Effective Theories for Interpretation of LHC Data: Part II

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Matthew Baumgart, Liam Fitzpatrick, Jared Kaplan, Tom Hartman,

and the LHCO community

Last week...

Philip talked about OSETs — descriptions of new physics scenarios in terms of the produced particles and their decay modes rather than full QFT.
OSETs capture most physics observable at early stages, little excess weight

- An alternative class of benchmark scenario?
- An *evolving* benchmark?

How could this evolution work?

Outline

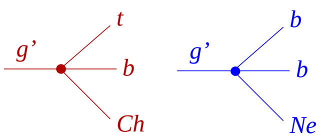
- Overview of MARMOSET—the unit step in OSET evolution
- Starting point for interpretation: discoveries have been made!
- Mass scale estimation and fitting.
- Process characterization and rate fitting
- Resolving overlapping processes
- OSET $\rightarrow$ theory guess $\rightarrow$ motivated searches

Examples from LHC Olympics — hundreds of fb^{-1} of experience in tens of models

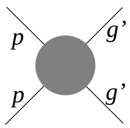
Simulating and evaluating (MARMOSET)

```
# New particles

GL      : charge=0 color=8 mass=450
Ch Ch~  : charge=3 color=0 mass=126
 MPT : charge=0 color=0 mass=125 pdg=1000022
```

particle decayed normally by Pythia




```
# Decay modes

GL > t bbar Ch~
GL > b bbar Ne
 Ch > MPT e+ e-
```

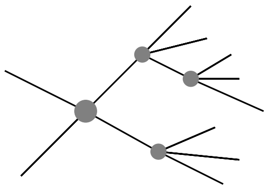



```
#Hard Processes

g g > GL GL : name=GLPair matrix=2
```

extensible parameterized ME^2

Simulating and evaluating (MARMOSET)

```
t2 $ g g > (   GL > MPT bbar b   )
           (   GL > ( Ch~ > nu_ebar e− MPT ) t bbar )
t3 $ g g > (   GL > MPT bbar b   ) ( GL > MPT bbar b )
```

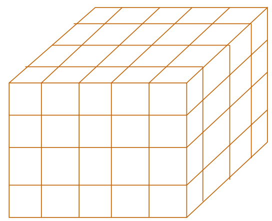


→ Coefficient (product of rates, branching ratios)

→ generate events in Pythia, simulate, and evaluate signatures

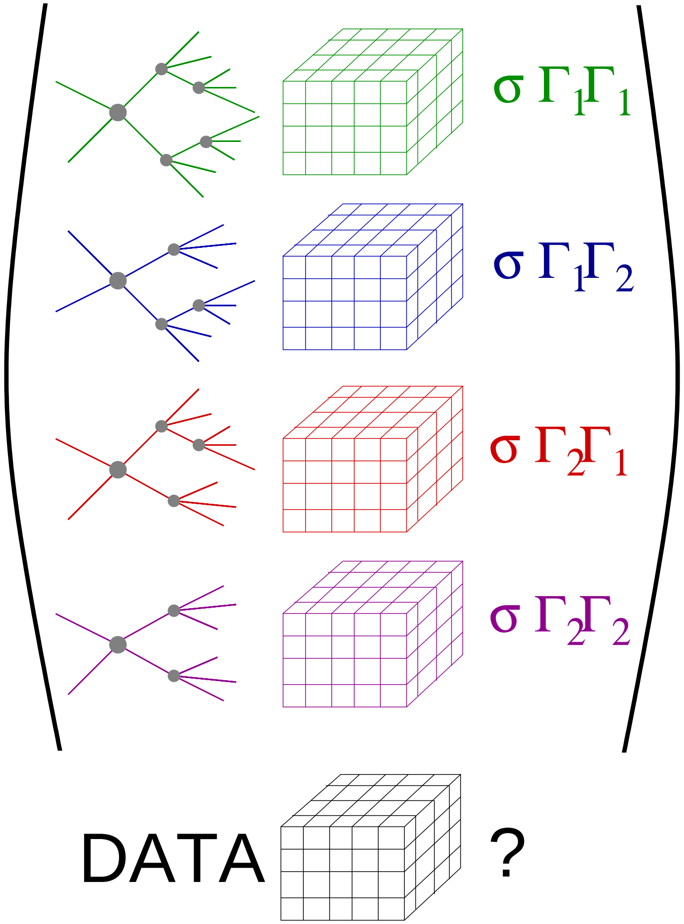
↓

3 or 4D histogram binned by lepton b, jet counts and by M_{eff}



count in each bin → kernel density for likelihood estimation‘

Simulating and evaluating (MARMOSET)



→ Fits to OSET parameters

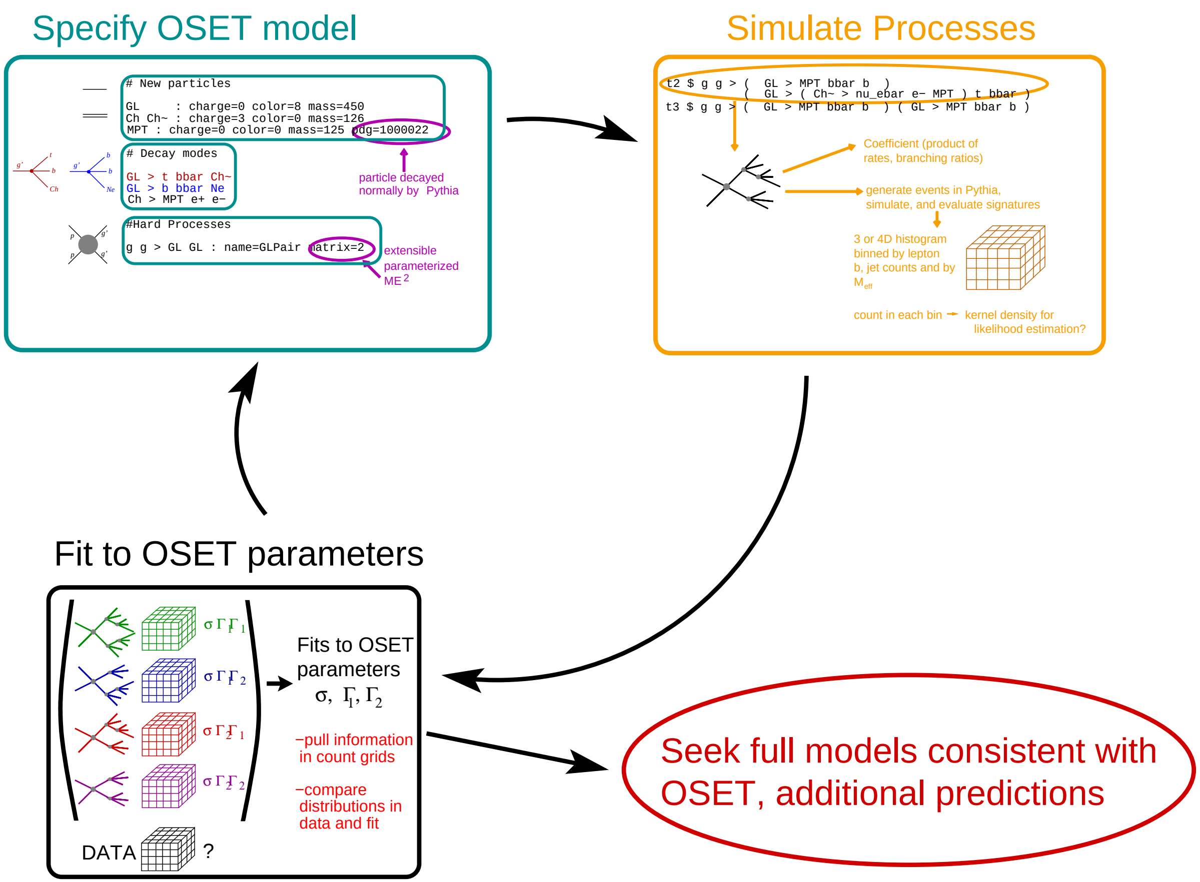
$\sigma, \; \Gamma_1, \Gamma_2$

↓

−pull information in count grids

−compare distributions in data and fit

Simulating and evaluating (MARMOSET)

