Top quark pole mass measurements in ATLAS

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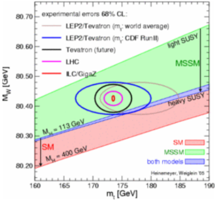
Outline

- Top quark relevance
- Measure m_{top}^{pole} using $t\bar{t}$+jet.
- The measurement at 7Tev.
- Outlook to 8Tev data.
- Conclusions.

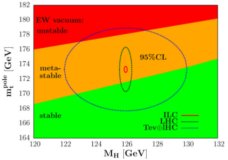
Why is the top quark important?

- The only (almost)free quark
- Heaviest particle in Standard Model (SM)
- Important in EWSB mechanism:
    - Strongest coupling to Higgs boson.
    - M_{top}, M_W, M_H test the SM.
- Plays a role in EW vacuum stability.
- Important in many new physics (NP) models.

arXiv:hep-ph/0604147



Ph.Lett. B 716 (2012) 214–219



Measuring the Top-quark properties with high accuracy is a test on the validity of the SM.

The top quark

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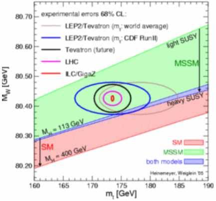

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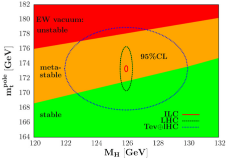

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Let's focus on the top-quark mass!

The top-quark mass

Quarks masses are parameters of the SM Lagrangian:

- They are not observables, due to confinement.
- Some observables depend on these parameters$\rightarrow$ fit is possible!.
- Precise values depend on the renormalization scheme used.
- NLO is required to fix renormalization scheme.

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  - MS or $\overline{\text{MS}}$ renormalization
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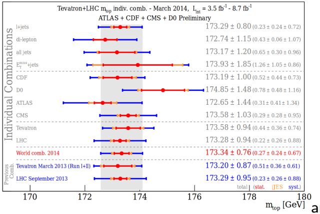
But how to measure them in experiments?

The top-quark mass: measurements

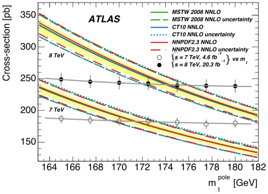
Two methods to measure top-quark pole mass:

- Kinematic reconstruction→ top is reconstructed from its decay products.
  - High experimental precision.
  - m^{reco} should be close to m^{pole}, but it is not well defined.



arXiv:1403.4427

- Inferred from cross section → $\sigma_{t\bar{t}}$ depends on the pole mass of the top-quark.
  - Well defined teoretically (NLO fixes the renormalization scheme).
  - Less sensitivity to m^{pole} and larger experimental errors.



arXiv:1406.5375

The top-quark mass: a new method

Use $t\bar{t} + 1\text{JET}$! $\longrightarrow$

- relatively big sample (30% of $t\bar{t}$).
- available at NLO (renormalization scheme fixed).
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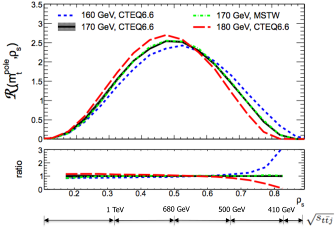
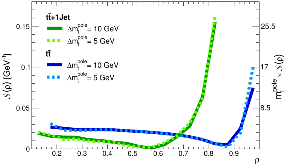
Use the variable:

$$\mathcal{R}\left(m_t^{\text{pole}}, \rho_s\right) = \frac{1}{\sigma_{t\bar{t}+1-\text{jet}}} \frac{d\sigma_{t\bar{t}+1-\text{jet}}}{d\rho_s}\left(m_t^{\text{pole}}, \rho_s\right) \; ; \qquad \text{where} \quad \rho_s = \frac{340\text{GeV}}{\sqrt{s_{t\bar{t}+1-\text{jet}}}}$$

arXiv:1303.6415

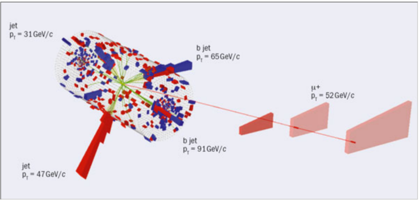




$\approx$ 5 times more sensitive to m_t^{pole} than $t\bar{t}$!

The 7TeV analysis: The event reconstruction

$t\bar{t}+1$-jet events have to be reconstructed from final particles detected.



