Summary of the Characterization of New Physics Effort in ATLAS

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thanks to Paul de Jong and Sascha Caron for slides and everyone else for the work

Introduction

- We are out to route out *model-dependence*, so...
- There are two "degrees" of model dependence in experimental searches
  1. Model dependence in selections
     - *Motivation*: Identify regions in observables where New Physics stands out above SM
     - *Crime:* Needlessly make a search insensitive to a larger class of models
  2. Model dependence in interpretation of search results
     - *Motivation:* Setting limits or extracting parameters
     - *Crime:* Masking the sensitivity to larger class of models
- ATLAS has historically presented results in a model dependent manner (eg mSUGRA)... but I'll show that:
  - It's mostly a 2nd degree offense, not 1st.
  - We are moving away from 2.

Disclaimers

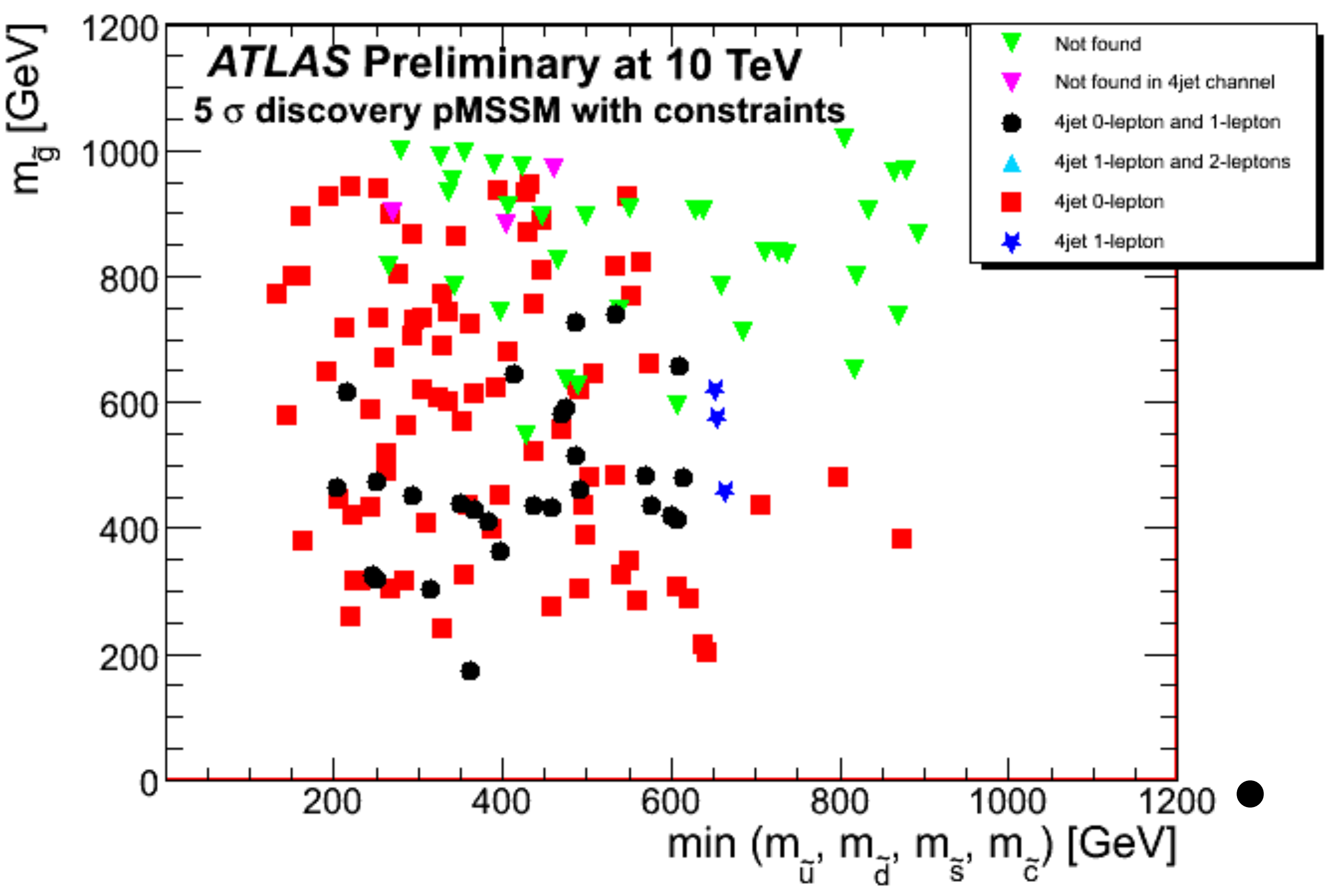
- I’ll only mention large MET signature searches viewed through SUSY lens because that’s where I have something to show
  - This is arguably the right priority...
  - Seems to fits well the topologies from the theory side
  - Obviously, not everything...
- Since our priorities are analyzing data rather than looking at Monte Carlo, no effort was made to push the model-independent efforts through our approval process for this workshop.
  - I can’t show you plots... so this talk shouldn’t take the full allotted time.
- *My opinion:* Due to historical reasons, ATLAS has a somewhat artificial separation of New Physics searches between “SUSY” and “Exotics”.
  - Overlap is large (eg SUSY and UED)... but not 100% (eg W’, Z’)
  - This is naturally resolving itself because we have mostly transitioned from model-based to signature-based searches...

Signature Based Searches

- For experimental reasons, we naturally perform signature-based searches which are fundamentally model independent...
- For example MET ATLAS signatures (about a dozen):
  - 1,2,3,4 jets + MET
  - 2,3,4 jets + MET + lepton
  - 2 (SS or OS), 3 + MET
  - taus or b-jets or photons + MET
- *In most cases*, the selections are motivated by
  - trigger
  - control of instrumental backgrounds
  - avoidance of SM dominated regions
- It is usually only in the interpretation (ie putting limits) that models are assumed.
- Note that it is possible that optimizing for specific models/parameters would provide better sensitivity in specific regions... but at expense of wider coverage
  - If we can identify problematic regions, we can make it up with dedicated searches...

