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Beyond the Standard Model: Results with the 7 TeV LHC Collision Data

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Drell-Yan Production of Metastable Sleptons at the LHC

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Metastable Staus at the LHC

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

Based on Jan Heisig, JK, `arXiv:1106.0764 [hep-ph]`, and work in progress

Outline

1. Introduction
2. Drell-Yan Production
3. Cascade Production

LSP and Dark Matter Candidates

Assumption: LSP forms all dark matter

- $\Rightarrow$ Electrically neutral
- $\Rightarrow$ Uncolored
- $\Rightarrow$ Lifetime $>$ age of universe
  $\rightsquigarrow$ assume R parity conservation $\Rightarrow$ stable
- $\Rightarrow$ Massive
- $\Rightarrow$ Non-relativistic during structure formation (cold dark matter)

Candidates in MSSM with supergravity

- Lightest neutralino
- Sneutrino (ruled out by direct searches)
- Gravitino (superpartner of graviton)

Expectations for Gravitino Mass

Depend on scenario for mediation of SUSY breaking

	Gravitino mass	Gravitino LSP?
Gravity mediation	$m_{3/2} \gtrsim 100\,\text{GeV}$	possible
Gaugino mediation	$m_{3/2} \gtrsim 10\,\text{GeV}$	
Gauge mediation	$m_{3/2} \ll 1\,\text{GeV}$	yes
Anomaly mediation	$m_{3/2} \gtrsim 10\,\text{TeV}$	no

Gravitino Problem

- Thermal production in early universe

$$\Omega_{3/2}^{\mathrm{tp}} h^2 \propto \frac{T_{\mathrm{R}}}{m_{3/2}}$$

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- Thermal production in early universe

$$\Omega^{\text{tp}}_{3/2} h^2 \simeq 0.11 \left(\frac{T_{\text{R}}}{2 \cdot 10^9\,\text{GeV}}\right)\left(\frac{67\,\text{GeV}}{m_{3/2}}\right)\left(\frac{M_{\tilde{g}}}{10^3\,\text{GeV}}\right)^2$$

- Observed dark matter abundance: $\Omega_{\text{DM}} h^2 \simeq 0.11$
- Inflation, leptogenesis
  $\rightsquigarrow$ large reheating temperature $T_{\text{R}} \sim 10^9$ GeV desirable

$\rightsquigarrow$ Consider $m_{3/2} \gtrsim 1\,\text{GeV}$

- Gravitino interacts via gravity $\rightsquigarrow$ extremely weakly
  $\rightsquigarrow$ lifetime $\sim 10^{-2}$ s ... years for unstable gravitino
- Energetic decay products destroy nuclei produced in Big Bang Nucleosynthesis (BBN)
  $\rightsquigarrow$ $T_{\text{R}} \lesssim 10^7$ GeV or $m_{3/2} \gg 1$ TeV

$\rightsquigarrow$ Consider gravitino LSP

Gravitino LSP and BBN

- Next-to-LSP (NLSP) decays to gravitino via gravity $\rightsquigarrow$ long-lived

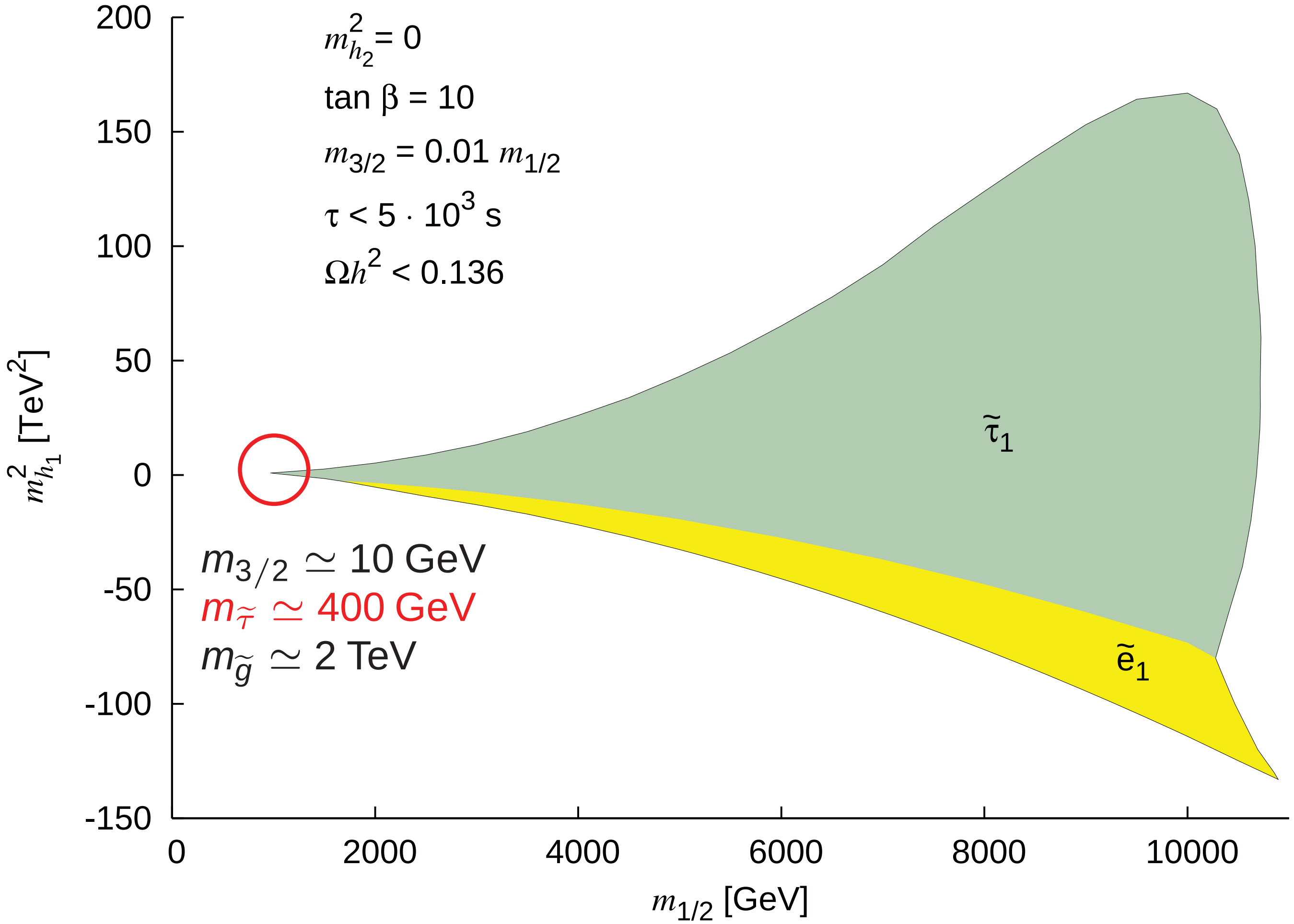
  E.g., for stau: $\tau_{\tilde{\tau}} \simeq 6 \cdot 10^4\,\text{s} \left(\frac{m_{3/2}}{1\,\text{GeV}}\right)^2 \left(\frac{100\,\text{GeV}}{m_{\tilde{\tau}}}\right)^5$

