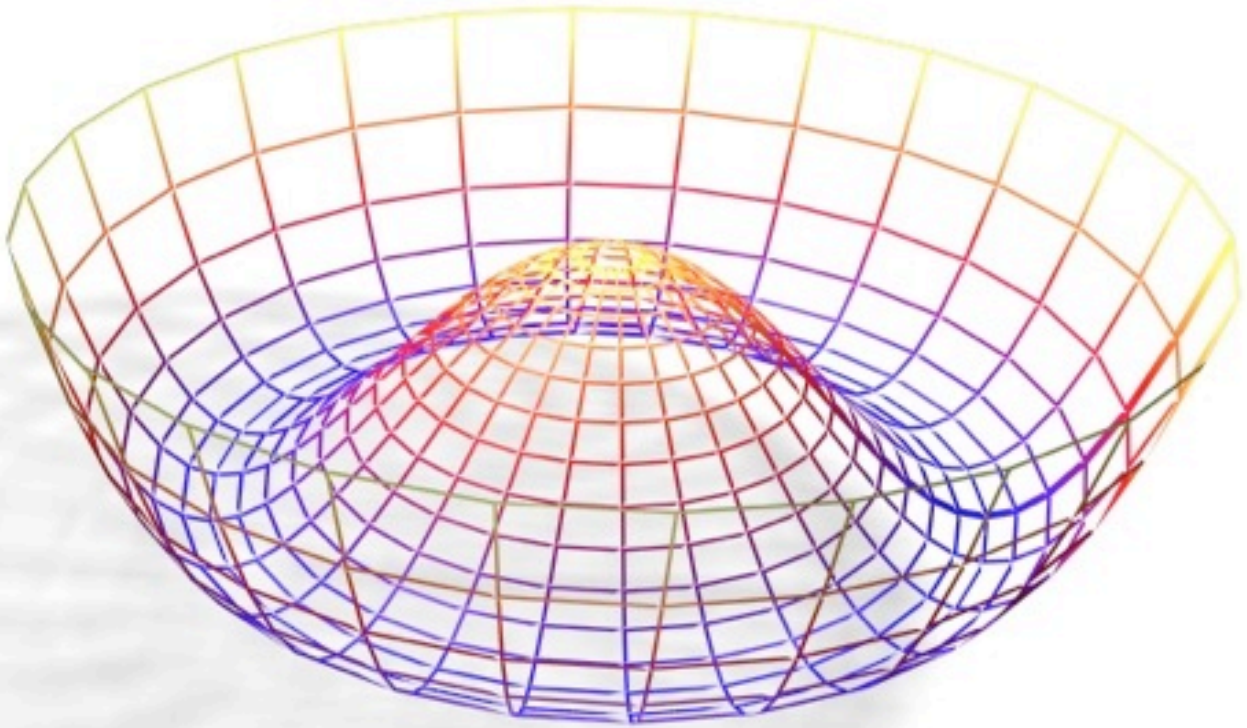
Center for
Cosmology and
Particle Physics

Presenting LHC Results: A path forward



Kyle Cranmer,
New York University

After campaigning that we publish our likelihood functions

Searches for New Physics: Les Houches Recommendations for the Presentation of LHC Results

S. Kraml[1], B.C. Allanach[2], M. Mangano[3], H.B. Prosper[4], S. Sekmen[3,4] (editors), C. Balazs[5], A. Barr[6], P. Bechtle[7], G. Belanger[8], A. Belyaev[9,10], K. Benslama[11], M. Campanelli[12], K. Cranmer[13], A. De Roeck[3], M.J. Dolan[14], T. Eifert[15], J.R. Ellis[16,3], M. Felcini[17], B. Fuks[18], D. Guadagnoli[8,19], J.F. Gunion[20], S. Heinemeyer[17], J. Hewett[15], A. Ismail[15], M. Kadastik[21], M. Krämer[22], J. Lykken[23] F. Mahmoudi[3,24], S.P. Martin[25,26,27], T. Rizzo[15], T. Robens[28], M. Tytgat[29], A. Weiler[30]

Recommendation 3c: *Additionally provide a digitized implementation of the likelihood that is consistent with the mathematical description.*

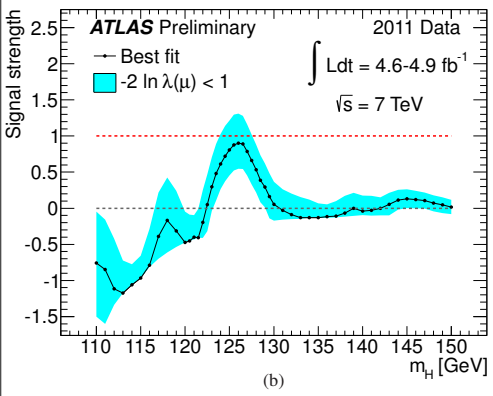
I will start with the recommendation document and

- provide some critical remarks
- discuss some reaction and reality
- outline our progress

Eur. Phys. J. C 72 (2012) [arXiv:1203.2489]

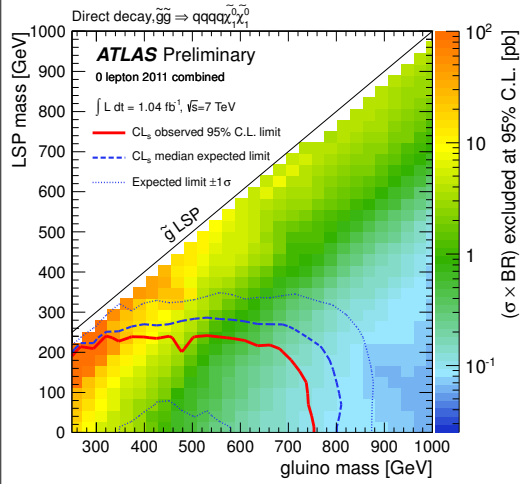
An important point

In the request to experiments to publish likelihood functions, we should have been making a fundamental distinction between:



1. Parameters that modify cross sections and branching ratios

- keeping fixed the kinematics, acceptances, shapes
- the parametrization here is not up for debate, it is a simple scaling
- ie. 125 GeV, spin-0, CP-even “Higgs” with generic couplings



2. Parameters that modify kinematics, acceptances, & shapes

- changing these parameters require detector simulation and discrete points and an interpolation algorithm between those points
- this is and will continue to be a controversial issue

I think we have some hope to see 1.

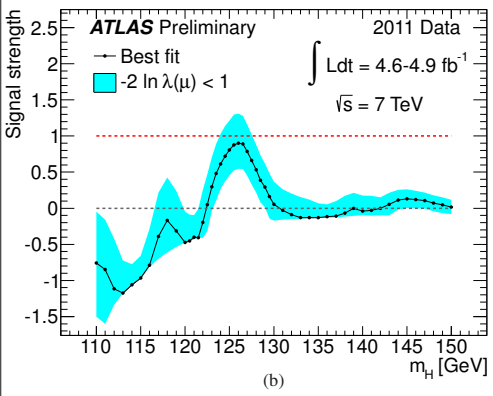
Example feedback

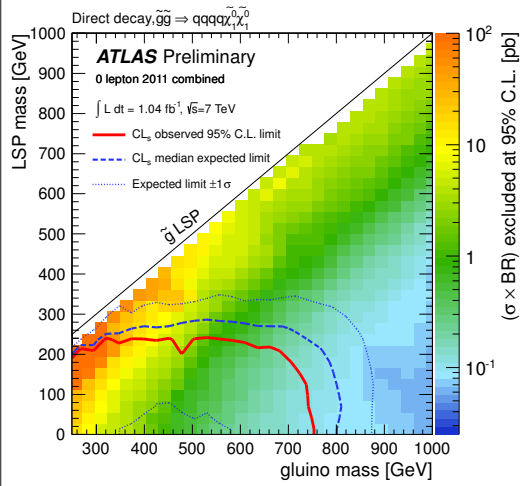
Recommendation 3c: *Additionally provide a digitized implementation of the likelihood that is consistent with the mathematical description.*

- rec 3c: "possible, needs to be discussed"

"...For the same reason, we have doubts about providing the final likelihood function (in parameterised or digitised form) - in practice, we have often found it better to follow the approach of giving grids of efficiencies, acceptances and excluded cross-sections over a parameter space of benchmark models (as also advocated in recommendation 4)."

↑ clearly thinking about scenario 2 where acceptances change.





Recommendation 2b: *Provide and maintain a public simulator developed by the collaboration, or provide official support of an existing one. The public simulator would provide the mapping from the pre-detector data to the post-reconstruction data.*

- 2b: We don't think it is practical to provide a 'public simulator' which would provide a significantly more accurate result than that which can be obtained from simple fiducial cuts and efficiency maps / parameterisations.

- Rec 2b: "NO"

Example feedback

Recommendation 3a: *Provide all crucial numbers regarding the results of the analysis, preferably in tabulated form in the publication itself. Further relevant information, like fit functions or distributions, should be provided as auxiliary material.*

In the case of a single-bin counting experiment these numbers include:

- D — the number of observed events in the signal region,
- δS — the systematic error on the expected number of signal events across the parameter space of the new physics model considered,
- B — the background estimate,
- δB — the estimated background uncertainty,
- $\mathcal{L}$ — the integrated luminosity estimate, and
- $\delta\mathcal{L}$ — the integrated luminosity uncertainty.

If the background estimate is the result of extrapolating from a control region (e.g, from a side-band) to the signal region, the following should also be provided (perhaps in the auxiliary information):

- Q — the observed number of events in the control region
- Q' — the expected number of events in the control region from simulations and its uncertainty
- k — the ratio of expected background in the control region to the expected background in the signal region. If the uncertainty δk on k is not negligible, it should also be included.

In the case of a multi-bin analysis, the above numbers should be given for each bin.

Recommendation 3b: *Provide a mathematical description of the final likelihood function in which experimental data and parameters are clearly distinguished, either in the publication or the auxiliary information.*

- Addendum to 3a: "This is too complicated and often will be misinterpreted"
- Rec 3b: "this is hard to do and needs to be discussed"

- “The experiments have problems giving out information that in principle can’t be used properly” -Yuri Gershtein (approximate)

Marked Poisson Process

Channel: a subset of the data defined by some selection requirements.

- eg. all events with 4 electrons with energy > 10 GeV
- n: number of events observed in the channel
- ν: number of events expected in the channel

Discriminating variable: a property of those events that can be measured and which helps discriminate the signal from background

- eg. the invariant mass of two particles
- $f(x)$: the p.d.f. of the discriminating variable x

$$\mathcal{D} = \{x_1, \ldots, x_n\}$$

Marked Poisson Process:

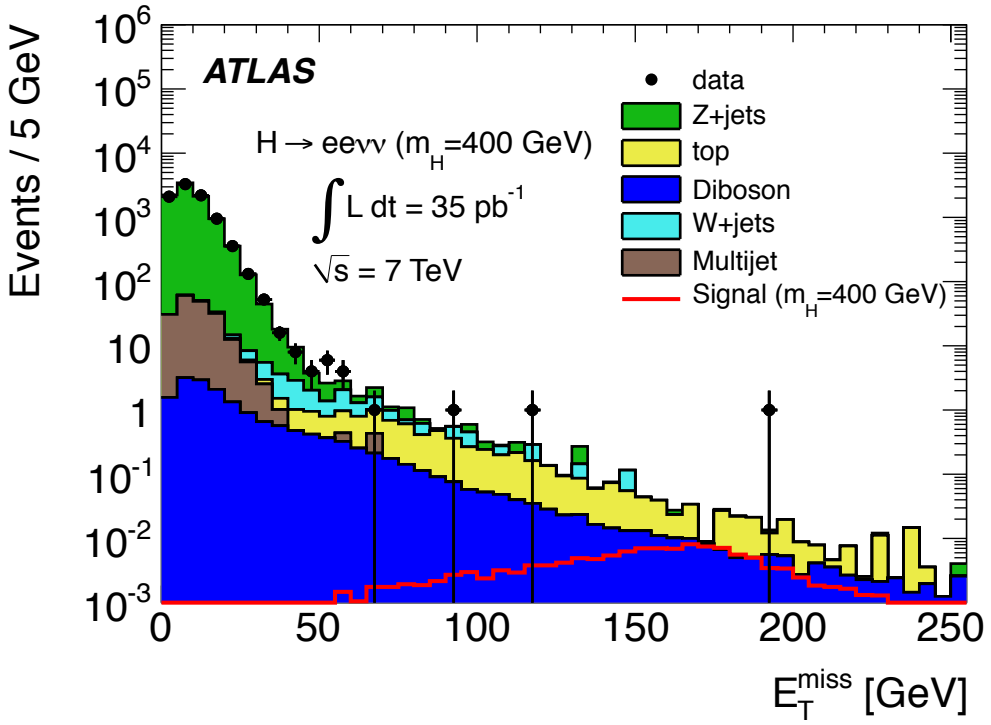
$$\mathbf{f}(\mathcal{D}|\nu) = \mathrm{Pois}(n|\nu) \prod_{e=1}^{n} f(x_e)$$

Mixture model

Sample: a sample of simulated events corresponding to particular type interaction that populates the channel.

- ie. components of a mixture model

$$f(x) = \frac{1}{\nu_{\text{tot}}} \sum_{s \in \text{samples}} \nu_s f_s(x) \,, \qquad \nu_{\text{tot}} = \sum_{s \in \text{samples}} \nu_s$$



Parametrizing the model

Parameters of interest: parameters of the theory that modify the rates and shapes of the distributions

- eg. the unknown mass of the Higgs boson m_H
- eg. "signal strength" μ=0 no signal, μ=1 predicted signal rate

Nuisance parameters: parameters associated to uncertainty in:

- systematic uncertainty in the response of the detector
- phenomenological model of interaction in non-perturbative regime

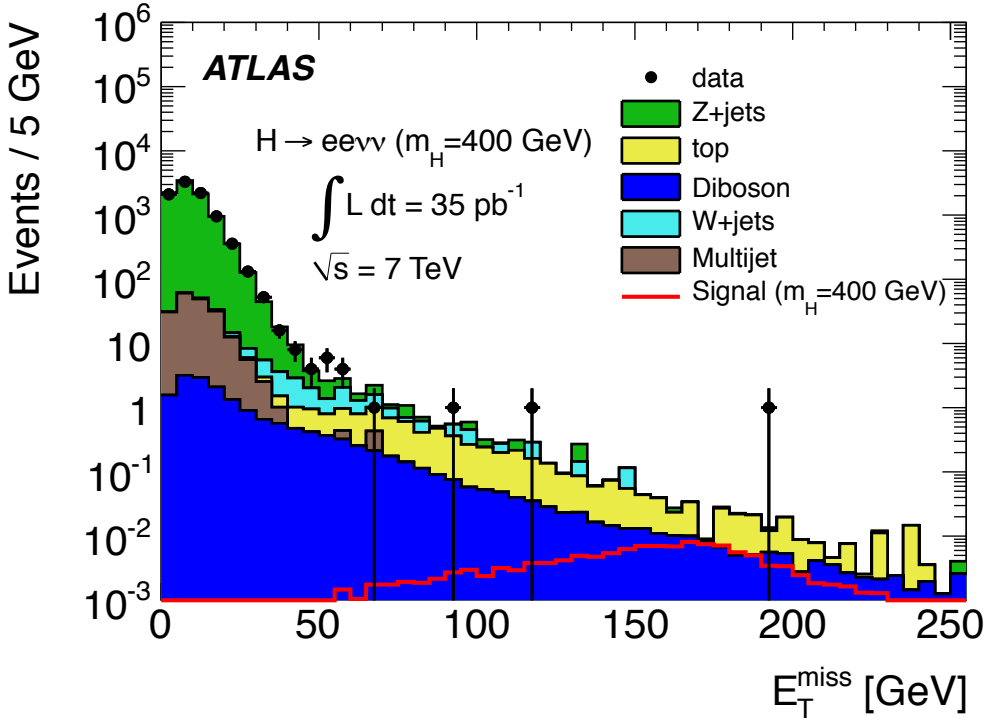
Lead to a parametrized model: $\nu \to \nu(\boldsymbol{\alpha}), f(x) \to f(x|\boldsymbol{\alpha})$

$$\mathbf{f}(\mathcal{D}|\boldsymbol{\alpha}) = \mathrm{Pois}(n|\boldsymbol{\alpha}) \prod_{e=1}^{n} f(x_e|\boldsymbol{\alpha})$$

Incorporating Systematic Effects

Tabulate effect of individual variations of sources of systematic uncertainty

- typically one at a time evaluated at nominal and "± 1 σ"
- use some form of interpolation to parametrize i^{th} variation in terms of **nuisance parameter** α_i



	samp 1	samp 2	samp 3	...
syst 1				
syst 2				
...				

$$\mathbf{f}(\mathcal{D}|\boldsymbol{\alpha}) = \mathrm{Pois}(n|\boldsymbol{\alpha}) \prod_{e=1}^{n} f(x_e|\boldsymbol{\alpha})$$

