Gaugino physics at (V)LHC

Sunghoon Jung
KIAS

11/11/2013 @ 3rd KIAS pheno conference

S.Jung, J.D.Wells: To appear soon,
S.Gori, S.Jung, L.T.Wang: 1307.5952

- No SUSY particles have been found.
- Limits are about 1TeV for squarks and gluinos, weaker for stops, and even weaker for gauginos.
- Higgs at 125GeV, somewhat heavy for SUSY…
- Either heavy stops of 10TeV~10^8TeV, or large stop mixing needed (in minimal SUSY)…
- Large stop mixing (w light stops) may mean less tuning among mass parameters (consistent with SUSY limits), but model building not so simple.

- Along the growing pessimisms, split SUSY (or PeV-SUSY) becomes another popular candidate particle physic model of SUSY.
- Well-known features of split SUSY: heavy scalars and light fermions.
- Admits that Higgs mass is somewhat fine tuned with very heavy stops.
- Easily no signal so far.
- No scalar-induced pheno issues — flavor, CP.
- Keeping good SUSY properties — unification, DM.

- Interestingly, a half of universe maybe generically split SUSY-like.
- Charged SUSY breaking leads to it.
- Gaugino masses are typically AMSB-induced, loop suppressed.

$$S = S + \sqrt{2}\psi\theta + F_S\theta^2$$

$$\int d^2\theta \frac{S}{M_{\rm Pl}}\mathcal{W}\mathcal{W} \to \frac{F_S}{M_{\rm Pl}}\lambda\lambda. \qquad \int d^2\theta d^2\bar{\theta}\frac{S^\dagger S}{M_{\rm Pl}^2}\Phi_i^\dagger\Phi_i \to \frac{F_S^\dagger F_S}{M_{\rm Pl}^2}\phi_i^*\phi_i.$$

$$m_\lambda^2 = \frac{F_s^2}{M_{Pl}^2} \quad \sim \quad m_\phi^2 = \frac{F_s^2}{M_{Pl}^2} \sim m_{3/2}^2$$

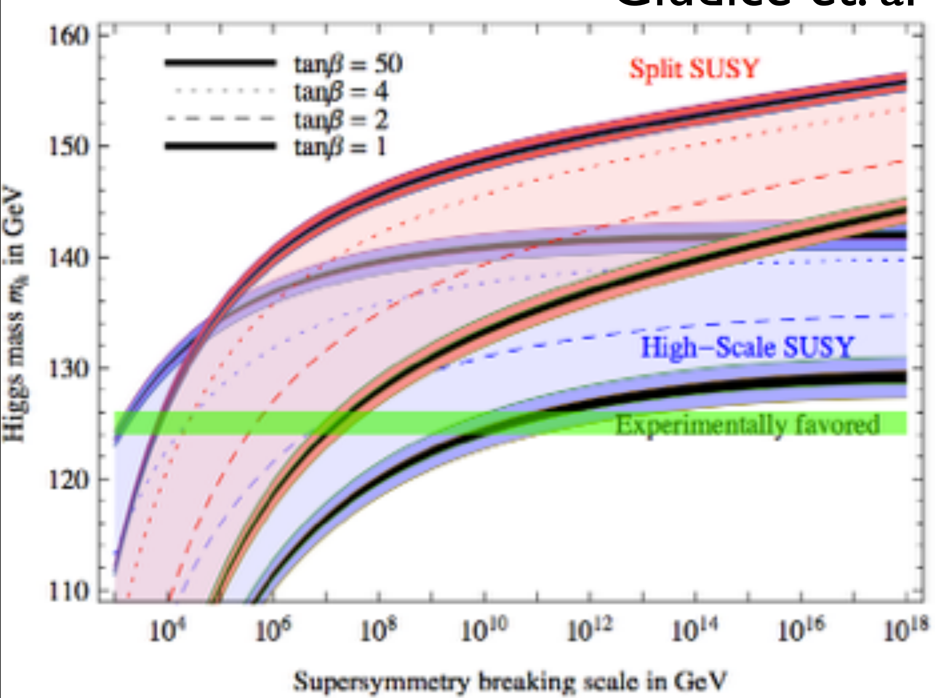
$$m_\lambda = \frac{\beta(g_\lambda)}{g_\lambda} m_{3/2}$$

- Importantly, split SUSY is NOT an arbitrarily heavy version of weak-scale SUSY.

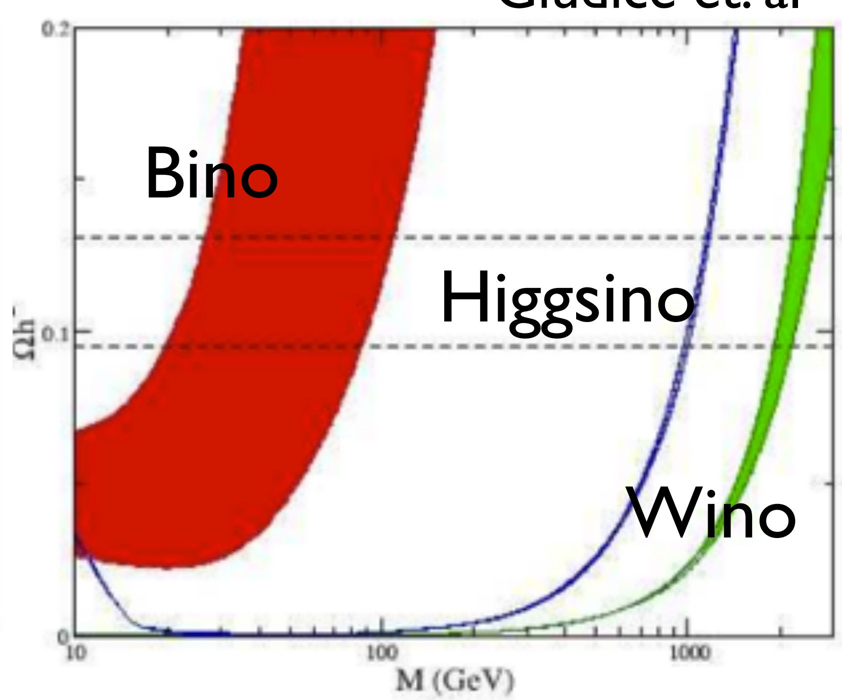
- Too heavy squarks, gluinos and stops induce too heavy Higgs.

- Too heavy LSPs will likely remain too much by now in cosmological history. (Wino<3.1TeV, Higgsino<1TeV)

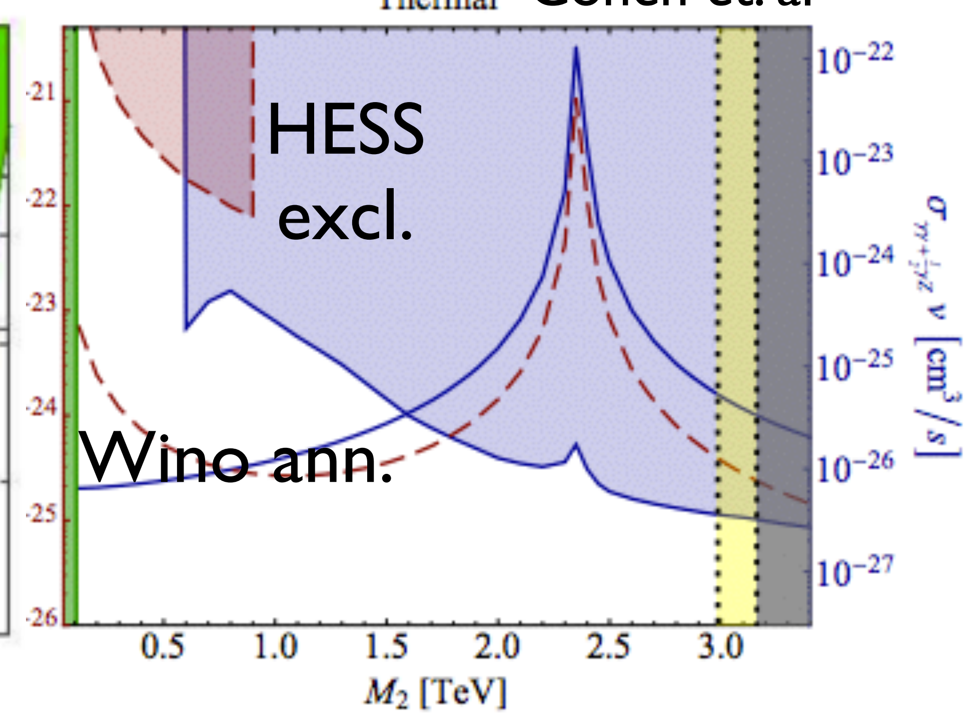
Giudice et. al



Giudice et. al



Cohen et. al



- Given those upper bounds on gaugino/higgsino masses,
- What do we really need to test split SUSY scenario? What shall we improve?
    - (which channel, what energy, luminosity, and which collider, which variable and correlations…?)

