ATLAS EXPERIMENT

5th Helmholtz Alliance annual meeting. Bonn, Dec 7 – 9, 2011

Measurements of the top-quark mass from ATLAS data using the template method

- Introduction
- Template method for m_{top} measurements
- ATLAS results from 2010 and 2011 data
- Summary and conclusions

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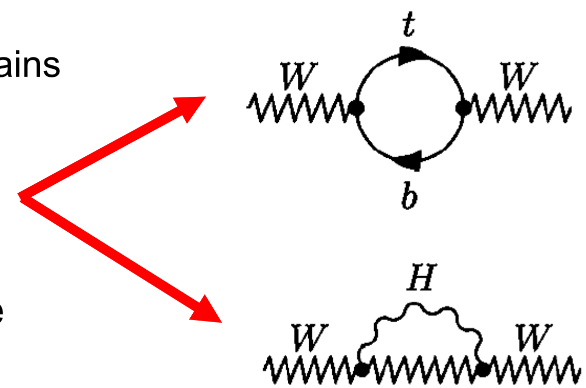
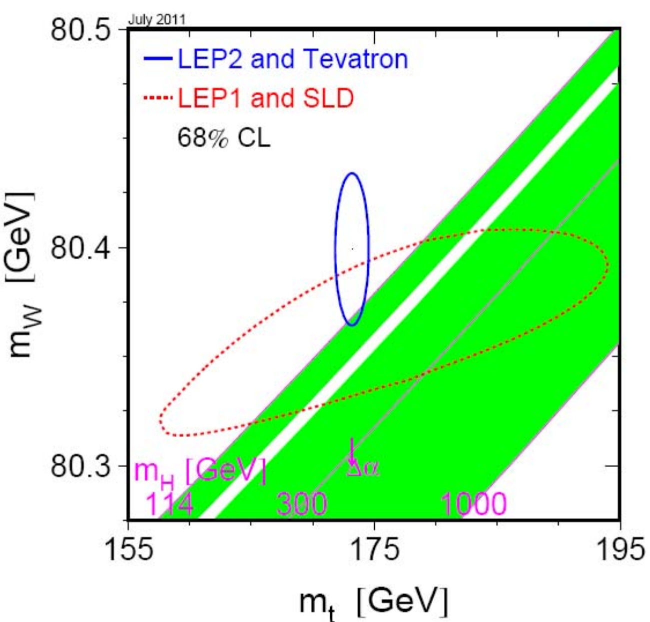
Top-quark relations to the SM Higgs

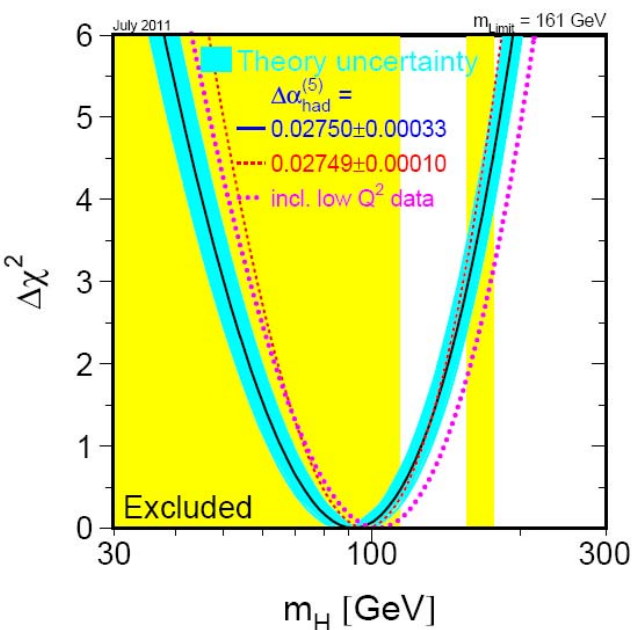
- The Higgs boson is the SM last missing piece
  - although it has been searched for by several experiments it remains still un-observed

Higgs, top-quark, and W boson masses are related



- A precise determination of m_{top} can be used to constrain the Higgs boson mass when combined with EW precision measurements





$M_H = 92^{+34}_{-26}$ GeV/c^2

$M_H < 185$ GeV/c^2 95%C.L.

Increasing the precision of the direct determinations of m_W and m_{top} allows to better constrain m_H

Paths towards top mass

methods	*Main characteristics / highlights*
Indirect determination from SM electroweak precision measurements	■ Performed ***BEFORE top quark discovery*** ■ Model dependent (fully assume SM) ■ Limited precision (loop corrections)
Extraction from the measured top pair production x-sec	■ No reconstruction of top quark decay involved (count evts.) ■ Precision bounded by theoretical and experimental x-sec unc. ■ Theo. pred. available @ a well defined renormalization scheme
Lepton p_T b-quark decay length	■ Minimal event information exploited (limited stat precision) ■ Reduced sensitivity to Jet Energy Scale uncertainty ■ Complementary systematics wrt other direct methods
TTbar event reconstruction: Templates / kinematic reconstruction	■ Different level of reconstruction sophistication (Geometrical reco/Full kinematic fit to the decay hypothesis) ■ Different methods depending on the decay channel
Matrix Element (or Ideogram method)	■ Makes best use of event information (eventually in conjunction with LO matrix element predictions). Best statistical power ■ Can be computationally challenging

