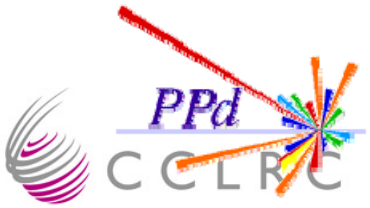
Linear Collider Flavour Identification

Physics and Mechanical Studies

Steve Worm
Rutherford Appleton Laboratory

for the LCFI Collaboration



LCFI Physics Studies

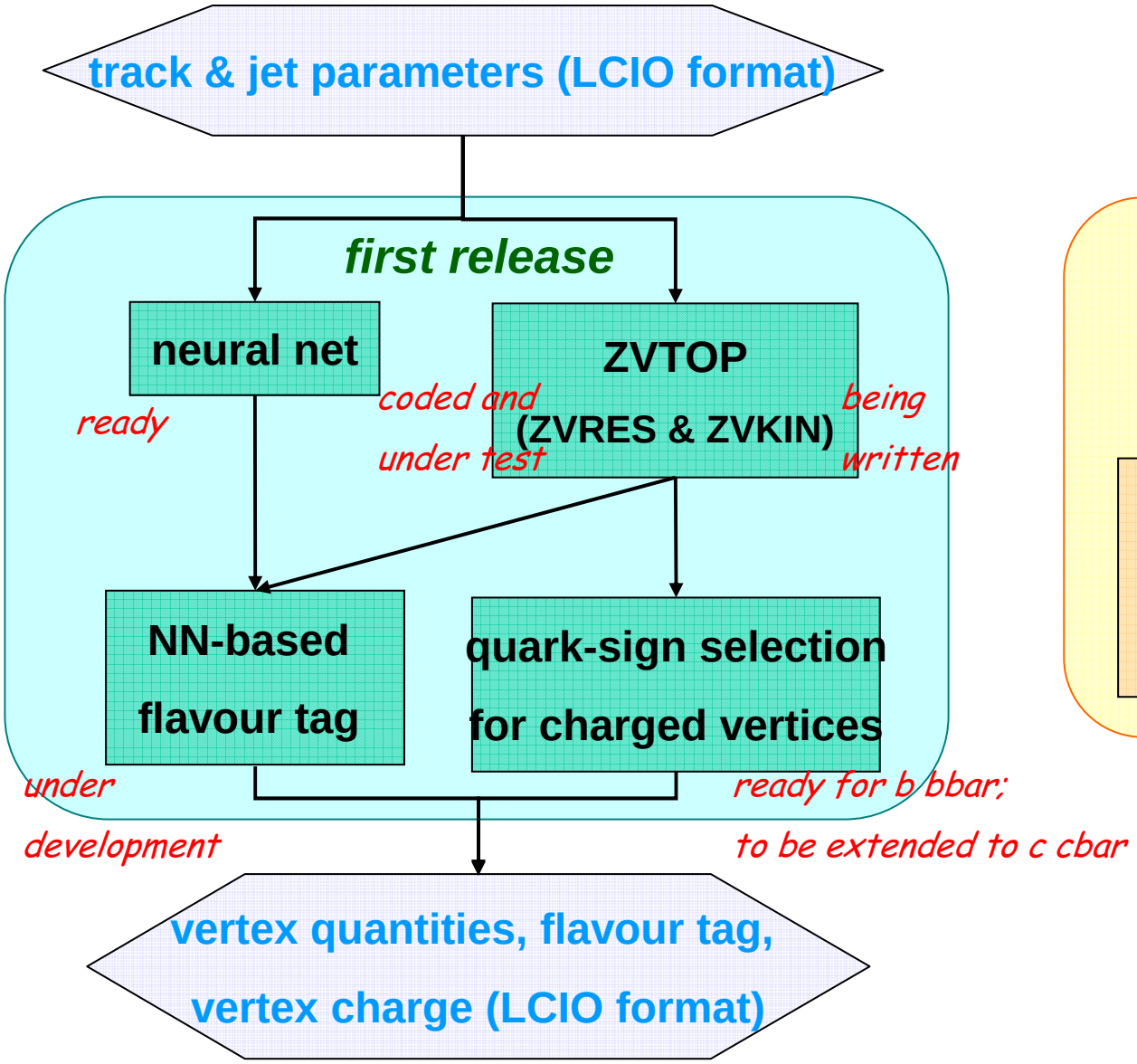
Goal: to optimise vertex detector parameters and evaluate its performance

- Current focus:
  - Develop *C++ based vertex package*
  - Vertex finding: ZVTOP, flavour tag, quark sign selection
    → *to be interfaced to LCIO and released mid of this year*

- In parallel:
  - Performance comparison of different detector designs using fast MC SGV
  - Begin studies of benchmark processes and sensor charge deposition

- Recently started:
  - Studies of occupancy on innermost vertex detector layer
  - Take into account maximum hit density from jets and pair-background
    → *feed information back to readout chip design*

Vertex Package under development



later extensions

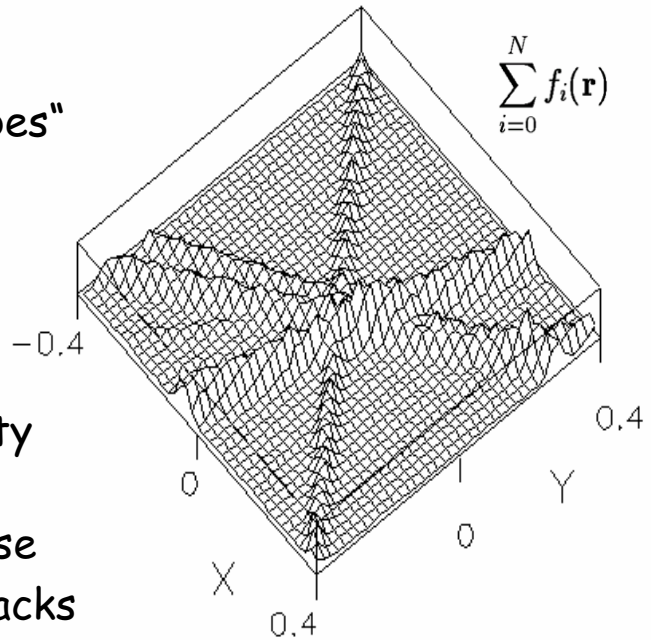
- **charge dipole**
- **use of additional information (e.g. particle ID)**

