Solving the L.H.C Inverse Problem

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with: Philip Schuster
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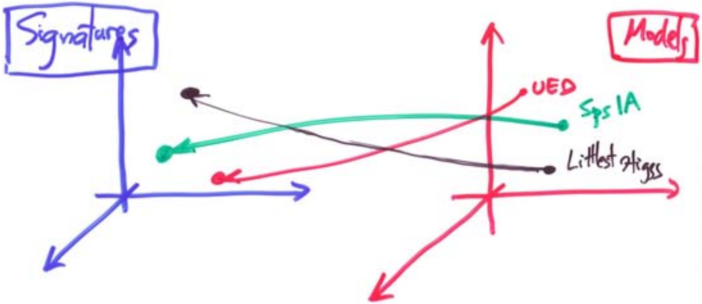
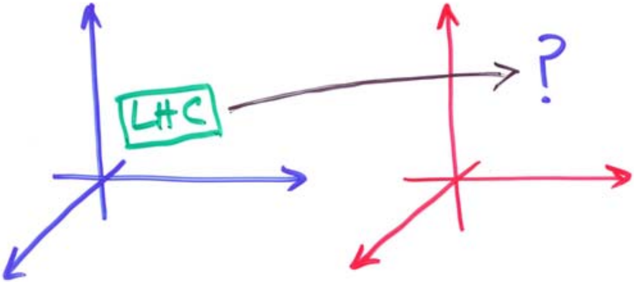
Jesse Thaler
Lian-Tao Wang
Bruce Knuteson
Steve Mrenna
+ the LHC Olympics community



most work to date.

What is really wanted:



"Inverse" Problem.

Tackling this problem was the inspiration for the "LHC Olympics"

[Feb '06 CERN
Aug '06 KITP
March '07 Princeton]

where "Black boxes" were "realistically" simulated, and theorists had to go back + figure out underlying model.

Very instructive to try such excercises – things are more challenging in inverse direction!

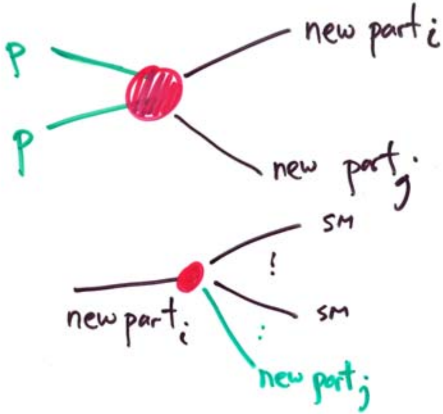
What would it mean to "solve"
the inverse problem?

- The weak scale $\mathcal{L}_{eff}$?

This may not even be unique,
+ majority of int. aren't even relevant.
Lots of wasted time simulating...

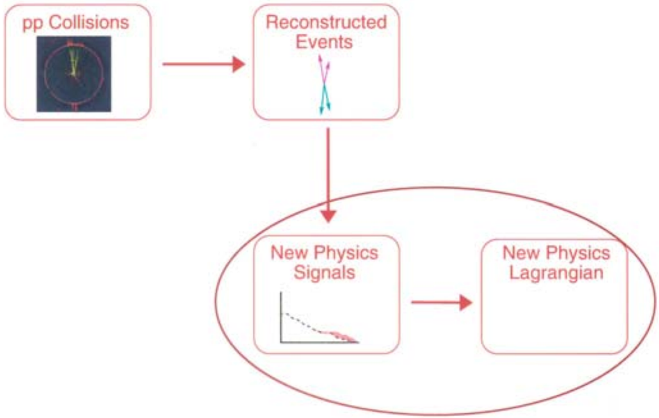
- What is a more invariant characterization of the Data?

On-shell Effective Theory



masses m_i, σ's, Br. ratios.