- Late NLSP decays threaten BBN
- Stau NLSP possible
- Charged NLSPs form bound states with nuclei
  - $\rightsquigarrow$ BBN reaction rates change $\rightsquigarrow$ overproduction of ^{6}Li
  - $\rightsquigarrow$ Stau must decay before BBN: $\tau_{\tilde{\tau}} \lesssim 5 \cdot 10^3\,\text{s}$

$\rightsquigarrow$ Relatively heavy stau

Gravitino LSP and BBN

Gaugino mediation



$\rightsquigarrow$ Maximal stau mass detectable at the LHC?

Scenario

- Gravitino LSP
- Stau NLSP
- R parity $\rightsquigarrow$ pair production
- Stau metastable: leaves detector before decay ($\tau_{\tilde{\tau}} \gtrsim 10^{-8}$ s)
- Charged $\rightsquigarrow$ direct detection possible, no missing E_T

$\rightsquigarrow$ Signal: pair of slow, charged particles leaving the detector

Production Channels

Cascades: $p\bar{p} \to \widetilde{g}, \widetilde{q}, \chi^{\pm} \to \widetilde{\tau}$

- Large cross section if $\widetilde{g}$ etc. not too heavy
- Many parameters relevant

Direct Drell-Yan production: $p\bar{p} \to Z, \gamma \to \widetilde{\tau}^{+}\widetilde{\tau}^{-}$

- 2 parameters relevant: (lighter) stau mass $m_{\widetilde{\tau}}$, mixing angle $\theta_{\widetilde{\tau}}$
  $\leadsto$ model-independent analysis possible
- Always present (dominant for large mass gap to heavier sparticles)
  $\leadsto$ assured discovery potential, strict exclusion limits

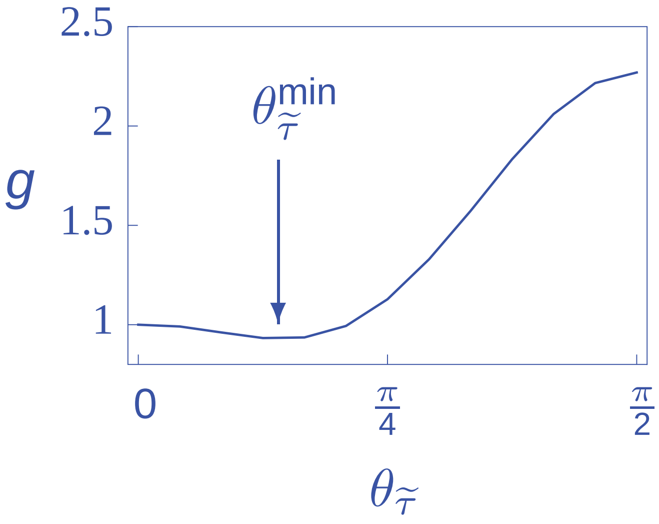
$\leadsto$ Focus on Drell-Yan production here

Dependence on Mixing Angle

- $\begin{pmatrix} \widetilde{\tau}_1 \\ \widetilde{\tau}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{\widetilde{\tau}} & \sin\theta_{\widetilde{\tau}} \\ -\sin\theta_{\widetilde{\tau}} & \cos\theta_{\widetilde{\tau}} \end{pmatrix} \begin{pmatrix} \widetilde{\tau}_\mathrm{R} \\ \widetilde{\tau}_\mathrm{L} \end{pmatrix}$
- Approximate factorization:

$$\sigma_{\widetilde{\tau}}(m_{\widetilde{\tau}}, \theta_{\widetilde{\tau}}, \text{kinematics}) \simeq f(m_{\widetilde{\tau}}, \text{kinematics}) \cdot g(\theta_{\widetilde{\tau}})$$

