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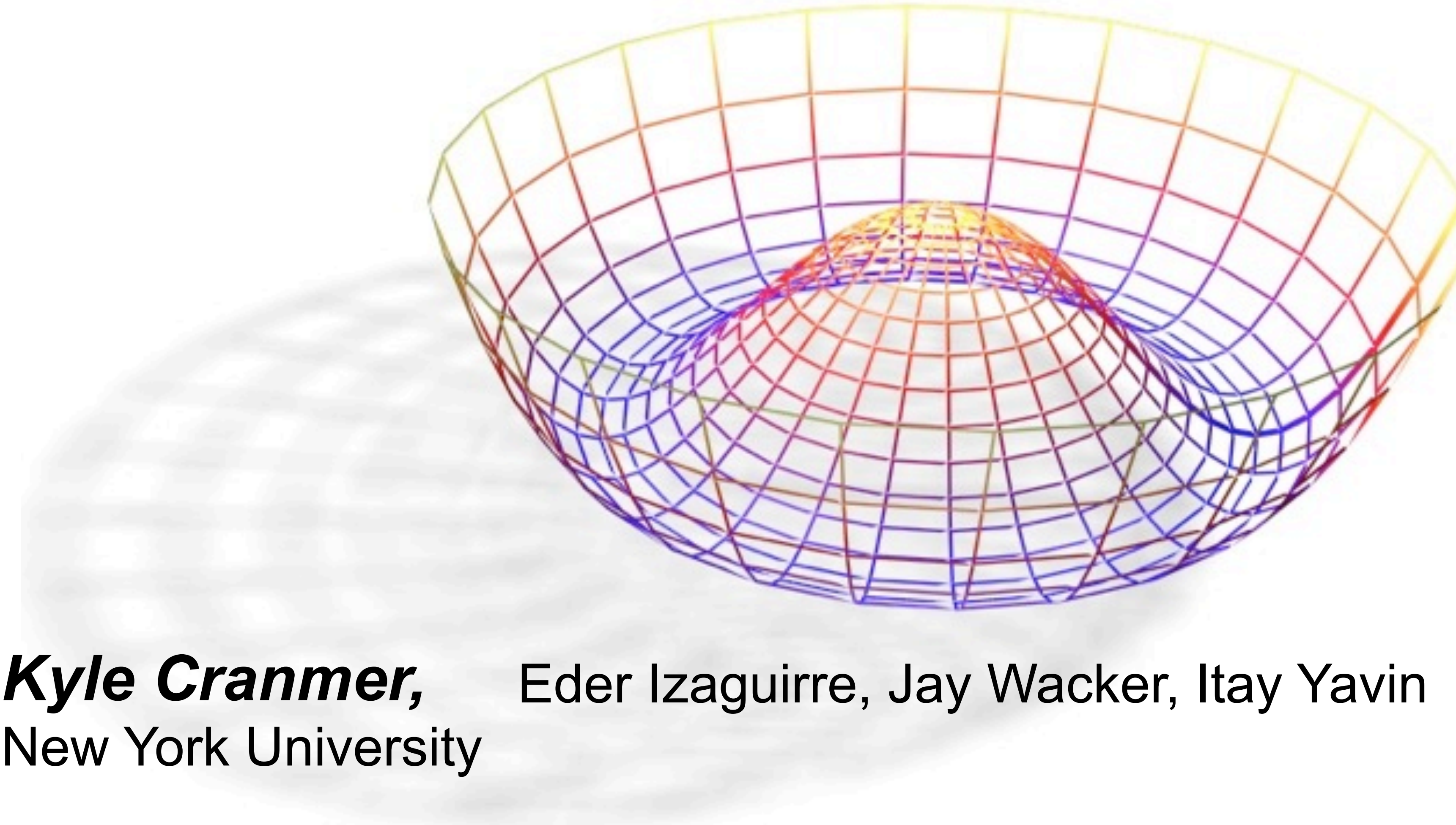
Cosmology and
Particle Physics

RECAST, Closure tests, and a Roadmap for Efficient use of Simplified Models

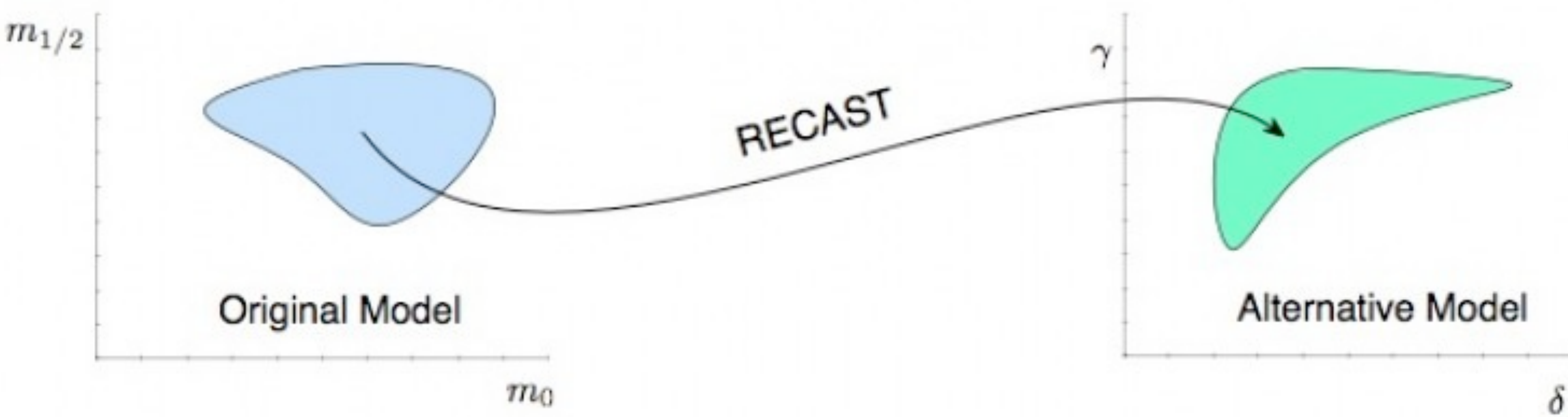


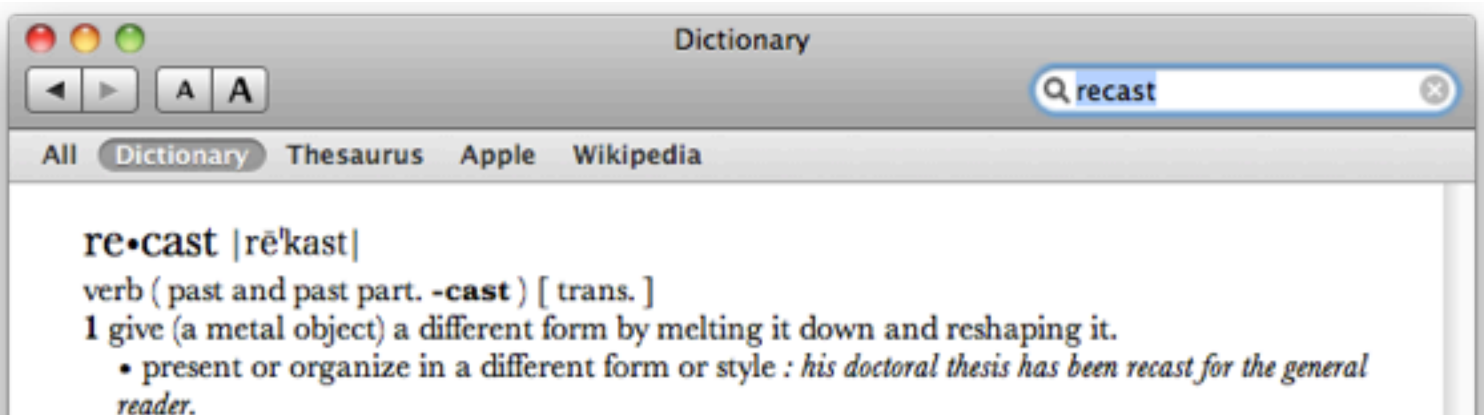
Kyle Cranmer, Eder Izaguirre, Jay Wacker, Itay Yavin
New York University

The recasting technique

Often searches are sensitive to a broader class of models than they were originally designed to test, thus it is natural to ask

What impact does an existing analysis have on an alternative signal?





The standard search approach

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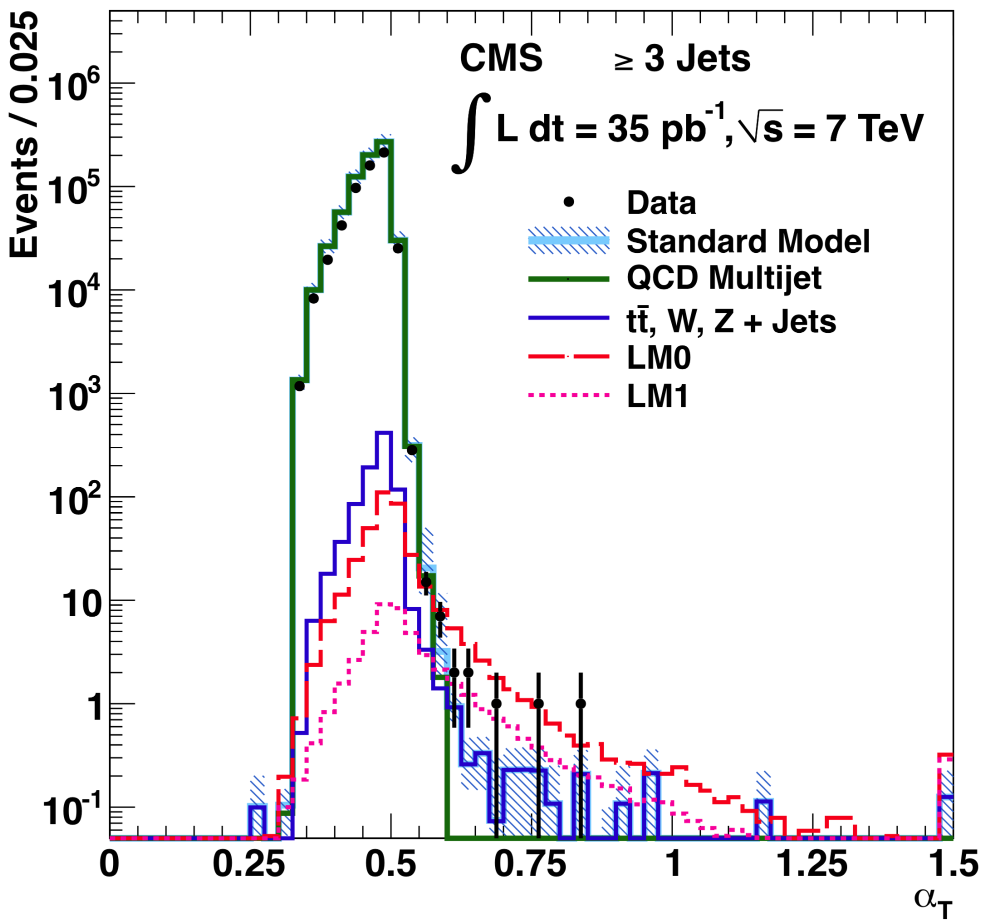


Select search region (optimized in some way, not a concern here)

Estimate some backgrounds from Monte Carlo and develop data-driven background estimation techniques for others

- Quantify uncertainties on these estimates

Observe data

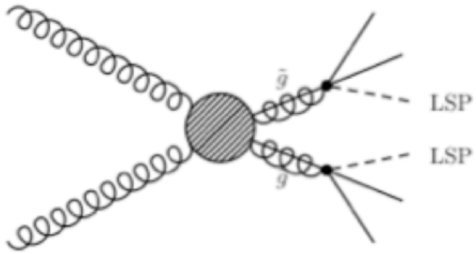
- check compatibility with b-only
- check compatibility with additional signal contribution(s)
  - find "fiducial limit" on N or σ (ok for number counting)
  - constrain a particular model
    - requires an estimate signal efficiency & uncertainty

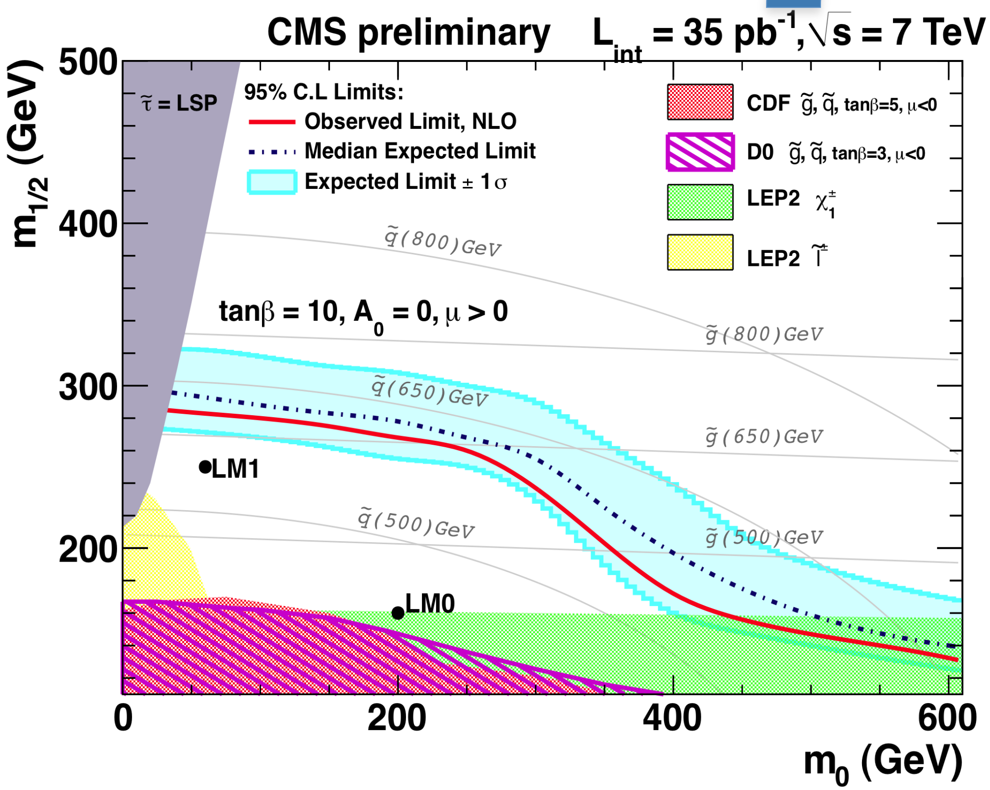
The sticky issue

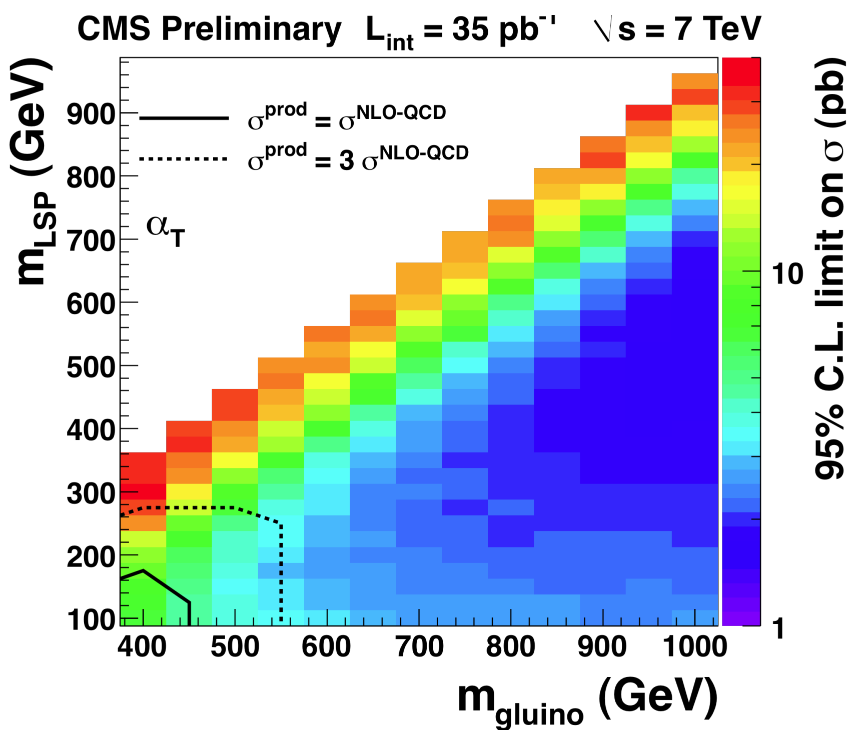
Recasting

One can, of course, re-interpret the same search (without changing selection) for alternative signal models:

this requires estimate of signal efficiency for alternative model

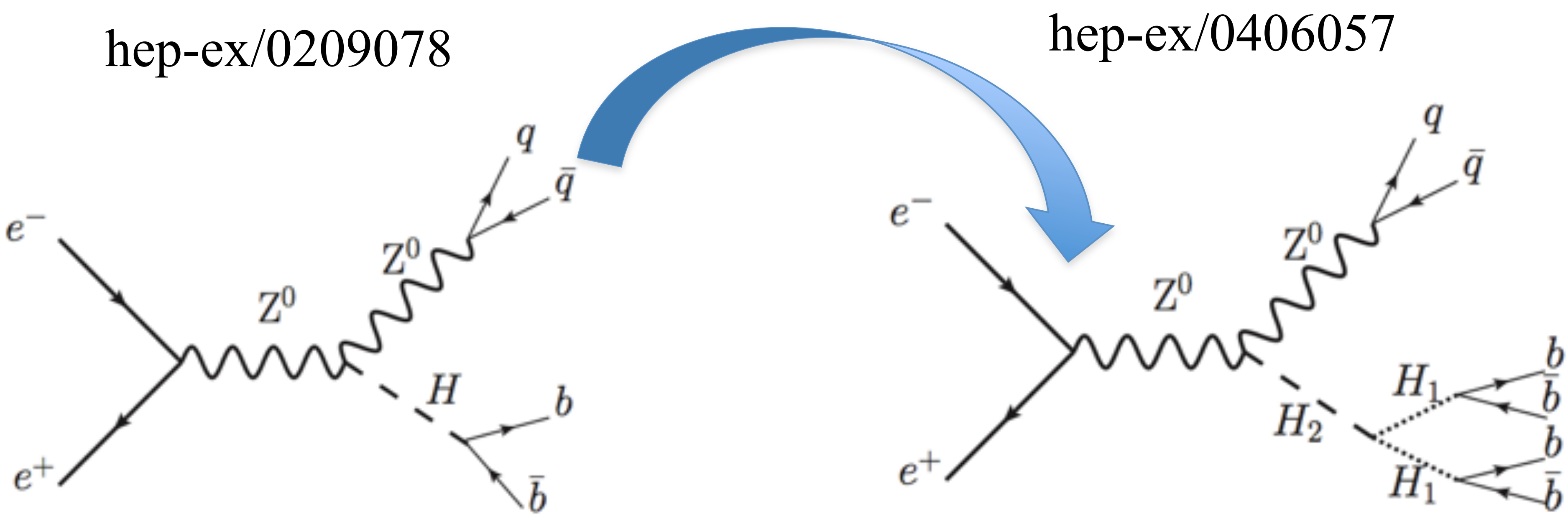






OPAL Higgs Searches

In hep-ex/0406057 OPAL recasted a previous search for Standard Model Higgs to place constraints on MSSM Higgs scenarios Text



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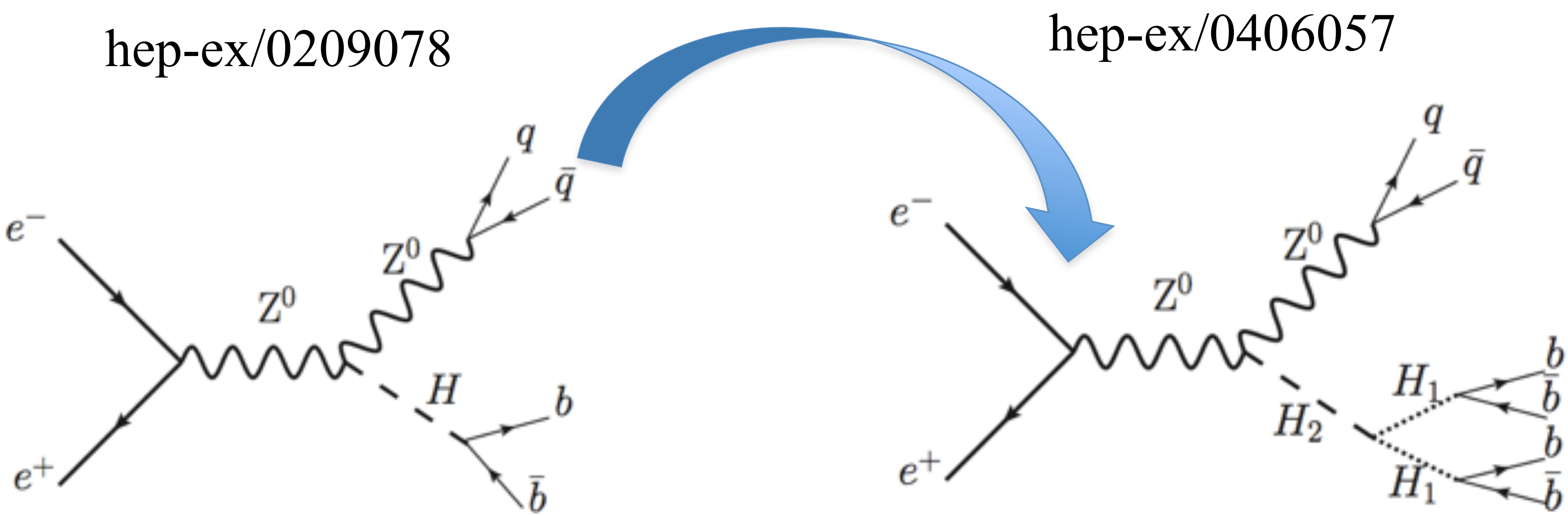
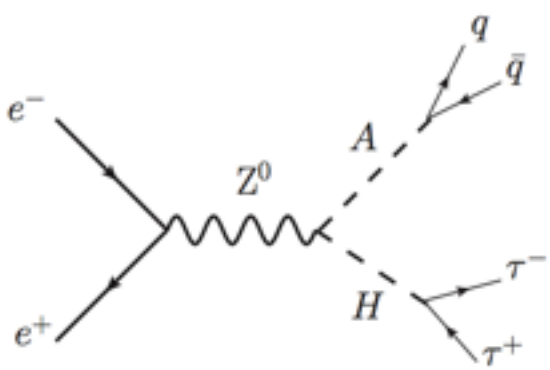


Efficient recasting

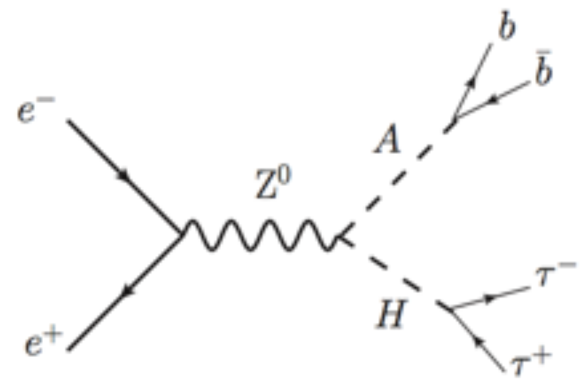
$m_{\mathcal{H}_2}$ (GeV)	$m_{\mathcal{H}_1}$ (GeV)	Efficiency for the process $\mathcal{H}_2 Z \to b\bar{b}b\bar{b}q\bar{q}$ at $\sqrt{s}$ 192 GeV	196 GeV	200 GeV	202 GeV	206 GeV
100.	12.	0.689	0.684	0.717	0.733	0.693
100.	20.	0.651	0.639	0.653	0.659	0.586
100.	30.	0.460	0.461	0.461	0.470	0.480
100.	40.	0.270	0.260	0.283	0.315	0.323
100.	48.	0.328	0.325	0.361	0.392	0.400

DELPHI Higgs Searches

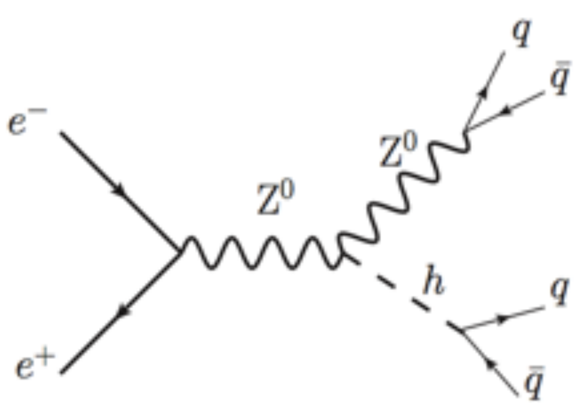
Similar recasting of previous SM Higgs searches was done at DELPHI



