Measurement of the Top Quark Mass with the Template Method in the ttbar->lepton+jets Channel using ATLAS Data

The Atlas Collaboration

Anthony Hawkins on behalf of ***the Best Group Ever***

Backup

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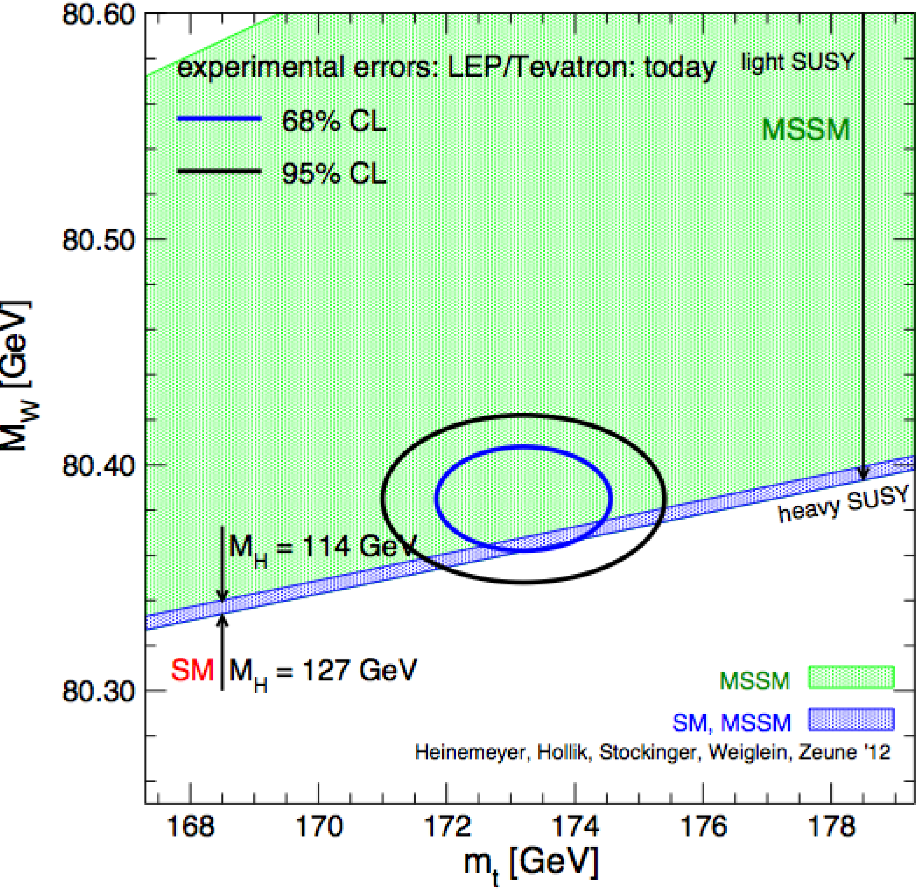
Outline

- Introduction
- The ATLAS detector
- Event preselection
- Template method
- 1d-analysis
- 2d-analysis
- Systematics
- Results/Conclusion

Introduction



$$\sigma^{t\bar{t}}_{SM@NNLO} = 167^{+17}_{-18} \text{ pb at } \sqrt{s} = 7TeV$$

$$for\ m_{top} = 172.5\ GeV$$

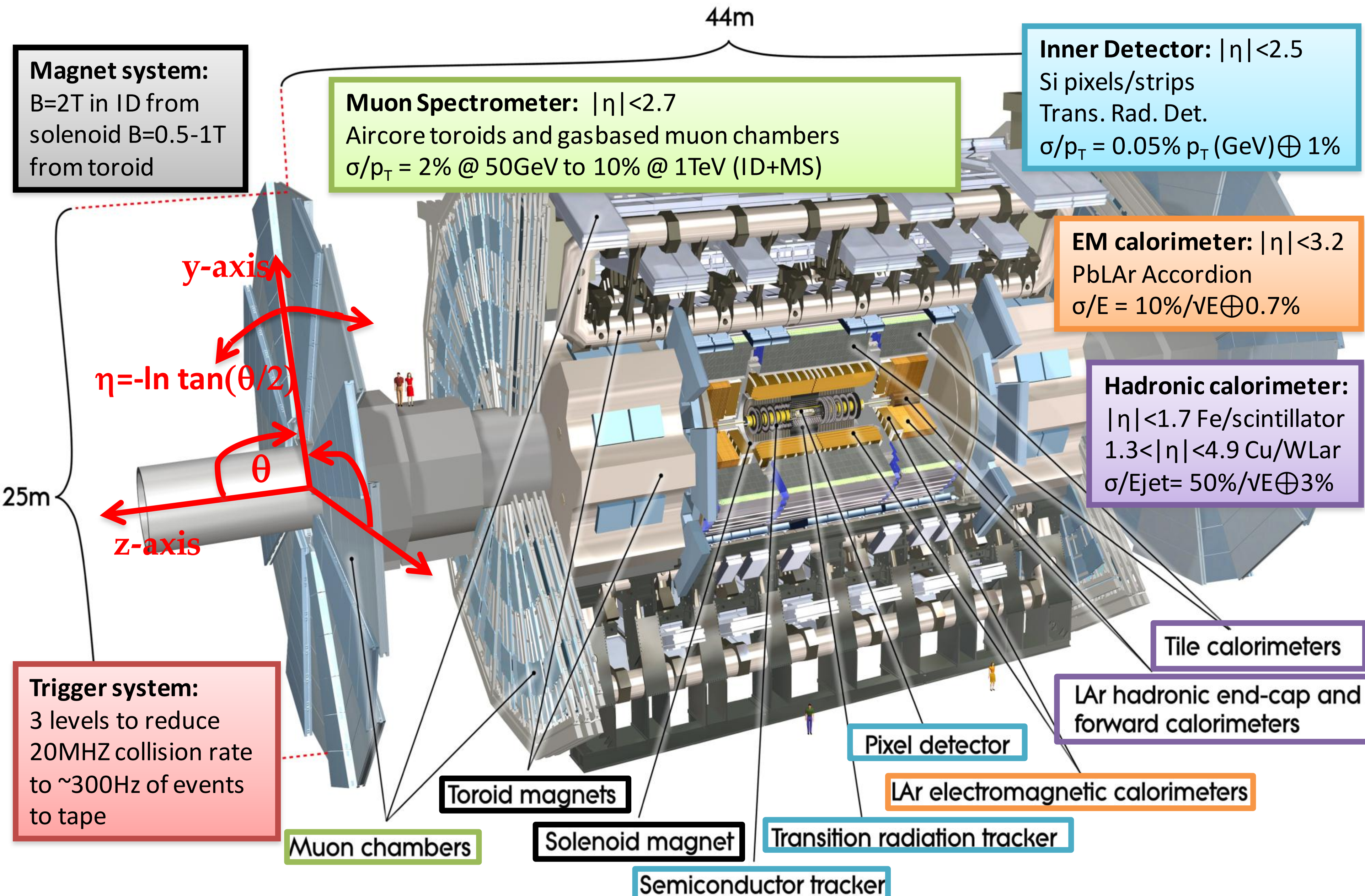
~ 177k tt pairs expected in 1.04 fb^{-1}

