HEC Group Activities 2007-2010

Visit of the Fachbeirat — Sven Menke, MPP München — 27-Oct-2010, MPP München

on behalf of the MPP Munich HEC Group:
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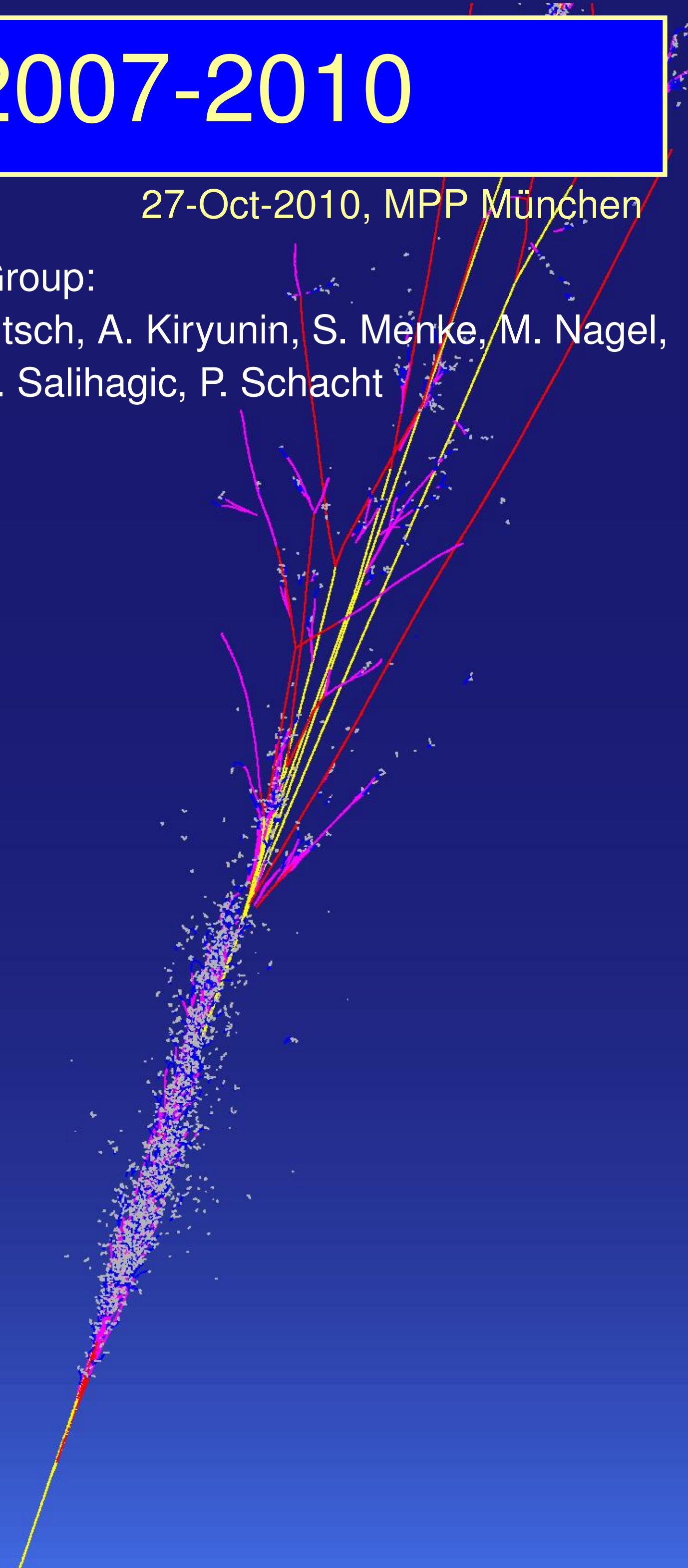
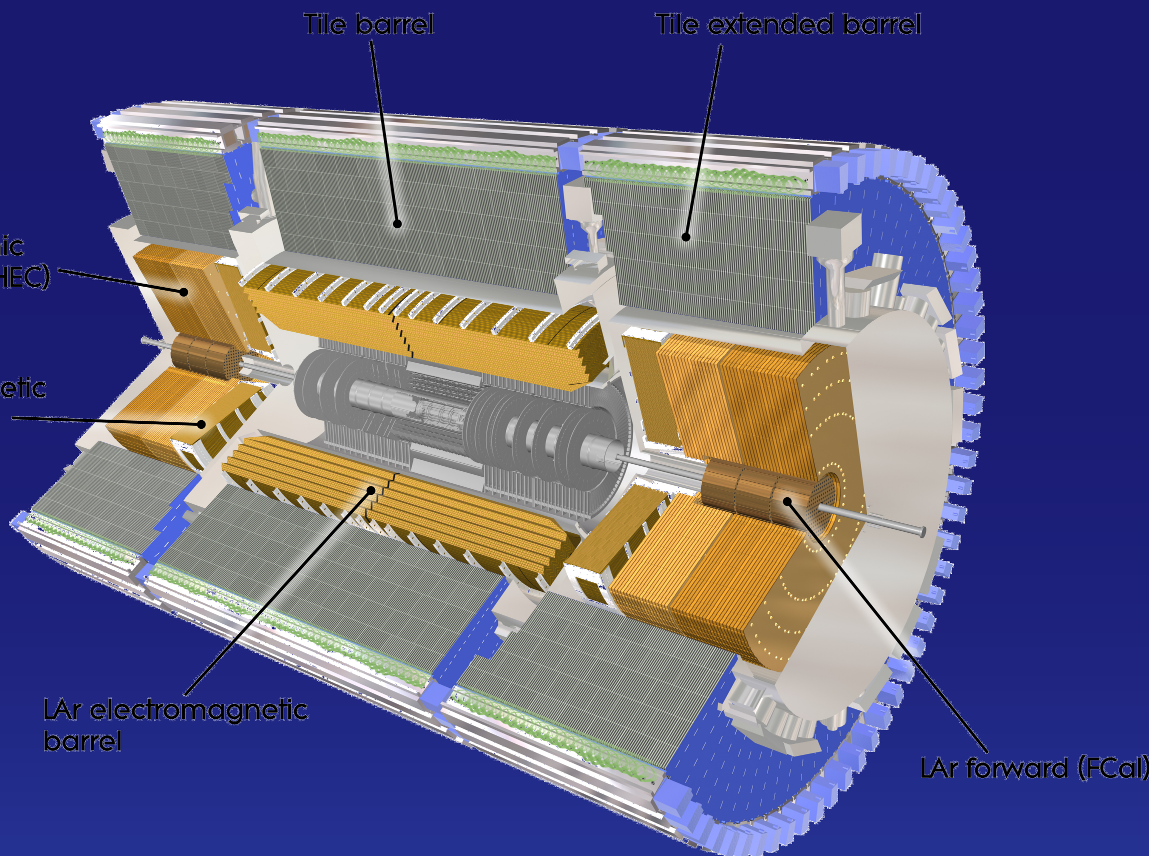
- The ATLAS Hadronic Endcap Calorimeter
- Commissioning
  - Cosmics
  - Beam Splash Events
  - Collisions
- Hadronic Calibration
  - Local Hadron Calibration
  - Jet-level Corrections
  - Validation with Testbeam and Collisions Data
- Analysis
  - Top-mass Measurements in the Semi-Leptonic and All-Hadronic Channel
- Upgrade Activities for sLHC
  - Cold Electronics
  - Low Voltage Power Supplies