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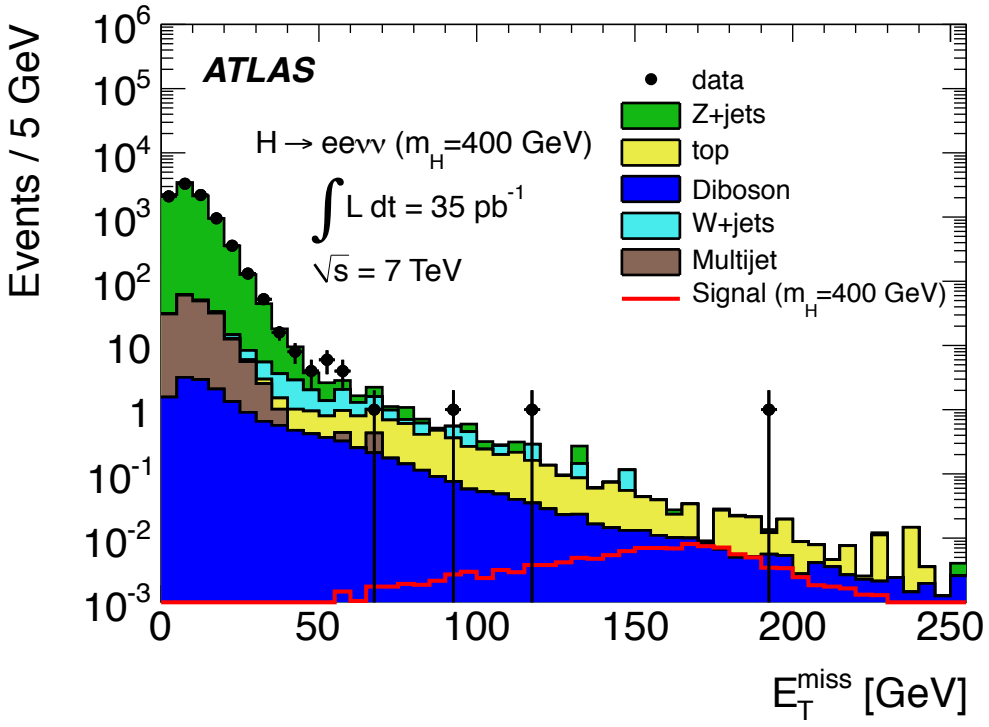

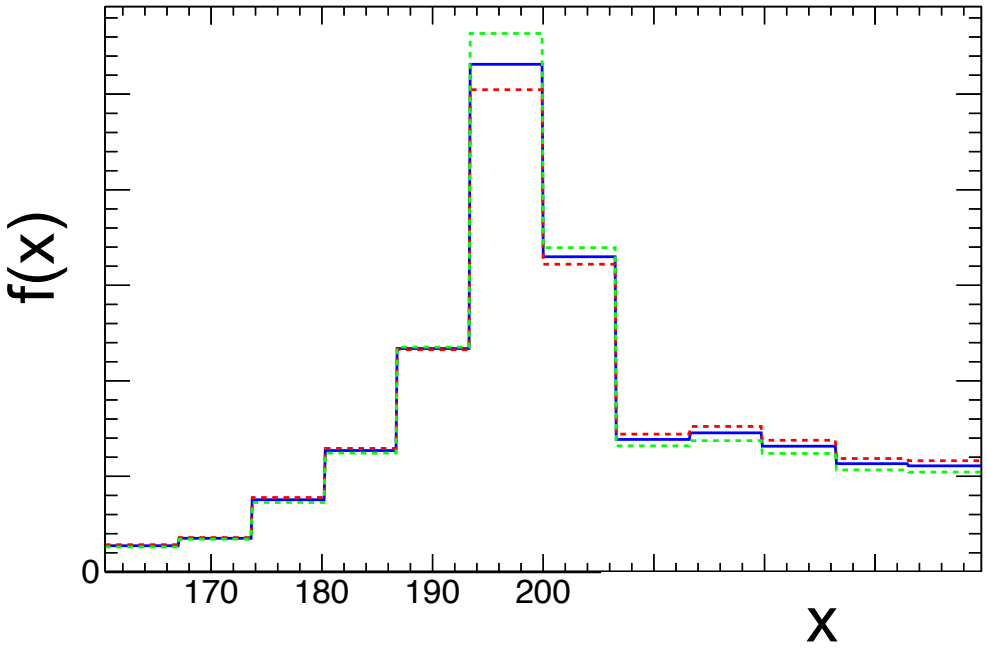

$$\mathbf{f}(\mathcal{D}|\boldsymbol{\alpha}) = \mathrm{Pois}(n|\boldsymbol{\alpha}) \prod_{e=1}^{n} f(x_e|\boldsymbol{\alpha})$$

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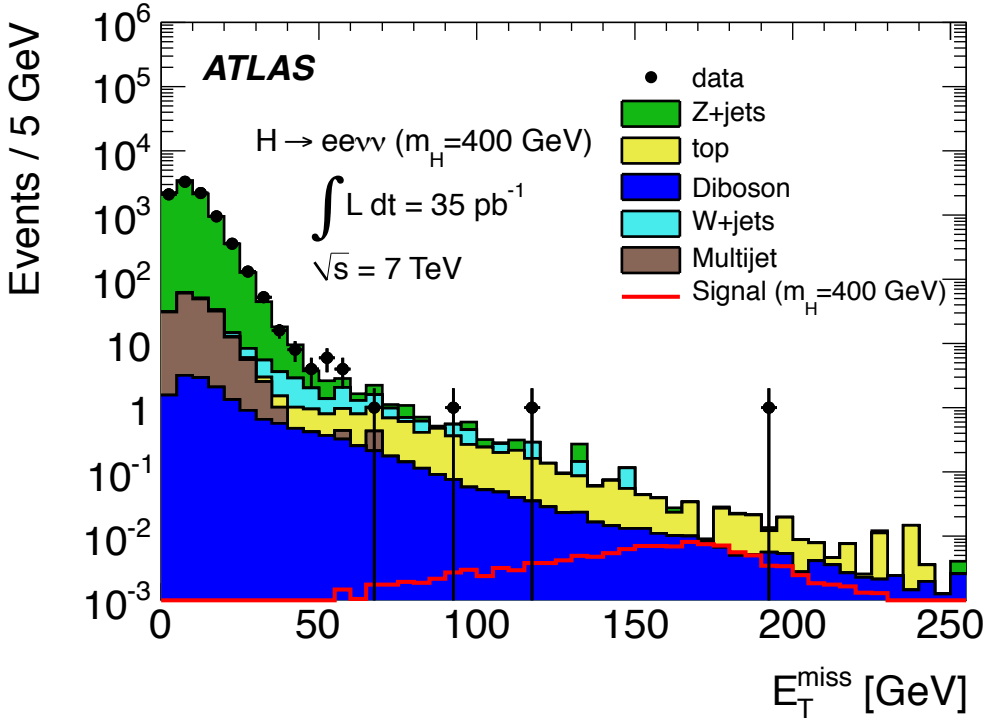
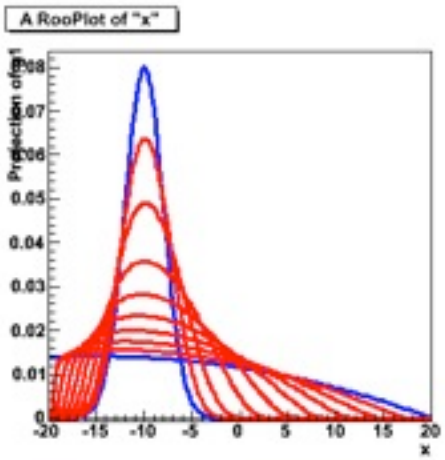
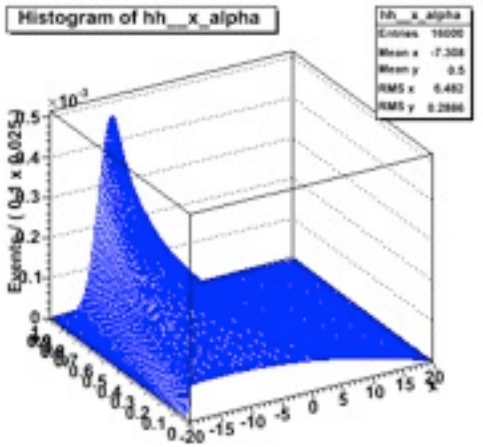






$$\mathbf{f}(\mathcal{D}|\boldsymbol{\alpha}) = \mathrm{Pois}(n|\boldsymbol{\alpha}) \prod_{e=1}^{n} f(x_e|\boldsymbol{\alpha})$$

Simultaneous multi-channel model

Control Regions: Some channels are not populated by signal processes, but are used to constrain the nuisance parameters

Constraint Terms: Often auxiliary measurements for certain nuisance parameters summarized / idealized as

$$f_p(a_p|\alpha_p) \qquad \text{for} \;\; p \in \mathbb{S}$$

Simultaneous Multi-Channel Model: Several disjoint regions of the data are modeled simultaneously. Identification of common parameters across many channels requires coordination between groups such that meaning of the parameters are really the same.

$$\mathbf{f}_{\text{tot}}(\mathcal{D}_{\text{sim}}, \mathcal{G}|\boldsymbol{\alpha}) = \prod_{c \in \text{channels}} \left[\text{Pois}(n_c|\nu_c(\boldsymbol{\alpha})) \prod_{e=1}^{n_c} f_c(x_{ce}|\boldsymbol{\alpha}) \right] \cdot \prod_{p \in \mathbb{S}} f_p(a_p|\alpha_p)$$

where

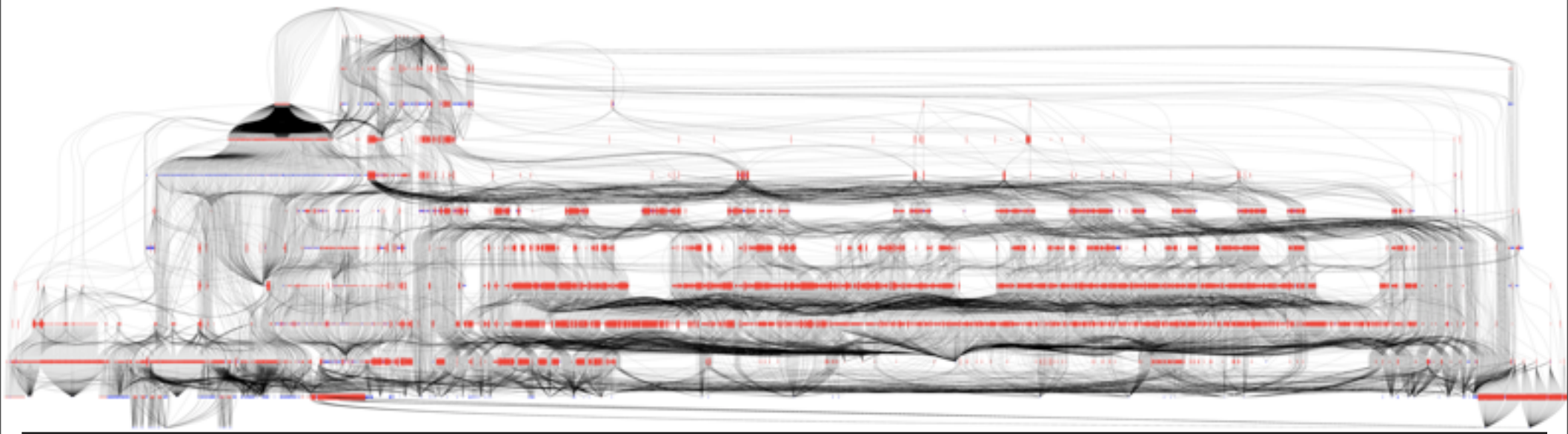
$$\mathcal{D}_{\text{sim}} = \{\mathcal{D}_1, \ldots, \mathcal{D}_{c_{\max}}\}, \quad \mathcal{G} = \{a_p\} \;\text{ for }\; p \in \mathbb{S}$$

Visualizing the combined model

State of the art: Our most recent combined Higgs search includes 70 disjoint channels and >100 nuisance parameters

- Models for individual channels come from about 12 sub-groups performing dedicated searches for specific Higgs decay modes

$$\mathbf{f}_{\text{tot}}(\mathcal{D}_{\text{sim}}, \mathcal{G}|\boldsymbol{\alpha}) = \prod_{c \in \text{channels}} \left[\text{Pois}(n_c|\nu_c(\boldsymbol{\alpha})) \prod_{e=1}^{n_c} f_c(x_{ce}|\boldsymbol{\alpha}) \right] \cdot \prod_{p \in \mathbb{S}} f_p(a_p|\alpha_p)$$

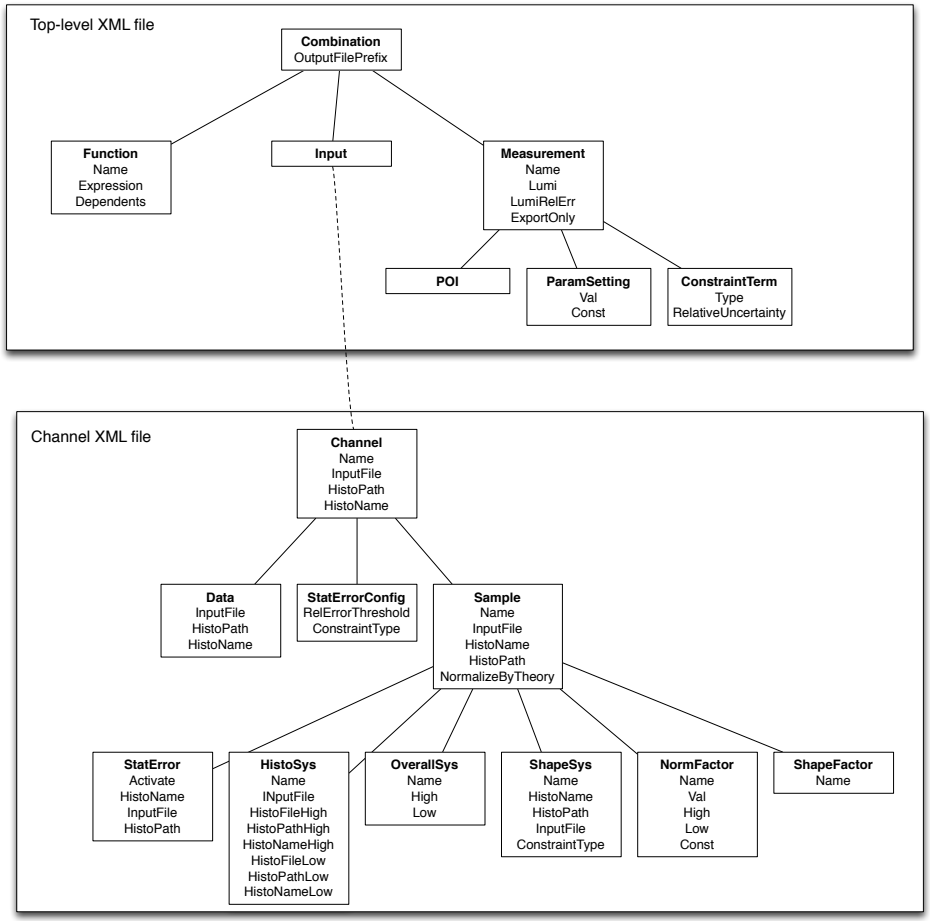


HistFactory XML

For binned analyses, the HistFactory tool that ships with ROOT solves this problem

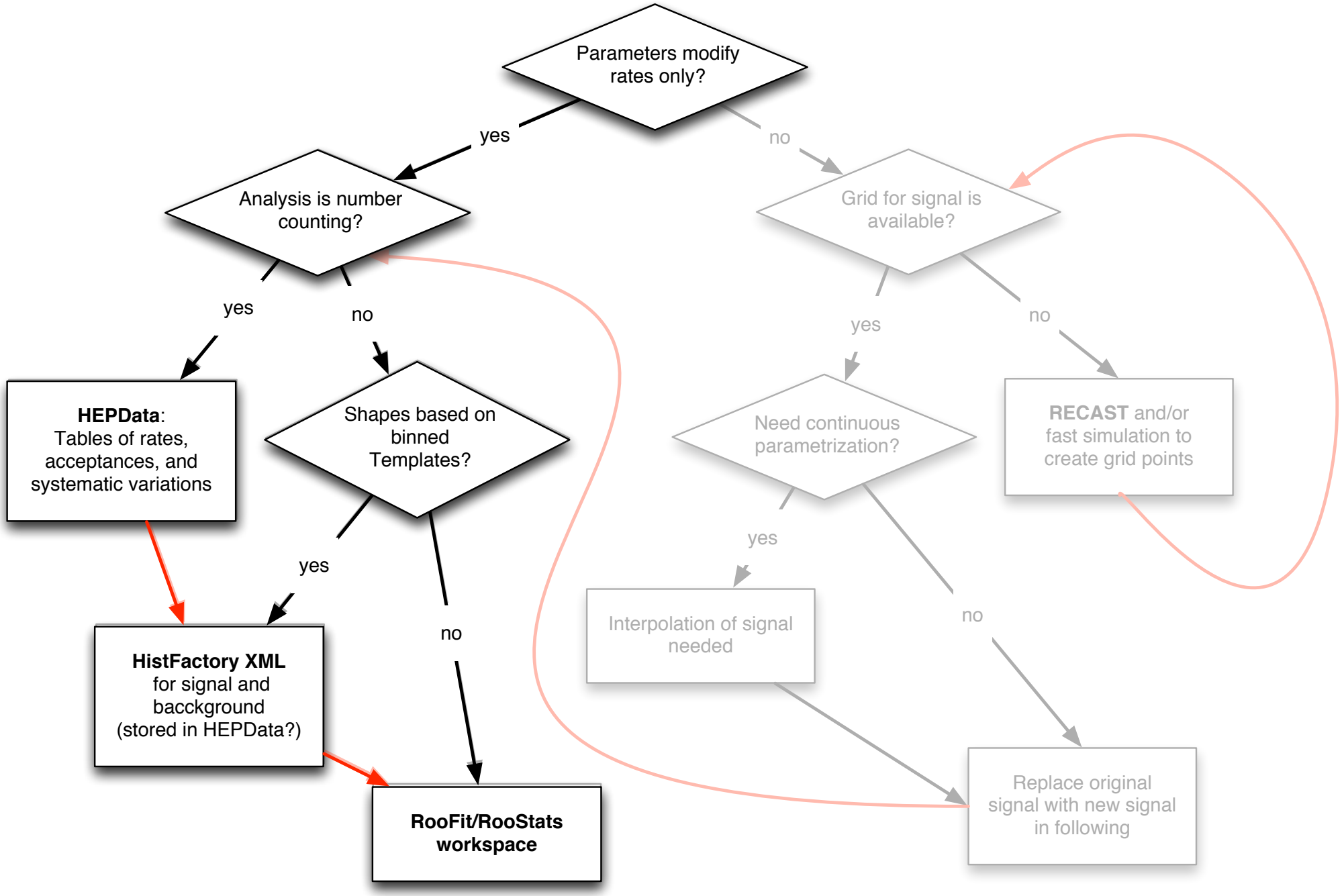
- XML files organize the histograms
- conventions define model exactly
- command line tool creates likelihood

$$\mathbf{f}_{\rm tot}(\mathcal{D}_{\rm sim},\mathcal{G}|\boldsymbol{\alpha}) = \prod_{c\in\text{channels}}\left[\text{Pois}(n_c|\nu_c(\boldsymbol{\alpha}))\prod_{e=1}^{n_c} f_c(x_{ce}|\boldsymbol{\alpha})\right]\cdot\prod_{p\in\mathbb{S}} f_p(a_p|\alpha_p)$$




```
<!DOCTYPE Channel  SYSTEM 'HistFactorySchema.dtd'>

  <Channel Name="A" InputFile="./data/ABCD.root"  >
    <Data HistoName="A_data" HistoPath="" />

    <!-- This is the signal (eg. mu)-->
    <Sample Name="A_signal" HistoPath="" HistoName="unit_histogram">
      <!-- now mu is number of events-->
      <NormFactor Name="mu" Val="1" Low="0" High="200" />
      <OverallSys Name="syst1" High="1.01" Low="0.99" />
    </Sample>

    <!-- This bkg is estimated from MC (eg. mu_A^K) -->
    <Sample Name="A_backgroundMC" HistoPath="" NormalizeByTheory="True" HistoName="unit_histogram"  >
      <NormFactor Name="mu_K_A" Val="100" Low="0" High="200" />
    </Sample>

    <!-- Background 2 is completely Data-Driven -->
    <Sample Name="A_backgroundDD" HistoPath="" NormalizeByTheory="False" HistoName="unit_histogram" >
      <NormFactor Name="mu_D_U" Val="100" Low="24500" High="26000" />
      <NormFactor Name="etaB" Val="1" Low="0." High="0.02" Const="False" />
      <NormFactor Name="etaC" Val="1" Low="0." High="0.3" Const="False" />
      <!-- NormFactor and ShapeFactor same for a 1-bin histogram. But we can name NormFactor-->
    </Sample>

  </Channel>
```

