MSSM $H^{\pm} \rightarrow \chi_i^0 \chi_j^{\pm}$ Searches in the 3 Lepton + Missing Transverse Energy

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On behalf of the ATLAS Collaboration

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Supersymmetry and the Higgs Boson

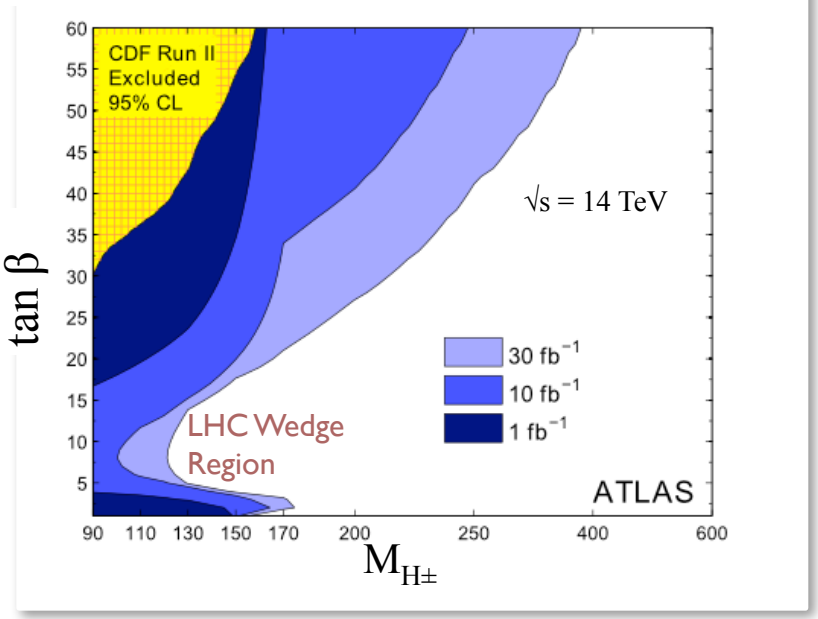
- **Supersymmetry (SUSY)**
  - One of the most popular theories describing physics beyond the standard model.
  - Solves hierarchy problem of standard model.
  - Predicts several new particles, including dark matter candidates.
- **Minimal Supersymmetric Standard Model (MSSM)**
  - Minimum extension to standard model that provides supersymmetry.
  - Used as primary benchmark scenario for most current experimental SUSY searches.
- **Higgs boson under MSSM**
  - MSSM requires at least two Higgs doublets, resulting in five physical Higgs bosons.
    - 3 Neutral (h, H, and A)
    - 2 Charged (H^+ and H^-)
- **Discovery of a charged Higgs boson would be a clear sign of physics beyond the standard model.**

$H^{\pm}$ Searches

Standard $H^{\pm}$ Searches

- Well exercised search channels suppressed in "LHC Wedge Region"
- $H^{\pm} \rightarrow tb$ suppressed by low $H^{\pm}tb$ coupling near $\tan\beta \sim 7$.
- $H^{\pm} \rightarrow \tau\upsilon$ suppressed at $M_{H+} > M_{top}$ for low $\tan\beta$.

ATLAS $H^{\pm}$ 5-σ Discovery Sensitivity



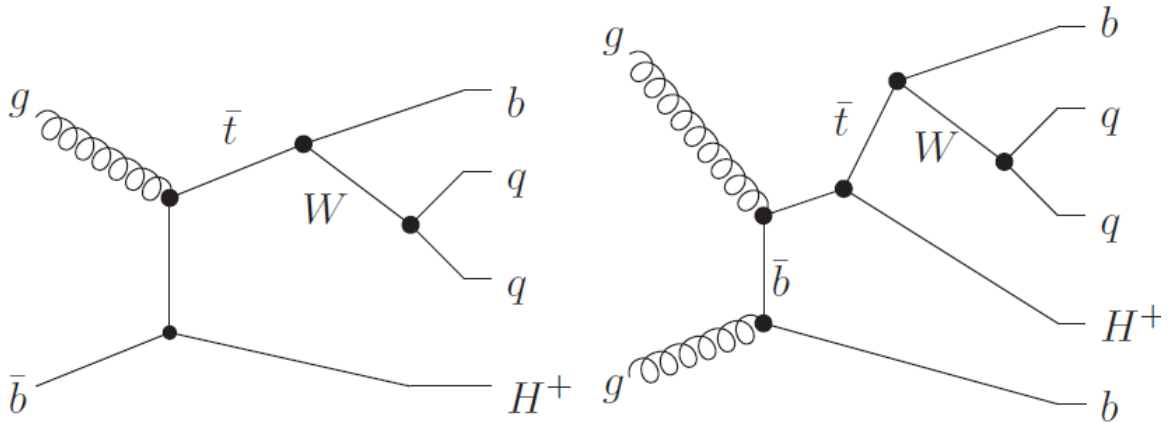
*CERN-OPEN-2008-020 (arXiv:0901.0512)

tan β = ratio of vacuum expectation values of Higgs doublets.

