Early LHC Opportunities

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SLAC

Feb 17, 2011

New Data from the Energy Frontier
Aspen Winter Conference

Where we’re at during Aspen 2011:

$40\ pb^{-1}$ at 7 TeV

LHC is just beginning
to broadly push past Tevatron limits

Where we’ll be at by Aspen 2012:

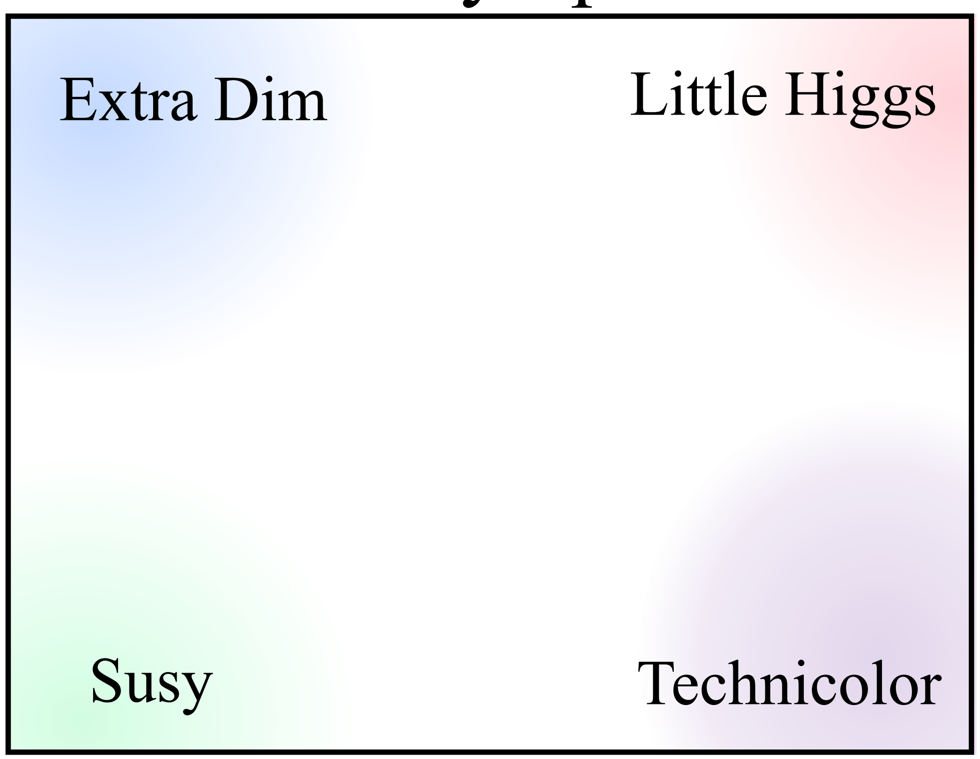
$2\ fb^{-1}$ at 7 TeV

The reach (in mass) will double

An opportunity to improve the design of searches

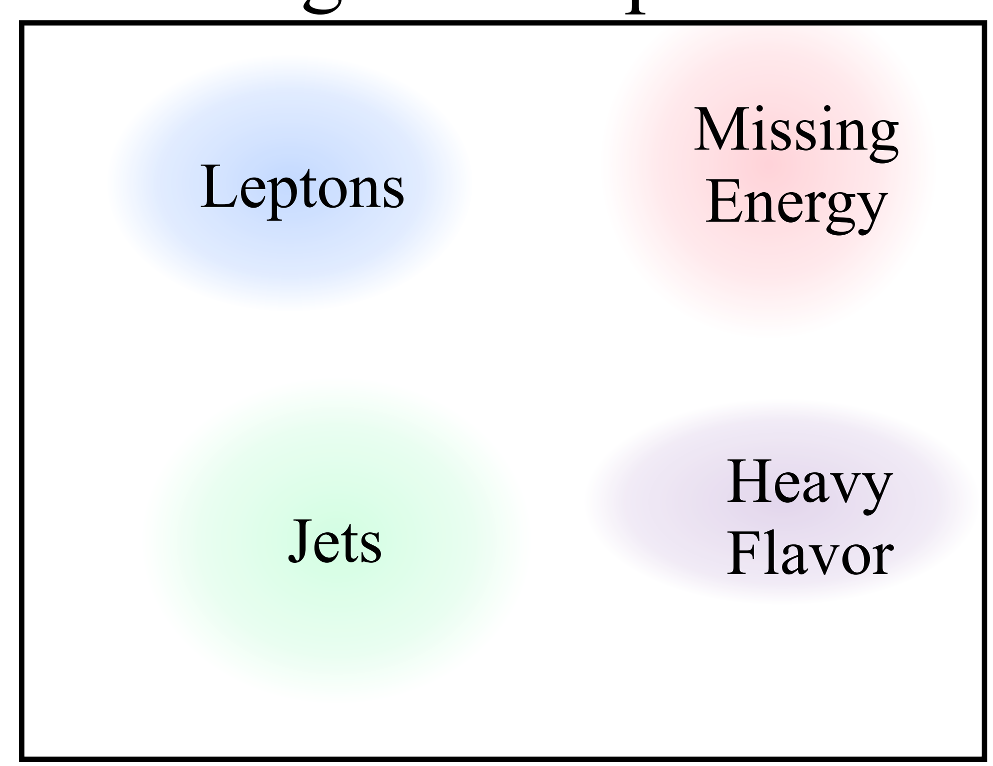
Over the past few years there's been a push for less model dependent searches

Theory Space



Constructing Signature Space
from Theory Space
not easy/efficient

Signature Space



Need axes for
Theory Space to map into
Signature Space

Supersymmetry as an example

Too many parameters so we make an ansatz

$$m_{\frac{1}{2}}, m_0^2, A_0, B_\mu, \mu$$

$$B_\mu, \mu \to v_{\rm EW} = 246 \text{ GeV}, \tan\beta$$

Gaugino Masses

$$\frac{d}{dt} M_a = \frac{1}{8\pi^2} b_a g_a^2 M_a$$

Scalar Masses

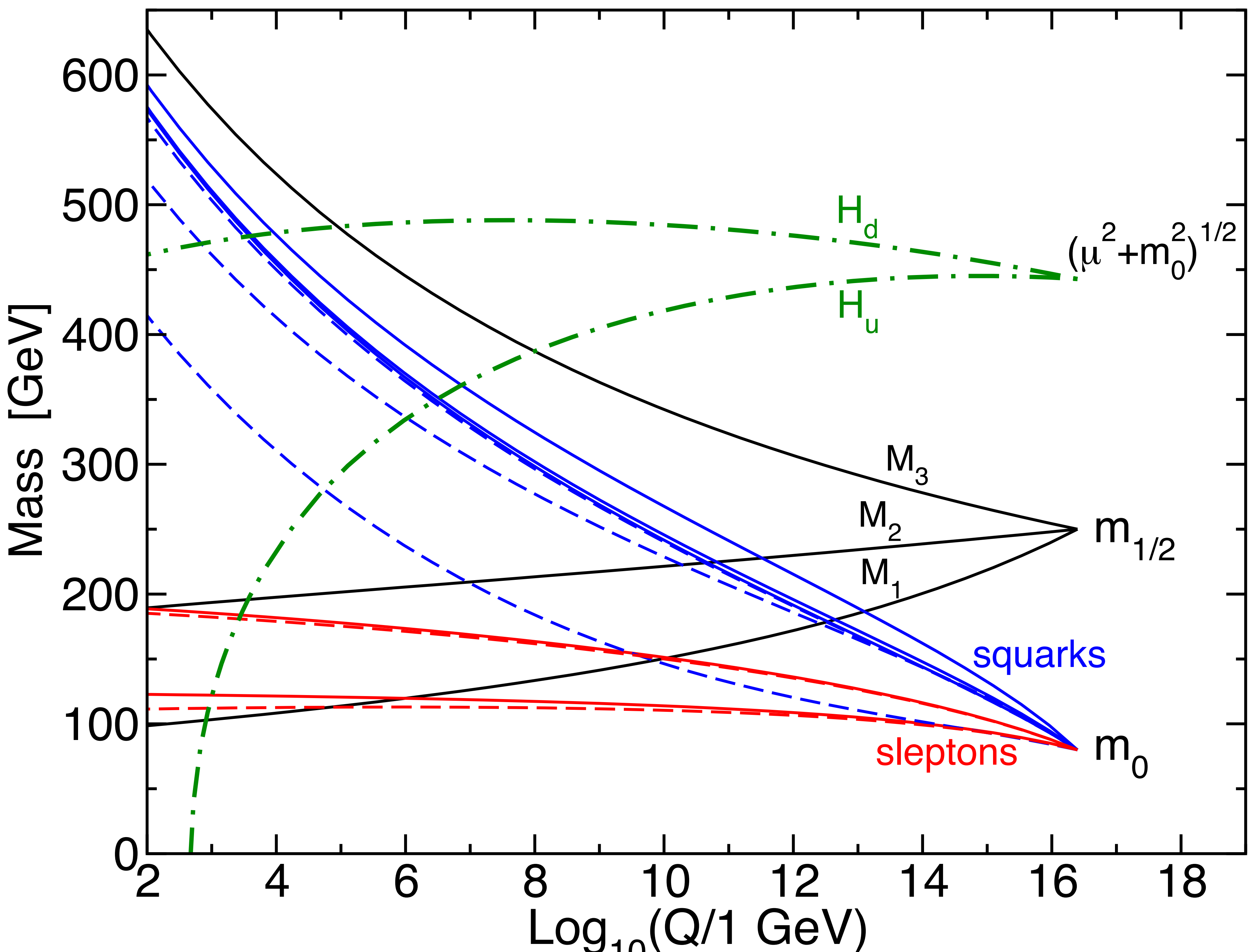
$$\begin{aligned} 16\pi^2 \frac{d}{dt} m_{Q_3}^2 &= X_t + X_b \\ &- \frac{32}{3} g_3^2 |M_3|^2 - 6 g_2^2 |M_2|^2 \\ &- \frac{2}{15} g_1^2 |M_1|^2 + \frac{1}{5} g_1^2 S, \end{aligned}$$

Gauge interactions make particles heavier

Yukawa interactions make particles lighter

Typical mSUGRA Spectrum

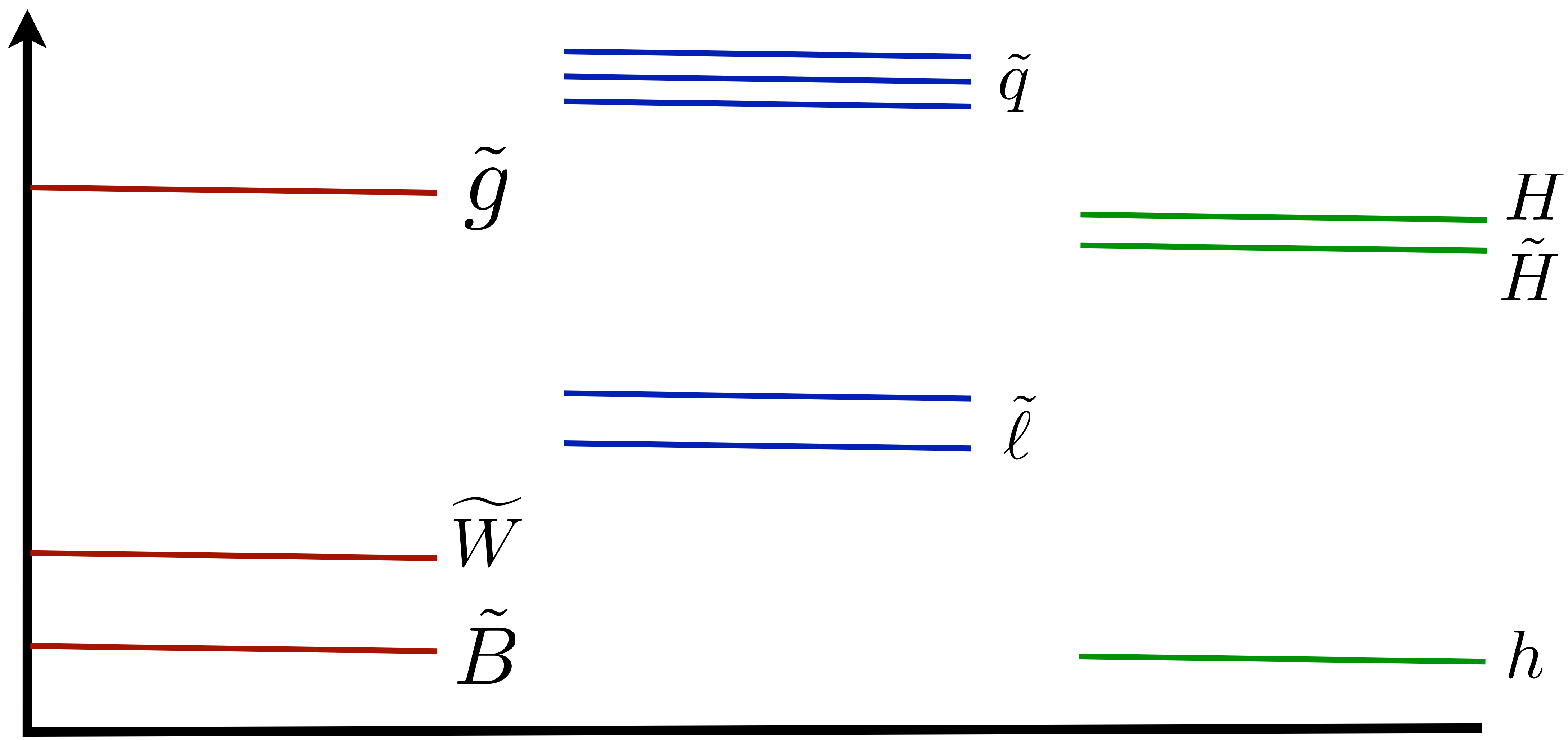
	Principle	Fine	HyperFine
Structure:	$SU(3)_c$ Charged Heavier	$SU(2)_L$ Charged Heavier	3rd Generation Lighter



mSugra and "Gaugino Mass Unification"

$$m_{\tilde{g}} : m_{\tilde{W}} : m_{\tilde{B}} = \alpha_3 : \alpha_2 : \alpha_1 \simeq 6 : 2 : 1$$

Most models look like this



Diversity is whether squarks & Higgsinos are lighter than gluinos and sleptons are lighter than the winos

