ATLAS: Searches for new physics and outlook

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What is SuperSymmetry?

- Fundamental symmetry between fermionic and bosonic particles.
- To each fermionic particle (spin 1/2) in the SM, a scalar (spin 0) partner is introduced ("sfermion"), and to each bosonic particle in the SM, a fermionic partner is introduced ("gaugino"):

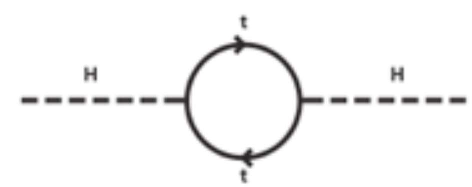
$$e_L \Rightarrow \tilde{e}_L \qquad W^+ \Rightarrow \tilde{W}^+$$

electron selectron W Wino

- Leads to as many bosonic as fermionic degrees of freedom, and therefore cancels the radiative correction terms to the Higgs mass in an elegant way:

$$\Delta m_H^2 = \frac{y_S}{(4\pi)^2} \Lambda^2_{\text{cut-off}}$$

correction for scalars



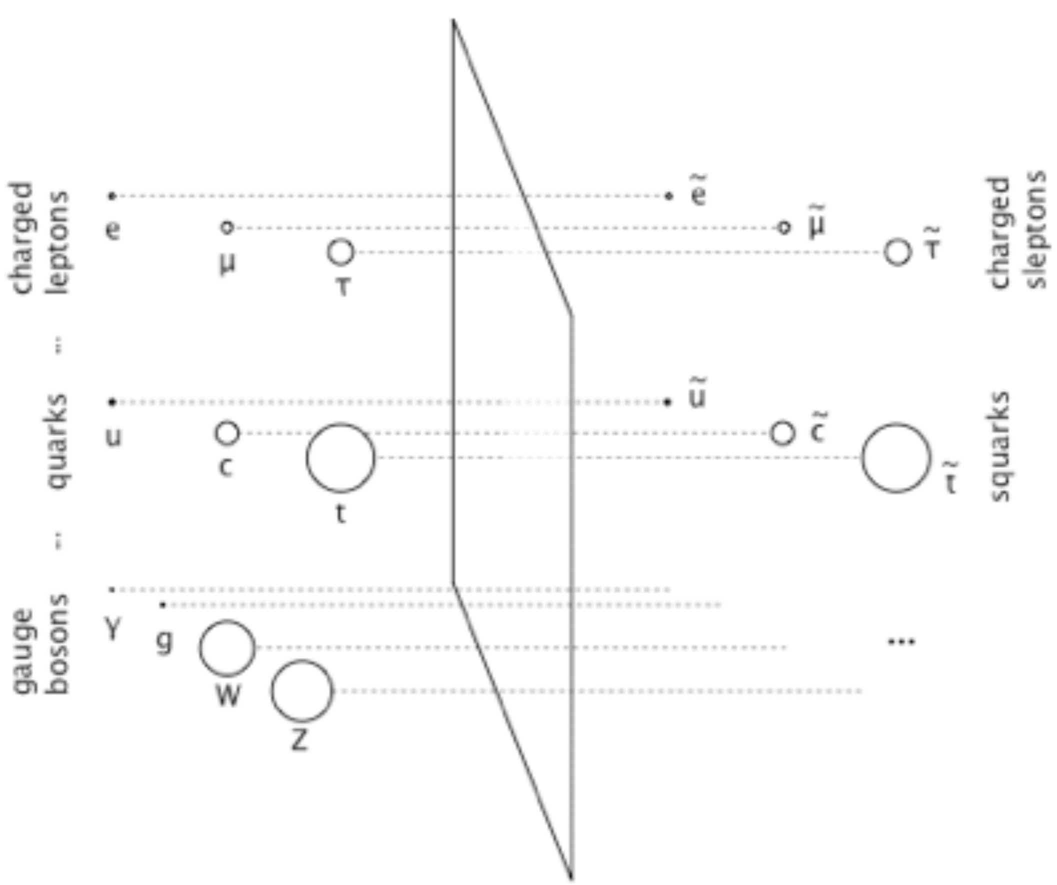
$$\Delta m_H^2 = -\frac{|y_f|^2}{(4\pi)^2} 2\Lambda^2_{\text{cut-off}}$$

correction for fermions

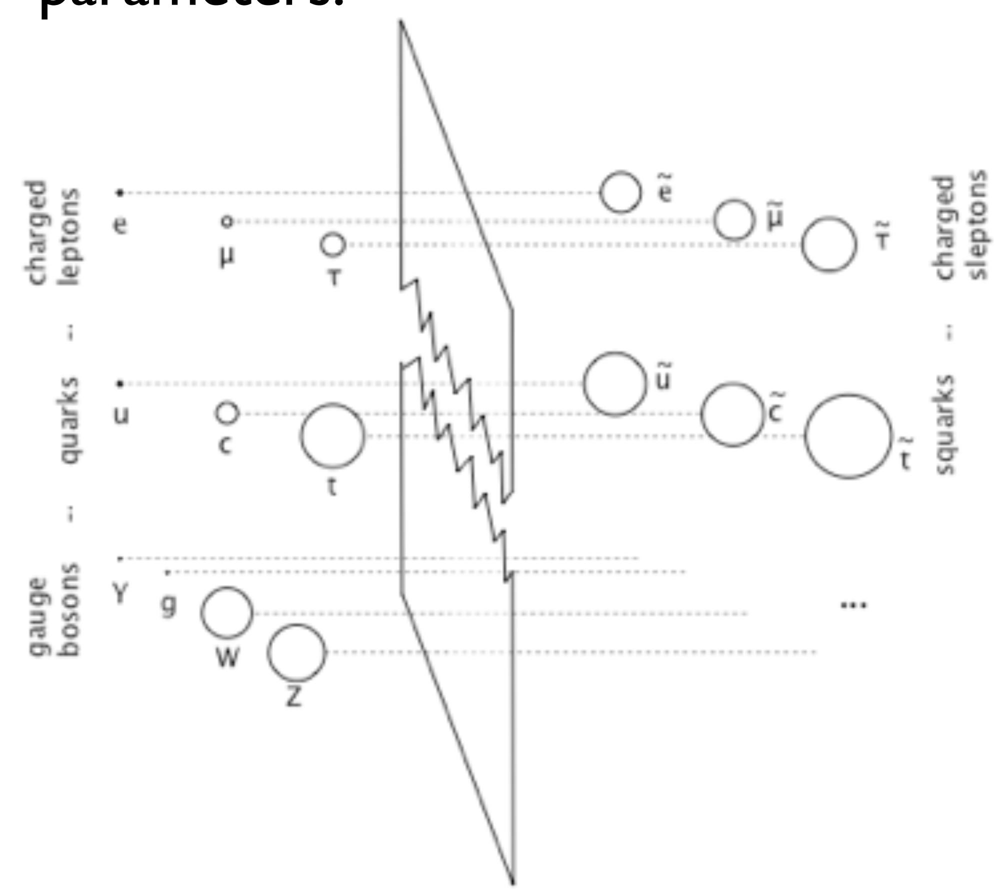
- Expected to be at the TeV scale and therefore accessible by LHC

Exact SuperSymmetry? no! ... must be broken

if Super Symmetry was exact: m (particles) = m(sparticles)
But then we would have already discovered the sparticles!



The masses of the sparticles must be much higher than their partner's mass. The breaking mechanism, however, introduces many new parameters.



The Minimal Supersymmetric Standard Model has 105 free parameters, most of them stemming from the breaking mechanism.

constrained SUSY models

- The minimal supersymmetric standard model has 105 free parameters, which are far too many to investigate. Exploiting physical argumentation, the parameter space can be constrained significantly, and simplified models can be created: mSUGRA with 5 parameters is one model under investigation which conserves R-parity.

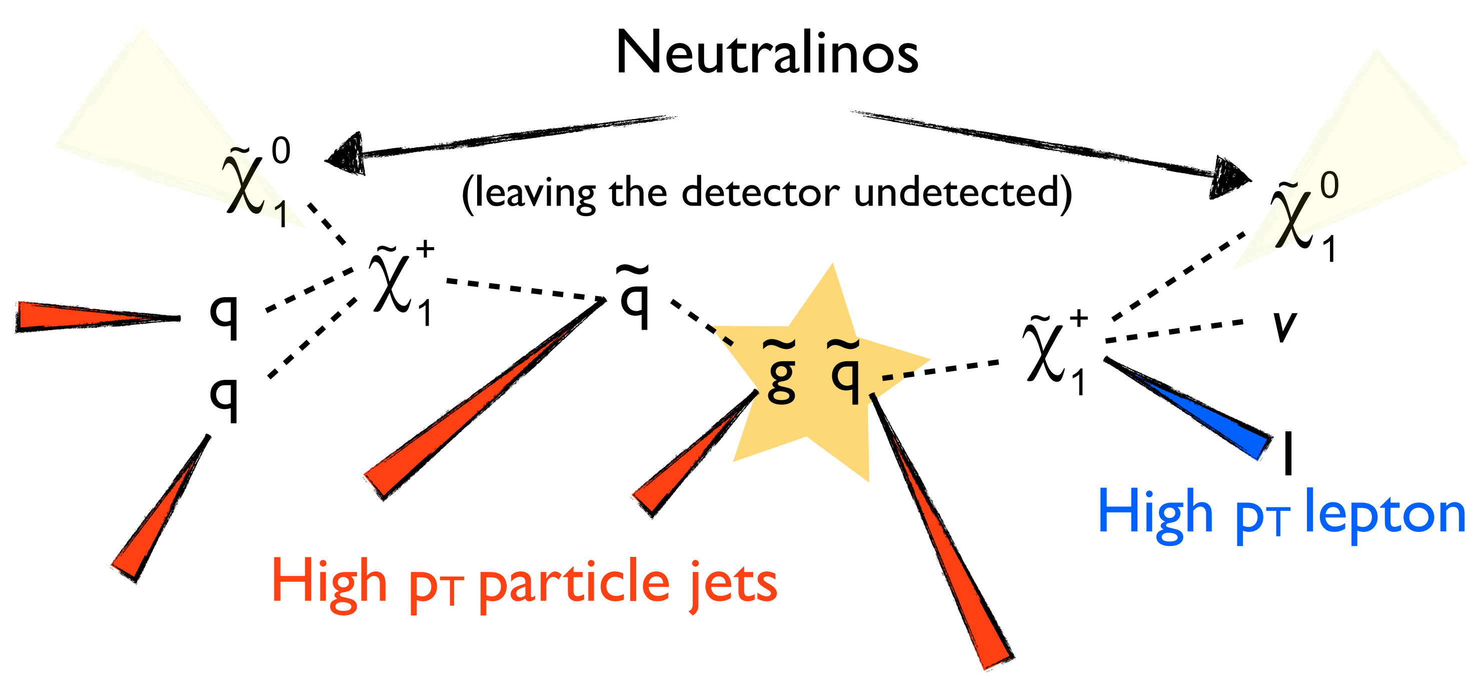
  R-parity conservation has the following consequences:

  $P_R = (-1)^{3(B-L)+2s}$

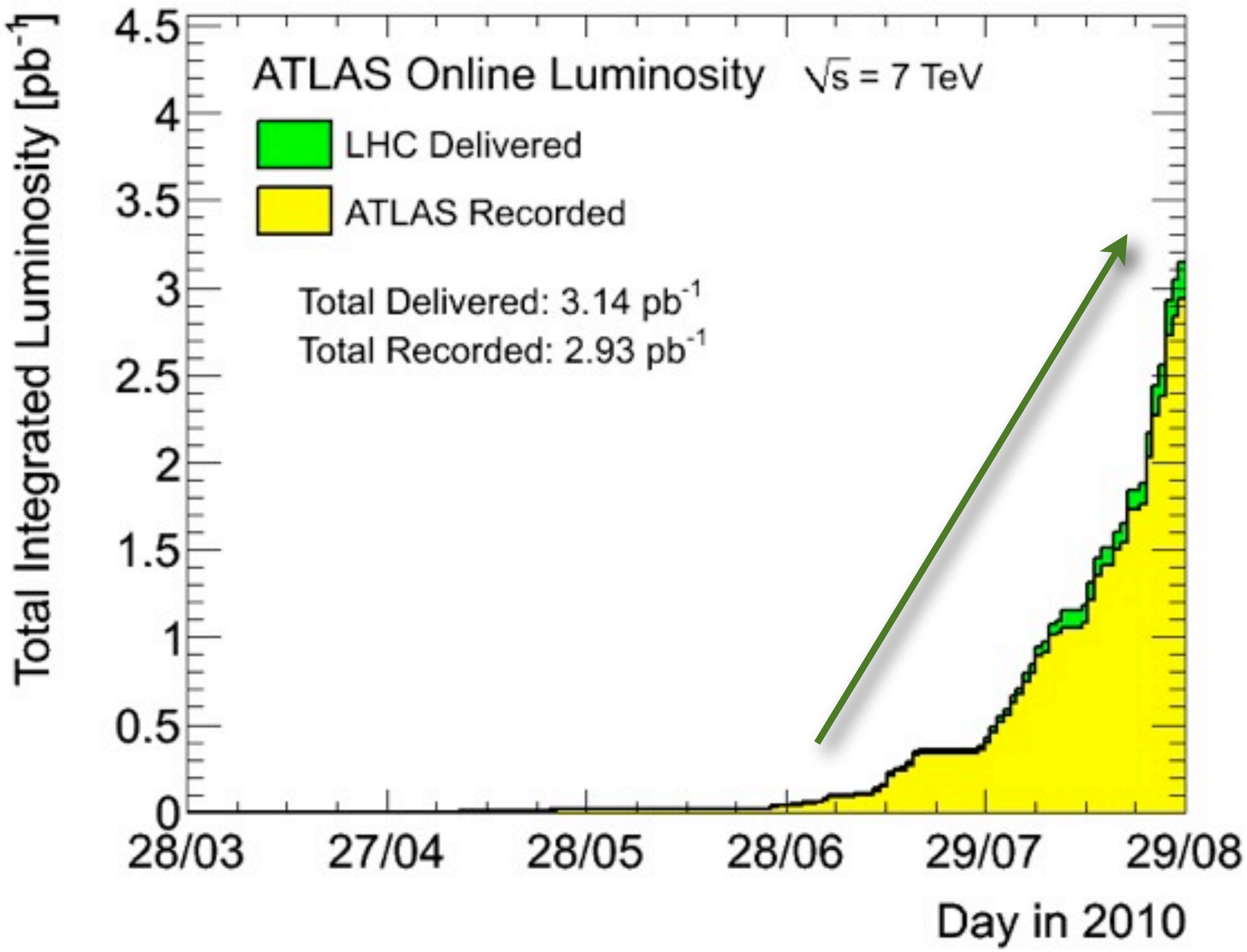
  B: baryon number, L: lepton number, s: spin

  - SUSY particles are always created in pairs
  - The lightest SUSY particle (LSP) must be stable. If it is also neutral, it is a candidate for Dark Matter. In many models, $\tilde{\chi}_1^0$ is the lightest SUSY particle.

  - Typical SUSY event:
    - multiple high p_T jets
    - large missing Energy
    - high p_T leptons



LHC operation & ATLAS data taking



Machine people are increasing

- Number of protons per bunch 10^{11}
- Number of bunches per beam 50
- Beam squeezing

$$\mathcal{L} = \frac{n_b^2 \cdot f_b}{4\pi \cdot \sigma_b^2}$$

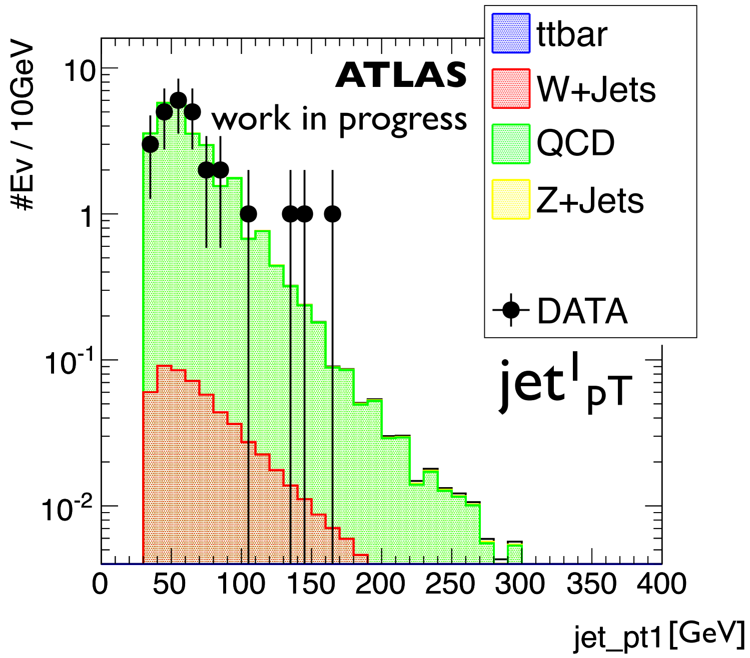
Integrated luminosity up to now collected ~3 pb^{-1}

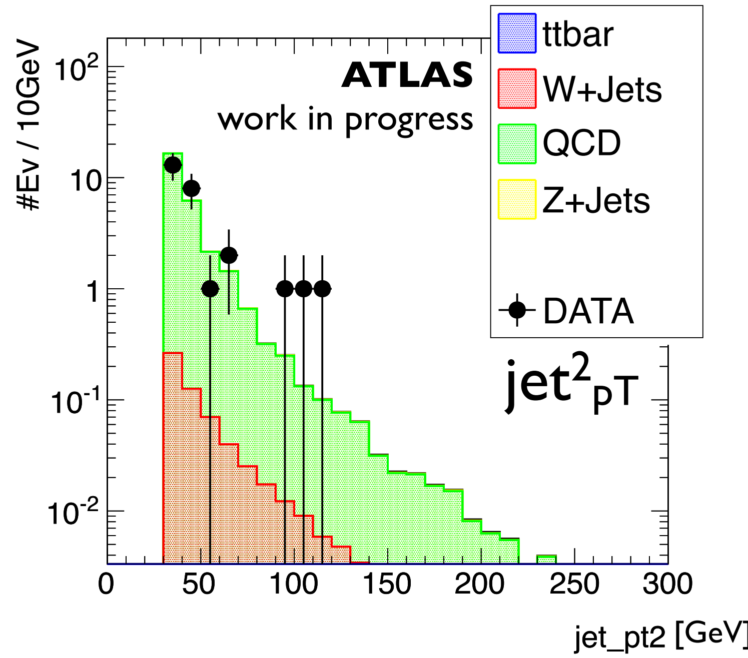
Machine will collide protons until end October 2010 (afterwards Heavy Ions run)

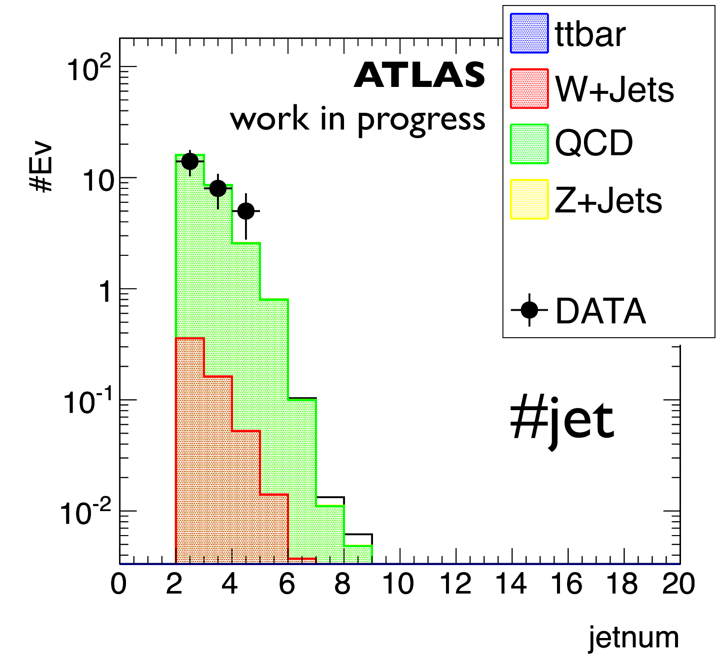
Planned to have ~10 pb^{-1} by then, collecting O(pb^{-1}/day)

First data Plots ~12 nb^{-1} (shown at SPS meeting in mid June)

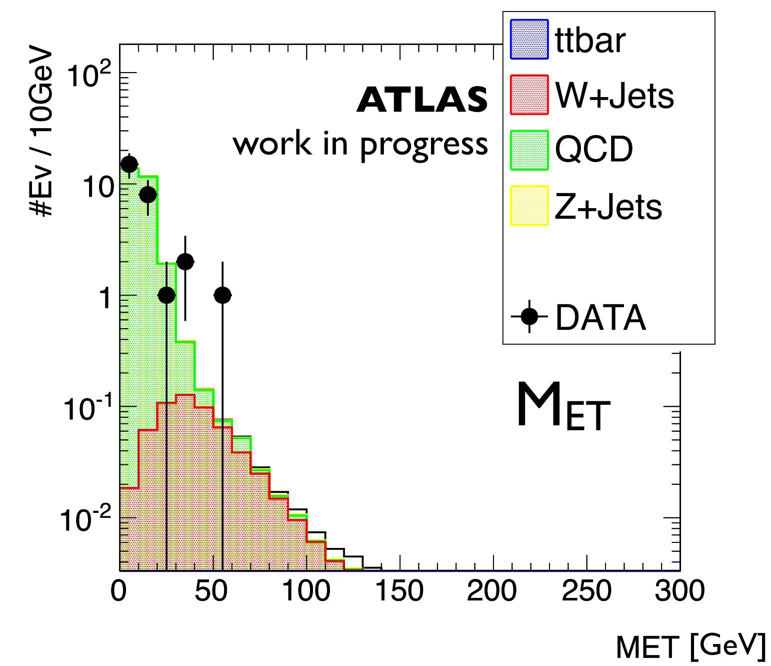
1-lepton electron channel: 1 electron with p_T > 20 GeV, 2 Jets with p_T > 30 GeV