The "Inverse" Problem



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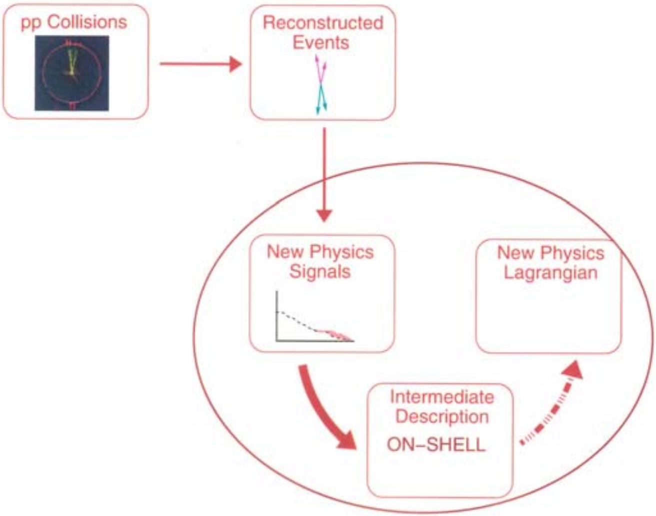


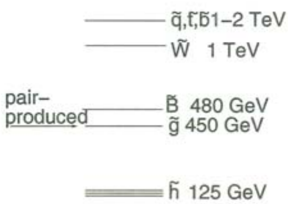
MARMOSET

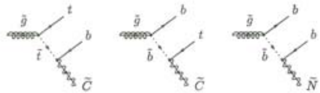
- Monte-carlo tools + a strategy for getting the On-shell eff. description.

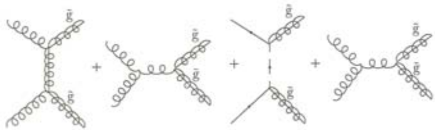
Invariant solution(s) of Inverse Problem, can be systematically improved as we get more data.

Example: Why OSET?

The "Michigan Black Box" from Winter '06 LHCO







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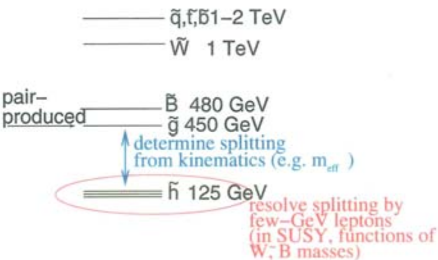

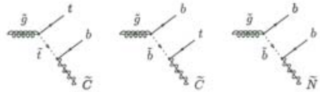

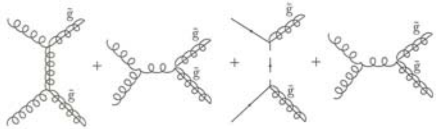

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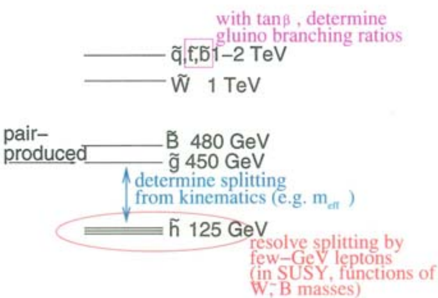

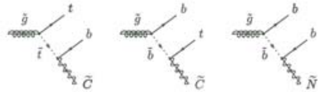

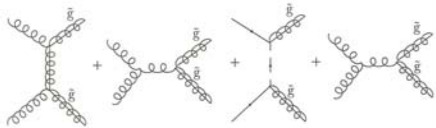

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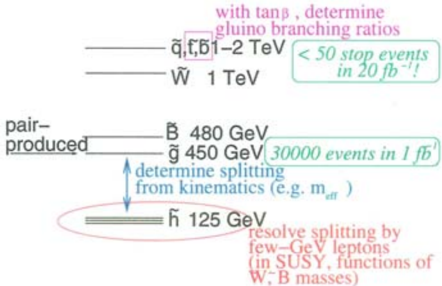

