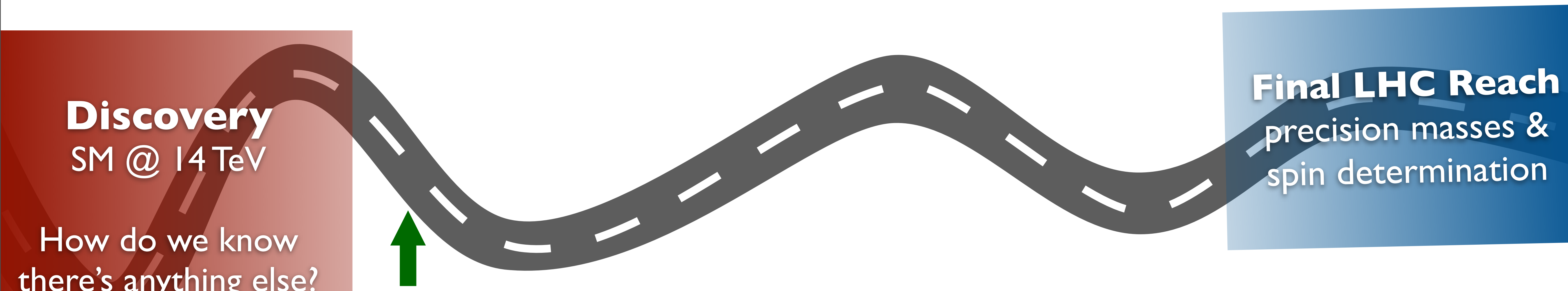
Characterizing the First New Physics at the LHC

Natalia Toro

hep-ph/0703088: Arkani-Hamed, et. al.
J. Incandela, S. Koay, R. Rossin, P. Schuster, NT (in progress)
J. Alwall, P. Schuster, NT (in progress)

The First New Physics at the LHC



Compelling evidence for new physics
Begin to characterize excesses *(>1 excess, distributions)*

We want:

- Qualitative properties of new physics **spectrum**
- Motivating 2nd-stage analyses, setting stage for precision physics
- Basic physics (dark matter, EWSB, hierarchy, SUSY mediation...)

How do we get there?

Why not wait?

- Practice (makes perfect)
- "What methods do you trust?" ← multiple examples
- Tevatron: good constraints, ambiguously presented
  What will good signals look like?

GOAL: Characterize early data by identifying **consistent processes,** constraining their **rates and masses**

Easy to compare to **any model of new physics**

How is this different?

<u>"Kinematic feature" analysis:</u>

- Very useful
- At low lumi, mostly leptons
- Also need to study SU(3) sector
  (this is even true for DM, a very electroweak question!)

<u>mSUGRA (e.g) scans:</u>

- Assume relations between masses and σ's, Γ's (also among m's)
- These can *reasonably* be violated; what then? (e.g. Is a model with the same parameters *but a lighter Wino* is consistent?)

Challenges

SM Backgrounds

Unprecedented freedom & complexity of phenomenology
(vs. Z/W/t)

A Proposal

Characterize early data by identifying **consistent processes,** constraining their **masses** and relative **rates:**

1) **Simulate arbitrary processes** using a minimal parametrization (masses & rates) until greater experimental resolution is possible

2) **Constrain processes using broad kinematics, counts** (and sharp features whenever possible) – often hard to isolate

3) **Focus on "most pertinent" processes** – what they are depend on what's seen; **process groups that cover the MSSM** are a good starting point.

Developing the Proposal

Characterize early data by identifying **consistent processes,** constraining their **masses** and relative **rates:**

1) **Simulate** in a simple framework for characterization (On-Shell Effective Theories) (quick review)

(Arkani-Hamed, et. al: hep-ph/0703088)

2) **Constrain processes** worked with experimentalists to consider realism, test with backgrounds, develop tools

(Work in progress: J. Incandela, S. Koay, R. Rossin, P Schuster, NT)
UCSB CMS

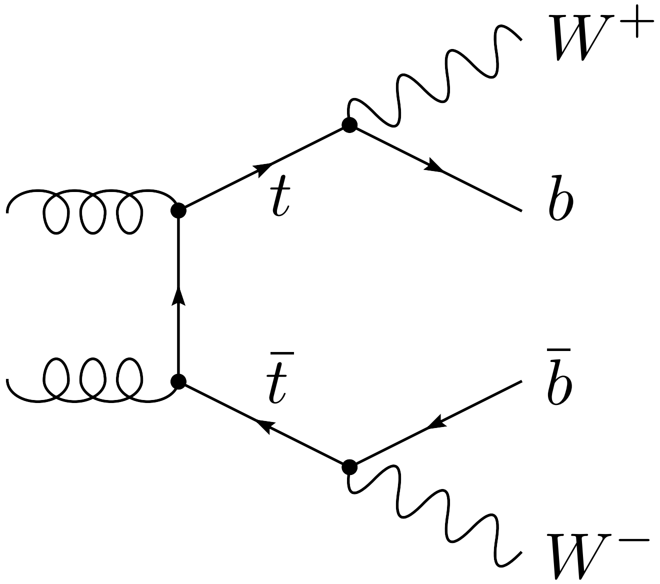
3) **Cover the MSSM** with templates (mutually consistent sets of processes w/ free parameters to vary)

(Work in progress: J. Alwall, P. Schuster, NT)

Application/Example:

Learning about SUSY Dark Matter in Early Data

Describing (and simulating) Processes as Simply as Possible



Dominant Top Properties:

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

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

m_t, m_W, m_b

(Detailed Top Properties:

$d\sigma/d\hat{t}$ $\quad W$ helicity

t charge)

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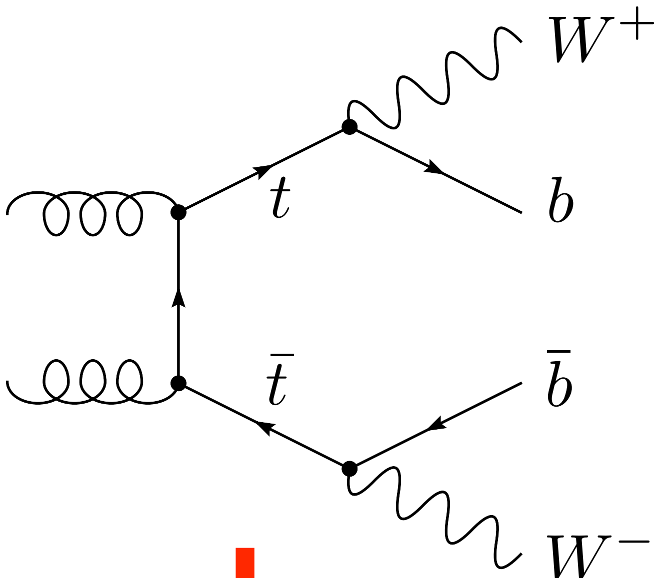

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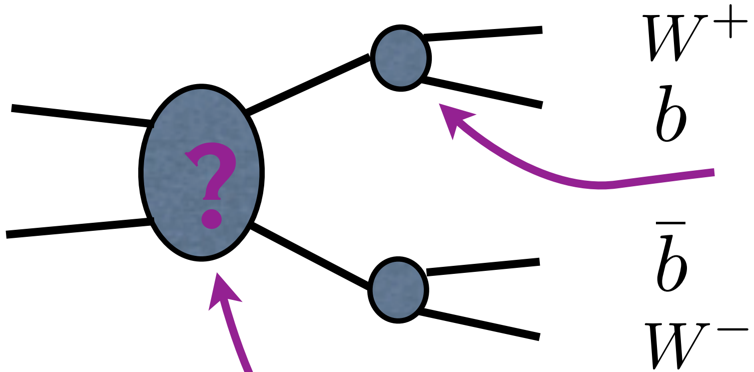


in first pass, try to describe only dominant properties

phase space

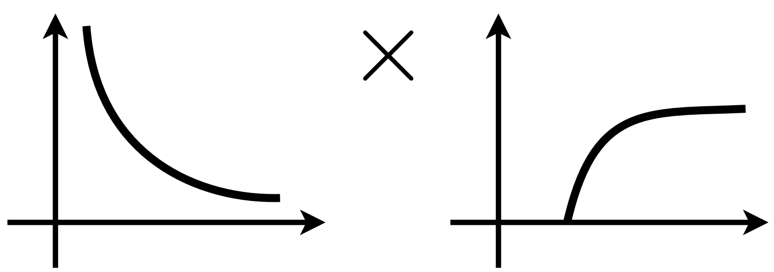
What is an appropriate parametrization for 2→2 production?

(For 2→1, spin-0 Breit-Wigner is simplest guess)

Modeling 2→2 Production

Cross Sections dominated near thresholds:

$$\frac{d\sigma}{d\hat{t}} = \int \text{(Parton Luminosity)} \times \text{(Phase Space (Threshold))} \times |\mathcal{M}|^2$$



&

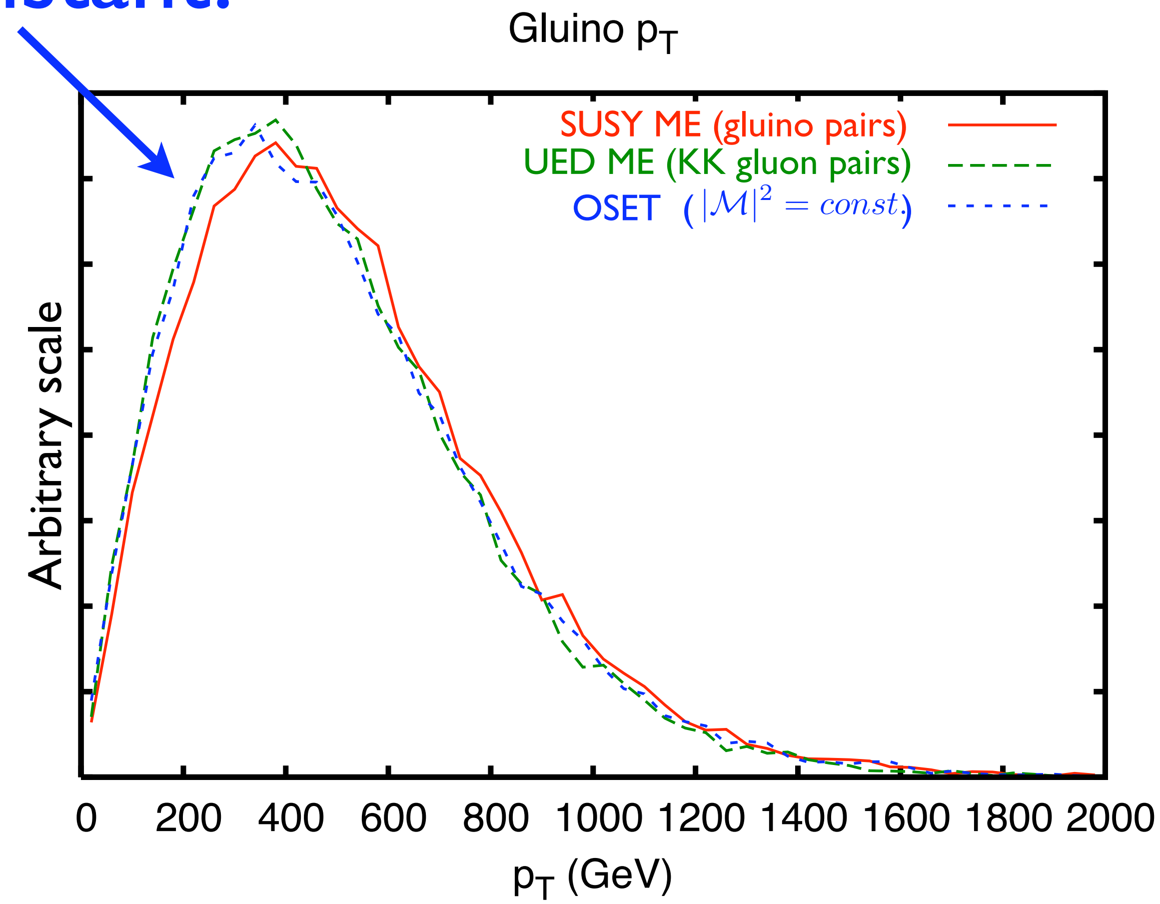
Homogeneity of PDF in E_{cm} and y_{cm}

→ $|\mathcal{M}|^2$ well approximated by constant!

(systematic & universal corrections necessary for highly asymmetric kinematics

formally correct for simple pT, eta observables; *useful* much more broadly)

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

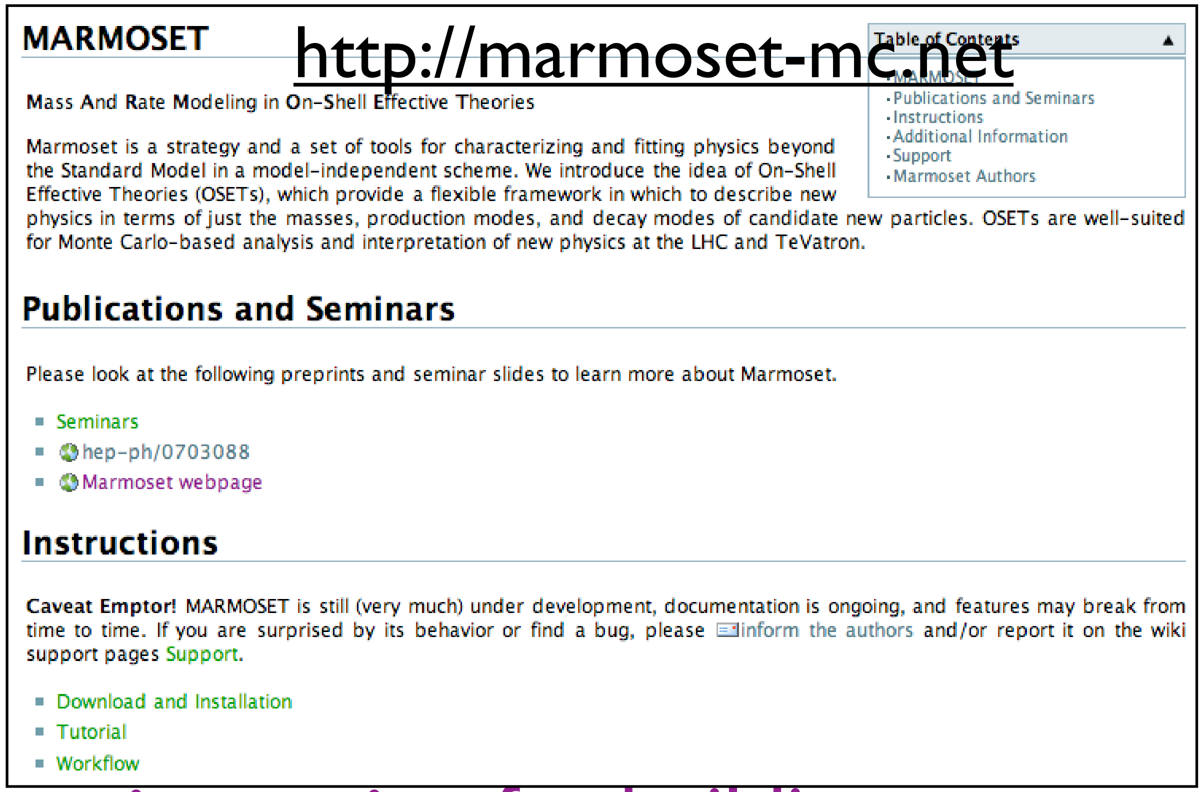


Messy collider environment turned to our advantage

On-Shell Effective Theories

- Model → Collection of processes
- Parametrized production & decay

    (In particular: *off-shell* three-body decays)



http://marmoset-mc.net

MARMOSET

Table of Contents
- MARMOSET
- Publications and Seminars
- Instructions
- Additional Information
- Support
- Marmoset Authors

Mass And Rate Modeling in On-Shell Effective Theories

Marmoset is a strategy and a set of tools for characterizing and fitting physics beyond the Standard Model in a model-independent scheme. We introduce the idea of On-Shell Effective Theories (OSETs), which provide a flexible framework in which to describe new physics in terms of just the masses, production modes, and decay modes of candidate new particles. OSETs are well-suited for Monte Carlo-based analysis and interpretation of new physics at the LHC and TeVatron.

Publications and Seminars

Please look at the following preprints and seminar slides to learn more about Marmoset.

- Seminars
- hep-ph/0703088
- Marmoset webpage

Instructions

Caveat Emptor! MARMOSET is still (very much) under development, documentation is ongoing, and features may break from time to time. If you are surprised by its behavior or find a bug, please inform the authors and/or report it on the wiki support pages Support.

- Download and Installation
- Tutorial
- Workflow

- Often useful to ignore:
    - very soft decay products
    - on-shell intermediate states

- These simplifications are useful as **starting point** for building increasingly detailed description

    (reintroduce detailed dynamics when it is observable or a guess is well motivated)

Tools for Process-Focused Analysis

work with J. Incandela, S. Koay, R. Rossin
(UCSB CMS group members) and P. Schuster

1. Worked through "early analysis" of BSM scenarios from observed signal through process-level characterization (using OSET MC)

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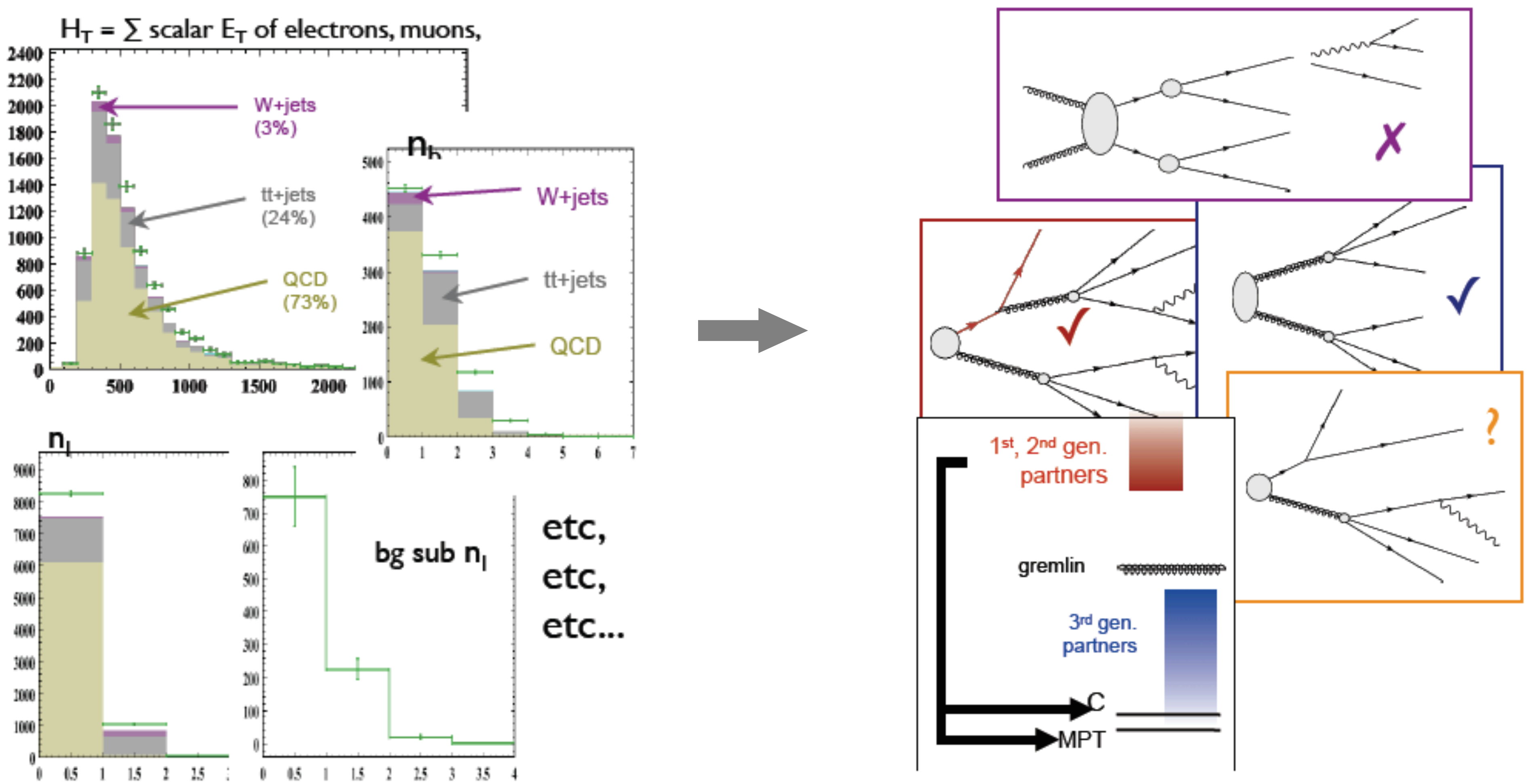

- Learning by doing, with “realism” and SM backgrounds (What SUSY processes are consistent with data? Mutually consistent? What to try next?) ...by trial and error

–also motivated systematizing set of important SUSY processes–

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   - Learning by doing, with "realism" and SM backgrounds
     (What SUSY processes are consistent with data? Mutually consistent? What to try next?) ...by trial and error

     –also motivated systematizing set of important SUSY processes–

   - Technical obstacles:
     - Compare (and convincingly set aside) models
     - Scan parameters for best agreement

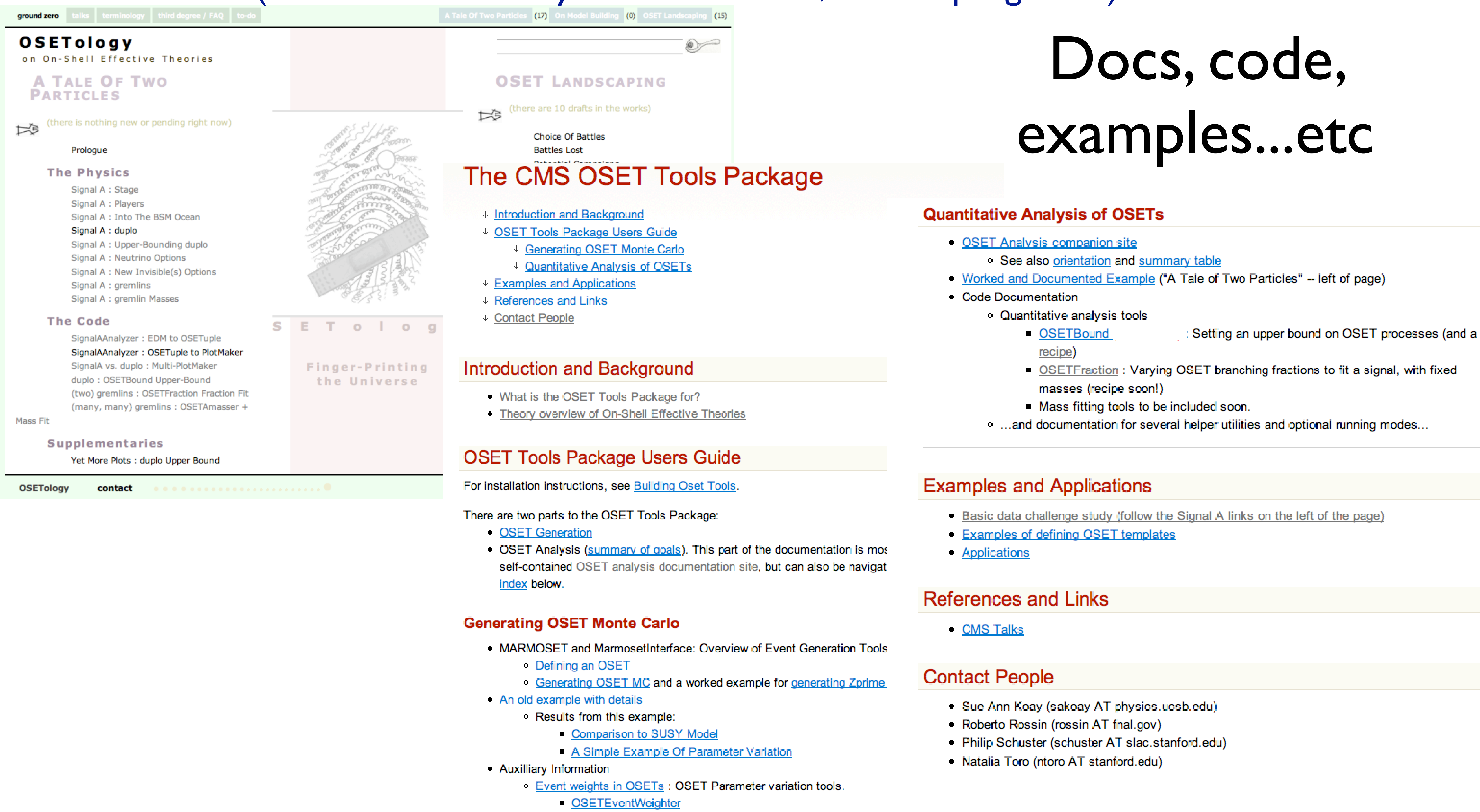
     standard tasks applied to process characterization

2. Developed analysis tools (for general CMS use) to solve these problems.

   - Illustrate their use in context
   - Essential step in extracting basic physics

CMS OSET Tools Package

(OSET MC and analysis tools in CMS, note in progress...)



ground zero | talks | terminology | third degree / FAQ | to-do | A Tale Of Two Particles (17) | On Model Building (0) | OSET Landscaping (15)

OSETology
on On-Shell Effective Theories

A TALE OF TWO PARTICLES

(there is nothing new or pending right now)

Prologue

The Physics

Signal A : Stage
Signal A : Players
Signal A : Into The BSM Ocean
Signal A : duplo
Signal A : Upper-Bounding duplo
Signal A : Neutrino Options
Signal A : New Invisible(s) Options
Signal A : gremlins
Signal A : gremlin Masses

The Code

SignalAAnalyzer : EDM to OSETuple
SignalAAnalyzer : OSETuple to PlotMaker
SignalA vs. duplo : Multi-PlotMaker
duplo : OSETBound Upper-Bound
(two) gremlins : OSETFraction Fraction Fit
(many, many) gremlins : OSETAmasser + Mass Fit

Supplementaries

Yet More Plots : duplo Upper Bound

S E T o l o g

Finger-Printing the Universe

OSET LANDSCAPING

(there are 10 drafts in the works)

Choice Of Battles
Battles Lost

OSETology contact

The CMS OSET Tools Package

- Introduction and Background
- OSET Tools Package Users Guide
  - Generating OSET Monte Carlo
  - Quantitative Analysis of OSETs
- Examples and Applications
- References and Links
- Contact People

Introduction and Background

- What is the OSET Tools Package for?
- Theory overview of On-Shell Effective Theories

OSET Tools Package Users Guide

For installation instructions, see Building Oset Tools.

