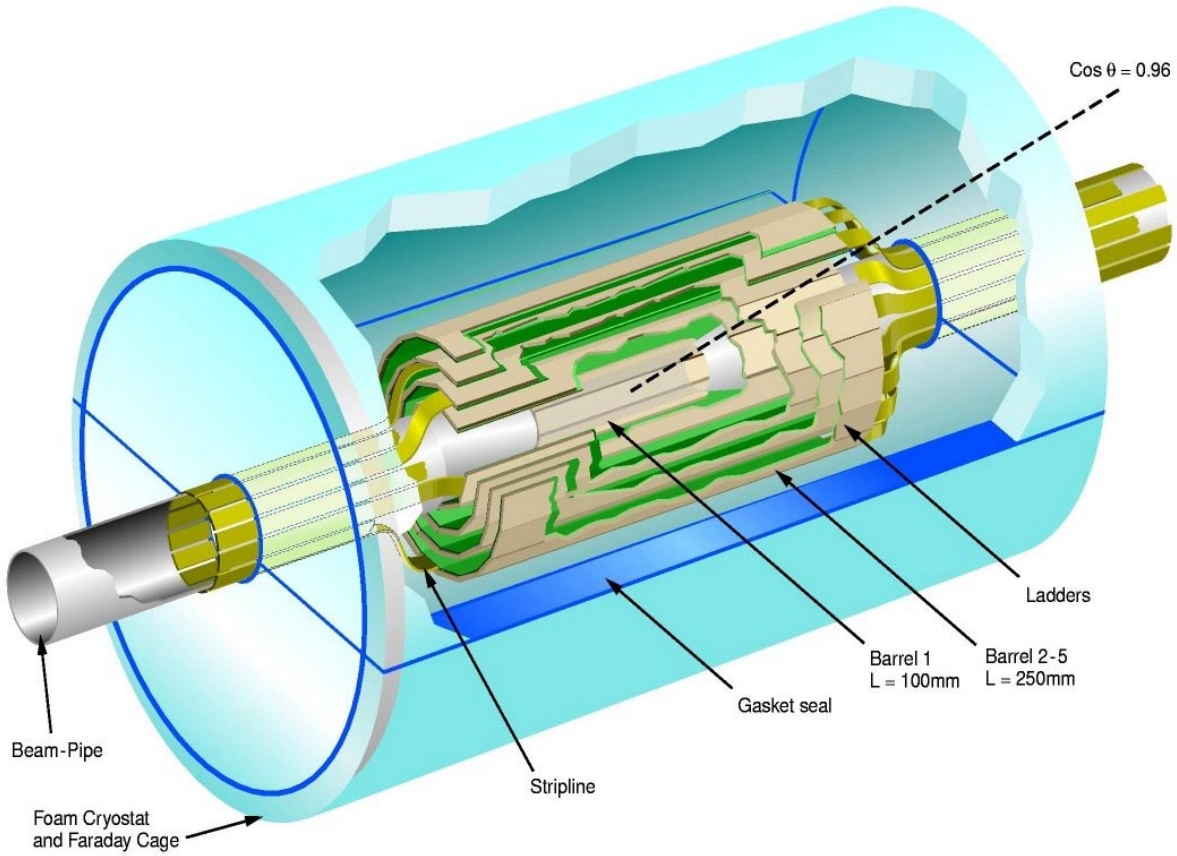
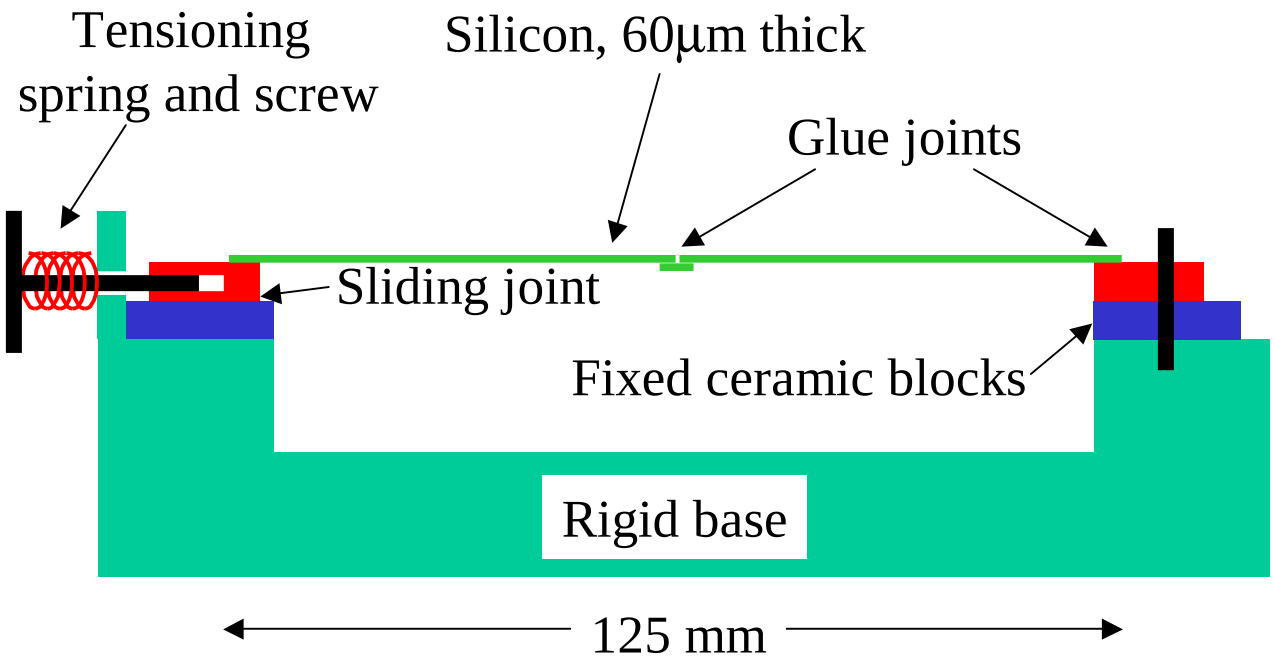
LCFI Research & Development Programme, Results and Plans



- Minimising the material budget.
- Operating CCDs at the LC.
  - Radiation damage.
  - Readout speed.
- Future R&D programme.
- Summary and request to PPESP.

