ALCPG07

Joint Meeting of the

American Linear Collider Physics Group

ILC Global Design Effort

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Quark charge determination: status and requirements

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on behalf of the LCFI collaboration

Outline of this talk

- Why quark charge determination is important for physics
- Measuring quark charge: vertex charge and charge dipole procedure
- Sensitivity of vertex charge reconstruction to detector design: fast MC results
- LCFI Vertex Package: software tools for full MC studies including quark charge
- Aspects of the vertex detector design that studies of quark charge can help optimise

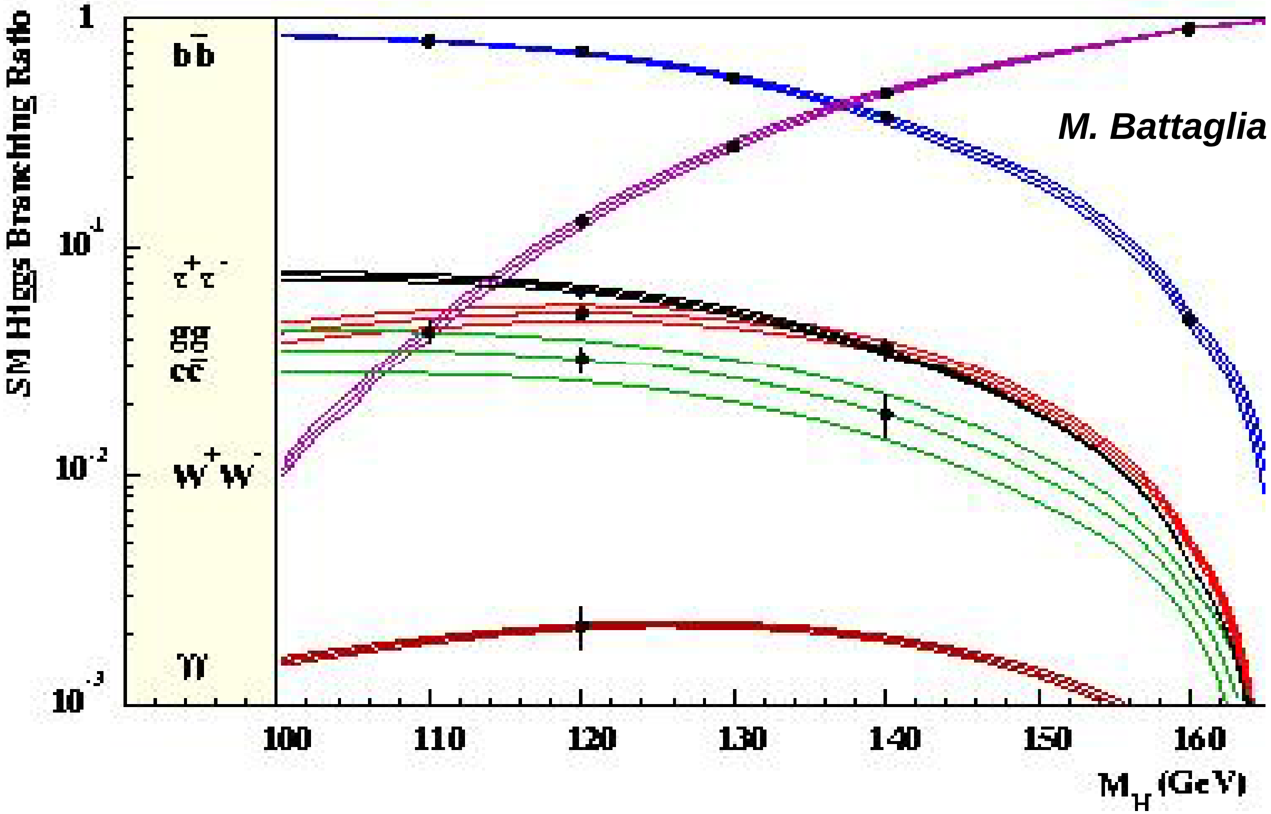
Dependence of physics reach on detector performance

- **Flavour tag needed for event selection and reduction of combinatoric backgrounds**
- **Quark charge sign determination used for measurement of A_{LR},**
  angular correlations (→ top polarisation) – vertex detector performance crucial

- **Examples:**

• **Higgs branching ratios:**
classical example of a process relying on flavour tag

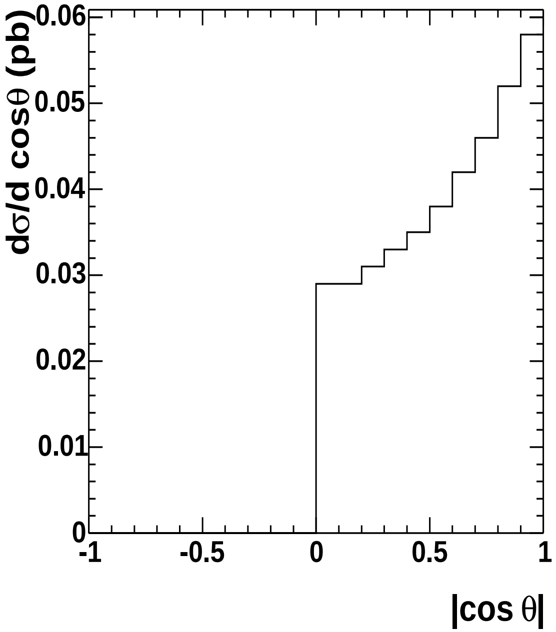
• **e+e- → ZHH:**
4 b-jets in final state requiring excellent tagging performance; could profit from quark charge sign selection



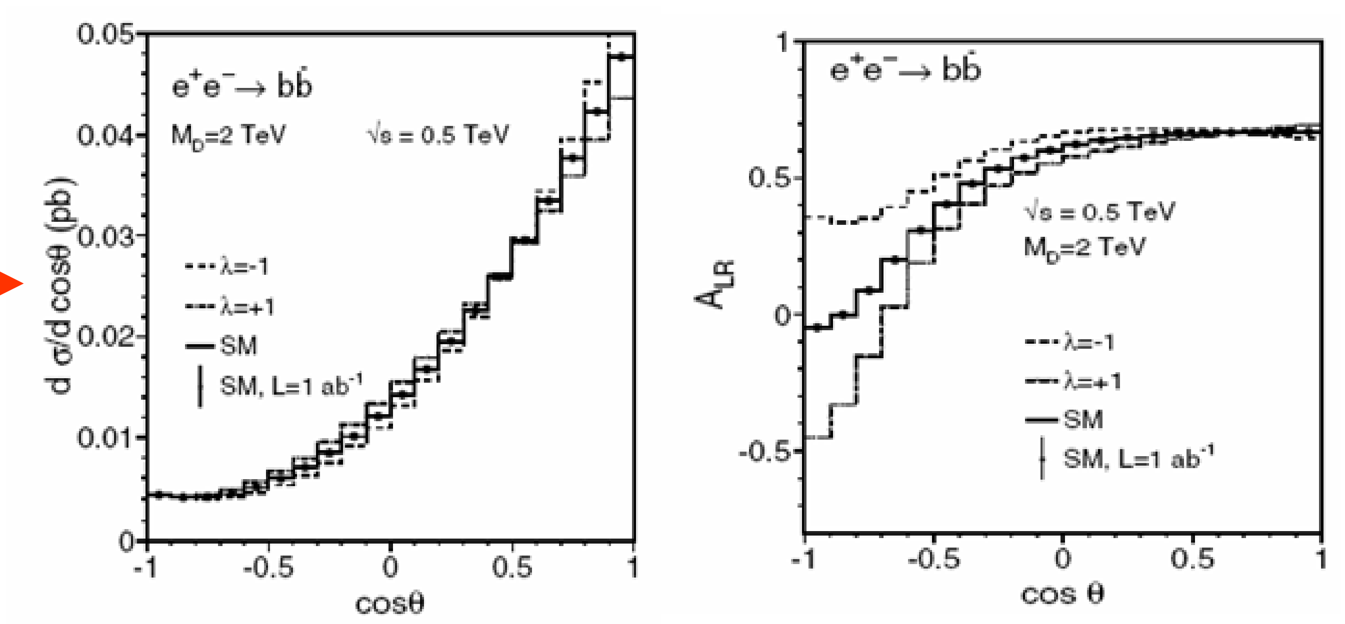
Processes requiring quark sign selection: e+e- → b bbar