There are two parts to the OSET Tools Package:

- OSET Generation
- OSET Analysis (summary of goals). This part of the documentation is mos self-contained OSET analysis documentation site, but can also be navigat index below.

Generating OSET Monte Carlo

- MARMOSET and MarmosetInterface: Overview of Event Generation Tools
  - Defining an OSET
  - Generating OSET MC and a worked example for generating Zprime
- An old example with details
  - Results from this example:
    - Comparison to SUSY Model
    - A Simple Example Of Parameter Variation
- Auxilliary Information
  - Event weights in OSETs : OSET Parameter variation tools.
    - OSETEventWeighter

Quantitative Analysis of OSETs

- OSET Analysis companion site
  - See also orientation and summary table
- Worked and Documented Example ("A Tale of Two Particles" -- left of page)
- Code Documentation
  - Quantitative analysis tools
    - OSETBound : Setting an upper bound on OSET processes (and a recipe)
    - OSETFraction : Varying OSET branching fractions to fit a signal, with fixed masses (recipe soon!)
    - Mass fitting tools to be included soon.
  - ...and documentation for several helper utilities and optional running modes...

Examples and Applications

- Basic data challenge study (follow the Signal A links on the left of the page)
- Examples of defining OSET templates
- Applications

References and Links

- CMS Talks

Contact People

- Sue Ann Koay (sakoay AT physics.ucsb.edu)
- Roberto Rossin (rossin AT fnal.gov)
- Philip Schuster (schuster AT slac.stanford.edu)
- Natalia Toro (ntoro AT stanford.edu)

Docs, code, examples...etc

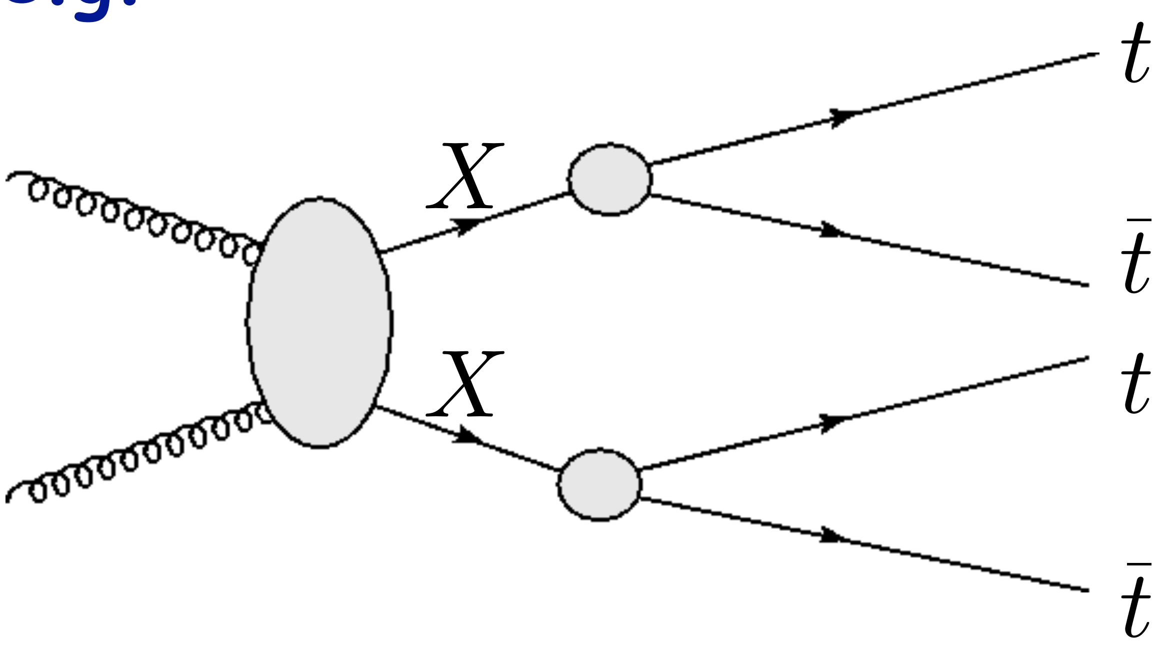
Physics application "mini-course" at CMS this summer, CMS public note in preparation

Upper Bounds for Processes

- "Signal" excess properties inferred from kinematics & multiplicities:
  - ~ 4 b's in many events
  - ~ 0, 1, and 2-lepton events (consistent with 2 W's per event)
  - ~ Significant $\not\!\!E_T$
  - ~ Mass scale (if pair production) about 0.5-1 TeV

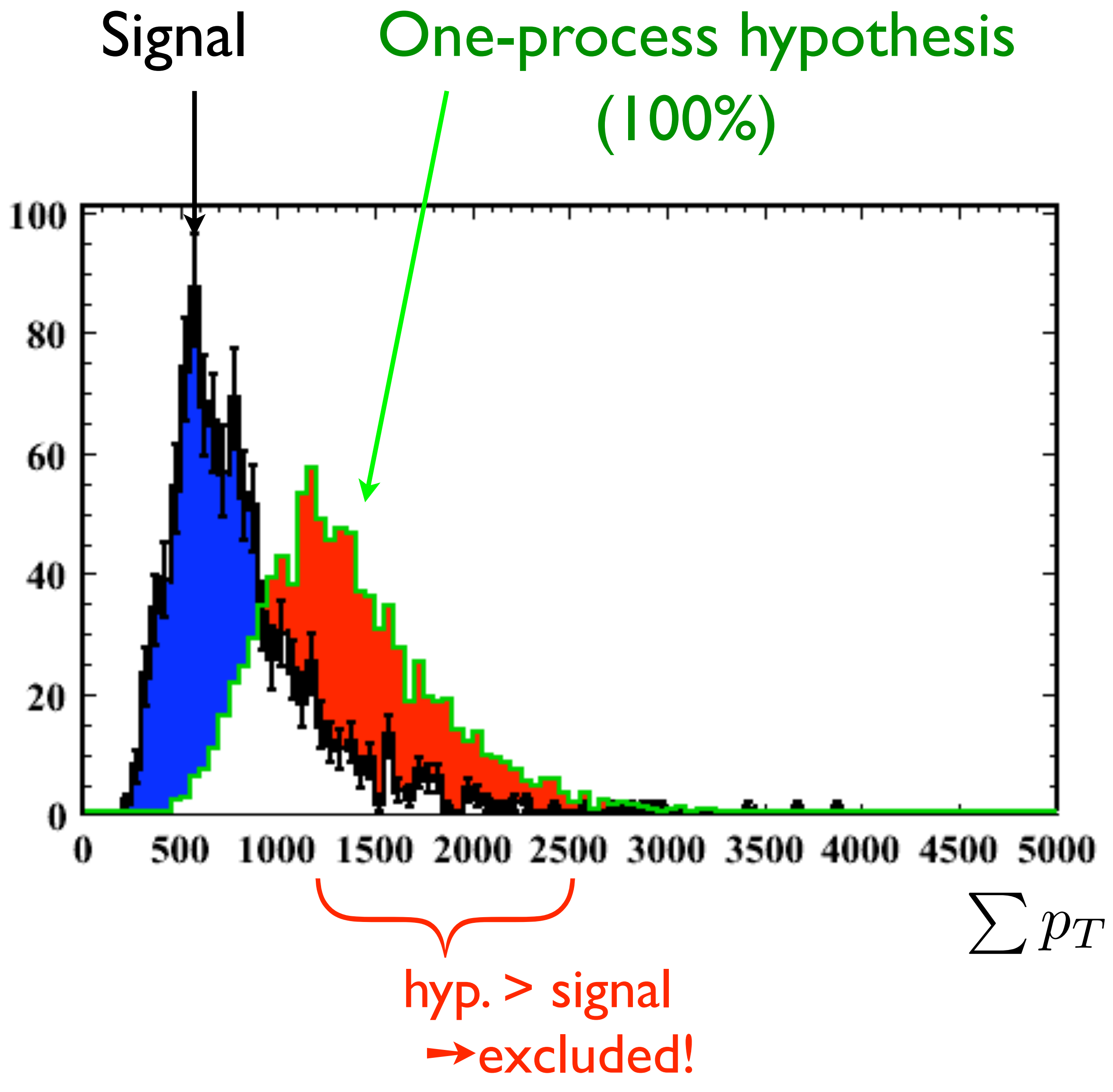
"We think it's SUSY (-like), but can we discriminate between alternatives?"

e.g.



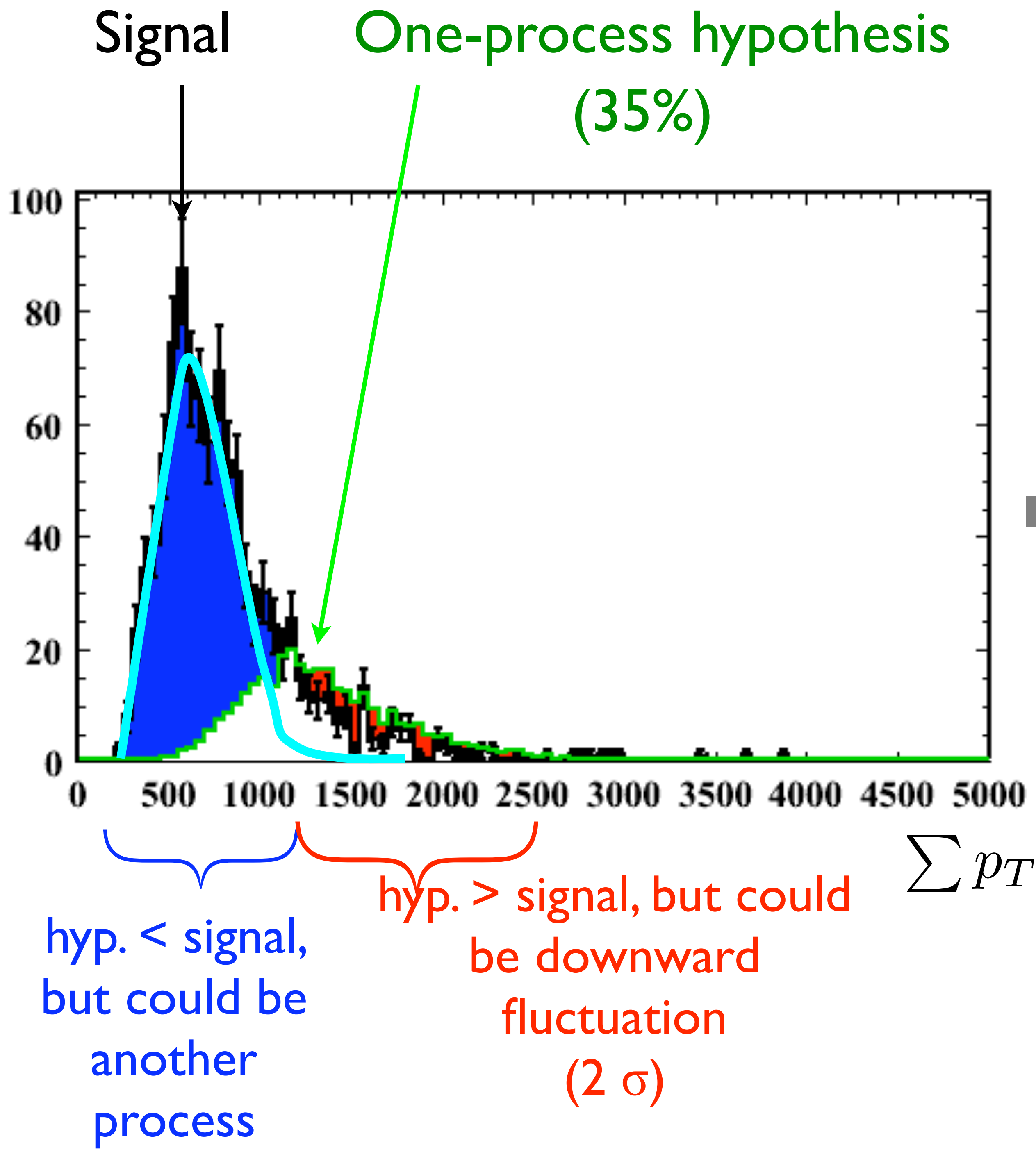
(even though it's strange)

Upper Bounds for Processes



(MET shape constrains models with lower new-particle mass)

Upper Bounds for Processes

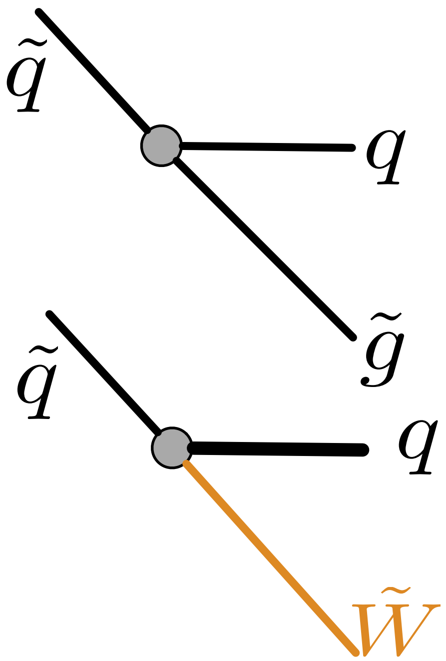


- Upper bound as a function of mass

  < 35% at 2 σ (are there related processes that could fill in remainder?)

- Most constraining distributions (here, not enough $\not\!\!E_T$ for given $\sum p_T$, and too many leptons) – try guesses with 2b, 2t (not 4t) and more $\not\!\!E_T$
- This is probably not an important process.

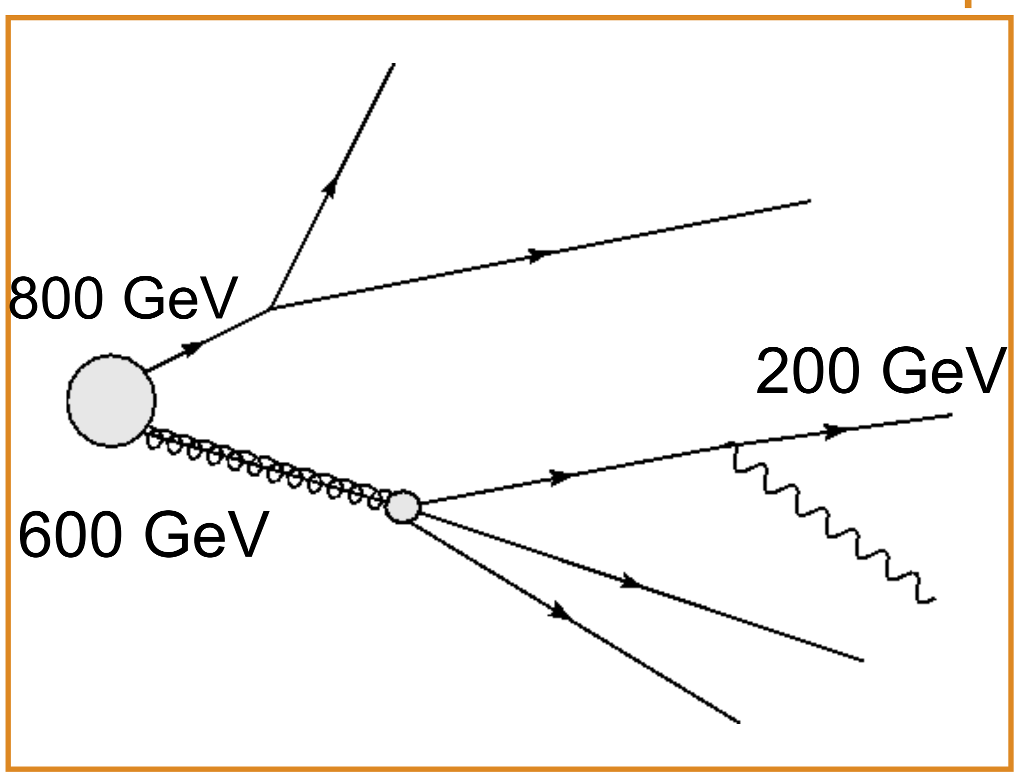
Upper bounds II

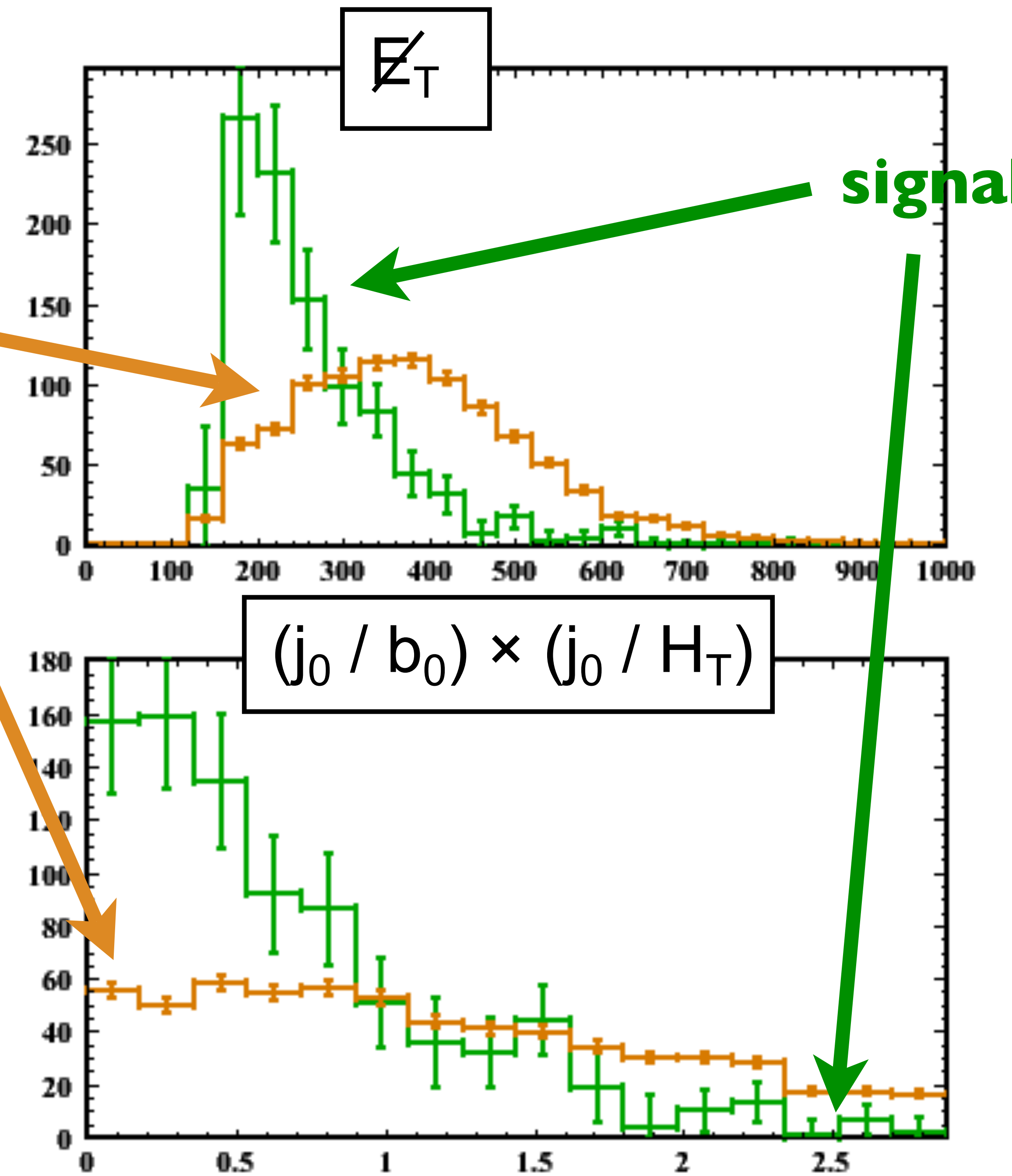


Heavy squark decays mostly to gluinos...

...but occasionally to Winos (if they're light and squarks are LH)

Using kinematics to place a model-independent bound on the **direct squark decay process** can rule out winos+LH squarks



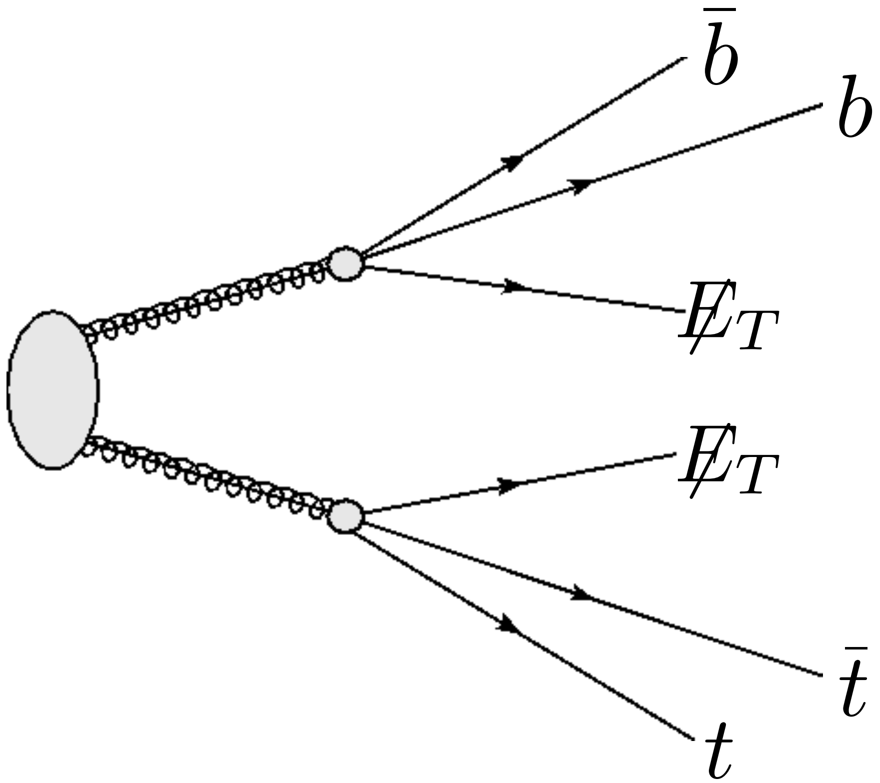


Quantitative answer is important!

Parameter-Scanning/Fitting I: Distinguishing Models

Two more guesses (competing or disjoint processes in SUSY)

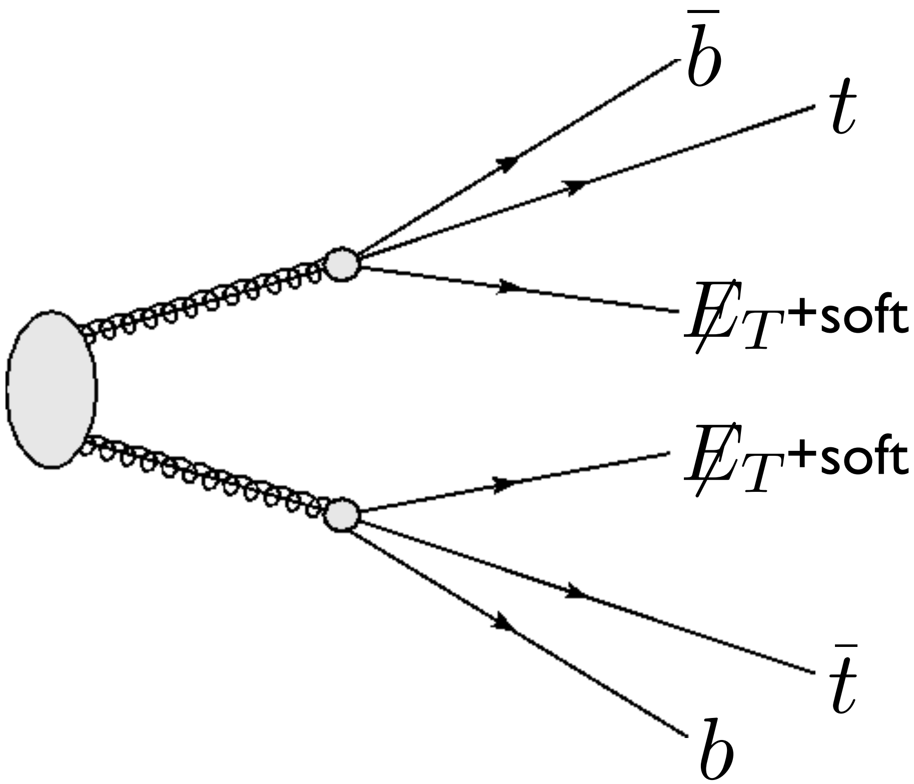
No light chargino,
decay via stop & sbottom



$+\, t\bar{t}\, t\bar{t}$ and $b\bar{b}\, b\bar{b}$

or

Chargino present,
just stop & $t\bar{t}$ kinematically forbidden
<u>or</u> just sbottom, small $\tan\beta$ to Higgsino



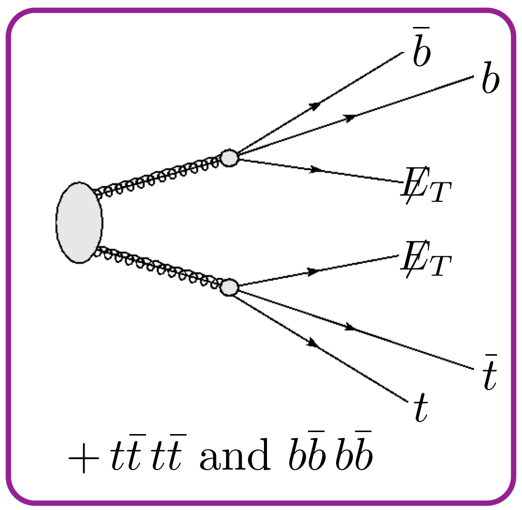
or both?