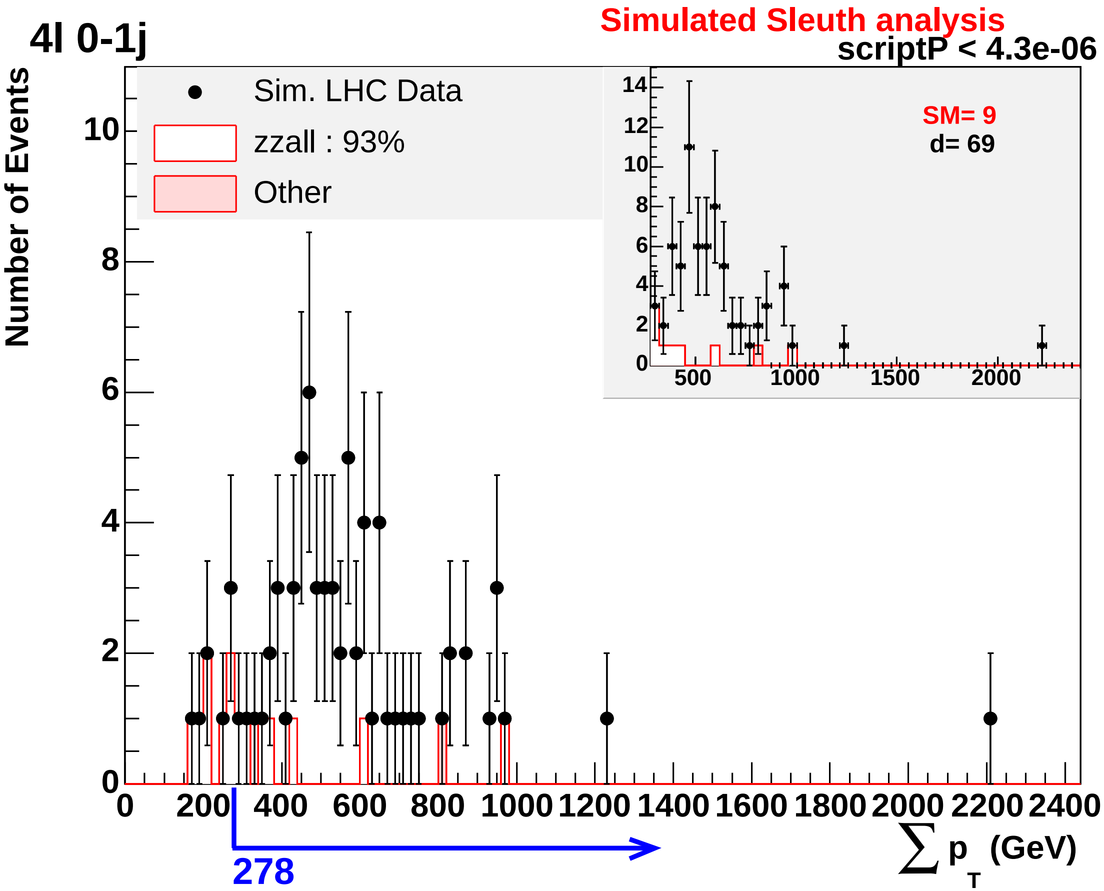


MARMOSET in practice

An Example: ABOX

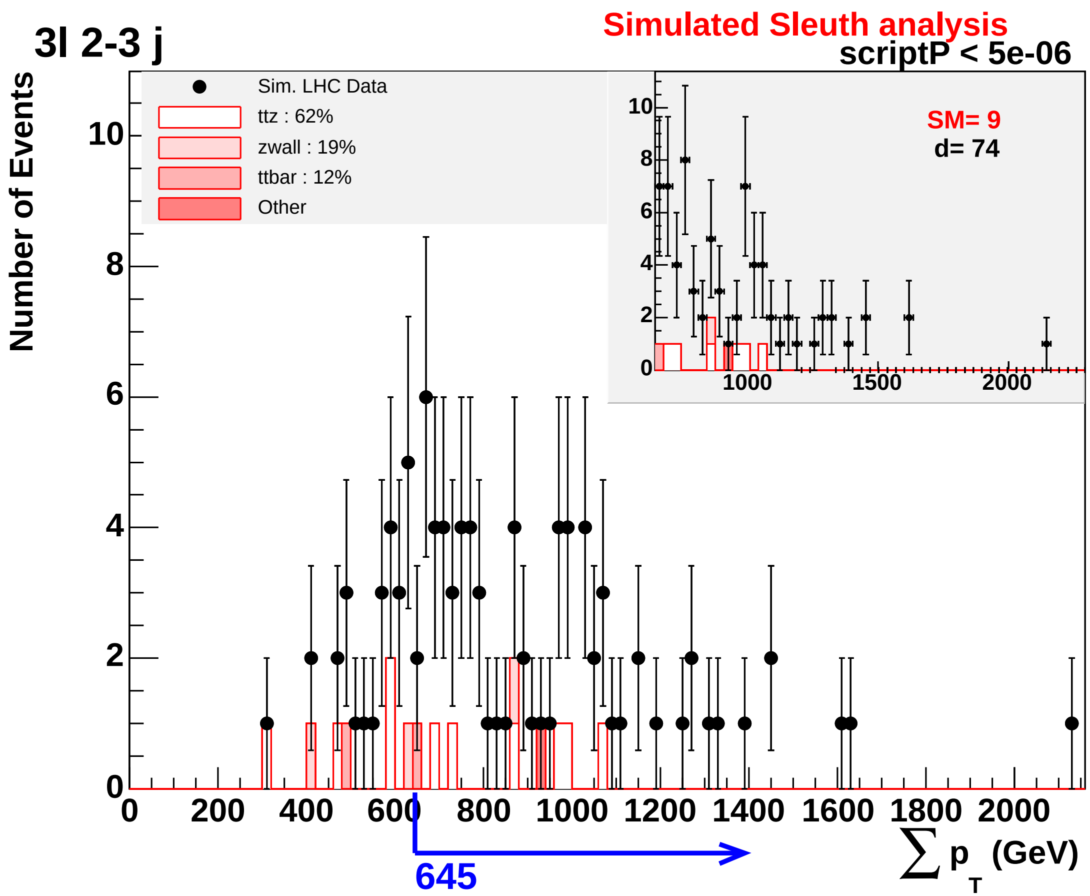
- SUSY model inspired by LHC Olympics Black Box C
- 4 fb^{-1} generated in pythia + backgrounds
- Background treatment is not fully realistic
- Simulated with PGS 3, as modified by Steve Mrenna, with triggers added by Harvard group
- Tools are in beta version, incorporate only primitive fitting...

