Hidden Valley Higgs Search
Update

Higgs Group

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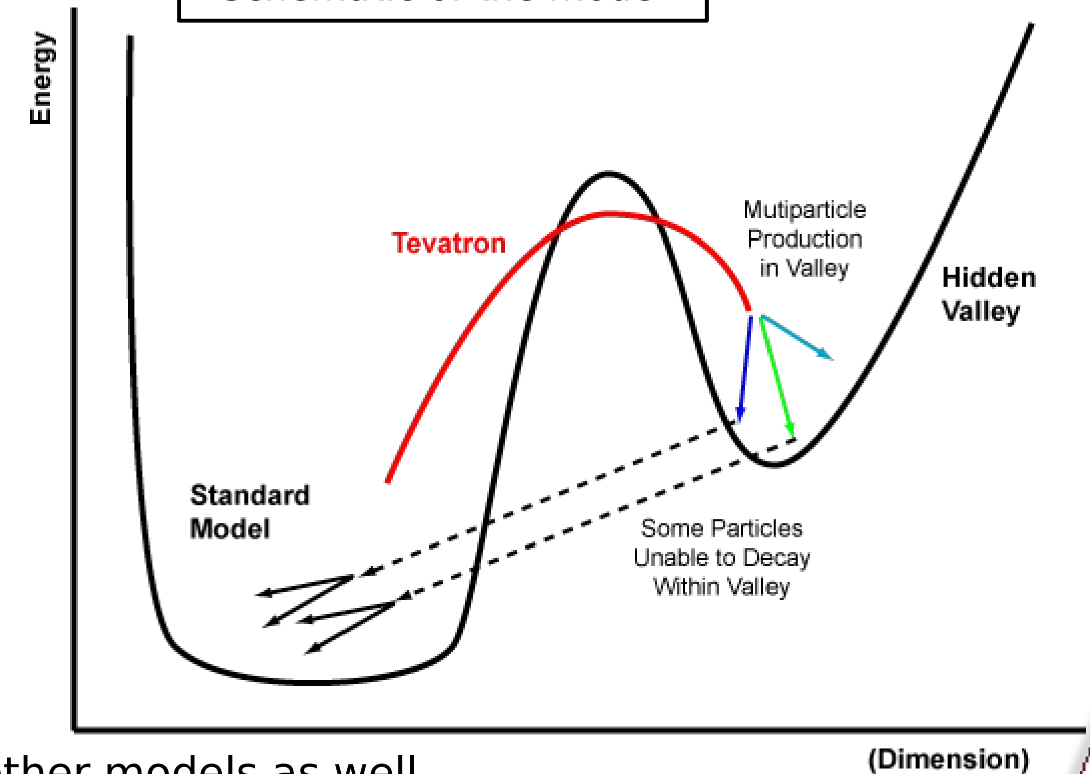
Outline

- Hidden Valley Summary
- Analysis Progress
- Background Estimate Algorithm Overview
- Analysis Variables
- Optimization Study
- Results

Hidden Valley

- Energy from collisions enter into the new sector.
- It is transformed into multiple particles through the dynamics of the new sector.
  - These valley-particles (or v-particles) behave in the same way as SM particles.
  - They obey a “v-QCD,”
  - Most likely decay is a v-π.
- Some of these particles decay back into SM particles.

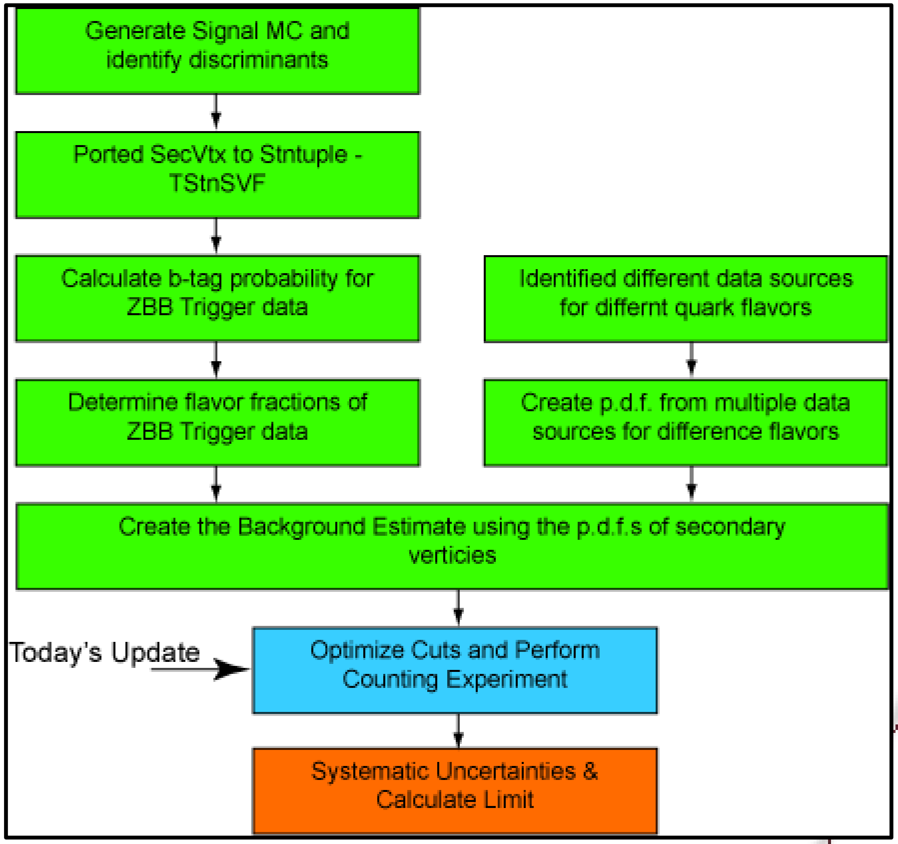
Schematic of the model



- This model can co-exist with other models as well.
  - SUSY, technicolor, etc.
- It may help in the search for the Higgs.
  - The Higgs may decays into long-lived neutral v-particles, which are heavy and meta-stable. They would decay at a displaced vertex.
  - These would then decay into the heaviest SM fermion available (b-quarks).
- Because this sector is dark, there may be Dark Matter/Astrophysics connections as well.
- In some models (see Kaplan, Luty, Zurek) $c\tau$ for the heavy metastable particle could be of order 1 cm.

Analysis Progress

- Analysis is at its last stages.
- Today's update will be about Optimization cuts and performing the counting experiment.
- Full Status is anticipated soon.



