MARMOSET:

The Path from LHC Data to the New Standard Model via On-Shell Effective Theories

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with Philip Schuster, Jesse Thaler, Natalia Toro,
Lian-Tao Wang, Bruce Knuteson, Steve Mrenna.

$$\begin{matrix}\text{LHC} \\ \text{Data}\end{matrix} \Rightarrow \mathcal{L}\,?$$

Collective Hadron Collider Discovery Experience

$$W/Z$$

No undetermined parameters

$$t$$

One unknown parameter (m_t)

In both cases, knew **exactly** what to look for...

The LHC is so exciting precisely because the answer to the question — what will we see? — has never been more uncertain!

The questions about new physics that must be answered first are therefore big-picture, structural ones:

What kinds of particles are produced with what rates?

What pattern of decays do they exhibit?

Only with this information can we tackle the fundamental questions:

What new physical principles are being revealed at the TeV scale?

Is nature supersymmetric?

Is the electroweak scale natural?

Natural Theories $\Rightarrow$ Rich Phenomenology

New Colored Particles < 2 TeV $\Rightarrow$ 10^3 – 10^6 produced at 5 fb^{-1}

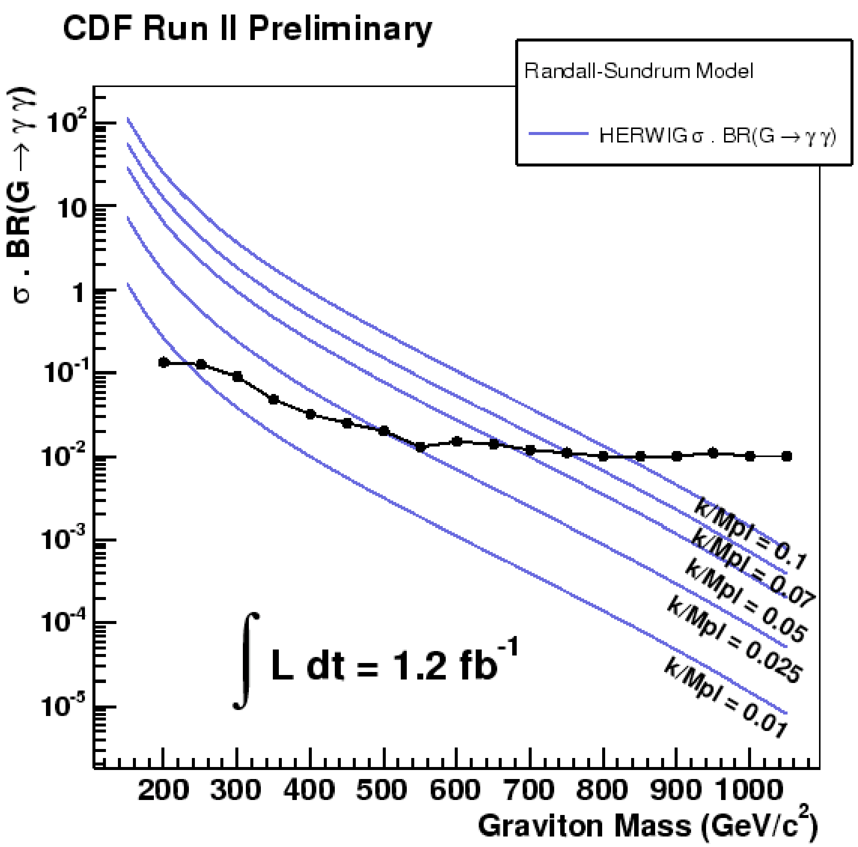
What is the New Physics?

What Information Should We Extract from LHC Data?

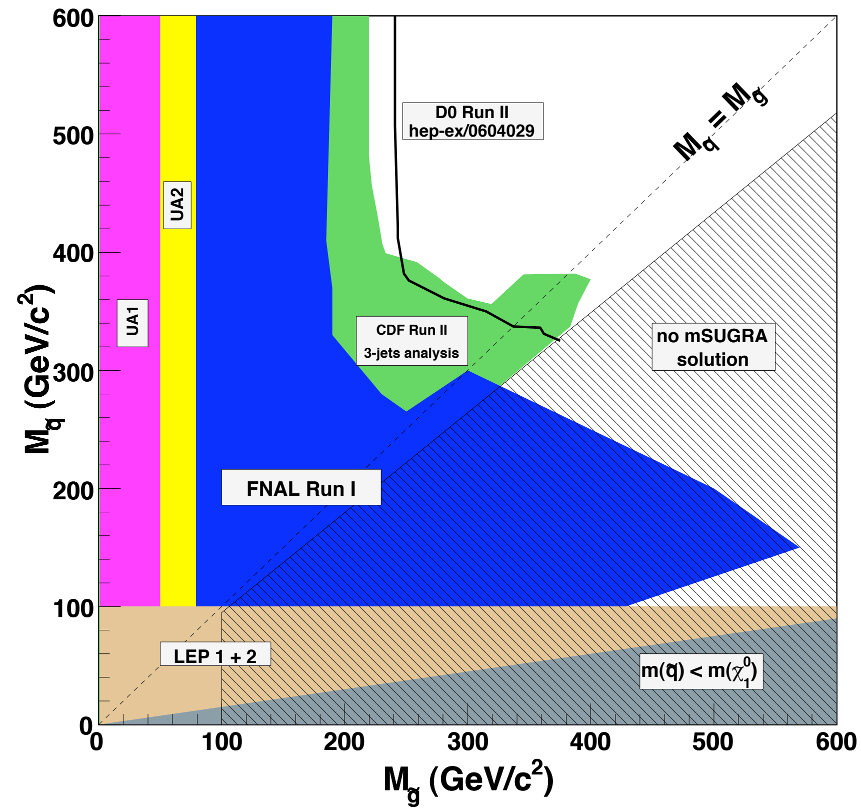
Only a few dynamical variables control the essential phenomenology of new physics at hadron colliders.

Characterizing new physics directly in terms of these variables permits a simple, accurate parametrization of almost **any** model of new physics —

an On-Shell Effective Theory.



vs.



Meaningful

Useless

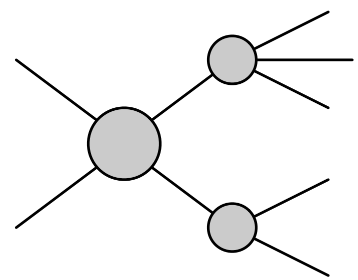
MARMOSET:

Callithrix jacchus

MARMOSET:

Mass And Rate Modeling in On-Shell Effective Theories

LHC Signatures $\Leftrightarrow$ OSET $\Leftrightarrow$ $\mathcal{L}$

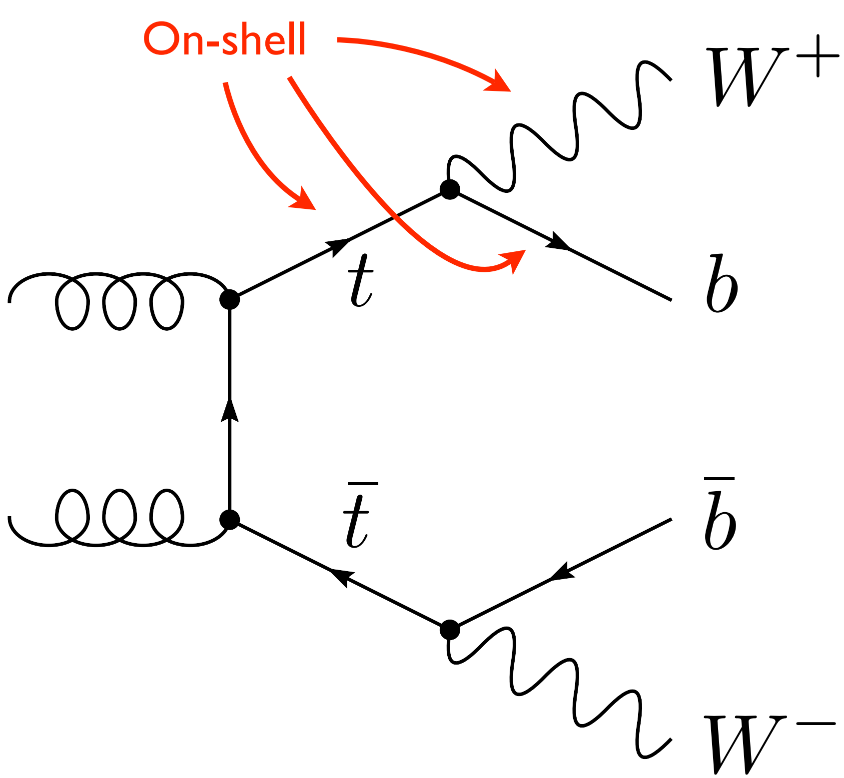


Masses, Cross Sections, Branchings Ratios

hep-ph/0703088 www.marmoset-mc.net

E.g.: Top Quark

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

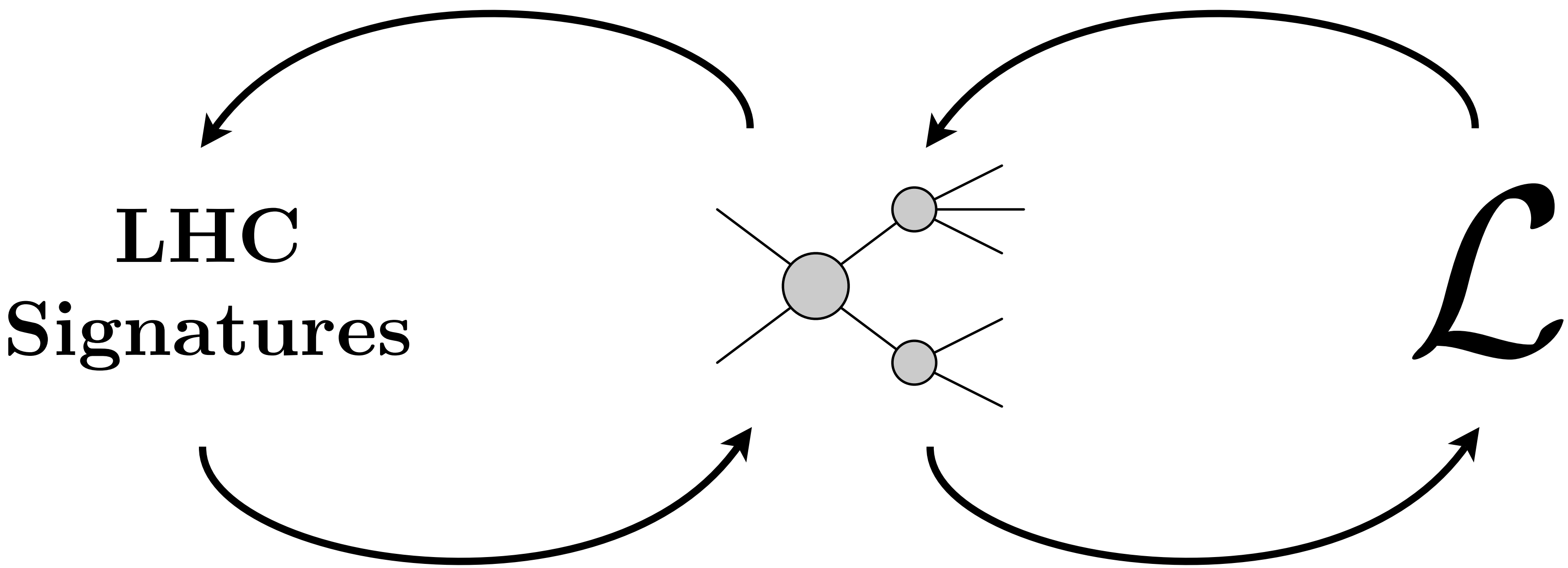
Detailed Top Properties:

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

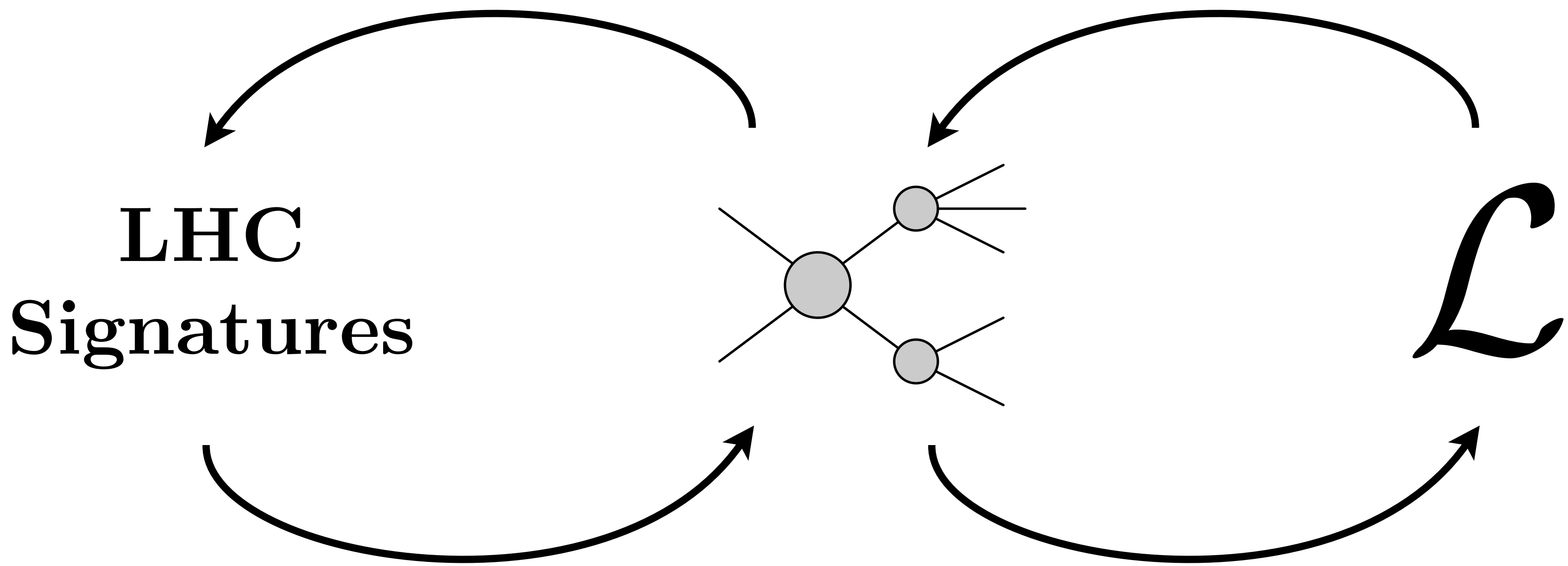
W helicity

t charge

OSET concisely describes many topologies with correlated rates

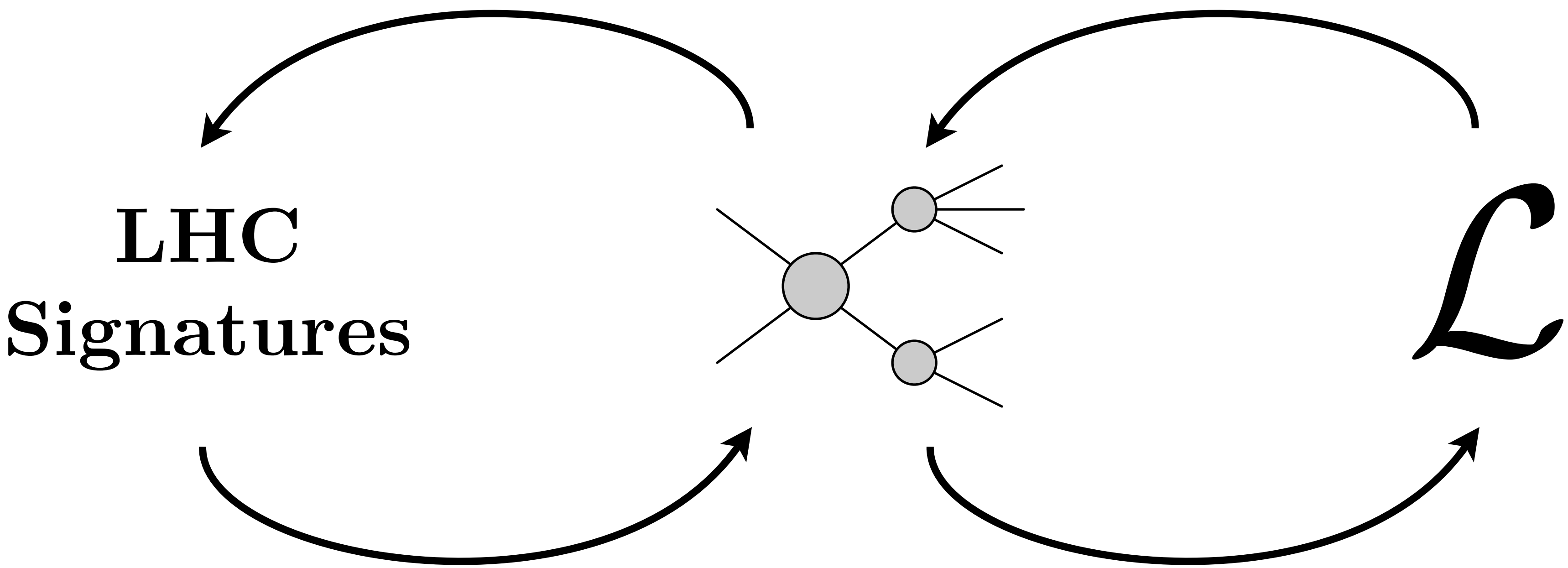


OSET concisely describes many topologies with correlated rates



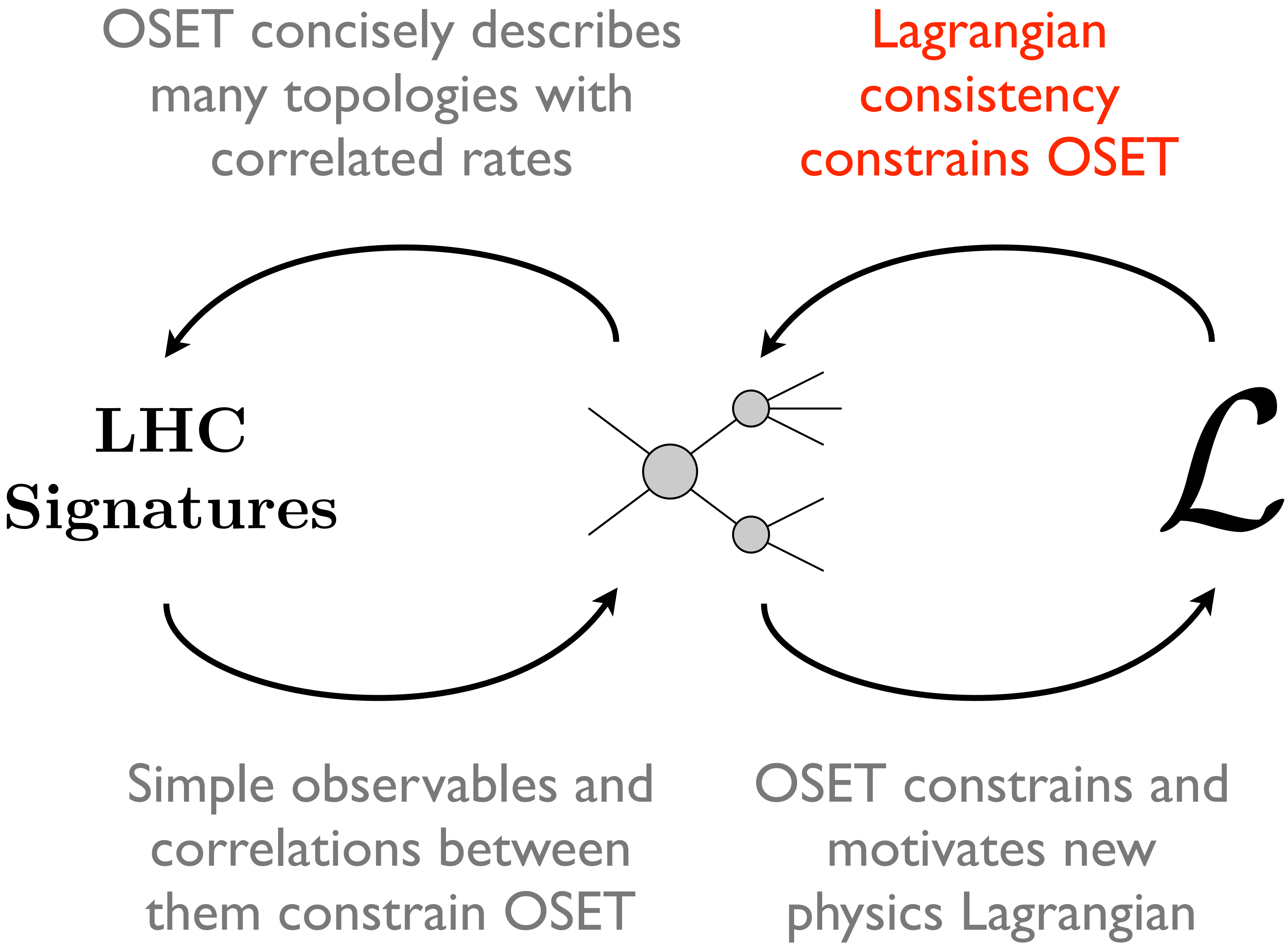
Simple observables and correlations between them constrain OSET