Low Mass: $\geq 3\ell, < 2j$



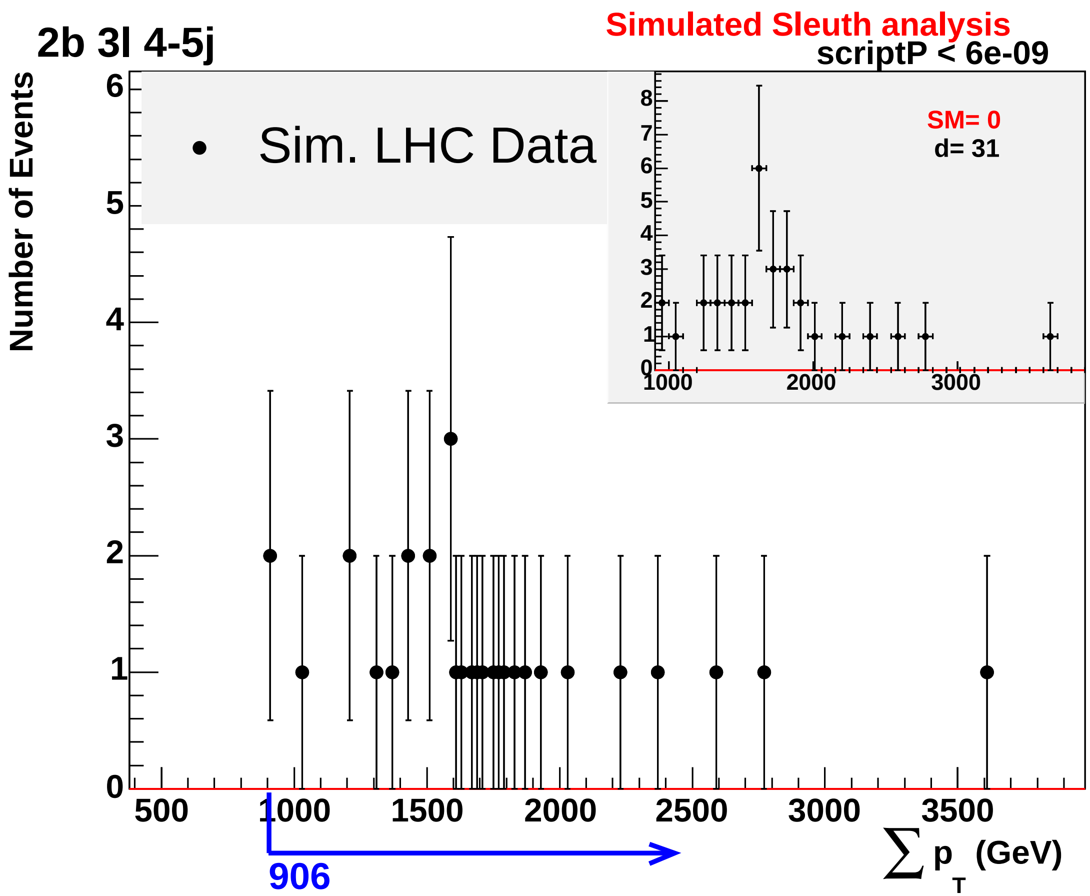
peak ~ 600 GeV

Mid-mass: $2-3j$



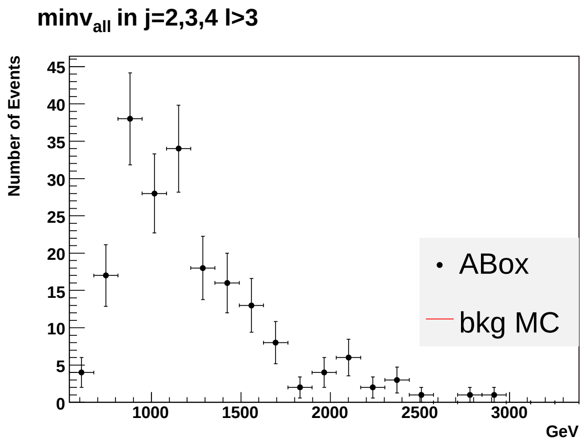
peak ~ 800 GeV

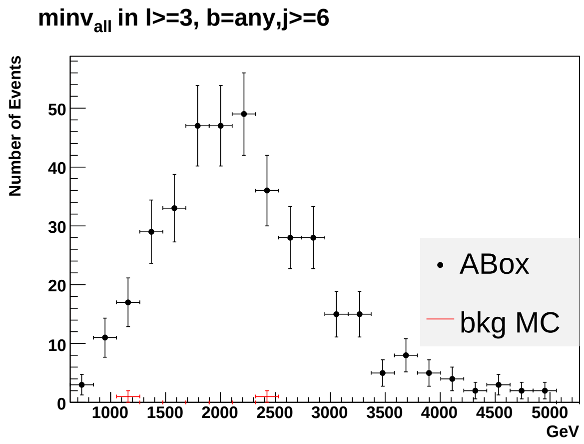
High Mass: $5 + j$

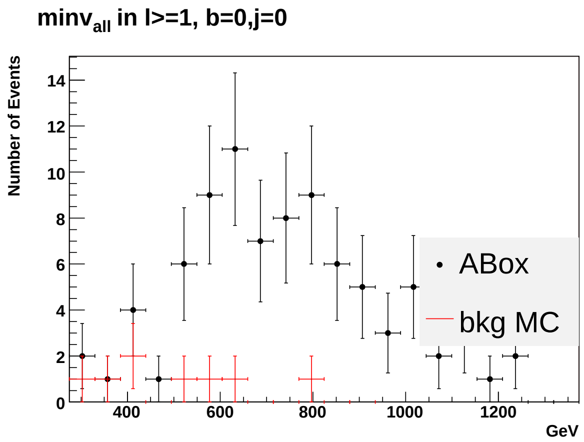


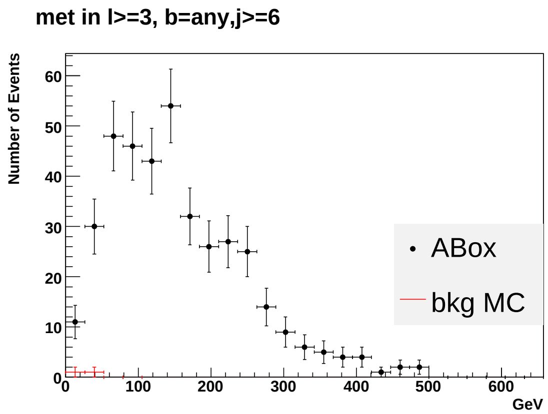
peak ~ 1800 GeV

Three Classes of Event









Counting

$\sum p_T$ — ℓ vs. j and b vs. j

< 700

*	j=0	j=2	j=4	j=6	j=8
l=0	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
l=1	$0_{1.}$	$0_{1.}$	$0_{1.}$	$8_{103.}$	$3_{74.}$
l=2	$0_{1.}$	$0_{1.}$	$47_{140.}$	$11_{58.}$	$3_{19.}$
l=3	$49_{10.}$	$57_{13.}$	$25_{10.}$	$8_{4.}$	$0_{1.}$
l=4	$41_{7.}$	$40_{8.}$	$9_{4.}$	$0_{1.}$	$0_{1.}$
l=5	$20_{5.}$	$6_{4.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
l=6	$2_{2.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
l=7	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

*	j=0	j=2	j=4	j=6	j=8
b=0	$110_{20.}$	$82_{15.}$	$48_{90.}$	$12_{35.}$	$4_{44.}$
b=1	$2_{3.}$	$15_{7.}$	$24_{41.}$	$14_{78.}$	$1_{29.}$
b=2	$0_{1.}$	$6_{4.}$	$9_{21.}$	$1_{42.}$	$1_{17.}$
b=3	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{10.}$	$0_{4.}$
b=4	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
b=5	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
b=6	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

$700 - 1400$

*	j=0	j=2	j=4	j=6	j=8
l=0	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
l=1	$0_{1.}$	$0_{1.}$	$0_{1.}$	$77_{93.}$	$79_{90.}$
l=2	$0_{1.}$	$0_{1.}$	$169_{58.}$	$174_{43.}$	$86_{27.}$
l=3	$18_{5.}$	$87_{17.}$	$143_{22.}$	$100_{18.}$	$33_{11.}$
l=4	$25_{5.}$	$53_{12.}$	$60_{13.}$	$25_{10.}$	$11_{6.}$
l=5	$17_{4.}$	$28_{9.}$	$12_{6.}$	$1_{1.}$	$0_{1.}$
l=6	$12_{4.}$	$6_{4.}$	$1_{1.}$	$0_{1.}$	$0_{1.}$
l=7	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