Unsupported CCDs

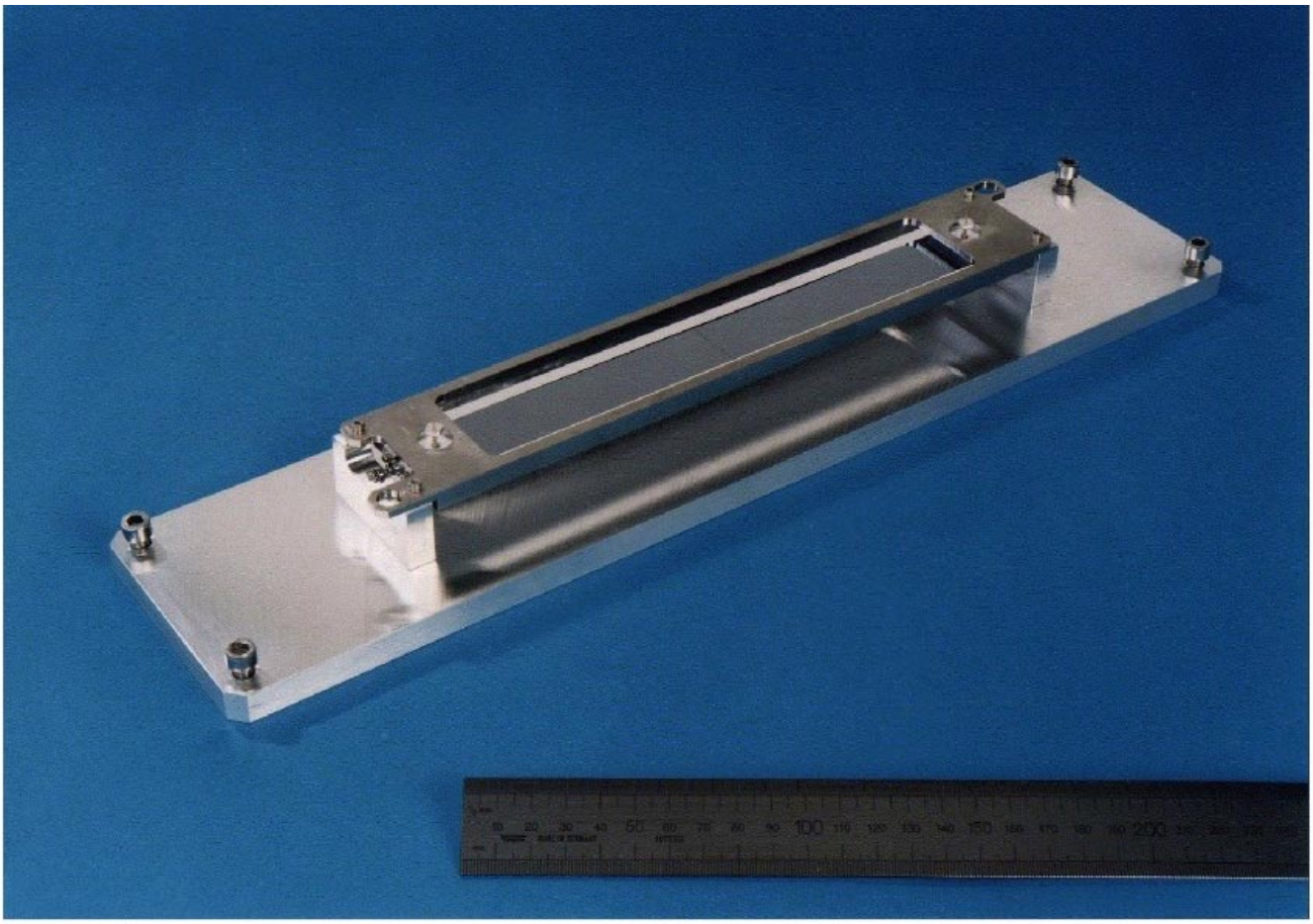
- Hold CCDs at ends, under tension.
- Particles see 60 μm of Si (0.06% X_0).
- C.f. world record of 0.4% X_0 to date (SLD vertex detector).
- Stability under temperature cycling?
- Schematic diagram of test rig:



- For various tensions, repeatedly disturb, measure sagitta using ATLAS SmartScope.

Unsupported CCDs

- Unsupported Si test rig.

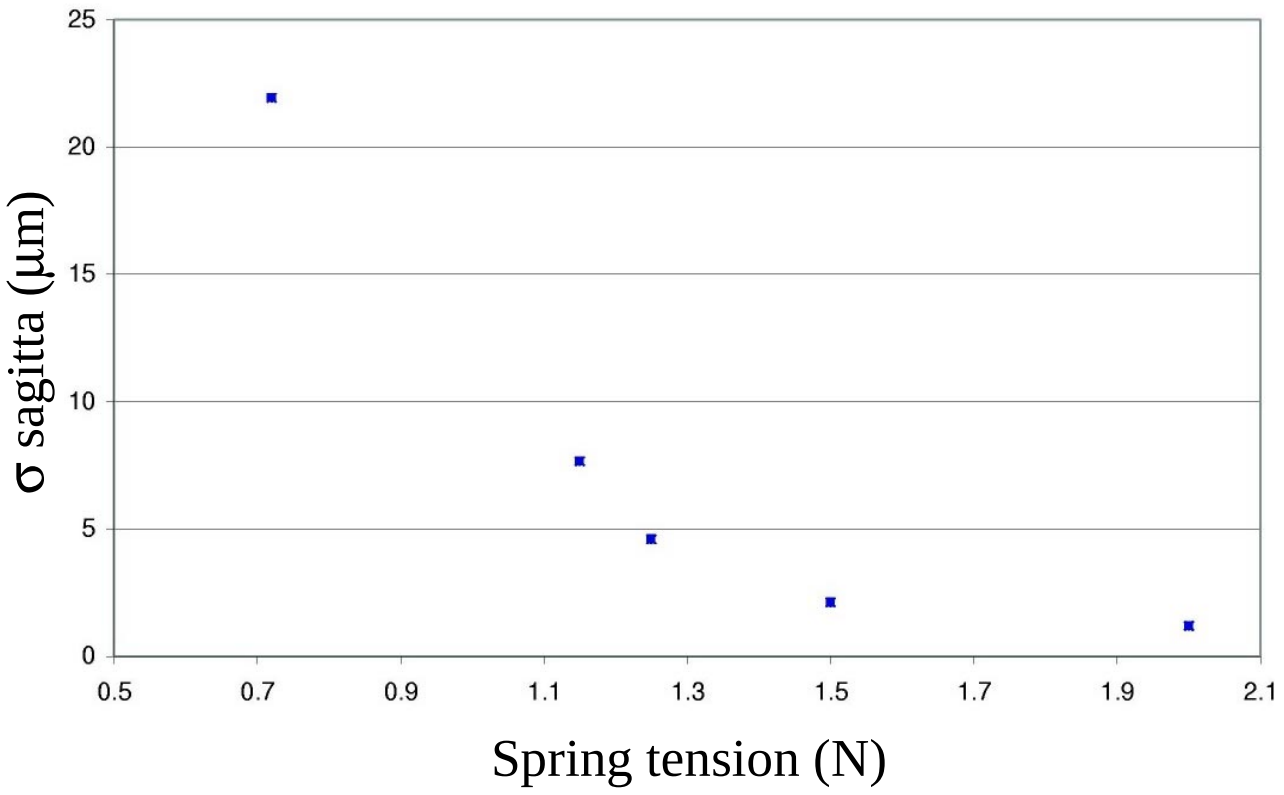


Unsupported CCDs

- Detail of Si tensioning mechanism.

