TRExFitter: A framework for binned template profile likelihood fits in ATLAS

Santu Mondal

New Vistas in Photon Physics in Heavy-Ion Collisions

Institute of Nuclear Physics Polish Academy of Sciences & AGH University of Science and Technology

20.09.2022



RESEARCH





SLEZSKÁ UNIVERZITA V OPAVĚ



Statistical Analysis in particle-collider physics: The way to extract quantitative information from collision data





In this talk:

- •
- Quick review of basic principles methods for statistical analysis in HEP
- Introduction to the TRExFitter
- Working mechanism & features of TRExFitter
- Current usage in publications
- Summary and overview



TRExFitter

- A profile likelihood fit package, powerful, configurable.
- Born with the name "TtHFitter" (in 2015), as a user-friendly interface to perform fits, extract CLs limits and produce post-fit data-vs-MC plots
- Later became more powerful, changing name to "TRExFitter"
- **TRExFitter** based on binned profile likelihood, with statistical inference based on maximum-likelihood principle, profile-likelihood-ratio test-statistics and asymptotic approximation

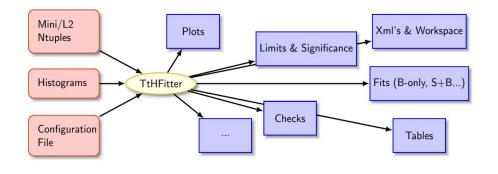


TRExFitter

• TRExFitter is a framework to create and operate statistical models



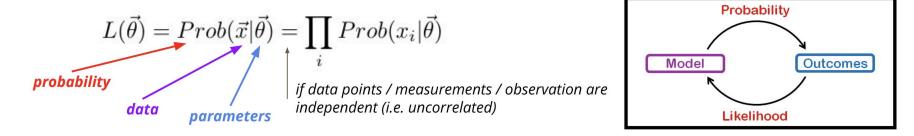
- Create RooFit workspaces, through HistFactory
- Process them through widely used RooStats macros to perform profile-likelihood fits, extract CLs limits and produce post-fit data-vs-MC plots
- Actively developed and used in many physics analyses : cross-section-fitting / signal-discovery machinery





• Likelihood:

Defined as probability of observing a certain set of data given a model / hypothesis (with certain parameter values)



Maximum Likelihood principle:

estimated value(s) of parameter(s) = value(s) maximizing the Likelihood

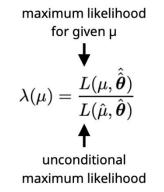
• "Fit":

parameter estimation procedure via Likelihood maximization



Profile likelihood

 In the case of a likelihood function depending on many parameters, but where one is interested in only one parameter μ and its uncertainty, one can use a *profile likelihood ratio* defined as

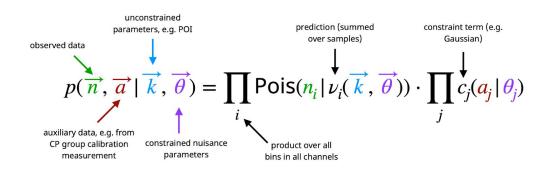


In the numerator, the parameters $\boldsymbol{\theta}$ are fitted to their MLE, $\hat{\boldsymbol{\theta}}$ for a given value of the parameter μ . In the denominator, μ is also estimated – the values $\hat{\mu}$ and $\hat{\theta}$ define the global maximum of the likelihood *L*.

• This method of profiling the likelihood is very popular for estimating uncertainties from a maximum-likelihood fit; in high energy physics it is known as the *Minos* method of the minuit program



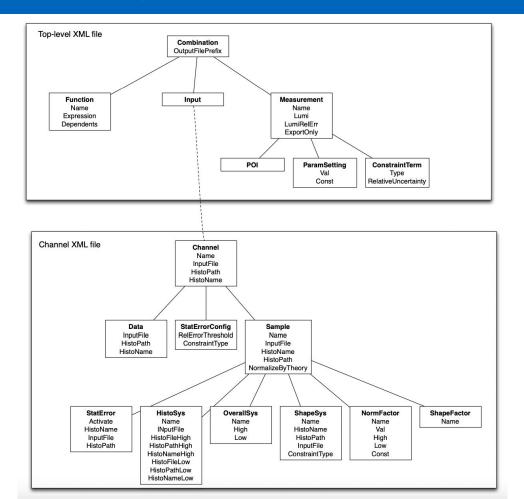
- HistFactory is the standard model used in ATLAS for binned statistical analysis
- Specifies how to construct the likelihood function from a set of building blocks
 - Channels (also called regions in TRExFitter) are regions of phase space
 - Distributions of samples (MC and data) in channels are provided by template histograms
 - Systematics act on samples and are specified via the distribution at $\pm 1\sigma$ shifts



https://pyhf.github.io/pyhf-tutorial/Int roToHiFa.html



The HistFactory model



Data Analysis in High Energy Physics, A Practical Guide to Statistical Methods -

Olaf Behnke, Kevin Kröninger, Grégory Schott, and Thomas Schörner-Sadenius

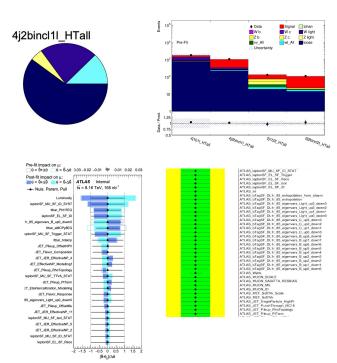


Using TRExFitter



Hang out with TRExFitter

- Declare a fit model, and provide input ntuples or histograms
- Framework provides diagnostics tools and allows to easily adjust the fit model to study the fit
- **TRExFitter** is controlled via a declarative configuration and a command line interface (CLI)
- "Steps" or "actions" in the CLI correspond to tasks executed by TRExFitter
- **TRExFitter** produces a lot output :
 - Figures: data/MC, fit model details, statistical inference results, ...
 - Tables: yields, effects of systematic
 ROOT, txt, YAML files with additional information
 - Also check for warnings and errors in the output!
 - Job settings contain methods to customize output





The configuration file

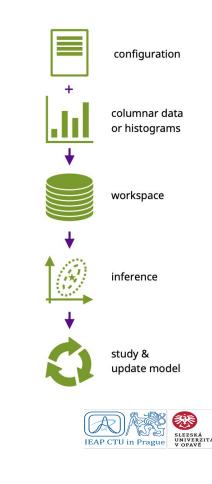
- Configuration file follows a custom plain text format
- Split into **blocks**, separated by blank lines
 - Job block: general options
 - Fit block: configuration of fit options
 - Region blocks: define distributions included in fit Exception: validation regions, but can project fit result onto them
 - Sample blocks: samples (data + MC) considered in fit
 - Systematic blocks: systematic uncertainties affecting samples