An Alternative Channel

- $H^{\pm} \rightarrow \chi_i^{\pm} \chi_j^0 \rightarrow$ 3 lepton and missing transverse energy.
  - Chargino ($\chi_i^{\pm}$) and neutralino (χ_j^0) are SUSY particles.
  - Decay less sensitive to $H^{\pm}tb$ coupling.
  - Effective for $M_{H+} > M_{top}$
  - Provides extra sensitivity in LHC Wedge Region.
  - See early study: Hansen C et al. (arXiv:hep-ph/0504216)

H+ Production



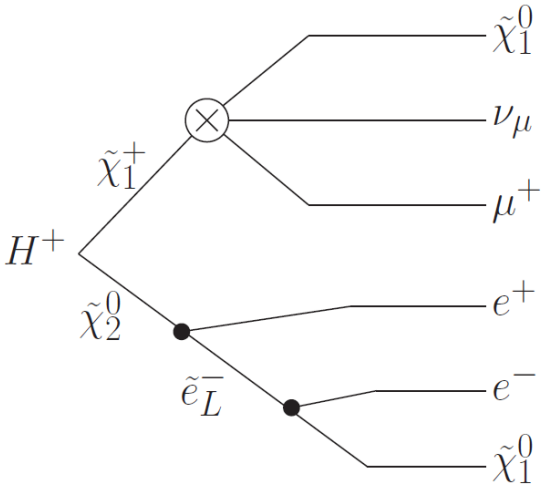
Example Production

- Production Mechanisms
  - gg, qq → tbH±
  - gb → tH±
- Note tbH+ vertex, suppressed in LHC wedge region. Our enhancement over $H^+ \rightarrow tb$ comes from decay

- Only considered SM → H^+ production
- We only consider heavy H^+ (heavier than top).
  - Light H^+ was considered, but the required $\chi_i^{\pm}$ and χ_j^0 masses to keep decay open are excluded by current experimental constraints.

H+ Decay

- Target decay chain is $H^{\pm} \rightarrow \chi_i^{\pm} \chi_j^0$
- Final State Signature:
  - Trileptons
    - *All combinations of muons and electrons*
  - Missing Transverse Energy (MET)
    - *LSP + ν*
  - Jets
    - *Associated t and b quarks*
- Important backgrounds include:
  - Direct $\chi_i^{\pm} \chi_j^0$ production.
  - $t\bar{t}$
  - Diboson
  - Z + Jets



