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Heavy flavour ID and quark charge measurement with an ILC vertex detector

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on behalf of the LCFI collaboration

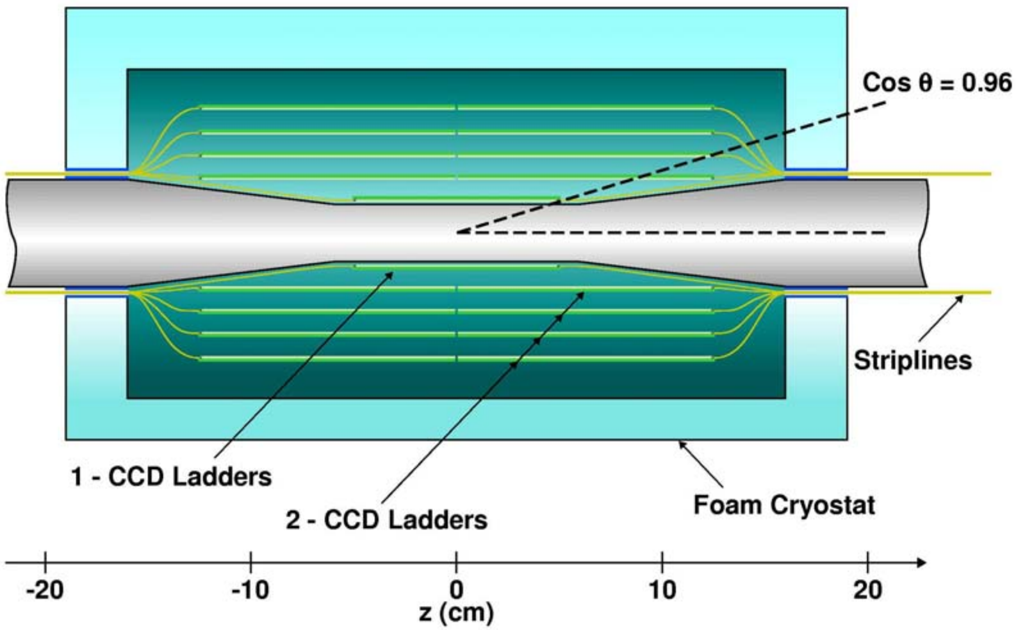
Introduction: Parameters to be optimised (future work)

Aim: optimise design of vertex detector and evaluate its physics performance

- **overall detector design: radial positions (inner radius!) and length of detector layers, arrangement of sensors in layers, overlap of barrel staves (alignment), strength of B-field**
- **material budget: beam pipe, sensors, electronics, support structure (material at large cos θ)**
- **simulation of signals from the sensors: charge generation/collection, multiple scattering**
- **simulation of data sparsification: signal & background hit densities, edge of acceptance**

plan to extend current fast MC (SGV) to full simulation of effects in vertex detector

The standard detector



Standard detector characterised by:

- **good angular coverage (cos θ = 0.96)**
- **proximity to IP, large lever arm:**

  5 layers, radii from 15 mm to 60 mm
- **minimal layer thickness (0.064 % X0)**

  to minimise multiple scattering
- **excellent point resolution (3.5 μm)**

Processes sensitive to vertex detector performance I

Excellent vertex detector performance, providing unprecedented flavour tagging and vertex charge reconstruction, will be crucial to maximise the physics reach of the ILC.

- charm tagging: scalar top production with small Δm (stop-neutralino mass difference)

- e+e- → qqbar: if standard model broken by absence of light Higgs, there may be resonances at large sqrt(s), which may be found by measurement of A^{LR}_{FB}, requiring quark sign selection;