- Smallest cross section for $\theta_{\widetilde{\tau}} = \theta_{\widetilde{\tau}}^{\text{min}} \neq 0$
  - $\leadsto$ conservative choice: $\theta_{\widetilde{\tau}} = \theta_{\widetilde{\tau}}^{\text{min}}$
  - $\leadsto$ 1 free parameter remaining



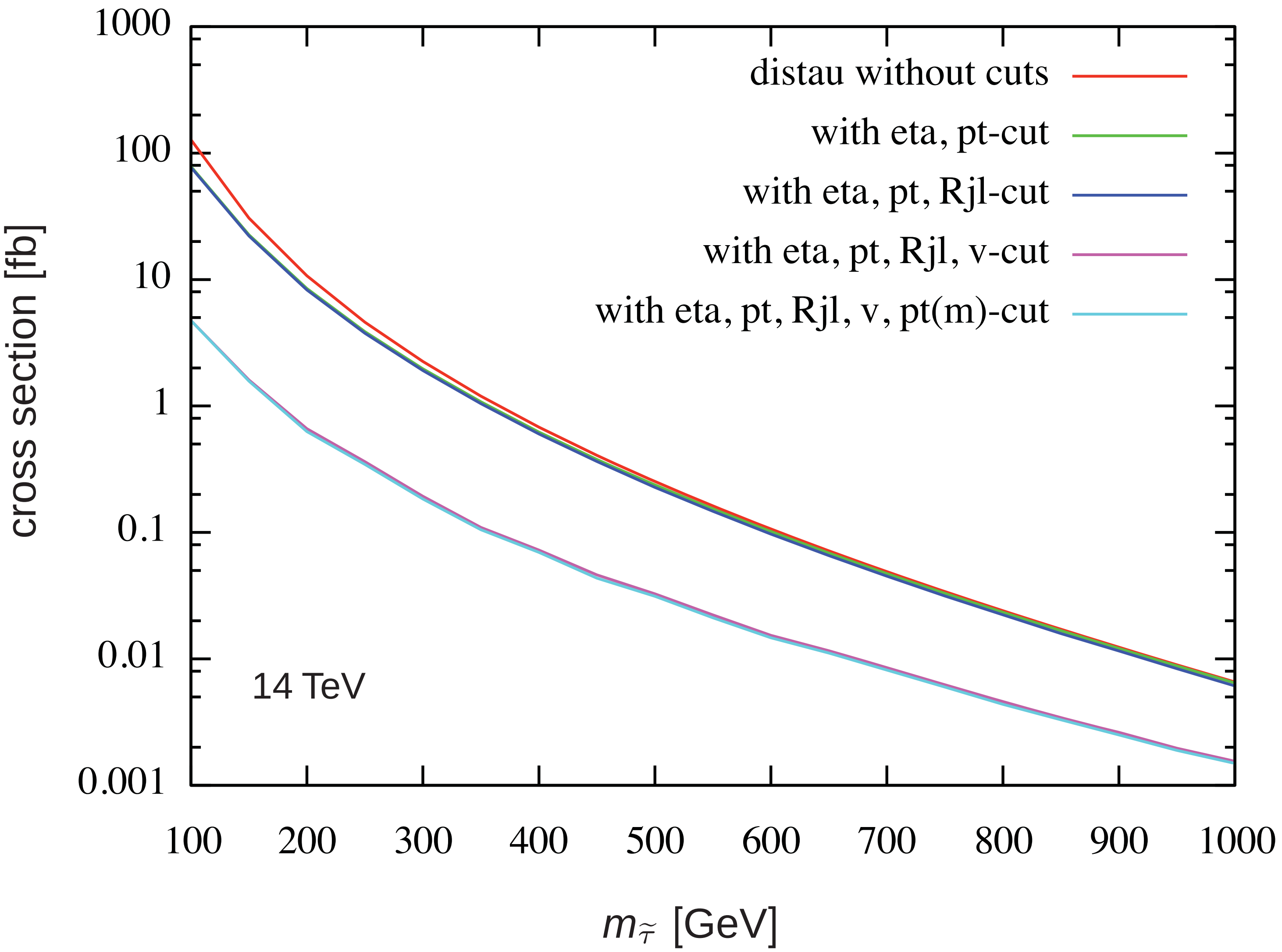
Background

- Background: muons
- Staus much heavier $\rightsquigarrow$ slower $\rightsquigarrow$ require velocity $\beta < 0.8$
- Velocity measurement:
  - Ionization energy loss in tracker
  - Time of flight to muon chambers
- Moderate precision for each, but uncorrelated
- Reach muon chambers before next bunch crossing $\rightsquigarrow$ $\beta > 0.6$
- Combination $\rightsquigarrow$ background rejection factor $r_\beta \simeq 10^{-7}$ for single stau candidate (for one particle) [CMS-PAS-EXO-08-003]
  $\rightsquigarrow$ $r_\beta = 10^{-14}$ for 2 particles?
- Conservative and sufficient choice: $r_\beta = 10^{-10}$
- Also consider worst case $r_\beta = 10^{-7}$