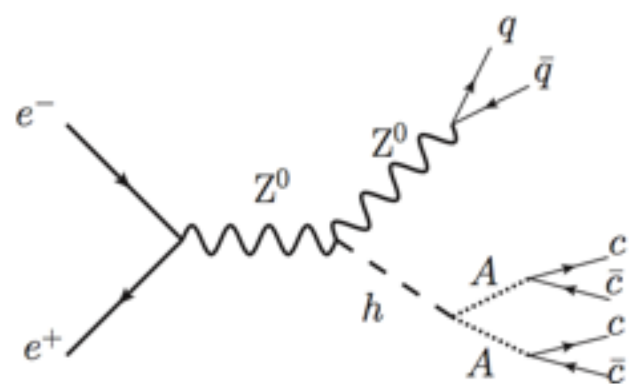
DELPHI Col., Eur. Phys. J. C38 (2004)



DELPHI Col., Eur.Phys.J. C54 (2008)



DELPHI Col., Eur. Phys. J. C23 (2002)

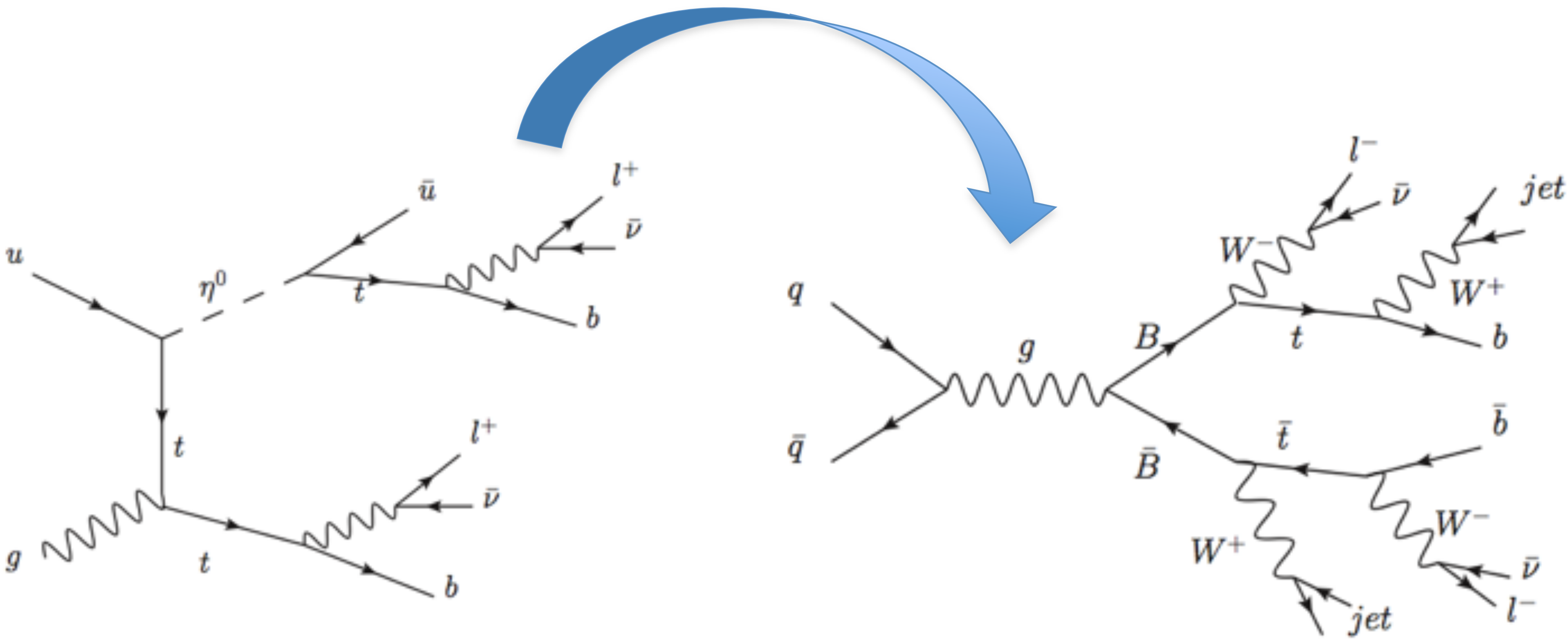


DELPHI Col., Eur.Phys.J. C54 (2008)

CDF 4th Generation Search

D. Whiteson for CDF recasted a previous search for maximal flavor violating scalars into a search for 4th generation b-quarks.

Both scenarios lead to $\ell^{\pm}\ell^{\pm}bj\not{E}_T$

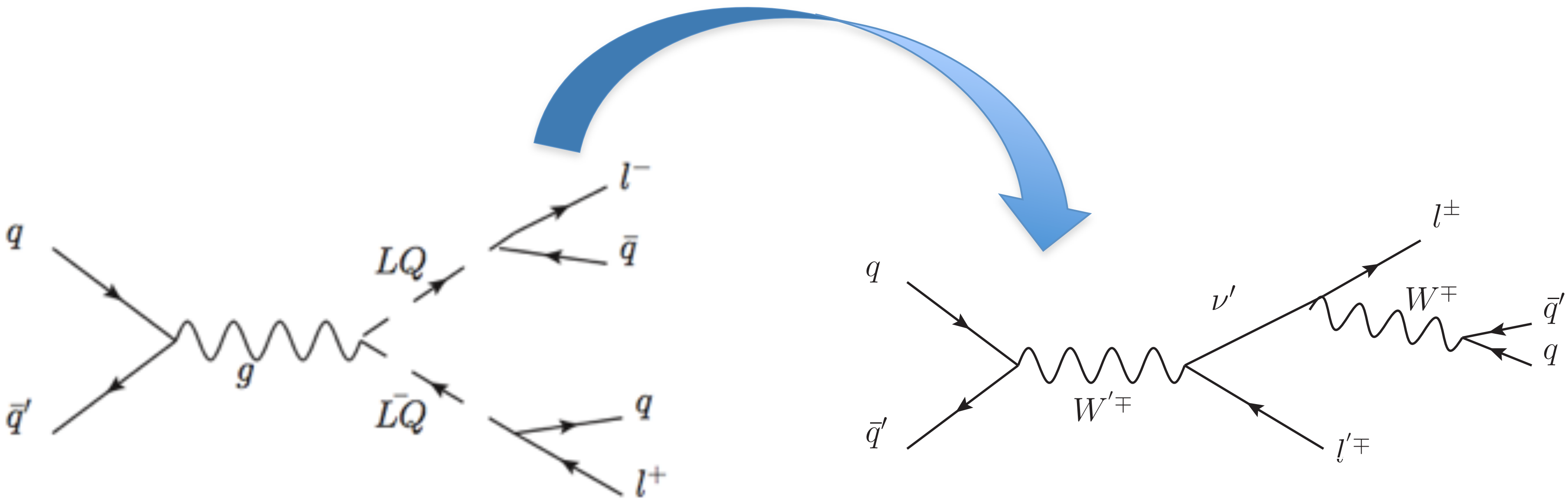


Phys. Rev. Lett. 102
hep-ex/0809.4903

Phys. Rev. Lett. 104
hep-ex/0912.1057

W’ hunt from Leptoquark search

M. Schmaltz and C. Spethmann suggested a recast of a leptoquark search that was done by DØ to place bounds on W’ particles expected in Little Higgs theories,



Phys.Lett.B636
hep-ex/0601047

????.????

Daniel's same-sign suite

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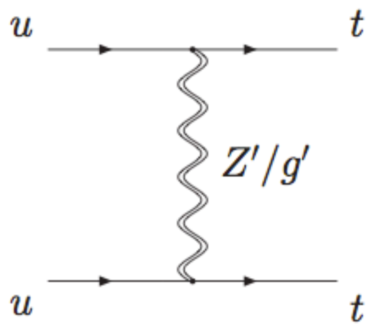
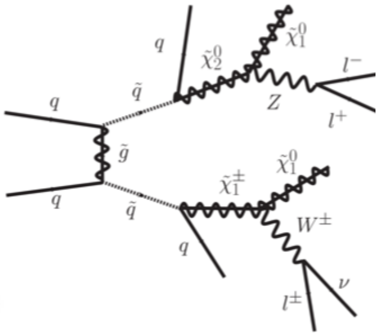
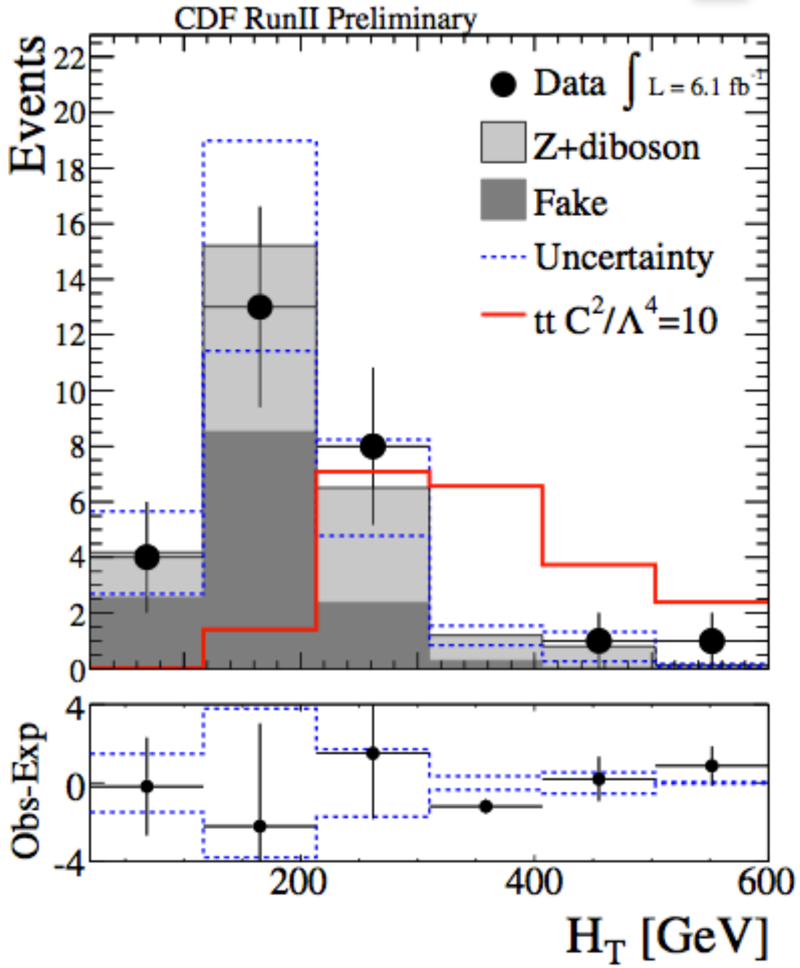
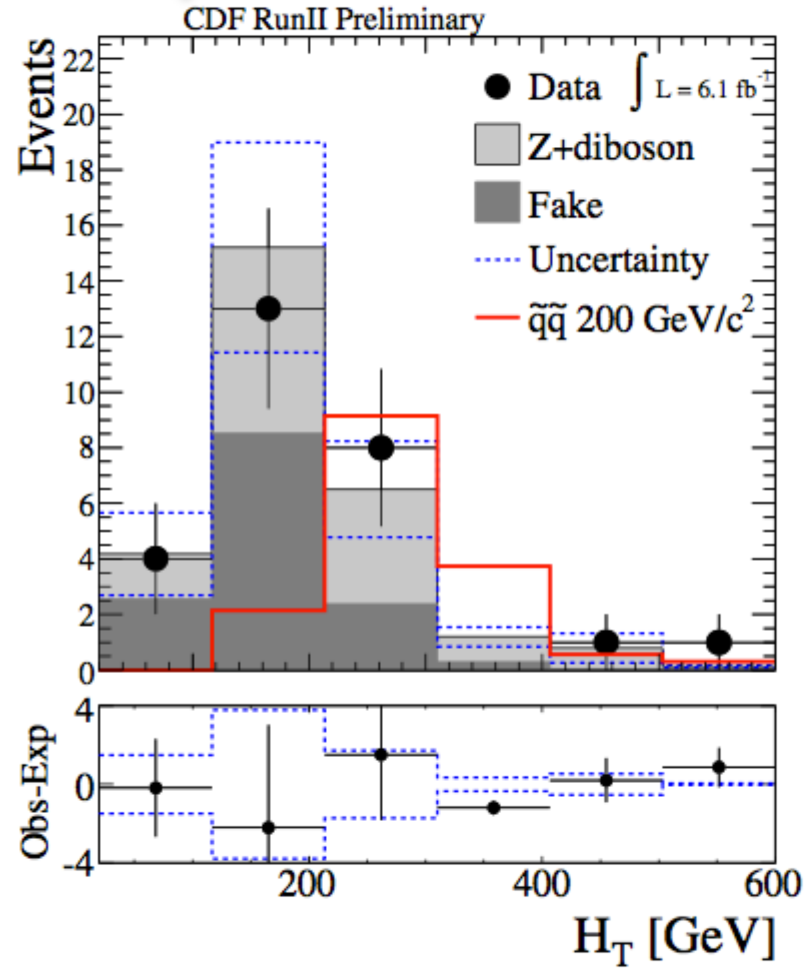




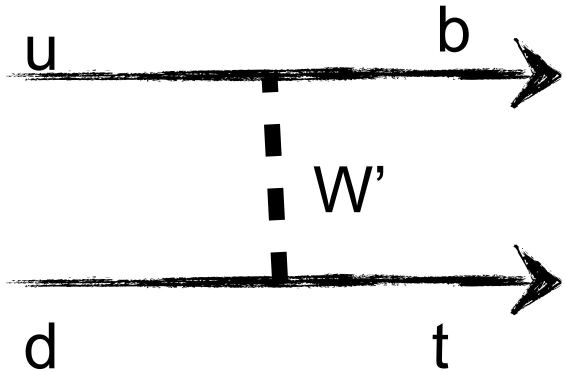




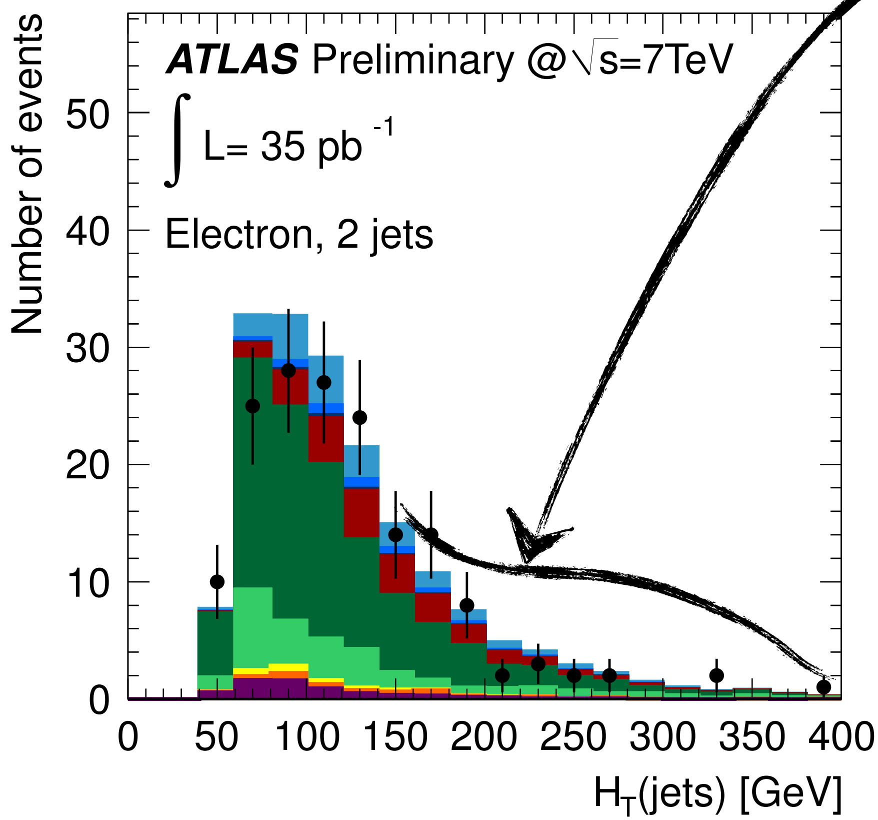
Recasting single-top

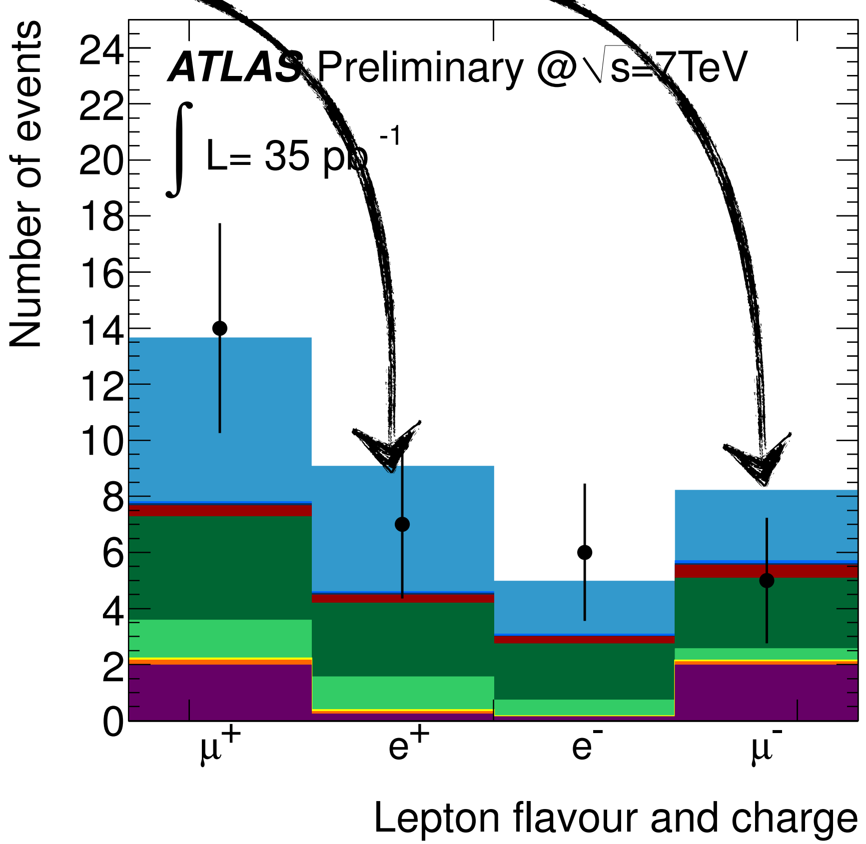
Several models for A_{FB}^{tt} have a t-channel Z' or W' with unusual flavor couplings

- often implies new single-top production modes
- existing single-top analyses with 35 pb^{-1} are already sensitive to these models



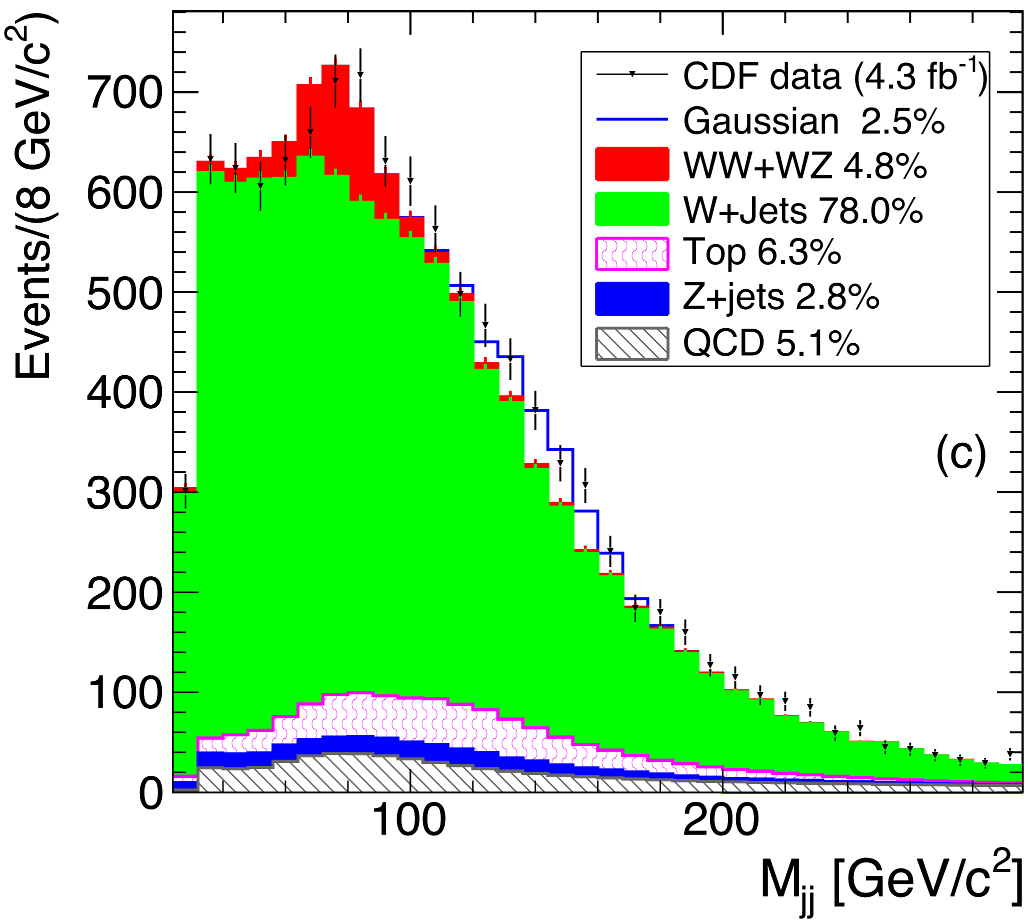
Signal region for these models





The CDF M_{jj} bump in lvjj

It would be nice to be able to properly recast the myriad of models that are about to be proposed for this bump with the actual detector simulation and reconstruction.



