LBNL and Electroweak symmetry breaking

Ian Hinchliffe LBNL

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Outline

- Current status and problems
- LHC's role
- Linear collider's role
- LBNL's role

The Status

Standard Model provides an excellent description of experimental phenomena.

Precision of better than 1% is achieved (LEP/SLC asymmetries, W/Z masses *etc*)

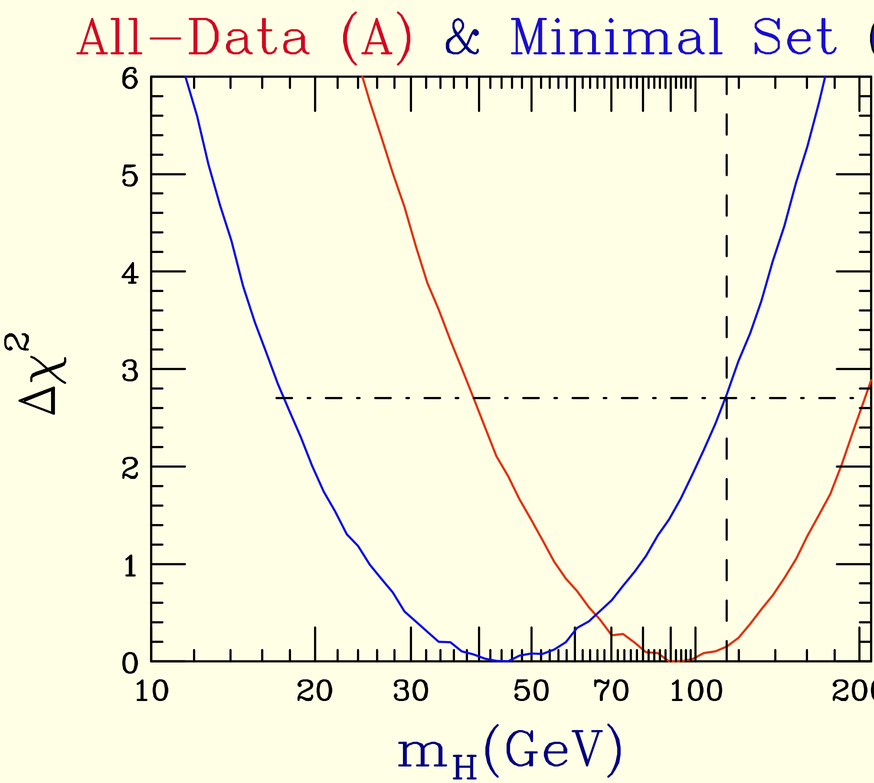
Need at least one extra particle to give mass to W/Z and all quarks/leptons — Higgs

Plot shows $\Delta\chi^2$ as function of Higgs mass

All data has prob. of 2% at min

Excluding Hadronic asymmetry and neutrino scattering (Blue line) has prob. of 71% at min

Fit is now inconsistent with direct limit $M_H > 114$ GeV



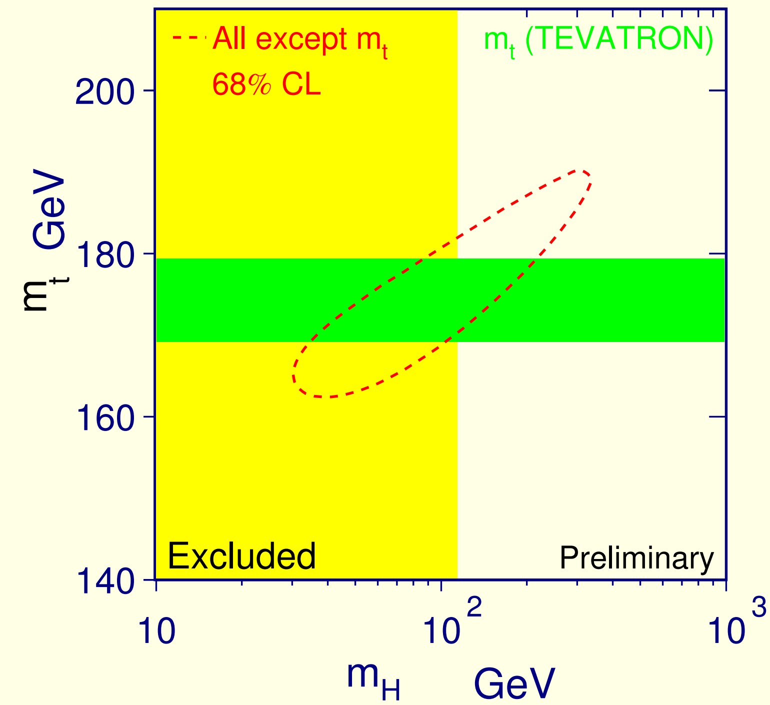
Message – Things cannot be improved by ignoring measurements

Either unlucky or new physics

Chanowitz: LBNL-52452

Important not to overstate the inconsistency

Inference of Top mass from precision measurements agrees with direct observation



If the SM is right, then $M_H < 200GeV$

If SM is not complete, could have many Higgs, SUSY, Extra dimensions, No weakly coupled Higgs...