In a simplest
AMSB split scenario
without Higgsinos,

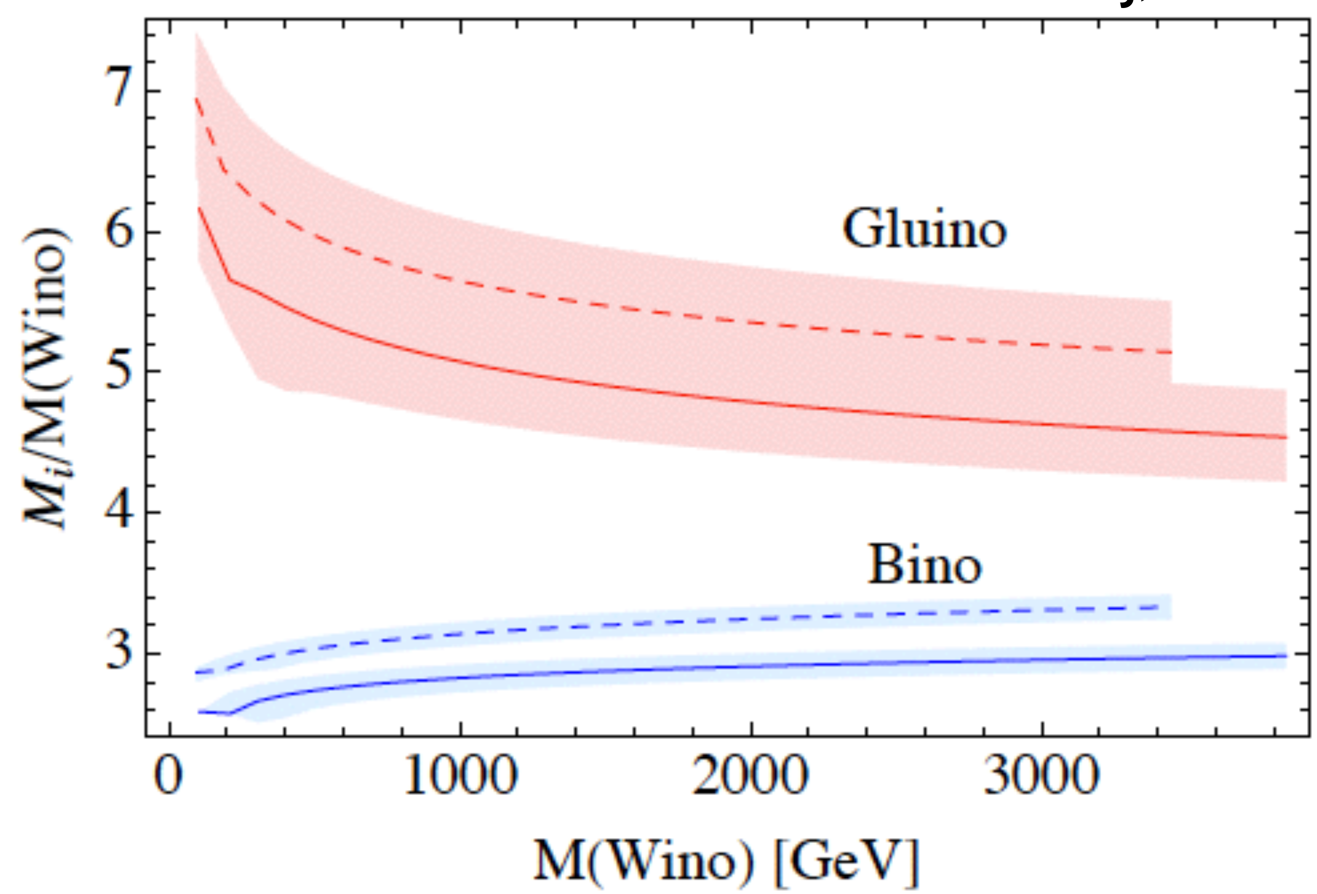
Squarks, sleptons,
higgsinos
heavy decoupled