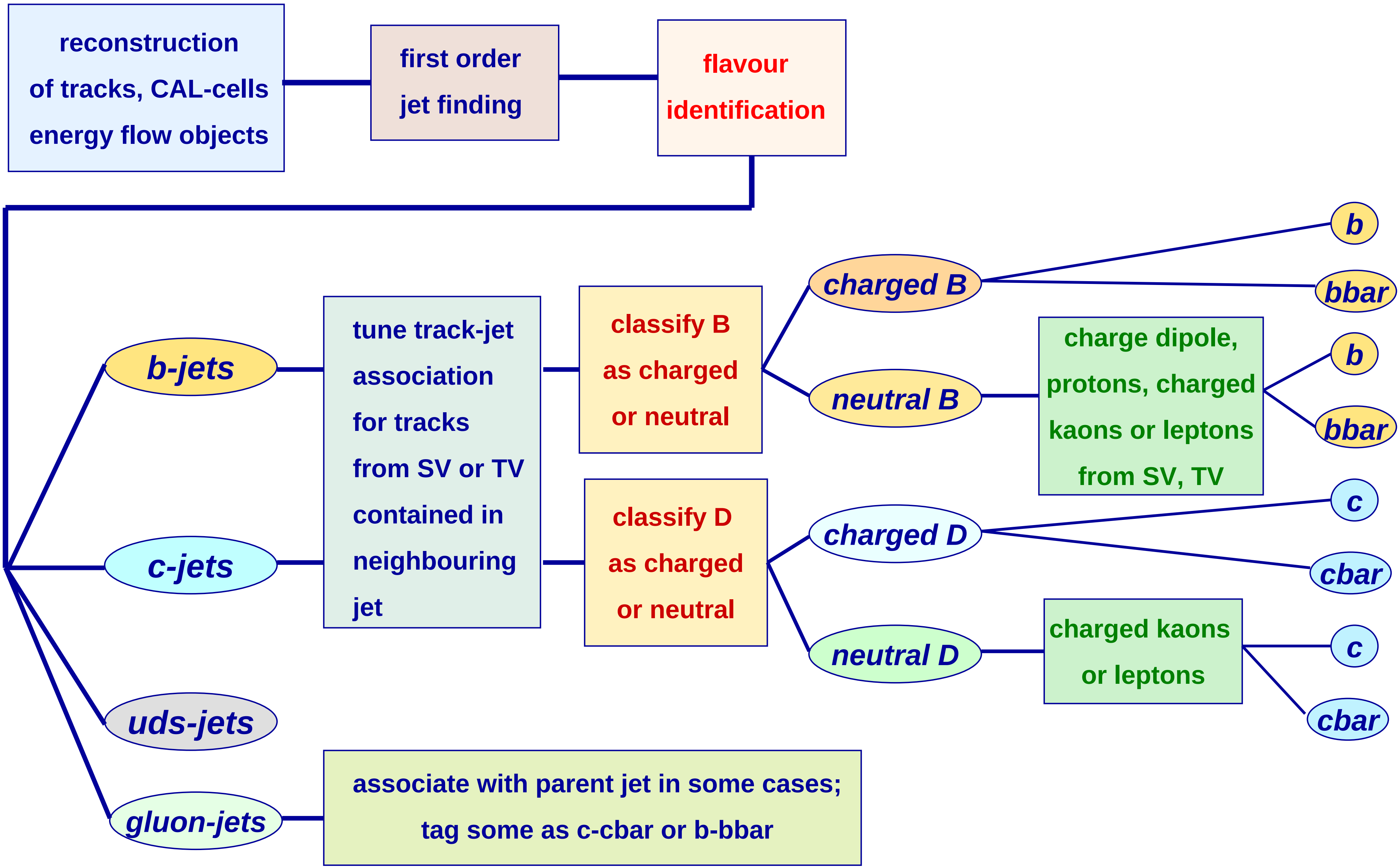
NB: FB asymmetry relies on detector performance at ends of polar angle range, particularly sensitive to detector design (material amount, multiple scattering)

Processes sensitive to vertex detector performance II

- BSM: quark sign selection valuable for spin-parity analysis of SUSY particles;
  leptonic final states considered most, but: low branching fractions, $A_l << A_b$

- top quark polarisation:
  top quark decays before spin can flip
  → polarisation at production reflected in decay;
  general tool with numerous applications, e.g. measurement of underlying SUSY parameters (E. Boos et al. hep-ph/0303110)

