Top Event Reconstruction with Kinematic Likelihood Fitting

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under supervision or in discussion with
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PHYSICS AT THE TERA SCALE
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FSP 101
ATLAS

Outline

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- Top Reconstruction Algorithms
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  - TopCommissioning
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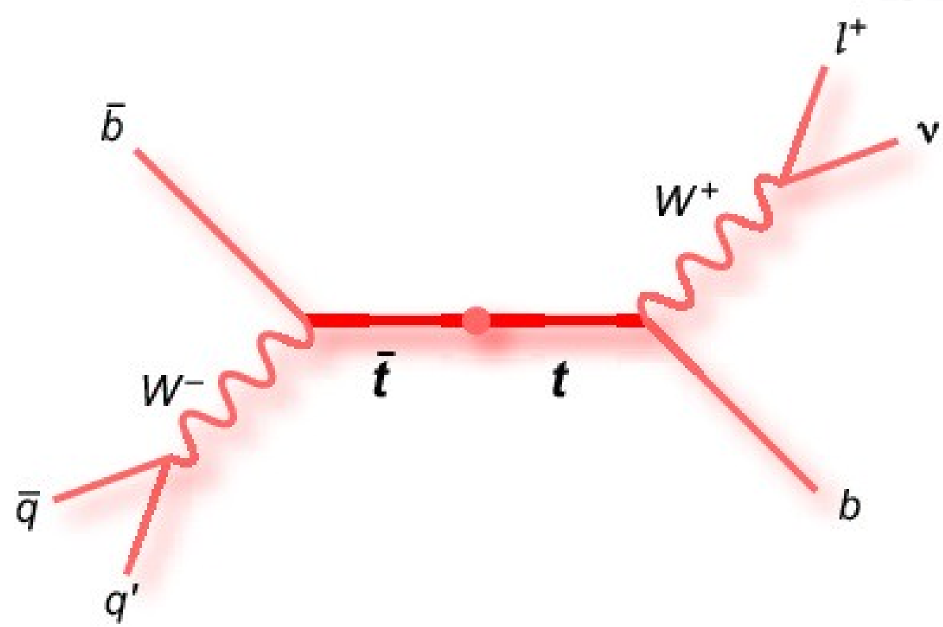
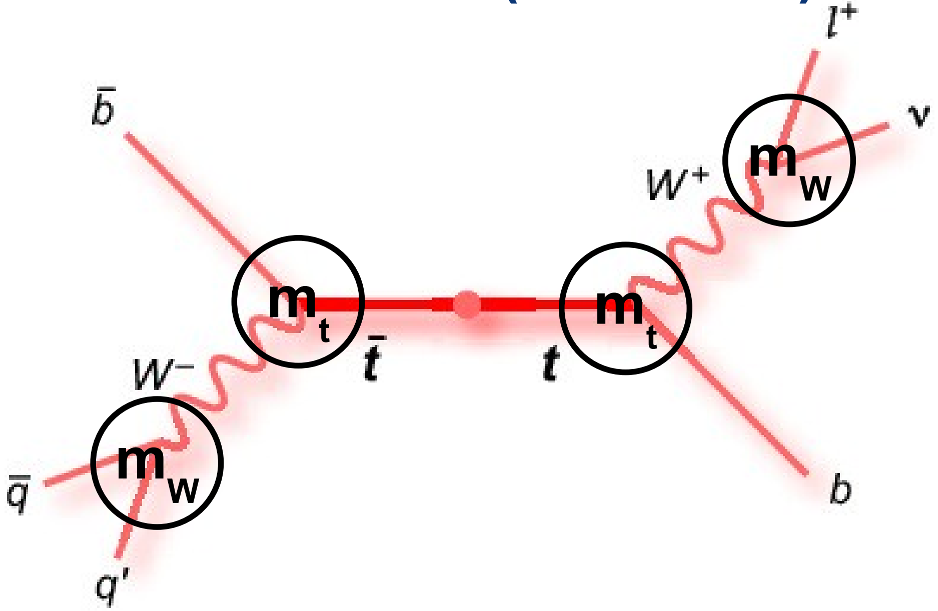
Reminder: Semileptonic $t\bar{t}$ Decay Channel