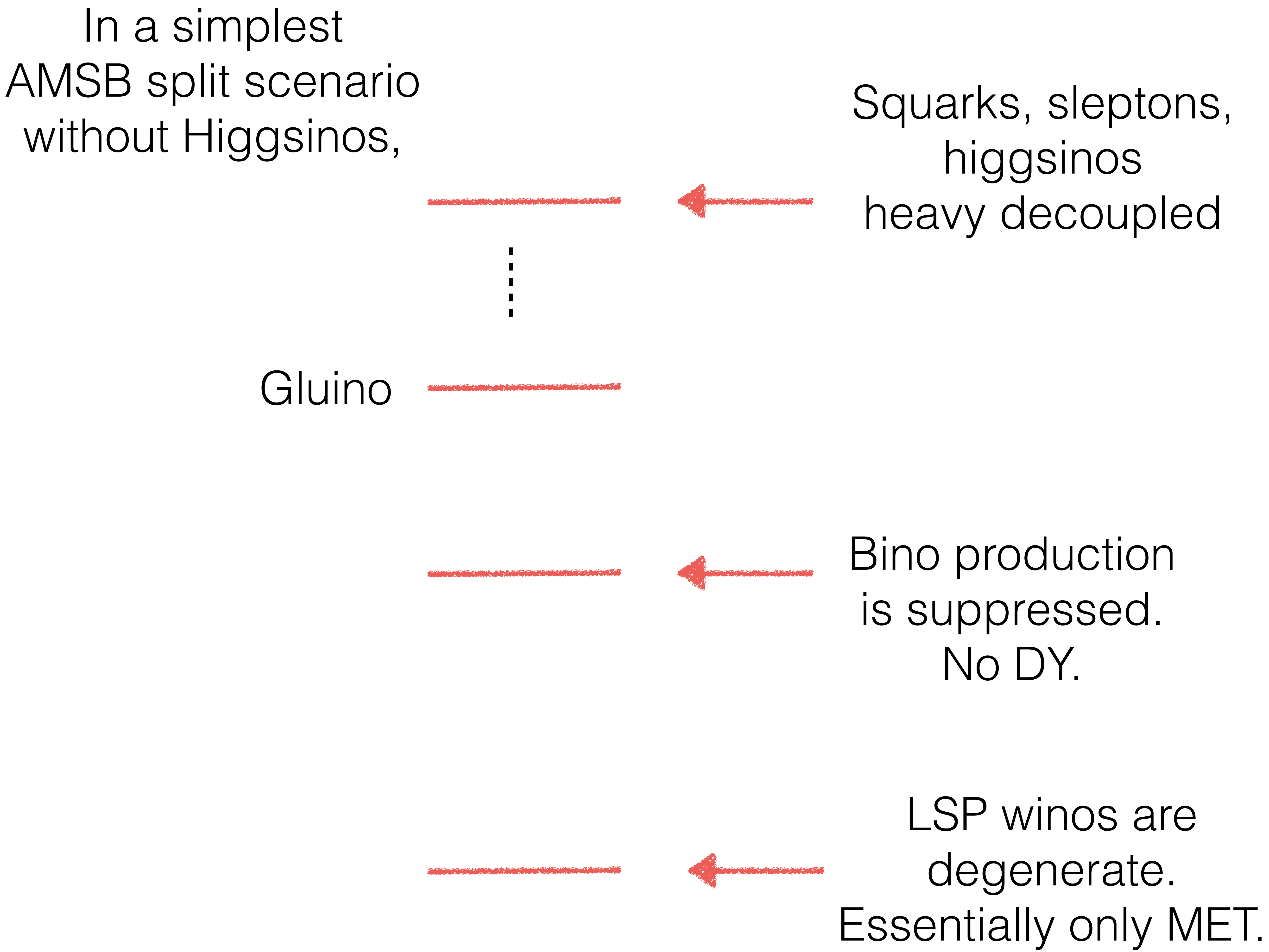
Gluino

NLSP bino

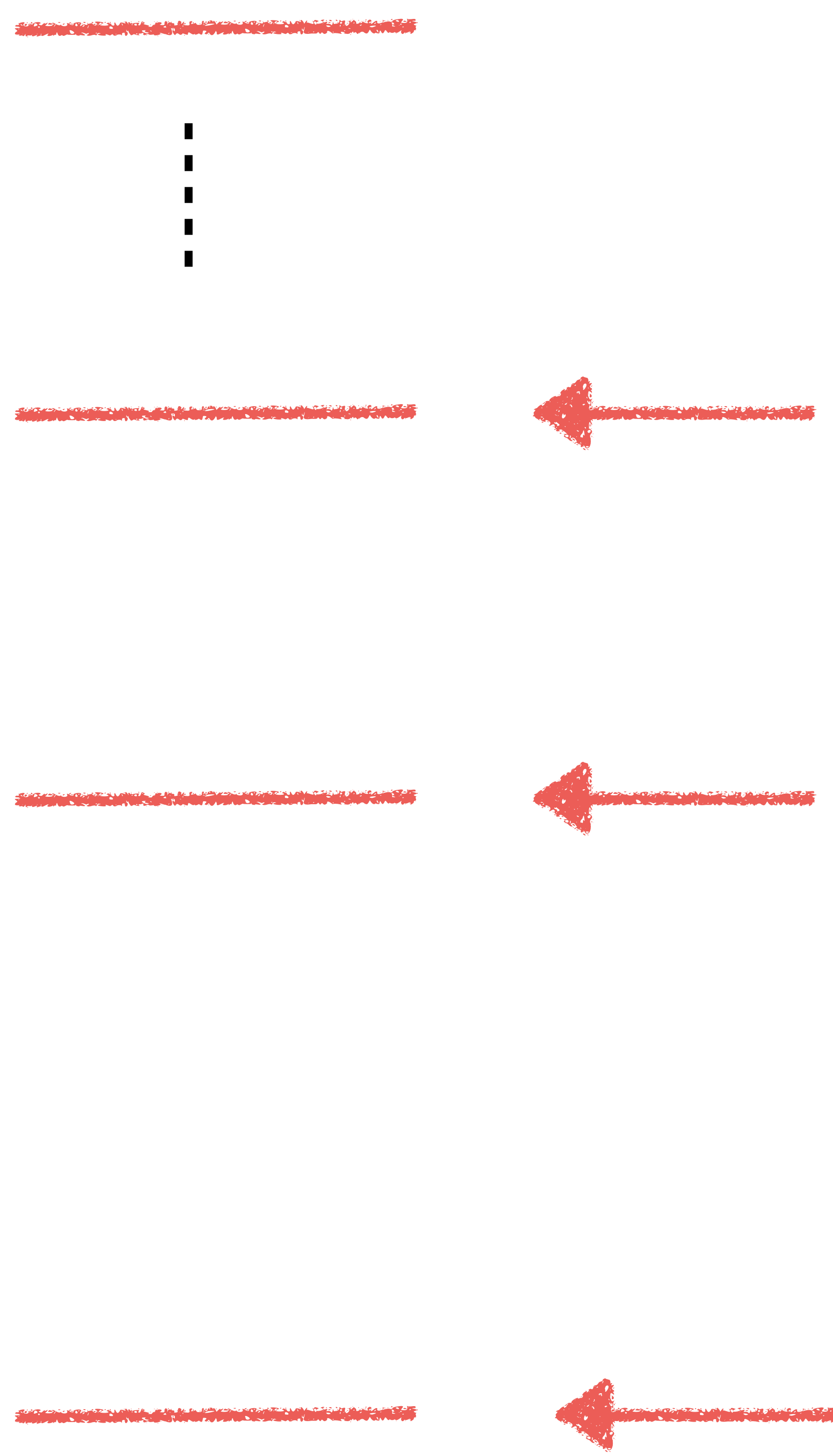
LSP wino

SJ,Wells




In a simplest
AMSB split scenario
without Higgsinos,
Squarks, sleptons,
higgsinos
heavy decoupled
Gluino
Bino production
is suppressed.
No DY.
LSP winos are
degenerate.
Essentially only MET.

In a simplest AMSB split scenario without Higgsinos,

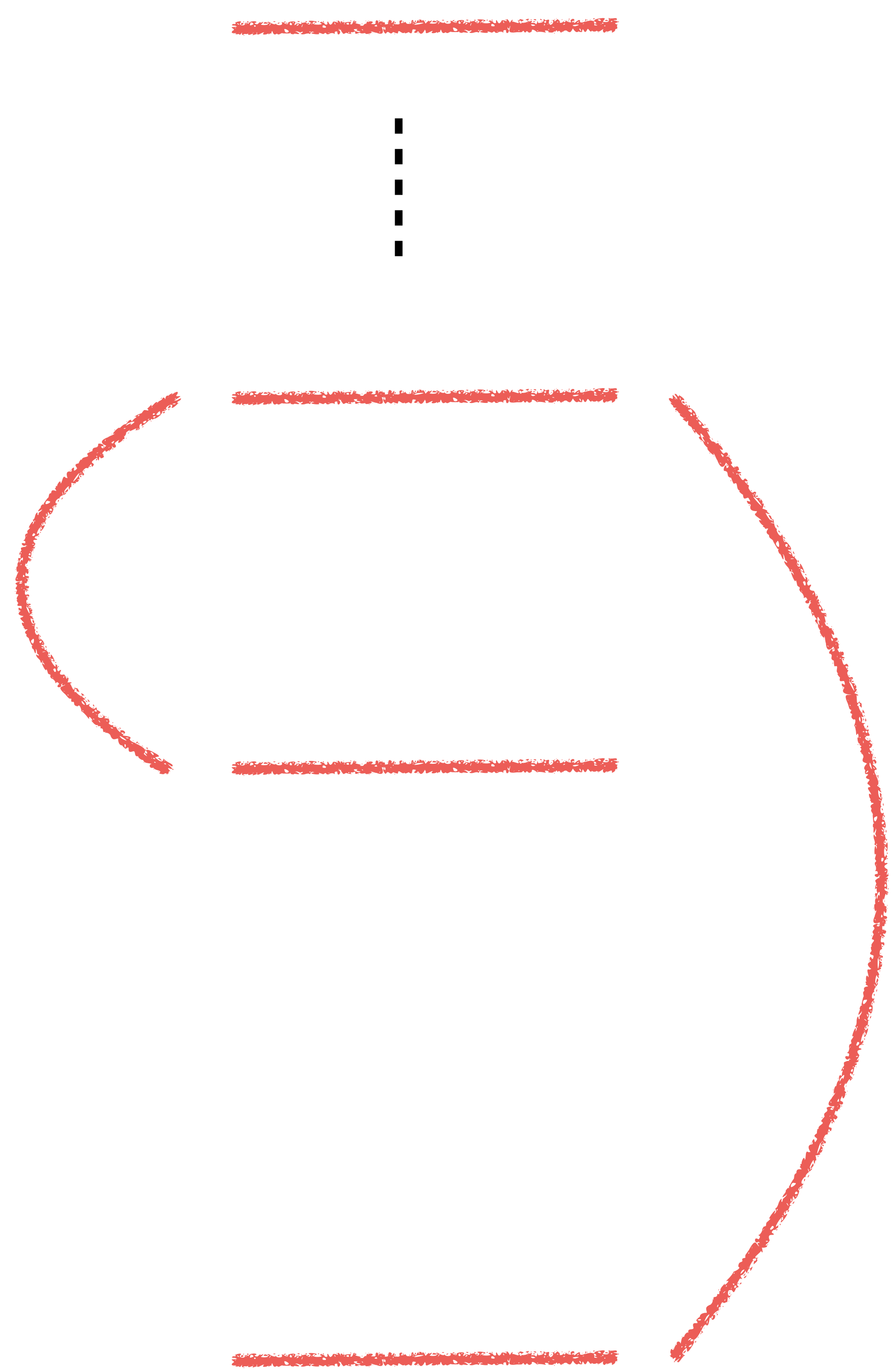


Gluino pair production maybe the only viable discovery channel.

Bino production is suppressed. No DY.

LSP winos are degenerate. Essentially only MET.

In a simplest AMSB split scenario without Higgsinos,



gluino decay

Bino much heavier, less multiplicities than winos.