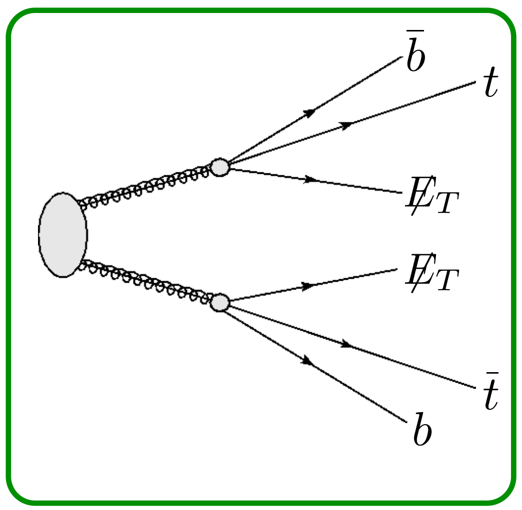
Main signature difference: distributions of lepton counts

Lepton Counts:

signal (tb-mode-dominated) at 100 pb-1

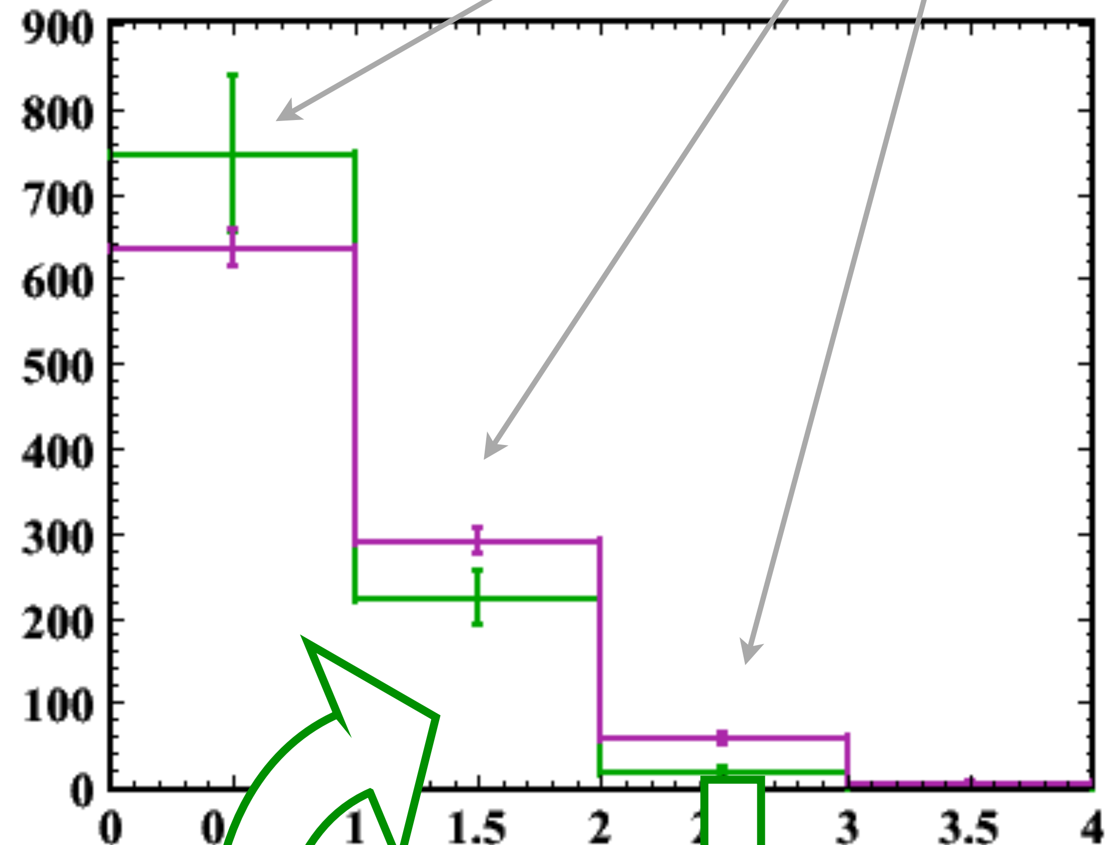
bb + tt modes ansatz





Different backgrounds in every bin

Number of leptons



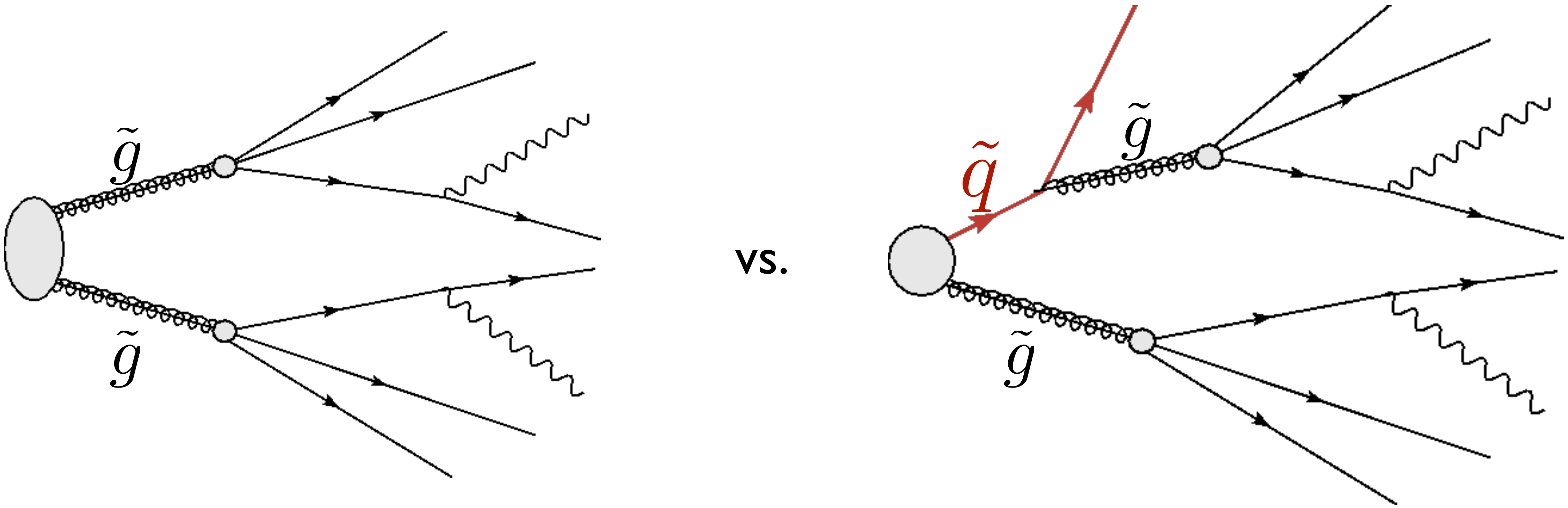
(+ more distributions)

constrains tttt mode

constrains bbtt mode

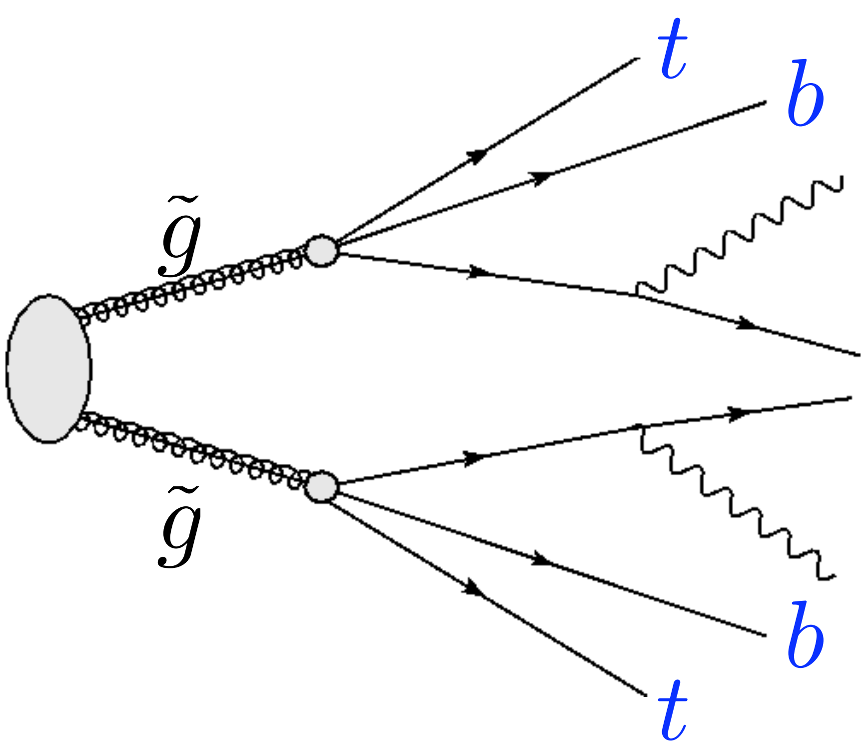
Main signature difference: distributions of lepton counts — to rule out left model, must consider **<u>all possible branching ratios</u> to** $\mathrm{t\bar{t}}$ / $\mathrm{b\bar{b}}$

Parameter-Scanning/Fitting II: Resolving Processes

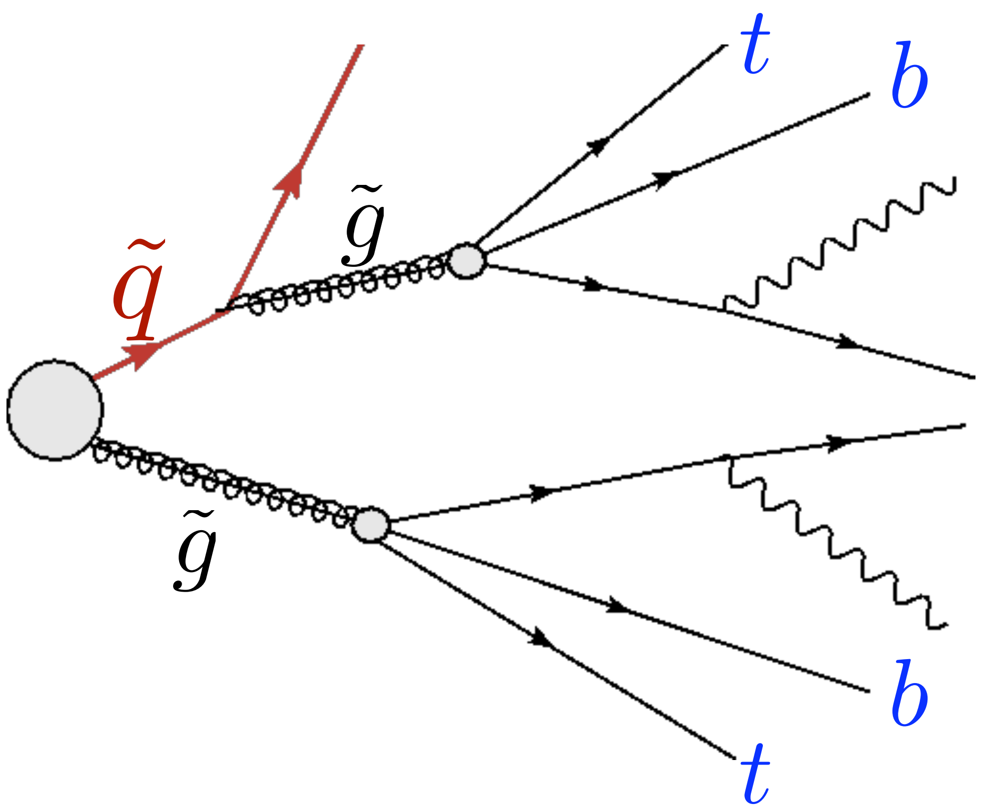


How much of each process?

Parameter-Scanning/Fitting II: Resolving Processes



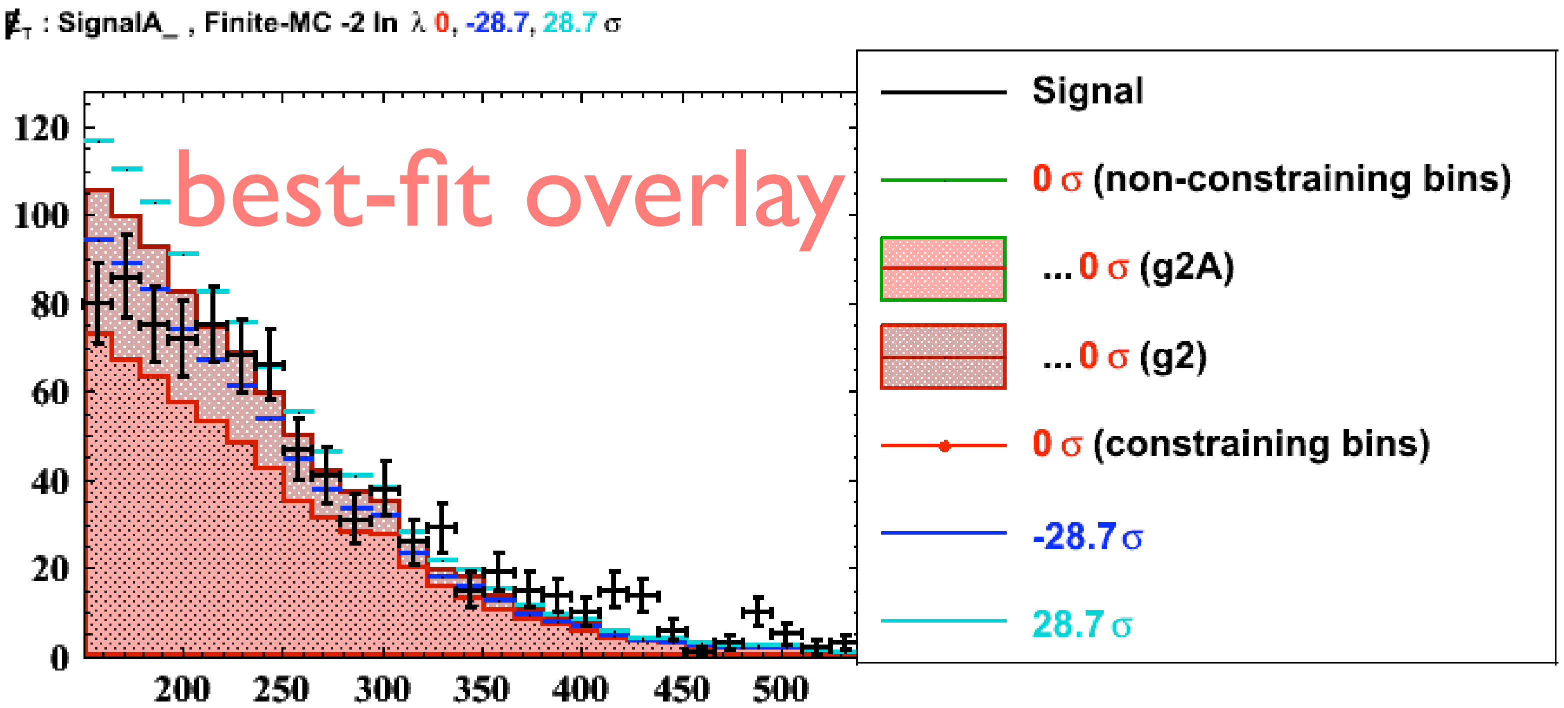
vs.



How much of each process?

(hard, but we get lucky–look for different kinematics between light and heavy flavor jets)

Using Parameter Scans to Separate/ Measure Different Processes



Applying rate metrics to

$\tilde{g}\tilde{g}$ topology

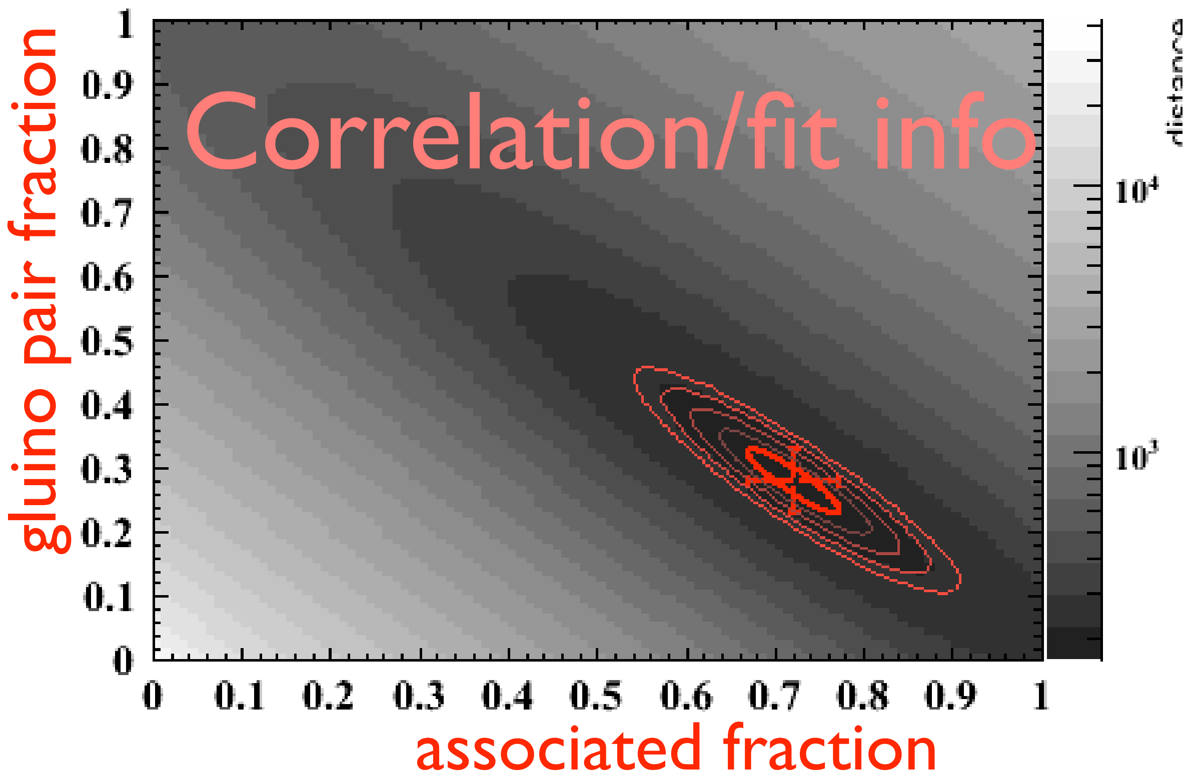
versus

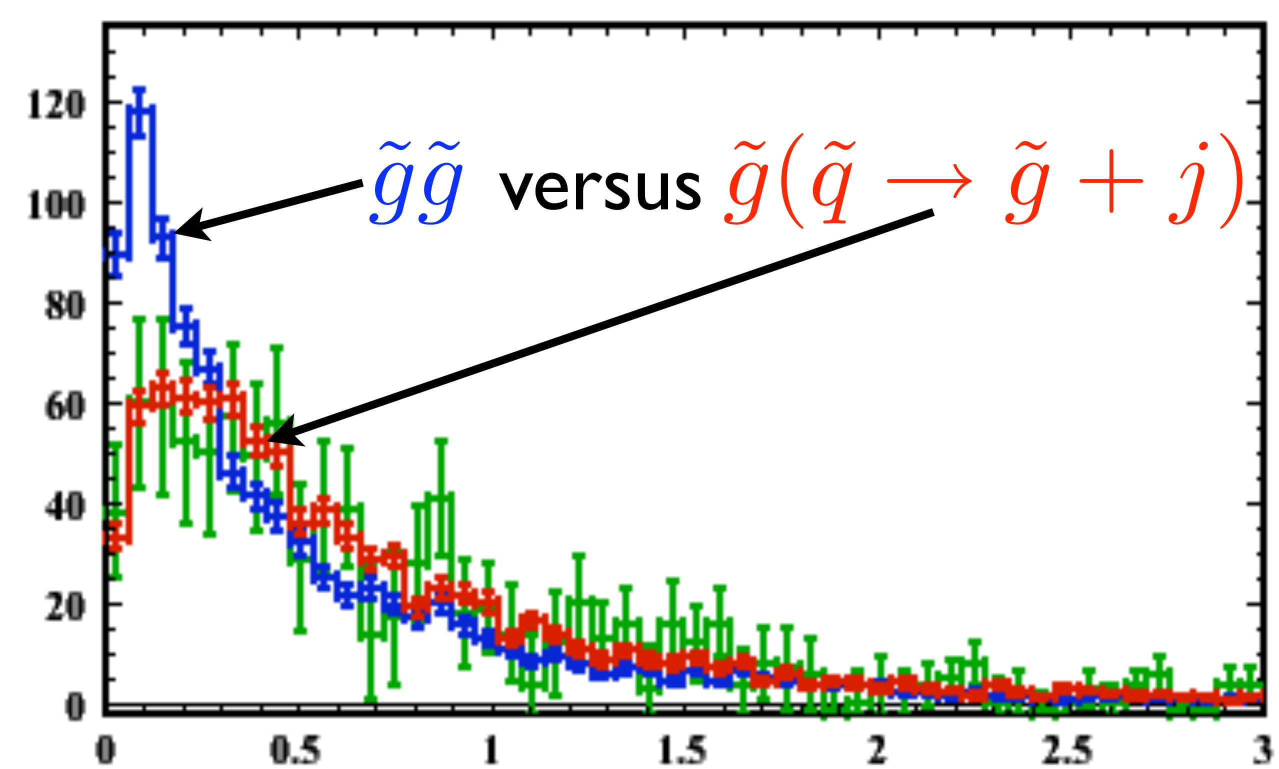
$\tilde{g}(\tilde{q} \rightarrow \tilde{g} + j)$ topology

OSET-motivated discriminator

(2D correlations collapsed)

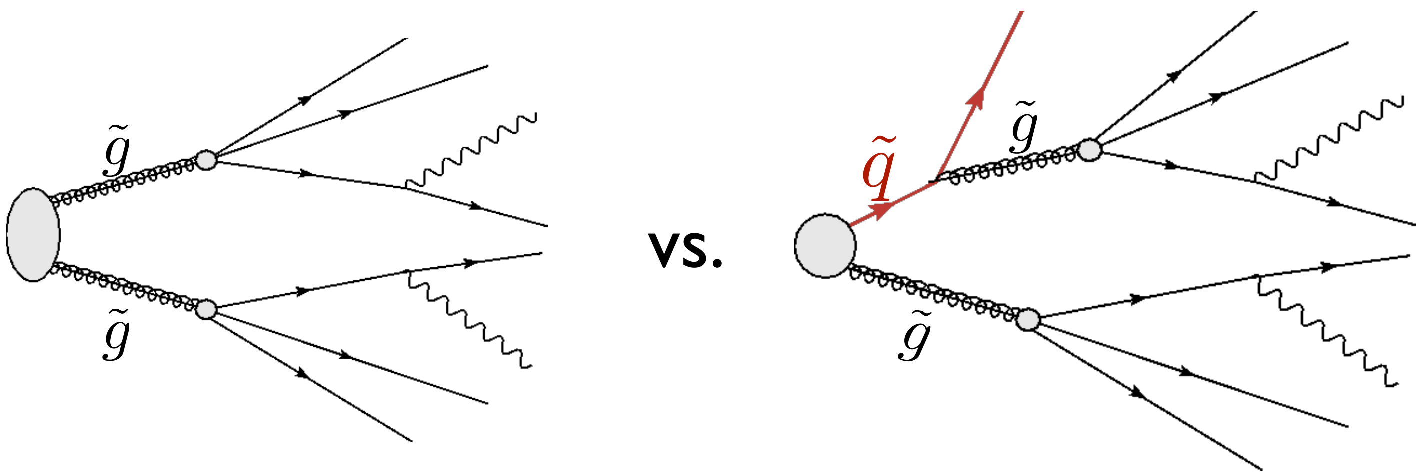
$(l_0 / b_0) \times (l_0 / H_T)$





(Plots made with OSET Tools package by Koay, Rossin)

Parameter-Scanning/Fitting III: Mass Scales

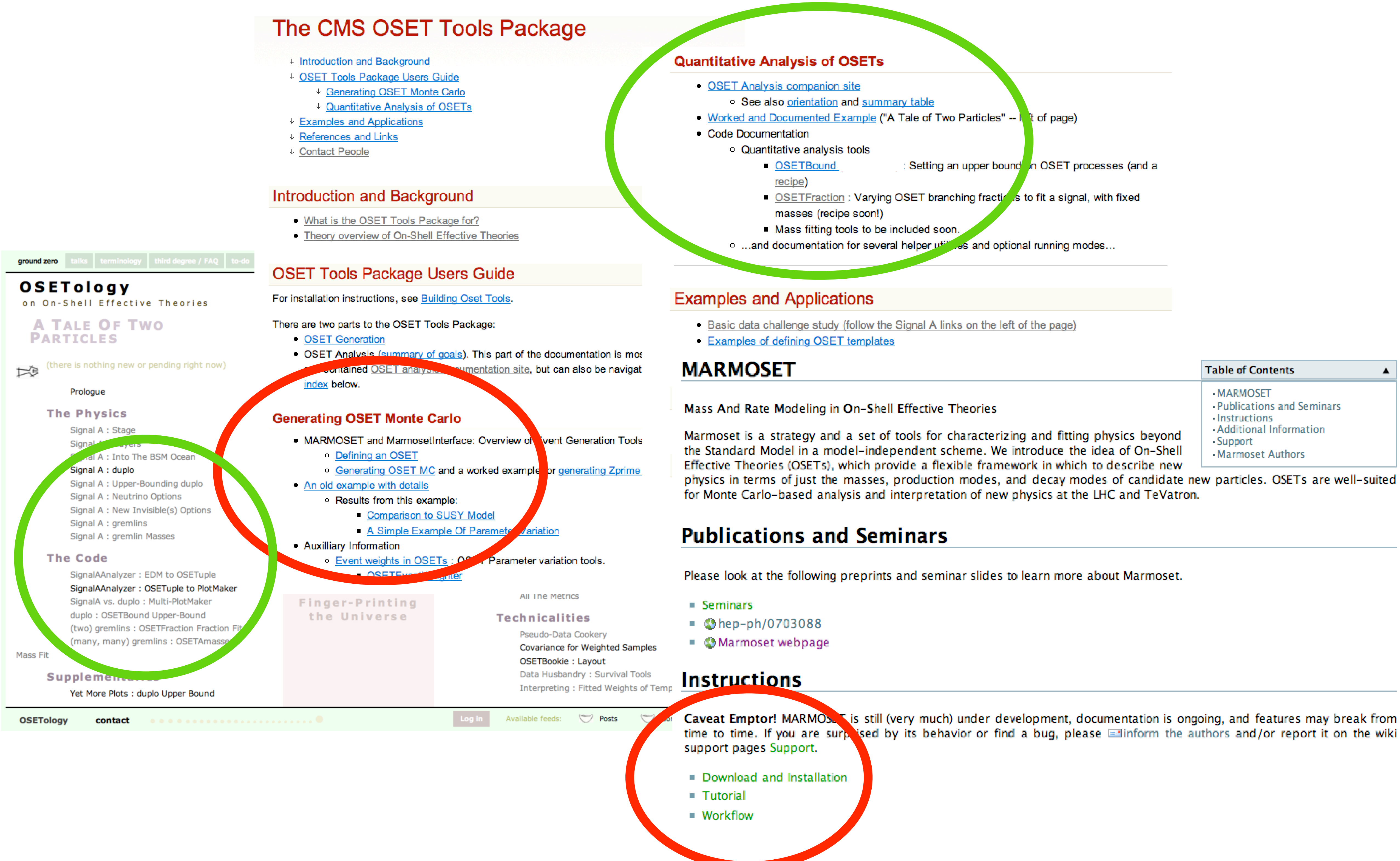


- Varying overall fractions or branching ratios "easy" because processes are independent!

