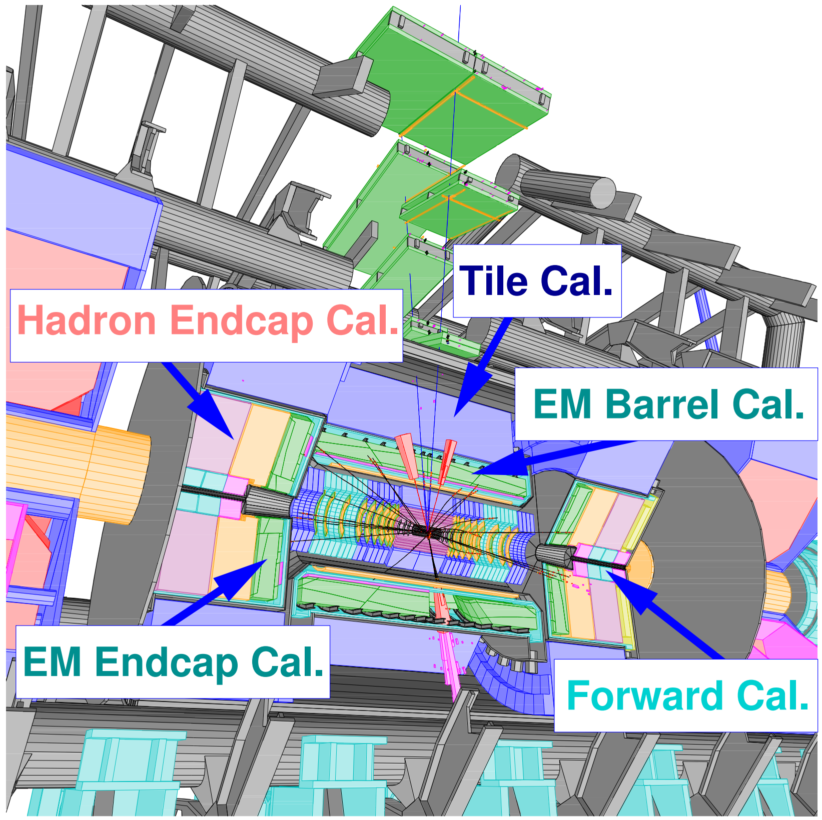
Top Quark Mass Measurement: Prospects of Commissioning Studies for early LHC Data in the ATLAS Detector



Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

Technische Universität München

Emanuel Rauter

Rigorosum

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Outline

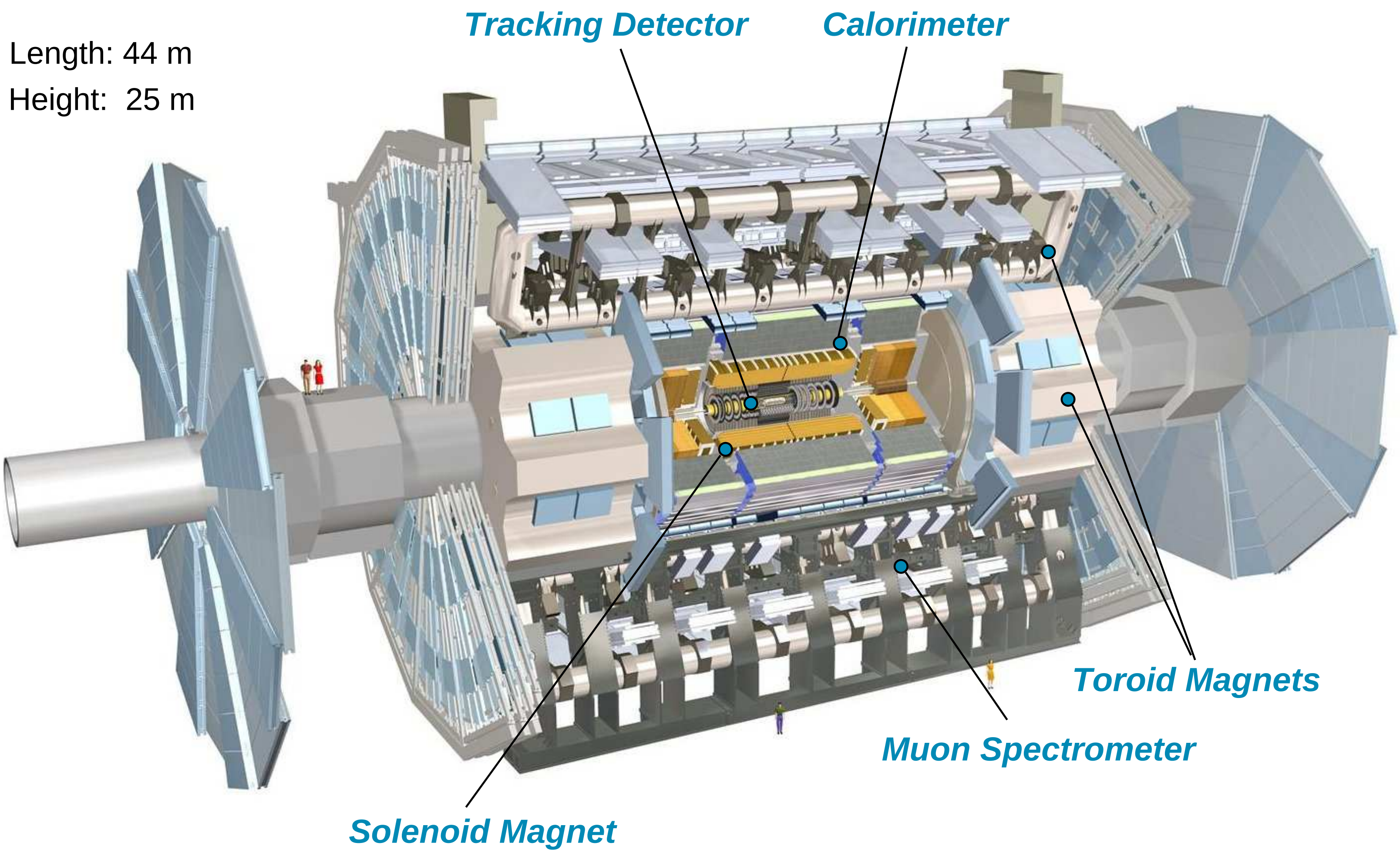
- the ATLAS detector at the LHC
- commissioning the Liquid Argon Calorimeter
  - electronics calibration
  - cosmic and single beam commissioning
- top quark mass reconstruction
  - physics process and background samples
  - event selection
  - top quark reconstruction
  - iterative in-situ calibration
  - systematics and results
- conclusion