- Consider $t\bar{t}$ production at the ATLAS experiment
- Semileptonic decay channel (excluding tau decays)
  - 1 W decays to $q\bar{q}'$
  - 1 W decays to $l\nu$
  - → 2 b quarks, 2 light quarks, 1 lepton, 1 neutrino
  - → 4 high p_T jets + high p_T lepton + E_T^{miss}



Kinematic Fitting

- Semileptonic $t\bar{t}$ events:
  - 4 jets → 24 possible jet combinations (no b-tagging)
  - Jets from W undistinguishable → 12 jet permutations
  - → Ambiguity in assigning jets to quarks
- Aims of kinematic fitting:
  - Find the correct jet permutation
  - Find (better) estimate for the particle energies
  - …
- Principle: fit events to known (assumed) decay topology



For example:
m_w fixed
$m(t) \sim m(\bar{t})$

Kinematic Likelihood Fitter (1/2)

- **Kinematic Likelihood Fitter (KLFitter):**
  - General kinematic fitting package developed in Göttingen
  - Based on a likelihood approach
  - Also made available for ATLAS $t\bar{t}$ events

- **Maximise a likelihood function for all jet permutations (example below: $t\bar{t} \rightarrow$ e+jets)**
- **Pick permutation with highest likelihood**

$$L = \left(\prod_{i=1}^{4} W(\tilde{E}_i, E_i)\right) \cdot W(\tilde{E}_l, E_l) \cdot W(E_x^{\mathrm{miss}}|p_x^{\nu}) \cdot W(E_y^{\mathrm{miss}}|p_y^{\nu}) \cdot \left(\prod_{i=1}^{4} W(\tilde{\Omega}_i|\Omega_i)\right) \cdot BW(m_{jj}|M_{\mathrm{W}}) \cdot BW(m_{e\nu}|M_{\mathrm{W}}) \cdot BW(m_{jjj}|M_{\mathrm{top}}) \cdot BW(m_{e\nu j}|M_{\mathrm{top}})$$

W: transfer functions (→ next slide)

BW: Breit-Wigner

17 parameters:

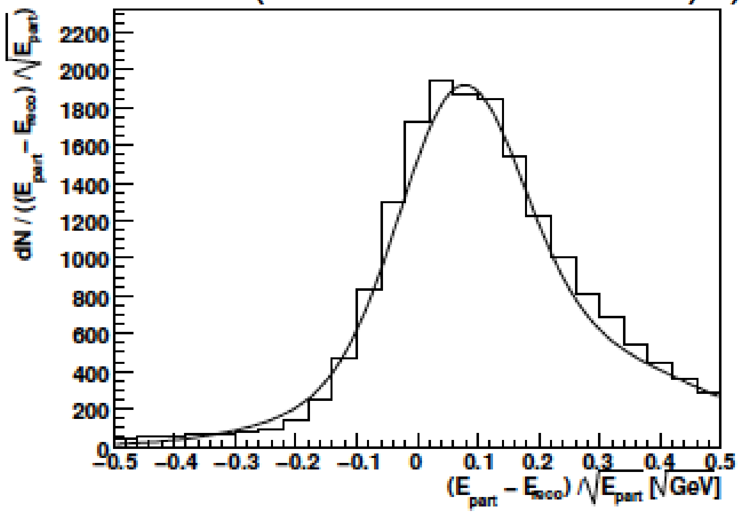
E_{jet} (4), E_e(1), Ω_{jet}(2x4), $p^{\nu}_{x,y,z}$(3), M_t (1)

Kinematic Likelihood Fitter (2/2)

- **Transfer functions $W(E_{measured} \mid E_{estimate/fit})$**
- **Now: extract from Monte Carlo (truth matching: $\Delta R < 0.3$)**
- **Later: derive methods to extract from data**
- **Fit double-Gaussian with 5 parameters, each a function of energy (→ 10 parameters) in 2D binned likelihood fit**

$$W(\tilde{E}, E) = \frac{1}{\sqrt{2\pi}(\sigma_1 + m \cdot \sigma_2)} \cdot \left(\exp\left(-\frac{\left(1 - \tilde{E}/E - \mu_1\right)^2}{2 \cdot \sigma_1^2} \right) + m \cdot \exp\left(-\frac{\left(1 - \tilde{E}/E - \mu_2\right)^2}{2 \cdot \sigma_2^2} \right) \right)$$

- **For electrons, light quark jets and b-jets**
- **For different regions in η**
- **Can cope with asymmetric tails**



b-jets (127 GeV/c^2 < E < 151 GeV/c^2, 1<η<1.7)

