Measurement of the top quark mass in final states with three jets and one charged lepton at $\sqrt{s} = 8\,\mathrm{TeV}$ with the ATLAS experiment

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November 18, 2015

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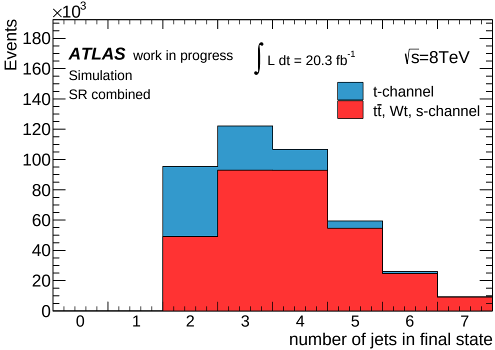
Content

Motivation for the Analysis

- first mass measurement in data enhanced with single top quarks with two jets in the final state in 2014 (`ATLAS-CONF-2014-055`)
- now: modified phase space with **three jets** in the final state
- orthogonal phase space compared to any other selection in a top quark mass measurement done before



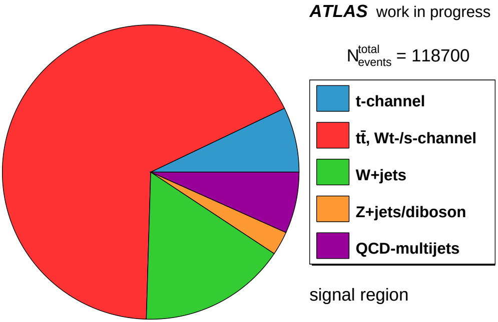
(preselection with $\geq$ 2 jets)

- more statistics for another top quark mass measurement
- composition of signal in 3 jet-bin:
  - 80 % *Wt*-, *s*-channel and $t\bar{t}$ processes
  - 20 % *t*-channel process

Event Selection

- exactly **3 jets** with $p_T > 30\,\mathrm{GeV}$: 1 *b*-tagged jet (MV1c50), 2 untagged jets (light jets)
- exactly 1 charged lepton with $p_T > 25\,\mathrm{GeV}$
- missing transverse momentum with $E_T^{\mathrm{miss}} > 30\,\mathrm{GeV}$
- triangular cut: $p_T(\ell) > 40\,\mathrm{GeV} \cdot \left(1 - \frac{\pi - |\Delta\varphi(j_1,\ell)|}{\pi - 1}\right)$
- transverse W-boson mass: $m_T(W) > 50\,\mathrm{GeV}$

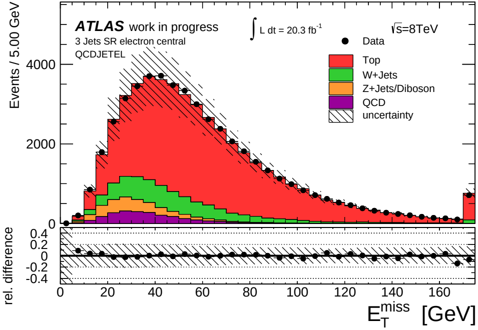
(triangular cut and transverse W-boson mass:) cuts to reject QCD-multijet events



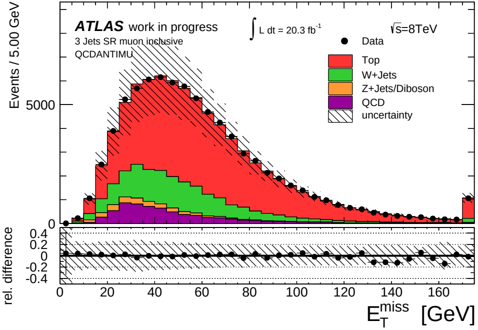
- selected sample is dominated by $t\bar{t}$ events

Background Estimation

- contribution of the QCD-multijet events is estimated by the use of two models:
  - electron channel: jet-lepton model; muon channel: anti-muon model
- data-driven determination of normalization for the QCD-models
- likelihood fit to the distribution of the missing transverse momentum