The recasting technique

- Does not require access to or reprocessing of the data
- Does not involve design of new event selection criteria
- Does not require additional estimates of background rates or systematic uncertainties

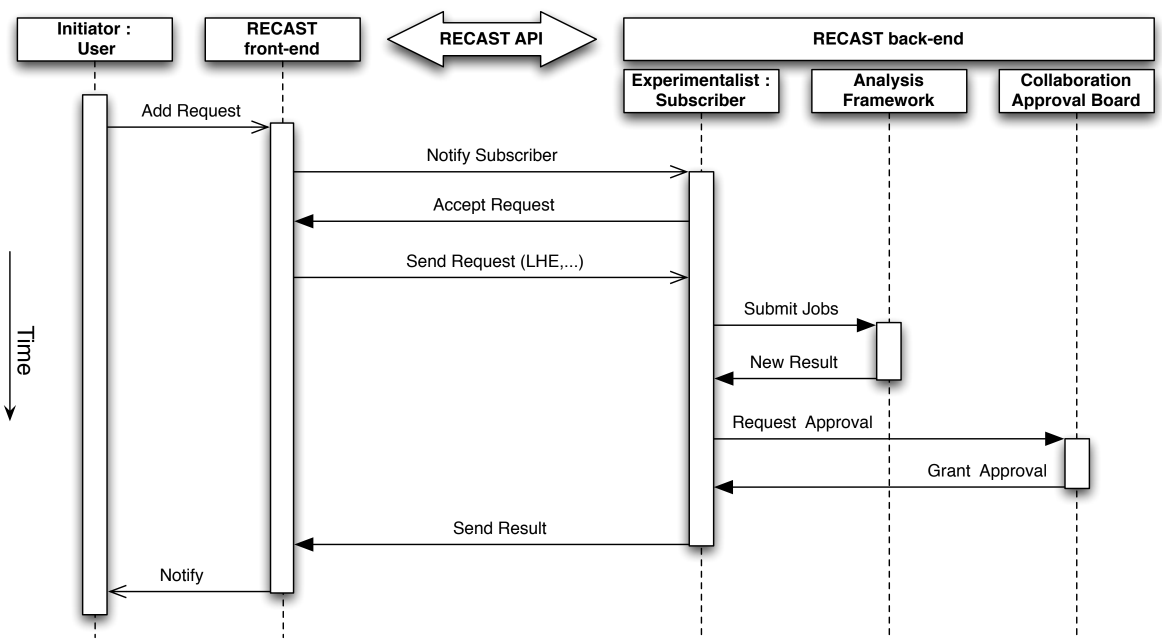
- Extends the impact of existing experimental searches
- Targets physics scenarios of interest to the community
- Provides accurate interpretation of model-independent and signature-based searches in the context of a specific model
- Facilitates the consideration of new models even after the analysis is done
- Allows collaborations to control the approval of new results
- Complements data archival efforts

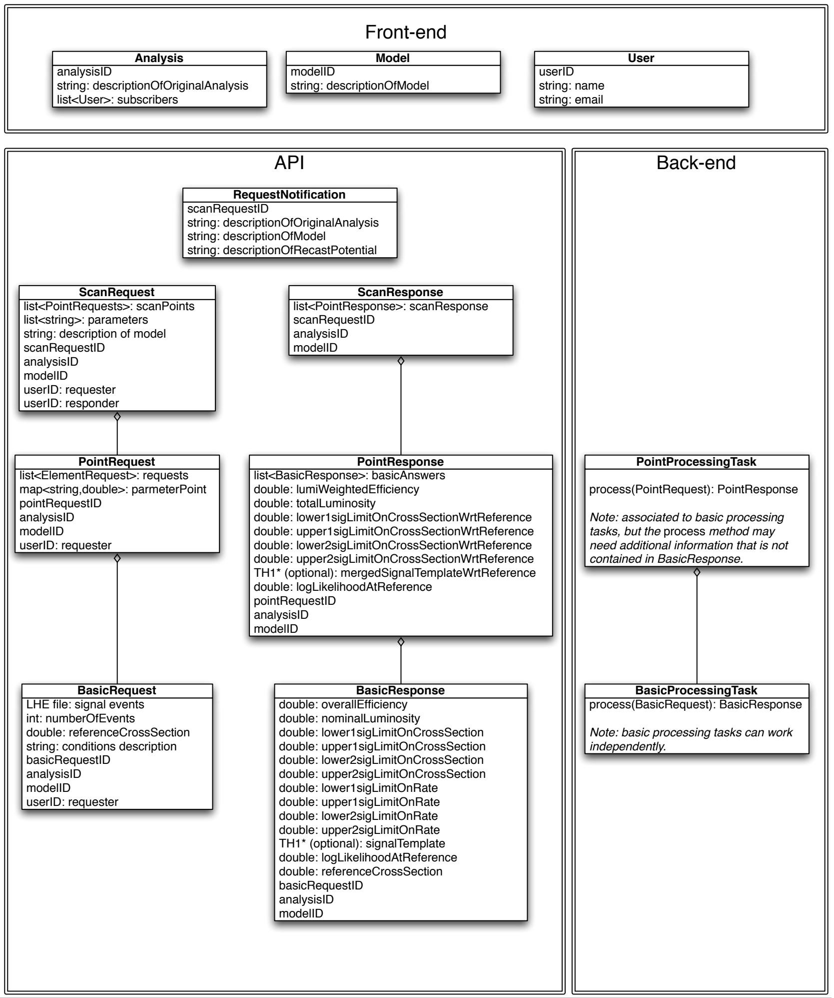
High Level Design

K.C., Itay Yavin [hep-ex/1010.2506], JHEP.

A first iteration on the high-level design is complete

- identified someone from ATLAS MC production system to start implementing, but this is a side project.
- verbal offer from CERN to provide person to link API with INSPIRE





Validating simplifying assumptions

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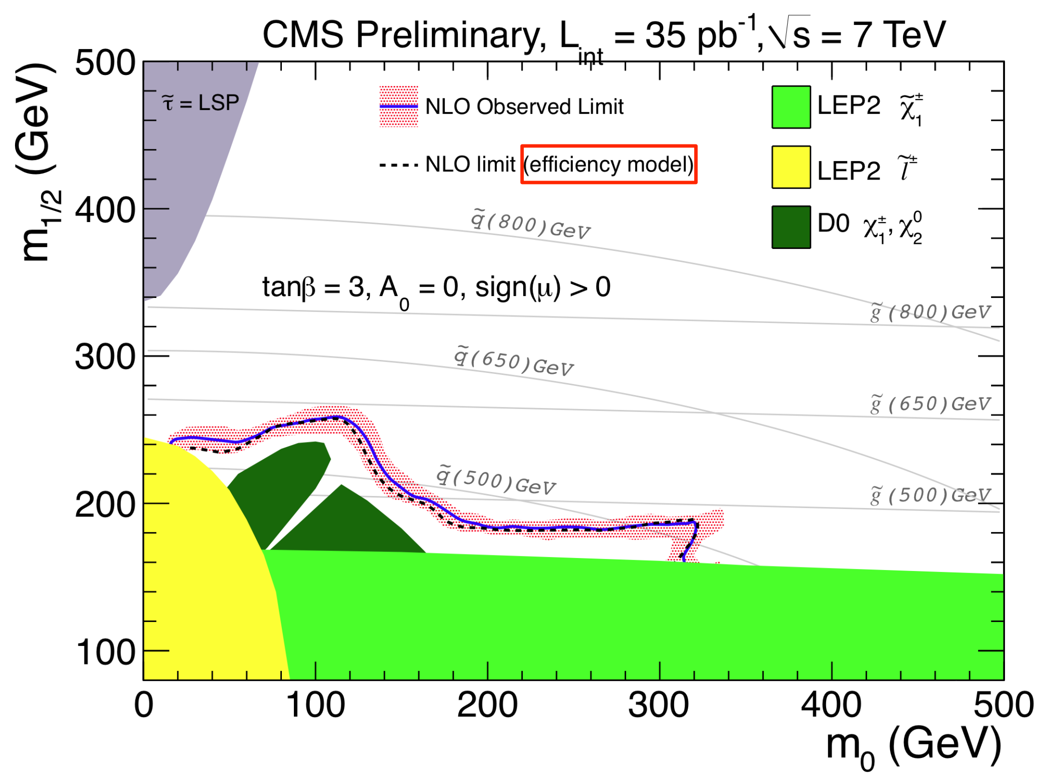
Often other simplifying assumptions can be made to estimate the efficiency for the simplified model, but it would is nice (required) to have a fully simulated "anchor" point for cross-checks

ATLAS	FEATURE
ISASUGRA generates spectrum & sparticle decays	SuSpect generates spectra with SUSY-HIT# for decays
NLO cross section using PROSPINO & CTEQ6M	NLO cross section for ~85 processes using PROSPINO** & CTEQ6.6M
Herwig for fragmentation & hadronization	PYTHIA for fragmentation & hadronization
GEANT4 for full detector sim	PGS4-ATLAS for fast detector sim

** version w/ negative K-factor errors corrected

version w/o negative QCD corrections & with 1st & 2nd generation fermion masses included as well as explicit small Δm chargino decays

Same sign di-lepton + jets + MET search



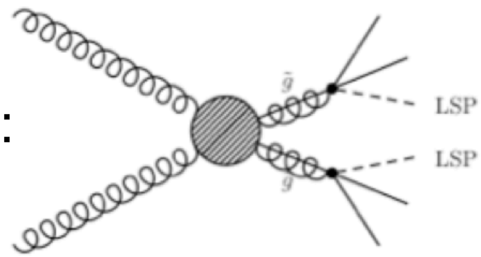
CMS SUSY Results, D. Stuart, April 2011, SUSY Recast, UC Davis

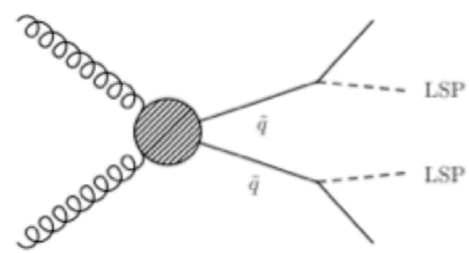
Paper includes a simple efficiency model (i.e. for PGS calibrations) and compares full limit to limit with simple model.

A Roadmap
going beyond individual simplified model topologies

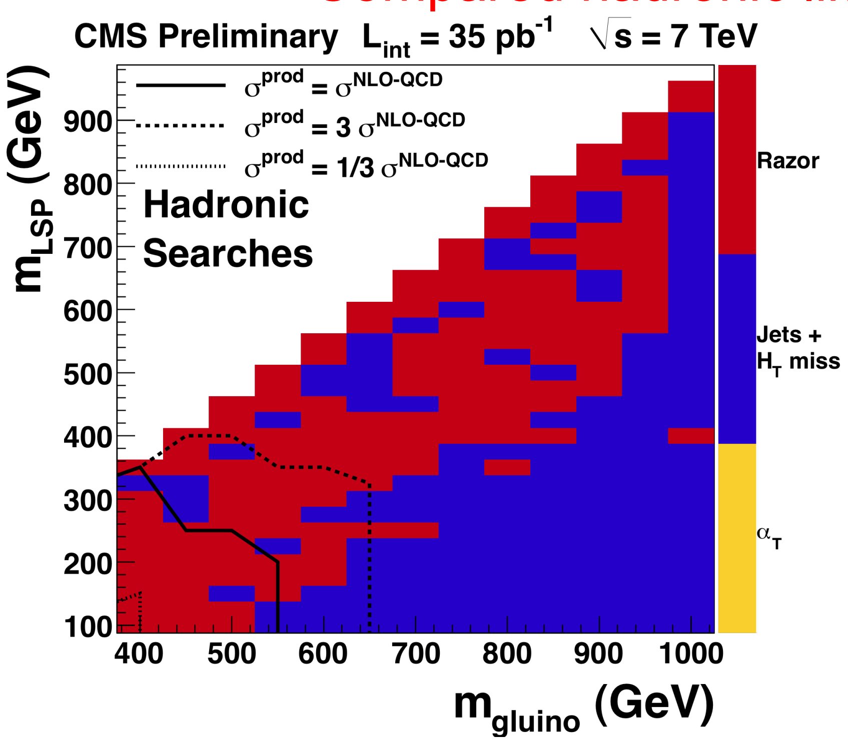
Simplified models

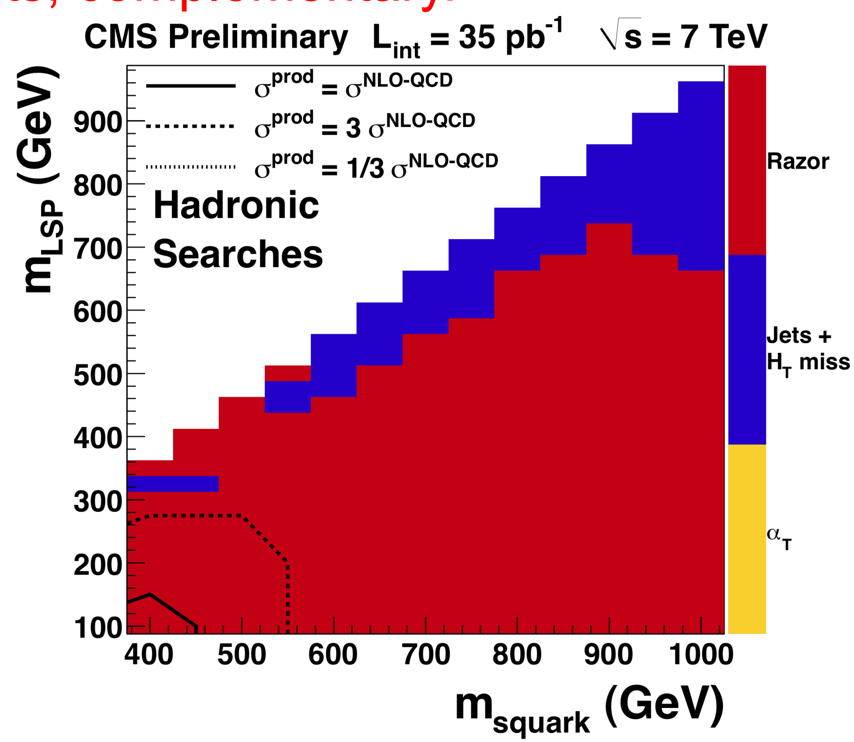
Interpreted hadronic searches
in two simple reference topologies:
gluino & squark pair production
http://www.lhcnewphysics.org





Compared hadronic limits; complementary.





CMS SUSY Results, D. Stuart, April 2011, SUSY Recast, UC Davis 41

Looking back, to look forward

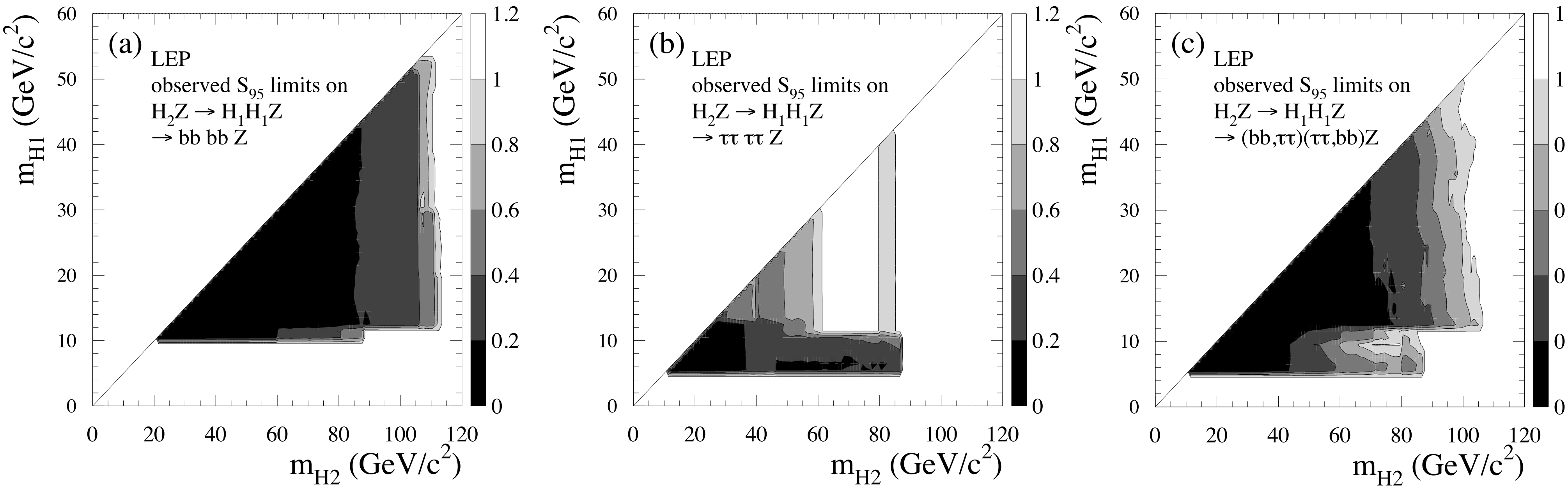
Nice set of results on neutral Higgs at LEP is a good example of the simplified model approach

- reused in tools like see HiggsBounds, which also chooses most constraining single search
- **NOT POSSIBLE TO OPTIMALLY COMBINE P-VALUES (LIMITS)**

NOTE: These approaches can't be used for different final states unless the search is "recastable"

(factor x SM cross section that corresponds to 95% exclusion)

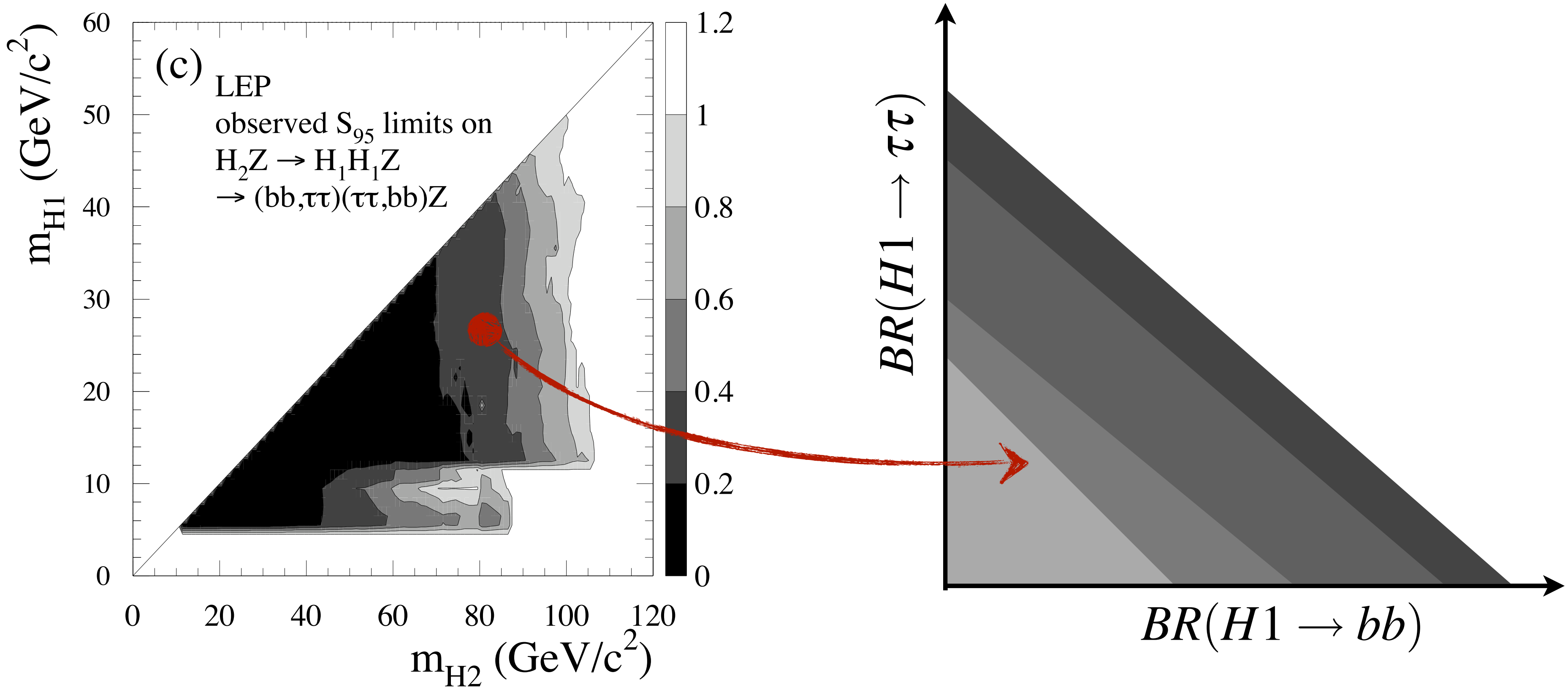
Eur.Phys.J. C33 (2004) [hep-ex/0602042]



For mixed decays

In the case of mixed decays, one would really like to be able know the limit for any point in the branching ratio space

- the LEP analysis only considered 50/50 branching ratios
- difficult to publish on paper
- again digital publishing would be ideal



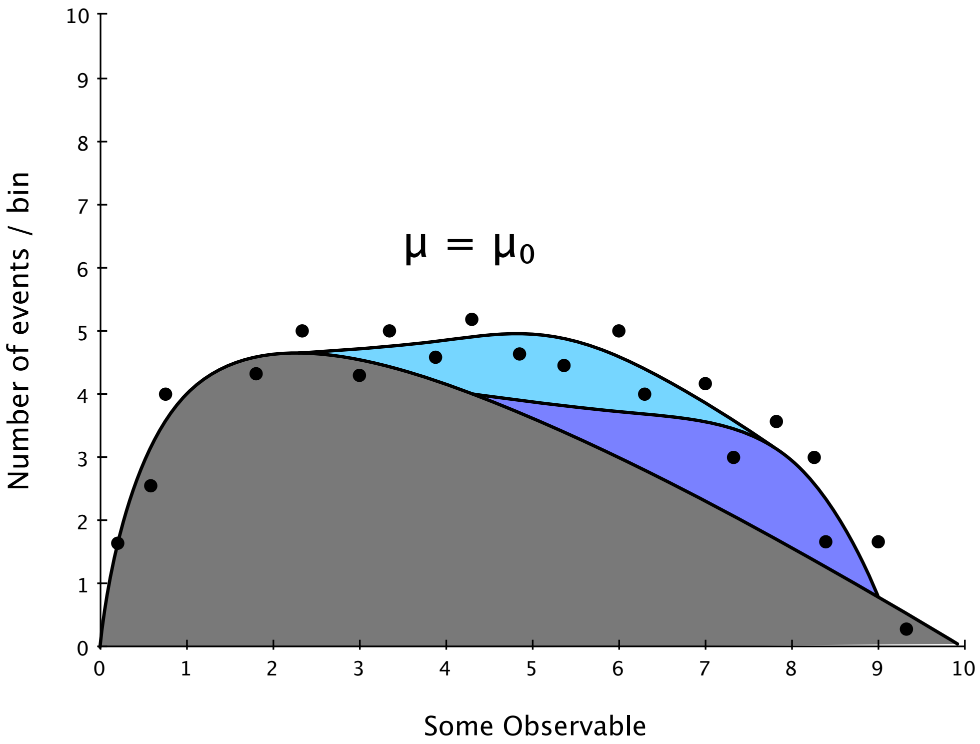
Acceptance

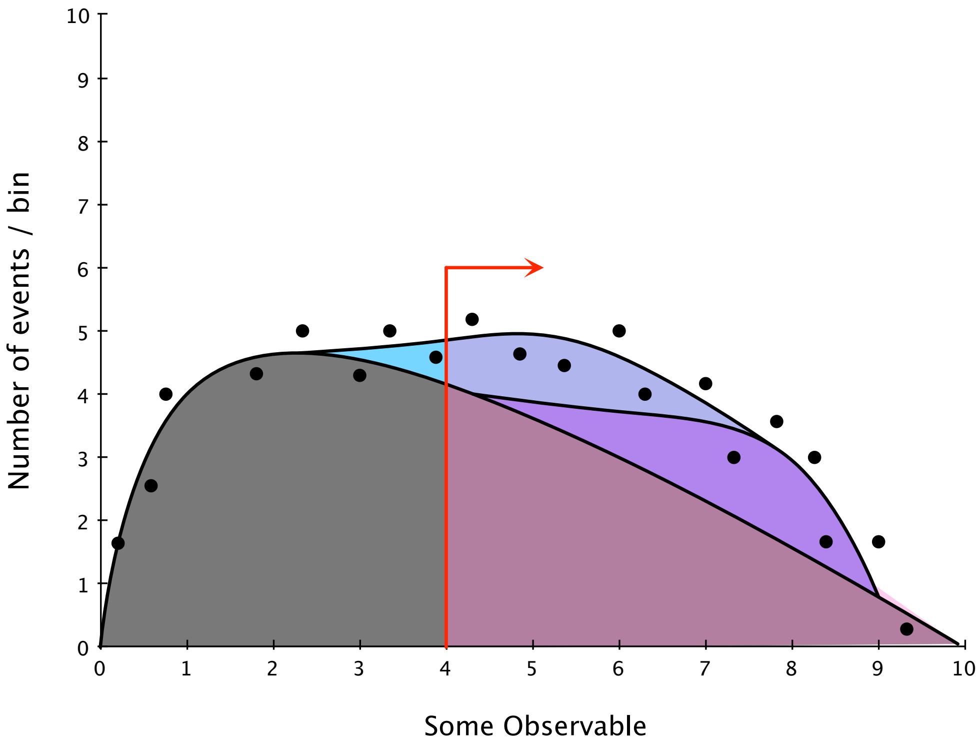
As we move around the model's parameter space the distributions change, thus changing the signal efficiency and acceptance.

- This is harder to parametrize than branching ratios fro different topologies

Remember that even at this fixed point in the model's parameter space, the efficiency and acceptance can change as you vary the nuisance parameters associated with systematic effects.