TopChi2Fitter

- X^2 fitter by Jean-Raphael Lessard, University of Victoria
- Make Gaussian approximations
- Define and minimise X^2 function:

$$\chi^2 = \sum_{i=1}^{4} \left(\frac{\alpha_i \tilde{E}_i - \tilde{E}_i}{\sigma_{\text{jets}}(\alpha_i \tilde{E}_i)} \right)^2 + \left(\frac{\lambda E_T^{\text{miss}} - E_T^{\text{miss}}}{\sigma_{E_T^{\text{miss}}}(\sum E_T^{\text{miss}})} \right)^2 + \left(\frac{m_{jj} - M_{\text{W}}}{\Gamma_{\text{W}}} \right)^2 + \left(\frac{m_{e\nu} - M_{\text{W}}}{\Gamma_{\text{W}}} \right)^2 + \left(\frac{m_{jjj} - m_{e\nu j}}{\Gamma_t} \right)^2$$

- Pick jet permutation with smallest X^2
- 5 parameters:
  jet rescaling parameters $\alpha_{jet} = E_{fit}/E_{measured}$ (4),
  rescaling parameter λ for the missing E_T (1)

TopCommissioning Algorithm

- Reconstruction algorithms previously used in top studies[1]
- Implementation for the top reconstruction framework:
  Dustin Urbaniec, Columbia University, New York

- Construction:
  - Find the 3-jet combination that gives the highest p_T
    → assign it to the hadronic top
  - Out of the 3 jets find the 2-jet combination closest to m_W
  - Next highest jet in p_T: b-jet from leptonic W decay
  - → unambigous assignment of 4 jets to 4 quarks

[1] The ATLAS Collaboration, *Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics*, CERN-OPEN-2008-020, arXiv.0901.0512.

Algorithm Comparison

- Comparison of KLFitter, X^2 fitter & commissioning algo.

- Use common tools:
  - Event Data Model for input and output
  - Tool for matching truth particles to reco. objects:

$$\Delta R = \sqrt{(\Phi_{reco} - \Phi_{truth})^2 - (\eta_{reco} - \eta_{truth})^2} < 0.3$$

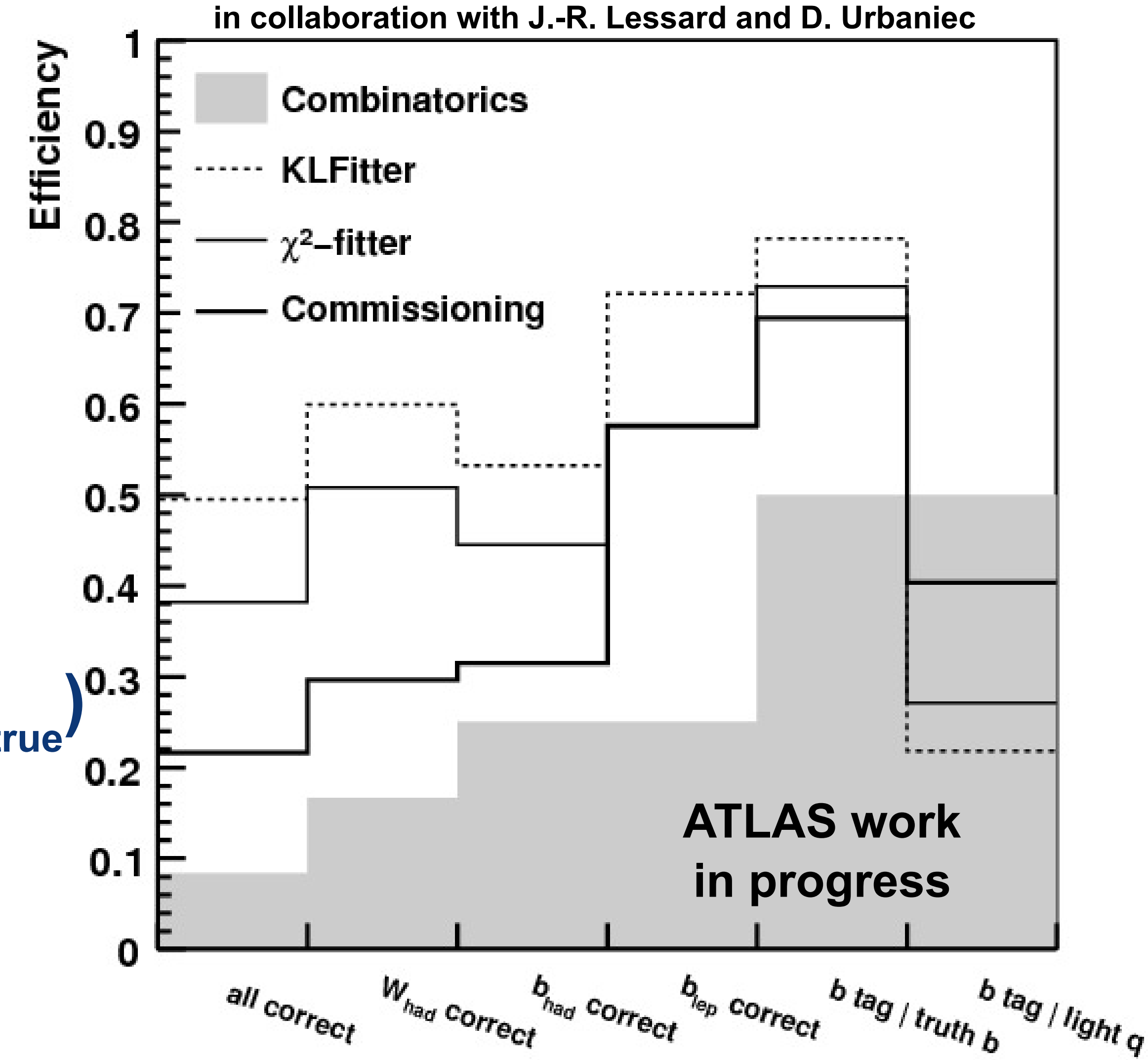
- $t\bar{t} \rightarrow$ e+jets generated with MC@NLO and full detector simulation, $\sqrt{s}$ = 10 TeV, m_t = 172.5 GeV

