UCSB

Sue Ann Koay

Roberto Rossin

with

SLAC

Philip Schuster

Stanford

Natalia Toro

MARMOSET @ CMS

Hep-ph/0703088 (N.Arkani-Hamed et al.)

Talks given at the CMS week 12/12/07

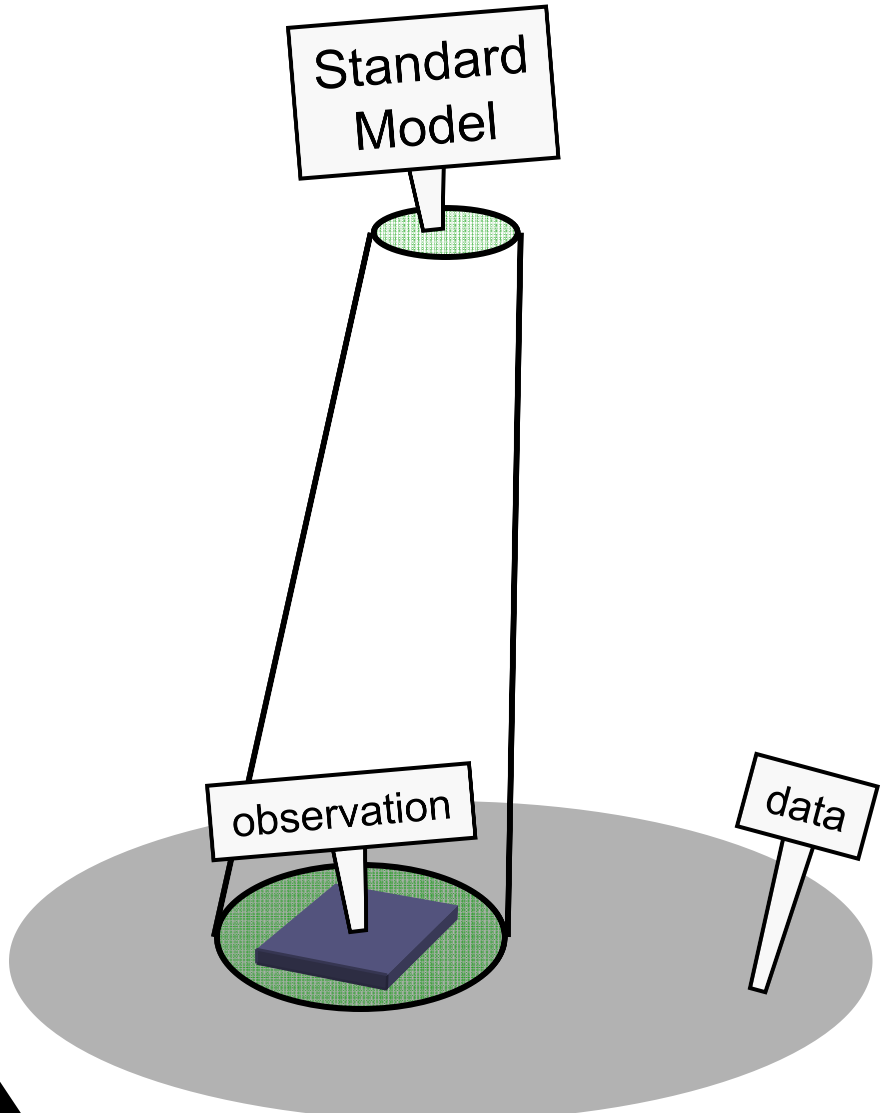
P. Schuster:

Preparing for new physics at the LHC with On-shell Effective Theories

S.A. Koay:

A tale of two particles

Present History of Physics searches



Specific predictions :

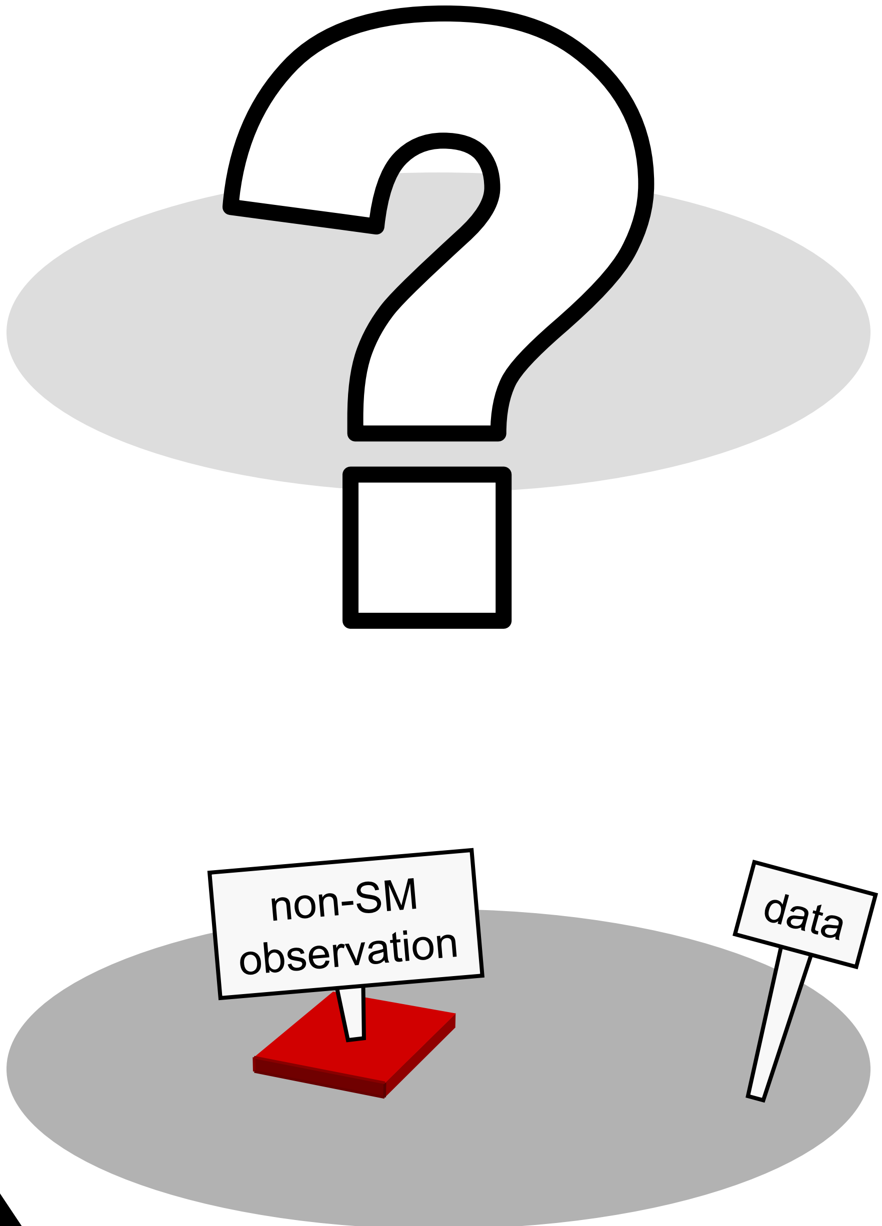
(e.g. $t\bar{t} \rightarrow bW\ bW \rightarrow bl\nu\ bl\nu$, …)

- topologies
- kinematics range
- distinguishing features

Analysis (the search)

- cross-sections
- masses
- …

fit → couplings …

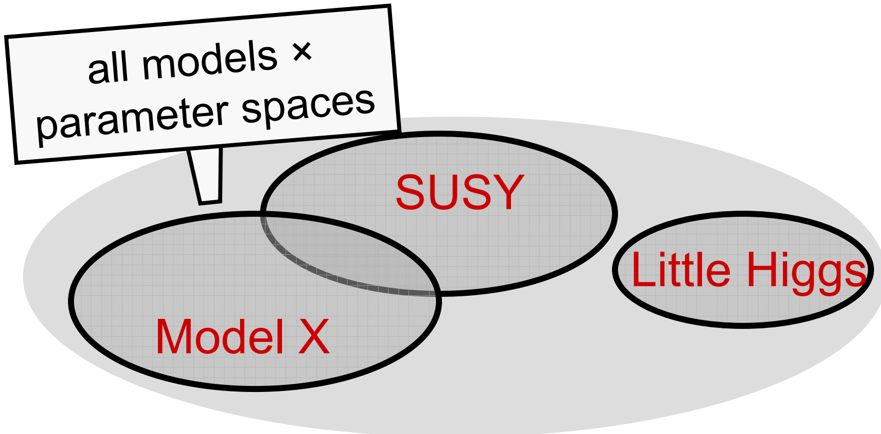


New-Physics searches

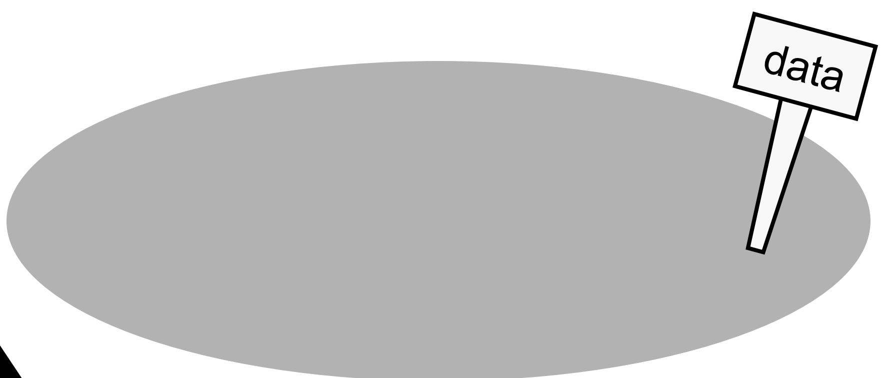
Interpretation?

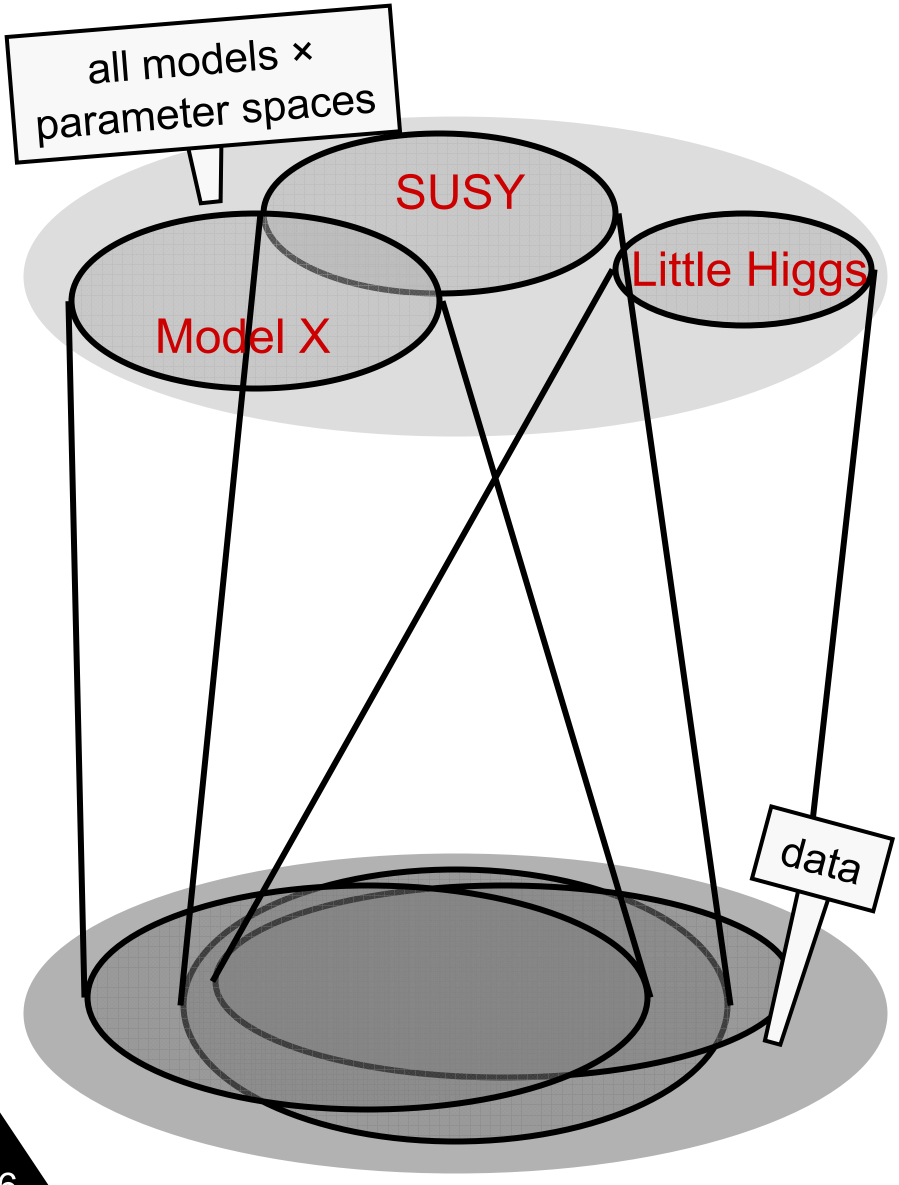
What next?

New-Physics searches



BSM models ~ O(∞)





New-Physics searches

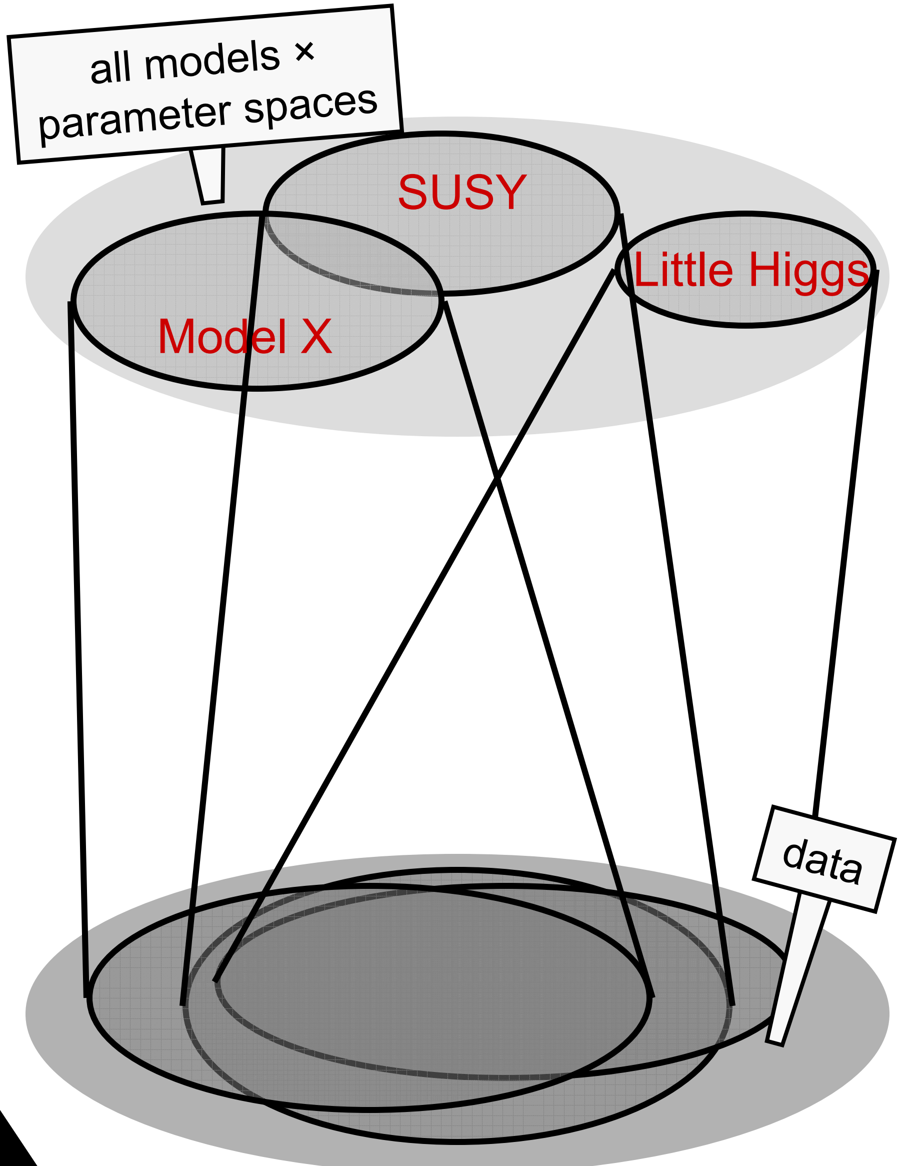
BSM models ~ O(∞)

within model parameter space

across models

Large degeneracies in predictions for the LHC

New-Physics searches



Full scan:

BSM models ~ O(∞)

within model parameter space

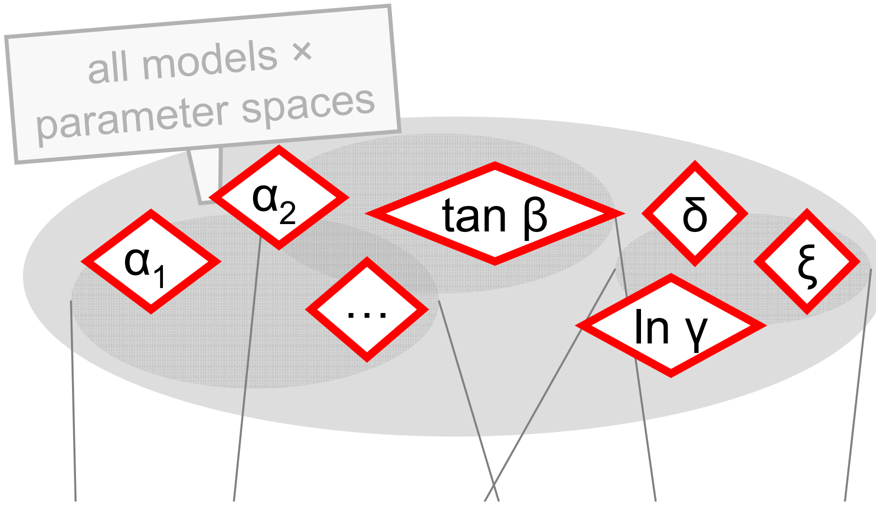
across models

predictions for the LHC

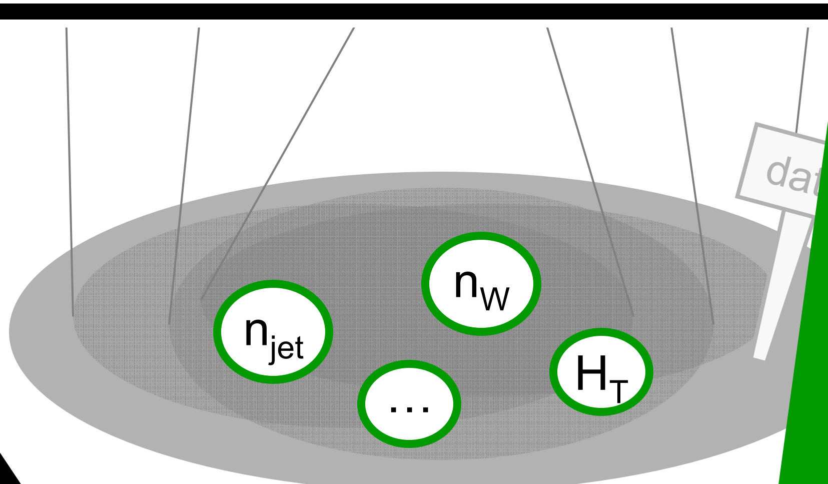
Computationally daunting

New-Physics searches

Full Models

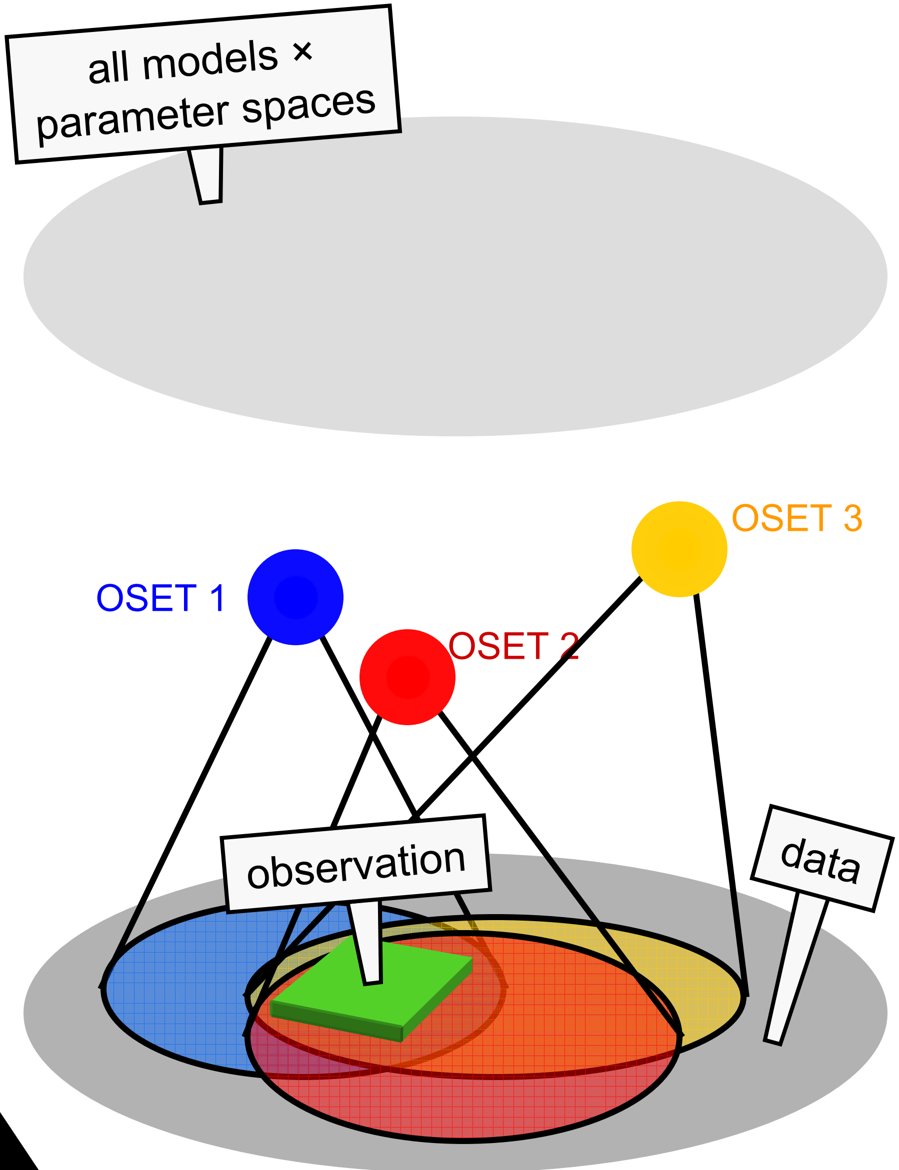


Intermediate characterization?



Pure-Experimental Observations

OSETs in New-Physics searches

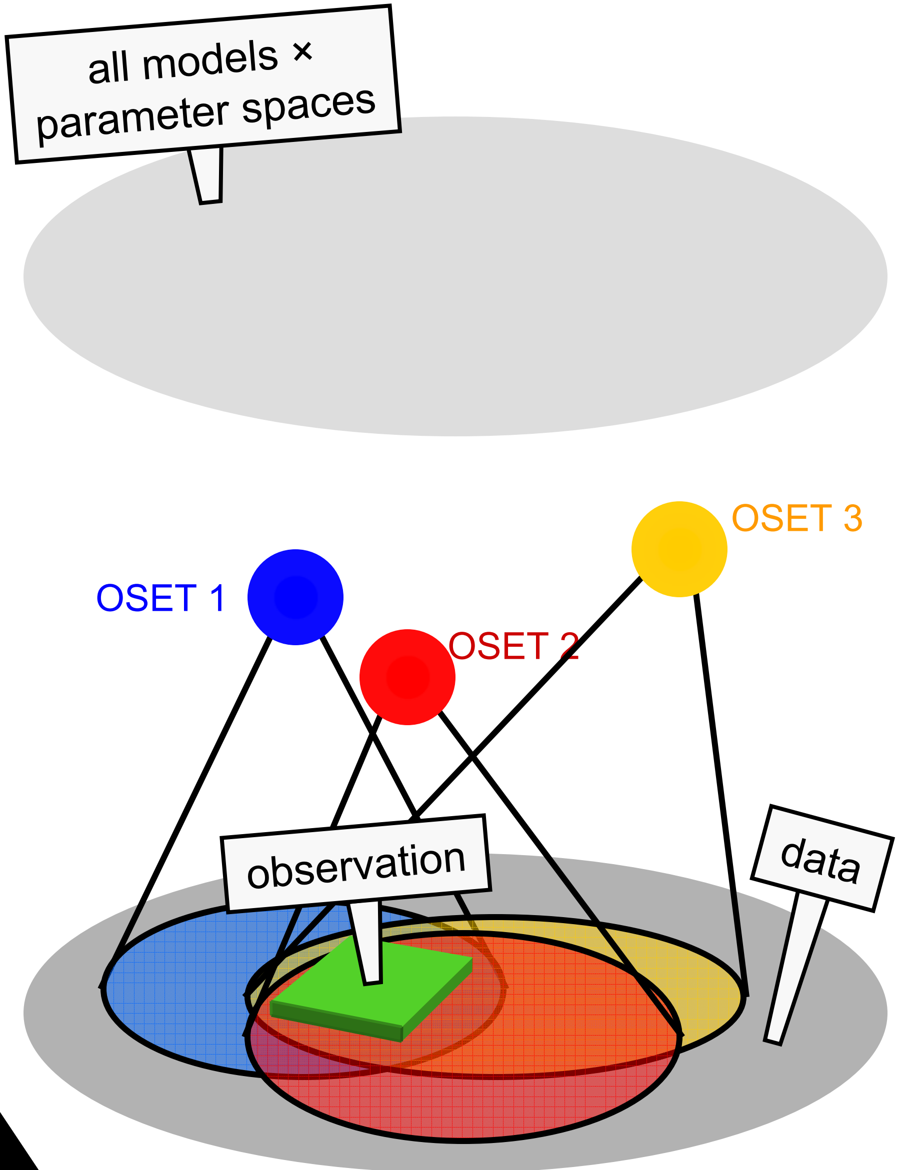


n- hell ffective heory

O S E T s ≡

observation-inspired
skeleton models

OSETs in New-Physics searches



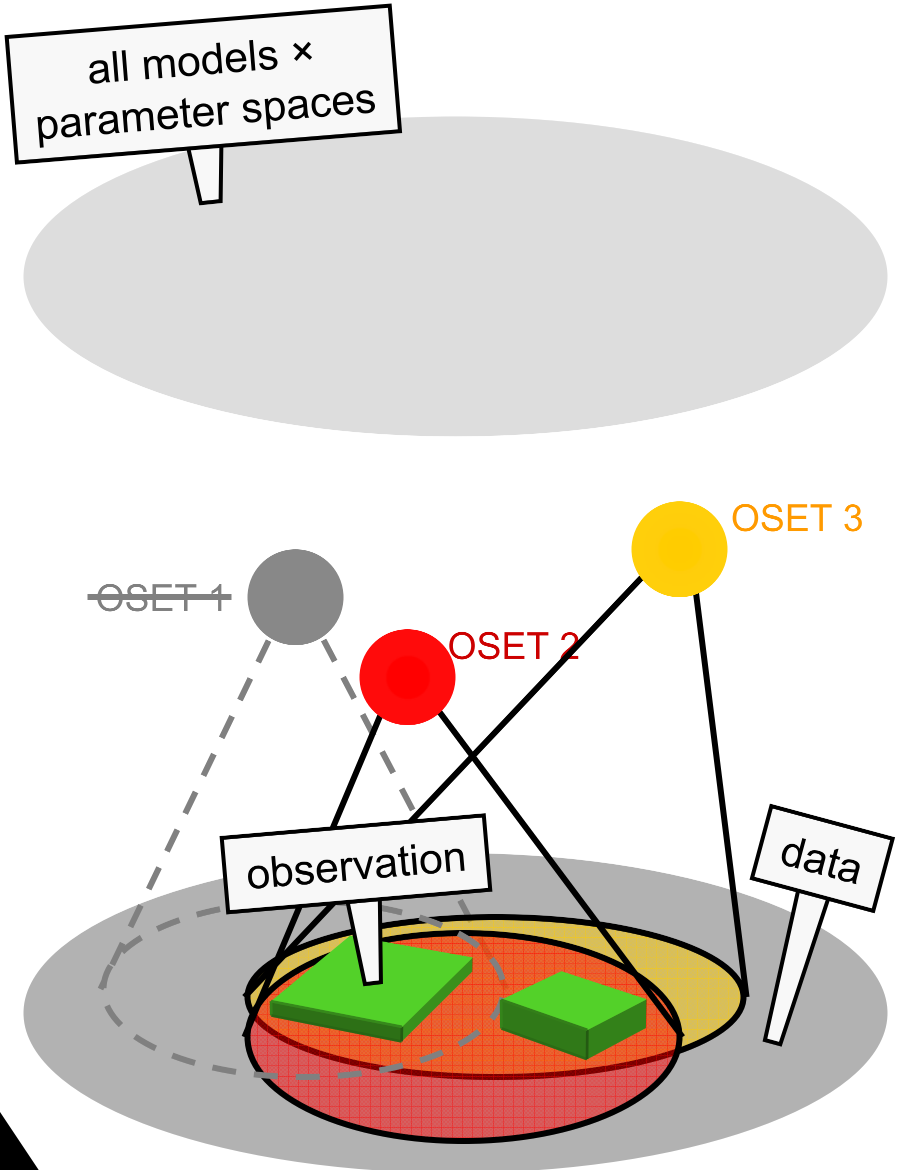
n- hell ffective heory

O S E T s ≡

observation-inspired skeleton models

Still with predictive power

OSETs in New-Physics searches



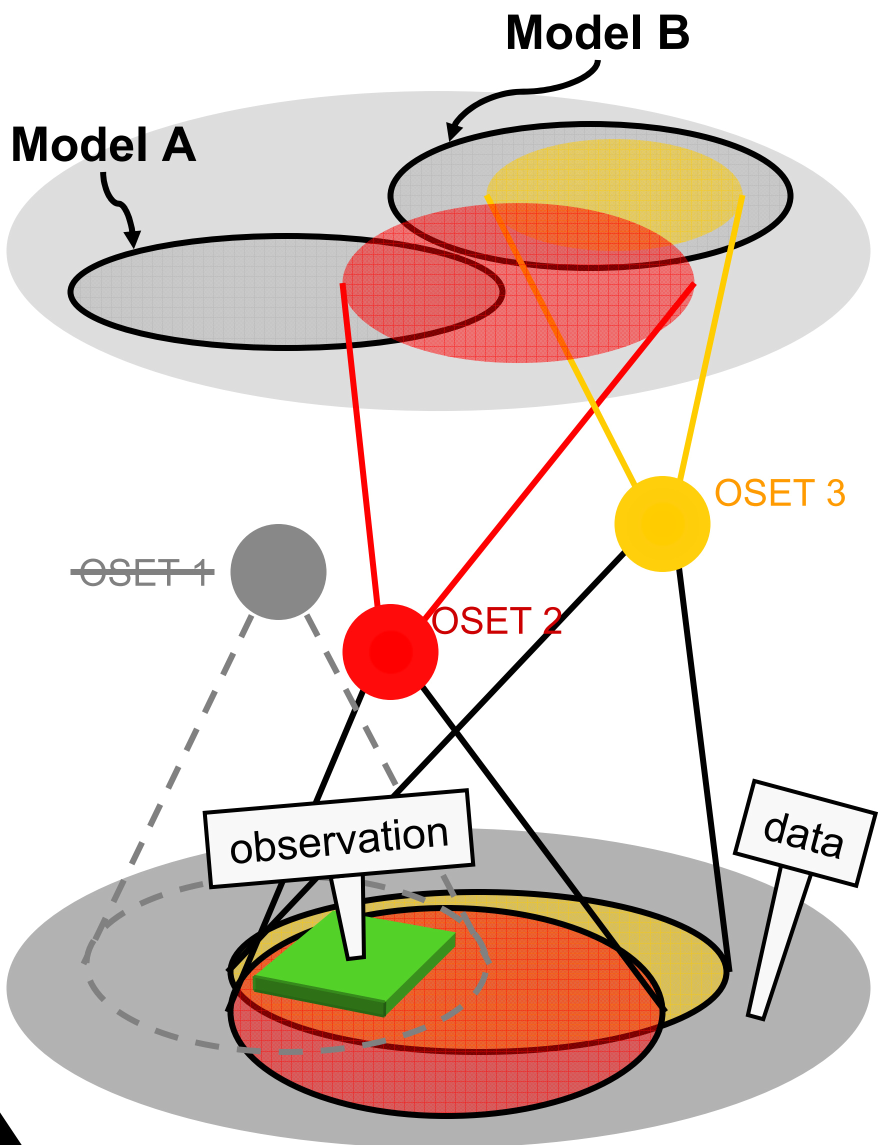
Summaries of
(part of) full models

On-Shell Effective Theory

OSETs ≡
observation-inspired
skeleton models

Still with predictive power

OSETs in New-Physics searches



Summaries of
(part of) full models

On-Shell Effective Theory

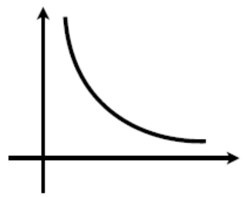
O S E T s ≡
observation-inspired
skeleton models

Still with predictive power

OSETs

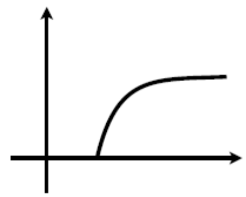
$$\frac{d\sigma}{d\hat{t}} = \int$$

Parton Luminosity



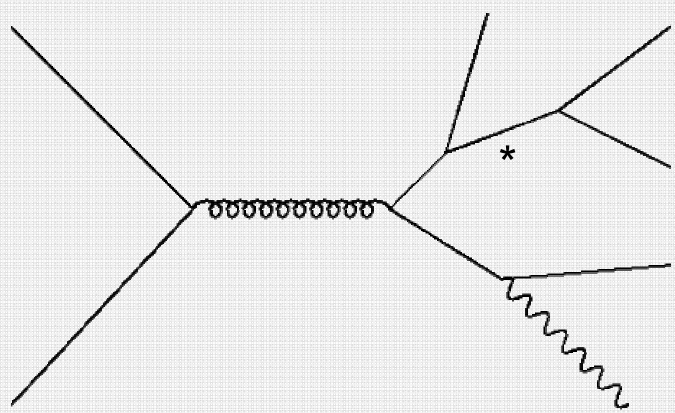
$\times$

Phase Space (Threshold)



$\times \; |\mathcal{M}|^2$

Full model calculation



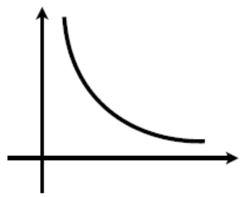
- spins
- couplings
- off-shell states
- …