- at first, maybe we can neglect this effect and it's an adequate approximation





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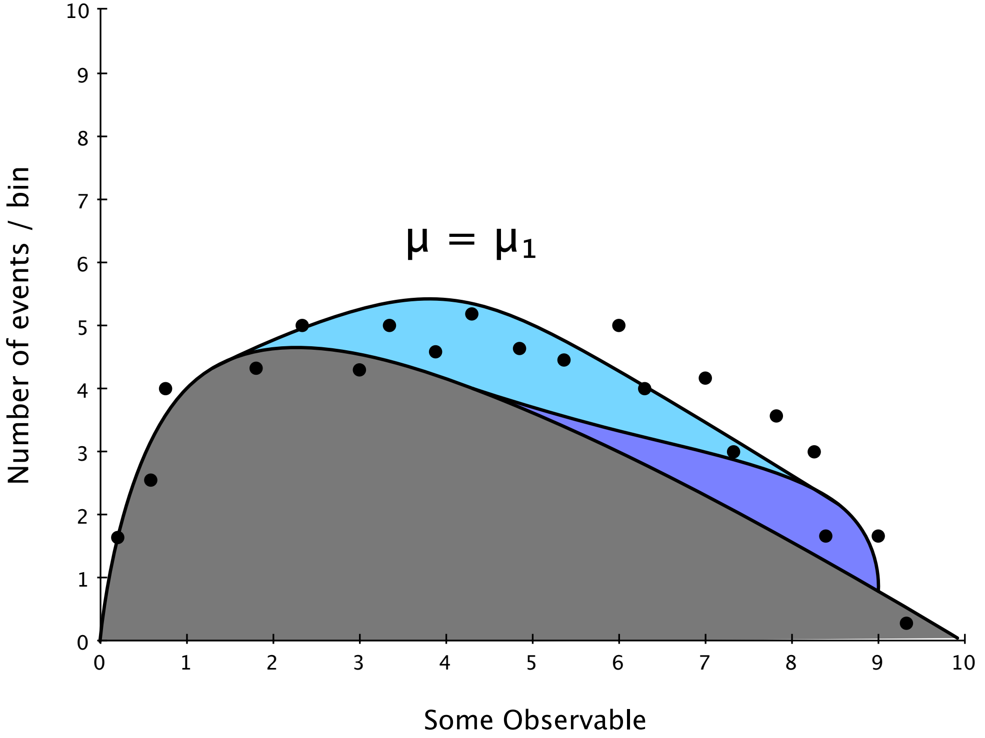

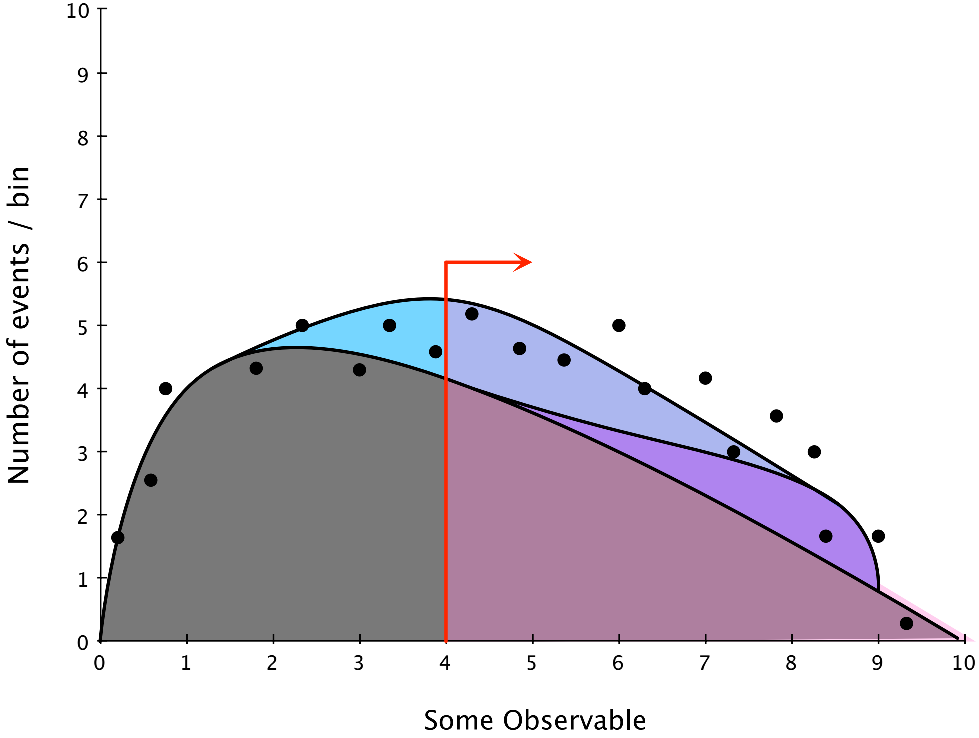

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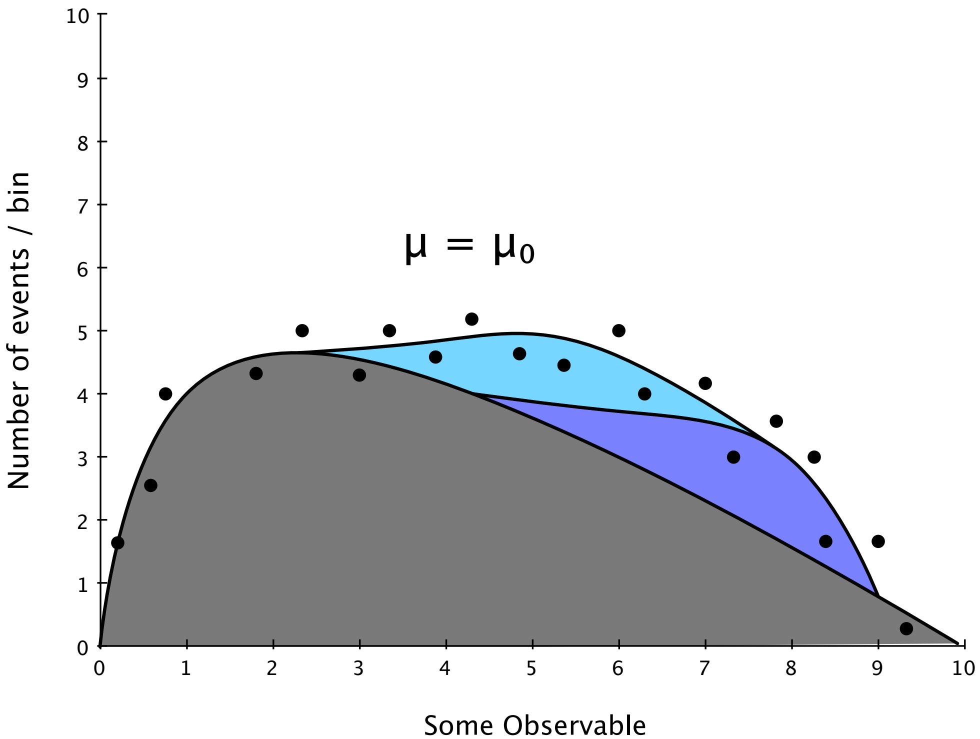

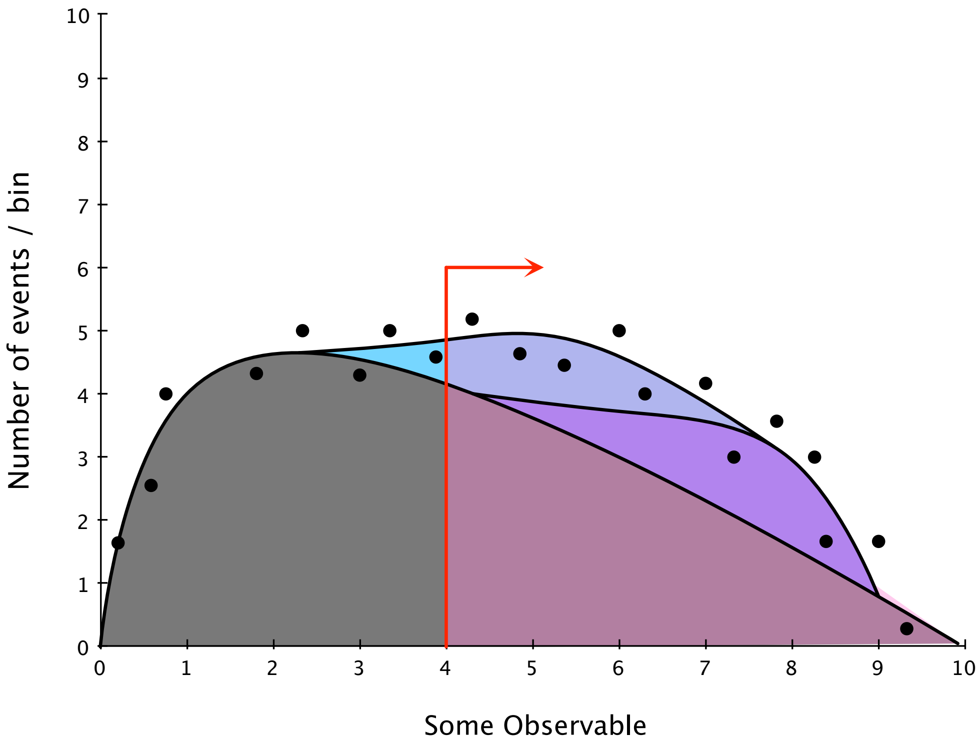

Interpolating

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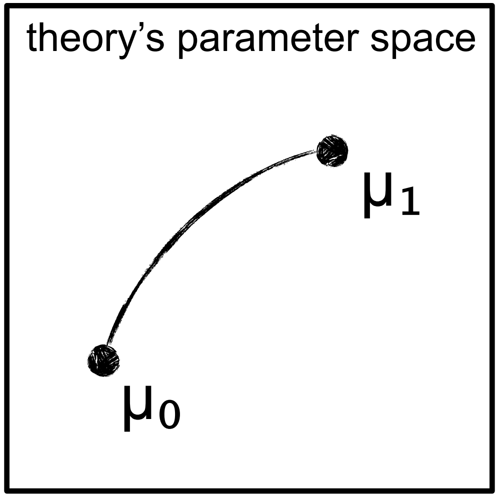
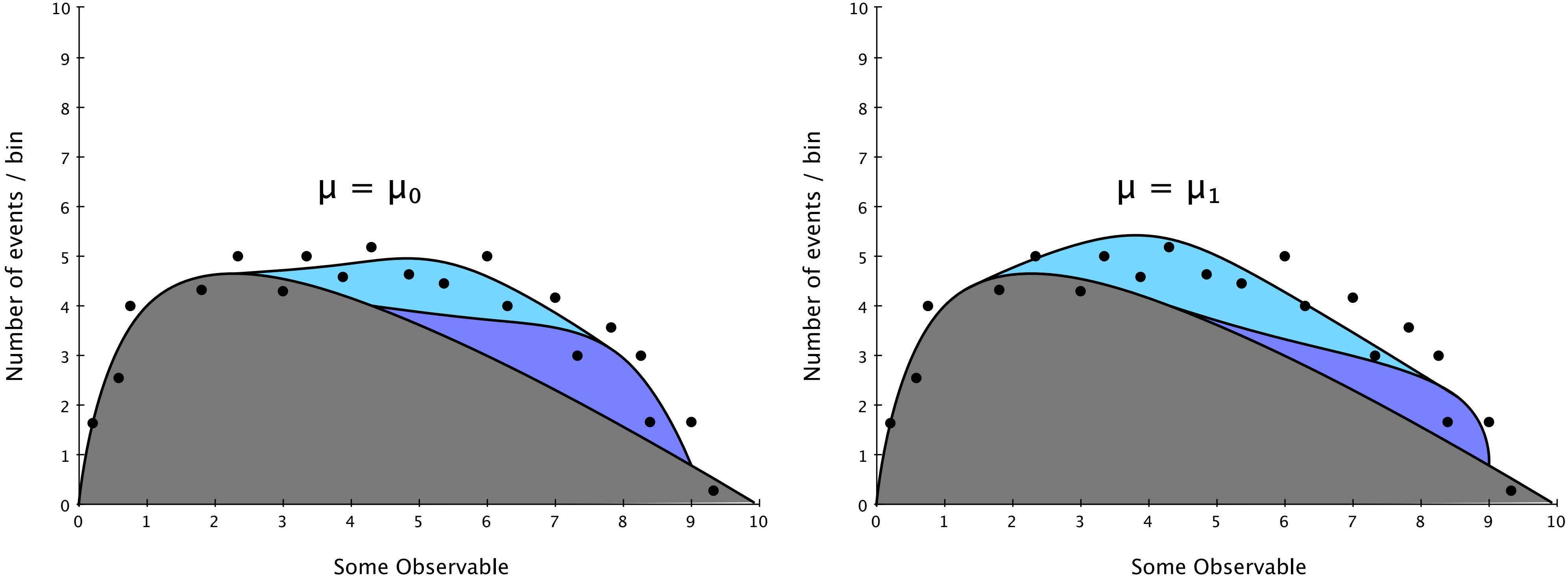
Most statistical techniques require ability to evaluate likelihood at arbitrary points in the parameter space ⇒



- Either need to have evaluated model at sufficiently many discrete parameter points
- Or have a way of interpolating expected signal distribution (including efficiency & acceptance)
  - Often by interpolating between template histograms



Extrapolating

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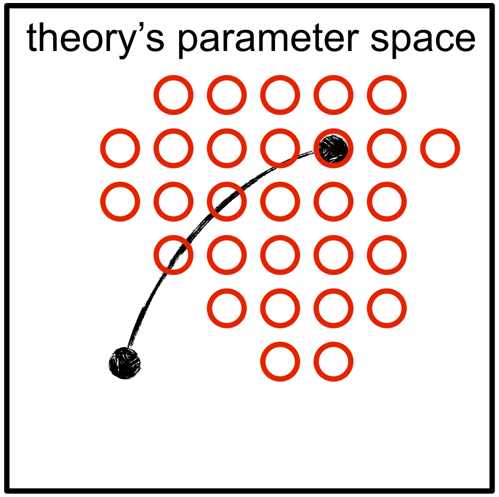
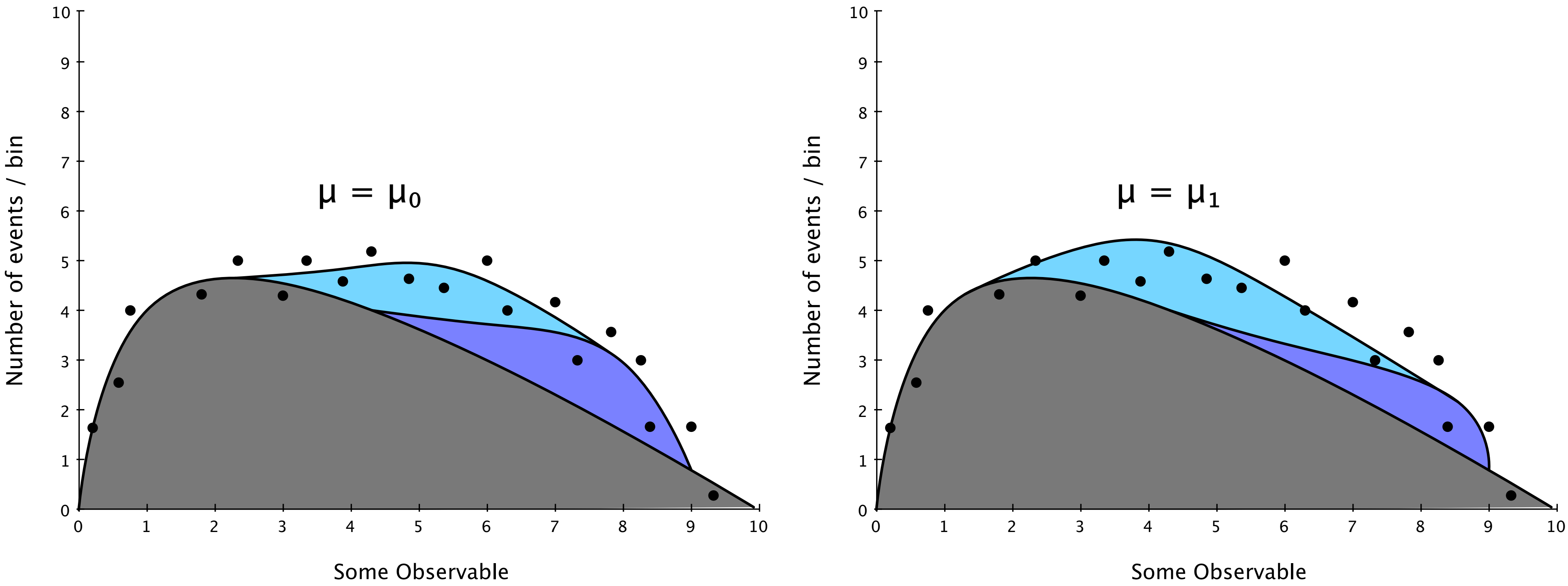
Initially the experiments may scan some initial set of model points.

- These define a domain of validity for the model

How does one go to model points outside this set?

- if the experiments had a service to provide signal templates for new model points, then one can interpolate between these new anchor points.





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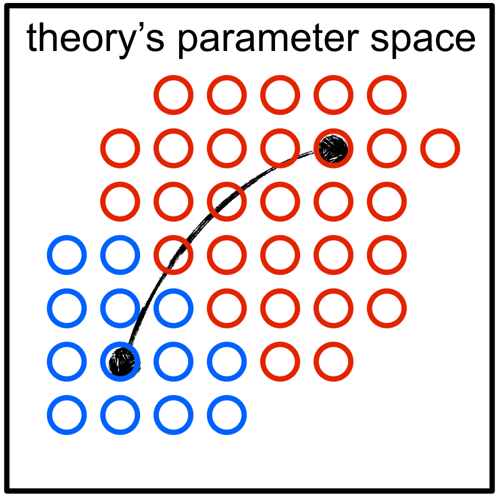

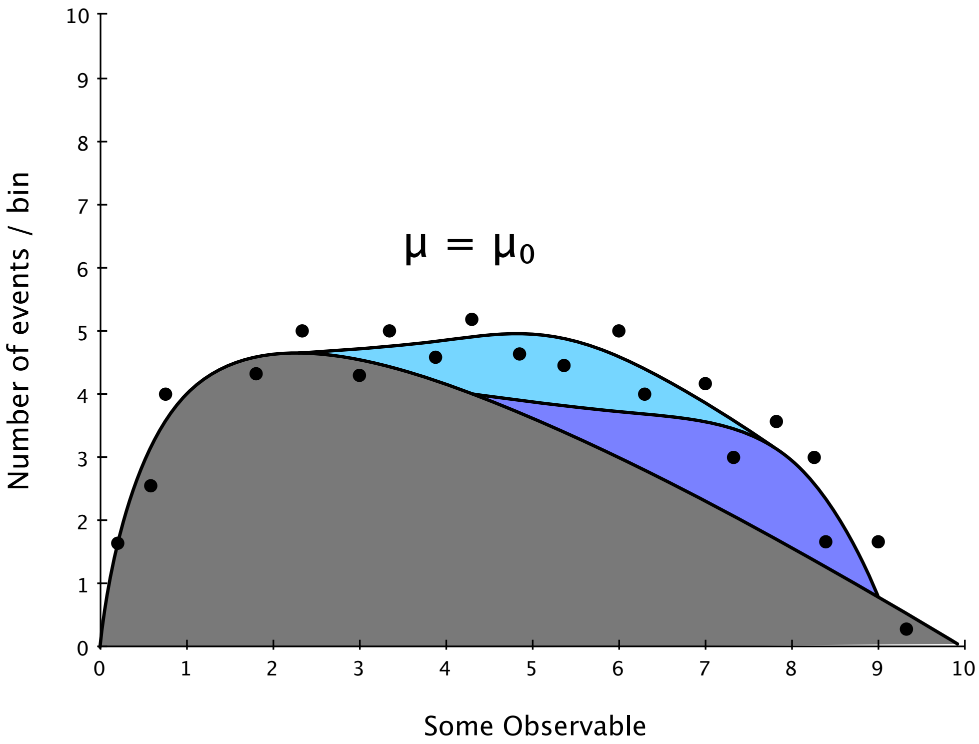

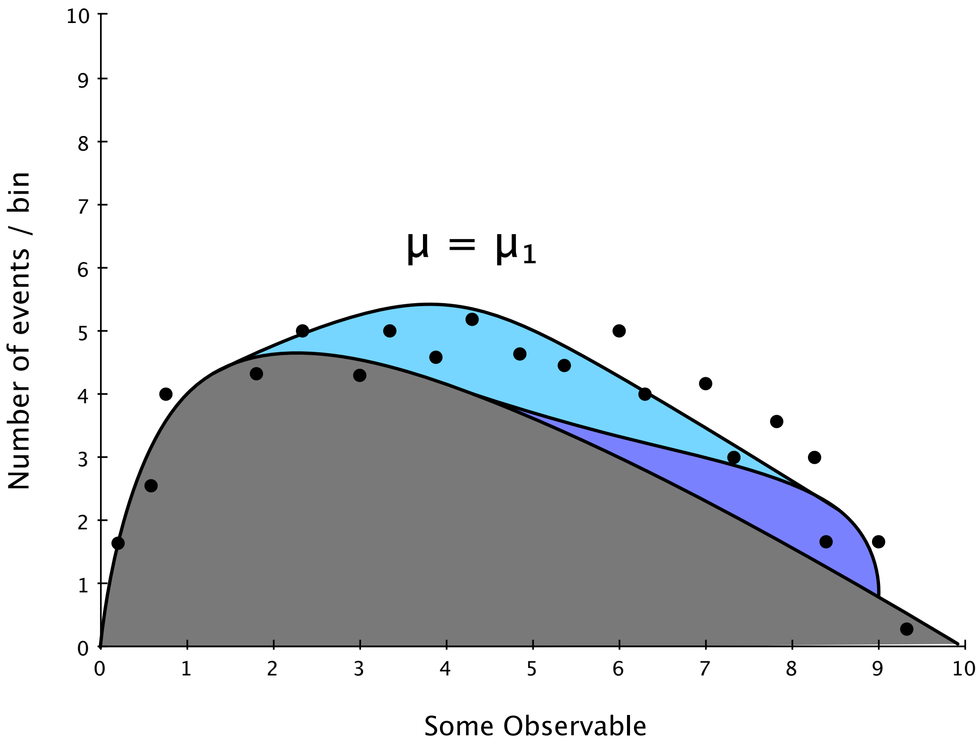

A Word Combining Searches and Publishing Likelihoods

4-channel ATLAS Higgs combination

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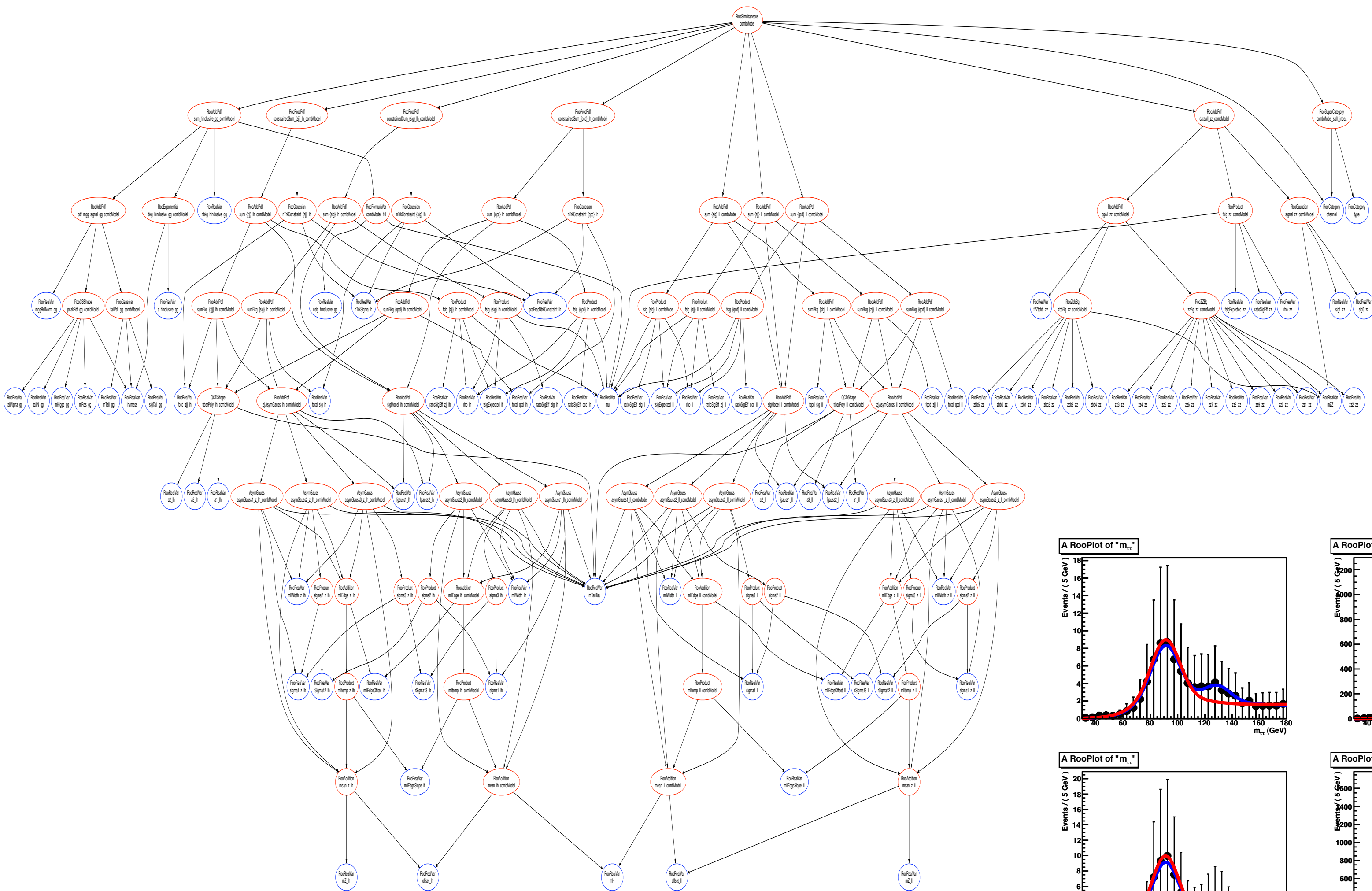

