Discovery Physics

with Early LHC Data

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Outline

- What early data means to me.
- Potential for new physics?
- Some interesting signals.
- Outlook

The Search for New Physics

(Not to scale)

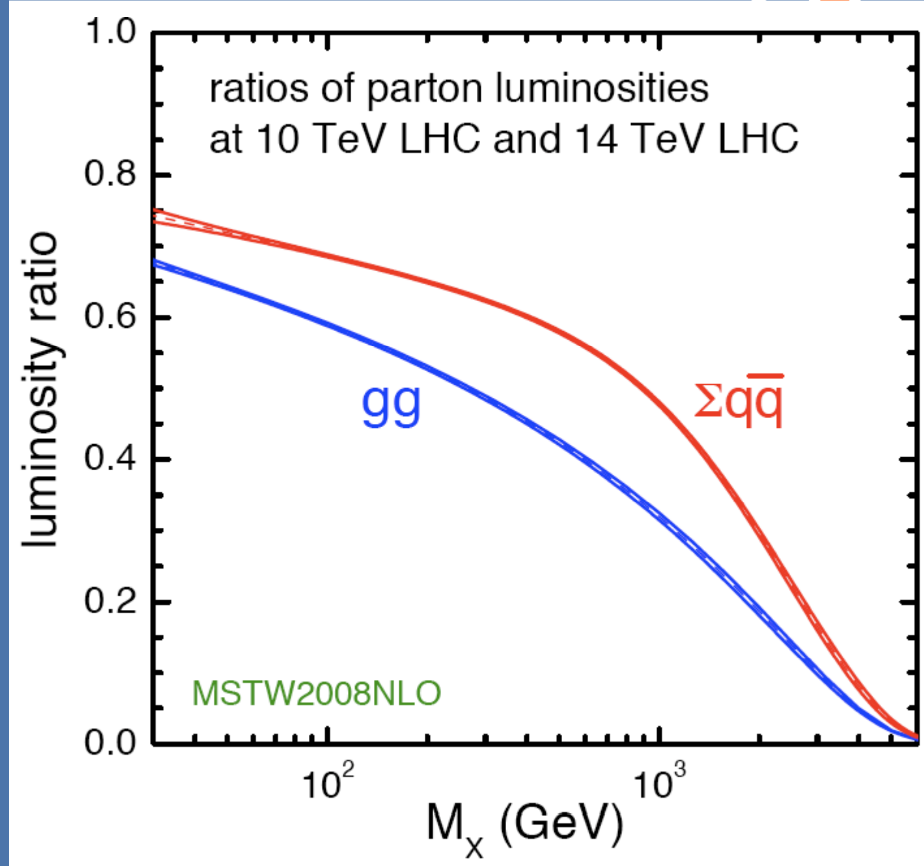
Looking for physics beyond the SM gives us something to do while we collect enough anti-matter to terrorize the Vatican...

“Early”

- Early is a relative concept.
- For the purposes of this talk, early means:
  - Center of mass energy of initially 10 TeV.
    - Many studies still only exist for 14 TeV.
    - Lower energy is not always worse for new physics!
  - Data sets below about one inverse fb.

Ten Versus Fourteen

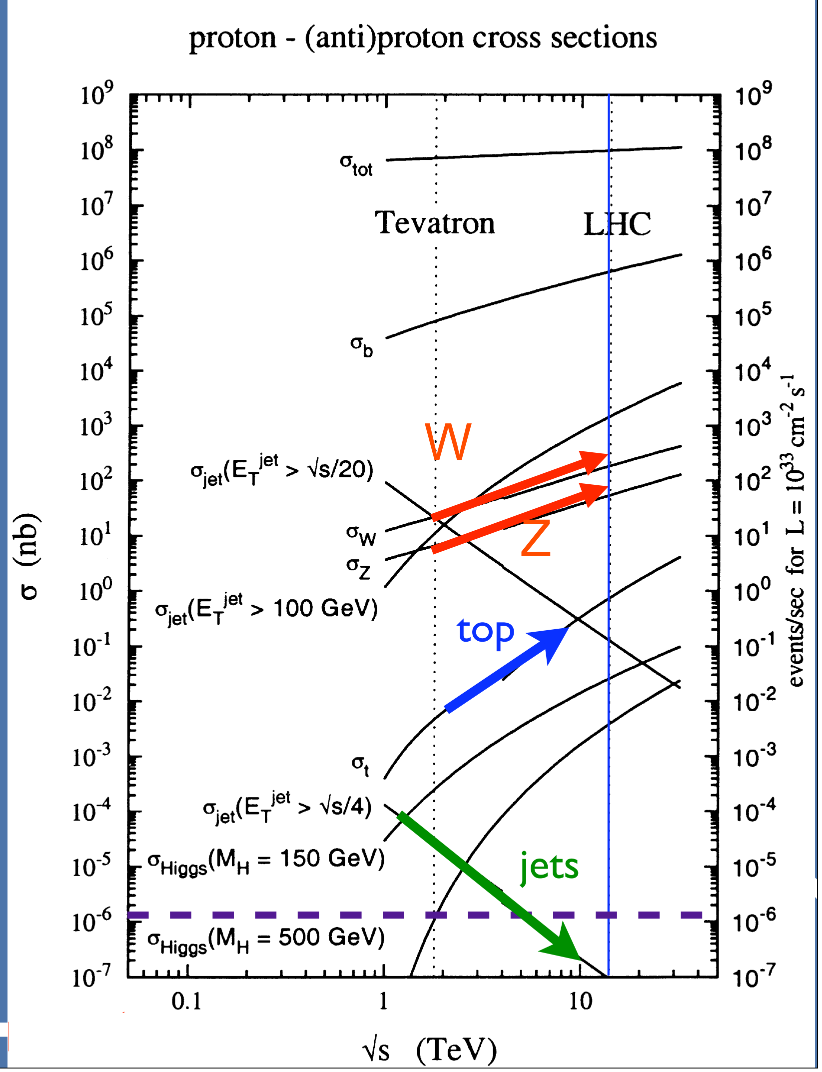
- At 10 TeV collision energy, signals involving high energy physics are always smaller.
- Rare, low background signals almost always lose compared to 14 TeV.
- Unless the reaction itself grows with energy, other cases are controlled by the parton flux.
- Electroweak signals, with significant top backgrounds can actually gain ground - high energy quark initial states lose less than gluon initial states.