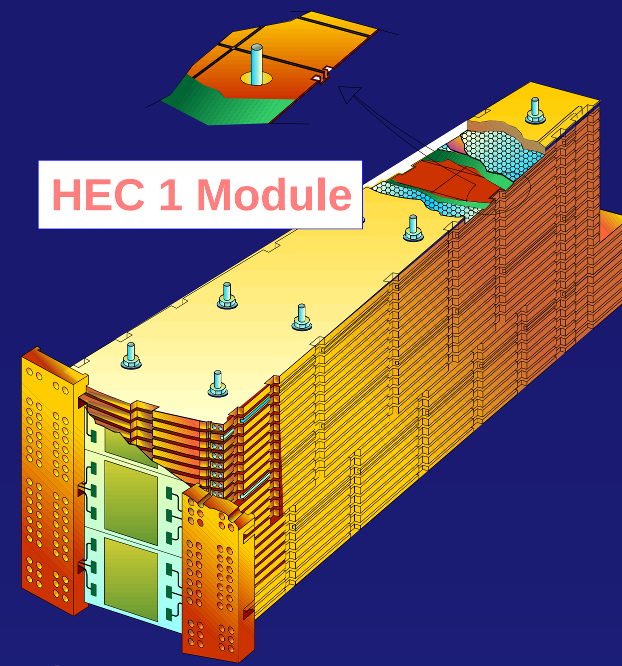


The ATLAS Detector ► Calorimetry

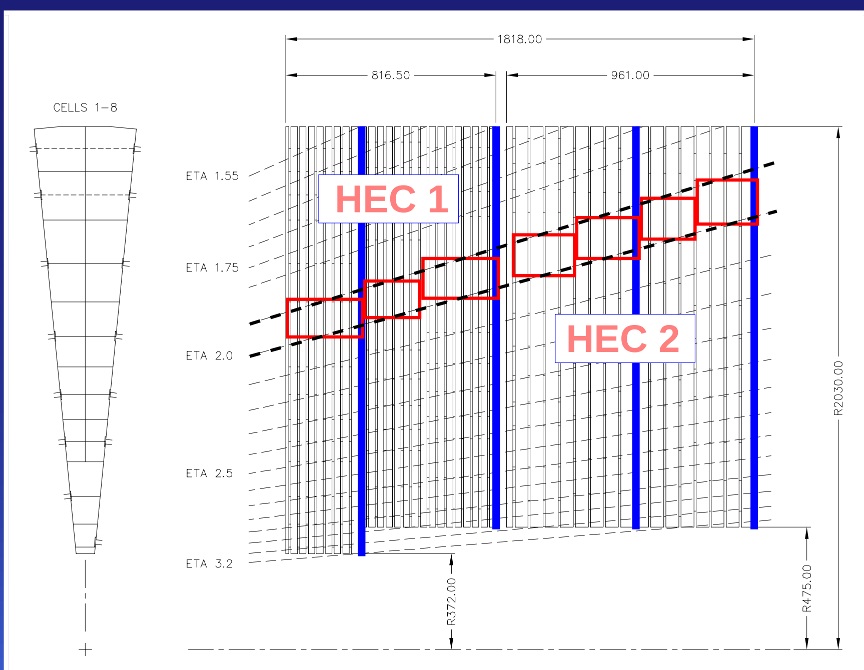
- Calorimeter coverage up to $|\eta| < 4.9$
- EM Barrel/Endcap: LAr/Pb Accordion $|\eta| < 1.4/1.375 < |\eta| < 3.2$
- Had Barrel: iron/scintillating tiles $|\eta| \lesssim 1.7$
- Had Endcap: LAr/Cu parallel plates $1.7 \lesssim |\eta| \lesssim 3.2$
- EM(HAD) Forward: LAr/Cu(W) tubular electrodes $3.2 \lesssim |\eta| \lesssim 4.9$



