Optimization of SiD

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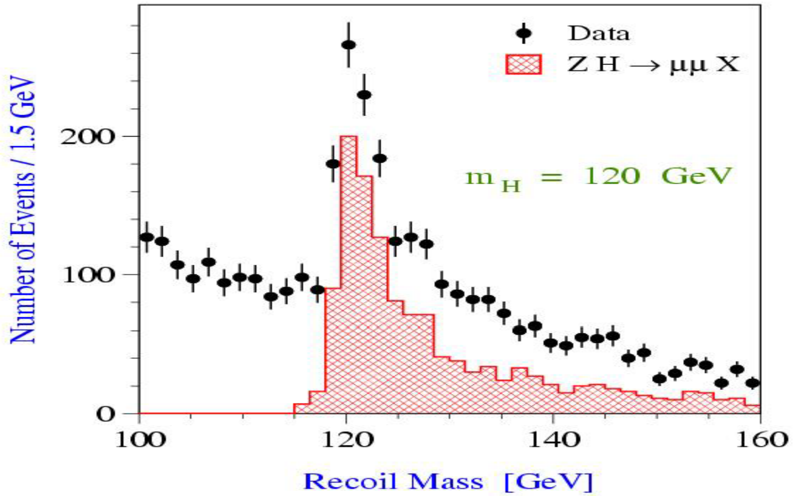
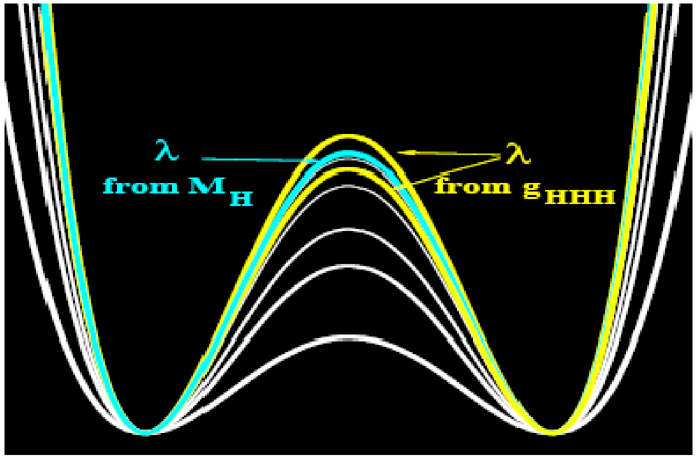
ECFA2008, Warsaw, 11 June 2008

Physics at ILC

- Emphasis on precision of measurements
- Studies of
  - Higgs properties
    - Model independent
    - Self-coupling
  - Unique for ILC
  - SUSY parameters





But many other things
are interesting and important

From Physics Studies to Optimization to Benchmarking

- Emphasis of physics studies shifted towards
  - Realities required by engineering: material (amount and distribution)
  - Realities required by reconstruction algorithms: tracking & PFA
  - Evaluation and comparison of detector choices
- Entered the phase of optimization and benchmarking
- Answer questions:
  - With added realism will it still deliver physics ?
  - How it compares to other concepts ?

Optimization & Benchmarking

- Ideally: simulate many detectors and optimize with full analyses
  - huge amount of work and data generation, not everything is available immediately
- SiD is doing step by step optimization
  - Global optimization of geometry and mag. field
  - Then subsystem optimization
  - Then benchmarking

Compulsory LOI Benchmarking List

At a Dec 7 meeting between Sakue Yamada and representatives of SiD, ILD, 4th Concept, an agreed that the following reactions will be used for LOI Physics Benchmarking:

1. $e^+e^- \to Zh, \to \ell^+\ell^- X, l = e, \mu;\ m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV
2. $e^+e^- \to Zh, Z \to q\bar{q}, \nu\bar{\nu};\ h \to c\bar{c}, \mu^+\mu^-;\ m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV
3. $e^+e^- \to \tau^+\tau^-$, at $\sqrt{s}$=0.5 TeV
4. $e^+e^- \to t\bar{t}$ at $\sqrt{s}$=0.5 TeV
5. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0 \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ / $ZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ at $\sqrt{s}$=0.5 TeV

- Proposed by WWS Software panel in consultation with the detector concepts and the WWS Roadmap Panel
- Based on the Benchmark Panel Report (Snowmass 2005)
- Had iterations to define observables more precisely
- Concept are free to add more processes which emphasize their strong sides

Benchmarking Processes

- Compulsory and additional processes will allow to benchmark subsystems
  - Vertexing
  - Tracking
  - EM and HAD Calorimetry
  - Muon system
  - Forward system
- To demonstrate strong sides of SiD
- and to compare SiD to other concepts

Metrics for Optimization

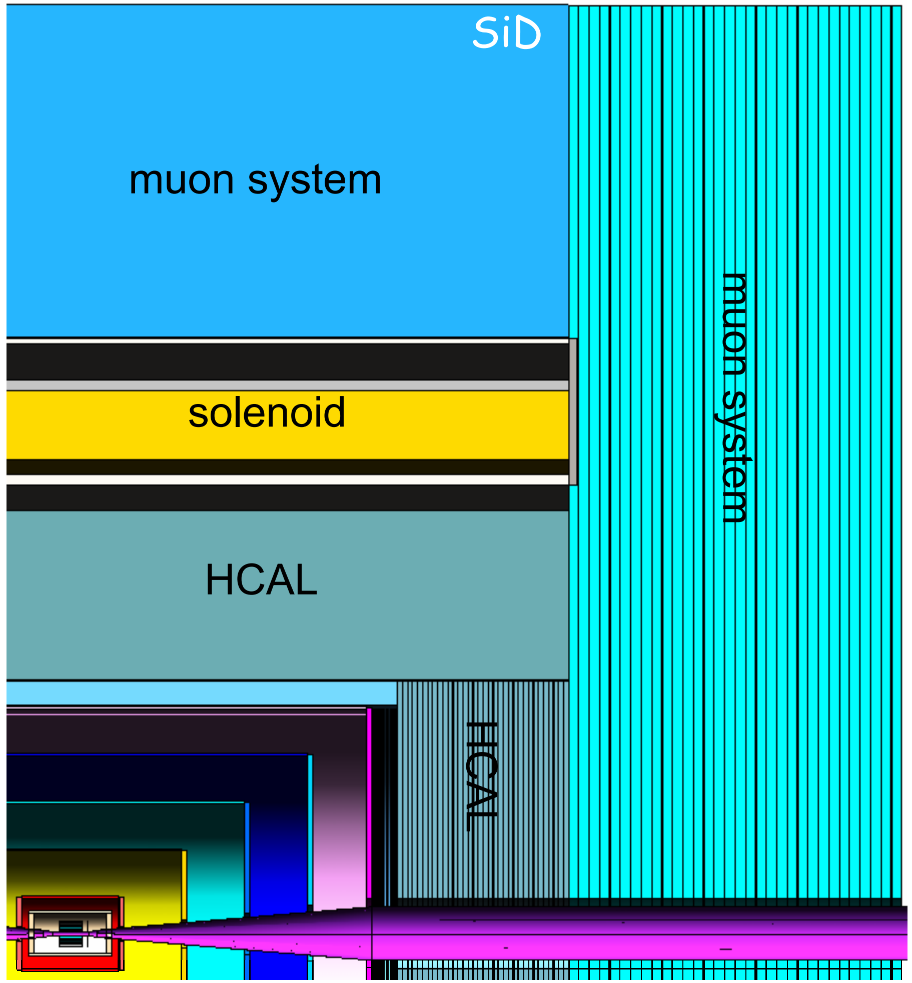
- Ultimate metric – sensitivity to physics
  - GEANT & Full reconstruction
- There are simpler ways to decrease vast parameter space
  - Studies of physics with Fast MC
  - Object level optimization
    - Jet energy resolution, di-jet mass resolution, tracking/vertexing resolutions
- Cost as a metric
  - A lot can be learnt with a simple model
- Optimization of calorimeter and magnet is critical since it involves main global parameters

SiD Detector

- Main parameters of SiD
  - VD : 1.4 - 18 cm
  - Tracker : 18 - 125 cm
  - ECAL : 125 - 138 cm
  - HCAL : 138 – 250 cm
  - Solenoid : 250 – 333 cm
  - Muon : 333 – 645 cm

  - Magnetic field 5 T
  - ECAL 30 W/Si layers
  - HCAL 34 Fe layers

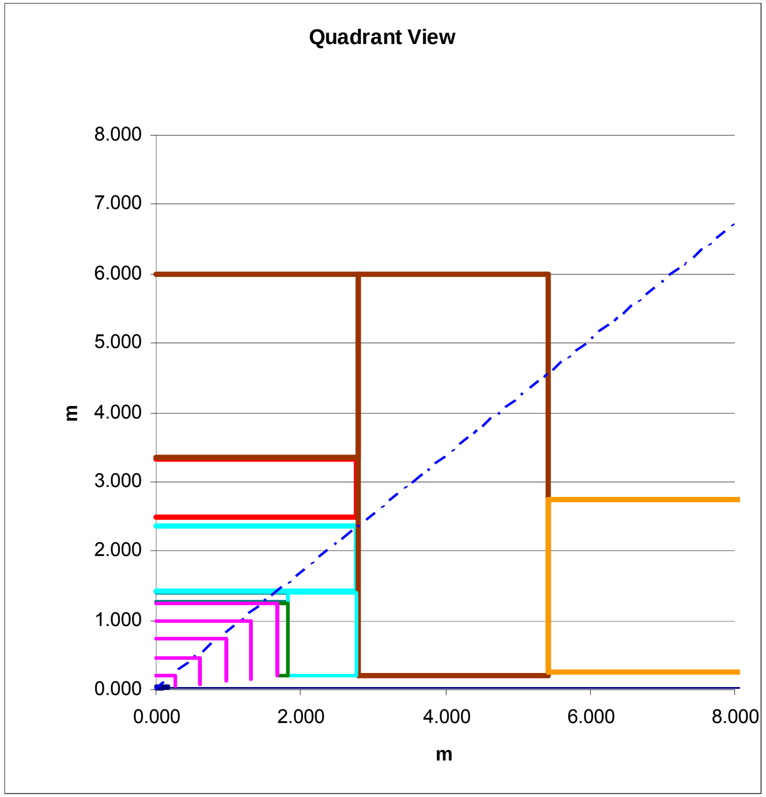
  - 5 layer VD (barrel + endcaps)

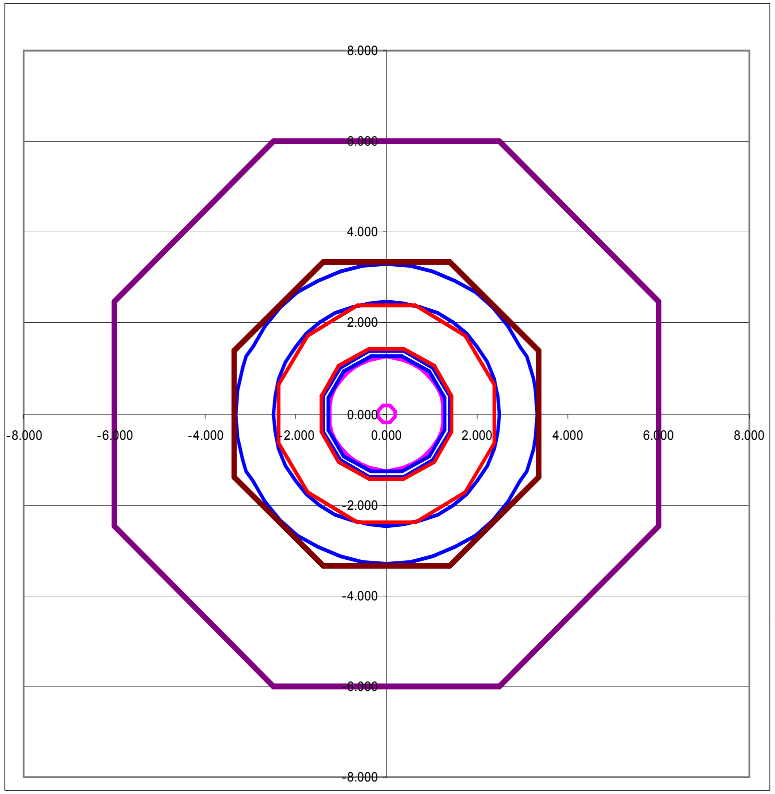


Optimization of SiD

Philosophy:

- Find an AFFORDABLE TECHNICAL solution, which also delivers the required physics performance
- Need a performance vs cost curve
  - SiD has a simple parametric model of cost (by Marti Breidenbach)
  - Detector is described by volumes
  - Assumes how cost of various things depends on their size and materials used