Example Decay

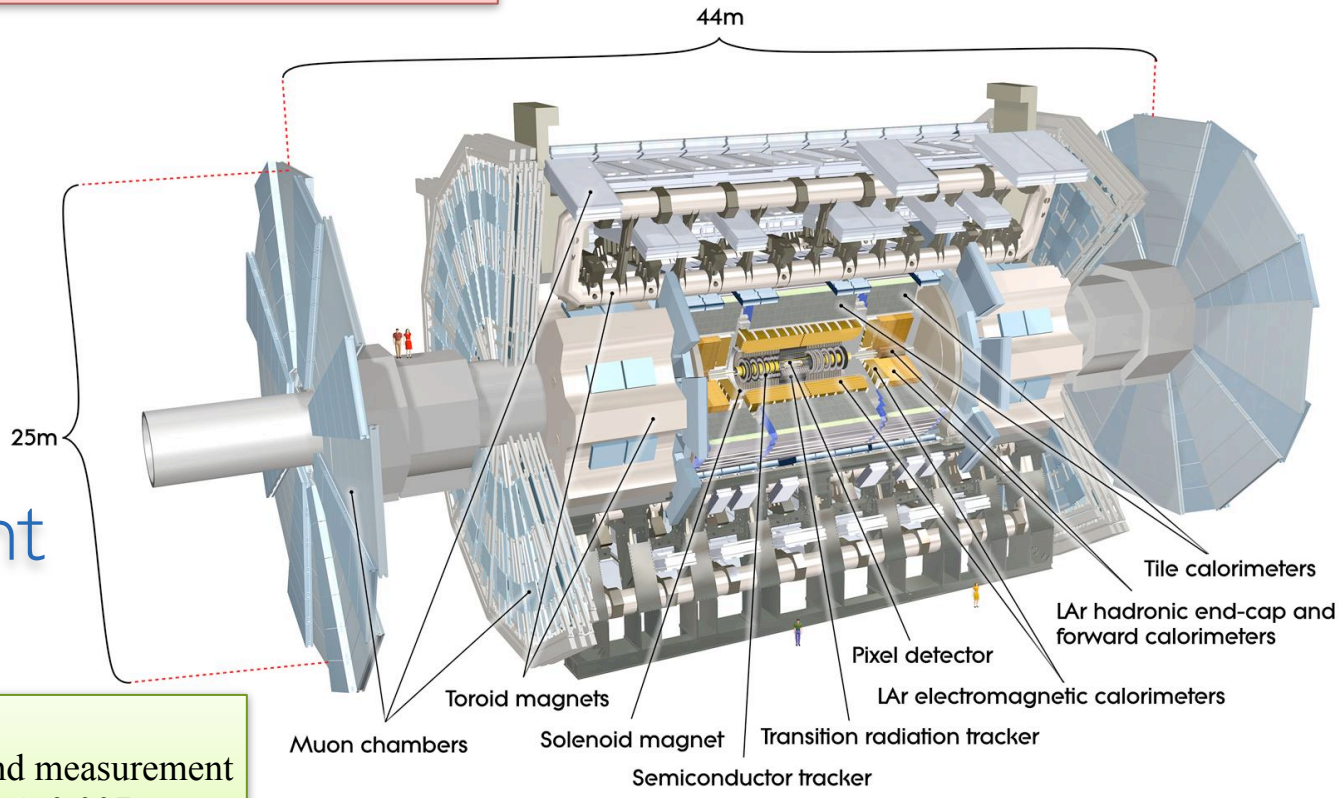
The ATLAS Experiment

Muon Spectrometer (|η| < 2.7): air-core toroids with gas based muon chambers. Muon trigger and measurement with momentum resolution < 10% up to $E_\mu \sim 1$ TeV

Inner Detector (|η| < 2.7, B=2T)

Si Pixels, Si strips, TRT

$\sigma/pT \sim 3.8\text{x}10\text{-}4\ pT\ (GeV) \oplus 0.015$



EM calorimeter: Pb-LAr
e/γ trigger, identification and measurement
E-Resolution: $\sigma/\sqrt{E} \sim 10\% \oplus 0.007$

Hadron Calorimetery (|η| < 4.9):
Fe/scintillator Tiles (central), Cu-LAr (endcap) E-Resolution: $\sigma/\sqrt{E} \sim 50\% /\sqrt{E} \oplus 0.03$
Cu/W-LAr (FWD) E-Resolution: $\sigma/\sqrt{E} \sim 90\% /\sqrt{E} \oplus 0.03$

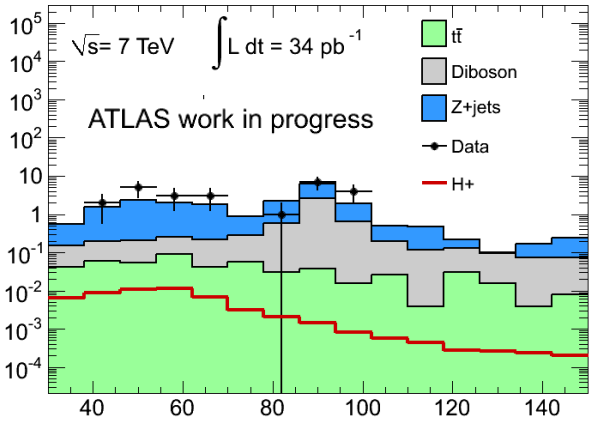
SUSY Scenario Monte Carlo

- Chose SUSY parameters inspired by m_h –max scenario, expanding out in the SUSY parameters μ and M_2.
- H^+ signal produced using Pythia + Matchig
- Full ATLAS GEANT4 simulation for m_{H+} = 400 GeV, then scanned through mass spectrum using fast simulation.
- Although several SUSY points tested, all results shown here use following parameter values, giving a 7 TeV production cross section of 1.16 fb.
  - Tan β = 7
  - μ = 200 GeV
  - M_2 = 310 GeV
  - M_{SUSY} = 1000 GeV, At=Ab= 2000 GeV
  - m_t^{pole} = 172.4 GeV
  - m_b = 4.25 GeV
  - M_{stau} = 250 GeV
  - M_{slep} = 150 GeV
  - $A_{tau} = A_{lep}$ = 0

