A CCD Vertex Detector for the future TeV-scale e^+e^- Linear Collider

CERN Workshop
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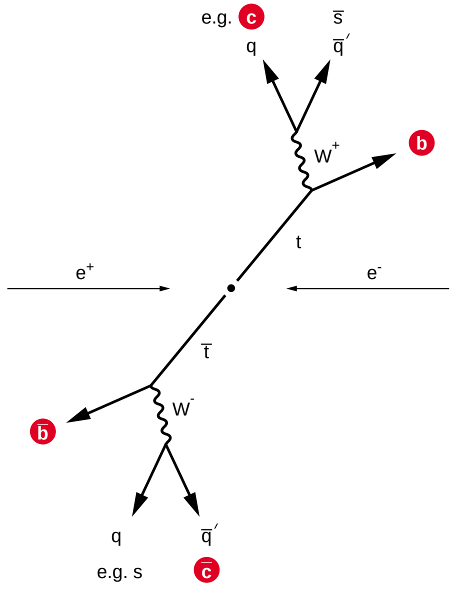
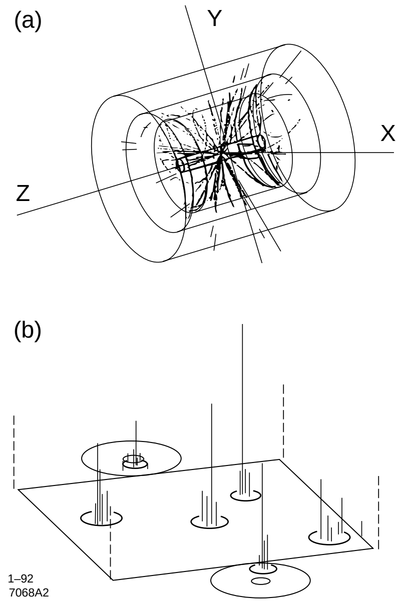
28 November 2001

- Luminosity 3.4×10^{34} cm^{-2} s^{-1} at 500 GeV
  - Physics requirements
  - Background conditions
  - Generic vertex detector design
  - CCD vertex detectors – track record for physics
  - LC vertex detector – CCD option
  - R&D programme – status and outlook
  - World-wide LC detector R&D - coordination

Physics Requirements

- At TeV scale, multi-jet processes for SM and beyond SM physics

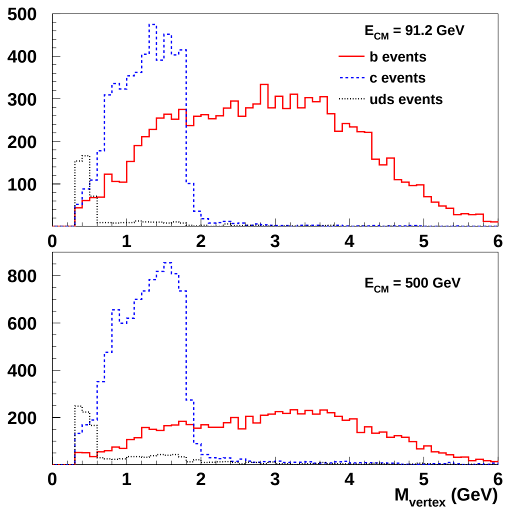


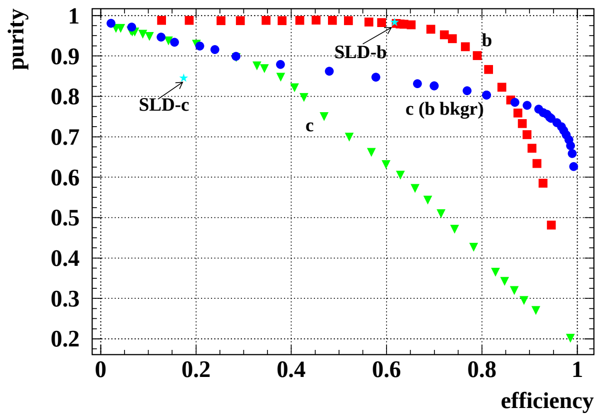


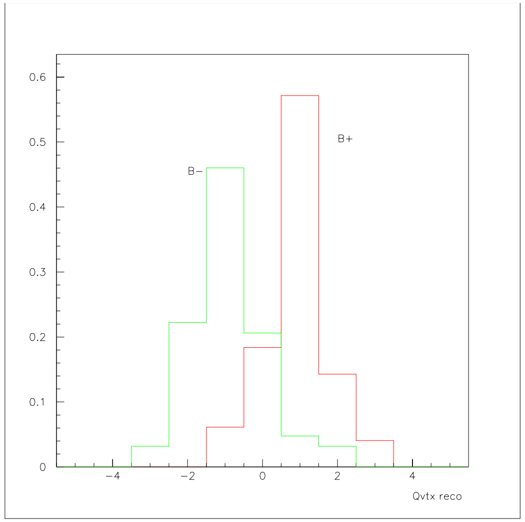
- Need high efficiency/purity for *b* and charm tagging
- Use of vertex charge and charge dipole to distinguish *b* from $\bar{b}$, *c* from $\bar{c}$
- This requires topological vertex reconstruction to level of PV vs SV/TV, hence high efficiency for track assignment to PV or SV/TV
- SLD detector approaches the desired performance for *b*, but falls short for charm
- Need untriggered deadtimeless operation: subtle event signatures possible
- Don’t need to read every BX, but fast enough to control background hit density

