ILC Detector R&D

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)

*** a collection of independent minds – others on the Panel surely see it differently**

Our first year …

- Our Panel was formed at LCWS March, 2005 (Stanford U, same time as the GDE)
  - Original task: gather information on the work under way, and write a report
- Dan Peterson organised the website,
  https://wiki.lepp.cornell.edu/ilc/bin/view/Public/WWS/
- We obtained reports from all the major groups and most of the minor ones
- We produced a document *'Status Report and Urgent Requirements for Funding',* 6 Jan 2006, available from our website
- This indicated ~ $33M p.a. established, ~ $55M p.a. required for timely completion of the urgent R&D programme
- 'urgent needs' or 'unrestrained desires'? Our next job was to find out …

The detector R&D reviews

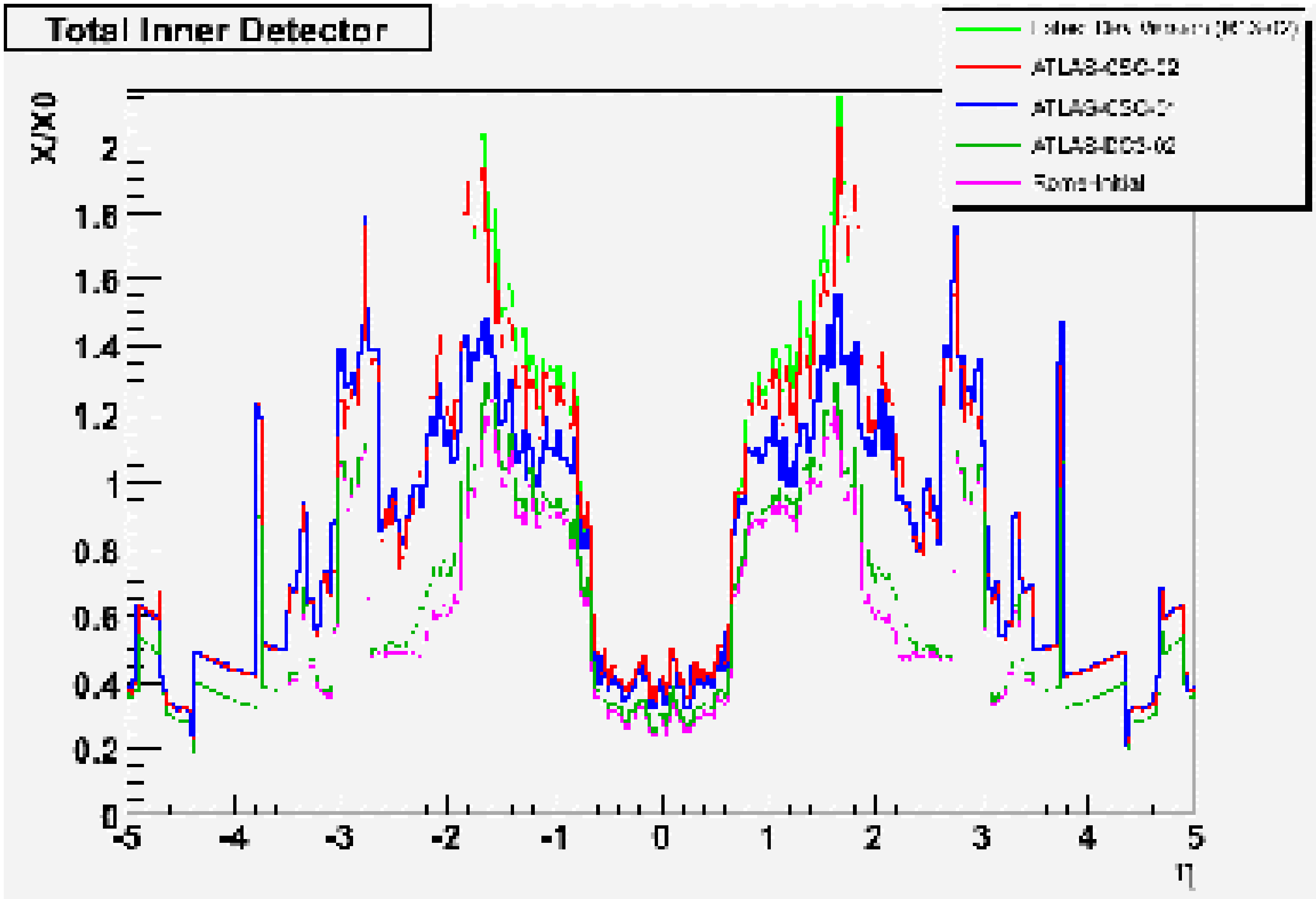
- The WWS-OC, supported by the GDE-EC, decided to initiate world-wide detector R&D reviews
- Main goal was improved communication leading to enhanced R&D programmes
- Get representatives of all R&D groups together for face-to-face discussions
- Engage world-leading consultants from outside the ILC community, who might provide new insights *– they did!*
- The *self-organising abilities* of our community were expected to lead to enhancements in the world-wide R&D programme – *they are doing so!*
- Reviews were included in regional workshops:
  - Beijing (Feb '07) Tracking
  - DESY (LCWS June '07) Calorimetry
  - Fermilab (Oct '07) Vertexing
  - Pending (if desired) PID, muon trkg, solenoid, beam diagnostics, DAQ
- Look in turn at the outcome of these reviews …

Tracking Review Committee

- Panel members: Chris Damerell (chair), Dean Karlen, Wolfgang Lohmann, Hwanbae Park, Harry Weerts
- External consultants: Peter Braun-Munzinger, Ioanis Giomataris, Hideki Hamagaki, Hartmut Sadrozinski, Fabio Sauli, Helmuth Spieler, Mike Tyndel, Yoshinobu Unno
- Regional representatives: Jim Brau, Junji Haba, Bing Zhou
- RDB chair: Bill Willis
- Local tracking experts: Chen Yuanbo, Ouyang Chun
- Admin support: Naomi Nagahashi, Maura Barone, Maxine Hronek, Xu Tongzhou

- 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. *Feasibility is not yet demonstrated*
- Forward tracking has generally performed badly. We all know the solution (dramatic reduction in material budget) but *can this be achieved in practice?*
- We became convinced of the need to construct large prototypes (~1 m diameter), and operate them under ILC-like beam conditions in a 3-5 T field, to establish what performance will be achievable at ILC, both for central and forward tracking
- Not all the R&D collaborations felt that this would be necessary

Lessons from LHC (ATLAS)



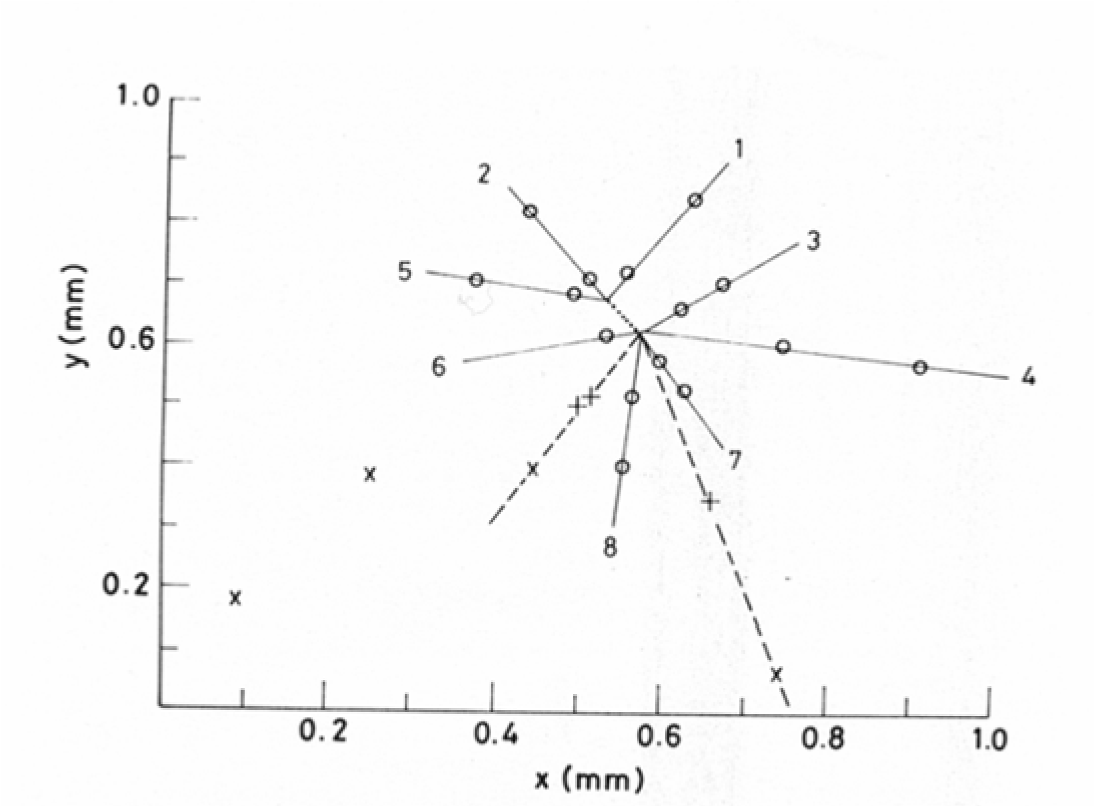
When last I asked, it was ‘still increasing’