  Model constraints imposed (optionally & easily) at 2nd stage

- What about masses?
  - Sometimes, measurable through sharp kinematic features, <u>but not guaranteed for jets in early data</u>
  - Challenging in any framework!
  - **Even fraction measurements depend on masses** (e.g. through cuts)
- Mass-scanning tool being tested & refined

We can simulate and study any processes we want...



What processes do we **want** to study?

Structure of SUSY OSETs

[in progress with J. Alwall, P. Schuster]

- Theorists mock mSUGRA, but it plays an essential role:
  - Navigable, well-defined "model space" to which data can be systematically compared.
  - (but too rigid – applying mSUGRA exclusions and measurements to other models is difficult)
- Can we define a similarly well-defined, but ***extensible*** space of "models" (collections of topologies) that covers most of the MSSM well enough for early data?

SU(3) × SU(2)xU(1) × Ultra-weak (e.g. GMSB/RPV...*small*)

(pick 1) (pick 1) (pick 1)

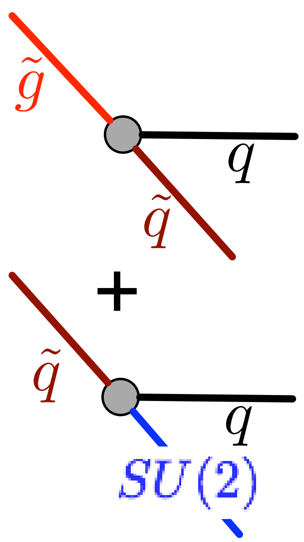
- Furnishes a good basis for testing SUSY, and for non-SUSY models too

Structure of SUSY OSETs

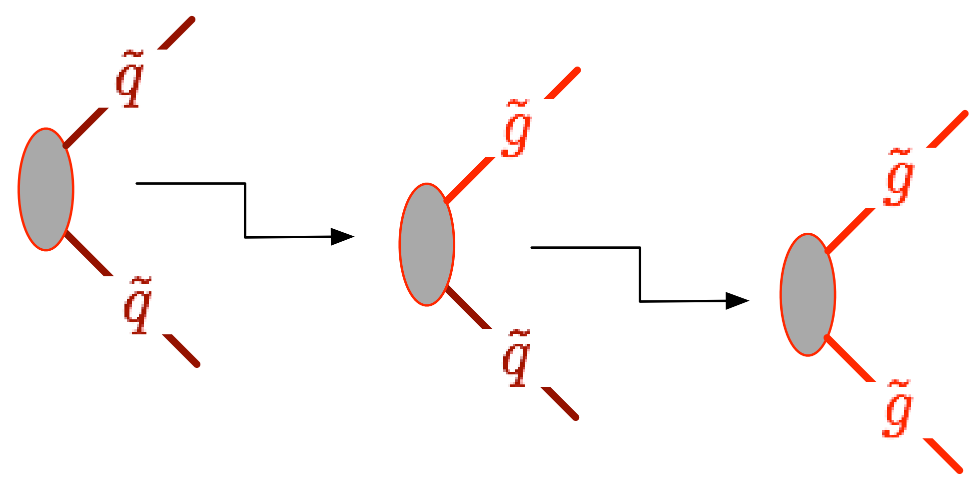
SU(3) X SU(2)xU(1) X Ultra-weak

First guess SU(3) structure: Heavy Gluino

Decay modes

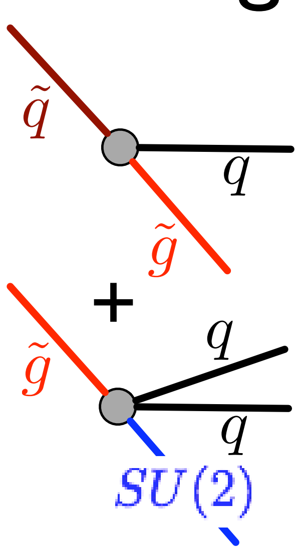


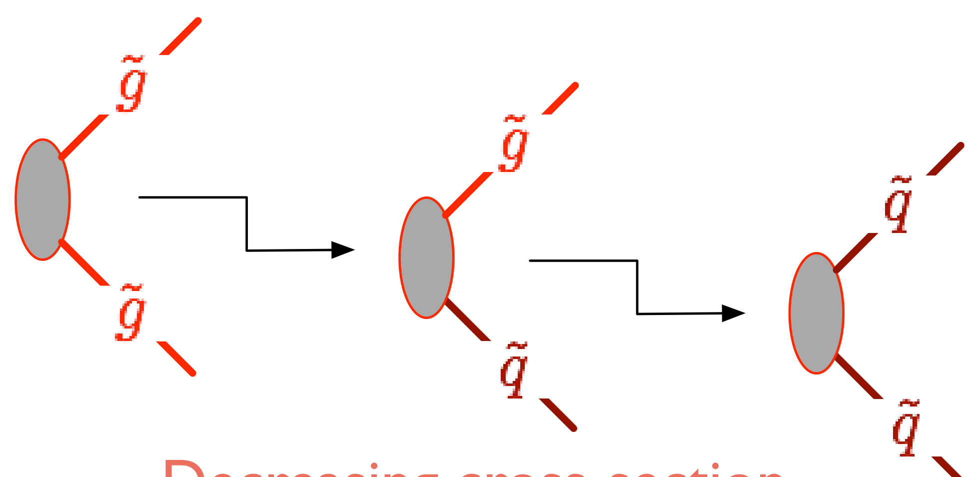
Production Modes



- Dominated by 2-3 quark production
- Heavy flavor fraction determined by phase space (~1/3-1/6)

Second guess: Heavy Squark





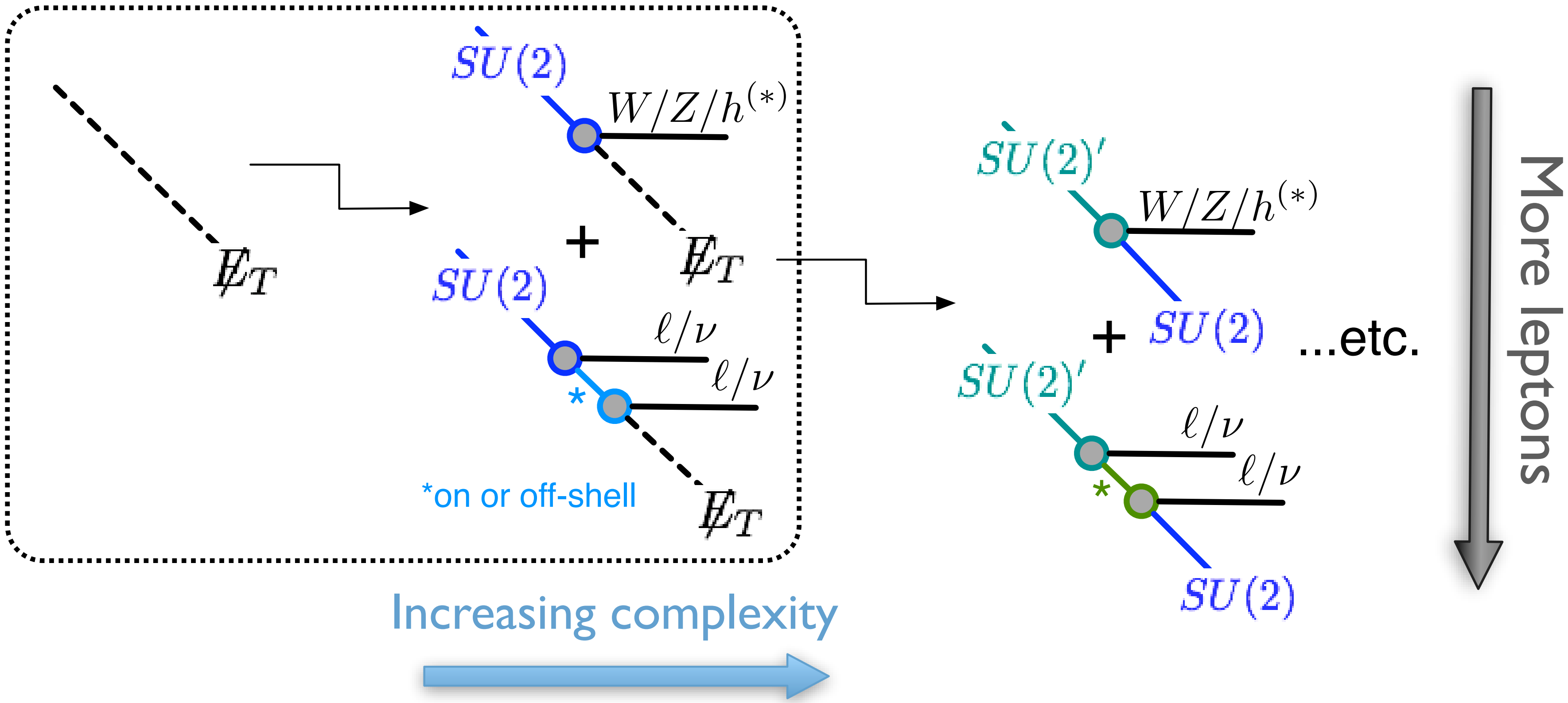
Decreasing cross-section

- Dominated by 4-5 quark production
- Heavy flavor fraction depends on SU(2) structure

Structure of SUSY OSETs

SU(3) ✕ SU(2)xU(1) ✕ Ultra-weak

First guess SU(2)xU(1) structure: "Neutralino LSP" (vs. "sneutrino")



- At low statistics, probably can fit counts with just left blocks.*
- Also: edge/endpoint
- <u>First</u> step to determining *ino composition (need top of spectrum to go further)

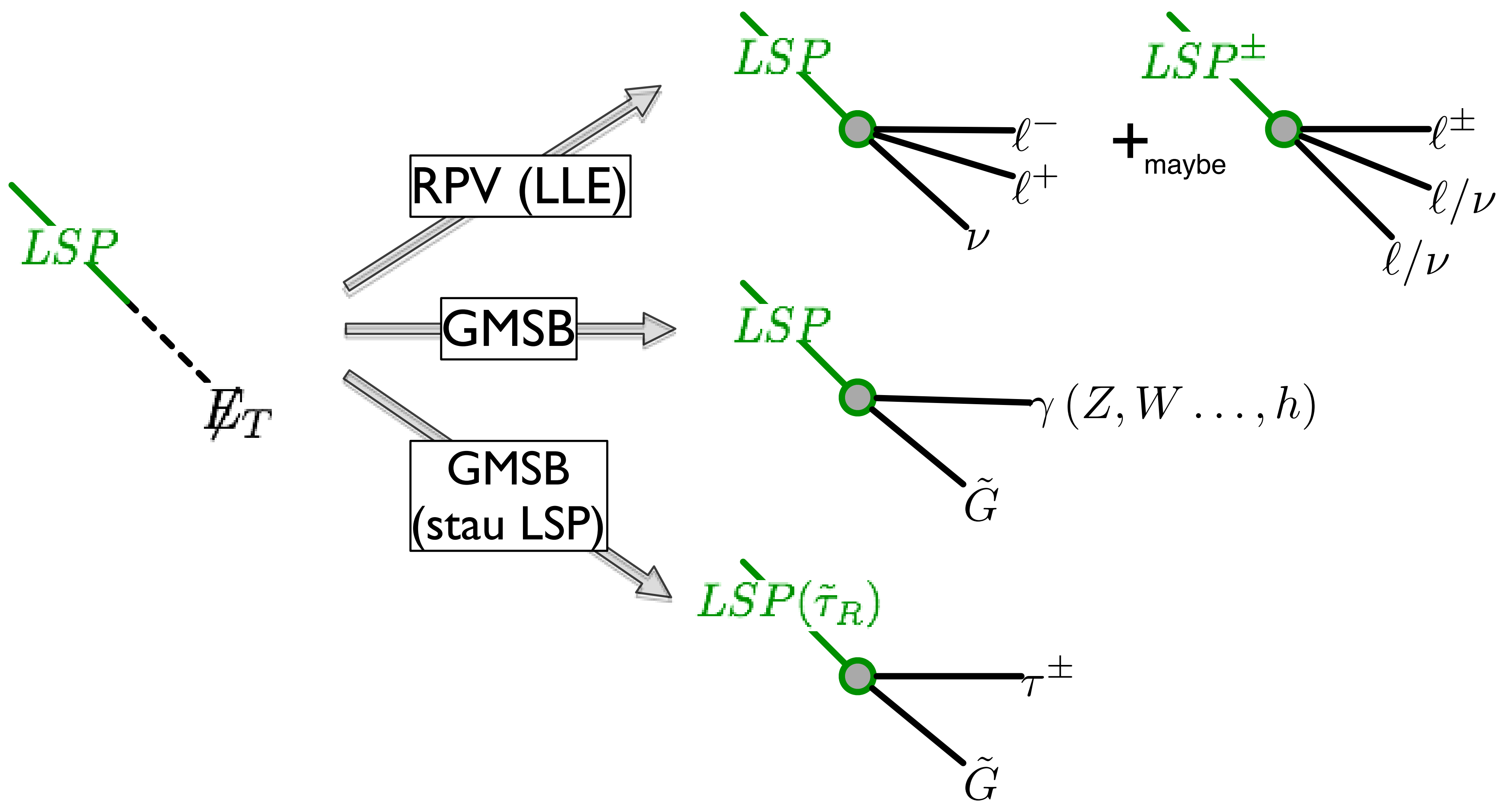
*With long & lepton-rich cascades, standard kinematic measurements more useful

Structure of SUSY OSETs

SU(3) × SU(2)xU(1) × Ultra-weak

Ultra-weak structures:

- Small violation → typically visible only in LSP decays



Conclusions (I)

- Model-independent characterization
  - Useful simplifications in modeling processes
  - Tools for process-level, model-independent analysis, in experimental hands
  - Mapping between OSETs and SUSY with simple topology-level building blocks (can generalize to other models)
- Enable us to
  - Build confidence in process-level description of data
  - Measure/bound parameters in a model-independent way
- Now, how do we apply these techniques to learn about basic physics?

OSETs & LSP Dark Matter

- OSETs facilitate factorization of LHC data interpretation:
  - well-understood & robust observables
  - with **qualitative** implications for spectrum/topologies
  - interpret model-independent (but motivated) constraints in broader contexts (e.g. non-mSUGRA, or NMSSM, or Little Higgs..)
- Hard generically, but easier if you're lucky – *there are many ways to be lucky and one should seek them out*
- Won't try to treat dark matter exhaustively!

  Dark matter at LHC:
  hep-ph/0602187 Baltz Battaglia Peskin Wizansky
  arXiv:0805.1905 Baer & Tata ← see Monday talk
- Strongest statement from qualitative features: "The LSP Cannot be Thermal DM"

(DM not thermal, MSSM is wrong, or more than one type of DM)
in practice, points to specific consistent regions of parameter space

LSP Dark Matter
Three Cases to Keep in Mind

For early data, focus on SUSY at <1 TeV with MET
assume there's a massive LSP*

Pure light bino under-annihilates/over-closes
Pure light wino/higgsino over-annihilates/under-closes

- Very light Bino annihilating through t-channel RH sleptons (100-110 GeV sleptons – just above LEP)
- Mixed and/or coannihilating Binos
  - Bino/Wino with mixing & mass splitting <~ 10%
  - Bino/Higgsino with mass splitting <~ 10%
  - Bino/Stau coannihilation, etc.... [won't talk about these]

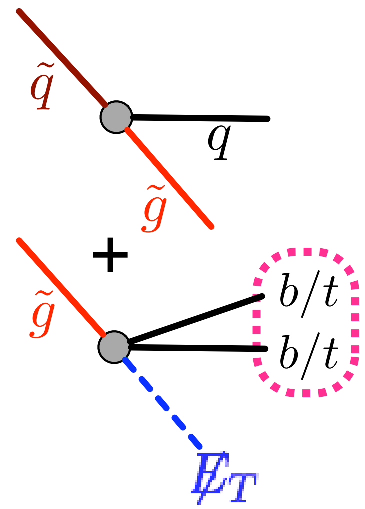
*this is a (surprisingly?) subtle point in its own right.

“The LSP Cannot be Thermal DM”

DM not thermal, MSSM is wrong, or more than one type of DM

True Spectrum

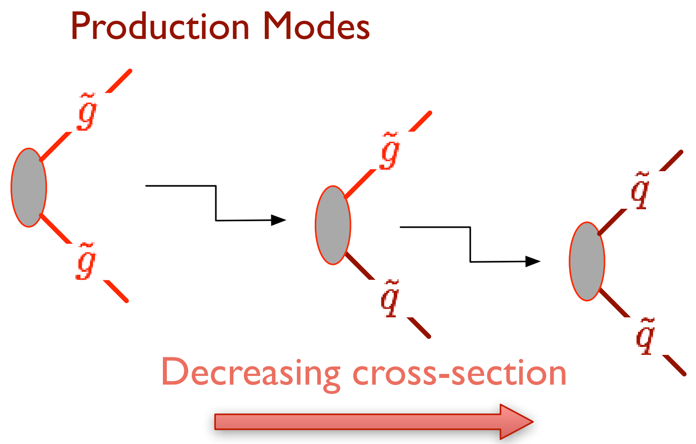
Possible conclusions from early data:



heavy squark$_{(1,2)}$
OSET template

gluino → 3rd gen.

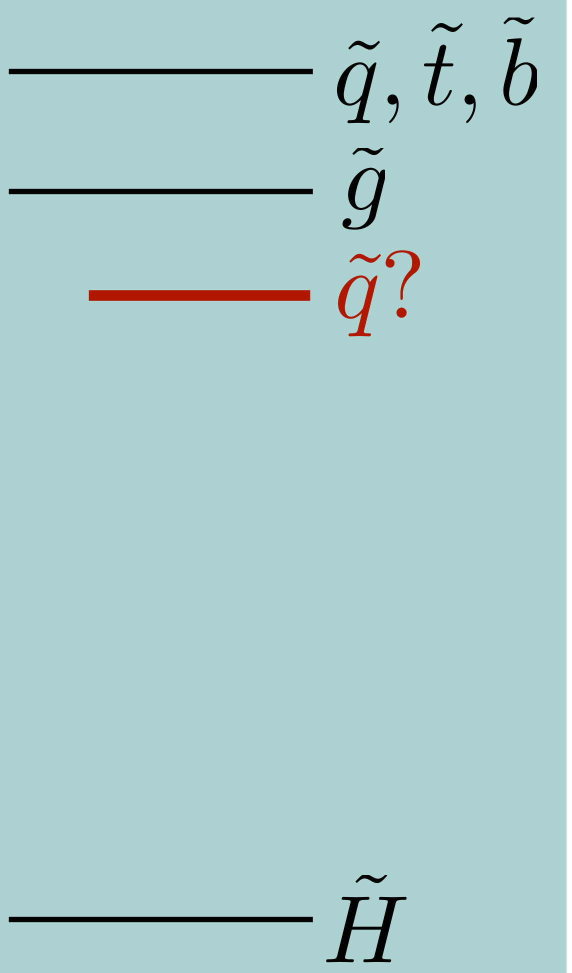
no lepton-rich cascade

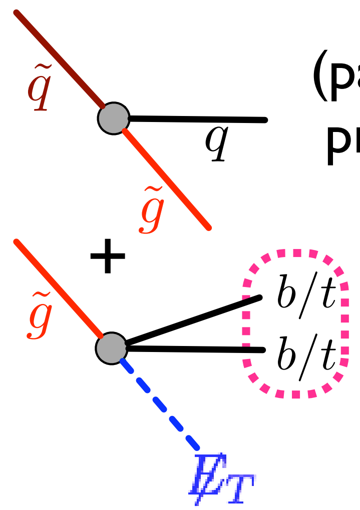


“Heavy squark”

Distinguishing heavy squark from heavy gluino template
(100 pb^{-1}, but PGS & stat. errors only)

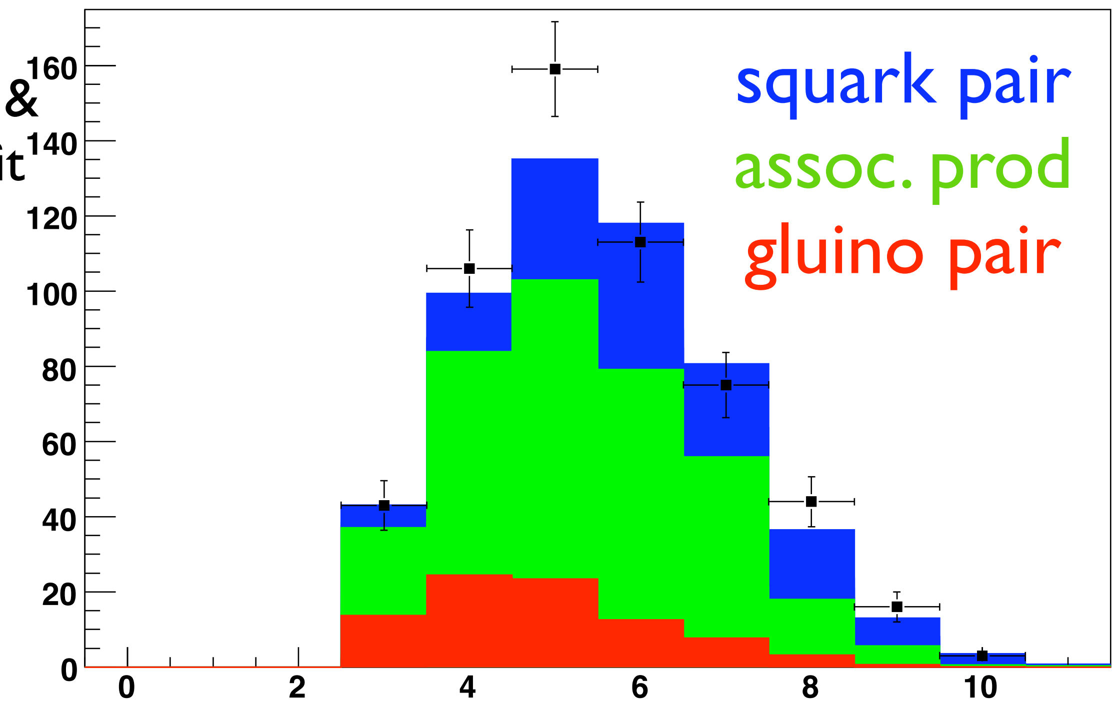
True **vs. guess**





(particular b/t fractions & production rates that fit many distributions)

# of jets (>50 GeV pT)



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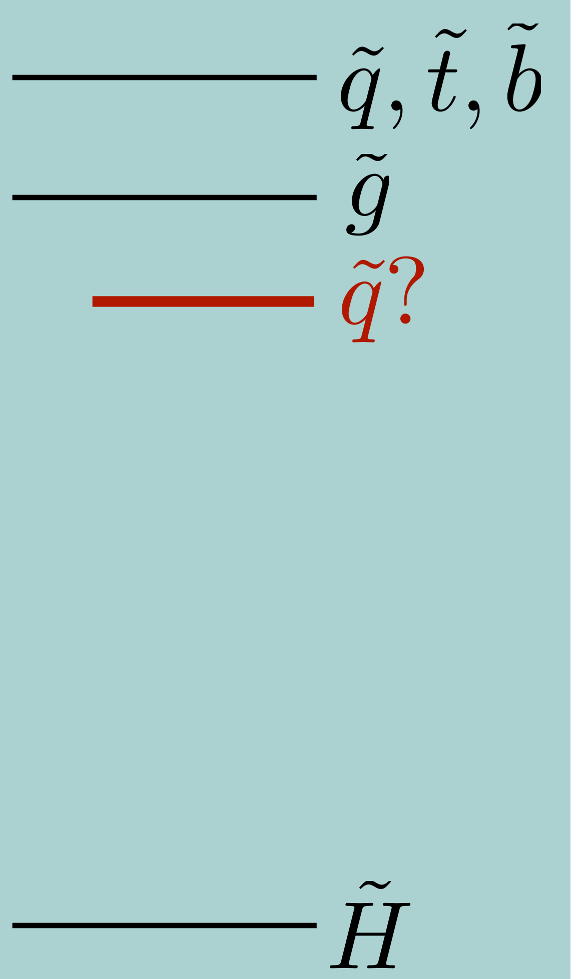
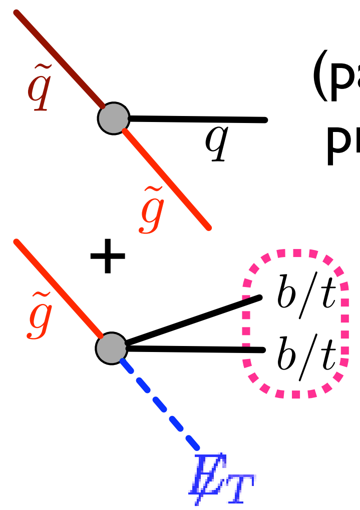
True **vs. guess**





