Model Independent Characterization of New Physics with Early Data

Philip Schuster (SLAC)

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work with Johan Alwall and Natalia Toro (arXiv:0810.3921)

Model-Independence?

For searches, model-independent means "recyclable":

Results should allow multiple model comparisons to broadly applicable exclusions

If a signal is observed, then what?

Characterizing New Physics

With a signal, the pretense behind "model-independence" is absent

There's only one model of nature -- we want to identify it!

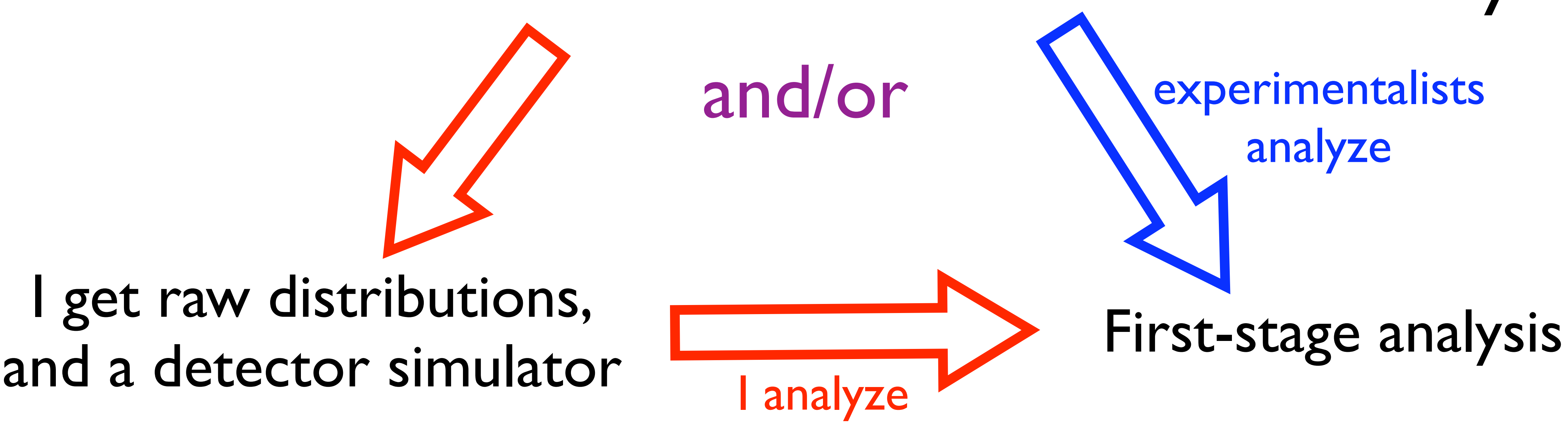
The point should be to describe the data, then draw and test inferences

One Theorist's Perspective

To learn what model describes nature, I want to check consistency of the data with a wide variety of guesses

I'm not an experimentalist, not a detector expert, and not particularly experienced doing careful exp. analysis

Is there a form of the data that I can study?



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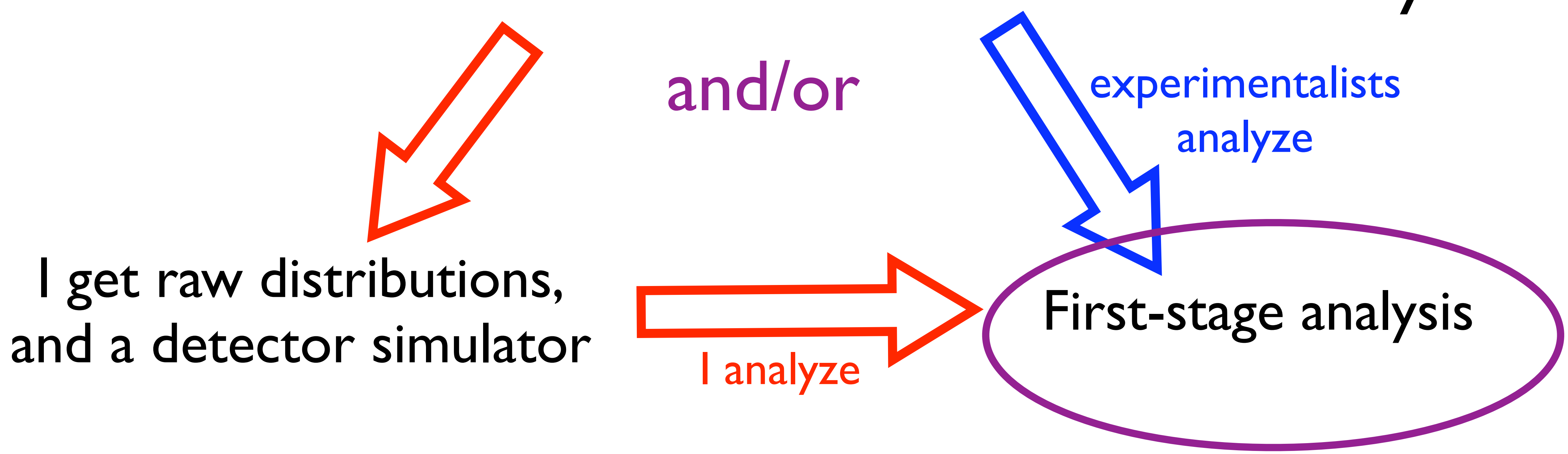


What and why?

(Who does what is an open question)

Simplify, Simplify, Simplify...

Establish approximate mass scale, quantum number,
and decay chain **determined by the data**...
(This is what a model-independent characterization means)

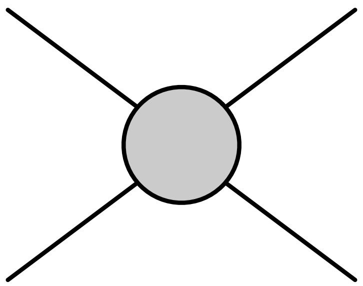
Simplify the model space to sift relevant from irrelevant and
resolvable from un-knowable details
(appropriate for early data, low statistics)

Disregard structure that's "hard" to measure

Simplify until description is typically over-constrained by data

How?

Production and Decay Approximation



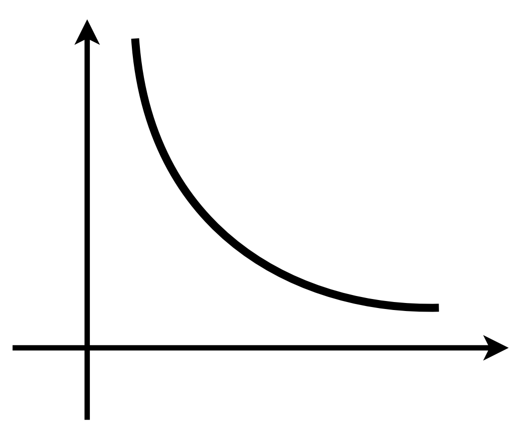
$$|\mathcal{M}|^2 = f(s,\xi) \qquad \xi = \beta_{34}\cos\theta = \frac{\hat{t}-\hat{u}}{\hat{s}} = \frac{p_z}{\sqrt{s}}$$

$$|\mathcal{M}|^2 = \frac{\pi\alpha_s^2}{s^2}\left(\frac{4}{9}\frac{m_{\tilde{g}}^2 - t}{s} + \frac{[(m_{\tilde{g}}^2 - t)s + 2m_{\tilde{g}}^2(m_{\tilde{q}}^2 - t)]}{(t-m_{\tilde{g}}^2)^2} + u + st + su + tu \quad \text{channels}\right)$$

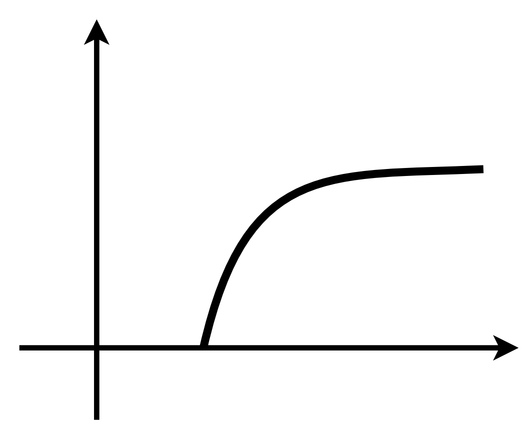
Parton Luminosity

Phase Space (Threshold)

$$\frac{d\sigma}{d\hat{t}} = \int$$



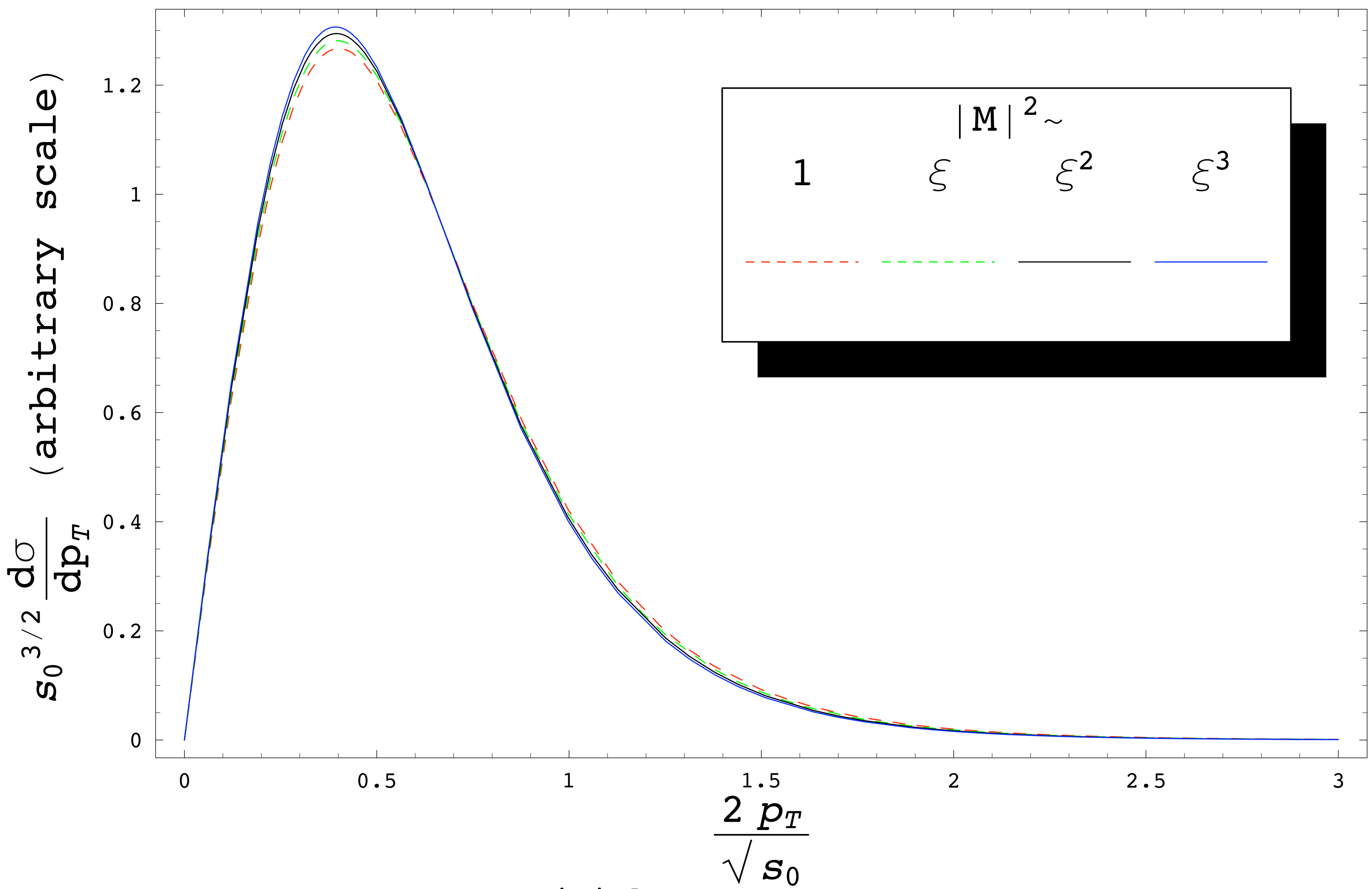
$$\times$$



$$\times\, |\mathcal{M}|^2$$

Well Approximated by Constant!

Homogeneous function of energy → uniform shape indep. of $|\mathcal{M}|^2$

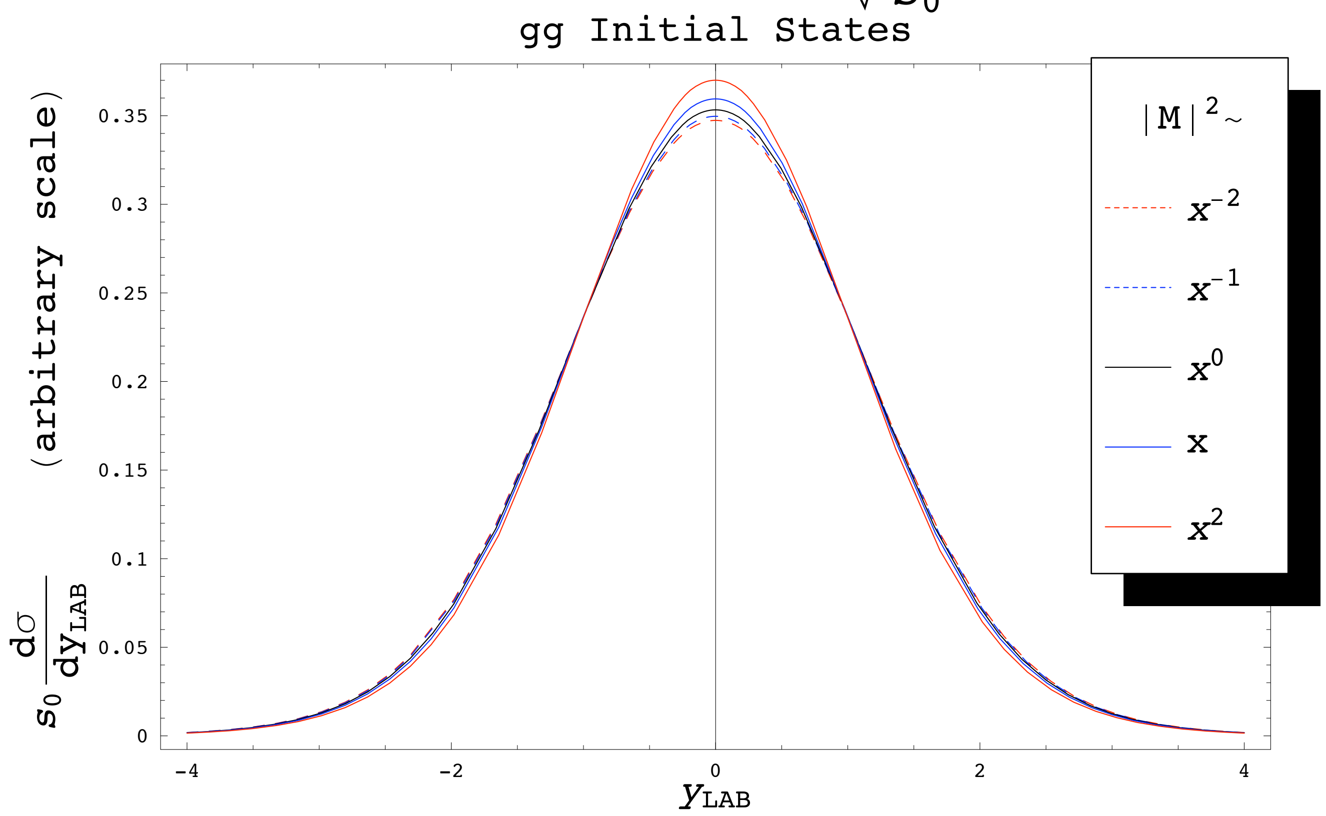


$$|\mathcal{M}|^2 \propto x^m \xi^n$$

implies

$$\frac{d\sigma}{dx_T} \propto x_T(1+x_T)^{m+q}$$

indep. of *n*!

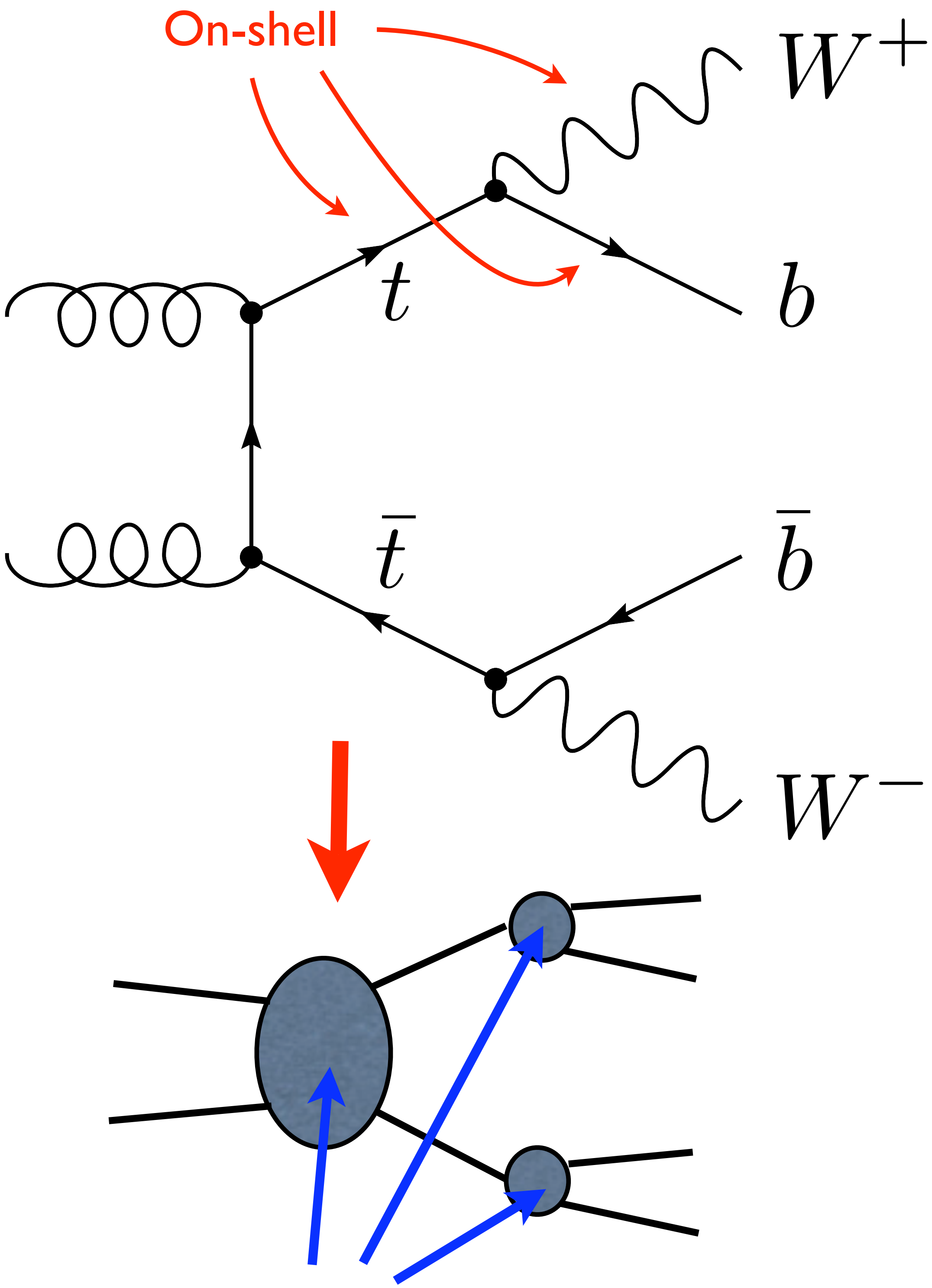


Similarly, rapidity distribution is indep. of *m*

Information is lost at hadron colliders!

