Extraction of the top quark mass in ATLAS: Theory meets experiment

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IMPRS Kolloquium

MPP

26th April 2018

Introduction

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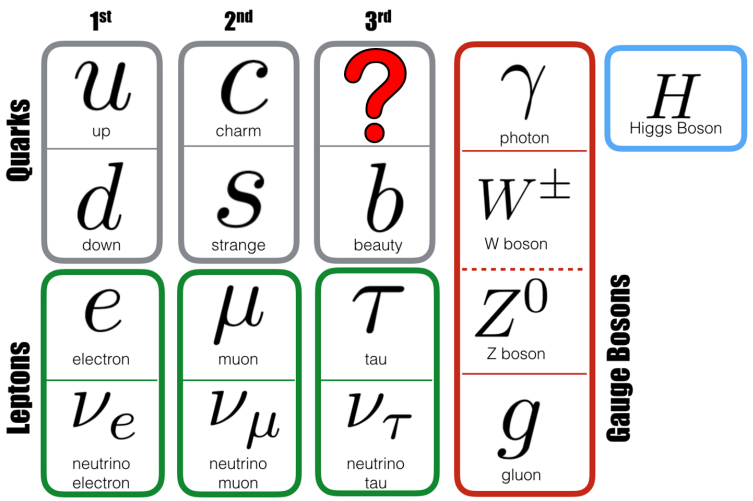

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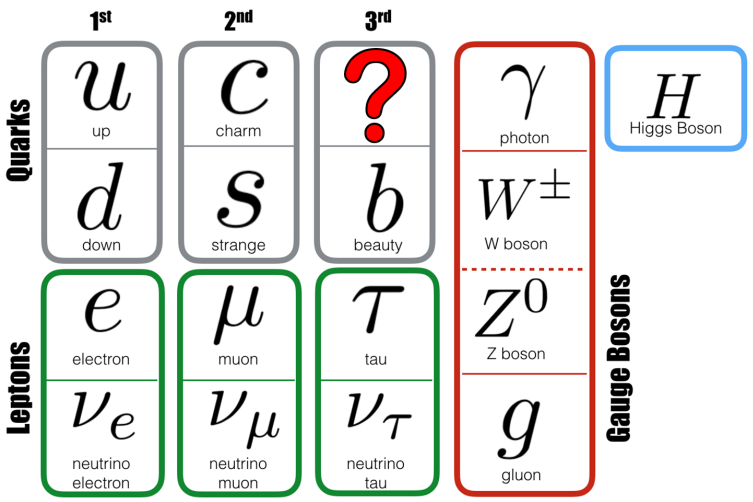

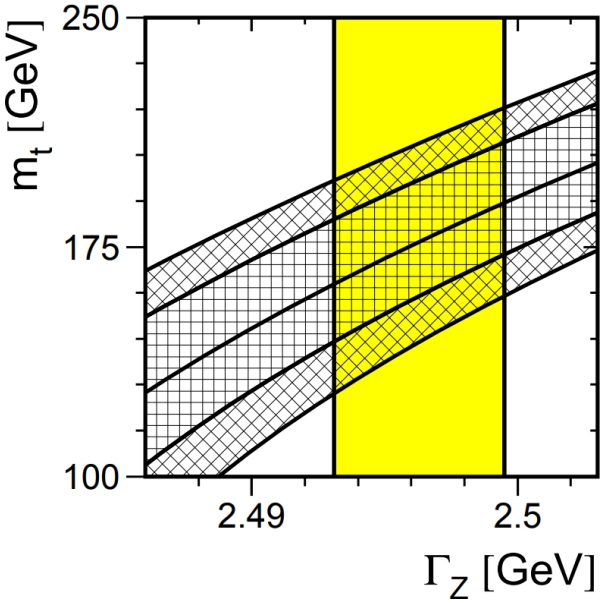

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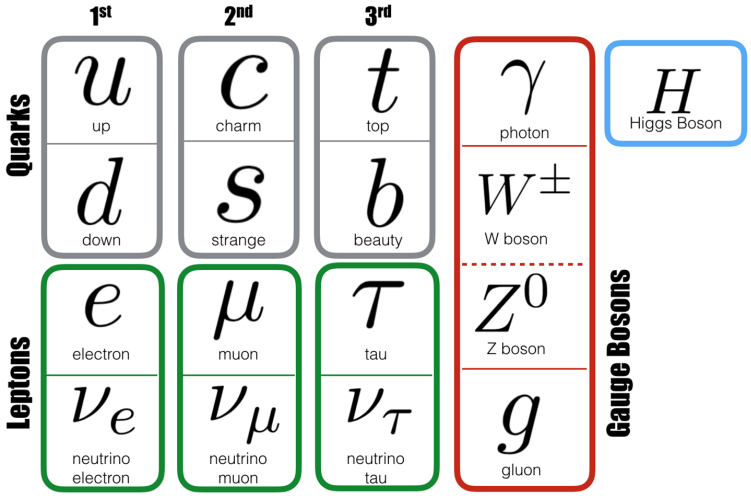
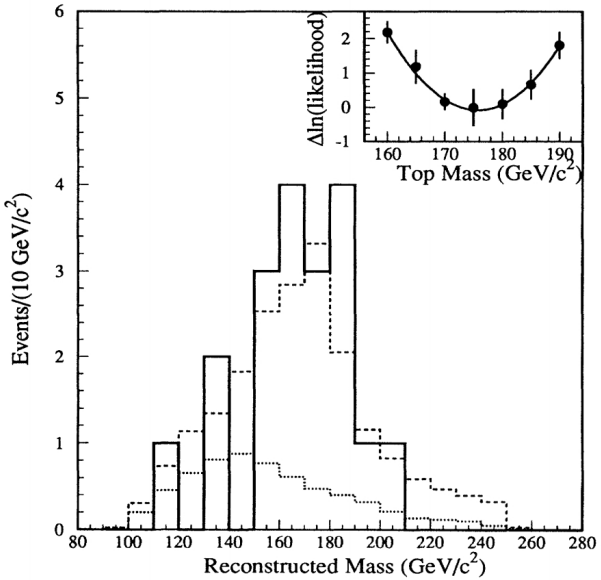


- Top quark discovered 18 years later at CDF and DØ!



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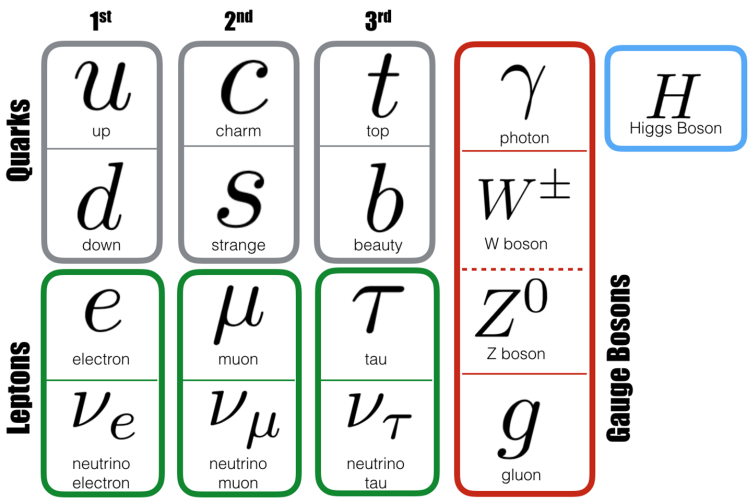

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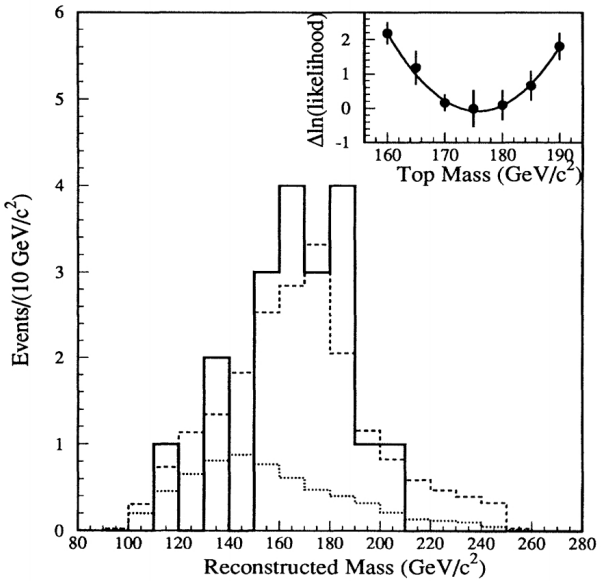
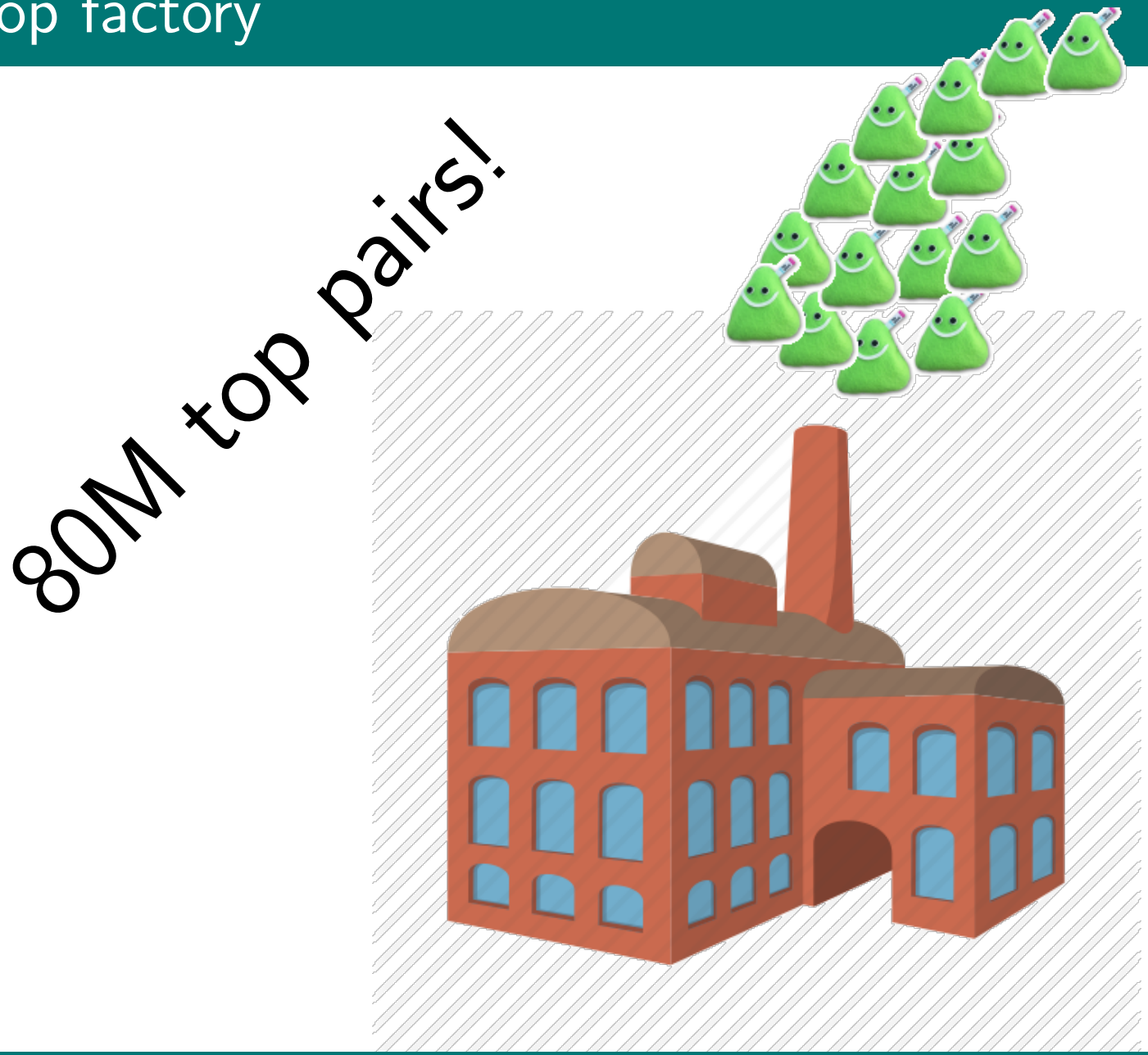