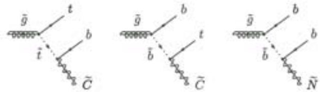

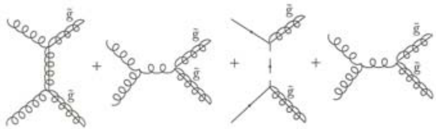

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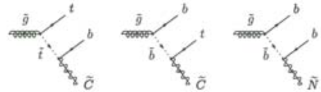

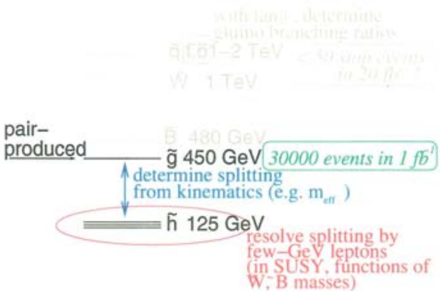

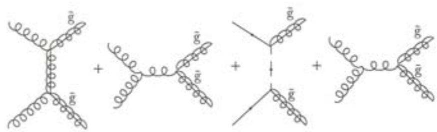

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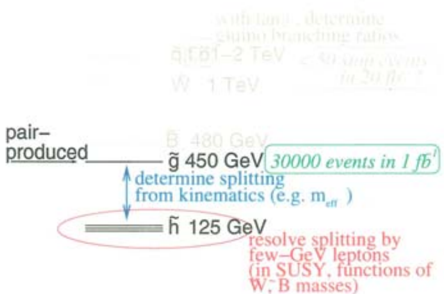

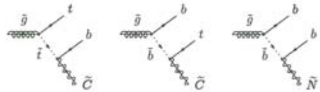

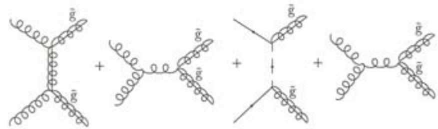

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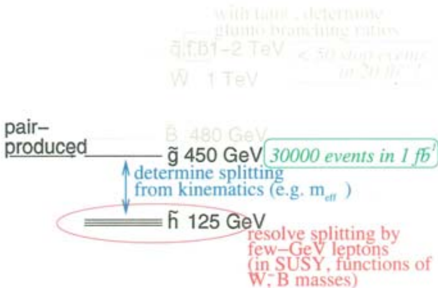

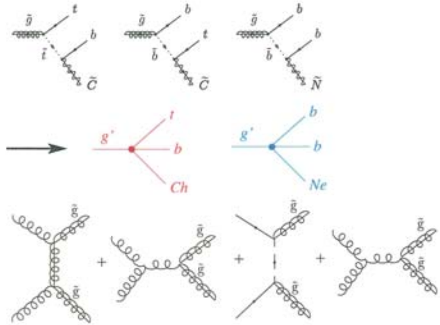

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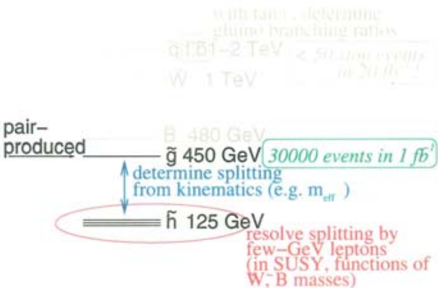
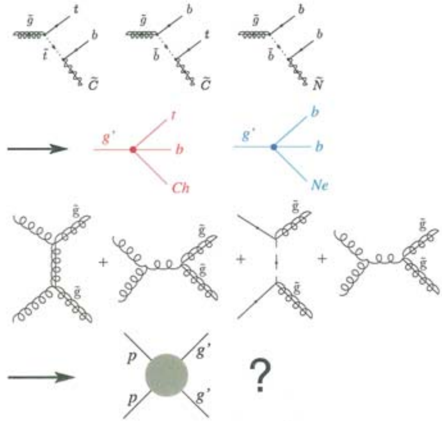




