Vertex Detector R&D for ILC

(as seen by the Detector R&D Panel, a Panel of the World-Wide Study Organising Committee)

(Jean-Claude Brient, Chris Damerell, Ray Frey, Dean Karlen, Wolfgang Lohmann, Hwanbae Park, Yasuhiro Sugimoto, Tohru Takeshita, Harry Weerts)

Chris Damerell (RAL)

WWS-OC asked us to review main R&D areas during regional workshops last year – tracking in Beijing, calorimetry at LCWS2007 in DESY, and vertexing in Fermilab, 23-26 Oct 2007

Vertexing Review Committee

- **Panel members: Chris Damerell, Hwanbae Park (chair)**
- **External consultants: Yasuo Arai, Dave Christian, Masashi Hazumi, Gerhard Lutz, Pavel Rehak, Petra Riedler, Steve Watts**
- **Regional representatives: Tim Bolton (North America), Chris Damerell (Europe), [Junji Haba (Asia)]**
- **GDE R&D Board chair: Bill Willis**
- **Local vertexing experts: Simon Kwan, Lenny Spiegel**
- **Admin support: Naomi Nagahashi**

Overview of the review

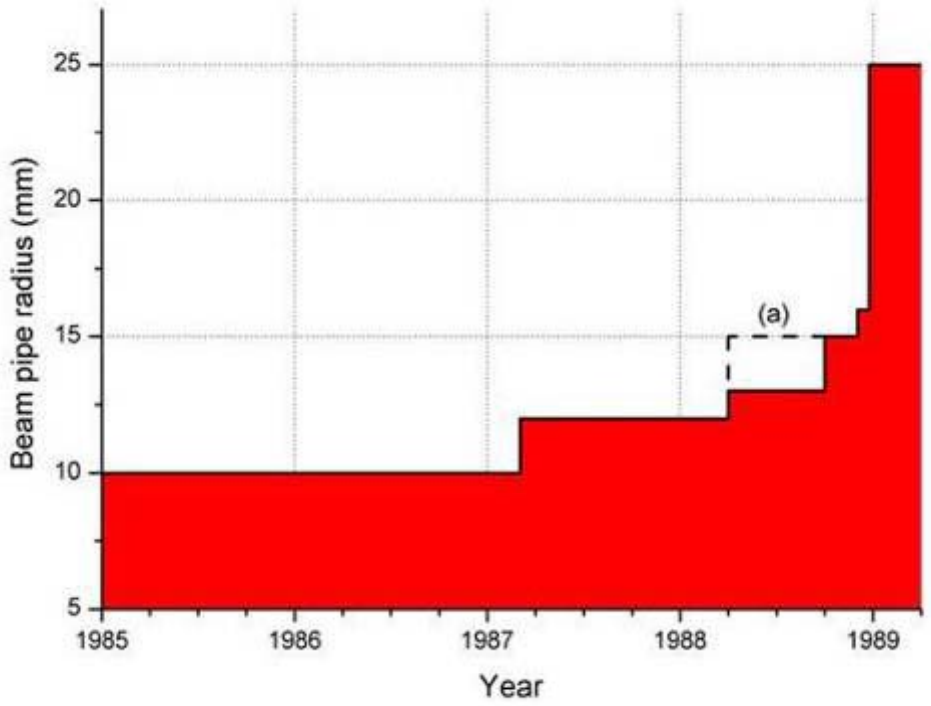
- We reviewed 10 technical options, FPCCD, CPCCD, CMOS MAPS, deep n-well, CAP, DEPFET, ISIS, Chronopixels, SOI-based, 3D-based
- All options hold promise – we were unable to eliminate any of them (but bear in mind that there has already been some pruning of options (micropixel/macropixel and others)
- Not as bad as it sounds – will end up with 2 and possibly 4 technologies in the startup ILC, and others could eventually provide upgrade paths
- Several of these options have possible applications in other fields, such as x-ray sensors for astronomy and SR systems and sensors for electron microscopy. Pixels (which enable creation of *pictures*) tend to be intrinsically multi-disciplinary
- Final version of our report can be found on ILC Wiki page, along with our earlier reports:

  http://www.linearcollider.org/wiki/doku.php

Some general recommendations (from 34 pages)