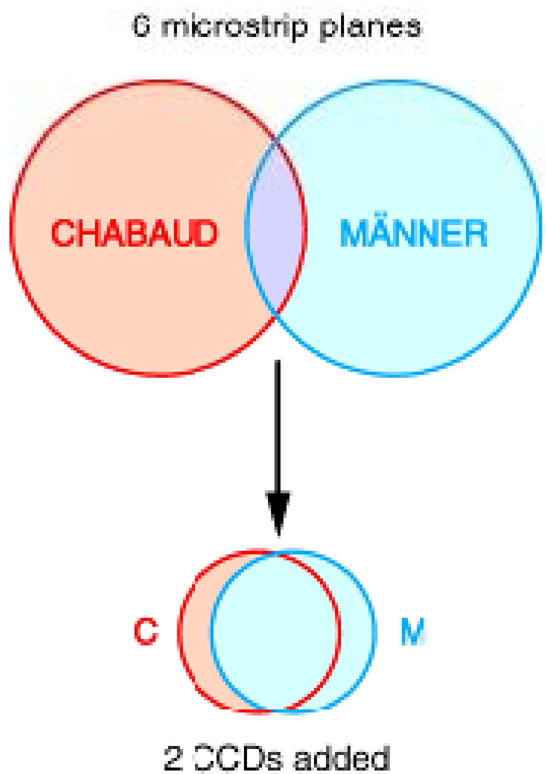
Contrast central and fwd J/psi reconstruction (Stephen Haywood et al)

A new idea – Silicon Pixel Tracker

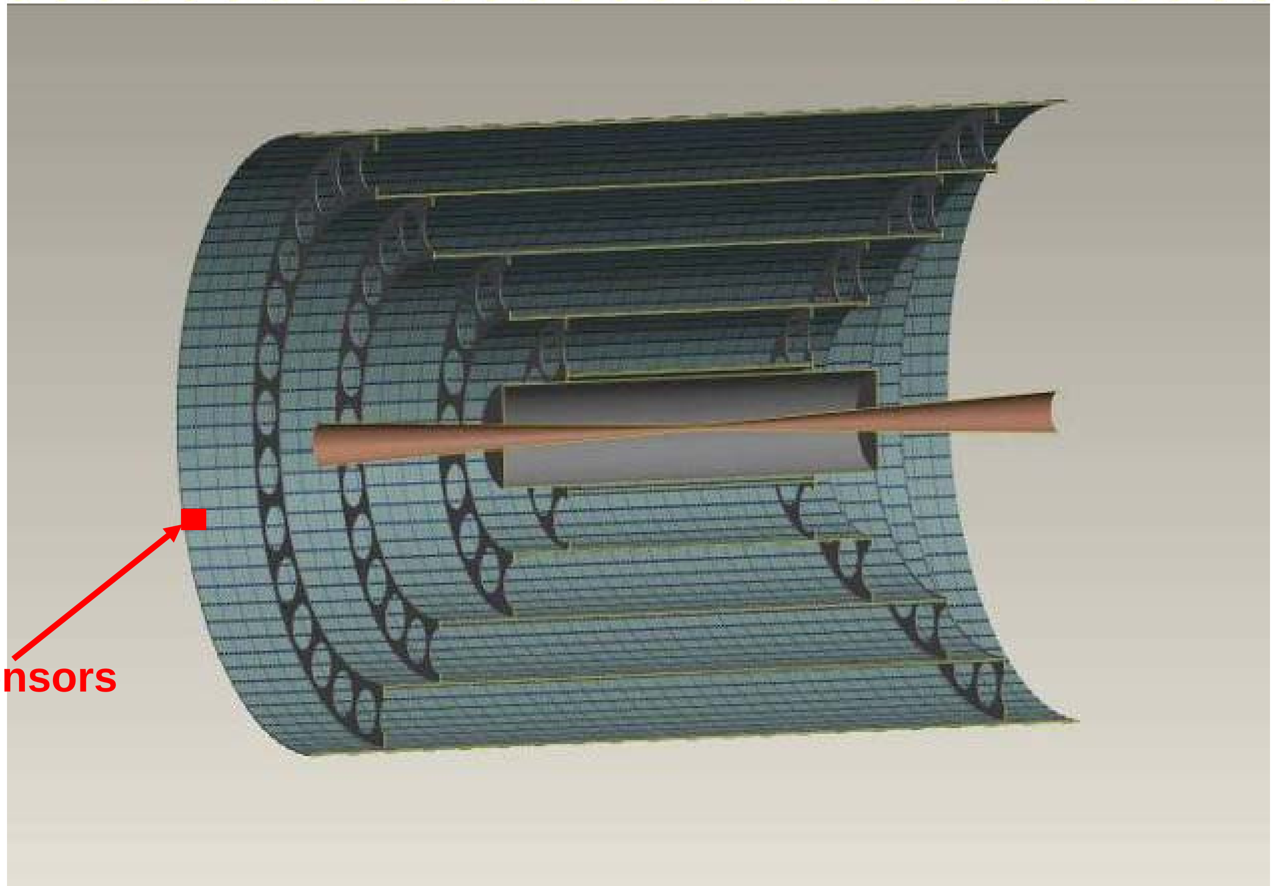
- The most serious concern of the committee was the material budget, particularly how badly this might degrade the forward tracking:
  - For TPC tracker, can the endplate thickness really be reduced to 'well below 0.3 X_0', say to 0.1 X_0? Our outside consultants were doubtful
  - The drift chamber could 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 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 talk in this workshop

- **A pixel tracker, being entirely free of ghost hits, has a proven record for excellent pattern recognition compared to microstrips in high multiplicity jet-like events (ACCMOR Collaboration, mid-1980s)**





200 GeV 'jets', detectors with 20 μm pixels 1-2 cm from IP. For ILC tracker, scale up by factor 10 or more



one of 11,000 sensors
8x8 cm^2

- **SiC foam support ladders, linked along length**
- **5 closed cylinders (incl endcaps, not shown) having excellent mechanical stability**
- **~0.5% X_0 per layer, 2.5% X_0 total, over full polar angle range**
- **The BIG question: is a 30 Gpixel system realistic?**

