SUSY searches

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Outline

- SUSY & the weak scale
- What we have learned from the 35 pb^{-1}/200 pb^{-1} studies
- Weak spots
- Outlook

- Many great SUSY searches from both ATLAS and CMS presented in the last 6 months.

- Present talk is mostly looking forward → few examples to stress missing regions (personal opinion)

Apologies for underrepresented searches/ experiments (mostly b/c of space)

SUSY & the weak scale

- SUSY provides a nice framework for stabilizing the ElectroWeak scale

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m^2_H$$

$$\delta m^2_H \simeq -\frac{3y_t^2}{8\pi^2}\left(m^2_{Q_3} + m^2_{U_3} + |A_t|^2\right)\ln\left(\frac{M}{m_{\tilde{t}}}\right)$$

- (some of the) superpartners have to be light enough

  ($\mu \rightarrow$ higgsinos, $m_{Q3}, m_{U3}, A_t \rightarrow$ stop (sbottom))

- more general than the MSSM (need two Higgs doublets, 4-dim N=1 SUSY for Higgs+3rd generation, perturbative Electroweak Sym' Breaking (e.g no SUSY-Technicolor, ...), ...)

- amount of cancelation has not been directly probed yet!

- What are the minimal requirements for a "natural" weak-scale SUSY?

("natural"? 10-9=1? 100-99=1? 1000-999=1? 1 part in 10^4? ...)

$$m_{\tilde{t}}^2 \lesssim \frac{(700\mathrm{GeV})^2}{1 + A_t^2/2m_{\tilde{t}}^2} \left(\frac{3}{\ln\left(\Lambda_M/m_{\tilde{t}}\right)} \right) \left(\frac{M_{higgs}}{200\mathrm{GeV}} \right)^2 \left(\frac{20\%}{\Delta^{-1}} \right)$$

(e.g. Kitano & Nomura 2006)

Less problems w/ low scale mediation

Needs something beyond the MSSM to increase the Higgs mass > 140GeV

MSSM, large M_{Higgs}: $m_{\tilde{t}}^2 \lesssim (500\mathrm{GeV})^2 \left(\frac{3}{\ln\left(\Lambda_M/m_{\tilde{t}}\right)} \right) \left(\frac{20\%}{\Delta^{-1}} \right)$

- Gluinos shouldn't be too heavy either

$$\delta m_{\tilde{t}}^2 \simeq \frac{8\alpha_s}{3\pi} M_3^2 \ln\left(\frac{\Lambda_M}{m_{\tilde{t}}}\right)$$

And feeds into the Higgs mass at two loops...

$$M_3 \lesssim 1.5\text{TeV}\left(\frac{3}{\log\left(\Lambda_M/m_{\tilde{t}}\right)}\right)$$

- Higgsinos (mass determined by μ) should also be fairly light

Digression: the MSSM

- The weak scale is determined by:

$$\frac{m^2_{Higgs}}{2} = -|\mu|^2 + \ldots + \delta m_H^2$$

$$\delta m_H^2 \simeq -\frac{3y_t^2}{8\pi^2}\left(m_{Q_3}^2 + m_{U_3}^2 + |A_t|^2\right)\ln\left(\frac{M}{m_{\tilde{t}}}\right)$$

- The physical Higgs mass is

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3}{4\pi^2}\frac{m_t^4}{v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12 m_{\tilde{t}}^2}\right)\right] \qquad X_t = A_t - \mu\cot\beta$$

