Top Anomalous Couplings with LCFI Vertexing Package

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Outline

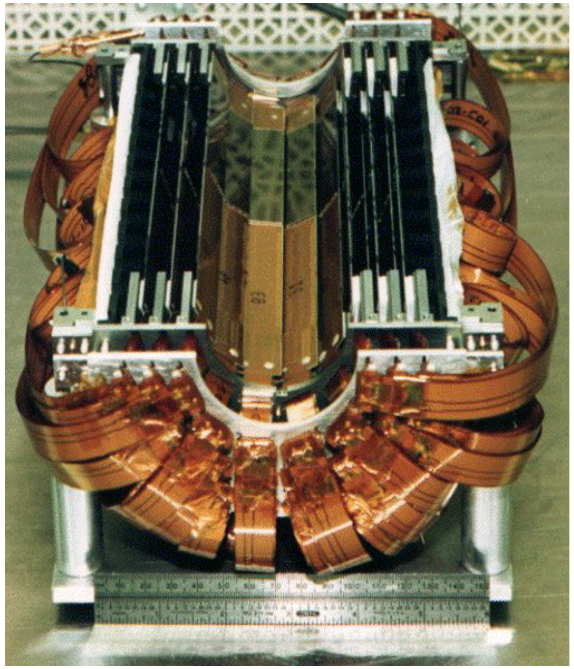
- LCFI Vertexing Package
  - B-tagging
  - Vertex Charge
- Top Anomalous Couplings

SLD Vertex Detector

- Arguably the best vertex detector ever built

IP resolution: $(8\ \mu m)^2 + (30\ \mu m / p)^2$

- Rmin=2.8 cm
- Sigma hit = 4 μm



The VXD3 upgrade vertex detector: 96 large CCDs, 307 Million pixels (1996)

- Resolution factor of 2 better than for LEP Vertex Detectors
- Very small fake rate

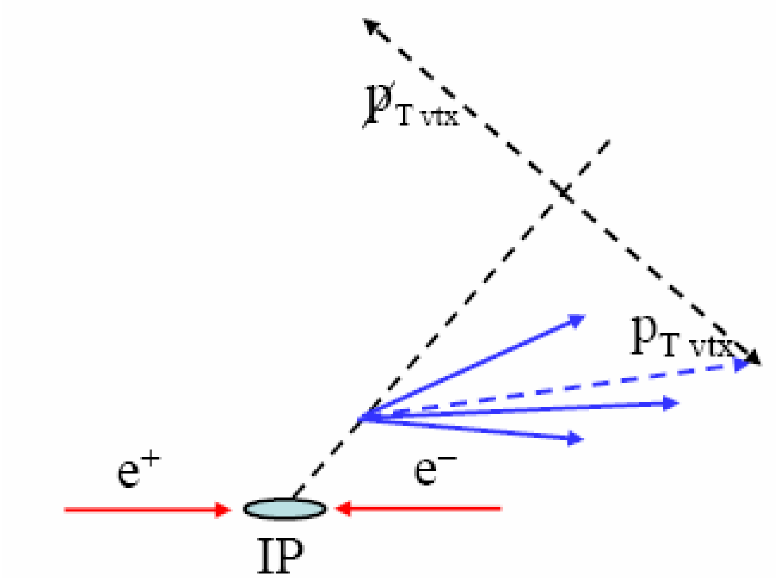
This allowed for innovative algorithms
- Vertex mass
- Vertex charge
- Vertex dipole

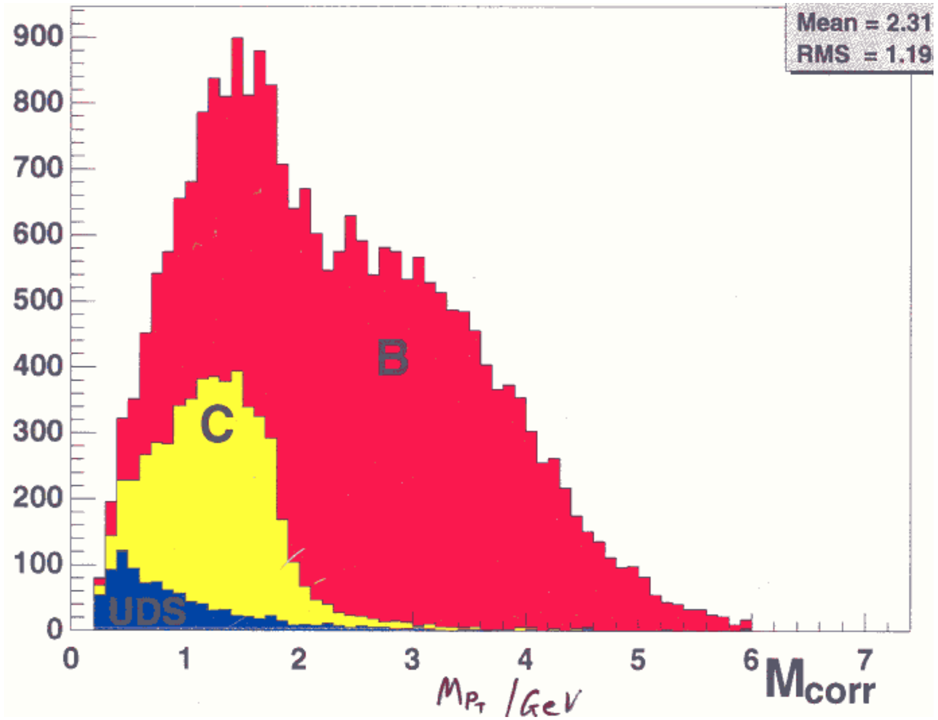
Goal for ILC : $(4\ \mu m)^2 + (8\ \mu m / p)^2$