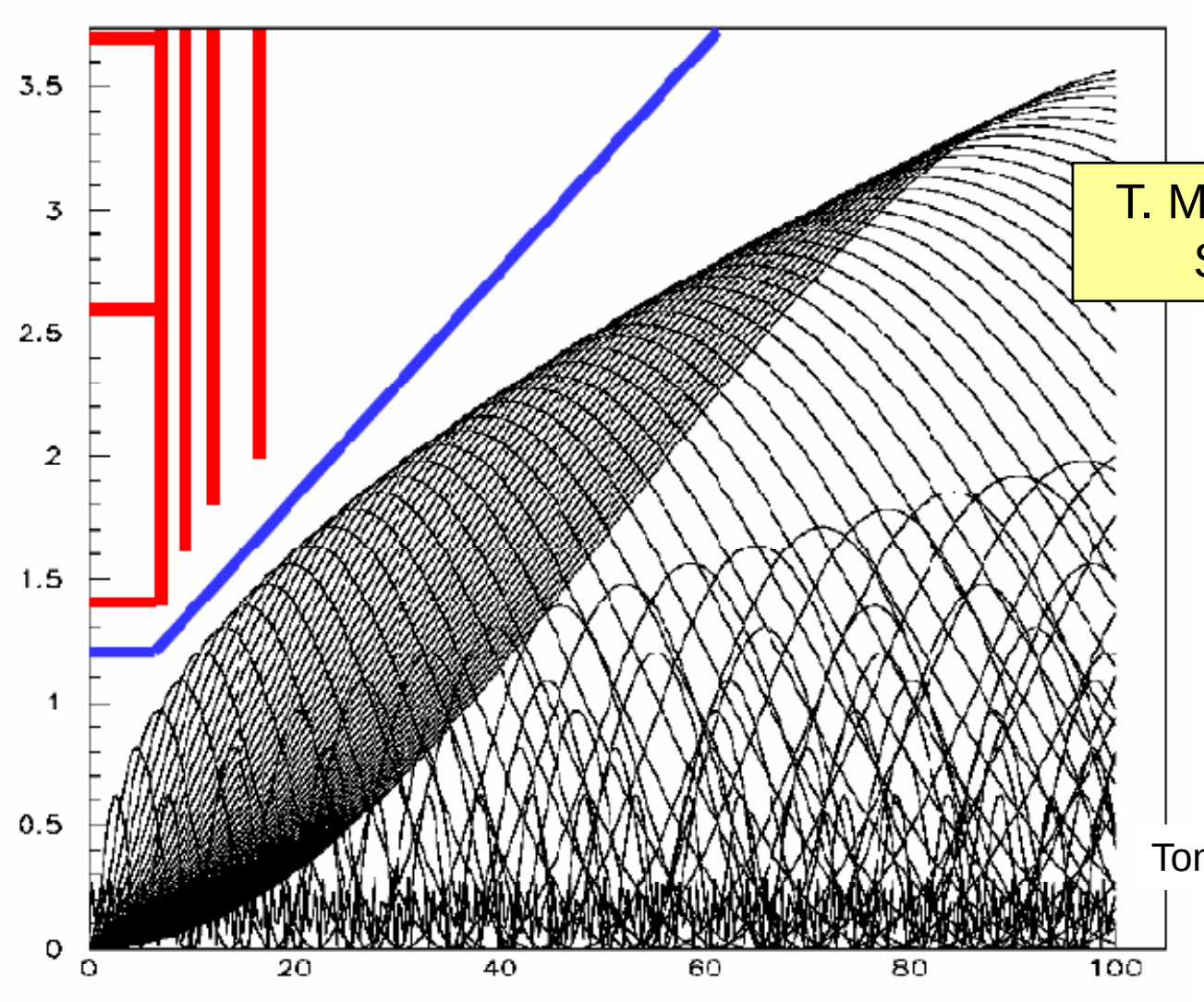
Environmental issues

- ***Ongoing close coordination needed with MDI Group***
  - to control pair bgd
  - to control neutron bgd from the current (less expensive but more risky) beam dump design
  - to control bgd related to wakefields in collimators (new UK studies)
  - overall, to preserve R_{bp} (in contrast to what happened at SLC)
- **Is high-Z liner needed,** and if so how thick? (results should come from studies of wakefields and all other sources of beam tails)
- As well as background in the data, we need to be concerned about **radiation damage** effects
  - e^+e^- pairs cause ionisation effects (notably flatband voltage shifts) and bulk damage (point defects)
  - Neutrons from local energy deposition (~10^9 n/cm^2 .yr) and from beam dump (similar) cause major displacement damage clusters
  - Dark current and point defects can be overcome by cooling, but not cluster damage which generates multiple trap levels through the bandgap
  - Most sensor designs are believed sufficiently robust, but ongoing testing is vital
- **If one has been too optimistic or pessimistic about any of these things, it may be possible to correct at first push-pull (if one has planned for it)**



- **In 1981, expected SLC beampipe was 'like a drinking straw'. However, this sort of time dependence (worst jump was only 3 years before startup!) is not inevitable**
- **LEP beampipe radius was *reduced* from 10.6 cm in 1991 to 5.6 cm in 1995**
- **Maybe the ILC design will be a balance between European conservatism, American optimism and Asian realism, hence more stable**
- **There must be concerns that the low-P option may (in difficult circumstances) force R_{bp} to move out …**

12mm Beam Pipe and SiD VXD (B = 5 T)



T. Maruyama
SLAC

Tom Markiewicz

Environmental issues (continued)

- **Time stability of IP position in x and y?**
  - Good discussion at SiD mtg 14/4/08 (Tom M and Phil B). Hopefully we can specify ~1 μm stability over periods of ~1 hour. Depends on issues related to optical anchor, floor sinking after push-pull, etc, that have not yet been studied
- **Need to monitor and eliminate beam-related and other machine-related RF during machine commissioning, before detector installed**
  - Sources (BPMs, kickers, pumps etc) can be pinned down by sub-ns timing from several wide-angle antennas (from ESA studies at SLAC)
  - Obvious that ~10^9 sensors of capacitance ~10 fF and thresholds ~100 e^- sampled during the bunch train may be challenging
  - A butterfly is more easily disturbed by a breeze blowing than is a large bird
  - Marvin Johnson's observations on Faraday cages