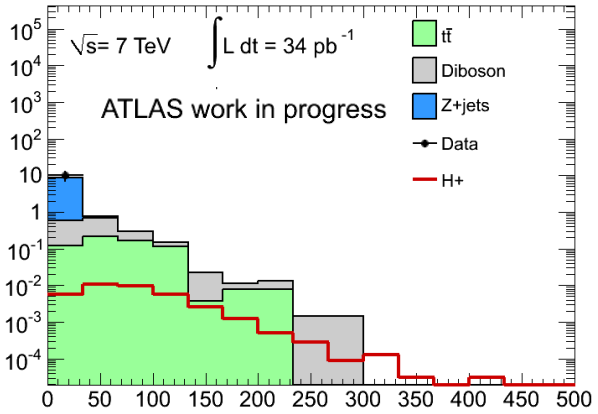
Analysis Details

- Cuts-based analysis developed in collaboration with SUSY multilepton group.
  - Topology very similar between H^+ and SUSY for 3-lepton events.
  - Cutflow optimized on SUSY benchmark points.
  - Effective for H^+.
- Presenting Study on 2010 data: 34 pb^{-1}.
  - Analysis in development on 2011 data, but not ready at this time.

Event Selection



M_{ll} [GeV]



MET [GeV]

Event Cuts

1. At least 3 leptons with $p_T \geq$ 20, 20, and 10 GeV.
2. No dilepton pair invariant mass within 5 GeV of Z mass.
3. Two Jets with $p_T \geq 50$ GeV
4. MET $\geq$ 50 GeV