A Roadmap


Parameters modify rates only?
yes
no
Analysis is number counting?
Grid for signal is available?
yes
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HEPData: Tables of rates, acceptances, and systematic variations
Shapes based on binned Templates?
Need continuous parametrization?
RECAST and/or fast simulation to create grid points
yes
no
yes
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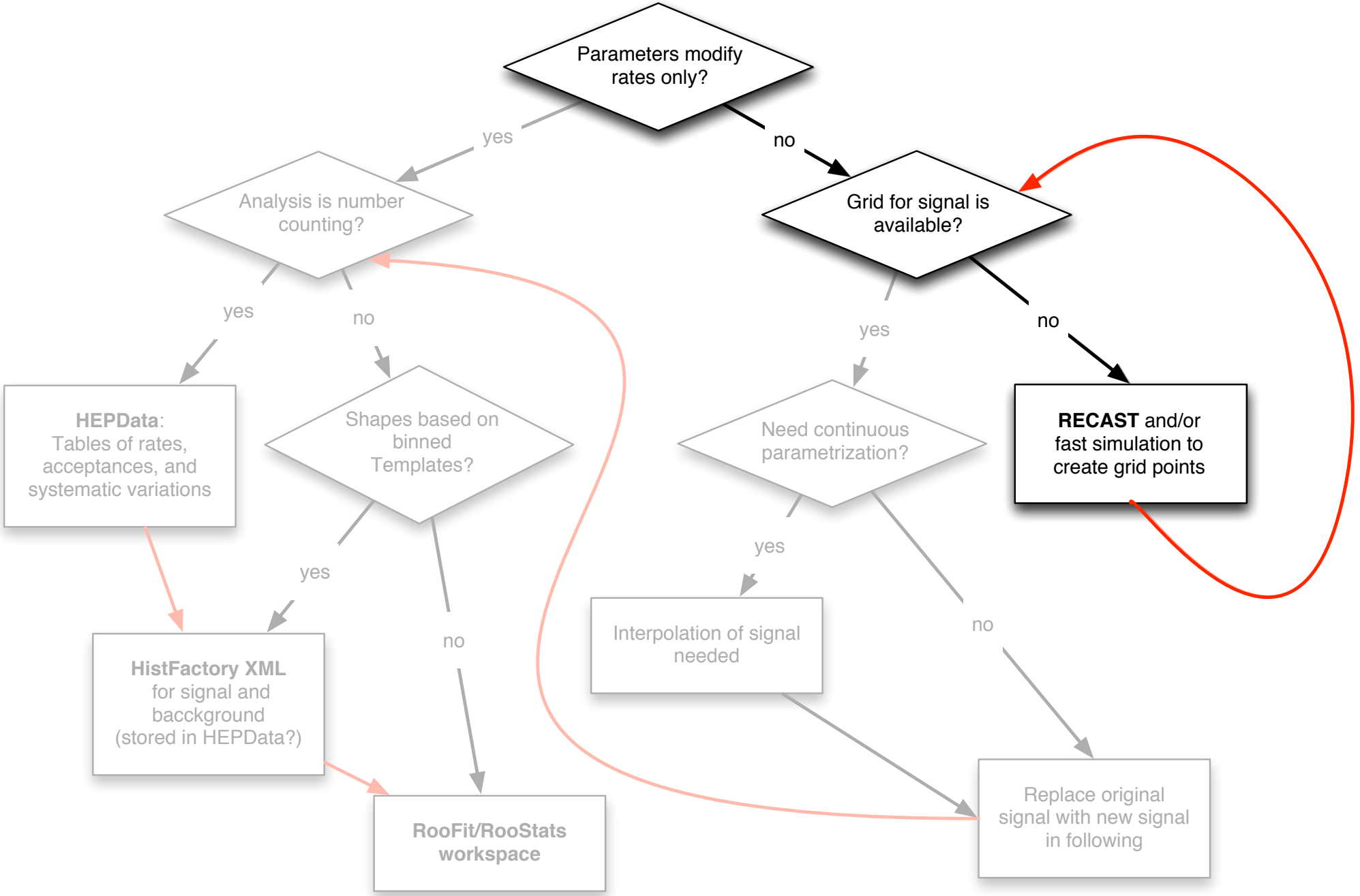
HistFactory XML for signal and backckground (stored in HEPData?)
Interpolation of signal needed
RooFit/RooStats workspace
Replace original signal with new signal in following

A Roadmap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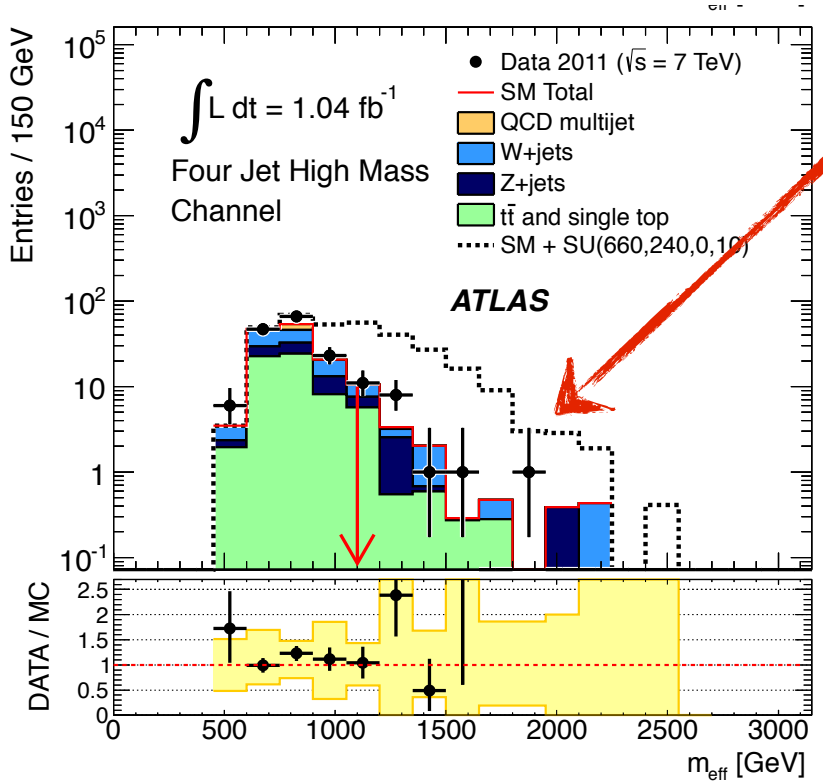
Analysis re-interpretation: "recasting"

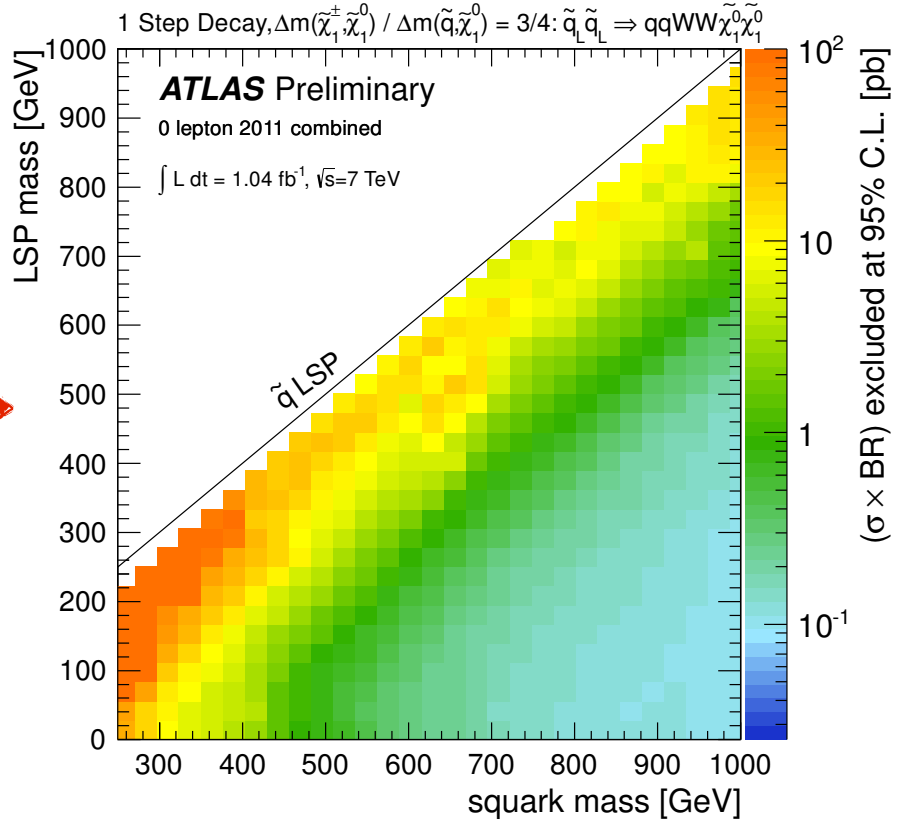
Information | Discussion (0) | Files

ATLAS Note

Report number	ATLAS-CONF-2011-155
Title	**Search for supersymmetry with jets and missing transverse momentum:** Additional model interpretations
Corporate Author(s)	The ATLAS collaboration
Imprint	14 Nov 2011. - mult. p.
In:	Hadron Collider Physics Symposium 2011,
Subject category	Detectors and Experimental Techniques
Accelerator/Facility, Experiment	CERN LHC ; ATLAS
Free keywords	supersymmetry ; SUSY ; simplified model ; extra dimensions

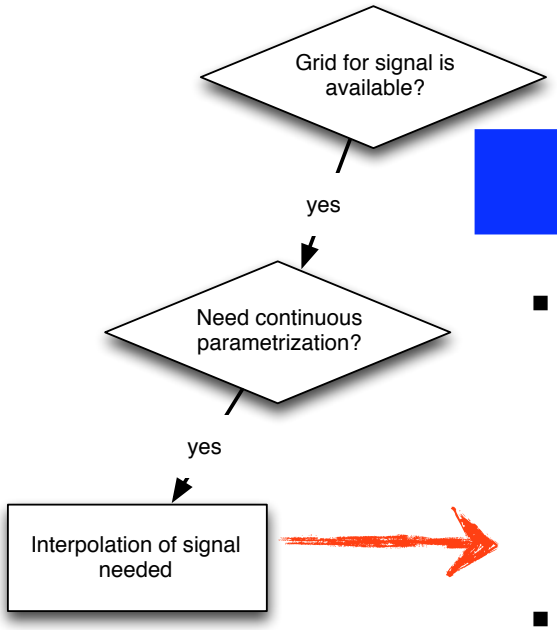
Additional model interpretations require a new signal histogram, which is obtained internally through full analysis chain.





Interpolating efficiencies in theory parameters

- [http://indico.cern.ch/getFile.py/access?contribId=14&resId=0&materialId=slides&confId=118137]



Interpolation examples

- Linear, non-linear, smoothed interpolation?
  - Non-trivial with >1 interpolation parameters
  - This will make a difference!
- Interpolation in what variable?
  - Signal expectation? Only works if background is constant over the grid.
    - ➢ Selections may change over grid to favor certain decay topologies
  - Likelihood?
- RooFit / RooStats allows for 3-dimensional interpolation
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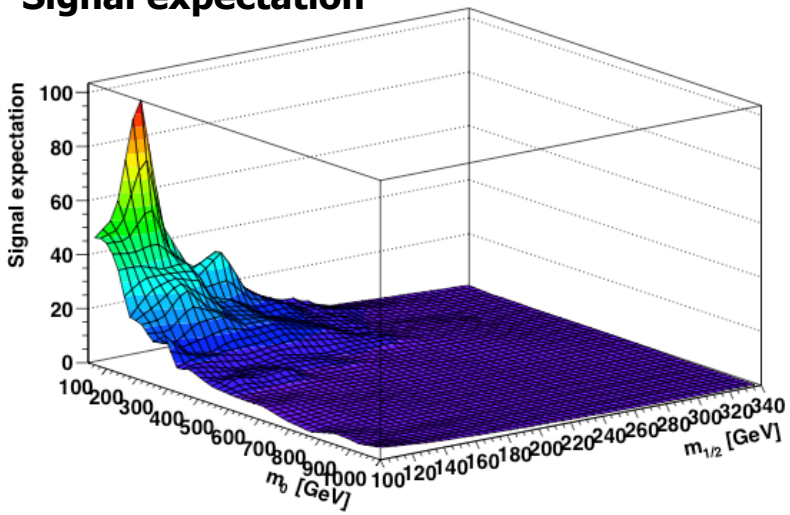
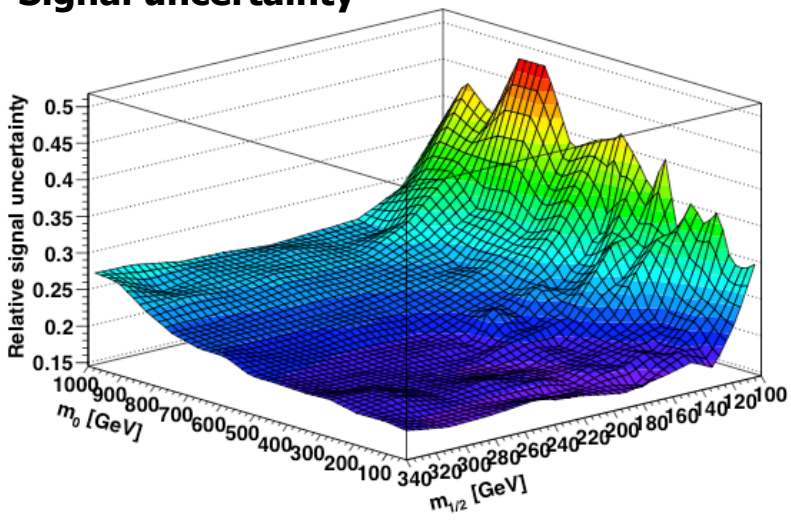
Signal expectation



Signal uncertainty



Max Baak (CERN)

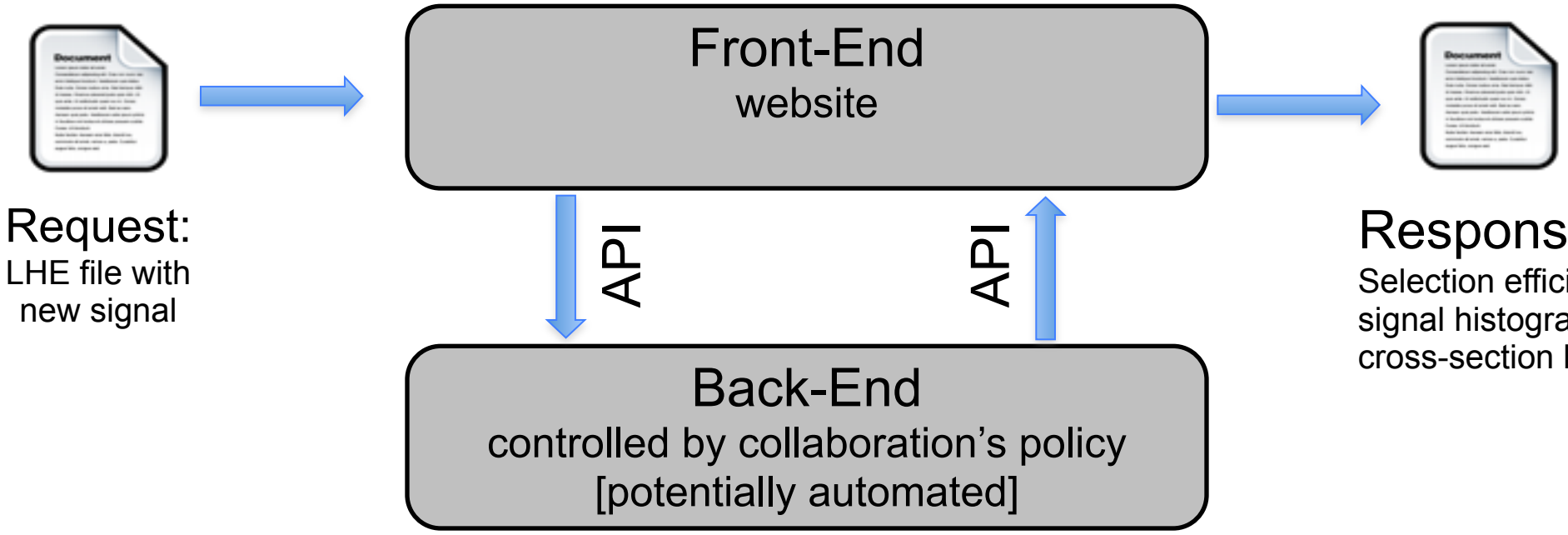
K.C., Itay Yavin [hep-ex/1010.2506], JHEP.