OSET concisely describes many topologies with correlated rates



Simple observables and correlations between them constrain OSET

OSET constrains and motivates new physics Lagrangian


OSET concisely describes many topologies with correlated rates
Lagrangian consistency constrains OSET
LHC Signatures
$\mathcal{L}$
Simple observables and correlations between them constrain OSET
OSET constrains and motivates new physics Lagrangian

MARMOSET @ Princeton

Nima	Path to the New Standard Model
Jesse	Physics of On-Shell Effective Theories
Philip (LHC Olympics)	MARMOSET in Practice (Cornell BB)
Natalia (MC4BSM)	An OSET Monte Carlo Tool
Johan (MC4BSM)	MadGraph and MARMOSET

hep-ph/0703088 @ arXiv.org

Sec. 1	Path to the New Standard Model
Sec. 2 (App. A, B, C)	Physics of On-Shell Effective Theories
Sec. 4	MARMOSET in Practice (Michigan BB)
Sec. 3	An OSET Monte Carlo Tool
...	MadGraph and MARMOSET

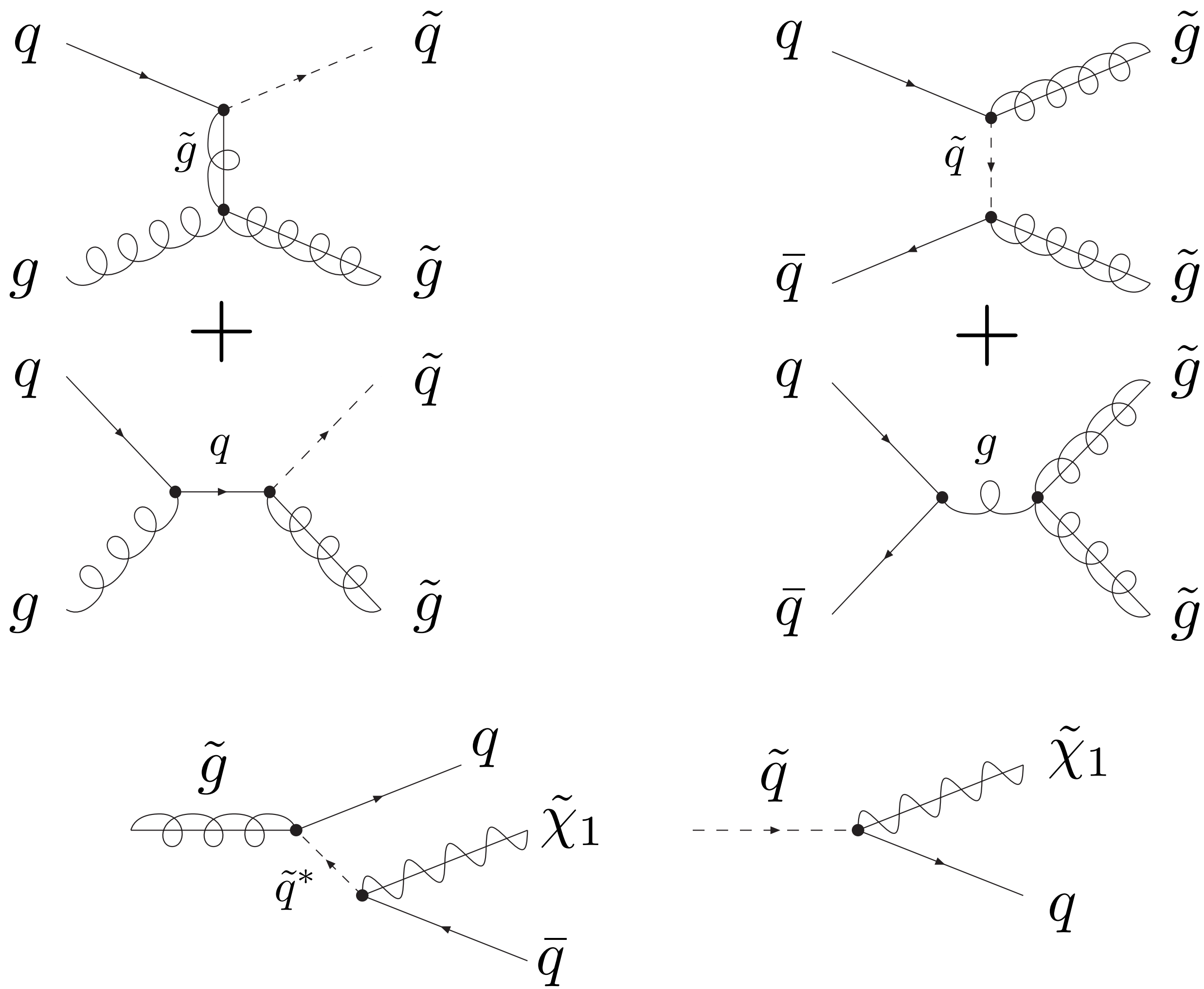
The Physics of MARMOSET

At hadron colliders, it is possible to parametrize production and decay of new particles with physical observables —

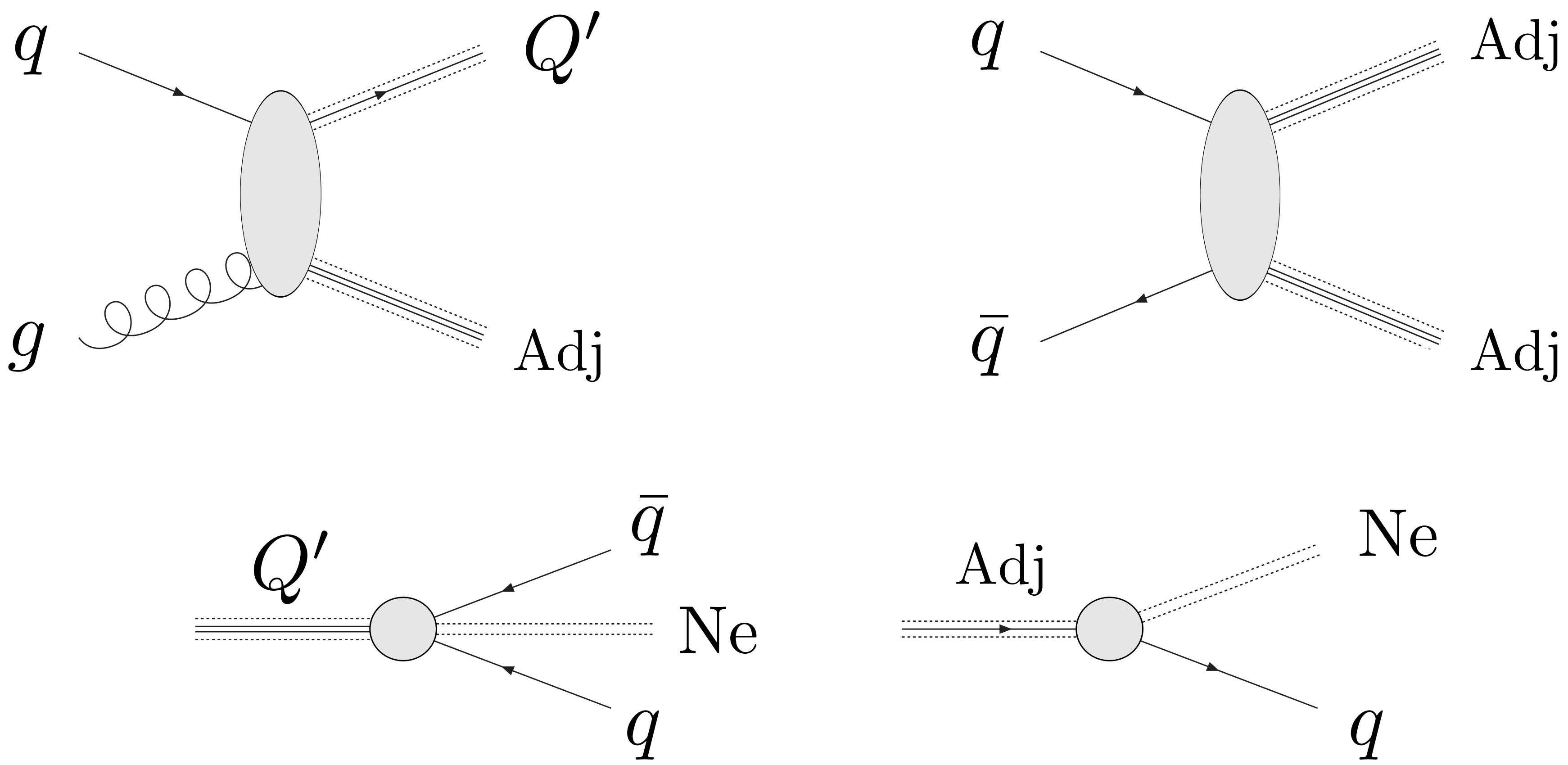
Masses, Cross Sections, and Branchings Ratios

are (almost) entirely sufficient to describe the dominant features of New Physics.

Quantum Amplitudes?



Simple Effective* Parametrization!



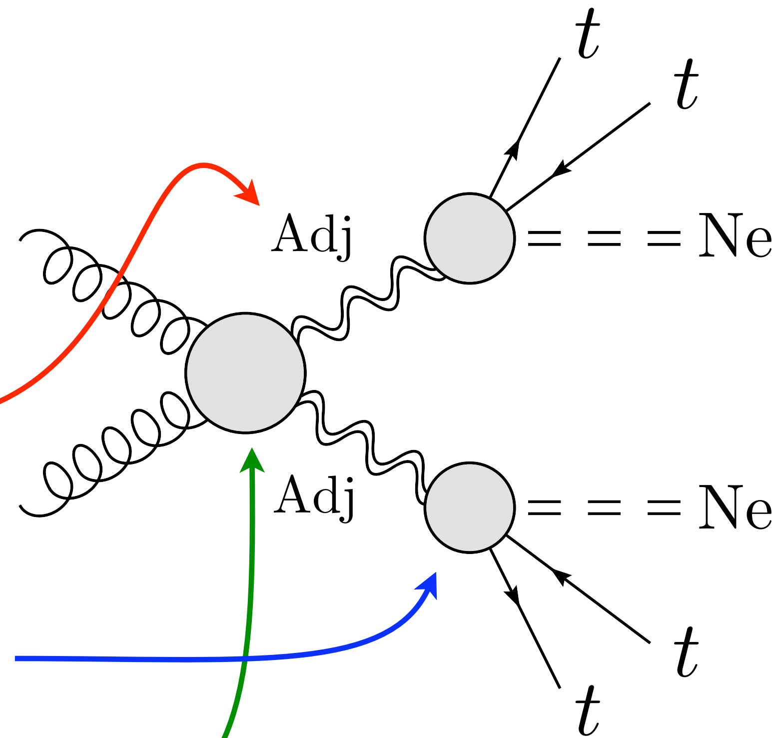
* ("Effective" in the "it works!" sense.)