Going On-Shell... The Basic Idea:

Example: Top Quark



Simple rules given for these parts

Masses, Rates, and Topology

vs. Amplitudes

Dominant Top Properties:

$\sigma(gg \to t\bar{t})$

$\mathrm{Br}(t \to bW)$

m_t, m_W, m_b

Detailed Top Properties:

$d\sigma/d\hat{t}$

W helicity

t charge

On-Shell-Effective-Theory

Production:

$2 \to 1$ Use Breit Wigner

$2 \to 2$

Usually dominates

"Normal" Behavior

$$|\mathcal{M}|^2 = A + B\left(1 - \frac{s_{\text{thresh}}}{s}\right)$$

or

"Contact" Operator Behavior

$$|\mathcal{M}|^2 = A + B\left(\frac{s}{s_{\text{thresh}}} - 1\right)$$

Dominant ξ correction can be included (not usually necessary)

$2 \to 3$ Use "standard" modes with OSET decay scheme

Decay:

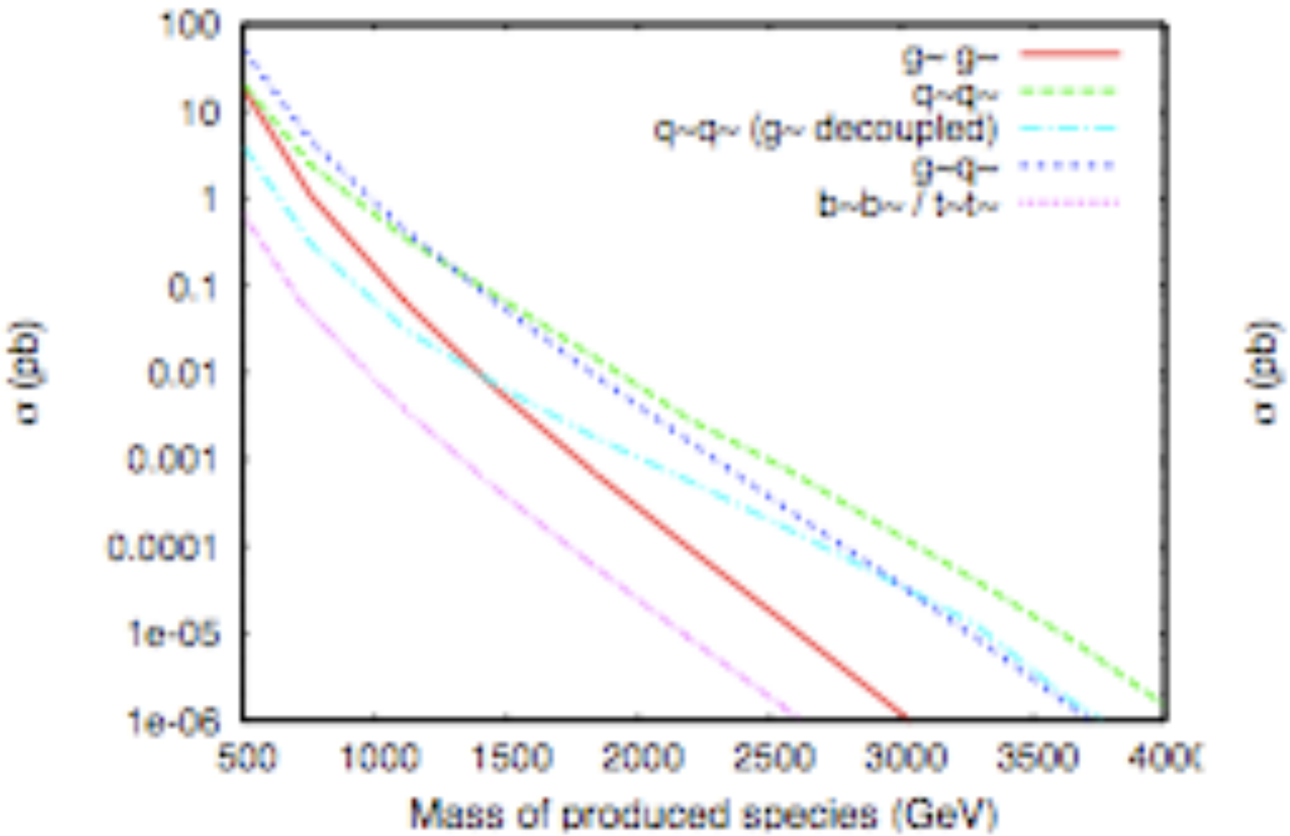
- Polynomial in $\cos\theta$: rank determined by spins, coefficients by masses. Spin correlations can be included...use a more powerful tool (i.e. MadGraph for example)

- Single-object lab-frame distributions, and many correlations, well approximated by phase space decays.

See: hep-ph/0703088 for detail...

PDFs Simplify Further...

Good physics reasons for simplicity of description



Cross sections fall like

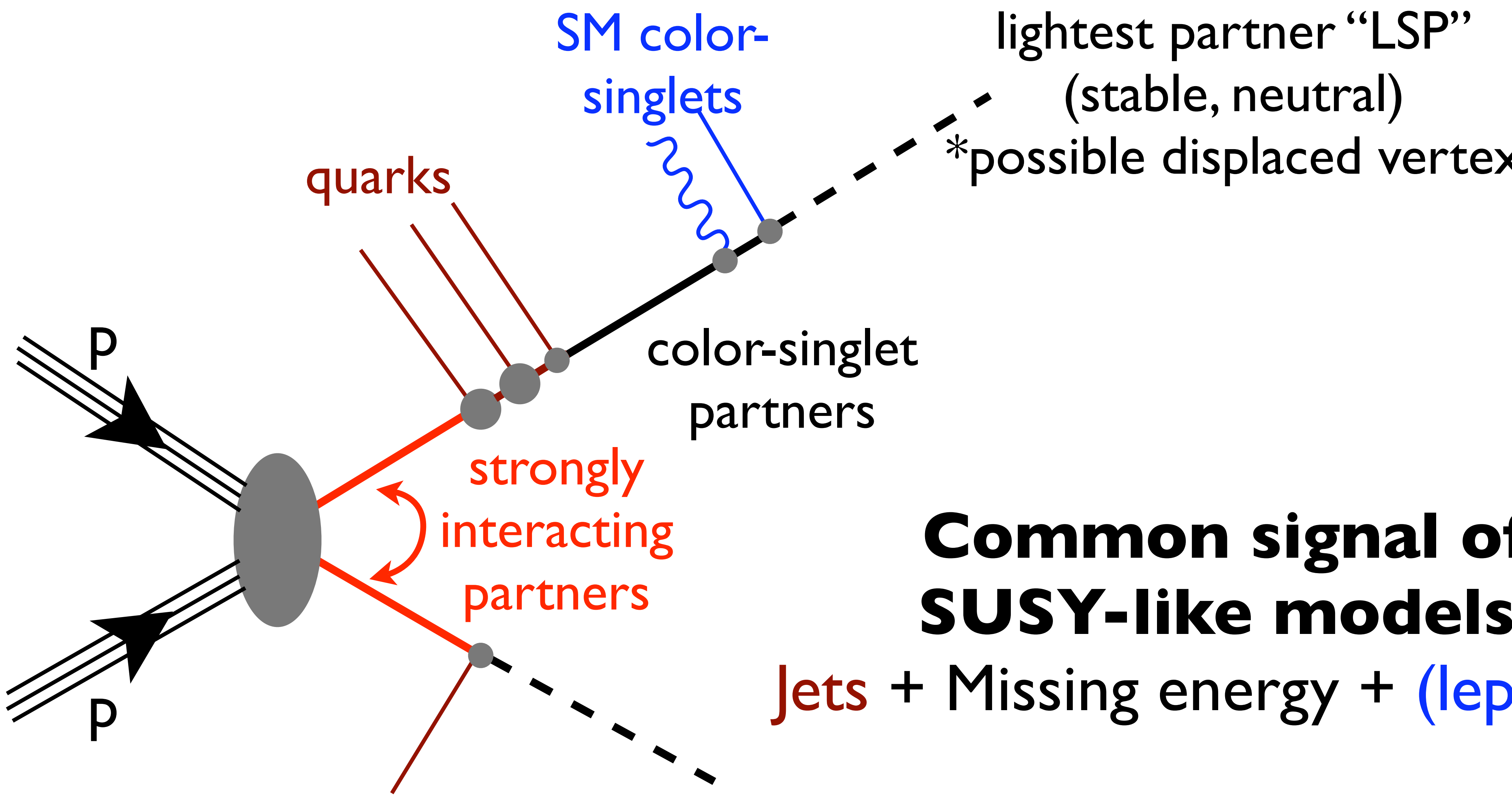
$$\sim \frac{1}{E^{5-6}}$$

Lowest mass process heavily dominates!

Single production hypothesis not bad

For a given model, the observable OSET is much simpler than the complete one.

Simplifying SUSY-like Physics



Common signal of SUSY-like models:

Jets + Missing energy + (leptons?)

If jets+MET+leptons excess(es) are seen, it's reasonable to assume SUSY-like physics interpretation!

The First Three Questions

Start building evidence for structure with questions that are (relatively) easy **and** of high theoretical interest.

1) Which colored particles dominate production?

2) What color-singlet decay channels are present, and in what fractions?

3) How b-rich are the events?

Easiest to frame <u>quantitative</u> questions in terms of sharply specified models – what models should we choose, to have a good chance of fitting any jets+MET+leptons signal from SUSY-like physics?

Four Simplified Models

1) Which colored particles dominate production?

Either Gluon partner G or Quark partner Q

study each in a <u>separate</u> model

2) What color-singlet decay channels are present, and in what fractions?

Models with ***one*** produced species, ***one***-stage cascade decay (produced species either G or Q).

3) How b-rich are the events?

G: Produce gluon partners that decay to $q\bar{q}$, $b\bar{b}$, or $t\bar{t}$ +LSP

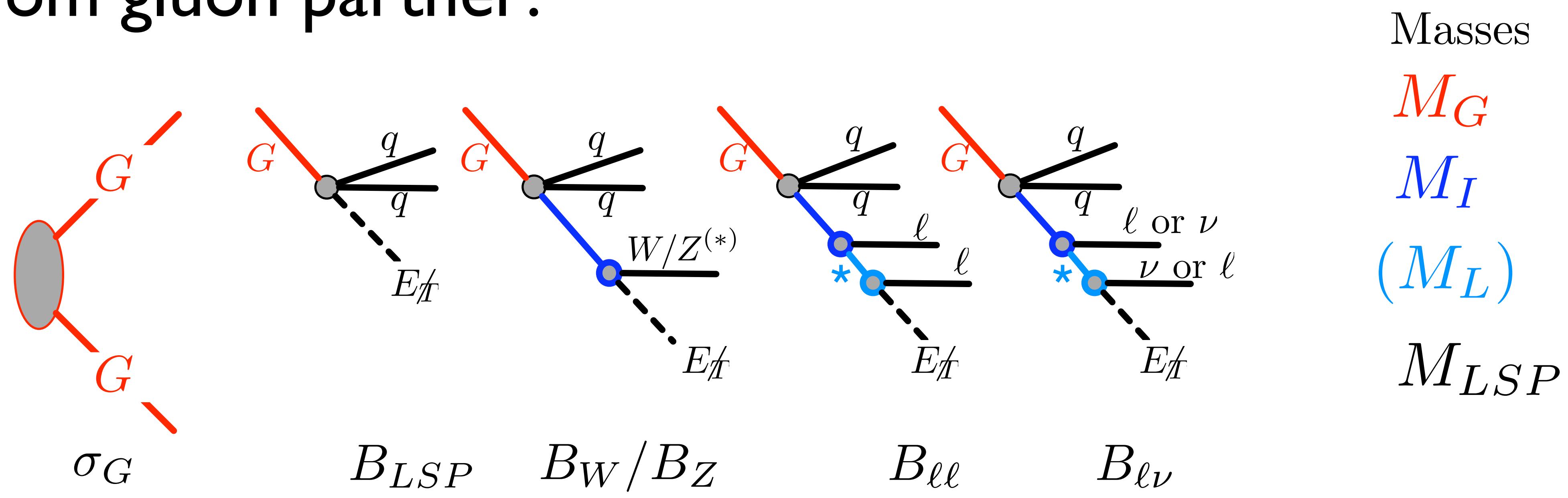
Q: Pair-produce parters of q_{12}, b, and t

➡ Total of four models

GOAL: As simple as possible to answer these three questions
+ fit ANY new physics in SUSY-like class well

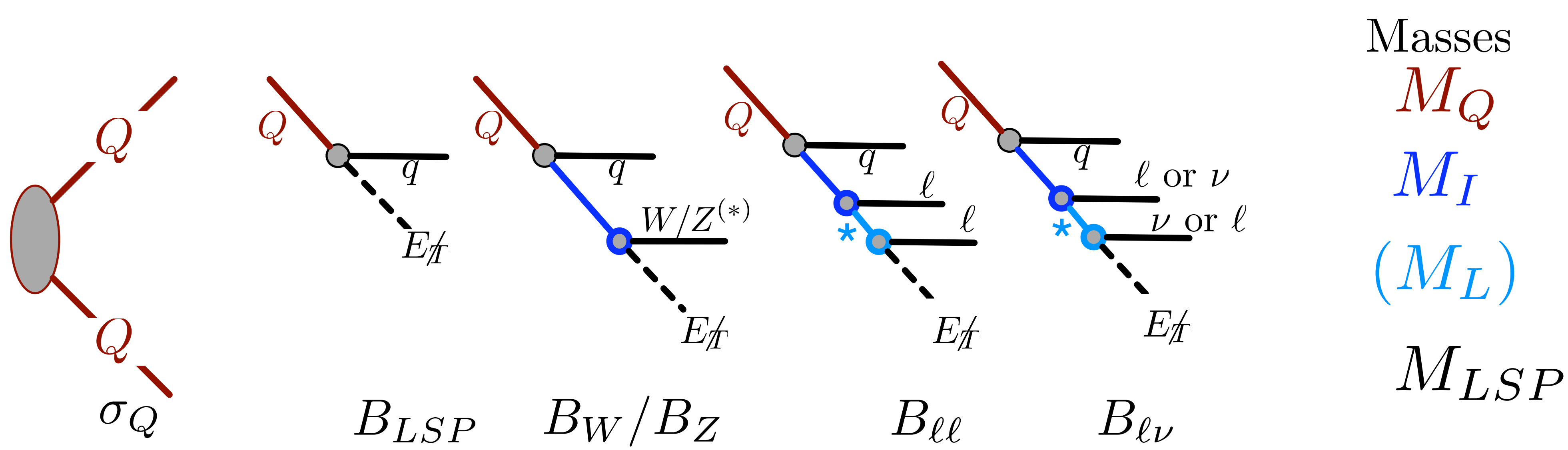
Simplified Models of Lepton Cascades

From gluon partner:

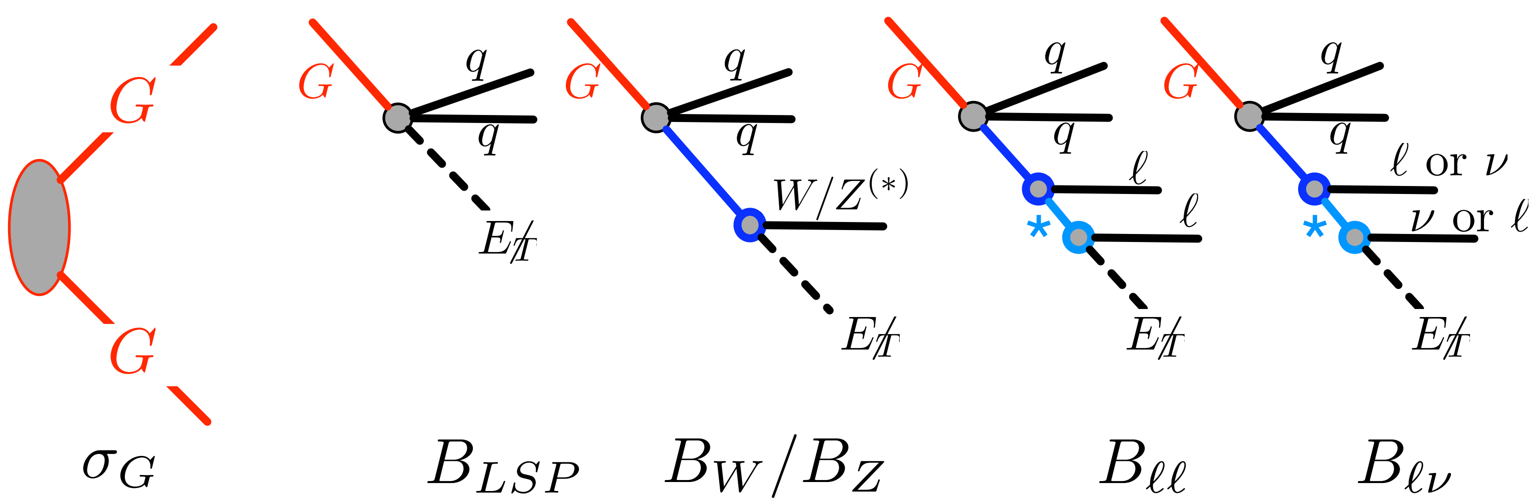


*on or off-shell

From quark partner:

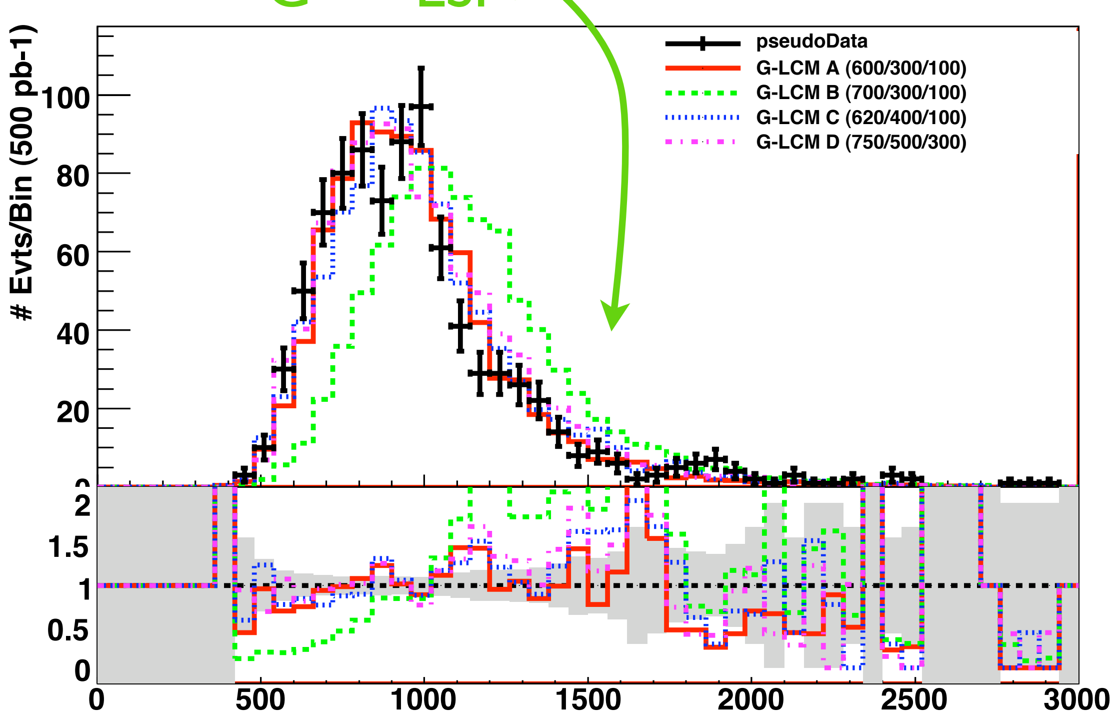


Constraining Masses



Masses
M_G
M_I
(M_L)
M_{LSP}

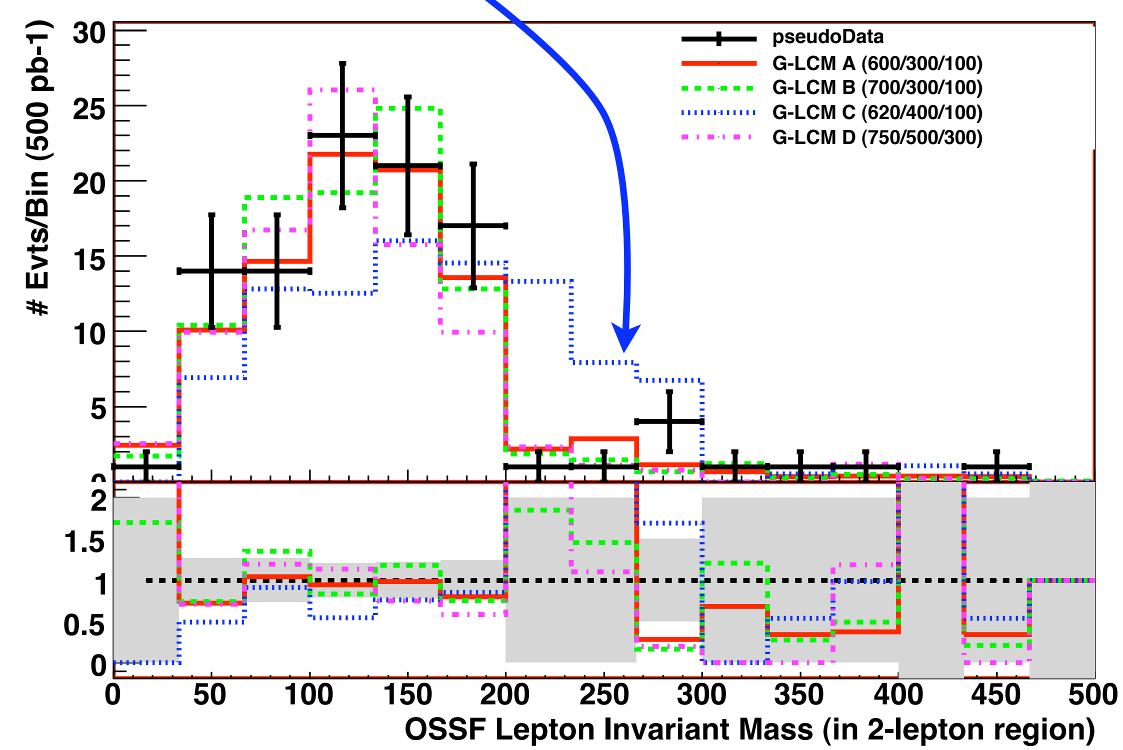
M_G-M_{LSP}:



$H_T=\sum p_T$ (GeV)

(sum over up to 4 jets + leptons + missing ET)