Gluino almost always decay directly to LSP winos:

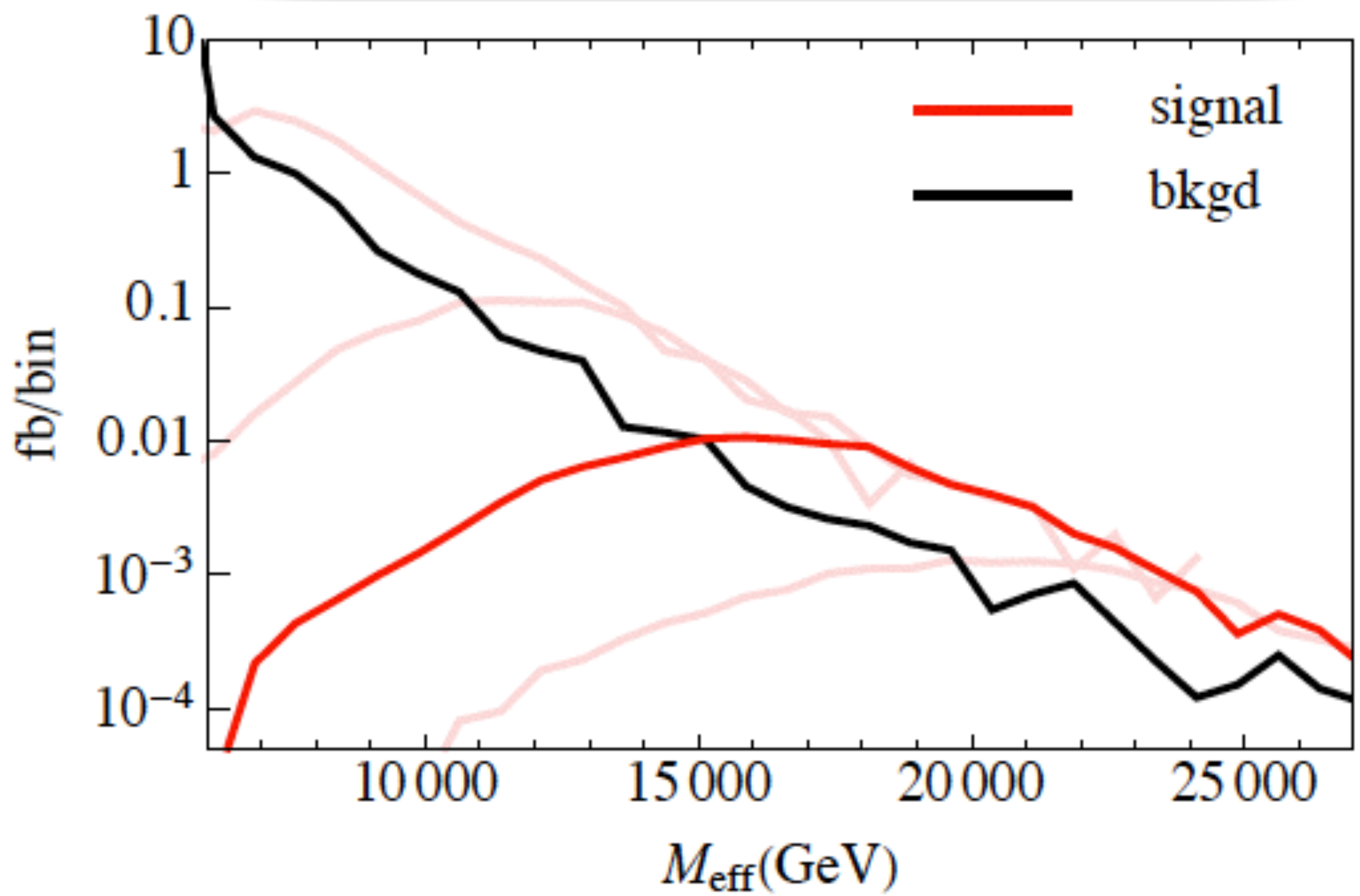
$$\tilde{g} \to \chi_1 q\bar{q}.$$

SJ, Wells

$$\tilde{g}\tilde{g} \to qqqq + MET$$

- Gluino pair production leads to "four quarks + MET".
- Traditional Meff (measuring hardness) variable works.

$$M_{eff} = \sum_i p_T(i) + E_T^{\text{miss}}$$

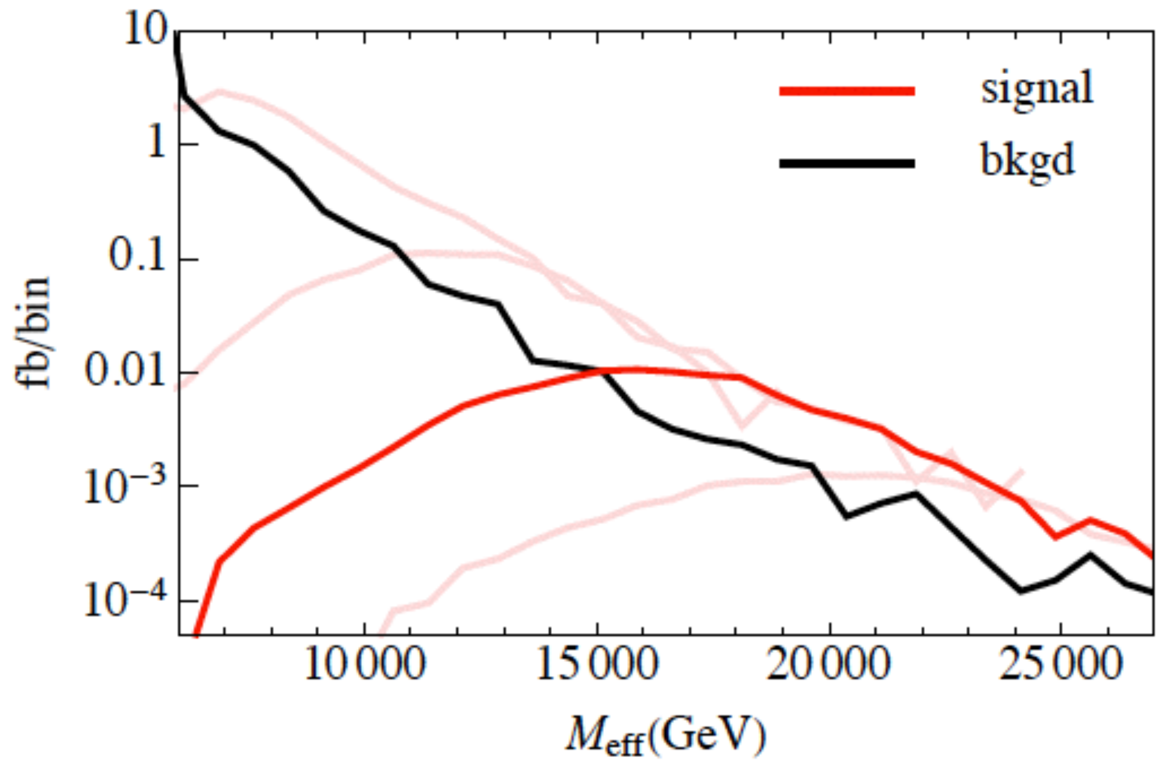


Gluino has just right mass and production rate for Meff to work!

- Peak location scales linearly with gluino mass.

$$M_{eff} = cM_{\tilde{g}}, \quad c \sim 1.5 - 1.7$$

- Gluino mass measurement?
- Known from a while ago by scanning mSUGRA models.
- Valid as long as gluino/LSP mass ratio > 3.



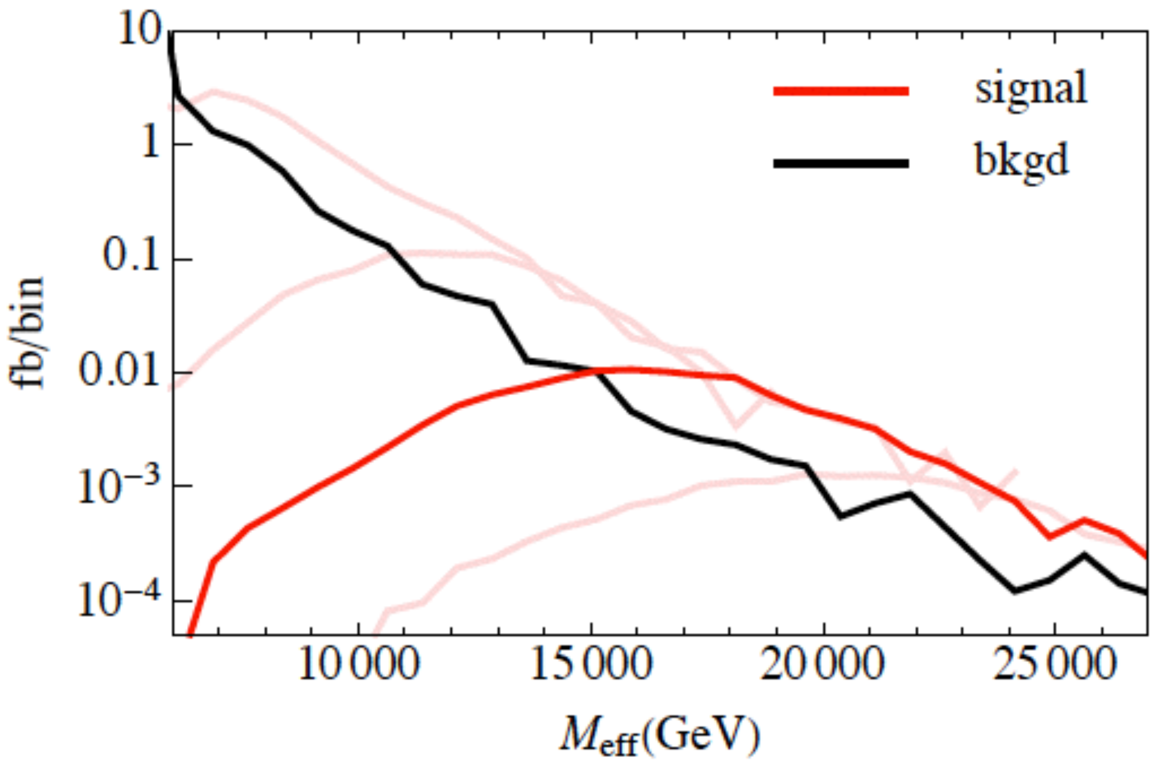
- We also observe that S/B is constant over range of gluino mass and collision energy.