- LEP bound $m_H > 114$ GeV requires heavy stops

- tuning of ~ few %

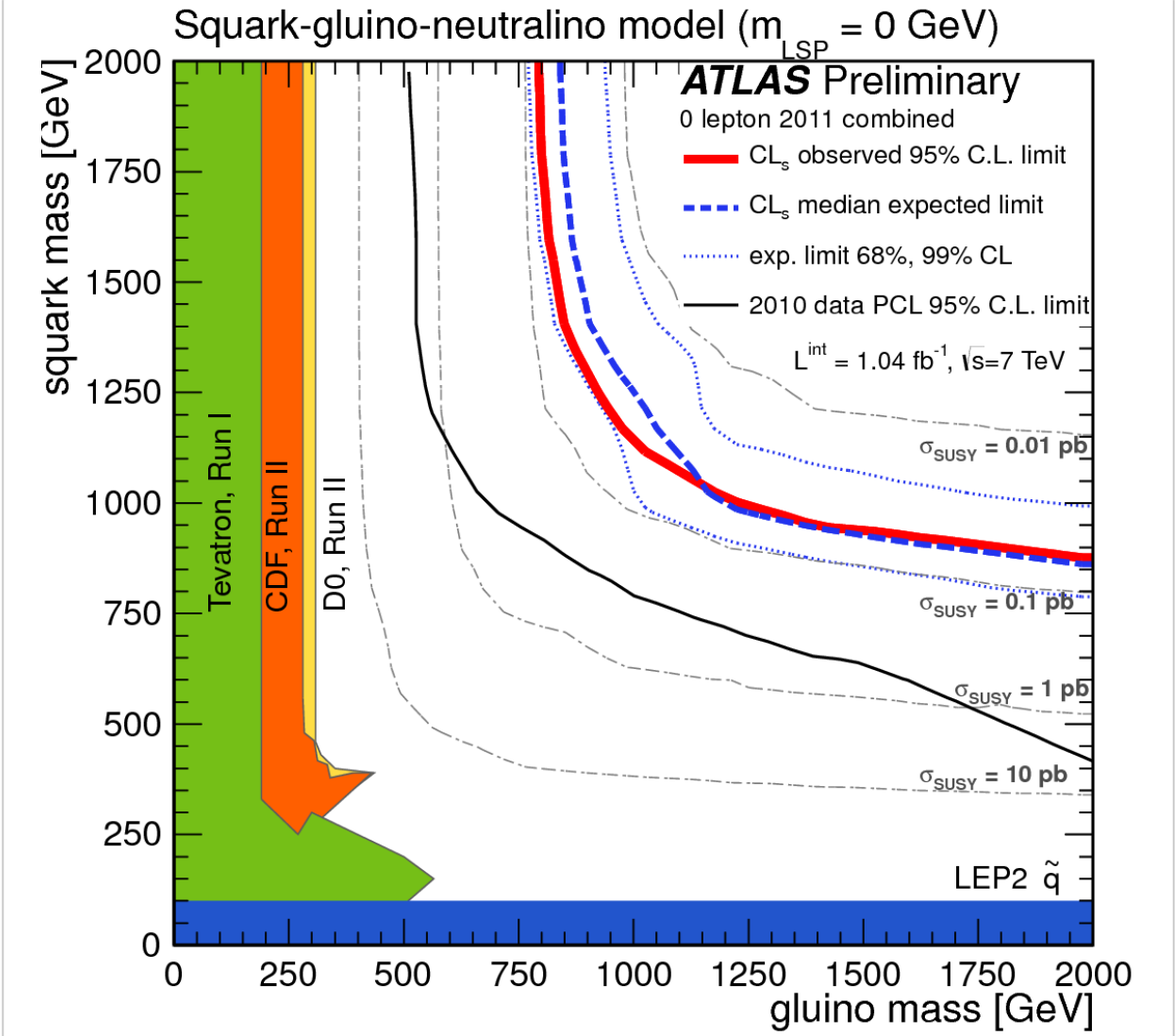
Current SUSY searches

- "low statistics" with $\mathcal{L}$<1fb^{-1} forced searches to look only for cascades initiated by gluinos/first two generation squarks

- R-parity conserving scenarios → fair amount of MET required (except a few searches, but then require fairly large H_T/M_{eff})

1st-2nd gen' squarks and gluinos?

(Taffard's talk)



Model independent fiducial cross section limit, 95% C.L.

≥2-jets	≥3-jets	≥4-jets M_{eff}>500 GeV	≥4-jets M_{eff}>10000 GeV	High mass
24 fb	30 fb	477 fb	32 fb	17 fb

- "Light" squarks and gluinos constrained to be > 800-1000 GeV from jets+MET searches with 1fb^{-1}

- >500-600 GeV from lower lumi (35-200pb^{-1}) in other channels (jets +leptons)

What we have learned?

