Higgs 126 GeV発見を受けて、 およびvs=14 TeVでのSUSY探索

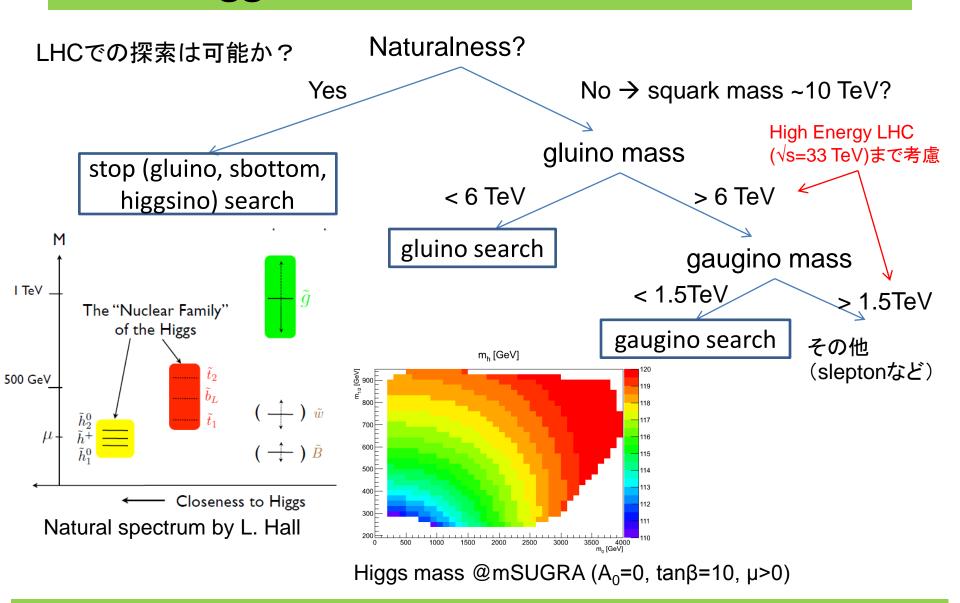
新学術領域研究 先端加速器LHCが切り拓くテラスケールの素粒子物理学



山中 隆志 東京大学 素粒子センター /

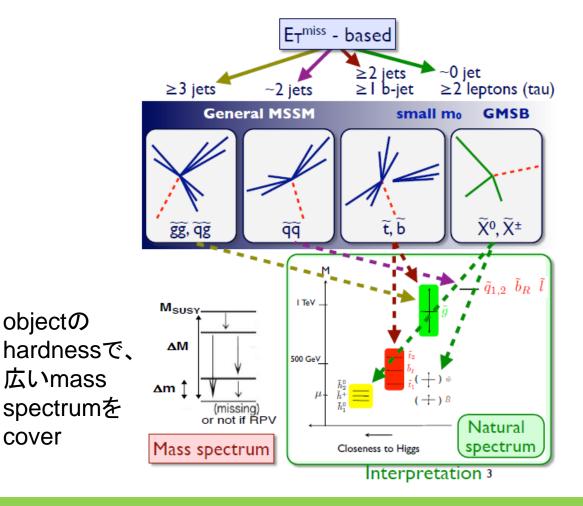


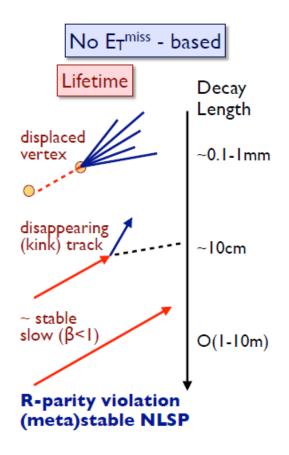
Higgs 126 GeVを受けてのSUSY



Search Strategy

探索すべきmodelは多岐にわたるが、signature baseで解析 することにより、広い領域を漏らさずにcoverする





cover

objectの

Stop, Sbottom Search

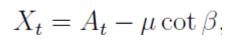
Stop Mixing

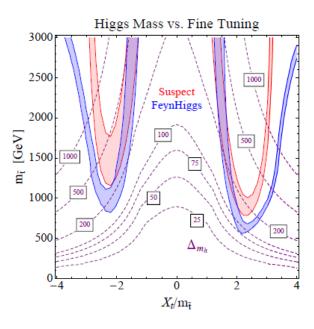
stopからのHiggs massへのradiative correction

$$\delta m_h^2 = \frac{3G_F}{\sqrt{2}\pi^2} m_t^4 \left(\log \left(\frac{\overline{m}_{\tilde{t}}^2}{m_t^2} \right) + \frac{X_t^2}{\overline{m}_{\tilde{t}}^2} \left(1 - \frac{X_t^2}{12\overline{m}_{\tilde{t}}^2} \right) \right)$$