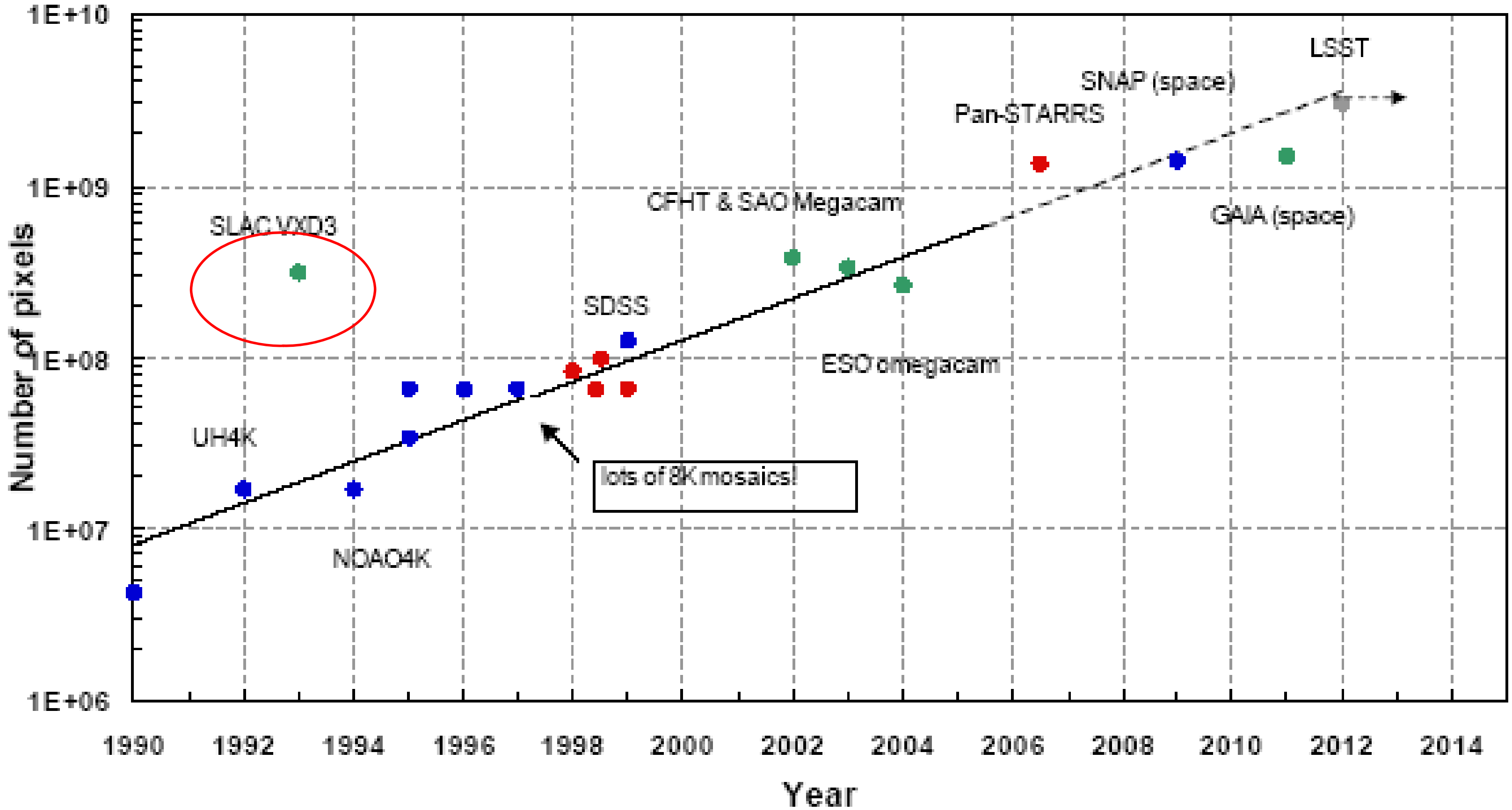


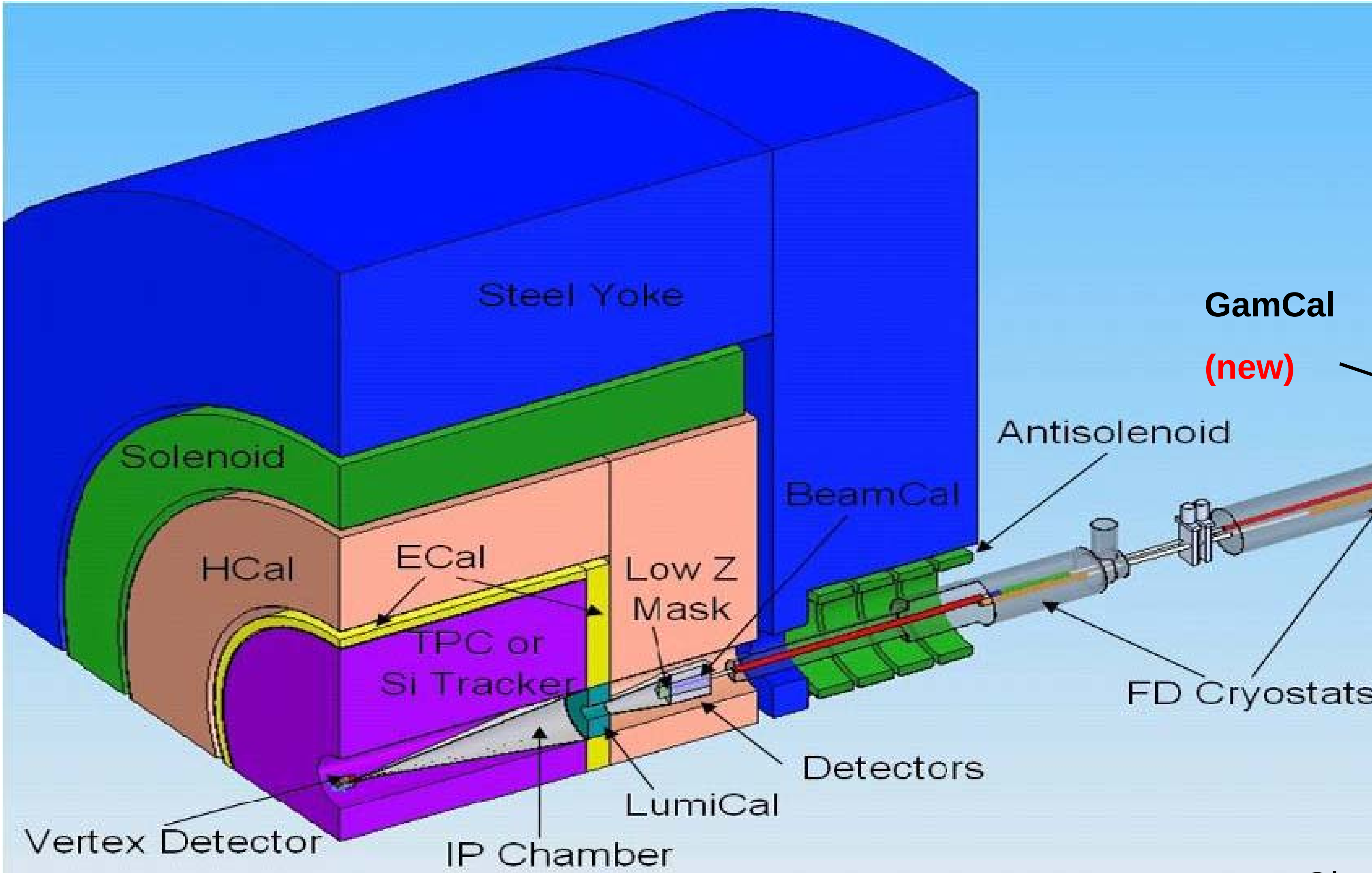
Illustration of focal plane sizes, from Luppino/Burke 'Moores' law

Focal plane size doubles every 2.5 years

From: Burke, Jorden, Vu, SDW Taormina 2005

Calorimetry Review Committee

- Panel members: Jean-Claude Brient, Chris Damerell, Wolfgang Lohmann (chair), Ray Frey
- External consultants: Marcella Diemoz, Andrey Golutvin, Kazuhiko Hara, Robert Klanner, Peter Loch, Pierre Petroff, Jm Pilcher, Daniel Pitzl, Peter Schacht, Chris Tully
- Regional representatives: Junji Haba, Michael Rijssenbeek, Jan Timmermans
- RDB chair: Bill Willis
- Admin support: Martina Mende, Naomi Nagahashi



GamCal

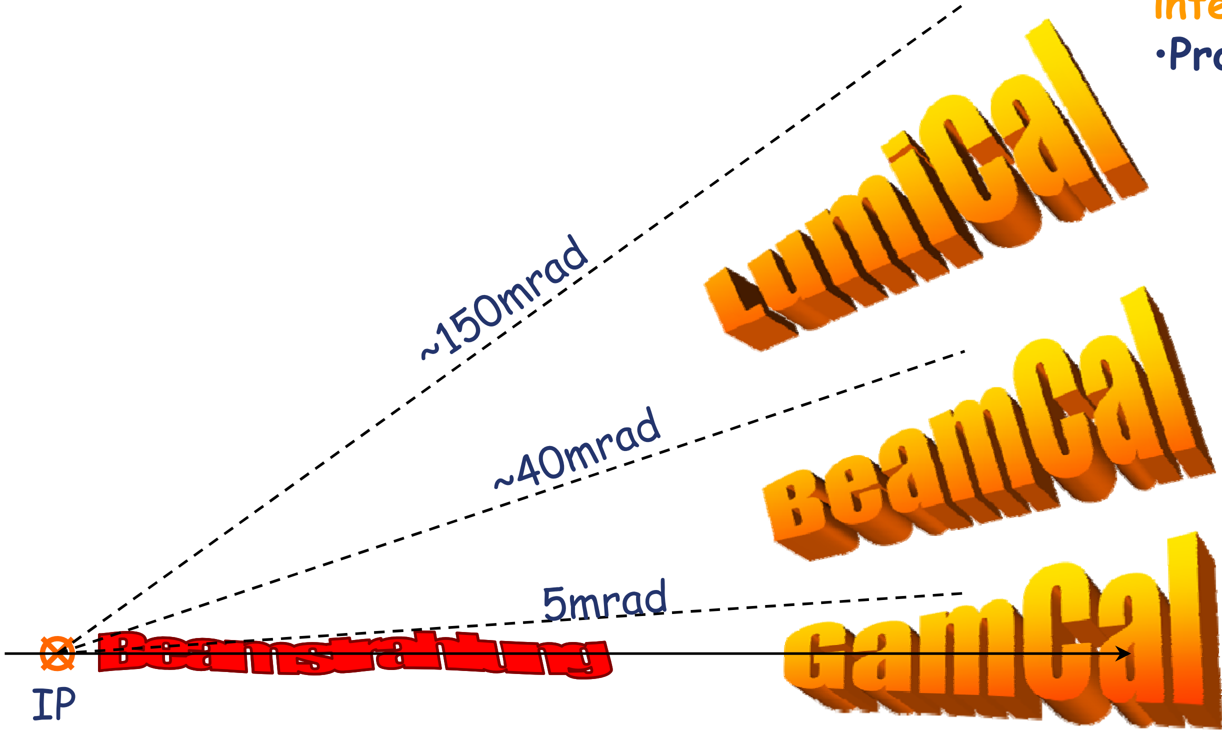
(new)

Ch Grah

Overview of the review

- **Two main categories:**
  - **Forward calorimetry (precision luminosity, hermeticity, beam diagnosics)**
    - **World-wide FCAL Collaboration (15 groups)**
  - **Doing a great job, but need additional resources, specially in USA**
  - **General calorimetry (precise jet energy measurement in multi-jet events, ΔE = 30%sqrt(E)**
    - **PFA approach: CALICE collab (41 gps), SiDCAL collab (17 gps, some in CALICE)**
    - **Compensating calorimetry: DREAM collab (8 gps), Fermilab gp**
    - **We were not able to exclude either option: much more work is required (and we might eventually need *both* to do the physics: PFA in barrel and compensating calorimetry forward)**

Tasks of the Forward Region



•Precise measurement of the integrated luminosity ($\Delta L/L \sim 10^{-4}$)
•Provide 2-photon veto

•Provide 2-photon veto
•Serve the beamdiagnostics using beamstrahlung pairs

•Serve the beamdiagnostics using beamstrahlung photons

Ch Grah

Challenges:

High precision, high occupancy, high radiation dose, fast read-out!

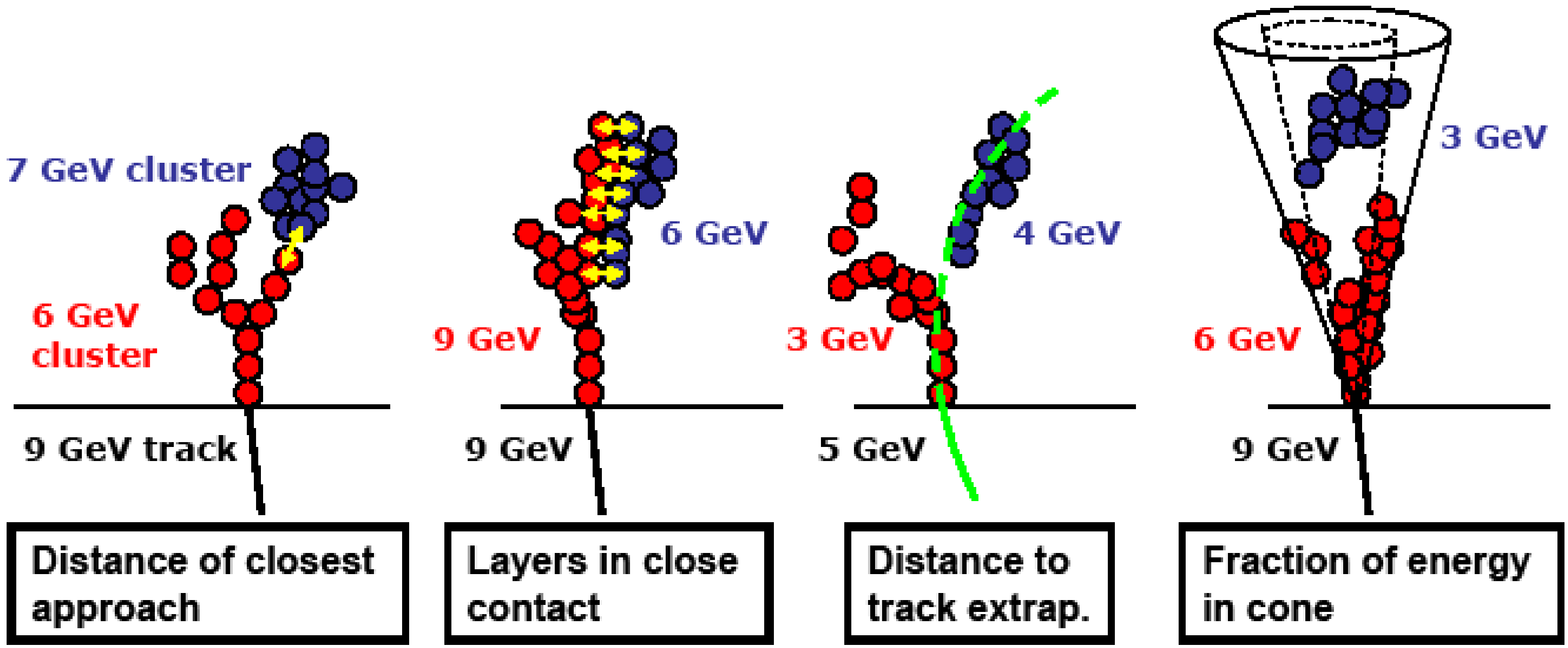
Main recommendations (FCAL)