LHC $\simeq$ 80M top pairs produced

A top factory



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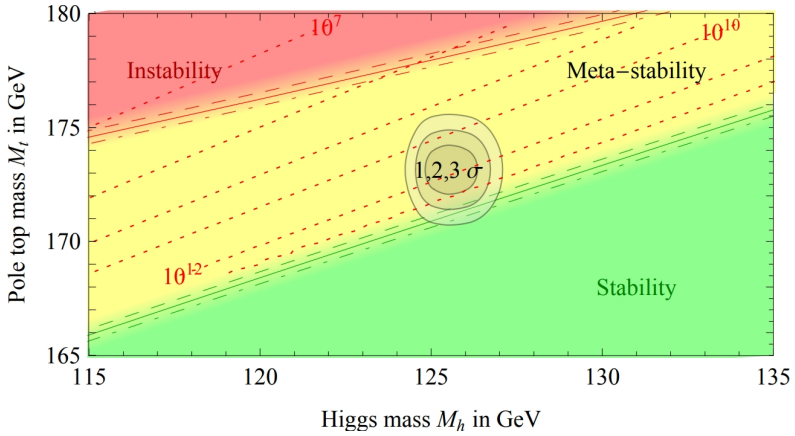

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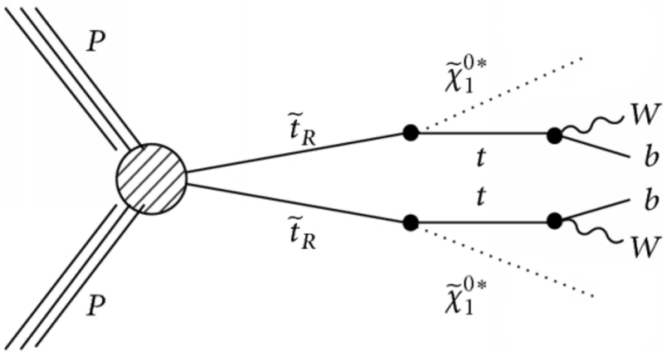
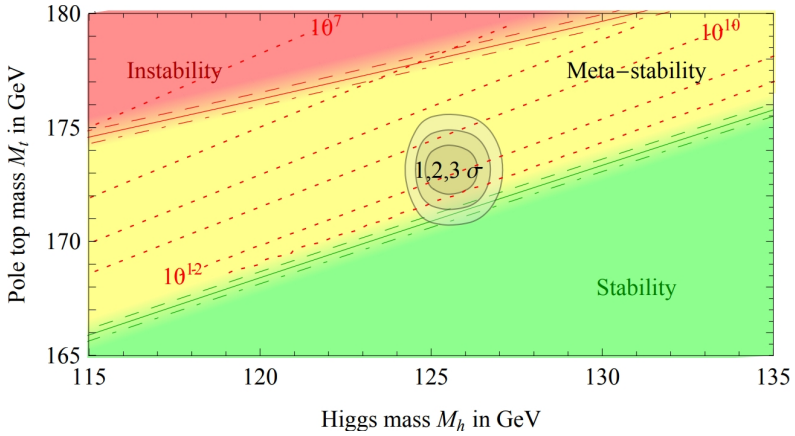
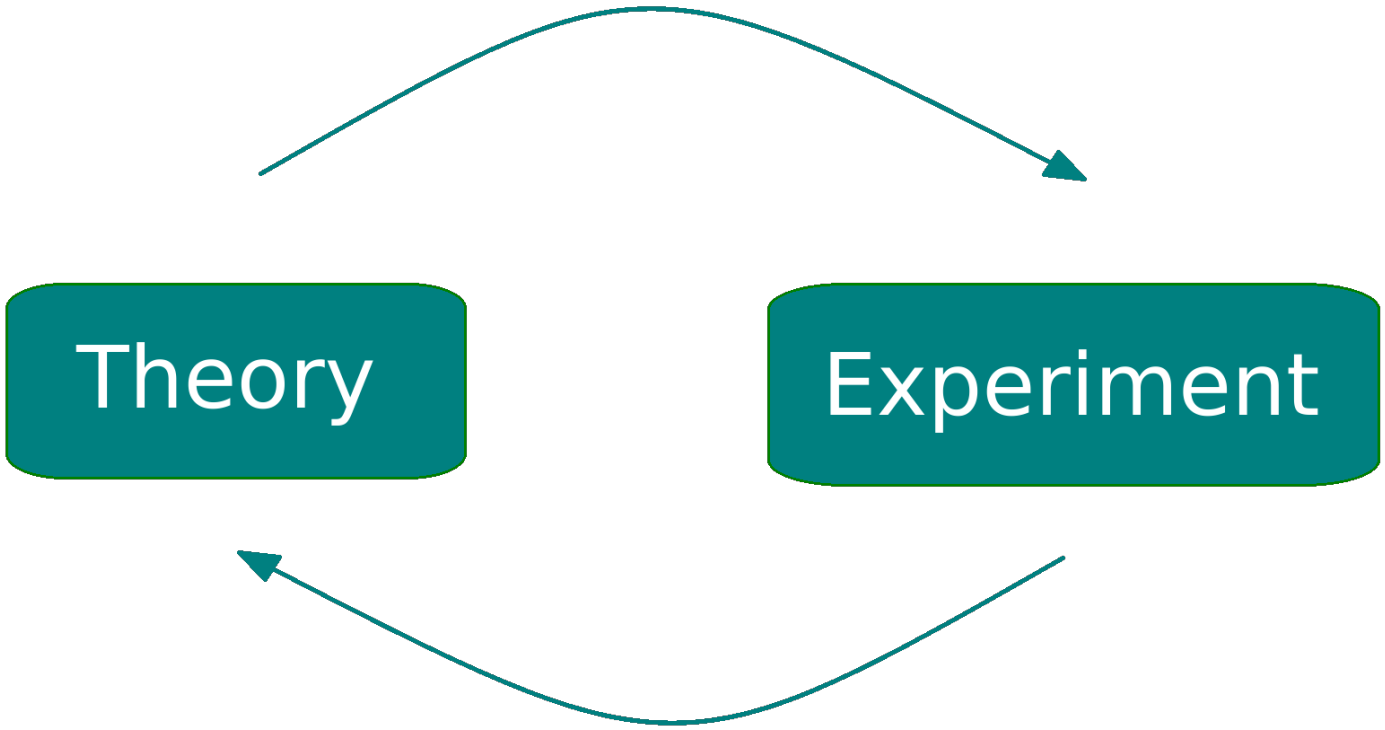
  - Important background in BSM searches





Theorists and experimentalists

Why is my friend acting so passive-aggressive towards me?



Mass measurements

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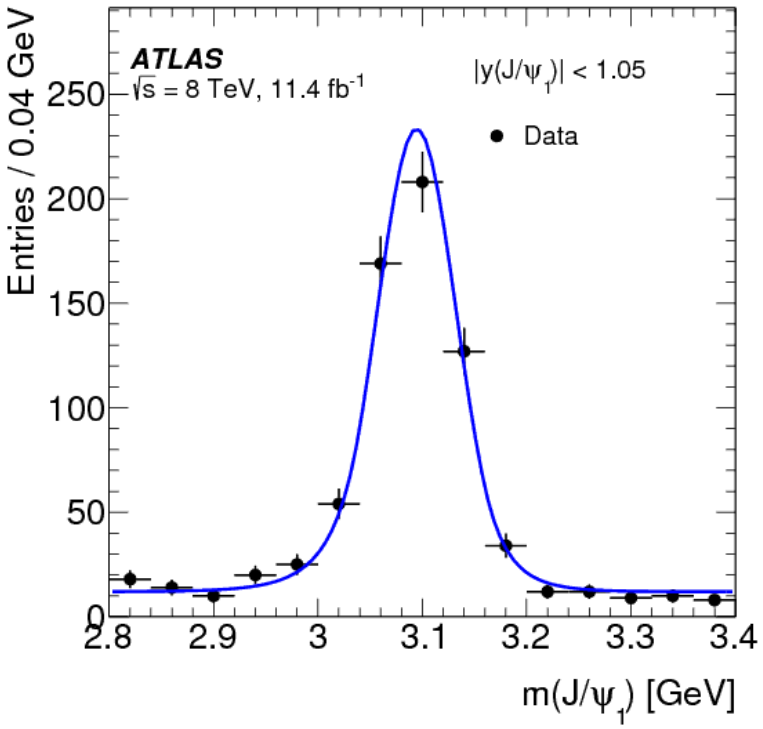

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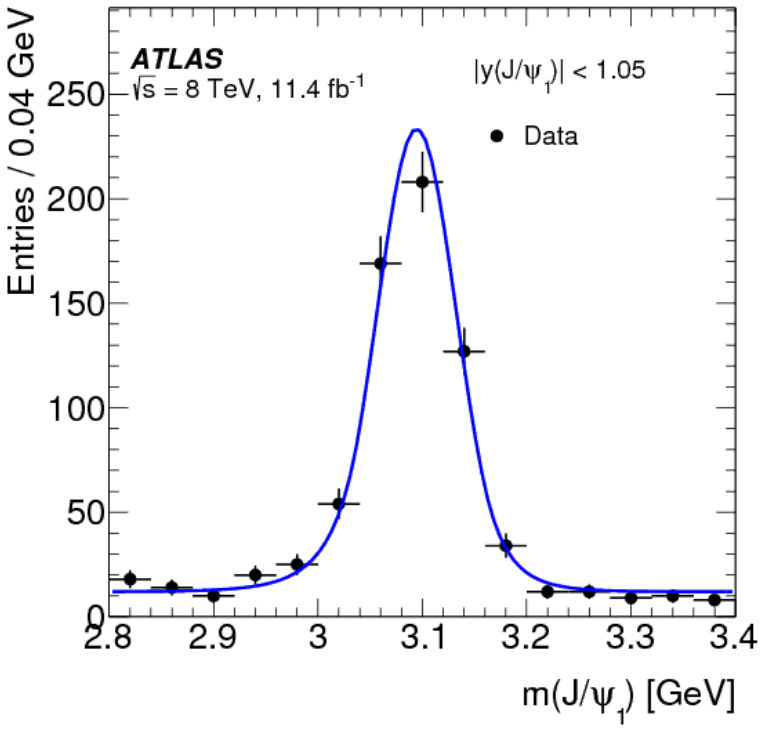
  - ...