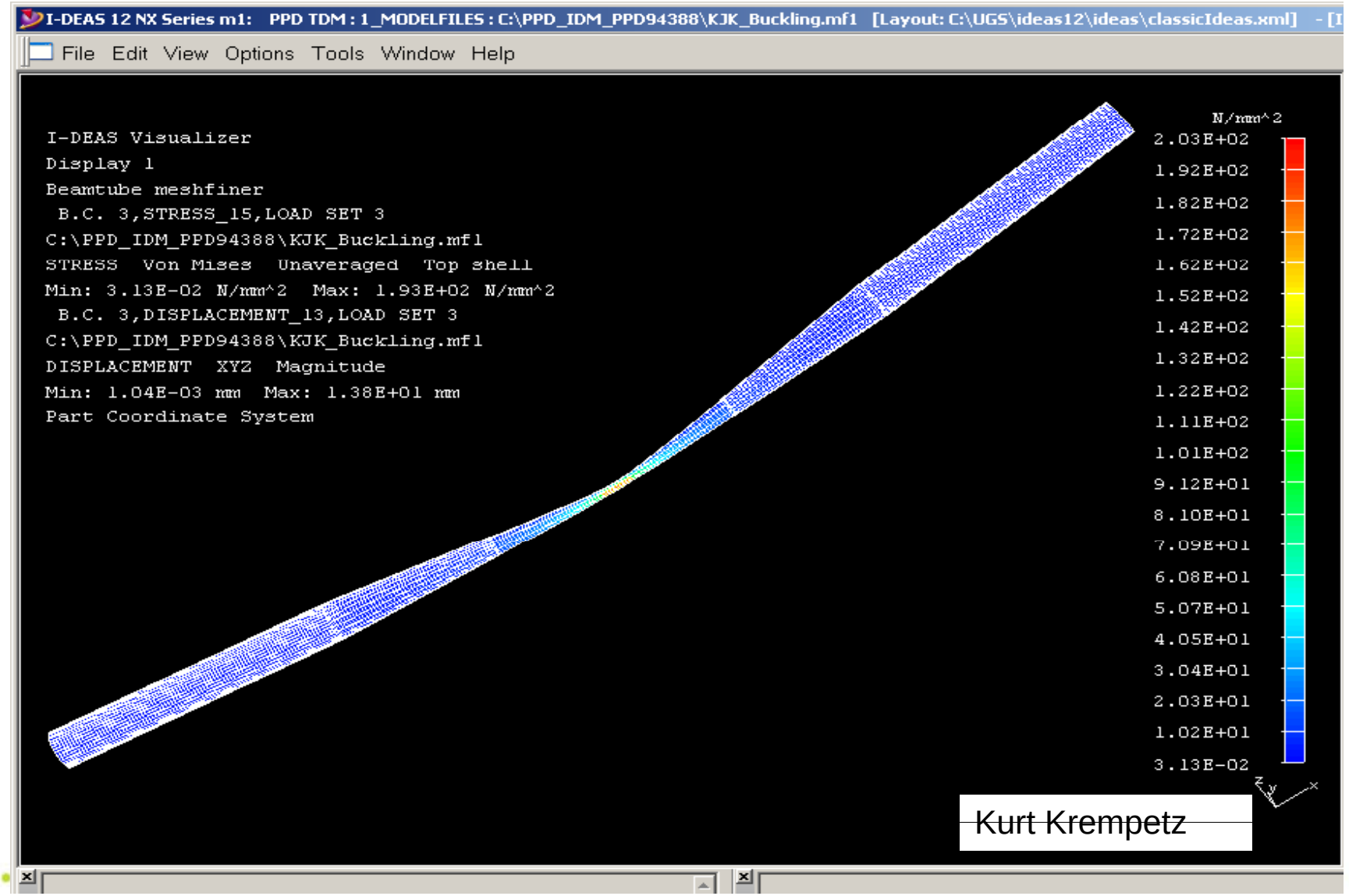
Engineering issues

- **Careful design of 'R20' system needed to preserve wall thickness of beampipe**

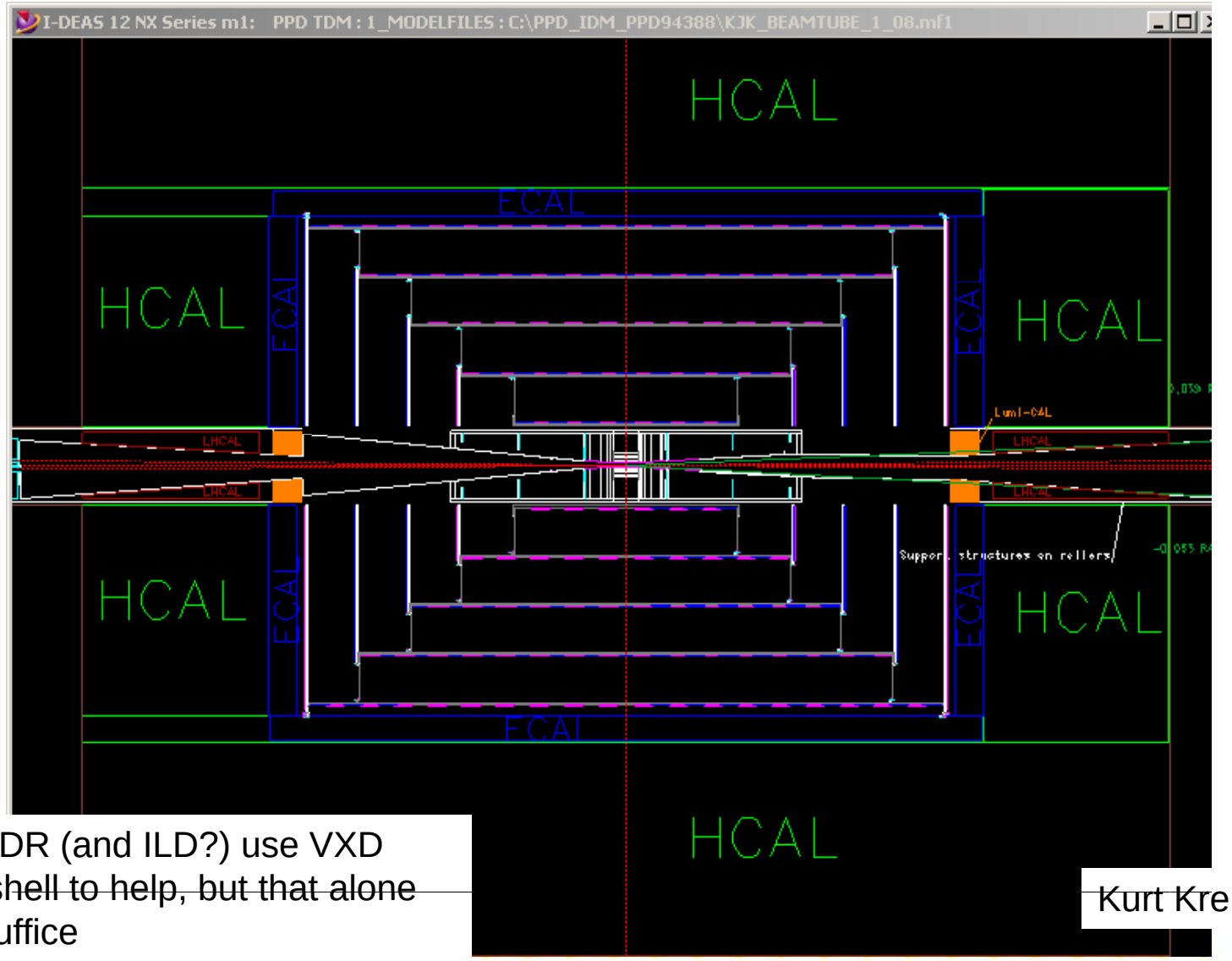
- **Long barrels vs short barrels+disks**
  - **will take a few more years to decide**
  - **excellent that two LOI concepts have different opinions**
  - **serial powering will work in favour of short barrels+disks**
  - **there will of course be fwd pixel disks – issue is whether inner ones should have ~3 μm or ~15 μm precision. Awaiting detailed physics studies when material budget at ladder ends can be reliably estimated**
  - **preference could change with future upgrade possibilities**

- **Layer 1 different?**
  - **May be a good idea**
  - **3-D or chronopixels may be obligatory if one really needs bgd as low as 1 hit/mm^2 Awaiting detailed studies …**
  - **Special conditions for layer 1 would permit differences such as higher power**

Beam Tube Deflections – if unstabilised



SiD Exoskeleton



TESLA TDR (and ILD?) use VXD support shell to help, but that alone will not suffice