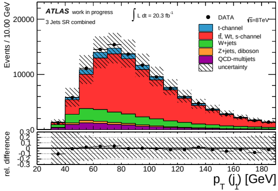


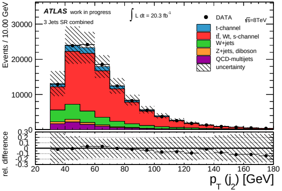
electron channel

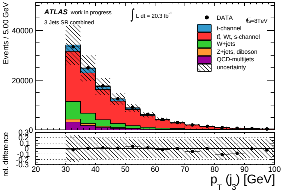


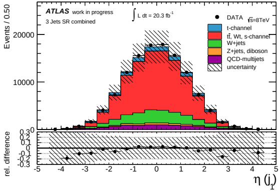
muon channel

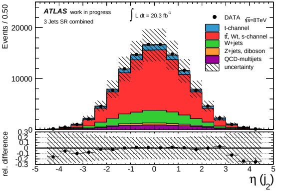
Control Plots

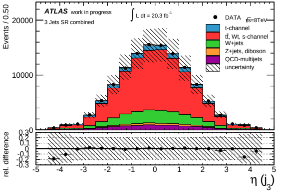


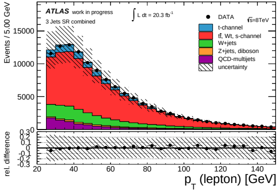


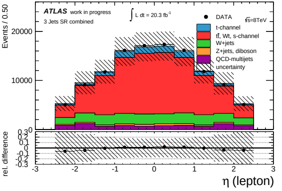












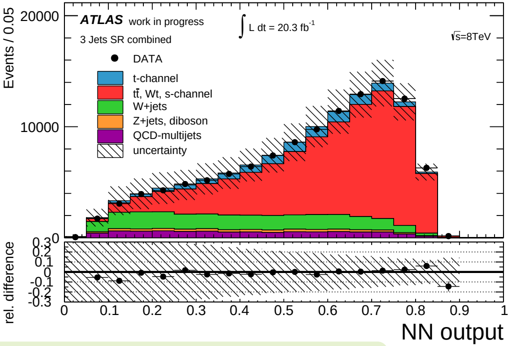
⇒ good agreement between Monte Carlo simulation and data in signal and control regions (not shown)

Neural Network

- use of a multivariate method as in the analysis with 2 jets (ATLAS-CONF-2014-055)
- training of all top processes ($t\bar{t}$, t-, Wt-, s-channel) versus W+jets, Z+jets and diboson processes
- eleven input variables, adopted from the t-channel cross section measurement (ATLAS-CONF-2012-132)

ATLAS work in progress

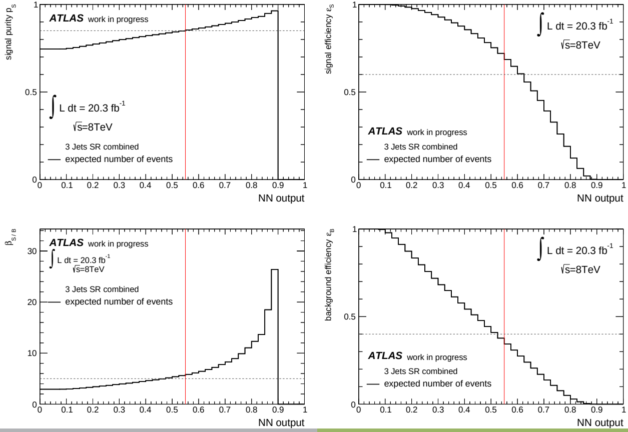
variable	ρ^{iter} [%]	σ^{iter}
$\lvert\Delta\eta(\ell, b)\rvert$	30.26	124.41
$H_T\left(\ell, \text{jets}, E_T^{\text{miss}}\right)$	18.22	74.92
$m(\ell, b)$	12.86	52.87
$m(j_1, j_2)$	10.63	43.70
$\Delta R\left(j_{l_2}, b\right)$	9.55	39.29
$\eta(\ell, E_T^{\text{miss}}, b)$	6.44	26.46
$m(j_1, j_3)$	6.51	26.75
$\left\lvert\eta\left(j_{l_2}\right)\right\rvert$	1.62	6.65
$\sum_{i=1}^{3}\eta(j_i)$	1.29	5.31
$\left\lvert\eta\left(j_{l_1}\right)\right\rvert$	1.65	6.77
$\lvert\Delta\eta(j_2, j_3)\rvert$	0.43	1.76



⇒ good separation between signal and background events

Choice of Cut Value

- selection of events exceeding a minimal neural network output value
- cut value fulfills minimal requirements on statistical quantities:
  - signal purity p_S and efficiency ε_S, ratio of signal to background events $\beta_{S/B}$ and background rejection ε_B