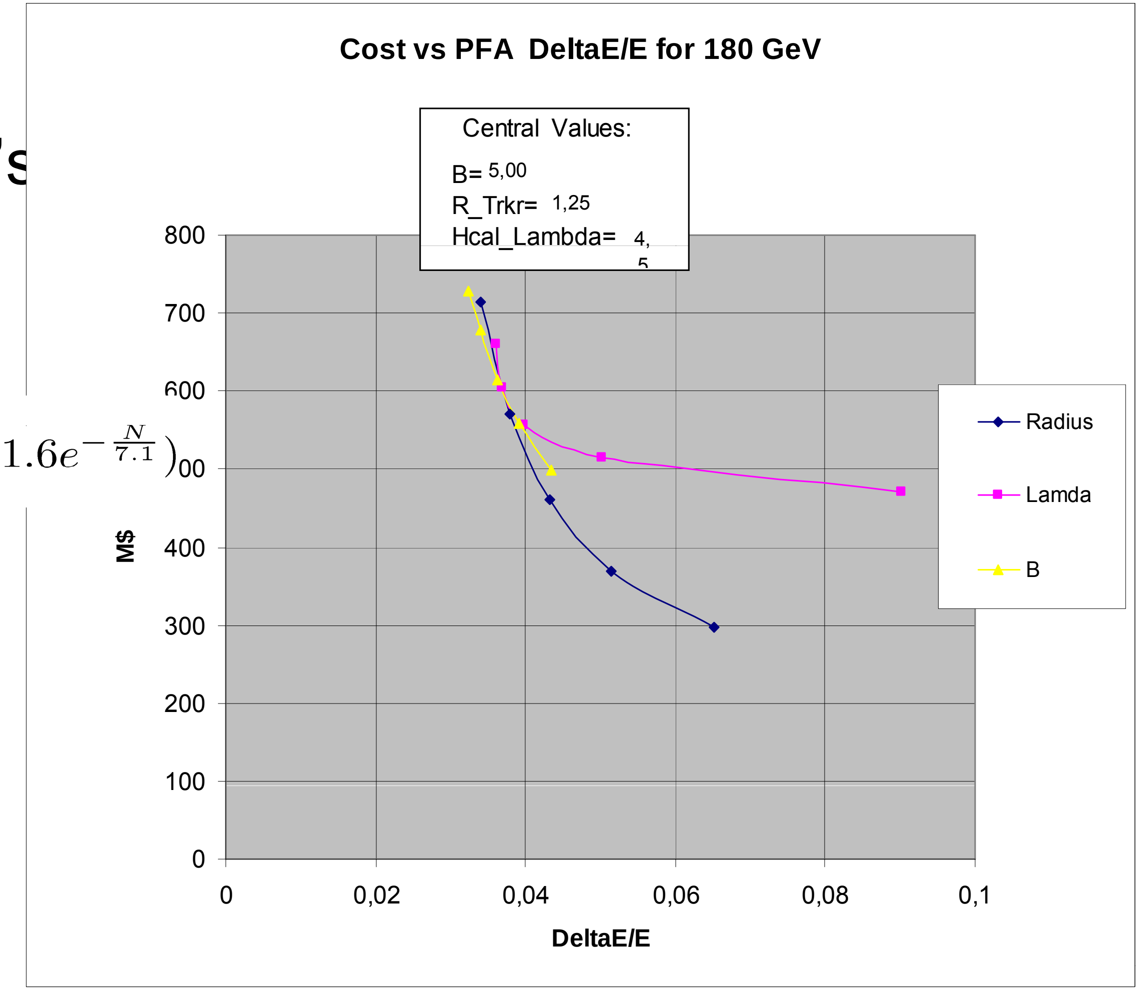


SiD Cost Model

- Cost drivers: Magnet, EMCAL (W/Si), HCAL (Fe/RPC)
- Assume Mark Thomson's ILD parameterization of $\Delta E_{jet}/E_{jet}$:

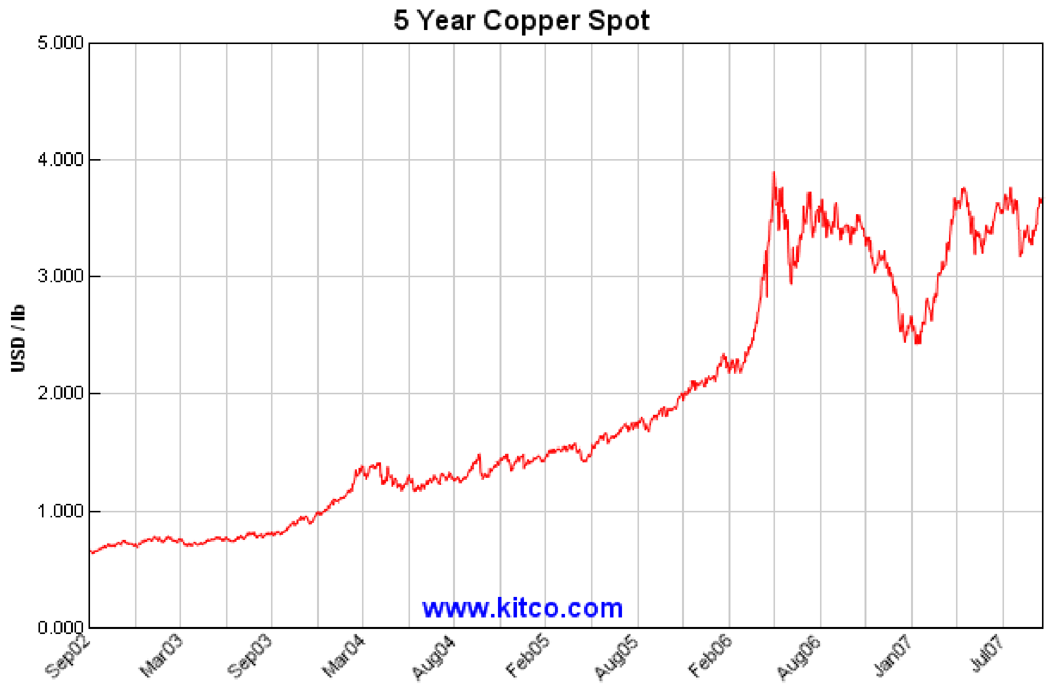
$$\alpha = 0.42 \left(\frac{B}{4}\right)^{-0.31} \left(\frac{R}{1.78}\right)^{-0.61} (1 + 21.6e^{-\frac{N}{7.1}})$$

- Convert to cost
- Study dependence on various parameters



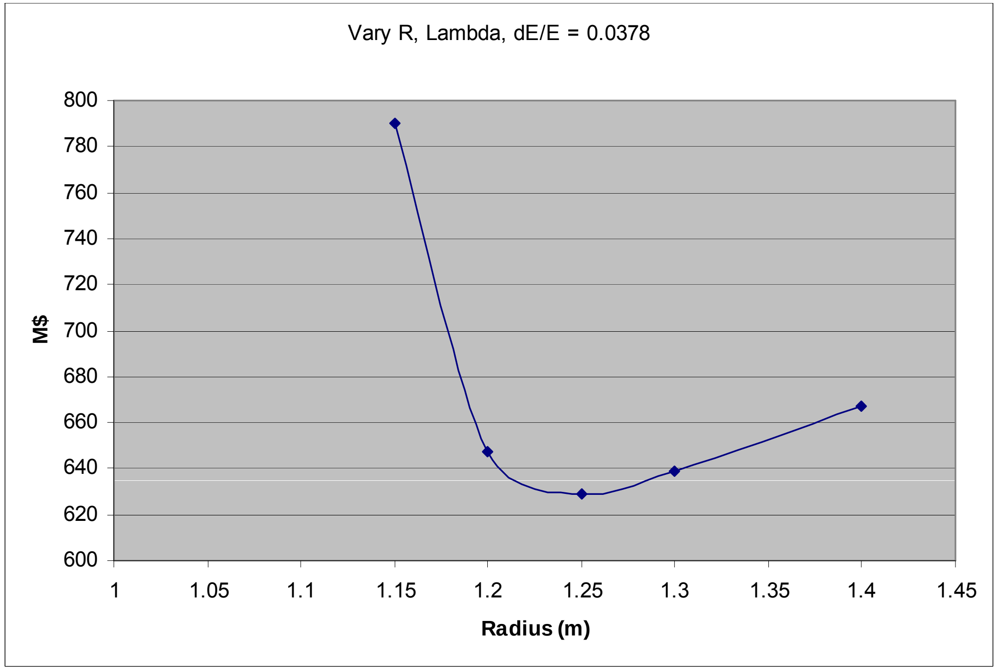
SiD Cost Model

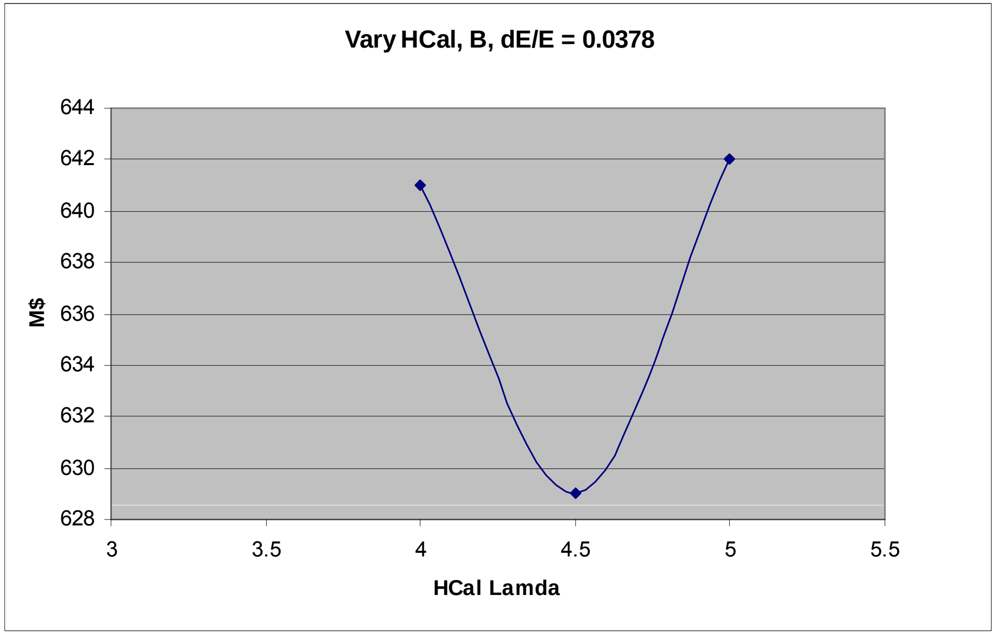
- M&S cost only (no labour, escalations etc)
- Many other caveats
  - Some things (like material costs) are not well predictable



SiD Cost Model

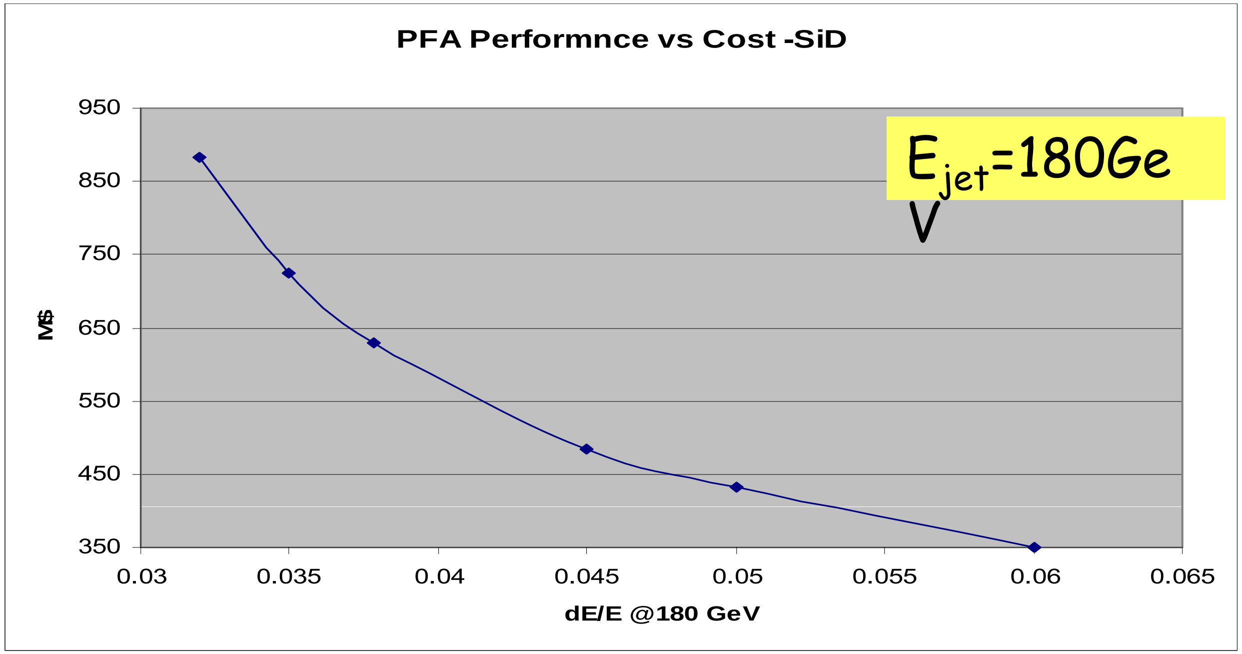
- Vary two parameters keeping jet energy resolution constant – the curve has a minimum
- SiD "Baseline" is optimal for this value of ΔE/E(180 GeV)
  - R_{trk} = 1.25 m
  - B = 5 T
  - HCAL λ = 4.5
  - ΔE/E(180 GeV) = 3.8%