Monica Vazquez Acosta, Pheno '09

Cross Sections

- With Luminosities of order inverse fb, we will collect unparalleled statistics for interesting SM processes:
  - High energy jets
  - Top quarks
- Cross sections of order fb can include many interesting search processes:
  - Higgs (sometimes)
  - Colored super-particles (light ones)
  - Z-primes



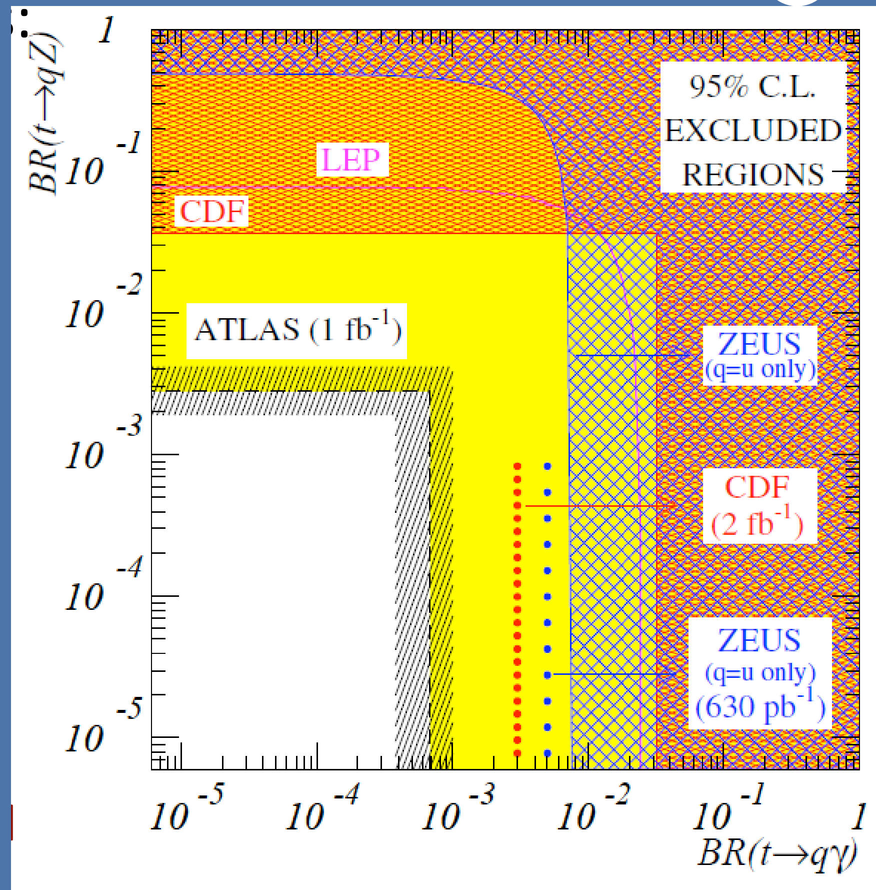
Early New Physics at LHC

- So where does the LHC have a shot at an early discovery? (Besides elevator shafts...)
  - Some properties of the new physics would help a lot:
    - High cross sections (strongly interacting).
    - Strong energy dependence of signal.
    - Low background / Striking morphology.
  - There is tension between early discovery at the LHC and not already being ruled out by Tevatron/LEP.

Strongly Interacting Particles

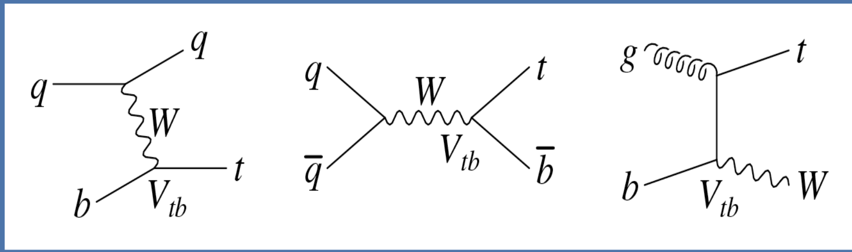
Top Decays

- With 1 fb^{-1}, LHC will produce about 10^6 top pairs.
- Such a large sample allows one to search for rare decays, such as into Zq or γq where q = u or c.
- SM BRs are expected to be around 10^{-9}. An early observation would be a clear sign of BSM physics.
- Large enhancements over the SM are possible from loops of i.e. MSSM particles.



