	28
5	60	125 x 22	6.9	20	25	0.1	28

Column-Parallel CCDs: Recent Results

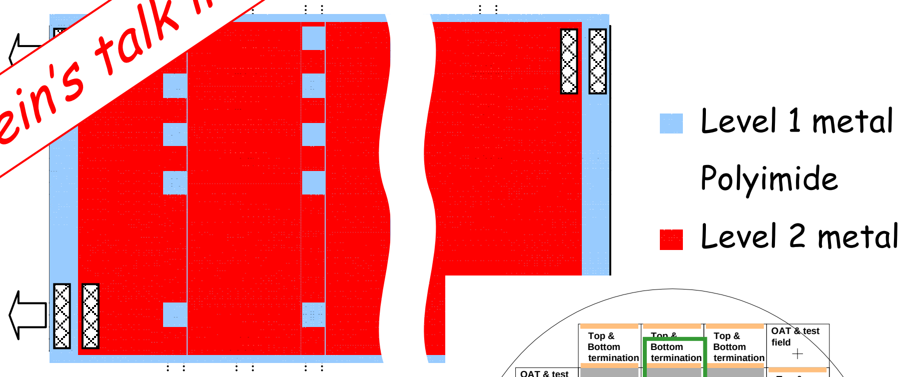
- First-generation tests (CPC1):
  - Noise ~100 e⁻ (60 e⁻ after filter).
  - Minimum clock potential ~1.9 V.
  - Max clock frequency above 25 MHz (design 1 MHz).
  - Limitation caused by clock skew

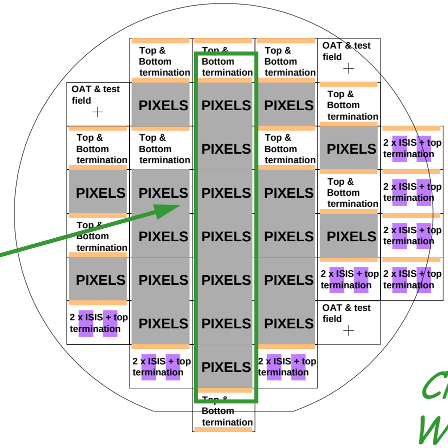
→ *Very successful!*



- Next generation in production (CPC2):
  - Busline free design (two-level metal)
  - Large area 'stitched' sensor, choice of epi layers for …ing depletion depth
  - Range of … sizes for test of clocl… …gation (up to 50 MHz)
  - … chips are nearly the right size

...more in Joel Goldstein's talk in Vertex session





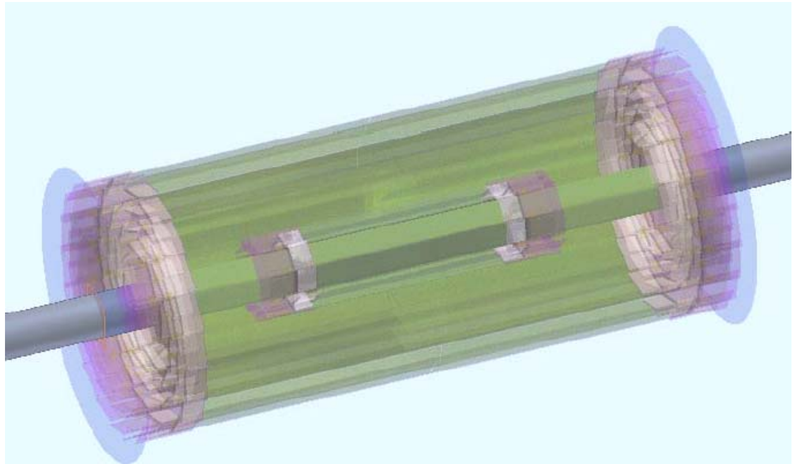
CPC2-70
9.2 cm

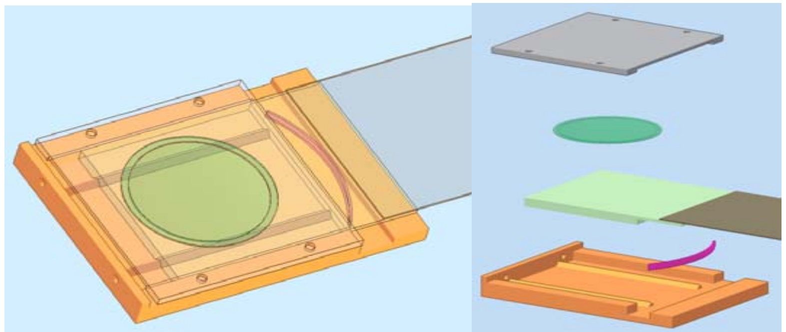
CPC2 Wafer

Additional Implications, Mechanical Considerations

- Requirements:
  - High precision sensors (20 micron or smaller pixels)
  - Low mass (0.1% X_0)

