Separation of B Decay Topologies via Aggressive Vertexing

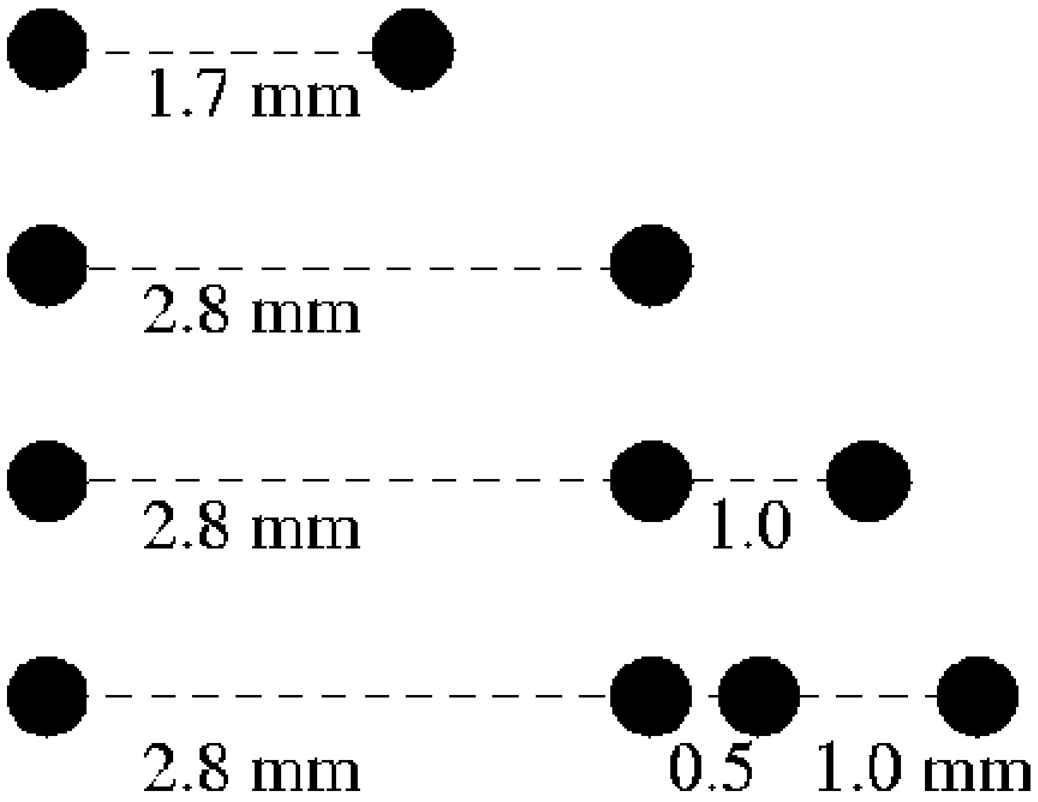
- Last time: Tom showed the scaling of neural net b-tagging with improved vertexing resolution
- Today: Separation of vertices in the b decay cascade. Try to tag:

  1) b -> 0D (b -> u, b -> s, b -> J/psi)

  2) b -> 1D (Dipole events for B_s mixing)

  3) b -> 2D (b -> c cbar s)

