Gluino reach and mass extraction at the LHC in radiatively-driven natural SUSY

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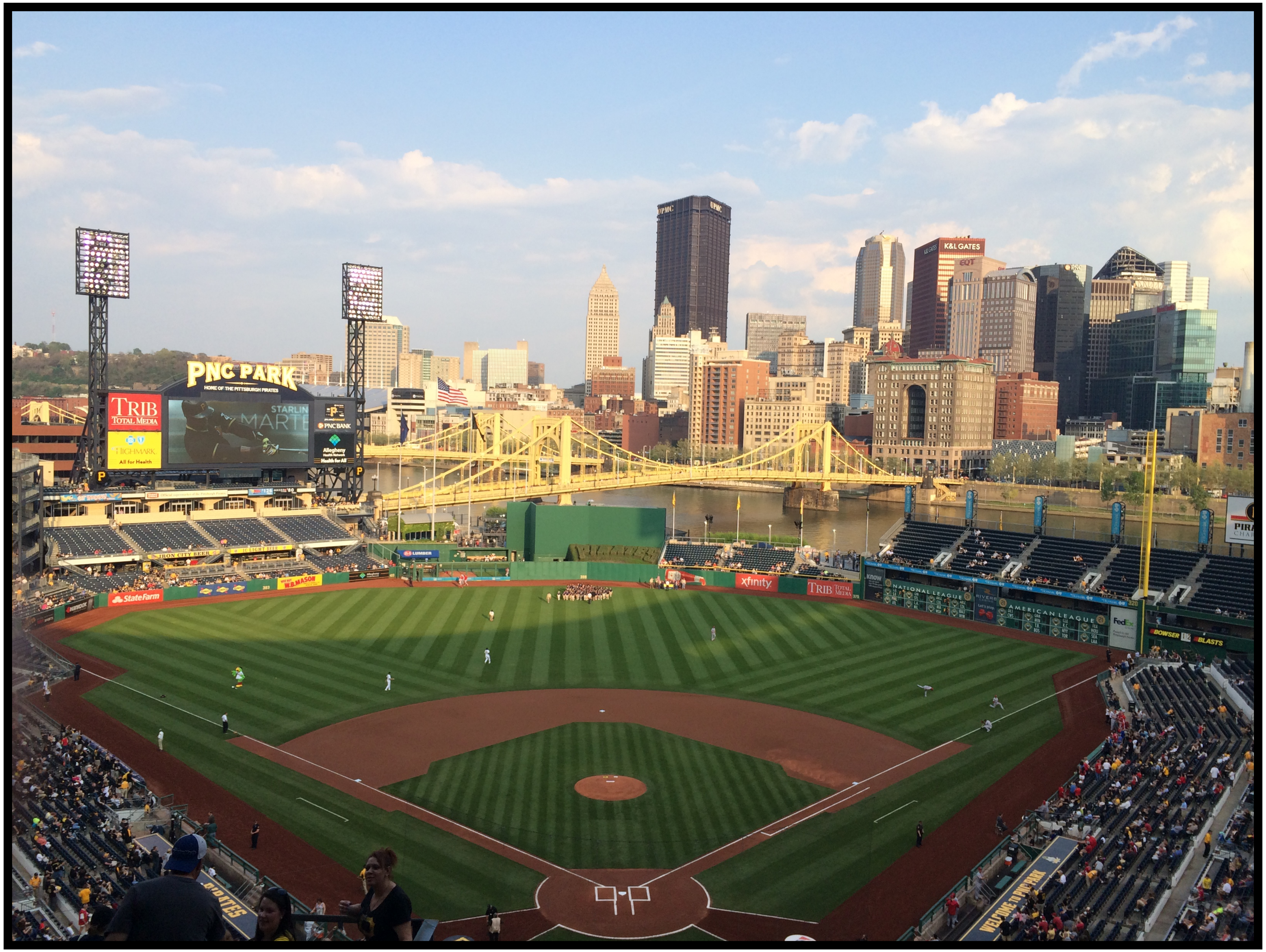
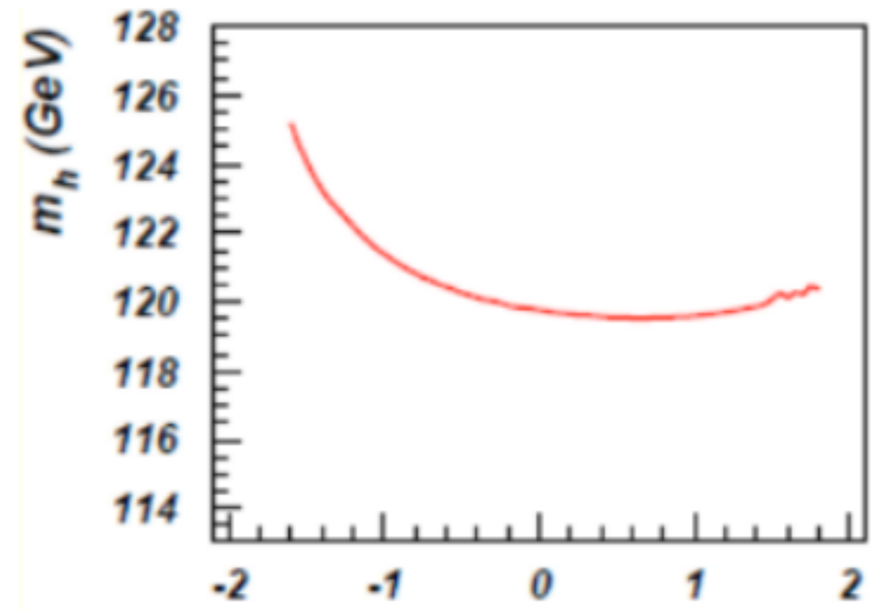


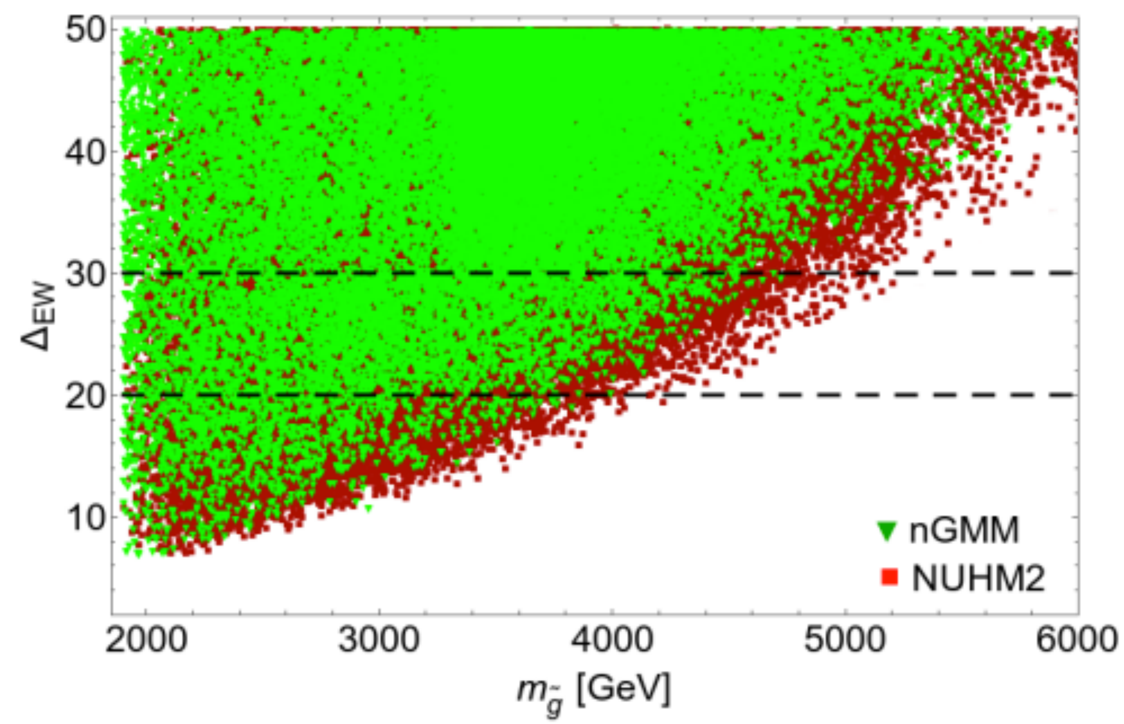
Baer, Barger, JG, Huang, Savoy, Sengupta, Tata

The Context: Theory

- No SUSY yet + 125 GeV Higgs → we must consider models in which somewhat heavier sparticles are natural
- We consider “Radiatively Natural SUSY” (Baer, Barger, Huang, Mickelson, Mustafayev, Sreethawong, and Tata, 2013)
    - NUHM2: small value of $-m^2_{H_u}$ at the SUSY scale
    - Large negative A_0 suppresses stop contributions to Higgs mass
    - Higgsinos are light (the LSP in models we consider)
- With gaugino mass unification, guaranteed LHC 14 discovery via winos (same sign dibosons) for $\Delta_{EW} <$ 30.
- How well can we discover such models without assuming gaugino mass unification?
- Gluino mass up to 5-6 TeV in this scenario.