- Higgs mass ~126 GeVを与えるにはstop massかXtが大きい
 - |Xt|=V6 m(~t)のとき(maximal mixing)、stop massを低く抑えつつHiggs massが最大 → naturalnessを満たすには不可欠
- 一方で、fine-tuningを避けるには

$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2} \left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2 \right) \ln \left(\frac{\Lambda}{m_{\tilde{t}}} \right)$$



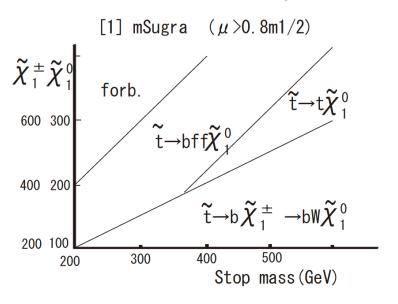


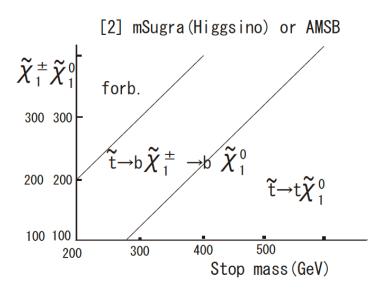
が小さくあってほしい

 Λ : messenger scale of susy breaking eg) $\Lambda = M_{pl}$ for Sugra

Direct Stop Pair Production

• modelによりstopのdecay modeも様々





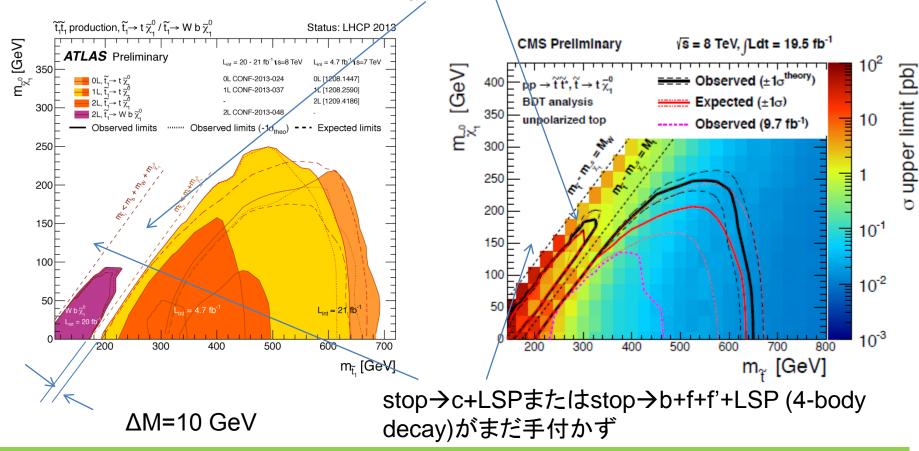
N(leptons)	0	1	2	
N(bjets)	>=1 o	0 or 2		
N(jets incl. b)	2,3 or 6	4	0 or 2	