- **e+e- → bb: indirect sensitivity to new physics, such as extra spatial dimensions, leptoquarks, Z´, R-parity violating scalar particles (Riemann, LC-TH-2001-007, Hewett PRL 82 (1999) 4765); quark charge sign selection to large cos θ needed to unfold cross section and measure A_{LR}:**

Sensitivity to deviations of extra-dimensions model from SM predicition (S. Riemann):

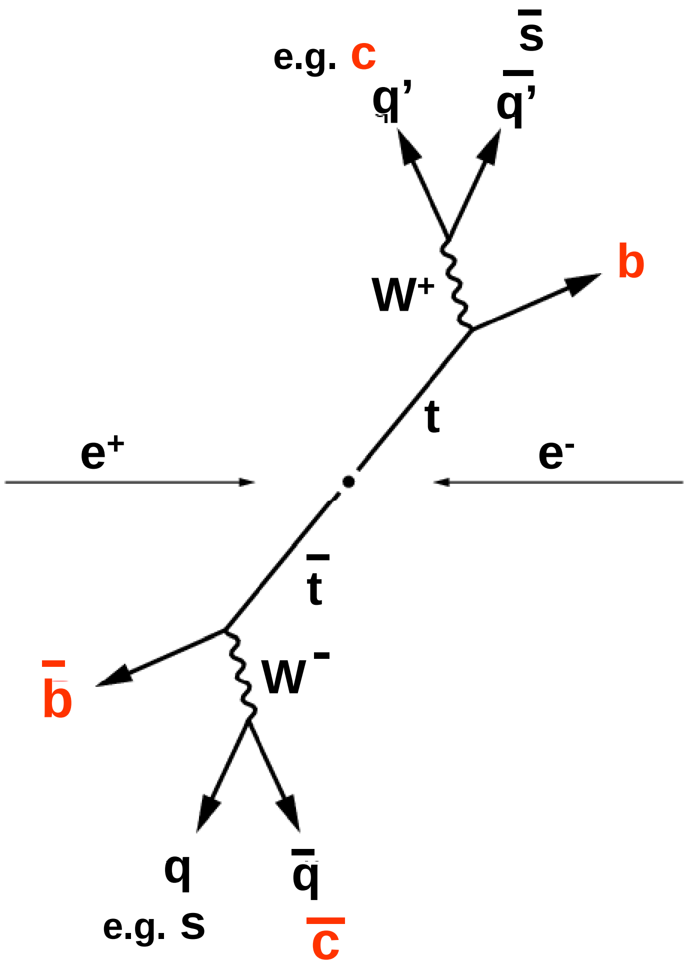


without quark sign selection



with perfect quark sign selection

Processes requiring quark sign selection: e+e- → t tbar



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

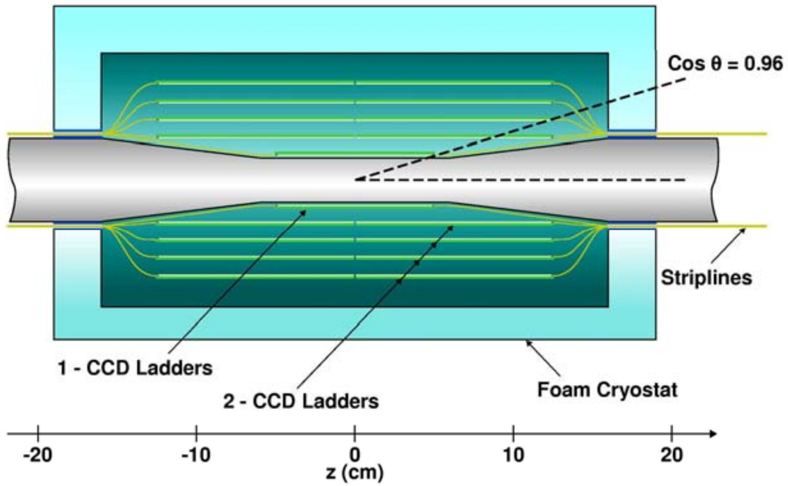
➢ $e+e- \rightarrow t\bar{t}$ demanding for vertex detector:

- multijet event: final state likely to include soft jets some of which at large polar angle
- flavour tag needed to reconstruct the virtual W bosons and top-quarks
- quark charge sign selection will help to reduce combinatoric backgrounds
- top decays before it can hadronise: polarisation of top quark can be measured from polarisation of its decay products; best measured from angular distribution of s-jet (quark charge)

Measuring quark charge

To measure quark charge efficiently one needs:

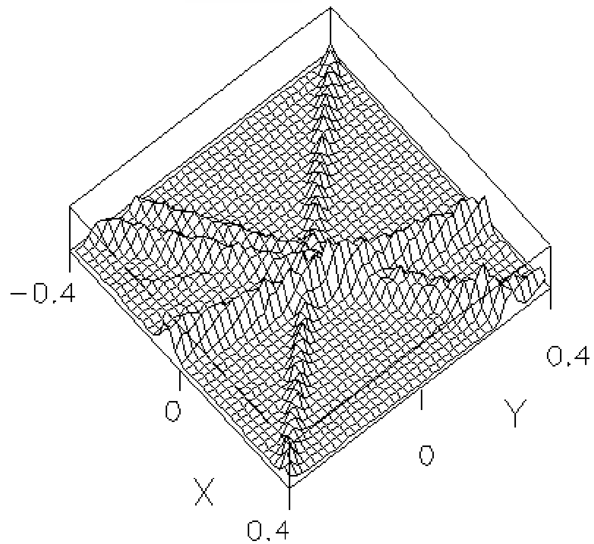
➢ **an excellent vertex detector:**



- **pixel-based system**
- **few micron point resolution**
- **small inner layer radius**
- **good polar angle coverage**
- **low mass support structure**
- **mechanical stability**

