Vertex Detector R&D for a* Linear Collider

(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

*** To satisfy UK funding agency 'guidelines'**

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)]
- RDB chair: Bill Willis
- Local vertexing experts: Simon Kwan, Lenny Spiegel
- Admin support: Naomi Nagahashi

* *someone has been nominated for each review, to report to the DESY PRC*

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
- First draft of our report was distributed (limited distribution) on 12th April. So far, some praise and no complaints, only a few corrections. That's a relief …
- Final version will be published soon on ILC Wiki page, where you can find our earlier reports:

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

Some general recommendations (from 34 pages)

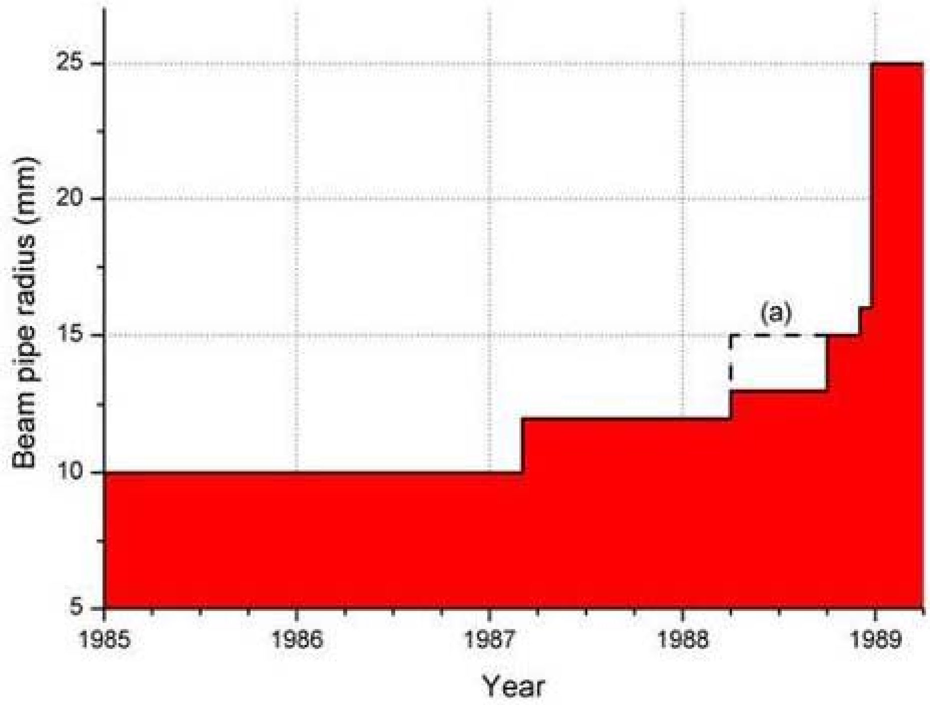
Environmental issues

- **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)**



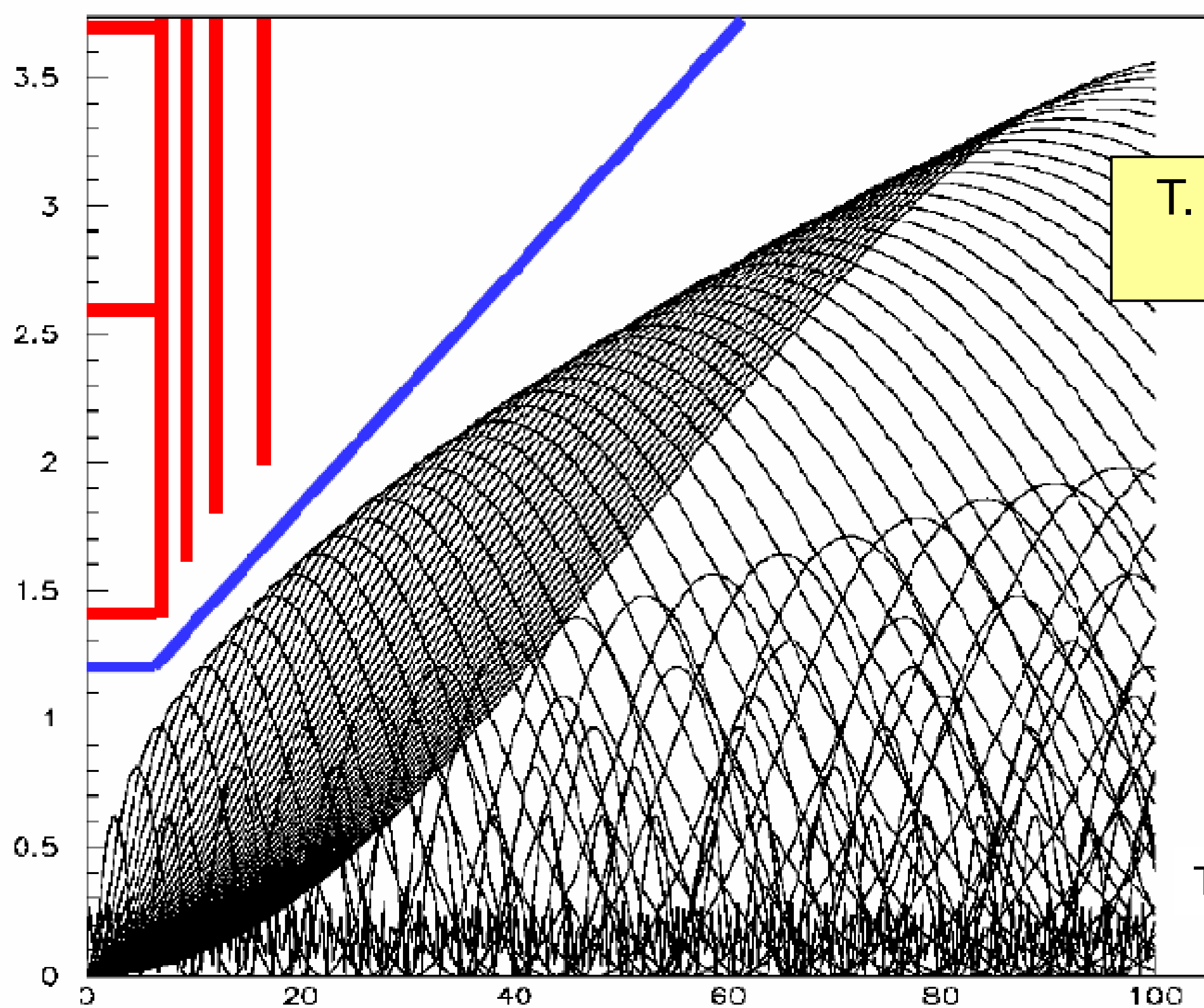
- In 1981, expected SLC beampipe was 'like a drinking straw'. Whatever Marty says, this sort of time dependence (worst jump was only 3 years before startup!) is not inevitable

- 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 VXD Detail (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**