The Challenges to Experiment and Theory

Theory – Why is Higgs light?

- Generally fits get worse if new particles of masses below few TeV are added.
- But radiative corrections to Higgs mass from top and W loops suggest a Higgs mass larger than the constraints allow.
- Calculate with a cut off $\Lambda = 10 TeV$
  top loop $\delta m_h^2 = \frac{3}{8\pi^2}\lambda_t^2\Lambda^2 \sim (2TeV)^2$
  W/Z loops $\delta m_h^2 \sim \alpha_w\Lambda^2 \sim -(750GeV)^2$

Theorists like to solve this by adding other new particles to cancel these effects – simplest example is SUSY where stop cancels top etc

This predicts other new particles

Open question is "What breaks ElectroWeak symmetry?"

There must be at least one particle yet to be discovered.

LHC's Task

Find the particle(s) responsible for mass generation.

Could be Higgs, many Higgs's, SUSY, Extra dimensions

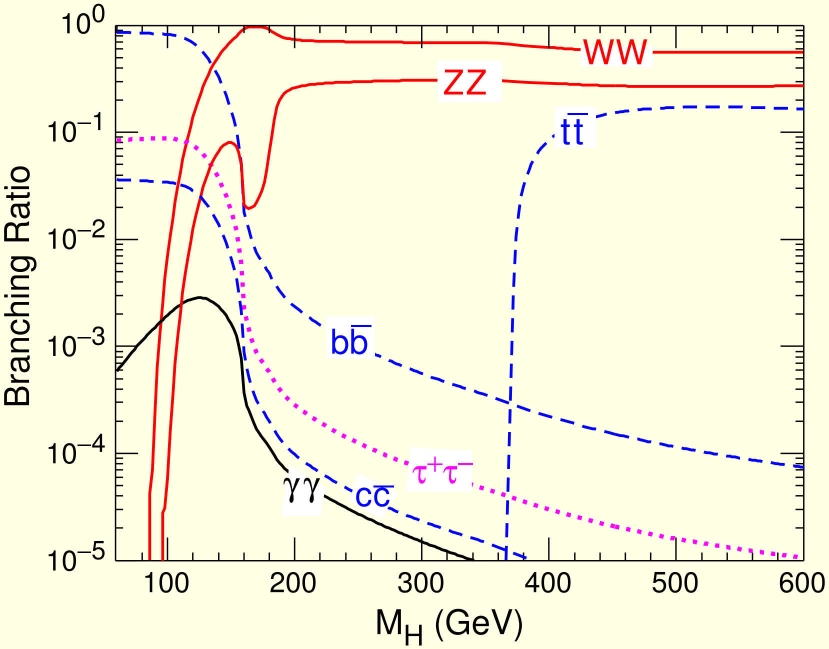
Power of LHC is its enormous mass reach relative to current facilities.

Even low luminosity will open a new window.

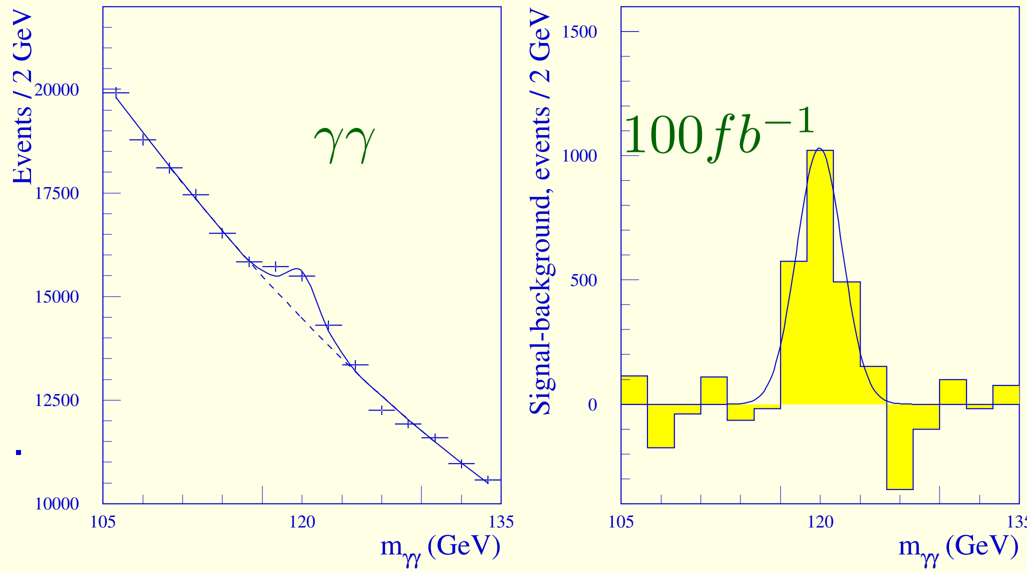
$10pb^{-1}$ (1 day at 1/100 of design luminosity) gives 8000 $t\bar{t}$ and 100 QCD jets beyond the kinematic limit of the Tevatron