Typical event processing at the ILC



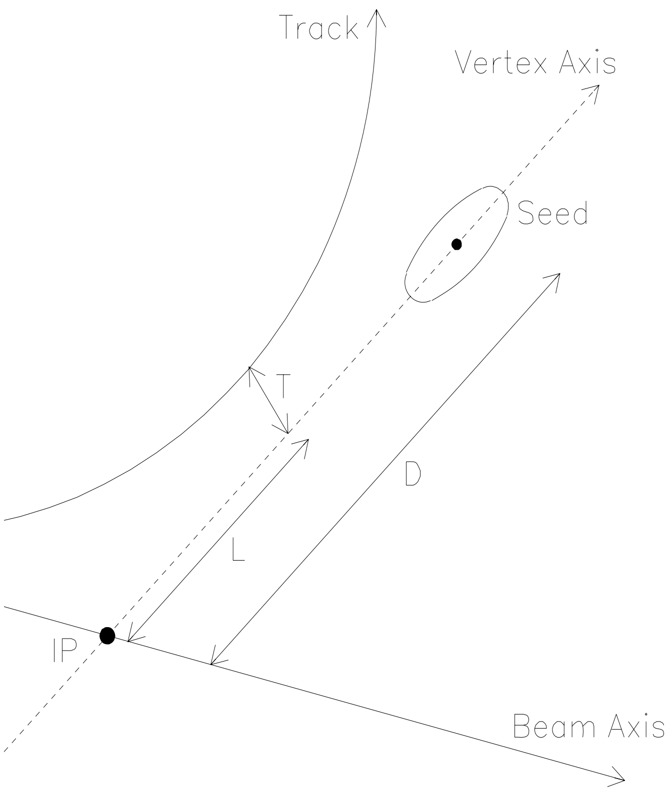
Vertex finding and track attachment

Vertex charge reconstruction studied in $e^+e^- \rightarrow \gamma Z \rightarrow b\bar{b}$ at E_{CM} = 200 GeV,

select two-jet events with jets back-to-back, contained in detector acceptance;

need to find all stable B decay chain tracks - procedure:

- run ZVTOP to find vertex candidates, require tracks to have d_0 < 1.0 cm



- seed vertex (candidate furthest from IP) used to define the vertex axis

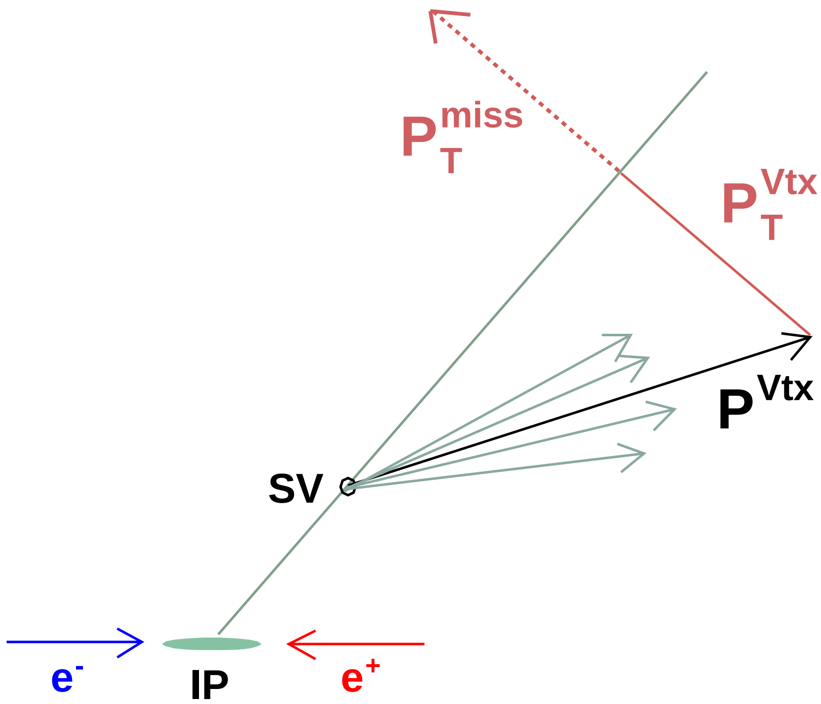
→ reduce the number of degrees of freedom

- assign tracks to B decay chain, which at point of closest approach to the vertex axis have
  - T < 1 mm: cleaning cut, only small effect
  - $(L/D)_{min}$ < L/D < 2.5: main cut, where $(L/D)_{min}$ is optimised for the detector configuration under study

Vertex charge and Pt-corrected mass

vertex charge Q_{vtx} and M_{Pt} determined from tracks assigned to B decay chain:

- sum of charges of these tracks: Q_{sum}
- reconstructed vertex charge $Q_{Vtx,r} = \begin{cases} +1 \text{ for } Q_{sum} = +1 \text{ or } +2 \\ -1 \text{ for } Q_{sum} = -1 \text{ or } -2 \end{cases}$