- 100k events selected:
  - 1 electron with p_T > 20 GeV, $|\eta|$ < 2.5
  - 4 jets with p_T > 20 GeV, of which 3 have p_T > 40 GeV
  - Jet $|\eta|$ < 2.5
  - E_T^{miss} > 20 GeV

Comparison: Reconstruction Efficiency

- Truth matching ($\Delta R<0.3$)

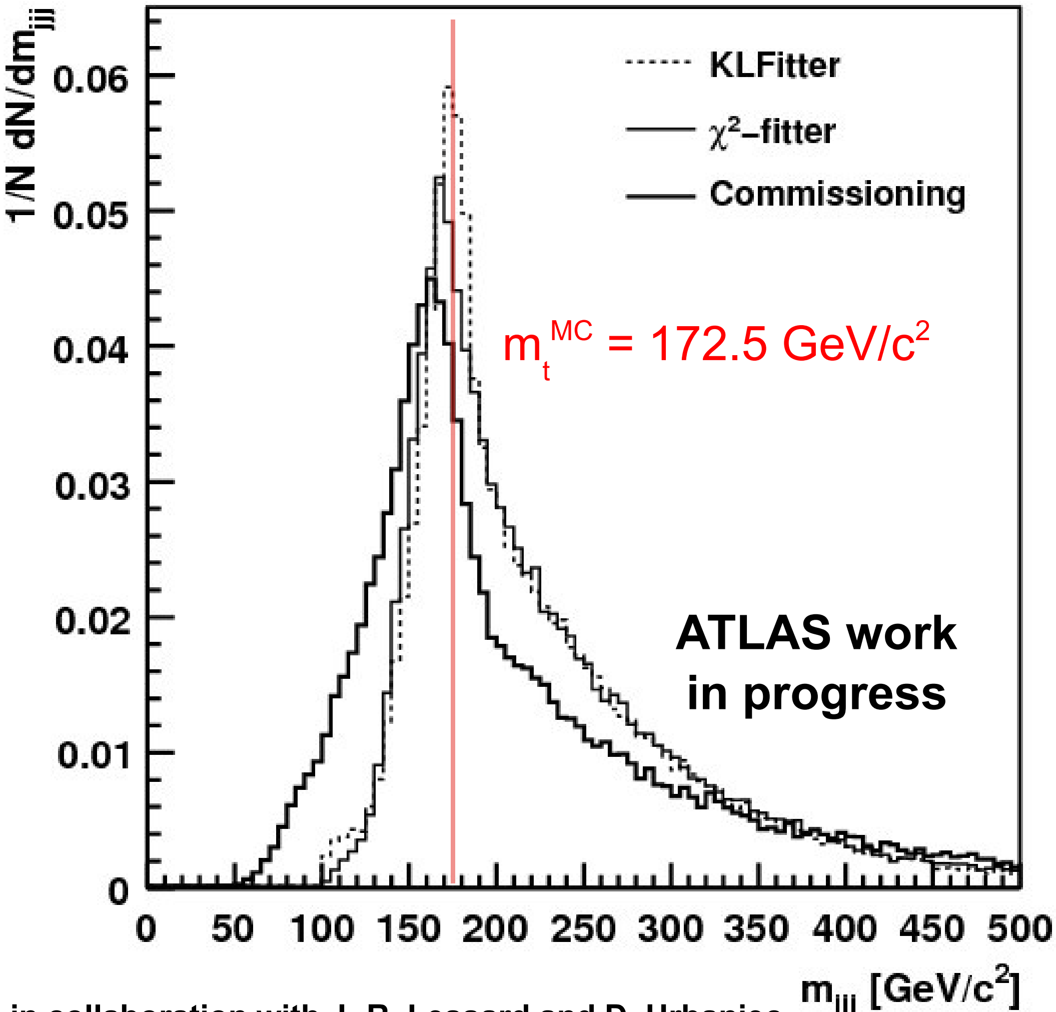
- bin 1: all jets correct
- bin 2: light jets correct
- bin 3: b_{had} correct
- bin 4: b_{lep} correct
- bin 5: $p(b_{tag} \mid b_{true})$
  (→ higher = better)
- bin 6: $p(b_{tag} \mid \text{light quark}_{true})$
  (→ lower = better)