RECAST is a framework for recasting that aims to collect, standardize, and facilitate the processing of recast requests from the community.

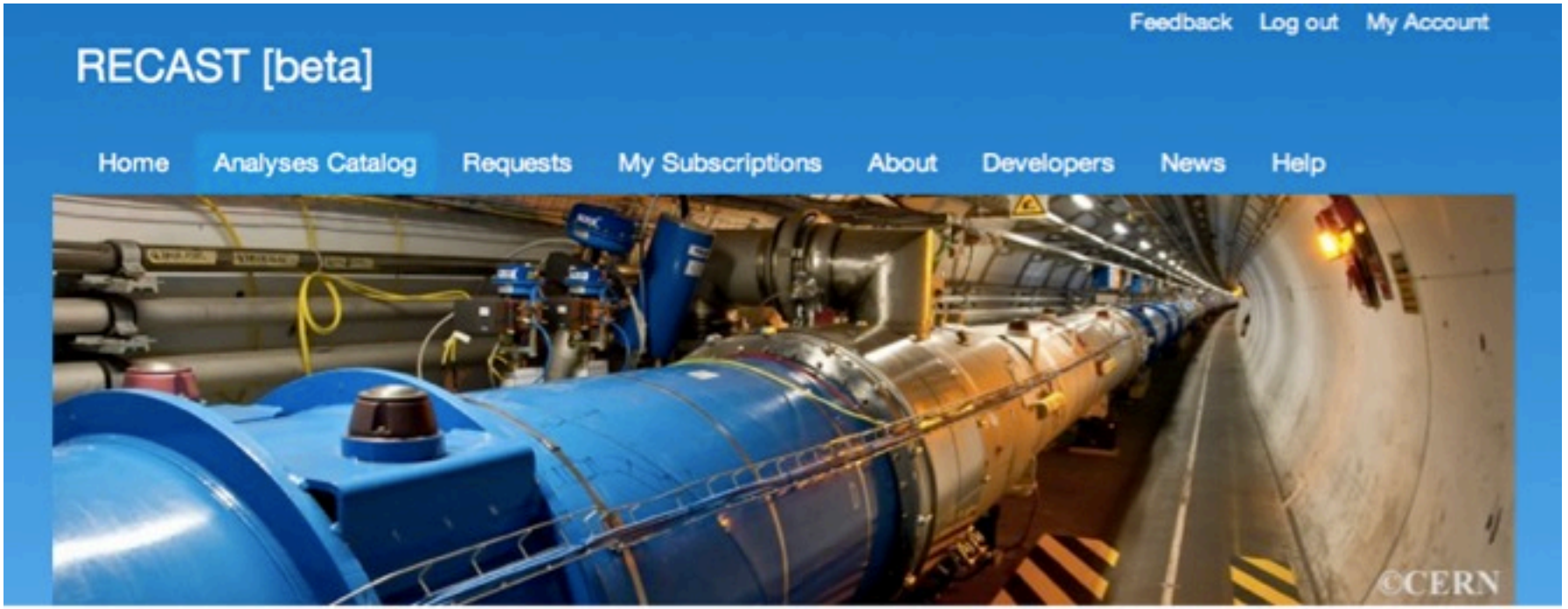
- cuts don't change: re-use background estimates and observation from original analysis
- what is needed is to archive the analysis cuts & provide a pipeline for new signal
- data is kept private, still goes through necessary approval process as determined by collaboration, original paper receives citation & recognition (doi's tracked by INSPIRE)

RECAST front-end is a website that collects and organizes the Requests and Responses

- standardizes request & response format, API allows for process to be automated,
- back-end implementation is up to collaboration



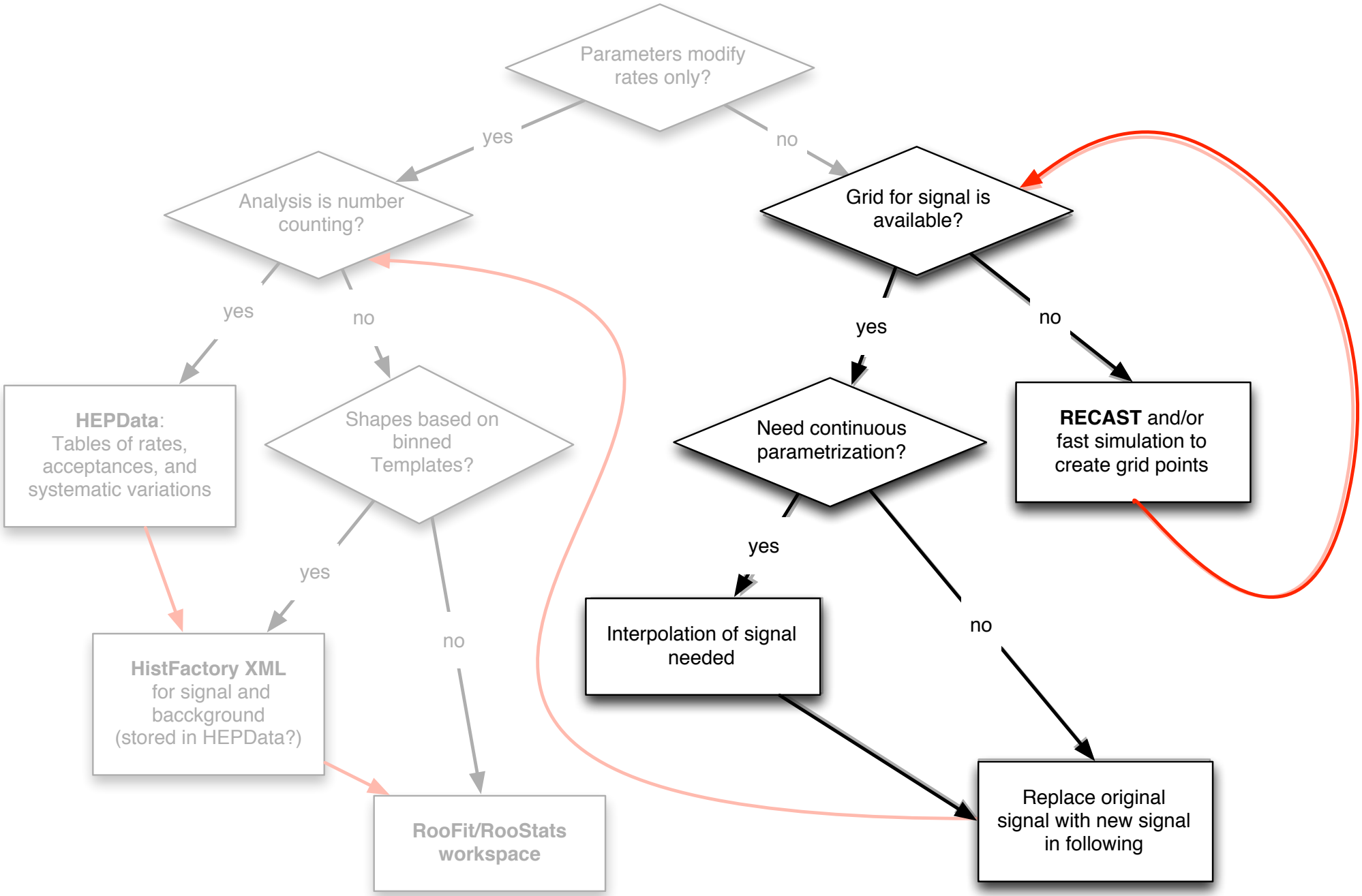
http://recast.perimeterinstitute.ca



Analysis Catalog | New Analysis

Analysis	Collaboration	Subscribers	Requests	Active	Completed	Actions
Search for Diphoton Events with Large Missing Transverse Momentum in 1 fb^-1 of 7 TeV Proton-Proton Collision Data with the ATLAS Detector	Atlas	1	1	0	1	view | edit | un-subscribe | add request
Search for New Phenomena in Events with Three or more Charged Leptons	Atlas	0	0	0	0	view | edit | subscribe | add request
Multileptonic SUSY searches	CMS	2	1	1	0	view | un-subscribe | add request
Search for Anomalous Production of Multilepton Events and R-Parity-Violating Supersymmetry in √s = 7 TeV	CMS	0	0	0	0	view | subscribe | add request
Search for a Vector-like Quark with Charge 2/3 in t + Z Events from pp Collisions at sqrt(s) = 7 TeV	CMS	0	0	0	0	view | subscribe | add request

Roadmap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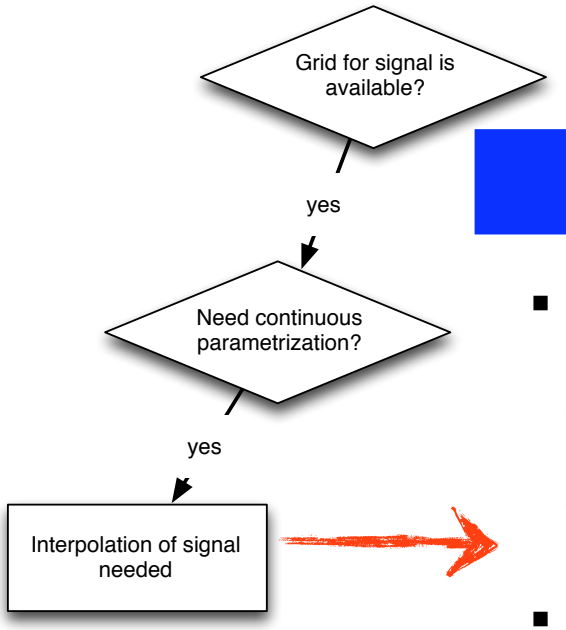

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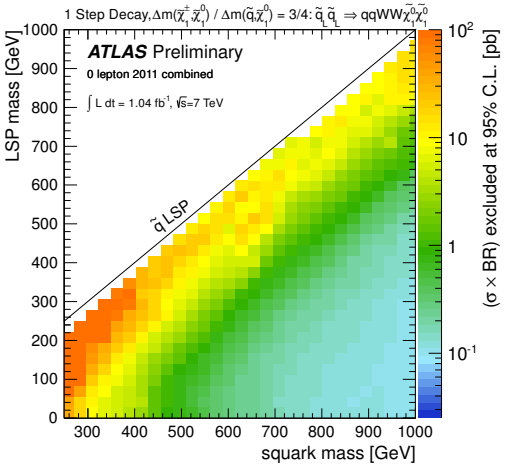

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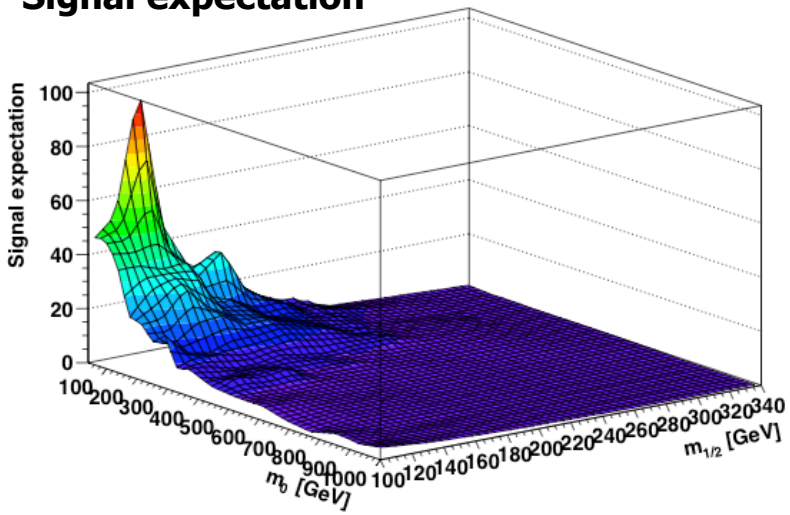
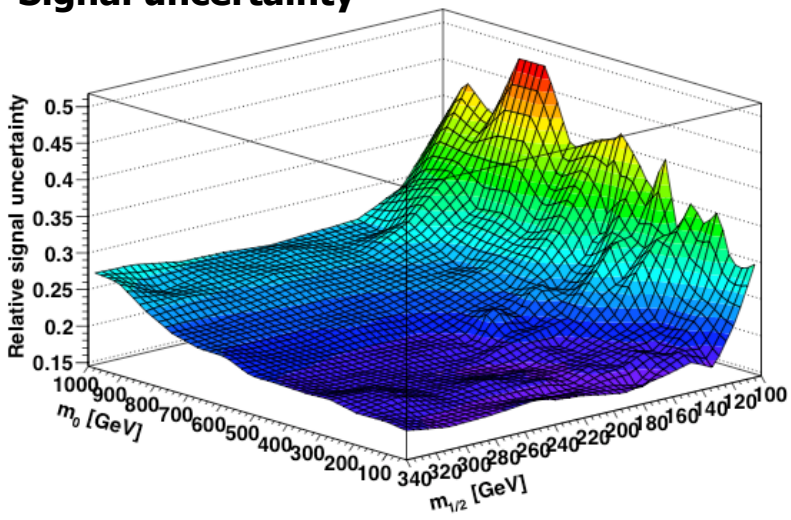


Signal uncertainty

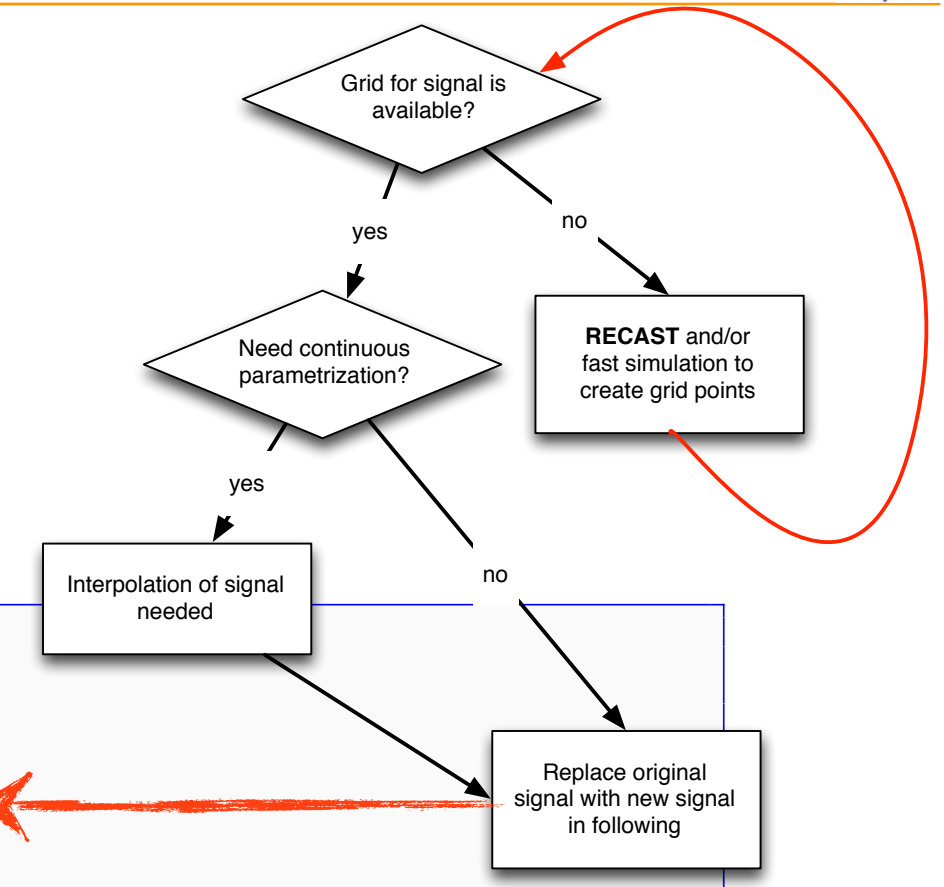


Max Baak (CERN)