B Decay Topologies



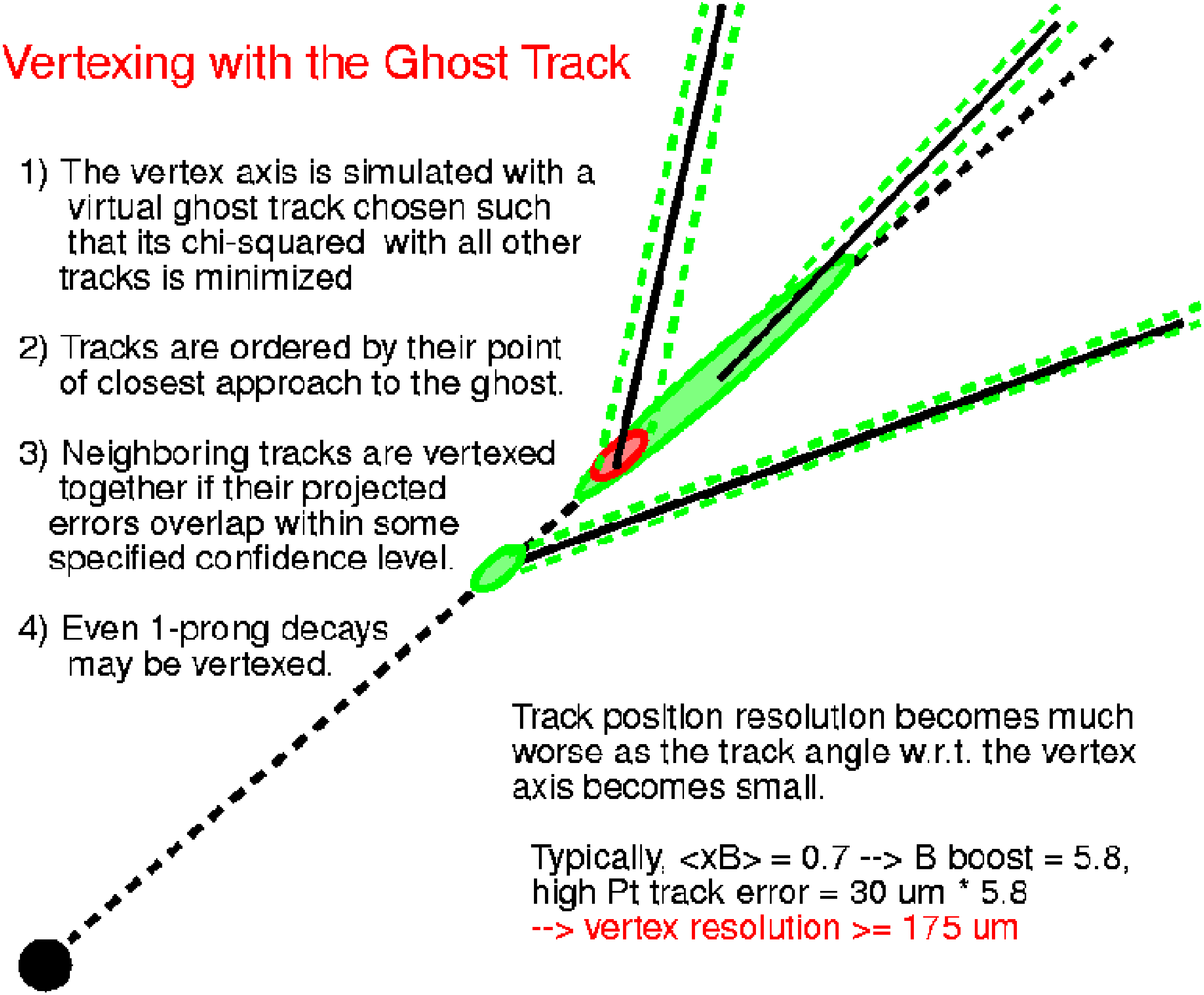
Z -> c (bkgd)

Z -> b -> 0D
(u, s, J/psi)

Z -> b -> 1D

Z -> b -> 2D

Vertexing with the Ghost Track



1) The vertex axis is simulated with a virtual ghost track chosen such that its chi-squared with all other tracks is minimized

2) Tracks are ordered by their point of closest approach to the ghost.

3) Neighboring tracks are vertexed together if their projected errors overlap within some specified confidence level.

4) Even 1-prong decays may be vertexed.

Track position resolution becomes much worse as the track angle w.r.t. the vertex axis becomes small.

Typically, <xB> = 0.7 --> B boost = 5.8,
high Pt track error = 30 um * 5.8
--> vertex resolution >= 175 um