*	j=0	j=2	j=4	j=6	j=8
b=0	$71_{17.}$	$109_{19.}$	$170_{47.}$	$100_{26.}$	$58_{46.}$
b=1	$1_{1.}$	$41_{12.}$	$156_{33.}$	$185_{76.}$	$72_{42.}$
b=2	$0_{1.}$	$23_{9.}$	$56_{19.}$	$74_{45.}$	$51_{29.}$
b=3	$0_{1.}$	$1_{1.}$	$3_{2.}$	$16_{15.}$	$23_{13.}$
b=4	$0_{1.}$	$0_{1.}$	$0_{1.}$	$2_{3.}$	$5_{4.}$
b=5	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
b=6	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

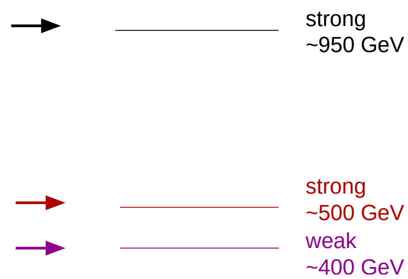
> 1400

*	j=0	j=2	j=4	j=6	j=8
l=0	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$
l=1	$0_{1.}$	$0_{1.}$	$0_{1.}$	$69_{30.}$	$171_{41.}$
l=2	$0_{1.}$	$0_{1.}$	$24_{14.}$	$81_{20.}$	$157_{29.}$
l=3	$0_{1.}$	$14_{6.}$	$24_{8.}$	$63_{17.}$	$82_{19.}$
l=4	$2_{2.}$	$5_{3.}$	$14_{8.}$	$27_{11.}$	$25_{11.}$
l=5	$0_{1.}$	$1_{1.}$	$2_{2.}$	$9_{6.}$	$3_{3.}$
l=6	$0_{1.}$	$0_{1.}$	$2_{2.}$	$1_{1.}$	$0_{1.}$
l=7	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

*	j=0	j=2	j=4	j=6	j=8
b=0	$2_{2.}$	$11_{6.}$	$21_{11.}$	$39_{14.}$	$75_{21.}$
b=1	$0_{1.}$	$4_{3.}$	$30_{13.}$	$99_{31.}$	$130_{27.}$
b=2	$0_{1.}$	$5_{2.}$	$13_{8.}$	$68_{23.}$	$136_{26.}$
b=3	$0_{1.}$	$0_{1.}$	$1_{1.}$	$37_{12.}$	$77_{18.}$
b=4	$0_{1.}$	$0_{1.}$	$1_{1.}$	$6_{4.}$	$14_{7.}$
b=5	$0_{1.}$	$0_{1.}$	$0_{1.}$	$1_{1.}$	$6_{4.}$
b=6	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

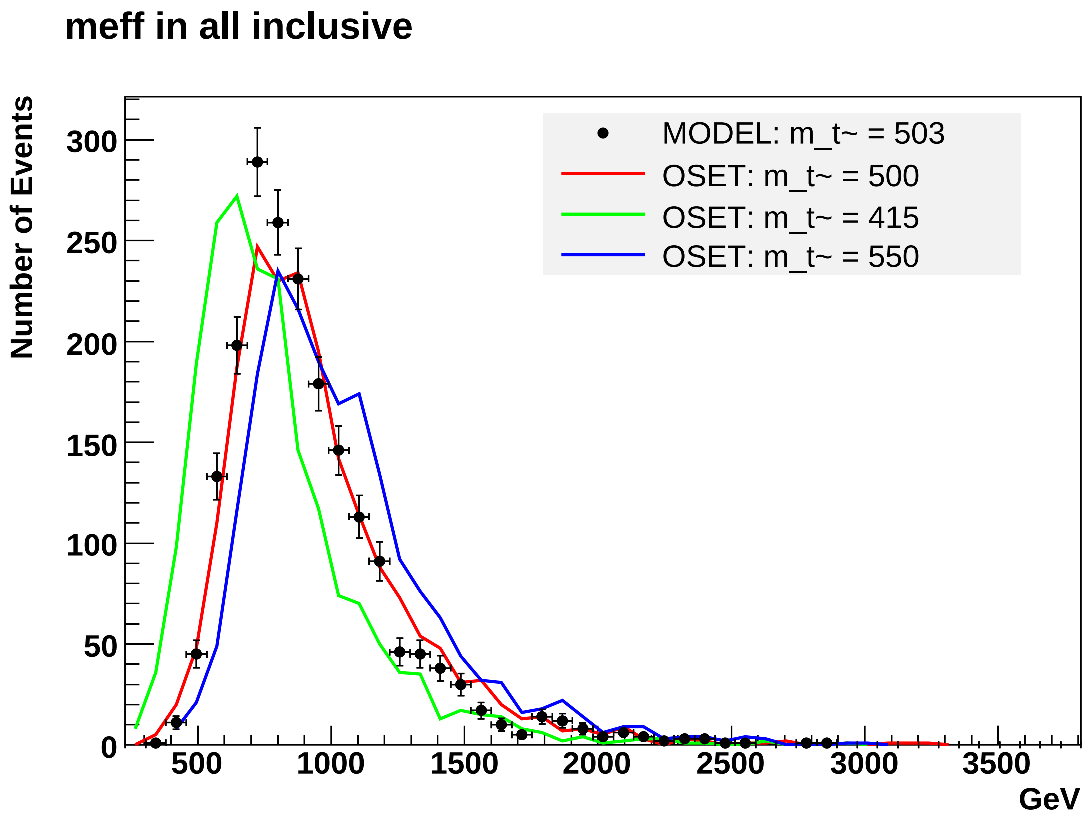
Starting points

- lepton-rich and b-rich
- 3 distinct scales in M_{eff}: $\sim$ 1800, 800, 600 GeV
- No new resonances visible $\rightarrow$ assume new physics pair production
- Producing new particles with mass $\sim$ 1 TeV (had), 500 GeV (had), 400 GeV (em)?
- More jets in high-M_{eff} peak—decays through second particle?