ZVTOP algorithm and ZVRES

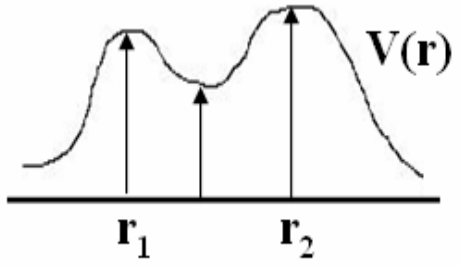
- ZVRES Procedure:
  - Tracks approximated as Gaussian "probability tubes"
  - "vertex function" constructed:

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

  - Search in 3-D for maxima that satisfy resoluibility criteria
  - Iterate over vertex fit, cutting on χ^2 and maximise
  - Function results in unambiguous assignment of tracks to vertices



- Well tested algorithm:
  - Long history and much recent effort: D. Jackson, (NIM A 388 247); B. Jeffery, M. Grimes, D. Bailey
  - Tested and proven with wide range of physics, energies, detectors



ZVRES Development

- Status:
  - Code complete, testing ongoing (comparing with FORTRAN ZVTOP)

- Recent improvements:
  - consistent use of one set of track parameters (BRAHMS/SGV: 4 conventions used in parallel)
  - parabolic approximation for helical track replaced by exact expression
  - analytic calculation of vertex position for 2-prong cases
  - increase in speed compared to early c++ version

- Remaining work:
  - more extensive testing with > 2 track events
  - detailed tests of the fitter performance
  - comparison with MC

ZVKIN (Ghost Track Algorithm)

- **Purpose:**

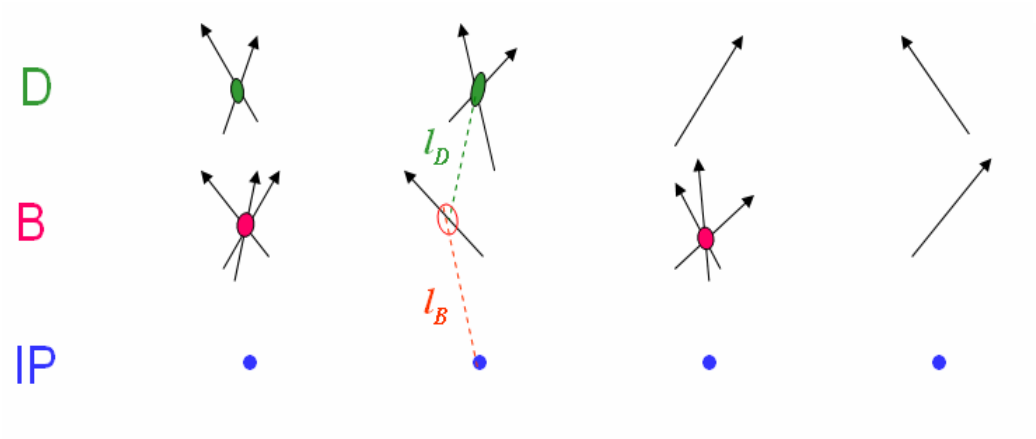
  specialised algorithm to improve coverage for b-jets in which a vertex is 1-pronged and/or in which the B is very short-lived

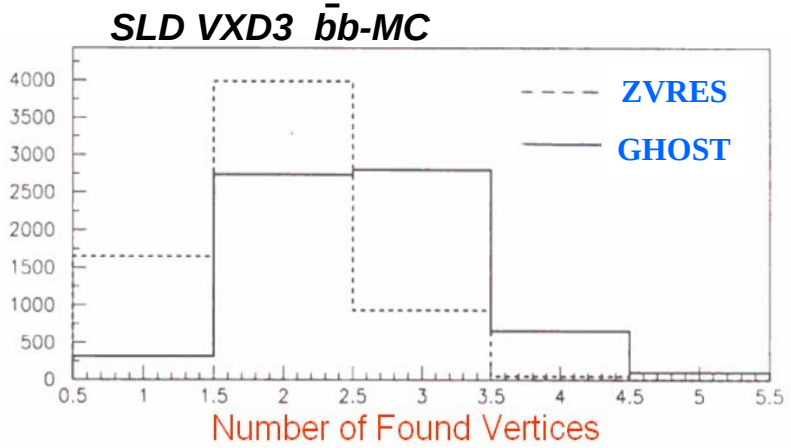
- **Approach:**

  algorithm relies on IP, B- and D-decay vertex lie on an approximately straight line due to the boost of the B hadron