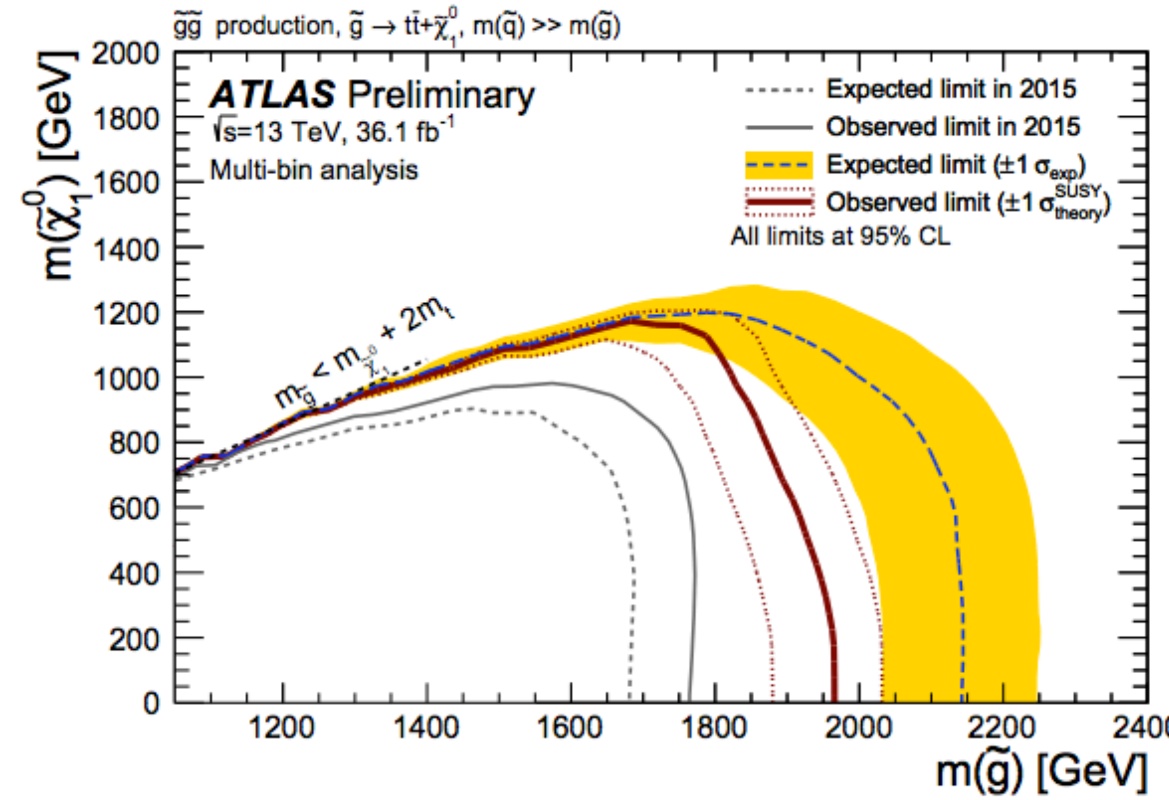
A_0 (TeV)

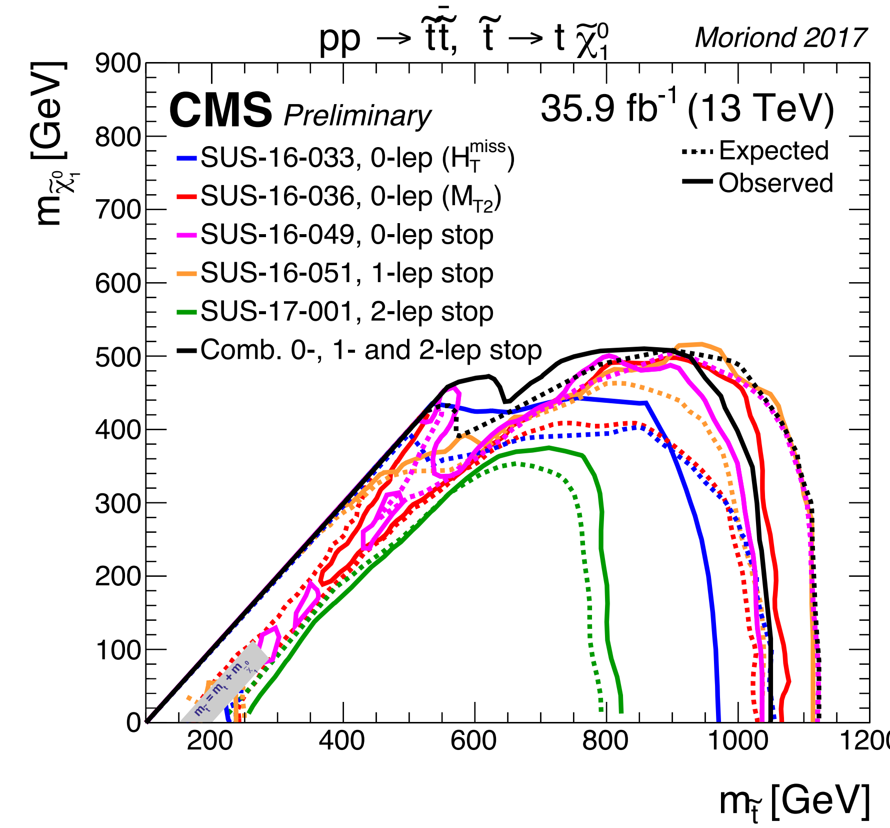


1702.06588, Same authors + Serce

The Context: Phenomenology

- LHC limits on stop (gluino) masses around 1 (2) TeV
- Cross sections for stop and gluino fall quickly
    - Roughly exponential in sparticle mass
    - Gluino cross section for ~2 TeV gluinos falls by a factor of e
      for every ≈ 200 GeV at the 14 TeV LHC
    - Stop cross section for ~1.5 TeV stops falls by a factor of e every ≈ 175 GeV
    - Would not see a gluino or stop “around the corner”
- Interesting on general grounds to look for models with gluinos in 2-3 TeV range, stops in 1-2 TeV range.





Big Questions

- **What is the gluino reach in RNS models?**
- **How well can we measure the gluino mass?**

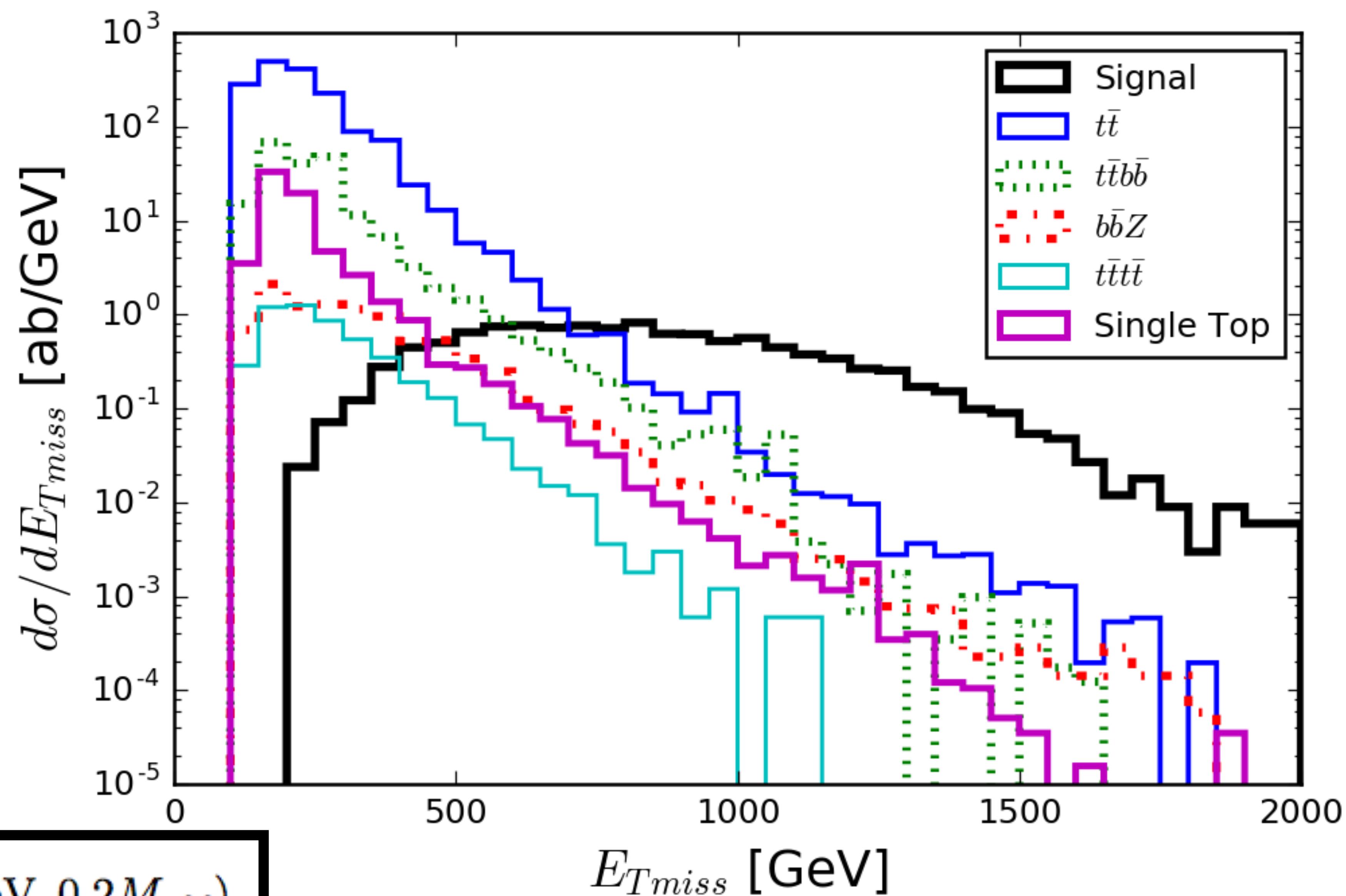
Signal and Background

- Our benchmark model for developing our analysis will be a RNS model with m_0 = 5000 GeV, $m_{1/2}$ = 800 GeV, A_0 -8000 GeV, tan β = 10, μ = 150 GeV, mA = 1000 GeV
- **Gluino mass ≈ 2000 GeV, light stop mass ≈ 1500 GeV, Higgsinos ≈ 140 - 160 GeV**
- We are going to employ a **cut-based analysis**.
- Conservative approach: generically MVA's boost sensitivity
- The signal is gluino pair production with gluinos decaying to on shell stops and tops, and the stops decaying to light higgsinos (charginos or neutralinos)
- The backgrounds are **tt*, ttbb, tttt, single top, Zbb**
- * We veto tt events with more than 2 truth b's to avoid double counting with ttbb

Take a Tour of Our Cut Flow

Preliminary Cuts

- We start by imposing some basic cuts.
- We use anti-kT jets with
  ΔR = 0.4,
  $p_T > 50.$,
  $|\eta| < 3.$