MARMOSET:
A Monte Carlo Tool

for simulating the OSET of almost any model

MARMOSET Input

No Amplitudes Means Vast Simplification of MC Input!

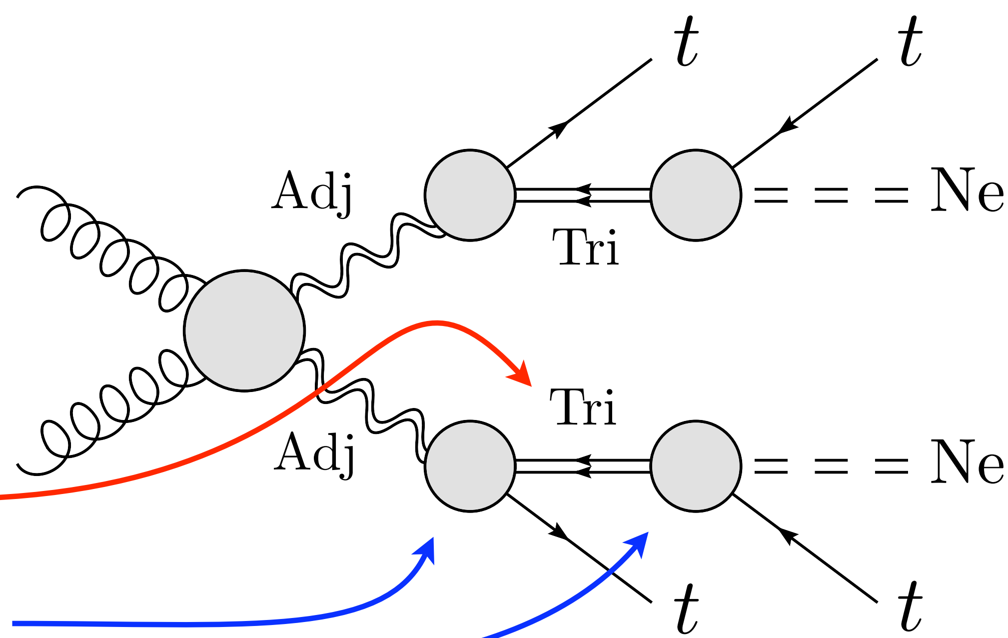



```
Adj        : m=700 EM=0 SU3=8
Ne         : m=200 EM=0 SU3=0

Adj > t tbar Ne   : matrix=const

g g > Adj Adj     : matrix=const

g g > ( Adj > t tbar Ne ) ( Adj > t tbar Ne )
```

(Cross Sections / Branching Ratios stored for later reweighting.)

MARMOSET Input

Easy to Extend/Modify Models. Reusable MC.




```
Adj       : m=700 EM=0 SU3=8
Ne        : m=200 EM=0 SU3=0
Tri Tri~  : m=500 EM=2 SU3=3

Adj > Tri tbar    : matrix=const
Tri > Ne  t       : matrix=const

g g > Adj Adj     : matrix=const
g g > Tri Tri~    : matrix=const

g g > ( Adj > ( Tri > Ne t ) tbar ) ( Adj > ( Tri~ > Ne tbar ) t )
```

(Monte Carlo generation with Pythia, output in StdHEP XDR format.)

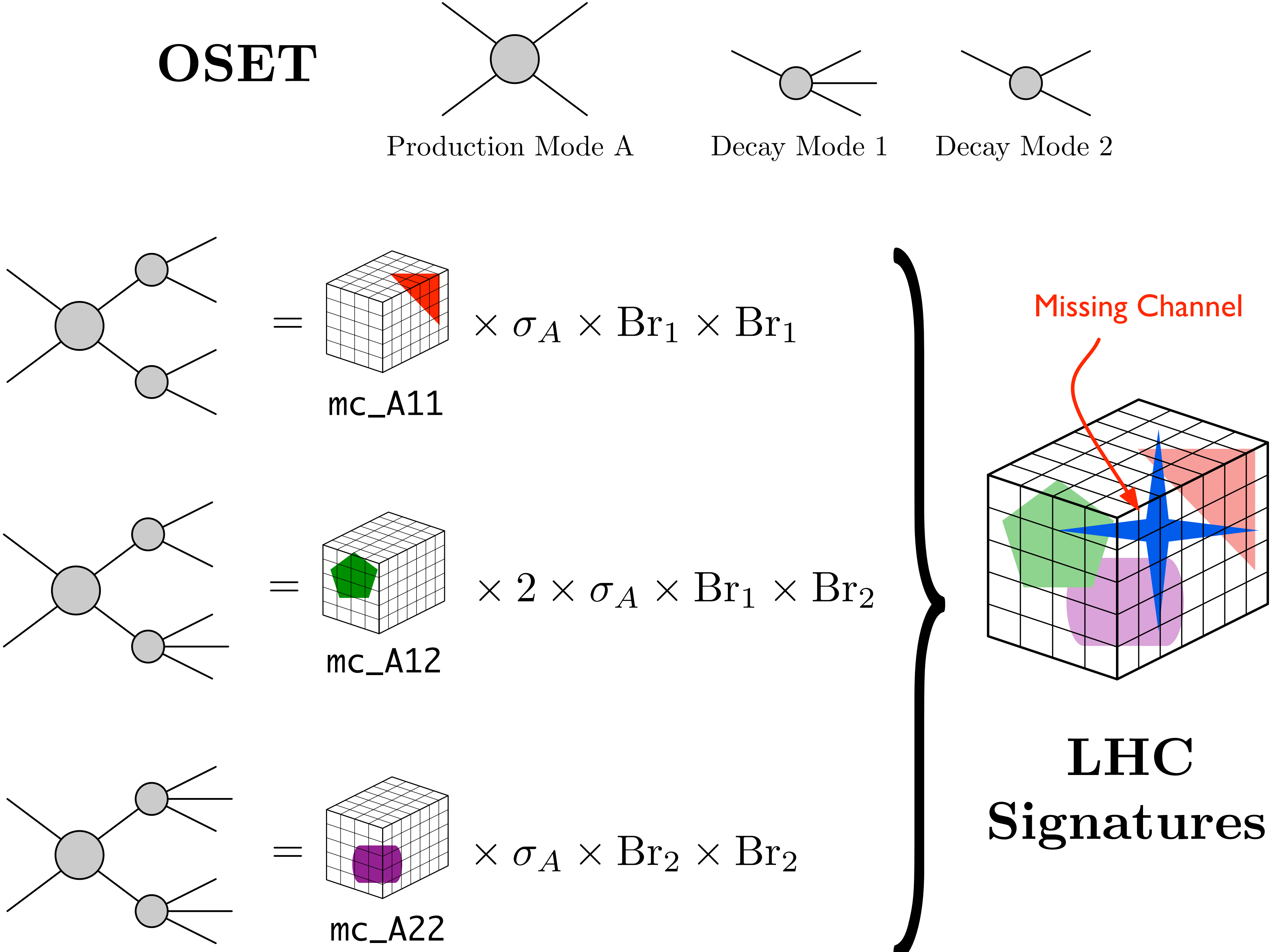
(MadGraph implementation in development.)

MARMOSET Output

```
# More Processes
p003 * b3 b3 s2 $ g g > (Adj > Ne bbar b) (Adj > Ne bbar b) : matrix=1
p004 * b3 b4 s2 $ g g > (Adj > Ne bbar b) (Adj > Ne cbar c) : matrix=1
p005 * b4 b3 s2 $ g g > (Adj > Ne cbar c) (Adj > Ne bbar b) : matrix=1
p006 * b4 b4 s2 $ g g > (Adj > Ne cbar c) (Adj > Ne cbar c) : matrix=1
p007 * b3 b3 s3 $ g g > (Adj > Ne bbar b) (Adj > Ne bbar b) : matrix=2
p008 * b3 b4 s3 $ g g > (Adj > Ne bbar b) (Adj > Ne cbar c) : matrix=2
p009 * b4 b3 s3 $ g g > (Adj > Ne cbar c) (Adj > Ne bbar b) : matrix=2
p010 * b4 b4 s3 $ g g > (Adj > Ne cbar c) (Adj > Ne cbar c) : matrix=2

# More Rates
s2 = 1000 $ Sigma( g g > Adj Adj : matrix=1 )
s3 = 1000 $ Sigma( g g > Adj Adj : matrix=2 )
b3 = 0.5 $ Br( Adj > Ne bbar b )
b4 = 0.5 $ Br( Adj > Ne cbar c )
@ b3 b4
```

rate information

each process is ready to simulate in Pythia


OSET
Production Mode A
Decay Mode 1
Decay Mode 2
$= \times \sigma_A \times \mathrm{Br}_1 \times \mathrm{Br}_1$
mc_A11
$= \times 2 \times \sigma_A \times \mathrm{Br}_1 \times \mathrm{Br}_2$
mc_A12
$= \times \sigma_A \times \mathrm{Br}_2 \times \mathrm{Br}_2$
mc_A22
Missing Channel
LHC
Signatures