Basic Idea: Conformal Scaling

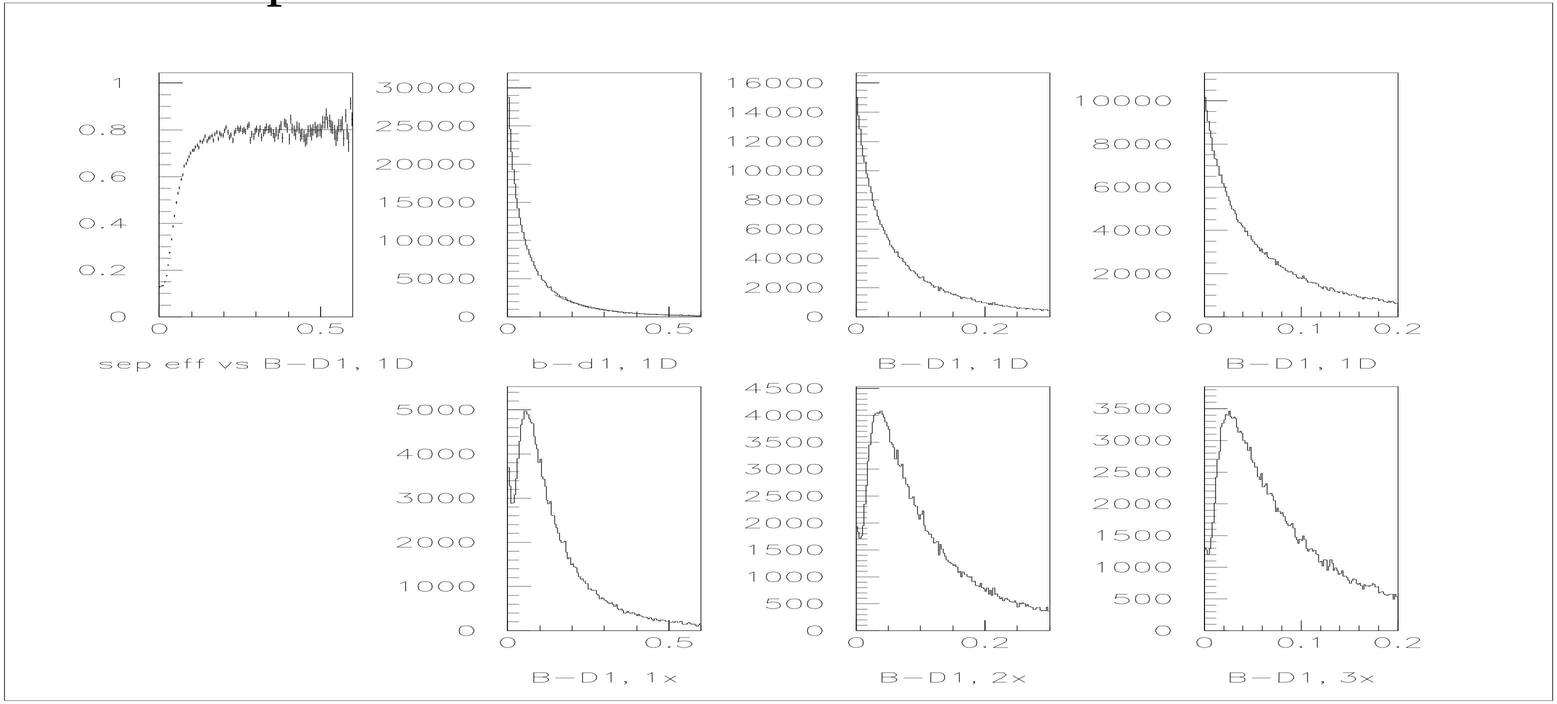
- The MC simulation calculates only numbers with implicit units. (e.g. VXD3 lyr 1 radius = 2.5 * [length])
- The units we decide to use are arbitrary.
- To conformally shrink the detector by a factor of n, interpret [length] = cm/n instead of cm.
- This also rescales physics quantities such as the decay lengths, so we can only extract detector information that is independent of such physics quantities.

==> get vertex separation efficiency plots

- Reinterpret the length scale on the efficiency plot and multiply it with the true decay length distributions to get hypothetical measured distributions.
- Calculate the ensemble average efficiency (to separate vertices) in each case.

Ex: Eff to separate B, D vertices in B -> 1D decay:

Vtx sep ε x 1 x 2 x 3



Is conformal scaling valid?

- Locally, a track may be approximated by a parabola:

$$x = x_0 + \phi \times s + {}^1\!/_2\, k \times s^2$$

(x = transverse position, ϕ = tangent angle, s = arclength, k = curvature)

- At SLD, k is measured by the drift chamber and:

$$\Delta k \approx {}^{100\,\mu m}\!\big/_{(100\,cm)^2} = 10^{-2}\ {}^{\mu m}\!/_{cm}$$

So the error induced by Δk is negligible on a vertex detector scale.

- Then approximate $\Delta x = \Delta x_0 + \Delta\phi \times s$

==> Track errors scale as [length]

For this study:

- Cluster sizes, layer1 radius, layer separation are all scaled by the same factor.

- $\Delta\phi$ is conformally invariant ==> the relative amount of the multiple scattering contribution to $\Delta\phi$ is unchanged so the tail population in the Δx distribution is unchanged. i.e. interaction lengths are unchanged by the scaling.