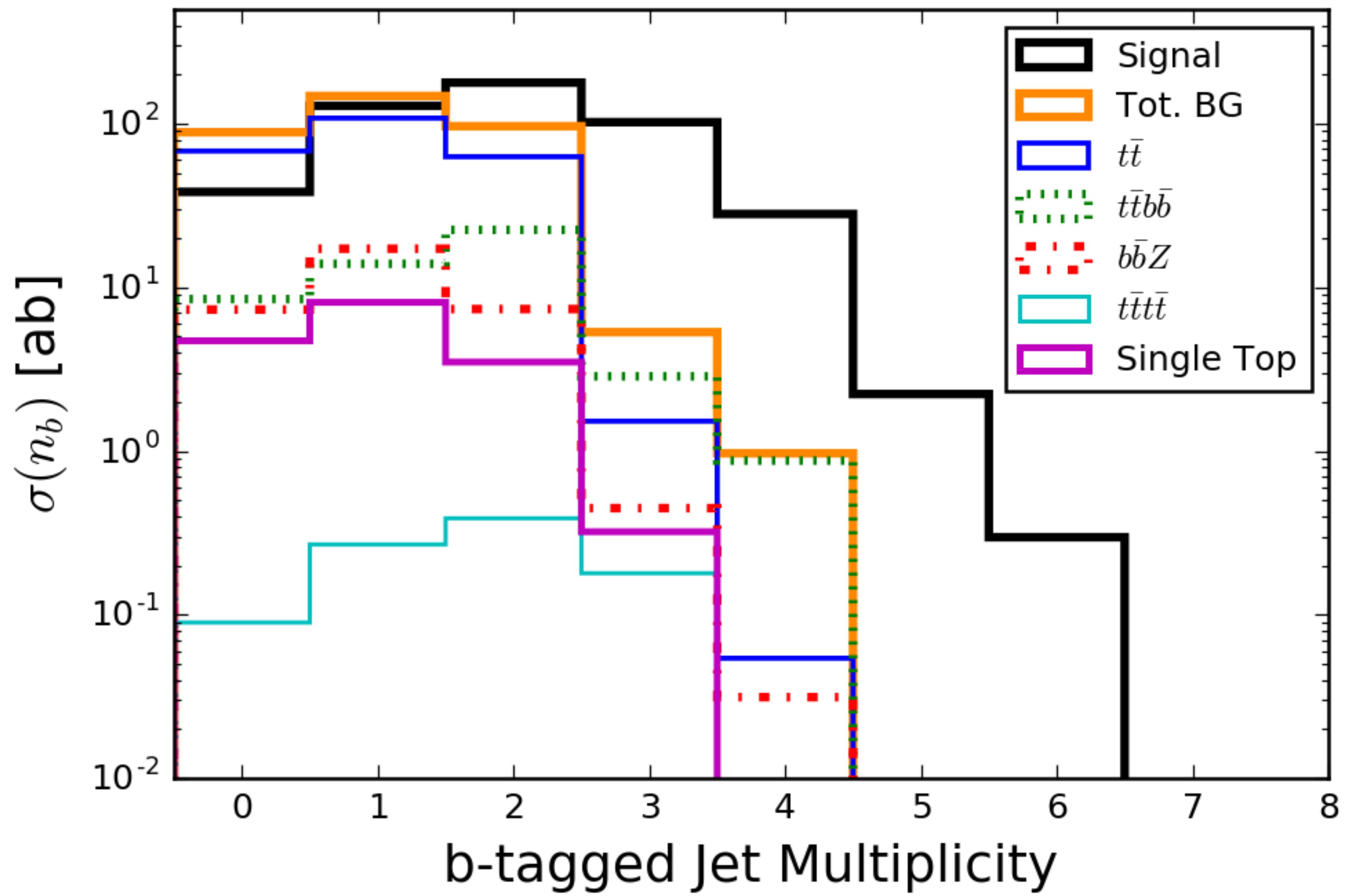
$$
\begin{aligned}
\not{E}_T &> \max(100\text{ GeV}, 0.2 M_{eff}), \\
n(jets) &\geq 4, \\
E_T(j_1, j_2, j_3, j_4) &> 100\text{ GeV}, \\
S_T &> 0.2, \\
m_T(\ell, \not{E}_T) &> 150\text{ GeV},\ \text{if } n_{lep} = 1.
\end{aligned}
$$

14 TeV LHC

all remaining figures from 1612.00795

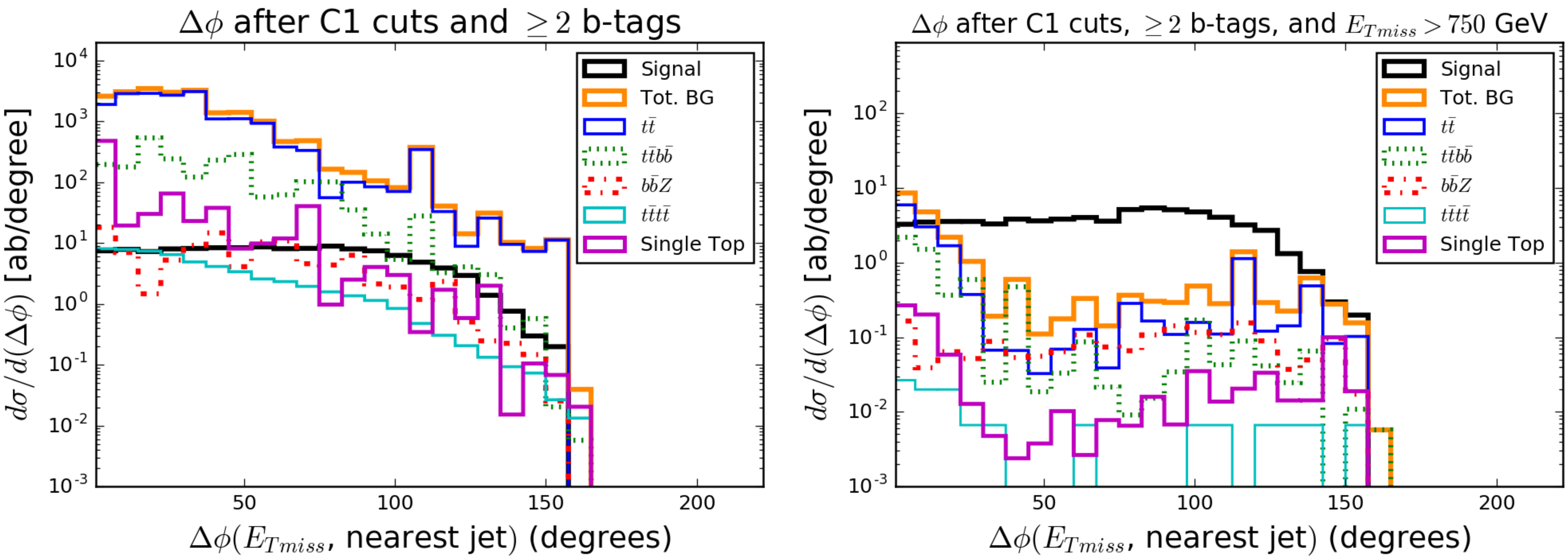
B-Jet Multiplicity

- Signals are b-enriched
- b-tagging and preliminary cuts remove QCD backgrounds
- tt is the main remaining background



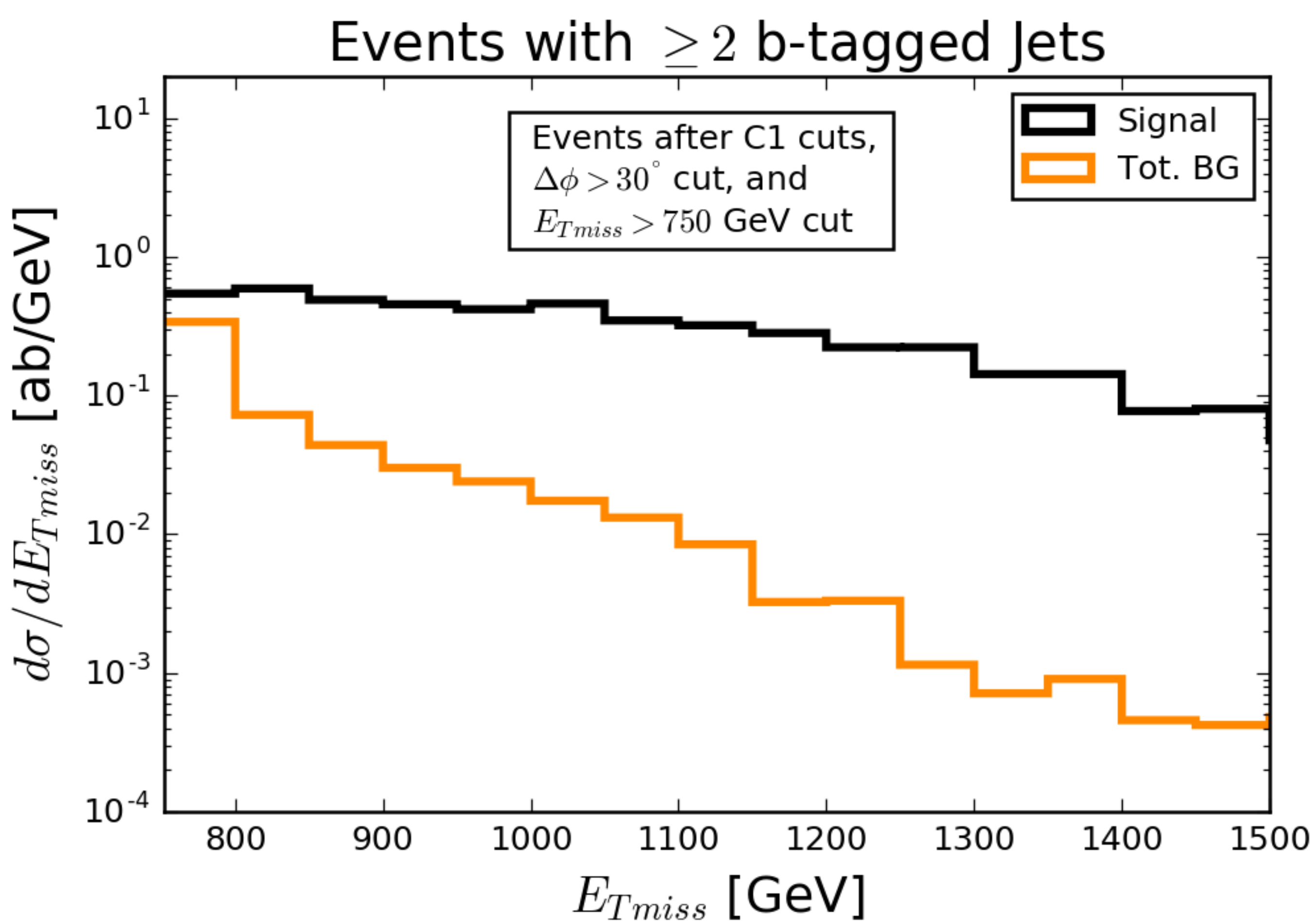
- Demanding 2 b-tags is essential, demanding 3 is better for S/B but worse in terms of S.