- **Status:**

  coding in progress





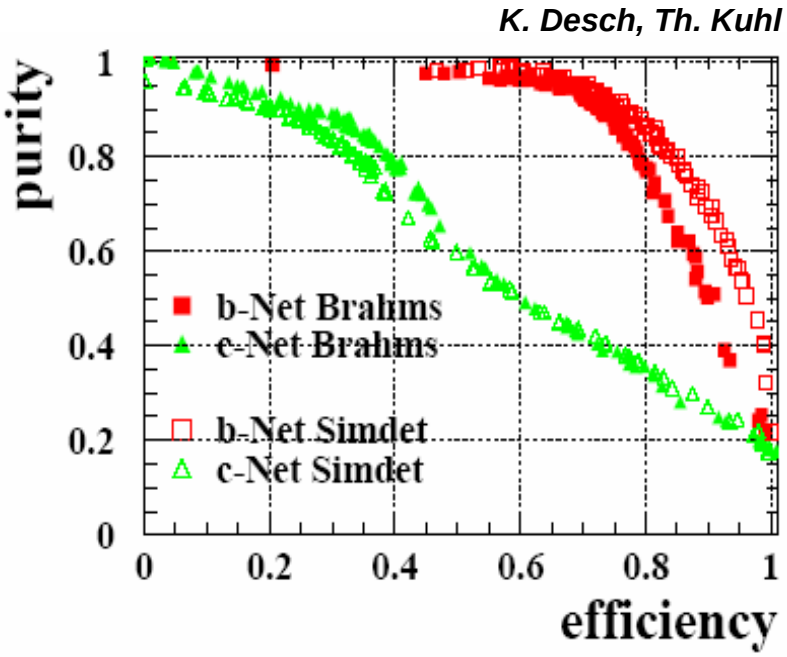
→ *should improve flavour tagging capabilities*

Flavour Tag

- Flavour tag to be included in package:
  - default neural net based flavour tag by R. Hawkings (LC-PHSM-2000-021)
  - recently used by K. Desch & T. Kuhl (LC note in preparation)
  - will allow users to tune the nets to fit their requirements

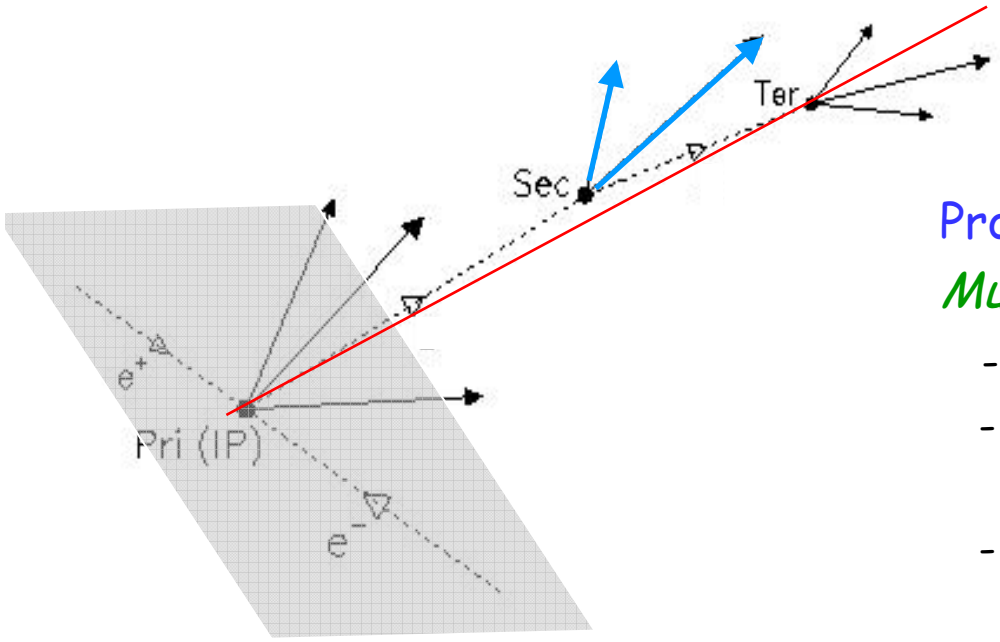
- NN-input variables for default flavour tag:
  - *if secondary vertex found:* M_{Pt}, momentum for secondary vertex, decay length and significance
  - *if only primary vertex found:* momentum and impact param significance in Rϕ and z for two most-significant tracks
  - *in both cases:* estimator of prob for all tracks to originate from primary vertex (joint probability in Rϕ and z)

- Current status:
  - basically ready; cross check with previous results in progress



Vertex charge reconstruction

Motivation: in the 40% of cases where b quark hadronises to charged B-hadron, quark *sign* can be determined from vertex charge



Procedure:

Must find all tracks from B decay chain

- define seed axis
- cut on L/D (distance from IP and projection of track POCA to seed axis)
- tracks that form vertices (other than IP) are assigned regardless of their L/D

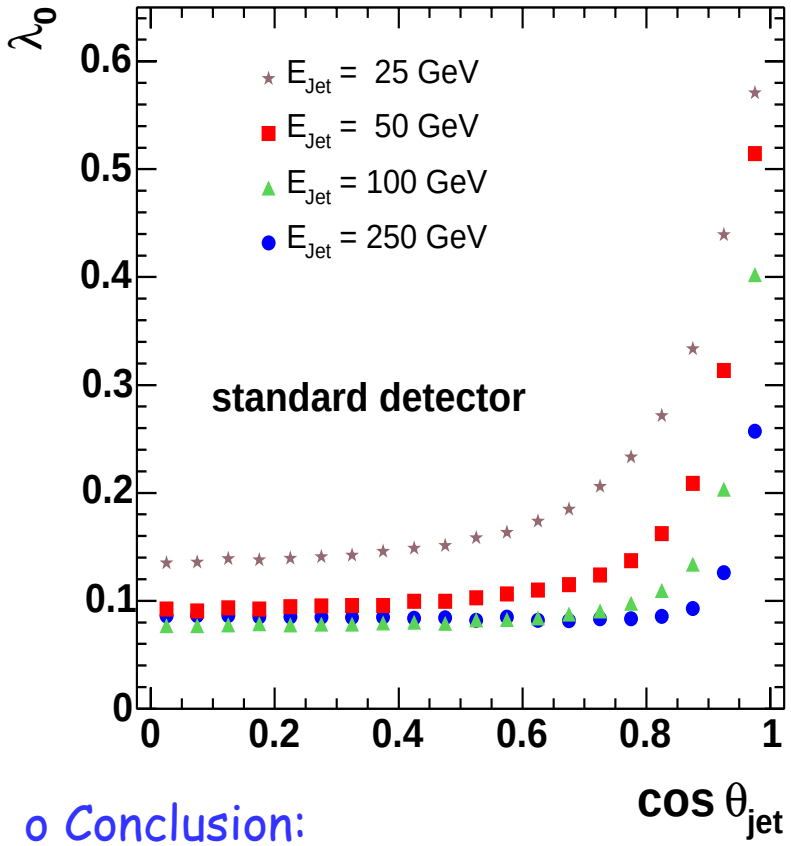
o performance and scope:

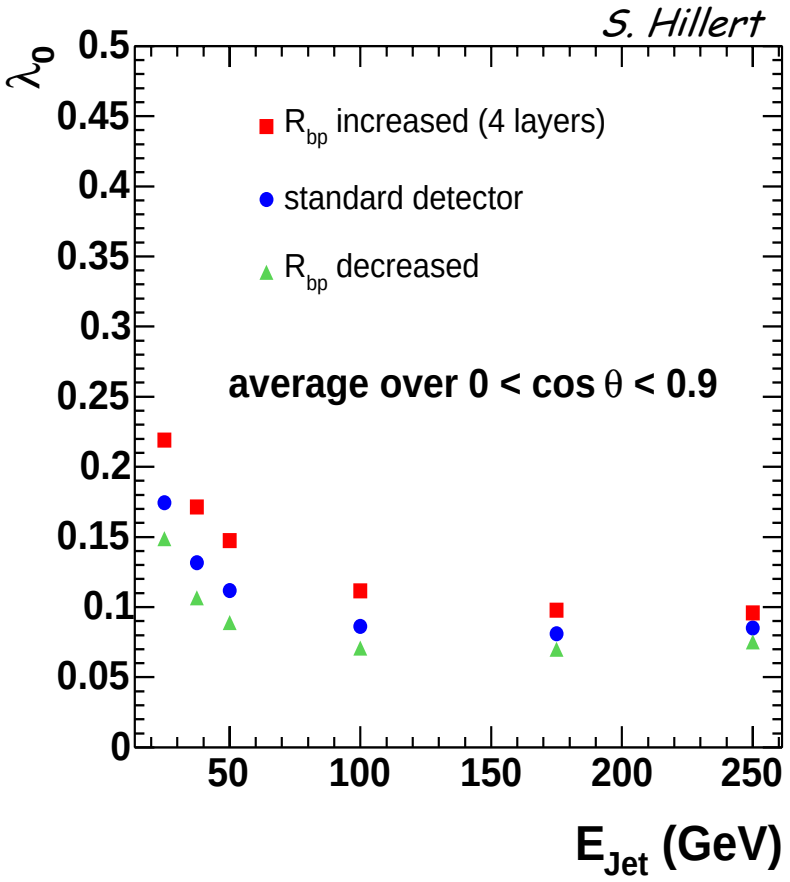
- probability of mis-reconstructing vertex charge is small
- neutral vertices require more complicated procedure (e.g. "charge dipole" from SLD) still to be developed for ILC

Comparison of Detector Designs

o Criterion for comparison:

probability of reconstructing neutral hadron as charged (λ_0)





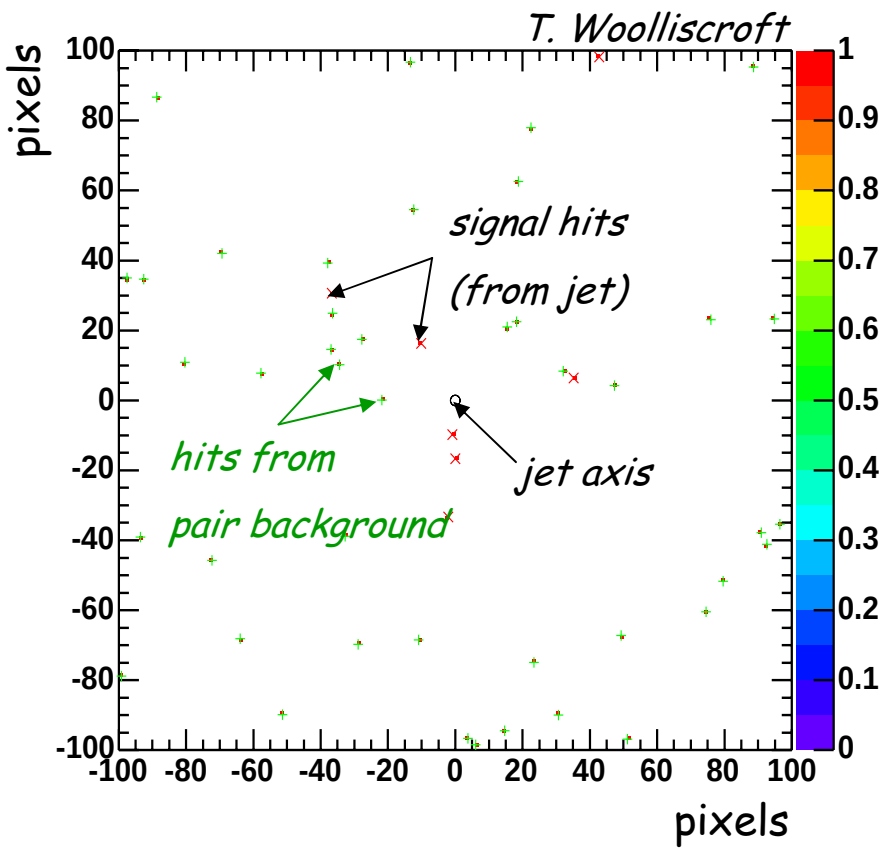
o Conclusion:

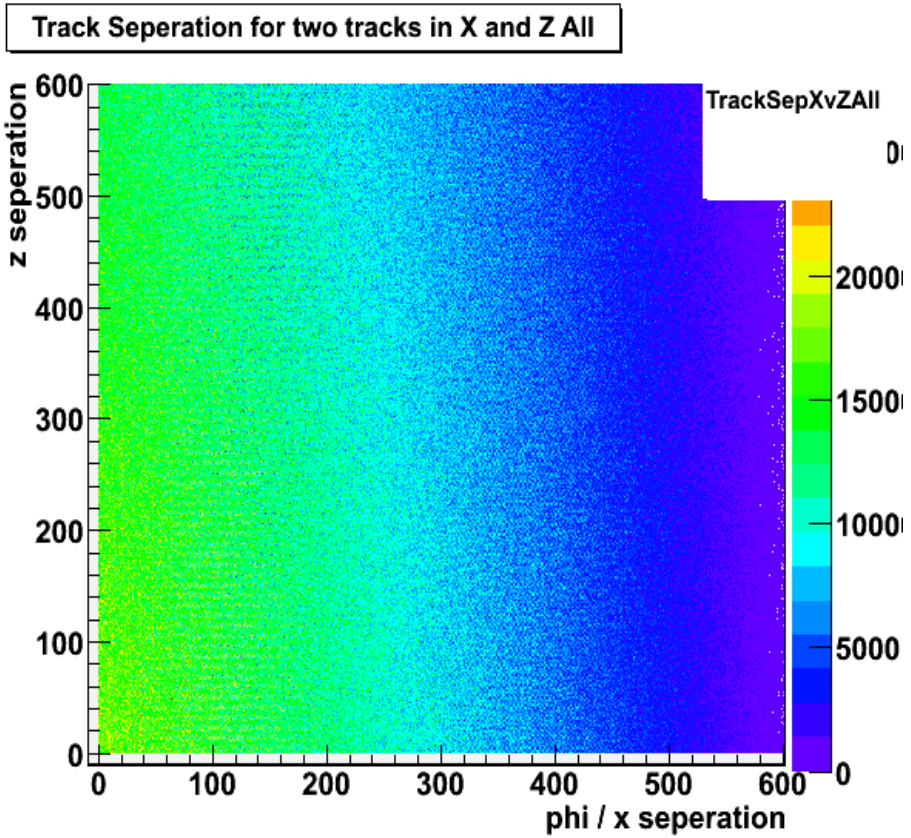
vertex charge performance strongly depends on low momentum tracks

→ *differences between designs most pronounced for low jet energy and large cos θ_{jet}*

Physics Studies for Readout Chip

Using highest energy d (dbar) jets from SGV and background hit density 3/mm²/150BX





- Preliminary conclusions and next steps:
  - need for deadtime-less readout confirmed
  - cluster elongation (Rϕ,z) to be studied & result used to optimise cluster finding

LCFI Physics Plans

Completion of vertex package by the summer has highest priority

- Future extensions may include...
  - reassessment/update of flavour tag and vertex charge using results from ZVKIN
  - quark sign selection for neutral vertices (´charge dipole´, hadron and lepton ID)

- Comparison of detector geometries:
  - look at combined performance of flavour-tag and quark sign selection for b/c jets
  - examine benchmark reactions such as e^+e^- → b bbar, c cbar asymmetries,
    e^+e^- → ZHH for Higgs self-coupling

LCFI Mechanical Studies

- Thin Ladder Mechanics
  - Materials and designs for $\Delta T \approx 100K$
  - Preference for uniform material in tracking volume
  - *CCDs routinely thinned to epitaxial layer*
- Global Design
  - Ensure ladder designs practical
- Cooling
  - Gas cooling assumed
  - Testing on bench and with models

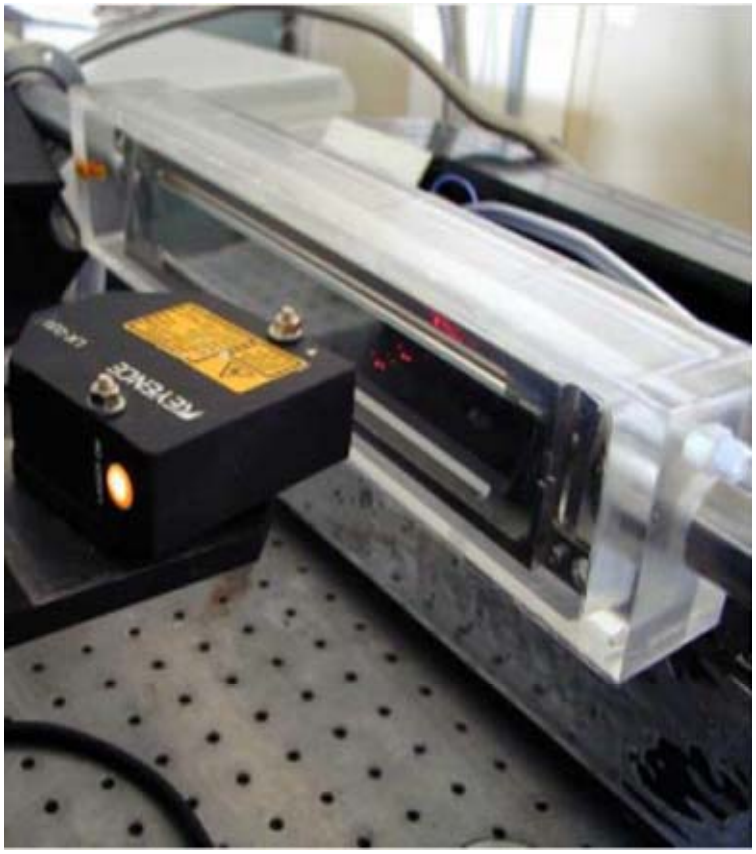
Mechanical Options

Target of 0.1% X_0 per layer (100μm silicon equivalent)