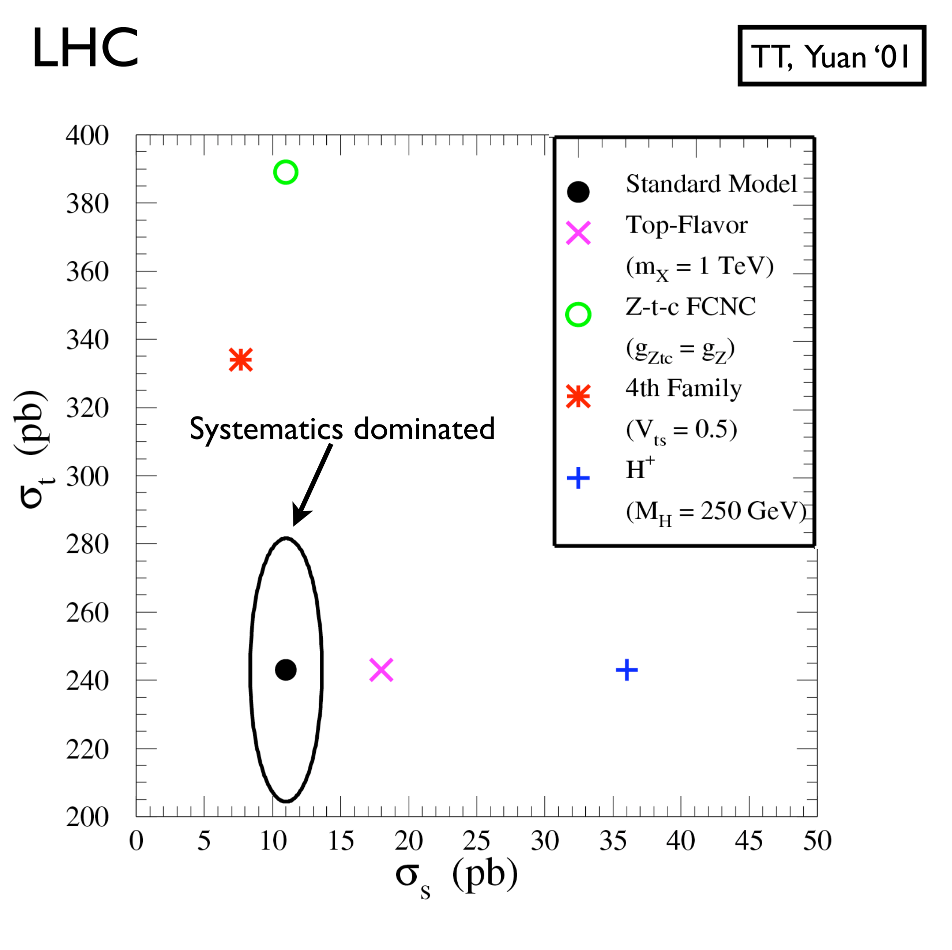
Single Top

- 1 fb^{-1} results in hundreds of single top events, and should allow observation of s-, t-, and tW modes.



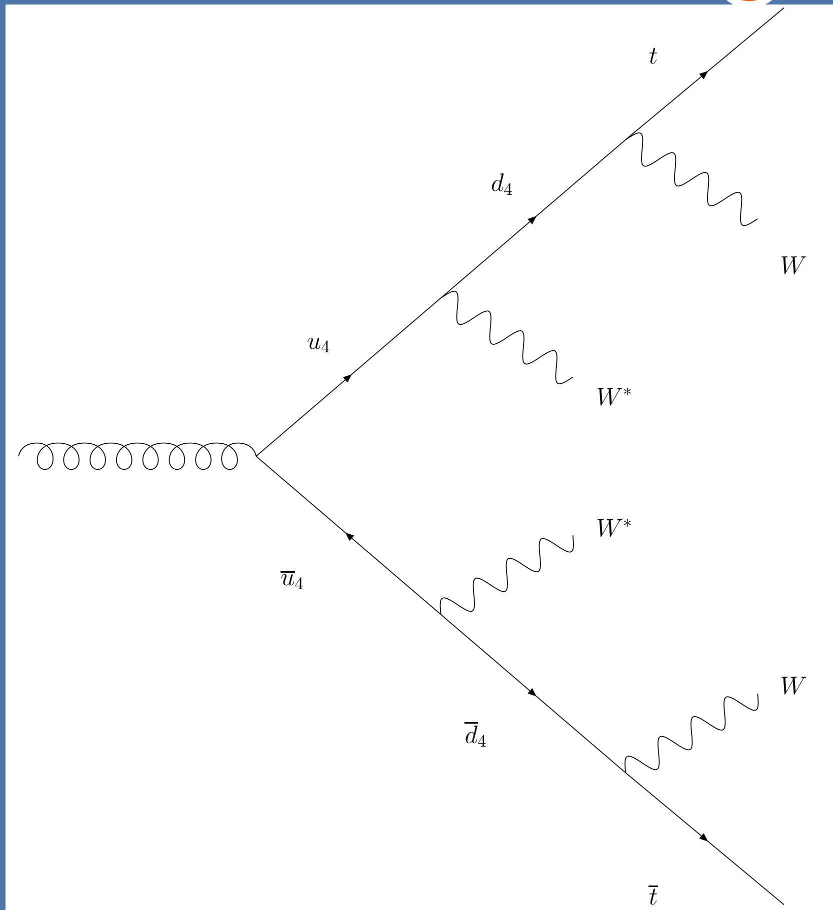
- Interesting deviations can be signs of new physics!
- LHC is the first opportunity to observe the tW associated mode, which is possible with 1 fb^{-1} !