- from sum of four-momenta: P_{vtx}, M_{vtx}
- apply kinematic correction (partly corrects for missing neutral particles):

$$M_{Pt} = \sqrt{M_{Vtx}^2 + |P_T^{Vtx}|^2} + |P_T^{Vtx}|$$

- M_{Pt} used as ‘b tag’ parameter

Changes since LCWS 2004

- between LCWS04 and ECFA workshop (Durham) :

  optimised cut on L/D, masked K_S and Λ

- dropped ISR while studying vertex charge reconstruction for fixed jet energy

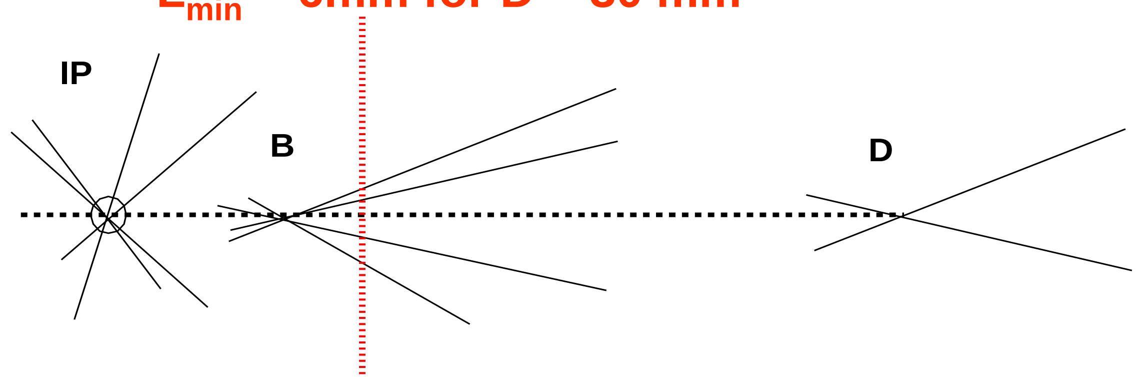
  (otherwise lose ~ 85% of generated events through back-to-back cut on jets)

- include information from inner vertices: seed vertex is ZVTOP vertex furthest from IP; assigning tracks contained in 'inner vertices' to B decay chain regardless of their L/D value improves vertex charge reconstruction (for large distances of seed vertex from IP, L/D cut is much larger than required to remove IP tracks)

