# RooFit in ATLAS Top group

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Introduction

- ATLAS top group has diverse physics programme
  - High stat. SM properties measurements
    - Top mass measurements
    - Inclusive/differential ttbar cross-section
    - Yukawa coupling
    - Charge asymmetry
    - ....
  - Low stat. SM measurements
    - T(tbar)+X (X=Z,W,ttbar, ...) cross-sections
  - Searches
    - FCNC searches with top quarks
- Many analyses require "fitting"
 - I.e. parameter extraction from data
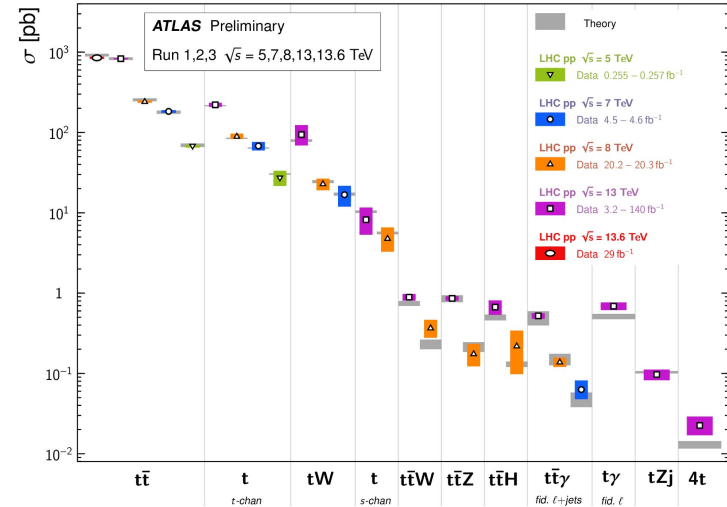
Different statistical approaches in the top group

- Most common approach: binned-likelihoods
  - One notable exception - top mass measurements (unbinned-likelihood)
- **Unfolding**
  - **IBU** commonly used for inclusive ttbar(+jets)
    - RooUnfold implementation
  - **FBU (Fully Bayesian Unfolding)** used in a handful of measurements
    - Does not use ROOT
  - **Profile-likelihood unfolding**
    - RooFit/HistFactory-like implementation
- **Non-unfolding measurements**
  - Profile-likelihood fits - HistFactory-like
    - Pure HistFactory
    - HistFactory with "extensions" - more details in the next slides
  - Pseudo-experiment approaches
   - Often custom code

TRExFitter

Top 10 statistical tools listed in phase-0 Glance entries

- Most commonly used tool for binned profile-likelihood fits
- A convenient tool to run HistFactory-like fits
- The tool:
  - Human readable text config (custom, yaml-like format)
    - No code needs to be written
  - Can read ntuples (very inefficient, uses ttree->Draw) or ROOT histograms
  - Can produce plots for the inputs - +- 1 sigma variations
  - Can produce the WS (HistoFactory-like)
  - Can run the fit (minimisation)
  - Can produce pre/post-fit plots (including variables/regions not used in the fit)
  - Can run significance/limit estimate (using xRooFit)
  - Can produce systematic breakdown
    - "Ranking" of each NP
    - "Grouped impact" for a set of NPs
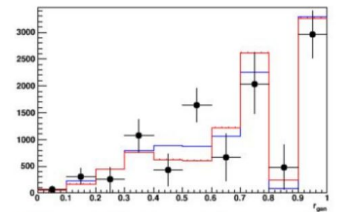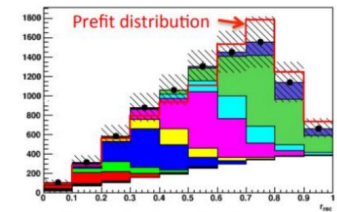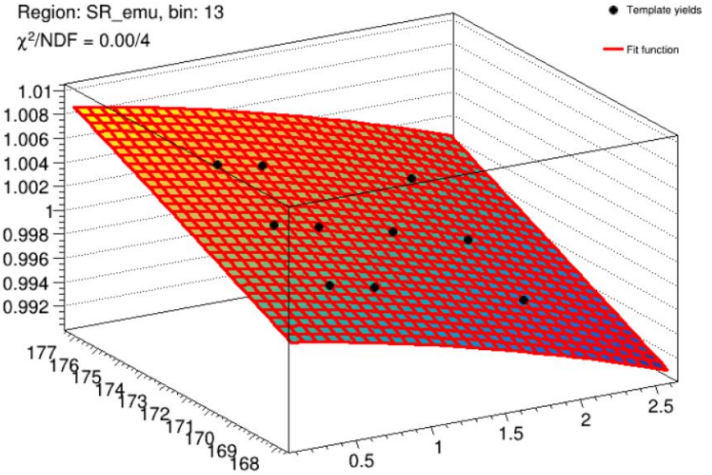 - Can produce "likelihood scan" (including 2D scan)
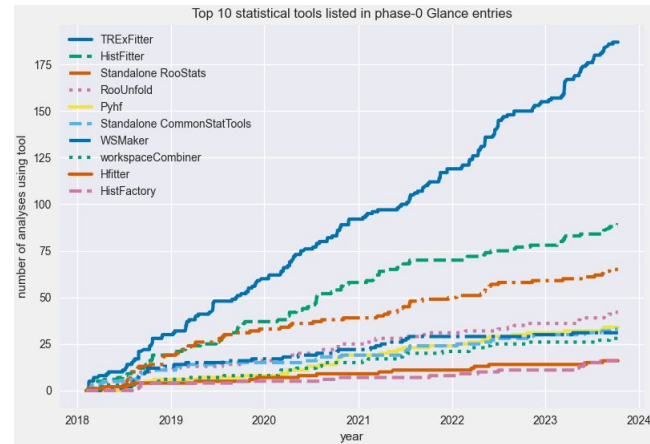
TRExFitter as HistFactory wrapper

