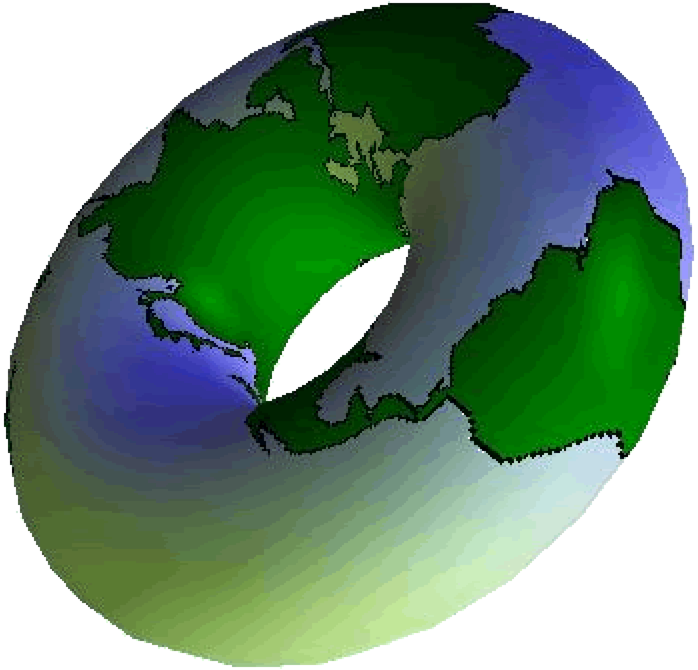
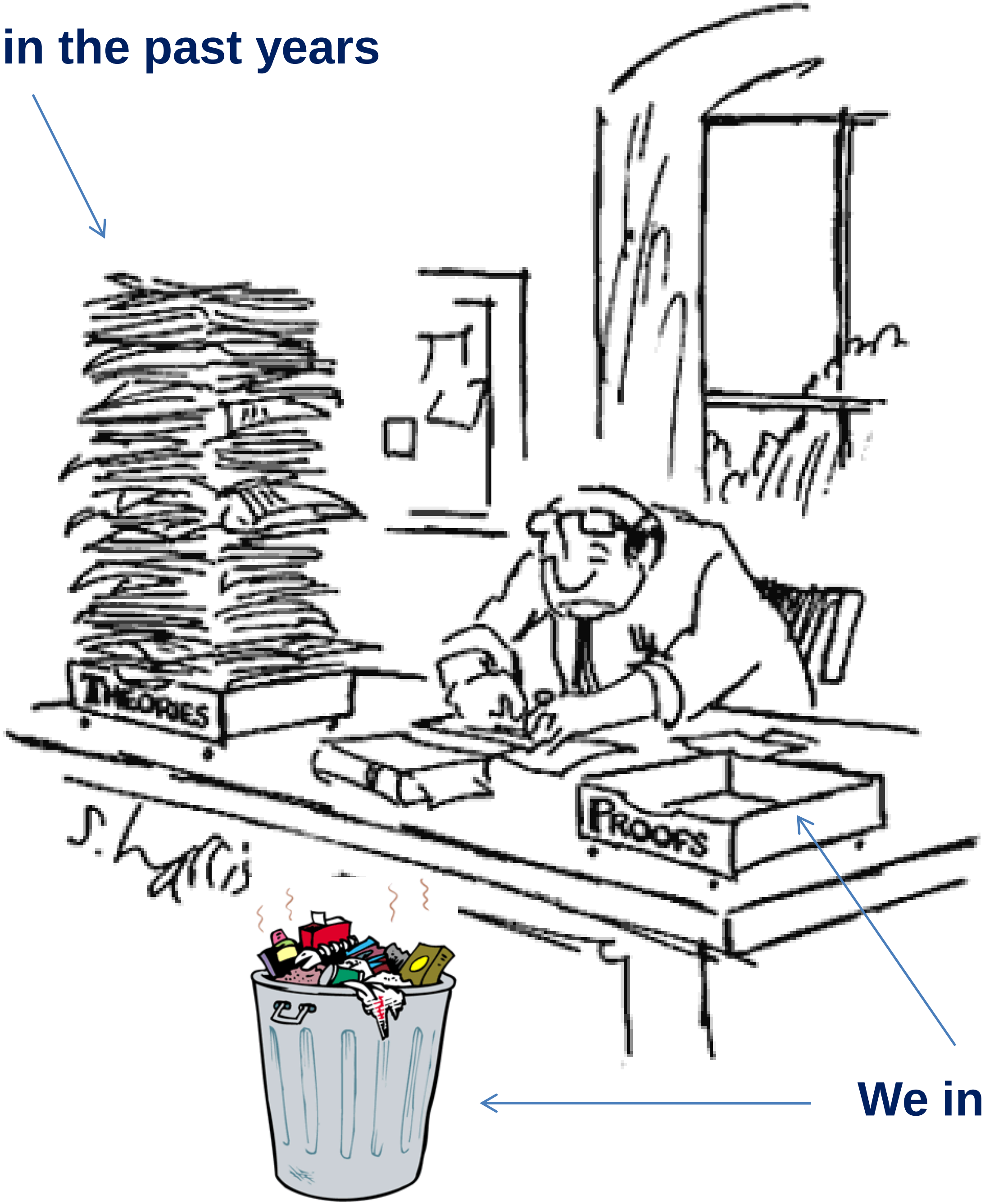
# ATLAS and topology-based searches



**You guys in the past years**




**We in the next years!**

**What is the role of topology-based analyses in ATLAS?**

Not much developed in the past (one notable exception)

Most analyses developed on wide variety of benchmarks in certain models, like mSUGRA / GMSB ("SU4" is such a benchmark point)
Tried to cover most (all?) mSUGRA phenomenology with benchmark variety

+ pMSSM, SO(10), AMSB, RPV, split-SUSY,…
Masses and decay chains, $M_{T2}$ , $M_{CT}$
Non-SUSY BSM searches: usually model-inspired

Starting to fit in topology-based approaches (rest of this talk)
→Generalizing the searches
→Presentation and publication of results
→(Characterizing a signal)

Focus a bit on SUSY searches in ATLAS

It should be noted that also if we use mSUGRA for sensitivity studies,
our search sensitivity is wider than such a model,
and NOT particularly mSUGRA-tuned

See for example Conley, Gainer, Hewett, Le, Rizzo arXiv:1009.2539
and Jamie Gainer's talk in this workshop

| 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
19 parameters, flat prior
Masses up to 1 TeV

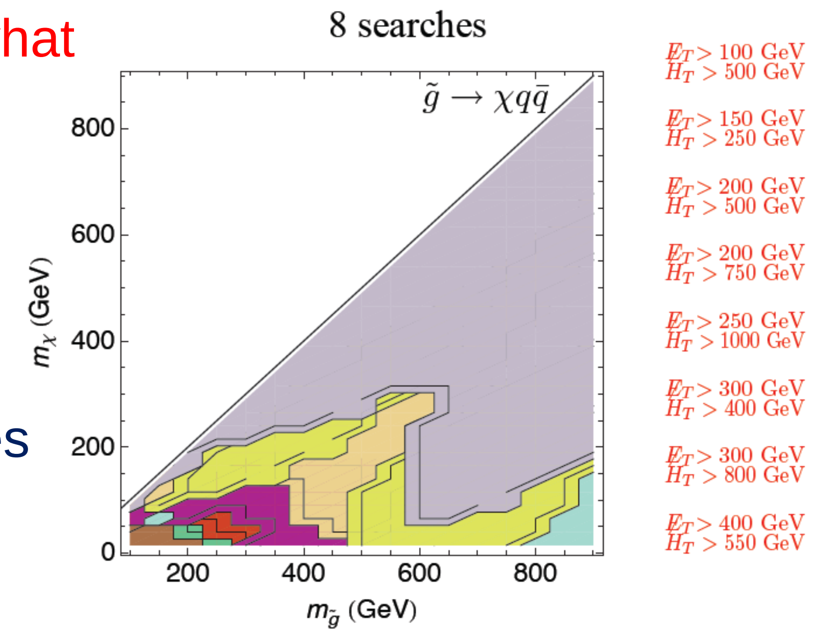
Find 99.6% of pMSSM models

Find 98% in 2 or more analyses

The cuts are also not particularly tuned for a specific region of parameter space.

Doing so could improve sensitivity somewhat

e.g. Izaguirre, Alves, Wacker:




But: runs the risk of: over-tuning
more false positives

Probably <u>stick to a small set of cuts</u>

Nevertheless, this does not mean we can not do better:

- What's up with the pMSSM models we miss?
- What further new physics might we miss?
- It helps to think of topologies to extract the essential features and see where we can improve (strategy, selection cuts, trigger)

Then why so often produce sensitivity contours in mSUGRA/GMSB ?