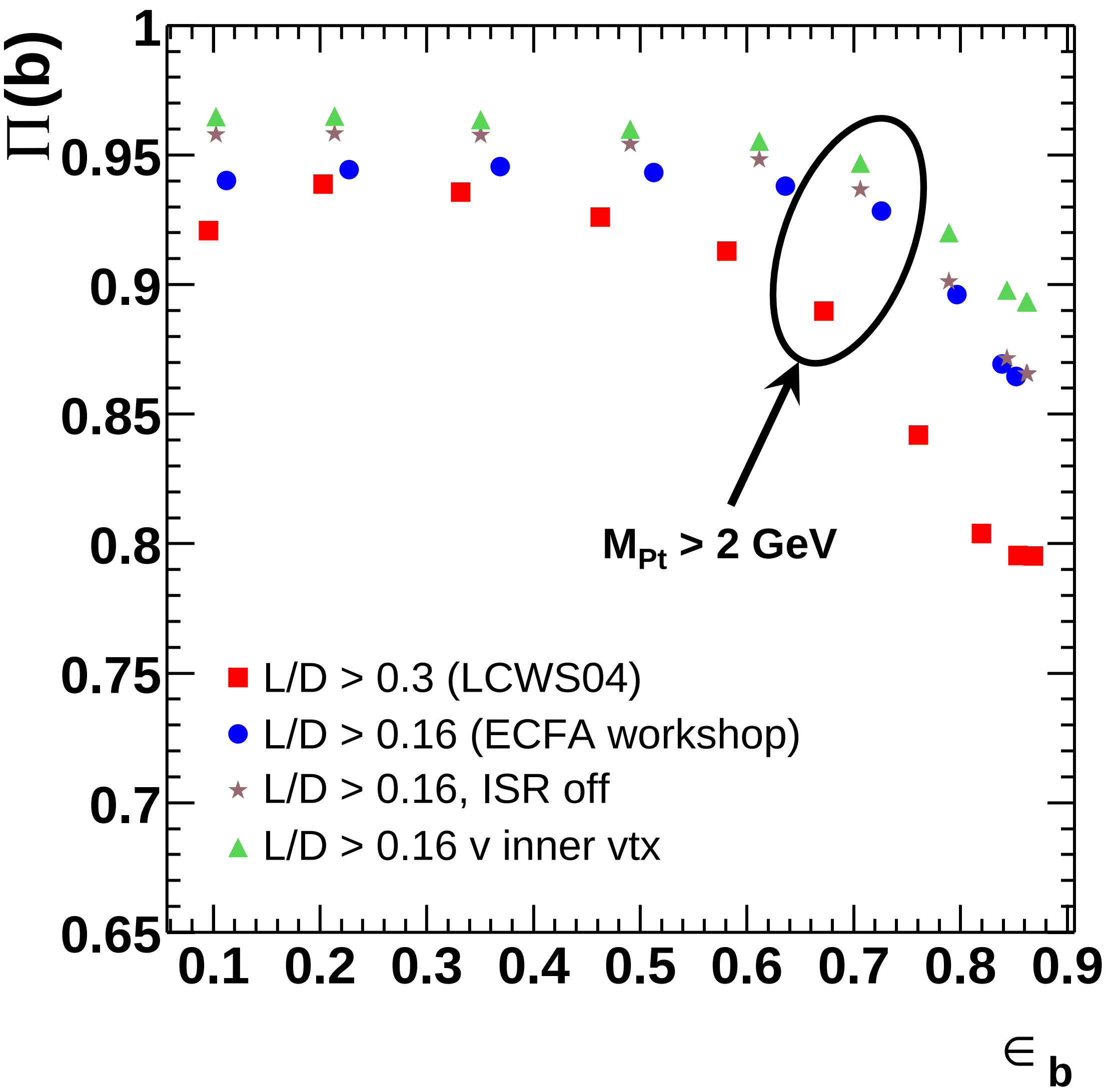
$L/D_{min} \sim 0.2$

$L_{min} \sim 6mm$ for $D \sim 30$ mm

an atypical event
with a large distance of
the seed vertex from the IP

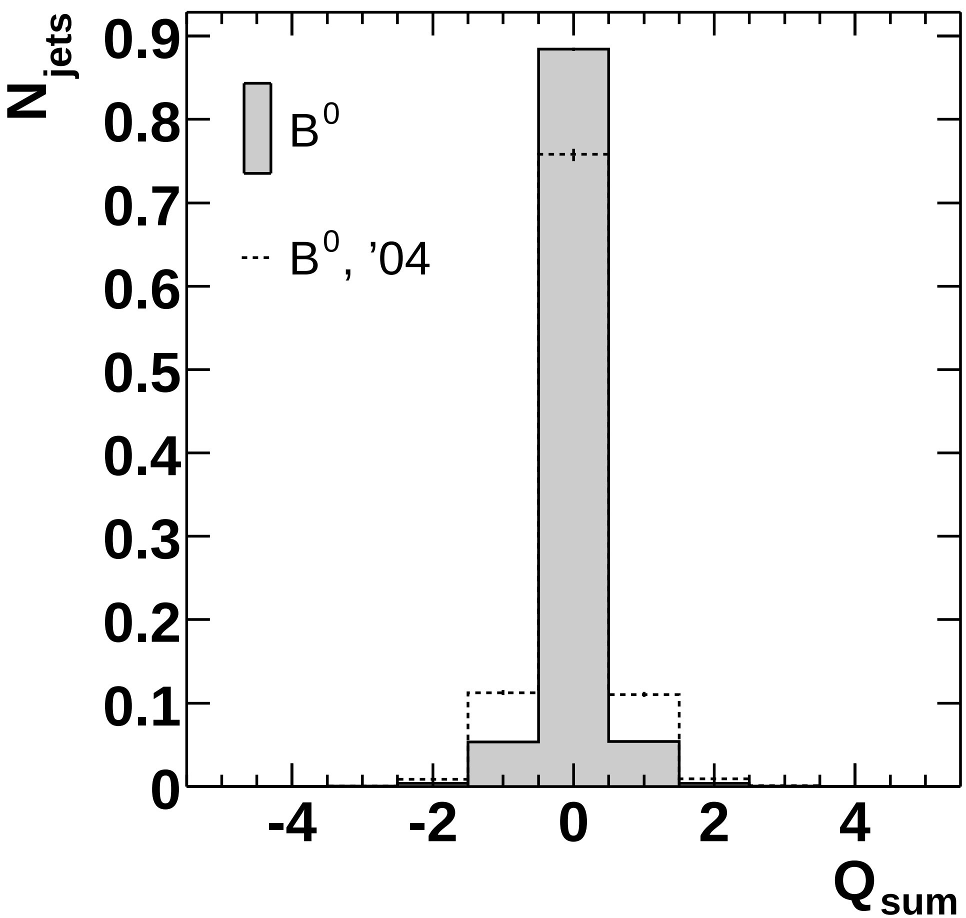


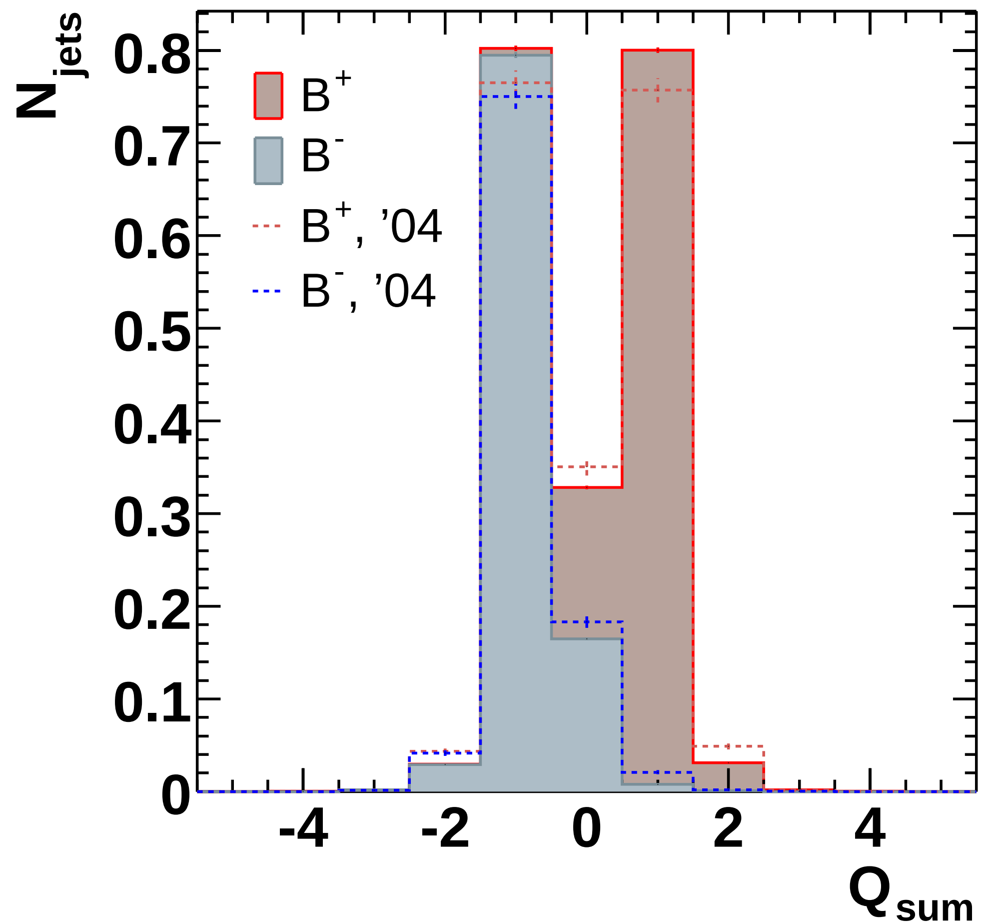
b-charge purity vs efficiency



- largest improvement from optimisation of L/D cut
- switching off ISR mainly affects low efficiency region
- further improvement at high efficiency (region of interest) from including inner vertex information
  ($\Delta\Pi(b)$ = 1% at M_{Pt} > 2 GeV)
- total improvement since LCWS04:
  $\Delta\Pi(b)$ = 5.7% at M_{Pt} > 2 GeV

Improvement of reconstructed vertex charge





Leakage rates – a new performance indicator

- **purity vs efficiency plots do not give the full picture:**

  effect of wrongly reconstructed vertices on purity depends on their true charge: if neutral at MC level, Π(b) decreases less than if charged, due to 50% chance that quark charge still correct