Vertex Mass

- Take all tracks from secondary vertex as π and calculate the invariant mass
- Add missing p_t to compensate for neutrals, p_t corrected mass:

$$M_{Pt} = \sqrt{M_{VTX}^2 + P_t^2} + |P_t|$$





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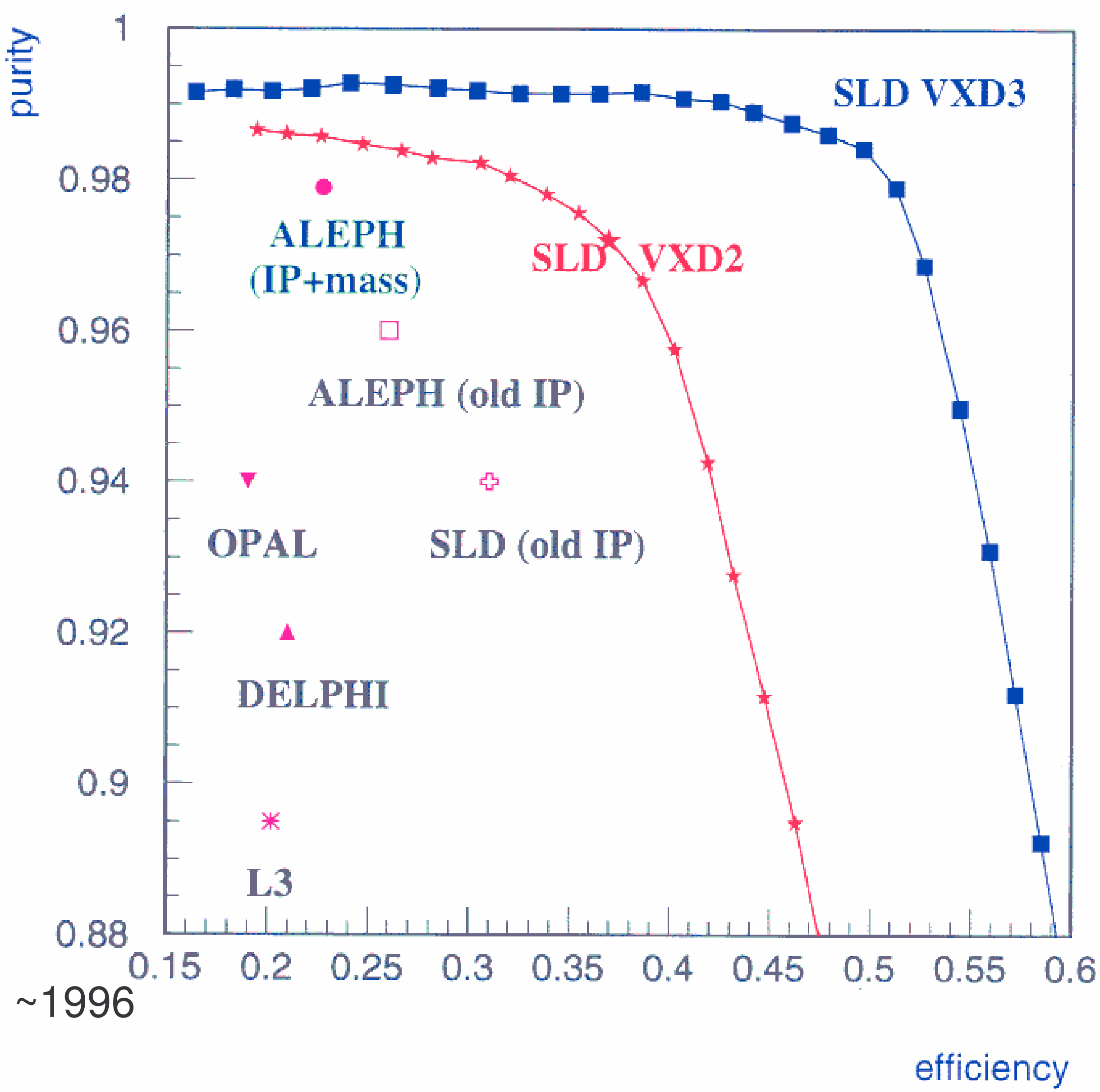
B-tagging based on Vertex Mass