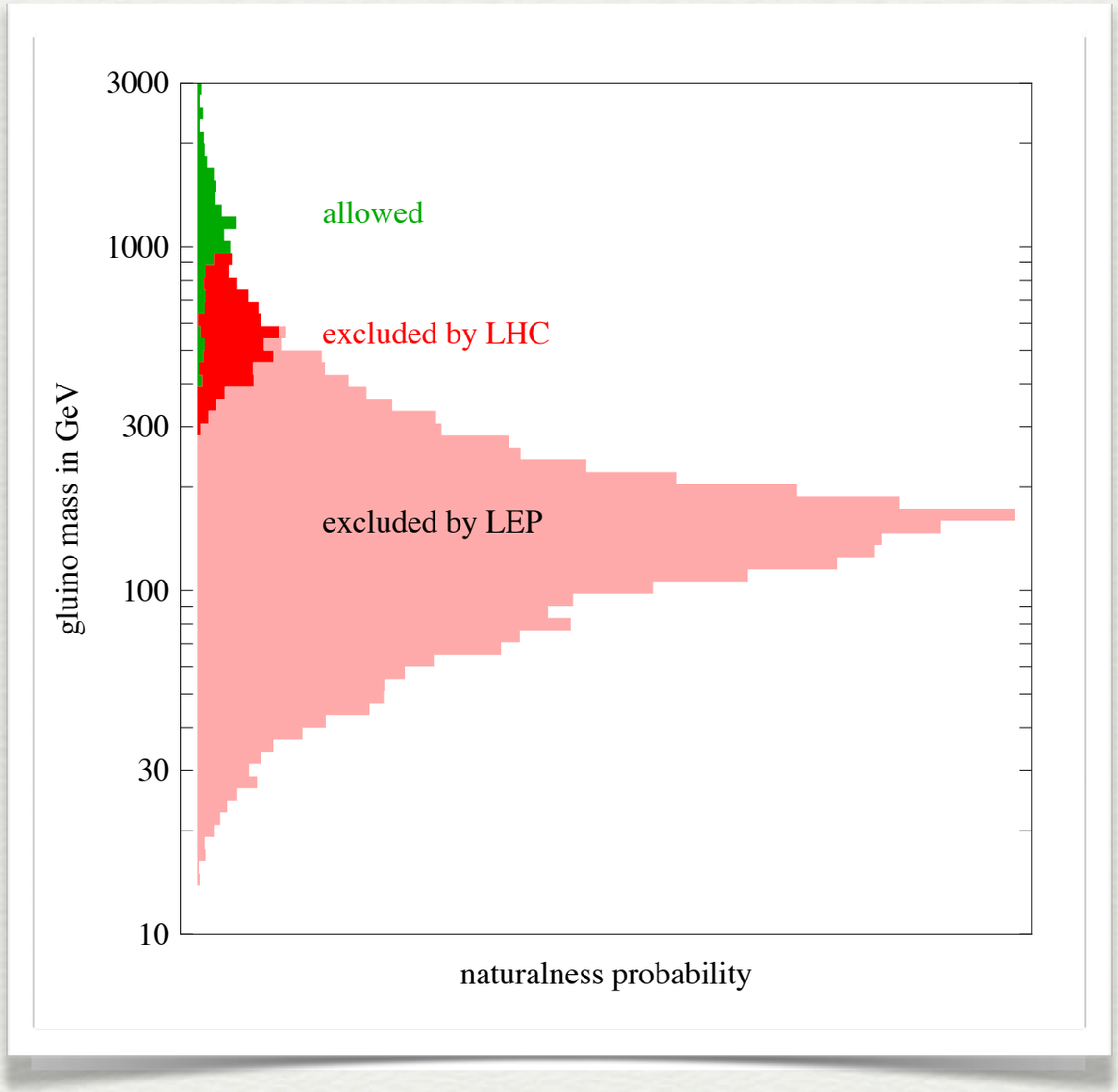
- If SUSY breaking is flavor blind (soft masses $\propto 1_{3x3}$ in generation space @ mediation scale Λ_M)
  - no problem with flavor physics bounds (~ Minimal Flavor Viol') ☺
  - strong bound on light squark masses translates into bound on stop masses ☹
- even at low Λ_M~10TeV:

$$m_{\tilde{t}} \simeq m_{\tilde{q}} \gtrsim 700\text{GeV} \quad \text{vs.} \quad m_{\tilde{t}} \lesssim (500 \div 700)\text{GeV}$$

A certain tension starts building up irrespective of the LEP Higgs bound...

with high scale mediation models situation is much worse (log enhancement)

e.g. in the CMSSM, after 35 pb^{-1}:

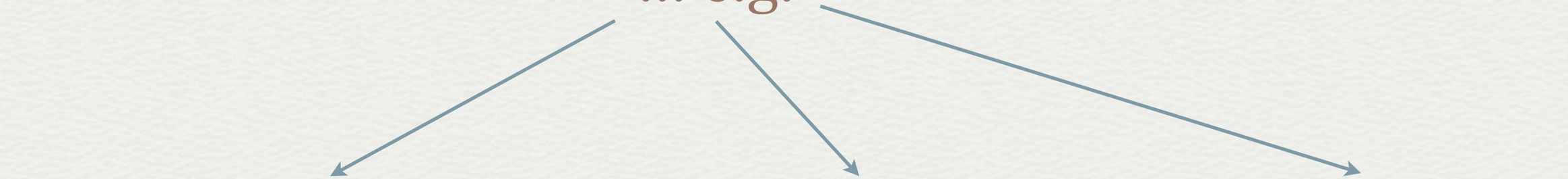


Strumia 2011

Missing something?