HistFactory XML

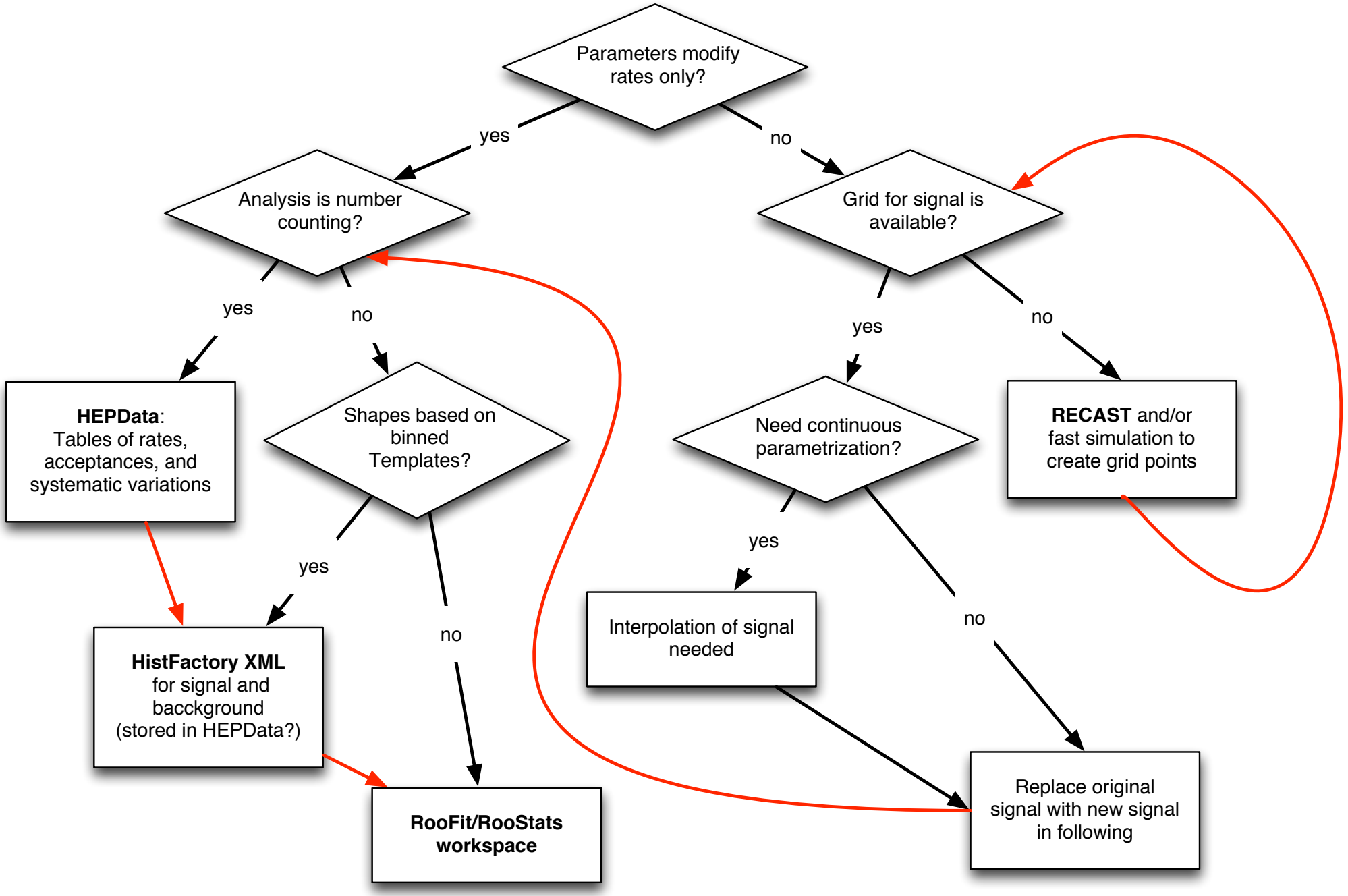
Once one has the histogram for the new signal, a straight forward editing of the XML file will produce a new likelihood with the same background model

- multiple different components for different production modes
- useful for simplified models




```
<!DOCTYPE Channel  SYSTEM 'HistFactorySchema.dtd'>

  <Channel Name="A" InputFile="./data/ABCD.root"  >
    <Data HistoName="A_data" HistoPath="" />

    <!-- This is the signal (eg. mu)-->
    <Sample Name="A_signal" HistoPath="" HistoName="unit_histogram">
      <!-- now mu is number of events-->
      <NormFactor Name="mu" Val="1" Low="0" High="200" />
      <OverallSys Name="syst1" High="1.01" Low="0.99" />
    </Sample>

    <!-- This bkg is estimated from MC (eg. mu_A^K) -->
    <Sample Name="A_backgroundMC" HistoPath="" NormalizeByTheory="True" HistoName="unit_histogram"  >
      <NormFactor Name="mu_K_A" Val="100" Low="0" High="200" />
    </Sample>

    <!-- Background 2 is completely Data-Driven -->
    <Sample Name="A_backgroundDD" HistoPath="" NormalizeByTheory="False" HistoName="unit_histogram" >
      <NormFactor Name="mu_D_U" Val="100" Low="24500" High="26000" />
      <NormFactor Name="etaB" Val="1" Low="0." High="0.02" Const="False" />
      <NormFactor Name="etaC" Val="1" Low="0." High="0.3" Const="False" />
      <!-- NormFactor and ShapeFactor same for a 1-bin histogram. But we can name NormFactor-->
    </Sample>

  </Channel>
```

Roadmap


Parameters modify rates only?
yes
no
Analysis is number counting?
Grid for signal is available?
yes
no
yes
no
HEPData: Tables of rates, acceptances, and systematic variations
Shapes based on binned Templates?
Need continuous parametrization?
RECAST and/or fast simulation to create grid points
yes
no
yes
no
HistFactory XML for signal and backcground (stored in HEPData?)
Interpolation of signal needed
RooFit/RooStats workspace
Replace original signal with new signal in following

Comments on Rivet & HiggsBounds

Rivet: Some analyses are being incorporated into Rivet.

- generally background subtracted and unfolded to particle-level
- primarily used for MC tunings

In that sense RECAST is complementary

- the detector simulation performs folding
  - as is done by current "additional model interpretations" documents
- primarily aimed at searches

One could imagine some interaction between the projects

HiggsBounds: HiggsBounds does aim to reinterpret existing constraints in the context of different Higgs sectors. Doing the best with what's available

- but not "arbitrary" Higgs sectors! It can only constrain model that has topologies that have explicitly searched for by experiments
- it is based on the topology with the strongest expected limit.
  - once there are several decay modes, this approach quickly looses power
  - to combine different searches need likelihoods.

Interaction with INSPIRE & HEPData

INSPIRE: Advanced discussions regarding the interaction of RECAST and INSPIRE.

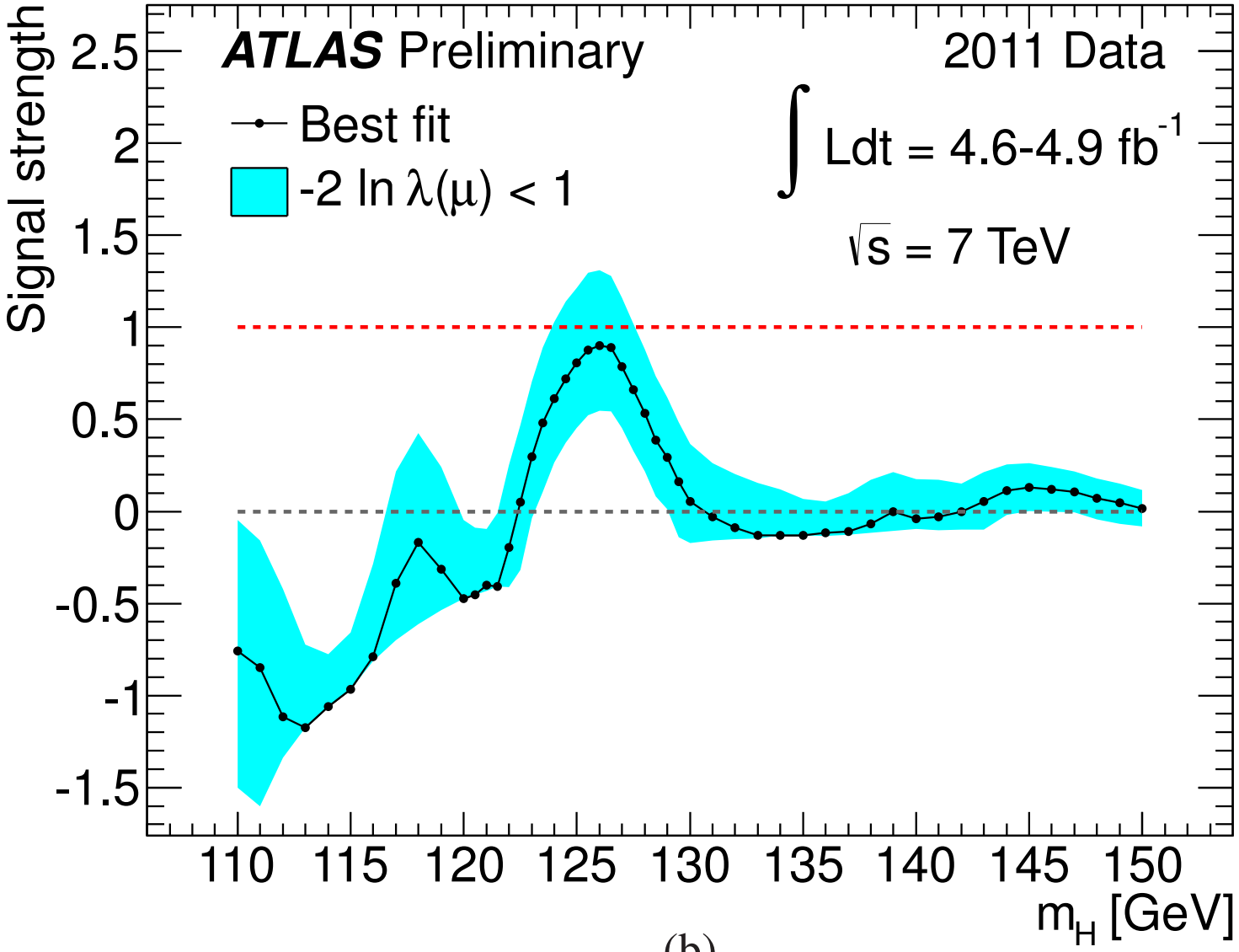
- New responses get DOI number from CERN, are aggregated with original collaboration publication. New responses are citable objects, and increment citation of original paper
- New requests (from theorists) get their own DOI number, so theorist can put out paper pointing to their request independently of a collaboration response

HEPData: Signal histograms from the new model could go into HEPData.

Now a word on the Higgs

μ plot

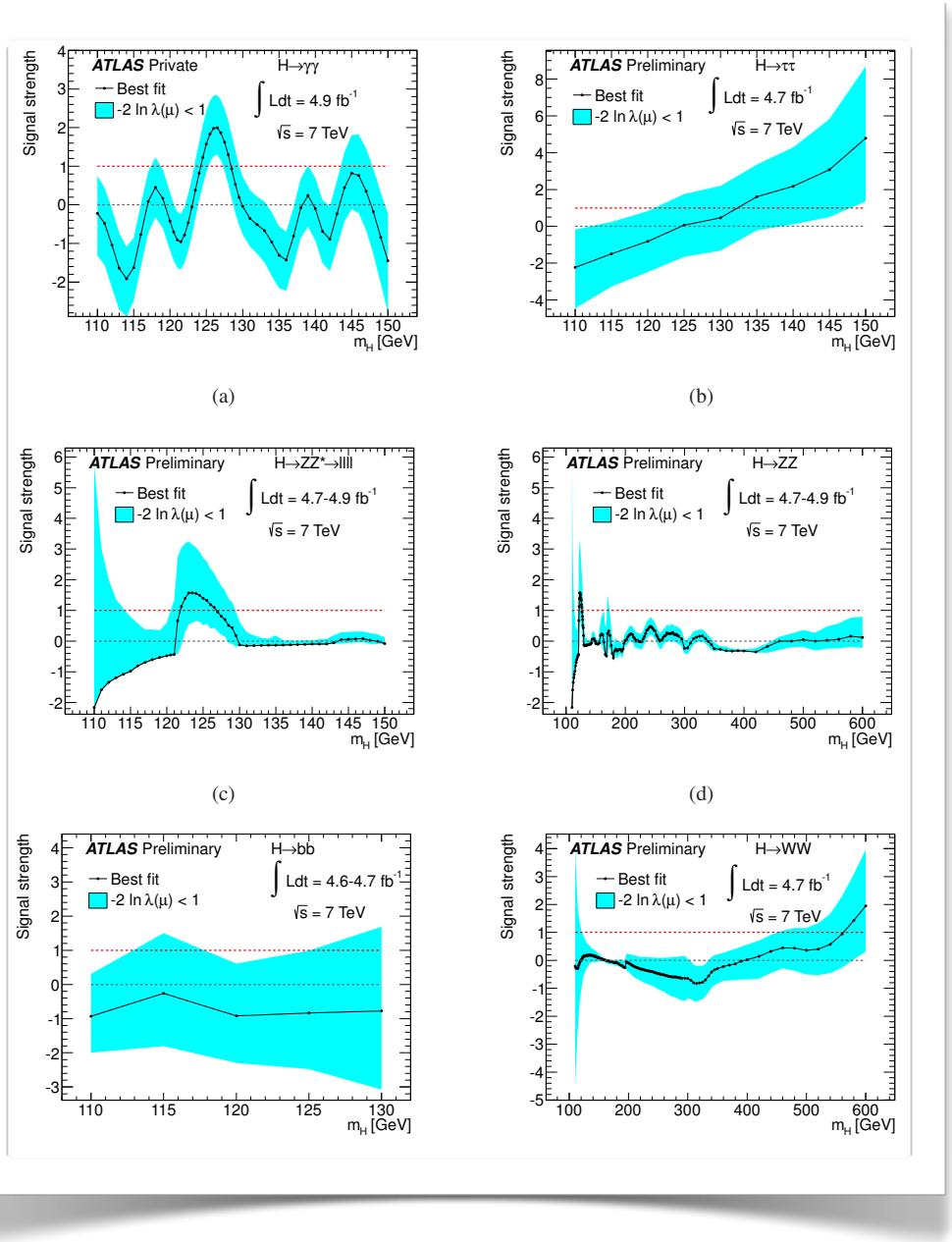
This is a global scaling of σ BR for all production and decay modes.



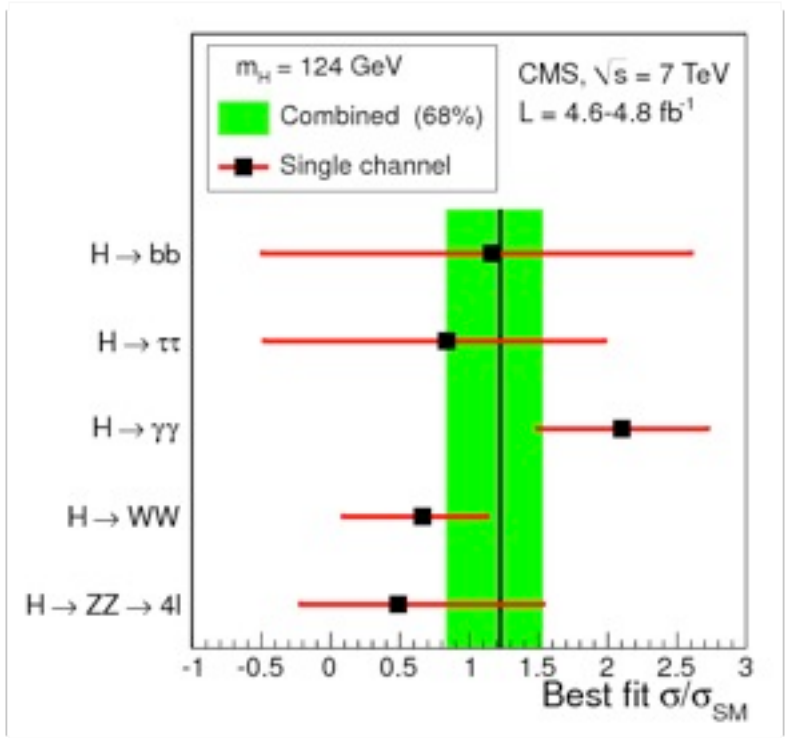
(b)

Individual μ plots

Recommendation 5: *For Higgs searches, provide all relevant information on a channel-by-channel basis.*



This is ***not*** what we need for the coupling measurements b/c the production modes are assumed to take their SM ratios

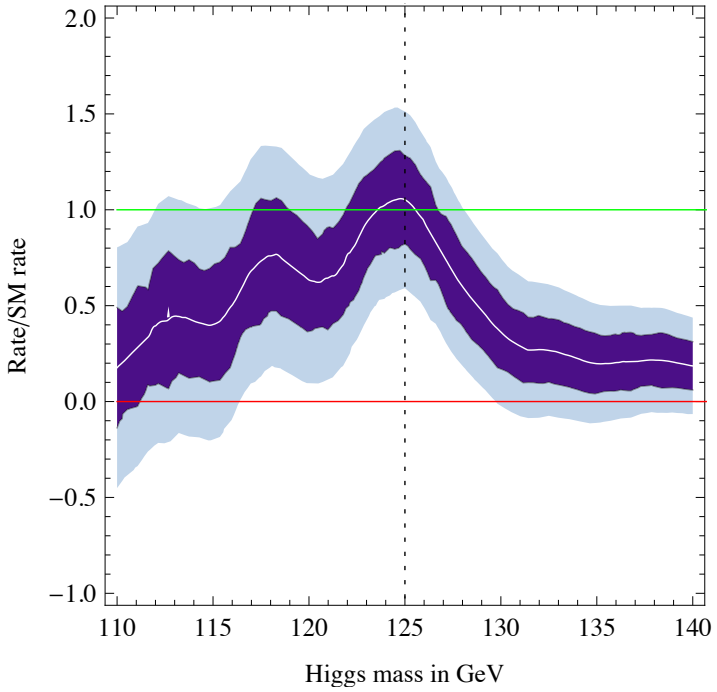


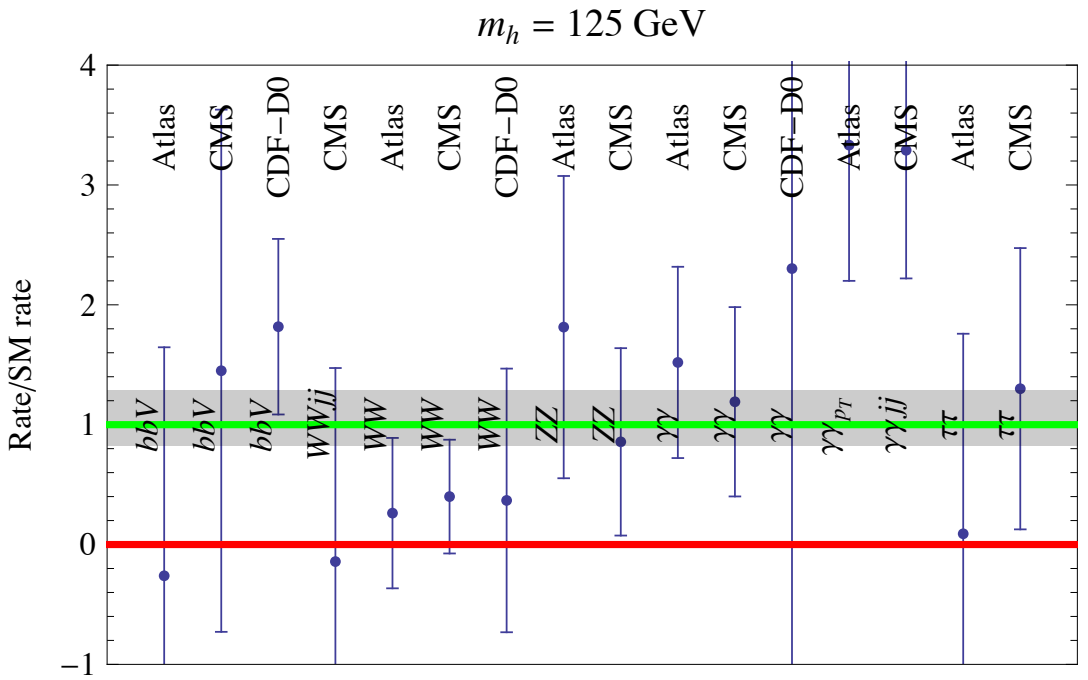
Reinterpreting the results

Clearly, if we don't release the necessary information, people will do the best they can with what we provide.