Stop→t+LSPなど

• m(~chi1+)>m(~t1)の場合

• stop→b+W+LSP (3-body decay)の場合にはCMSの方が強いlimit

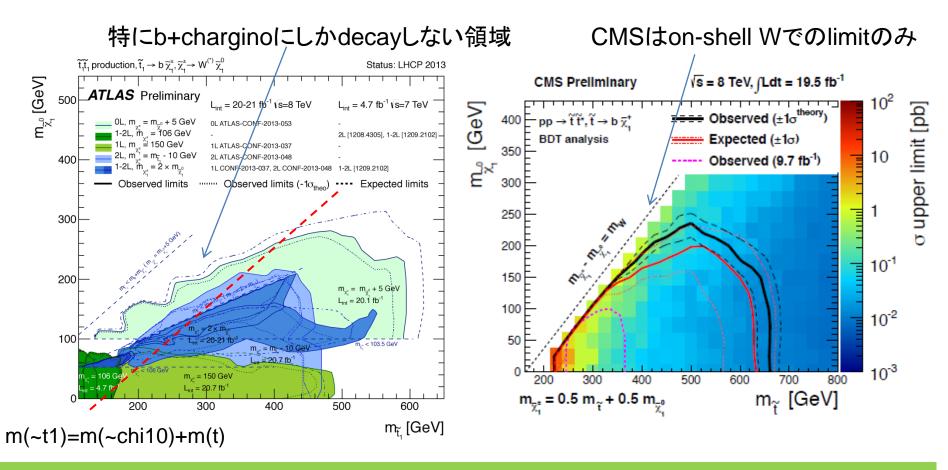
・いずれにせよまだ広い領域が残っている



Stop → b+Chargino

• m(~chi1+)<m(~t1)の場合

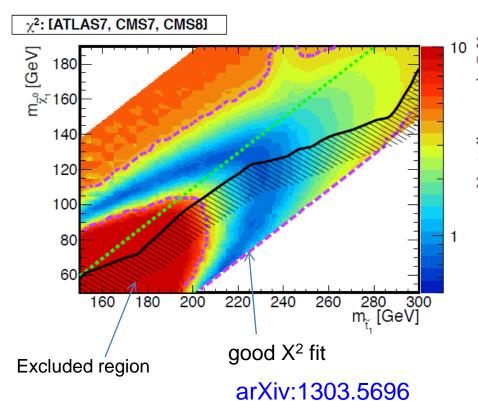
Naturalnessを考えるなら、Higgsino LSPの場合がより重要m(~chi1+)-m(~chi10)が小さい



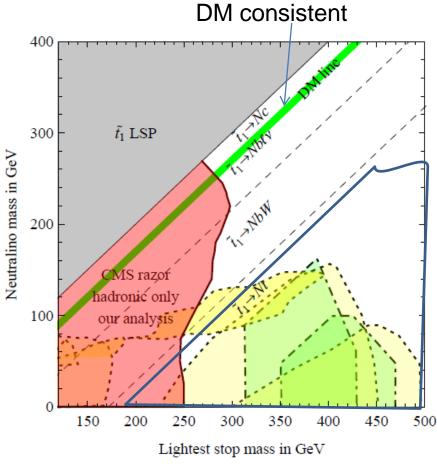
Miscellaneous

Light stops emerging in WW cross section measurements?

 $m(\sim t1)-m(\sim chi1+)=10 \text{ GeV}$ $\sim t1 \rightarrow b+\sim chi1+, \sim chi1+\rightarrow W(*)+\sim chi10$



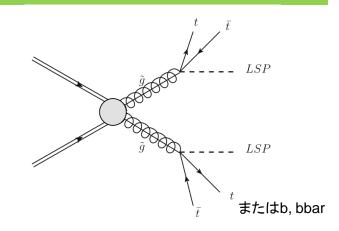
2012年12月時点での全てのconstraint

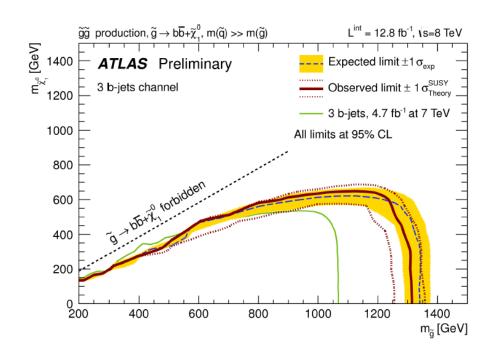


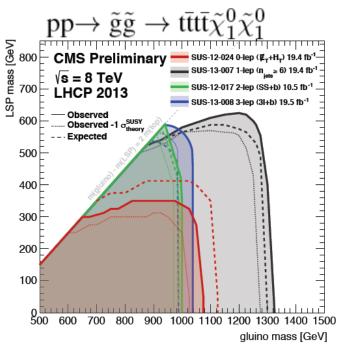
arXiv:1212.6847

Gluino Mediated Stop, Sbottom Production

• gluino pair productionから、 gluino decayによるstop, sbottom



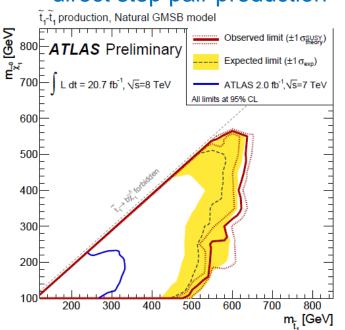




Natural GMSB

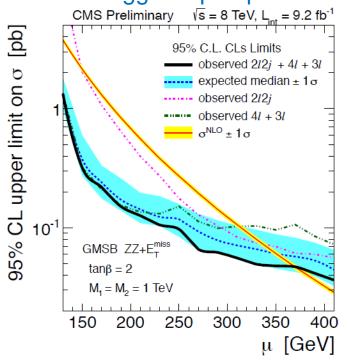
- GMSB case (Gravitino LSP):
 - HiggsinoがNLSPだとすると~chi10→G+Z/hから終状態にZを含む
- GMSBならばmessanger scaleが小さくてもよい→ naturalnessの条件が緩い
- •しかし、|A₀|は通常は大きく取れない → naïveなGMSBではHiggs 126 GeV困難