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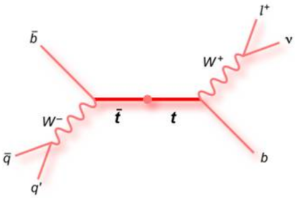

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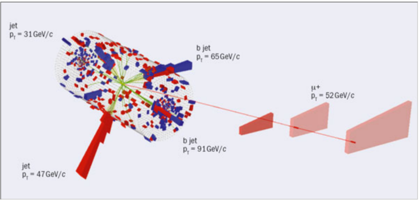

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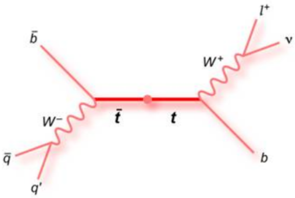

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- leptonic W: lepton + reconstructed neutrino + constraint on m_W
- hadronic W: two non b-tagged jets satisfying m_W and distance constraints
- Tops: combine *b*-jets with the Ws in such a way to minimize the mass difference between the two tops.
- Extra jet: the leading p_T jet between the remaining ones.

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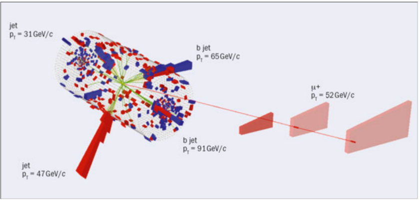

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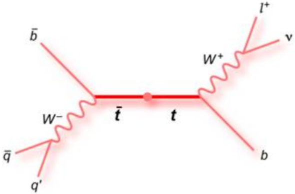

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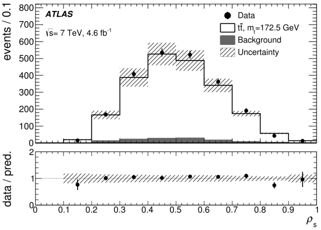
All the variables to compute $\mathcal{R}^{\text{reco}}\left(m_t^{\text{pole}}, \rho_s\right)$ are then available!

The 7TeV analysis: The unfolding

$$\mathcal{R}^{\text{reco}}\left(m_t^{\text{pole}}, \rho_s\right) = \frac{1}{\text{N}_{t\bar{t}+1-\text{jet}}} \frac{\text{dN}_{t\bar{t}+1-\text{jet}}}{\text{d}\rho_s}$$



$\longrightarrow$

Reconstructed level $\neq$ parton level

Only at parton level we can fit data to theoretical predictions.

$\downarrow$

Need to correct for the detector and hadronization effects:

unfolding

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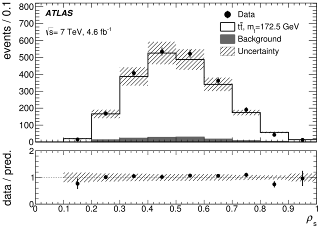

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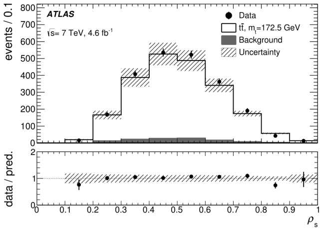
$$t\bar{t} + \text{1-jet (reco)} \longrightarrow t\bar{t} + \text{1-gluon (parton)} \longrightarrow t\bar{t} + \text{1-jet (parton)}$$

$$\mathcal{R}^{\text{cor-data}}(\rho_s) \equiv \left[\left(\mathcal{M}^{-1} \otimes \mathcal{R}^{\text{det-data}}(\rho_s)\right) \cdot \left(\frac{\mathcal{R}^{t\bar{t}+\text{g}}_{\text{acc.}}(\rho_s)}{\mathcal{R}^{t\bar{t}+\text{g}}(\rho_s)}\right)^{-1}\right] \cdot \left(\frac{\mathcal{R}^{t\bar{t}+\text{1-jet}}(\rho_s)}{\mathcal{R}^{t\bar{t}+\text{g}}(\rho_s)}\right),$$

The 7TeV analysis: Results

$$\mathcal{R}^{\text{reco}}\left(m_t^{\text{pole}}, \rho_s\right) = \frac{1}{N_{t\bar{t}+1-\text{jet}}} \frac{dN_{t\bar{t}+1-\text{jet}}}{d\rho_s} \qquad \mathcal{R}^{\text{parton}}\left(m_t^{\text{pole}}, \rho_s\right) = \frac{1}{\sigma_{t\bar{t}+1-\text{jet}}} \frac{d\sigma_{t\bar{t}+1-\text{jet}}}{d\rho_s}$$



unfolding
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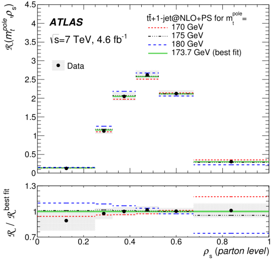

$$m_t^{\text{pole}} = 173.7 \pm 1.5(\text{stat}) \pm 1.4(\text{syst})^{+1.0}_{-0.5}(\text{theory})\ \text{GeV}$$

Total uncertainty is $\sigma(m_t^{\text{pole}}) = {}^{+2.3}_{-2.1}$GeV.

