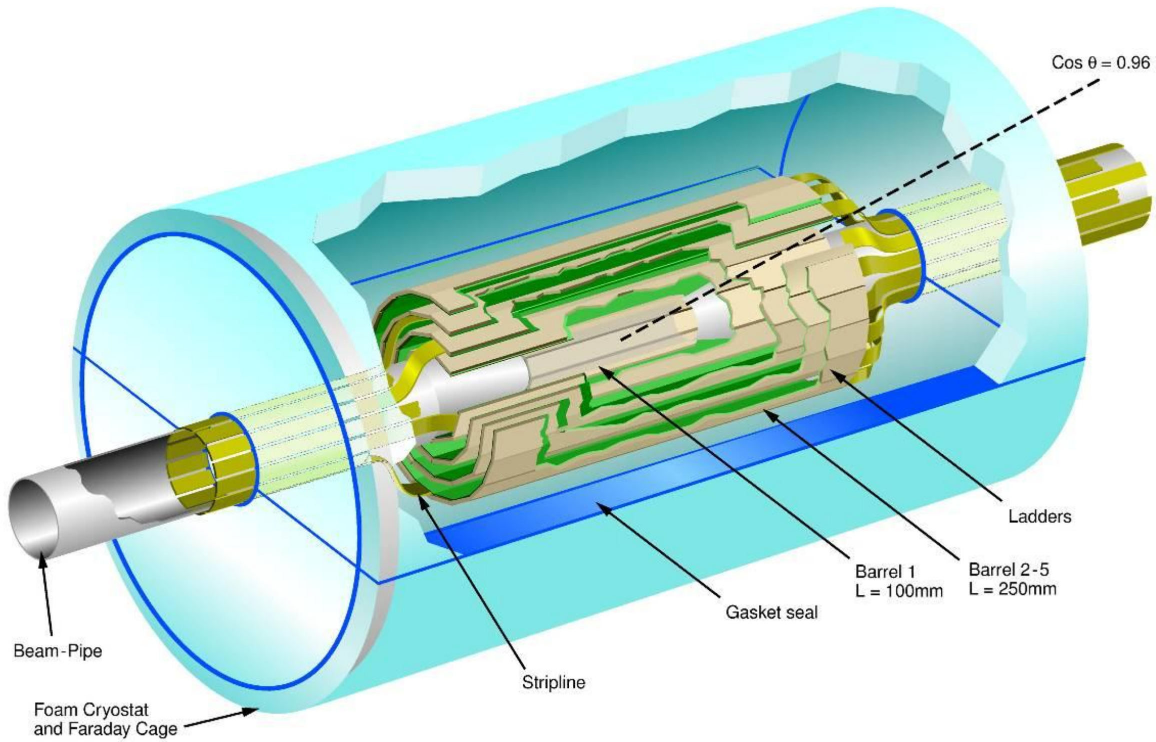
LCFI – some comments on the last three years

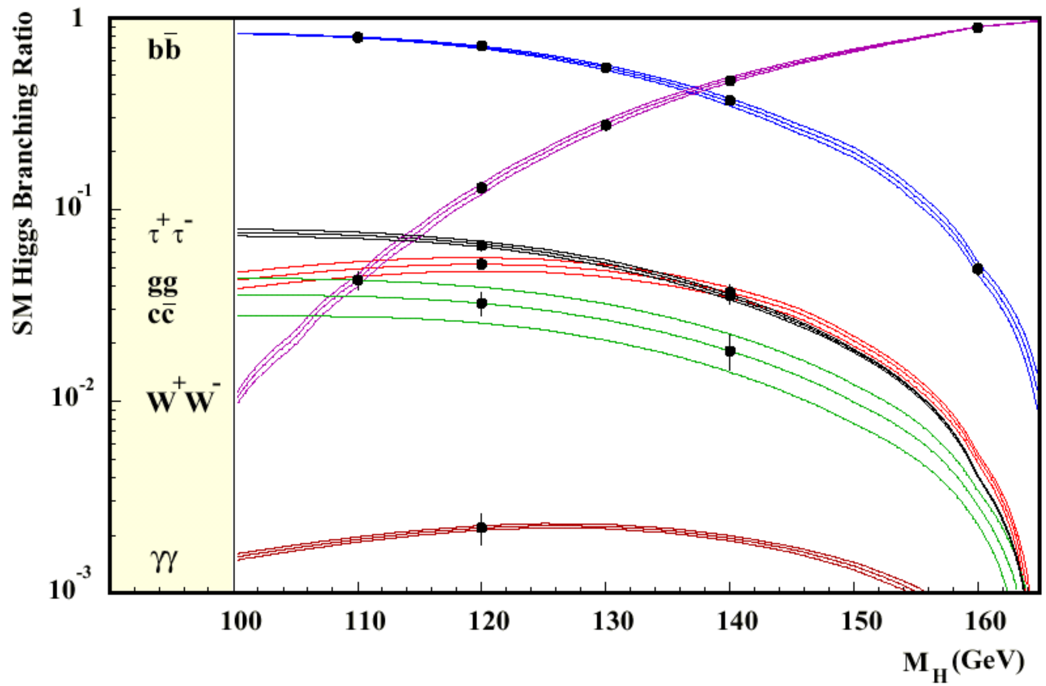
- Introduction.
- LCFI – the last three years:
  - Vertex Package and physics studies.
  - Sensor and electronics production and testing.
  - Mechanical studies.
- Proposed future projects in which LCFI personnel are involved.
- Summary.



Introduction

- The case for the (I)LC remains: not dependent on STFC!
- Two examples:
  - The LHC will allow measurement of ratios of many Higgs BRs to about 20%, the SLHC to about 10%.
  - The SLHC will allow measurement of the Higgs self-coupling to about 20%.
- It is likely that improved precision is needed for both measurements...and the way forward is then the ILC (or at least a LC).

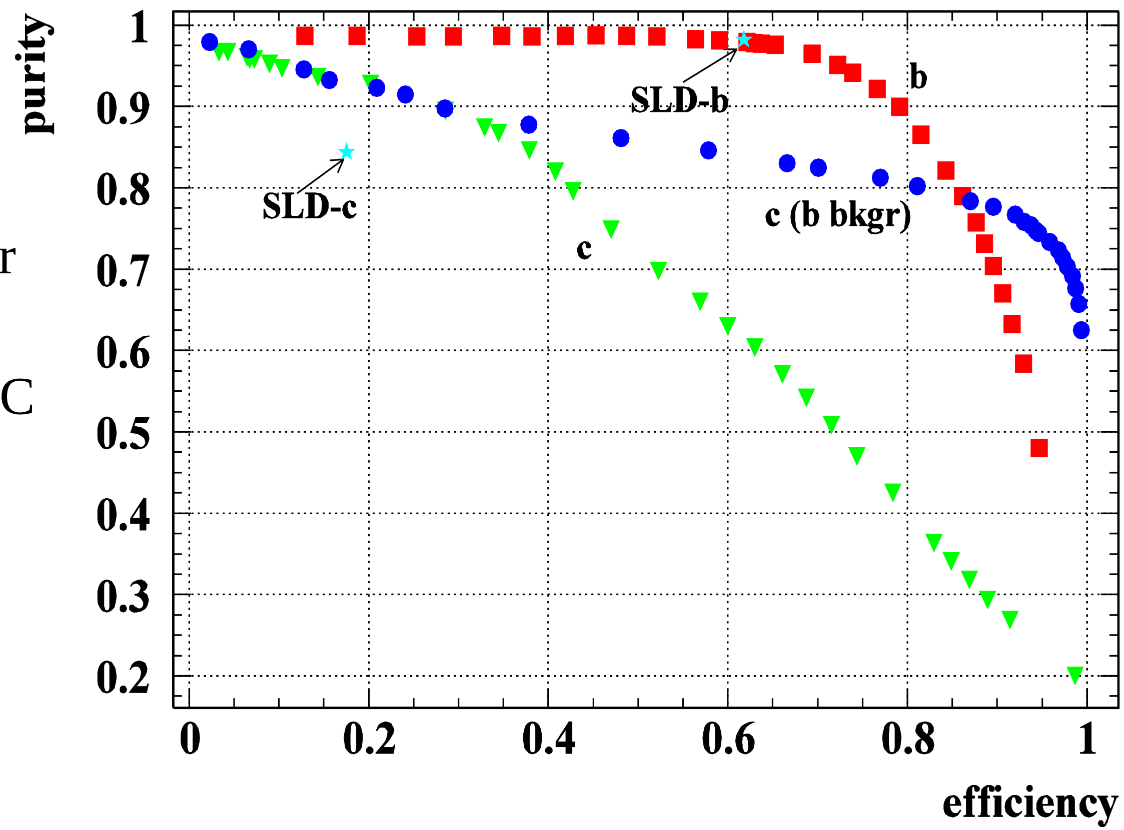
- C.f. Higgs BR measurements at ILC.