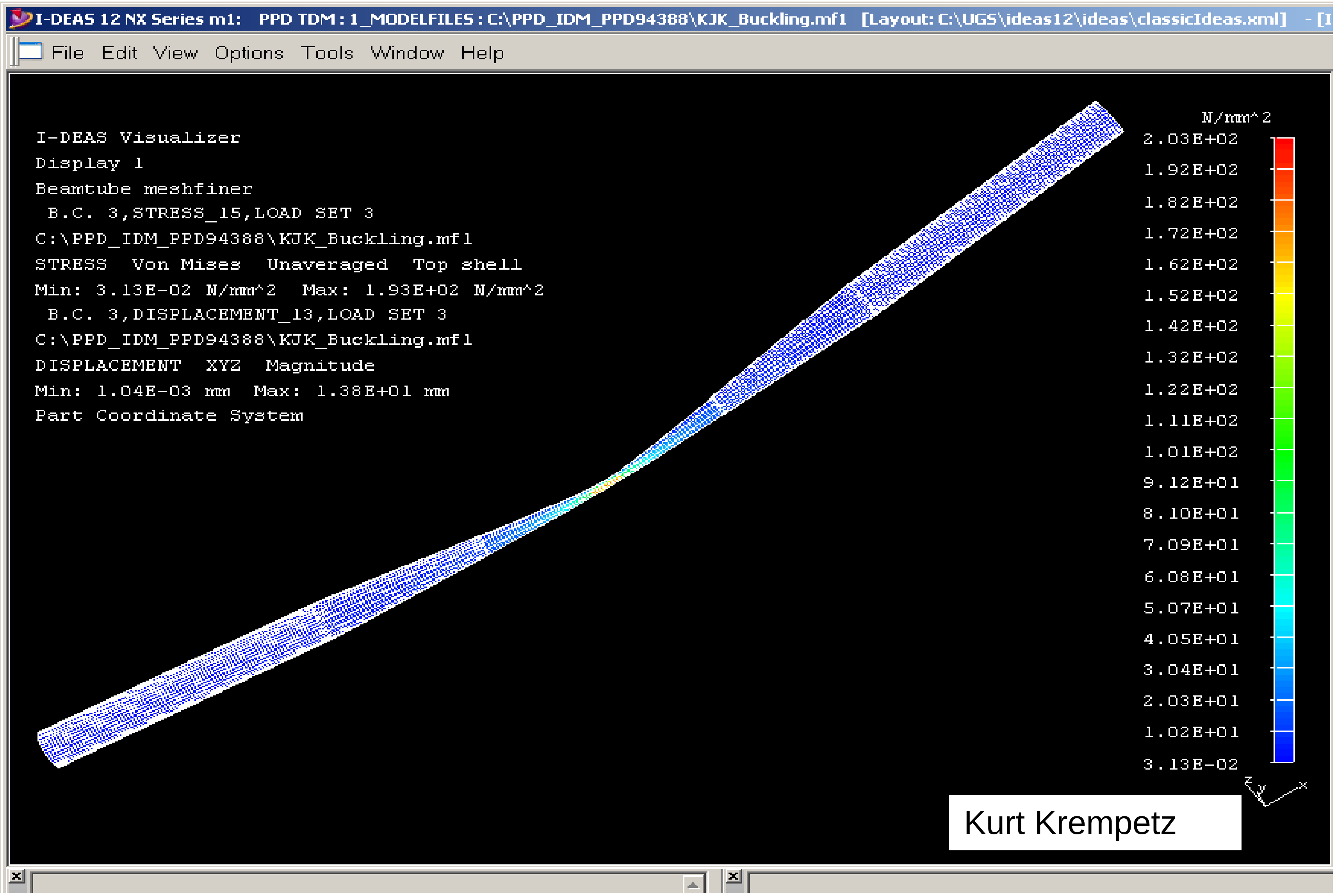
Engineering issues

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

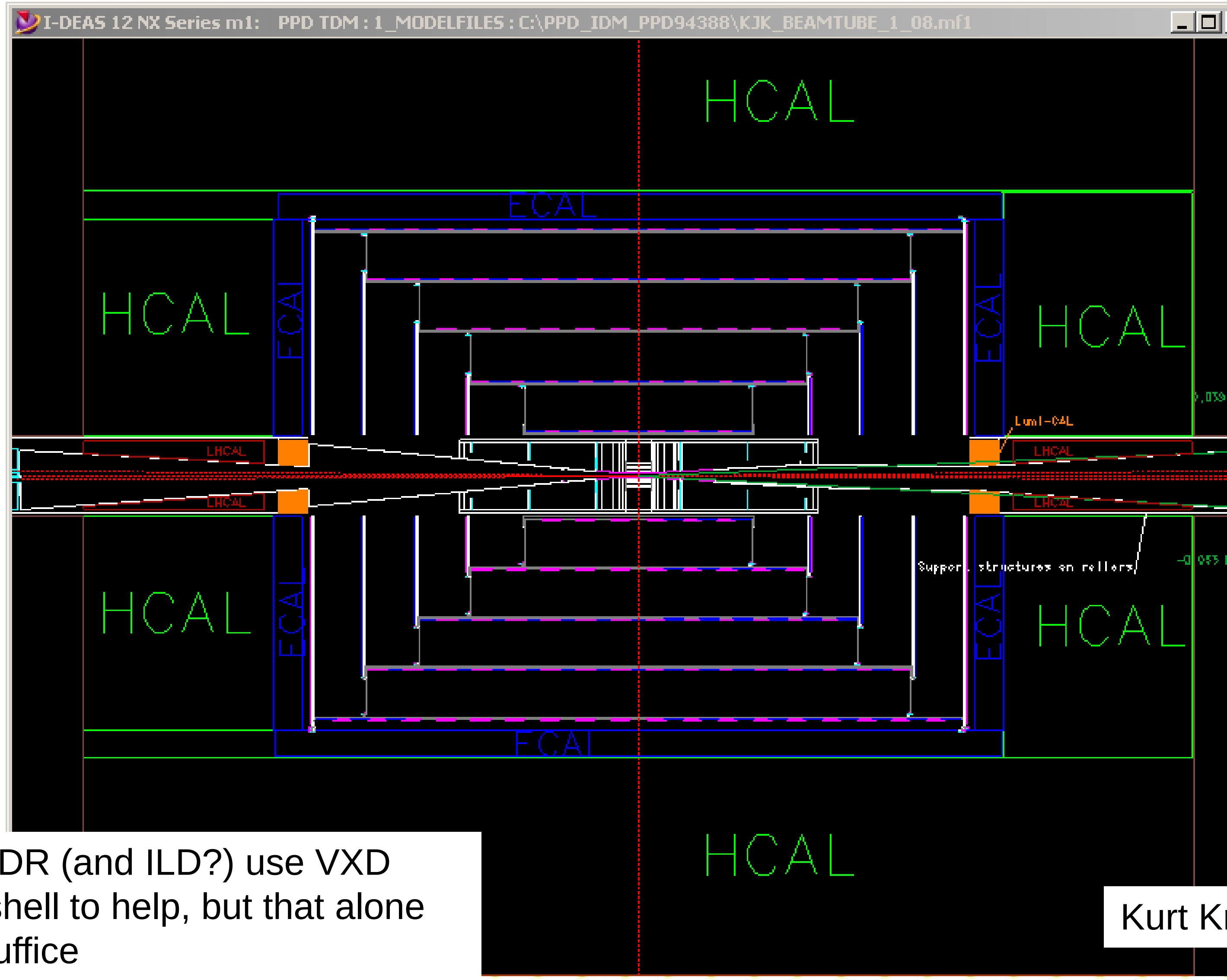
- **Long barrels vs short barrels+disks**
  - **will take a few more years to decide**
  - **excellent that two concepts for LOI have different opinions**
  - **serial powering will work in favour of short barrels+disks**
  - **there will of course be fwd pixel disks – issue is whether inner ones should 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 upgrade possibilities later**

- **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-with Vertex Detector



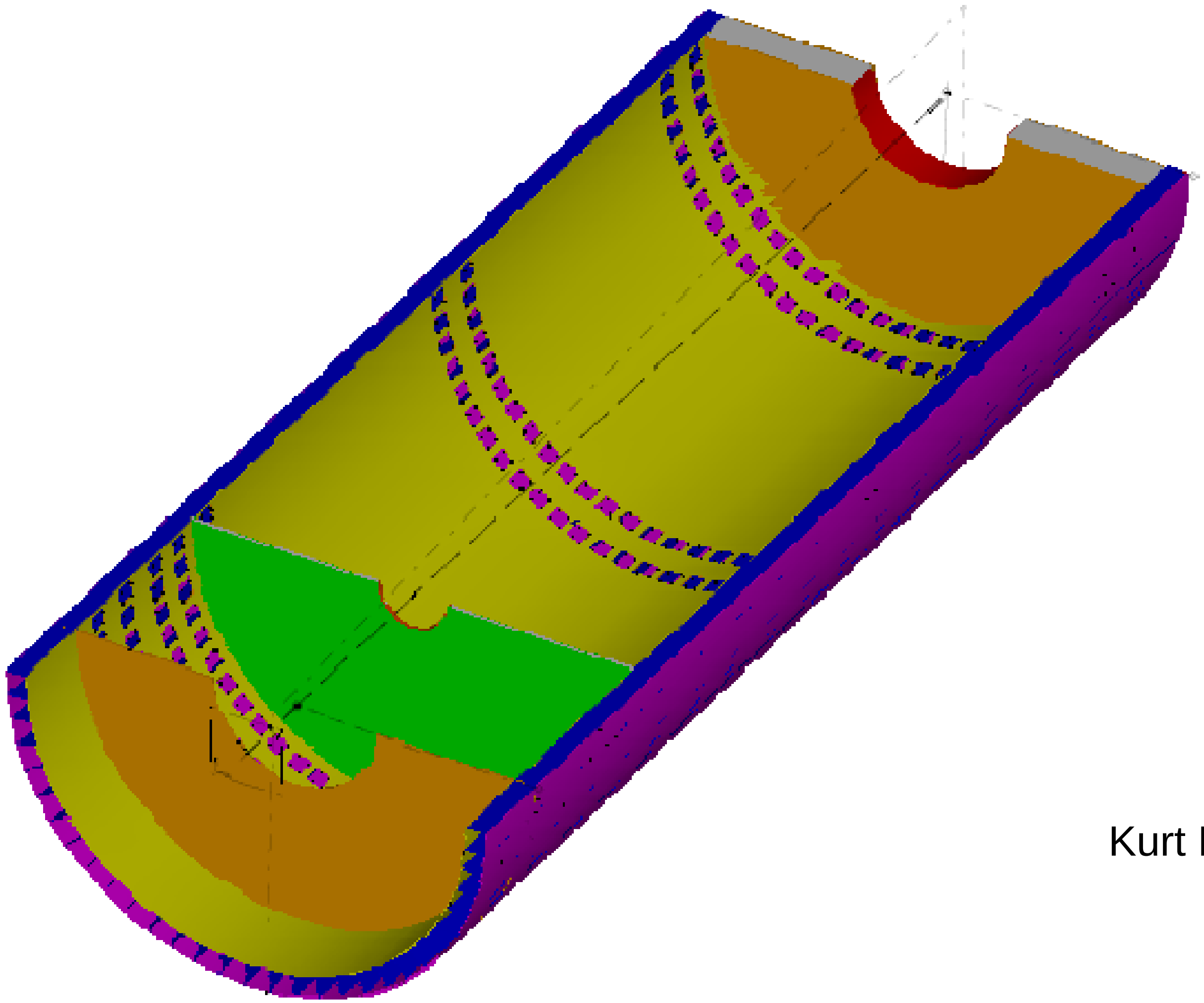
Other Beam Tube Proposals



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

Kurt Krempetz

Vertex Detector/Beam Tube Support Exoskeleton



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 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**