- Unsupported Silicon
  - Longitudinal tensioning provides stiffness
  - No lateral stability
  - Not believed to be promising
- Thin Substrates
  - Detector can be thinned to epitaxial layer (~20 μm)
  - Silicon glued to low mass substrate for lateral stability
  - Longitudinal stiffness still from moderate tension
  - Beryllium has best specific stiffness
- Rigid Structures
  - Foams look very promising
  - Will start to investigate shell structure supports

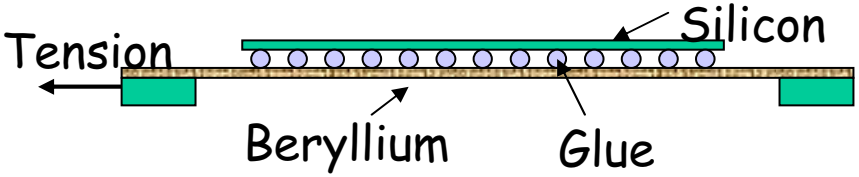
Laser Survey System

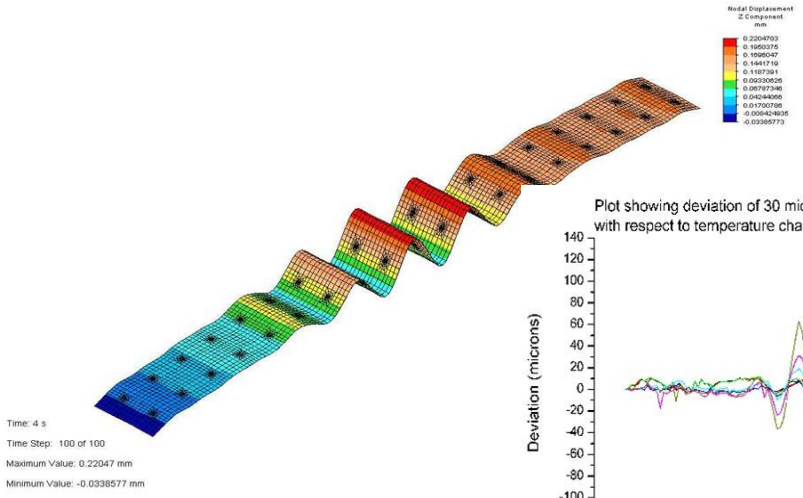
- Laser displacement meter
  - Z precision ~ 1 μm
- 2D motorised stage
  - X-Y precision < 1 μm
- Ladder in cryostat:
  - $\Delta T \sim 100^{\circ}C$
- Fast:
  - 1D scan < 1 minute
  - Scan during cooling

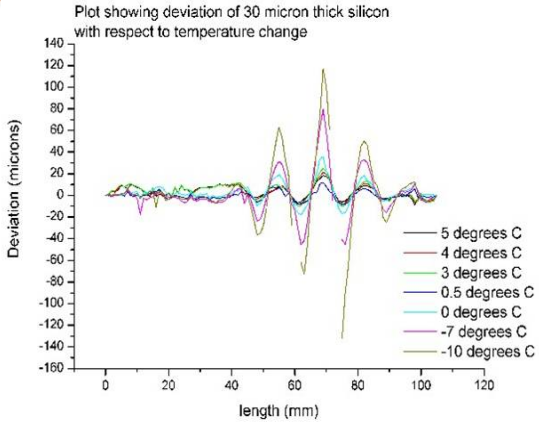


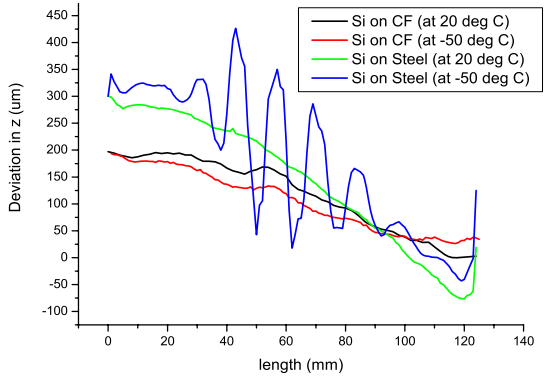
Ladder testing with Be and Carbon Fibre

- **Beryllium substrate**
  - Minimum thickness 0.15% X_0
  - Good qualitative agreement from FEA models and measurement
- **Carbon Fibre substrate**
  - Better CTE match than Be
  - ~0.09% X_0, no rippling to <200K
    → lateral stability insufficient