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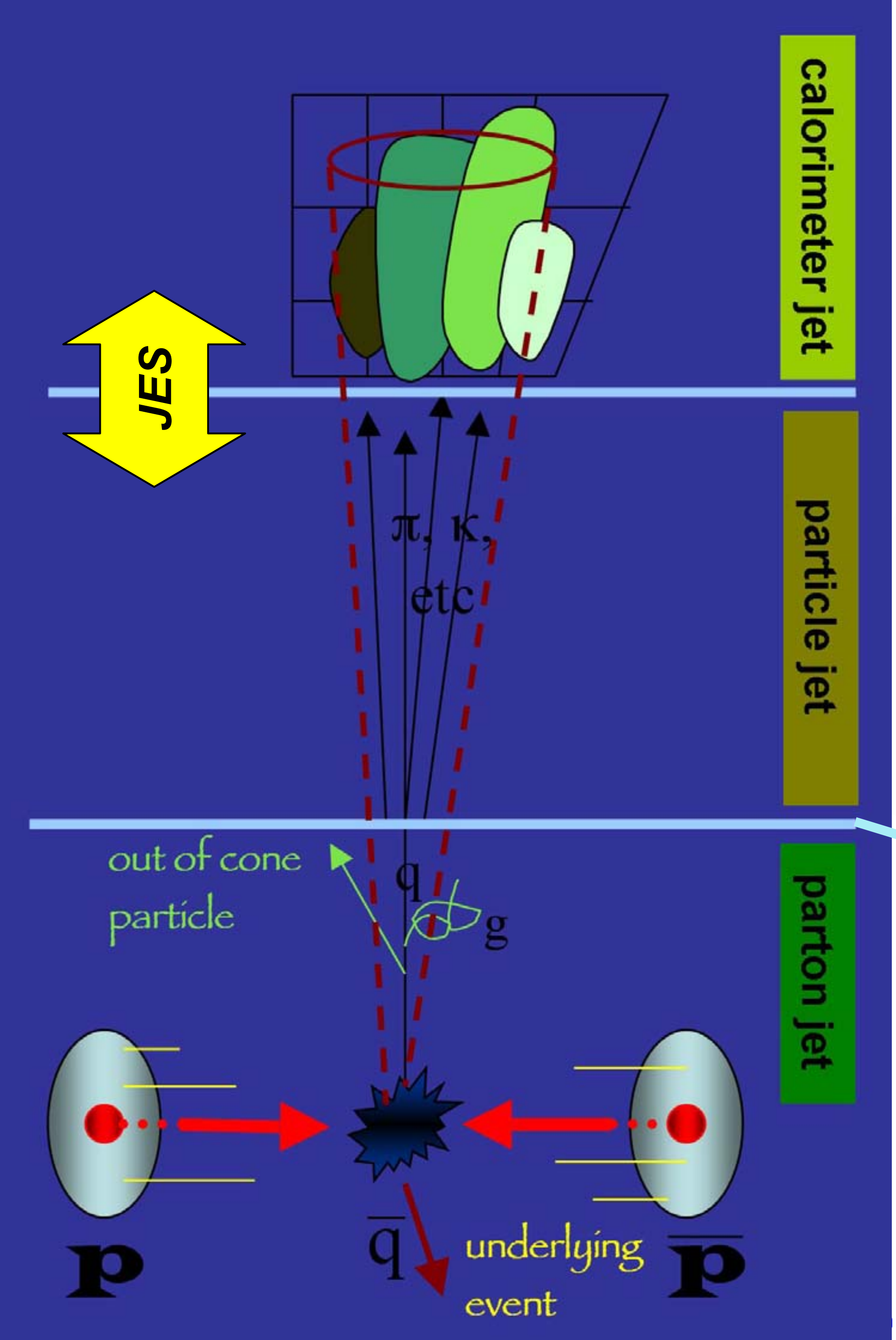
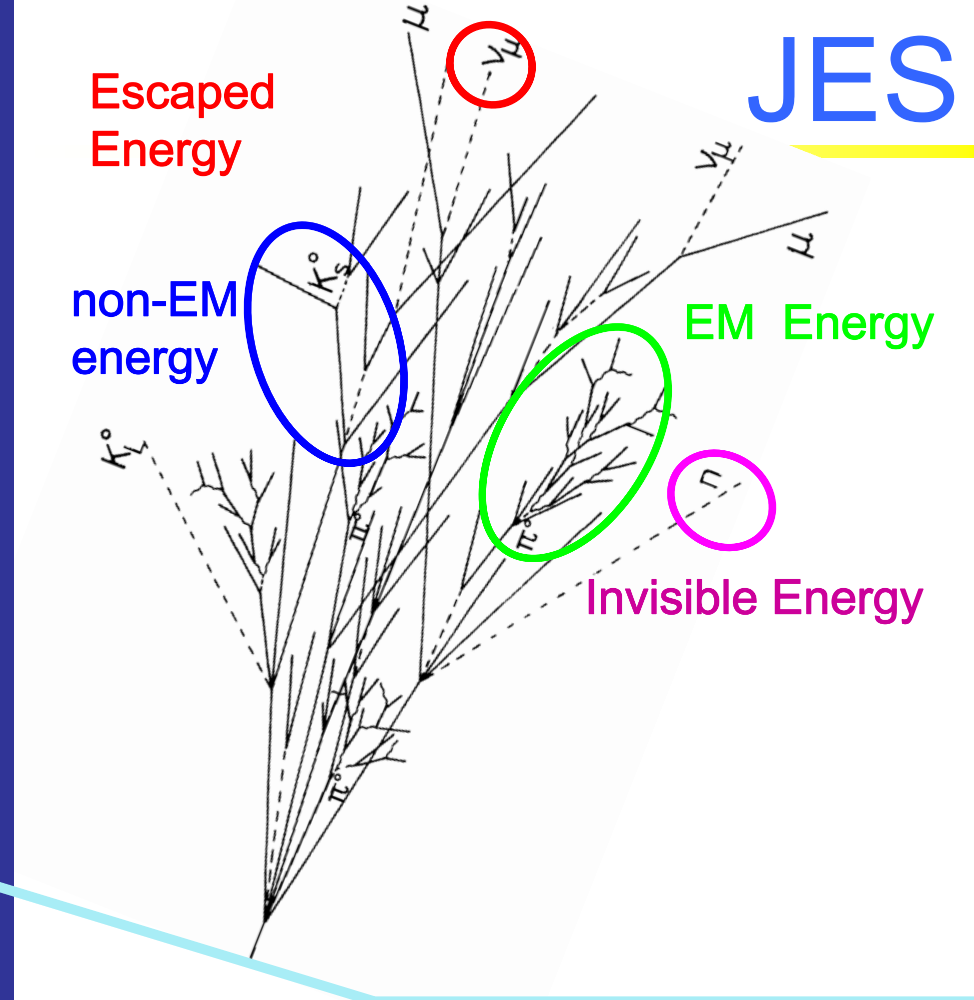
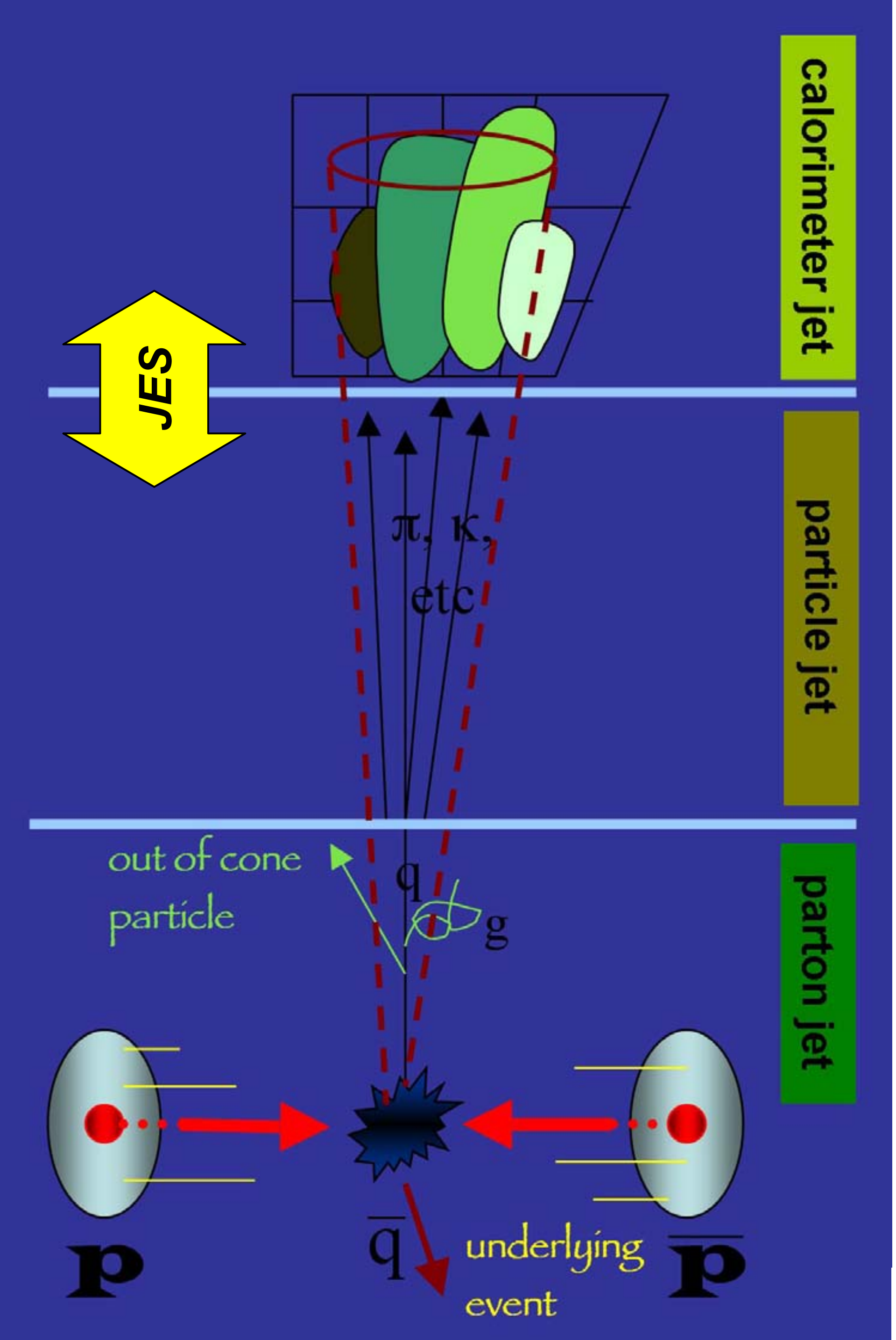
JES