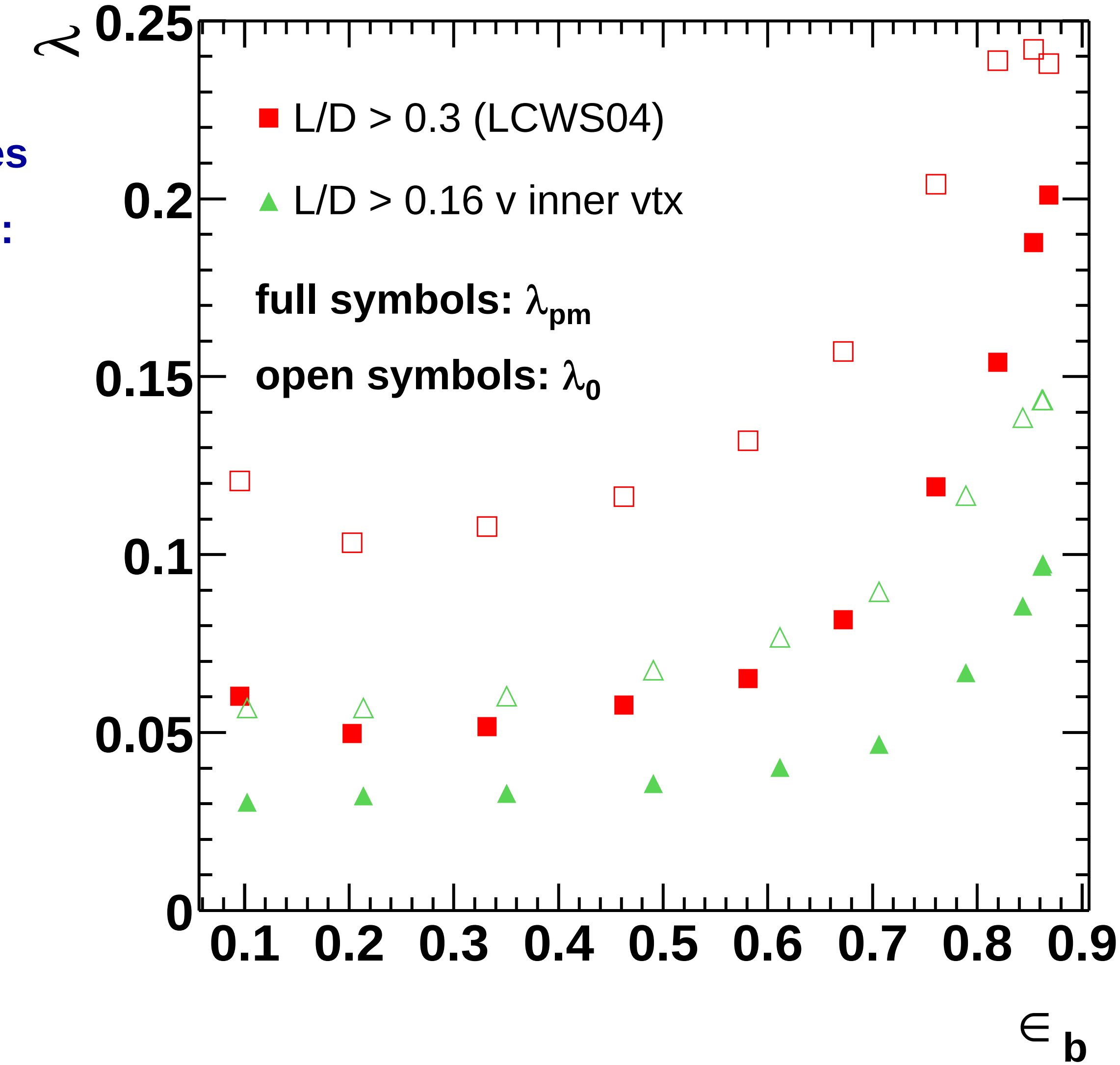
- **define leakage rates:**

  probability to obtain wrong Q_{vtx};