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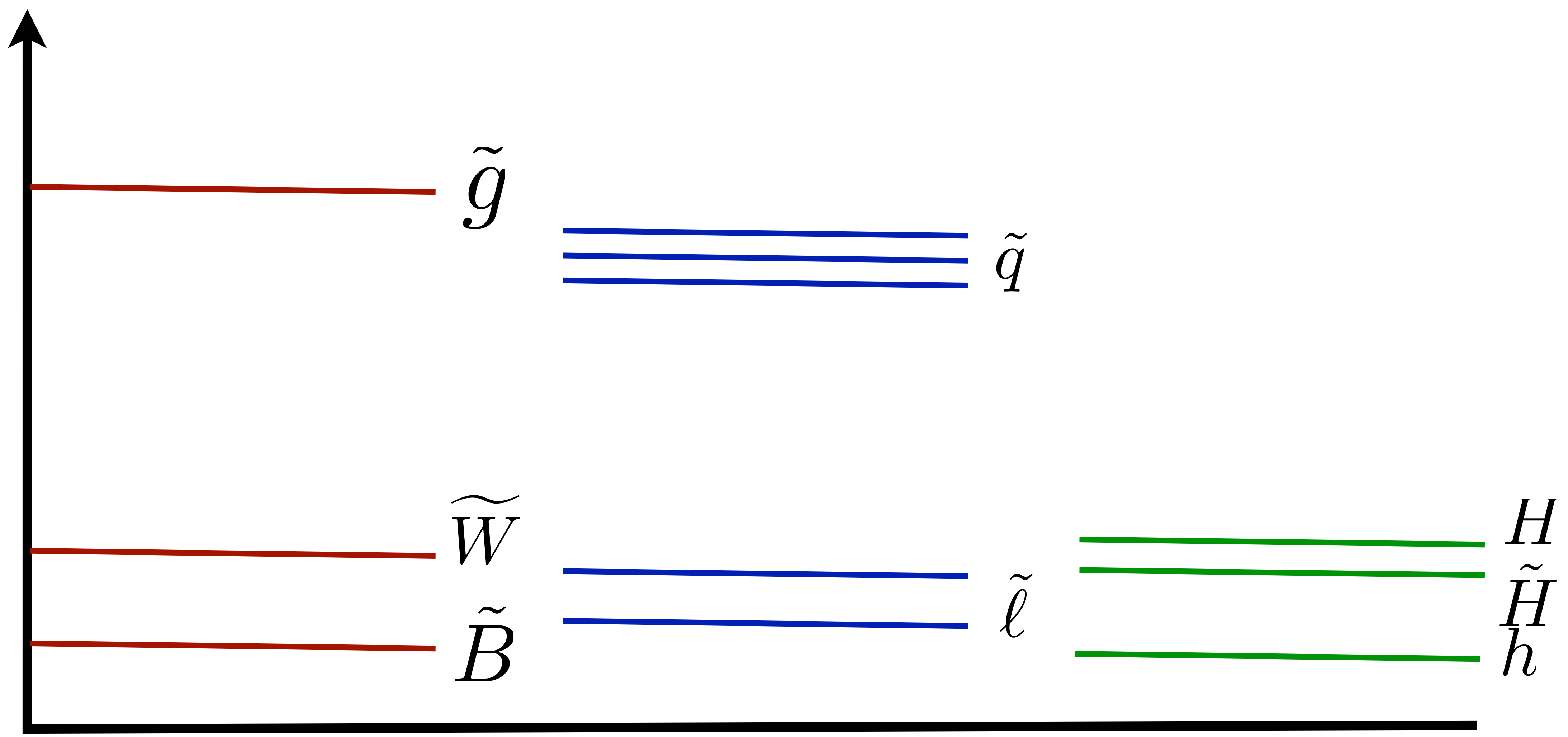

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The Phenomenological MSSM

The part of parameter space that was allowed circa 1981

$m^2_{\tilde{q}}, m^2_{\tilde{u}^c}, m^2_{\tilde{d}^c}, m^2_{\tilde{\ell}}, m^2_{\tilde{e}^c}$ — 5 for 1st 2 Generations, 5 for 3rd Generations

$m_{\tilde{g}}, m_{\tilde{W}}, m_{\tilde{B}}, \mu$ — 4 for *-ino masses

A_t, A_b, A_τ — 3 for A-terms

$m^2_{h_u}, m^2_{h_d}, B_\mu$ — 3-1 for Higgs Sector

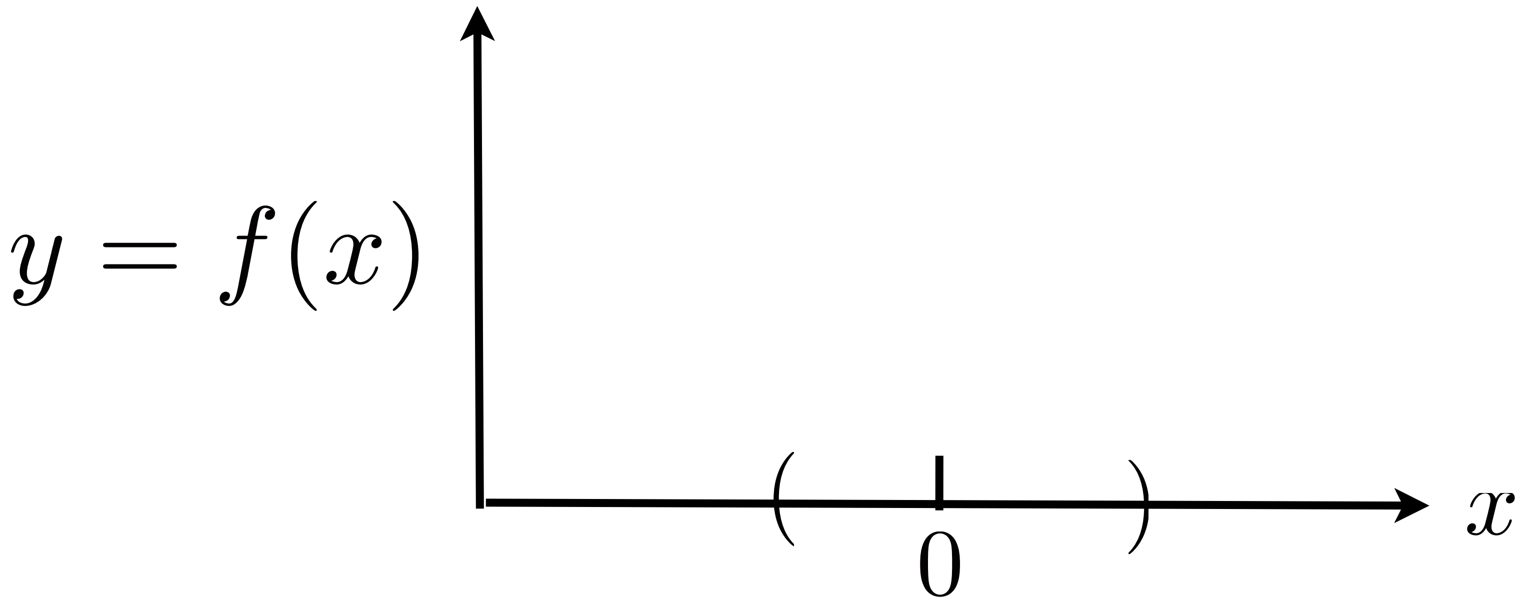
19 Dimensional Parameter Space

Challenging to explore in detail: $2^{19} \sim 0.5$ Million

Berger, Gainer, Hewett, Rizzo

Imagine a simpler world...

Theory of nature is a one parameter function, *y=f(x)*,
Can only do measurements of *y* near *x=0* that we don't know



A very complicated space to explore!

∞-dimensional

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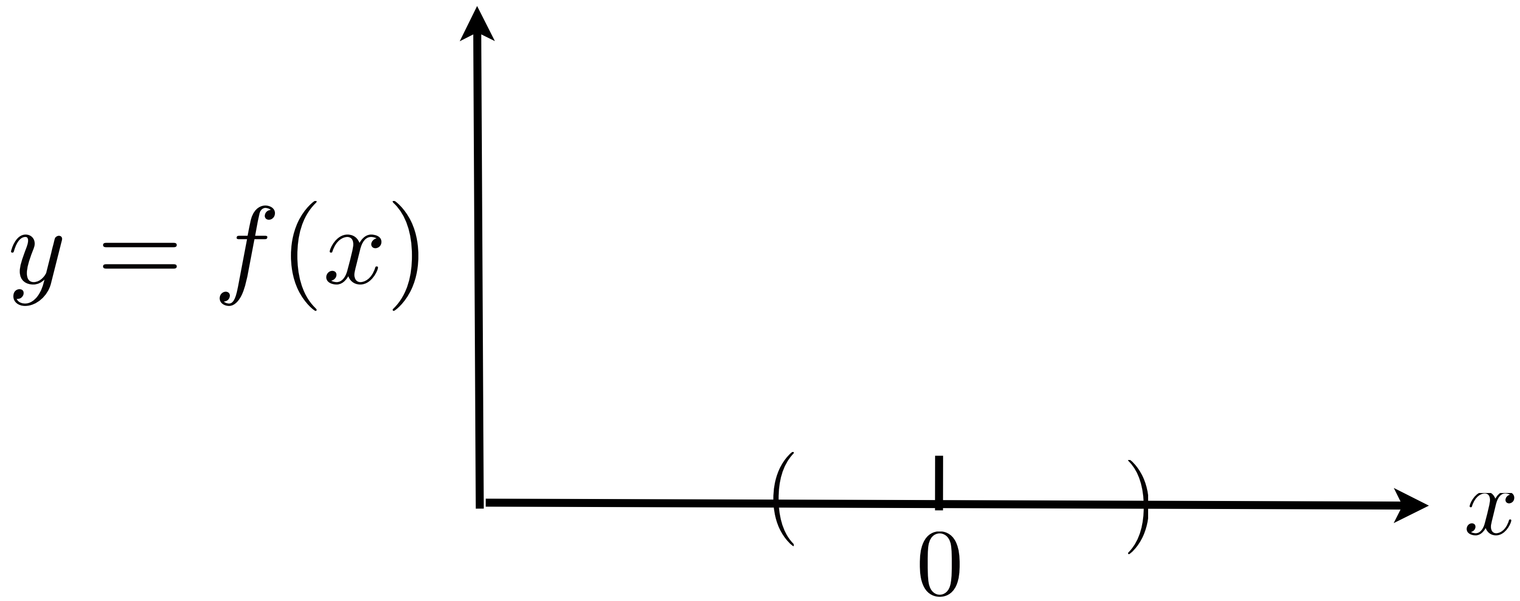

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In this world, the leading theory is $f(x) = e^{\alpha(x-x_0)}$

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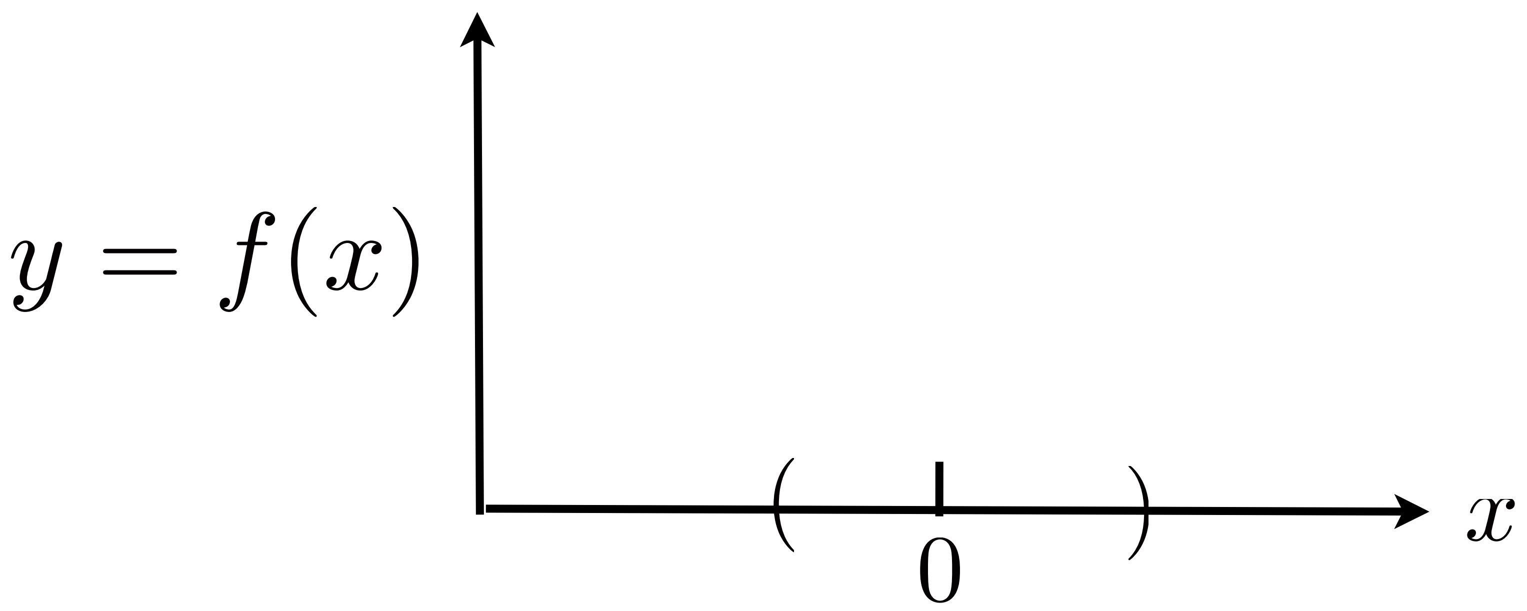

A very complicated space to explore!

∞-dimensional

In this world, the leading theory is $f(x) = e^{\alpha(x-x_0)}$

Could design a measurement strategy to discover

$$f(x) \neq 0,\ \alpha,\ x_0$$

Problem with this strategy

What happens if we're wrong about our theoretical assumption?

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$$f(x) = -e^{\alpha(x-x_0)}$$

f(x) is negative

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$$f(x) = \sinh(x)$$

f(x) vanishes at 0

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$$f(x) = \cosh(x) - 1$$

Function & slope vanish at 0

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$f(x) = \cos(x)$	Doesn't grow asymptotically

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Could enumerate all possibilities

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Could enumerate all possibilities

<u>A better strategy</u>

Mr. Taylor

$$f(x) = a_0 + a_1 x + a_2 x^2 + \cdots$$

Easy to identify special cases

Not a cure-all

Still infinite dimensional

But there is some notion of simplicity

$f(x) = -x^6 + x^{12}$ less likely than $f(x) = 1$

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<u>There could be technicalities:</u>