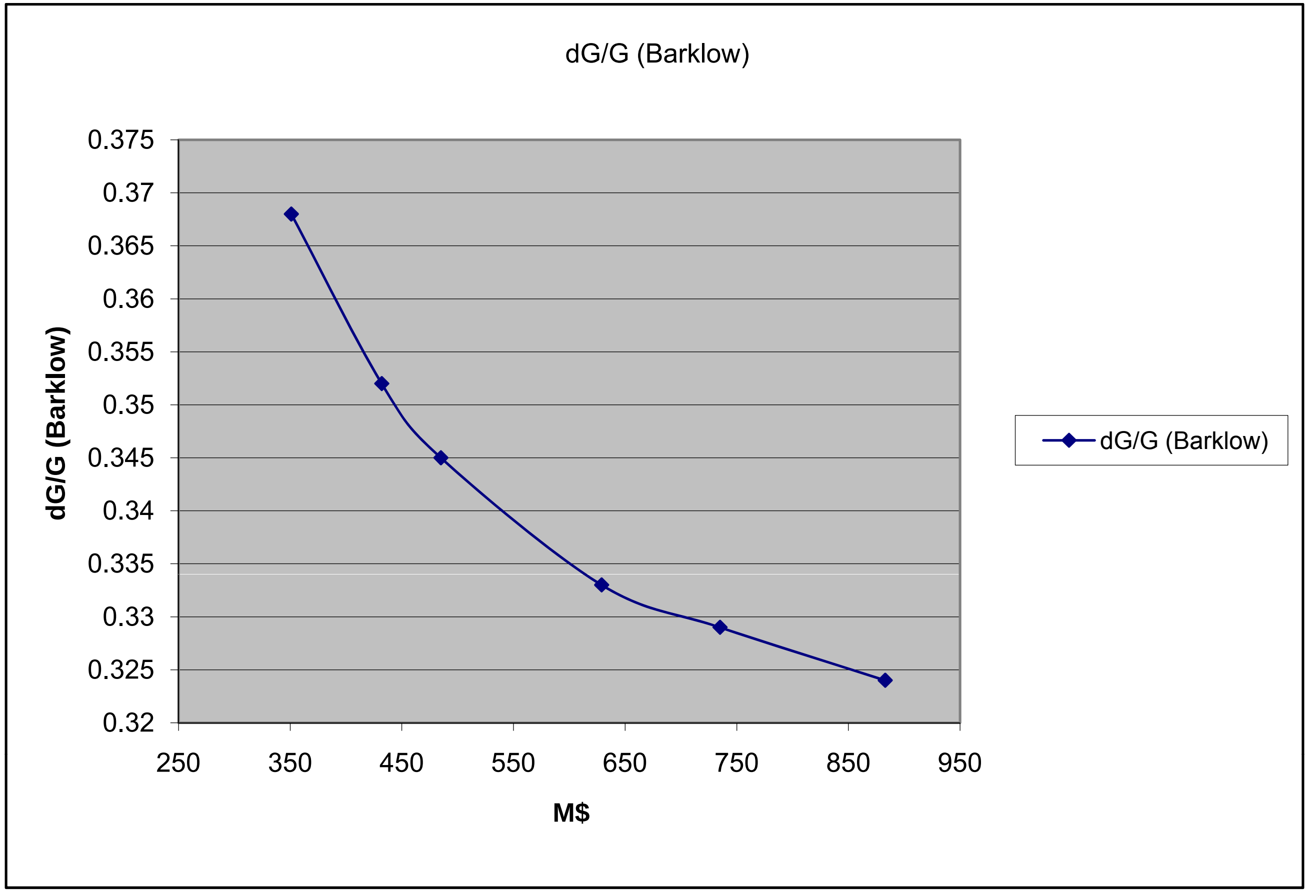
SiD Optimization: Step 1

- Assuming Mark Thomson's ILD Parameterization of $\Delta E_{jet}/E_{jet}$ and using Marty Breidenbach's Cost Model, find R, B, and λ which minimize cost for a given $\Delta E_{jet}/E_{jet}$
- This is a sequence of optimized SiDs
- Optimization is done using objects (jets), not physics



Step 2: Folding in Physics

- Use Tim Barklow's study of ZHH, which gives $\Delta g/g$ vs $\Delta E_{jet}/E_{jet}$
- This is one of many possibilities



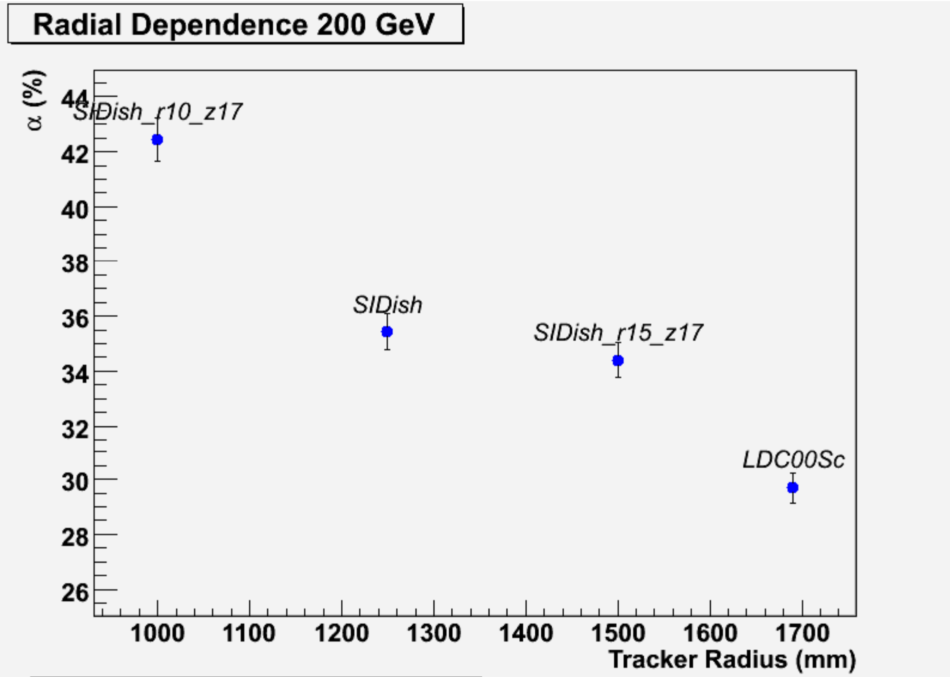
Refining Optimization

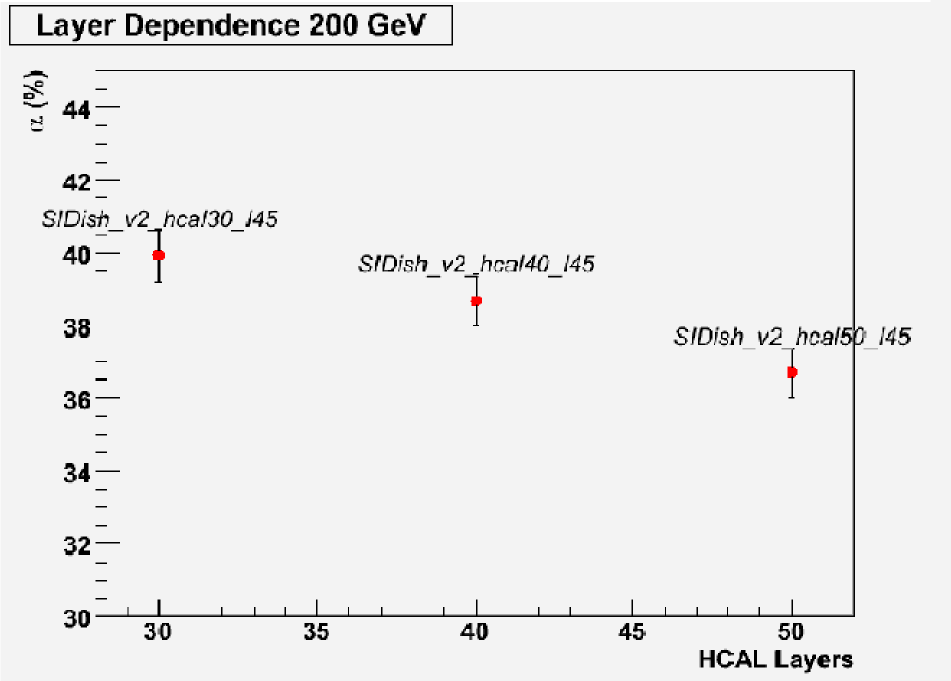
- Used PandoraPFA (M.Thomson) configured for SiD-like parameters
  - More sensitive to variation of parameters than current SiD PFA
  - See M.Stanitzki's talk

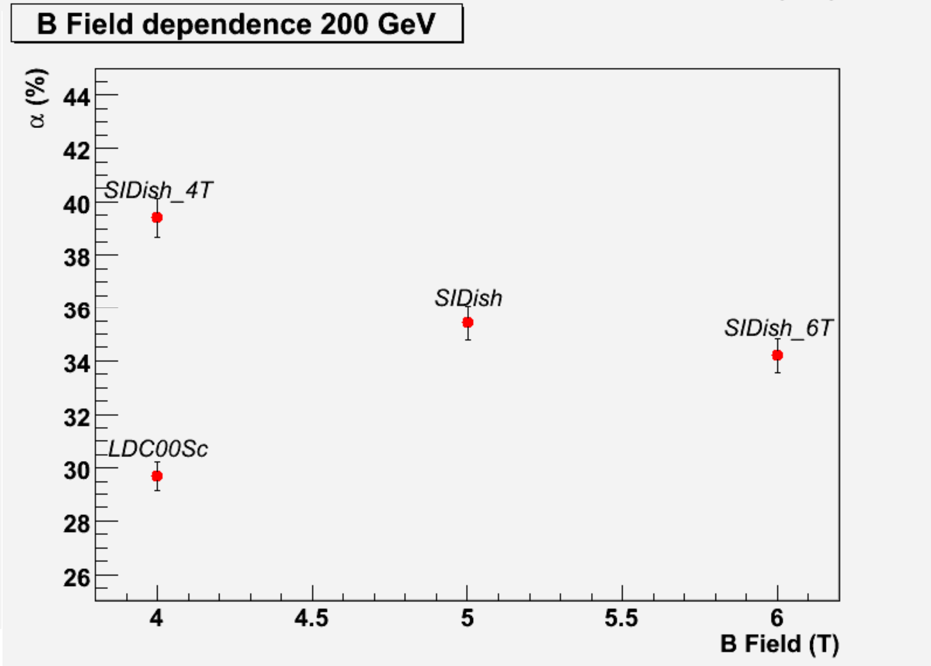
- EMCAL, HCAL and magnet are three most expensive items that define geometry
  - Assumed that tracking doesn't matter
- Optimize this looking at how jet energy resolution depends on most important parameters

Optimization of Global Parameters

- Jet energy resolution versus
  - B field (B)
  - Tracker radius (r)
  - Tracker length (z)
  - HCAL depth (λ)
  - HCAL segmentation (n_{Layers})

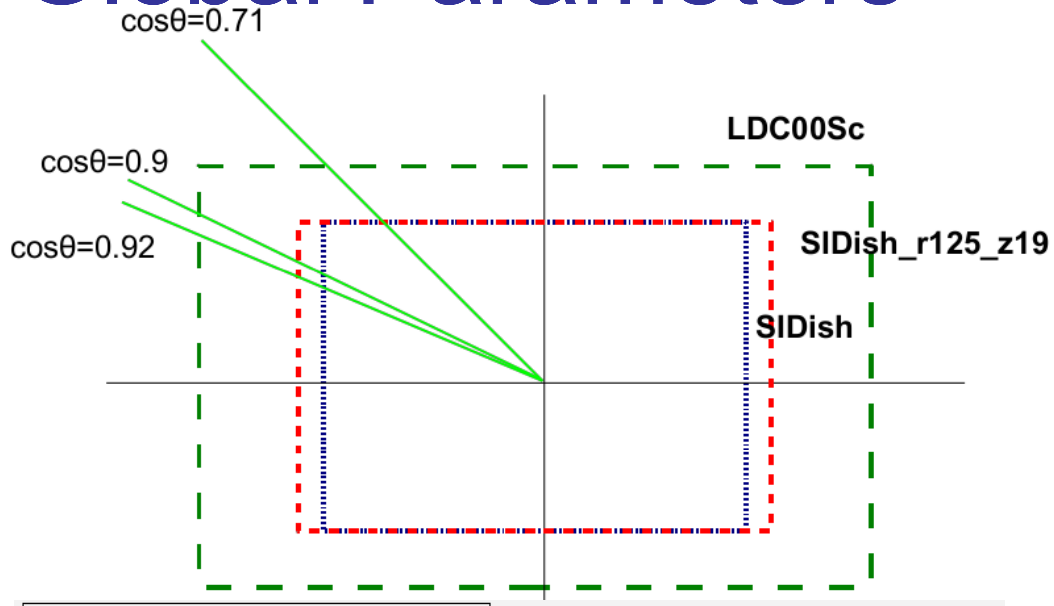


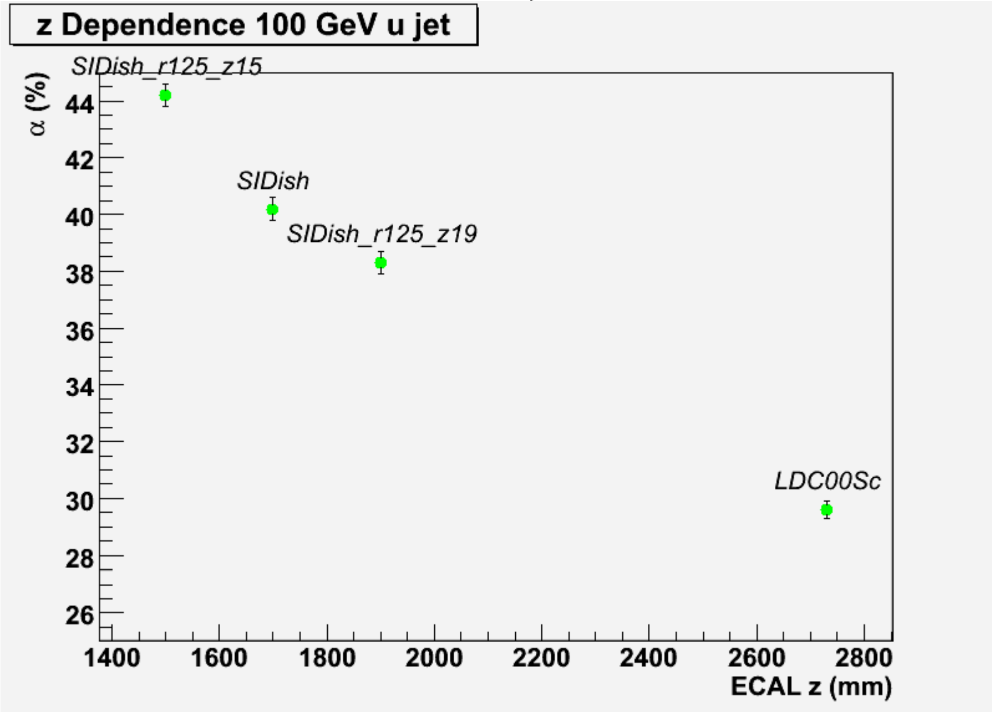




Optimization of Global Parameters

- Studied forward jets
  - one u jet at cosθ=0.92





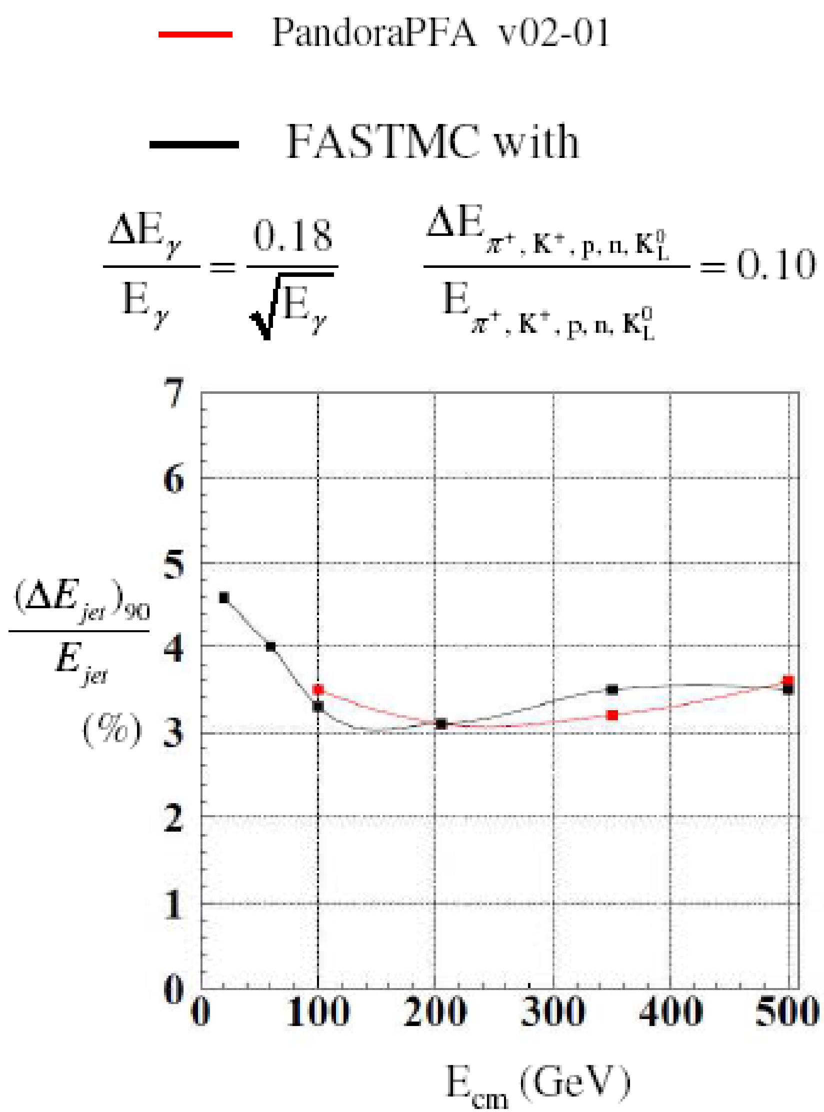
- These results will be a new input to the cost model
  - Much better approximation of SiD

Physics as Metrics

- Need to look at physics gains, not just at jet energy resolution
- Study by Tim Barklow
  - Di-jet mass resolution in various situations
  - Chargino mass measurement
  - Higgs mass measurement
  - Higgs self-coupling

Fast MC

- Used fast MC tuned to reproduce Pandora PFA
- SiD fast MC
  - Smear energies using different resolutions for photons and other particles
  - Cluster smeared particles to jets
  - Checked several parameterizations



Di-jet Mass Resolution

- First approximation:

$$M \approx 2E_1E_2(1-\cos\theta)$$

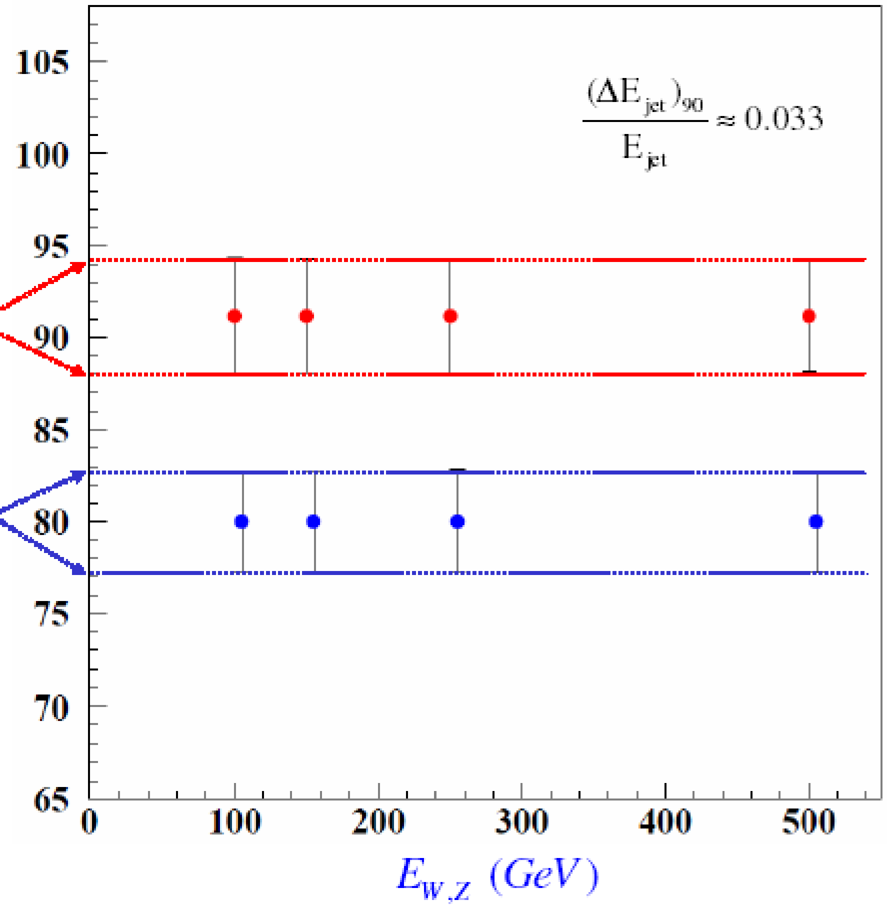
$$\frac{\Delta M}{M} \approx \frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right]$$

- How important are the jet mass and angular terms? Calculated full errors

$$\Delta M_Z = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_Z$$

$$M_{W,Z}$$

$$\Delta M_W = \pm\frac{1}{2}\left[\frac{\Delta E_1}{E_1} \oplus \frac{\Delta E_2}{E_2}\right] M_W$$



- Not important for boosted standalone W and Z

Di-jet Mass Resolution

- Studied 4-jet WZ configurations, effects of jet finding, gluon radiation and V0 reconstruction
- Dominated by PFA energy resolution, jet mass & angle terms are small
- "Physics" effects (jet finding, gluon radiation) are important but could be improved

Table of W,Z Mass Resolution Effects

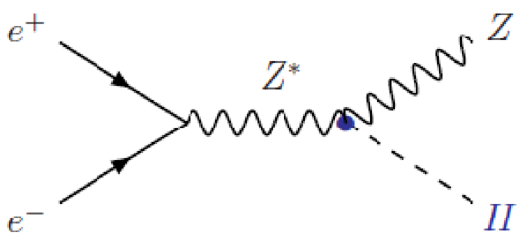
All units GeV

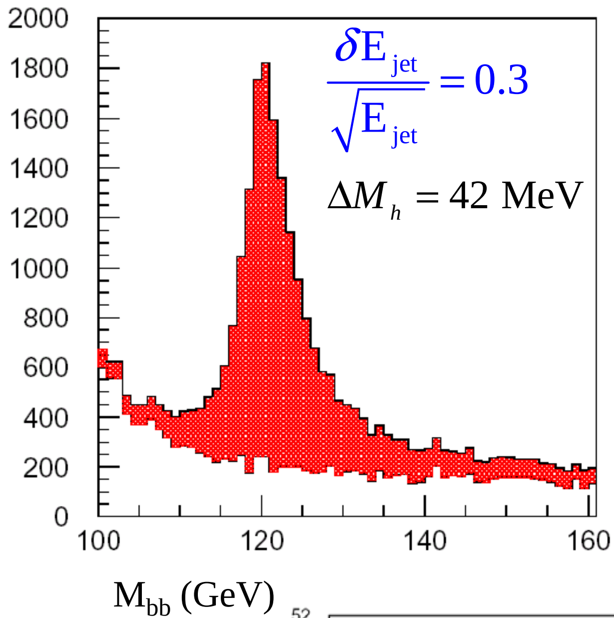
Source of Error	$E_W = 150$ ΔM_W	$E_Z = 150$ ΔM_Z	$E_W = 250$ ΔM_W	$E_Z = 250$ ΔM_Z
PFA Jet Energy	2.8	3.1	2.8	3.1
Jet Angle/Mass	< 0.5	< 0.5	< 0.5	< 0.5
Jet Finding, $\theta_{WZ} = \pi$	2.2	1.7	2.0	2.5
Jet Finding, $\theta_{WZ} = 0$	3.1	1.9	3.1	1.5
Gluon Rad.	9.2	9.5	7.2	8.6
Intrinsic Width	2.1	2.5	2.1	2.5
No V0 Finding	1.2	1.1	2.8	3.5

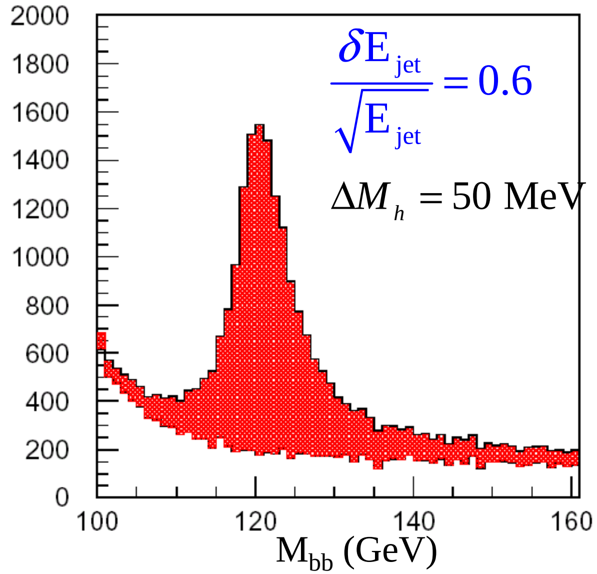
Folding in Physics

- Studied several physics processes to determine sensitivity to jet energy resolution

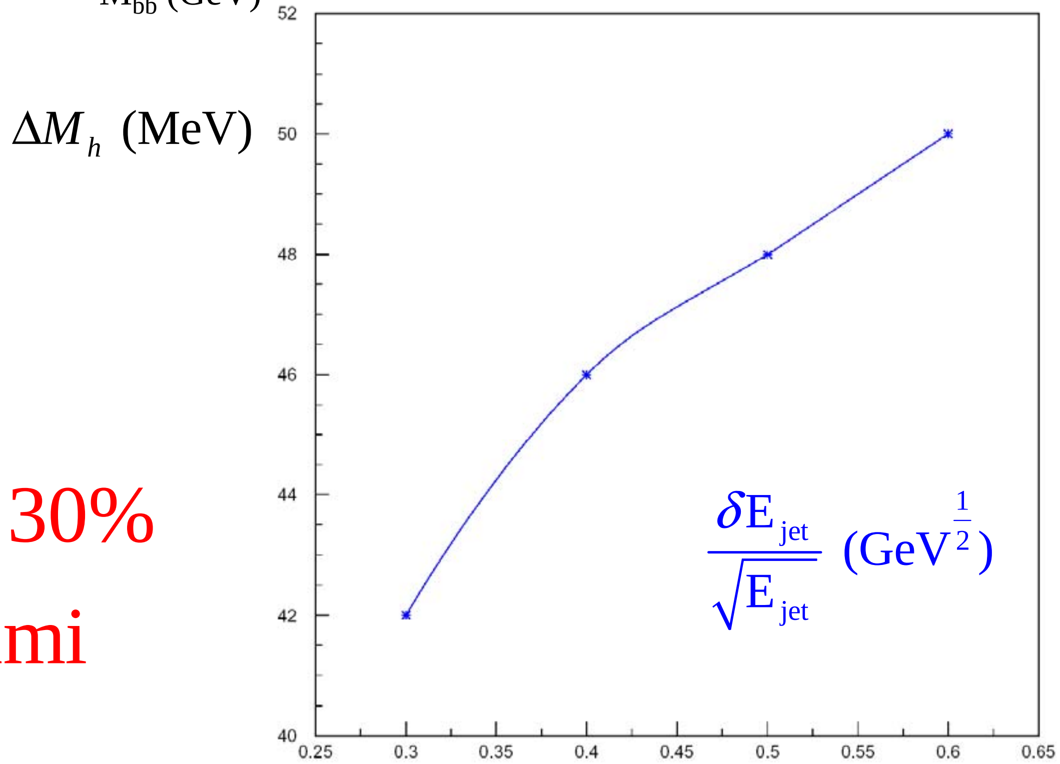
ZH → 4 jets







$$e^+e^- \to ZH \to qqb\bar{b}$$



$$\sqrt{s} = 350\, GeV$$

$$L = 500\ fb^{-1}$$

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

equiv to $1.4\times$ Lumi

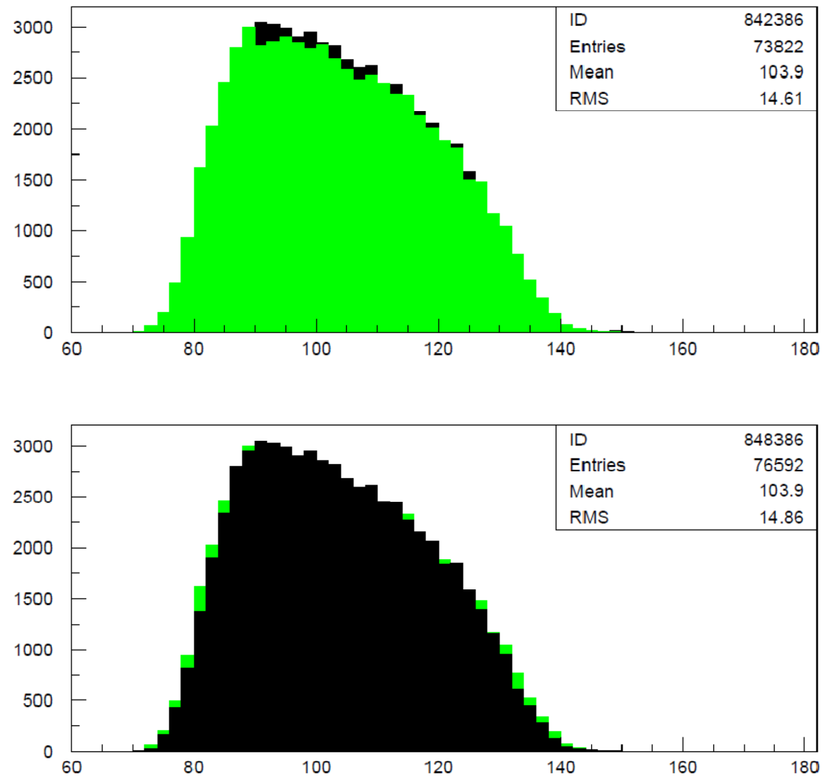
Chargino Pair Production

Black: $M_{\tilde{\chi}_1^+} = 198.4 \text{ GeV}$

Green: $M_{\tilde{\chi}_1^+} = 200.4 \text{ GeV}$

$$e^+e^- \to \tilde{\chi}_1^+ \tilde{\chi}_1^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 W^+ W^- \to \tilde{\chi}_1^0 \tilde{\chi}_1^0 qqqq$$

- Process 5 of compulsory benchmarking list
- Width of E_W distribution is sensitive to chargino mass



E_W (GeV)

$M_{\tilde{\chi}_1^0} = 106.2 \text{ GeV}$

$\sqrt{s} = 500 \text{ GeV}$

Chargino Pair Production

$M_{\tilde{\chi}_1^+} = 199.4 \text{ GeV}$

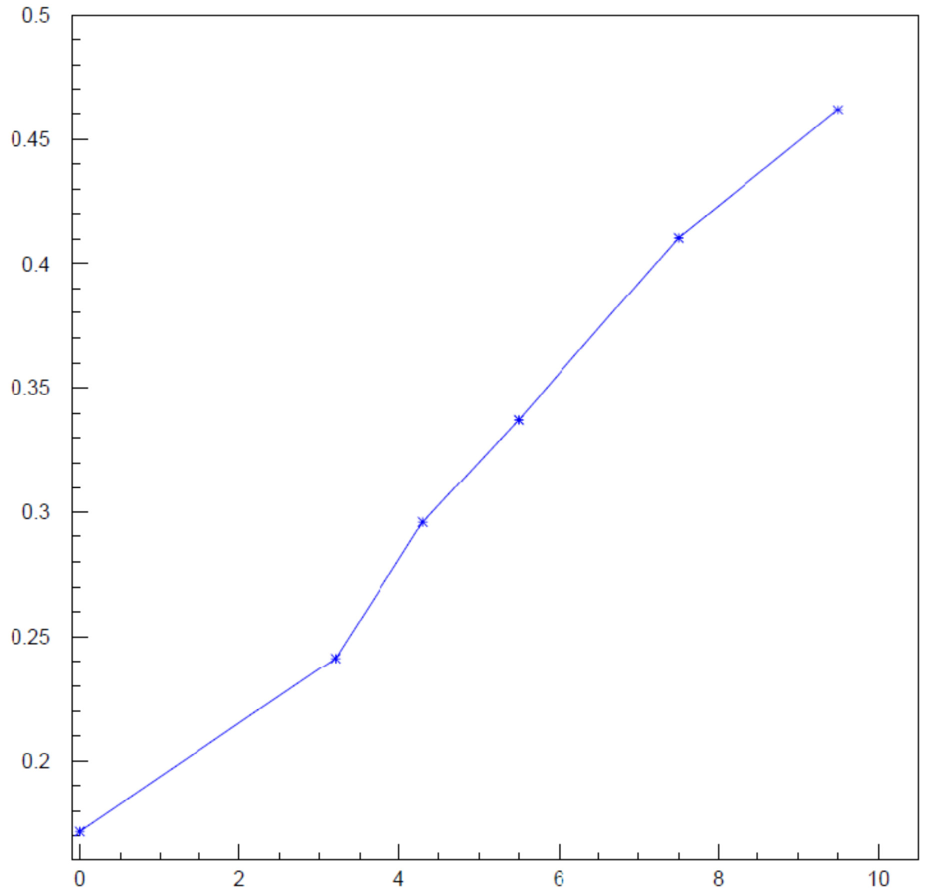
$M_{\tilde{\chi}_1^0} = 106.2 \text{ GeV}$

$\sqrt{s} = 500 \text{ GeV}$

$L = 500 \ fb^{-1}$

$$e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_1^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 W^+W^- \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 qqqq$$

$$\Delta M_{\tilde{\chi}_1^+} \ \text{(GeV)}$$



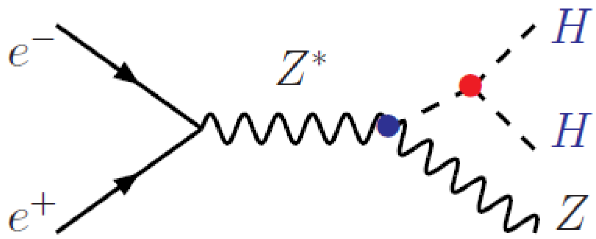
$$\left(\frac{\Delta E_{\text{jet}}}{E_{\text{jet}}}\right)_{90} \ (\%)$$

$$\left(\frac{\Delta E_{\text{jet}}}{E_{\text{jet}}}\right)_{90} = .06 \rightarrow .03$$

equiv to $2.1\times$ Lumi

Higgs Self Coupling

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

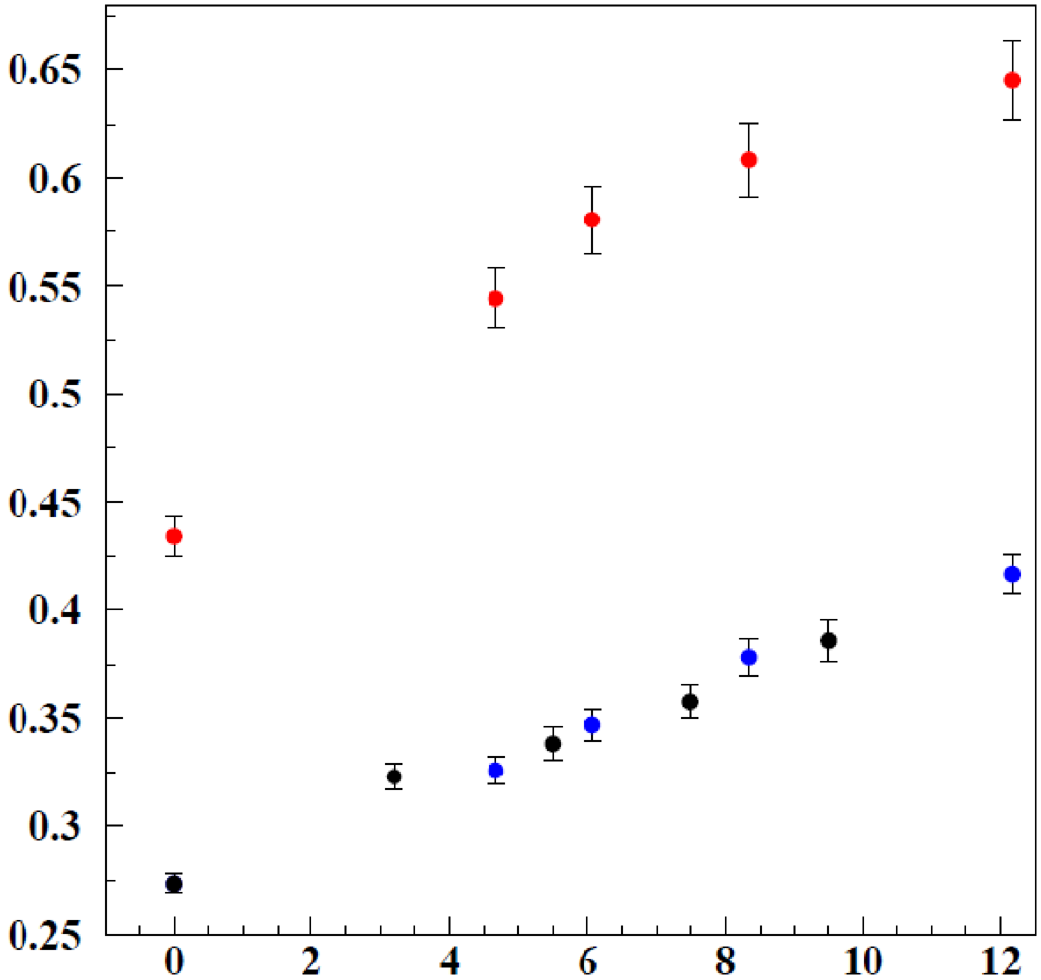


$\sqrt{s} = 500\ GeV$

$L = 2000\ fb^{-1}$

$\Delta E_{jet}/E_{jet} = .06 \rightarrow .03$

equiv to 1.3× Lumi



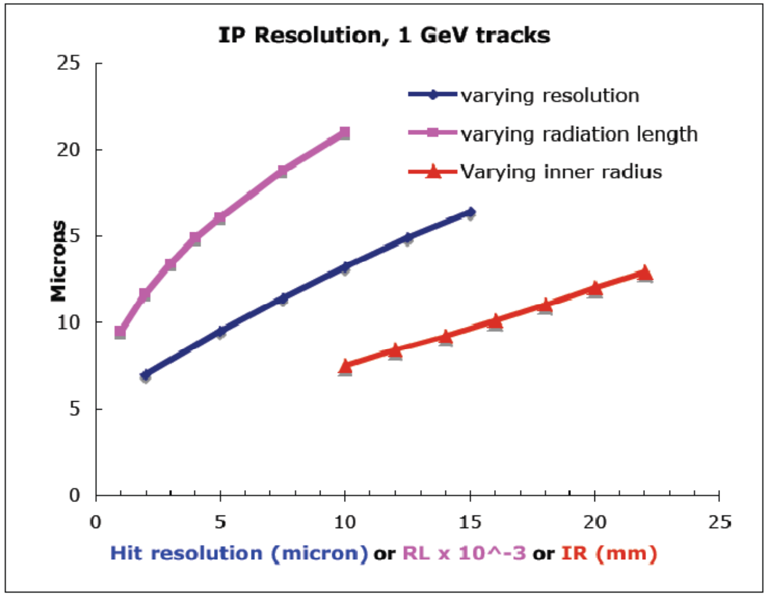
$\left(\frac{\Delta E_{jet}}{E_{jet}}\right)_{90}$ $\frac{\alpha_{90}}{\sqrt{50}}$ $\frac{\alpha_{90}}{\sqrt{50}}$ (%)

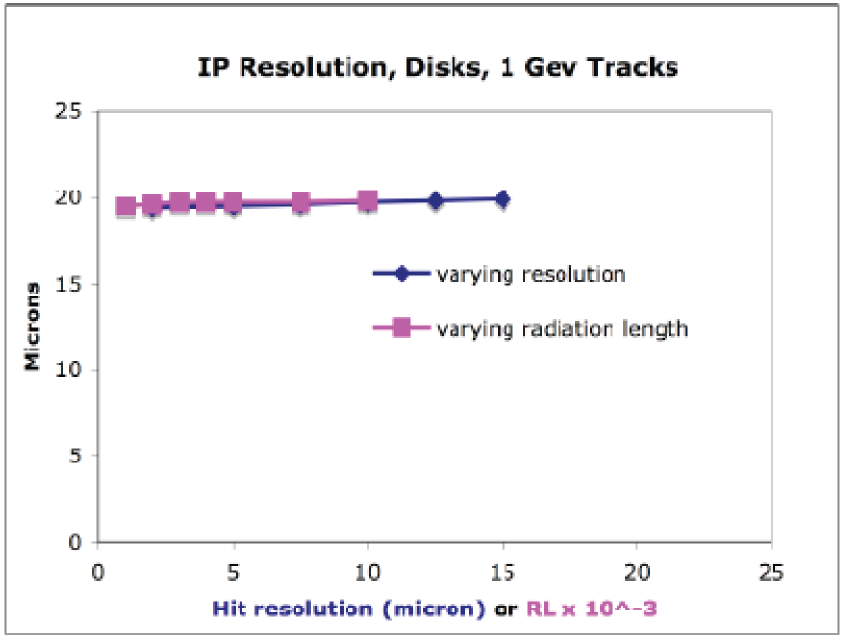
Using Physics as Metric

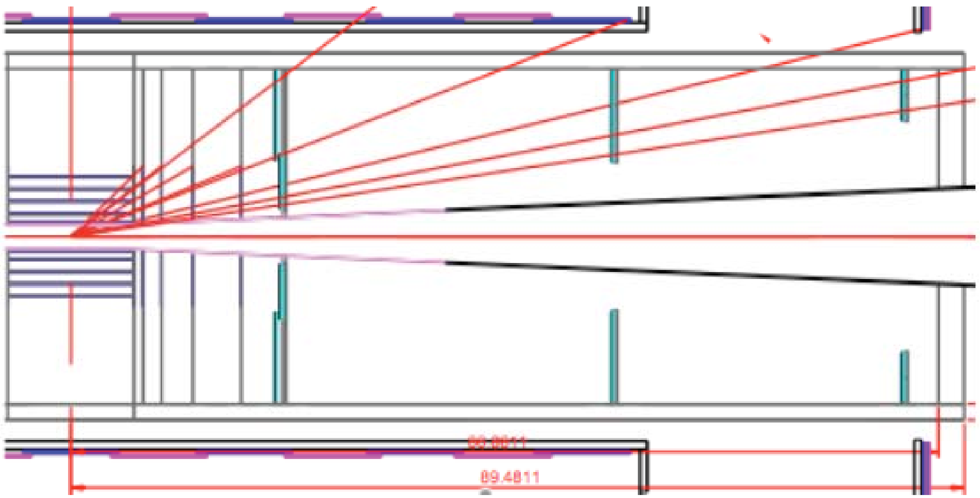
- So far : looked how physics sensitivity is affected by jet energy resolution
  - Still fast MC but checked for several different tunes
- Bottom line : jet resolution is important and for some processes more important than for others
  - Chargino mass precision (Process 5) looks like a particularly good benchmark
- Next step : fold in cost estimate

Resolution in VD

- Parametric study of resolution in barrel and forward vertex detector
- A forward track always has the first hit in the barrel so the precision of next hits doesn't matter much
- Optimization will come from pattern recognition issues



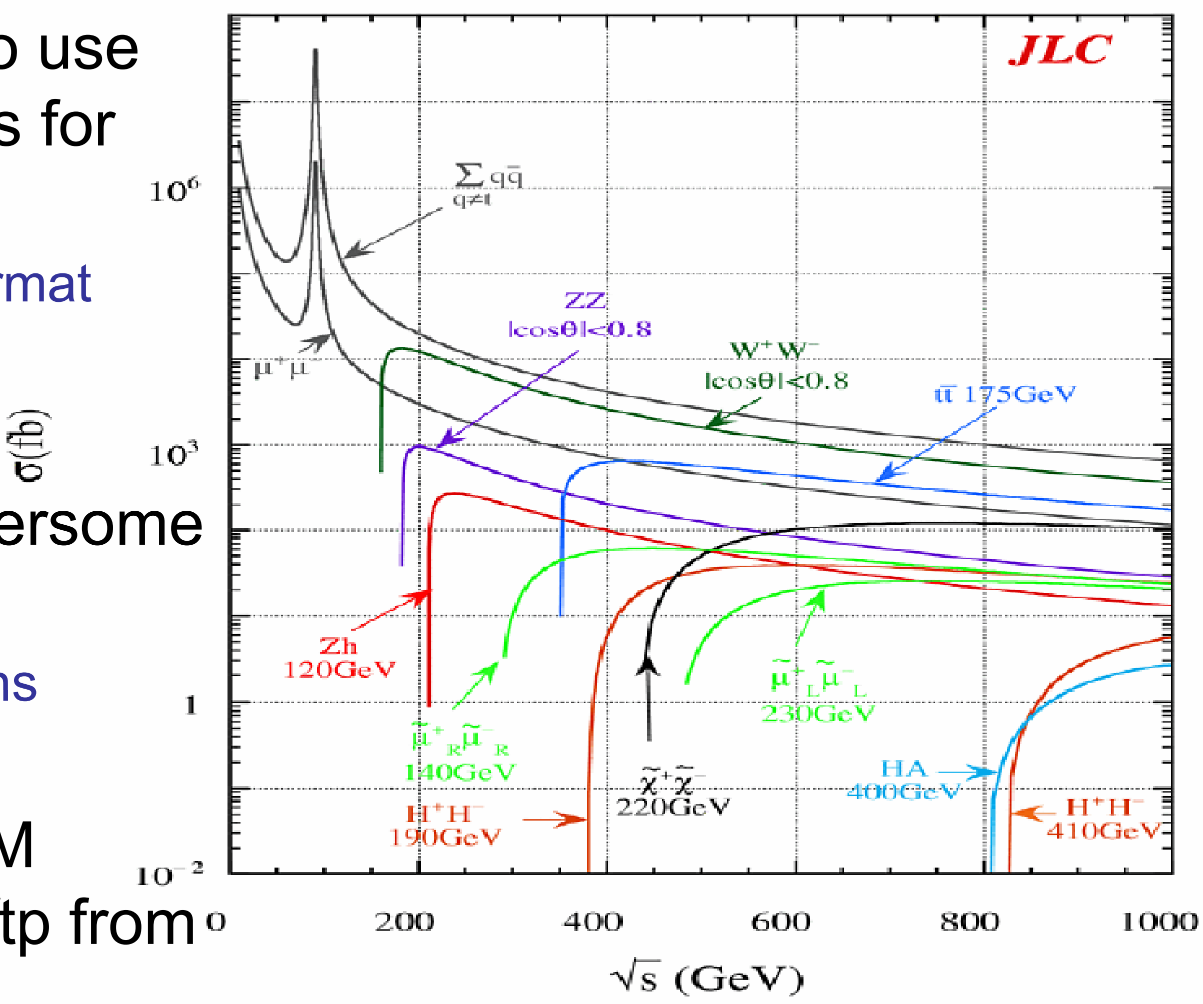




From Optimization To Benchmarking

Standard Model Samples

- All concepts agreed to use the same MC samples for benchmarking
  - Provided in .stdhep format
- Generation of SM backgrounds is cumbersome
  - Many processes
  - Range of cross sections
  - Events are weighted
- Full $2ab^{-1}$ 500 GeV SM sample available via ftp from SLAC.
  - Need to add 250 GeV sample



Whizard SM Sample

- WHIZARD Monte Carlo used to generate all 0,2,4,6-fermion and t quark dominated 8-fermion processes.
- 100% e^- and e^+ polarization used in generation. Arbitrary electron, positron polarization simulated by properly combining data sets.
- Fully fragmented MC data sets are produced. PYTHIA is used for final state QED & QCD parton showering, fragmentation, particle decay
  - TAUOLA for tau decays
- Remove 120 GeV Higgs from fermion final states at 500 GeV, and add explicit ffH, ffHH, etc. final states
  - Adds flexibility to vary Higgs mass without redoing the whole dataset

- Additional backgrounds
  - GuineaPig: e^+e^- pairs and photons
  - Muons and other backgrounds from upstream collimators & converted to stdhep
  - $\gamma\gamma\rightarrow$ hadrons generated as part of the “2ab^{-1} SM sample”

Polarization in SM Sample

- Each file corresponds to a particular initial e^-/e^+ polarization and final state

  ftp://ftp-lcd.slac.stanford.edu/ilc/whizdata/ILC500/

  Have to mix polarizations by hand

- 500 fb^{-1} sample of these events generated with 80% e^-, 30% e^+ polarizations, randomly mixed events from all processes
  - ftp://ftp-lcd.slac.stanford.edu/ilc/ILC500/StandardModel/

- See Norman Graf's talk for more details

SiD Analysis Model

- Use FastMC to develop analysis algorithms
  - Input is final signal and SM samples in .stdhep format
- Use full MC (SLIC) and Perfect PFA as intermediate step to develop a realistic analysis
  - Accounts for material effects in VD and Silicon Tracker
  - Much more sophisticated than fast MC, has more tails in resolutions
- Use final tracking and PFA for the analysis when ready
  - A drop-in replacement of algorithms

Tools for Benchmarking

Java based org.lcsim framework

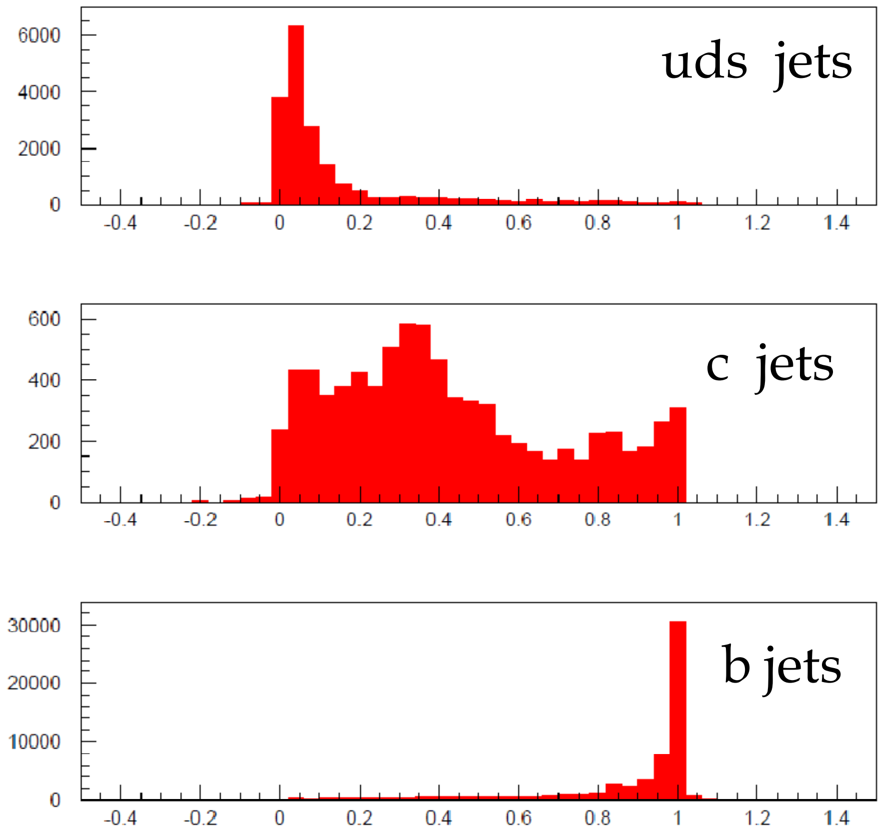
- org.lcsim FastMC
  - Smeared MC information
- org.lcsim full MC: SLIC
  - GEANT4 based
- Perfect PFA
  - by Ron Cassell
- Vertexing / Flavour tagging : LCFI package
  - See talk by Roberval Walsh
- Track reconstruction and Full PFA
  - See talks by Marcel Demarteau, Norman Graf and Marcel Stanitzki for status

Perfect PFA

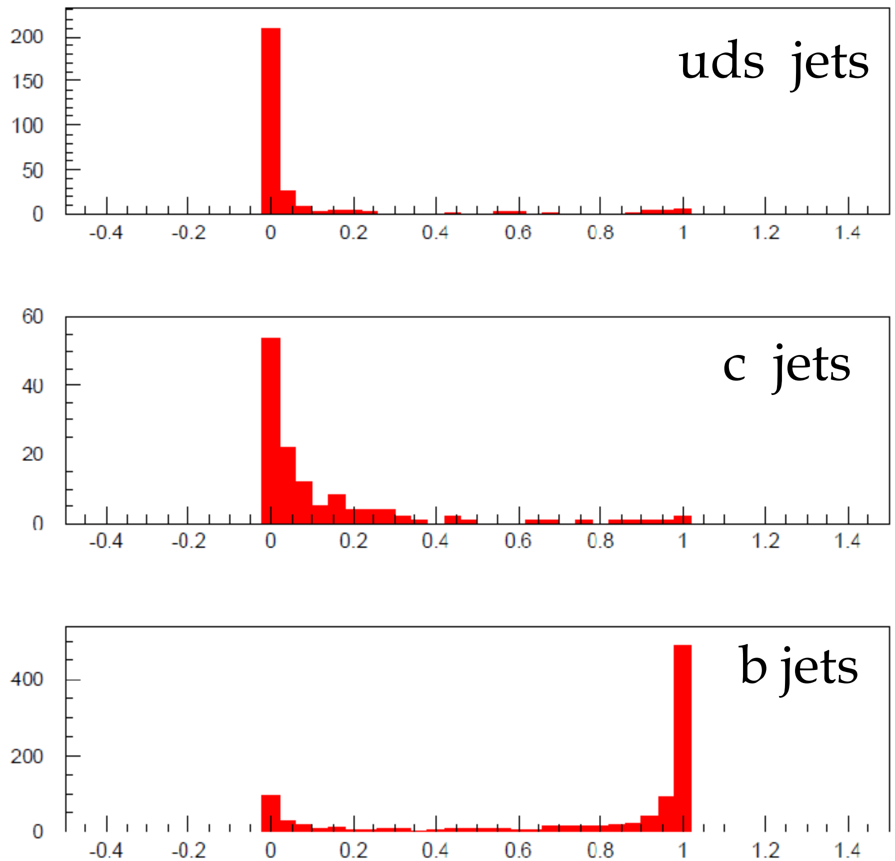
- Tracking
  - Define “trackable” charged particles
  - Smear as in FastMC
  - Full material effects (interactions and decays) before the calorimeter are taken into account
- Neutrals
  - For all “non-trackable” particles, assign energy deposits in the calorimeters
  - Do neutral particle reconstruction using those deposits with perfect pattern recognition (no confusion term)
  - Use actual detector responses for energy and direction
  - so most of the nasty nonlinear, non-gaussian effects are included

Flavour Tagging

- See considerable improvement, especially in charm ID, in ZHH analysis (T.Barklow) after switched to LCFI package



Before LCFI



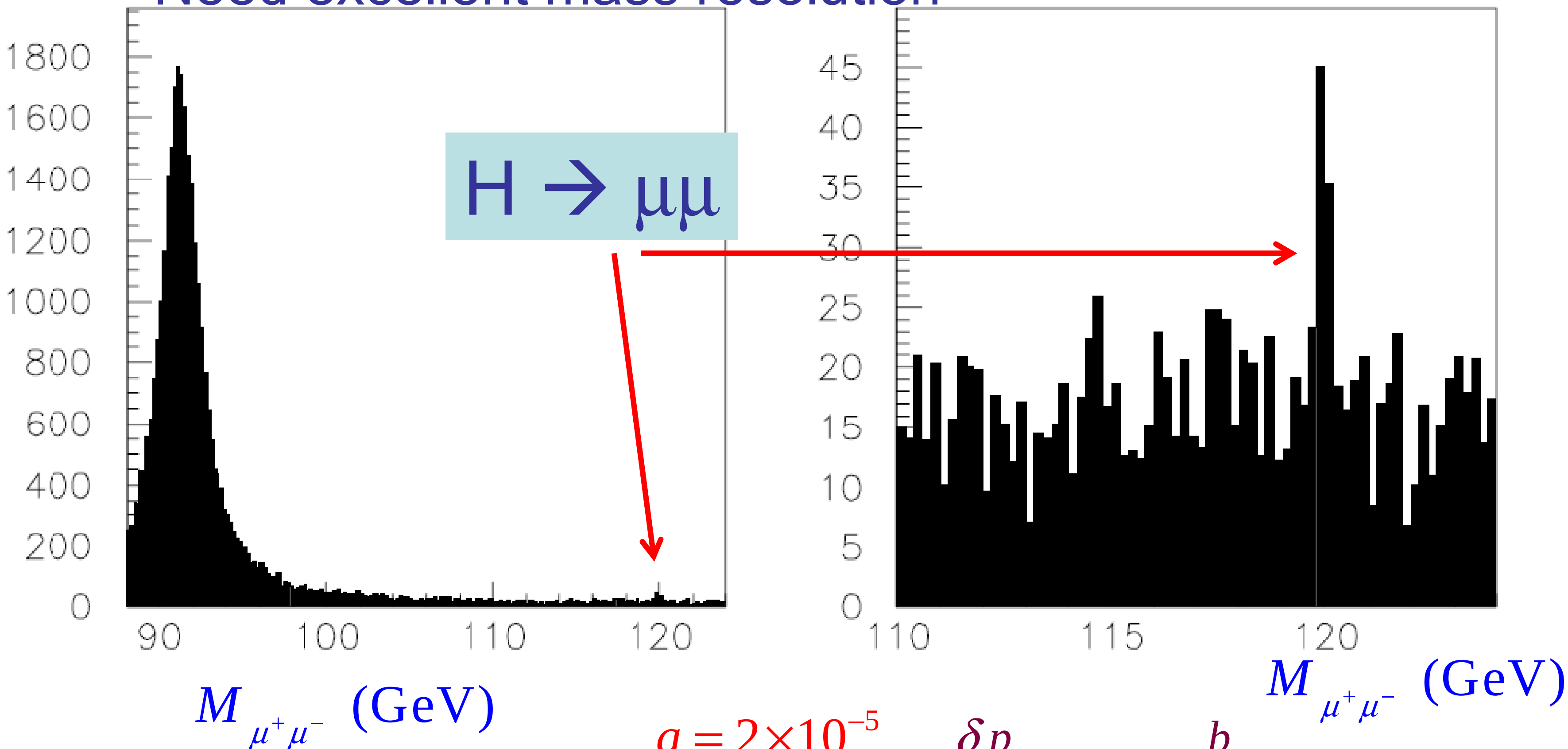
LCFI

Status of Benchmarking

- A number of analyses done previously used fast MC
  - ZH, ZHH, H→ $\mu\mu$, ttbar, chargino pairs …
  - ZH done for full MC
- Recent developments with tools
  - Switched to LCFI package for org.lcsim samples
  - Used Perfect PFA for ZHH analysis
- Started to work on analysis algorithms for Processes 1,2,4,5 from the compulsory list
- Pursue several other processes which are important for SiD
  - ZHH, anomalies in HF di-jets, cosmology motivated sbottom, top anomalous couplings, precise ee→$\mu\mu$, H→$\gamma\gamma$ (ECAL MAPS)

H→μμ (Process 1)

- One of important Higgs Br
- $M_{\mu\mu}$ distributions for NN>0.95 for signal and background summed
  - Need excellent mass resolution



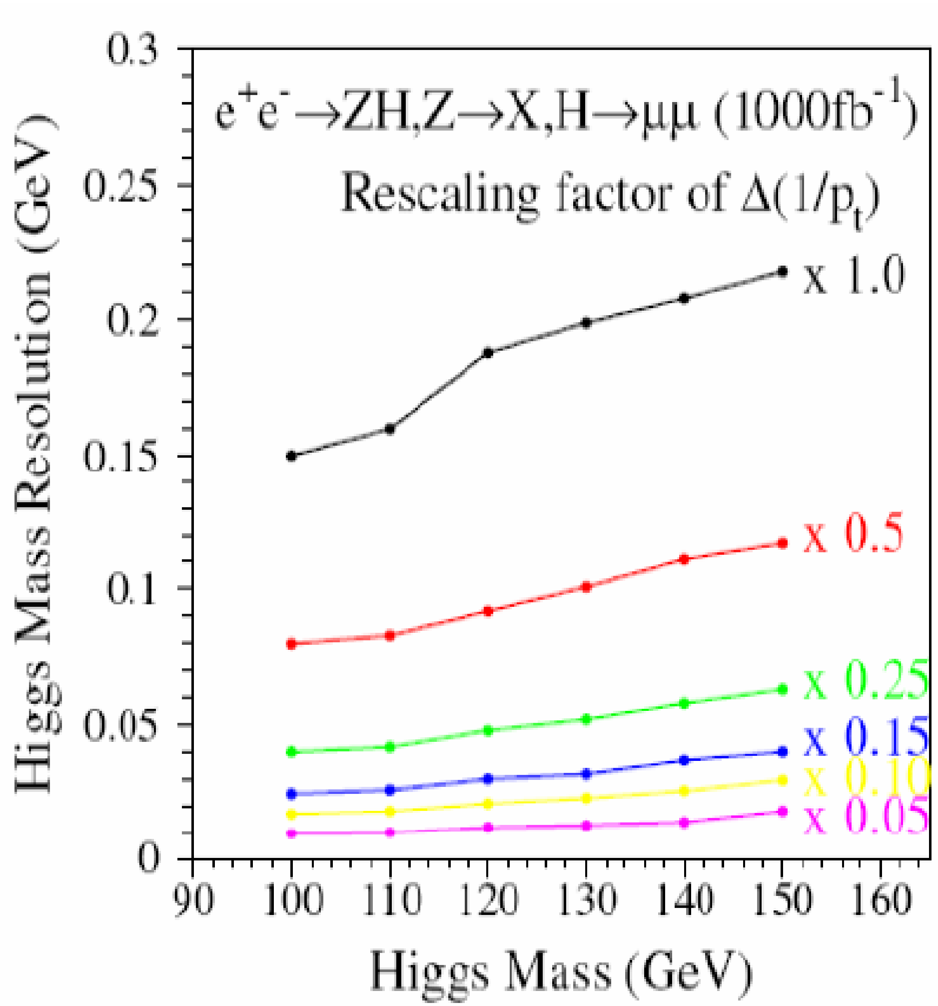
$a = 2\times 10^{-5}$

$b = 1\times 10^{-3}$

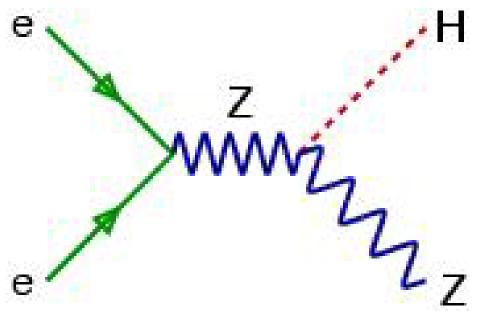
$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

H→μμ

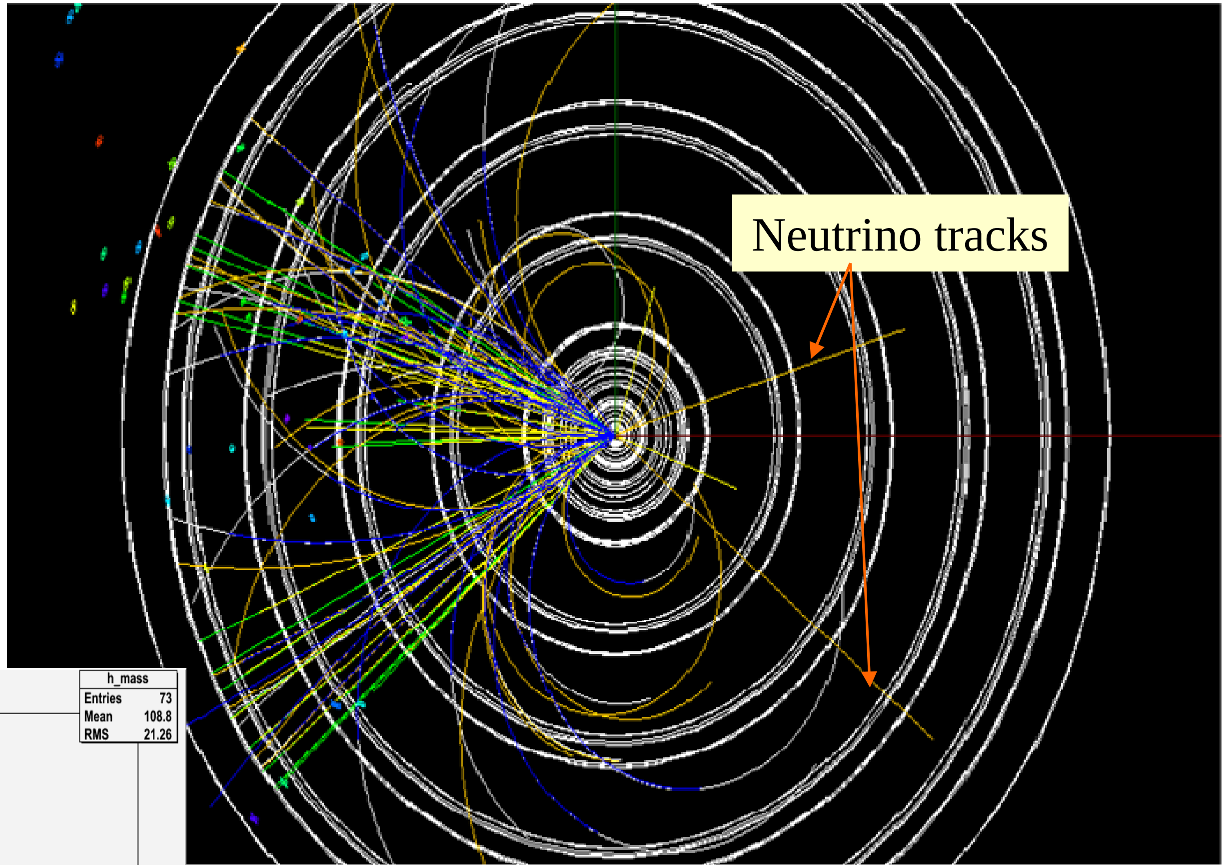
- Fast MC analysis maps Higgs mass resolution as function of momentum resolution (Haijun Yang)

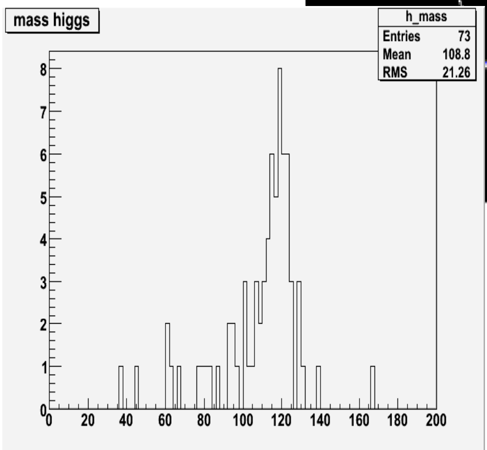


ZH→ccνν, ccqq (Process 2)



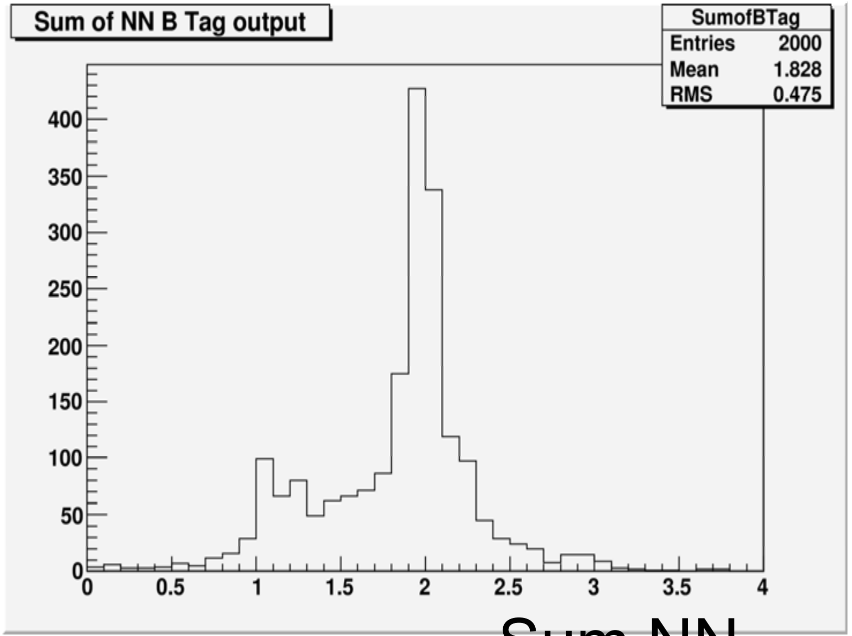
- Needs charm tagging which is difficult
- Main bkg H→bb and H→gg
- Work started
  - Y,Banda



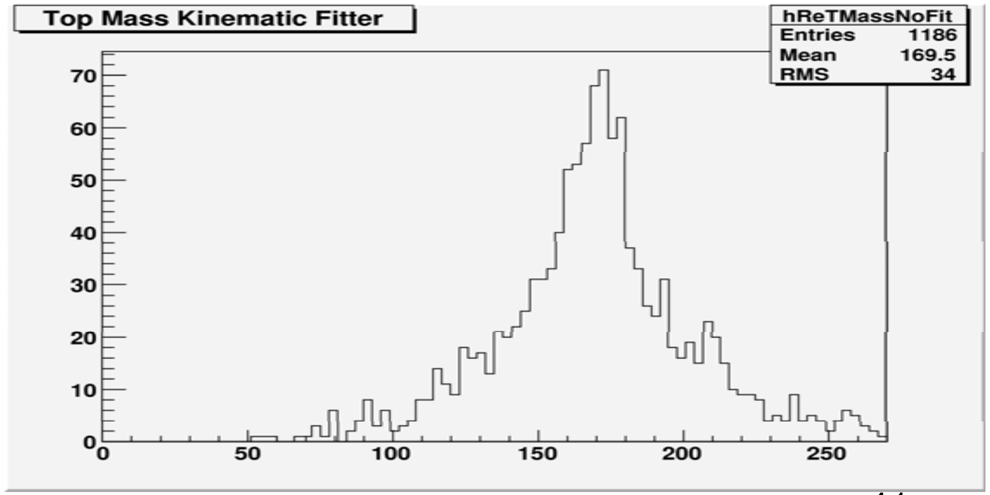


Top Pair Production (Process 4)

- Challenge: 6-jet final state
- Studied jet finding and b-tagging in dense environment (E.Devetak)
- First attempts to reconstruct top mass – work in progress
- Improving quark charge algorithms for asymmetry measurements
  - Top anomalous couplings



