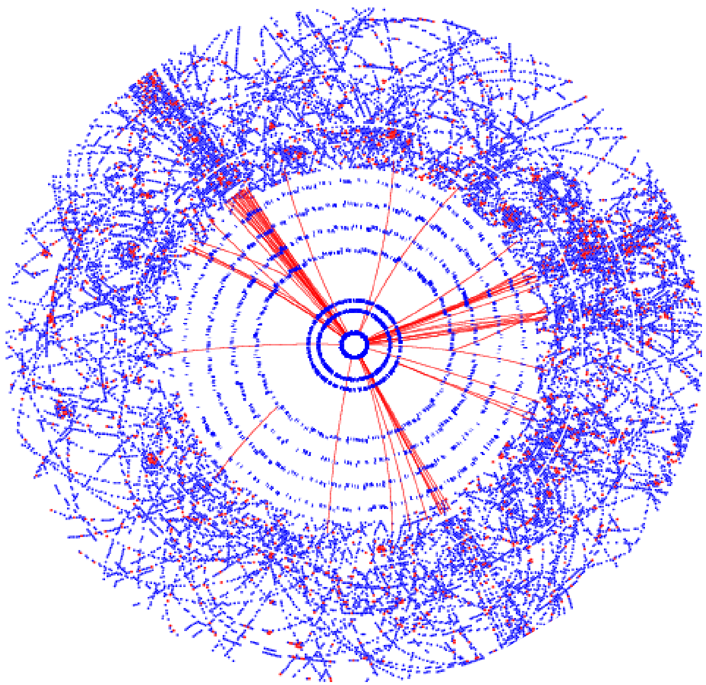
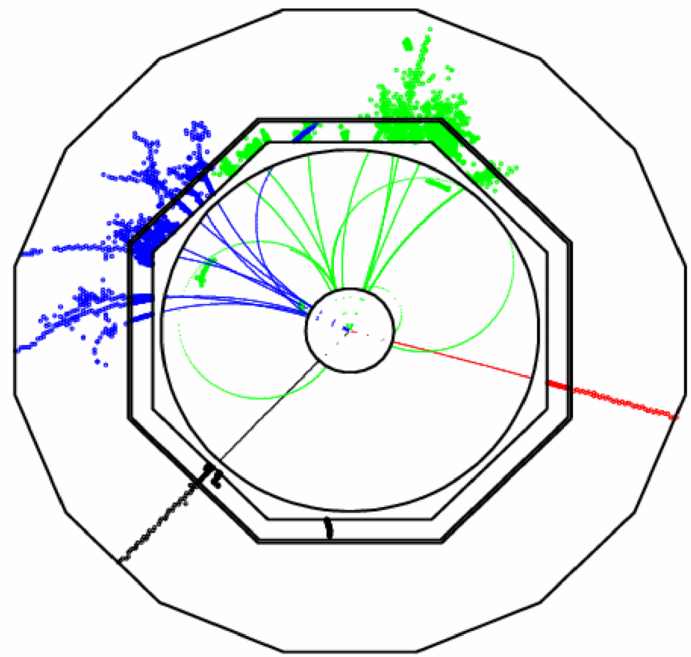
LCFI Programme and Contingency Plans

- Why the ILC and its VXD?
- Sensor development
- Mechanical studies
- Physics
- LCFI contingency plans
- Summary



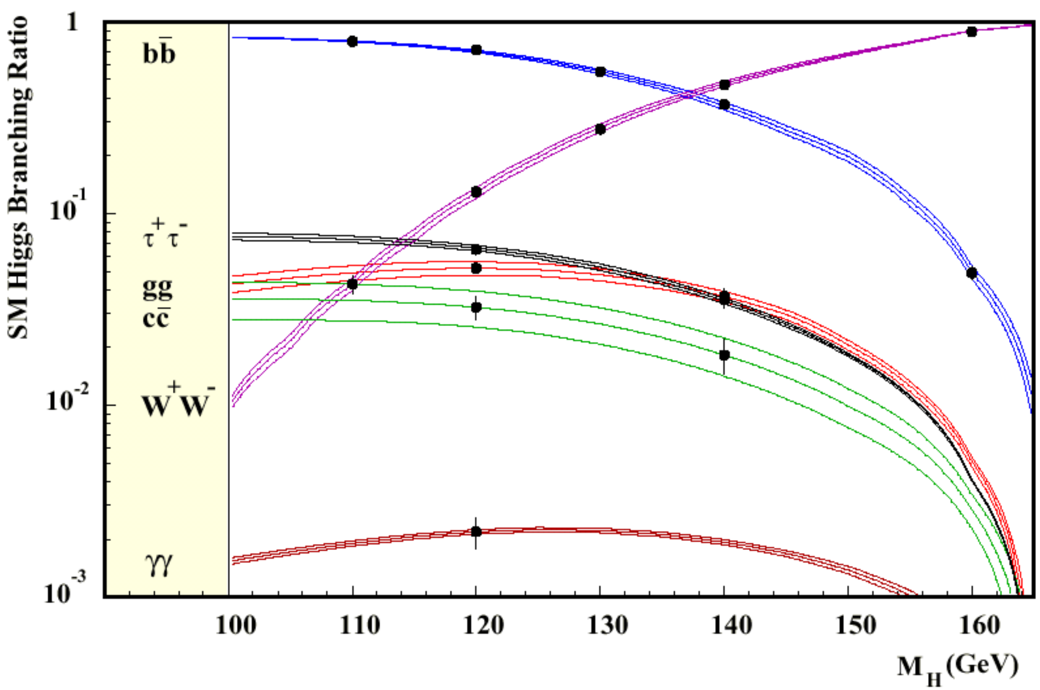
pp ⟶ HX in ATLAS detector at LHC

$e^+e^- \to$ HZ in LDC detector at ILC:



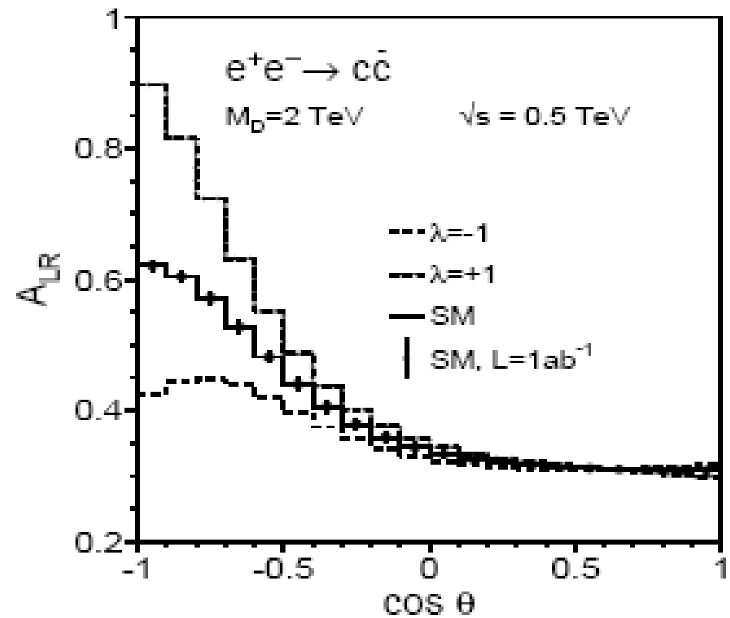
Why the ILC?

- The ILC and its detectors will allow precise measurements of cross sections, masses, branching ratios...
- E.g. Branching ratios of Higgs boson:



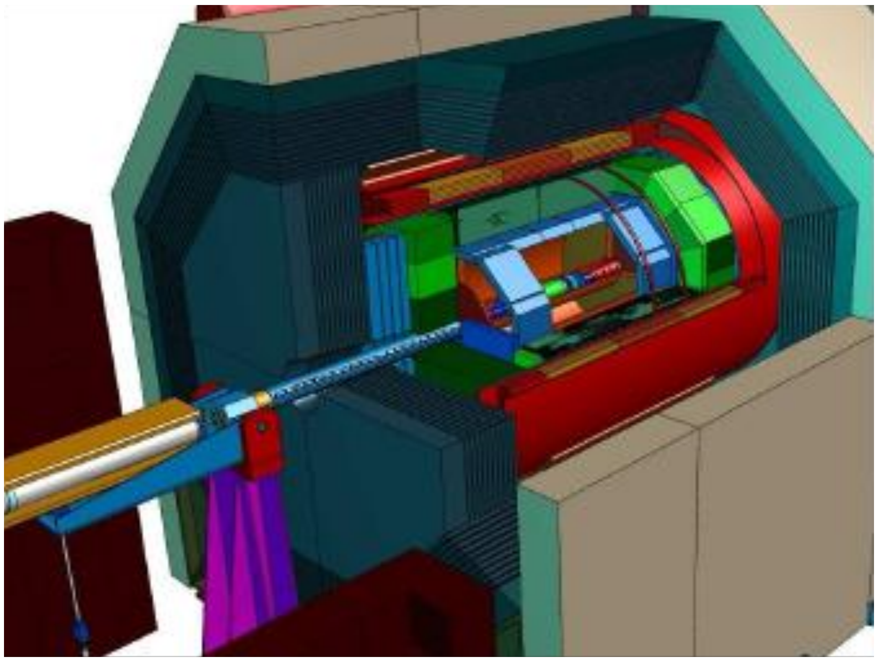
- Requires quark flavour identification.

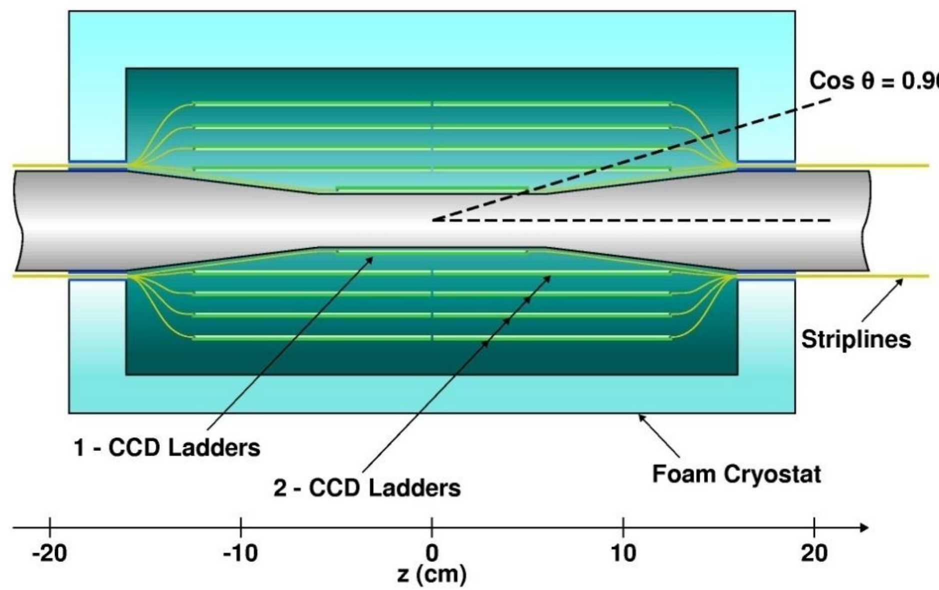
- Contribute to understanding of mass, dark matter, structure of space-time...
- E.g. effects of large extra dimensions on $A_{LR} = (\sigma_L - \sigma_R)/\sigma_{tot}$ as a function of $\cos\theta$ in process $e^+e^- \to f\bar{f}$.



- Requires quark charge identification.