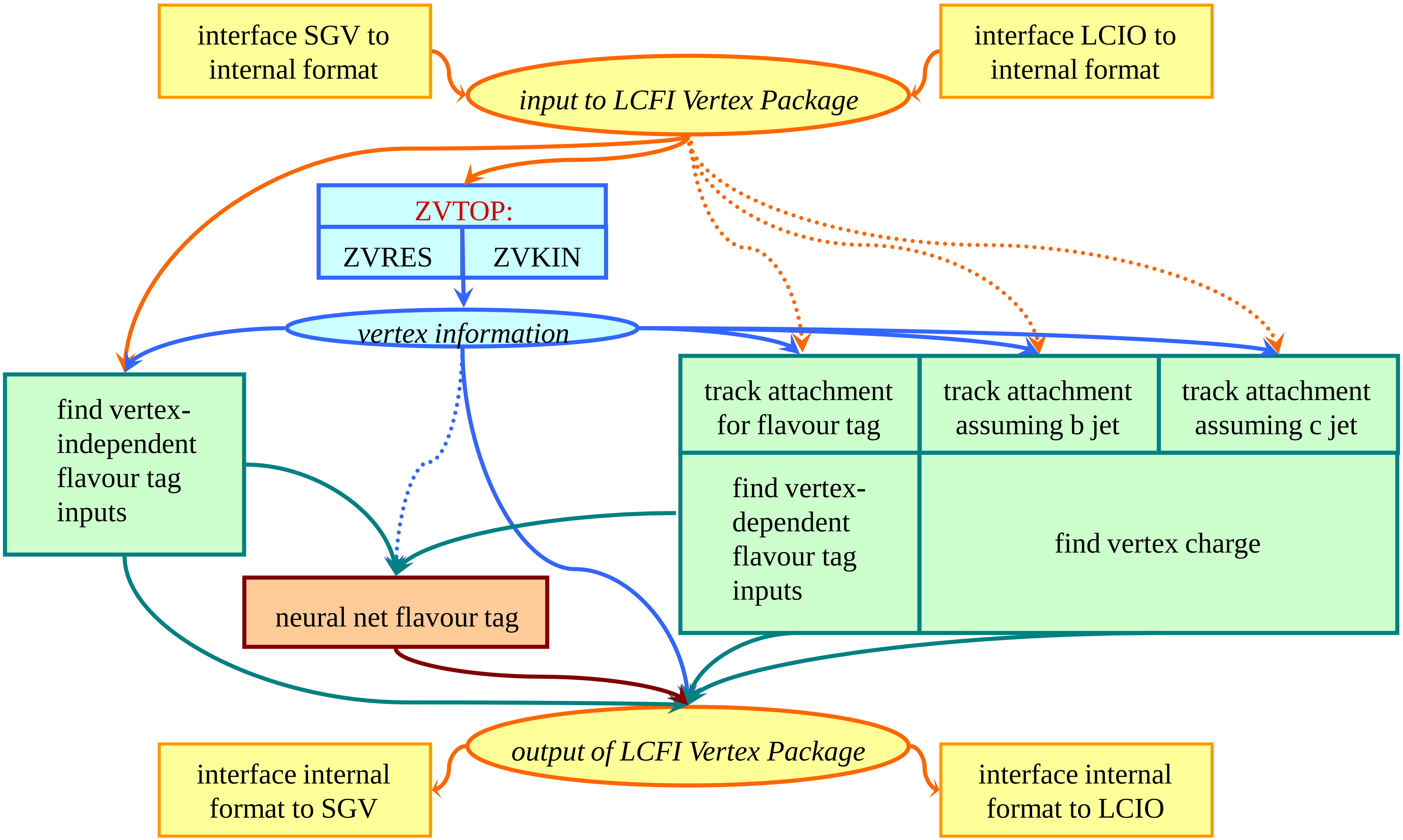
- Achieved because of clean interactions, understood initial state...
- ...and first class flavour ID.

Physics studies – the LCFI Vertex Package

- LCFI proposal submitted April 2005.
- LCFI had software, but not compatible with ILC software frameworks.
- Had performed studies of flavour and charge ID used fast MC.
- No pattern recognition – used MC information to form tracks.
- Identification of photon conversions, K_S^0 and Λ decays used MC info.
- No LCFI studies of performance of VXD and software for ILC physics.



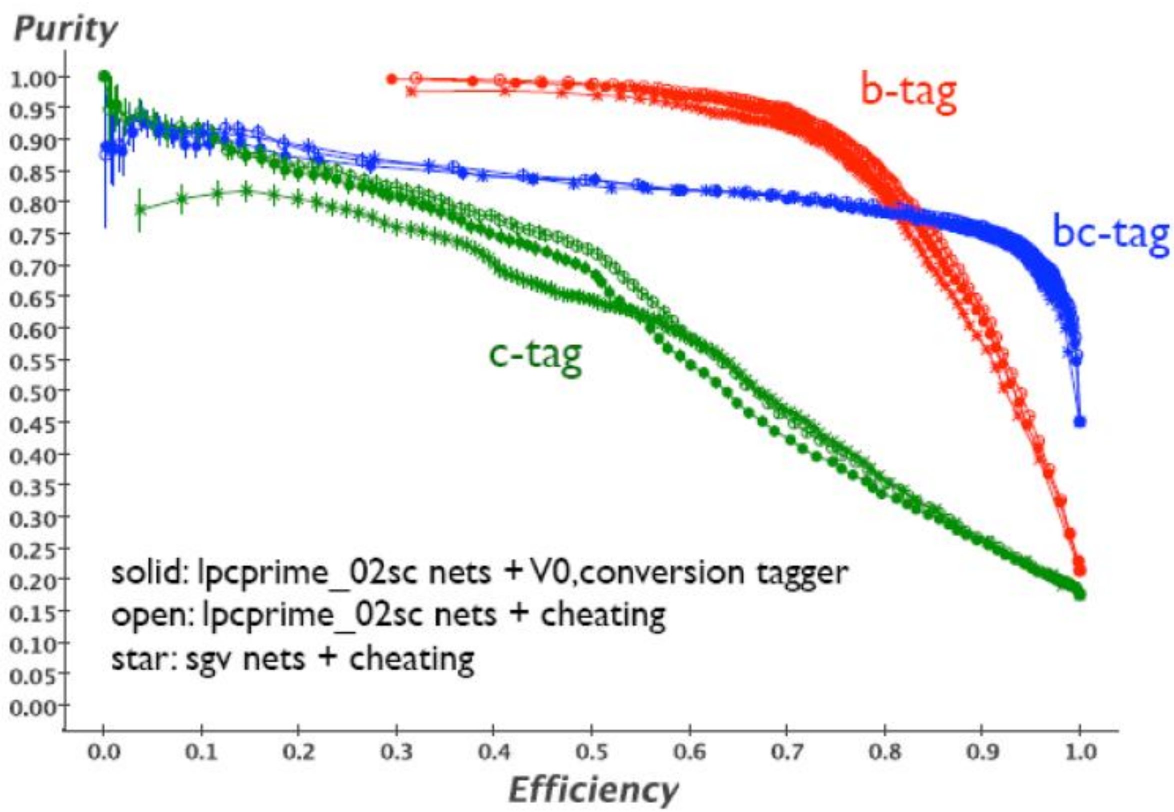
Physics studies – the LCFI Vertex Package



Physics studies – the LCFI Vertex Package

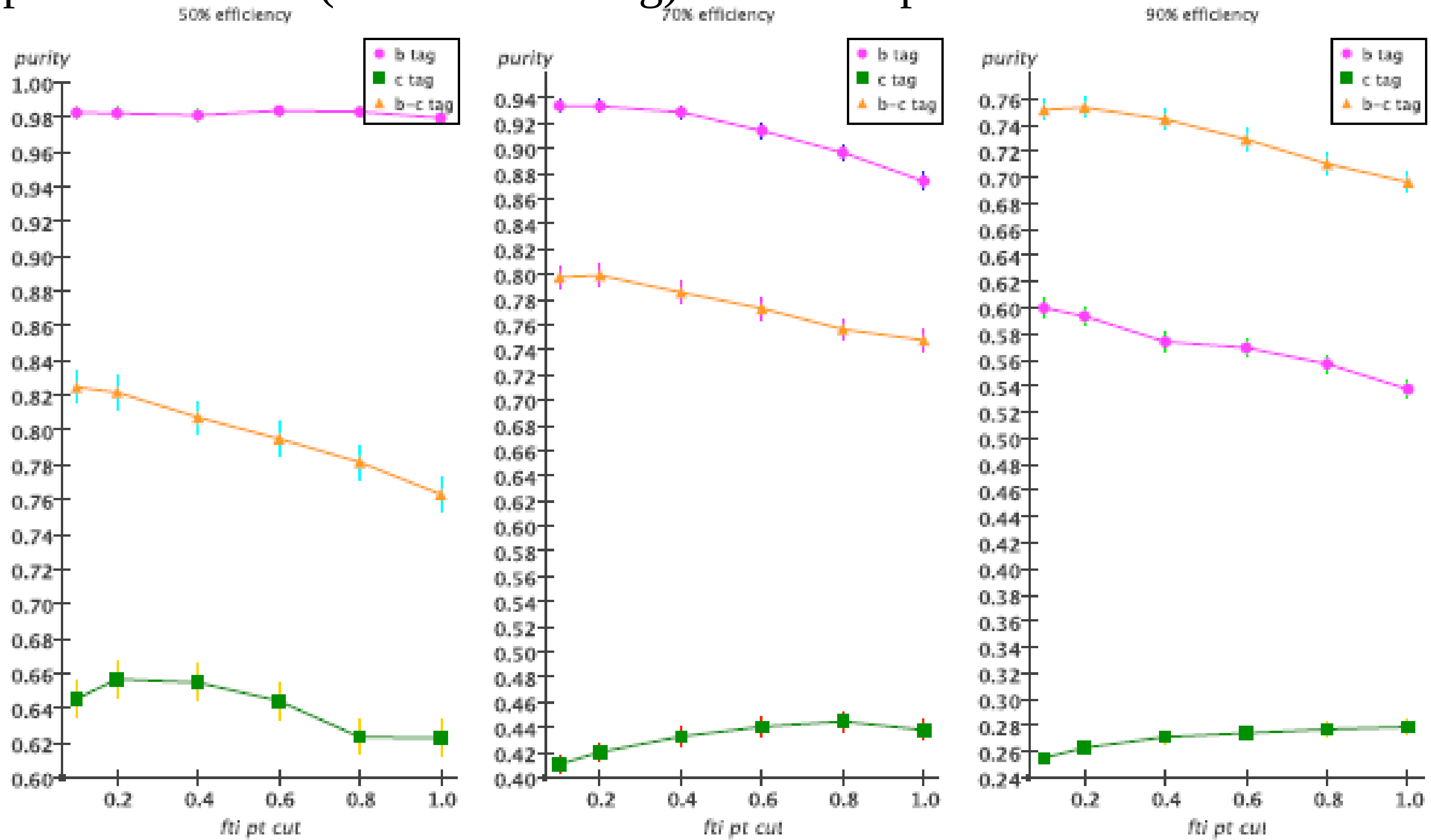
- Vertex Package now available to LC community.
- Fully integrated into ILD software framework and usable elsewhere through LCIO.
- Uses results of pattern recognition and track fitting.
- Identifies photon conversions, K_S^0 and Λ decays using measured tracks.
- Widely used, by LCFI and others, in context of both ILD and SiD.