1	Job: "FitExample"
2	Label: "Fit Example"
3	CmeLabel: "13 TeV"
4	LumiLabel: "300 fb^{-1}"
5	POI: "SigXsecOverSM"
6	ReadFrom: HIST
7	HistoPath: "ExampleInputs"
8	DebugLevel: 2
9	SystControlPlots: TRUE
10	UseGammaPulls: TRUE
11	
12	Fit: "myFit"
13	FitType: SPLUSB
14	FitRegion: CRSR
15	doLHscan: SigXsecOverSM
16 17	Desire 100 41
17	Region: "SR_1" Type: CONTROL
19	HistoName: "HTj"
20	VariableTitle: "H_{T} [GeV]"
20	Label: "Signal Region 1"
22	ShortLabel: "SR 1"
23	
24	Sample: "Data"
25	Title: "Data 2015"
26	Type: data
27	HistoFile: "data"
28	
29	Sample: "Bkg1"
30	Type: BACKGROUND
31	Title: "Background"
32	FillColor: 400
33	LineColor: 1
34	HistoFile: "bkg1"
35	
36	Systematic: "JES"
37	Title: "Jet Energy Scale"
38 39	Type: HISTO
39 40	HistoNameSufUp: "_jesUp" % HistoNameSufDown: "_jesDown"
40	Samples: Bkg1,Signal
41	Smoothing: 40
43	% Symmetrisation: TwoSided
44	Symmetrisation: ONESIDED
45	Category: Instrumental

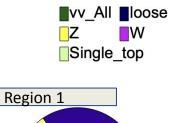
Basic workflow with TRExFitter

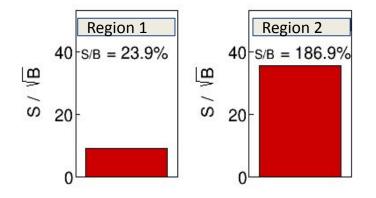
Define a fit model in a declarative configuration file:

- n/h step: TRExFitter reads input (ntuples or histograms) and produces histograms
- w step: TRExFitter constructs a HistFactory workspace from all template histograms
- **f** step: maximum likelihood fit
- **d/p** step: Pre-/post-fit data/MC visualization
- r/i Nuisance parameter ranking and impact step: TRExFitter steers statistical inference and visualizes results
- s step: discovery significance
- I step: parameter limits
- **TRExFitter** can run multiple regions at the same time.
- Modify fit model, study changes, converge on final model to be used in analysis



 PieChart and SignalRegions show background composition and fraction of signal in the regions defined







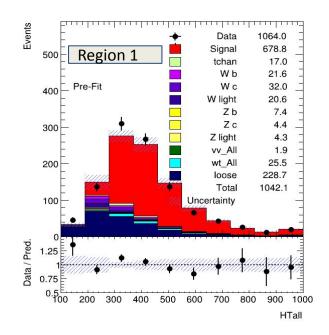
Histogram creation and first plots

• **TRExFitter** supports reading both ntuple and histogram inputs (via **n/h** steps)

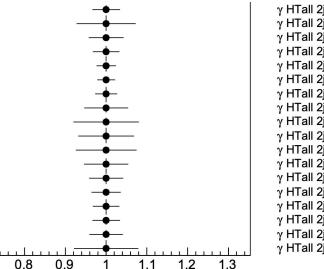
One plot like this generated per analysis region (channel)

- Total uncertainty of all sources evaluated and visualized
- Algorithms to automatically obtain suitable binning
- Especially useful for MVA output distributions
- Can of course also specify bins by hand

- Pre-fit fit model visualization via **d** step
 - provides data/MC plots and yields per region (channel), summary plots, background composition, S/B, etc.
 - Can customize appearance for publication-quality figures







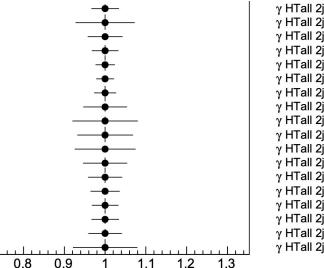
0.7

γ HTall 2j2bincl2l bin 0007 y HTall 2j2bincl2l bin 0006 γ HTall 2j2bincl2l bin 0005 y HTall 2j2bincl2l bin 0004 γ HTall 2j2bincl2l bin 0003 γ HTall 2j2bincl2l bin 0002 y HTall 2j2bincl2l bin 0001 γ HTall 2j2bincl2l bin 0000 γ HTall 2j1b2l bin 0009 γ HTall 2j1b2l bin 0008 γ HTall 2j1b2l bin 0007 γ HTall 2j1b2l bin 0006 γ HTall 2j1b2l bin 0005 γ HTall 2j1b2l bin 0004 γ HTall 2j1b2l bin 0003 γ HTall 2j1b2l bin 0002 γ HTall 2j1b2l bin 0001 γ HTall 2j1b2l bin 0000

Statistical uncertainty in prediction:

- Model uncertainties due to the finite number of events in simulation are described by dedicated nuisance parameters called gammas
- **TRExFitter** automatically creates these parameters for you.





0.7

γ HTall 2j2bincl2l bin 0007 γ HTall 2j2bincl2l bin 0006 γ HTall 2j2bincl2l bin 0005 γ HTall 2j2bincl2l bin 0004 γ HTall 2j2bincl2l bin 0003 γ HTall 2j2bincl2l bin 0002 y HTall 2j2bincl2l bin 0001 γ HTall 2j2bincl2l bin 0000 γ HTall 2j1b2l bin 0009 γ HTall 2j1b2l bin 0008 γ HTall 2j1b2l bin 0007 γ HTall 2j1b2l bin 0006 γ HTall 2j1b2l bin 0005 γ HTall 2j1b2l bin 0004 γ HTall 2j1b2l bin 0003 γ HTall 2j1b2l bin 0002 γ HTall 2j1b2l bin 0001 γ HTall 2j1b2l bin 0000

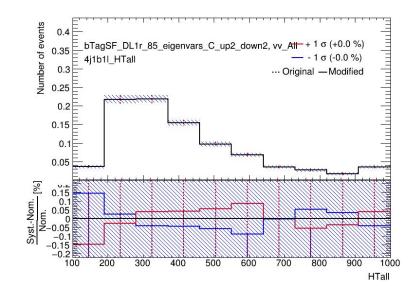
Asimov dataset:

- Dataset for which the maximum likelihood estimate of all parameters matches their "true" value - Can be built without reference to data
- No pulls when fitting this dataset
- Useful for studying expected performance (uncertainties, significance, limits, ...)