Closer Look at MET Signatures

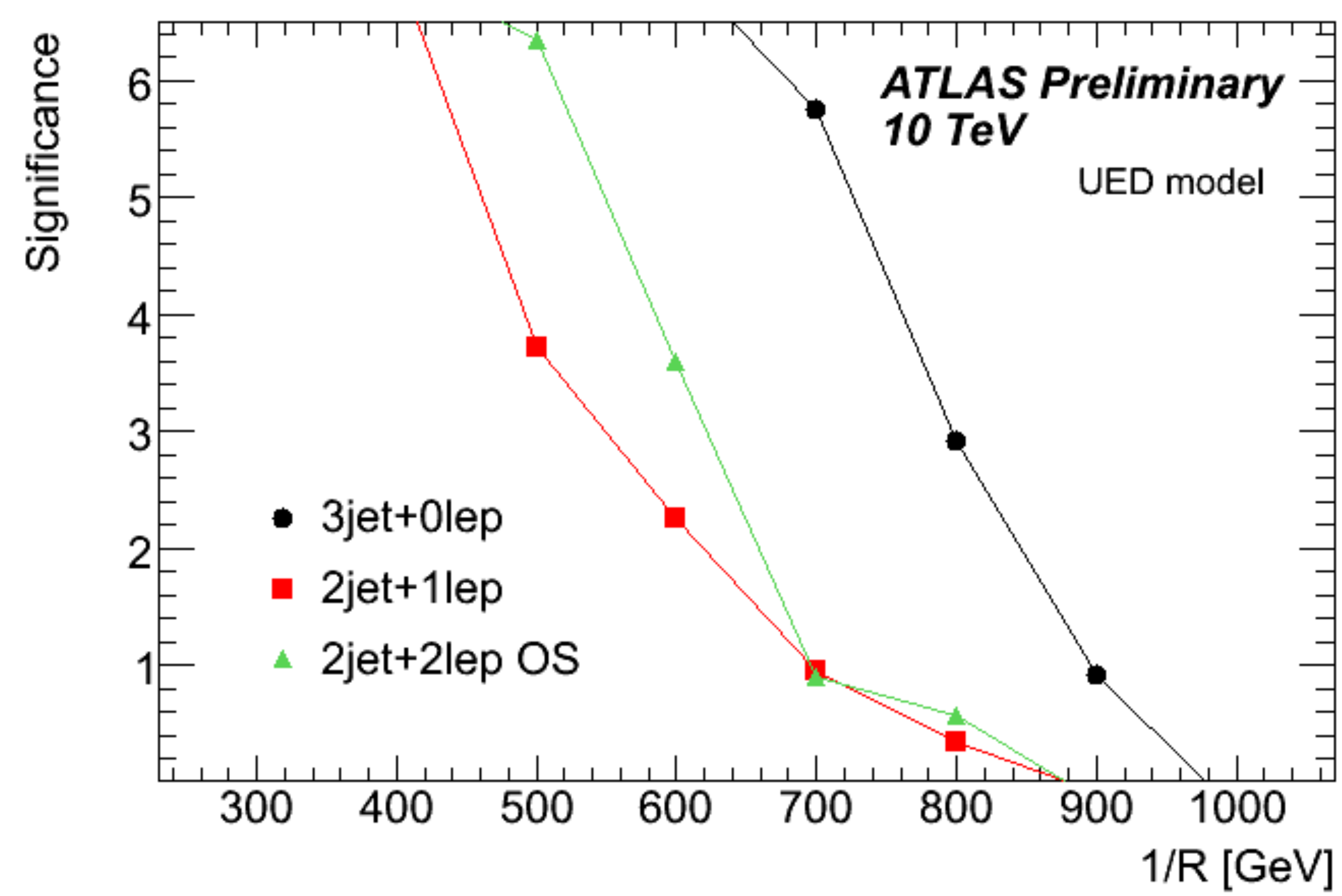
Number of analyses	Flat, 1 fb^{-1}	Flat, 10 fb^{-1}
0	0.56754	0.36796
1	1.3458	0.98841
2	3.396	2.5141
3	13.175	10.635
4	22.014	18.455
5	9.5512	10.3
6	15.227	16.929
7	20.081	17.697
8	7.6394	11.75
9	3.9205	6.3569
10	2.0825	2.7943
11	1.0013	1.2116



- pMSSM (Conley, Gainer, Hewett, Le, Rizzo arXiv: 1009.2539):
  - 19 dim reduction of MSSM, sampled with masses < 1 TeV
  - 98.8% discovered by at least one ATLAS search with 10/fb of 14 TeV data.
- ATLAS looked at pMSSM, assuming 200/pb of 10 TeV
  - Green is not found... rest is found
  - Closer look showed that not found because:
    - upper/right- low x-section
    - didn't consider b-jets channel
    - low p_T jets... difficult to see!
- So ATLAS coverage seems very good... we don't miss much because of model bias.

SUSY to UED

- Exact same searches give sensitivity to Minimal Universal Extra Dimensions
  - Provide similar reach in mass scale.
- Though our strategies are often inspired by a model (eg SUSY), our sensitivity is obviously not.



Interpretation

- Options:
  1. Experiments provide raw distributions, theorists use parameterized simulation (eg PGS) to compare to models. (eg Alves, Izaguirre, Wacker arXiv:1008.0407)
     - ATLAS generally not comfortable with PGS-based interpretation of our results and priority is to analyze data not tune/understand PGS.
  2. Experiments provide efficiency-corrected (but not acceptance-corrected) distributions, theorist compare to "theory" distributions after applying acceptance.
     - See David Cote's talk tomorrow.
  3. Theorists define models or topologies/parameter-space, experimentalists simulate these models and test their data against them.
     - ATLAS is already considering varieties of simplified models (see next slides)
     - If topology MCs are defined (and generated?), we will consider them too.
- Differences: where do we draw the experimentalist/theorist line?

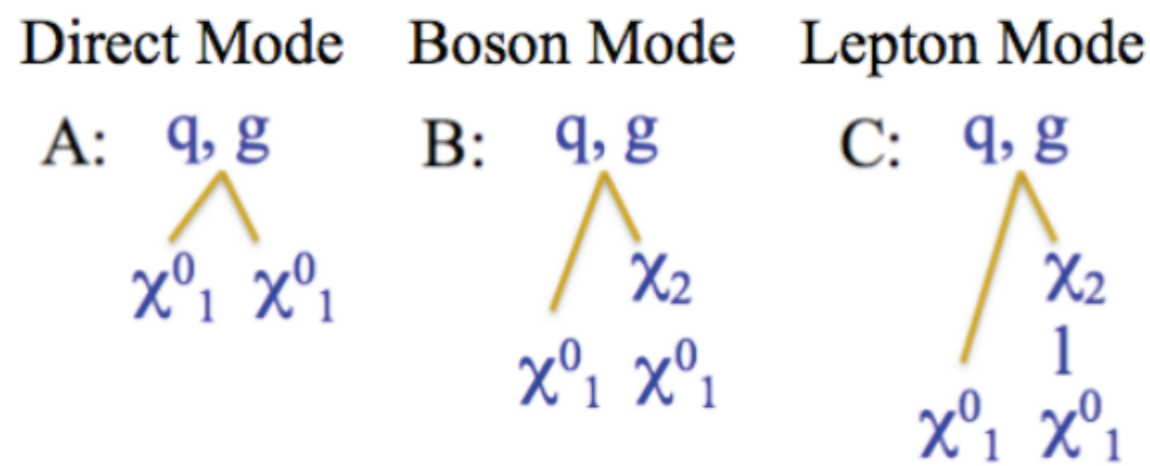
“Reduction of number of dimensions”