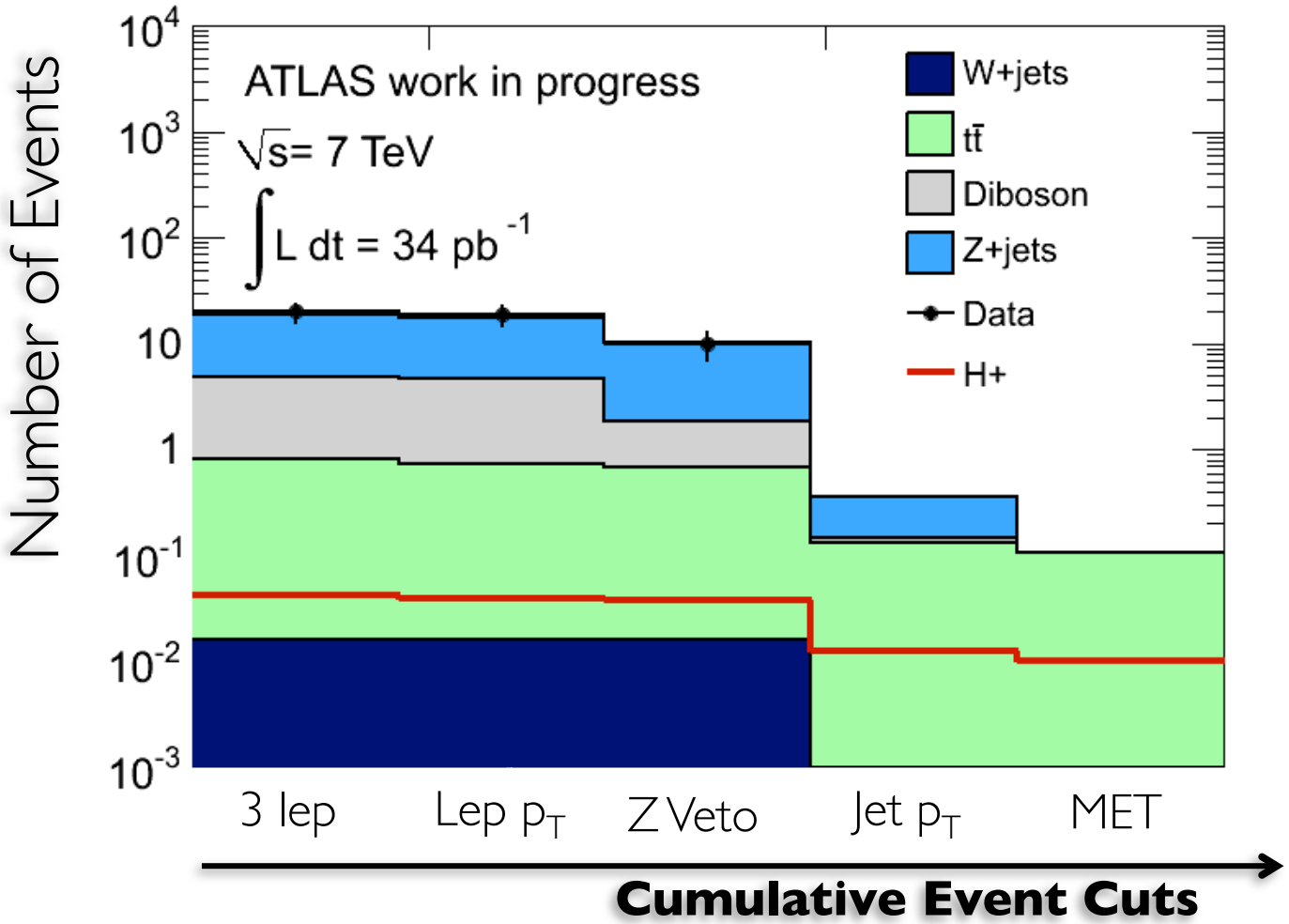
Vastly reduces SM background

Removes most remaining Z boson events

SM typically has softer jets than SUSY

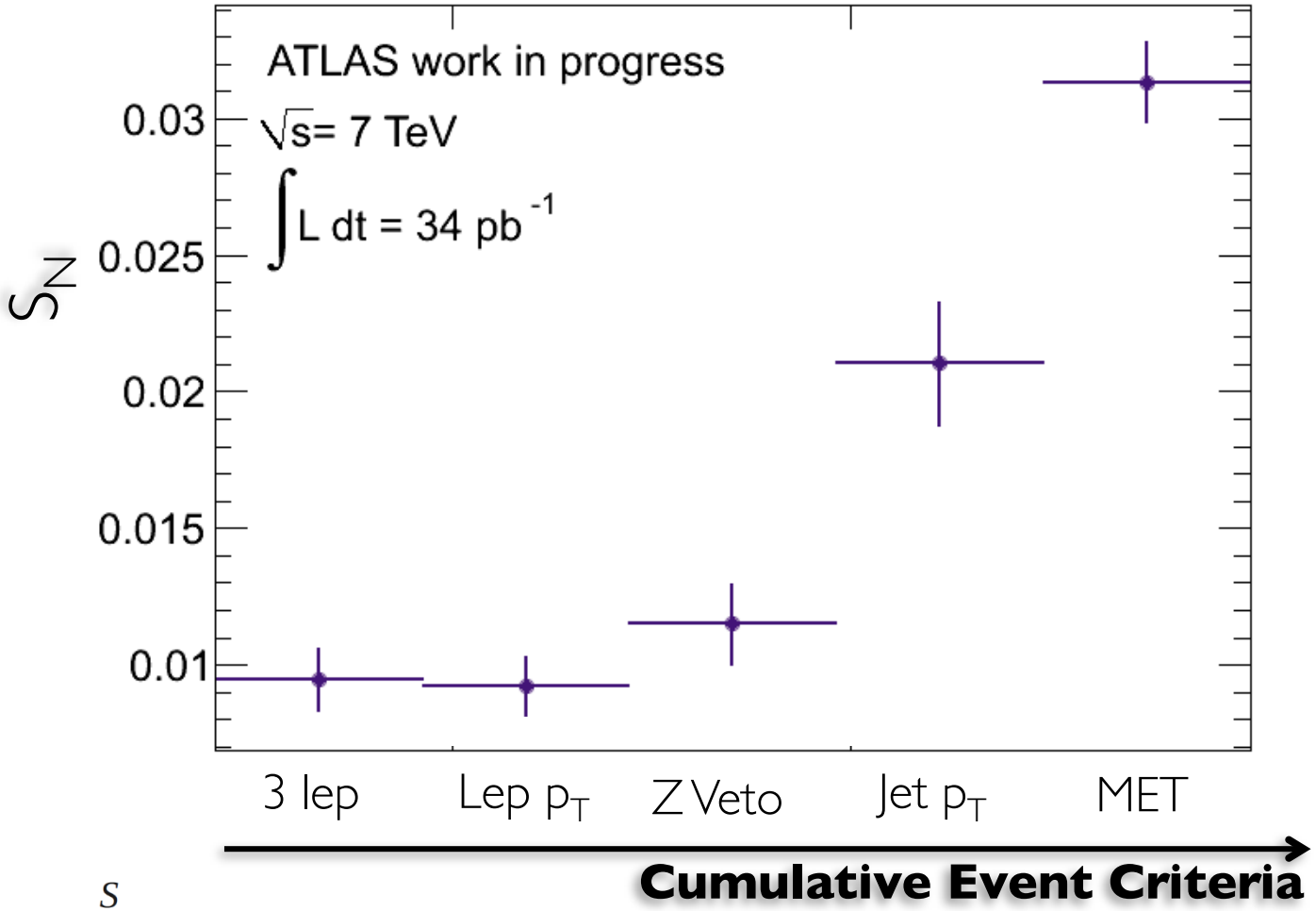
High MET from LSP

Event Selection



- Good agreement between MC and Data.
- No data events pass Jet p_T cut.
- $t\bar{t}$ is only substantial standard model background after all cuts.