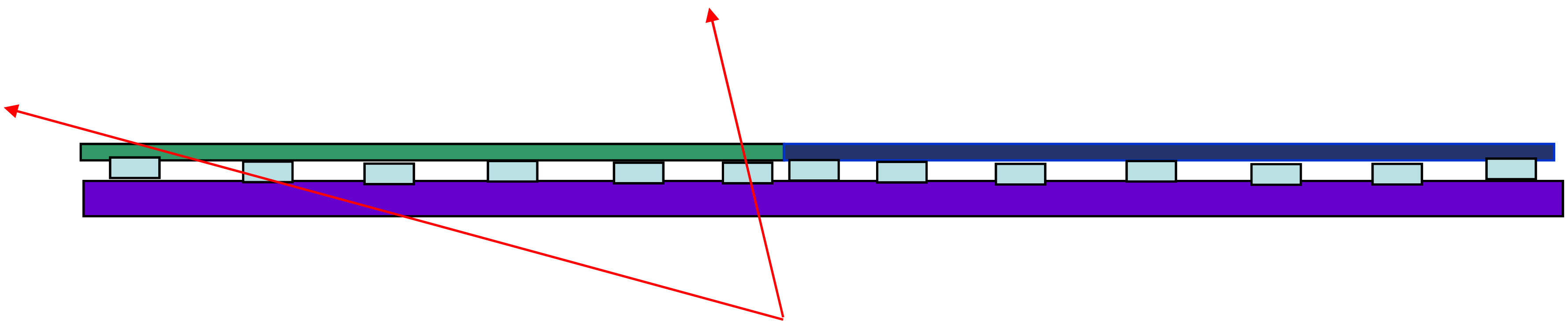
- **Fabrication of nested barrels**
  - **2 approaches – monocoque or separate ladders**
  - **don't need to make these assemblies easily demountable**
  - **SLD's 307 Mpixels comprised 60 ladders, and experienced *zero* failed pixels**
  - **assembly procedure can decide sequence (layers 1-5 or vice versa) and sensor orientation (inward or outward facing)**

- **Sensor attachment to substrates**

  - **thinned sensors will be bowed, hence require 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 sensor ends in SLD were negligible for polar angles near 90 degrees, but not at ends of angular coverage**



  - **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 systems 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 cabling 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 (mu-pairs just as useful as at LEP/SLD, though not precisely back-to-back) is then purely to relate these two stable systems to each other, which is easy**
  - **no need at all for Z-pole running for mechanical alignment**
  - **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

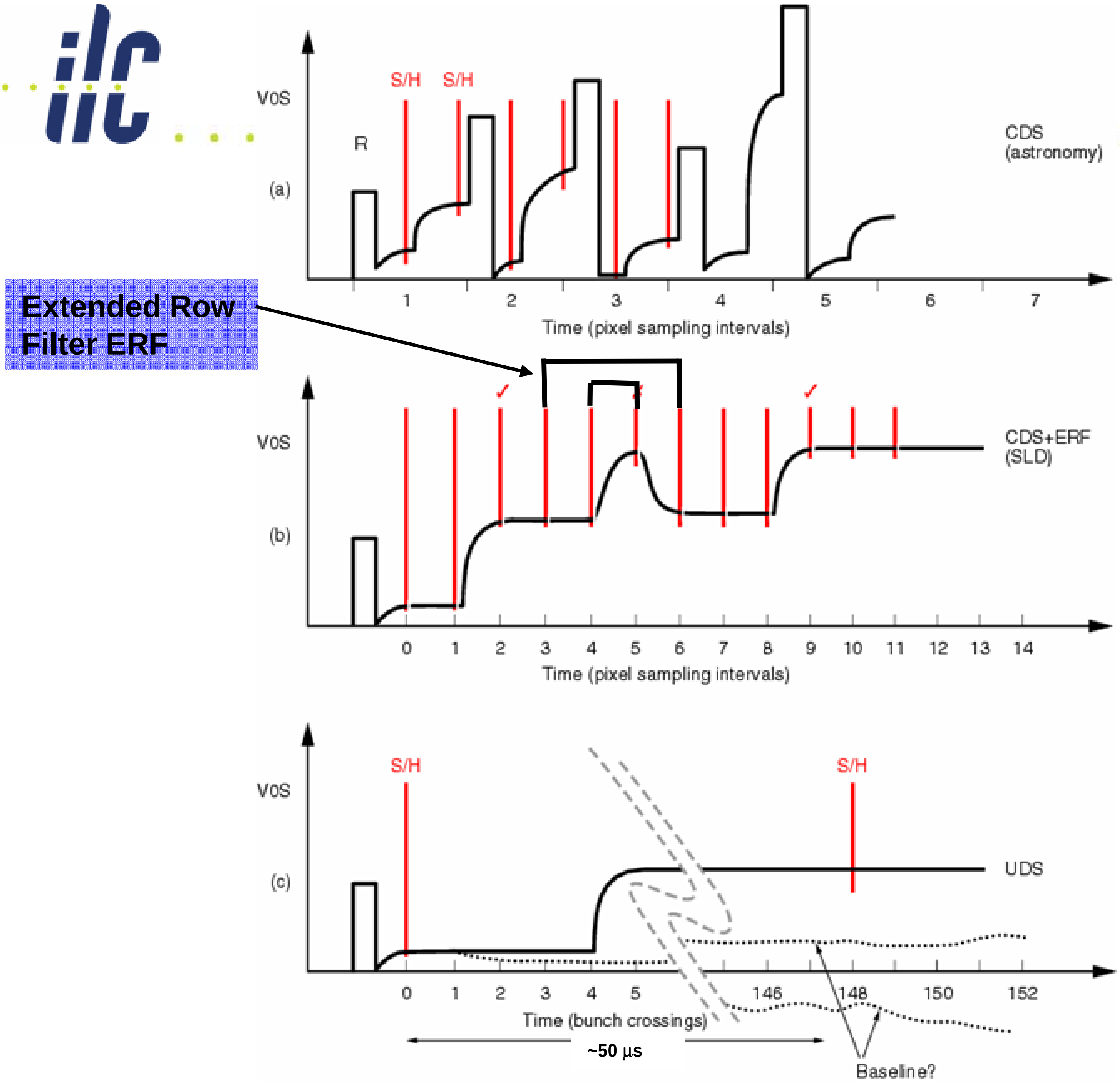
Electronics – shared issues

- CDS and ERF. Several technologies need to think more about it – could have significant power implications
- Power and cooling – serial power will help to greatly reduce material for all options. Much in common with studies under way for sLHC
- 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 ‘astronomy CDS’

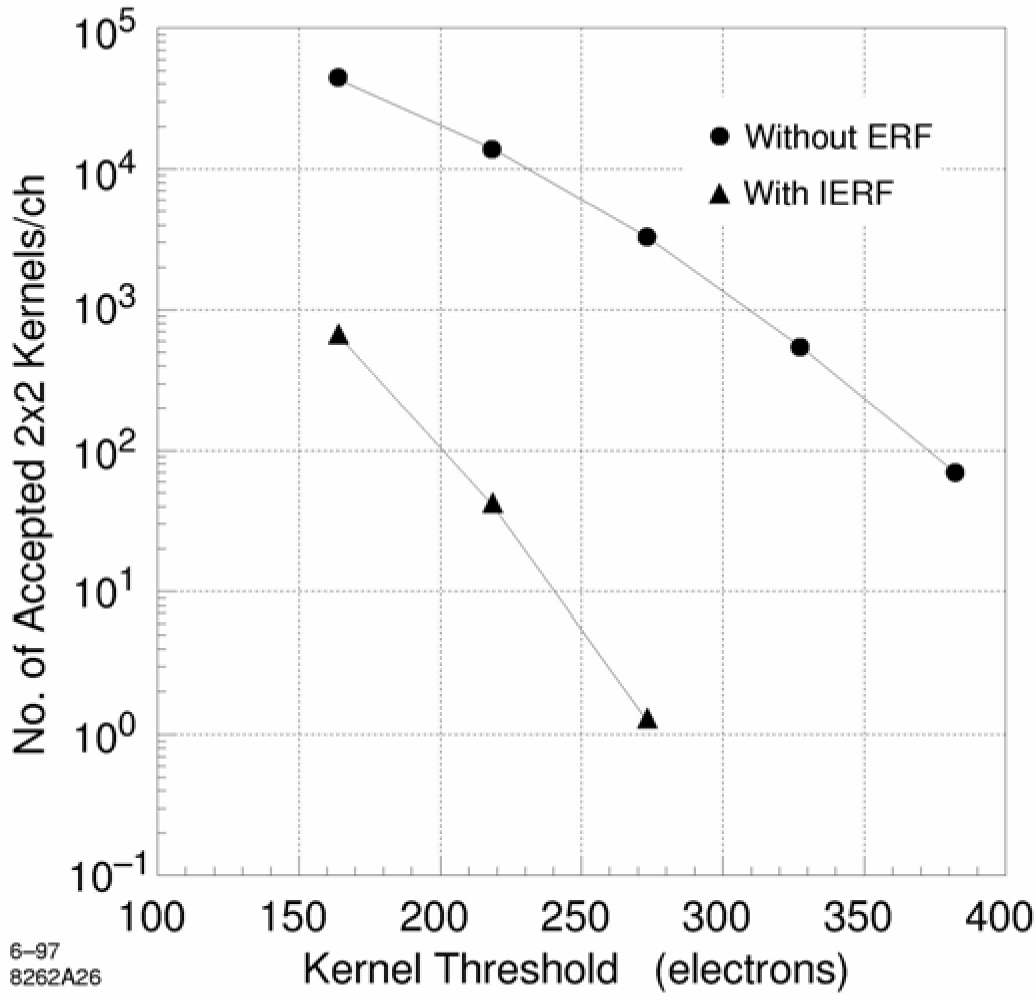
Baseline settles to a different level after each reset, due to kTC noise