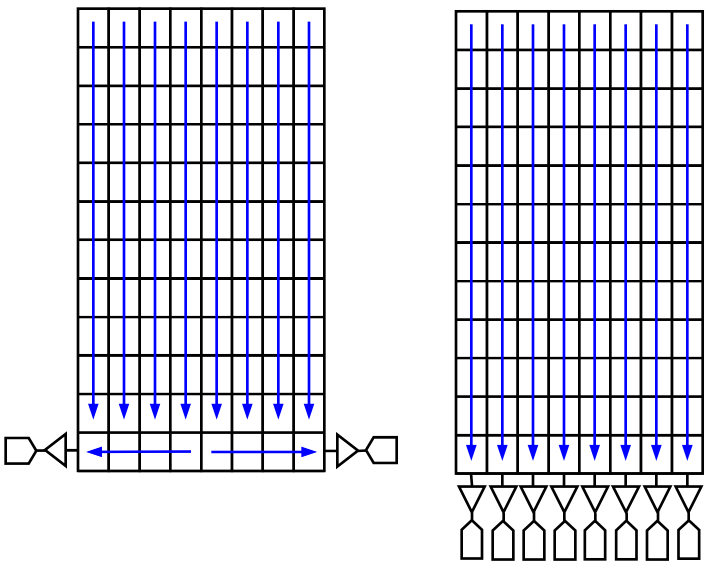
Detector – ILD and its VXD





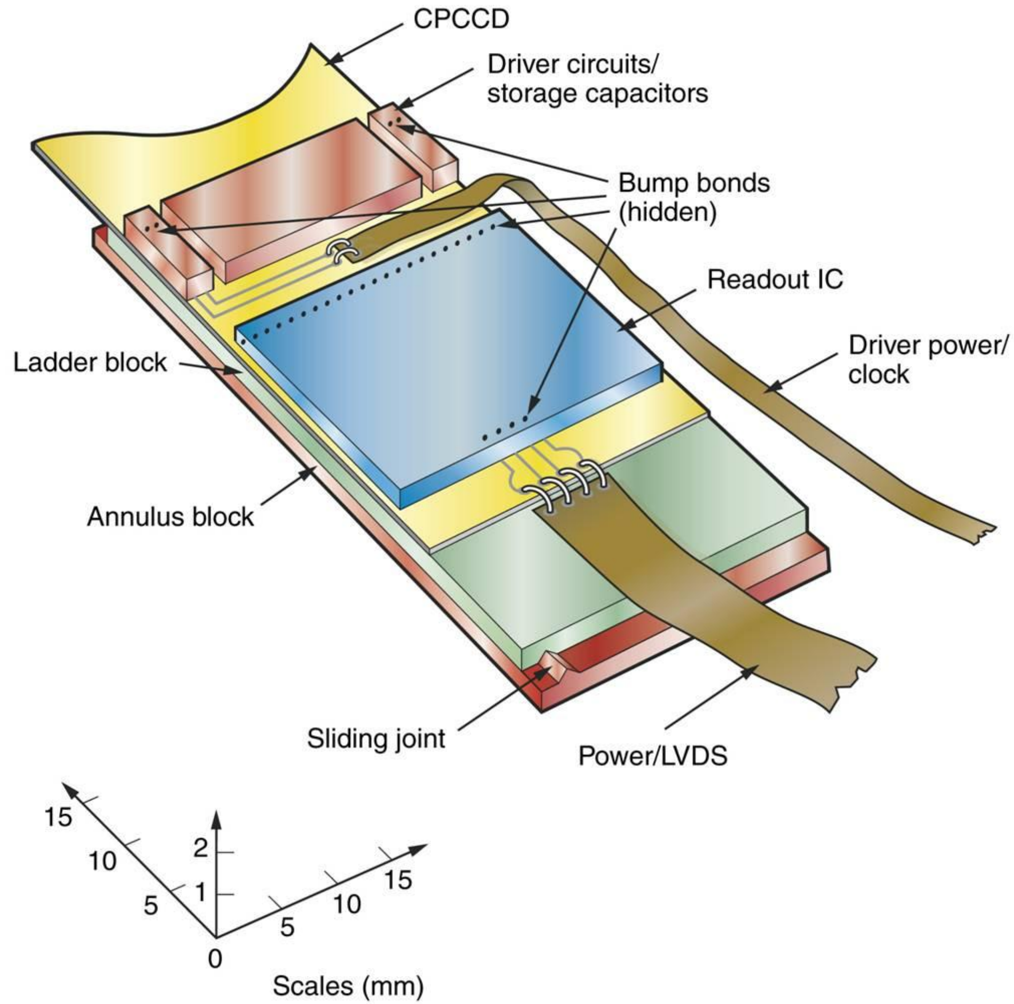
Sensors for the VXD – Column Parallel CCDs

- Achieve necessary readout speed with CCDs using column parallel architecture:



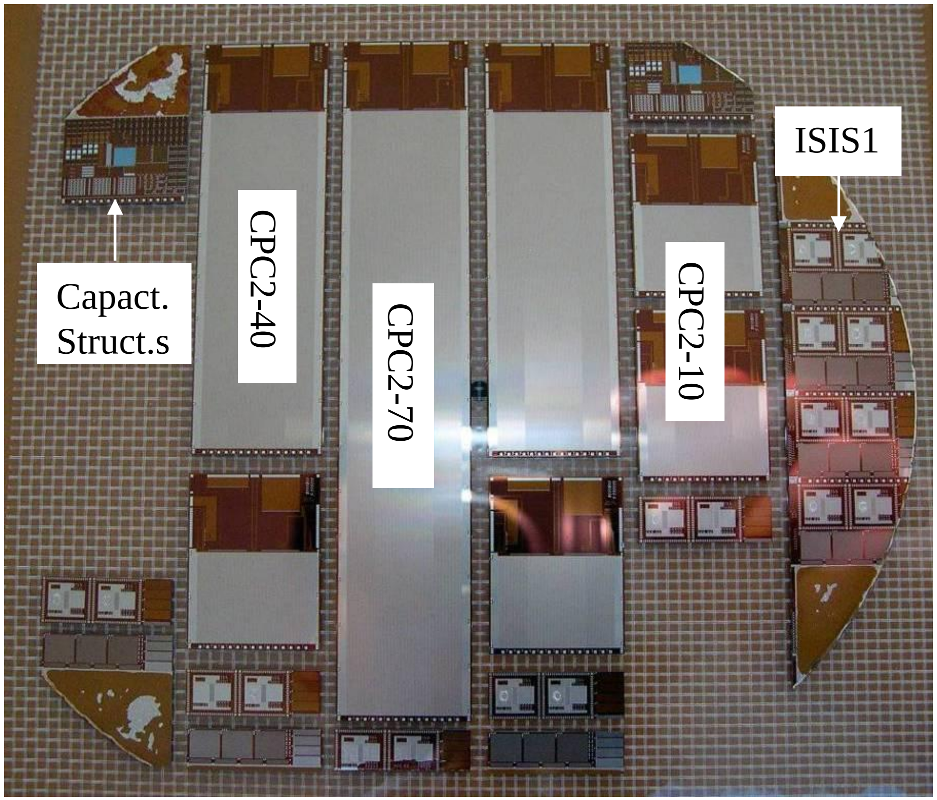
- Must drive image register at 50 MHz to readout in 50 μs.

- Conceptual "ladder" design:

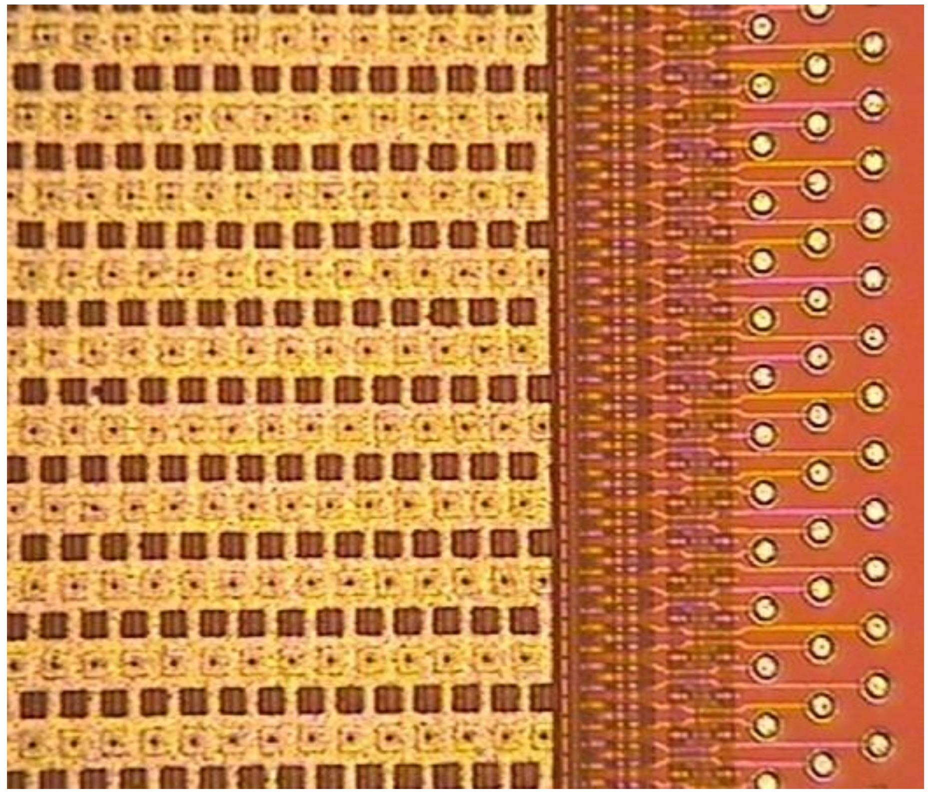


CPC2

- CPC2 wafer (100 Ω cm, 25 μm epi and 1.5 kΩ cm, 50 μm epi).
- Low speed (single level metal) and high speed versions of sensors:

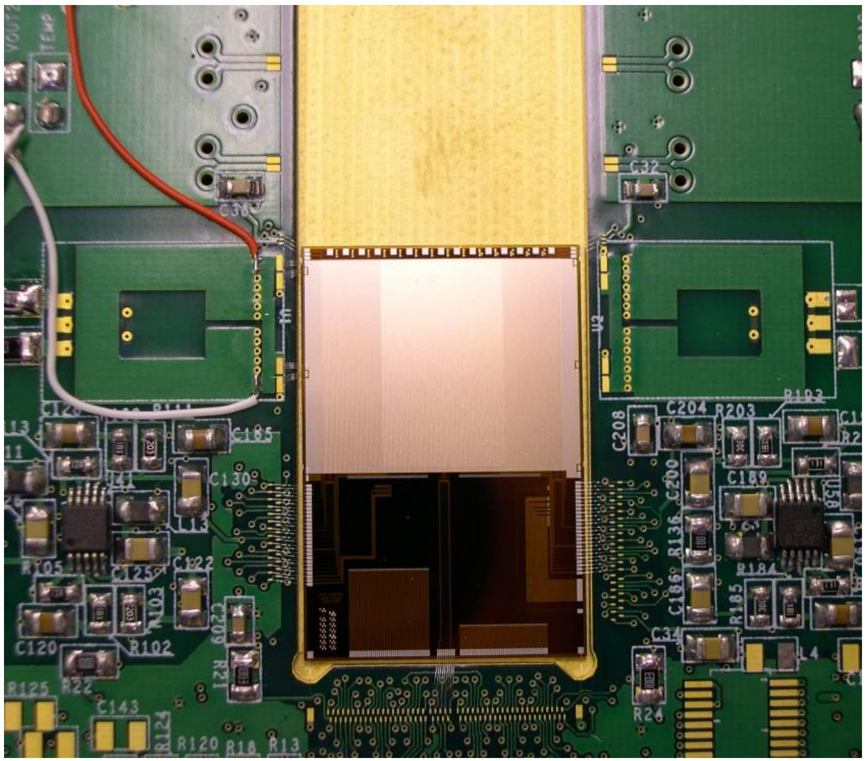


- High speed (busline-free) devices, whole image area is distributed busline
- Designed to reach 50 MHz.

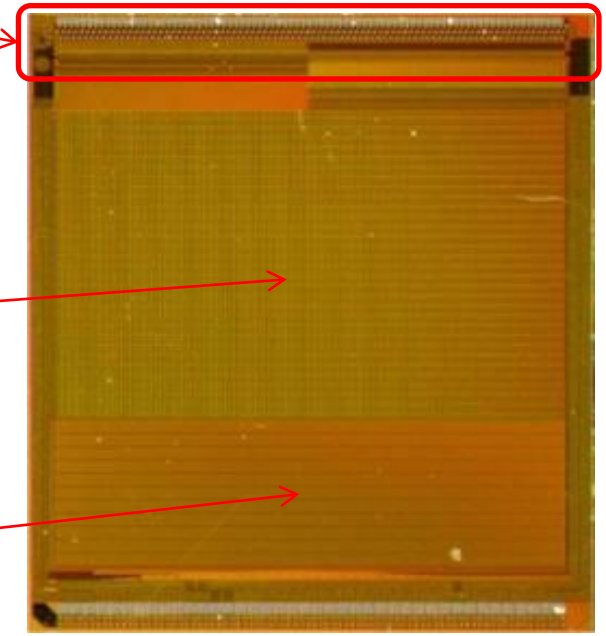


Testing the CPCCD at high speed

- CPC2-10 wire bonded to mother-board with transformer drive.
- ^{55}Fe X-ray signals observed at up to 45 MHz.



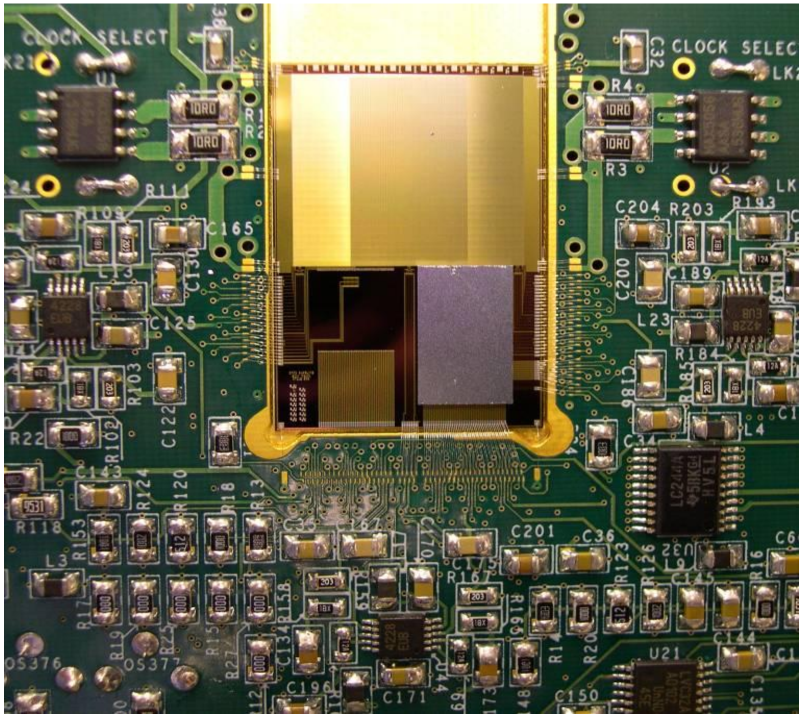
Readout chips – CPR1 and CPR2



Steve Thomas/Peter Murray, RAL

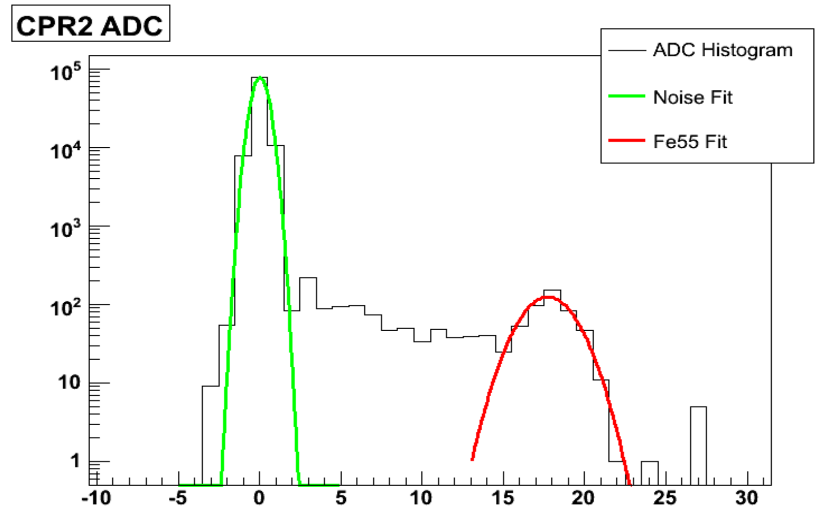
- CPR2 designed for CPC2 using results from CPR1 tests.
- Many test features.
- ¼ µm CMOS (IBM), 6 x 9.5 mm^2.