- For example, flavour identification performance of LDC′ detector using LCFI package, comparing various levels of realism:



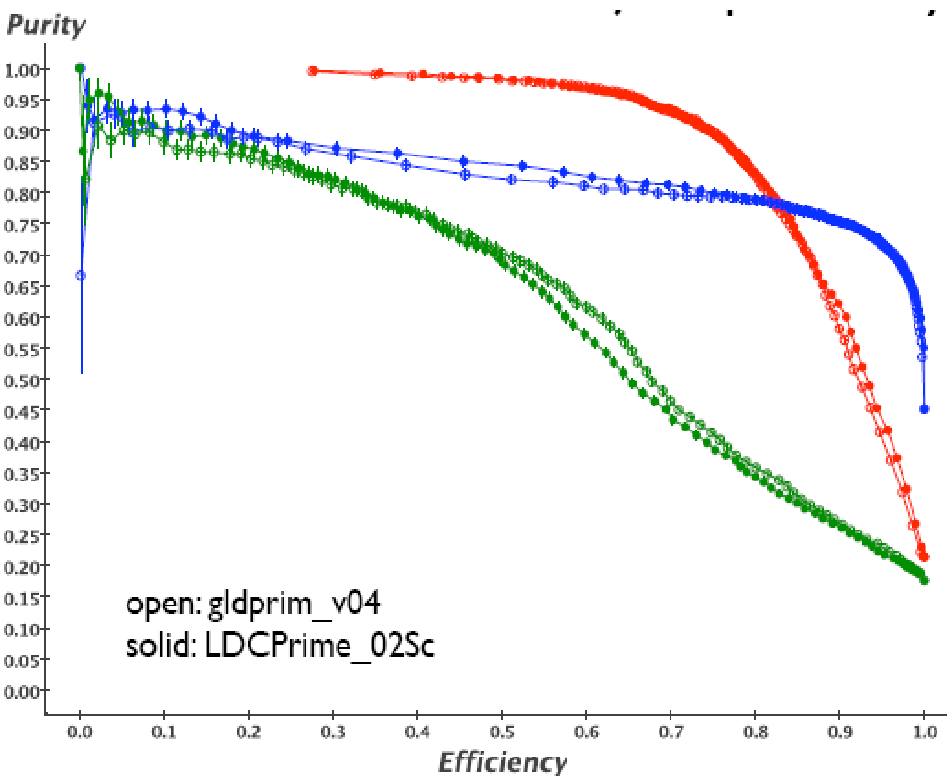
Physics studies – the LCFI Vertex Package

- Optimisation of Package also performed, train neural nets for specific detector (realistic tracking)...
- ...and choose parameters, e.g. cut on transverse momentum for flavour tag inputs:

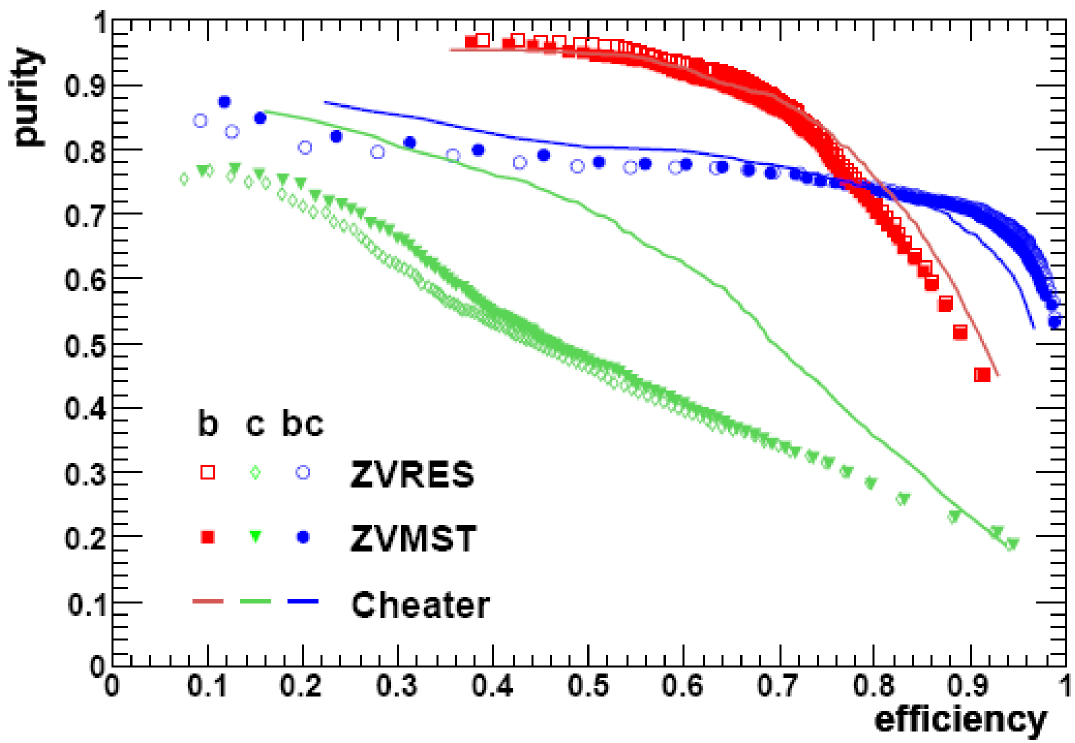


Physics studies – the LCFI Vertex Package

- Vertex Package has been used to compare performance of different detector designs.
- E.g. LDC′ and GLD′:



- New vertex finder (using minimum spanning tree) implemented.
- Competitive with ZVRES at Z pole (before tuning!).



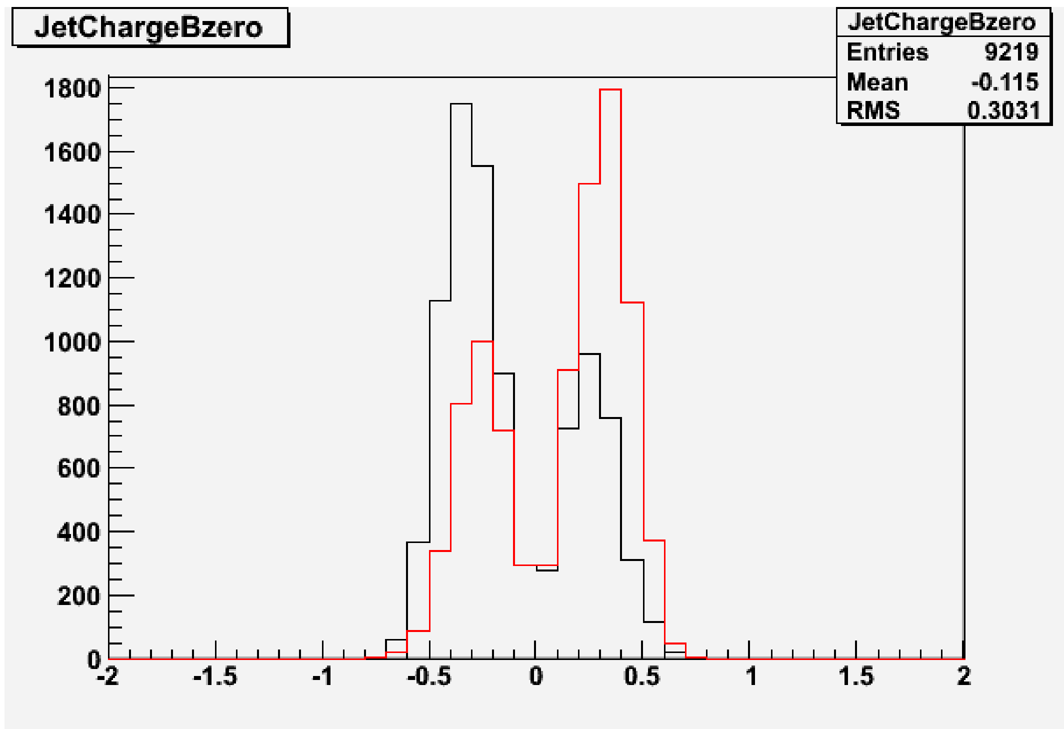
Physics studies – the LCFI Vertex Package

- Further extensions to Vertex Package:
- Neural net code and flavour tag processor now output relative importance of inputs.
- New jet charge determination added:

$$Q = \frac{\sum_{i=0}^{N_{tracks}} p_i^{\alpha} \times q_i}{\sum_{i=0}^{N_{tracks}} p_i^{\alpha}}$$

- Optimisation (using $e^+e^- \rightarrow t\bar{t}$ sample) gives $\alpha = 0.3$.

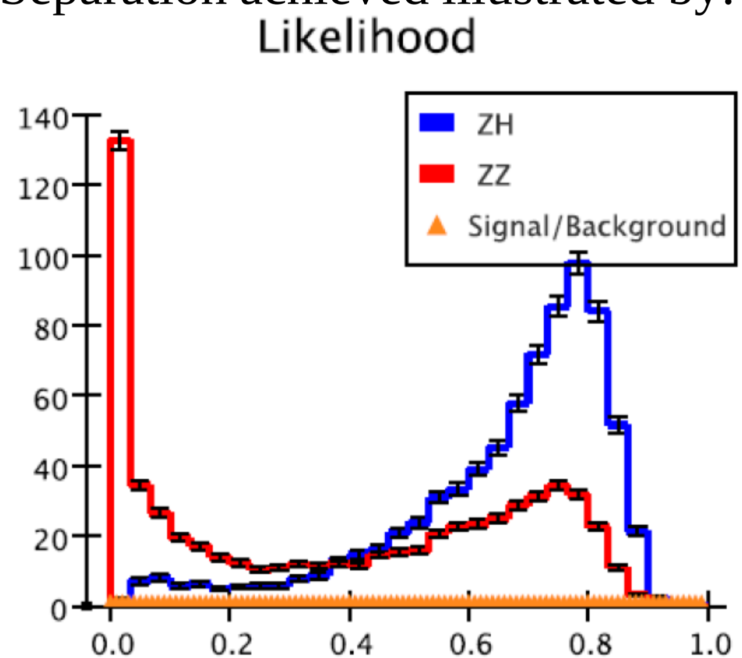
- Allows quark charge identification in cases that hadronisation results in B^0 production.
- (Fundamental limits set by $B^0\overline{B^0}$ mixing!)