If SUSY is correct, it could be found with $100pb^{-1}$

Let's start with quick reminder of a few Higgs signals

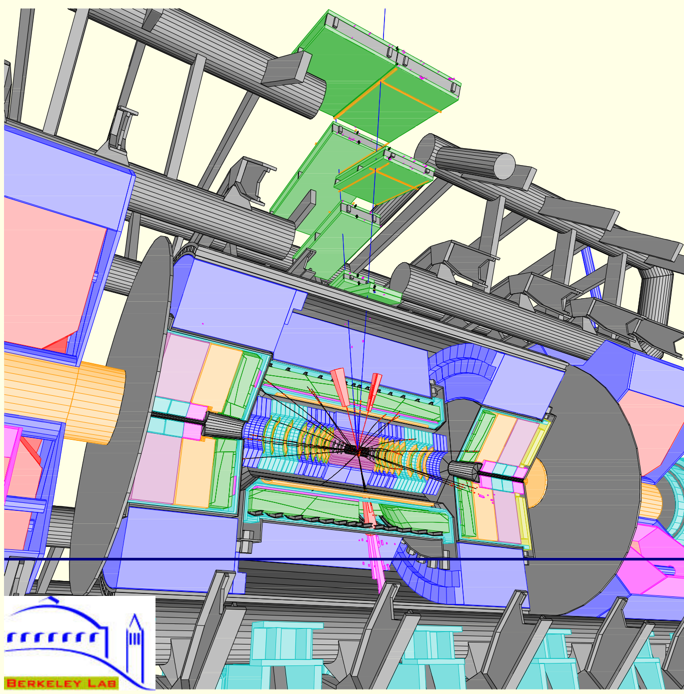


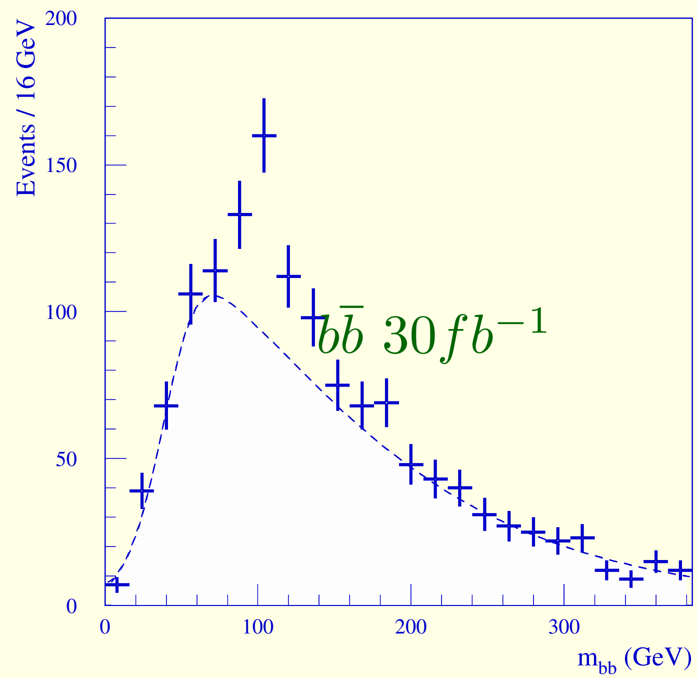
Branching Ratio
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
WW
ZZ
$t\bar{t}$
$b\bar{b}$
$\tau^+\tau^-$
$c\bar{c}$
$\gamma\gamma$
100
200
300
400
500
600
M_H (GeV)



Events / 2 GeV
20000
17500
15000
12500
10000
$\gamma\gamma$
105
120
135
$m_{\gamma\gamma}$ (GeV)
Signal-background, events / 2 GeV
1500
1000
500
0
$100 fb^{-1}$
105
120
135
$m_{\gamma\gamma}$ (GeV)