direct stop pair production



$$\delta m_{H_u}^2 = -\frac{3y_t^2}{8\pi^2} \left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2 \right) \ln \left(\frac{\Lambda}{m_{\tilde{t}}} \right)$$

direct higgsino pair production



√s=8 TeV解析の今後

- stopでまだ探索されていないdecay mode
 - stop \rightarrow c+LSP
 - $stop \rightarrow b+f+f'+LSP$
- ・これまでの探索で見落としていた可能性
 - compressed spectrum → soft lepton analysis
- Simplified modelからより現実的なmodelへ
 - Phenomenological MSSM
- Naturalnessを保つmodel
 - NMSSMなど

LHC@14 TeV

- 13-14 TeVでのLHC運転
 - bunch spacing 50 ns \rightarrow 25 ns
 - peak luminosity 2-3×10³⁴ cm⁻²s⁻¹、1回のビーム衝突時の平均反応 回数μ~69
- 2020年までに300 fb⁻¹ (Phase-I)
- High Luminosity LHCで3000 fb⁻¹ (Phase-II)
 - L=5 × 10^{34} cm⁻²s⁻¹, μ ~ 140
- PDFによるhigh mass particleのcross sectionの増加
- 一方でpileupによるresolutionの悪化など

Trigger@14 TeV

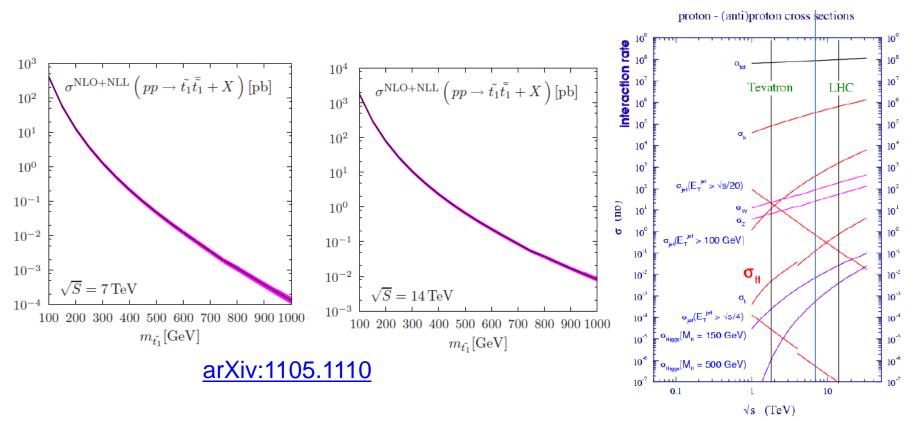
- High massのSUSY探索ではVs=14 TeVでのtrigger thresholdの上昇による影響はほとんどない
- ただし、縮退したmodelでは無視できない影響
 - R-parity conservationのmodelではMETとのcombined triggerなども考慮する必要あり

L=2×10³⁴ cm⁻²s⁻¹でのtrigger thresholdの予測値

	L1 threshold	Offline threshold
single electron (pT)	28 GeV	33 GeV
single muon (pT)	20 GeV	25 GeV
single jet (pT)	100 GeV	250 GeV
pure ETmiss	60 GeV	190 GeV

SUSY Cross Section

- Vs=7 TeV → 14 TeVによりlow massでは数倍程度しかcross sectionは増えないがhigh massになるほどPDFの効果で急激に14 TeVのcross sectionが増加が大きくなる
 - 一方でSM backgroundの生成断面積も増加する
 - → High massのsignalにre-optimizeしたselectionや高統計を利用した解析が必要

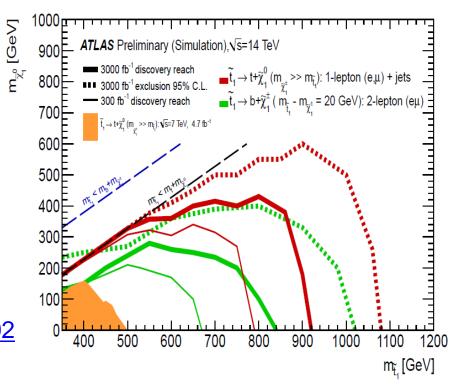


Stop Search@14 TeV

- Event selection (for t+LSP)
 - 1-lepton (electron or muon)p_T>25 GeV
 - $-4 \text{ jets p}_{T}>120,100,50,50 \text{ GeV}$
 - At least one b-tagged jet p_T>40
 GeV
 - E_T^{miss}>225 GeV
 - m_T(lepton, E_T^{miss})>140 GeV
 - Optimum 1st, 2nd jet p_T, E_T^{miss},
 E_T^{miss}/√H_T, m_T cuts for each
 signal point