- The energy determination of the impinging parton is complicated by
  - Hadronization, fragmentation effects
  - Not-instrumented regions of the detector
  - Energy contribution from multiple interactions (pile-up)



JES

- Describes difference between calorimeter jet and stable particle jet
- Non-trivial determination.

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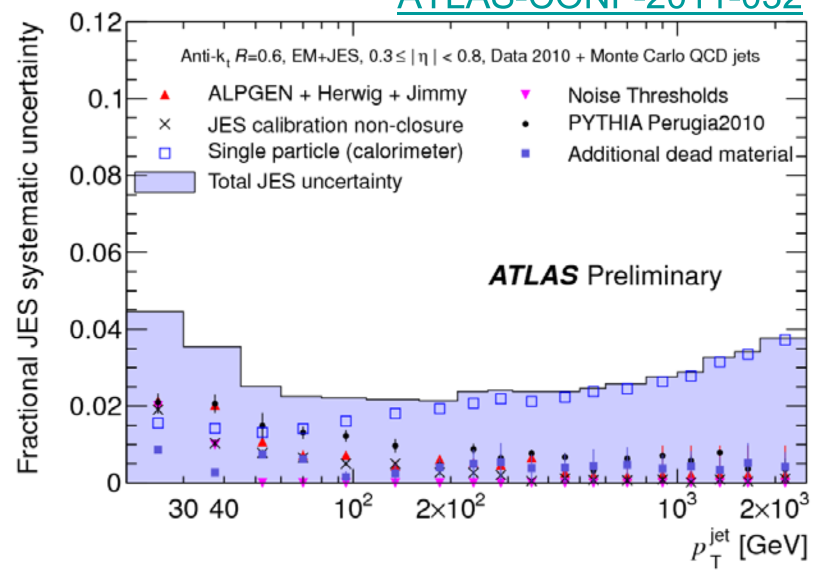
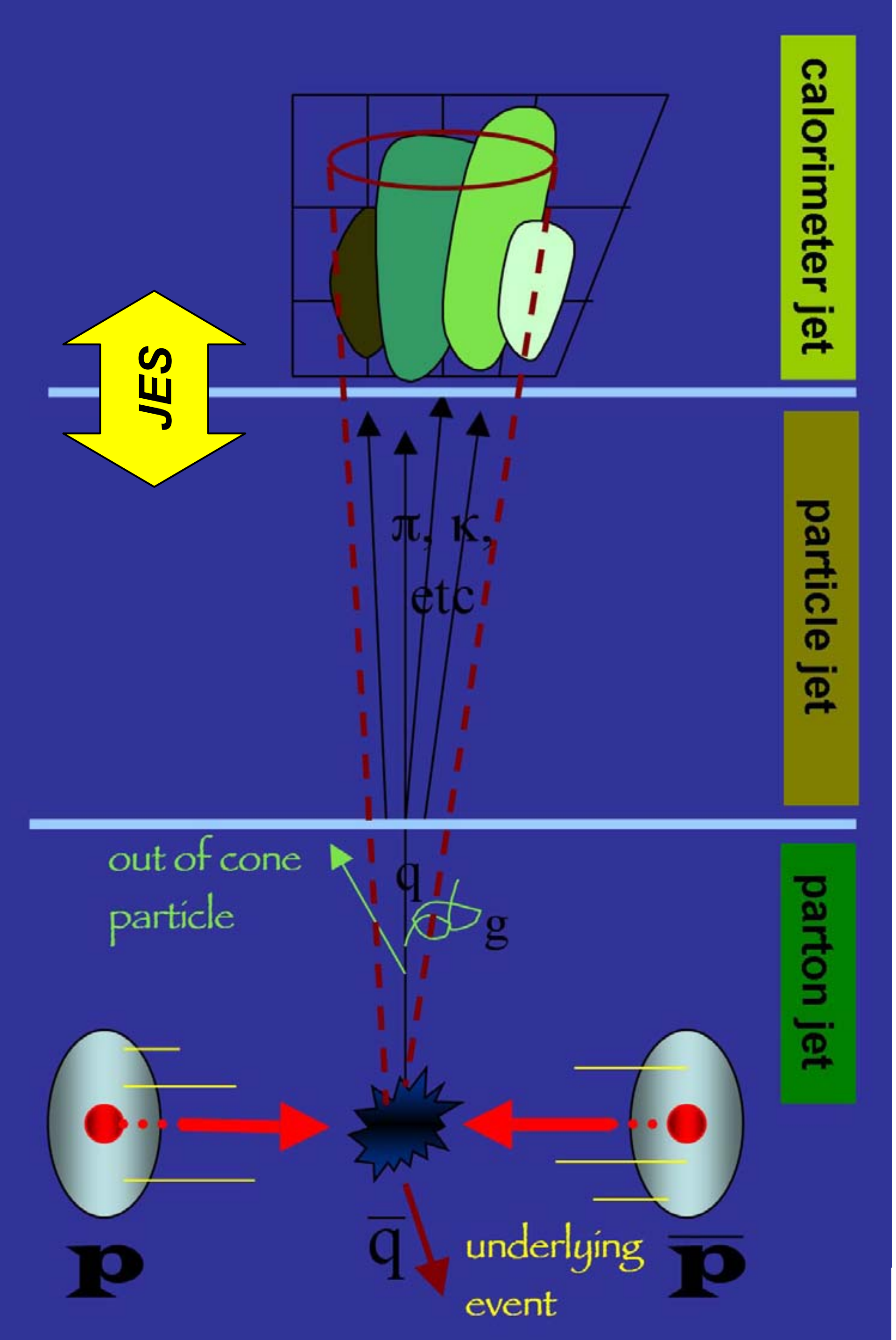


- Typically uncertainties are O(few %) and vary with jet properties (p_T, η)
  - ~100% correlated with top mass (when using jet info for its reconstruction)
  - ***σ(JES)= 3% → $\sigma(m_{top})$~5 GeV***