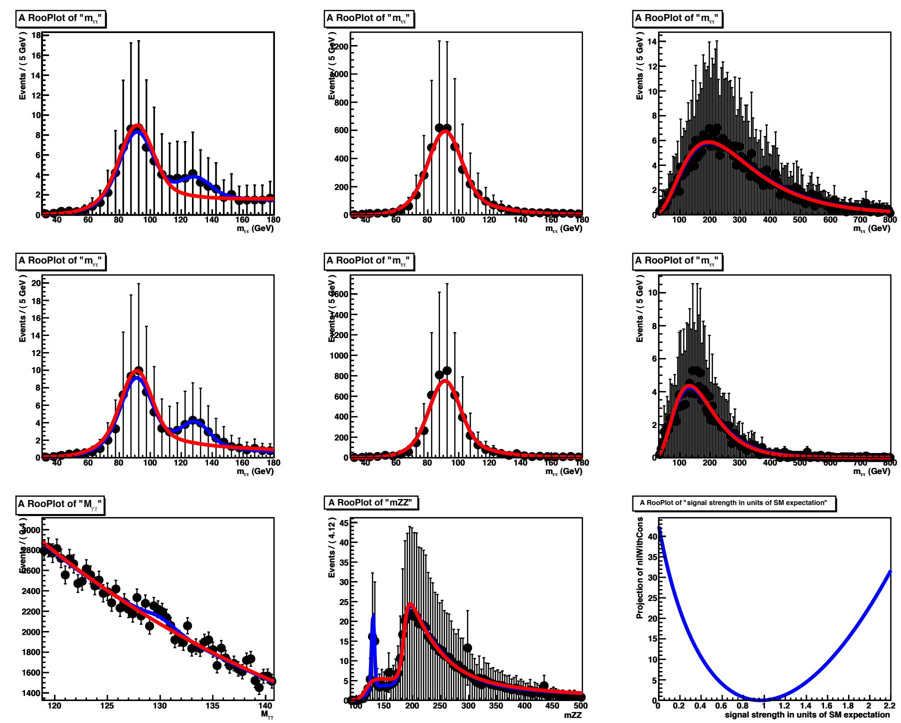

9 observations of continuous variables
1 parameter of interest
27 nuisance parameters

Visualization of the ATLAS+CMS Workspace

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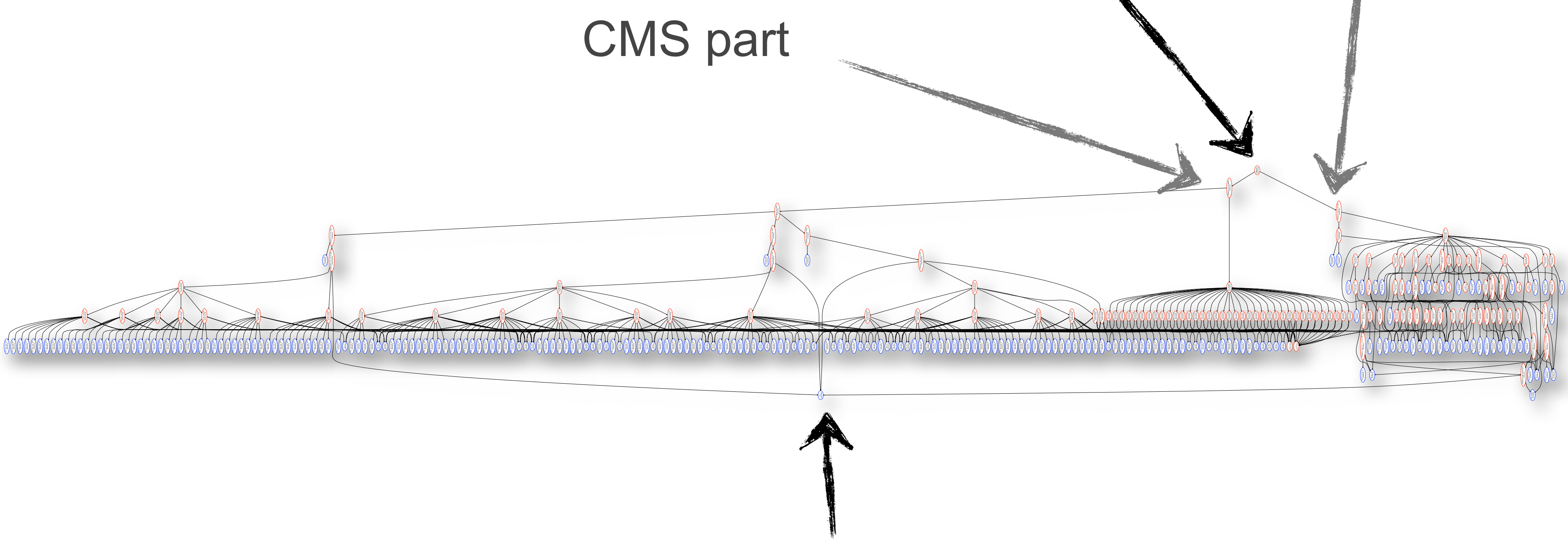
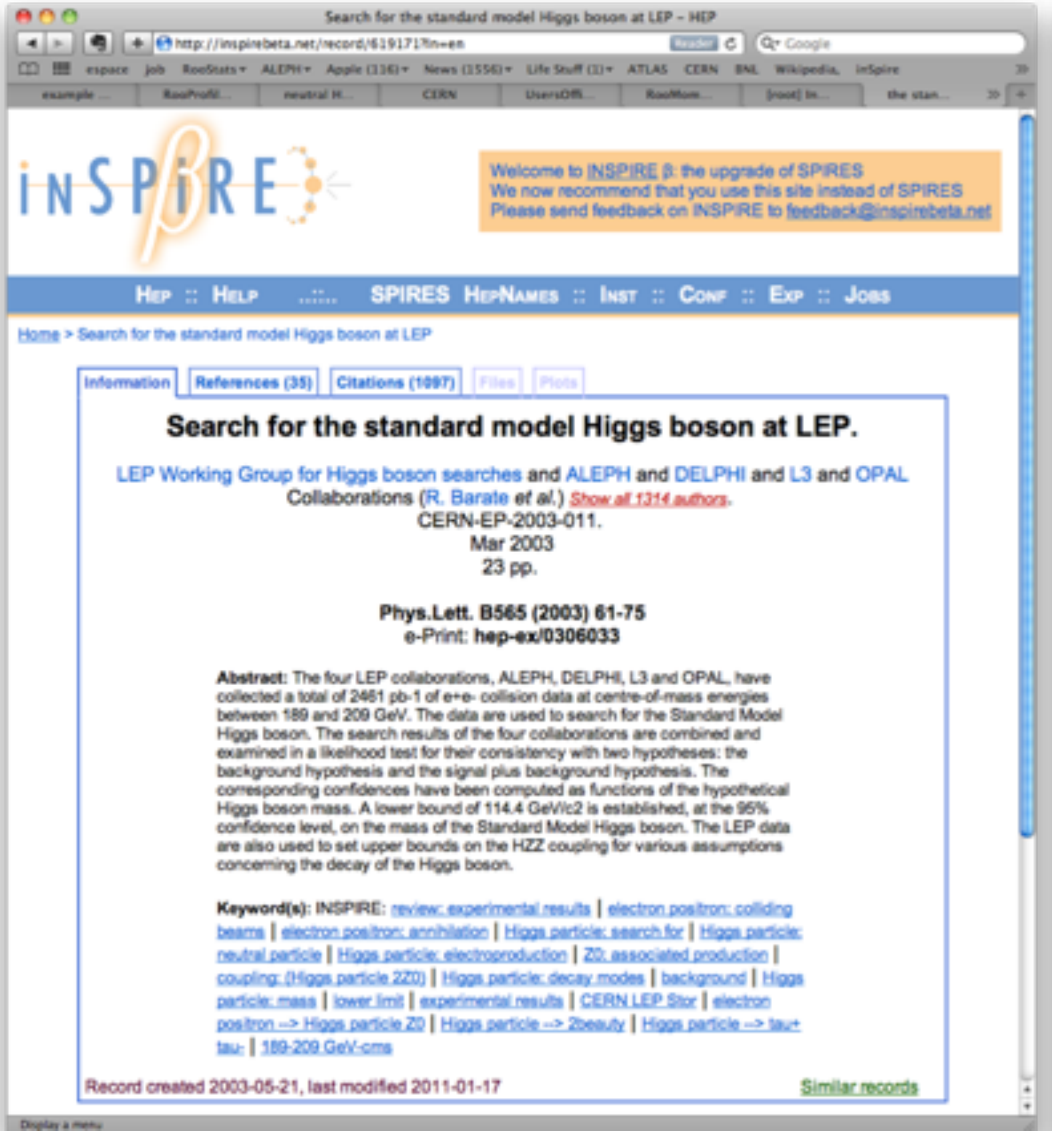
The full model has
12 observables and
~50 parameters

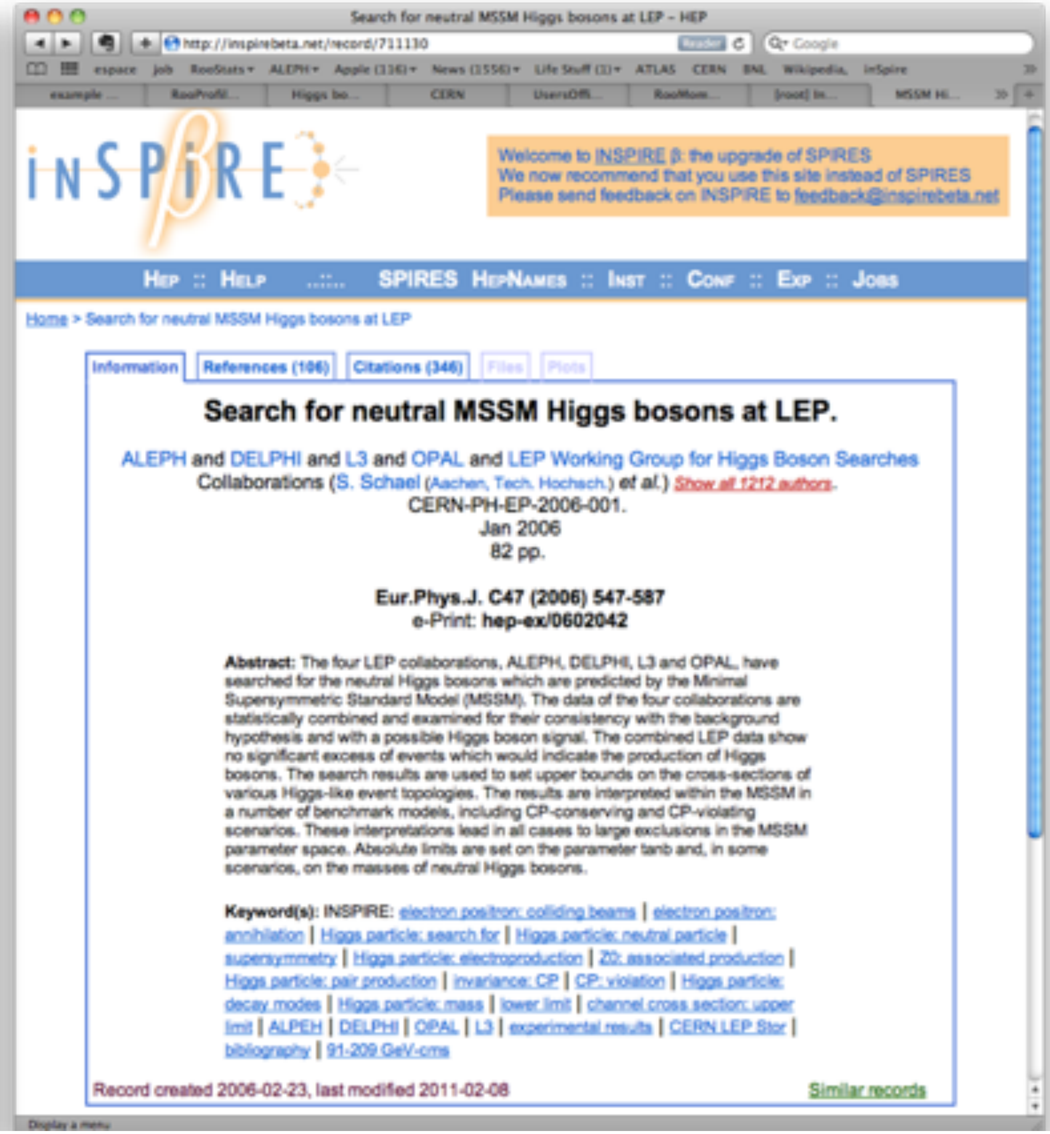


$$\mu = \frac{\sigma BR}{\sigma_{SM} BR_{SM}}$$

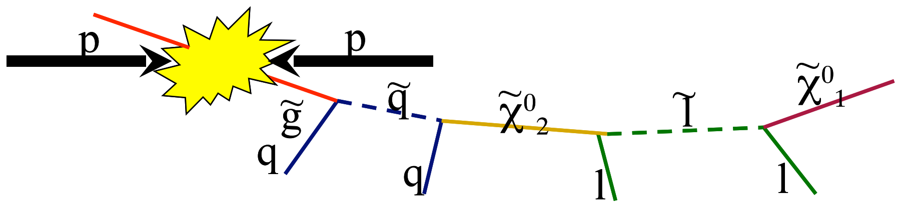
Publishing LEP Higgs as Likelihoods

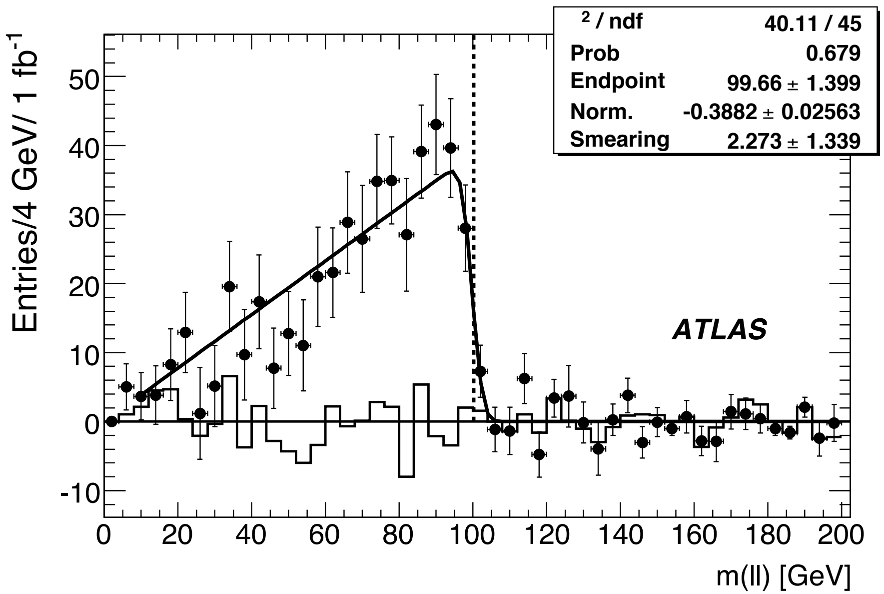
Agreement from all LEP collaborations to convert LEP Higgs searches into RooStats format and publish them (combination?)





Inference on which parameters?





$$m_{ll}^{\mathrm{edge}} = m_{\tilde{\chi}_2^0}\sqrt{1-\left(\frac{m_{\tilde{l}}}{m_{\tilde{\chi}_2^0}}\right)^2}\sqrt{1-\left(\frac{m_{\tilde{\chi}_1^0}}{m_{\tilde{l}}}\right)^2}$$

$$(m_{\tilde{l}}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_1^0}, \ldots)$$

$$(m_0, m_{1/2}, \tan\beta, A_0, \mathrm{sign}(\mu))$$

Most of the effort of the fitting groups has been on inferring parameters of more fundamental theories

- often needed more fundamental theory to relate observations in different experiments

However, most of the technical and statistical tools can be applied to inference on the physical parameters (sparticle masses, cross-sections, BRs)

- and for similar experiments it is clear how to relate and combine measurements

First interface with SuperBayes

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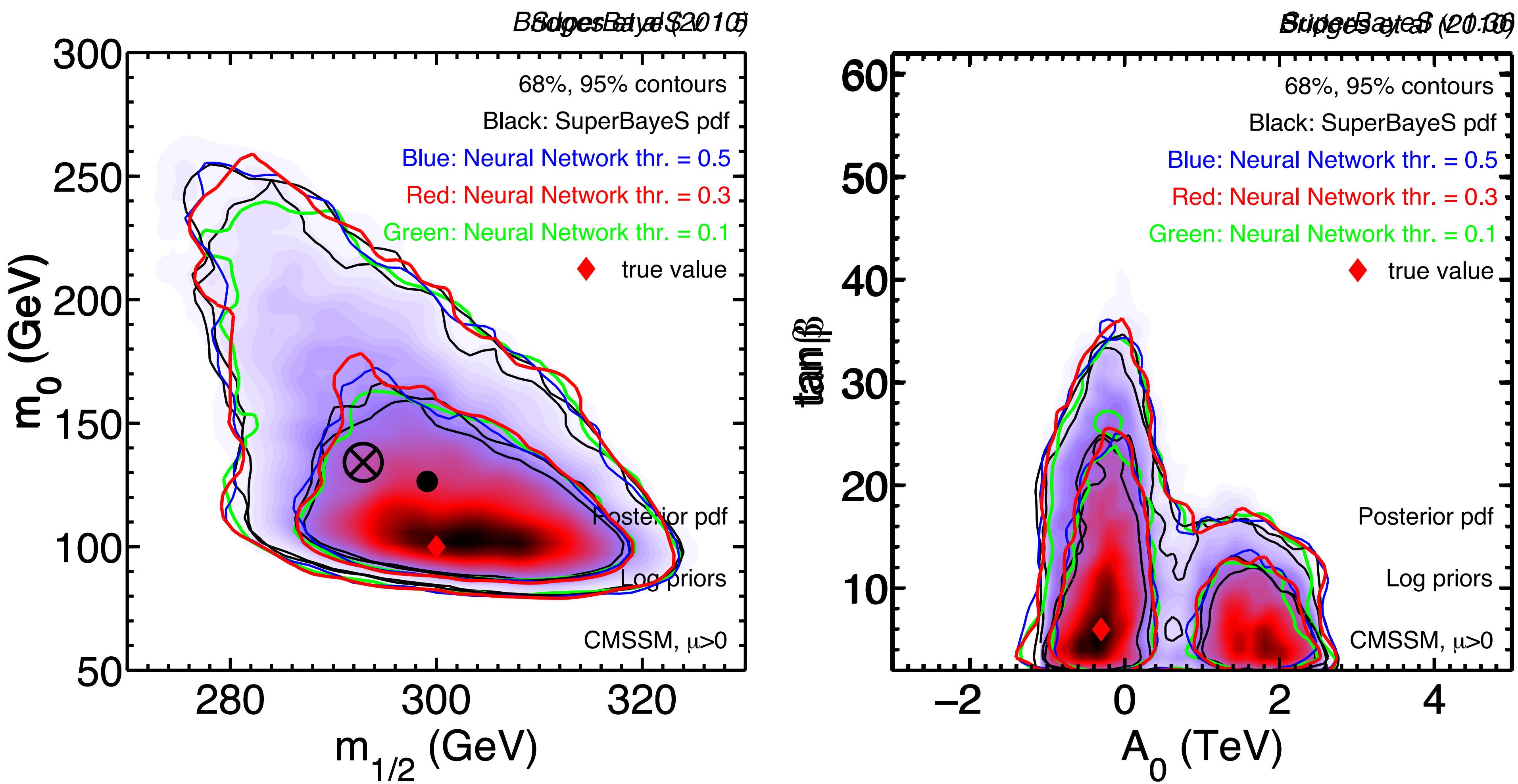
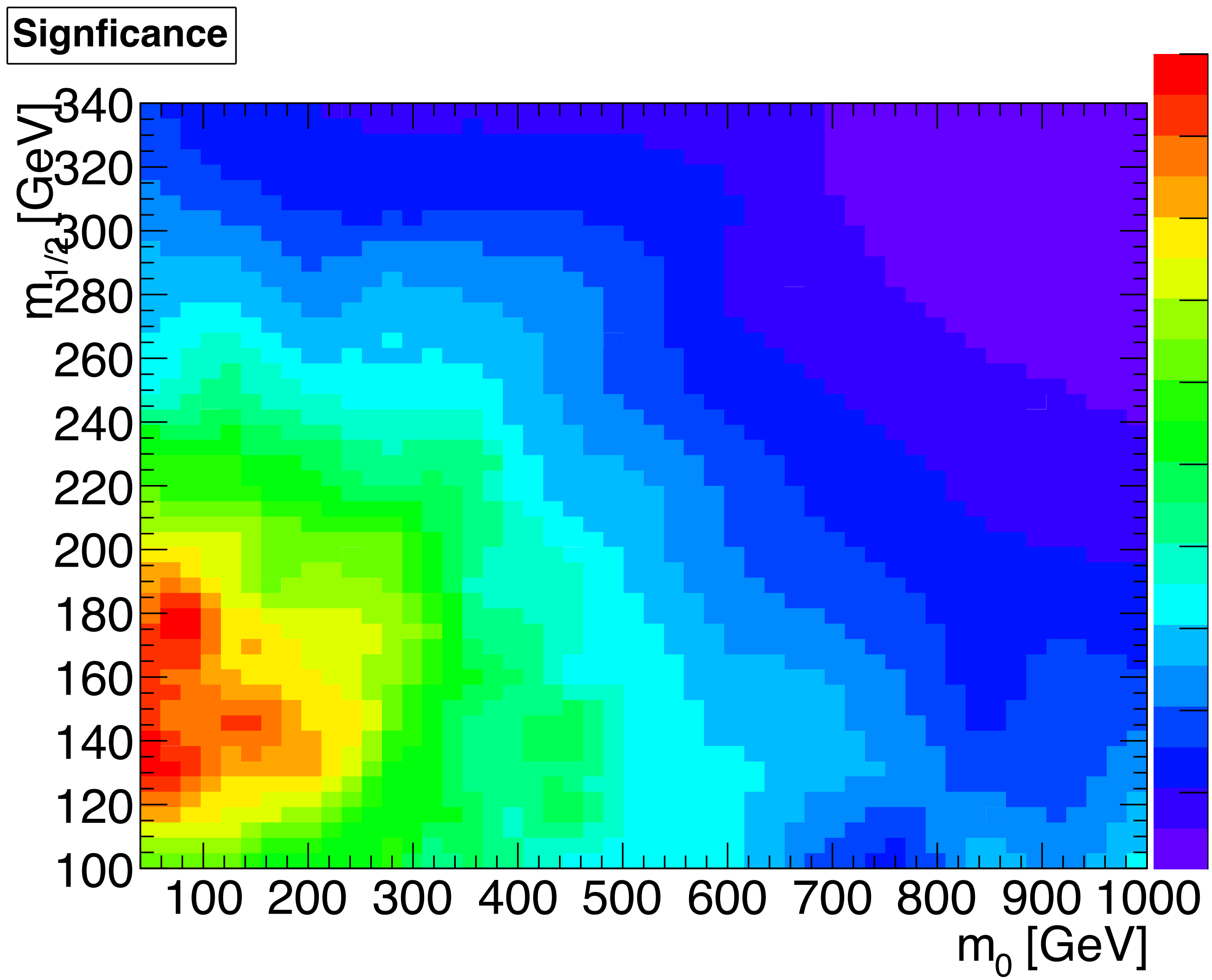
Repeated same analysis as Bridges, KC, Trotta et al (1011.4306) with RooStats likelihood

- see consistent results!