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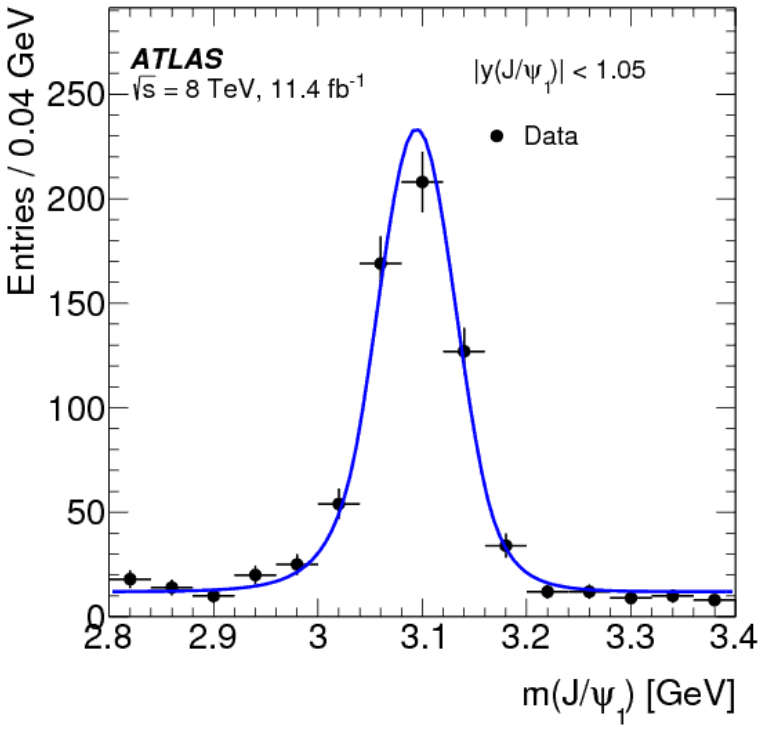
$$\Gamma(\text{decay}) \leftrightarrow \frac{\text{S}}{\text{B}}, \text{ resolution, } ...$$



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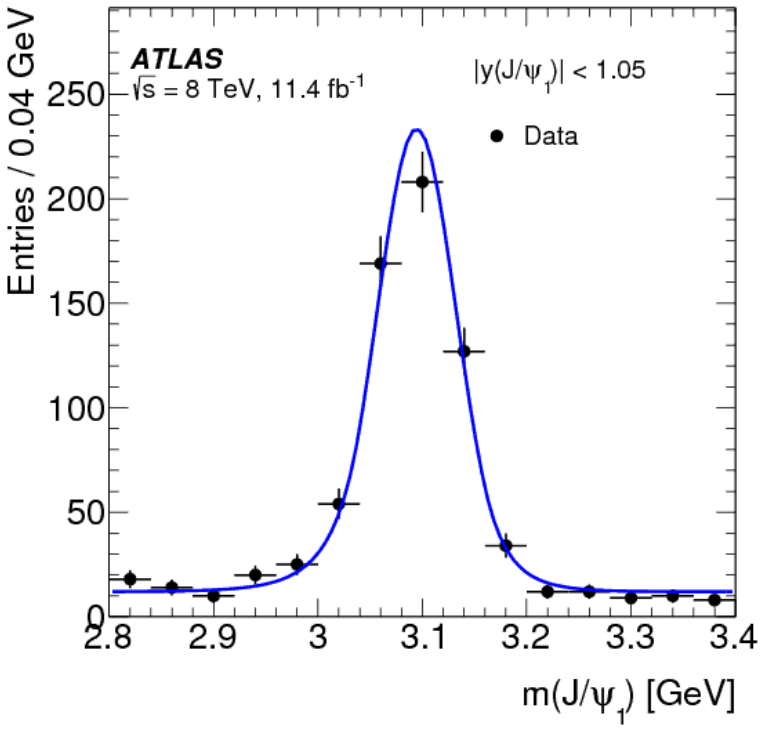

$\longrightarrow$ Top decay reconstruction

Top pair production: event topology

- Top decay: $\Gamma(t \to Wb) = 0.998$
  - $\Gamma(W \to q\,\bar{q}') = 0.67$
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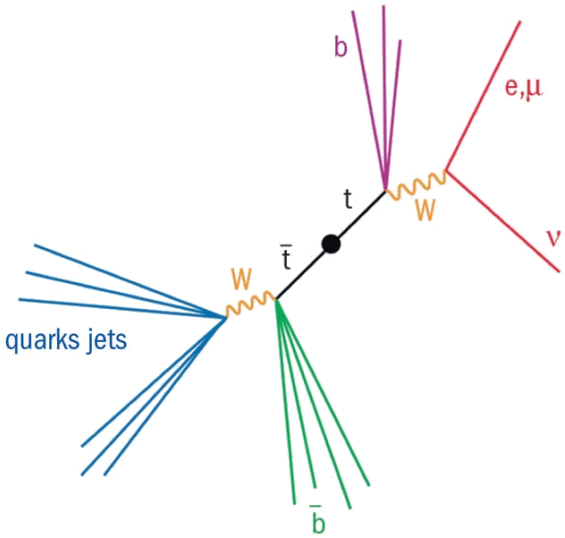

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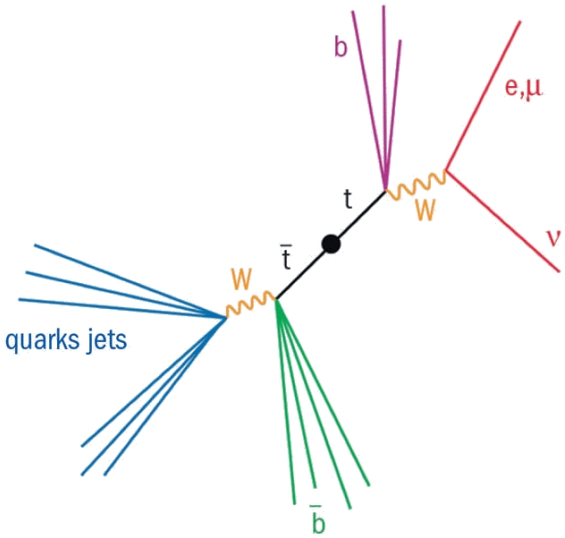
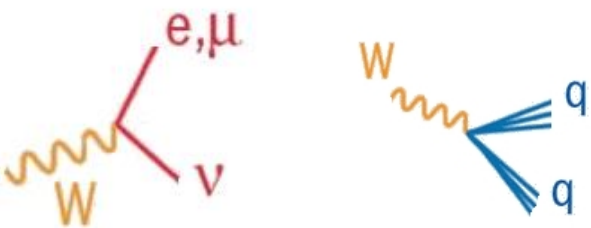
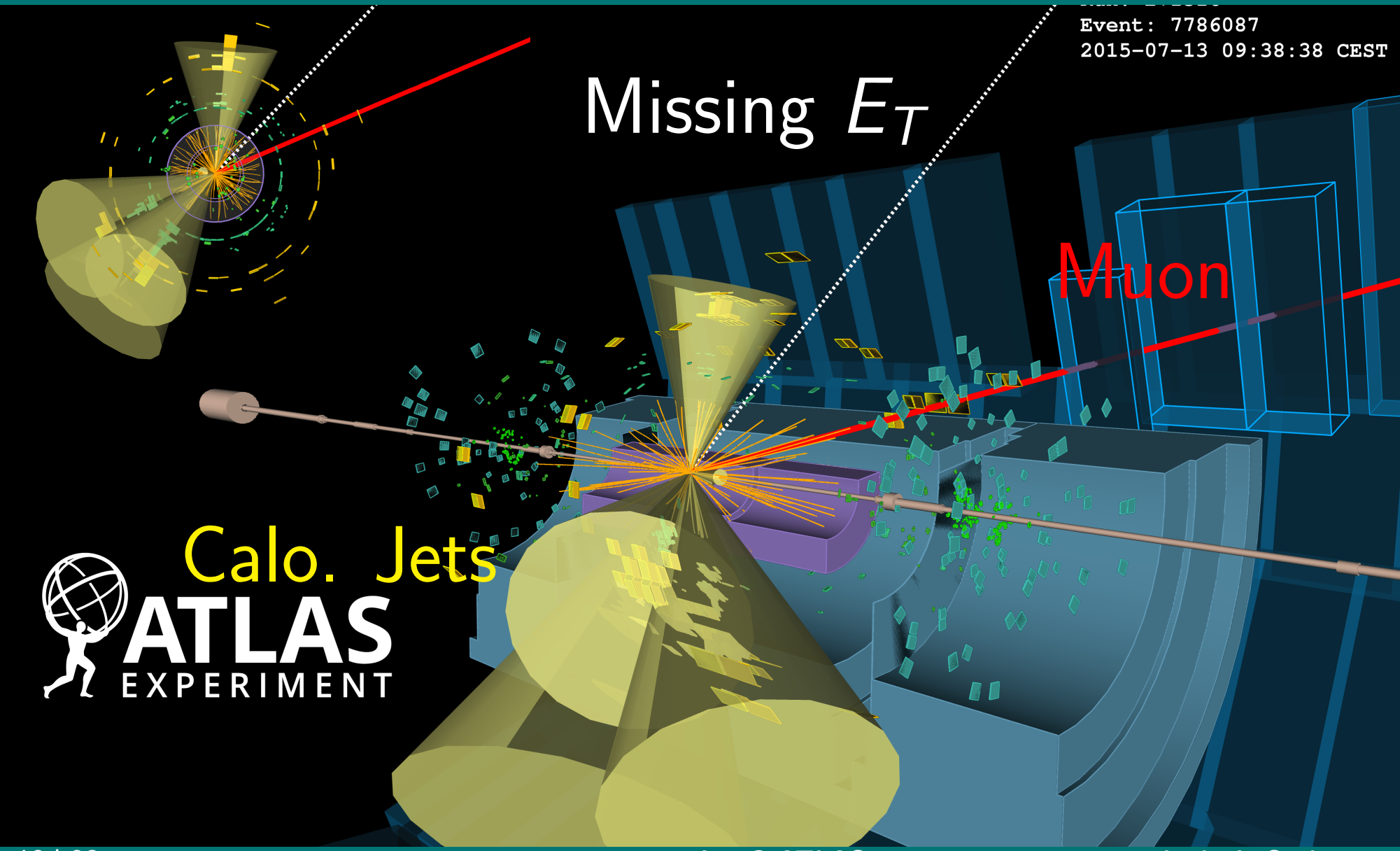