JES



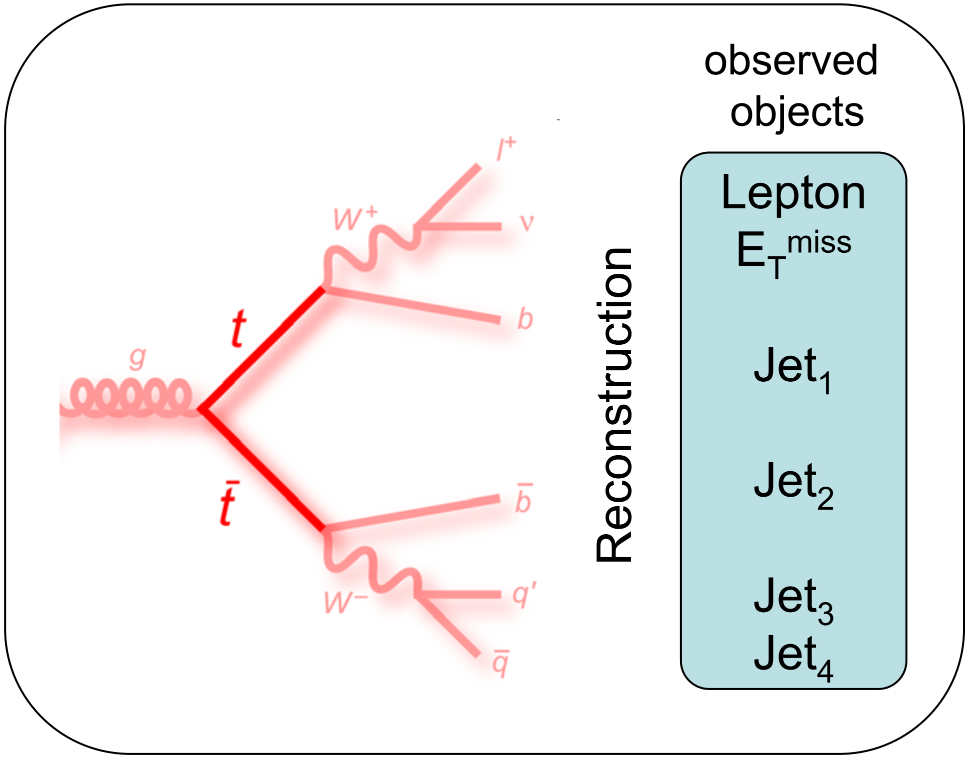
- ***To limit JES syst impact on m_{top} different approaches can be followed:***

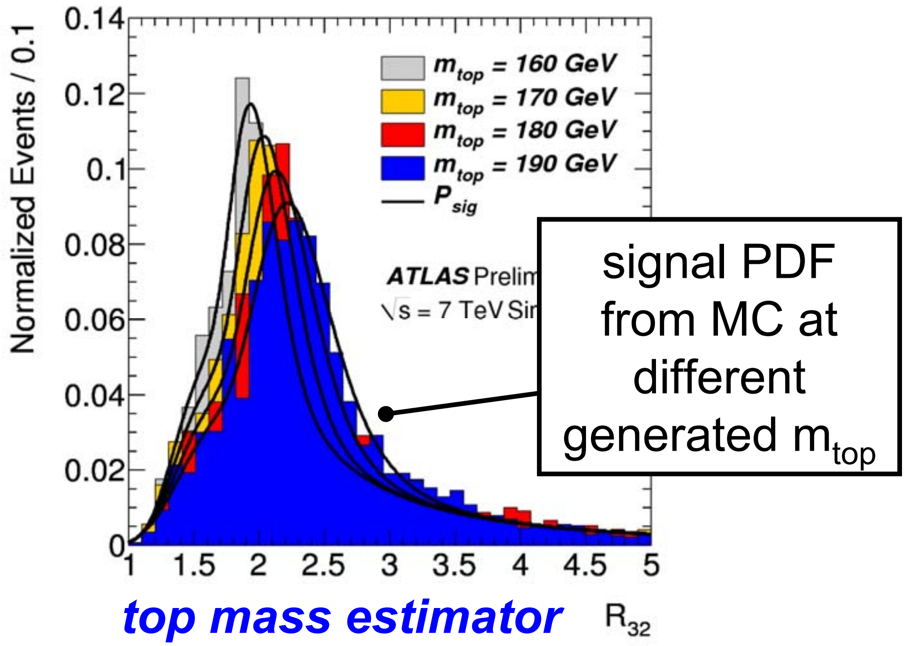
1. adopt **observables/estimators** sensitive to top mass changes but as much as possible **independent from the JES**

2. constrain the JES using the same data as for the measurement (**in situ calibration**)

Template method

- The idea is to fit the data distribution of a given m_{top} estimator (i.e. m_{top}^{rec}) to the sum of signal and background PDFs (probability distribution functions)
- The estimator is obtained via the event reconstruction:





l+jets channel:

simple reconstruction method (2010) among the jets in the sel. events:

m_{top}^{reco} = jet-triplet that maximizes the p_T

m_W^{reco} = the untagged jet-pair or the jet-pair with ΔR_{min} in the top rest-frame

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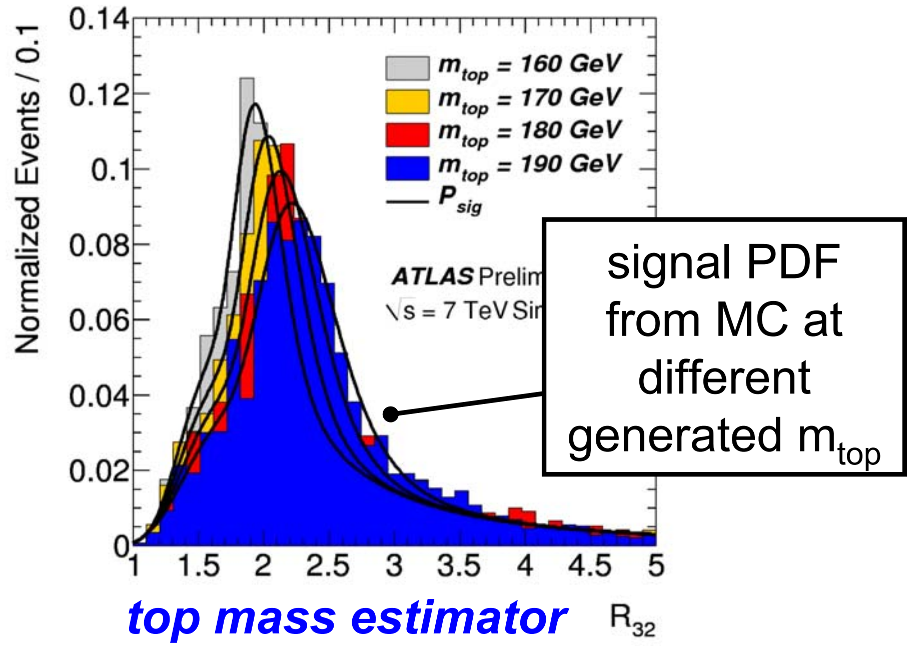

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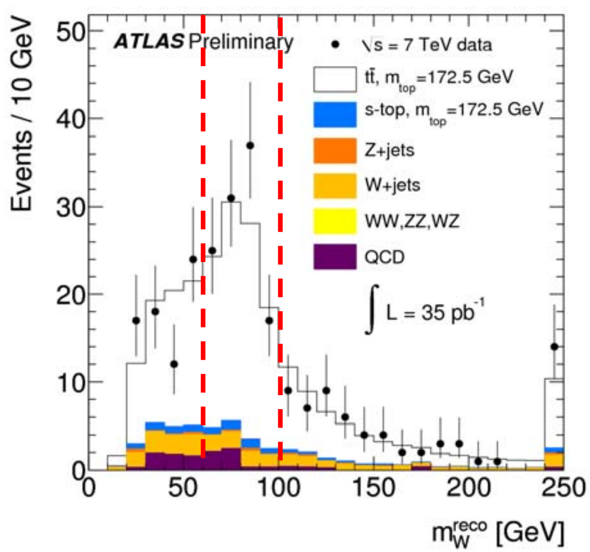
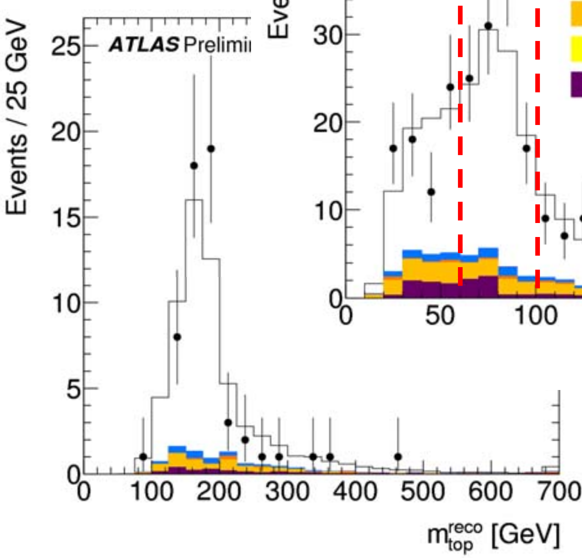
Plots for μ+jet channel