Significance vs Event Selection



$S_N = \frac{S}{\sqrt{B+\sigma_B^2}}$, gives very low S_N (significance) at 34 pb^{-1}

- S is number of signal events
- B is number of standard model background events

Limit Setting

- Set limit on H^+ cross section × branching ratio
- CLs method.
  - T. Junk, Nucl. Instrum. Methods Phys. Res. A 434 (1999) 435–443.
  - TLimit (part of ROOT analysis framework)
  - Calculate CLs for rising input signal cross sections, until 1-CLs > 0.95 for 95% CL limit.
- Low statistics forced application of limit at 3 lepton cut level.
  - Low statistics gave unstable results for stricter cuts.
- Simple event counting: no shape information in limit.
- Produced toy MC using fast ATLAS simulation at different M_{H+} from 375 GeV to 500 GeV in increments of 25 GeV

Systematic Uncertainties

Largest systematic uncertainties

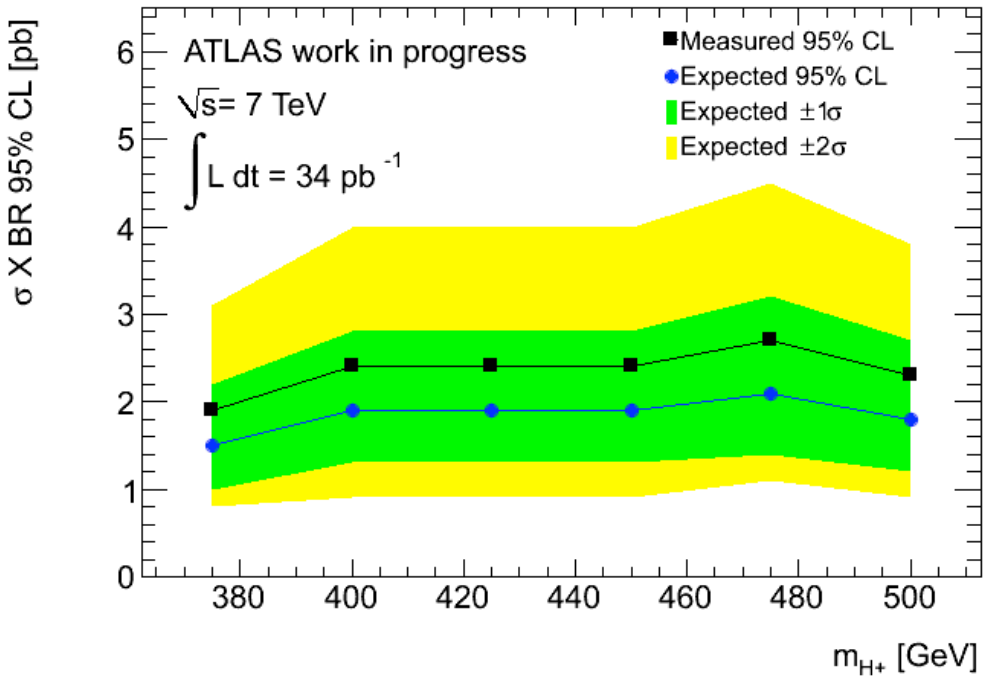
- Luminosity
- Pileup
- Theoretical cross section
- Jet energy scale
- Electron energy scale & resolution
- Muon energy scale & resolution
- Dead electron sensors.