- The simple scaling rule of the discovery reach.

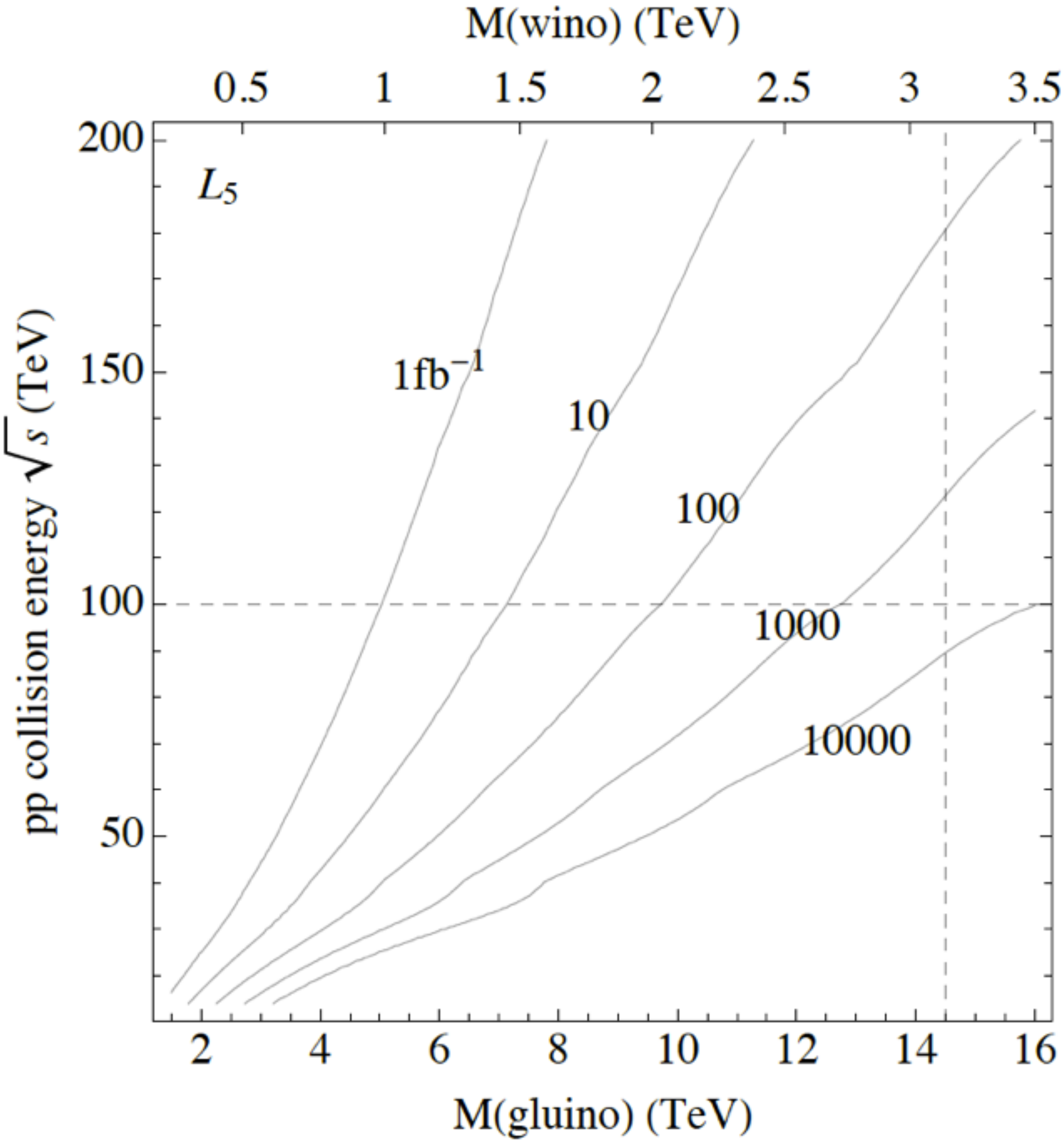
$$\frac{\sigma_i}{\sigma_j} = \sqrt{\frac{\sigma_{Si}\mathcal{L}_i}{\sigma_{Sj}\mathcal{L}_j}}$$

- Not always true. Same validity range.

- Very useful. No need to repeat numerical analysis for each parameter space.



SJ, Wells



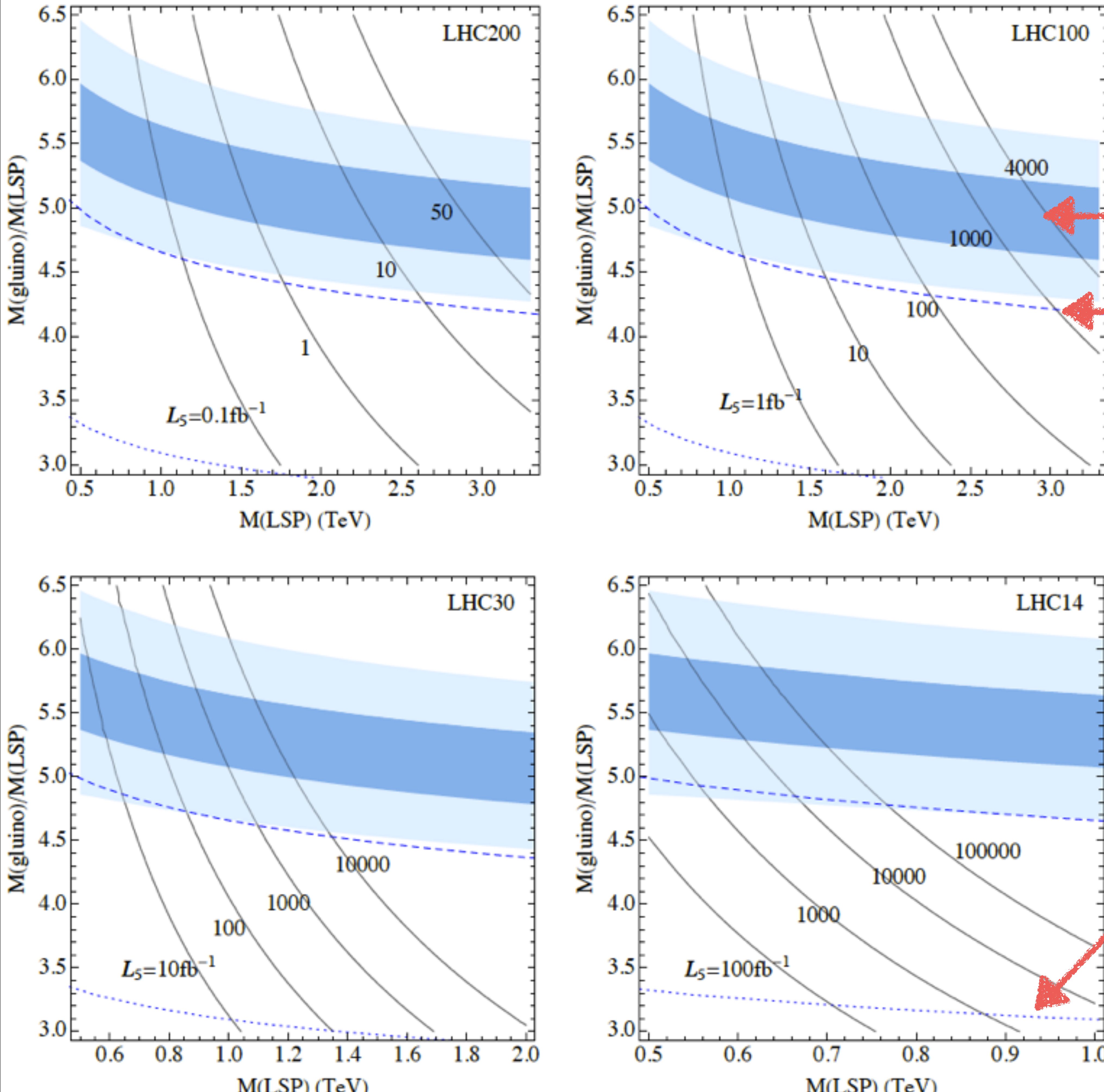
$$\frac{\sigma_i}{\sigma_j} = \sqrt{\frac{\sigma_{Si}\mathcal{L}_i}{\sigma_{Sj}\mathcal{L}_j}}$$

- Generalize spectrum by allowing higgsinos, different LSP, and variable mass ratio..

