A CCD Vertex Detector for the Future e^+e^- Linear Collider

LCWS 2000

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on behalf of the LCFI Collaboration
http://hep.ph.liv.ac.uk/~green/lcfi/home.html

Ideas based on SLD vertex detector (307 M Pixels), extended to 799 M pixels.

- Physics goals
- Detector design overview
- Layer thickness
- Readout rate; CCD architecture

Physics Goals

- TeV regime may be characterised by a wide range of SM and beyond-SM processes, typically with small cross-sections, many with high multiplicities of heavy-quark jets, eg

$e^+e^- \rightarrow t\bar{t}$	usually 6 jets, two *b*-flavoured and two *c*-flavoured
$e^+e^- \rightarrow t\bar{t}h$	usually 8 jets, four *b*-flavoured
$e^+e^- \rightarrow AH$	12 jets, four *b*-flavoured

- Precision measurements (eg of Higgs branching ratios) can distinguish between SM and other models.

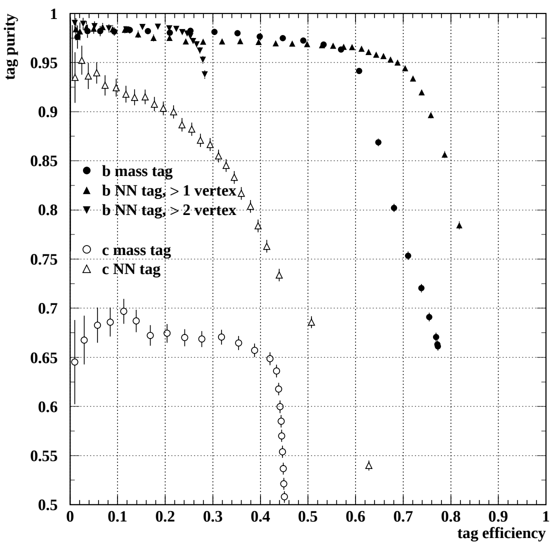
  $\rightarrow$ Thus, need for highly efficient and pure *b* and *c* tags is evident

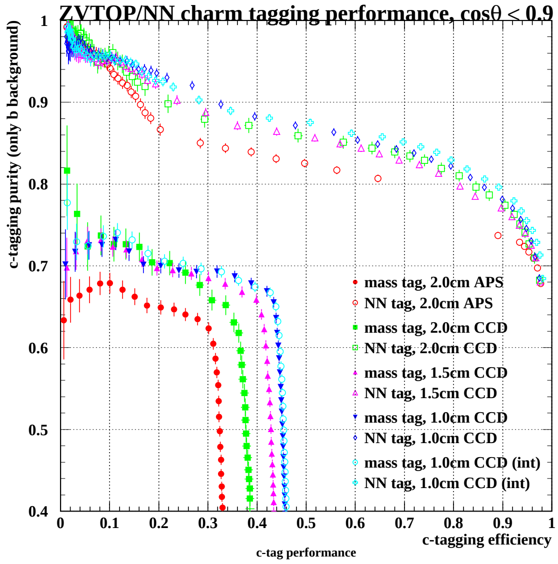
- Vertex charge is valuable to distinguish *b* from $\bar{b}$ and *c* from $\bar{c}$

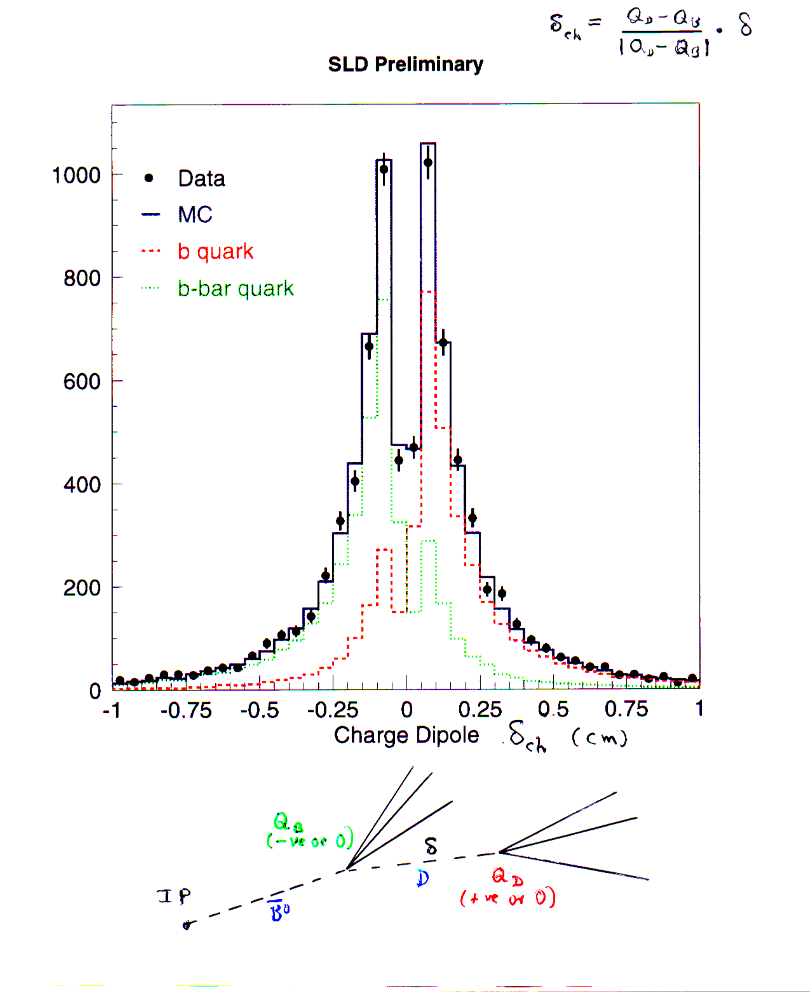
  Important for angular anayses eg for

  ZZH and $Z\gamma H$ anomalous couplings

- Charge dipole (demonstrated in SLD) can distinguish *b* from $\bar{b}$ even in case of B^0 final state

