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

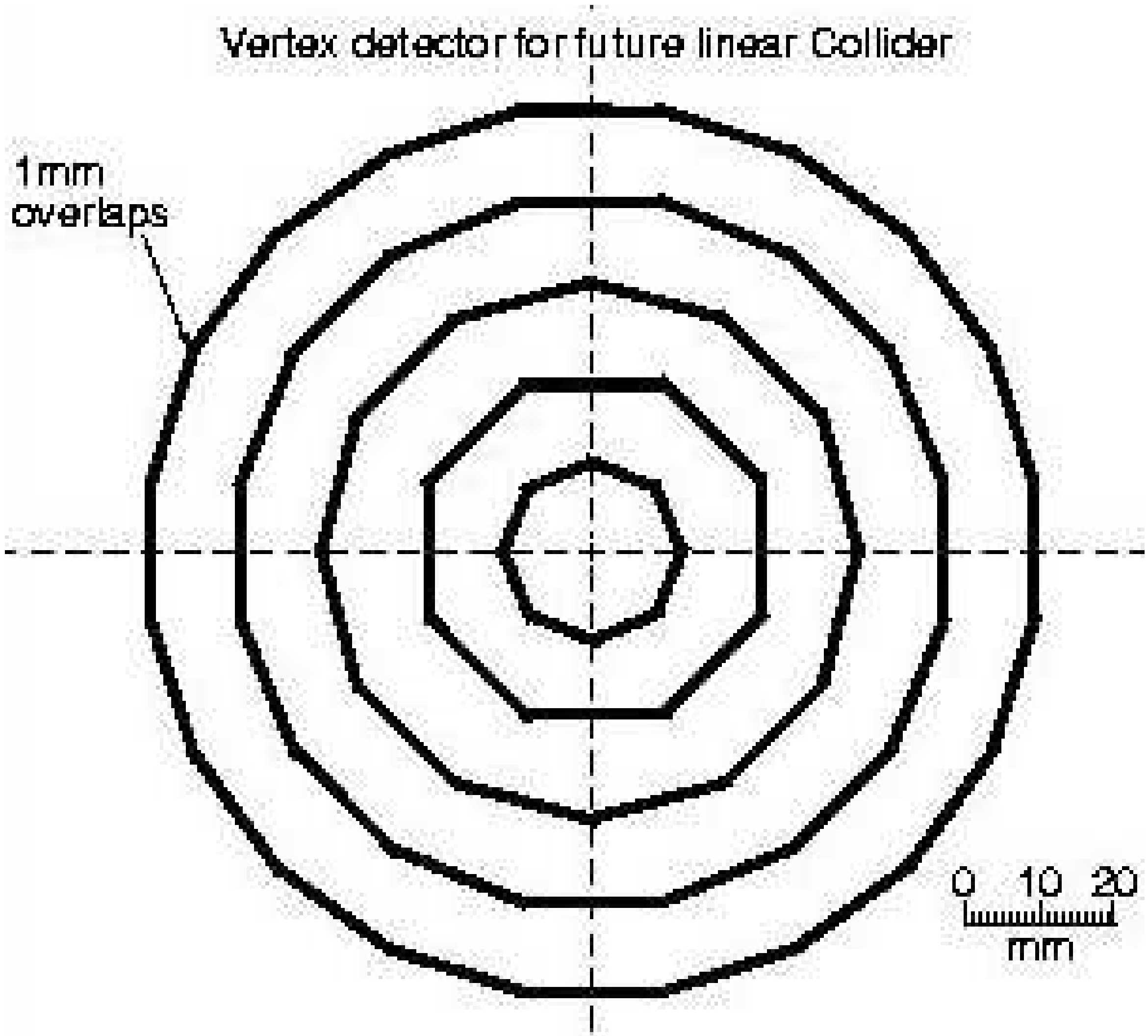
NLC/JLC

TESLA

- Current design.
- Physics performance.
- Areas in which R&D needed:
  - Radiation tolerance.
  - Readout speed.
- New physics challenges.
- Improving VXD performance.

VXD for future LC

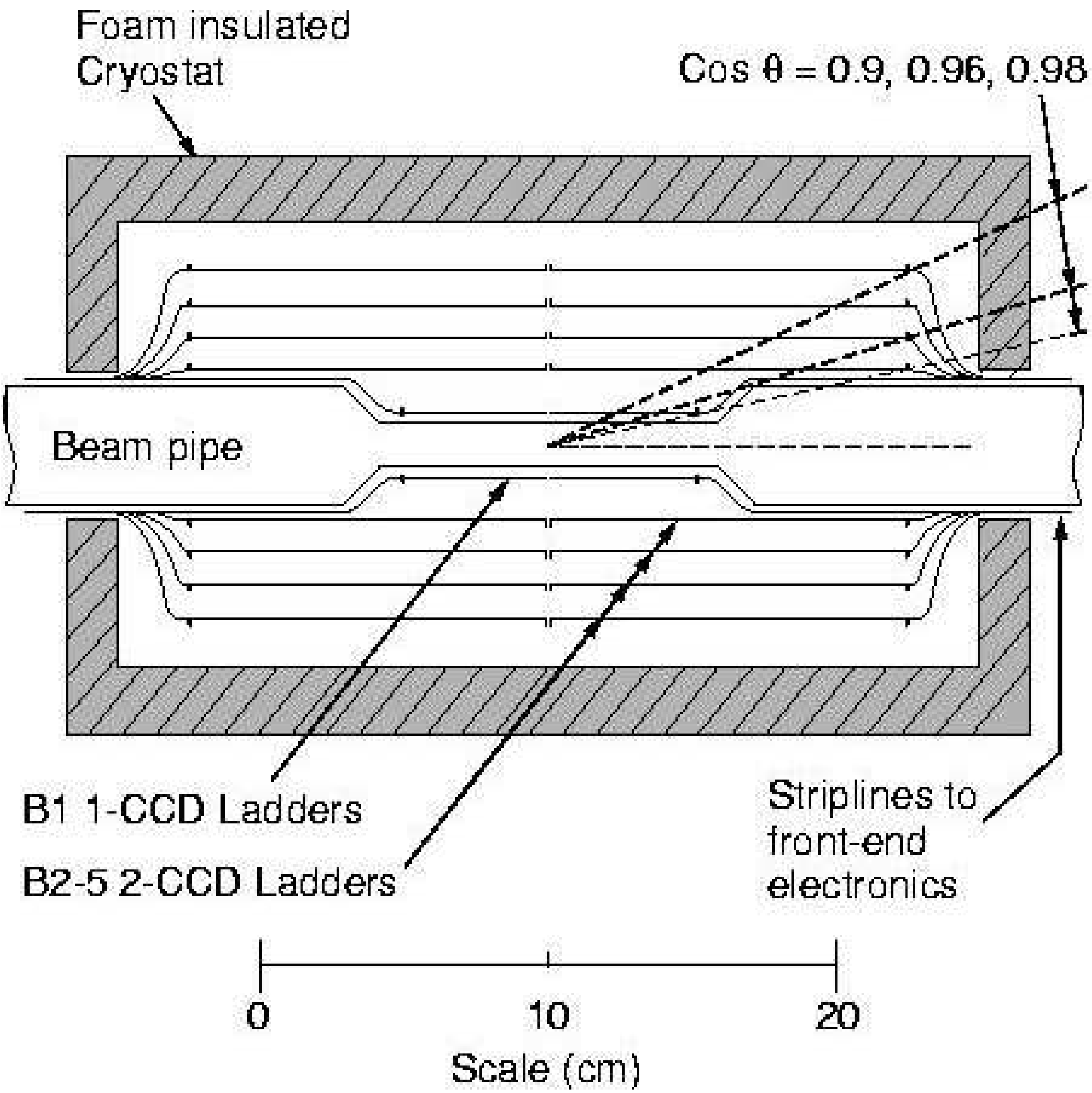
- End view



- 5 hits allow stand-alone pattern recognition.

