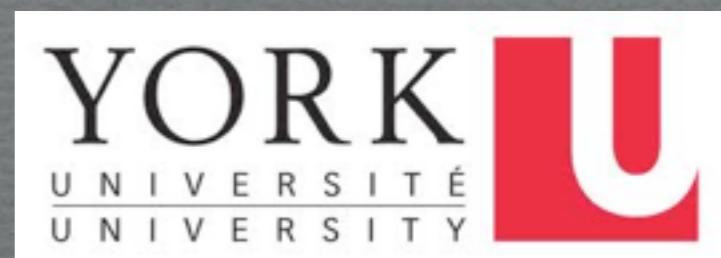


# Looking for Stops

Veronica Sanz  
CERN and YorkU

Planck 2012, Warsaw



There is no hint of SUSY  
in the LHC 2011 searches

There is no hint of SUSY  
in the LHC 2011 searches

Worried?

depends on the  
scope & reach

# Scope of searches

MET signatures

MET + nj + nb + nl + nph + ...

nj=0-9

nb=0-2

nl=0-4

nph=0-2

No MET

RPV (multijet, emu resonances)

LLP: CHAMPS, R-hadrons

...

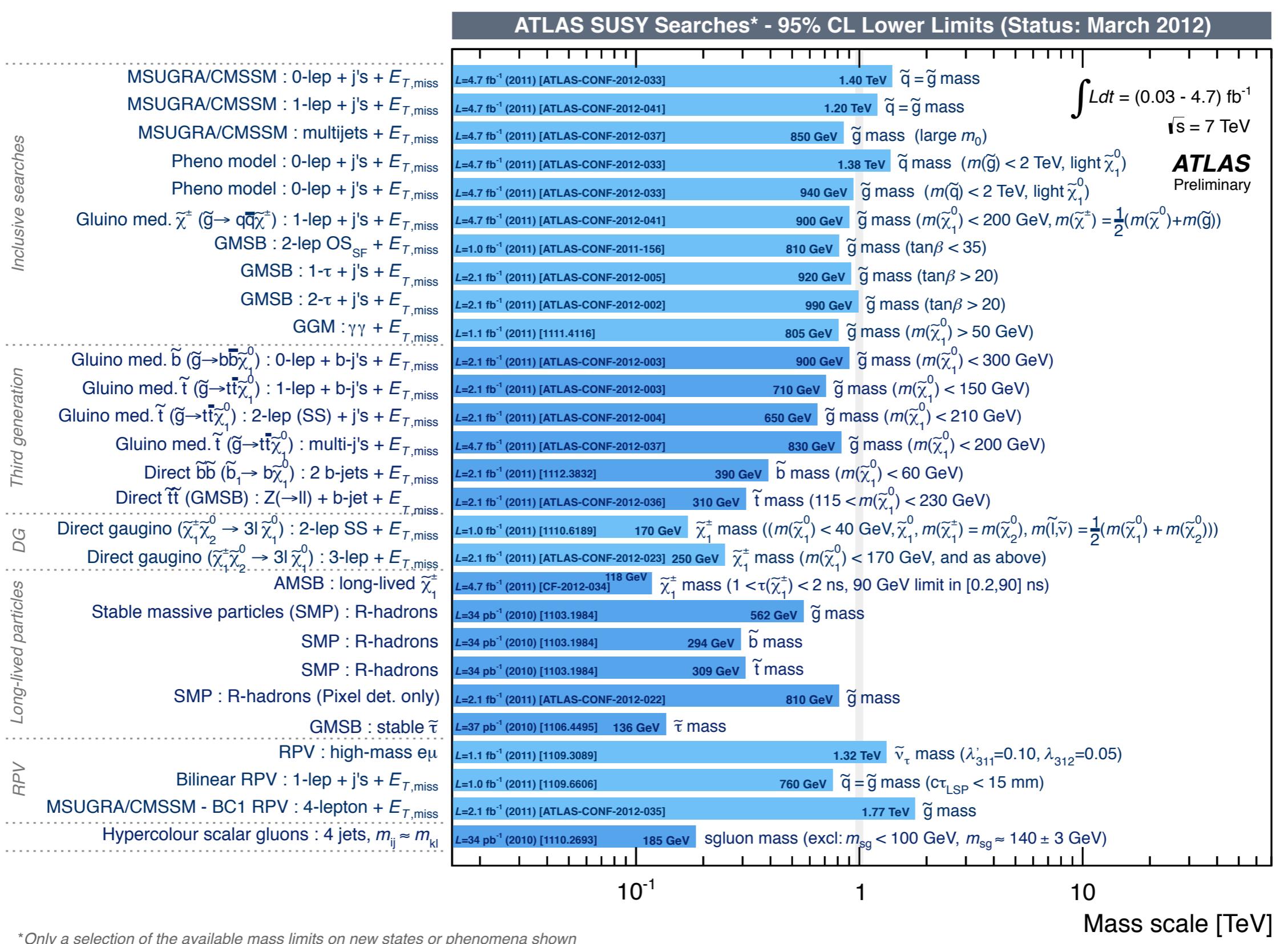
Reach mass exclusion

Interpretation null results

model dependent

simplified models and specific scenarios:

CMSSM, mSUGRA, GMSB, AMSB

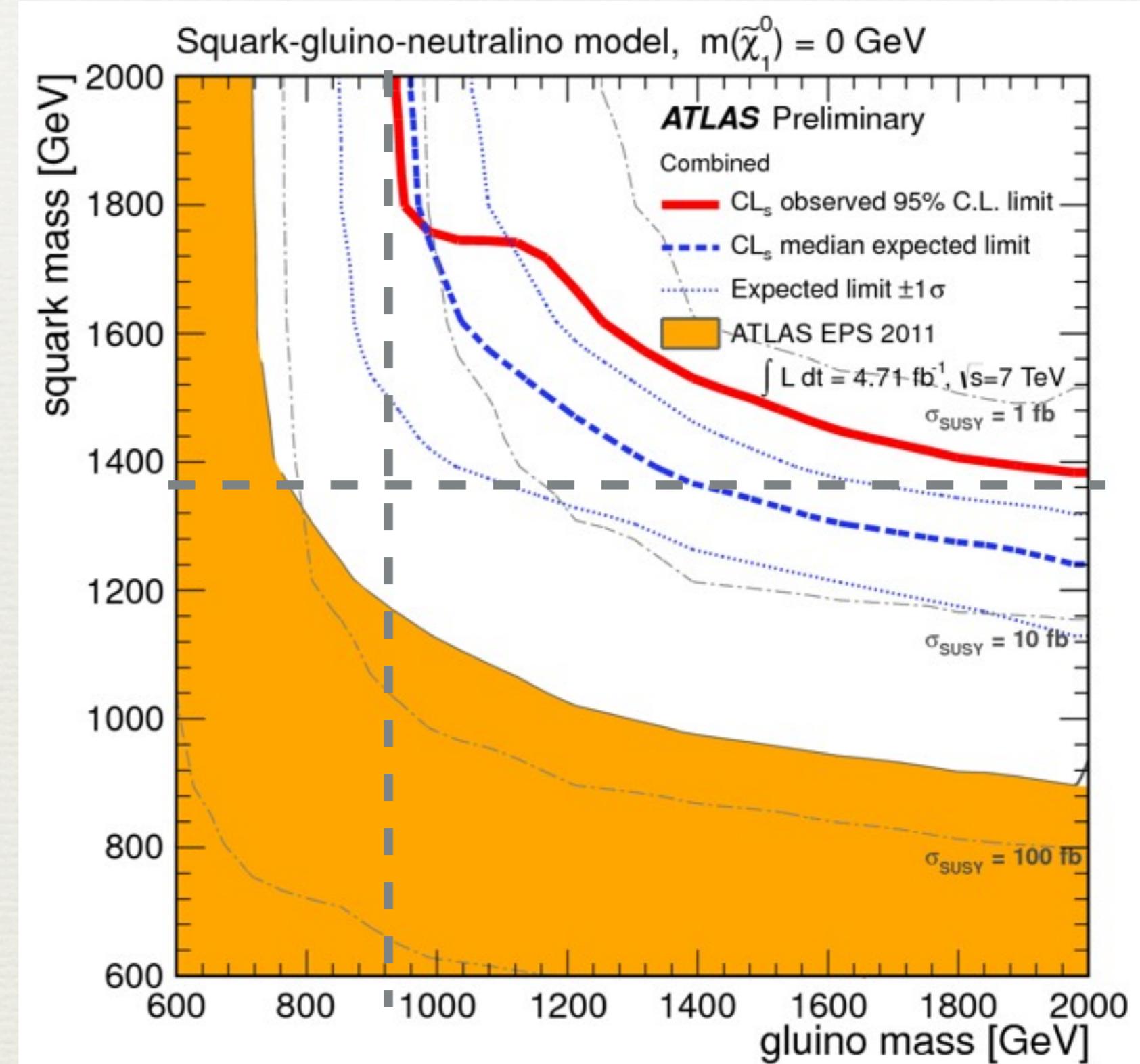


\*Only a selection of the available mass limits on new states or phenomena shown

Colored and EW states

Simplified  
model

1st and 2nd generation squarks



gluino

Broad scope  
Near TeV reach

LHC 2011 pushing SUSY beyond EW scale

# LHC 2012?

rule of thumb

$$\sqrt{s} \rightarrow \sqrt{s} + 1 \text{ TeV}$$

or

$$\mathcal{L} \rightarrow 2 \mathcal{L}$$



increase reach by  
100-300 GeV

8 TeV, 20 ifb: 300-900 GeV

assuming no new combination, no  
improvement

LHC 2011-12 pushing SUSY well beyond EW scale

We do care

Supersymmetry is a solution to  
the hierarchy problem  
(stabilization of the EW scale)

Natural SUSY

naively

SUSY partners ~ EW scale

## Natural SUSY

= corrections from SUSY breaking to EWSB  
shouldn't de-stabilize the EW scale

## FINE-TUNING

shift in  $m_Z$  due to SUSY loops  
one-loop stop contribution

Ellis et al '86

Barbieri et al '88

$$\boxed{\delta_t m_Z^2} = \frac{3}{16\pi^2} \left( y_t^2 (m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 - 2m_t^2) + \frac{(m_{\tilde{t}_1}^2 - m_{\tilde{t}_2}^2)^2}{4v^2 \sin^2 \beta} 4 c_{\tilde{t}}^2 s_{\tilde{t}}^2 \right) \log \left( \frac{2\Lambda^2}{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \right)$$

EW

Yukawa

SUSY

cutoff: messenger scale

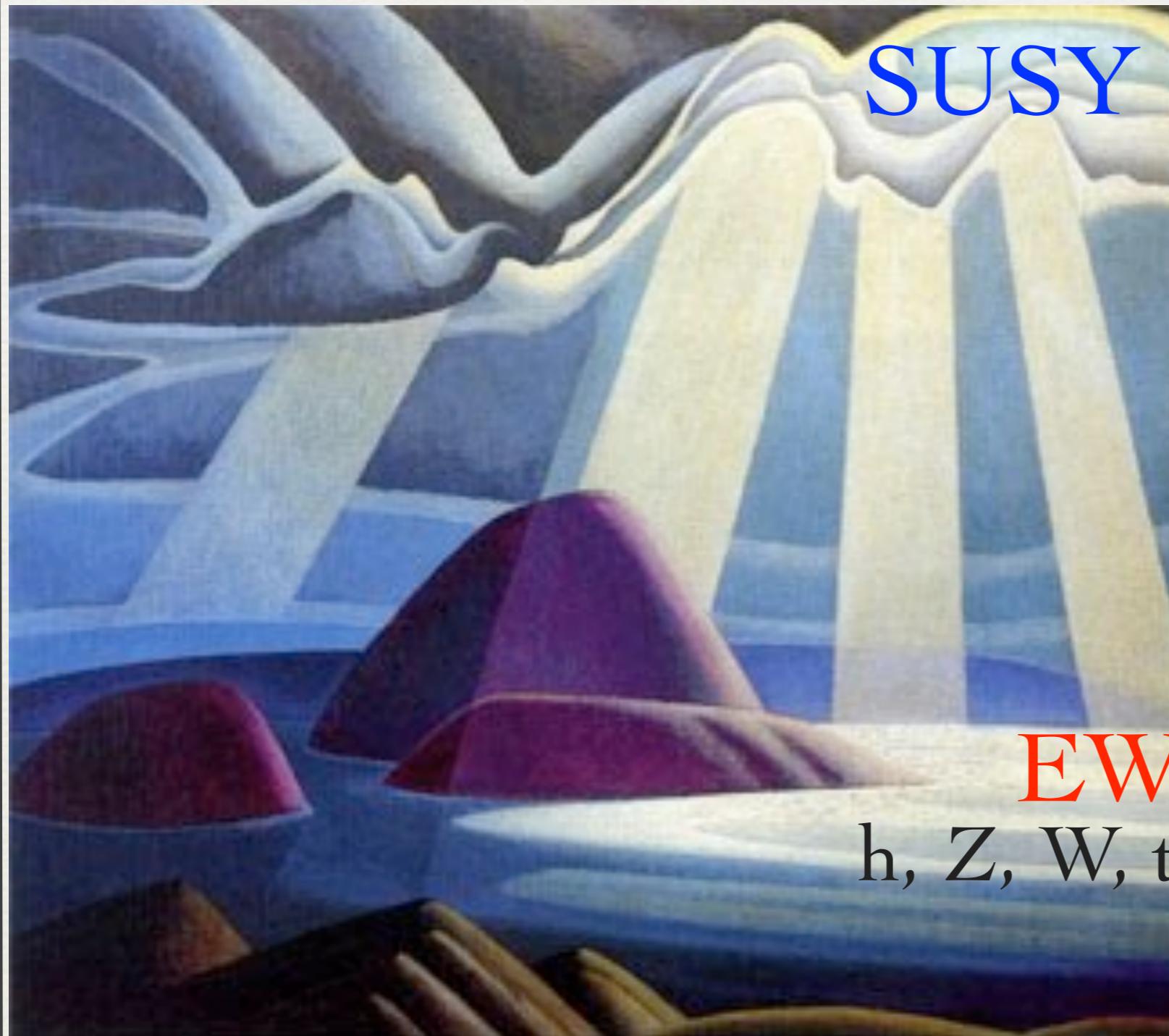
more contributions:

Higgsinos, two-loop gluino, etc

E



E



SUSY

EW  
h, Z, W, t

LHC 2011-12

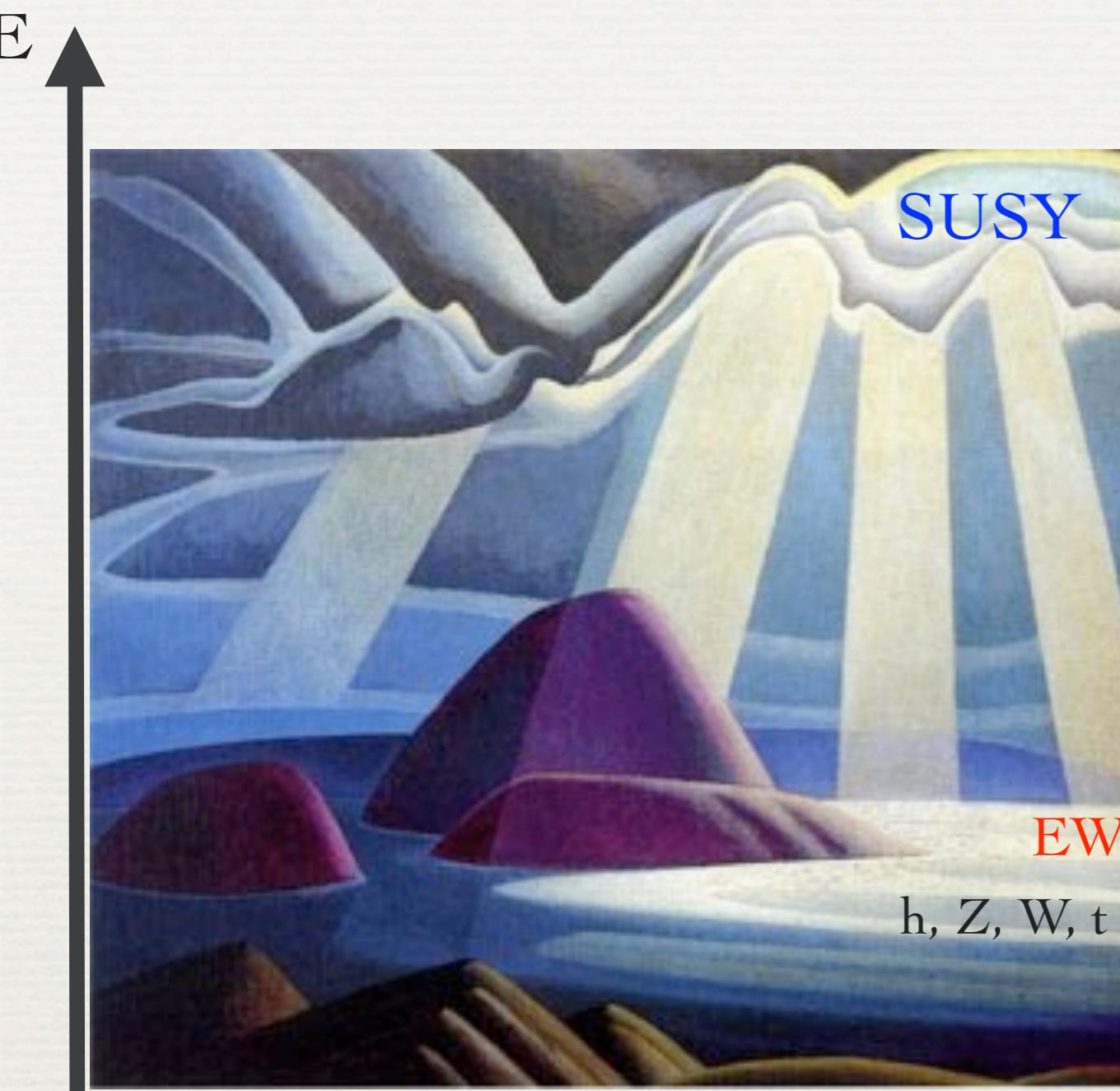
~ TeV?

de-stabilization  
EW scale

Or maybe there is a problem  
with the scope or  
interpretation of searches

i.e. what are the **ways out** of current constraints?

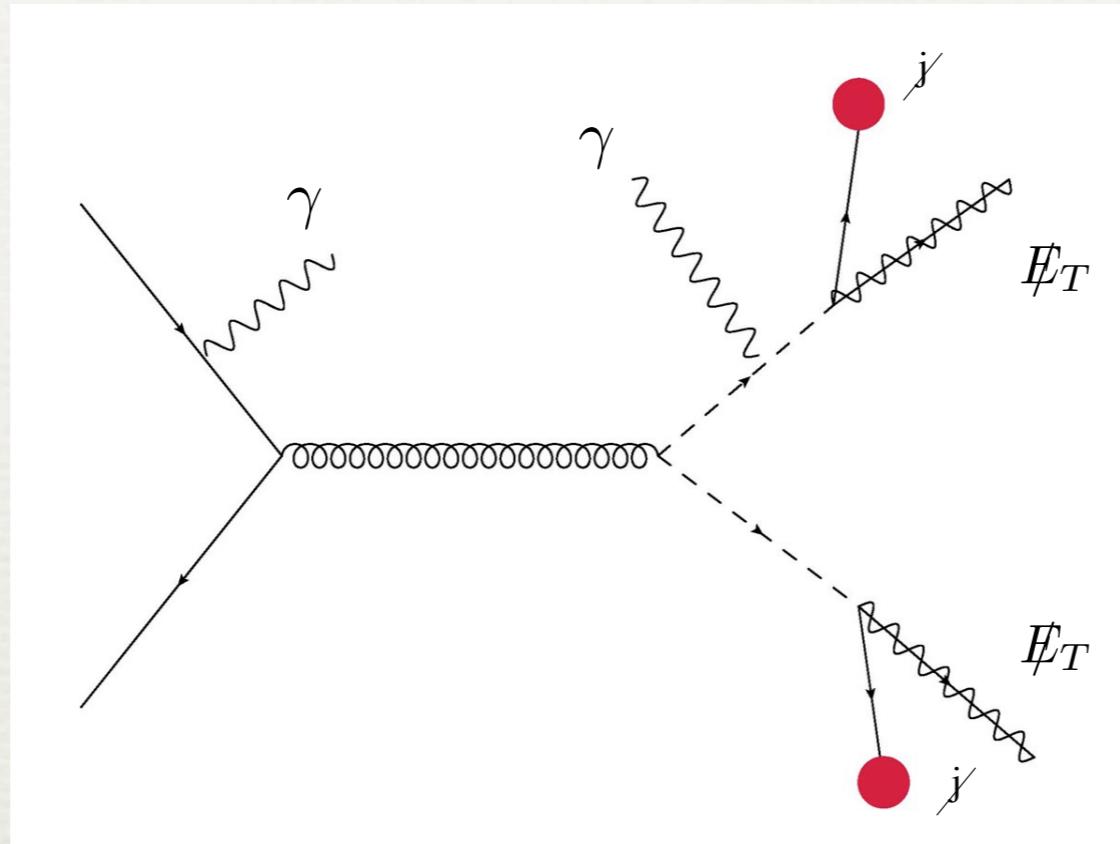
Way out #1  
Compressed spectrum



$\tilde{g} \ \tilde{q} \ \tilde{\chi}^0$

MET+high-pT decay  
fail compressed spectrum

# Look for MET+ ISR-FSR



Monophoton

Belanger, Heikinheimo, VS.  
1205.1463

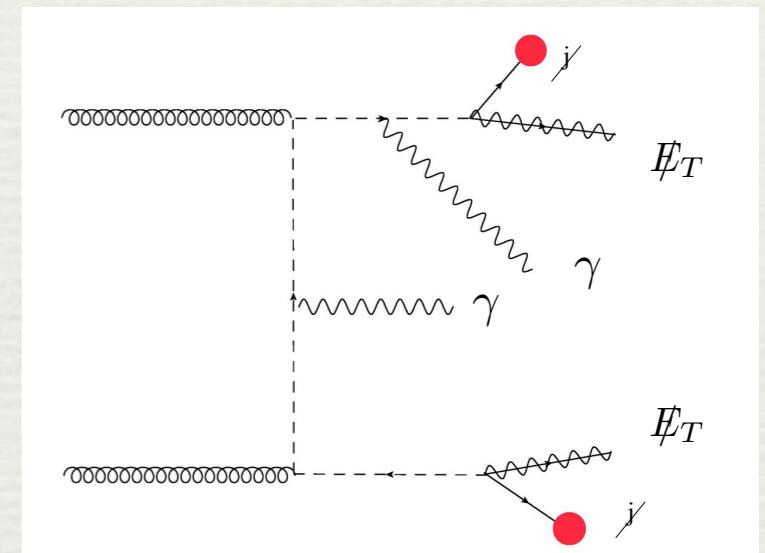
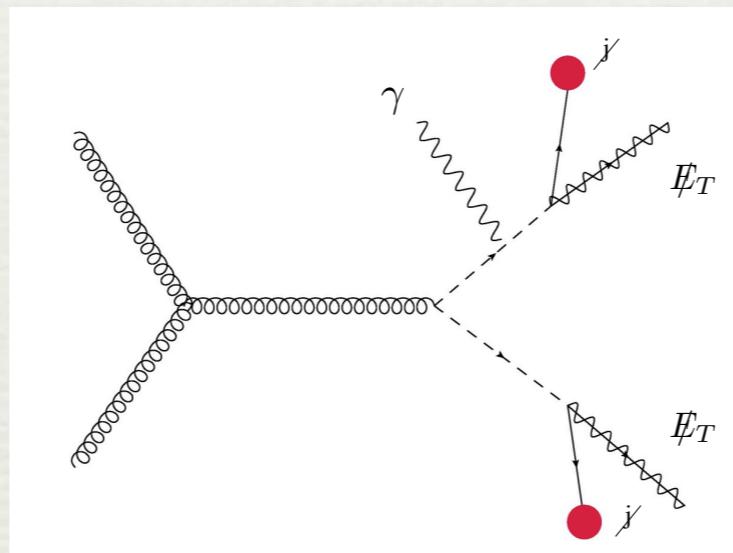
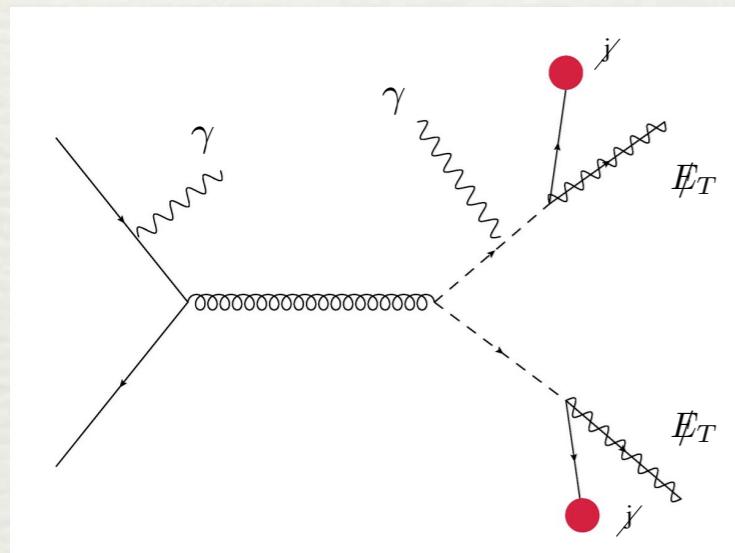
Monojet