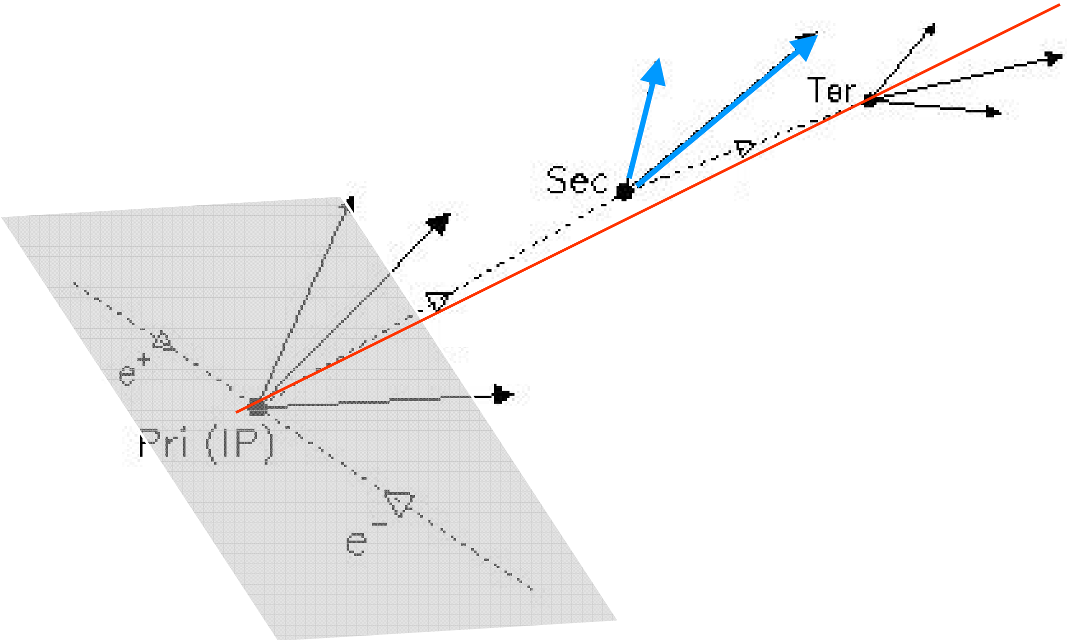
➢ **appropriate high-level reconstruction software, e.g.:**

- **topological vertex finding**
- **flavour tagging**
- **vertex charge reconstruction (charged hadrons)**
- **charge dipole reconstruction (neutral B hadrons)**



Vertex charge reconstruction

- b-jets contain a complex decay chain, from which the charge has to be found
- 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

- need vertex finding as prerequisite (definition of seed axis)
- in most analyses, only calculate charge for jet of specific flavour: need flavour tagging
- probability of mis-reconstructing vertex charge is small for both charged and neutral cases

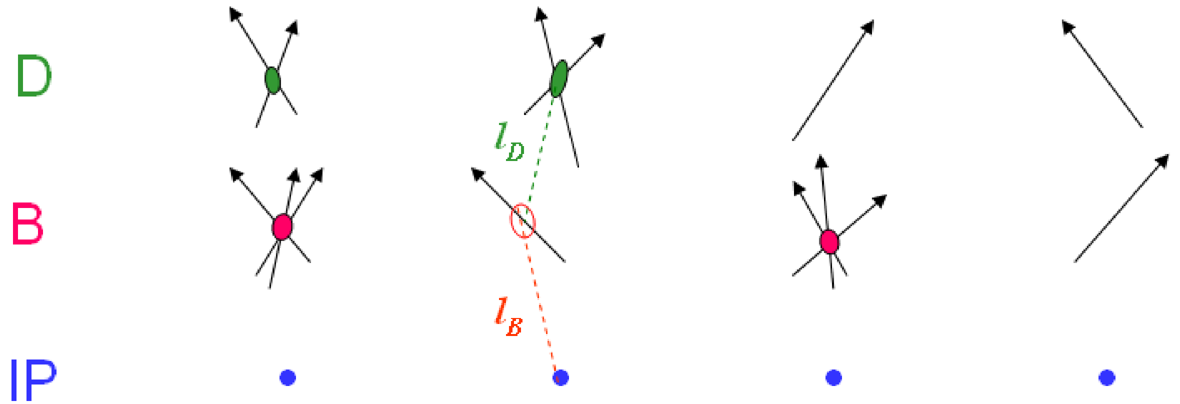
Charge dipole procedure

- For neutral vertices, quark charge is obtained from the charge dipole formed by B- and D-decay vertex.

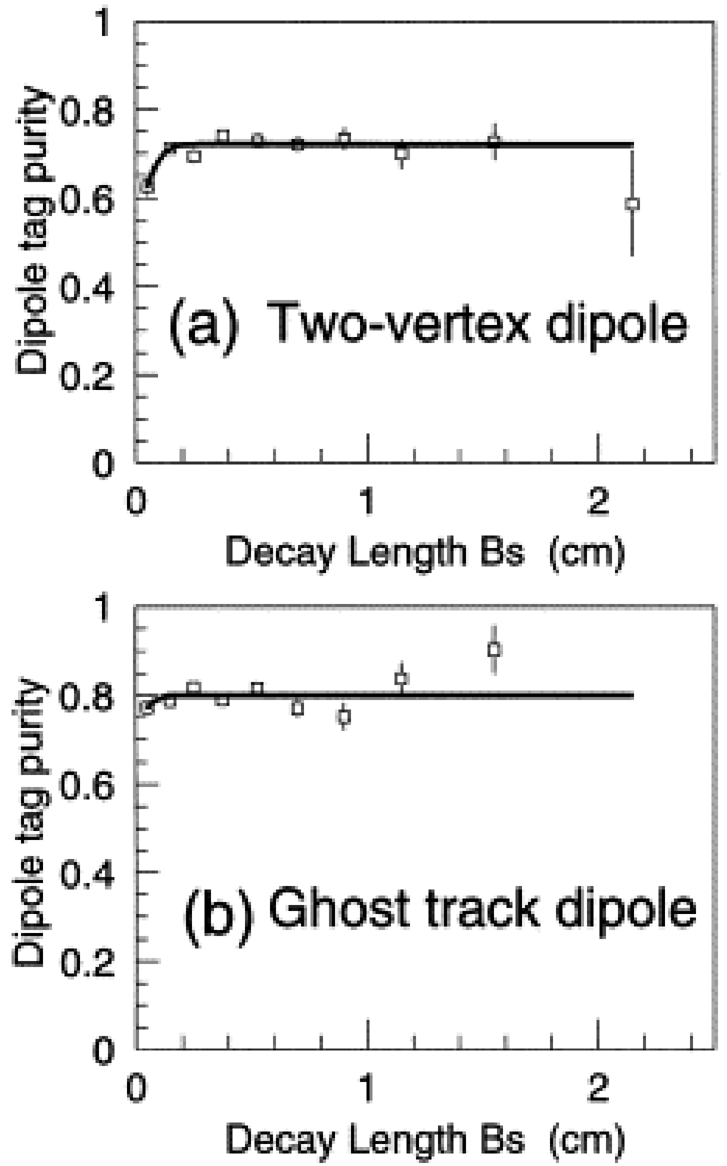
- "ghost track" vertexing algorithm (aka ZVKIN) developed at SLD, was shown to yield higher purity for charge dipole than standard ZVTOP code (ZVRES, cf p12)