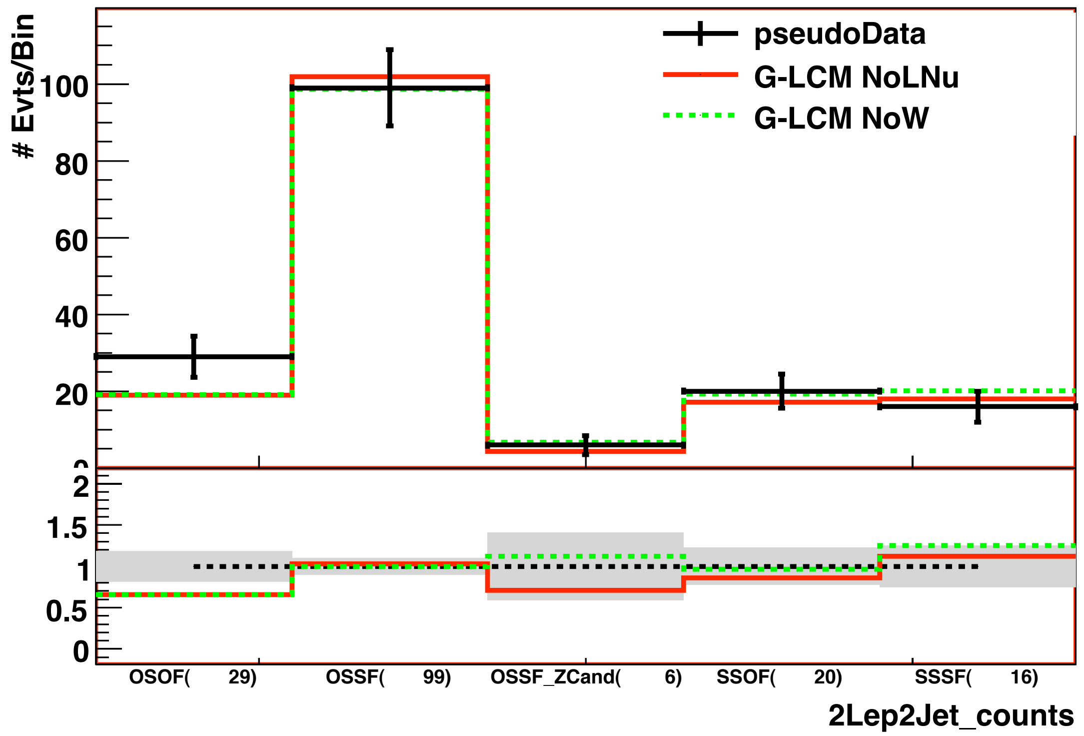
M_I-M_{LSP}:

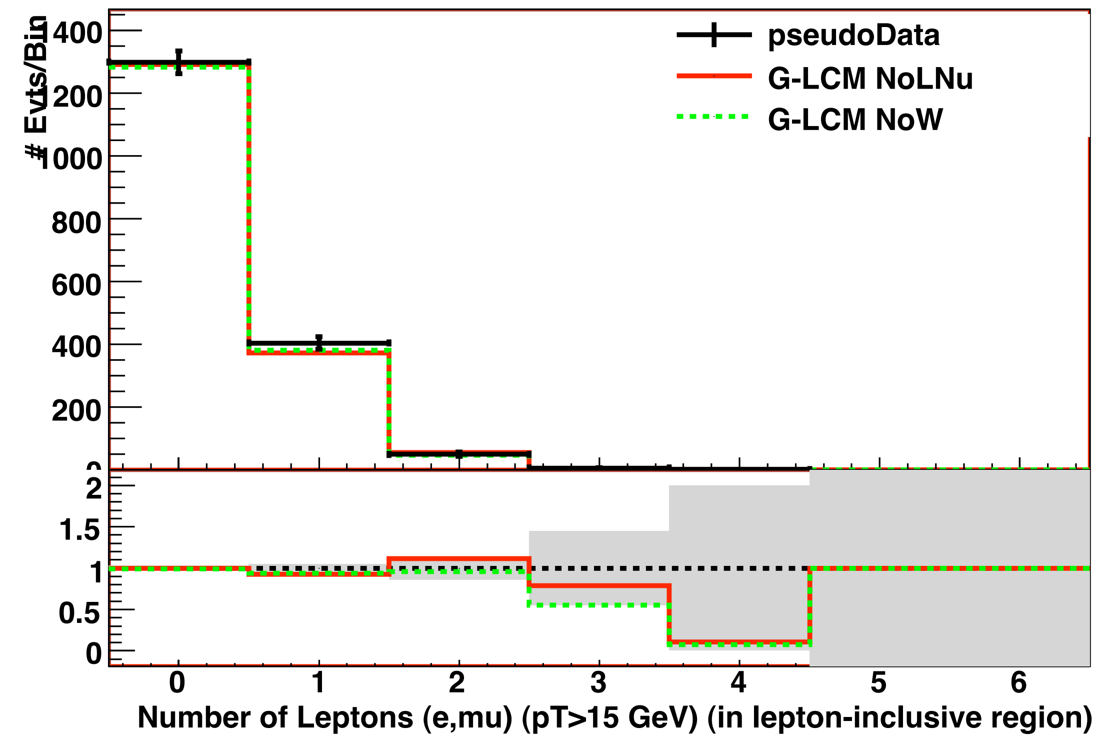


OSSF (e+e- and μ+μ-) events: di-lepton invariant mass

Plots from PGS study:
- data=SUSY model
- 500 pb-1
- details in 0810.3921

Constraining σ and BR's





Branching ratios are a **detector-independent translation** of the lepton counts!

	σ (pb)	B_{LSP}	B_{W}	B_{Z}	B_{ll}	$B_{l\nu}$
Red	11.3	0.0	0.914	0.02	0.063	—
Green	13.1	0.613	—	0.03	0.052	0.30
± (**)	0.1	0.04	0.05	0.02	0.005	0.01

Plots from PGS study
- data=SUSY model
- 500 pb-1
- details in 0810.3921

Claim:

For a wide variety of signatures, and MSSM parameter regions, these simplified models work remarkably well!

Suggests that applicability will extend beyond the MSSM.

Designed for answering early new-physics questions and establishing the correct range of topologies and rates.

see: arXiv:0810.3921

Building Models from Simplified Models

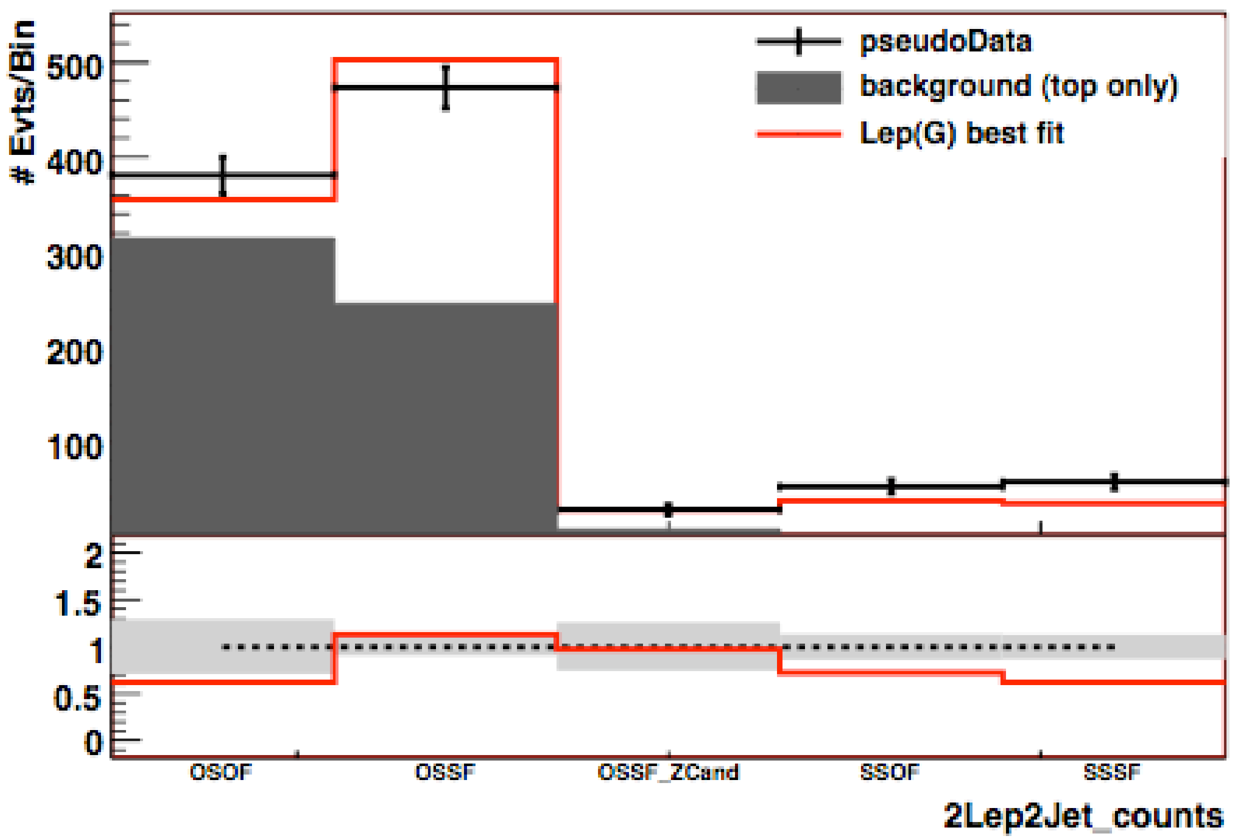
Experimental comparison:

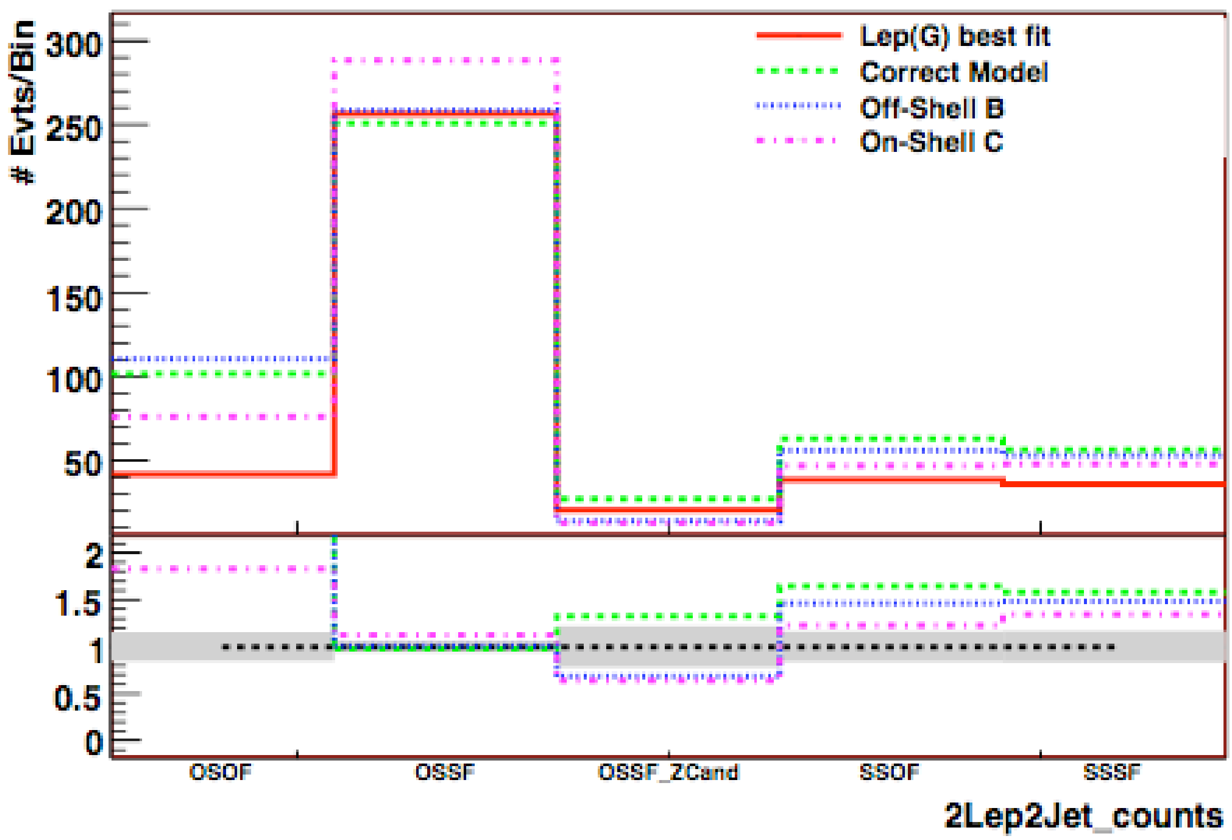
Simplified Model (Leptons)
vs. Data
(shown over ttbar background)

Theorist's comparison

Simplified Model (PGS)
vs. 3 SUSY models (PGS)

(**not** PGS vs. CMS/ATLAS!)





Many systematic errors factor out for a PGS vs. PGS comparison...

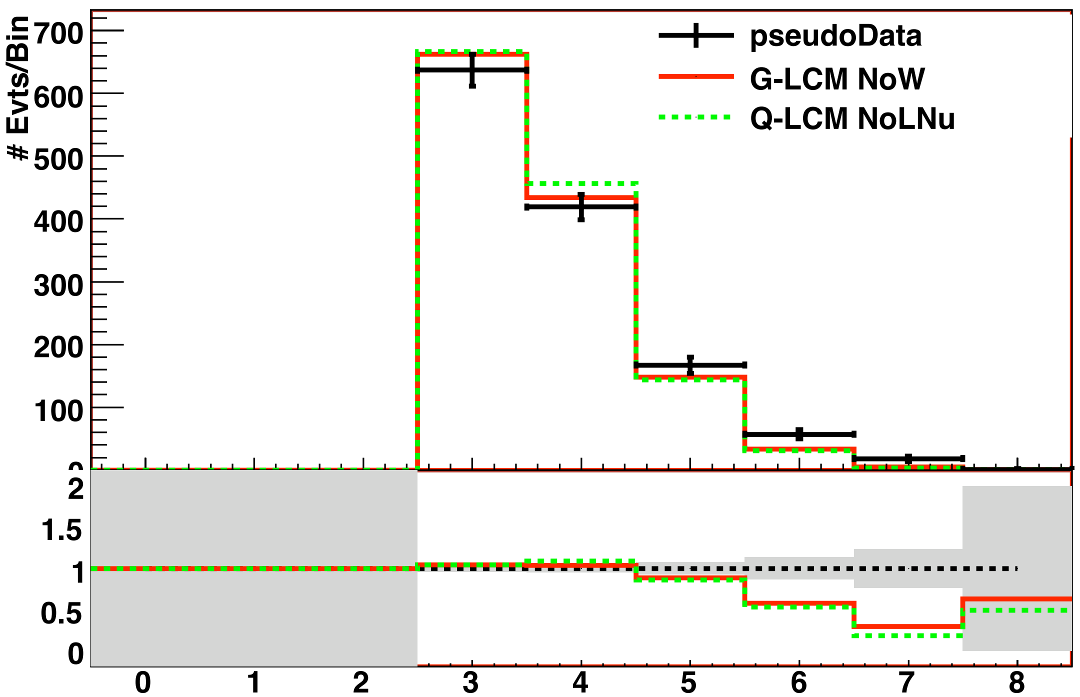
Comparing Gluon and Squark Partners

Two ways to get jet & lepton counts in simplified models:

- quark partner decays to 1 jet with W's in cascades
- gluon partner decas to 2 jets with no hadronic W/Z in cascades

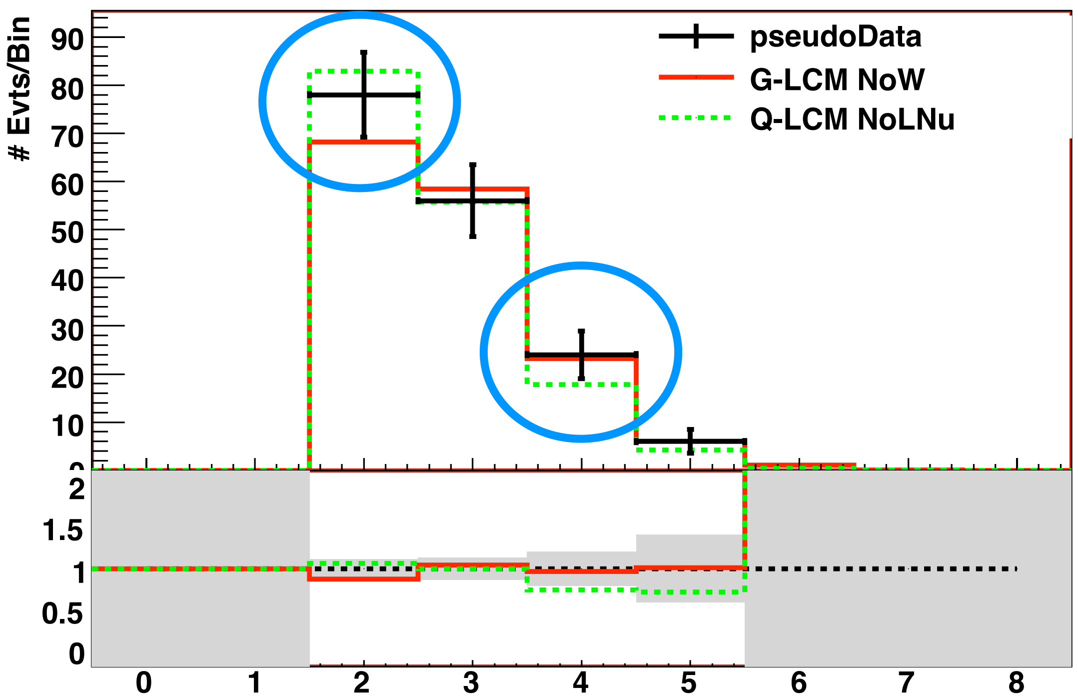
Real physics can interpolate between the two!

Lepton-veto region



# of jets (p_T> 75 GeV)

2-Lepton region (different cuts)



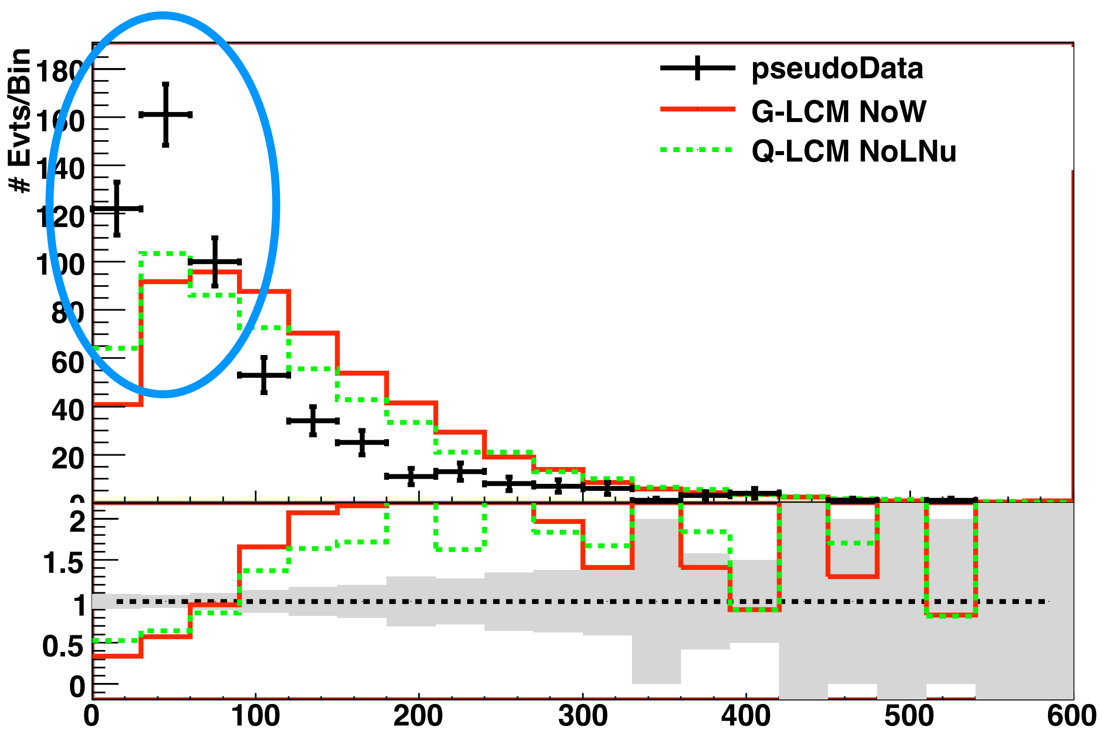
# of jets (p_T> 75 GeV)

Models look different, but only distinguishable with more statistics!