The ATLAS Detector at the LHC

- LHC: pp collider with design $\sqrt{s} = 14\mathrm{TeV}$ and $\mathscr{L} = 1.5 \cdot 10^{34}\,\mathrm{cm}^{12}\mathrm{s}^{-1}$
- end of 2009 first physics run with $\sqrt{s} \simeq 10\mathrm{TeV}$ to accumulate first $\sim 200\mathrm{pb}^{-1}$

Length: 44 m

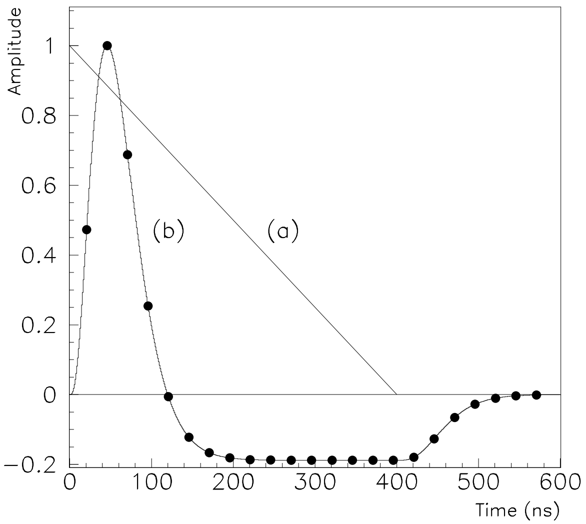
Height: 25 m

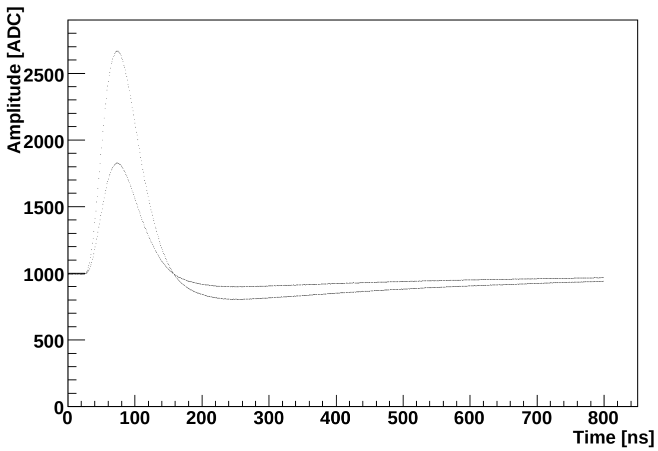


Commissioning the ATLAS Liquid Argon Calorimeter

- commissioning in different steps:
  1. checks of installed hardware
     - finding dead and faulty channels, on detector, in readout-, calibration- or HV - system
     - understanding pedestal and noise in readout, testing the calibration chain
     - filling data base with calibration constants
     - first electronics performance checks (signal shape, timing)
  2. cosmic rays as first physics signal
     - test trigger and read-out system
     - signal studies to validate and improve pulse shape prediction
  3. proceed with single beam events
     - signal studies with beam halo muons
     - response and homogeneity studies in ’beam-splash’ events
  4. physics commissioning as final goal: ’rediscovering the SM’ e.g. top quark and use known W boson mass for calibration