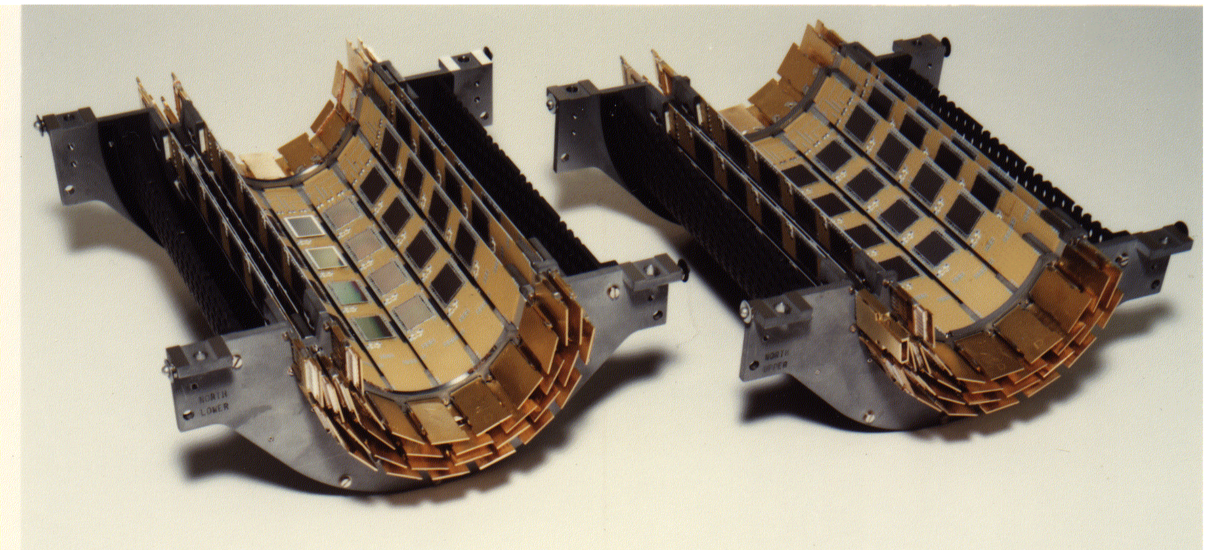

tag purity
tag efficiency
b mass tag
b NN tag, > 1 vertex
b NN tag, > 2 vertex
c mass tag
c NN tag


ZVTOP/NN charm tagging performance, cosθ < 0.9
c-tagging purity (only b background)
c-tagging efficiency
c-tag performance
mass tag, 2.0cm APS
NN tag, 2.0cm APS
mass tag, 2.0cm CCD
NN tag, 2.0cm CCD
mass tag, 1.5cm CCD
NN tag, 1.5cm CCD
mass tag, 1.0cm CCD
NN tag, 1.0cm CCD
mass tag, 1.0cm CCD (int)
NN tag, 1.0cm CCD (int)

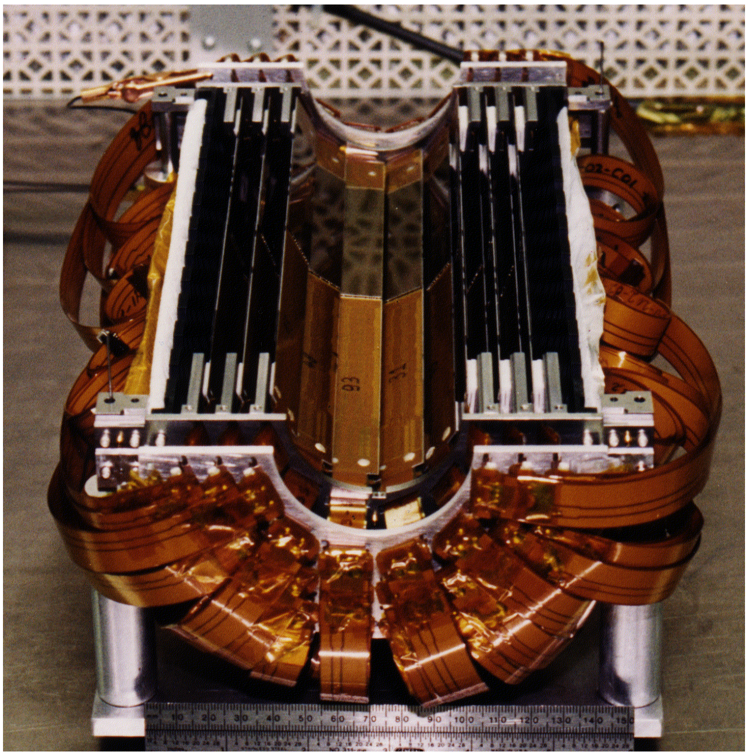

$\delta_{ch} = \frac{Q_D - Q_B}{|Q_D - Q_B|} \cdot \delta$
SLD Preliminary
Data
MC
b quark
b-bar quark
Charge Dipole δ_{ch} (cm)
IP
$\bar{B}^0$
Q_B (-ve or 0)
δ
D
Q_D (+ve or 0)

The SLD Vertex Detectors

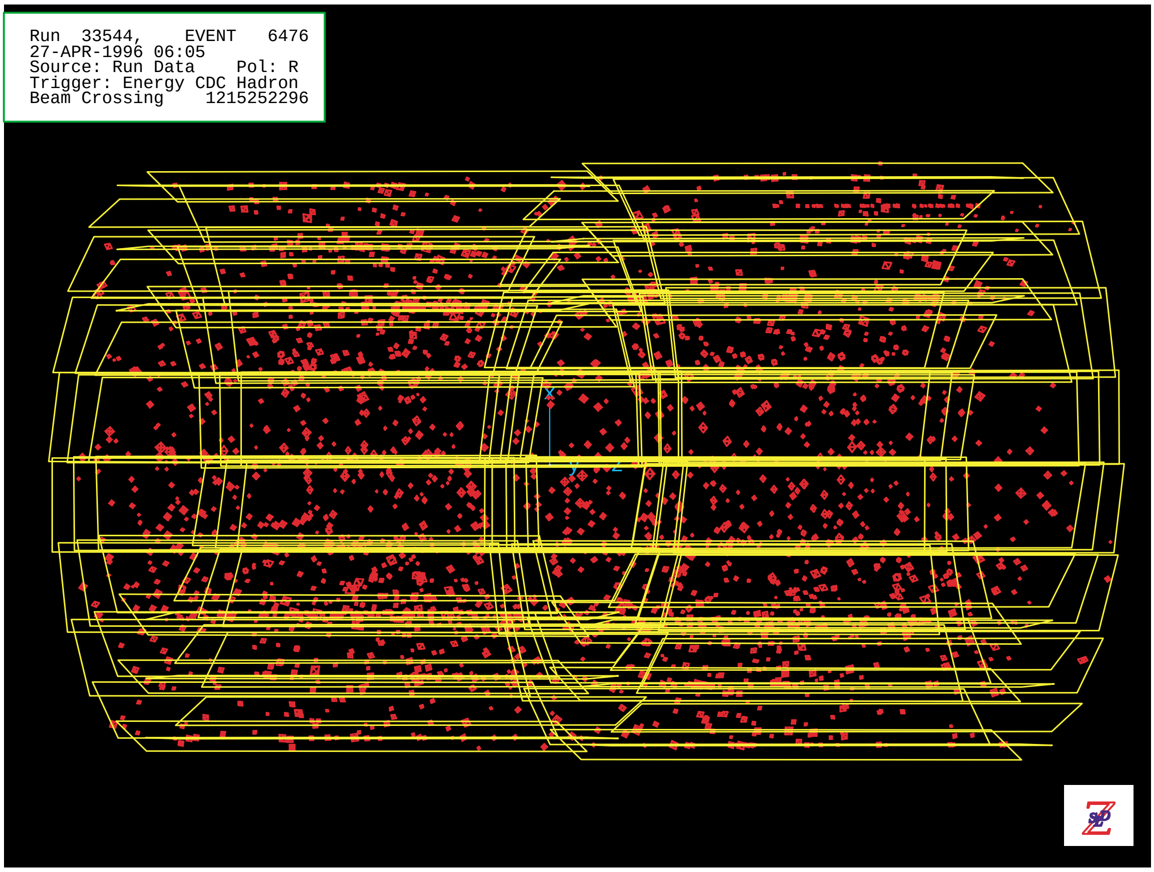
VXD2 Proc 26th Int Conf on HEP, Dallas TX (1992)