Benchmark based on counting

Max Baak's demonstrated interpolation of signal yield and uncertainties in a 3-d mSUGRA scan with a simple number counting analysis



The Closure Test

Statement of the Closure Test

One of the nagging complaints about the Simplified Model approach is that it hasn't been demonstrated that one can make equivalent statements about a "full model" by bringing together results from simplified models

Closure Test:

Vague statement: show that you can make equivalent statements about the full model based on simplified models

Weak form: limits on the full model parameters based on results from testing the simplified models are always **weaker** than the equivalent statement made directly from the full model (eg. not optimal, but not wrong)

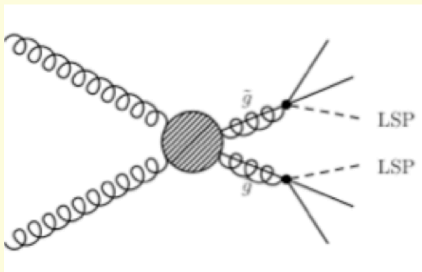
- seems pretty obvious, unless you made a mistake

Strong form: limits on the full model parameters based on results from testing the simplified models are equivalent to the equivalent statement made directly from the full model

- clearly, you would need to cover all the topologies in the full model to expect this could work

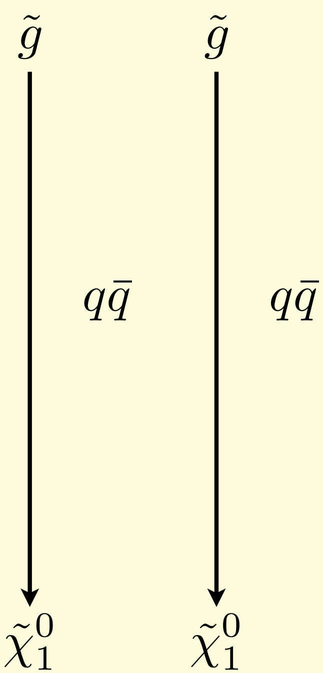
Closure test setup

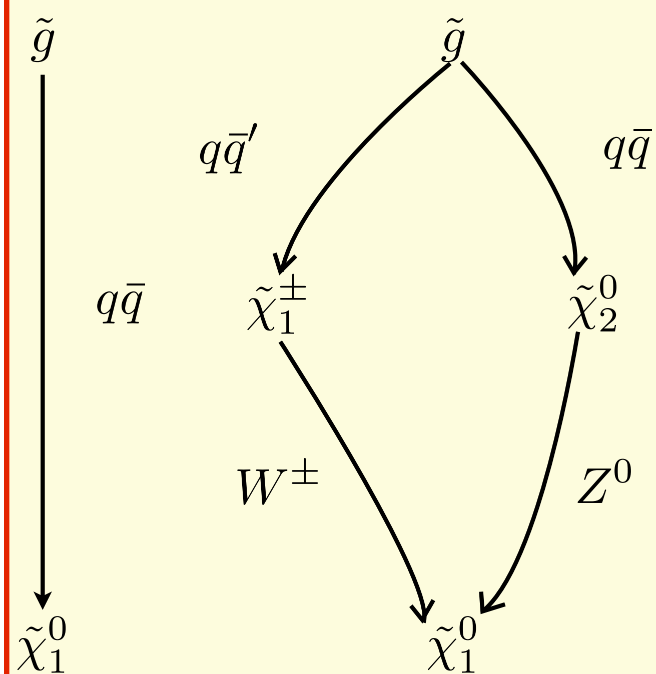
We considered gluino pair-production, and two possible gluino decays.
Two sides to the event gives three “topologies” (not counting W, Z decays)

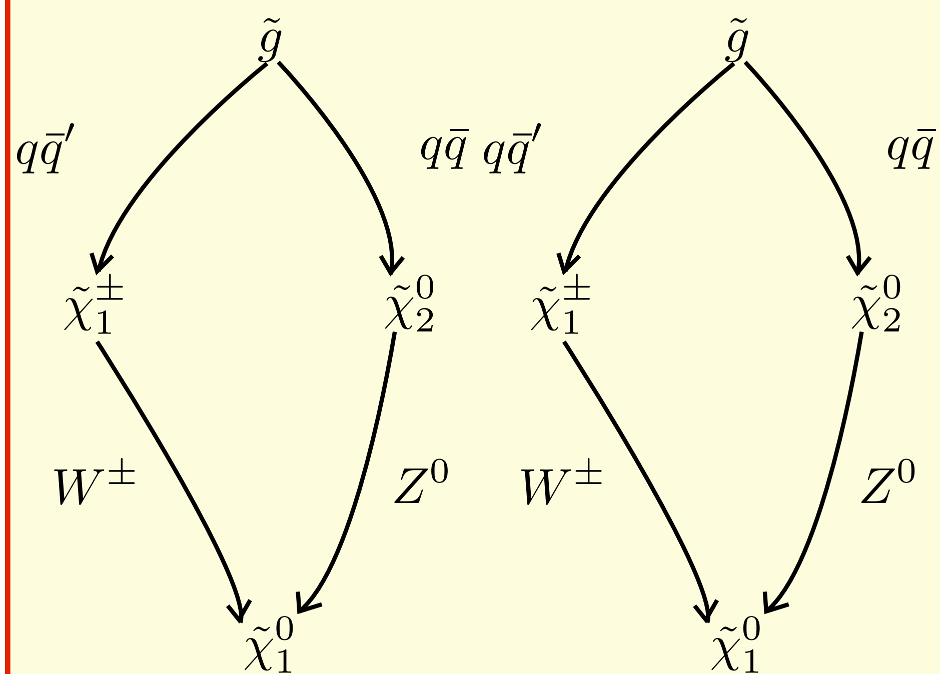


Scanned over mass of gluino, winos (degenerate), and bino.

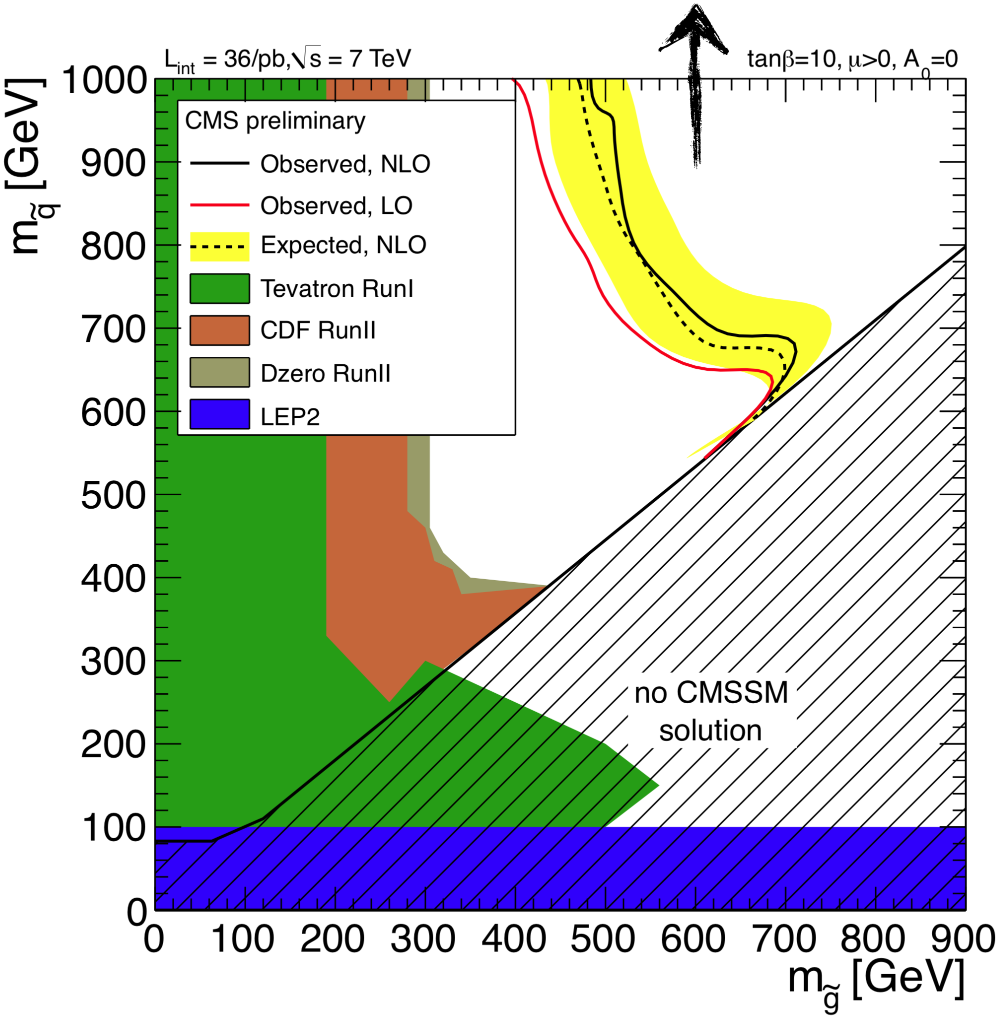
When comparing to full model, choose closest mass point

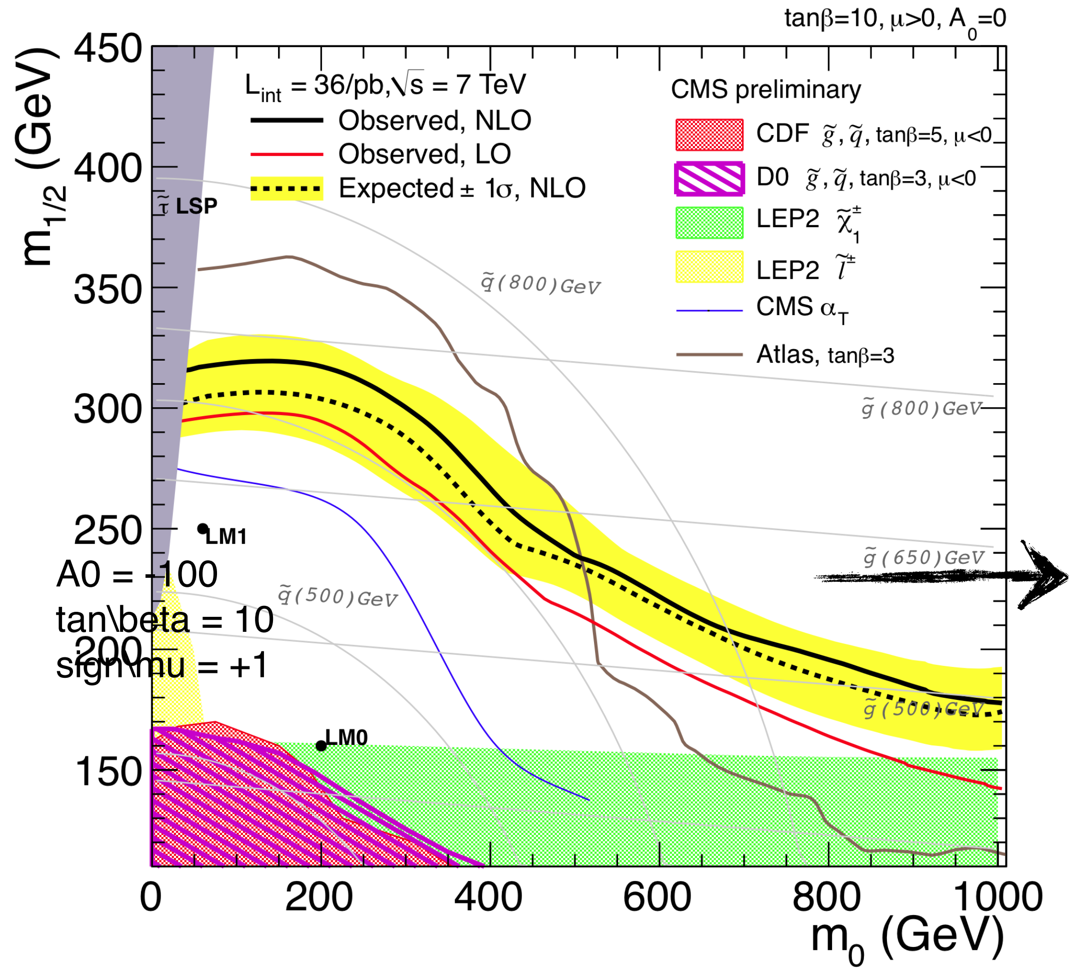






Benchmark Full Model





Choose m_0=4 TeV, $m_{½}$~250 GeV (A_0=-100, tanβ =10, sign μ = +1) so squarks decouple, and we only have gluino pair production

Gives glino mass 600 GeV, wino mass 160 GeV, bino mass 90 GeV

Full Model

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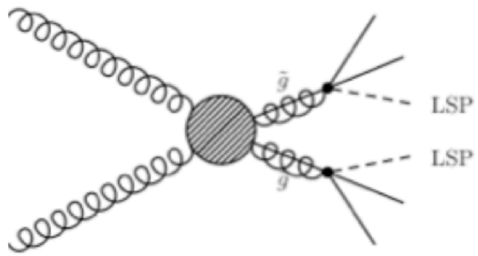
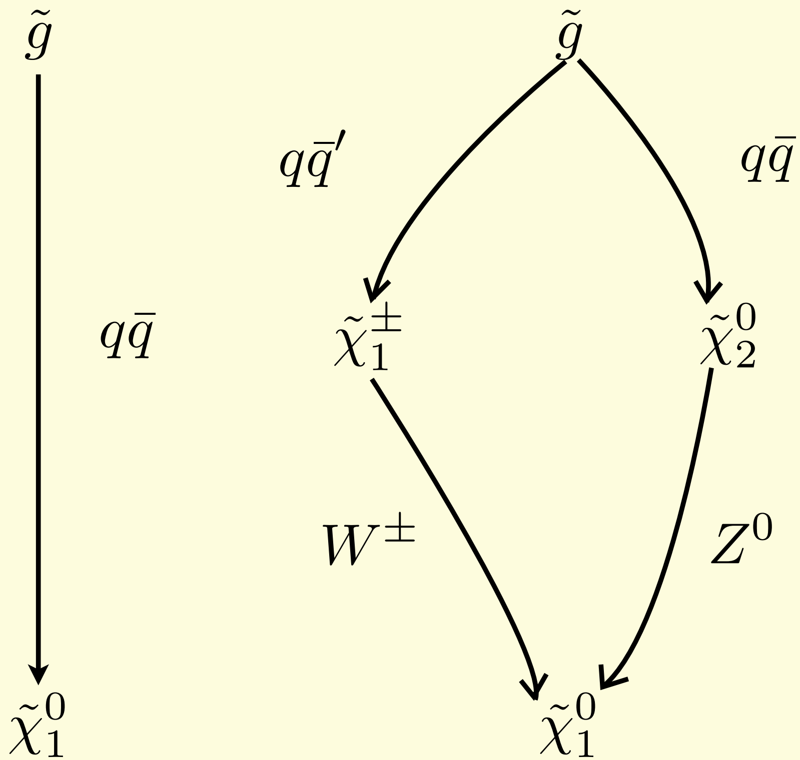
Unfortunately, the point we chose also has significant t,b production, and $\chi_2^{\pm}$ complicating matters -- but also provides a learning lesson

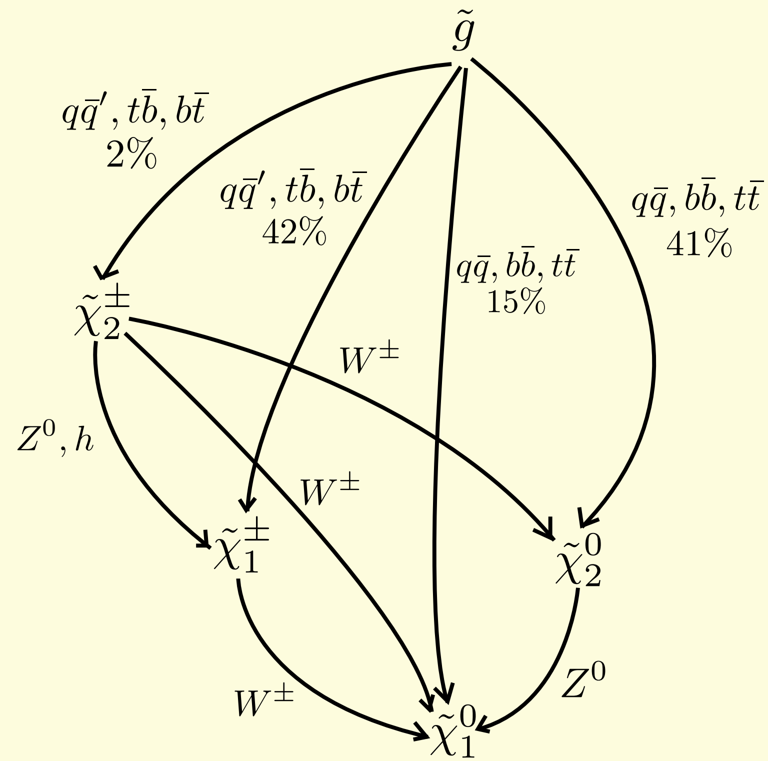


Simplified Model Topologies



"Full Model"

m_0=4 TeV, $m_{½}$~250 GeV (A_0=-100, tanβ =10, sign μ = +1)



Other full model comparison points

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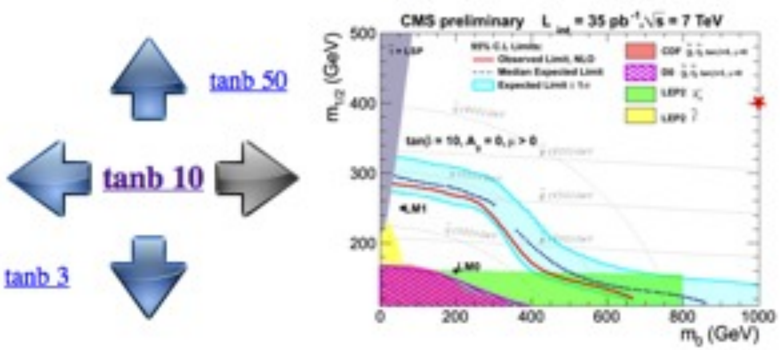
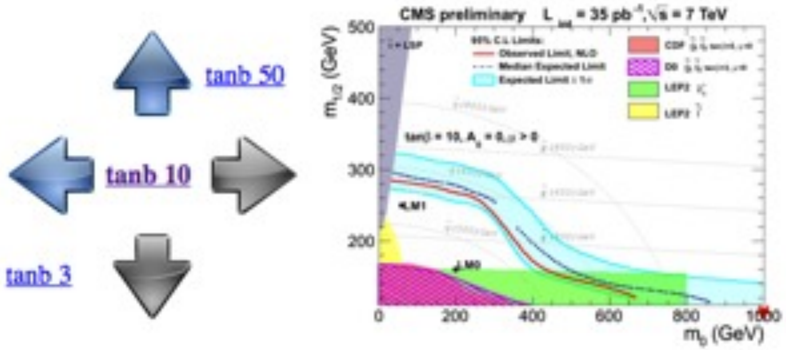
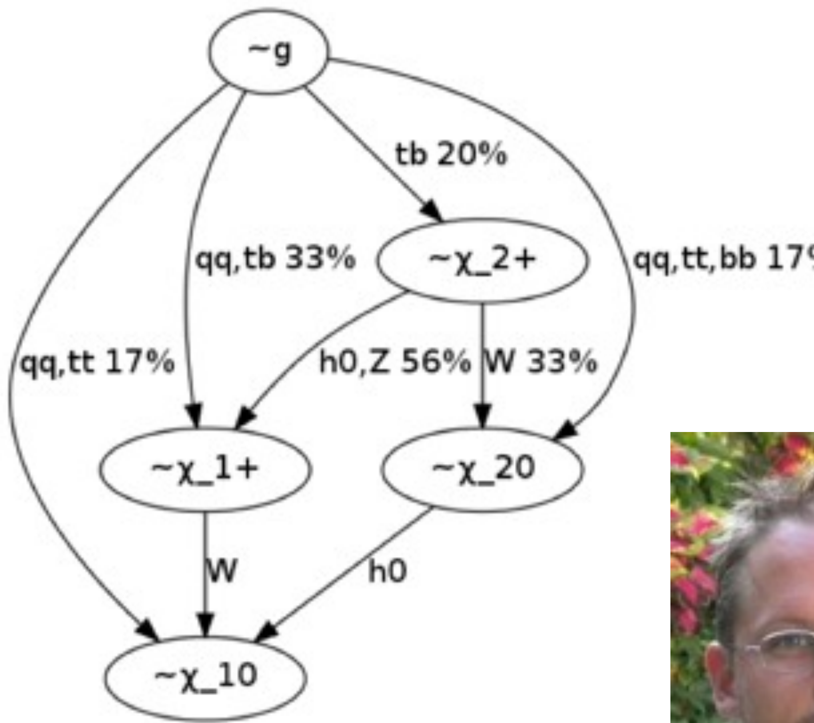
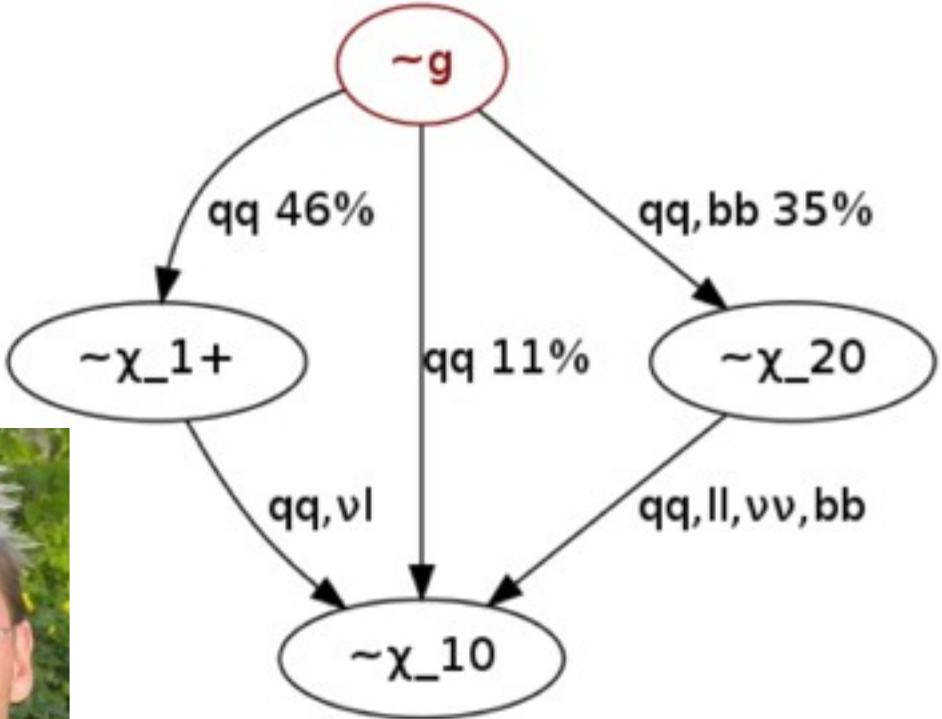
Particle Physics

Using Wolfgang Waltenberger, found better choice for test





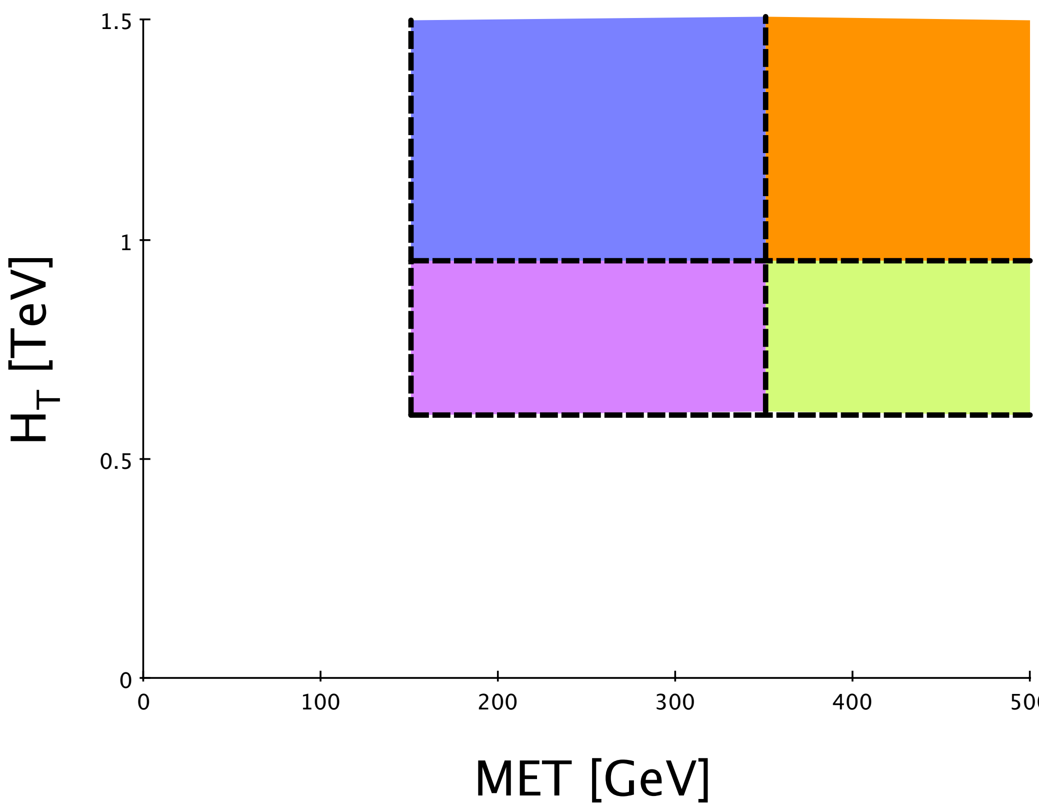




Selection Regions

We wanted to go beyond a single number counting experiment, so we considered several search regions