LAr Signal and Electronics Calibration



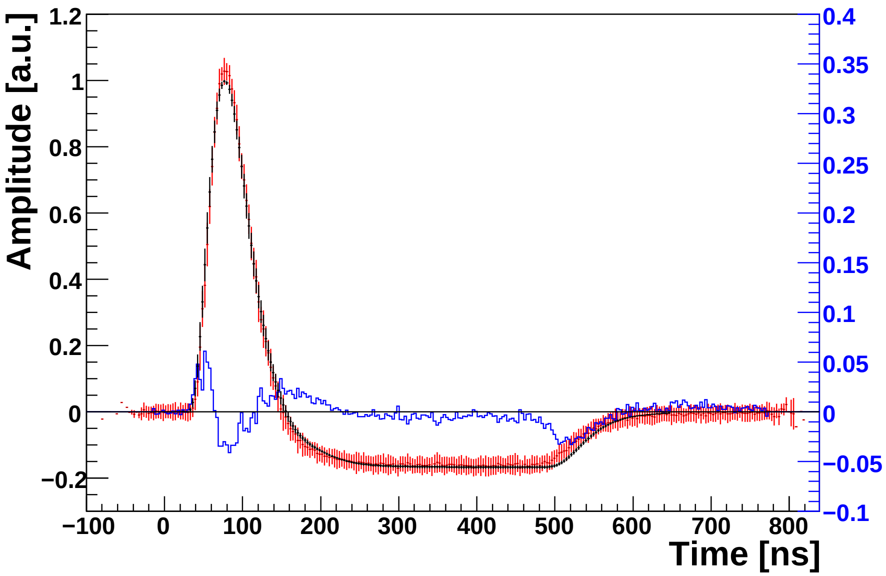


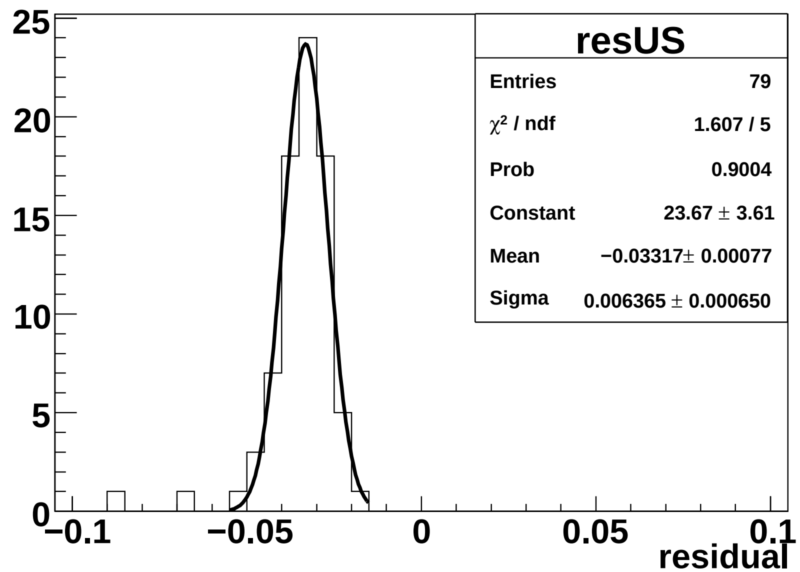
- drifting ionisation electrons result in a triangular current signal
- energy reconstructed from samples of shaped signal with *optimal filtering*
- need knowledge of signal shape for reconstruction with OF

$$E_{cell} = F_{\mu A \rightarrow MeV} \cdot F_{DAC \rightarrow \mu A} \frac{1}{\frac{M_{phys}}{M_{cali}}} \sum_{i=1}^{M_{ramps}} R_{iADC \rightarrow DAC} \left[\sum_{j=1}^{N_{samples}} a_j (s_j - p) \right]^j$$

- exponential calibration pulse to imitate physics signal
- sampling fraction from test beam measurements

