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)

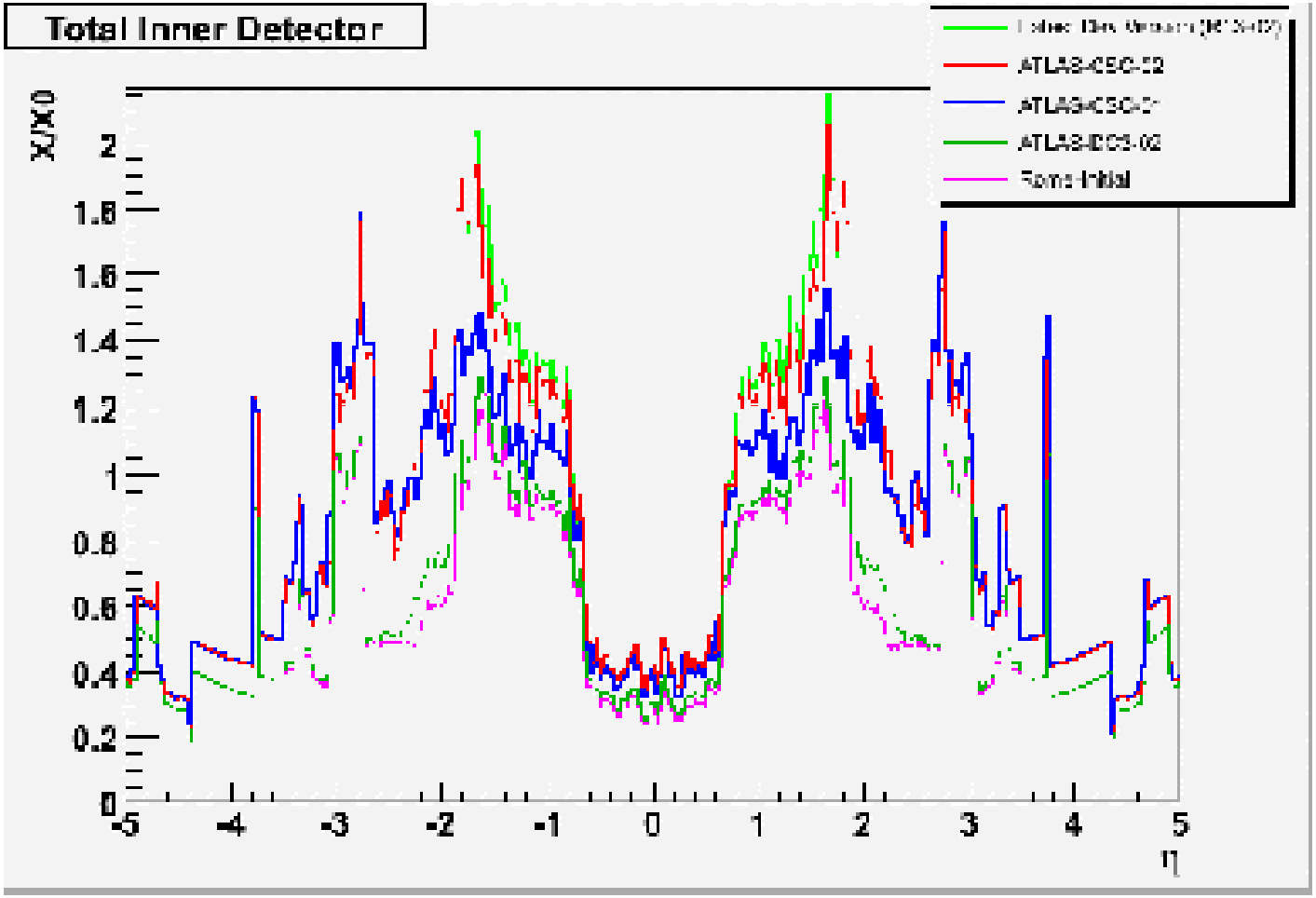
WWS-OC asked us to review main R&D areas during regional workshops through 2007 – tracking in Beijing, calorimetry at LCWS2007 in DESY, and vertexing in Fermilab

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. *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?*
- 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)



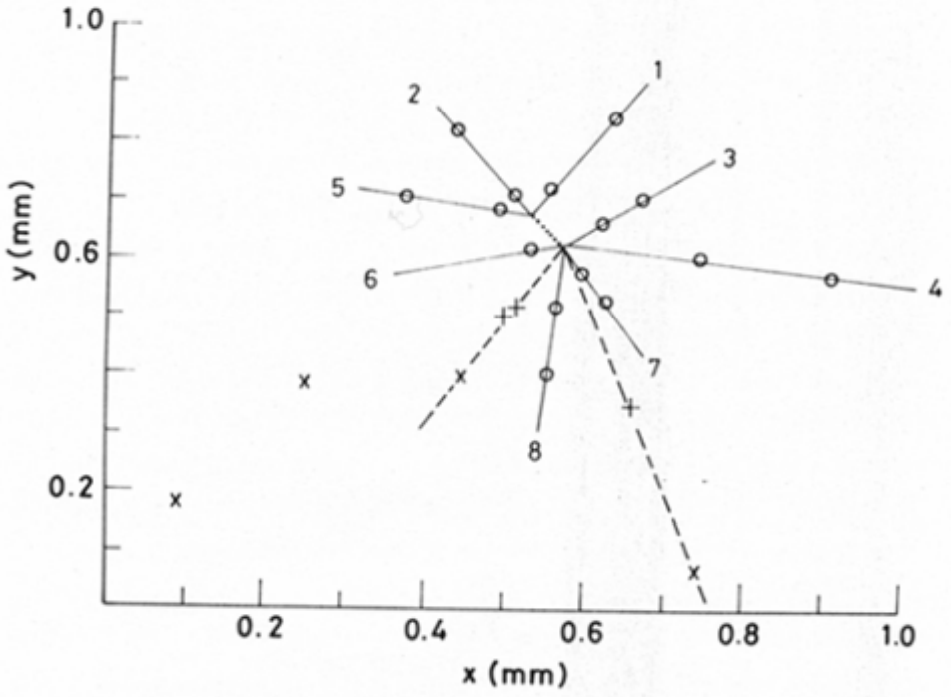
When last I asked, it was 'still increasing'

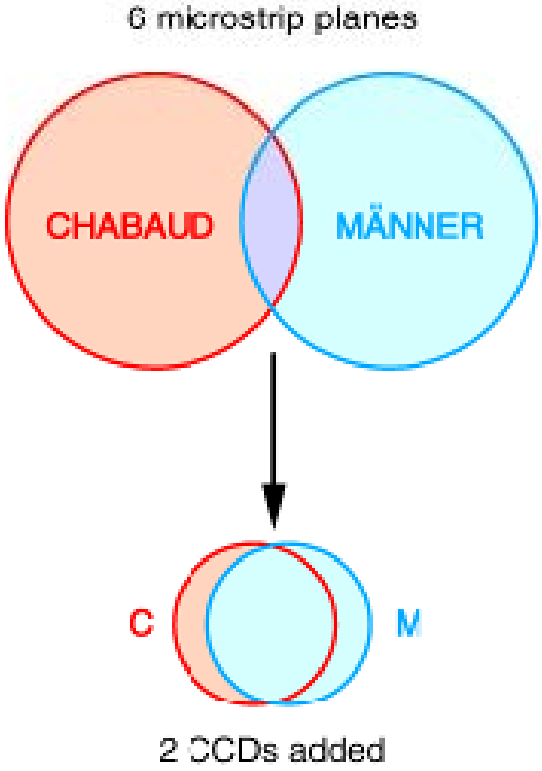
Contrast central and fwd J/psi reconstruction