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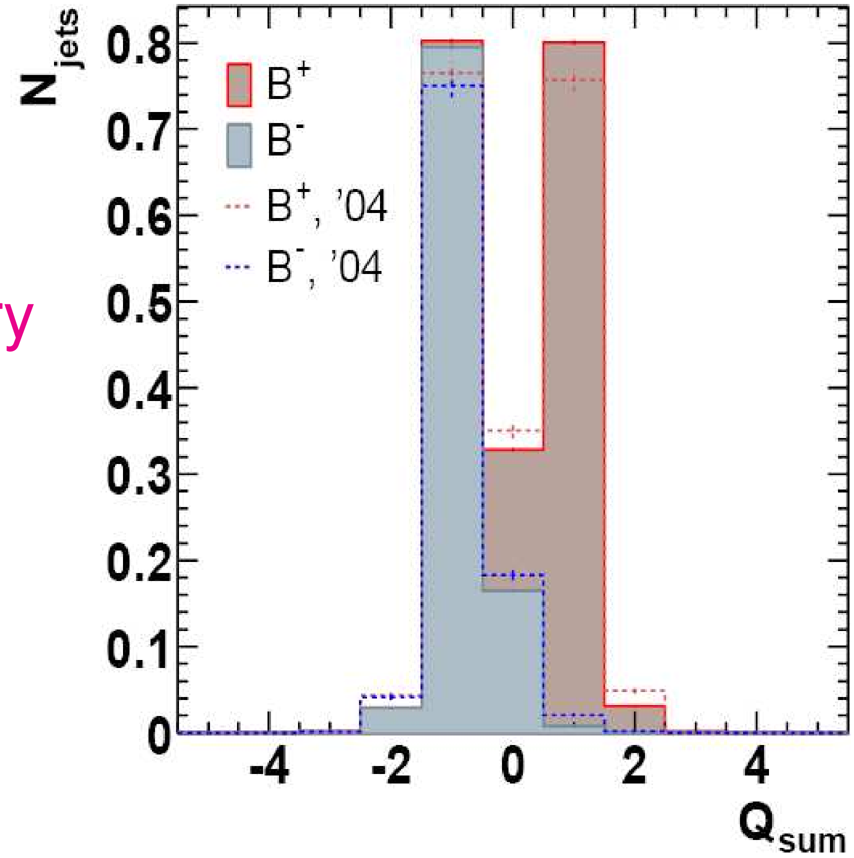
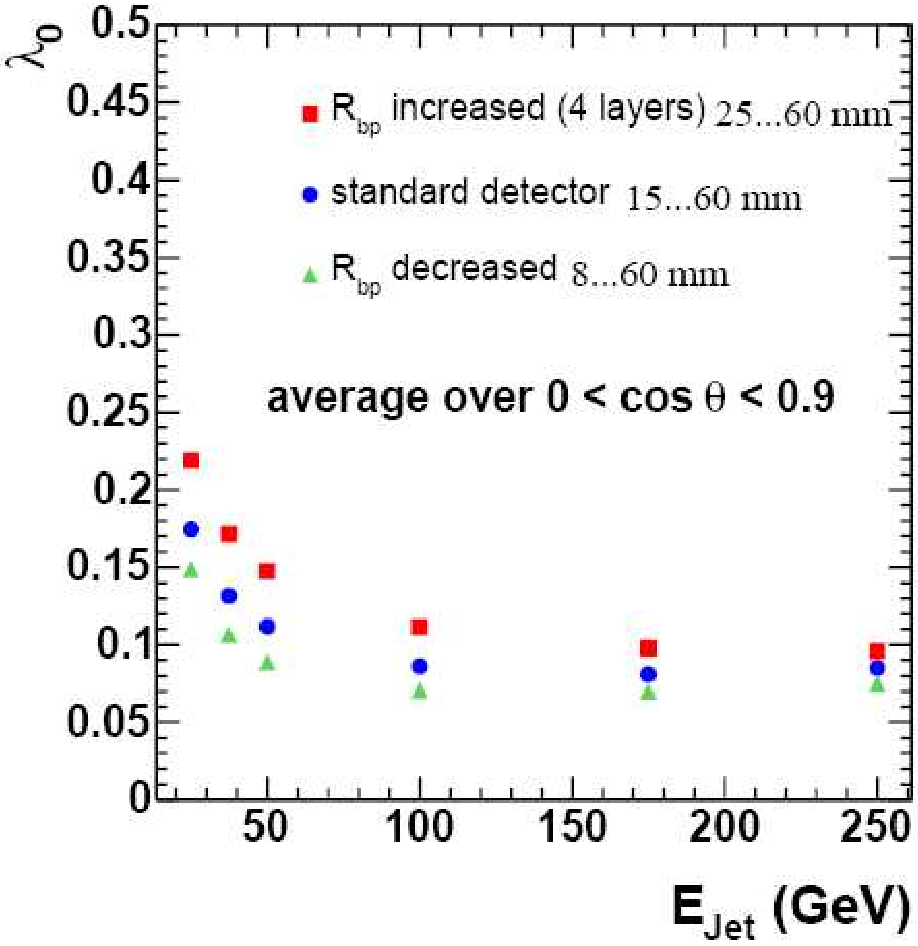
Vertex Charge

- Total charge of tracks associated with a vertex
  - Binary behaviour : a lost or wrongly assigned track changes the charge → every track is important