Physics studies

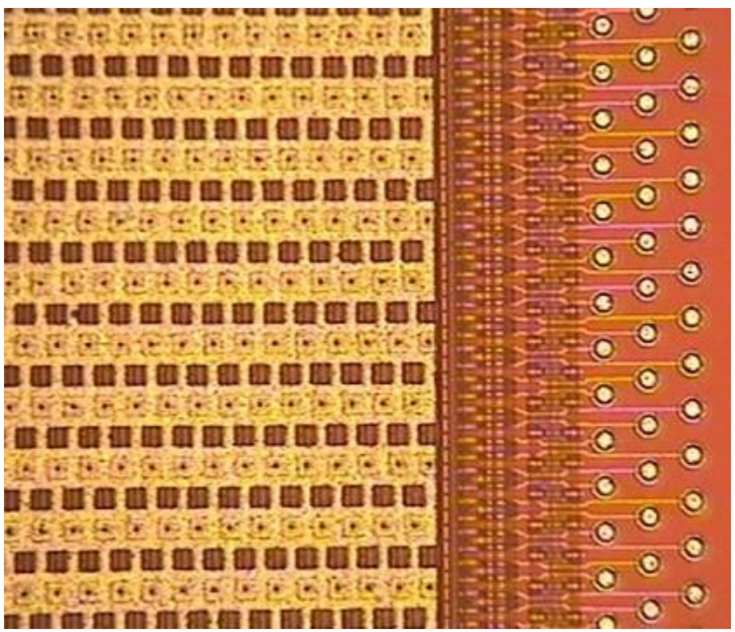
- LCFI has made major progress with its physics benchmark studies:
  - Measurement of Higgs branching ratios.
  - $e^+e^- \to ZH \to \nu\bar{\nu}\, c\bar{c}$ (with SiD).
  - Anomalous Wtb coupling in $e^+e^- \to t\bar{t}$ (with SiD).
  - top reconstruction in the 6-jet channel (with ILD).
  - $e^+e^- \to ZHH$ (with SiD).
- Studies performed in collaboration with the relevant groups in the two detector concepts.
- Will form part of Letters of Intent of the SiD and ILD concepts.

- E.g. Higgs BR in $e^+e^- \to ZH \to l\bar{l}\, q\bar{q}$ channel.
- LCFI study using full Geant4-based simulation of ILD, including background processes.
- Separation achieved illustrated by:

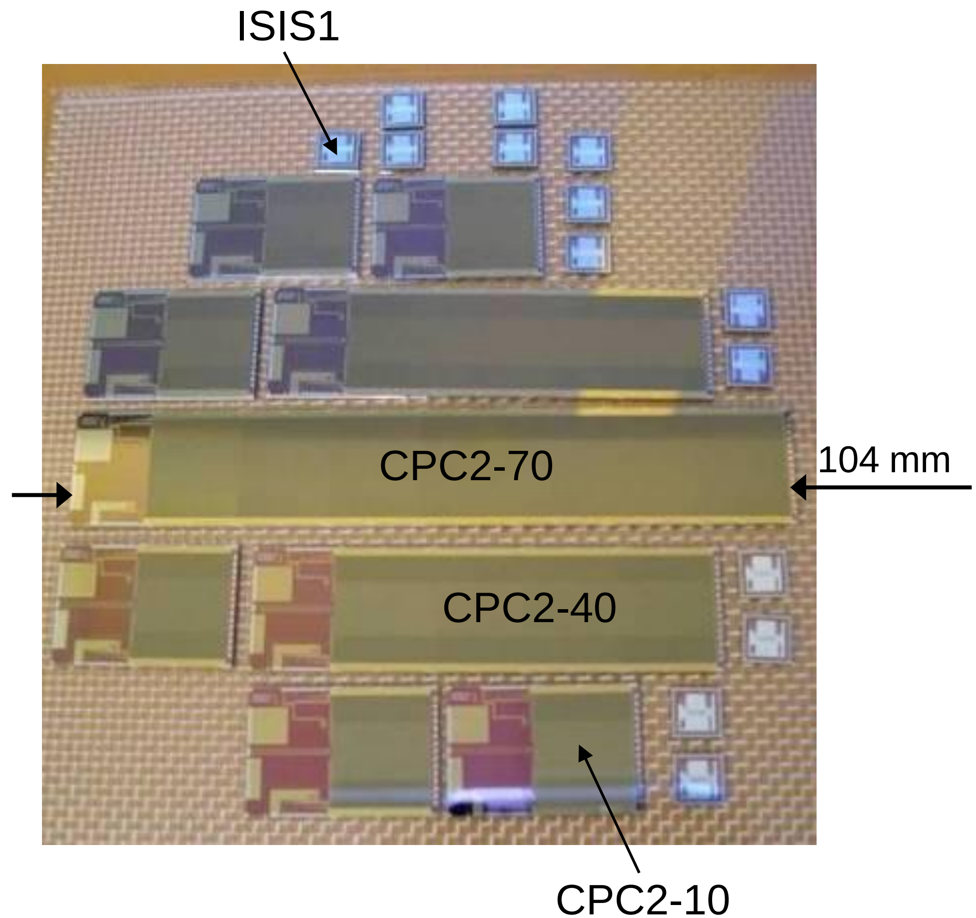


Sensors – column parallel CCDs

- In 2005 we had CPC1 and CPR1, but the resistance of the CPC clock lines was and too high, there was no cluster finding on the readout chip and we didn't have a drive chip at all.
- Now have busline free...

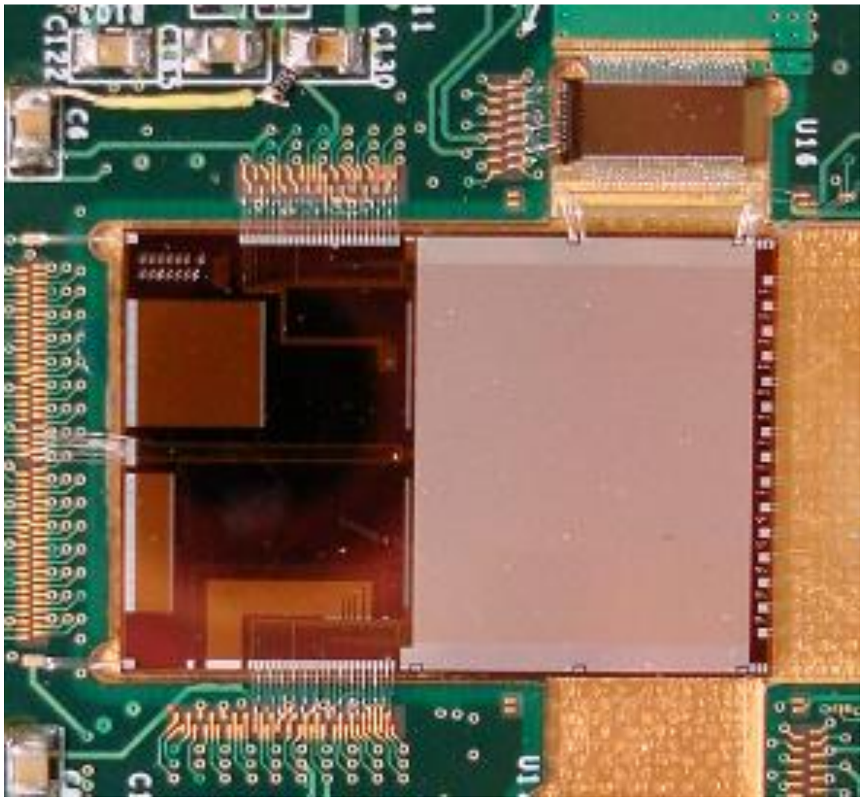


- ...CPC2:

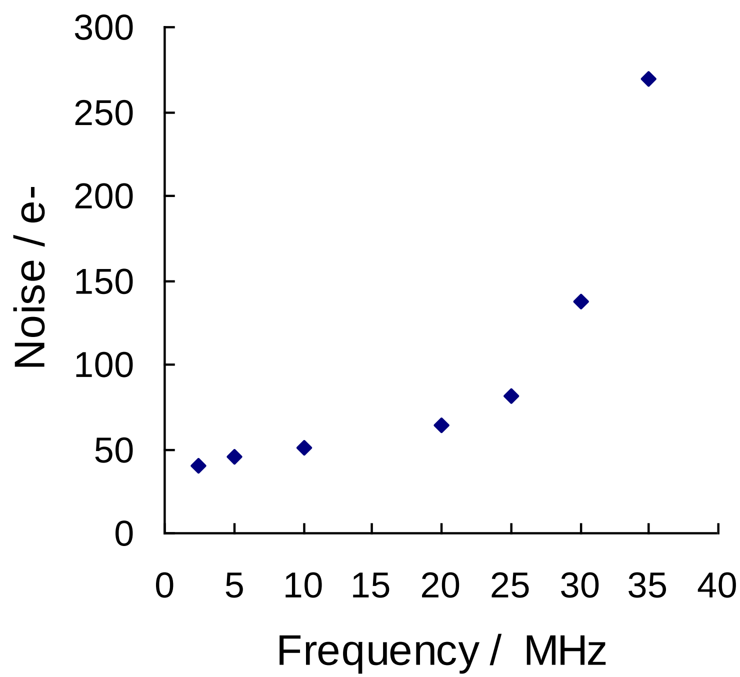


Sensors – CPCCDs and CPCCD drive

- Also have CPD1 drive chip, capable of producing ~ 20 A per phase, here shown wire-bonded to CPC2-10:



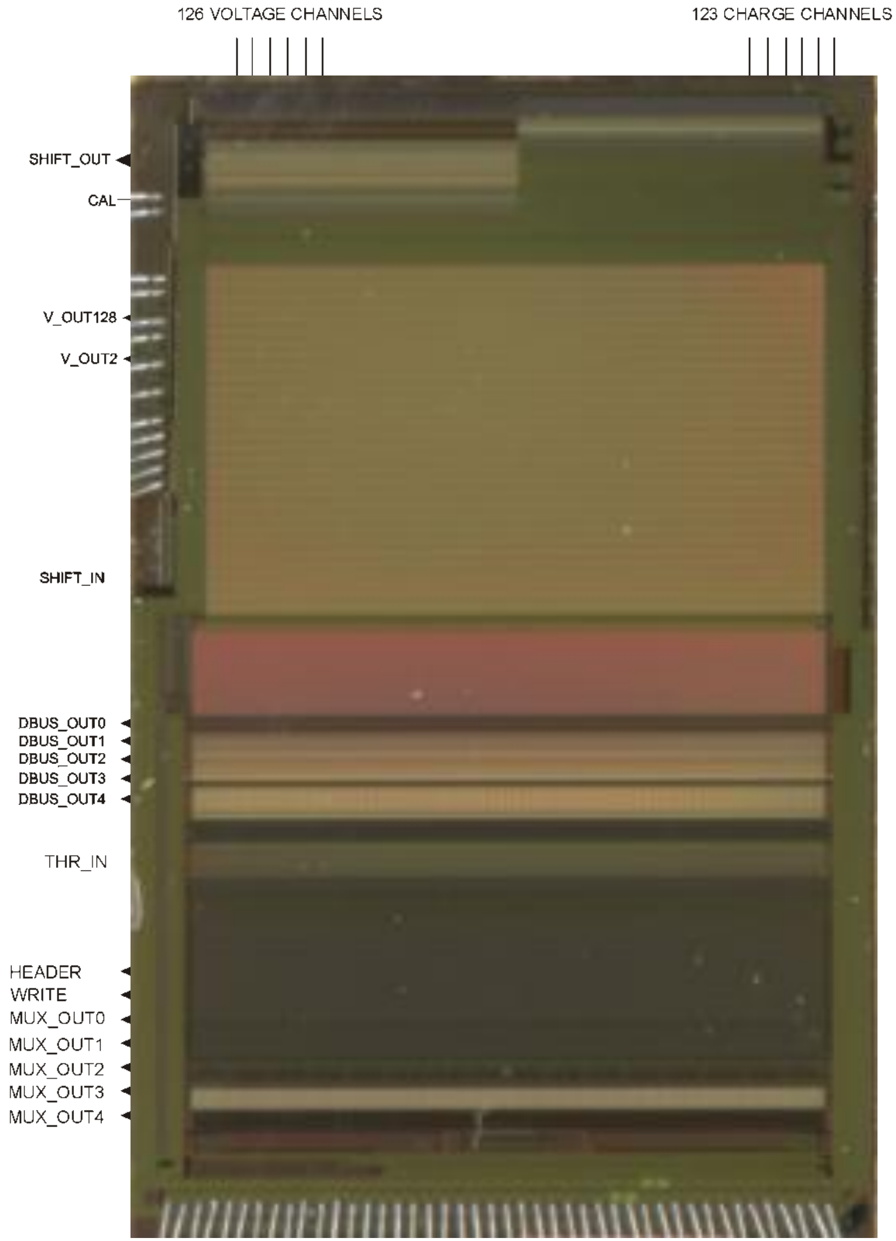
- Low noise operation up to 30 MHz achieved, operation to 50 MHz possible.



- Limitation “substrate bounce”.

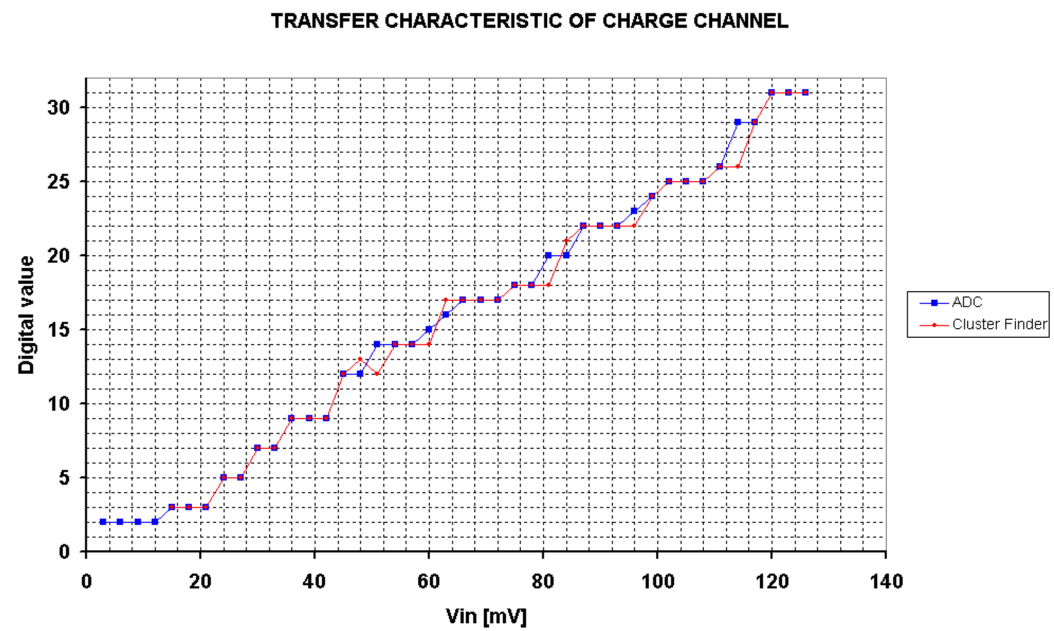
Sensors – CPCCD readout

- CPR2A has:
  - 125 voltage and charge amplifier channels.
  - Analogue and digital test inputs.
  - 5-bit flash ADCs on 20 μm pitch.
  - Cluster finding logic.
  - Sparse readout circuitry.
  - 3-fold increase in column buffer over CPR2.
  - Individual column threshold.
  - Analogue calibration circuit.
  - Improvements to analogue circuitry.



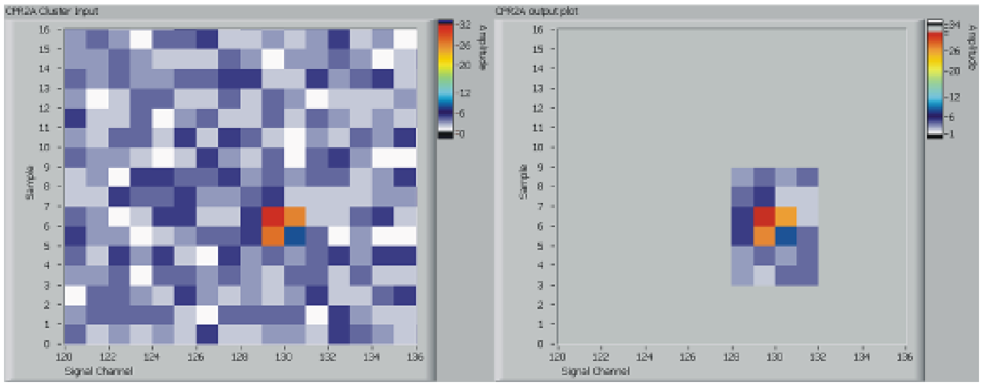
Sensors – CPCCD readout

- Major success: operation of analogue inputs and cluster finding demonstrated for both voltage and charge amplifiers.
- E.g. tests of ADC linearity for charge channel:

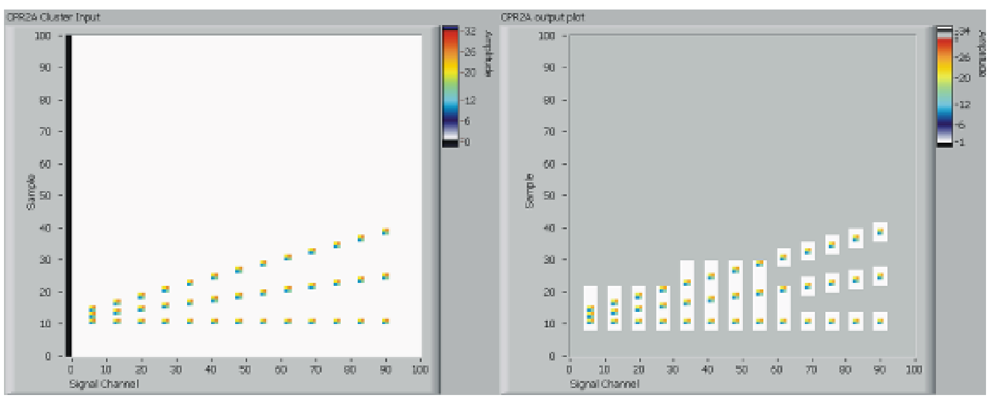


Sensors – CPCCD readout

- Cluster funding performance good.
- E.g. of performance with noise:



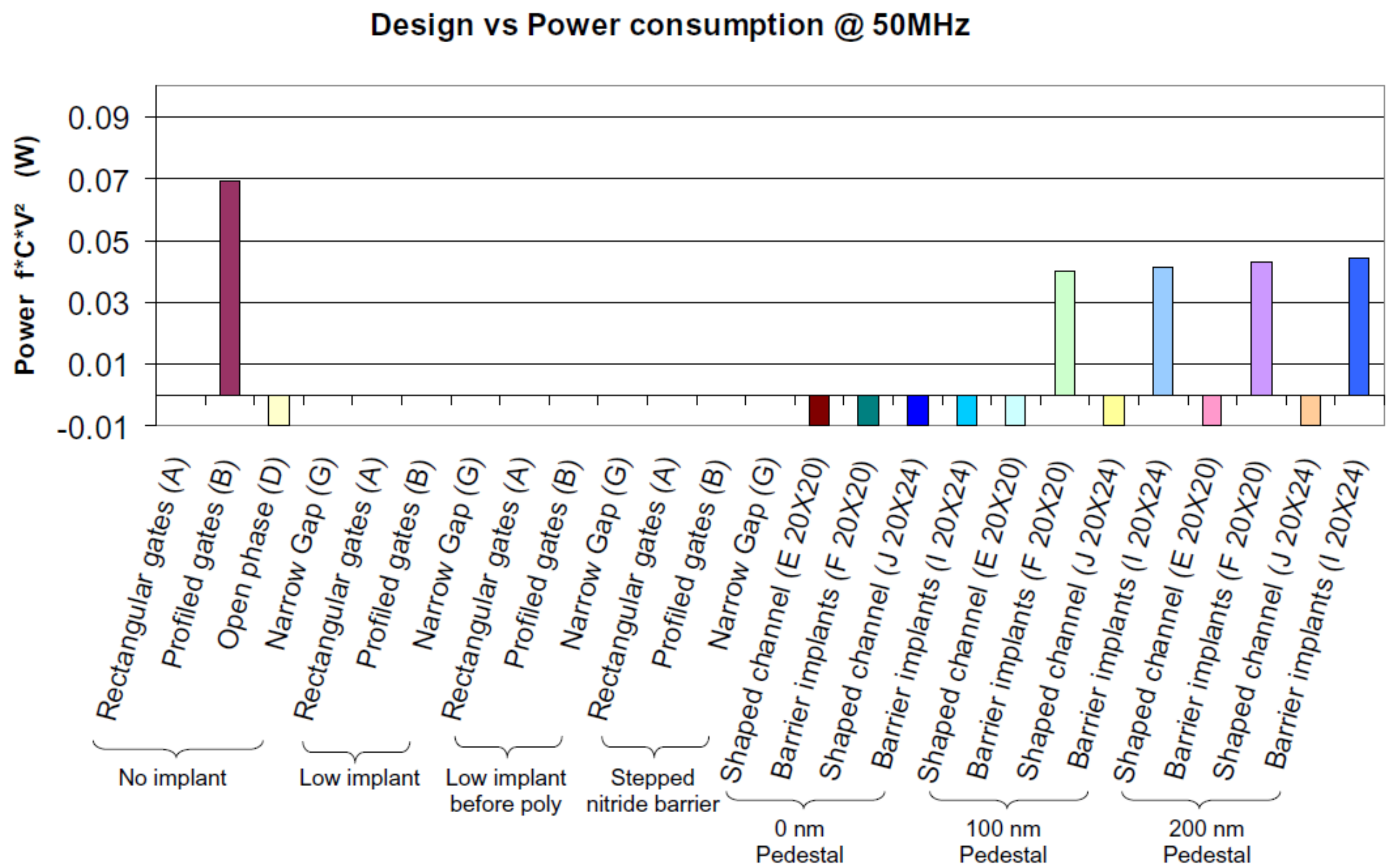
- Check of cluster output optimisation:



- Chip functions without errors to 0.2% occupancy.
- Remaining limitations arise from manufacturing process chosen and are understood.
- Feasibility of column parallel CCD with low mass drive and column parallel readout has been demonstrated.

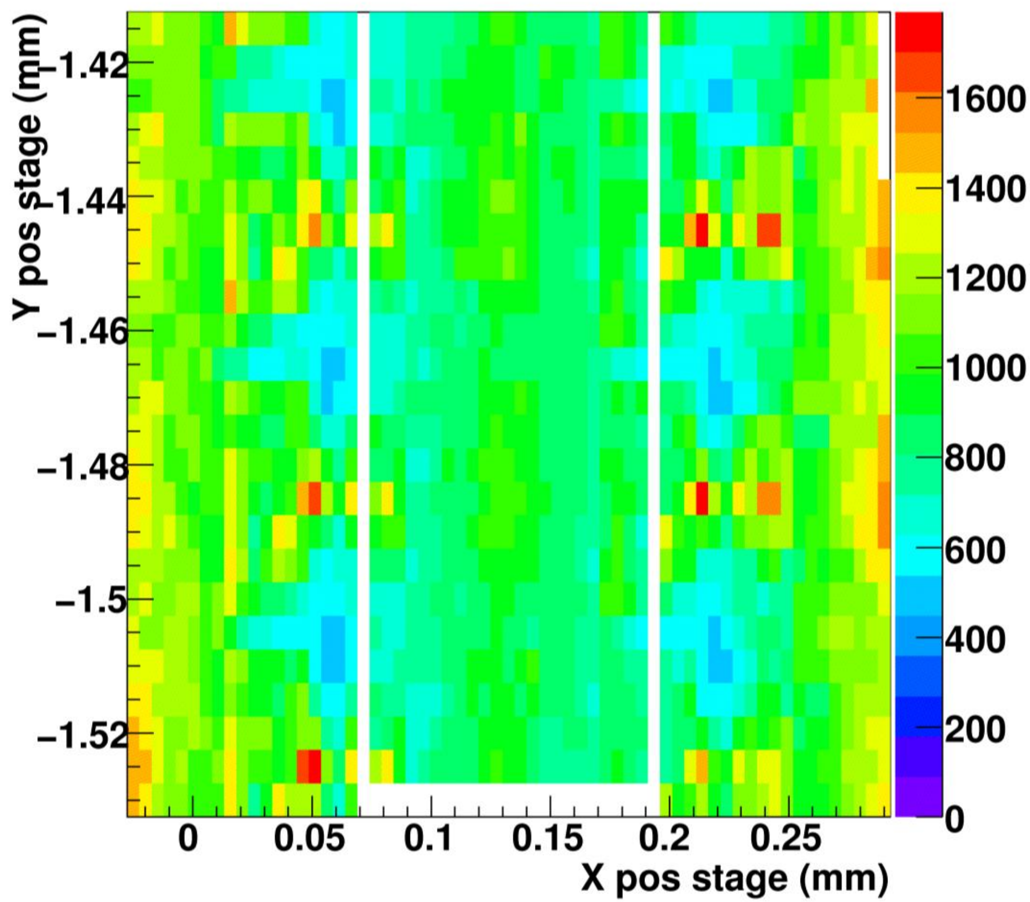
Sensors – reducing CPCCD power requirements

- Test devices (30!) designed to study min inter-gate barriers/clock amplitudes.
- Figure of merit f×C×V^2 (~ power), -ive values indicate device doesn't function.



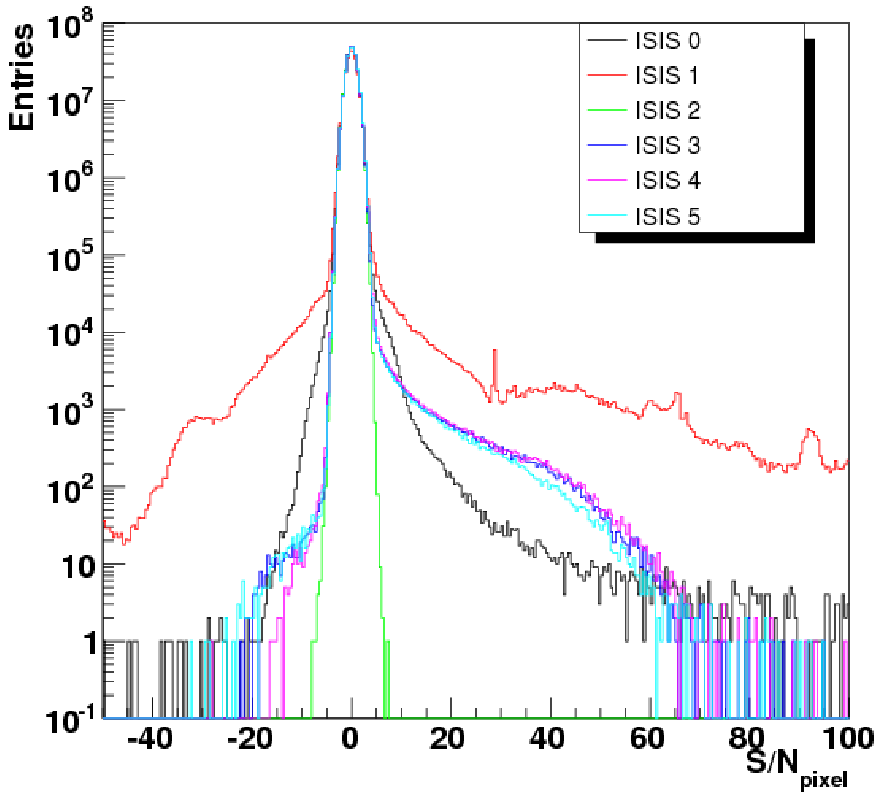
Sensors – tests of ISIS1

- In April 2005, principle not proven.
- ISIS1 (no p-well) studied in test beam at DESY (1...6 GeV electrons) in Oct 2007.
- Noise =13.406 ± 0.005 ADC counts.
- Signal to noise close to photogate 36.8 ± 0.2 ADC counts.
- Position resolution 9.4 ± 0.2μm.
- Efficiency = 59.3%!
- Inefficiency due to large and asymmetric pitch of proof-of-principle devices.
- Confirmed by laser measurements of signal as function of position:

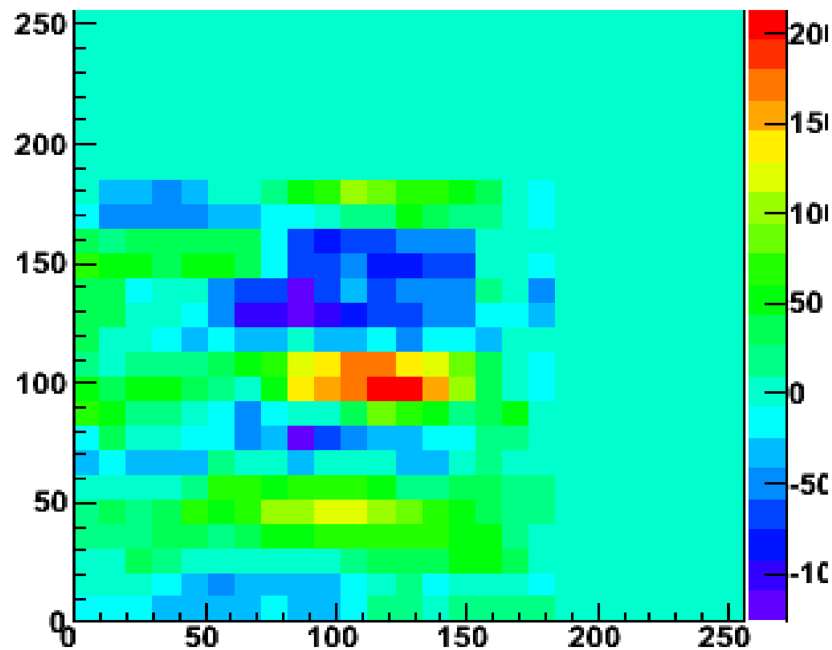


Sensors – tests of ISIS1

- Beam test at CERN (HE π beam) Aug 2008 using EUDET telescope.
- Hits in ISIS1 with (0, 1, 2 dead) and without (3, 4, 5) p-well:



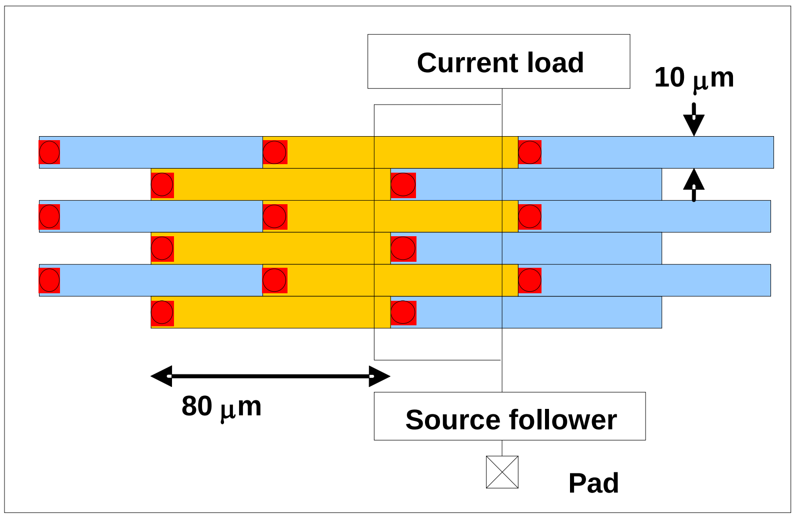
- Tracks observed through ISIS and telescope.
- Here show telescope hits when signals in ISIS5:



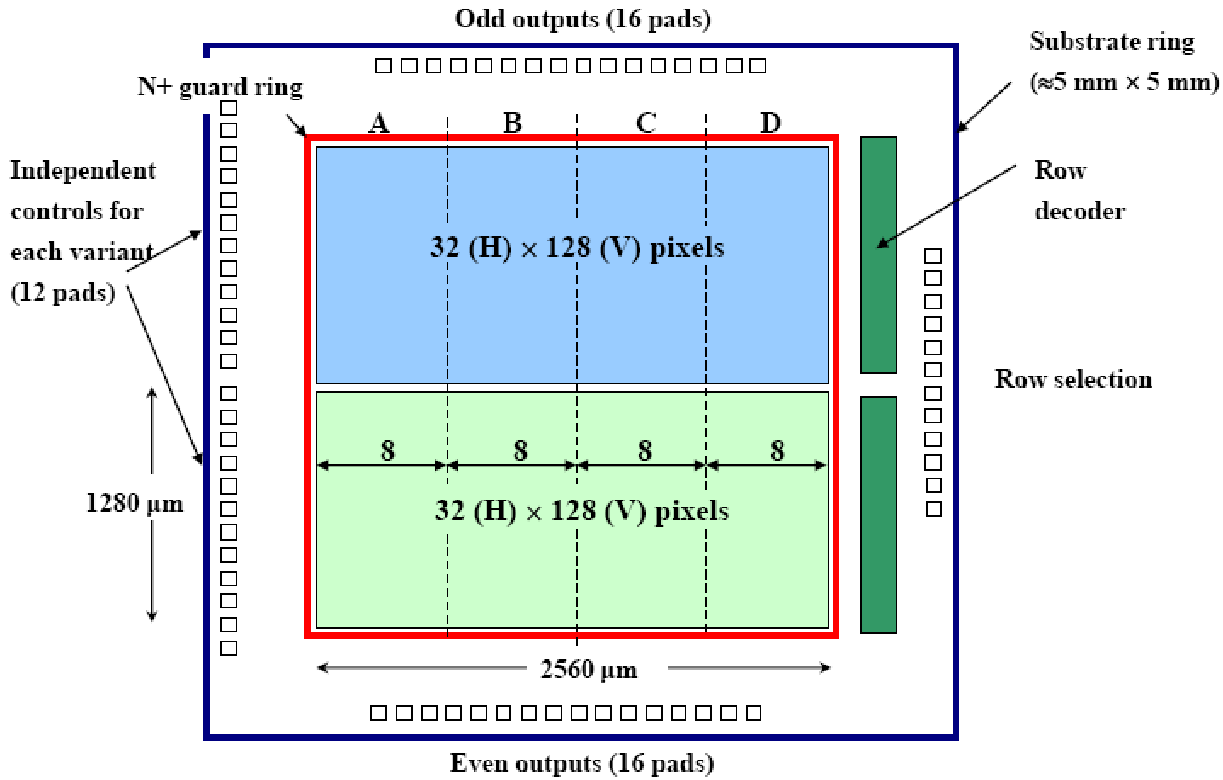
- Now working on alignment.

Sensors – ISIS2

- ISIS2 manufactured by Jazz Semiconductor.
- Developed buried channel and deep p+ implants for LCFI.
- Pixels 80 × 10 μm^2, buried channel 5 μm wide.
- Gates doped poly-silicon, 3 metal layers.

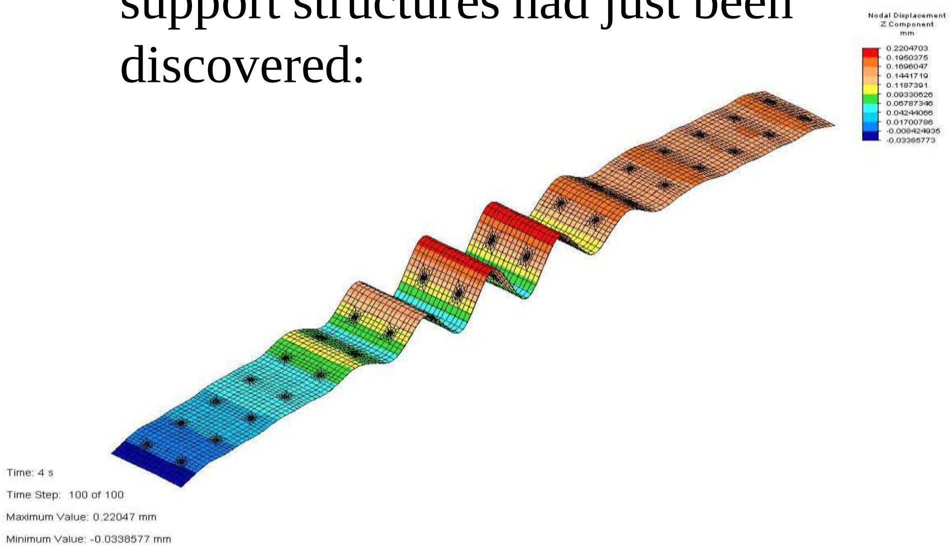


- Many variants to test, with different dopant levels, reset transistor configurations, with/without deep p+, with/without charge collection hole...



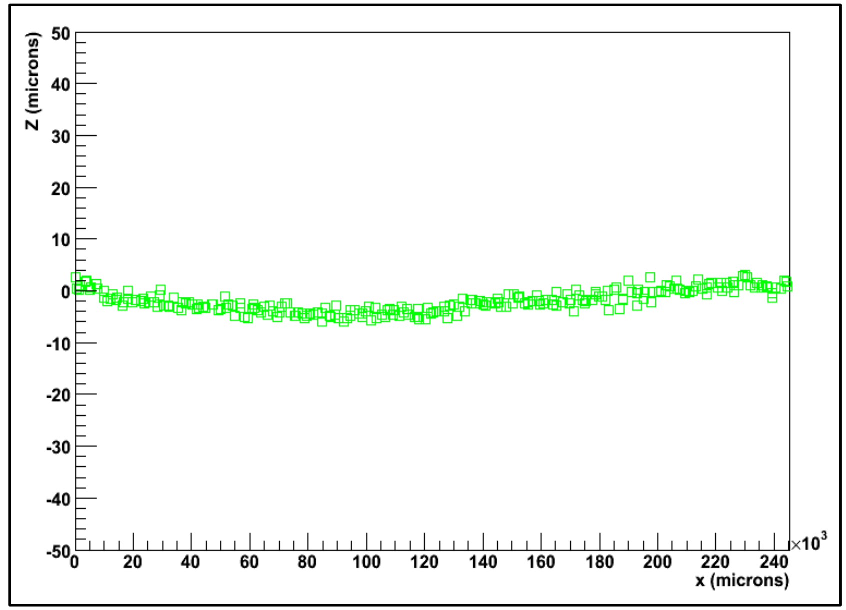
Mechanical studies

- In 2005, the problems with “all silicon” ladders and beryllium support structures had just been discovered:

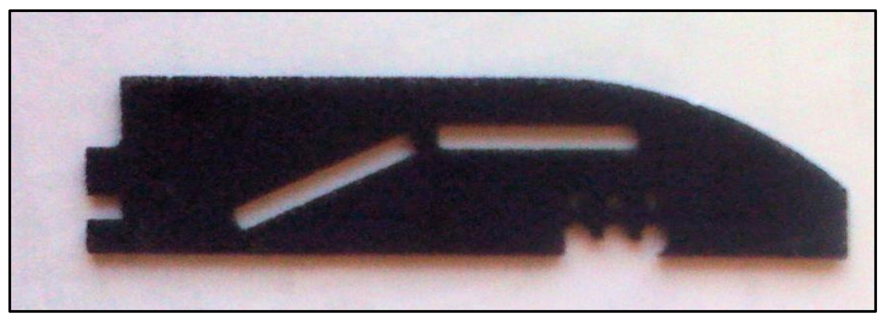


- Search for new, material had begun.
- Have now studied SiC and RVC foams.
- Recently constructed ladders with new fixtures, SiC excellent again.