- advantage: one-prong vertices identified by vertex finder
  → increased efficiency, especially at short B decay lengths

- at ILC, charge dipole procedure still to be explored



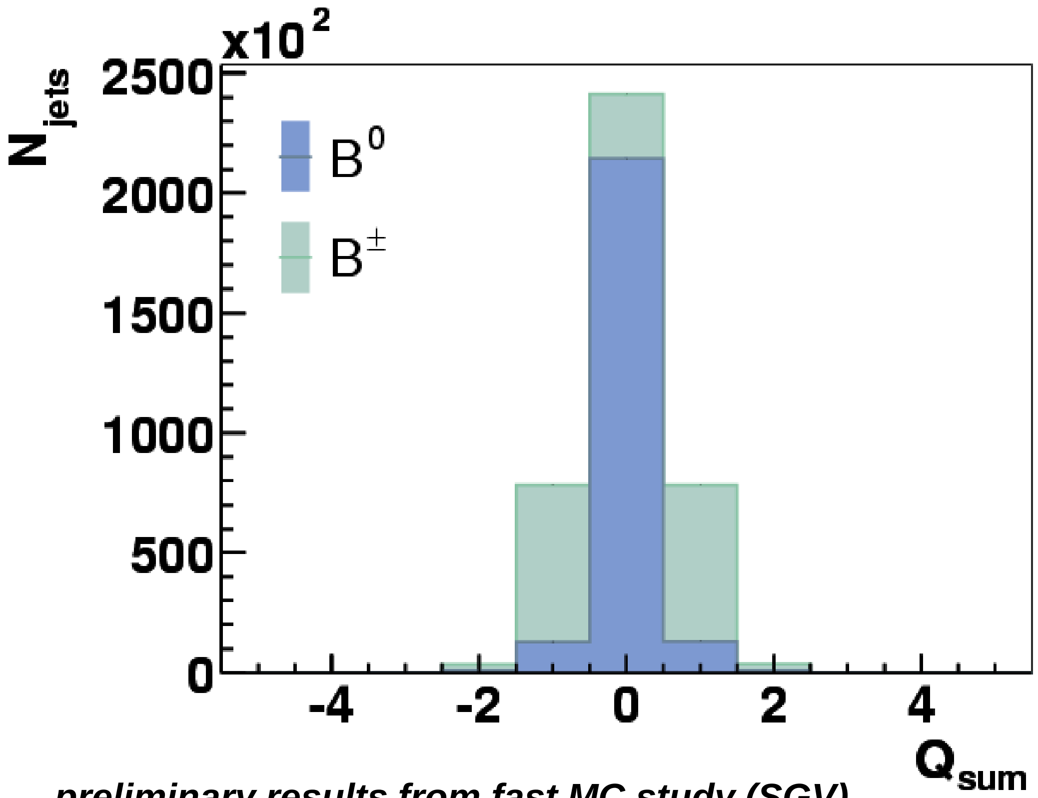
SLD, NIM A 447 (2000) 90-99



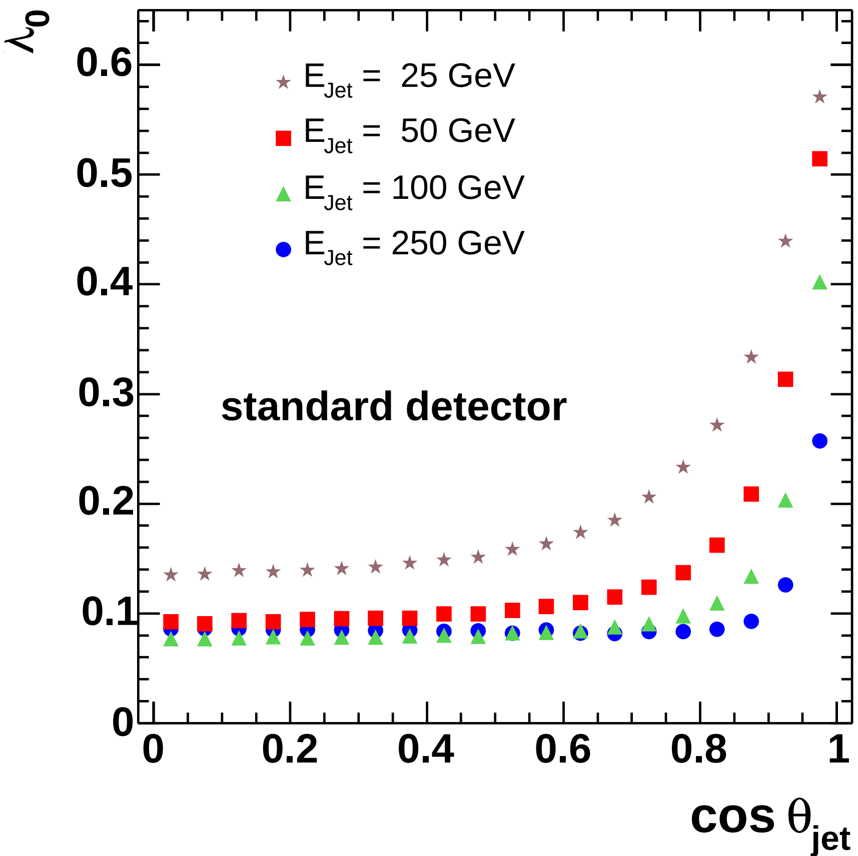
Performance of charge reconstruction: leakage rates

- define leakage rate λ_0 as probability of reconstructing neutral hadron as charged
- performance strongly depends on low momentum tracks:

  largest sensitivity to detector design for low jet energy, large cos θ



preliminary results from fast MC study (SGV)