Sensitive to low pT tracks
Sensitive to material



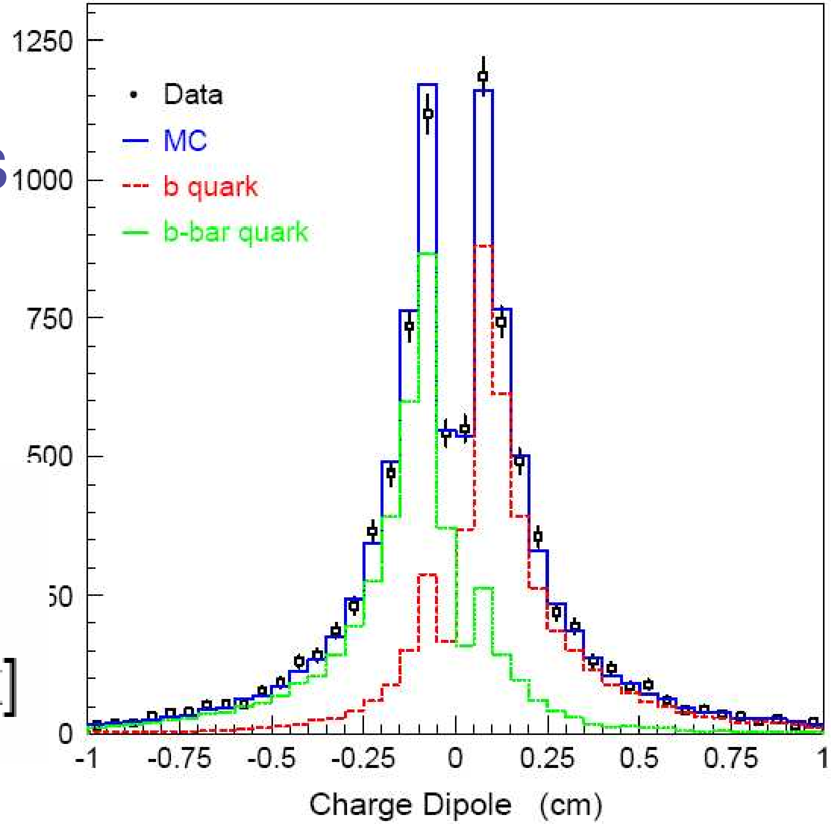
Vertex Charge Performance



- Figure of merit: mistag rate
  - Deteriorates for smaller energies, bigger BP and more material
- Used to study effects of BP radius

Vertex Dipole

- Vertex Dipole: identify b or anti-b for neutral B hadrons
- Dipole = signed distance between SV and TV



$B^0 \rightarrow D^- \pi^+$ [+ve secondary vertex]

$\hookrightarrow K^+ \pi^- \pi^- \pi^+$ -ve tertiary vertex]

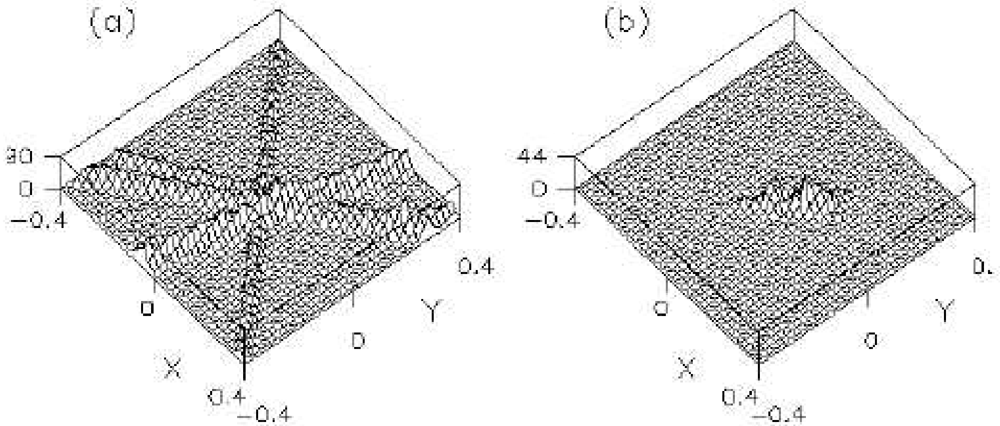
- Worse performance compared vertex charge

Topological Vertex Reconstruction

- Vertex Package developed by LCFI, includes
  - Topological vertex finder
  - Additional ‘ghost track’ enhancement algorithm
  - Flavour tagging based on Neural Net
- Released in April