Cuts

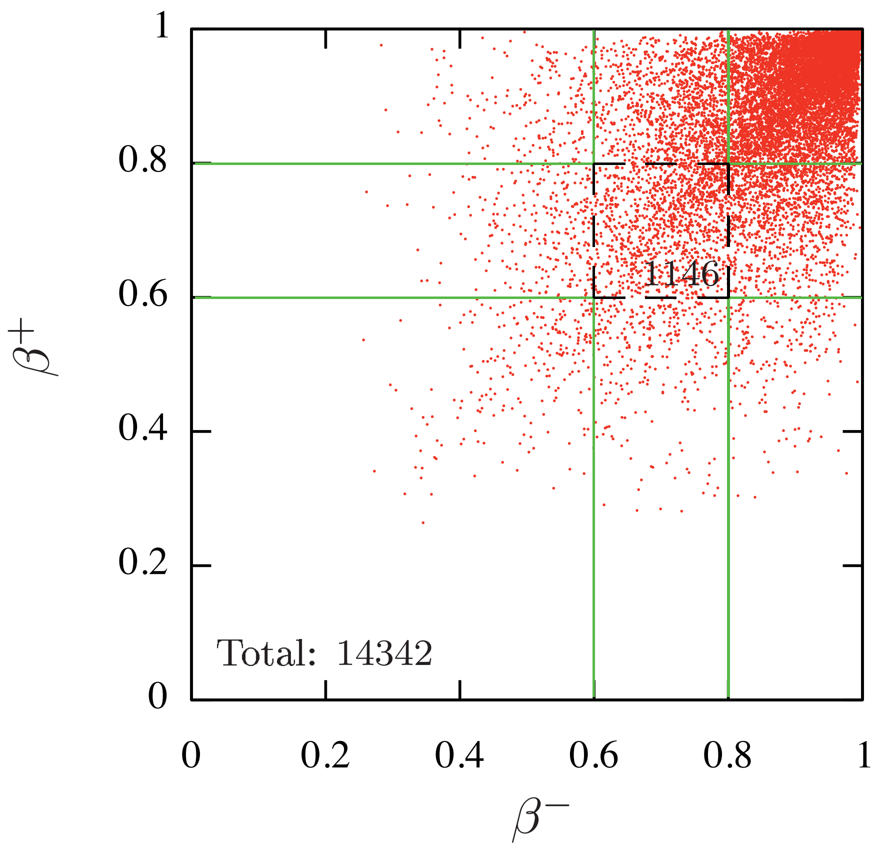
- $0.6 < \beta < 0.8$
- $p_{\mathrm{T}} > 50$ GeV
- Pseudorapidity $|\eta| < 2.5$
- Isolation from jets: $\sqrt{\Delta\eta^2_{\mu,\mathrm{jet}} + \Delta\phi^2_{\mu,\mathrm{jet}}} > 0.5$ for jets with $p_{\mathrm{T}} > 50$ GeV