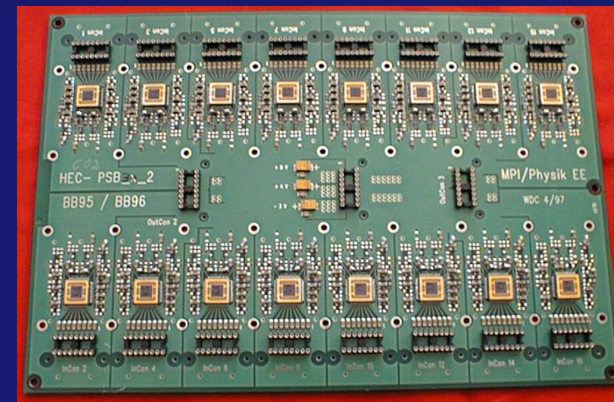
- typical cell sizes $\Delta\eta \times \Delta\phi = 0.025 \times 0.025$ (EM) and 0.1×0.1 (HAD); 3 to 7 samplings; at least $10\,\lambda$
- e/γ: $\sigma_E/E \simeq 10\%/\sqrt{E}$
- jets: $\sigma_E/E \simeq 50\%/\sqrt{E} \oplus 3\%$



- HEC absorber structure
  - Absorbers plates parallel to beam axis
  - 2.5 cm thick Cu plates in HEC 1
  - 5.0 cm thick Cu plates in HEC 2



- HEC readout structure
  - $\delta\eta \times \delta\phi \simeq 0.1(0.2) \times 0.1(0.2)$
  - Layer1 (HEC1 Front): $\sum 8$ gaps
  - Layer2 (HEC1 Back): $\sum 16$ gaps summed pseudo pointing in η
  - Layer3&4 (HEC2 Front&Back): $\sum 8$ gaps summed pseudo pointing in η
  - 5632 readout channels



- Cold Electronics
  - GaAs based readout electronics made by MPP
  - radiation hard up to 3×10^{14} n/cm^2 corresponding to ~ 15 times the expected fluence after 10 years of LHC

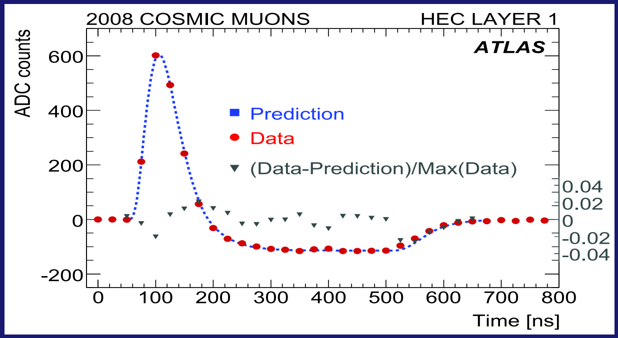
- Construction/Installation (up to 2006)
  - about $1/4$ of all modules assembled at MPP
  - stacking of copper plates, cabling, quality control including beam tests (see bottom picture for one full wheel)

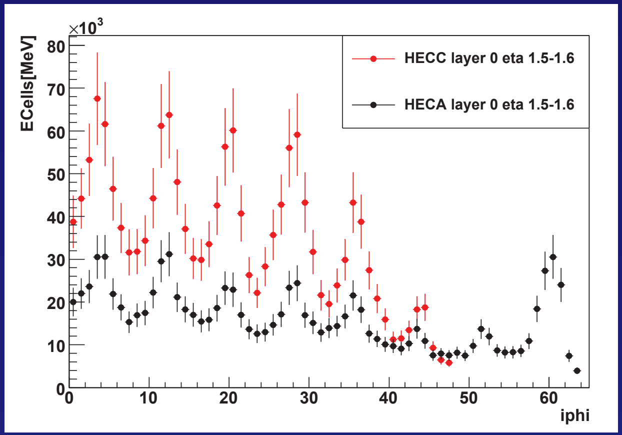
- Commisioning (2007-2009)
  - Pulse shape and noise measurements with Cosmic Muons and Beam Splash events

- Calibration (since 1999)
  - Cluster reconstruction and Hadronic Calibraton
  - Validation with test beam and collisions data

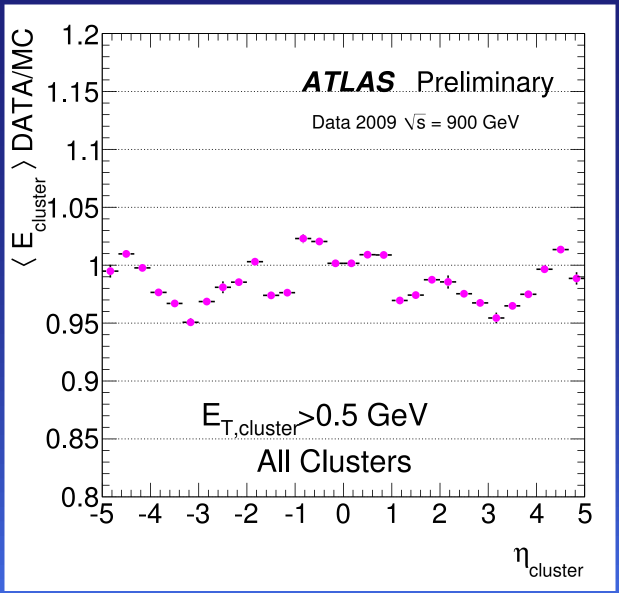
Commissioning

- Commissioning with cosmics muons
  - selecting cells with large enough energies from muons traversing LAr gaps in the HEC allows to check the pulse shape
  - only small deviations from predicted shape ($3 - 5\%$) have been observed