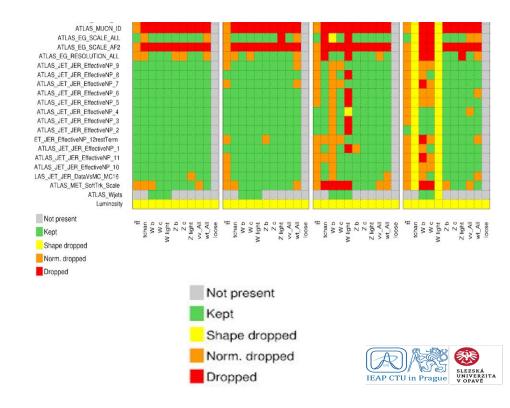


Investigating systematics templates

- **TRExFitter** visualize the effect of all systematic variations
 - Per Region (channel), per sample, per variation
 - Important to validate the physics
- Study these plots to ensure fit inputs are robust
 Strange behavior frequently caused by template issues
- Each (independent) source of systematic uncertainty included in the likelihood as constrained NP:
 - Affecting S+B prediction in a coherent way
 - Effect interpolated and extrapolated from 3 discrete values (0 = nominal, 1 = "up" var., -1 = "down" var.) to range of continuous values

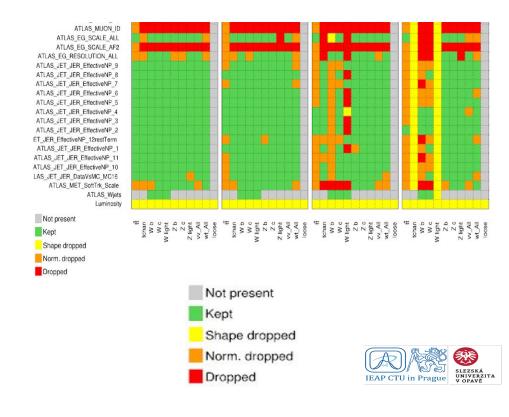






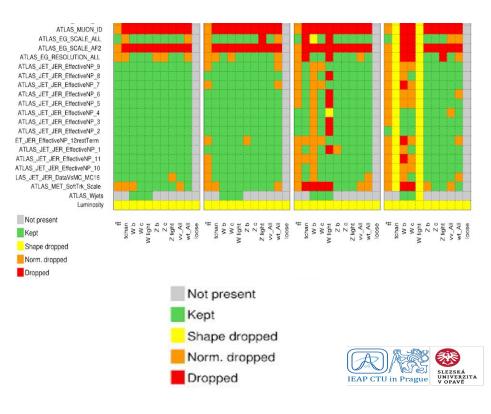
Workspace production and pruning

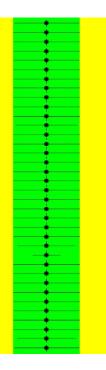
- Pruning at this step removes negligible effects from systematic variations
 - Control the threshold via
 SystPruningNorm
 SystPruningShape



Workspace production and pruning

- Pruning at this step removes negligible effects from systematic variations
 - Control the threshold via
 SystPruningNorm
 SystPruningShape
- Study the effect of the pruning you apply!





ATLAS_leptonSF_MU_SF_ID_STAT ATLAS leptonSF EL SF Trigger ATLAS leptonSF EL SF Reco ATLAS leptonSF EL SF Isol ATLAS_leptonSF_EL_SF_ID ATLAS ivt ATLAS bTagSF DL1r 85 extrapolation from charm ATLAS bTagSF DL1r 85 extrapolation ATLAS_bTagSF_DL1r_85_eigenvars_Light_up3_down3 ATLAS bTagSF DL1r 85 eigenvars Light up2 down2 ATLAS_bTagSF_DL1r_85_eigenvars_Light_up1_down1 ATLAS bTagSF DL1r 85 eigenvars Light up0 down0 ATLAS_bTagSF_DL1r_85_eigenvars_C_up3_down3 ATLAS bTagSF DL1r 85 eigenvars C up2 down2 ATLAS bTagSF DL1r 85 eigenvars C up1 down1 ATLAS bTagSF DL1r 85 eigenvars C up0 down0 ATLAS bTagSF_DL1r_85_eigenvars B_up8_down8 ATLAS_bTagSF_DL1r_85_eigenvars_B_up7_down7 ATLAS bTagSF DL1r 85 eigenvars B up6 down6 ATLAS bTagSF DL1r 85 eigenvars B up5 down5 ATLAS bTagSF DL1r 85 eigenvars B up4 down4 ATLAS bTagSF DL1r 85 eigenvars B up3 down3 ATLAS bTagSF DL1r 85 eigenvars B up2 down2 ATLAS bTagSF DL1r 85 eigenvars B up1 down1 ATLAS bTagSF_DL1r_85 eigenvars B up0 down0 ATLAS Wjets ATLAS MUON SCALE ATLAS MUON SAGITTA RESBIAS ATLAS MUON MS ATLAS MUON ID ATLAS MET SoftTrk Scale ATLAS_MET_SoftTrk ATLAS JET SingleParticle HighPt ATLAS JET PunchThrough MC16 ATLAS JET Pileup RhoTopology ATLAS JET Pileup PtTerm

Useful to monitor NP pulls and constraints:



ATLAS leptonSF MU SF ID STAT ATLAS leptonSF EL SF Trigger ATLAS leptonSF EL SF Reco ATLAS leptonSF EL SF Isol ATLAS_leptonSF_EL_SF_ID ATLAS ivt ATLAS bTagSF DL1r 85 extrapolation from charm ATLAS bTagSF DL1r 85 extrapolation ATLAS bTagSF DL1r 85 eigenvars Light up2 down2 ATLAS_bTagSF_DL1r_85_eigenvars_Light_up1_down1 ATLAS_bTagSF_DL1r_85_eigenvars_C_up3_down3 ATLAS bTagSF DL1r 85 eigenvars C up2 down2 ATLAS bTagSF DL1r 85 eigenvars C up1 down1 ATLAS bTagSF DL1r 85 eigenvars C up0 down0 ATLAS bTagSF DL1r 85 eigenvars B up8 down8 ATLAS_bTagSF_DL1r_85_eigenvars_B_up7_down7 ATLAS bTagSF DL1r 85 eigenvars B up6 down6 ATLAS bTagSF DL1r 85 eigenvars B up5 down5 ATLAS bTagSF DL1r 85 eigenvars B up4 down4 ATLAS bTagSF DL1r 85 eigenvars B up3 down3 ATLAS bTagSF DL1r 85 eigenvars B up2 down2 ATLAS_bTagSF_DL1r_85_eigenvars_B_up1_down1 ATLAS bTagSF DL1r 85 eigenvars B up0 down0 ATLAS Wjets ATLAS MUON SCALE ATLAS MUON SAGITTA RESBIAS ATLAS MUON MS ATLAS MUON ID ATLAS MET SoftTrk Scale ATLAS_MET_SoftTrk ATLAS JET SingleParticle HighPt ATLAS JET PunchThrough MC16 ATLAS JET_Pileup_RhoTopology ATLAS JET Pileup PtTerm

- ATLAS_bTagSF_DL1r_85_eigenvars_Light_up3_down3 ATLAS_bTagSF_DL1r_85_eigenvars_Light_up0_down0
 - Useful to monitor NP pulls and constraints
 - They are "nuisance", but they can be important!