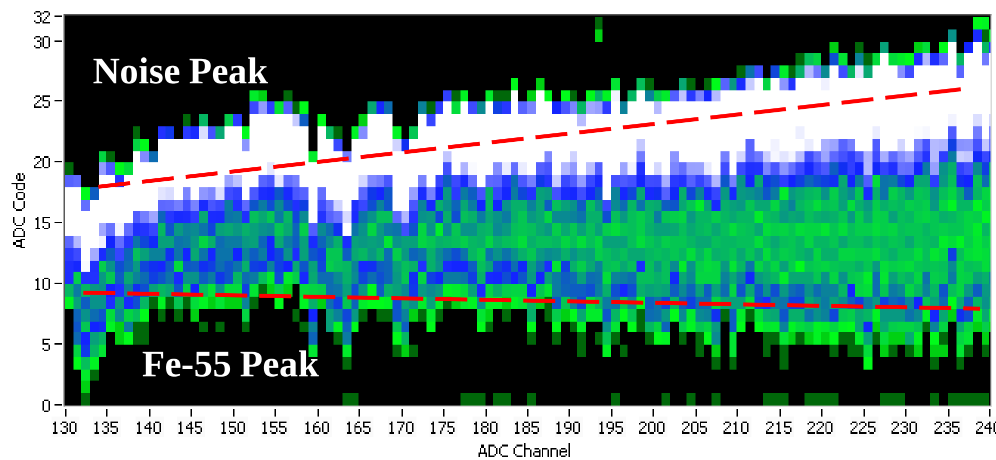
CPR2 bump-bonded to CPC2 – test results



- Voltage channels work well at ~ 2 MHz, deterioration if f > 5 MHz.
- Gain ~ 50% lower at centre of chip.
- Noise around 60…80 e^-.

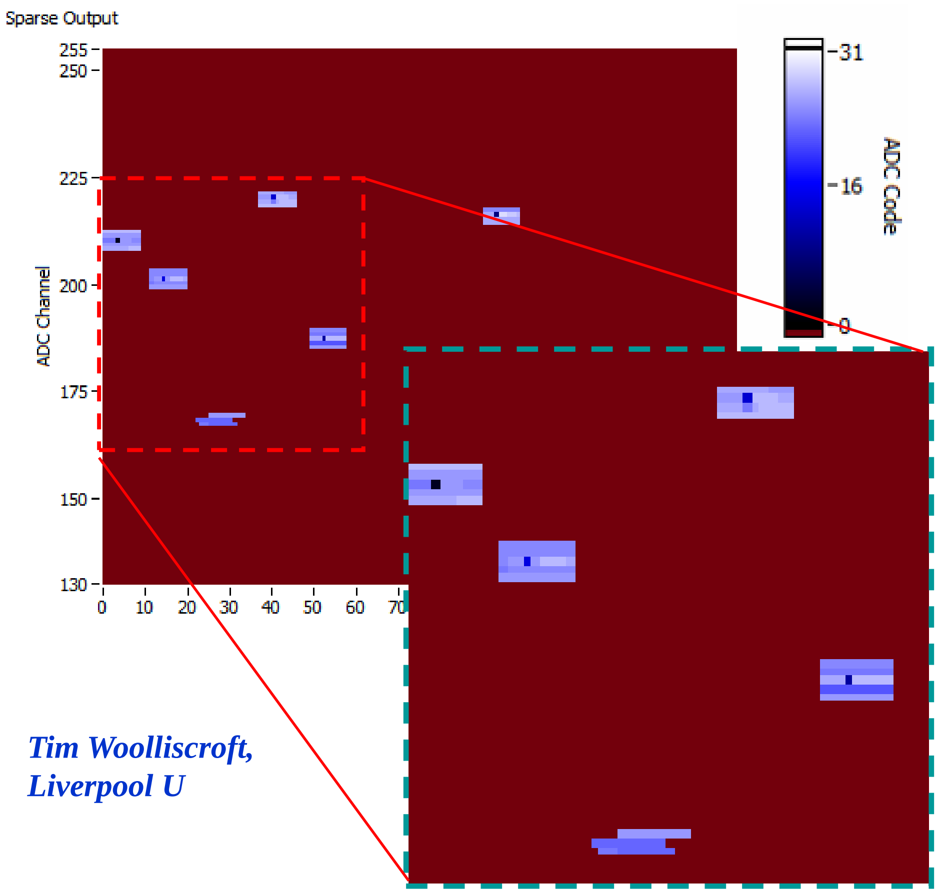
- E.g. of ^{55}Fe spectrum, map of chip:





Tim Woolliscroft, Liverpool U

CPR2 bump-bonded to CPC2 – test results

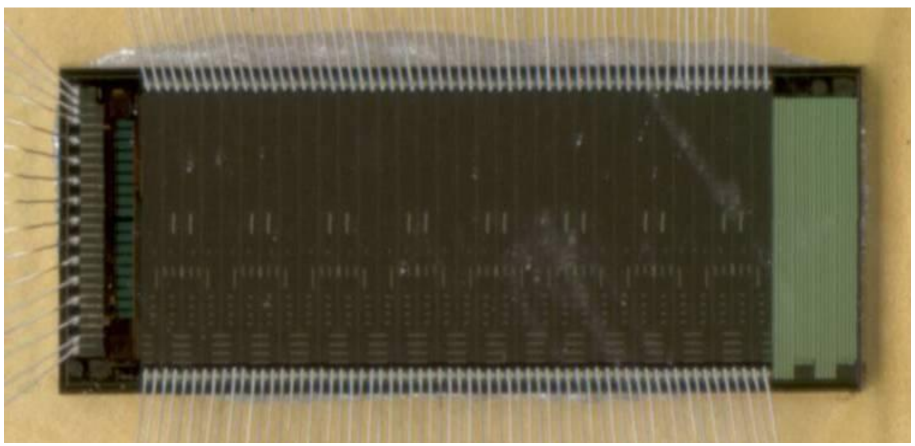


Tim Woolliscroft, Liverpool U

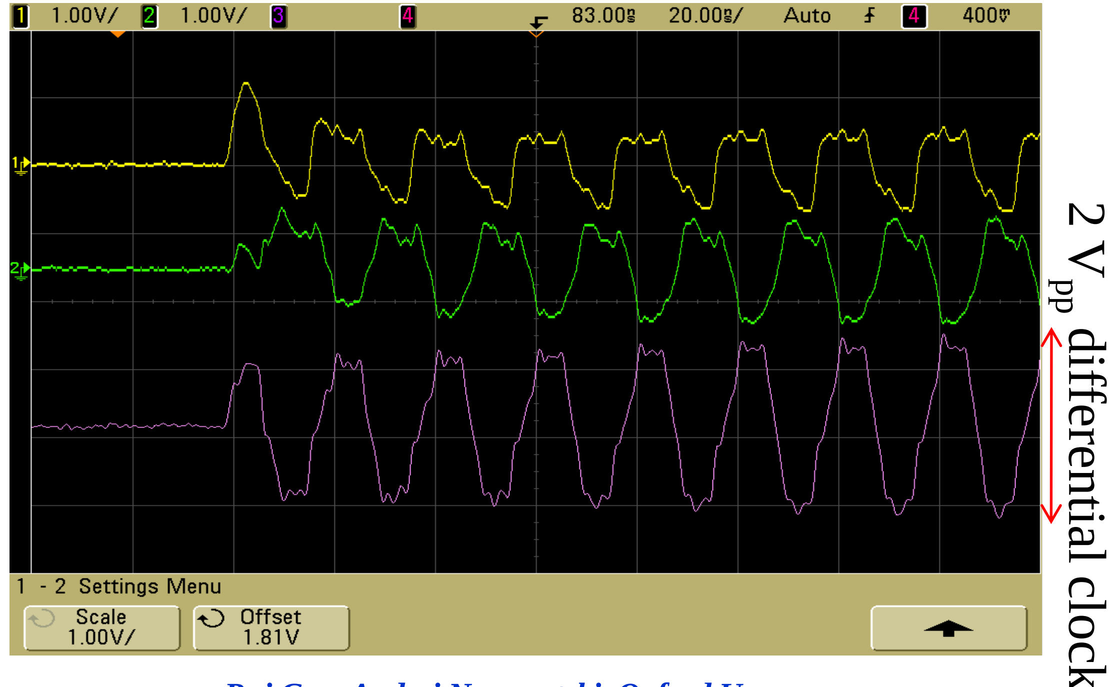
- Parallel cluster finder, 2 x 2 kernel.
- Global threshold.
- If threshold exceeded, 4 x 9 pixels flagged for readout.
- Cluster finding works with X-ray data.
- Dead time discovered, leads to loss of data if clusters close.
- Range of improvements for new chips CPR2A, B and C.
- E.g. 3-fold increase in column memory (reduces dead time).
- Column thresholds.
- Analogue calibration circuit.

Clock driver for CPC2 – CPD1

- Chip designed to drive outer layer CPCCDs (130 nF/phase at 25 MHz) and innermost CPCCDs (40 nF/phase at 50 MHz).
- Currents of ~20 A/phase needed!
- 0.35 mm CMOS, 3 x 8 mm^2.



Steve Thomas, Peter Murray, RAL

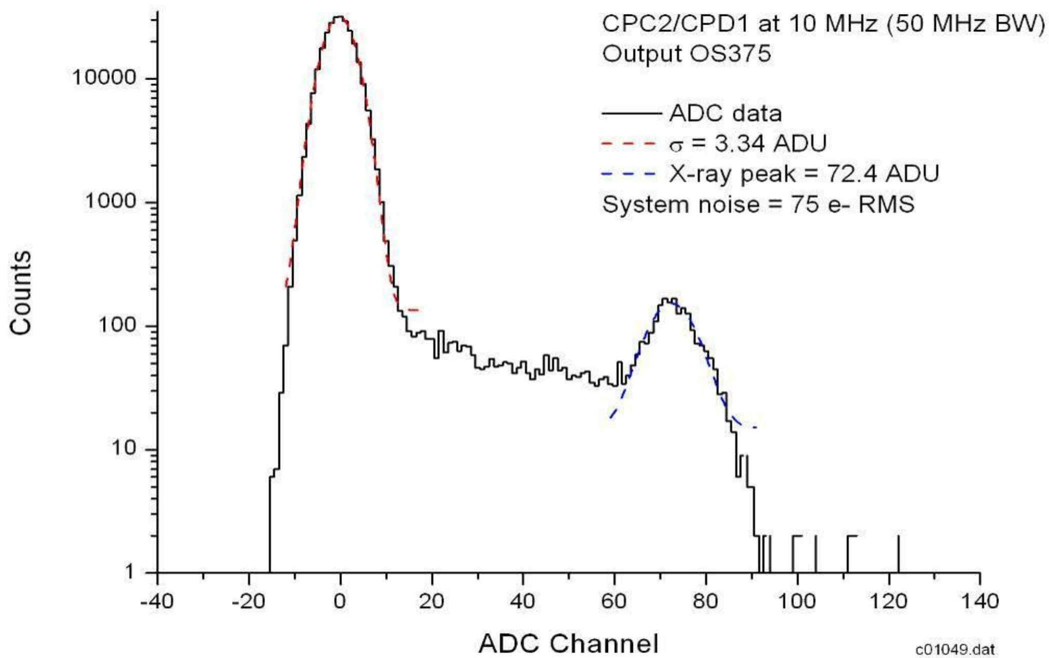


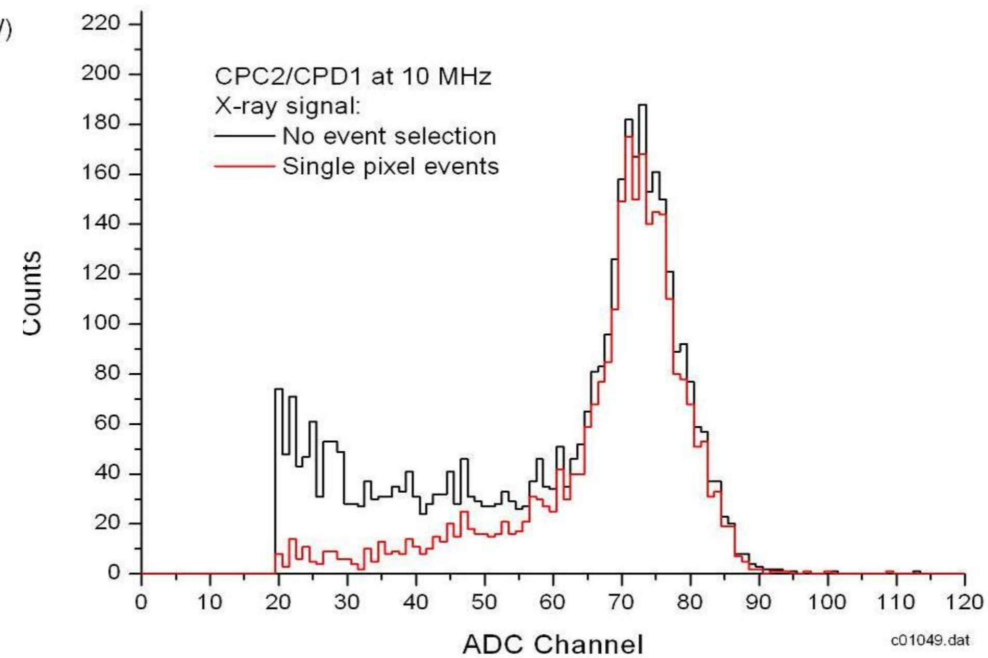
Rui Gao, Andrei Nomerotski, Oxford U

- Test shows CPD1 driving 32 nF equivalent internal load at 50 MHz.
- Hope to achieve same performance with chip bump-bonded to CPCCD.