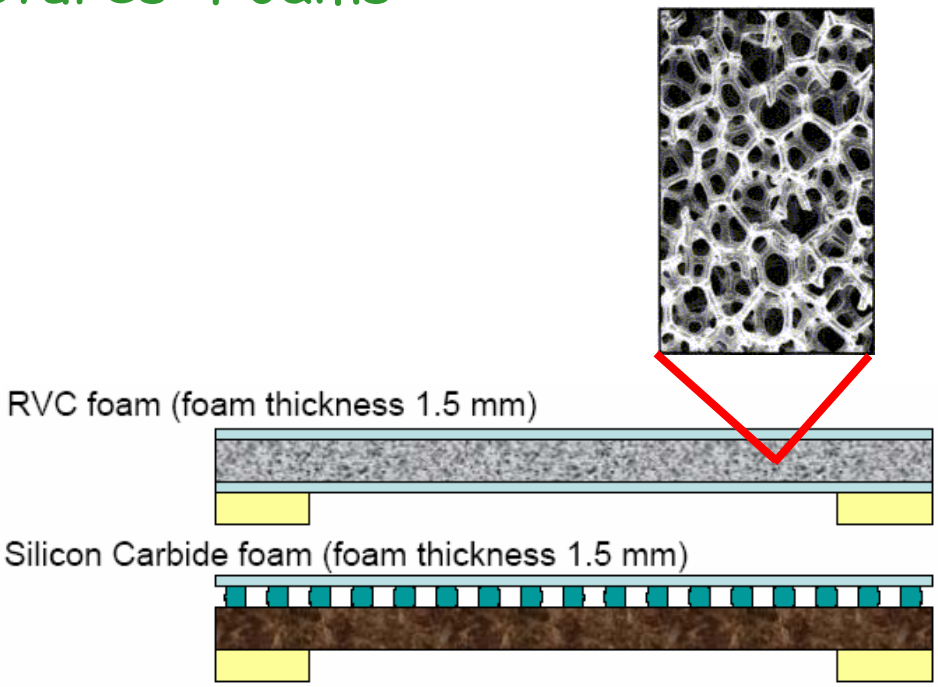


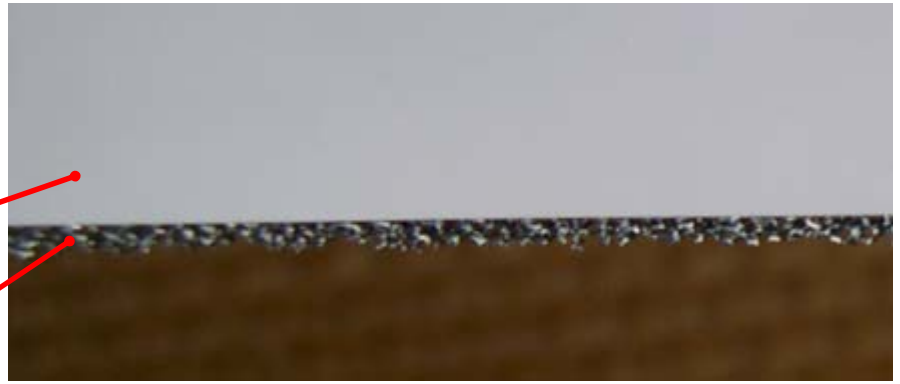
Rigid Structures: Foams

- Properties:
  - Open-cell foam
  - Macroscopically uniform
  - No tensioning needed

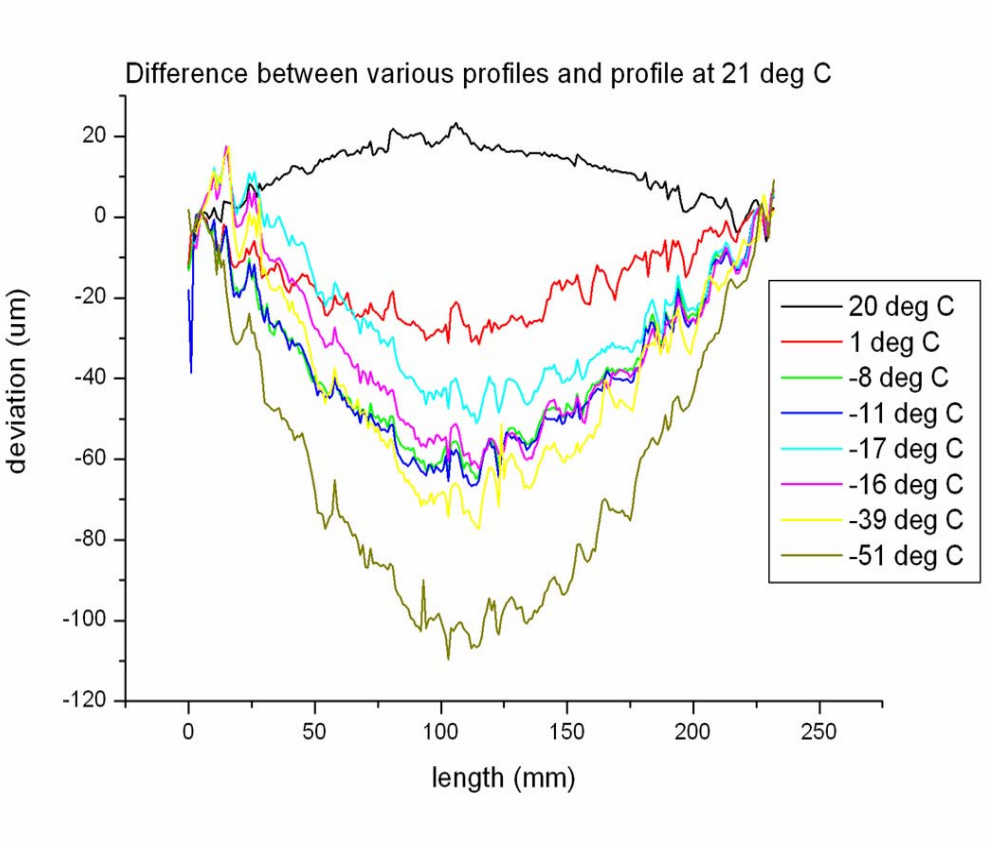
- 3% RVC prototype
  - Sandwich with foam core
  - 0.09% X_0
  - Mechanically unsatisfactory
  - Working on glue application