MARMOSET in Practice

Blackbox Examples

The Michigan Black Box

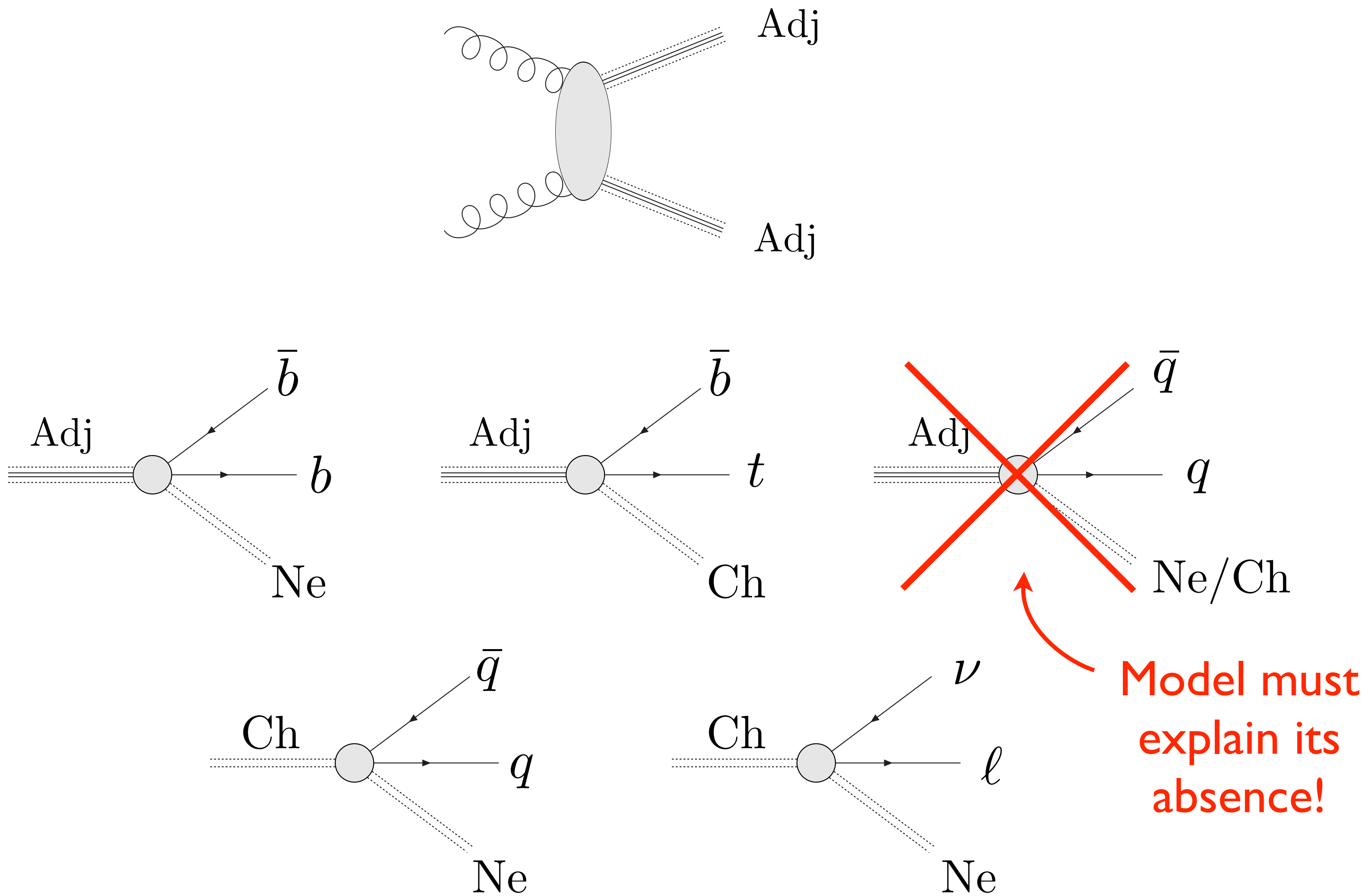
1st and 2nd LHC Olympics

$\tilde{q}_{1,2}$	1.8–2.1 TeV
$\tilde{b}_R$	2.0 TeV
$\tilde{t}_R, \tilde{q}_{3L}$	1.4 TeV
$\widetilde{W}$	1.0 TeV
$\widetilde{B}$	480 GeV
$\tilde{g}$	450 GeV
$\tilde{h}$	125 GeV

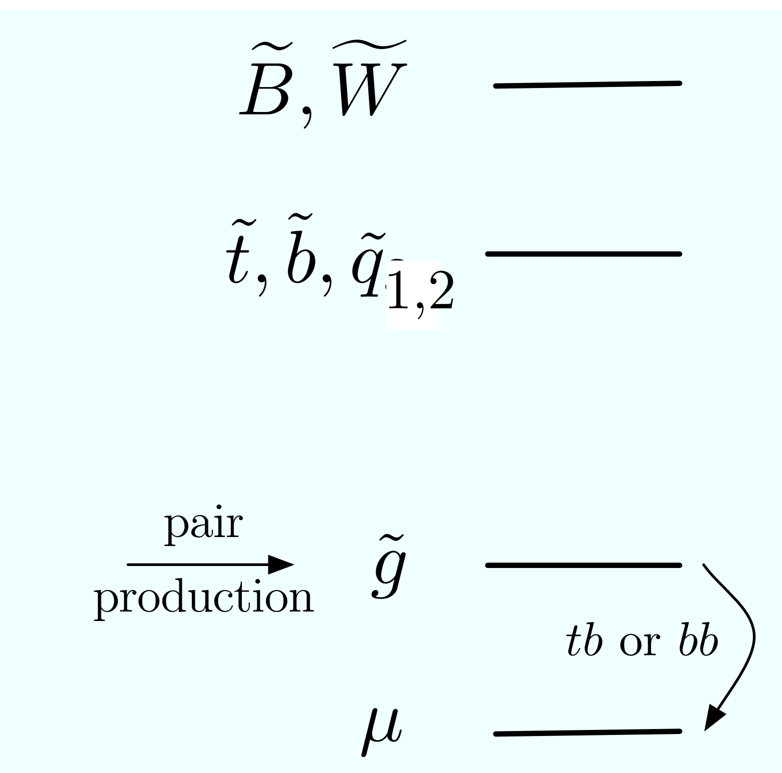
$(\tan\beta = 19)$

A trip down
memory lane...