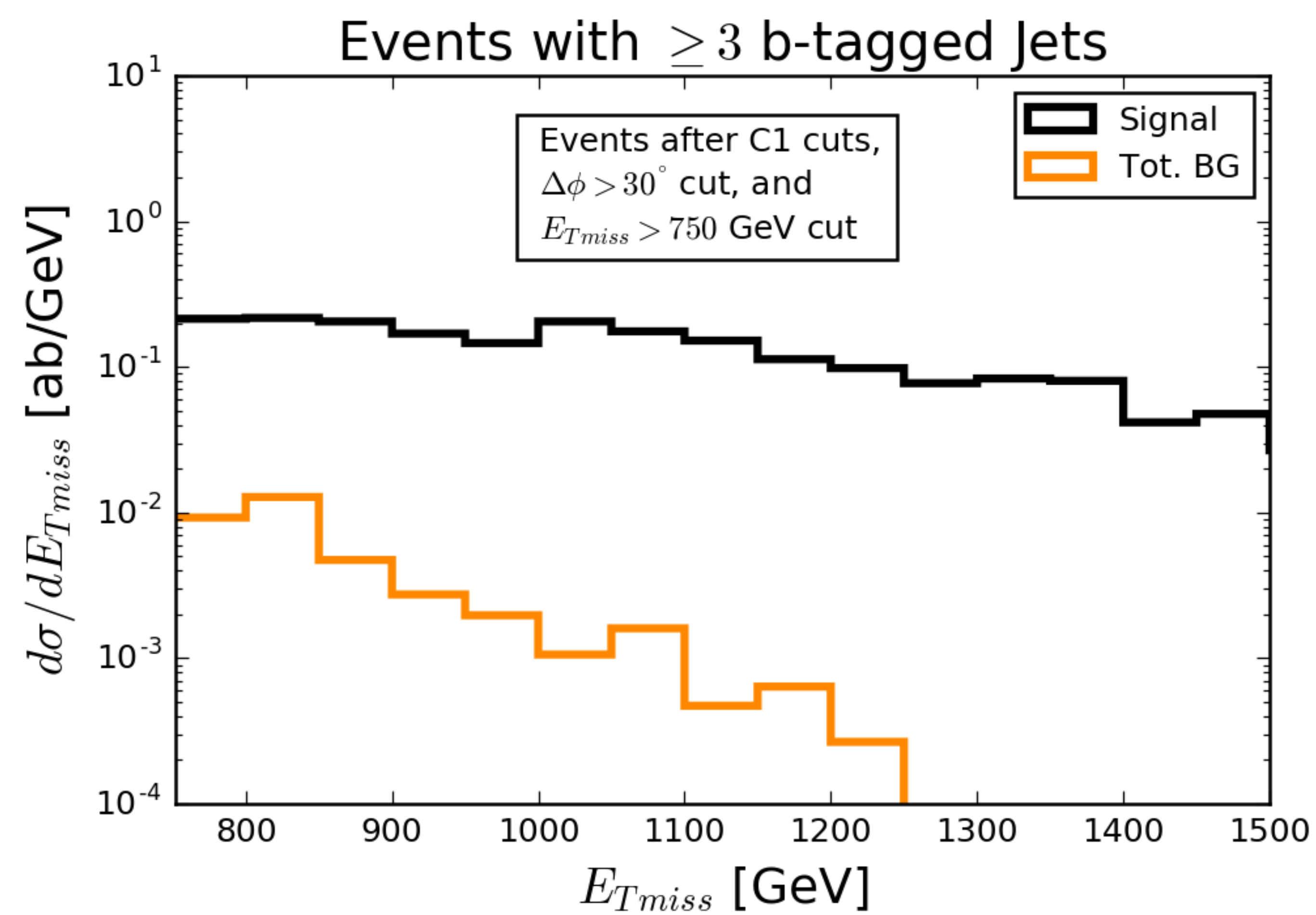
Δϕ



- In tt events with MET from leptonic decay of top, should be a b-jet close to the MET
- Especially true with large missing ET → boosted tops
- So we impose a cut of Δϕ > 30°

