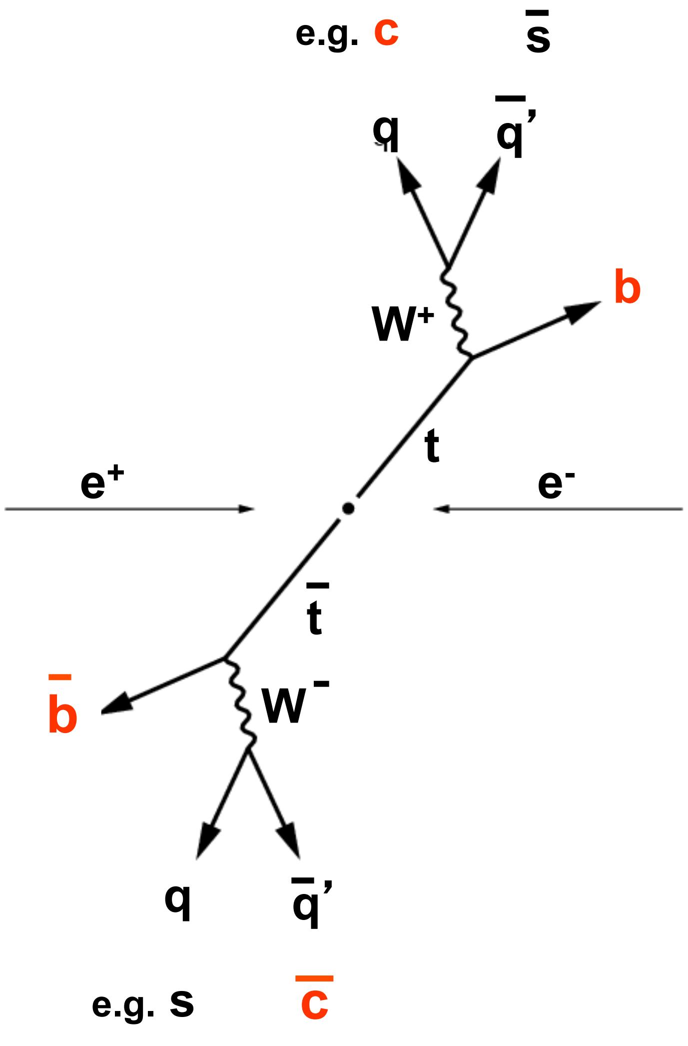
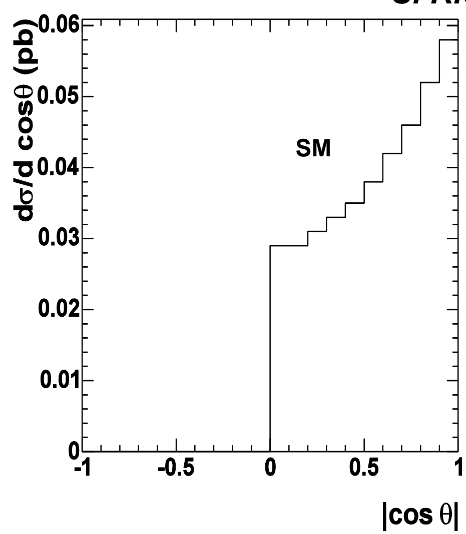
Vertex detector contribution to physics analyses



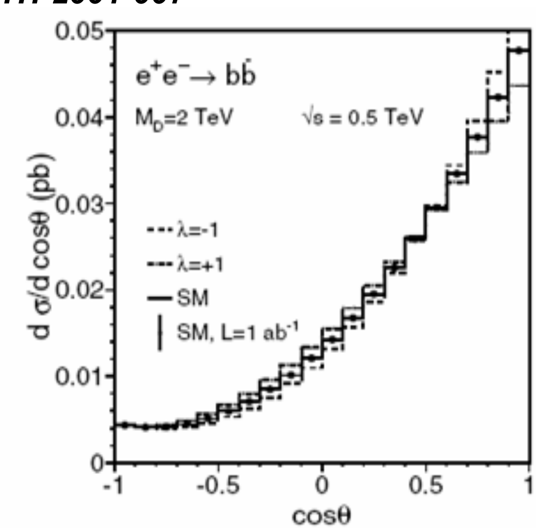
a typical $e^+e^- \rightarrow t\,\bar{t}$ event:

- **vertex finding: identify subsets of tracks inside a jet, which are then fit, yielding vertex position, momentum, mass, fit-c^2**
- **identification of quark flavours of all jets in event**
- **quark sign selection: distinguishing whether jet stems from quark or antiquark useful for e.g. studying top polarisation, and unfolding cross sections**