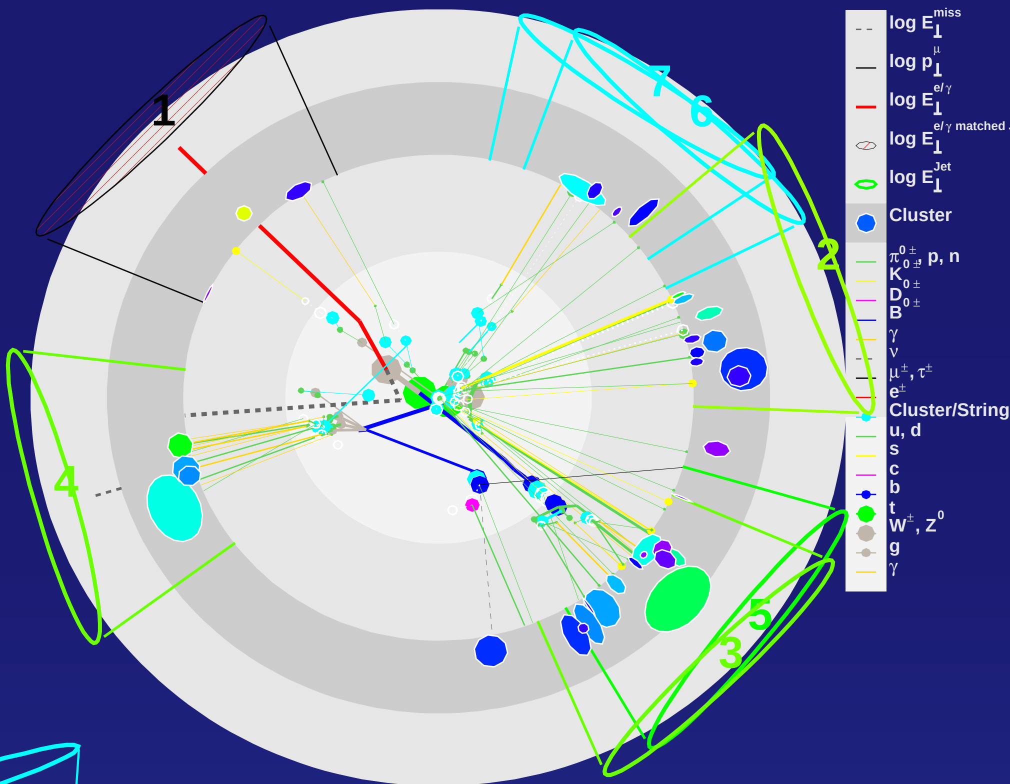
- Commissioning with beam splash events
  - Average energy of HEC cells in one layer and η-bin allows to detect regions with reduced high voltage

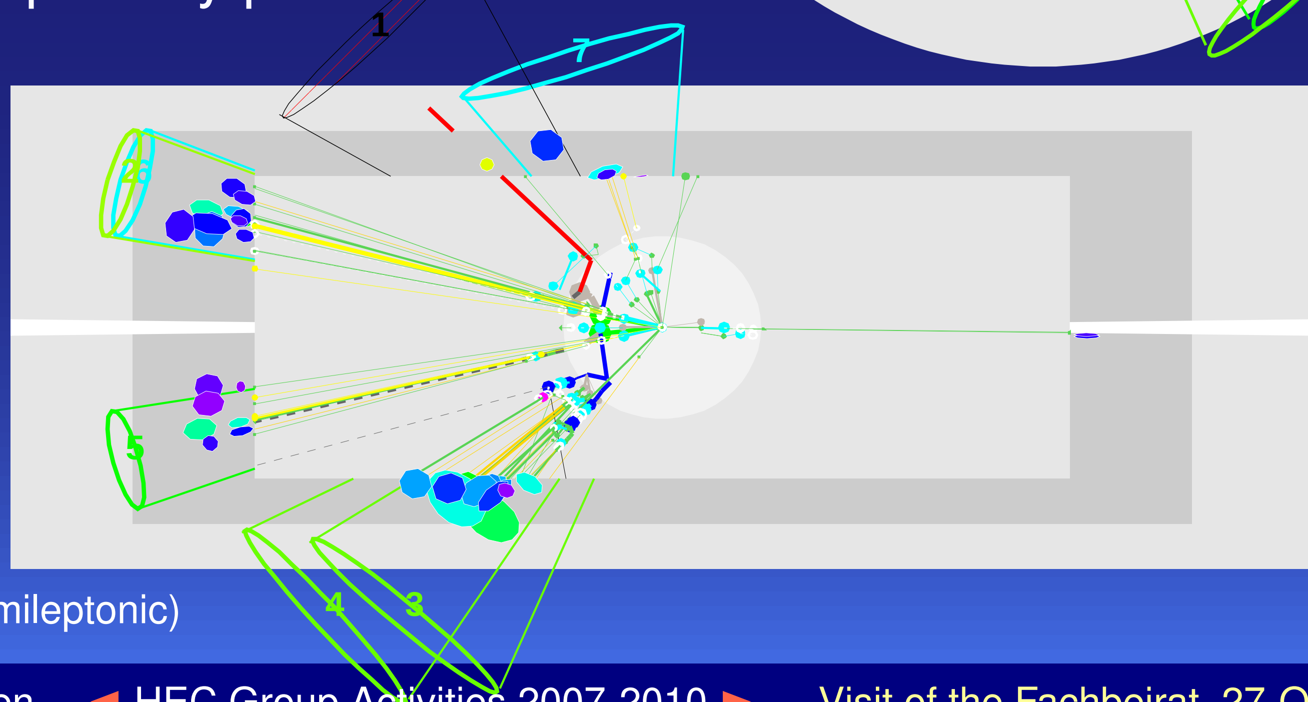


- Commissioning with collisions
  - Ratio of Cluster energy in Minium Bias events at $\sqrt{s} = 900$ GeV in Data over Monte Carlo simulations shows agreement already on 5% level