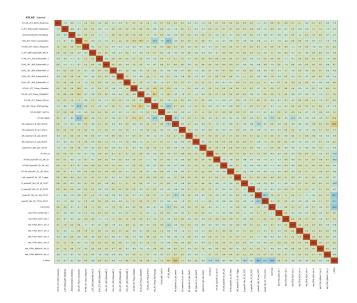


Correlations

ATLAS Internal																																									
LAS_JET_BJES_Response	100.0	-1.3	-0.8	-1.1	1.2	0.0	-0.2	0.2	-0.1	-0.5	0.1	0.5	1.8	1.2	-1.5	0.1	5.2	0.3	0.4	-0.2	-0.7	-1.8	0.2	0.7	0.4	0.4	0.0	0.9	0.2	-1.1	-0.1	0.9	0.1	-0.0	0.1	0.1	-0.2	0.1	0.7	-0.9	-7.5
ET_EffectiveNP_Modelling1	-1.3	100.0	-3.8	-8.1	6.0	0.5	-0.9	-1.4	0.3	0.6	0.2	3.3	8.9	2.3	-9.5	0.8	-4.7	-1.2	0.5	0.1	-0.4	-0.7	0.3	0.1	0.1	0.1	-0.0	0.5	-0.0	-4.6	-1.0	-0.0	-0.2	-0.7	1.0	-0.3	-0.3	1.7	1.4	.1.3	-3.7
taintercalibration_Modelling	-0.8	-3.8	100.0	-6.6	4.8	0.3	-1.1	-1.1	0.5	0.8	0.6	2.6	6.9	1.3	-7.5	0.9	-8.0	-2.0	0.2	0.2	-0.3	0.3	0.1	-0.2	-0.1	-0.1	-0.0	-0.3	0.0	-1.9	-0.8	-0.7	-0.5	-0.4	0.3	-1.4	0.5	1.8	0.9	-0.7	-2.7
S_JET_Playor_Composition	-1.1	-8.1	-6.6	100.0	11.5	-0.3	-2.7	-3.7	3.1	4.4	1.5	12.6	19.6	1.7	-22.3	-1.9	-34.3	-3.0	0.5	0.2	1.0	3.8	-0.4	-1,4	-0.7	-0.8	-0.1	-2.0	-0.6	-2.8	-1.4	-2.1	-1.8	-4.2	0.6	0.9	-0.5	-6.7	1.7	-1.6	-3.2
LAS_JET_Flavor_Response	1.2	6.0	4.8	11.5	100.0	-0.4	1.3	1.4	-0.7	-0.4	-1.2	-3.4	-9.7	-3.2	9.8	-0.5	14.2	5.3	0.4	-0.8	0.5	-0.3	-0.1	0.1	-0.0	0.0	0.1	-0.1	0.5	8.1	1.5	0.8	1.0	-0.0	-1.1	1.9	0.9	-1.0	-2.0	1.0	3.4
ET_JER_DataVsMC_MC16	0.0	0.5	0.3	-0.3	-0.4	100.0	3.3	4.6	-3.5	-4.2	2.0	-0.1	-2.5	1.0	3.7	0.4	-4.9	-4.0	-0.4	0.6	-0.6	-2.3	-0.2	-0.1	-0.0	-0.0	-0.1	0.0	0.3	1.4	-0.2	1.1	-0.6	-0.0	-3.1	0.1	-3.2	0.5	0.2	-0.4	-5.5
AS_JET_JER_EffectiveNP_1	-0.2	-0.9	-1.1	-2.7	1.3	3.3	100.0	-5.2	5.0	5.6	0.6	0.4	2.5	-0.4	-3.0	0.4	1.5	4.1	1.0	-0.7	0.8	2.6	-0.0	0.9	0.3	0.3	0.1	0.3	-0.2	-1.3	0.0	0.2	0.5	-1.1	-0.1	0.6	5.8	0.3	0.5	-1.0	3.9
S_JET_JER_EffectiveNP_2	0.2	-1,4	-1.1	-3.7	1.4	4.6	-5.2	100.0	5.3	6.4	-0.9	1.3	5.2	-1.3	-6.7	0.6	0.7	4.0	0.6	-0.5	1,4	3.4	0.0	0.3	-0.0	-0.0	0.1	-0.5	-0.2	-0.8	-0.0	-1.0	0.3	-1.3	2.8	-0.3	5.3	0.5	-0.1	-0.8	5.7
S_JET_JER_EffectiveNP_3	-0.1	0.3	0.5	3.1	-0.7	-3.5	5.0	5.3	100.0	-6.4	1.2	-0.8	-3.5	1.6	5.0	-0.1	-0.9	-4.3	-0.7	0.6	-1.3	-3.6	0.1	-0.4	-0.1	-0.0	-0.1	0.3	0.0	-0.8	-0.4	1.0	-0.1	1.1	-1.8	0.3	-4.5	0.2	0.1	-0.2	-4.5
S_JET_JER_EffectiveNP_4	-0.5	0.6	0.8	4.4	-0.4	-4.2	5.6	6.4	-6.4	100.0	1.5	-1.5	-4.9	2.2	7.1	-0.3	2.7	-5.6	-0.8	0.8	-1.9	-5.3	0.1	0.5	0.4	0.4	-0.1	1.1	0.2	-2.0	-0.5	1.9	-0.3	2.0	-2.4	-0.1	-5.7	0.0	0.6	-0.5	-7.4
IS_JET_JER_EffectiveNP_6	0.1	0.2	0.6	1.5	-1.2	2.0	0.6	-0.9	1.2	1.5	100.0	1.4	1.8	-1.9	-3.8	-1.2	3.7	5.3	1.0	-0.7	1.3	3.1	0.1	-0.3	-0.1	-0.1	-0.0	0.1	0.2	2.2	1.1	-2.2	0.7	1.4	-0.0	2.2	0.6	-0.1	-0.4	-0.2	4.4
TLAS_JET_Pileup_OffsetMu	0.5	3.3	2.6	12.6	-3.4	-0.1	0.4	1.3	-0.8	-1.5	1.4	100.0	-8.9	0.2	10.9	2.3	15.3	-2.2	-1.1	0.5	-0.8	-2.7	0.2	1.0	0.5	0.5	0.0	1.0	0.2	-0.7	0.1	2.0	0.7	0.9	1.4	-2.0	-1.0	5.3	-0.3	0.9	1.5
AS_JET_Pleup_OffsetNPV	1.8	8.9	6.9	19.6	-9.7	-2.5	2.5	5.2	-3.5	-4.9	1.8	-8.9	100.0	-0.4	25.1	-1.3	14.7	-3.3	-1.8	0.7	-1.4	-4.0	0.0	0.7	0.3	0.4	0.0	0.8	-0.2	-0.1	0.0	3.0	1.3	3.0	-2.8	-0.7	-0.2	-3.1	-1.3	1.7	7.8
ATLAS_JET_Pleup_PfTerm	1.2	2.3	1.3	1.7	-3.2	1.0	-0.4	-1.3	1.6	2.2	-1.9	0.2	-0.4	100.0	-1.5	0.2	-7.8	4.4	0.5	-0.6	2.1	5.2	-0.5	-1.1	-0.6	-0.7	-0.0	-1.5	0.1	6.9	1.5	-2.6	-0.7	-0.1	-0.4	0.9	0.8	1.4	-1.5	0.7	0.9
IET_Pileup_RhoTopology	-1.5	-9.5	-7.5	-22.3	9.8	3.7	-3.0	-6.7	5.0	7.1	-3.8	10.9	25.1	-1.5	100.0	1.2	-20.3	6.7	2.4	-1.2	2.7	7.8	-0.2	-1.5	-0.7	-0.8	-0.0	-1.7	0.2	3.1	0.7	-5.1	-1,4	-3.4	3.2	2.4	0.3	4.1	8.0	-1.5	-7.2
ATLAS_MET_SoftTrk	0.1	0.8	0.9	-1.9	-0.5	0.4	0.4	0.6	-0.1	-0.3	-1.2	2.3	-1.3	0.2	1.2	100.0	-0.6	0.8	-0.2	-0.1	0.1	1.1	0.0	0.1	-0.0	0.0	-0.0	0.1	-0.3	-1.7	-0.1	-0.4	0.0	1.0	-0.0	1.4	-0.7	-7.3	-0.0	-0.2	1.2
ATLAS_Wjots	5.2	-4.7	-8.0	-34.3	14.2	-4.9	1.5	0.7	-0.9	2.7	3.7	15.3	14.7	-7.8	-20.3	-0.6	100.0	-19.2	-7.3	3.3	0.1	9.6	-3.3	-0.1	-0.3	-0.4	-2.4	0.6	-0.3	2.7	-0.5	-15.7	5.9	-0.3	-12.2	-5.0	-5.5	-0.5	-3.9	5.7	16.4
eigerwars_B_up0_down0	0.3	-1.2	-2.0	-3.0	5.3	-4.0	4.1	4.0	-4.3	-5.6	5.3	-2.2	-3.3	4.4	6.7	0.8	-19.2	109.0	-6.3	4.7	-4.2	-6.9	0.1	-1.6	-0.7	-0.8	-0.1	-3.3	-0.8	-13.5	-8.4	0.6	-0.9	3.4	-2.9	-6.2	-4.0	-0.0	2.0	0.5	30.6
5_eigenvars_B_up1_down1	0.4	0.5	0.2	0.5	0.4	-0.4	1.0	0.6	-0.7	-0.8	1.0	-1.1	-1.8	0.5	2.4	-0.2	-7.3	-6.3	100.0	1.0	-0.6	-0.5	-0.0	-0.6	-0.3	-0.3	-0.0	-0.9	-0.3	-2.8	-1.6	-0.3	-0.3	0.8	0.4	-1.2	-1.3	-0.6	0.1	0.3	7.1
eigenvars_B_up2_down2	-0.2	0.1	0.2	0.2	-0.8	0.6	-0.7	-0.5	0.6	0.8	-0.7	0.5	0.7	-0.6	-1.2	-0.1	3.3	4.7	1.0	100.0	0.5	0.7	-0.0	0.3	0.1	0.1	0.0	0.5	0.1	2.2	1.3	0.0	0.1	-0.6	0.2	1.1	0.8	-0.0	-0.3	-0.2	-5.5
eigenvars_C_up0_down0	-0.7	-0.4	-0.3	1.0	0.5	-0.6	0.8	1.4	-1.3	-1.9	1.3	-0.8	-1.4	2.1	2.7	0.1	0.1	-4.2	-0.6	0.5	100.0	-5.0	0.4	0.8	0.4	0.5	0.0	0.8	0.1	-2.8	-1.3	1.9	0.8	0.2	-0.2	-1.2	-0.4	-0.7	0.7	-0.3	4.2
genvars_Light_up0_down0	-1.8	-0.7	0.3	3.6	-0.3	-2.3	2.6	3.4	-3.6	-5.3	3.1	-2.7	-4.0	5.2	7.8	1.1	9.6	-6.9	-0.5	0.7	-5.0	100.0	0.6	3.4	1.9	2.2	-0.0	4,4	0.8	-4.0	-1.1	6.4	2.6	-0.5	-0.5	-1.7	-0.8	-0.4	1.0	-1.1	-5.3