Unsupported CCDs

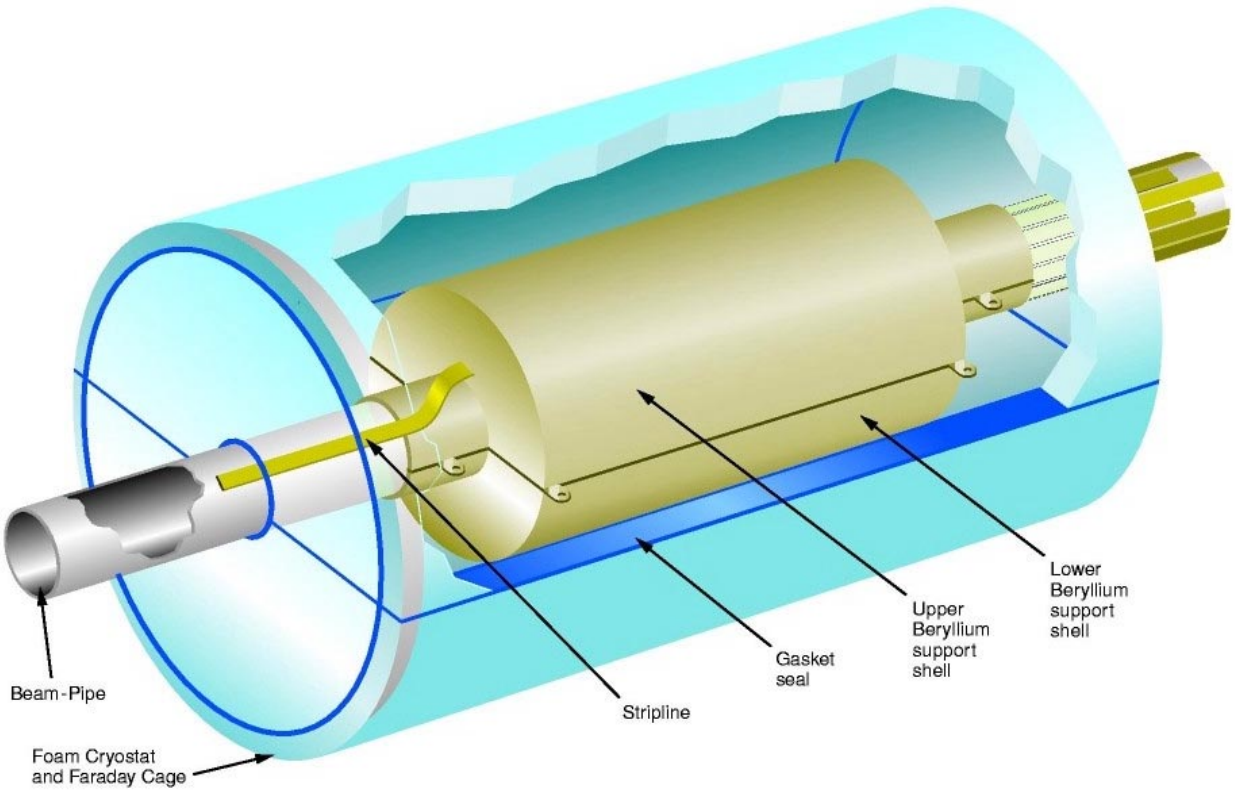
- Results:



- First studies show σ ~ 3 μm for tension > 1.5 N.

Unsupported CCDs, VXD design

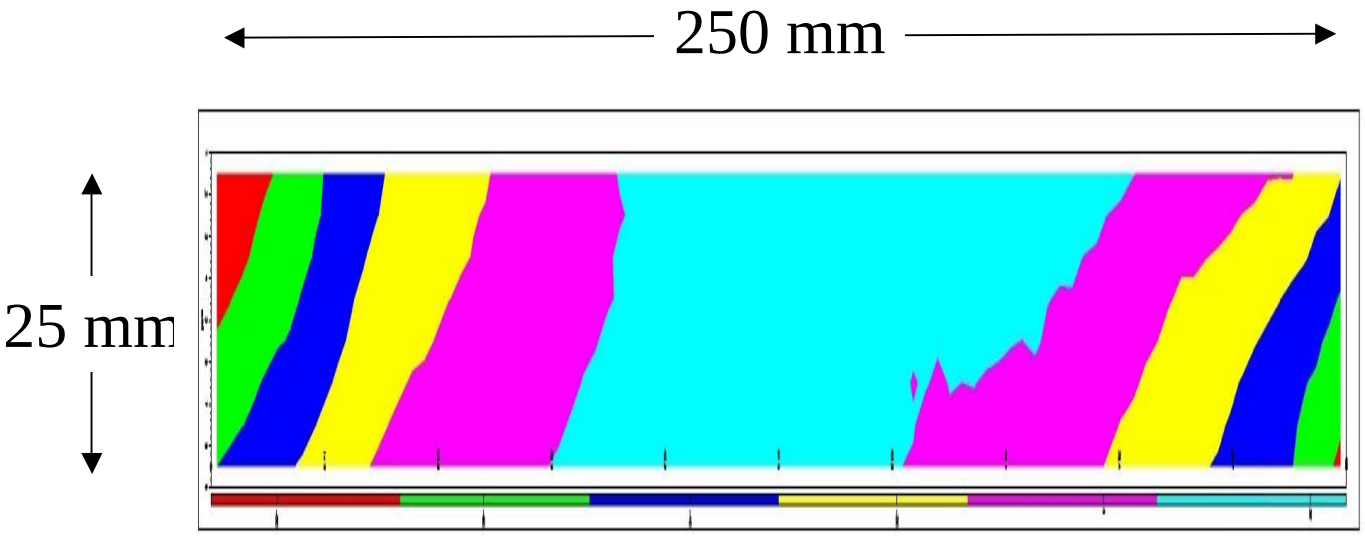
- Maintain gains achieved by very thin CCD layers.



- Be shell outside inner tracking volume, thickness 1…2 mm.
- Beampipe thickness ~ 0.25 mm Be (0.07% X_0).

Surveying CCD ladders

- Two metrology systems:
  - Upgraded Oxford ATLAS WhIPM system.
  - RAL ATLAS Smartscope.
- Portable LN_2 cryostat for use on either system, study thermal distortions.
- WHiPM profile of dummy ladder (contours at 20 μm intervals, resolution better than 5μm):

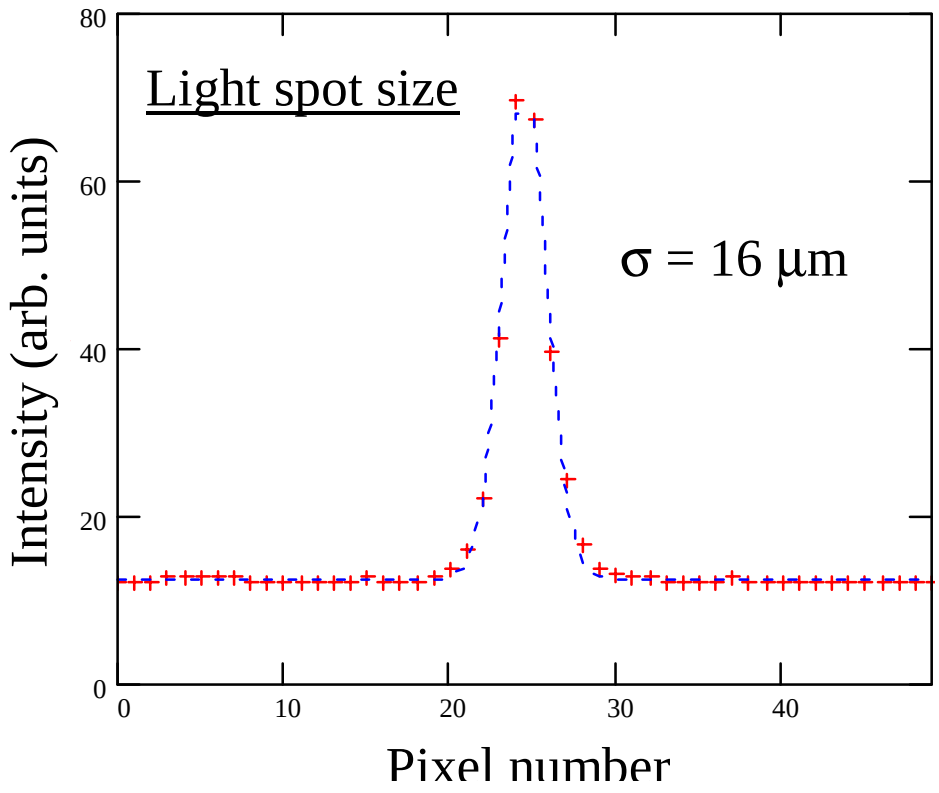


Surveying CCD ladders

- Cryostat with cooling system on SmartScope at RAL.