Hadronic Calibration

- Aim is to have best possible response to hadrons and electrons in physics channels like $t\bar{t} \to Wb\,Wb \to l\nu j_b\, jjj_b$
  - pseudo event display in $r-\phi$ and $r-z$ illustrates this
  - use calorimeter objects calibrated to stable particle level to form jets which point back to primary partons

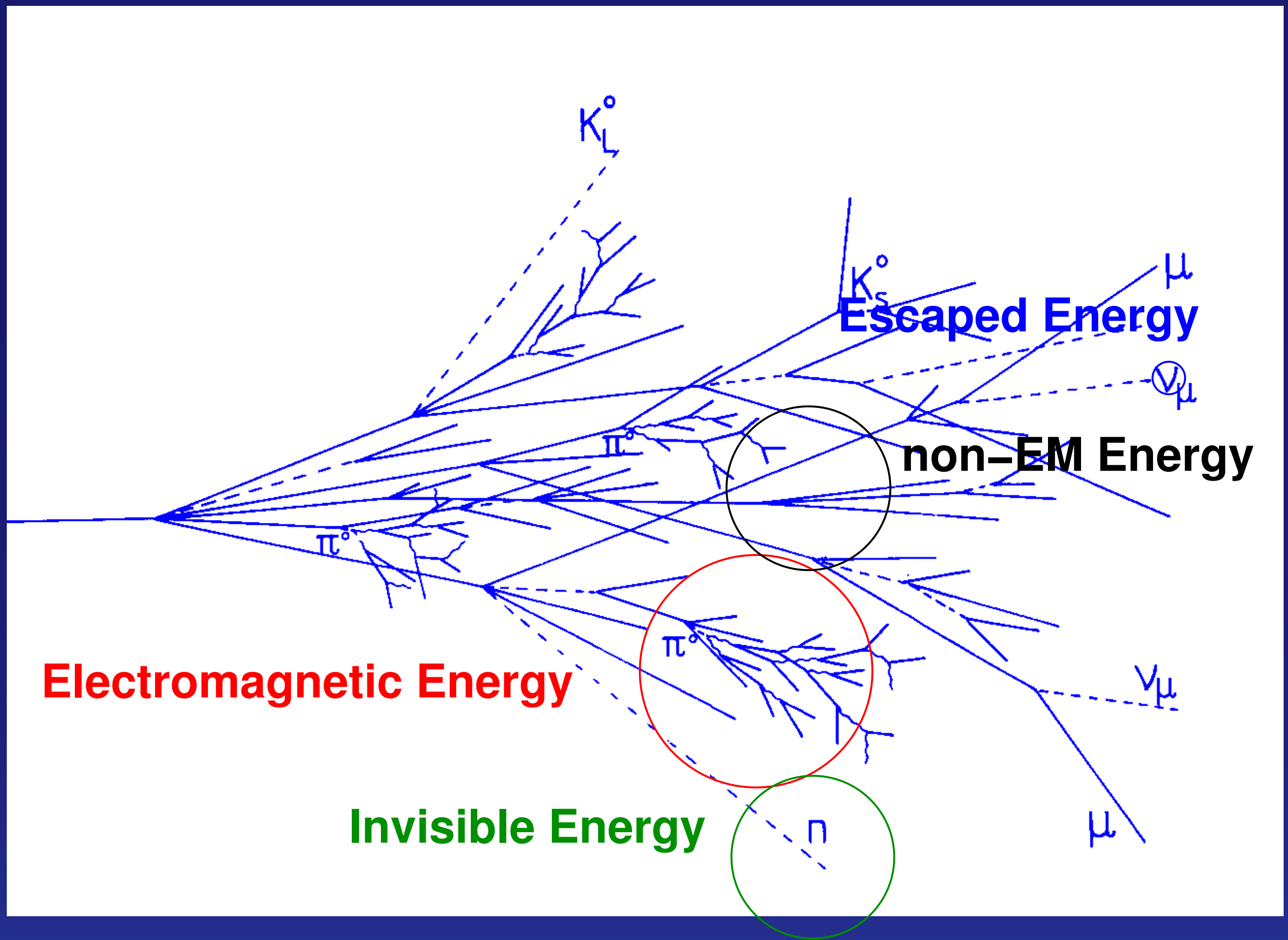




MC@NLO $t\bar{t}$ Event (semileptonic)