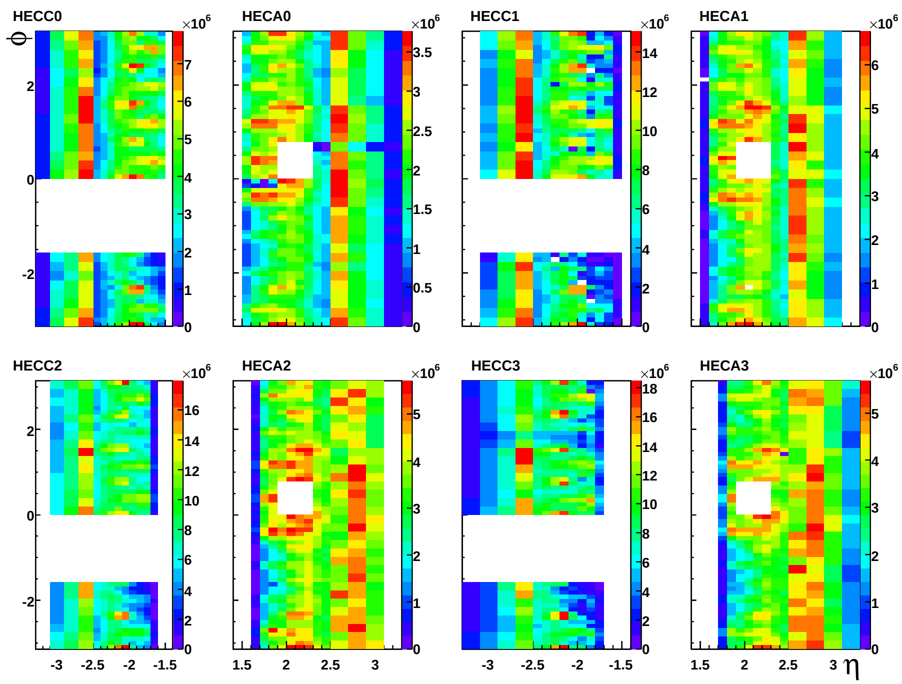
Cosmic Commissioning: Signal Studies

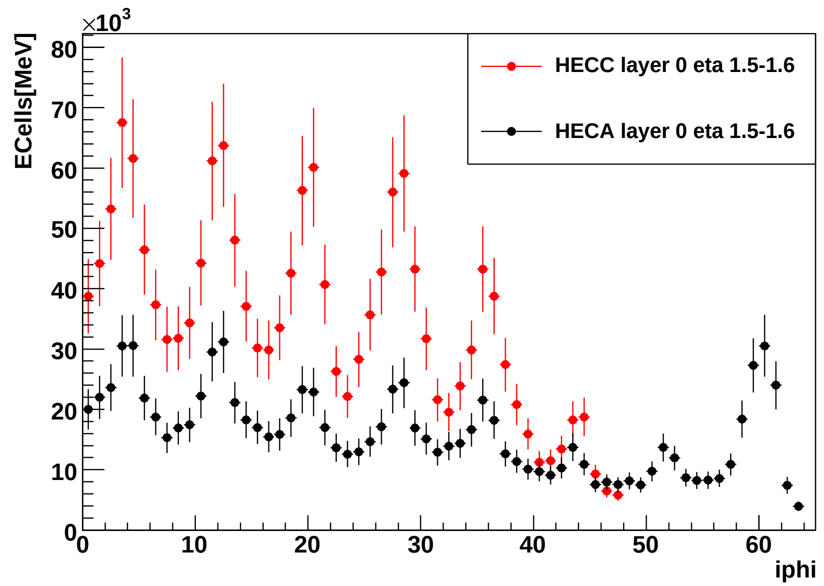




- trigger on LAr, TILE and minimum-bias scintillators
- residual of predicted vs measured shape:
  - normalise data shape with use of reconstructed amplitude and time
  - compute residual and give feedback to prediction e.g. adjust drift time
  - study distorted and pathological channels