CMS PLB 710 (2012)

For a Higgs boson having a mass, m_H, of 120 GeV the overall acceptance times selection efficiency of the dijet tag for Higgs boson events is 15% (0.5%) for those produced by VBF (gluon–gluon fusion). This corresponds to about 2.01 (0.76) expected events. Events passing this tag are excluded from the four classes defined by R_9 and pseudorapidity, but enter the fifth class. About 3% of Higgs boson signal events are expected to be removed from the four classes defined by diphoton properties. In the mass range $100 < m_{\gamma\gamma} < 180$ GeV the fractions of diphoton events in the selected data, which pass the dijet VBF tag and enter the fifth class, and which would otherwise have entered one of the four classes defined in Table 2, are 0.8%, 0.5%, 0.3% and 0.4%, respectively.





P. P. Giardino, K. Kannike, M., A. Strumia. arXiv:1203.4254

Difficulties interpreting our results

Searches often optimized for a given production and decay, but several production and decay modes populate those regions of phase space

- confused by the fact the selections are often labeled “VBF” etc.
- Note: older coupling studies were based on analyses with much more severe “VBF” cuts and gluon fusion contributions were smaller

Most results do not document the relative contributions from various production and decay processes to the total signal rate

- ie. ATLAS $H \to \gamma\gamma$ does not give breakdown of ggF and VBF in the 9 sub-channels. Why not?

Even if we did, the distributions are different, so we would really need to give detailed description of the shapes

- “The experiments have problems giving out information that in principle can’t be used properly” -Yuri Gershtein (approximate)
- Note: many older studies based idealized analyses, shapes were not an issue

Likely that the coupling measurements will initially be done by collaborations

- thus important that we have open discussion with theorists about how this is done

Moving beyond a single μ

In practical terms, we need a parameter for each branching ratio and a parameter for each production cross-section ("experimental parametrization").

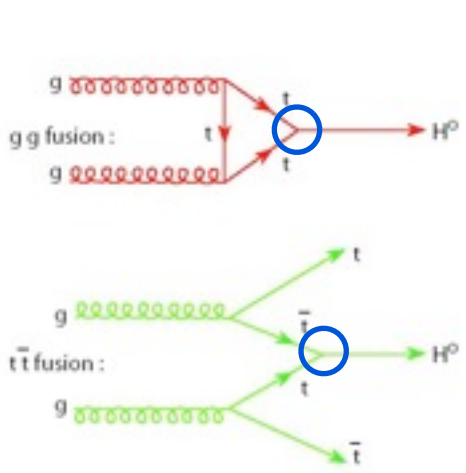
- We need signal contributions for different production mode separately
- Call them μ_i and μ_j where i is production index and j is decay index
- take into account cross-contamination (ie. H→WW→lvlv in H→ZZ →llvv)
- subtleties around theoretical uncertainties in these more general models

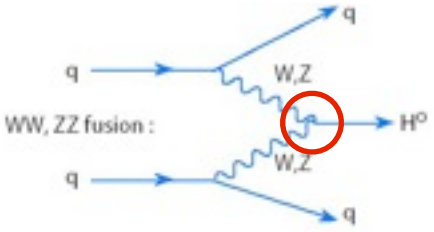
Only consider SM-like interactions at first

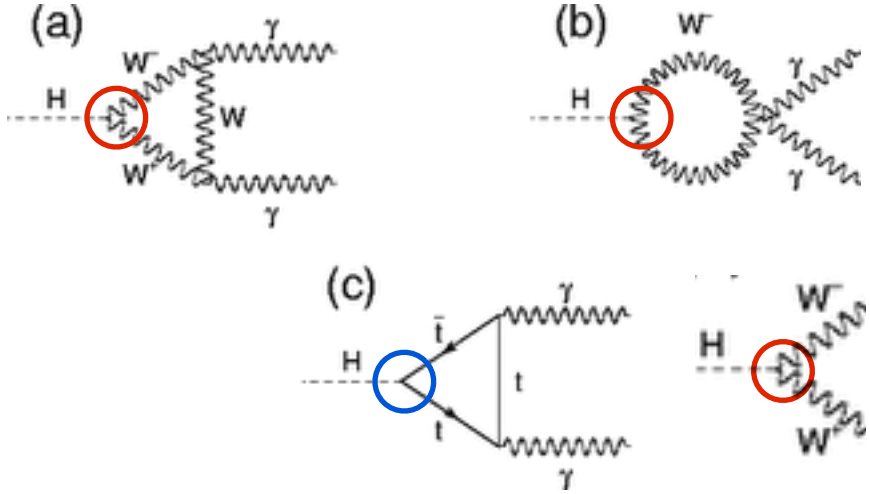
- much more work needed if kinematic distributions change

However, the production and decay really are not independent

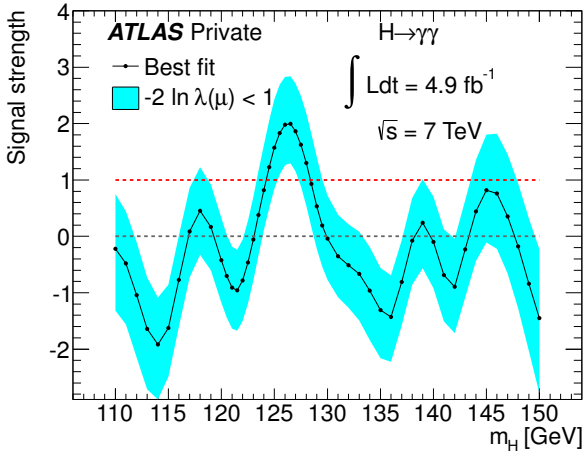
- prepare to re-parametrize in terms of couplings

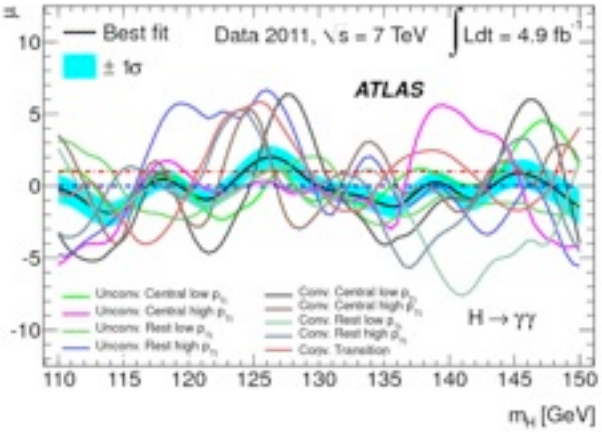


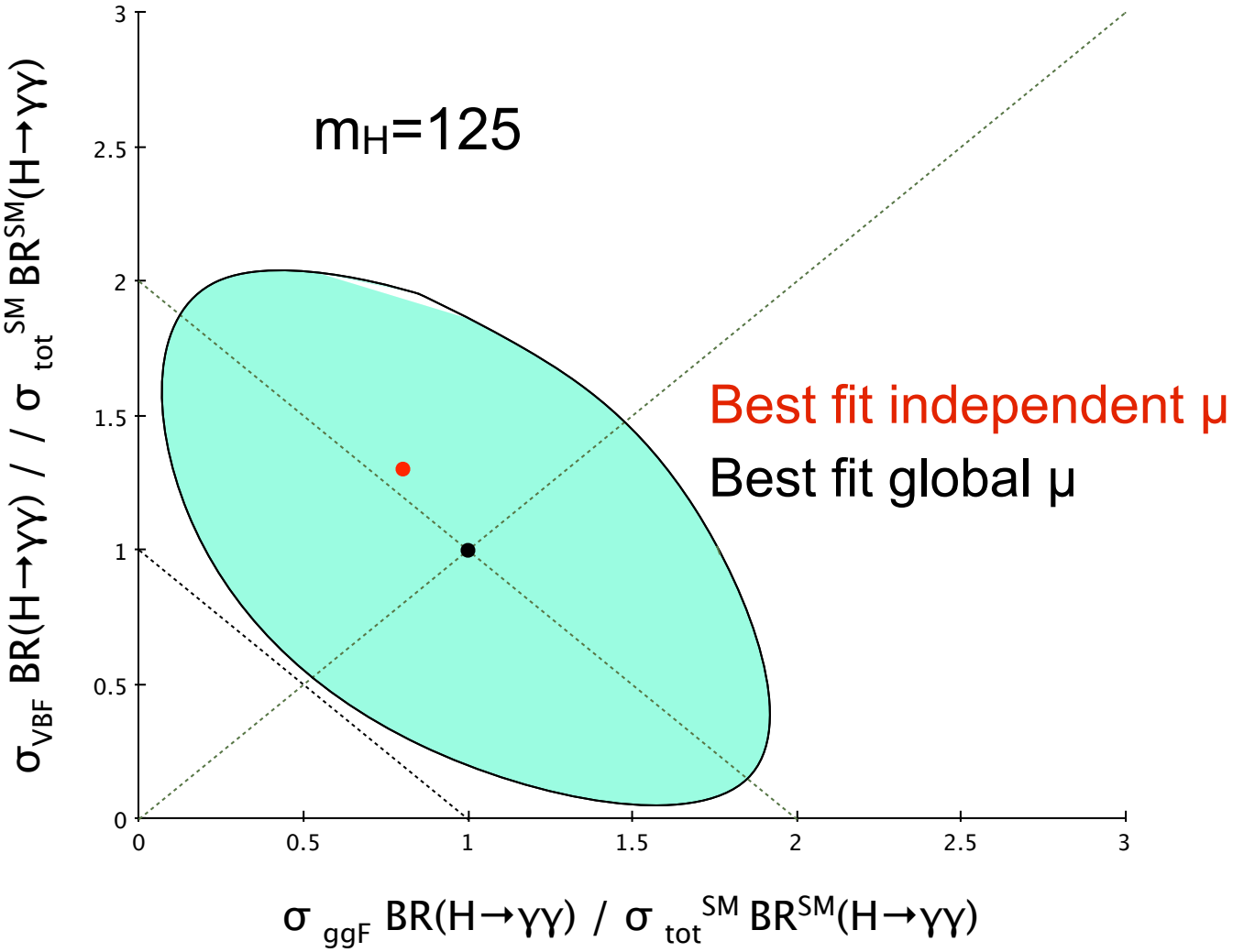




μ_i contours for individual channels







Above drawn with equal efficiencies, different efficiencies will lead to a tilted contour.

Need significant differences in shape or relative efficiency across sub-channels to break degeneracy among production modes

If we introduce additional σ_X for each production mode profile will fill plane

Narrow width approximation

The basic starting point for the various parametrizations :

$$\sigma(H) \times \mathrm{BR}(H \to xx) = \frac{\sigma(H)^{\mathrm{SM}}}{\Gamma_p^{\mathrm{SM}}} \cdot \frac{\Gamma_p \Gamma_x}{\Gamma}$$

No useful direct constraint on total width at LHC

- allow for invisible? allow for unseen / buried / etc.?

Various strategies:

- not a higher SU(2) representation: $\Gamma_V \leq \Gamma_V^{\mathrm{SM}}$
  - together with $\Gamma_V^2/\Gamma = \mathrm{meas} \quad \Rightarrow \quad \Gamma_{\mathrm{vis}} \leq \Gamma \leq \Gamma_{V,SM}^2/\mathrm{meas}$
- SFitter: $\Gamma_{\mathrm{tot}} = \sum_{\mathrm{obs}} \Gamma_i(g_{iiH}) + \text{generation universality}$
- "Invisible Higgs Hypothesis" $\Gamma = \Gamma_{\mathrm{vis}} + \Gamma_{\mathrm{inv}}$
- ....

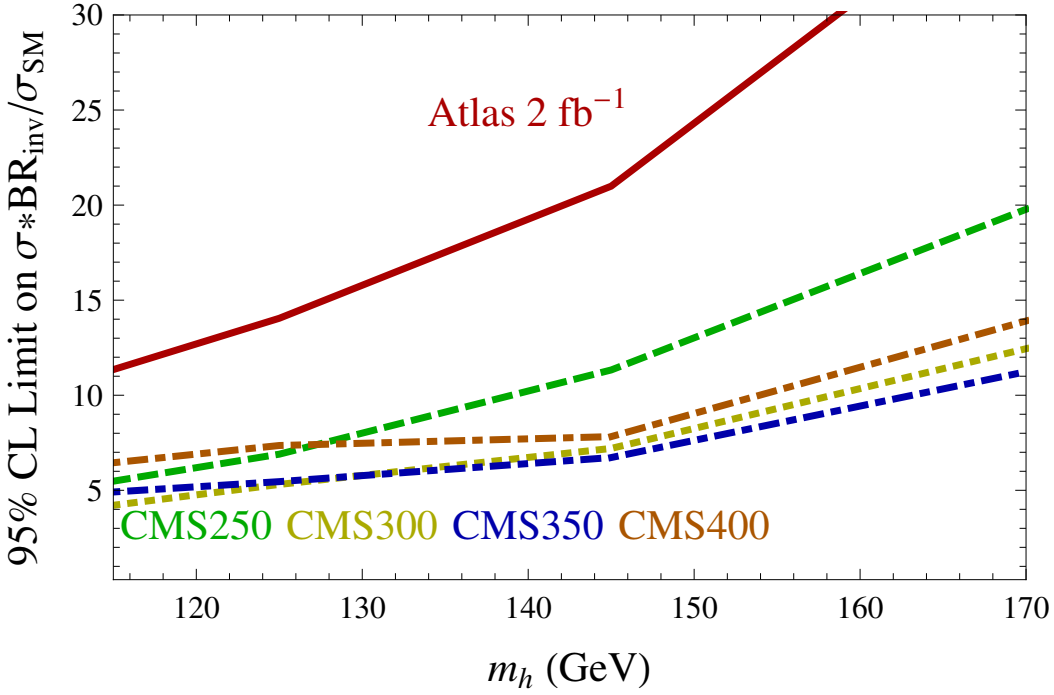
Or give up on total width and measure ratios

Recasting for H→ invisible

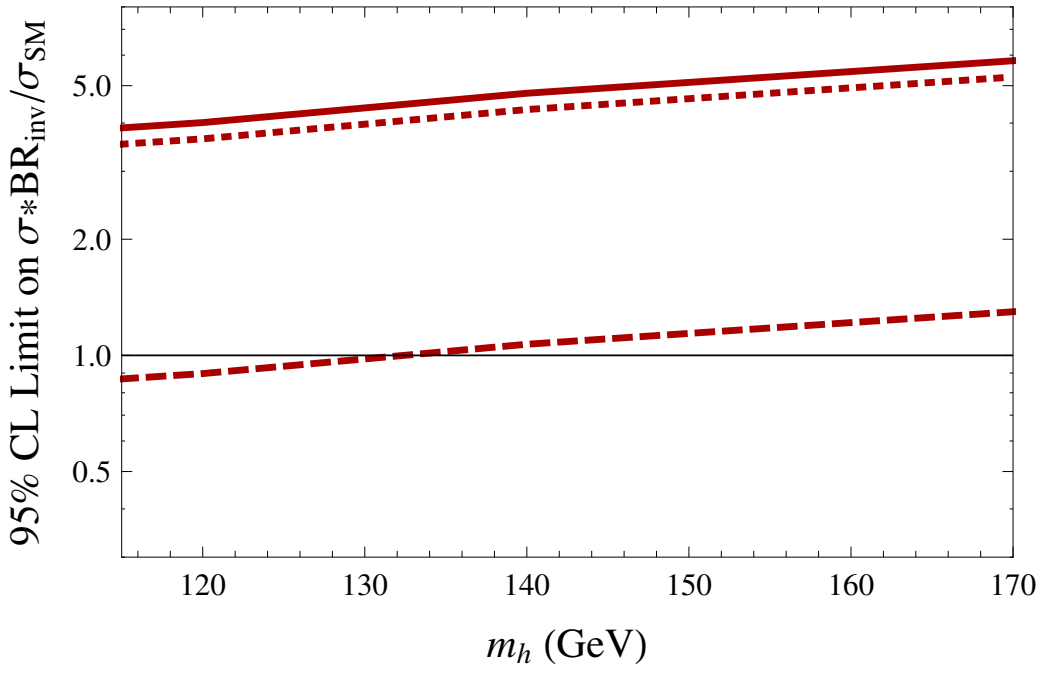
Bai, Draper, Shelton [arXiv:1112.4496] reinterpreted searches for monojets and H→ZZ→llνν to constrain H→ invisible

Request	Analysis	Model	Status
1205.0033	Search for the standard model Higgs boson in the H→ZZ→2l2ν channel in pp collisions at s√ = 7 TeV	Invisible Higgs	Active
1205.0032	Search for a Standard Model Higgs in the H->ZZ->llνν decay channel with 4.7 fb−1 with the ATLAS detector	Invisible Higgs	Active

Bai, Draper, Shelton [arXiv:1112.4496]



H→ZZ→llνν to constrain pp→ ZH



Monojet to constrain pp→ H

Conclusions

We have the technical ability to publish likelihood functions digitally (RooFit/RooStats)

- We should make fundamental distinction between parameters that scale only rates and those that change acceptance, efficiencies, etc.