Operating CCDs at the LC: radiation damage

- Neutron dose at LC ~ 4 x 10^8 1 MeV equivalent n/cm^2 and year.
- Conventional CCDs can tolerate 8…1500 x 10^9 1 MeV n/cm^2 before CTI drops to 5 x 10^{-5}.
- Column parallel CCDs less sensitive.
- Liquid He/N_2 cryostat constructed at Liverpool with optical charge injection.



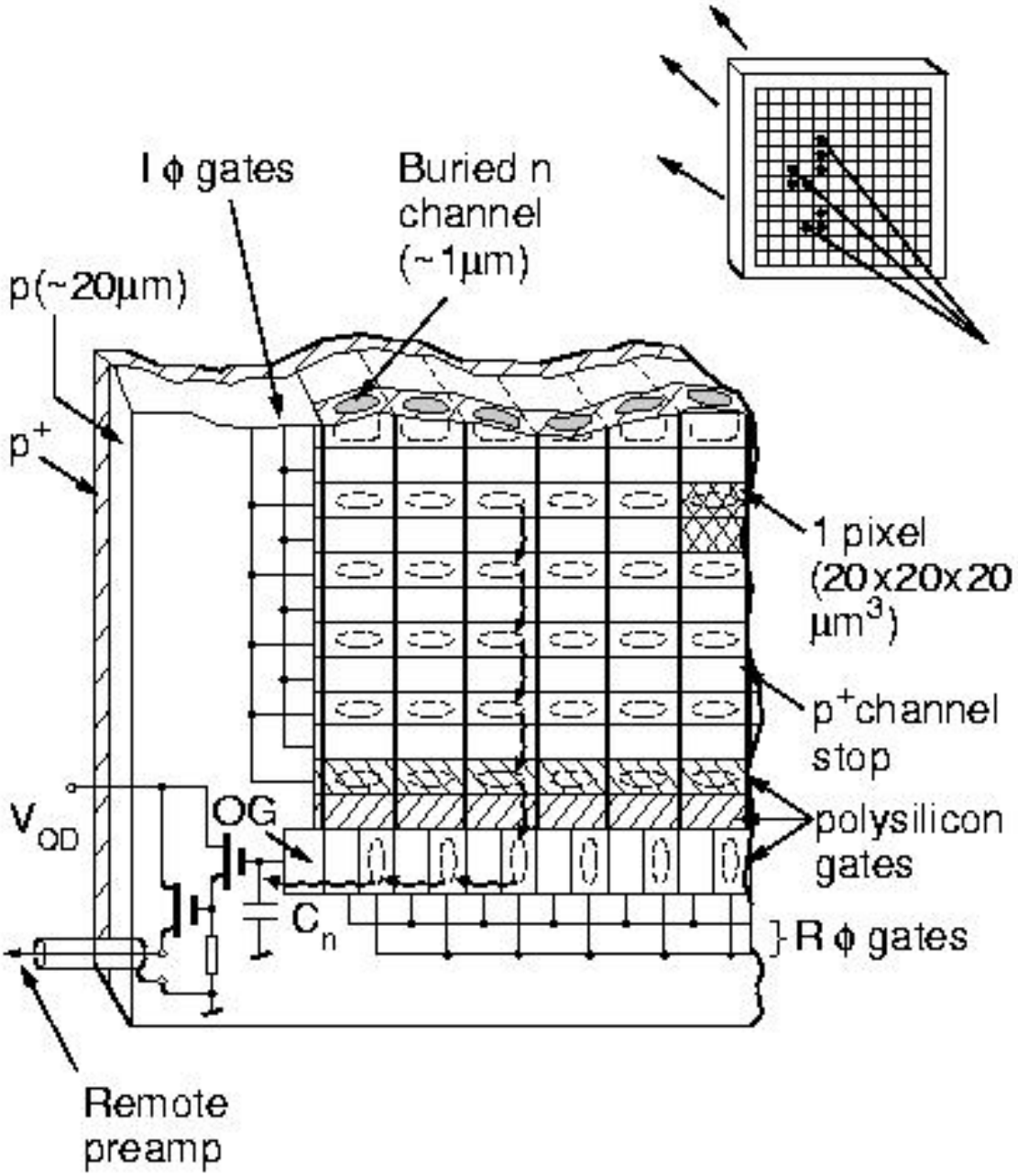
Operating CCDs at the LC: readout speed

- Major concern here e^+e^- pair production.

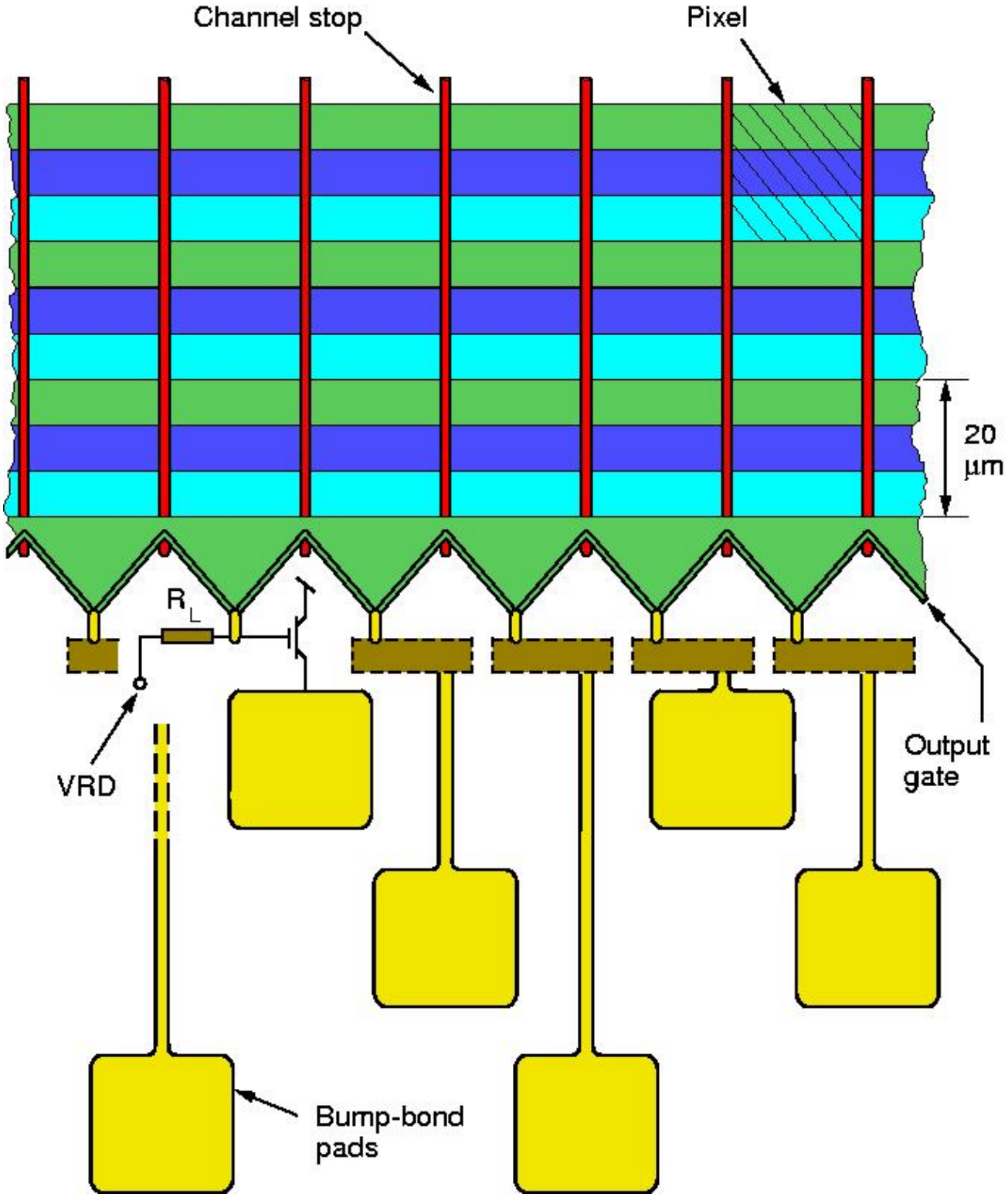
	NLC	TESLA
$\sqrt{s}$ (TeV)	0.3…1.0	0.09…0.8
$\mathcal{L}$ ($\times 10^{34}$ cm^{-2} s^{-1})	0.5…3.4	3.4…5.0
Rep. Rate (Hz)	120	5…3
Bunches/pulse	95…190	2820…4500
Bunch sep. (ns)	2.8…1.4	337…189
Radius (cm)	1.2	1.5
Hits (mm^{-2} BC^{-1})	0.03	0.03
Hits (mm^{-2} BT^{-1})	4	80