S. Riemann LC-TH-2001-007



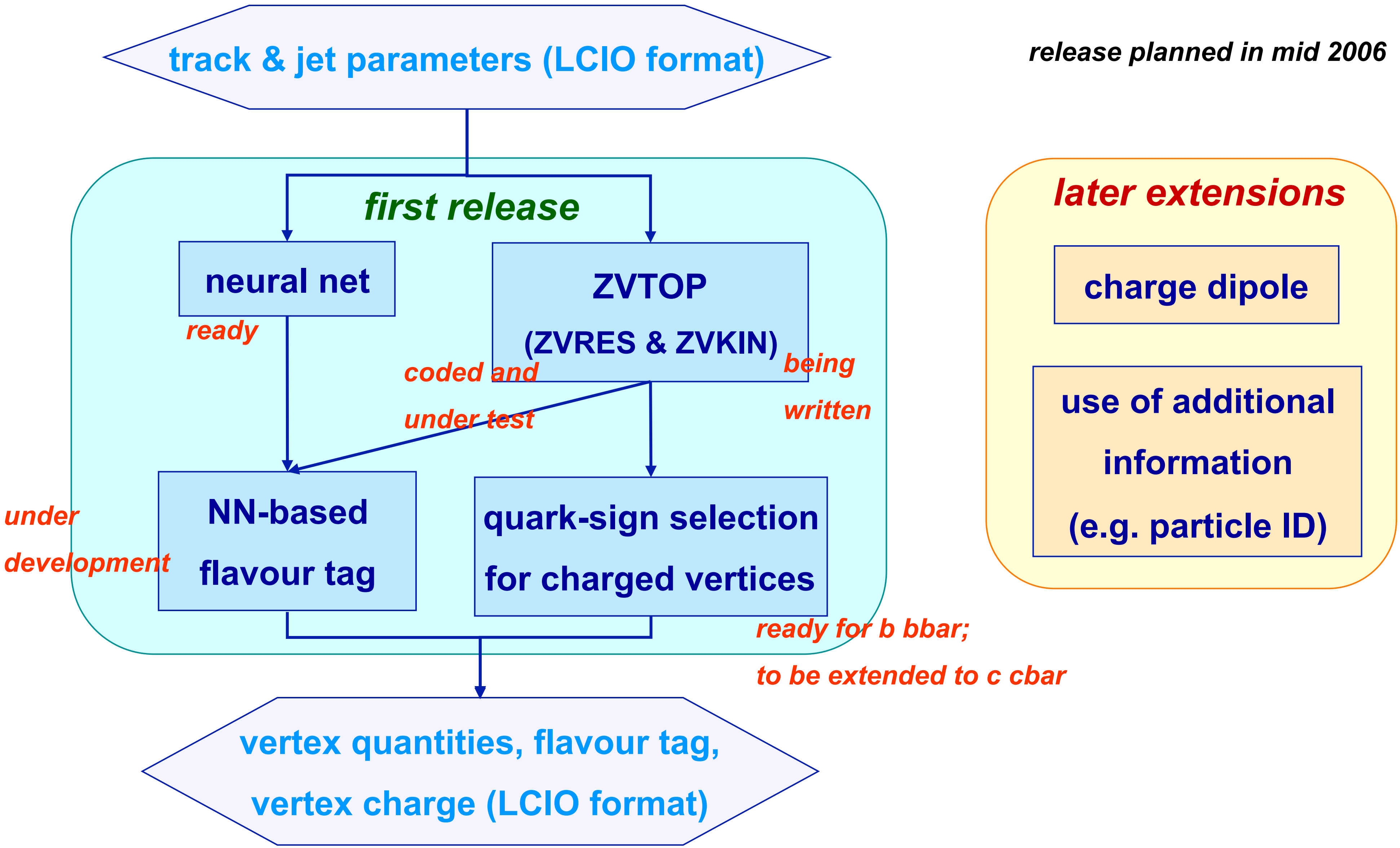
without quark sign selection



with perfect quark sign selection

The LCFI Vertex Package

release planned in mid 2006



Vertex Package Validation

- fast MC SGV provides good basis for testing the new software:
  - results for performance obtained with FORTRAN ZVTOP available for cross-checks
  - detailed comparison of different versions possible by using identical input events
  - current status of ZVRES-testing: see Ben Jeffery's talk

- C++ based code should perform at least as well as FORTRAN version;
  improvements of code wrt FORTRAN will be guided by comparison with MC information

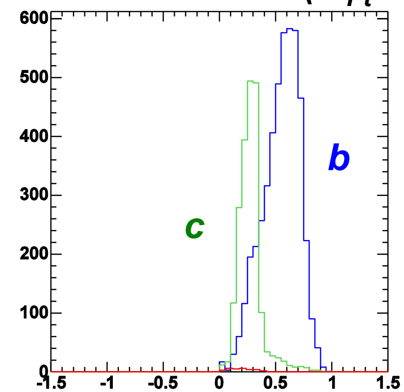
- first replace core ZVTOP, then also replace calculation of input variables for flavour tag
  neural net and vertex charge reconstruction; at each stage compare performance

- final step before release:
  interface to LCIO to allow package to be included in the standard ILC software

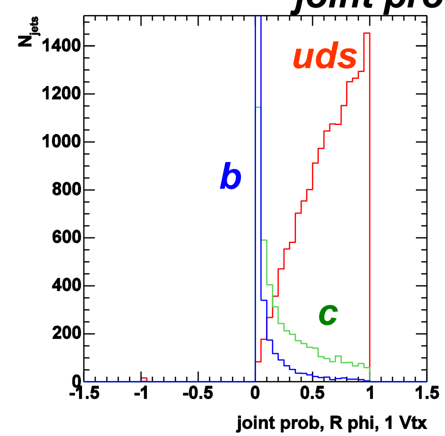
- following slides: combined flavour tag and vertex charge performance using FORTRAN ZVTOP

Flavour tag

- **Vertex package will provide flavour tag procedure developed by R. Hawkings et al (LC-PHSM-2000-021) and recently used by K. Desch / Th. Kuhl as default**



- **NN-input variables used:**
  - **if secondary vertex found: M_{Pt}, momentum of secondary vertex, and its decay length and decay length significance**
  - **if only primary vertex found: momentum and impact parameter significance in R-f and z for the two most-significant tracks in the jet**
  - **in both cases: joint probability in R-f and z (estimator of probability for all tracks to originate from primary vertex)**



- **will be flexible enough to permit user further tuning of the input variables for the neural net, and of the NN-architecture (number and type of nodes) and training algorithm**

Initial checks: flavour tag at the Z-peak

- use SGV and FORTRAN ZVTOP with neural net software developed at Bristol (Dave Bailey) – BaBar, looking for NN-code to include in their analysis software, chose this NN implementation because of its user-friendliness