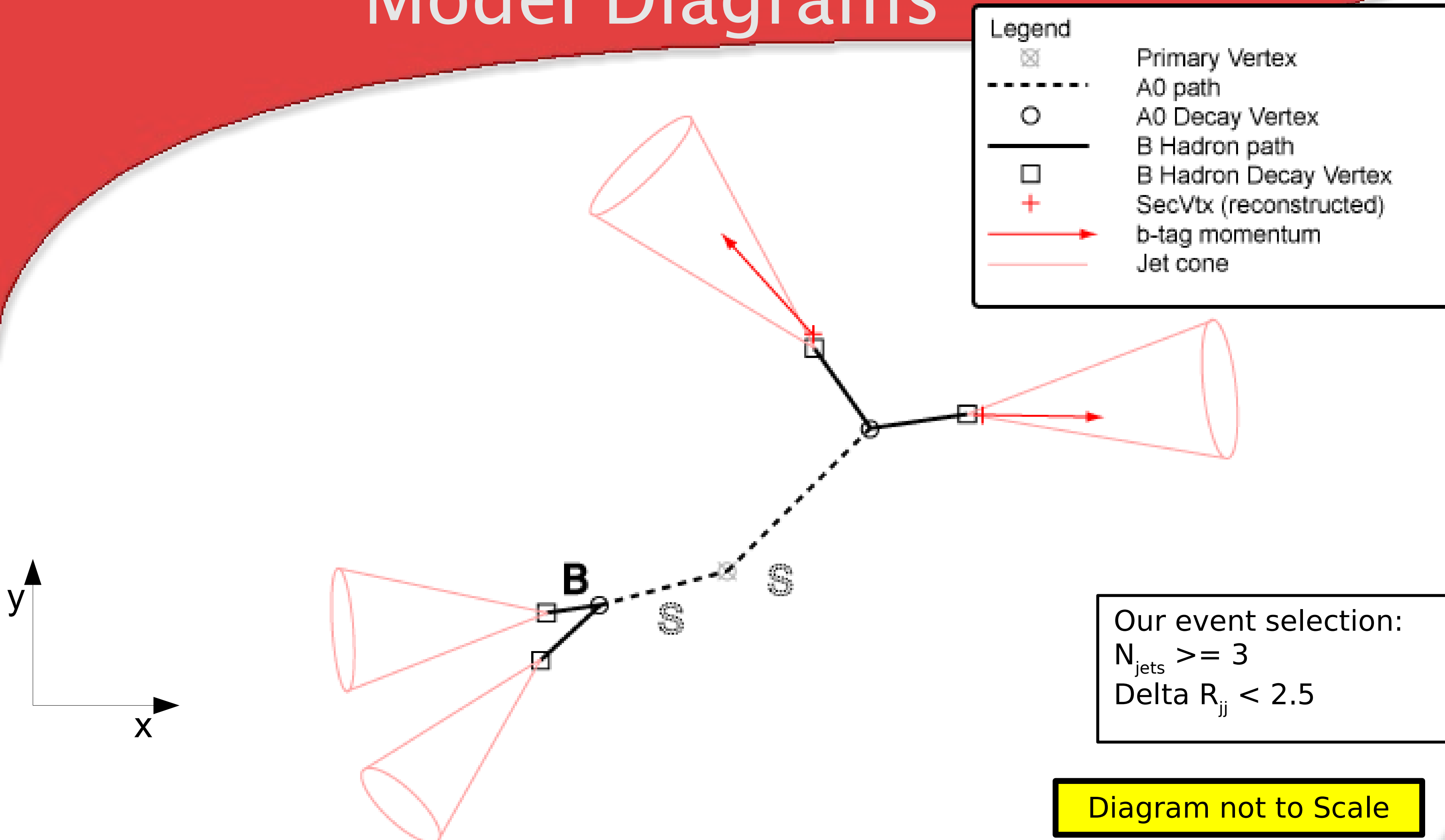
Big Picture

- The trigger in which we are searching for this signature is the ZBB trigger data.
- We are building p.d.f.s for single jets to form the background estimate.
  - We split the jets into four E_T bins, L5 corrected,
  - and the number of SVT tracks that pass the ZBB trigger requirements.
    - split into 3 SVT track bins
  - Why? The ZBB trigger is our signal trigger. It has a SVT track requirement. We separate our jets into these bins to account for the fact that this SVT requirement sculpts the distributions.
    - Details of the ZBB trigger are in the Backup slides.
- TStnSVF is a (T)Stntuple Secondary Vertex Finder.
  - The algorithm is the same as SecVtx, but the input data is from the Stntuple instead of Production data.
  - The code allows the user to change the parameters of the module in the same way as the tcl talk-tos for SecVtx.
  - Adjustments can be made to the jet, track, and vertex cuts used by the algorithm.
  - We run this b-tagger over 20 max $|d_0|$ cuts for the tracks in the jet, in order to find a d_0 cut which maximizes the efficiency for finding a signal.

Analysis Strategy

- We want to use real data to estimate our background.
  - Build p.d.f.s for background jets for a couple of variables
    - Mundane b background: QCD bb, ttbar, Z etc.
    - Mundane c background: QCD cc, Z
    - Light flavor background: QCD qq/gg
    - (Others such as tau hadronic)
  - Use data triggers when possible to build these p.d.f.s.
    - Muon/Electron calibration data, which is rich is heavy flavor jets
    - Pythia QCD cc MC
    - Single Tower 5, jet data, for light-quark and gluon jets
  - These p.d.f. are per jet (not per event).
  - These per jet p.d.f.s can be applied to multijet QCD production, either data or MC, to estimate the final background and decide on cuts.
- What p.d.f. variables?
  - The variables are those dealing with the secondary vertex. Specifically characterizing the secondary vertex's position and momentum.
  - Three variables: u, v, α.
  - Encapsulate all the information about a secondary vertices position (u, v) and direction (α).
    - See the Higgs Group Meeting 2010-04-23, *Hidden Valley Higgs search (Update).*

Model Diagrams



Our event selection:
$N_{jets} >= 3$
Delta $R_{jj} < 2.5$

Diagram not to Scale

Here the Higgs decays at the primary vertex (the X). S represents the heavy pseudoscalar with a long lifetime, which decays into bbbar pairs.

The pink cones represent the hadronization of the B hadrons into jets.

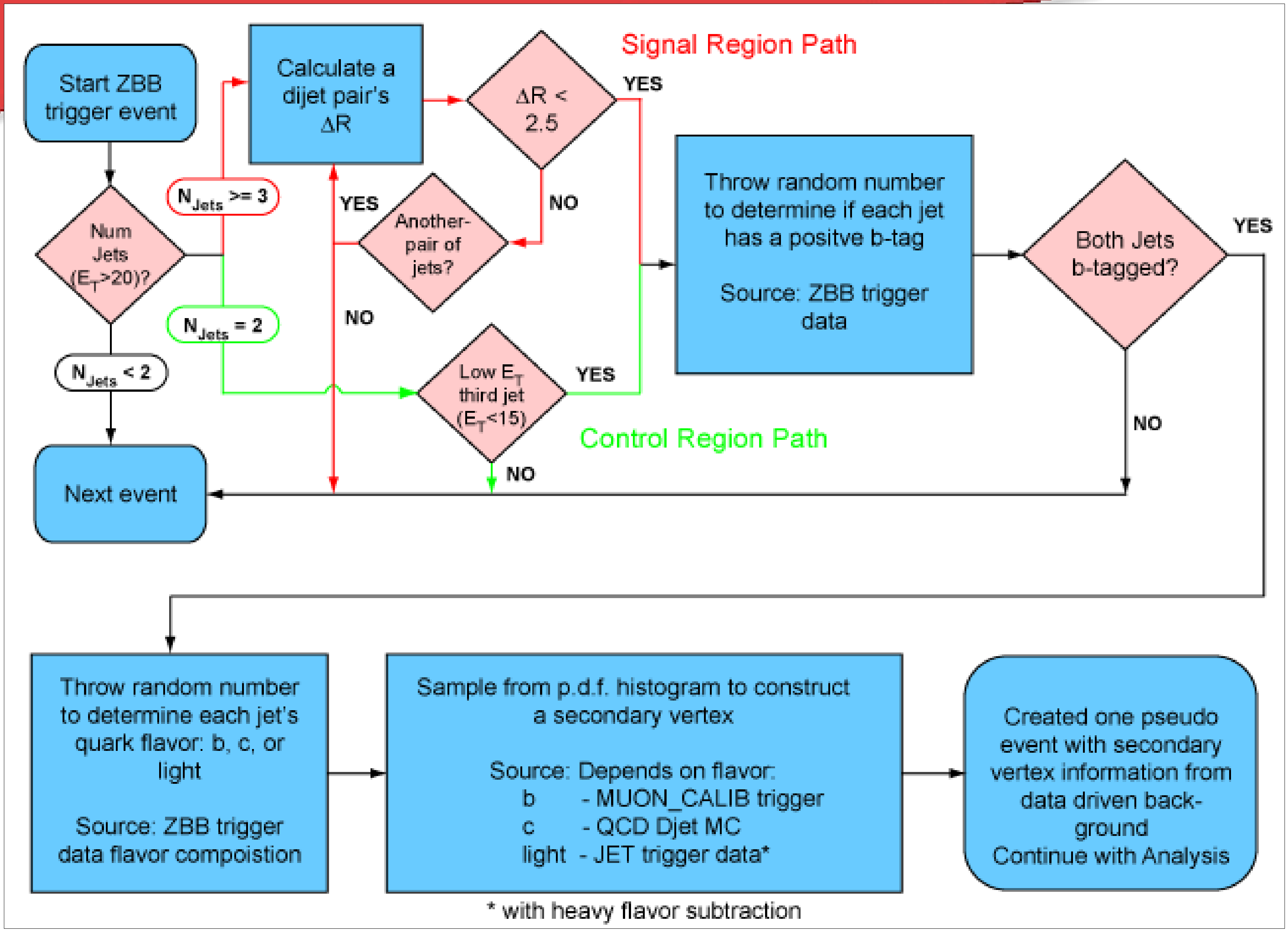
The red represents reconstructed secondary vertices and their corresponding momenta.

Black is the “truth” information.

Signal Event Selection

- We will be looking for events with central b-tagged jets, with a relatively low E_T requirement. "Signal Region"
  - All jets are required to have:
    - E_T > 20 GeV, corrected at Level-5
    - $|\eta|<1.0$
  - Jet multiplicity: $N_{jet} \geq 3$
  - For the dijet system, require that it be in a region that would be populated by signal.
    - $\Delta R < 2.5$
- A "Control Region" is defined which contains events orthogonal to the Signal Region,
  - Two tight central jets ($N_{jet} = 2$)
  - A third jet with Level 5 corrected E_T < 15 GeV.