- Must readout TESLA CCDs 10 times per BT to keep occupancy at ~ 4 hits mm^{-2}.
- Need column parallel readout at 50 MHz.

Conventional CCD

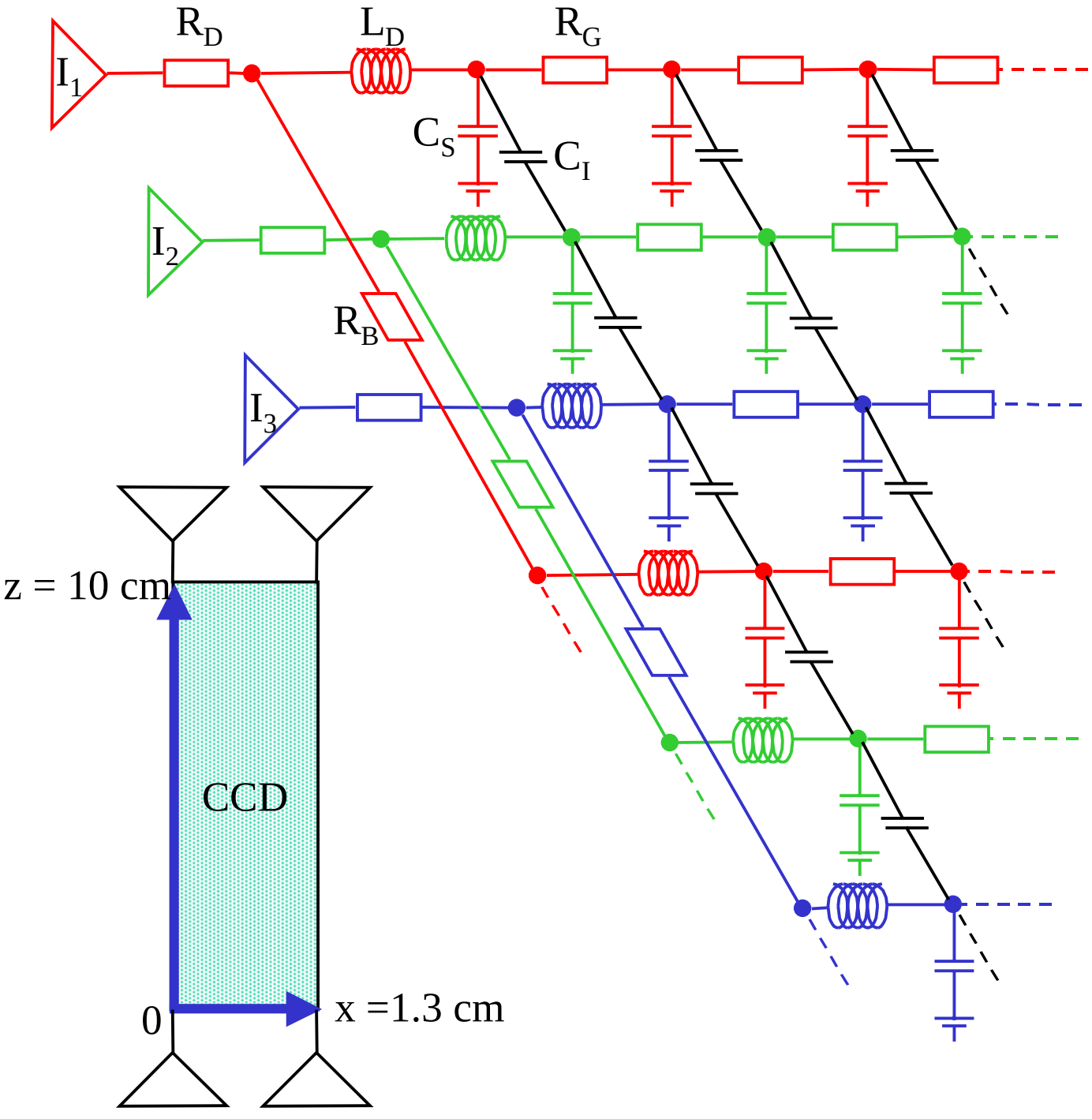


Column parallel CCD



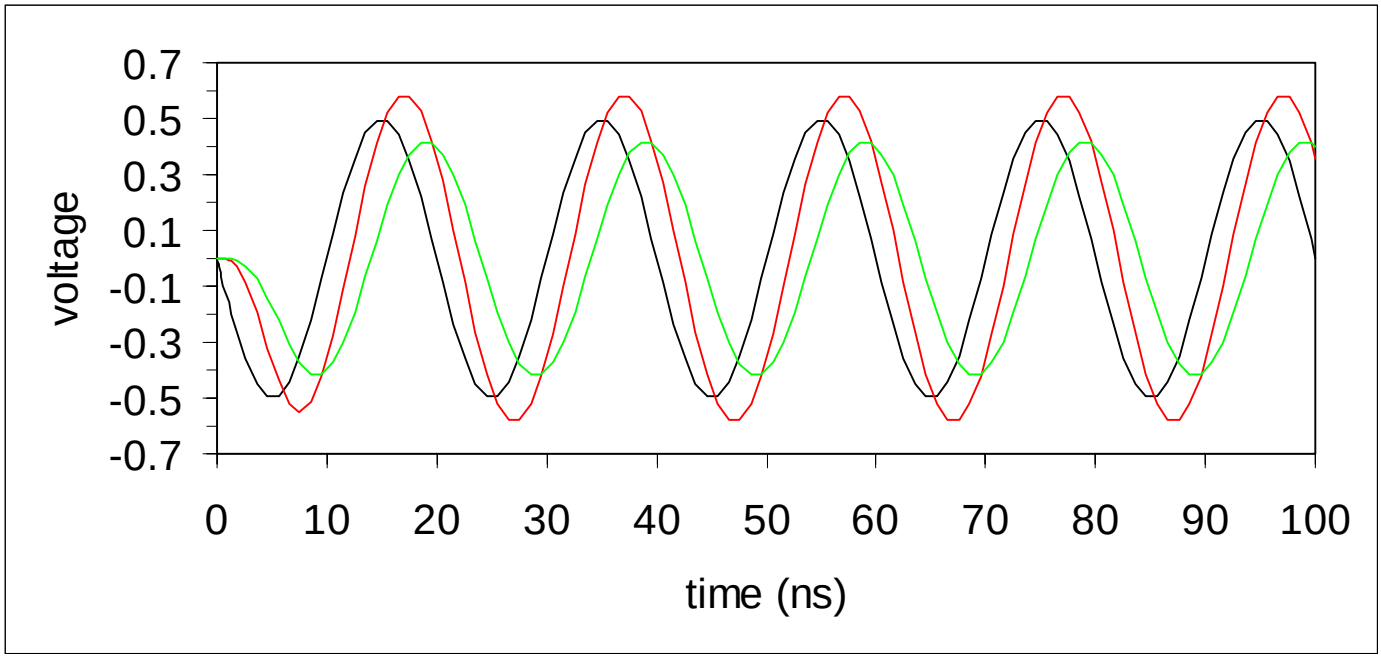
SPICE model, inner barrel CCD

- Can the I gates be clocked at 50MHz?



SPICE simulation results

- Reduce gate resistance by addition of 1 μm thick 3 μm wide Al strips.
- Reduce bus line resistance by increasing thickness of Al.
- Try 2-phase sinusoidal drive pulses.

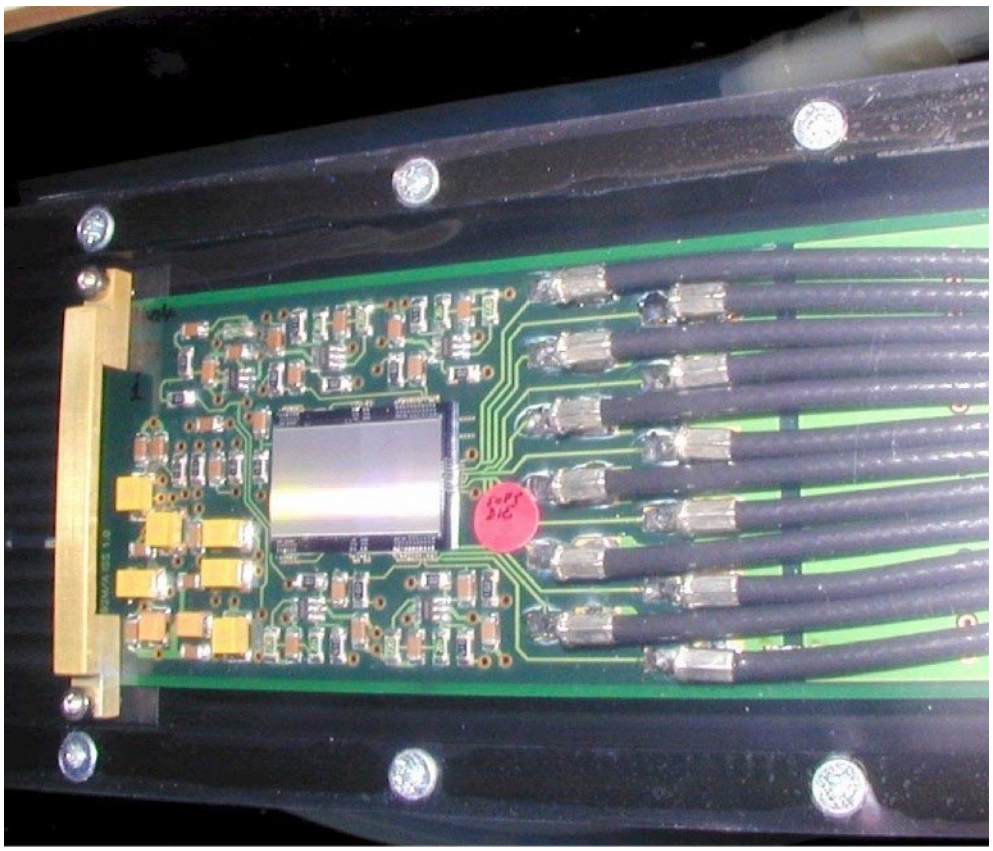