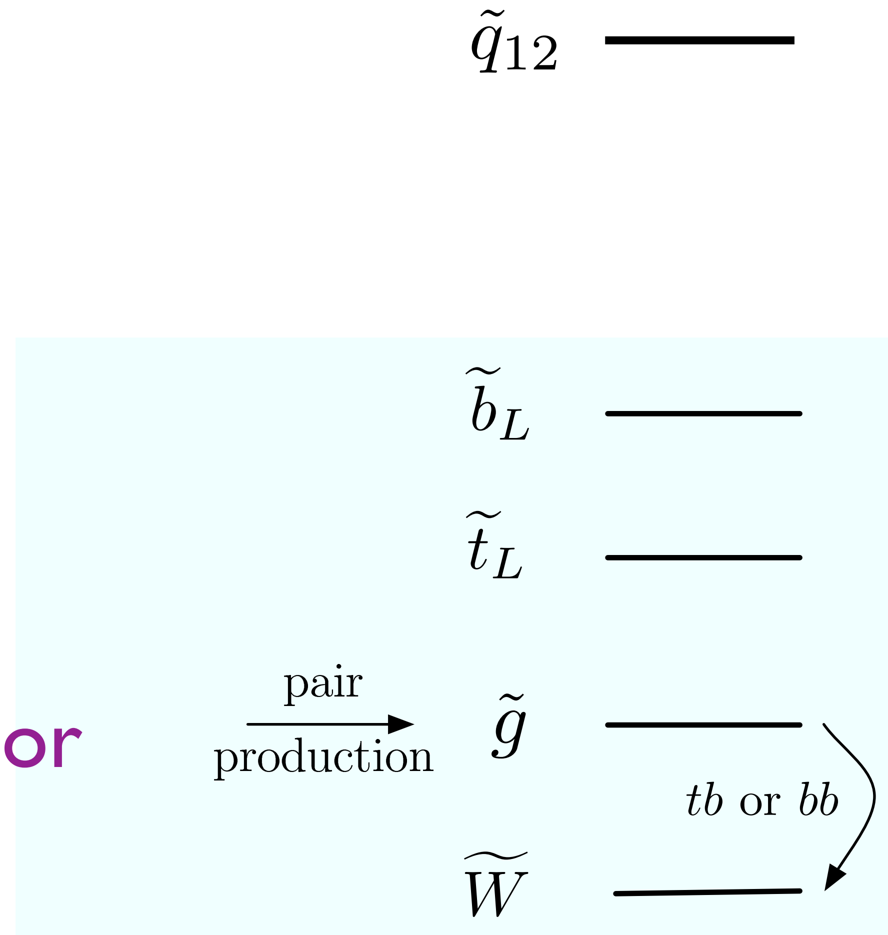
The Michigan Black Box



Two SUSY Scenarios



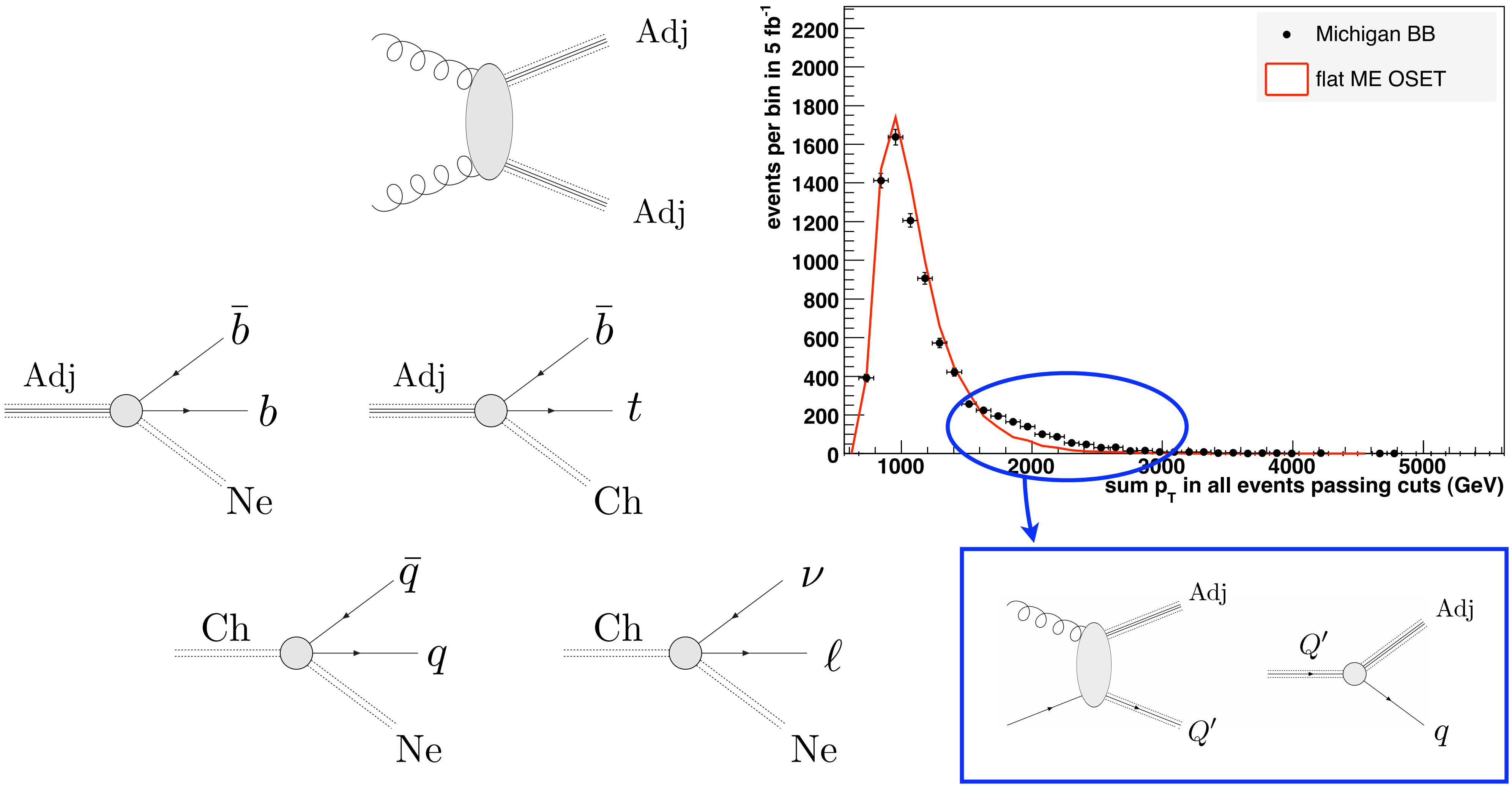
or



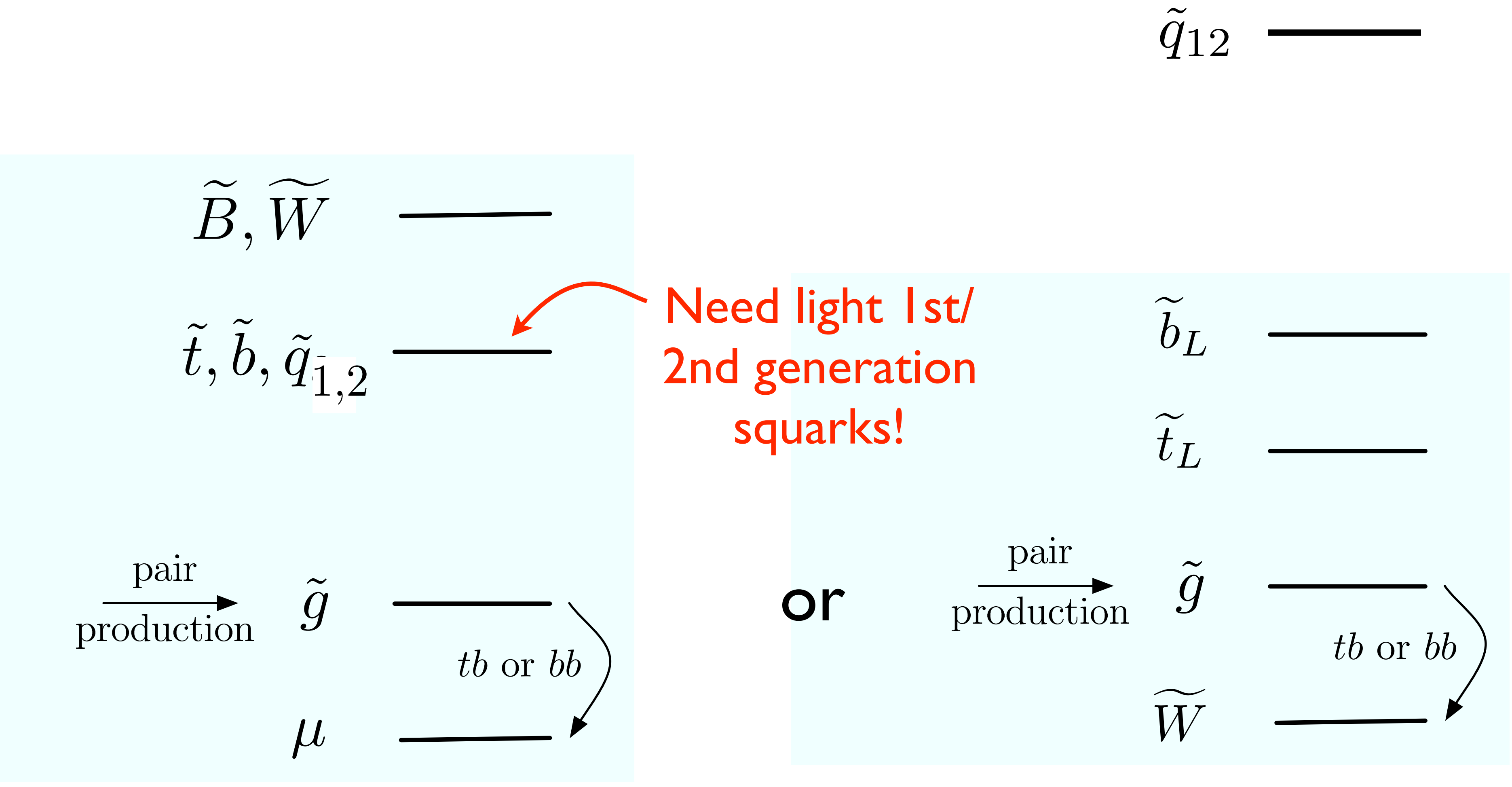
2j channel suppressed
by small couplings to Higgsino

2j channel suppressed
by high squark mass

The Michigan Black Box



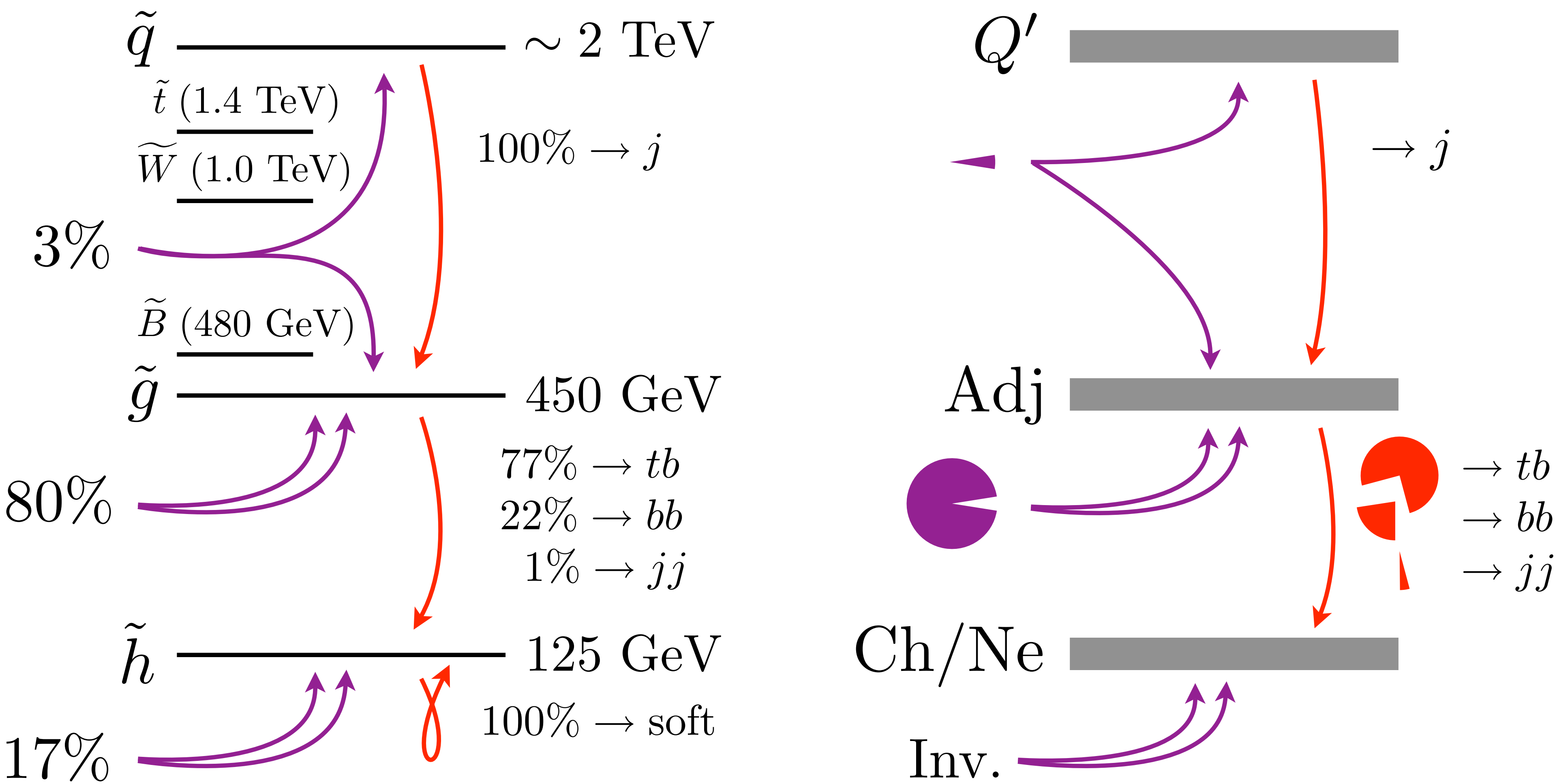
Two SUSY Scenarios



2j channel suppressed
by couplings to Higgsino

2j channel suppressed
by off-shell propagator

Michigan Box (MSSM)



Michigan Lessons

1st and 2nd LHC Olympics

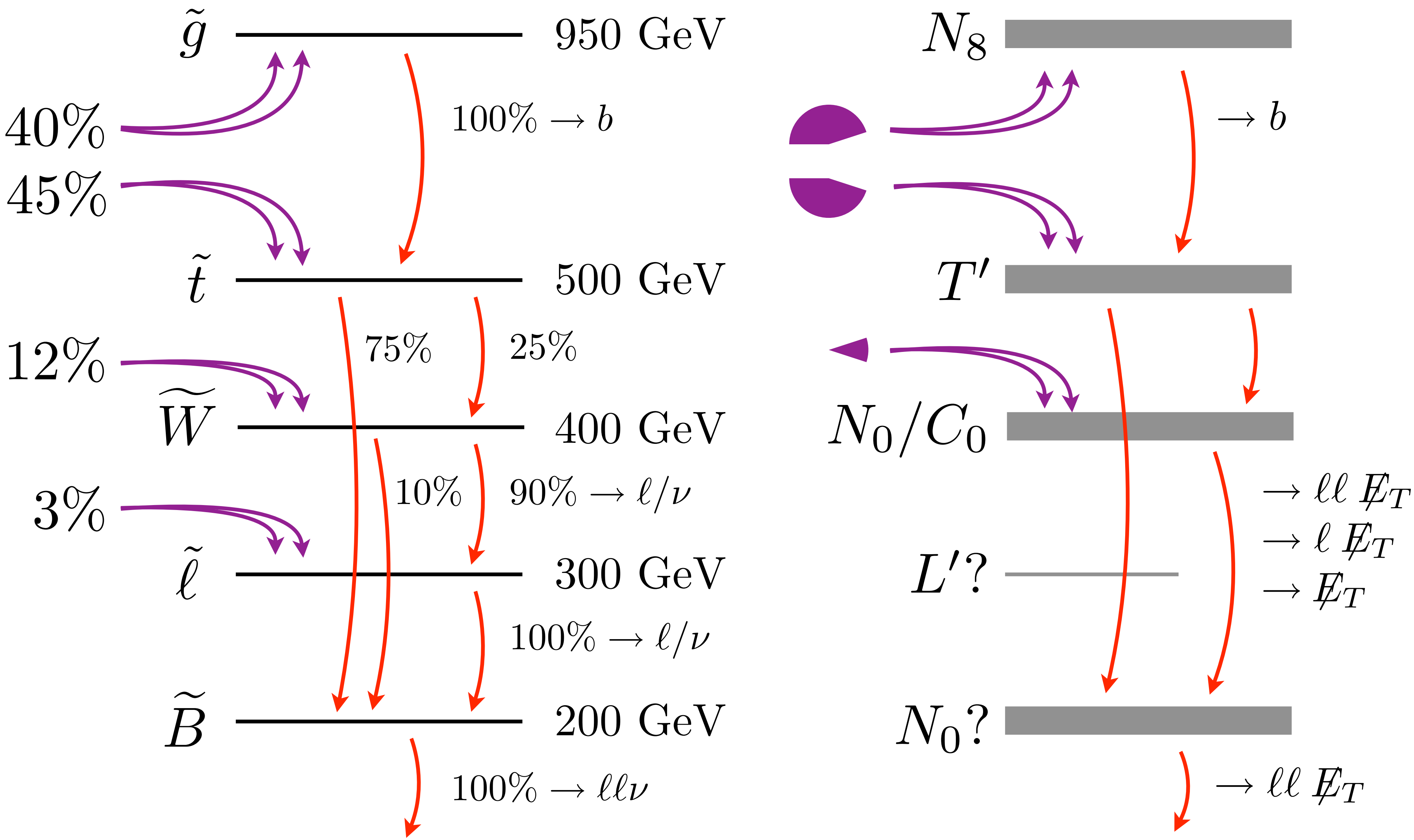
- 3000 CPU hours? Where's the physics? Does data uniquely determine Lagrangian?