- **Preprocessing of histograms**
  - Smoothing (reduce MC stat impact)
  - Pruning (remove noise, speed up)
  - Symmetrisation
  - ...
- Pass histograms to HistFactory to **build the model/WS**
- In some setups: heavily leveraged "**AddPreprocessFunction()**"
  - Allows huge flexibility
    - Fit charge asymmetry instead of cross-section
    - Template fits (e.g. top quark mass, CP-odd Higgs, ...)
    - EFT limit extraction!
  - Really changed the fit from "cross-section" to "almost any parameter that you can get from the cross-section"
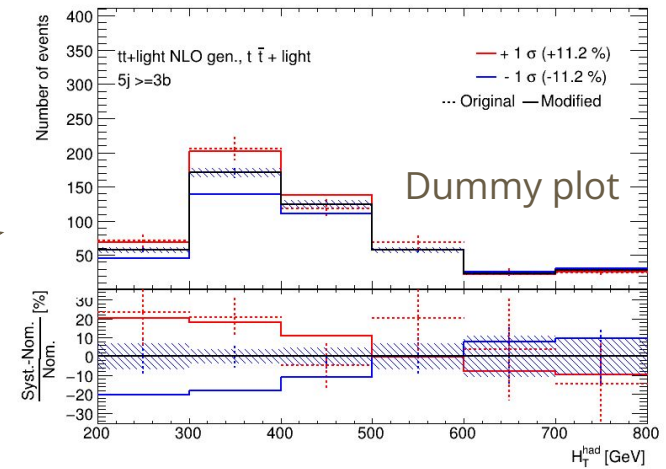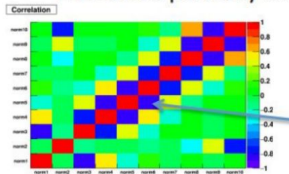
TRExFitter as not only HistFactory wrapper

- Sometimes the HistFactory model is too limiting
  - **Reparametrisation of ShapeFactors** is needed
    - Template parametrisation per bin
    - Replace ShapeFactors with the formulae
  - **Additional likelihood terms** are needed
    - E.g. regularisation in the unfolding

Prefit distribution

Fit worked perfectly ....

But unfolded result has oscillations about the true distribution (blue) (red is the MC truth distribution)

From W. Buttinger

Strong anti-correlations to neighbour bins

- Can include **regularization** as additional *likelihood term*:
  - Entropy- based term
  - Derivative-based term : Tikhonov $e^{-\frac{1}{2}\chi^2} = e^{-\frac{1}{2}\tau^2\Sigma(x_i - x_i^{ref})^2}$

Region: SR_emu, bin: 13
$\chi^2/NDF = 0.00/4$

- Template yields
- Fit function

- Done by RooFit workspace manipulations
  - Not calling HistFactory methods

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Usage of RooStats in TRExFitter

- Using **RooStats to build the WS**
  - HistFactory methods
- Using **ModelConfig** in multiple places for metadata bookkeeping
- **Limits/significance calculation with toys** (not-asymptotics)
  - Using RooStats methods/classes for the limit estimate
    - FrequentistCalculator
    - ProfileLikelihoodTestStat
    - ToyMCSampler
    - HypoTestInverter
    - HypoTestInverterResult
  - Using xRooFit for the asymptotic estimate

Some observations

- **Reasons I have heard why people prefer/like TRExFitter**
  - Simple configuration - no code needed to make paper-quality plots/results
  - Good support if things do not work (mattermost and mailing list - fast turnaround)
    - Something to consider for ROOT (e.g. mattermost support channel)?
  - Can do many things
    - Not just results, but validation plots, pre-processing etc
  - Allows extensions - i.e. not "just" HistFactory model
    - Opportunities to use a known tool for new types of measurements
  - Relatively decent documentation (for HEP standards)
- **What people do not like about TRExFitter**
  - The code is huge (50k+ lines of c++) and often not so nice
  - Sometimes we break things, sometimes changes in ROOT break things (e.g. fit no longer converges when it converged in the previous version)
- **Relatively long turnaround time for ROOT releases**
  - Issues are often fixed fast, but releases can take many months
    - Often build our own untagged versions which is not great
- **We often get questions about statistics** and not related to TRExFitter or Roofit

Possible future improvements (RooFit)

- **Performance improvements**
  - Parallelisation, GPU support, autodiff, …
  - Often multiple fit runs that are close (e.g. limits, LH scan)
    - Possible speed up as the minima should not be far apart?
- **Minuit2/minimisation improvements?**
  - E.g. recent strategy 3 addition helped to solve a lot of numerical problems
    - More improvements possible on numerical precision?
  - Lacking documentation for the strategy descriptions (or hard to find)
- **Better support for toys?**
  - E.g. LEE estimate? More-dimensional LEE estimate?
  - Toys for postfit yield estimate per bin?
    - Using bootstrap sampling
  - Should be kept outside of RooFit e.g. in xRooFit?
- **General**
  - Often running EFT fits - non-quadratic NLL - problematic?
  - Documentation for less-common RooFit functions/methods

What can we (ATLAS) do to help?

- Would making our code (TRExFitter) **public** be helpful/useful?
- Do you need **more realistic WSs**?
  - Only problematic ones?
  - Or also "standard" WS that have no obvious issues?
- Are you interested in some **performance numbers**?
  - E.g. running time/memory consumption?

- **We are willing and happy to help!**

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