- Impressive report – physics requirements and technical implications were clearly presented
- Design of LumiCal and BeamCal well advanced – GamCal (BS monitor) studies are at an early stage
- BeamCal sensor development profits from close collaboration with groups developing rad hard sensors for hadron machines, notably sLHC
- Need increased funding for their dedicated US collaborators (even before FY08 disaster), for travel and for system-level engineering

PFA approach to jet energy measurement

- Goal is to separate depositions from charged and neutral hadrons in the ECAL/HCAL system, particularly challenging in the core of jets
- Challenge *(confusion term)* increases with jet energy and with reduced polar angle

★ Look for "evidence" that a cluster is associated with another



Mark Thomson

- Impressive simulation results. Can they be achieved in a real system?

- If possible, obtain data from charged and neutral hadrons in 'physics prototypes'

- Even so, there's the additional uncertainty regarding the fragmentation of these high energy quark jets. Chgd/neutral ratio in the simulations could be incorrect

- Progress since our review (Jose Repond, Rajendran Raja) in establishing practical conditions for calibration with tagged neutrals (neutrons, K_L , even anti-neutrons) using the MIPP2 facility in MCentral beamline at Fermilab Problems discussed previously such as DAQ can be overcome

- Nobody is suggesting to run the detector simulations using shower libraries provided by these data

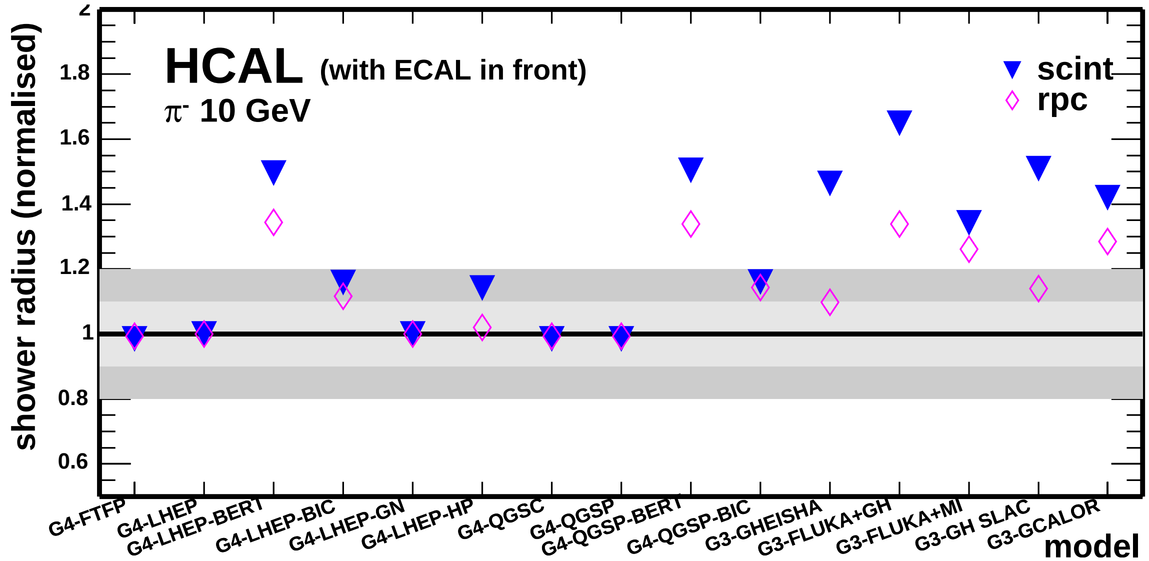
- Comparing simulated shower shapes with data, then tuning simulation parameters to match the data, is considered realistic. However such tuned simulator programs can only be used for the hardware they are tuned for in an interpolating fashion and have no predictive power for design of new systems

- MIPP Upgrade will in addition provide high statistics particle production data on 30 nuclei which will improve the predictive power of shower simulation programs significantly

- The vertex detector and tracking system can and probably will be upgraded during ILC running, but **not the coil or calorimetry** – we do need to get these right when experiments choose their technologies

Main recommendations (PFA systems)

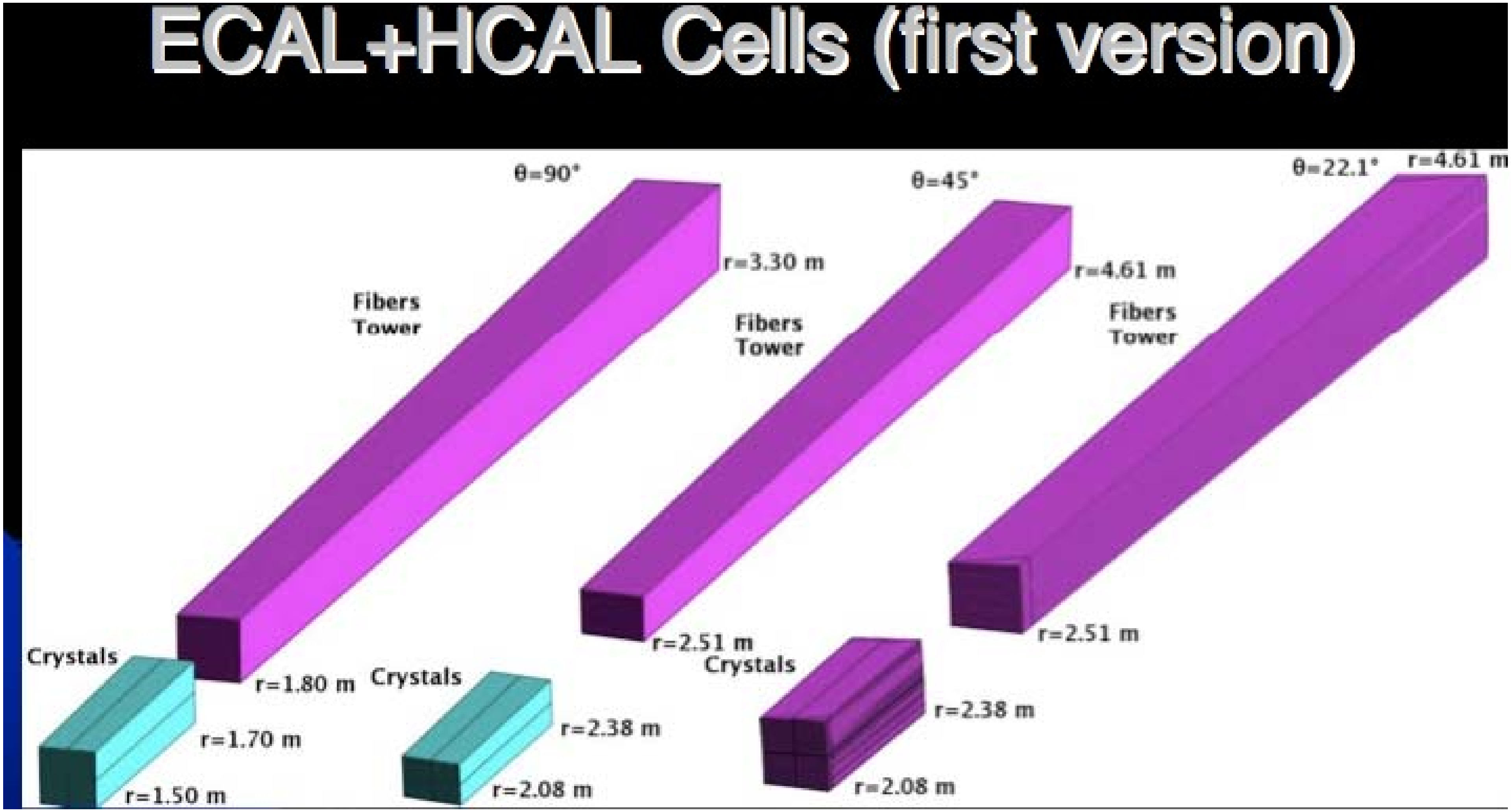
- While extremely promising, all studies to date (beyond the early experience with ALEPH and SLD) are based on *simulations,* hence subject to considerable uncertainty



- These are only the *average* shower radii. There is even greater uncertainty in the shape variability between individual showers, involving different inelastic scattering processes