- Why did we ever use mSUGRA (or GMSB, AMSB, etc...) for our interpretations?
  - Historical...
  - We were doing feasibility studies for a long time
  - *Primary Reason*: Reduction of number of dimensions (aka parameters)
    - Too many parameters (and differing phenomenology) in MSSM
- The remaining slides, I’ll show that ATLAS has gradually moved to
  - categorization of phenomenology and mapping to signatures
  - reduction of number of dimensions to handful of relevant TeV-scale parameters
- But in most cases, this is done by examining specific regions of MSSM space (with IsaJet/Pythia) rather than starting from simplified-model approaches
  - As long as our observables don’t violate “shape-invariance”, these should be equivalent.

A Top-down Attempt

Claus Horn

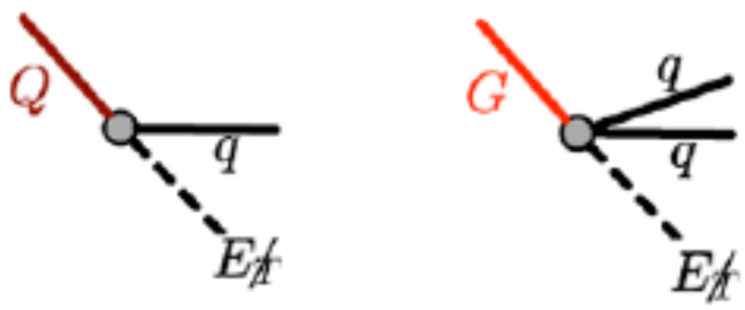
- Attempt to categorize SUSY
- Instead of topologies, consider "Eigenmodes" of squark/gluino decays
- Tried to address:
  - coverage of SUSY by eigenmodes
    - mSUGRA coverage seemed good
    - no approved plots, sorry!
- Starting from the signature (bottom-up) is clearer...
  - that's what the majority in ATLAS who are interested in these ideas are doing



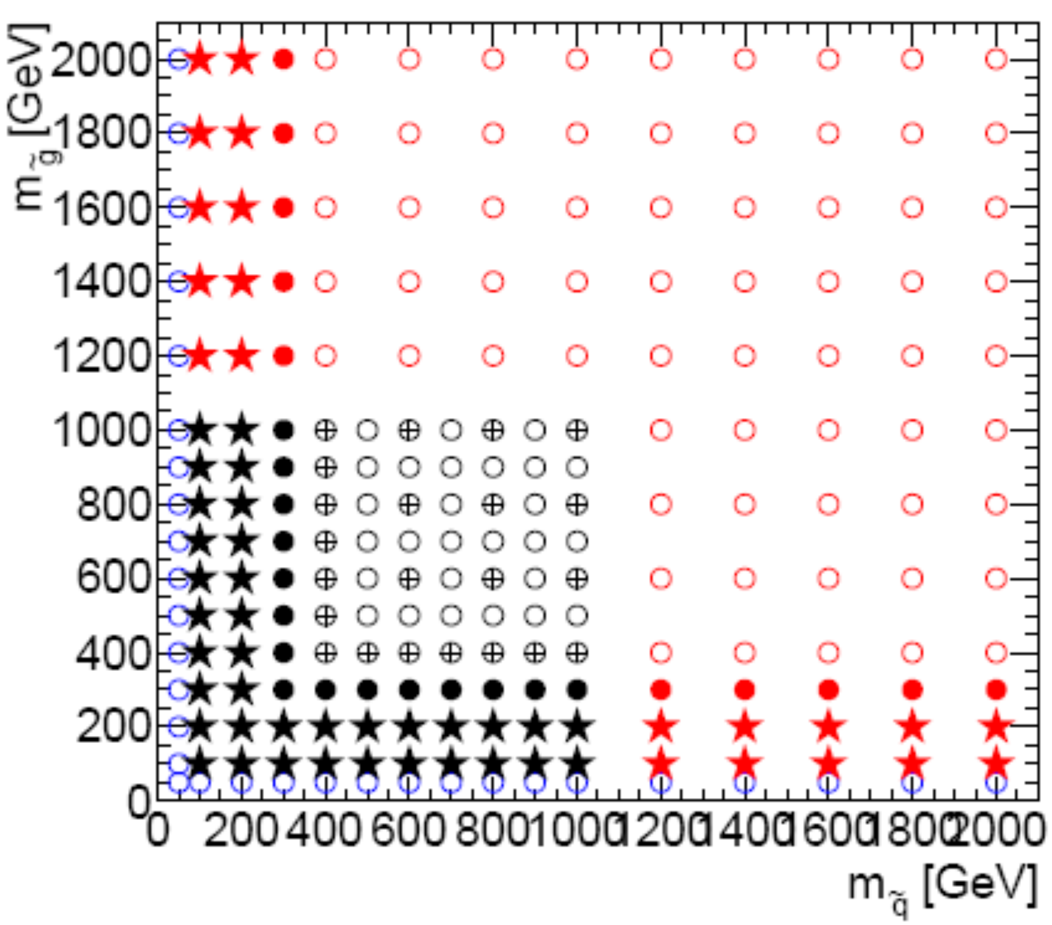
Legend: q,g : squark, gluino
chi2: neuralino2 or chargino1
l : slepton
chi1: invisible LSP
chi2 chi1 via emission of W/Z in mode

- Also considered
  - mixed boson-lepton modes
  - double boson

Jets + MET



$\tilde{q} \rightarrow q\tilde{\chi}_1^0$ $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$



- 3 "topology-motivated" grids
  - m(gluino) vs m(quark) assuming light LSP (0, 50, 100 GeV)... other gauginos heavy
  - m(gluino) vs m(chi0), assuming other masses high
  - m(squark) vs m(chi0), assuming other masses high
- These are not simplified models
  - SUSY x-sections/branching fractions
  - But probably equivalent to simplified model considered at this workshop:
    - Maps to topologies
    - Strong squark/gluino prod
    - large "other" masses = BR ~ 1
    - "shape invariance"