- Exciting synergy with energy flow calorimetry (60×10^6 elements)

- P_T-corrected mass of SLD approach may be sharpened by inclusion of π^0s







- Partial reconstruction of missing neutrinos may enhance determination of energy of these ‘sub-standard’ jets

- All this is in its infancy; remember that synergy between vertexing and electron polarisation at SLD was initially dismissed

Background Conditions

- Hadronic event rate <1 Hz (compare pp at same luminosity) so radiation environment is negligible
- Not quite:
  - Beam power 11 MW/beam $\Rightarrow$ significant but remote neutron sources
  - e^+e^- production from beam-beam interaction $\Rightarrow$ significant small-radius background; mostly confined by 4T solenoid
- Few $\times 10^9$ n/cm^2 and few 10s of krad ionising radiation in detector lifetime
  $\Rightarrow$ CCDs, MAPS, DEPFET pixels are all candidates

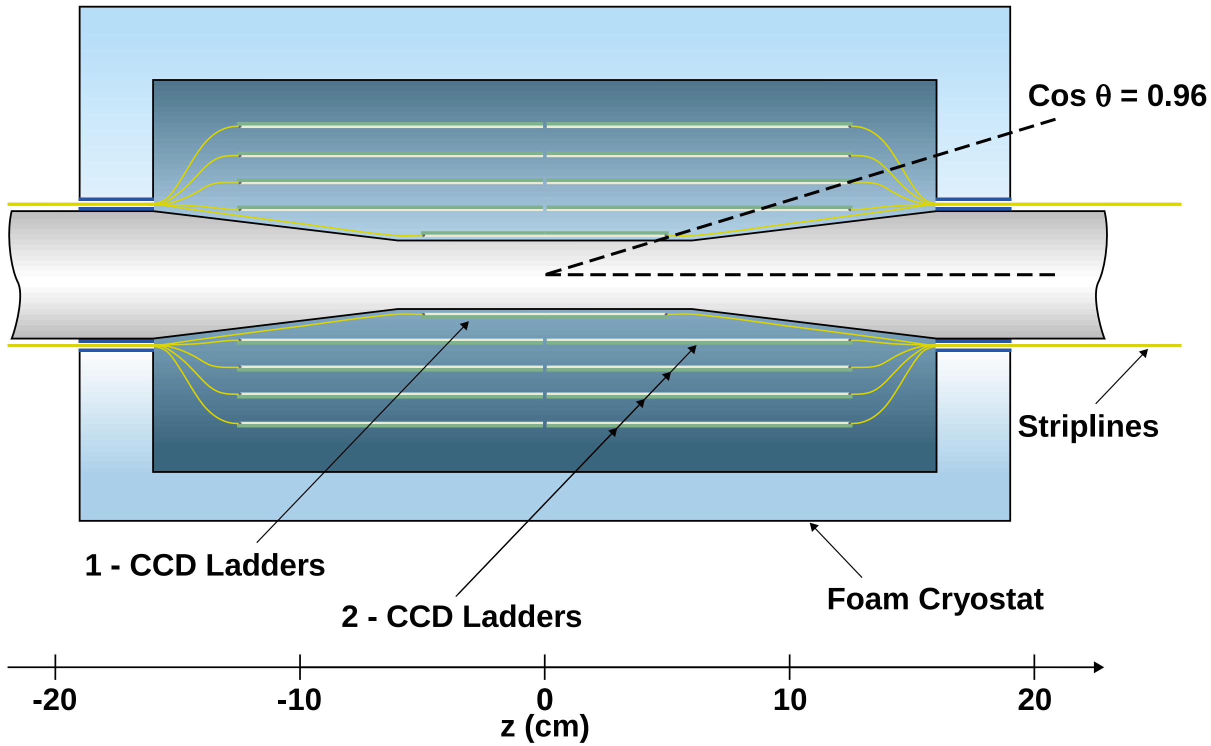
  [HAPS provides overkill in speed/radiation tolerance, but excessive pixel size and thickness]
- Readout time requirement from background hit rate on Layer 1. Need $\lesssim 10/\text{mm}^2$

  NLC: readout between bunch trains (8 ms) is adequate

  TESLA: need ~ 50 μs readout time during bunch train (~ 20 frames during 1 ms, at 200 ms period)

  [average readout rate for both options is ~ 100 Hz reflecting similar design luminosity]

- Now almost unanimous agreement on optimal detector layout:



- Pixel-based (microstrips faded out in 1993)

- Concentric long barrels ('lampshade' variant still considered up to time of TESLA TDR.
  Would make sense in context of a thick-layer fallback option)