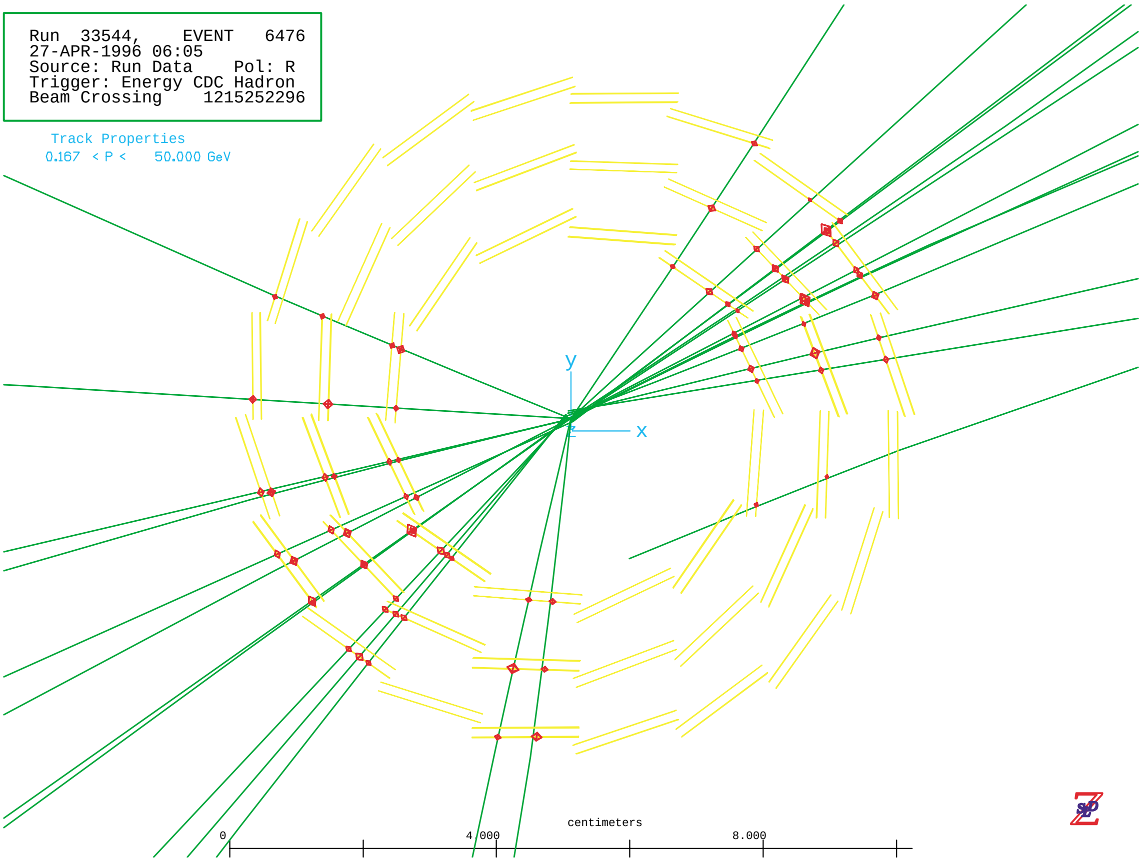
VXD3 NIM A400 (1997) 287



e^+e^- linear collider will inevitably have high background at small radii



A pixel detector is extremely tolerant of this background

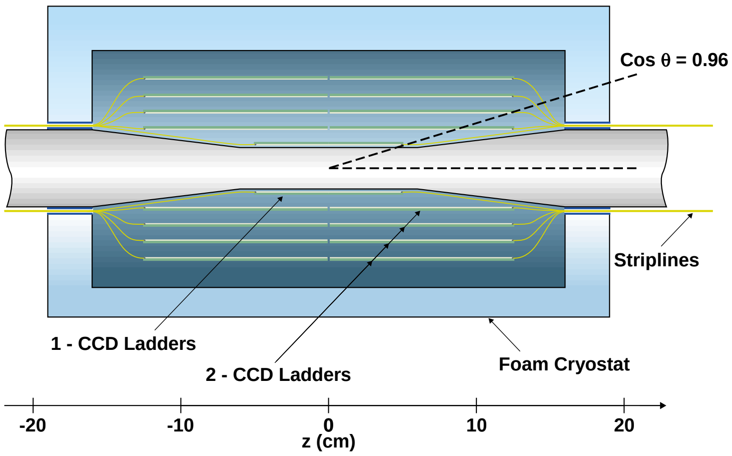


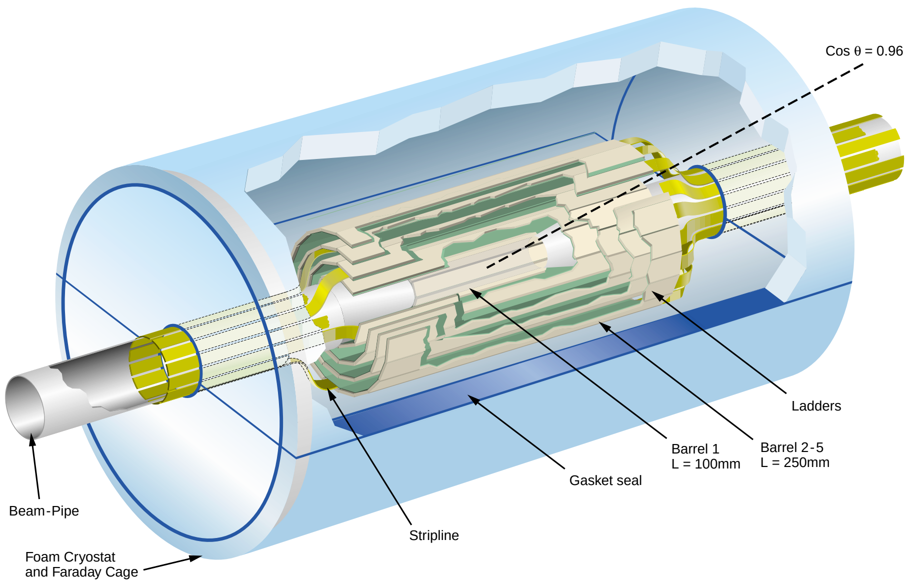
The future LC vertex detector

- Studies of the Linear Collider Flavour ID collaboration (LCFI)
- Detailed studies in context of TESLA detector:
  - R_{bp} = 14 mm and 4 Tesla solenoid