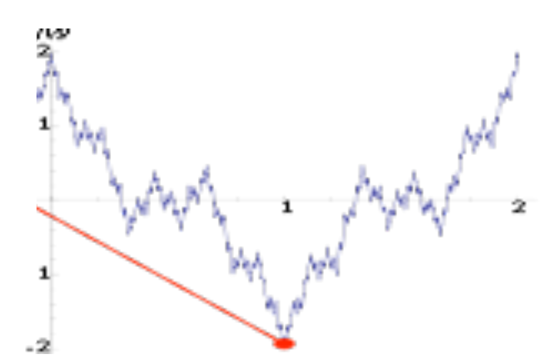
Radius of convergence problems

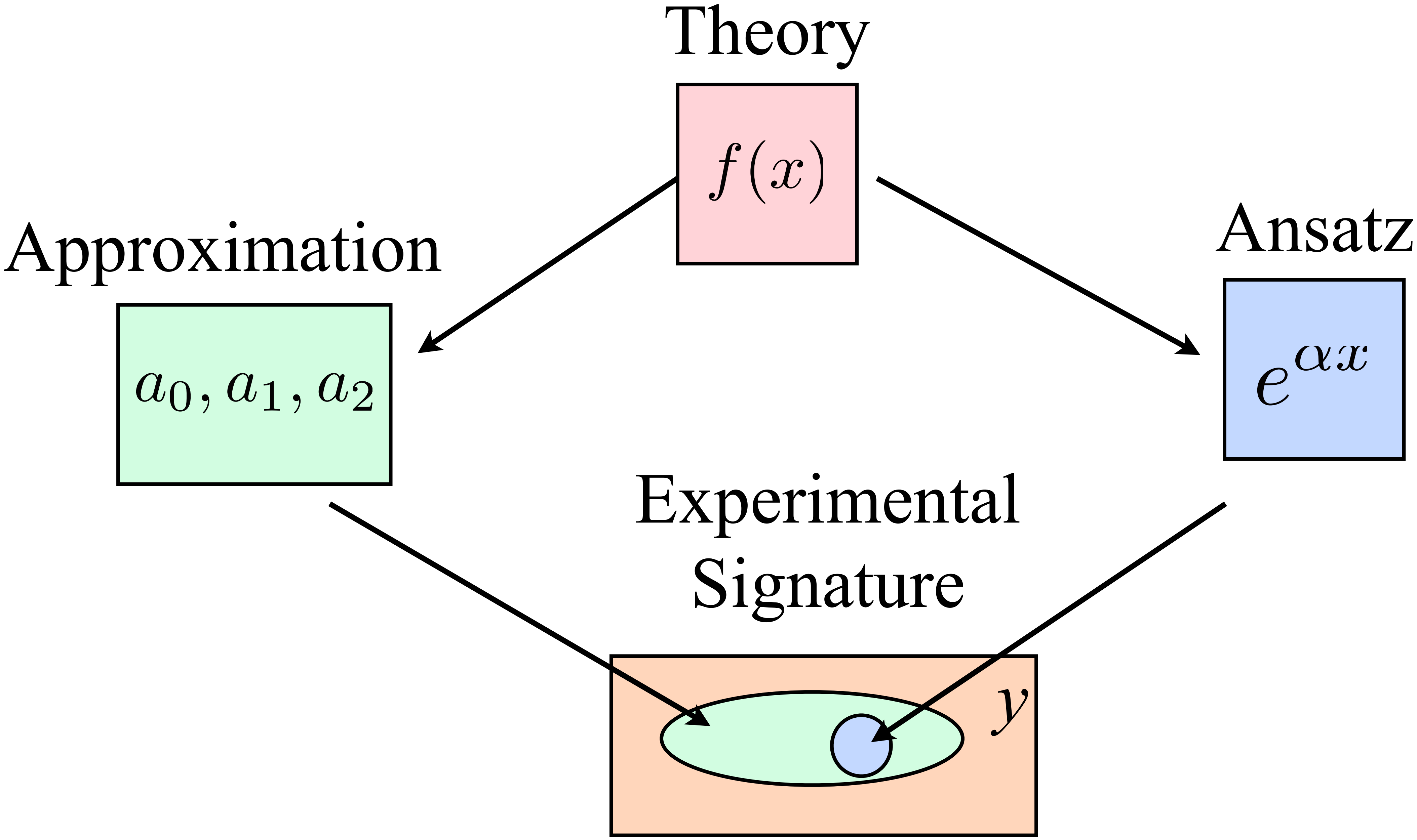
$$f(x) = \log(1+x)$$

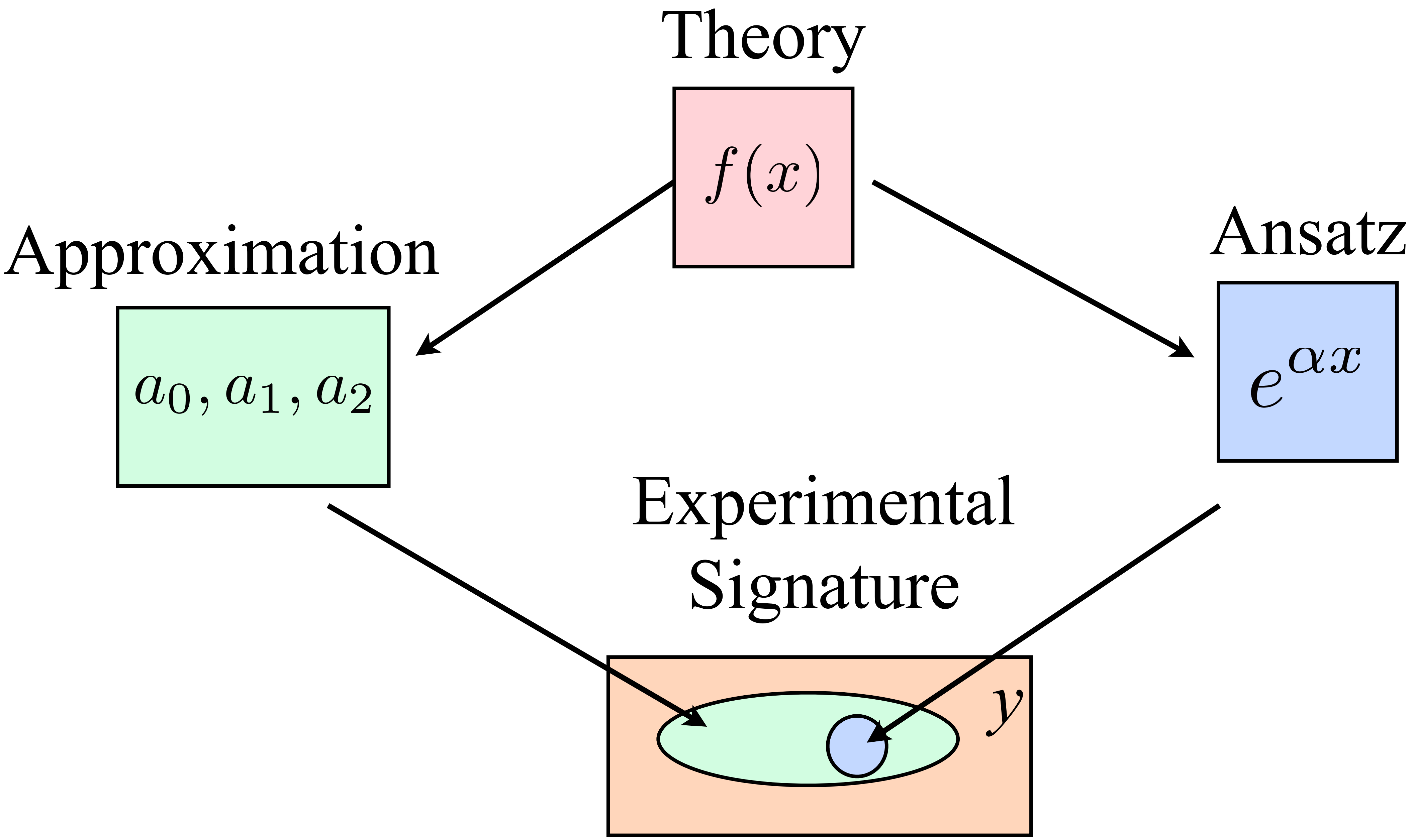
Assumes the function is continuous/differentiable

$$f(x) = \Theta(x)$$

$$f(x) = \sum_{n=0}^{\infty} a^n \cos(b^n \pi x)$$



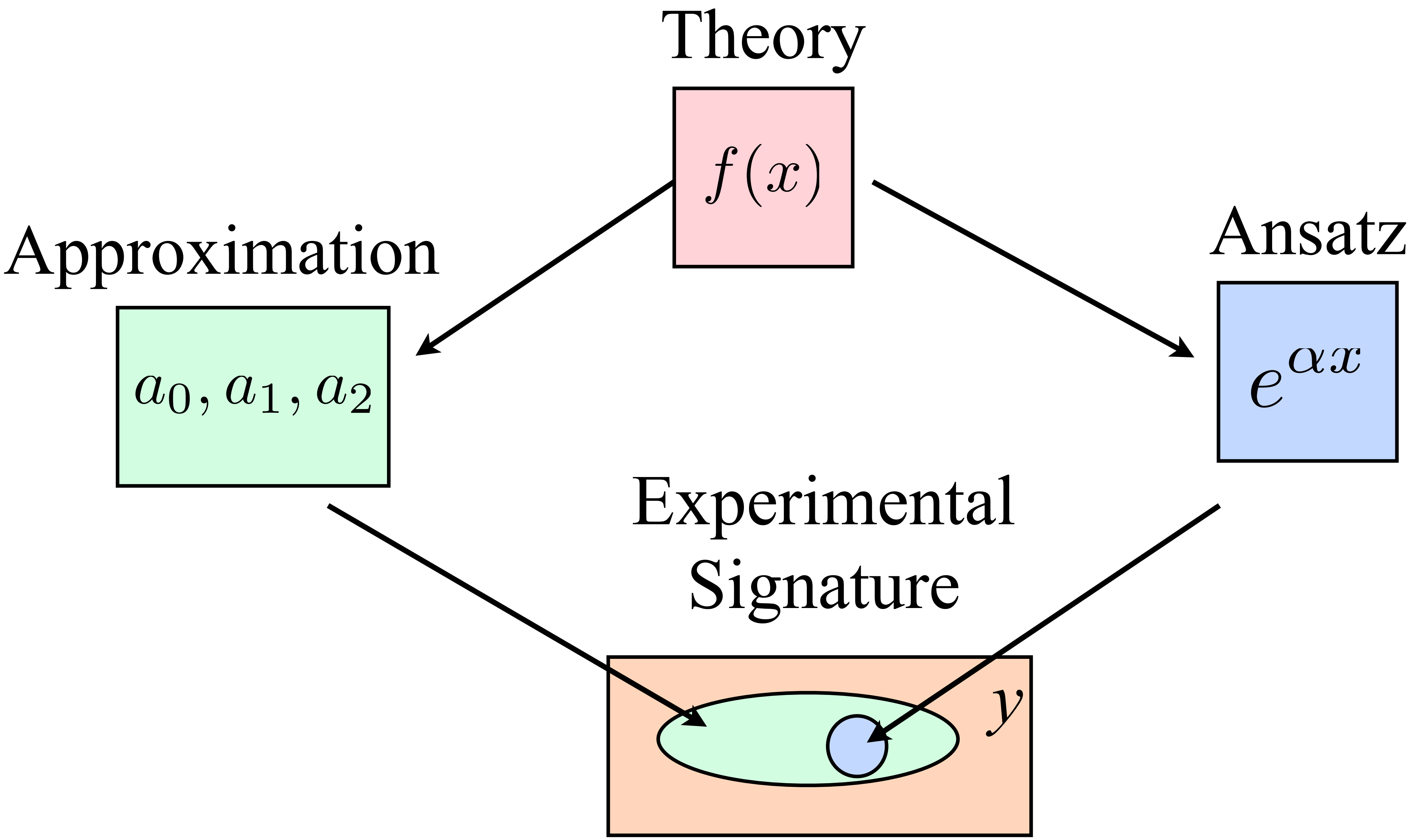

Theory
$f(x)$
Approximation
a_0, a_1, a_2
Ansatz
$e^{\alpha x}$
Experimental
Signature
y



f(x) = All theories beyond the Standard Model

e^x= mSUGRA

y = A typical LHC observable, *e.g.* Missing Energy



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What is a Taylor Series?

Simplified Models

(Effective Field Theories for Collider Physics)

Limits of specific theories

Only keep particles and couplings relevant for searches

A full Lagrangian description

Removes superfluous model parameters

Masses, Cross Sections, Branching Ratios

Add in relevant modification to models (*e.g.* singlets)

Not fully model independent, but greatly reduce model dependence

Captures specific models

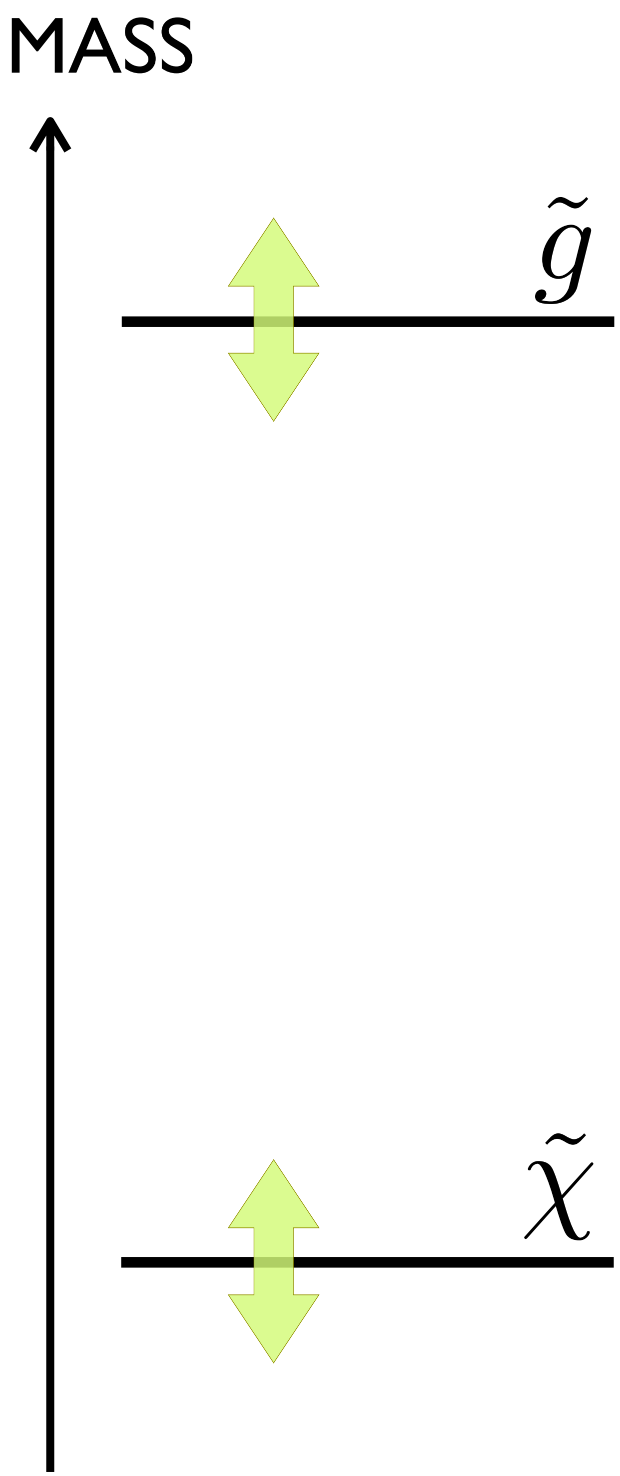
Including ones that aren't explicitly proposed