VXD for future LC

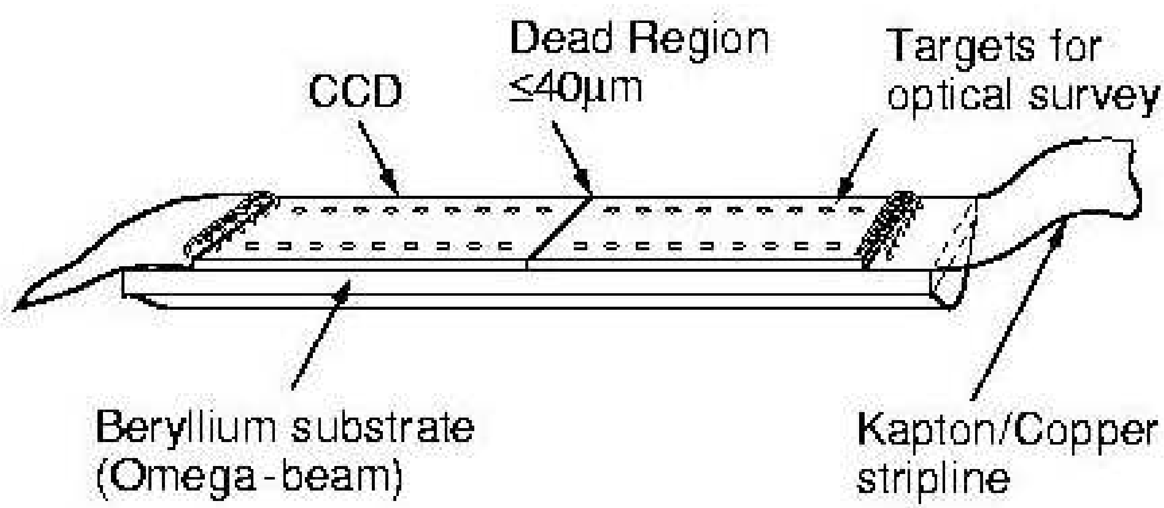
- Side view



- 3 hits out to $\cos\theta = 0.96$

VXD for future LC

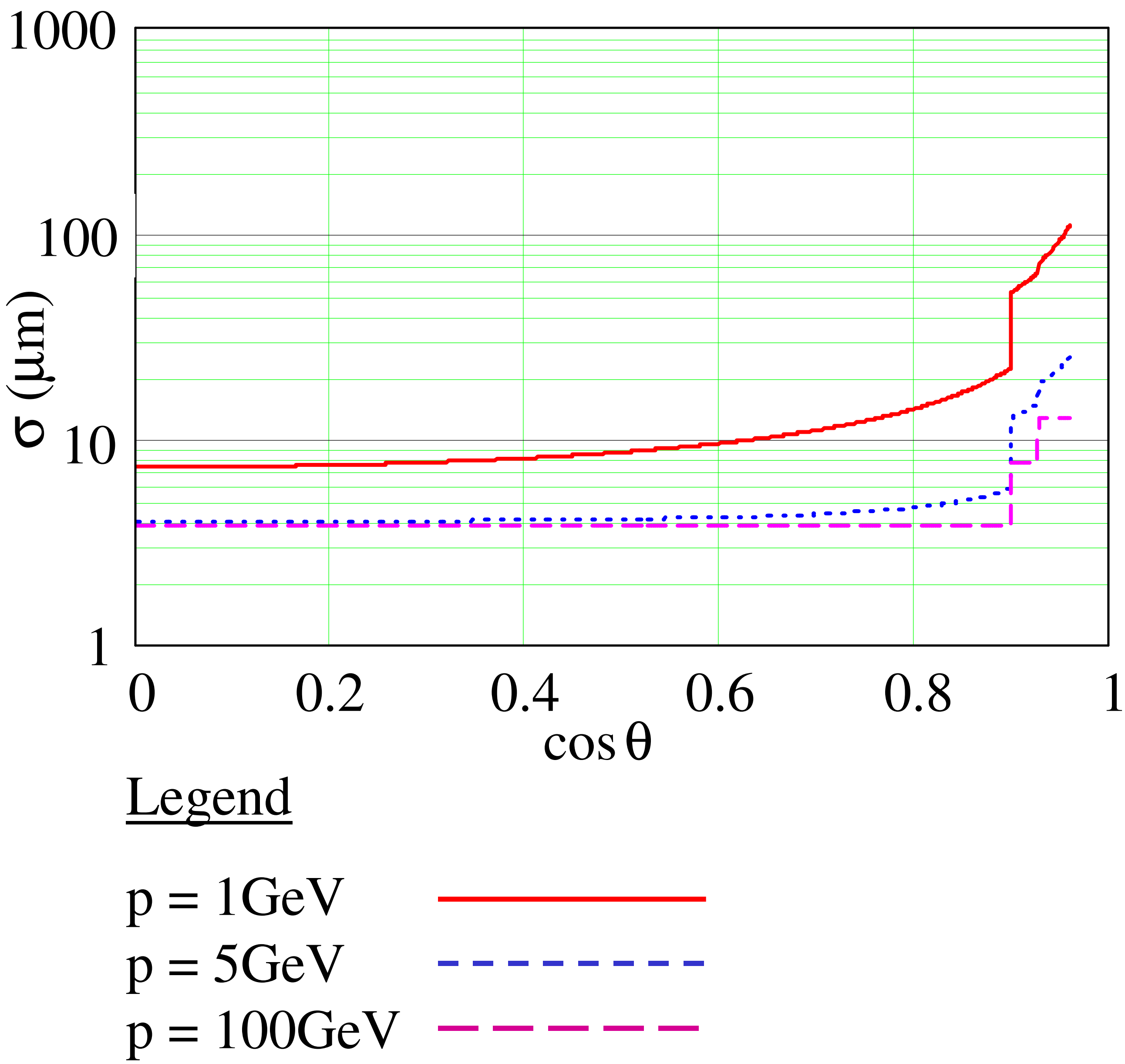
- Low mass critical as mean momentum in heavy flavour jets ~ 1…2GeV: multiple scattering is still an issue!
- Mount 30µm CCDs on 250µm Be Ω or V beam:



- Result ~ 0.12% X_0 per layer, of which Be + glue etc. contribute ~ 0.08%.
- 20 x 20µm^2 pixels, σ_{point} ~ 3.5µm.

Physics performance

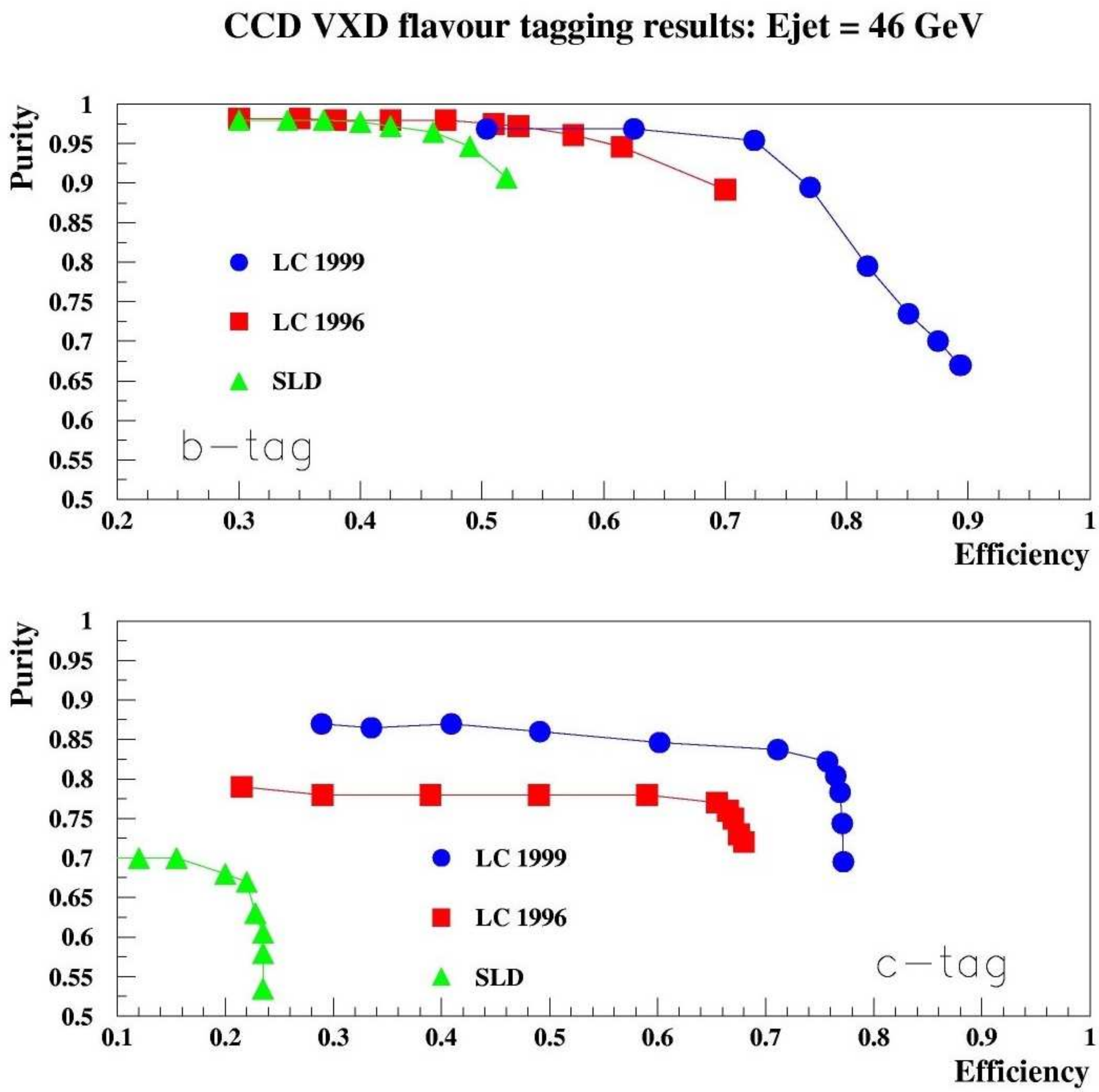
- Impact parameter resolution:



Physics performance

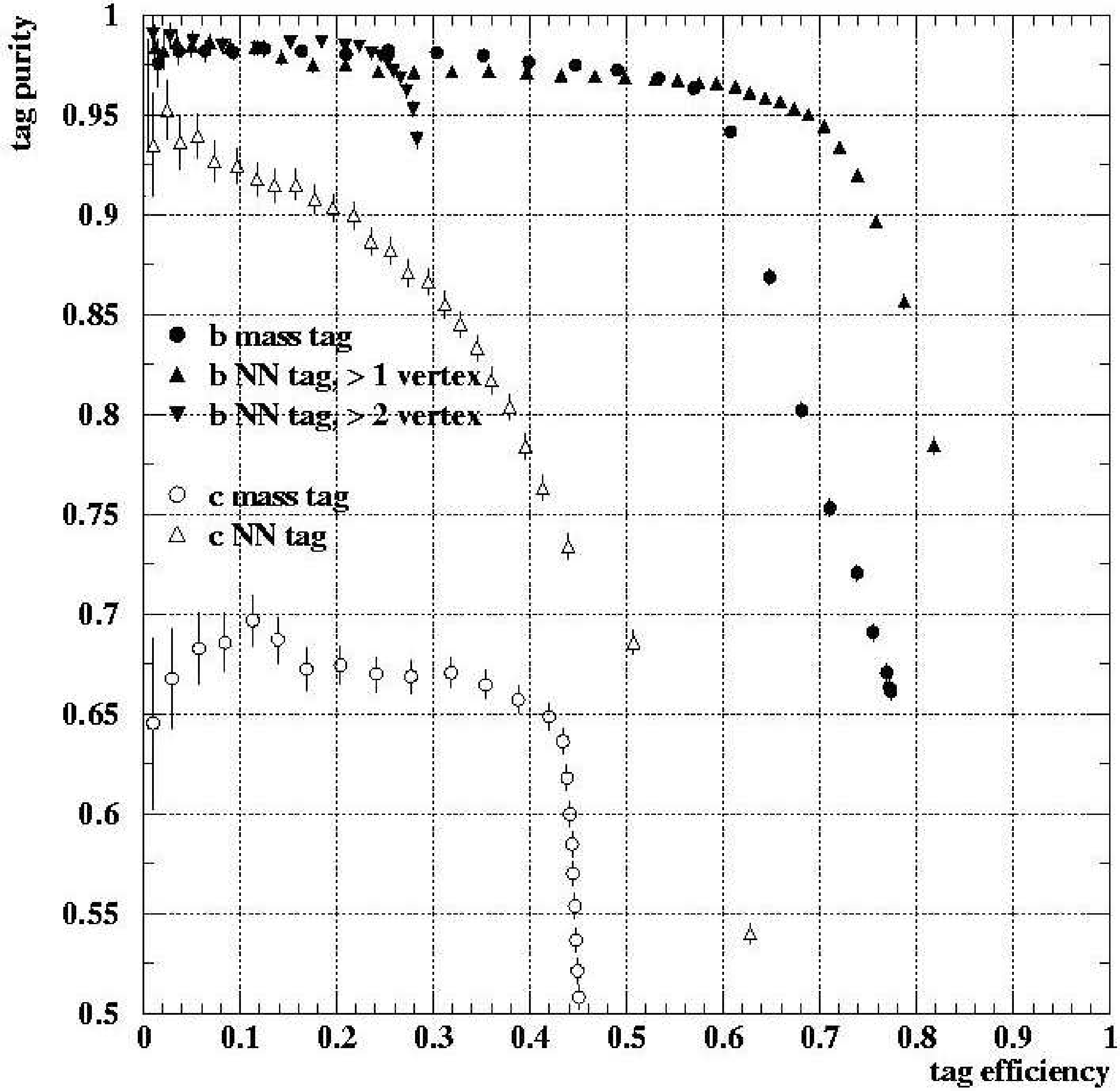
- Possible question for $\sqrt{s} \sim 500$GeV LC, is light Higgs SM or MSSM?
- Study BR of decay to "up" and "down" type quarks, i.e. to charm and beauty.
- Challenge is high efficiency and purity charm identification.
- Techniques used:
  - SLD ZVTOP algorithm ("mass tag").
  - Neural Net.
- Results shown for $\sqrt{s} = m_Z$.

Physics performance

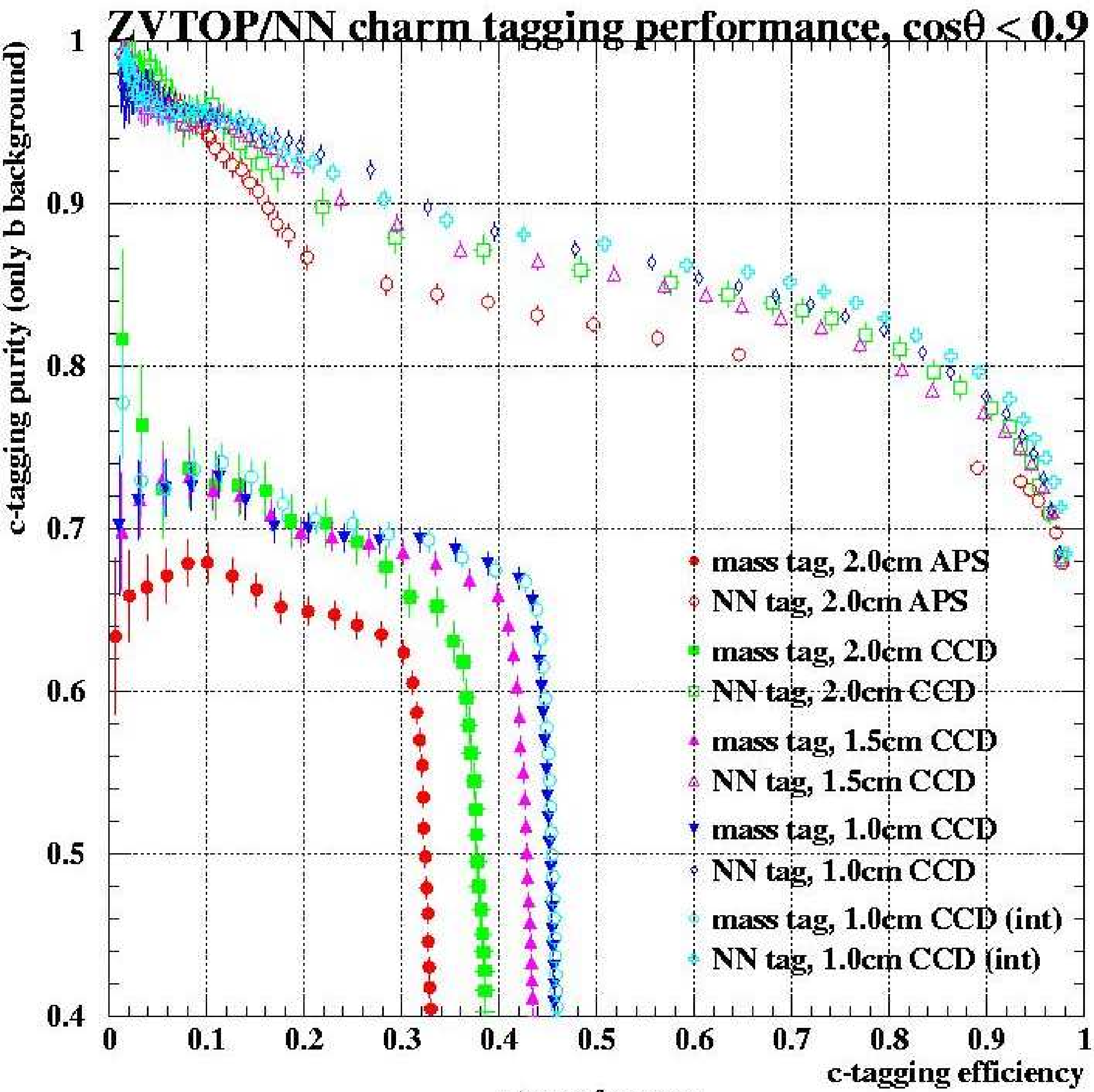


Physics performance

- ZVTOP/NN b and c tagging performance, $\cos\theta < 0.9$.



Physics performance



c-tag performance

Necessary R&D

- Demonstrate CCDs can tolerate neutron radiation levels of ~ 10^9 cm^{-2} $year^{-1}$ (1MeV equivalent).
- Readout speed:
  - Conventional clocking at 50MHz OK for NLC.
  - TESLA requires new approach to readout, the column parallel CCD.