- Important to push limits up, but with more statistics more important to systematically close windows for light sparticles with suppressed xsec…

… e.g.



"Flavor-Split" spectra (heavy 1st-2nd gen squarks, gluino below 1-1.5 TeV, light 3rd gen)

"Squashed" spectra (everything below ~500GeV but splittings are small, O(10GeV))

Low MET scenarios (not necessarily RPV)

“Flavor-Split” spectra

(~“Effective SUSY” Cohen et al. 1996)

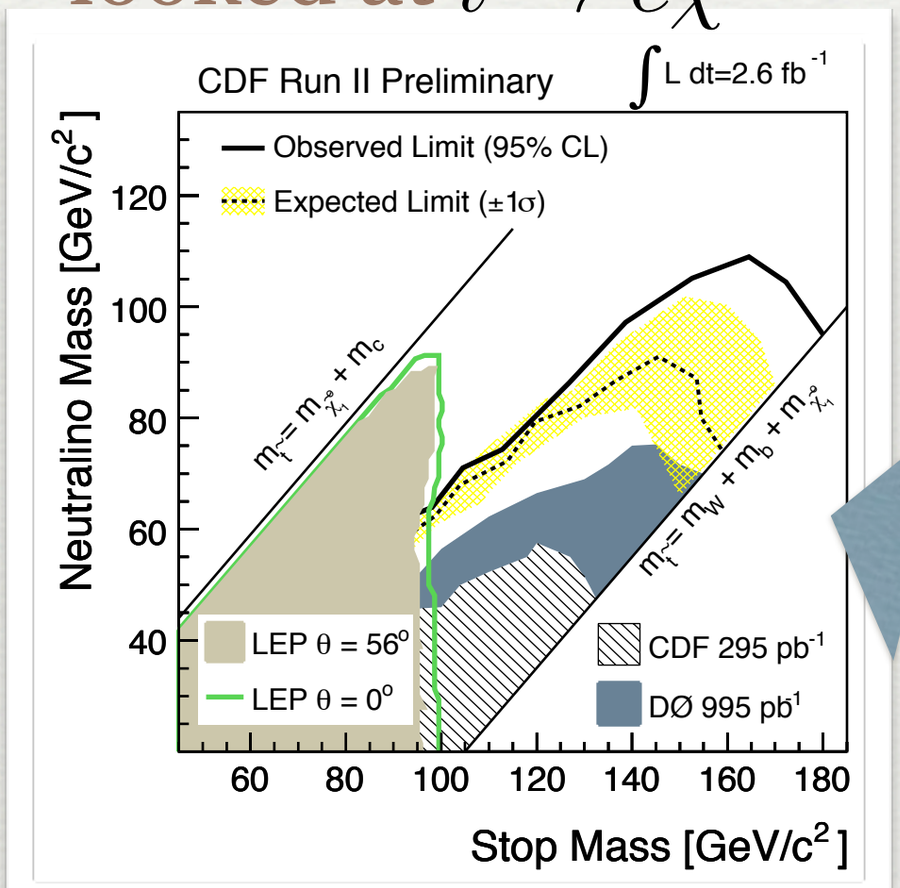
- 3rd generation “light” vs. 1st-2nd generations “heavy”
  - natural for Electroweak Symmetry Breaking
    (w/ also light higgsinos, not-too-heavy (<1-1.5TeV) gluinos)
- Two questions:
  - Is it already constrained in SUSY searches?
  - What about flavor bounds?

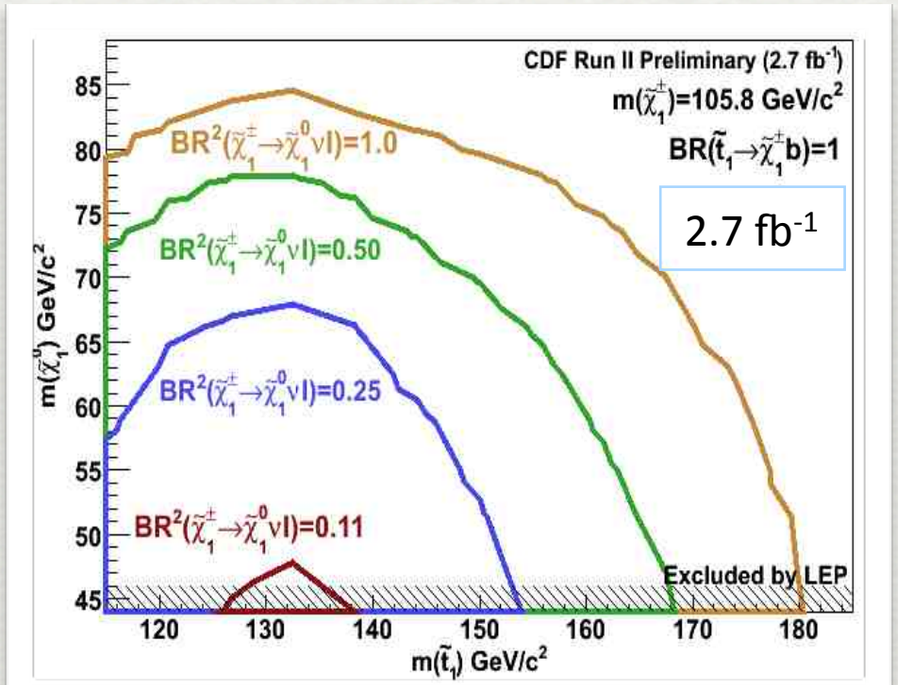
Is it constrained?