HEPData might store signal & background histograms

- need meta-information to organize this info (including systmatics)
  - HistFactory XML is a concrete solution for binned histograms

In order to extend analyses to different signal with different efficiencies and acceptances, need to run simulation.

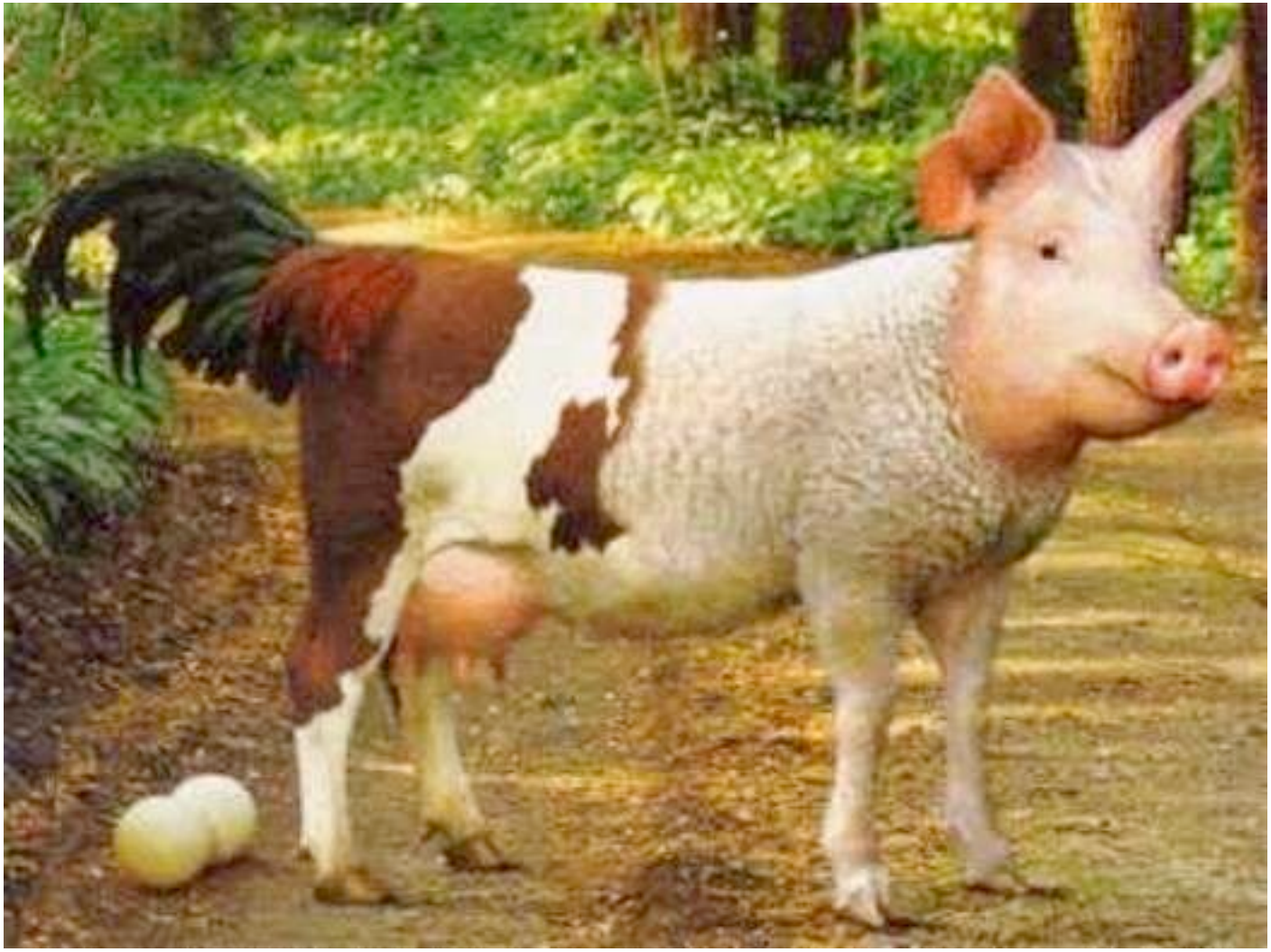
- Fast simulation and/or parametrization for fine scans
- RECAST for validated reinterpretation via the experiments

Moving beyond SM Higgs searches towards Higgs coupling measurements is very important and also delicate

- critical to take into account different production modes in each of the search channels. Current results usually don't provide this information
- if the experiments are going to do final coupling fits, then we need good interaction with theorists

We are making progress, the Higgs is likely to change the discussion

Eierlegende Wollmilchsau



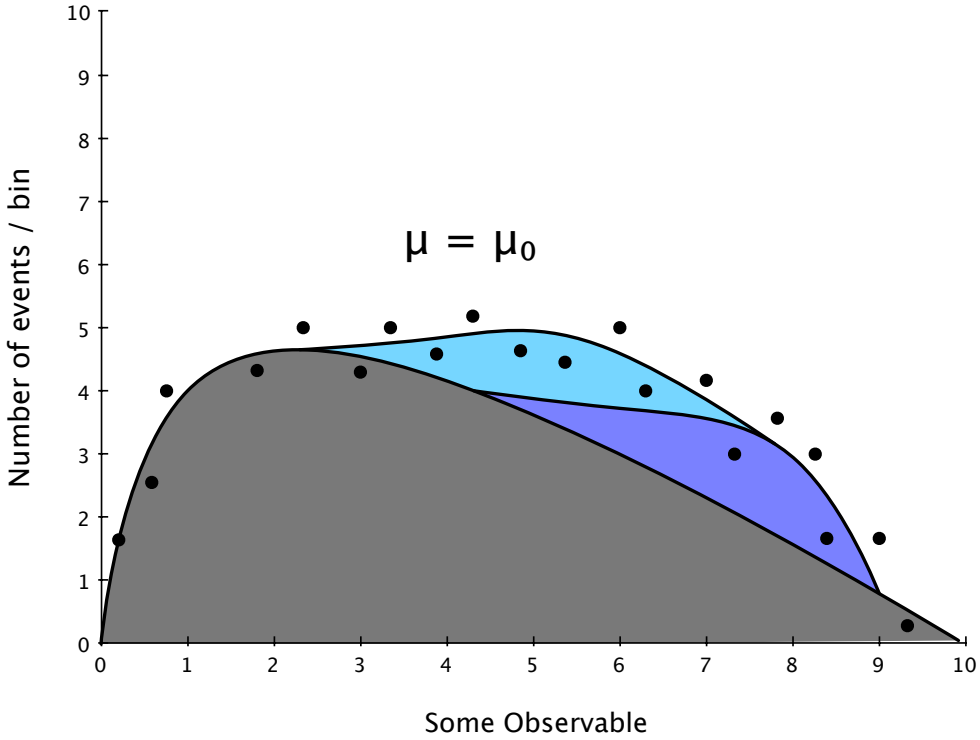
Acceptance

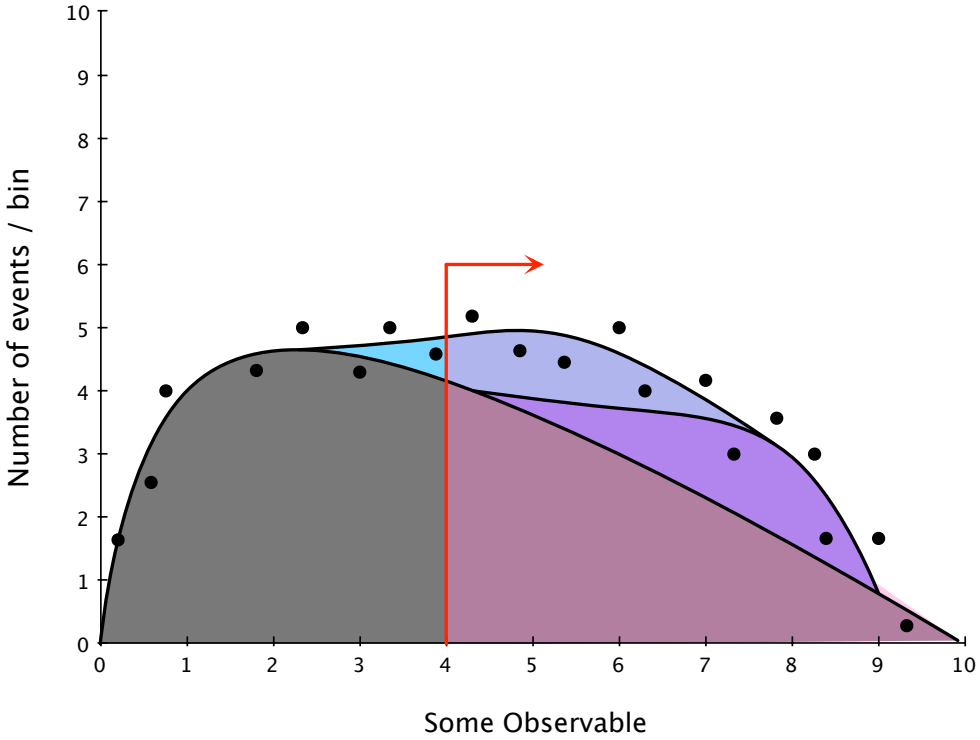
As we move around the model's parameter space the distributions change, thus changing the signal efficiency and acceptance.

- This is harder to parametrize than branching ratios for 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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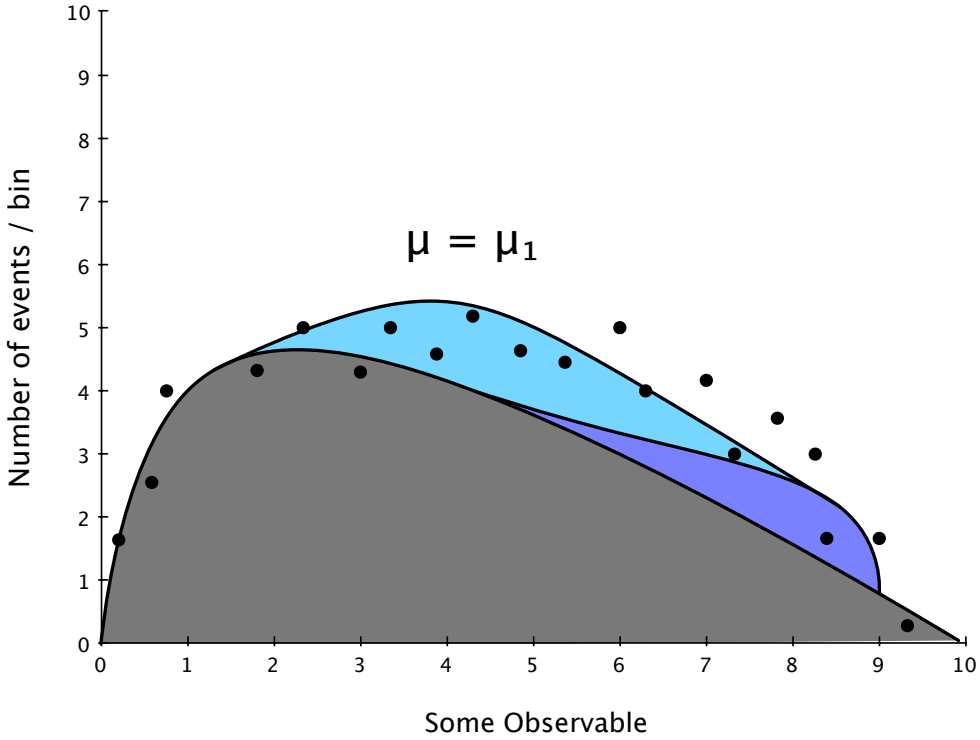

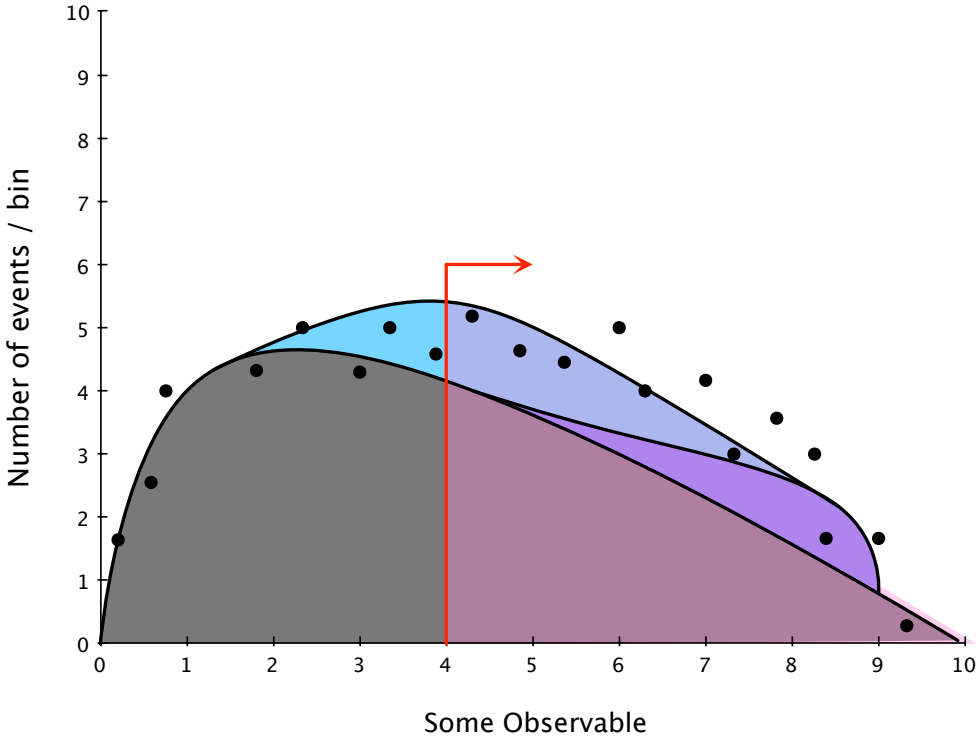

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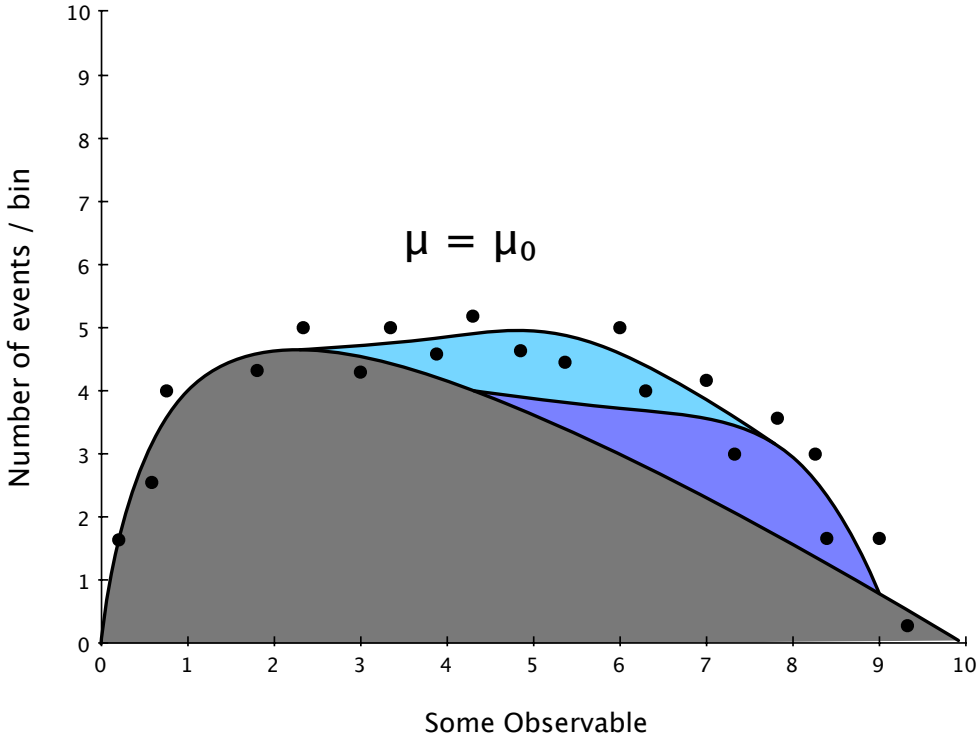
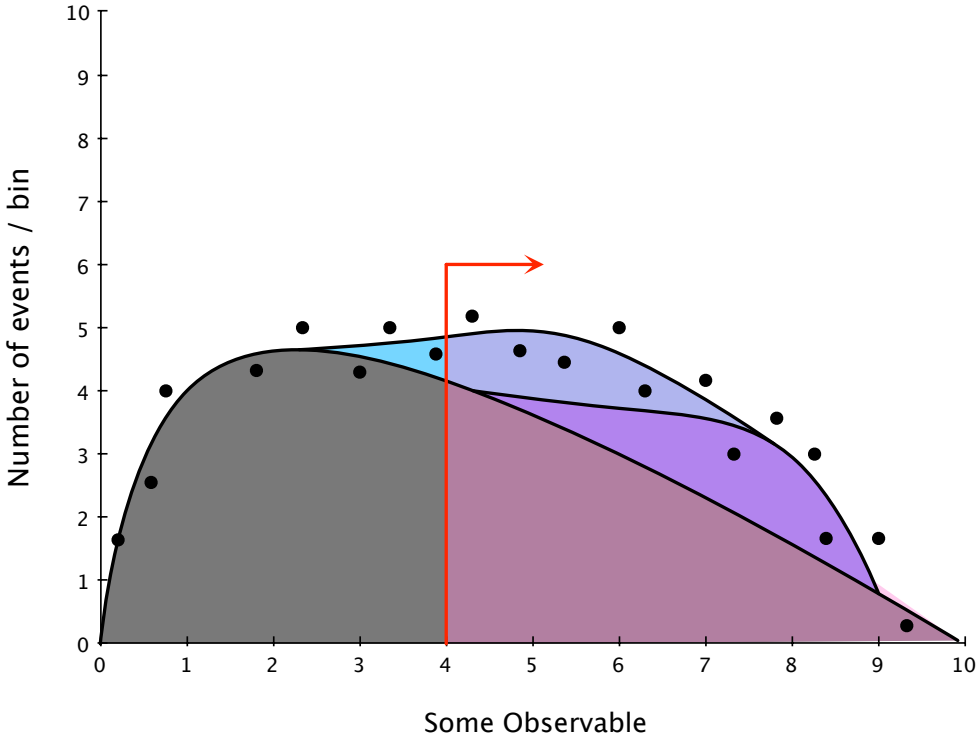
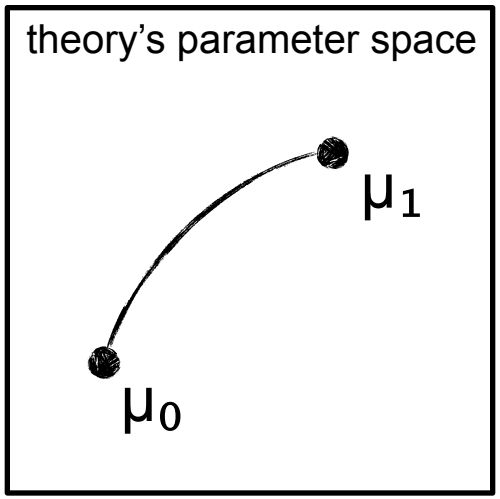