$ZZ \to \mu^+\mu^- e^+ e^-$





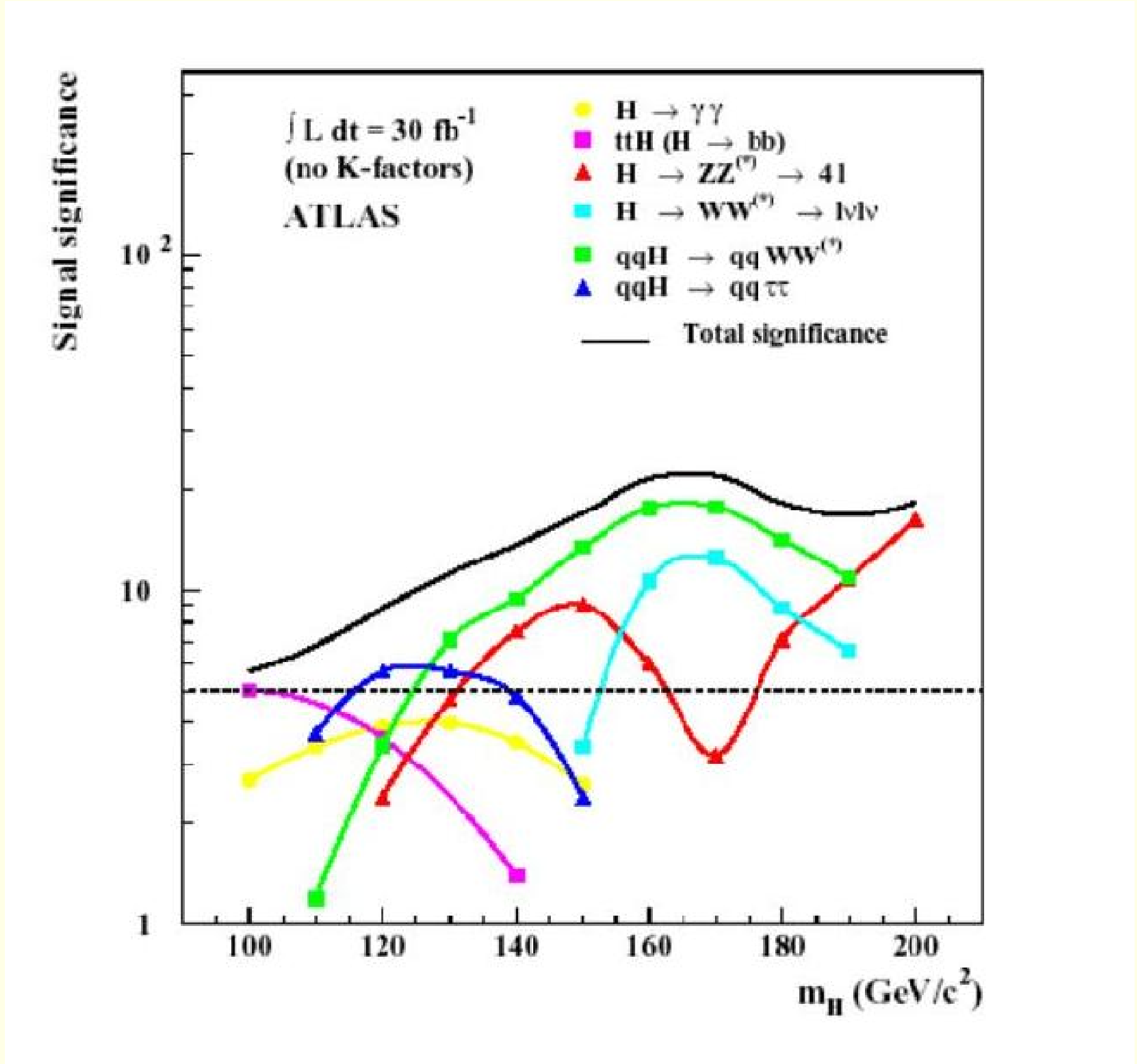
Events / 16 GeV
200
150
100
50
0
$b\bar{b}$ $30 fb^{-1}$
0
100
200
300
m_{bb} (GeV)

Higgs is not a "typical" LHC discovery as it demanding of luminosity

Plot shows statistical significance for 30 fb^{-1}

Easiest channel depends on mass

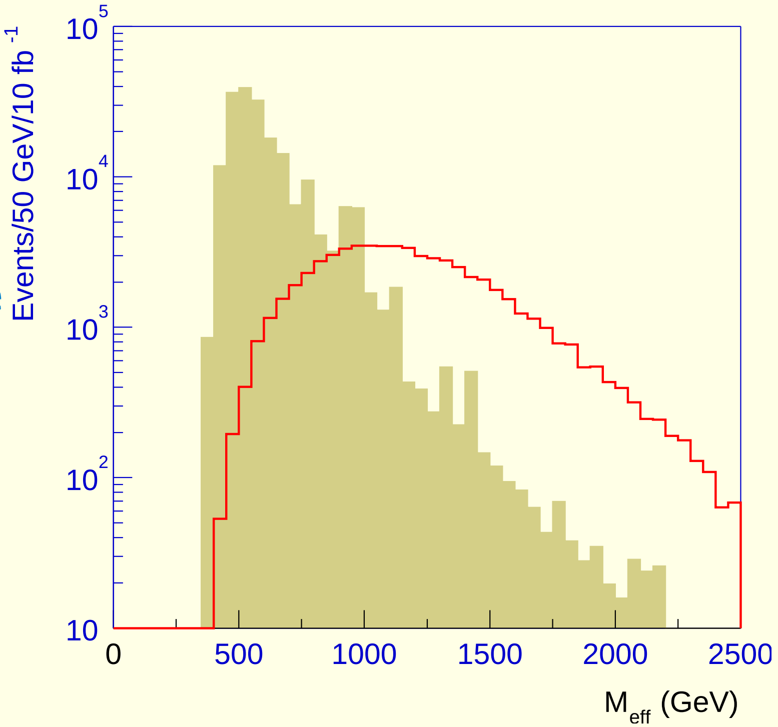
The black curve shows the combined result



New particle example – SUSY

Produces events with jets and missing transverse energy

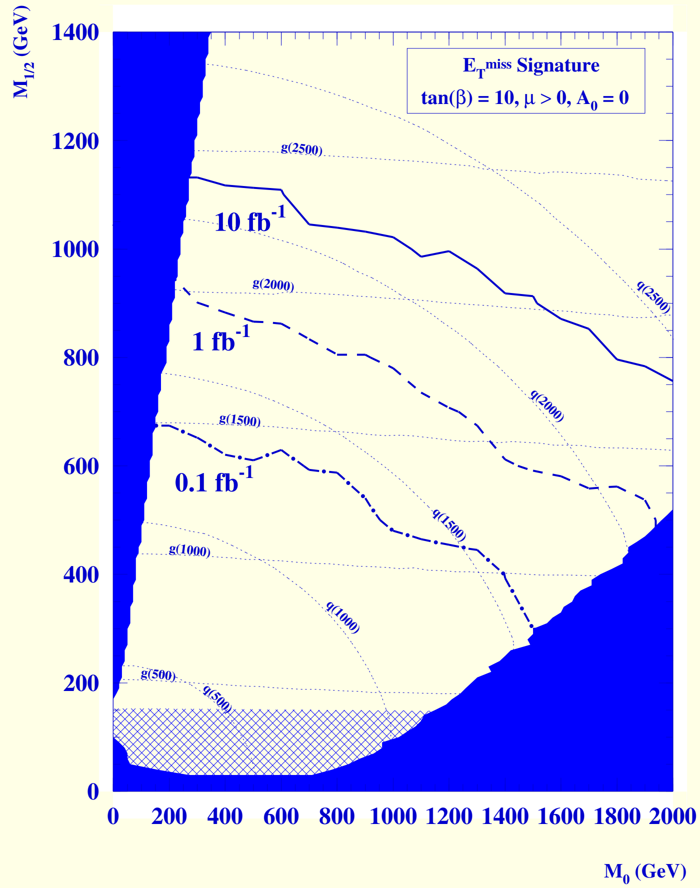
- Select events with at least 4 jets and Missing E_T
  A simple variable:
  $M_{\rm eff} = P_{t,1} + P_{t,2} + P_{t,3} + P_{t,4} + \not{E}_T$
- At high $M_{\rm eff}$ non-SM signal rises above background (shaded histogram)
  Note scale – huge event rate
- Peak in $M_{\rm eff}$ distribution correlates well with SUSY mass scale
  $M_{\rm SUSY} = \min(M_{\tilde{u}}, M_{\tilde{g}})$
  This example has susy masses around 700 GeV



This signal is characteristic of any new physics at a large mass

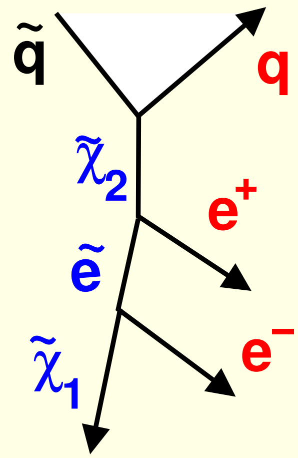
How fast can SUSY be found?

Plot shows reach in SUSY model space
Solid region is not allowed
Hatched region is already ruled out by LEP
Contours label squark and gluino masses and luminosity
Example – $0.1 fb^{-1}$ discovers gluino of mass 1 TeV
This is 1 year at 1/1000 of design luminosity!



Need to be ready to do physics at day one

An example of a recent full simulation study



Decay $\tilde{q}_L \to q\widetilde{\chi}_2^0 \to q\widetilde{\ell}\ell \to q\ell\ell\widetilde{\chi}_1^0$
Produces a pair of e^+e^- or $\mu^+\mu^-$ with an invariant mass in a restricted range.

100K events simulated and reconstructed with new software (LBNL lead role)

Corresponds to $5fb^{-1}$

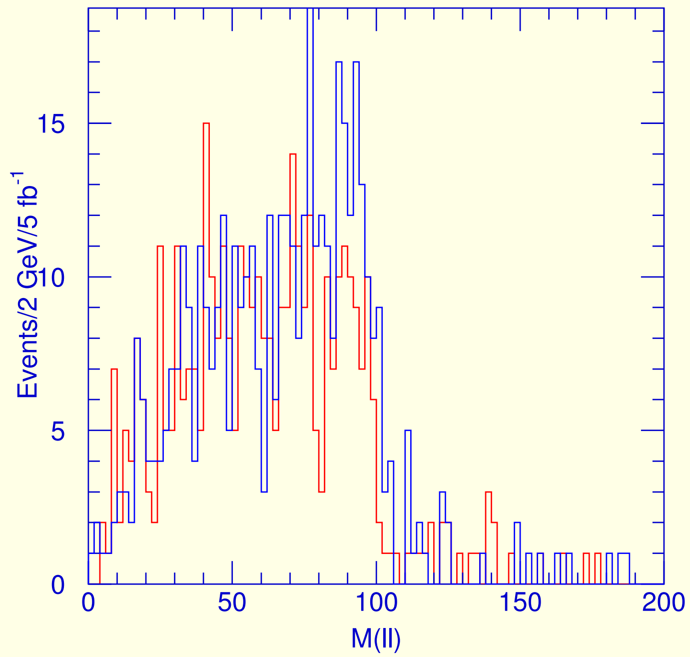
Needed 50k CPU hrs for simulation: approx half of this was done on PDSF (NERSC at LBNL)

Needed 50k CPU hrs for reconstruction: all of this was done on PDSF.

First "physics test" of new reconstruction, results shown at Physics workshop and available ATLAS-PHYS-COM-2003-055

Will investigate case relevant for Dark Matter (WMAP) in DC2.

Plot shows invariant mass distribution of $\mu^+\mu^-$ (blue) and e^+e^- (red)
Note this example is $5fb^{-1}$
Standard model background not shown, it is mainly from $t\bar{t}$ and is very small

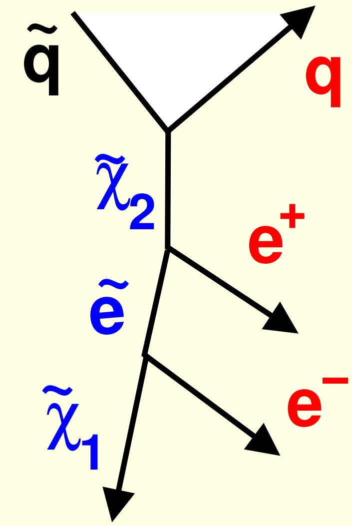


Leads to measurements of some masses to 1 GeV precision

More complicated topologies can be reconstructed starting here and adding jets.

Measuring the squark mass

Attempt to find $\tilde{q}_L \to q\tilde{\chi}_2^0 \to q\tilde{\ell}\ell \to q\ell\ell\tilde{\chi}_1^0$



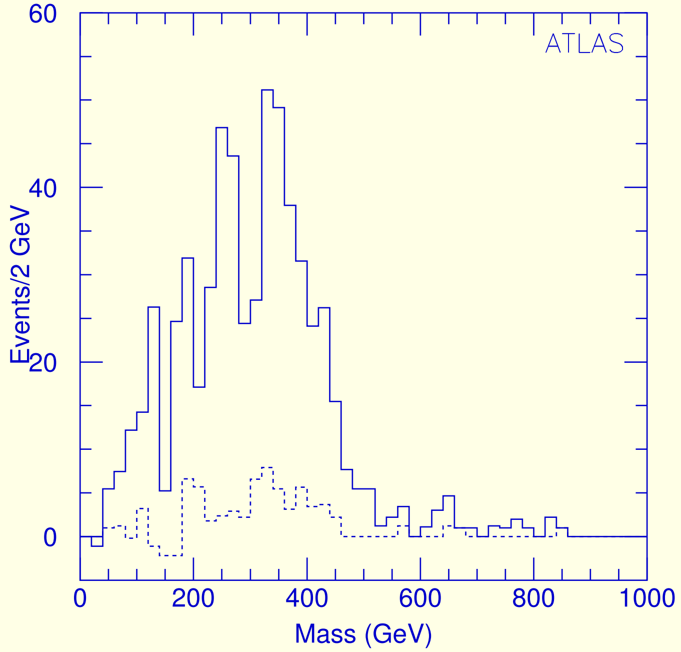
Identify and measure decay chain

- 2 isolated opposite sign leptons; $p_t > 10$ GeV
- ≥ 4 jets; one has $p_t > 100\ GeV$, rest $p_t > 50$ GeV
- $\not{E}_T > max(100, 0.2M_{eff})$

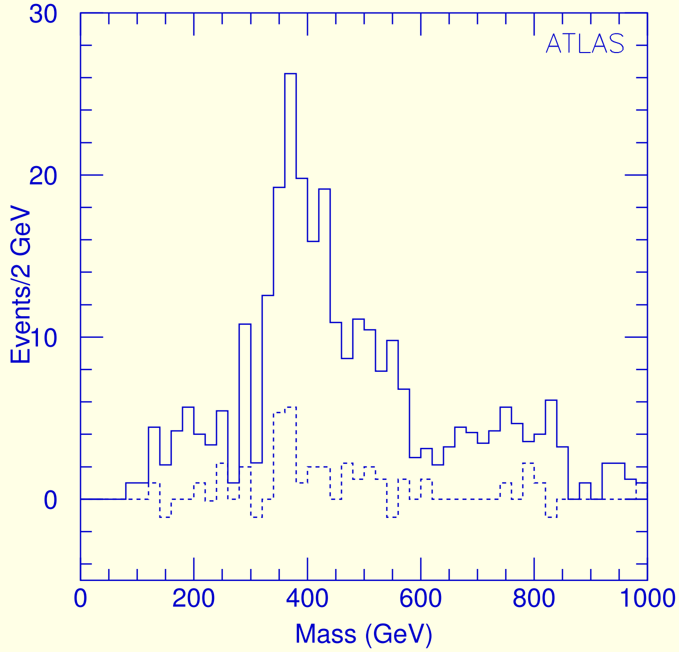
Mass of $q\ell\ell$ system has max at

$$M_{\ell\ell q}^{\max} = [\frac{(M_{\tilde{q}_L}^2 - M_{\tilde{\chi}_2^0}^2)(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\chi}_1^0}^2)}{M_{\tilde{\chi}_2^0}^2}]^{1/2} = 552.4\,\mathrm{GeV}$$

and min at 271 GeV (in the example shown)



smallest mass of possible $\ell\ell jet$ combinations



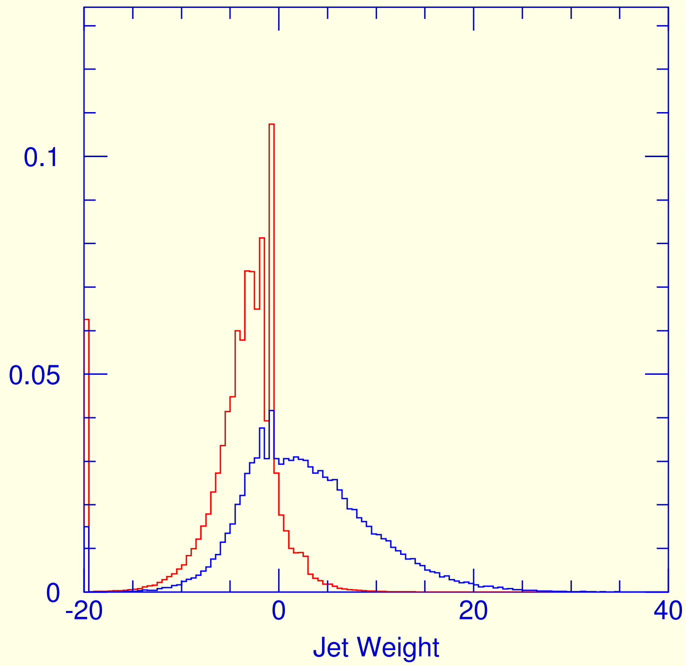
largest mass of possible $\ell\ell jet$ combinations

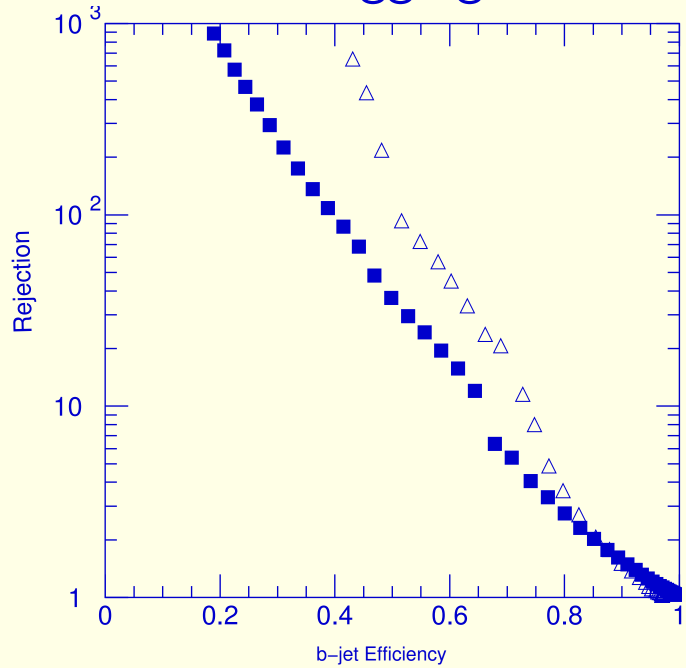
Kinematic structure clearly seen

Dashed histograms are b-jets — next slide.

B-tagging is vital in SUSY

b quarks are copious in SUSY events –New results on b-tagging in the SUSY events





Impact parameter of tracks inside jet used to assign a weight

Plot shows weight from both b-jets (BLUE) and light quark jets (RED)

Cut on weight and get a btagging efficiency as a function of non-bjet rejection

Higgs events shown as triangles for comparision

Jet rejection is worse than in previous (Higgs) studies due to more complex events.