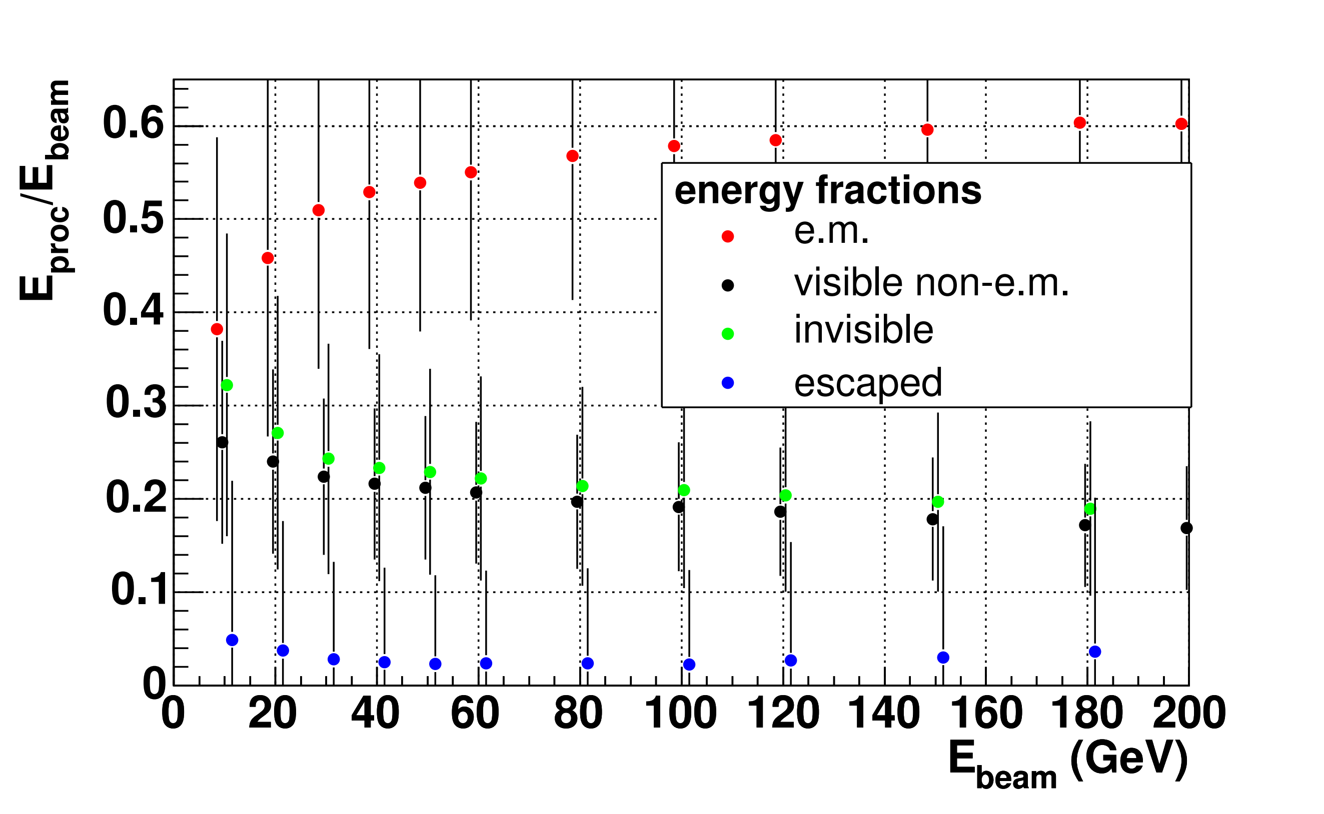
Hadronic Calibration ► Hadron Shower Components

- A hadronic shower consists of
  - EM energy (e.g. $\pi^0 \to \gamma\gamma$) $O(50\,\%)$
  - visible non-EM energy (e.g. dE/dx from $\pi^\pm$,$\mu^\pm$, etc.) $O(25\,\%)$
  - invisible energy (e.g. breakup of nuclei and nuclear excitation) $O(25\,\%)$
  - escaped energy (e.g. ν) $O(2\,\%)$
- each fraction is energy dependent and subject to large fluctuations



- invisible energy is the main source of the non-compensating nature of hadron calorimeters
- hadronic calibration has to account for the invisible and escaped energy and deposits in dead material and ignored calorimeter parts

- From a Geant4 simulation of endcap calorimeters



- EM energy strongly anti-correlated with visible non-EM energy
- visible non-EM energy strongly correlated with invisible energy

- need to separate EM part of the shower from the non-EM part
- apply a weight to the non-EM part to compensate invisible energy

- How to separate EM fraction from non-EM fraction?
  - $X_0 \ll \lambda \simeq 20$ cm
  - high energy density in a cell denotes high EM activity
  - low energy density in a cell corresponds to hadronic activity
  - apply weights as function of energy density

- Local Hadron Calibration is a modular approach with 5 steps developed at MPP for hadronic calibration

  Classification clusters are classified as electromagnetic or hadronic based on shower shape variables (cluster moments)

  Weighting cells in hadronic clusters are corrected as function of energy density (e/h compensation)

  Out-Of-Cluster energy deposits outside clusters but inside the calorimeter are corrected on cluster level

  Dead-Material energy deposits outside the calorimeter are corrected on cluster level

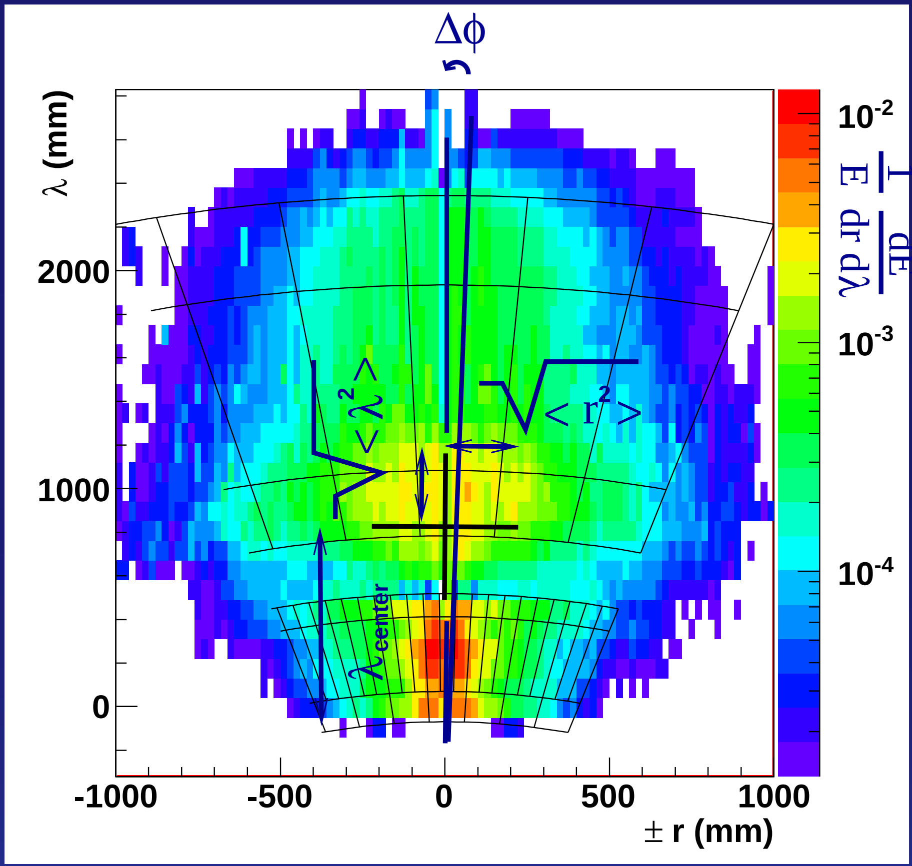
  Jet-Correction final jet-level corrections compensate particles without any calorimeter signal