ATLAS work in progress

statistical quantity	arbitrary threshold
p_S	$> 85\,\%$
ε_S	$> 60\,\%$
$\beta_{S/B}$	> 5
ε_B	$< 40\,\%$

$\Rightarrow$ **$NN > 0.55$**

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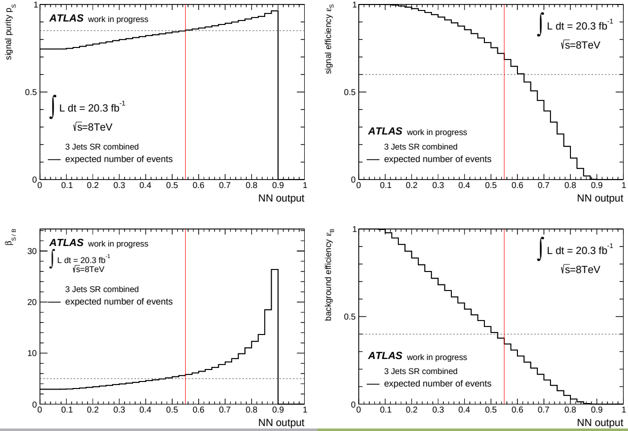

ATLAS work in progress

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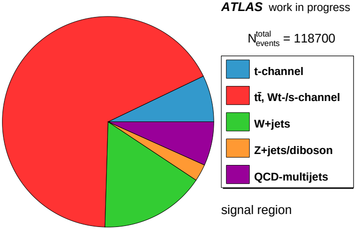
first guess:

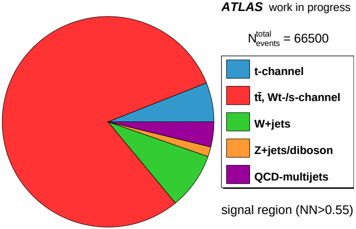
$\Rightarrow$ **$NN > 0.55$**

later on: cut variations to evaluate the minimal uncertainty on the measured mass

Event Yields

- decrease of total background fraction from 25 % to 14 %



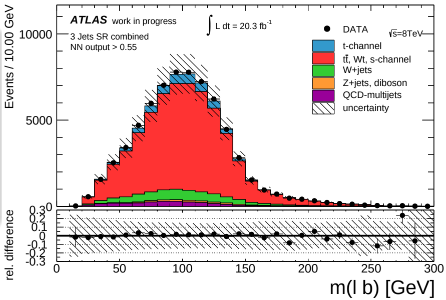


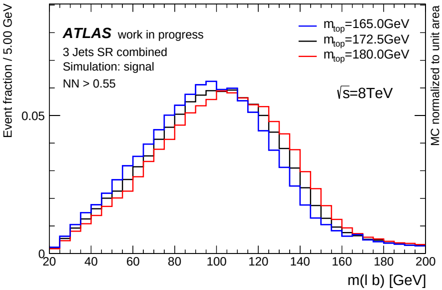
ATLAS work in progress

	signal region ($NN > 0.55$) process	combined channel total
expected signal events	*t*-channel	4000 ± 400
	s-channel	246 ± 25
	Wt-channel	3460 ± 350
expected background events	$t\bar{t}$	$49\,500 \pm 5000$
	W+jets	5800 ± 3500
	Z+jets/diboson	1000 ± 100
	QCD-multijets	2600 ± 1300
	total expected	$66\,500 \pm 6500$
	data	67194
	bkgd. fraction r_{MC} [%]	14.0 ± 5.0

Template Method for Top Quark Mass Measurement

- $m(\ell b)$-distribution depends on the top quark mass m_{top}
- used as estimator sensitive to m_{top} in the template method
- distribution must be effectively parametrized

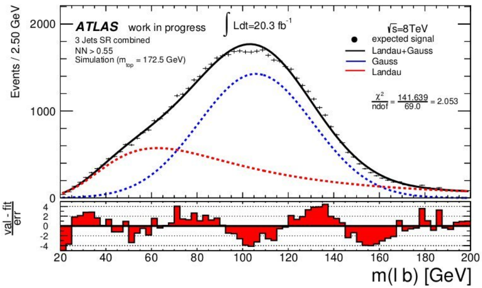


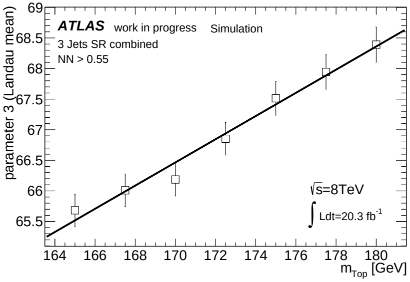


- two templates are generated separately for the signal and background contribution
- 7 discrete mass points are simulated in a range from 165.0 GeV to 180.0 GeV
  - generating a **mass dependent** signal template