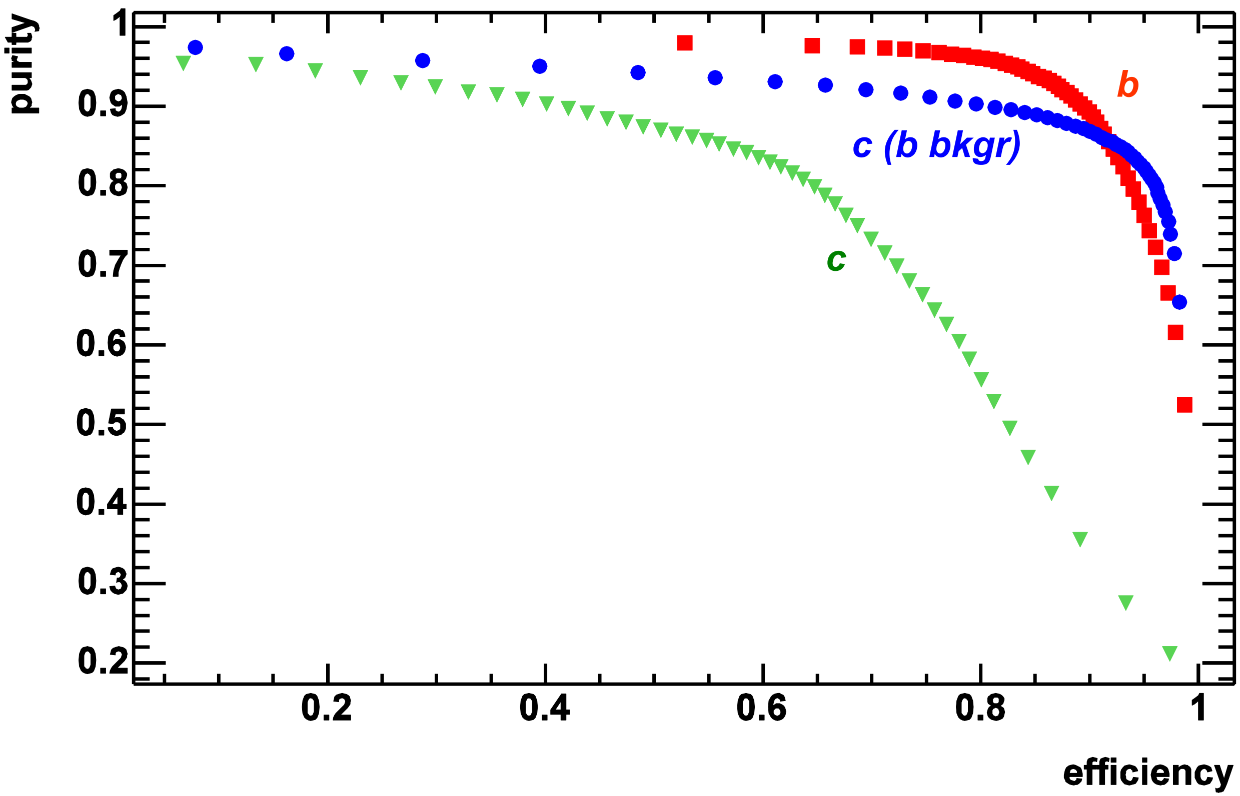
- look at q qbar sample (all flavours except top) at the Z peak; this consists of:

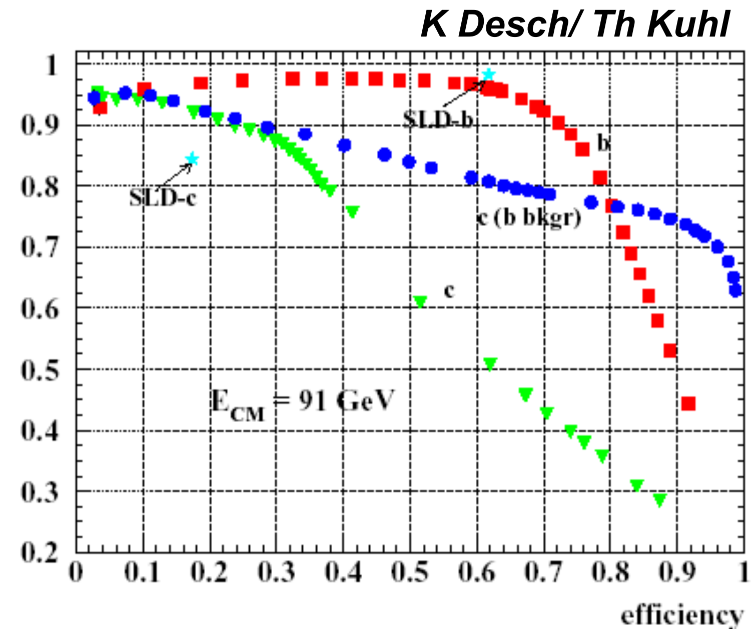
	b-jets (MC-truth)	c-jets	light quark jets
1 vertex (only IP)	2723	9656	64213
2 ZVTOP vertices	13005	8798	77
3 ZVTOP vertices	6493	214	0

- train separate nets for jets with 1, 2 and 3 ZVTOP vertices found; for each category, train three types of net: b-net and c-net to identify b- and c-quarks, respectively and bc-net to identify c-quarks with background only from b-jets