Top quark pair production @ ATLAS



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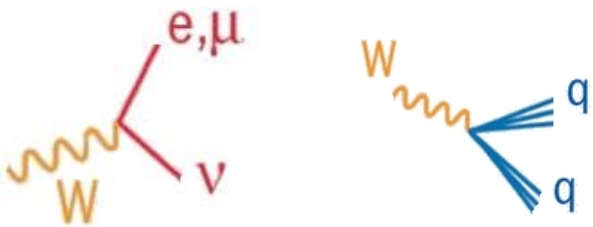

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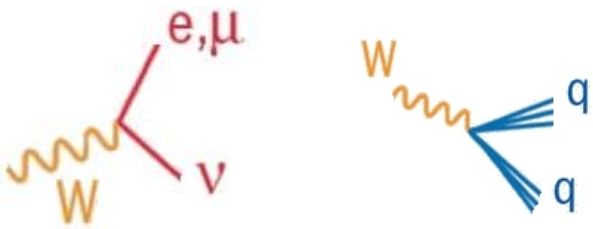

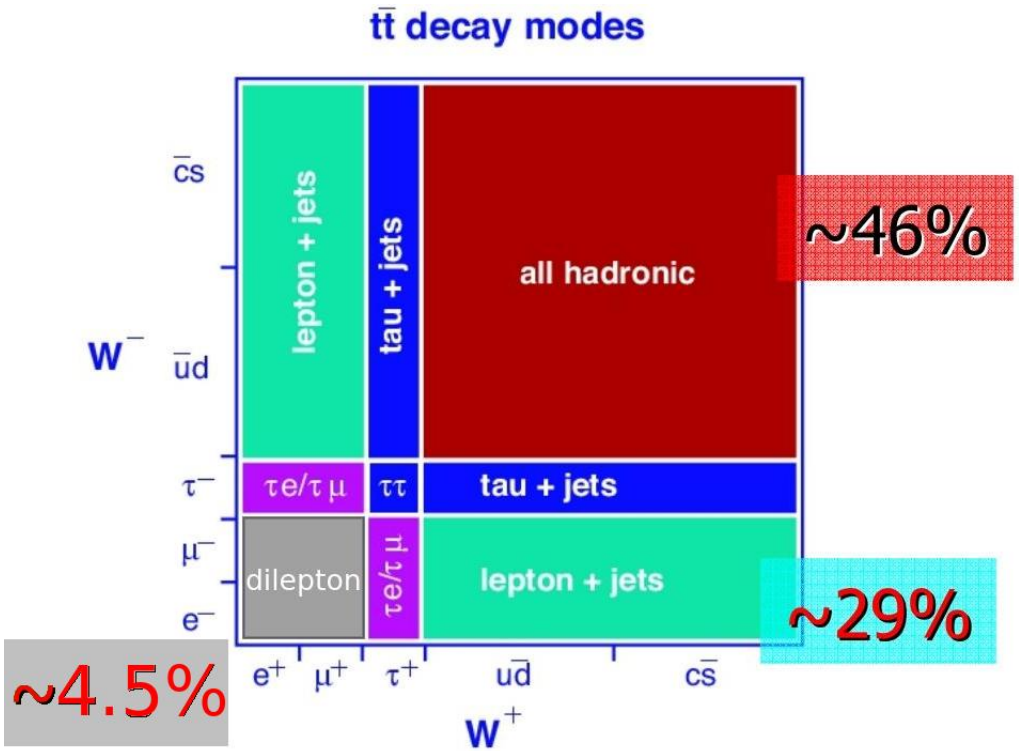

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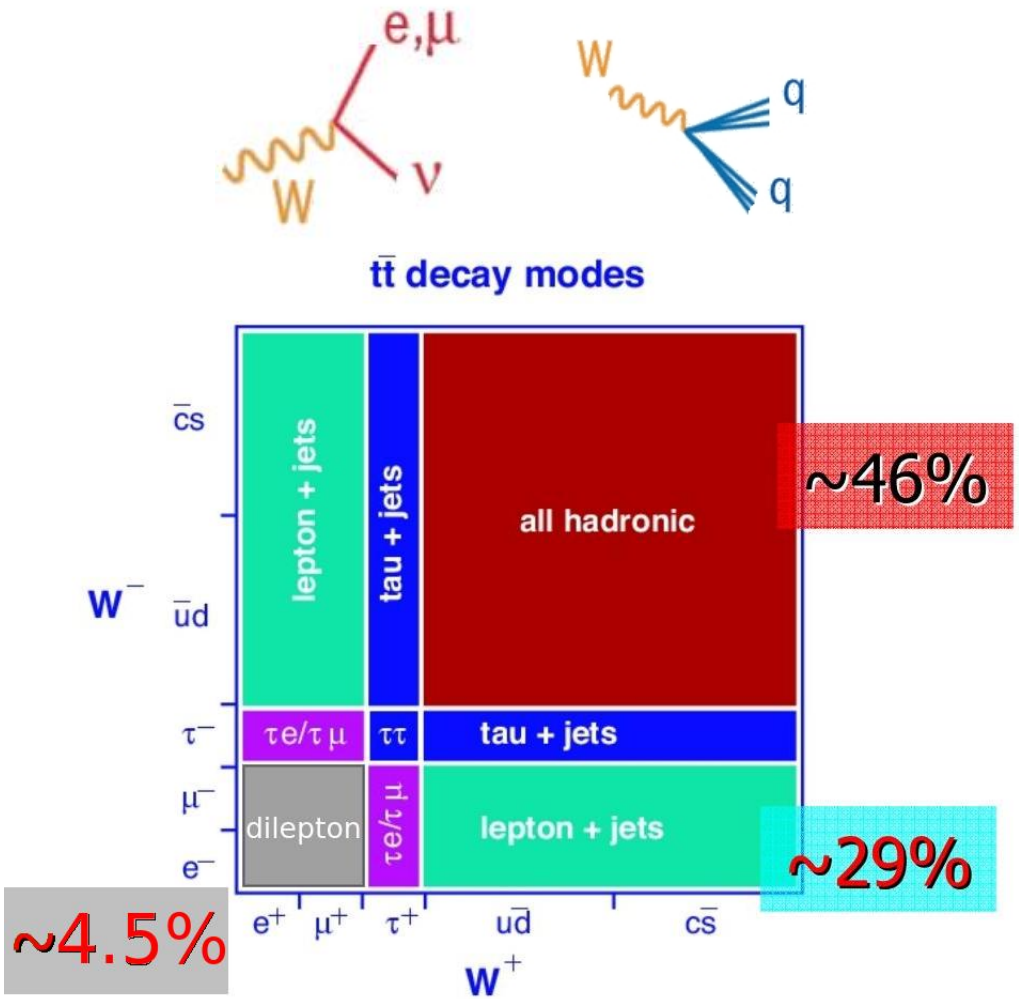

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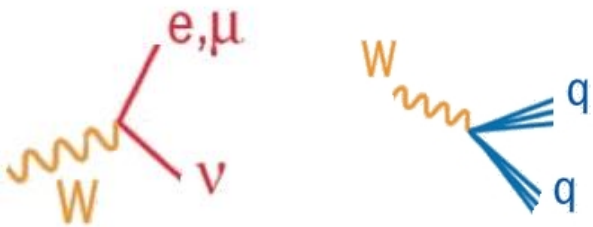
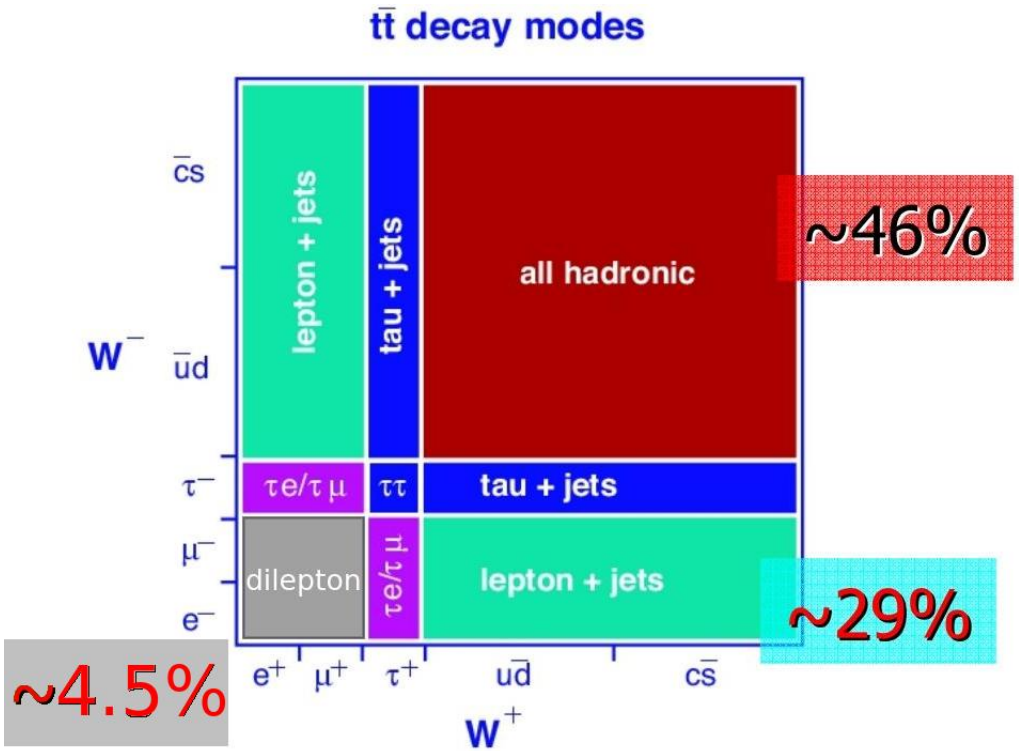
  - Dilepton
    - \+ Clean signature
    - \- No full reconstruction