ATL-PHYS-PUB-2013-002

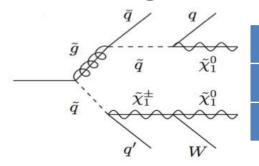
300 fb⁻¹ではstop→t+LSPの場合、 stop mass 800 GeV (LSP mass ~0 GeVのとき) まで発見の可能性あり



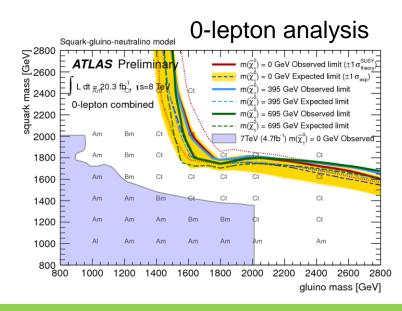
Gluino (Squark) Search

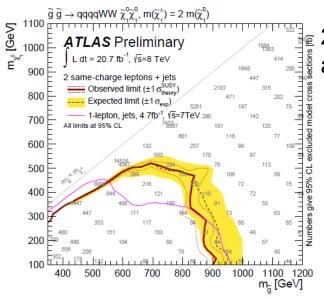
Gluino/Squark Search

一般性を失わないようsignature baseに categorizeし、inclusiveにsearch



N(leptons)	0	1 (soft)	1	2 (SS)	2
N(jets incl.b)	2-6, 6-9	2	3,7	3,4	2,4
N(bjets)				0,1,3	



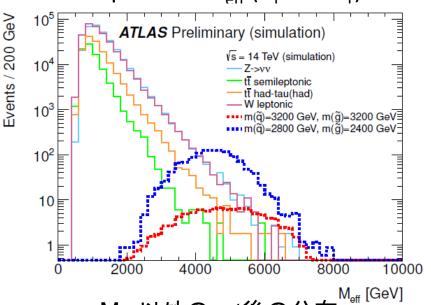


2-lepton SS analysis

Squark, Gluino Search@14 TeV

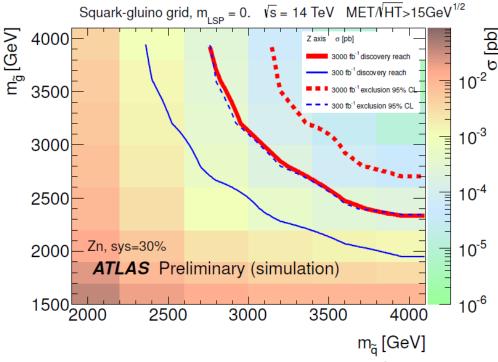
- vs=14 TeVでの発見感度の予測
- Event selection
 - No electron or muon (p_T>20 GeV)
 - At least 4 jets p_T>60 GeV
 - $E_T^{miss}/VH_T>15 GeV^{1/2}$

- Optimum M_{eff} ($E_{T}^{miss} + H_{T}$) cut for



M_{eff}以外のcut後の分布[™]

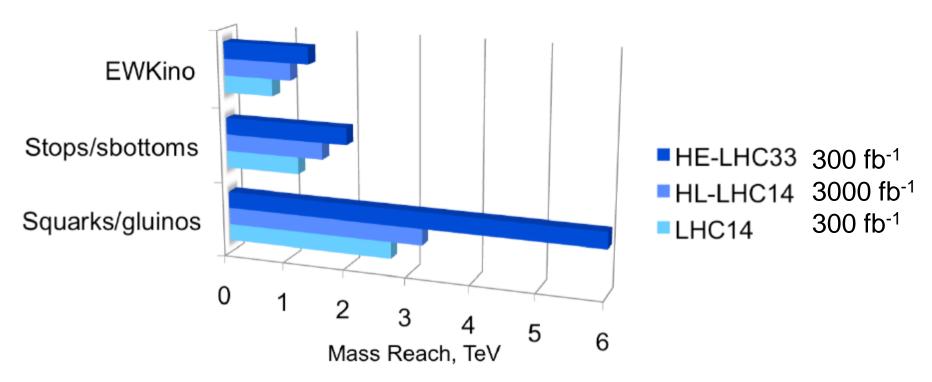
300 fb⁻¹ではsquark mass 2.4 TeV, gluino mass 2 TeV程度まで発見の可能性あり