Performance worse with initial detector, which only has 2 pixel layers

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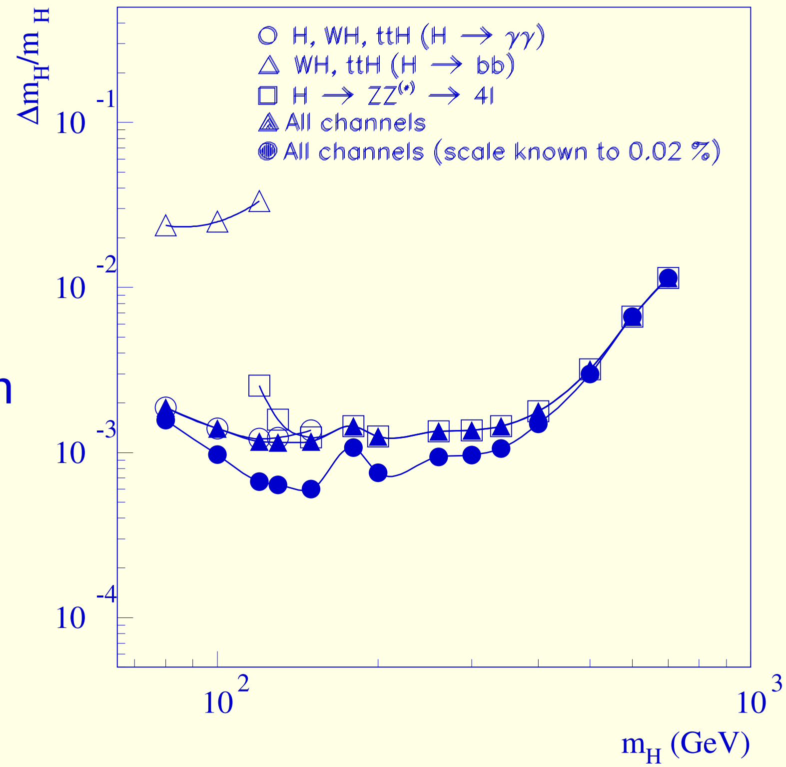
On to the Linear Collider...



LHC can measure the mass of Higgs precisely
Plot shows mass error for various masses from ATLAS

LHC's measurements of Higgs decay properties depend on mass.
In low mass (favored) region precision is limited by:

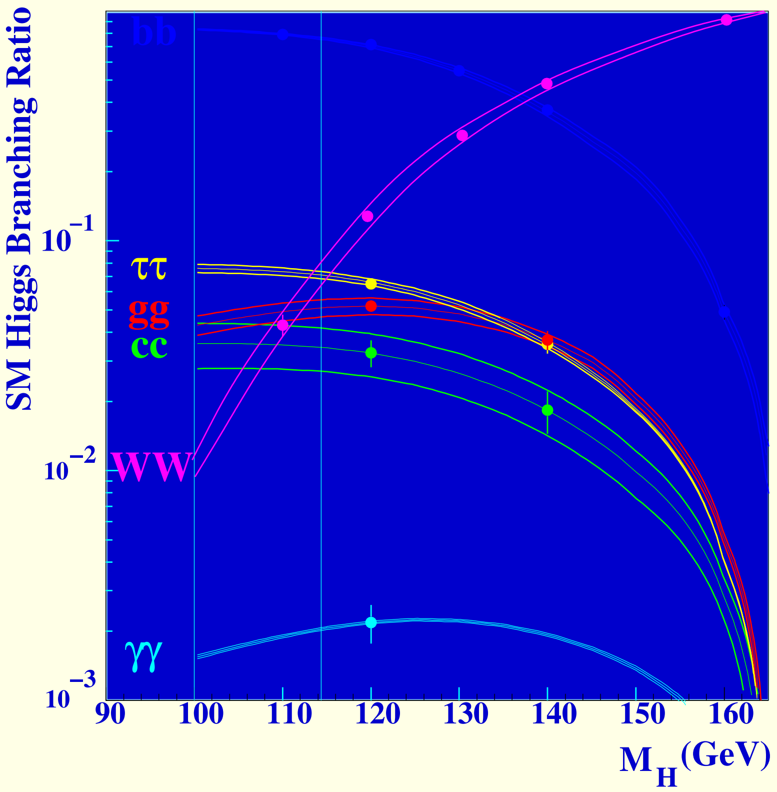
- theoretical uncertainties in cross-sections
- absolute luminosity measurement
- statistics and backgrounds

Not all channels will be visible. Need LC for rest

Precision studies will need another facility

Precision measurements of decay modes will require facility that can produce the Higgs in a controlled environment. Such a facility will be to the Higgs what LEP was for Z

Plot shows the Higgs branching ratios as a function of mass
errors from an LC simulation (Battaglia) of $300 fb^{-1}$



LBNL participation in important EW milestones

- 1984: Hinchliffe *et al* "SuperCollider Physics"
- 1986: SSC Central design group
- 1989-1993: SDC
- 1990-Present: Precise W mass from Tevatron (CDF)
- 1992-Present: Precise Tevatron top mass (D0 and CDF)
- 1989: Measurement of Z mass (mark II at SLC and CDF)
- 1994: Join ATLAS
- 1996: Peskin and Murayama Linear collider Physics "Ann.Rev.Nucl.Part.Sci"
- 2001: "A CONSTRAINED STANDARD MODEL FROM A COMPACT EXTRA DIMENSION" Hall, Nomura
- 2000: Implications of precision EW data (Chanowitz)
- 200x: Susy discovered by ATLAS
- 201x: Linear collider measures all Higgs branching ratios