- Precision measurements of the top and W mass provide a better constraint on the Higgs mass than the combination of many EW observable
- Plays an important role in many extensions of the SM
- Constrain gluon PDF at larger x
- Direct background in H -> $W^+ W^-$
- The mass of the top quark has been measured with high precision (< 1%) at CDF and D0:

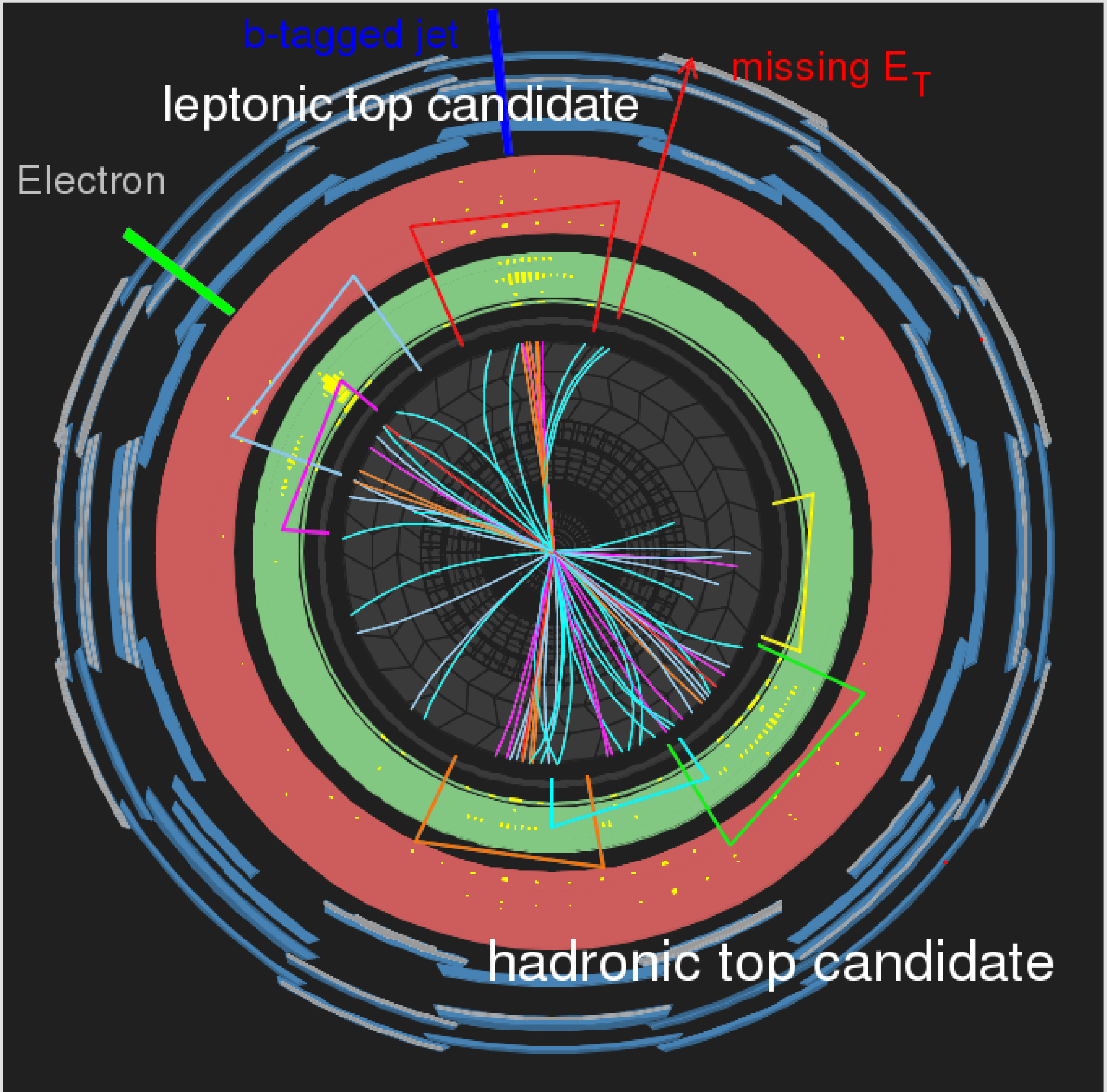
m_t = 173 ± 0.6(stat) ± 0.8(syst) GeV

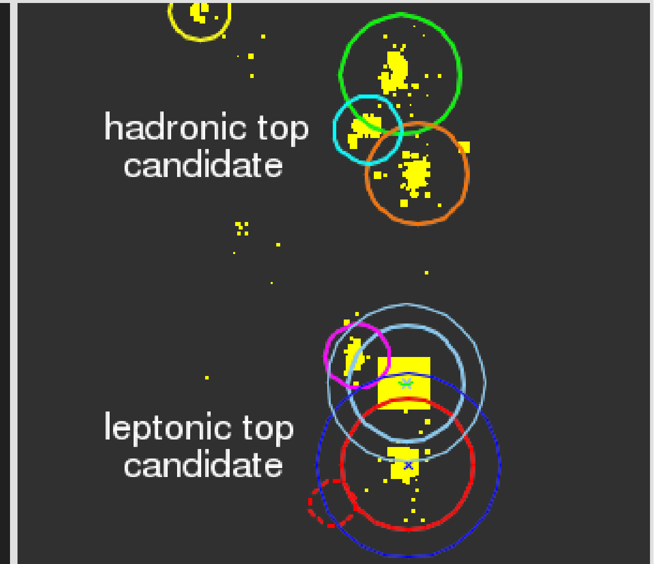
(arXiv:1107.5255)

ATLAS Detector

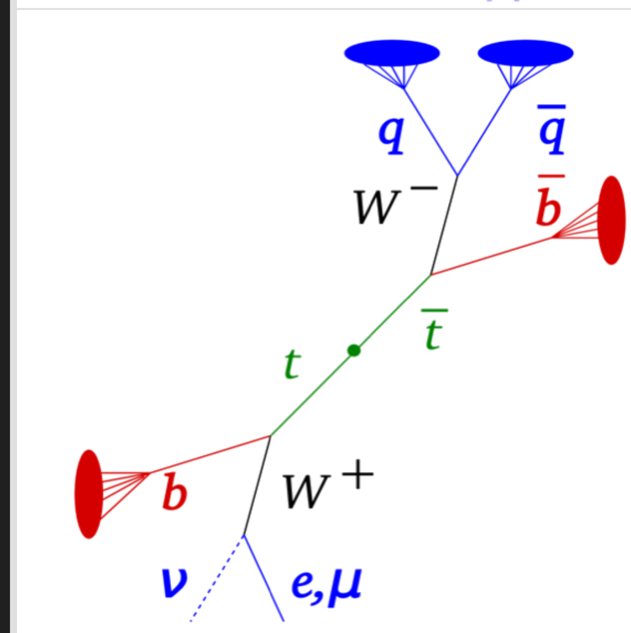


Single lepton decay (1)