SPICE simulation results

- Waveforms in centre of CCD adequate for efficient operation.
- Total power dissipation/CCD (continuous operation) ~ 4 W.
- TESLA duty cycle ~ 1/200 and outer CCDs can be clocked at lower frequency.
- Total VXD power consumption is few watts.
- Cooling can be achieved with gentle gas flow.

Experimental studies of readout

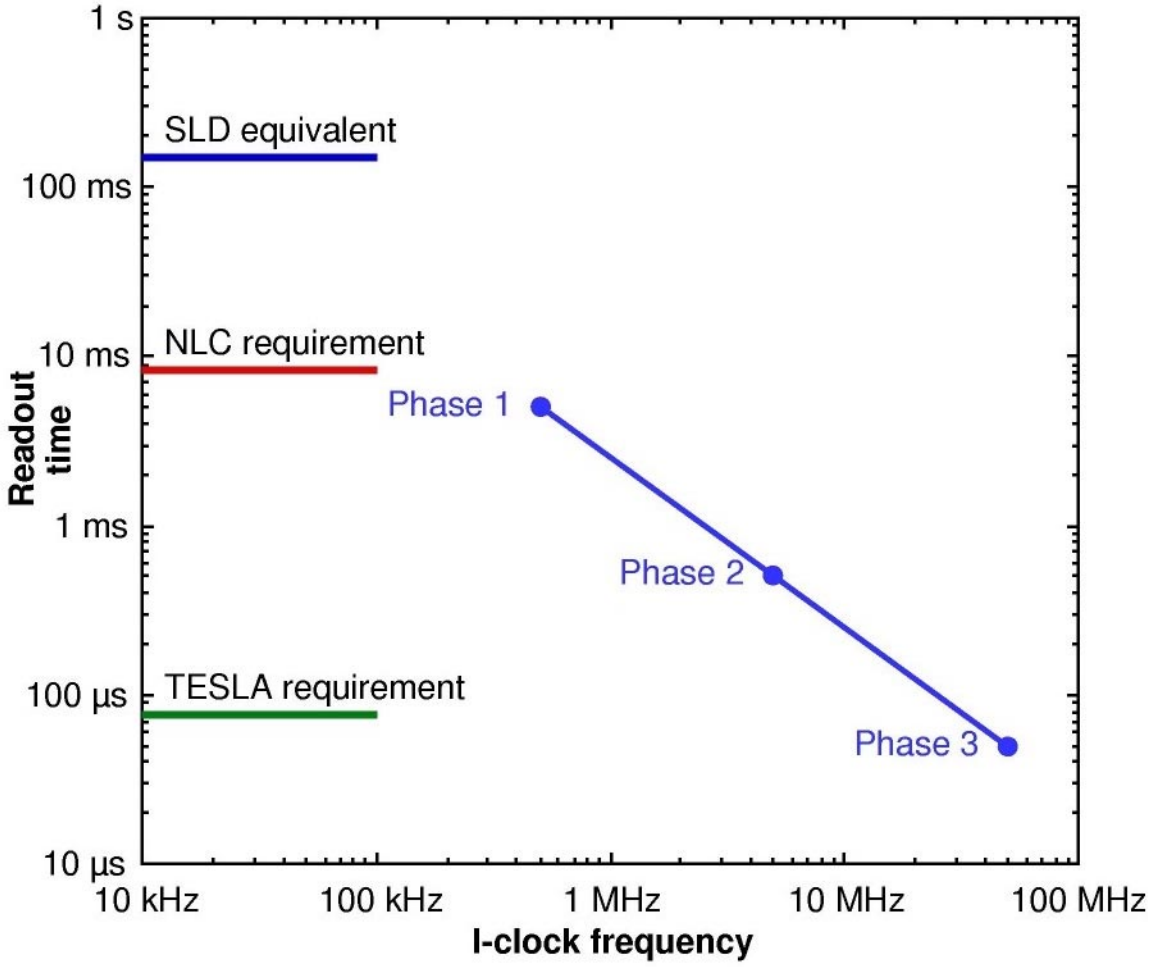
- VME based 50 MHz drive and readout electronics designed and under construction.
- CCD58 on motherboard delivered by Marconi.