Kurt Krempetz

Mechanics and alignment

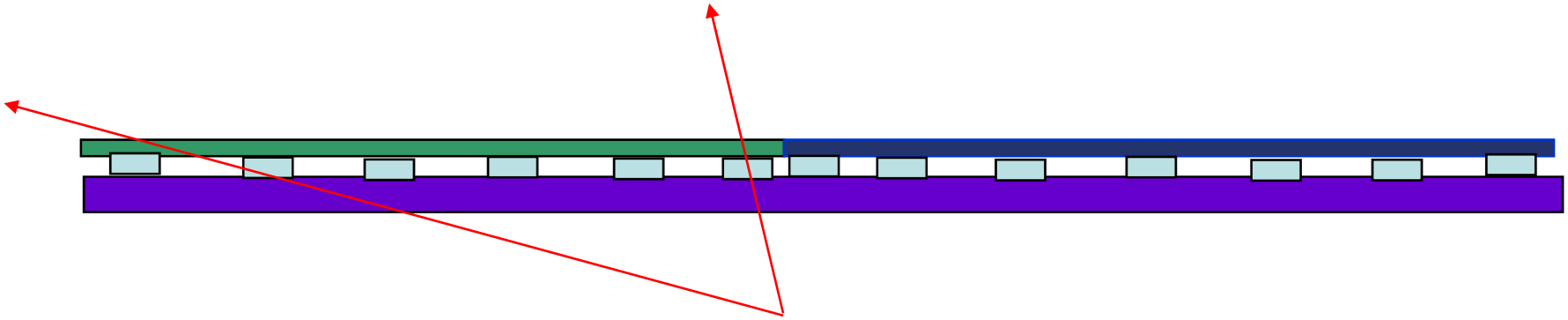
- **Material budget goal of 0.1% X_0 per layer**
  - within active volume, this is almost within reach for several technologies
  - material for services at ladder ends is far from defined for all technologies – several years away
- **Large sensors or mosaics of reticle-scale devices?**
  - penalty in material budget associated with mosaics depends on sensor technology
  - yield for large sensors may be higher than one infers from average over small devices
- **Fabrication of nested barrels**
  - 2 approaches – monocoque or separate ladders
  - don't need to make these assemblies easily demountable
  - SLD's 307 Mpixels comprised 60 ladders, and experienced *zero* failed pixels
  - assembly procedure can decide sequence (layer 1 first or last) and sensor orientation (inward or outward facing)

- **Sensor attachment to substrates**

  - thinned sensors will be bowed, hence require a small flattening force, which **probably** increases: CCD –> CMOS –> SOI –> 3-D

  - assemblies don't need to be flat, but do need to be mechanically stable

  - instabilities at ends of sensors in SLD were negligible for polar angles near 90 degrees, but not at ends of angular coverage. This illustrates a general point:



  - adhesive pads? Probably no longer needed for cte mismatch, but have other advantages, eg avoiding adhesive at sensor edges
  - can use temporary shims for assembly and for secure, robust wire bonding

- **Optical survey and beam-based alignment**
  - modern laser CMMs permit micron-level precision in depth, as well as in x,y
  - survey during assembly of nested cylinders at operating temperature could provide full 3-D map of sensor surfaces to the required precision
  - assembly onto beampipe with 3-point kinematic mounts, and care to minimise cable stresses, could preserve surveyed shapes for installed detector
  - similar procedure could be followed for the main tracker, mounted by similar low-stress supports from the ECAL
  - then these shapes will be preserved through multiple push-pull cycles
  - job of beam-based alignment (muon-pairs being just as useful as at LEP/SLD, though not precisely back-to-back) is then purely to relate these two stable systems to one other, which is easy
  - Should be no need at all for Z-pole running for mechanical alignment, though possibly required for other calibrations
  - major repairs and upgrades don't require beampipe bakeout. That is needed once only

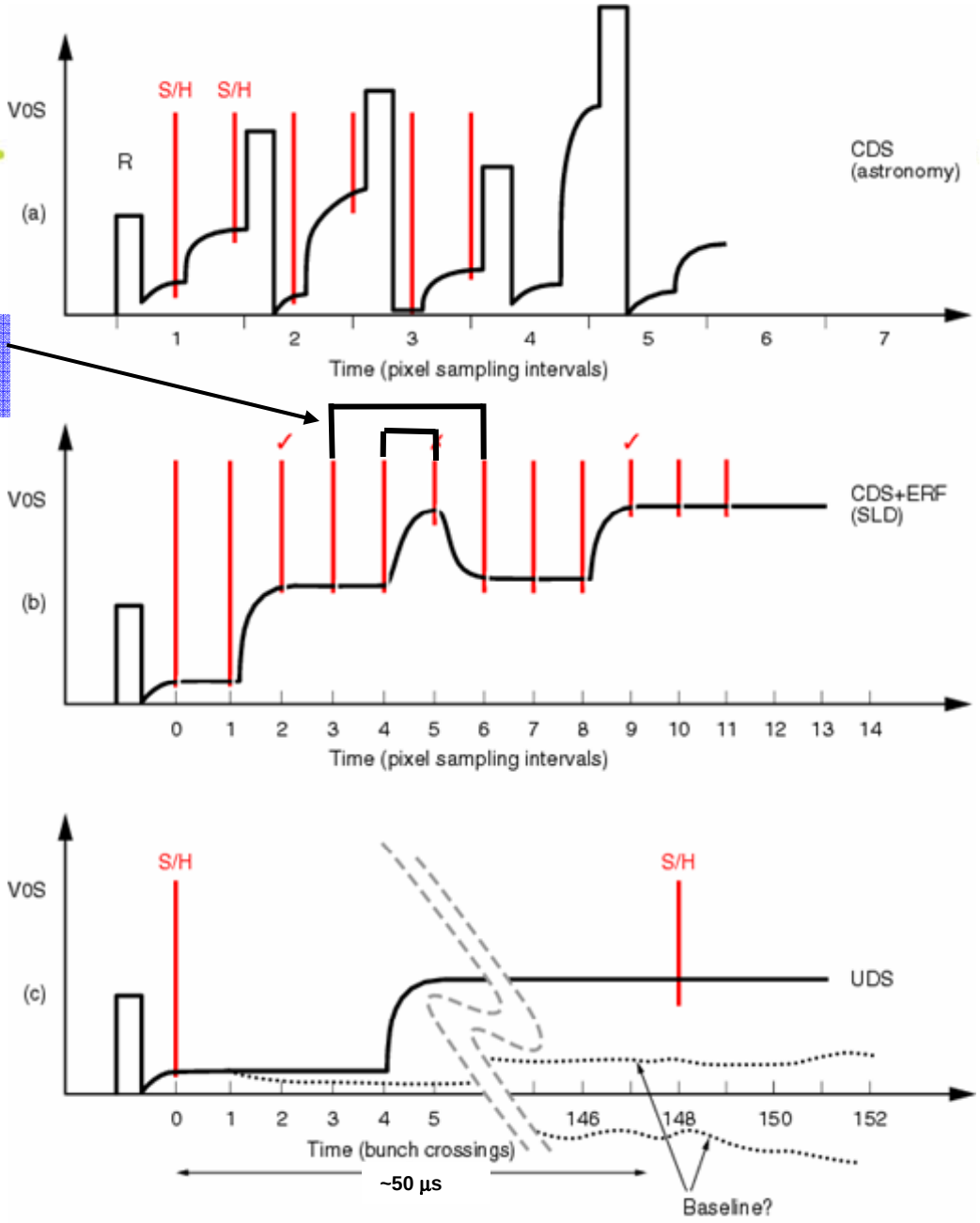
- **Laser alignment between FF quad doublets is now considered to reference the 'bedrock' below. No need for a laser running through the IR close to VXD**