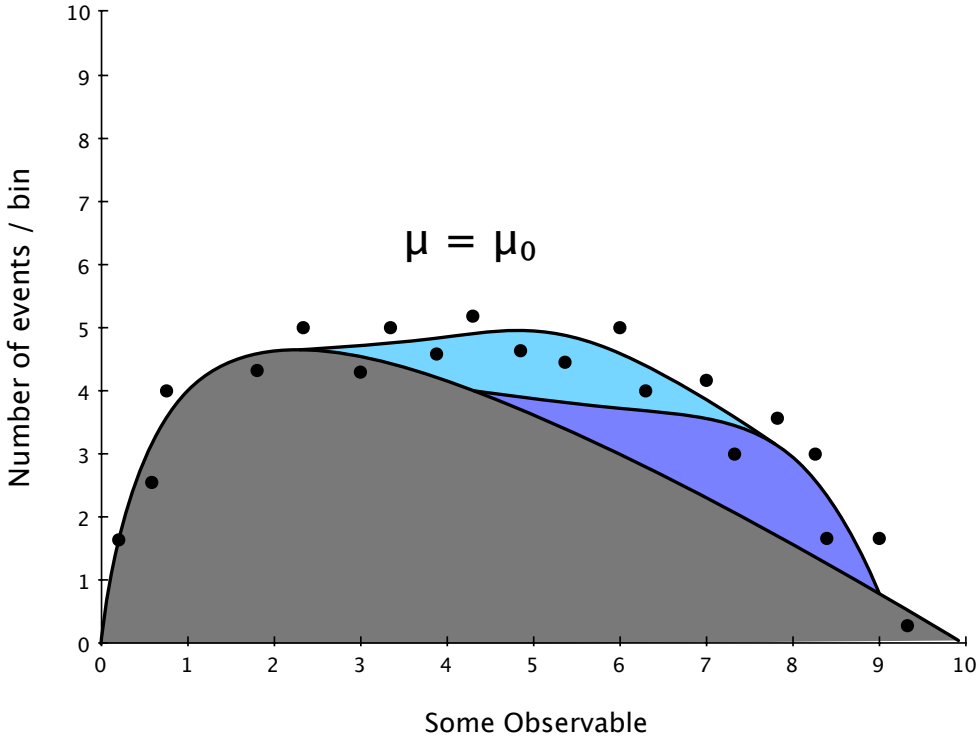


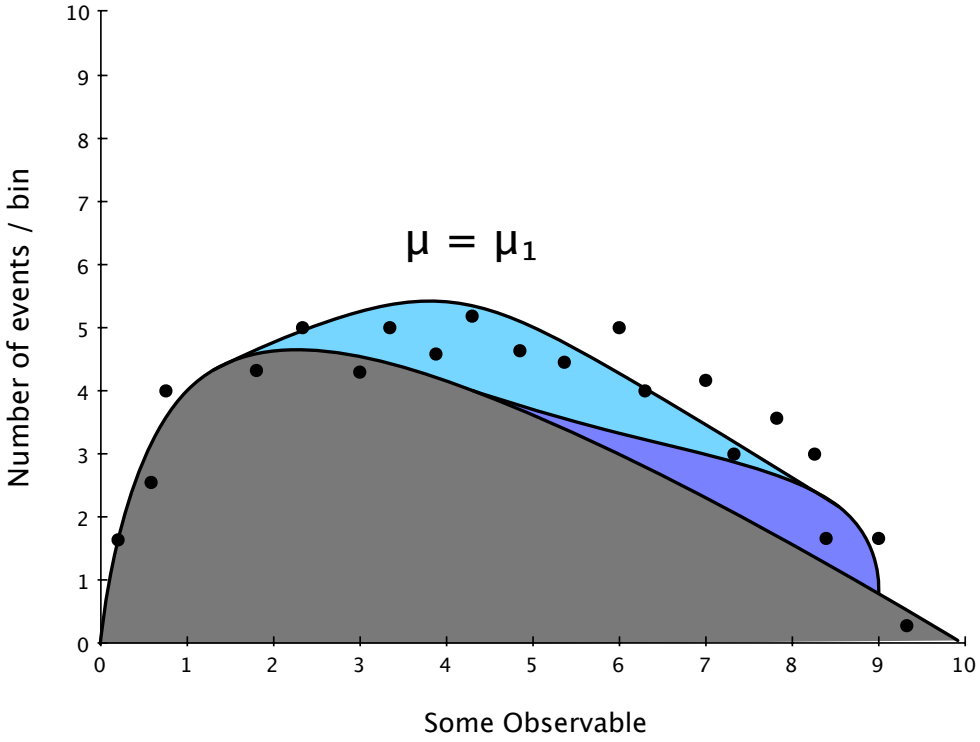
Interpolating

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





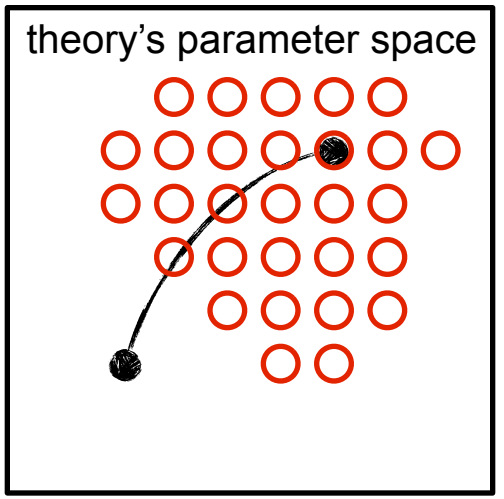
Extrapolating

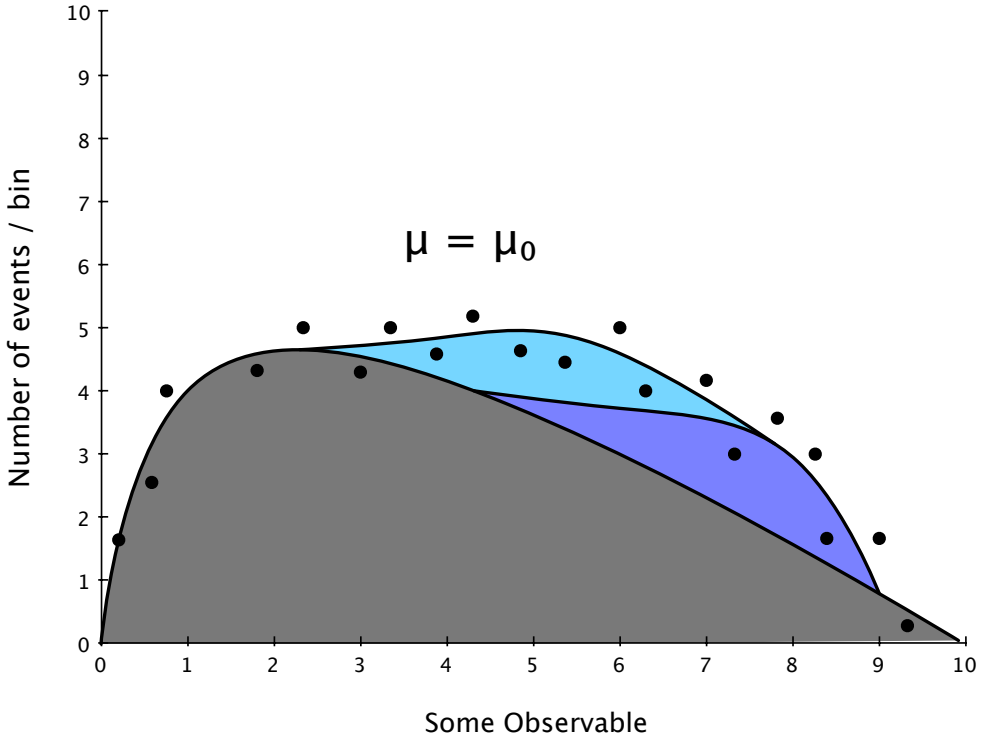
Initially the experiments may scan some initial set of model points.

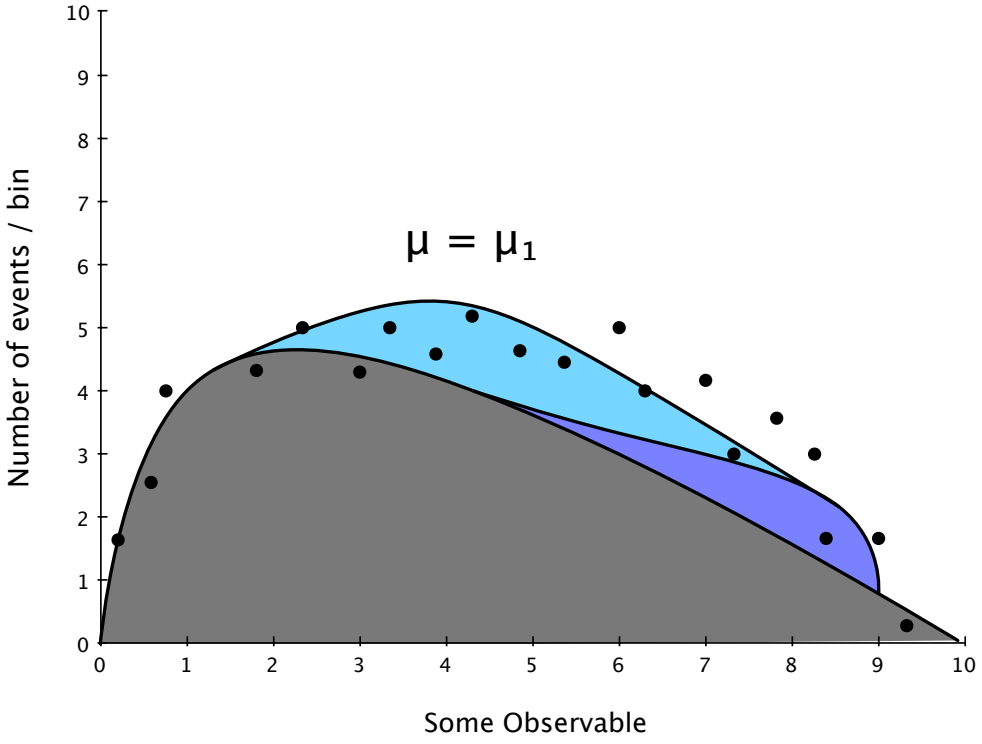
- These define a domain of validity for the model

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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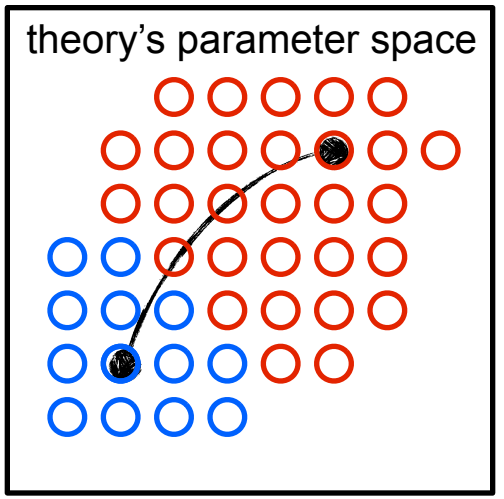

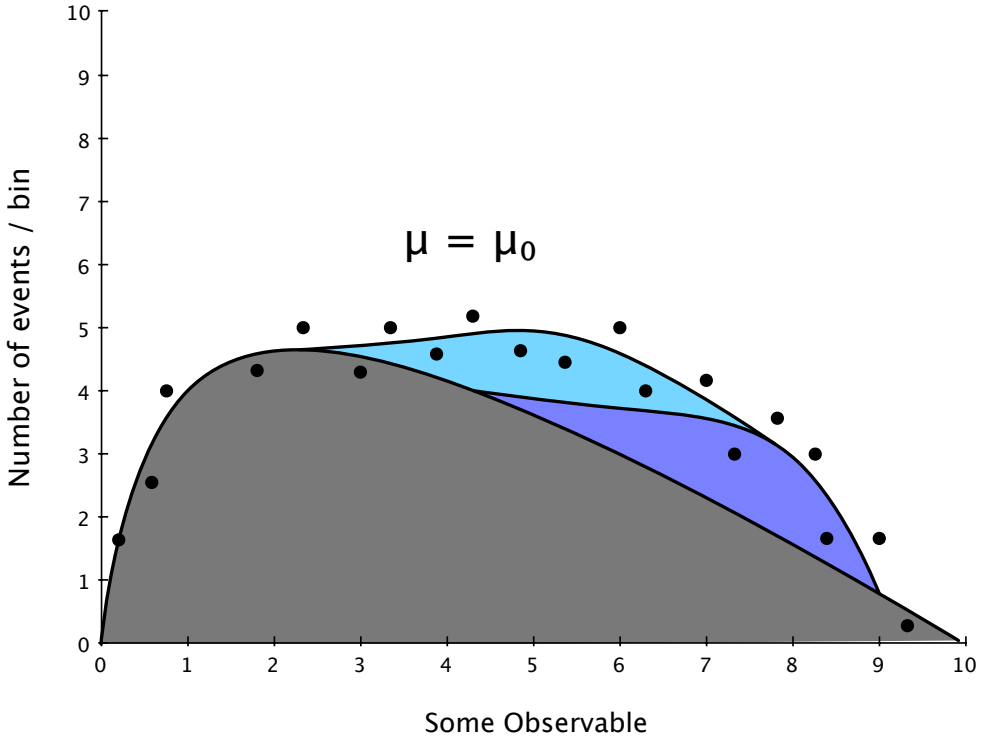

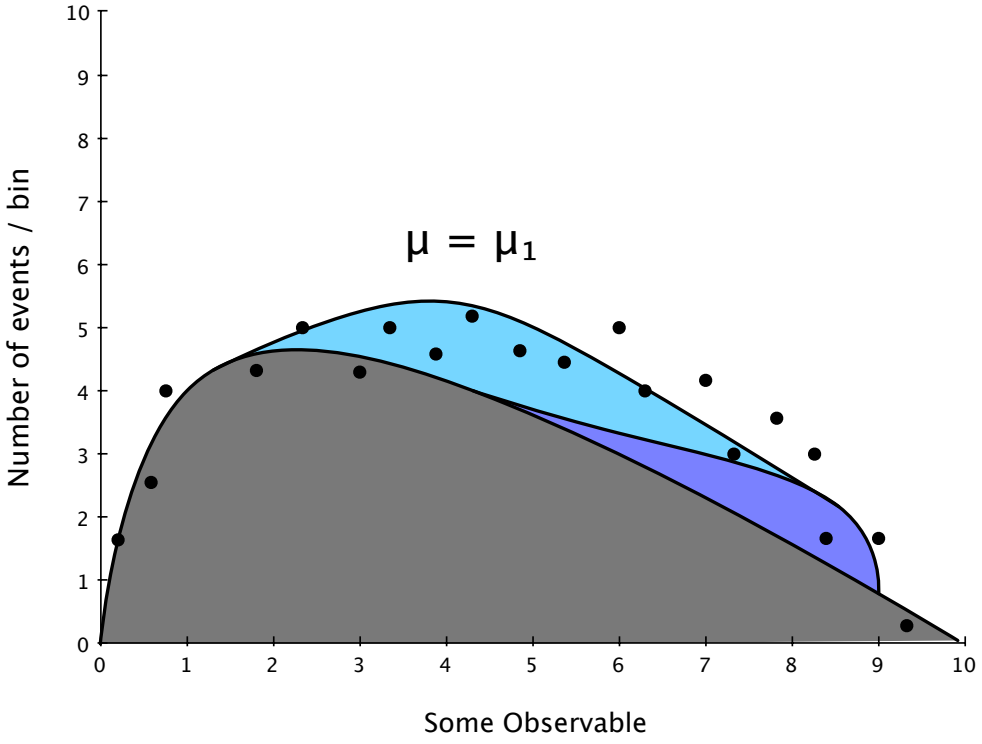

First interface with SuperBayes

Center for Cosmology and Particle Physics

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

- see consistent results!