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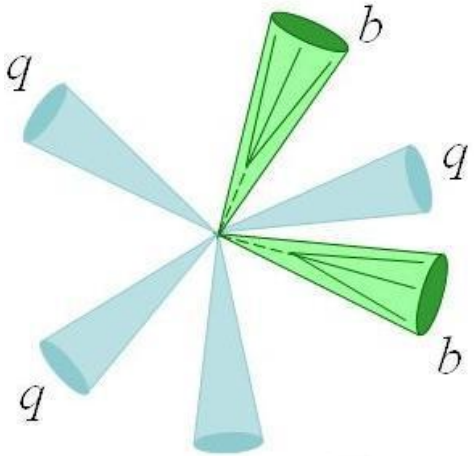
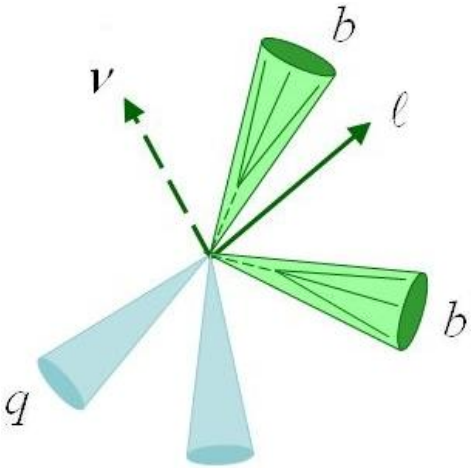
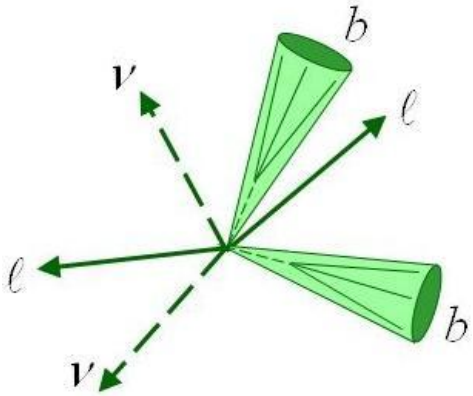
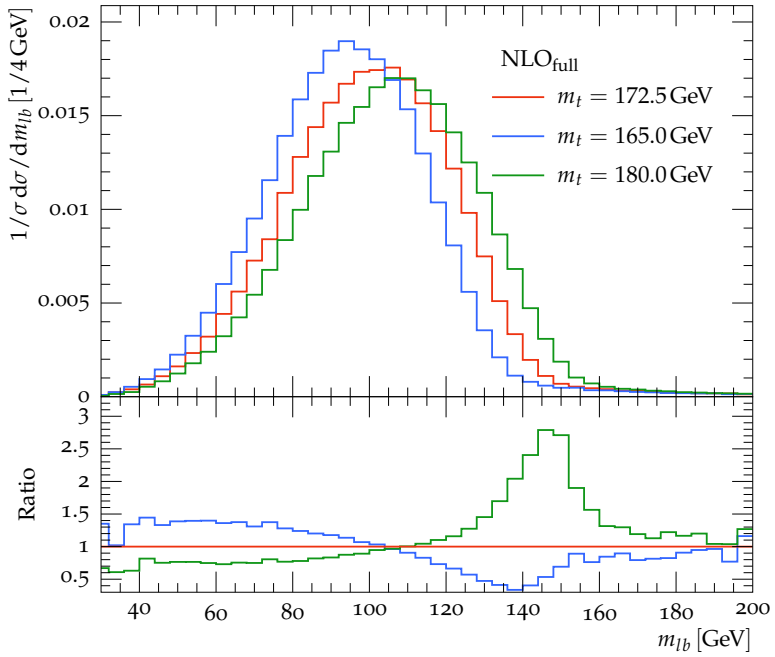
		
$t\bar{t} \to qqqqb\bar{b}$	$t\bar{t} \to \ell\nu qqb\bar{b}$	$t\bar{t} \to \ell^+\nu\ell^-\nu b\bar{b}$
≥ 4 light jets	≥ 2 light jets	–
0 id. leptons	$= 1$ id. lepton	$= 2$ id. leptons
–	MET	MET

The template method

General idea

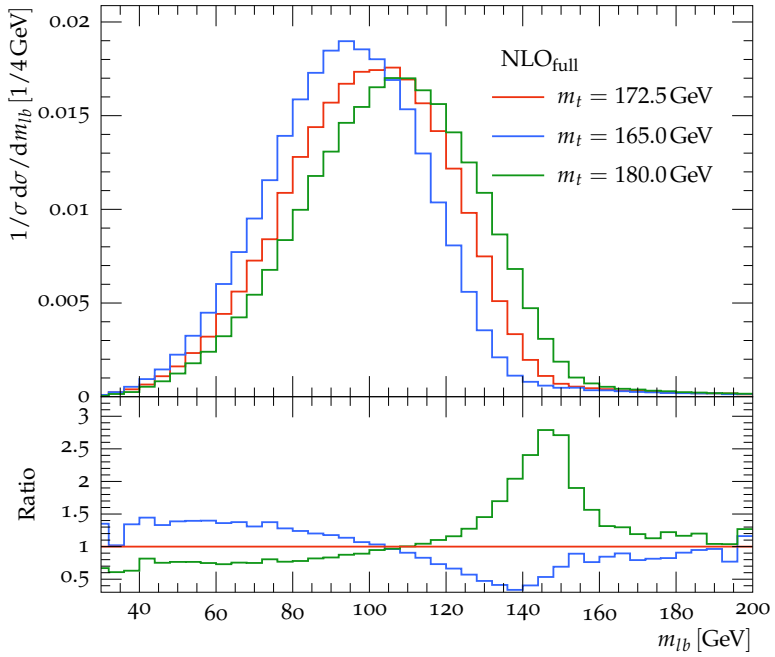
- 1. Choose distributions sensitive to the top-quark mass



General idea

- 1. Choose distributions sensitive to the top-quark mass
- 2. Generate distributions for different input m_t^{in}:

$$m_t^{in} \in [165.0, 172.5, 180.0] \ \mathrm{GeV}$$



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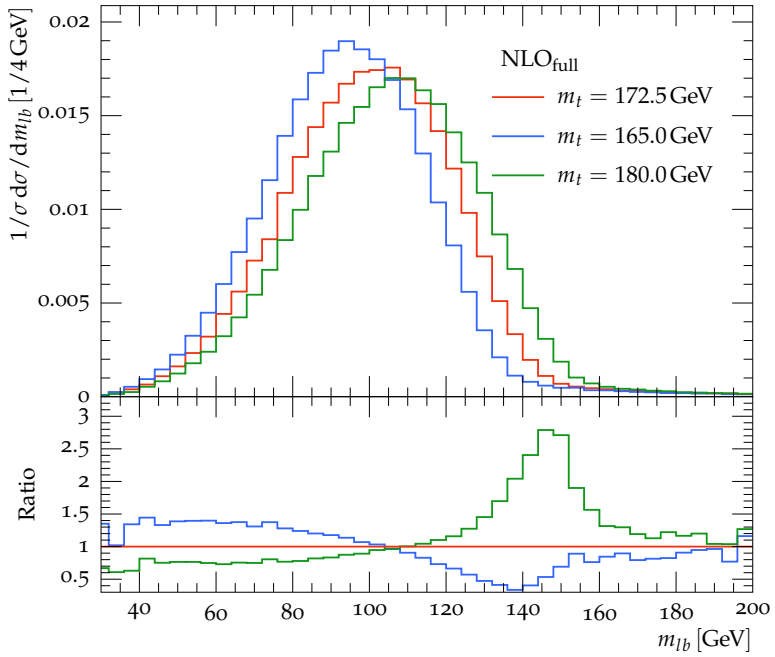
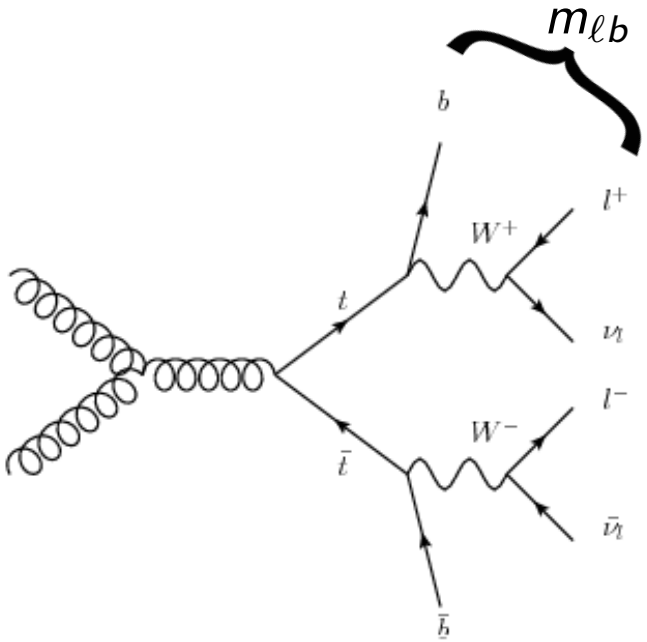
- 3. Fit the data to extract m_t^{in}



Simple example: dilepton channel @ 8 TeV

[Phys. Lett. B 761] ATLAS Collaboration, 2016

- 1. Choose $m_{lb}^2 = (p_\ell + p_b)^2$



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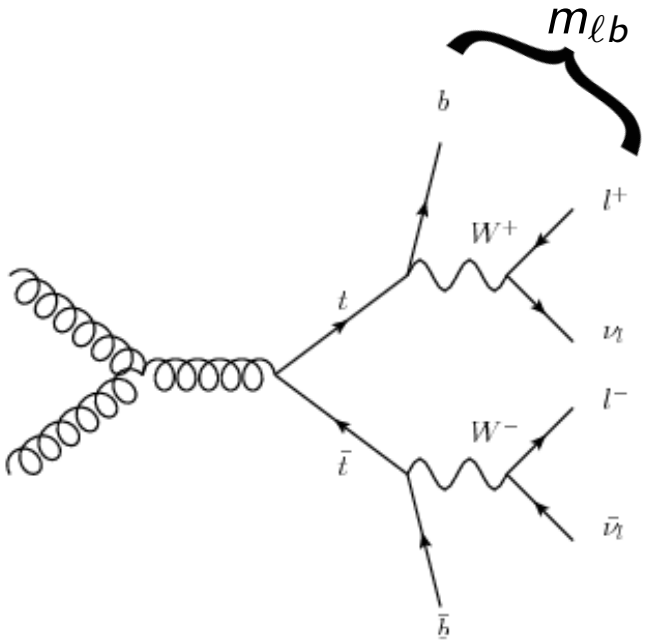