OS Effective Theories

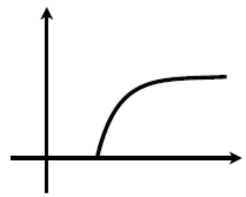
Parton Luminosity

Phase Space (Threshold)

$$\frac{d\sigma}{d\hat{t}} = \int$$

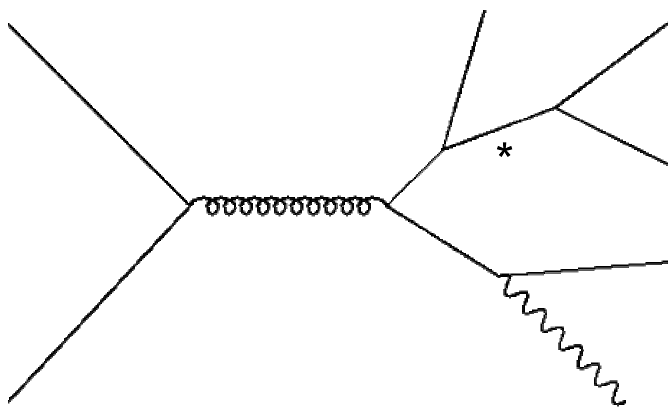


$\times$

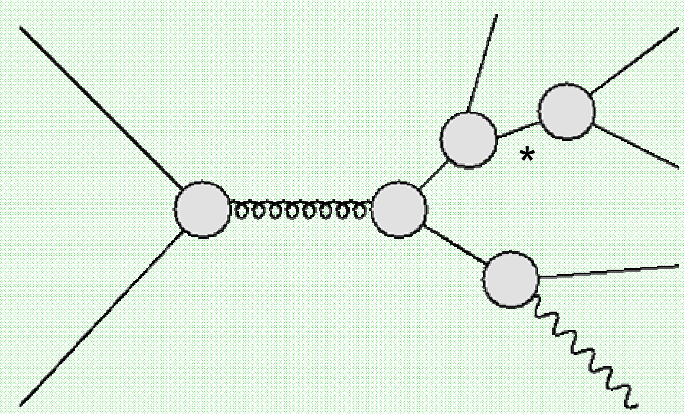


$\times \; |\mathcal{M}|^2$ ~ constant

Full model calculation



Parameterization



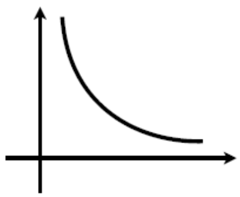
- spins
- couplings
- off-shell states
- …

branching ratios

On-Shell Effective Theories

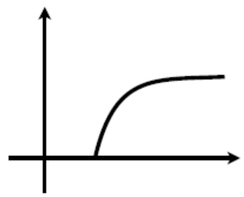
$$\frac{d\sigma}{d\hat{t}} = \int$$

Parton Luminosity



$\times$

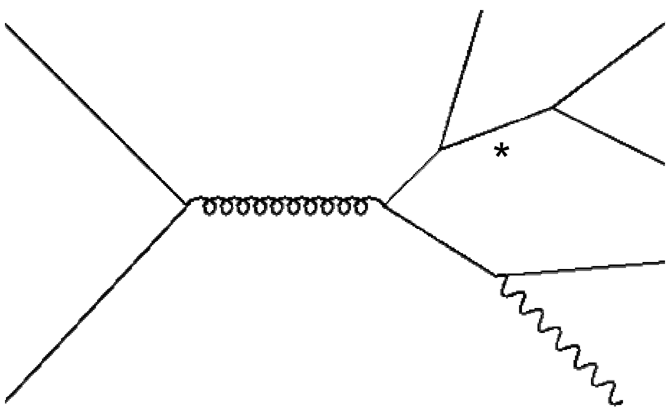
Phase Space (Threshold)



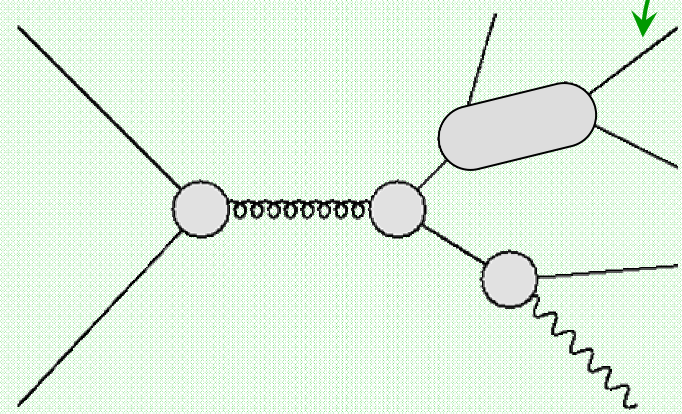
$\times \; |\mathcal{M}|^2$ ~ constant

all lines on-shell

Full model calculation



Parameterization

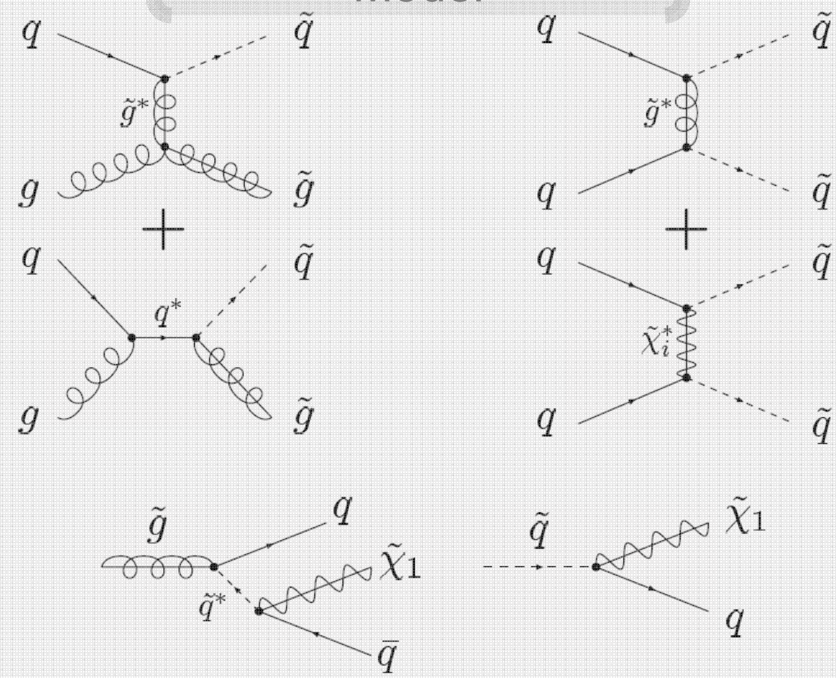


- spins
- couplings
- off-shell states
- …

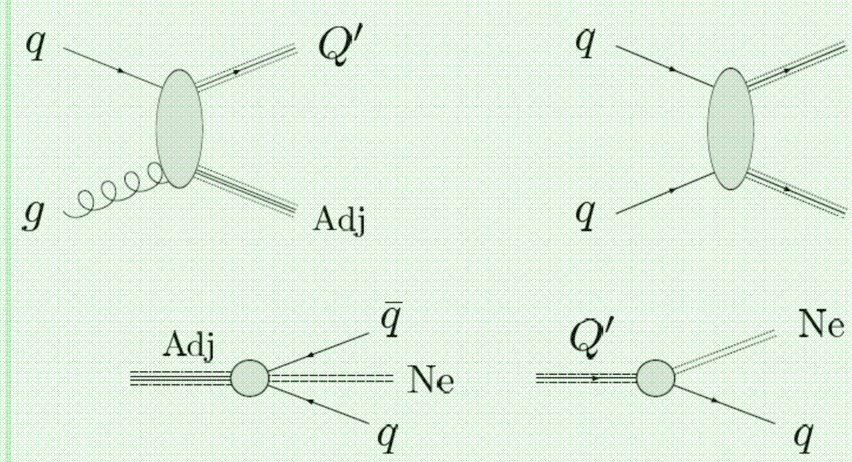
branching ratios

A SUSY example

Model



Parameterization

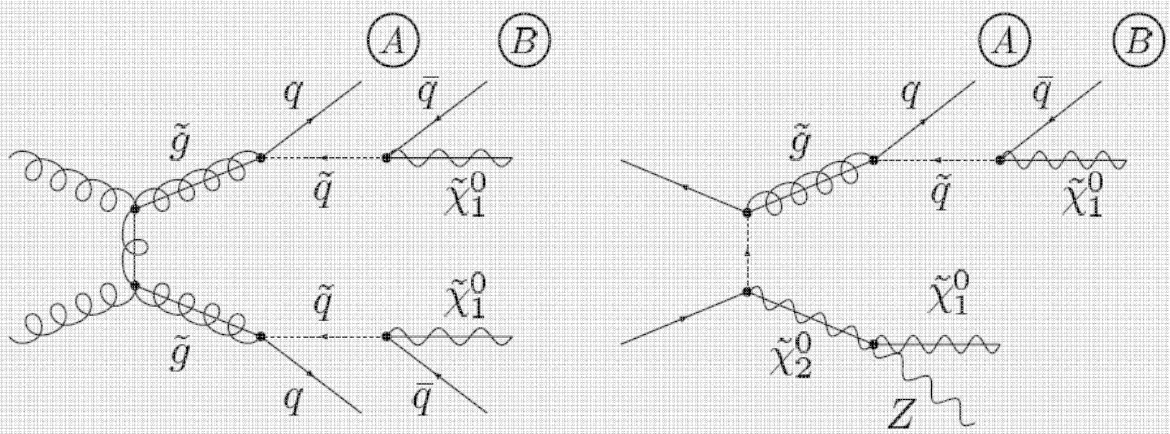


- on- and off-shell masses
- several couplings
  control both kinematics and rates

- Production contributions:
  Associated q̃-g̃: intermediate q and g̃
  Same sign q̃: g and 4 neutralinos

- “blobs” represent dynamics that are parameterized by one rate and possibly an additional shape parameter
- Off-shell particle do not appear, their effects present in the rates
  - gauginos do not appear in the OSET

Another SUSY example



Particle	Mass (GeV)
$\tilde{g}$	992
$\tilde{q}$	700
$\tilde{\chi}_2^0$	197
$\tilde{\chi}_1^0$	89

$$|\mathcal{M}(gg \to \tilde{g}\tilde{g})|^2 \propto \left(1 - \frac{t_g u_g}{s^2}\right)\left[\frac{s^2}{t_g\, u_g} - 2 + 4\,\frac{m_{\tilde{g}}^2 s}{t_g u_g}\left(1 - \frac{m_{\tilde{g}}^2 s}{t_g u_g}\right)\right]$$

$$|\mathcal{M}(q\bar{q} \to \tilde{g}\tilde{g})|^2 \propto \left[\frac{t_g^2 + m_{\tilde{g}}^2\, s}{s^2} + \frac{4}{9}\frac{t_g^2}{t_q^2} + \frac{t_g^2 + m_{\tilde{g}}^2\, s}{s\, t_q} + \frac{1}{18}\frac{m_{\tilde{g}}^2 s}{t_g\, u_g} + (t \leftrightarrow u)\right]$$

$$t_g = (p_{g,1} - p_{\tilde{g},1})^2 - m_{\tilde{g}}^2,\ u_g = (p_{g,1} - p_{\tilde{g},2})^2 - m_{\tilde{g}}^2$$

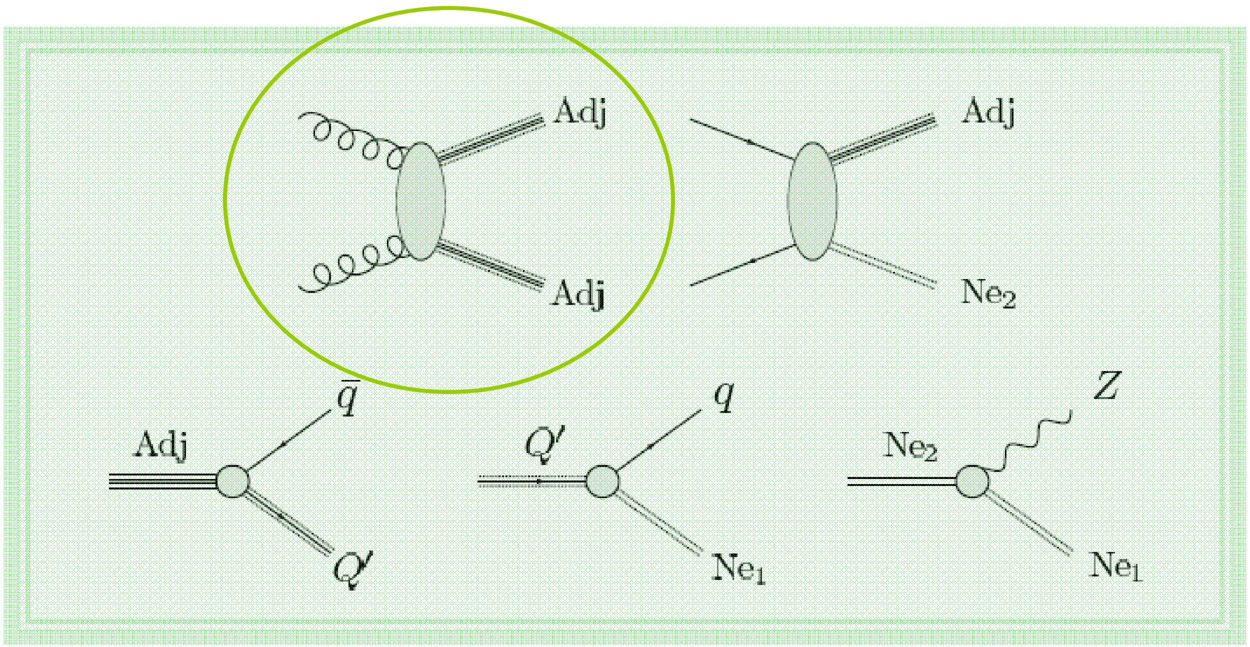
$$t_q\ \ (u_q) = (p_{g,1} - p_{\tilde{g},1(2)})^2 - m_{\tilde{q}}^2$$

Another SUSY example

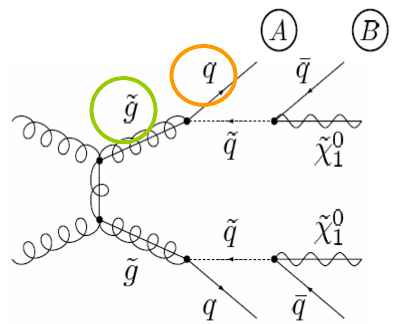
How can we manage to approximate the ME?
If the matrix element $|M|^2$ varies smoothly over energy,
while parton luminosities fall rapidly about threshold

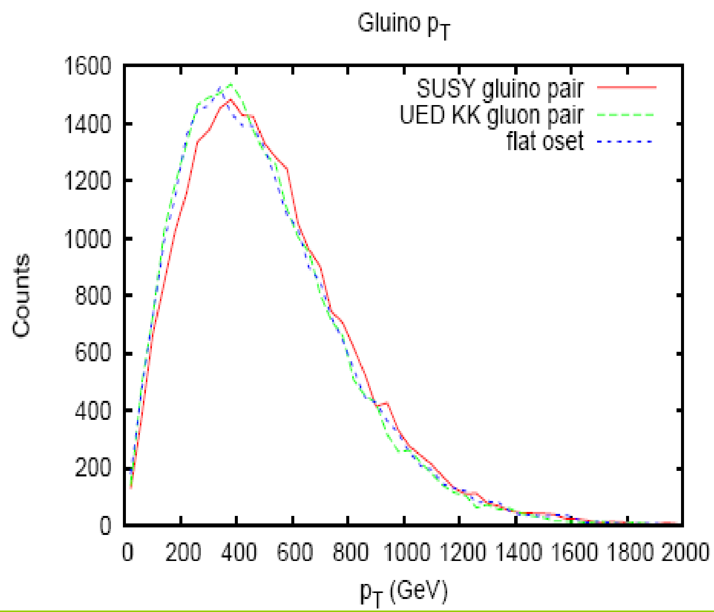
$$|\mathcal{M}|^2 = \text{constant}$$

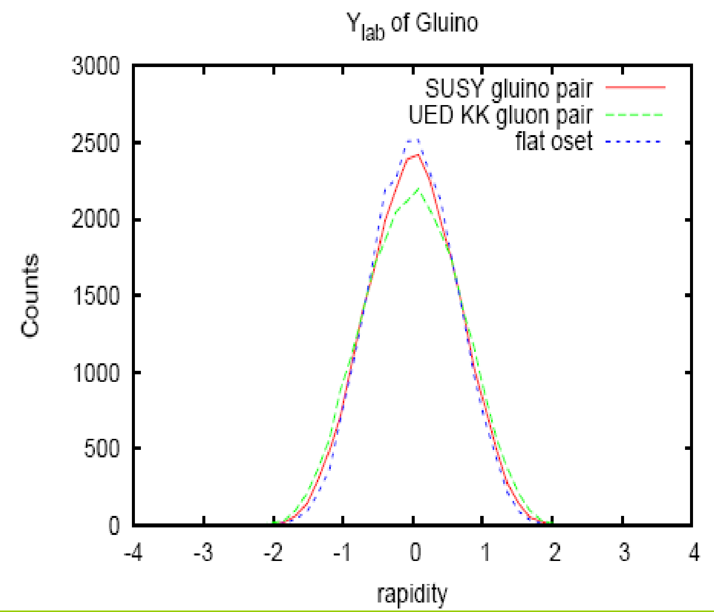
reproduces well the kinematics of the hadron production
This is indeed true for the gluino pair-production