- continous refinement of calibration constants to keep up with changes in the simulation (G. Pospelov, S. Menke)
- jet level corrections derived as part of PhD thesis (A. Jantsch)
- validation on test beam (J. Erdmann, A. Kiryunin, G. Pospelov) and collisions data (P. Giovannini) and application to MET and top-quark pairs (T. Barillari)

- shape variables calculated from the positive cells in a cluster
- first a principal value analysis is run on the cluster cells
  - provides centroid and 3 major axes of the shower
- angles of the major axis w.r.t. IP-shower-center direction are calculated
- other shape quantities defined by moments of the form

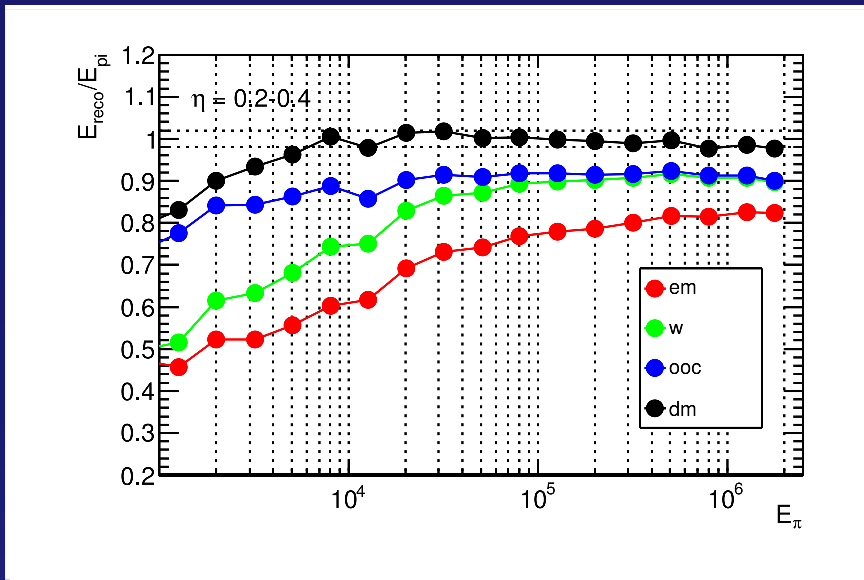
$$\langle x^n \rangle = \frac{1}{E_{\text{norm}}} \times \sum_{\{i|E_i>0\}} E_i\, x_i^n, \text{ with}$$

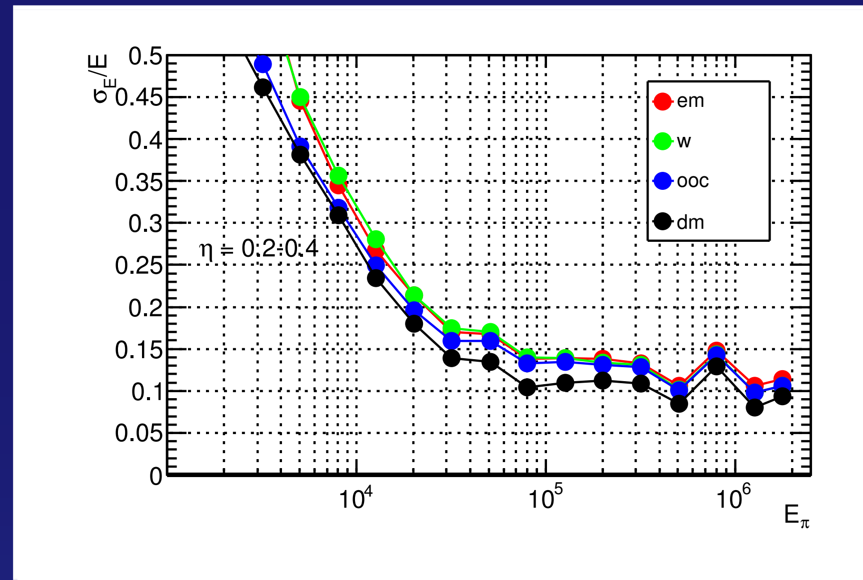
$$E_{\text{norm}} = \sum_{\{i|E_i>0\}} E_i .$$