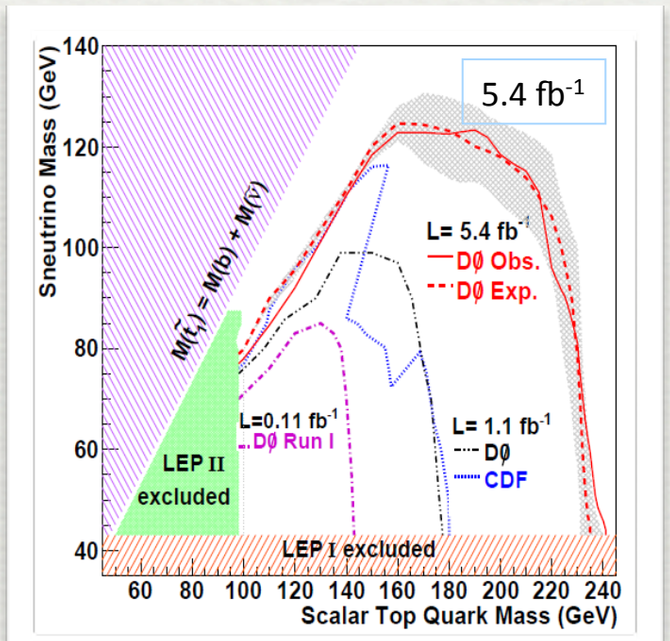
- Stop: direct prod' probed at Tevatron

(see Kajfasz's talk)

looked at $\tilde{t} \to c\chi^0$







no $\tilde{t} \to bW^{(*)}\chi^0$ search but

$\tilde{t} \to \tilde{\nu}\ell b$ and $\tilde{t} \to b\chi^+ \to b\ell\nu\chi^0$

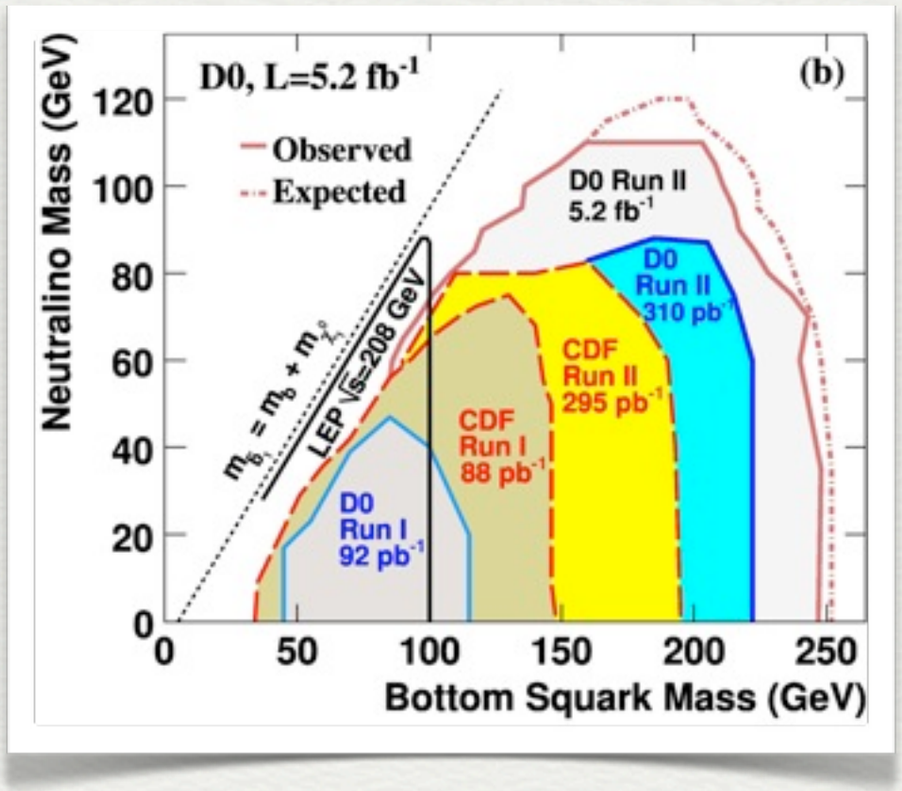
...not constraining yet...