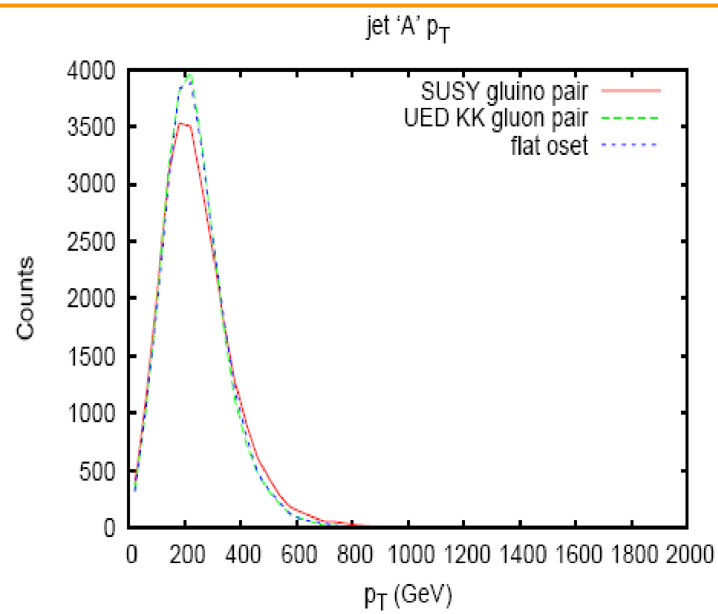


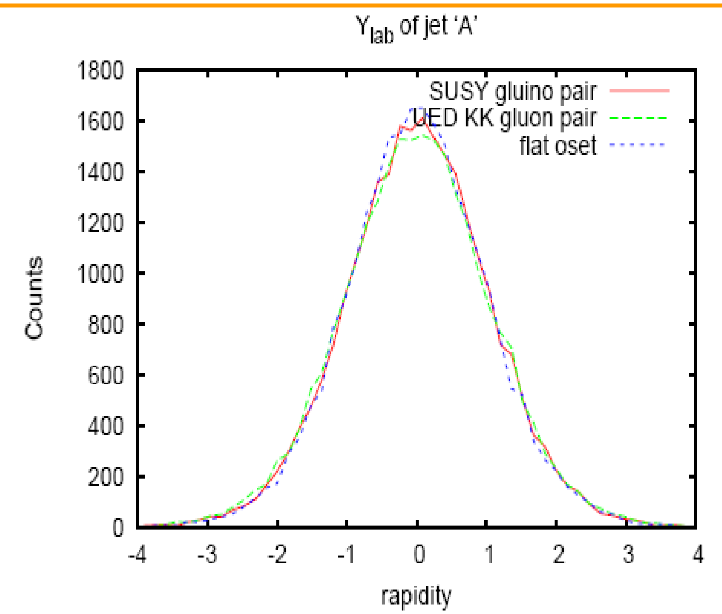
Another SUSY example











Parametrization scheme

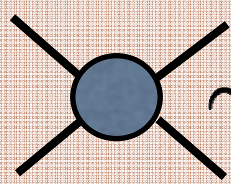
Introduce dimensionless energy and angular variables

$$X \equiv \hat{s}/s_0,$$

$$\xi \equiv \frac{\hat{t}-\hat{u}}{\hat{s}} = \beta_{34}\cos\theta^*$$

s_0 is the minimum possible value of sˆ
b^2_{34} is the relative velocity of the products
θ* is the scattering angle in the center-of-mass frame.
ξ ∝ z-component of momentum of the particles in the center-of-mass system

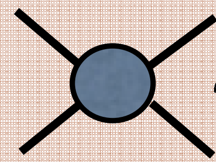
to parameterize corrections to constant $|M|^2$:



$$\sim |M|^2 = \sum_{p,q} C_{pq} X^p \xi^q$$

Parametrization scheme

Near threshold one term of the expansion dominates:

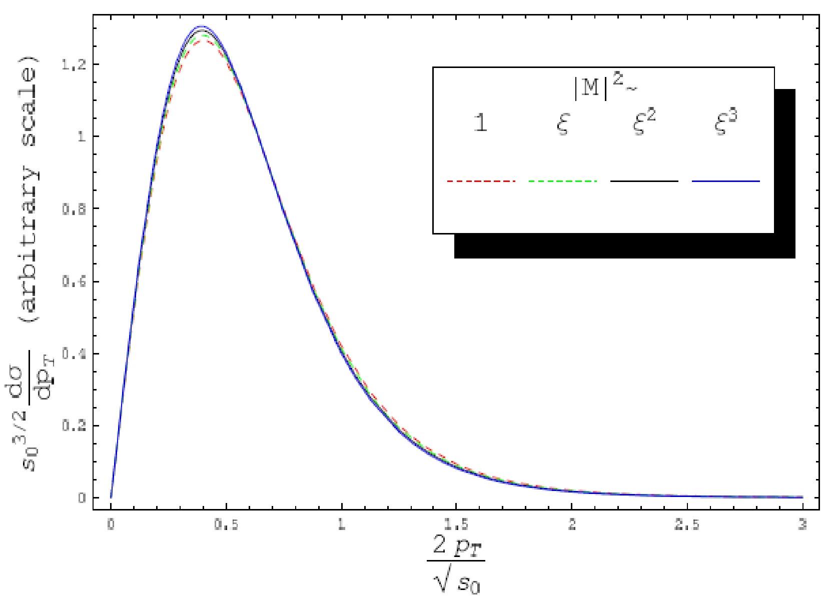


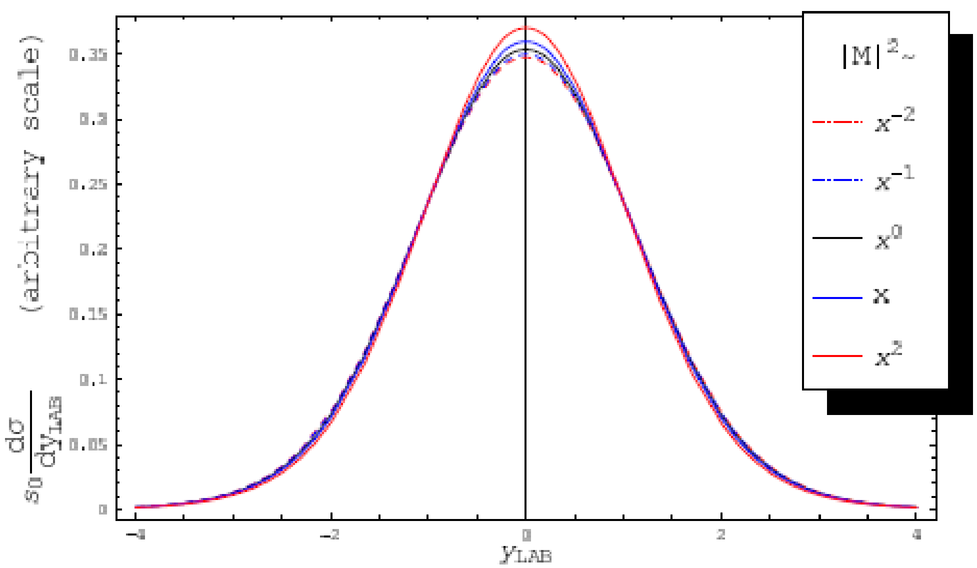
$$\sim |M|^2 \sim X^q \xi^p$$

PDF E_{cm} and y_{cm} homogeneity properties

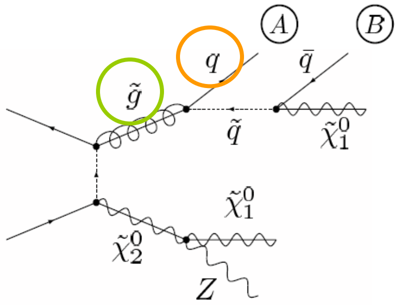
- Inclusive p_T shape invariant under $X^q\,\xi^p \longrightarrow X^q$
- Inclusive y_{lab} shape invariant under $X^q\,\xi^p \longrightarrow \xi^p$

p=0 usually dominates
Cascade decays wash out dependence



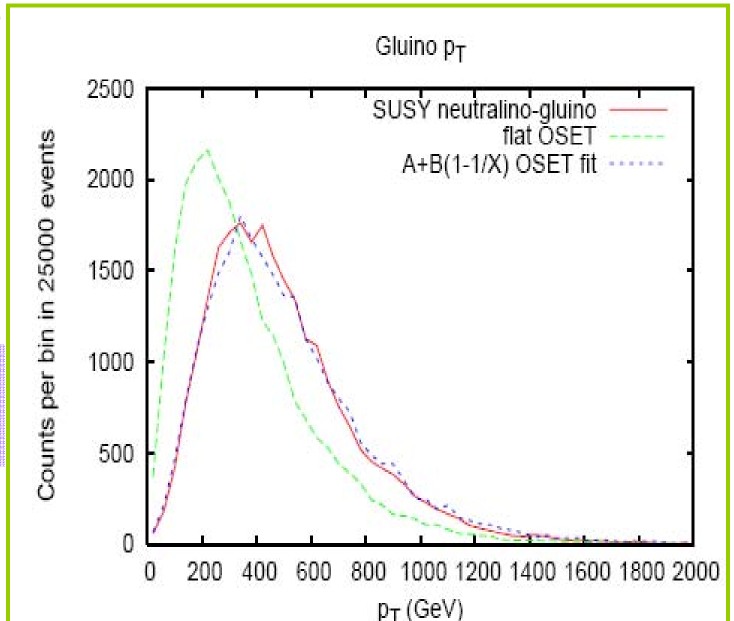


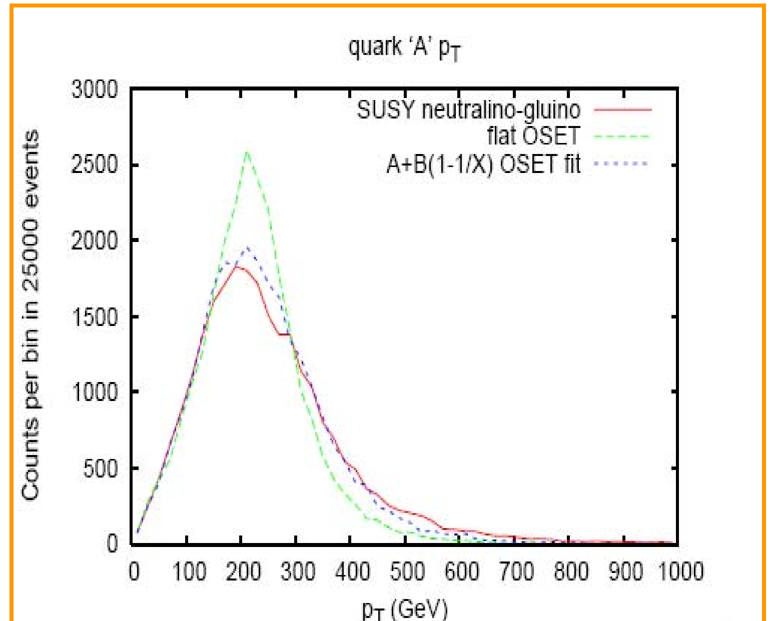
Parametrization scheme

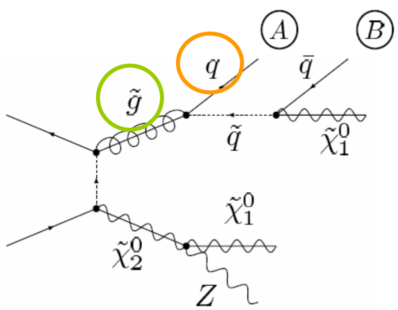


$$|\mathcal{M}|^2 \to A + B(1 - 1/X)$$

p-wave dominated

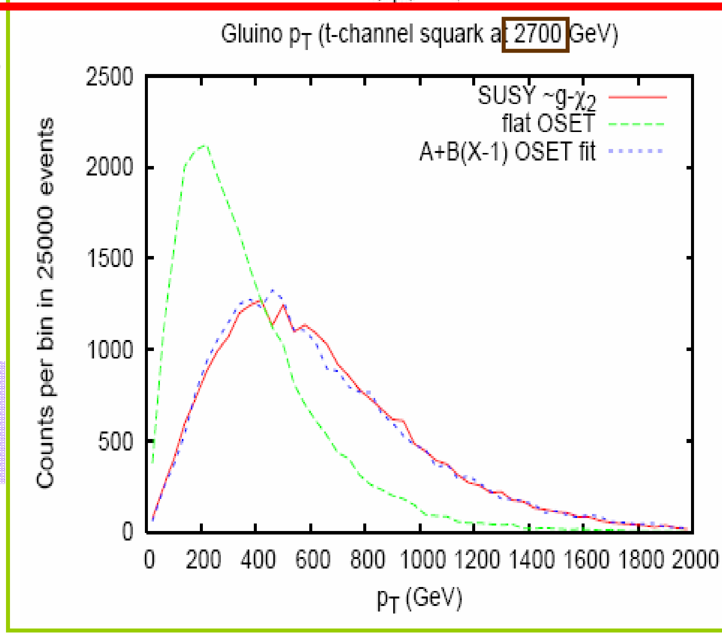


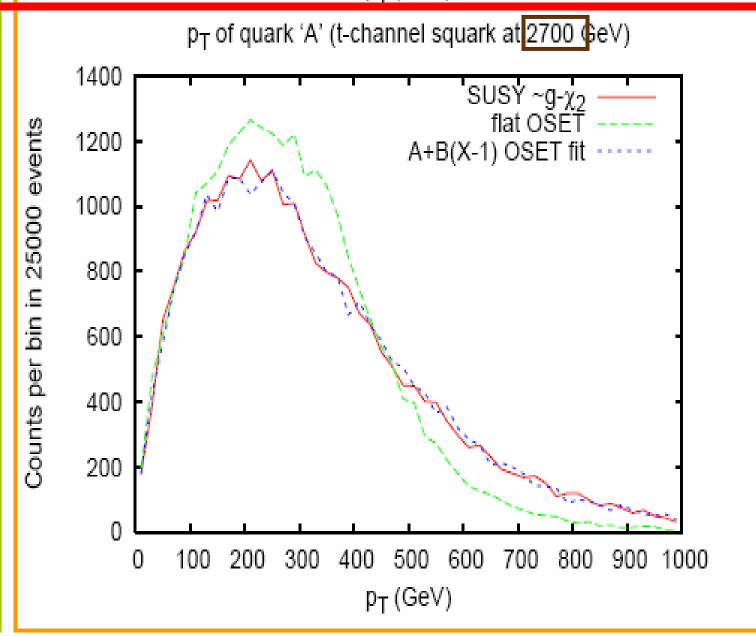




$$|\mathcal{M}|^2 \to A + B(X - 1)$$

Contact interaction





MARMOSET

MARMOSET is a Pythia based Monte Carlo tool which implements the parametrization in X and ξ variables

In this framework an OSET is defined by:

- A spectrum of new particles w/ given masses
- The $U_{EM}(1)$ and $SU_C(3)$ gauge quantum numbers
- Observable production and decay modes
  In terms of on-shell particles
- A parametrized ME $|M|^2$ for each vertex

BLOBS

- $2 \rightarrow 1$ Resonant production
- $2 \rightarrow 2$ Pair or associated production
- $2 \rightarrow 3$ Production
- $1 \rightarrow n$ Decay

OSETs @ CMS

- Framework for a first understanding of BSM signals (complementary to full-model searches)
  - Phrase/answer structural questions:
    - Quantum numbers
    - Mass hierarchy
    - Decay modes
  - Model topologies → signatures, discriminating variables
  - Model constraints → further analysis directions
  - → More flexible/manageable complexity than full model