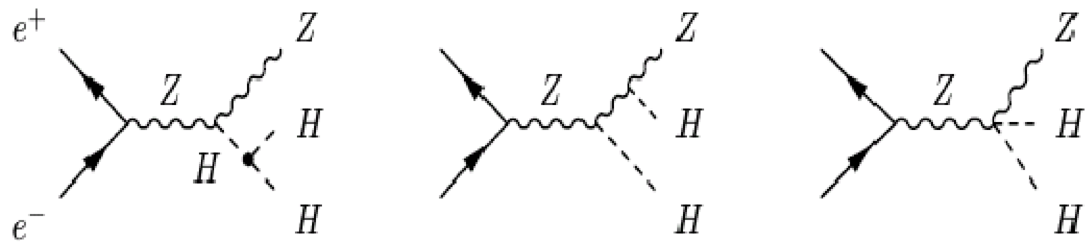
Sum NN



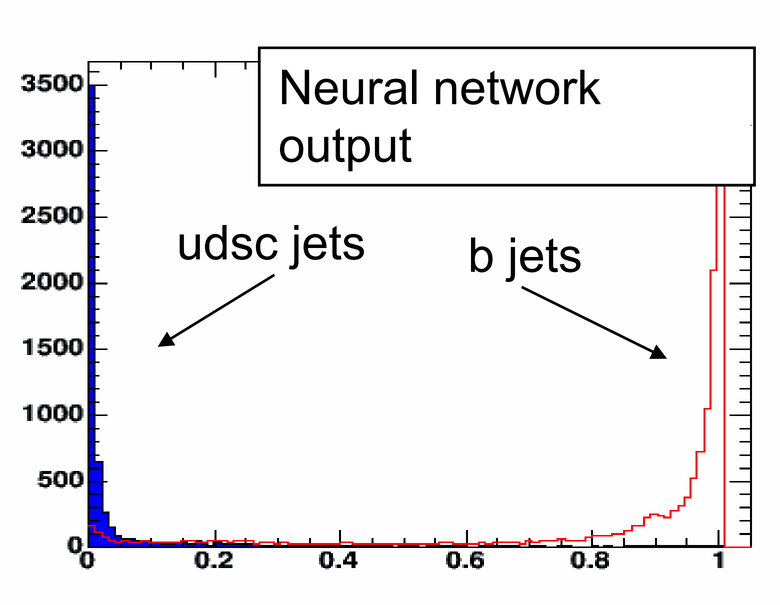
Top Mass, GeV

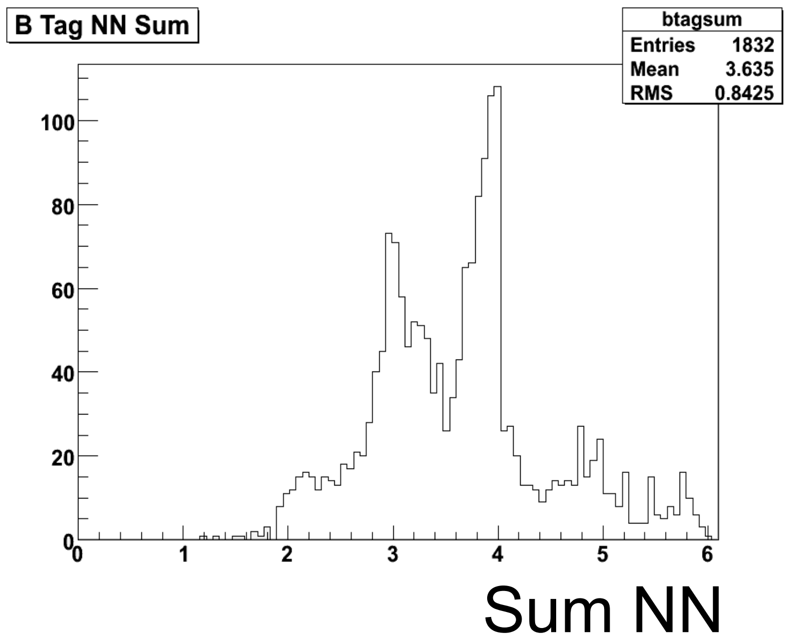
ZHH

Double Higgstrahlung: $e^+e^- \rightarrow H^0 H^0 Z^0$



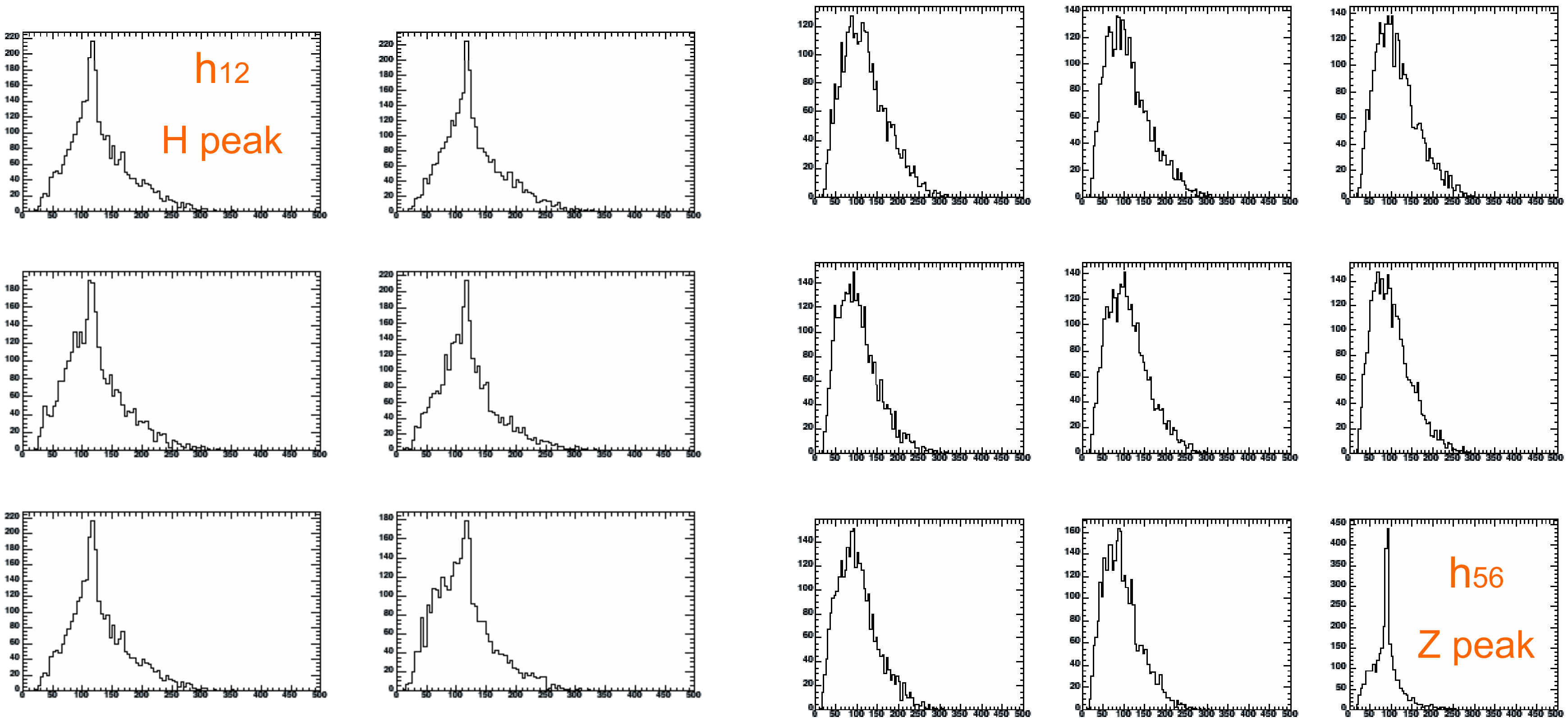
- Higgs potential can be derived independently from M_H and from g_{HHH} and compared
- Four b-jets in the final state → b-tagging is very important
- Using Perfect PFA to develop algorithms (T.Lastovicka, Y.Li)





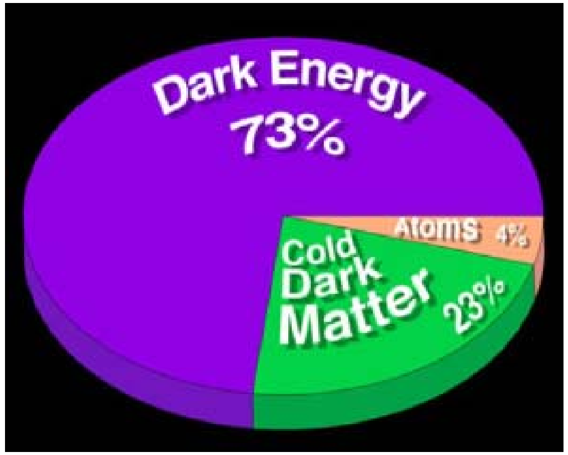
ZHH

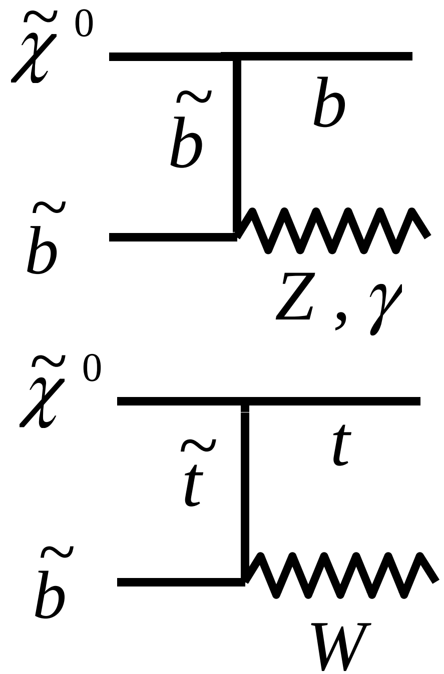
- Invariant masses: clear H and Z peaks
  - Jets ranked in b-tagging NN output
  - Will be used in selections



Cosmology Motivated SUSY Scenarios

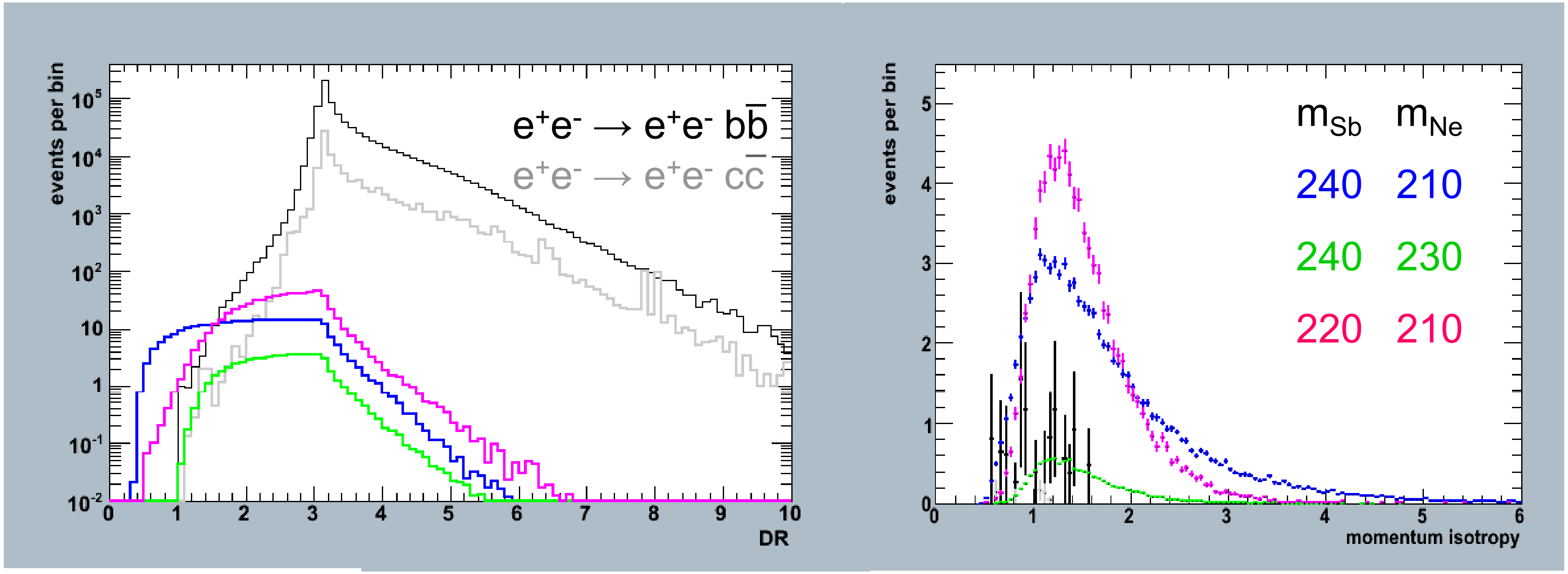
- In SUSY : DM is neutralino, co-annihilation with other SUSY particles regulate how much DM is left after Big Bang
  - Need small mass splitting
- Small mass split between LSP and NLSP = small visible energy in the detector
  - ee → stops, sbottoms, staus
  - Important case to motivate the massless Tracker with zero P_T cutoff
- Large two –photon backgrounds





Sbottom Pair Production

- Two photon bb production is the main bkg
  - Analysis by T.Lastovicka, G.Medin, A.Belyaev
- Developing selections, evaluating b-tagging for small jet energy
- Signal and bkg before and after cuts



Countdown for LoI

- April 2009 : submit LoI
- February 2009 : results available
- October 2008 : all MC samples available
  - SM sample is most CPU intensive
- September 2008 : start production
  - Reconstruction ready
- September 2008 : all analyses developed on fast MC and PPFA, generator level samples ready

Summary

- SiD will be optimized in steps
  - Global parameters, driven by magnet and calorimeters
  - Then all subsystems
  - Then benchmarking
- Developed a cost model which can be referenced to physics performance
- Full simulation and reconstruction tools had good progress in the last months
- Benchmarking effort has taken off

- SiD is on track to LoI