A new idea – Silicon Pixel Tracker

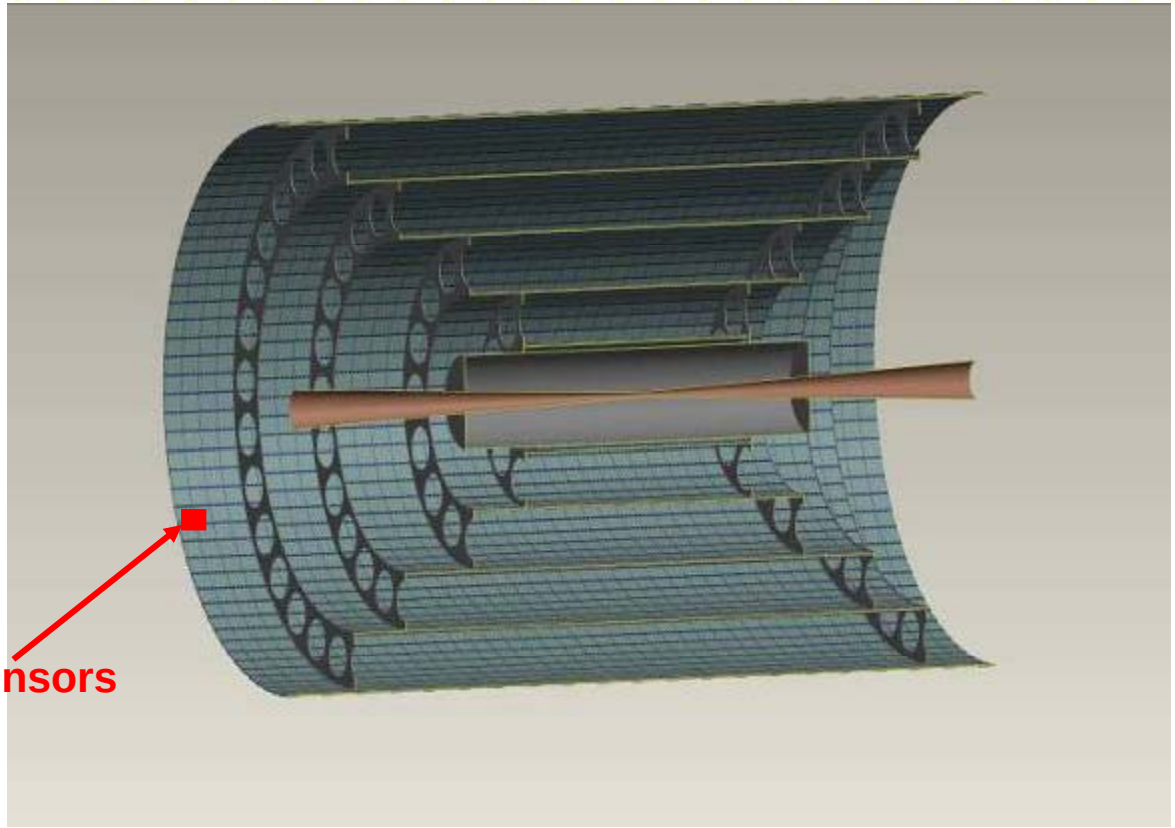
- **The most serious concern of the committee was the material budget, particularly how badly this might degrade the forward tracking:**
  - **For TPC tracker, can the endplate thickness really be reduced to 'well below 0.3 X_0', say to 0.1 X_0? Our expert consultants were doubtful**
  - **The drift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

- **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?