Electronics – shared issues

- **CDS and ERF. Several technologies need to think more about it – could have significant power implications**
- **Power and cooling – serial power may help to greatly reduce material for all options. Much in common with studies under way for sLHC**
- **If using pulsed power, beware of Lorentz forces, transmitted to the delicate VXD support structure, creating unacceptable mechanical vibrations during the bunch train**

Installation and access

- **Push-pull helps. In the garage position, one can open the doors by 3 m. Then follow SLD procedure of rolling the tracker and removing the inner system of beampipe plus detectors, for major work or to install complete upgrade detector, in clean room**



Extended Row Filter ERF

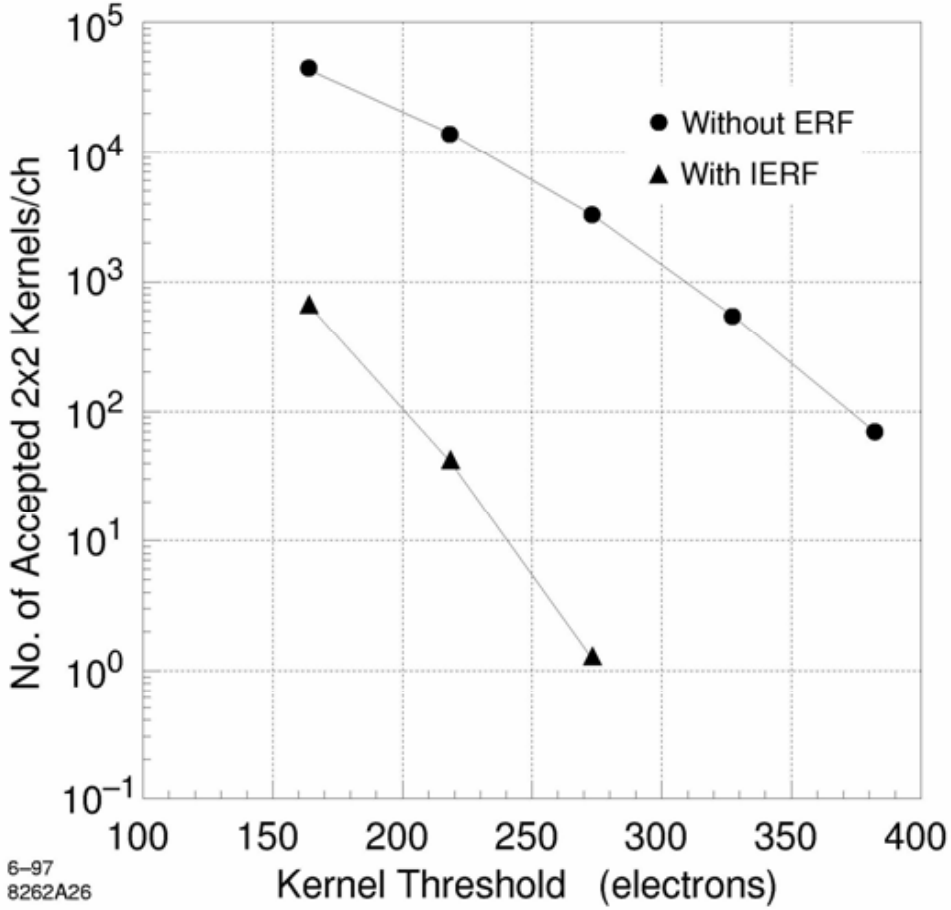
‘astronomy CDS’

Baseline settles to a different level after each reset, due to kTC noise

‘pixel rate CDS’

‘frame rate CDS’

SLD experience:



Without ERF, rate of trigger pixels would have deluged the DAQ system

Read out at 5 MHz, during 'quiet' inter-bunch periods of 8 ms duration

Origin of the pickup spikes? We have no idea, but not surprising given the electronic activity, reading out other detectors, etc

With hundreds of millions of channels, one is sensitive to some low-level effects that would have been negligible with earlier detector systems

Technology choices

- **Reviews of individual projects - see 18 pages of our report**
- **Regarding choices, this will take time - need to wait for fully serviced ladders in test beams, except where groups decide themselves to change direction**
- **Very important not to prematurely down-select or ‘pick winners’, despite pressure from funding agencies**

- **Past experience provides a warning …**
- **SLC Experiments Workshop 1982 (just 8 years before physics startup)**
- **Fortunately, they didn't rush to take a decision**
- **Now move on just two years …**