- tried to keep the selection simple and mirror the search strategies of ATLAS and CMS



4 disjoint control regions:

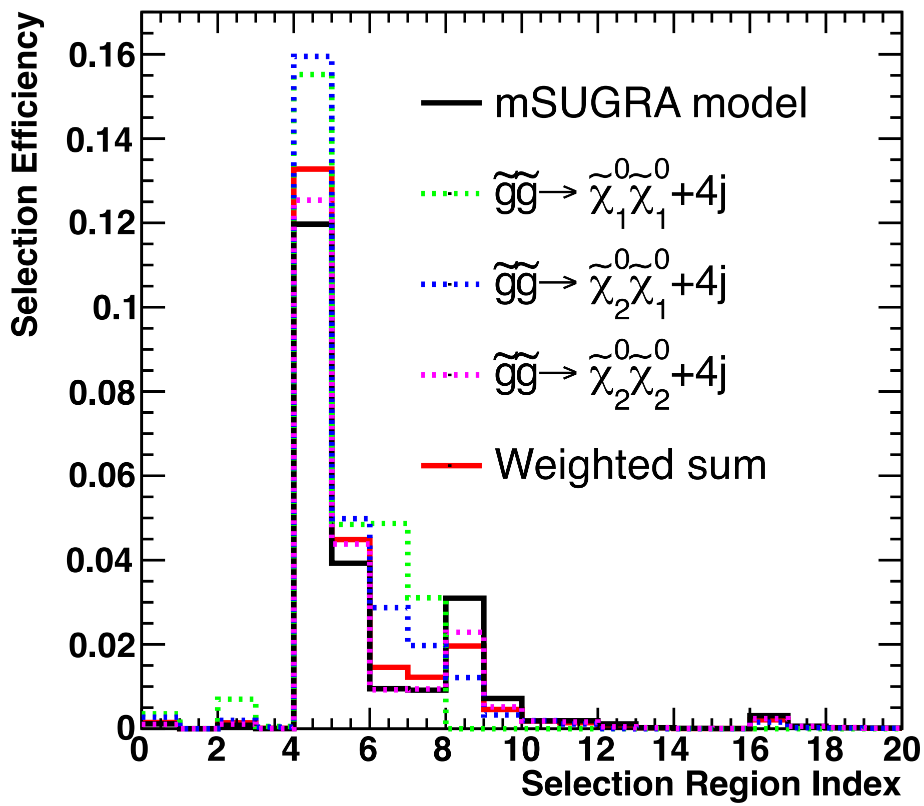
⊗ 2jets + 0 leptons

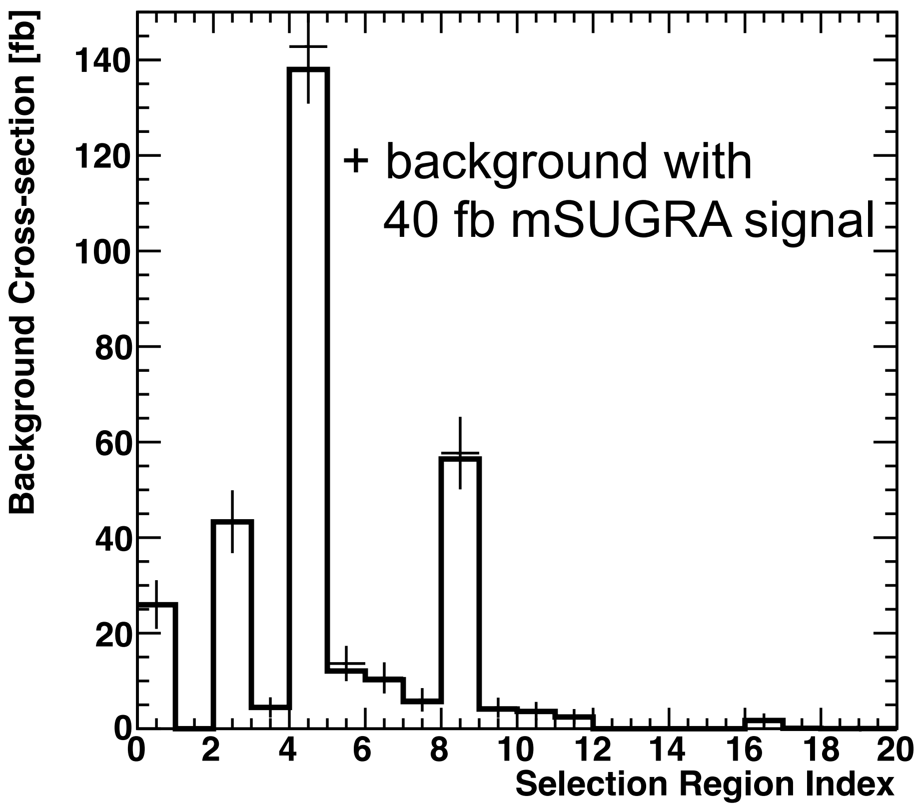
16 disjoint signal regions:

⊗ 4jets + {0l, 1l, 2l (OS), 2l (SS)}

Efficiencies

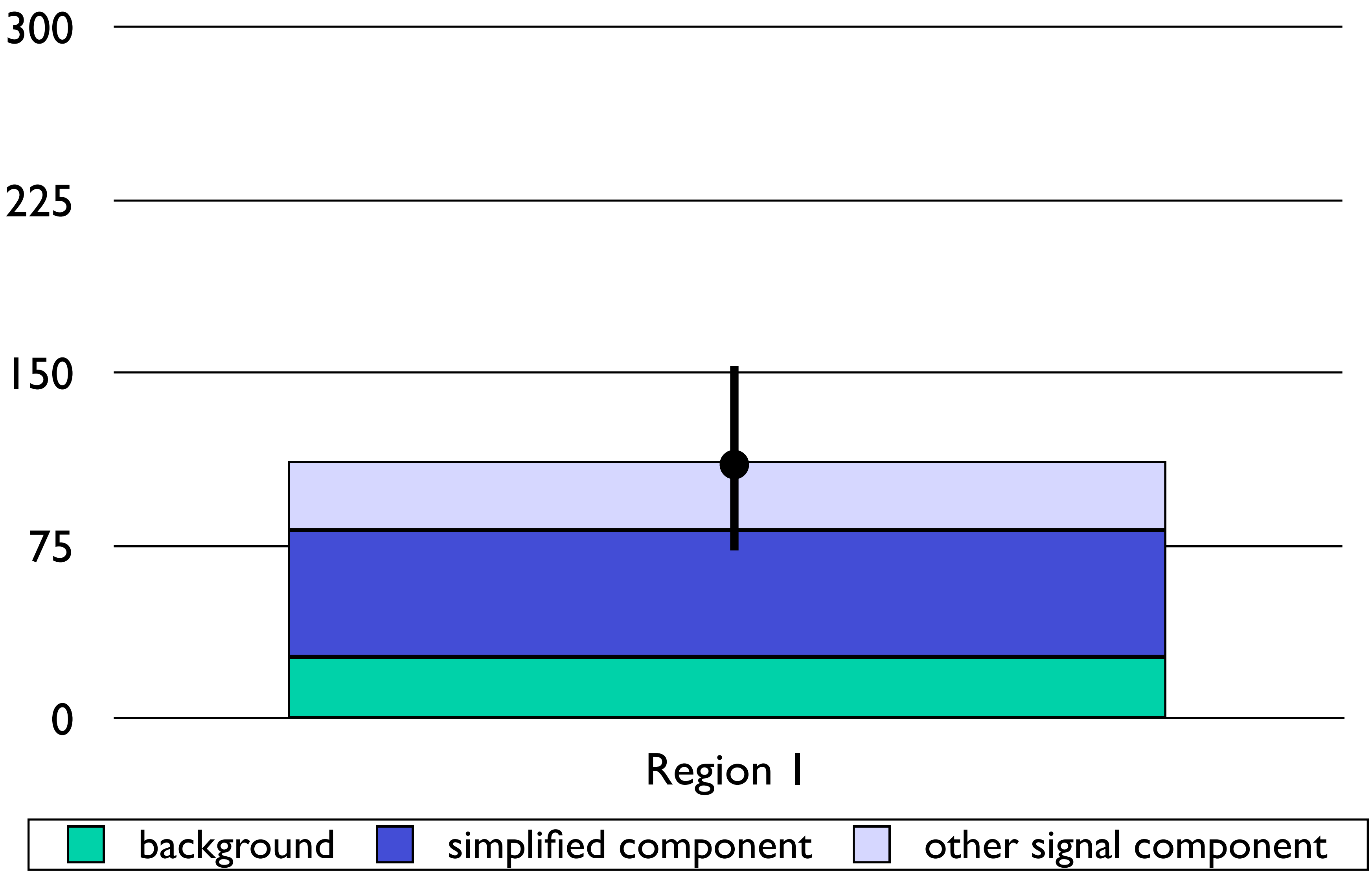
Below we see comparison of efficiencies in the full model, individual simplified model topologies, and the weighted sum of simplified models representing the subset of the full model





Single search region

Assume histogram is drawn corresponding to the full models predicted cross-section. Limit from simplified model alone necessarily larger.



Complications from multiple search regions

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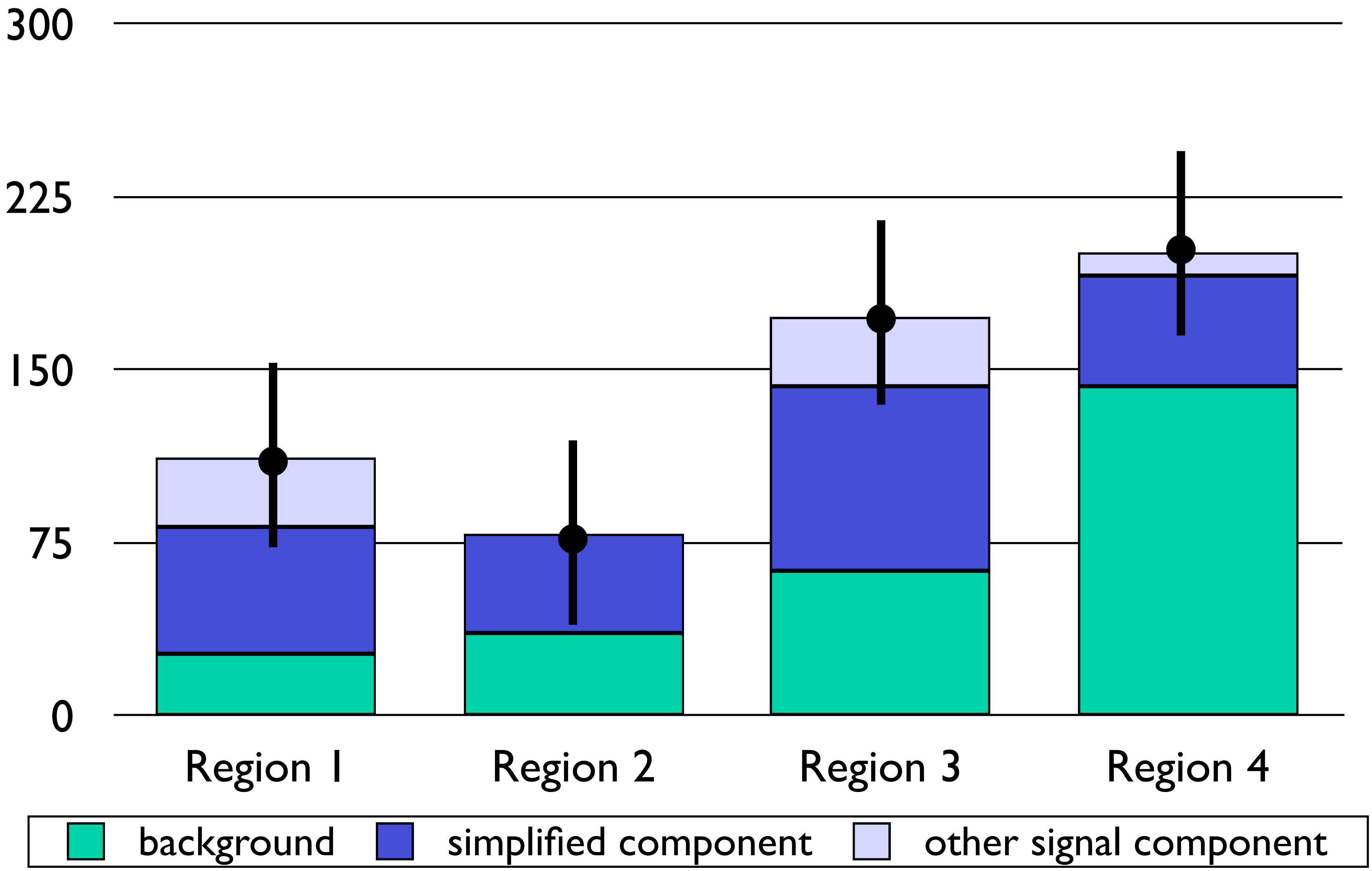
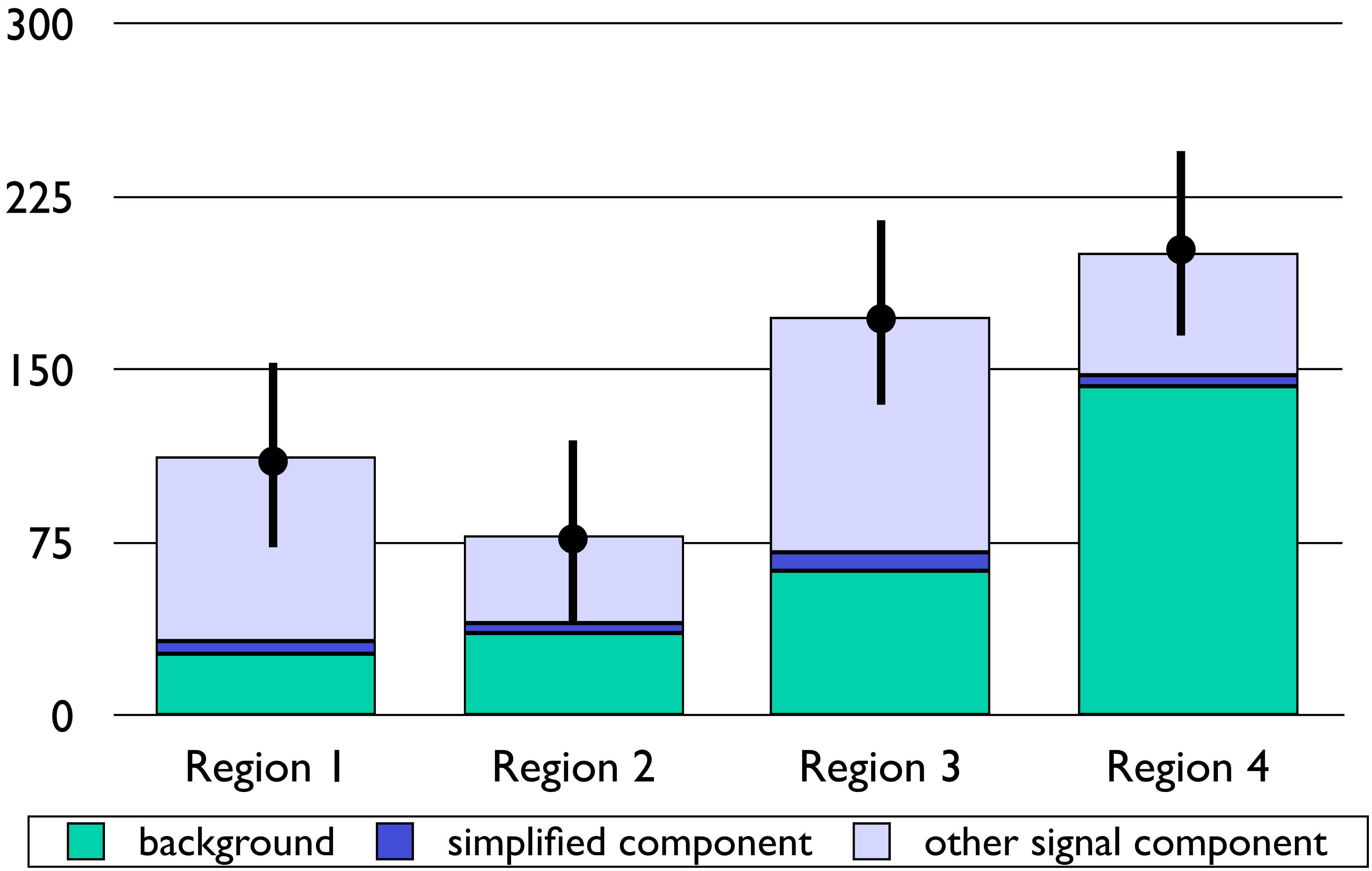
With multiple search regions, one region (2) will be constraining first.



Complications from multiple search regions

Center for Cosmology and Particle Physics

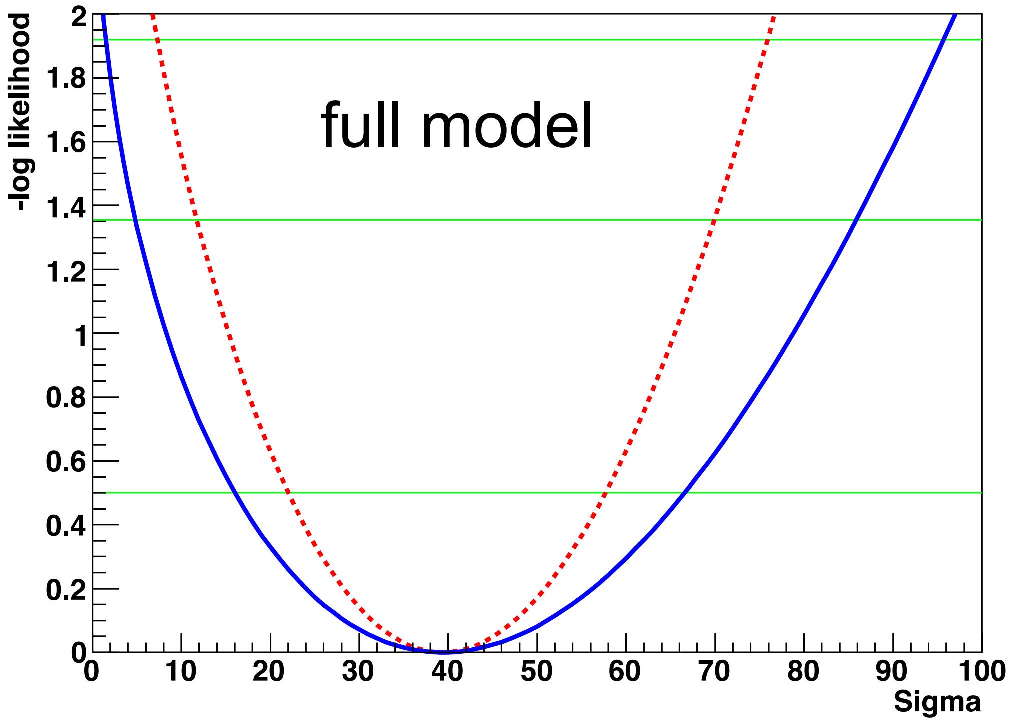
No constraint from too few events from simplified model, b/c can always make up the difference with unknown contribution from other signal components.

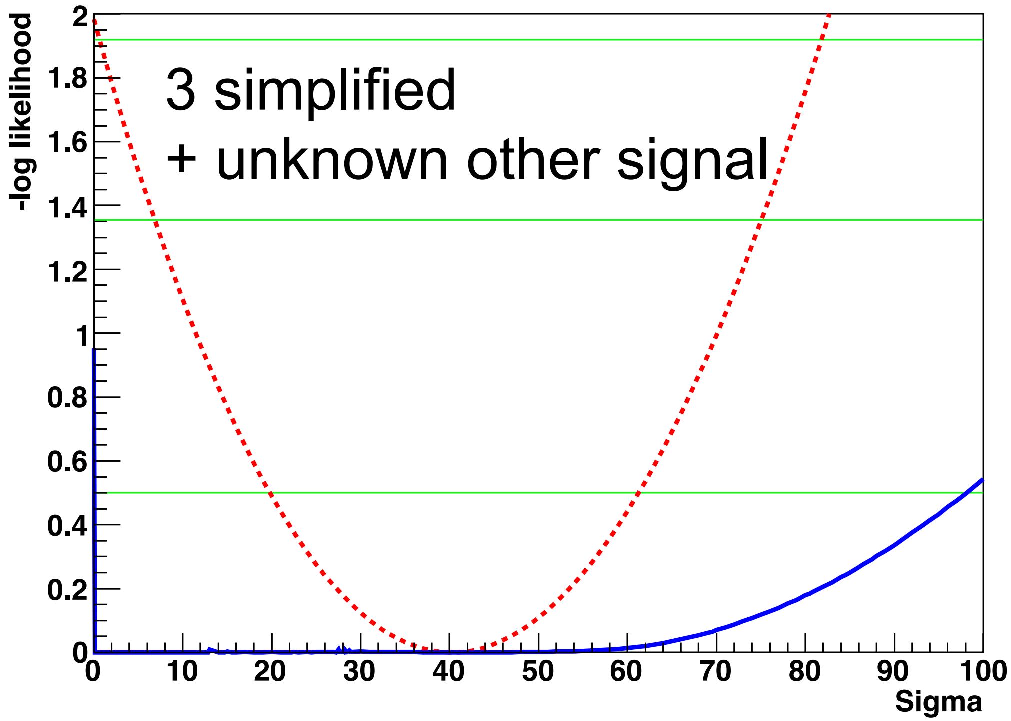


Weak Closure

bin-by-bin w/ unknown acceptance from other topologies

- no lower-limit on x-sec b/c other topologies can be responsible for observed excess
- upper limit has at least one search channel contributing (eg. presence of other topologies is 0), but multiple channels might contribute