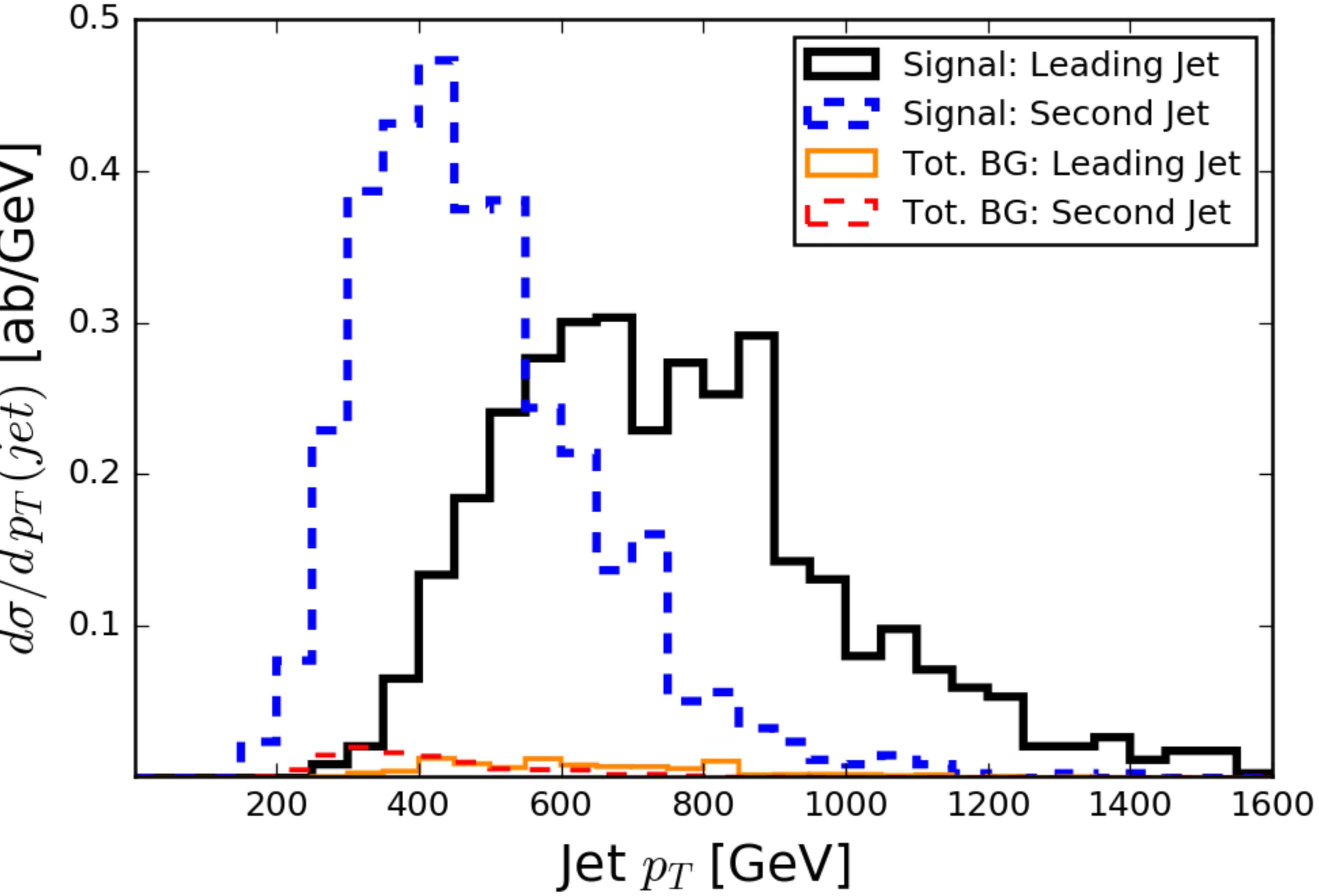
Final MET Cut

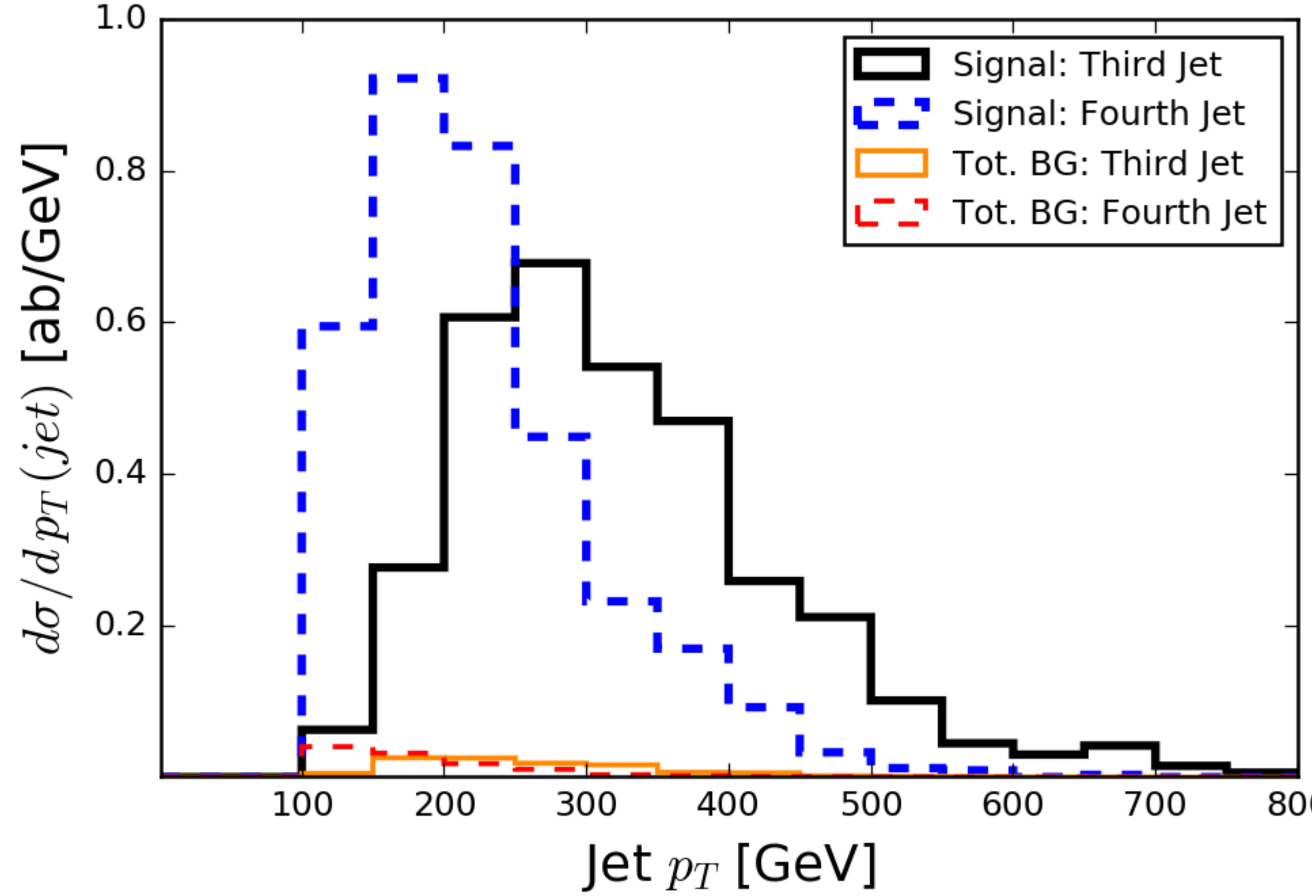


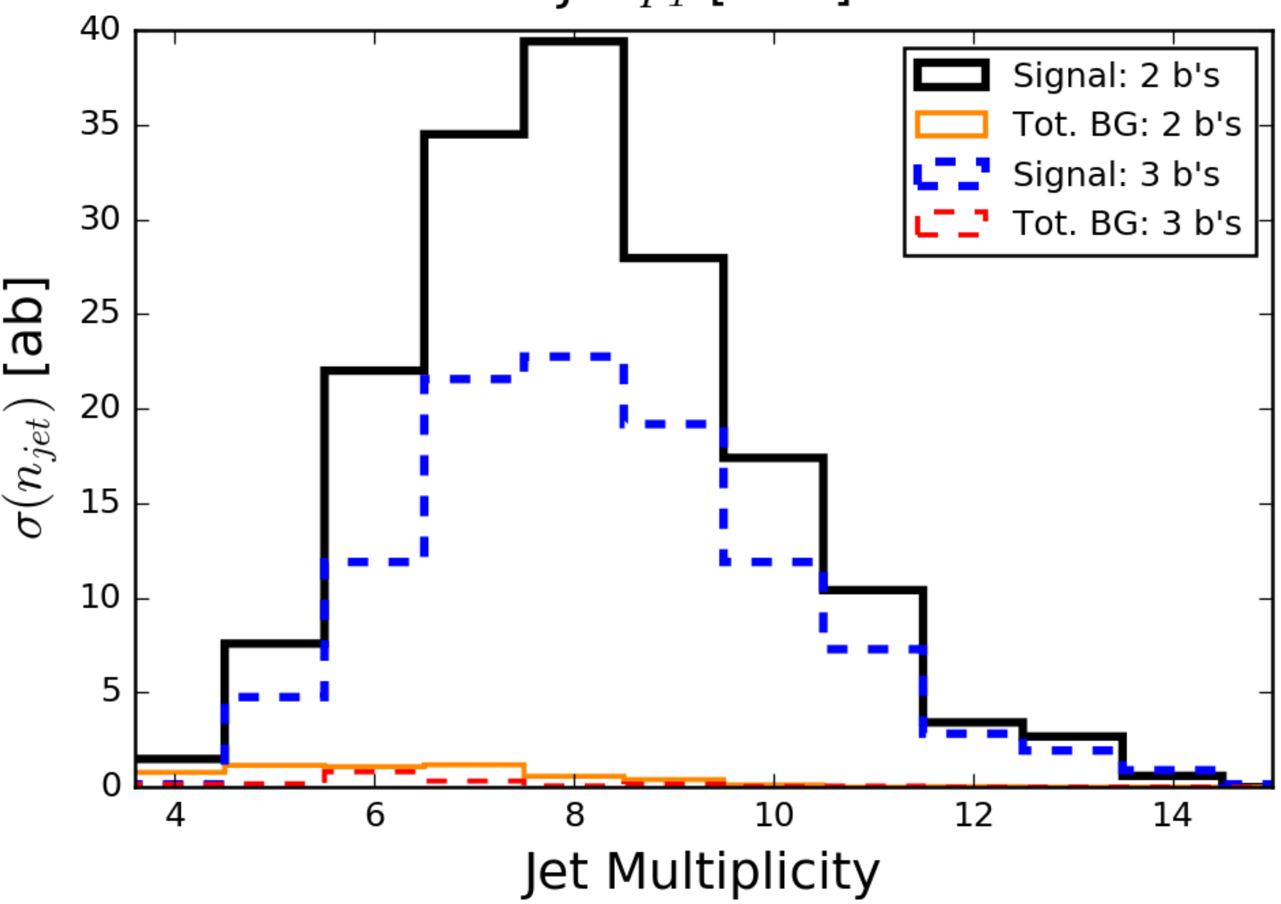


- We note that S/B is dramatically better when we demand 3 b-tags
- But much of the 2 b-tag background is at relatively low MET
- So we consider both approaches, i.e., we have one set of cuts with >= 3 tags and no further cuts and one set of cuts with >= 2 b-tags where we demand MET > 900 GeV