    $\rightarrow$ L1 active length 10 cm

    $\rightarrow$ 3-hit coverage to $\cos\theta = 0.96$



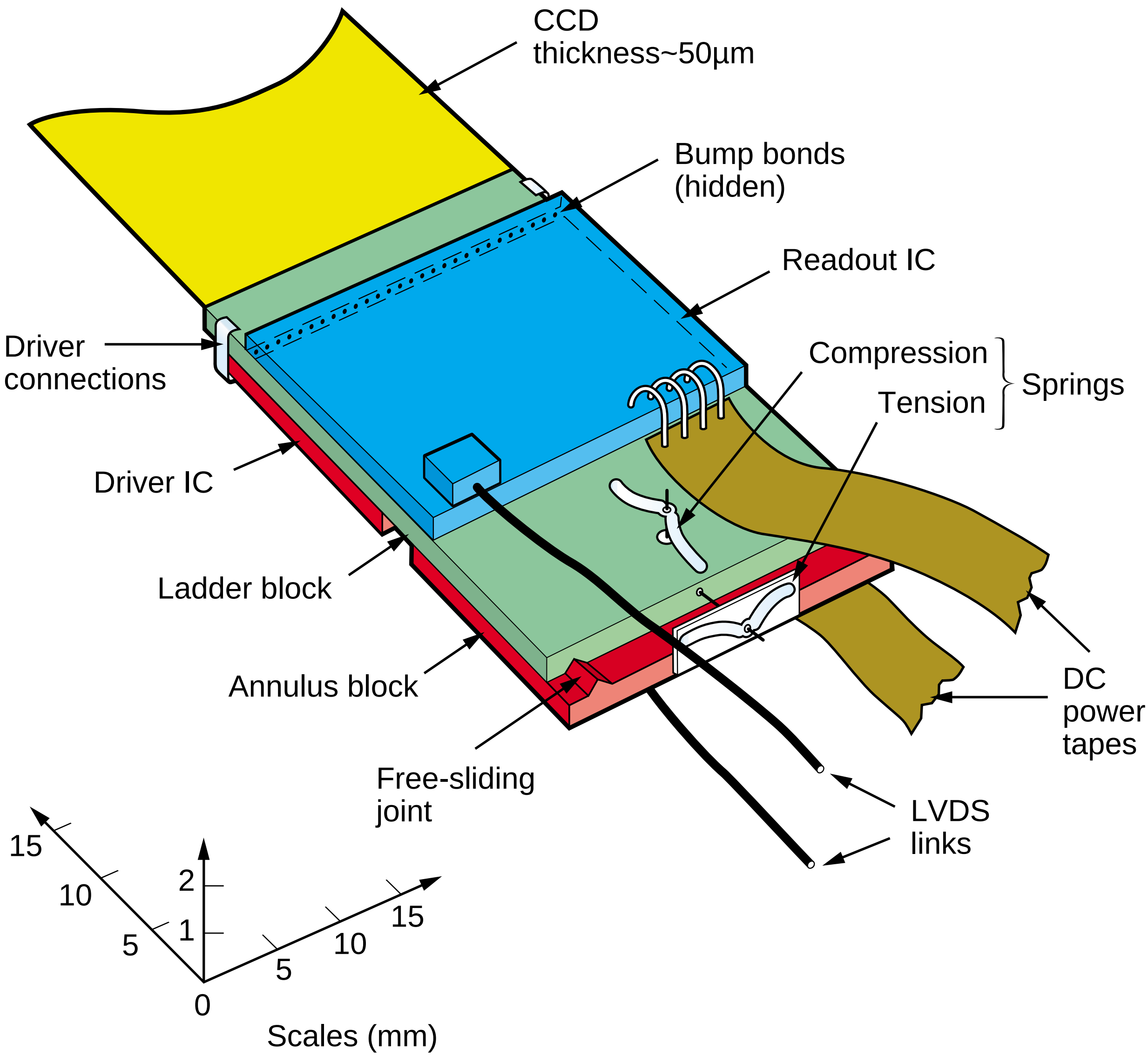


SLD & Future LC Detector Properties

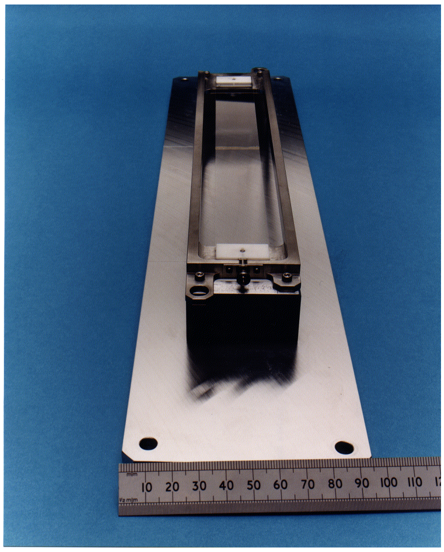
Detector	VXD2	VXD3	Future LC
CCDs	480	96	120
CCD active area (cm^2)	1.2	12.8	27.5
Number of pixels ($\times 10^6$)	120	307	799
Effective no. of layers	2	3	5
Inner layer radius (mm)	28	28	15
Layer thickness (% X_0)	1.1	0.4	0.06
$(\cos\theta)_{max}$ (2-hit)	0.75	0.90	0.96
Imp. param resoln. $\sigma_{r\phi}$	$11 \oplus 70/p\sin^{3/2}\theta$	$9 \oplus 33/p\sin^{3/2}\theta$	$3.5 \oplus 6.5/p\sin^{3/2}\theta$
σ_{rz}	$38 \oplus 70/p\sin^{3/2}\theta$	$17 \oplus 33/p\sin^{3/2}\theta$	$3.5 \oplus 6.5/p\sin^{3/2}\theta$
Readout time	160 ms	216 ms	50/250 μs (8 ms for NLC)