Alvarez, Bai. 1204.5182  
Belanger, Heikinheimo, VS, in  
preparation

# Monophoton searches

## Model-independent bound on squarks

Only one squark and LSP



# CMS search monophoton+MET interpretation in LED and DM

## Basic cuts

Photon quality (PHQ):  $|\eta_\gamma| < 1.44$  ,  $p_T^\gamma > 145 \text{ GeV}$  and

Missing energy (MET):  $\cancel{E}_T > 130 \text{ GeV}$  .

## Límit

$$\sigma(m_{\tilde{q}}^{\text{limit}}) = \frac{N_{obs} - N_{max,exp}(3\sigma)}{\mathcal{L}} \simeq 5 \text{ fb}$$

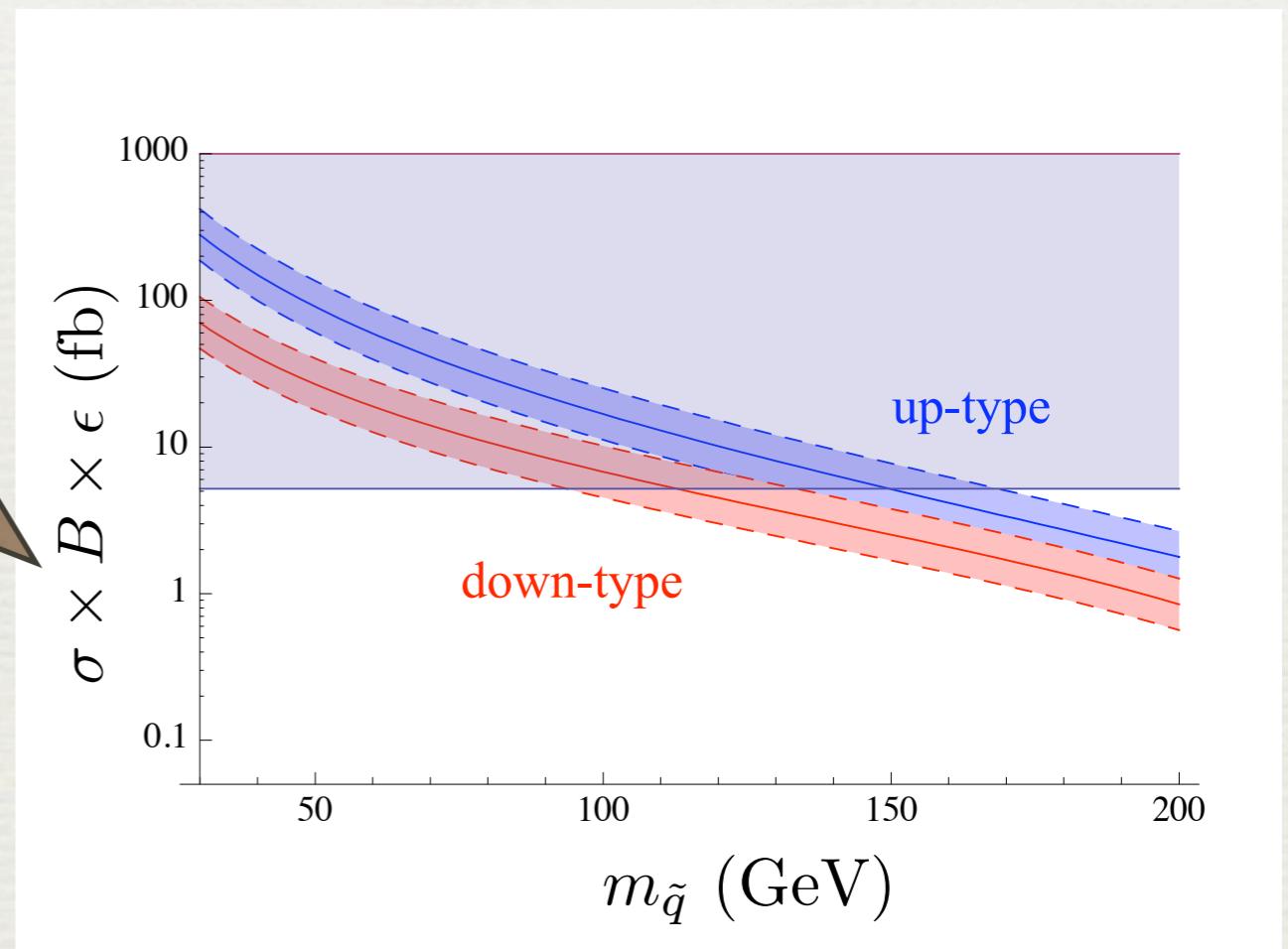
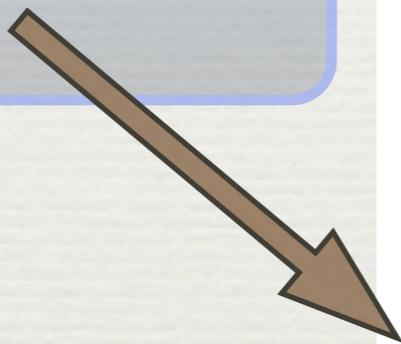
Simulation

parton level MG5

show/had pythia

detector sim Delphes\_CMS

Analysis ROOT



$m_{\tilde{q}} \gtrsim 150$  (110) GeV, for *any* up (down) type squark.