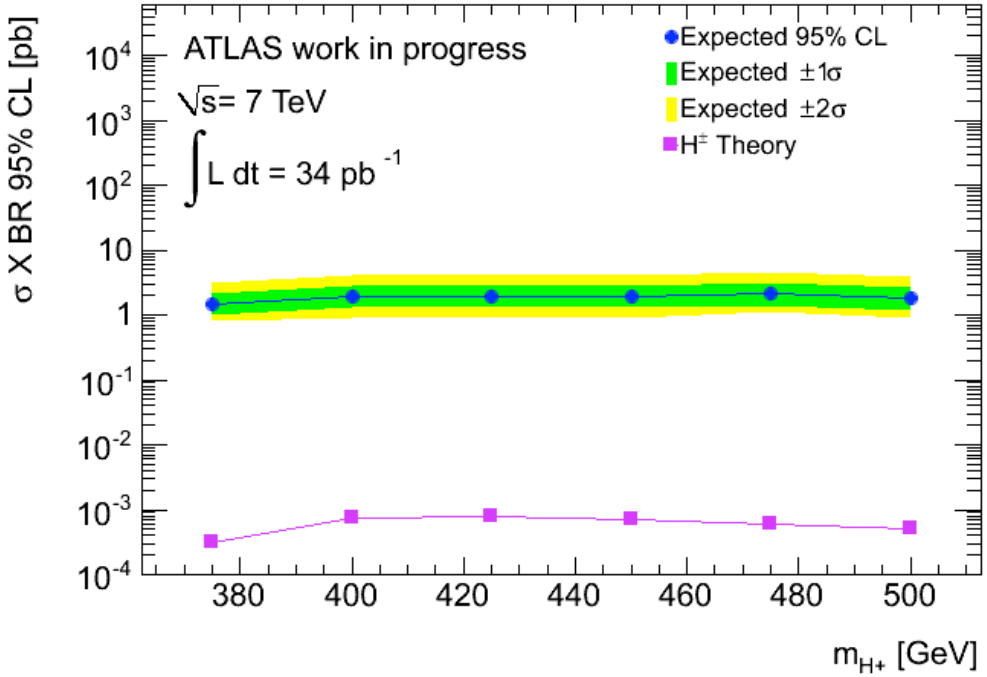
Net Systematics

- Signal: ~26%
- Background: ~22%

Limit

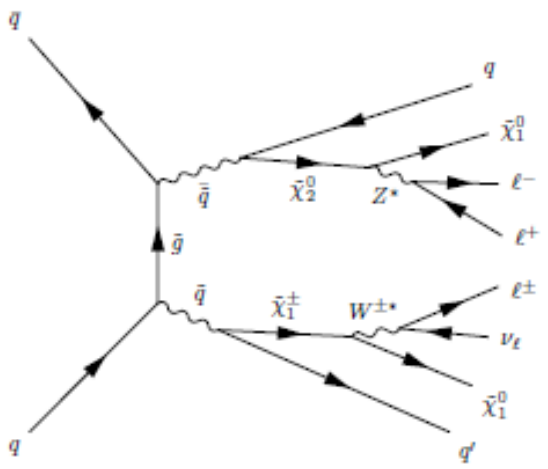
- Scan through m_{H+} from 375 to 500 GeV.
- Limit from 2 to 2.5 pb.
- Theoretical cross section times branching ratio at ~10^{-3} pb.
- Will require over100 fb^{-1} to exclude this scenario.





Next Steps

Typical 3-lepton SUSY Event



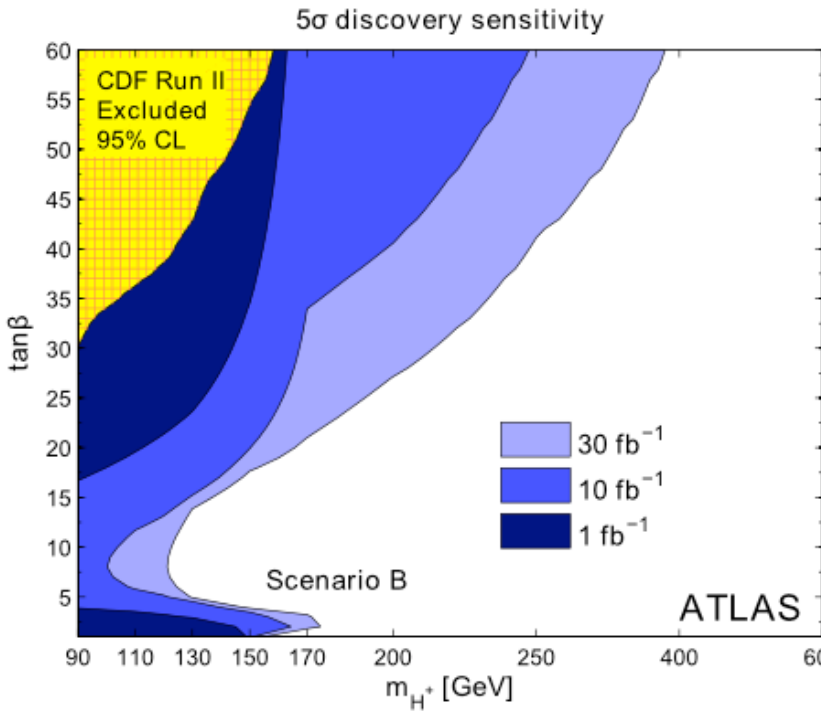
- Studied H^+ scenarios have little sensitivity to current ATLAS data.
- Looking for alternative scenarios with greater sensitivity.
- As soon as possible will release results from 2011 data:
  - Will give us ~1fb^{-1} more statistics (and counting).
  - Allow using full cut flow for limit setting, further improving sensitivity.
  - Still don't expect to be able to exclude H^+.
- Shifting focus onto inclusive SUSY 3-lepton analysis.
  - Analysis highly complementary, so can easily maintain H^+ analysis.