- Two-step decay via NLSP opens. Still, the majority of gluino pair (70-90%) lead to multi-jet (no lepton) final states.

- Meff still work! Similar discovery reach applies as long as gauginos and higgsinos are well-separated in mass.

SJ, Wells



$$M_i \propto \frac{b_i \alpha_i}{4\pi}\Lambda$$

NLO AMSB

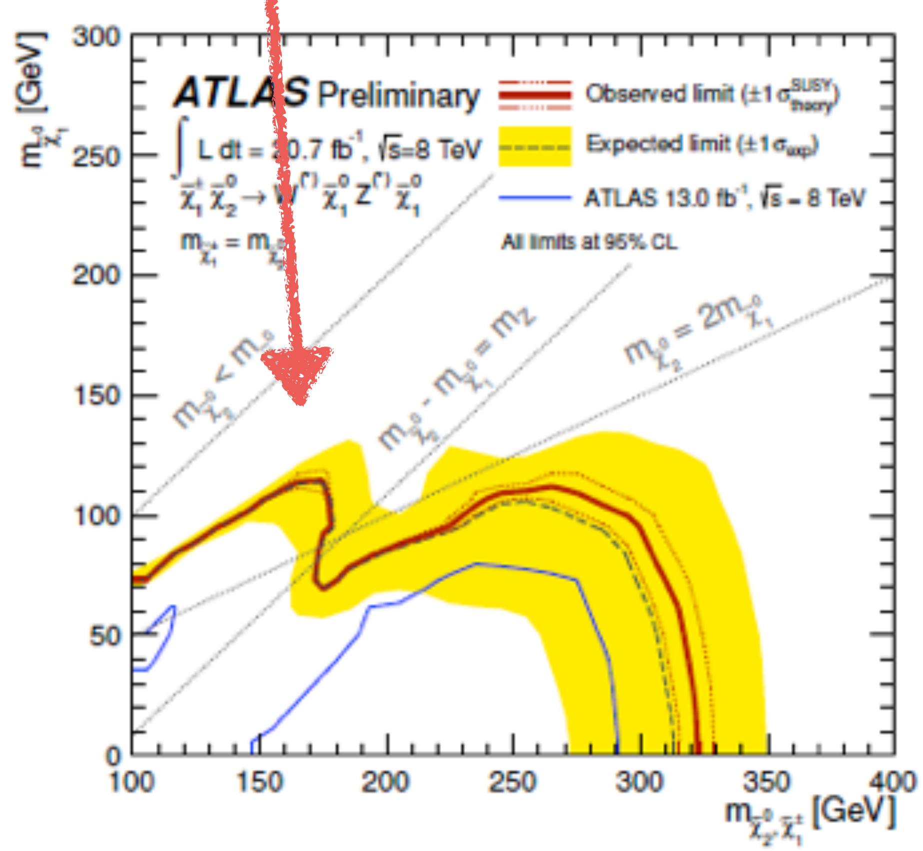
NLO mSUGRA

$$M_i \propto \frac{\alpha_i}{4\pi}\Lambda$$

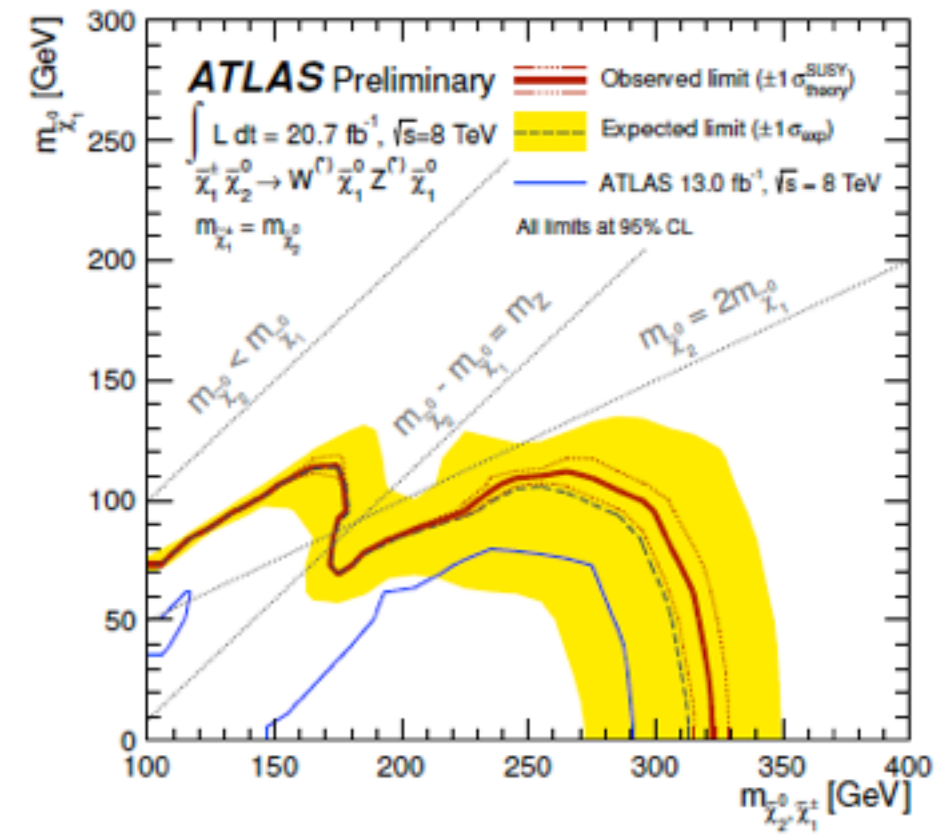
NLO mirage (alpha=0.5)

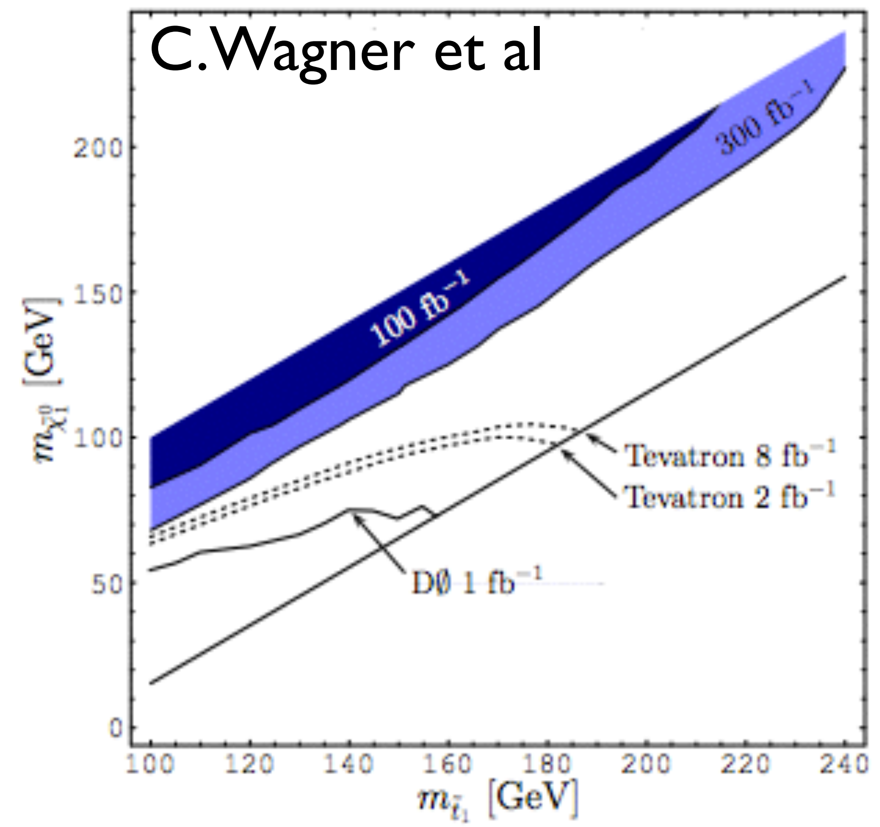
$$M_i \propto \alpha_i (1 + b_i \alpha)\Lambda$$