Easy to explore

Example Simplified Model

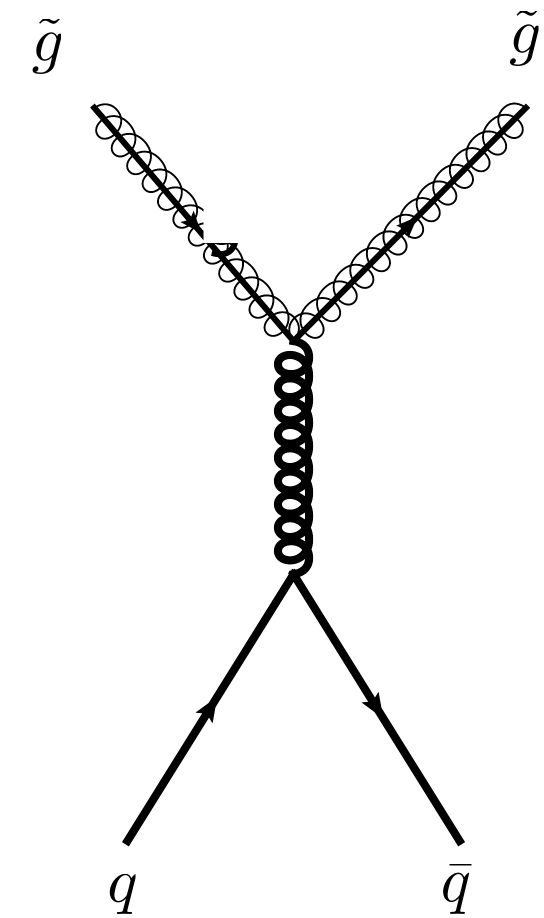
$$f(x) = a_0$$

Direct Decays

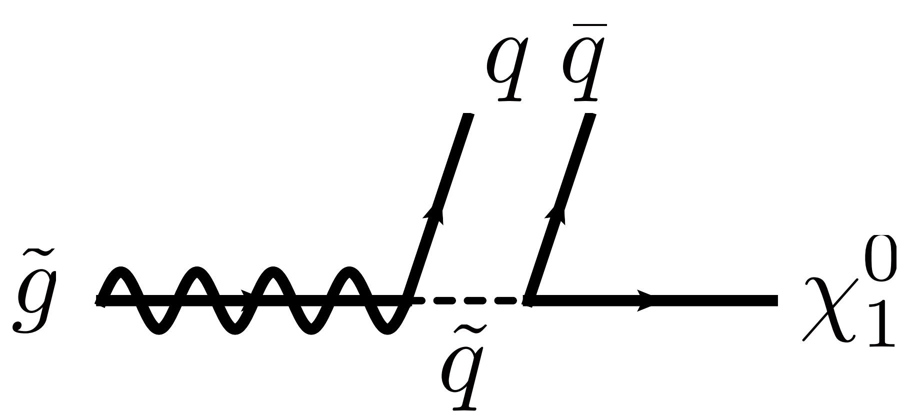


color octet majorana fermion ("Gluino")

neutral majorana fermion ("LSP")



Three-Body Decay

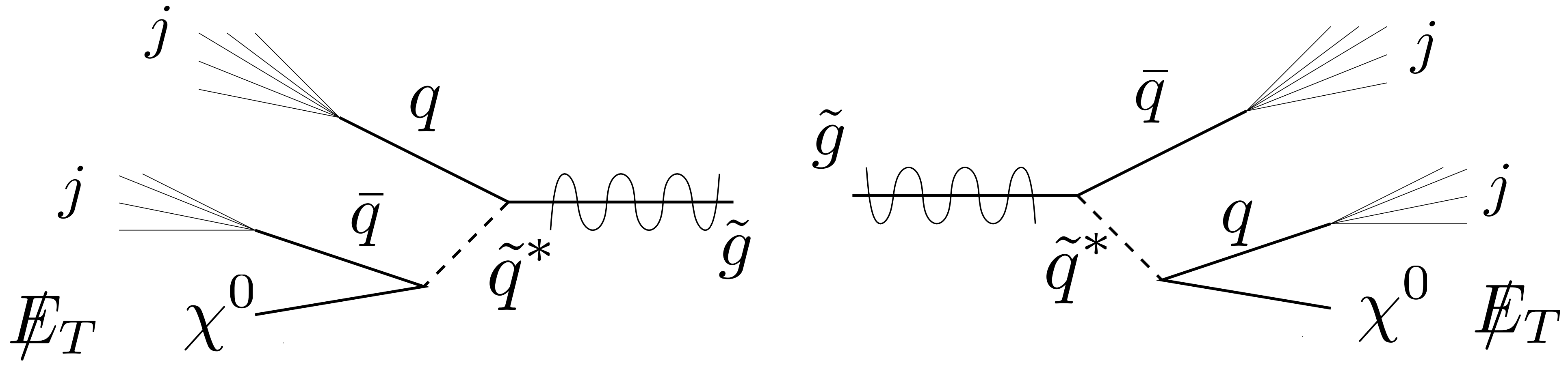


(off-shell squark that is too heavy to be seen)

Directly Decaying Gluino

Keep masses and total cross section free

$$m_{\tilde{g}} \quad m_{\chi^0} \quad \sigma(pp \to \tilde{g}\tilde{g}X)$$

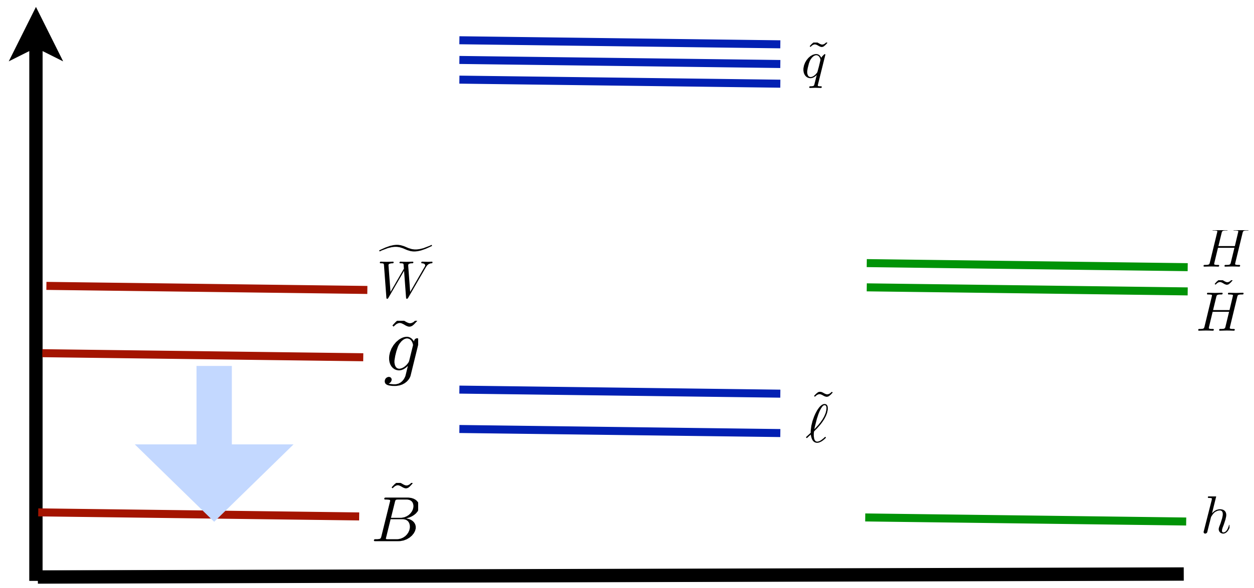


Typical signature is 4 jets plus missing energy

Directly Decaying Gluino

Study one decay mode $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}^0$

Sometimes this is the exact theory



$\mathrm{Br} = 100\%$

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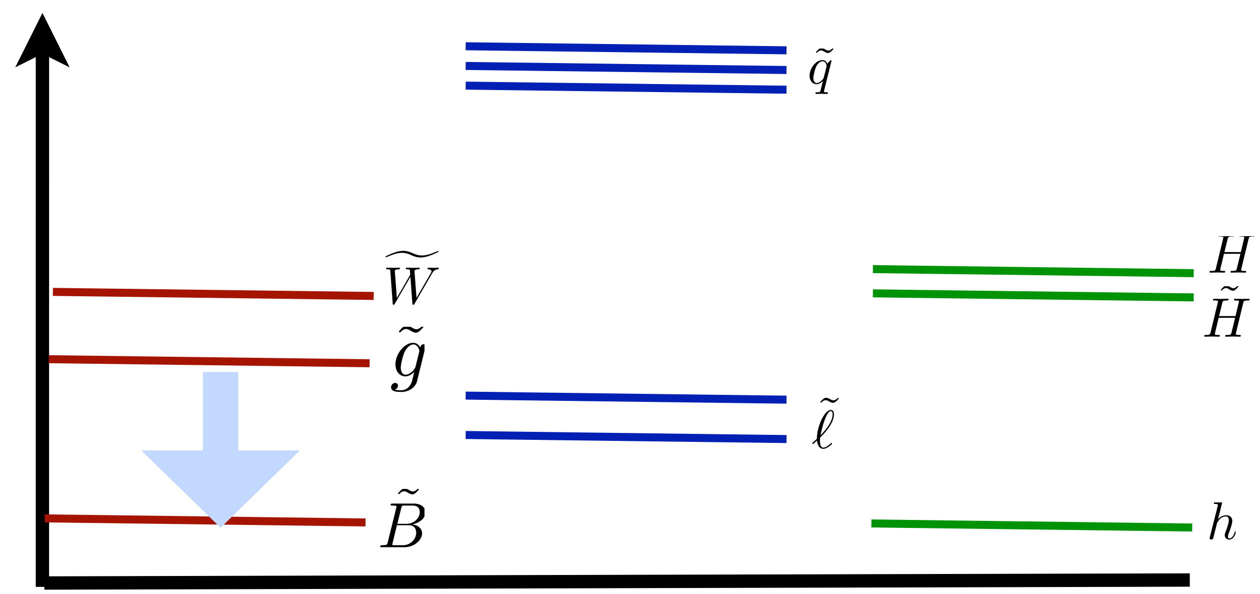
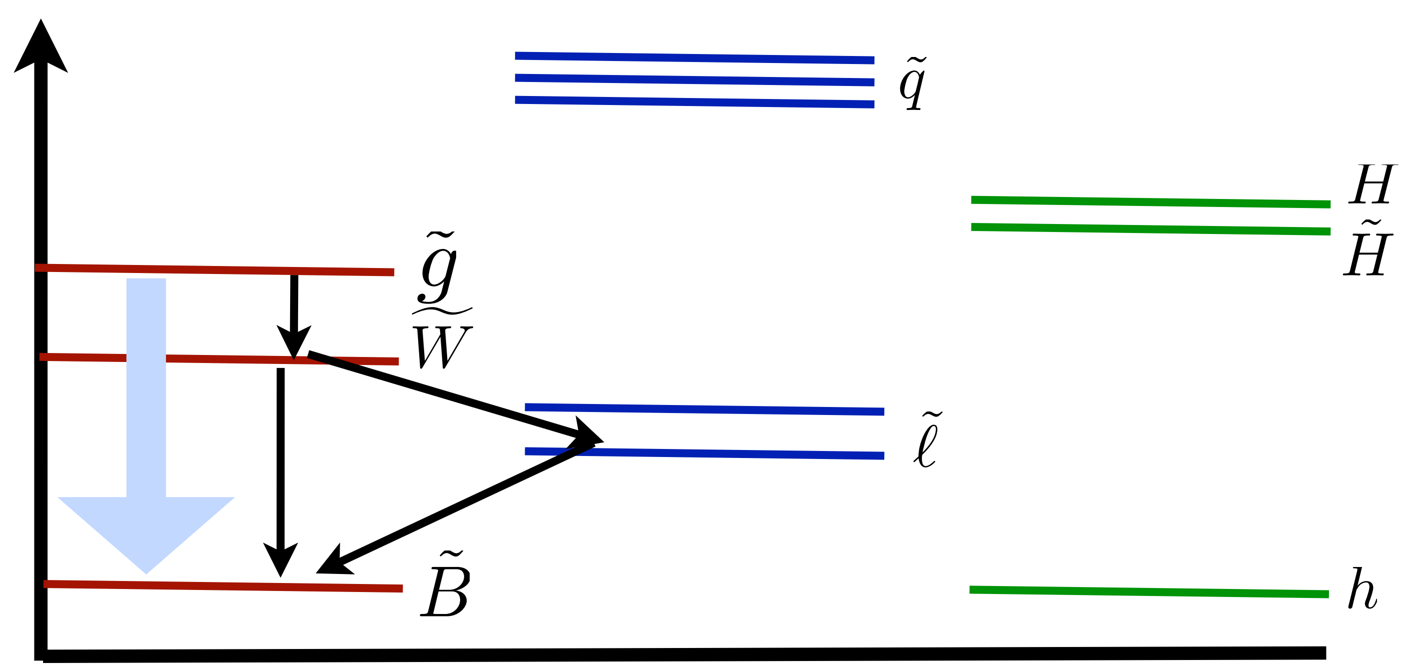


$\mathrm{Br} = 100\%$

Other times this is a subdominant branching ratio



$\mathrm{Br} \sim 10\%$

New Spectra to Consider

Imagine having a 300 GeV Gluino

mSUGRA would predict LSP is 50 GeV

4 jets of 90 GeV
130 GeV of Missing Energy

Hard to miss

LSP could have mass of 270 GeV

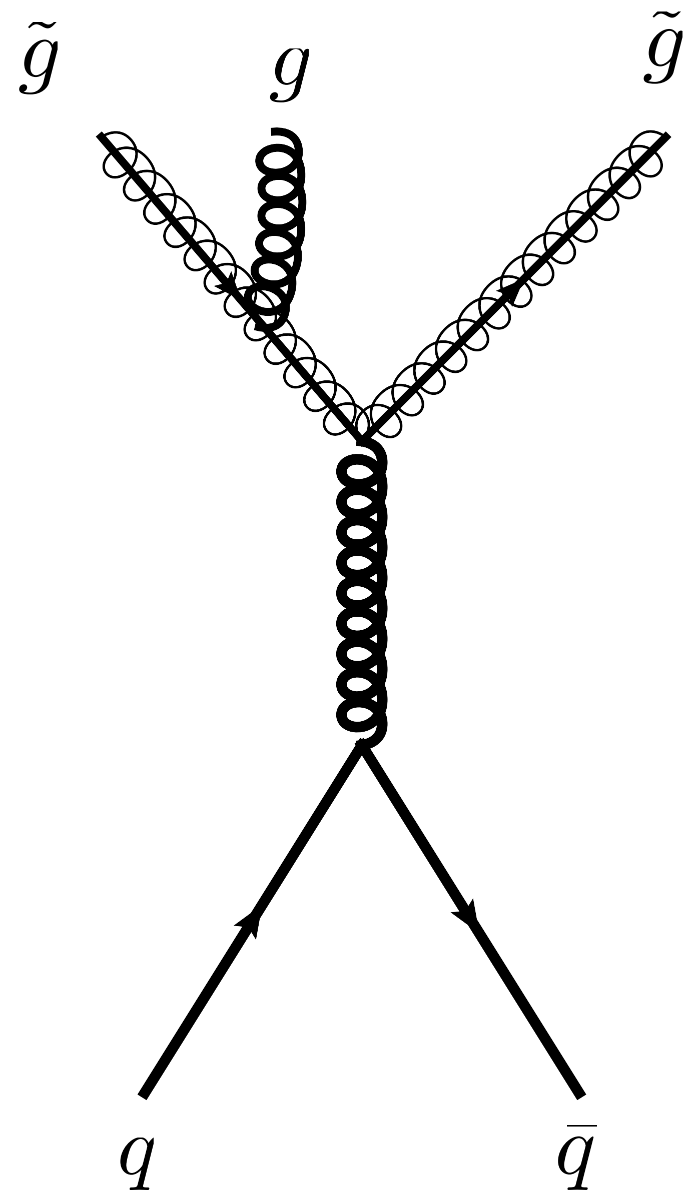
4 jets of 8 GeV
15 GeV of Missing Energy