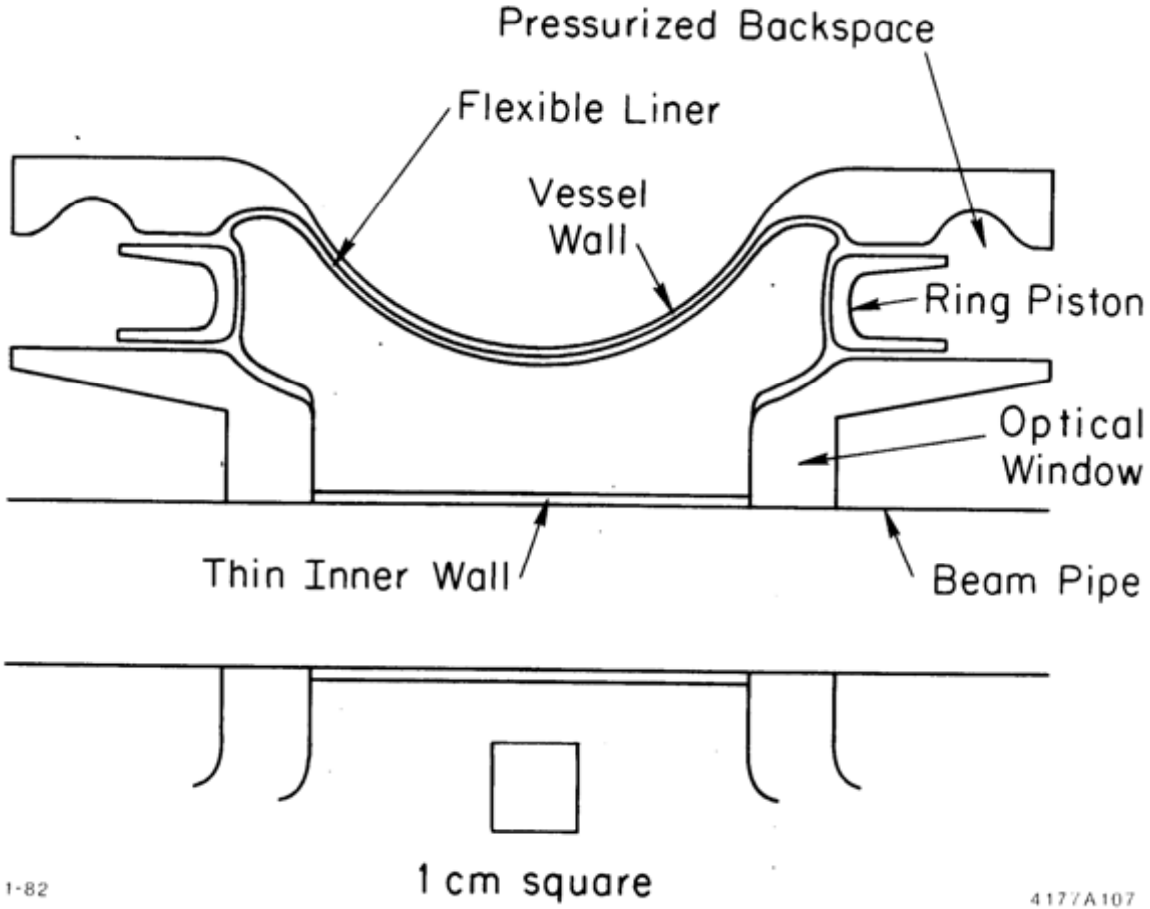
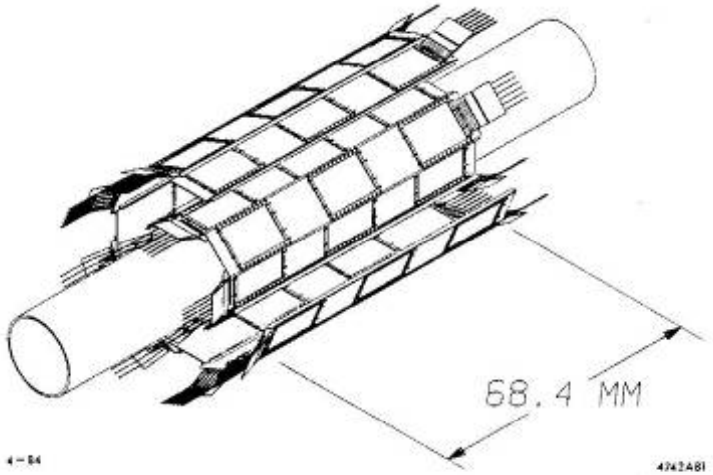
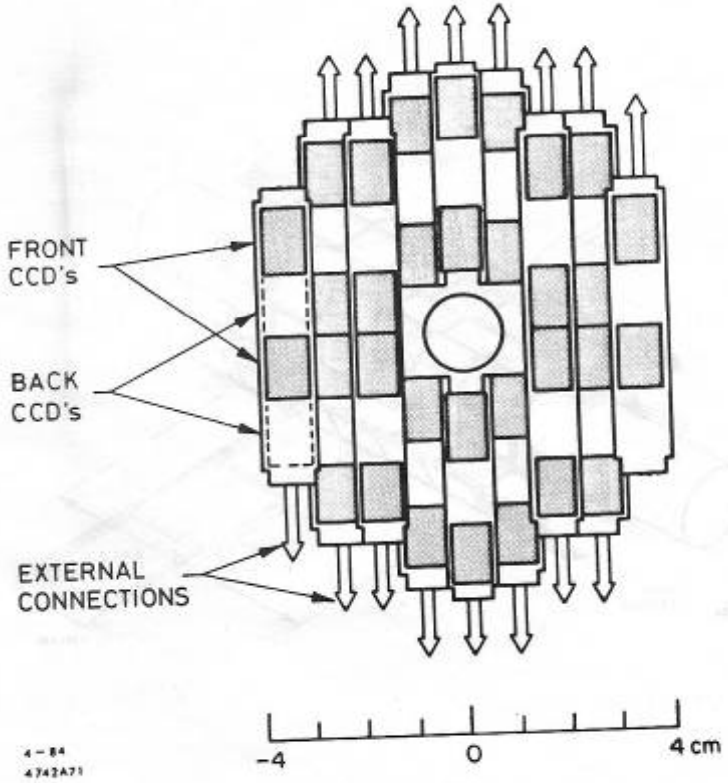


Fig. 7. Conceptual design of a propane bubble chamber vertex detector.