Simplified modelでの予測感度

CMS 14 TeV Expectation

- 現在の探索結果から外挿した予測値
 - おおよそATLASと同程度の感度

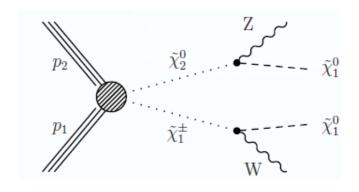


CMS Submission to the European Strategy Preparatory Group

EW Gaugino Search

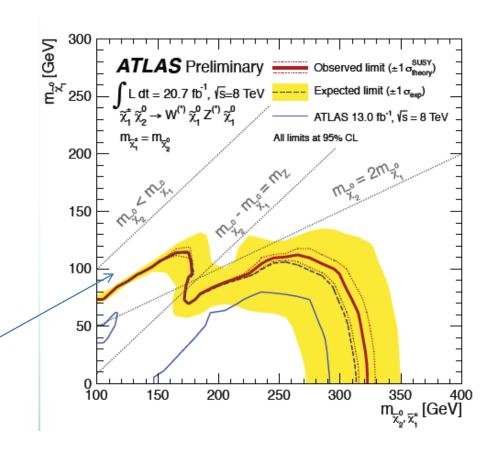
EW Gaugino Search

- squark, gluinoが重い(>10 TeV)場合
 - gaugino massは軽くても良い



Bino LSP, Wino NLSP的なmodel を仮定

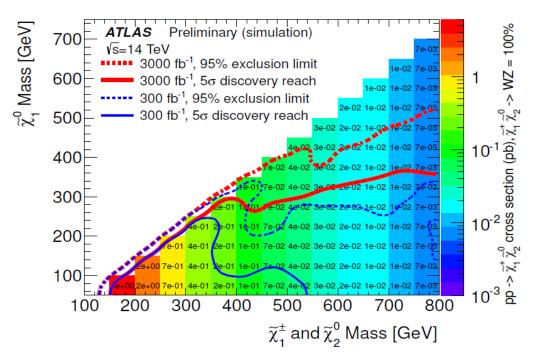
m(~chi1+,~chi20), m(~chi10) が縮退した場合がここでも課題



EW Gaugino Search@14 TeV

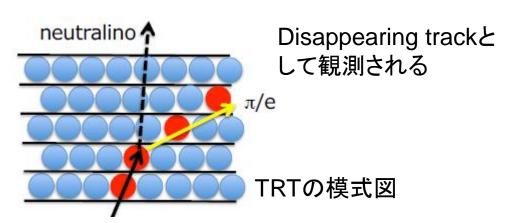
- vs=14 TeVでのEW gauginoの発見感度
- Event selection
 - 3 lepton pT>10 GeV, at least one lepton pT> GeV
 - no b-jet
 - same flavor, opposite sign lepton pair mass > 20 GeV
 - $E_T^{miss} > 150 \text{ GeV}$
 - Multivariate of E_T^{miss}, mT, lepton pT, mll, pT(II), ΣpT(jet)

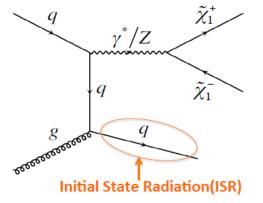
300 fb⁻¹ではneutralino2, chargino mass 540 GeV (LSP mass ~50 GeV のとき) まで発見の可能性あり



AMSB

- Anomaly Mediated SUSY Braking model
 - − Bino:Wino:Gluino ~ 3:1:8
 - NLSP,LSP→wino-like, Δm(~chi1+ -~chi10)~150 MeV
 - → charginoの寿命は~0.1-1 ns → O(1-10) cm



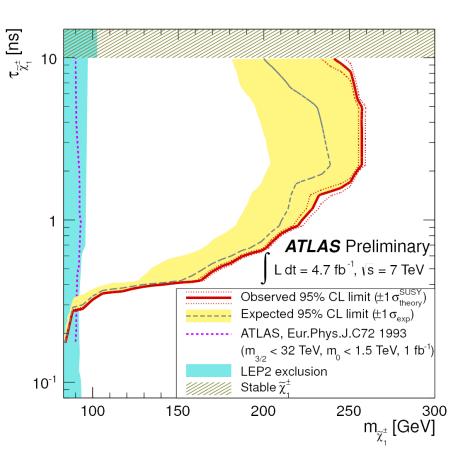


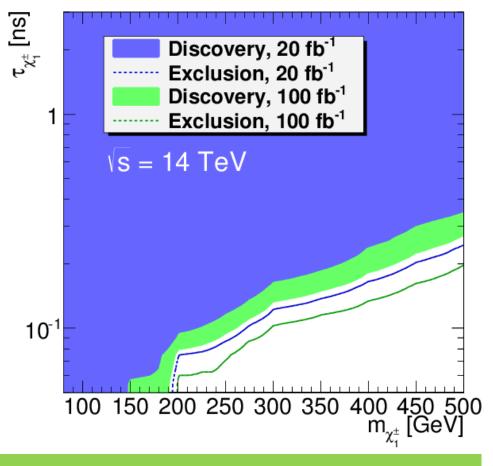
Eventを triggerする ためISR-jet を利用

AMSB Limit and Expectation

√s=7 TeVでのexclusion limit 8 TeVでは現在解析が進行中 (coming soon)

√s=14 TeVでの感度予測





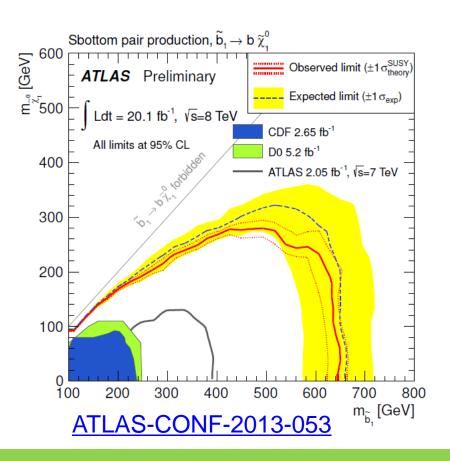
まとめ

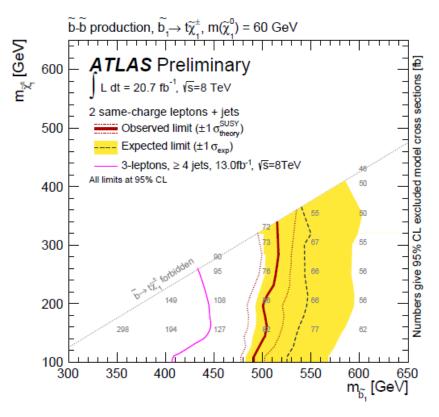
- ~126 GeVのHiggs発見を受けてのSUSY
 - Naturalnessを信じるならstop (他gluino, sbottom, higgsino)が比較的軽いことが期待されるが、未だ 兆候はない
 - どこまでNaturalnessを信じる?
 - まだ残っているparameter spaceへの対処
 - Naturalnessを放棄した場合でも、gluino、EW gauginoは軽くても良い
 - vs=14 TeVでの探索に期待