(b/c BR's and kinematics)

Is it constrained?

- Sbottom: direct prod' probed at Tevatron

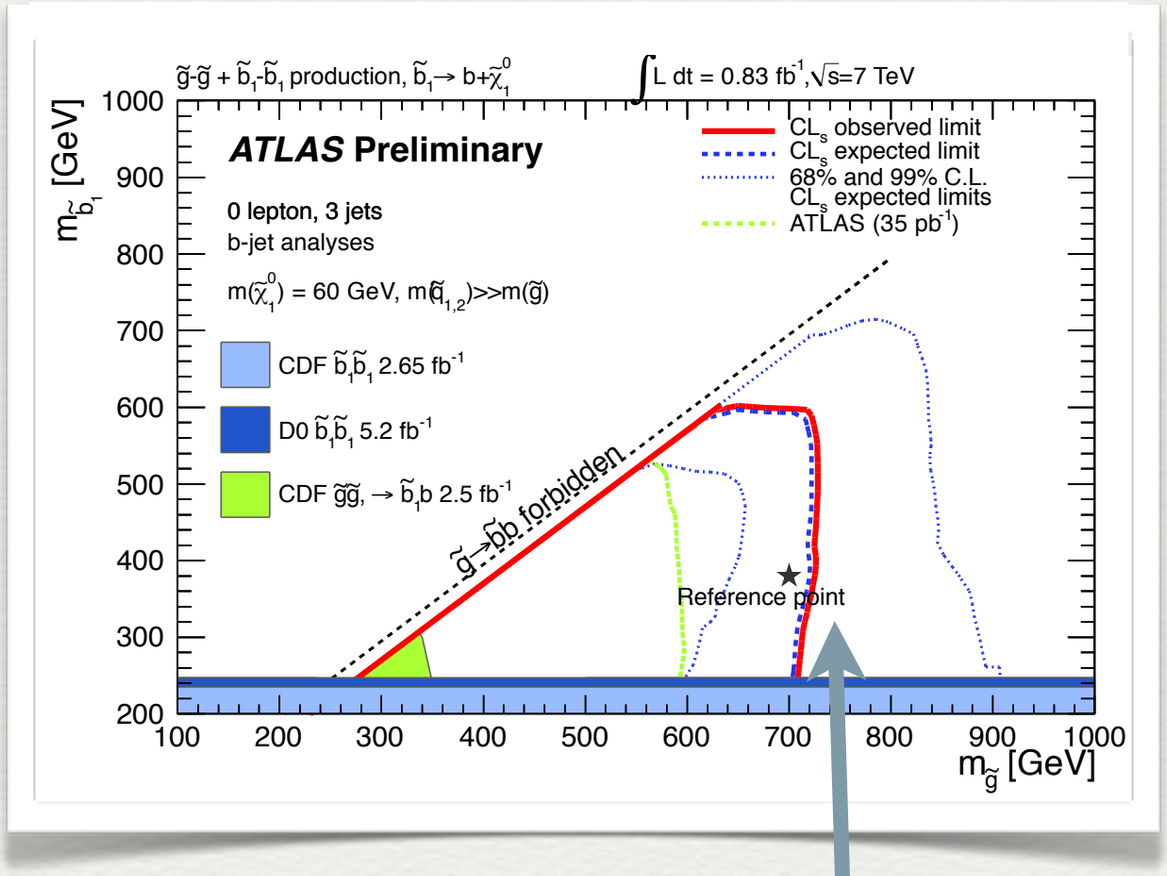
Looked at $\tilde{b} \to b\chi^0$

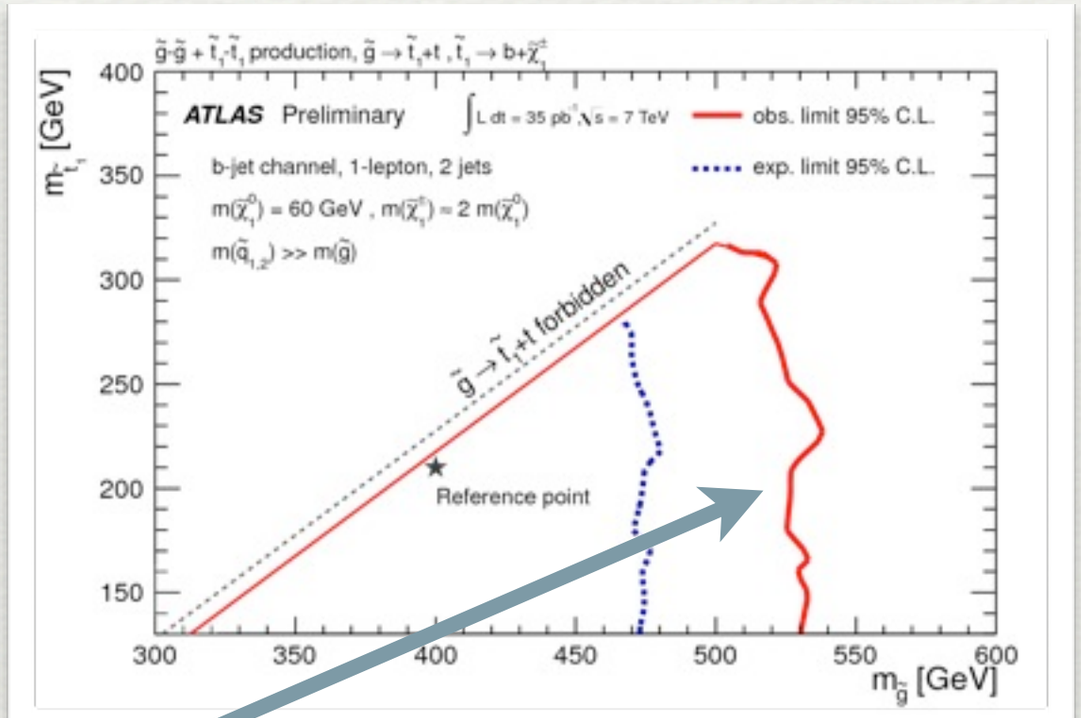


- Bottomline:
  - Stops can still be light (even 120-180 GeV) (promptly decaying)