First Data from LHC: Single Beam Events

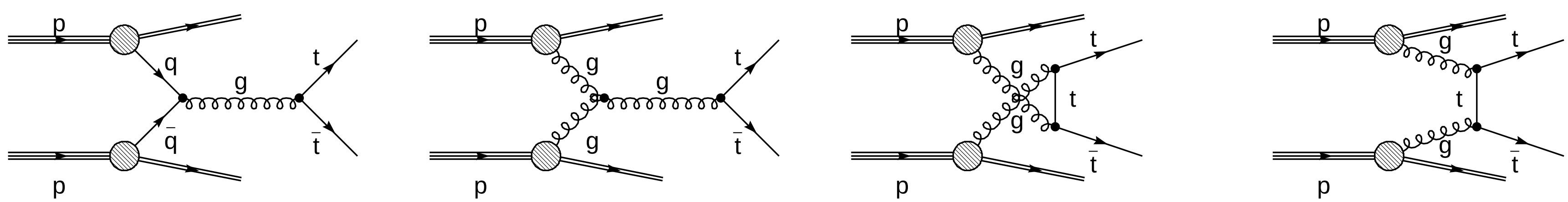




- single beam hitting collimator on C-side about 140 m before the IP
  - accumulated cell energy in $\eta - \phi$ plane of HEC for 86 single beam events, some cells with several TeV
  - periodic structure is due to the material in the endcap toroid magnets
  - decrease for high ϕ, i.e. the lower half of the HEC caused by additional material below beam pipe

Top Quark Physics

- after indirect constraints from LEP discovered in 1995 at TeVatron as 6th quark, prepare study to re-discover it in ATLAS (physics commissioning)
- production at TeVatron mainly via quark annihilation and in future at LHC mainly via gluon fusion



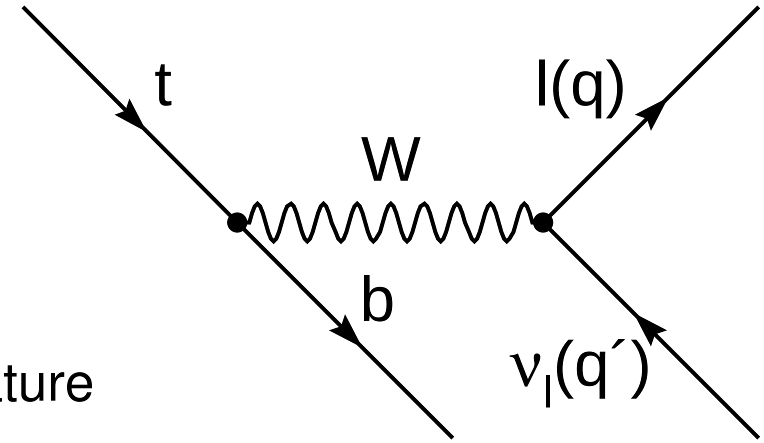
- for pp at LHC $\sigma_{t\bar{t}}(14\,\mathrm{TeV}) = 880$ pb decreases to $\sigma_{t\bar{t}}(10\,\mathrm{TeV}) = 400$ pb

$\Rightarrow$ LHC produces high rates of top quarks, high statistics will be available

- 'special role' in SM
  - 'heavy as gold'
  - due to its short lifetime the top decays before hadronisation
  - reconstructing top decay allows for measurement of its weak decay
  - top mass together with W mass provide indirect constraints on Higgs boson mass

Top Quark Reconstruction

- $t\bar{t}$ decay channels classified according to the decays of the W bosons
  - all leptonic
  - all hadronic
  - lepton plus jets



- golden channel: lepton plus jets
  - leptonic side offers clean trigger signature
  - hadronic side is fully reconstructable
  - in this analysis only muon or electron as lepton
- simulated data corresponding to 145 pb^{-1} with $t\bar{t}$ signal and following background processes:
  - top mass dependent: all hadronic channel, single top
  - inclusive $Z \rightarrow \ell\ell$ and $W \rightarrow \ell\nu$ plus jets
  - di-boson events
  - QCD (not fully simulated but extrapolated from PYTHIA)