- So far, we have discussed TeV-scale heavy gaugino/higgsino physics.
- Light gauginos… Typical blind spot —compressed spectrum— remains. Maybe we can just wait for (much) more data, more channels to open…
- Or, we can try to improve!
- Second part of my talk…



- Mono-jet +MET or mono-photon +MET are widely studied.
- Stoponium useful, but wimponium not.
- Monojet work for very small-gap region. What about moderate gap?
- Rejecting boosted (visible) leptons maybe too much waste of signal.
- We attempt to use boosted leptons (and boost correlations)…

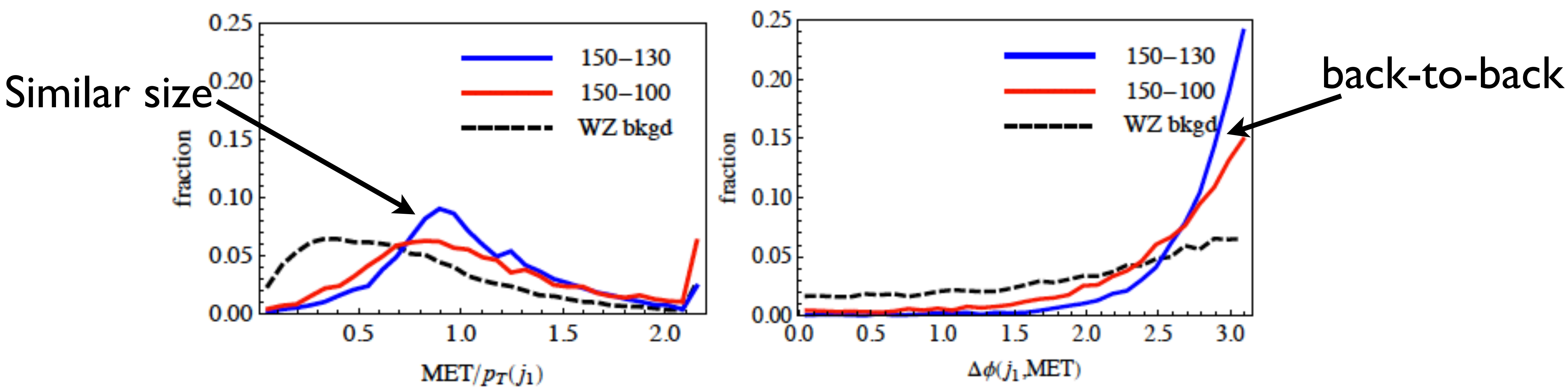




Gori, SJ, Wang

Correlations: MET and ISR

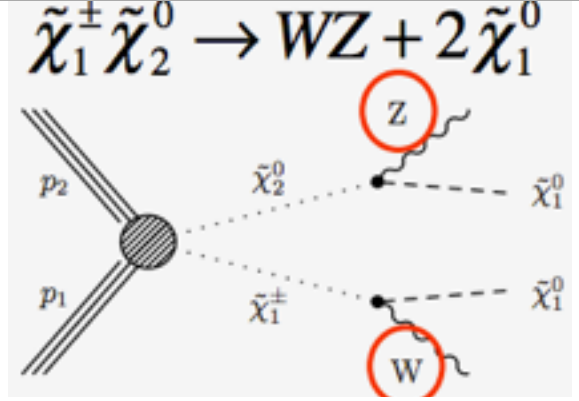
- Large MET in the signal arises only by recoiling against hard ISR. By momentum conservation, the sizes and the directions of MET and pT(ISR) are correlated.



- NB: For WZ bkgd (dominant), single neutrino produces MET, and correlation is different.

Gori, SJ, Wang

Leptons under boost

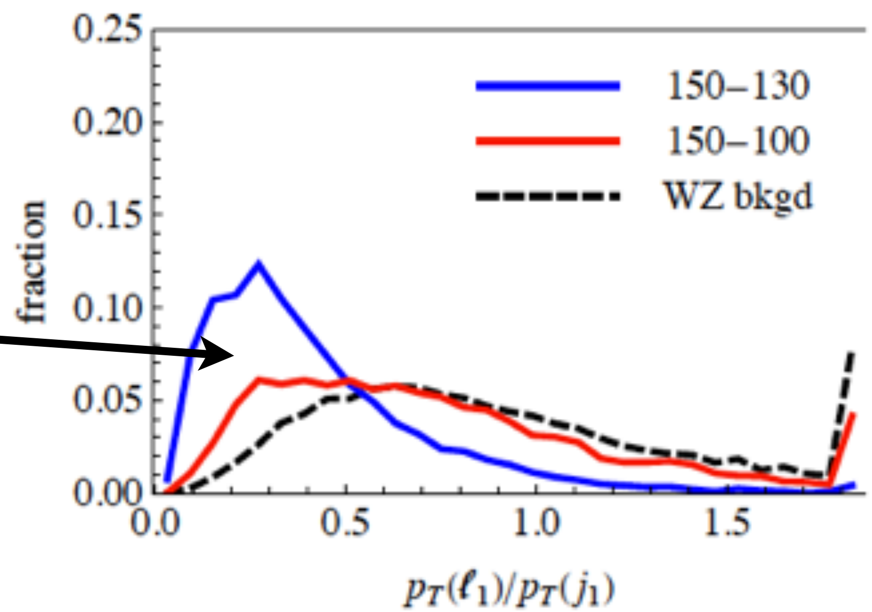


- Leptons are soft at first. How are they boosted?
- The ratio variable pT(lep)/pT(ISR) measures how.
- For given pT(ISR), signal system is heavier and less boosted (wrt ISR).

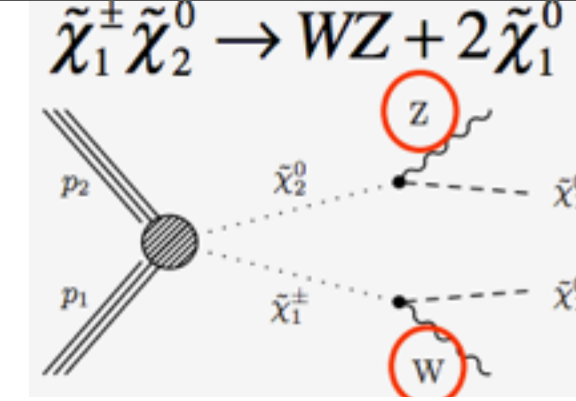
$$p_T(\ell) \sim \gamma E_\ell^0, \qquad \gamma \sim \frac{\sqrt{p_T^2(j_1)/4 + M^2}}{M}.$$

$$M = m(\chi_{\rm NLSP}) \qquad M = m_{\rm W/Z} \qquad m(\chi_{\rm NLSP}) > m_{\rm W/Z}$$

Signal leptons tend to stay soft wrt ISR.