  - Sbottoms should be > 250 GeV (promptly decaying)
  - Additional small "holes" near kinematic degeneracies

Constraints from LHC?

w/ bjets: ATLAS: 1103.4344, CONF-2011-098 CMS: 1106.3272





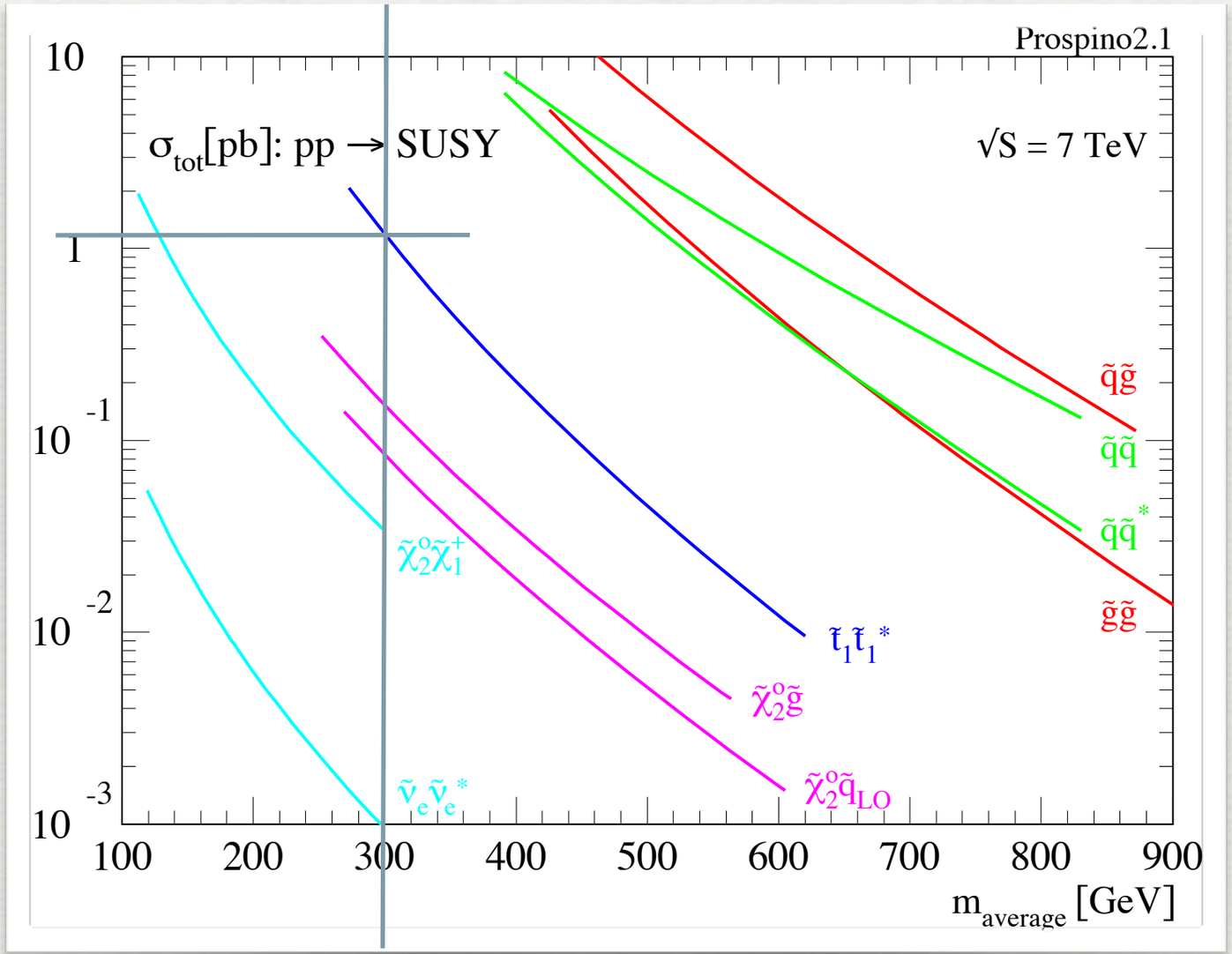
Reach is clearly dominated by the gluino production