TT '99

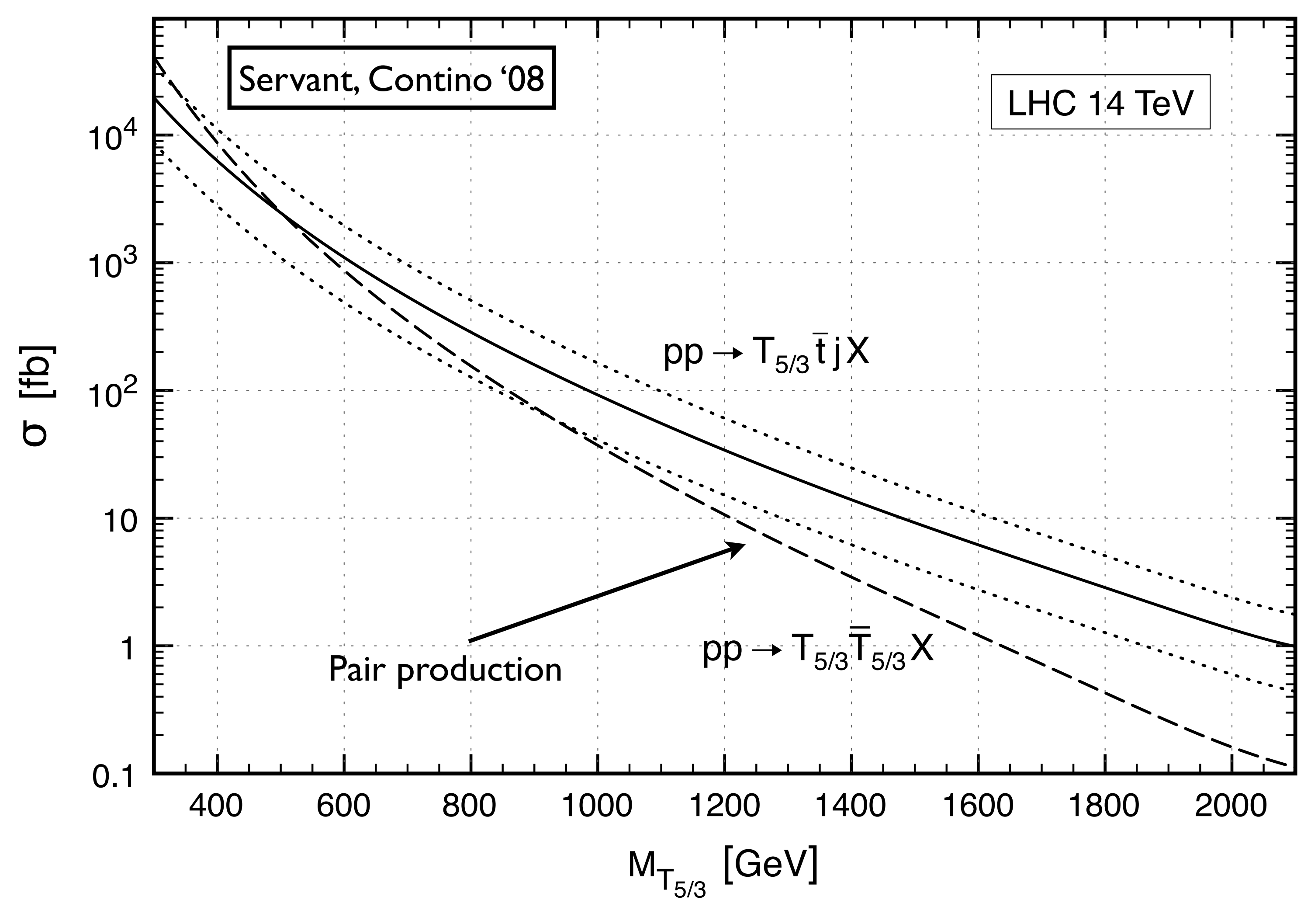


New Quarks?

- New quarks can be produced in pairs through the strong interaction.
- Chiral fourth generation quarks decay through W's into lighter quarks.
    - Precision electroweak measurements limit their masses to below about 500 GeV.
    - Six W's and 2 b's! Wow!
- Vector-like quarks can have FCNC decays involving Z or Higgses.
    - Beautiful Mirrors - A^b_{FB}!



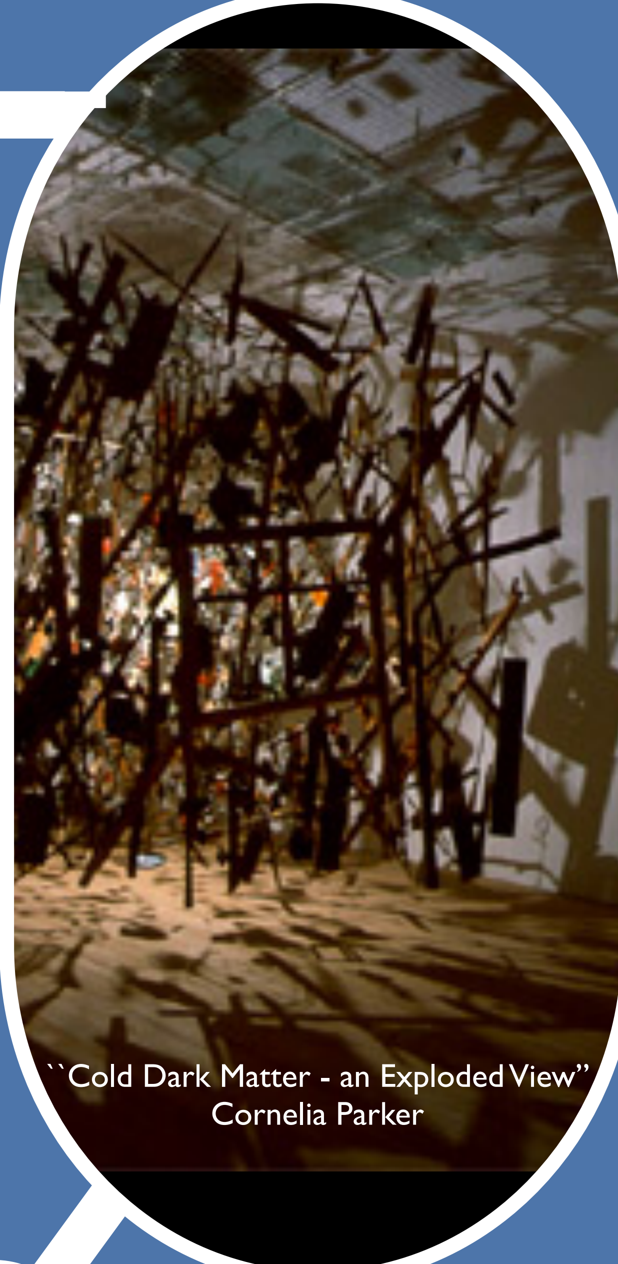
Choudhury, TT, Wagner '01



Pair production results in appreciable events up to masses of around 1 TeV.