→ **The key phrase is “Reduction of Number of Dimensions”**

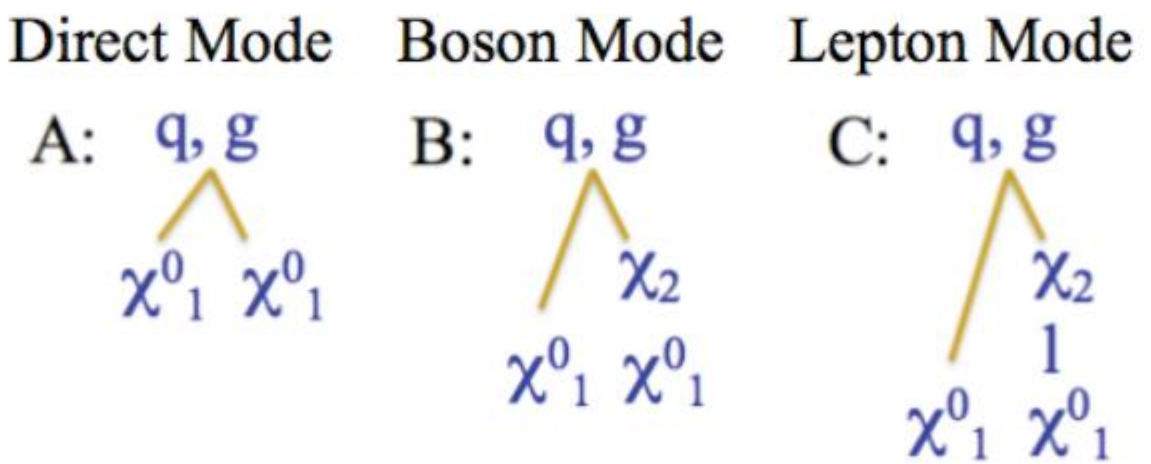
The MSSM has too many parameters, the NMSSM even more so…
The pMSSM still has too many

mSUGRA / GMSB is convenient.
For non-SUSY searches, the same holds for other models
→We will also keep publishing interpretations in models

But we also want to move beyond:
We are considering: pMSSM with further assumptions
topologies
(and often these are almost identical!)

Topology-based searches in ATLAS initiated by Claus Horn (SLAC)

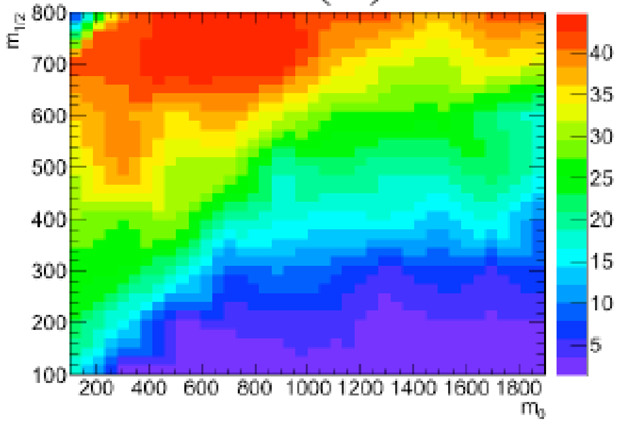
Topologies as “eigenmodes” of squark/gluino decays



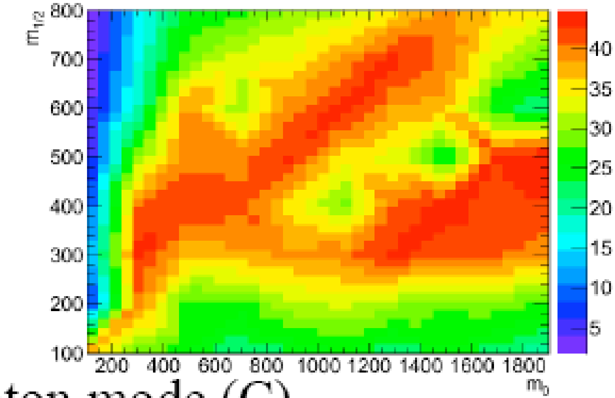

**Legenda: q,g : squark, gluino**
**chi2: neuralino2 or chargino1**
**l : slepton**
**chi1: invisible LSP**
**chi2 → chi1 via emission of W/Z in mode B**

# Eigenmode Coverage in mSUGRA

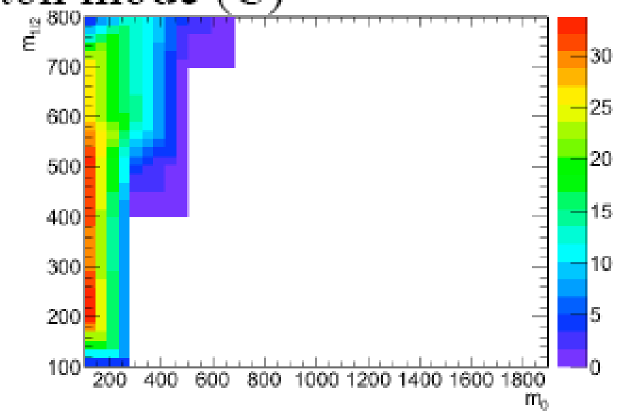
direct mode (A)




boson mode (B)



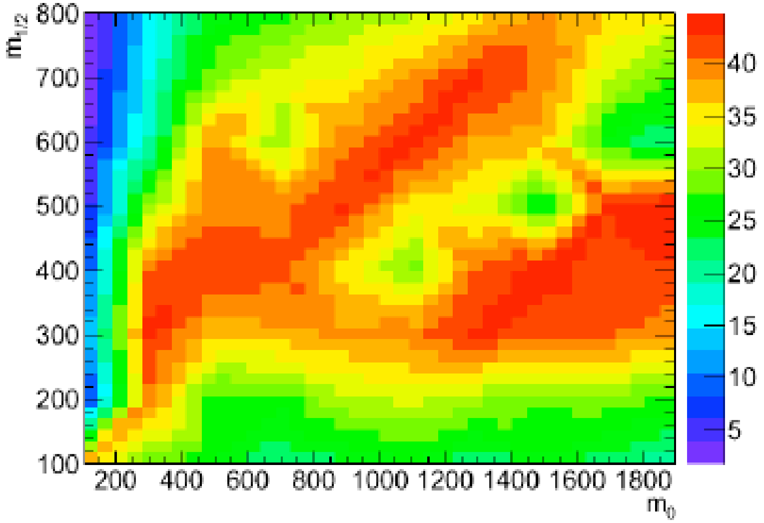

lepton mode (C)



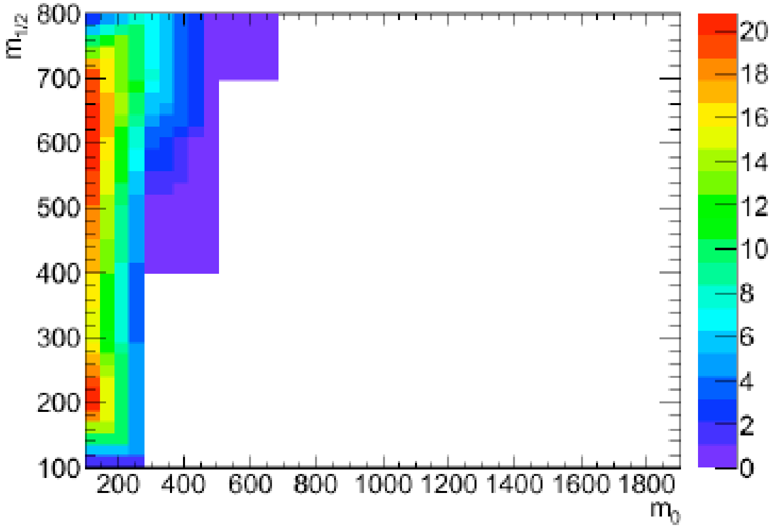

All plots for tanβ=10, μ>0 and 500 evts/point.

# Long Symmetric Modes

double boson mode

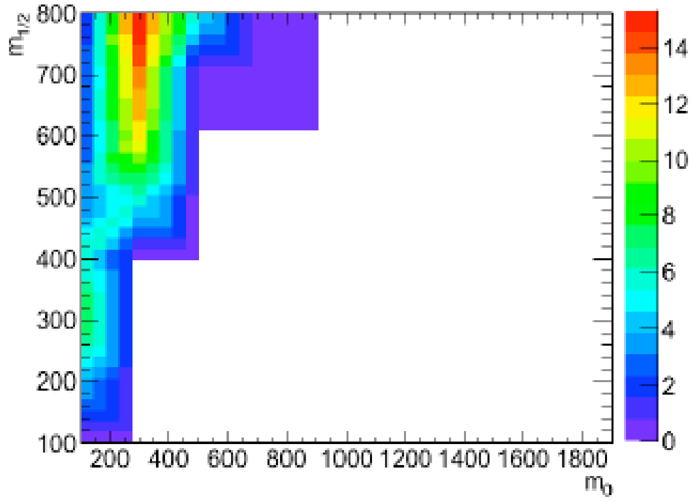



double lepton mode

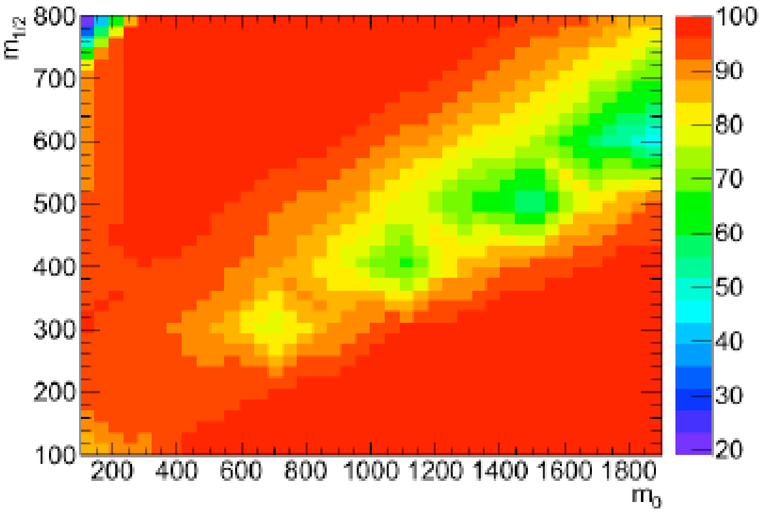


# Other Modes

mixed boson-lepton mode




all (A+B+C+bb+cc+bc) modes



## Searches largely organized according to object and signature

Object: electron, muon, tau, photon, jet, b-jet, MET, displaced vertex, CHAMP,…

Signatures:
- jets + MET
- 1 lepton + jets + MET
- di-leptons: OS + jets/MET (/ = AND/OR)
  - SS + jets/MET
  - inclusive SS
- tri-leptons + jets/MET (includes >3 leptons)
- photon + jets/MET
- di-photons + jets/met
- photon + lepton
- tau(s) + jets + MET
- b-jets + MET
- Z + MET
- multi-jets (no MET)
- lepton + jets (no MET)
- displaced vertex + jet
- di-jet (resonant, non-resonant)
- di-lepton (resonant), lepton + MET, ….