- OSET is simple and readily obtained.

- OSET captures important features of the theory and strongly constrains its structure.

ABox (RPV SUSY)

Variant of Rutger's Blackbox (3rd LHC Olympics)



DBox

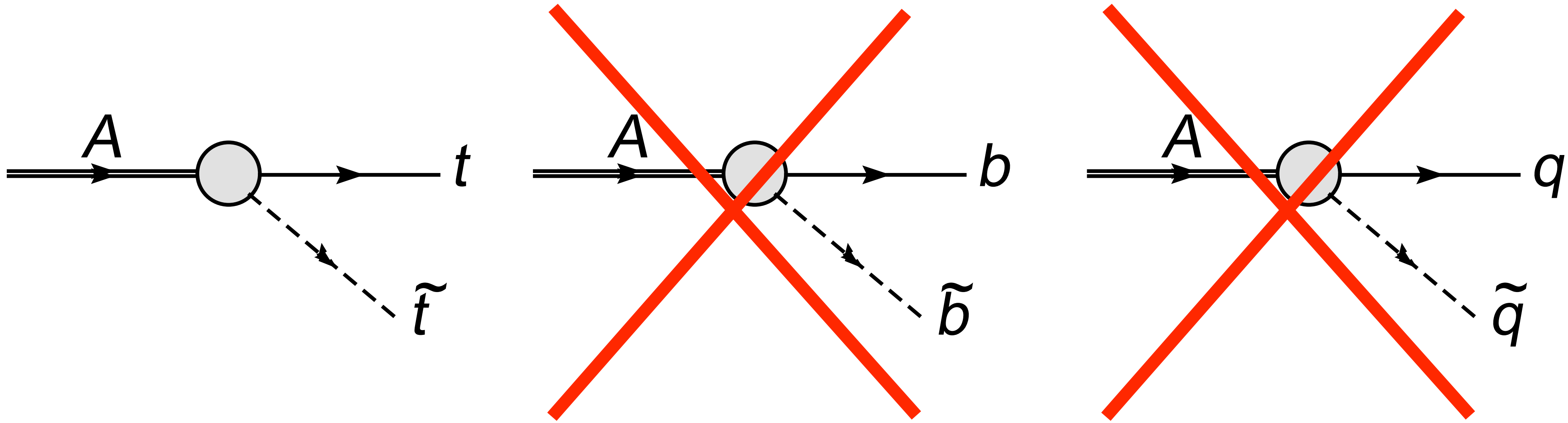
Nima & Natalia vs. Jesse & Philip
(Marmoset Smackdown)

- SUSY with very heavy gauginos (> 5 TeV)
- Light scalars
- **also** light colored adjoint Φ decaying through

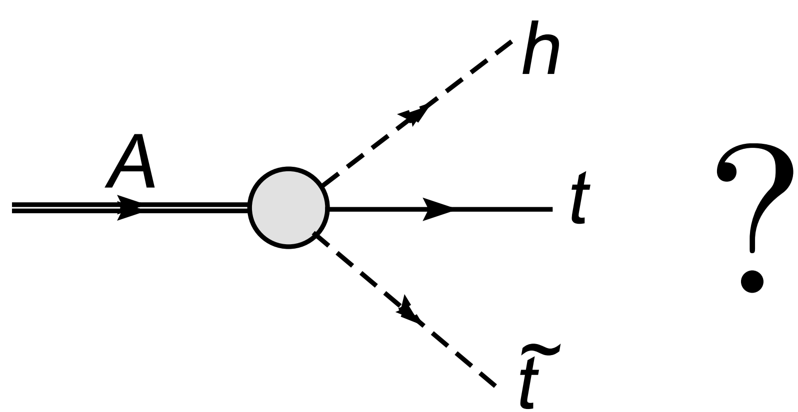
$$W \supset \frac{\Phi}{M} Q_3 H_u U_3^c$$

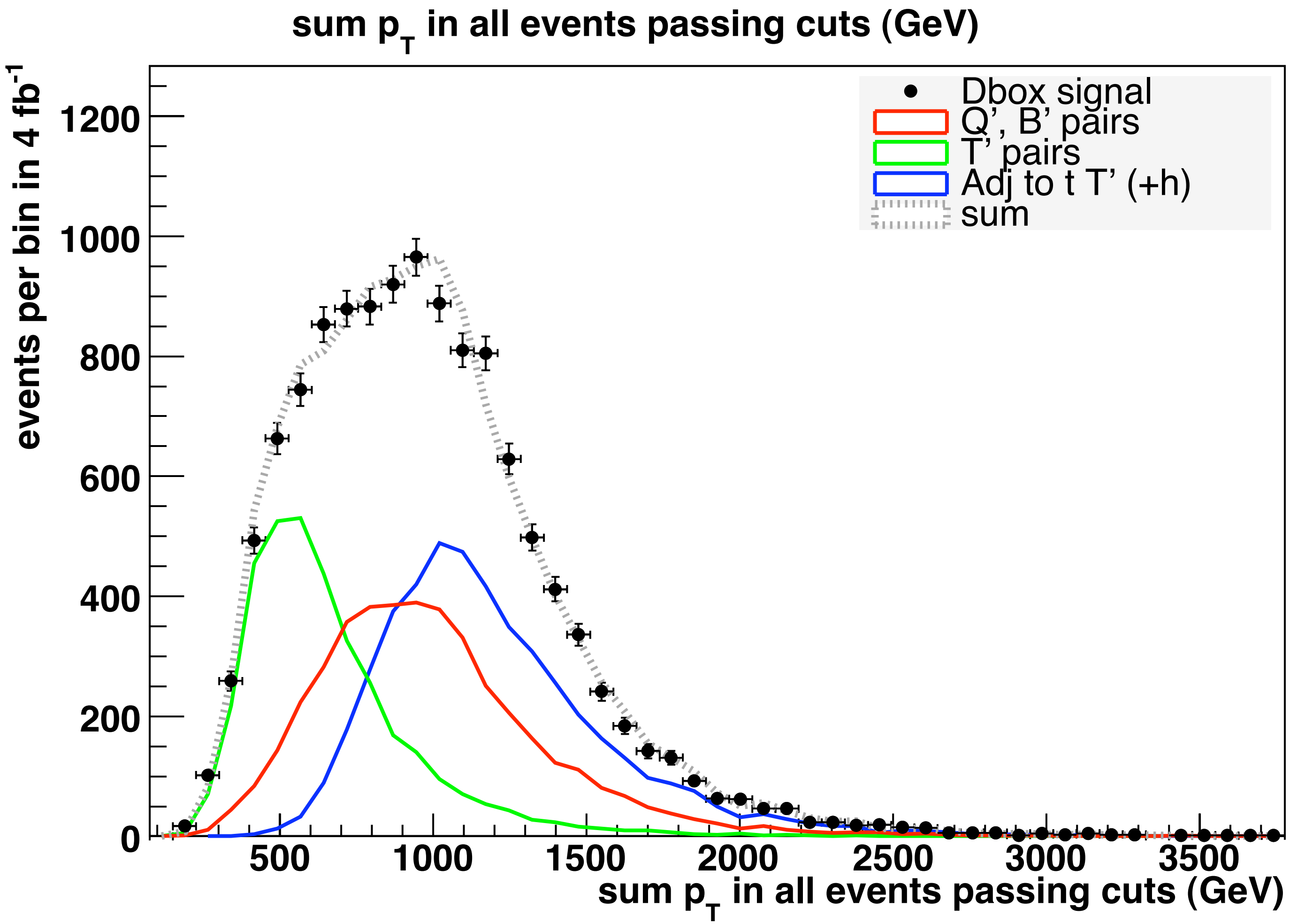
- looks like gluino with wrong decay modes!

DBox "Gluino" Decays?



Hints of a rare decay? (some many-b events, two jets+$\gamma\gamma$ with $m_{\gamma\gamma} = 114$ GeV

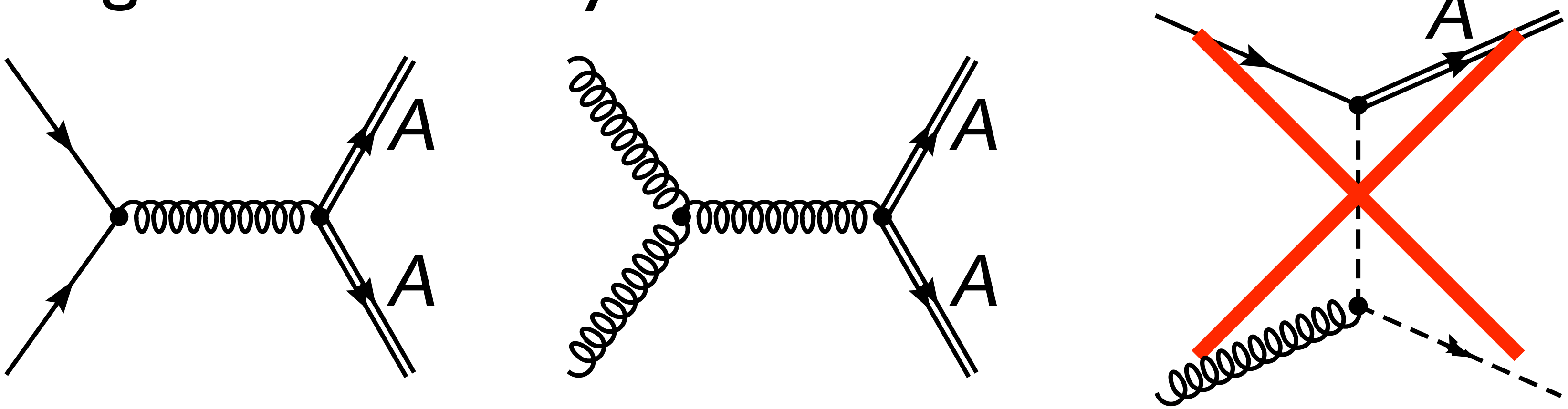




$$H_T = \sum_i E_T^i + \not{E}_T$$

DBox "Gluino" Production

rate consistent with QCD production through fermion only...