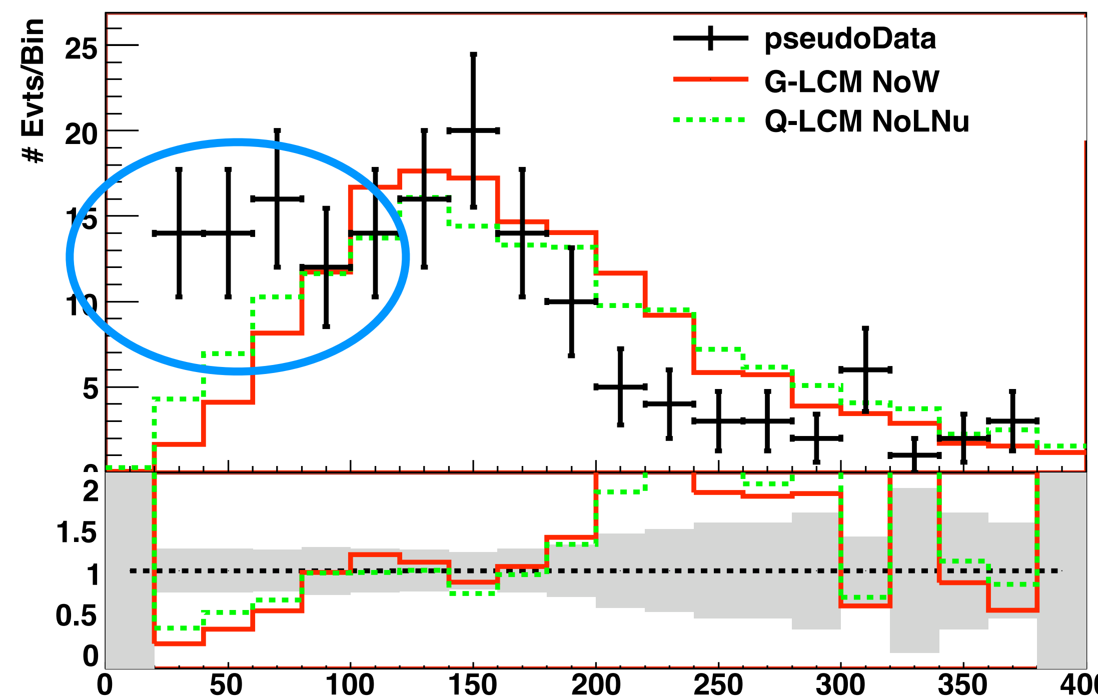
Can't even distinguish 100% gluino from 100% squark, let alone mixture

Over-constrained Models are Useful

Identify Distributions that cannot be explained
without adding structure beyond simplified models



Lepton p_T (one-lepton region)

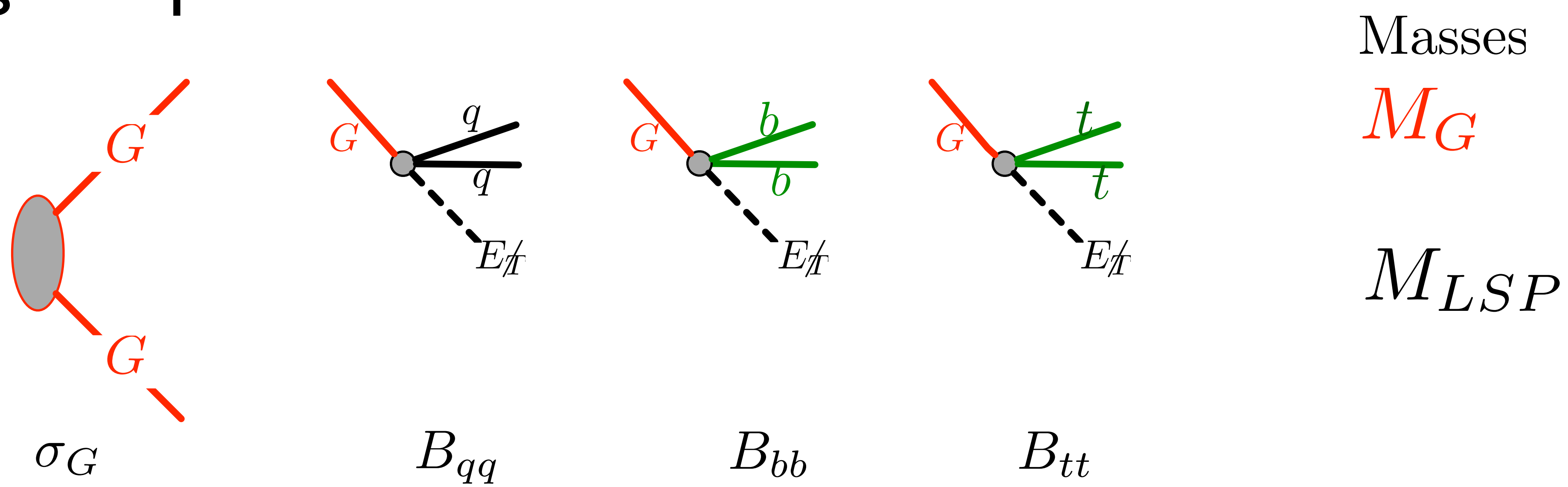


Leading lepton p_T (two-lepton region)

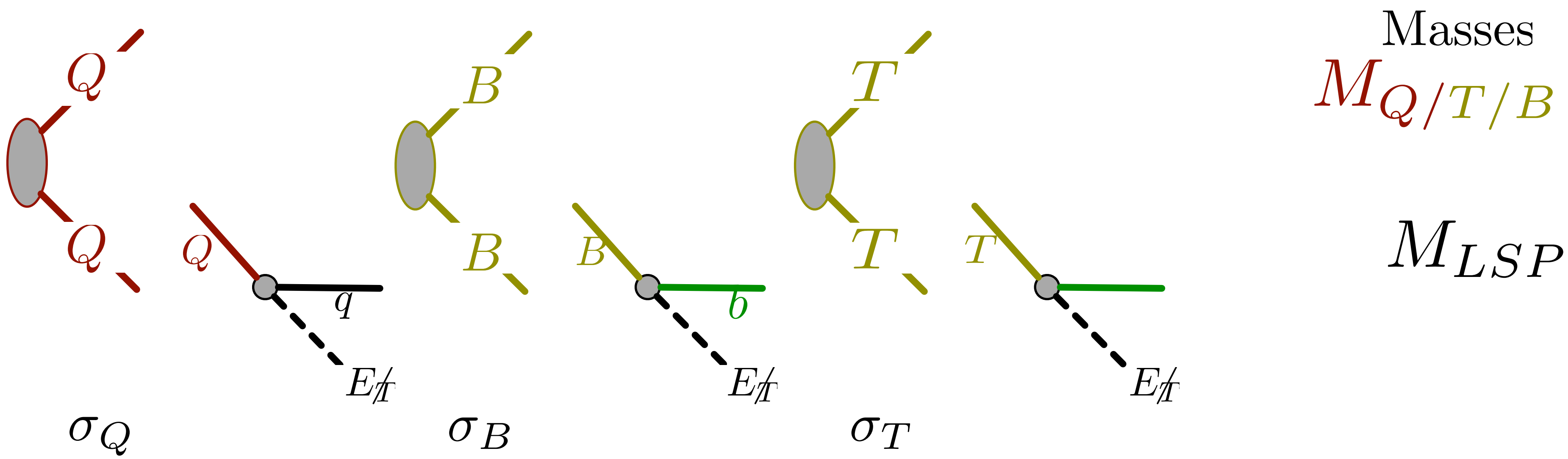
Softer lepton source in signal than simplified models: can't match while keeping invariant mass distribution agreement – indicative of e.g. multiple cascades, but refined two-cascade model <u>would be *under-constrained*</u>

(Study heavy flavor separately from leptons)

From gluon partner:



From quark partner:



Different structures / <u>different patterns</u> of b-tag multiplicity

Using Simplified Model Fits

Important to see several kinds of results

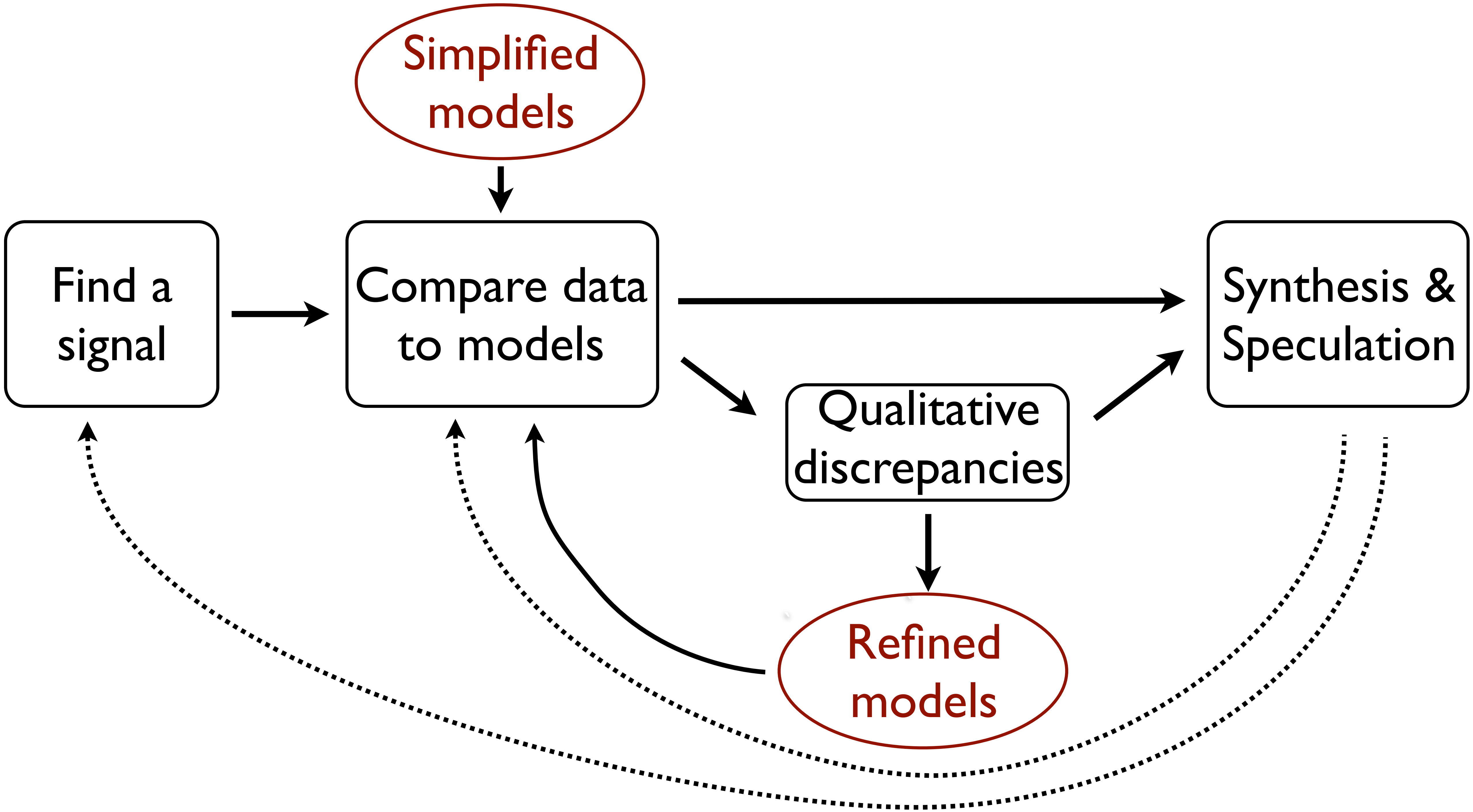
- Simplified model best fits
- Parameter uncertainties, particularly careful treatment of weakly constrained parameters
- Comparisons of the data to expectations for best-fit simplified model — both for distributions used in the fit and for diagnostics

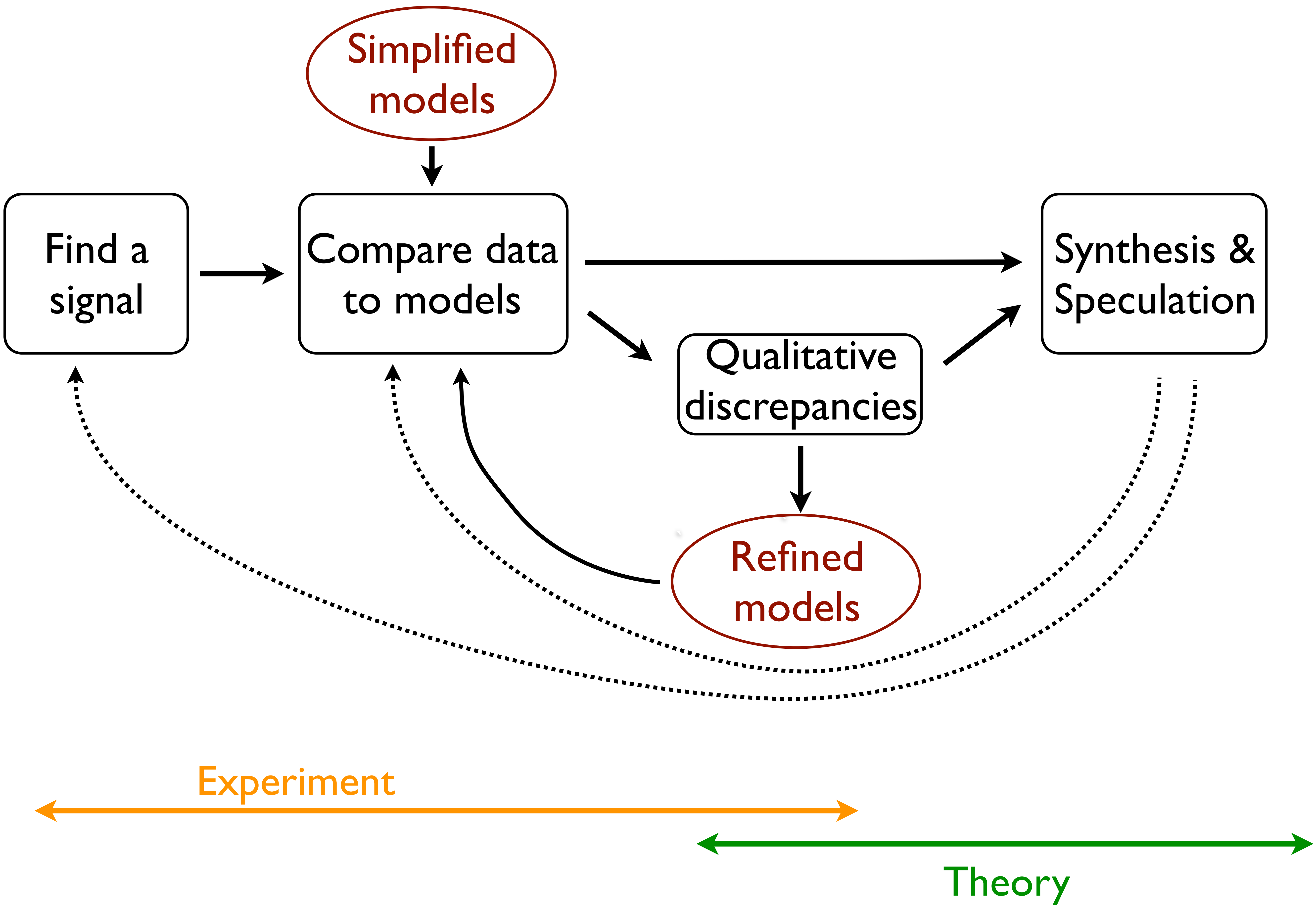
Back-of-the-envelope analysis

- "Good fit" suggests what regions of parameter space to study in model-building
- "Bad fit" suggestive of additional structure (multiple species production, multiple cascades in decays, etc...)

Quantitative comparison

- Can compare predictions of any model to simplified model predictions (e.g. in PGS) to gauge consistency with data.


Simplified models
Find a signal
Compare data to models
Synthesis & Speculation
Qualitative discrepancies
Refined models


Simplified models
Find a signal
Compare data to models
Synthesis & Speculation
Qualitative discrepancies
Refined models
Experiment
Theory

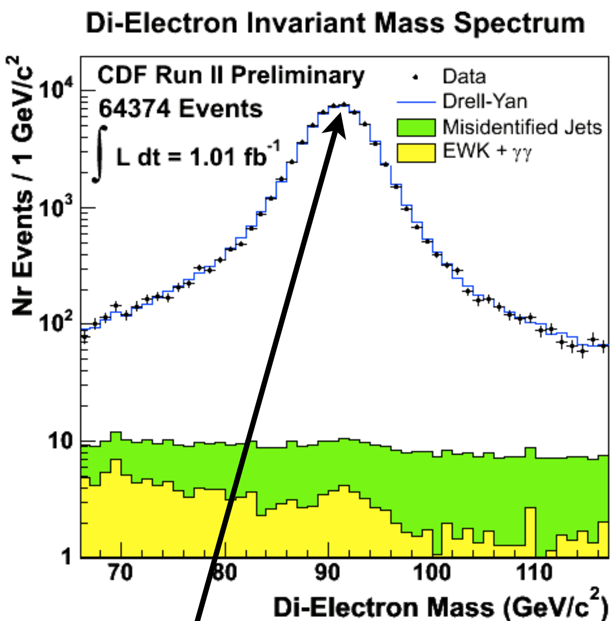
Discussion...

Backup

Preliminary Interpretation

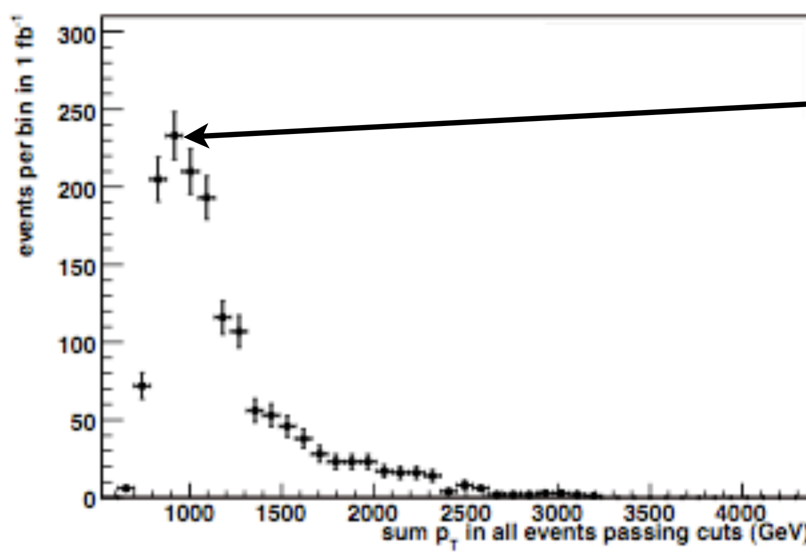
When we do get distributions, there will be a lot we can do

Easy Cases:

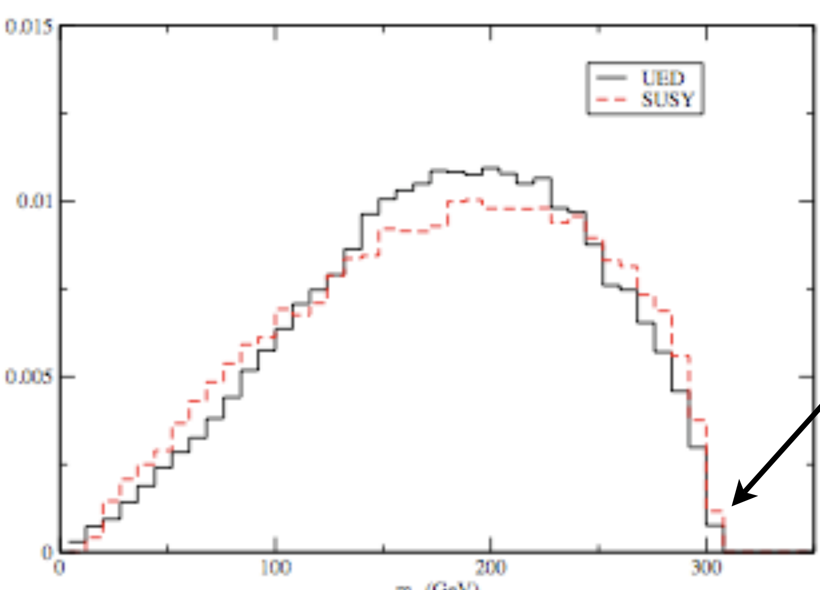


Self-calibrating signal, like a mass peak

HT observable

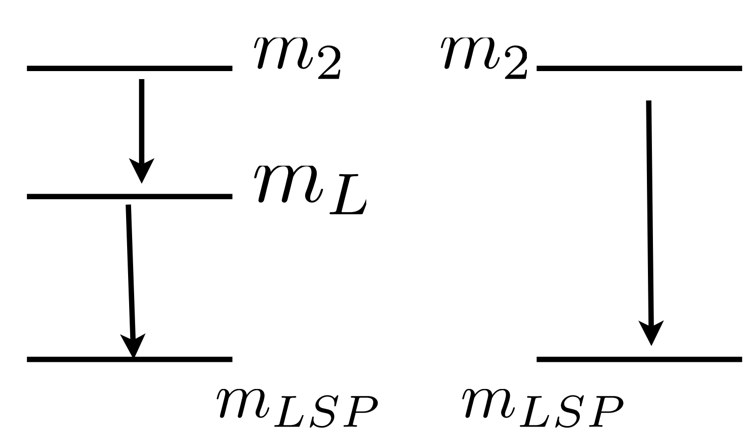


peak~1.7*Mass difference (depending on decay chain) is roughly encoded



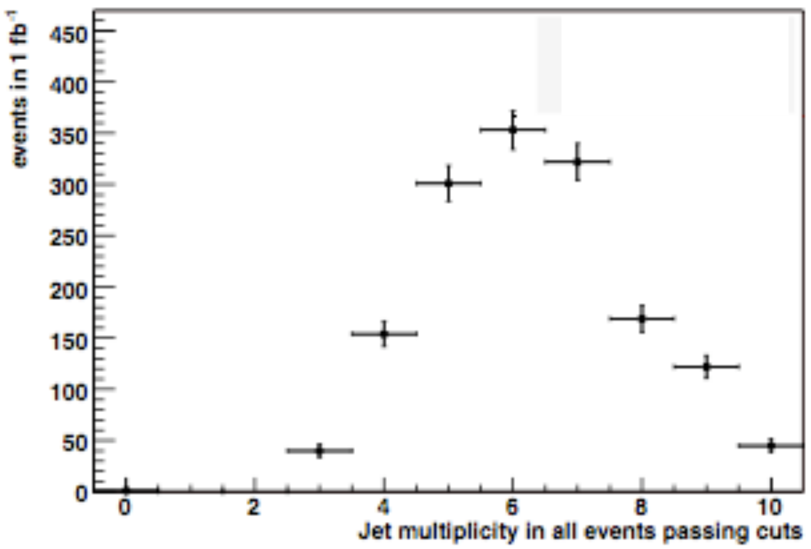
di-object mass can have distinctive phase space cutoff, giving a constraint on decay chain mass difference

$$m_{edge} = \frac{\sqrt{(m_2^2 - m_L^2)(m_L^2 - m_{LSP}^2)}}{m_L}, \qquad \text{or } m_{end} = m_2 - m_{LSP}.$$