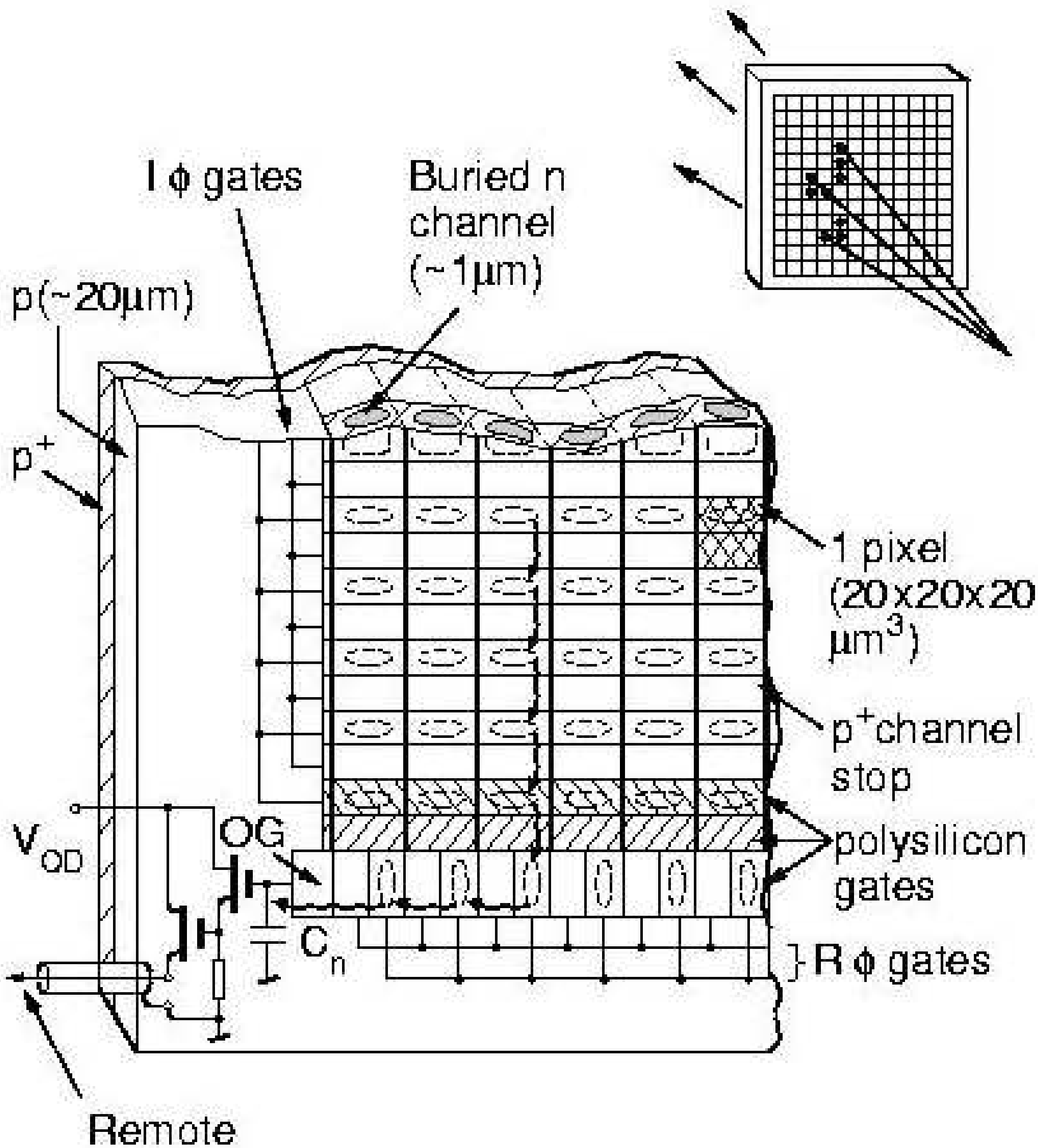
Backgrounds at the future LC

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

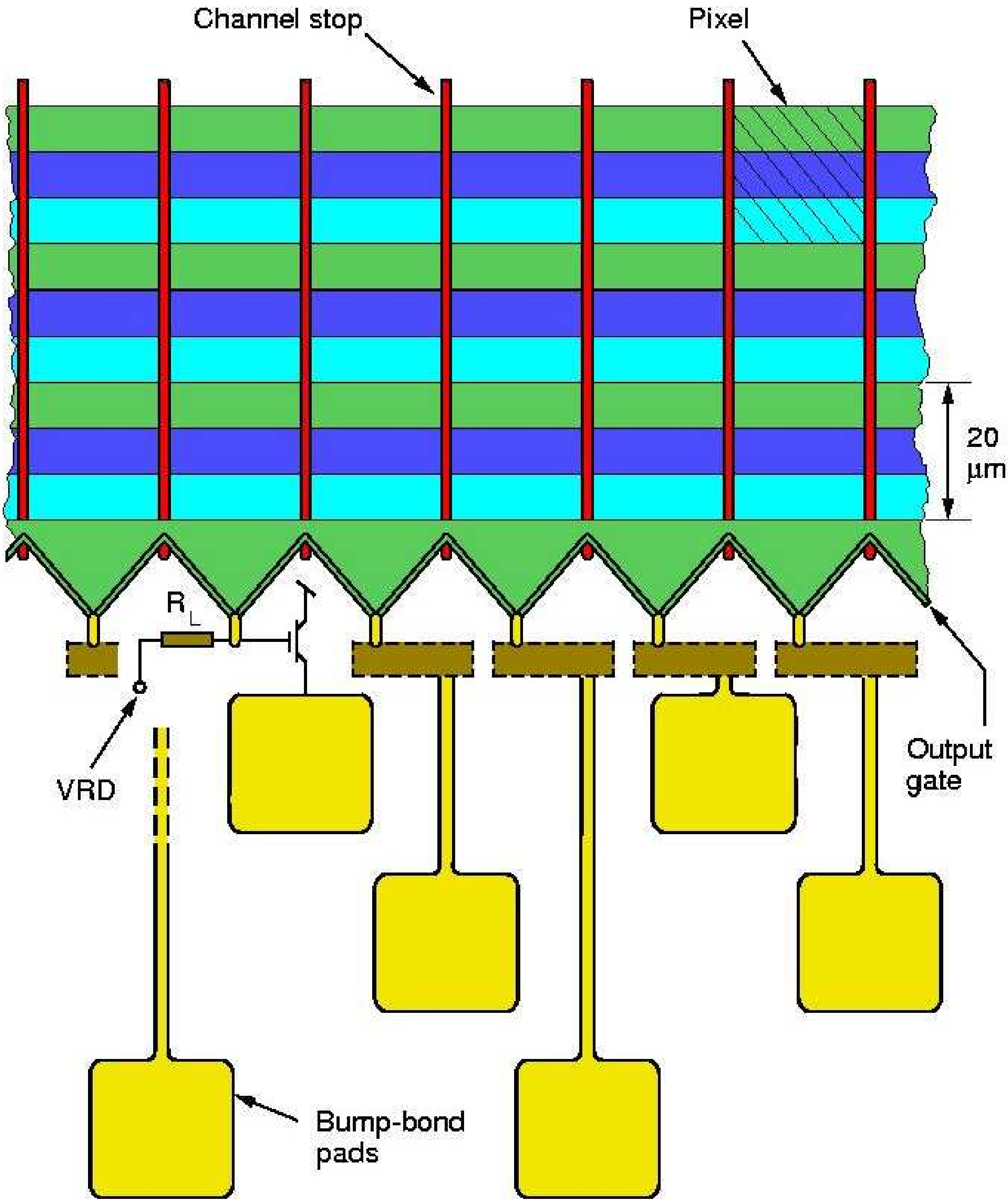
	NLC	TESLA
√s (TeV)	0.3…1.0	0.09…0.8
$\mathcal{L}$ (x10^{34} cm^{-2} s^{-1})	0.5…3.4	3.4…5.0
Rep. Rate (Hz)	120	5…3
Bunches/pulse	95…190	2820…45000
Bunch sep. (ns)	1.4…2.8	337…189
Radius (cm)	1.2	1.5
Hits (mm^{-2} BC^{-1})	0.1	0.05
Hits (mm^{-2} BT^{-1})	9.5	225

- Must readout TESLA CCDs 10 times per BT to keep occupancy at ~ 1% level.
- Need column parallel readout at 50 MHz.

