LCFI Report to the

ALCPG 2007 Vertex Detector Review

❖ **WP1: Simulation and Physics Studies**

Sonja Hillert (Oxford University)

Introduction

- **Design of an ILC vertex detector requires physics simulations to**
  - **quantify vertex detector performance, feeding into performance of ILC detector**
  - **compare different approaches and parameter choices to optimise the design**

- **These simulations need to be performed using GEANT-based MC and realistic reconstruction to arrive at valid conclusions. Development of realistic reconstruction tools thus needs to proceed in parallel to the design optimisation.**

- **Simulations serve to estimate performance of**
  - **benchmark quantities: impact parameter resolution, flavour tag, vertex charge reconstruction**
  - **reconstruction of physics quantities obtained from study of benchmark physics processes**

- **Vertex detector-related software cannot be developed in isolation:**
  - **vertexing, flavour tag, vertex charge rec´n performed on a jet-by-jet basis (depends on jet finder)**
  - **strong dependence on quality of input tracks (i.e. hit and track reconstruction software)**
  - **physics processes to optimise calorimeter also depend on tagging performance (e.g. ZHH)**

Outline of this talk

- **Quark charge selection and its sensitivity to vertex detector parameters**

- **The LCFI Vertex Package:**

  The LCFI R&D collaboration has developed and is maintaining the LCFI Vertex Package, which is becoming the default software for vertexing, flavour tagging and vertex charge reconstruction. Current scope and areas of future work will be described.

- **Benchmark physics processes:**

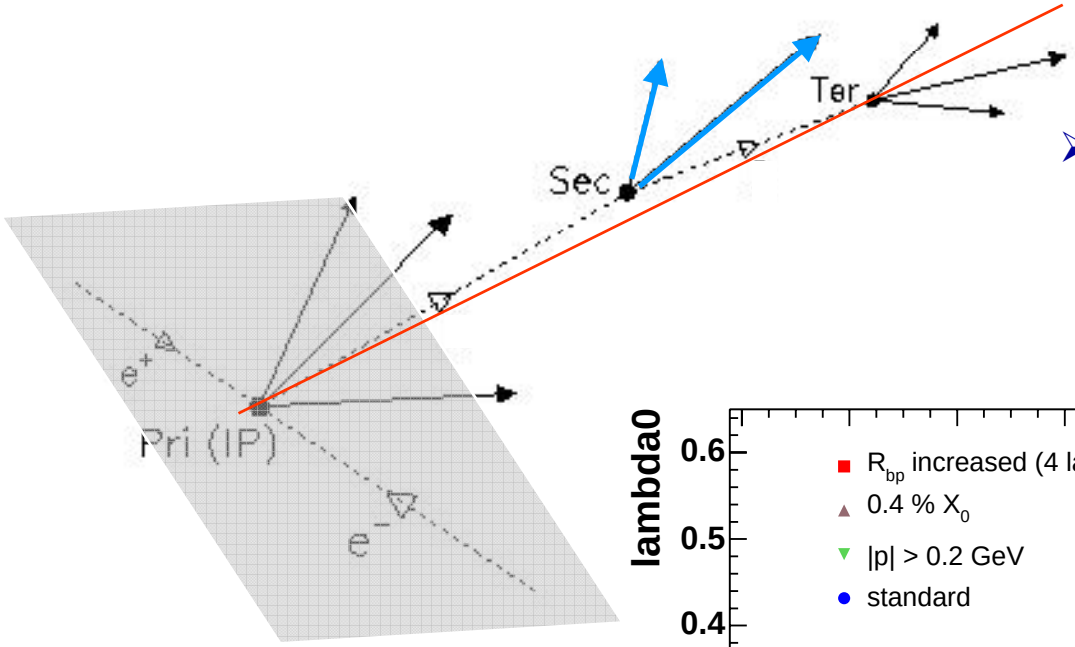
  Based on some example processes it will be shown how benchmark processes can be used for optimisation of the vertex detector design.

- **Vertex detector optimisation:**

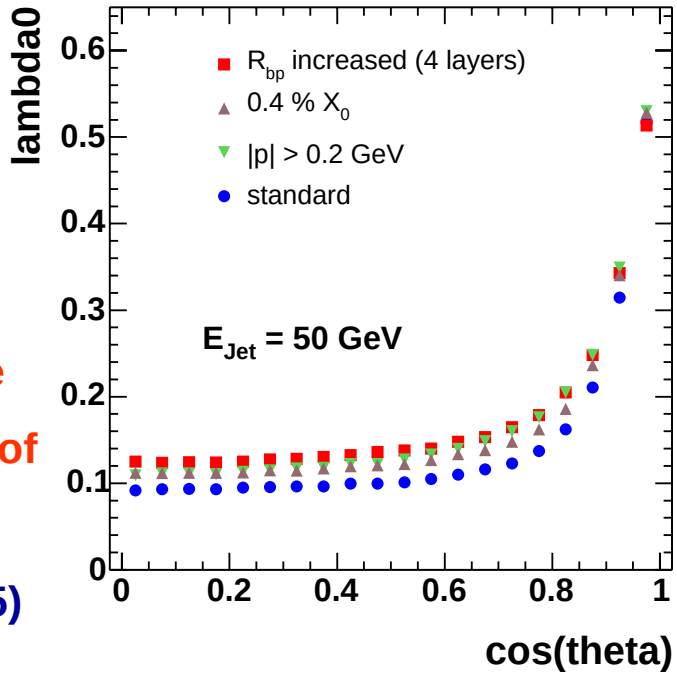
  The last section of the talk will give an overview of the aspects of the vertex detector design that will need to be optimised.

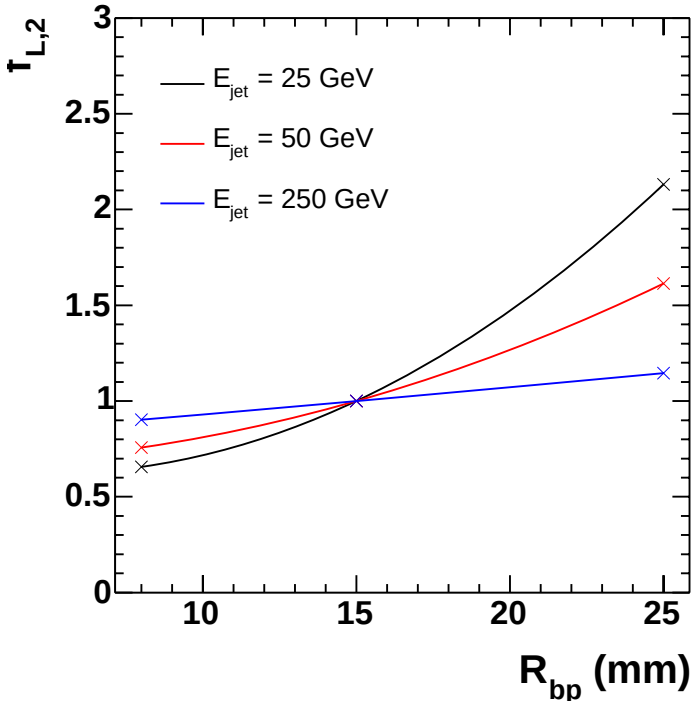
Quark charge selection

Motivation: quark sign can be determined from vertex charge, if b-quark hadronises to charged B-hadron (40% of b-jets) - need to find all stable tracks from B-decay chain



- **performance strongly depends on low momentum tracks: largest sensitivity to detector design for low jet energy, large cos θ**





- **vertex charge performance study showed importance of small beam pipe radius**

(fast MC study, Snowmass 05)

Scope of the LCFI Vertex Package

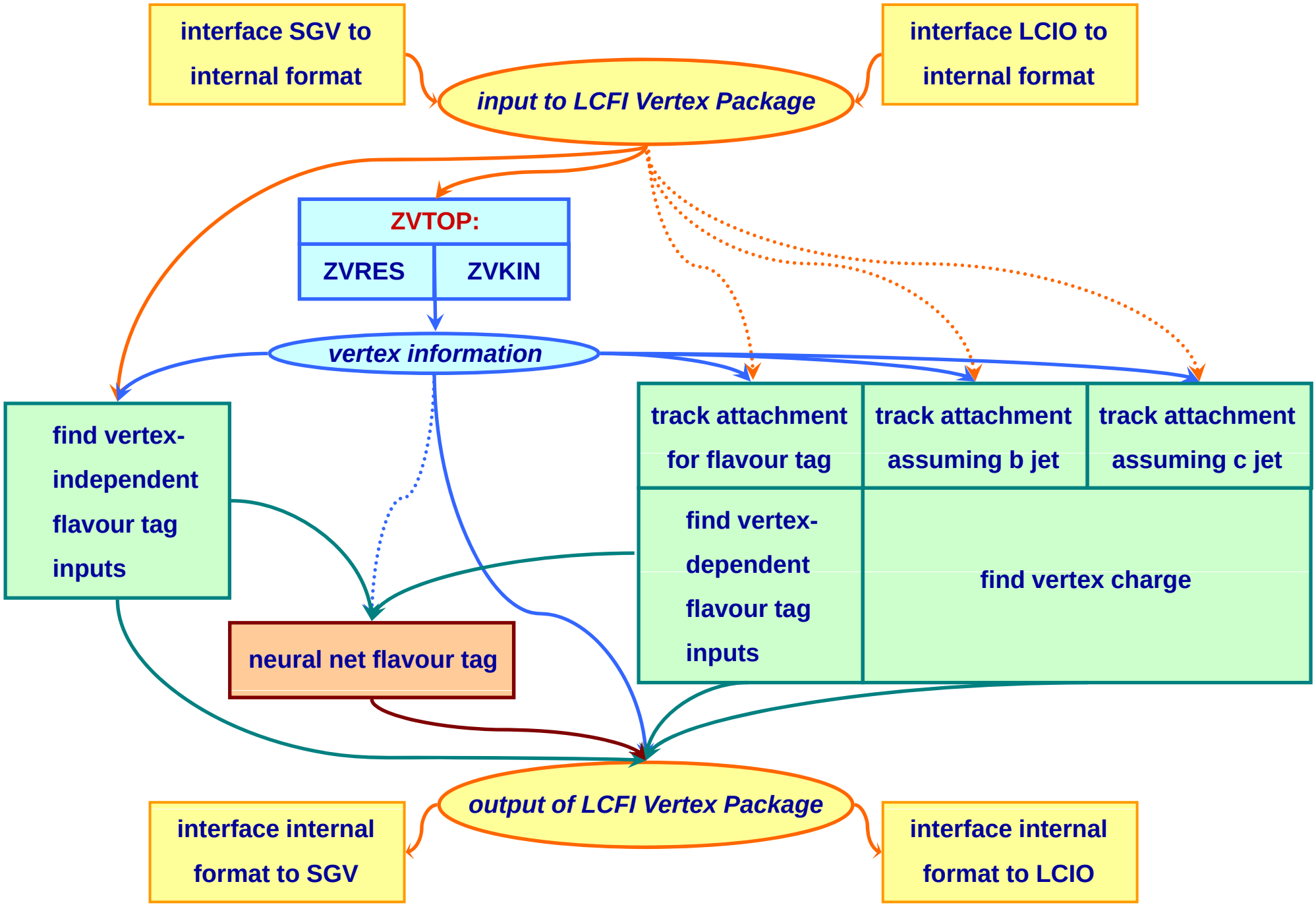
- **The LCFIVertex package provides:**
  - **vertex finder ZVTOP with branches ZVRES and ZVKIN (new in ILC environment)**
  - **flavour tagging based on neural net approach (algorithm: R. Hawkings, LC-PHSM-2000-021; provides full neural net package; flexible to allow change of inputs, network architecture**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

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

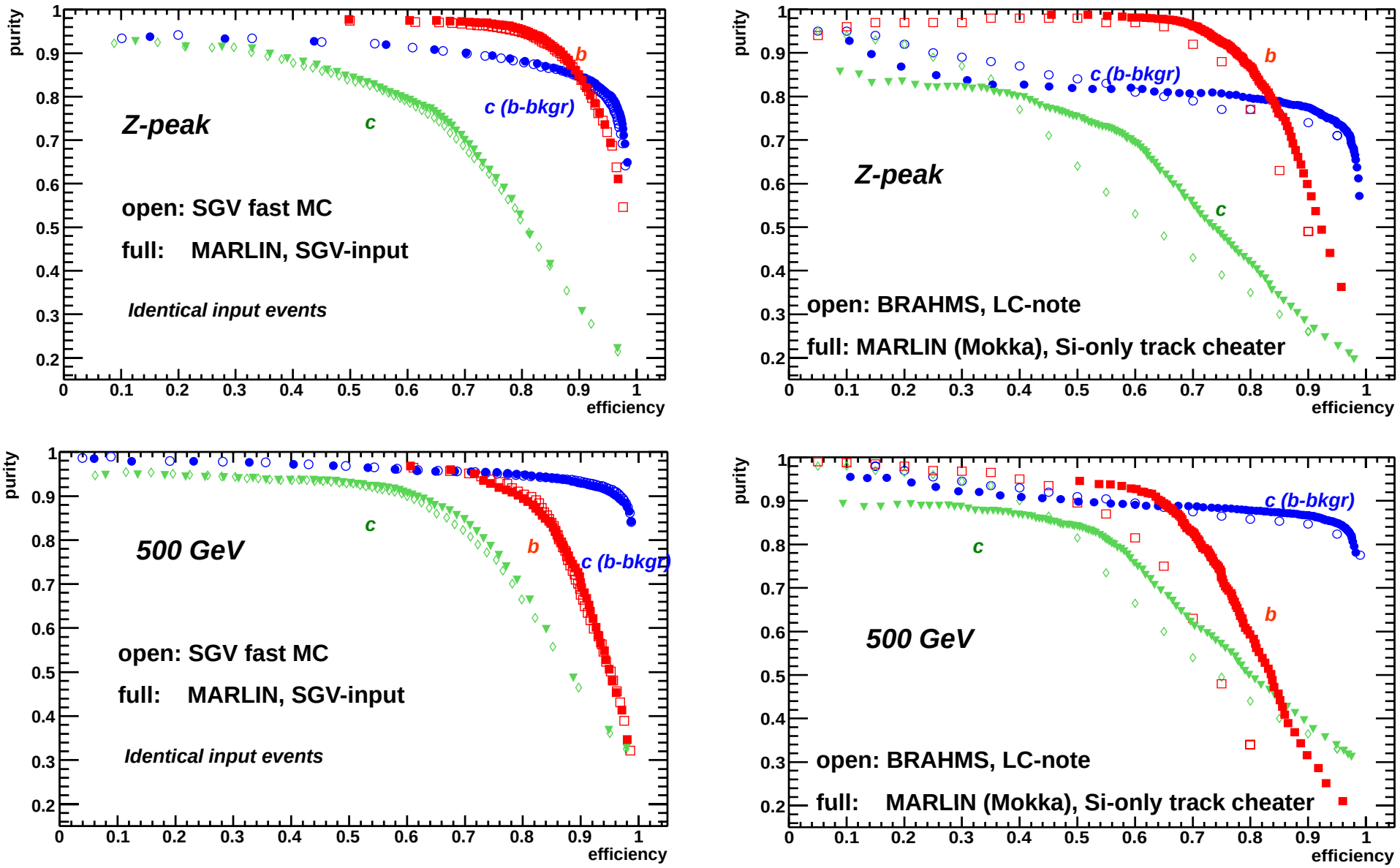
  code, default flavour tag networks and documentation available from the ILC software portal

  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**

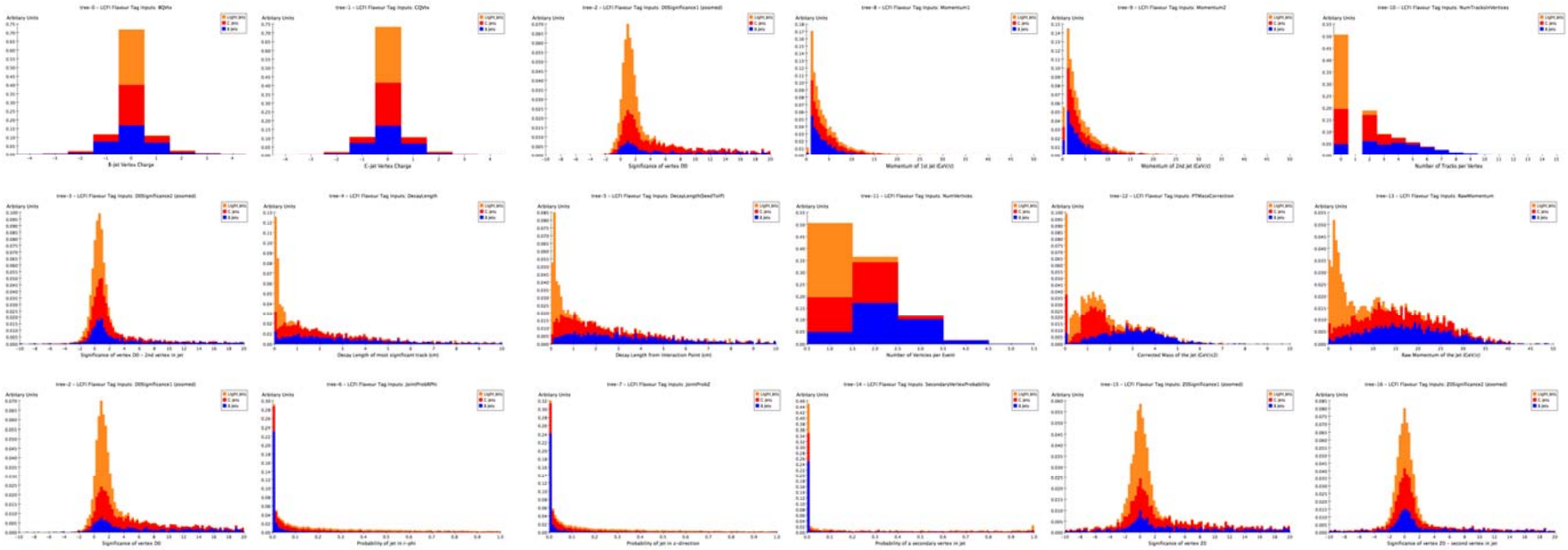

interface SGV to internal format
input to LCFI Vertex Package
interface LCIO to internal format
ZVTOP:
ZVRES
ZVKIN
vertex information
find vertex-independent flavour tag inputs
track attachment for flavour tag
track attachment assuming b jet
track attachment assuming c jet
find vertex-dependent flavour tag inputs
find vertex charge
neural net flavour tag
output of LCFI Vertex Package
interface internal format to SGV
interface internal format to LCIO

Flavour tagging performance (RDR results)



Diagnostic features

- plan to make available **inputs and outputs for ZVRES & flavour tag** (later: vertex charge)
- nearly complete: **LCFIAIDAPlot** – module for **flavour tag diagnostics** based on AIDA
  - input and output variables of the flavour tag neural nets, separately for b-, c-, light jets
  - graphs of purity vs efficiency and flavour leakage rates (i.e. efficiencies of wrong flavours) vs efficiency separately for the 1-, 2- and 3-vertex case
  - JAS3-macro to plot these easily
  - optionally: raw numbers of jets vs NN-output, AIDA tuple with flavour tag inputs written out



example: inputs to flavour tag

New vertex fitter: Kalman filter

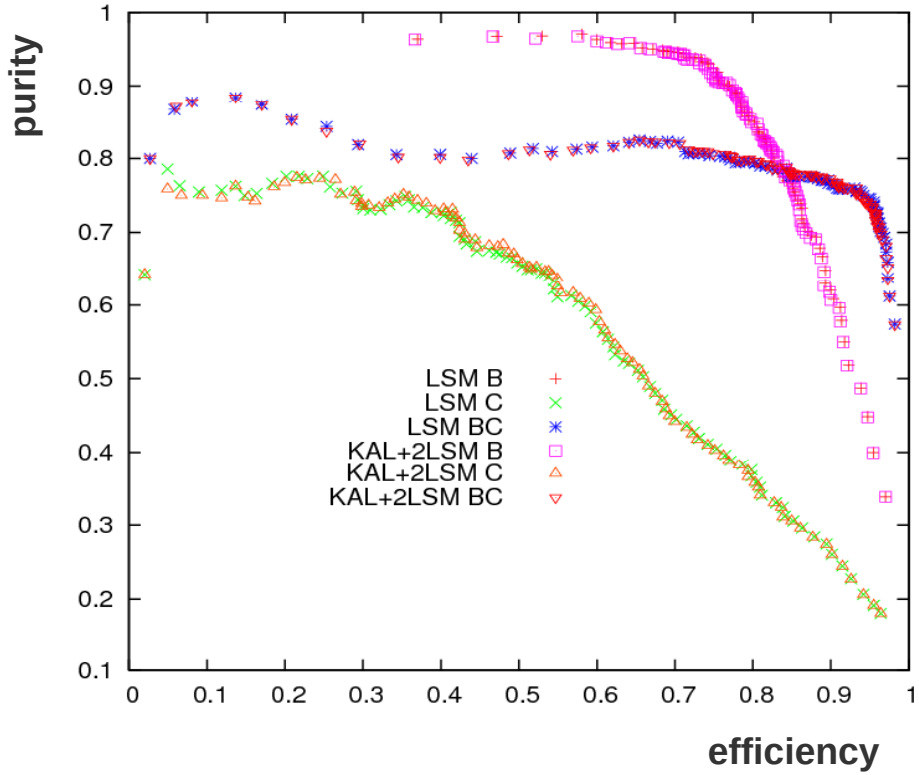
- **Motivation: improve run time performance by replacing the "space-holder" Least-Squares-Minimisation (LSM) fitter of first release**

- **Kalman filter code by S. Gorbunov, I. Kisel interfaced to Vertex Package**

- **Testing far advanced: find same flavour tagging performance as with LSM-fitter**

- **resulting improvement in run time performance: overall run time of Vertex Package is reduced to ~ 25% of the 1st-release value**

- **still to be done before release:**
  - **add switch to select which fitter to use**
  - **documentation**



Towards a realistic simulation

- **Current simulations are based on many approximations / oversimplifications.**

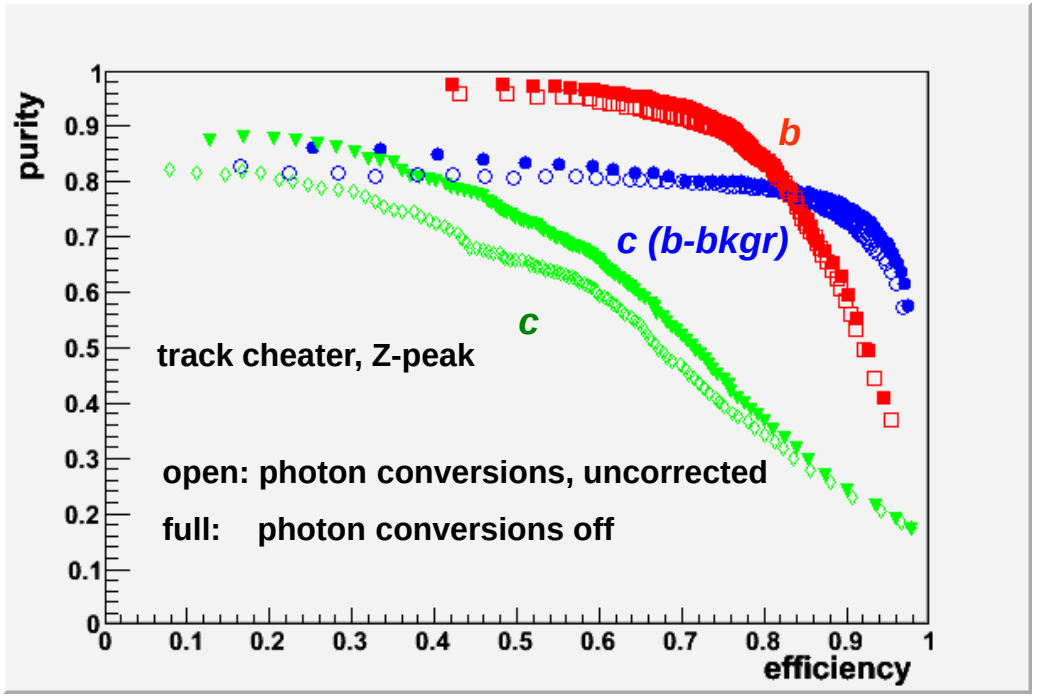
  The resulting error on performance is at present unknown and could be sizable, especially when looking at particular regions in jet energy, polar angle (forward region!)

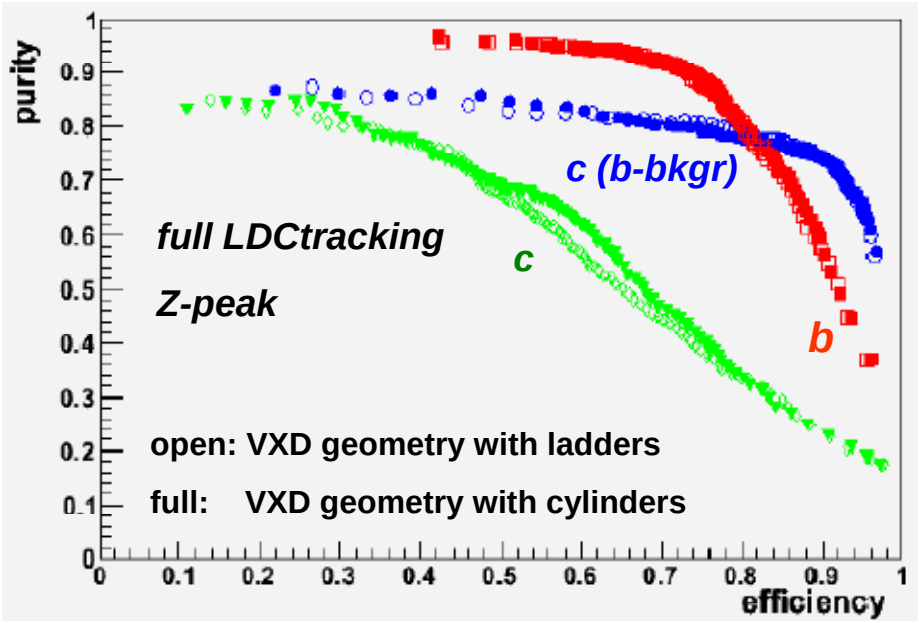
- **Issues to improve:**

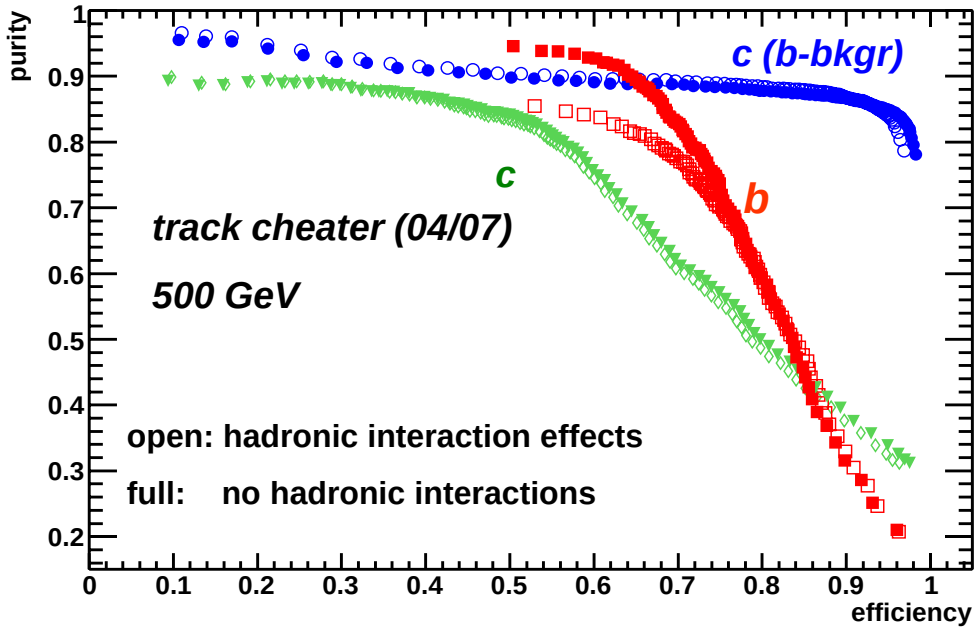
- **Vertex detector model: replace model with cylindrical layers by model with barrel staves**
- **GEANT4: switched off photon conversions for time being (straightforward to correct)**
- **hit reconstruction: using simple Gaussian smearing at present; realistic code exists only for DEPFET sensor technology, 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







Further development of the Vertex Package

Areas of relevance for wider user community:

- **integration into ALCPG software framework org.lcsim: drivers under development in the US, to be released as soon as possible (N. Graf)**

- **consistent IP treatment, based on per-event-fit in z and on average over N events in Rϕ**

- **Vertexing:**

- **explore use of ZVKIN branch of ZVTOP for flavour tag and quark charge determination:**
  - **optimise parameters**
  - **study performance at the Z-peak and at sqrt(s) = 500 GeV**
  - **explore how best to combine output with that of ZVRES branch for flavour tag**
  - **use charge dipole procedure (based on ZVKIN) to study quark charge determination for (subset of) neutral hadrons**

Improvements and extensions

Areas of relevance for wider user community cont^d:

- **Flavour tagging: explore ways to improve the tagging algorithm, e.g. through use of**
  - **different input variables and/or different set-up of neural nets that combine these**
  - **improvements to MPt calculation using calorimeter information, e.g. from high-energy π^0**
  - **vary network architecture (number of layers & nodes, node transfer function), training algorithm**
  - **explore new "data mining" and classification approaches (e.g. decision trees, …)**

- **Vertex charge reconstruction:**
  - **revisit reconstruction algorithm using full MC and reconstruction (optimised with fast MC)**

Functionality specifically needed for vertex detector optimisation:

- **Correction procedure for misalignment of the detector and of the sensors will need to be developed, adapted or interfaced (see optimisation of the detector)**

Benchmark Physics Studies - Introduction

- Benchmark physics processes should be typical of ILC physics and sensitive to detector design.
- A Physics Benchmark Panel comprising ILC theorists and experimentalists has published a list of recommended processes that will form the baseline for the selection of processes to be studied in the LoI- and engineering design phases.
- Following processes were highlighted as most relevant by the experts (hep-ex/0603010):

particularly sensitive to vertex detector design

0. Single $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, π^{0}, $K^{\pm}$, K^{0}_{S}, γ, $0 < |\cos\theta| < 1$, $0 < p < 500$ GeV
1. $e^+e^- \to f\bar{f}$, $f = e, \tau, u, s, c, b$ at $\sqrt{s}$=0.091, 0.35, 0.5 and 1.0 TeV;
2. $e^+e^- \to Z^0h^0 \to \ell^+\ell^-X$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
3. $e^+e^- \to Z^0h^0$, $h^0 \to c\bar{c}, \tau^+\tau^-, WW^*$, $M_h = 120$ GeV at $\sqrt{s}$=0.35 TeV;
4. $e^+e^- \to Z^0h^0h^0$, $M_h = 120$ GeV at $\sqrt{s}$=0.5 TeV;
5. $e^+e^- \to \tilde{e}^+_R\tilde{e}^-_R$ at Point 1 at $\sqrt{s}$=0.5 TeV;
6. $e^+e^- \to \tilde{\tau}^+_1\tilde{\tau}^-_1$, at Point 3 at $\sqrt{s}$=0.5 TeV;
7. $e^+e^- \to \tilde{\chi}^+_1\tilde{\chi}^-_1/\tilde{\chi}^0_2\tilde{\chi}^0_2$ at Point 5 at $\sqrt{s}$=0.5 TeV;

Physics interests of UK groups participating in LCFI

- **Over the past months, UK groups working on ILC Vertex Detector R&D within LCFI have expressed interest in a range of physics processes, covering the "Vertex Detector Optimisation Processes" from the above list.**
  Work is beginning at the level of setting up software frameworks:

  - **Higgs branching ratios (*process 3*)**
  - **scalar top study**
  - **e+e- → ZHH (*process 4*)**
  - **e+e- → $t\bar{t}$ (anomalous Wtb coupling),**
  - **e+e- → $b\bar{b}$ (*process 1*)**
  - **soft b-jets in sbottom decays**

- **Note that discussions of the choice of benchmark processes to be studied for the LoI phase are currently ongoing in the LoI groups and the higher ILC management; to be decided soon.**

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**

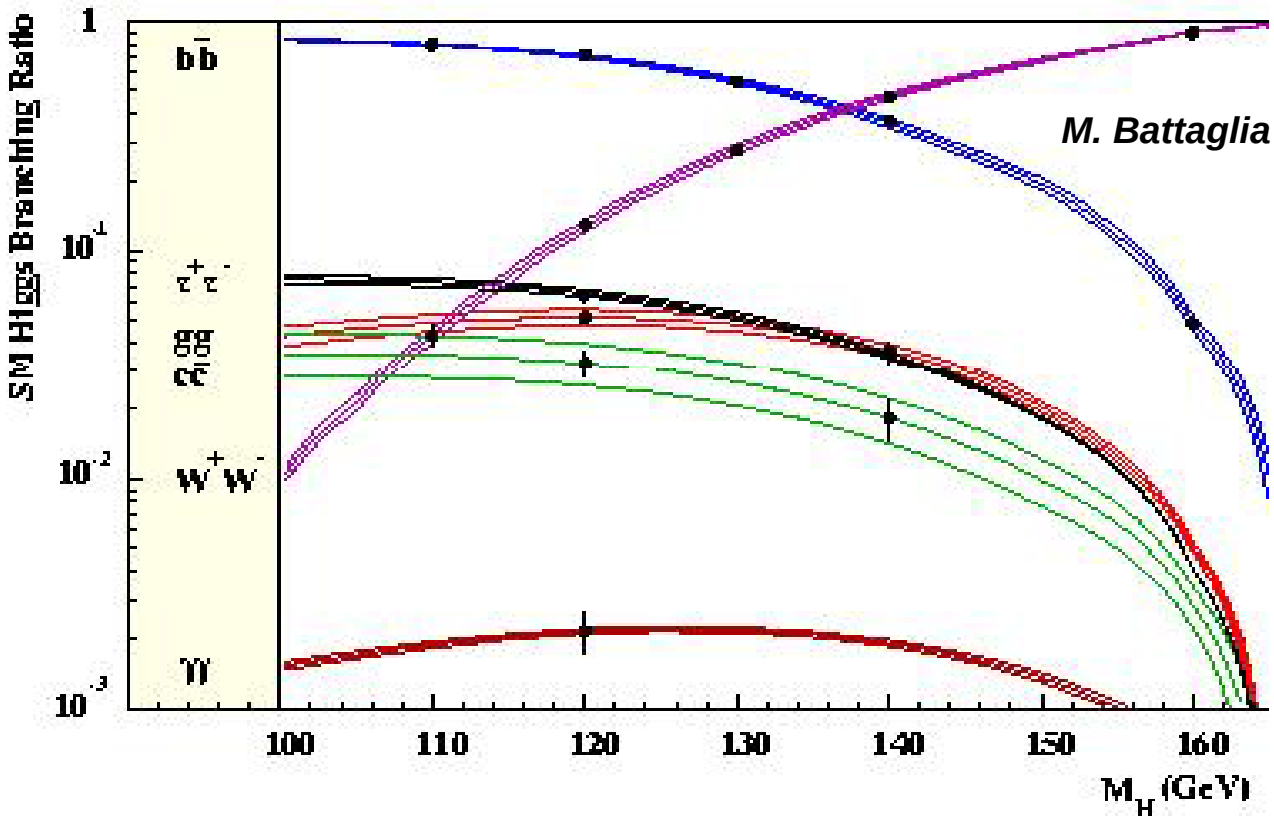
- **Examples:**

• Higgs branching ratios:

classical example of a process relying on flavour tag

• e+e- → ZHH:

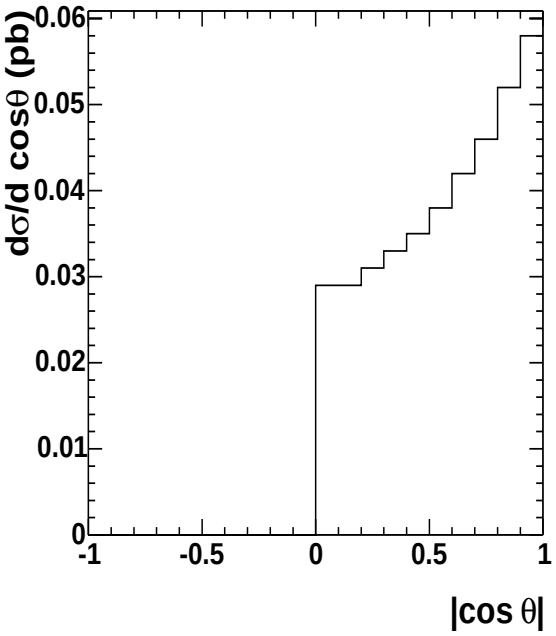
4 b-jets in final state requiring excellent tagging performance; could profit from quark charge sign selection

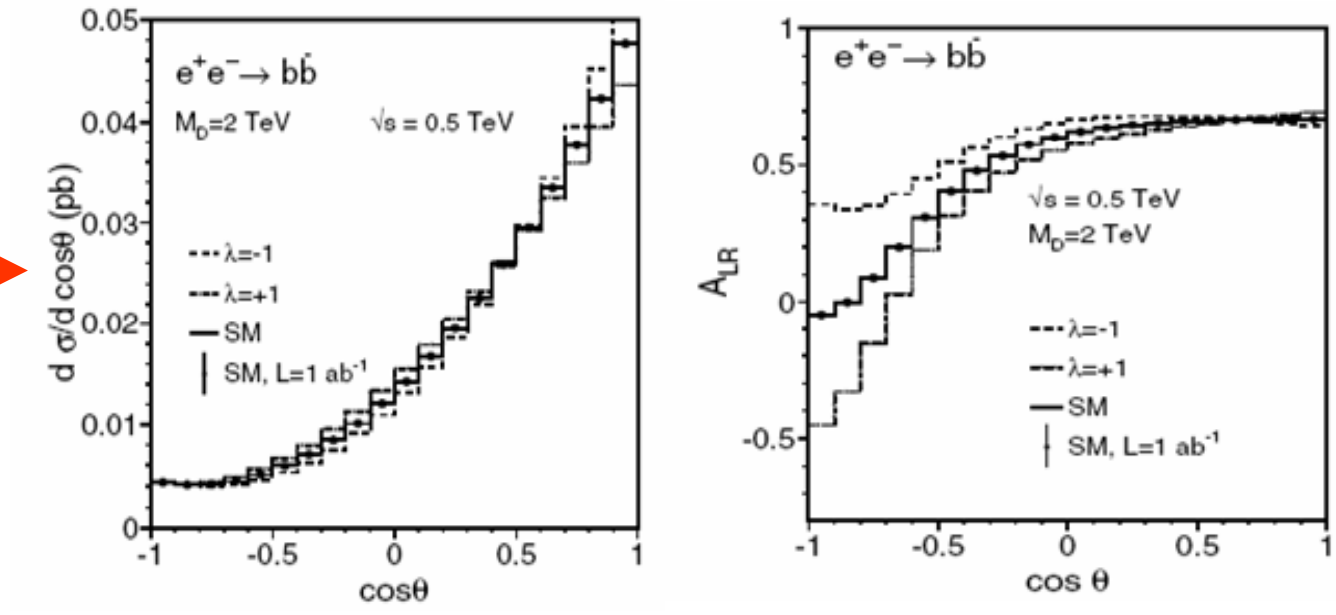


Processes relying on quark sign selection 1

- **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}:

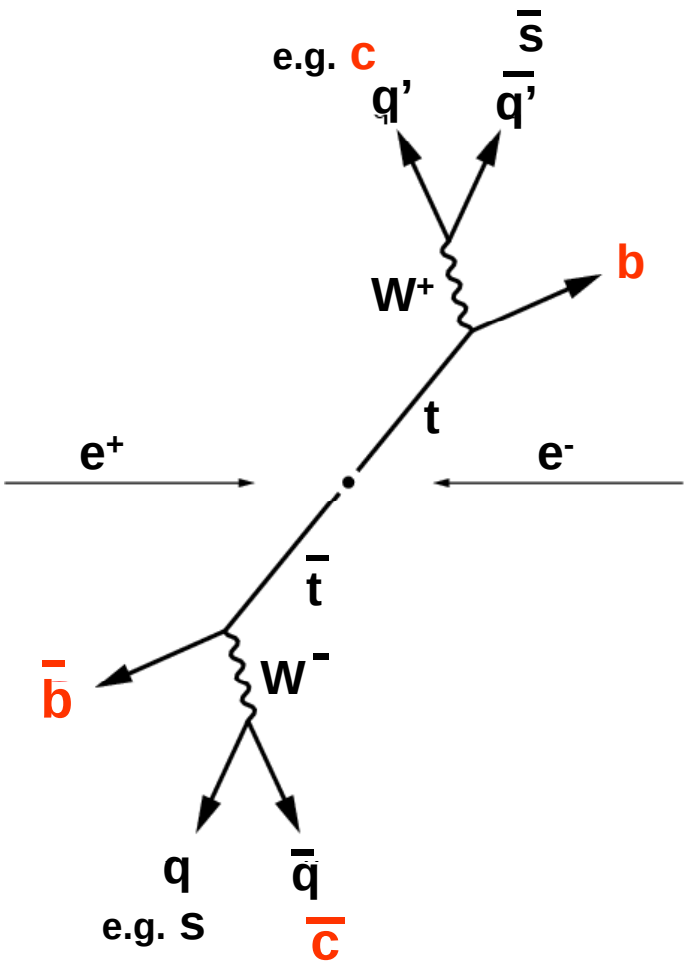
Sensitivity to deviations of extra-dimensions model from SM prediction (S. Riemann):





without quark sign selection ***with perfect quark sign selection***

Processes relying on quark sign selection 2



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)**

Parameters and aspects of design to be optimised

- Plan to vary the following design aspects and to study their impact on detector performance:

- Beam pipe radius
- Sensor thickness
- Material amount, type of mechanical support (e.g. RVC, Silicon carbide foams), shell structures
- Material amount at the ends of the barrel staves
- 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

- Including a 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

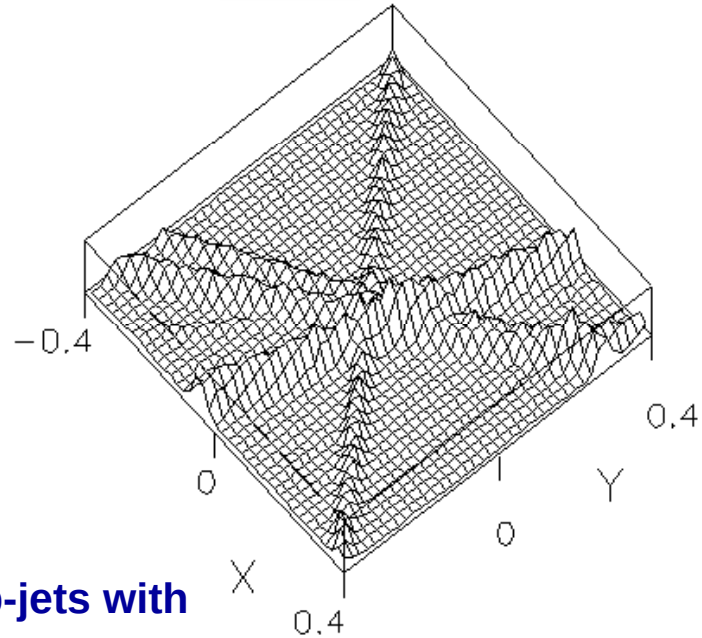
The ZVTOP vertex finder

D. Jackson,

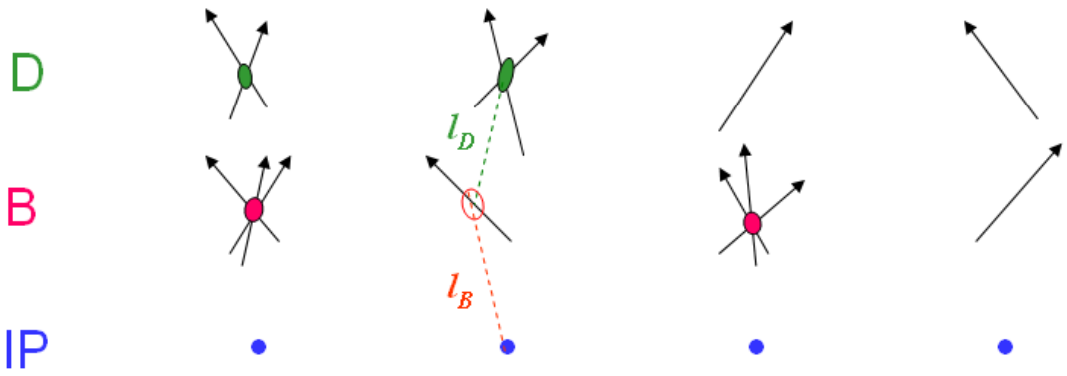
NIM A 388 (1997) 247

- **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**



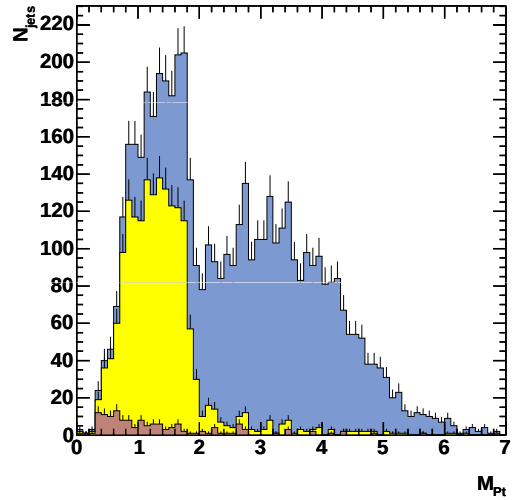
- **ZVKIN: more specialised algorithm to extend coverage to b-jets with 1-pronged vertices and / or a short-lived B-hadron not resolved from the IP**



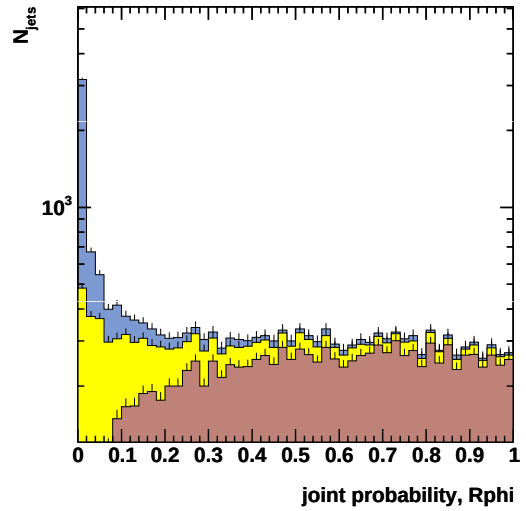
- **additional kinematic information (IP-, B-, D-decay vertex approximately lie on a straight line) used to find vertices**
- **should improve flavour tag efficiency and determination of vertex charge**

Flavour tagging approach

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