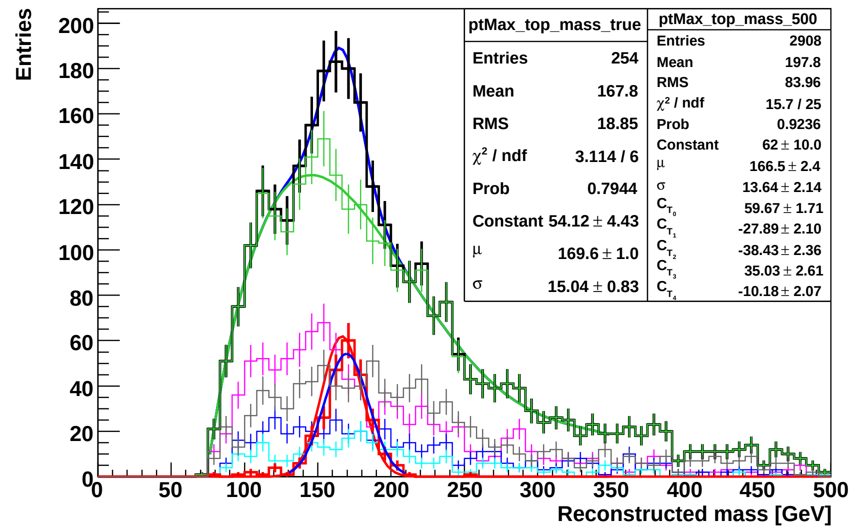
Event Selection

- Trigger: electron or muon with E_T of more than 20 GeV
- lepton selection i.e electron or muon:
  - p_T of more than 20 GeV
  - $|\eta| < 2.5$
  - isolation: additional transverse energy in $\Delta R = 0.2 < 6$ GeV
- jet selection:
  - (Anti)Kt4-Algorithm on local hadron calibrated topo clusters
  - p_T of more than 20 GeV
  - $|\eta| < 2.5$
  - minimal distance to leptons $\Delta R = 0.4$
  - NO b-tagging used
- event selection cuts:
  - exactly one lepton
  - more than 4 jets, 3 of them with p_T above 40 GeV
  - $E_\mathrm{T}^\mathrm{miss}$ above 20 GeV

Top Mass Measurement

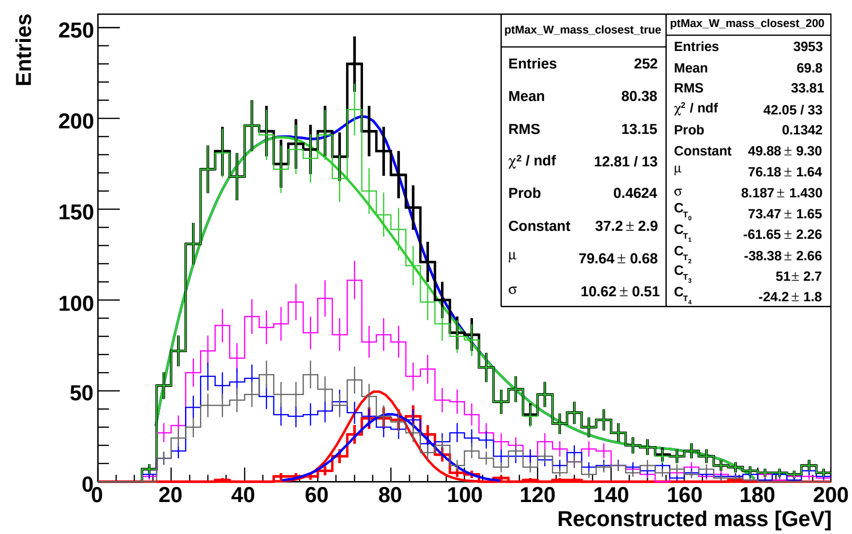
top quark reconstruction:

- take jet triplet maximising p_T as top candidate
- method chooses the correct combination in 25% of the cases
- fit invariant mass spectrum with convolution of Gaussian and Chebychev polynomial
- example plot in electron channel



W boson reconstruction:

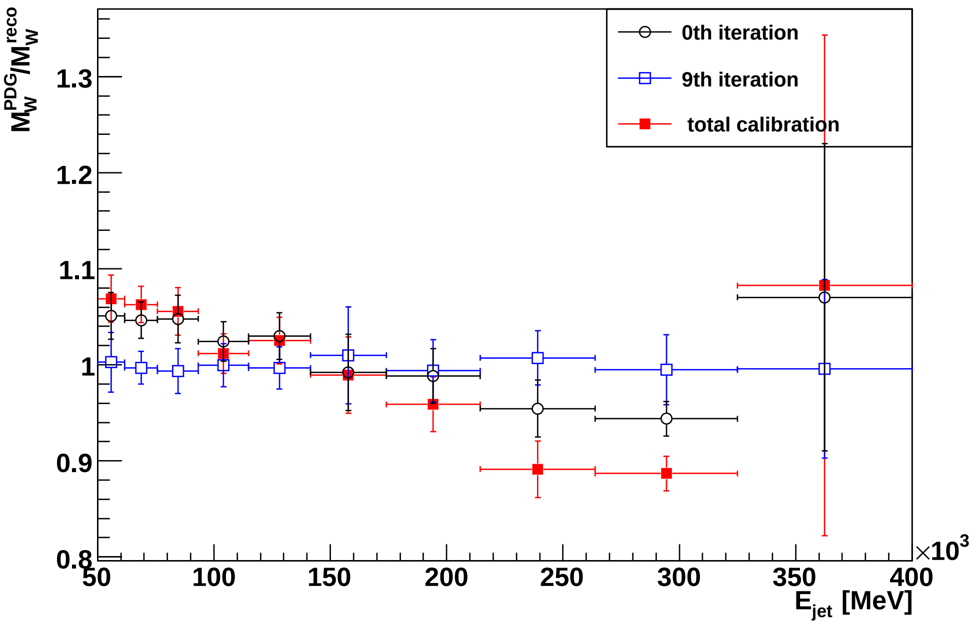
- boost to top CM system and take the closest two jets in triplet as W boson candidate
- fit invariant mass spectrum with convolution of Gaussian and Chebychev polynomial



