Simple and Complex Objects: Strategies for Event Reconstruction at the LHC

Lecture III:

Combining Objects- Top, Higgs , SUSY

Marjorie Shapiro

UC Berkeley/LBNL

August 12

Outline

- Top
  - Production and Decay
  - Analysis Strategy
  - Object 7: b-quark jets
  - Mass Reconstruction
- Higgs
  - Production Modes
  - Decay Modes
  - Object 8: Photons
  - Some example searches
- SUSY
  - Why?
  - Production
  - Analysis Strategy
  - An example analysis

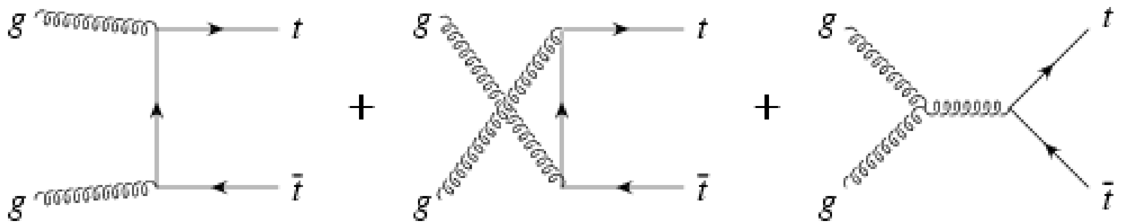
The Top Quark

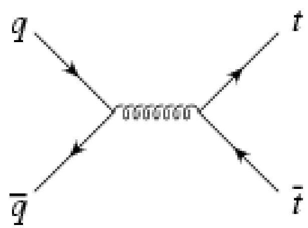
- First discovered at Tevatron more than 10 years ago
  - But still have only isolated hundreds of events
- What do we know?
  - Mass: 171.4 +- 2.1 GeV (CDF/D0 combined)
  - σ Tevatron: 7.3 $\pm$ 0.5(stat) $\pm$ 0.5 (sys) $\pm$ 0.4 (lumi) pb (CDF)

    $8.6^{+1.3}_{-1.7}$ (stat) $\pm$ 1.1 (sys) $\pm$ 0.6 (lumi) (D0)
  - BR ($t \rightarrow Wb$): > 0.61 95% CL (CDF)
- LHC will produce 1 ttbar pair per second

  Opportunity for precision measurements
- Excellent sample for testing complex reconstruction strategies

Top Production





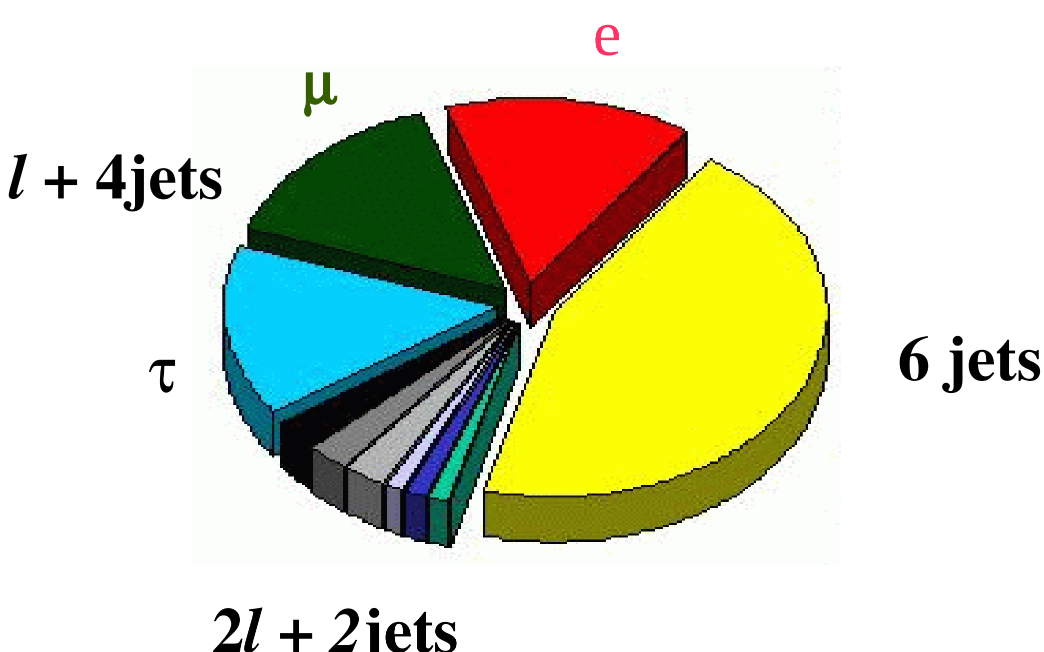
90% gg, 10% qq at LHC

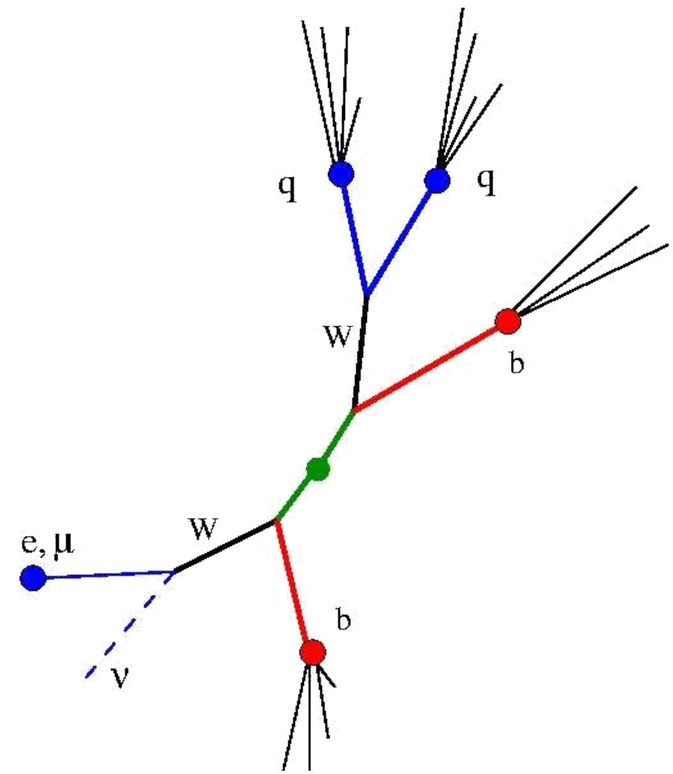
15% gg, 85% qq at Tevatron

- Strong Production: Tops are pair produced
  - (EW production of single top also possible: W $\rightarrow$ tb)
- At Tevatron, production suppressed but to high top mass (small parton luminosities)
- S:B much better at LHC

Top Decay

- t $\rightarrow$ Wb BR 100% in Standard Model
- Top lifetime $\cong$ 5 x 10^{-25} sec:
  - Decays before it hadronizes
- Top pair production gives:





- Fully hadronic: 4/9
- Single lepton: 4/9
- Dilepton: 1/9

Top Reconstruction: The Basics

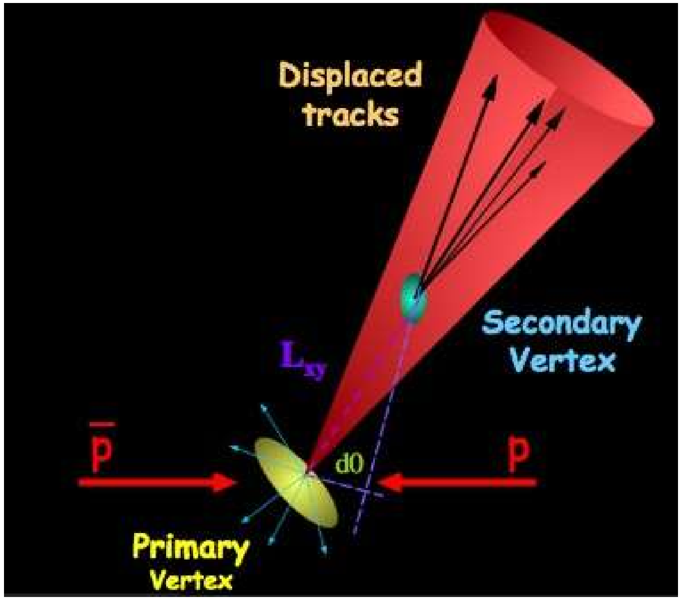
- Top pairs yield 6 high P_T objects
- Separate search strategies for dilepton, single lepton and all-hadronic modes
  - Dileptons clean, but 2 ν so full reconstruction of mass not possible
  - Single lepton: Good S:B. This is the golden channel
  - All-hadronic: Must separate signal from QCD background: possible with b-tagging (more later)

Top Analysis Strategy

- Goal: Maximize top signal while reducing QCD bckgnd
- Top decays products central and at high P_T
  - Typical Tevatron cuts: P_T > 15 GeV and $\eta < 2$
- Di- and single lepton channels have missing E_T
- All channels have large total energy in our objects:
  - Define $H_{T} = \Sigma E_T$ over the reconstructed objects
- Two b-jets in final state: identification of jets from b-quarks greatly reduces background

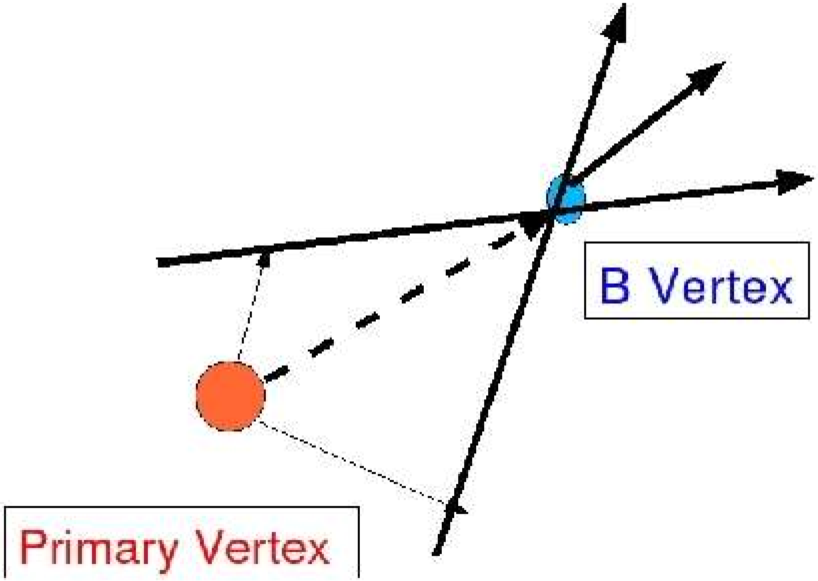
Object 7: Jets Produced from b-quarks

- Characteristics of B decays:
  - B lifetime long: $c\tau \sim 460\ \mu$
  - Semileptonic BR 10% per lepton species
- Two methods of b-tagging
  - Displaced vertex (or track from it)
  - “Soft” leptons close inside jets
- Vertex tagging has higher efficiency and better purity
  - But can combine both techniques



B-Tagging From Secondary Vertices

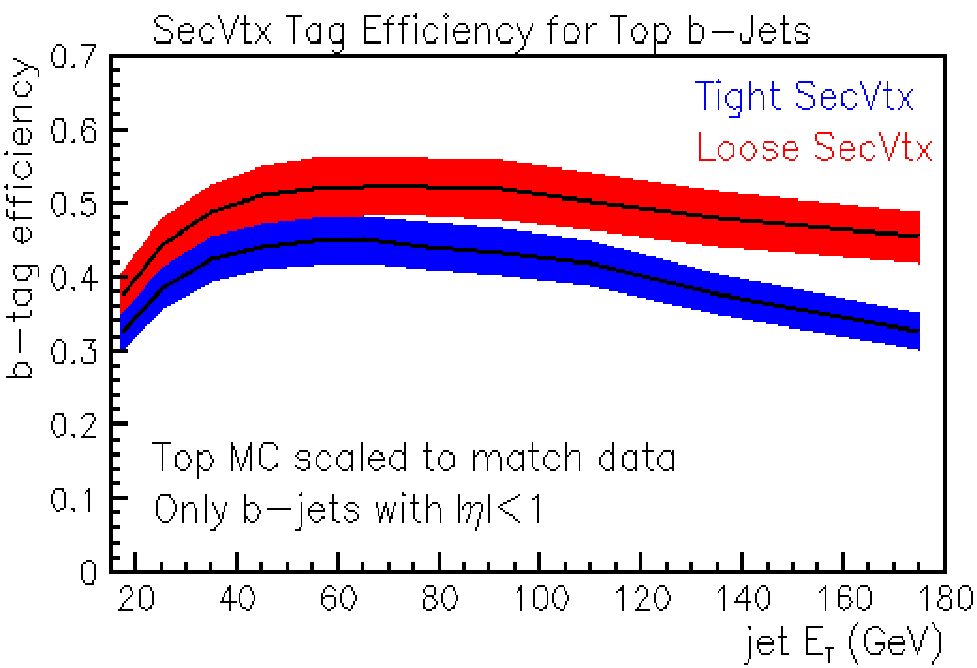
- Study track impact parameter
- Two options:
  - Secondary Vertex Finding:
    2 or more tracks consistent
    with a single vertex
  - Jet Probability:
    Combined likelihood that all
    tracks come from primary
    vertex

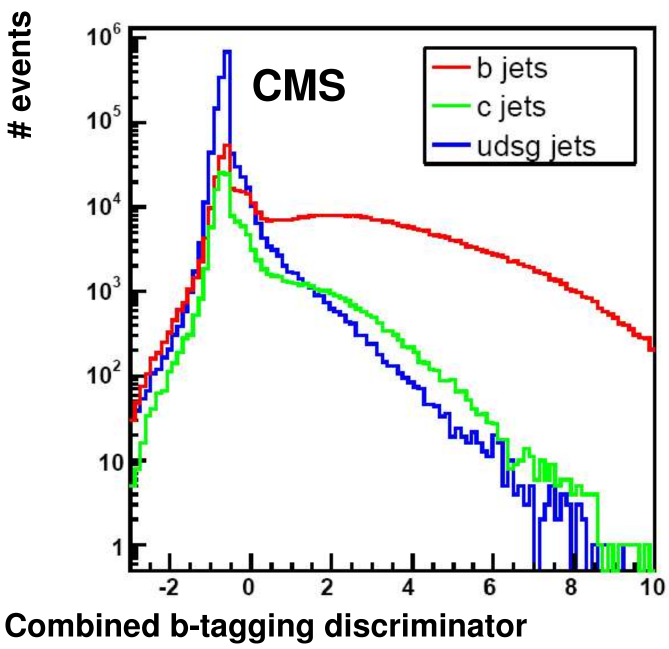


Details of algorithm discussed in Aaron Dominguez's talk Monday

b-Tagging Performance Depends on Background

- Charm also long-lived: less rejection
- Performance E_T dependent

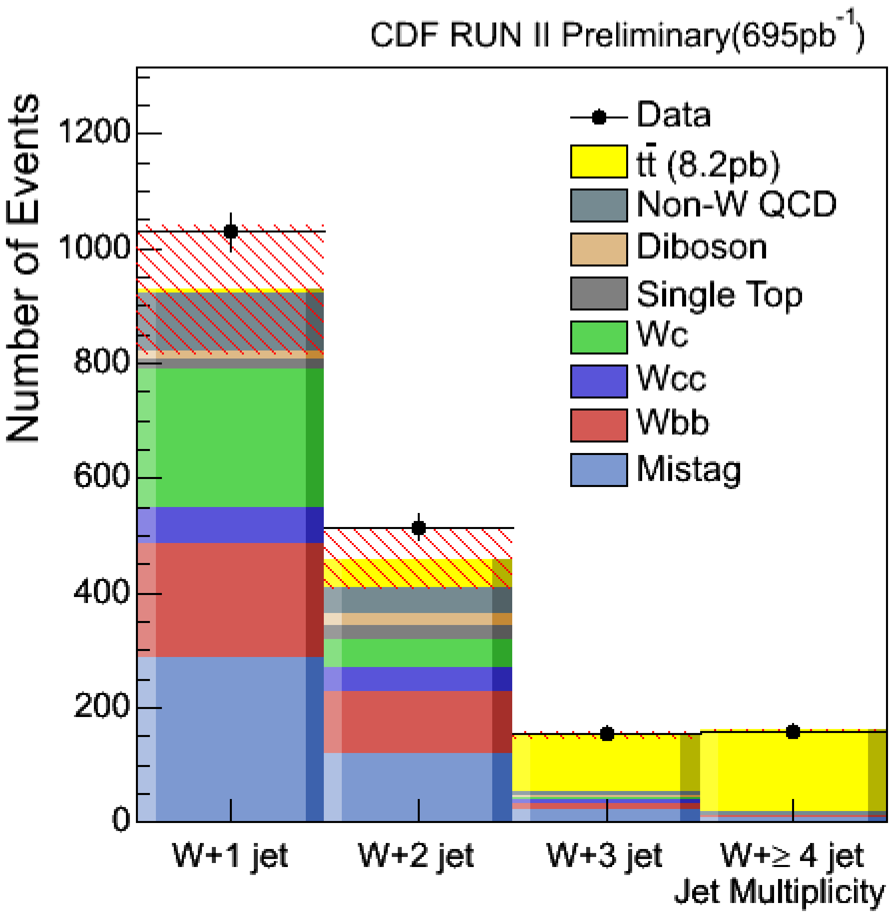


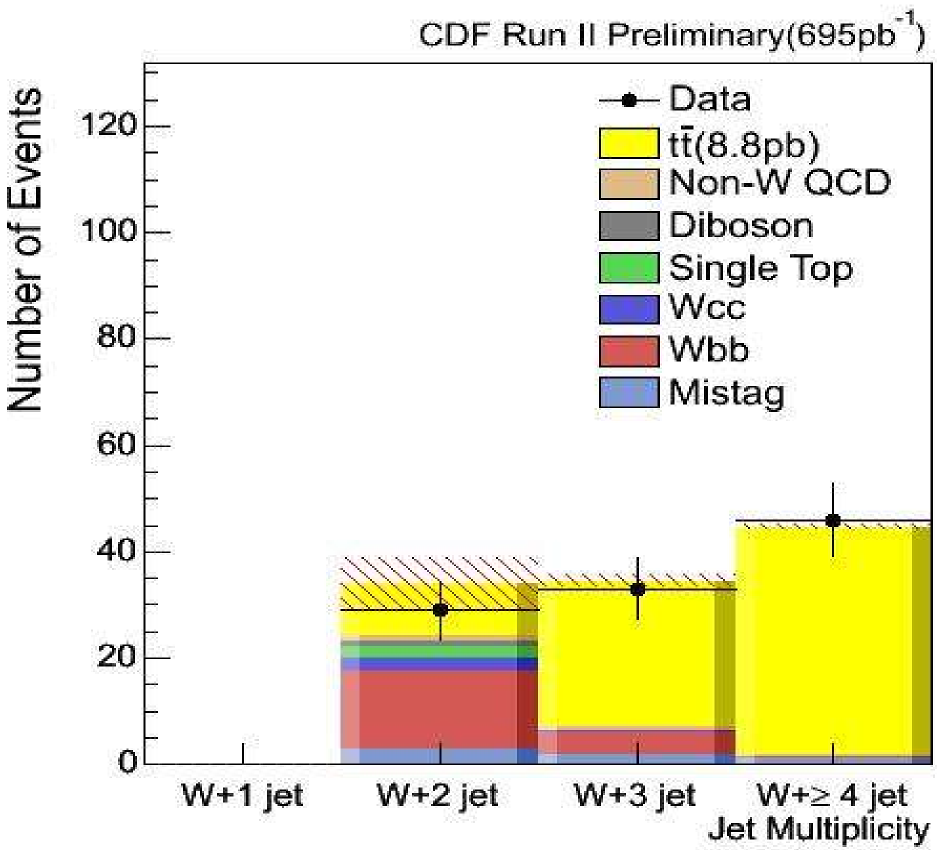


Reconstructing Top in Single Lepton Channel

- Sample contains lepton, missing energy and 4 jets
  - 2 jets reconstruct to W mass
  - 2 jets are b jets
  - W+b-jet reconstructs to Top
- Many possible combinations: Can apply above constraints to pick right matching or use all combinations with appropriate probabilities
- Signal can be observed without b-tagging if strong H_T cut applied
  - b-tagging reduces combinatorial background

With b-tagging, Top dominated sample can be selected at Tevatron



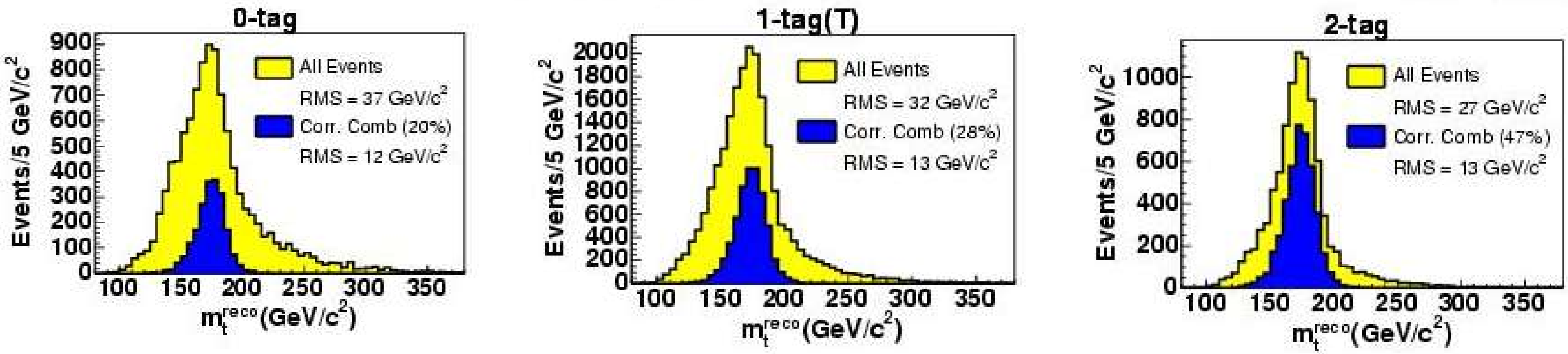


Single b-tag and HT>200 GeV

Double Tag

Using b-tags to Select Correct Combination in Top Events

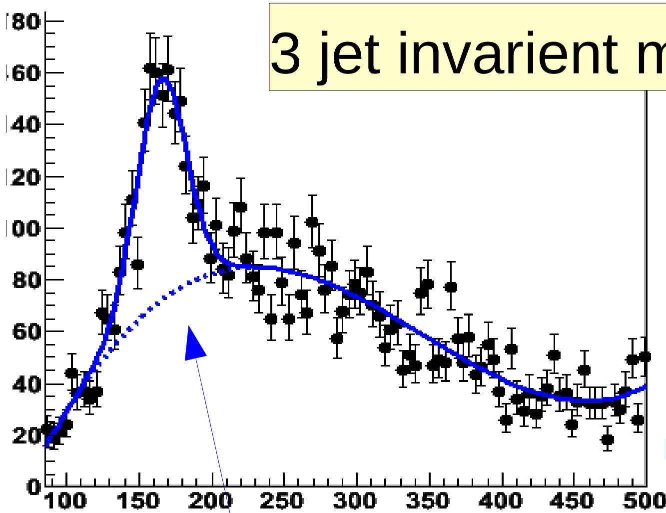
CDF study



Signal only: All combinations of jets to form 2 Top Decays

- b-tagging increases probability of selecting correct combination: improved resolution

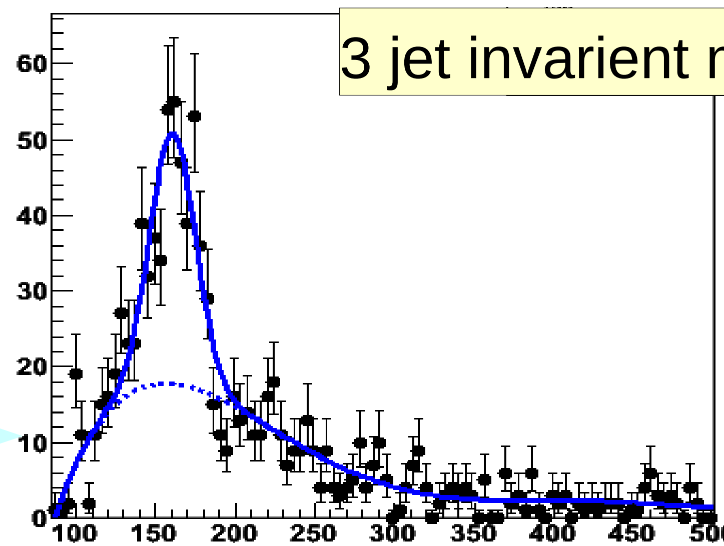
Top at the LHC



3 jet invarient mass

No b-tagging

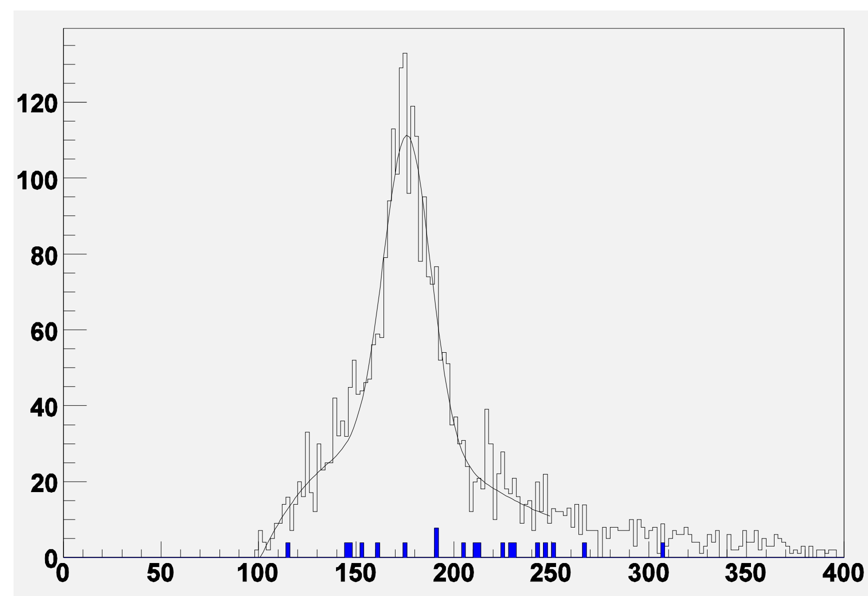
Cut on W Mass



3 jet invarient mass

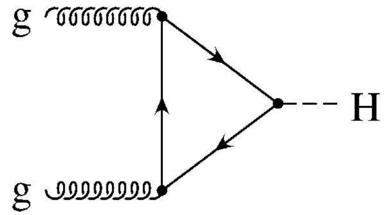
W+Jet background

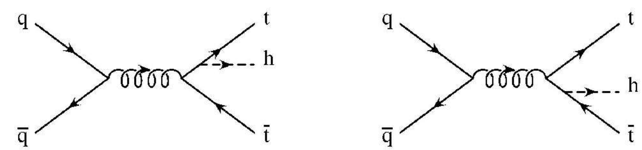
After Requiring 2 b-tags:



Higgs Production at LHC
(reminder from Sally Dawson's talk)

gluon fusion

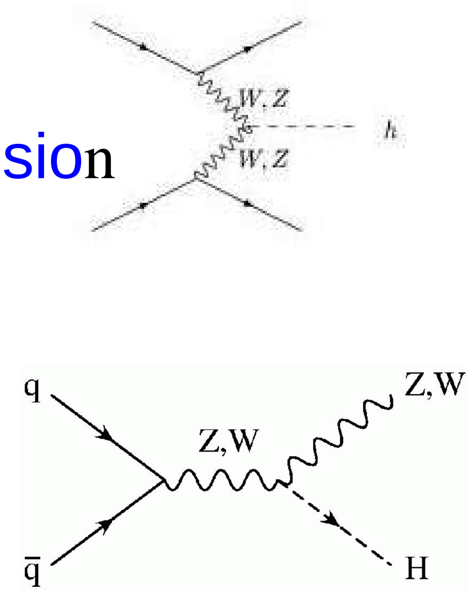


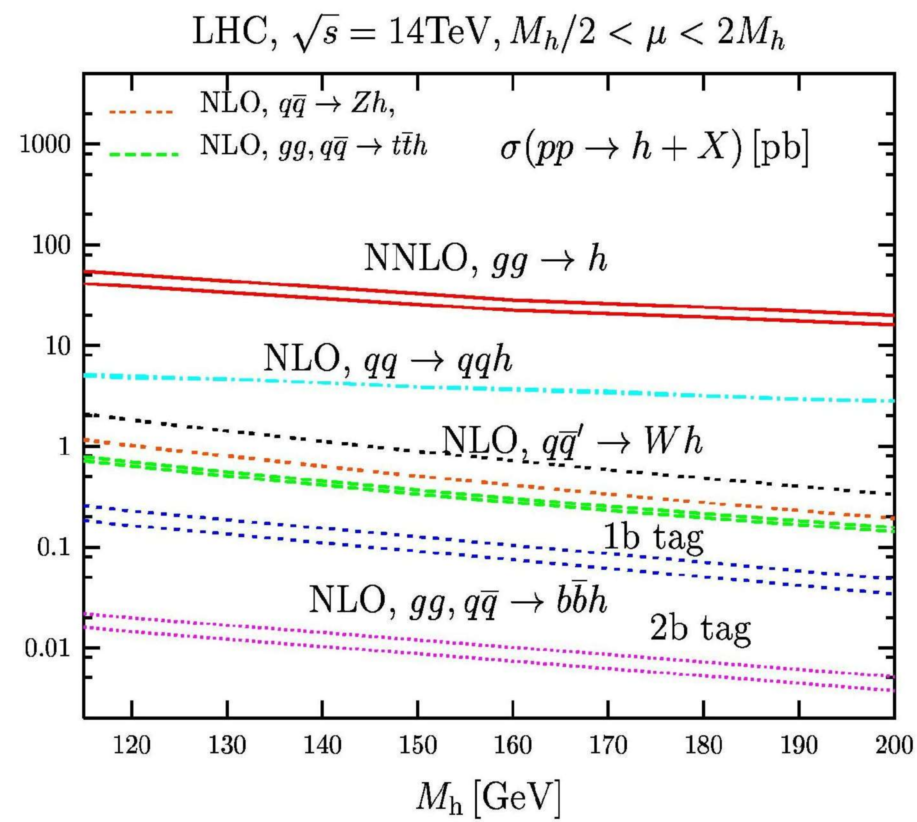


ttbar-h

vector boson fusion

W(Z)-strahlung

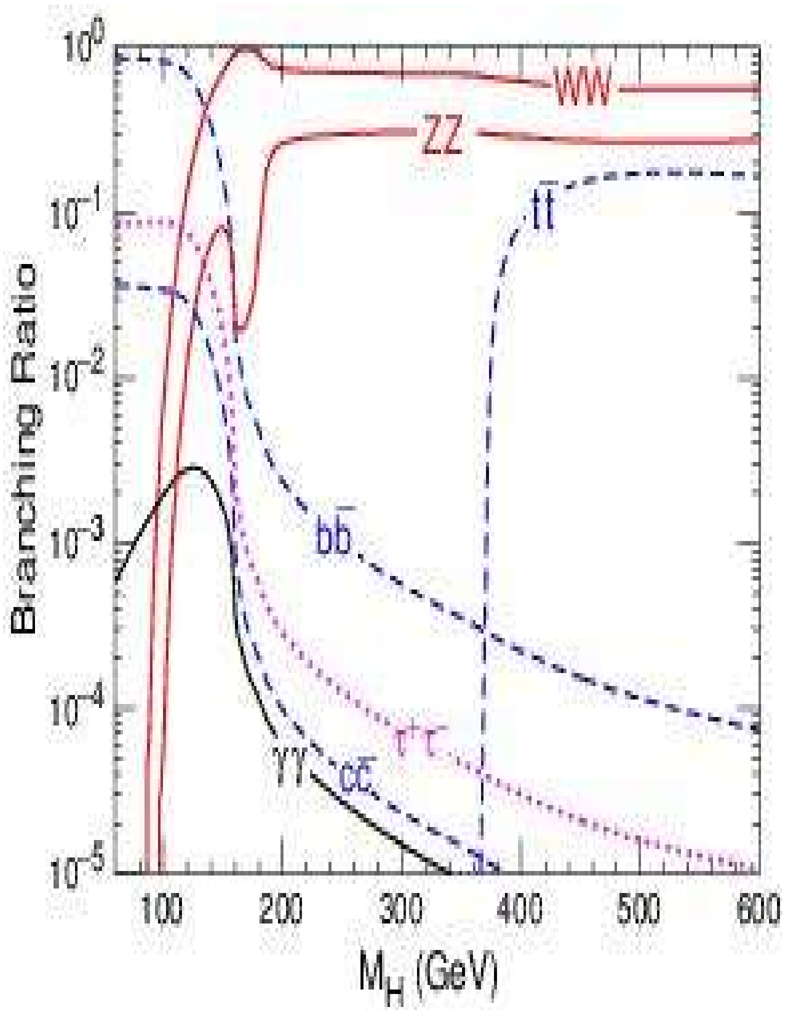




Each channel has its own signature

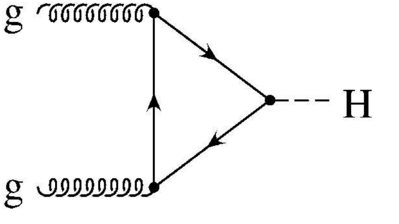
Decays the SM Higgs

- Higgs decay modes depend on Higgs' mass
- Couples to heaviest accessible particles
- Some modes easier to observe that others
- Greatest experimental difficulties in the low mass region



Low Mass Higgs: h$\rightarrow\gamma\gamma$

- Direct Production has largest rate
- But cannot see dominant h$\rightarrow$ bb decay above bckgnd
- Photon decay mode rare, but very good mass resolution possible (ECAL design critical)
- Will require every trick in the book



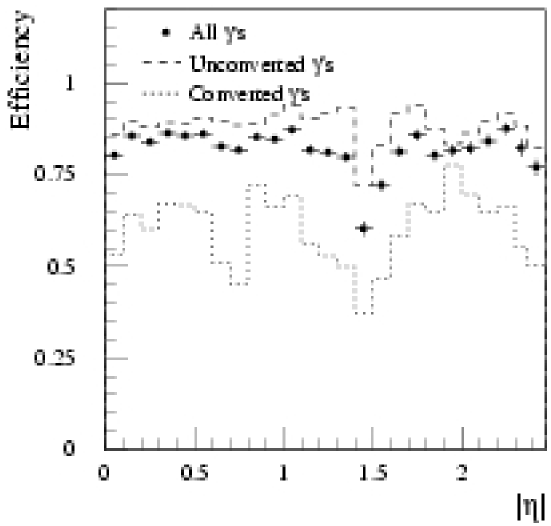
Object 8: Photons

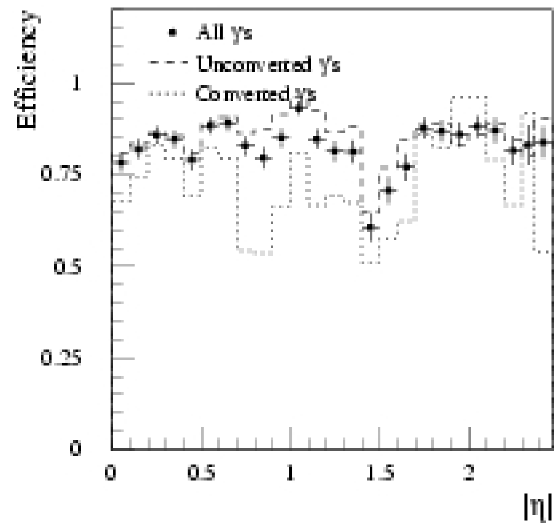
- Use same variables as for electron selection, with tighter cuts
  - Unconverted photons have track veto
  - Converted photons independently analyzed by looking for the second track
  - Emphasis on shower shape variables
    - Photons shower later than electrons
    - π^0 decay to 2γ so probability of early shower twice as large
- Isolation is critical

ATLAS and CMS have different emphasis due to different detector designs, but overall performance for Higgs similar

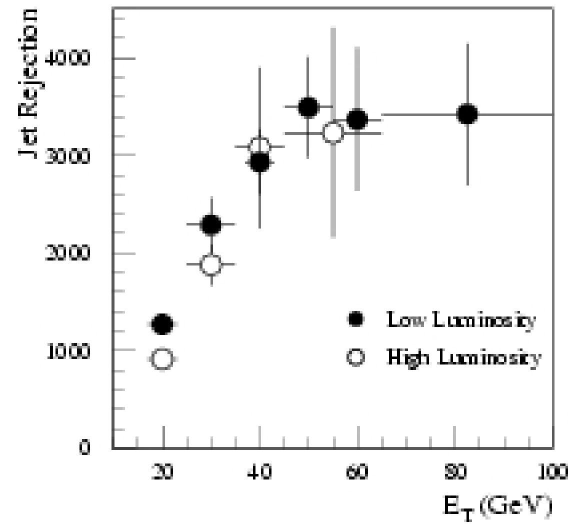
Efficiency and Background Rejection for Higgs Photons

Atlas: Efficiency: Low and High Luminosity

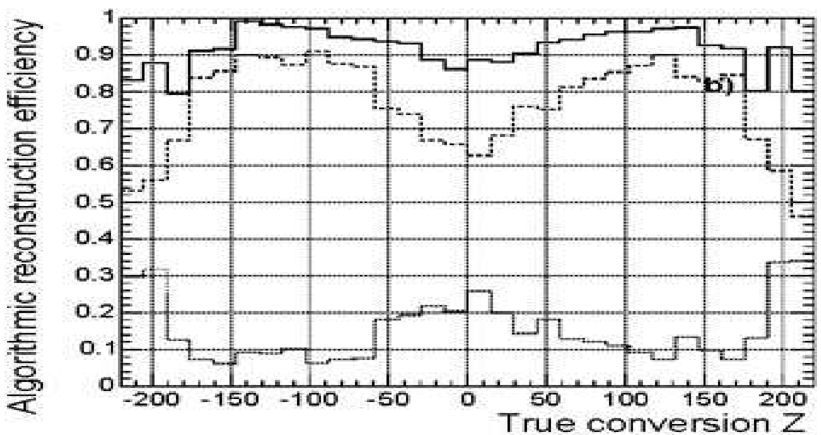




Atlas Jet Rejection

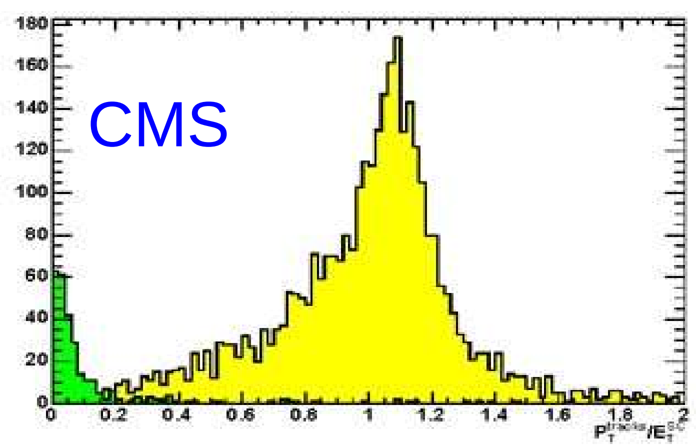


CMS



Conversion Probability vs η

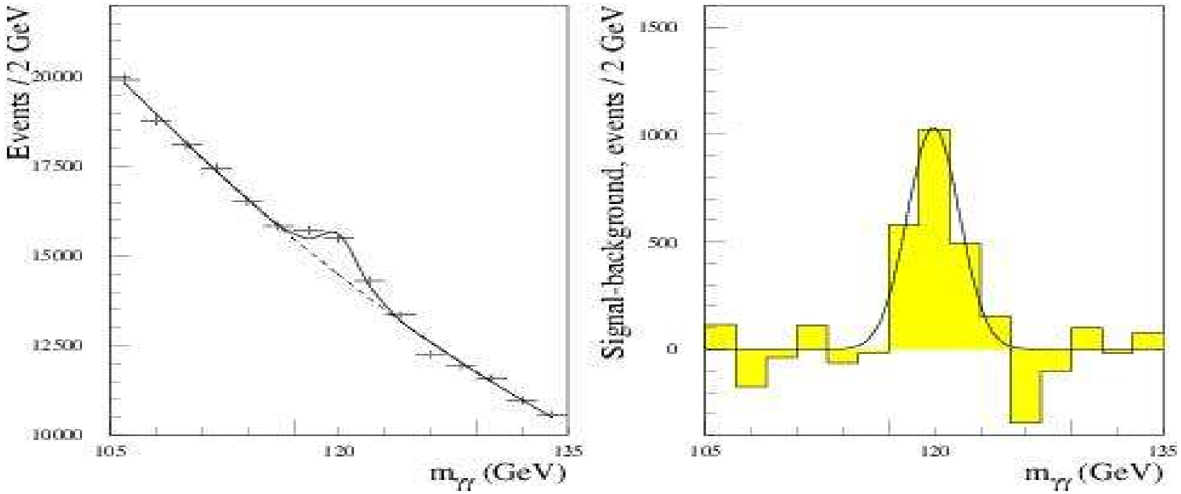
CMS



Pt Tracks/Et ECAL

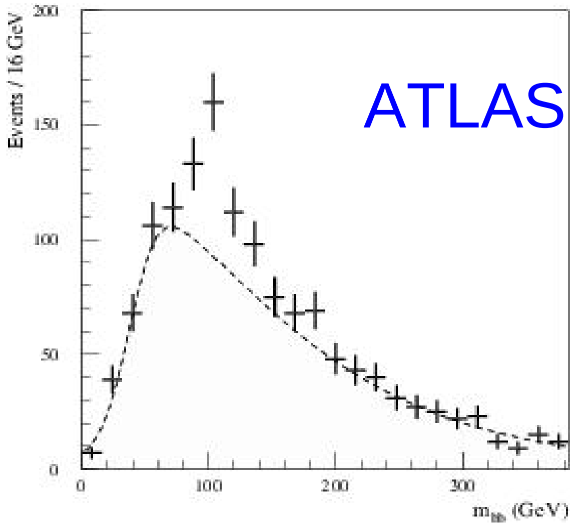
Irreducible Background for $h \rightarrow \gamma\gamma$

- Even best particle ID cuts can't remove real photons
- Background from QCD production of di-photons large
  - Must subtract large background statistically



ATLAS: 100 fb^{-1}

Other Higgs Modes: See Sally's Talk for More

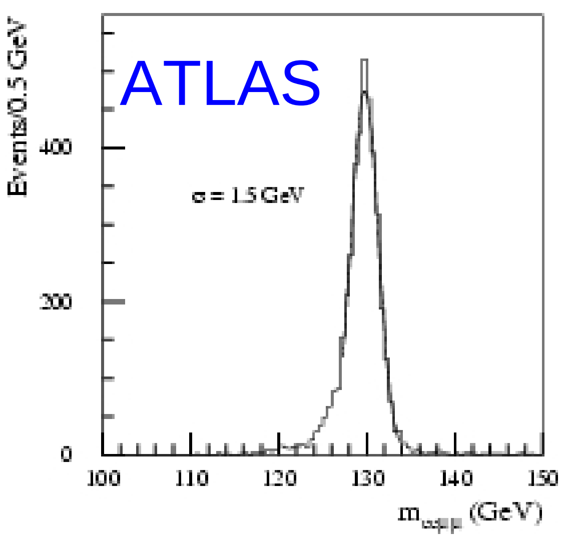


M_{bb} for tt-higgs Events

M_H=100 GeV

Issues:

- bb peak close to threshold
- uncertainty in rate
- large background
- difficult, busy events

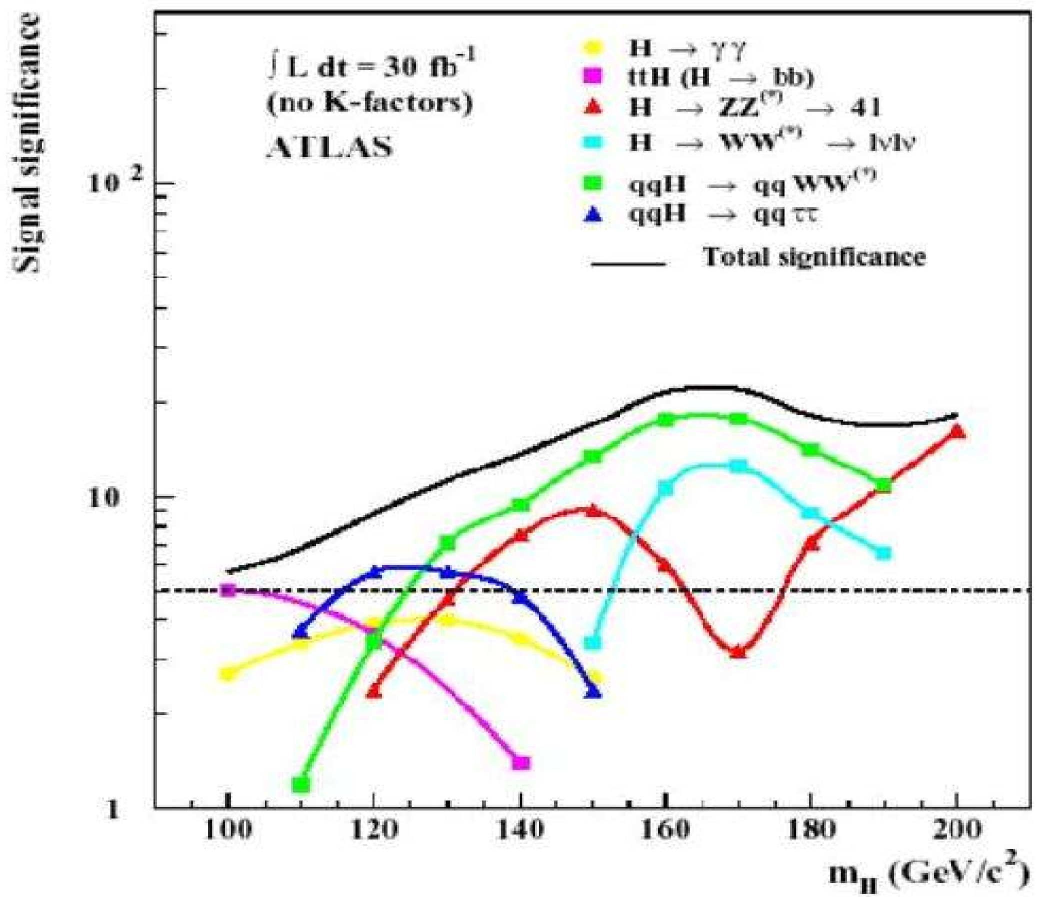


$M_{ee\mu\mu}$ for ZZ^* Events

M_H=130 GeV

Clean Signal, little background

Higgs Sensitivity vs Mass



3 Years Initial Luminosity Running

Supersymmetry (SUSY)

- Partner for every know particle
  - fermions have spin 0 partners
  - bosons have spin ½ partners
- Theoretically favored extension to SM
  - Solves hierarchy problem (sparticle and particle loops cancel)
  - Provides Dark Matter candidate
  - Required by String Theory
- Requires 5 Higgs bosons (h, H, A, H+-)

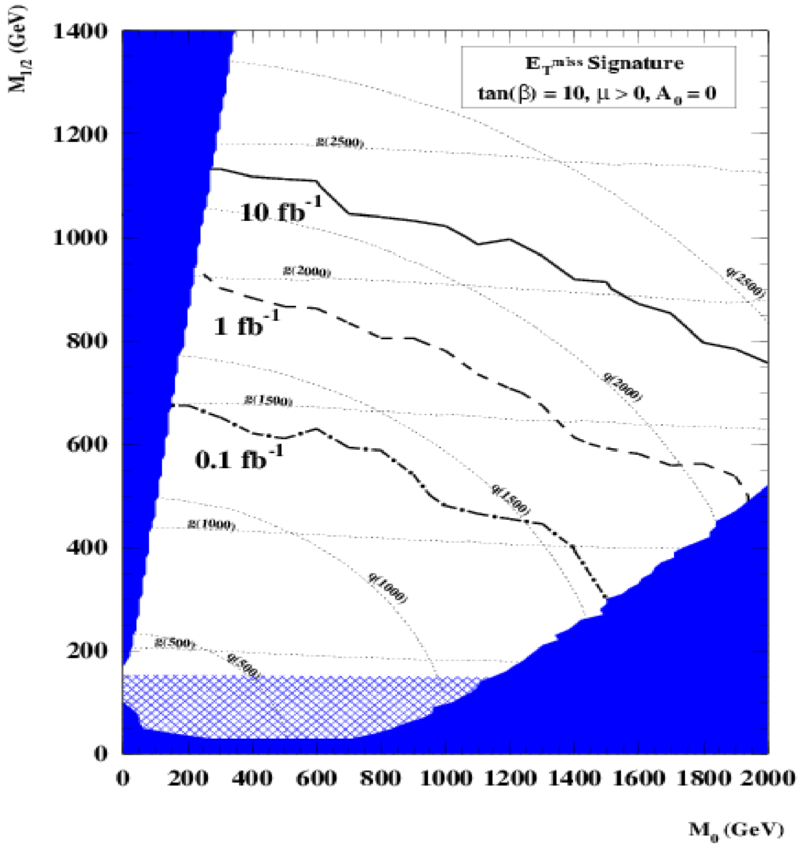
If SUSY the source of EWSB, then expect sparticles at the TeV Scale

- Since each know particle has a partner, large number of sparticles to be discovered
- Spectrum of masses very model dependent
- In general, strongly interacting particles the heaviest: they decay to gauginos
- Lightest SUSY particle (LSP) stable (or quasi-stable)

Signals with apparent missing momentum

How Fast Can SUSY be Found?

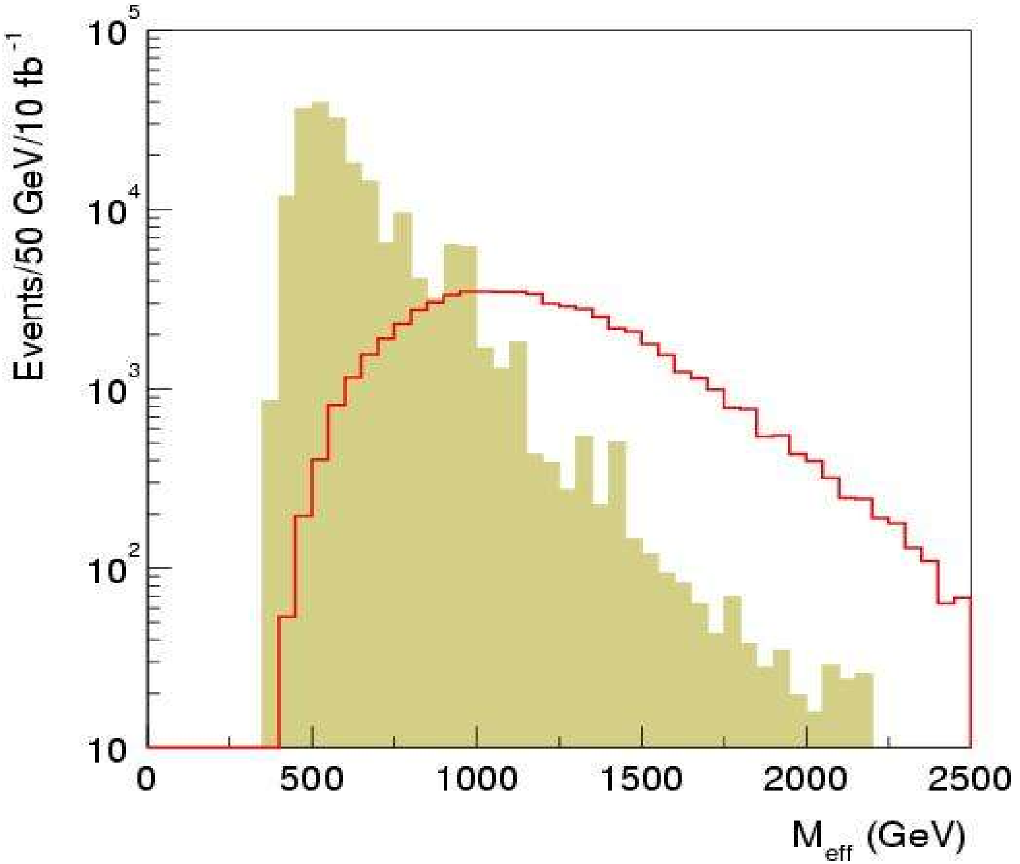
- Plot shows reach in SUSY space
- Solid regions not allowed
- Hatched region ruled out by LEP
- Contours in luminosity for specified squark and gluino masses
- Example: 100 pb-1 discovers gluino of 1TeV



<u>We must be ready for Physics on Day 1</u>!