- SLD vertexing algorithm inefficiencies are obviously assumed.
  1) SLD tracking efficiency ≈ 95%. This has a big effect on efficiencies to find low multiplicity vertices. (Fix this in a future study.)
  2) Track impact parameter (to IP) cuts to remove non-IP, non-secondary tracks cause vertexing inefficiencies at long decay length. Scaling of this physics-based cut and the resulting loss of vertexing efficiency is unavoidable in our approach, but should only be a small correction to the results.
  3) The ghost track algorithm appears to suffer some inefficiency in low multiplicity b decays.

Measurement 1: B -> 0D (to get V_{ub})

- Tag b -> 0D by requiring only 1 vertex in the b hemisphere.
- To get 1 vtx: $\varepsilon_1 = 0.835$ (scales with b-tagging ε)
  0 vtx: $\varepsilon_0 = 0.050$ (intrinsic algorithm inefficiency)
  ≥2 vtx: $\varepsilon_2 = 0.115$ (from track error tails)

- Background comes from the 1D, 2D topologies failing to yield separated vertices ($1- \langle\varepsilon_2\rangle$). (see previous eff plot.)

Scale factor	$\langle\varepsilon_2\rangle$ for 1D decays	tag purity
1	0.467	0.088
2	0.580	0.109
3	0.635	0.124
4	0.667	0.134

with charged vtx requirement for neutral B decay:

1	0.495	0.093
2	0.616	0.118
3	0.674	0.136
4	0.708	0.150

Measurement 2: B -> 2D

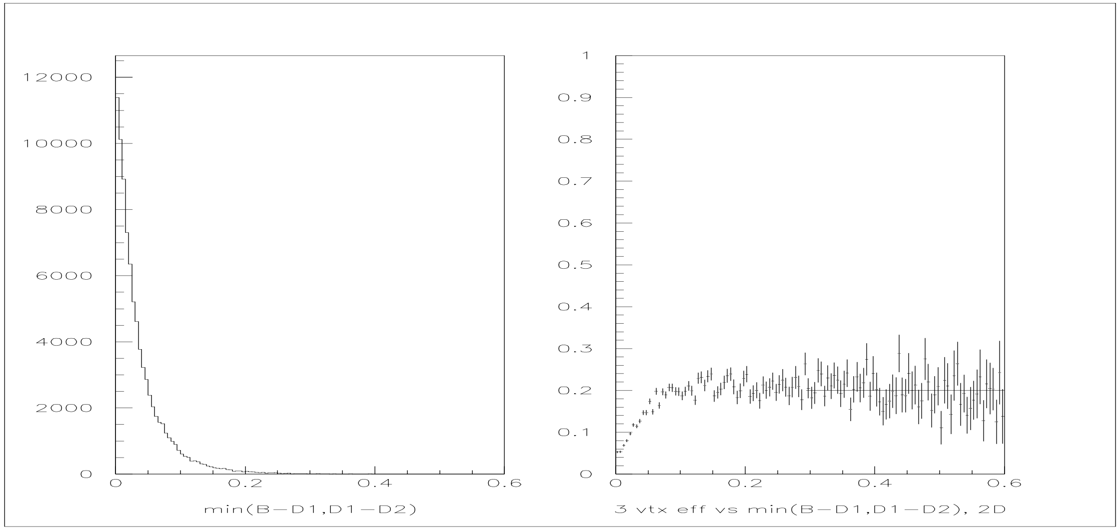
- Tag by requiring $\geq$ 3 vertices in the b hemisphere.
- The maximum possible ε_3 is 0.545 when $\exists$ 3 charged vtxs.
- Background comes from 0D,1D topologies yielding $\geq$ 3 vertices due to tails in the track error distribution.

Scale factor	ε_3 for 2D	ε_3 for 1D	tag purity
1	0.111	0.044	0.386
2	0.143	0.059	0.377
3	0.159	0.067	0.372
4	0.169	0.073	0.367

- The purity doesn't improve because as resolution improves, more of the decays in the core of the 1D exponential become resolved, and thus unprotected from yielding additional fake 'tail' vertices (ε_3).
- Reduction of the track error tails can give large gains in purity. Reducing the tails by a factor of 2 reduces impurity by a factor of 2.
- The tag efficiency could in reality be a factor of 2 higher because in this study, the SLD tracking efficiency causes a factor of 2 loss in ε_3 for 2D. (see plot on next slide.) The purity then becomes 55%

The efficiency to find ≥3 vtxs in 2D decays plotted vs the minimum distance between true decay vertices.

The efficiency is much lower than the 54.5% possible because the large number of low multiplicity vertices in 2D decays makes the measurement more susceptible to the 5% tracking inefficiency.



Measurement 3: Tag neutral B->1D for dipole tag Bs mixing

- In neutral Bs, $\exists$ 2 charged vtxs ==> use charged vtx sep ε undiluted by the intrinsic neutral vtx inefficiency
- B->2D reconstructed as 2 vtx gives random sign final state tag.
- Problem: As vtx resolution improves, the previous 2D 2 vtx bkgd migrates into the 3 vtx bin. However, the 2D 1 vtx population also migrates into the 2 vtx bin, thus producing new bkgd.

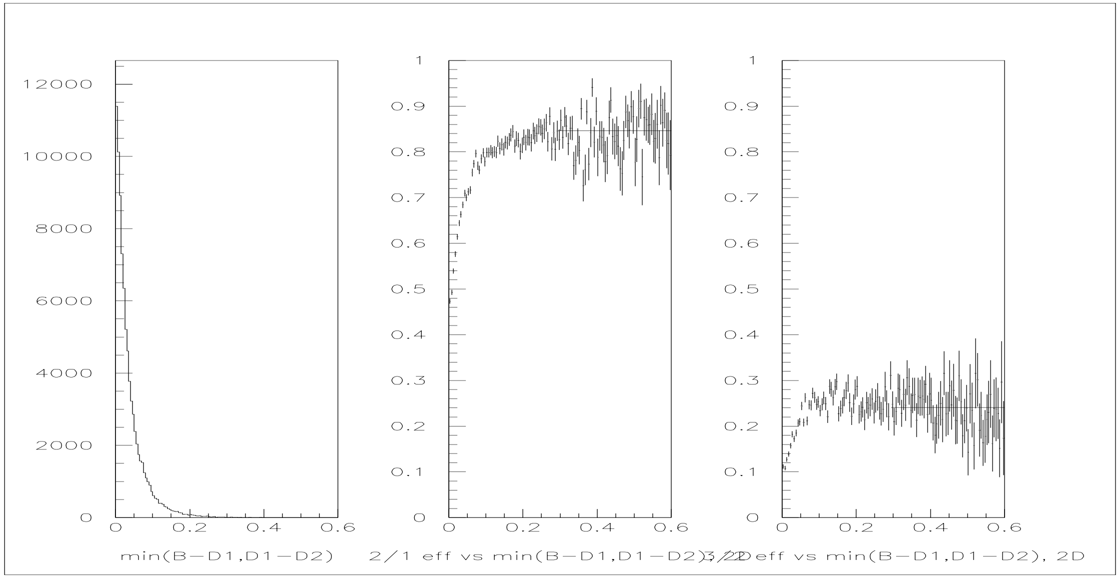
  If ε_3 is not large enough, there is a net increase in the 2 vtx bin.

Scale factor	1D: $\varepsilon_2=\varepsilon_{\geq 2\mid\geq 1}\times(1-\varepsilon_{\geq 3\mid\geq 2})$	2D: ε_2	tag π
1	0.475	0.517	0.775
2	0.591	0.550	0.801
3	0.646	0.567	0.810
4	0.679	0.579	0.815

- The signal still increases faster than the background so an overall improvement in purity is seen.
- $\varepsilon_{\geq 3\mid\geq 2}$ for 1D $\approx$ 0.04 so a 4% improvement in both ε, π is possible by eliminating the track res tails.

For 2D, $\varepsilon_{\geq 2|\geq 1}$ (= nvtx ≥2 / nvtx≥1) and $\varepsilon_{\geq 3|\geq 2}$ plotted vs the minimum true vertex separation.

- Again, tracking inefficiencies may play an important role.



Summary

1) 0D: ε improves with B tag, π slightly improved but still dominated by the small BR(b->0D)
2) 2D: ε slightly improved, π unaffected (dominated by tails)
3) 1D: ε gets big gain, π slightly better. Possible small improvements in both by controlling tails.

- For separation of topologies, the track error tail resolution may be the most important figure of merit.
- This study needs to be redone with better control of tracking efficiency.