Experience working with RooFit/RooStats "Workspaces"

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SUSY/BSM Fit Working Group
22-23 November 2010
DESY

Previous SUSY/BSM workshop

- Presentation by Kyle Cranmer: "Publishing the Likelihood function with the RooFit/RooStats Workspace"
- Excellent overview on what workspaces can do for SUSY/BSM Fits
- http://indico.desy.de/materialDisplay.py?contribId=12&sessionId=1&materialId=slides&confId=3079
- (I will give a mini review here.)
- This presentation: experience of using workspaces in (ATLAS) SUSY environment

Context

- I'm pushing forward workspace concept in ATLAS SUSY group.
- Inclusive ATLAS SUSY searches for event excess in channels:
  - N^{+} jets + missing energy + M leptons
    - Eg. 3+ or 4+ jets, 0 or 1 lepton
- Setup of analysis and performing of fit to data:
  - Fit to data control samples to estimate background level in signal region
  - Plus, simultaneously, fit to a signal region to estimate signal excess.
- Combination of search channels
  - Eg. of (most sensitive) 1-electon, 1-muon, and 0-lepton inclusive channels
- Exclusion / discovery limits in SUSY mass plane
- As member of Gfitter group, try to ensure results are easily useable when made public to outside groups

Caveats

1 This is a presentation in part about work currently ongoing in the ATLAS experiment.

- I'm only allowed to show publicly approved ATLAS results
  - Both data and Monte Carlo results
- Hence somewhat restricted in material (no latest plots ;-)

2 Decisions on workspace publication still to be taken by LHC experiments. (More about this later.)

- However, can give you flavor of how *I* think …
  - First (ATLAS) SUSY results will be published.
  - To incorporate these results in external SUSY fits.

Overview

- Why workspaces?
- RooFit/RooStats project
  - 'Workspaces'
- Experimental benefits
- Theoretical caveats
- Concerns from LHC management
- Prospects / conclusions

The situation 10 years ago...

Origins I: The First "Statistics in HEP" conference

WORKSHOP ON CONFIDENCE LIMITS

CERN, Geneva, Switzerland
17–18 January 2000 CERN 2000–005

Massimo Corradi

Does everybody agree on this statement, to publish likelihoods?

Louis Lyons

Any disagreement? Carried unanimously. That's actually quite an achievement for this Workshop.

...[Fred James wants to be able to calculate coverage, Don Groom wants to able to calculate goodness of fit]...

Cousins

I thought the point of unanimity was that publishing the likelihood function was a *necessary* condition, not a sufficient condition.

But a practical problem remained: *How* to communicate multi-D likelihood?

http://indico.cern.ch/conferenceDisplay.py?confId=100458

RooFit / RooStats

- RooFit is …
  - Modeling language in ROOT to describe probability models of arbitrary complexity
  - Used extensively in HEP since 10 years (origin BaBar experiment)
  - O(100)-O(1000) publications based on RooFit

- RooStats is …
  - Set of statistics tools in ROOT, based on the RooFit modeling language.
  - Primarily tools for limit setting
    - ➢ RooStats has at least one implementation of the major Frequentist, Bayesian, Hybrid, Likelihood-based techniques
  - Used by more-and-more people in LHC experiments
  - https://twiki.cern.ch/twiki/bin/view/RooStats/WebHome

Workspaces

- The RooFit/RooStats workspace:
  - "allows one to capture the entire probability model – both the likelihood function and the ability to generate toy data."

- "Future of digital publishing" – K. Cranmer

Practically a workspace means:

- One file contains complete experimental analysis: both dataset and full physics model used to fit data
- Given this root file:
  - You can refit the data
  - Redo entire (published) physics analysis

What goes in a Workspace

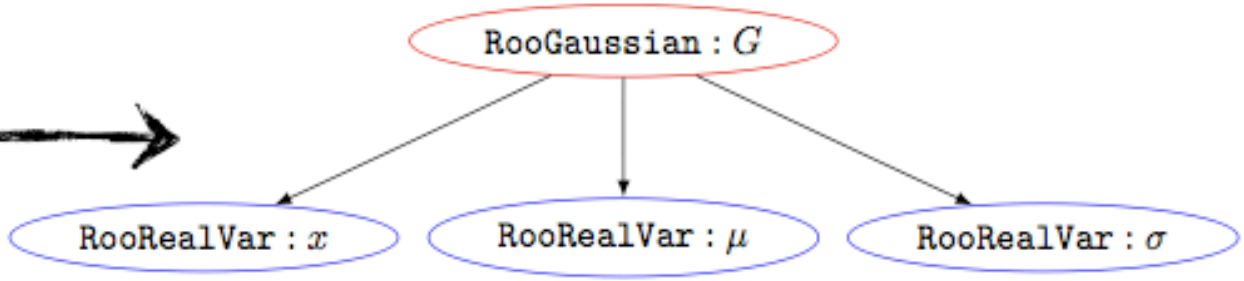
Center for Cosmology and Particle Physics