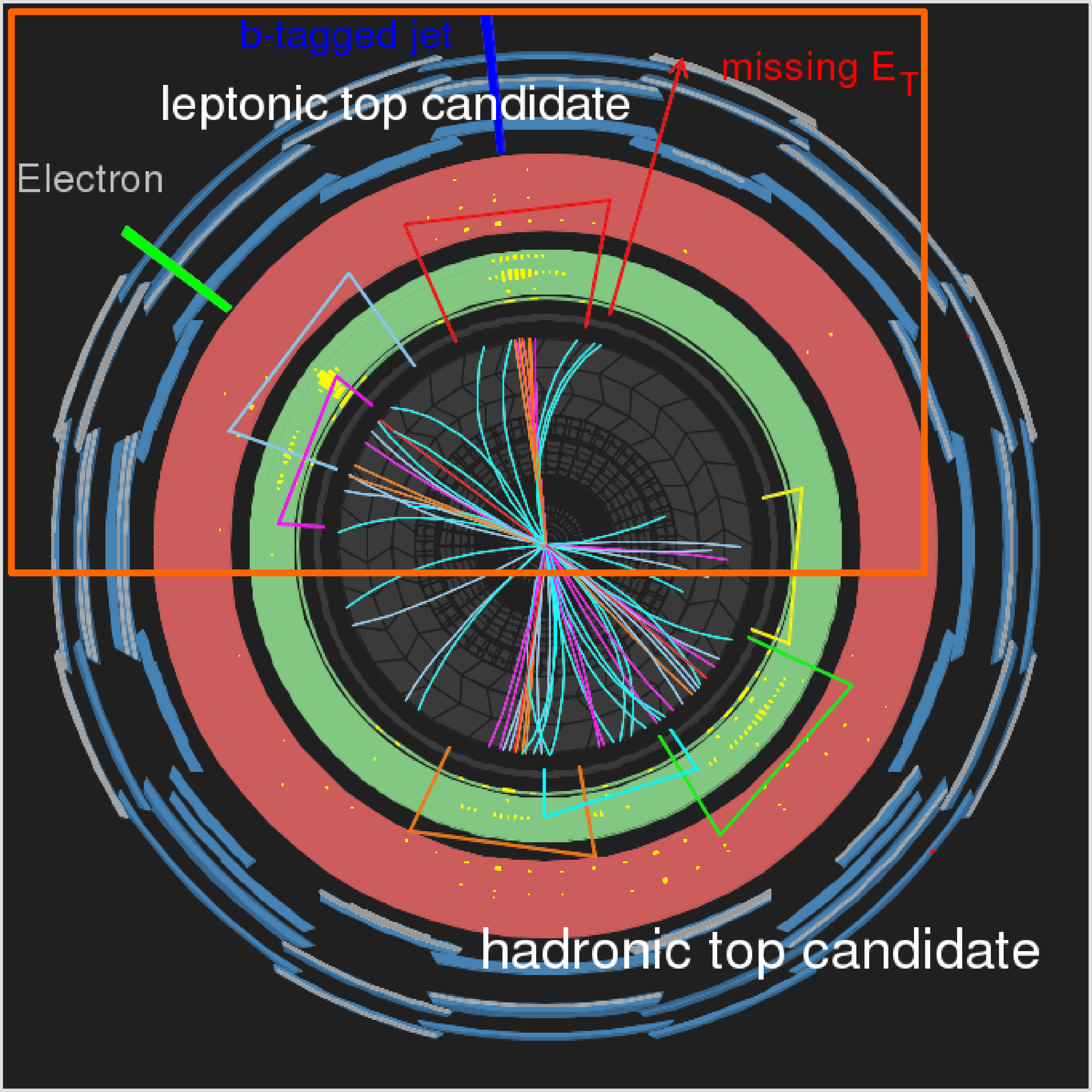


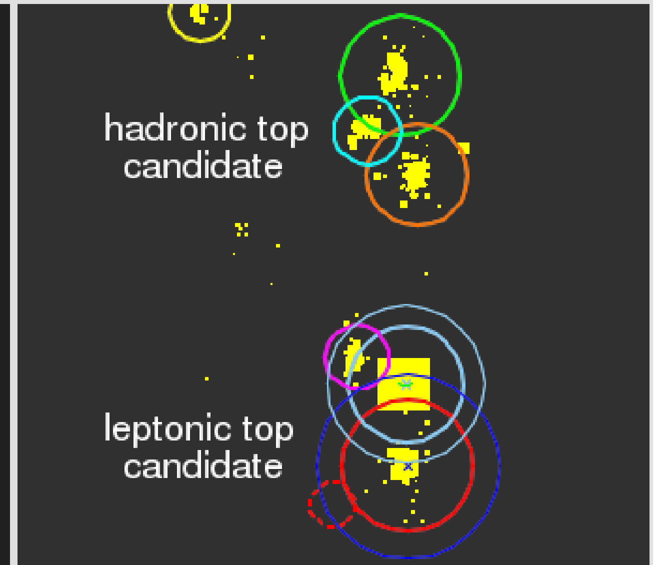


$t\bar{t} \rightarrow W^+ b \; W^- \bar{b} \rightarrow q\bar{q}b \; l\nu\bar{b}$

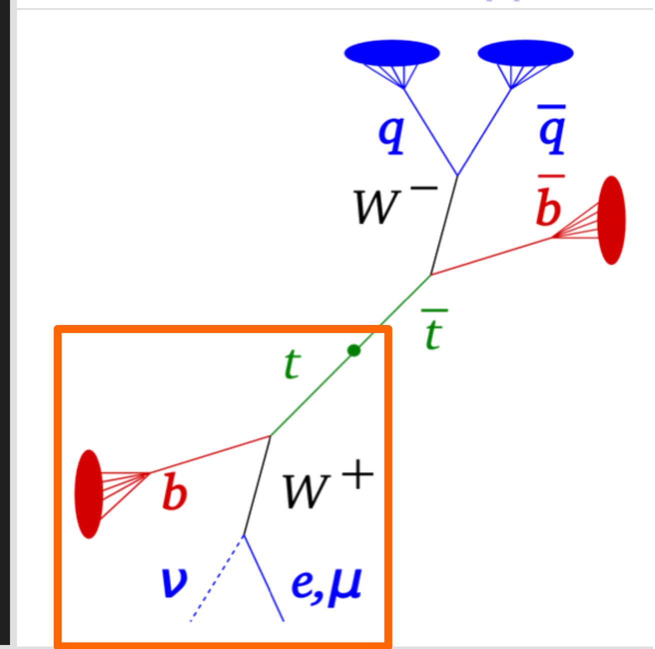


Single lepton decay (1)