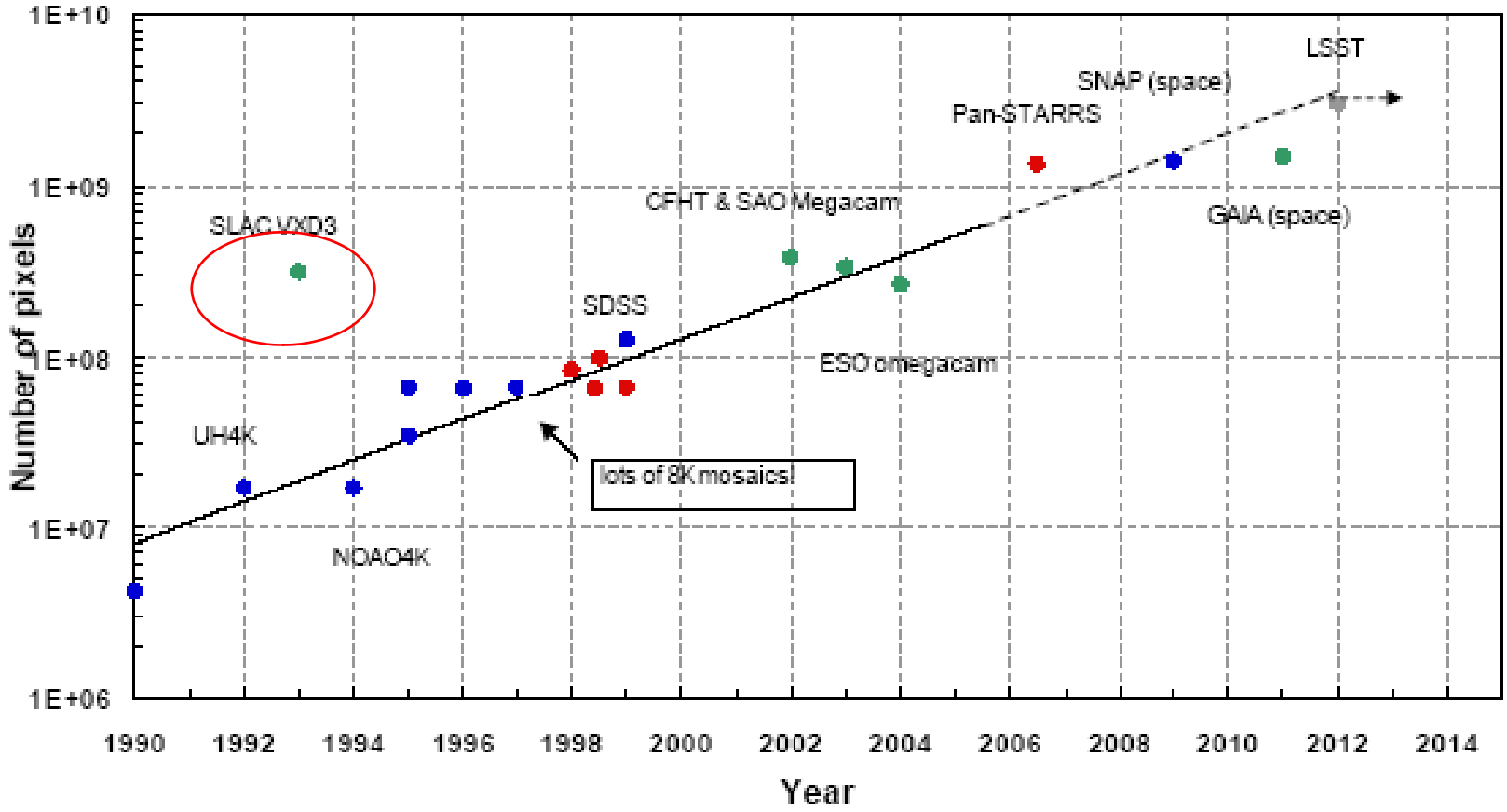


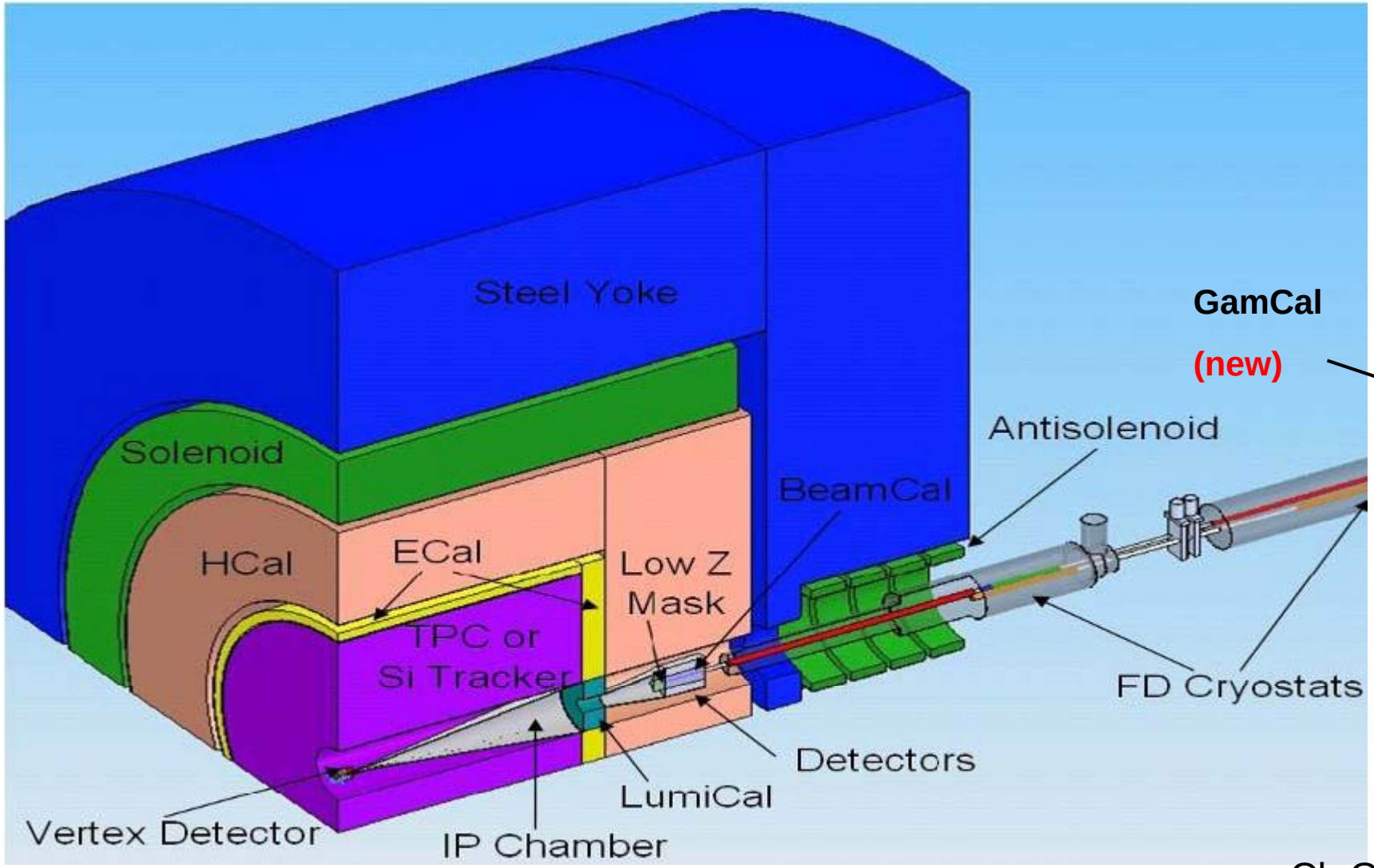
Illustration of focal plane sizes, from Luppino/Burke 'Moores' law

Focal plane size doubles every 2.5 years

From: Burke, Jorden, Vu, SDW Taormina 2005

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**

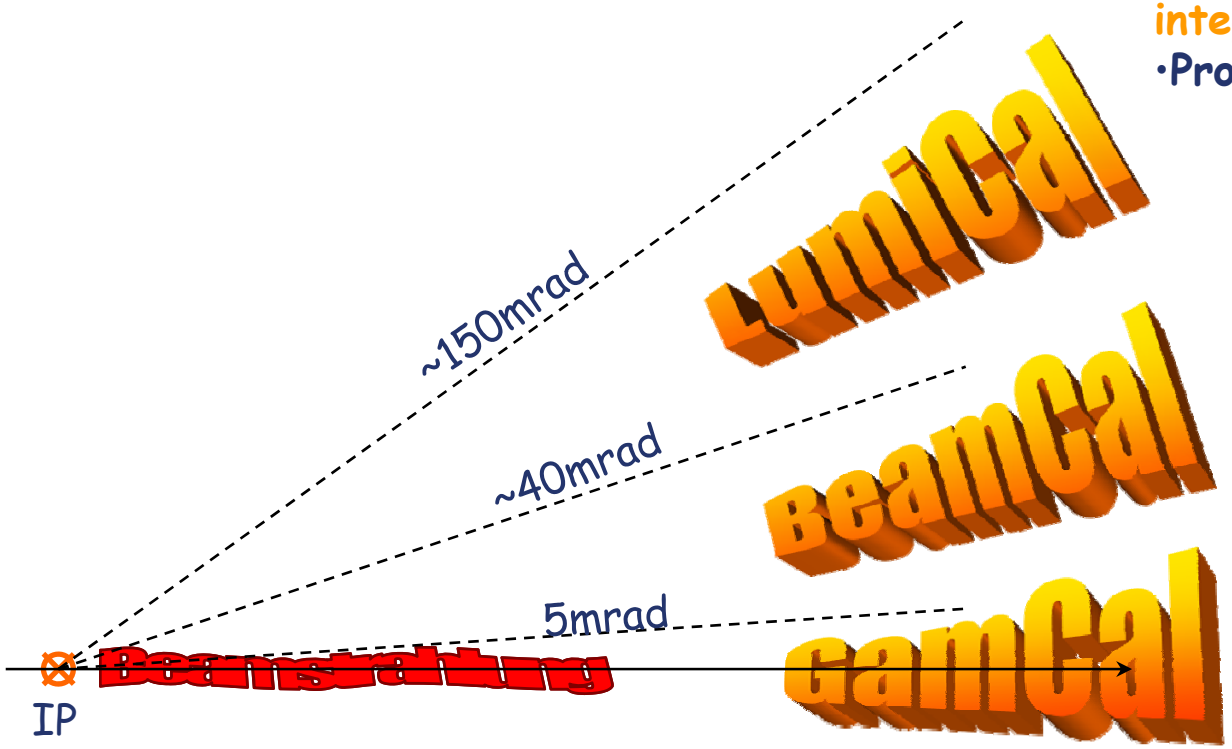

Steel Yoke
Solenoid