‘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

Collaboration-specific recommendations

- **Please read the draft report and provide feedback.** *If you don't have a copy, ask me or your contact person*
  - **there will surely be mistakes in the text, and our delay in writing it hasn't helped**
  - **will aim to reach agreement on all points before publishing**
  - **main goal is to reinforce the case for enhanced funding over the next 5 years**
  - **If you can provide some more realistic showstoppers that keep you awake at night, that will be really helpful**
  - **Fortunately, the vertexing community doesn't contain any groups which claim to be able to now build a detector that can do the job – such exaggerated claims weaken the R&D and endanger the potential physics performance in some areas**

Technology choices

- **The ILC community should not rush – need to wait for fully serviced ladders in test beam, except where groups decide themselves to give up**

It's much too early to 'pick winners'

- Past experience provides a warning …
- SLC Experiments Workshop 1982 (just 8 years before physics startup)

•Fortunately, they didn't then take a decision

- Now move on just two years …

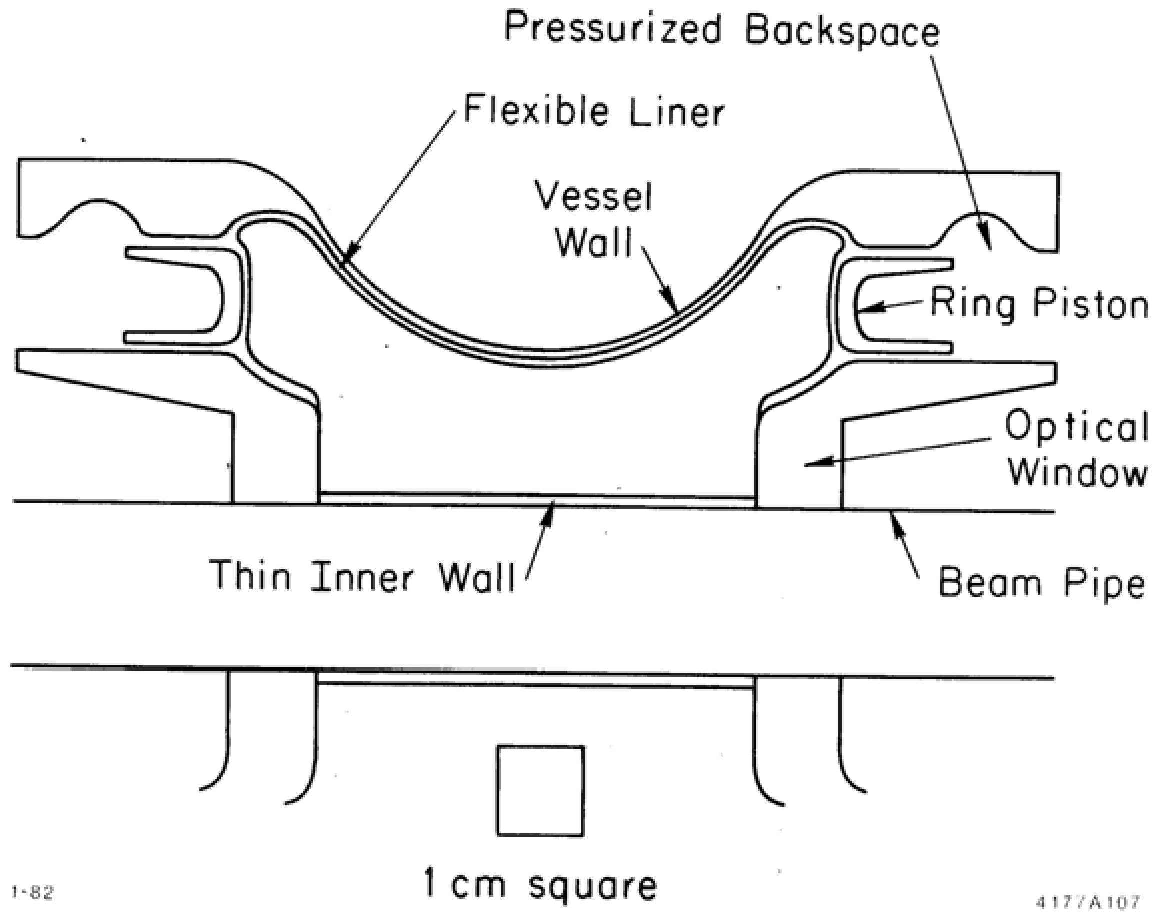
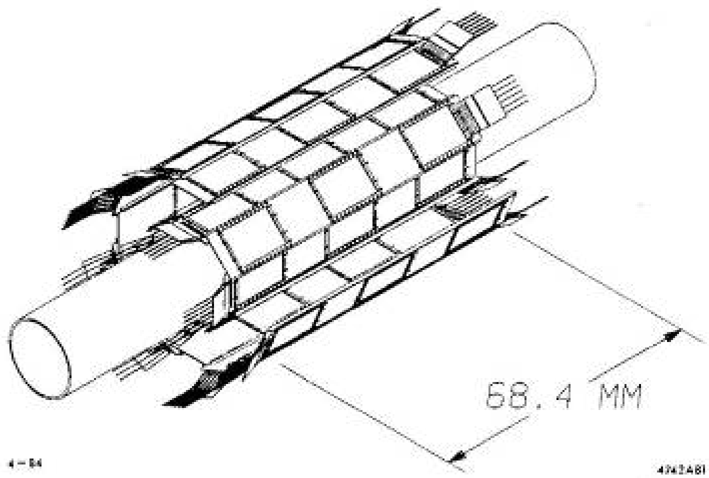
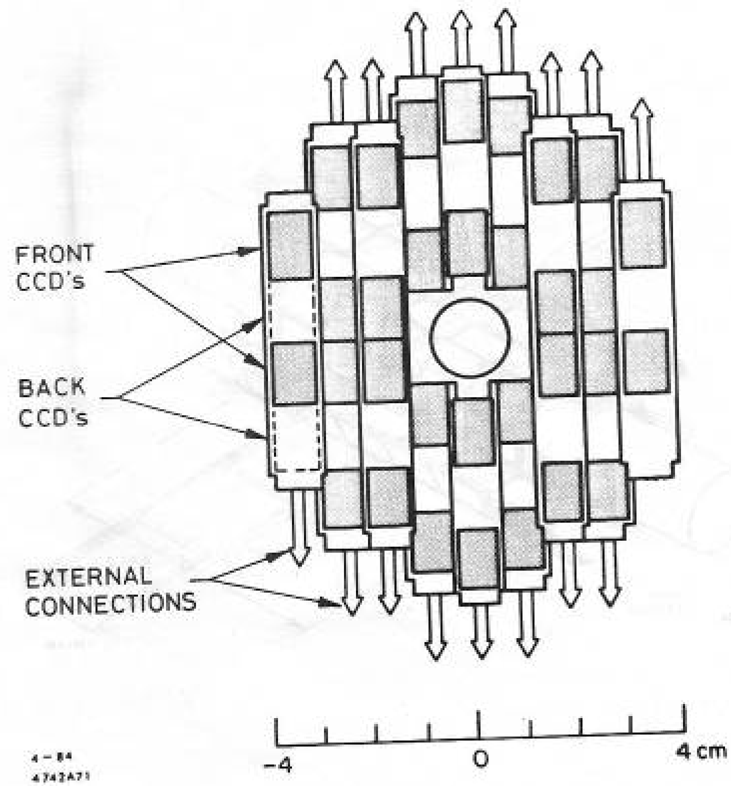