Flowchart



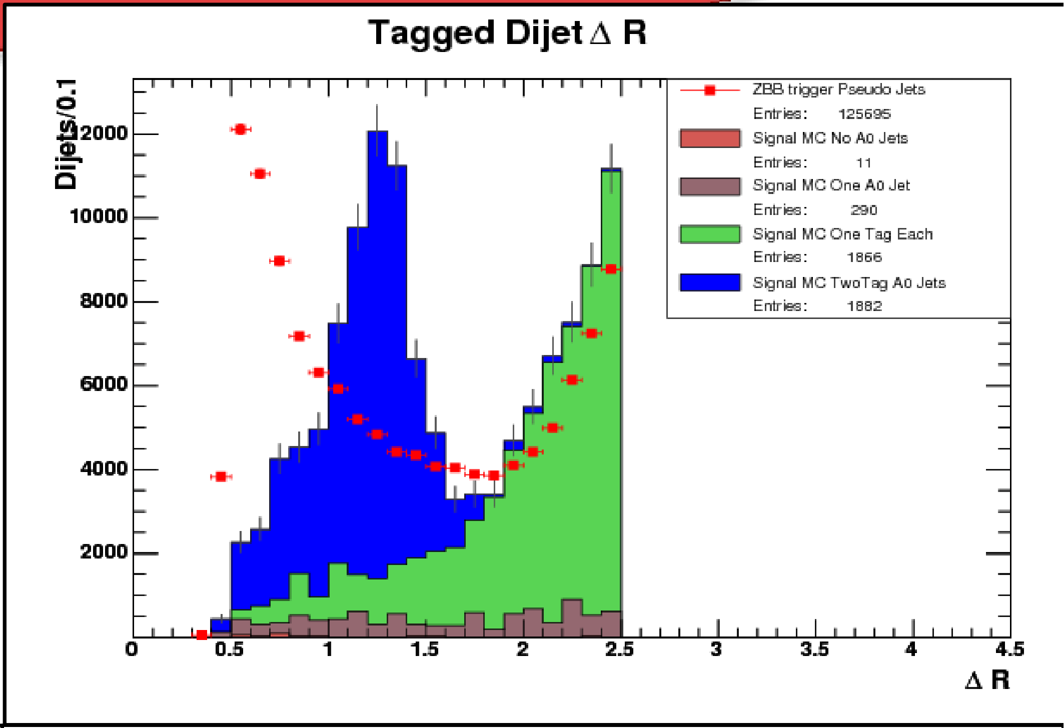
This flowchart shows the background estimate / pseudo event generating algorithm.
In the b-tag and flavor boxes, the two jets are correlated, so the b-tag and flavor algorithms take into account this correlation.

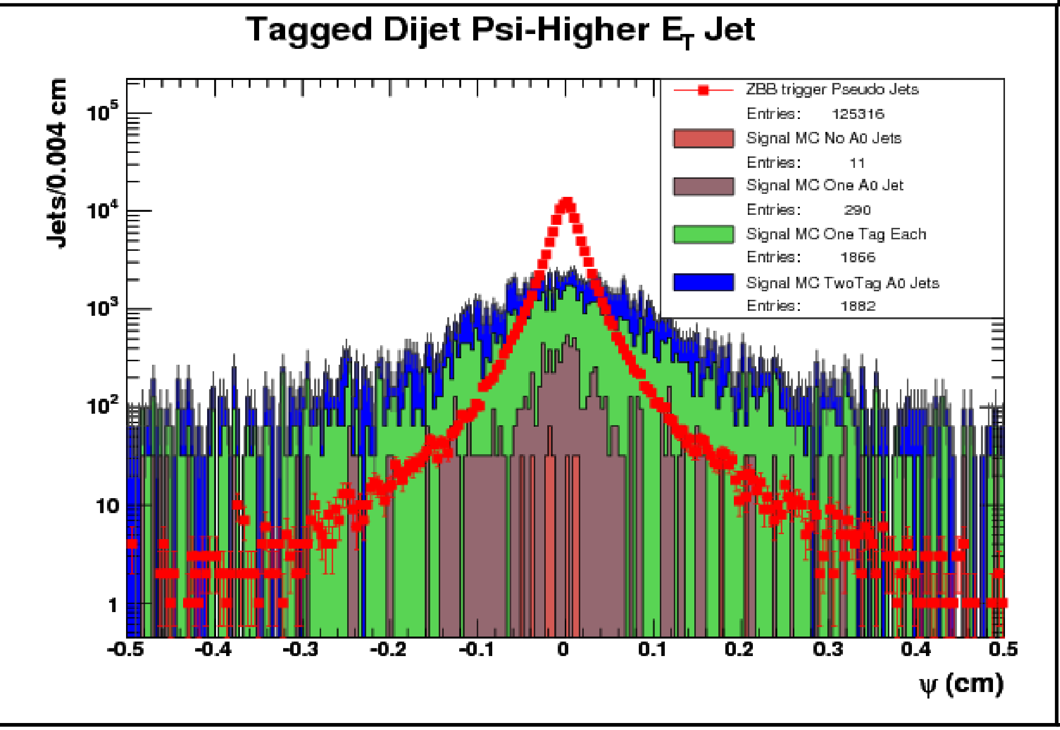
Analysis Variables

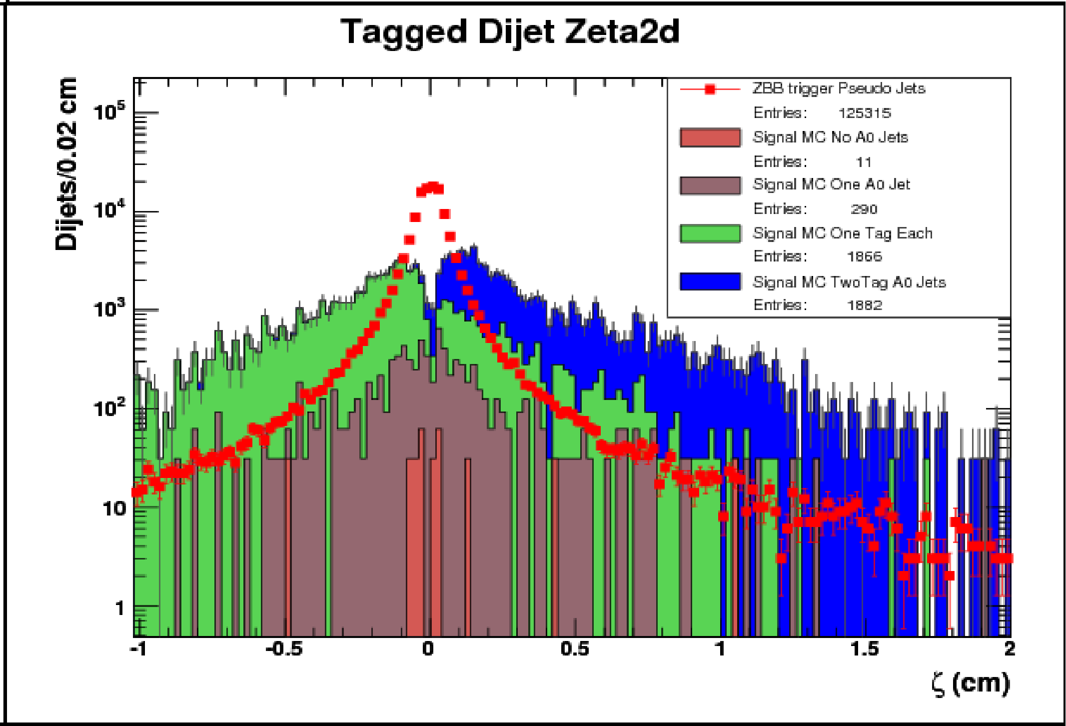
- Variables we use to isolate the signal
- ΔR – the opening angle between the two jets in the dijet pair
- ψ – the “impact parameter” variable for a jet w/ a secondary vertex
- ζ – the reconstructed decay vertex of the hidden valley (HV) particle.
  - See backup slides for diagrams
- Also a variable, but indirectly, is the maximum $|d_0|$ cut on the tracks used for vertexing in the TStnSVF algorithm.
- Perform a S/Sqrt(B) analysis to optimize the cuts for these variables.