The workspace stores the full probability model and any data necessary to evaluate the likelihood function

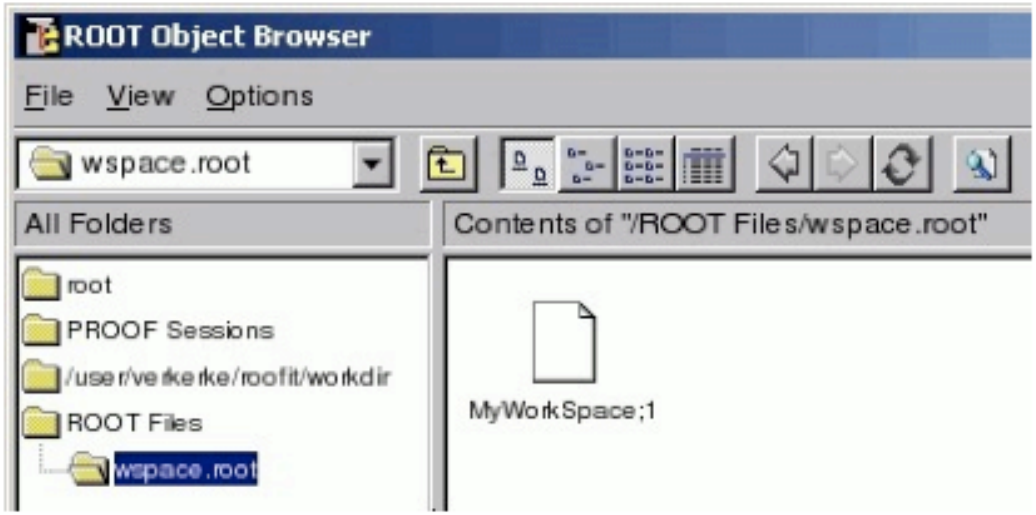
- it is the code necessary to evaluate the likelihood function at an arbitrary point in the parameter space. It is not a big table of likelihood values!
- we are using the same ROOT technology that the LHC experiments are using to save their data
  - well supported, and supports "schema evolution" / backwards compatibility
- the probability model also allows you to generate toy data for any given parameter point
  - necessary for frequentist methods, goodness of fit, coverage)
- PDFs and functions can be extended by the user (source stored in workspace)

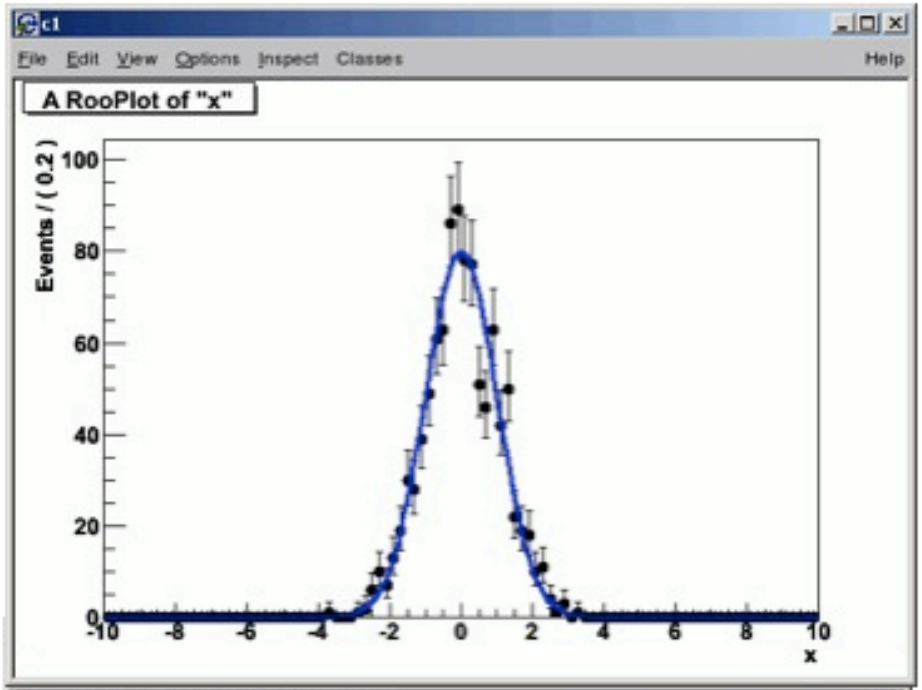
I will show some visualization of real-life LHC probability models. Let's start with a simple example:

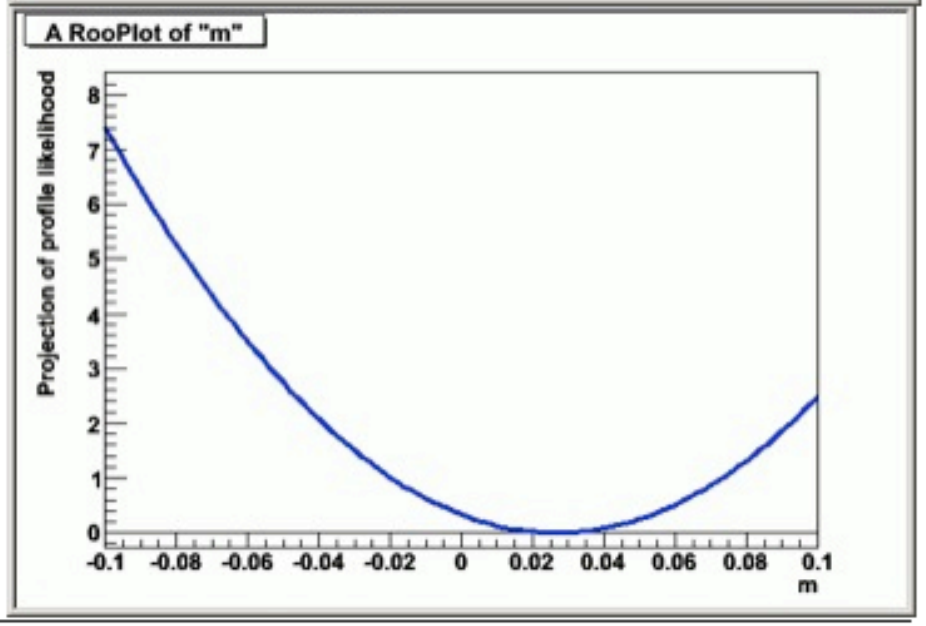
$G(x|\mu,\sigma)$ ⟶



The RooFit/RooStats workspace







RooStat's Workspace can save in a file the full likelihood model and the minimal data necessary to reproduce likelihood function.

The technology is generic, we decide how to parametrize the model.

Being used by ATLAS/CMS Higgs group for very complicated models

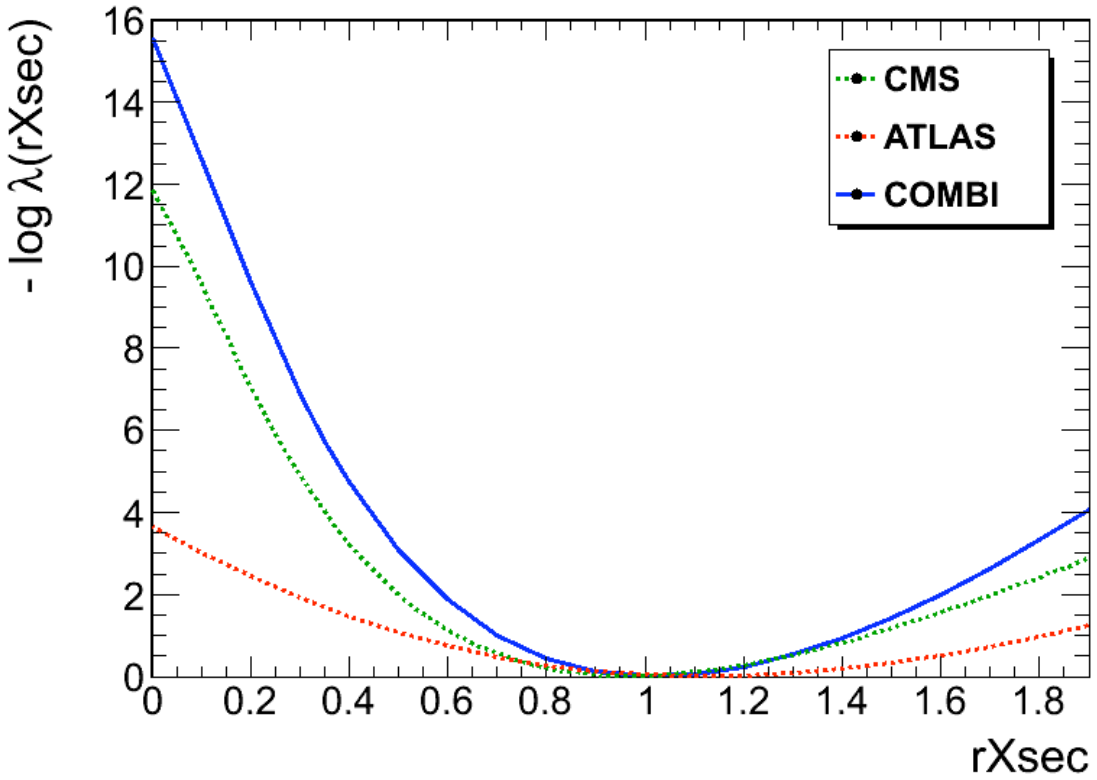
Need this for combinations, exciting potential for publishing results.