Bus-line free CPC2-10 with CPD1

- ^{55}Fe signal (1630 e^-, MIP like).
- CPD1 clocks in range 3.3…1.2 V.
- Noise 75 e^- (c.f. 200 e^- with transformer drive).
- CPC2 works with clock amplitude down to 1.35 V_{pp}.

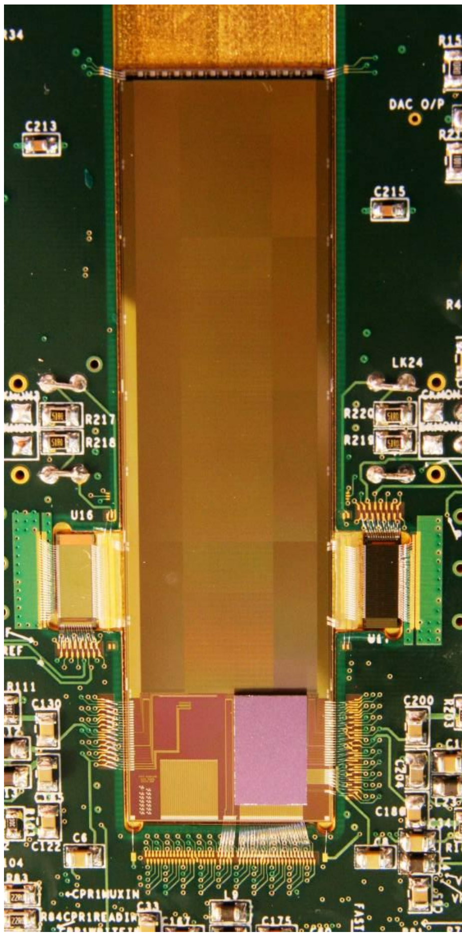


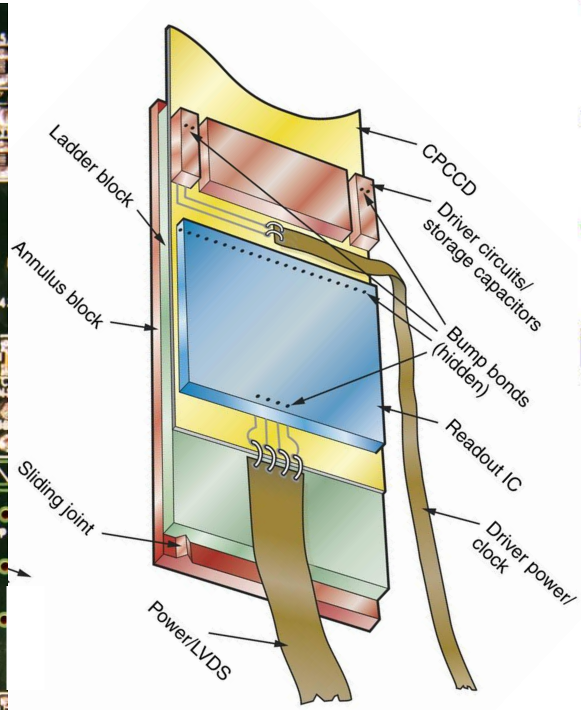


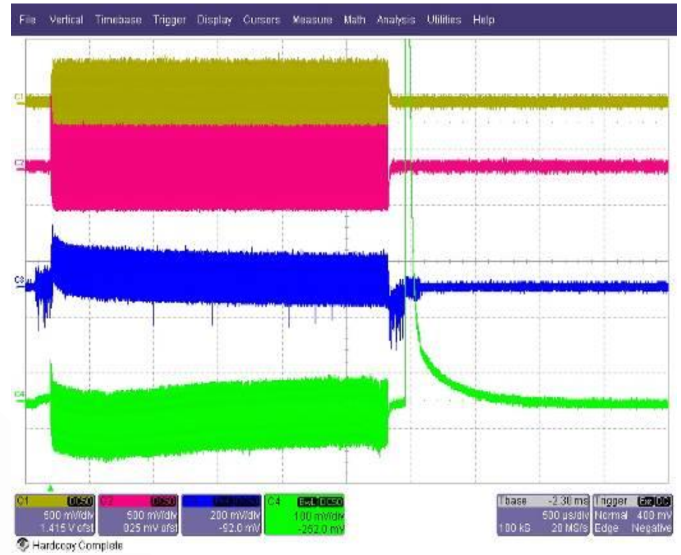
Konstantin Stefanov, RAL

Towards a prototype ladder

- CPC2 with CPD1 driver chip and CPR2 readout chip:



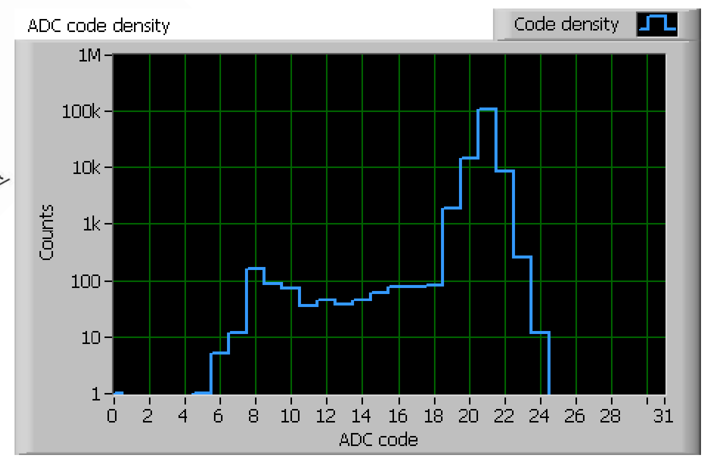




$1.5V_{PP}$ Clocks

CPR2 Voltage Amplifier output

CPC Source follower output

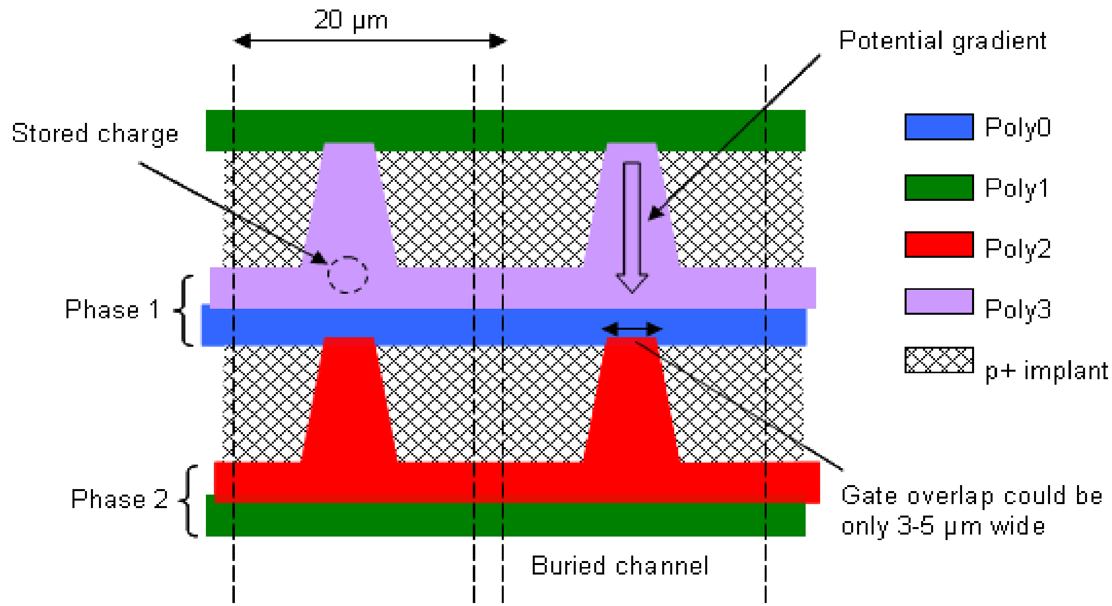


Tim Woolliscroft, Liverpool U

CPCCD capacitance reduction

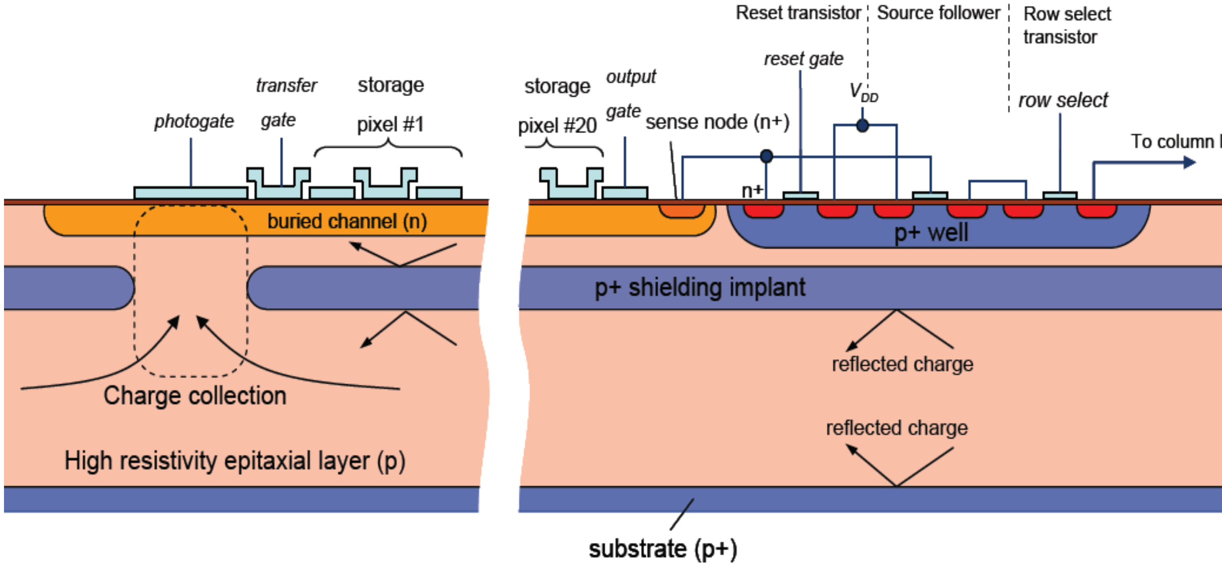
- CPCCD is difficult to clock because of large currents required.
- Can we reduce capacitance?
- Dominant contribution is inter-gate capacitance.
- Several ideas for reducing this: pedestal gate CCD; shaped channel CCD; open phase CCD.
- Studies also ongoing to understand minimum clock voltage needed to efficiently transfer charge in CCDs.
- Test structures from e2v will be delivered in next few weeks.

- Open phase CCD:



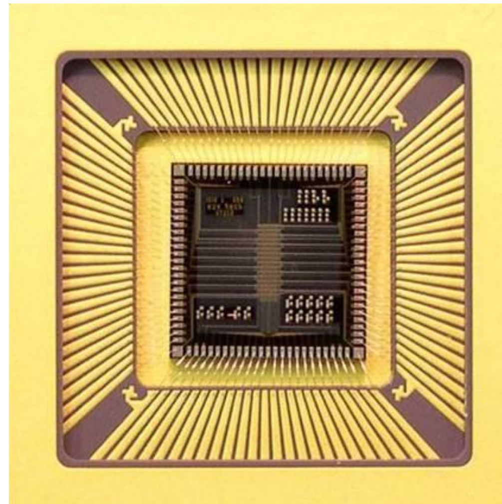
Sensors for the VXD – In-Situ Storage Image Sensor

- Alternative to fast readout: store signal in pixel during bunch train.



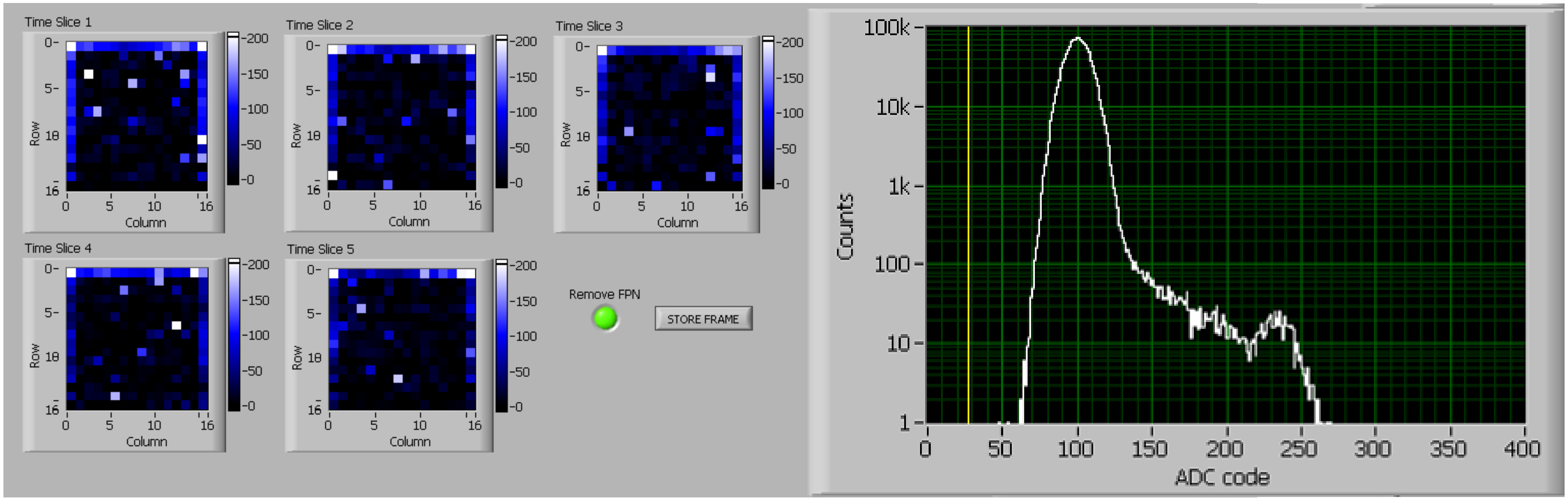
- Drive at 20 kHz during bunch train.
- 1 MHz column parallel readout between bunch trains.
- Charge to voltage conversion when least affected by EMI.