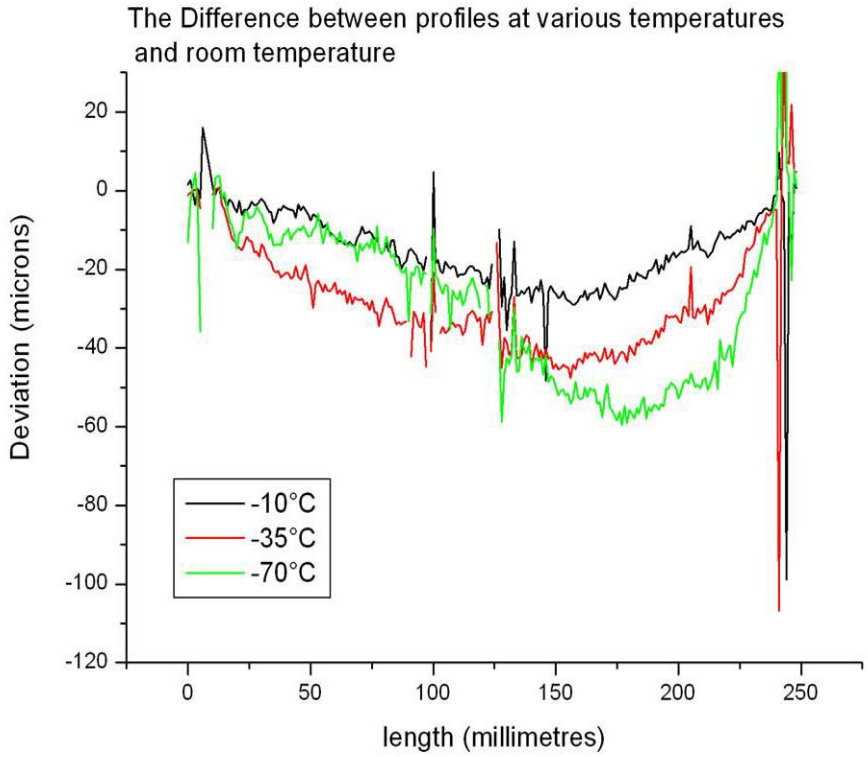
- 8% Silicon Carbide prototype
  - Single-sided: substrate + foam
  - 0.14% X_0
  - 3-4% believed possible





Silicon Carbide Foam





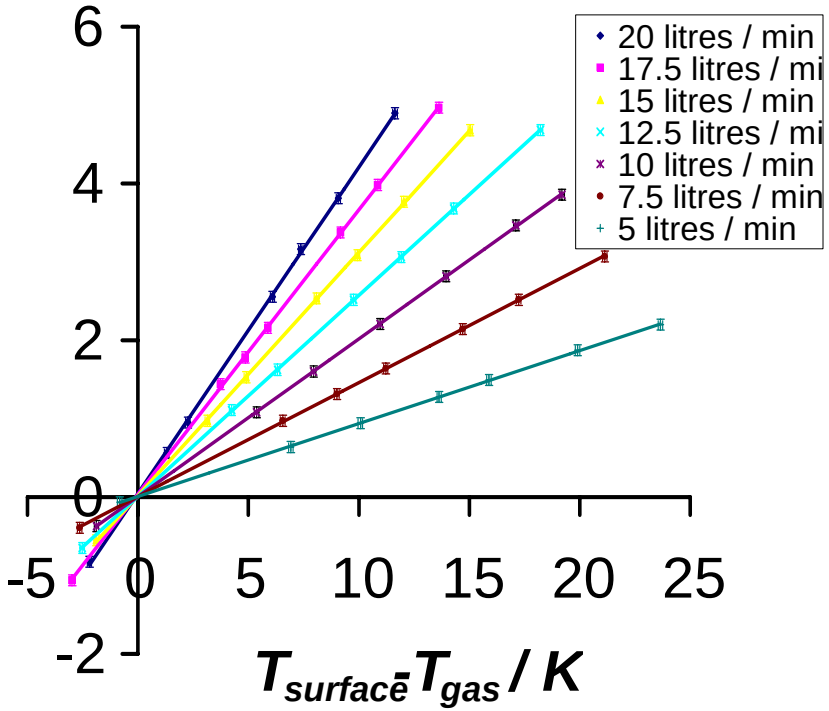
Thin glue layer

Glue "pillars"

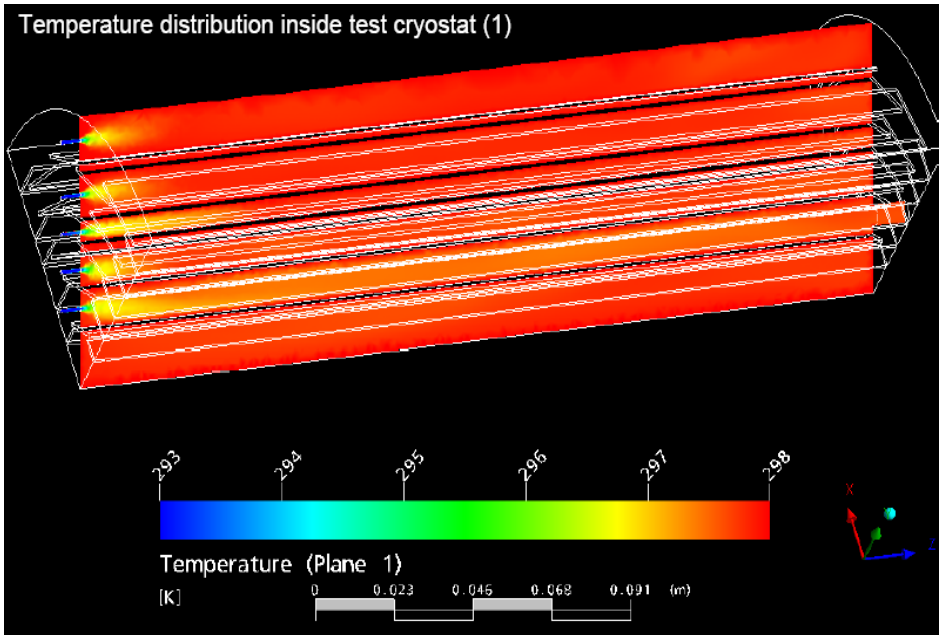
Cooling Studies

- Gas cooling test stand established
  - Cold nitrogen flow
  - Model of 1/4 detector
- CFD simulation work in parallel

Measurements from test stand:



Simulation of same setup:



→ next step: more detailed comparison

Linear Collider Flavour Identification: Summary

- Mechanical studies very active:
  - Emphasis shifted to new materials and foams
  - Look at production issues for a few candidate support technologies
  - Continue and expand cooling tests
- Physics studies
  - Finish coding ZVKIN
  - Finish testing
  - Integrate package, document
  - Distribute by summer

Good start, looking forward to the future!