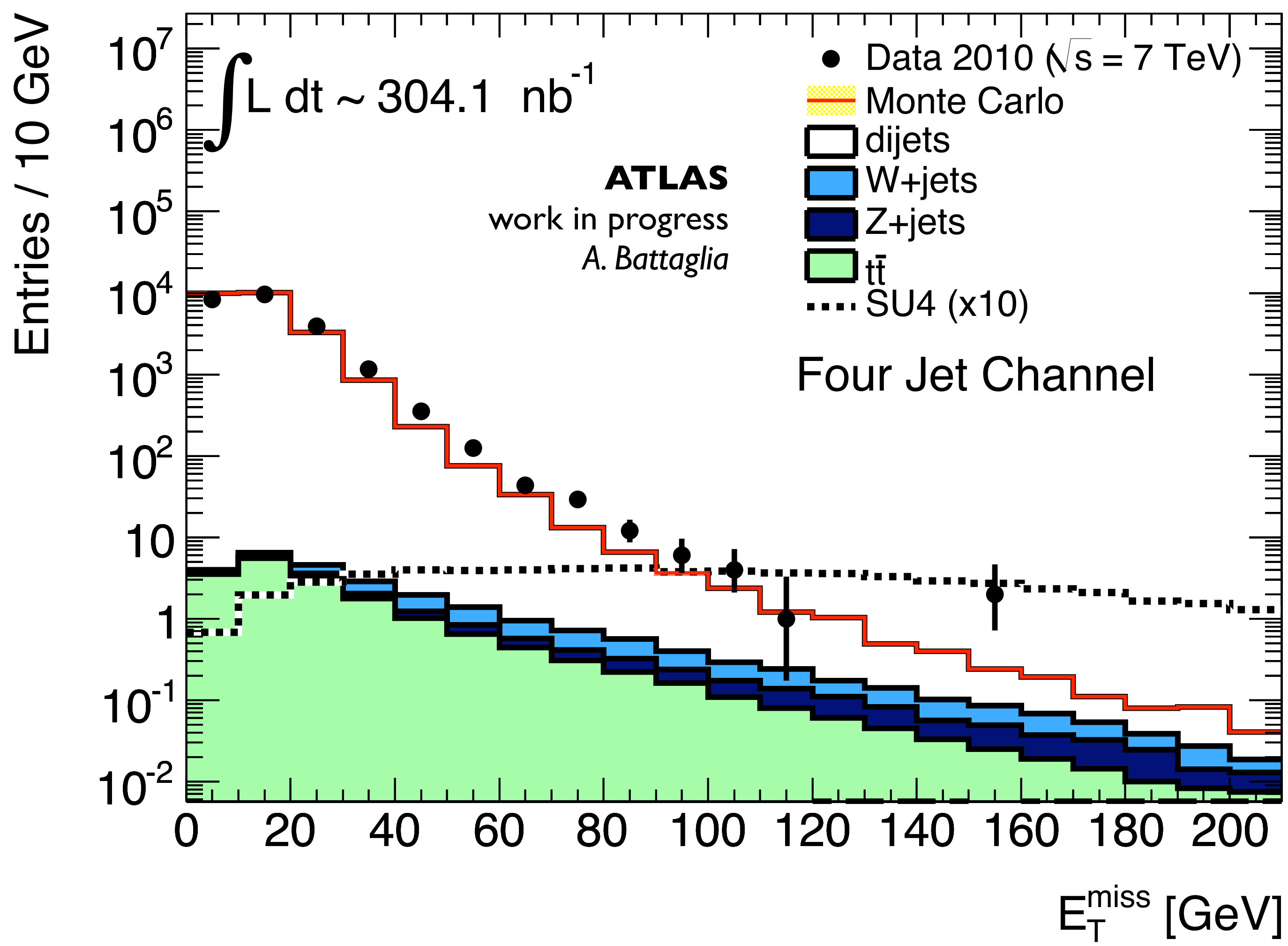


- Normalization
  - relative normalization of histograms according to cross-section
  - sum normalized to number of events in data
- Data consists of physics runs:
  155073, 155112, 155160, 155634, 155678, 155697, 156682
- Good agreement of shape.
- Still working on normalization, trigger efficiencies, jet scale, data format etc.



Analysis has just started!

Plots with 300 nb-1



0-lepton channel:

veto any event with a lepton

Leading Jet with $p_T > 70$ GeV

3[nd], 3[rd], 4[th] Jet with $p_T > 30$ GeV

- Main Background QCD
- Good agreement between MC and data

SU4 ATLAS Benchmark Scenario

msugra parameters:

m_0 = 200 GeV

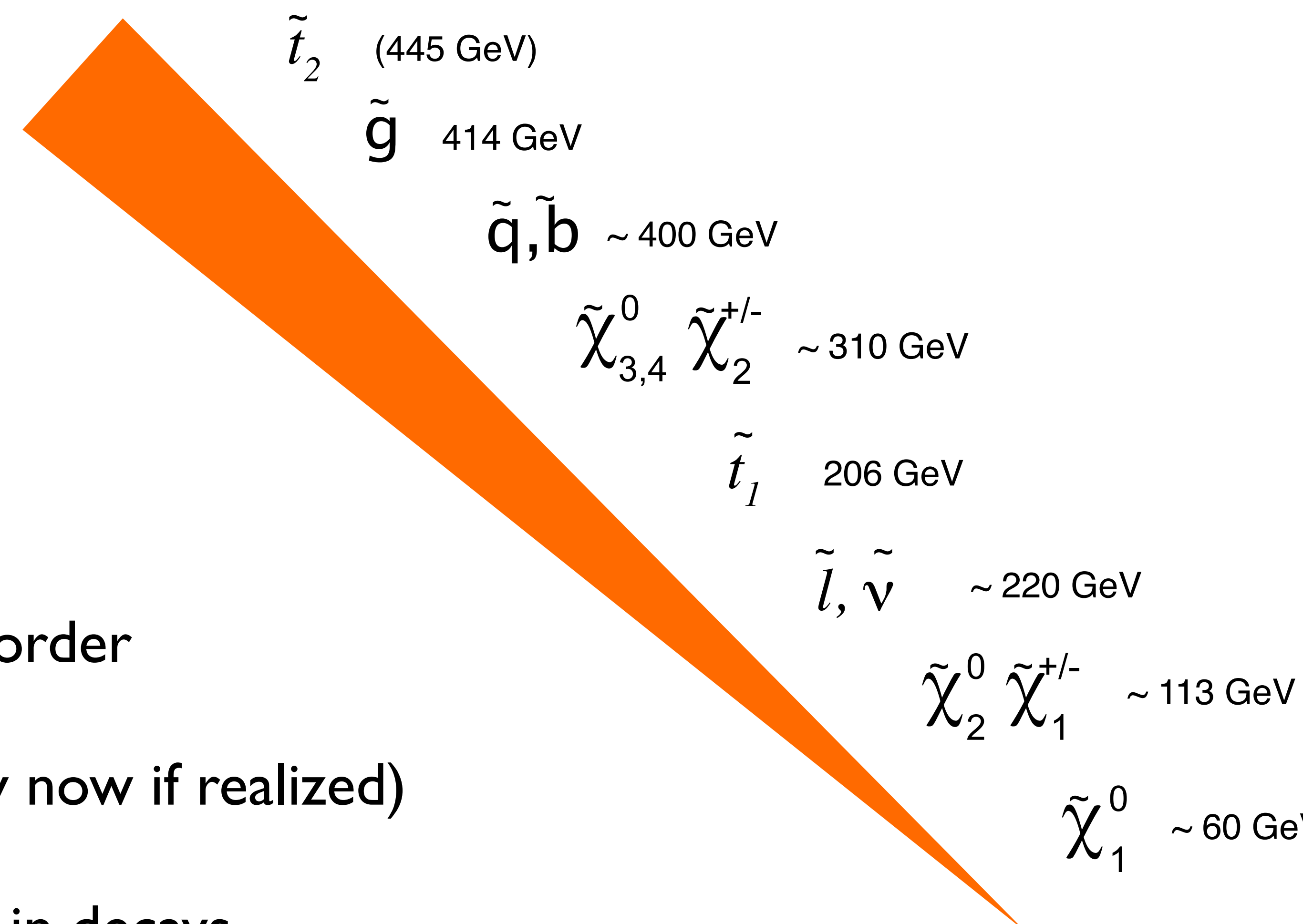
$m_{1/2}$ = 160 GeV

A_0 = - 400 GeV

tan β = 10

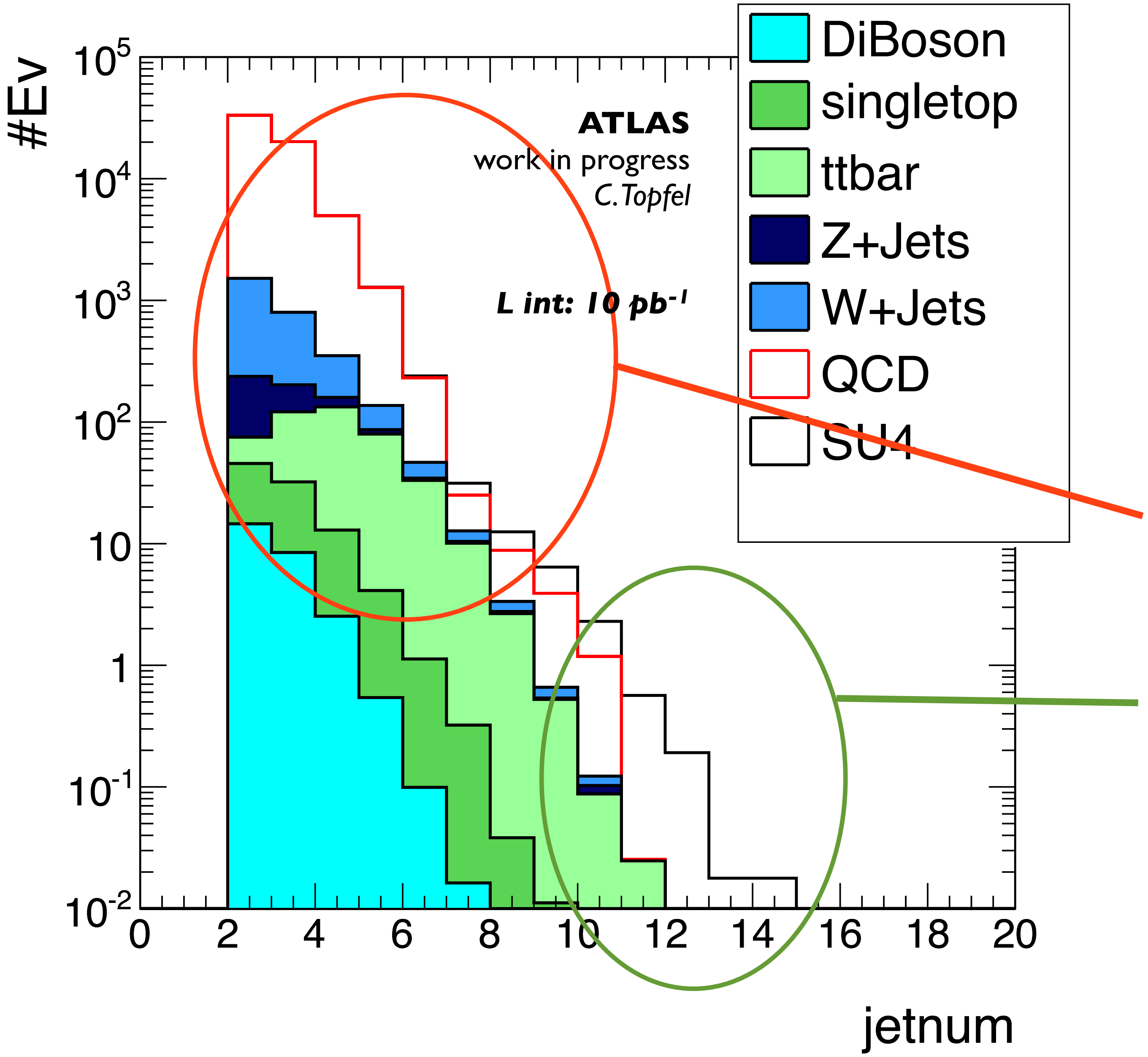
sgn(μ) = 1

Mass hierarchy:



- Benchmark Scenario near the Tevatron border
- Relatively low masses
- High cross-section (several 100 events by now if realized)
- Very "toppy" (because of low stop mass)
  - many top and bottom quarks involved in decays
  - therefore difficult to distinguish from top decays

Discovery and Exclusion (1)



Starting Point

1-lepton, 4 jet channel, jet multiplicity:

2 Jets with $p_T > 30$ GeV

1 electron with $p_T > 20$ GeV
(no additional leptons)

- Dominated by backgrounds:
  - QCD
  - top, W/Z+Jets
- SU4 at high jet multiplicities (as expected)

- Need strong cuts to separate BG from possible SUSY Signal

Apply Cut: $\mathrm{Jet}_{pt\ 1,2,3,4}$ > 70, 30, 30, 30 GeV

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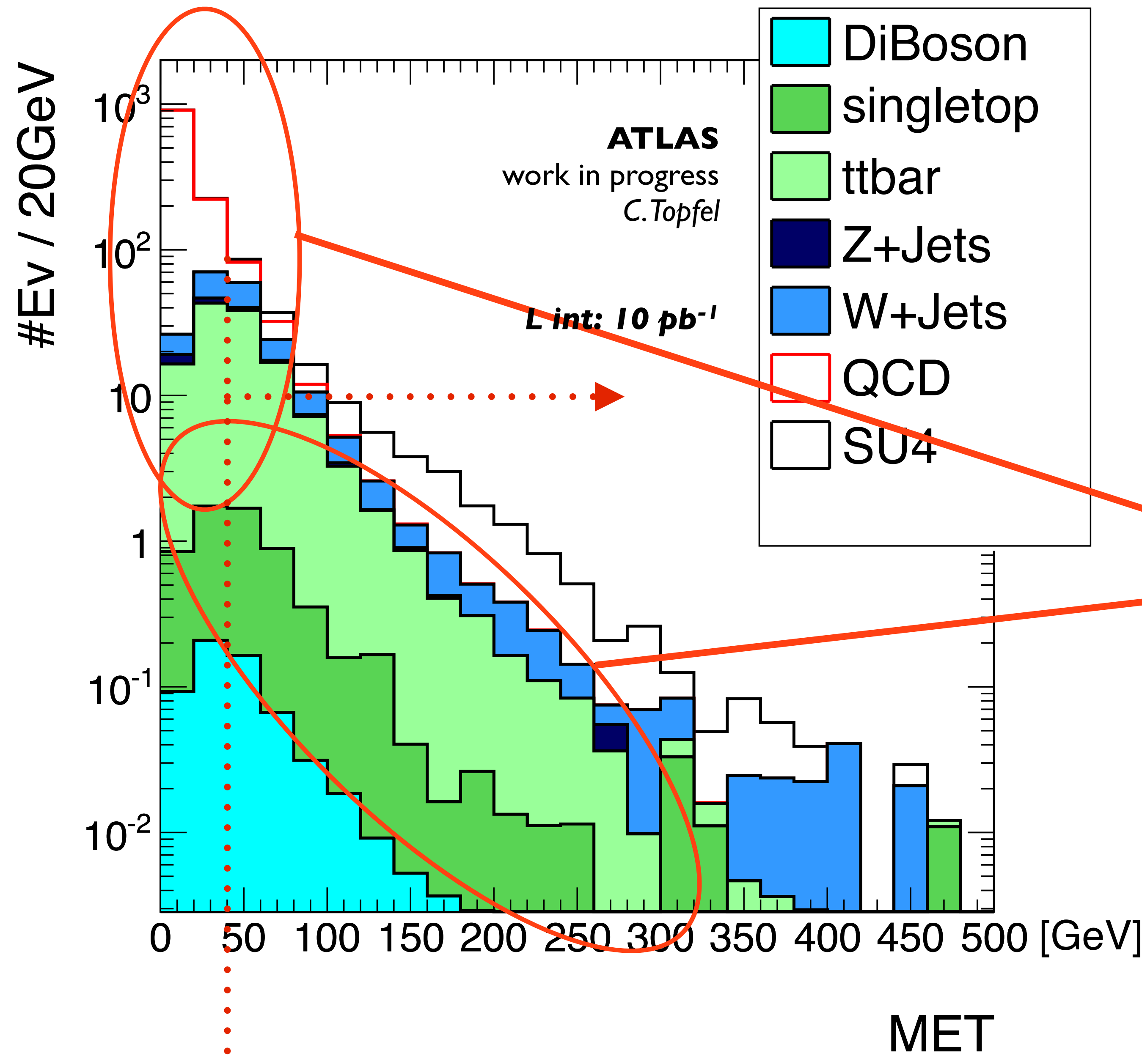
Discovery and Exclusion (2)



Transversal Missing Energy (E_T^{miss})

Cuts applied so far:

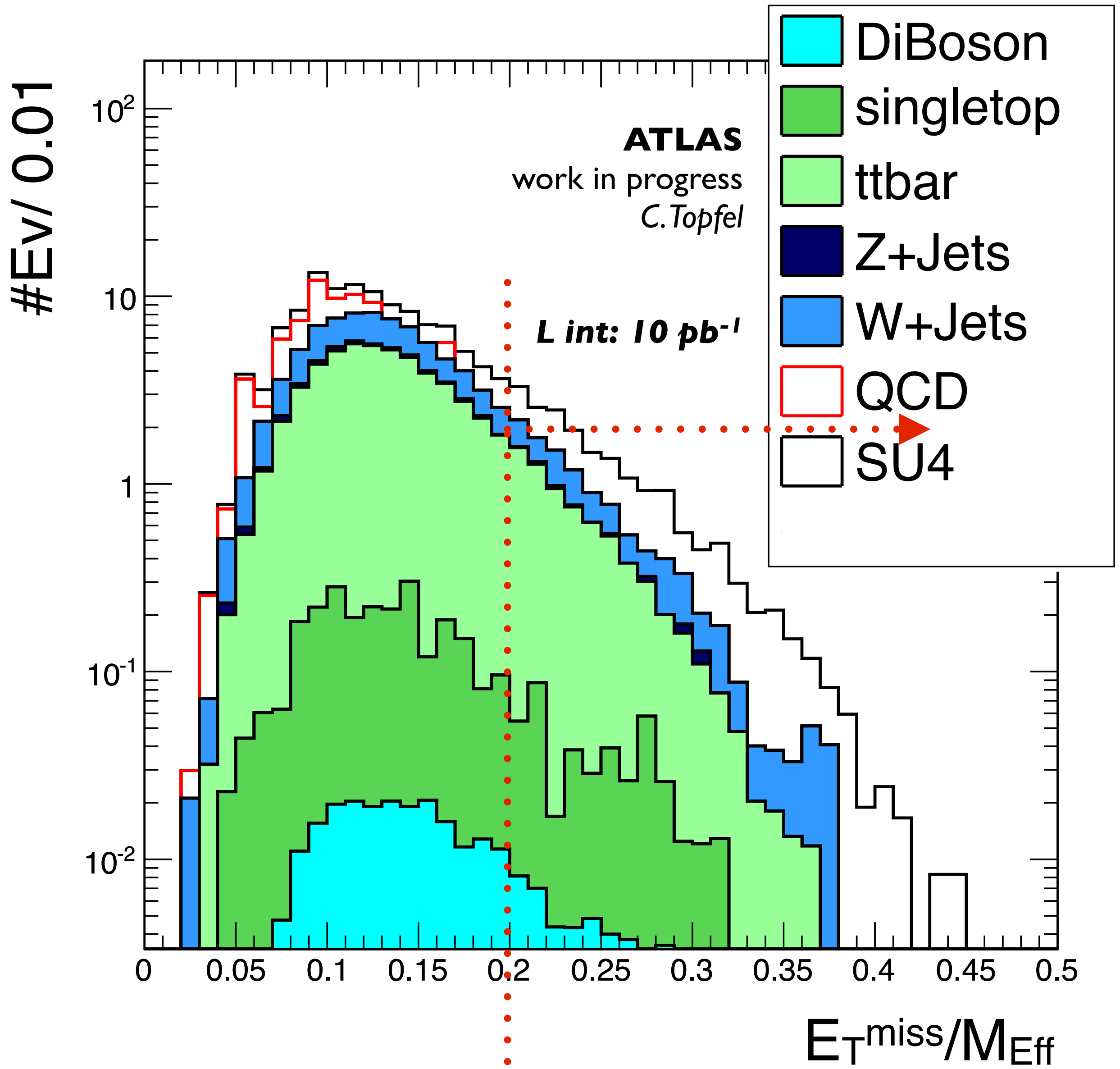
- $Jet_{pt\ 1,2,3,4}$ > 70, 30, 30, 30 GeV

- Background contribution:
  - QCD at low E_T^{miss}
  - W+Jets and top are main backgrounds at higher E_T^{miss} values.
- SU4 has many entries with large M_T^{miss} values

- Apply E_T^{miss} cut to get rid of more QCD background

Cut: E_T^{miss} > 40 GeV

Discovery and Exclusion (3)



E_T^{miss}/M_{Eff}

$$M_{eff} \equiv \sum_{i=1}^{N_{jets}} p_T^{\mathrm{jet},i} + \sum_{i=1}^{N_{lep}} p_T^{\mathrm{lep},i} + E_T^{\mathrm{miss}}$$