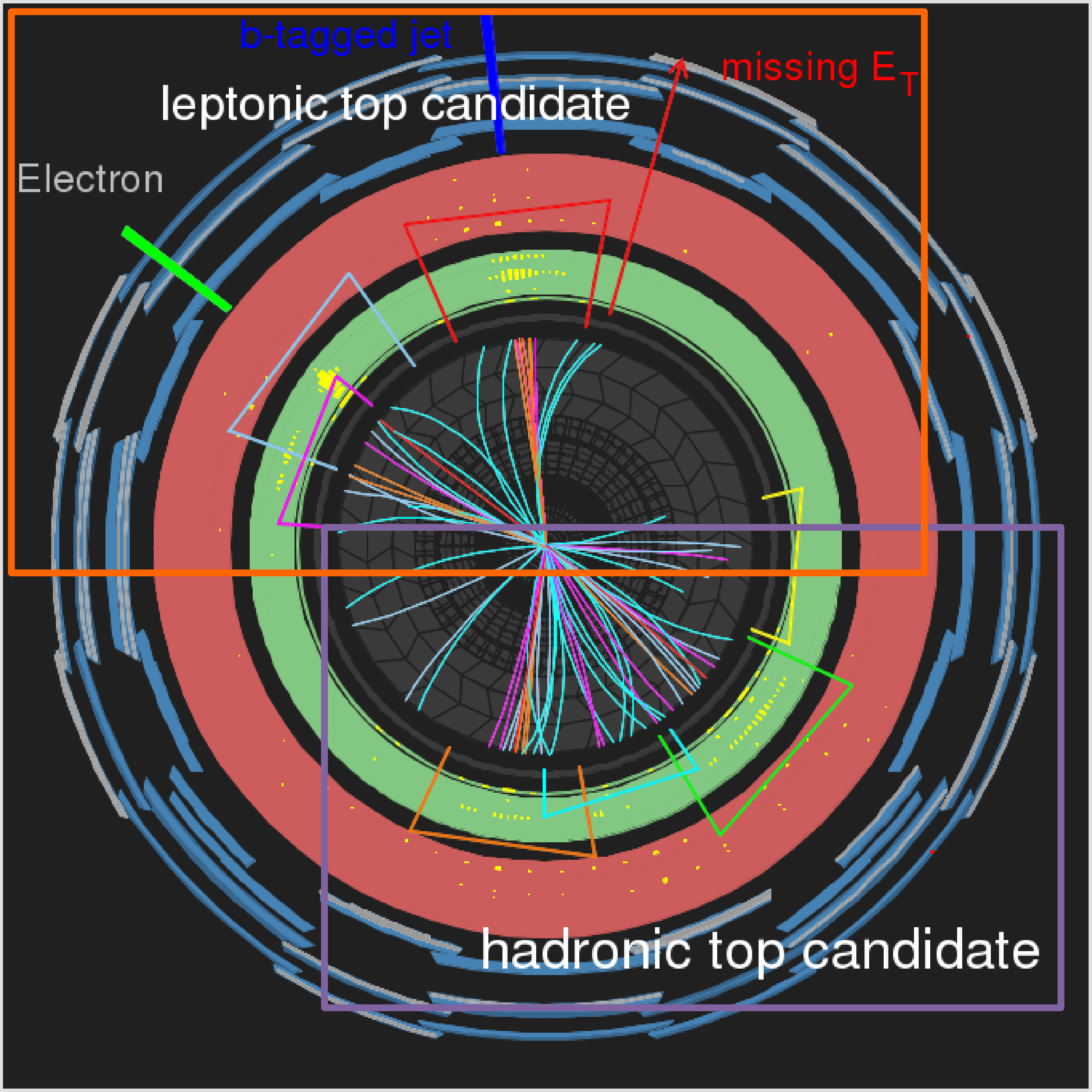


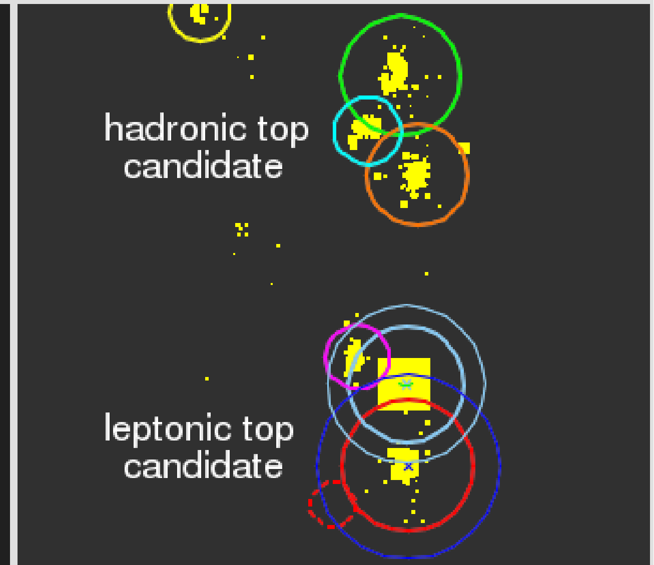


$t\bar{t} \rightarrow W^+ b\ W^- \bar{b} \rightarrow q\bar{q} b\ l\nu\bar{b}$

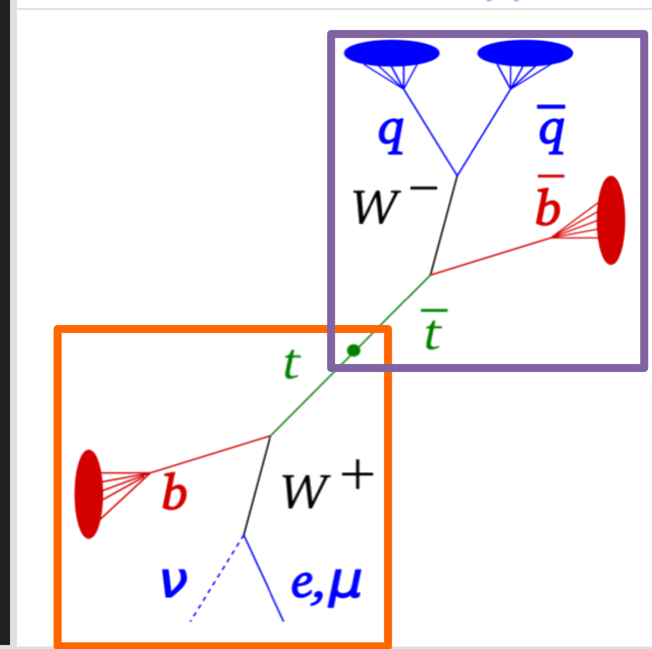


Single lepton decay (1)