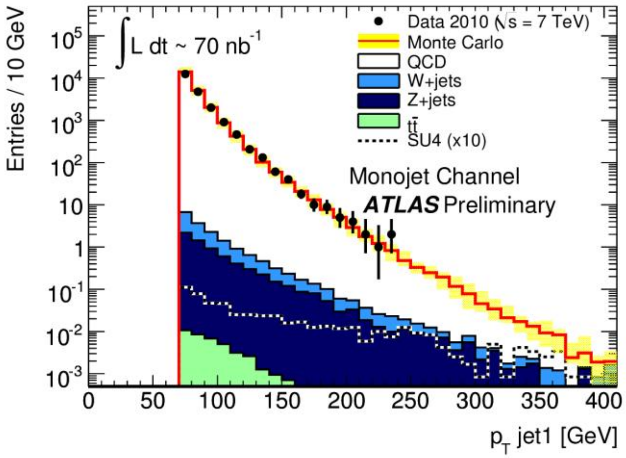
(non-exhaustive list…)

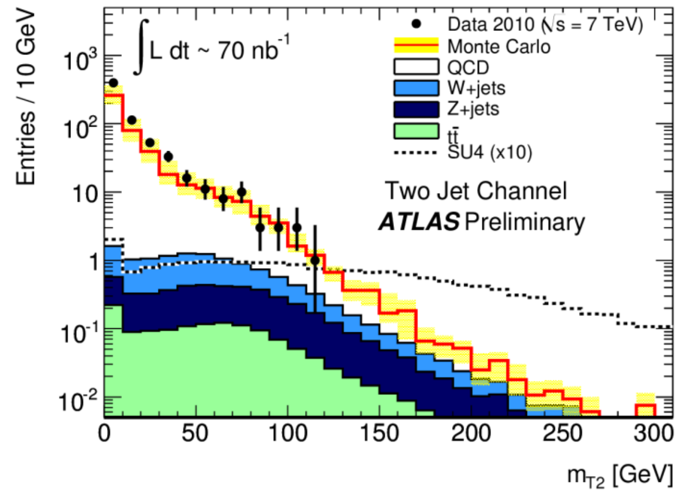
## Discuss a number of signatures and see where topologies can help

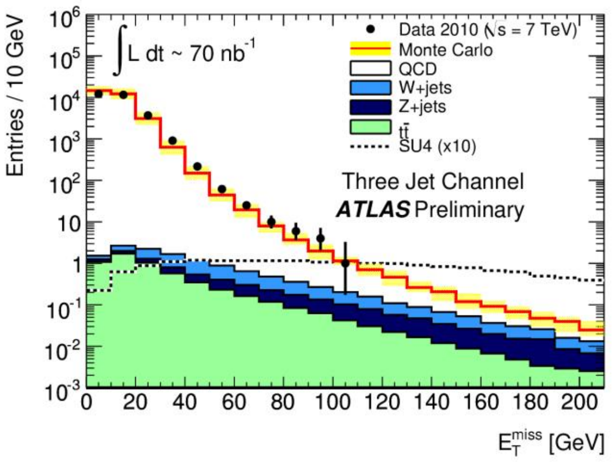
Jets + MET (no leptons)
1 lepton + jets + MET
Multileptons + MET
B-jets + MET

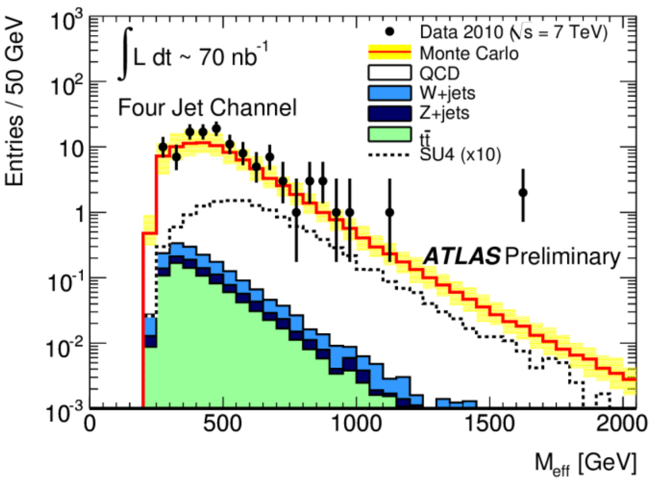
And I will end with general remarks and questions to you…

# SUSY searches in jets + MET channel (with lepton veto)
# ATLAS@ICHEP 2010

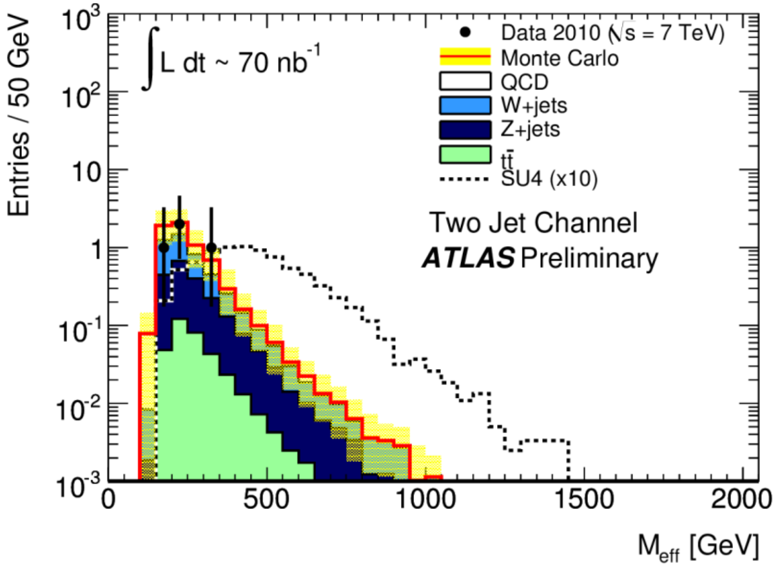


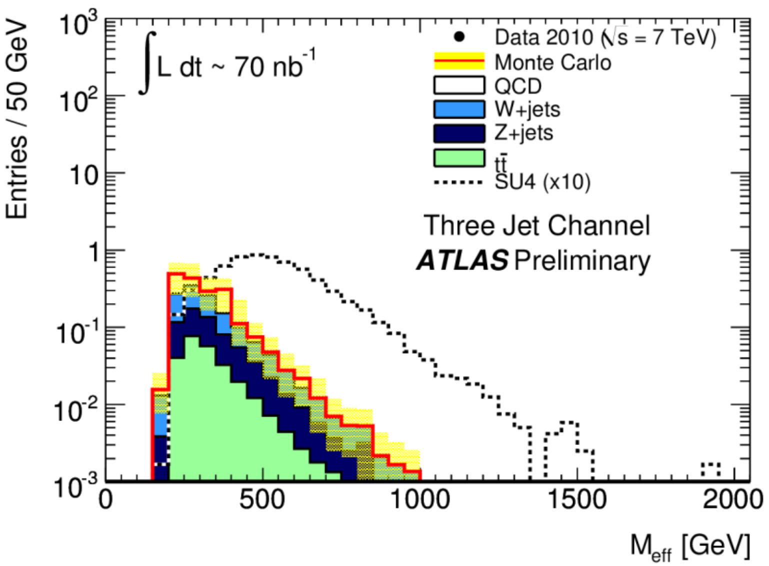



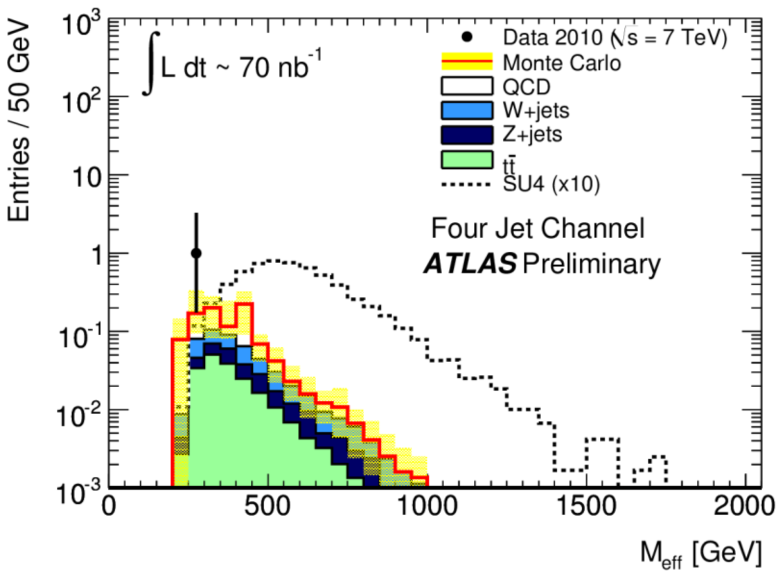



# And after selection cuts:



**ICHEP 2010: appetizer of what is to come!**

Just distributions, no interpretation.
Not optimal → theory community will interprete with PGS
**You should not need PGS to interprete our results!**
The actual ATLAS simulation is MUCH more complex than PGS
Data and MC agree with each other through hard labor on MC…

<u>Challenges for the paper on 2010 data set</u>:

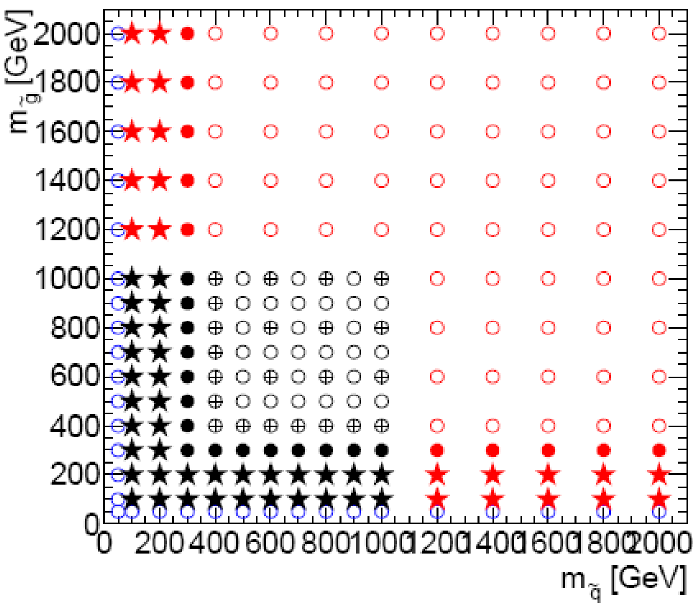
background estimations and systematics without MC
→ data-driven methods
need statistics, starts to be possible now

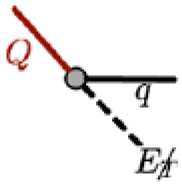
model-independent sensitivity

interpretation and presentation

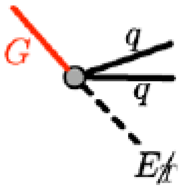
# 3 "topology-motivated" grids for 0-lepton channel

A)




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




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

Assume $\tilde{\chi}_1^0$ light: 0, 50, 100 GeV

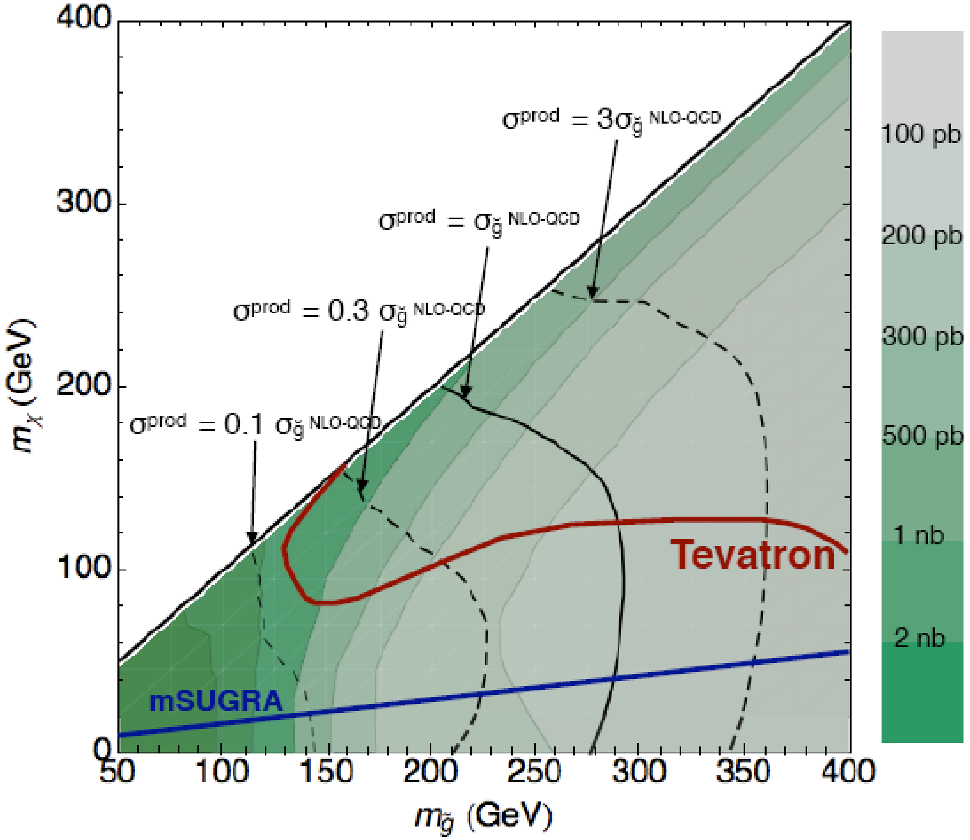
Assume other gauginos heavy

B) $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$ In a grid of m(gluino) vs m(chi0), assuming other masses high

C) $\tilde{q} \rightarrow q\tilde{\chi}_1^0$ In a grid of m(squark) vs m(chi0), assuming other masses high

**B en C good for compressed spectra: tune cuts & generalize the search**

# Use these grids also for interpretation




Upper limits on the effective cross section

In plane of m(gl)-m(chi0)

Or m(gl)-m(gl-chi0)

And idem for the two other grids: m(sq) vs m(gl), m(sq) vs m(chi0)

## One lepton + jets + MET

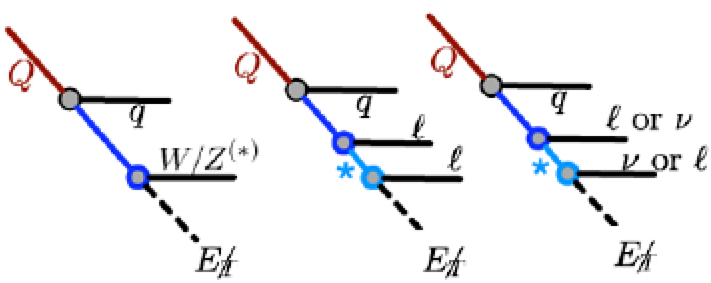
$$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_2^0 \qquad \tilde{\chi}_2^0 \rightarrow (Z^{(*)}/h)\tilde{\chi}_1^0 \qquad \tilde{\chi}_2^0 \rightarrow \tilde{l}\,l \rightarrow ll\tilde{\chi}_1^0$$

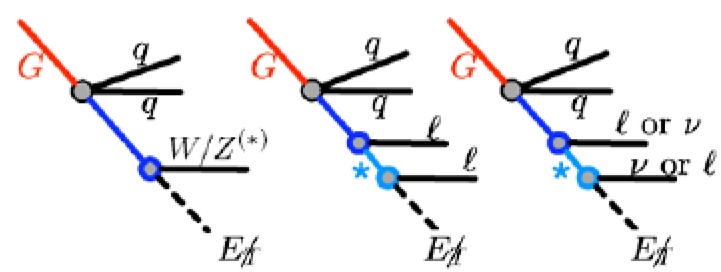
$$\tilde{g} \rightarrow q\bar{q}'\tilde{\chi}_1^{\pm} \qquad \tilde{\chi}_1^{\pm} \rightarrow W^{(*)}\tilde{\chi}_1^0 \qquad \tilde{\chi}_1^{\pm} \rightarrow \tilde{l}\,\nu \rightarrow l\nu\tilde{\chi}_1^0$$

$$\tilde{q} \rightarrow q\tilde{\chi}_2^0$$

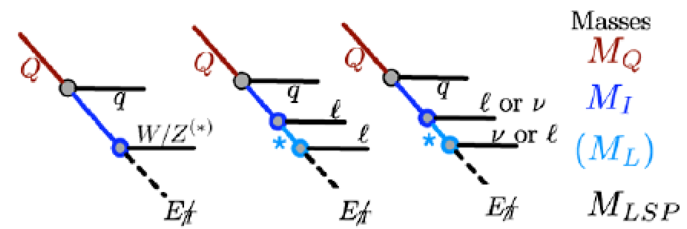
$$\tilde{q} \rightarrow q'\tilde{\chi}_1^{\pm}$$

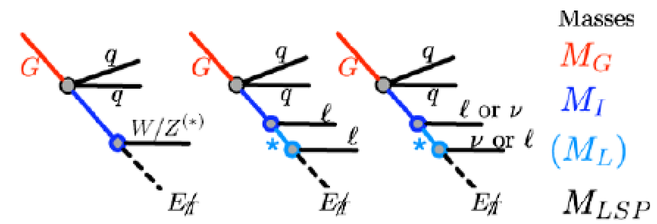
+ similar decays



**A grid to tackle this:**




M(sq) – M(chi2/chi+-) – M(chi1)
M(sq) – M(chi2/chi+-) – M(sl) – M(chi1)

Assuming gluino very heavy

M(gl) – M(chi2/chi+-) – M(chi1)
M(gl) – M(chi2/chi+-) – M(sl) – M(chi1)

Assuming squark very heavy

And assuming chi1 is ~bino, chi2 is ~wino, M(chi2)=M(chi+-)

Leptonic W/Z decays: lepton(s) + jets + MET signature
Hadronic W/Z decays actually belong to jets + MET (0-lepton) signature

## Di-leptons

More complicated!

$$\tilde{\chi}_2^0 \rightarrow (Z^{(*)}/h)\tilde{\chi}_1^0$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}\, l \rightarrow ll\tilde{\chi}_1^0$$

Partly covered by same grid as 1 lepton
But possibly more topologies
Investigating, help from this workshop?
Especially interested in topologies for same-charge di-leptons

## Tri-leptons

EW-ino modules are a start, but not studied yet

## Searches with b-tagged jets

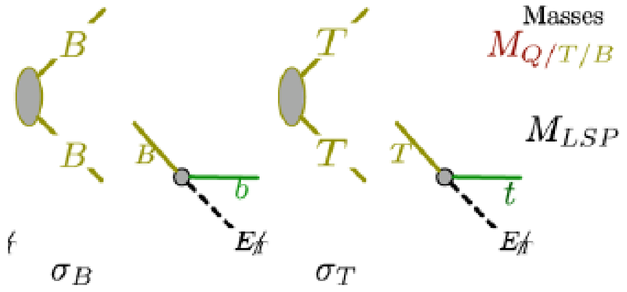
Strong production of b, t partners: $\tilde{b}\bar{\tilde{b}}, \tilde{t}\bar{\tilde{t}}$