Gori, SJ, Wang

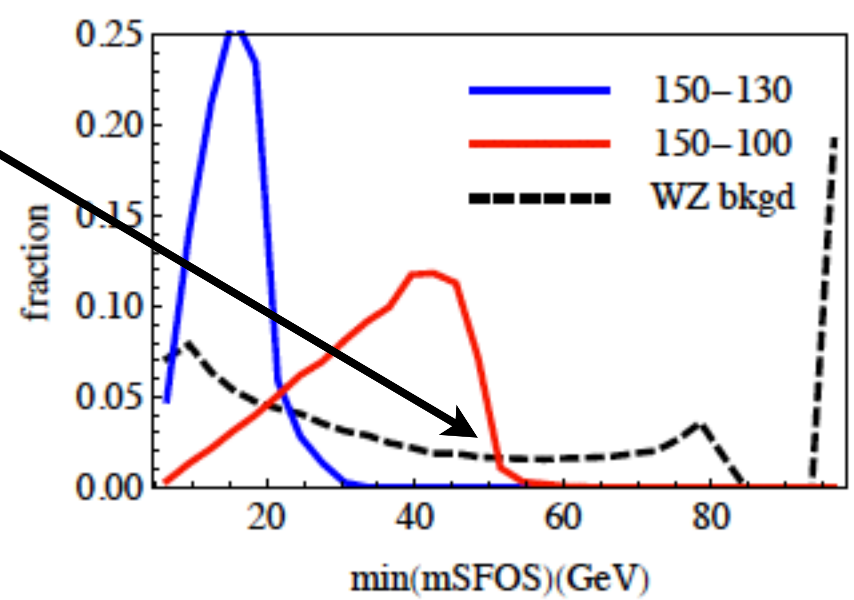


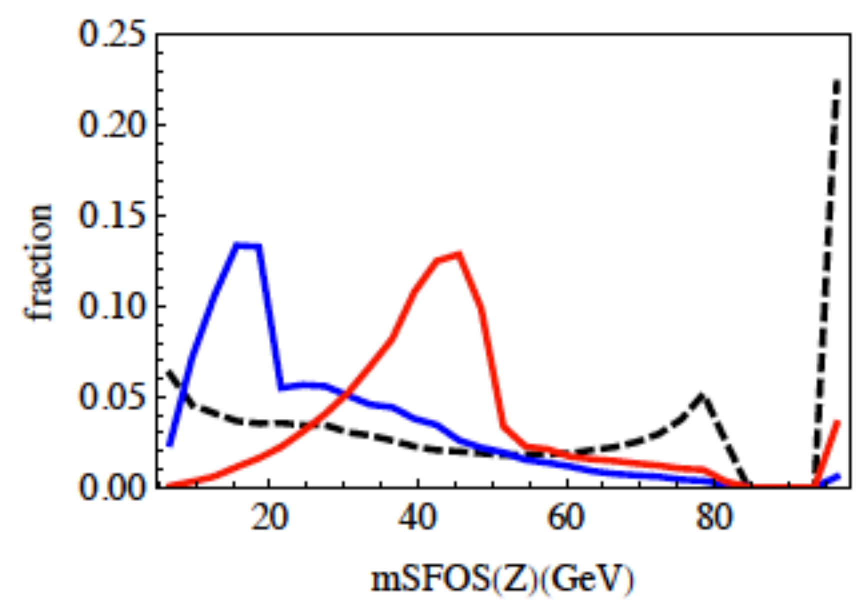
Lepton invariant masses

- Correct SFOS pair is useful discriminator: from on-shell Z(WZ bkgs) or off-shell Z(compressed signal).
- If there are two possible SFOS pair, how to pick a right one? mSFOS(Z)'s been used for bkgd.
- New "min(mSFOS)" works well for signal pairs rejecting bkgd additionally. Correct pair has kinematically limited inv. mass.

$$m_{SFOS} \lesssim m_{\chi_2} - m_{\chi_1}$$

clear edge





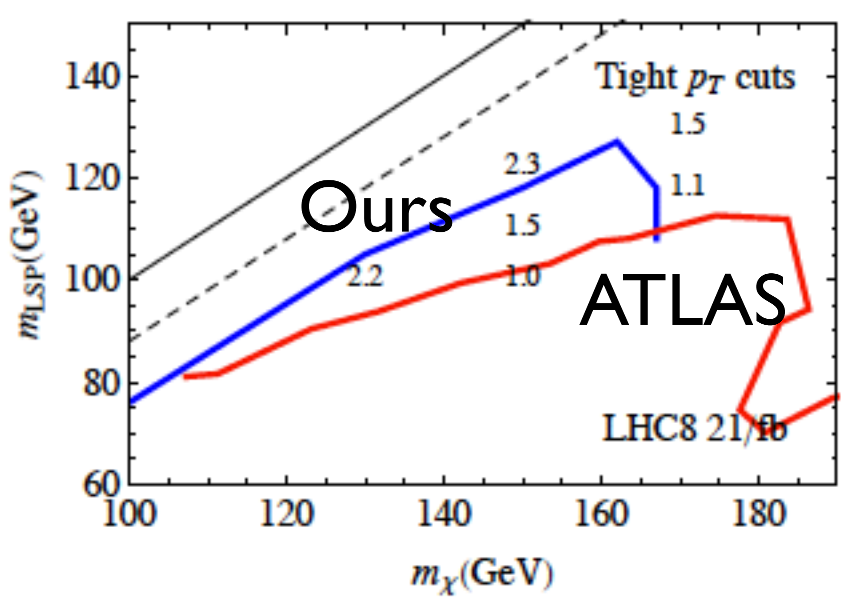
ordinary variable has blurred edge.

Gori, SJ, Wang

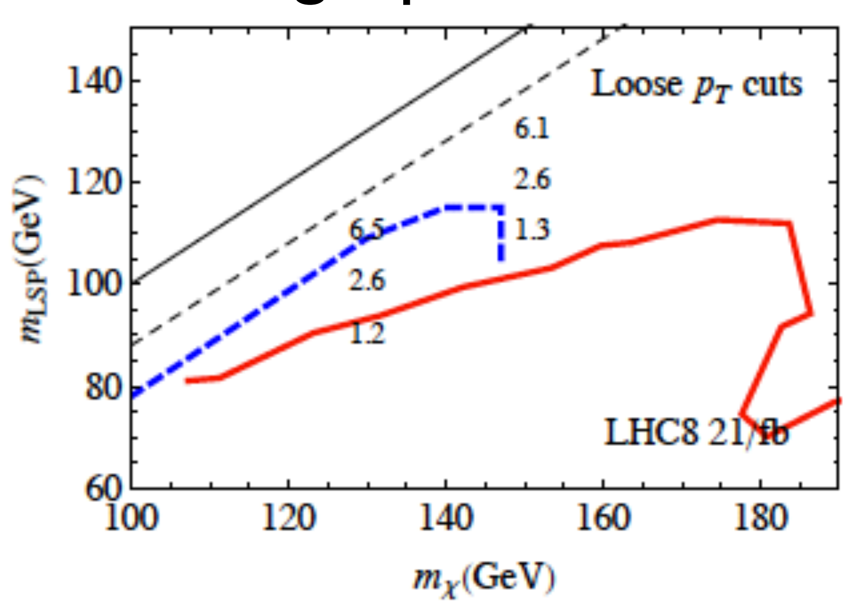
LHC8,14 prospect

- Lepton pT threshold and low-mass hadronic resonance bkgd are main obstacles.
- LHC14 is expected to reach ~320GeV with 300/fb.

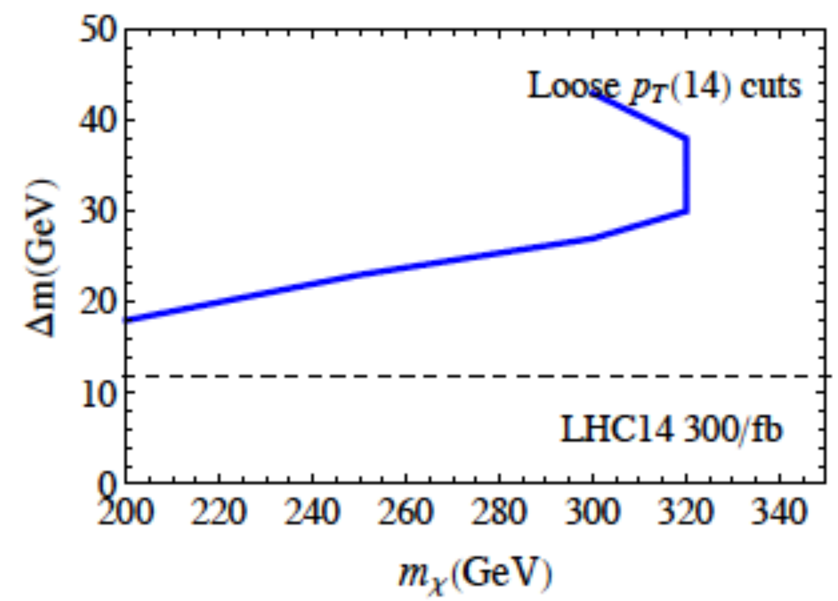
Standard improved



Relaxing lepton threshold



LHC14



Summary and conclusion

- Given Higgs mass at 125GeV, no detection of SUSY particles so far may not be so surprising.
- Some models may predict SUSY just behind current reach…
- In large model space, given current thy and exp situations, gaugino physics is an important way to go.
- Anywhere from just behind to multi-TeV seems possible.

- In split scenario, Gluino pair production maybe most useful channel. Simple Meff variable works.

- Gluino/LSP mass ratio is a crucial factor both for discovery and the test of SUSY breaking mediation model.

- For AMSB, LHC30 may reach about 1TeV higgsino LSP, LHC100 can cover whole 3.1TeV wino LSP case.

- Boosted leptons, correlations and new invariant mass can improve moderately small-gap region.