Parametrization and Calibration Curves

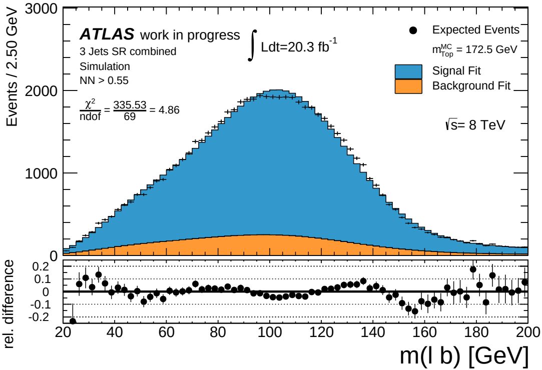
- signal and background distributions can be parametrized by the same function
  - sum of Landau and Gaussian function
- parameters are linearly interpolated in dependence of the top quark mass
  - mass dependent calibration curves





- final templates are given by the probability density functions $P_{\text{signal}}\left(m(\ell b)|m_{\text{top}}\right)$ and $P_{\text{bkgd}}\left(m(\ell b)\right)$

Template Fit



Final template fit has three parameters

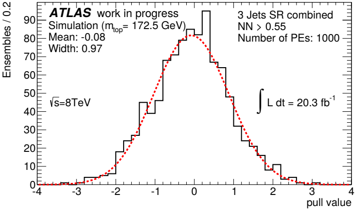
1. Top quark mass: m_{top}
2. Background fraction: f_{back}
3. Overall normalization: N

Estimated templates are used as the input to a binned maximum likelihood fit to the data with:

$$\mathcal{L}(m_{\text{top}}, N, f_{\text{back}}) = \prod_{\text{bin}} \text{Poisson}_{\lambda_{\text{bin}}} \left(m(\ell b)^{\text{data}}_{\text{bin}} \right) \cdot \text{G}\left(f_{\text{back}}, r_{\text{MC}}, \sigma_{r_{\text{MC}}}\right)$$

$$\lambda_{\text{bin}} = N \cdot \left[(1 - f_{\text{back}})\, P_{\text{signal}}\left(m(\ell b)_{\text{bin}} | m_{\text{top}}\right) + f_{\text{back}} P_{\text{bkgd}}\left(m(\ell b)_{\text{bin}}\right) \right]$$

Statistical Validation and Estimation of Systematic Uncertainties



- method is tested by generating sets of pseudodata
- each mass point is validated
- constructing pull distributions: pull = $\frac{\langle m_{top}^{fit} \rangle - m_{top}^{MC}}{\sigma_{top}^{fit}}$
  - pull distribution: $\mu \overset{!}{=} 0$ and $\sigma \overset{!}{=} 1$

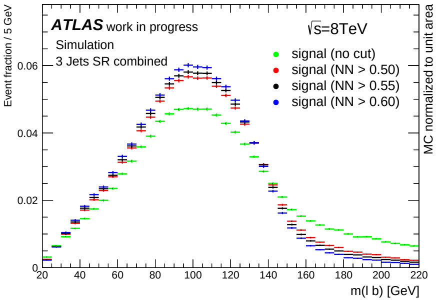
- various sources of systematic uncertainties influence the measurement
  - object energy scale/resolution and efficiencies
  - modeling uncertainties of signal processes
  - modeling uncertainties of background processes

dominant systematic sources:

- jet energy scale
- electron energy scale
- $t\bar{t}$ ISR/FSR
- $t\bar{t}$ MC generator
- QCD-multijet normalization

Influence of the NN Cut Value on the Total Uncertainty

- $m(\ell b)$-distribution depends on the cut value selected
- four cut scenarios are assumed
  - no cut, $NN > 0.50$, $NN > 0.55$, $NN > 0.60$
- for each scenario own templates are constructed
- statistical validations show no deviations