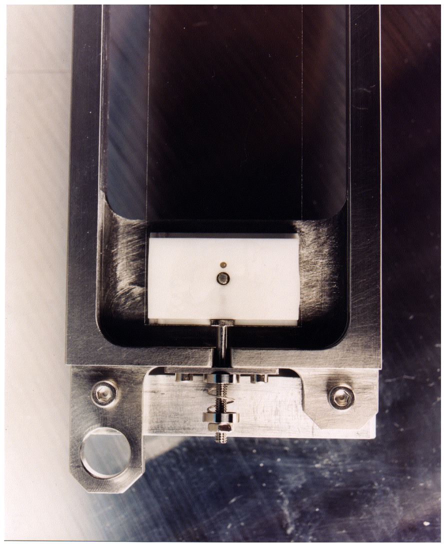
Layer Thickness

- Currently pushing the ‘unsupported silicon’ option

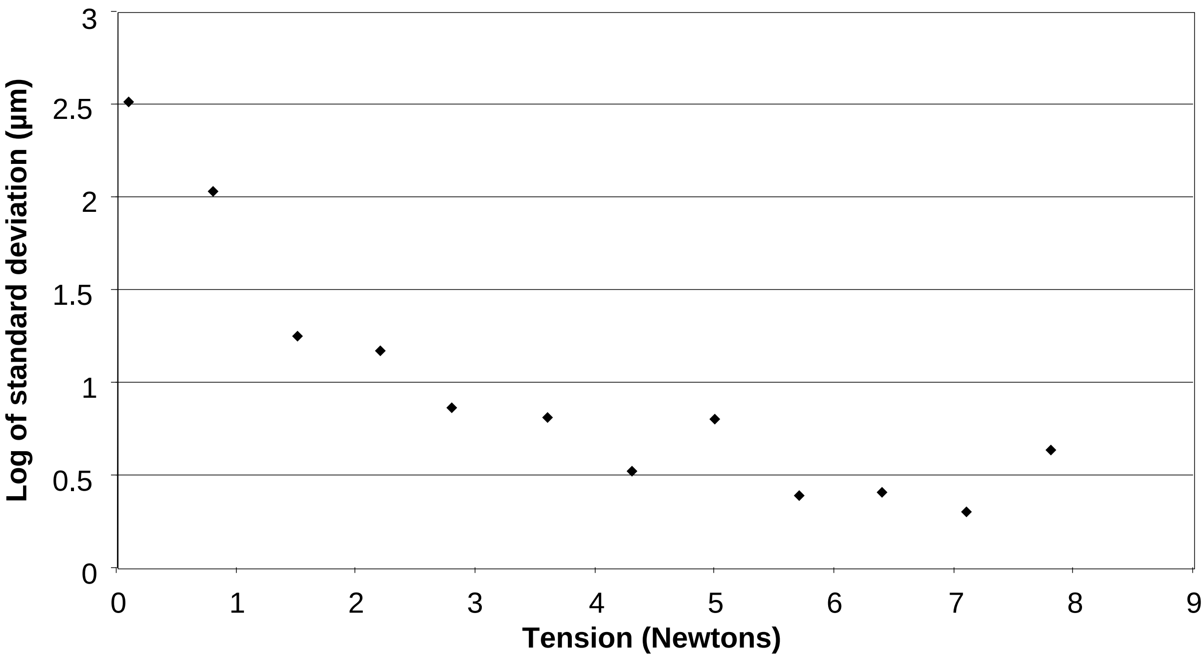


- Results with thin glass CCD models are most encouraging

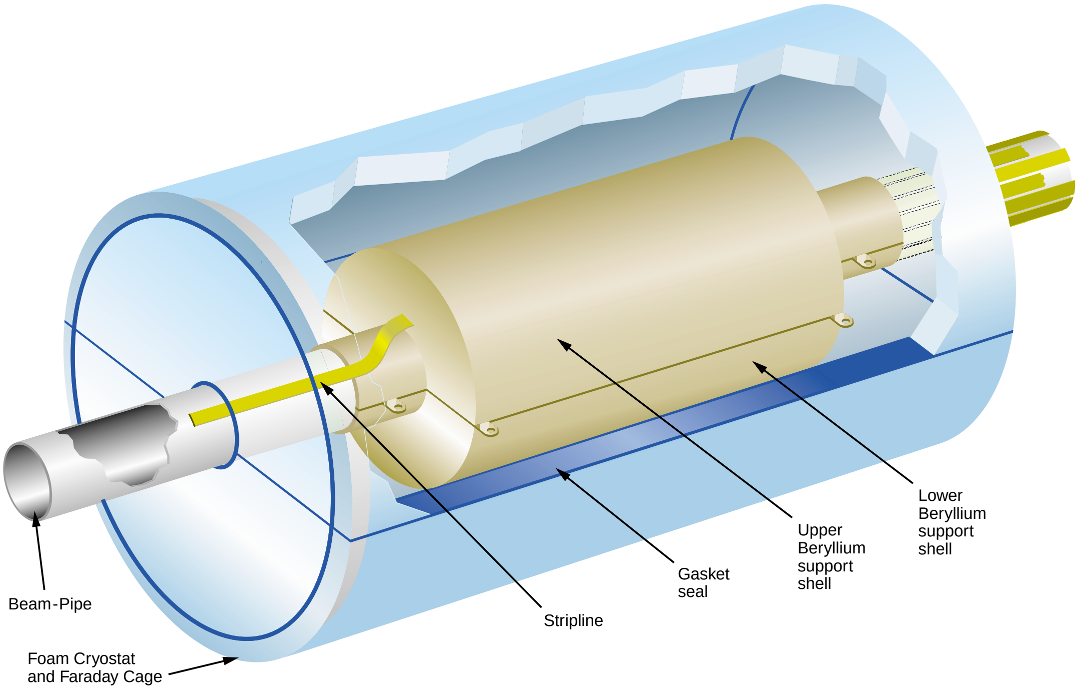




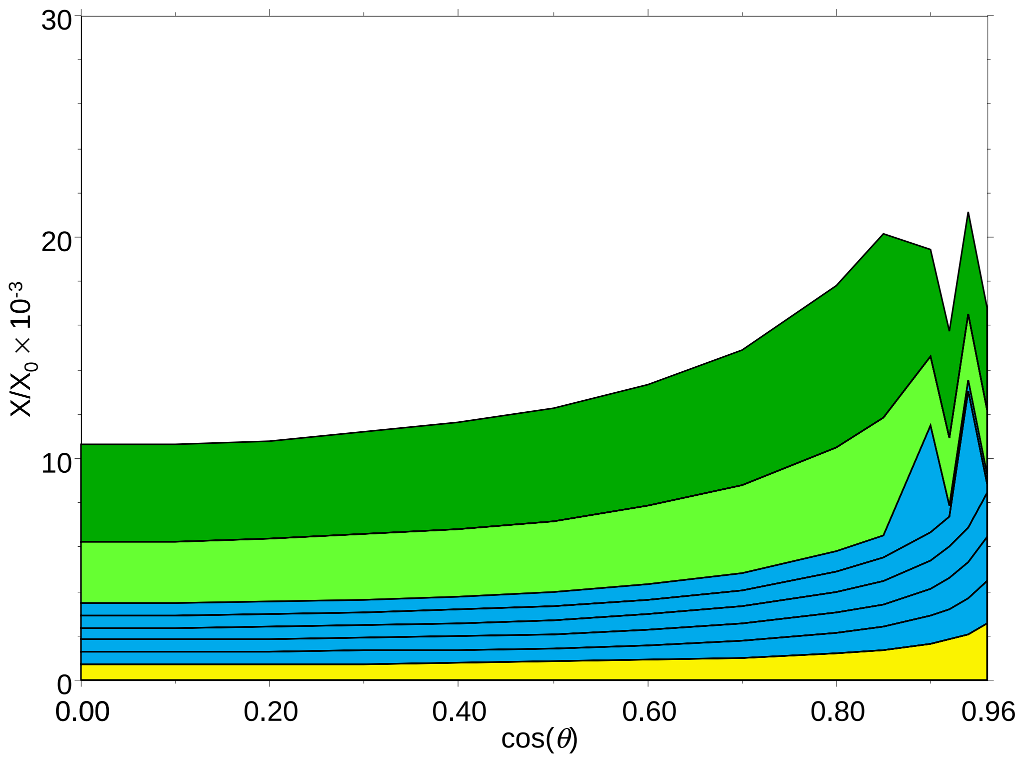
- Assisted by the strong technology evolving for PTPs (paper-thin packages)



0.06% X_0/layer would be excellent, but this imposes pressure on the beampipe thickness



- 0.07% X_0 may be possible (0.25 mm beryllium), by using the VXD support shell for strain relief



- Layer 1-3 provide first class coverage to $\cos\theta = 0.96$
- < 1% X_0 total

Readout Rate/CCD Architecture