Cross Section for Direct Stau Pair Production

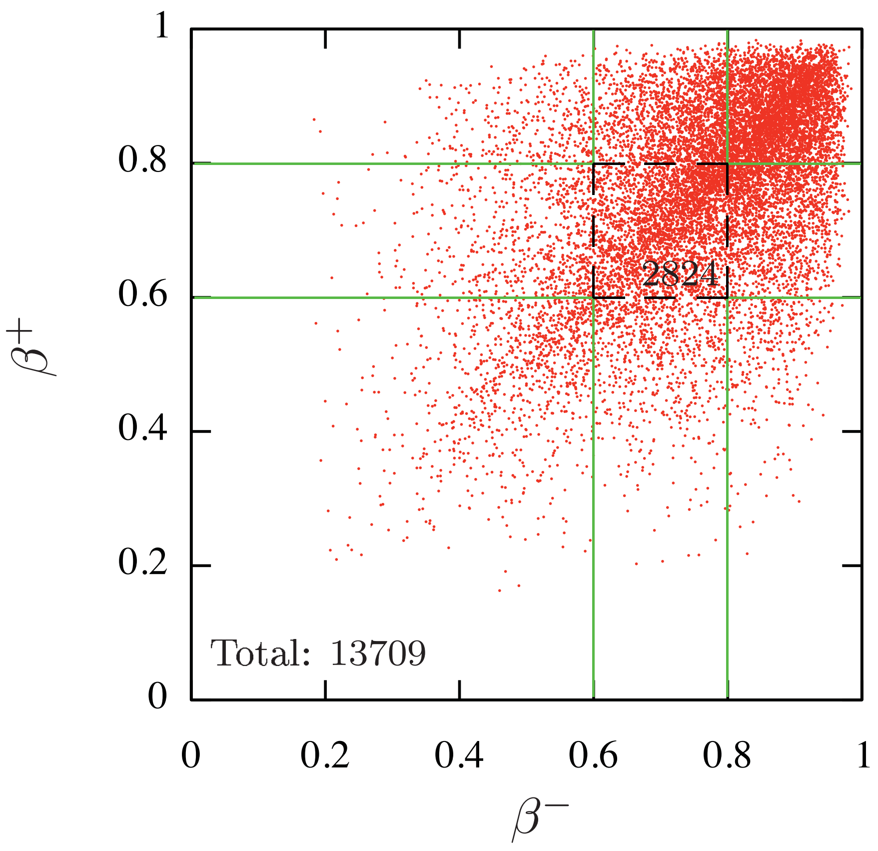


Stau Velocity Distribution

$m_{\tilde{\tau}} = 200\,\text{GeV}$



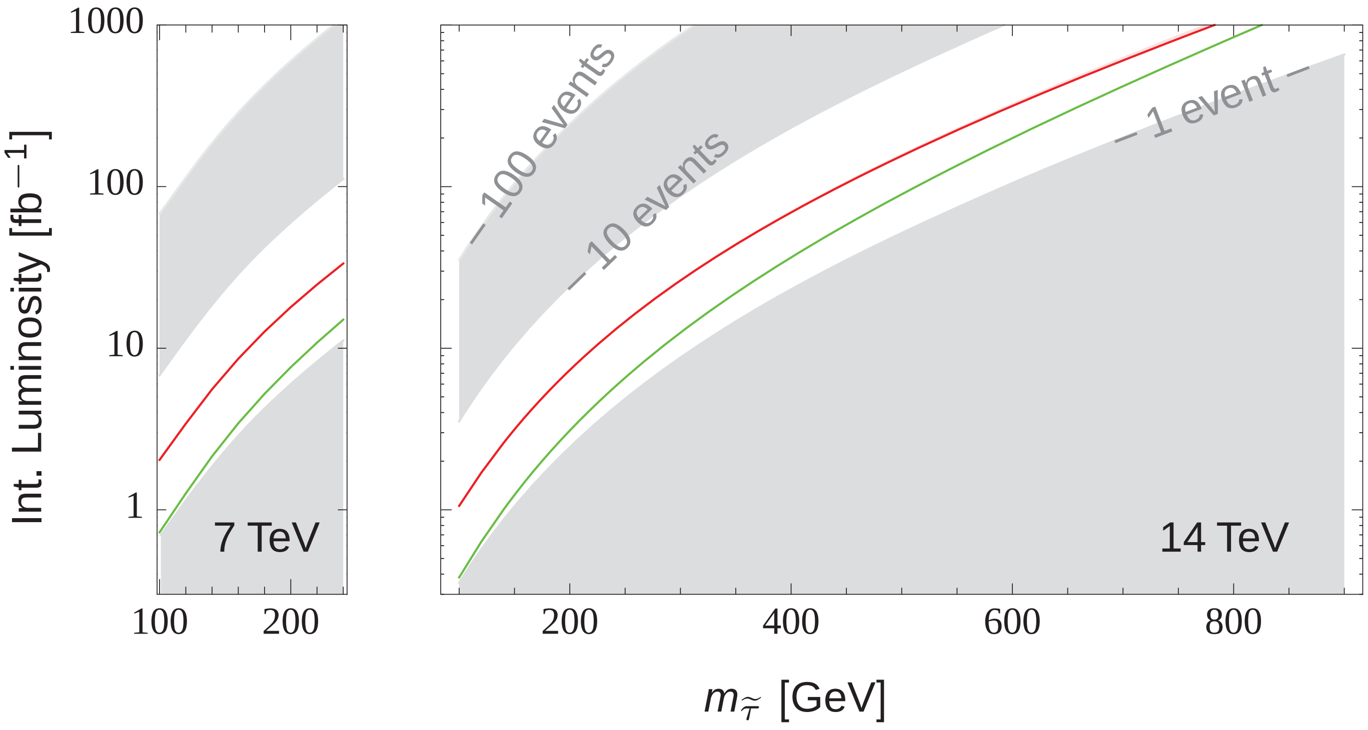
$m_{\tilde{\tau}} = 800\,\text{GeV}$



Discovery and Exclusion Potential

Expected luminosity required for

- 5σ discovery
- 95% CL exclusion



Computed using MadGraph + Pythia

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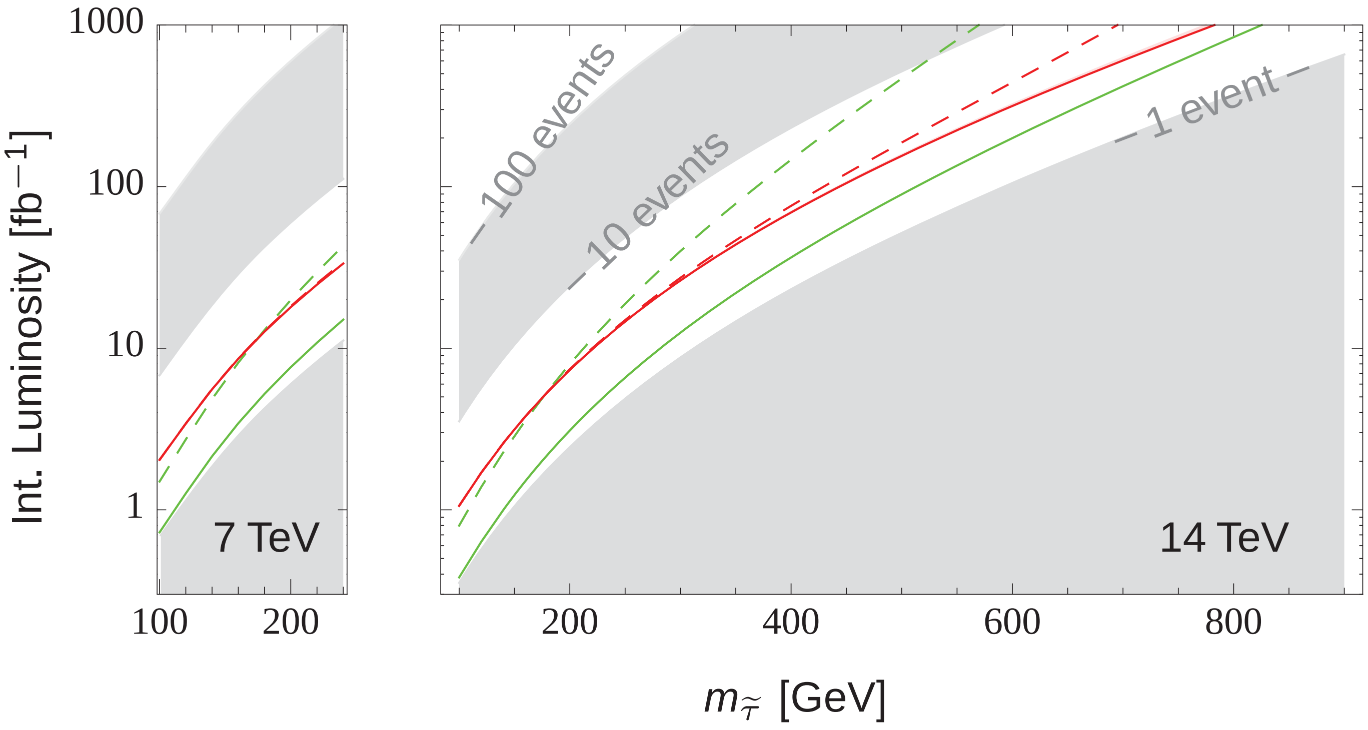