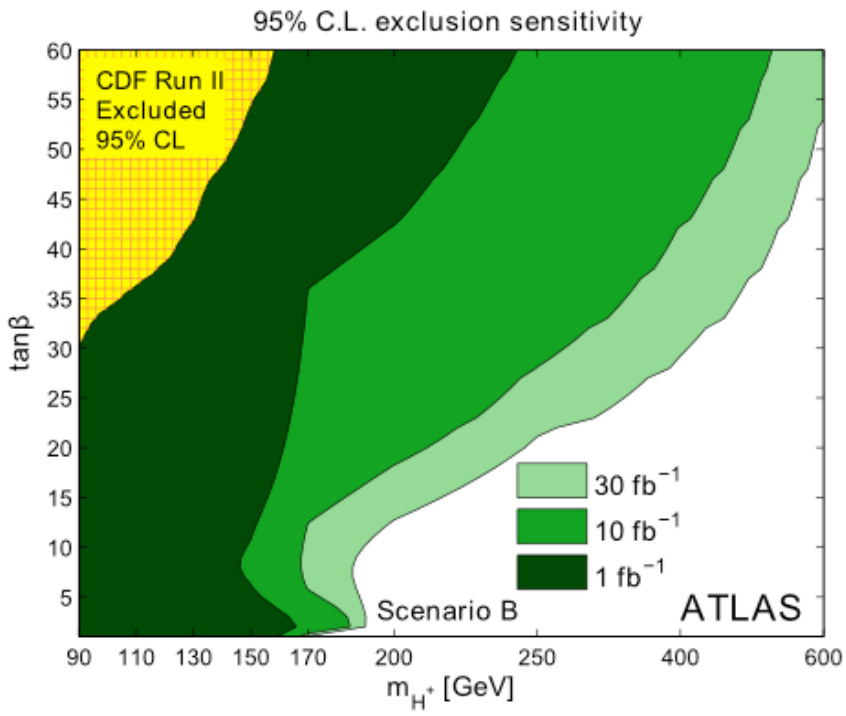
Conclusions and Outlook

- $H^{\pm} \rightarrow \chi_i^{\pm} \chi_j^0$
  - Final state: Jets + trileptons + missing transverse energy.
  - Provides extra sensitivity to the $H^{\pm}$ in "LHC wedge region" of SUSY parameter space.
- Cutflow optimized for inclusive SUSY 3 lepton events effective for $H^{+} \rightarrow \chi_i^{\pm} \chi_j^0$
- Have set first ATLAS limit on $H^{\pm} \rightarrow \chi_i^{\pm} \chi_j^0$ cross section × branching ratio.
  - For this scenario, need over 100 fb^{-1} of data before we can exclude or observe $H^{\pm}$ for this scenario.
- Focusing on inclusive SUSY searches while maintaining $H^{\pm}$ analysis.

BACKUP SLIDES

Discovery and Exclusion Sensitivity





- From m_h–max scenario
- See CERN-OPEN-2008-020 (arXiv:0901.0512)

Full SUSY parameter set

Scenario	μ (GeV)	M_2 (GeV)	Tan β	σ for 400 GeV H+ @ 7 TeV (fb)
A	135	210	7	2.73
A	135	210	15	2.07
B	200	310	7	1.16
B	200	310	15	1.10

← *Results from here.*

Static Parameters

- m_{H+} = 400 GeV
- M_{SUSY} = 1000 GeV, At=Ab= 2000 GeV
- m_t^{pole} = 172.4 GeV
- m_b = 4.25 GeV
- M_{stau} = 250 GeV, M_{slep} = 150 GeV
- $A_{tau} = A_{lep} = 0$