Backup

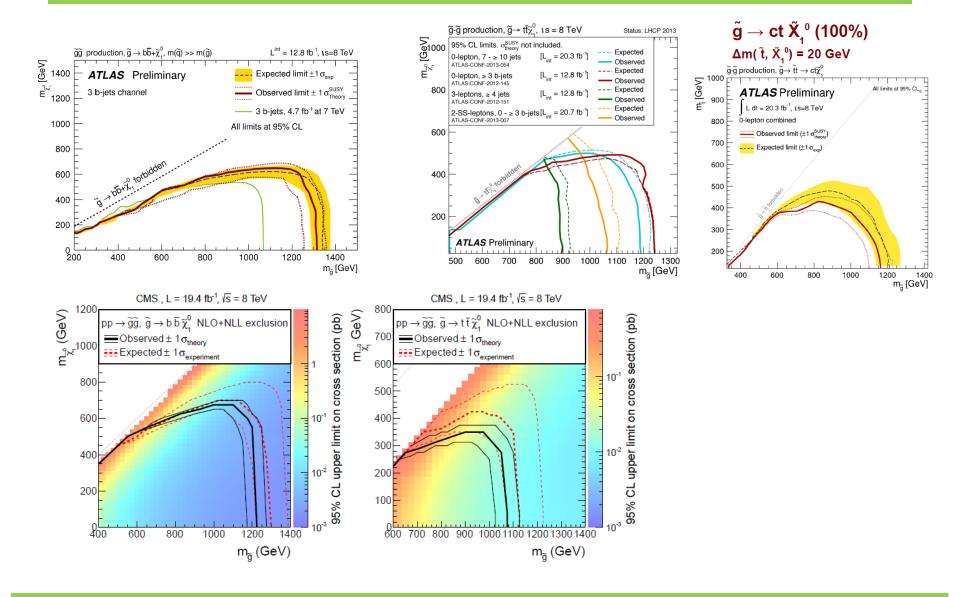
Direct Shottom Pair Production

• m(~tL)=m(~bL)なことから、sbototmも軽いと考えられる



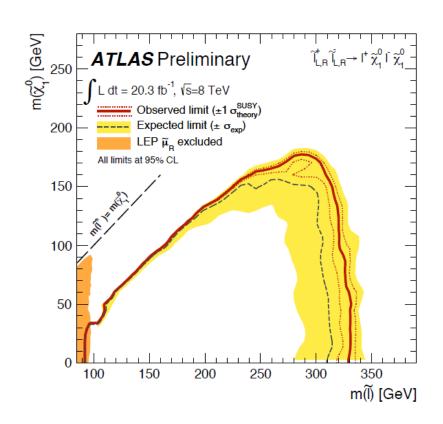


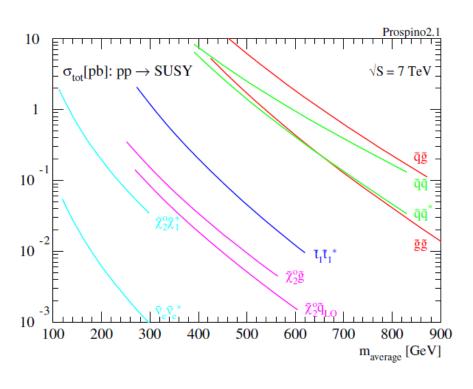
Gluino Mediated Production



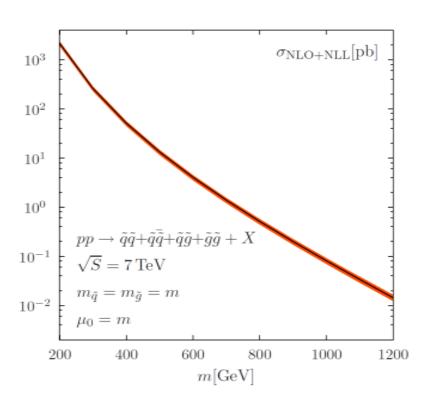
Slepton Search

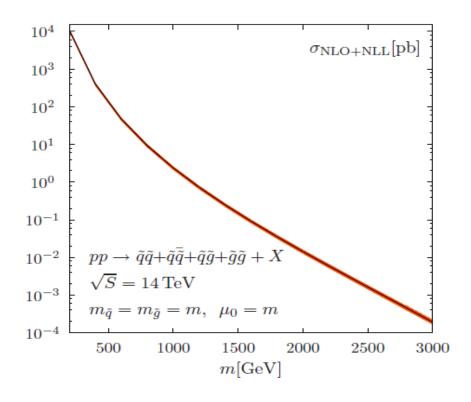
• LHCではDirect gaugino productionより更に一 桁小さいcross section





Gluino/Squark Cross Section

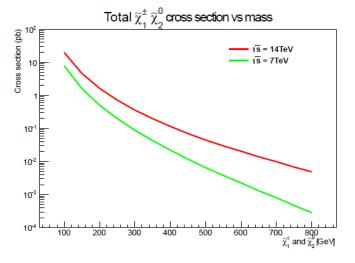


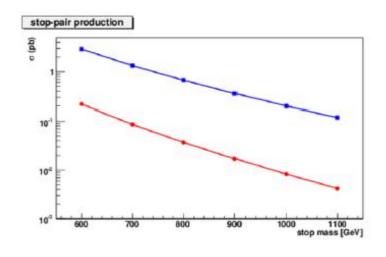


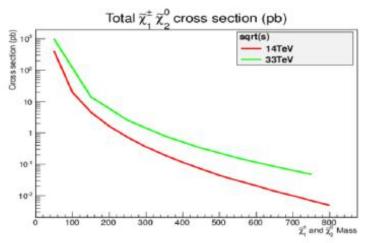
Cross Section @ vs=33 TeV

• 14 TeV → 33 TeVでもsusyのcross sectionはお

よそ10倍程度上昇







Higgs Constraint CMSSM/mSUGRA Grid

|A₀|, tanβを高く取り、Higgs mass~126 GeVに広い領域でconsistent
• 特にXt=At-√6µcotβ ~0と取ることでstop massを低く保ったまま
Higgs massを高くすることができる。

$$m_H^2 \approx \frac{m_Z^2 \cos^2 2\beta}{m_Z^2 \cos^2 2\beta} + \frac{3}{(4\pi)^2} \frac{m_t^4}{v^2} \left[\ln \frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2} \left(1 - \frac{X_t^2}{12m_{\tilde{t}}^2} \right) \right]$$
 m²_H is large if stop mass is large and/or mixing term is maximized

$$A_0 = -2m_0$$
, $\tan \beta = 30$