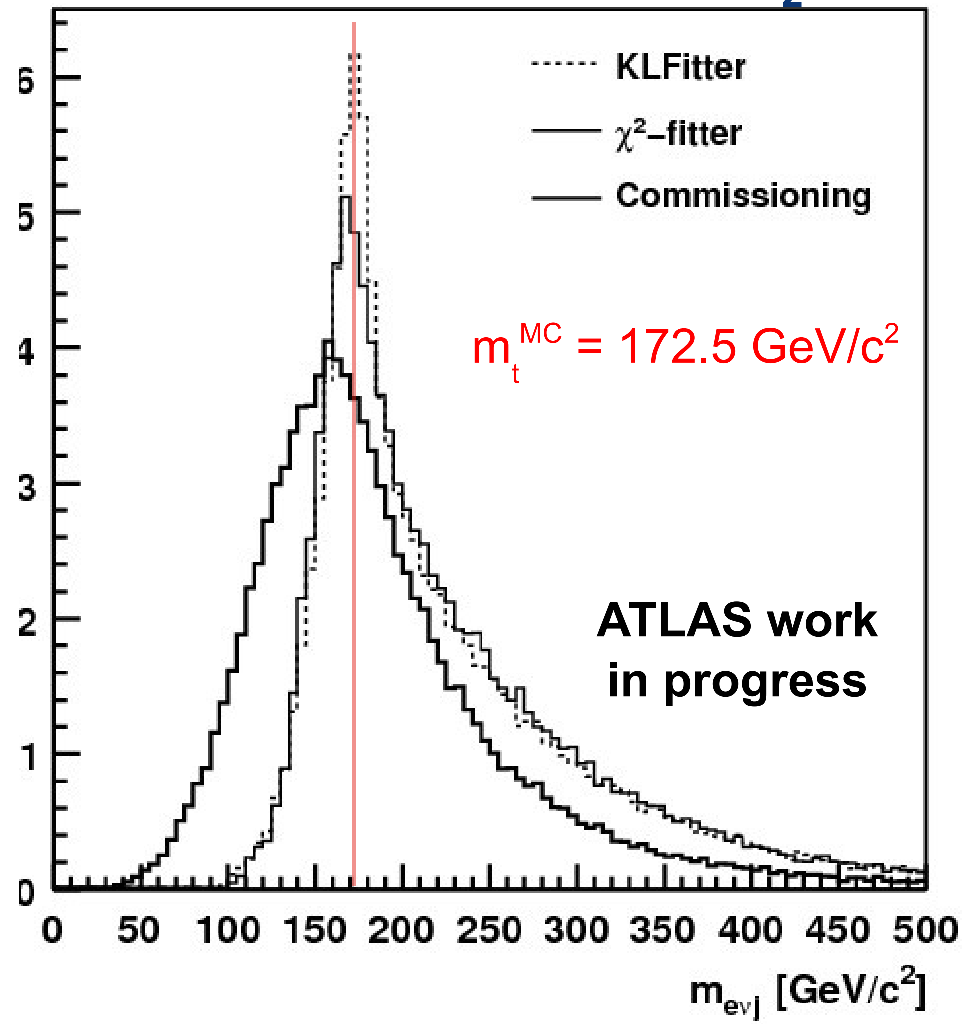


- Both fitters better than TopCommissioning
- KLFitter performs better than X^2 fitter

Comparison: Top Mass

- Left: inv. 3-jet mass from best jet combination (t_{had})