Both m_{top}^{reco} and m_W^{reco} directly depend on the Jet Energy Scale:
Strong sensitivity to the JES uncertainty

Plots for
μ+jet channel

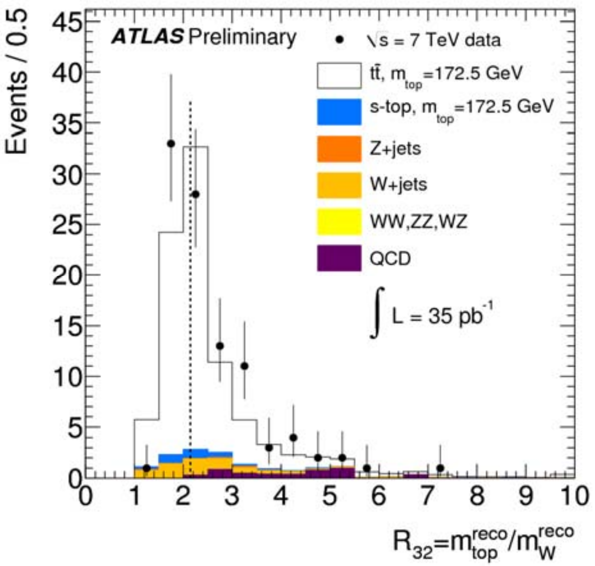
Template method

top mass estimator (1d-template)

$$R_{32} = \frac{m_{top}^{reco}}{m_W^{reco}} = \frac{M(jet, jet, bjet)}{M(jet, jet)}$$

at first order JES cancels

~3x reduced JES syst



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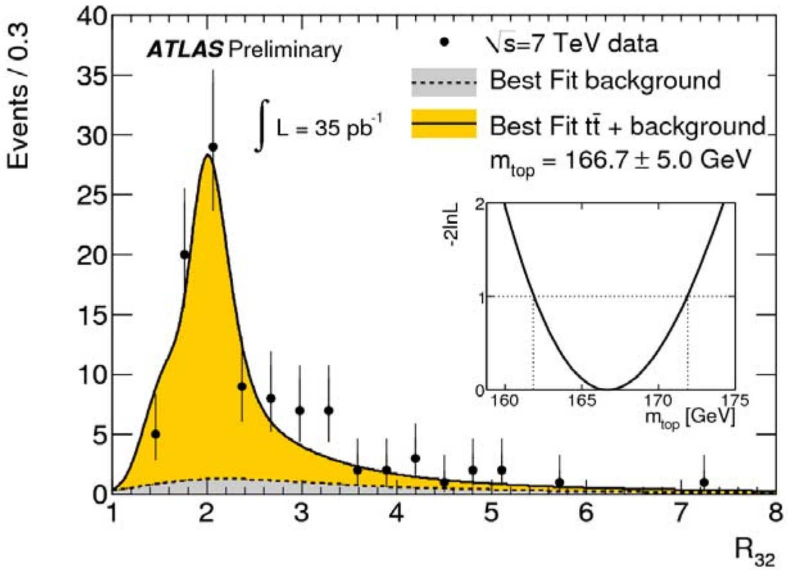


L_{int} = 35 pb^{-1}
~150 events used for the measurement

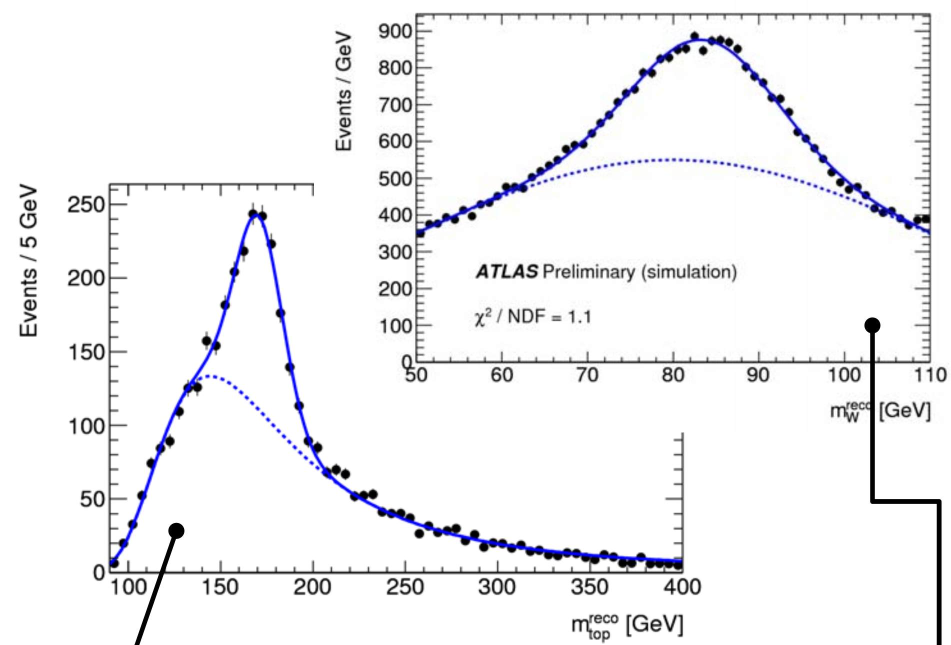
combined (e/μ+jets) ***L_{int}=35 pb^{-1}***

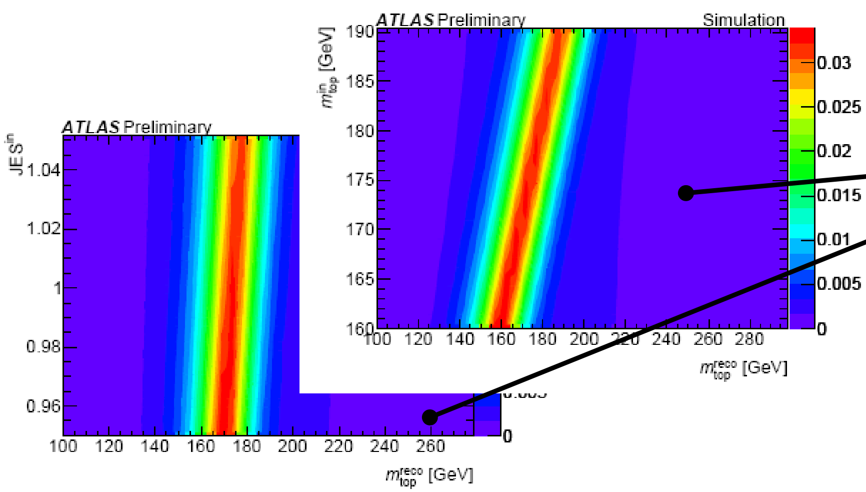
m_{top} = 169.3± 4.0 (stat) ± 4.9 (syst) GeV