ATLAS work in progress

threshold value	stat. unc. Δm_{top}	syst. unc. Δm_{top}	tot. unc. Δm_{top}
no cut	*a*	*b*	
$NN > 0.50$	$+15\,\%$	$-15\,\%$	↓
$NN > 0.55$	$+27\,\%$	$-20\,\%$	
$NN > 0.60$	$+42\,\%$	$-25\,\%$	

- total uncertainty decreases with increasing cut value
  - more studies necessary to evaluate the optimal cut value

Summary and Conclusion

Summary

- selection of events in a phase space that has never been used in a top quark mass measurement before
- full analysis has been done
- studies on different cut values on the neural network output distribution have been performed

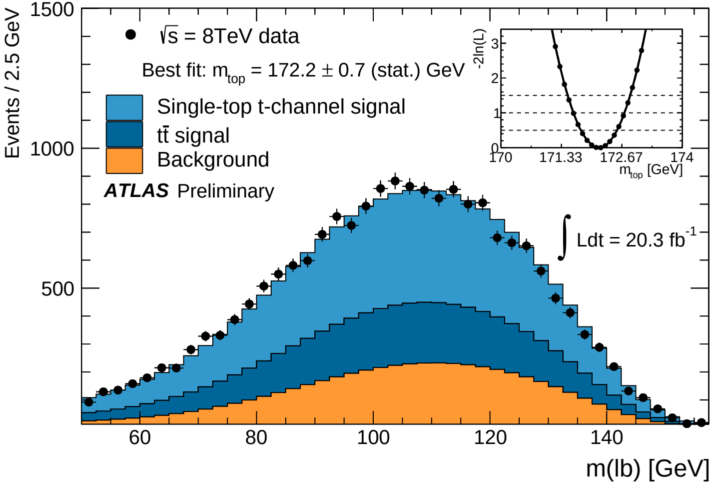
Conclusion

- investigation of this phase space for a top quark mass measurement has good prospects

Backup

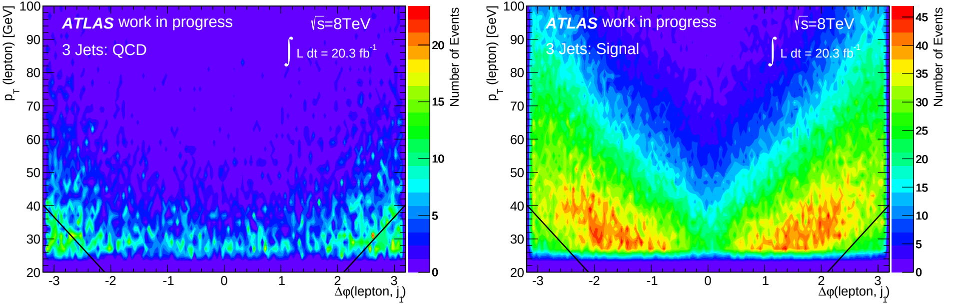
Result of the Analysis with 2 Jets in the Final State

(ATLAS-CONF-2014-055)



$$m_{\text{top}} = 172.2 \pm 0.7(stat.) \pm 2.0(syst.)\,\text{GeV}$$

Visualization of the Triangular Cut



$$p_T(\ell) > 40\,\mathrm{GeV} \cdot \left(1 - \frac{\pi - |\Delta\varphi(j_1,\ell)|}{\pi - 1}\right)$$

- cut is used to suppress QCD-multijet events
- they mostly arise from dijet events that show a different kinematic signature compared to signal events

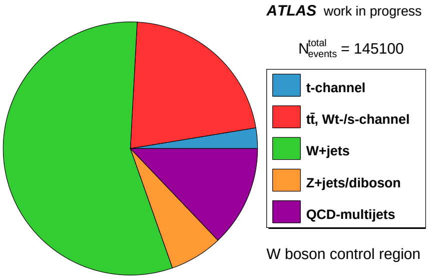
Control Regions

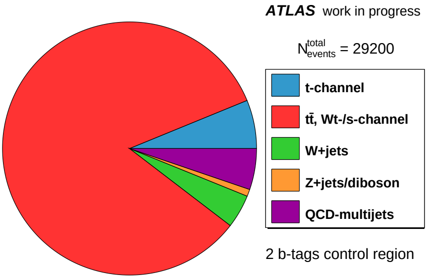
W-boson control region

- looser *b*-tagging efficiency
- signal region is excluded

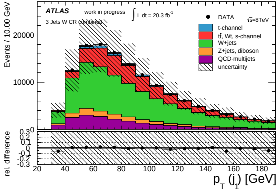
2 *b*-tags control region

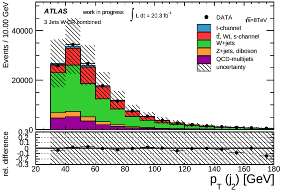
- second *b*-tagged jet is required
- no overlap to signal region