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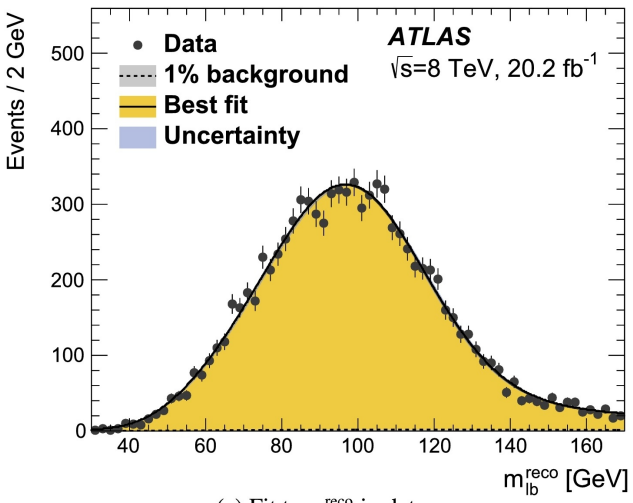
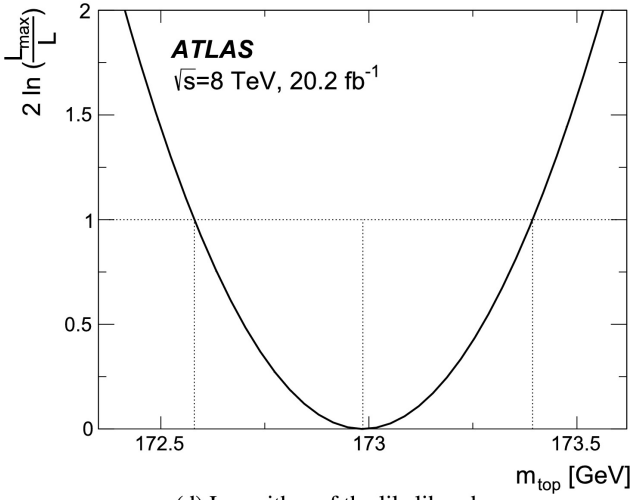


(c) Fit to $m_{\ell b}^{reco}$ in data



(d) Logarithm of the likelihood

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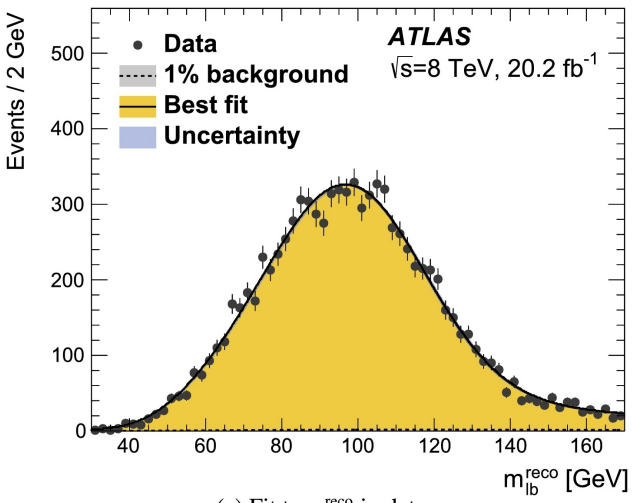
$$m_t = 172.99 \pm 0.41(\mathrm{stat})\ \mathrm{GeV}$$



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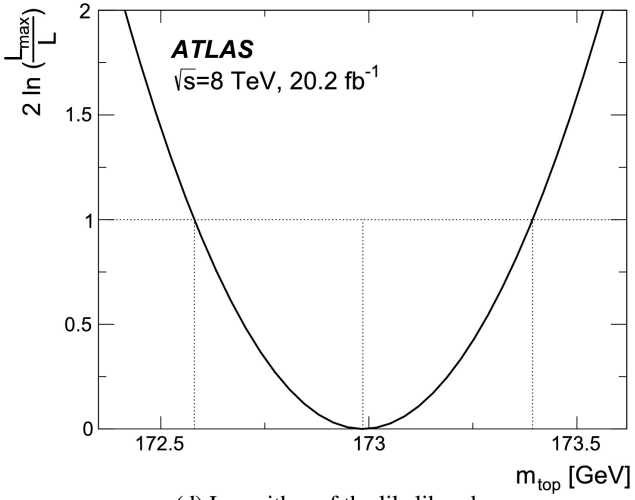

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A more complex example: ℓ + jets @ 7 TeV

[Eur. Phys. J. C72] ATLAS Collaboration, 2012

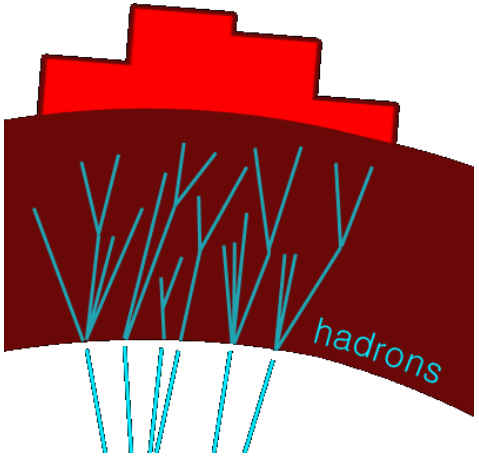
Jet energy scale (JES)

- ⋆ From 7 TeV analysis:
  - JES, b-JES are the largest systematic uncert.

	e+jets	μ+jets
Measured value of m_{top}	172.93	175.54
Data statistics	1.46	1.13
Jet energy scale factor	na	na
Method calibration	0.07	< 0.05
Signal MC generator	0.81	0.69
Hadronisation	0.33	0.52
Pileup	< 0.05	< 0.05
Underlying event	0.06	0.10
Colour reconnection	0.47	0.74
ISR and FSR (signal only)	1.45	1.40
Proton PDF	0.22	0.09
W+jets background normalisation	0.16	0.19
W+jets background shape	0.11	0.18
QCD multijet background normalisation	0.07	< 0.05
QCD multijet background shape	0.14	0.12
Jet energy scale	1.21	1.25
b-jet energy scale	1.09	1.21
b-tagging efficiency and mistag rate	0.21	0.13
Jet energy resolution	0.34	0.38
Jet reconstruction efficiency	0.08	0.11
Missing transverse momentum	< 0.05	< 0.05
Total systematic uncertainty	2.46	2.56
Total uncertainty	2.86	2.80

Jet energy calibration

- Jets energy measured by hadron calorimeter deposits



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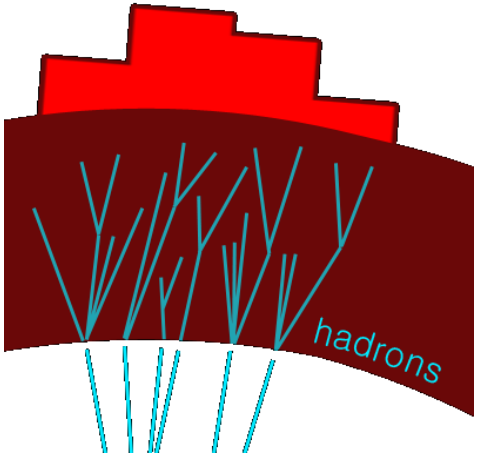

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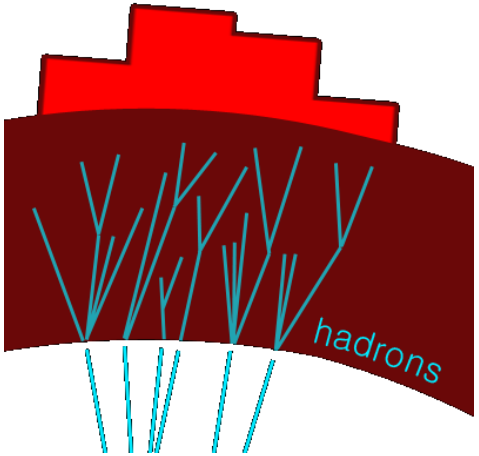
  - MC simulation: JES= $\frac{E_{\mathrm{MC}}}{E_{\mathrm{meas}}}$



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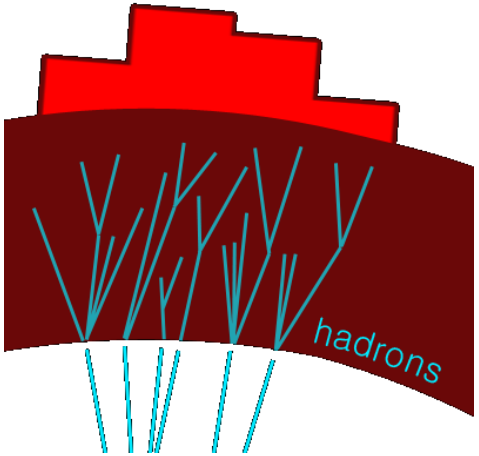

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- Not 100% effective → correction factors
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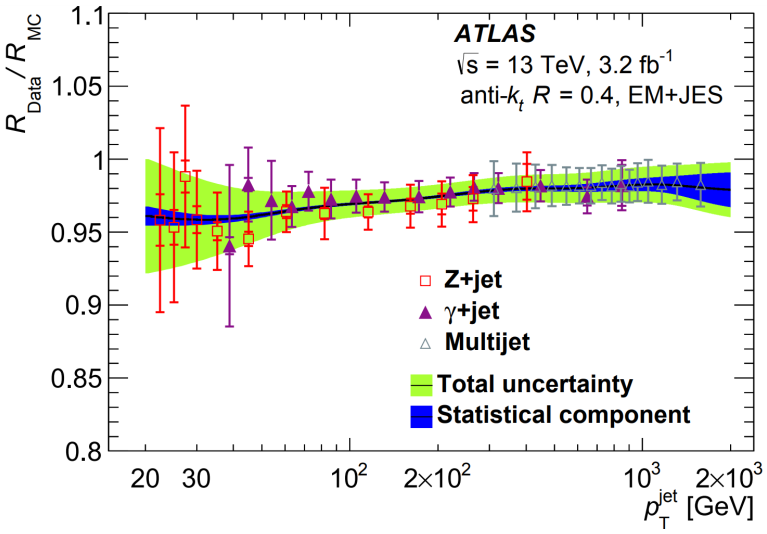
  - ...



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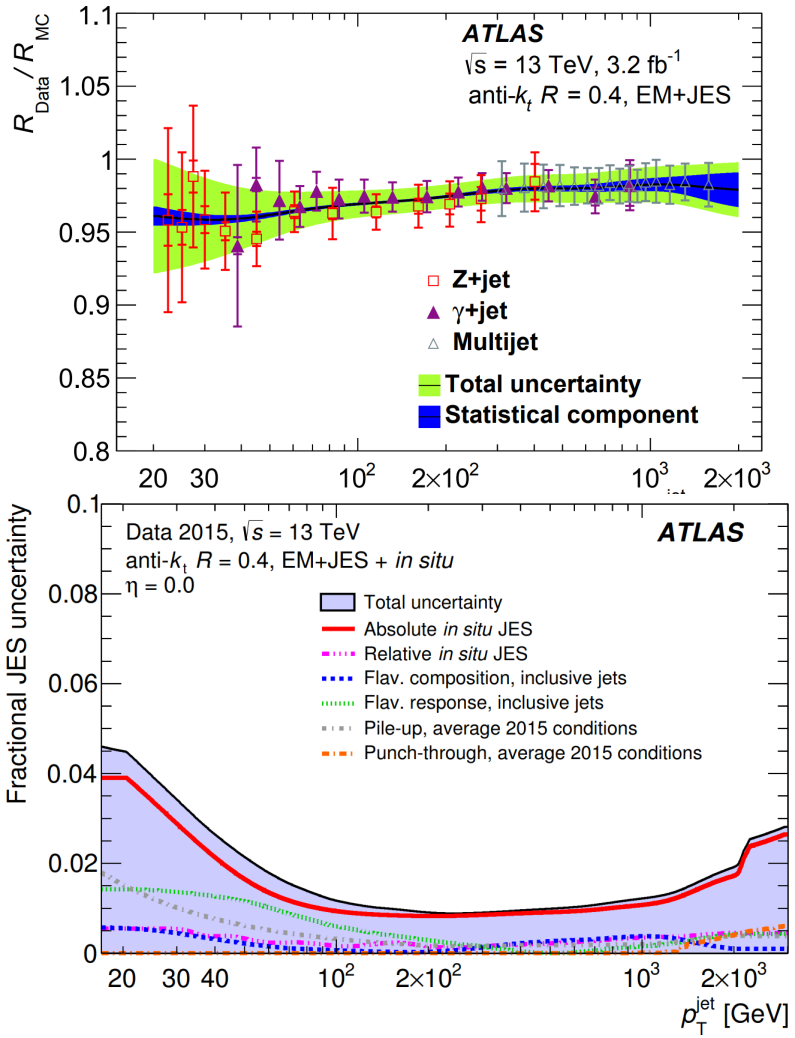

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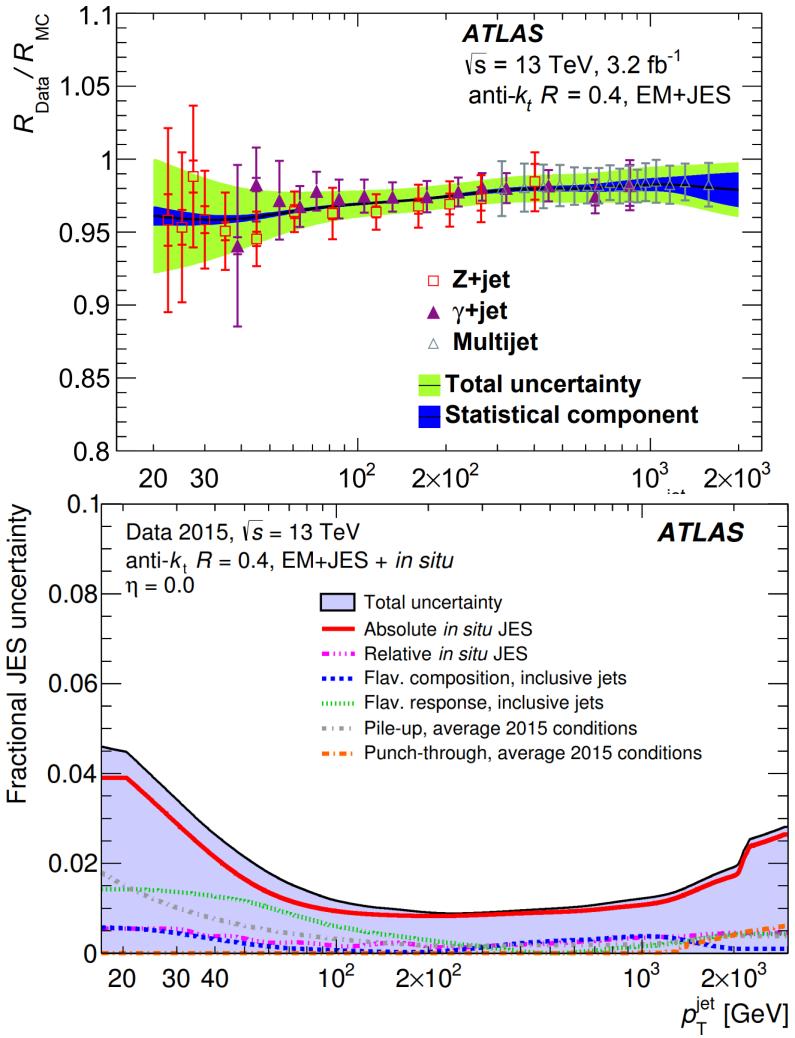

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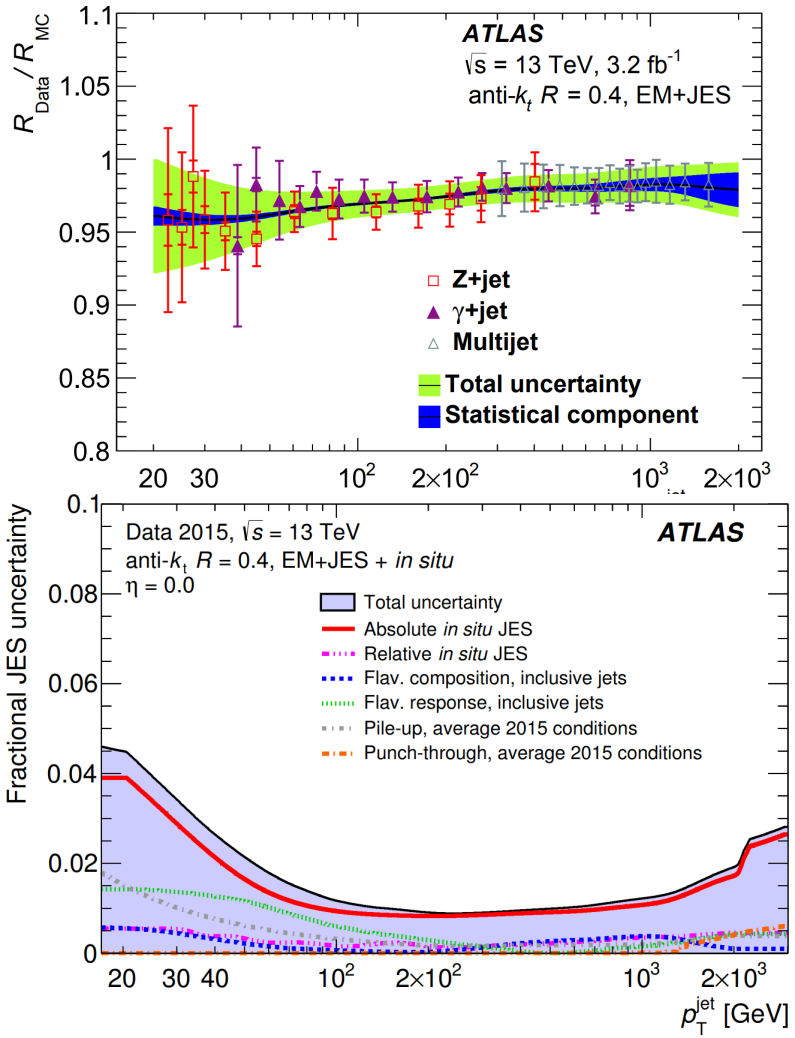

A more complex example: ℓ + jets @ 8 TeV

[Eur. Phys. J. C72] ATLAS Collaboration, 2012

- ⋆ From 7 TeV analysis:
  - JES, b-JES are the largest systematic uncertainty

	e+jets	μ+jets
Measured value of m_{top}	172.93	175.54
Data statistics	1.46	1.13
Jet energy scale factor	na	na
Method calibration	0.07	< 0.05
Signal MC generator	0.81	0.69
Hadronisation	0.33	0.52
Pileup	< 0.05	< 0.05
Underlying event	0.06	0.10
Colour reconnection	0.47	0.74
ISR and FSR (signal only)	1.45	1.40
Proton PDF	0.22	0.09
W+jets background normalisation	0.16	0.19
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QCD multijet background normalisation	0.07	< 0.05
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Jet energy scale	1.21	1.25
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b-tagging efficiency and mistag rate	0.21	0.13
Jet energy resolution	0.34	0.38
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Missing transverse momentum	< 0.05	< 0.05
Total systematic uncertainty	2.46	2.56
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ℓ + jets @ 8 TeV

[ATLAS-CONF-2017-071] ATLAS Collaboration, 2012

- 3 parameters to fit: m_t^{in}, JSF, bJSF
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  - Reco. top mass $m_t^{\mathrm{reco}} \propto m_t^{\mathrm{in}}$, JSF, bJSF
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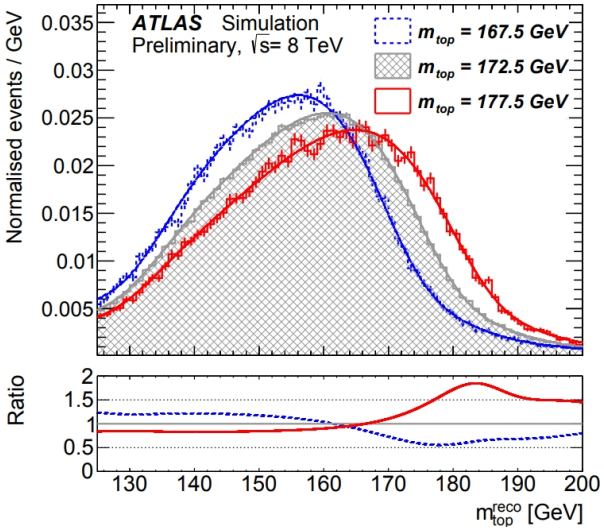
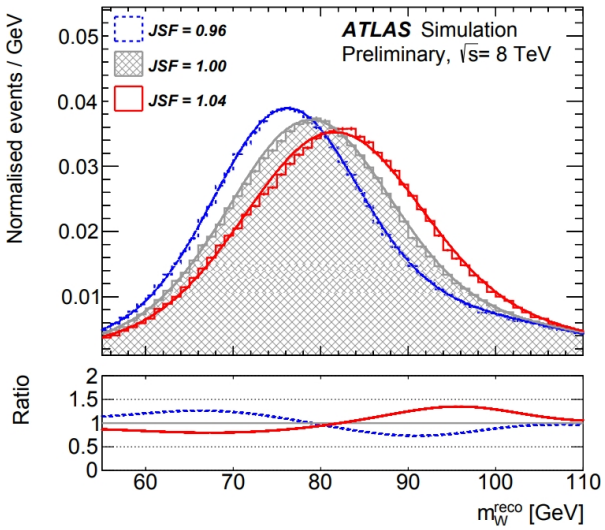
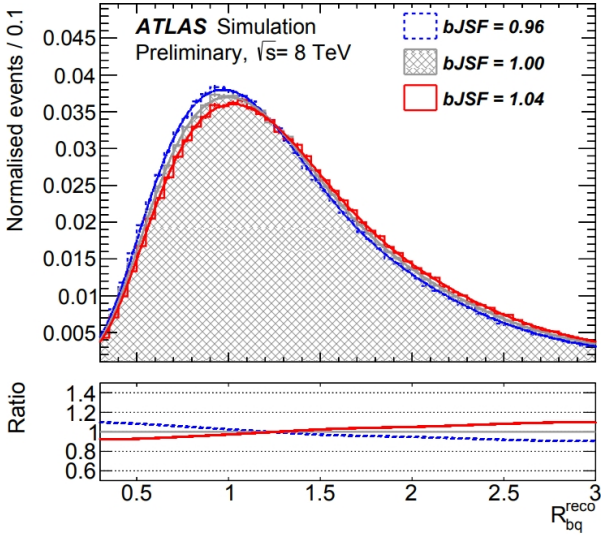