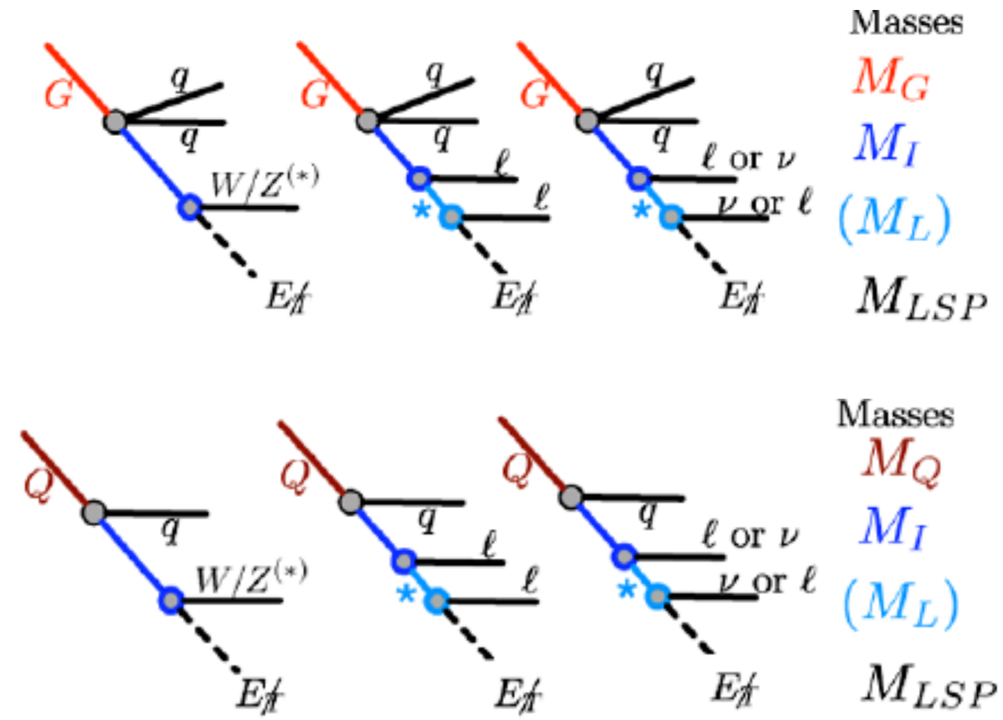
One lepton + Jets + MET

$\tilde{g} \to q\bar{q}\tilde{\chi}_2^0$

$\tilde{g} \to q\bar{q}'\tilde{\chi}_1^\pm$ $\quad \tilde{\chi}_2^0 \to (Z^{(*)}/h)\tilde{\chi}_1^0$ $\quad \tilde{\chi}_2^0 \to \tilde{l}\,l \to ll\tilde{\chi}_1^0$

$\tilde{q} \to q\tilde{\chi}_2^0$ $\quad \tilde{\chi}_1^\pm \to W^{(*)}\tilde{\chi}_1^0$ $\quad \tilde{\chi}_1^\pm \to \tilde{l}\,\nu \to l\nu\tilde{\chi}_1^0$

$\tilde{q} \to q'\tilde{\chi}_1^\pm$



- Grids:
  - M(sq) – M(chi2/chi+-) – M(chi1) (heavy gluino)
  - M(sq) – M(chi2/chi+-) – M(sl) – M(chi1) (heavy gluino)
  - M(gl) – M(chi2/chi+-) – M(chi1) (heavy squark)
  - M(gl) – M(chi2/chi+-) – M(sl) – M(chi1) (heavy squark)
- And assuming chi1 is ~bino, chi2 is ~wino, M(chi2)=M(chi+-)
- Note Hadronic W/Z decays belong to 0 lepton signature

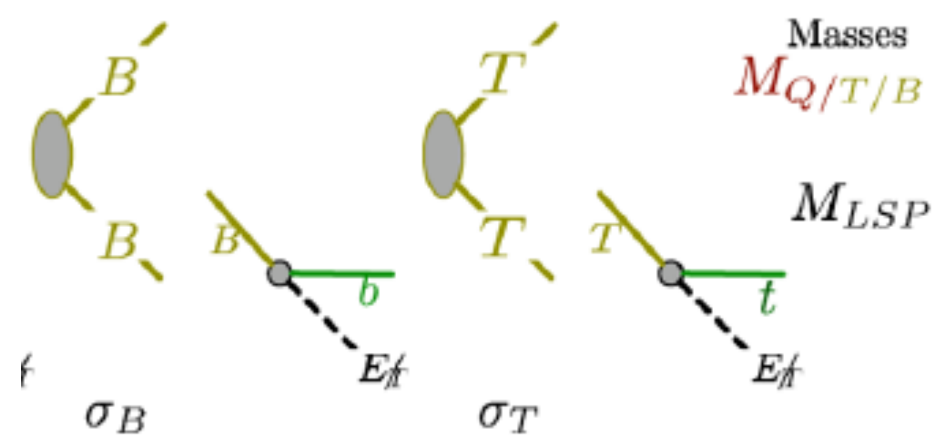
Multilepton + (Jet) + MET

- Dilepton
  - More complicated!
  - Partly covered by same grid as 1 lepton
  - But possibly more topologies
  - Investigating (with help from this workshop?)
  - Especially interested in topologies for same-charge di-leptons
- Trilepton
  - EW-ino modules are a start, but not studied yet

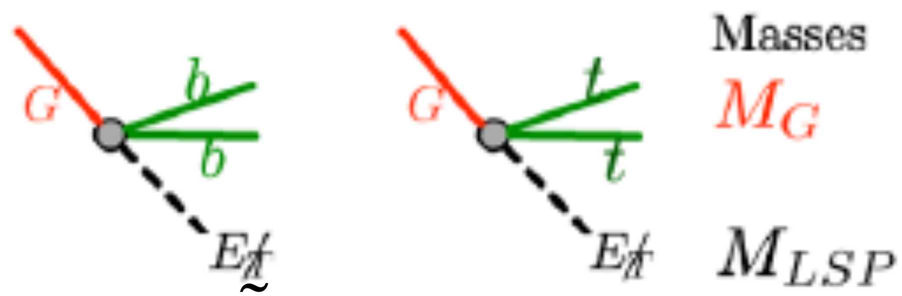
Heavy Flavors

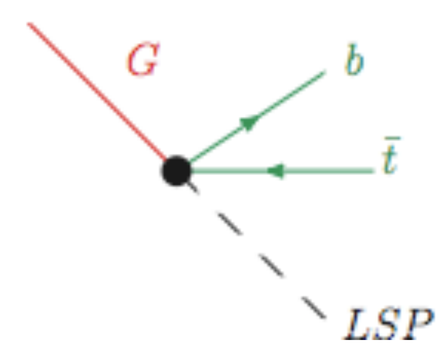
- Heavy flavors is a good example of possible complications, and how topology-based approaches can help develop a search.
- Heavy Flavor Production:
  - strong b,t partner production