(particular b/t fractions & production rates that fit many distributions)

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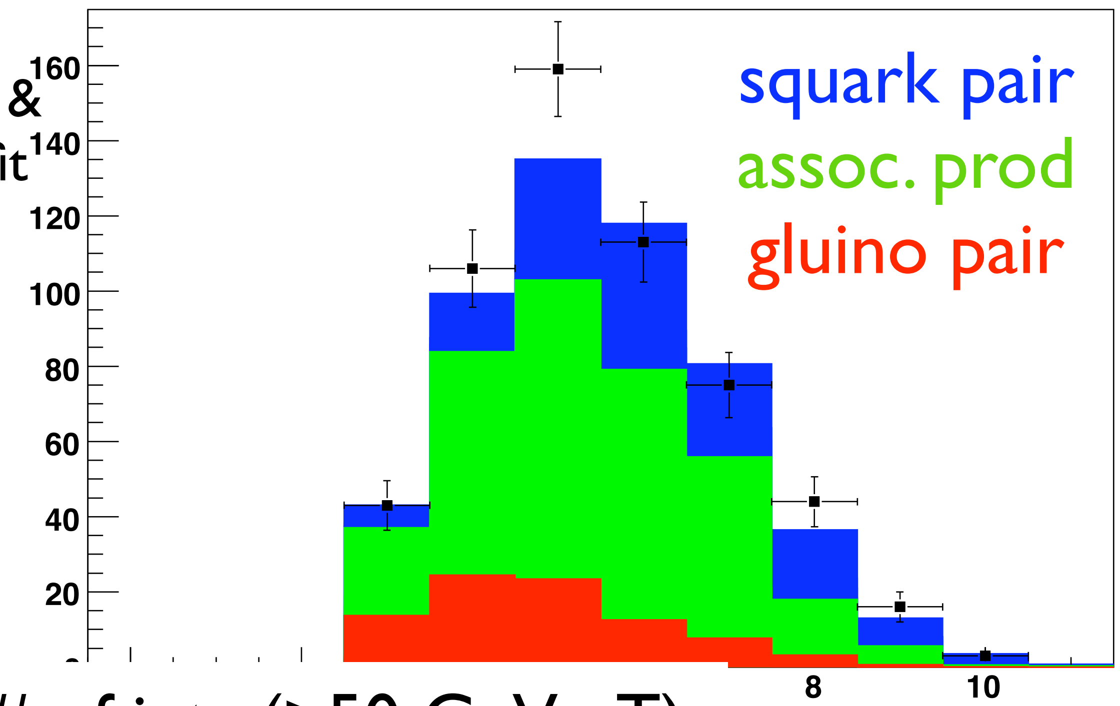
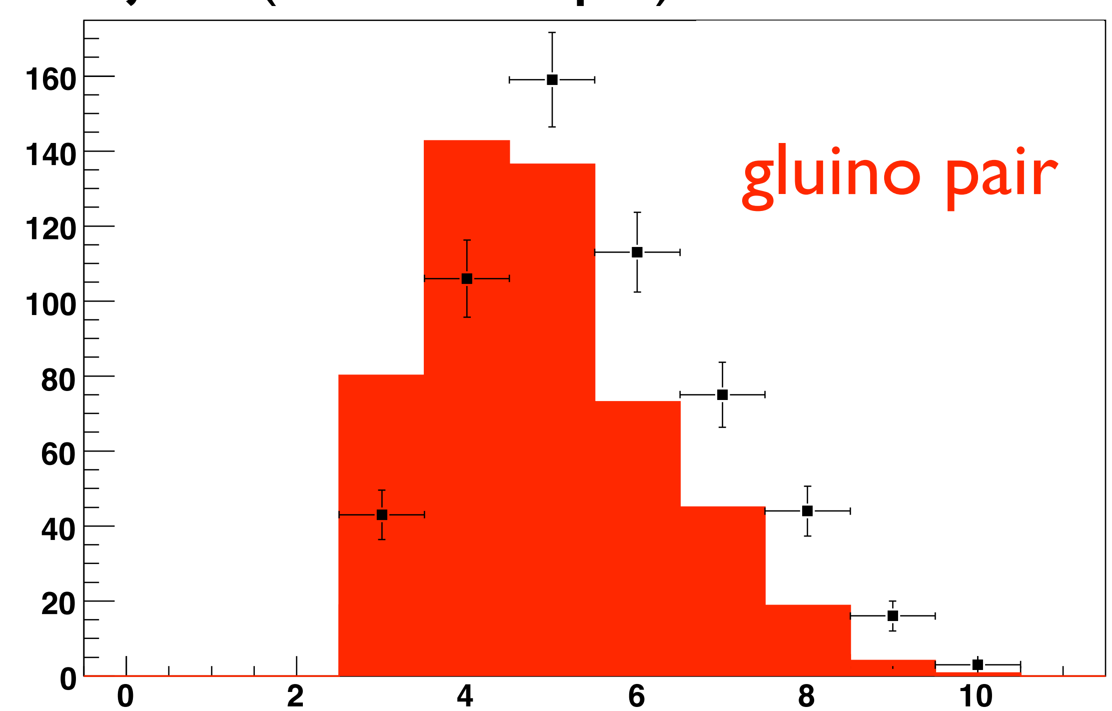


# of jets (>50 GeV pT)

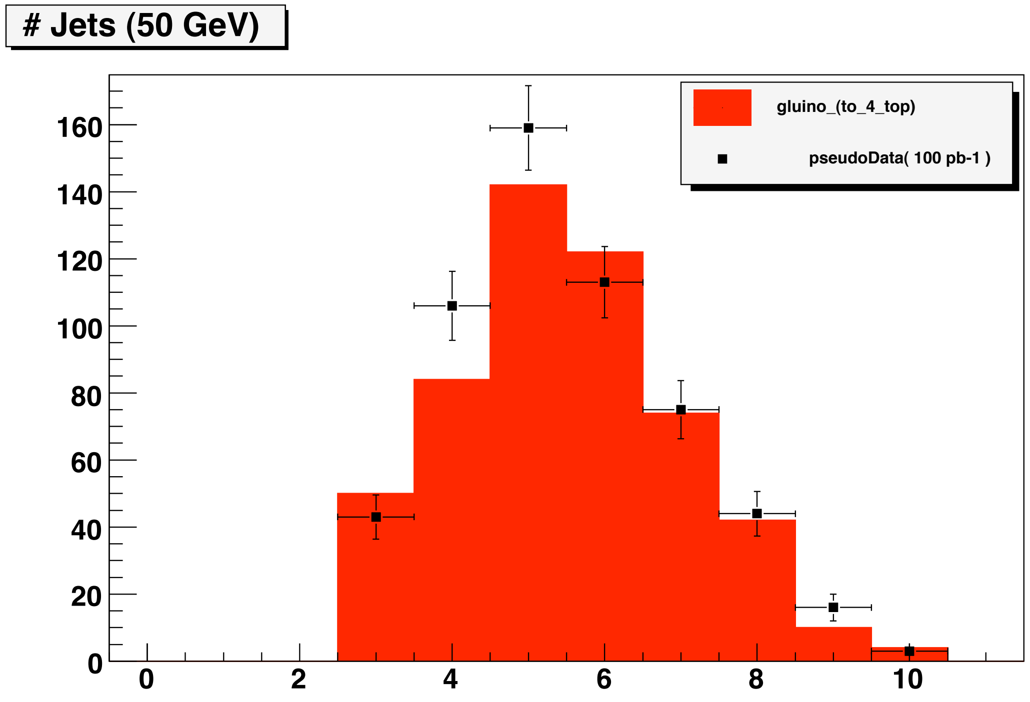
vs. just gluino production: (most jetty scenario for light-squark template)



Caution:

There are other parameters, too

Gluino pairs only, going to
t tbar every time→more jets ✓

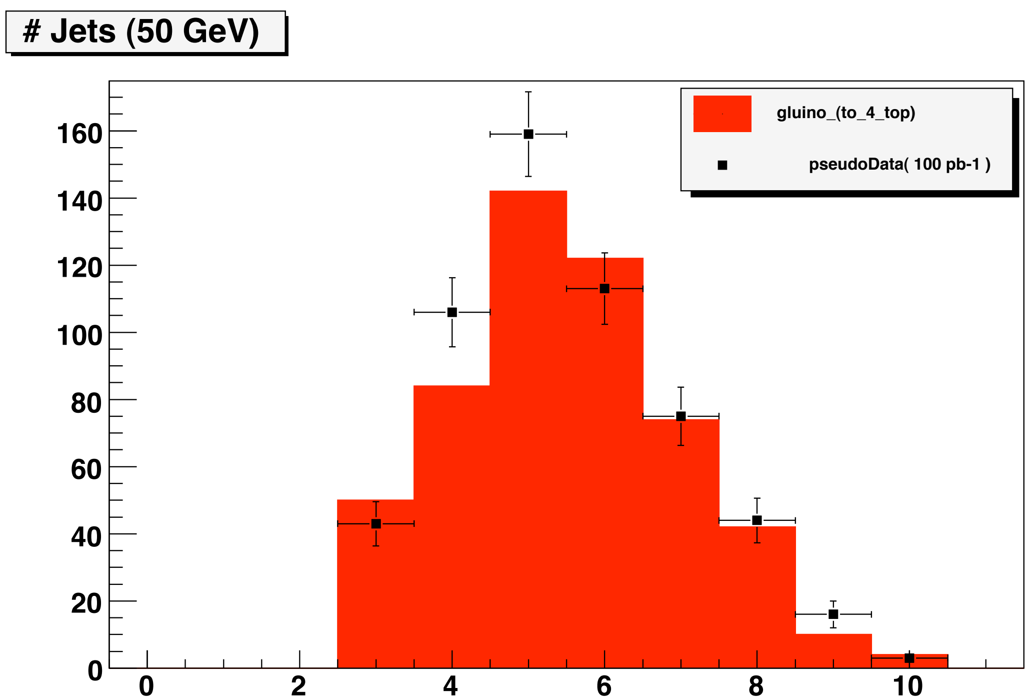


Caution:

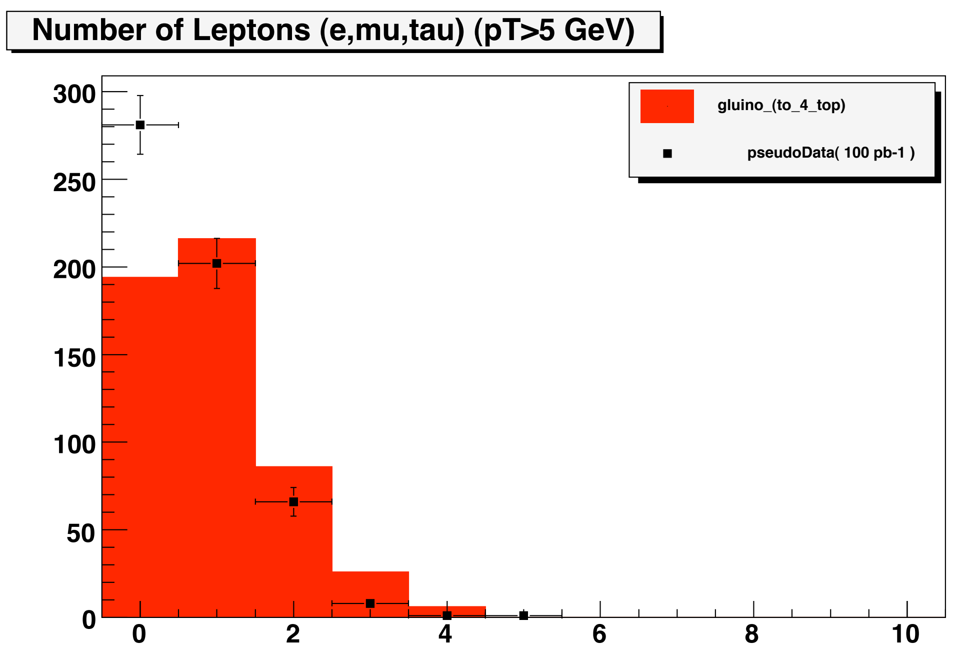
There are other parameters, too

(but also other distributions)

Gluino pairs only, going to t tbar every time→more jets ✓



and more leptons ✗



Caution:

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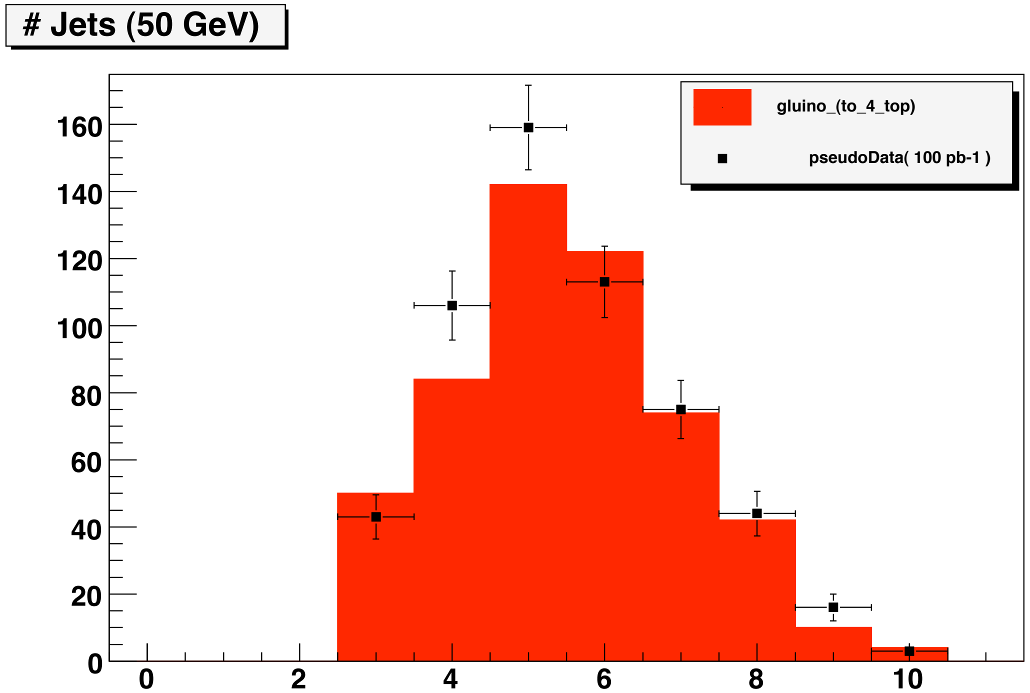
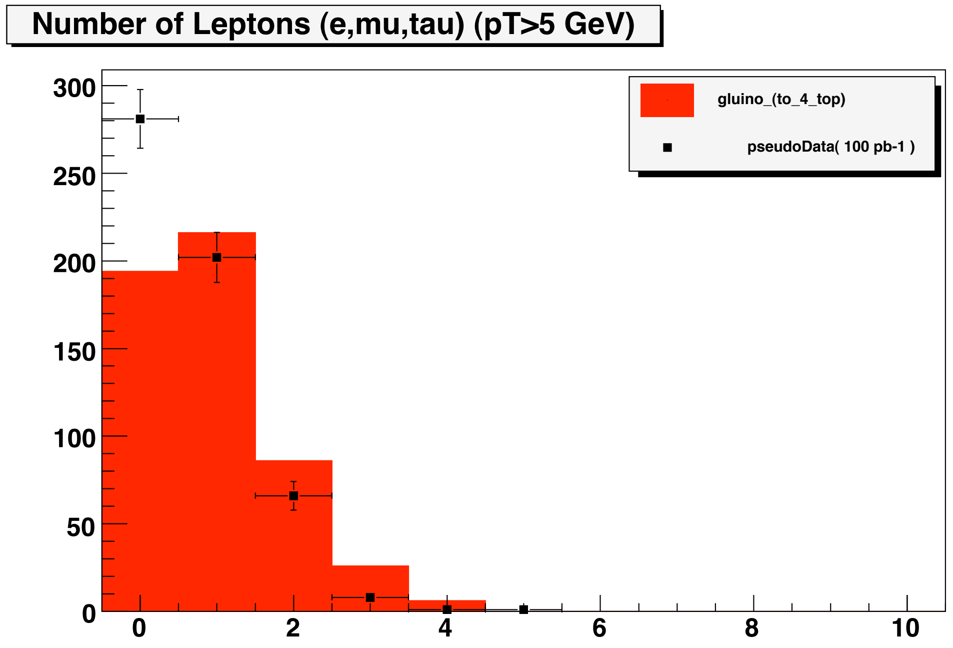




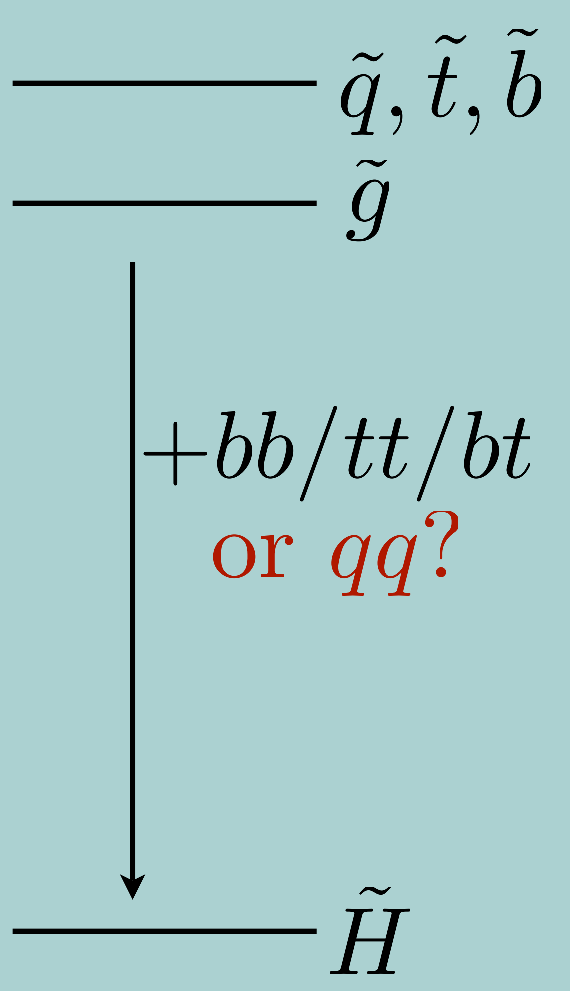
....need to run through the possibilities, check many distributions

(but they are constraining)

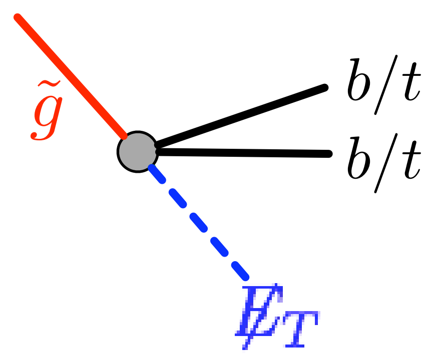
“All” 3rd-generation

Refine the “heavy-squark” template:
how much decay to 3rd generation?

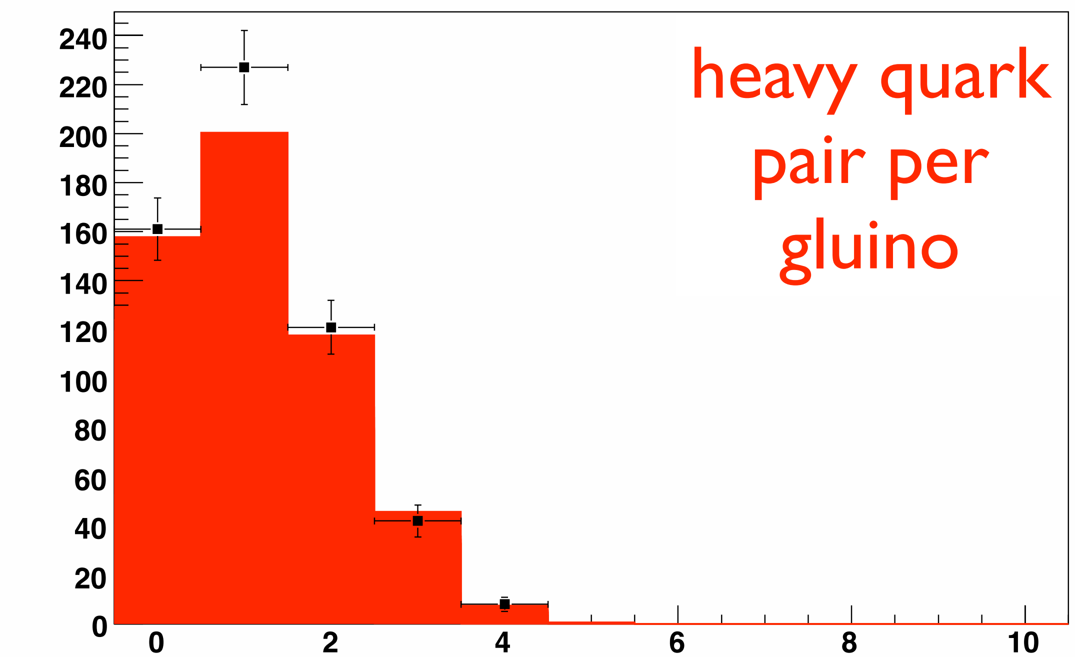
True **vs. guess**



...all heavy modes: ✓



# of tagged jets (>30 GeV pT)

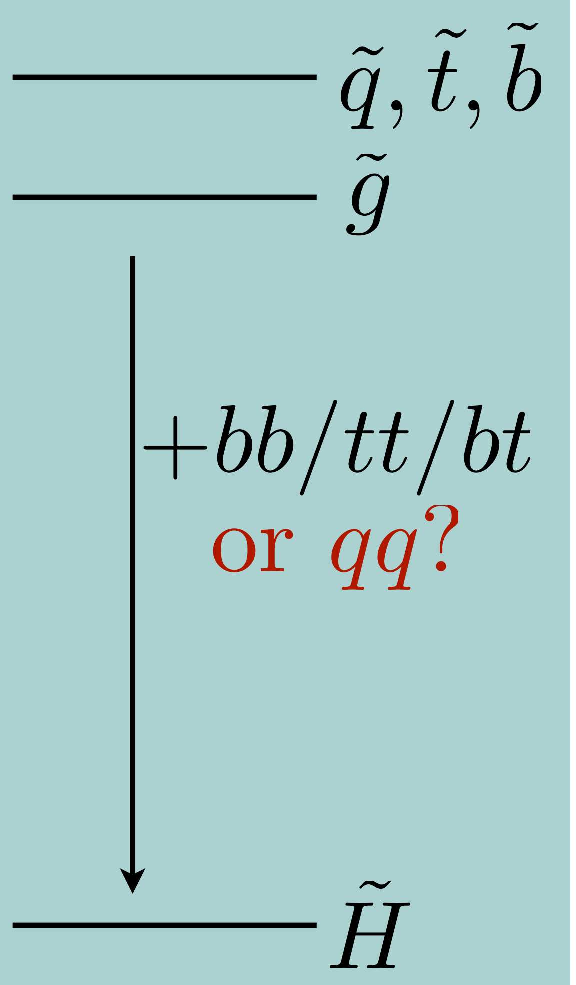


tagged jet

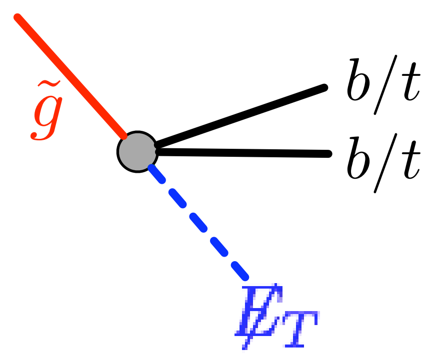
"All" 3rd-generation

Refine the "heavy-squark" template:
how much decay to 3rd generation?