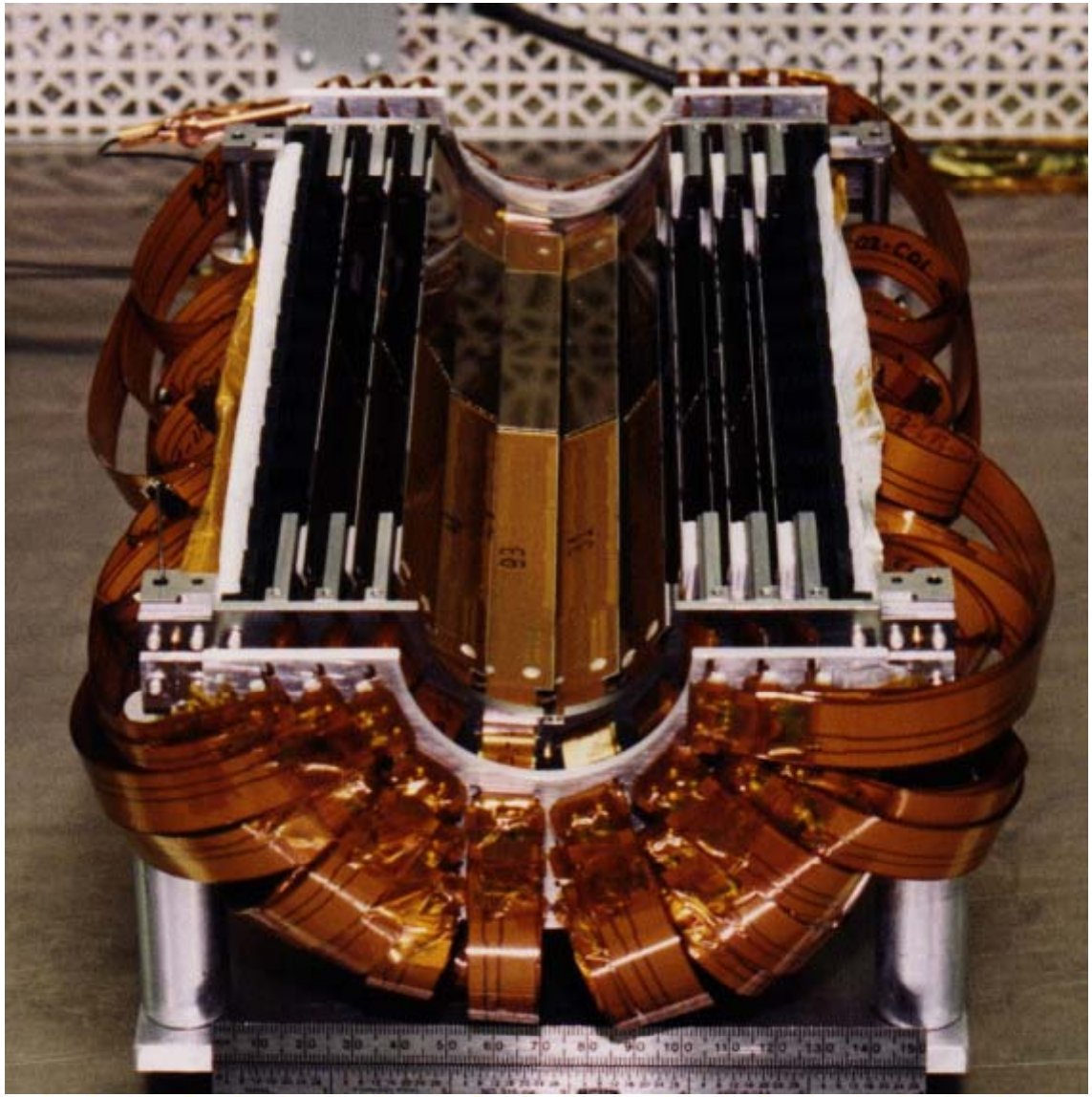
SLD's Vertex Detector Design in 1984 (thanks to Marty Breidenbach)



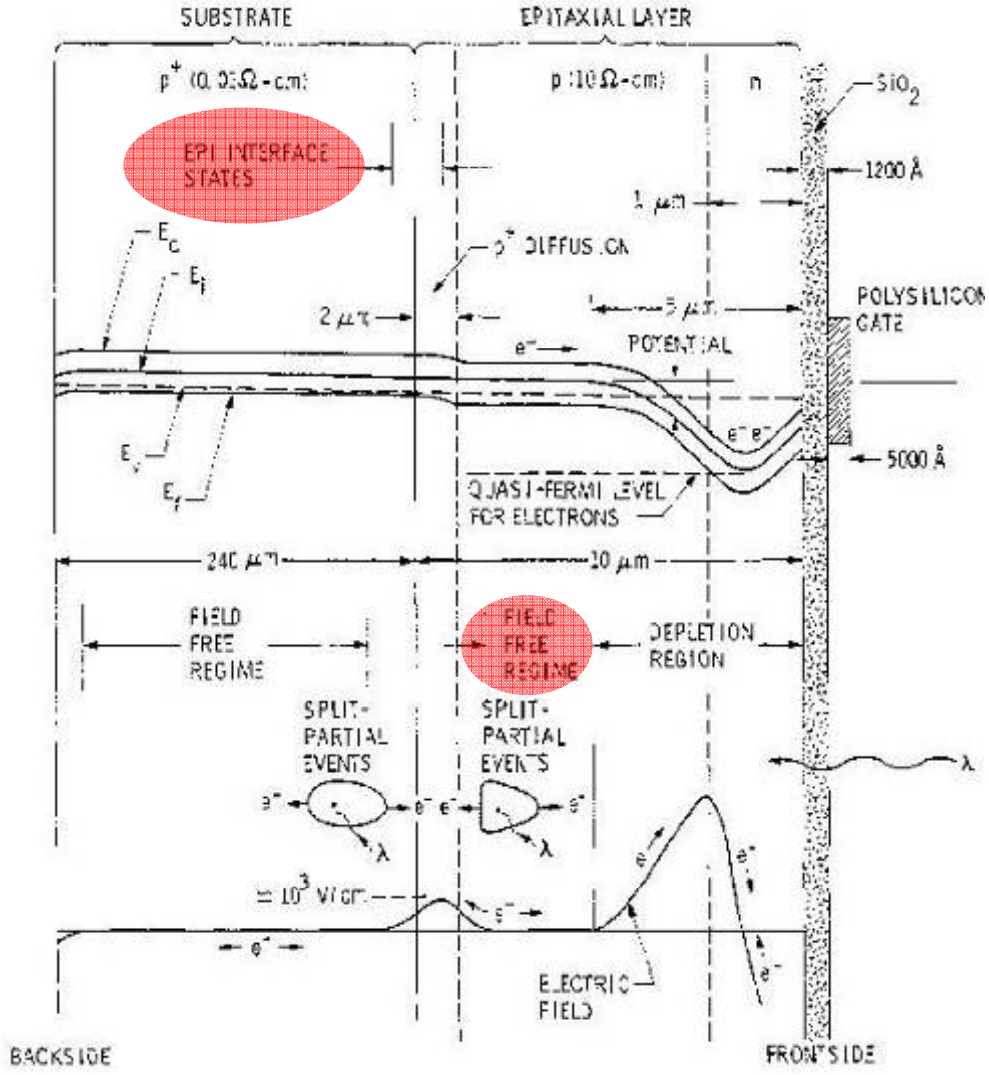


Right technology choice, but still the wrong choice of detector layout …

- **What was installed in 1993**
- **Ladder supports, connectors and services tipped the balance in favour of *long barrels without endcaps***
- **However, it should be possible to greatly reduce these end-of-ladder components in future, so the balance may change**