- plot flavour tag purity vs efficiency; angular cut $30^o < q_{thrust} < 150^o$

Flavour tag purity vs efficiency at the Z-peak



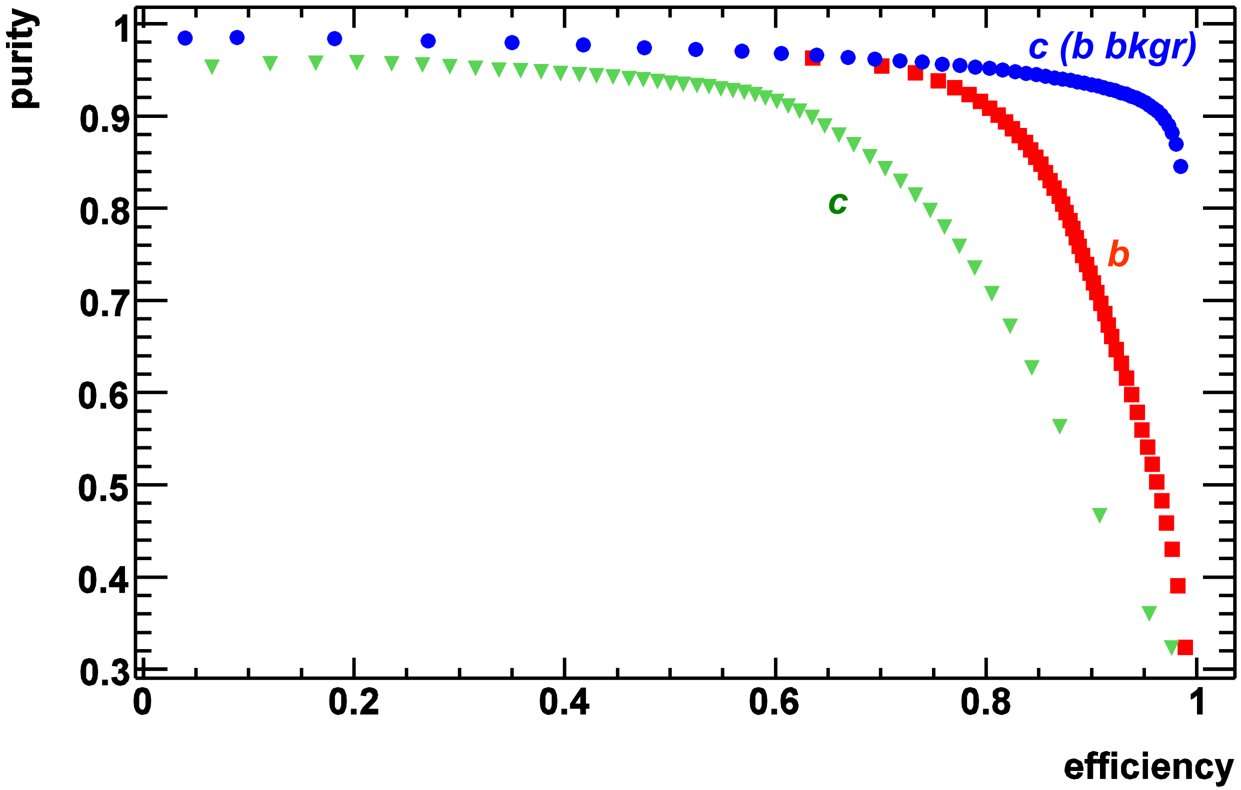


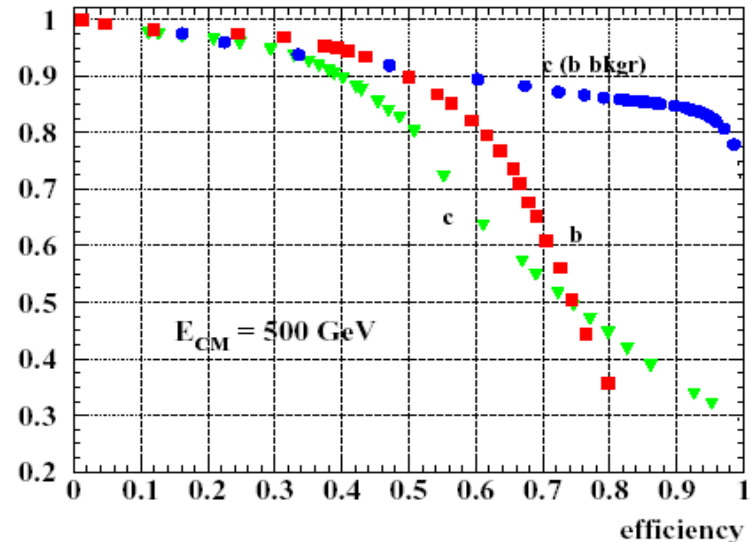
better performance than obtained previously (TESLA-TDR, Desch/Kuhl):

- high b-jet purity up to larger efficiencies;
- c-purity for c with only b-background higher; also improvement for c-tag
- possible reasons include masking of K-shorts and Lambdas, track selection, angular range (region where tracks are more likely to be lost is omitted in present study)

Tagging performance at E_{CM} = 500 GeV

left: momentum and decay length significance of secondary vertex and momentum of most and of second-most significant track in jet scaled with jet energy

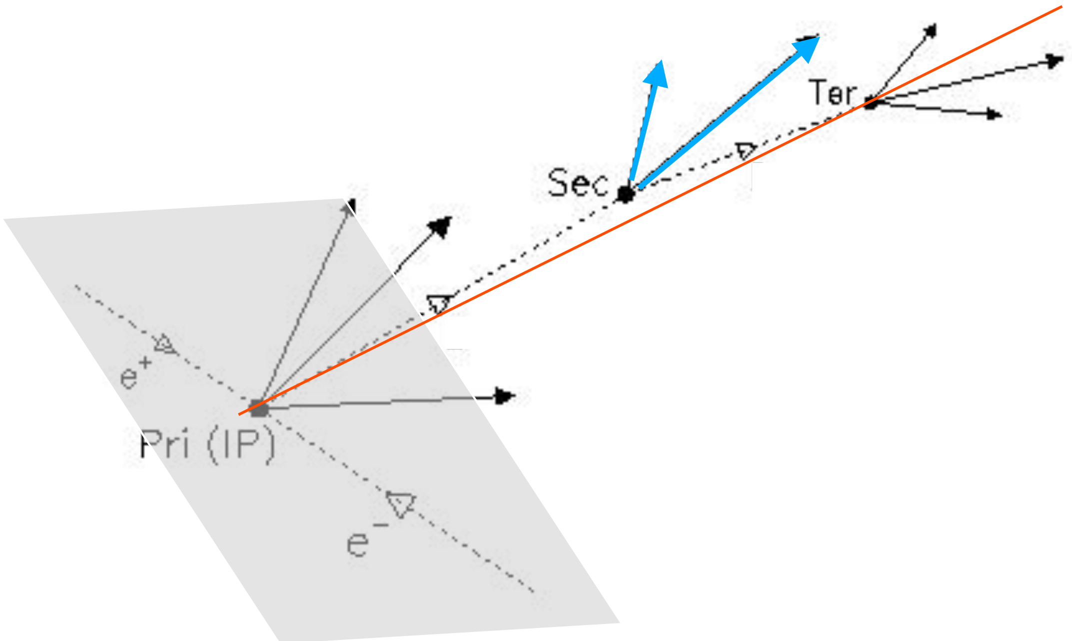




- **b-tag worse, c (b-bkgr) tag improved at 500 GeV compared to Z-peak, consistent with change in contributions of b- and c-jets to sample**
- **comparison with previous result (right) not fully possible (see previous slide)**

Vertex charge reconstruction

- in the 40% of cases where b quark hadronises to charged B-hadron quark sign can be determined by vertex charge