Missing Energy

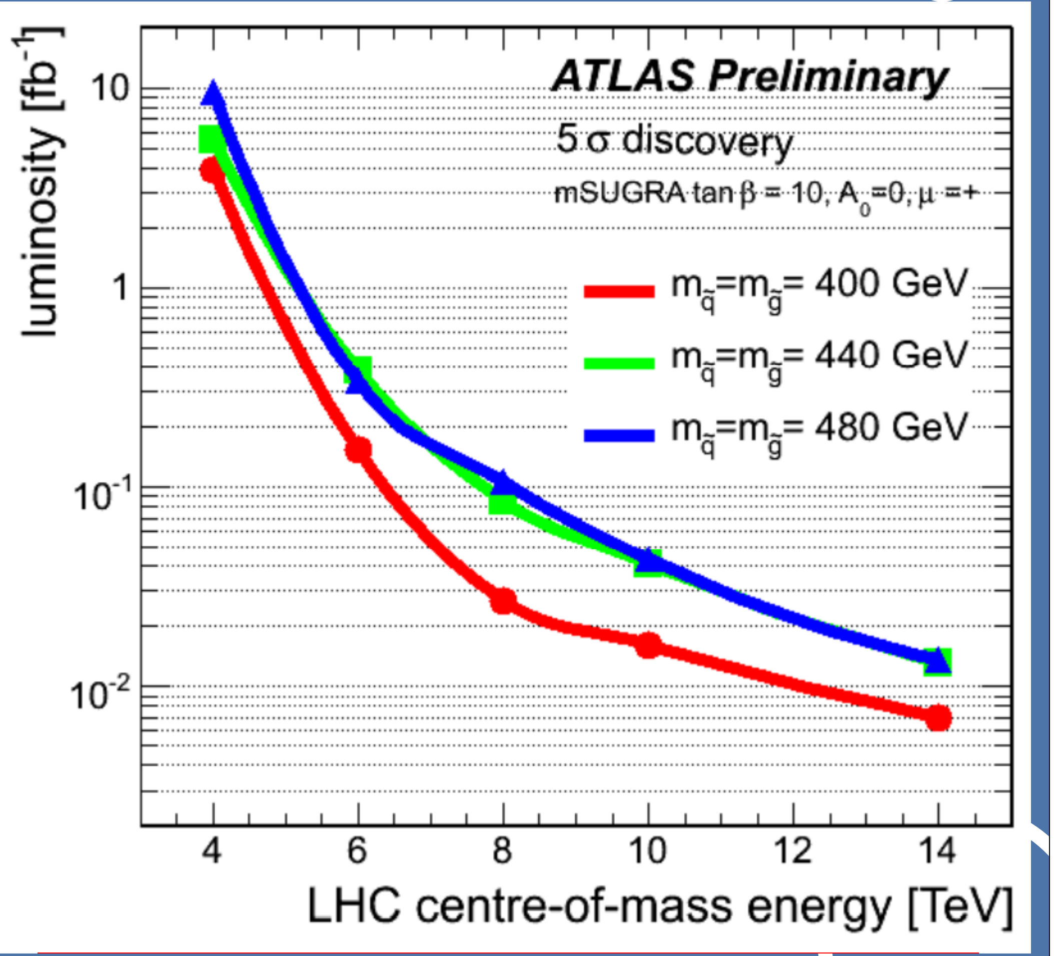
- The cosmological existence of dark matter is strong motivation to search for new forms of missing energy.
- Nowadays almost any vision of BSM physics has or can be extended to include a dark matter candidate
  - Lots of examples yesterday...
- Missing energy is a calibration-intensive observable.
  - There is Tension between large missing E_T and low production of heavy mass states.