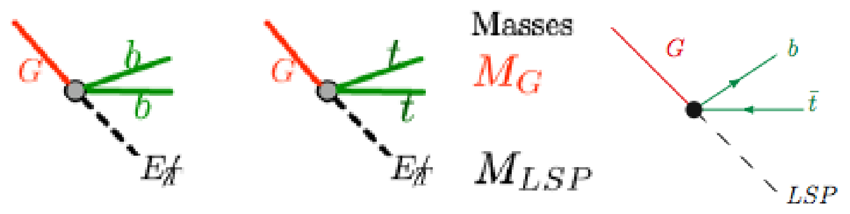
Or gluino production: $\tilde{g} \rightarrow t\tilde{t} \quad \tilde{g} \rightarrow b\tilde{b}$

A number of decay modes are possible, depending on masses other sparticles:

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

**Simplified models:**




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

# Heavy flavor simplified models (1)

- Signature of 0-leptons, jets and MET energy with heavy flavor
- Search everywhere
  - What kinematics are expected
- Analysis strategy
  - What kinematics are we sensitive to
  - Specific challenging regions of kinematics
  - Trigger
- Use simplified models to help understand basic features

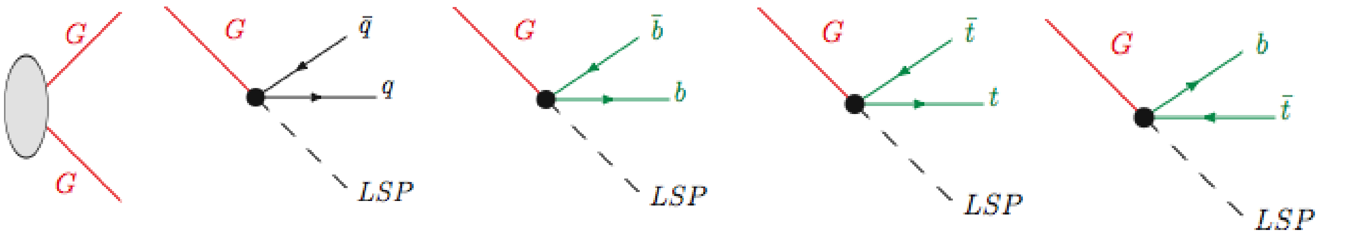
**Preliminary analysis of what simplified model can do for b-jet SUSY search**

# Heavy flavor simplified models (2)

- Consider basic pair production and decay

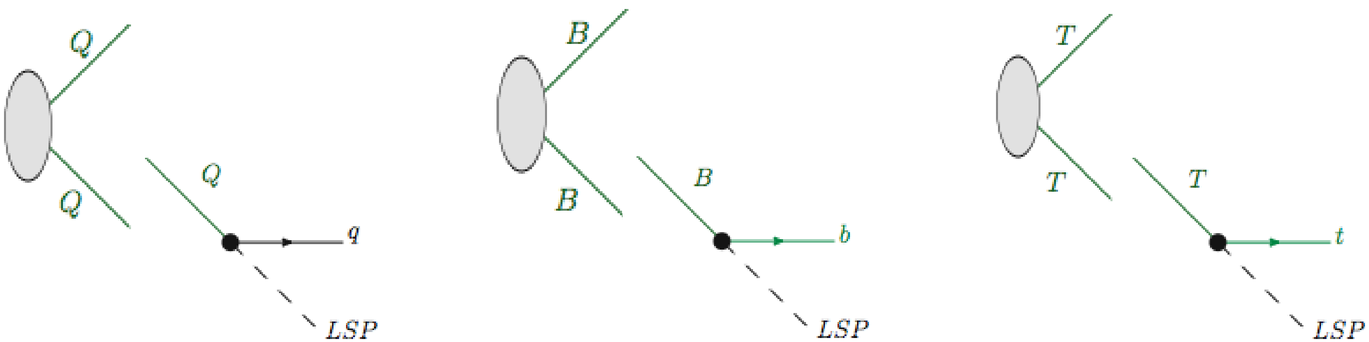
*From gluon partner*

Masses




$M_G$
$M_{LSP}$

*From quark partner*



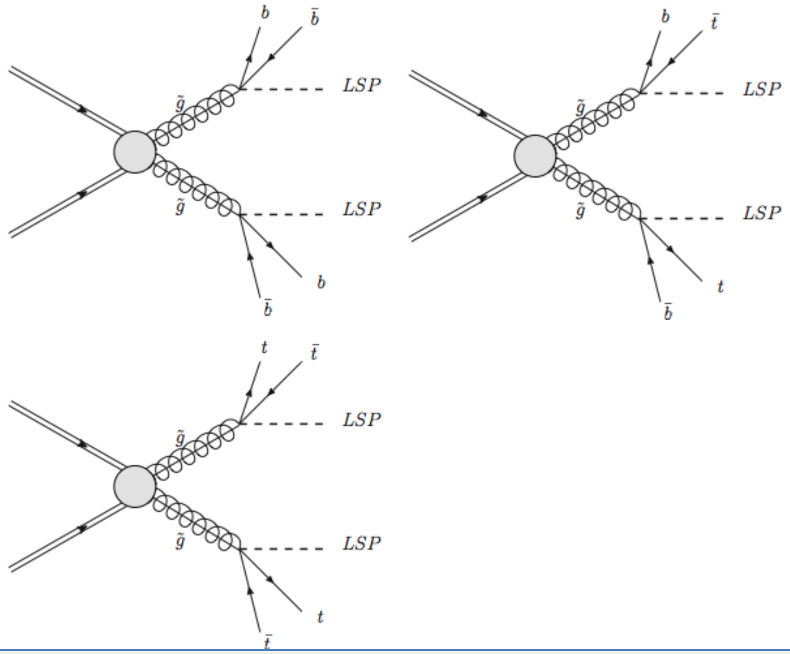

$M_{Q/B/T}$
$M_{LSP}$

- Note that parameters are masses; cross-sections and branching ratios can be achieved 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)

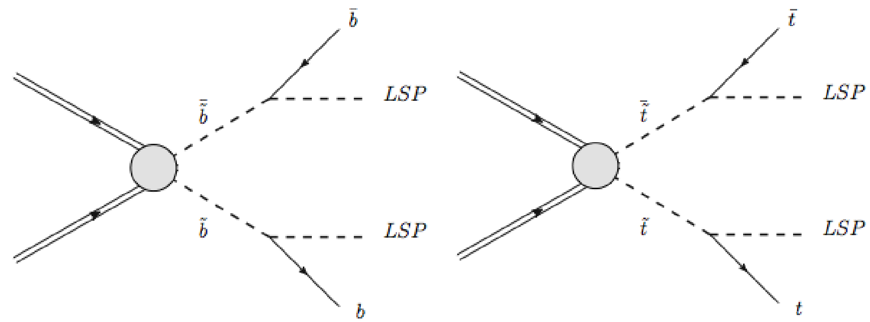
# Heavy flavor simplified models (3)

- Even basic rules (with heavy flavor restriction) give rise to large set of topologies
- Here: 100% branching ratios to b/t (light branching ratio has wider scope)

“4b+MET signature”

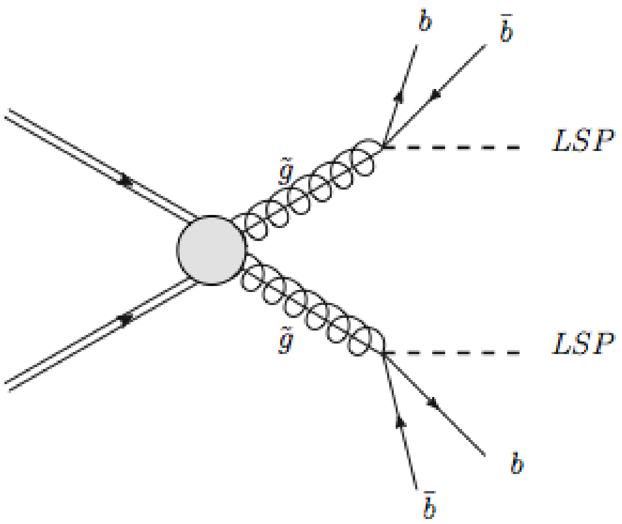


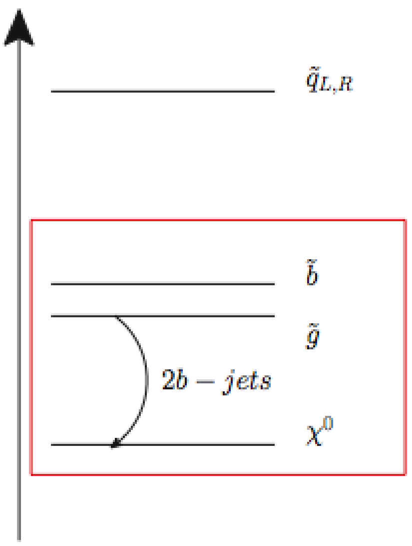

“2b+MET signature”