HCal
ECal
TPC or
Si Tracker
Low Z
Mask
BeamCal
Antisolenoid
GamCal
(new)
FD Cryostats
Detectors
LumiCal
Vertex Detector
IP Chamber

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, $\Delta E = 30\%\sqrt{E}$)**
    - **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!

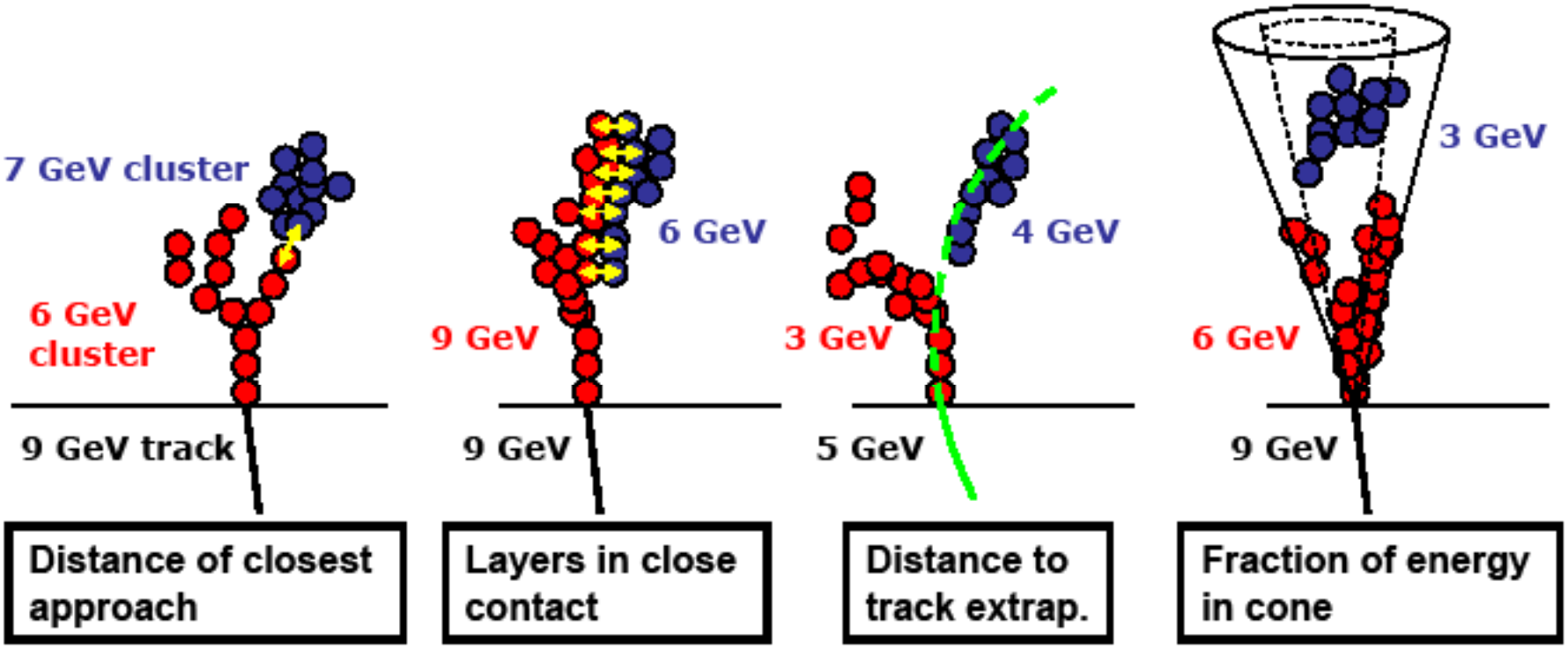
Main recommendations (FCAL)