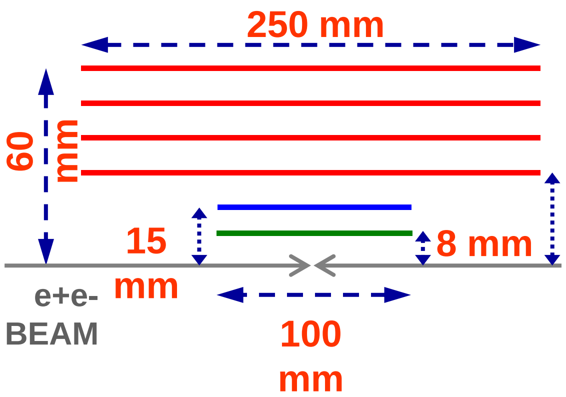


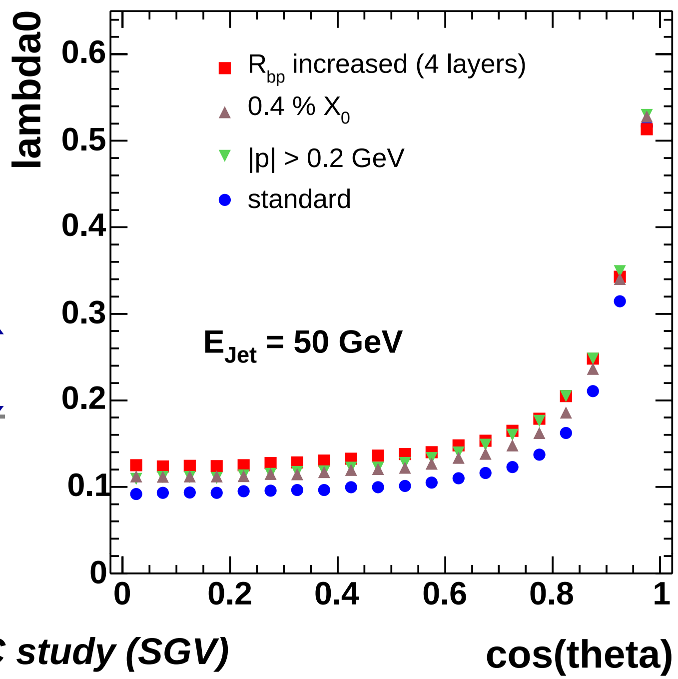
Using vertex charge for detector optimisation

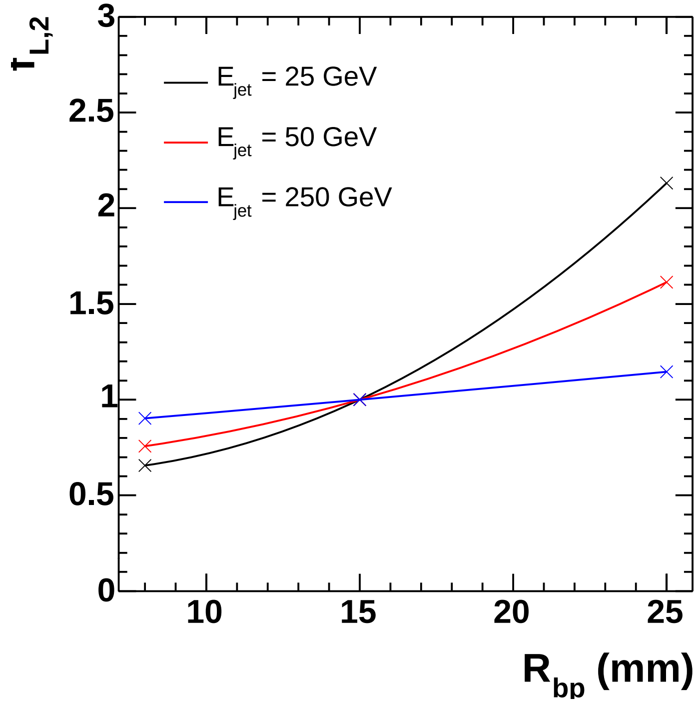
- **Using fast MC SGV, studied dependence of leakage rate on vertex detector design:**
  - **compared detectors with different inner layer radii (→ beam pipe radii)**
  - **varied amount of material per detector layer (factor 4 compared to baseline)**
- **translated into integrated luminosity required to obtain physics results of same significance**

  for processes requiring independent quark charge measurement in 2 jets,

  increase of beam pipe from 15 to 25 mm has sizeable effect (factor 1.5 – 2)







preliminary results from fast MC study (SGV)

The LCFI Vertex Package

- **The LCFIVertex package provides, in a full MC and reconstruction framework:**
  - **vertex finder ZVTOP with branches ZVRES and ZVKIN (new in ILC environment)**
  - **flavour tagging based on neural net approach (algorithm: R. Hawkings, LC-PHSM-2000-021; includes full neural net package; flexible to allow change of inputs, network architecture**
  - **quark charge determination, currently only for jets with a charged 'heavy flavour hadron'**

- **first version of the code released end of April 2007:**

  code, default flavour tag networks and documentation available from the ILC software portal

  http://www-flc.desy.de/ilcsoft/ilcsoftware/LCFIVertex

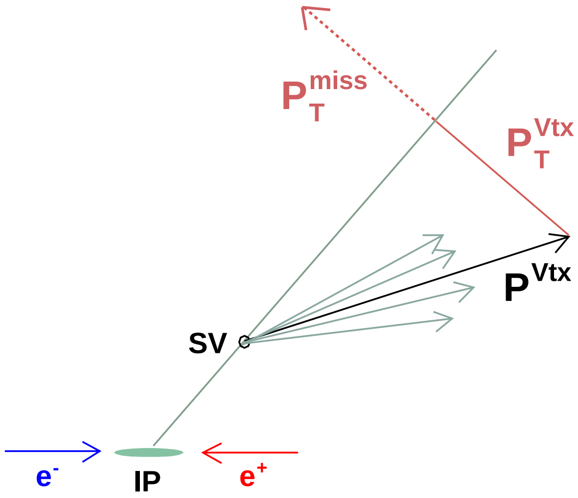
- **next version planned to be released shortly after ALCPG 2007:**
  - **minor corrections, e.g. to vertex charge algorithm; further documentation**
  - **diagnostic features to check inputs and outputs**
  - **module to derive fit parameters used in joint probability calculation (flavour tag input)**
  - **new vertex fitter based on Kalman filter to improve run-time performance**
- **for longer term plans see LCFI WP1 presentation at the Vertex Detector Review**

ZVTOP vertex finder, Pt-corrected mass

- two branches: ZVRES and ZVKIN (already mentioned when discussing charge dipole)
- The ZVRES algorithm *(D. Jackson, NIM A 388 (1997) 247)*

  very general algorithm that can cope with arbitrary multi-prong decay topologies

  - 'vertex function' calculated from Gaussian ´probability tubes´ representing tracks
  - iteratively search 3D-space for maxima of this function and minimise χ^2 of vertex fit

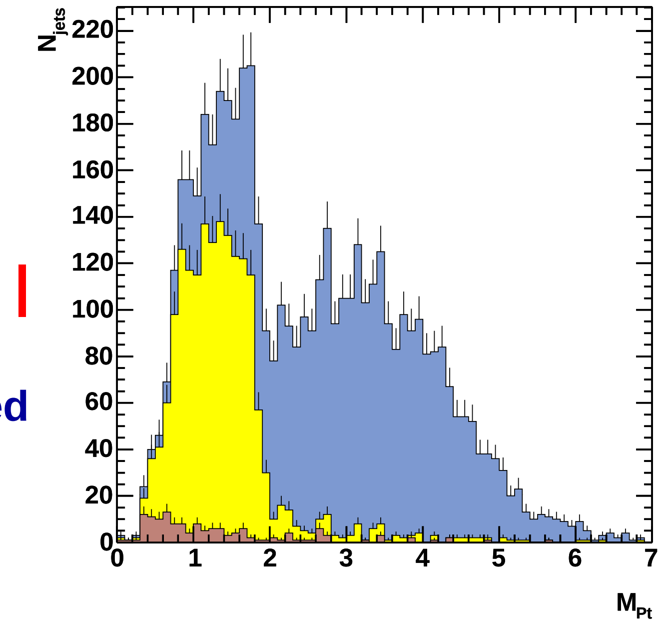


- central for flavour tag:

  pT-corrected vertex mass

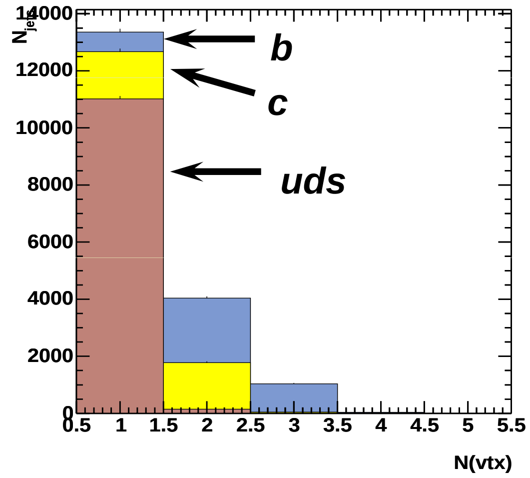
$$M_{Pt} = \sqrt{M_{Vtx}^2 + |P_T^{Vtx}|^2} + |P_T^{Vtx}|$$

- this kinematic correction is applied to partly account for undetected neutral particles

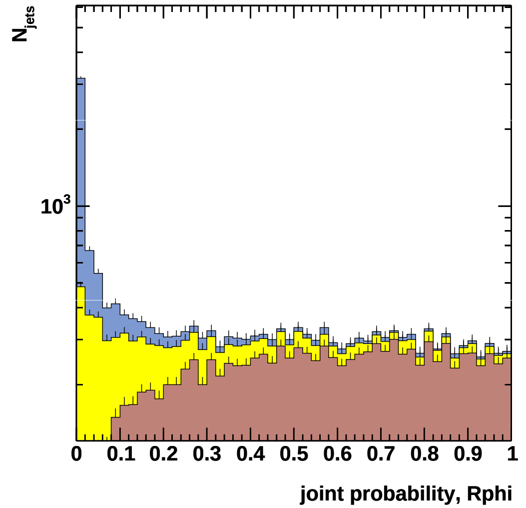


Flavour tagging approach

- Vertex package provides flavour tag procedure developed by R. Hawkings et al (LC-PHSM-2000-021) as default

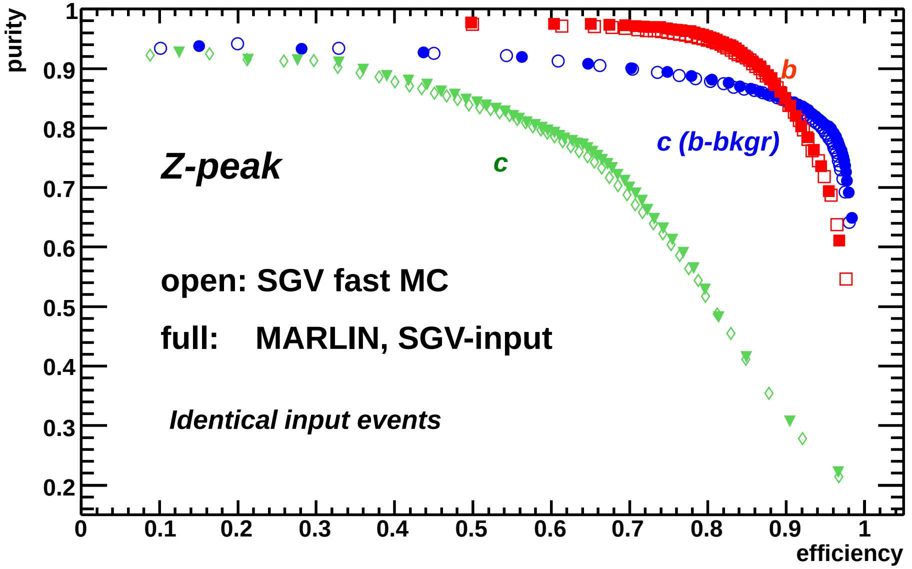


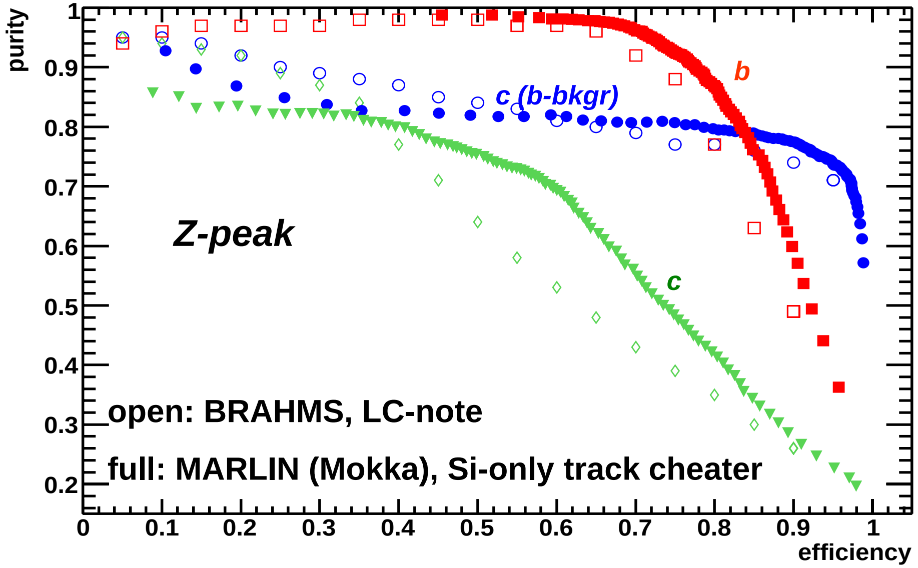
- number of vertices found determines which NN input variables are used:
  - if secondary vertex found: M_{Pt}, momentum of secondary vertex, and its decay length and decay length significance
  - if only primary vertex found: momentum and impact parameter significance in R-ϕ and z for the two most-significant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