Experimental advantages

- Access to *full* physics model and dataset
  - If model has nuisance parameters for systematics, these are included
  - (Non-linear) correlations between model parameters / systematics
  - Proper asymmetrical errors
  - Full likelihood of each measurement. Can do refit to the data.
  - Allows one to do goodness-of-fit and coverage tests
- Ideal tool for making combinations of measurements.
- Very easy to combine different experiments
  - Correlated parameters between different measurements (eg. Higgs mass) or systematics (eg. Luminosity, theory)
- … or to combine different analyses within experiments
  - Easy to define common parameters (eg. cross-section) or systematics (jet energy scale, b-tagging, x-section uncertainty)
- (Examples follow)

Higgs Combination Example

- Successful ATLAS/CMS Higgs toy combination example, based on workspace technology
  - Performed back in July by ATLAS and CMS Higgs & statistics group
  - http://indico.cern.ch/conferenceDisplay.py?confId=100458



SUSY Combination Example

Workspace for 0 lepton channel

Individual constraints on x-sec, lumi, JES

Workspace for 1 muon channel

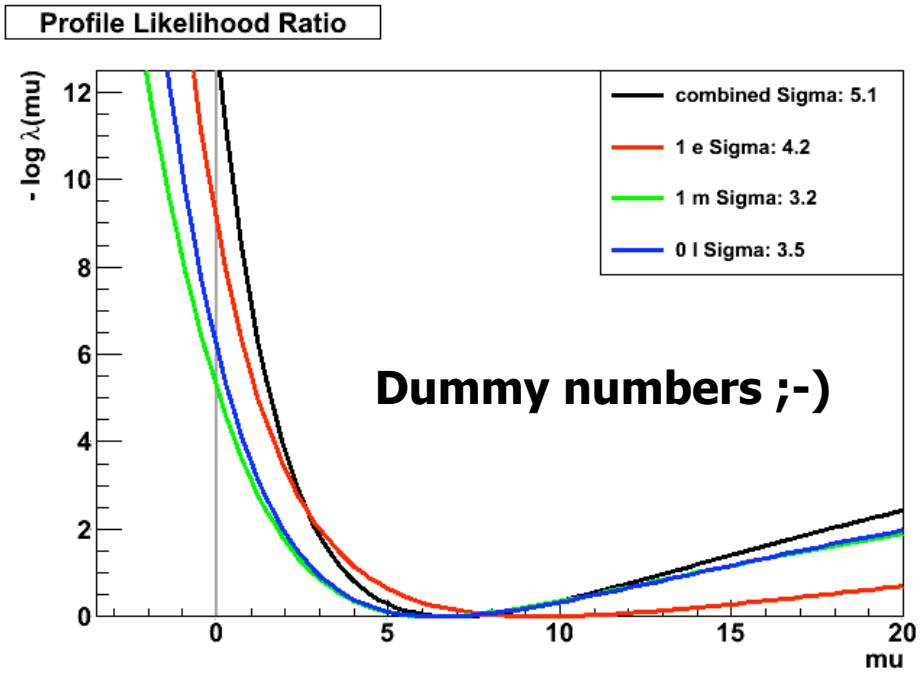
Individual constraints on x-sec, lumi, JES

Workspace for 1 electron channel

Individual constraints on x-sec, lumi, JES

- Identify common model parameters (x-section uncertainty, JES, lumi, etc) between channels