- ISIS1, "proof of principle" device built by e2v.



- 6 × 16 array of ISIS cells, each with 5-pixel buried channel CCD storage register.
- Cell pitch 40 × 160 μm^2, no edge logic.
- Chip size 6.5 × 6.5 mm^2.

ISIS1 tests



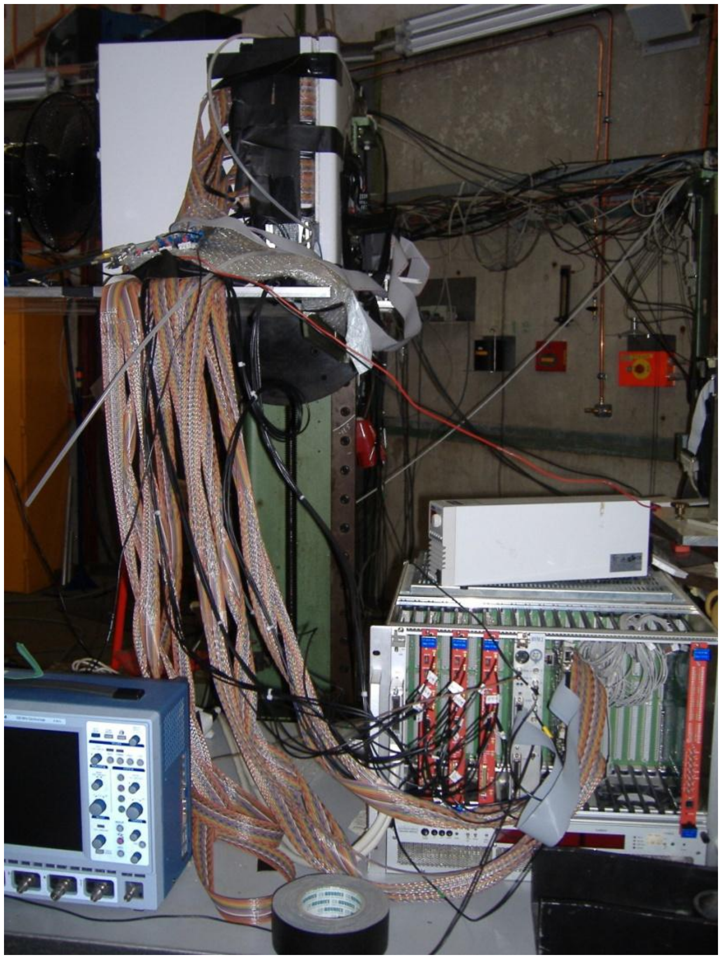
Konstantin Stefanov, RAL

- Tests with 55Fe source.
- ISIS1 works well with and without p-well.
- The p-well successfully prevents parasitic charge collection.

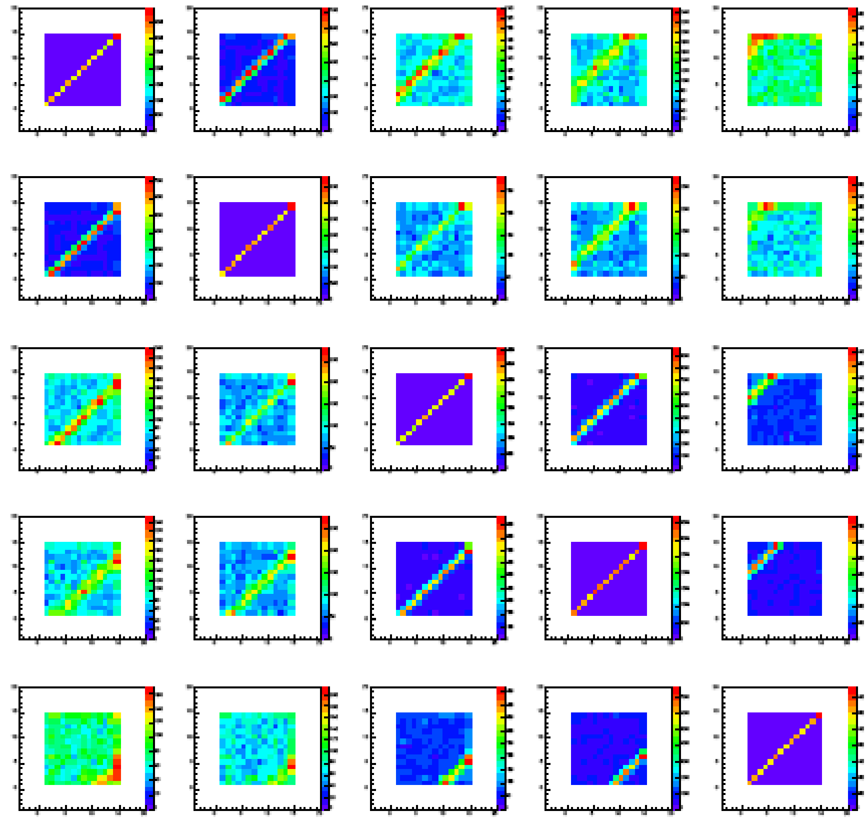
- Contract signed with Jazz for design and manufacture of ISIS2 signed with Jazz Semiconductor.
- Will incorporate control logic on-chip.

ISIS1 in test beam

- Telescope made of five ISIS1 sensors studied in test beam at DESY.



- Set up started Mon...tracks seen Tues.

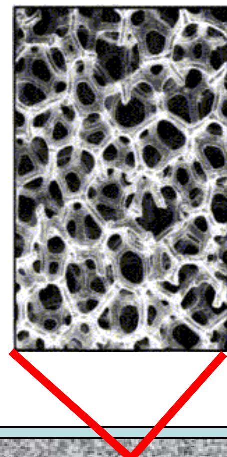


Jaap Velthuis + ... Bristol U

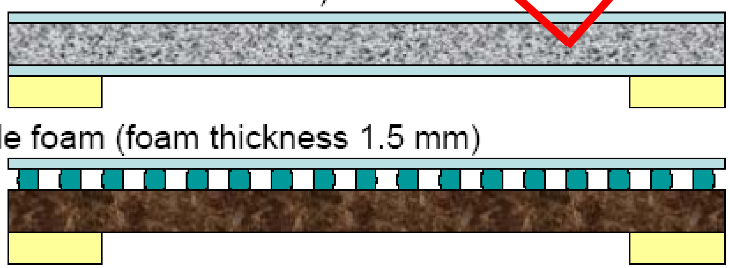
- First prel. result, resolution in "short" direction 11μm (c.f. $40/\sqrt{12} = 12\mu m$).

Mechanical studies

- Goal is 0.1% X_0 per ladder with operation at ~ 170 K.
- Try foam supports:

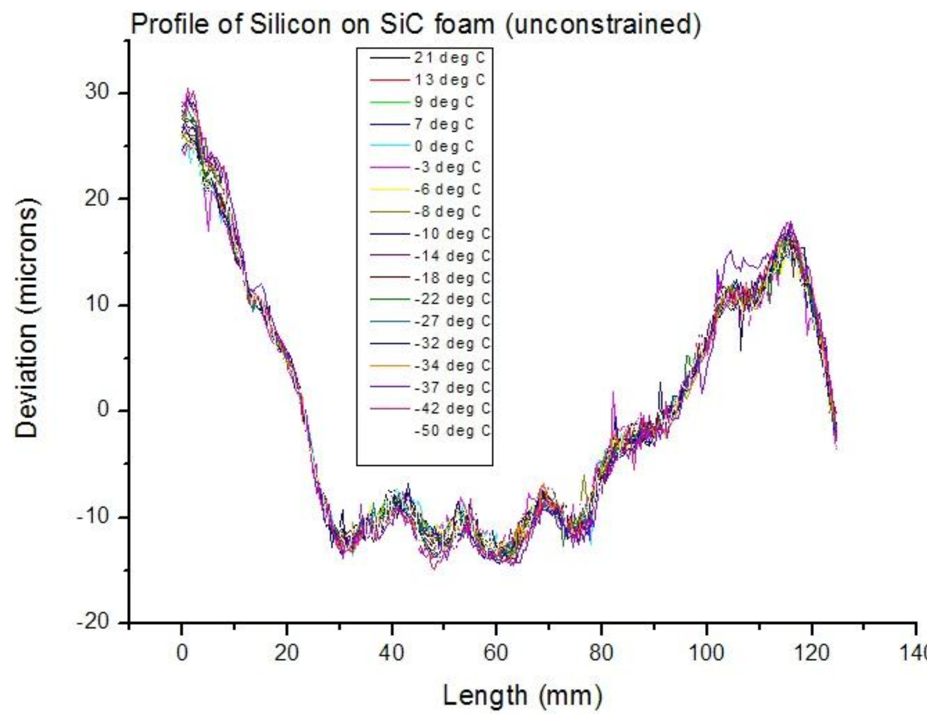


RVC foam (foam thickness 1.5 mm)



Silicon Carbide foam (foam thickness 1.5 mm)

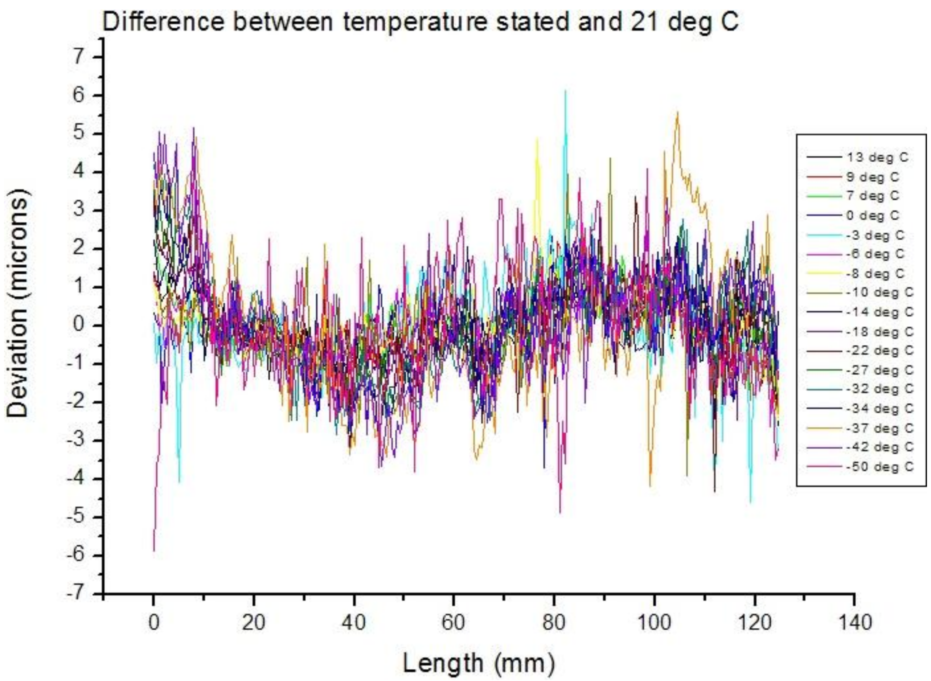
- Effect of temperature variations on Si-C/Si ladder:



E. Johnson, J. Goldstein

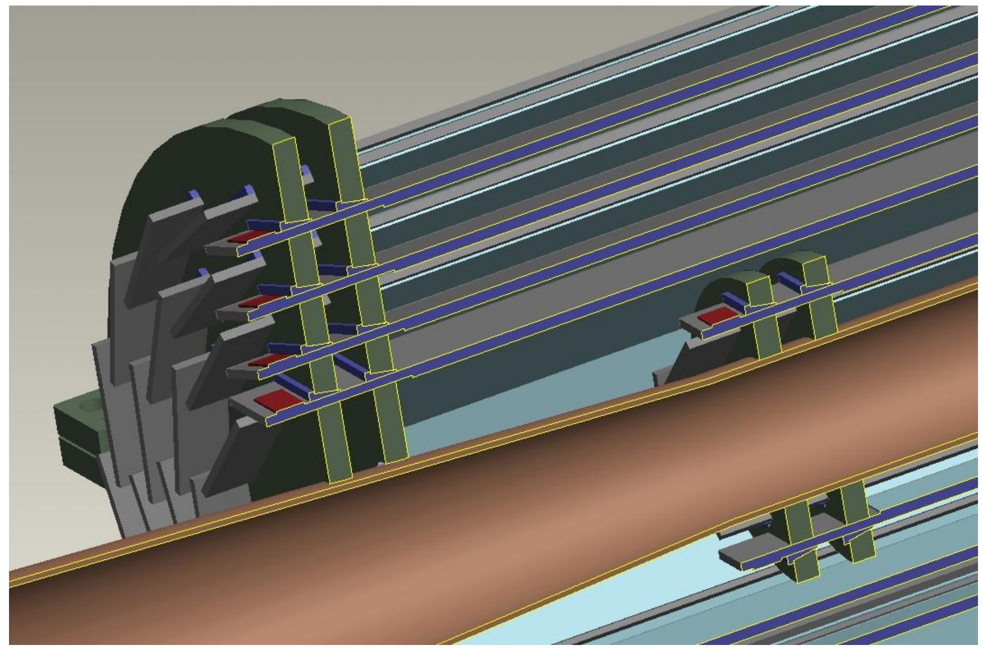
Mechanical studies

- Look at deviations with temperature:



- Very good CTE match of Si and SiC ensures excellent temperature stability.