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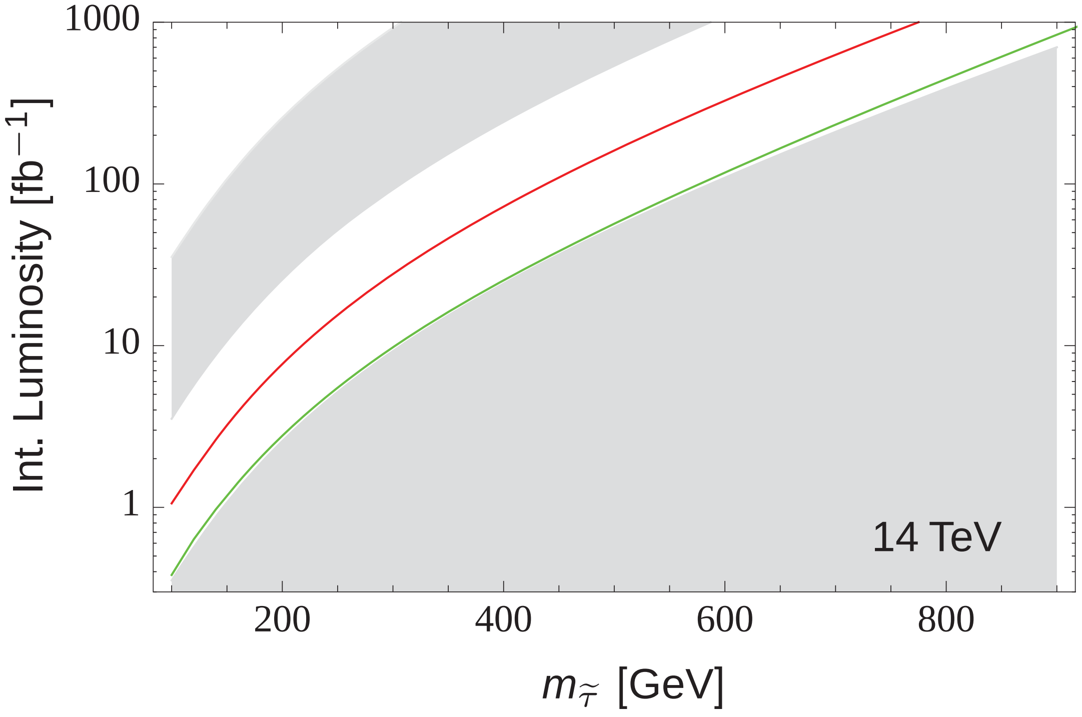
Optimized p_T Cut

Muon background drops drastically with p_T
$\rightsquigarrow$ Adjust p_T-cut according to $m_{\tilde{\tau}}$: $p_\mathrm{T} > 0.4 \cdot m_{\tilde{\tau}}$