NLC: $190 \times 120 = 22.8 \times 10^3$ bunches/s

TESLA: $2820 \times 5 = 14.1 \times 10^3$ bunches/s

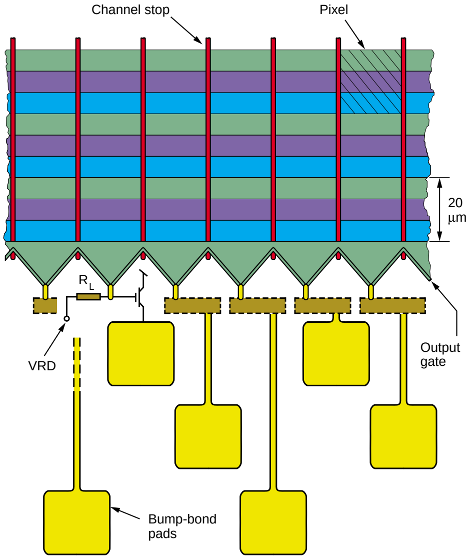
Luminosity and background per bunch are similar.

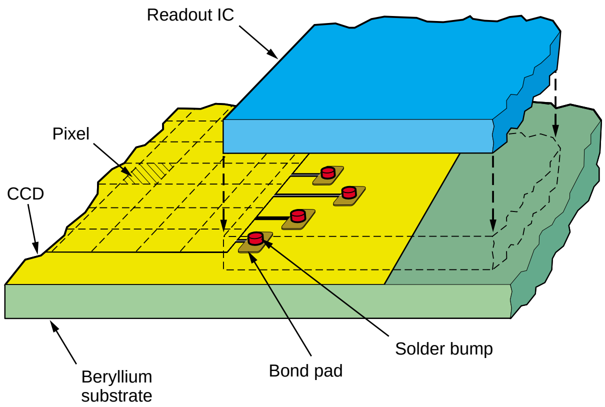
NLC: CCD readout in 8 ms between bunch trains provides adequate background control

TESLA: 15 times more luminosity per train, so need to read repeatedly during each train of 950 μs

$\rightarrow$ Concept of column-parallel readout in 50 μs, which is interesting for other CCD application areas.

[An earlier option of fast clear, fast trigger and kicker magnet to kill the bgd was excluded by GMSB and other subtle signatures: the LC DAQ *must* run in an untriggered mode.]