ATLAS_M	0.2	0.3	0.1	-0.4	-0.1	-0.2	-0.0	0.0	0.1	0.1	0.1	0.2	0.0	-0.5	-0.2	0.0	-3.3	0.1	-0.0	-0.0	0.4	0.8	100.0	-0.0	-0.0	-0.0	-0.1	0.0	0.1	1.3	0.5	-0.3	-0.3	0.0	-0.4	-0.0	0.0	0.1	-0.2	0.1	-11.8
ATLAS_leptonSF_EL_SF_ID	0.7	0.1	-0.2	-1.4	0.1	-0.1	0.9	0.3	-0.4	0.5	-0.3	1.0	0.7	-1.1	-1.5	0.1	-0.1	-1.6	-0.6	0.3	0.8	3.4	-0.0	100.0	-1.5	-1.8	0.2	-3.8	-0.7	-0.5	-1.5	-2.1	-1.3	-0.0	-0.3	-0.1	0.1	0.3	-0.0	0.7	-16.2
TLAS_leptonSF_EL_SF_lool	0.4	0.1	-0.1	-0.7	-0.0	-0.0	0.3	-0.0	-0.1	0.4	-0.1	0.5	0.3	-0.6	-0.7	-0.0	-0.3	-0.7	-0.3	0.1	0.4	1.9	-0.0	-1.5	100.0	-0.8	0.1	-1.9	-0.4	-0.3	-0.8	-1.1	-0.6	-0.0	-0.2	-0.0	0.1	0.0	-0.0	0.4	-8.4
AS_leptonSF_EL_SF_Reco	0.4	0.1	-0.1	-0.8	0.0	-0.0	0.3	-0.0	-0.0	0.4	-0.1	0.5	0.4	-0.7	-0.8	0.0	-0.4	-0.8	-0.3	0.1	0.5	2.2	-0.0	-1.8	-0.8	100.0	0.1	-2.2	-0.4	-0.4	-0.9	-1.2	-0.8	-0.0	-0.2	0.0	0.1	0.1	-0.0	0.4	-9.5
S_leptonSF_EL_SF_Trigger	0.0	-0.0	-0.0	-0.1	0.1	-0.1	0.1	0.1	-0.1	-0.1	-0.0	0.0	0.0	0.0	-0.0	-0.0	-2.4	-0.1	-0.0	0.0	0.0	-0.0	-0.1	0.2	0.1	0.1	100.0	0.4	0.1	0.6	0.4	-0.0	-0.0	0.1	-0.0	-0.1	-0.1	0.0	-0.1	-0.1	-6.7
leptonSF_MU_8F_ID_STAT	0.9	0.5	-0.3	-2.0	-0.1	0.0	0.3	-0.5	0.3	1.1	0.1	1.0	0.8	-1.5	-1.7	0.1	0.6	-3.3	-0.9	0.5	0.8	4.4	0.0	-3.8	-1.9	-2.2	0.4	100.0	-1.1	-2.9	-3.5	-2.6	-1.7	-0.2	-0.5	0.1	0.1	0.4	0.2	1.2	-19.8
eptonSF_MU_SF_ID_SYST	0.2	-0.0	0.0	-0.6	0.5	0.3	-0.2	-0.2	0.0	0.2	0.2	0.2	-0.2	0.1	0.2	-0.3	-0.3	-0.8	-0.3	0.1	0.1	0.8	0.1	-0.7	-0.4	-0.4	0.1	-1.1	100.0	-5.6	-1.6	-0.4	-0.3	-0.0	0.1	0.3	0.1	-0.7	0.1	0.4	-4.7
ptonSF_MU_SF_tsol_STAT	-1,1	-4.6	-1.9	-2.8	0.1	1.4	-1.3	-0.8	-0.8	-2.0	2.2	-0.7	-0.1	6.9	3.1	-1.7	2.7	-13.5	-2.8	22	-2.8	-4.0	1.3	-0.5	-0.3	-0.4	0.6	-2.9	-5.6	100.0	-20.7	1.6	0.1	1.1	2.4	1.1	-1,1	-3.4	2.4	1.3	-35.7
mSF_MU_SF_TTVA_STAT	-0.1	-1.0	-0.8	-1.4	1.5	-0.2	0.0	-0.0	-0.4	-0.5	1.1	0.1	0.0	1.5	0.7	-0.1	-0.5	-8.4	-1.6	1.3	-1.3	-1.1	0.5	-1.5	-0.8	-0.9	0.4	-3.5	-1.6	-20.7	100.0	-0.1	0.1	0.2	-0.3	-0.3	-0.5	-0.3	1.1	0.7	-27.7
Luminosity	0.9	-0.0	-0.7	-2.1	0.8	1.1	0.2	-1.0	1.0	1.9	-2.2	2.0	3.0	-2.6	-5.1	-0.4	-15.7	0.6	-0.3	0.0	1.9	6.4	-0.3	-2.1	-1.1	-1.2	-0.0	-2.6	-0.4	1.6	-0.1	100.0	-1.1	0.9	-0.1	0.1	-0.2	0.7	-0.6	0.7	-34.6
stat_HTall_2(1b21_bin_1	0.1	-0.2	-0.5	-1.8	1.0	-0.6	0.5	0.3	-0.1	-0.3	0.7	0.7	1.3	-0.7	-1.4	0.0	5.9	-0.9	-0.3	0.1	0.8	2.6	-0.3	-1,3	-0.6	-0.8	-0.0	-1.7	-0.3	0.1	0.1	4.1	100.0	0.6	-0.4	-0.3	-0.2	-0.0	-0.2	0.3	2.5
stat_HTall_4j1b11_bin_1	-0.0	-0.7	-0.4	-4.2	-0.0	-0.0	-1.1	-1.3	1.1	2.0	1.4	0.9	3.0	-0.1	-3.4	1.0	-0.3	3.4	0.8	-0.6	0.2	-0.5	0.0	-0.0	-0.0	-0.0	0.1	-0.2	-0.0	1.1	0.2	0.9	0.6	100.0	2.3	0.9	-0.1	0.5	-0.6	0.1	7.3
stat_HTall_4j1b11_bin_2	0.1	1.0	0.3	0.6	-1.1	-3.1	-0.1	2.8	-1.8	-2.4	-0.0	1.4	-2.8	-0.4	3.2	-0.0	-12.2	-2.9	0.4	0.2	-0.2	-0.5	-0.4	-0.3	-0.2	-0.2	-0.0	-0.5	0.1	2.4	-0.3	-0.1	-0.4	2.3	100.0	2.2	2.4	0.9	0.6	-0.3	-3.8
stat_HTall_4j1b11_bin_3	0.1	-0.3	-1,4	0.9	1.9	0.1	0.6	-0.3	0.3	-0.1	2.2	-2.0	-0.7	0.9	2.4	1.4	-5.0	-6.2	-1.2	1.1	-1.2	-1.7	-0.0	-0.1	-0.0	0.0	-0.1	0.1	0.3	1.1	-0.3	0.1	-0.3	0.9	22	100.0	1.6	0.3	0.3	0.3	-5.5
stat_HTall_4j1b11_bin_4	-0.2	-0.3	0.5	-0.5	0.9	-3.2	5.8	5.3	-4.5	-5.7	0.6	-1.0	-0.2	0.8	0.3	-0.7	-5.5	-4.0	-1.3	0.8	-0.4	-0.8	0.0	0.1	0.1	0.1	-0.1	0.1	0.1	-1.1	-0.5	-0.2	-0.2	-0.1	2.4	1.6	100.0	0.8	0.3	0.2	-3.4
stat_HTall_4j1b11_bin_8	0.1	1.7	1.8	-6.7	-1.0	0.5	0.3	0.5	0.2	0.0	-0.1	5.3	-3.1	1.4	4.1	-7.3	-0.5	-0.0	-0.6	-0.0	-0.7	-0.4	0.1	0.3	0.0	0.1	0.0	0.4	-0.7	-3.4	-0.3	0.7	-0.0	0.5	0.9	0.3	0.8	100.0	-0.1	0.1	0.2
stat_HTal_4j2binc11_bin_2	0.7	1.4	0.9	1.7	-2.0	0.2	0.5	-0.1	0.1	0.6	-0.4	-0.3	-1.3	-1.5	0.8	-0.0	-3.9	2.0	0.1	-0.3	0.7	1.0	-0.2	-0.0	-0.0	-0.0	-0.1	0.2	0.1	2.4	1.1	-0.6	-0.2	-0.6	0.6	0.3	0.3	-0.1	100.0	0.5	-6.7
stat_HTall_4j2binc11_bin_4	-0.9	-1.3	-0.7	-1.6	1.0	-0.4	-1.0	-0.8	-0.2	-0.5	-0.2	0.9	1.7	0.7	-1.5	-0.2	5.7	0.5	0.3	-0.2	-0.9	-1.1	0.1	0.7	0.4	0.4	-0.1	1.2	0.4	1.3	0.7	0.7	0.3	0.1	-0.3	0.3	0.2	0.1	0.5	100.0	-5.9
h (tipes)	-7.5	-3.7	-2.7	-3.2	3.4	-5.5	3.9	5.7	-4.5	-7,4	4.4	1.5	7.8	0.9	-7.2	1.2	16.4	30.6	7.1	-5.5	4.2	-5.3	-11.8	-16.2	-8.4	-9.5	-5.7	-19.8	-4.7	-35.7	-27.7	-34.6	2.5	7.3	-3.8	-5.5	-3.4	0.2	-6.7	-5.9	100.0
	ATLAS_LET_BJES_Response	UET Effectivele® Modeling1	Etsinkercalibration_Modelling	US_JET_Flave_Composition	ATLAS_JET_Flavy_Response	JET JER Deavend MO16	LAS_, ET_JER_EffectiveNP_1	LAS_JET_JER_ENdow/P_2	LAS_ET_ER_Ehodower_3	LAS , ET JER EffectiveNP 4	LAS_JET_JER_ENCONNP_6	ATUAS_JET_Ploup_OffsetMu	TLAS_LET_Plique_ObjetVPV	ATLAS_LET_Piecp_PiTerm	AS_,ET_Pleup_PhoTopology	ATLAS_MET_SOTTIK	ATLAS_Wjets	85 eigenvars. B. up0. down0	55 eigenvars 8 up1 down1	85_eigenvars_B_up2_down2	85_ eigenvan _C_up0_doen0	ageness Light up0 down0	MENTA	ATLAS_leponiSF_EL_SF_ID	ATLAS_lectorisF_EL_SF_100	TLAS_liquest_BL_SF_Pico	AS_loptorSF_B_SF_Tisper	Inposite MU_SF_ID_STAT	Inpoch MU SF ID SYST	JostorSF_MU_SF_Isol_STAT	ploceP_MU_SP_TTVA_STAT	Lurinoshy	star_HTall_2(1b2_bh_1	sac,HTal_4(tb1_bin_1	ster_HTal_4/stall_bin_2	star_HTal_4/th/libn_3	ster, HTal_40b/l, bn_4	stat_HTat_4(text_bin_8	stat_MTail_420inc11_bin_2	stat_HTall_4[Zbind11_bin_4	(Ithar) µ