- Measure space points with precision < 5 μm in each layer

- Layer thickness $\lesssim 0.1\%$ X_0

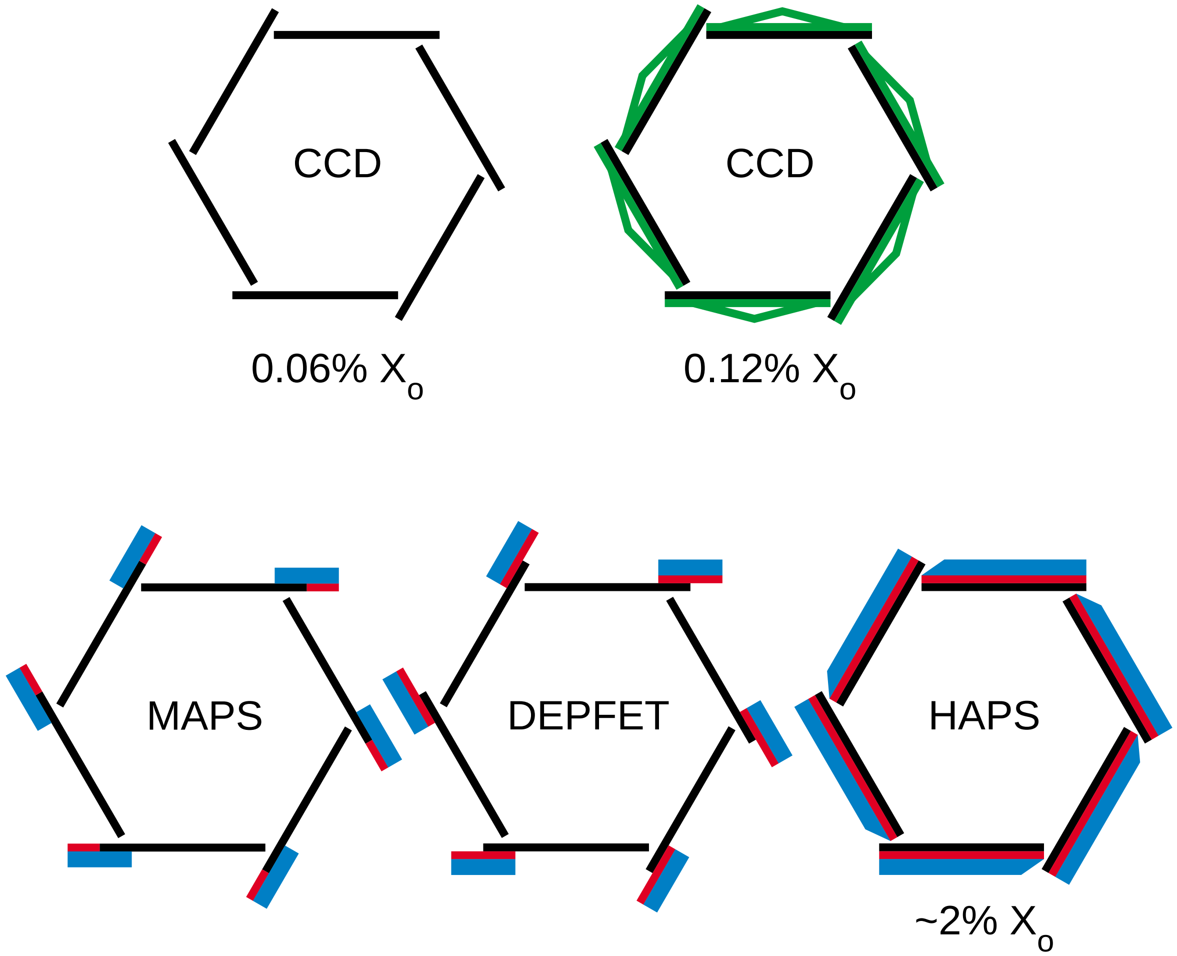
- Layer 1 readout time $\lesssim$ 50 μs required for TESLA
  8 ms OK for NLC/JLC
  (this became clear in November 1998)

- Modest radiation hardness

- While the goals are clear, the means to get there are not

- Very dynamic: 4 technologies being pursued (CCD, MAPS, DEPFET and HAPS)

- $r - \phi$ views



- Material requirements beyond active ladder ends are relatively unknown for all options

- If more than one technology achieves the above goals, decision will probably become clear on basis of material budget
  - This matters all the way to $|\cos\theta| = 0.996$ (LAT outer edge at 83 mrad)
    [similar considerations relevant to TPC/silicon tracker comparison]
  - γ conversions and secondary interactions are dangerous for energy flow quality of forward jets
  - Mechanical supports need to provide ~ 1 μm stability
  - Inner electronics material budget by no means quantified
  - Cables and optic fibres probably modest for all options
  - Cooling requirements could be decisive
- Need full sized, fully functional prototype ladder before taking *any* technology seriously
  [the devil is in the details]
- Meanwhile, important for all concerned to avoid overselling any option