- Investigate possibility of constructing entire VXD using SiC:

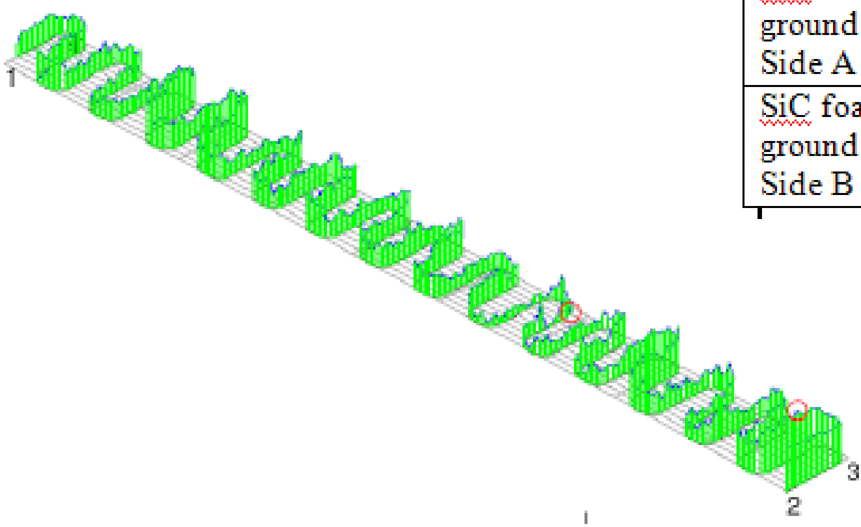


- Many problems to solve, machining SiC, choice of adhesive, CTE effects...

Mechanical studies

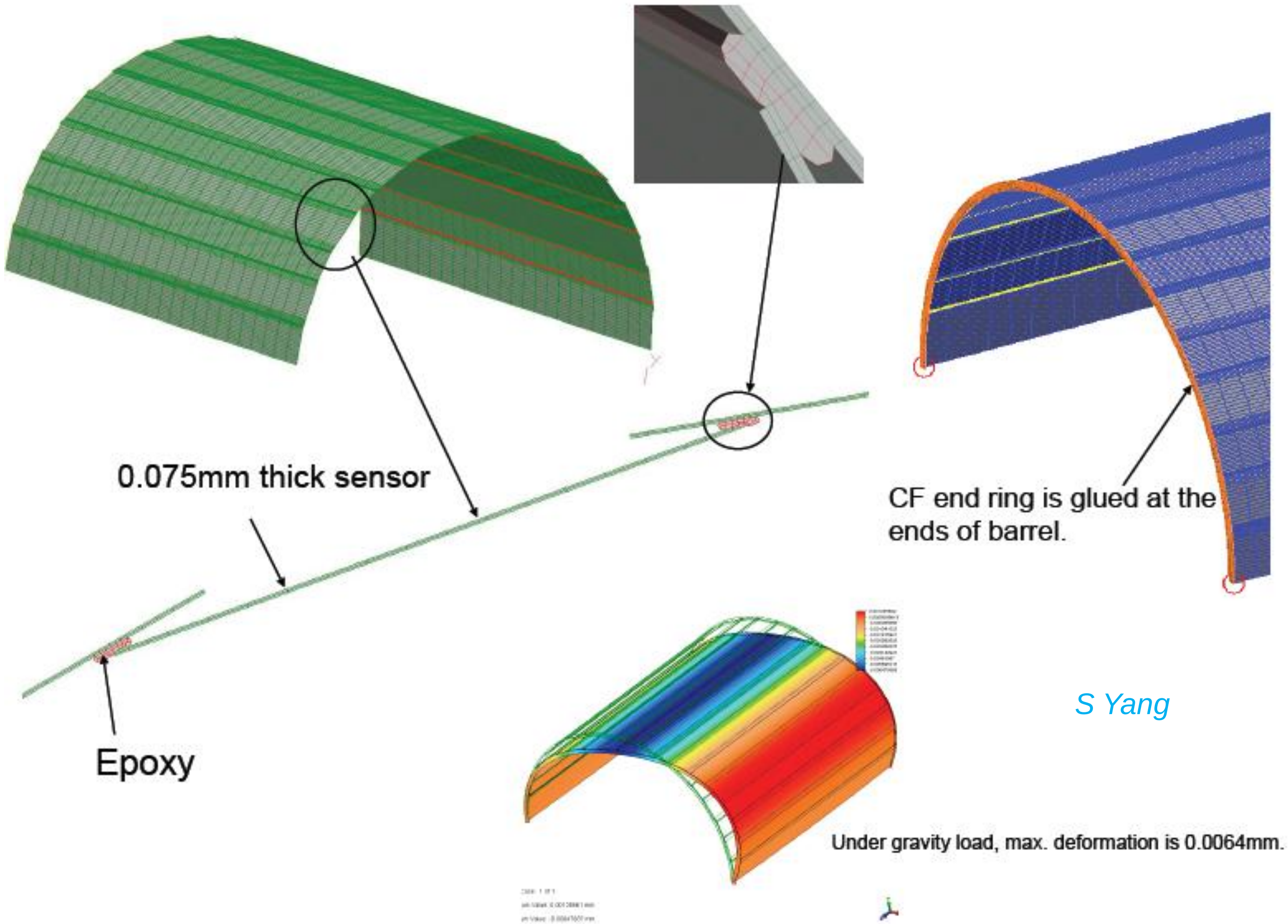
- Develop techniques for measuring and machining foams, e.g. silicon carbide:
- Measurements made using large diameter low force touch probe.

Substrate	Height (mm to 3sf)				Flatness (microns to 2 sf)
	Corner 1	Corner 2	Corner 3	Corner 4	
SiC foam ungrounded Side A	1.93	1.88	1.88	1.92	**340**
SiC foam Ungrounded Side B	1.94	1.93	1.94	1.95	**300**
SiC foam ground flat Side A	1.52	1.55	1.52	1.50	77
SiC foam ground flat Side B	1.49	1.53	1.54	1.51	**84**



Mechanical studies

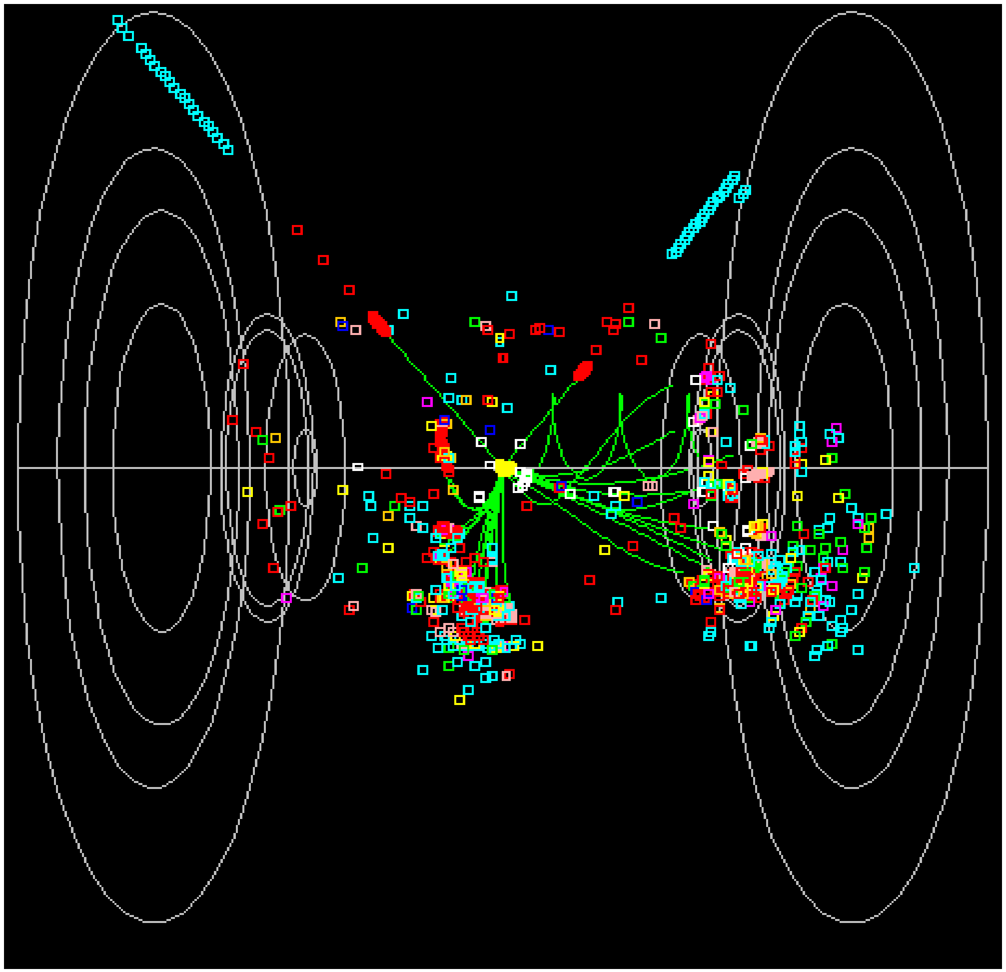
- Also investigating other new ideas…



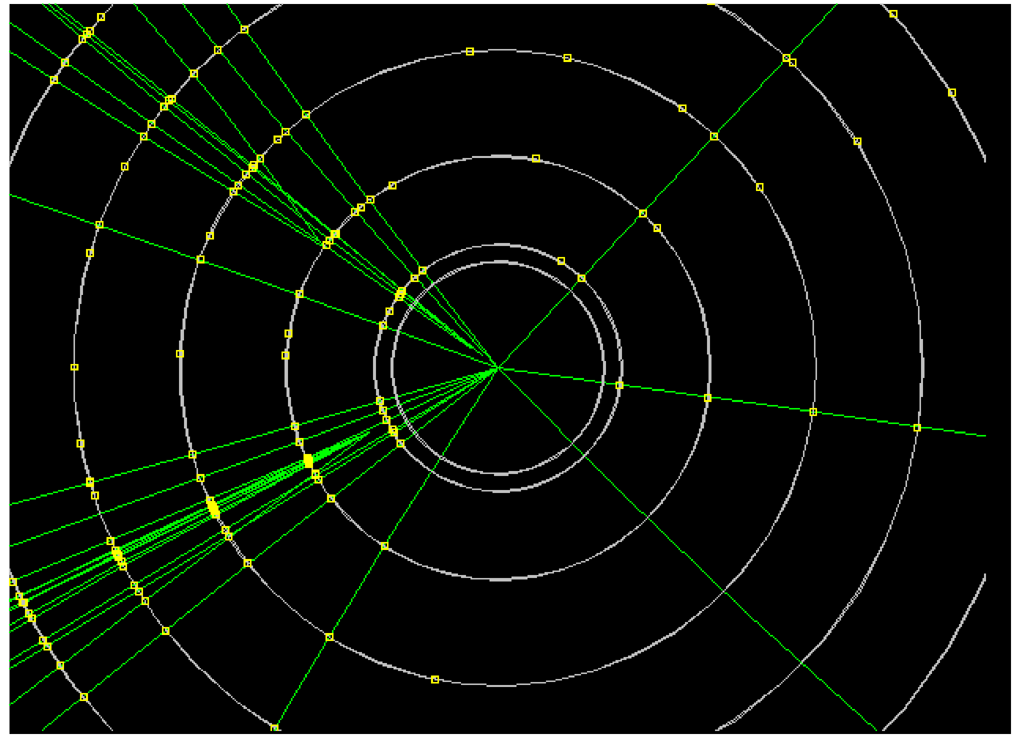
S Yang

Finding decay vertices using the vertex detector

- E.g. $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-$ jet jet.



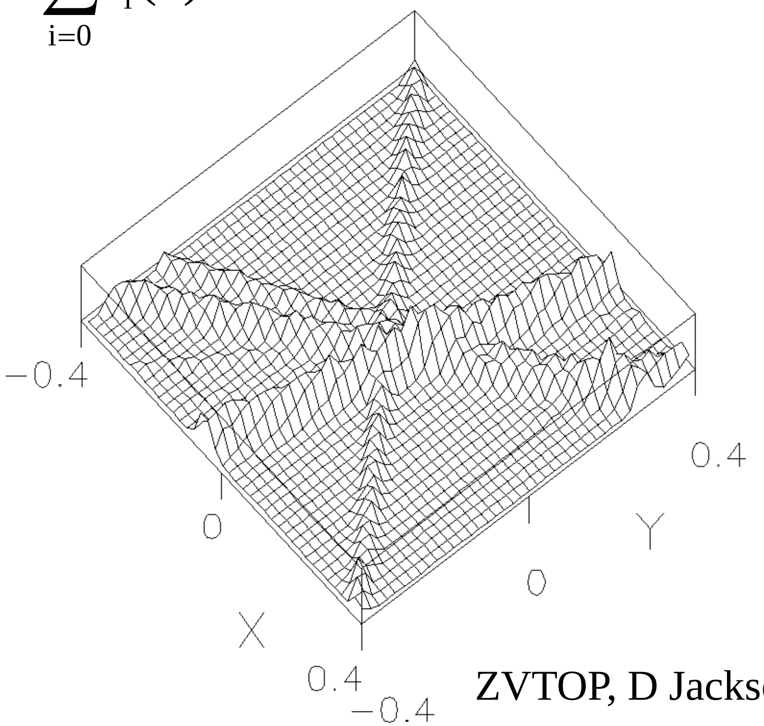
- Vertex region:



- Challenge is to associate all charged tracks with correct vertex in high track density environment.