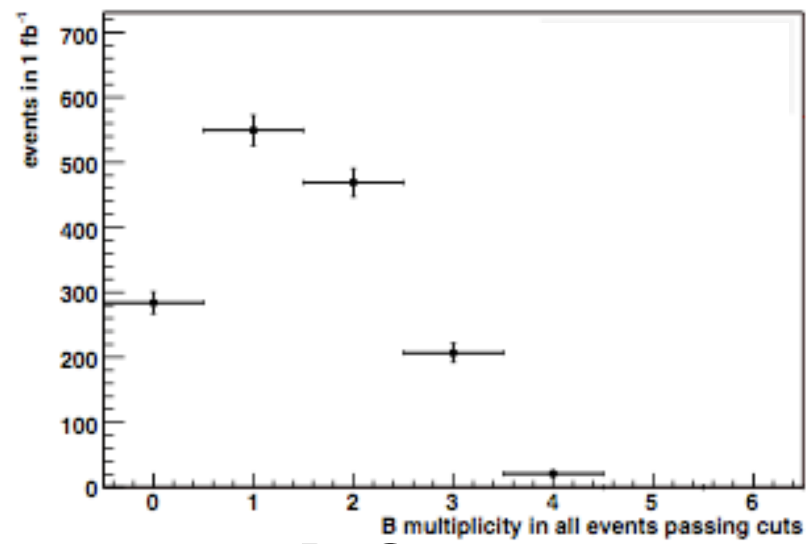


Preliminary Interpretation

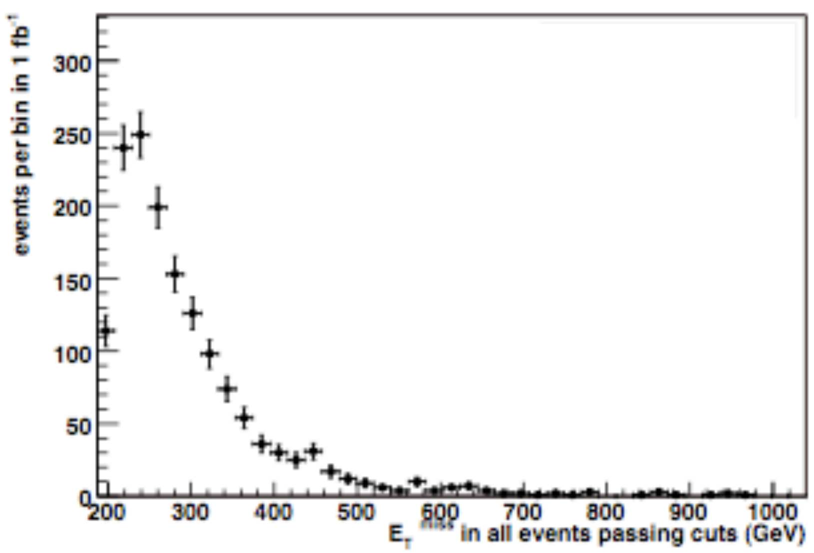
What about less kinematically sharp distributions?



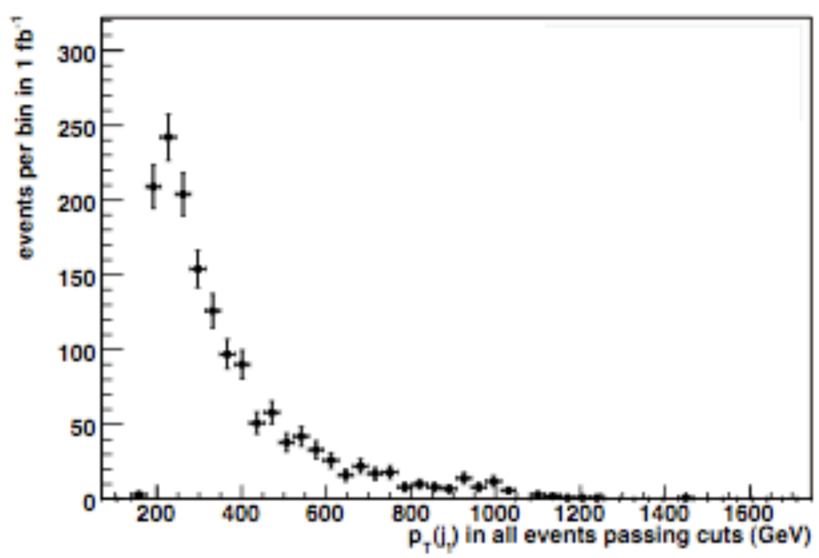
Jet Count



B Count



Jet ET



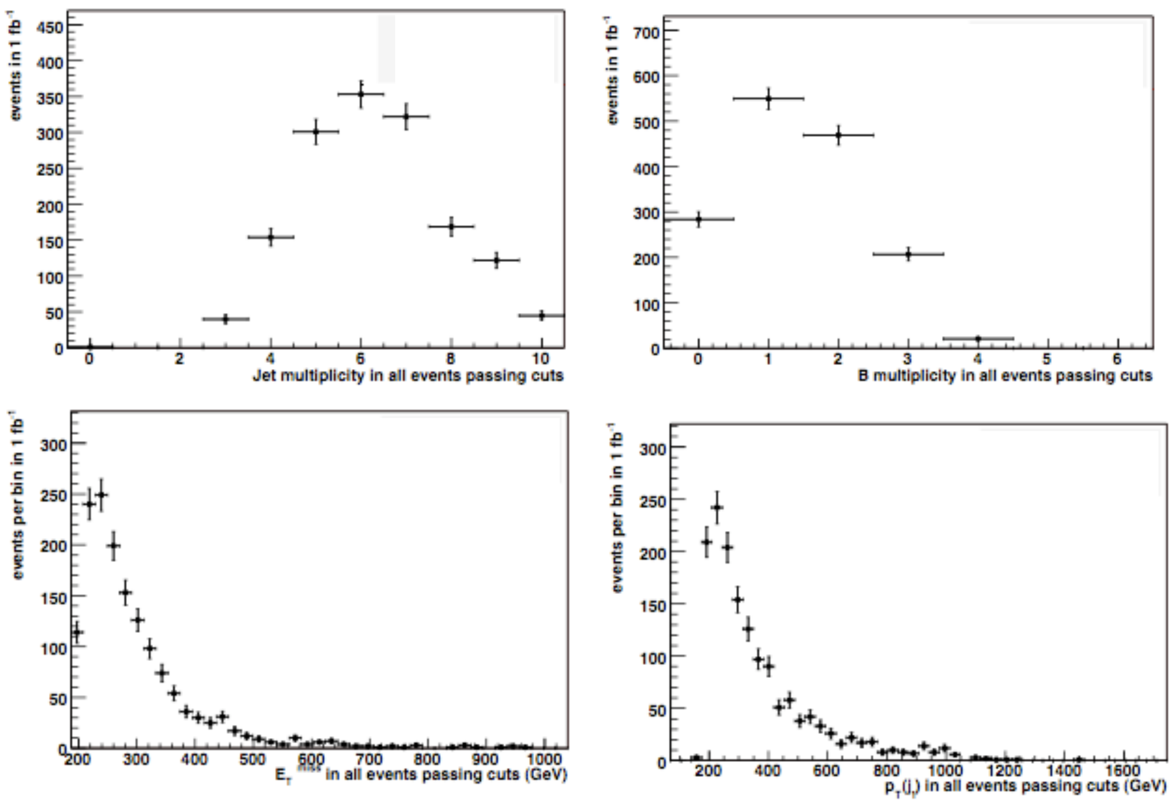
Lepton ET

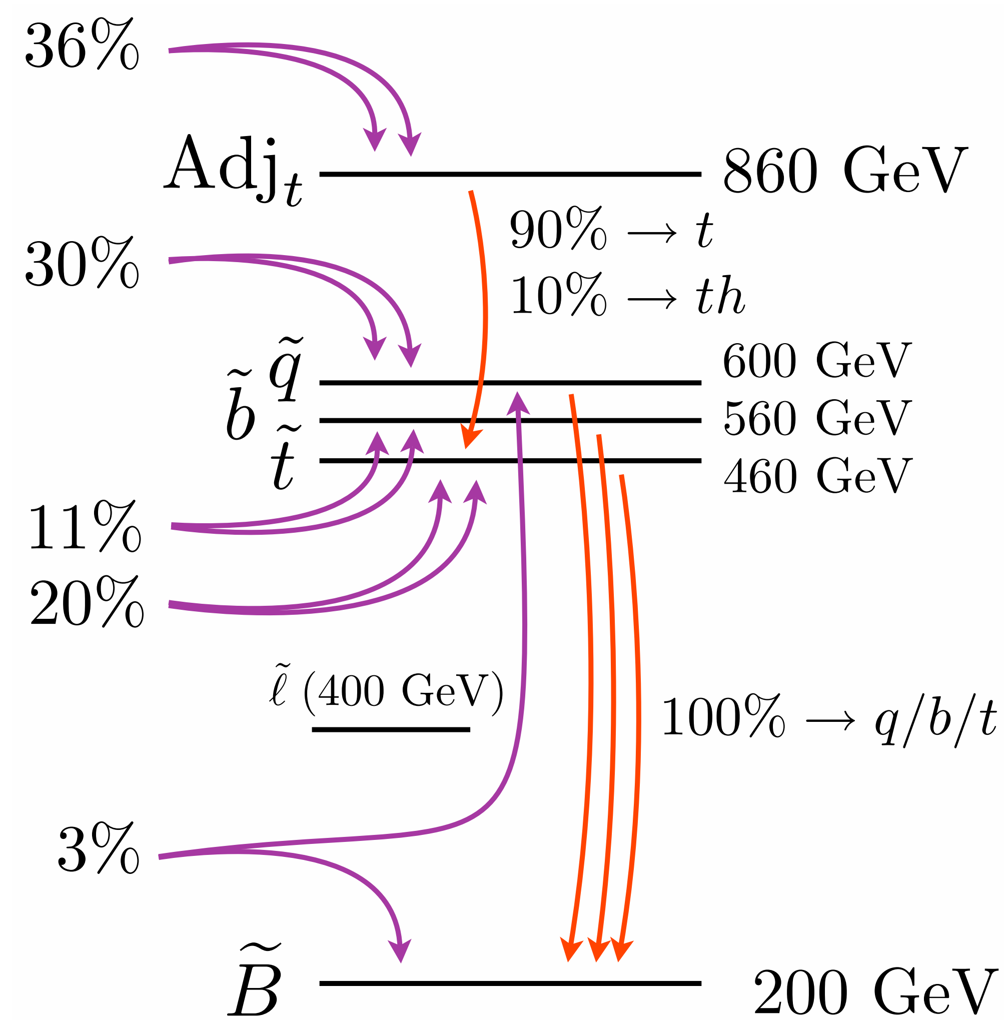
even in principle, distributions not narrow

further smeared by detector

Easy to compare to well-simulated guesses...much harder to turn out physical quantities (masses, branching ratios, cross sections ...or even “detector-corrected” distributions)

Goals for Early Characterization





cross sections
branching ratios
masses

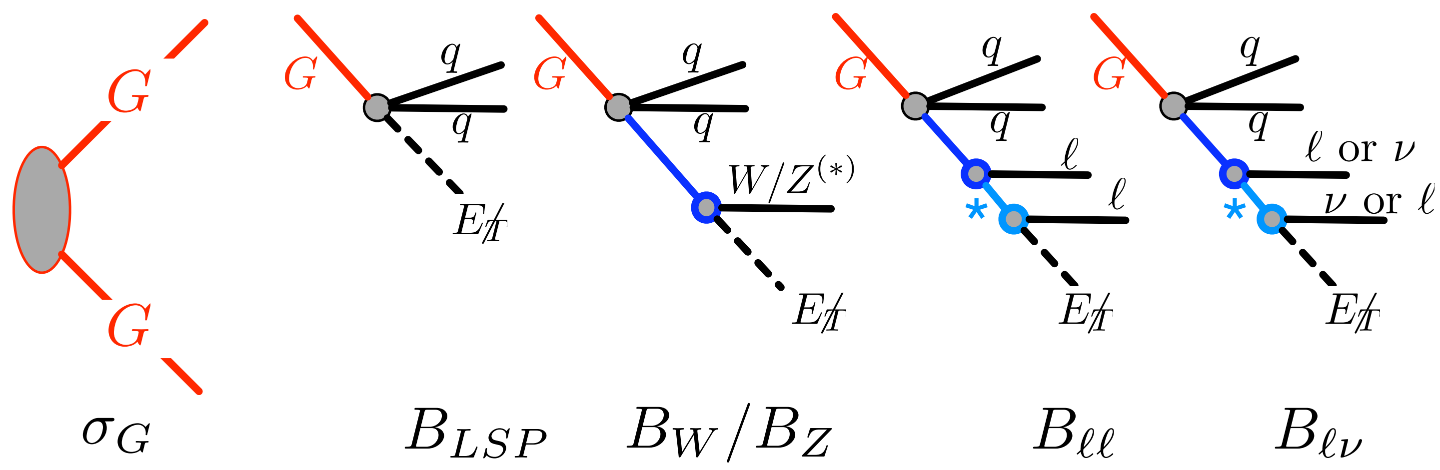
We want to find consistent & predictive explanations of all the data

...then discriminate options, measure parameters...etc

Obstacles:

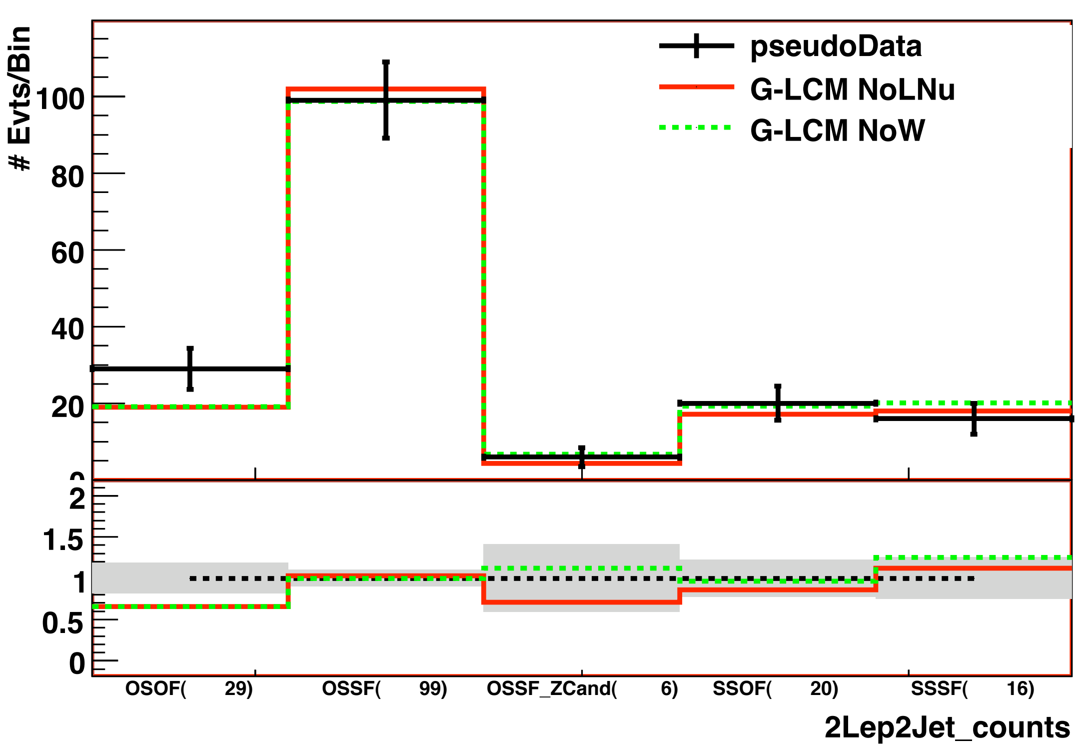
- distributions with no sharp features do not map clearly onto a set of particles, masses and decays
- many regions of parameter space to consider in each model

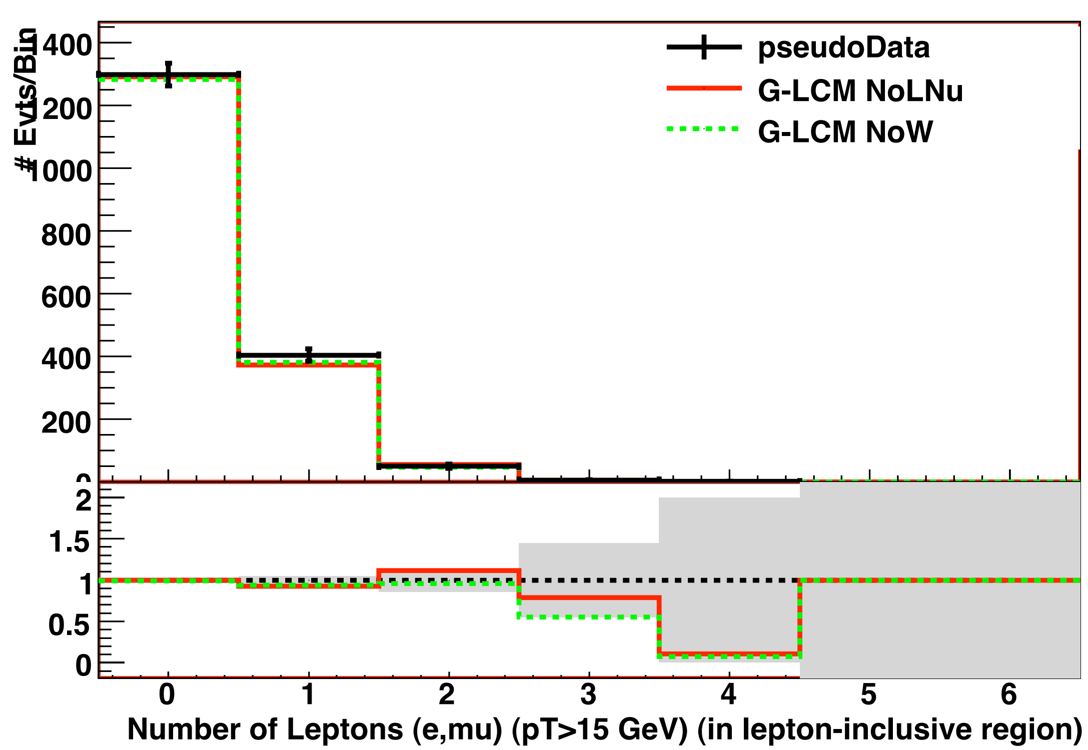
Constraining σ and BR's



Signatures quite distinctive (dilepton pairs on Z peak, opposite-flavor leptons, ...) *except* B_W looks like $B_{l\nu}$ x 0.32 + B_{LSP} x 0.68.

Study extreme limits, e.g. B_W=0, or $B_{l\nu}$=0





Additional constraints

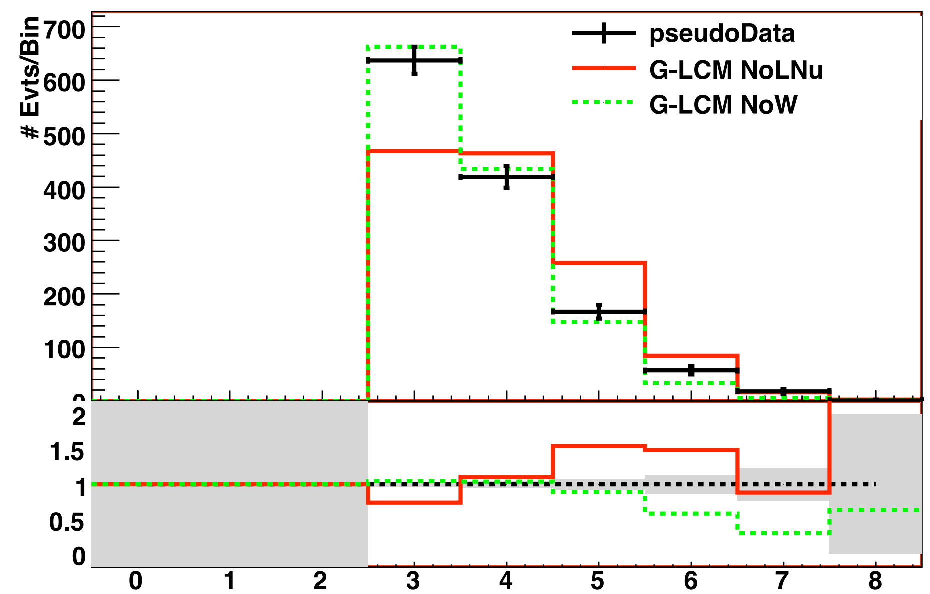
Exchanging W↔(lν+direct)

changes jet multiplicities, and correlation with lepton counts.

Choosing gluon/squark partner also changes jet multiplicities.