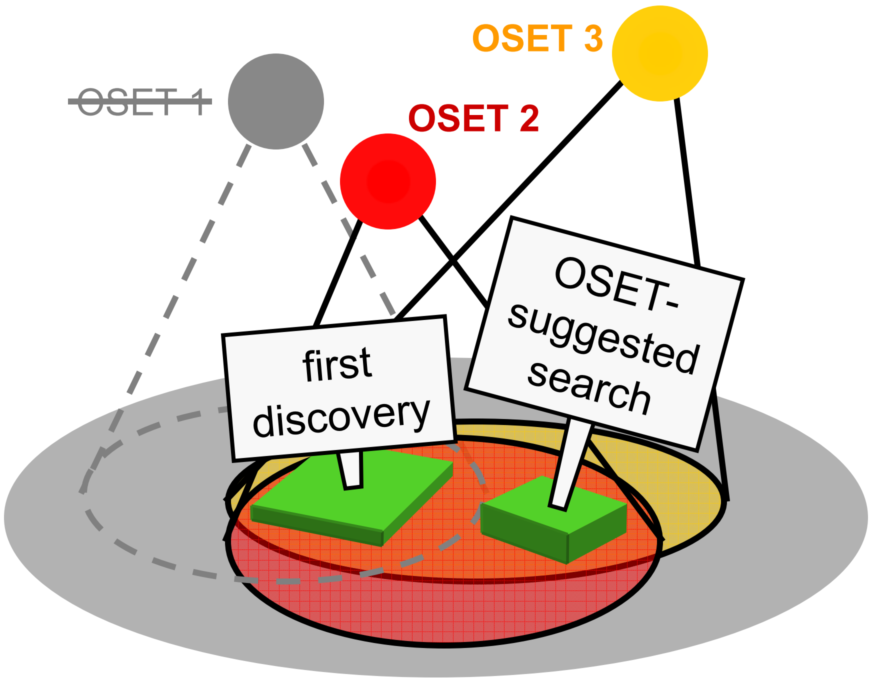
Results of new physics searches

theorist ⟺ experimentalist communications

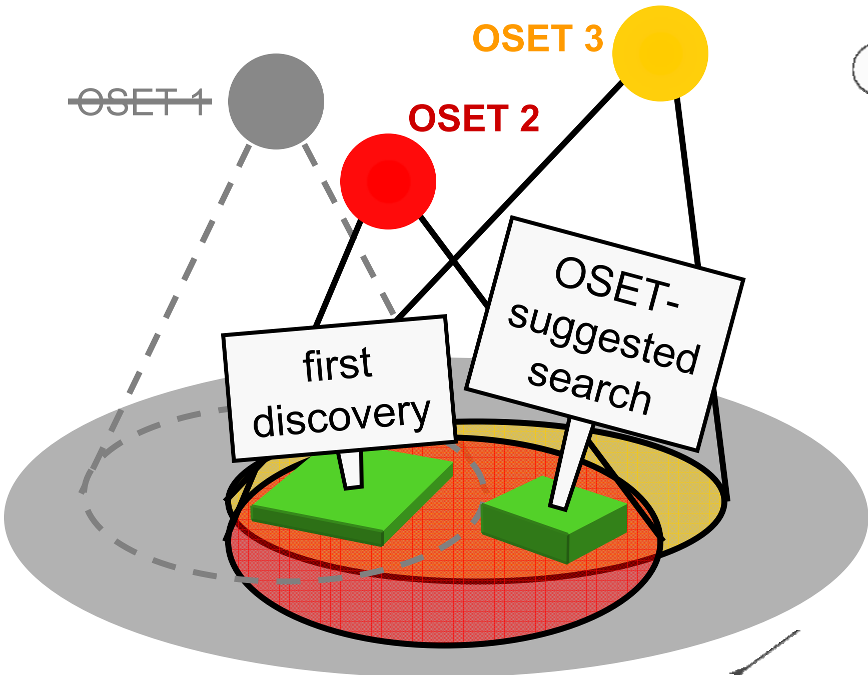
- Case studies, usage examples
- Guidelines, cautions, caveats, issues, …
- Maps for BSM model → OSET
- Systematization of:
  - OSET construction
  - Goodness of "OSET fit"

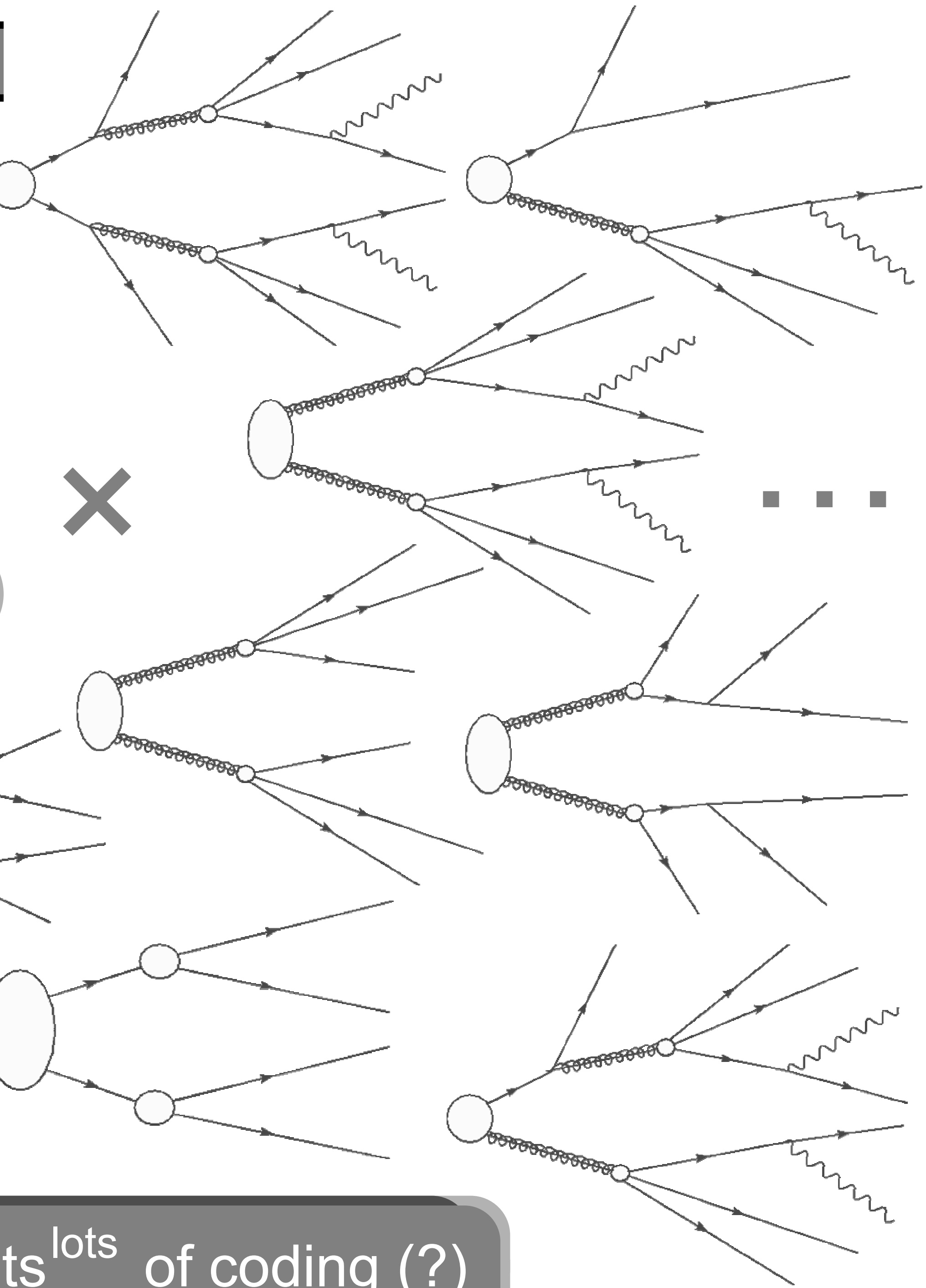
} Training exercises
Data challenges
Workshops
…

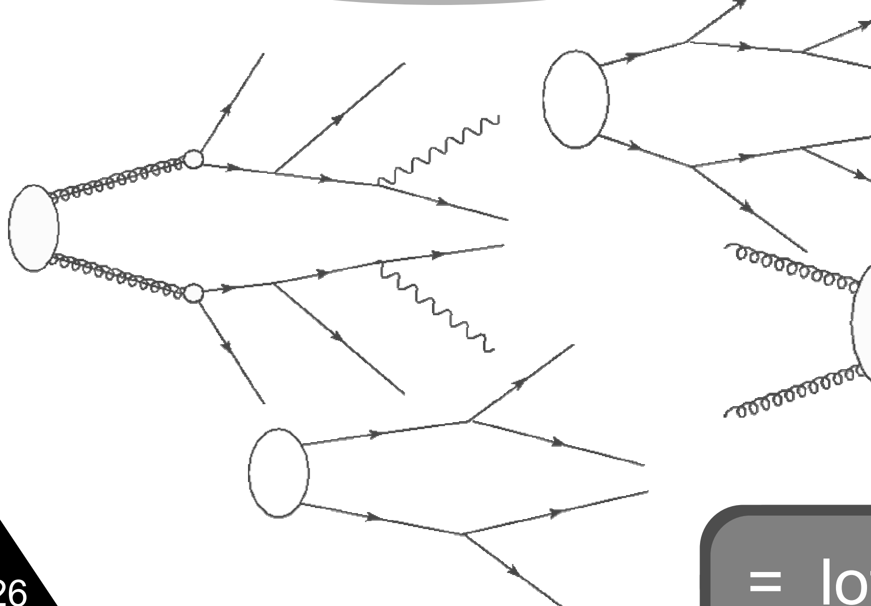
OSETs in new-physics analyses



OSETs in new-physics analyses







= lots$^{\text{lots}}$ of coding (?)

The Monte-Carlo "scripting language"

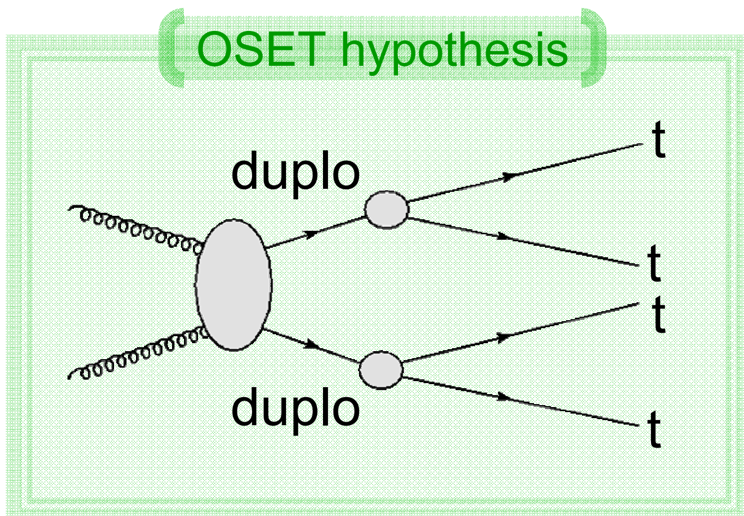
Quantum numbers / mass

New particle

Decay mode

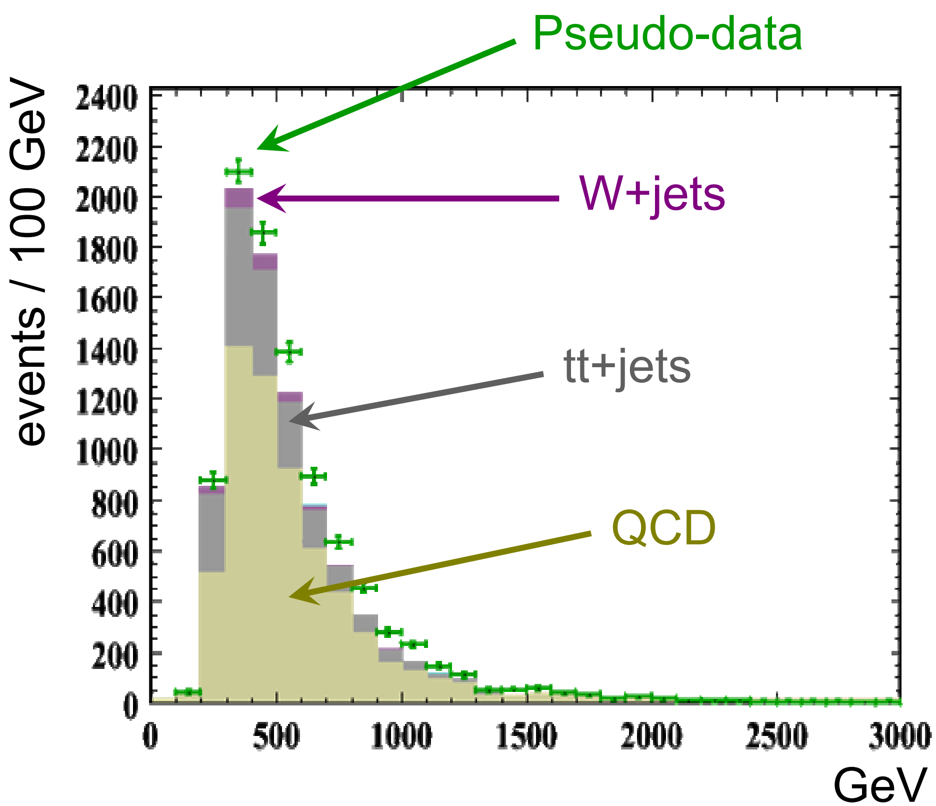
Production mode

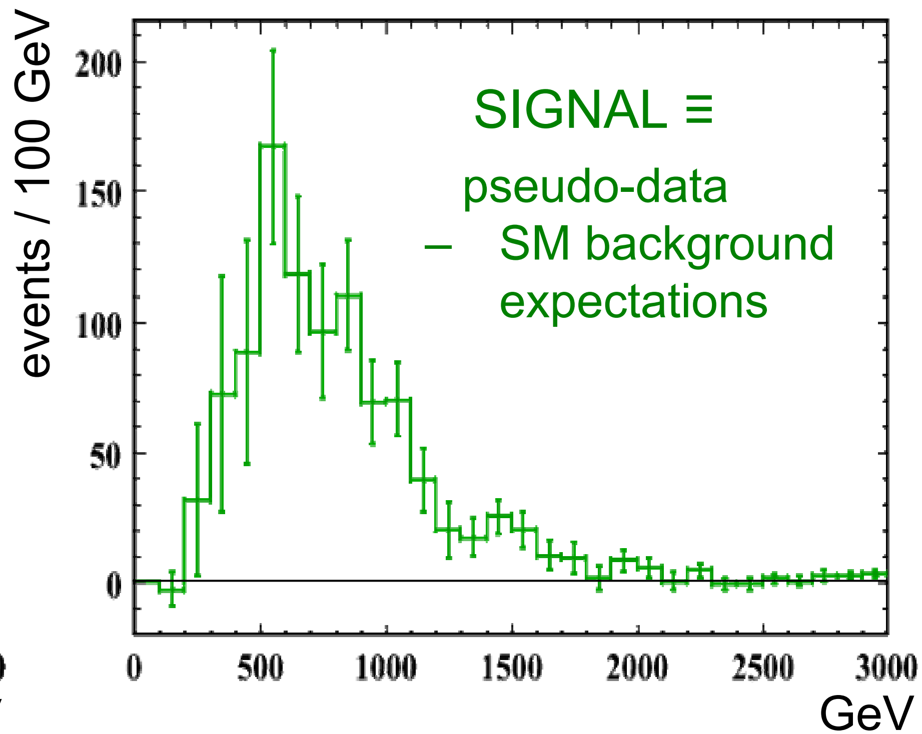
```
duplo :   charge=0 color=0 mass=800

duplo > t tbar

g g > duplo duplo : matrix 1
```



Case Study: Jets + MET channel

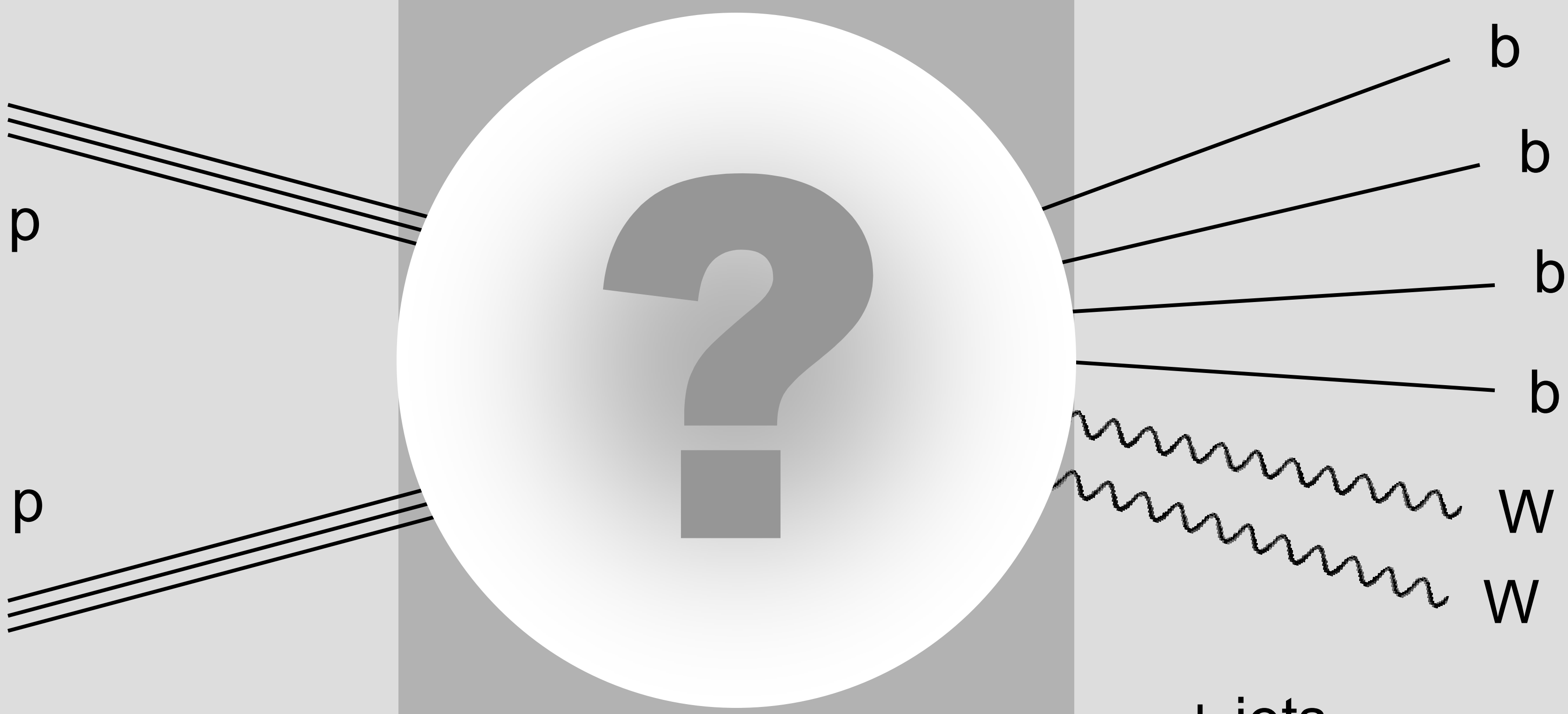
$H_T \equiv \sum$ scalar E_T of electrons, muons, jets