Simulating and evaluating (MARMOSET)

MARMOSET is both a set of MC tools and a strategy.

```
# 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

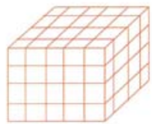
Simulating and evaluating (MARMOSET)

```
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)

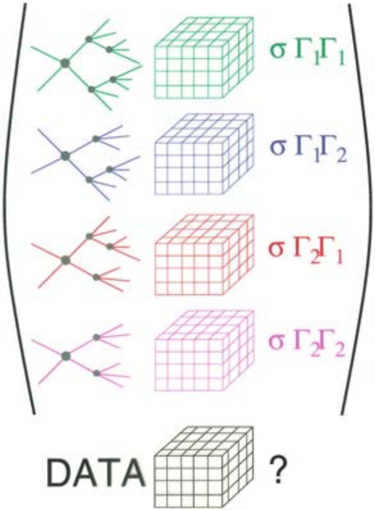
generate events in Pythia, simulate, and evaluate signatures

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

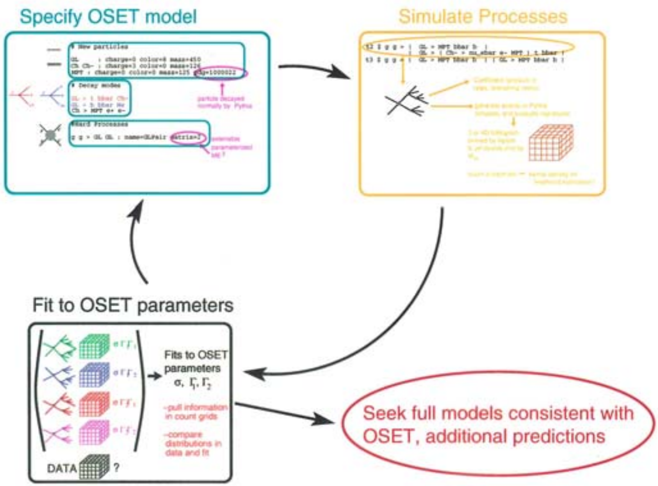
$\sigma,\ \Gamma_1, \Gamma_2$

↓

–pull information in count grids

–compare distributions in data and fit

Simulating and evaluating (MARMOSET)

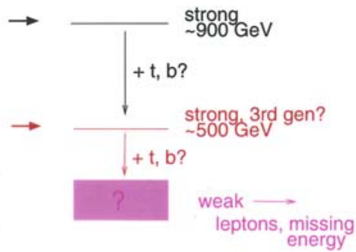


An Example: ABOX

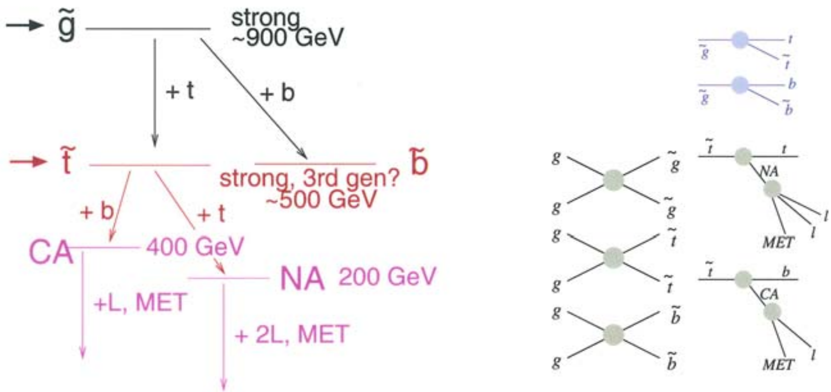
- SUSY model inspired by LHC Olympics Black Box C
- 4 fb^{-1} generated in pythia + backgrounds
- Background treatment is not fully realistic
- Simulated with PGS 3, as modified by Steve Mrenna, with triggers added by Harvard group
- Tools are in beta version, incorporate only primitive fitting...
-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

Starting points

- 2 distinct scales in $M_{eff} \equiv \sum |p_T| + \not{E}_T$: $\sim$ 1800 GeV (≥ 4 jets), 600-800 GeV (≤ 4 jets)
- No new resonances visible $\rightarrow$ assume new physics pair production
- Lepton-rich and b-rich
- Producing new particles with mass $\sim$ 1 TeV, 500 GeV?
- More jets in high-M_{eff} peak—decays through second particle?