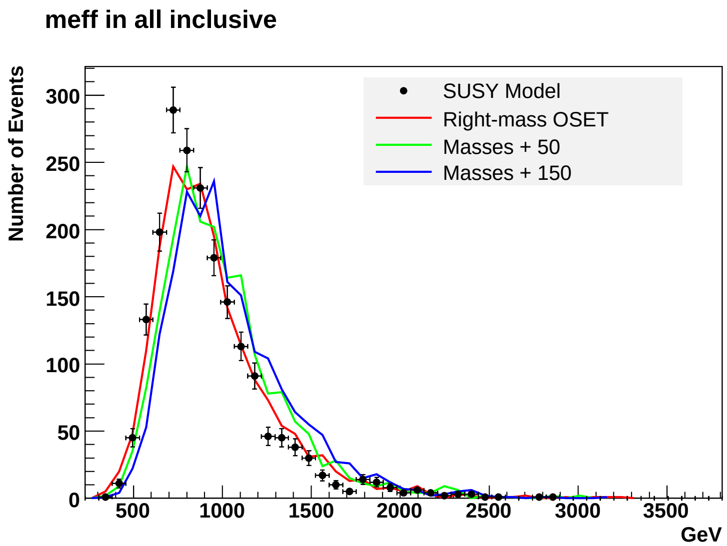
Resolving masses: case study I

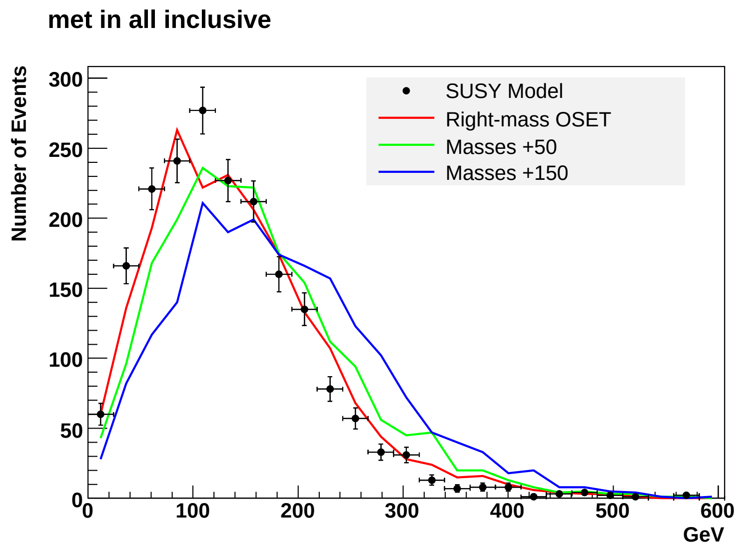
Changing the $\tilde{t}$ mass:



Resolving masses: case study II

Changing all masses together $\tilde{t}$:





Characterizing new physics

- OSETs simply capture *almost* all the observable physics, little excess
- Motivate guesses/benchmarks by where new physics is discovered, refine by comparison of MC to data

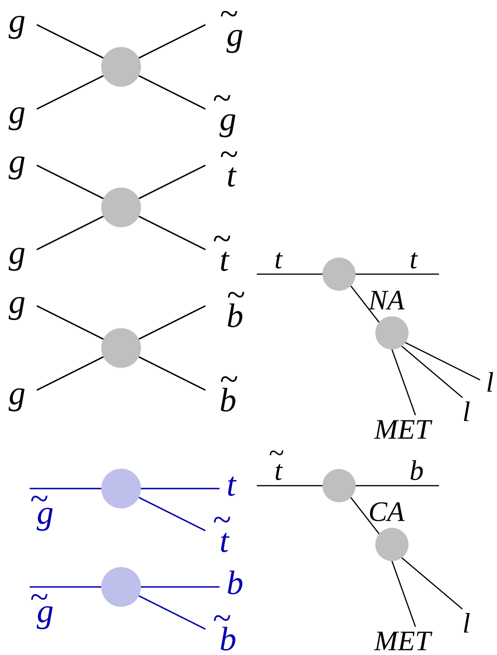
A starting guess

The gluino/stop decays often produce 4 leptons. The few 6ℓ events come from leptonically decaying tops?

To ignore possible direct EW production, demand ≥ 4 jets

```
# New Particles
GL          : charge=0 color=8 mass=990
Stop Stop~  : charge=2 color=3 mass=560
Sbot Sbot~  : charge=-1 color=3 mass=580
NA          : charge=0 color=0 mass=240
CA CA~      : charge=-3 color=0 mass=390
MPT         : charge=0 color=0 mass=100 pdg=1000022

GL > Stop tbar
GL > Sbot bbar
Stop > NA t
Stop > CA~ b
Sbot > NA b
Sbot > CA t

NA > e- mu+ MPT    # (2-lepton)
@ ( e- mu+ nu_tau | e- e+ nu_tau )
CA > MPT e- nu_e   # (1-lepton)
@ ( e- nu_e | mu- nu_e )
```

```
g g    > GL GL : name=GLprod matrix=2
g g    > Stop Stop~ : name=Stopprod matrix=2
g g    > Sbot Sbot~ : name=Stopprod matrix=2
```



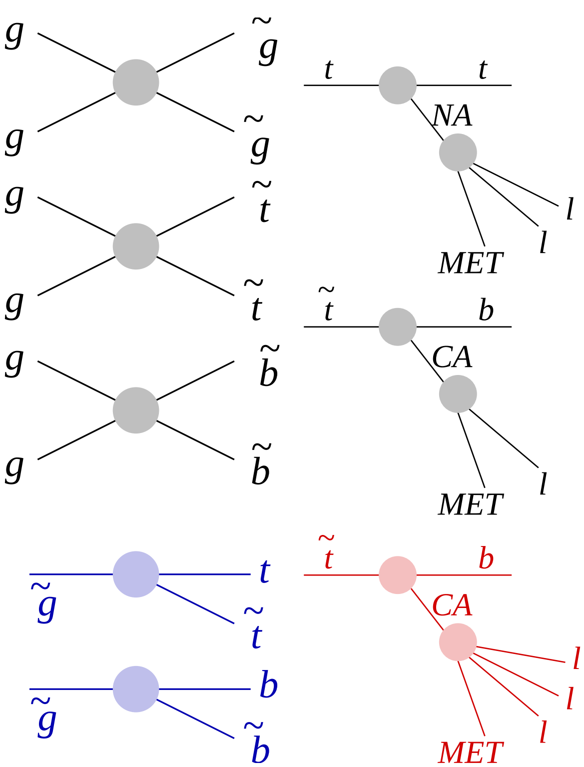
Starting guess: problems

Fit pushes `Sbot > NA` b to boundary of physical region—need to produce b in conjunction with more leptons...

```
######Channel################## Target   Fit    Error  Pull ****|****+
l=2  b=1  j=4  (  700<pT<  1400)  69.0  111.1   19.6    2.1     |**
l=2  b=2  j=4  (  700<pT<  1400)  25.0   45.4   11.1    1.8     |**
l=3  b=2  j=6  (  700<pT<  1400)  14.0   22.4    5.2    1.6     |**
l=2  b=1  j=8+ (  700<pT<  1400)  28.0   41.7    8.8    1.6     |**
l=1  b=2  j=8+ ( 1400<pT< 10000)  49.0   66.5   10.8    1.6     |**
l=3  b=0  j=6  (     0<pT<   700)   5.0    0.7    2.6   -1.6   **|
l=3  b=0  j=4  ( 1400<pT< 10000)  10.0    4.2    3.6   -1.6   **|
l=4  b=0  j=4  ( 1400<pT< 10000)   7.0    1.9    3.1   -1.7   **|
l=4  b=1  j=8+ ( 1400<pT< 10000)   7.0    1.5    3.0   -1.8   **|
l=4  b=3  j=8+ ( 1400<pT< 10000)   7.0    0.7    3.0   -2.1   **|
l=3  b=0  j=4  (     0<pT<   700)  17.0    6.8    4.9   -2.1   **|
l=3  b=0  j=4  (  700<pT<  1400)  63.0   41.8    9.6   -2.2   **|
l=4  b=0  j=4  (     0<pT<   700)   7.0    0.2    2.9   -2.3   **|
l=4  b=1  j=4  (  700<pT<  1400)  27.0   10.2    5.8   -2.9  ***|
l=4  b=0  j=4  (  700<pT<  1400)  26.0    9.1    5.7   -3.0  ***|
l=3  b=2  j=8+ ( 1400<pT< 10000)  34.0   14.6    6.4   -3.0  ***|
```