$$\tilde{b}\bar{\tilde{b}}, \tilde{t}\bar{\tilde{t}}$$



  - gluino production





$$\tilde{g} \to b\tilde{b} \qquad \tilde{g} \to t\tilde{t}$$

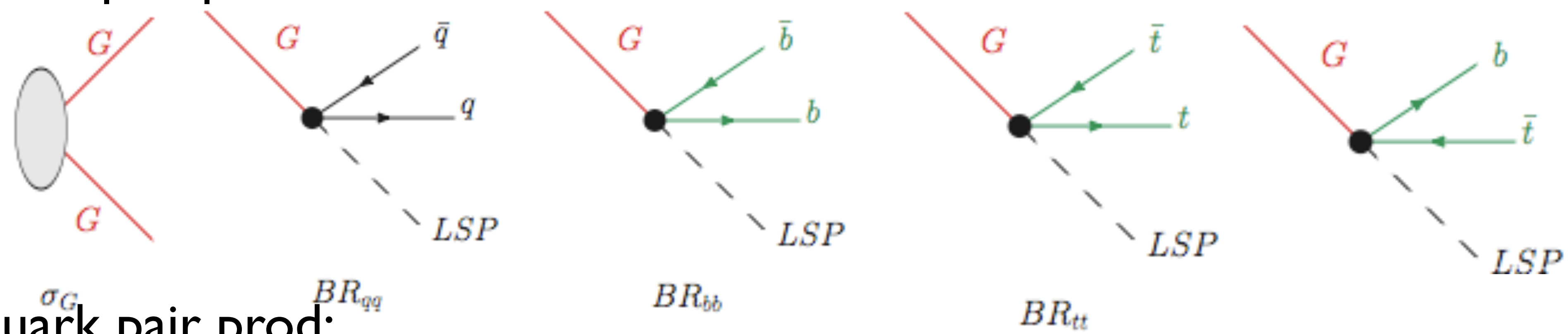
- Decay: various possible depending on other sparticle masses

$$\tilde{b} \to b\tilde{\chi}_1^0 \quad \tilde{b} \to t\tilde{\chi}_1^{\pm} \quad \tilde{t} \to (t/c)\tilde{\chi}_1^0 \quad \tilde{t} \to b\tilde{\chi}_1^{\pm}, bl\tilde{\nu}$$

- Parameters: M(gluino) - M(stop)/M(sbottom) - M(chi0)

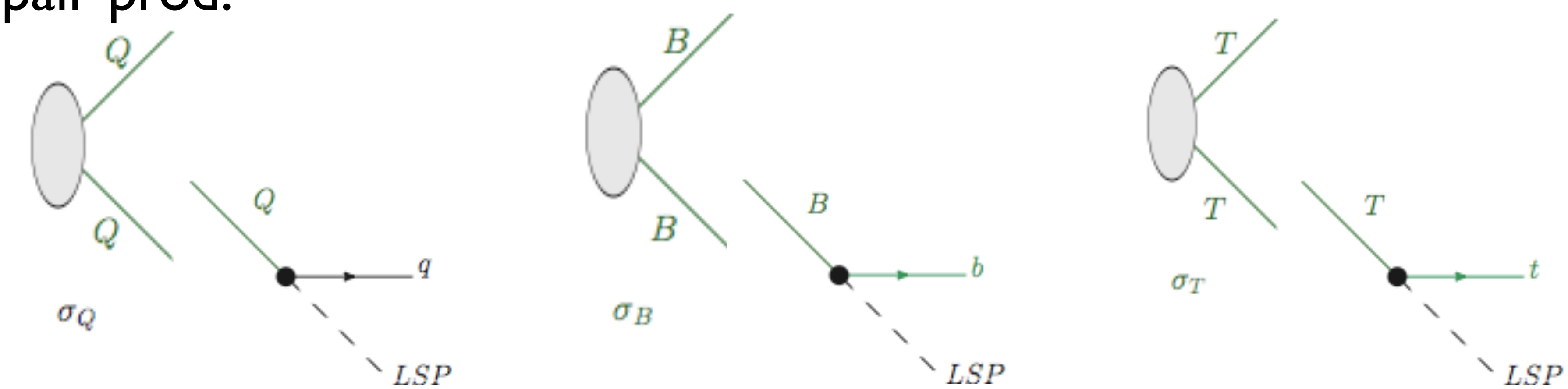
Heavy Flavor Parameters

- Must simultaneously consider all basic production and decay
  - eg gluino pair prod:



M_G
M_{LSP}

  - eg squark pair prod:



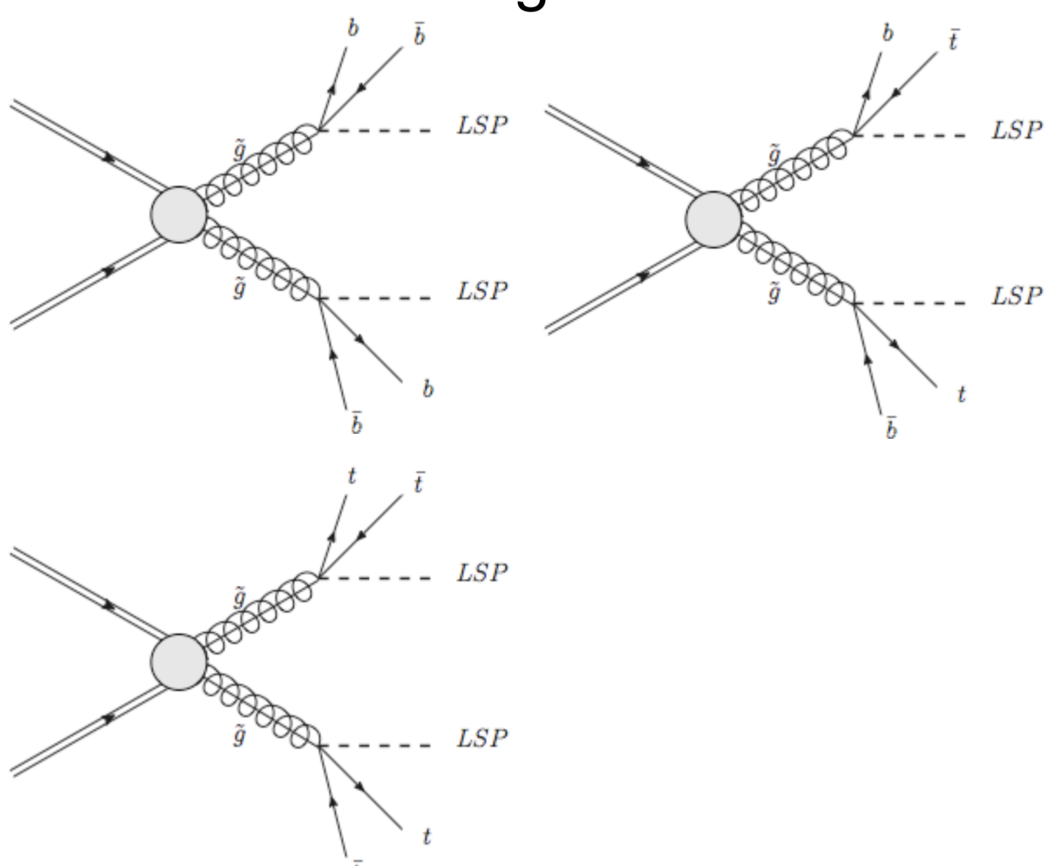
$M_{Q/B/T}$
M_{LSP}

  - Note that parameters are masses
  - Scan cross-sections and branching ratios by weighting events
  - Note that this is a subset of the simplified model case study in e.g. arXiv:0810.3921 which includes wider scope to constrain new physics (e.g. lepton count)

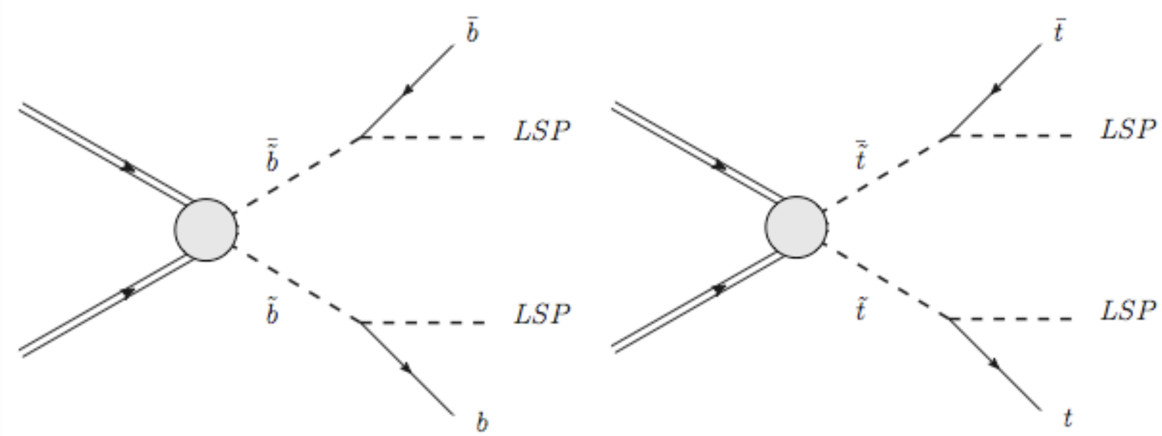
Mapping to Signatures

- Even with heavy flavor restriction, multiple topologies map to each signature
- Here assume 100% branching ratios to b/t (light branching ratio has wider scope)

"4b+MET signature"

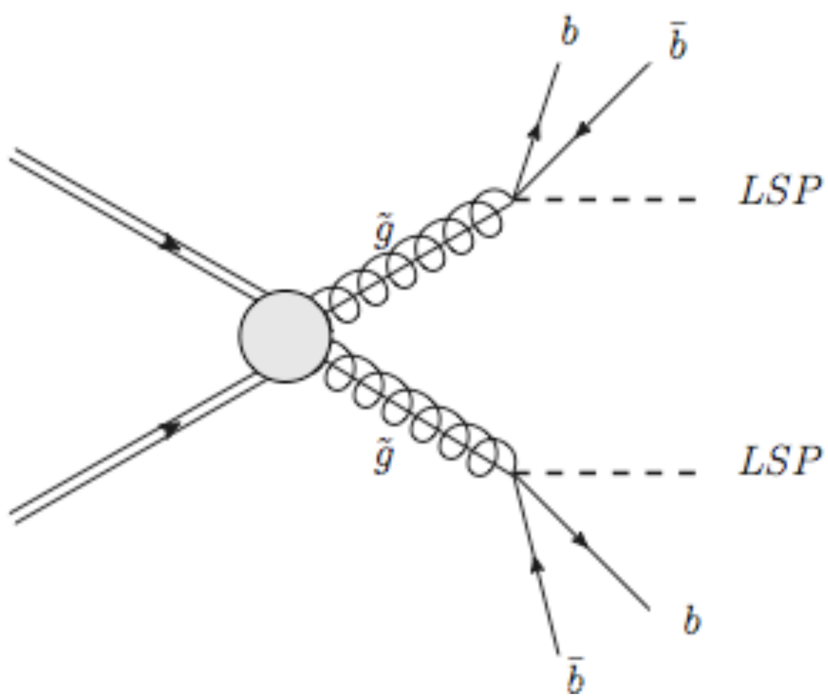


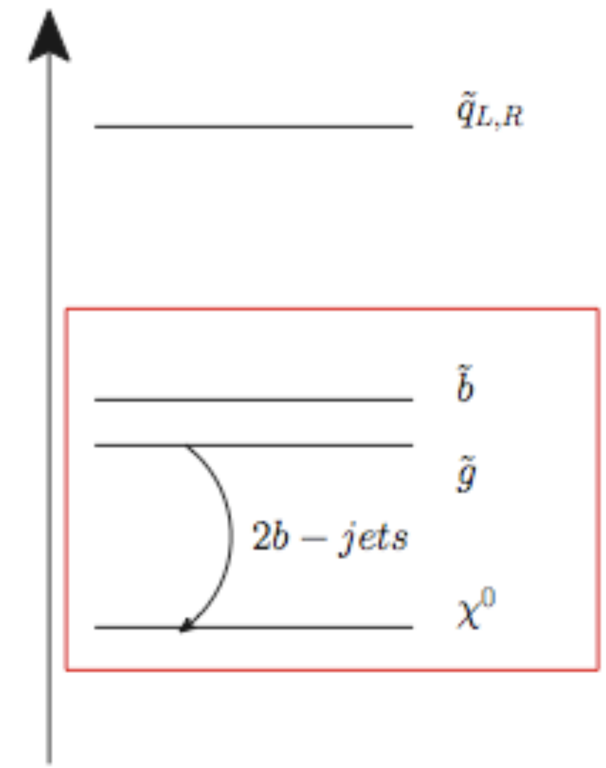
"2b+MET signature"



Let's look at the topologies one by one...

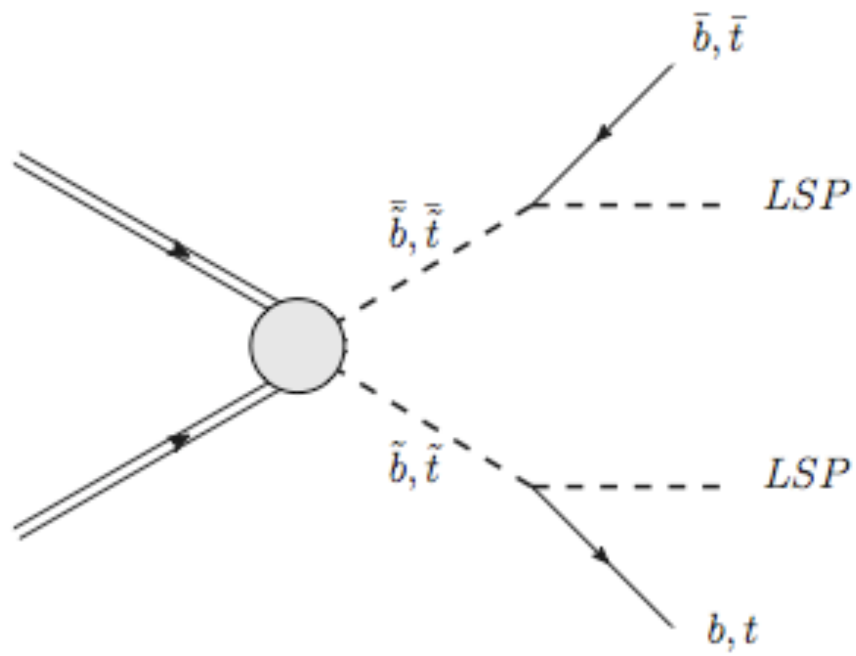
Gluino→ 4b-Jets + MET

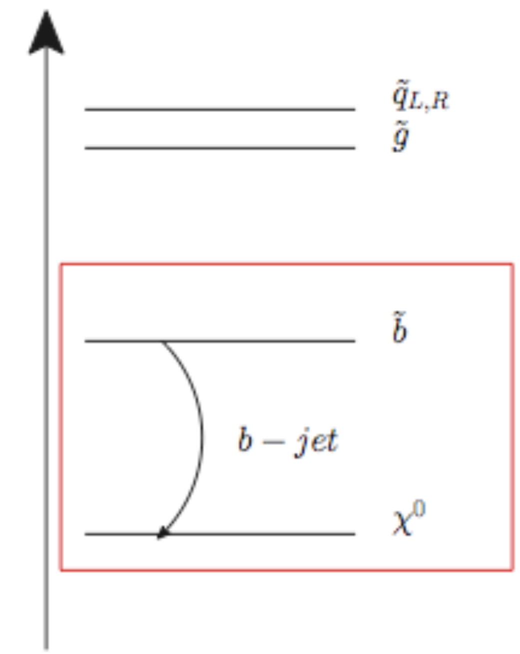




- 4b Jet signature
- We find that:
  - Observables such as Jet pT, M_{eff}, and MET are nearly only sensitive ΔM(~g,χ0)
  - Gluino mass affects mainly cross-section, not sensitivity
  - All 4 leading jets sensitive to mass difference
  - Expect b-jets with low pT

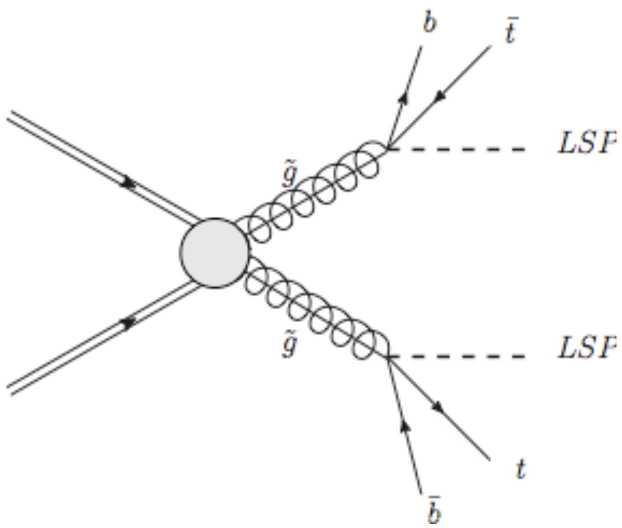
Squark→ 2 b-Jets + MET

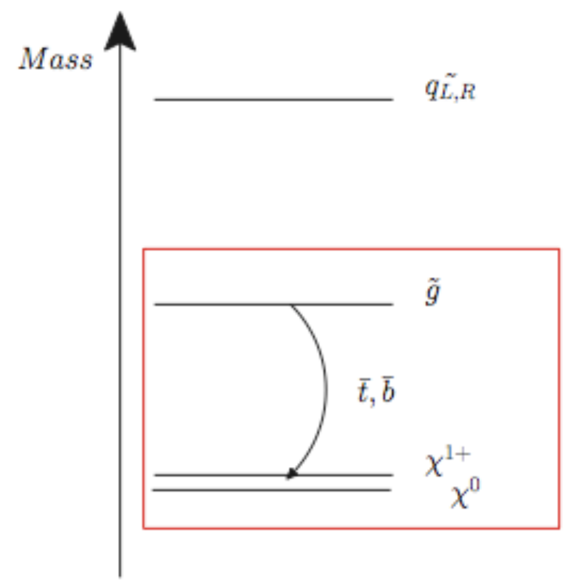




- Considered 2 b-jet signature only
  - 2 stop prod: more complicated final state is possible -> softer b-jets
- We find that:
  - Observables such as Jet pT, M_{eff}, and MET are nearly only sensitive to ΔM(~b,χ0)
  - Squark (partner) mass determines x-section, not sensitivity
  - Two (b-)jets sensitive to mass difference
  - Additional light jets not sensitive to mass difference (see 4th leading jet pT)
  - Low overall jet multiplicity: largely unaffected by mass difference

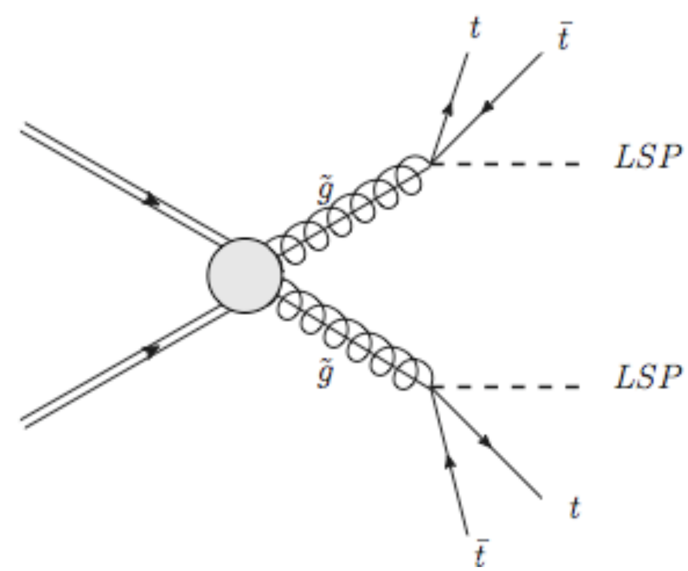
Gluino→ t/b-Jets + MET

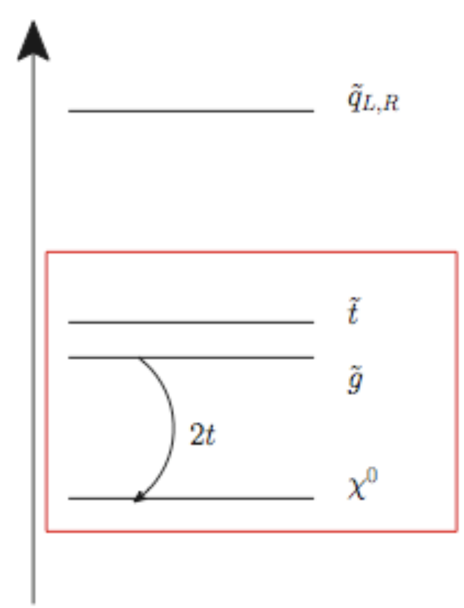




- 2b2t + MET
  - 4 b-jet signature
  - Top production creates more complicated final state
    - Softer b-jets
    - Higher light jet multiplicity
  - ΔM(~g,χ0) still main parameter for jet and MET kinematics
  - Might expect two hard and two softer b-jets

- 4t + MET
  - 4 b-jet + MET signature
  - ΔM(~g,χ0) determines available jet and LSP kinematics
  - Moderated by top decay -> expect less sensitivity to mass difference
    - Softer b-jets
    - High (light) jet multiplicity (low pT)
  - Requires rather large gluino partner mass





Heavy Flavor Analysis Strategy

- Looking at topologies, we can develop an analysis strategy
- Helps trigger optimization
- Hard to create one analysis with good sensitivity in all signatures.
- Example strategy:
  - **Case 1: 2 high pT b-jets + large MET**
    - Can cover topologies
      - B->b+LSP or T->t+LSP w/ large ΔM
      - G->tb+LSP large ΔM
    - Possibly low jet multiplicity
    - Trigger: MET+jets, b-jets
  - **Case 2: 2 low pT b-jets + low MET**
    - Extends into cases with low pT 3rd, 4th b-jet
    - Can cover topologies (generally low ΔM)
      - B->b+LSP or T->t+LSP w/ small ΔM
      - G->2b/2t2b+LSP (small ΔM) and G->2t+LSP
    - Low pT b-tag optimization
    - Event variables
    - Trigger: b-jets,MET+jets
  - **Case 3: 4 high pT b-jets + large MET**
    - Generally 4b signatures with high ΔM
    - Can cover topologies: Gluino->4b and 2t2b
    - High b-tag multiplicity (>=3?, 4?)
    - Small backgrounds?
    - Trigger: b-jet, MET+jets, multijets
  - **Case 4: 4 low pT b-jets + small MET**
    - Generally 4b signatures with low ΔM
    - Can cover topologies: Gluino->4b, 2t2b, 4t
    - High b-tag multiplicity (>=3?, 4?)
    - Small backgrounds?
    - Trigger: b-jets, MET+jets

Future ideas

- Ideas which we are no where close to providing, but may be good long-term goals:
  - Encapsulating our data in a way that can be shared ...
    - eg experiments provide a "Likelihood" with backgrounds properly handled and efficiency (and acceptance?) corrections applied.
    - Theorists "input" a model and get some statistical test.
    - Good way to encapsulate our results for the future
    - Perhaps Kyle Cranmer will mention this tomorrow.
  - Matrix Element Approaches (think top)
    - The simplified models provide a simple enough signal model for us to create ME-based discriminants or fits.
    - If no observation... these will extend our reach.
    - If observation, then this will help extract model parameters.
- We should also develop strategies for extracting model parameters in case of observation
  - Templates, fits, ???

Simplified Models

- Hopefully an outcome of this workshop is some manageable number topologies + parameter spaces and their associated generator files.
- We may also wish to consider centrally generating LHE files which we can share between ATLAS and CMS
  - Use MC Database?
  - ATLAS/CMS can then run them through their Monte Carlo Chain.
- If this happens quickly, we have a good chance of using common simplified models for winter conferences (~45/pb searches)
- In our limited discussions on the topic, there is a clear preference in ATLAS for tools like MadGraph over OSETs
  - From experimental perspective, OSETs aren't any *easier* than MadGraph
  - MadGraph will more correct (eg initial state radiation).

Summary/Remarks

- ATLAS's Signature-based New Physics search strategy covers SUSY (and likely other models) well...
- Current efforts focus on mapping specific signatures to SUSY topologies and reducing the number of dimensions.
  - Furthest along: heavy flavors, Jet + MET, 1 lepton + Jets + MET
  - These efforts will not only help us provide more meaningful interpretations of our results, in some cases (eg heavy flavors) they help us determine the analysis strategy.
- Topologies from this workshop will likely map well to these efforts.
  - ATLAS will consider them, once they are defined (generated?)
- I have not covered all things model-independent... eg limits on dijet signatures ... see Georgios Choudalakis talk today (or next slide).

High Multiplicity Final States

295/nb

ATLAS-CONF-2010-088

- Model Independent Search in final states with high multiplicity.
- Check invariant mass of n≥3 high p_T objects
  - Central Jets p_T>40 GeV
  - e/γ/μ p_T>20 GeV
- *Control Region*: normalize data to MC
  - $\sum pT > 300$ GeV and 300 GeV < M_{inv} < 800 GeV
- *Signal Region*: look for deviations
  - $\sum pT > 700$ GeV and M_{inv} > 800 GeV
- *No deviation from SM*
  - Upper limit (95% C.L.):
    - σ x Acceptance = 0.34 nb