- First tests imminent.

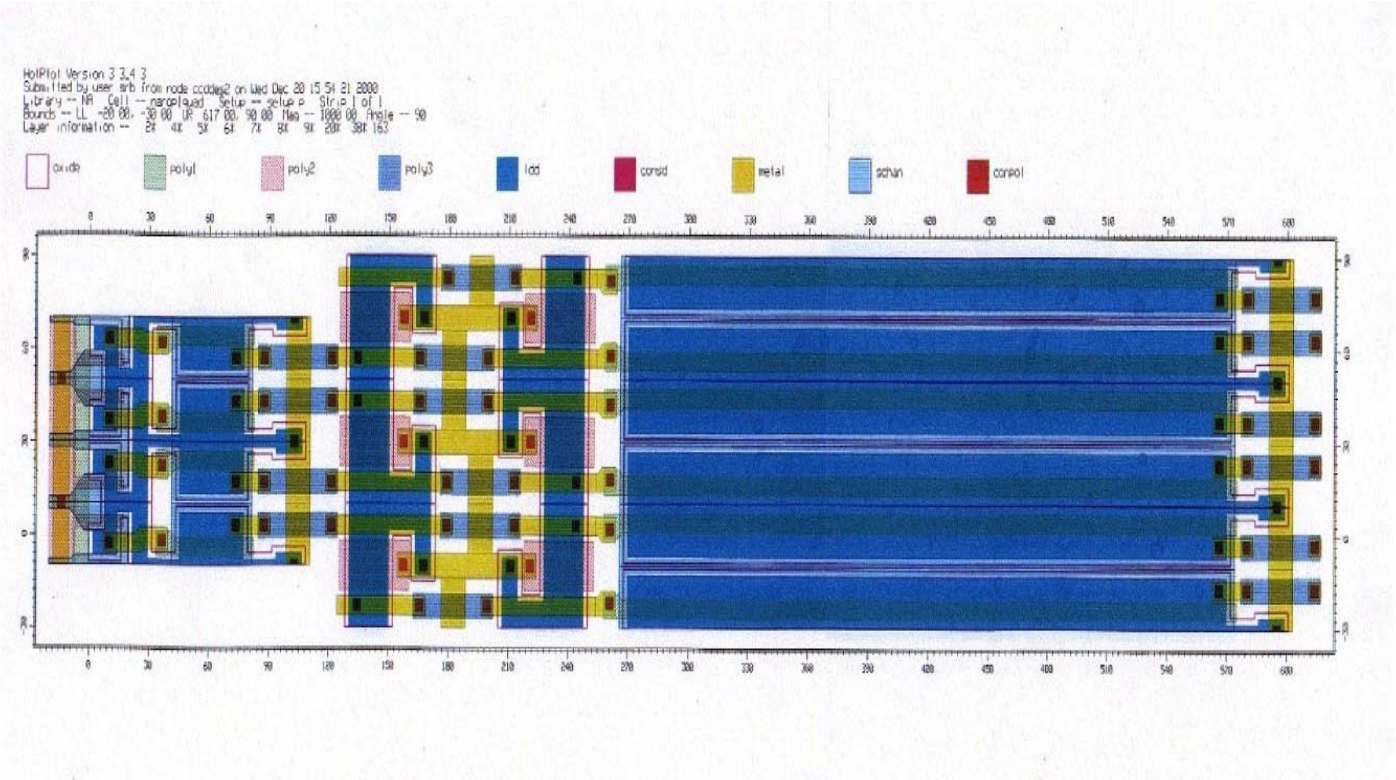
Future R&D

- Three phase programme proposed:

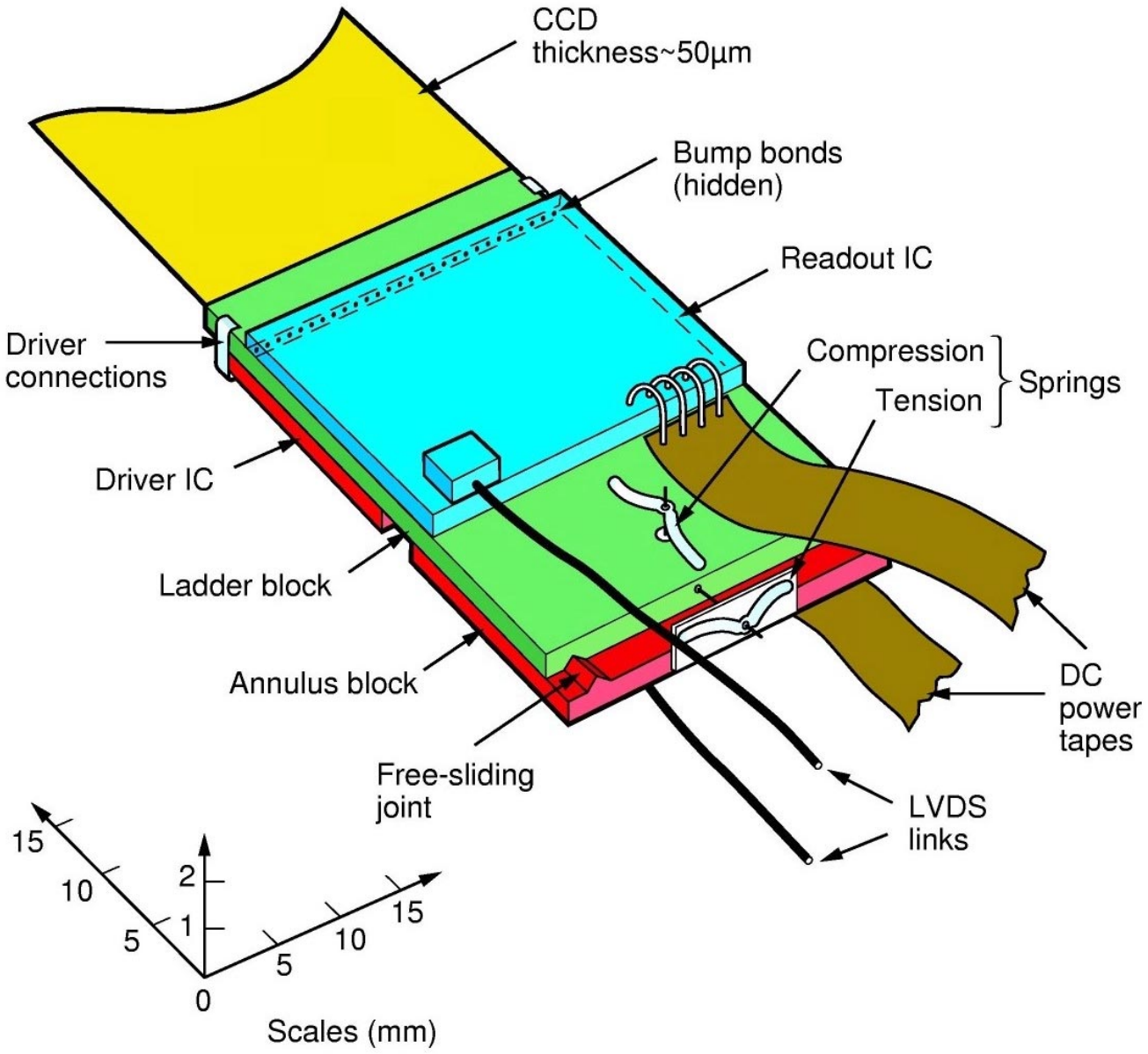


Future R&D, phase 1

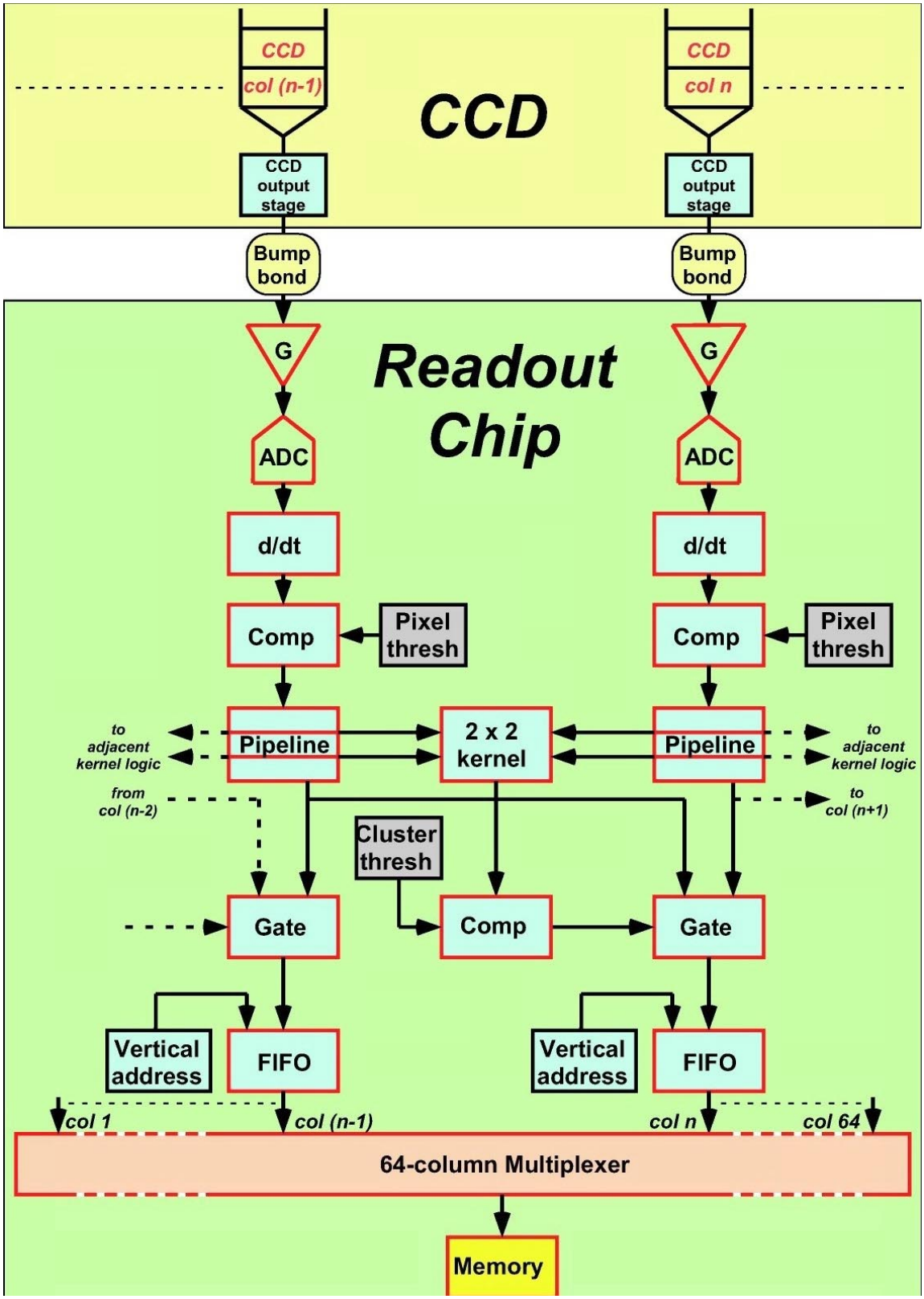
- Move to column parallel readout, but with standard clock frequencies and voltages.
- Main challenge is production of output circuits on pitch of 20 μm.
- Marconi designed possible output circuit following discussions with LCFI.



Detail of ladder end



Readout logic



Future R&D, phases 2 and 3

- Increase readout speed by factor 100 in two steps.
- These steps will depend on results obtained in phase one, but 50 MHz operation requires:
  - Metal buttressing.
  - Reduced clock voltages.
- Marconi have proposals for achieving above.
- Guide developments and experimental studies using simulations.
  - Semiconductor devices modelling group at RAL.
  - ISE TCAD at Liverpool.

CCD modelling

- First task:
  - Must understand CCD L, C and R for 50 MHz operation.
  - C and R known.
  - Simulation of CCD needed to find L.
  - Develop test structures to measure L.
- Later:
  - Produce full 3D simulation of minimum ionising particle charge collection and transfer in 4 T magnetic field.

Summary of progress to date

- The LCFI collaboration has made significant progress in the last two years:
  - The VXD design goals are now clear.
  - Test rigs are now available.
  - 50 MHz capable drive and readout electronics are available, with final systems expected within months.
  - First CCDs obtained from Marconi.
  - Simulation studies advancing.
  - Unsupported silicon tests successful.

Future plans

- A three phase and four year programme has been developed which will provide:
  - Studies of LC physics involving flavour identification.
  - Column parallel CCDs meeting the specifications necessary for the NLC and TESLA.
  - Thin unsupported CCD ladder structures.
  - High speed readout and driver chips.
- These developments will be useful for SR imaging, space-based applications and time resolved spectroscopy in addition to HEP.