Analysis Variables

- Histograms of these variables
  - max |d0| < 0.90 cm
  - ΔR between two b-tagged jets
  - |ψ| of both jets (one shown here)
  - ζ of the dijet pair







Signal MC Details

- The details of the Signal MC we used is now relevant.
- Five signal samples generated.
  - h_0 mass : M_{h0} = 130, 170 GeV
  - HV mass : M_{HV} = 20, 40 , 65 GeV
    - Only the former two for 130 GeV Higgs.
  - HV lifetime : $c\tau$ = 1 cm
  - For the analysis cuts, I have two groups: low and high mass HV particle
    - The lower mass HV particles have decay daughters that are more co-linear.

Dataset Name	M_{h0} (GeV)	M_{HV} (GeV)	$c\tau_{HV}$ (cm)	Notes
ahhs2d	130	20	1.0	low mass
ahhs2s	170	20	1.0	low mass
ahhs2i	130	40	1.0	high mass
ahhs2x	170	40	1.0	high mass
ahhs22	170	65	1.0	high mass

- Processed with Stntuple.
- ZBB Trigger is simulated.
- The expected number of signal events can be calculated. We have the luminosity of the ZBB data, the cross-section is $gg \rightarrow h_0$ with a presumed 100% BR to HV particle.
- We have the trigger, signal region selection, and analysis cut efficiencies.

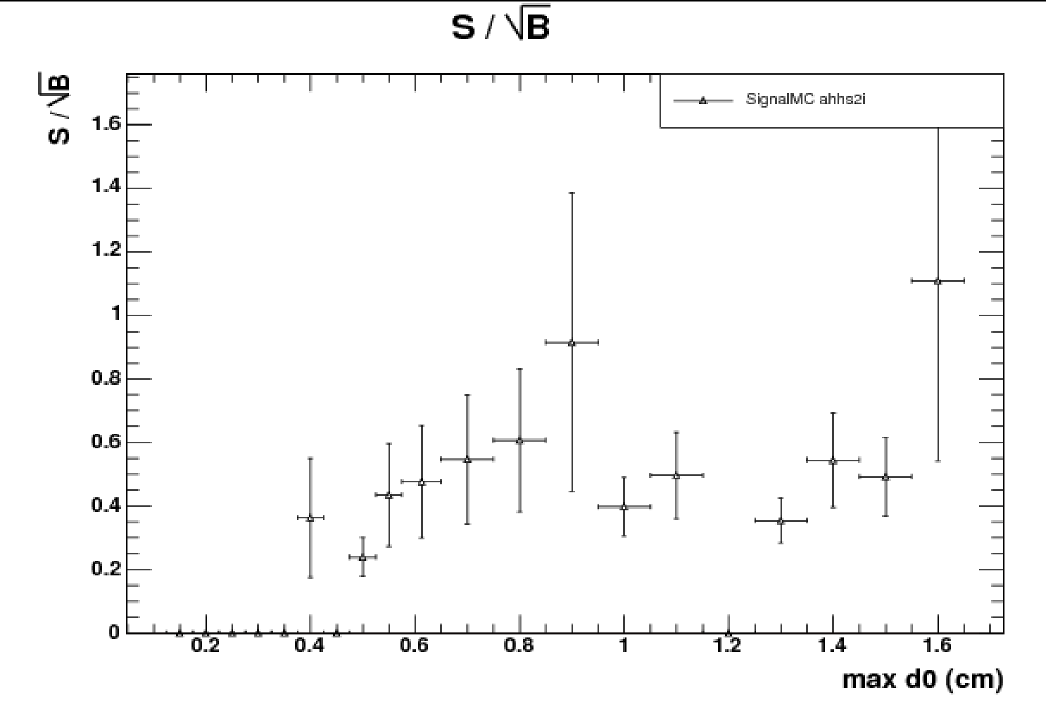
Analysis Cuts

- After Optimization the cuts for the High Mass Group are:
- max $|d_0| < 0.90$ cm
- $0.75 < \Delta R < 2.0$
- $|\psi| > 0.12$ cm
- $\zeta > 0.4$ cm

- After Optimization the cuts for the Low Mass Group are:
- max $|d_0| < 0.80$ cm
- $\Delta R < 0.75$
- $|\psi| > 0.12$ cm
- $\zeta > 0.4$ cm

- Next are the S/Sqrt(B) optimization cuts used to arrive at these cuts.
- One variable is moved while the others are held constant.
- I am showing the "last set" of plots. Many more graphs were produced along the way.
- For all plots, please see the two following links:
  - http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/SigBgdEstAnalysisCuts02
  - http://www-cdf.fnal.gov/htbin/twiki/bin/view/ZtoBBbar/SigBgdEstAnalysisCuts03MD11

Optimizing Cuts

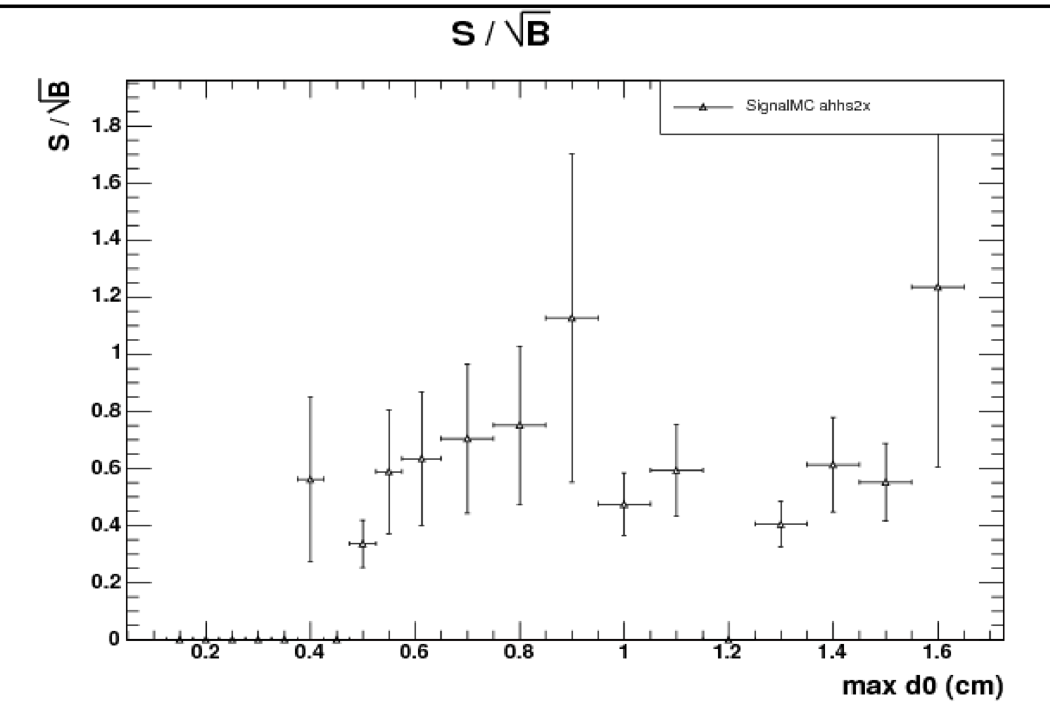


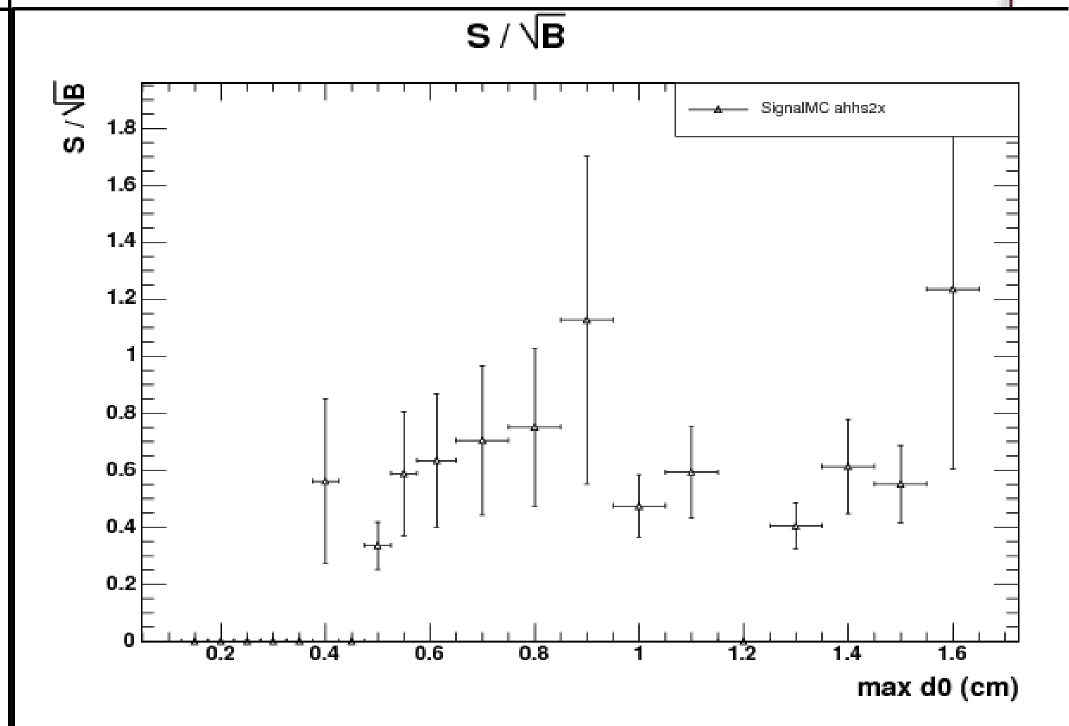
- Top: M_{h0} = 130 GeV

  Bottom : M_{h0} = 170 GeV
- Left : M_{HV} = 40 GeV

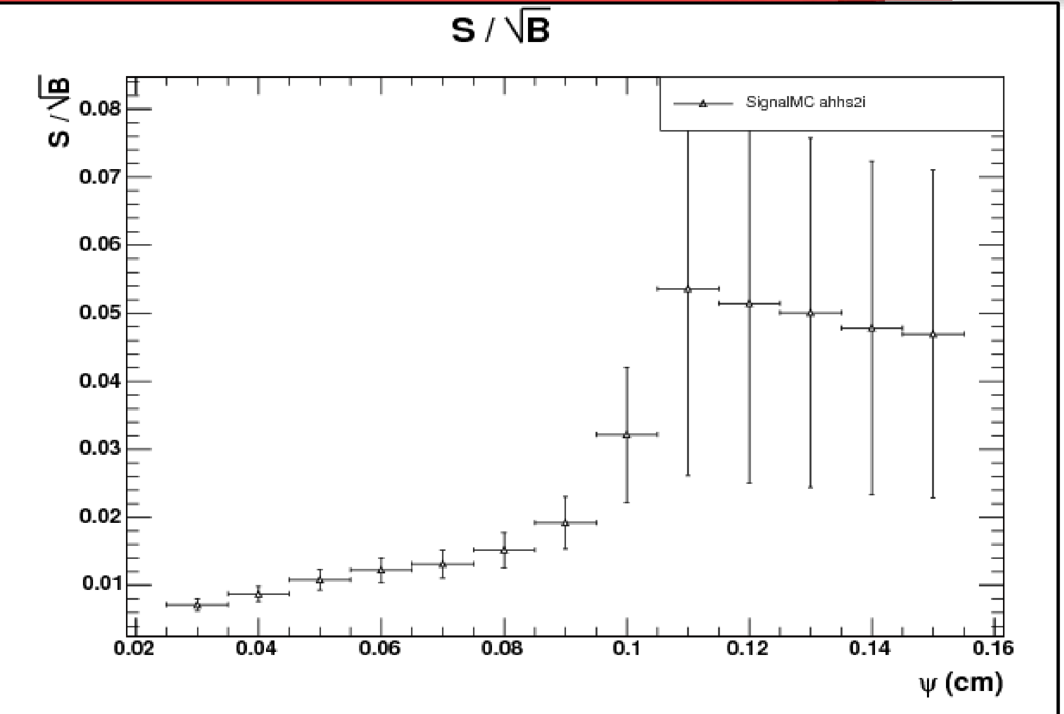
  Right : M_{HV} = 65 GeV

  High Mass Group
- As function of max $|d_0|$ (cm) with other variables held constant.

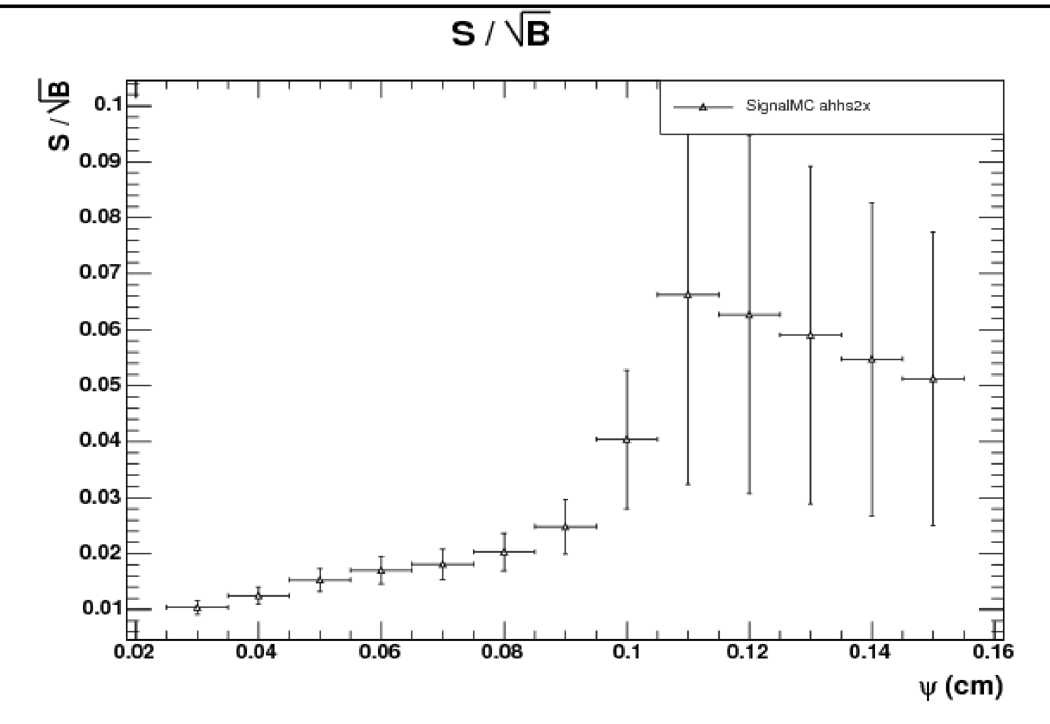


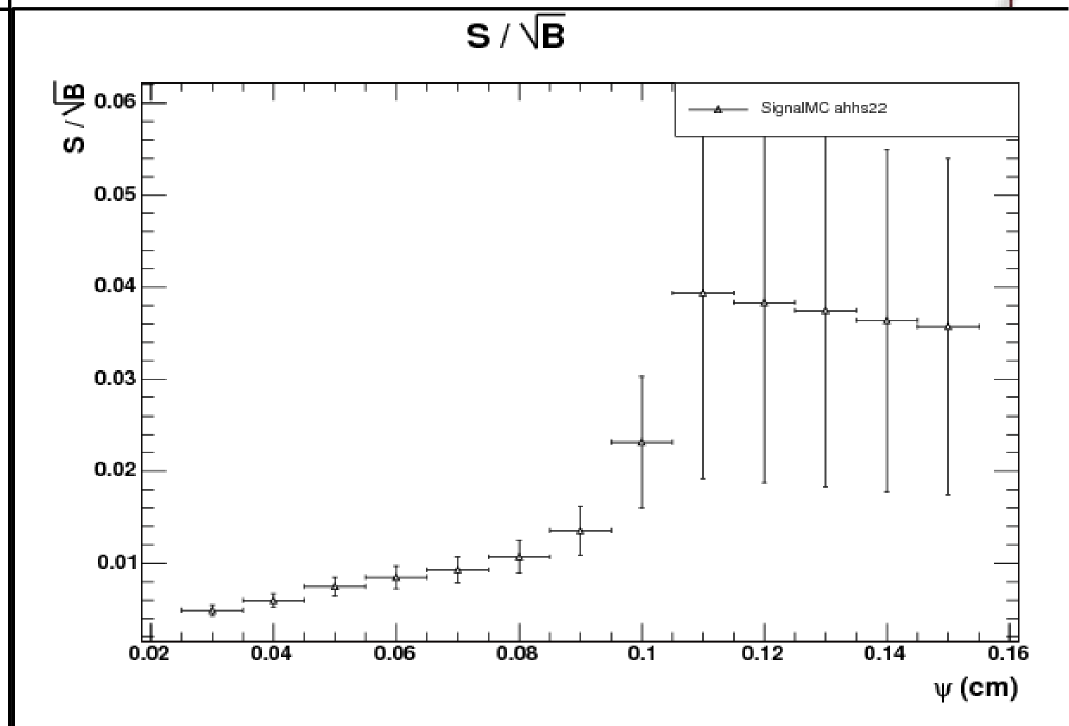


Optimizing Cuts

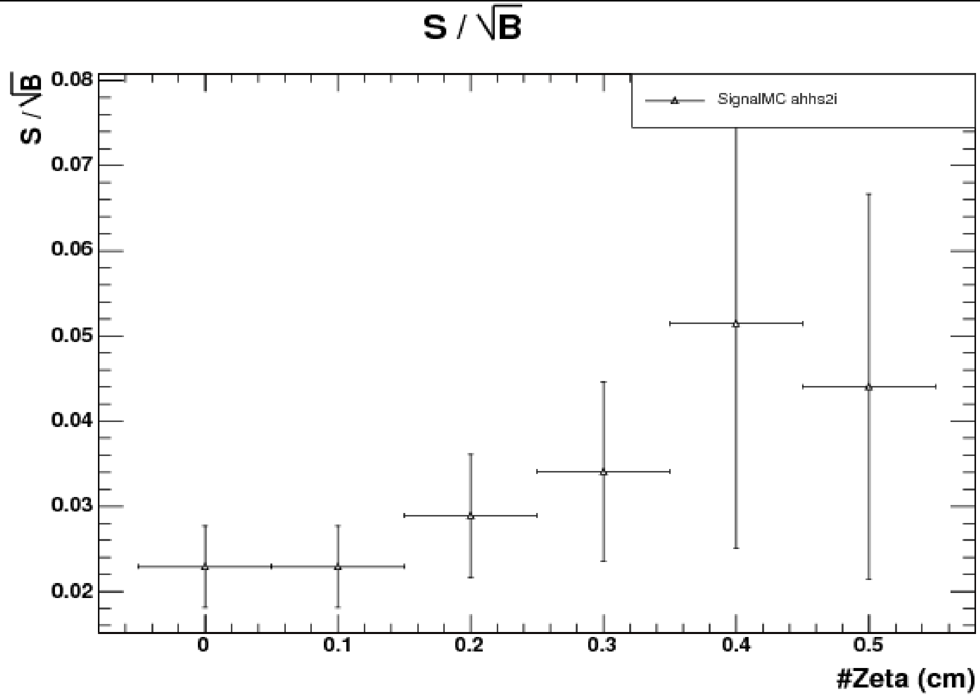


- Top: M_{h0} = 130 GeV
  Bottom : M_{h0} = 170 GeV
- Left : M_{HV} = 40 GeV
  Right : M_{HV} = 65 GeV
  High Mass Group
- As function of |ψ| (cm) with other variables held constant.





Optimizing Cuts

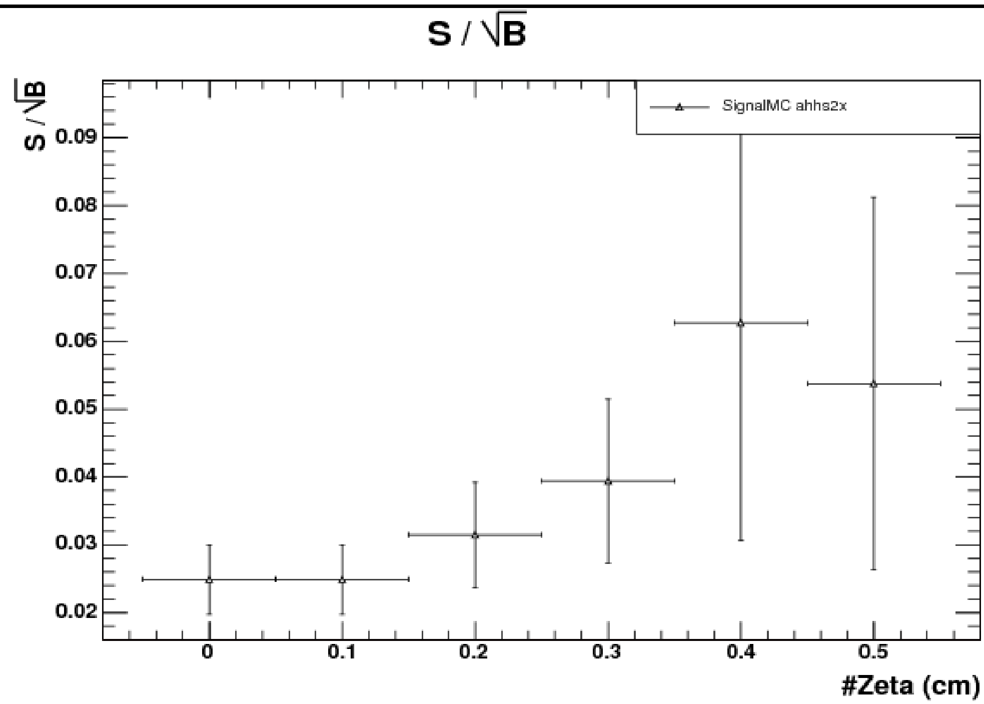


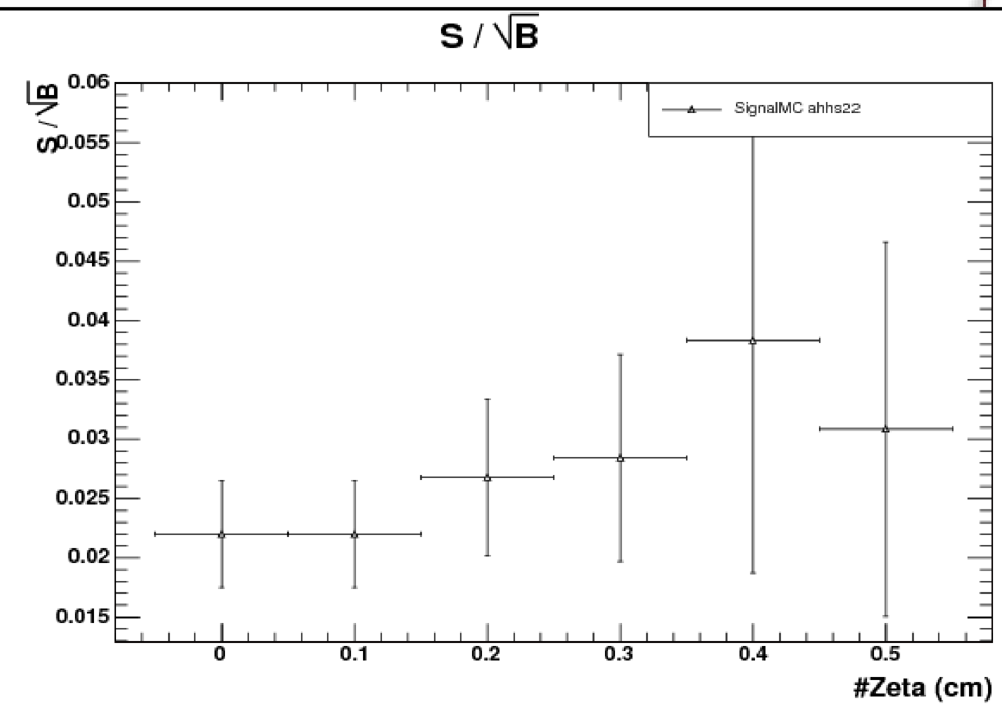
- Top: M_{h0} = 130 GeV

  Bottom : M_{h0} = 170 GeV
- Left : M_{HV} = 40 GeV

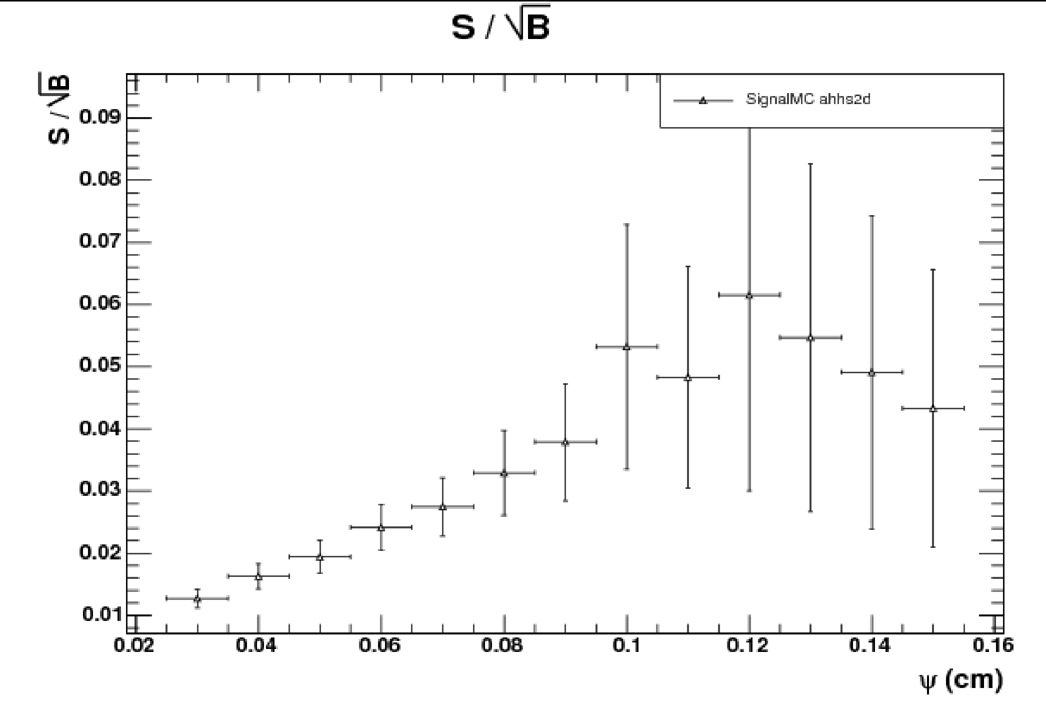
  Right : M_{HV} = 65 GeV

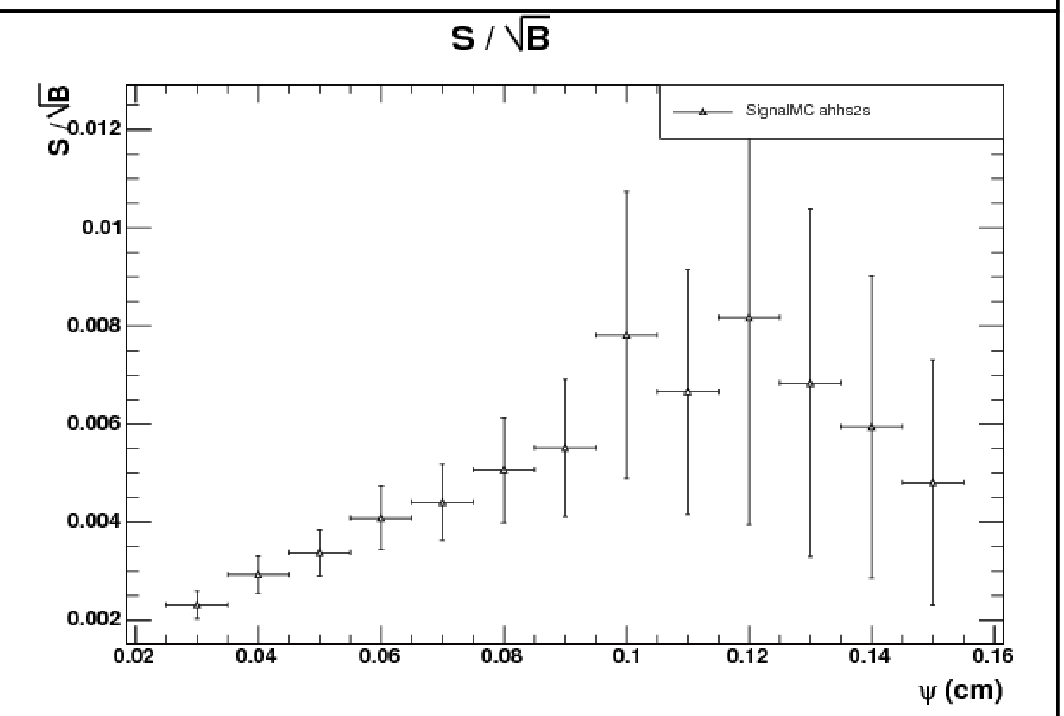
  High Mass Group
- As function of ζ (cm) with other variables held constant.





Optimizing Cuts





- Top: M_{h0} = 130 GeV
  Bottom : M_{h0} = 170 GeV
- Left : M_{HV} = 20 GeV

Low Mass Group

- As function of |ψ| (cm) with other variables held constant.

Results

- After making these cuts we look in the ZBB data (N obs).
- N bkgd exp is the expected number of background events from the SM, derived from the background estimate algorithm.
- N sig MC is the number of expected signal MC events.

Dataset Name	N sig MC	σ (stat only)	N bkgd exp	σ (stat only)	N obs	σ (stat only)
ahhs2d	1.1326	1.0642	1	±1	3	1.73
ahhs2s	0.1507	0.3883	1	±1	3	1.73
ahhs2i	0.9155	0.9568	1	±1	2	1.41
ahhs2x	1.1266	1.0614	1	±1	2	1.41
ahhs22	0.6716	0.8195	1	±1	2	1.41

- With these numbers we can calculate a limit on the cross-section for Hidden Valley production.
- However, the question at hand is: What is the uncertainty on the one background event?
  - Systematic uncertainties will play a role here.

Systematic Uncertainties

- Systematic Uncertainties include:
- P.d.f. shapes
  - Probably the largest systematic uncertainty is the shapes of the p.d.f.s used to generate the background estimate.
  - One way to do this is via bootstrapping. (CDF Note NNNN)
- P.d.f. binning
  - The p.d.f. is binned data (in 3D histograms) which may affect the final results.
  - Generate p.d.f.s with coarser binning and creating a new background estimate.
- Flavor composition uncertainty
  - Varying the flavor fraction uncertainty, would generate different background estimate.
- Others include the b-tagging scale factor (affects the signal MC), any effects the (pseudo) b-tagging generation may have on the final results.

Conclusion

- Using the background estimate and signal MC we have optimized our analysis cuts to find our signal.
- In observed data we don't see a statistically significant excess.
- Systematic uncertainty, esp. on the background estimate need to be done.
- With these uncertainties, we can calculate a limit on the Hidden Valley production at CDF.