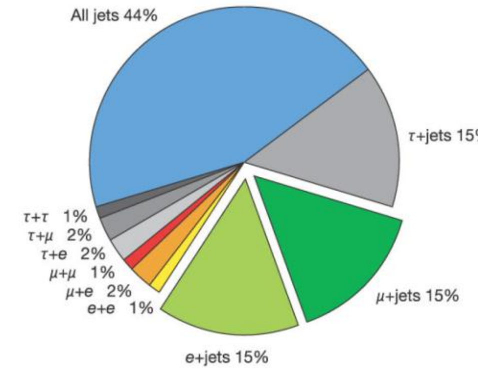




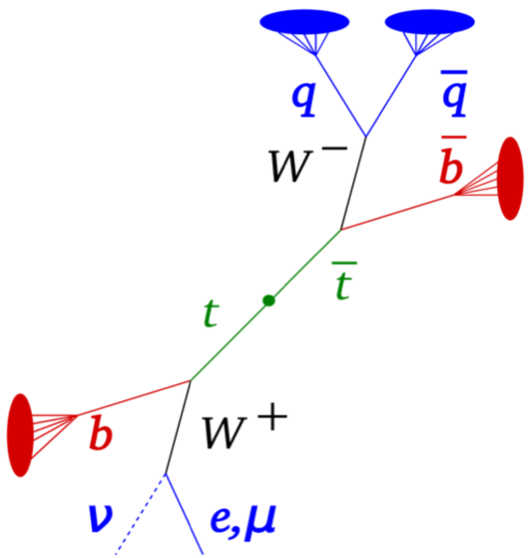
$t\bar{t} \rightarrow W^+ b\ W^- \bar{b} \rightarrow q\bar{q}b\ l\nu\bar{b}$



Single lepton decay (2)



$$t\bar{t} \rightarrow W^{+}b\ W^{-}\bar{b} \rightarrow q\bar{q}b\ l\nu\bar{b}$$



- BR(t -> Wb) ~ 1
  - BR(W -> lν) = 0.108 (for each l = e, μ, τ)
  - BR(W -> q$\bar{q}$) = 1 – 3 x 0.108 = 0.676
    - ➡ BR(DILEPT.) = (3 · 0.108)2 ~ 11%
    - ➡ BR(FULLY HAD.) = 0.6762 ~ 46%
    - ➡ **BR(SINGLE LEPT.) ~ 43%***

* τ channel not used here

Main backgrounds (common to 1d & 2d analysis):

- **W+ jets** (major background)
- **QCD multijet** (fake high-p_T lepton & MET mis-measurement)
- **Z+ jets** (missing one lepton & bad jet recons.)
- **ZZ/WZ/WW** (minor background)
- **Single top** (only for the 2d analysis)

Event preselection

Common requirements for 1d & 2d analysis:

Cut	μ+jets	e+jets
Lepton Transverse Energy	p_T>20 GeV	p_T>25 GeV
Pseudorapidity	$\|\eta\|<2.5$	$\|\eta\|<2.47$ excluding $1.37<\|\eta\|<1.52$
Missing E_T	E_T^{miss} > 20 GeV	E_T^{miss} > 35 GeV
Transverse Mass	$E_T^{miss} + m^T_W$ > 60 GeV	m^T_W > 25 GeV
Isolation	E_T (ΔR =0.2)<3.5 GeV	E_T (ΔR=0.3)<4 GeV
Jets (Anti-k_t R=0.4)	≥4 jets & p_T>25 GeV & $\|\eta\|<2.5$ & >=1 b-jet.	

Specific requirements, depending on the analysis (1d or 2d), will be further described

Template method

- Choice of observables x_i which are sensitive to m_{top}
- Create MC -Samples for different m_{top} : *160, 170,172.5,175,180,190* GeV
- Find continuous parametrization of shape of x_i as function of m_{top} (and other parameters)
- Estimate m_{top} from DATA distribution

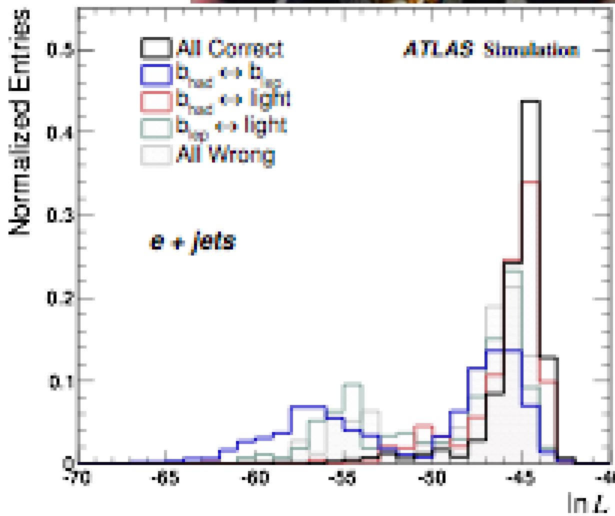
1-d	2-d
$$x_1 = R_{32} = \frac{m_{top}^{reco}}{m_W^{reco}}$$ • Fitting m_{top}, n_{bckg} • In this ratio the dependency on the JES scale is reduced significantly	$$x_1 = m_{top}^{reco}$$ $$x_2 = m_W^{reco}$$ • Fitting m_{top},JSF, n_{bkg} • JSF as a fitting parameter

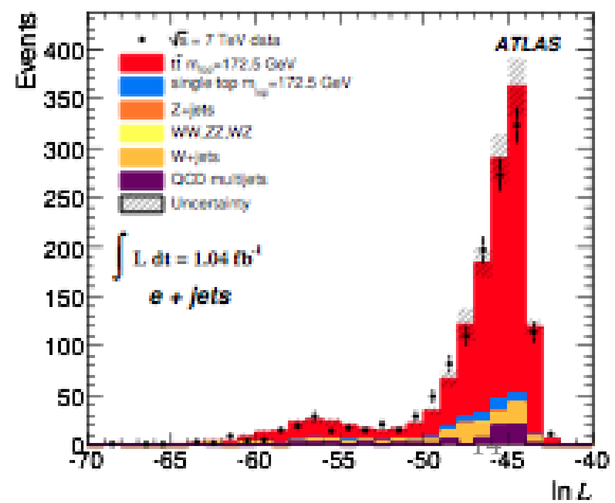
1D Template

- Selection of the top associated jets: kinematic likelihood relating the objects to the $t\bar{t}$ decay products predicted by Monte Carlo (MC@NLO)
- Maximum likelihood built from the 4 jet combinations per each event
- Use the reconstructed four vectors objects (jets and leptons) and Missing Transverse Momentum
- The maximized value of the likelihood discriminates mismatches and correct matching (cut at -ln L=50)

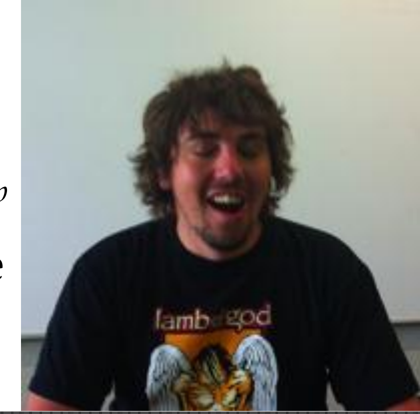
T Transfer function between reconstructed objects and MC generator level matched objects
B Breit Wigner functions modeling the top and W masses.
Wbtag Weights containing b-tagging information