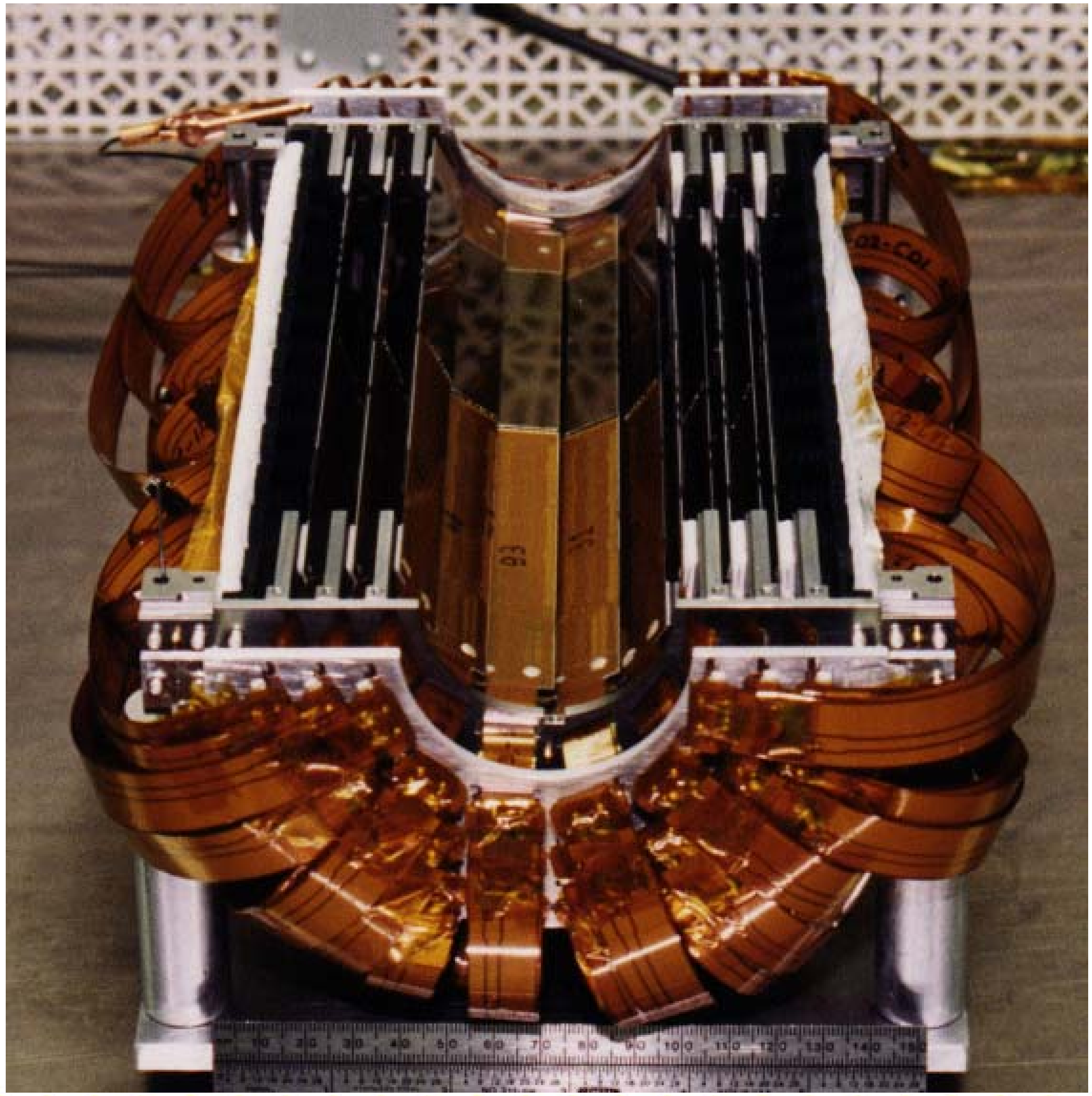
Fig. 7. Conceptual design of a propane bubble chamber vertex detector.

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



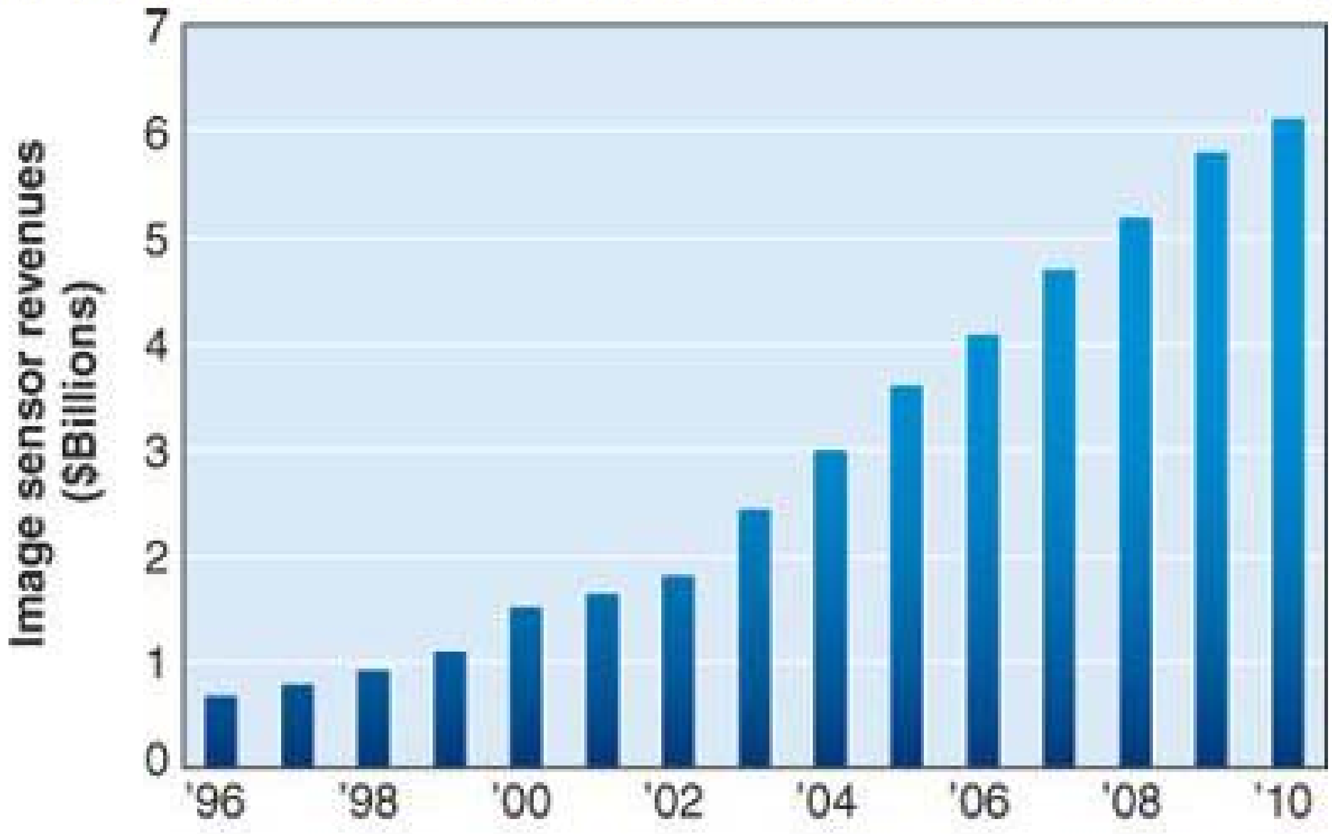


- **What was installed in 1993**
- **Ladder supports, connectors and services tipped the balance in favour of *long barrels without endcaps***
- **However, these end-of-ladder components can be greatly reduced in future, so the balance may change**



Common 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 suggest setting this up via the Vertexing Coordination Group (VCG, details on Slide 32). One of their first jobs will be to find a lab prepared to host this for ~5 years (CERN or Fermilab) and work together to build up these resources