More Leptons

We need to add a $b + 3\ell$ decay mode!




```
# New Particles

GL           : charge=0 color=8 mass=990
Stop Stop˜   : charge=2 color=3 mass=560
Sbot Sbot˜   : charge=-1 color=3 mass=580
NA           : charge=0 color=0 mass=240
CA CA˜       : charge=-3 color=0 mass=390

GL > Stop tbar
GL > Sbot bbar
Stop > NA t
Stop > CA˜ b
Sbot > NA b
Sbot > CA t

NA > e- mu+ MPT
@ ( e- mu+ nu_tau | e- e+ nu_tau )
CA > MPT e- e+ mu-
CA > MPT e- nu_e
@ ( e- nu_e | mu- nu_e )

g g    > GL GL : name=GLprod matrix=2
g g    > Stop Stop˜ : name=Stopprod matrix=2
g g    > Sbot Sbot˜ : name=Stopprod matrix=2
```

More Leptons

Param	Low	BestFit	High	Name
total	0.2769	0.2839	0.2909	Sum Sigma
s0	0.3043	0.3260	0.3477	Sigma(g g > GL GL : name=GLprod matrix=2)
s1	0.5772	0.6167	0.6561	Sigma(g g > Stop Stop˜ : name=Stopprod matrix=2)
s2	0.0283	0.0573	0.0864	Sigma(g g > Sbot Sbot˜ : name=Stopprod matrix=2)
b0_0	0.6951	0.8047	0.9144	Br(GL > tbar Stop)
b0_1	0.0856	0.1953	0.3049	Br(GL > bbar Sbot)
b1_0	0.9099	0.9367	0.9634	Br(Stop > NA t)
b1_1	0.0366	0.0633	0.0901	Br(Stop > CA˜ b)
b2_0	0.0000	0.0002	0.2552	Br(Sbot > NA b)
b2_1	0.7448	0.9998	1.0000	Br(Sbot > CA t)
b3_0	1.0000	1.0000	1.0000	Br(NA > mu+ e- MPT)
b4_0	0.7983	0.9998	1.0000	Br(CA > mu- e- e+ MPT)
b4_1	0.0000	0.0002	0.2017	Br(CA > nu_e e- MPT)

...indeed, vastly favored over 1ℓ channel...

Alternatives...

We can check variants:

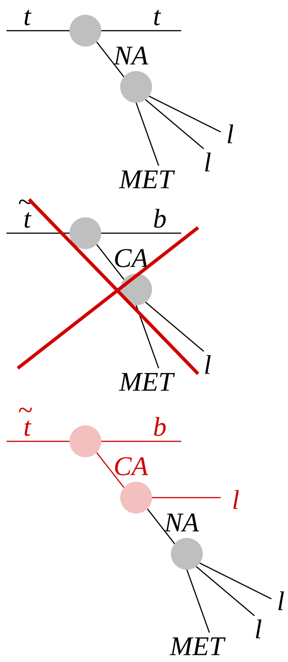
- interchange $\tilde{g}$, $\tilde{t}$—one extra hard parton on each decay
- Additional 1st/2nd generation squark channel
- Non-SUSY-like decays

Exhaustive list of reasonable guesses?

Challenges

- Exhaustive search
- Fast sim. not good enough?
- Reliability of BR fits?
  - Mass offsets $\longrightarrow$ trigger efficiency offset! Compromises fit

Theory and three leptons



...trilepton decays are quite striking! Tempting to assume intermediate NA!

Distinguishable? not sure... Take cascade option seriously for now, but should look for evidence!

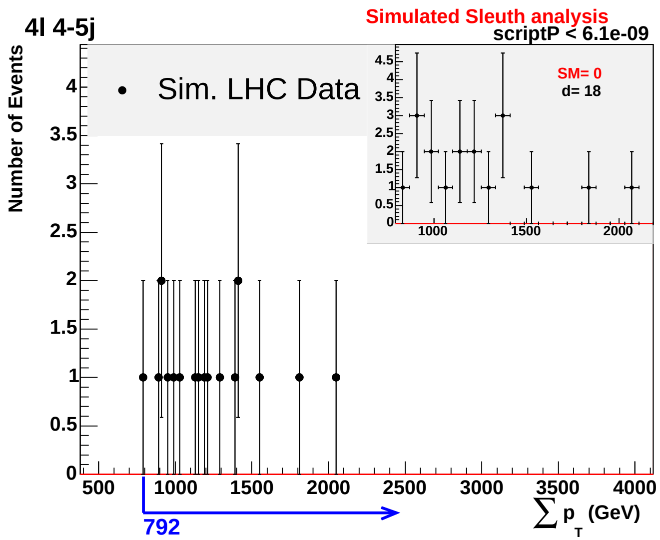
Resolving multiple processes

- How do we resolve overlapping new physics
- Requires a model of the process!
- An ambiguous example and a more solid one

- How to do this conservatively?
- Exhaustive searching
- When do you stop?

Something we missed

```
######Channel################    Target    Fit     Error   Pull ******|******+
l=3  b=1  j=8+ (  700<pT<  1400)   9.0   17.2     3.9      2.1         |**
l=2  b=4+ j=6  ( 1400<pT< 10000)   0.0    2.8     1.3      2.1         |**
l=3  b=4+ j=8+ ( 1400<pT< 10000)   1.0    4.0     1.7      1.7         |**
l=4  b=0  j=6  ( 1400<pT< 10000)   8.0    3.2     3.1     -1.5       **|
l=4  b=0  j=4  (    0<pT<   700)   7.0    2.0     3.0     -1.7       **|
l=4  b=0  j=4  ( 1400<pT< 10000)   7.0    1.5     2.9     -1.9       **|
l=4  b=0  j=4  (  700<pT<  1400)  26.0   15.5     5.6     -1.9       **|
```



Need more light-flavor jets, but too few to be squarks...

This is Higgsino production, but not 5σ discovery because other channels give background!

A bigger omission!

Unmask low jet counts: Leaving out EW production $\rightarrow$ very bad fit tells us where new physics is left out!

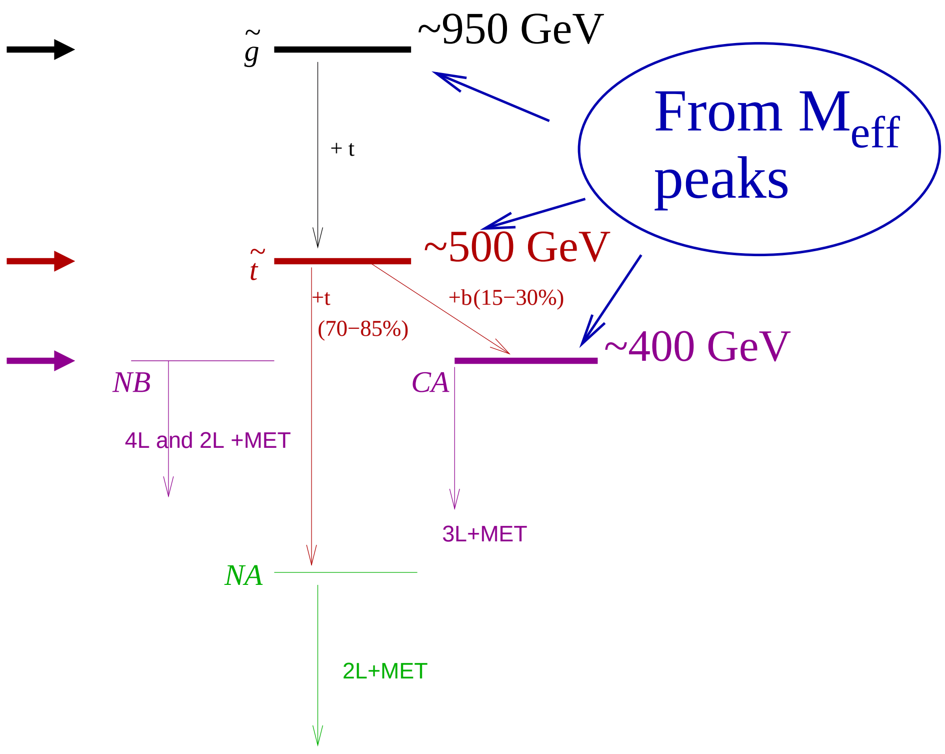
```
#########CHANNEL#########  TARGET    FIT    ERR   PULL
l=4  b=0  j=0  (pT < 700)   41.0     0.7    6.6   -6.1 +*****|
l=3  b=0  j=0  (pT < 700)   48.0     0.4    8.1   -5.9 +*****|
l=3  b=0  j=2  (700-1400)   54.0    17.0    7.8   -4.7  *****|
l=4  b=0  j=2  (pT < 700)   34.0     6.4    6.0   -4.6  *****|
l=4  b=0  j=0  (700-1400)   25.0     1.6    5.2   -4.5   ****|
l=3  b=0  j=2  (pT < 700)   44.0    12.4    7.5   -4.2   ****|
l=5  b=0  j=0  (pt < 700)   19.0     0.3    4.5   -4.2   ****|
l=5  b=0  j=0  (700-1400)   17.0     0.3    4.3   -3.9   ****|
l=4  b=0  j=2  (700-1400)   33.0    10.5    6.0   -3.8   ****|
l=3  b=0  j=0  (700-1400)   17.0     1.8    4.3   -3.5   ****|
l=6  b=0  j=0  (700-1400)   12.0     0.1    3.6   -3.3    ***|
l=5  b=0  j=2  (700-1400)   19.0     4.5    4.5   -3.2    ***|
l=3  b=0  j=4  (700-1400)   63.0    48.5    8.8   -1.6     **|
l=3  b=0  j=6  (pt < 700)    5.0     1.3    2.5   -1.5      *|
```