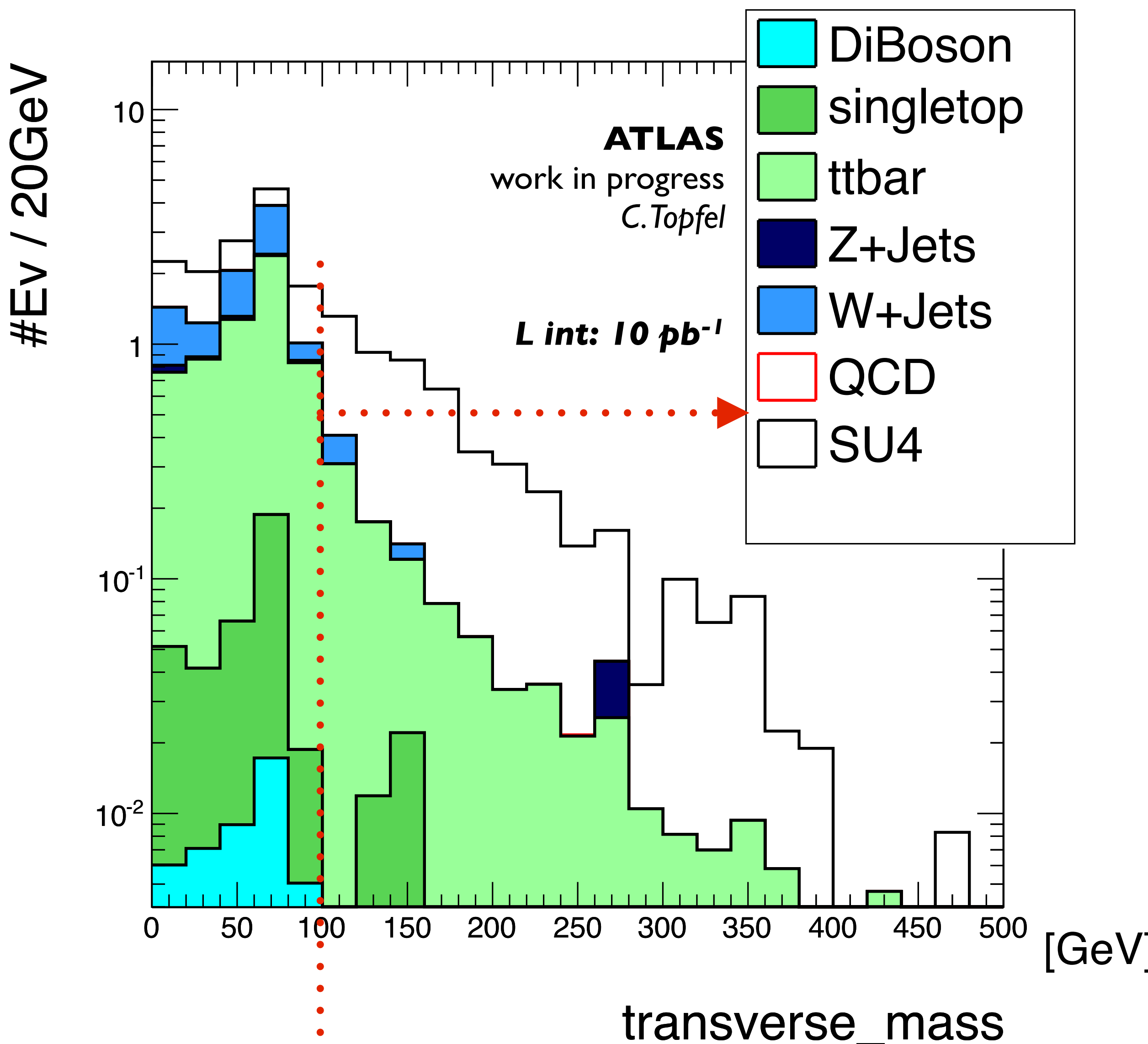
Cuts applied so far:

- $Jet_{pt\ 1,2,3,4}$ > 70, 30, 30, 30 GeV
- E_T^{miss} > 40 GeV

- QCD vanishes beyond 0.2 E^T_{miss}/M_{Eff}
  - (also for lower MET cuts)
- Very effective to get rid of QCD

Cut: $E^T_{miss}/M_{Eff} > 0.2$

Discovery and Exclusion (4)



Transverse Mass (M_T)

$$M_T^2(\mathbf{p}_T^\alpha, \mathbf{p}_T^{\text{miss}}, m_\alpha, m_\chi) \equiv m_\alpha^2 + m_\chi^2 + 2\left(E_T^\alpha E_T^{\text{miss}} - \mathbf{p}_T^\alpha \cdot \mathbf{p}_T^{\text{miss}}\right)$$

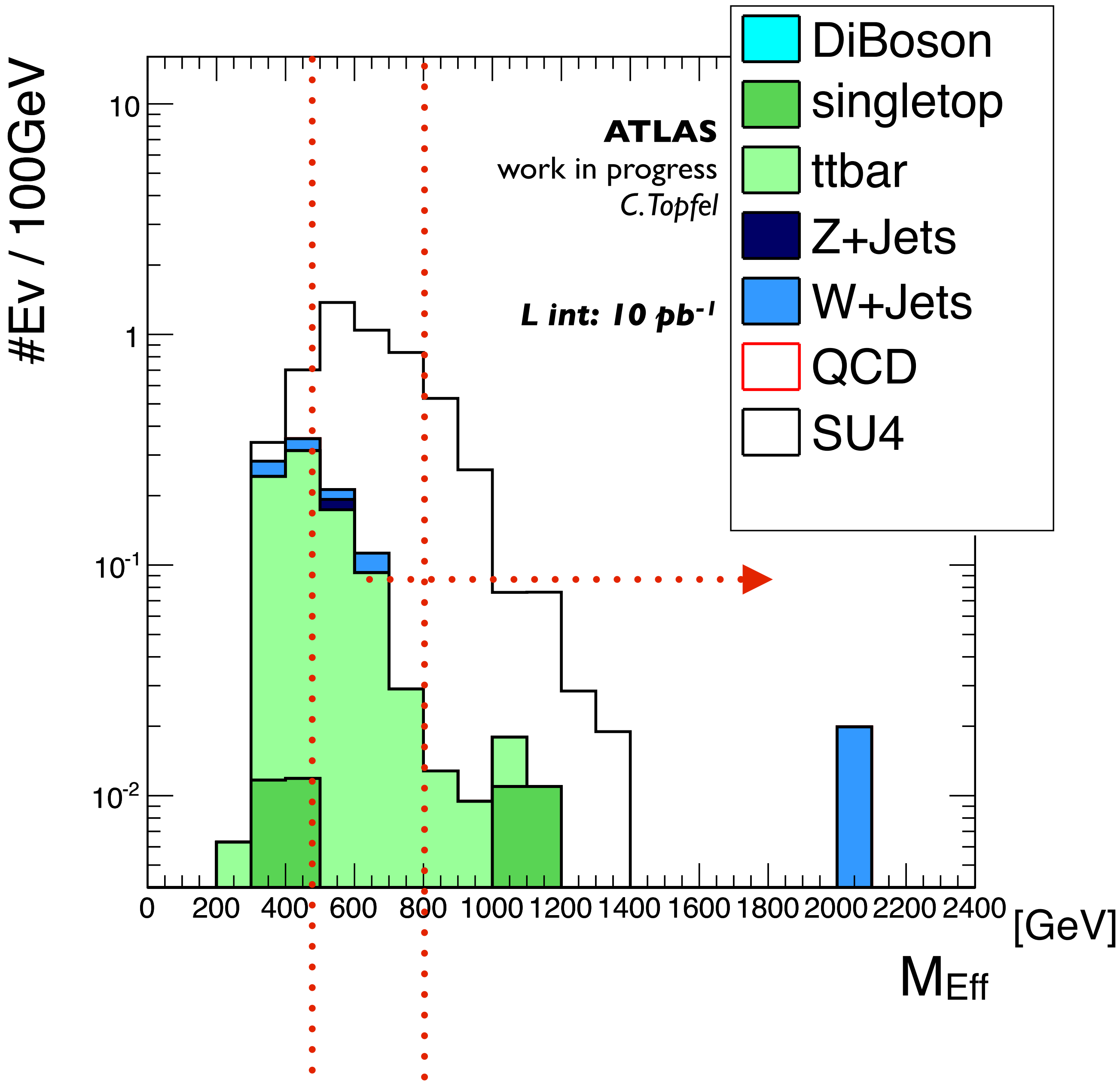
Cuts applied so far:

- $Jet_{pt\ 1,2,3,4}$ > 70, 30, 30, 30 GeV
- E_T^{miss} > 40 GeV
- E^T_{miss}/M_{Eff} > 0.2

- Strong reduction of 1-lepton background after M_T > 100 GeV
  - ttbar
  - W+Jets
- In fact, remaining ttbar is largely dileptonic, where 1 lepton is missed.

Cut: M_T > 100 GeV

Discovery and Exclusion (5)



Cut: M_{Eff} > 500 - 800 GeV

Effective Mass (M_{Eff})