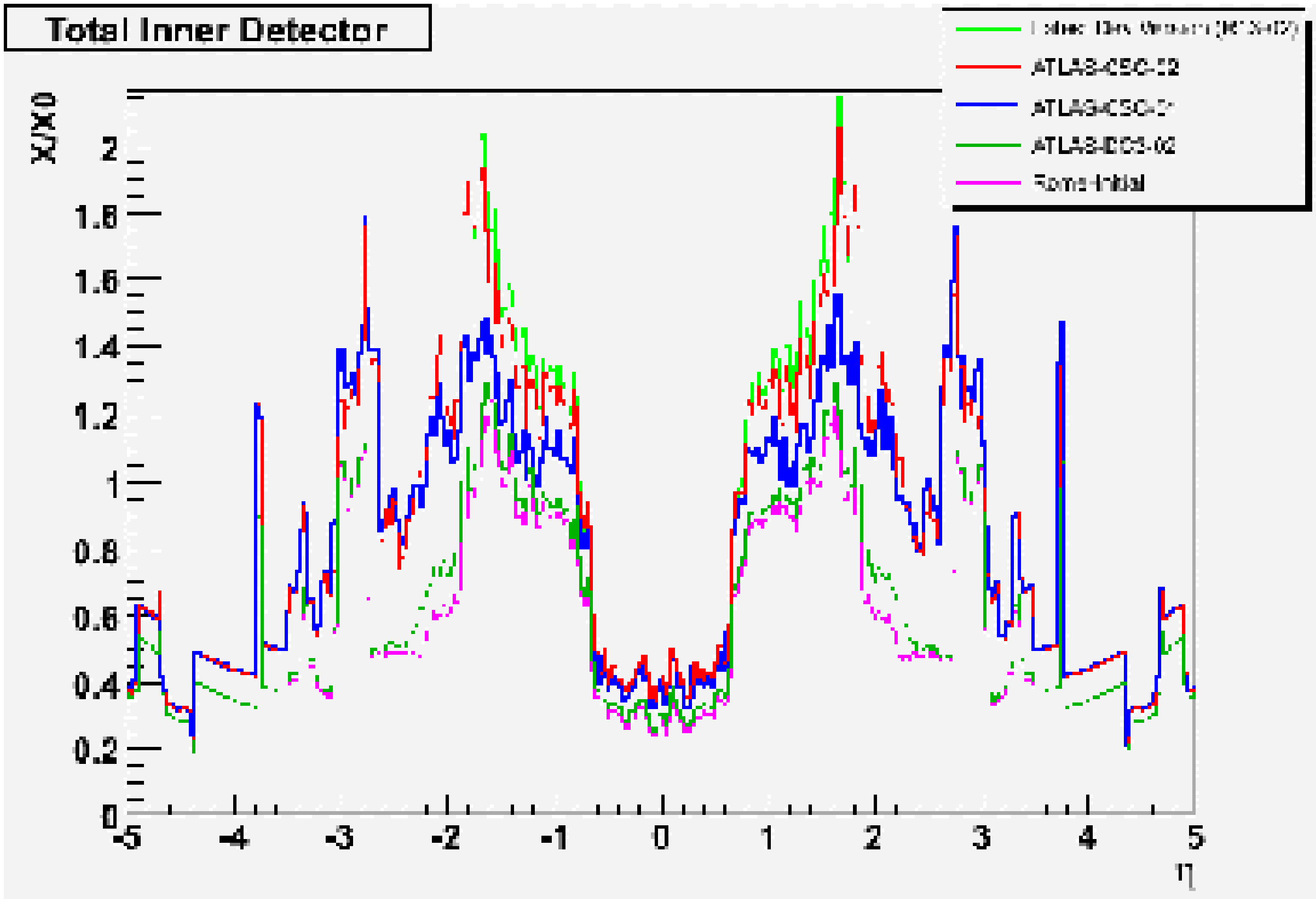


As with developments in microelectronics, we (the particle physics community) are now small fish in a very large pond.

Recent fallout from the tracking review

- **We reviewed the LCTPC, CLUCOU, SiLC and SiD tracking R&D collaborations**
- **We were extremely impressed by the R&D programmes of all these groups, in some cases with very limited resources**
- **However, we concluded that we are currently far from the goals, for all tracking options**
- **Building a tracking system with excellent performance for θ_p >7 degrees will be challenging.** ***Never achieved before and feasibility is not yet demonstrated***
- **Forward tracking has generally performed badly. We all know the solution (drastic reduction in material budget) but** ***can this be achieved in practice?***

Lessons from LHC (ATLAS)



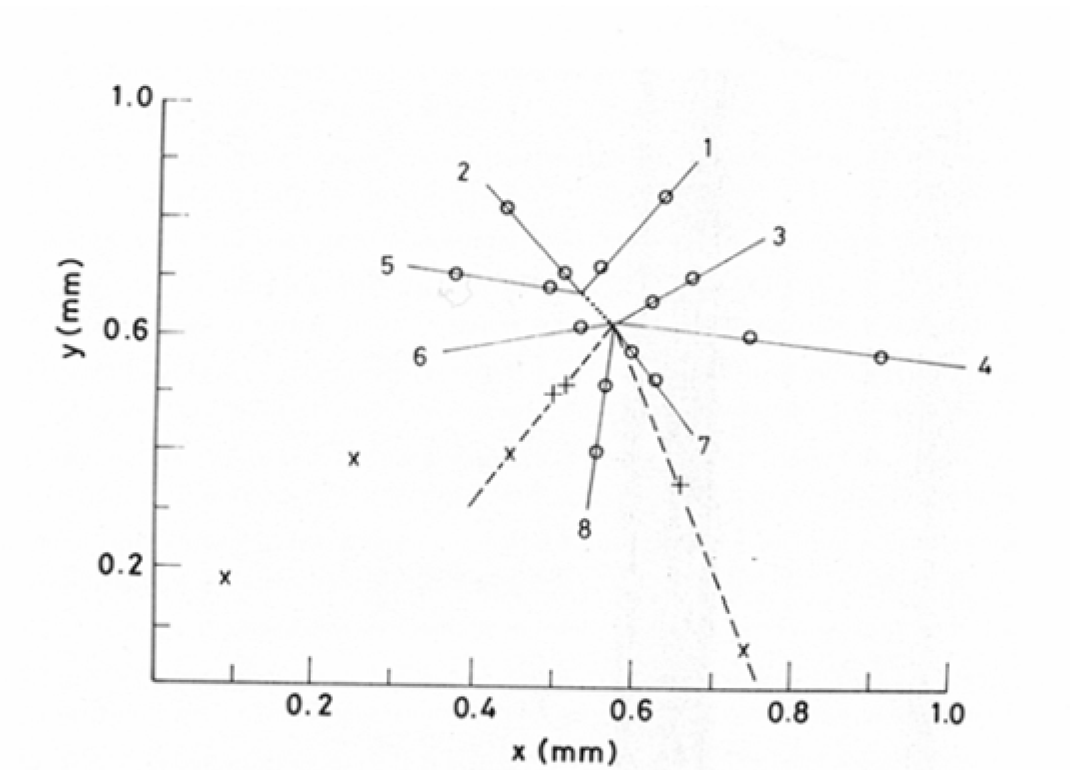
When last I asked, it was 'still increasing'

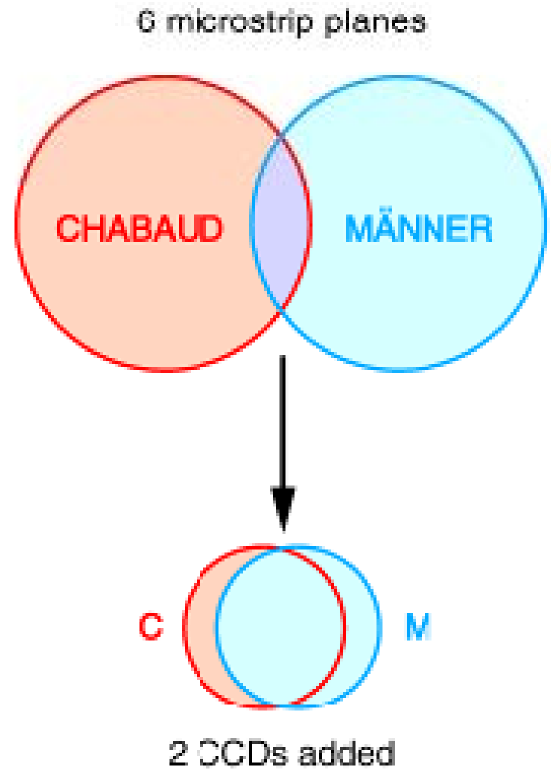
Contrast central and fwd J/psi reconstruction

A new idea – Silicon Pixel Tracker

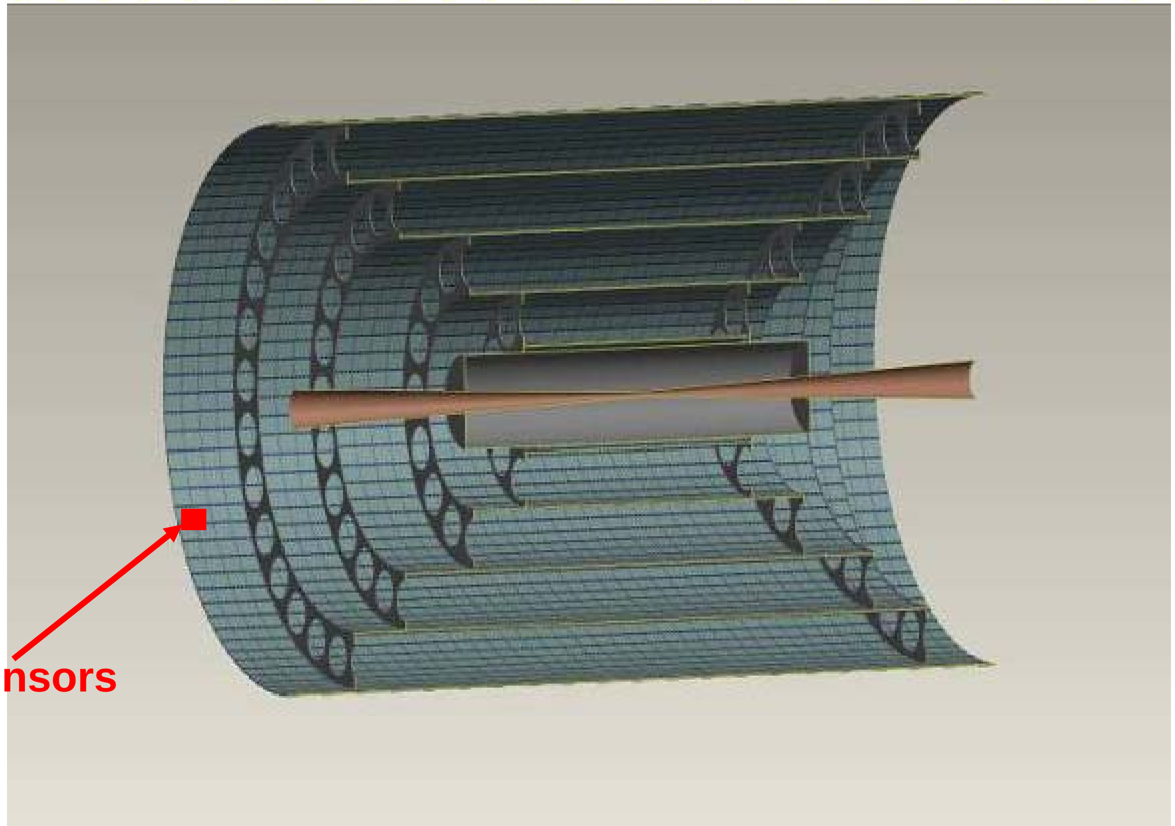
- **The most serious concern of the committee was the material budget, particularly how badly this might degrade the forward tracking:**
  - **For TPC tracker, can the endplate thickness really be reduced to 'well below 0.3 X_0', say to 0.1 X_0? Our expert consultants were doubtful**
  - **The drift chamber could probably be made thinner, but will it provide robust track finding for high energy jets? Detailed simulations needed**
  - **For a silicon strip tracker, everyone now agrees that the 'momenter' concept is flawed. Will 5 single-sided layers (barrel or disks) suffice, or will there be serious pattern recognition problems, for example for high energy jets containing long-lived Bs, necessitating more layers and hence more material?**
- **Ongoing discussions with our consultants led to a new suggestion – a silicon pixel tracker (SPT) which could deliver excellent pattern recognition for tracks in high energy jets, with very little material over the full range of polar angles**
- **A preliminary study of this idea by Konstantin Stefanov looks promising – see his two talks in the recent Asian regional ILC workshop at Tohoku U: http://www.awa.tohoku.ac.jp/TILC08/**