- Right: inv. e-ν-bjet mass from best jet combination (t_{lep})
- Fitters perform similar --- TopComm. worse (no reco p_z^{ν}!)





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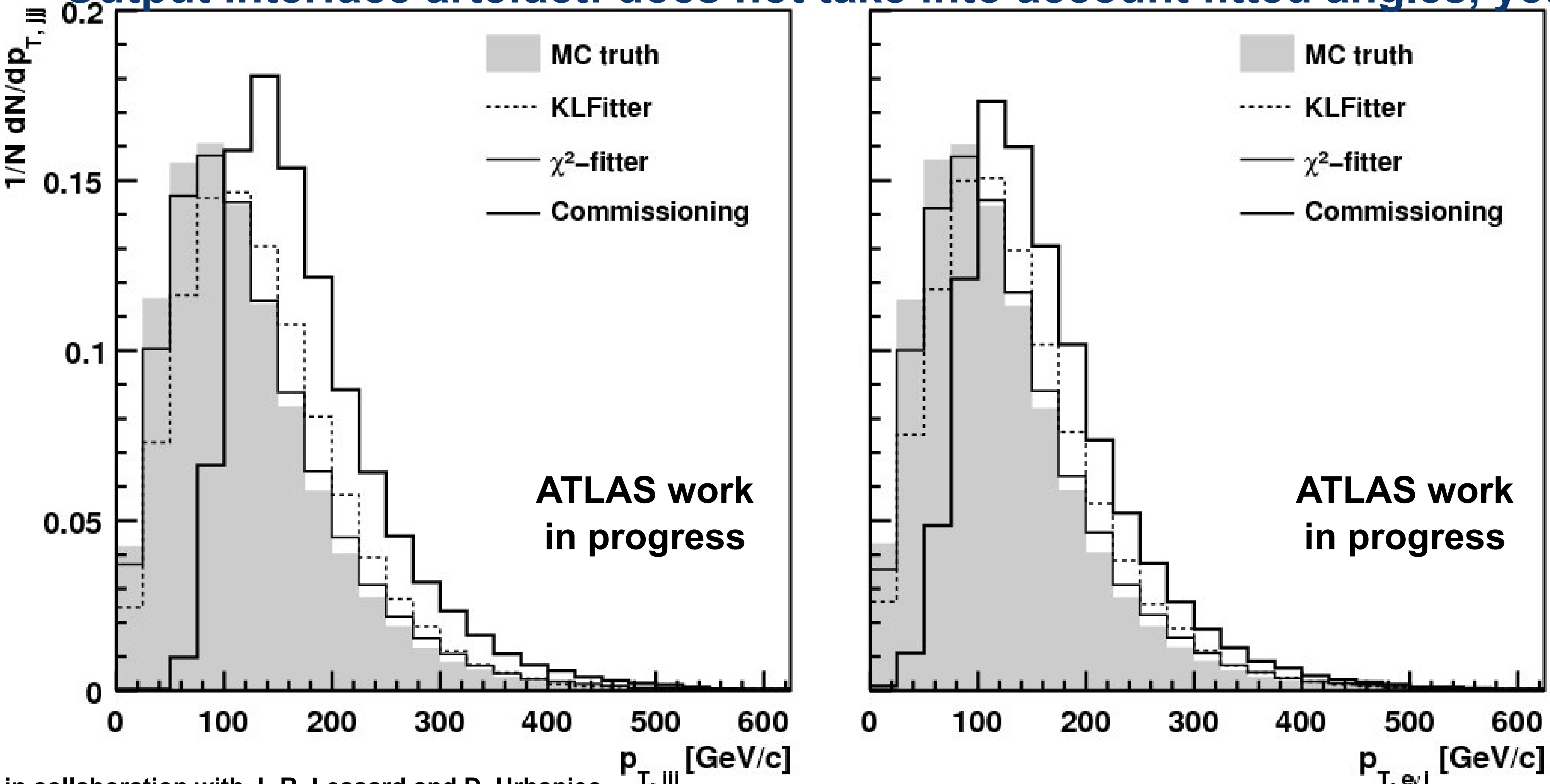
Comparison: Top P_T