- “Look in all places”: understand sensitivity for all dominant signatures

# Gluino production: 4b+MET

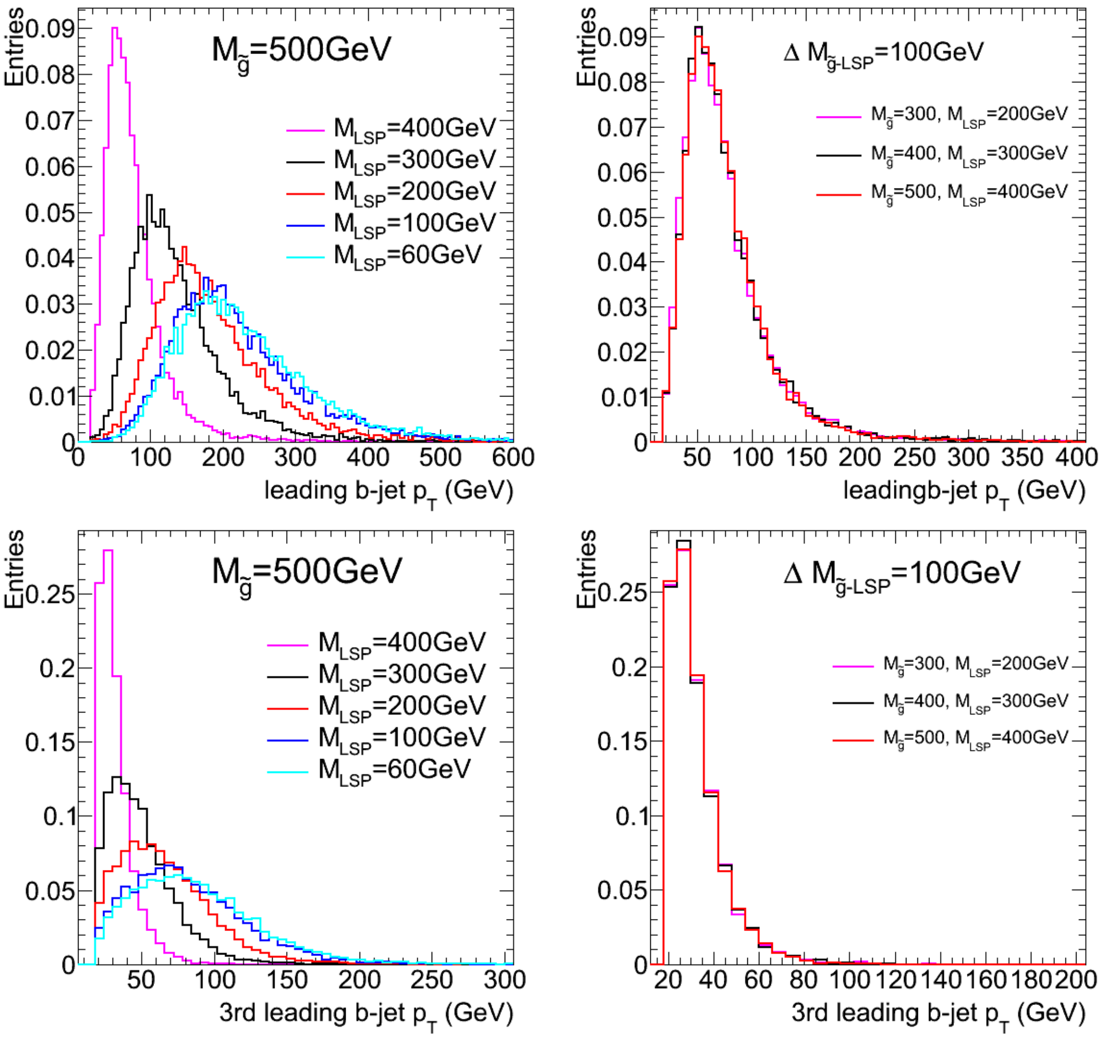



- 4 b-jet + MET signature
- $\Delta$M(~g,$\chi^0$) determines jet and LSP kinematics
- Gluino mass affects mainly cross-section, not sensitivity