True **vs. guess**

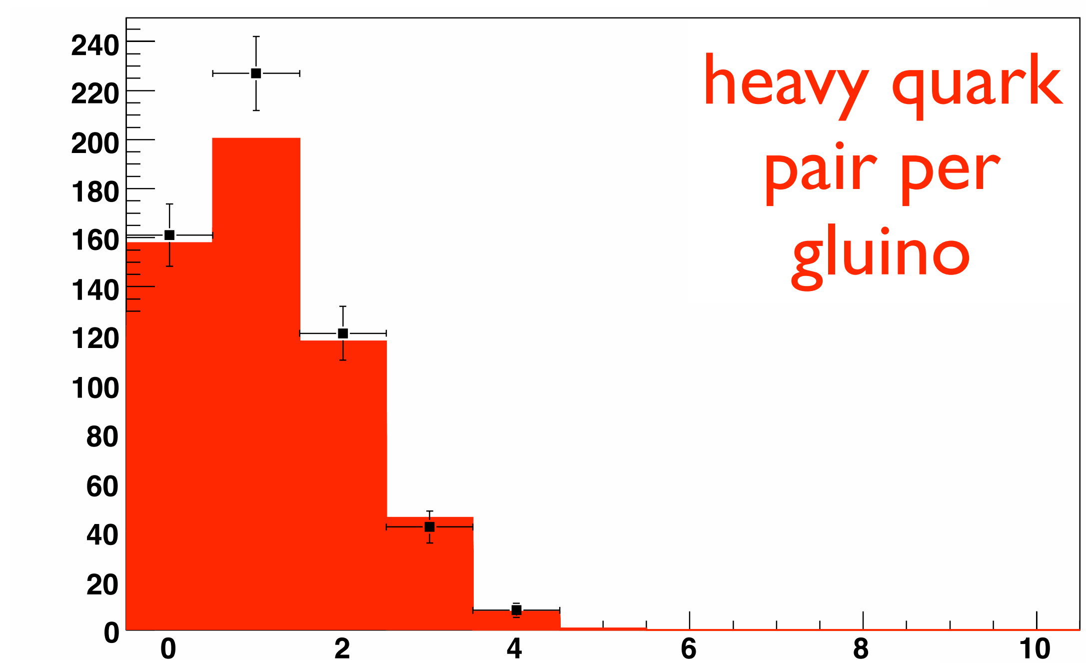


...all heavy modes: ✓

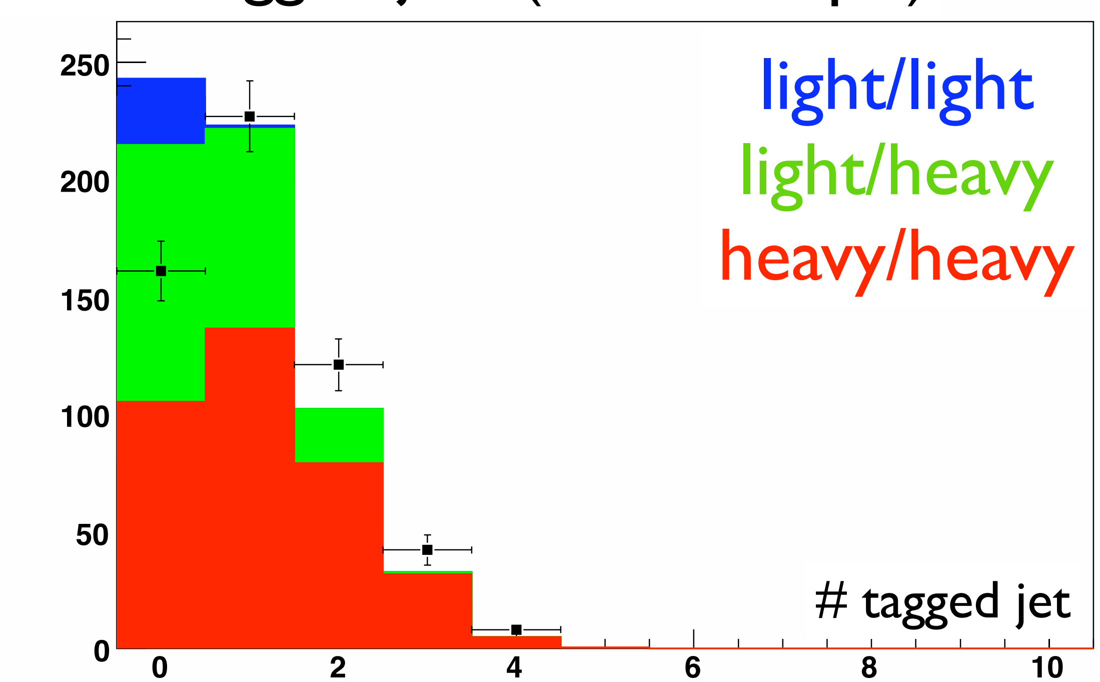


...with 20% $\tilde{g} \to q\bar{q}\tilde{\chi}$
("light mode")

# of tagged jets (>30 GeV pT)

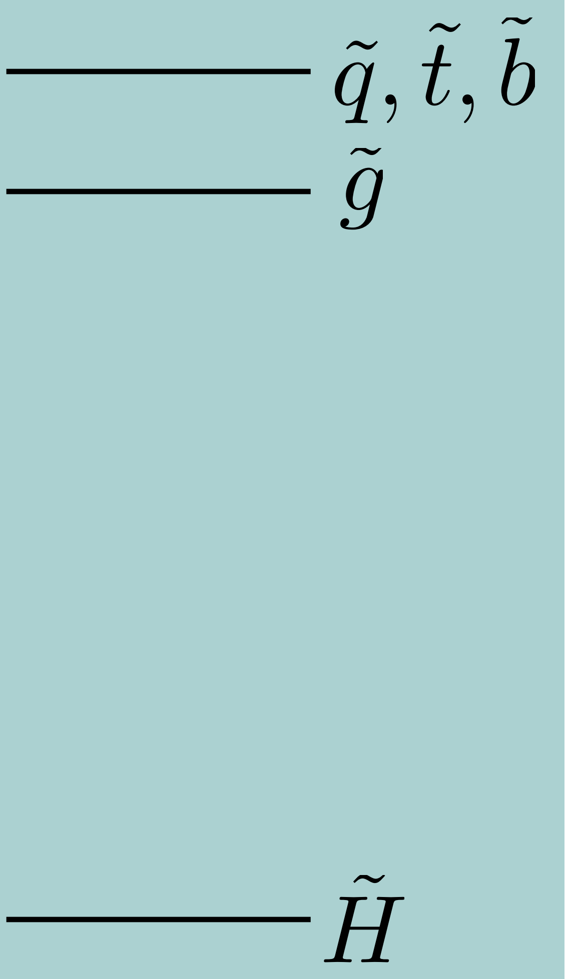


# of tagged jets (>30 GeV pT)

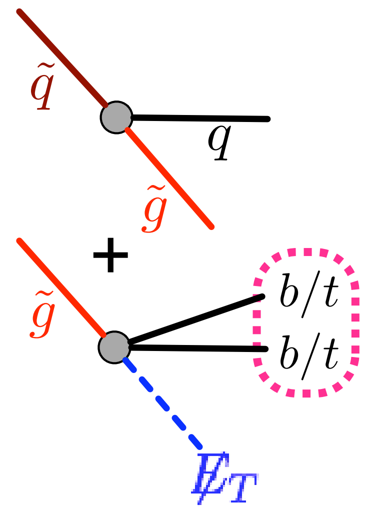


"The LSP Cannot be Thermal DM"

True Spectrum



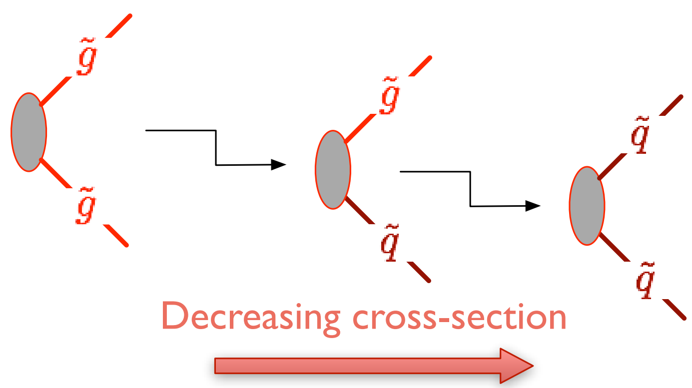
Possible conclusions from early data:



heavy squark(1,2) OSET template

gluino → 3rd gen.

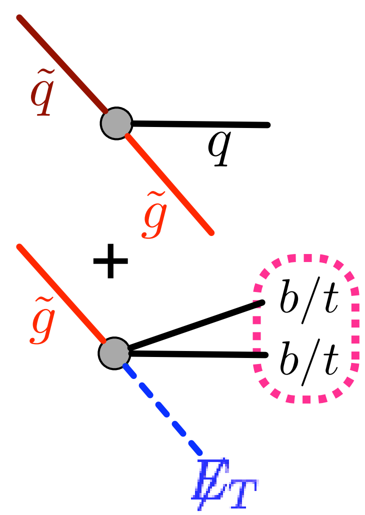
no lepton-rich cascade



“The LSP Cannot be Thermal DM”

True Spectrum

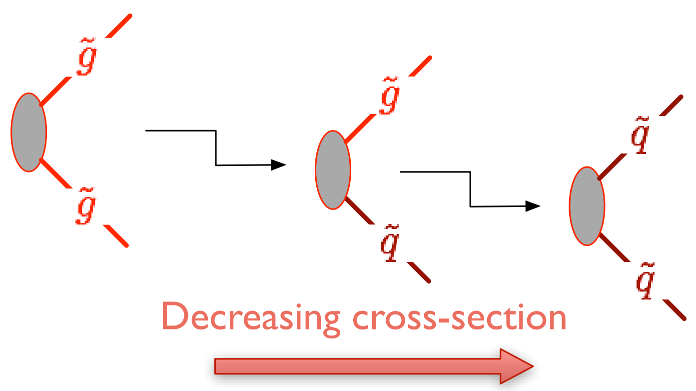
Possible conclusions from early data:



heavy squark(1,2)
OSET template

gluino → 3rd gen.

no lepton-rich cascade



Alternative -ino spectra:

(1)Light Wino?

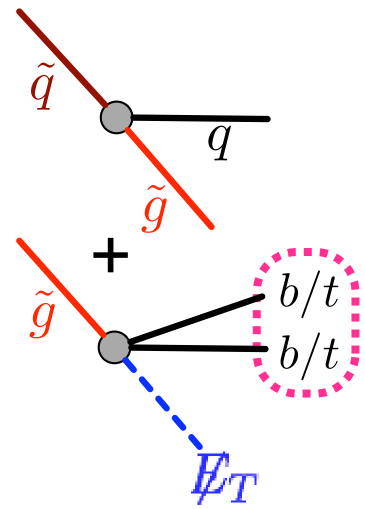
(2)Only Bino light?
(light 3rd-gen squarks)

(3) Higgsino
near Bino LSP

“The LSP Cannot be Thermal DM”

True Spectrum

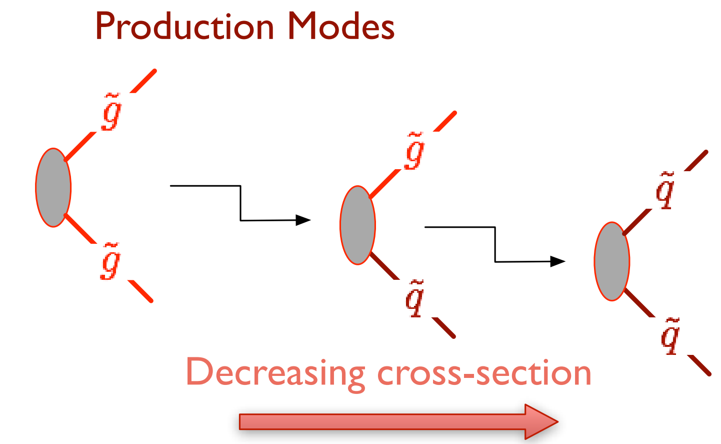
Possible conclusions from early data:



heavy squark(1,2)
OSET template

gluino → 3rd gen.

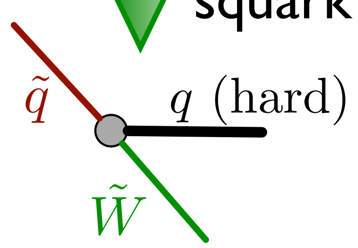
no lepton-rich cascade



Alternative -ino spectra:

(1)Light Wino?

(unless LH squark absent)



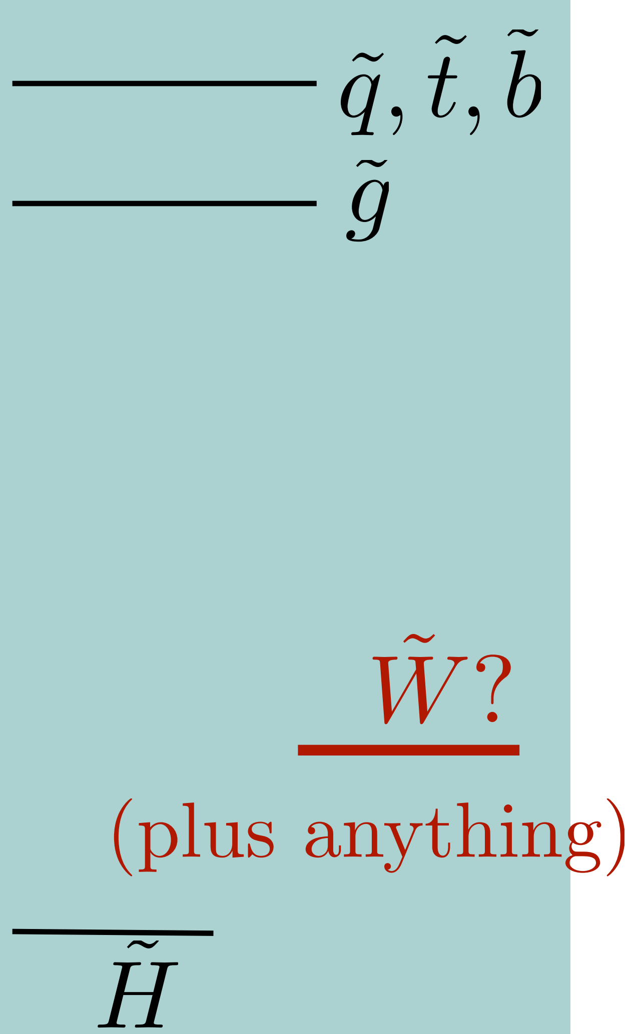
direct squark decay
($\gtrsim 20\%$)

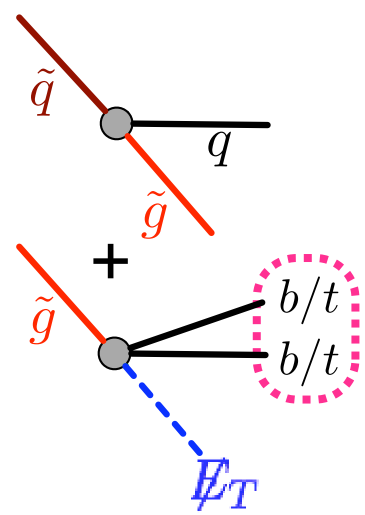
(2)Only Bino light?
(light 3rd-gen squarks)

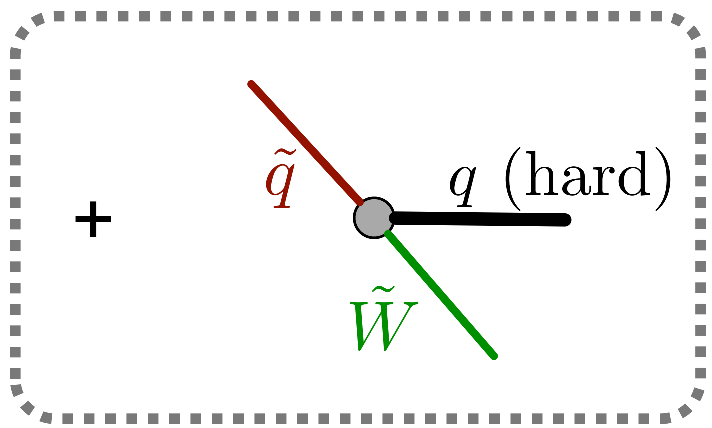
(3) Higgsino near Bino LSP

“No light Wino”

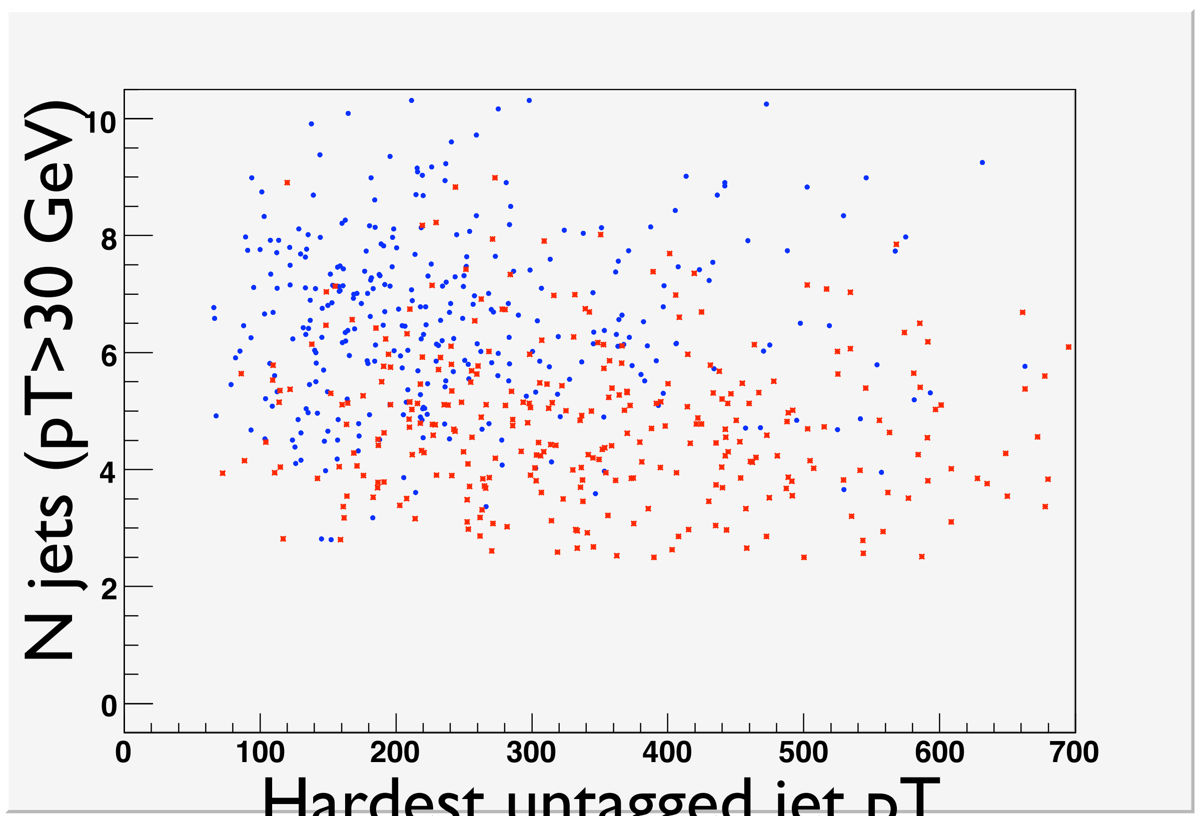
True **vs. guess**







(sub-dominant process not in starting OSET templates)

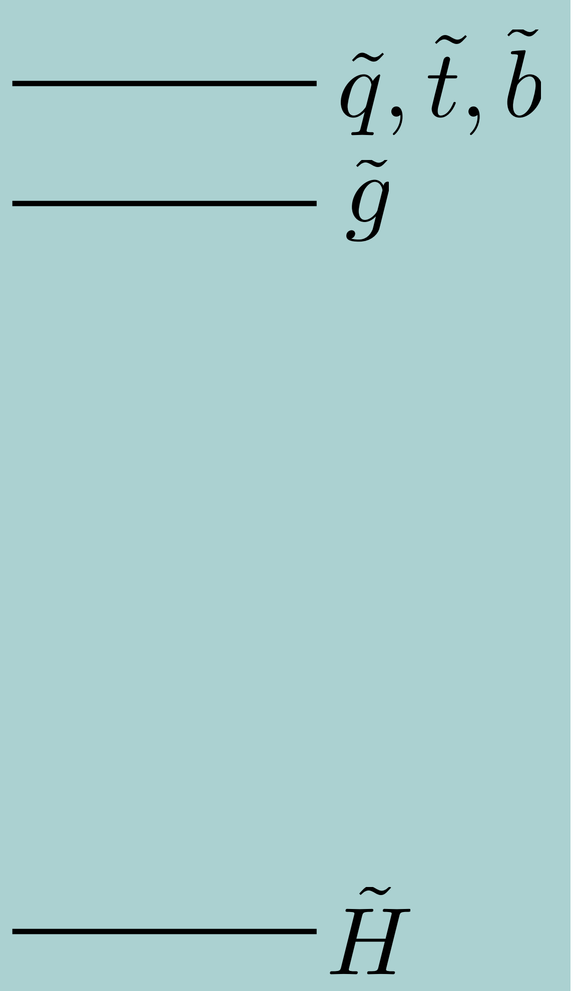


dominant process &
wino decay process
are kinematically different
–here and other ways–

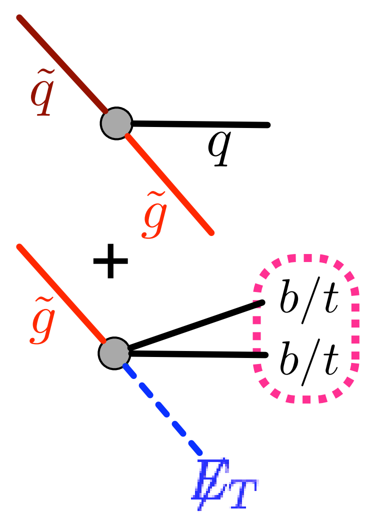
(sufficiently different to distinguish at ~20%?)

“The LSP Cannot be Thermal DM”

True Spectrum



Possible conclusions from early data:

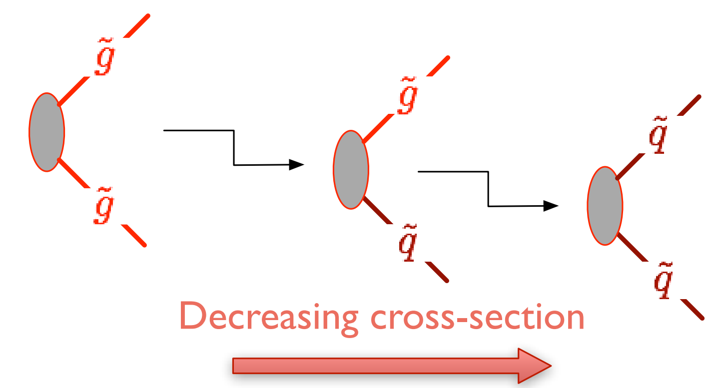


heavy squark$_{(1,2)}$
OSET template

gluino → 3rd gen.

no lepton-rich cascade

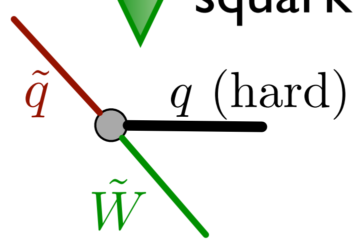
Production Modes



Alternative -ino spectra:

(1)Light Wino?

(unless LH squark absent)



direct squark decay
($\gtrsim 20\%$)

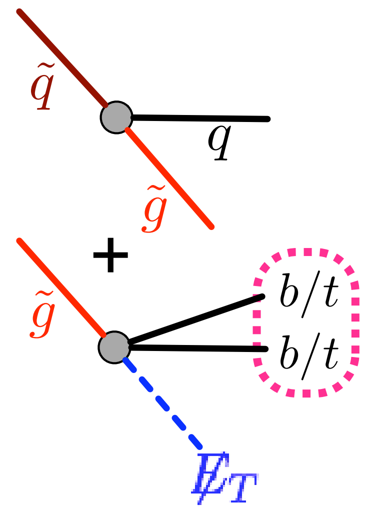
(2)Only Bino light?
(light 3rd-gen squarks)

(3) Higgsino near Bino LSP

"The LSP Cannot be Thermal DM"

True Spectrum

Possible conclusions from early data:



heavy squark(1,2)
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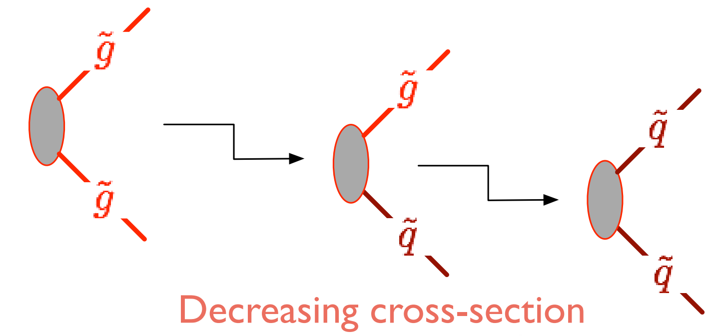
gluino → 3rd gen.

no lepton-rich cascade

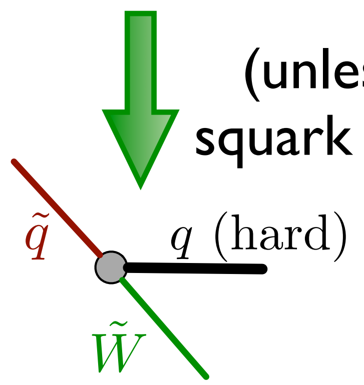
Production Modes



Decreasing cross-section

Alternative -ino spectra:

(1)Light Wino?