(a) $m_{\text{top}}^{\text{reco}}$ as a function of m_{top}

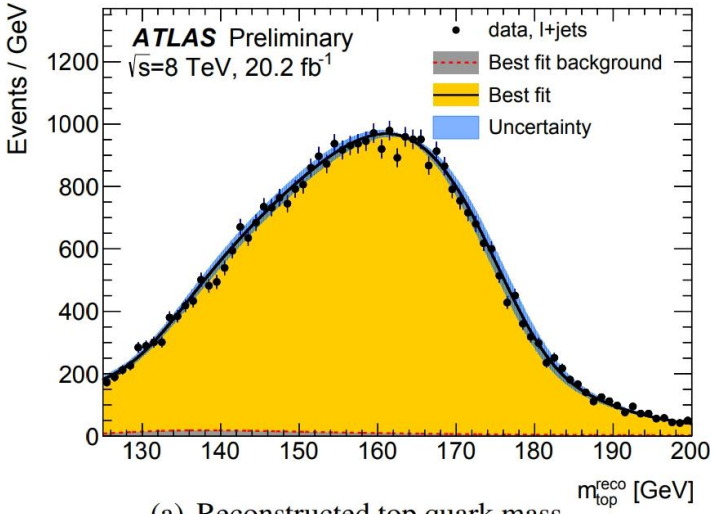


(d) m_W^{reco} as a function of JSF

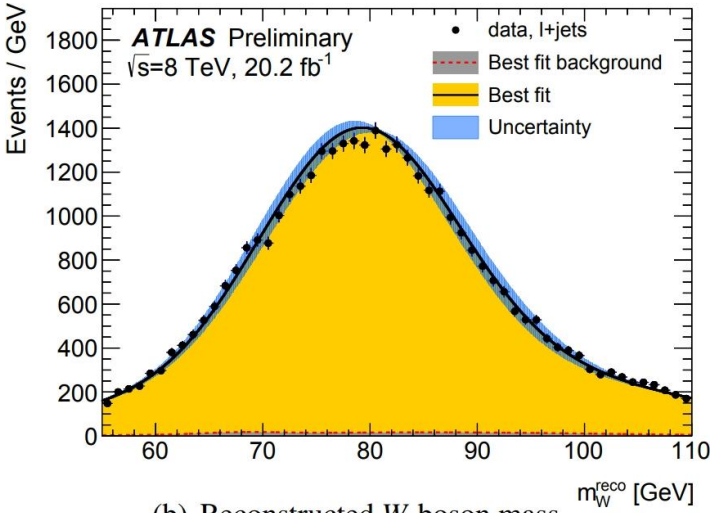


(f) R_{bq}^{reco} as a function of bJSF

ℓ + jets @ 8 TeV: fit results



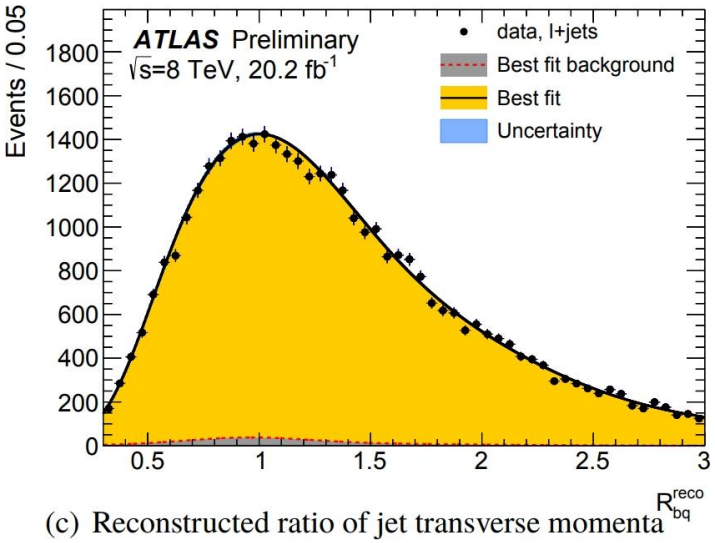
(a) Reconstructed top quark mass



(b) Reconstructed W boson mass

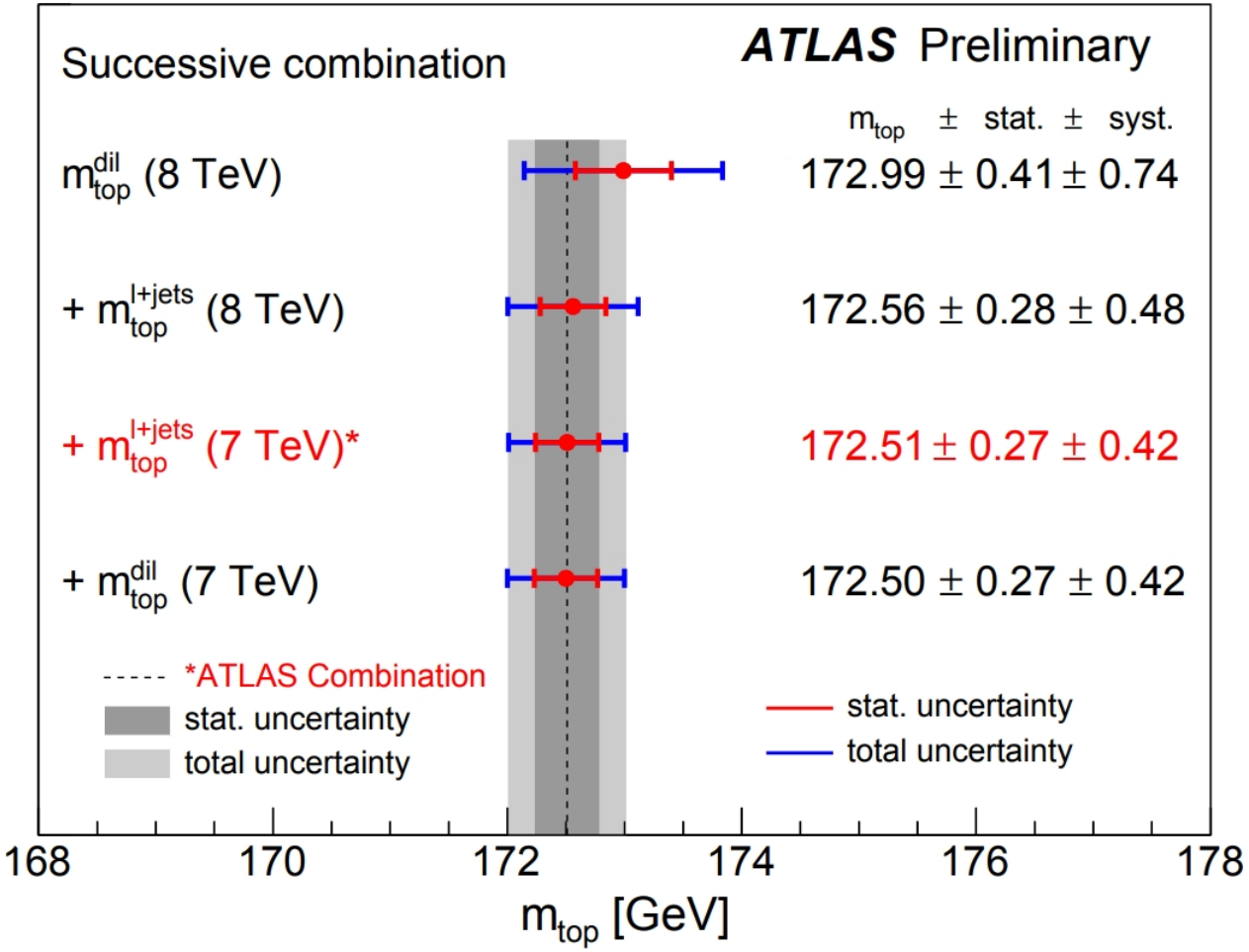
- Determine values for the three parameters in a simultaneous fit

$$m_t = 172.08 \pm 0.39(\text{stat})\ \text{GeV}$$
$$\text{JSF} = 1.005 \pm 0.001(\text{stat})$$
$$\text{bJSF} = 1.008 \pm 0.005(\text{stat})$$



(c) Reconstructed ratio of jet transverse momenta

ATLAS Top mass results



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Thank you!

Backup

Results summary

Pseudo-data	Calibration	Offset [GeV] m_{lb}	Offset [GeV] m_{T2}	χ^2
$\mathbf{NLO}^{\mathbf{LOdec}}_{\mathbf{NWA}}$	$\mathrm{LO}^{\mathrm{LOdec}}_{\mathrm{NWA}}$	$+0.51 \pm 0.06$	$+0.48 \pm 0.04$	0.17
$\mathbf{NLO}^{\mathbf{NLOdec}}_{\mathbf{NWA}}$	$\mathbf{NLO}^{\mathbf{LOdec}}_{\mathbf{NWA}}$	-1.80 ± 0.06	-1.67 ± 0.04	3.25
$\mathbf{NLO}^{\mathbf{NLOdec}}_{\mathbf{NWA}}$	$\mathrm{LO}^{\mathrm{LOdec}}_{\mathrm{NWA}}$	-1.38 ± 0.07	-1.24 ± 0.05	2.65
$\mathbf{NLO}_{\mathbf{full}}$	$\mathbf{LO}_{\mathbf{full}}$	-1.52 ± 0.07	-1.62 ± 0.05	1.35
$\mathbf{NLO}_{\mathbf{full}}$	$\mathbf{NLO}^{\mathbf{NLOdec}}_{\mathbf{NWA}}$	$+0.83 \pm 0.07$	$+0.60 \pm 0.06$	6.22
$\mathbf{NLO}_{\mathbf{full}}$	$\mathbf{NLO}_{\mathbf{PS}}$	$+2.55 \pm 0.07$	$+2.38 \pm 0.06$	3.40
$\mathbf{NLO}_{\mathbf{PS}}$	$\mathbf{NLO}^{\mathbf{LOdec}}_{\mathbf{NWA}}$	-3.43 ± 0.07	-3.62 ± 0.06	4.25
$\mathbf{NLO}_{\mathbf{PS}}$	$\mathbf{NLO}^{\mathbf{NLOdec}}_{\mathbf{NWA}}$	-1.60 ± 0.07	-1.67 ± 0.06	0.58
$\mathbf{NLO}_{\mathbf{PS}}$	$\mathbf{NLO}_{\mathbf{PS}}(\mu_{t\bar{t}})$	-0.07 ± 0.07	-0.05 ± 0.06	0.05

Table : Summary of the offsets observed when analysing pseudo-data listed in the first column with template fit functions calibrated based on various theoretical predictions as given in the second column.