CCD Vertex Detectors
Track Record for Physics

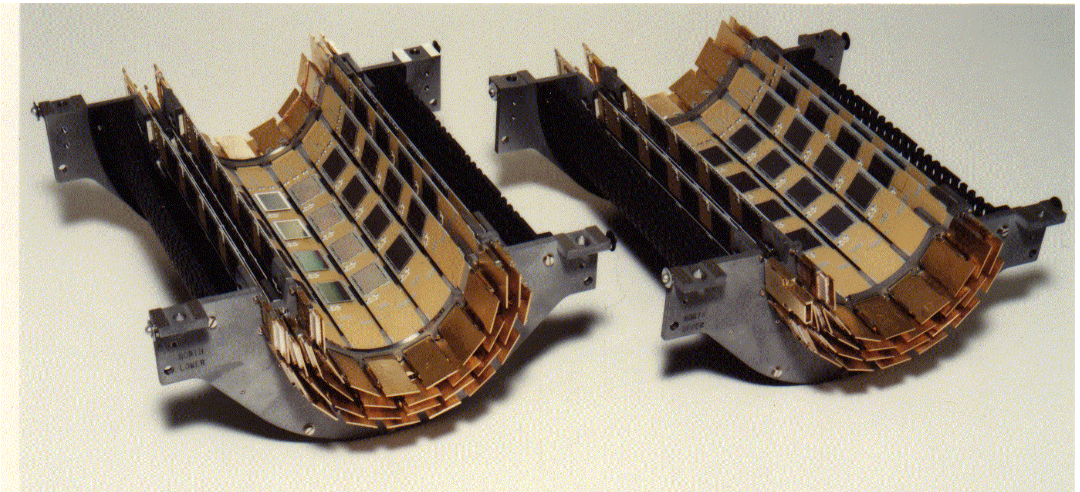
- Possibility for clean charm tagging was established by ACCMOR collaboration in early ‘80s
- Extended to the e^+e^- collider environment in SLD;

  VXD2/VXD3

- Topological vertex reconstruction was the key to success in both experiments
- Novel track-based alignment techniques were essential in SLD

The SLD Vertex Detectors

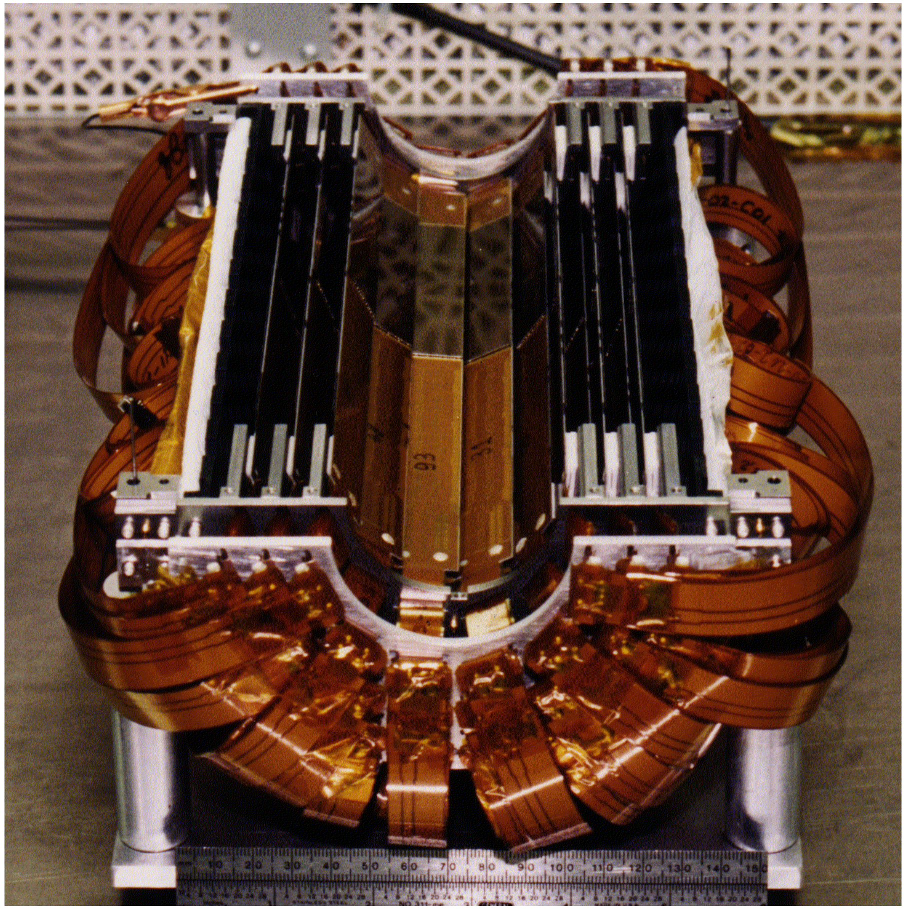
VXD2



120 Mpixels

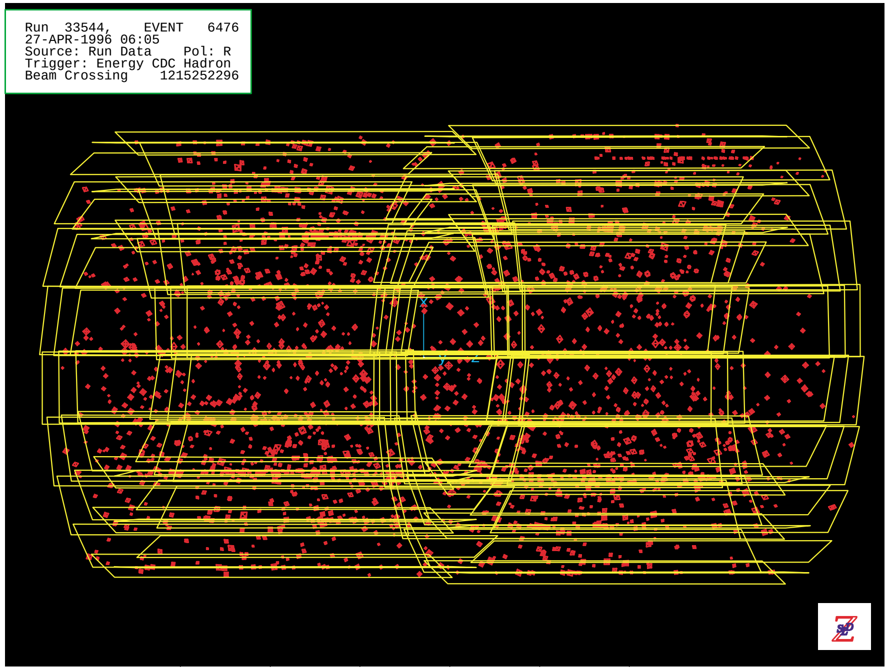
Proc 26th Int Conf on HEP, Dallas TX (1992)