EW Production

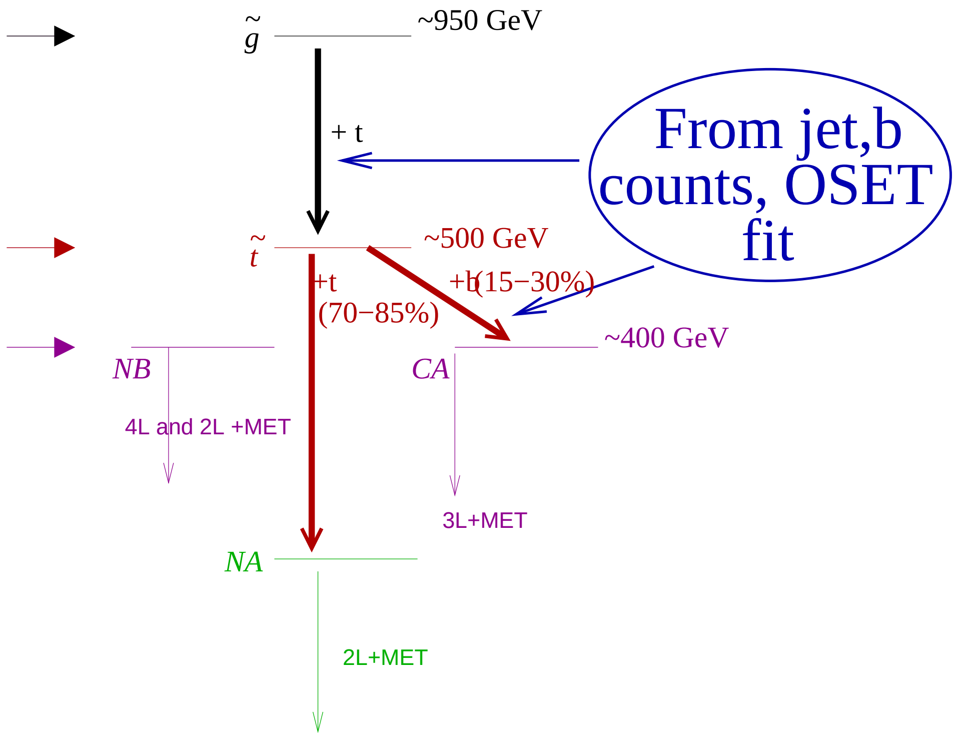
Model agreement requires production of the electroweak intermediate states we introduced. ($\sum p_T < 700$ does a good job isolating this component from other processes in OSET)

Also requires production of a new state with 4ℓ decay mode. Useful to have found, but nowhere near gold-plated