Correlations



- Important to consider also NP correlations:
 - uncertainties on NPs (and POI) extracted from covariance matrix, which includes correlation coefficients

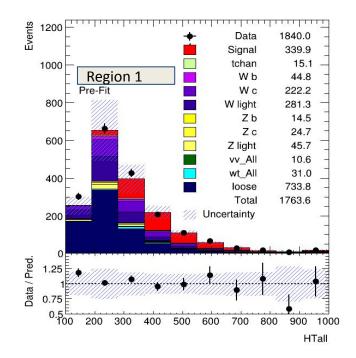
■ correlation built by the fit, even if completely independent / uncorrelated sources of uncertainty before the fit (correlation in the improved knowledge of the parameters)

■ (anti-)correlations can reduce total post-fit uncertainty!



Core framework task: run a profile likelihood fit. Many configuration possibilities:

- Data or Asimov (pseudo-) data
- Including a signal or background-only
- Which regions to include



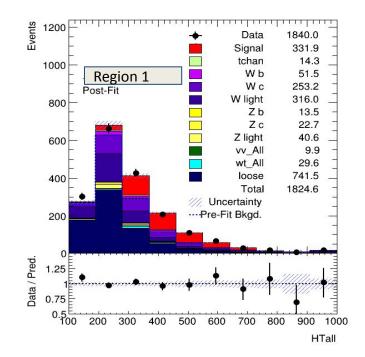


Core framework task: run a profile likelihood **fit**. Many configuration possibilities:

- Data or Asimov (pseudo-) data
- Including a signal or background-only
- Which regions to include

Many plots and files generated to document and understand the fit

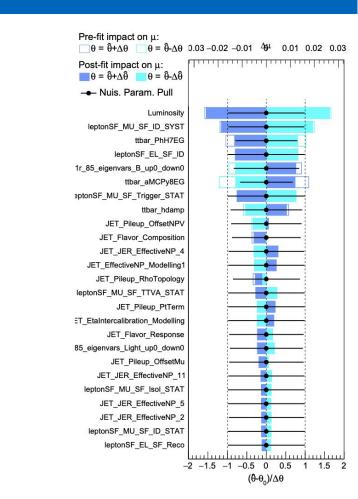
- Best-fit values of all nuisance parameters and associated uncertainties
- Correlations of fit parameters





Impact of NP on the POI (Parameter of Interest)

- To see which nuisance parameter has the largest impact on the uncertainty of our signal strength, we make use of the r action.
- "Ranking plot" shows pre-fit and post-fit impact of individual NP on the determination of μ (Parameter of Interest/POI).