Backup Slides

- ZBB Trigger Details
- Jet binning
- Additional Diagrams

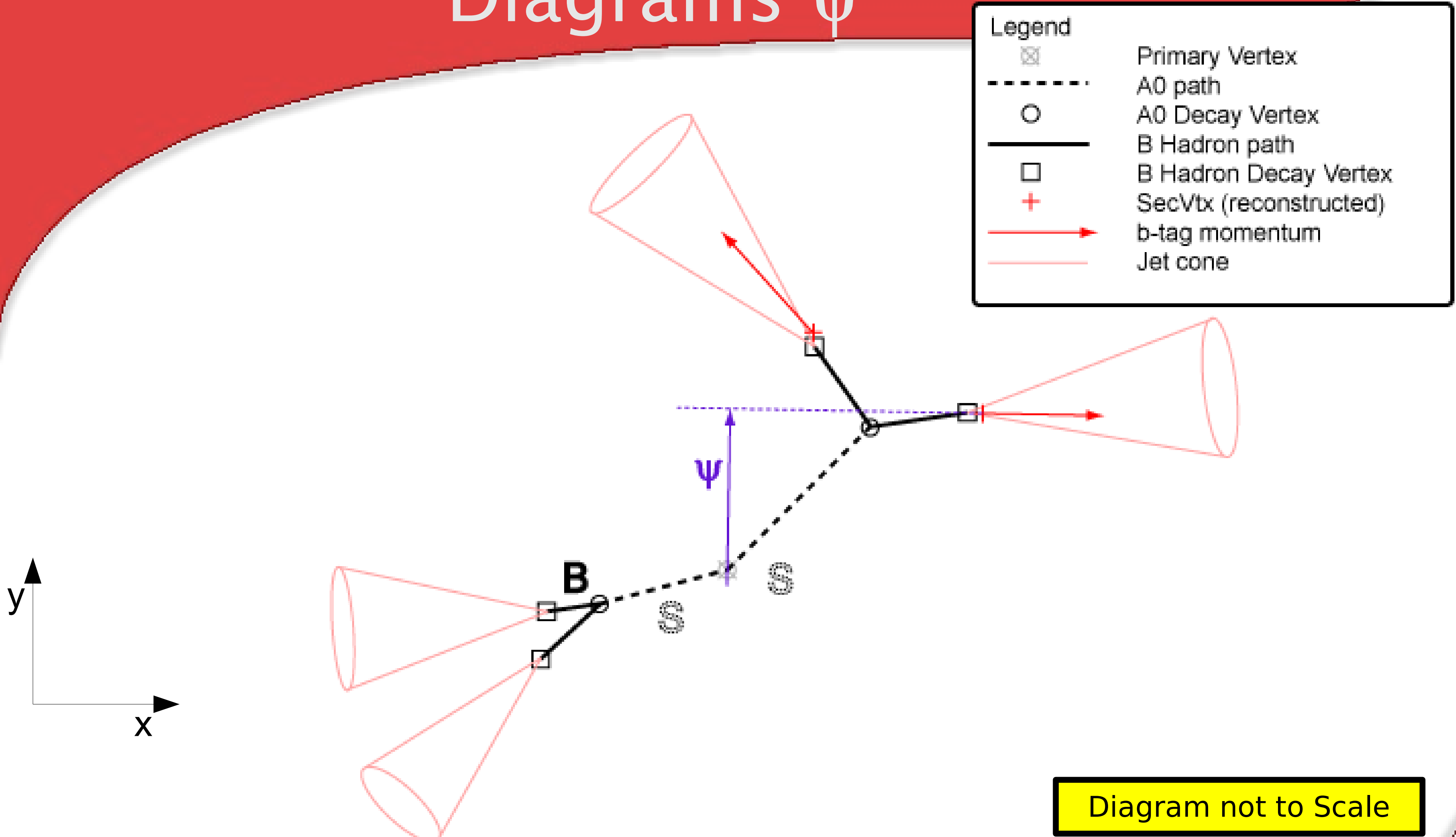
ZBB Trigger

- Details of the trigger in the trigger table:
  - L1 :
    - one central tower with $E_T > 5$ GeV
    - two XFT tracks, $p_T^1 > 5.48$ GeV, $p_T^2 > 2.46$ GeV
  - L2 :
    - veto events w/ clusters with $E_T > 5$ GeV, $|\eta| > 1.1$
    - requires two clusters $E_T > 5$ GeV, $|\eta|<1.1$ which have $9 < \Delta\text{Wedge} < 12$
    - two SVT tracks with $p_T > 2$ GeV, $d_0 > 160$ microns, $d_0 < 1000$ microns, $\chi^2 < 12$,
      - $150 < \Delta\phi < 180$ "Opposite Side"
      - $0 < \Delta\phi < 30$ "Same Side"
      - This triggers on displaced tracks in the event.
  - L3:
    - two R=0.7 jets with $E_T > 10$ GeV, $|\eta| < 1.1$
    - two SVT tracks with $p_T > 2$ GeV, $d_0 > 160$ microns, $d_0 < 1000$ microns, $|\eta| < 1.2$
    - two tracks with $p_T > 1.5$ GeV, $d_0 > 130$ microns, $d_0 < 1000$ microns, $|\eta| < 1.2$, IP significance $Sd_0>3$, $\Delta z < 5$ cm
  - Dynamically Prescaled Trigger
  - This is for the latest trigger "chunk," #17. Chunks 10-16 are nearly the same, with minor changes in the cut values, but the structure is the same.

Jet Binning

- Out jets are split into 12 different bins.
  - Four bins of E_T: [20,30) [30, 70) [70,110) [110,200)
  - Three bins of # SVT tracks: 0, 1, (>=2)
- The E_T bins are the result of the jet trigger
  - SINGLETOWER5 → [20,30)
  - JET_20 → [30,70), etc.
- The # SVT track bins are split as such because the ZBB trigger requires two SVT tracks in the event, not per jet.
  - In order to account for the differences in tag probability, flavor, and b-tag kinematics, it is necessary to split our QCD jet sample into the same SVT tracks requirements that the ZBB trigger uses.

Diagrams ψ



ψ is the impact parameter of a jet with a secondary vertex.

This is in two-dimensional space.

Diagrams ζ

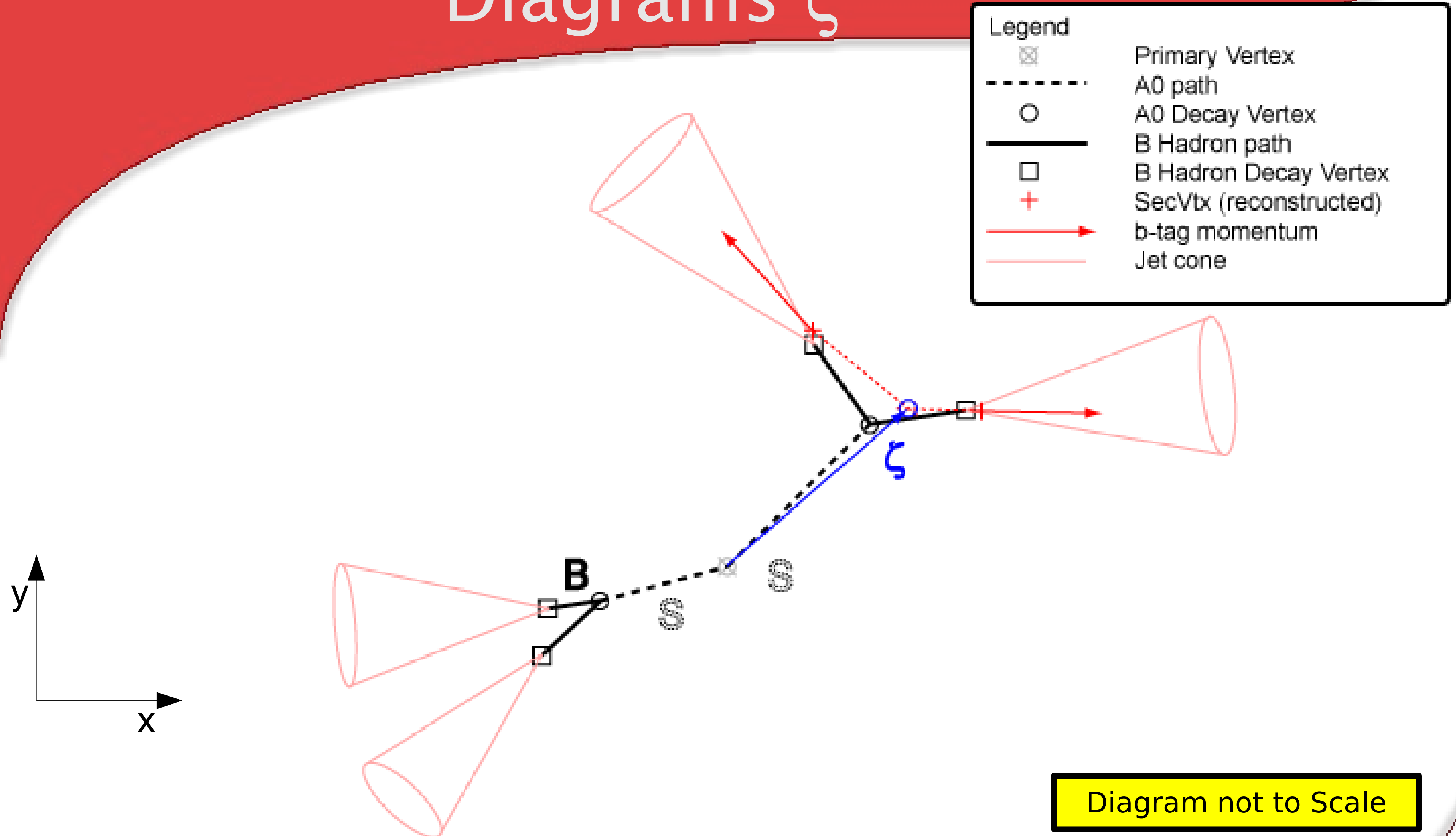


Diagram not to Scale

ζ is the reconstructed decay distance of the heavy pseudoscalar S (A_0). It requires two tagged jets.

This is in two-dimensional space.

Comparison with D0

- D0 performed a similar analysis with the same Hidden Valley Model.
  - hep-ex/0906.1787v2
- M_{h0} = 100, 120, & 200 GeV
- M_{HV} = 15 & 40 GeV
- $c\tau_{HV}$ = 5.0 cm for the above six
- $c\tau_{HV}$ = 2.5, 5.0, & 10.0 cm for one mass point:
  - M_{h0} = 120 GeV, M_{HV} = 15 GeV
- Our lifetime is shorter because of the SVT.
- A direct comparison is not possible because the Higgs masses are slightly different, M_{h0} = 120 GeV v. M_{h0} = 130 GeV.