Conventional CCD

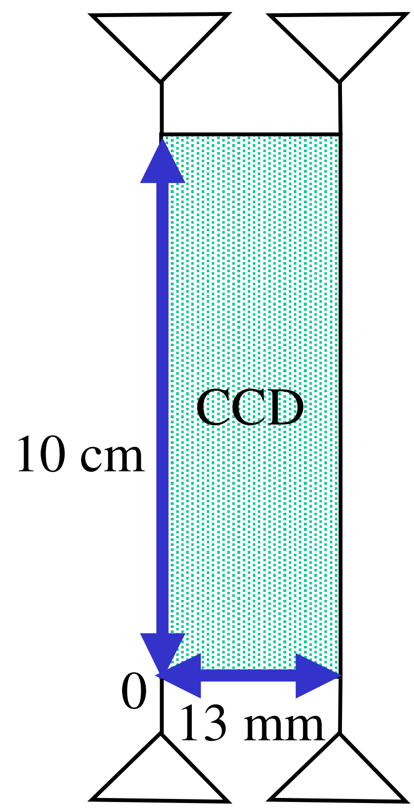


Column parallel CCD

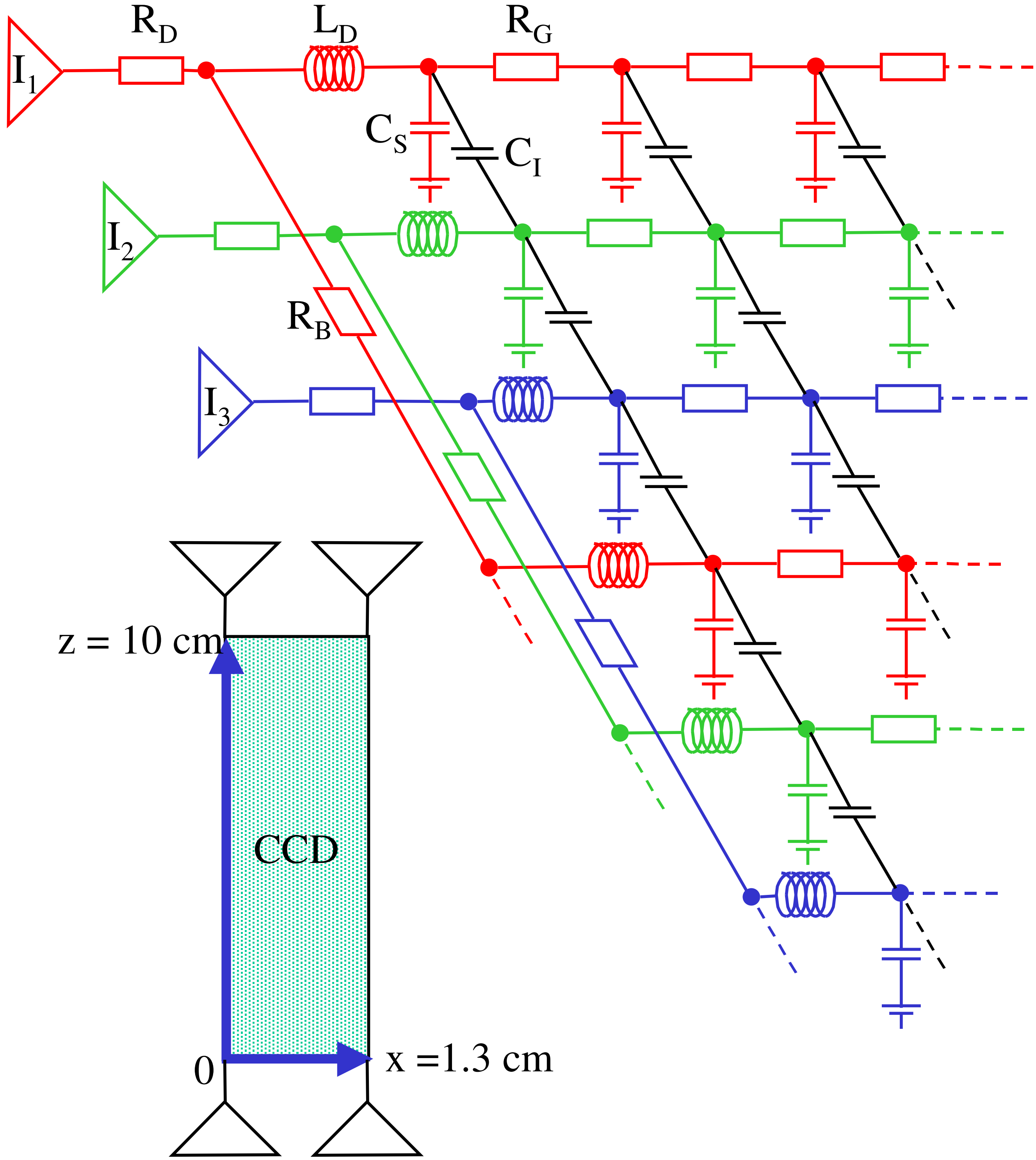


Column parallel CCD

- Can the I gates be clocked at 50MHz?
- Model CCD using SPICE assuming:
  - I-gate to substrate C = 3.3pF/mm^2 (buried channel and channel stop regions depleted).
  - Gate to gate C = 2.5pF/mm^2.
  - Polysilicon gate R = 3kΩ/mm.
  - Al clock bus line R = 0.5Ω/mm.
  - 1V square wave signals at 50MHz.
  - Negligible driver o/p impedance.
  - Driver to clock bus L negligible.

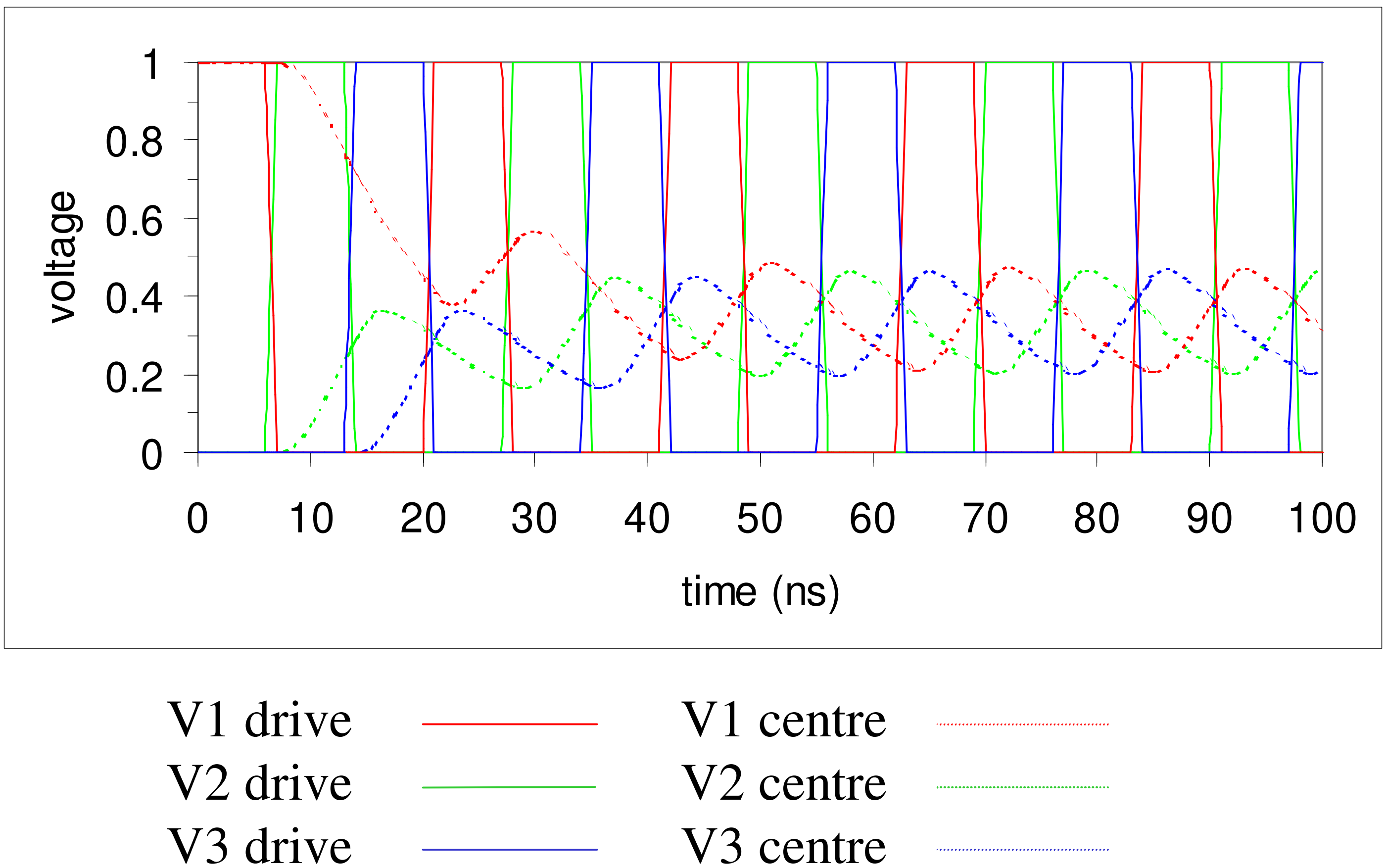


SPICE model, inner barrel



SPICE simulation results

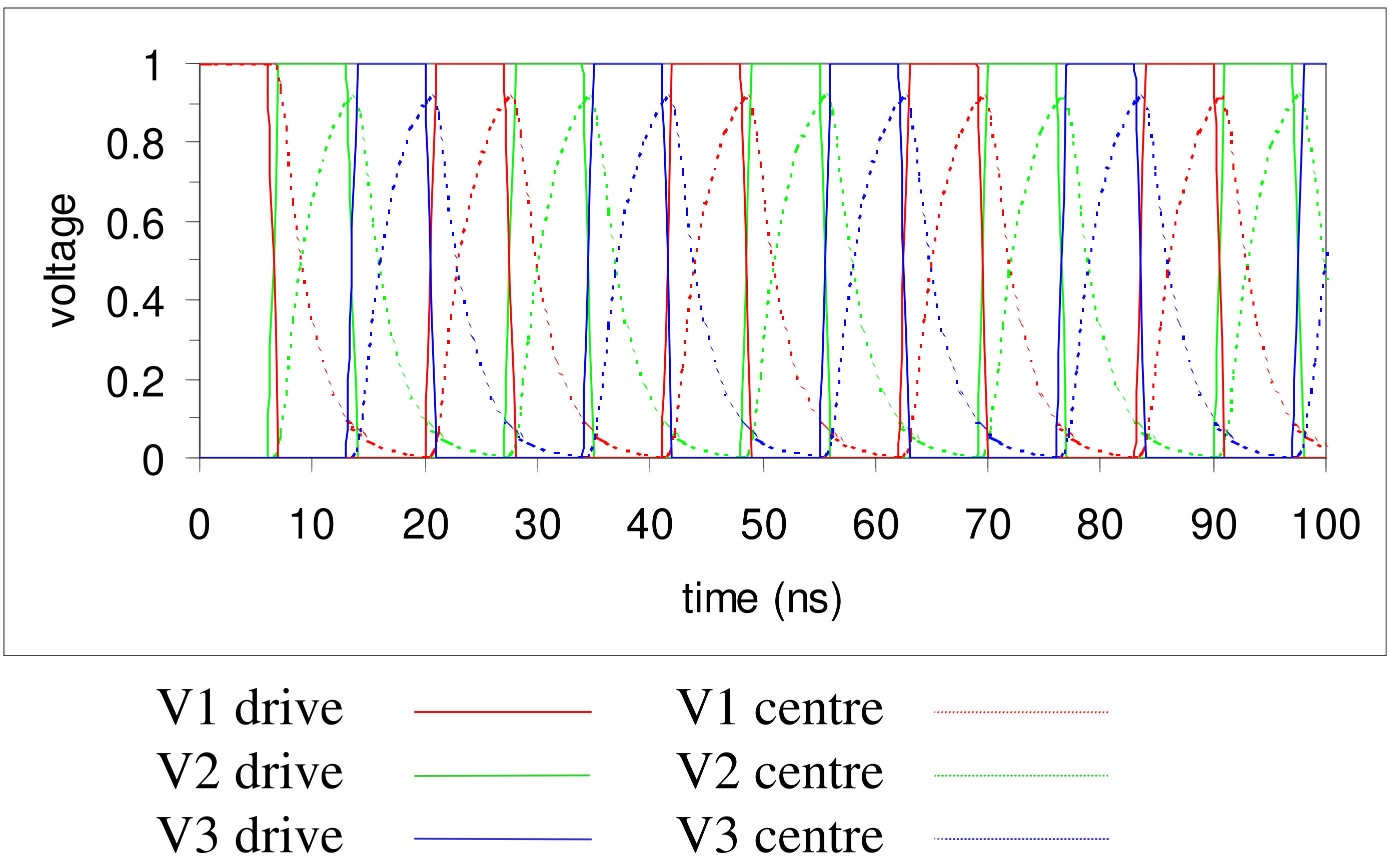
- Look at drive pulses at z = 0 or 10 cm.