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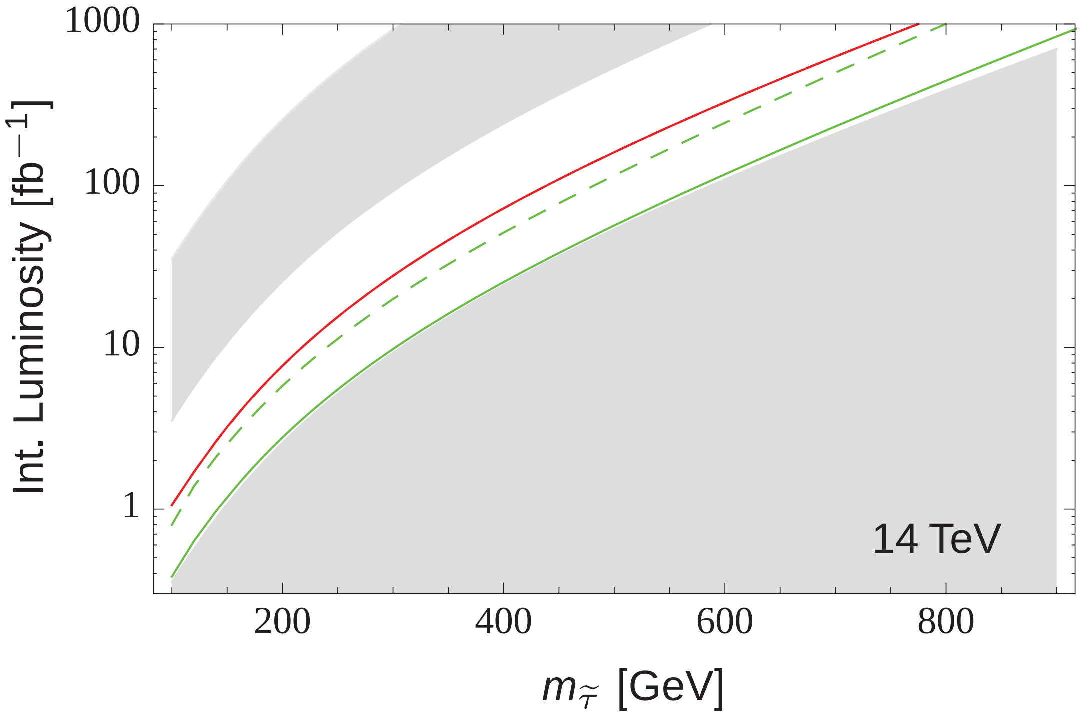
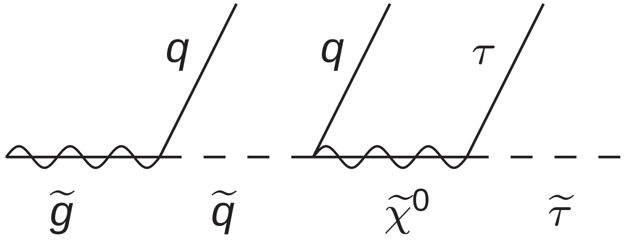


Production via Cascades

- Production of colored sparticles likely to dominate
- More parameters but which are really relevant?
- Consider simplified scenario
    - Gluino
    - Squarks $\widetilde{u}_\mathrm{L}, \widetilde{u}_\mathrm{R}, \widetilde{d}_\mathrm{L}, \widetilde{d}_\mathrm{R}$ with common mass $m_{\widetilde{q}}$
    - Lightest neutralino
    - Stau NLSP
- Minimal decay chain