Energy scale ≲ 500 GeV to 1 TeV

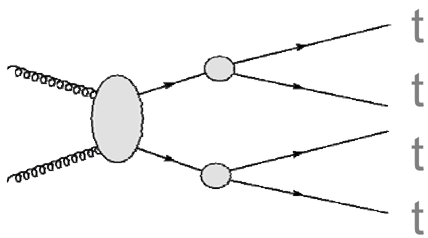
Case Study: Jets + MET channel



+ jets
+ significant $\not{E}_T$

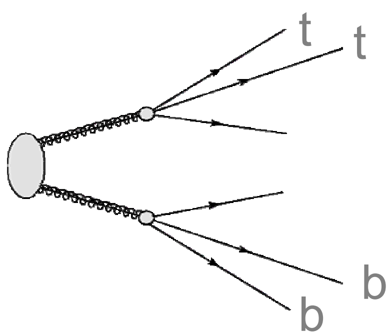
"Most salient" final state

(Some) Attempted OSETs



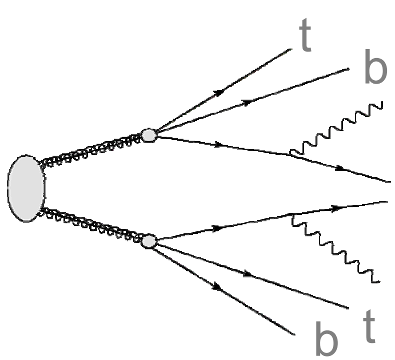
Too many leptons
Not enough missing energy

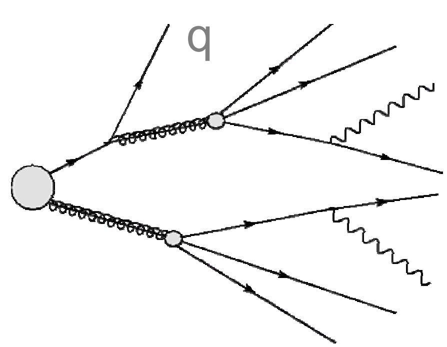
Massive missing energy particle required

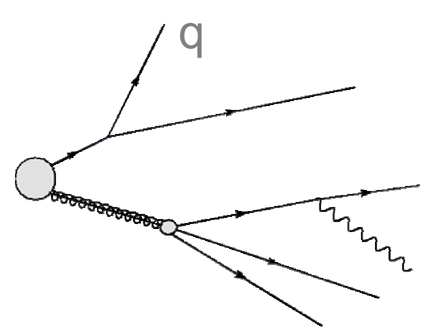


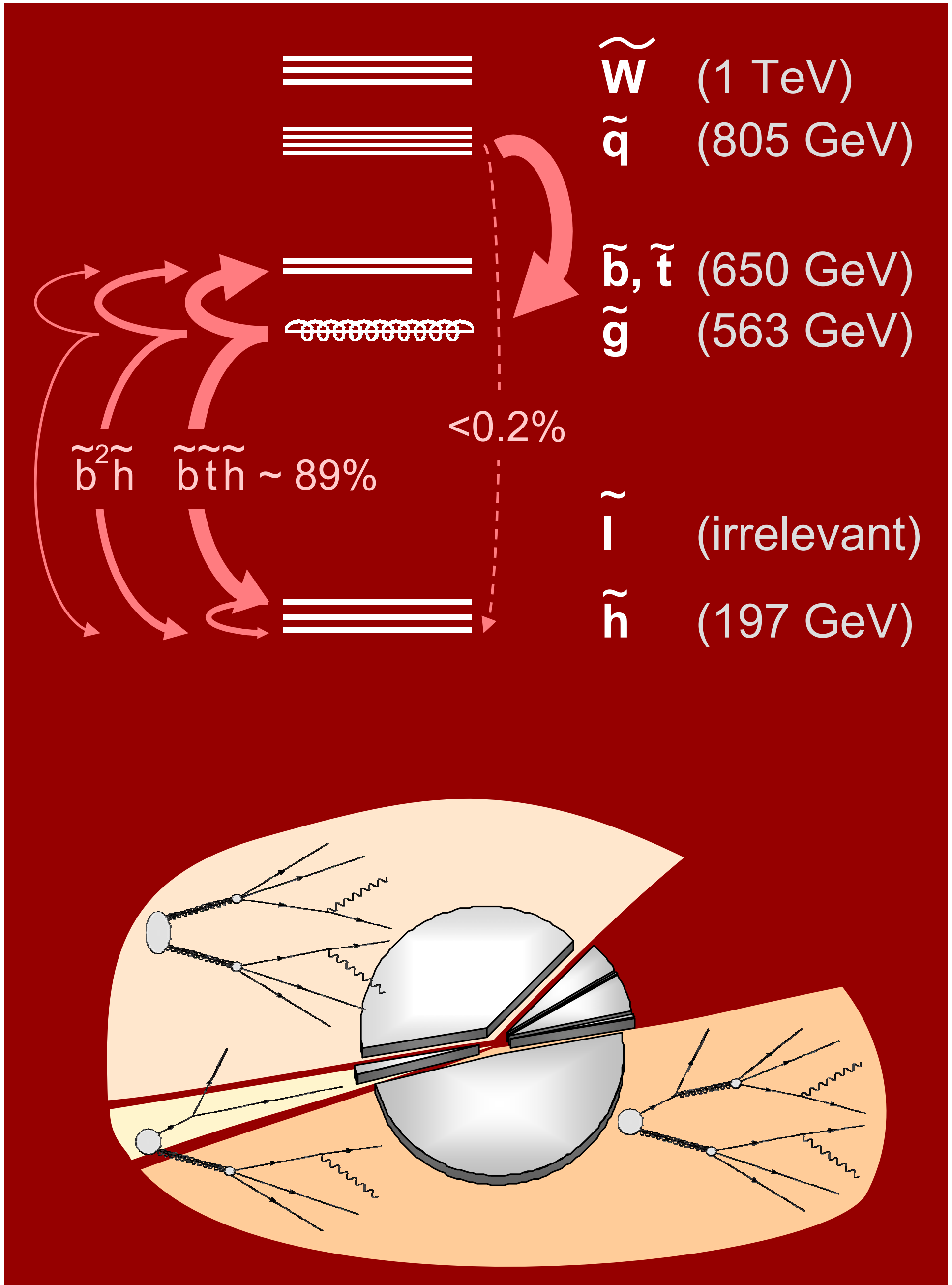
t^4 final state has too many leptons

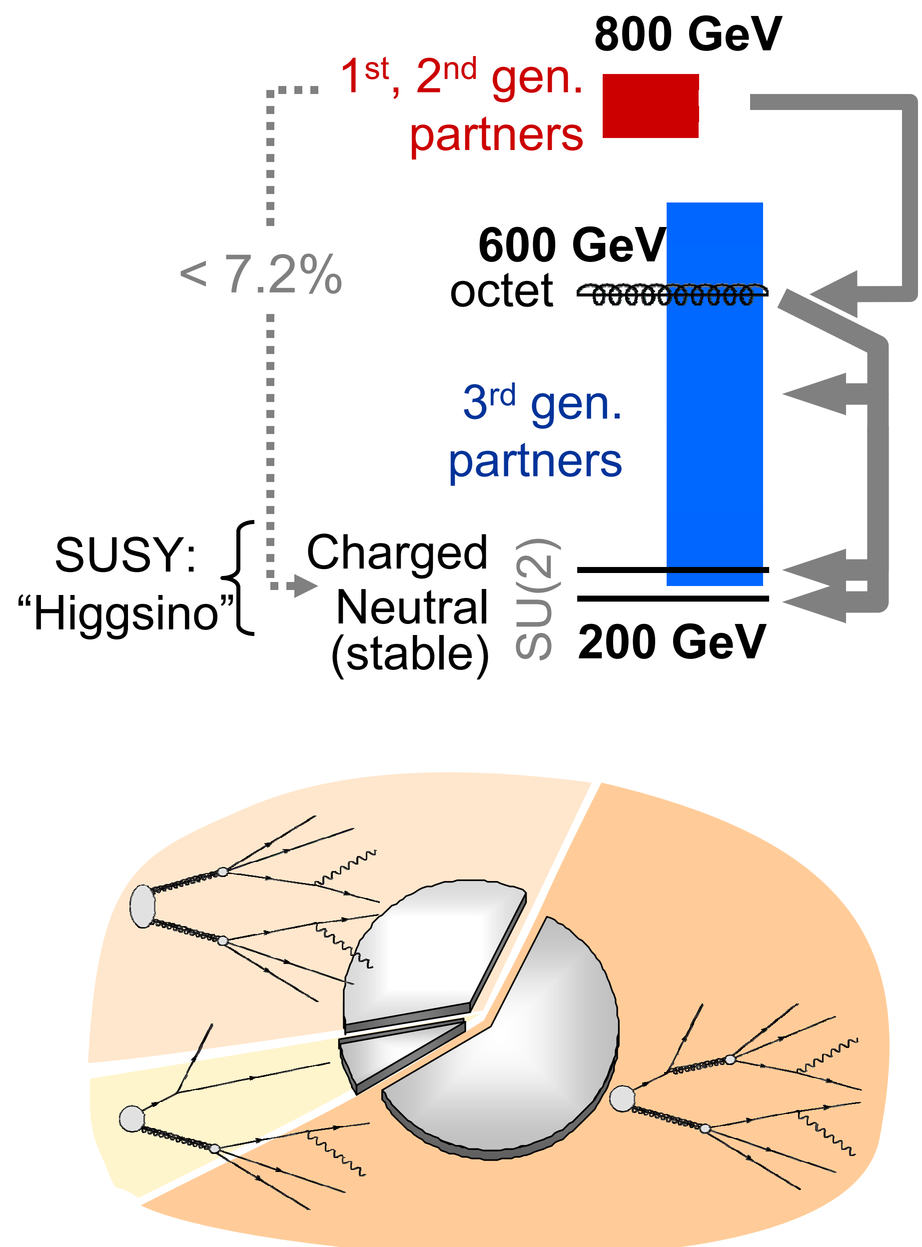
Implied for model consistency







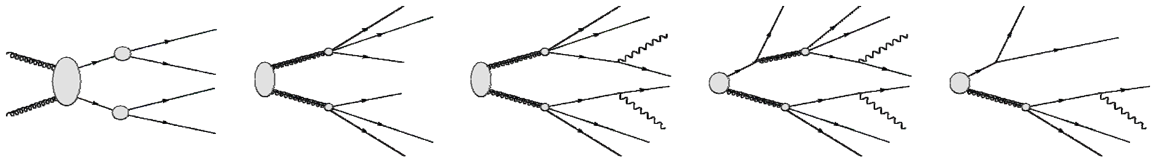




Actual Model **OSET Deduction**

O
S
E
T

Where did OSETs come in?



\+ O(many)

Monte Carlo “scripting” : Effortless / ~~Wait-less~~ } to simulate hypotheses

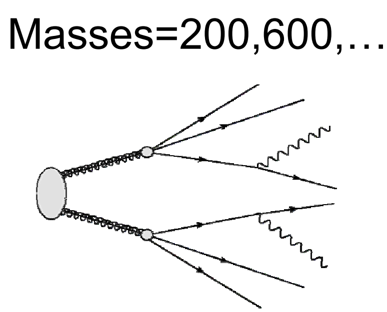
What made (quick) model-deduction possible?

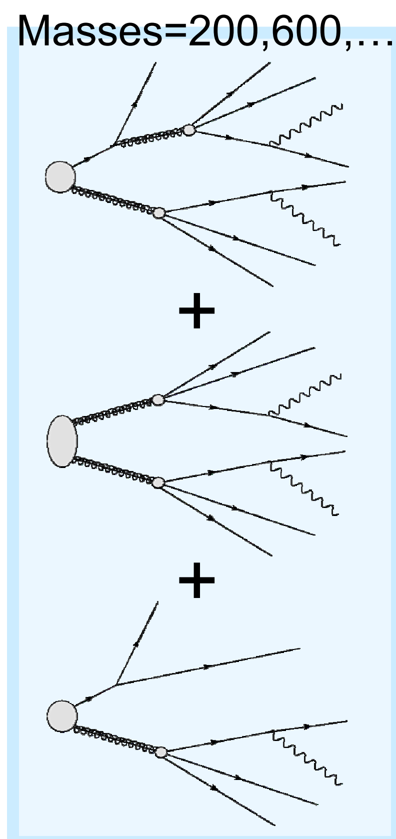
- Standard Model → BSM constraints
  (charge conservation, small rate of flavor violation, …)
- Minimal addition of new content (a negotiable assumption)
- Factorization into subsets of salient signatures
- Hypothesized topologies ⇒ new signatures and searches
- Number of parameters (masses, branching ratios, …) << full model

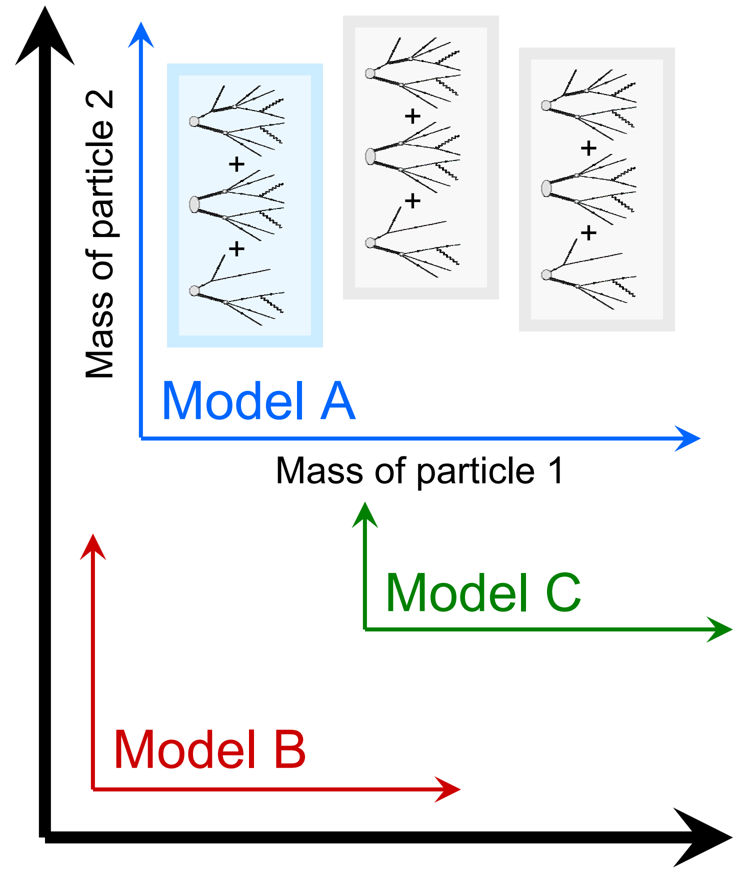
o l o g y @ CMS

Concept Level

OSET Process	OSET Model	BSM Physics







Apropos

Upper-bound:

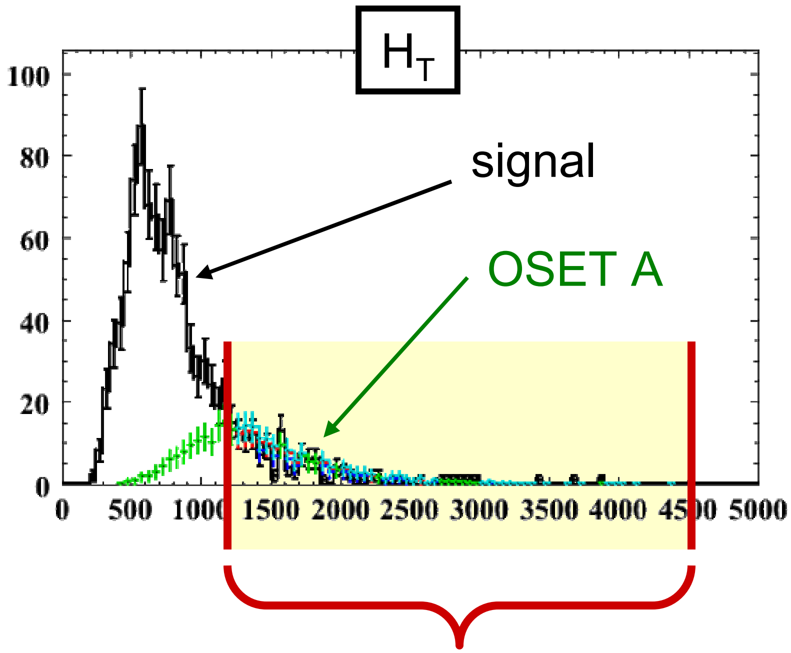
- Determine if a given process is important
- Indicate regions that require contributions from other processes

Fit to signal:

- Extract best-fit model parameters for a given set of mass hypotheses

Goodness-of-fit:

- Compare mass hypotheses to locate most likely spectrum
- Compare distinct models



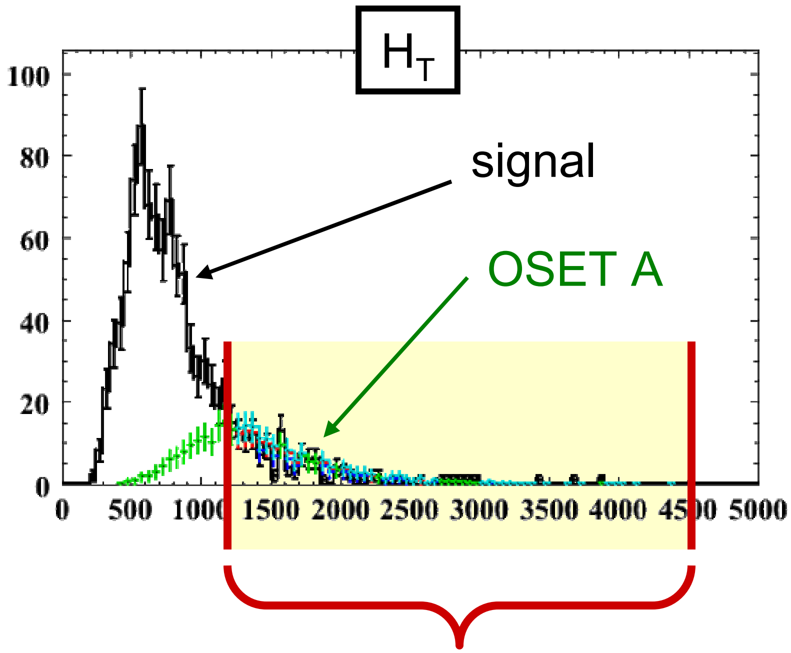
Compute a "constrained distance" (χ^2 or the Poisson equivalent) in only those bins where the OSET A prediction exceeds the number of signal events.