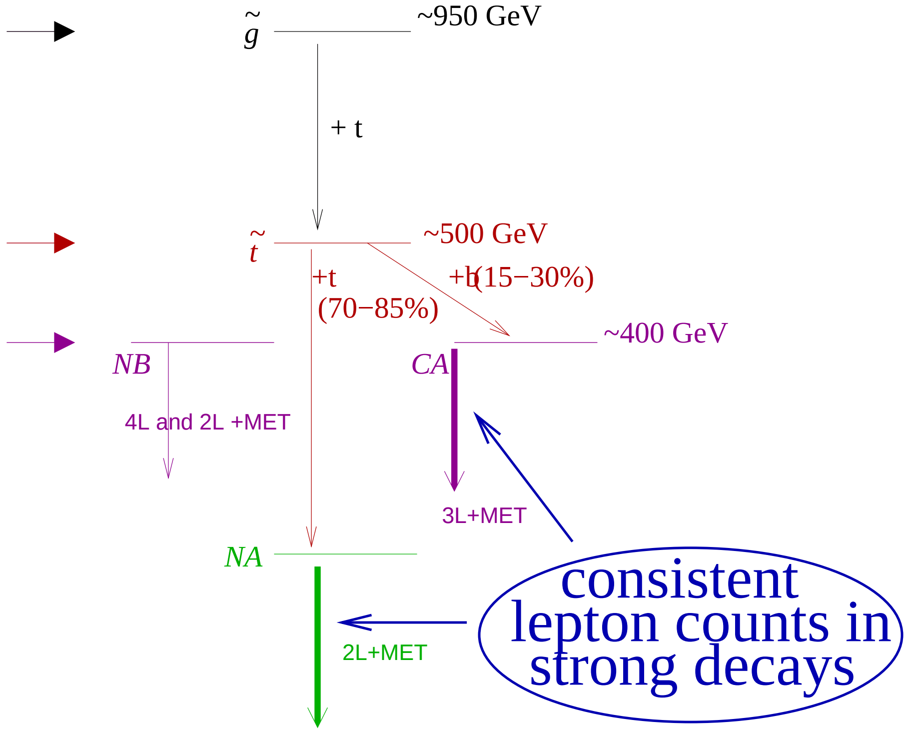
Abox OSET summary



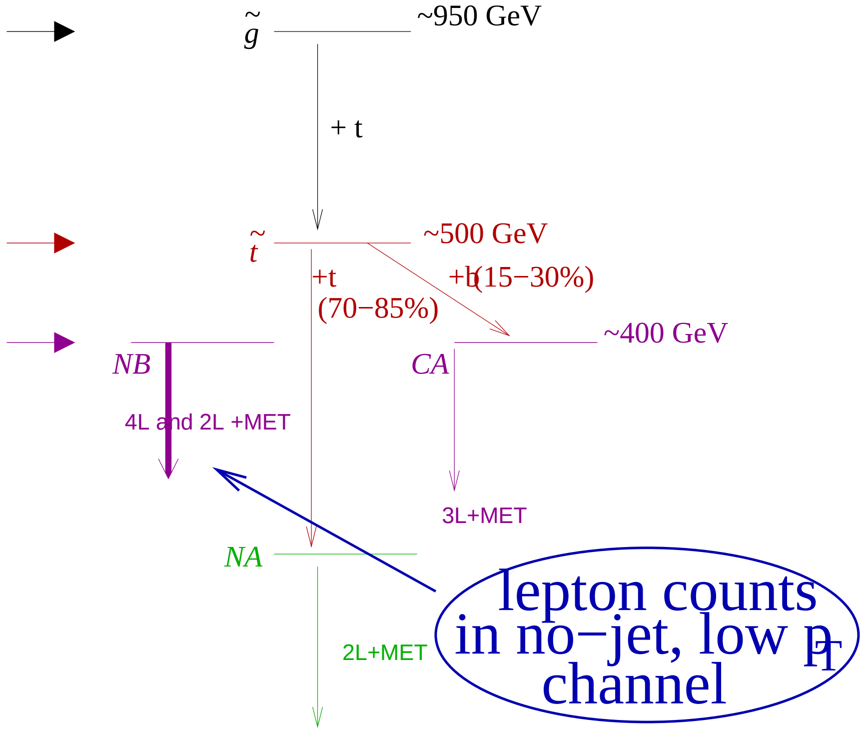
Abox OSET summary



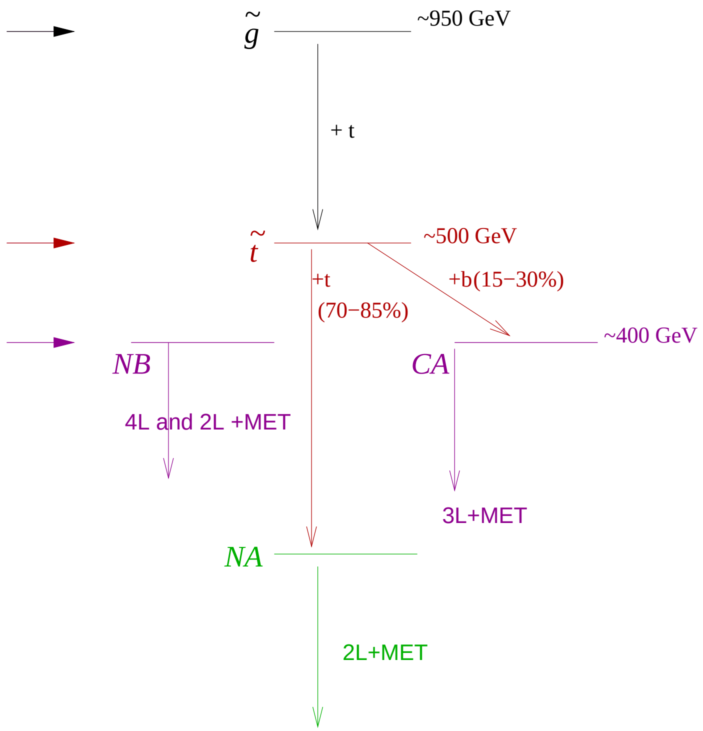
Abox OSET summary



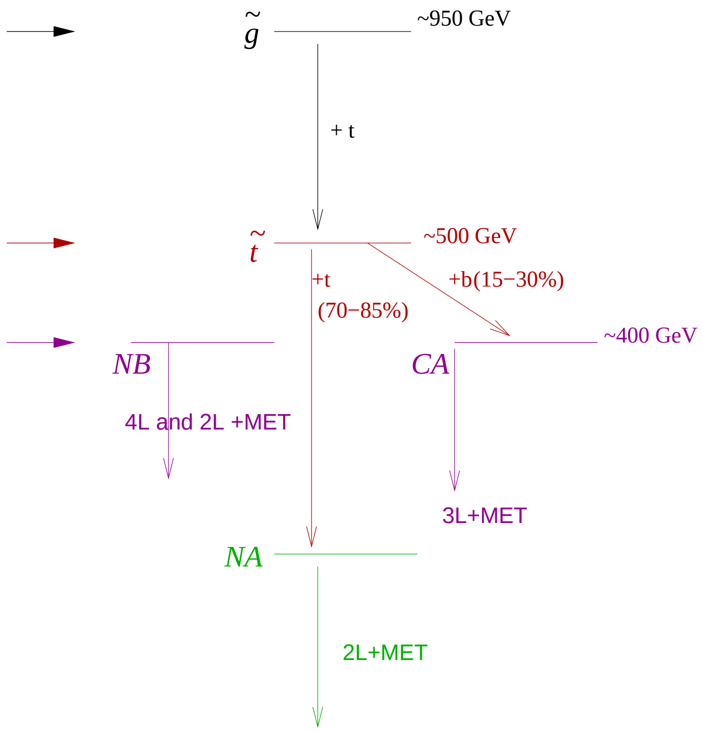
Abox OSET summary



Abox OSET summary



Abox OSET summary



where are all these leptons coming from? Why don't decays go through jets? Motivates extra on-shell leptonic states

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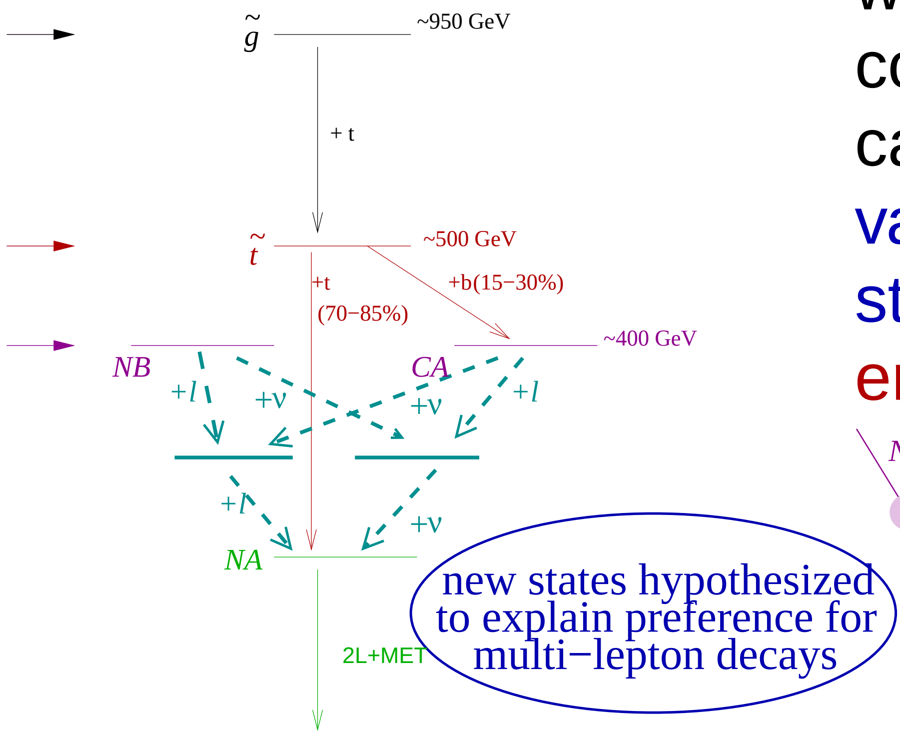
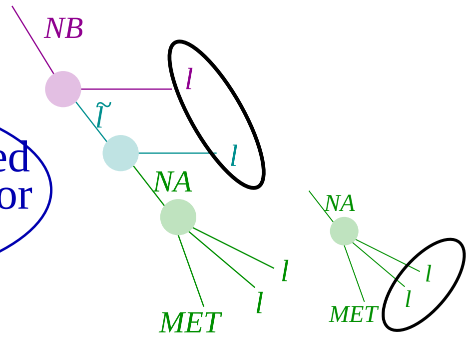


where are all these leptons coming from? Why don't decays go through jets? Motivates extra on-shell leptonic states— look for edges and endpoints!



Summary

- Pre-chosen OSET is an interesting alternative class of benchmarks
- Evolving OSET encapsulate structure of new physics as early as possible
- An invariant characterization of data that is accessible to people outside the experiment
- Facilitates model development, which in turn can motivate further new physics searches and direct search for kinematic features