Iterative In-Situ Calibration in W $\rightarrow$ jj

- exploit precise knowledge of the W boson mass
  - jet angle is measured better than jet energy, hence in the the massless limit for the invariant mass we derive scale factors for the jet energy as $K = M_W^{PDG}/M_{jj}$
  - simplified rescaling results in an effective jet energy scale
  - rescaling is repeated in I iterations resulting in a final scale factor as $K_i = \prod_{j=1,I} K_i^j$
- fill jets constituting the W boson candidate into histograms, according to their energy
- apply fitting function and fill M_W^{PDG}/M_W^{reco} into a calibration histogram
- apply calibration to jets and iterate the method until it converges

Application of Iterative In-Situ Calibration



- final calibration function closely follows the first iteration, but due to higher order effects is not the same
- method results in an effective calibration
- application of the calibration method within statistical errors, i.e. initial calibration was good w.r.t. precision achievable with available statistics
- in case of a deliberate rescaling of jet energy, the jet energy scale is recovered to a good extent by the method

$\Rightarrow$ reduction of systematic error

Systematic Effects

	mean of Gaussian fit [GeV]	
	before in-situ calibration	after in-situ calibration
	standard analysis	
m_t electron	166.55 $\pm$ 2.38	167.22 $\pm$ 2.36
m_t muon	166.78 $\pm$ 2.99	166.90 $\pm$ 2.69
	Δmean (μ)	Δmean (μ)
	jet energy scale $\pm$5%	
Δm_t electron	$\pm$ 7.96	- 1.60
Δm_t muon	$\pm$ 8.21	- 1.19
	b jet energy scale $\pm$5%	
Δm_t electron	$\pm$ 2.42	$\pm$ 1.89
Δm_t muon	$\pm$ 2.45	$\pm$ 2.54
	physics background variation $\pm$50%	
Δm_t electron	$\pm$ 0.14	$\pm$ 0.02
Δm_t muon	$\pm$ 0.57	$\pm$ 0.08
	fit uncertainty	
Δm_t	+ 3.2 $\pm$ 2.7	

- application of the in-situ calibration largely recovers lJES, bJES not to same extent
  - lJES: Δm_{top} no longer symmetric, shift in one direction $\Rightarrow$ method is over-compensating
- rescaling physics background showed no significant effect as main contribution is combinatorial
- Gaussian part of the fitting function shifted to lower values
  - reason: it absorbs a significant part of combinatorial peaking background
  - shift not known precisely $\Rightarrow$ not applied as correction but treated as systematic
  - for samples with higher statistics: Chebychev polynomial of 7^{th} order significantly improves the situation
- jet algorithm: change from Kt4 to AntiKt4 as typical $\Delta m_{top} = \pm 3.96$ GeV

Analysis Results

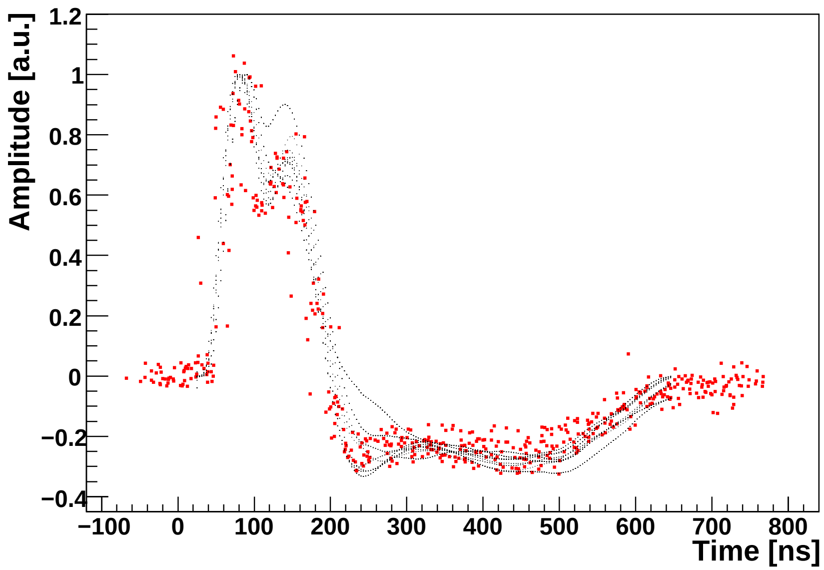
- simulated data with an integrated luminosity of 145 pb^{-1}, the top quark mass was reconstructed in the lepton plus jets decay channel using local hadron calibrated Kt4 jets resulting in a top mass e.g. in the electron channel
  - before in-situ calibration:
    $$m_t^{electron} = 166.55 \pm (2.38)_{stat} \, (^{+9.58}_{-9.10})_{syst} \text{ GeV}$$
  - after in-situ calibration:
    $$m_t^{electron} = 167.22 \pm (2.36)_{stat} \, (^{+3.9}_{-2.49})_{syst} \text{ GeV}$$
- compatible with input top mass value of 172.5 GeV.
- before the application of the in-situ calibration, the dominant errors are the light jet energy scale and the combinatorial background
- after application of the in-situ calibration, only the latter remains dominant
- with samples of higher statistics the combinatorial background is expected to decrease and the fitting procedure is expected to become more stable