New development from Nick Sinev



- **Cluster shapes with x-rays in CCDs establish very precisely the different regions, including a precisely field-free region in the undepleted epi material**
- **However, Nick Sinev, simulating the chronopixel with DESSIS, finds a weak but significant electric field in this region …**

Jim Janesick, p 334

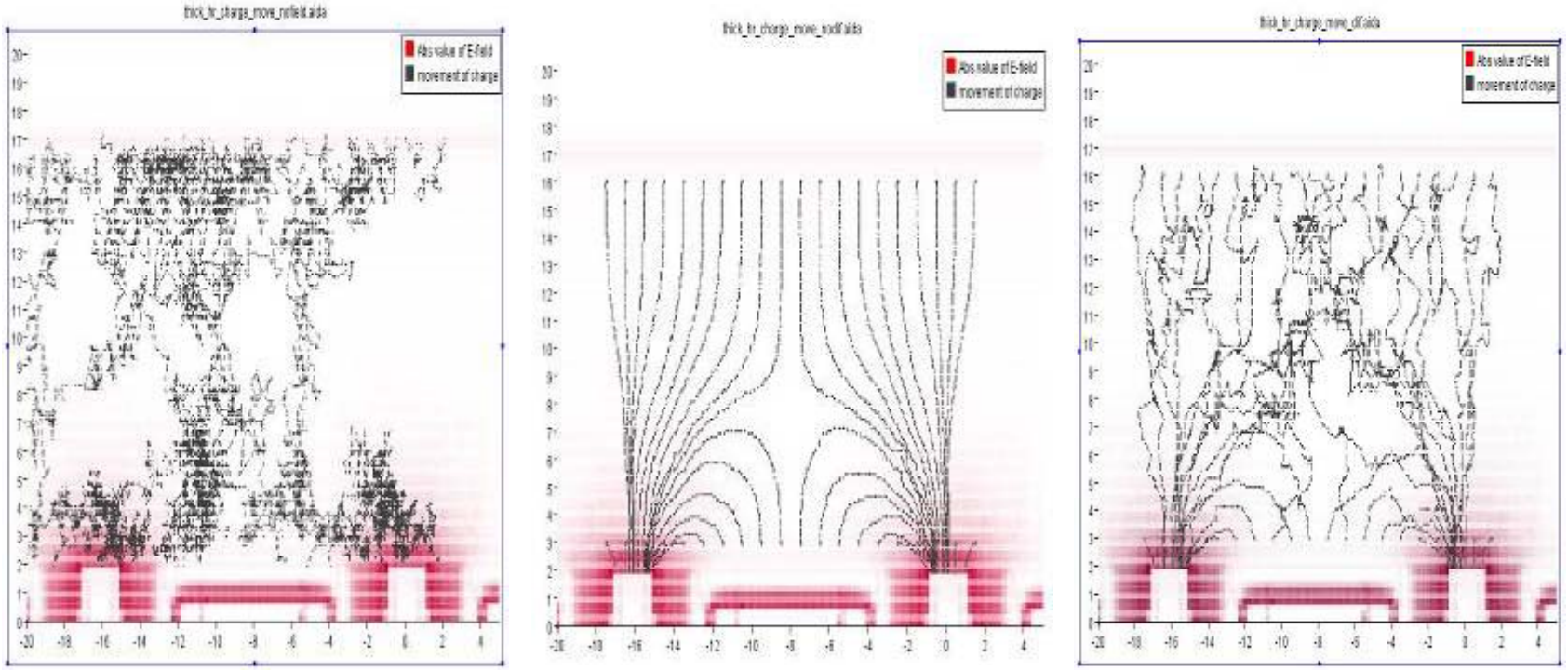


Illustration of the electric field effect on the charge collection in silicon sensor:
On the left picture only diffusion is simulated, in the middle charge is moving only by electric forces, and the right picture shows how it moved in our simulations

Nick Sinev

What is going on? Two possibilities – dopant gradient as result of the production process (unlikely?) or effect of dark current (simulation is at room temperature). Nick will investigate when he returns from Moscow. Could be really interesting for other technologies …

Shared infrastructure

- We suggest (supported by all groups who came to the review) a single world-wide test facility, to be equipped as follows:
  - Test beam, ~100 GeV π^- , having the coarse time structure of ILC (1 ms on, 200 s off)
  - 3-5 T split coil solenoid of length and diameter ~1 m, with apertures in the return yoke for incident beam at θ_P = 90 degrees, and several oblique angles
  - Anechoic chamber for controlled measurements of noise immunity for all ladder assemblies
  - Optical equipment for measuring stability of supported, fully serviced ladders (notably pulsed power, if relevant to that technology) in the solenoid field
  - etc, etc. There will surely be more
- We suggested setting this up via a Vertexing Coordination Group. One of their first jobs would be to find a lab prepared to host this for ~5 years (CERN or Fermilab?) and work together to build up these resources

Suggestions/Conclusions

- **It's really important not to weaken the detector R&D groups by excessive emphasis on LOI collaborations – need to maintain a careful balance**
- **The LOI collaborations *as in the past* provide the overall frameworks essential to evaluate *any* detector systems – we cannot study any detector issue (PFA vs compensating calorimetry, long barrel VXD vs short barrel plus disks, etc) other than in full MC simulation of an overall detector concept**
- **Our Detector Directorate might consider whether to invite R&D groups to form coordination groups. We can continue for a while as we are, but once groups are producing full-scale prototype ladders, the shared infrastructure will be essential for objective evaluation**
- **This suggestion by the vertex detector community was expressed unanimously in the review, and reiterated at the ILC Vertex Detector Workshop in April in Como**