- Practical aspects:
  - Alignment possibility
  - Sensors must be low power, gas cooled
  - Low mass ladder ends
  - Cables, services routed so as not to add mass
  - Mechanical stability to few microns
  - Must withstand thermal cycling
  - Full detector layout
  - Must be able to hold the ladders

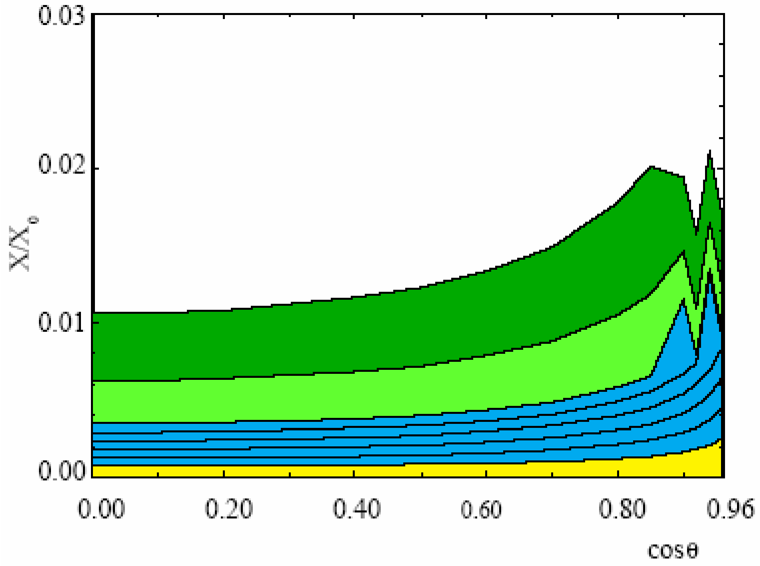




→ Many interesting mechanical challenges

Review of the Detector Layout

- (Re)optimising the layout
  - How many layers, length?
  - Forward disks, how many, where?
  - Inner layer size, location?
  - Is the distribution of mass acceptable?
  - What is impact on physics?



- Does the VTX work well with expected beam structure?
  - Are we sensitive to beam parameter variations?
  - Are recent background studies correct?

→ *Should revisit all detector layout questions in coming year.*

Beam and IP parameters for 500 GeV cms

	TESLA	USSC	Nominal	Low Q	Large Y	Low P	High L
E_{cms} (GeV)	500	500	500	500	500	500	500
N (10^{10})	2.0	2.0	2.0	1.0	2.0	2.0	2.0
n_b	2820	2820	2820	5640	2820	1330	2820
t_b (ns)	336.9	336.9	307.7	153.8	307.7	461.5	307.7
bucket interval	438	438	400	200	400	600	400
I_{ave} (mA)	9.5	9.5	10.4	10.4	10.4	6.9	10.4

Next Steps

Important VTX questions to address (or re-visit):

1. Inner radius (as it will be fixed soon)
2. Backgrounds
   - Assumptions about backgrounds being hard-wired into VTX designs… all calculations should be reviewed.
   - How precisely do we know beamstrahlung, backsplash from masks, neutrons from dumps, etc.?
   - How well is the radiation environment known?
   - Can we run with reduced field? What does this to inner VTX layer?
3. Thermal/mechanical issues
   - How much power does your favorite sensor technology require?
   - Does cooling result in mass in the central/forward region?
   - How much does pulsed power help?
4. Readout details of VTX, and connection to physics
   - Simulations do not yet include operational details or detector response.
   - Need to state detector optimisation in terms of benchmark processes.
5. Mechanical design, including assembly, services, cable routing, etc.

Conclusions

Our goal is to further optimise the vertex detector by taking into account:

- modified machine design parameters
- updated physics benchmarks
- results from ongoing detector R&D, new ideas

→ *The LDC VTX concept well developed, but still time for improvement!*