- **A pixel tracker provides far more information per layer, is entirely free of ghost hits, and has a proven record for excellent pattern recognition compared to microstrips in high multiplicity jet-like events (ACCMOR Collaboration, mid-1980s)**





200 GeV 'jets', Clean pattern recognition by two pixel planes 1 and 2 cm from the IP



one of 11,000 sensors
8x8 cm^2

- SiC foam support ladders, linked mechanically to one another along their length
- 5 closed cylinders (incl endcaps, not shown) will have excellent mechanical stability
- Major reduction in material for services, by using a radially varying sensitive window matched to the bgd
- Can probably integrate through entire train for R>~30 cm
- ~0.8% X_0 per layer, 4.0% X_0 total, over full polar angle range
- One obvious question: is a 30 Gpixel system realistic?

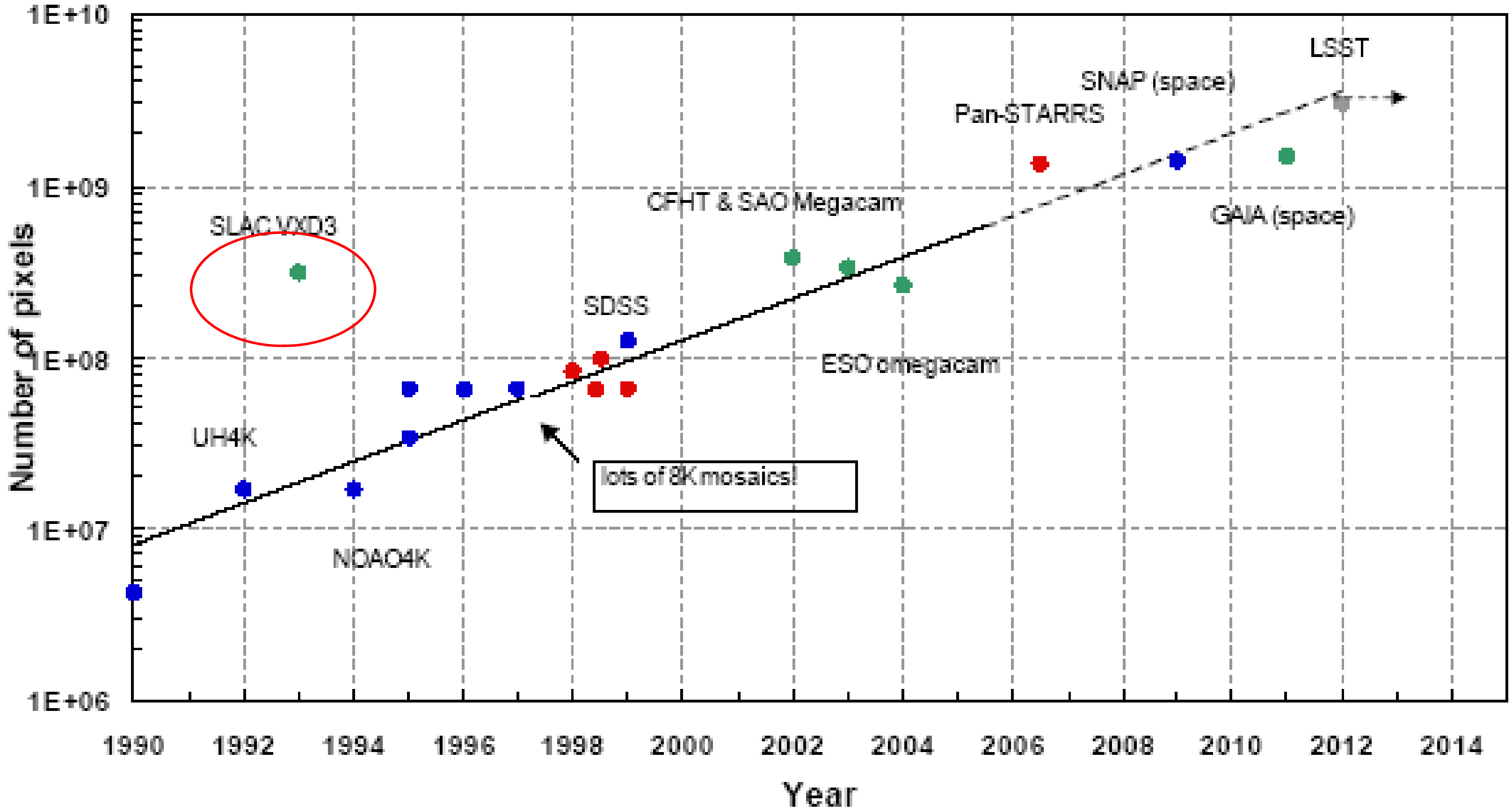
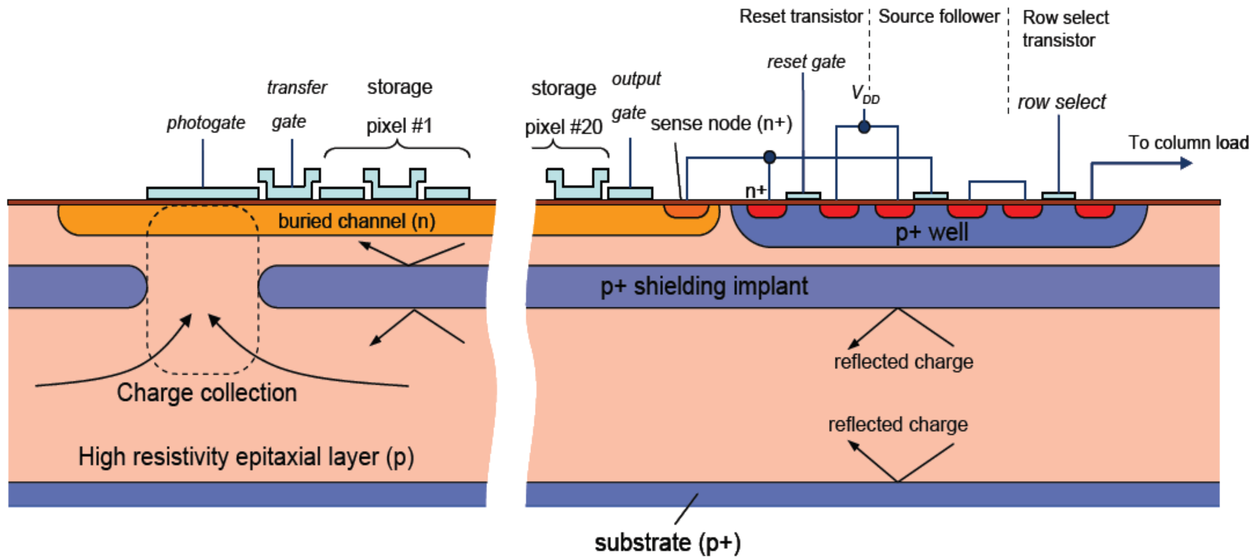