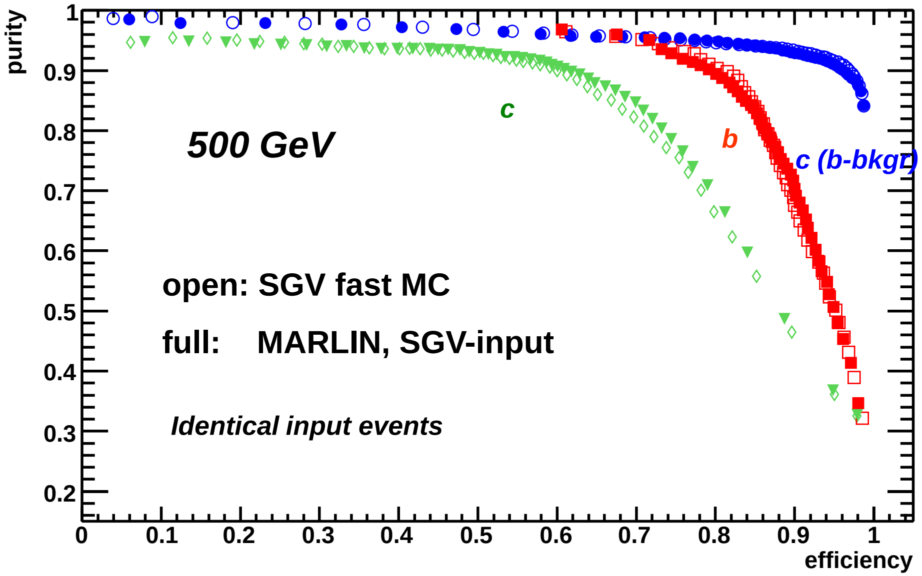


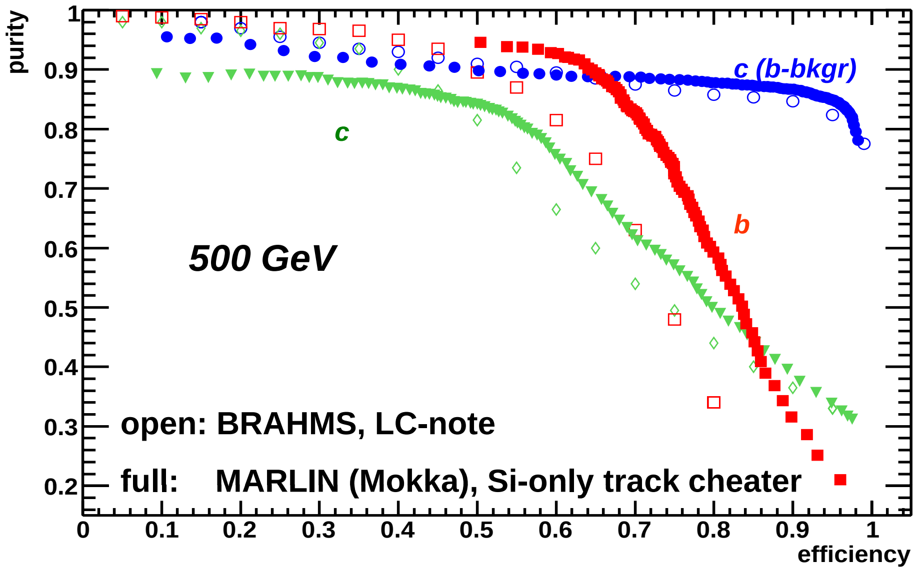
- flexible: permits user to change input variables, architecture and training algorithm of NN

Flavour tagging performance (RDR results)









Towards a realistic simulation

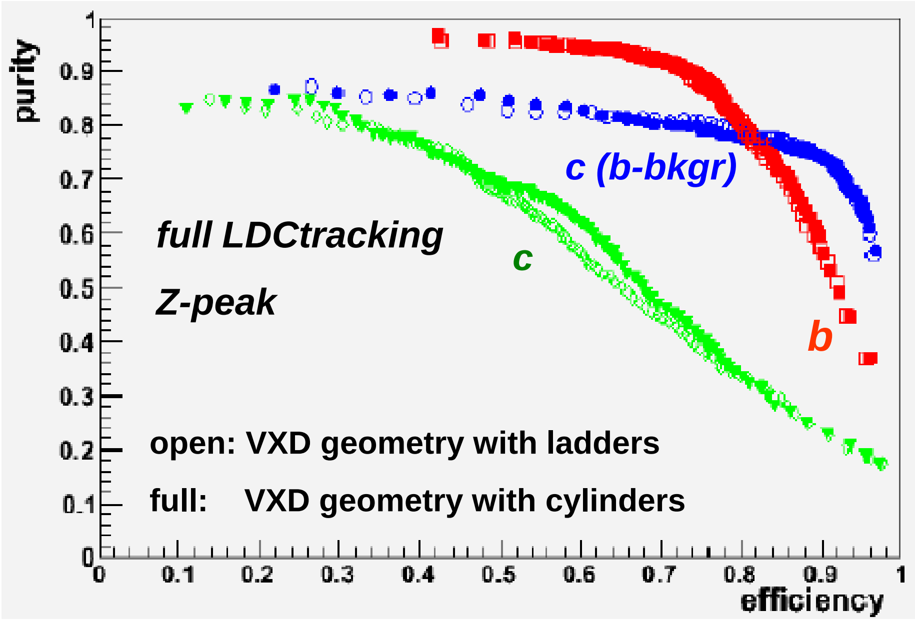
➢ **Current simulations are based on many approximations / oversimplifications.**
The resulting error on performance is at present unknown and could be sizable, especially when looking at particular regions in jet energy, polar angle (forward region!)