``Cold Dark Matter - an Exploded View"
Cornelia Parker

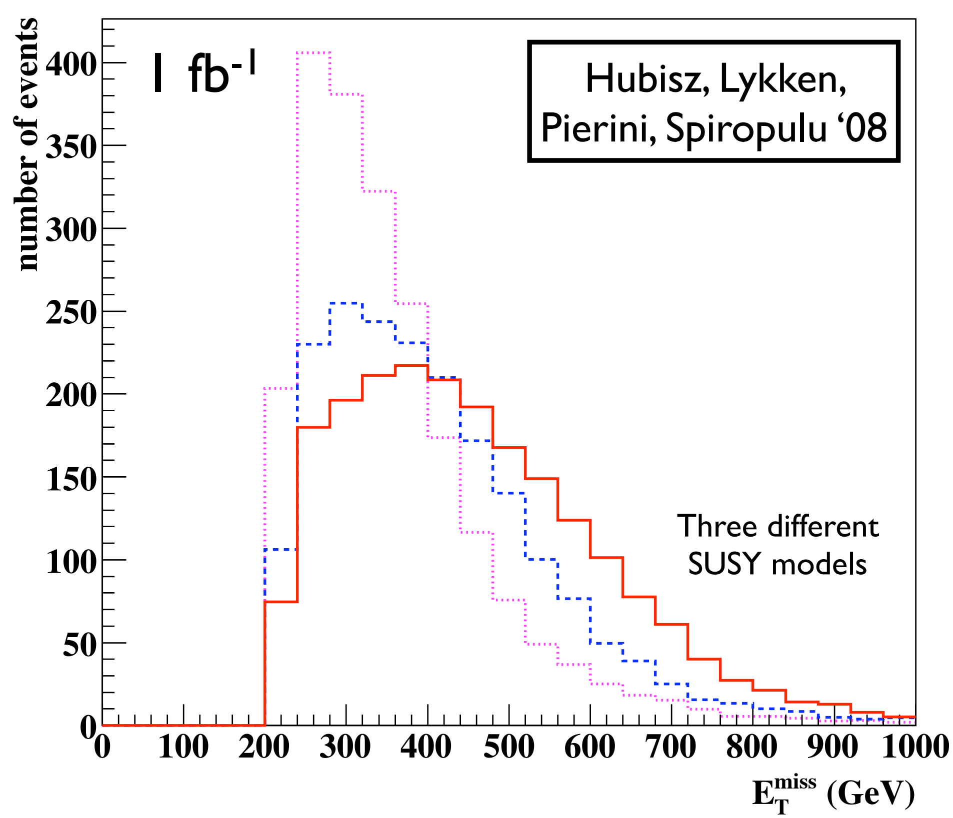
Early SUSY Searches

- Provided the colored states are not too heavy, there can be enough rate.
- Decays involving charged leptons help a lot.
- Generic SUSY models may take quite a bit longer.



Model Discrimination

- At one inverse fb, we begin to be able to to distinguish some models from another.
- This study considers a CMS-like detector and compares the spectrum of missing energy resulting from three different SUSY models.

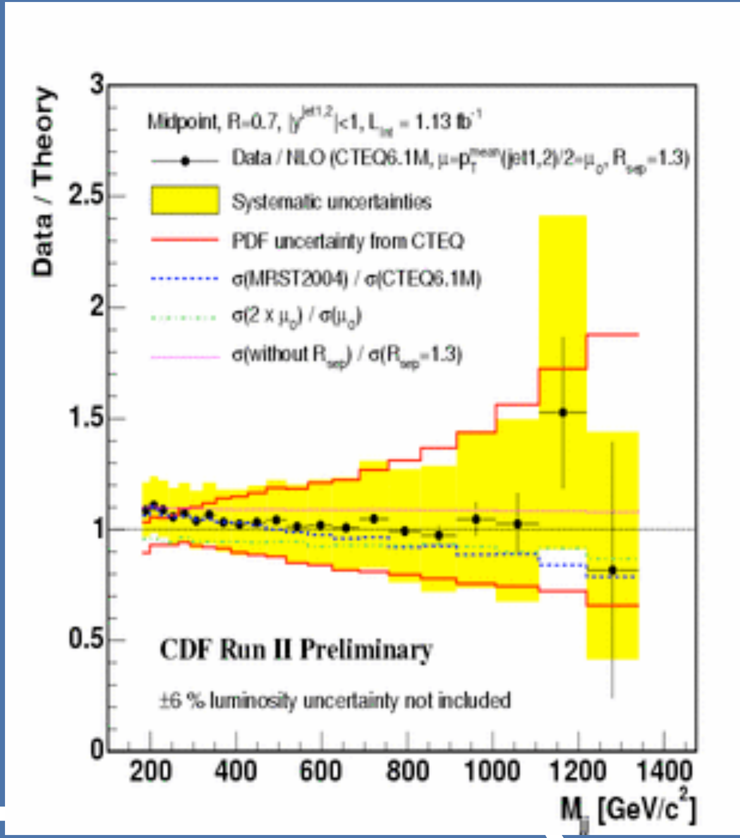


Strong Energy Dependence

Compositeness

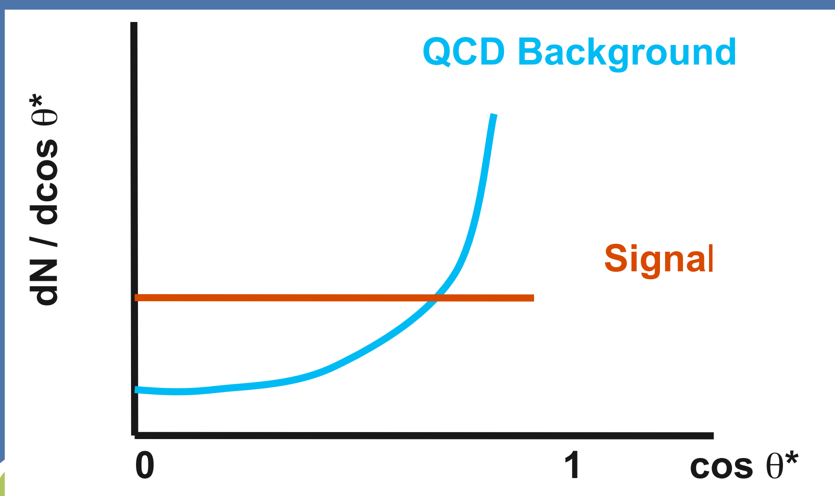
$$\frac{g^2}{\Lambda^2}\,[\bar{q}\gamma^\mu q]\,[\bar{q}\gamma_\mu q]$$