Way out #2  
Interpretation

E



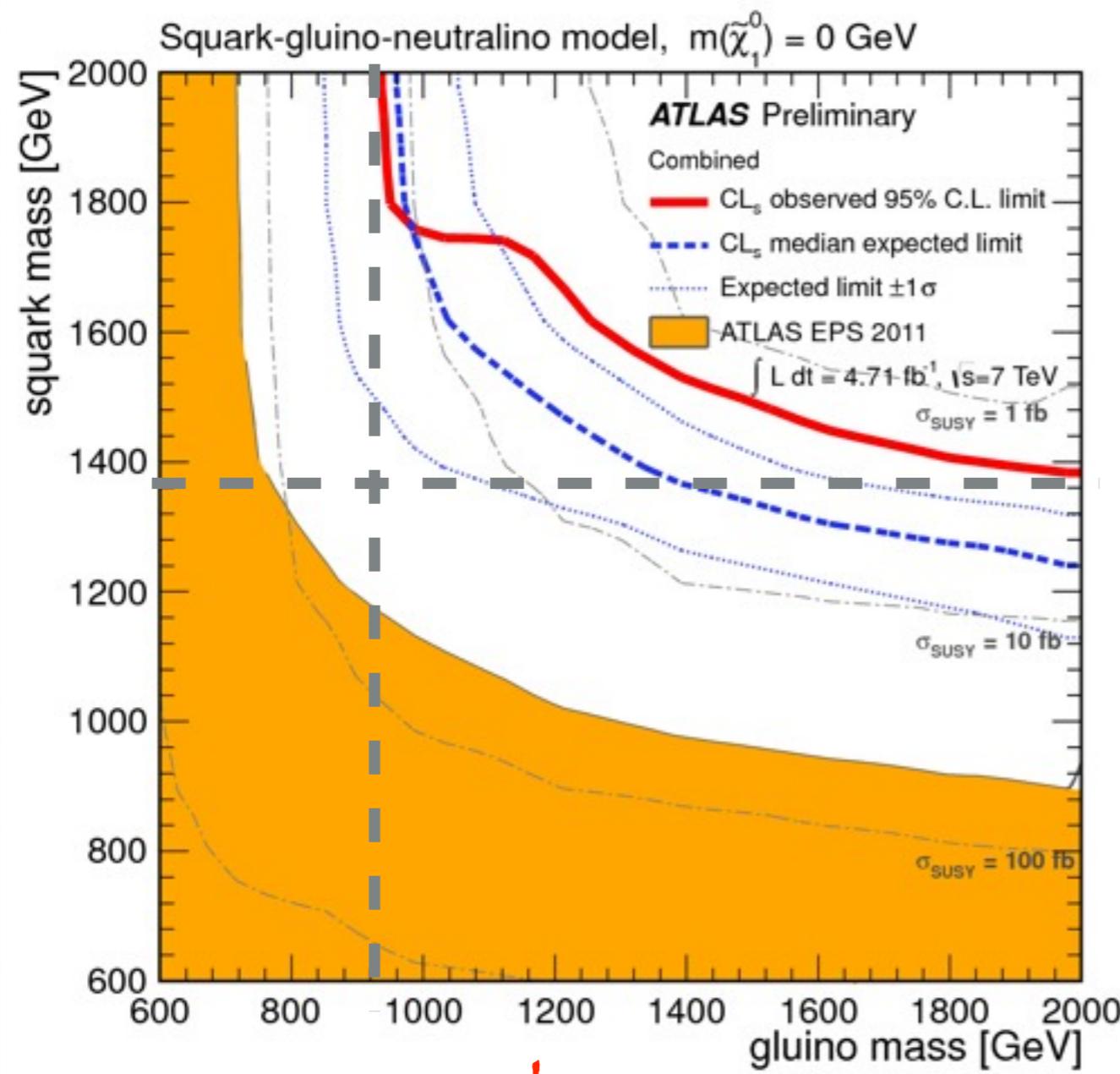
SUSY

~ TeV

EW

h, Z, W, t

# 1st and 2nd generation squarks



gluino

Key assumptions

Degenerate 1st-2nd

Wed Mahbubani

Fri Perez

Majorana gluinos

Heikinheimo, Kellerstein, VS.

1111.4322

Kribs, Martin. 1203.4821

# ATLAS jets+MET

arXiv:1109.6572 [hep-ex]

+lepton veto

Bin 1   Bin 2   Bins 3/4   Bin 5

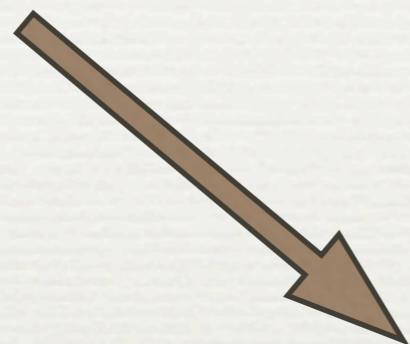
Signal Region	$\geq 2\text{-jet}$	$\geq 3\text{-jet}$	$\geq 4\text{-jet}$	High mass
$E_T^{\text{miss}}$	> 130	> 130	> 130	> 130
Leading jet $p_T$	> 130	> 130	> 130	> 130
Second jet $p_T$	> 40	> 40	> 40	> 80
Third jet $p_T$	–	> 40	> 40	> 80
Fourth jet $p_T$	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{\text{miss}})_{\text{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
$E_T^{\text{miss}}/m_{\text{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
$m_{\text{eff}}$	> 1000	> 1000	> 500/1000	> 1100

For each mass point, choose bin highest sensitivity

# What if gluinos are Dirac?

ATLAS jets+MET

arXiv:1109.6572 [hep-ex]



Theory analysis  
 $N=2$  in FeynRules

Parton level MG5+Bridge  
w/baseline cuts of ATLAS

Pythia v6.4

ATLFAST sim

analysis ROOT

Validate theory simulation w/MSSM simplified model

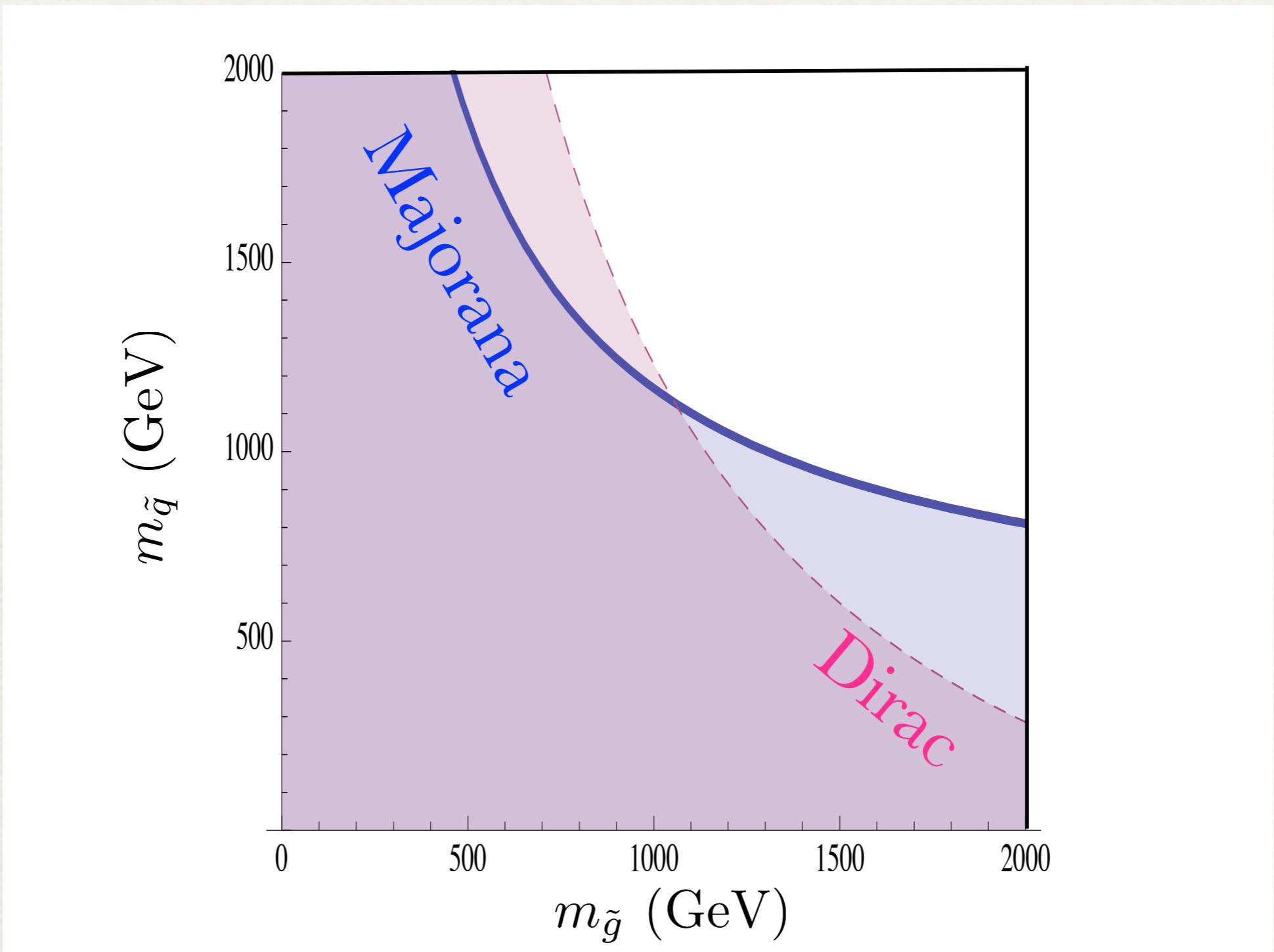
ATLAS paper: BG in each region and a limit of  
 $\sigma \cdot A \cdot \epsilon$  for each bin

use validation to obtain the bin w/ highest  
sensitivity for Majorana at each mass point  
= bin used for exclusion

estimate loss/gain sensitivity

Generate Dirac sample with same gluino mass,  
and vary squark mass to get the same number of  
events as Majorana

Effect: weaken the squark limit



Way out #3  
The stop exception



The stop saves  
the day!