# Gluino production: 4b+MET

## *(b-)jet kinematics*

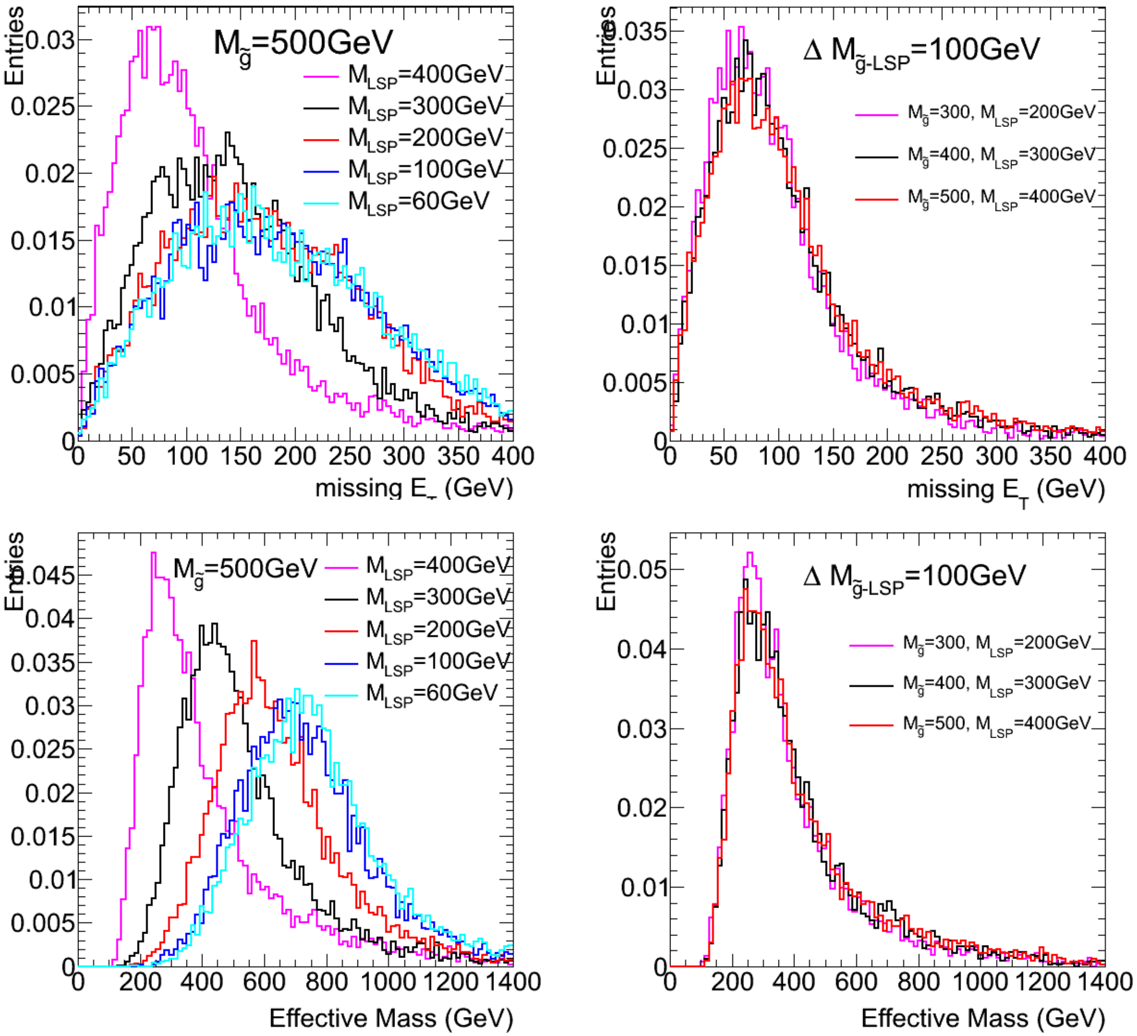



All 4 leading jets sensitive to mass difference

**Expect b-jets with low pT**

# Gluino production: 4b+MET

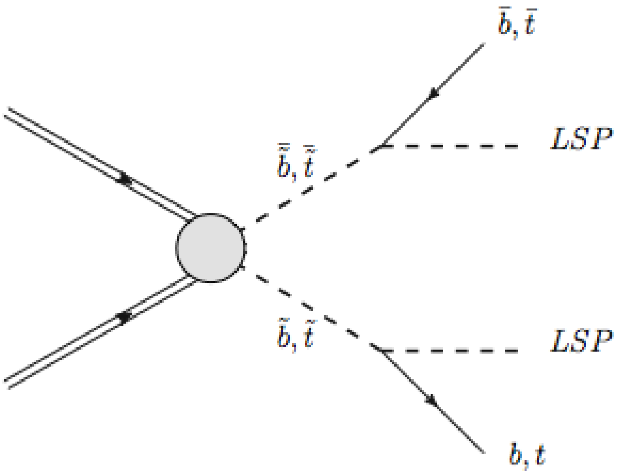
***MET/$M_{eff}$***

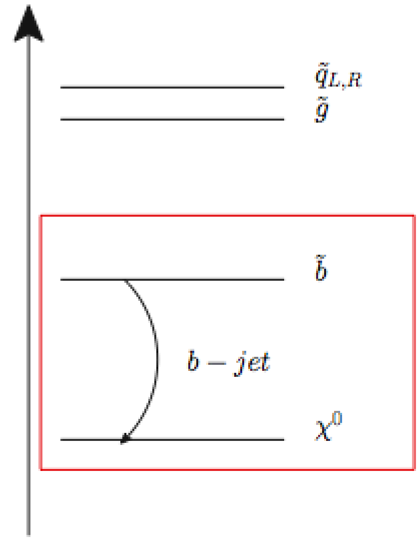



Similar mass difference dependence follows for MET and effective mass

Little less pronounced for MET due to the 2b-jets

# Squark production: 2b+MET



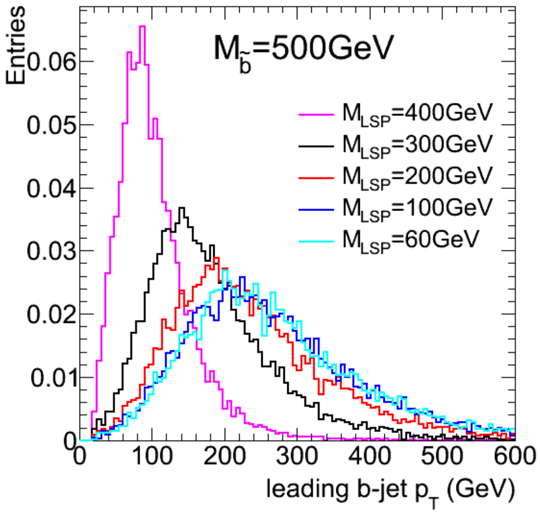



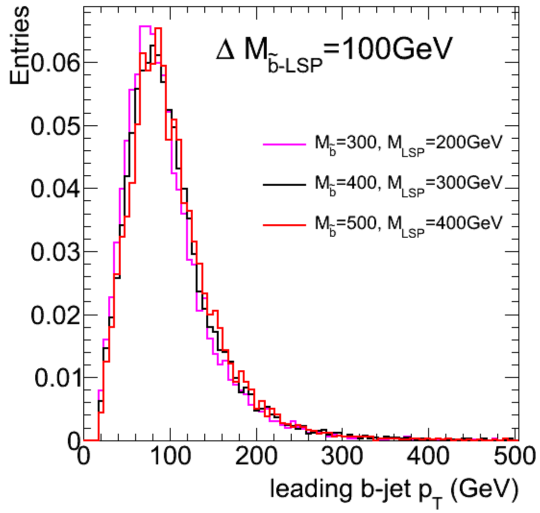

**(consider only sbottom here)**

- 2 b-jet signature
  - (2 stop prod: more complicated final state is possible -> softer b-jets)
- $\Delta M(\sim b, \chi^0)$ determines jet and MET kinematics
  - Squark (partner) mass determines overall normalization
- Expect two (hard) b-jets from direct decay + soft additional light jets
- Additional jets not sensitive to mass difference

# Squark production: 2b+MET

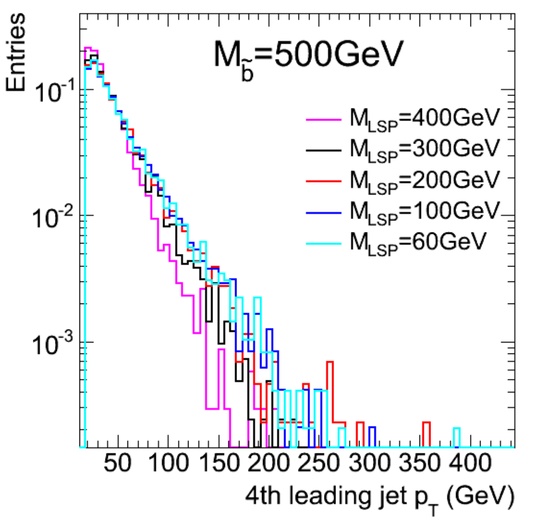
## ***(b-)jet kinematics***

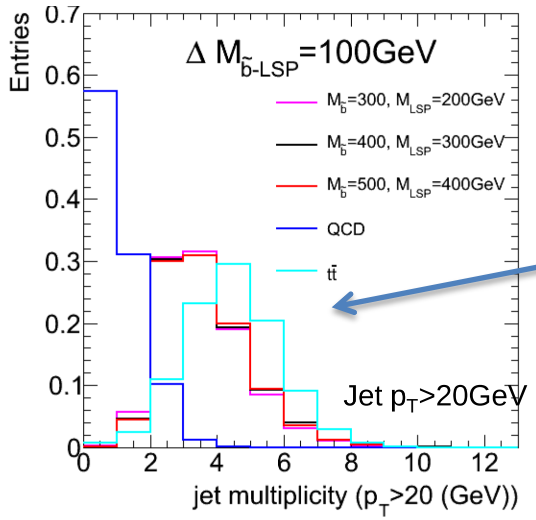



Two (b-)jets sensitive to mass difference

Additional light jets not sensitive to mass difference (see $4^{th}$ leading jet $p_T$)

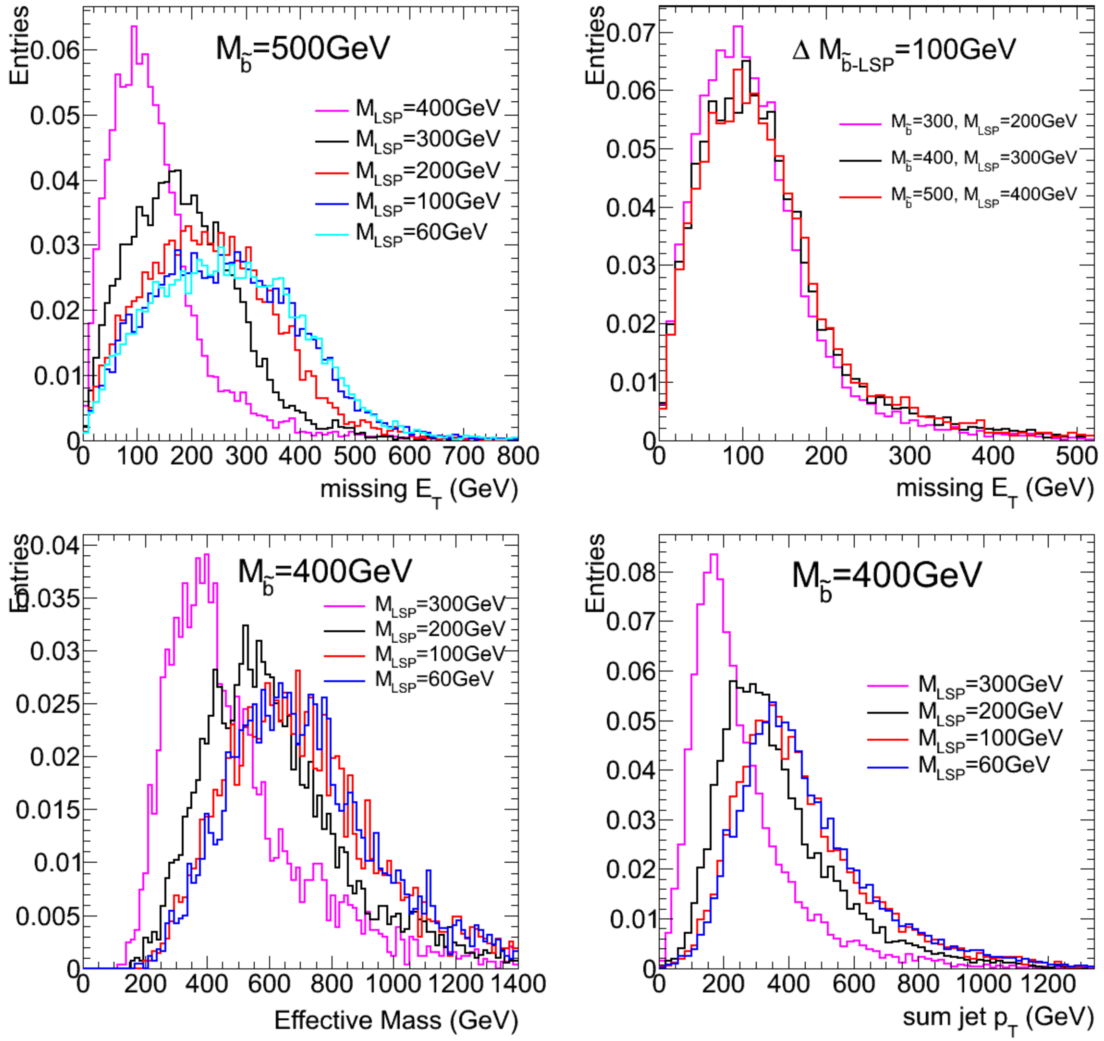



Low overall jet multiplicity: largely <u>unaffected</u> by mass difference

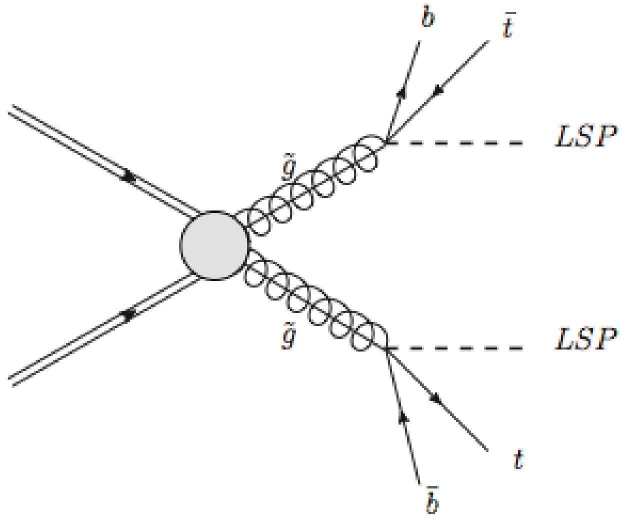
# Squark production: 2b+MET

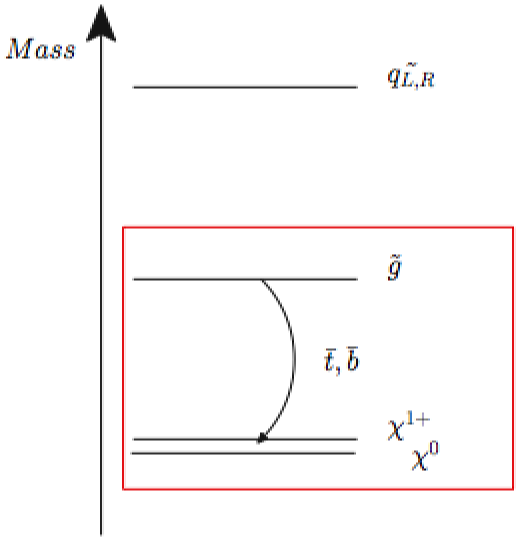
## ***MET/M$_{eff}$/H$_T$***




Similar dependence on mass difference

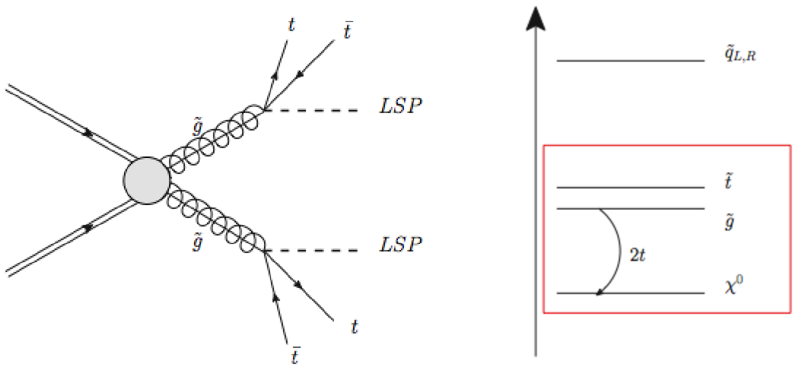
# Gluino production:2b2t+MET

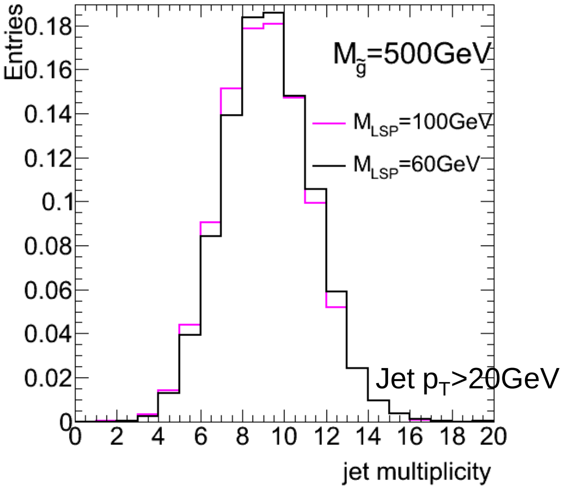


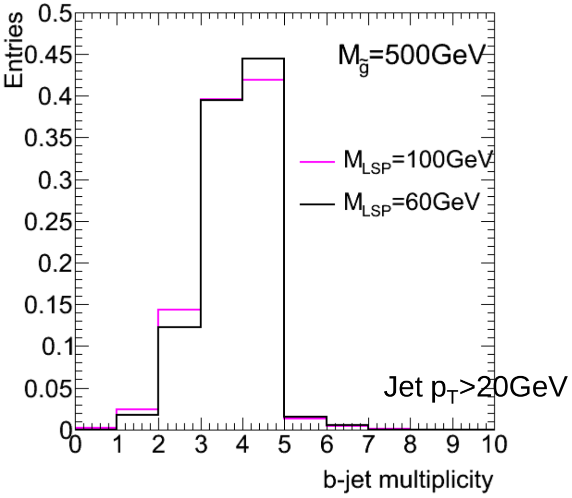

- 4 b-jet signature
- Top production creates more complicated final state
  - Softer b-jets
  - Higher light jet multiplicity
- $\Delta$M(~g,$\chi^0$) still main parameter for jet and MET kinematics
- Might expect two hard and two softer b-jets

# Gluino production: 4t+MET

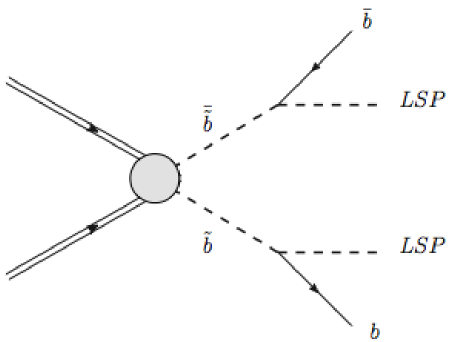


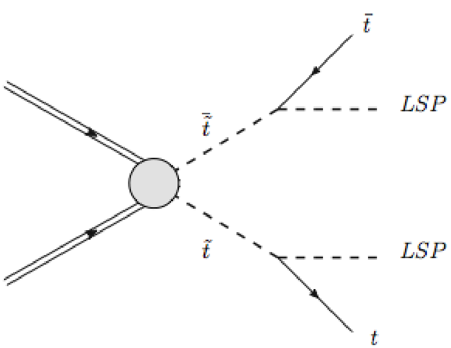

- 4 b-jet + MET signature
- ΔM(~g,$\chi^0$) determines available jet and LSP kinematics
- Moderated by top decay -> expect less sensitivity to mass difference
  - Softer b-jets
  - High (light) jet multiplicity (low pT)
- Requires rather large gluino partner mass



# Summary of "2b-topologies"

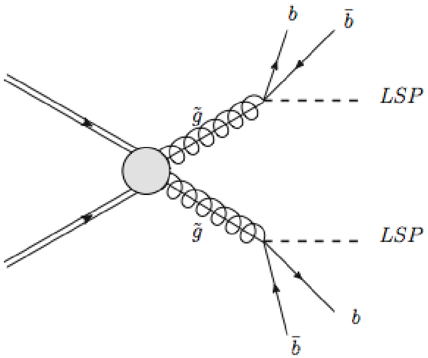



- Two b-jets
- Low jet multiplicity (~independent of ΔM)
- Mass difference governs (b-)jet kinematics
  - 2 hard b-jets + high MET
  - 2 soft b-jets + low MET

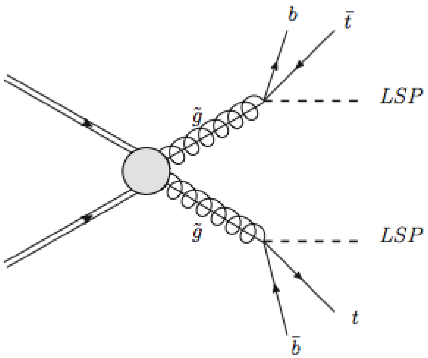



- Two b-jets
- Higher (light) jet multiplicity
- Mass difference governs (b-)jet kinematics
  - 2 hard b-jets + high MET + softer light jets
  - 2 soft b-jets + low MET+ softer light jets

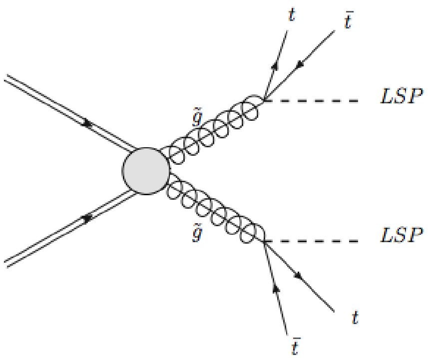
# Summary of “4b-topologies”




- Many (4) b-jets: all sensitive to ΔM
- Low light jet multiplicity
- Mass difference governs (b-)jet kinematics
  - 4 harder b-jets + high MET
  - 4 soft b-jets + low MET




- Four b-jets
- 2 b-jets less sensitive to ΔM
- Higher (light) jet multiplicity
- Mass difference governs (b-)jet kinematics
  - Harder b-jets + high MET
  - Less effect on light jets




- Four “medium-hard” b-jets
- b-jet kinematics less sensitive to ΔM
- High light jet multiplicity

# Search strategy

- Simplified models allows to see that qualitatively very different topologies need to be covered
  - Different number of b-jets
  - Jet $p_T$ and MET spectrum varies over large range
- Trigger optimization can benefit
- Backgrounds will be very different
- Hard to use one analysis with (good) sensitivity in all signatures
  - b-tagging optimization, missing $E_T$ and jet kinematic selection
  - A good discriminating variable in one case can be useless in another e.g. Pt2ratio, $M_{eff}$ (see next slide)
- Try to design search strategy based on the qualitative features observed
  - Understand “overlaps” in topologies

# Example of analysis strategy

**Case 1: 2 high pT b-jets + large MET**

- Can cover topologies
  - B->b+LSP orT->t+LSP w/ large ΔM
  - G->tb+LSP large ΔM
- Possibly low jet multiplicity
- Trigger: MET+jets, b-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 2: 2 low pT b-jets + low MET**

- Extends into cases with low pT 3$^{rd}$, 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 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

## Some experimental constraints in optimizations:

Leptons: minimum $p_T$ defined by trigger
acceptance of tracking detectors
fake rates depend on $p_T$ , $\eta$, busy-ness of event

Jets: if no lepton to trigger event: single jet / MET / multi-jet / jet+MET triggers
define the minimum $p_T$ threshold
jet finding efficiency depends on $p_T$ , $\eta$; drops at low $p_T$
jet energy scale calibration: more difficult at low $p_T$
b-tagging efficiencies: depend on $p_T$ , $\eta$
rely on understanding tracking: improving in time

The ATLAS detector simulation treats this correctly
+ pile-up, noise, changing beam-spot, changing detector configurations,…
PGS does not

## Questions/Requests to you:

-We need a map between signatures and topologies

-Topologies for multi-leptons, in particular same-charge di-leptons

-Topologies that predict “weird” signatures that we otherwise might miss

-Are taus just like other leptons, or do they deserve special topologies?

-Non-SUSY BSM topologies without MET
(actually also for RPV SUSY)

-Your continuing input on how to present results is welcome.
Especially if the number of free parameters > 3
Especially for signatures with a complicated map to topologies

**- THE END -**