- CCD would not function.

SPICE simulation results

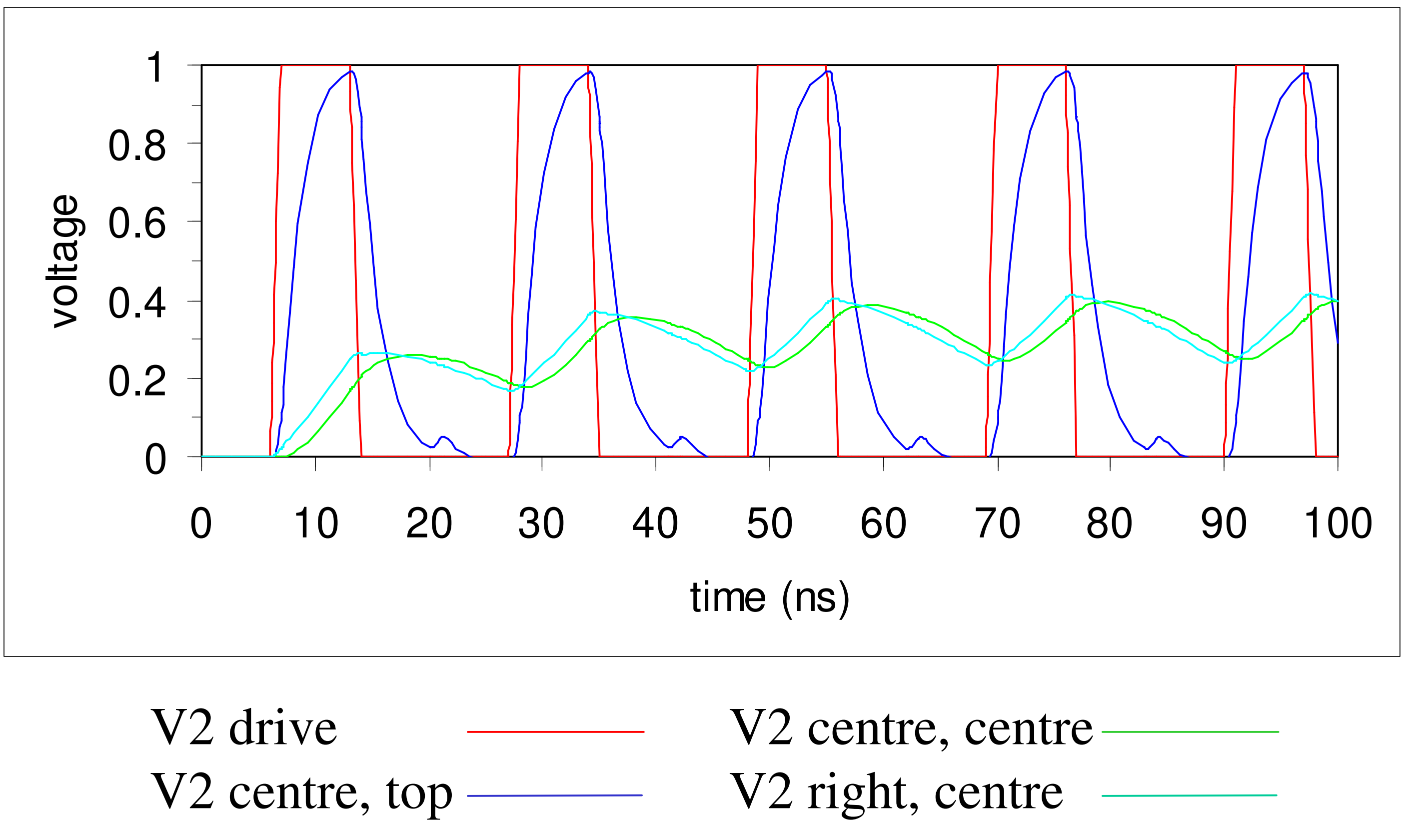
- Reduce gate resistance by addition of 3μm of Al.
- Look at pulses at z = 0 or 10 cm



- Phases sufficiently defined to allow operation of CCD.

SPICE simulation results

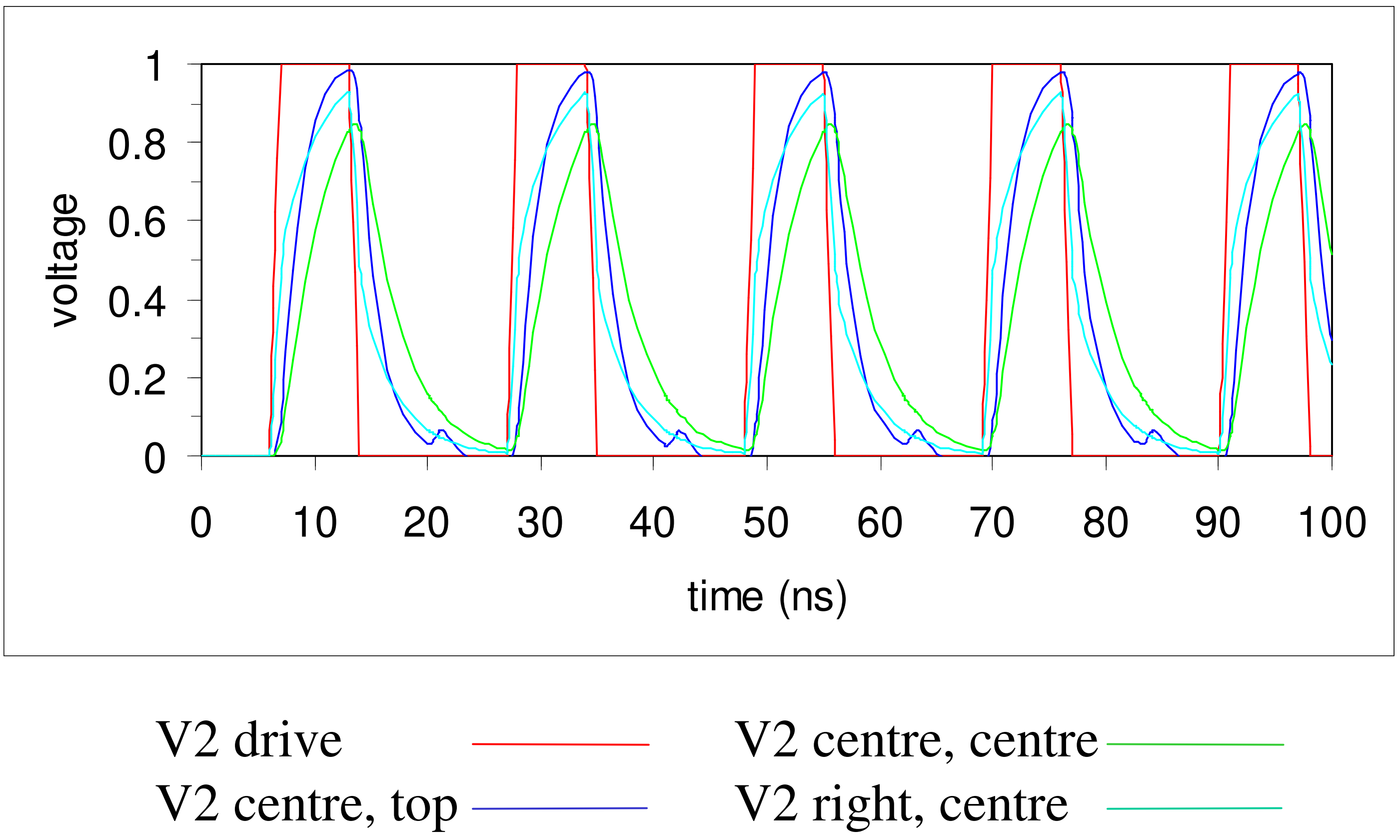
- Now look at pulses at various (x, z) values.



- CCD inoperable.