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

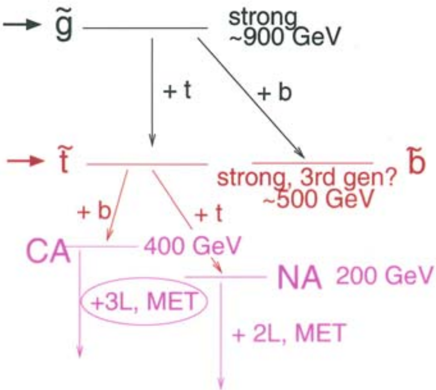
Starting guess: problems

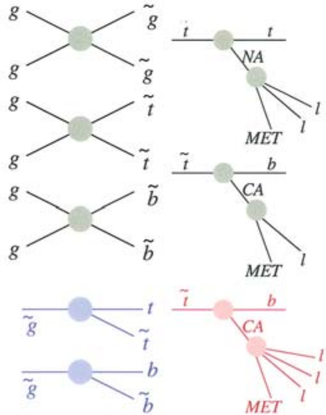
Fit: need to produce `b` with more leptons...

```
######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 + 3ℓ decay mode!



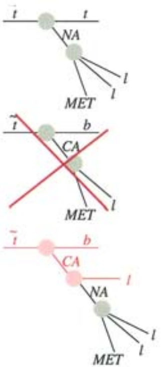


More Leptons

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...

Theory and three leptons

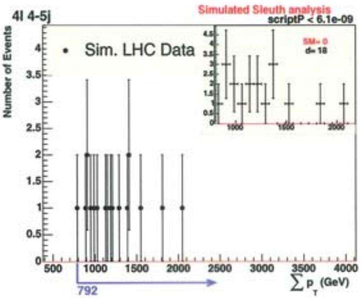


...trilepton decays are quite striking! Tempting to assume intermediate NA!

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

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—do OSETs help in isolating it from other BSM channels before we know exactly what they are?

A bigger omission!

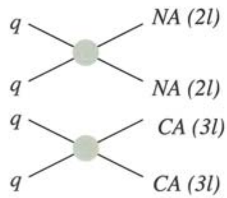
Unmask low jet counts: Leaving out EW production $\rightarrow$ very bad fit tells us where new physics is left out!