$$\begin{aligned} L = {} & \mathcal{T}\left(E_{\mathrm{jet}_1}|\hat{E}_{b_{\mathrm{had}}}\right)\cdot\mathcal{T}\left(E_{\mathrm{jet}_2}|\hat{E}_{b_\ell}\right)\cdot\mathcal{T}\left(E_{\mathrm{jet}_3}|\hat{E}_{q_1}\right)\cdot \\ & \mathcal{T}\left(E_{\mathrm{jet}_4}|\hat{E}_{q_2}\right)\cdot\mathcal{T}\left(E_x^{\mathrm{miss}}|\hat{p}_{x,\nu}\right)\cdot\mathcal{T}\left(E_y^{\mathrm{miss}}|\hat{p}_{y,\nu}\right)\cdot \\ & \left\{\begin{array}{ll}\mathcal{T}\left(E_e|\hat{E}_e\right) & e\text{+jets} \\ \mathcal{T}\left(p_{\mathrm{T},\mu}|\hat{p}_{\mathrm{T},\mu}\right) & \mu\text{+jets}\end{array}\right\}\cdot \\ & B\left[m(q_1\,q_2)|m_W,\Gamma_W\right]\cdot B\left[m(\ell\,\nu)|m_W,\Gamma_W\right]\cdot \\ & B\left[m(q_1\,q_2\,b_{\mathrm{had}})|m_{\mathrm{top}}^{\mathrm{reco,like}},\Gamma_{\mathrm{top}}\right]\cdot \\ & B\left[m(\ell\,\nu\,b_\ell)|m_{\mathrm{top}}^{\mathrm{reco,like}},\Gamma_{\mathrm{top}}\right]\cdot W_{\mathrm{btag}}\,. \end{aligned}$$

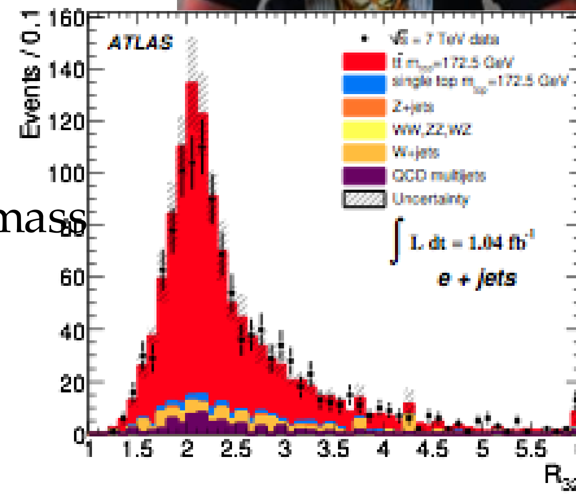




1D Template



- Combination of single top and $t\bar{t}$ contribution for each choice of m_{top}
- Parametrization of R32 templates by a ratio of two gaussians (for the two mass distributions) summed to a Landau (modeling the tail contribution)
- Linear assumption on the parameters dependance to m_{top}
- Overall χ^2 minimization of R32 at all mass points
- Template fit with binned likelihood for signal yield and top mass

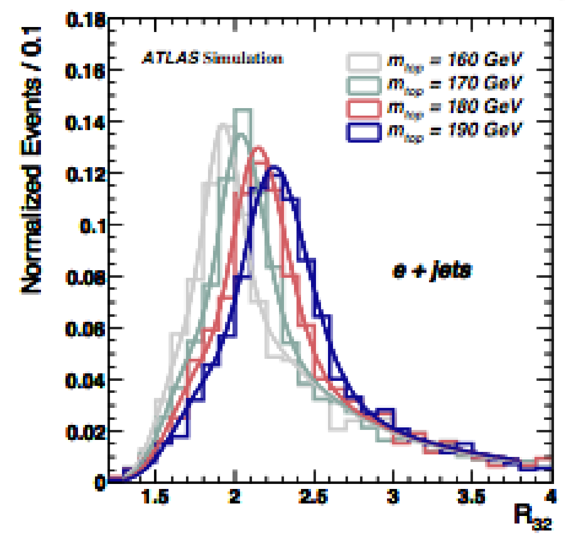


$$L(R_{32}|m_{top}) = L_{shape}(R_{32}|m_{top}) \times L_{bkg}(R_{32})$$

$$L_{shape}(R_{32}|m_{top}) = \prod_{i=1}^{N_{\rm bins}} \frac{\lambda_i^{N_i}}{N_i!} \cdot e^{-\lambda_i} \qquad L_{bkg}(R_{32}) = \exp\left\{-\frac{(n_{bkg}-n_{bkg}^{pred})^2}{2\sigma^2_{n_{bkg}^{pred}}}\right\}$$

$$\lambda_i = (N - n_{bkg}) \cdot P_{sig}(R_{32}|m_{top})_i + n_{bkg} \cdot P_{bkg}(R_{32})_i$$

- Performance of this algorithm tested with pseudo-experiments
  - Poisson statistics for signal events
  - Background fluctuations around expected values (S.M. predictions)
  - Linearity between input and estimates



e +jets
$$m_{top} = 172.9 \pm 1.5$$
μ+jets
$$m_{top} = 175.5 \pm 1.1$$

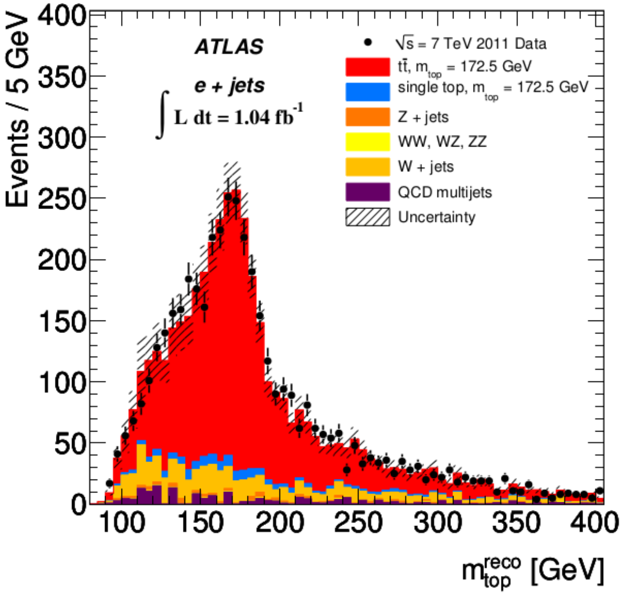
$$m_{top} = 174.4 \pm 0.9 \text{ GeV}$$

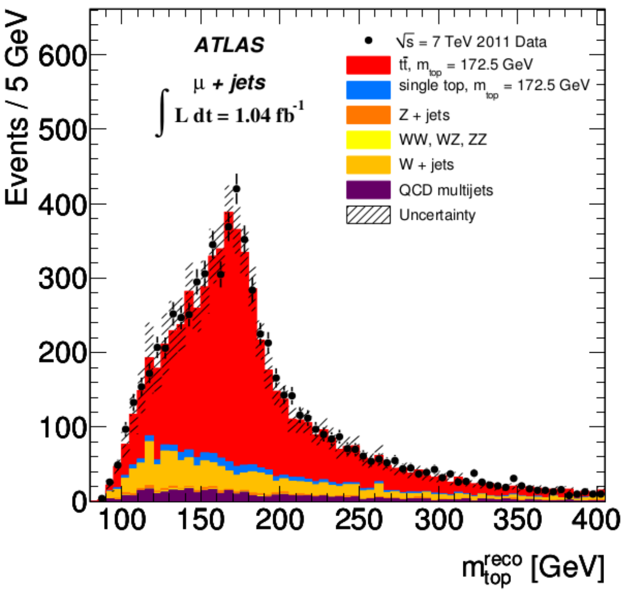
2D Template

- Construct jet triplet, 1 b-jet & 2 light jets
- Build m_{top}^{reco} with b-jet (unscaled) and light jets(scaled)
- Build m_{W}^{reco} with unscaled light jets