Distributions

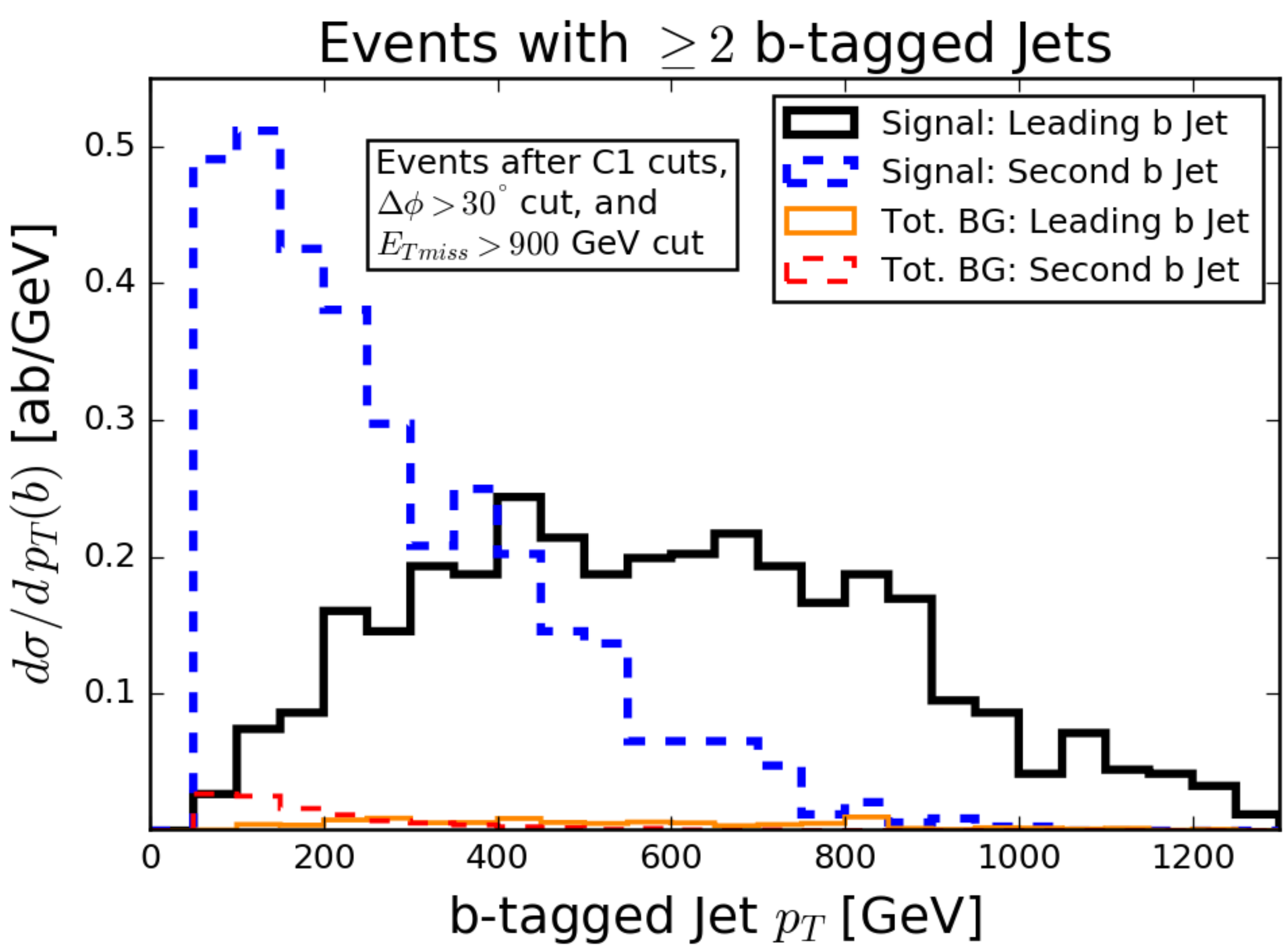


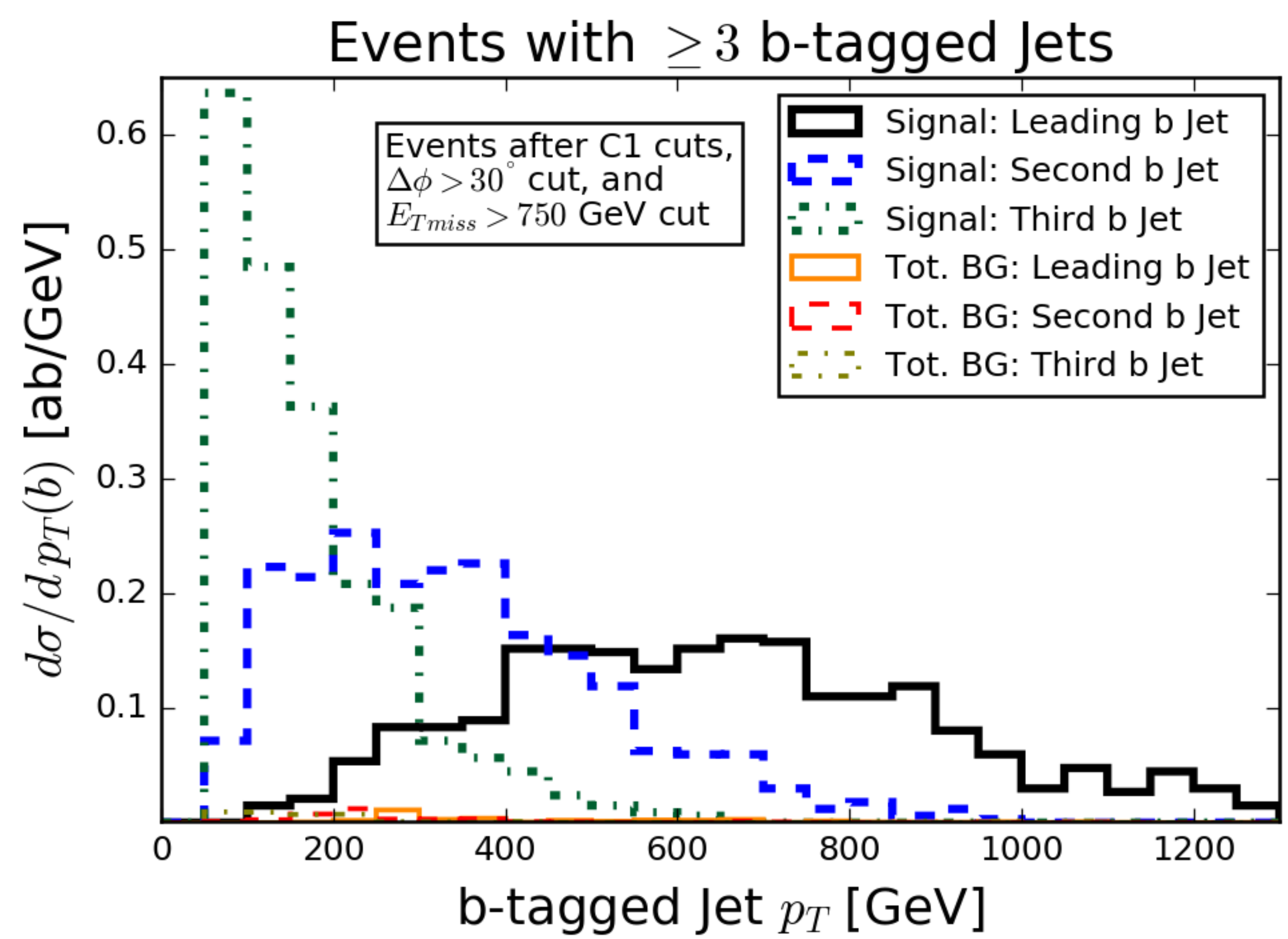




- Peak of j_1, j_2, j_3, j_4 distributions at p_T's of ~ 700, 400, 300, 200 GeV
- Signal after cuts is relatively jetty

Distributions





- Signal distributions of b-jets broader, and somewhat softer
- Signal events generally have ~4 hard truth b's, but b-tagging efficiency is finite, so sometimes one of these truth b-jets isn't tagged
- Also distributions of hardest jets on previous slides receives contributions from ISR, etc.

Cross Sections after Cuts

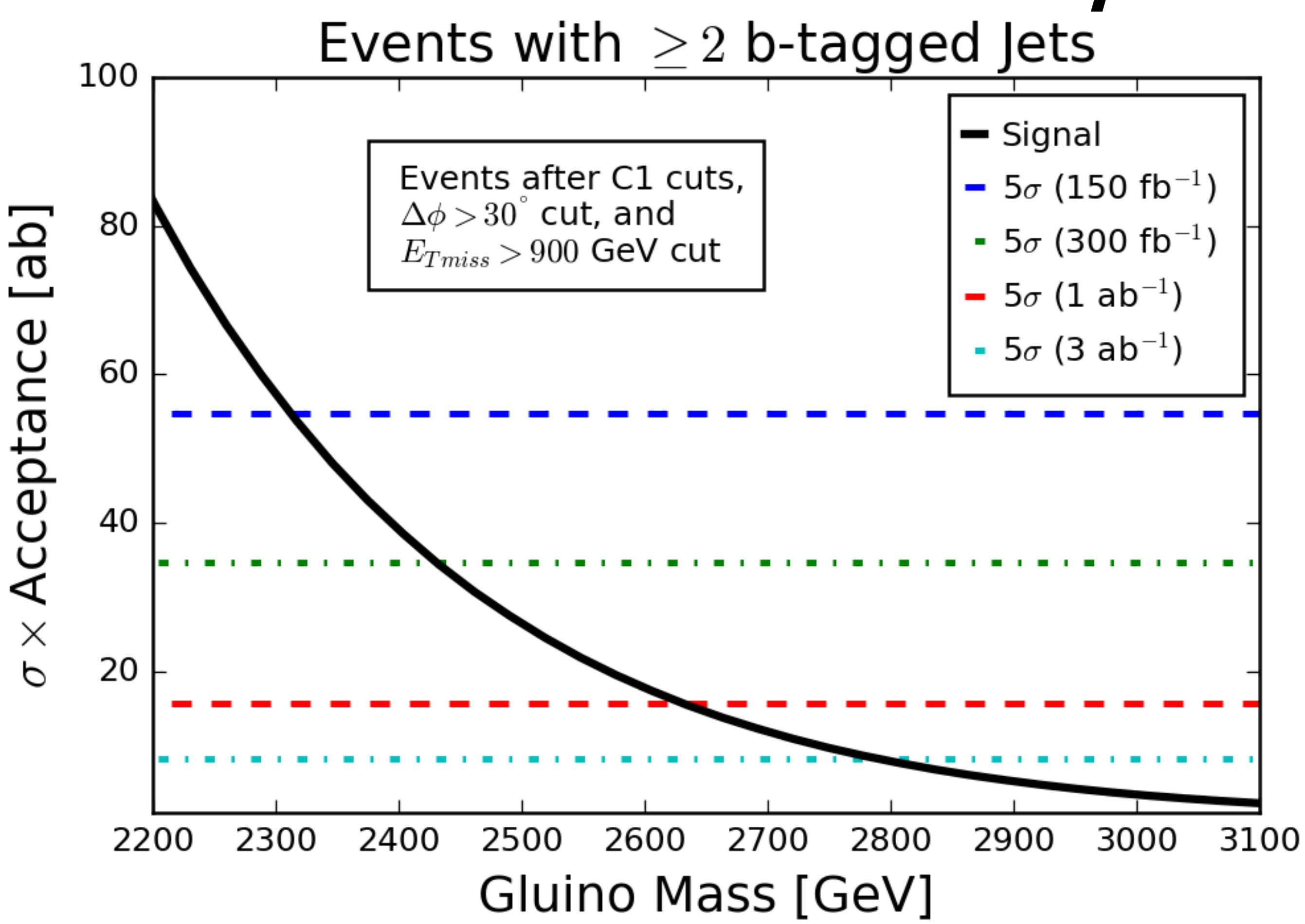
Cut	$2b$ Sig.	$2b$ BG	$3b$ Sig.	$3b$ BG
C1	872	5.14×10^5	872	5.14×10^5
$\not{E}_T > 750$ GeV	479	340	479	340
b-tagging	311	103	133	6.31
$\Delta\phi > 30°$	249	28.1	105	1.78
Final $\not{E}_T$ cut	167	5.31	105	1.78

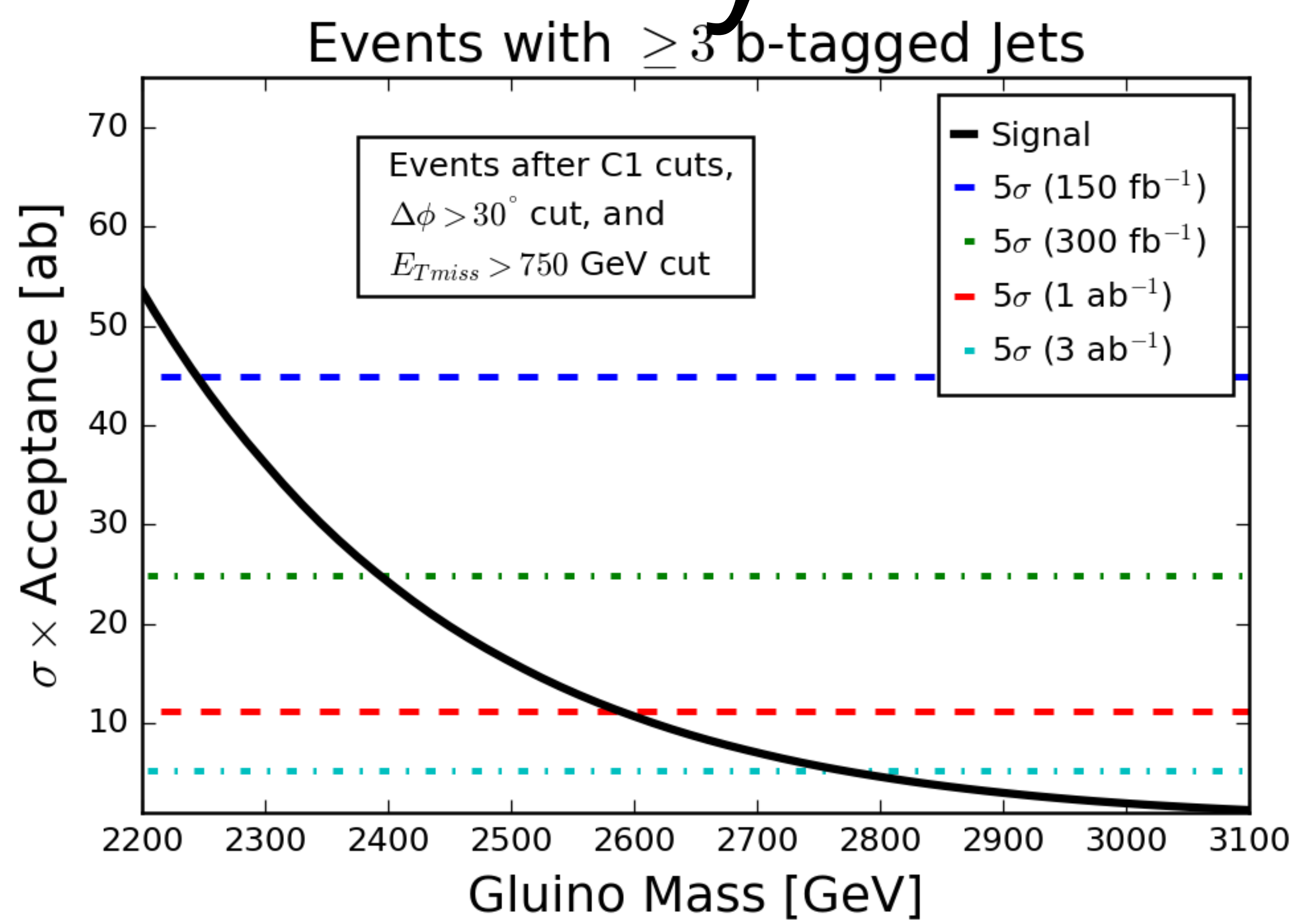
- Cut table for signals and backgrounds
- End up with 100-200 ab signal, large S/B

	Isajet	CMS Medium	CMS Tight
≥ 2 tagged b jets, $\not{E}_T > 900$ GeV	167 (32)	207 (25)	121 (39)
≥ 3 tagged b jets, $\not{E}_T > 750$ GeV	105 (59)	182 (47)	61.1 (78)