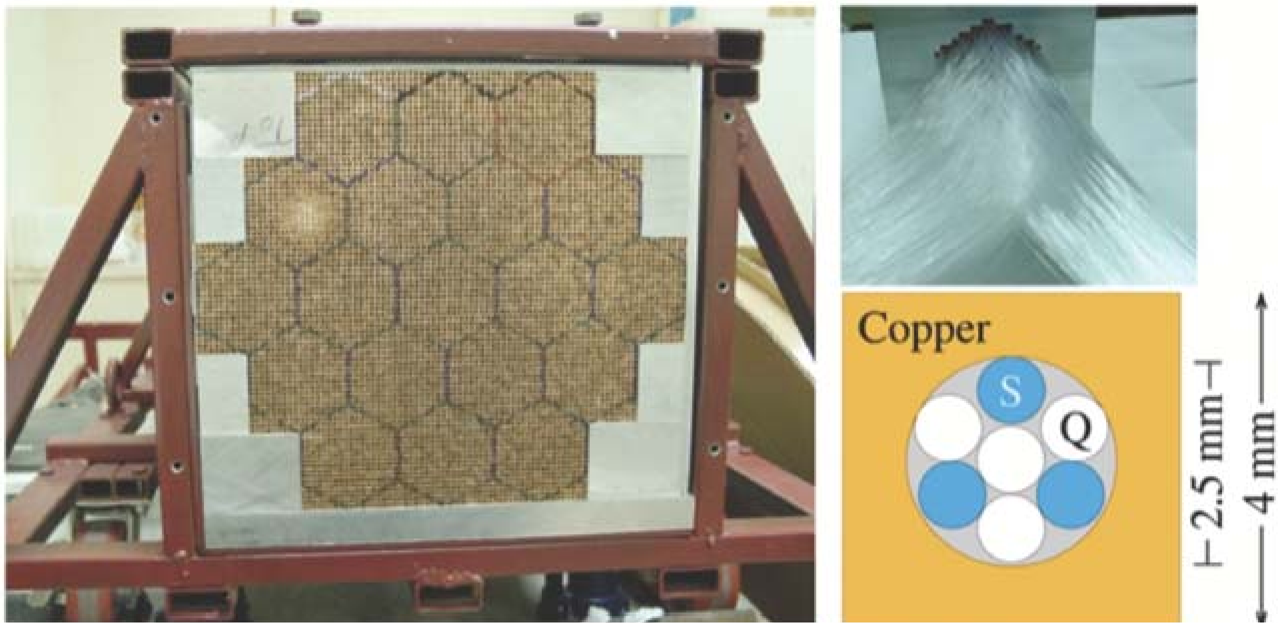
- Simulations alone cannot be trusted. Given the need to disentangle hits from charged and neutral showers, data are desirable on both, in large-scale 'physics prototypes' to:
  - Establish the performance truly achievable with such a calorimetry system
  - Establish which HCAL sensor technology (scintillator, RPCs, etc) will give the best performance

Compensating calorimetry option



Promising test beam results

DREAM: Structure

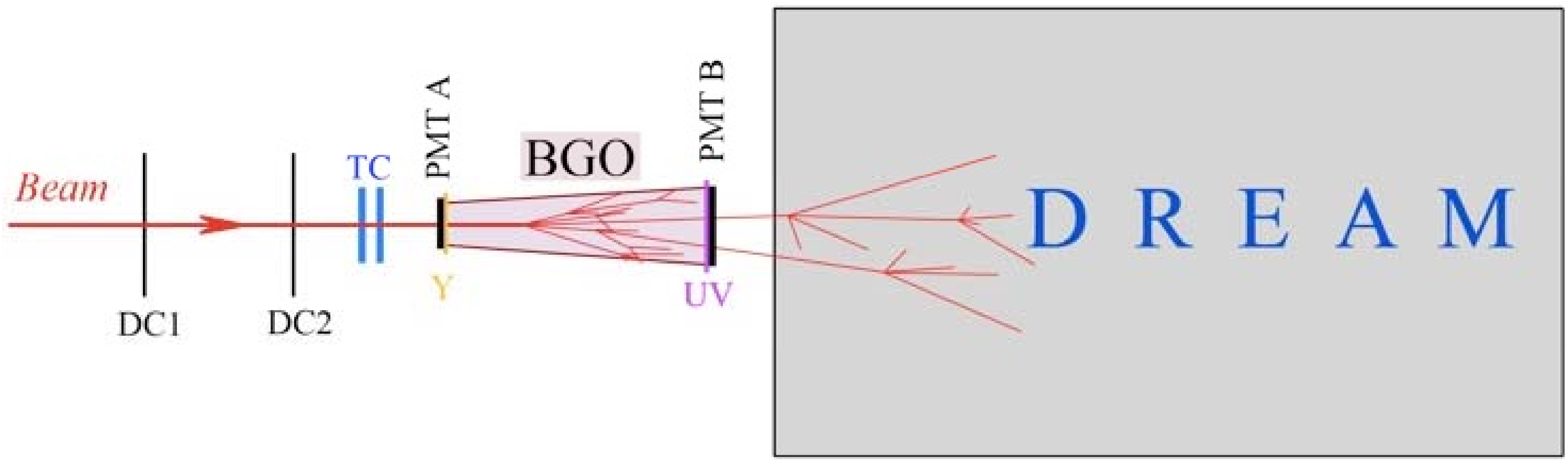


- Make no attempt to resolve the particles in jet cores, within the calorimeter

- Crystal EM section, with dual readout of scintillation and Cerenkov light by timing , followed by a hadronic section with dual readout by quartz and scintillator fibres

- No longitudinal segmentation, but SiPMs and local readout chips will permit excellent hermeticity. HCAL thickness 10λ or more

•Simulations indicate they could achieve ΔE = 20-25%sqrt(E) for isolated jets. Not clear yet how well their *pfa* (John Hauptman) will sort out the crosstalk in multi-jet events


Beam
DC1
DC2
TC
PMT A
Y
BGO
PMT B
UV
D R E A M

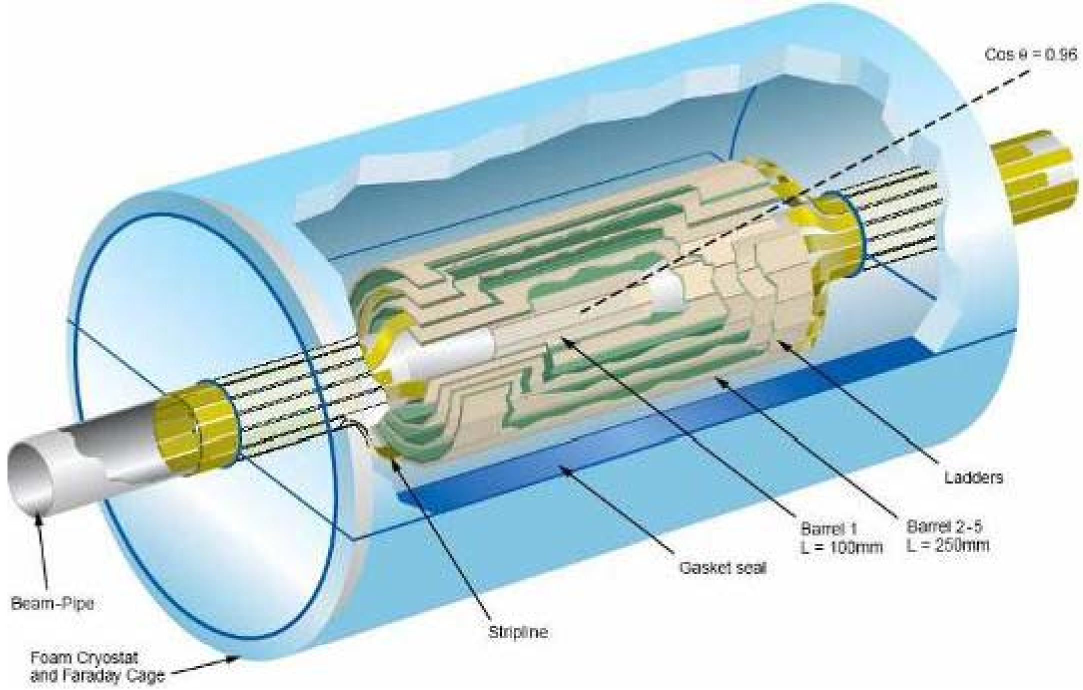
Main recommendations (compensating calorimetry)

- PFA performance would surely degrade in the forward region, where for t-tbar and much BSM physics, one or more jets will generally be directed
- Cannot afford to let the tracking ‘go to hell in the forward region’ as in the past, but even if track reconstruction is robust, the poorer momentum measurement will degrade the PFA performance
- Less spreading of charged tracks may also favour a hardware compensating calorimeter and and *pfa* approach (John Hauptman terminology)
- Before moving to a large scale prototype, the review recommended they investigate a number of concerns, some by simulations, others by lab tests
- Their collaboration needs more people, and we encourage others to join. Their approach could prove to be the outright winner, particularly in the special forward region

Vertexing Review Committee

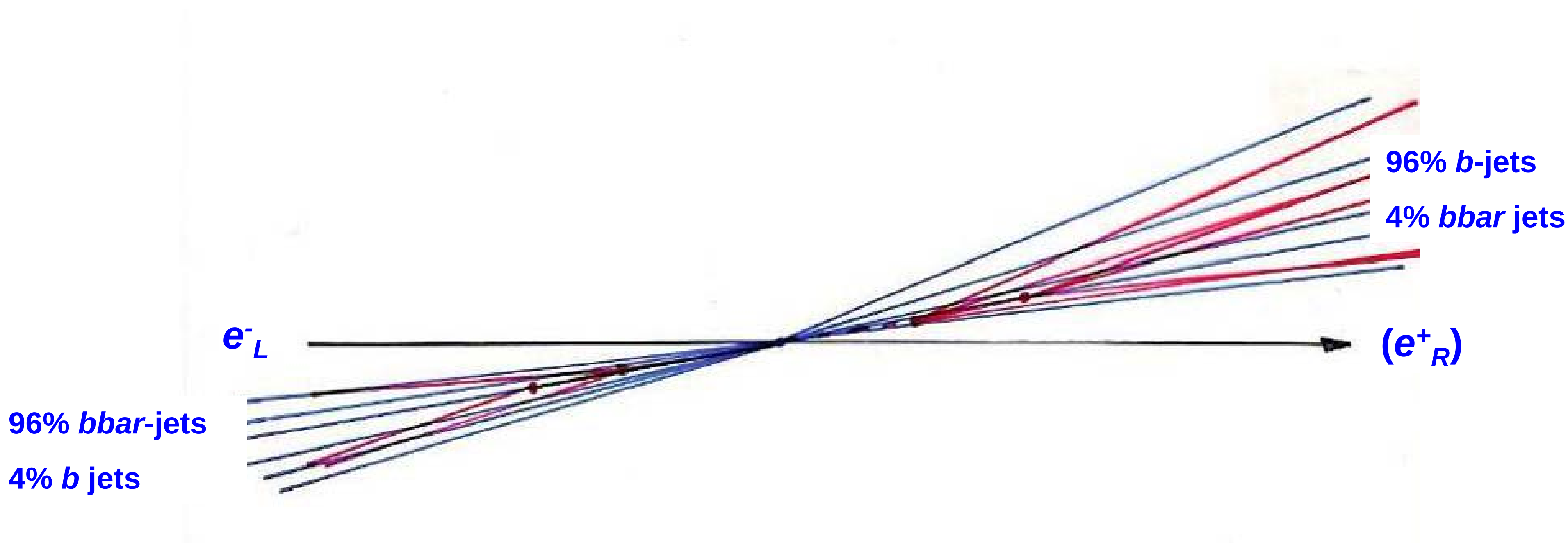
- Panel members: Chris Damerell, Hwanbae Park (chair)
- External consultants: Yasuo Arai, Dave Christian, Masashi Hazumi, Gerhard Lutz, Pavel Rehak, Petra Riedler, Steve Watts
- Regional representatives: Tim Bolton, Chris Damerell, (Junji Haba)
- RDB chair: Bill Willis
- Local vertexing experts: Simon Kwan, Lenny Spiegel
- Admin support: Naomi Nagahashi
- Report not yet completed – blown away by the UK funding crisis, ~50 e-mails per day since 11th December. First draft 1 will be completed in next week or two.