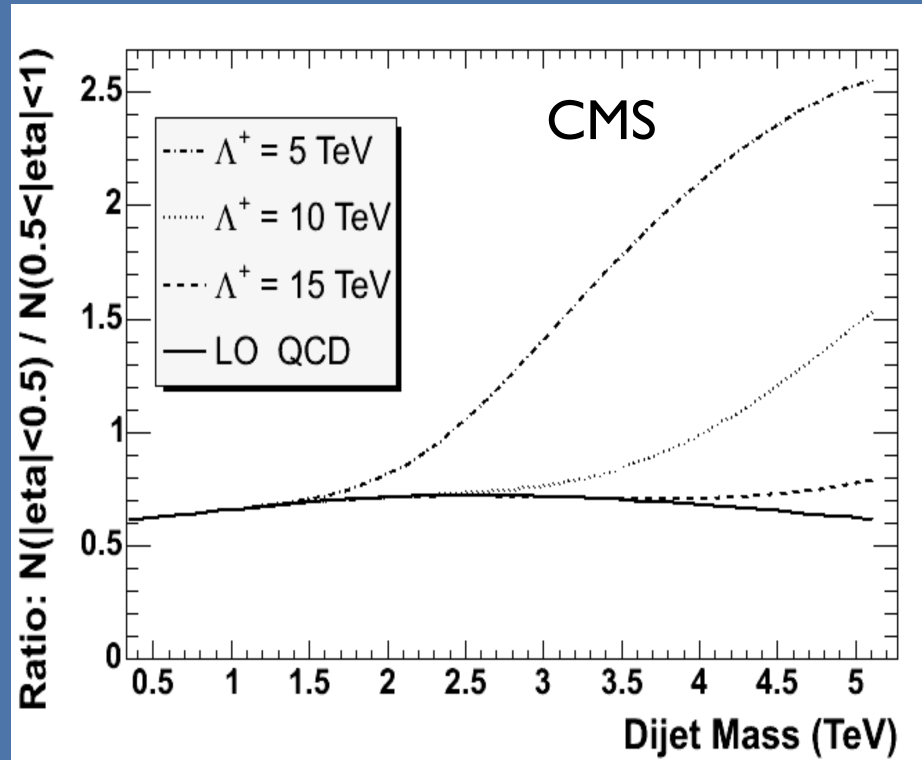
- Compositeness is modeled using effective field theory, by adding higher dimensional operators to the SM Lagrangian.
- (In fact, this is model-independent description of heavy physics as seen at low energies)
- Tevatron limits (real analyses only exist from run I data) can be guestimated to bound the scale Λ to be greater than around 2-3 TeV.



Compositeness

- Higher dimensional operators produce cross sections which grow with energy!
- Going from 2 to 10 TeV can produce huge effects!