- Results relatively robust to choice of b-tagging algorithm

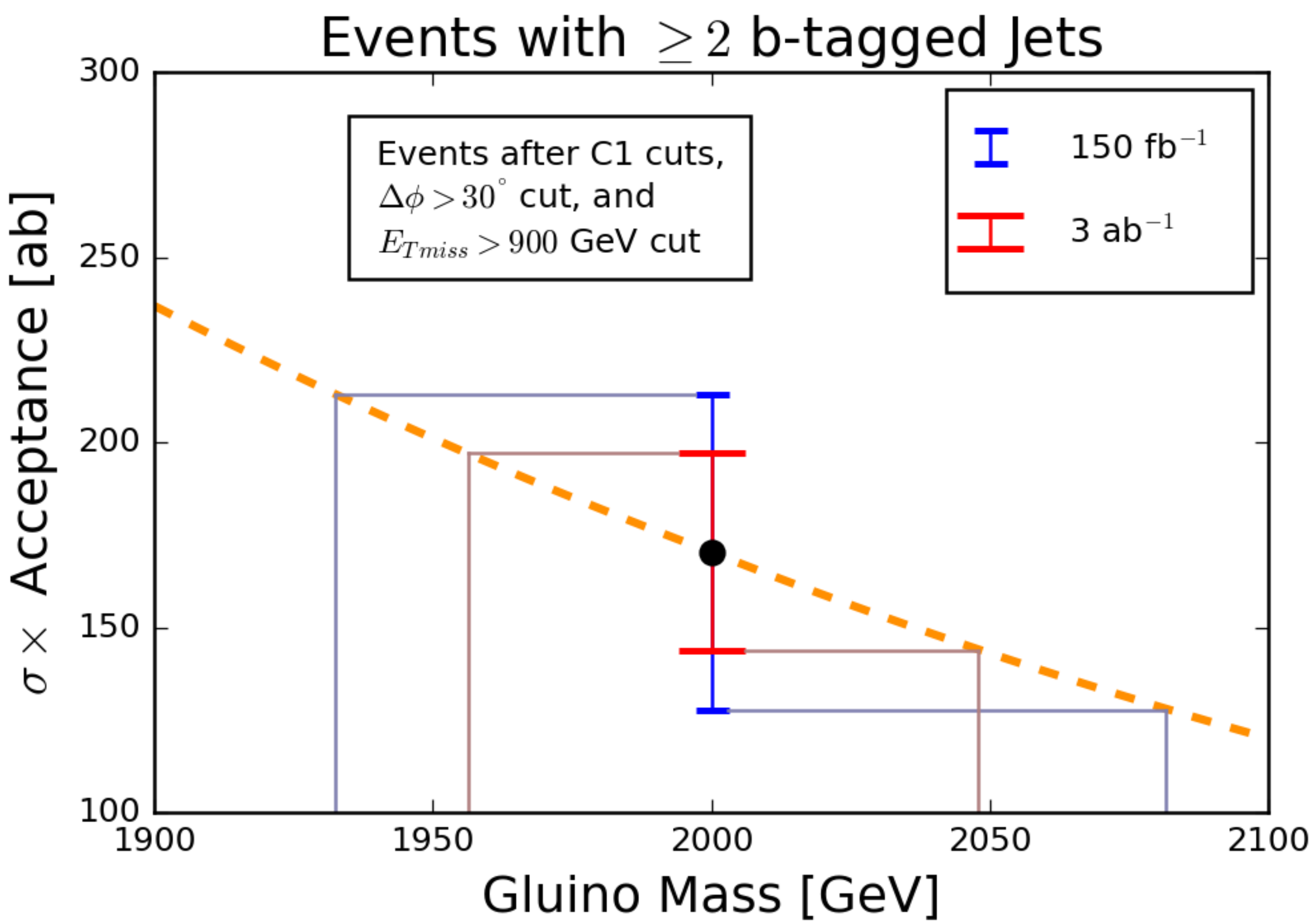
Reach/ Discovery

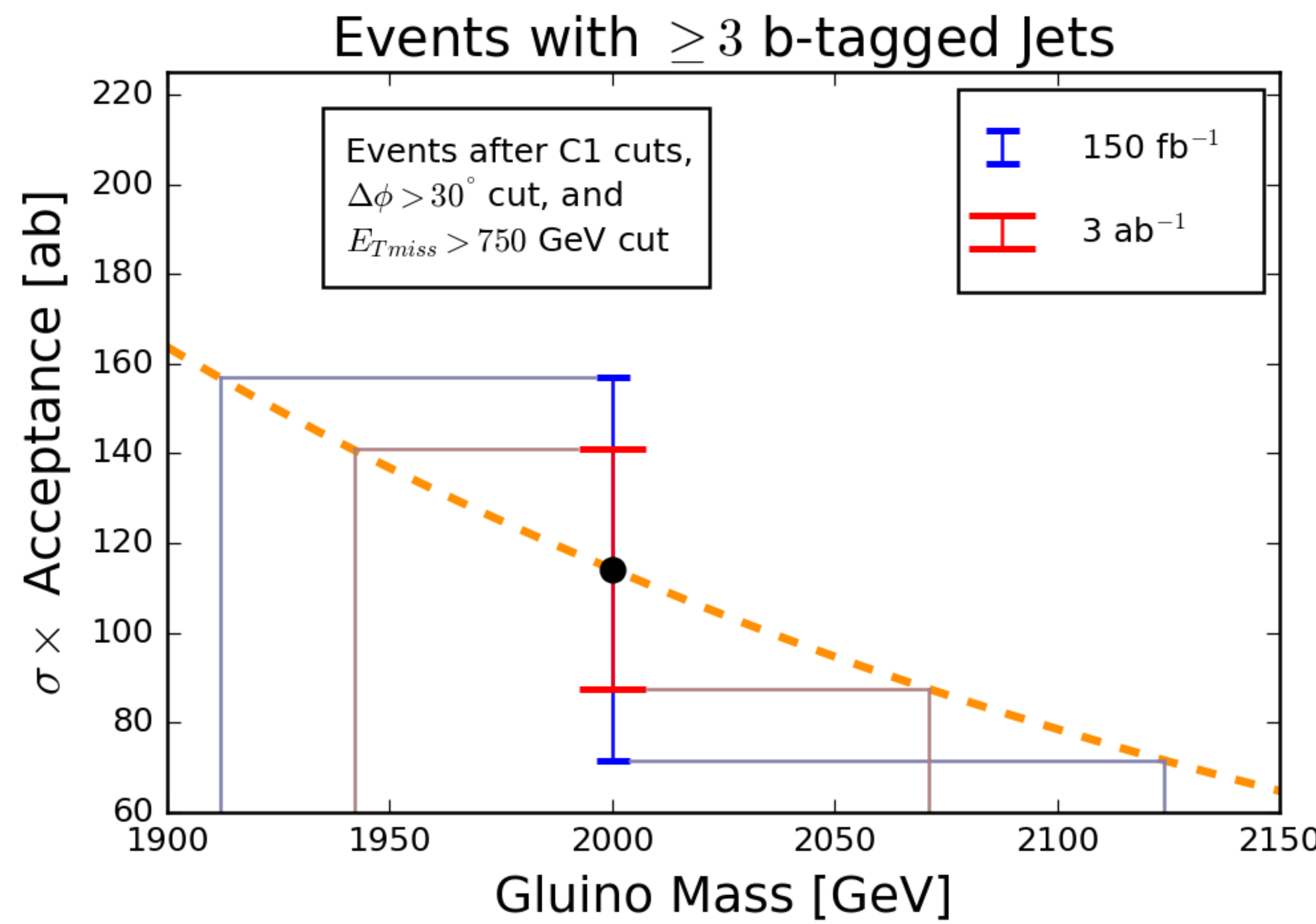




- Using signal cross sections x efficiency along model line (varying $m_{1/2}$)
- Background cross sections x efficiency from previous slide
- Determine signal cross section for which Poission p-value for background only hypothesis drops below 5σ if the expected number of (S+B) events observed
- Ultimate reach ~2800 GeV for high luminosity LHC