How SUSY Might First Be Observed

- Select events >= 4 jets and missing Et
- Meff: Sum of 4 jet and missing Et's
- Peak correlates well with SUSY mass scale
- Example has Susy masses ~700 GeV
- Signal characteristic of any model with new particles (strongly coupled) at large mass



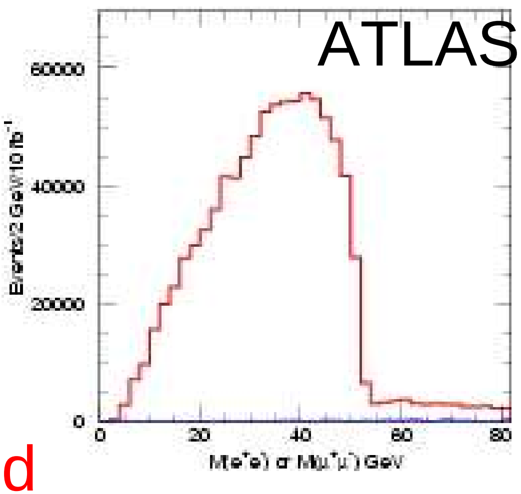
If SUSY is Found, Will Require Many Measurements to Constrain Model

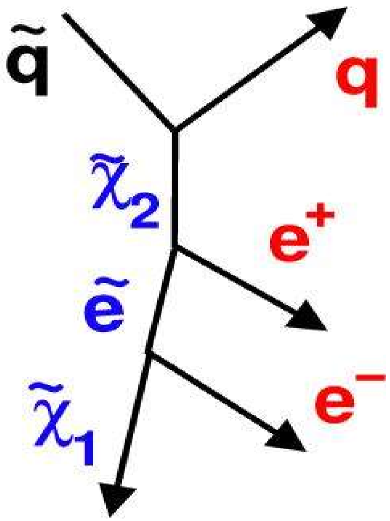
- Different SUSY models will have different phenomenology
  - Must explore different regions in SUSY parameter space
- Basic Principle: Work down decay chains
  - Measure masses and mass differences
  - Test universality among generations

Using Kinematics to Constrain SUSY models

- As an example, take the squark decay to q e^+ e^-
  - Dilepton mass has endpoint at χ2-χ1 mass difference
- SUSY is pair produced: For event selection require:
  - 2 isolated leptons (opposite charge, same species)
  - 2 high Pt jets
- Plot dilepton invariant mass

Clear kinematic bound
observed in mass spectrum





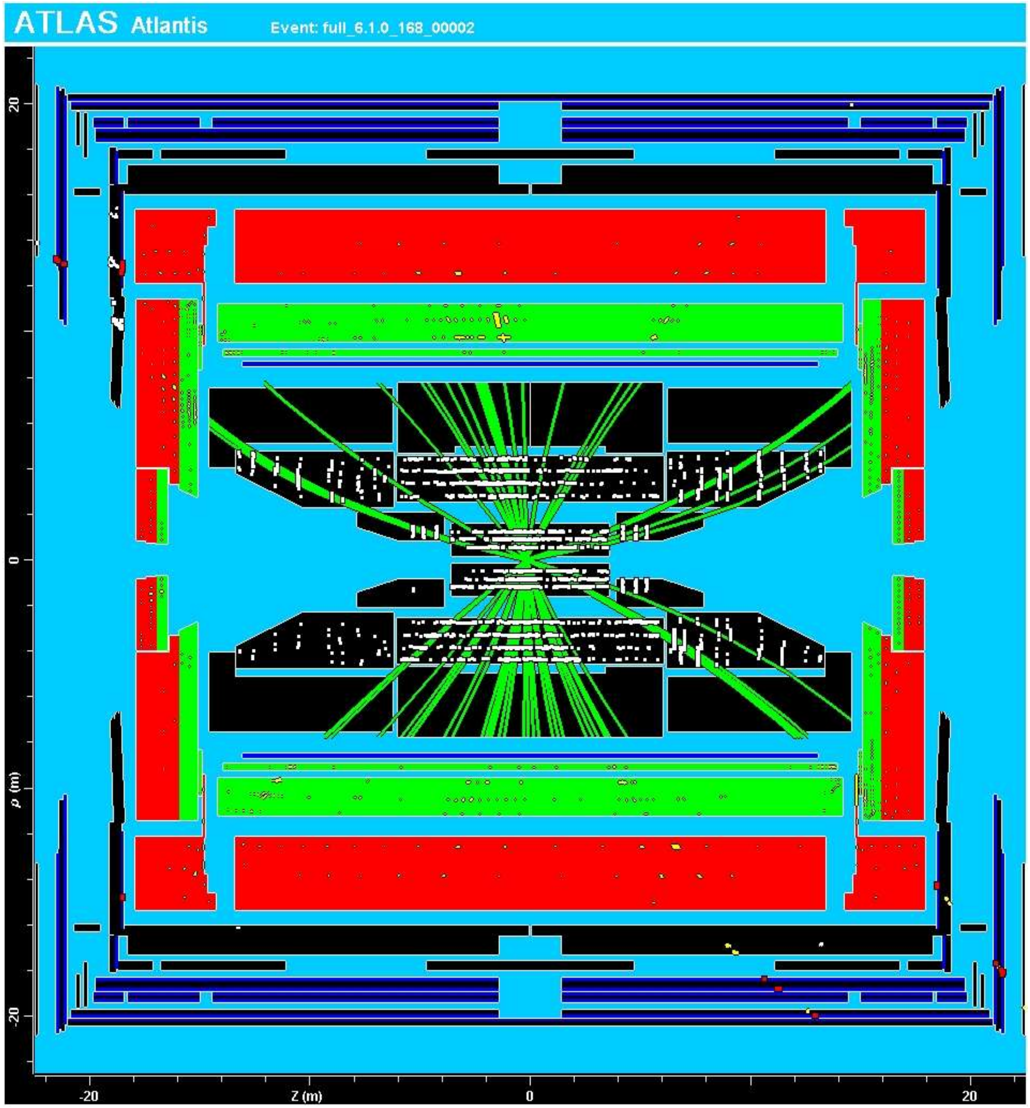
Many other examples explored

Many Other Things are Possible Besides SUSY

- We don't know what causes EWSB
- No reason to believe SUSY is right
- Many other possibilities for new phenomena
  - New W or Z
  - WW, ZZ resonances (a la technicolor)
  - Extra Dimensions

But whatever we find, it will decay into the particles of the SM and its backgrounds will be the SM

A Mini-Black Hole as Simulated in the ATLAS Experiment



Are you ready to find this?

Conclusions

- Clean samples of the fundamental objects (jets, charged leptons, neutrinos, photon, b-jets) can be reconstructed as LHC
- Selection criteria must be optimized for relevant physics
- Simple objects can be combined to find more complex ones: W, Z, Top, Higgs, SUSY, Black Holes ...
- There's an exciting new world about to open up

You will all be part of it !