- t_{had} and t_{lep} p_T from best combination
- MC truth: shaded histogram
- TopCommissioning worse than fitters
- Output interface artefact: does not take into account fitted angles, yet...



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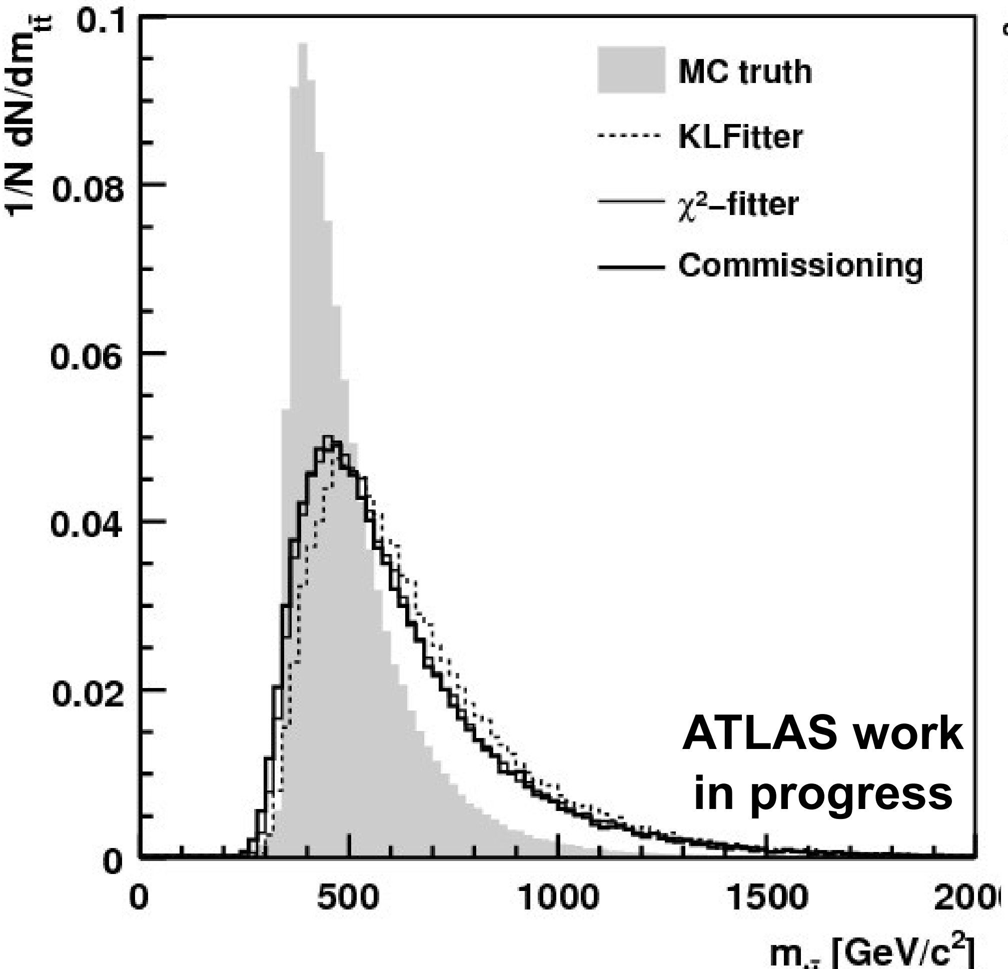
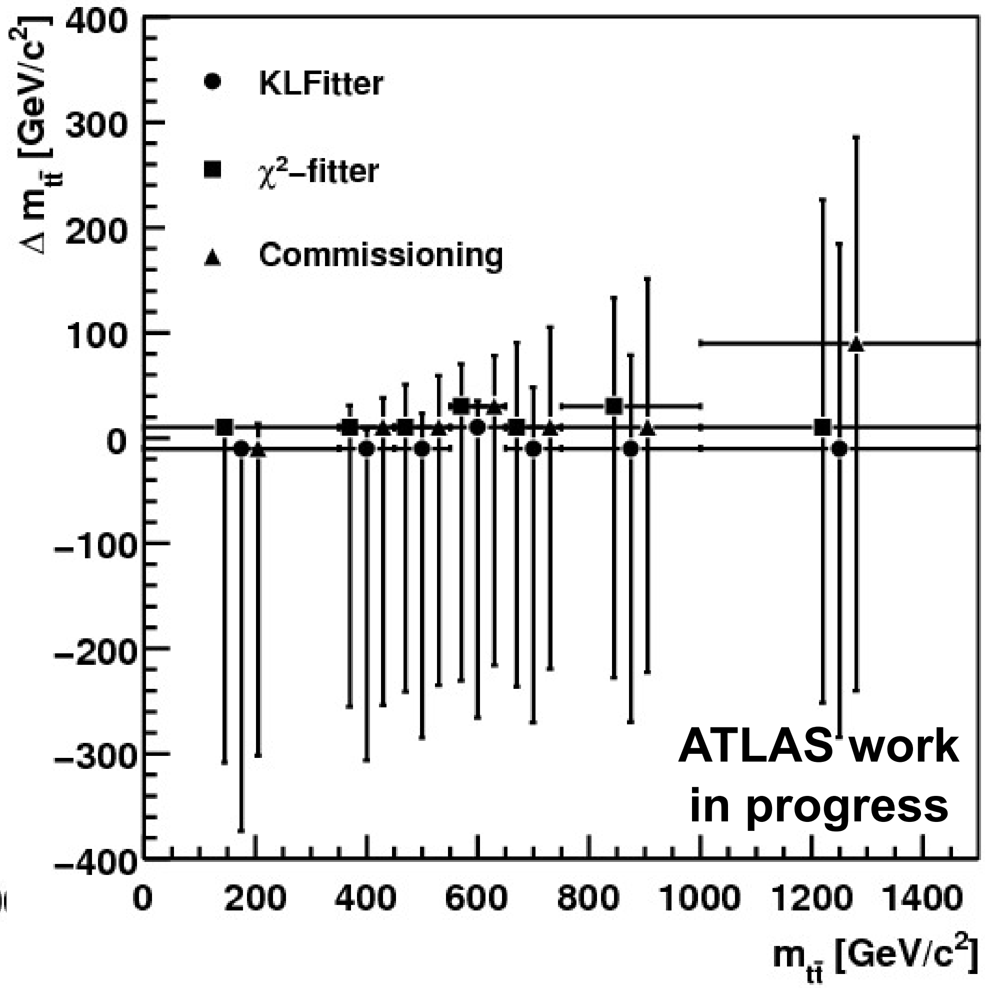
Comparison: Invariant $t\bar{t}$ Mass