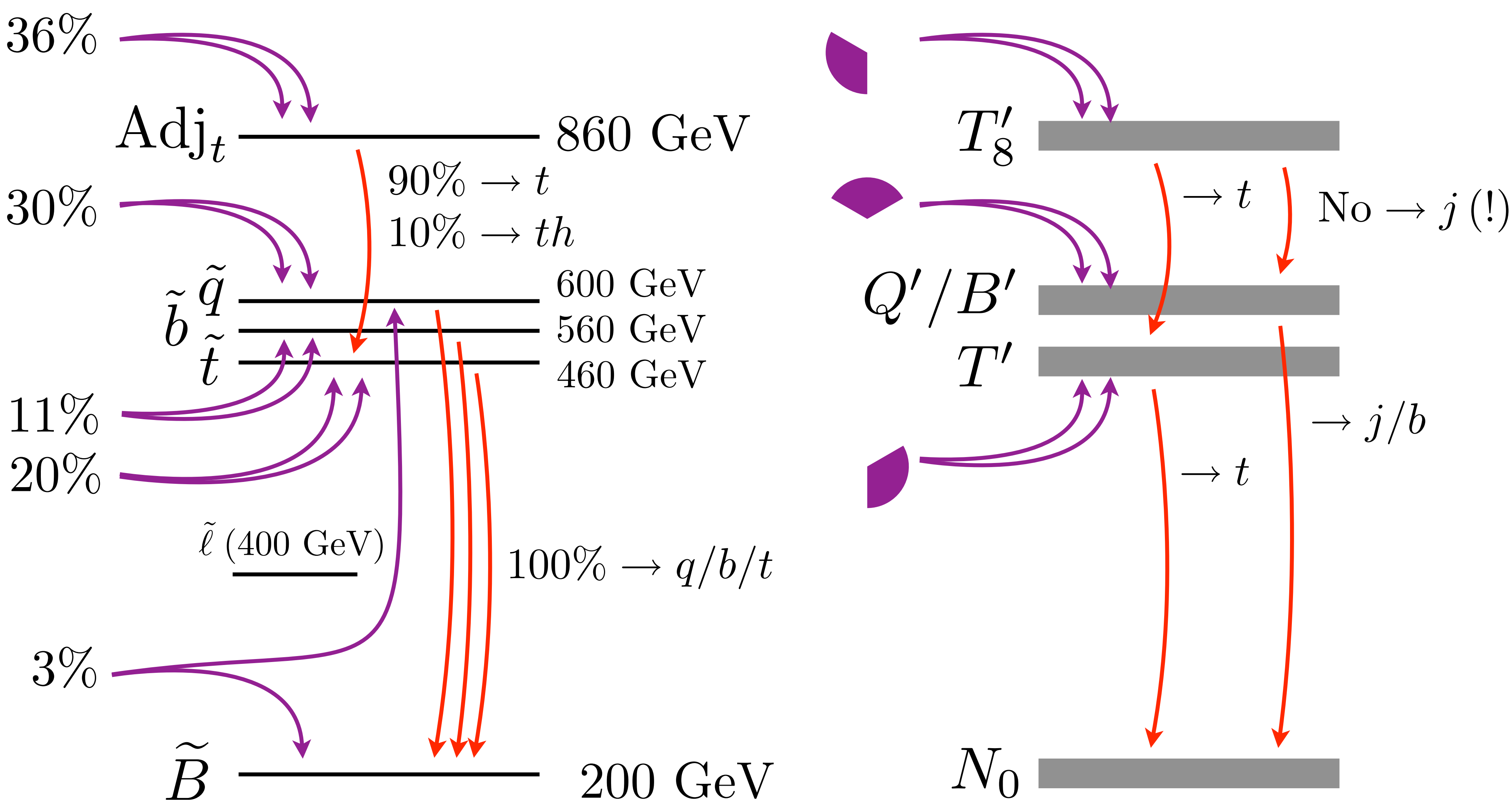


...and no associated production with squark.

It's not a gluino!

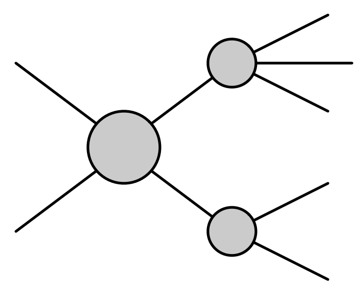
$$\text{Only couples to tops} \rightarrow W \supset \frac{\Phi}{M} Q_3 H_u U_3^c$$

DBox



36%
30%
11%
20%
3%
Adj_t
860 GeV
90% → t
10% → th
$\tilde{q}$
$\tilde{b}$
$\tilde{t}$
600 GeV
560 GeV
460 GeV
$\tilde{\ell}$ (400 GeV)
100% → $q/b/t$
$\widetilde{B}$
200 GeV
T_8'
→ t
No → j (!)
Q'/B'
T'
→ j/b
→ t
N_0

LHC Signatures $\Longleftrightarrow$ OSET



$\Longleftrightarrow \mathcal{L}$

Please try this at home!

So far, trial testing on data challenges
has taught us a lot

Should try it on as many (qualitatively different)
data challenges as possible!

Using these techniques on real data would be best!

Easy-to-use (beta version) of MARMOSET:
www.marmoset-mc.net

```
cvs checkout Marmoset
```

arXiv paper: hep-ph/0703088

Only a few dynamical variables control the essential phenomenology of new physics at hadron colliders.

Characterizing new physics directly in terms of these variables permits a simple, accurate parametrization of almost **any** model of new physics —

an On-Shell Effective Theory.

MARMOSET:
Simple Monte Carlo for Any Model

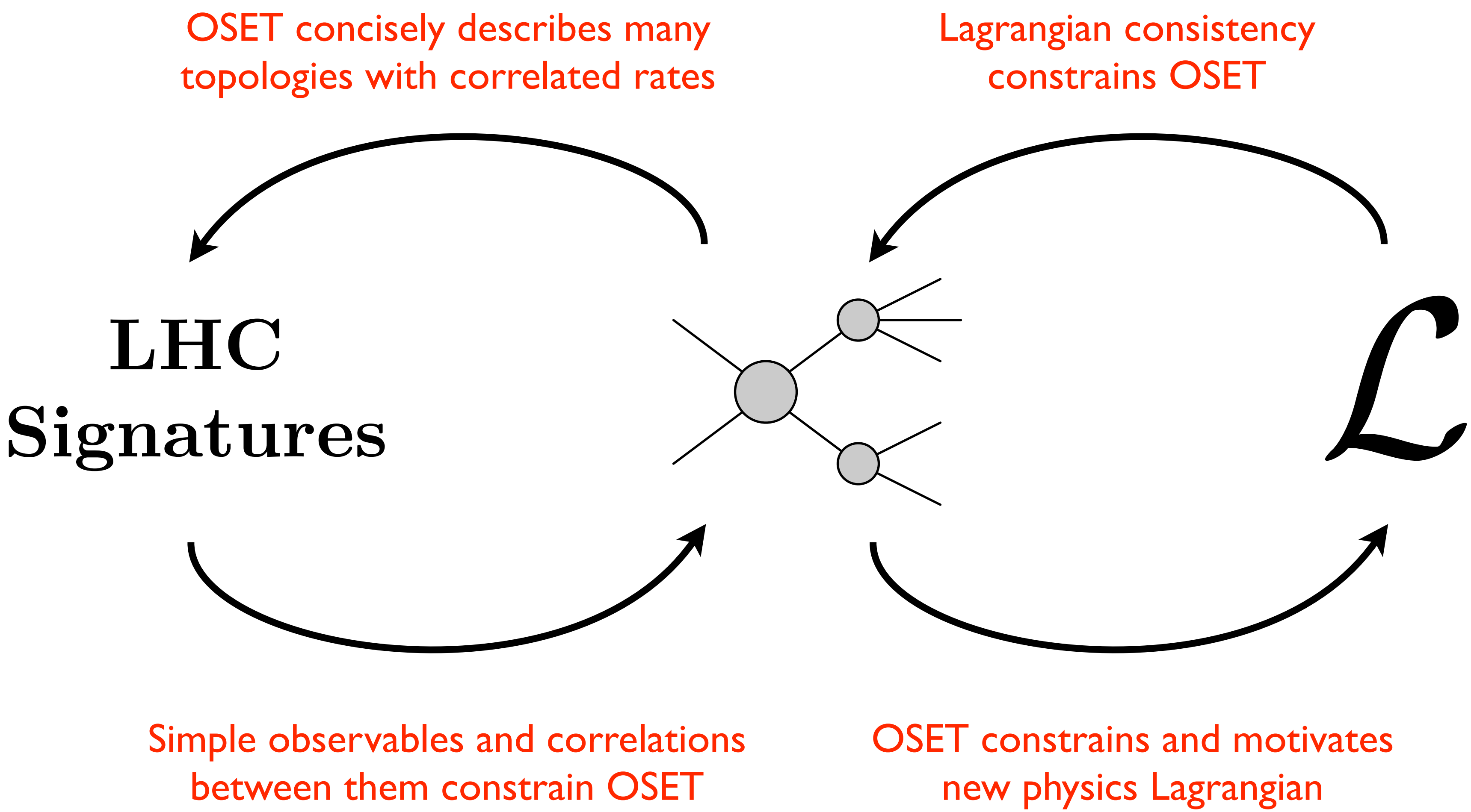
Coarse Mass Scanning

Rate Scanning by Reweighting Existing Monte Carlo

vs.

Lagrangian Simulation

Intricate dependence of σ,Br on many Lagrangian parameters demands fine scanning of all of them.



A successful Lagrangian characterization may be derived from the top down or from the bottom up, and will be most convincing when understood in both ways.

An OSET characterization of LHC data is not an end in itself but a waystation on the path to a fundamental theory.

The OSET framework will only be successful if it leads to a compelling Lagrangian that obviates the need for an OSET description.

Ultimately, understanding the structure of this effective Lagrangian will unveil the new principles of Nature long anticipated at the weak scale.