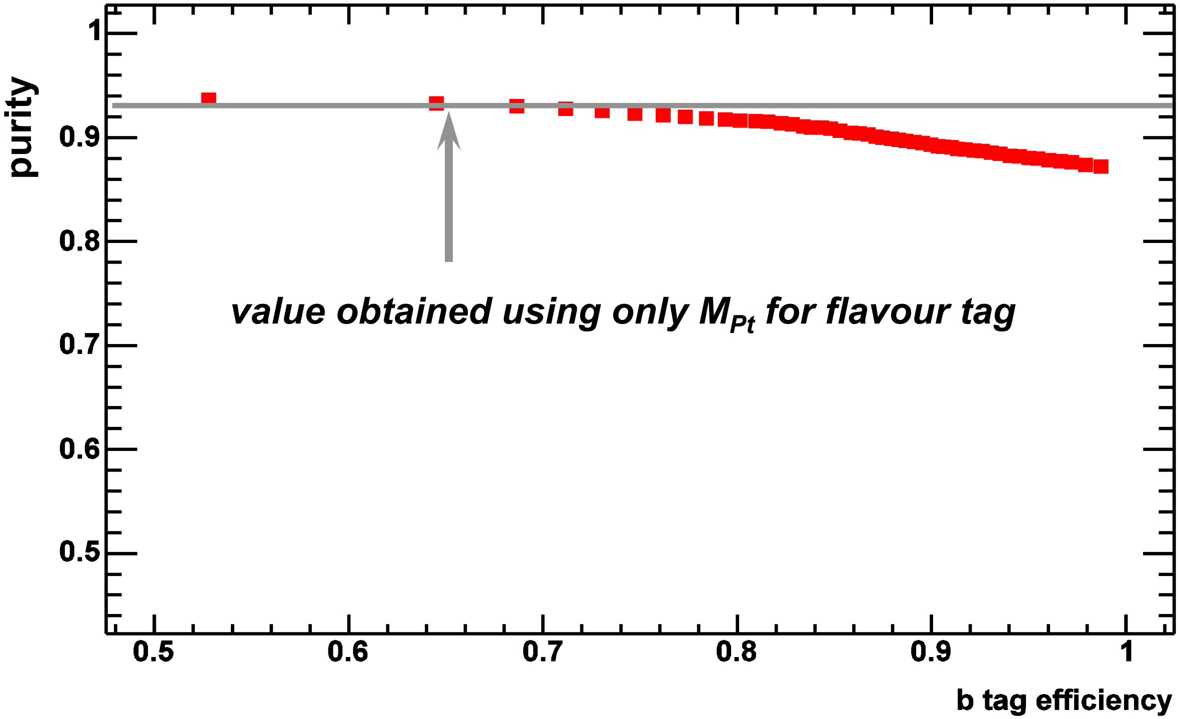


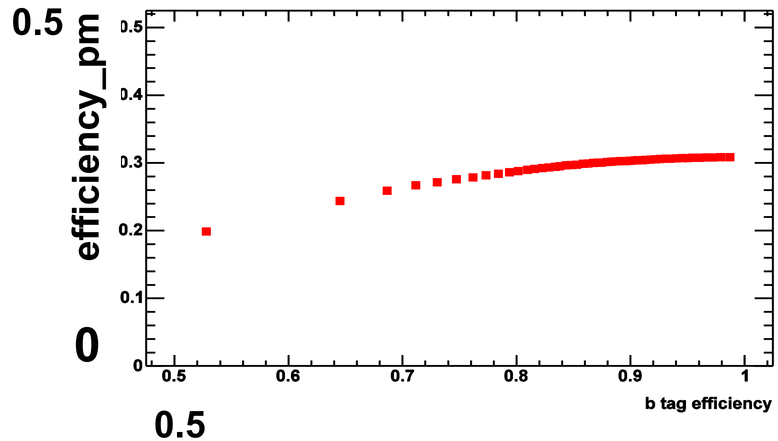
- need to find all stable tracks from B decay chain:
  - define seed axis
  - cut on L/D (normalised distance between IP and projection of track POCA onto seed axis)
  - tracks that form vertices other than IP are assigned regardless of their L/D

- probability of mis-reconstructing vertex charge is small for both charged and neutral cases
- neutral vertices require 'charge dipole' procedure from SLD still to be developed for ILC, relying on ghost track / ZVKIN

Vertex charge reconstruction at the Z peak

- start with sample containing all flavours, first apply b-tag, then reconstruct vertex charge
- look at purity and efficiency of finding vertex charge other than 0, plotted vs b-tag efficiency





- previously used pure b bbar sample and cut on M_{Pt} for 'flavour-tag', typical cut value 2 GeV corresponding to ~ 65 % efficiency; grey line: average over polar angle range considered

→ good agreement with previous results

Summary and outlook

- The LCFI Vertex Package (ZVTOP, flavour tag, quark sign selection) is coming together well.

- Testing of the 'standard' branch of ZVTOP (ZVRES) is far advanced: see Ben Jeffery's talk

- setup for comparing flavour tag and vertex charge for different versions put together, currently look at combined flavour tag & vertex charge performance using FORTRAN ZVTOP:
  - flavour tag: purity stays high out to larger efficiency than in previous studies, but not directly comparable (K-short, Lambda masking, track selection …)
  - vertex charge performance in agreement with results from M_{Pt}-only flavour tag
  - next step: replace FORTRAN by C++ ZVTOP

- C++ ZVTOP contains extensions (ZVKIN) and improvements wrt FORTRAN version, which will improve flavour tag and vertex charge; full exploration of how tag and charge reconstruction will profit will extend beyond time of release in summer this year

Additional Material

Towards inclusion of vertex package in full MC and reconstruction framework

- **initial tests to be performed using SGV:**
  - C++ version of ZVTOP code to be tested against expected performance (ongoing) and compared to results obtained from SLD version
  - in parallel test Hawkings flavour tag within SGV

- **then interface vertex package to LCIO; perform further tests, continuing beyond time of code release:**
  - comparison of performance using full MC and reconstruction to SGV results in 2 steps:
    1) full MC, but use ´cheaters´ for reconstruction
    2) replace cheaters with full track reconstruction input

  - to interpret results of step 2) would be good if developers of track reconstruction code could provide study of track reconstruction over full momentum and full polar angle range, including tracks originating outside the vertex detector

Areas for later upgrades I

➢ Components of the vertex package are likely to need further optimisation and extension after release, e.g.

- choice of input variables for flavour tag neural net

- quark sign selection: reassess reconstruction procedure once c-jets are included,
  extend to neutral vertices (charge dipole)

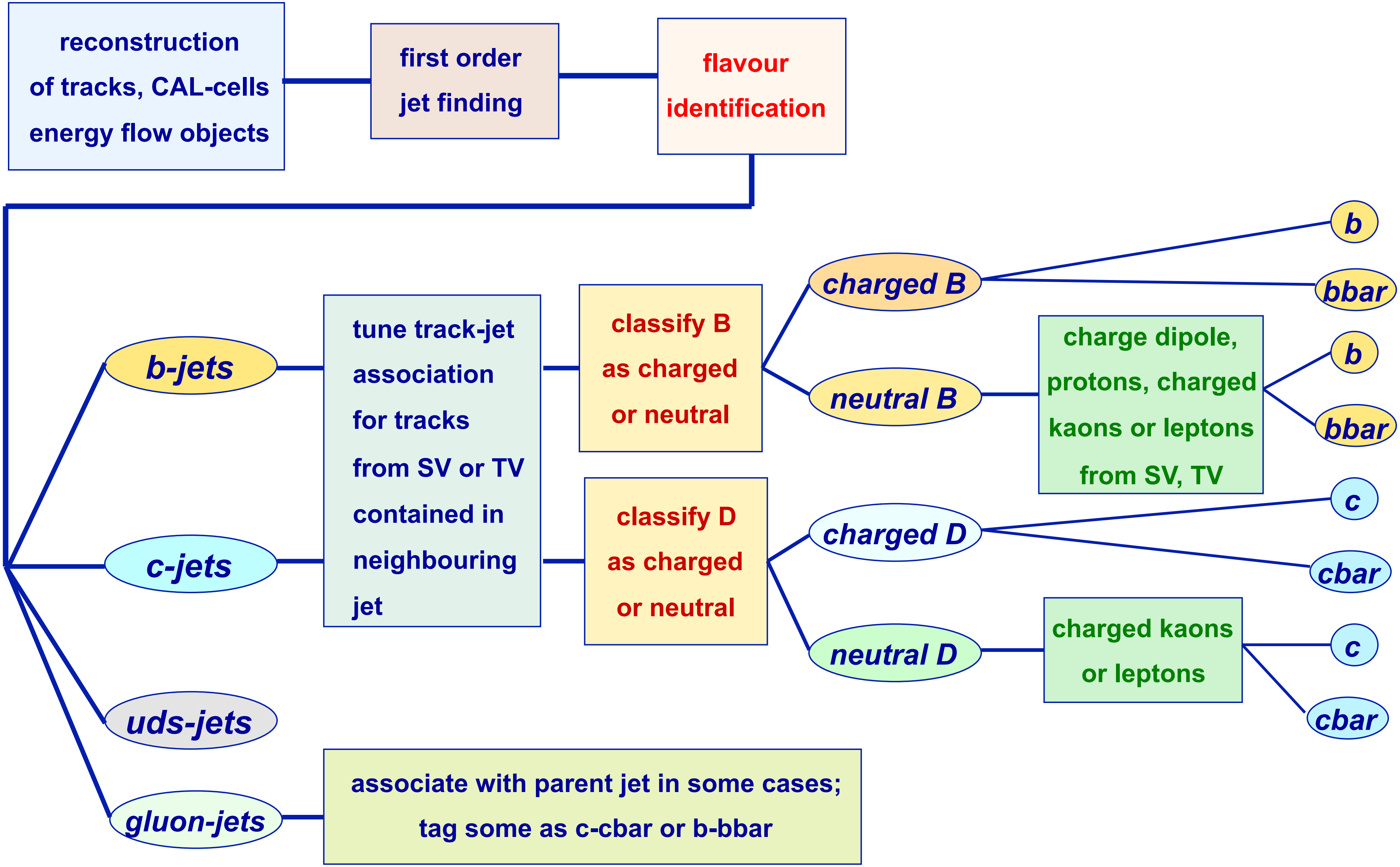
- where available from particle-ID and ECAL, take additional information (e.g. from Kaons, leptons) into account

Areas for later upgrades II

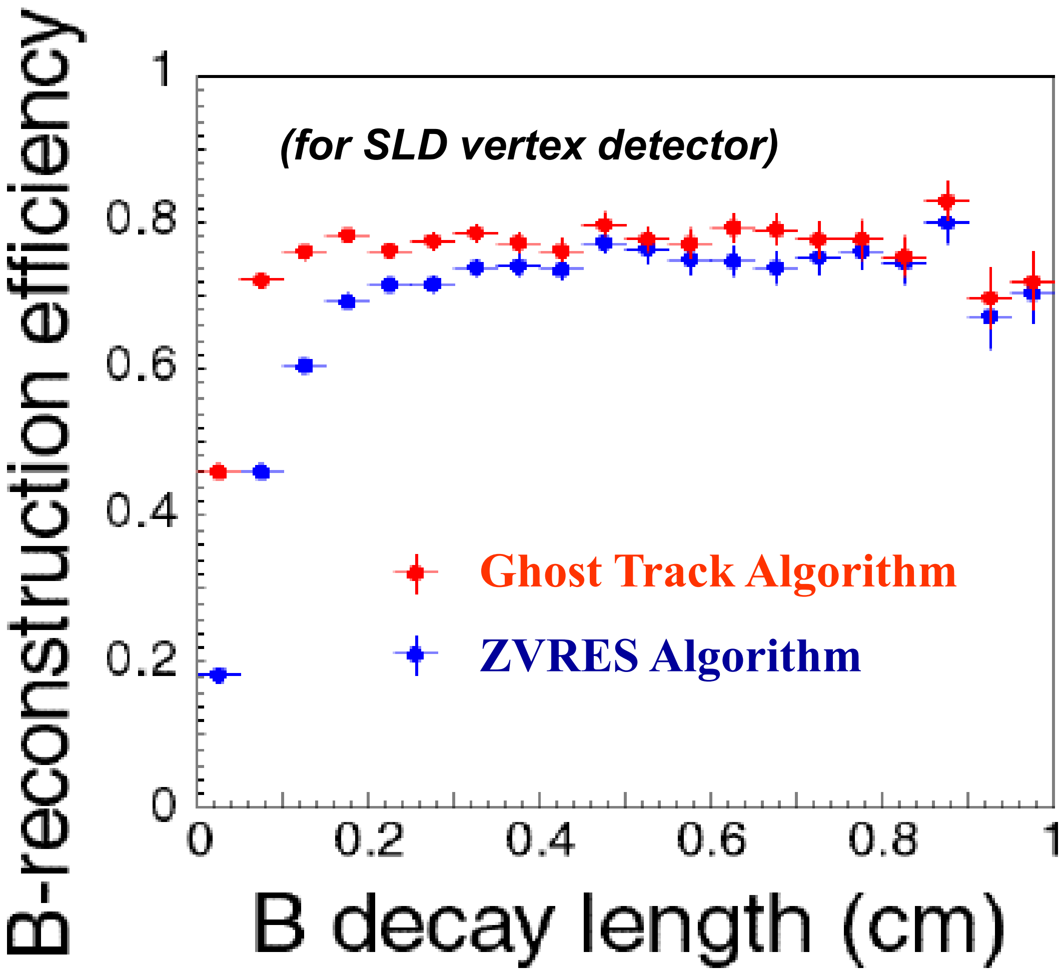
- also interplay between components and between vertex package and global event reconstruction will need to be explored and could lead to further improvement, e.g.
  - improvement of flavour tag using information from ghost track algorithm
  - use of vertex information to improve track-jet-assignment

- to some extent, optimal procedure will depend on the physics channel studied:
  - vertex package will provide enough flexibility to allow user to tune e.g. which inputs are used for flavour tagging;
  - this flexibility should be used, in a similar way as one would tune a jet-finder (don‘t consider the software as a ‘black-box‘!)
  - LCFI to study $e^+e^- \rightarrow b\bar{b}$ and Higgs self-coupling; code should be useful for many other channels – the more widely the package will be used the better

Typical event processing at the ILC



Efficiency improvement obtained from ZVKIN algorithm



b jets:

- 5% overall higher efficiency
- much improved at short decay length

c jets:

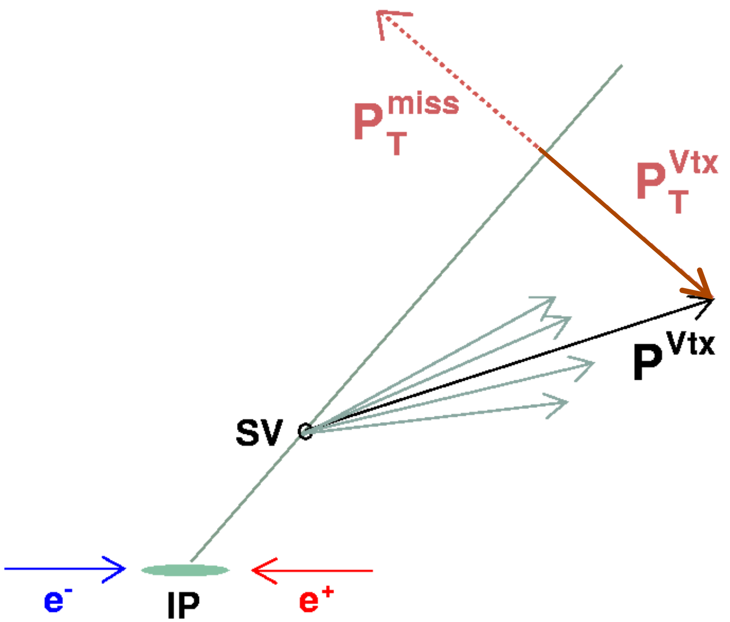
a simpler approach using 1 high p track away from IP gives 10% eff and purity

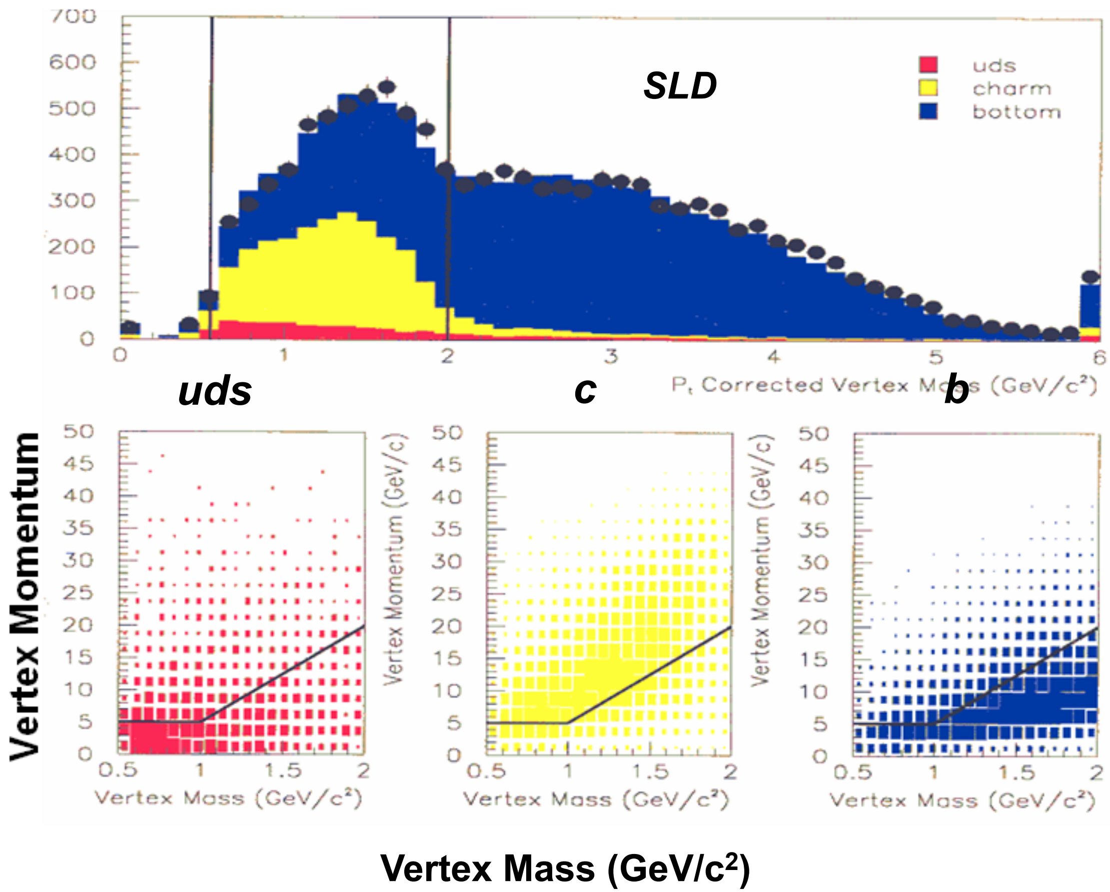
N. deGroot 'From Pixels to Physics', Contribution to Vertex 2001 workshop

Flavour tag

- aim: distinguish between b-jets, c- jets and light-quark / gluon jets
- heavy flavour jets contain secondary decays, generally observed as secondary vertices
- if secondary vertex is found variables with highest separation power are

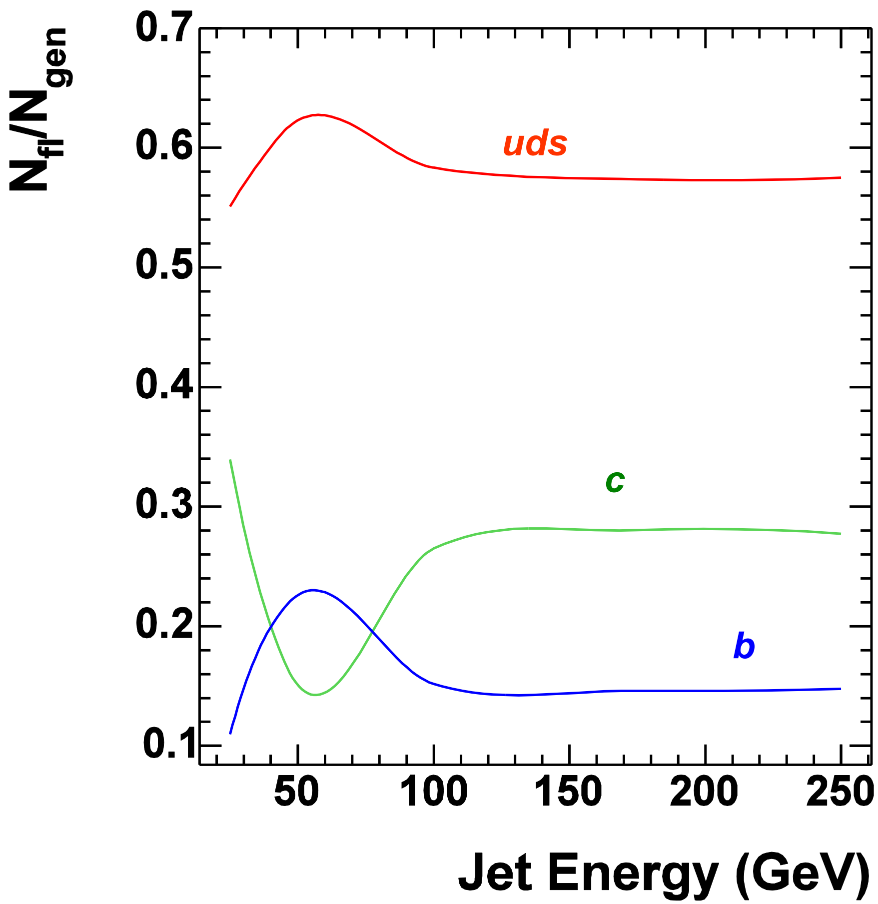
Pt-corrected vertex mass $M_{Pt} = \sqrt{M_{Vtx}^2 + |P_T^{Vtx}|^2} + |P_T^{Vtx}|$ and vertex momentum

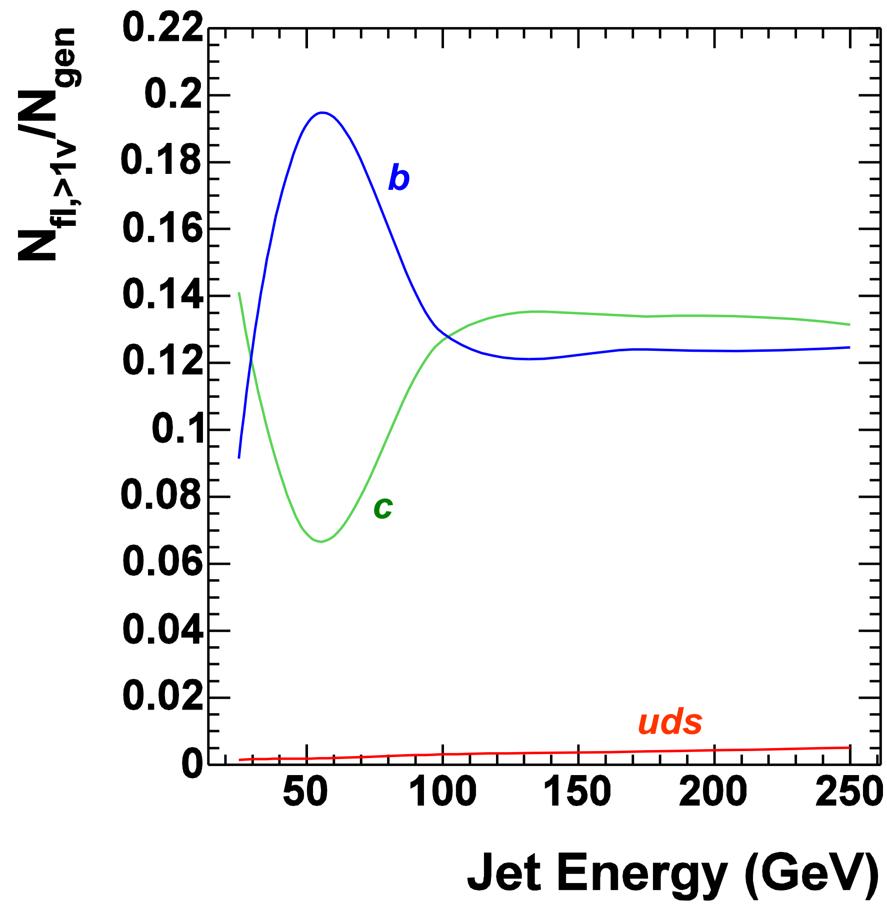




Flavour composition of sample at different energies

left: contributions of b, c and uds jets in generated sample, right: require > 1 ZVTOP vertex





fractions of b- and c-jets become more similar at higher energies → in that respect, b-tag becomes more challenging; increase in average decay length makes vertex finding easier

Vertex charge reconstruction