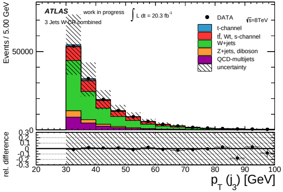


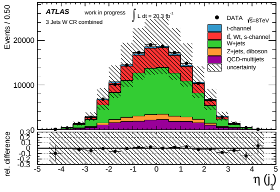


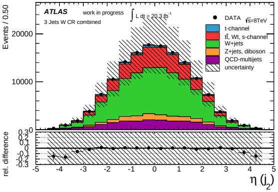
Control Plots in the *W*-Boson Control Regions

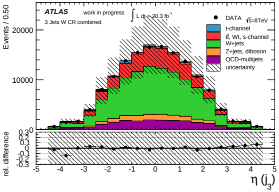


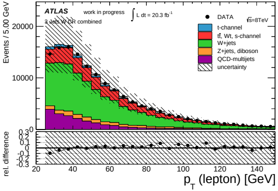


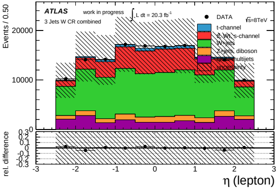




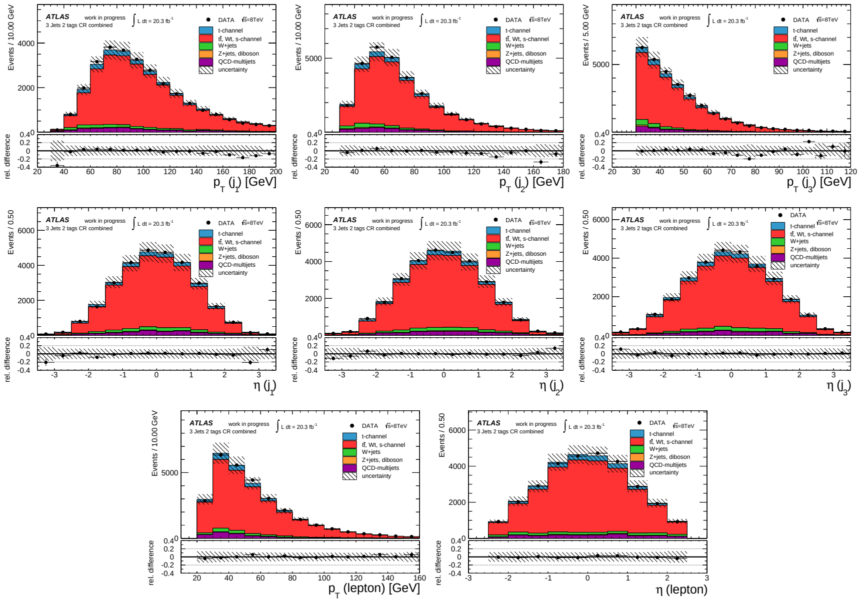




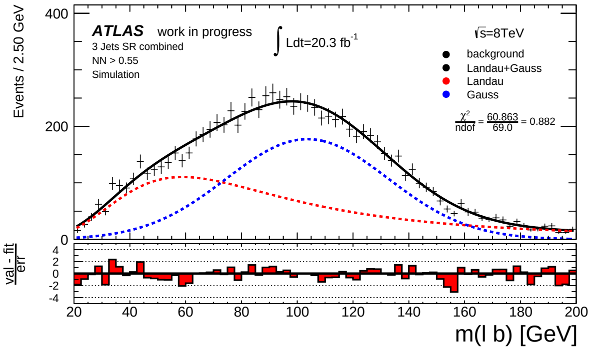




Control Plots in the 2 *b*-tags Control Regions



Parametrization of the Background Contribution to the $m(\ell b)$-Distribution



- the same effective parametrization as for the signal contribution:

$$f\left(p_1 \ldots p_6, x = m(\ell b)\right) = p_1 \cdot \left[p_2 \cdot \mathrm{L}(x, p_3, p_4) + (1 - p_2) \cdot \mathrm{G}(x, p_5, p_6)\right]$$