SPICE simulation results

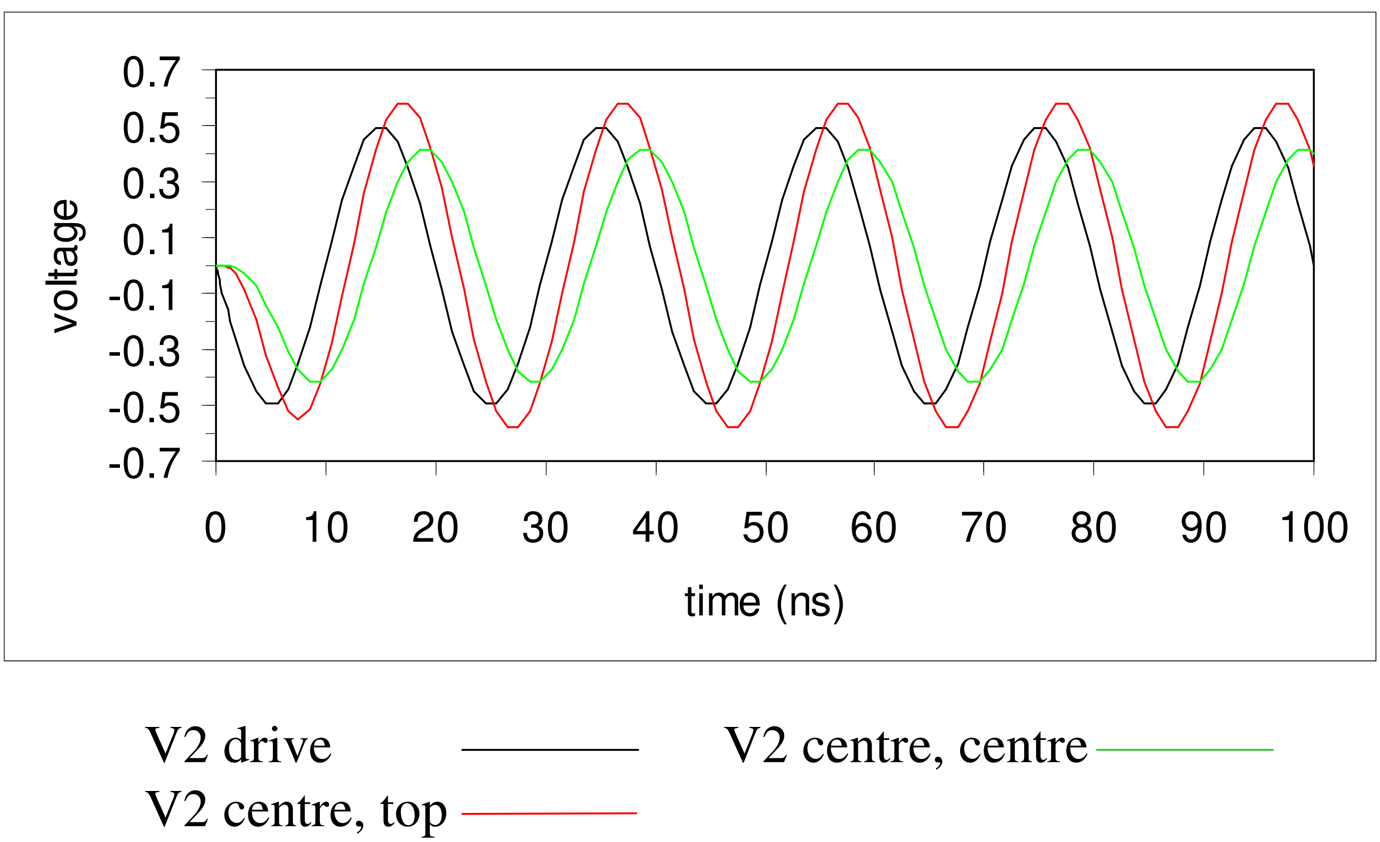
- Reduce bus line resistance by increasing thickness of Al.



- Gate voltages attenuated by < 15% in centre, will allow efficient operation over entire CCD.

SPICE simulation results

- Try 2-phase sinusoidal drive pulses.
  - Lowest possible driver frequency spectrum.
  - Reduced peak current demands.
  - Balanced anti-phase waveforms so minimal cross-talk to CCD o/p.

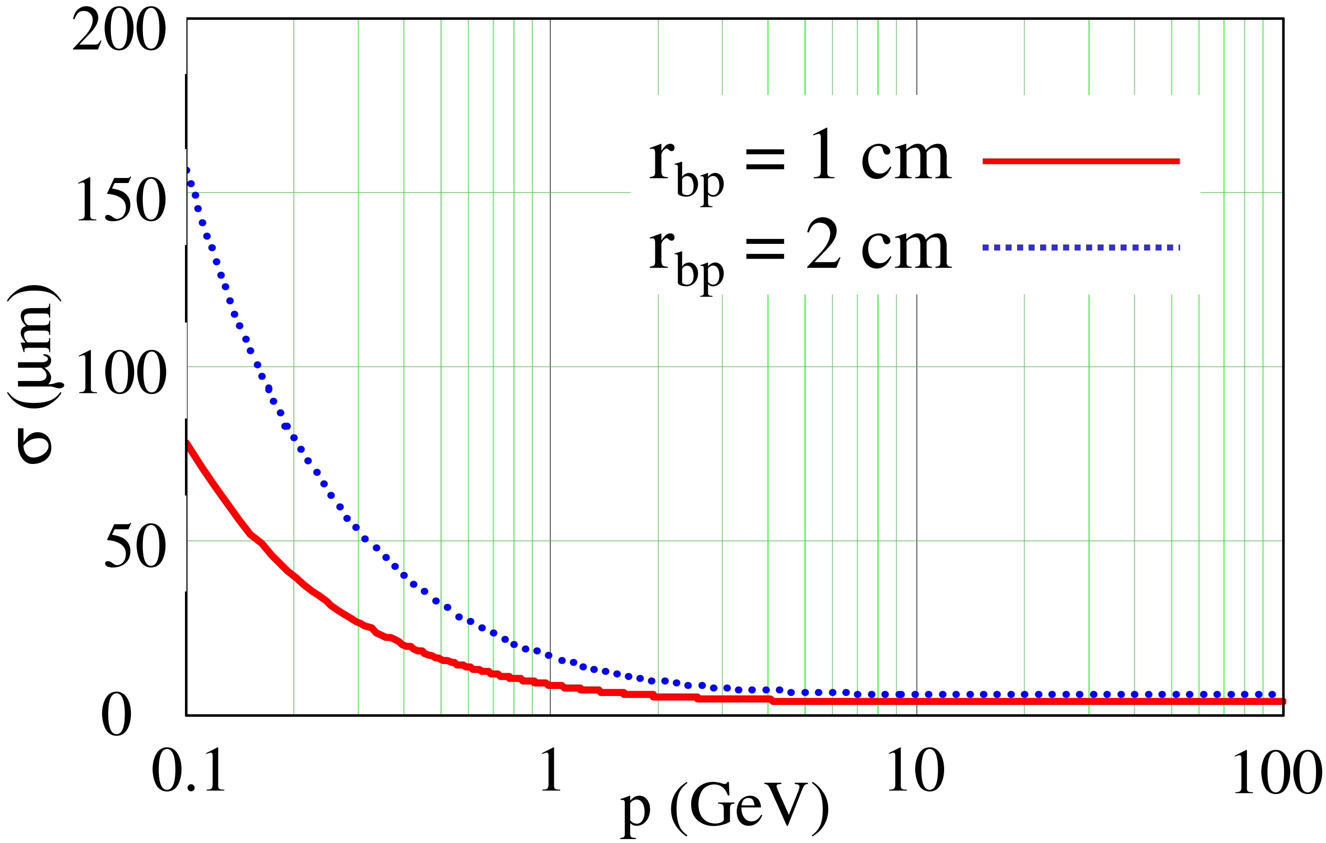


SPICE simulation results

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

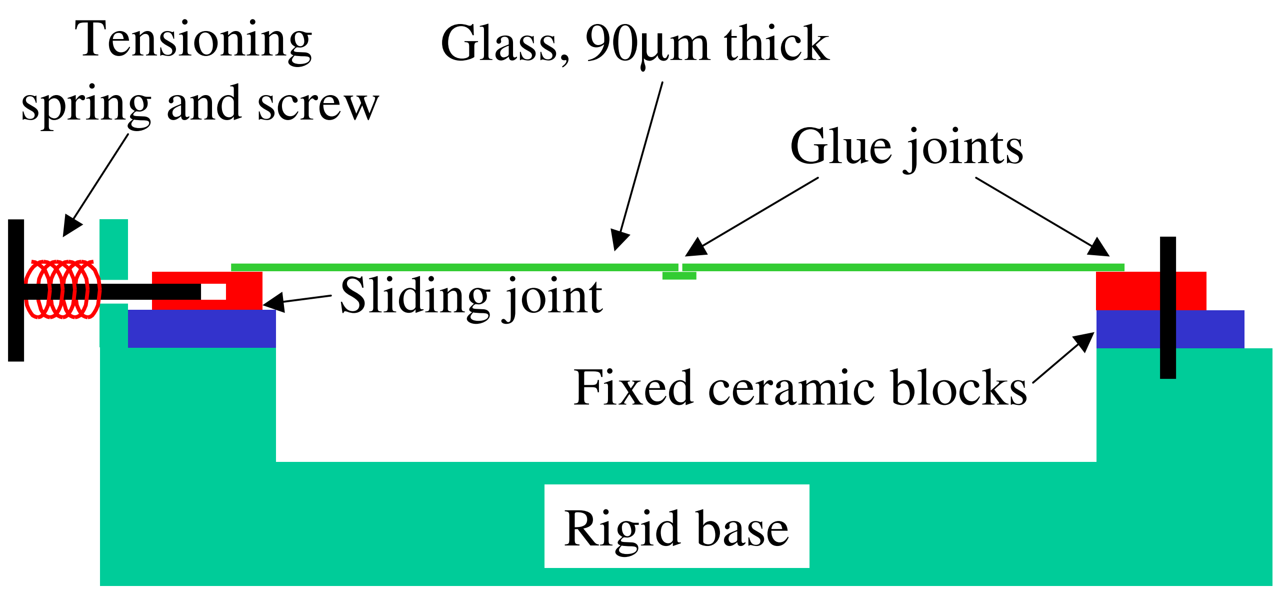
New physics challenges

- Correctly assign all tracks to primary, secondary or tertiary vertices.
- Allows identification of b or $\bar{b}$, c or $\bar{c}$.
- Problem, low momentum tracks!
- Multiple scattering dominates impact parameter resolution at low p:



Self-supporting CCDs

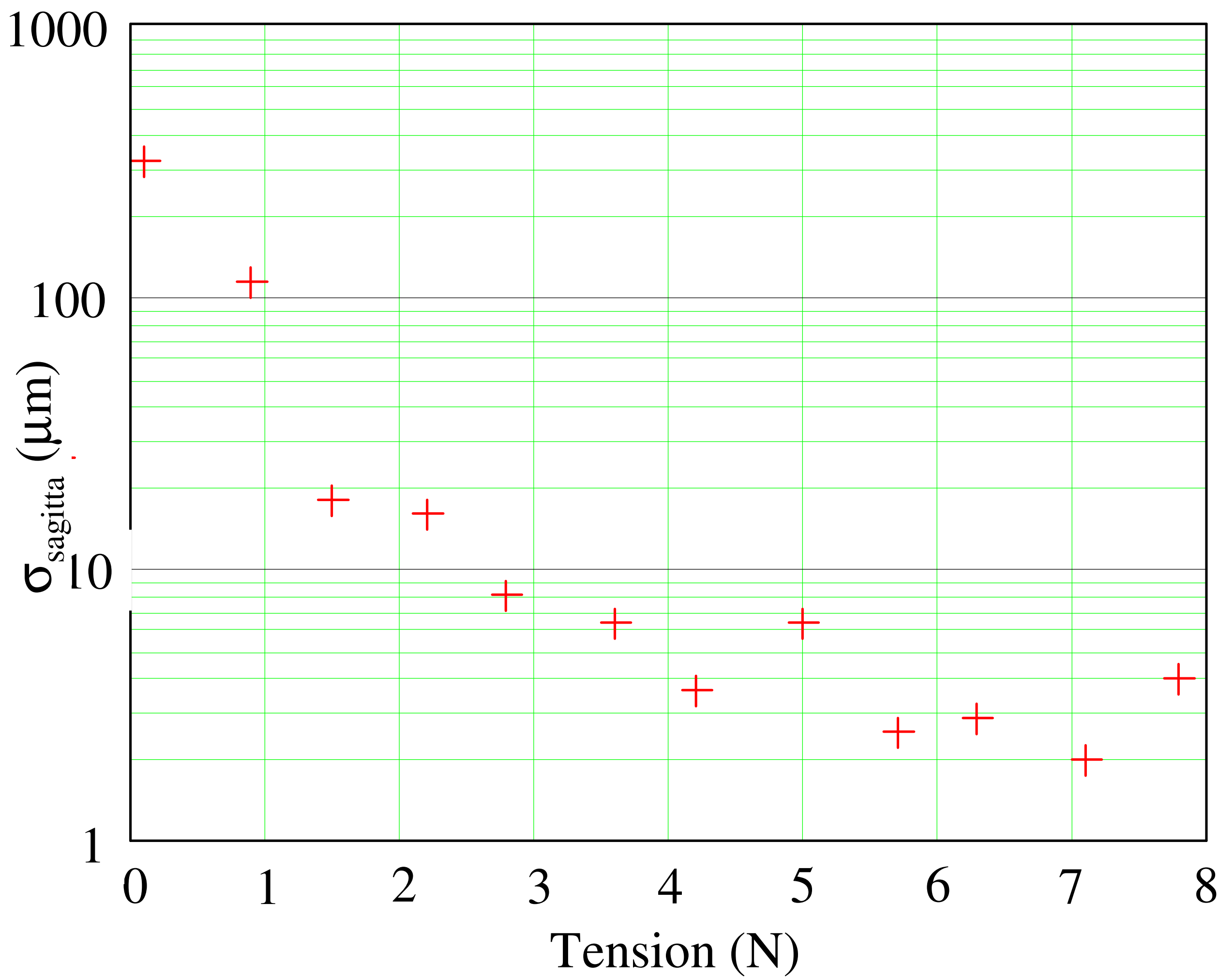
- Hold thinned CCDs at ends only, under tension.
- Mechanical stability (e.g. under temperature cycling)?
- Test rig:



- For various tensions repeatedly disturb, measure sagitta.

Self-supporting CCDs

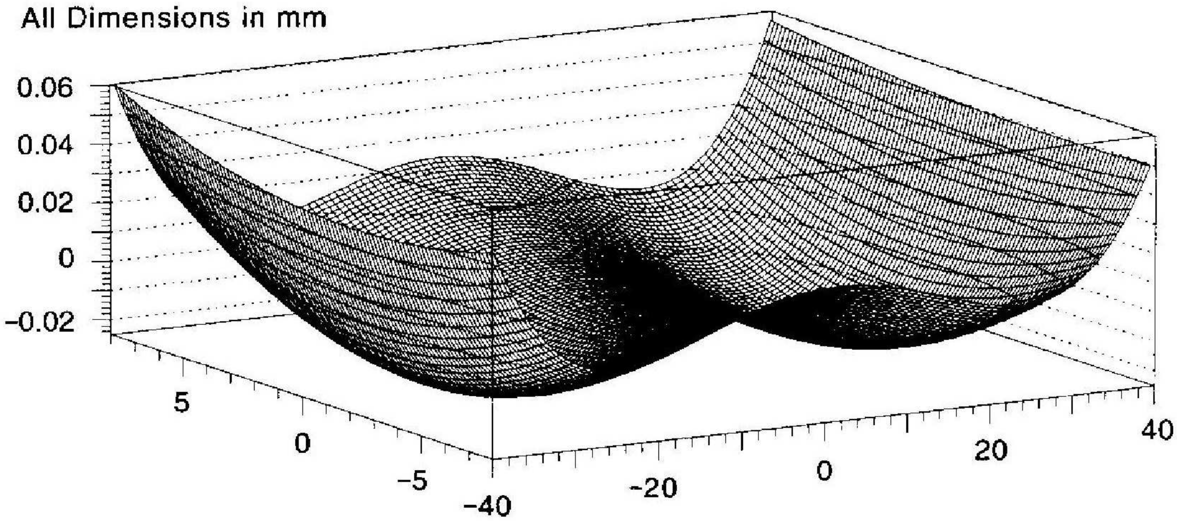
- Results:



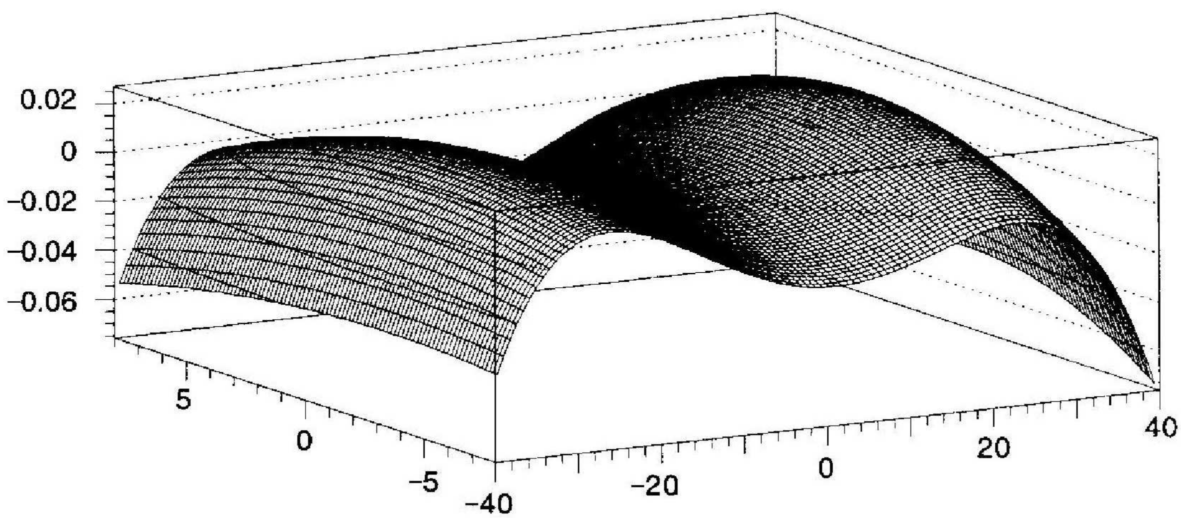
- First studies show σ ~ 3μm for T > 5N.
- Move to studying 60μm Si, then CCDs.

Self-supporting CCDs

- Compare with measurements of SLD CCDs:



North CCD



South CCD

Summary

- CCD based vertex detector will give exceptional flavour tagging performance at a future LC.
  - NLC, conventional readout possible.
  - TESLA, column parallel readout needed, first simulations look encouraging.
  - Measurements of effects on neutron radiation needed.
- Further reduction of material budget allows new physics studies.
  - Measurements suggest self-supporting CCDs may allow layer thickness of $0.06\%X_0$.