For heavy enough gluinos (>700 GeV) no quoted bounds

Estimating the current limits

e.g. ATLAS-CONF-2011-098

M_{eff}>500(700)GeV cut: should be highly inefficient for m<250-350 GeV



- direct sbottom prod': N_{jet}>2, suppressed acceptance
- direct stop prod': σ~1pb for m~300GeV
  - lepton veto → hadronic tops
  - M_{eff} built from 3 leading jets → M_{eff}<$2m_{stop}$ → low ϵ·A even for 300 GeV stops (~150 GeV "lost")

- stops: ϵ·A~1% at 300GeV, 10% at 400GeV

← "theorist estimates" (M.P. & A.Weiler in progress)

Estimating the current limits

- Similar situation with $35pb^{-1}$ analyses: bounds in the 150-250GeV ("theorist estimates") depending on the neutralino/chargino spectra (in decay chains)

- Public LHC searches not designed to probe direct 3rd generation squarks production (no "need" until now, given low statistics)

- Necessity of more targeted searches for the multi-fb^{-1} era

- Complement direct "inos" searches when electroweak prod' will become accessible (μ vs. m_{stop})

Flavor constraints?

(Straub's talk)

- SUSY breaking distinguish generations → "Flavorful" SUSY scenarios
  - recently studied by Craig et al. 2011, Barbieri et al. 2011, ...
- Generically expect deviations in flavor measurements
- size easily compatible with current uncertainties/may be used to account for discrepancies (B_s mixing, ...)

Interplay of direct high-pT searches with indirect flavor searches (ATLAS+CMS vs. LHCb)

"Compressed" spectra?

- Running from high scale tend to open up the SUSY spectrum → low scale SUSY breaking required

- Generically more fine-tuned

- Low efficiency with present searches b/c of softness of decay products (→ harder to estimate reach at "theorist level")

- May use hard ISR to overcome energy thresholds by recoiling against a hard jet (need statistics to compensate the xsec price)

Further (experimental) study needed

Low missing ET?

- arXiv:1105.5135 (Fan et al.) “Stealth SUSY”→ easy to extend the MSSM to get R-parity conserving scenarios with suppressed MET
- Basic idea: have a squashed spectrum in another sector (~“hidden valley”) where SUSY breaking effects are naturally small
  - Simplest model: add a singlet to the MSSM (~NMSSM)
- would be natural target of Exotica or RPV searches
- Some signatures already looked for: e.g. 3-jet “resonances”
- Other signatures new: e.g. “resonances” in 1jet+2photons

Further explorations needed

Outlook

- Current Luminosity is the divide between constraining only 1st-2nd gen' squarks & gluinos cascades or looking at direct production of 3rd gen' squarks and electroweak "inos"

- Strong limits on squarks and gluinos are currently "trouble" only for (high-scale) flavor-universal scenarios

- light stops and sbottoms not really constrained yet (need "flavorful" SUSY scenarios) - key to constrain with dedicated searches

- Squashed spectra (tuned?) and scenarios with low MET are other avenues to evade the bounds (may need dedicated study)

- Higgs searches will provide complementary info (e.g. ruling out the MSSM if m_{Higgs}>130-140GeV or perturbative SUSY if no Higgs)