(unless LH squark absent)

direct squark decay
($\gtrsim 20\%$)

(2)Only Bino light?
(light 3rd-gen squarks)

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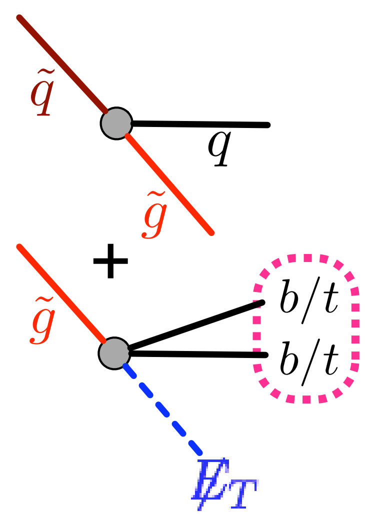
“The LSP Cannot be Thermal DM”

True Spectrum

Possible conclusions from early data:

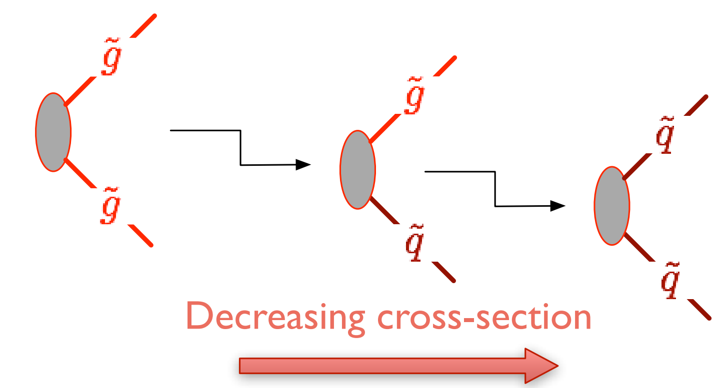


heavy squark(1,2)
OSET template

gluino → 3rd gen.

no lepton-rich cascade

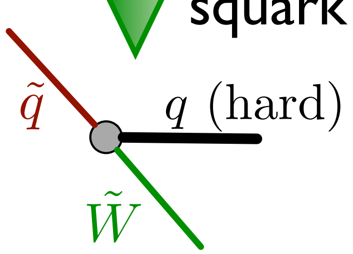
Production Modes



Alternative -ino spectra:

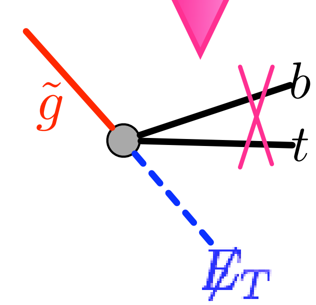
(1)Light Wino? ✗

(unless LH squark absent)



direct squark decay
$(\gtrsim 20\%)$

(2)Only Bino light?
(light 3rd-gen squarks)

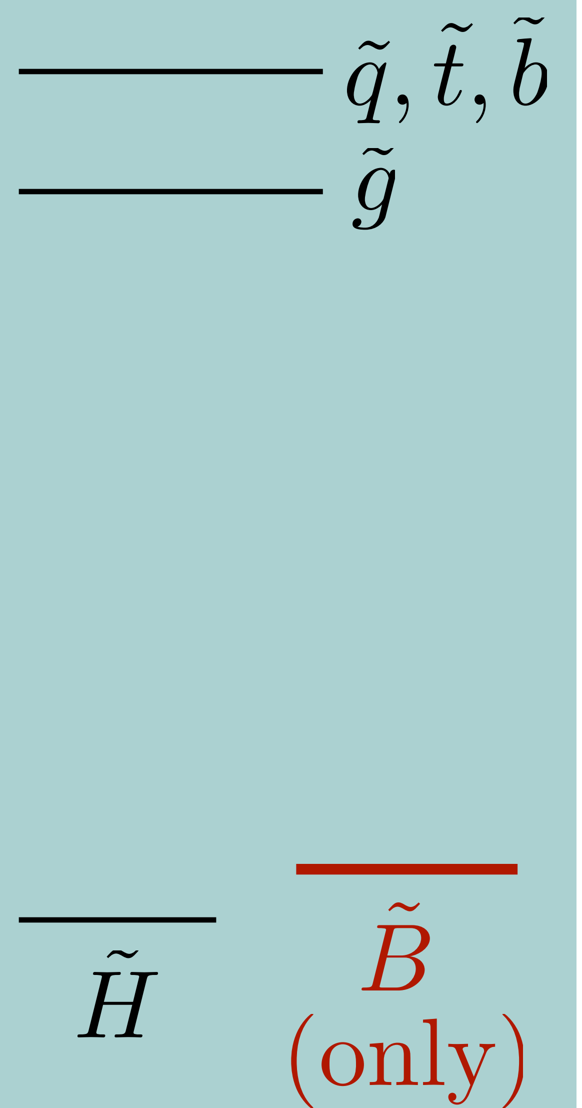


No b/t decay

(3) Higgsino
near Bino LSP

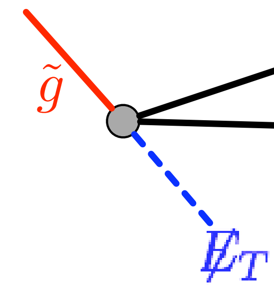
"There is a chargino"

True **vs. guess**



- another refinement of SU(3)

  (similar approach for SU(2))

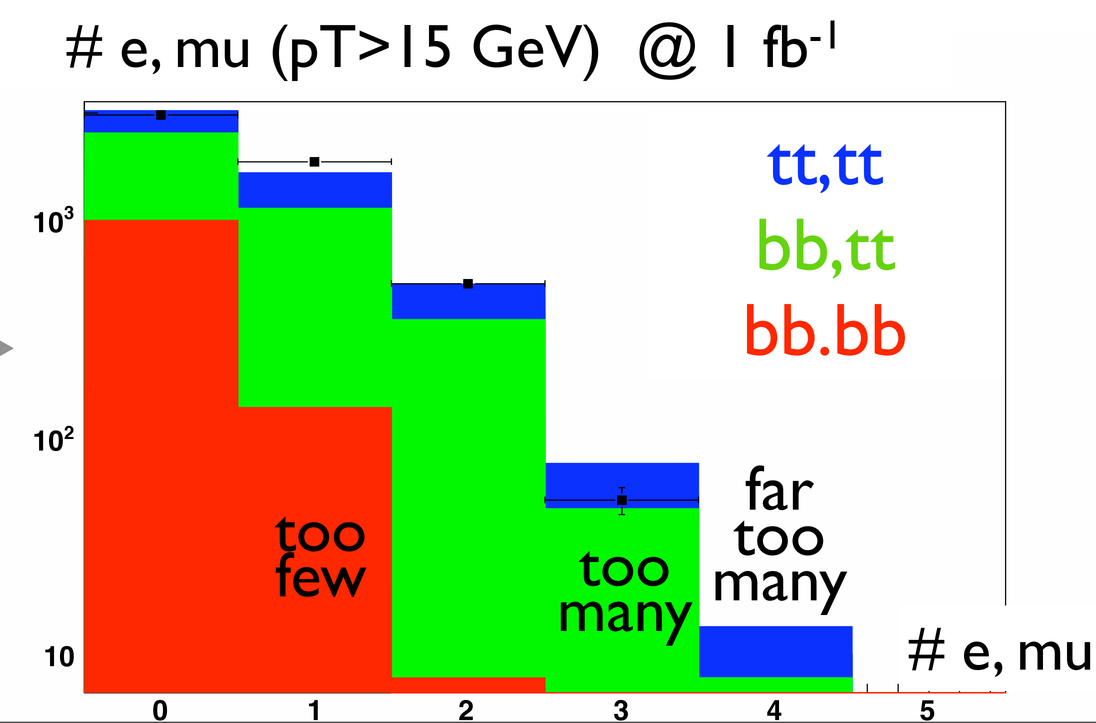


N_W	**0**	**1**	**2**	**3**	**4**
neutral only	Γ_{bb}^2		$2\Gamma_{bb}\Gamma_{tt}$		Γ_{tt}^2
+ charged		$2\Gamma_{bb}\Gamma_{bt}$	Γ_{bt}^2	$2\Gamma_{bt}\Gamma_{tt}$	

(+ soft W^*)

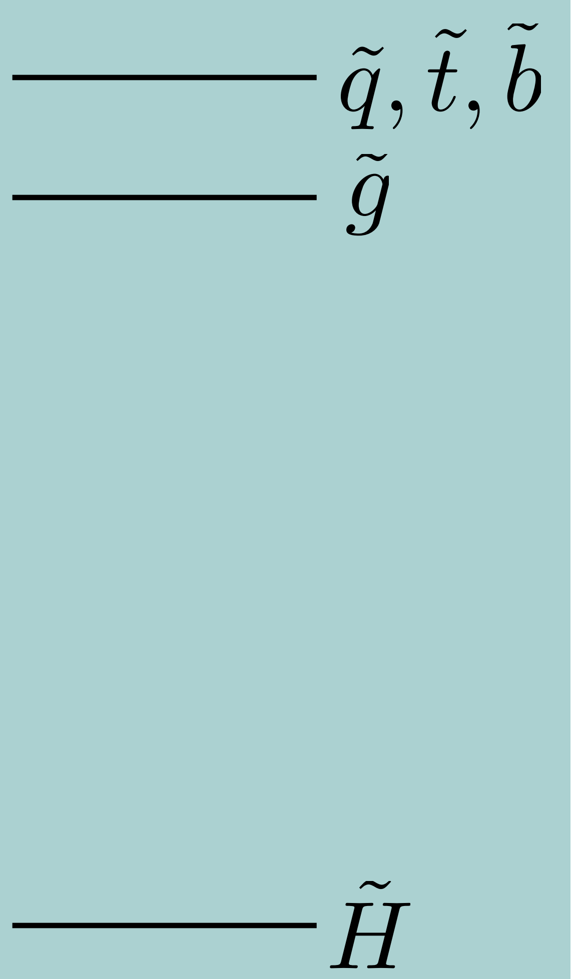
→ lepton counts (also signs)

Try to fit with just bb, tt modes

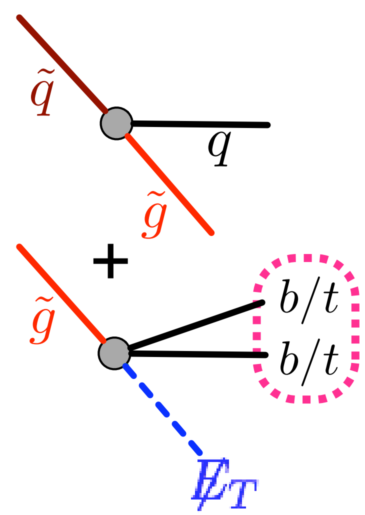


“The LSP Cannot be Thermal DM”

True Spectrum



Possible conclusions from early data:

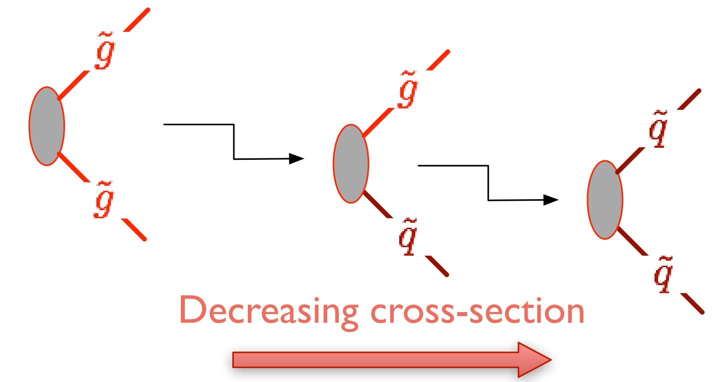


heavy squark(1,2)
OSET template

gluino → 3rd gen.

no lepton-rich cascade

Production Modes

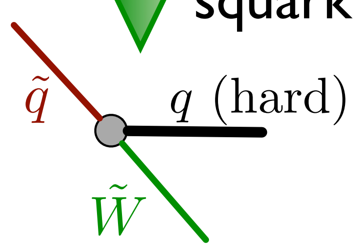


Decreasing cross-section

Alternative -ino spectra:

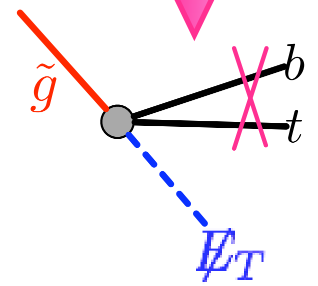
~~(1)~~Light Wino?

(unless LH squark absent)



direct squark decay
($\gtrsim 20\%$)

(2)Only Bino light?
(light 3rd-gen squarks)



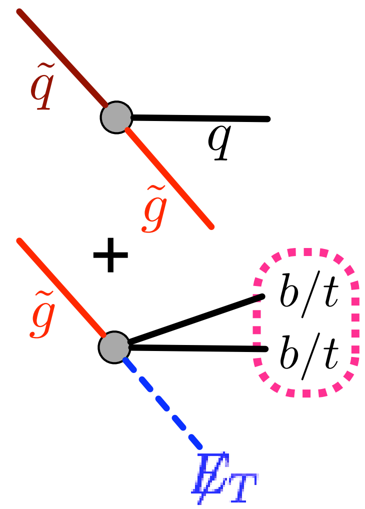
No b/t decay

(3) Higgsino near Bino LSP

“The LSP Cannot be Thermal DM”

True Spectrum

Possible conclusions from early data:



heavy squark$_{(1,2)}$
OSET template

gluino → 3rd gen.

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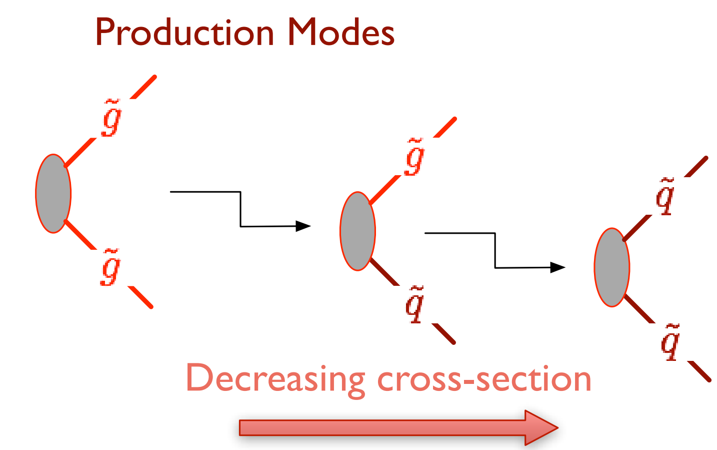
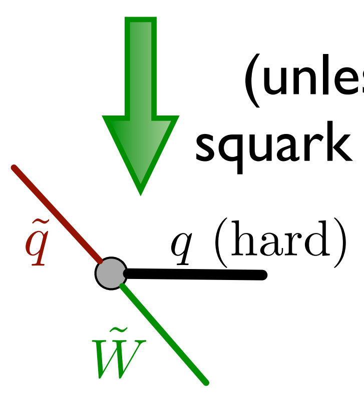


Alternative -ino spectra:

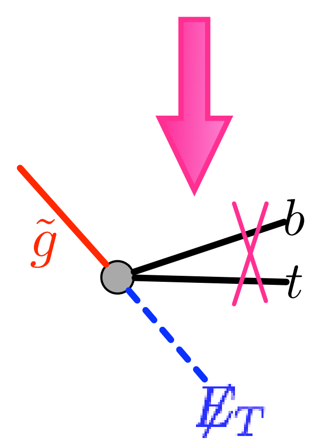
✗ (1) Light Wino?



(unless LH squark absent)

direct squark decay
($\gtrsim 20\%$)

✗ (2) Only Bino light?
(light 3rd-gen squarks)



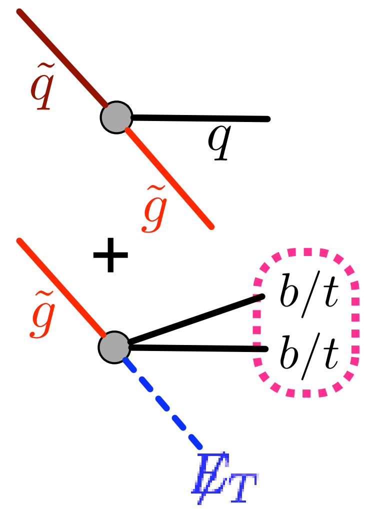
No b/t decay

(3) Higgsino near Bino LSP

“The LSP Cannot be Thermal DM”

True Spectrum

Possible conclusions from early data:



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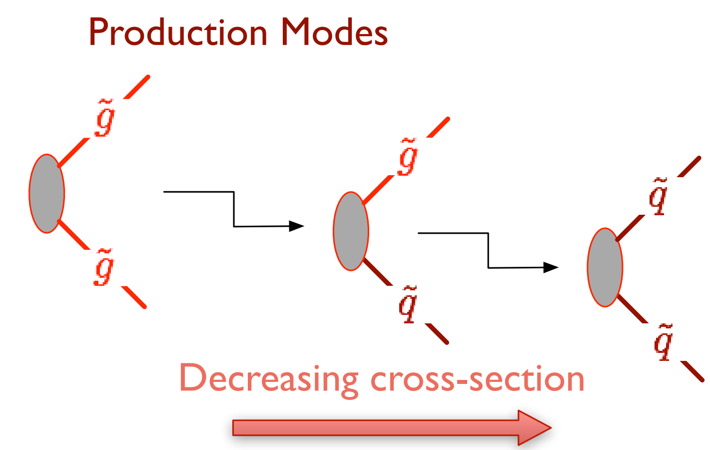
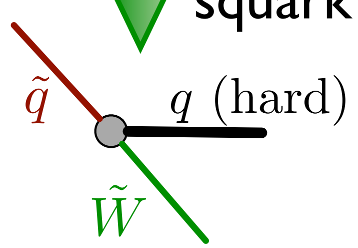


Alternative -ino spectra:

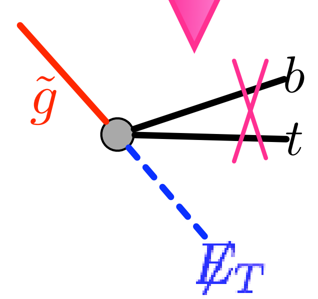
✗(1)Light Wino?

(unless LH squark absent)



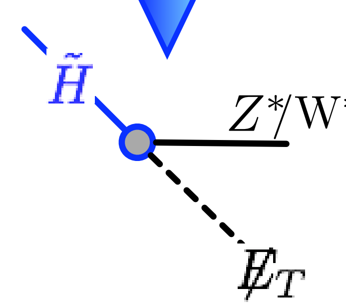
direct squark decay
($\gtrsim 20\%$)

✗(2)Only Bino light?
(light 3rd-gen squarks)



No b/t decay

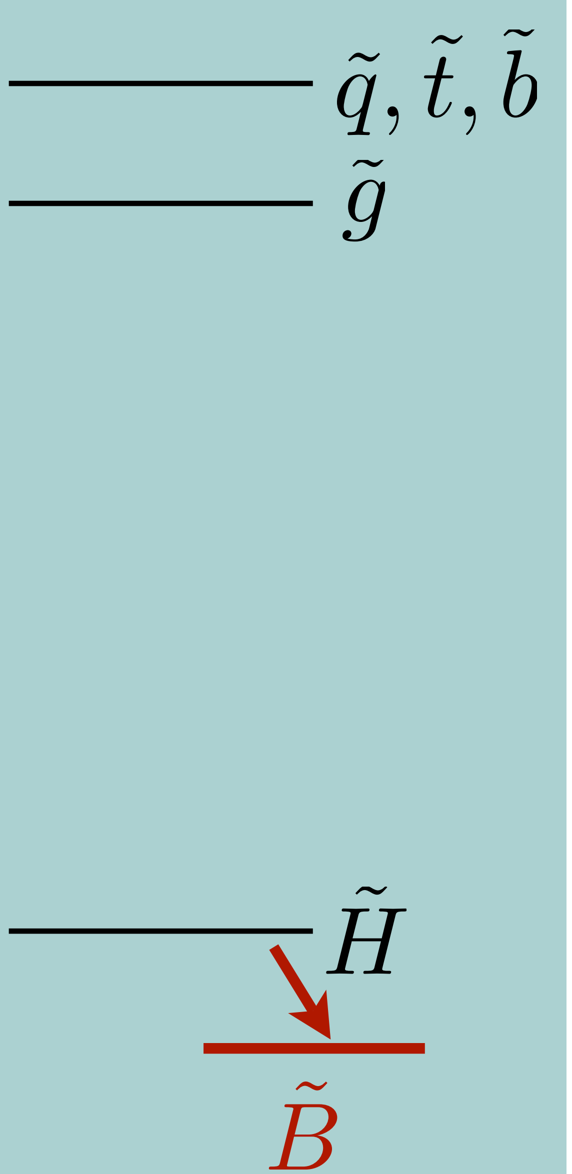
(3) Higgsino near Bino LSP



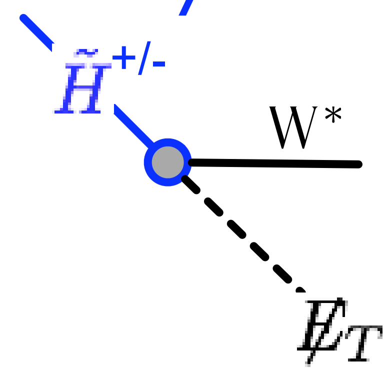
Striking decay:
$Z^* \rightarrow \ell^+\ell^-$

"No Higgsino to Bino"

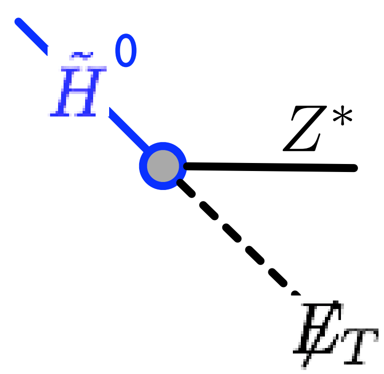
True **vs. guess**



Weak decays:



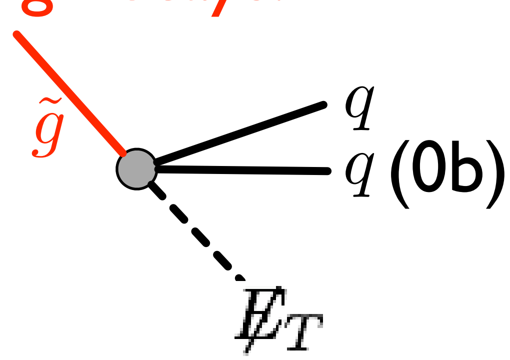
N_W	0	1	2	3	4
neutral only	Γ_{bb}^2		$2\Gamma_{bb}\Gamma_{tt}$		Γ_{tt}^2
+ charged		$2\Gamma_{bb}\Gamma_{bt}$	Γ_{bt}^2	$2\Gamma_{bt}\Gamma_{tt}$	
~~+ soft W~~*			$2\Gamma_{bb}\Gamma_{bt}$		Γ_{bt}^2 + $2\Gamma_{bt}\Gamma_{tt}$



→ kin. endpoint in dilepton mass

(same sign, same flavor only vs. flavor-uncorrelated backgrounds from W's)

Strong decays:



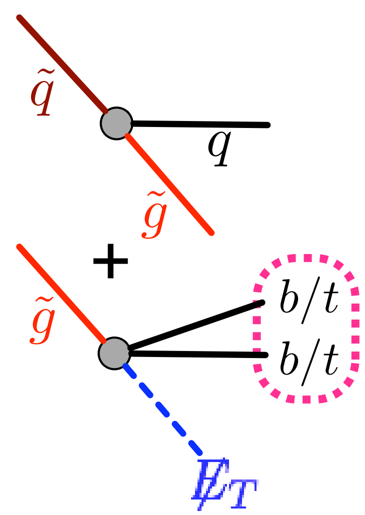
- All of these are very model-dependent;
- <u>can't rule out MSSM DM without the MSSM</u>

- Model-independent limits on processes allow most general analysis

“The LSP Cannot be Thermal DM”

True Spectrum

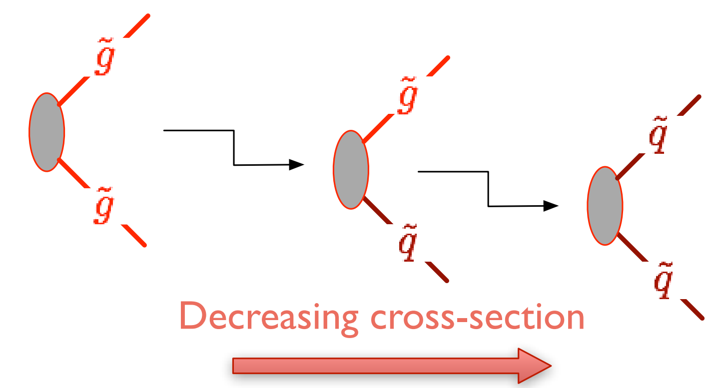
Possible conclusions from early data:



heavy squark(1,2)
OSET template

gluino → 3rd gen.

no lepton-rich cascade



Alternative -ino spectra:

✗(1)Light Wino? (unless LH squark absent)

✗(2)Only Bino light? (light 3rd-gen squarks)

✗?(3) Higgsino near Bino LSP

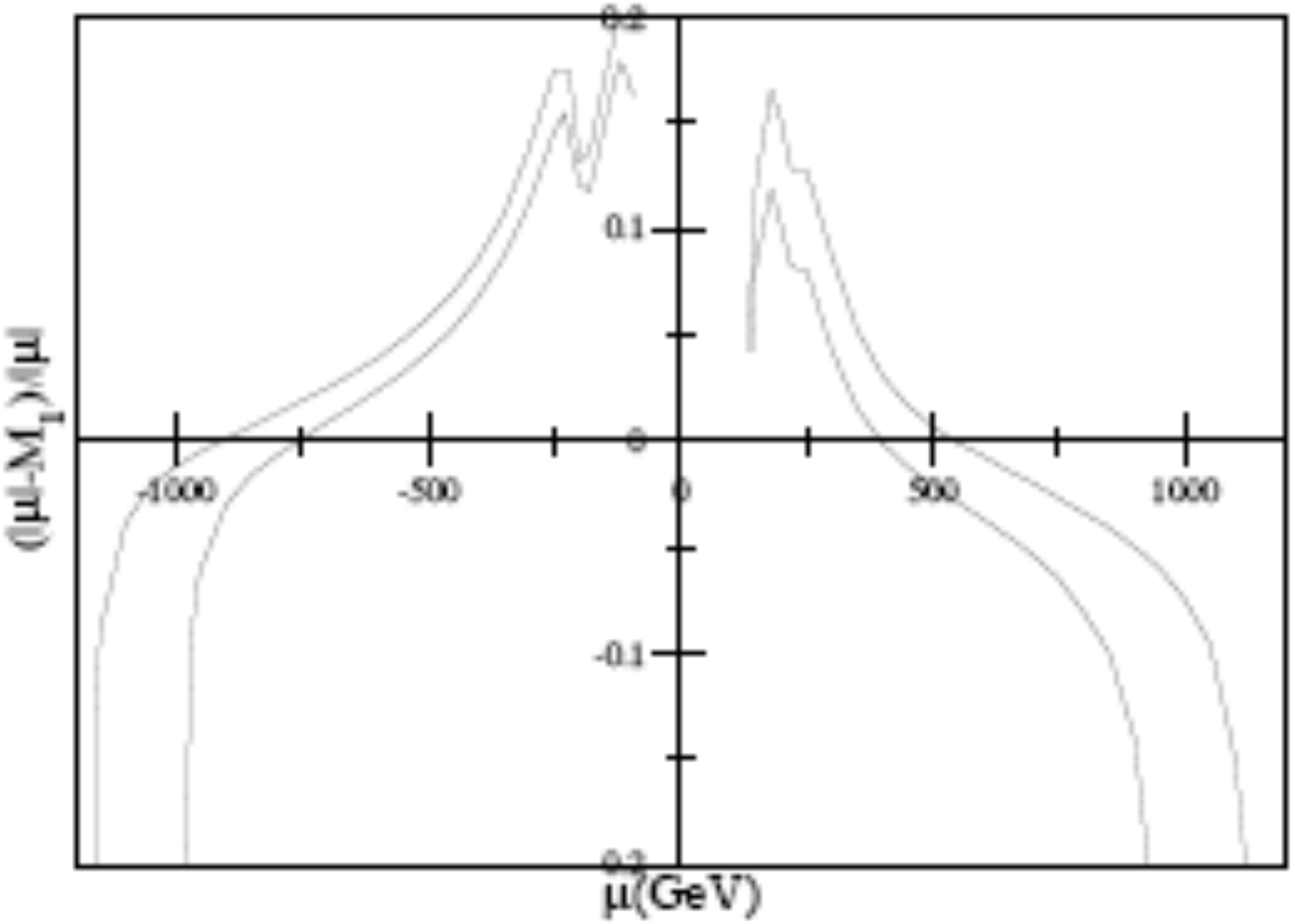
In this universe, a few process-level constraints would put a lot of pressure on MSSM dark matter, and favor particular dark matter phenomenology (annihilation modes, nuclear recoil xsec...)