ILC vertex detector – a vital component



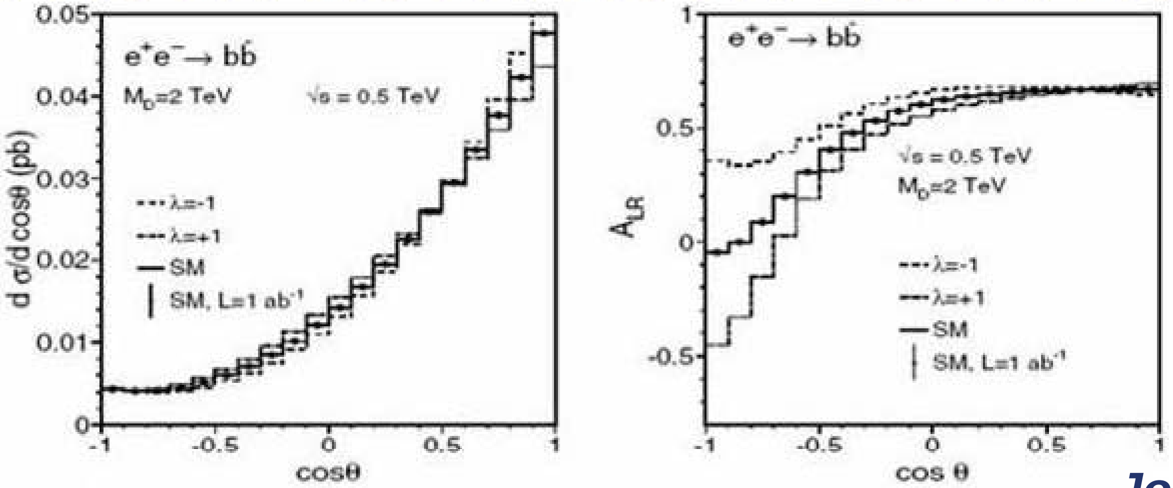
- **Extremely efficient track reconstruction and precise measurement of jet energies is not enough**
- **Which are b-jets, charm-jets or light quark jets?**
- **For the heavy quark jets, which are quarks and which anti-quarks?**
- **Answering these questions is the job of the vertex detector, by observing the particles which emerge from decay of *B* and *D* hadrons, with lifetimes ~10^{-12} s**
- **Establishing the required performance is the task of this ILC R&D topic**

Quark charge determination from 'vertex charge'



In this event, total charge in decay chain for backward jet resolves the forward-backward ambiguity – pioneered in, and unique to, SLD

A physics example – $e^+ e^- \rightarrow$ b bbar



Joanne Hewett,
Sabine Riemann

- **Need clean b-tag to distinguish from other q-qbar processes**
- **Need vertex charge to distinguish between b and bbar jets, otherwise see folded angular distributions**
- **Need nearly 100% longitudinally polarised electron beams**
- **Reward will be sensitivity to new physics via ‘oblique corrections’, where direct observation may be beyond the reach of both ILC and LHC**
- **Another important example – if LHC finds the Higgs, is it the SM Higgs, SUSY Higgs, or what? Precision measurements of branching ratios by ILC, including c-cbar and tau-tau will be essential**

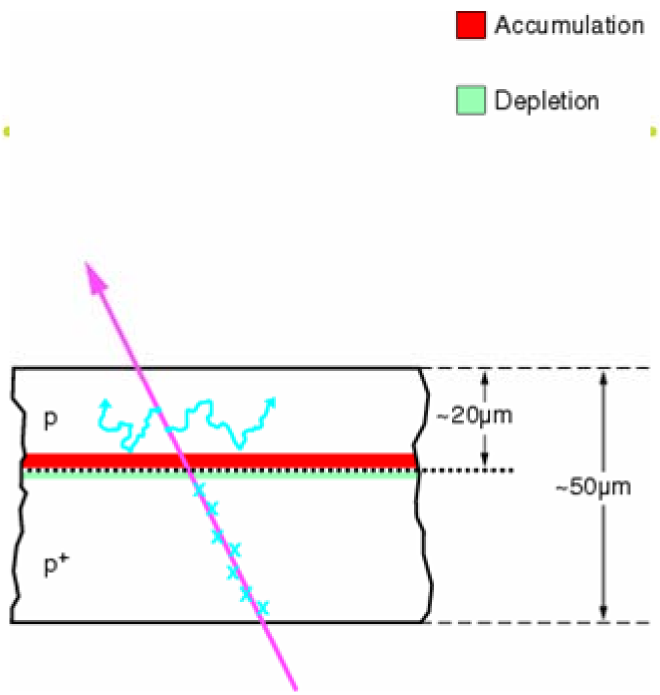
Overview of the review

- 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 historically, discussions within the VXD community have resulted in some pruning of options)
- Not as bad as it sounds – will end up with 2 and possibly 4 technologies in the startup ILC, and others could provide upgrade paths
- Several of these options have or may have applications in other fields, such as x-ray sensors for astronomy and SR systems. Pixels (enabling pictures) tend to be intrinsically multi-disciplinary
- Not time to describe all of them – just explain a few nearly universal aspects

Minority carrier diffusion length

~ 200 μm

~ 0.1 μm



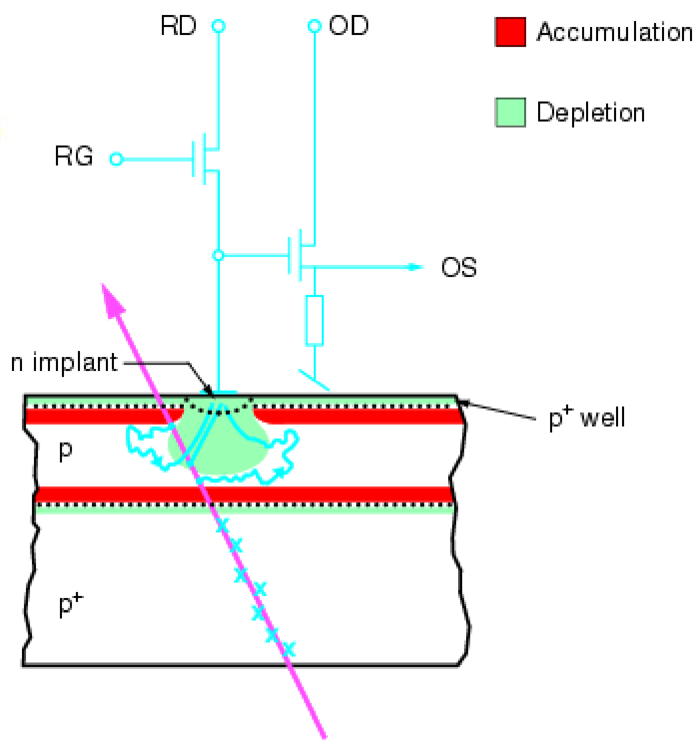
What epi-layer thickness?

Prefer it thin, to avoid losing precision for angled tracks

But not too thin, or lose tracking efficiency

20 μm is 'about right'

- **Imagine *p* and *p+* material brought into contact at same potential**
- **Holes pour from *p+*, leaving a negative space-charge layer (depletion) and forming a positive space charge layer in the p material (accumulation)**
- **This space-charge must of course sum to zero, but it creates a potential difference, which inhibits further diffusion of majority carriers from *p+* to *p* and *incidentally* inhibits diffusion of minority carriers (electrons) from *p* to *p+***
- **This barrier is thermally generated, but the 'penetration coefficient' is temperature independent, and is simply the ratio of dopant concentrations. eg 0.1/1000, so 10^{-4} - this interface is an almost perfect mirror!**



- We can repeat this on the top surface – here the *p*-well can be used to implant structures (notably NMOS transistors), 'monolithic' with respect to the detector layer below
- Positively biased n implants (reverse-biased diodes) serve to collect the signal charge, partly by diffusion, partly by drift in depleted regions created in the *p*-type epi layer
- Overlaying dielectric layers, and photolithographically patterned metal layers complete the toolkit for interconnecting the circuit
- Here you have the essentials of a MAPS (monolithic 'active' pixels sensor, having transistors within the pixel; in contrast to 'passive' CCDs)

•To learn about all the beautiful options for ILC vertex detectors, refer to the slides of the Fermilab review

It's much too early to 'pick winners'

- The groups pushing these options are too talented to be wasting their time

•Technology is moving fast!