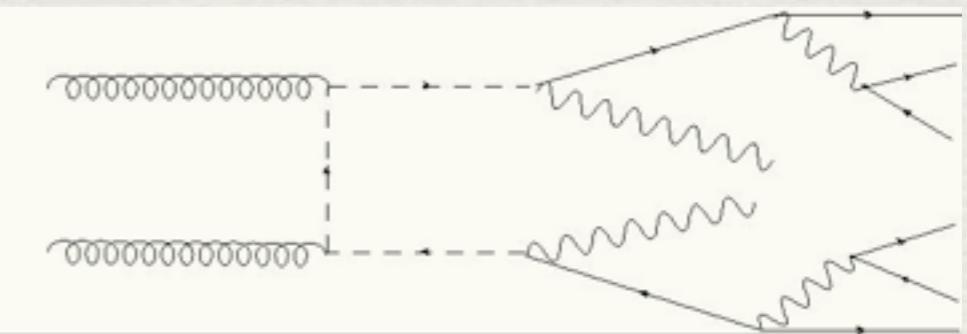
Stops could be light



The stop saves  
the day!

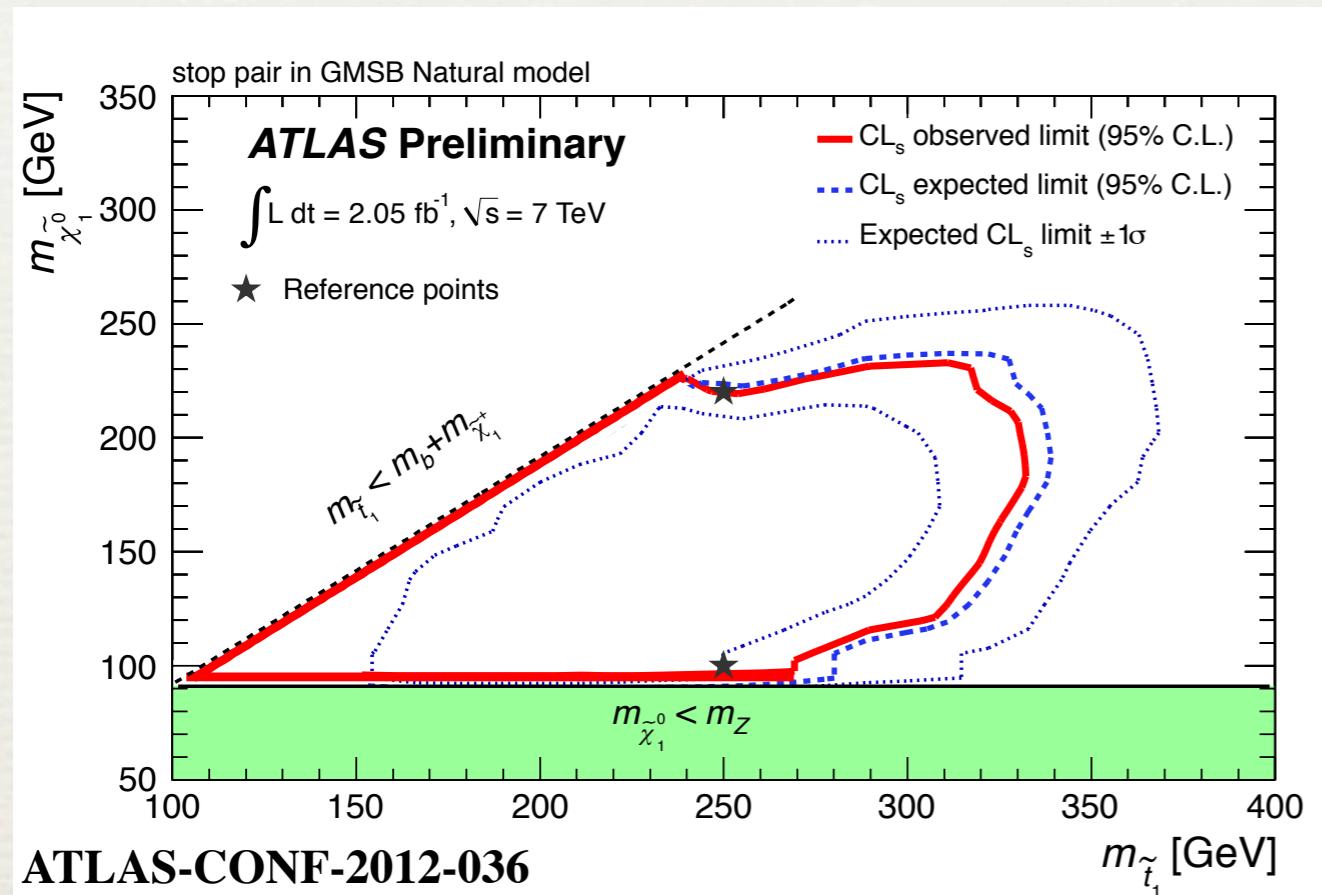
Stops could be light

stop searches are tough  
leptonic  $t\bar{t}$  + MET



looks a lot like  
leptonic  $t\bar{t}$

No stop direct production limits  
 searches on their way  
 Instead, gluino-assisted, leptonic-Z+MET...



**theory papers**

Bai, Cheng, Gallicchio, Gu. 1203.4813  
 Han, Katz, Khron and Reece. 1205.5808  
 Alves, Buckley, Fox, Lykken, Yu.  
 1205.5805  
 Kaplan, Rehermann, Stolarski. 1205.5816