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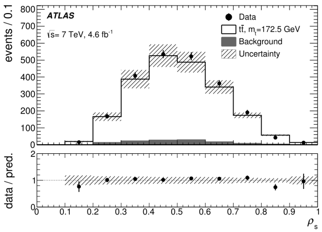

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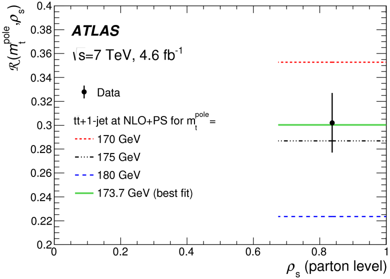

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8TeV improvements

Description	Value [GeV]	%
m_t^{pole}	**173.71**	
Statistical uncertainty	**1.50**	**0.9**
Scale variations	(+0.93, −0.44)	(+0.5, −0.3)
Proton PDF (theory) and α_s	0.21	0.1
Total theory systematic uncertainty	**(+0.95, −0.49)**	**(+0.5, −0.3)**
Jet energy scale (including b-jet energy scale)	0.94	0.5
Jet energy resolution	0.02	< 0.1
Jet reconstruction efficiency	0.05	< 0.1
b-tagging efficiency and mistag rate	0.17	0.1
Lepton uncertainties	0.07	< 0.1
Missing transverse momentum	0.02	0.1
MC statistics	0.13	< 0.1
Signal MC generator	0.28	0.2
Hadronization	0.33	0.2
ISR/FSR	0.72	0.4
Colour reconnection	0.14	< 0.1
Underlying event	0.25	0.1
Proton PDF (experimental)	0.54	0.3
Background	0.20	0.1
Total experimental systematic uncertainty	**1.44**	**0.8**
Total uncertainty	**(+2.29, −2.14)**	**(+1.3, −1.2)**

@8Tev
much more events $\rightarrow$

- less statistical uncertainty.
- different binning of R^{parton} possible. (increasing sensitivity)

The top-quark running mass can also be measured (theoretical work in progress).

$\approx$ 1 GeV uncertainty or less is possible.

Conclusions and outlook

Conclusions:

- Top-quark is important for SM and BSM scenarios.
- Is essential to well define the quark mass we want to measure.
- A new method has been developed using $t\bar{t} + 1$-jet events (by the Valencia and Berlin groups).
- A measurement using 7Tev data has been done of m_t^{pole}.
  It is the first and most precise measurements of m_t^{pole}.

Outlook (or "my job"):

- Using 8TeV data is possible to reduce to ≤ 1 GeV the total uncertainty on m_t^{pole}.
- First measurement of the top-quark running mass.

Thanks for you attention!

(thanks to P.Fernandez and A.Irles for the 7TeV analysis and 8TeV help,
to supervisors M.Vos, J.Fuster, R.Pittau for even more help and support)

Backup

Renormalizations:

Renormalized propagator: $S(p) = -\frac{i}{\not{p} - m_t^0 + \Sigma^R(p, m_t^0, \mu)}$

$$\Sigma^R \sim \left[\frac{1}{\epsilon} - \gamma + \ln 4\pi + A(m_t^0, p, \mu)\right] \not{p} - \left[4\left(\frac{1}{\epsilon} - \gamma + \ln 4\pi\right) + B(m_t^0, p, \mu)\right] m_t^0 + (Z_2 - 1)\not{p} - (Z_2 Z_m - 1)m$$

On-shell renormalization (pole mass) - Z_2 and Z_m are determined by means of:

$$\Sigma^R(p) = 0 \text{ and } \frac{\partial \Sigma^R}{\partial \not{p}} = 0 \text{ for } \not{p} = m$$

$\overline{\text{MS}}$ renormalization: counterterm to subtract $(1/\epsilon + \gamma_E - \ln 4\pi)$

$$S^R_{o.s.}(p) \sim \frac{i}{\not{p} - m_{\text{pole}}} \;\; ; \;\; S^R_{\overline{\text{MS}}} \sim \frac{i}{\not{p} - m_{\text{MS}} - (A - B)m_{\text{MS}}}$$

Pole vs $\overline{\text{MS}}$ mass:

Relation pole/$\overline{\text{MS}}$ mass at 4 loops $[\bar{m} = \bar{m}(\bar{m})$ and $\bar{\alpha}_S = \alpha_S(\bar{m})/\pi]$ (P.Marquard et al, PRL'15)

$m_{\text{pole}} = \bar{m} \times \left[1 + c_1\bar{\alpha}_S + +c_2\bar{\alpha}_S^2 + c_3\bar{\alpha}_S^3 + c_4\bar{\alpha}_S^4 + \dots\right]$; $c_4\bar{m}_t\bar{\alpha}_S^4 \approx 200$ MeV

For top quarks: $m_{\text{pole}} = \bar{m}[1 + 0.046 + 0.010 + 0.003 + 0.001 + \dots]$

Backup

PDF, scale, color reconnection uncertainties: