Benchmark Studies with the LCFI Vertex Package

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Outlook

- LCFI Vertex Package
- Physics Benchmark Processes

  Higgs self-coupling: ZHH channel

  SUSY: sbottom Production Analysis
- Summary

LCFI Vertex Package

LCFI Vertex Package

- LCFI Collaboration has developed and is maintaining the LCFI Vertex Package
  - which is becoming the default software for vertexing, flavour tagging and vertex charge reconstruction within the ILD and SiD detector concepts.
  - Written in C++/Marlin environment (Ben Jeffery, Erik Devetak, …)

- The package provides:
  - Vertex finder ZVTOP with branches ZVRES and ZVKIN
    - New in ILC environment
  - Flavour tagging based on Neural Net approach
    - Includes NN package
  - Quark charge determination
    - Currently only for jets with a charged ‘heavy flavour hadron’

LCFI Vertex Package

- Other features
  - Fast Kalman filter vertex fitter
    - Using full 6x6 covariance matrix, generic (not helix-model dependant).
  - Additional diagnostic tools
    - To monitor efficiency, purity, resolution, track-vertex assignment…

- Code, default flavour tag Neural Networks and documentation are available from the ILC software portal
  http://www-flc.desy.de/ilcsoft/ilcsoftware/LCFIVertex

- The package was carefully tested on 2-jet events
  - and just starts being used in other challenging analyses
    - Large number of jets in events (ZHH, tt).
    - Very soft jets, below 20-30 GeV (sbottom, stau).

Higgs Self-Coupling Analysis

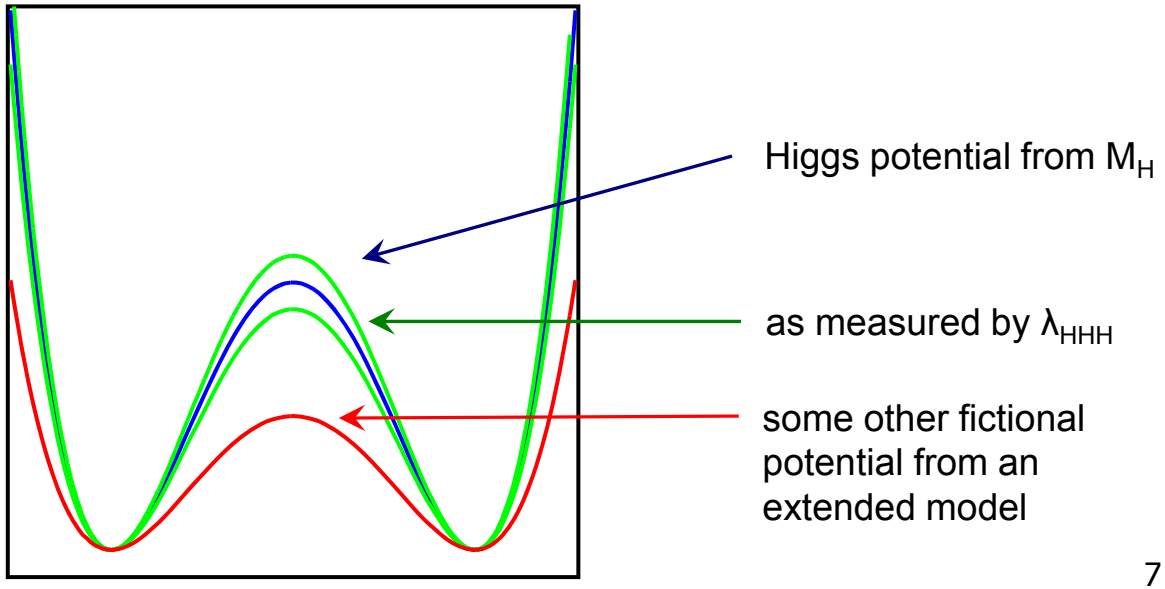
6-jet final state mode

Reconstructing Higgs Potential

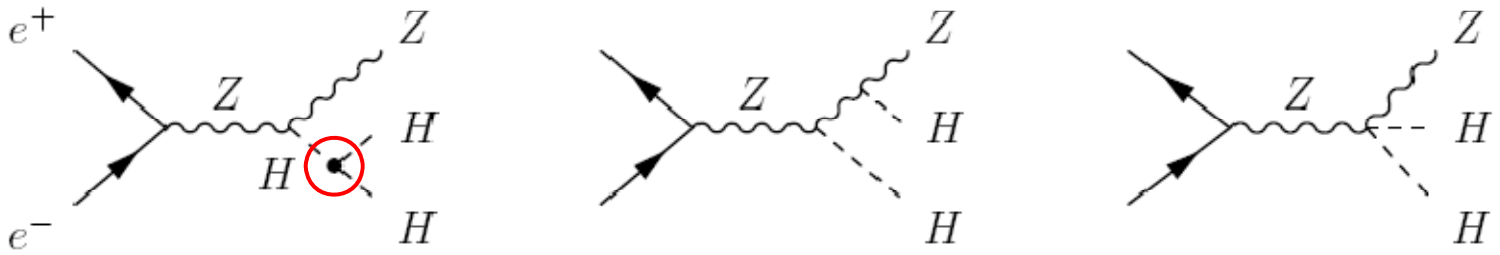
- To experimentally determine the shape of the Higgs potential the self-coupling of the Higgs field must be measured

$$V(\Phi^*\Phi) = \lambda(\Phi^*\Phi - \tfrac{1}{2}v^2)^2$$

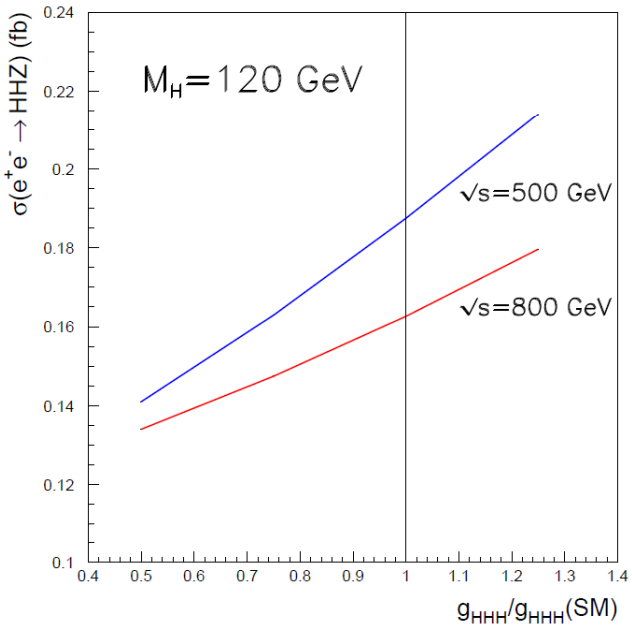
- In Standard Model $g_{HHH} = \frac{3}{2}\frac{M_H^2}{v}$, independent measurement may reveal an extended nature of the Higgs sector:



Why ZHH Channel?



- Measurement of $e^+e^- \rightarrow Zhh$ cross section gives a handle to measure the Higgs self-coupling constant.
- Benchmark channel for ILC.
  - To evaluate various detector concepts.
- Another option is WW fusion channel.
  - Small cross section @ 500GeV.



Roughly $\Delta\lambda/\lambda \sim 1.75*\Delta\sigma/\sigma$

SiD Results – ZHH Channel

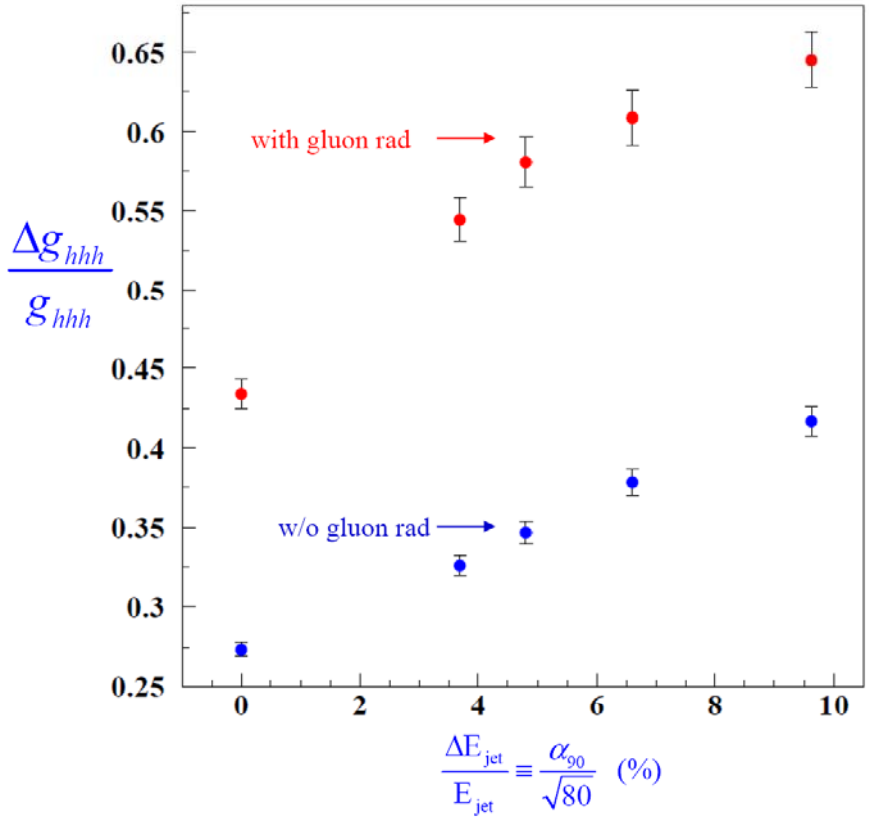
- At LCWS 2007 Tim Barklow reported an observation of a large measurement sensitivity to the gluon radiation.
- $qqb\bar{b}b\bar{b}$ channel only

$$e^+e^- \rightarrow ZHH$$
$$\rightarrow qqb\bar{b}b\bar{b}$$

$$\sqrt{s} = 500\ GeV$$
$$L = 2000\ fb^{-1}$$

$$\Delta E/\sqrt{E} = 60\% \rightarrow 30\%$$

equiv to $1.4\times$ Lumi



SiD Results – ZHH Channel

- Results replicate TESLA TDR result when BR(H→bb) is increased from 0.687 to 0.853 and when adding $\mathrm{hhZ}\to\mathrm{b\bar{b}b\bar{b}}\ell^+\ell^-$ channel.

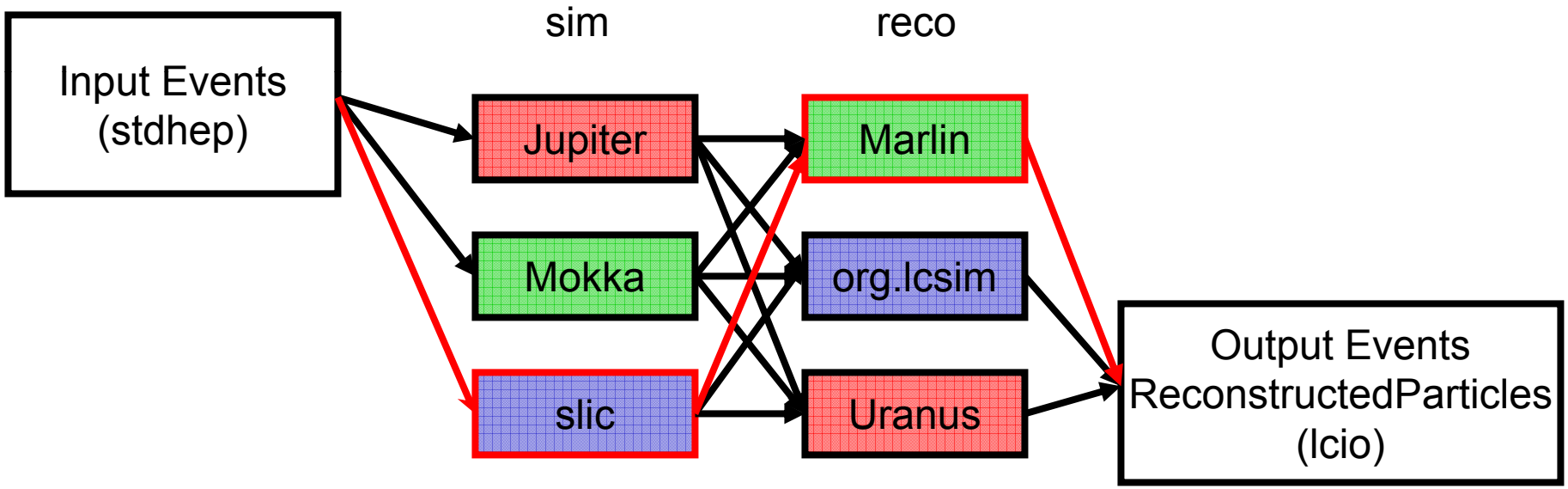
- Gluon radiation issue may be solved with more sophisticated jet algorithms and jet tagging.
  - Move to the LCFI vertex package.
  - Which should also allow for b/bbar discrimination
    - Leading to a significant combinatorics reduction.

Higgs self-coupling analysis with LCFI

- We used SiD FastMC and Perfect Particle Flow simulations:
  - SiD slcio files
    - Marlin/LCFI package used from jet finding on.
    - ZHH signal and tt (tbW) background so far.
    - Final state gluon radiation is **ON**.
  - After few minor issues solved it runs flawless…
- Main aim so far
  - Demonstrate that LCFI package can be used in SiD
    - Although it was not explicitely written for it...
    - …and even when run under Marlin
  - Evaluate package performance
    - Compare to existing results.

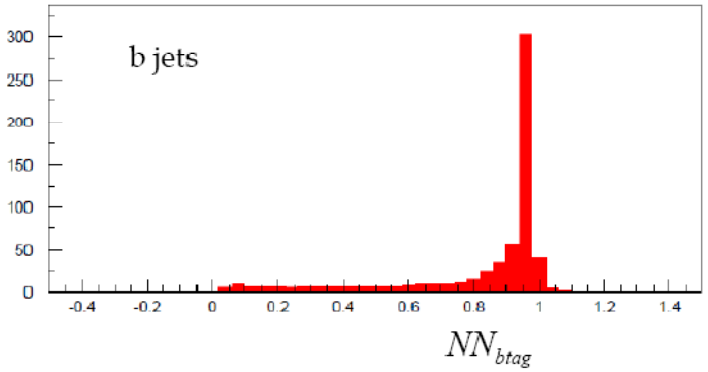
Analysis Flow

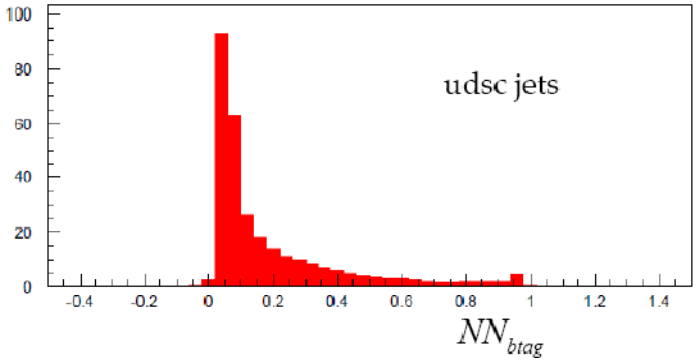
- Path in Norman's analysis flow diagram (shown yesterday)



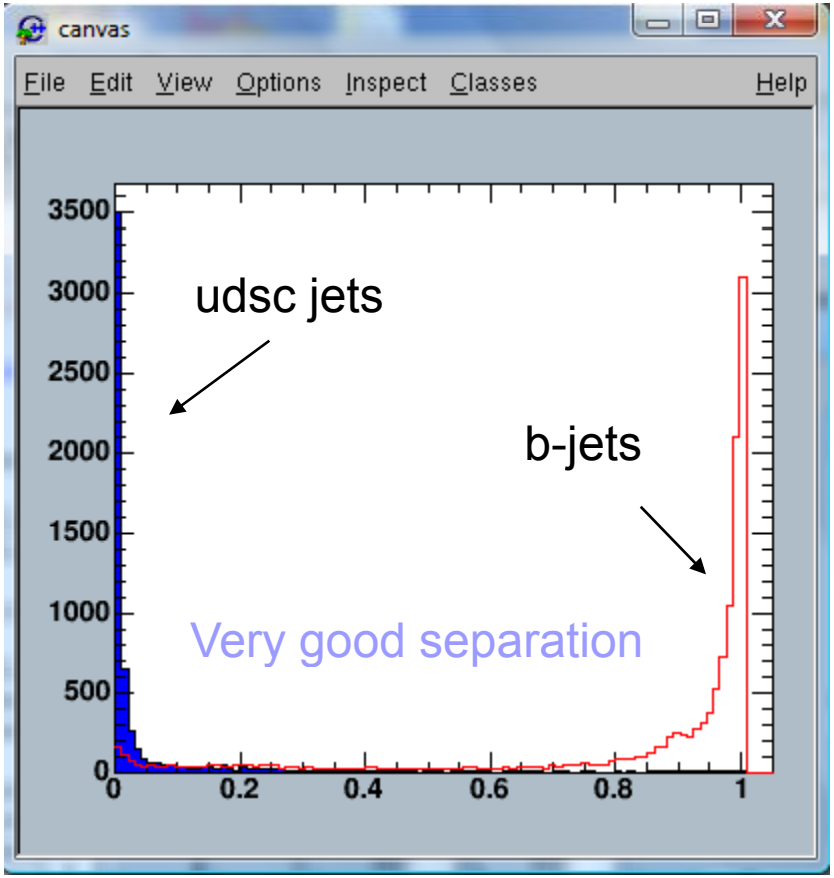
Neural Net Outputs

Previous SiD analysis



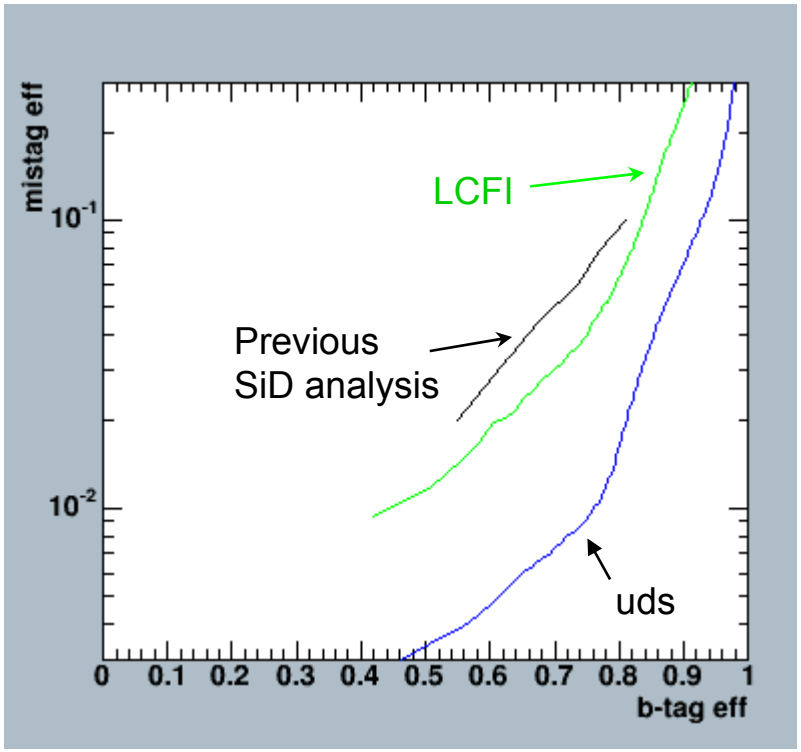


LCFI

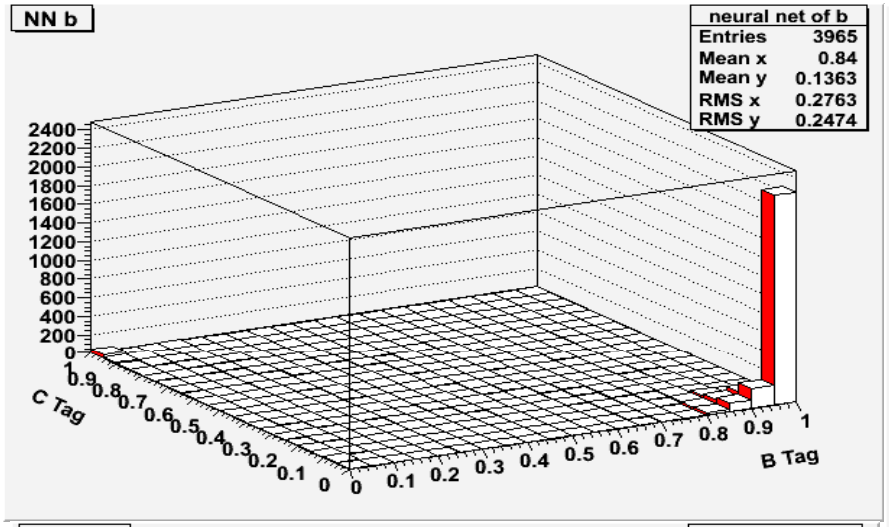


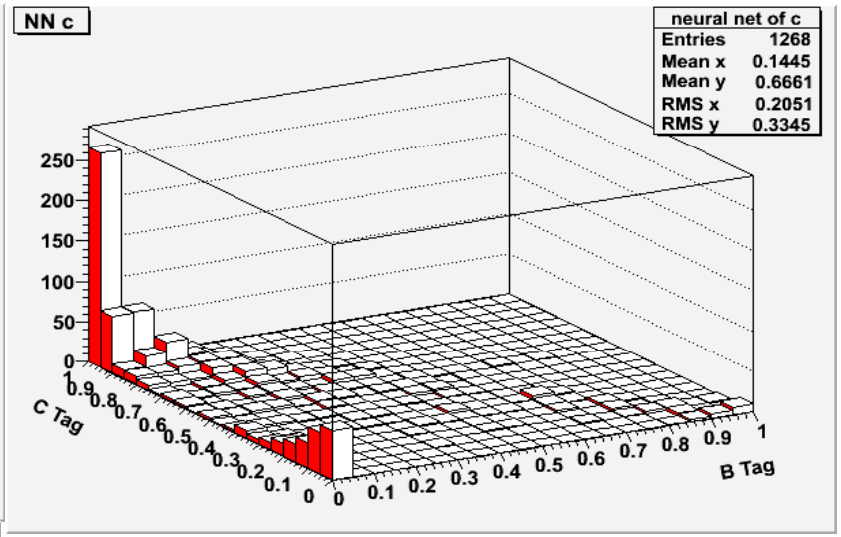
NN performance comparison

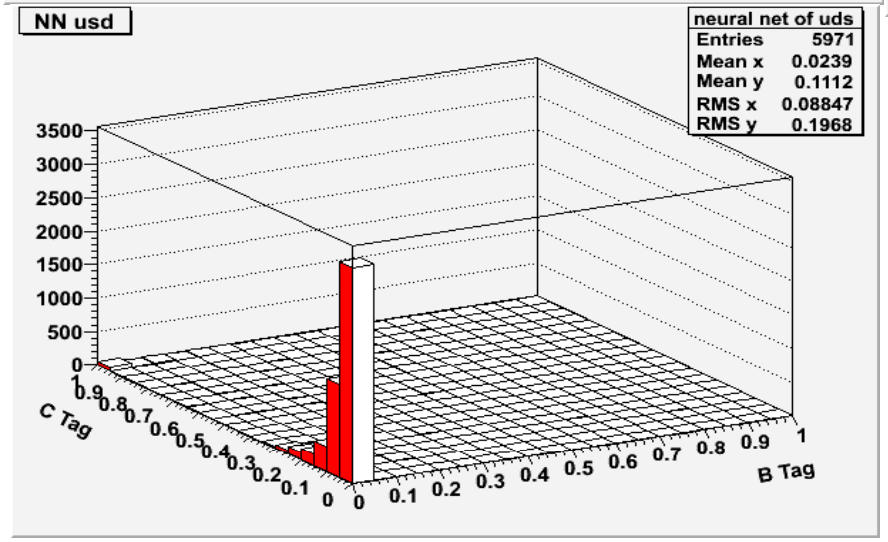
- c-mistag efficiency versus b-tagging efficiency
- LCFI package gives higher efficiencies
  - Note the logarithmic scale.
  - ZHH events (signal)
  - Light jet mistag shown for a comparsion.



Jet Tagging Performance Tests



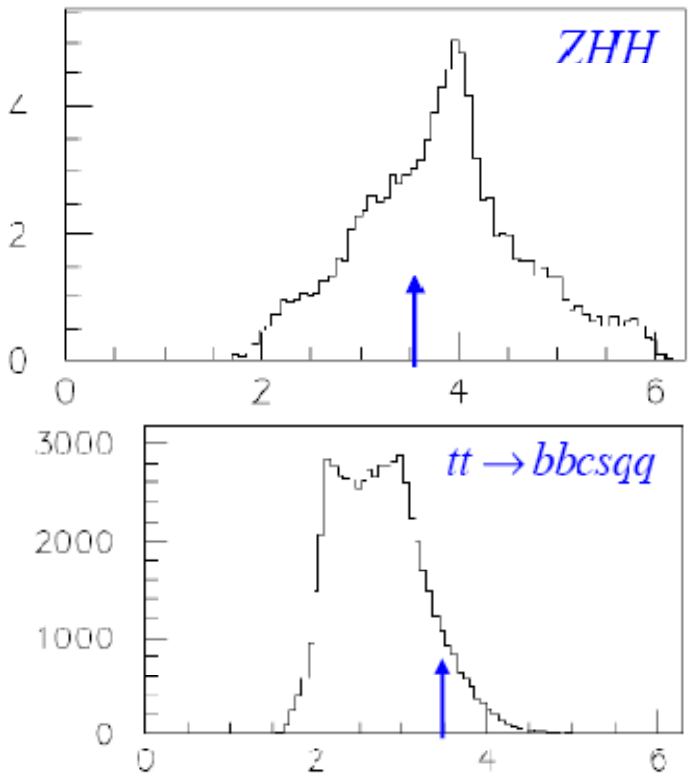




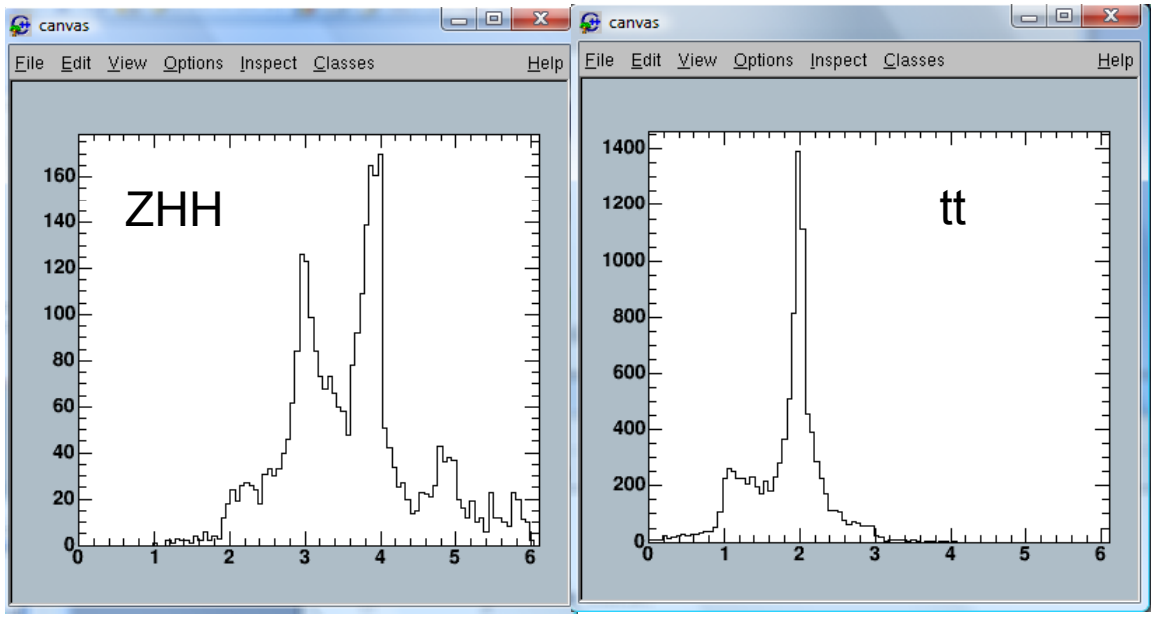
- Another way to look at Neural Net outputs
  - NN output for B-tag vs NN output for C-tag (two different nets)
  - For truly b,c and light jets separately.
  - NN trained on 2-jet events
    - Appears to work for complex 6-jet evets just fine.

Sum of neural net outputs for all jets

SiD analysis



LCFI

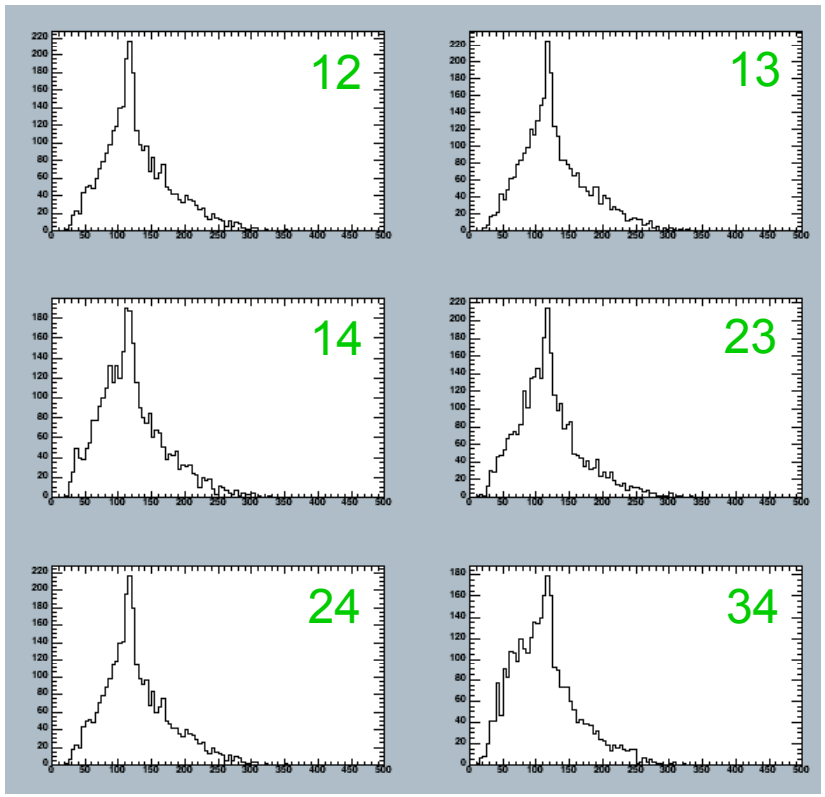


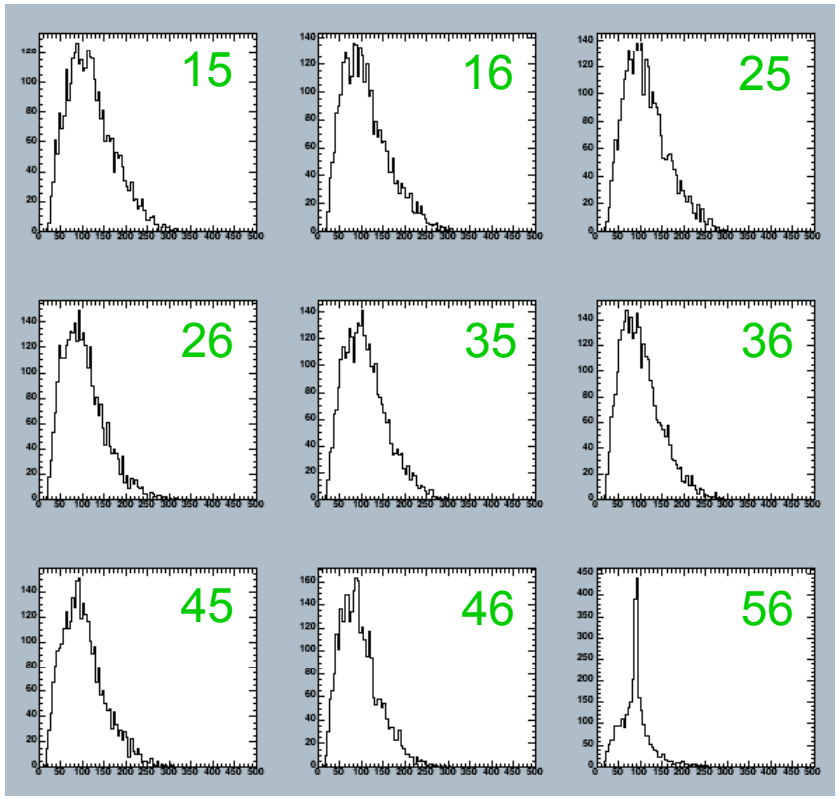
Rather different shapes. LCFI has more binary behaviour.

Invariant masses

- Jets ordered according to their tagging NN output
  - most b-like comes first (number 1)
  - …
  - …
  - …
  - …
  - least b-like comes last (number 6)

ZHH Event Sample





Higgs peaks clearly visible (left side) as well as Z^0 peak (last plot)

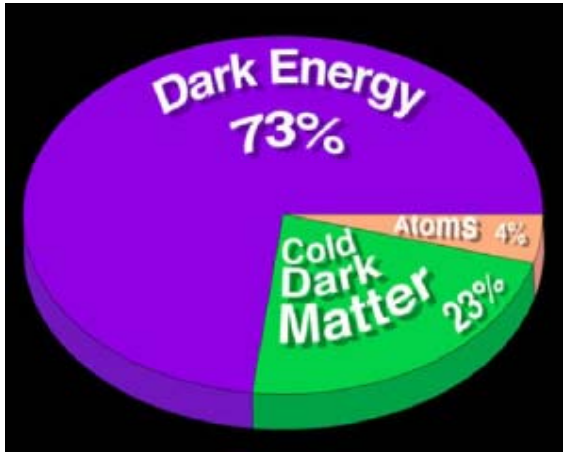
Next Steps

- LCFI package proven to work with both FastMC and PPFA SiD data
- The results are rather promising
  - Note that Neural Nets were not re-trained on 6-jet events
  - It is default NNs coming with the package
    - Which will be eventually re-trained in future.
- Perform signal selection
  - Use vertex charge information.
- Evaluate precision of λ_{HHH} determination.

Sbottom Analysis

In collaboration with University of Montenegro
(Gordana Medin and Marija Kovačević)

SUSY and Cosmology

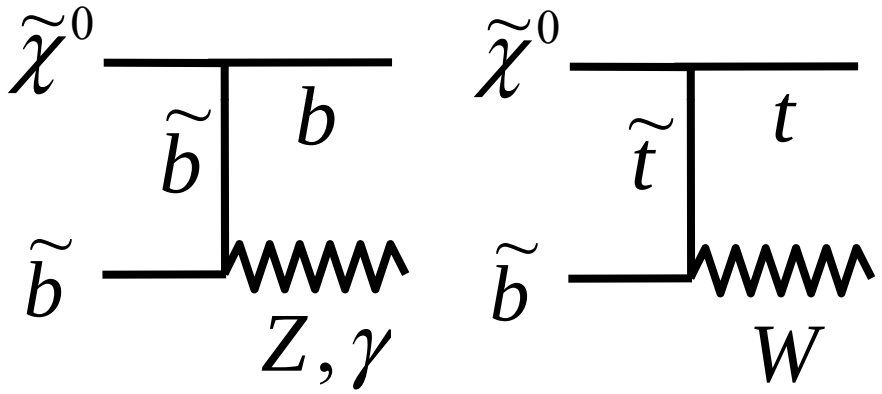


- There is 23% of Cold Dark Matter in Universe – as measurements tell us.
- Neutralino is Dark Matter candidate.
- During Universe expansion at some point supersymmetric particles are no longer produced but the existing ones may annihilate – the rate can be calculated.
- In most of the SUSY parameter space there are still too many neutrinos left.
- Cold Dark Matter favors some particular SUSY scenarios.

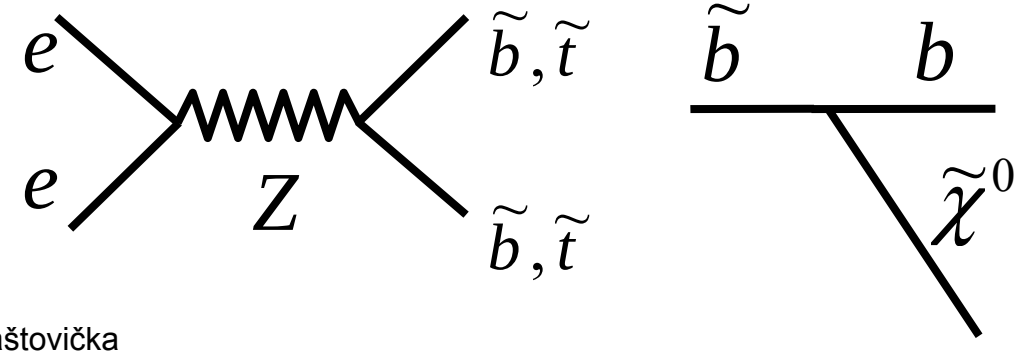
  For effective co-annihilation of particles the mass splitting should be small – leading to small energies of visible particles.

sbottom and neutralino

- If sbottom (stop) and neutralino have a small mass split they can account for co-annihilation in early Universe through this type of diagrams:



- Sbottom can be produced at ILC, then it decays to b and neutralino:

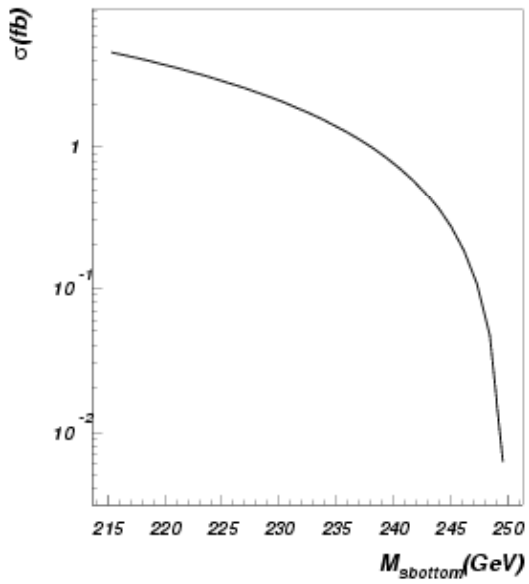


If the mass split is low (as suggested) this would lead to very soft b-jets and missing p_T.

Analysis Overview

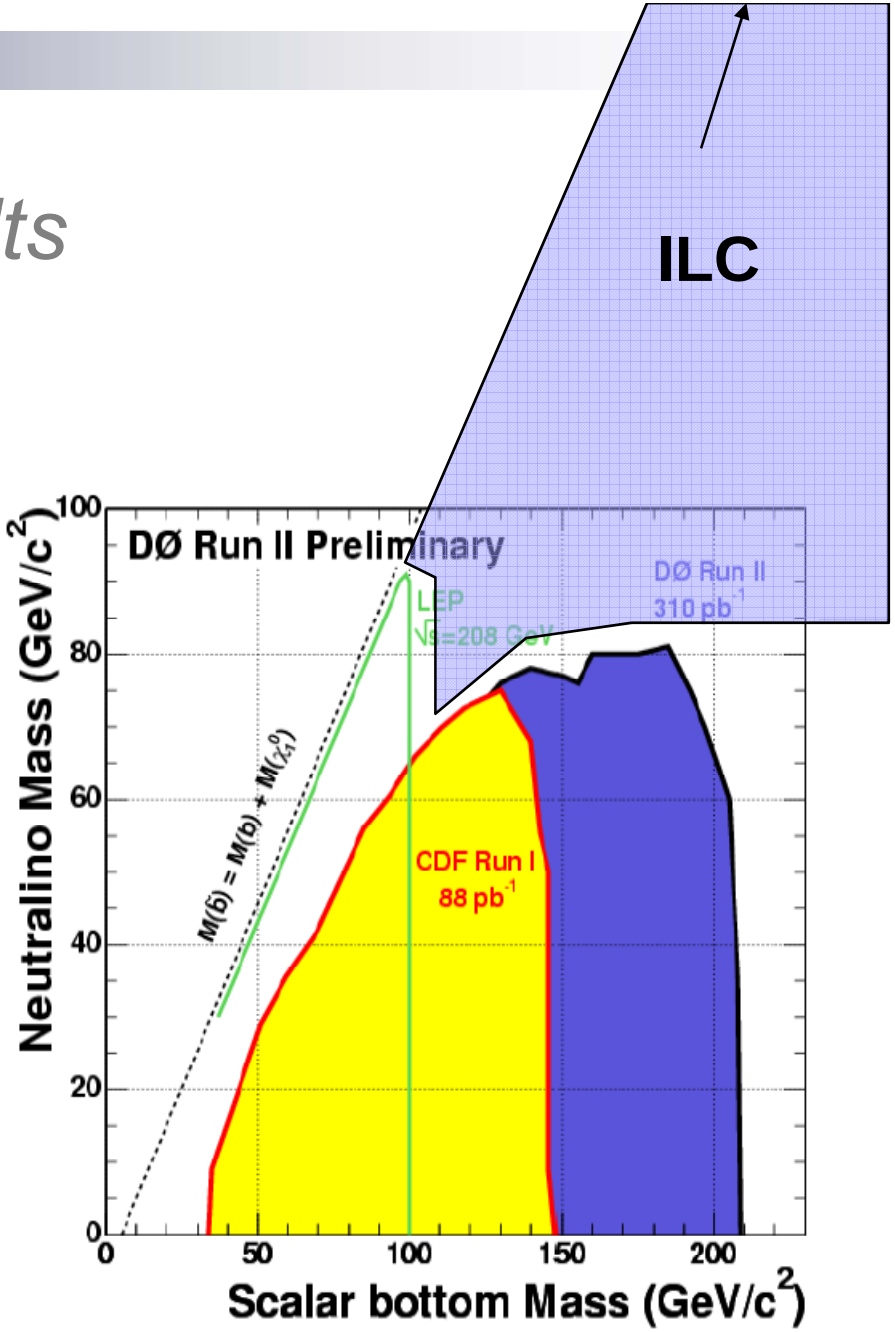
- Analysis focus point
  - High masses of sbottom and neutralino (above 200GeV)…
  - …with small mass split (10-30GeV)

- Two steps
  1) Study on a generator level
     - Detector acceptance/reconstruction is approximated
     - Aim: learn about events and background issues
  2) Events fully simulated and reconstructed
     - Not yet started
     - Major issue: Pythia 8 can not write stdhep files…



LEP and CDF/D0 Results

- CDF/D0 – measurement at high masses but still relatively hard jets (due to triggers) which are not favored by the dark matter scenario.
- LEP – able to measure in the region where the mass difference is only few GeV.
- ILC should not be too much worse but at higher masses.
- Small (meaning tiny) mass splitting is not accessible at ILC.



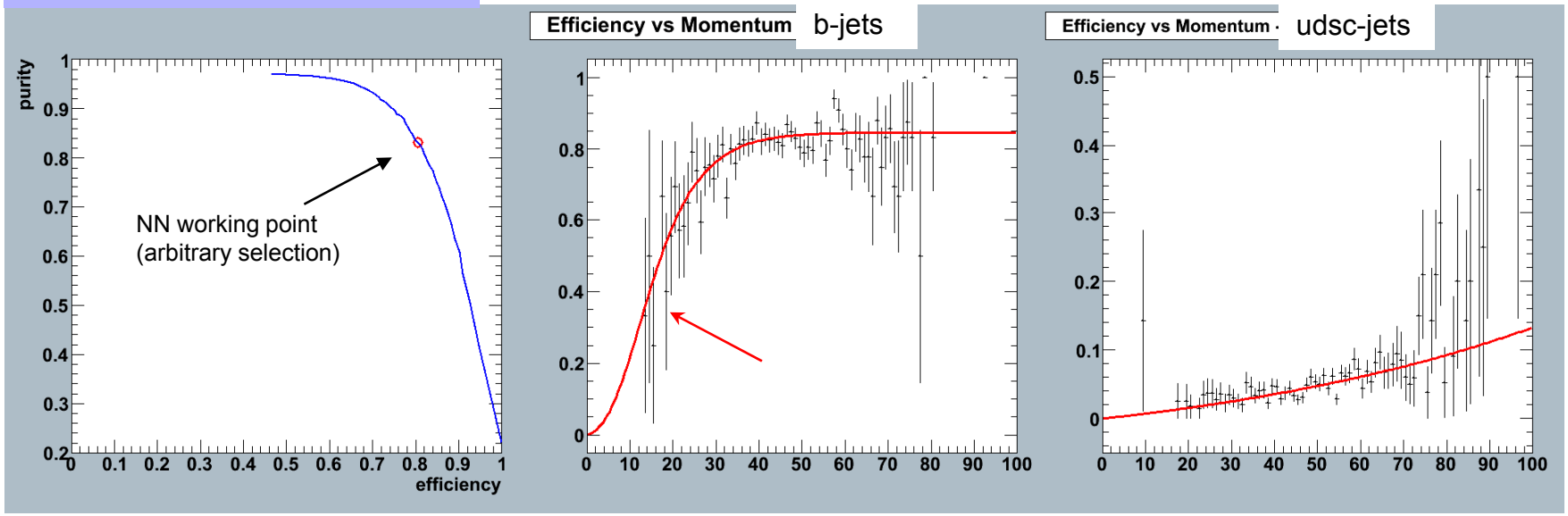
Analysis Framework

- CalcHep
  - Used to generate events.
  - Write them in Les Houches format and feed to…
- Pythia 8
  - Used for fragmentation, decays and jet finding
  - It is C++
  - Aimed at LHC (rather than ILC)
  - Contribution to Pythia 8 debugging

Jet Tagging and True Flavour

- True jet flavour evaluated from Pythia's event tree.
- Tagging efficiency studied as a function of jet momenta in LCFI VP.

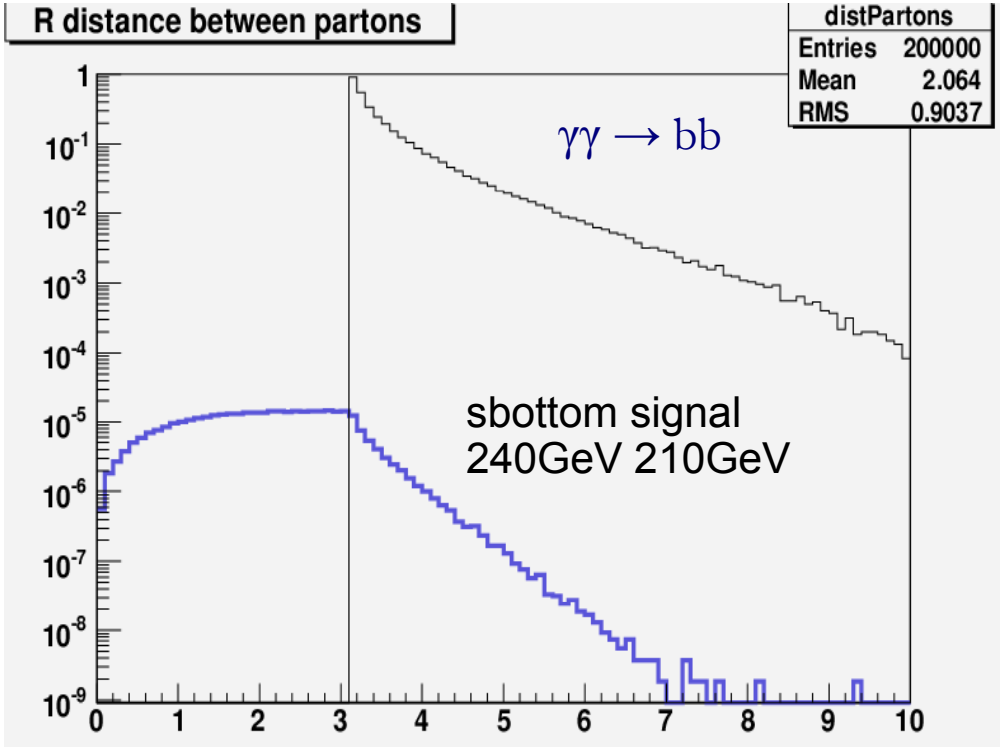
b-tagging (Z-pole data)



Fit: Gompertz-like curve = a.exp(b.exp(c.z)) – a.exp(b)
slow rise at 'beginning' and 'end'
suits better than sigmoid functions

Background Issues

- Major background contribution is due to 2-photon events
  - AA → bb (cc)
  - bb: 4 orders of magnitude higher cross section than signal (M_{sb} = 240GeV)
    - 3 orders when sbottom mass is 210GeV
  - Ideally could be perfectly supressed using e.g. distance in η-φ plane:

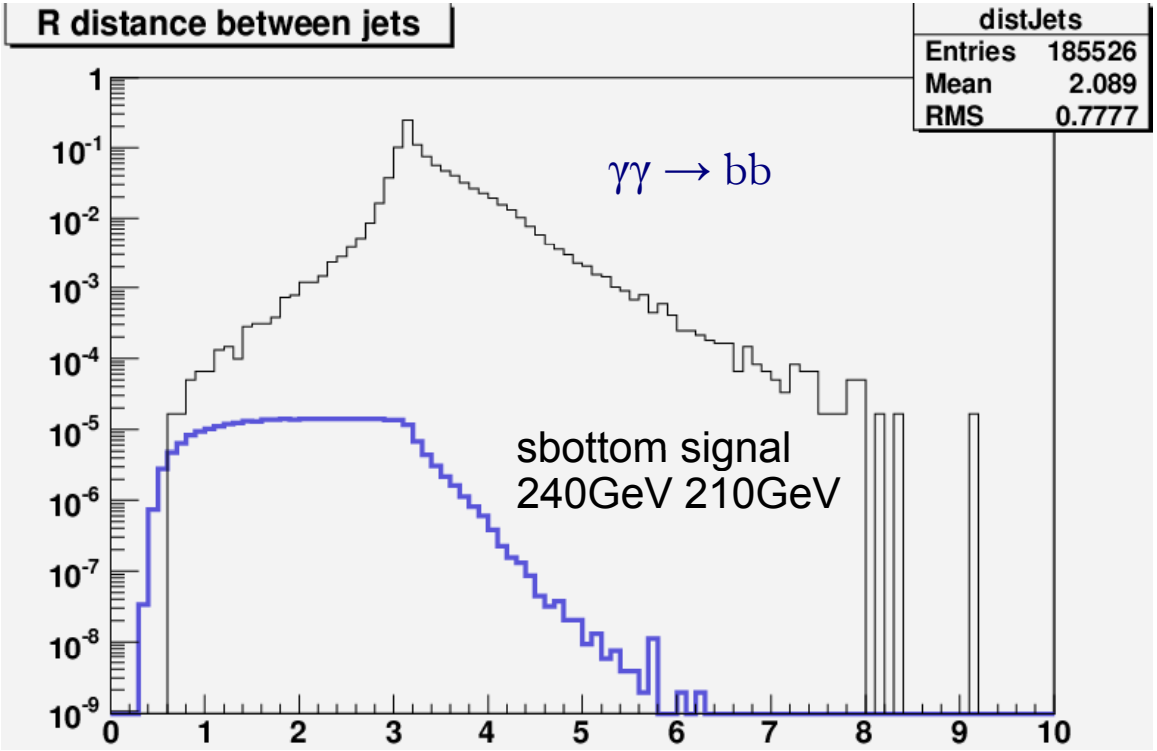


$$\Delta R_{bb} = \sqrt{\Delta\eta_{bb}^2 + \Delta\phi_{bb}^2}$$

ΔR_{bb} separation for b-jets from background is always above π at the parton level

Background issues

- Imperfect event reconstruction leaks background events to dR < π region
  - Even tiny leakage has devastating effects due to high cross section.



Current Status and Next Steps

- Cut optimisation for signal selection
  - Larger mass split and lower sbottom masses OK
  - However, small mass split and high sbottom mass require additional information…
  - …such as electron/positron veto from very forward regions.
- Install and run CalcHep on 64-bit machine
  - To simulate 2-photon background properly
    - done with equivalent photon approximation so far

Summary

- LCFI vertex package is a mature software package used in ILD and SiD detector concepts.
- Its application to 6-jet ZHH (SiD) events looks very promising
  - existing results on Higgs self-coupling may be improved.
- It is used in sbottom analysis indirectly (so far)
  - Very challenging due to softness of these events

- There are more analysis within the LCFI collaboration under way I have not covered in this talk (e.g. tt, stau).

Thank you for attention…