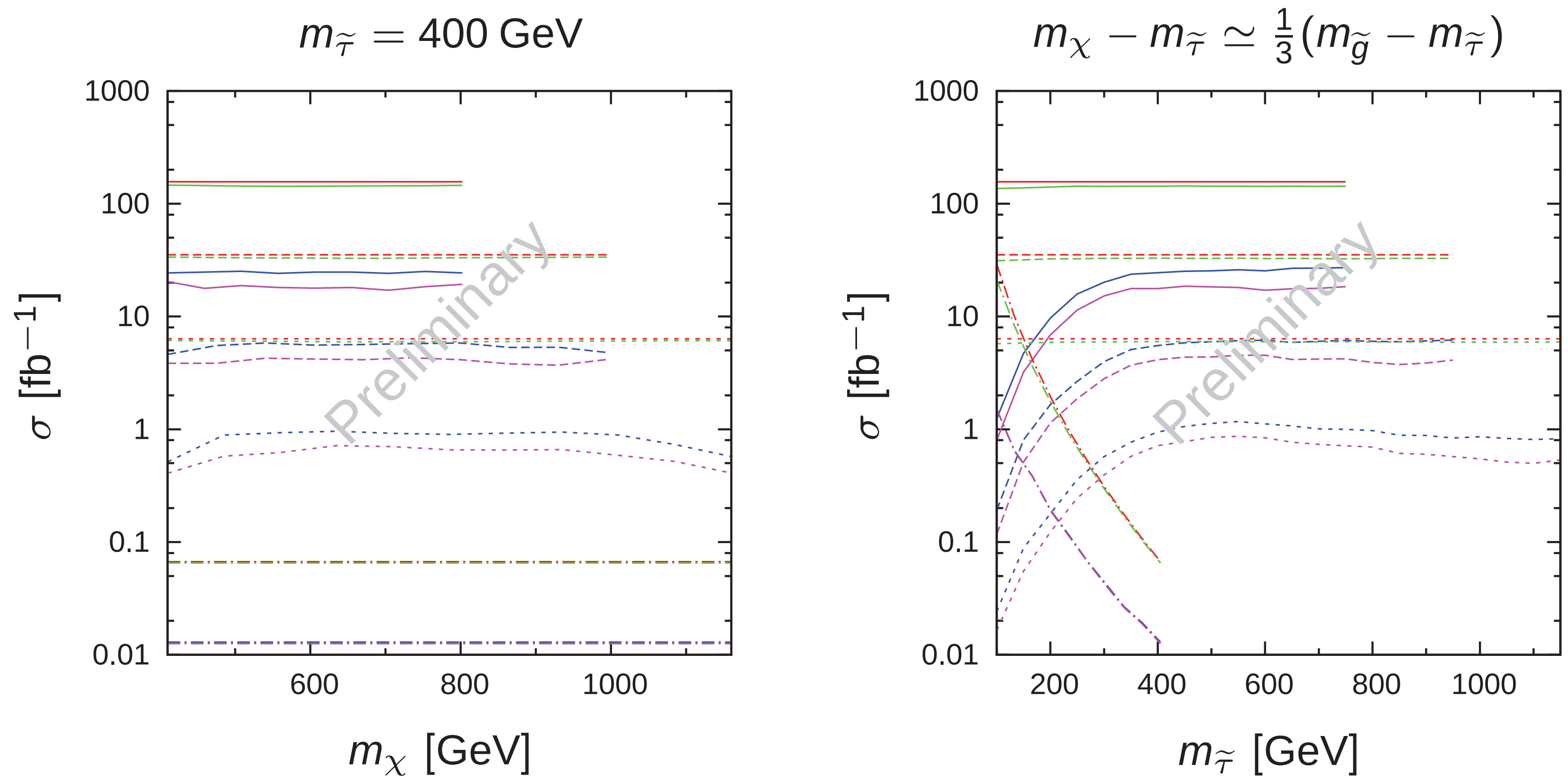


- Same cuts as before
- Consider 7 TeV LHC

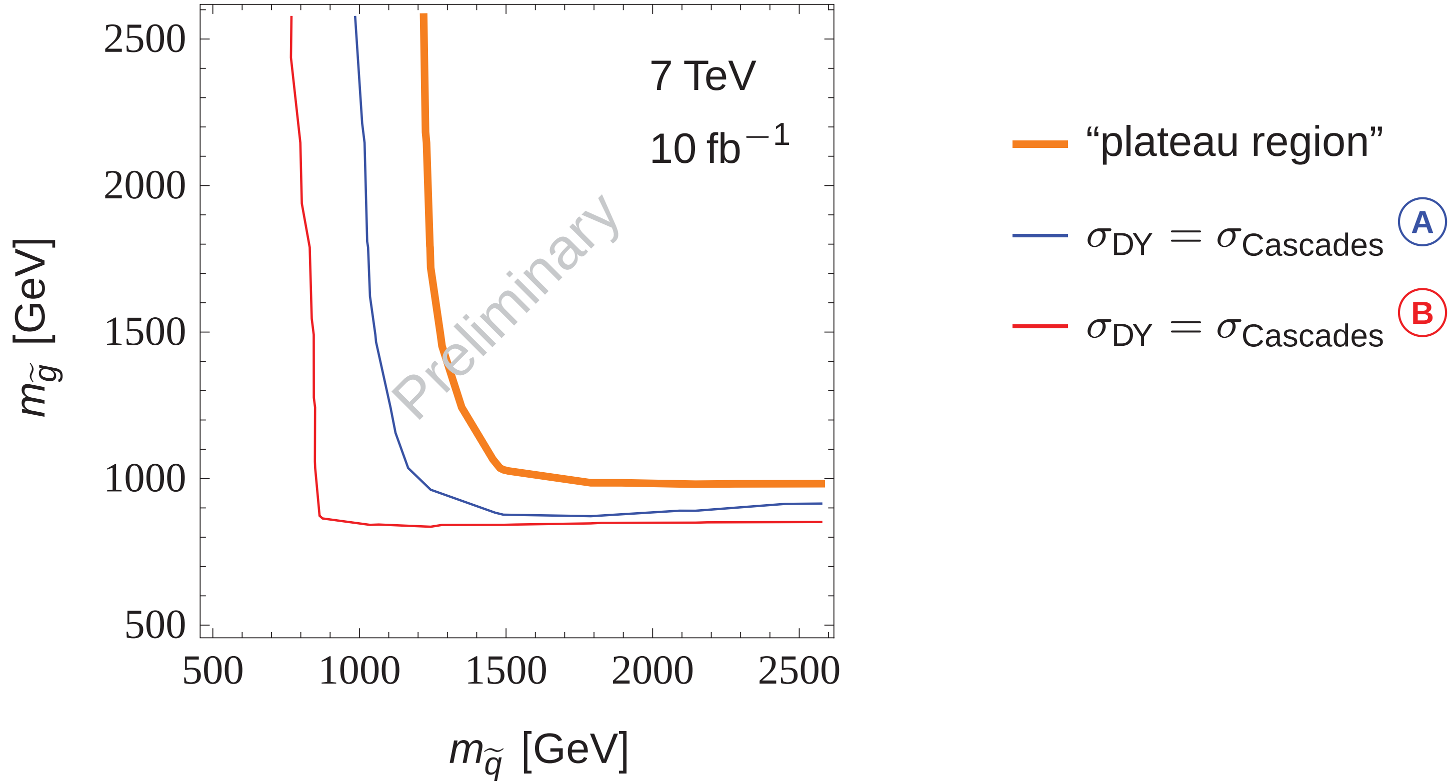
Dependence on Stau and Neutralino Masses

Velocity of final staus not very sensitive to $m_{\tilde{\tau}}$ and m_χ for sufficiently small mass gap to $m_{\tilde{g}}$ and $m_{\tilde{q}}$

$$m_{\tilde{g}} = m_{\tilde{q}} \in \{900\,\text{GeV}, 1000\,\text{GeV}, 1250\,\text{GeV}\}$$



Exclusion Potential



Conclusions

- Metastable charged SUSY particle gives prominent signature
  $\rightsquigarrow$ high background rejection possible
- Upper limit on velocity most crucial for gaining sensitivity
- Drell-Yan production
  $\rightsquigarrow$ model-independent results (one parameter only)
- With 14 TeV and 300 fb^{-1}: Exclusion up to 600 GeV, discovery up to 750 GeV
- Cascade production depends mainly on gluino and squark masses $\rightsquigarrow$ exclusion plot for simplified model seems feasible
- Valid for all scenarios with a metastable charged slepton

Muon Background