2-dimensional, Template Method

The method aims at reducing the JES syst uncertainty, by ***fitting simultaneously m_{top}^{reco} and m_W^{reco}***

- The 2-d method transfers the JES syst. into an additional but reduced stat. unc.
- Good JES stability
- The method has been commissioned using first 2010 ATLAS data and produced the Summer 2011 ATLAS top-mass measurement



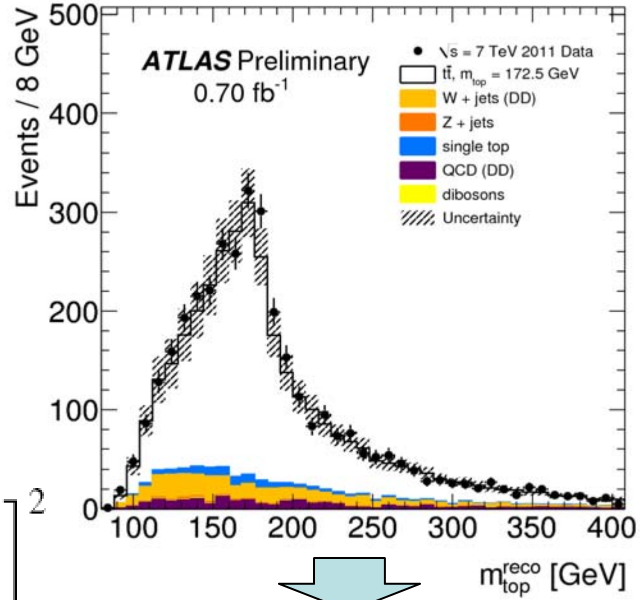


- ***Templates:***
  - Signal m_{top}^{reco} templates parameterized vs (m_{top}, ***JSF****= effective data/MC Jet Energy Scale Factor*).
  - m_W^{reco} is independent from the underlying top-quark mass but can be used for an “in-situ” determination of the JSF. Reconstructed W is parameterized as a function of a constant JSF factor (0.9-1.1).

2-dimensional, Template Method

- ***m_{top} and m_W reconstruction:***
  - Among all jjb triplets with 50 GeV < m_{jj} < 110 GeV (b=b-tagged jets), choose the triplet maximizing p_T(jjb) for m_{top} and the corresponding light jet pair for m_W.
  - Only for m_{top}^{reco}, the jet energies are rescaled according to the output of the following χ^2:

$$\chi^2 = \sum_{i=1}^{2} \left[\frac{E_{\mathrm{jet,i}}(1-\alpha_{\mathrm{i}})}{\sigma_{\mathrm{jet,i}}} \right]^2 + \left[\frac{M_{\mathrm{jet,jet}}(\alpha_1,\alpha_2) - m_W}{\Gamma_W} \right]^2$$



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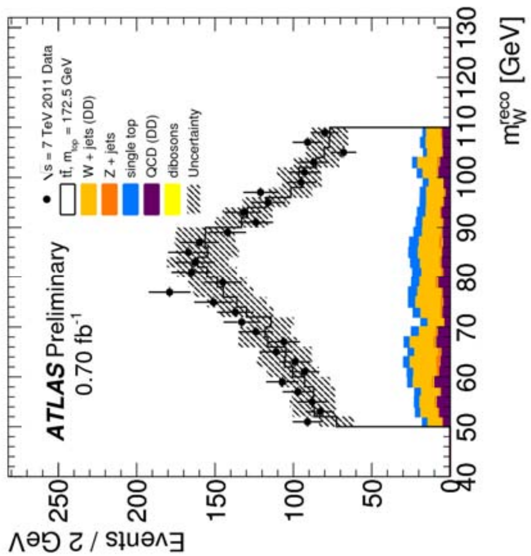
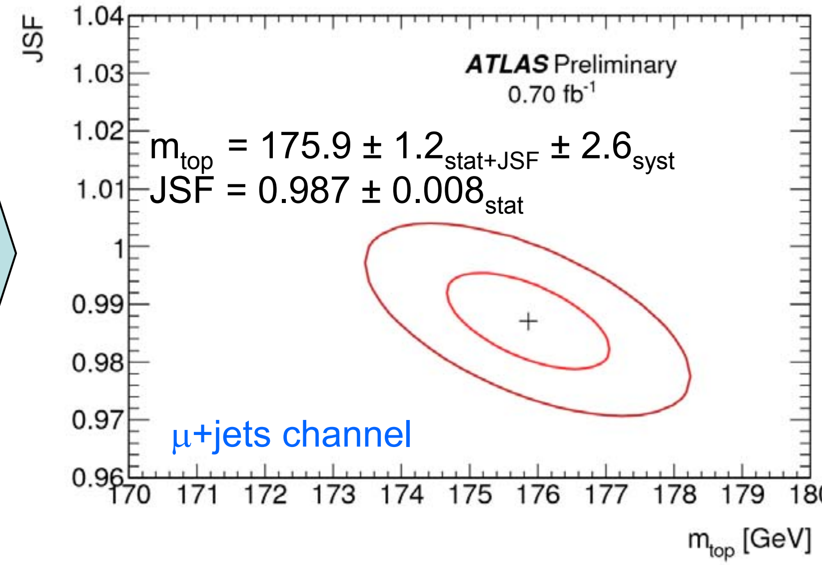
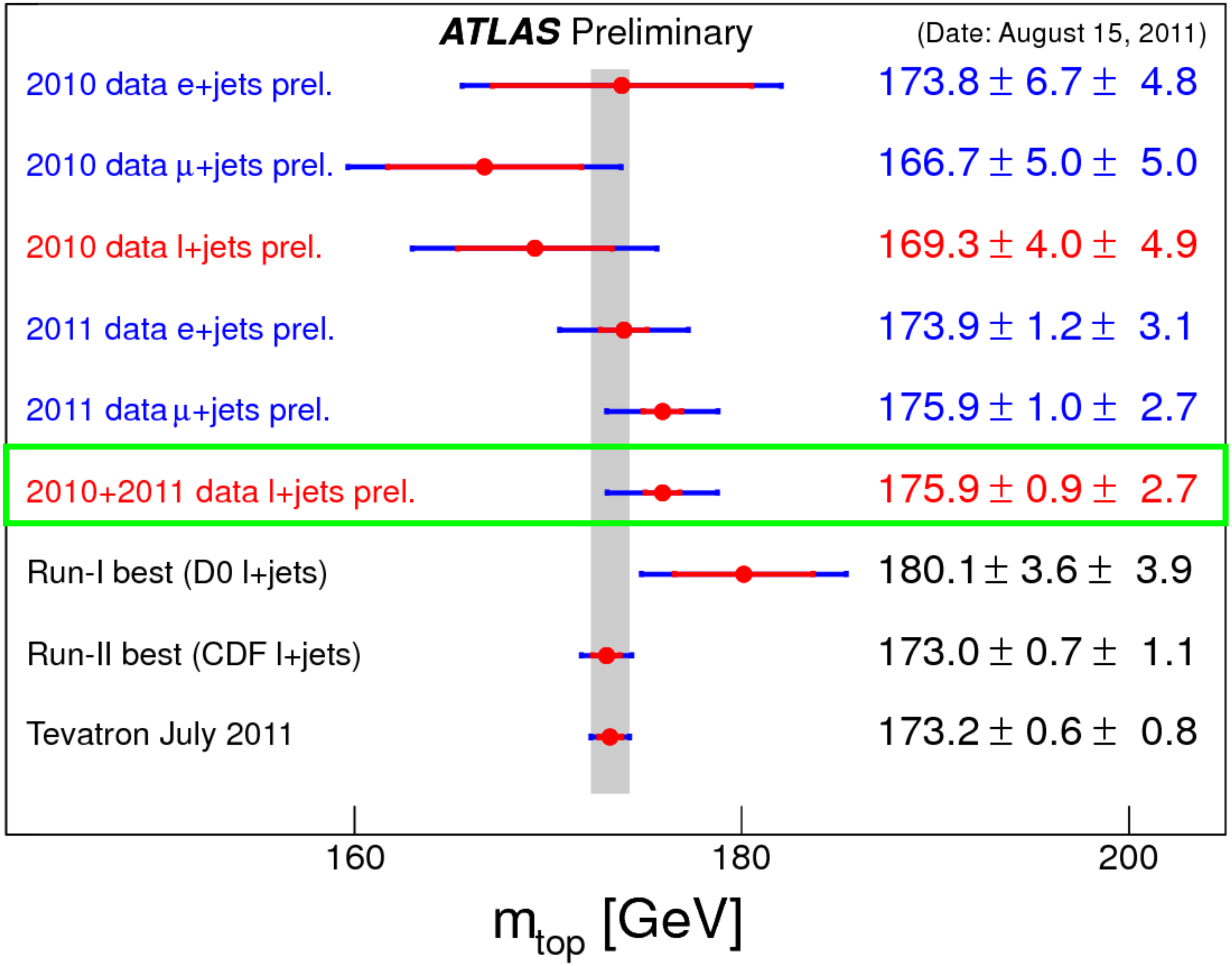
L_{int} = 700 pb^{-1}
~6.2k events used
for the measurement