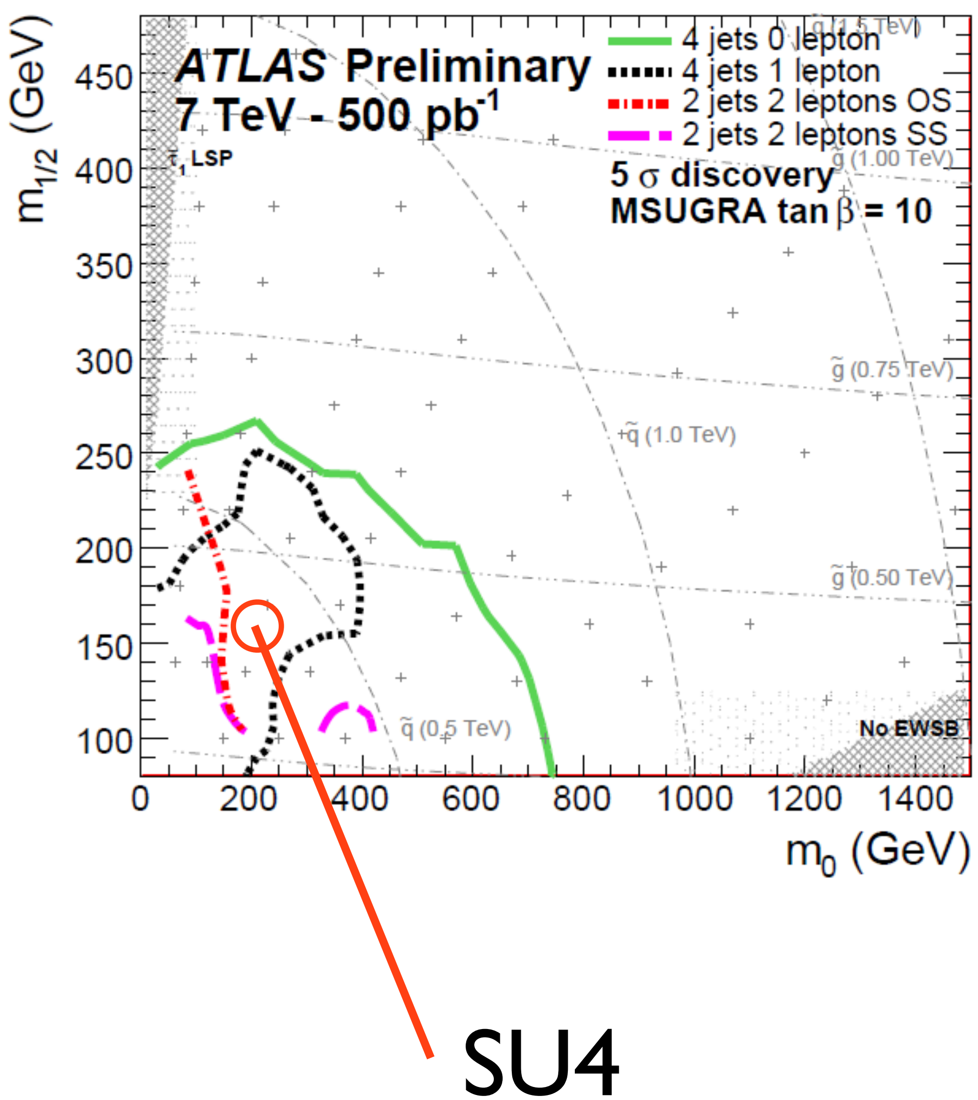
$$M_{eff} \equiv \sum_{i=1}^{N_{jets}} p_T^{\mathrm{jet},i} + \sum_{i=1}^{N_{lep}} p_T^{\mathrm{lep},i} + E_T^{\mathrm{miss}}$$

Cuts applied so far:

- $Jet_{pt\ 1,2,3,4}$ > 70, 30, 30, 30 GeV
- E_T^{miss} > 40 GeV
- E^T_{miss}/M_{Eff} > 0.2
- M_T > 100 GeV

- M_{Eff} has some interesting properties:
  - Many entries at high values for generic SUSY scenarios
  - "Peak" value of signal distribution strongly correlated to the mass of the produced SUSY particles.
- Statistical methods to discover or exclude scenario is performed on this observable

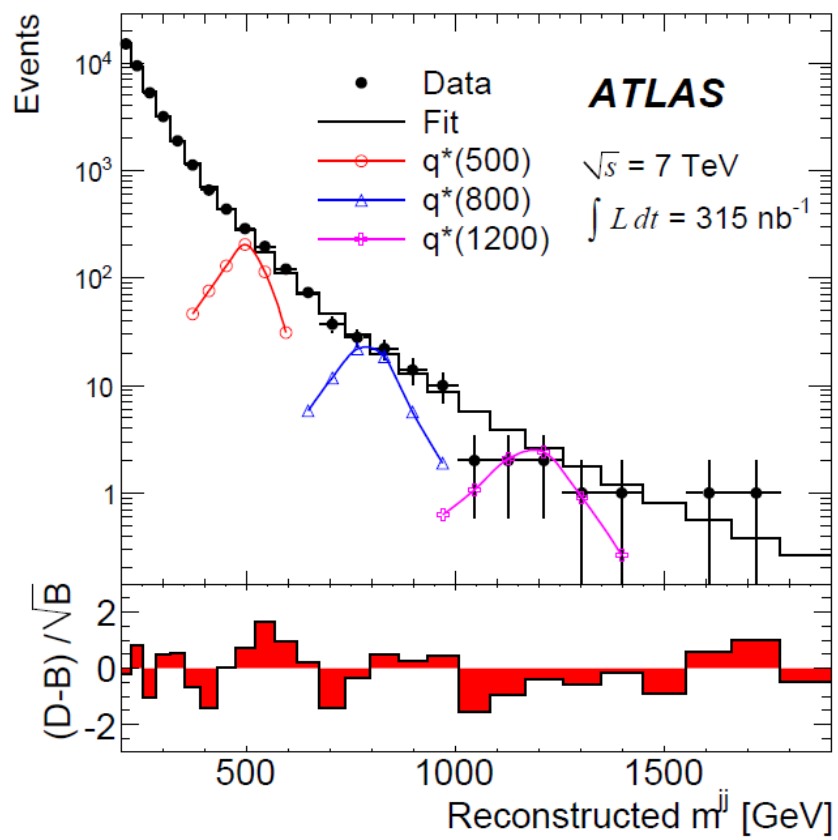
Discovery and Exclusion (6)

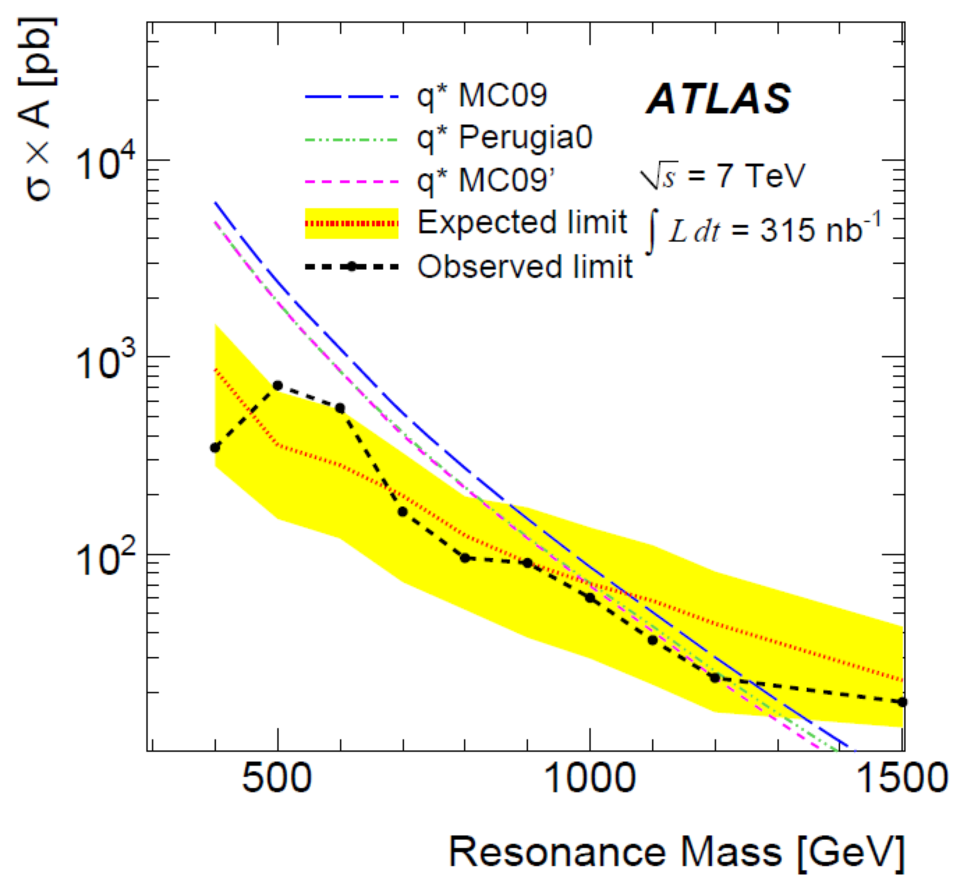


- We want to probe parts of the mSUGRA parameter space (so called m_0 - $m_{1/2}$ plane)
- With 500 pb^{-1} (data by end 2011) we will be able to discover SUSY up to masses of squarks and gluinos of 700 GeV
- We will be able to start to exclude scenarios by the end of this year (Exceed the Tevatron limits)
- Bright prospects!

First Results: dijet mass

- **Search bumps** in the reconstructed **di-jet mass** distribution m(jj)
- Compare to prediction of excited quarks q* decaying into two jets