- Inv. $t\bar{t}$ mass: all algorithms far away from MC truth shape
- No obvious degradation towards high $t\bar{t}$ masses
- "Error bars" → width of distribution (≠ expected error)





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Summary and Outlook

- KLFitter: general stand-alone tool for kinematic fitting
  → easy to adopt to other topologies and experiements
- ATLAS common tools for top reconstruction in place
- Different algorithms work:
  KLFitter, X^2 fitter, TopCommissioning

Outlook for KLFitter

- Adopt output EDM to cope with fitted angles
  → check again top p_T and inv. $t\bar{t}$ mass
- Methods for extracting transfer functions from data
- Likelihood as a background rejector and as input to cross section measurement (→ S. Guindon, Likelihood Method)
- Extract errors on estimators
- Apply to other event topologies (for example $t\bar{t}\gamma$)

BACKUP

- Use a physics independent piece of software (**BAT**):
  - General tool for data analysis
  - Parameter estimation, model comparison, goodness-of-fit
  - Uses Markov Chain Monte Carlo as basic sampling algorithm
  - Easy to use and interface, only depends on ROOT functionality
  - Stand-alone (no ATHENA dependence)
  - Common output structures (ROOT trees, .txt files)
  - Package developed at the MPI Munich, the University of Göttingen and at CERN
  - Available at http://www.mppmu.mpg.de/bat/