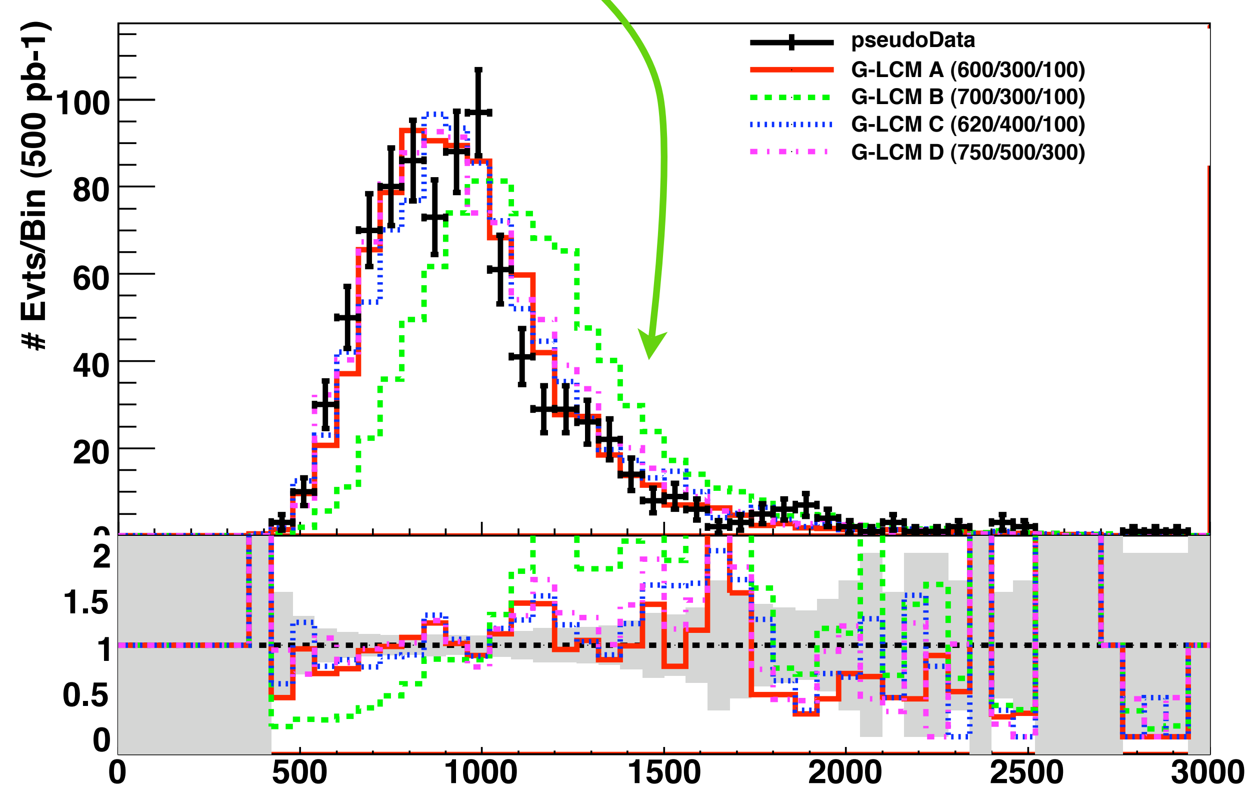
Varying particle masses changes kinematic distributions

Lepton-veto region



# of jets (p_T> 75 GeV)

M_G-M_{LSP}:



$H_T=\sum p_T$ (GeV)

(sum over up to 4 jets + leptons + missing ET)

Building Models from Simplified Models

Experimental comparison:

Simplified Model (Leptons)
vs. Data
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Theorist's comparison

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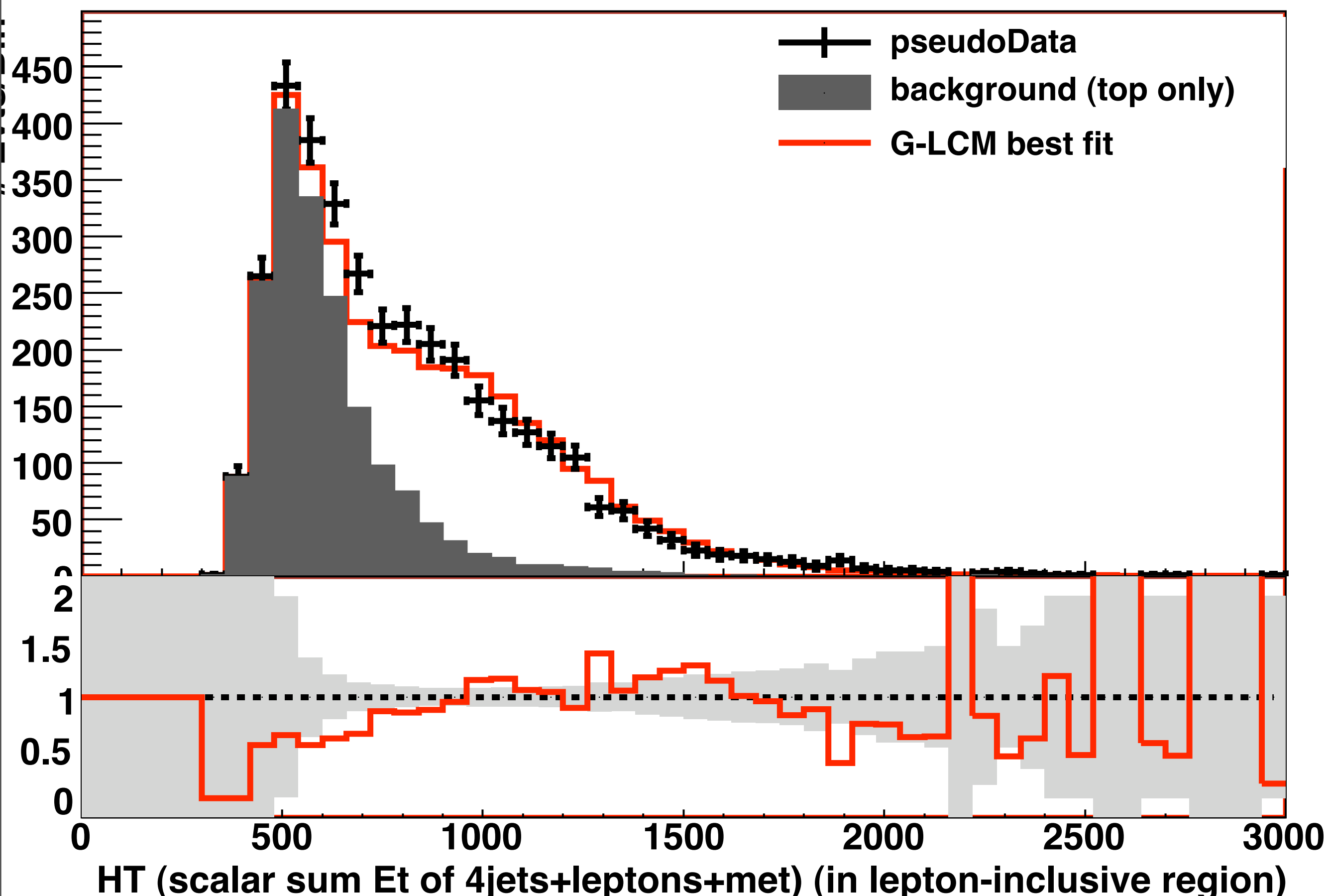
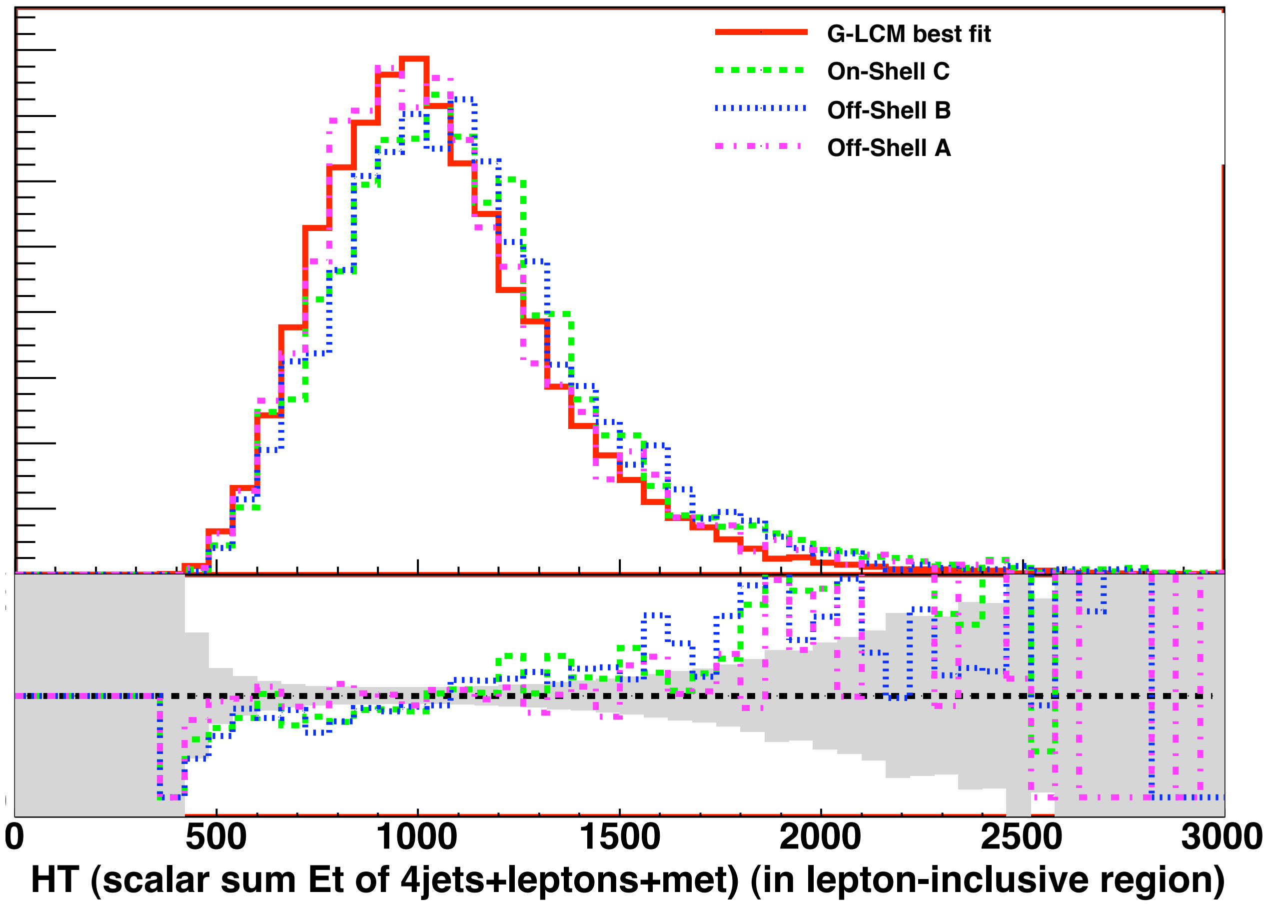
(**not** PGS vs. CMS/ATLAS!)





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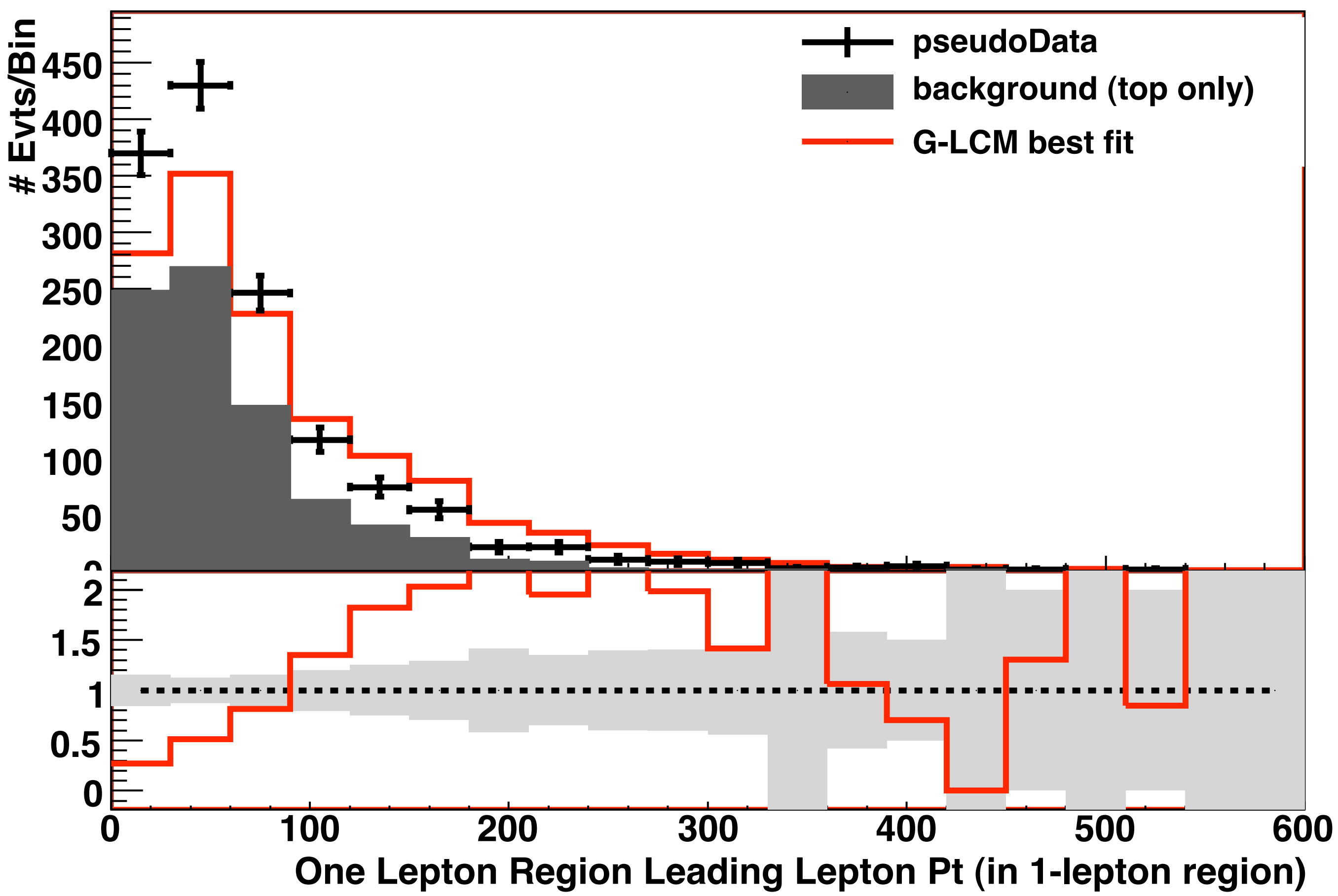

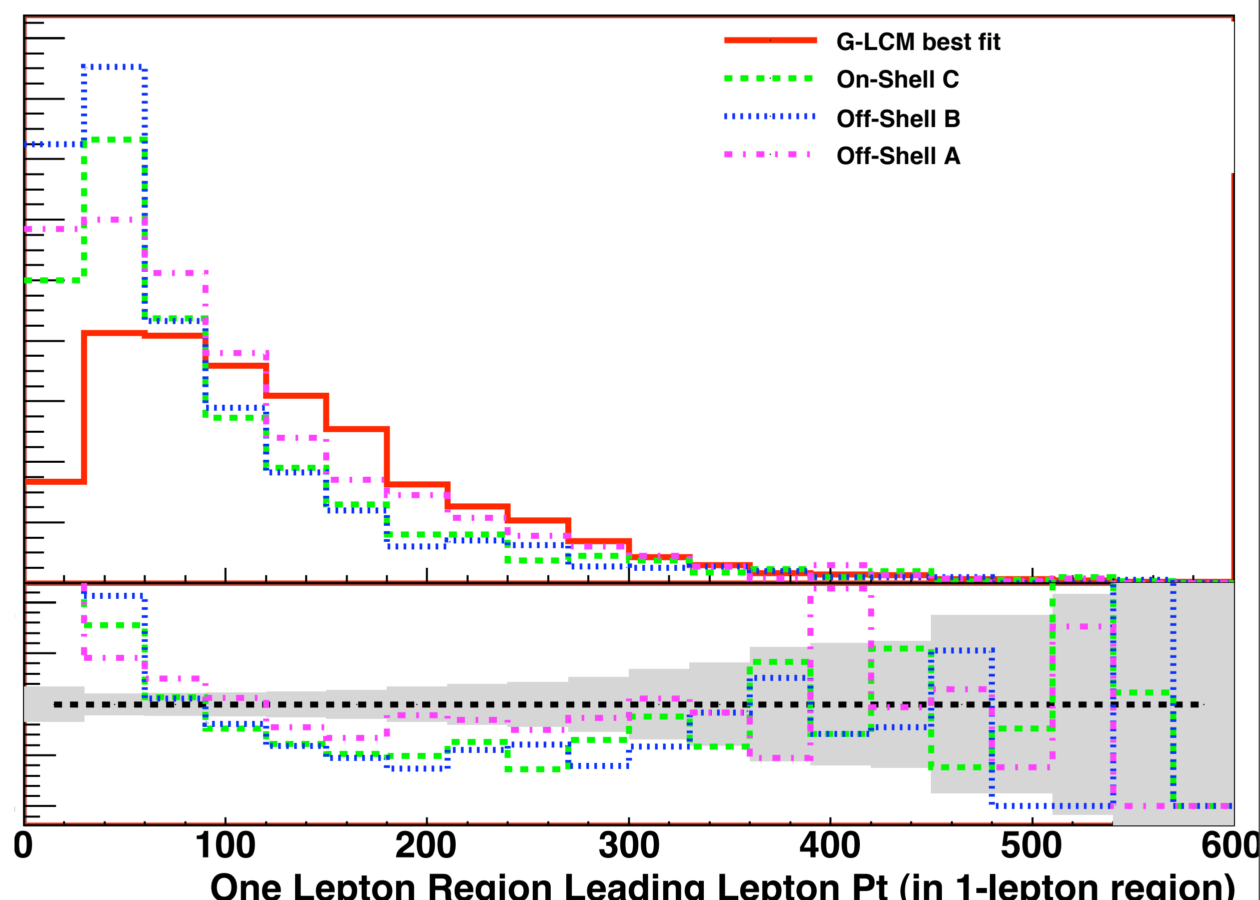

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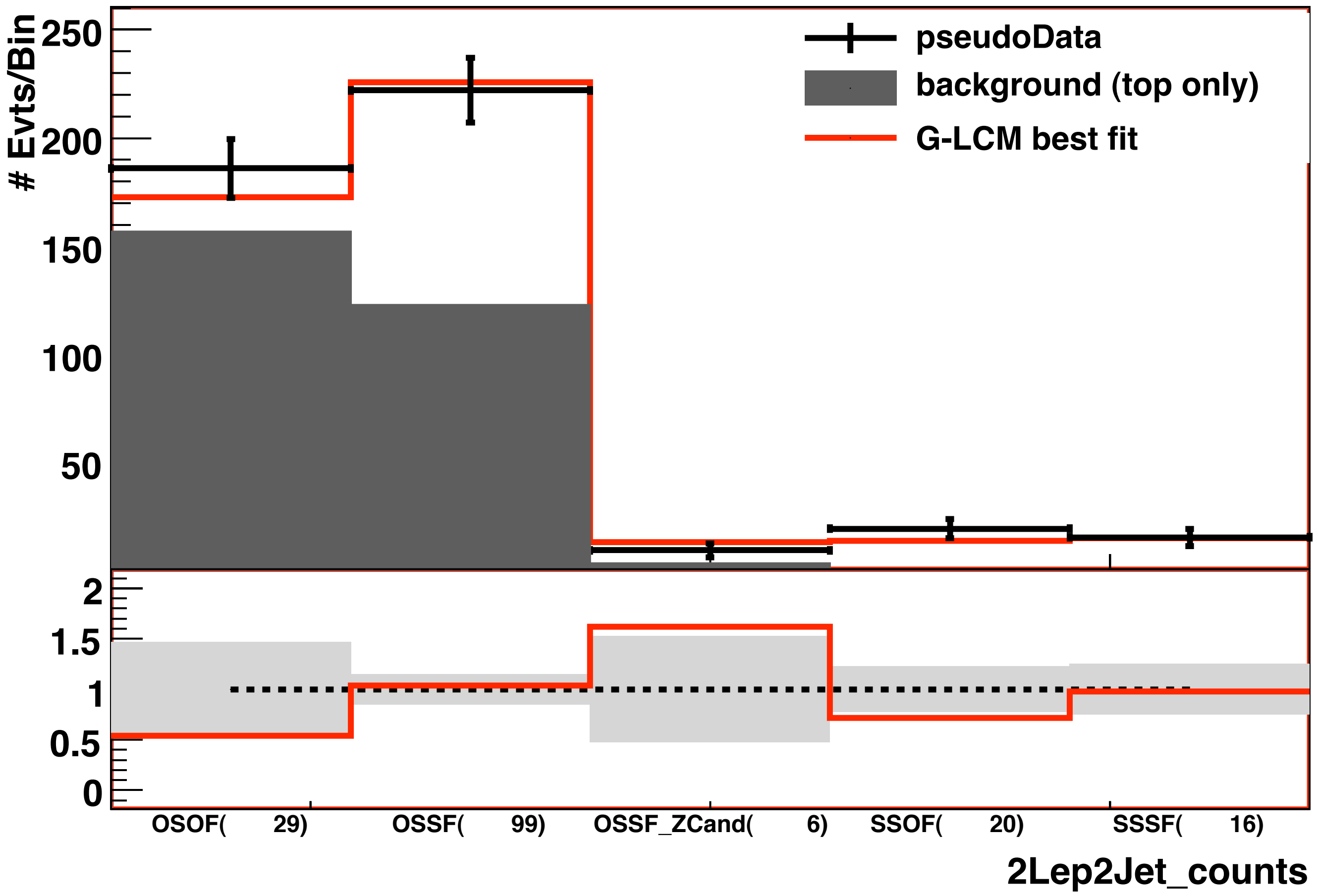
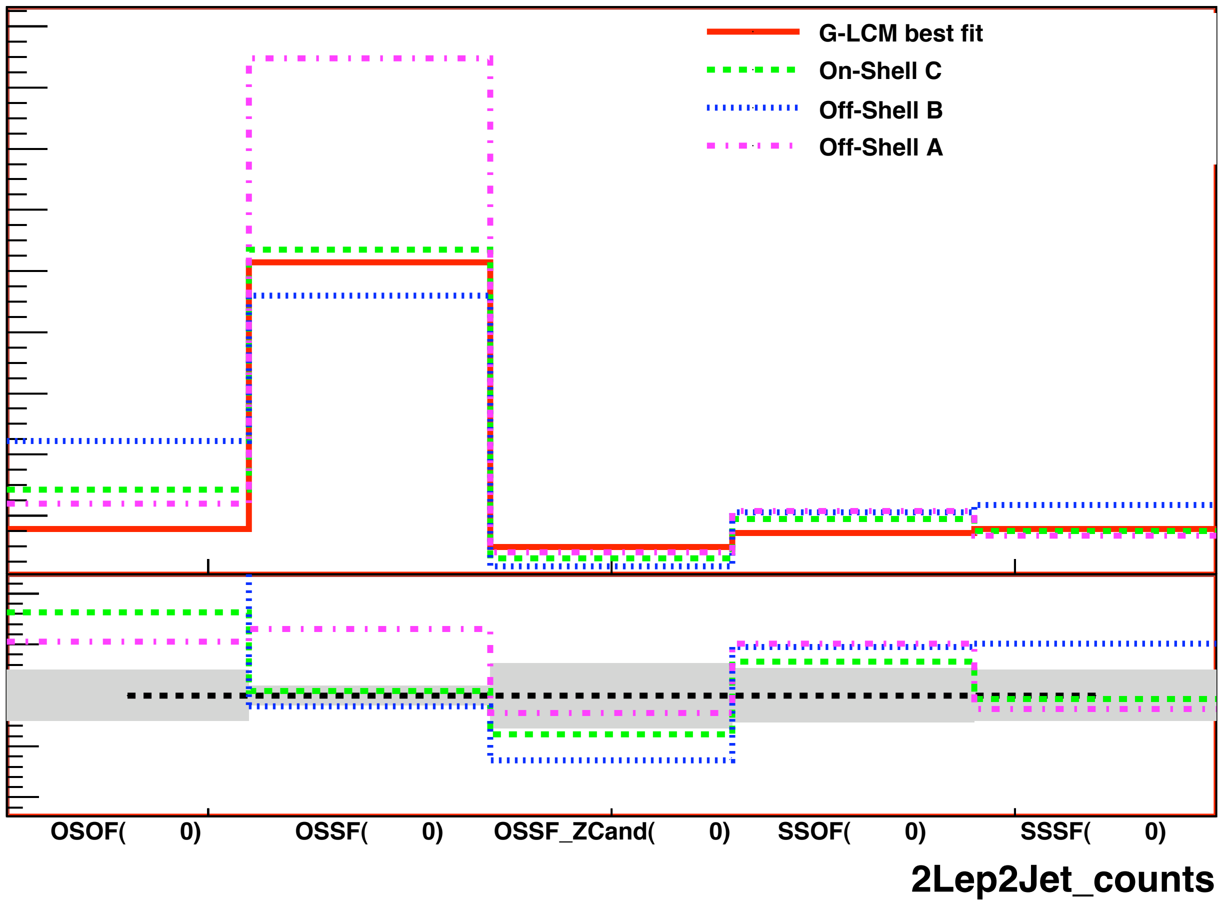
Simplified Model
vs. 3 SUSY models