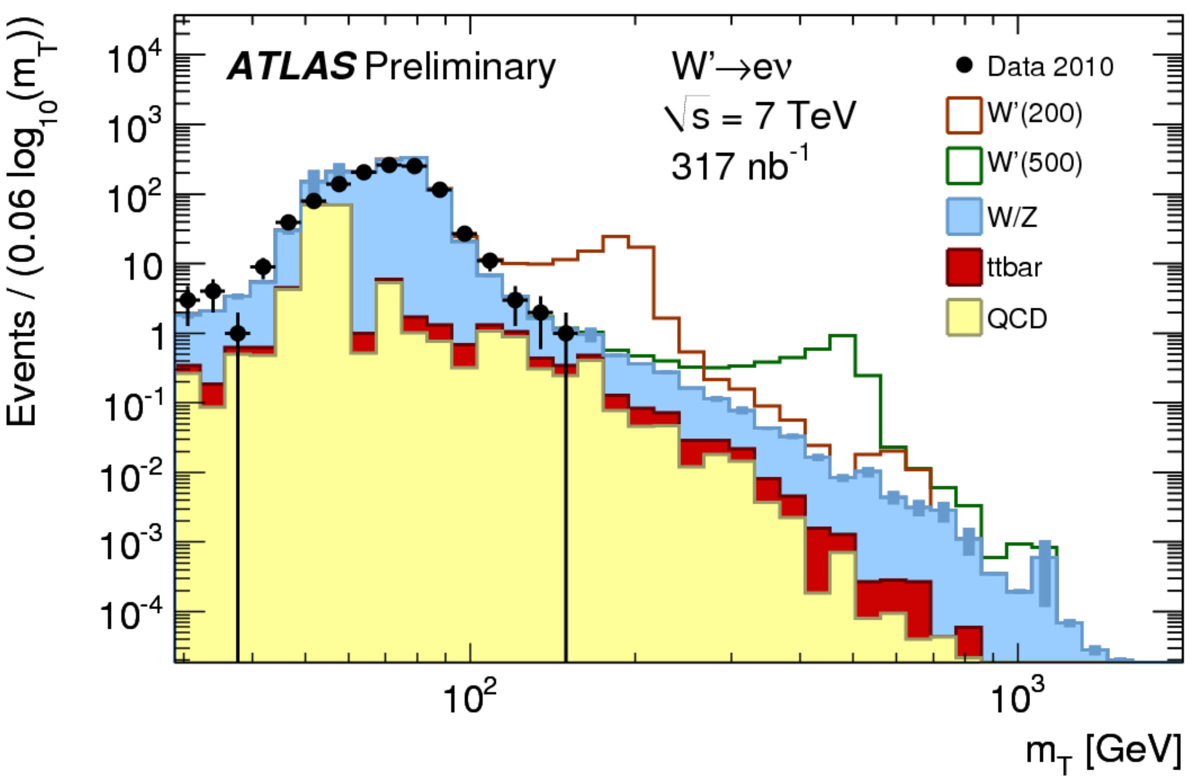




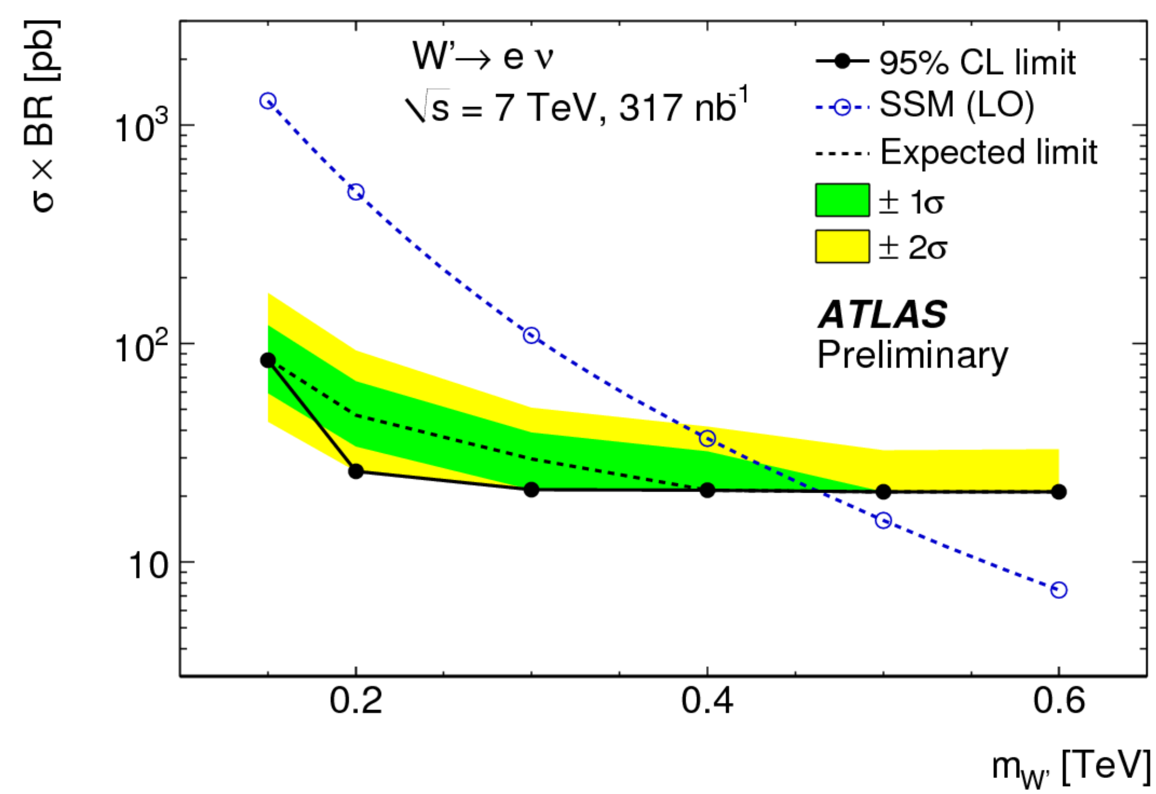
- Distribution is compatible with a smooth monotonic function (no bumps)
- Exclude **(95% CL) q* with mass 0.40 TeV < m(q*) < 1.26 TeV**
- **arXiv:1008.2461v1**, submitted to PRL Aug 14th 2010

First Result: W'

Transverse mass distribution



Extract limits



- 317 nb^{-1}
- Exclude a W' of a Sequential Standard Model with mass below 465 GeV
- Tevatron excluding up to ~1 TeV W' bosons

Conclusions & Outlook

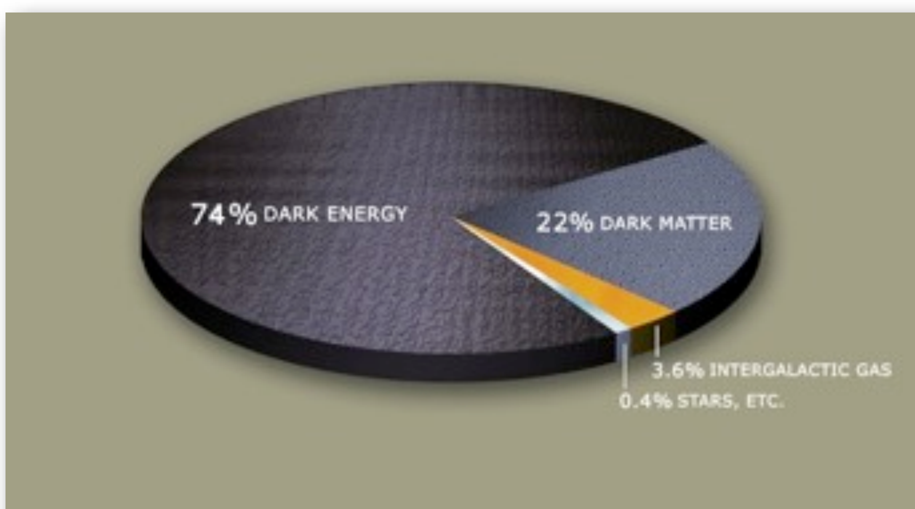
- SUSY is an attractive theory to solve certain problems of the Standard Model
- SUSY is accessible by the LHC if the mass scale is at 1 TeV
- instantaneous luminosity will further rise, e.g. by gradually increasing the number of Bunches: 48 (now) - 96 (end sep) - 144 - 196 - 240 - 288 - 366 (October)
- Plan to reach $L = 10^{32}\ cm^{-2}s^{-1}$ and int.L = 5 pb^{-1}/day by the end of October
- Can start to exclude new areas in the mSUGRA parameter space soon
- Already exclude
  - excited quark masses of up to 1.2 TeV
  - W' up to 430 GeV

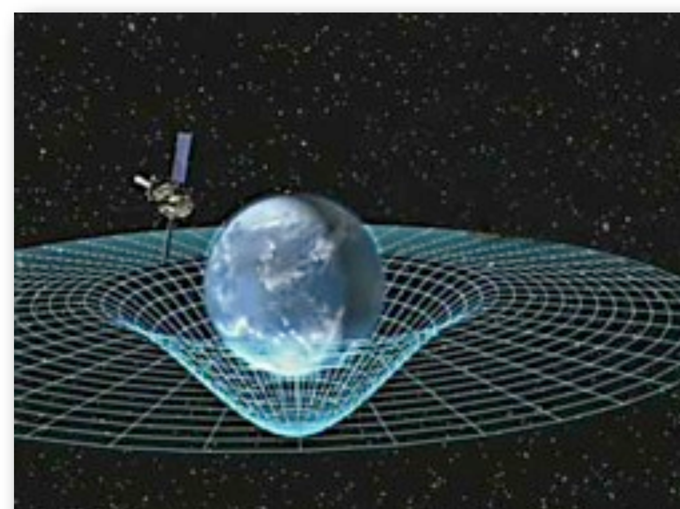
The Swiss Alps - Picture taken from Radio Tower Bantiger (Bolligen) on September 1, 2010

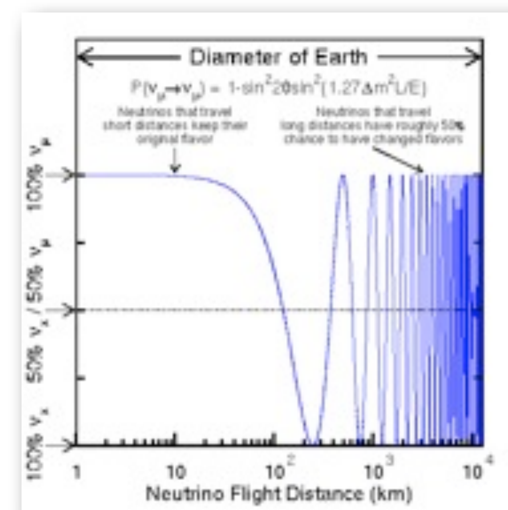
Backup

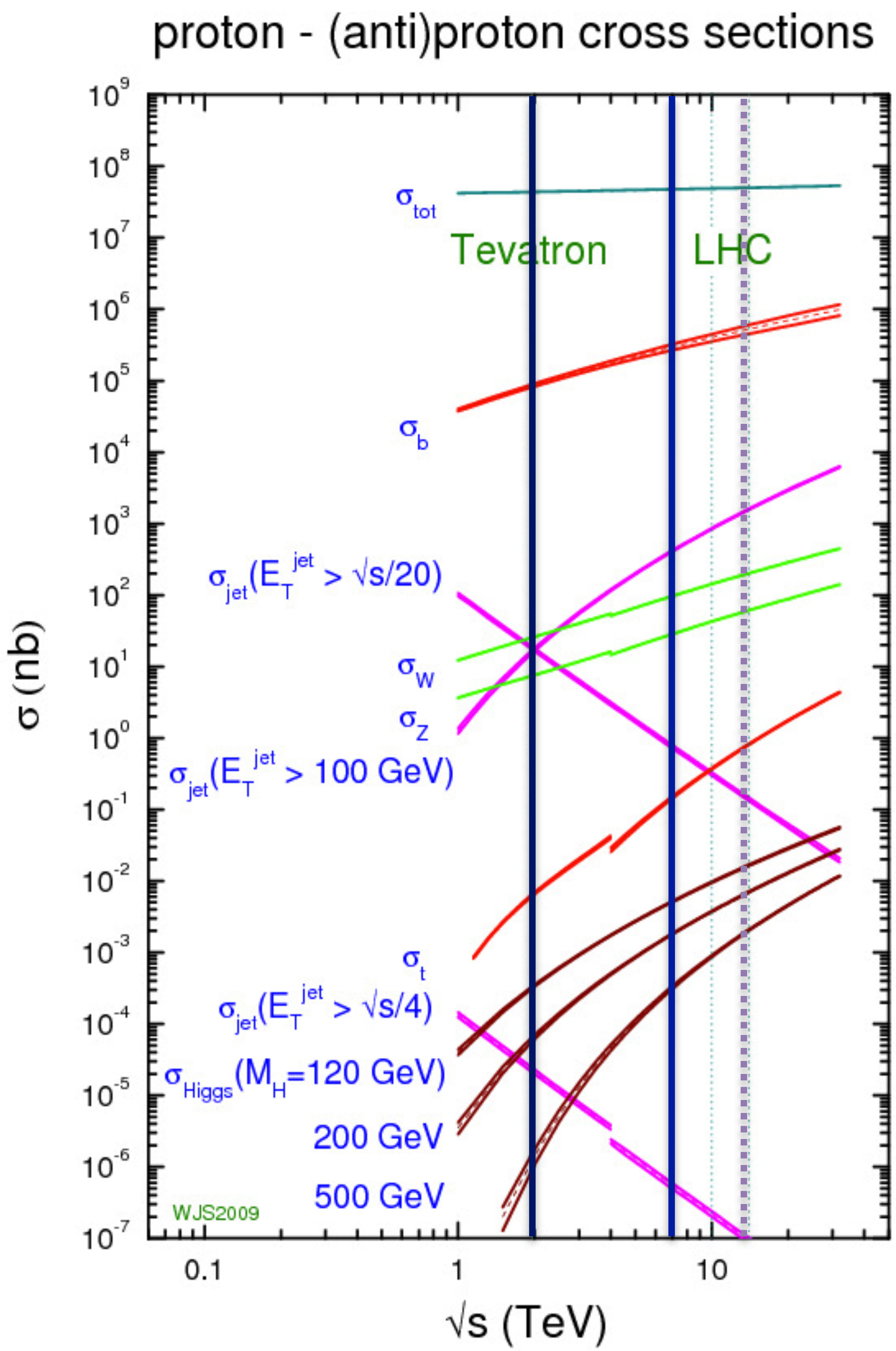
Why new physics?