- Remove and replace common/ correlated constraints in final pdf
  - Eg. don't apply luminosity constraint twice

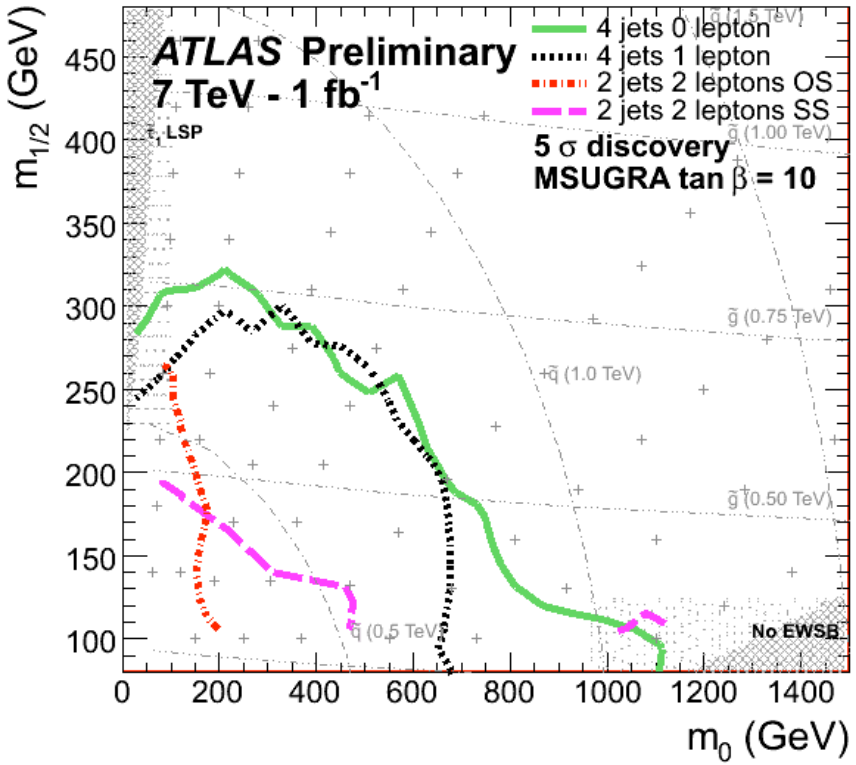


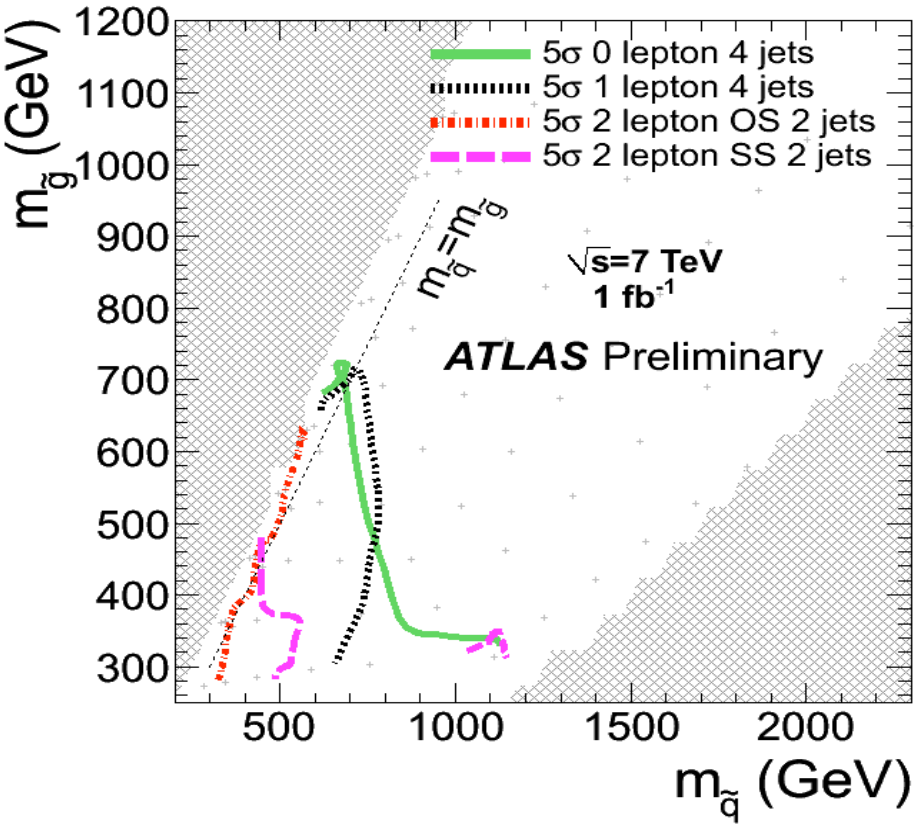
Create final pdf in combined workspace, before passing on to RooStats