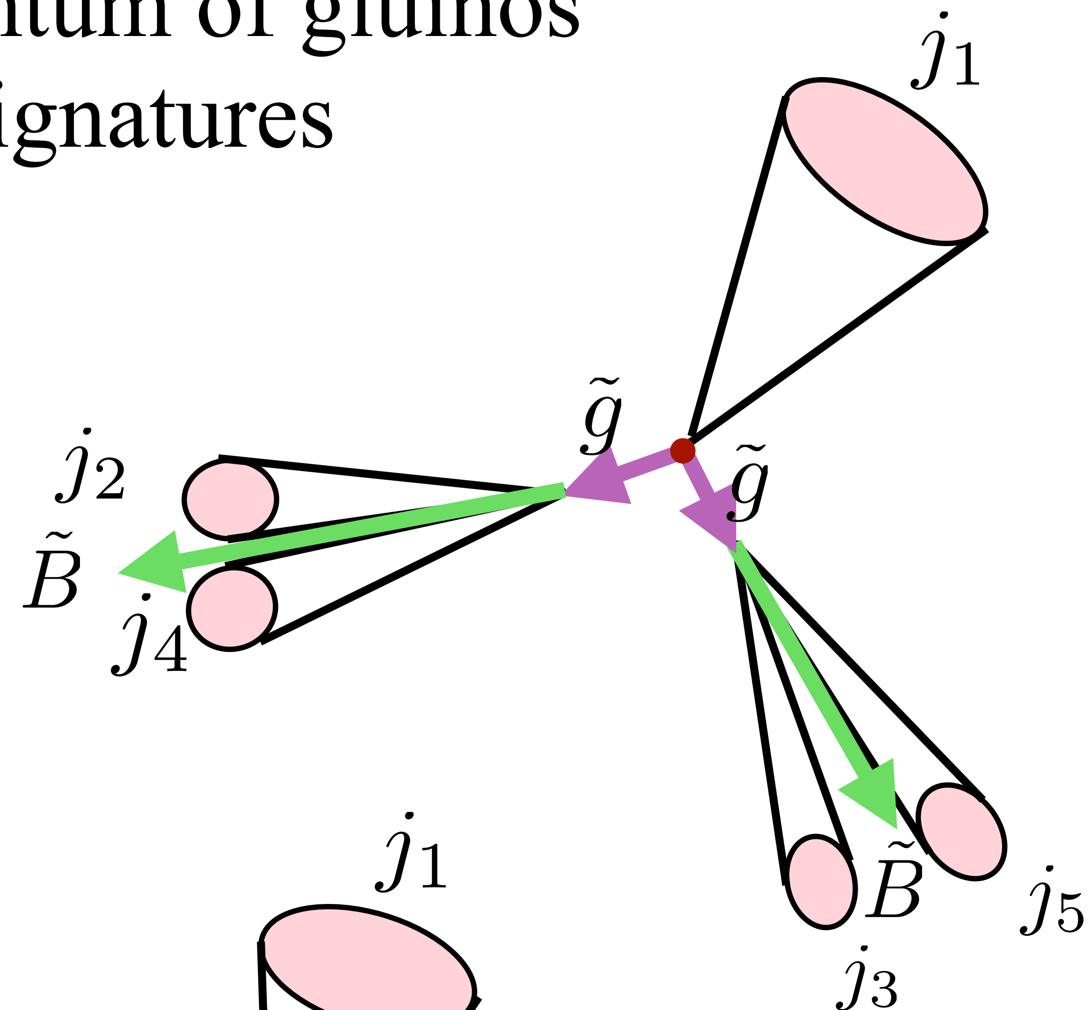
Nearly impossible to see!

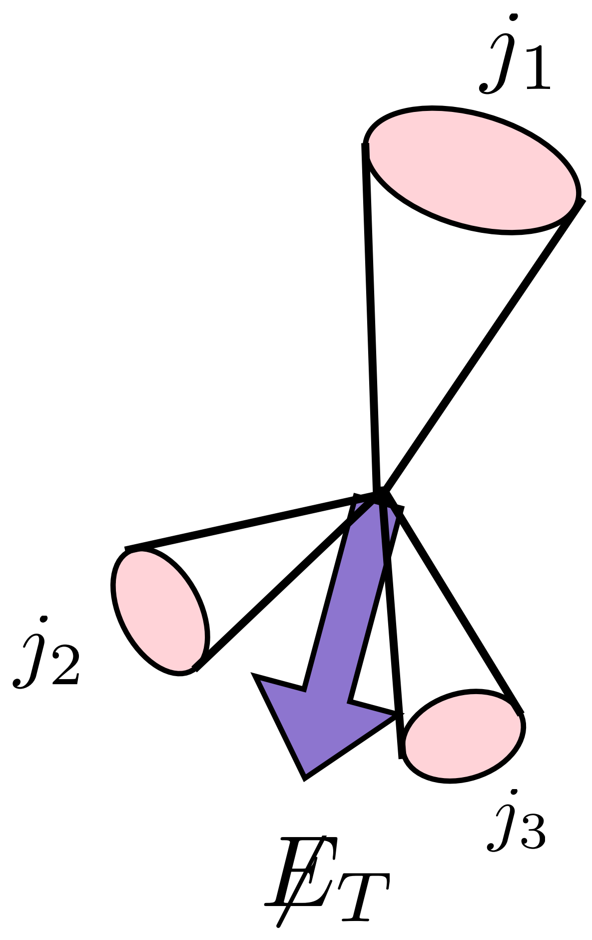
Radiate off additional jet

Unbalances momentum of gluinos

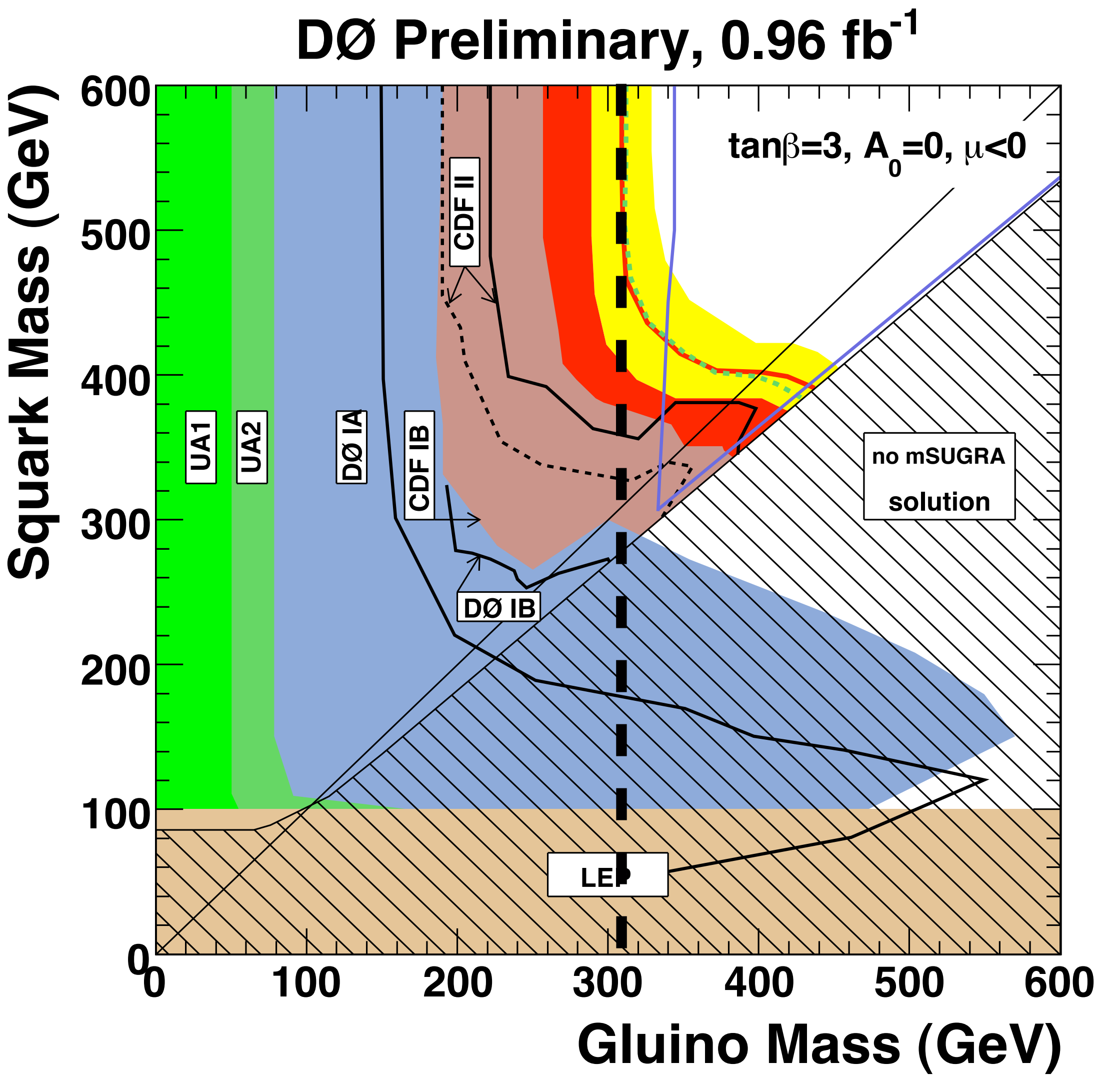
Monojet signatures

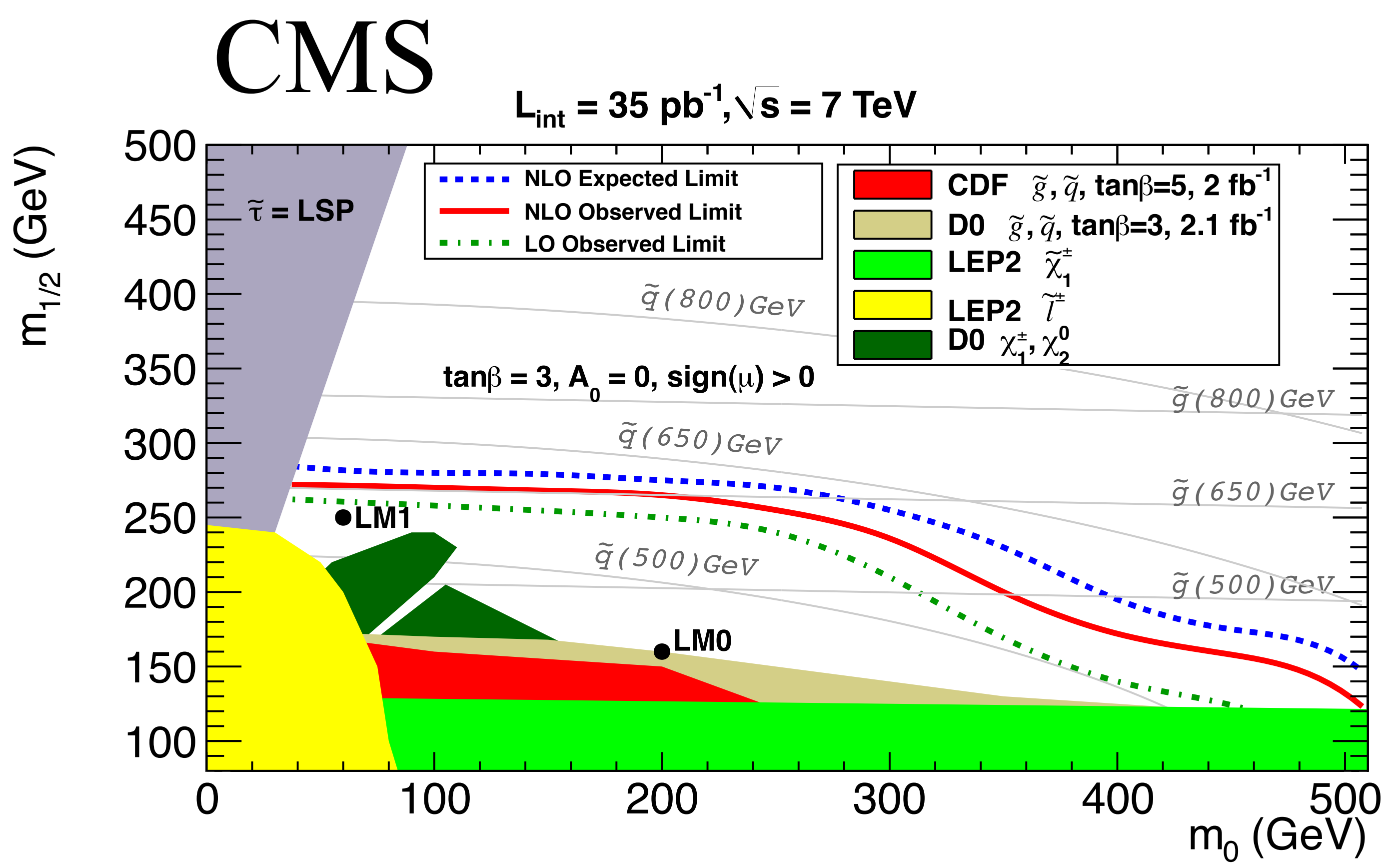






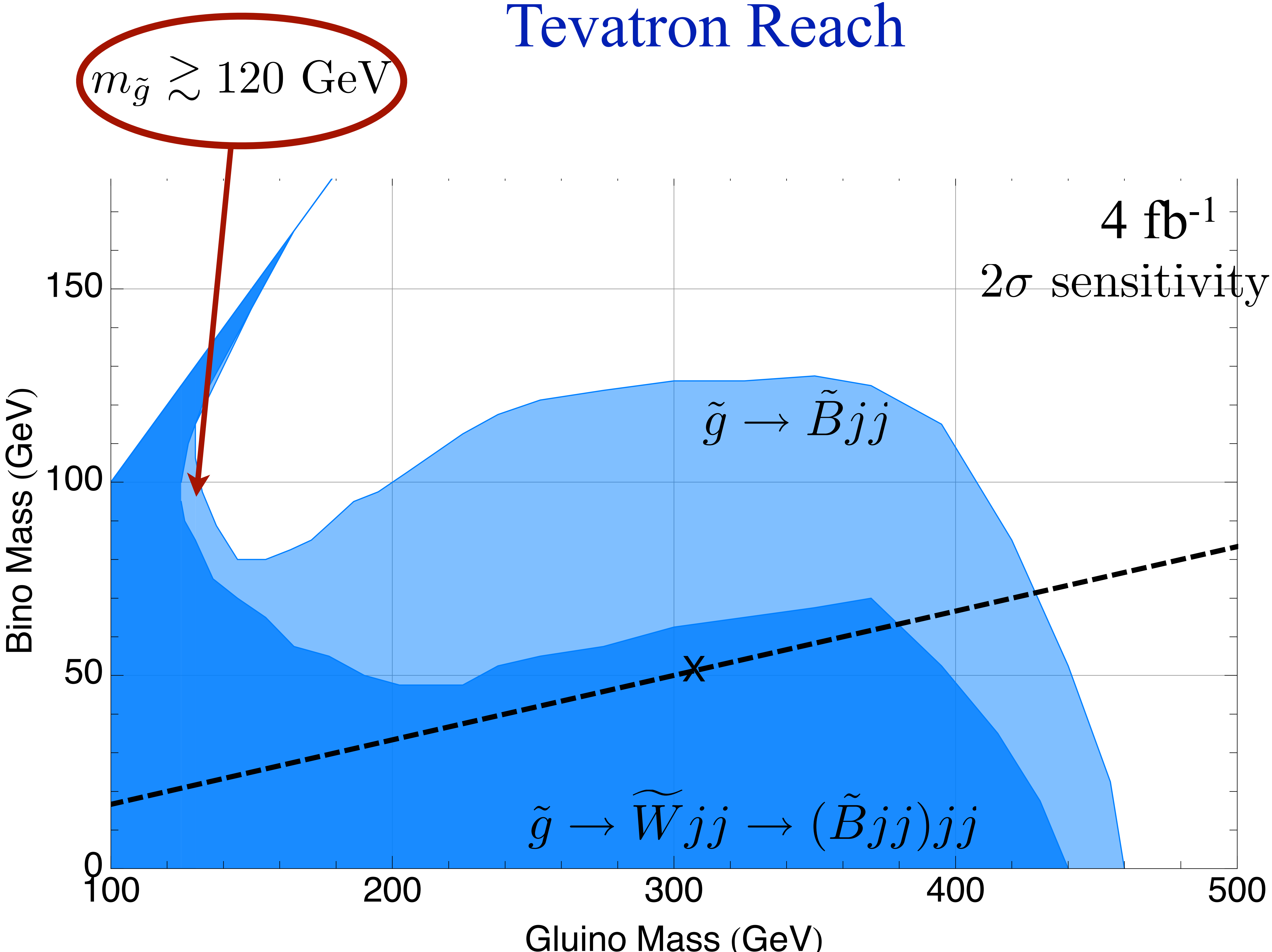
What are the current limits?





Hard to interpret more generally

Tevatron Reach

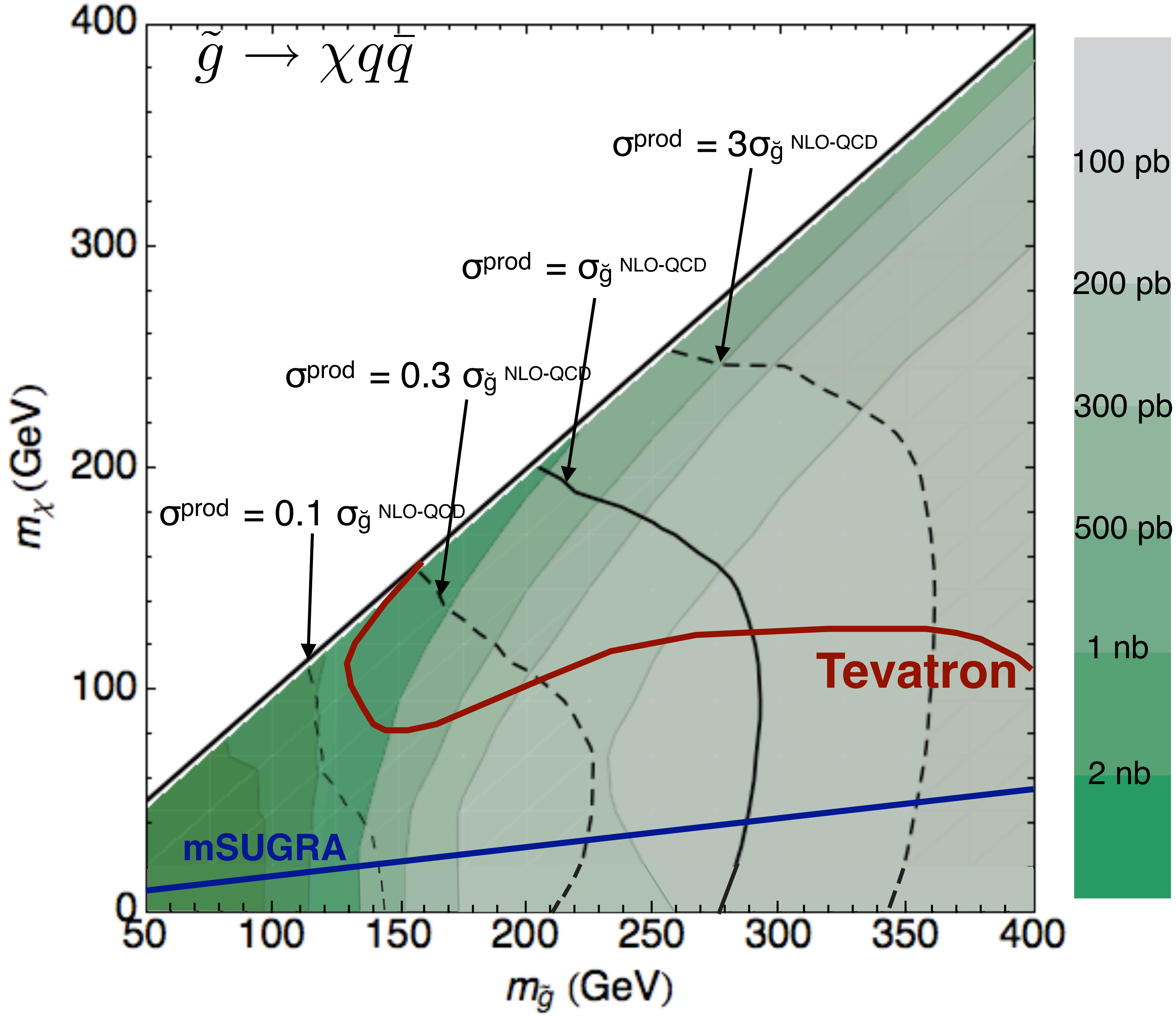


Alwall, Le, Lisanti, JW

The ATLAS with 70 nb^{-1}

There could have been discoveries

$$m_{\tilde{g}} \qquad m_{\chi^0} \qquad \sigma(pp \to \tilde{g}\tilde{g}X)$$



Alves, Izaguirre, JW

Going Forward into 2011

Want to ensure coverage isn’t an accident

4 Simplified Models:

2 Body Direct Decay

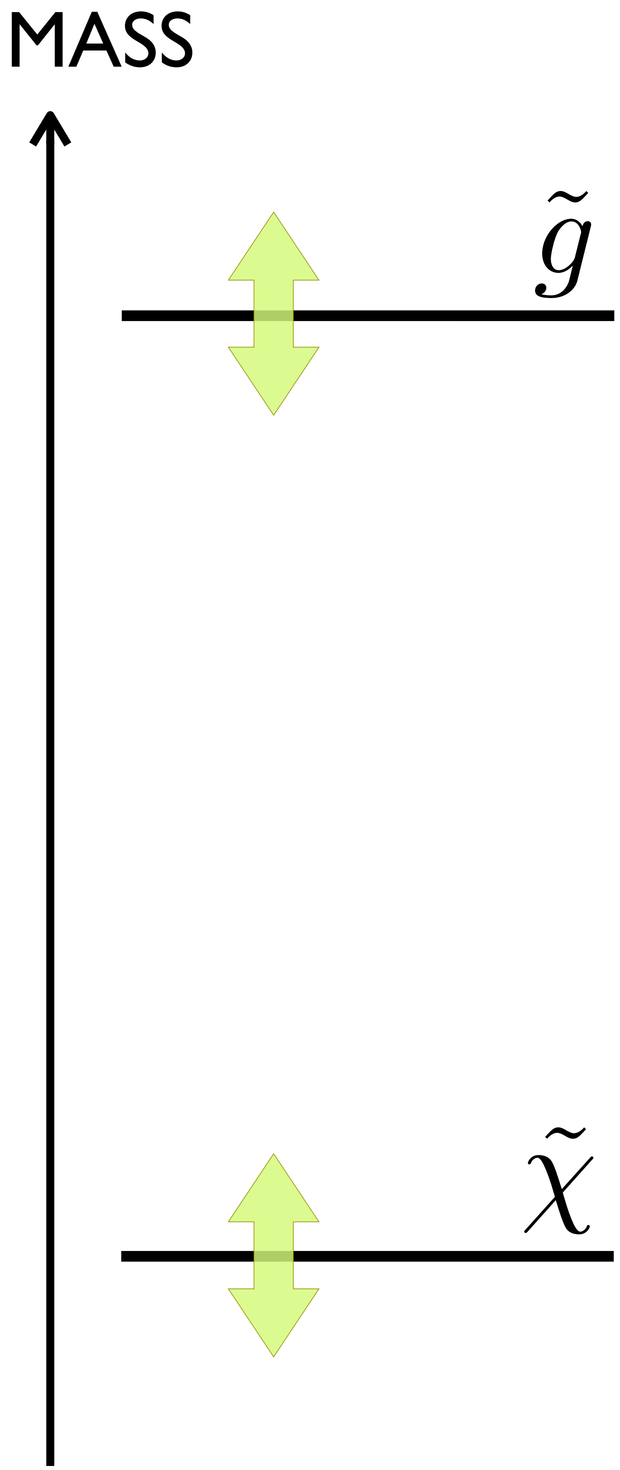
3 Body Direct Decay

1 Step Cascade Decay

2 Step Cascade Decay

Simplified Models

Direct Decays



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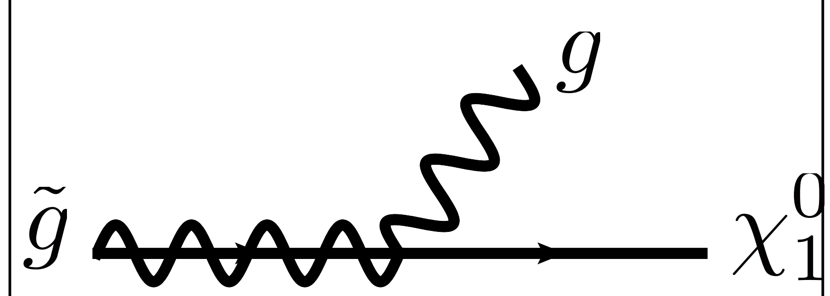
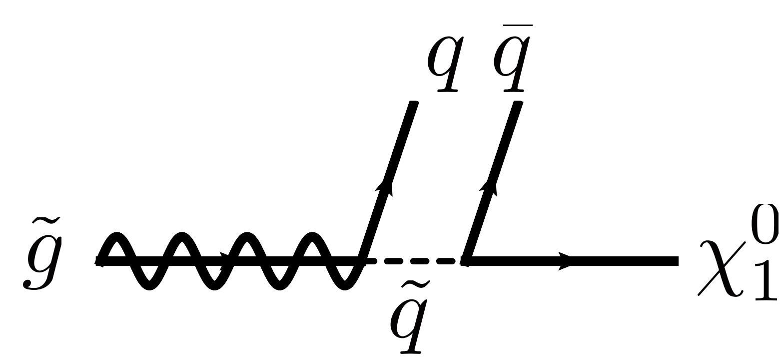
TWO-BODY

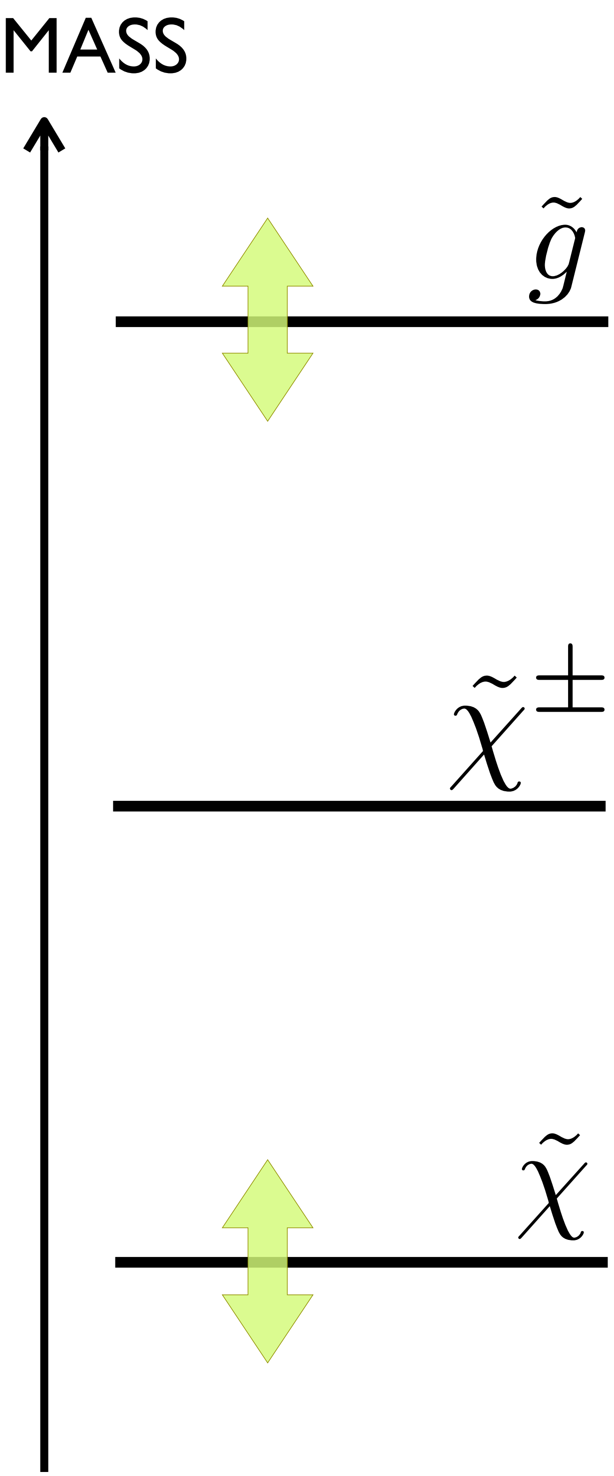


THREE-BODY



Simplified Models

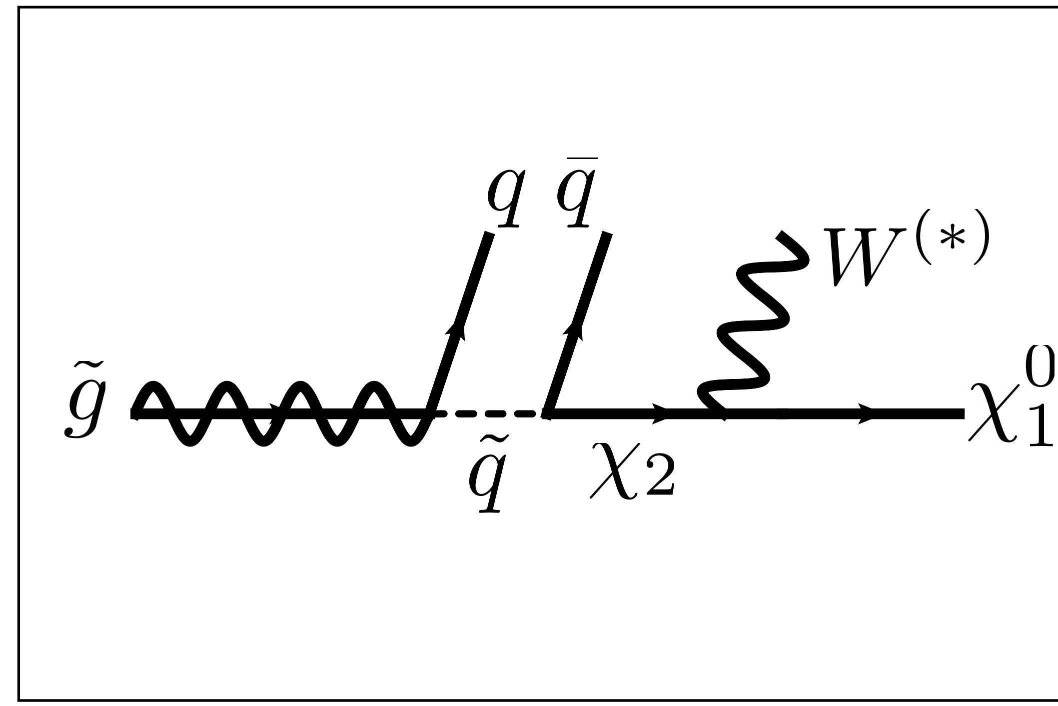
One-Step Cascade Decays



color octet majorana fermion ("Gluino")

electroweak majorana fermion ("Wino")

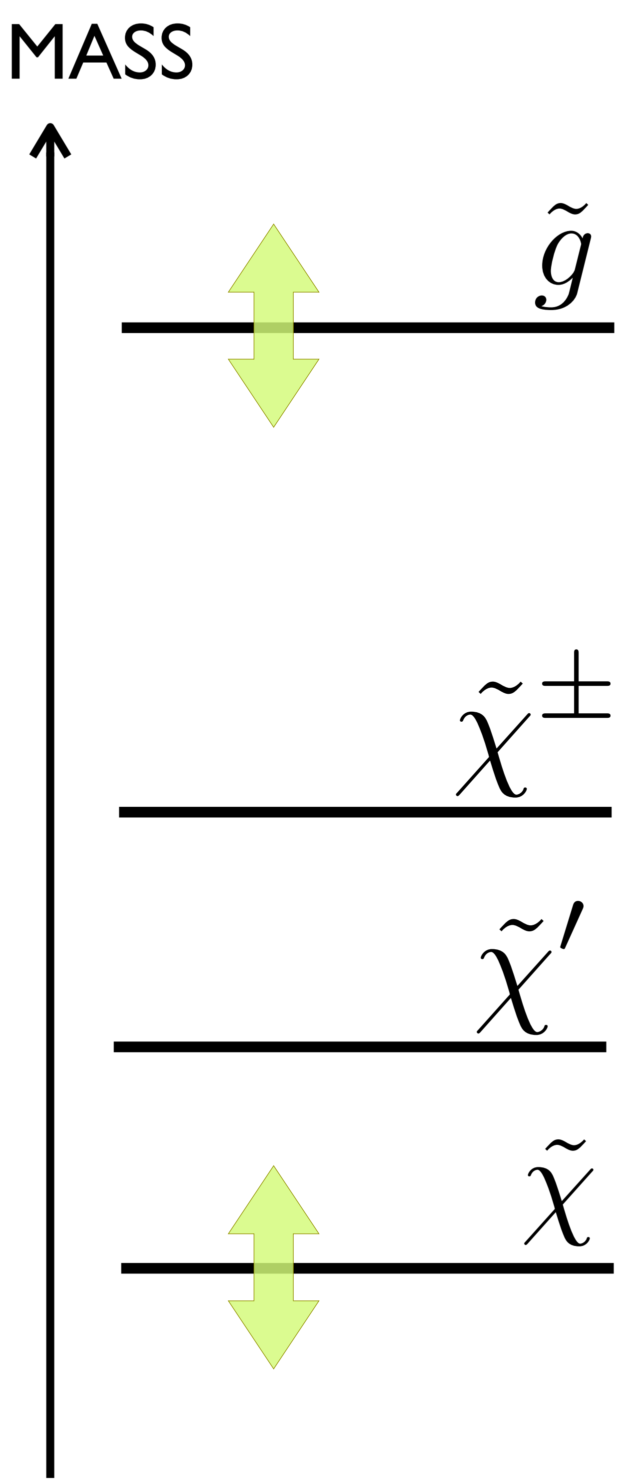
neutral majorana fermion ("LSP")



$$m_{\tilde{\chi}^{\pm}} = m_{\tilde{\chi}} + \frac{3}{4}\left(m_{\tilde{g}} - m_{\tilde{\chi}}\right)$$

Simplified Models

Two-Step Cascade Decays

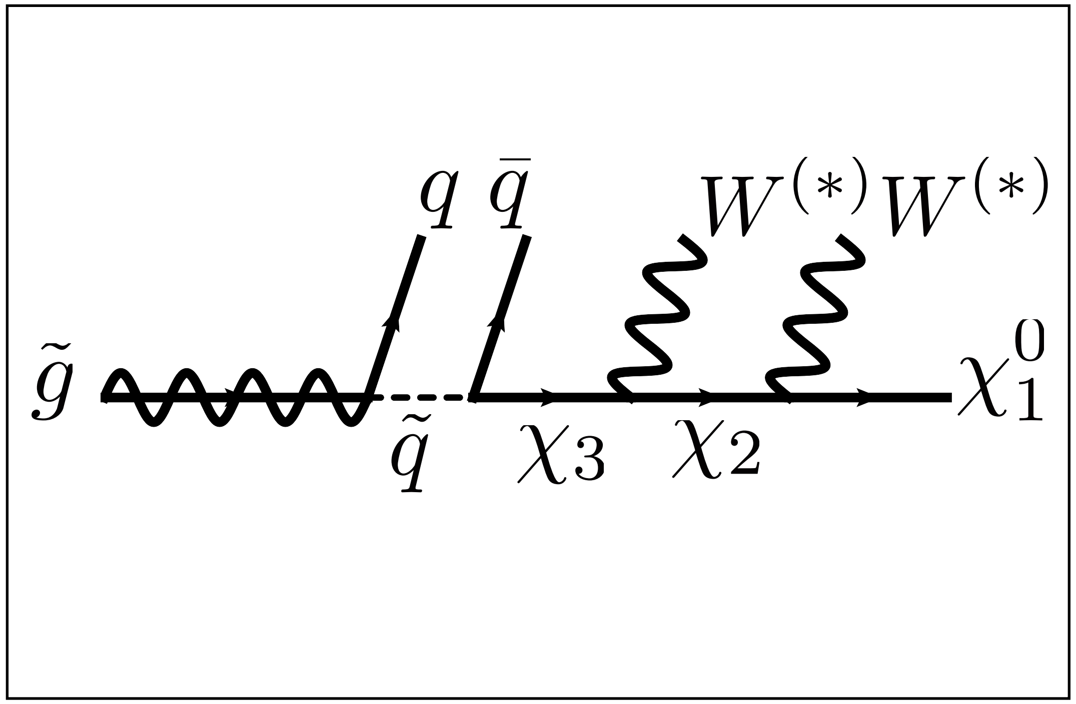


$\tilde{g}$ color octet majorana fermion ("Gluino")

$\tilde{\chi}^{\pm}$ electroweak majorana fermion ("Wino")

$\tilde{\chi}'$ neutral majorana fermion ("Bino")

$\tilde{\chi}$ neutral majorana fermion ("Singlino")



$$m_{\tilde{\chi}^{\pm}} = m_{\tilde{\chi}} + \frac{1}{2}(m_{\tilde{g}} - m_{\tilde{\chi}})$$

$$m_{\tilde{\chi}'} = m_{\tilde{\chi}} + \frac{1}{2}(m_{\tilde{\chi}^{\pm}} - m_{\tilde{\chi}})$$

Multiple Search Regions

- find minimal set of *search regions* whose combined reach has universal coverage

  for all masses and decay modes

  for three luminosity scenarios: $10\ \mathrm{pb}^{-1}$, $100\ \mathrm{pb}^{-1}$, $1\ \mathrm{fb}^{-1}$

- Number of search regions depends on desired "Efficacy"

$$\mathcal{E}(\mathcal{M},\mathcal{S}) = \frac{\sigma_{\mathrm{lim}}(\mathcal{M},\mathcal{S})}{\sigma_{\mathrm{lim}}^{\mathrm{best}}(\mathcal{M})} \geq 1$$

$\mathcal{M} =$ Model

$\mathcal{S} =$ Search Region

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$$\mathcal{E}(\mathcal{M},\mathcal{S}) = \frac{\sigma_{\rm lim}(\mathcal{M},\mathcal{S})}{\sigma_{\rm lim}^{\rm best}(\mathcal{M})} \geq 1 \qquad \begin{array}{l} \mathcal{M} = \text{ Model} \\ \mathcal{S} = \text{ Search Region} \end{array}$$

if $\mathcal{E} > \mathcal{E}_{\rm crit}$ for all $\mathcal{M}$

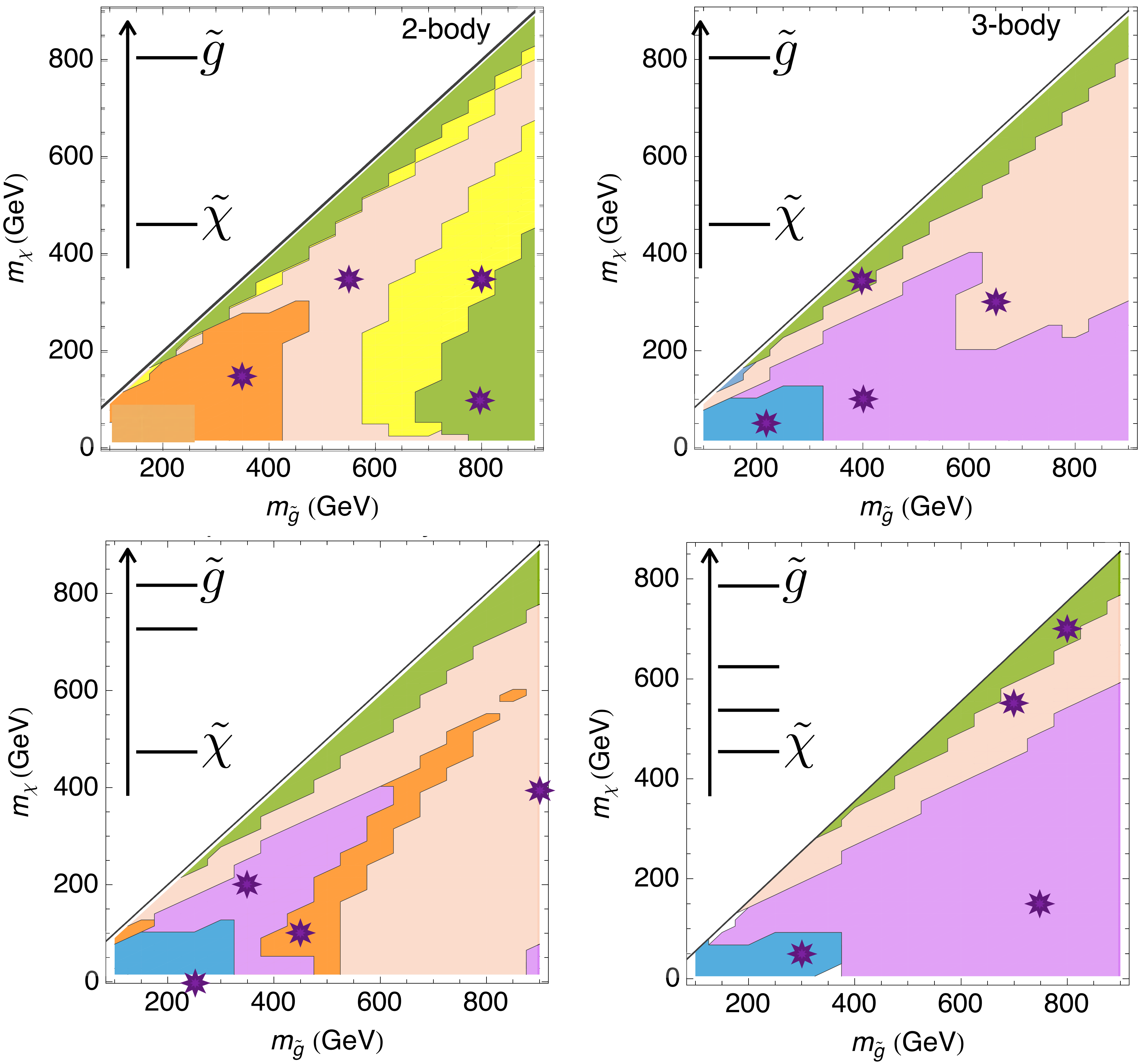
- 1.05 $\longrightarrow$ $\mathcal{O}$(30 search regions)
- 1.10 $\longrightarrow$ $\mathcal{O}$(16 search regions)
- 1.30 $\longrightarrow$ $\mathcal{O}$(6 search regions)
- 1.50 $\longrightarrow$ $\mathcal{O}$(4 search regions)

Multiple Search Regions

- 6 search regions necessary:

Dijet high MET	$\not{E}_T > 500$ GeV, $H_T > 750$ GeV
Trijet high MET	$\not{E}_T > 450$ GeV, $H_T > 500$ GeV
Multijet low MET	$\not{E}_T > 100$ GeV, $H_T > 450$ GeV
Multijet very high H_T	$\not{E}_T > 150$ GeV, $H_T > 950$ GeV
Multijet moderate MET	$\not{E}_T > 250$ GeV, $H_T > 300$ GeV
Multijet high MET	$\not{E}_T > 350$ GeV, $H_T > 600$ GeV

Multiple Search Regions



cut	ch	MET	H_T
	2^+j	500	750
	3^+j	450	500
	4^+j	100	450
	4^+j	150	950
	4^+j	250	300
	4^+j	350	600

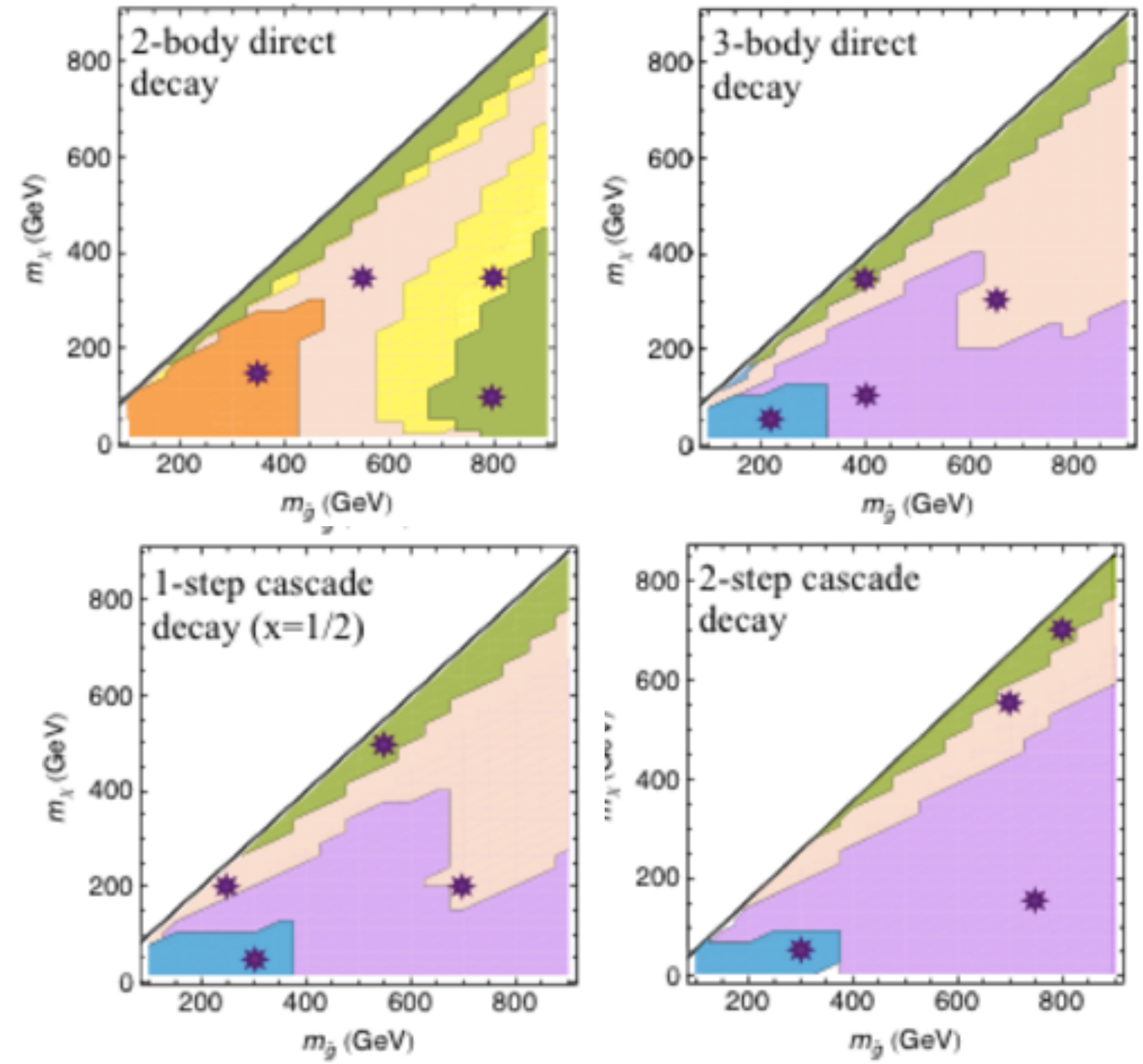
Designing Optimal Regions

- Choice of multiple search regions depends upon
  - backgrounds
  - detector efficiencies & acceptances
  - how good is good enough
  - etc

- Not something a theorist should be designing too closely

- Scans are expensive for experiments, providing benchmark theories saves effort

- We've done rough exploration of corners of parameter space looking for



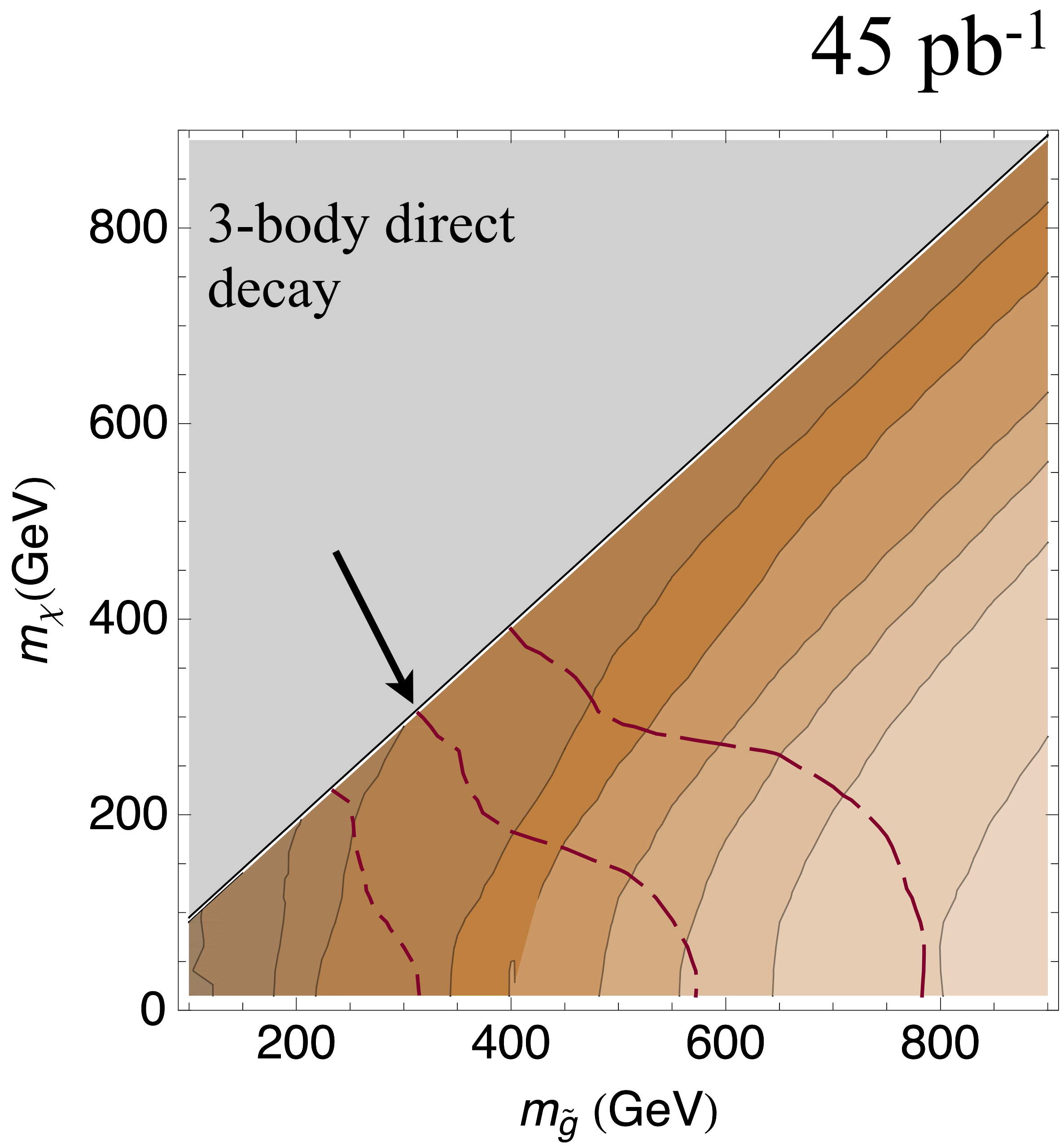
List of Benchmark Models

- Chosen to maximize differences in how they appear in given searches
- Simple and easy to define
- Consistent theories on their own

Name	$m_{\tilde{g}}$ (GeV)	$m_{\tilde{\chi}^0}$ (GeV)	Decay
$\mathcal{M}_1$	800	100	direct 2-body
$\mathcal{M}_2$	800	350	direct 2-body
$\mathcal{M}_3$	550	300	direct 2-body
$\mathcal{M}_4$	350	150	direct 2-body
$\mathcal{M}_5$	250	50	direct 3-body
$\mathcal{M}_6$	400	100	direct 3-body
$\mathcal{M}_7$	400	350	direct 3-body
$\mathcal{M}_8$	650	300	direct 3-body
$\mathcal{M}_9$	150	50	1-step cascade (x=1/4)
$\mathcal{M}_{10}$	400	80	1-step cascade (x=1/4)
$\mathcal{M}_{11}$	450	350	1-step cascade (x=1/4)
$\mathcal{M}_{12}$	600	200	1-step cascade (x=1/4)
$\mathcal{M}_{13}$	250	200	1-step cascade (x=1/2)
$\mathcal{M}_{14}$	300	50	1-step cascade (x=1/2)
$\mathcal{M}_{15}$	550	500	1-step cascade (x=1/2)
$\mathcal{M}_{16}$	700	200	1-step cascade (x=1/2)
$\mathcal{M}_{17}$	250	0	1-step cascade (x=3/4)
$\mathcal{M}_{18}$	350	200	1-step cascade (x=3/4)
$\mathcal{M}_{19}$	450	100	1-step cascade (x=3/4)
$\mathcal{M}_{20}$	900	400	1-step cascade (x=3/4)
$\mathcal{M}_{21}$	300	50	2-step cascade
$\mathcal{M}_{22}$	750	150	2-step cascade
$\mathcal{M}_{23}$	750	550	2-step cascade
$\mathcal{M}_{24}$	800	750	2-step cascade

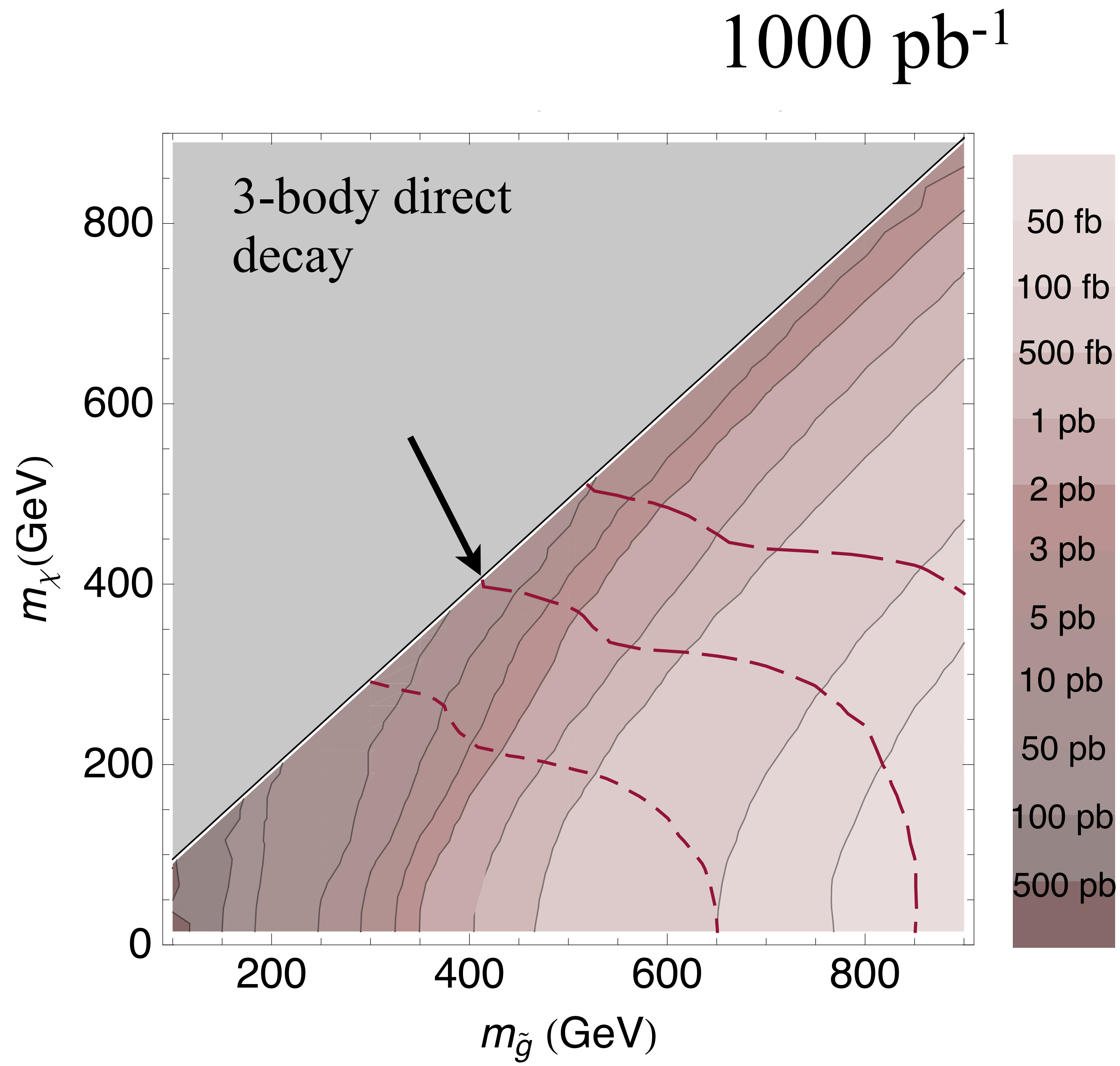
$$m_{\chi^\pm} = m_{\chi^0} + x(m_{\tilde{g}} - m_{\chi^0})$$

Expectations for Full 2010 & 2011 Data Sets



Full Coverage up to 300 GeV

Reach up to 600 GeV



Full Coverage up to 375 GeV

Reach up to 850 GeV

Alves, Izaguirre, JW

Future Work

Need to Expand Simplified Model Catalogue

On June 4-5, 2010 ATLAS & CMS called
for more models to be searched

Workshop on Topologies for Early LHC Searches

September 22 - 25, 2010 at SLAC

Over 100 Participants

Developed 50 Simplified Models

Leptons

S. Chang
W. Cho
J. Evans
E. Izaguirre
J. Kaplan
M. Lisanti
M. Luty
M. Nojiri
T. Okui
M. Park
M. Perelstein
J. Ruderman
V. Sanz
P. Schuster
D. Shih
S. Su
T. Tait
B. Thomas
N. Toro
J. Wacker
F. Yu

Hadrons

D. Alves
J. Gainer
M. Gomez
E. Izaguirre
C. Kilic
M. Nojiri
D. Krohn
M. Schwartz
J. Shelton
M. Spannowsky
M.Strassler
J. Wacker

Resonances

Y. Bai
H. Cheng
J. Evans
A. Freitas
T. Han
J. Hewett
T. Liu
V. Rentala
S. Su
T. Tait

Photons

P. Fox
R. Kitano
T. Okui
D. Shih
T. Roy
J. Ruderman

Exotics

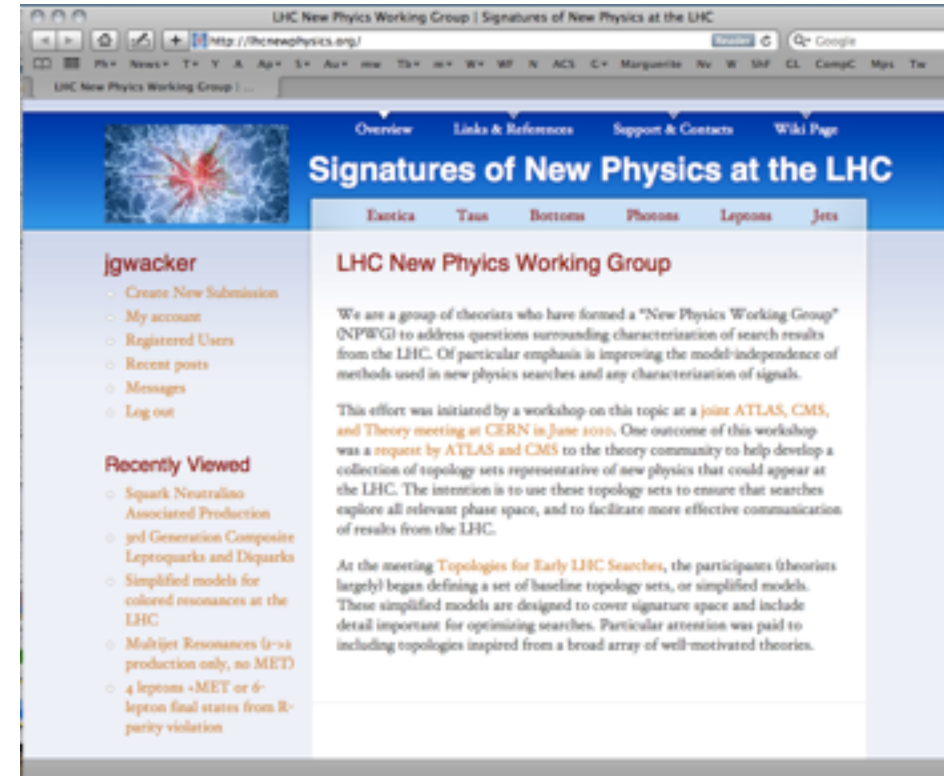
S. Chang
M. Baumgart
R. Essig
J. Hubisz
D. Krohn
P. Meade
D. Morrissey
M. Papucci
D. Phalen
J. Shao
T. Volansky
I. Yavin
K. Zurek

Heavy Flavor

M. Buckley
R.S. Chivukula
L. Fitzpatrick
R. Francescini
P. Fox
J. Kaplan
P. Ko
E. Kuflik
R. Lu
S. Mrenna
M. Peskin
K. Rehermann
M. Schmaltz
M. Schwartz
E. Simmons
C. Spethmann
M. Strassler
T. Tait
N. Toro
W. Waltenberger

Follow-up to the Workshop

http://LHCNewPhysics.org



Now approaching a fully featured website with supplemental information:

Definitions of Models, Model files,
LHE Files, Presentations,
Refereeing, Discussions

ATLAS & CMS are beginning to use in preliminary proposals for upcoming analyses

ATLAS studying 10 Simplified Models from 0 in August

Changing their triggers