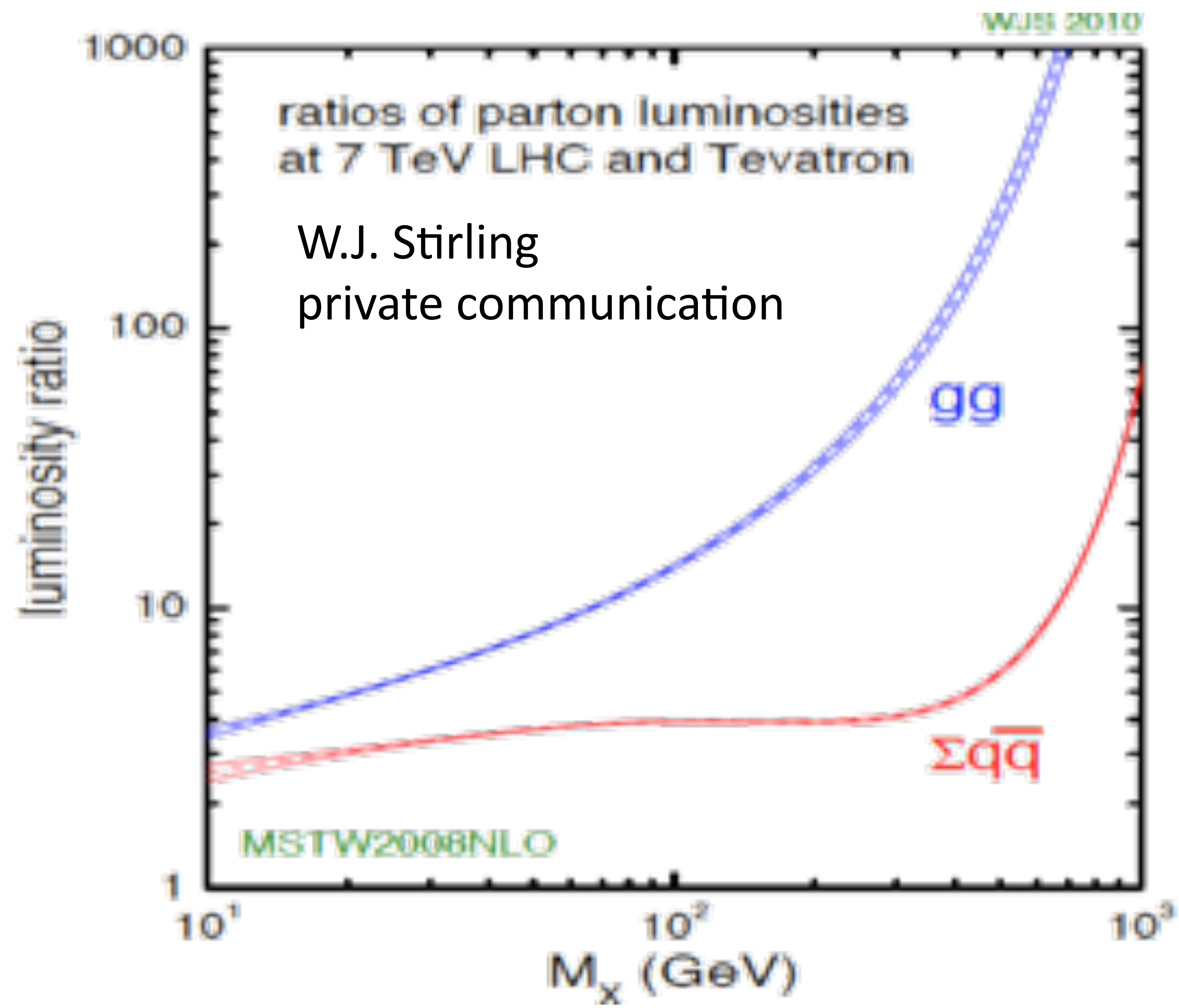
- The Standard Model is not complete
  (gravity, dark matter/energy, neutrino oscillations...)
- Standard Model does not answer fundamental questions: matter-antimatter asymmetry, fermion family number...
- Candidate to explain certain effects: SuperSymmetry
- Hierarchy Problem (why Planck scale >> weak scale, quadrative radiative corrections to the Higgs mass that drive the higgs mass to high values if not extremely fine tuned.)











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private communication

Tevatron-LHC Comparison 2011:

Tevatron at 10 fb^{-1} vs. LHC 1 fb^{-1} at 7 TeV

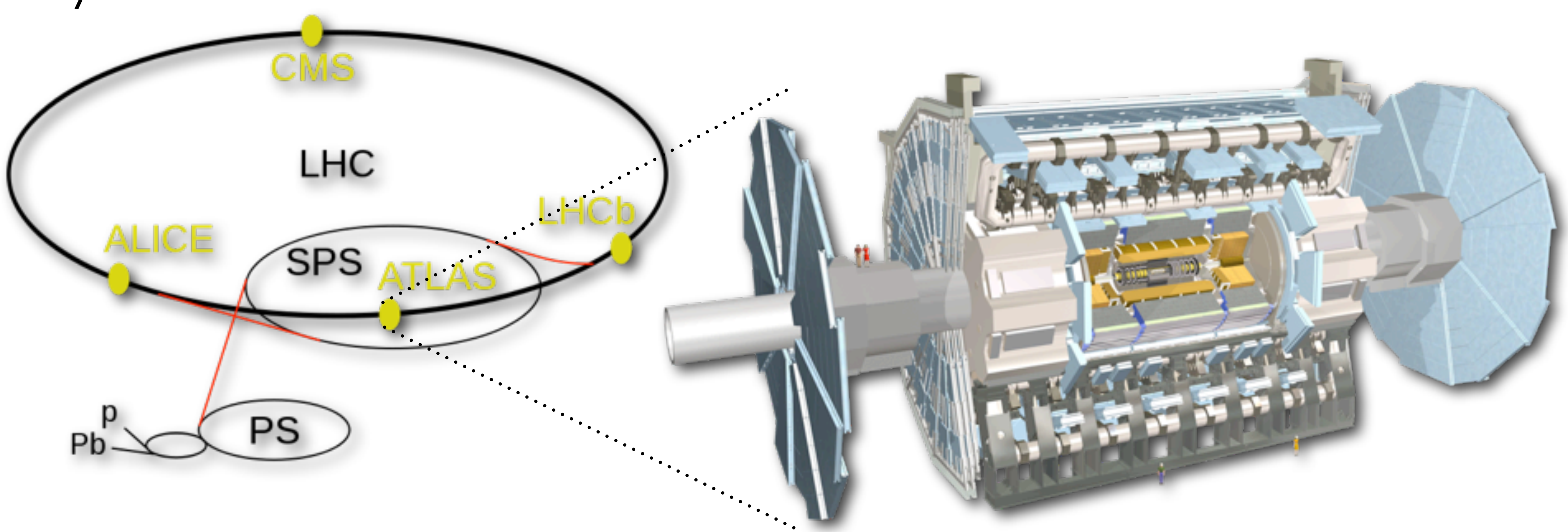
LHC has **2.5 x top**

LHC has **10 x heavier objects**

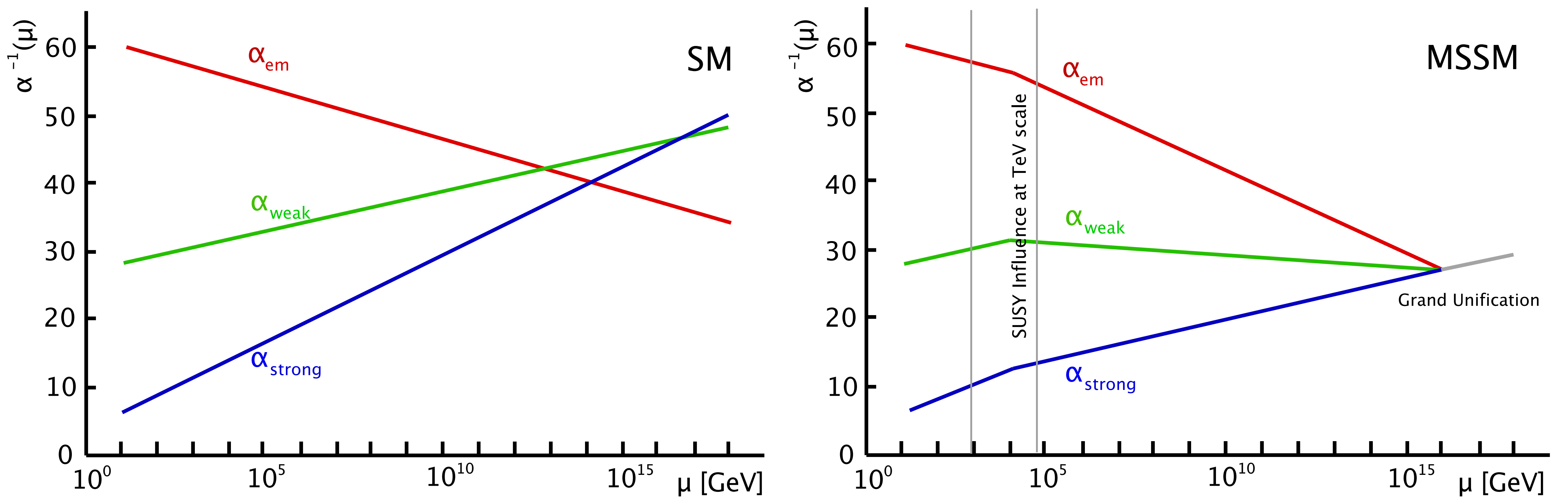
More statistics ! Better limits ! Discoveries are not excluded !

LHC / ATLAS

- LHC (re-)started operation end 2009
  - Center-of-mass energy: 7 TeV (3.5 on 3.5 TeV)
  - Will run at this energy until 2011 to achieve 1 fb^{-1} of integrated luminosity
  - Target instantaneous luminosity 10^{32} $cm^{-2}s^{-1}$ by fall
- ATLAS: General purpose detector:
  - search for new Physics
    - SuperSymmetry
    - Higgs
  - ... but also re-discover Z, W, top



SuperSymmetry supports Grand Unification



- In the Standard Model, the fundamental forces miss each other at high energy scales.
- In the Minimal Supersymmetric Standard Model, the running coupling constants “meet” at a high scale. This is an indication for SuperSymmetry supporting Grand Unification of the Forces.