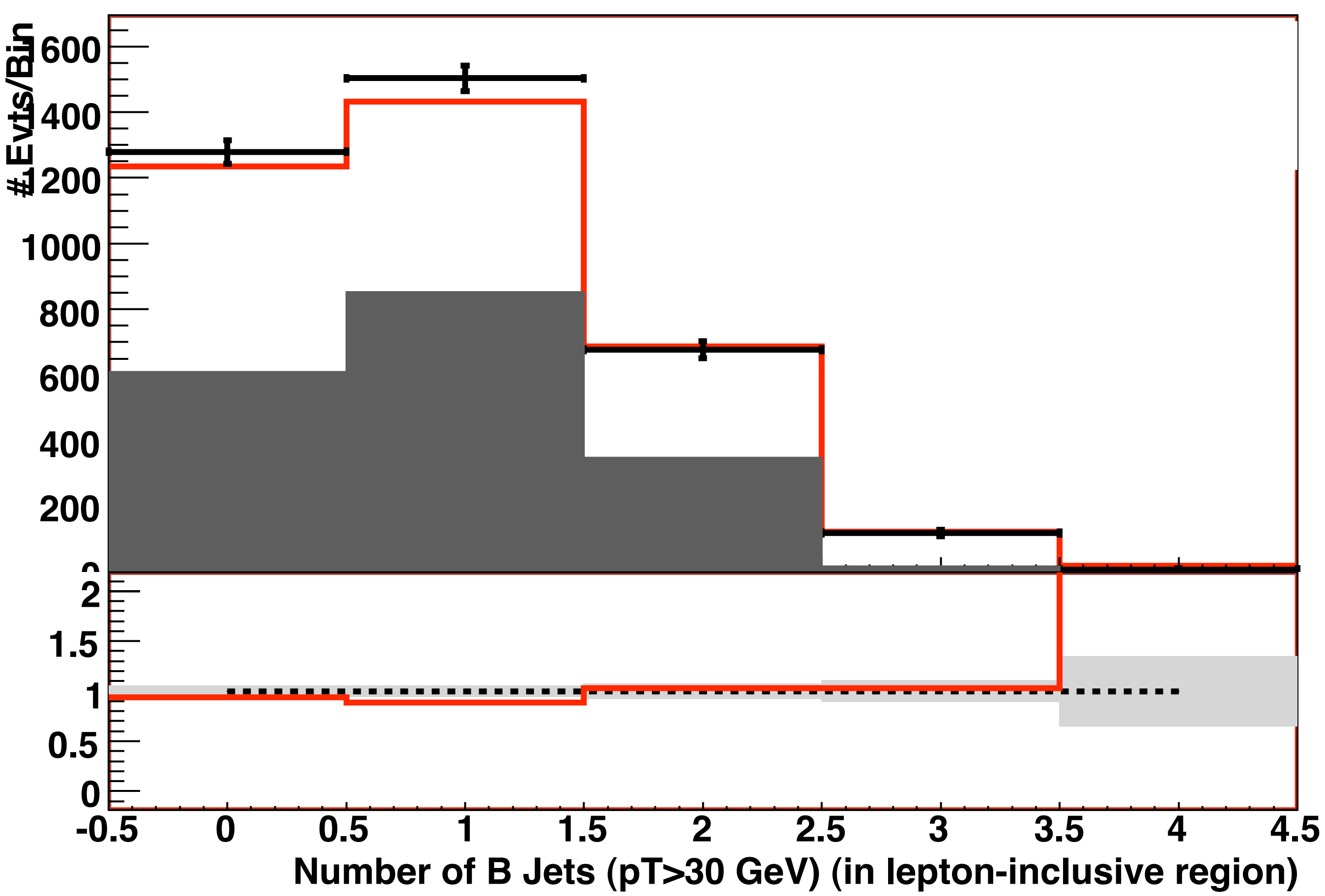
Building Models from Simplified Models

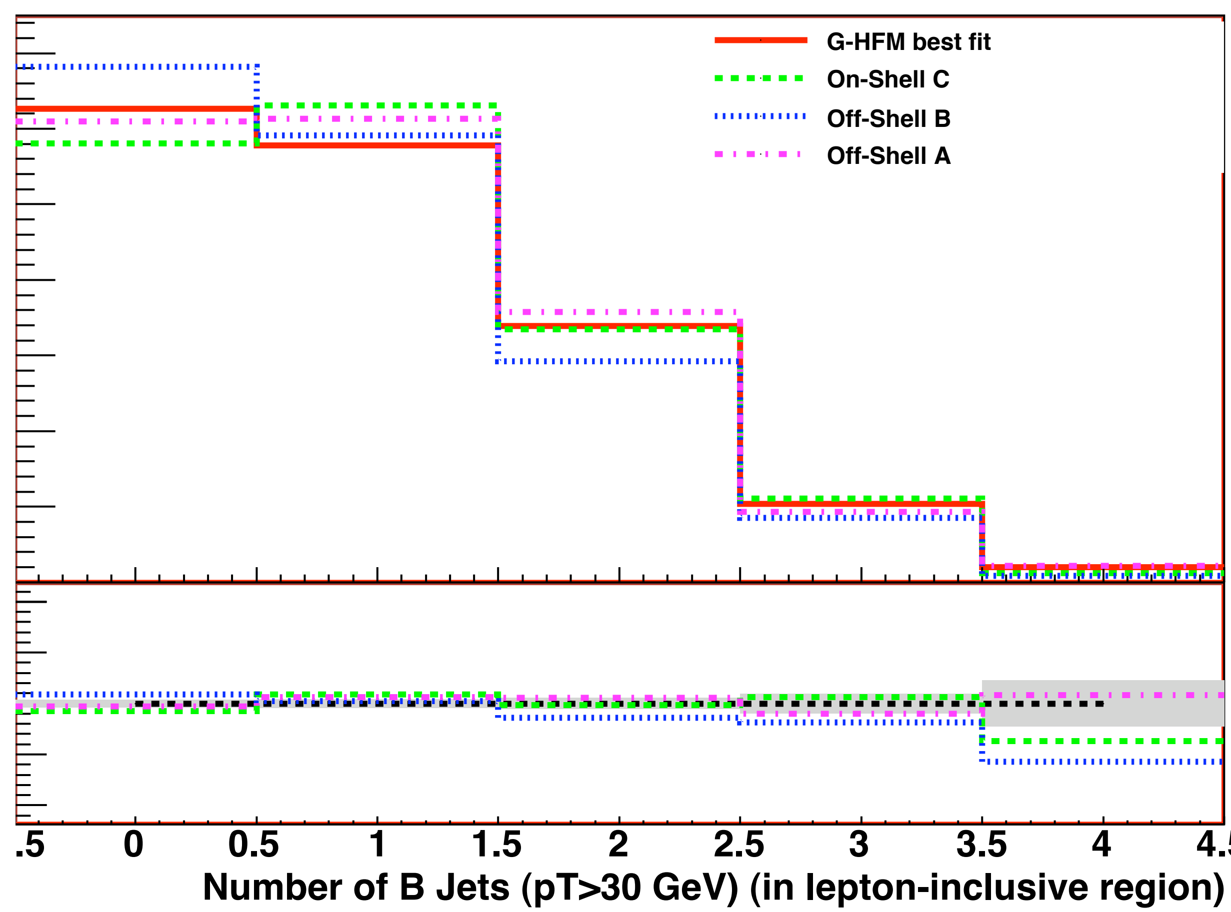
Experimental comparison:

Simplified Model (Heavy flavor)
vs. Data
(shown over ttbar background)

Theorist's comparison

Simplified Model
vs. 3 SUSY models





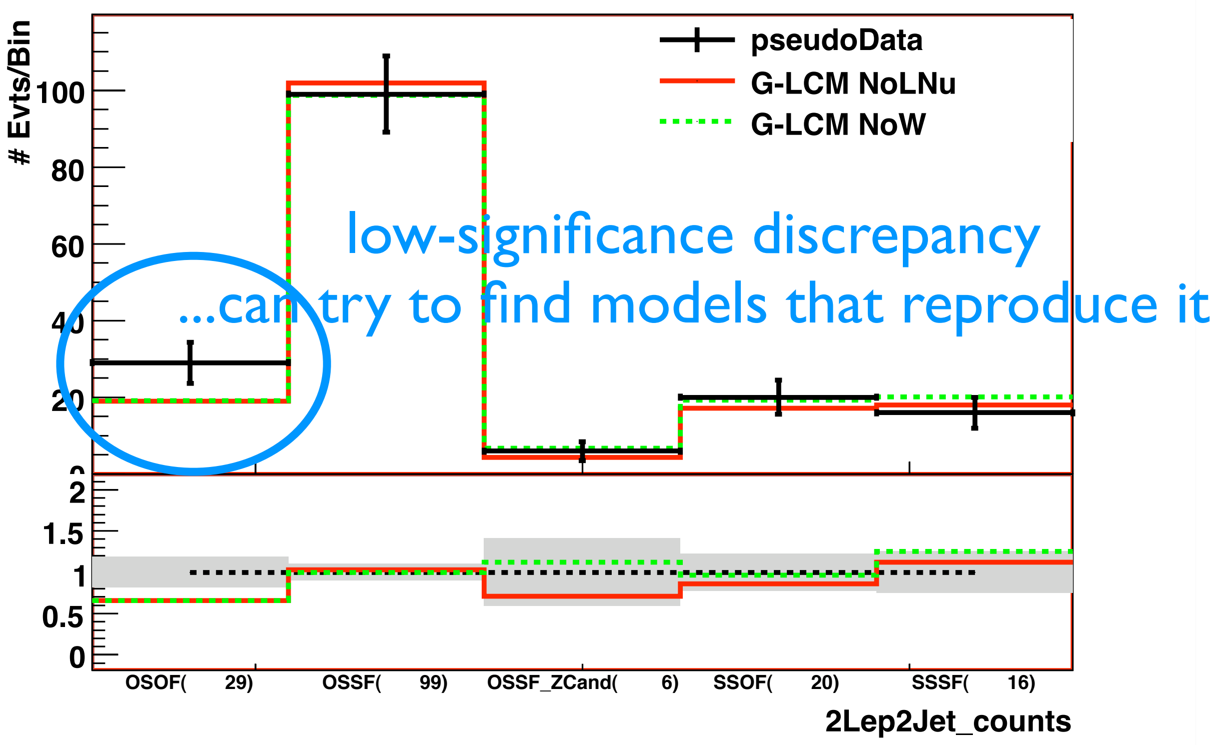
Constraining σ and BR's

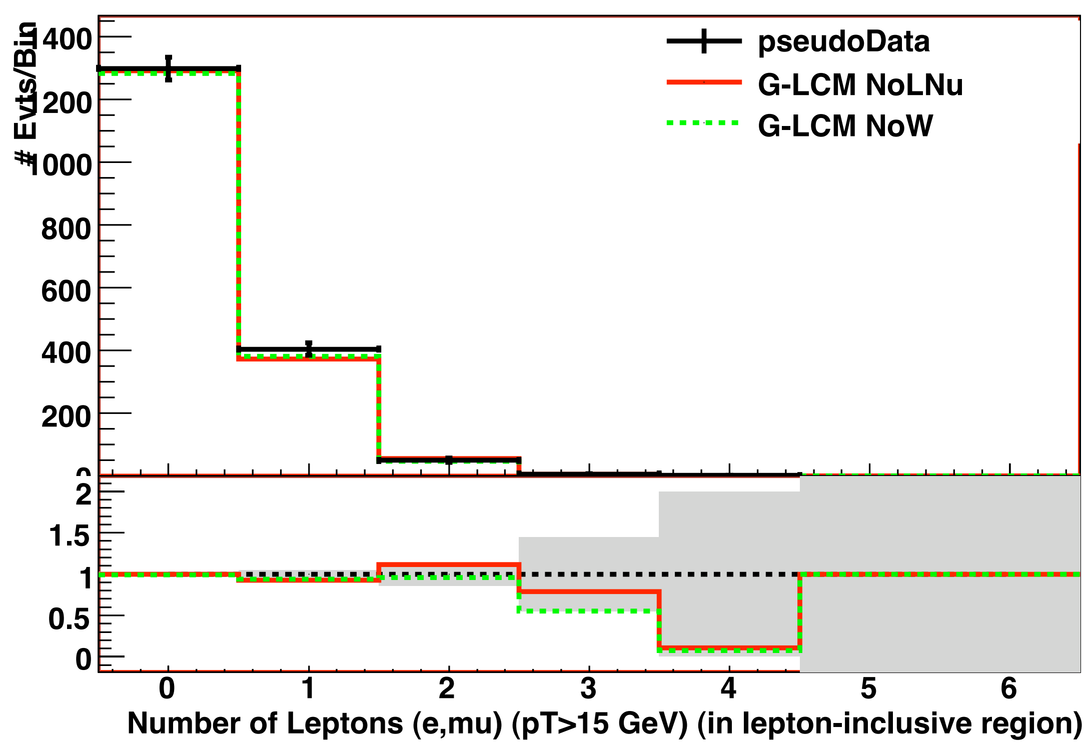
Branching ratios well constrained by these counts (aside from the W/Lnu ambiguity):

	σ (pb)	B_{LSP}	B_W	B_Z	B_{ll}	$B_{l\nu}$
Red	11.3	0.0	0.914	0.02	0.063	—
Green	13.1	0.613	—	0.03	0.052	0.30
± (**)	0.1	0.04	0.05	0.02	0.005	0.01

Masses: Best fit to kinematics, with LSP fixed at 100 GeV

** Don't take these errors too seriously!! No backgrounds, etc.



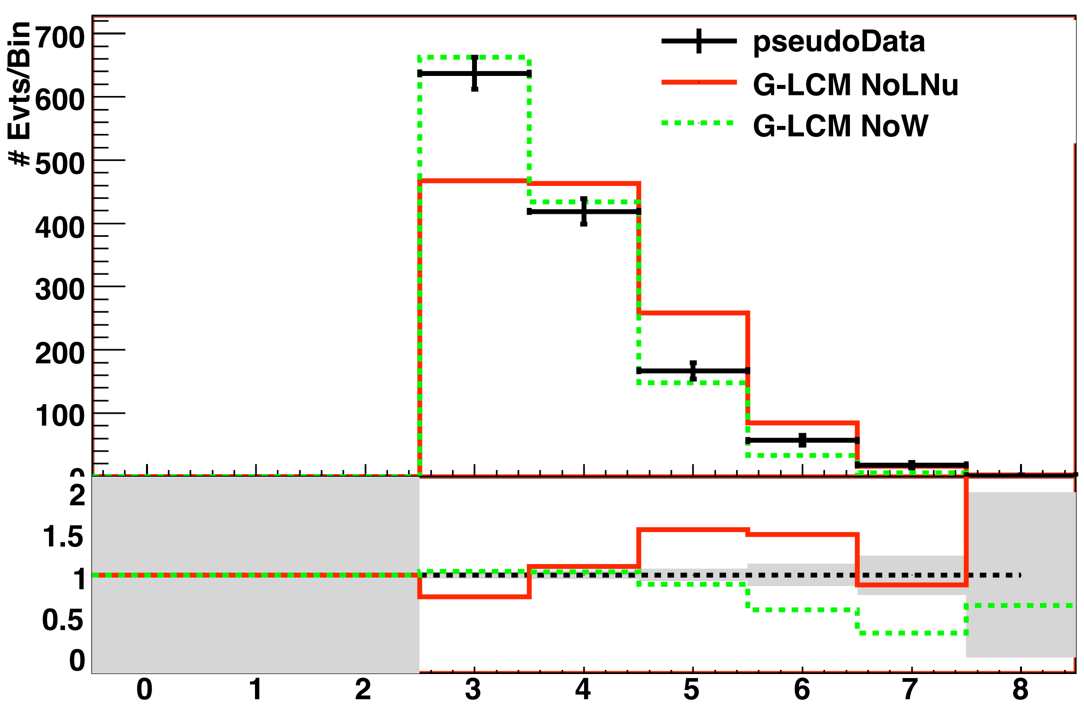


W vs lnu Modes

Within each of the two models (quark-partner or gluon-partner initiated), W↔(lν+direct) changes jet multiplicities, and

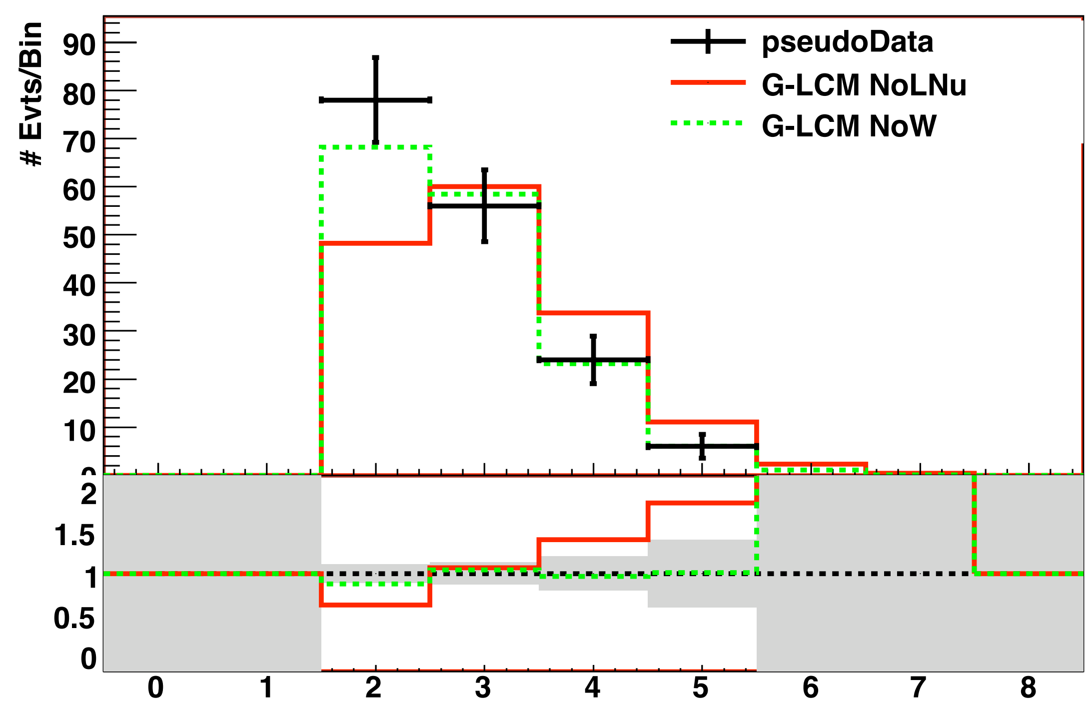
correlation with lepton counts.