Turn on of constraining searches

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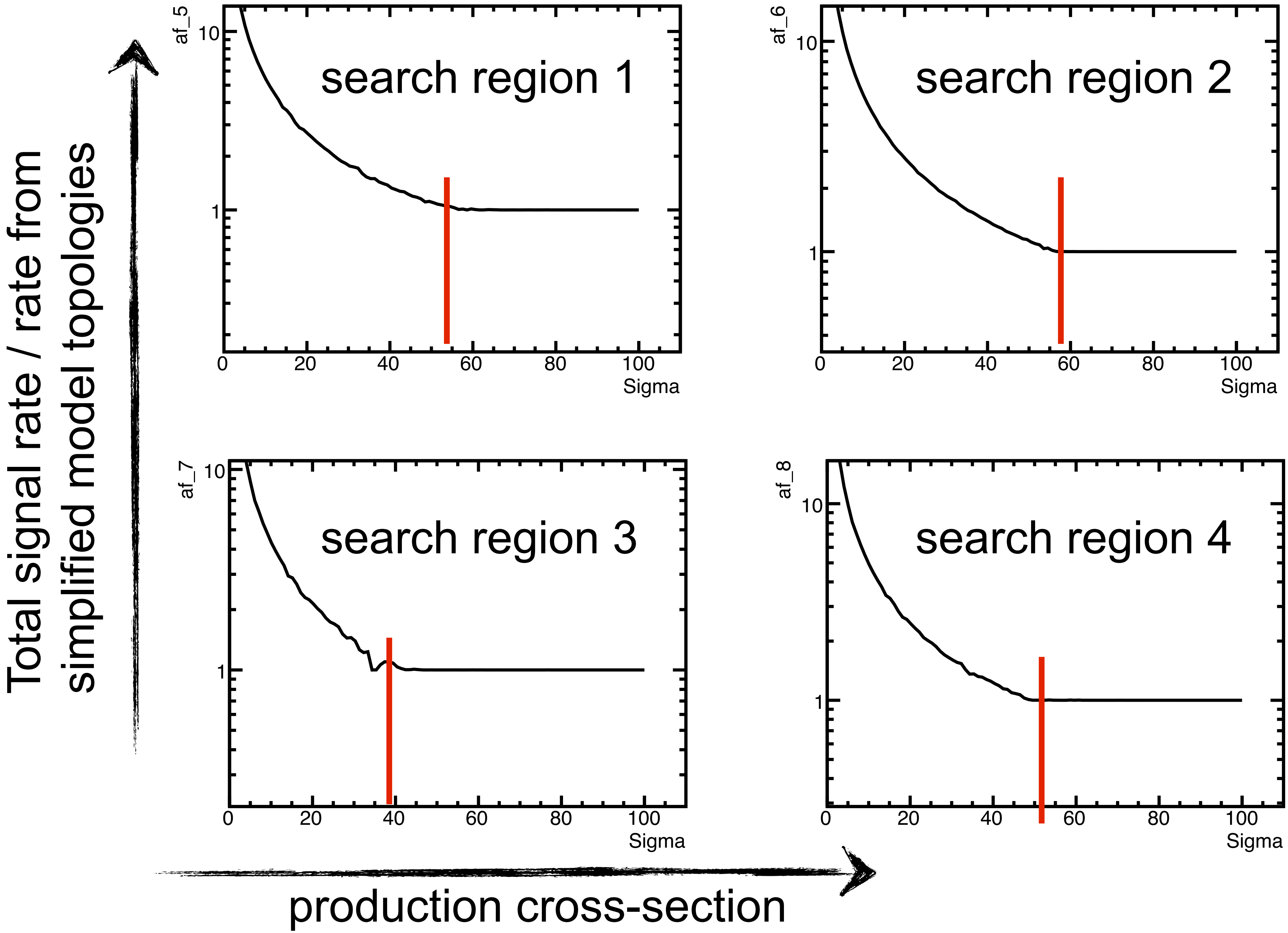
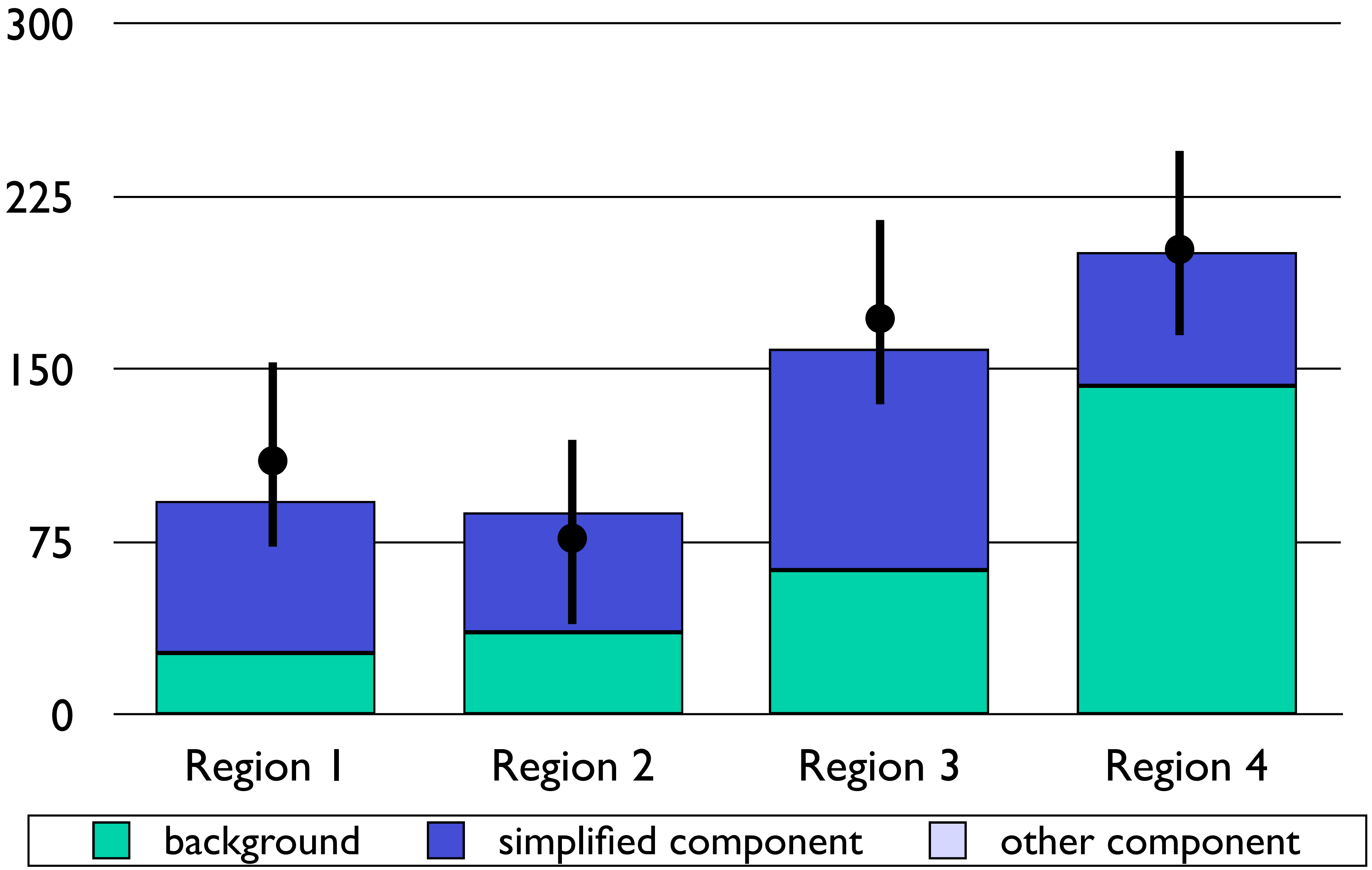


Potential pitfall

If you forget to allow for signal contribution from topologies not covered by the simplified models, then closure tests fail.



Weak closure

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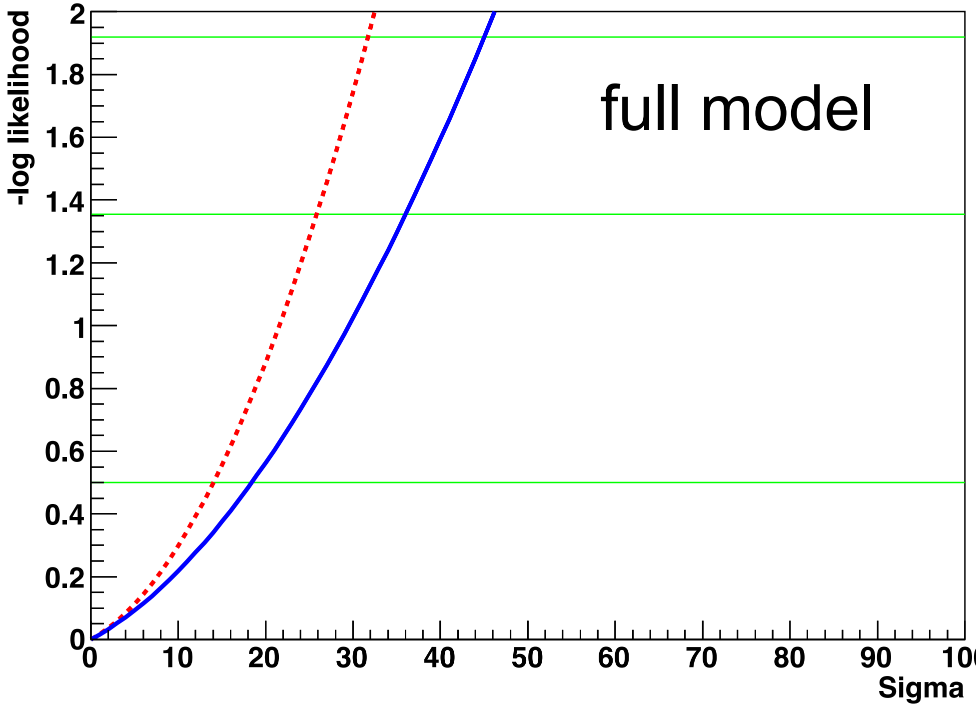
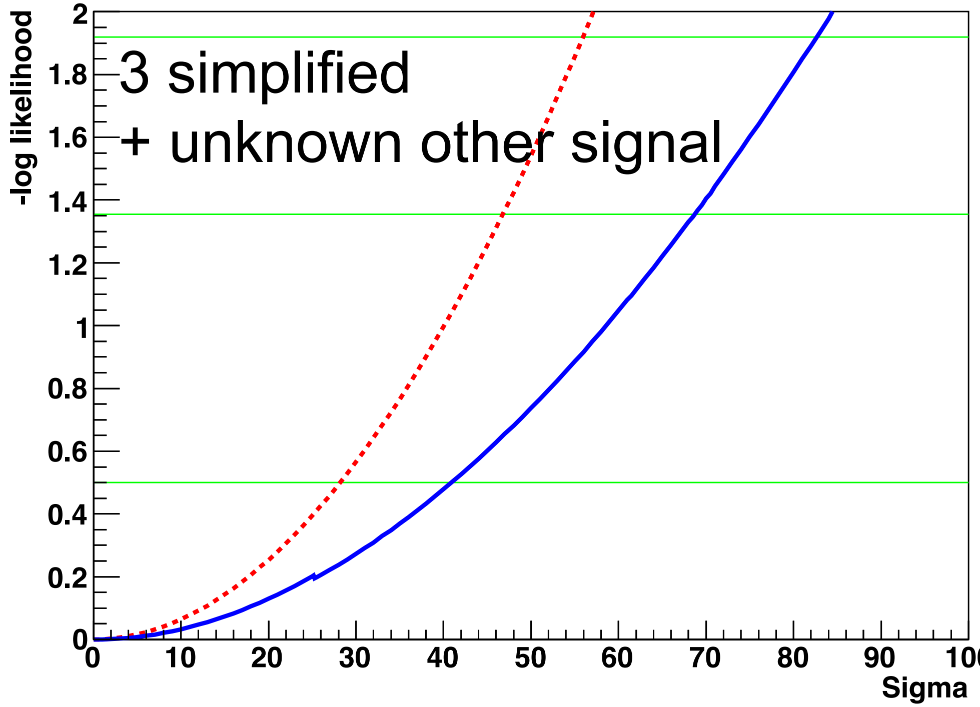
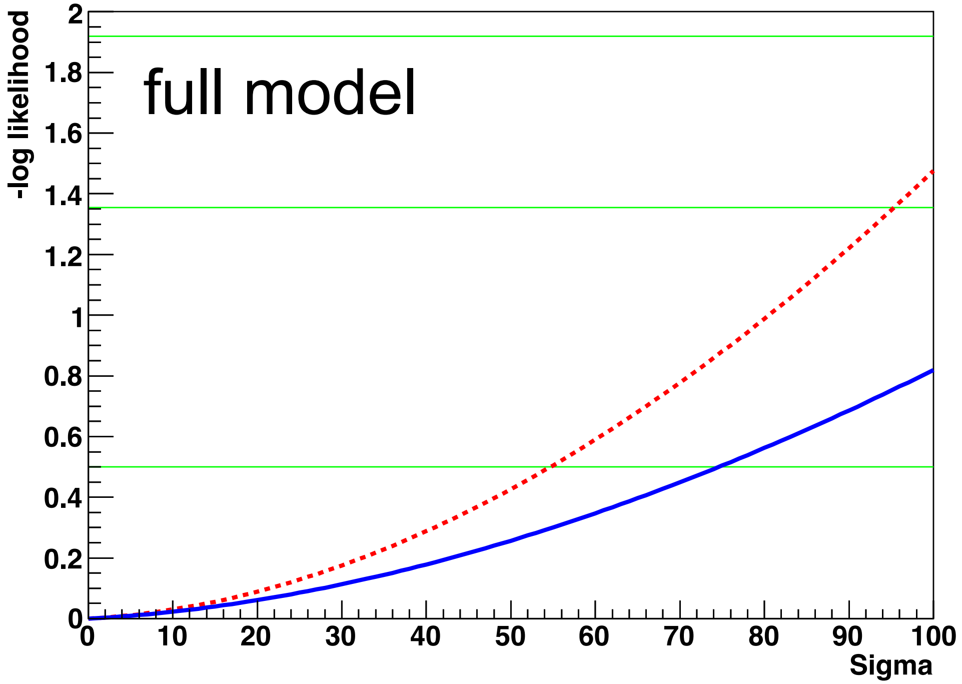
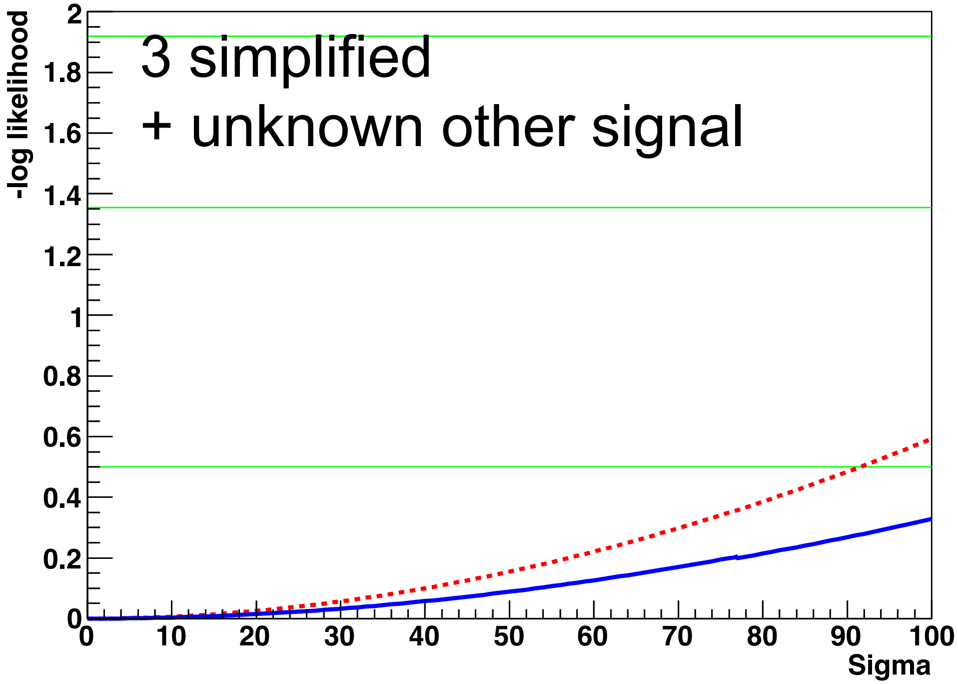
Expected limits obtained from b-only data and 10 fb^{-1}





Expected limits obtained from b-only data and 1 fb^{-1}

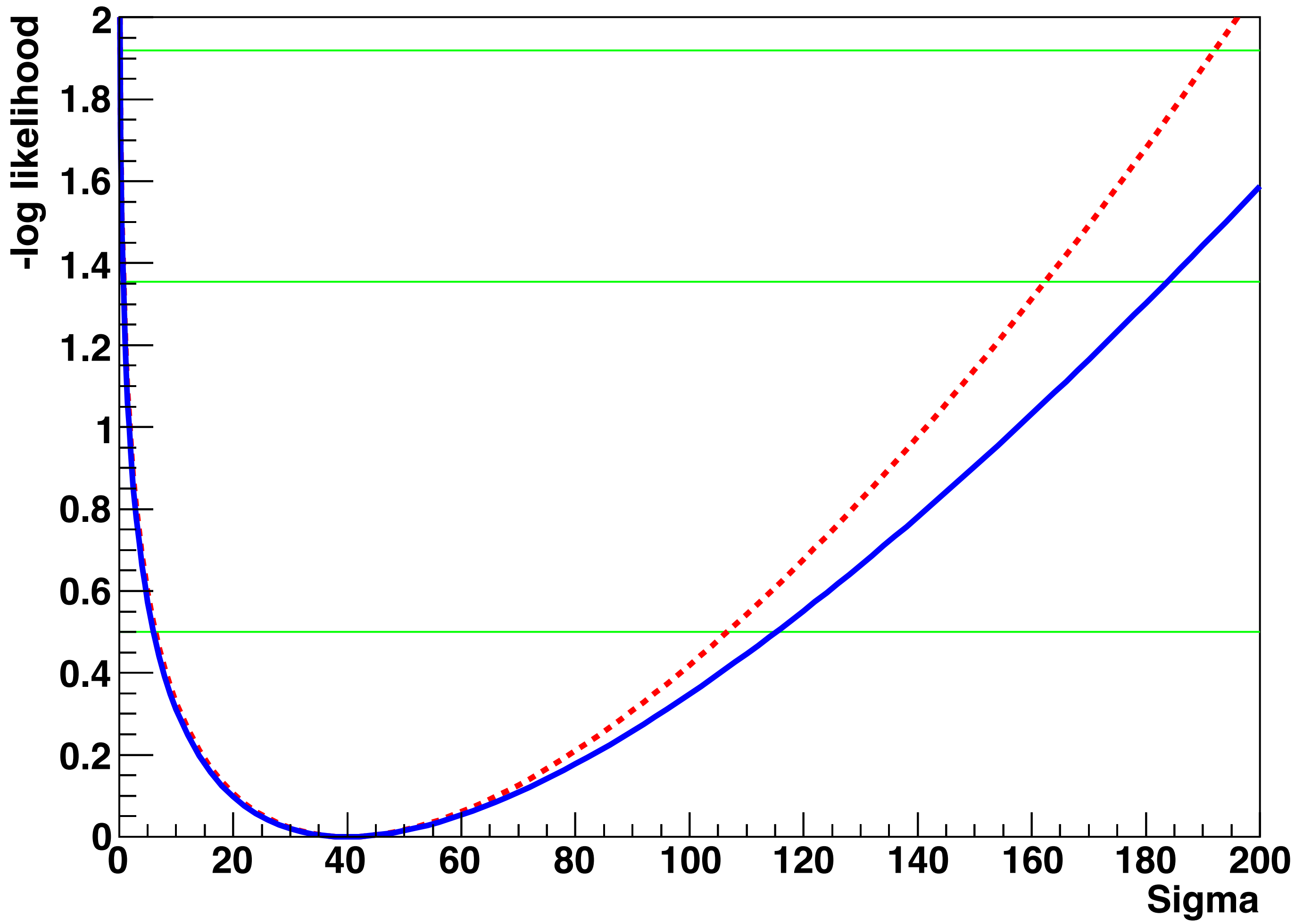




Strong Closure

The only strong closure test we have now is basically a tautology

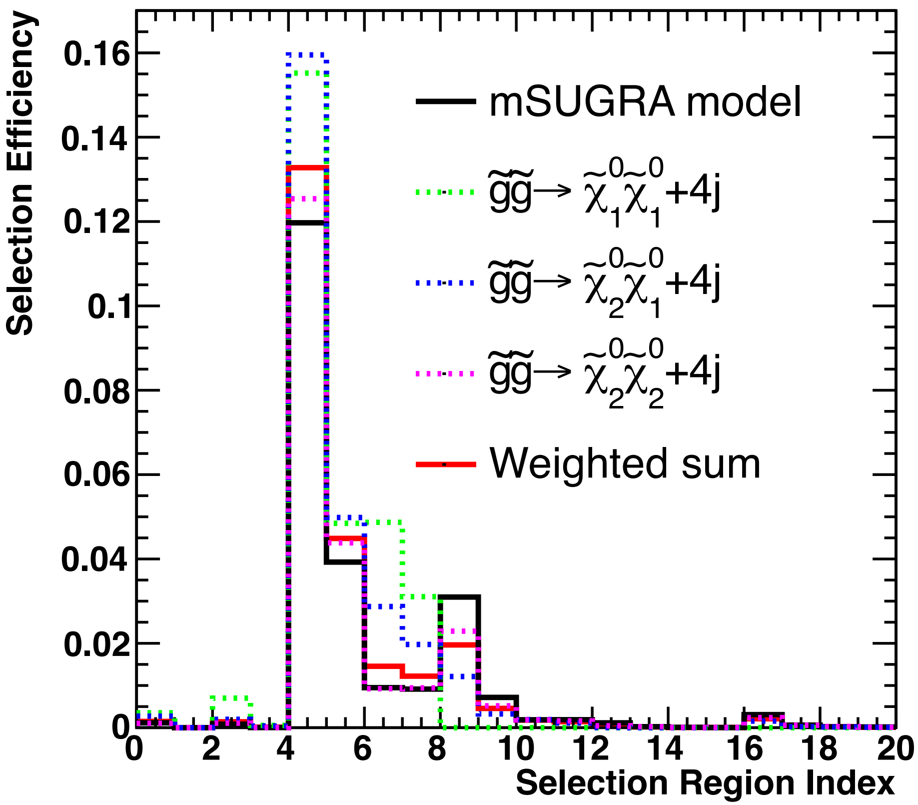
- a new “full model” signal is made from a mixture of simplified models
- Vacuous but at least a technical demonstration

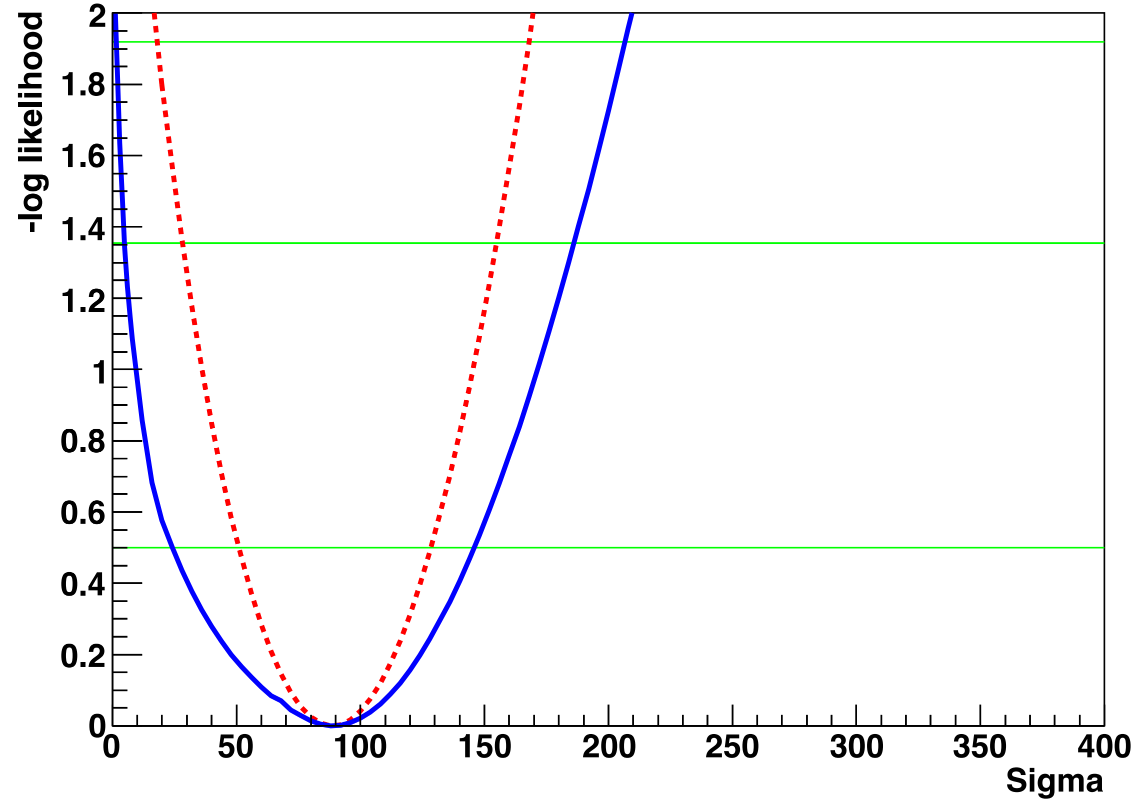


Allowing branching ratios to float

Instead of fixing the relative branching ratios associated to each simplified model, let the branching ratios float in a fit, and let data constrain the ratios

- this leads to weaker limits as expected (kinks from saturating branching ratios at 0 or 1)





Conclusions

Conclusions

Existing analyses are sensitive to signals other than the ones they were originally designed to test.

- Recasting those searches for alternative signal models extends the impact of those analyses
- Efficient use of resources

Running simplified models through the existing searches is an example of recasting. The infrastructure developed can be seen as an early form of a RECAST backend for the experiments.

To test full models in the simplified model approach, we need to be able to:

- aggregate signal efficiencies (shapes, yields) for multiple simplified models
  - cross-section limits from individual models ok for “weak closure”, but is not sufficient for “strong closure”
- may need to extend the “grid” scans in the mass parameters of the simplified models

All of these considerations are relevant after discovery when we are trying to figure out what the new physics is.