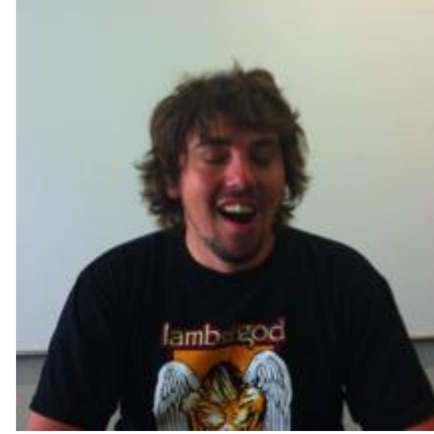
Construct templates with JSF varied from 0.9-1.1 and m_{top} from 160-190 GeV

- Parameterize likelihood functions with the templates.

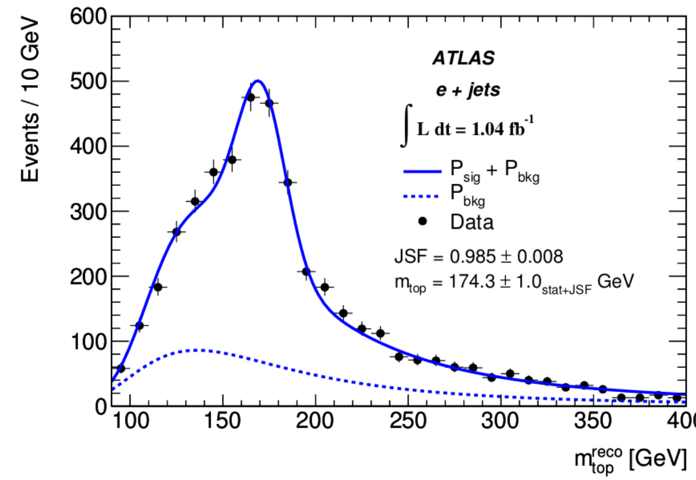


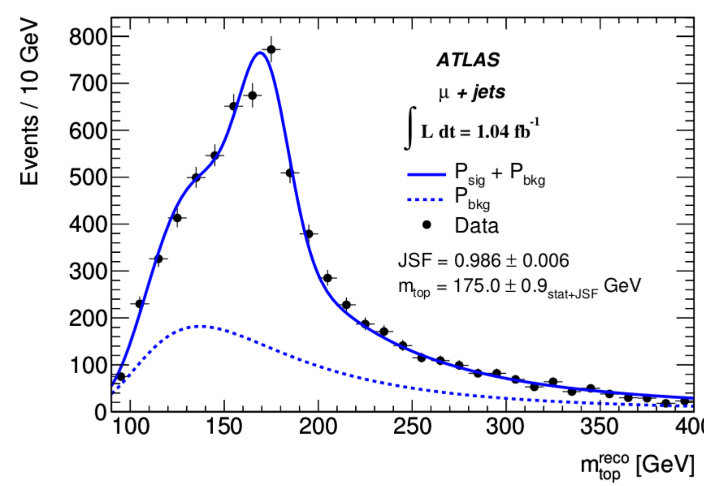


2D Template (Cont'd)



- Parametrization found to have good linearity for JSF and m_{top}
- Maximized likelihood with data and found





- e+jets: $m_{top}=174.3 \pm 0.8_{stat} \pm 2.3_{syst}$ GeV
- μ+jets: $m_{top}=175.0 \pm 0.7_{stat} \pm 2.6_{syst}$ GeV

Systematic Uncertainties

- vary parameters $\pm 1\sigma$
- run pseudo-experiments with changed parameters
- add in quadrature, no correlation

	1d template	2d template
Jet energy scale	0.71%	0.38%
b-jet energy scale	0.67%	0.91%
ISR and FSR	0.81%	0.58%
TOTAL	1.43%	1.32%

Largest contributions:

•Jet energy scale:

- Impact smaller than JES itself:
  - minimized in R32 observable for 1d fit.
  - constrained in 2d fit.

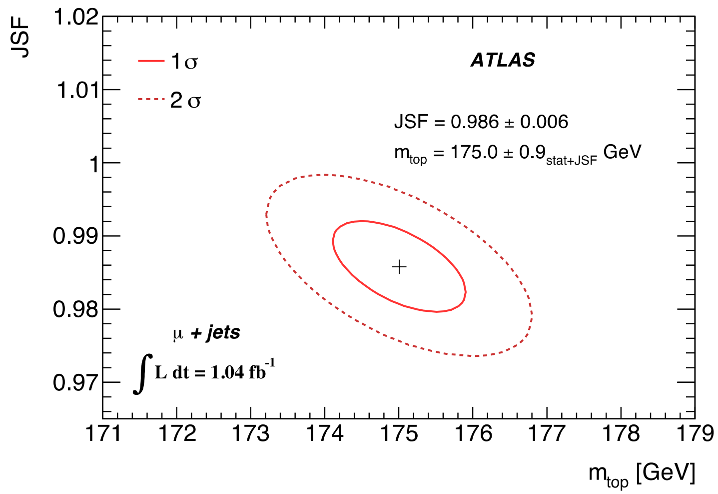
•b-jet energy scale

- Differences in fragmentation and hadronization of jets from light-quarks and b-quarks

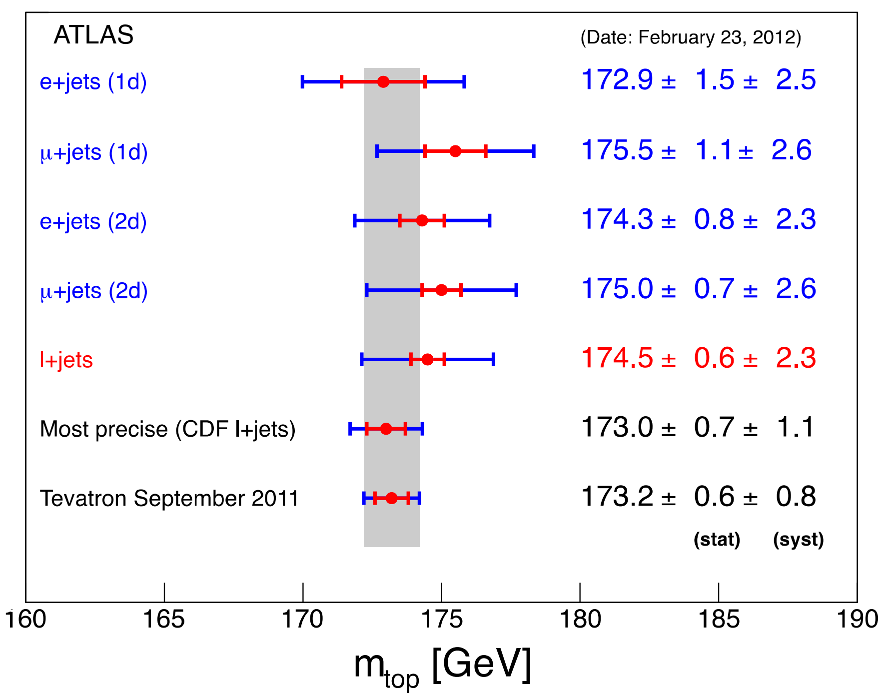
•ISR and FSR

- pseudo-experiments with dedicated signal samples where Pythia shower parameters are varied.

Conclusion



(b) μ+jets channel



- Top mass measured using 2 different methods

- Both mitigating the impact of the 3 largest systematics

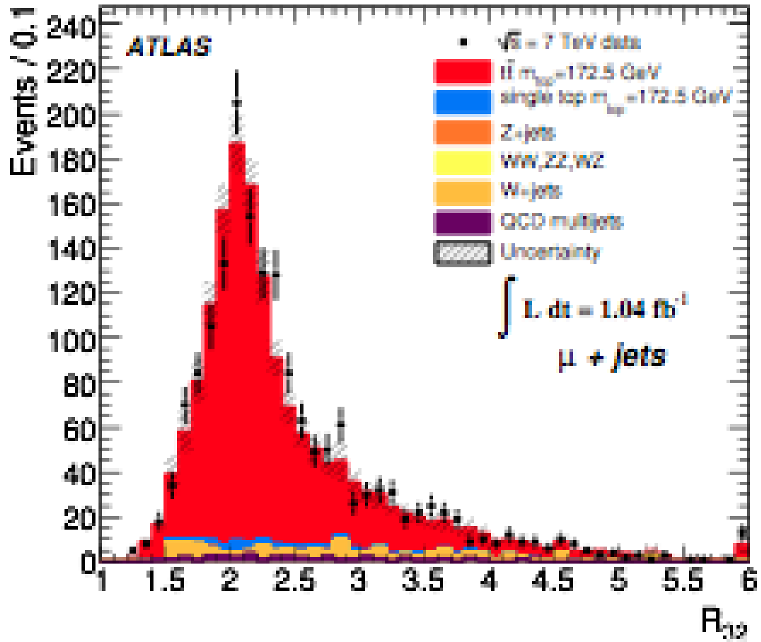
m_t = 174.5 ± 0.6(stat) ± 2.3(syst) GeV

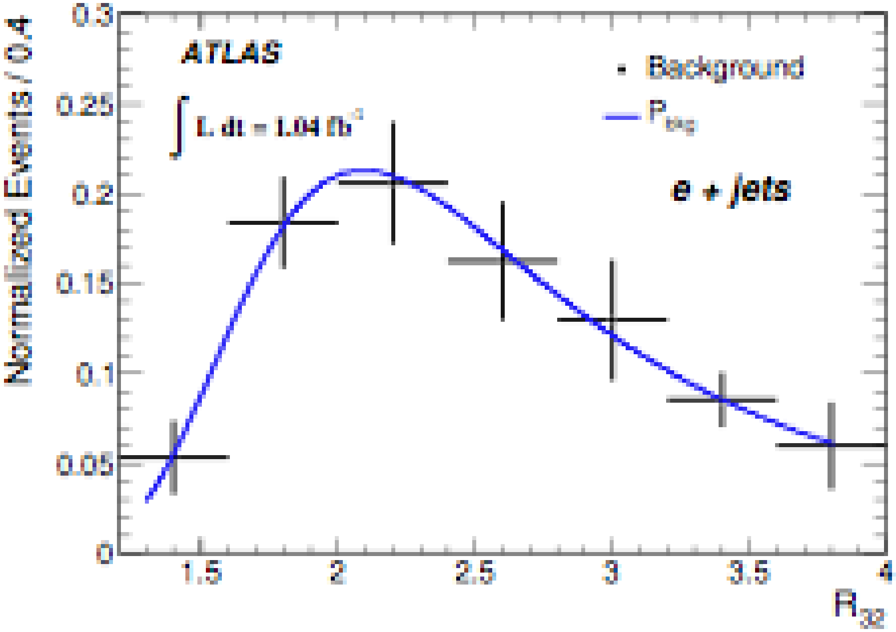
(2d analysis)

Back-up slides

Full systematics

	1d-analysis		2d-analysis		Combinations		Correlation
	e+jets	μ+jets	e+jets	μ+jets	1d	2d	ρ
Measured value of m_{top}	172.93	175.54	174.30	175.01	174.35	174.53	
Data statistics	1.46	1.13	0.83	0.74	0.91	0.61	
Jet energy scale factor	na	na	0.59	0.51	na	0.43	0
Method calibration	0.07	< 0.05	0.10	< 0.05	< 0.05	0.07	0
Signal MC generator	0.81	0.69	0.39	0.22	0.74	0.33	1
Hadronisation	0.33	0.52	0.20	0.06	0.43	0.15	1
Pileup	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	1
Underlying event	0.06	0.10	0.42	0.96	0.08	0.59	1
Colour reconnection	0.47	0.74	0.32	1.04	0.62	0.55	1
ISR and FSR (signal only)	1.45	1.40	1.04	0.95	1.42	1.01	1
Proton PDF	0.22	0.09	0.10	0.10	0.15	0.10	1
W+jets background normalisation	0.16	0.19	0.34	0.44	0.18	0.37	1
W+jets background shape	0.11	0.18	0.07	0.22	0.15	0.12	1
QCD multijet background normalisation	0.07	< 0.05	0.25	0.33	< 0.05	0.20	(1)
QCD multijet background shape	0.14	0.12	0.38	0.30	0.09	0.27	(1)
Jet energy scale	1.21	1.25	0.63	0.71	1.23	0.66	1
b-jet energy scale	1.09	1.21	1.61	1.53	1.16	1.58	1
b-tagging efficiency and mistag rate	0.21	0.13	0.31	0.26	0.17	0.29	1
Jet energy resolution	0.34	0.38	0.07	0.07	0.36	0.07	1
Jet reconstruction efficiency	0.08	0.11	< 0.05	< 0.05	0.10	< 0.05	1
Missing transverse momentum	< 0.05	< 0.05	0.12	0.16	< 0.05	0.13	1
Total systematic uncertainty	2.46	2.56	2.31	2.57	2.50	2.31	
Total uncertainty	2.86	2.80	2.46	2.68	2.66	2.39	


ATLAS
√s = 7 TeV data
tt̄ m_top=172.5 GeV
single top m_top=172.5 GeV
Z+jets
WW,ZZ,WZ
W+jets
QCD multijets
Uncertainty
∫ L dt = 1.04 fb⁻¹
μ + jets
Events / 0.1
R32


ATLAS
Background
P_bkg
∫ L dt = 1.04 fb⁻¹
e + jets
Normalized Events / 0.4
R32