Lepton-veto region



# of jets (p_T> 75 GeV)

2-Lepton region (different cuts)



# of jets (p_T> 75 GeV)

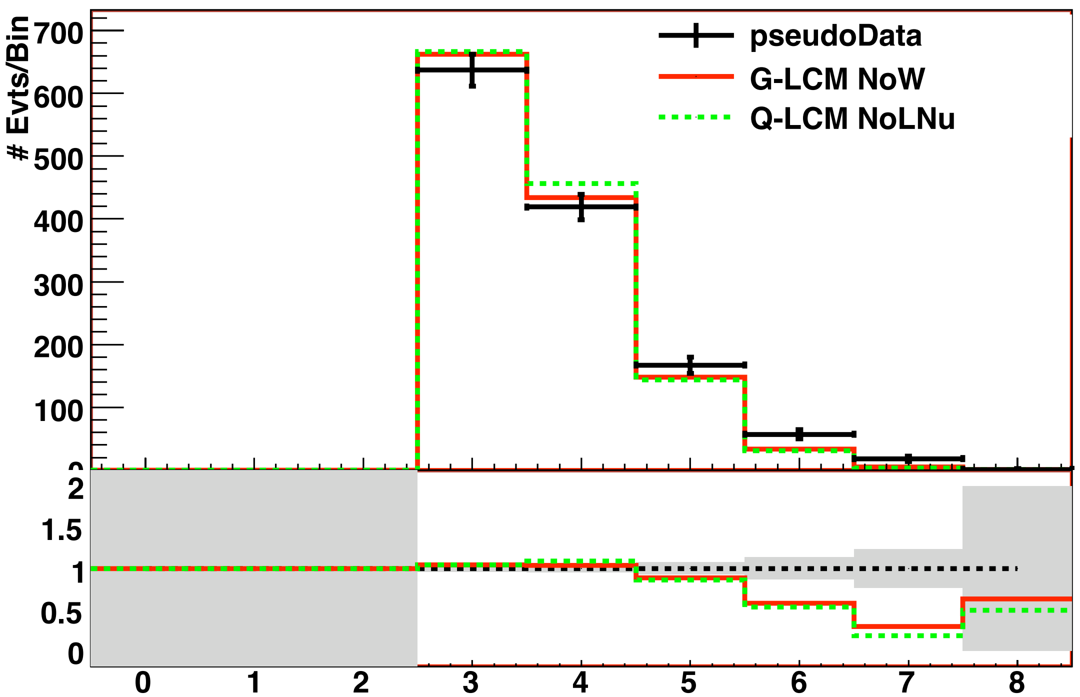
(in some cases, lepton kinematics also constrains these fractions)

Comparing Gluon and Squark Partners

Two ways to get jet & lepton counts in simplified models:
- quark partner decays to 1 jet with W's in cascades
- gluon partner decas to 2 jets with no hadronic W/Z in cascades

Real physics can interpolate between the two!

Lepton-veto region



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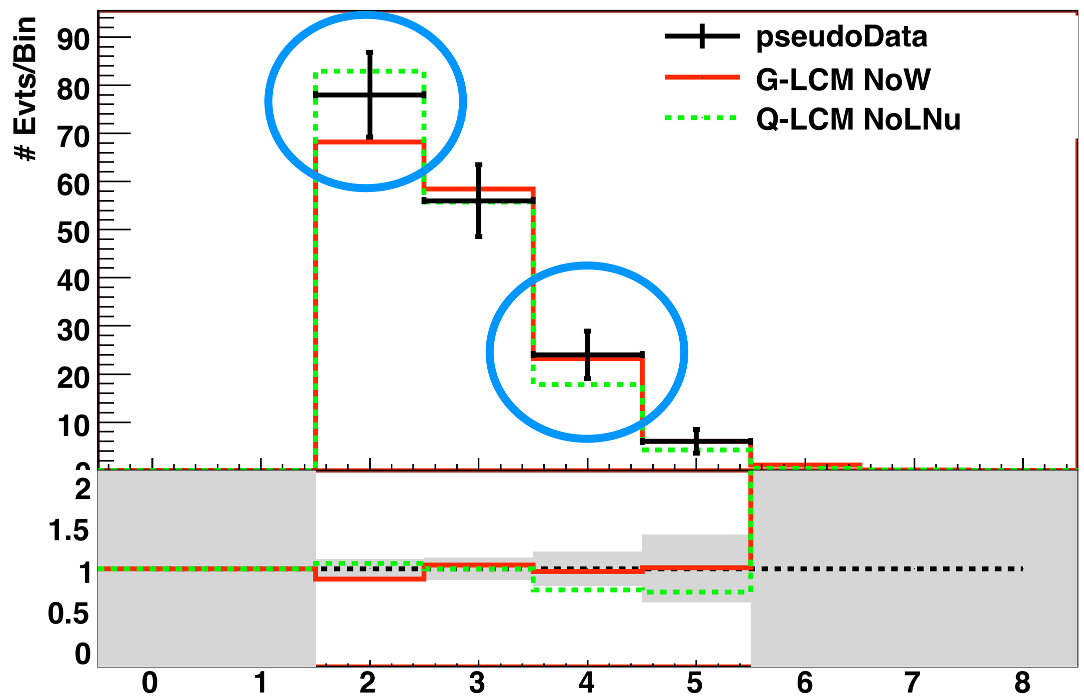


# of jets (p_T> 75 GeV)

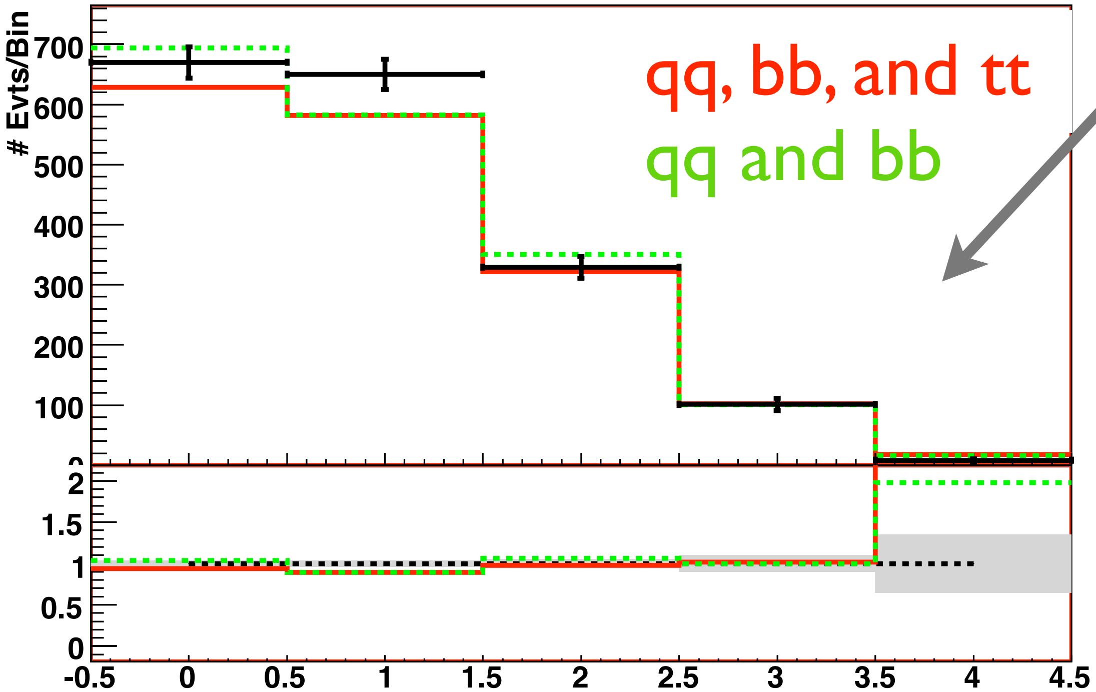
Models look different, but not distinguishable without more statistics!
Better observables also help.

Constraining σ and BR's

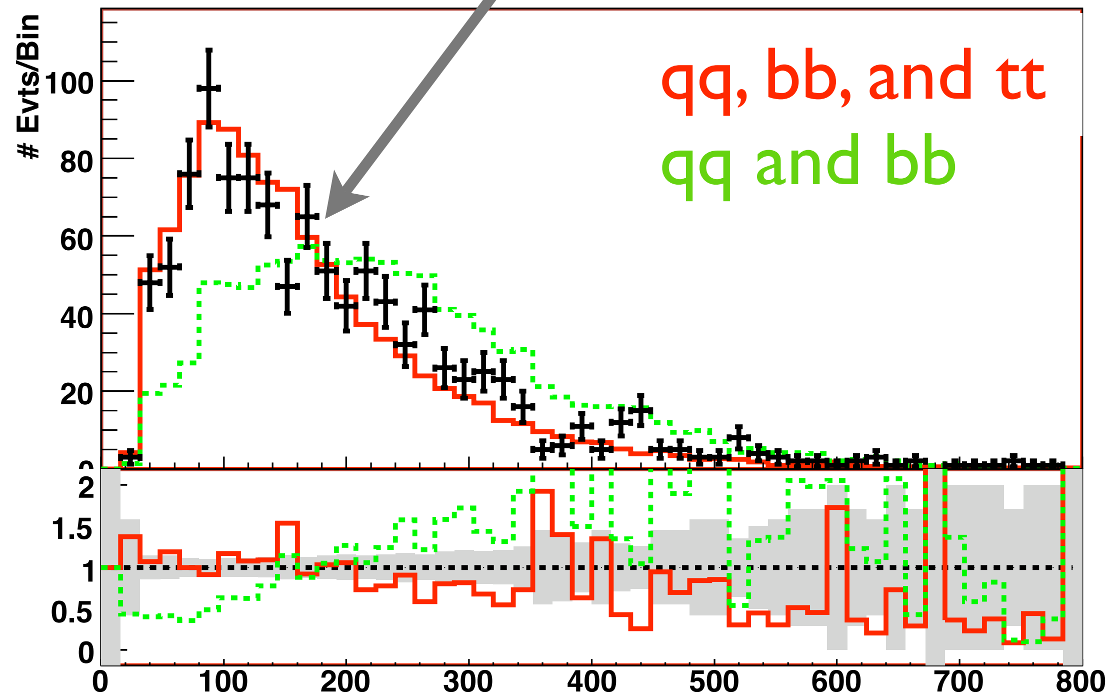
	σ (pb)	B_{qq}	B_{bb}	B_{tt}
Green	11.4	0.44	0.56	—
Red	11.4	0.33	0.03	0.64

Counts appear consistent with one pair-produced particle decaying to bb or q's (high heavy-flavor fraction)

b kinematics most consistent with top pairs



# of b-tagged jets (p_T > 30 GeV)



p_T of leading b-tagged jet

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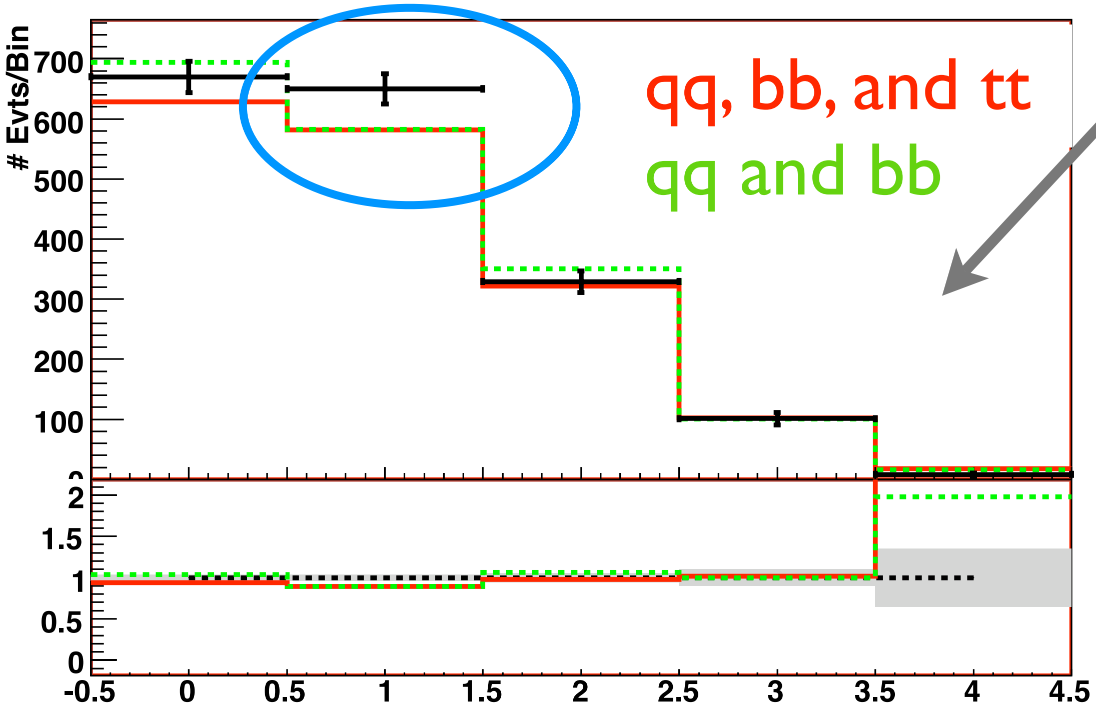

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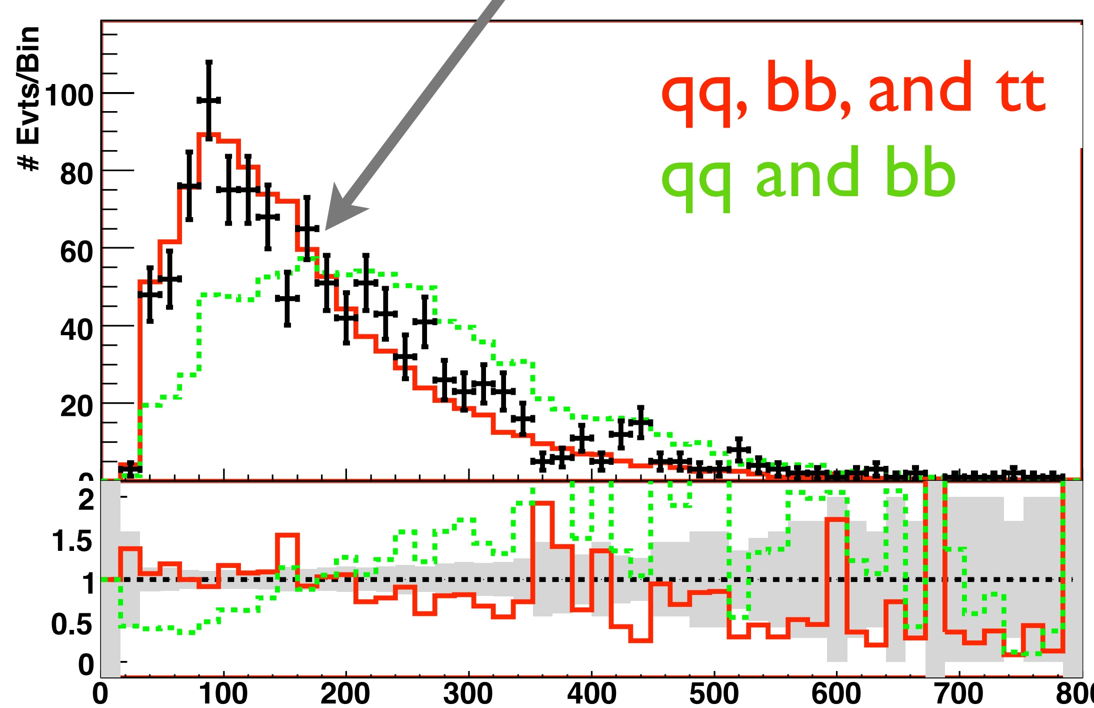

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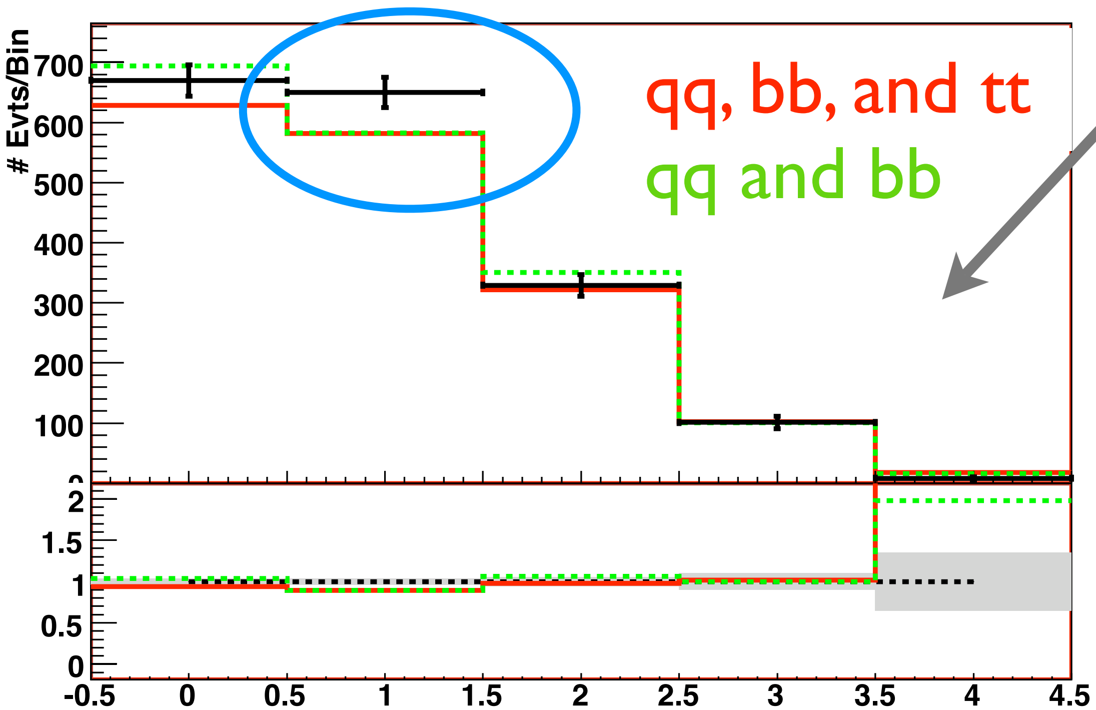

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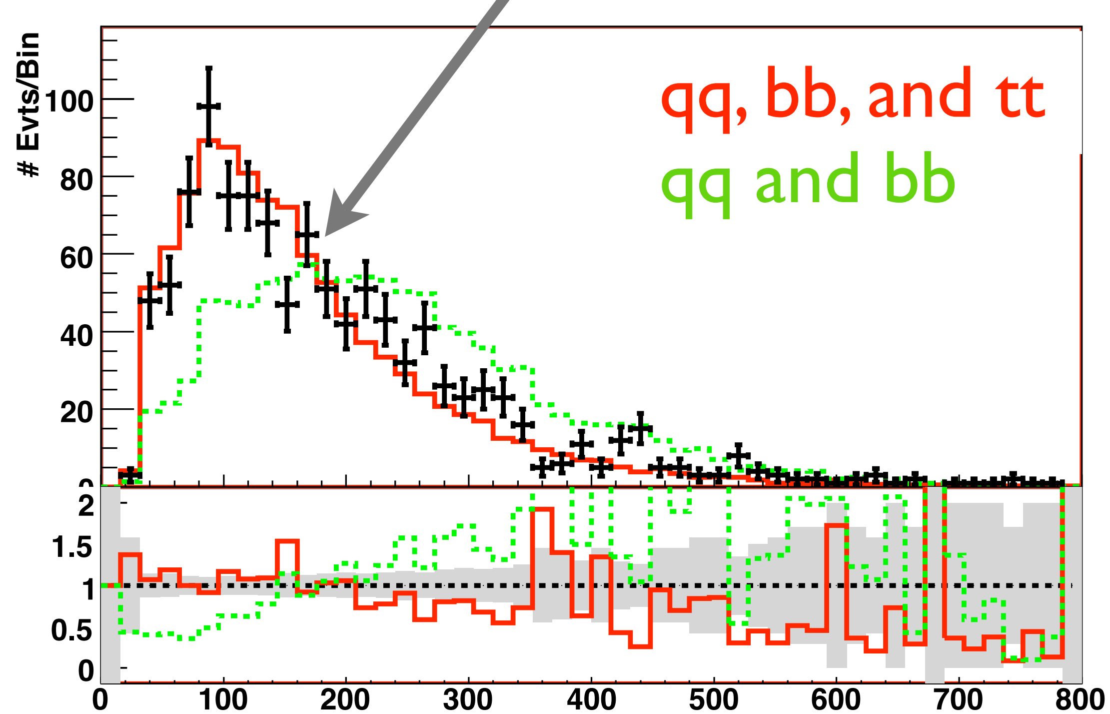

p_T of leading b-tagged jet

Weak deviation suggestive of additional 2b source that does not also imply 4b (e.g. in SUSY – top squark direct production, gluino-squark assoc. production)