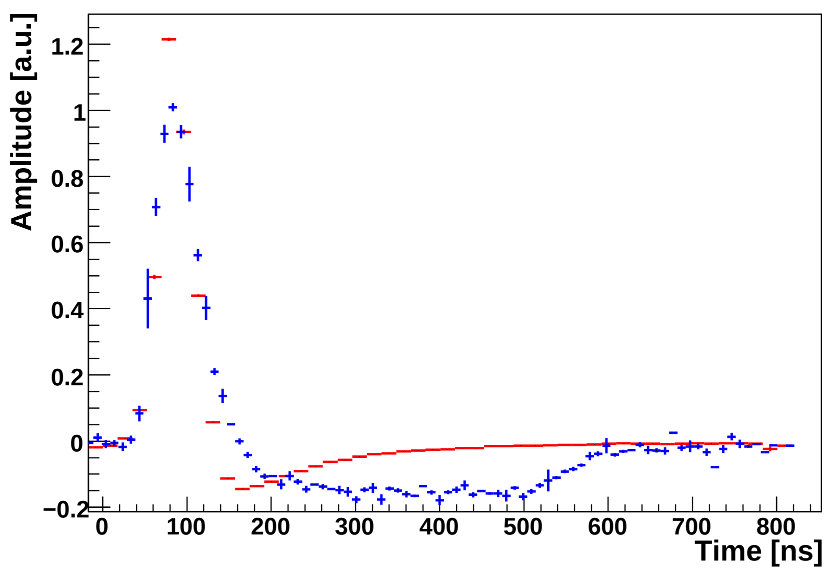
Conclusion

- Commissioning
  - shape studies showed reasonable prediction in first iteration
  - some distorted shapes remain to be understood
  - beam splash events are a good test bench for homogeneity studies, e.g. of the HV response
- top quark analysis for early data without b-tagging
  - in-situ calibration decreases systematic due to JES
  - method suffers from combinatorial background
  - fitting procedure is expected to become more stable with higher statistics
  - method needs to be calibrated with MC samples at different mass-points
  - if b-tagging information is available, other reconstruction methods will be more promising

Backup Slides

Cosmic Commissioning: Signal Studies





- shape:
  - scale predicted shape to reconstructed amplitude and time
  - understand differences to prediction
  - e.g. HV or pad displacement
  - look at timing w.r.t. TILE calorimeter - X-talk studies
  - understand distortions

Systematic Effects

- jet energy scale re-scaled by $\pm 5\%$
  - $\Rightarrow$ reconstructed top mass follows both, W mass only lJES variation
  - $\Rightarrow$ lJES: Δm_{top} of ± 7.96 (± 8.21) GeV in the electron (muon) channel
  - $\Rightarrow$ bJES: Δm_{top} of ± 2.42 (± 2.45) GeV in the electron (muon) channel
- application of the in-situ calibration largely recovers lJES, bJES not to same extent
  - lJES: Δm_{top} no longer symmetric, shift of -1.60 (-1.19) GeV in the electron (muon) channel
  - $\Rightarrow$ method is over-compensating
  - bJES: remaining Δm_{top} of ± 1.89 (± 2.54) GeV in the electron (muon) channel.
- Gaussian part of the fitting function shifted to lower values
  - reason: it absorbs a significant part of combinatorial peaking background
  - shift is known to 1 σ only, not applied as correction, but treated as systematic, positive error of 3 GeV.
  - samples with higher statistics: a Chebychev polynomial of 7^{th} order significantly improves the situation not applicable here, as fit then follows the statistical fluctuations in the tail
- jet algorithm: change from Kt4 to AntiKt4 as typical $\Delta m_{top} = \pm 3.96$ GeV
- rescaling physics background by 50%(150%) showed no significant effect as main contribution is combinatorial