- Past experience provides a warning …

- SLC Experiments Workshop 1982 (just 8 years before physics startup)

- Move on just two years …

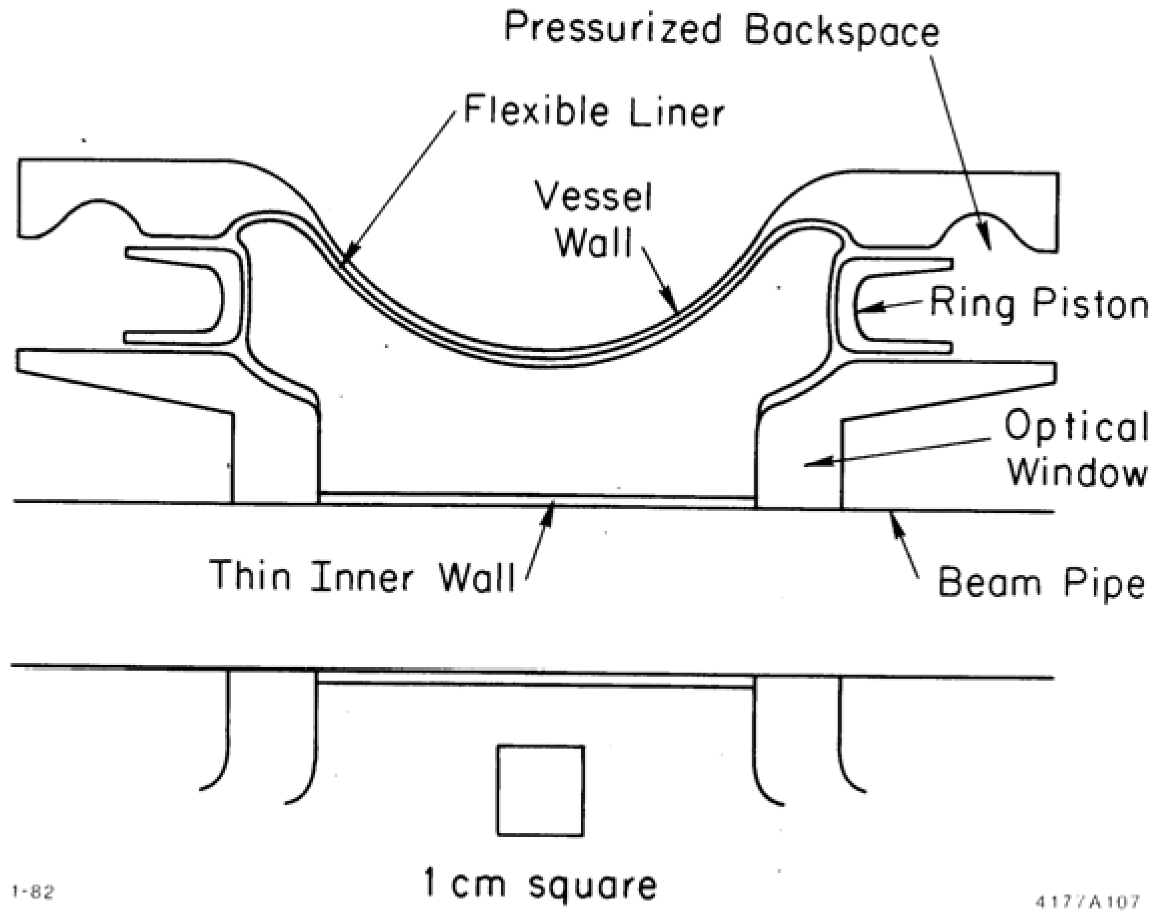
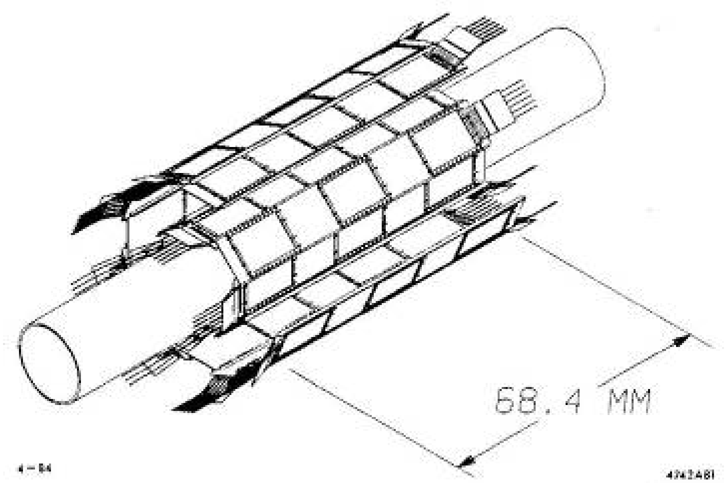
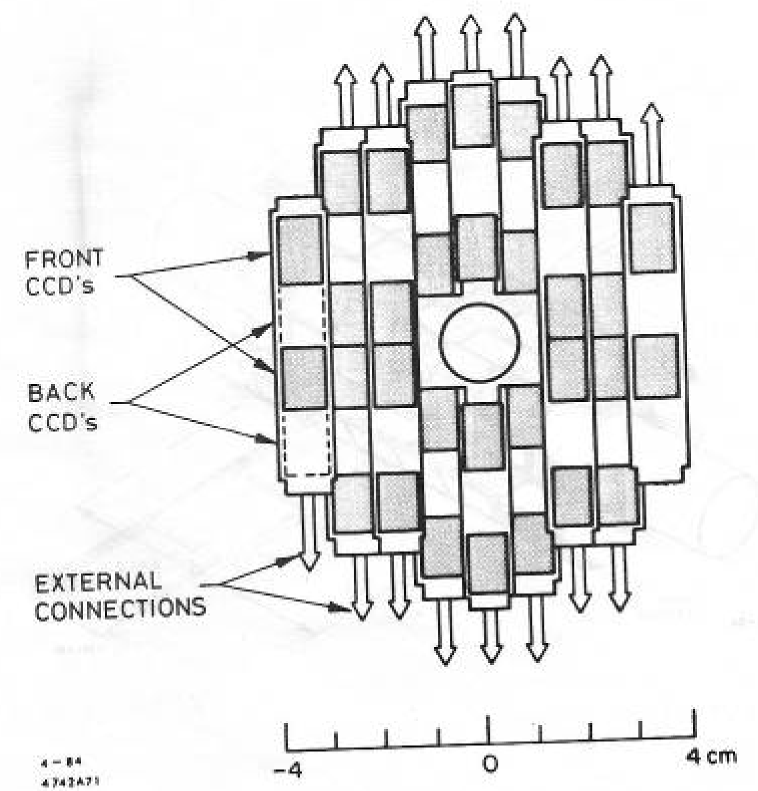


Fig. 7. Conceptual design of a propane bubble chamber vertex detector.