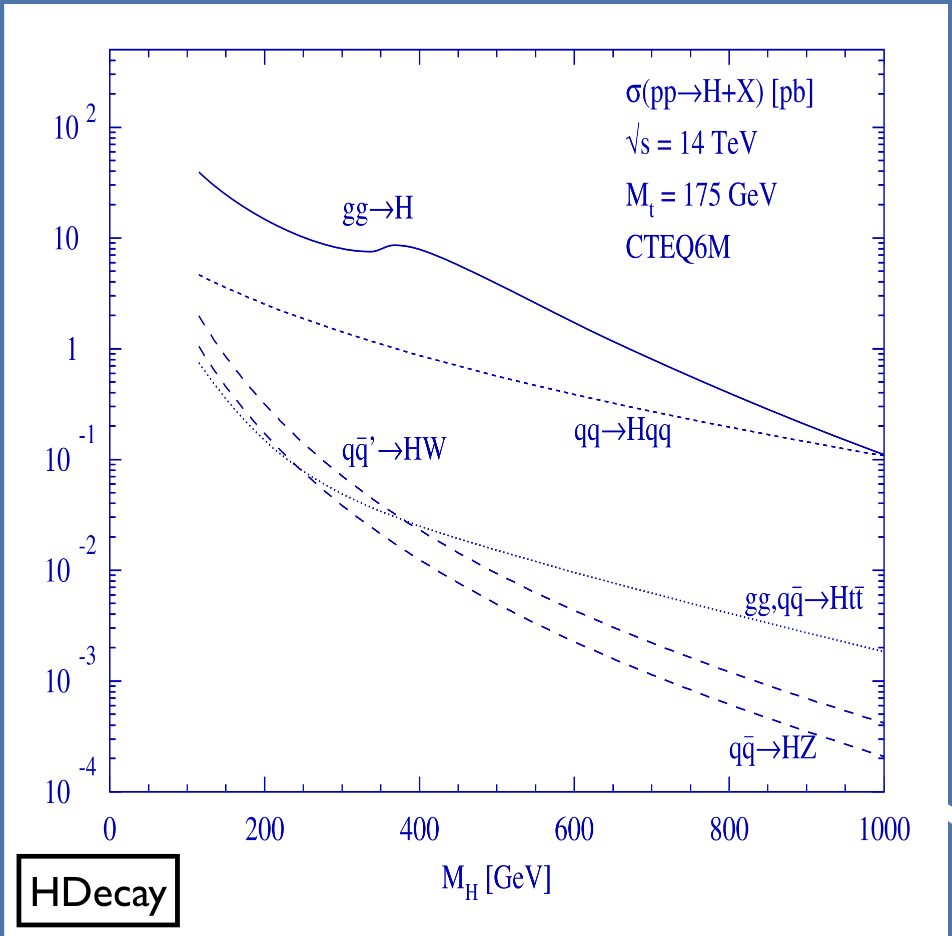
T LeCompte Pheno '07

Striking Signals

Higgs at the LHC

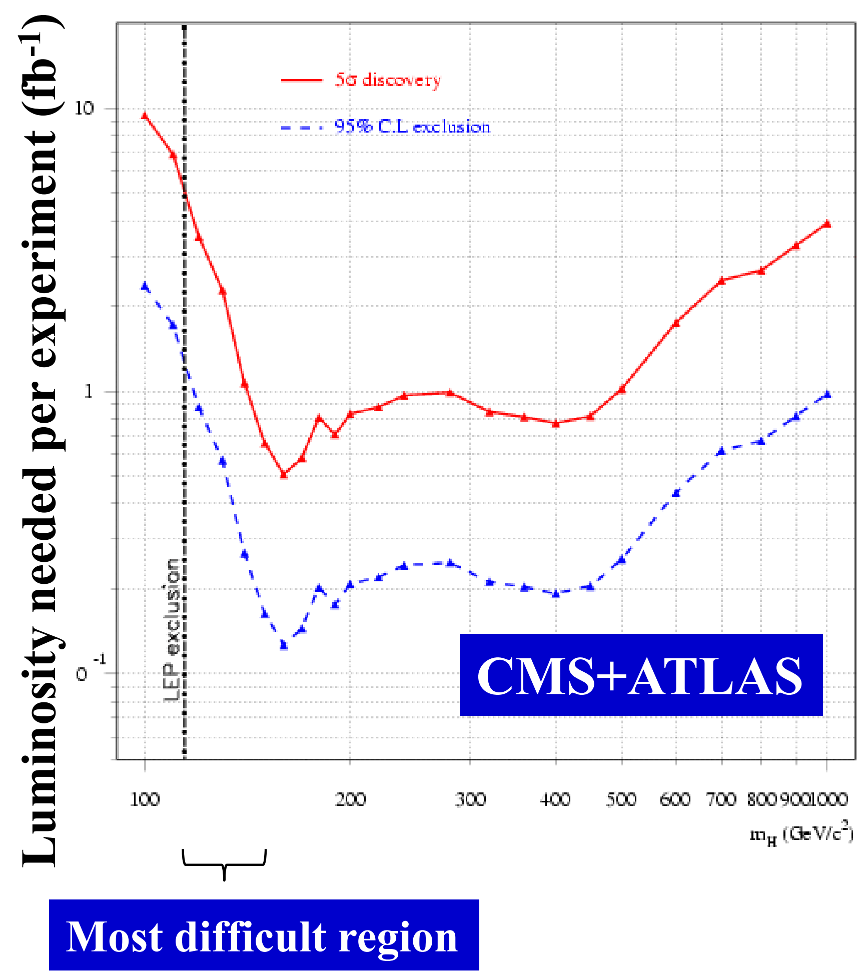
Higgs

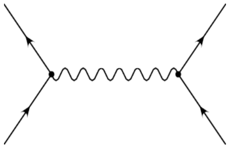
- With small data sets, Higgs is a challenge.
- There is rate for gluon fusion production modes, but it must be paired with an observable decay mode.
  - Low mass Higgs decays are not always 'striking'.
- WBF has more handles, but with smaller rates. It is probably tough to take advantage of with 1 fb^{-1}.



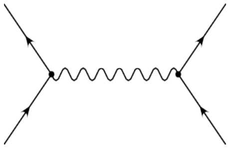
Heavy Higgs

- With 1 fb^{-1}, heavier Higgs masses can be discovered, decaying into weak bosons.
- This would already be a hint of things to come - precision electroweak tells us such a heavy Higgs will come with some other kind of new physics.
  - Something to discover alongside the Higgs, or something to look forward to...

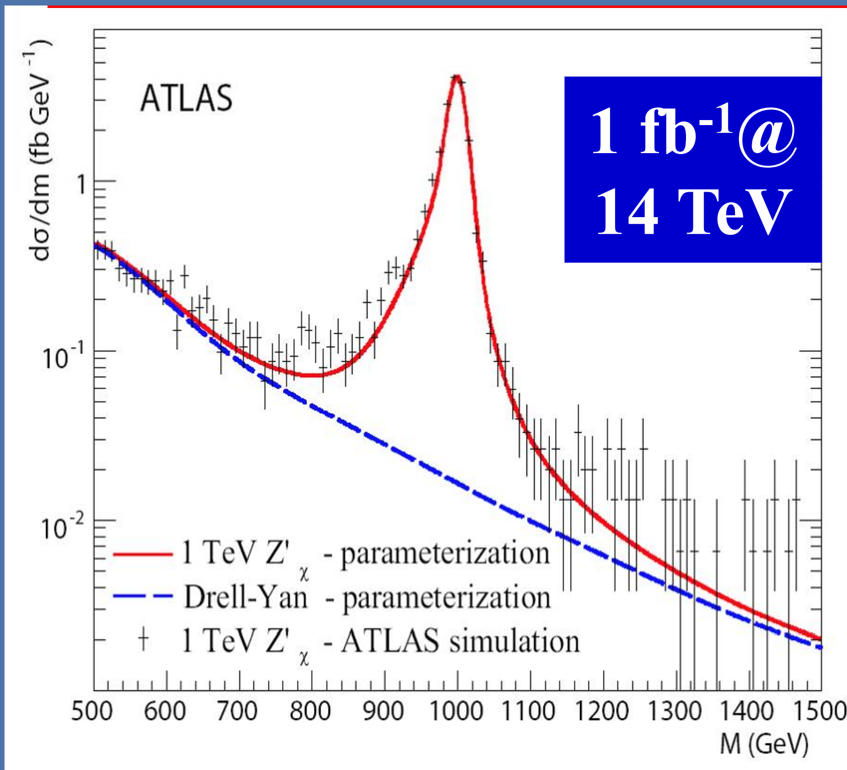




Z-prime



- I left the most obvious example for last. A high mass resonance in lepton pairs is a striking signal, with low (EW) background.
- Z's occur in extended GUT models, topcolor, little Higgs models, EFT of extra dimensions, WIMPonium...
- Tevatron is unable to get much past masses of 1 TeV, because the parton flux just gives out too fast.
- A Z' could be an early discovery, and would leave a lot left for us to do to fit it into the big picture!



Seth Quackenbush told us about this on Monday!

Outlook

- There is a lot of potential for early discoveries with the LHC.
  - But we do need to get a break with the new physics!
- Signals for an early discovery not already ruled out by earlier experiments will either:
  - Involve low mass strongly interacting particles
  - Have cross sections which grow with energy
  - Have striking signals involving small and easily understood backgrounds.
- Any of these options are motivated, would be exciting, and raise a lot of new questions we will have more fun answering!