Topological vertex reconstruction

- Using VXD hits, tracks approximated as probability tubes, $f_i(\vec{r})$, beam spot as ellipsoid, $f_0(\vec{r})$.
- E.g. N tracks, integrating over z, $\sum_{i=0}^{N} f_i(\vec{r})$:

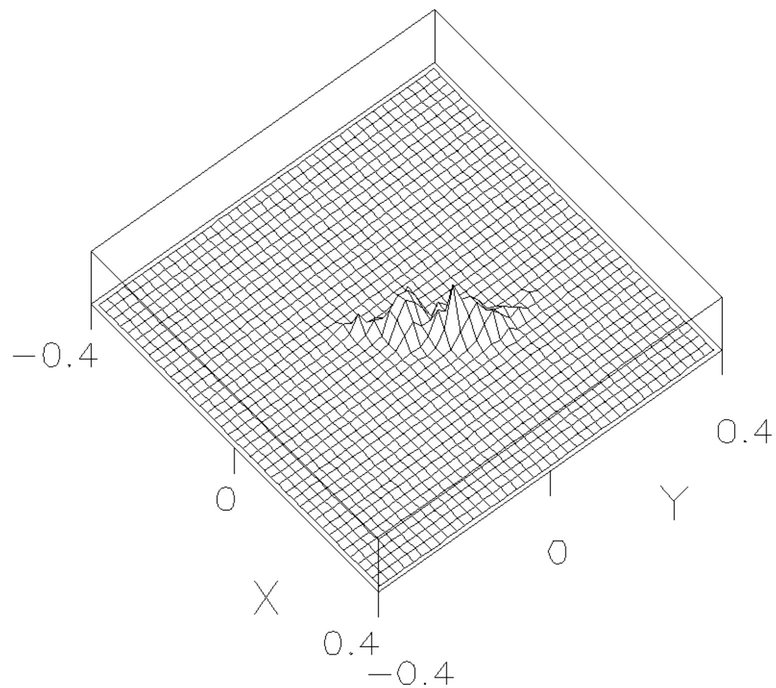


ZVTOP, D Jackson

- From these define vertex function:

$$V(\vec{r}) = \sum_{i=0}^{N} f_i(\vec{r}) - \frac{\sum_{i=0}^{N} f_i^{\,2}(\vec{r})}{\sum_{i=0}^{N} f_i(\vec{r})}$$

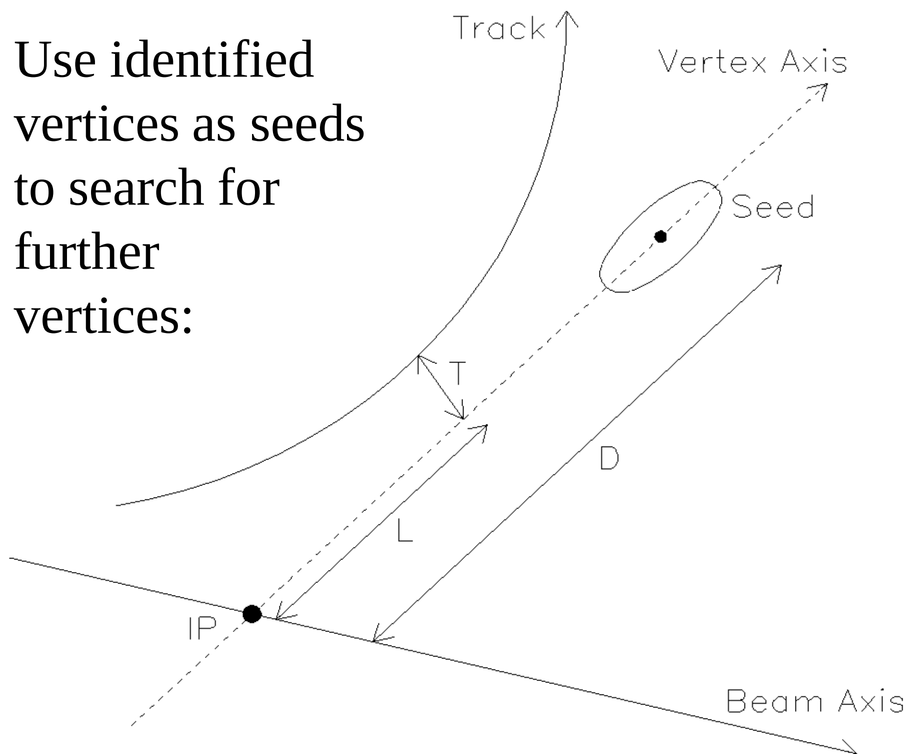
- Returning to e.g.:



Topological vertex reconstruction

- Find "seed" maxima in $V(\vec{r})$ for track-track and vertex-track pairs which are "resolvable" and for which χ^2 good.
- Search around seeds for true maxima in $V(\vec{r})$, including all tracks and vertex.
- Spatially resolved maxima form candidate vertices if associated with 2 or more tracks.
- Track/vertex association ambiguities are decided according to largest $V(\vec{r})$ after quality cuts.
- Vertex that includes the IP ellipsoid is primary vertex.

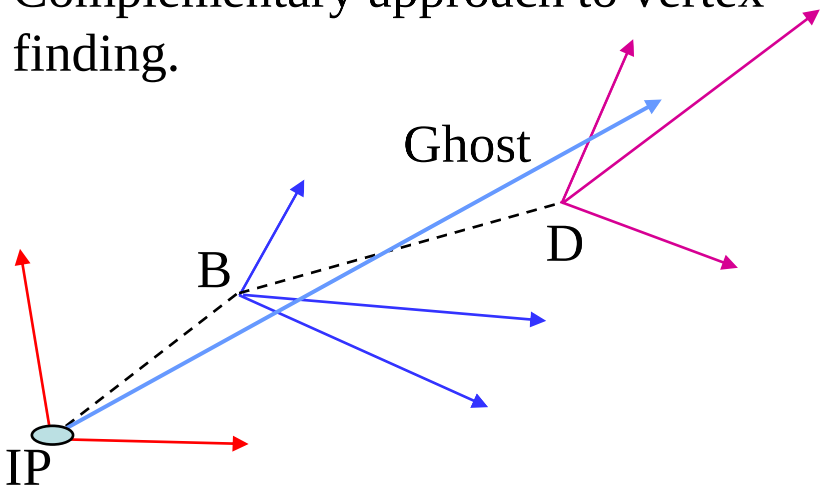
- Use identified vertices as seeds to search for further vertices:



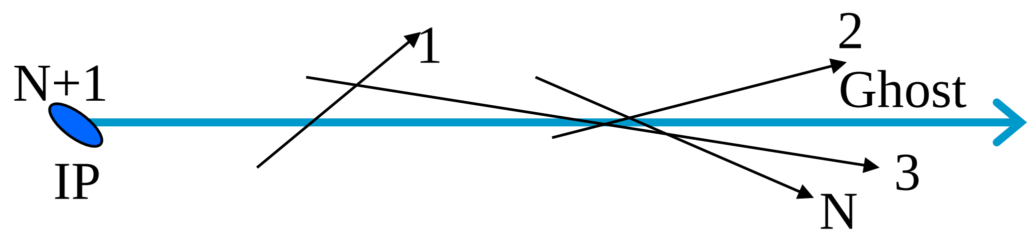
- Tune cut on L/D to find new vertices, possibly "one prong".
- (Additional weighting factors can be applied to favour vertices near jet core, to suppress vertices v. close to IP etc.)

Ghost track algorithm

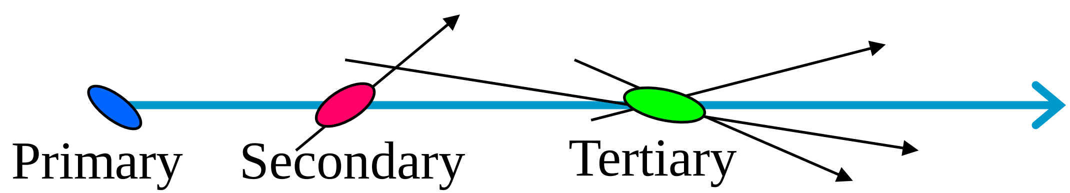
- Complementary approach to vertex finding.



- Start with straight "ghost" track at IP along jet axis direction.
- Calculate χ^2 of DCA each track in jet to ghost track.
- Swivel ghost track in θ and φ to minimise $\sum\chi^2$ for all tracks in jet.
- Now have N (tracks) + 1 (IP) initial vertex candidates.



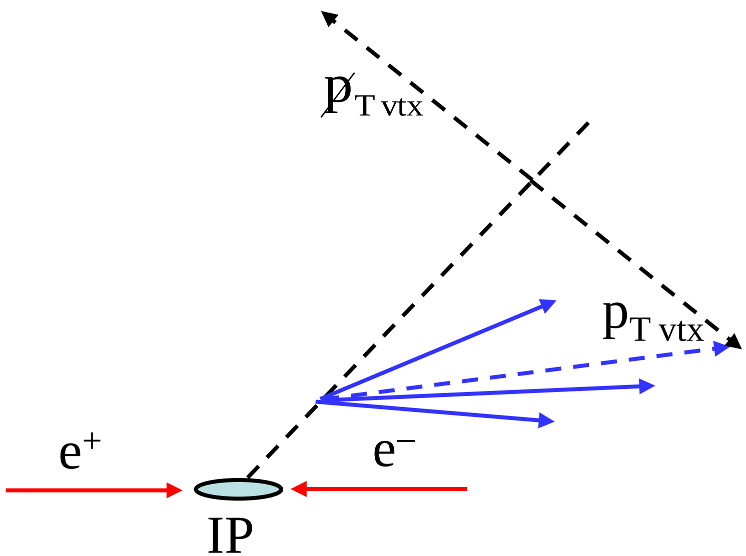
- Calculate fit probability for all track-ghost track or track-IP combinations.
- If prob. high, combine objects to form vertex.
- Iterate.



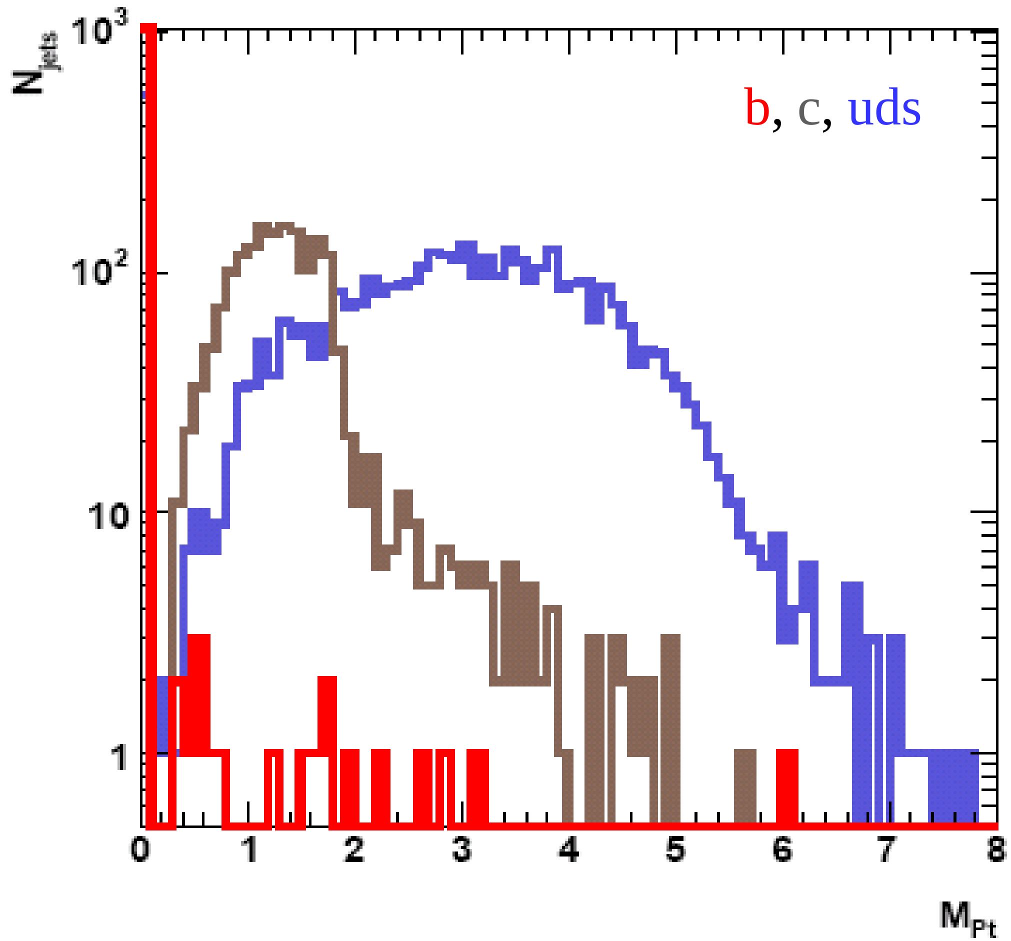
Flavour identification

- Identify variables that provide discrimination between uds/gluon and c and b jets.
- E.g., if vertex found, p_T corrected mass, m_{pT}, is useful variable,

$$m_{pT} = \sqrt{m_{vtx}^2 + p_{T\,vtx}^2} + p_{T\,vtx}.$$



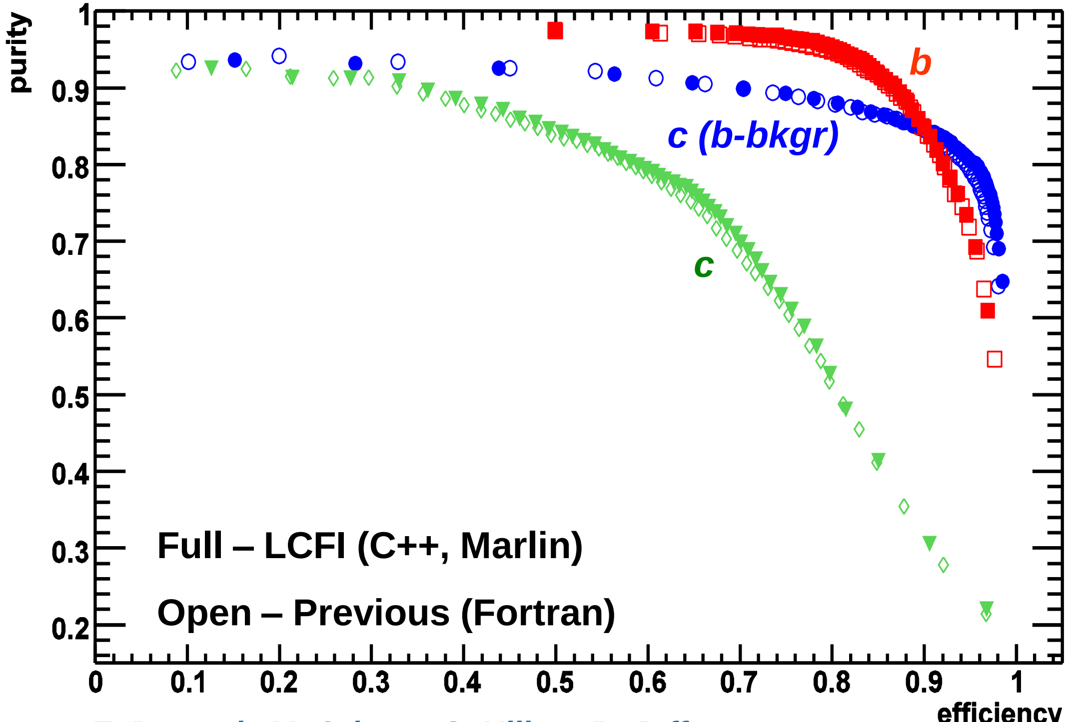
- m_{pT} distributions:



Flavour identification

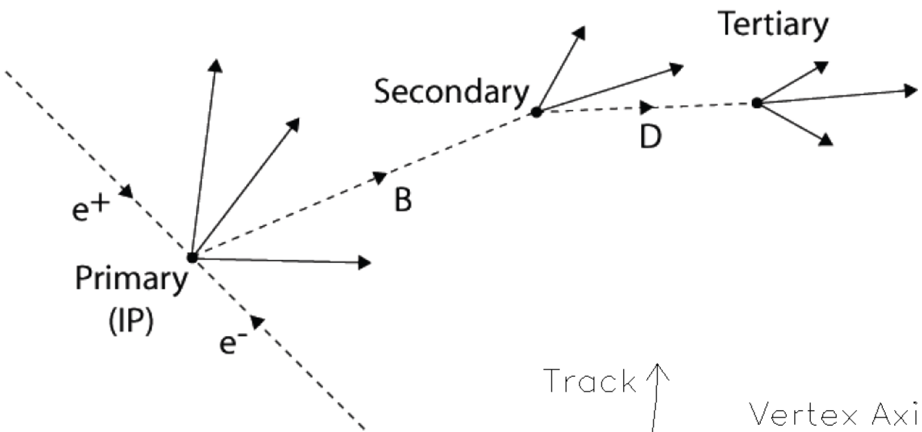
- Combine variables using neural net.
- Input variables:
  - Momentum and impact parameter significance in r-ϕ and z of two most significant tracks.
  - Probability in r-ϕ and z that all tracks originate from IP.
- Additionally, if secondary vertex found:
  - m_{pT}.
  - Momentum associated with vertex.
  - Decay length.
  - Decay length significance.

- Resulting flavour identification performance (here at $\sqrt{s} = m_Z$) using fast MC simulation.

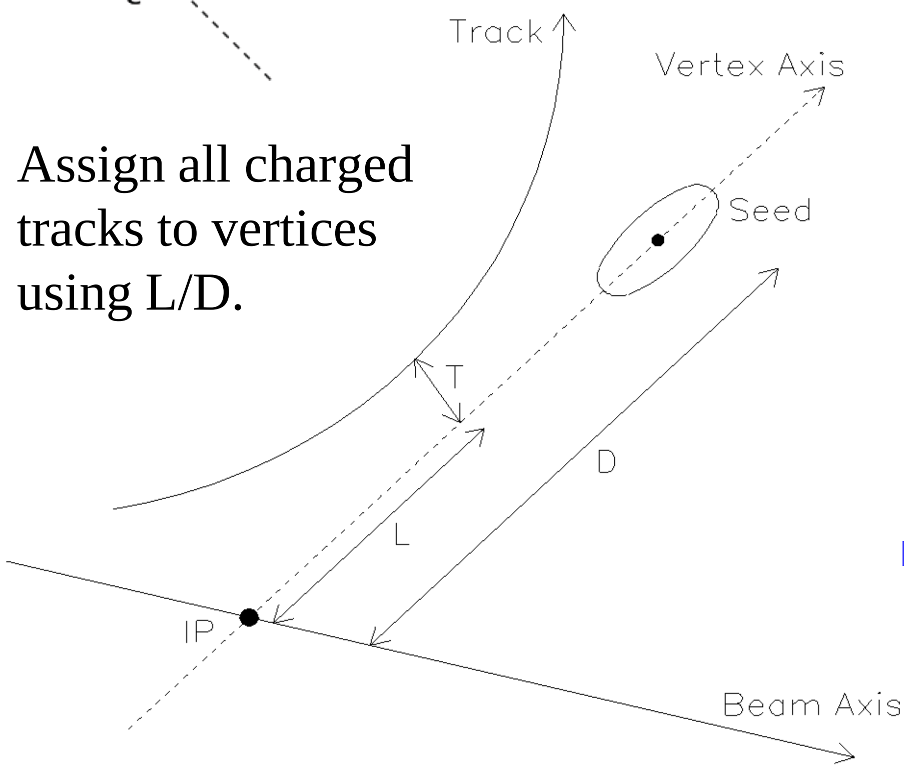


E. Devetak, M. Grimes, S. Hillert, B. Jeffery

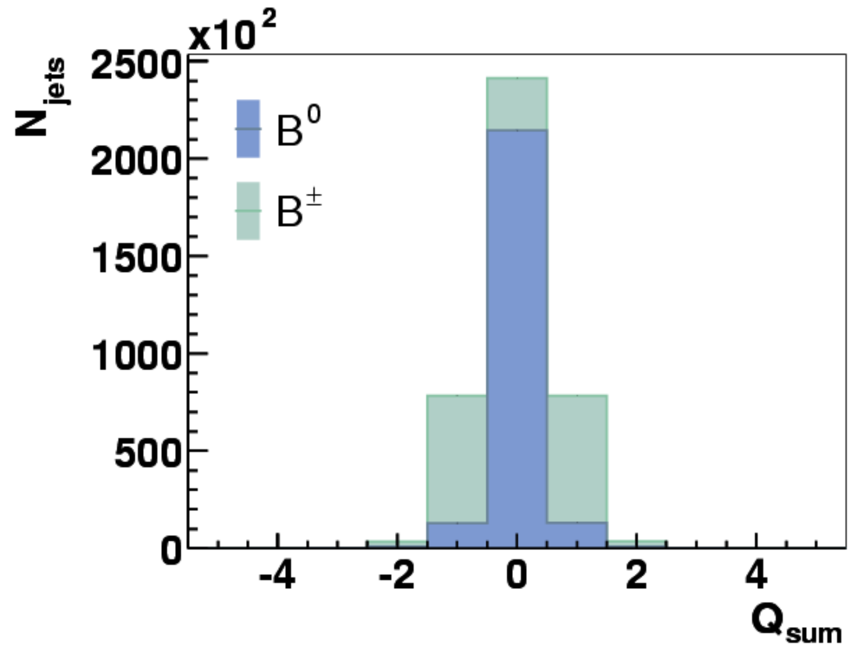
Quark charge identification



- Assign all charged tracks to vertices using L/D.



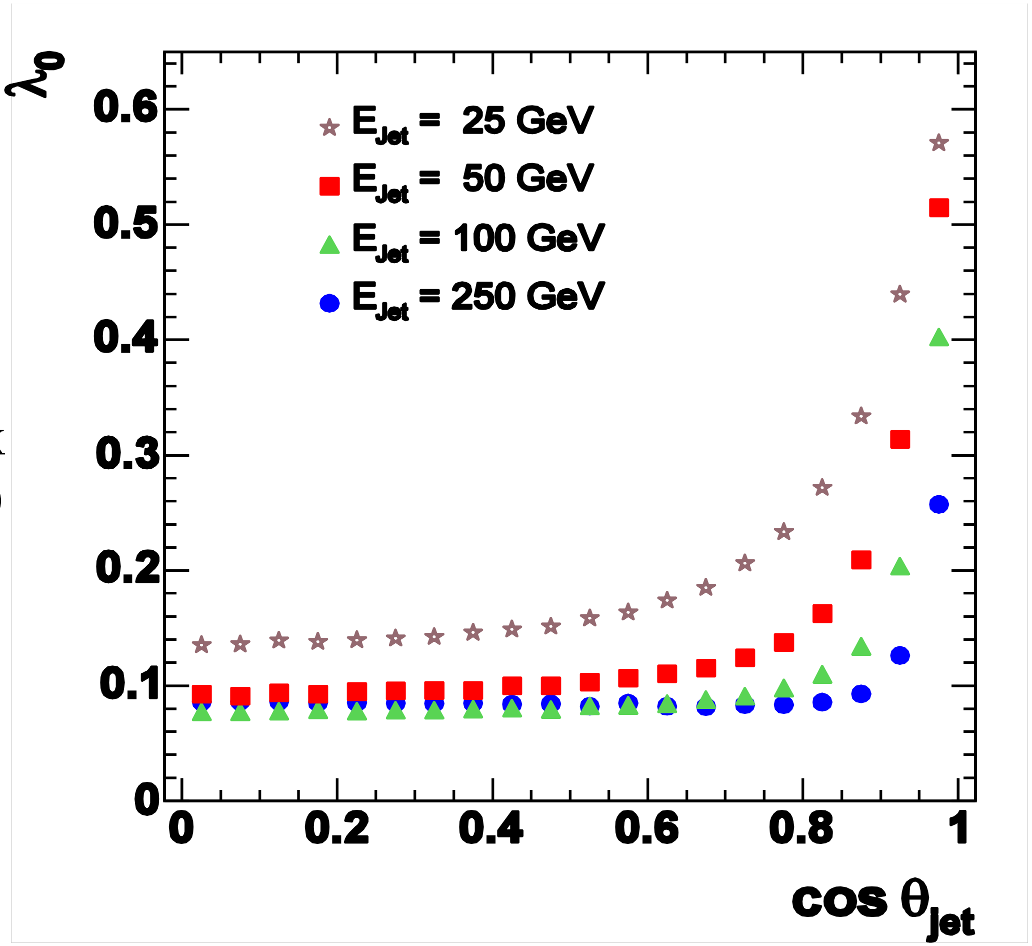
- Sum charge of tracks at secondary vertex to form Q_{sum}:



- Define $Q_{vtx} = \mathrm{sgn}(Q_{sum})$.

Quark charge identification

- Quantify performance in terms of λ_0, probability of reconstructing neutral B hadron as charged.
- Degradation at large cos θ caused by loss of tracks and multiple scattering.
- Effect stronger at lower jet energy (broader jets, lower momenta...)
- Recent progress with LCFI c++ Vertex Package in simulation of realistic CCD signals, using tracking information (from Pandora PFA), improving speed through incorporation of Kalman Filter...



Contingency plans

- Attempt to obtain STFC resources for aspects of programme that cannot be continued using only University supported staff.
- Identify particularly "attractive" components of programme, e.g. offering potential for Knowledge Exchange.
- Attempt to continue other components of programme through efforts of University supported staff, students, groups not funded by STFC...
- Request STFC support for sensor studies...

Programme element	Effort (FTE)	Funding (k£)
Testing CPC-T, CPR2	1	50
CPC3	0.2	380
CPR3	1.5	60
Bump-bond, test CPC3	1	40
Totals	3.7	530

- ISIS2 measurements, Nijmegen and UK Universities.
- ...and for mechanical work:

Programme element	Effort (FTE)	Funding (k£)
Prototype design	0.9	0
Construction	0	150
Prototype testing	0.4	0
Totals	1.3	150

Summary

- LCFI progress good.
- Vertex package now basis of most worldwide flavour physics studies.
- Column Parallel CCD operated at high speed.
- Column Parallel Drive and Readout chips operated with CPCCD.
- ISIS1 functions in Lab and at Test Beam.
- ISIS2 design/manufacture underway.
- Promising work on use of SiC foams for extremely light support structures.
- Many reasons to be cheerful...
- Strategy is to decide in 2010(?) if ILC is correct next machine for HEP.
- ...but if necessary can maintain some aspects of LCFI programme, and produce useful "deliverables" at reduced cost.
- Require STFC support for:
- Continued development of CPCCD and its readout.
- (Continued studies of ISIS.)
- These sensors either are already a source of "Knowledge Exchange" or have the potential to be.
- Attempt to maintain physics studies through University supported academics and PhD students.

Guardian...

- In praise of ... Britain's astronomers and particle physicists

  Leader
  Monday December 17, 2007

  Sir Isaac Newton and Edmund Halley would have been horrified. The great British physicist and his astronomer friend helped create a tradition of pioneering research that is being threatened to save a few million pounds. This month astronomers and particle physicists learned of a 25% cut in research spending - partly to cope with cost overruns on big projects and partly because the recent spending review was not generous. The cuts would force Britain's retreat from some of the world's leading research projects and the work of hundreds of scientists is at risk.

- Among the schemes under threat are Britain's share of the International Linear Collider, intended to carry out research into the creation of the universe. Britain's part in the Gemini North telescope, on Mauna Kea in Hawaii, studying deep space, may survive in reduced form. But this country's role in its companion observatory in the southern hemisphere, based in Chile, will not. The board of the collaborative Gemini scheme issued a statement expressing its dismay at the news. So did a group of senior astronomers, writing to the Guardian. The new Science & Technology Facilities Council says that the cuts are necessary to fund big overruns in research projects in Britain, and it is true that modern astronomy and particle physics are among the most expensive areas of science. But primary research into the origins of the universe is something that this country is good at and should remain committed to.