- 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



- **Impressive simulation results. Can such performance be achieved in a real system?**

- **If possible, obtain data from charged and neutral hadrons in 'physics prototype' calorimeter system, and use them in conjunction with simulation of ILC jets to create more realistic hit patterns in the calorimetry system, hence determine how well PFA will handle real ILC events**

- **There has been 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 MCentre beamline at Fermilab DAQ problems of concern previously can be overcome**

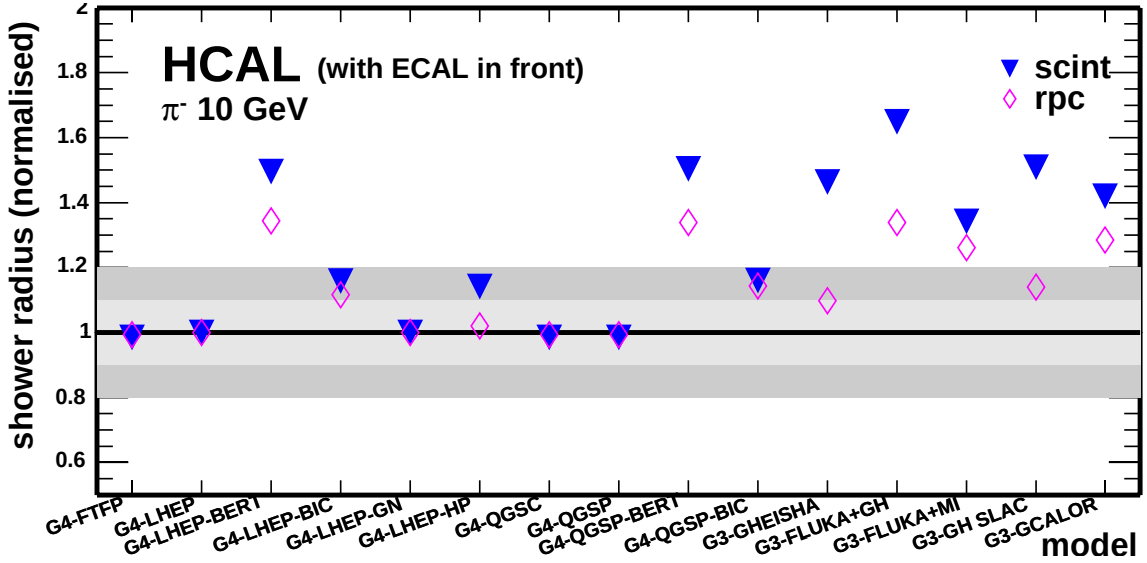
- **Don't wait forever for Fermilab to pay for the modest MIPP upgrades to do this. The push needs to come from the ILC detector community, via our new directorate.**

- **This programme requires a significant effort, but this is better than discovering in 2025 that the PFA approach was a poor second choice**

- **The vertex detector and tracking systems 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)

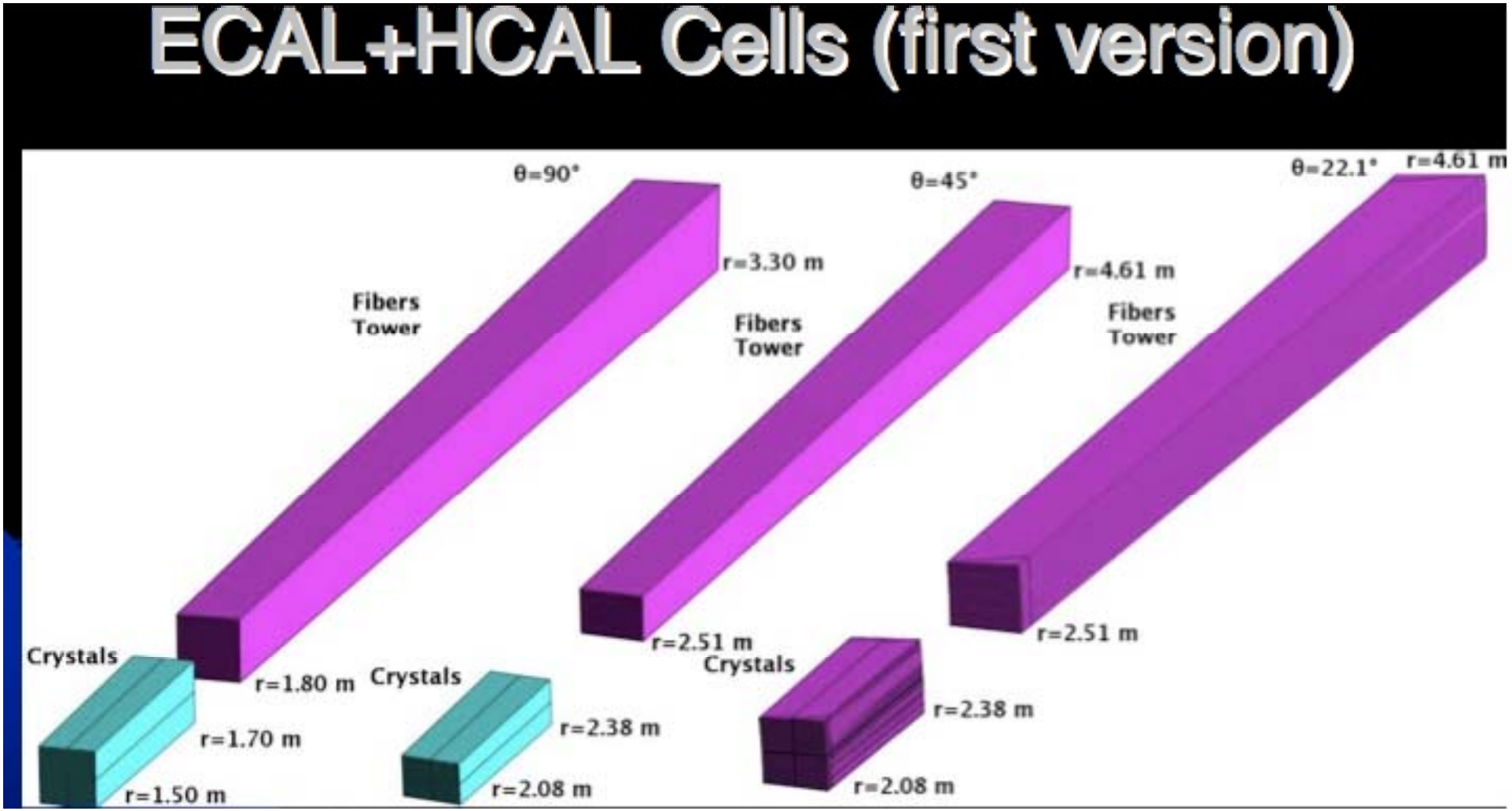
- While extremely promising, all studies to date (beyond the early experience with ALEPH and SLD) are based on *simulations,* hence subject to considerable uncertainty



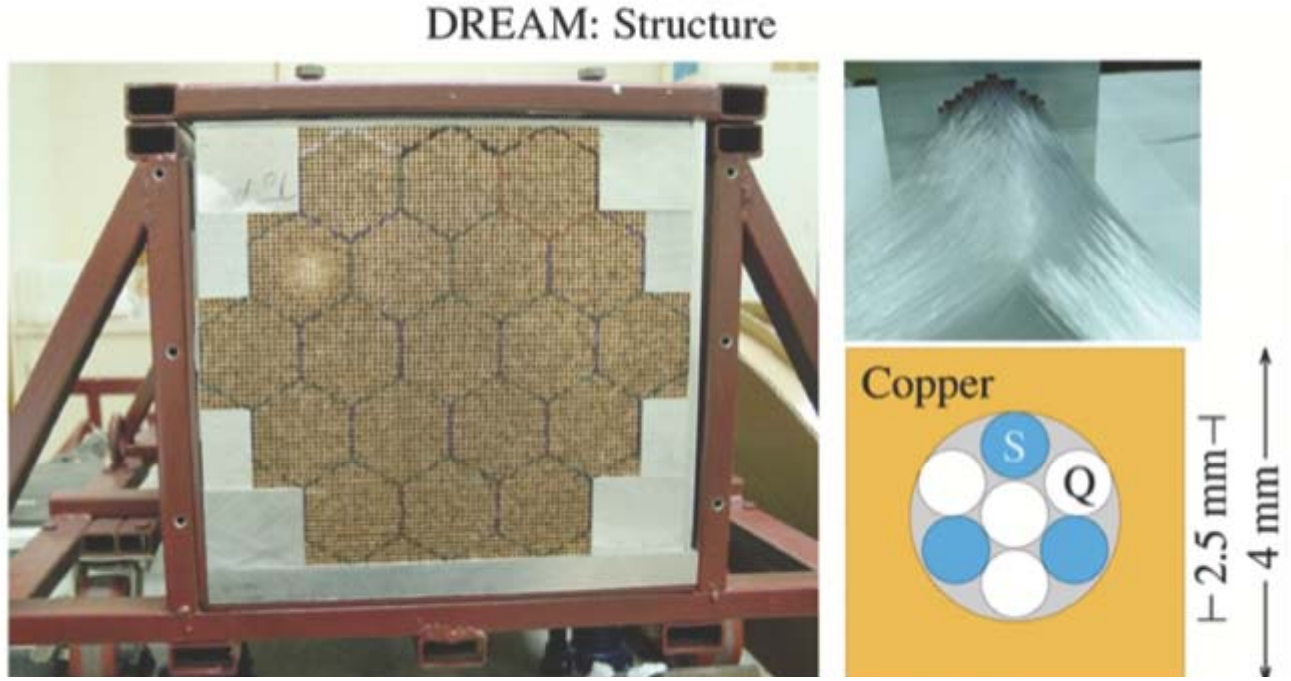
- These are only the *average* shower radii. There is much greater uncertainty in the shape variability between individual showers, involving different inelastic scattering processes

- 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



- 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 can be 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

Main recommendations (compensating calorimetry)

- PFA performance is expected to 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
- Less spreading of charged tracks may also favour a hardware compensating calorimeter and and *pfa* approach
- 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 – we simply don't know yet

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**

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 discussions within the VXD community have already 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 eventually provide upgrade paths
- Several of these options have possible applications in other fields, such as x-ray sensors for astronomy and SR systems. Pixels (enabling pictures) tend to be intrinsically multi-disciplinary
- First draft of our report was distributed on 12th April. So far, some praise and no complaints, just a few minor corrections

Some of the recommendations (from 34 pages)

Environmental issues

- Ongoing close coordination needed with MDI group, to maintain stability of pair bgd, hence Rbp (in contrast to SLC), and control of neutron bgd from beam dump
- Careful design of 'R20' system needed to preserve wall thickness of beampipe
- High-Z liner needed? Maybe resolve in first push-pull cycle
- Need to monitor and eliminate beam-related RF during machine commissioning, before detector installed
- Time stability of IP position in x and y?

Layout and mechanics

- Long barrels vs short barrels+disks – will take a few years to decide. Great that two concepts have different opinions. Serial powering will help a lot
- Layer 1 different? May be a good idea, maybe obligatory if one really needs bgd as low as 1 hit/mm^2
- Mechanics and alignment – few pages. Push-pull OK

Electronics – shared issues

- CDS and ERF. Several technologies need to think more about it – could have major power implications
- Power and cooling – serial power will help to greatly reduce material for all options

Installation and access

- Push-pull helps, in the garage position, can open the end-doors by 3 m. Otherwise, follow SLD procedure

Technology choices

- Don't rush – need to wait for fully serviced ladders in test beam, unless groups decide themselves to give up

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 …**

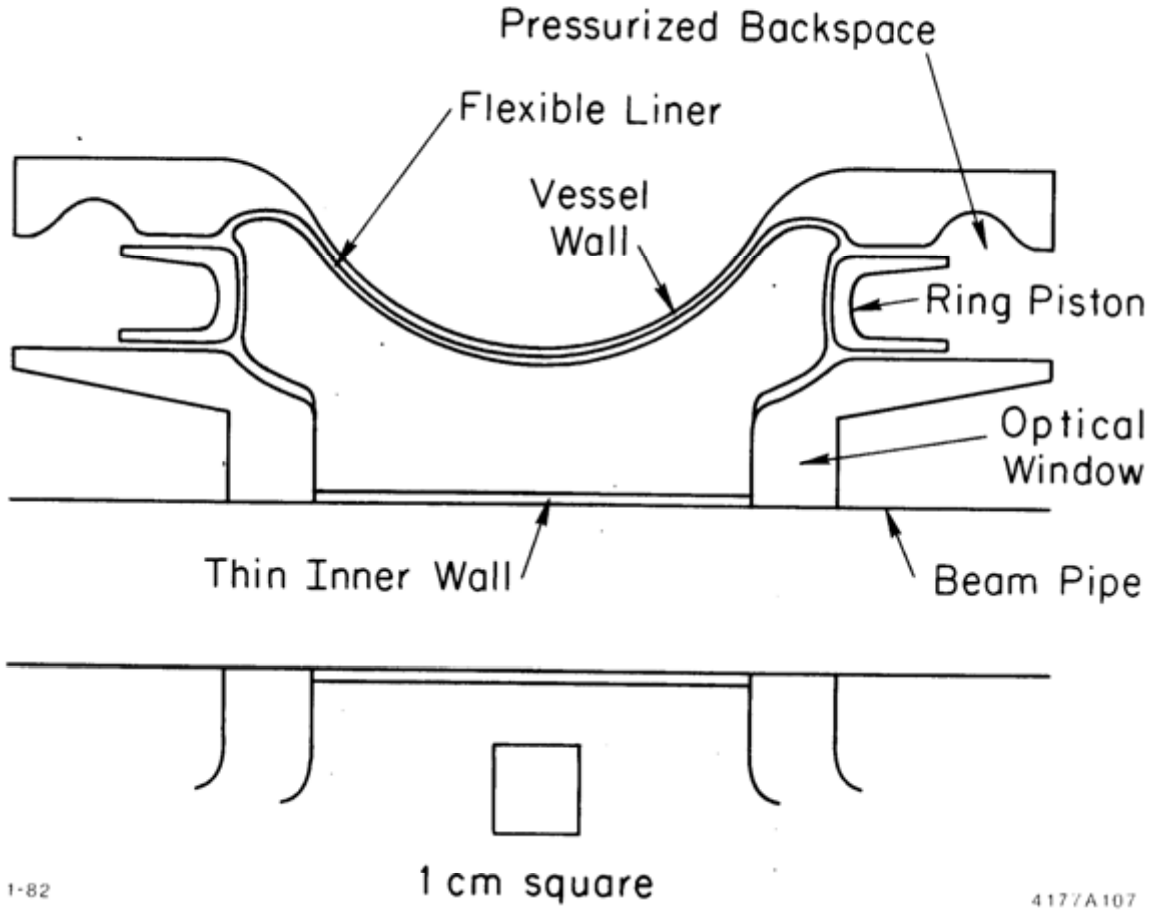
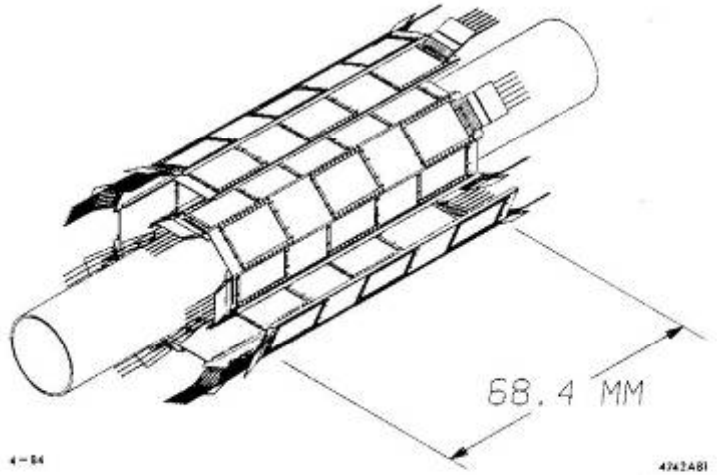
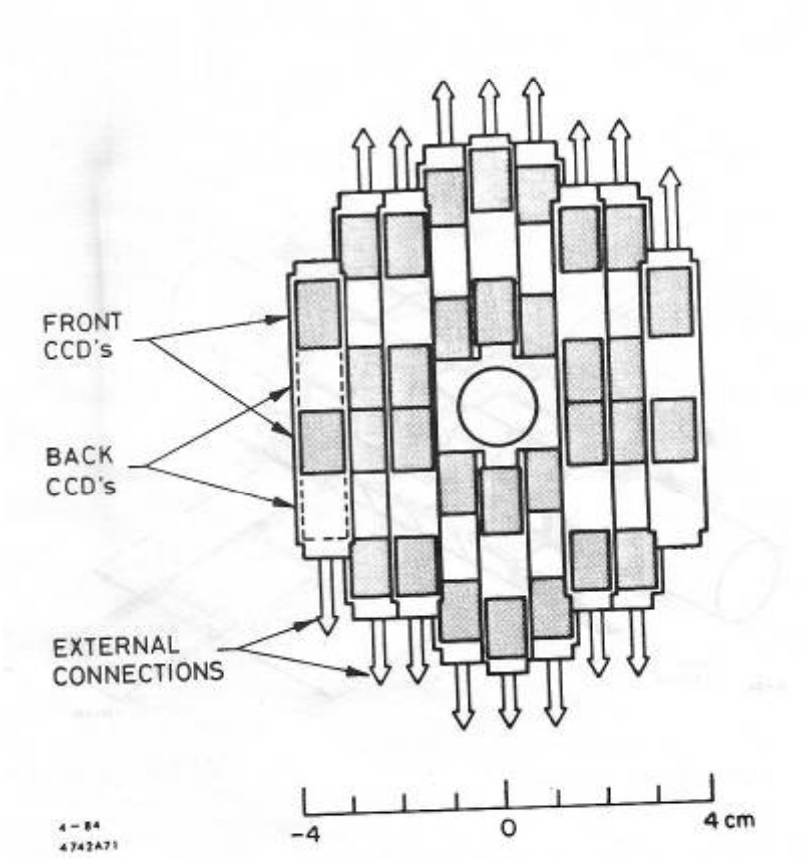


Fig. 7. Conceptual design of a propane bubble chamber vertex detector.

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



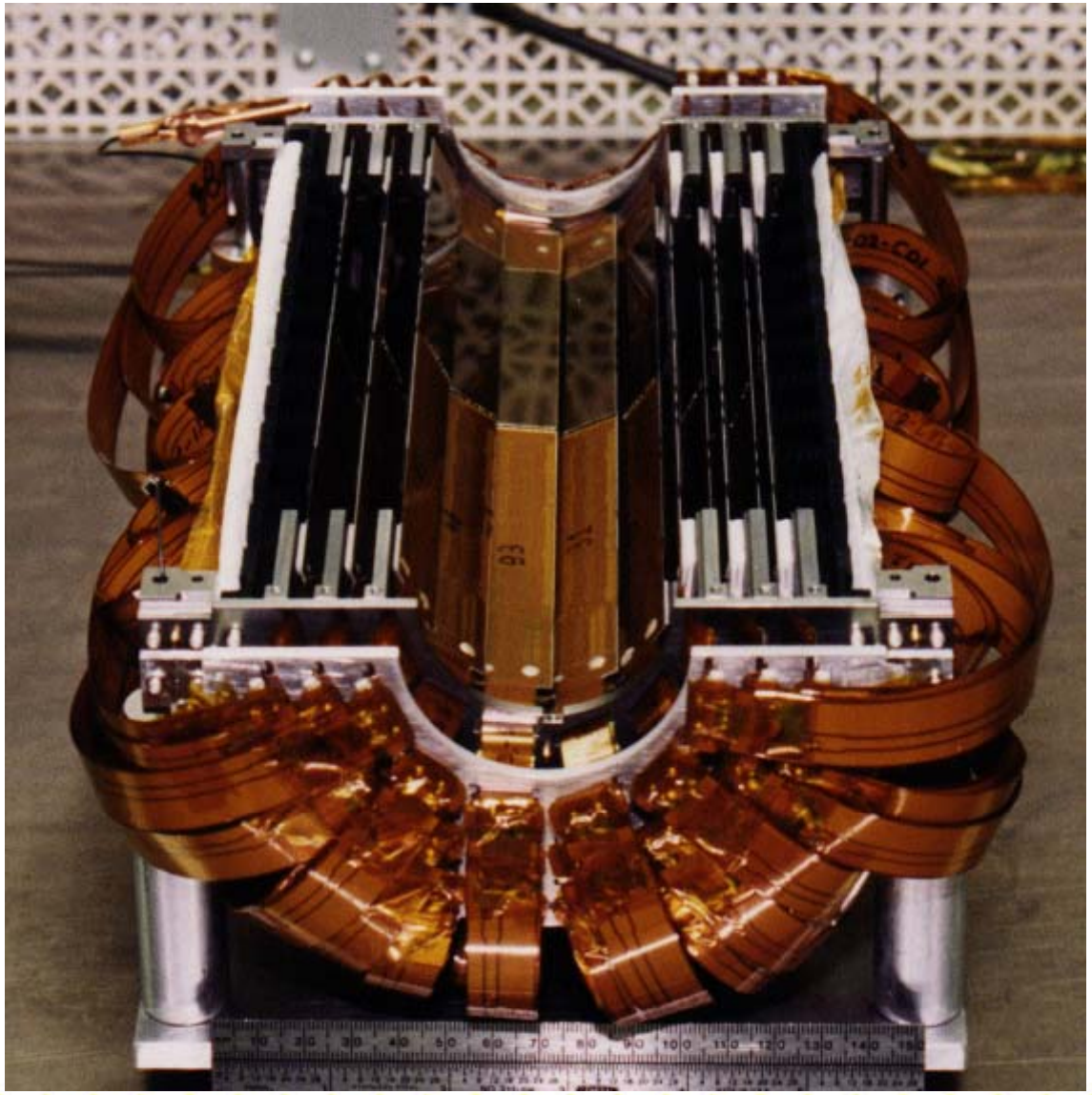


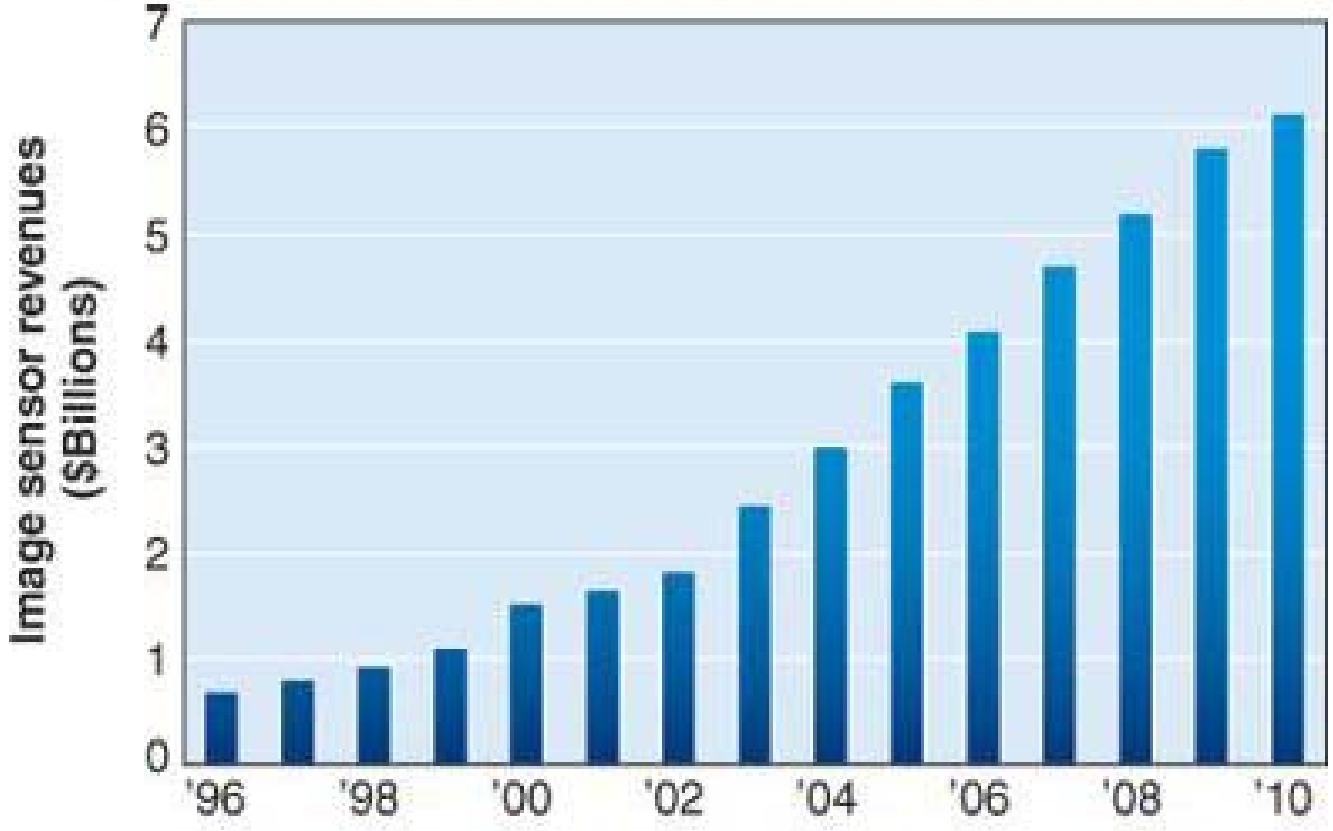
- **What was installed in 1993**

- **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 provide world-wide coordination of the ILC accelerator R&D, to wonder about the utility of Coordination Groups (TCG, CCG, VCG, TBCG, …)

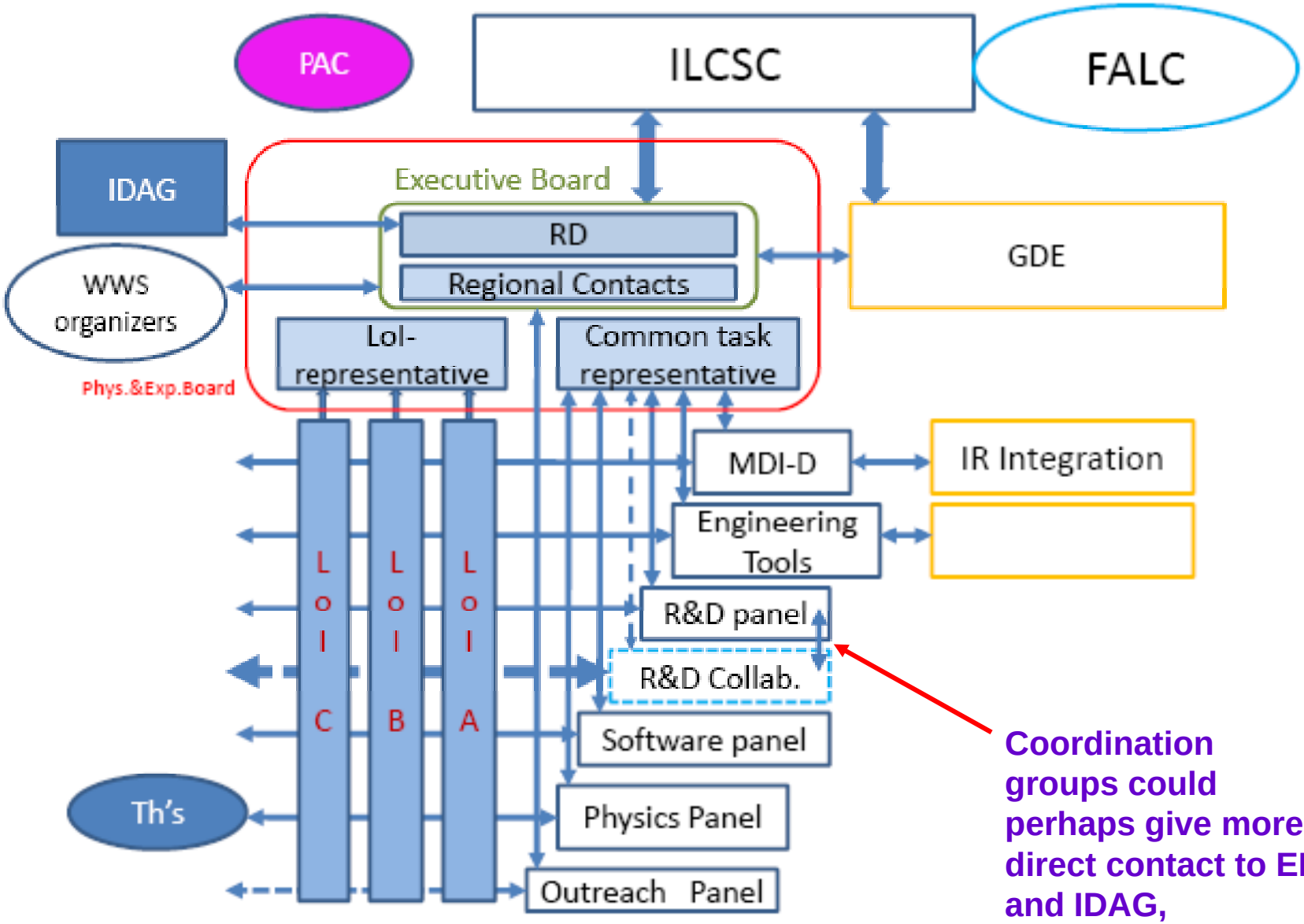
- NOT some external body (like the Review Committees) but one or two 'insiders' from each R&D group, plus (where relevant) cross-members from other CGs (notably the TBCG). Maybe one member of each to be a member of the R&D Panel

- 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

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 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'**

    'STFC did not wish to support a standing army for 15 years'

Suggestions/Conclusions

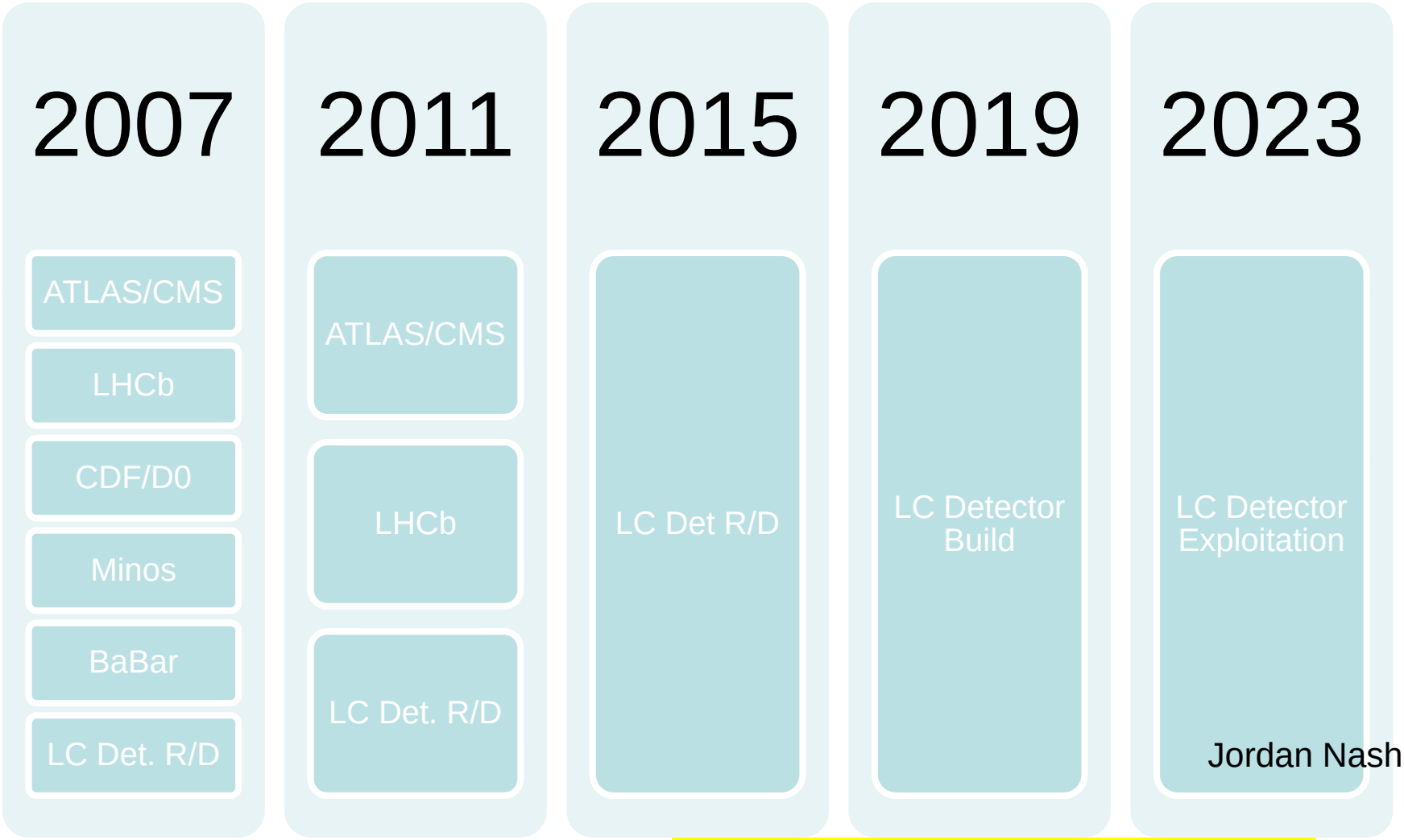
- It's really important not to weaken the detector R&D groups by excessive emphasis on LOI collaborations – need to maintain a careful balance
- The LOI collaborations *as in the past* provide the overall frameworks essential to evaluate *any* detector systems – we cannot study any detector issue (PFA vs compensating calorimetry, long barrel VXD vs short barrel plus disks, etc) other than in full MC simulation of an overall detector concept
- *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"
- Some detector R&D 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

Input to the ILC decision

- Past year brought some new perspectives
  - **Orbach predicted (Feb 07) mid-20's for time scale after full costing of $13.5B for 500GeV ILC**
  - **ILC collaborations (detector concepts) started to form but no funds for LHC-upgrades had yet been planned (by design!!: CERN subscription)**
  - **detector R&D had already cost us ~£1M/yr (about 5 years)**
  - **accel R&D (excluding centres) ~£3M/yr (pre-FEC) since 04/04**
  - **Other international funding partners expressed difficulty in seeing how to fund ILC and LHC upgrades**
  - **UK had almost no other programme planned after first phase of LHC (LHC GPD + LHC-B) if LC work continued at this level**
  - **UK government would not be forthcoming with £300M for ILC given other priorities**

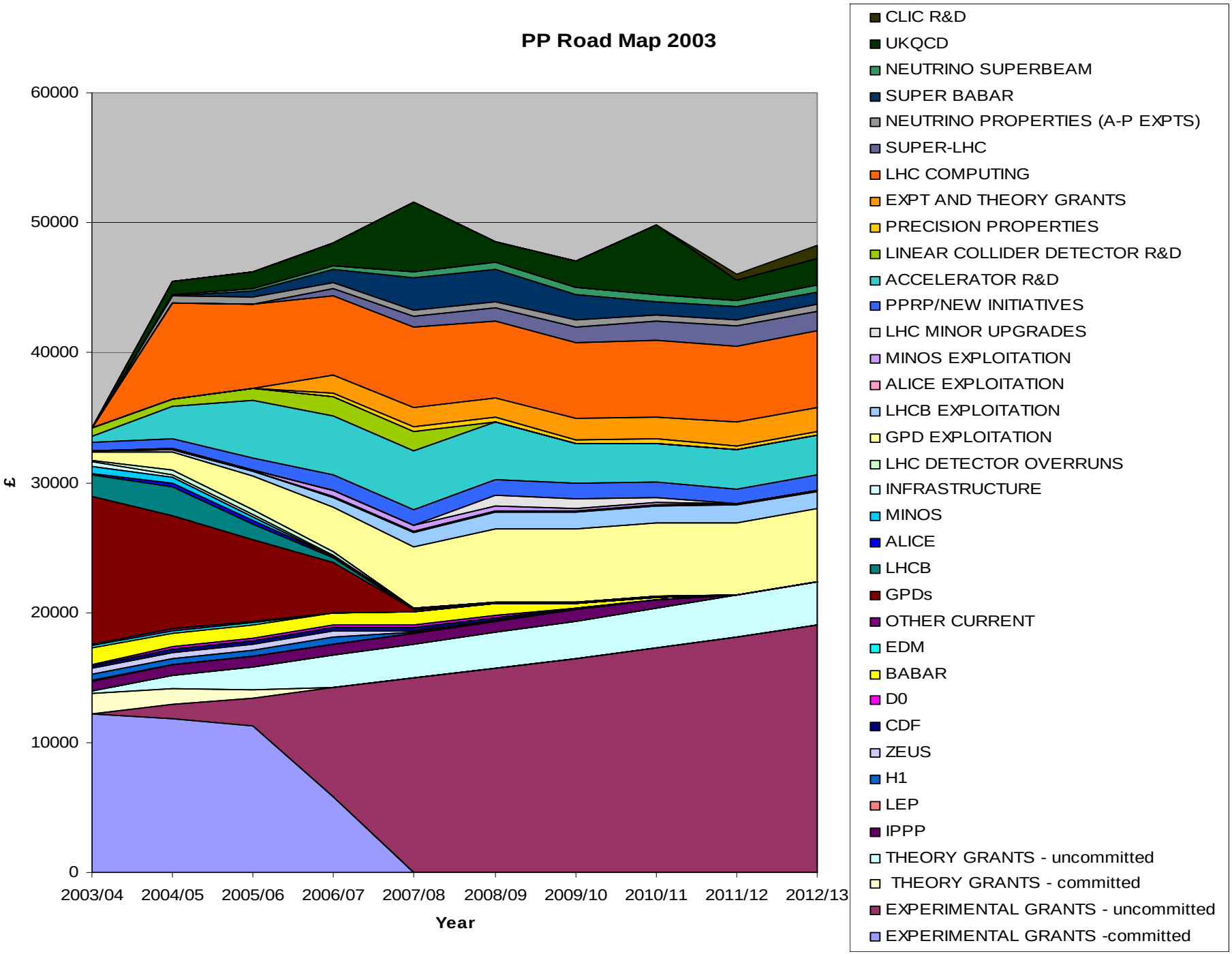
Jenny Thomas

What was in the planning tables coming into PR



Jordan Nash

No provision for LHC Upgrades, no neutrino programme


PP Road Map 2003
60000
50000
40000
30000
20000
10000
0
£
2003/04
2004/05
2005/06
2006/07
2007/08
2008/09
2009/10
2010/11
2011/12
2012/13
Year
CLIC R&D
UKQCD
NEUTRINO SUPERBEAM
SUPER BABAR
NEUTRINO PROPERTIES (A-P EXPTS)
SUPER-LHC
LHC COMPUTING
EXPT AND THEORY GRANTS
PRECISION PROPERTIES
LINEAR COLLIDER DETECTOR R&D
ACCELERATOR R&D
PPRP/NEW INITIATIVES
LHC MINOR UPGRADES
MINOS EXPLOITATION
ALICE EXPLOITATION
LHCB EXPLOITATION
GPD EXPLOITATION
LHC DETECTOR OVERRUNS
INFRASTRUCTURE
MINOS
ALICE
LHCB
GPDs
OTHER CURRENT
EDM
BABAR
D0
CDF
ZEUS
H1
LEP
IPPP
THEORY GRANTS - uncommitted
THEORY GRANTS - committed
EXPERIMENTAL GRANTS - uncommitted
EXPERIMENTAL GRANTS -committed