Suppose that we think "signal" consists of 25% events from a model like OSET A.

If we overlay the shapes of the H_T distribution (OSET A scaled to 25% number of signal events), they would look like this.

Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes

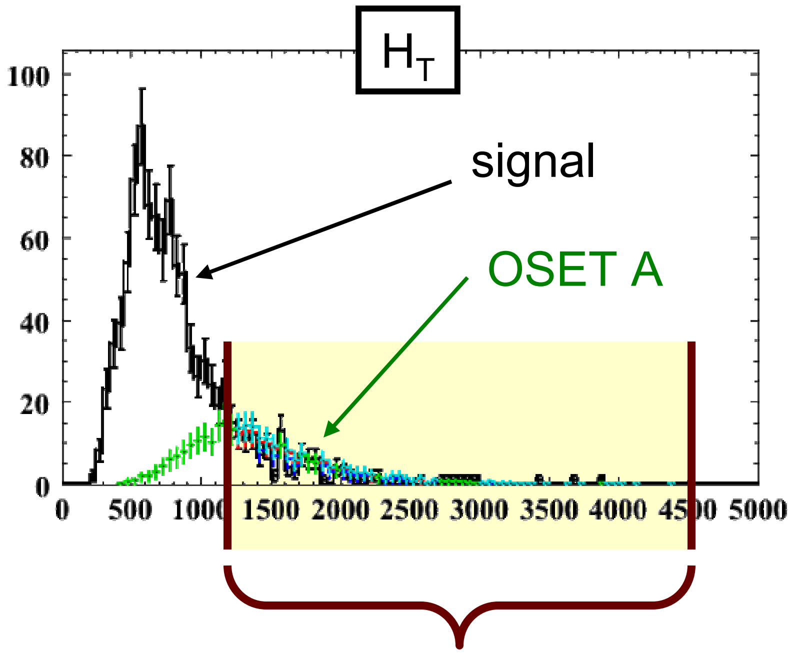


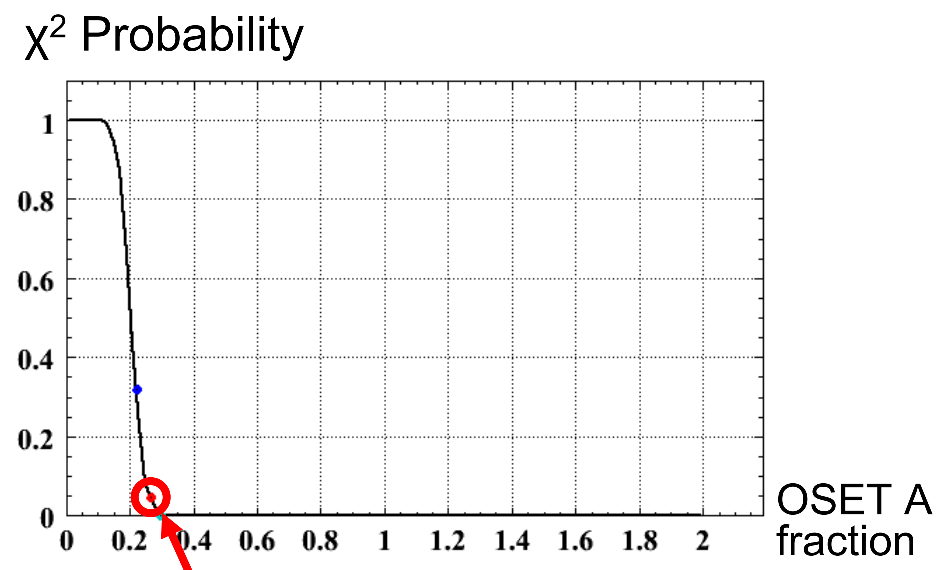
Assuming that OSET A *is* the correct model in this region, how likely are we to measure the "constrained distance" that we measured (in this pseudoexperiment)?

Compute a "constrained distance" (χ^2 or the Poisson equivalent) in only those bins where the OSET A prediction exceeds the number of signal events.

Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes





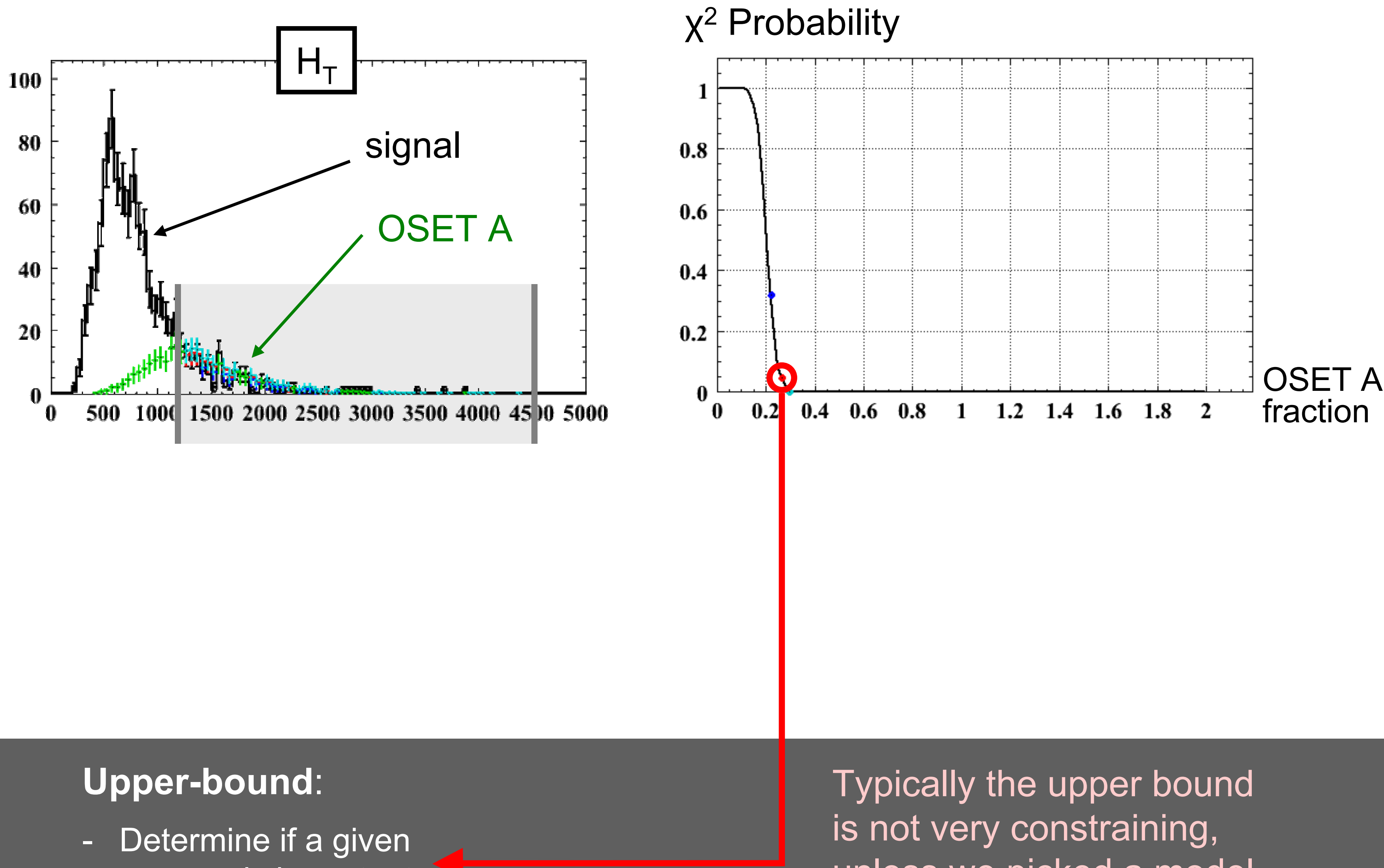
Compute a "constrained distance" (χ^2 or the Poisson equivalent) in only those bins where the OSET A prediction exceeds the number of signal events.

Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes

the maximal OSET fraction such that it can explain all signal events *in the constraining region*,

… supposing that there was a total downward fluctuation of, say 2σ, down from expectation.

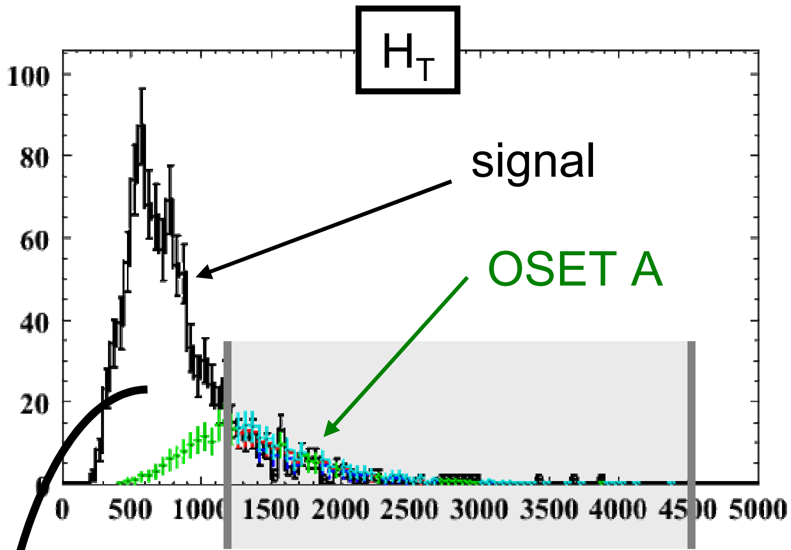


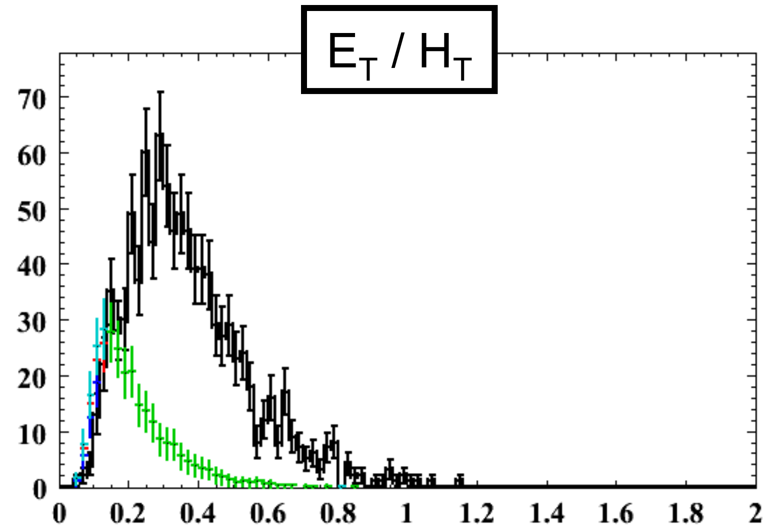
Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes

Typically the upper bound is not very constraining, unless we picked a model that is obviously wrong.

But that's just life.

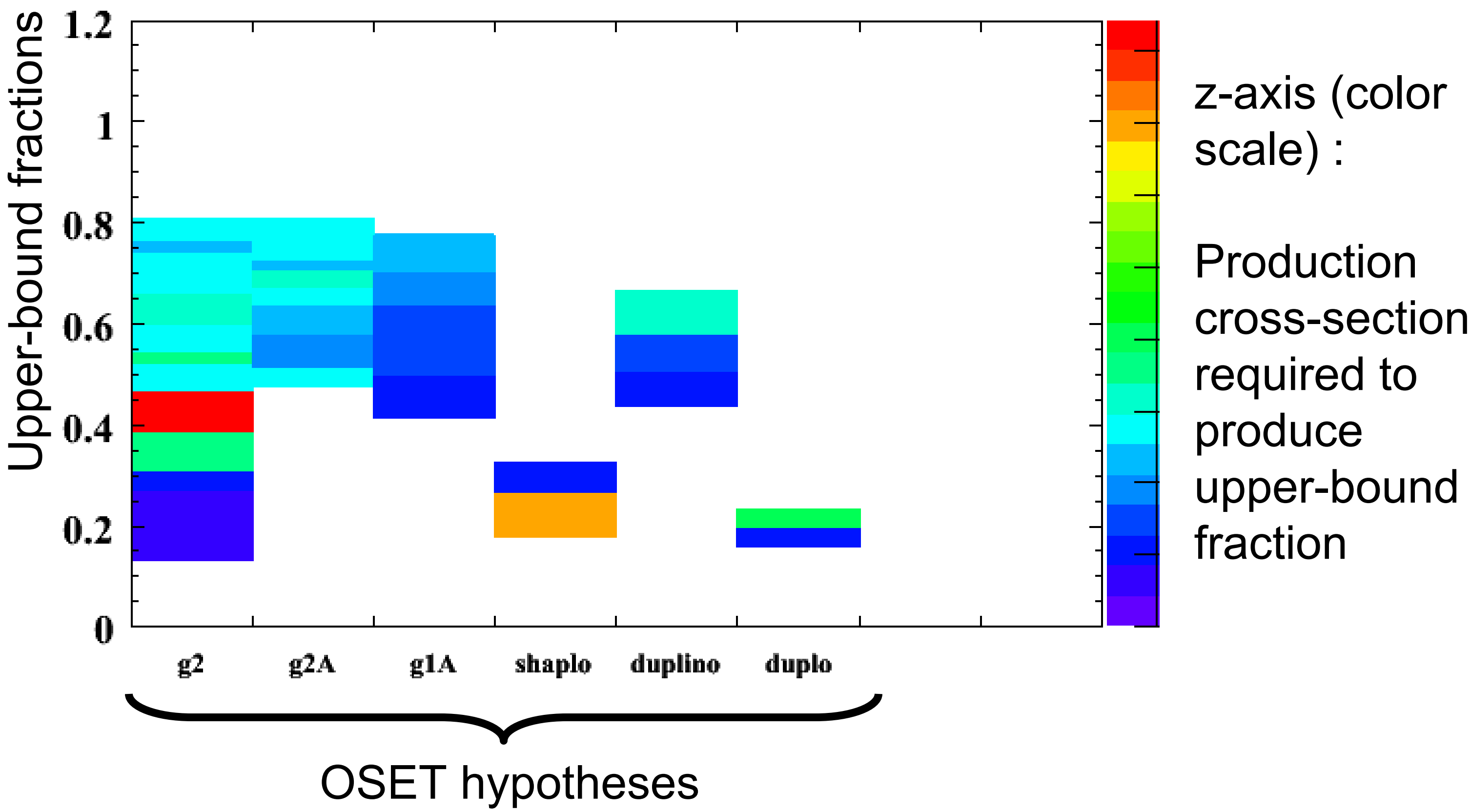




The upper-bound is usually computed simultaneously over multiple distributions

Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes

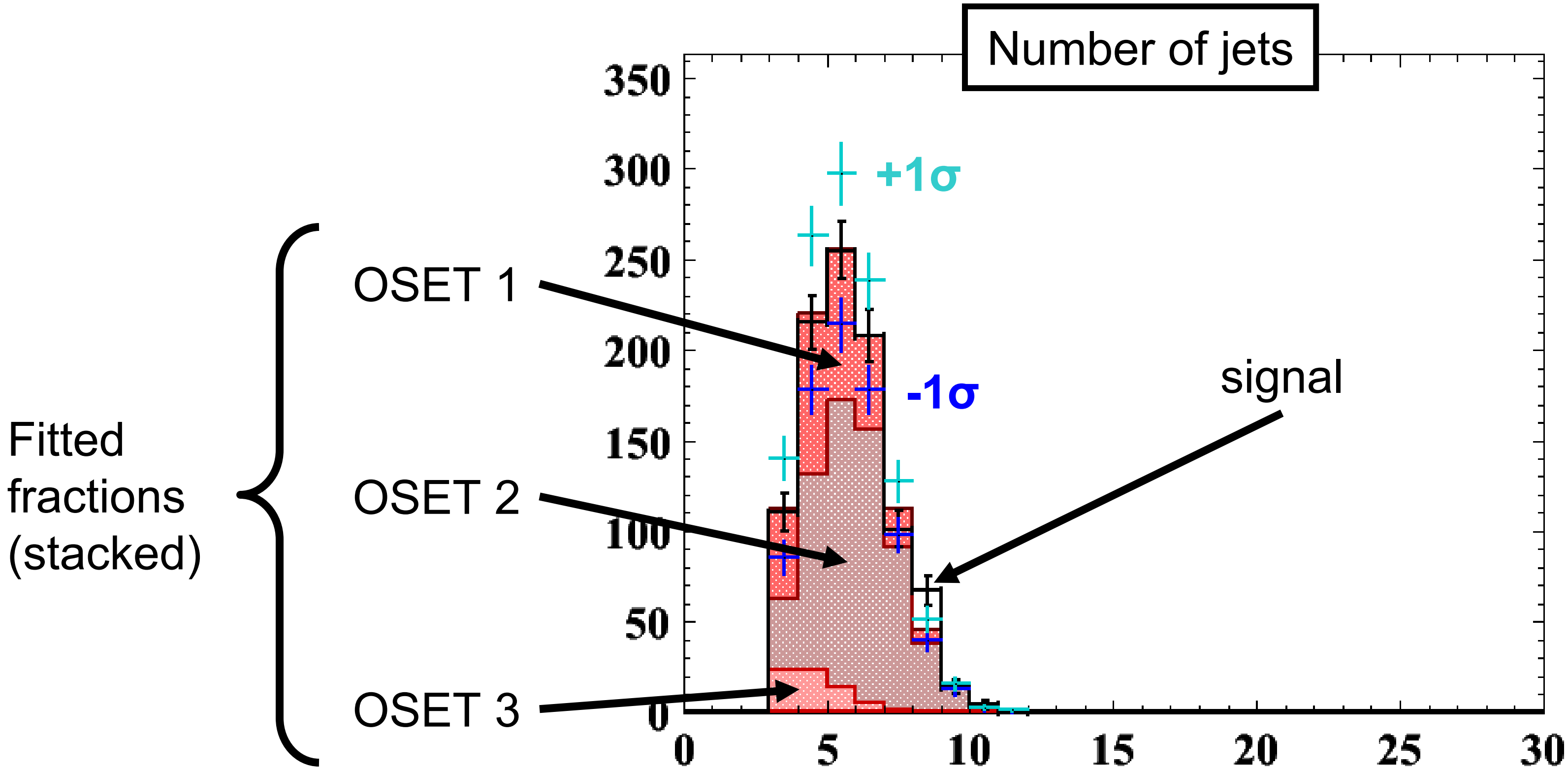


Upper-bound:

- Determine if a given process is important
- Indicate regions that require contributions from other processes

This is an example summary plot indicating the maximal fractions of various hypotheses.