How light could be the stop?  
 Monophoton: 150 GeV  
 but also sbottom searches

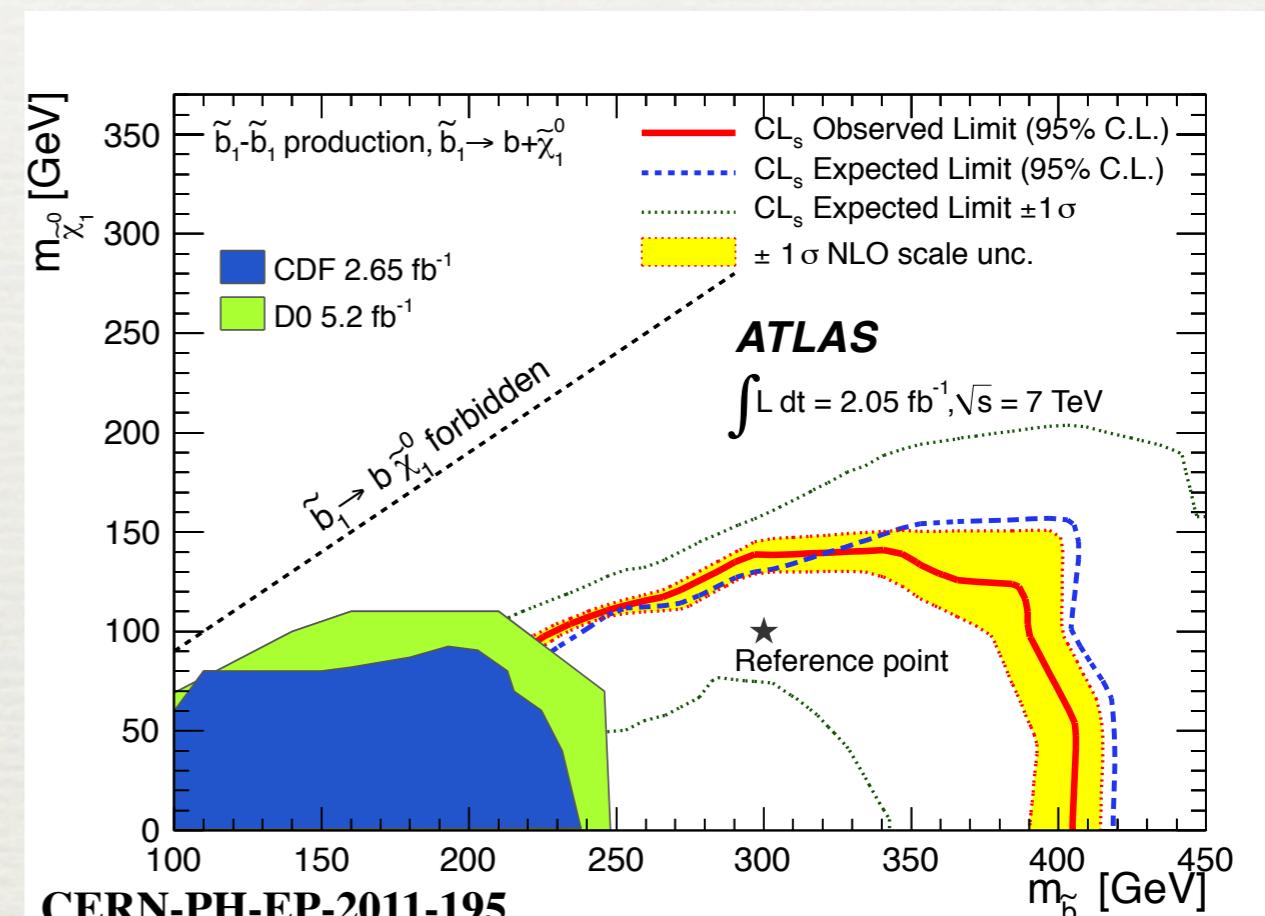
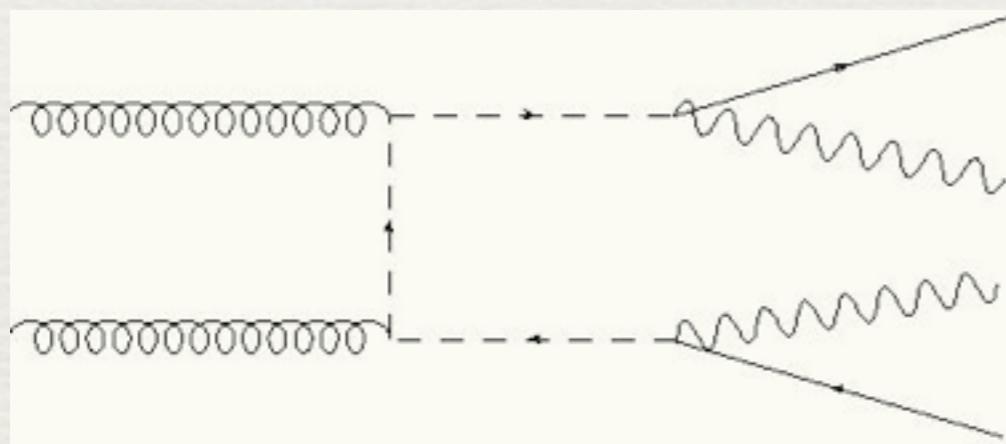


sbottom/stop  
splitting constrained  
by custodial  
symmetry

Min Lee, VS, Trott.  
1204.0802

# Sbottom searches are simpler, and underway

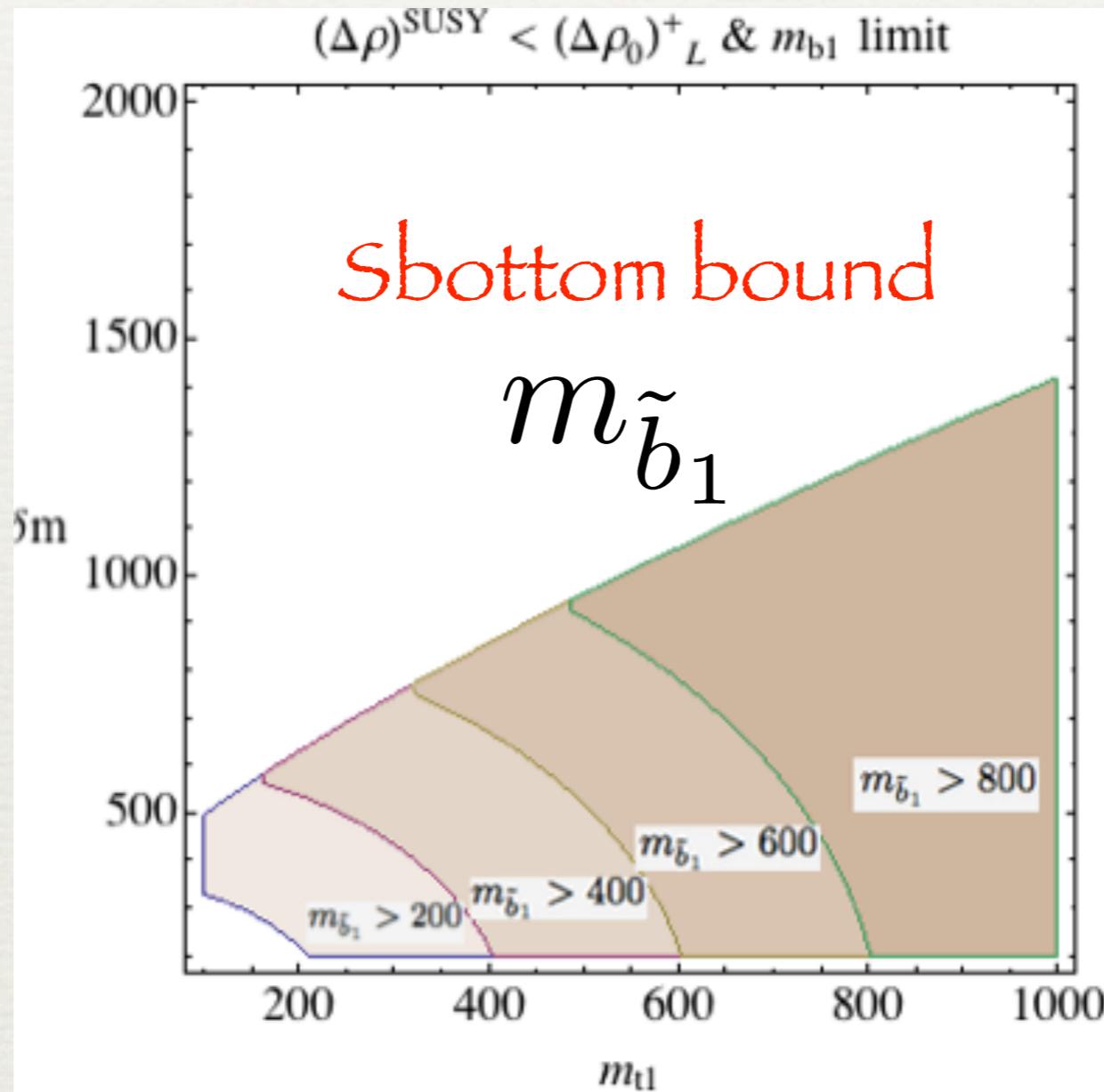
$$m_{\tilde{b}_1} \rightarrow (\theta_{\tilde{t}}, m_{\tilde{t}_1}, m_{\tilde{t}_2})$$