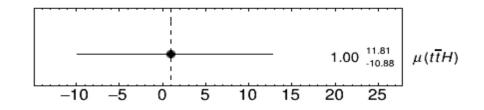
- Besides the ranking feature, **TRExFitter** includes another way of calculating how much certain nuisance parameters "matter".
- The feature discussed here is also called "grouped impact". It is particularly useful to evaluate the uncertainty on a parameter of interest (POI) due to a group of nuisance parameters (NPs).

Uncertainty Source	$\Delta \mu$	up	down
EGamma	0.013	0.014	-0.013
FTAG	0.013	0.013	-0.013
JET	0.011	0.011	-0.011
Luminosity	0.026	0.027	-0.025
MET	0.001	0.001	-0.001
Muon	0.023	0.024	-0.022
Modelling	0.024	0.024	-0.023
FullSyst	0.050	0.052	-0.049
Gammas (sim. stat. unc.)	0.009	0.010	-0.009



POI (Parameter of Interest)

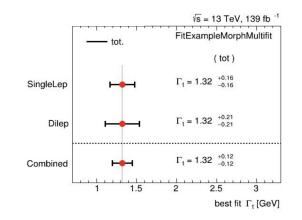
• The following plot shows you the result for the fit we performed, including the best-fit value for the parameter we ultimately want to extract:





Additional features

- Lots of features implemented beyond a simple fit:
- Combined impact of nuisance parameter groups
- Combination and comparison of different fits
- Toys to evaluate effect of statistical fluctuations in templates defining systematic uncertainties
- Template fitting / morphing
- Exclude nuisance parameters or fix them to specific values
- Correlate or de-correlate nuisance parameters
- Create custom Asimov datasets and fit them



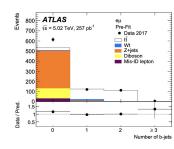


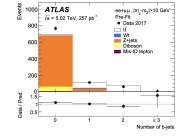
Publications and TRExFitter

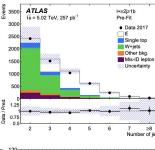
Measurement of the *tt* production cross-section in *pp* collisions at \sqrt{s} = 5.02 TeV with the ATLAS detector

https://arxiv.org/pdf/2207.01354.pdf

Category		$\delta\sigma_{t\bar{t}}$ [%]	
	Dilepton	Single lepton	Combination
$t\bar{t}$ generator [†]	1.2	1.0	0.8
tt parton-shower/hadronisation*,†	0.3	0.9	0.7
$t\bar{t}$ h_{damp} and scale variations [†]	1.0	1.1	0.8
$t\bar{t}$ parton distribution functions [†]	0.2	0.2	0.2
Single-top background	1.1	0.8	0.6
W/Z + jets background*	0.8	2.4	1.8
Diboson background	0.3	0.1	< 0.1
Misidentified leptons*	0.7	0.3	0.3
Electron identification/isolation	0.8	1.2	0.8
Electron energy scale/resolution	0.1	0.1	< 0.1
Muon identification/isolation	0.6	0.2	0.3
Muon momentum scale/resolution	0.1	0.1	0.1
Lepton-trigger efficiency	0.2	0.9	0.7
Jet-energy scale/resolution	0.1	1.1	0.8
$\sqrt{s} = 5.02 \text{ TeV JES correction}$	0.1	0.6	0.5
Jet-vertex tagging	< 0.1	0.2	0.2
Flavour tagging	0.1	1.1	0.8
$E_{\mathrm{T}}^{\mathrm{miss}}$	0.1	0.4	0.3
Simulation statistical uncertainty*	0.2	0.6	0.5
Data statistical uncertainty*	6.8	1.3	1.3
Total systematic uncertainty	3.1	4.2	3.7
Integrated luminosity	1.8	1.6	1.6
Beam energy	0.3	0.3	0.3
	7.5	4.5	3.9







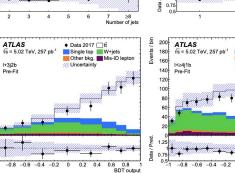
100

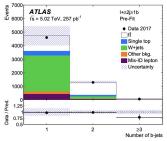
80

Data / Pre

0.5

Ne e





● Data 2017 □ tī

// Uncertainty

Single top W+jets

Other bkg. 📕 Mis-ID lepton



- TRExFitter, a very powerful and configurable tool
- User friendly and not a black-box
- Used in many physics analysis including our recent ongoing top-quark pair production in proton-lead collisions



Thank You



• Best-fit result (unconditional maximum likelihood estimate) of measurement

• Maximize likelihood by varying $\vec{k}, \vec{\theta}$, POI μ is part of \vec{k}

• For significance / limit, make use of profile likelihood ratio (reference: <u>arXiv:1007.1727</u>)

▶ In asymptotic limit (more than ~10 events / bin), can quickly calculate significance/limits

 $\left\{ \begin{array}{ll} -2\ln\frac{L(\mu,\theta(\mu))}{L(0,\hat{\theta}(0))} & \hat{\mu} < 0 \ , \\ -2\ln\frac{L(\mu,\hat{\theta}(\mu))}{L(\hat{\mu},\hat{\theta})} & 0 \le \hat{\mu} \le \mu \ , \end{array} \right.$

• Discovery significance:
$$q_0 = \begin{cases} -2\ln\lambda(0) & \hat{\mu} \ge 0 \\ 0 & \hat{\mu} < 0 \end{cases}$$

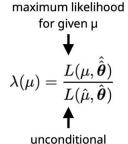
• $Z_0 = \sqrt{q_0}$

Takes two fits to calculate

• Upper parameter limits: $ilde{q}_{\mu}$ test statistic, $ilde{q}_{\mu}=$

We also use the CL_s method (<u>reference</u>)

 * Vary μ to find the CLs = 5% crossing for 95% parameter limits



maximum likelihood