Mass Measurement

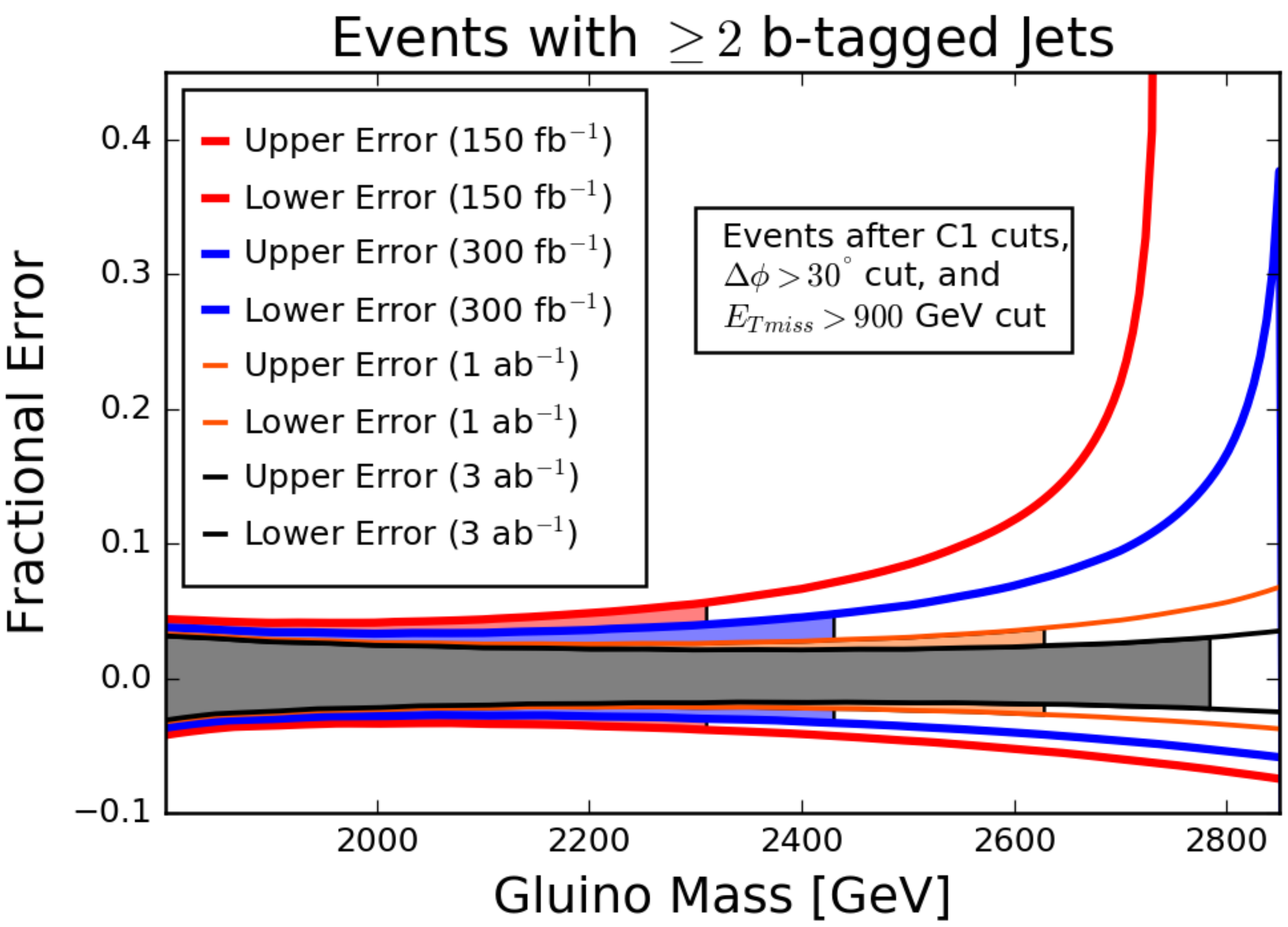


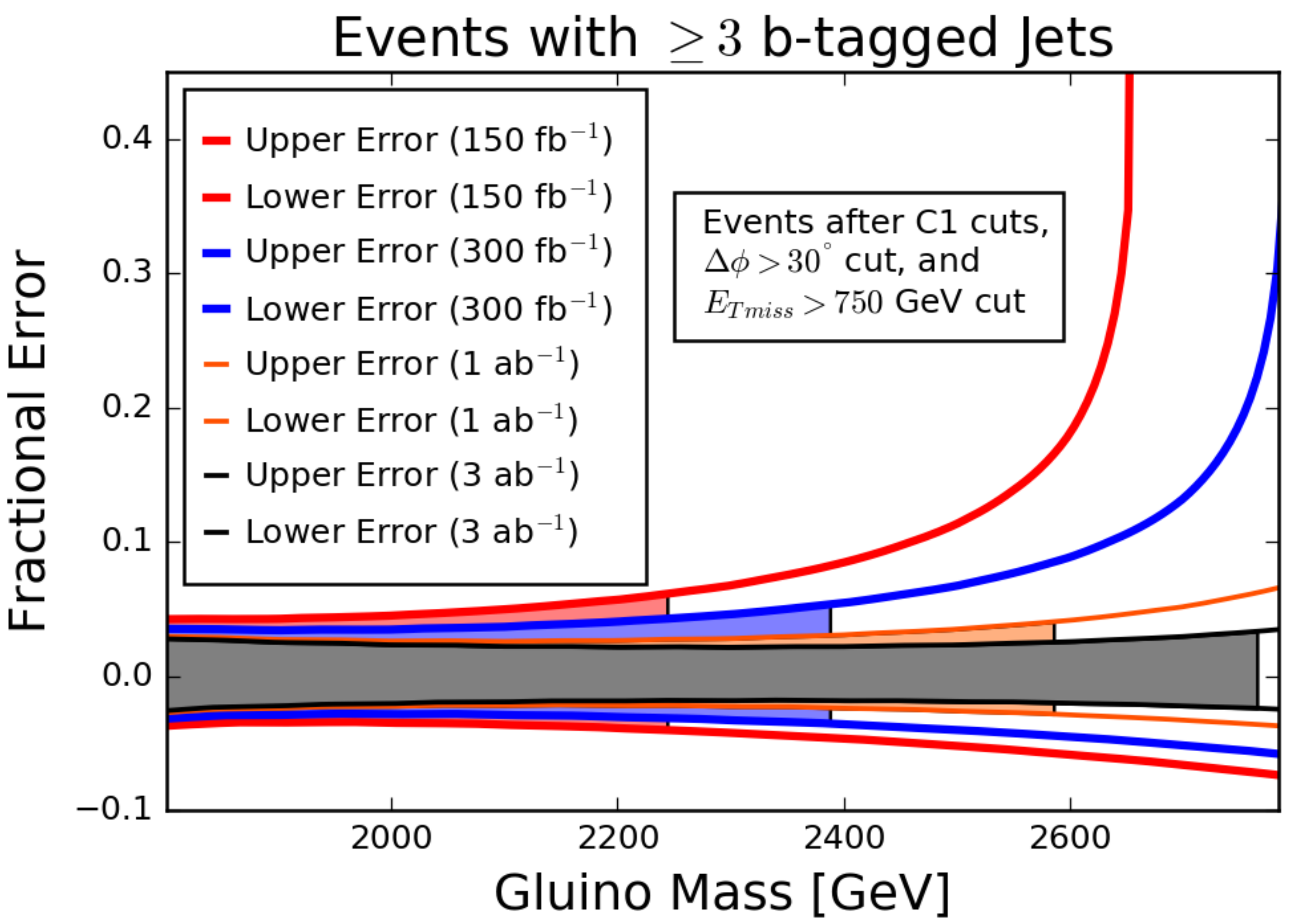


Error bars include systematics and statistical errors

- To perform a mass measurement we use the observed number of events to infer a gluino mass
- We assume symmetric 15% uncertainty on the theory cross sections times efficiency
- Currently theory cross section errors are ~30-40%, but much of this comes from uncertainties in the gluon pdf, so should drop significantly by the time these measurements could be made
- Errors on our efficiencies harder to estimate, cuts were conservative to reduce these errors

Mass Measurement





- Expressed as a percent error on the gluino mass, we find 2-5% measurements are possible for all discoverable gluino masses

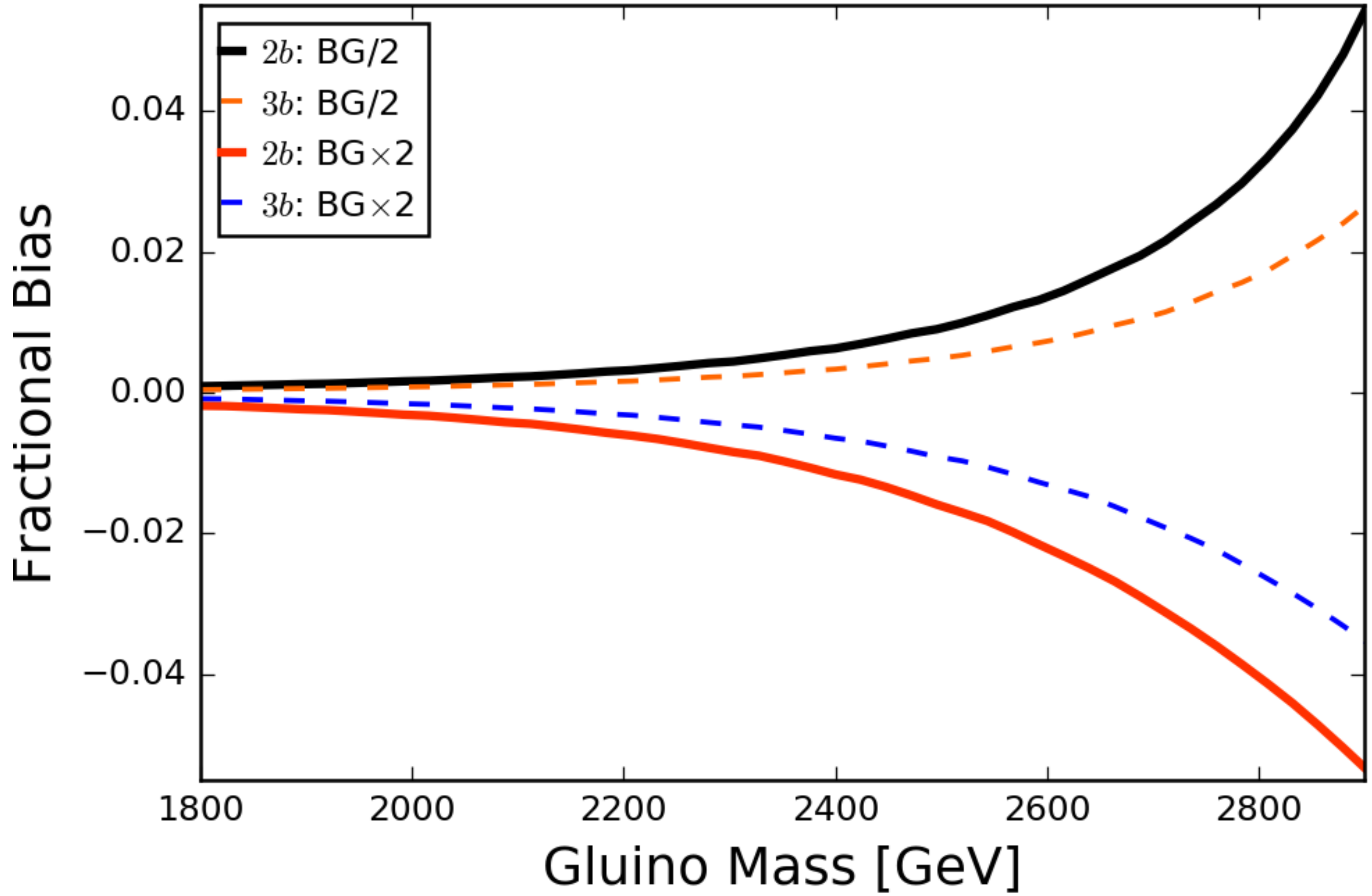
- Relatively precise measurements for lower luminosities as well

- (Roughly) systematics limited in the left half of plots, statistics limited in the right half

Bias

- Errors on our background cross sections x efficiency can bias our measurement

- Factor of 2 errors have a modest effect on our results



- This relative robustness to background errors is the result of our conservative strategy of emphasizing low background rates

- Looser cuts would have reduced statistical errors

Future Directions

- RNS-like models with low fine-tuning (Δ_{EW} < 30) without gaugino mass unification can have gluinos with mass up to 5-6 TeV
- Similar analyses give a gluino mass reach of 5-6 TeV at 33 TeV (depending on luminosity). (Baer, Barger, JG, Huang, Savoy, Serce, Tata, 1702.05588 and work in progress to optimize the reach.)
  - Suggests 33 TeV should be sufficient to discover all RNS type models if it not discovered at the LHC
  - Similar conclusions for stops where the 1 ab^{-1} limit is ~2.8 TeV (work in progress), close to the maximum for low fine-tuning RNS models
- Working to make analyses more robust at 14 and 33 TeV
  - off the model line → pMSSM limits for this topology
  - reduced dependence on systematics, esp. cross section theory error
  - Kinematic variables, multiple cut choices
  - Stay tuned!