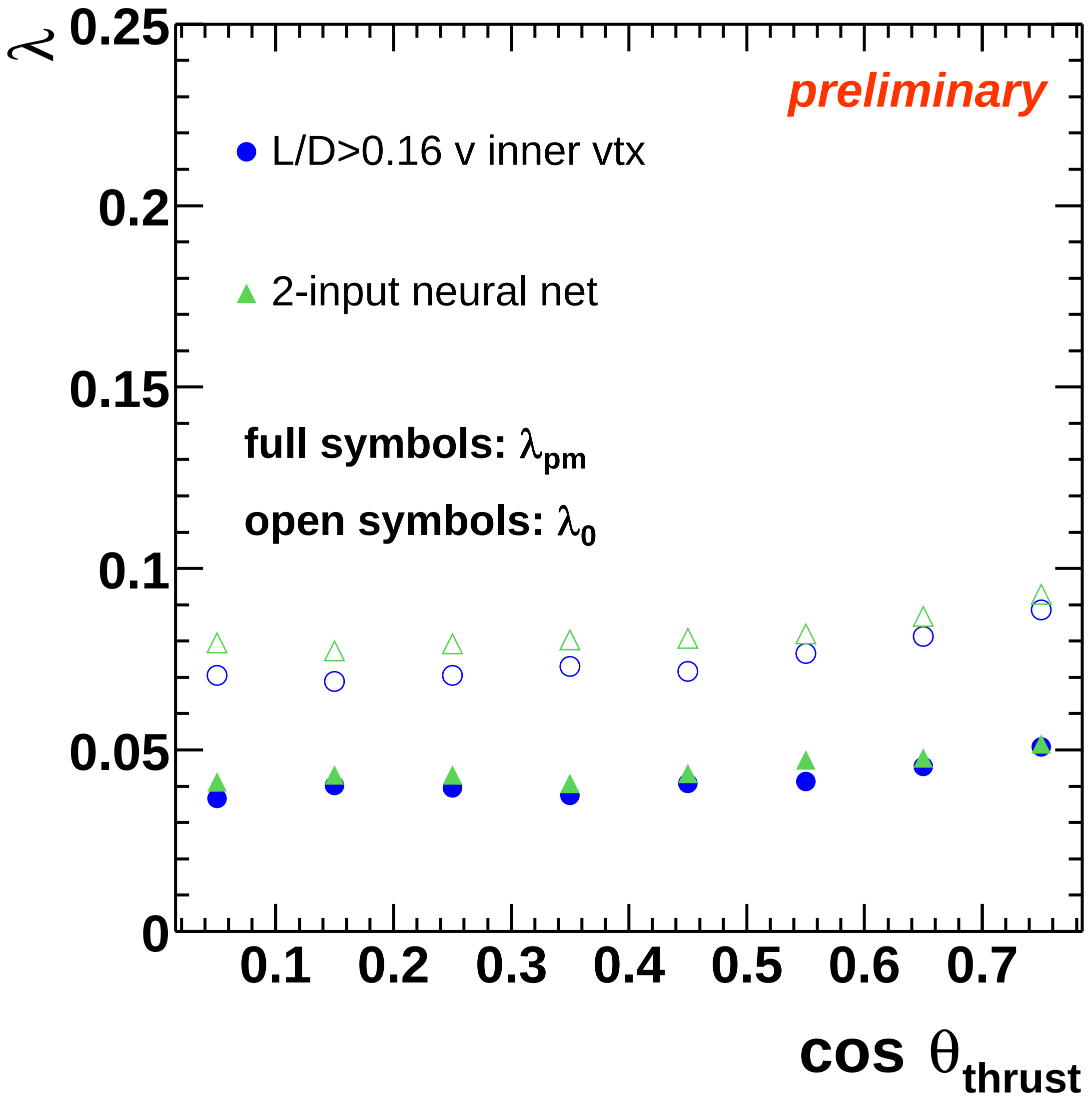
  with N_{ab} = number of vertices generated with charge a, reconstructed with charge b, define

  $\lambda_0 = 1 - N_{00}/N_{0X}$

  $\lambda_{pm} = 1 - (N_{11} + N_{-1-1}) / (N_{1X} + N_{-1X})$



Dependence of leakage rates on thrust angle



- beginning to study polar angle dependence (very preliminary!)
- plot: comparison of the two best methods for vertex charge reconstruction so far:
  L/D approach using inner vertex information, neural net (NN) with input variables (L/D, 3D Dnorm);
- λ_0 decreases by 2%, λ_{pm} by 1% towards the edge of cos θ_{thrust} range
- 'L/D v inner vtx' approach better than the best-to-date neural net

Summary

- The ILC physics programme depends on excellent vertex detector performance.

- improvement of vertex charge reconstruction:

  Π(b) increased by 5.7% at $M_{Pt} > 2$ GeV from optimisation of L/D cut and including inner vertex information

- leakage rates (probability to obtain wrong vertex charge from reconstruction) complement the information contained in the quark charge purity

- first preliminary results on thrust angle dependence indicate 1% (2%) increase in leakage rate for charged (neutral) vertices towards edge of acceptance region

Future plans

- **plans for Q_{vtx} study: extend to range of jet energies, other quark flavours, improve NN**

- **plans for simulation and physics studies in general:**
  - **extend current fast MC (SGV) to full MC simulation of effects in the vertex detector**
  - **improve 'high level reconstruction tools' (vertexing, flavour tagging, Q_{vtx} reconstruction)**
  - **move increasingly to study of benchmark processes sensitive to vertex detector design**