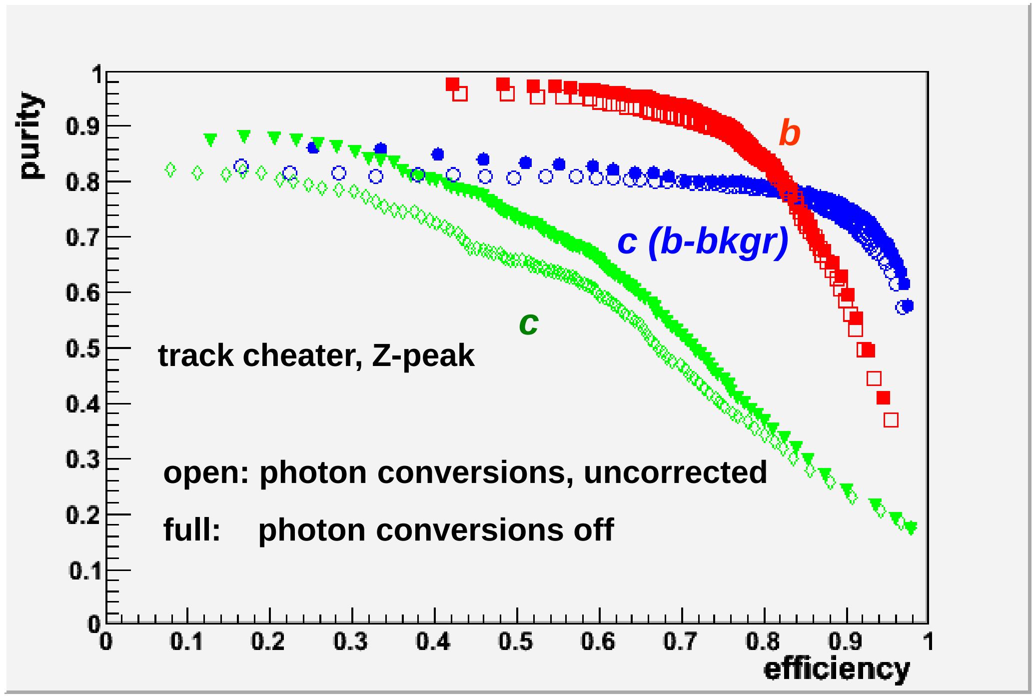
➢ **Issues to improve:**

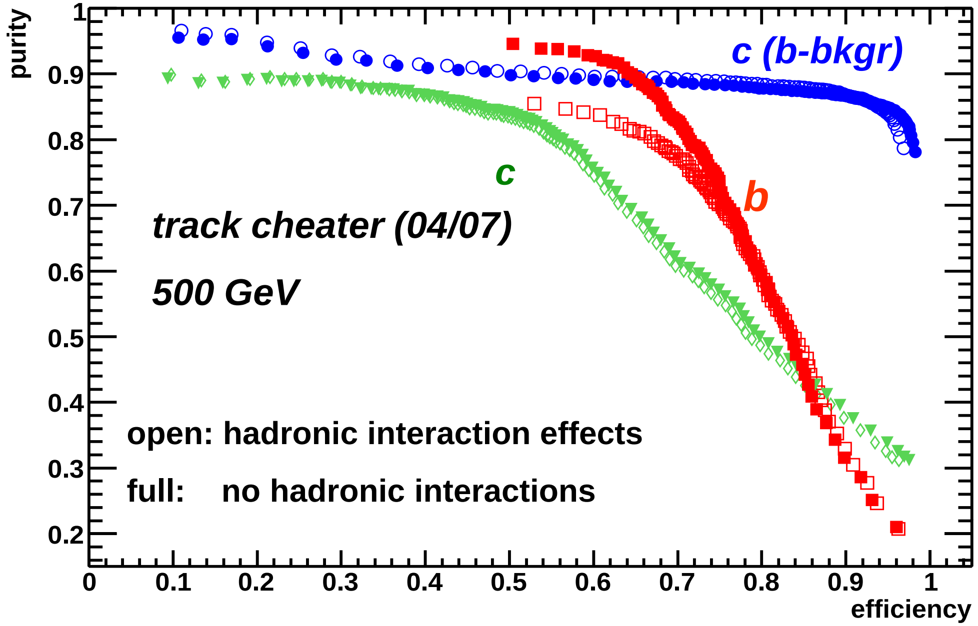
- **Vertex detector model: replace model with cylindrical layers by model with barrel staves**
- **GEANT4: switched off photon conversions for time being (straightforward to correct)**
- **hit reconstruction: using simple Gaussian smearing at present; realistic code exists only for DEPFET sensor technology, not for CPCCDs and ISIS sensors developed by LCFI**
- **track selection:**
  - **K_S and Λ decay tracks suppressed using MC information**
  - **tracks from hadronic interactions in the detector material discarded using MC info – only works for detector model LDC01Sc (used for code validation) at present**
- **current default parameters of the code optimised with fast MC or old BRAHMS (GEANT3) code**
- **default flavour tag networks were trained with fast MC**

Examples of impact of simplifications

- effects of simplifications can be sizeable;
- note: photon conversions and hadronic interactions in detector material can efficiently be corrected for
- currently making initial checks needed for implementing these corrections







Parameters and aspects of design to be optimised

- The Vertex Package, embedded into full MC and reconstruction frameworks, permits the following aspects of the vertex detector design to be optimised:
  - Beam pipe radius
  - Sensor thickness, material amount at the ends of the barrel staves
  - Material amount and type of mechanical support (e.g. RVC, Silicon carbide foams)
  - Overlap of sensors: linked to sensor alignment, tolerances for sensor positions along the beam & perpendicular to it
  - Arrangement of barrel staves
  - Long barrel vs short barrel plus endcap geometry

- Study of trade-offs, involving variations of more than one parameter, should be aimed at

- Physics simulation results will be only one of the inputs that determine the detector design – the more decisive input may well be provided by what is technically feasible.

Additional Material

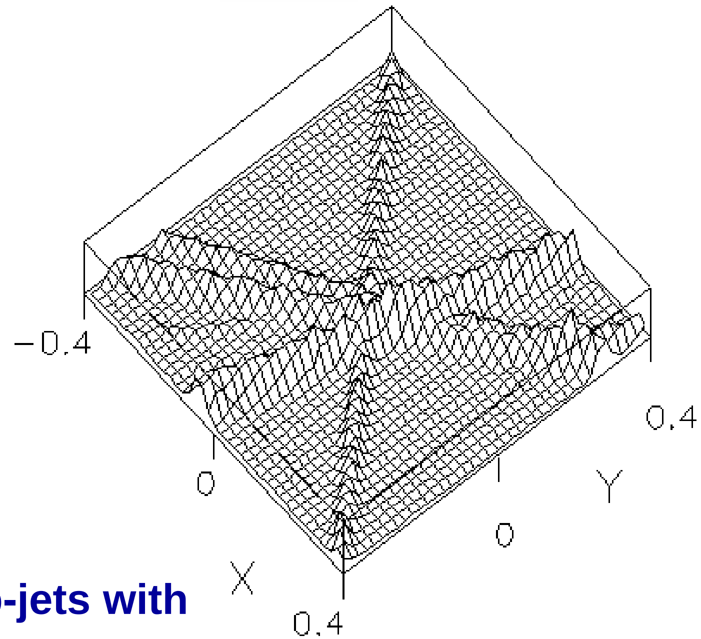
The ZVTOP vertex finder

D. Jackson,

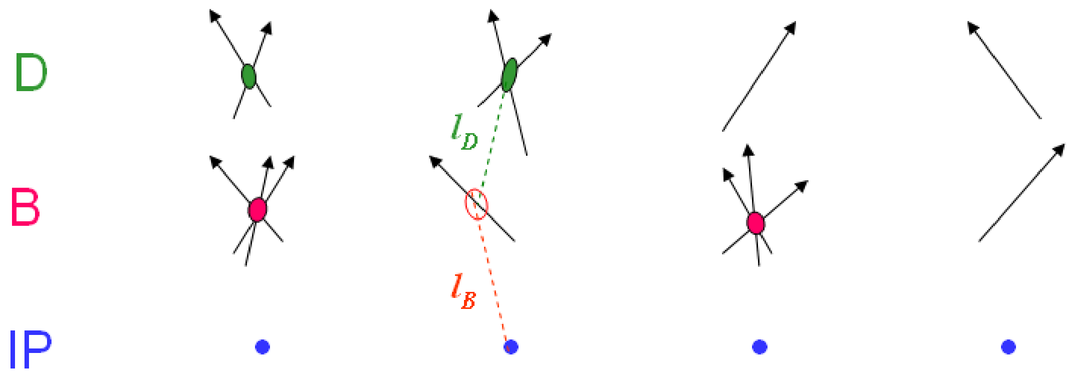
NIM A 388 (1997) 247

- two branches: ZVRES and ZVKIN (also known as ghost track algorithm)

- The ZVRES algorithm: very general algorithm that can cope with arbitrary multi-prong decay topologies
  - 'vertex function' calculated from Gaussian ´probability tubes´ representing tracks
  - iteratively search 3D-space for maxima of this function and minimise χ^2 of vertex fit



- ZVKIN: more specialised algorithm to extend coverage to b-jets with 1-pronged vertices and / or a short-lived B-hadron not resolved from the IP



- additional kinematic information (IP-, B-, D-decay vertex approximately lie on a straight line) used to find vertices
- should improve flavour tag efficiency and determination of vertex charge