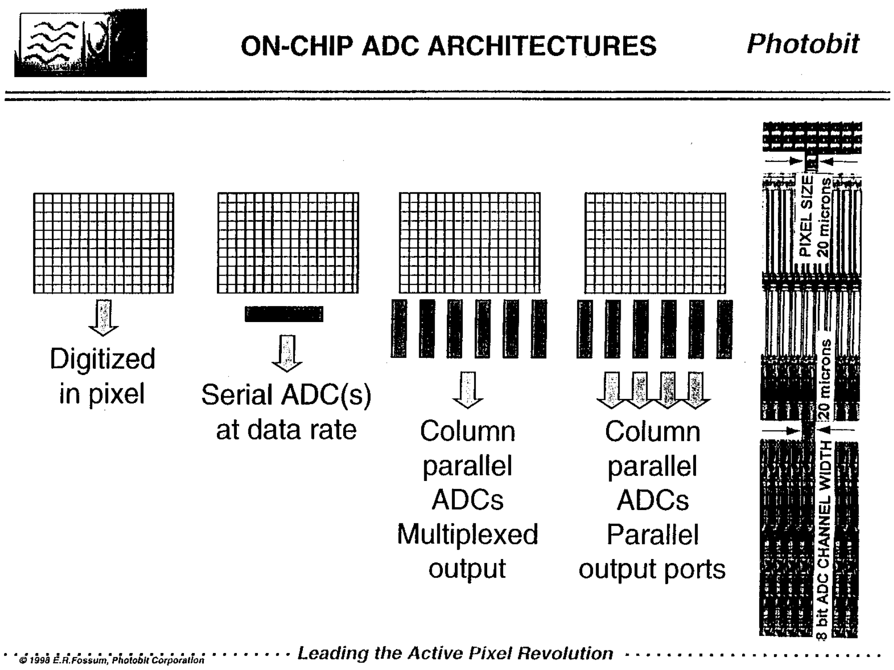




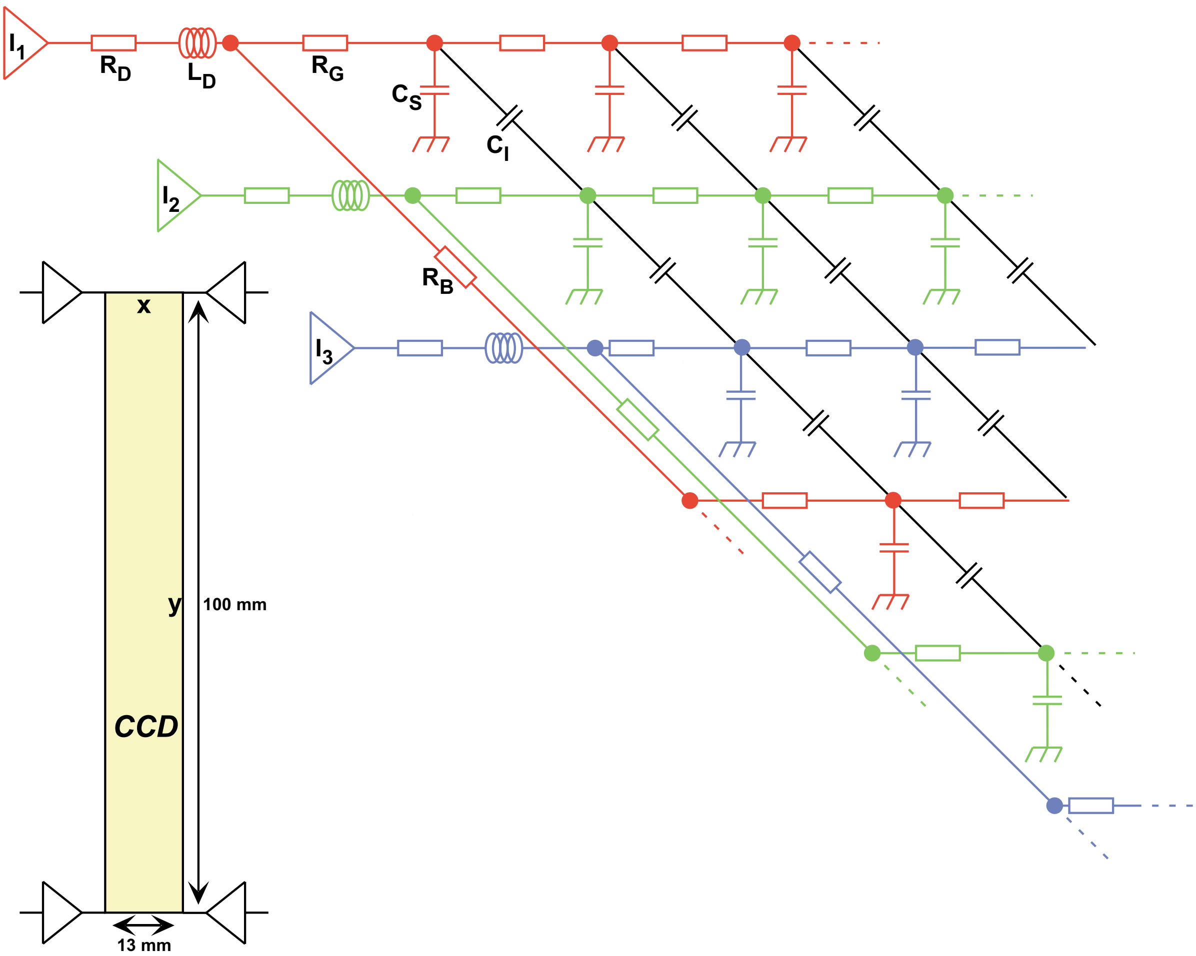
- Maybe no-reset output with resistive load
- Single row of staggered bump bonds follows standard industrial practice
- Goal is 50 MHz parallel clocking with 1-3 V drive voltages

  $\rightarrow$ what implications for on-CCD buslines, in-detector cooling?

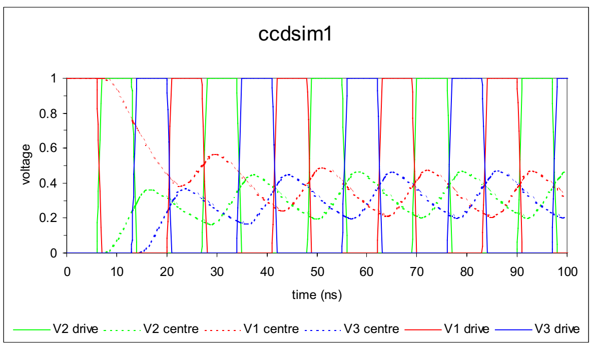
- Signal processing well-matched to 0.25 μm processing. Much can be learned from CMOS active pixel imaging devices

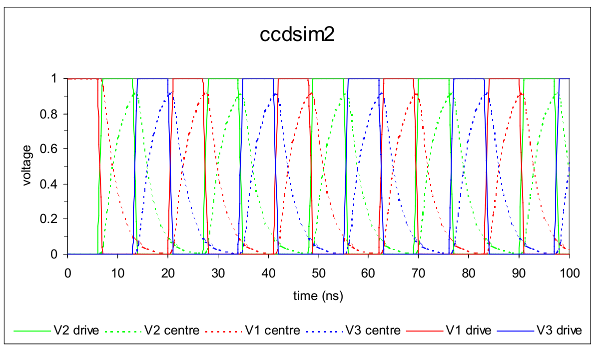


Initial studies based on 3-phase clocking

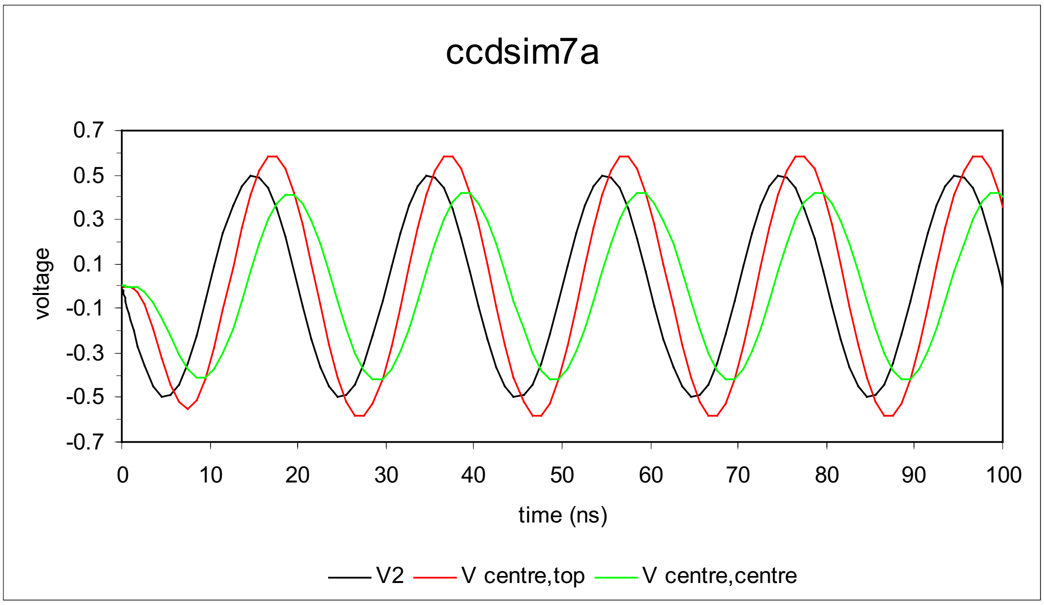


SPICE model of column-parallel CCD gate structure
(VXD layer 1 dimensions)





However, the LC lends itself to 2-phase sinusoidal operation, starting slightly before the bunch train

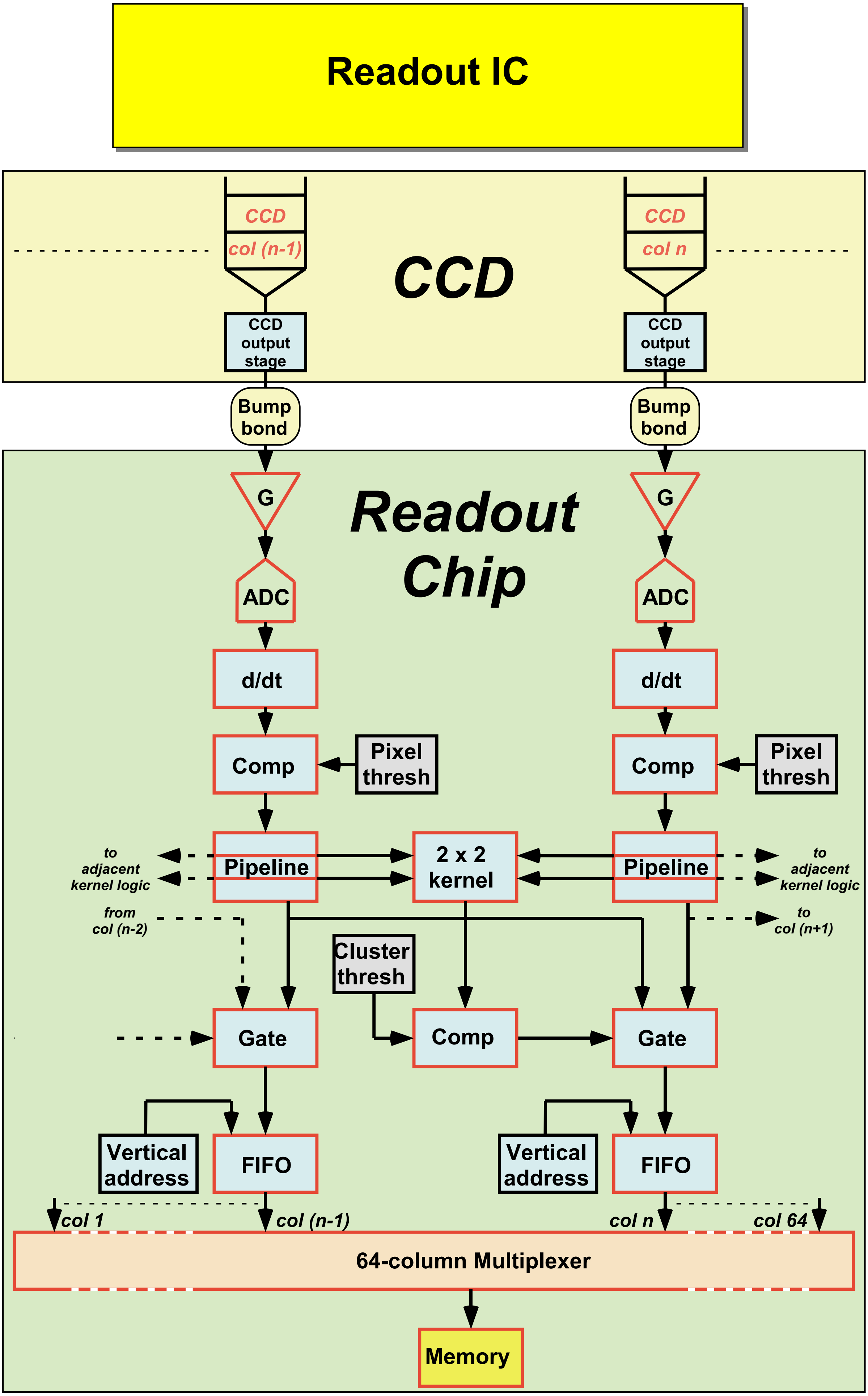


Latest estimates:

In detector power dissipation ≈ 9 Watts!

→ a very gentle flow of cooling gas

[Ladder ends will need more aggressive cooling: ‘no problem’.]



Readout IC
CCD
col (n-1)
CCD
col n
CCD
CCD output stage
CCD output stage
Bump bond
Bump bond
Readout Chip
G
G
ADC
ADC
d/dt
d/dt
Comp
Pixel thresh
Comp
Pixel thresh
to adjacent kernel logic
Pipeline
2 x 2 kernel
Pipeline
to adjacent kernel logic
from col (n-2)
to col (n+1)
Cluster thresh
Gate
Comp
Gate
Vertical address
FIFO
Vertical address
FIFO
col 1
col (n-1)
col n
col 64
64-column Multiplexer
Memory

- Background occupancy 5.9 hits/mm^2 (layer 1) to 0.6 hits/mm^2 (layer 5)

  $\rightarrow$ ~ 2.6×10^6 hits/train

  $\rightarrow$ 15 MB stored on detector during train and read out to a selected available processor between trains

  $\rightarrow$ a few optical fibres each end

Conclusions

- We have about 5 years of R&D before technology choices need to be made

- CCDs, while promising, could run up against show stoppers such as:

  present goals achieved too late or not at all

  manufacturers losing interest

  radiation environment (specially neutrons)

- For *all* options, CCDs, hybrid pixels and CMOS pixels, important to push hard. Much scope for development; physics prizes could be immense

- All these technologies are in demand for many applications. Developments are likely to make brisk progress into the distant future, independent of HEP community

- The preferred technology may well change during the life of the collider

- Therefore vital to ensure convenient access to the inner detector, in order to permit instrumentation upgrades (vertex detector, beamsize monitor, beam position monitors) every few years.