Illustration of focal plane sizes, from Luppino/Burke 'Moores' law

Focal plane size doubles every 2.5 years

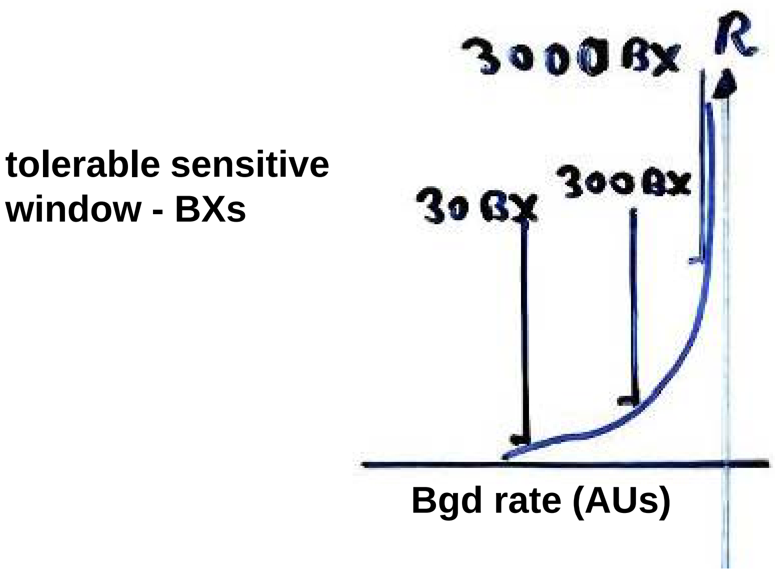
From: Burke, Jorden, Vu, SDW Taormina 2005

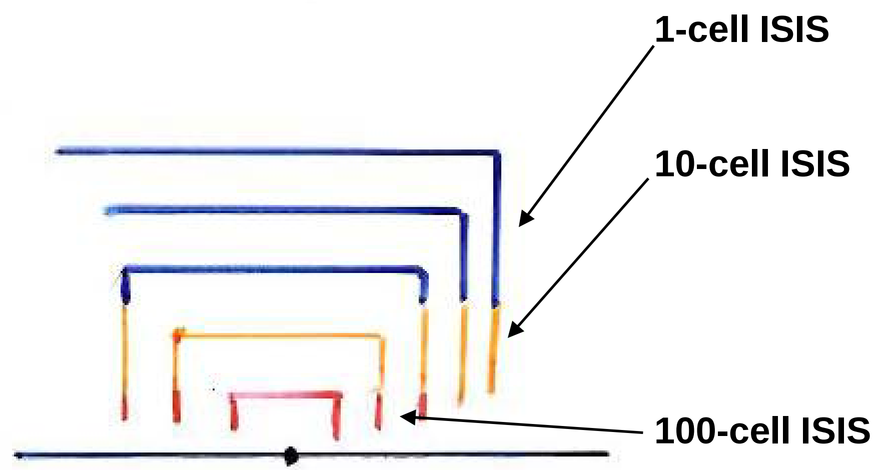


Operating principles of the ISIS:

- Charge collected under a photogate
- Charge is transferred to N-cell storage CCD in situ, N times during the 1 ms-long train
- Converted to voltage and read out in the 200 ms-long quiet period after the train (insensitive to beam-related RF pickup)
- For SPT, 50 µm pixels with binary readout will suffice
- Proof-of-principle ISIS-1 (e2V) worked fine, small-pixel version ISIS-2 now going for production with Jazz Semiconductors

Posible application to ILC tracking system





- **during bunch train, quiescent, collecting charge, with occasional advance to next storage cell**
- **between bunch trains, read with on-ladder local sparsification of data from each sensor**
- **Precise timing (to single bunch level) is provided by cluster in ECAL. This will be recorded for *EVERY* track, even the lowest p_T**

Detector R&D: organisational considerations

- We were encouraged by the success of the task-forces that provide world-wide coordination of the ILC accelerator R&D, to wonder about the utility of Coordination Groups (TCG, CCG, VCG, TBCG, …)

- NOT some external body (like the Review Committees) but one or two 'insiders' from each R&D group, plus (where relevant) cross-members from other CGs (notably the TBCG). Maybe one member of each to be a member of the R&D Panel

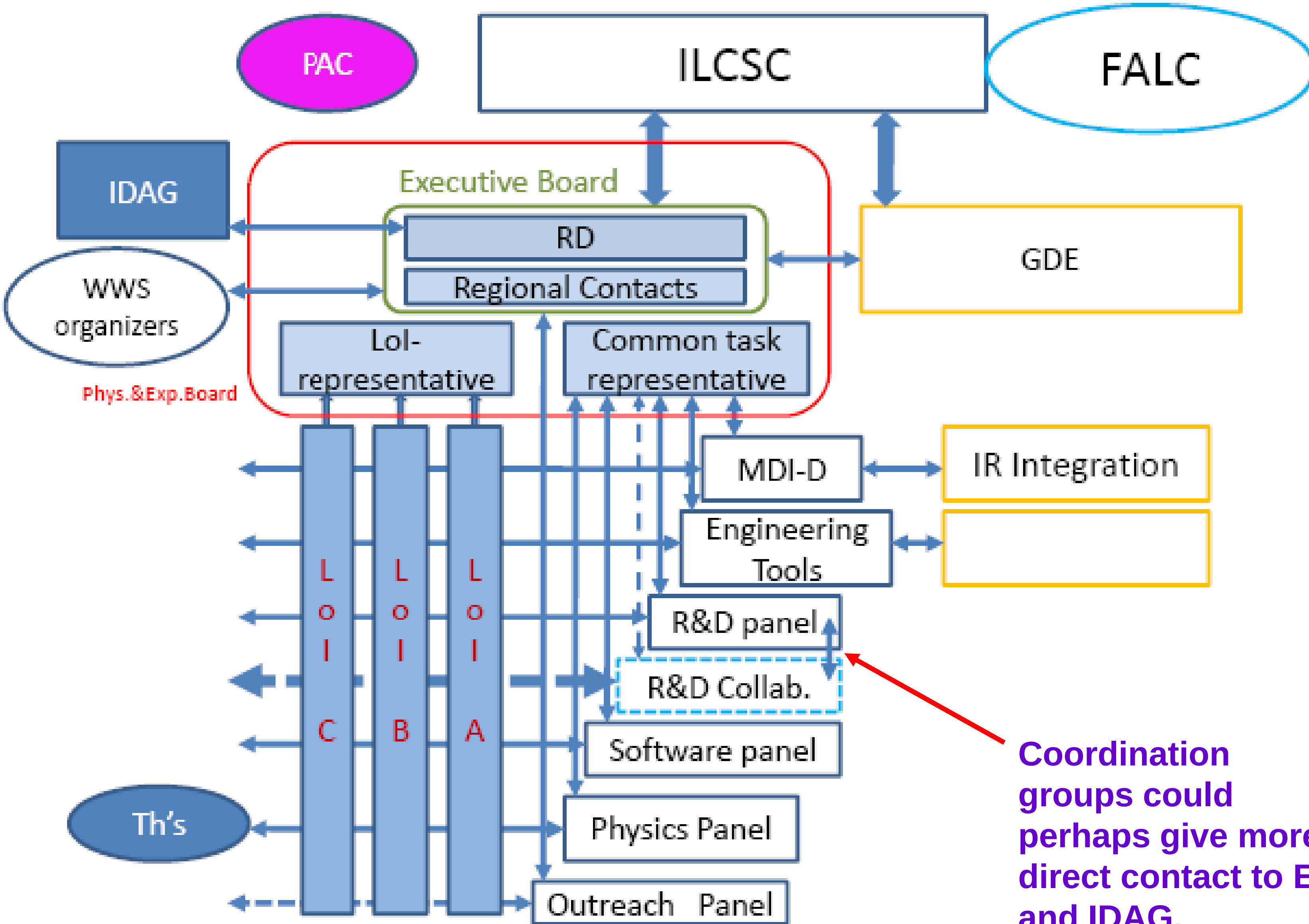
- They *would be free to work out their own charge,* within some very general guidelines, possibly including the following:
  - Negotiate for appropriate funding for shared infrastructure, coordinate the use of these facilities, and ensure objective evaluation and presentation of the test results

- An important by-product would be that these individuals would rapidly become *THE* experts on all aspects of the world-wide R&D for their detector system, and hence become a valuable source of wisdom in the community (eg Lutz Lilje on current status of SCRF cavity R&D world-wide)

- The *choice of technologies* will as usual eventually be made by experiment collaborations, but the CGs would aim to *inform* those decisions in the most objective way possible

- Note the not-entirely supportive reaction of some in the tracking and calorimetry communities, in contrast to unanimous support from the vertexing community. The WWS chairs passed it to the Detector Directorate, who are passing it to the IDAG ….

Jan.09,2008



Coordination groups could perhaps give more direct contact to EB and IDAG, bypassing this link

LOI Collaborations

- Not really new, rather an extension of what we have had for many years:
  - ~1996: Detector concepts: JLD,TESLA detector, NLD
  - ~2000: Concept groups: GLD, LDC, SiD, 4th
  - 2007: LOI collaborations: ILD, SiD, 4th
- This was seriously misunderstood by UK funding agency people

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 [This has now been agreed by everyone]**

- **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**

- ***Eminent Japanese accelerator physicist (not in ILC):* "The activity of the ILC seems to be much thicker in the head and thinner in the body. I mean there have been so many meetings and phone conferences. On the other hand quite a small number of people are doing the R&D"**

- **Detector Directorate and IDAG might consider whether to invite R&D groups to form coordination groups**