- SiC foam ladder dev. $\Delta T = 30$ C:



- Machining SiC foam:

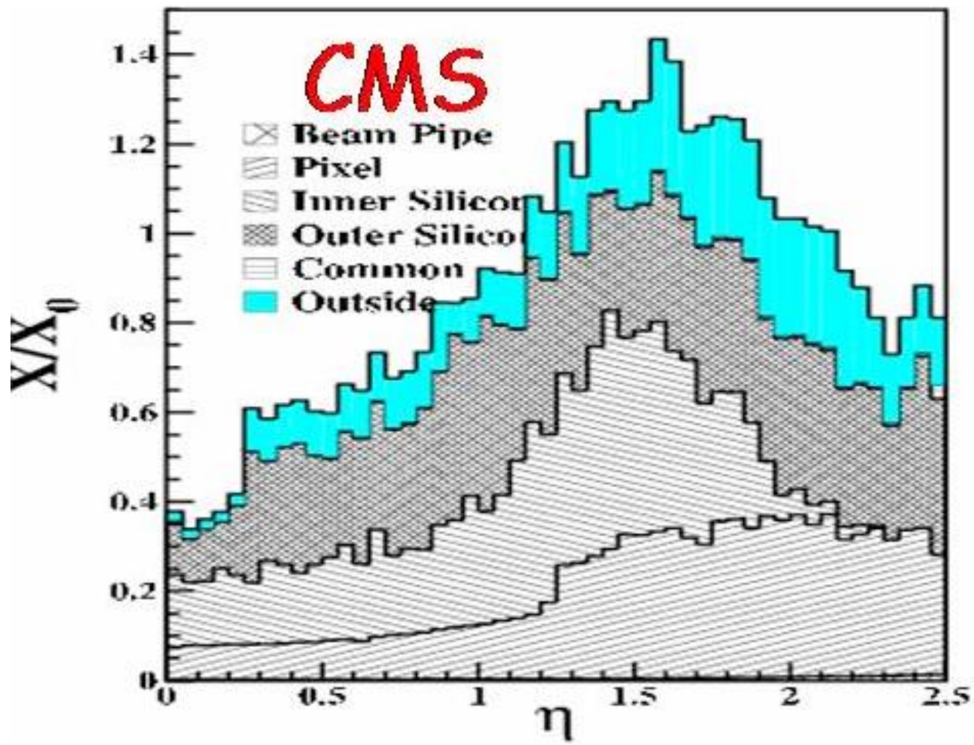


New projects

- Physics studies (FLUID)
  - Apply vertexing algorithms over larger centre-of-mass energy range (e.g. up to CLIC and muon collider energies).
  - Study and optimise flavour and charge identification for extremes of jet energy where current results poor.
  - Investigate vertexing at LHC.
  - Systematic study of new techniques (decision trees...).
- Silicon sensors (SPIDER)
  - Investigate design of silicon sensors for HEP (vertexing, tracking, calorimetry) and other applications.
  - Key technical issues:
  - Complex circuitry for in-pixel processing and prevention of parasitic charge collection e.g. using deep p-well.
  - Robust storage of analogue signals in-pixel.
  - Efficient charge collection from large pixels.

New projects

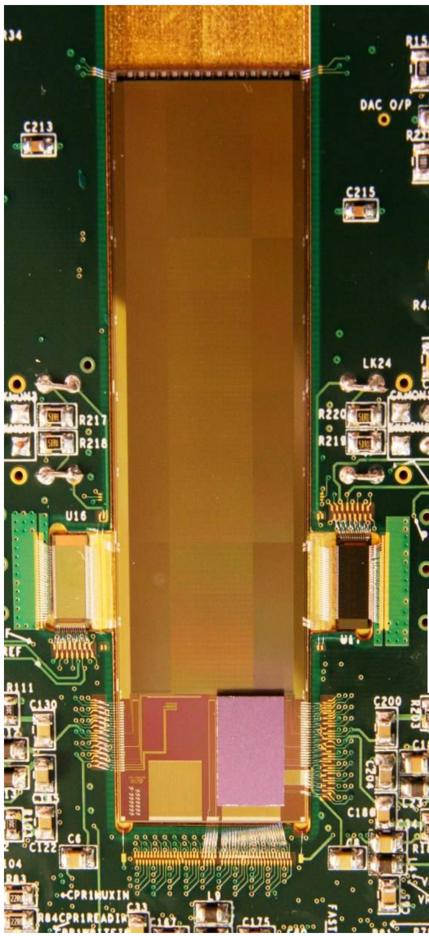
- Mechanical studies (LSSSD).
- Look at application of new materials (e.g. SiC foam) to construction of vertex and tracking detectors for future LC and LHC detectors.
- (Further) develop machining and manufacturing techniques.
- Study gas and liquid cooling of structures.
- Measure characteristics of foams and develop FEA models of detector structures.
- Material budget of CMS tracker:

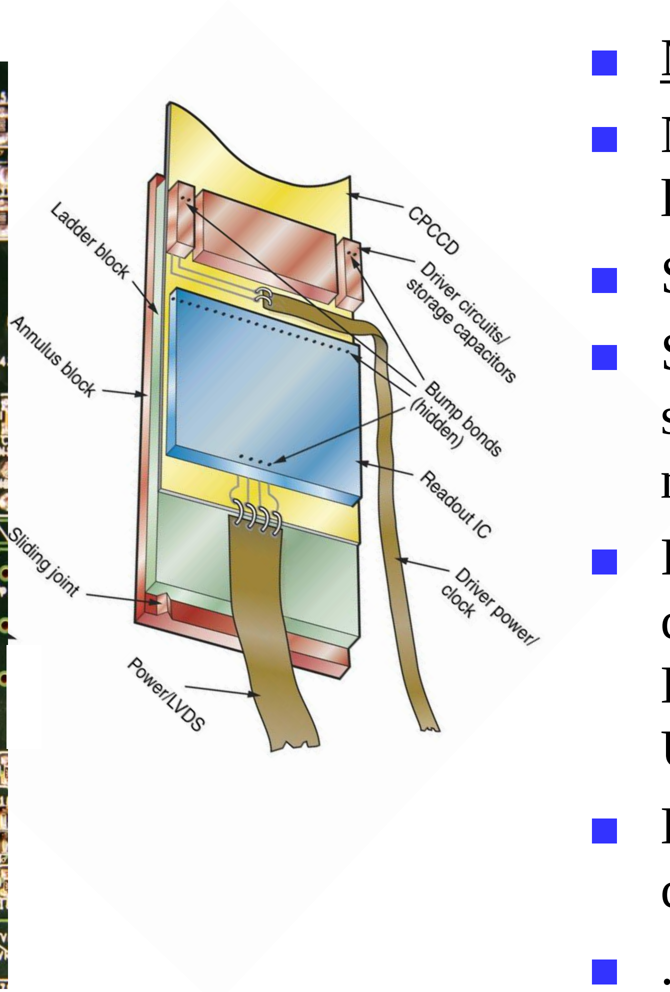


Summary one

- LCFI programme "successfully completed" (Oversight Committee).
- Physics
- Vertex Package developed from tool for specialists to software routinely used by ILC community.
- Now use full simulation and reconstruction.
- New algorithms continue to be added to the Package and optimisation performed.
- Used to compare detector designs and to study specific physics channels by LCFI.
- Sensors
- CPCCD concept shown to be possible solution for VXD at ILC.
- Low noise operation at 30 MHz, operation up to 45MHz demonstrated.
- Drive and readout concepts shown to function.
- Proof of principle ISIS with and without p-well functions well.
- Second generation ISIS designed and constructed using augmented CMOS process, includes control circuitry on chip.

Summary two

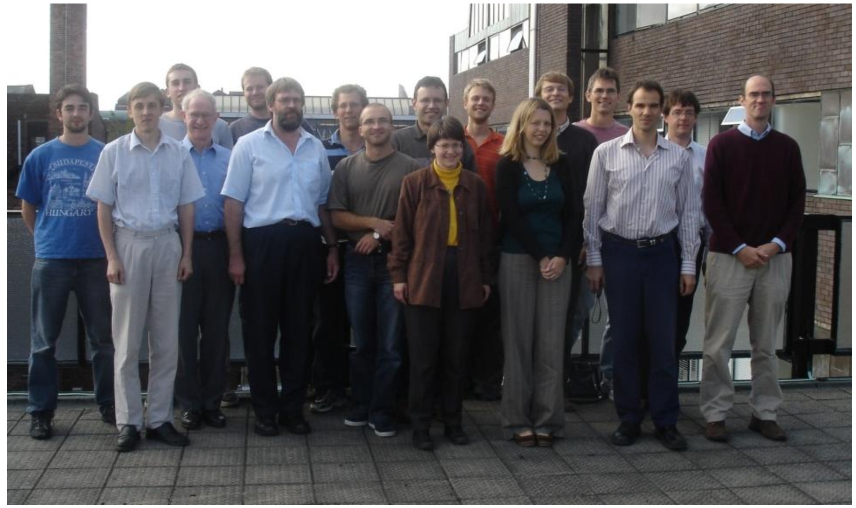




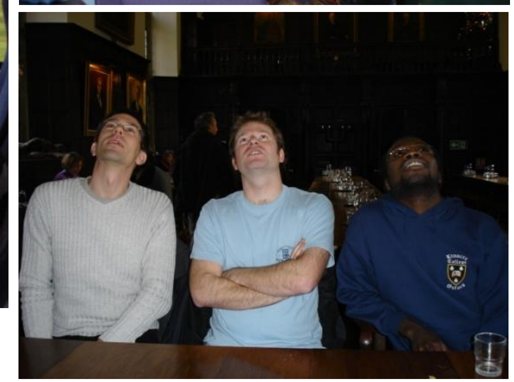
- <u>Mechanical studies</u>
- New fixtures commissioned, new ladders built.
- SiC ladder performance excellent.
- SiC foam successfully machined, starting to map out potential as material for construction of VXD.
- Proposals submitted to PPRP will carry many important aspects of LCFI work forward, with CALICE-UK.
- Hope this provides a route for continued participation in ILC...
- ...and wider application of LCFI work.

Summary three

- Must make sure results published, e.g.
  - Test beam studies.
  - Vertex Package.
  - Physics studies.
  - Sensor tests.



- Complete tests of ISIS2.



- Many thanks to all members (past and present) of LCFI for what has been a very productive and enjoyable collaboration!