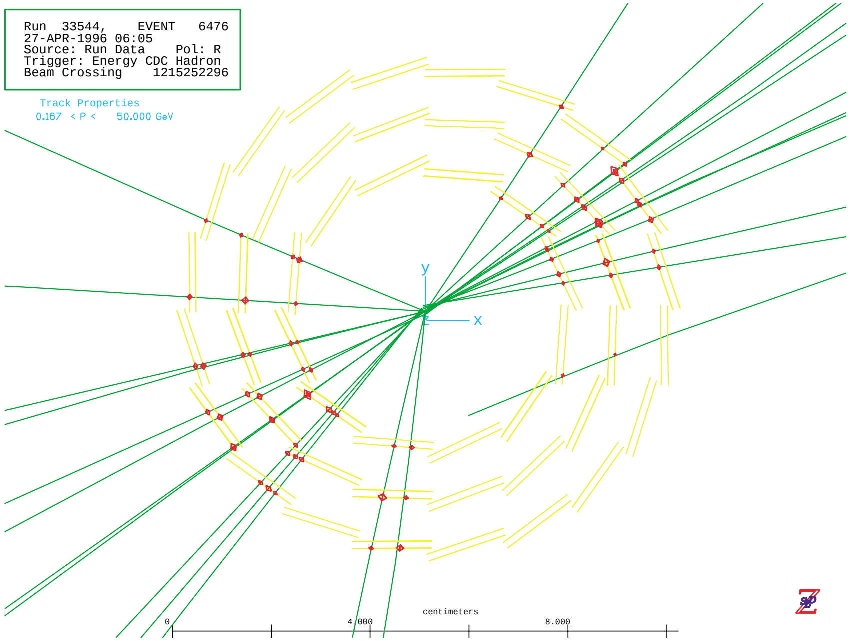
VXD3

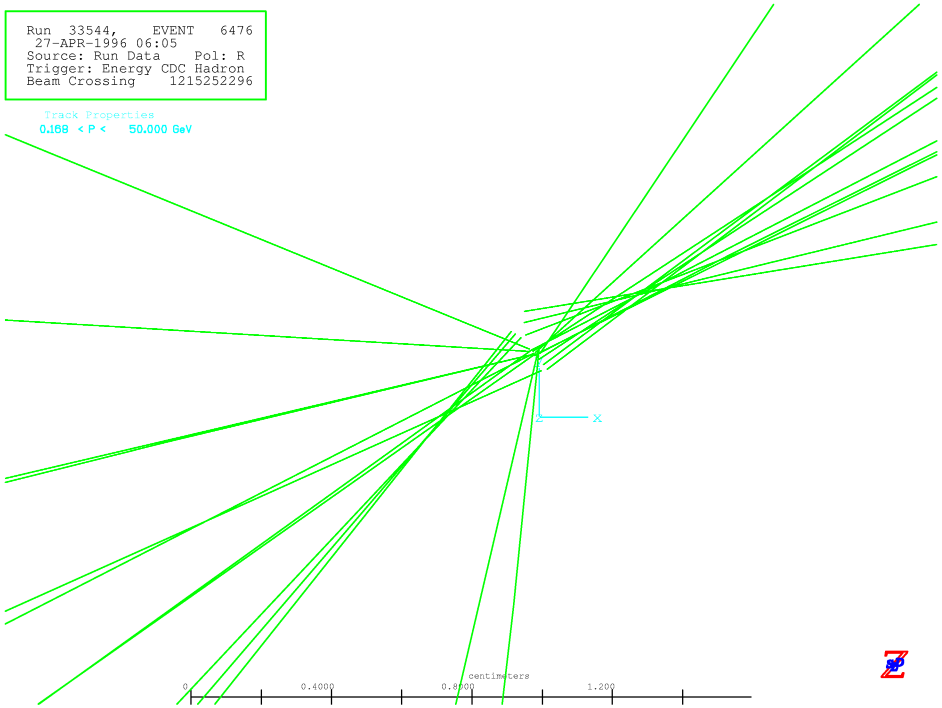


307 Mpixels

NIM A400 (1997) 287







- Saved by shrinking microelectronics/fibre-optics
- Layer thickness 0.4% X_0 (from 1.2% X_0 in VXD2)
- Best imp param resolution of any LEP/SLC expt

$$\sigma_{r\phi} = 9 \oplus \frac{33}{p\sin^{3/2}\theta}\,\mu\text{m}$$

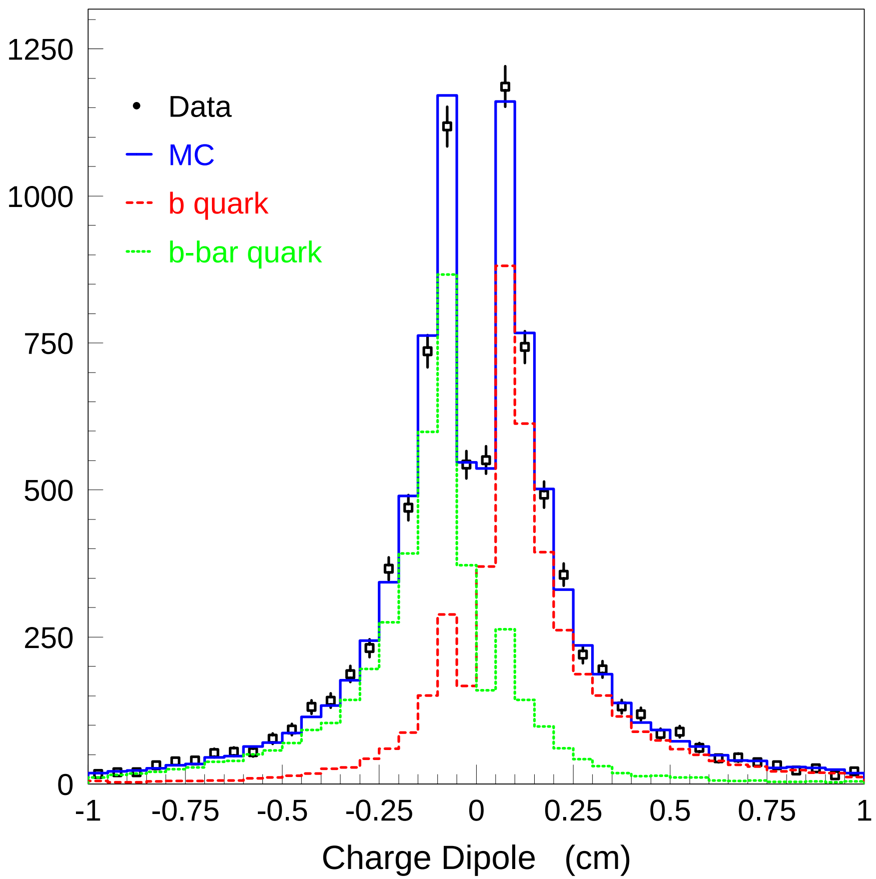
$$\sigma_{rz} = 17 \oplus \frac{33}{p\sin^{3/2}\theta}\,\mu\text{m}$$

Strong programme of b and charm physics, despite having only few percent of the LEP Z sample

- best measurement of $g \to b\bar{b}$
- best measurement of b quark fragmentation
- second most precise measurement of R_b
- best sensitivity to B_s^0 mixing at high Δm_s
- Vertex charge used to distinguish b wrt $\bar{b}$, c wrt $\bar{c}$
- Charge dipole does this for neutral B decays

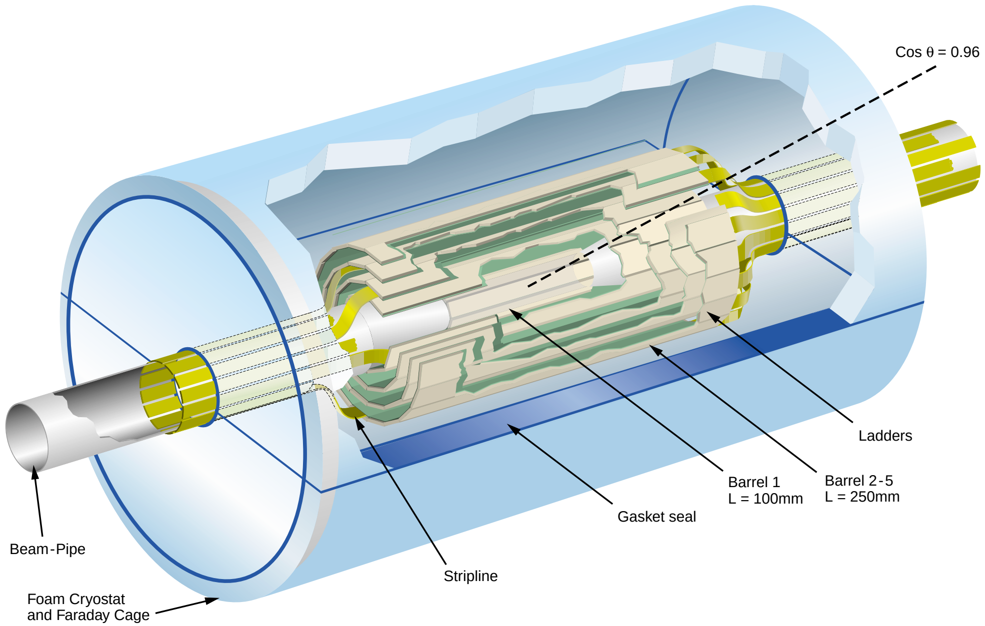
eg $B_s^0 \to D_s^- \pi^+$ [+ve secondary vertex]

$\hookrightarrow K^+ K^- \pi^-$ [-ve tertiary vertex]



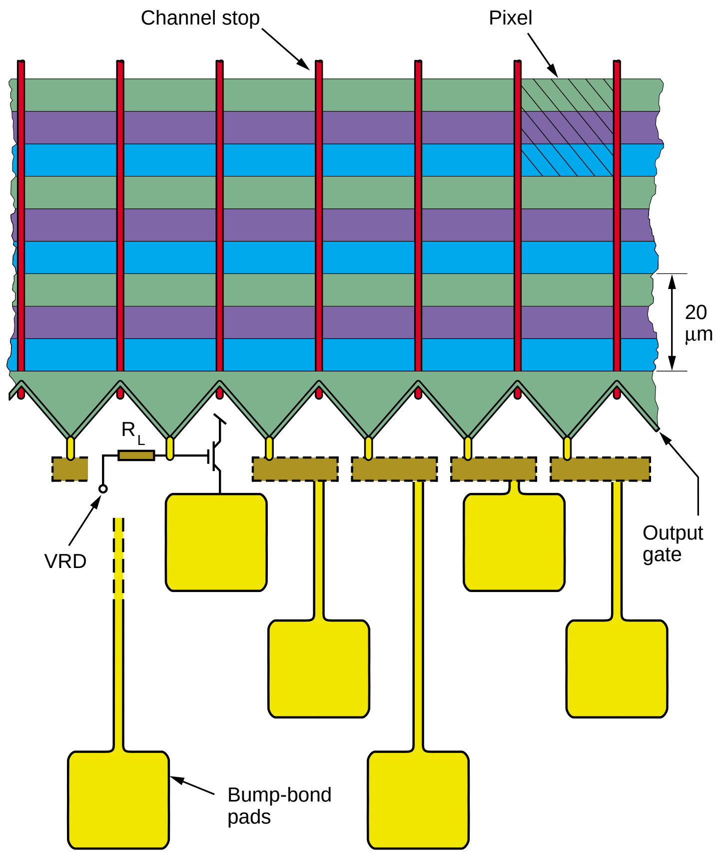
SLD Charge dipole

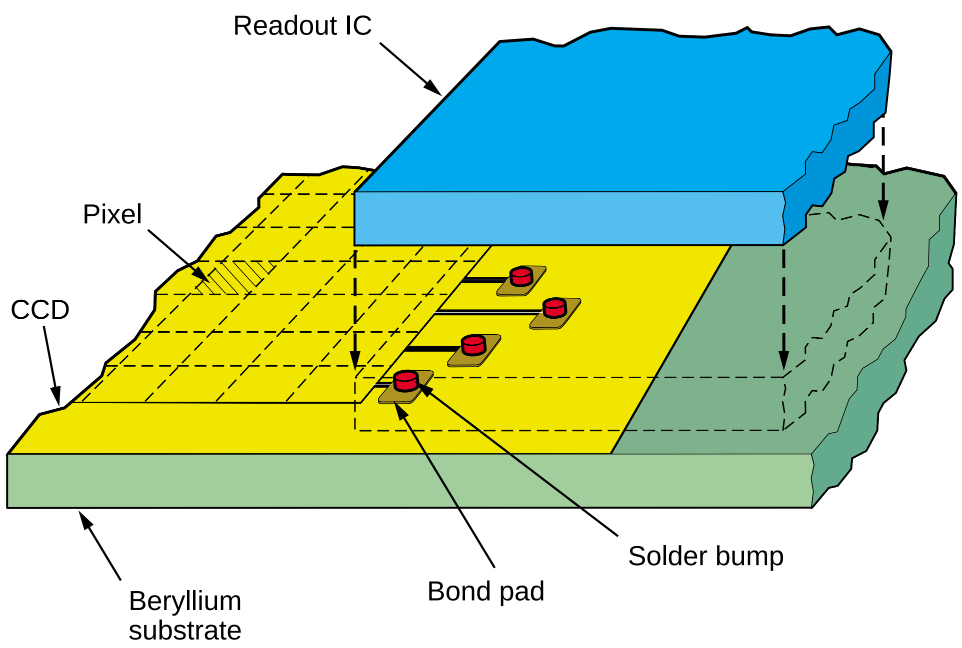
LC Vertex Detector
CCD Option



- Layer 1 radius 15 mm
- Layers 1-3 provide coverage to $|\cos\theta|=0.96$
- Single CCD on Layer 1 ladder (10 cm length)
- 2 CCDs on Layer 2-5 (12.5 cm length)
- Electrical connections (bias, drive, readout) only at ladder ends outside volume for precision tracking
- Stand-alone track reconstruction – extremely important for measurement of jet energy
- 800 Mpixels (compared with 307 Mpixels for VXD3)

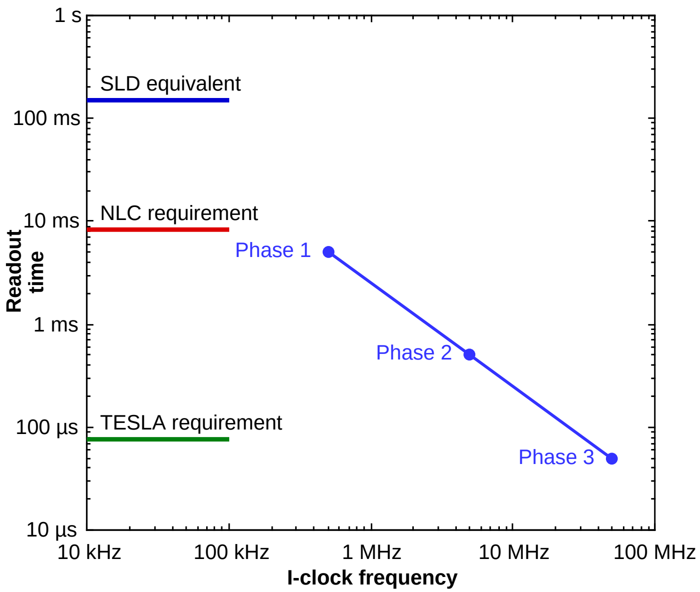
- Column parallel CCD connected to a deep submicron readout chip

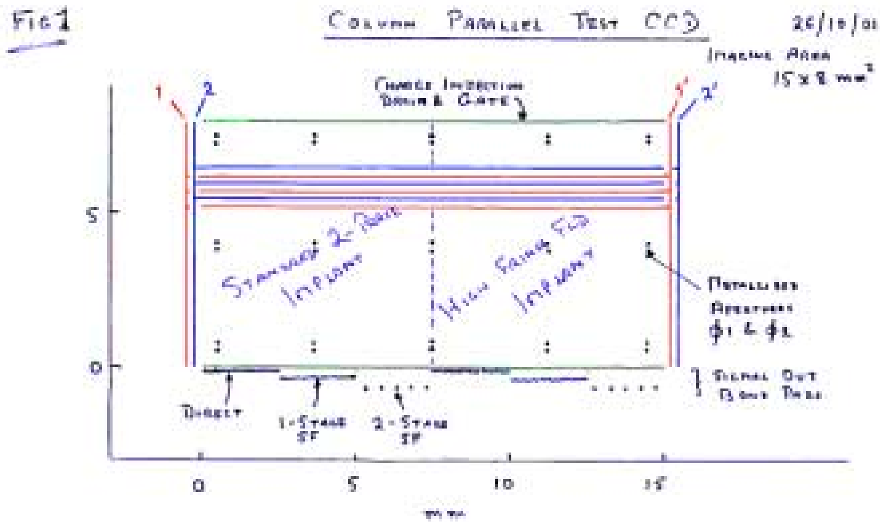




CCD R&D Status

- Proposal to PPESP of March 2001 was cautiously staged



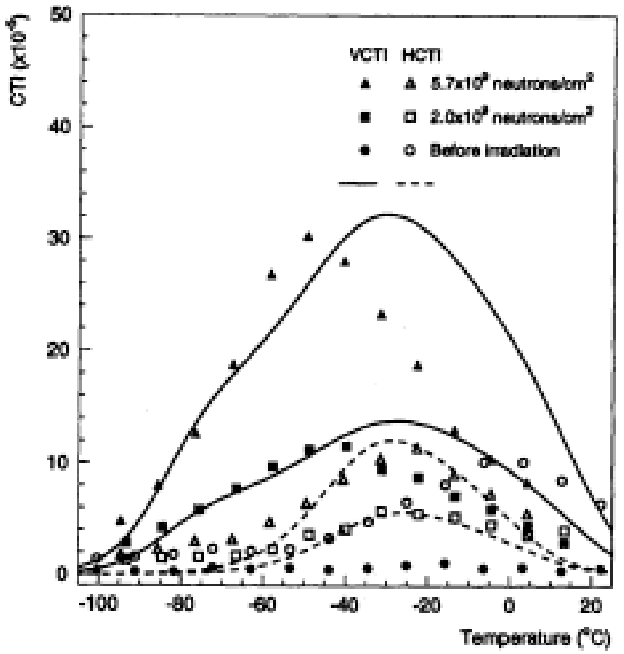


- Has recently metamorphosed into a multi-faceted set of test CCDs which will explore all three phases in parallel

- Experience at MTech with XMM and other recent CCD designs is proving invaluable

- 'Dream team' of David Burt et al, Marcus French, Steve Thomas, Konstantin Stefanov, Tony Gillman…

- Column parallel ideally suited to real-time pipelined data sparsification
- Reduced clock voltages the key to acceptable power dissipation. Hope to retain massless gas cooling
- Test devices should be available by Summer 2002
- Radiation hardness – good news for CCDs



- Each technology has its list of possible show-stoppers. One for the CPCCD (recently solved) was the busline inductances. More dangerous are the ones we don't know about!

World-wide LC Detector R&D

- Accelerator GAN – there will only be one!
- May be two LC detectors, but essential to overcome regional focus in design and R&D
- Open access to meeting notes and design studies on Web – encourage information sharing and active collaboration

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

- Not confined to LC; RHIC vertex detector R&D has a strong overlap – recent BNL workshop
- Document listing current activities, web sites and suggestions for enhanced coordination being prepared for ICFA Lab Directors Conference in February 2002
- Goal, when LC becomes a real project, is to ensure that nobody feels left out.