(Possibly!) Published workspaces …

(If workspaces are published …)

- Every *model* tested by ATLAS to be published as a separate file.
- Each grid mass-point is a workspace in this file.
  - Note: every mass point is separate physics analysis.
    - ➢ Has different selection, distribution, x-section, efficiency, etc.
  - Interpolation between grip points to be provided.





Theoretical caveats

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Remarks on use in fitter groups

- Published workspace gives a lot of analysis information, but workspace alone not is not sufficient.

For example: Published Higgs limits

- Extensive statistical coverage tests normally done by experiments is missing from published log likelihood ratio.
- Experiments also publish confidence levels! In this case, it is unclear how to combine them with the indirect constraints.
- For example: Use of published log likelihood ratio directly in fit may well give undercoverage or overcoverage.
  - Eg. LLR known to provide overcoverage in case of low background expectation.

- Good news is: full information to do this coverage study available from workspace

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For example: New physics searches

- Published searches are performed for specific models.
  - Eg. mSUGRA
- Reinterpretation of published data in terms of different NP model needs detector reconstruction information for that model.
  - Obviously missing from publication

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- Published workspace gives a lot of analysis information, but workspace alone not is not sufficient.

For example: New physics searches

Instead, need model-independent publication (ongoing discussion!):

- Publication of signal excess in terms of "detector-unfolded" fiducial cross-section (ie. corrected for reconstruction effects)
- Or: Experiments publish in terms of simplified physics models. Theorists map their NP model onto (set of) simplified models.
  - See recent LPCC workshop for many detials: http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=107769

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- (Option where theorists obtain reconstruction efficiency from standalone detector simulation (PGS/Delphes) is strongly disfavored by experiments.)

LHC management decisions …

- ATLAS managements (and CMS?) has not yet taken a decision on whether to publish workspaces or not.
- In particular: publication of full dataset in workspace is a contentious issue.
- … Allowing for external re-analysis and publication on full dataset
  - For example: external search for peaks in di-photon mass spectrum
- No problem foreseen for first SUSY publications
  - In ATLAS, simple "cut and count analyses" with binned datasets
- Decision most likely will come soon though, before Moriond
- Decision taken per experiment

Alternatives to full published dataset

Wild(!) alternatives for publication of full dataset:

- Reduced dataset: binned dataset instead of fully unbinned dataset.
  - Already the case for first SUSY publications ("cut and count analyses")
- Encrypted unbinned dataset, still with access to full likelihood
- No dataset, with a parametrized log-likelihood curve as function of model parameters of interest.
  (Here you loose the ability to refit the data.)
- Discussion ongoing. However, confident that good compromise will be found in time.

Personal conclusion

- Workspaces are proven, great tool for combination of different analyses and different experiments.
  - Already much used in ATLAS and CMS experiments
  - Rapidly becoming the standard
- Will certainly be used for combination between experiments
- Will (imo) most likely be used for first publication of SUSY limits.
  - Analyses done with simple binned datasets. No problem foreseen.
- Discussion ongoing on how to deal with publication of (unbinned) datasets.
  - Confident a reasonable solution will be found.

Personal conclusion

- Though necessary tool, workspace is not sufficient.
  - Statistical interpretation is missing, though reproducable.
  - A published analysis (= workspace) remains model-dependent.
  - For reinterpretation of data, need NP model-dependent information (reconstruction efficiency) not provided by experiment.

- Studies ongoing on model-independent publication: simplified models & detector unfolding
  - Simplified models are easier and seem current favorite.
  - See recent LPCC workshop for details:
    - http://indico.cern.ch/conferenceOtherViews.py?view=standard&confId=107769

To do list

- Soon to initiate (dummy) combination of SUSY results between ATLAS and CMS.
  - Ala ATLAS CMS Higgs combination
- (If workspaces are used there, and they probably will be, I see no reason why not to publish them.)

- (Kyle and) I will send around a dummy workspace with workspaces of squark/gluino (or m0/m12) mass plane.
- Plus instructions on how to use them in fitter programs.