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



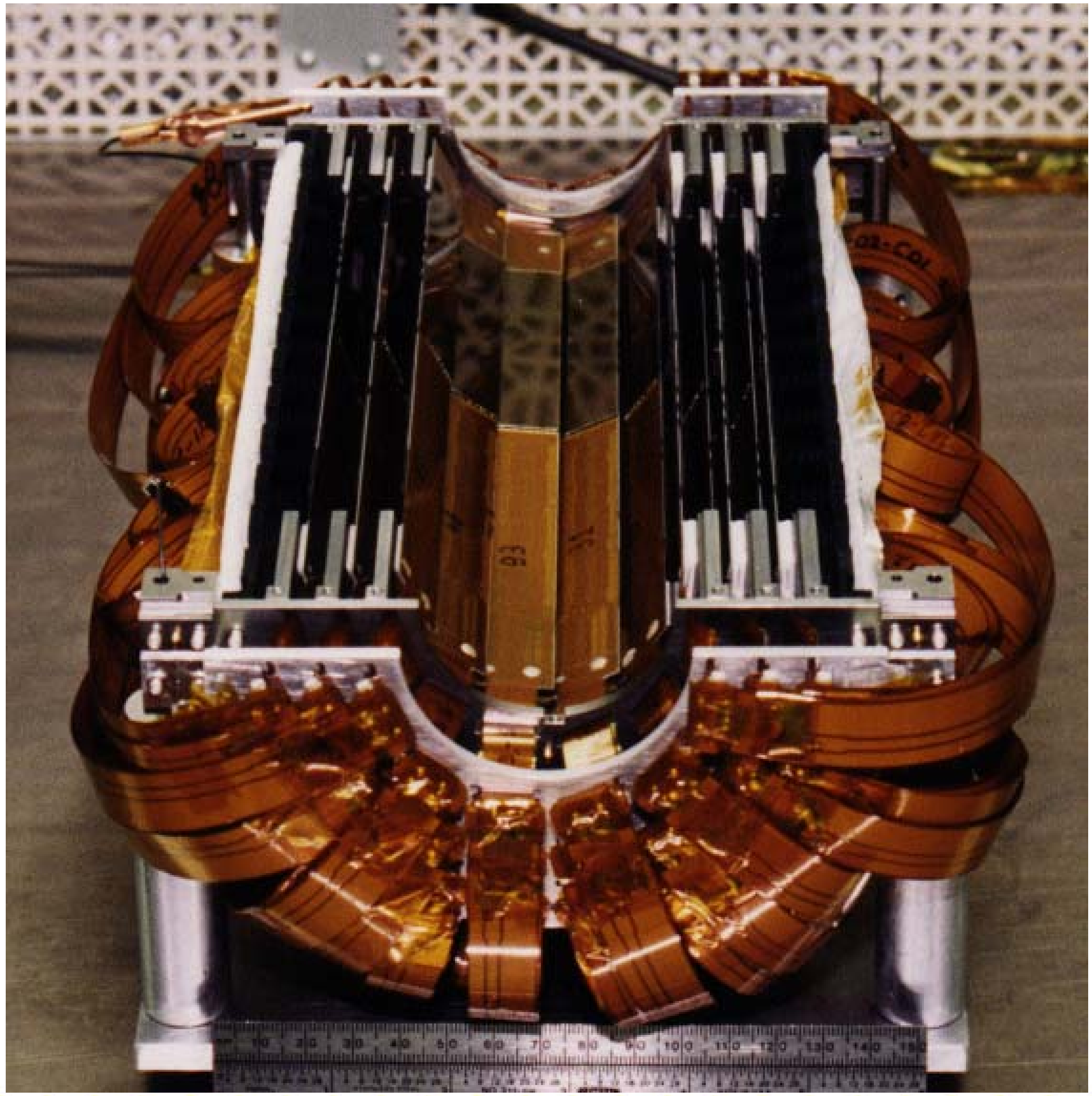


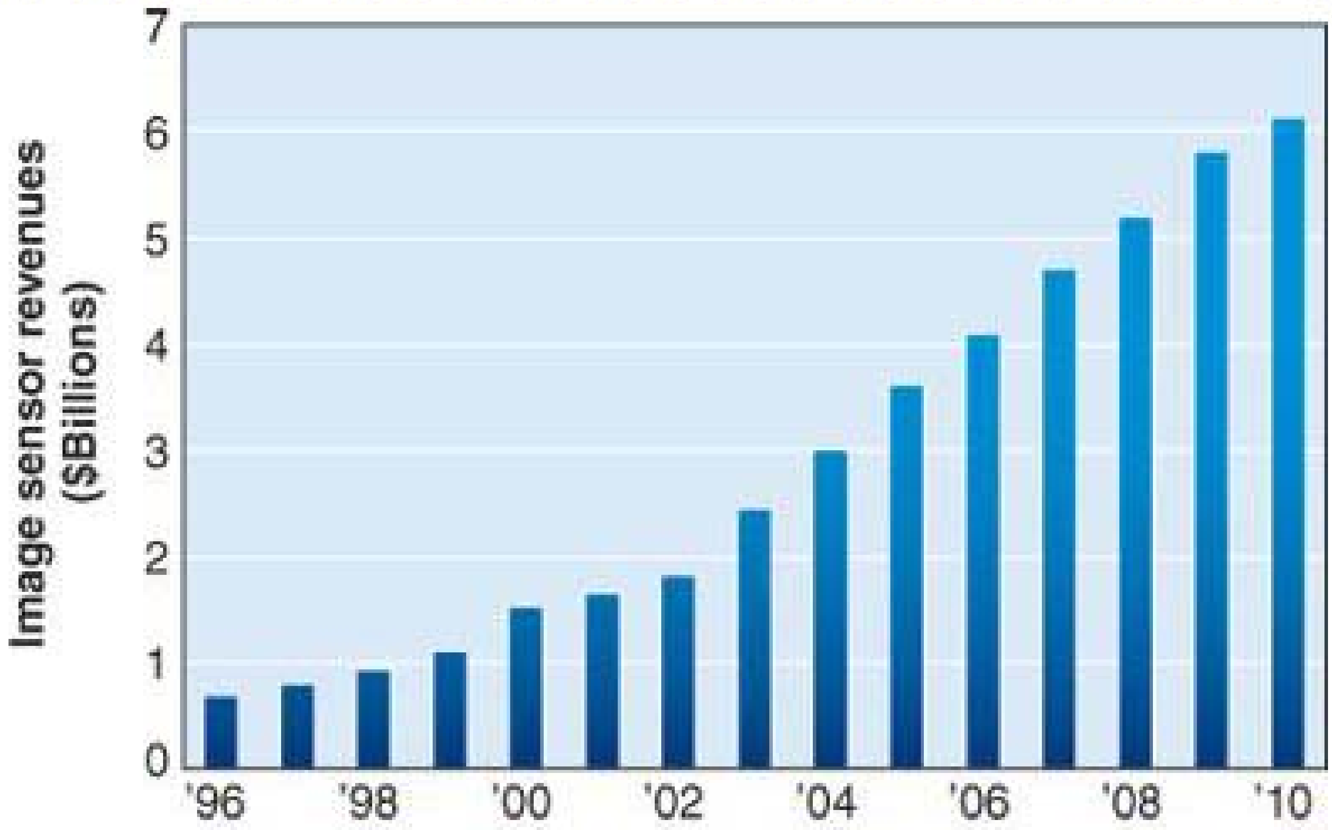
- **What was installed in 1993**

- **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**

- **There will of course be forward tracking pixel disks: the issue is whether it is useful to make any with ~3 μm precision as opposed to ~15 μm precision**





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

Detector R&D: organisational considerations

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

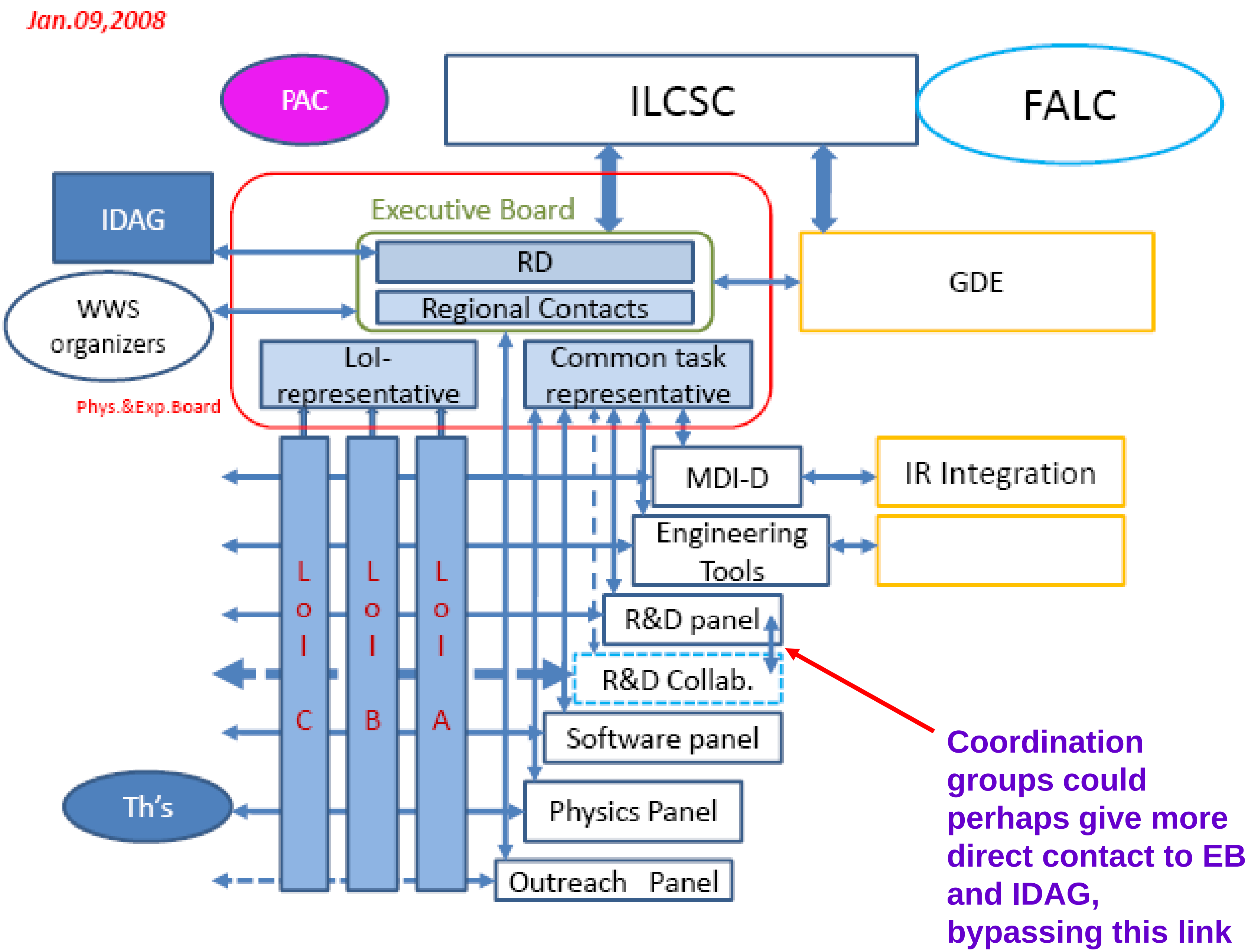
- NOT some external body (like the Review Committees) but one or two 'insiders' from each R&D group, plus (where relevant) cross-members from other CGs (notably the TBCG). Maybe one member of each to be a member of the R&D Panel

- 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)

- Our Panel lacks the necessary intimacy of contact with every R&D group 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



Jan.09,2008
PAC
ILCSC
FALC
IDAG
Executive Board
RD
Regional Contacts
GDE
WWS organizers
LoI-representative
Common task representative
Phys.&Exp.Board
MDI-D
IR Integration
Engineering Tools
R&D panel
R&D Collab.
Software panel
Physics Panel
Outreach Panel
Th's
LoI C
LoI B
LoI A
Coordination groups could perhaps give more direct contact to EB and IDAG, bypassing this link

LOI Groups

- Not really new, rather an extension of what we have always had:
  - ~1996: Detector concepts: JLD, NLD, TESLA detector
  - ~2000: Concept groups: GLD, SiD, LDC, 4th
  - 2007: LOI groups: ILD, SiD, 4th
- This was severely misunderstood by STFC people in UK:
  - J Thomas (Deputy chair, Science Board) ~15 Dec 2007: 'The formation of two collaborations for the ILC over the last months had an extremely negative effect on the credibility of the project from the point of view of STFC'
  - K Mason (CEO) 27 Feb 2008: 'We didn't want particle physics to put all its eggs into a basket that might not deliver chicks'

Suggestions/Conclusions

- It's really important not to weaken the detector R&D groups by excessive emphasis on LOI groups (just my opinion; some would like the LOI groups to take over the R&D)
- The LOI groups as in the past provide the overall frameworks **essential** for us to evaluate *any* detector systems – we cannot study any issue (PFA vs dual readout, 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"
- Given the stretched funding world-wide, we need to establish support for the most urgent R&D. Much of this easily passes the test of being **'generic'** – which in some countries helps to get the work funded
- Detector Directorate and IDAG might consider whether to invite R&D groups to form co-ordination groups