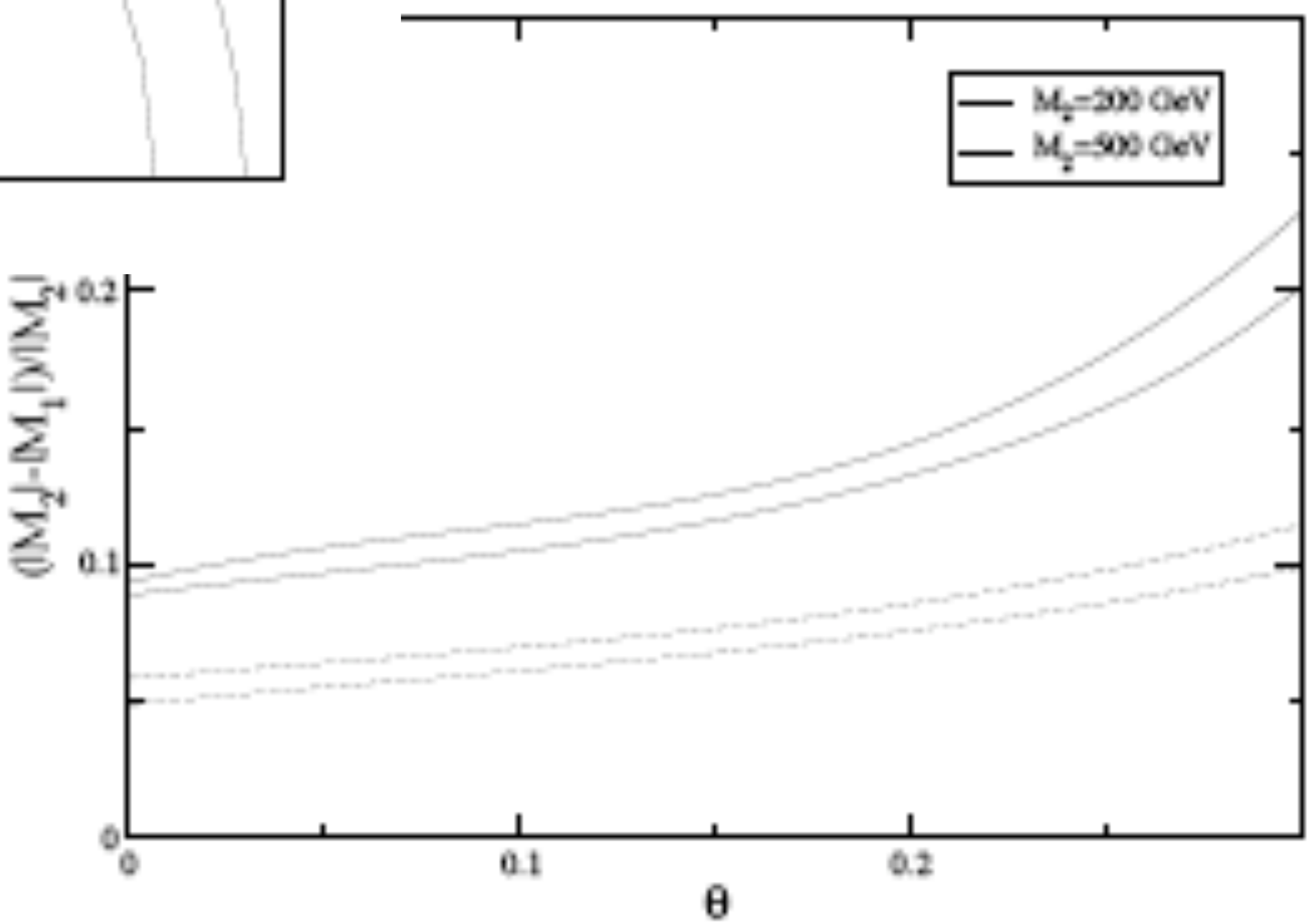
...we will want to do similar hypothesis-testing in our universe

Conclusions

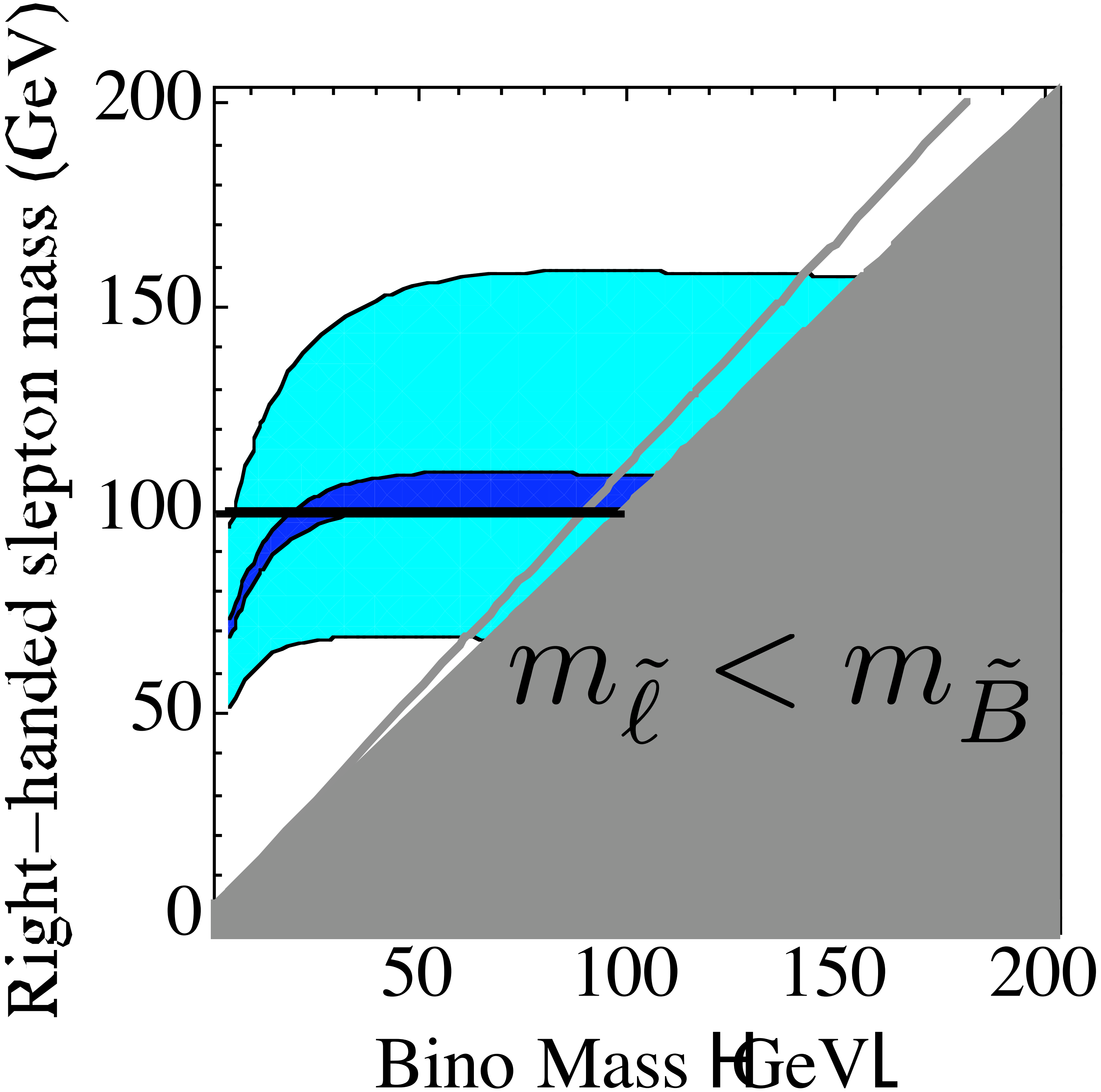
- Model-independent characterization
  - Useful simplifications in modeling processes
  - Tools in experimental hands for process-level, model-independent analysis
  - Mapping between OSETs and SUSY (can generalize to other models)
- Enable us to
  - Build confidence in process-level description of data
  - Measure/bound parameters in a model-independent way
- Will be a useful stepping stone in understanding physics of the TeV scale.
- Potentially a lot to see, **and a lot to learn** in the first year of running!

Mixed Bino/Wino and Bino/Higgsino dark matter





(plots from hep-ph/0601041 Arkani-Hamed, Delgado, Giudice



Light Bino DM

(analytic formula from hep-ph/0601041 Arkani-Hamed, Delgado, Giudice

Modeling Production

Universal PDFs, threshold and shape invariance

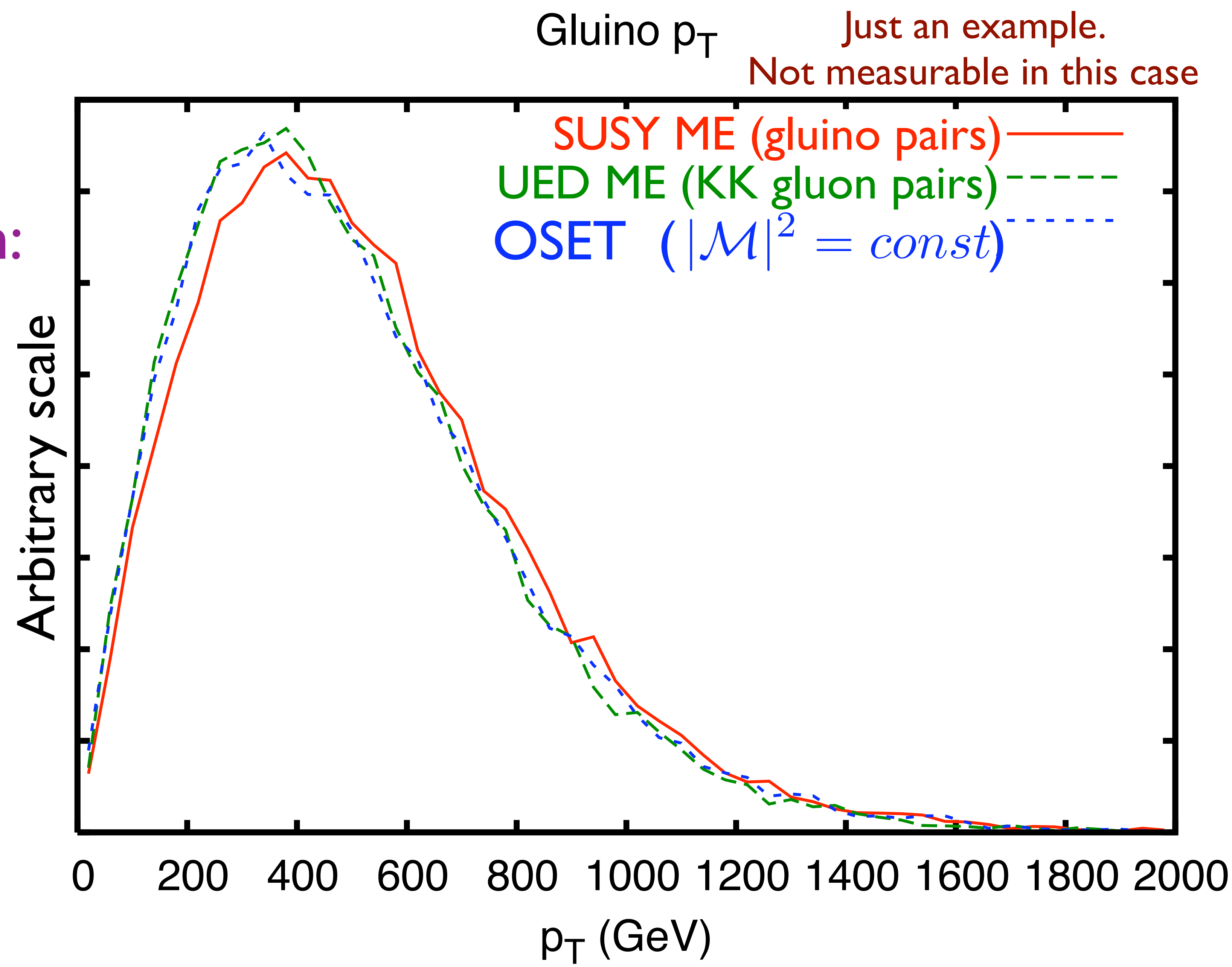
⇒very simple approximation:

$$|\mathcal{M}|^2 = const.$$

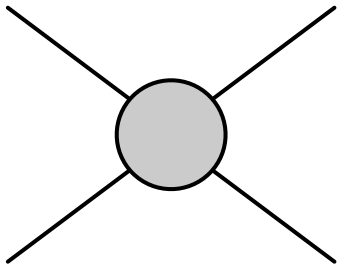
is **quantitatively** correct for:

- Massive particle production (100's of GeV)
- Both products with comparable masses

(Second assumption is improvable with simple, universal corrections)



Thresholds & Shape Invariance



$$|\mathcal{M}|^2 = f(s,\xi)$$

Angular variable:
$\xi = \beta_{34}\cos\theta = \frac{\hat{t}-\hat{u}}{\hat{s}} = \frac{p_z}{\sqrt{s}}$

$$= \sum_{p,q} C_{pq} s^p \xi^q \sim s^{p_{min}} \xi^{q_{min}}$$

(one piece dominates near threshold)

Homogeneity of PDF in E_{cm} and y_{cm} →

Inclusive p_T distribution invariant under

$$X^p \xi^q \to X^p \qquad (\xi\text{–independent})$$

Inclusive y_{lab} distribution invariant under

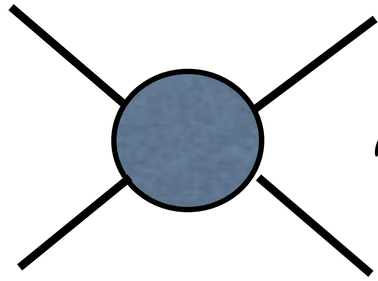
$$X^p \xi^q \to \xi^q \qquad (s\text{–independent})$$

→Simple, universal corrections to constant ME!

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

Caveats:
- Correct PDFs necessary
- Large final state mass asymmetry requires care
- Transverse momentum-rapidity correlations not included

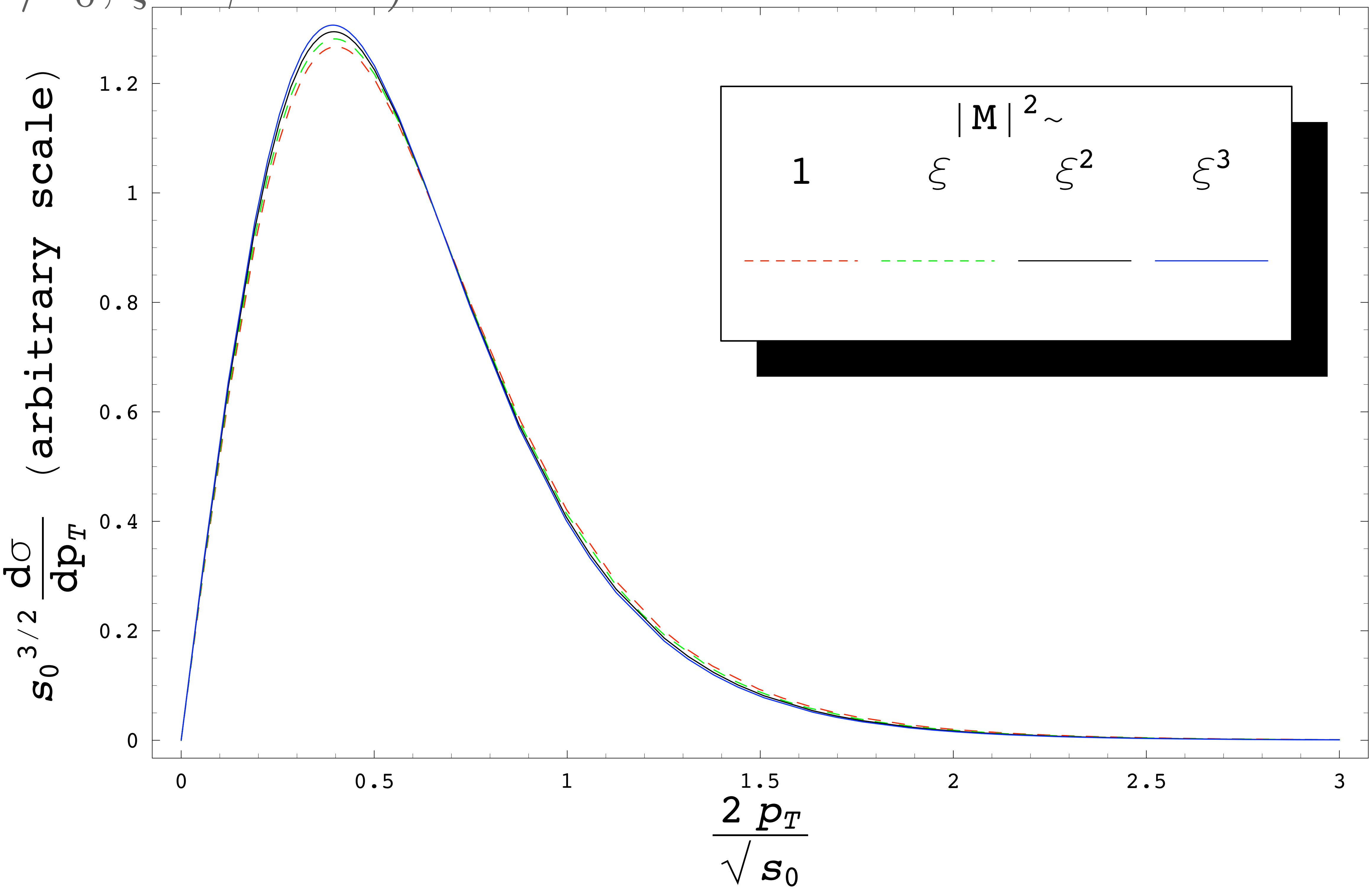
Messy collider environment turned to our advantage



$\sim |M|^2 \sim X^q \xi^p$

ξ-Independence of Transverse Shape!

$(X = \hat{s}/s_0, \xi = \beta \cos\theta)$

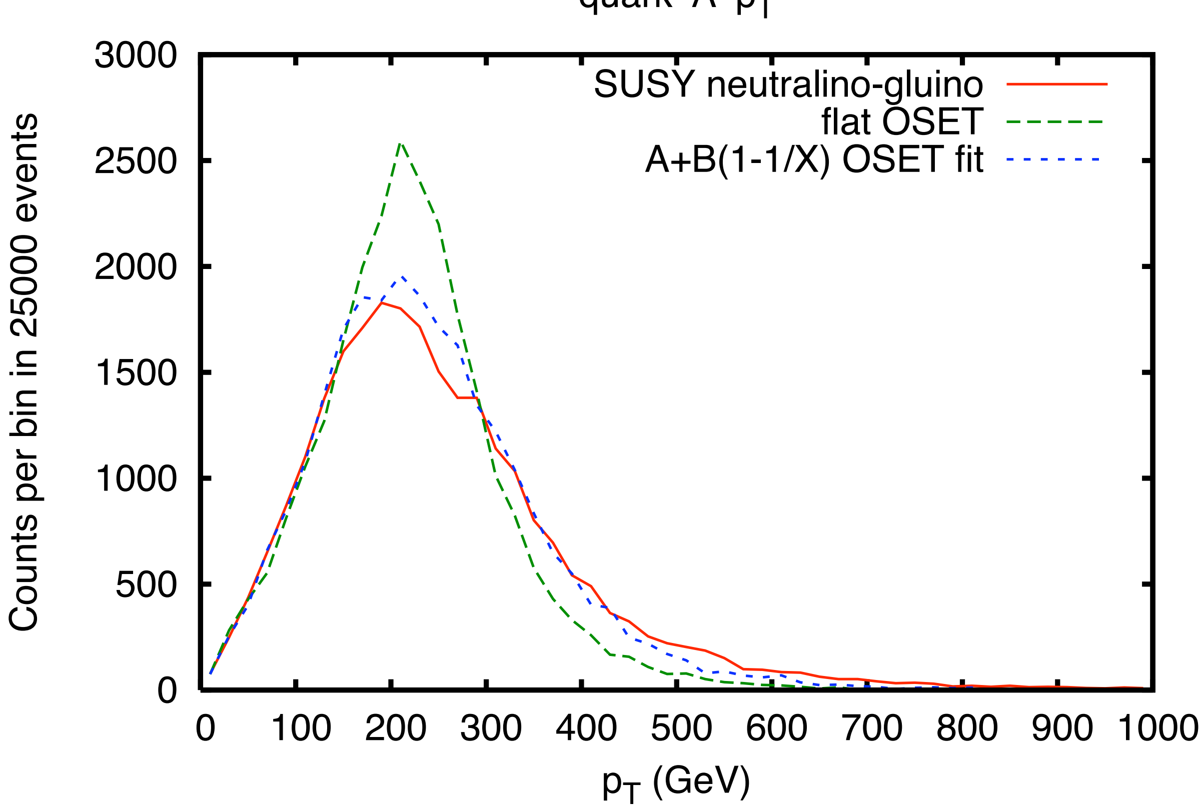


Handling extreme kinematics

Two cases to keep in mind

$m_{t\text{-chan}} \sim m_{\tilde{g}}$

p-wave $\rightarrow$ $\propto \beta^2$
suppressed
near threshold.



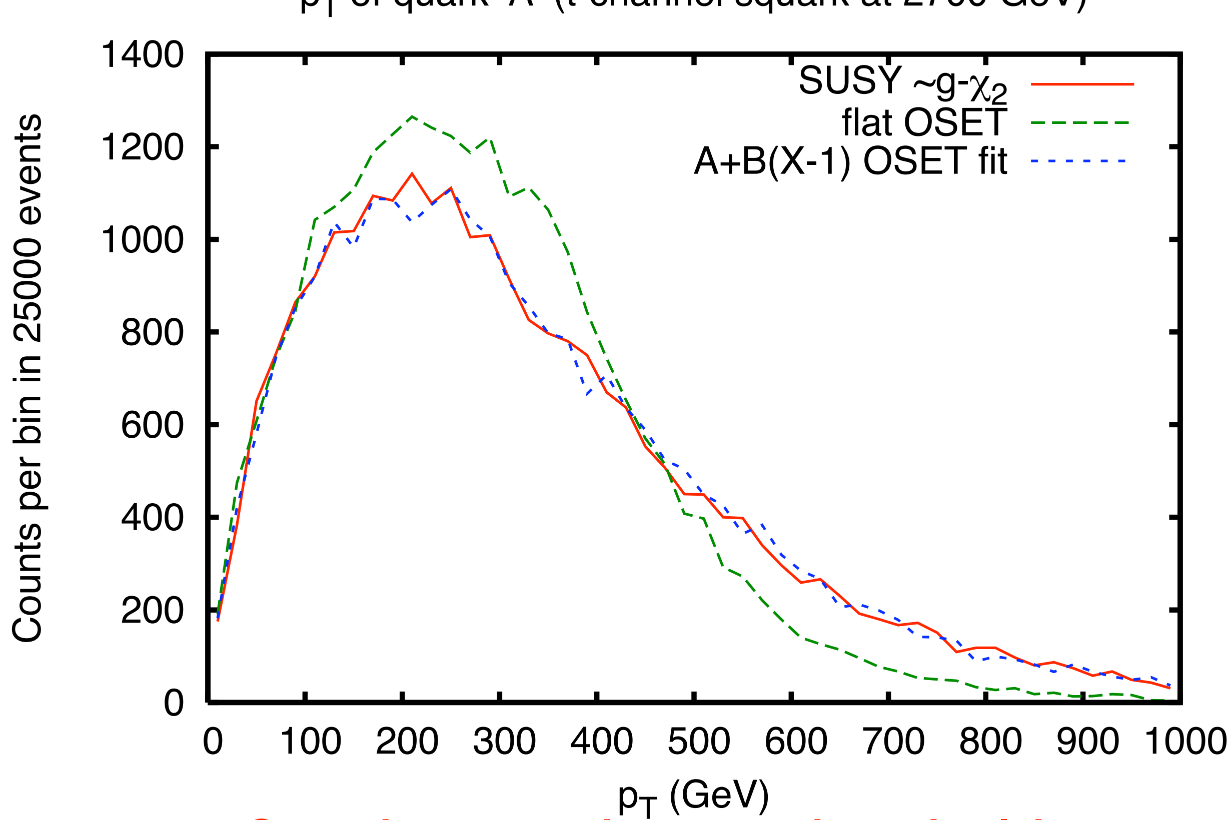
$$|\mathcal{M}|^2 = A + B\left(1 - \frac{s_{\text{thresh}}}{s}\right)$$

s/p-wave "dominated" near-threshold modulation

$m_{t\text{-chan}} \gg m_{\tilde{g}}$

contact interaction

up to $\sqrt{s} \sim m_{t\text{-chan}}$



Steady growth near-threshold

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