veto on leptons, no veto on extra-jets

ATLAS 1112.3832

$$\delta m = m_{\tilde{t}_2} - m_{\tilde{t}_1}$$

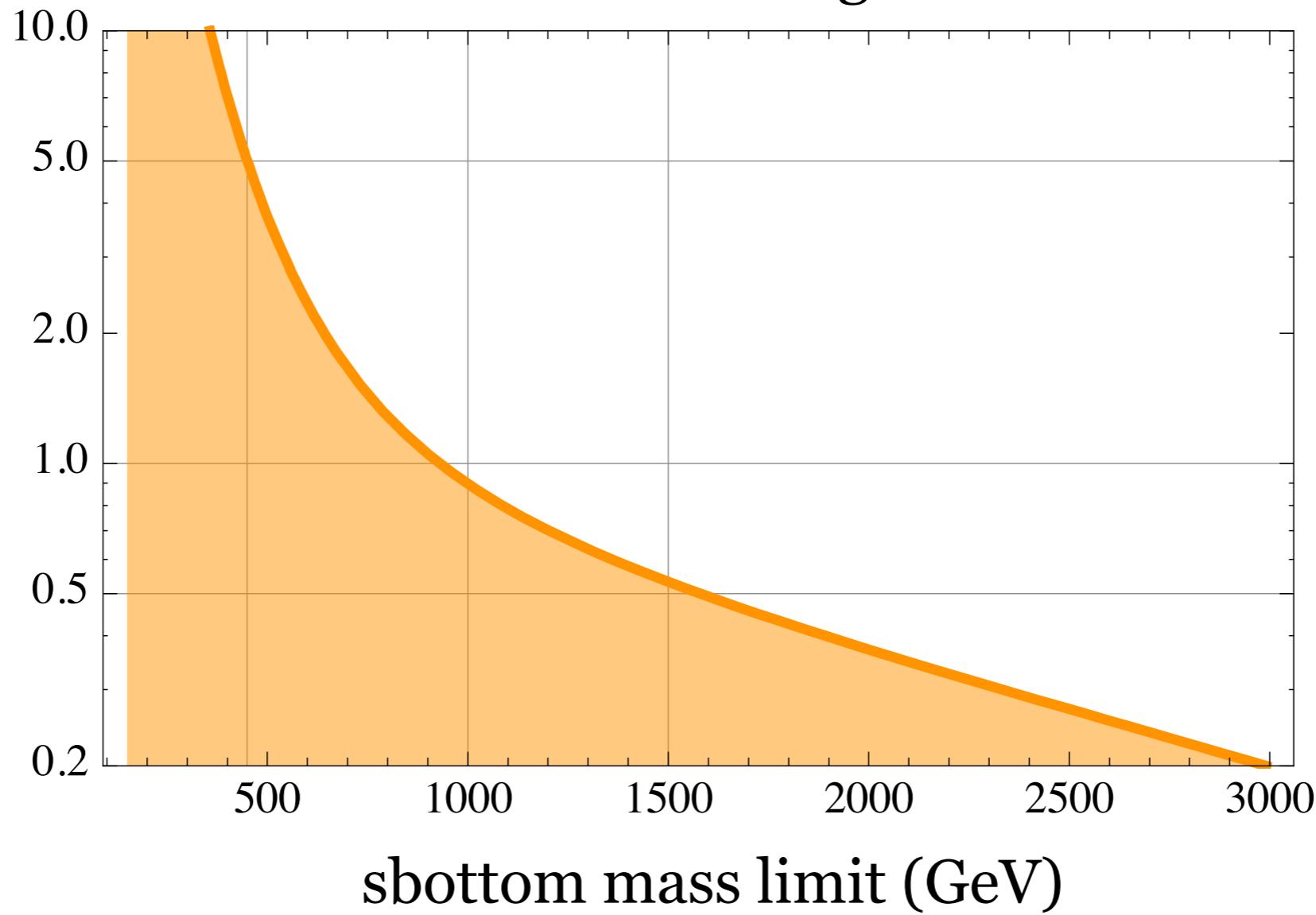


$m_{\tilde{t}_1}$

maximal mixing case

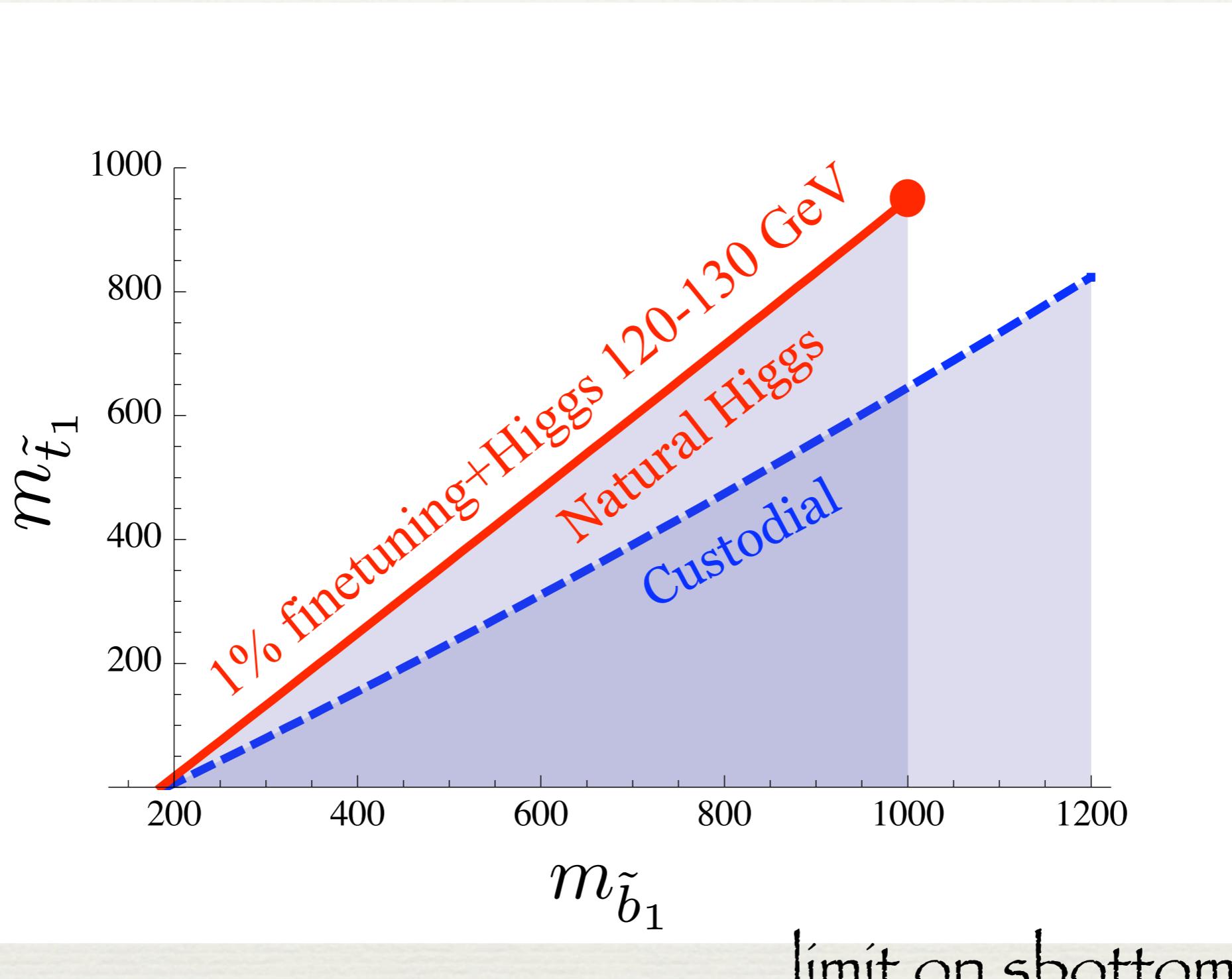
# Bound on sbottom: minimum amount of fine-tuning

Minimum amount of fine-tuning  
maximal mixing case



# In MSSM Higgs

derived limit on stop



# Conclusions

SUSY searches are broad and reaching far in the natural SUSY scenario

Null results in 2012 would disqualify SUSY as a natural solution to the hierarchy problem

We need to keep thinking on re-interpreting searches in a even broader range of scenarios (Dirac gluinos, compressed spectrum)

Stops are key to SUSY viability, and linked to existing sbottom searches

# Backup