Summary



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Outlook

- ATLAS preliminary results form 2010 and 2011 have been combined:
  - $m_{top} = (175.9 \pm 0.9_{stat} \pm 2.7_{syst})$ GeV
    $= (175.9 \pm 2.8_{tot})$ GeV
- The total relative uncertainty is at the level of 1.6% (already a factor >2 improvement with respect to 2010 data analyses)
  - Main syst: b-light relative JES, ISR/FSR, signal modeling
  - Next efforts will be concentrated on systematic uncertainty reduction.

… stay tuned!

- backup -

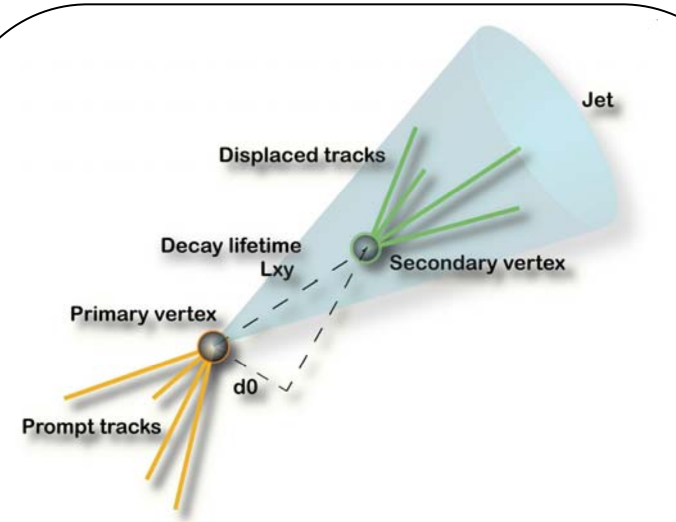
ATLAS 2011 uncertatinty table

	e+jets	μ+jets	ρ
Statistics	1.2	1.0	0
Method calibration	< 0.05	0.1	0
Signal MC generator	1.2	1.2	1
Hadronization	< 0.05	0.4	1
Pileup	< 0.05	< 0.05	1
Color reconnection	0.6	0.9	1
ISR and FSR (signal only)	1.6	0.7	1
Proton PDF	0.1	0.1	1
W+jets background normalization	0.2	0.1	1
W+jets background shape	< 0.05	0.1	1
QCD background normalization	0.4	0.4	0
QCD background shape	0.2	0.3	0
Jet Scale Factor	1.0	0.7	0
Jet energy scale	0.7	0.8	1
b-jet energy scale	2.0	1.7	1
b-tagging efficiency and mistag rate	0.1	0.3	1
Jet energy resolution	0.3	0.2	1
Jet reconstruction efficiency	< 0.05	< 0.05	1
Missing transverse energy	0.1	0.1	1
Total systematic uncertainty	3.1	2.7	

m_{top} from x-sec

- The measured top pair production cross sections can be used to extract the top mass, when compared with theoretical predictions

- In general the l+jets channel is used
- Lepton (e/μ)+jets decays provide
  - clear trigger signatures
  - a rich final state that can be exploited for background reduction
    - ▶ high p_T, isolated charged lepton
    - ▶ missing E_T, and transverse W mass
    - ▶ many jets (2 from b-quarks)

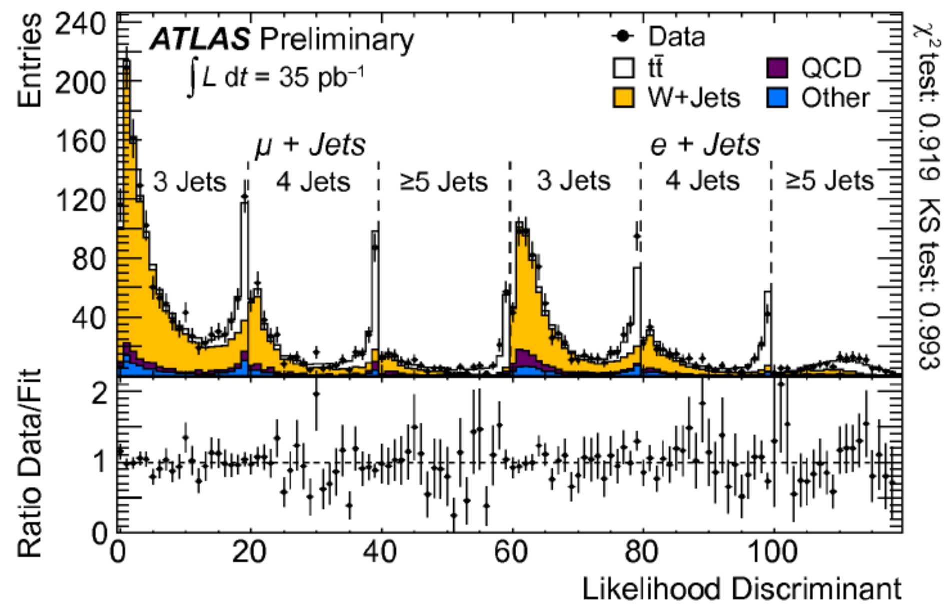


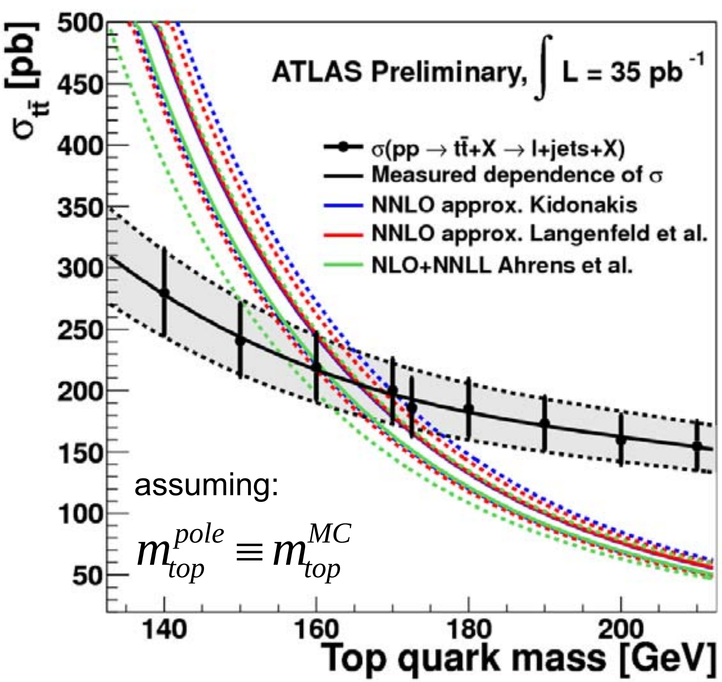
b-jet identification:

1. Secondary vertices reconstruction from b-decays within jets
2. Use tracks impact parameters to determine the probability that the jets originates from light-quark (JetProb)
3. More advance taggers combining multiple b-decays characteristics (lifetime and semi-leptonic decays)

m_{top} from x-sec

- ATLAS x-sec analysis, on top of basic selection on N_{jet} = 3, =4, ≥5 jets, lepton- and jet-p_T, exploits additional topological information (Lepton |η|, b-tagger weights, etc) to build a likelihood discriminant to further distinguish signal from background.





- The top mass is determined by maximizing the likelihood, built from the theoretical and experimental probability density functions:

$$f\left(m_{top}\right) \propto \int f_{th}\left(\sigma \mid m_{top}\right) \cdot f_{ex}\left(\sigma \mid m_{top}\right)$$

L_{int}=35 pb^{-1}

m_{top} = $166.4^{+7.8}_{-7.3}$ GeV (approx NNLO-Langenfeld)

Template methods

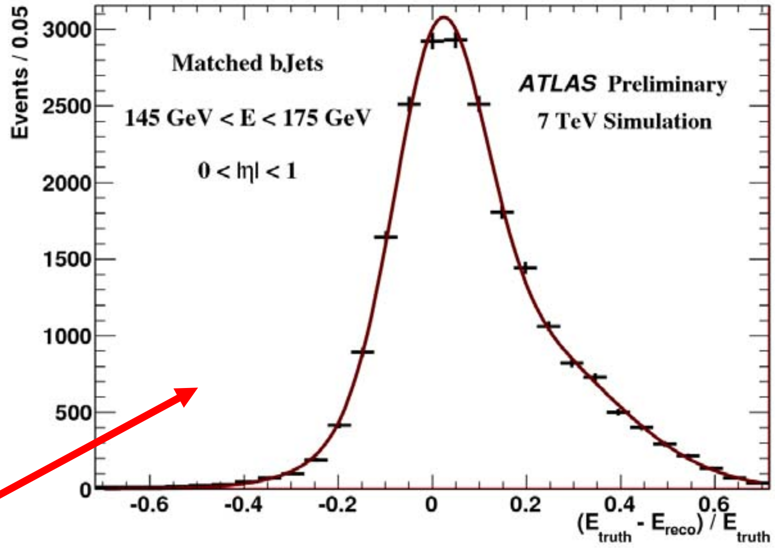
- The first LHC data, have been used by ATLAS to commission more elaborated and complementary techniques, with different sensitivities to stat and syst uncertainties:

  KLFitter for the event reconstruction

  (Choose the object topology that best fits the decay hypothesis). Reco objects are mapped to the response of partons from the hard scattering via LO transfer functions (TF).

  - Apply BW constraints (Γ_{top} and Γ_W) for m_{top}^{reco} and m_W^{reco} (for both had/lep sides), the latter to m_W^{PDG}.
  - Reduce combinatorics by introducing in the likelihood b-tag information:
    - The fraction of entirely correct object-parton assignments is increased from 52% to 67%

example of a Transfer Function



$$L = BW\left(m_{(jj)/(l\nu)} \mid m_W, \Gamma_W\right)$$
$$\cdot BW\left(m_{(jjj)/(l\nu j)} \mid m_{top}, \Gamma_{top}\right)$$
$$\cdot TF\left(E^{miss}_{(x,y)} \mid p^{\nu}_{(x,y)}\right) \cdot TF\left(E / p_T^{lepton} \mid E / p_T^{lepton}\right)$$
$$\cdot \prod_{i=1}^{4} TF\left(jet\left(E_T, \eta, \phi\right) \mid quark\left(E_T, \eta, \phi\right)\right)$$

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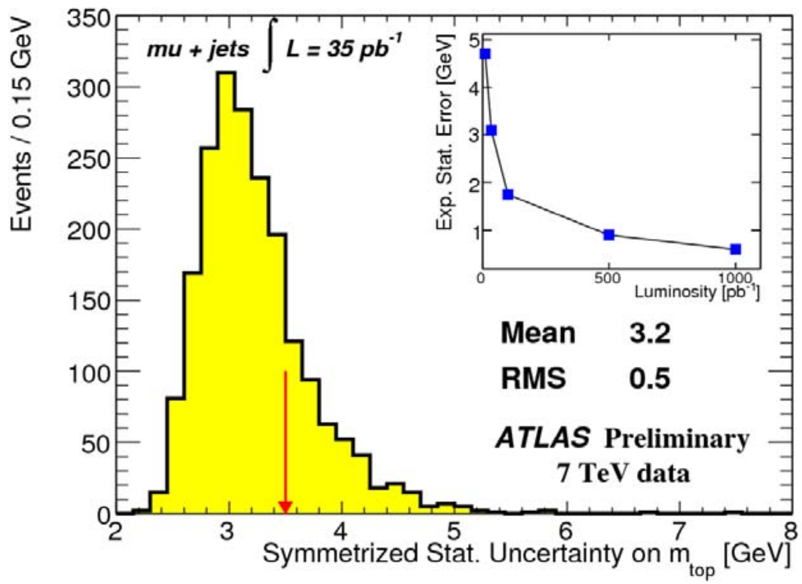
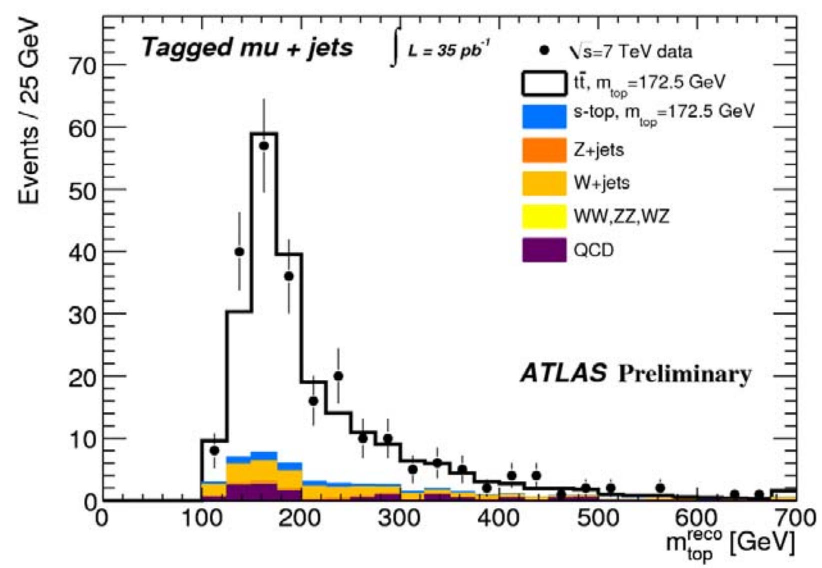
- Improved resolution and stat precision





Winter 2011 results

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