S.Hillert
B.Jeffery
E.Devetak
M.Grimes

Vertexing: ZVTOP



•Tracks are described as Gaussian probability tubes in 3D

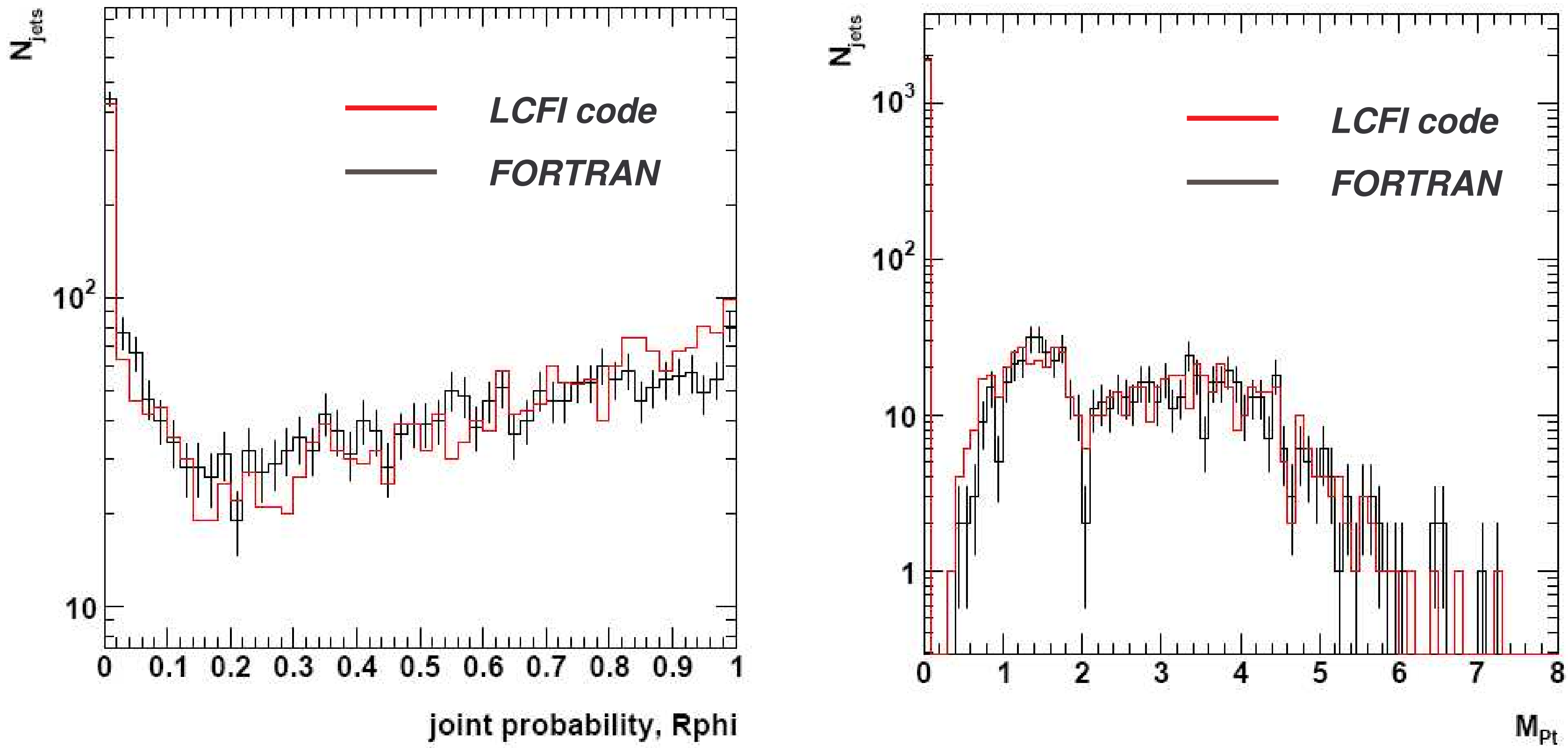
•Look for regions of overlap away from the IP

•These are *seed* vertices

Vertex Package – More Details

- Package design overview
  - Vertex package interfaces to MarlinReco framework
  - Framework consists of software modules (processors), enabled and configured via XML
  - *Input:* LCIO events
  - *Processors:*
    1. Track selection cuts for ZVTOP, flavour tag, vertex charge
    2. IP fit processor
    3. ZVRES
    4. ZVKIN
    5. **Jet flavour MC truth information**
    6. **Calculation of NN input variables**
    7. **Training NN for flavour tag**
    8. **NN outputs from trained nets**
    9. **PlotProcessor for standard plots**
  - *Output:* dedicated vertex class in LCIO format, with vertex information, flavour tag inputs, NN flavour tag output and vertex charge
- Status and Plans
  - Fully functional, ~20,000 lines of c++ code
  - Works in MARLIN framework and detailed testing in progress
  - Testing with full LDC tracking in progress
  - Move to more realistic vertex detector geometry (ladders, not cylinders)
  - Further optimisation of cuts, parameters and algorithms

Vertex Package - Comparisons

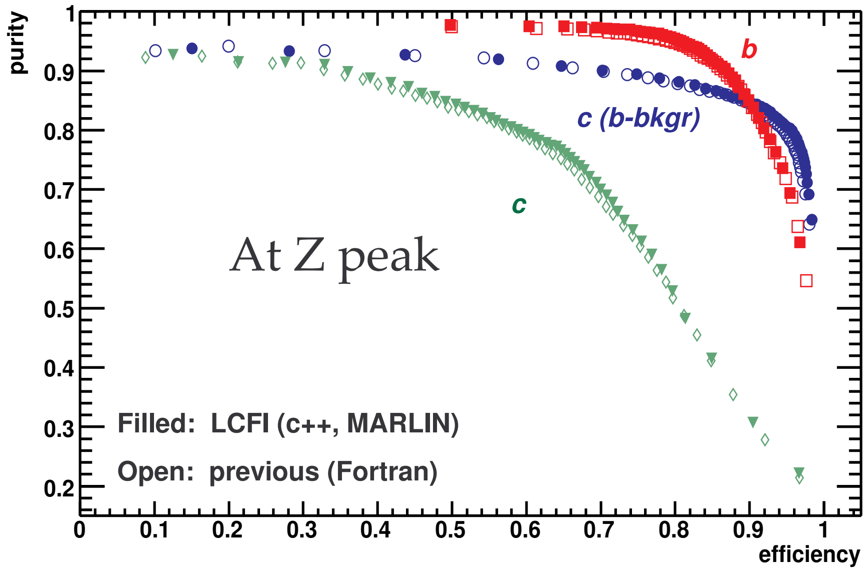


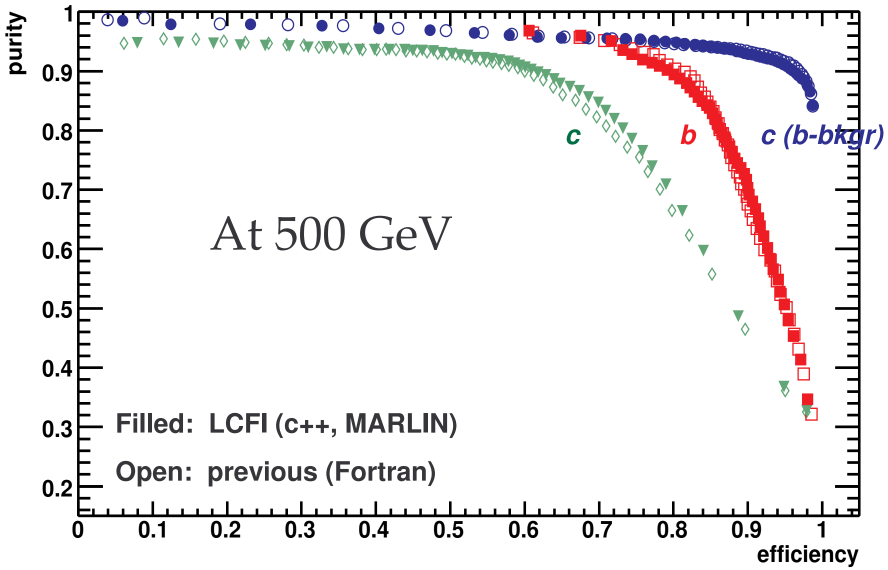
- Joint probability and P_T-corrected vertex mass
  - Shown are the two most important flavour tag inputs
  - Excellent agreement between LCFI code and previous Fortran results

Flavour Identification

- Combine several variables into Neural Net
  - Vertex mass
  - Vertex momentum
  - Decay length
  - Decay length significance
  - Jet Probability
- Example plots: Purity vs. Efficiency
  - **Analysis at Z-peak energy (left) and at 500 GeV (right)**
  - **Plots based on 'fast' MC**
- Main contributors are Vertex Mass and Jet Probability
- Part of the Vertexing Package

E. Devetak, M. Grimes, S. Hillert, B. Jeffery





Top Anomalous Couplings

- Heavy top quark is a sensitive probe of new physics → expect larger effects in its couplings: Ztt (production) and Wtb (decay)
- Wtb plays crucial role as responsible for all decays → defines top width and characteristics of all decay products

- Wtb can be studied using tagging variables sensitive to flavour: Vertex Charge and Vertex Dipole
- **In addition to exciting physics this is a promising process to optimize the Vertex Detector design**

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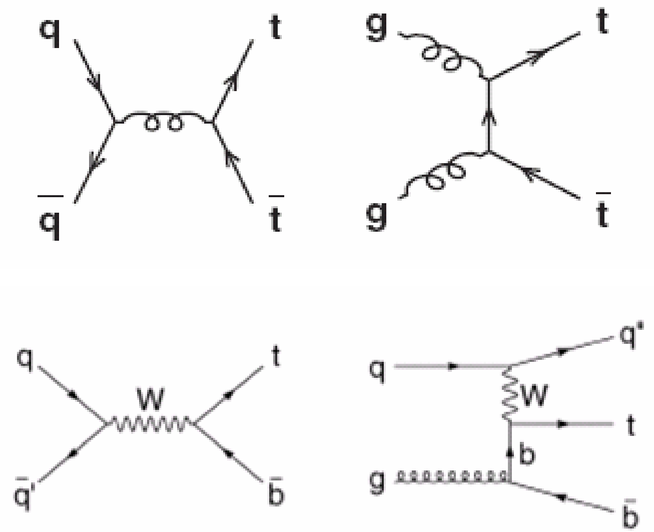
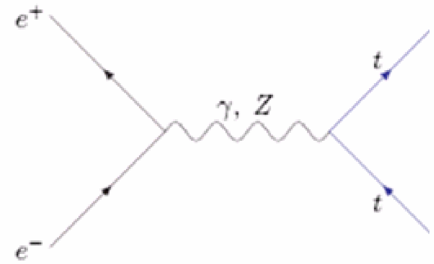
Wtb at LHC and ILC

LHC



ILC



- LHC can access Wtb through rates of single top processes, pair production rate is not sensitive to Wtb structure
    - Also can look at angular distributions in top rest frame
- ILC is able to study Wtb vertex in decays through observables sensitive to its structure
    - These observables (typically asymmetries) are easier at ILC due to well defined initial state e+e- and low background

Wtb Effective Lagrangian

V-A; =1 in SM V+A; =0 in SM

$$\mathcal{L} = \frac{g}{\sqrt{2}}\Big[\quad W_\mu^- \bar{b}(\gamma_\mu f_{1L} P_- + \gamma_\mu f_{1R} P_+)t$$
$$- \frac{1}{2M_W} W_{\mu\nu} \bar{b}\sigma^{\mu\nu}(f_{2R}P_- + f_{2L}P_+)t \Big]$$

Magnetic couplings; = 0 in SM

- Magnetic couplings are anomalies in SM – this is main interest in this study
  - Can be non-zero if quarks have structure - compositeness
- Current limit on $f_{1R} \leq 0.4 \times 10^{-2}$
  - From $b \rightarrow s\gamma$ assuming universality

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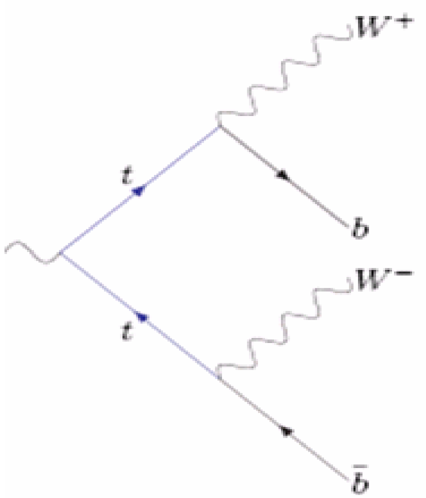
Angular Distributions in Top Decay



- Differential x-sections in SM: Parity violating (of course!) terms from V-A weak current structure and spin-spin correlations

$$\frac{d^4\sigma(e^+e^- \to t\bar{t} \to W^+bW^-\bar{b})}{d\cos\Theta\, d\cos\theta d\varphi\, d\cos\theta^* d\varphi^*}$$
$$= \frac{3\alpha^2\beta}{32\,\pi\, s} Br(t \to W^+b) Br(\bar{t} \to W^-\bar{b}) \Sigma(\Theta, \theta, \varphi, \theta^*, \varphi^*)$$

$$\Sigma(\theta, \varphi, \theta^*, \varphi^*) \;=\; \Sigma_{unpol} + k\,P\;\cos\theta + \bar{k}\,\bar{P}\;\cos\theta^* + \cos\theta\cos\theta^*\,k\,\bar{k}\,Q$$
$$+\quad (\varphi, \varphi^*\ dependent\ terms).$$

Values of unpolarized x-section, polarization and spin-spin correlation functions in SM

$$\Sigma_{unpol} \;:\; P \;:\; \bar{P} \;:\; Q \;=\; 1 \;:\; -0.18 \;:\; 0.18 \;:\; -0.63$$

Polarization degree of top in SM

$$k = \frac{m_t^2 - 2\,m_W^2}{m_t^2 + 2\,m_W^2} = 0.41$$

From E.Boos et al hep-ph/0001048

Forward-Backward Asymmetry

$$A_{FB} = \frac{\sigma(\theta < 90^\circ) - \sigma(\theta > 90^\circ)}{\sigma(\theta < 90^\circ) + \sigma(\theta > 90^\circ)} = \frac{k}{2}\frac{P}{\Sigma_{unpol}}$$

- A_{FB}(b quark) = 28% in e^+e^- frame
  - Superposition of production and decay asymmetries

  = 3.6% in top frame
  - Pure decay asymmetry

- Experimentally requires to determine vertex charge of b (or bbar) → single flavour tagging

FB Asymmetry for Spin-Spin Correlations

$$A_s^b = \frac{k}{2}\frac{P}{\Sigma_{unpol}}\left(1 + \bar{k}\,\frac{Q}{2P}\right)$$

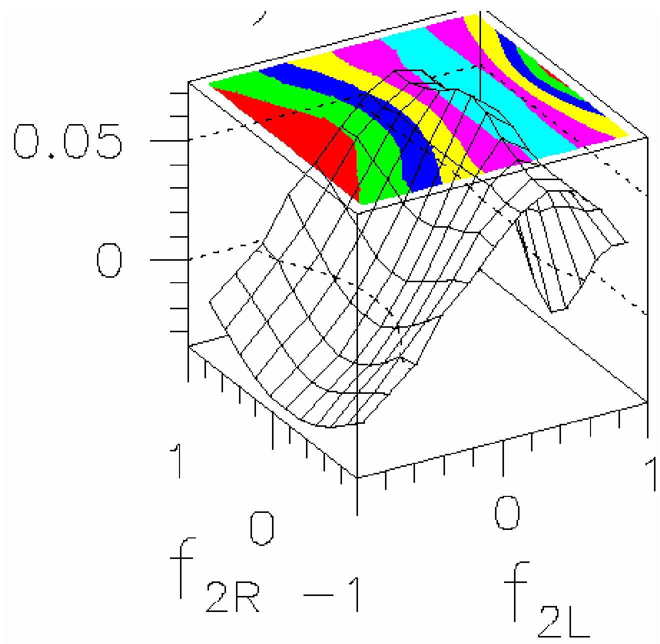
- Spin-Spin correlations have considerable effect on asymmetry
  - Constraints on second b in event can boost "signal" (=asymmetry) of first b
- If one b is observed in forward hemisphere of its parent top rest frame then A_{FB}(b quark) = 6.2% in other top frame
  - Amplified sensitivity to anomalous couplings
- Experimentally need double tagging – pay in efficiency

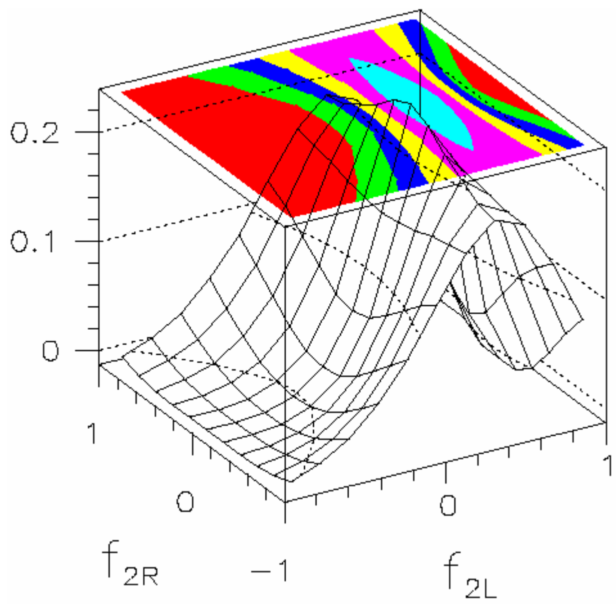
Dependence on Magnetic Anomalous Couplings

- Magnetic couplings change angular distributions → asymmetry is sensitive to this

- Effect mapped for A_{FB} in single and double b-tagging, see graphs from E.Boos et al.
- Polarization of electrons increases effect in asymmetry by x2-3 (in addition to x3 increase in x-section)

- Note ambiguities in determination of f_{2L} and f_{2R}

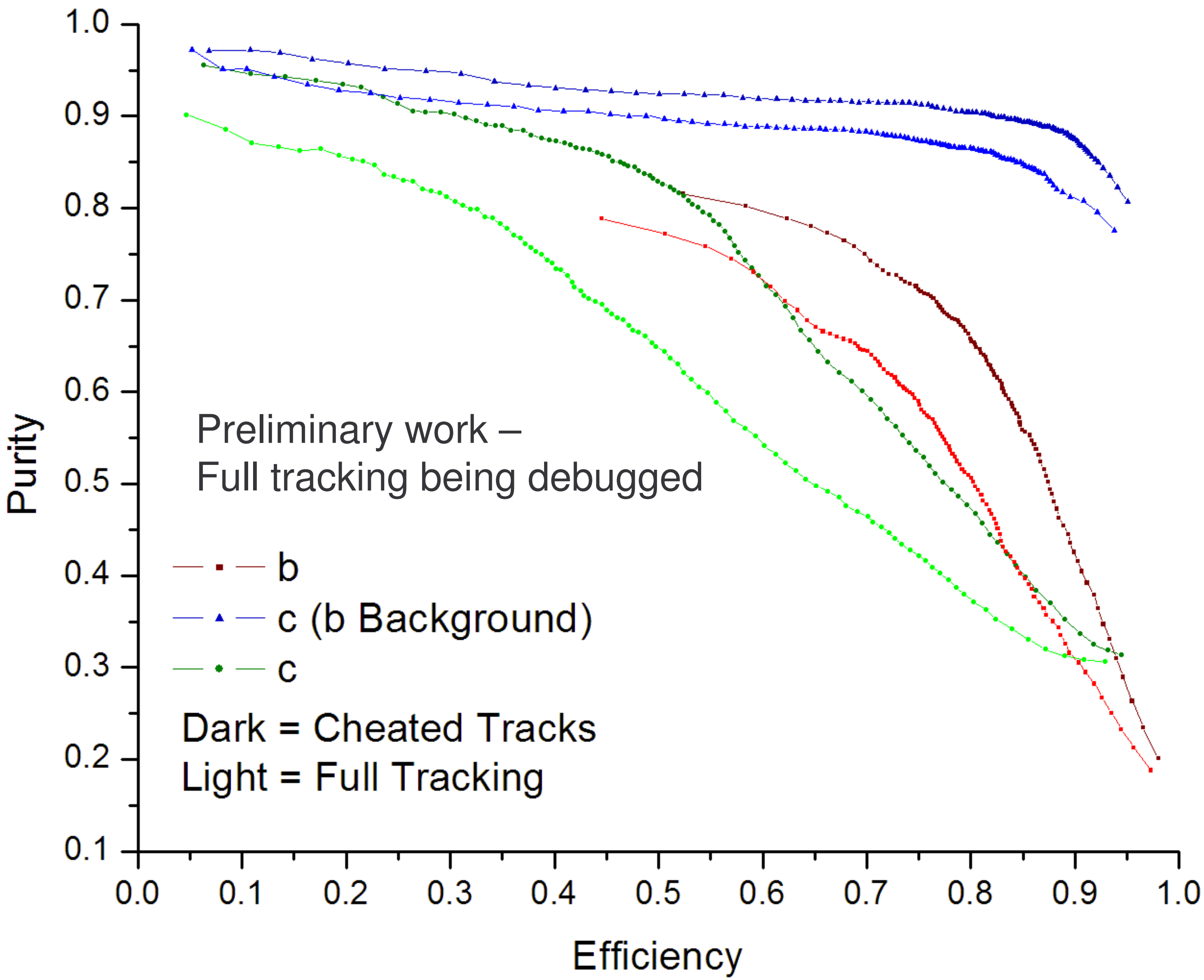




Folding in Experimental Realities

- Top ID algorithm
  - Consider different event topologies (dileptons, lepton + jets, jets), develop selections, optimize efficiency of top ID
  - Top jets (collimation of several jets at high energies)? Probably not but needs studies
- Improvement of flavour - anti-flavour tagging
  - Complement vertex charge with vertex dipole algorithm
  - Look for more sensitive flavour tagging than just $\Sigma q_{i,}$ - take inspiration from B-meson oscillation analyses
  - Combine tagging variables
- Use full angular information instead of simple A_{FB}
- Look at tradeoffs between single and double tagging
- Look for more sensitive observables
  - For ex. Angle between top production plane and b-quark production plane – up to 95% asymmetries but much less sensitive to magnetic couplings
- Look at sensitivities to more specific models (ED, CP-violating effects etc)

B-tagging: Ideal vs Real Tracking



Summary

- LCFI vertexing package released in April
- Includes flavour tagging
- Performance carefully tested

- Anomalous top couplings is one of benchmark processes under study with this package – expect fast progress in the near future