The bands are produced by scanning over some possible masses.

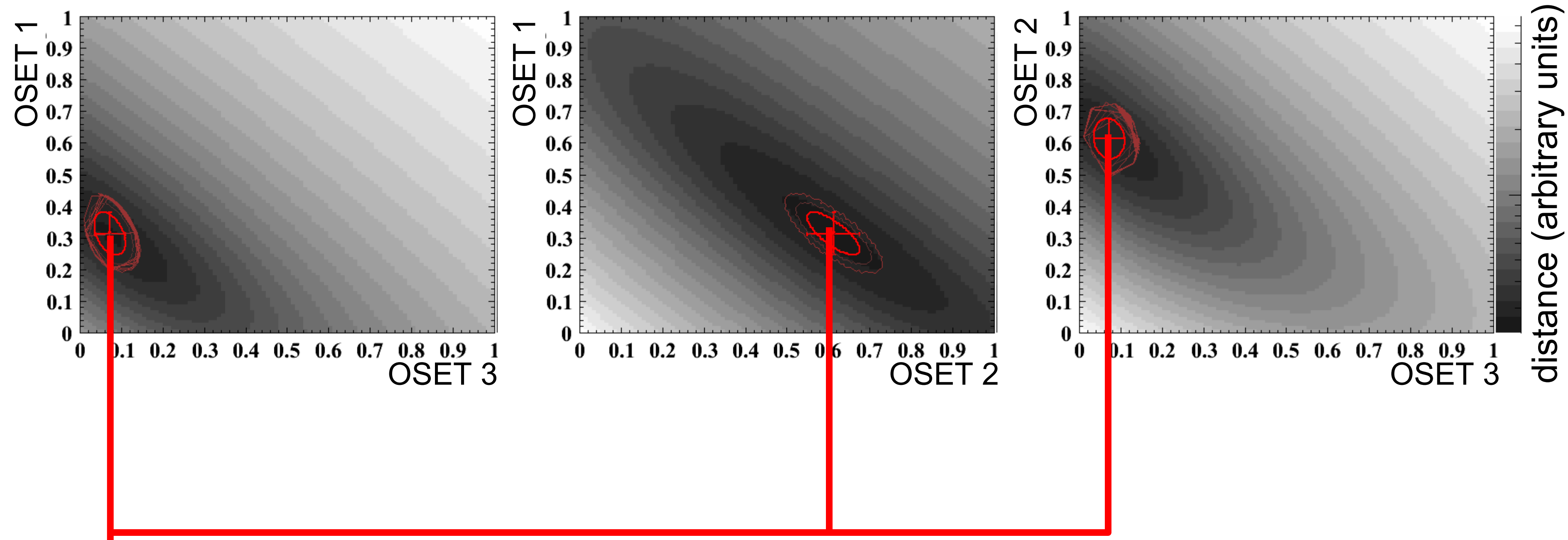


When we have the set of most significant processes, we can fit for their fractions the usual way (minimizing distance between signal and summed templates).

Fit to signal:

- Extract best-fit model parameters for a given set of mass hypotheses

Landscape of distance used in the fit — 2D slices (3 OSETS = 3 parameters)

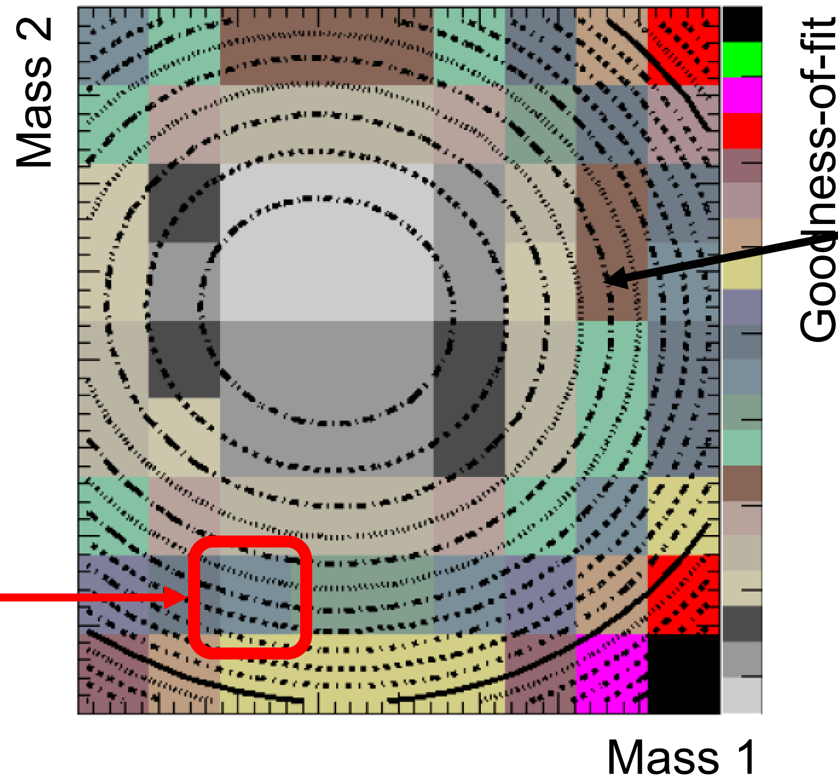


Fit to signal:

- Extract best-fit model parameters for a given set of mass hypotheses

The contours of the Minuit2 fit are used as error bars. But pay attention to the contour plots for they contain more information about flat directions (similar processes).

For a specific set of mass hypotheses (at this point of the mass grid): record how well we can fit the three processes to explain signal.



Contours of parabolic fit interpolating between points in (possibly coarse) grid

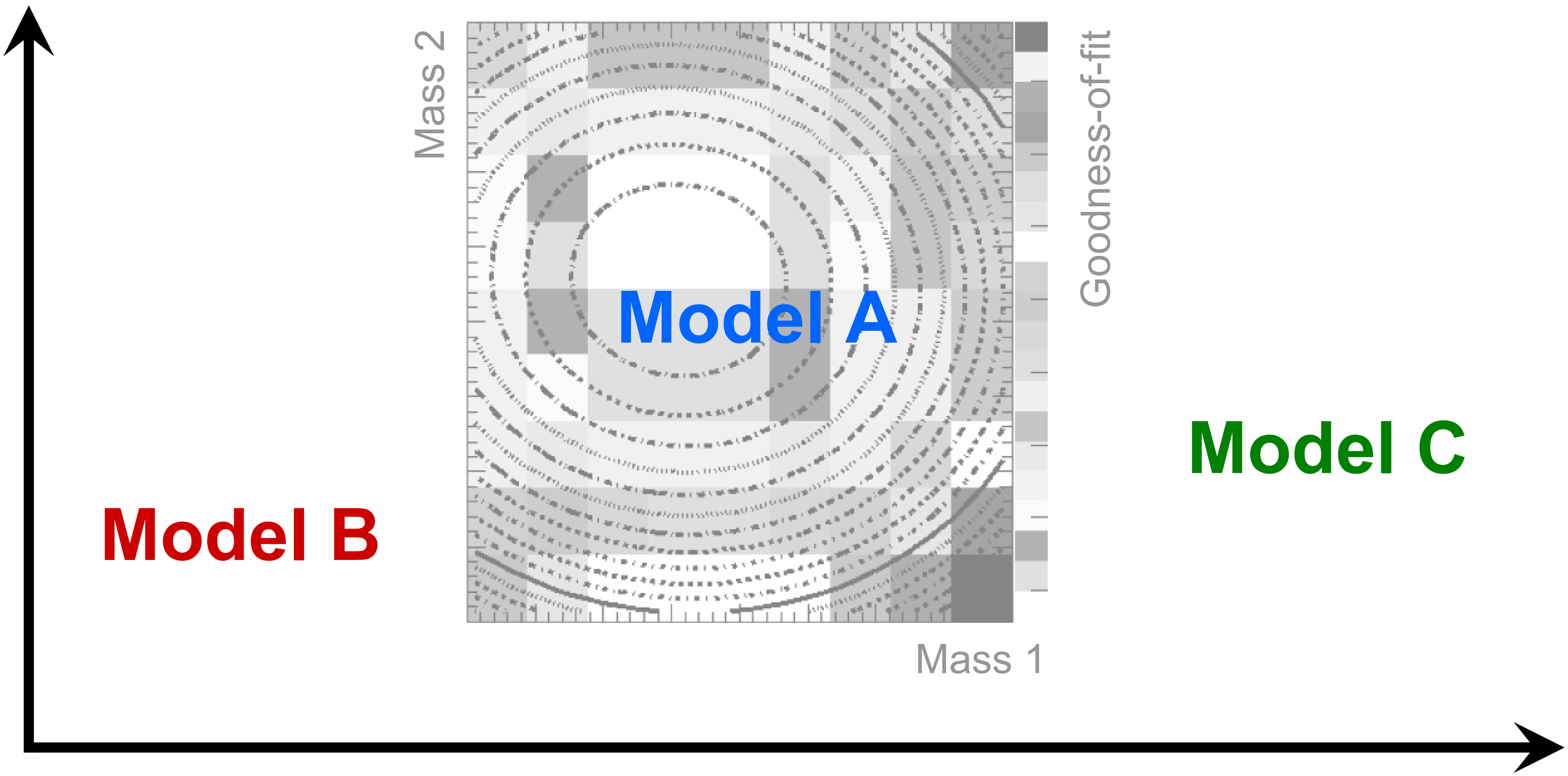
Refine grid after roughly locating minimum

For each particular model:

The goodness-of-fit (for the various processes) as we vary the mass parameters can be used to locate the most probable mass spectrum.

Goodness-of-fit:

- Compare mass hypotheses to locate most likely spectrum
- Compare distinct models



This procedure has a natural generalization to comparisons of models, provided we understand the number of degrees of freedom.

Goodness-of-fit:

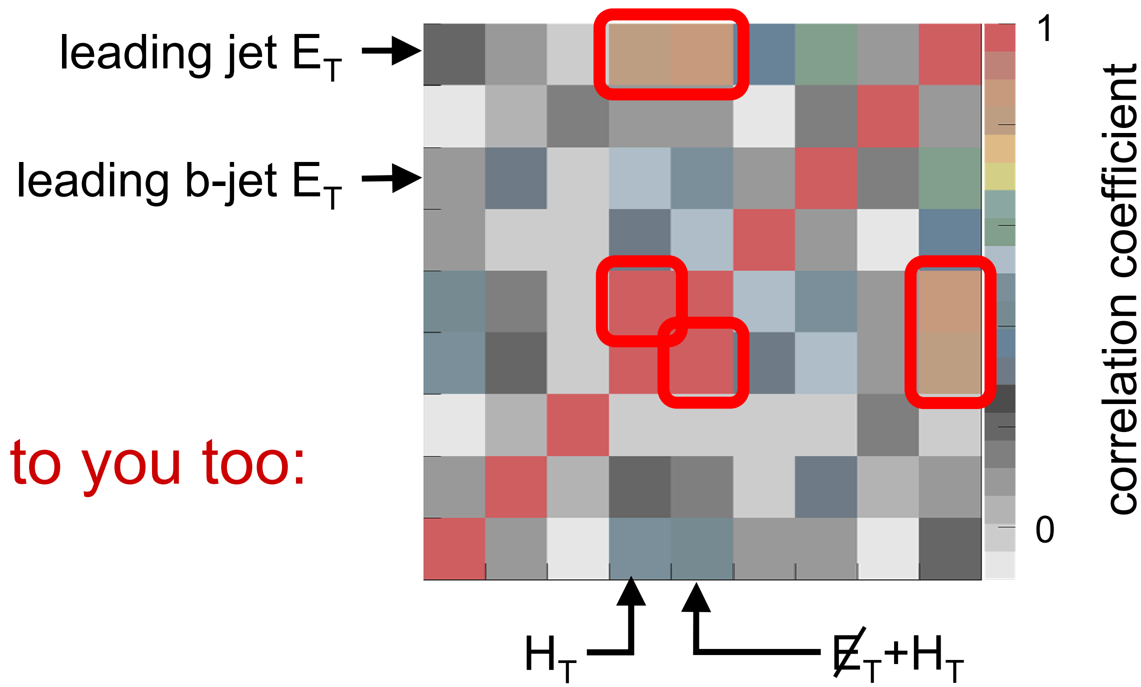
- Compare mass hypotheses to locate most likely spectrum
- Compare distinct models

[redacted]

Suppose a naïve graduate student performs a 10-histogram fit with:

$$\not{E}_T + \underbrace{H_T + H_T + H_T + H_T + H_T + H_T + H_T + H_T + H_T}_{\text{Unfairly weighted, wrong degrees-of-freedom count}}$$

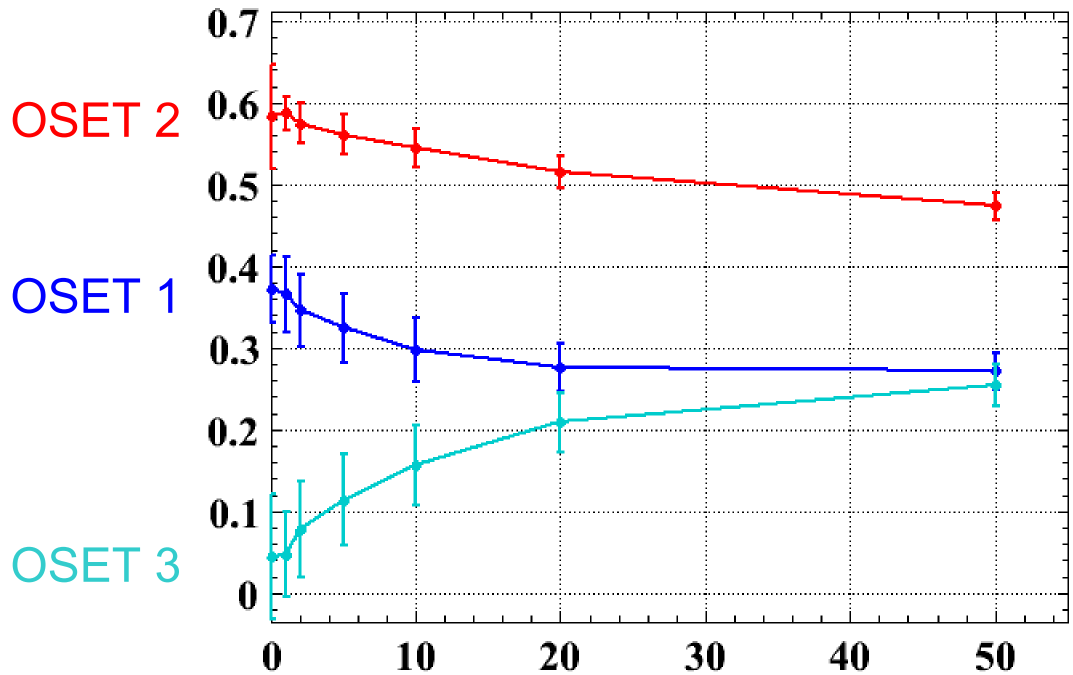
… but it can happen to you too:



Issues

- Correlated variables ⟵ Principal components analysis:
  - Diagonalize to a de-correlated basis
  - Remove redundant variables
- Non-discriminating variables ("garbage")

Fractions reported by fitter



Number of *non-discriminating* plots

Inclusion of non-discriminating plots (i.e. where all hypotheses have the same shape) tends to wash out the information in such a way that the fractions are biased towards equal numbers — unless we have perfect (∞ statistics) templates.

Issues

- Correlated variables
- Non-discriminating variables ("garbage")

Metric for sorting plots according to discriminating power — examining the trend as we increase template statistics provides even more information.