```
#########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      *|
```

Minimal EW production

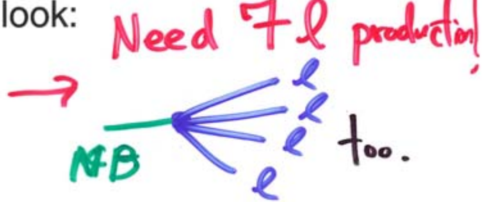
Add CA (3ℓ decay) and NA (2ℓ decay) direct production to OSET–is this enough to fill low-jet-count bins? (should also include assoc.)

*	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	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$	$0_{1.}$

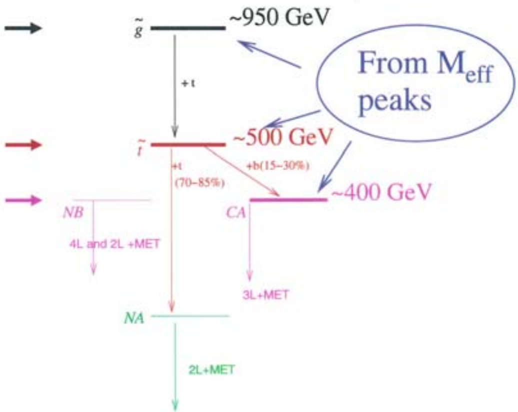


Again, the OSET tells us where to look:

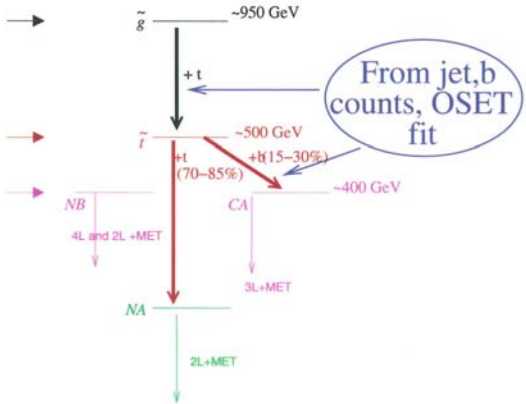
#########CHANNEL#########		TARGET	FIT	ERR	PULL	
l=4 b=0 j=2	(pT < 700)	34.0	14.7	6.0	-3.2	***|
l=5 b=0 j=2	(700-1400)	19.0	8.6	4.6	-2.3	**|
l=4 b=2 j=2	(700-1400)	11.0	3.7	3.5	-2.1	**|
l=6 b=0 j=0	(700-1400)	12.0	4.7	3.7	-2.0	**|
l=4 b=0 j=4	(pT < 700)	7.0	1.8	2.9	-1.8	**|



Abox OSET summary



Abox OSET summary



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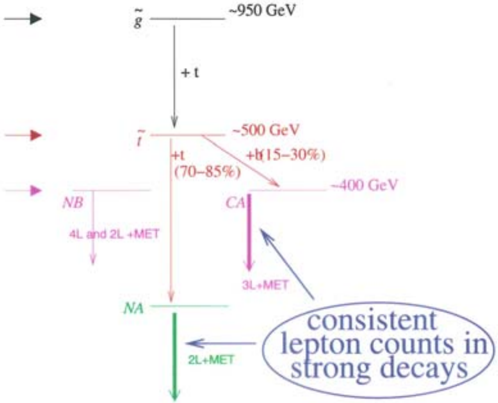

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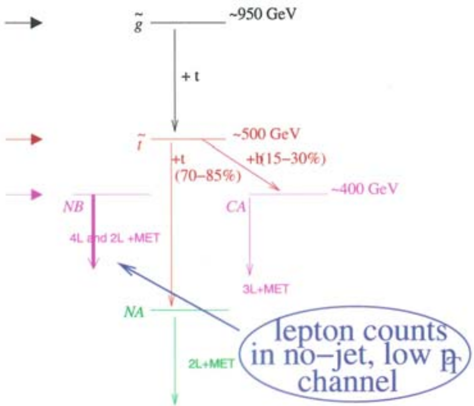

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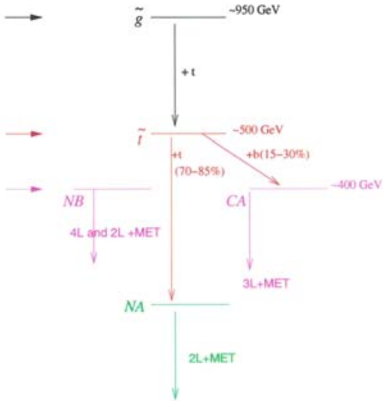

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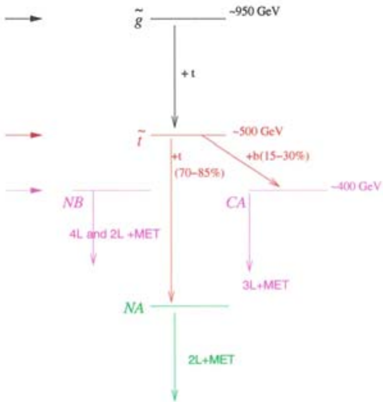

where are all these leptons coming from? Why don't decays go through jets? Motivates extra on-shell leptonic states

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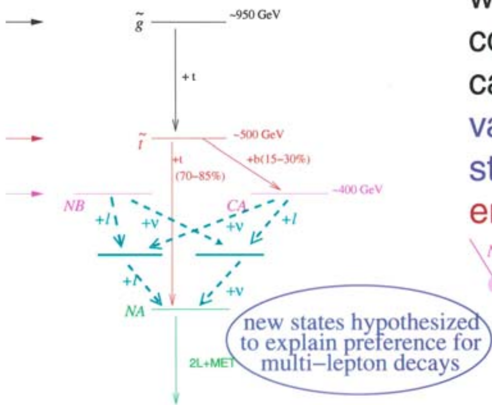
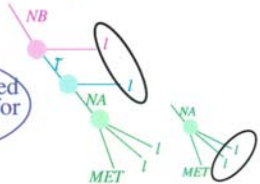


where are all these leptons coming from? Why don't decays go through jets? Motivates extra on-shell leptonic states— look for edges and endpoints!



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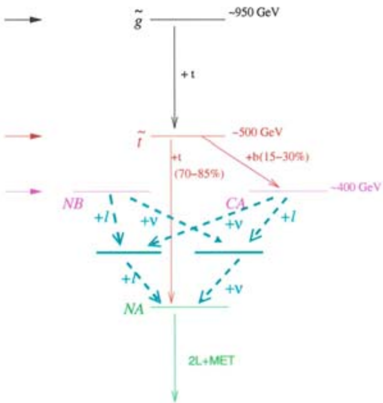

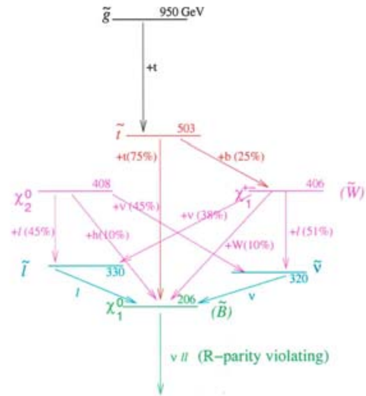

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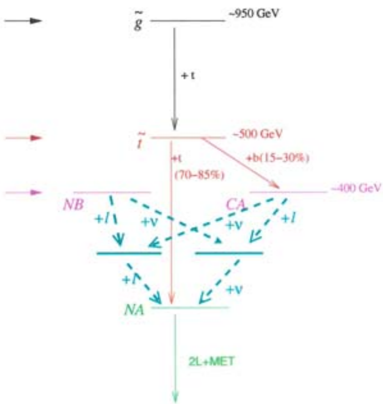

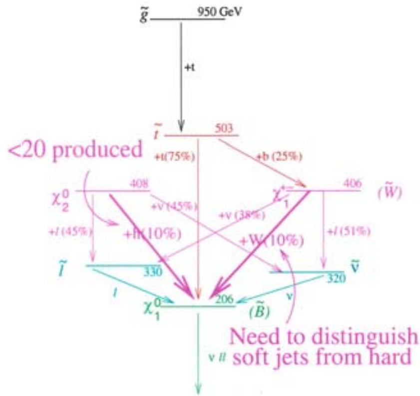

Summarizing

- On-shell description is physical, invariant characterization on new physics [Preferable to fits to benchmarks!].
- Most natural starting point for going back to underlying $\mathcal{L}_{eff}$! And then thinking about models in turn motivates new searches for e.g. kinematic features.

MARMOSET

- Introductory paper w/ motivation + examples out by January.
- M.C. tools + documentation by early spring
- We think it will be useful to model-builders, collider physicists + experimentalists alike, and await feedback!
- < 2 yrs to be <u>really</u> <u>really</u> ready!