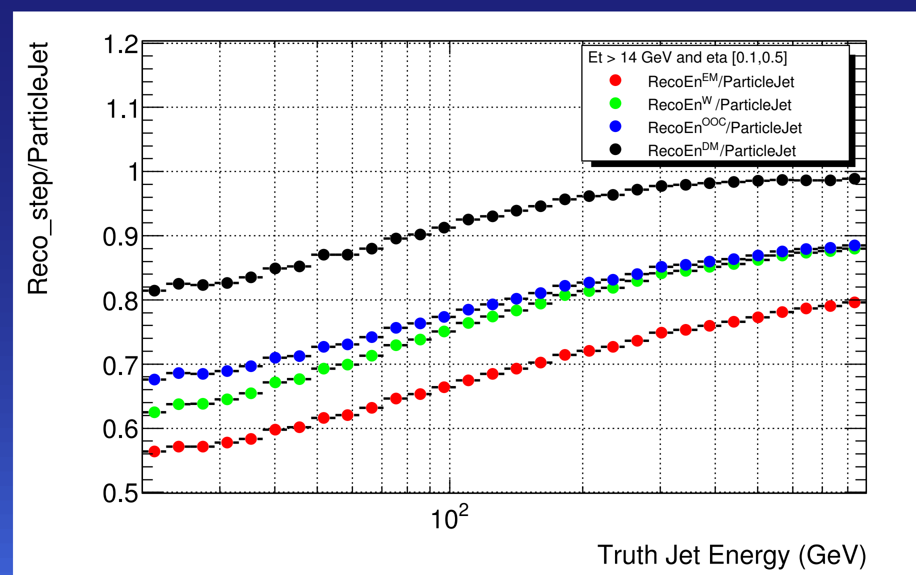
- typical choices for x: energy density $\rho = E/V$, radial distance from shower axis r, longitudinal distance along major shower axis λ
- plot shows cell energy distribution for charged pion showers in $r - \lambda$ space and some shape variables superimposed

- Linearity (left) and Resolution (right) after each calibration step as function of pion energy

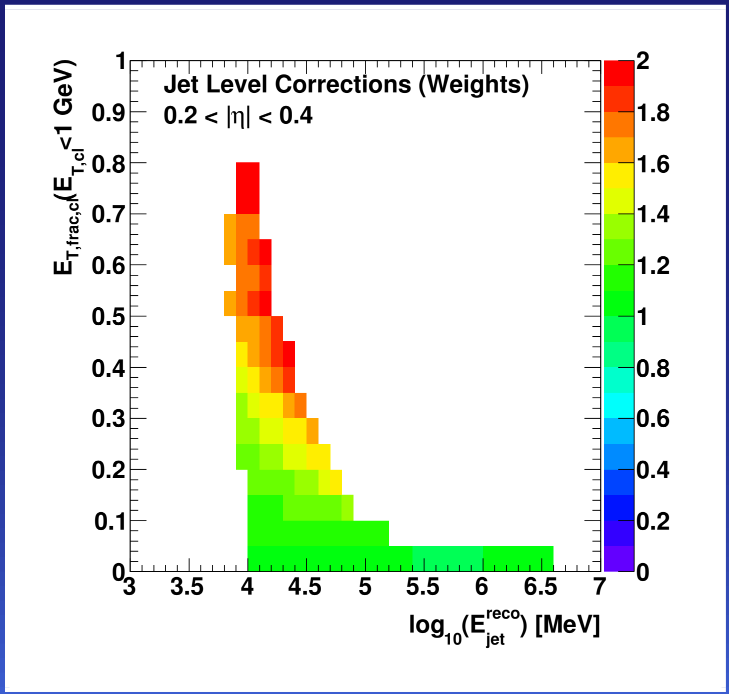


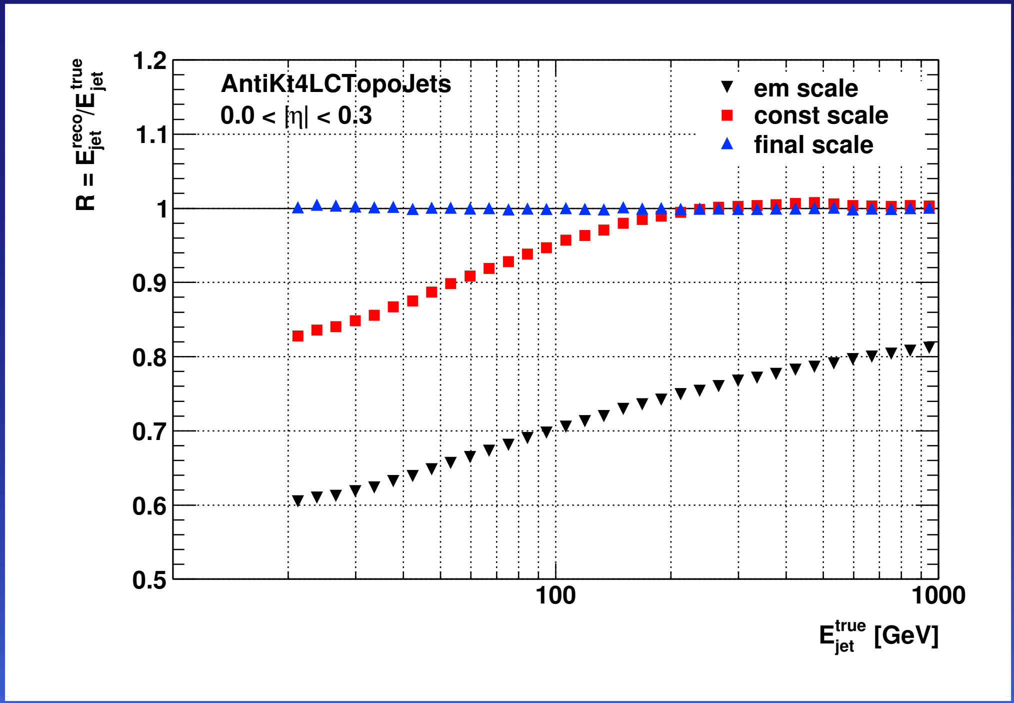


- linearity and resolution improve in every step
- linearity on jet level after each calibration step shown on the right
- especially at low jet energies final jet-level corrections are needed due to lost particles

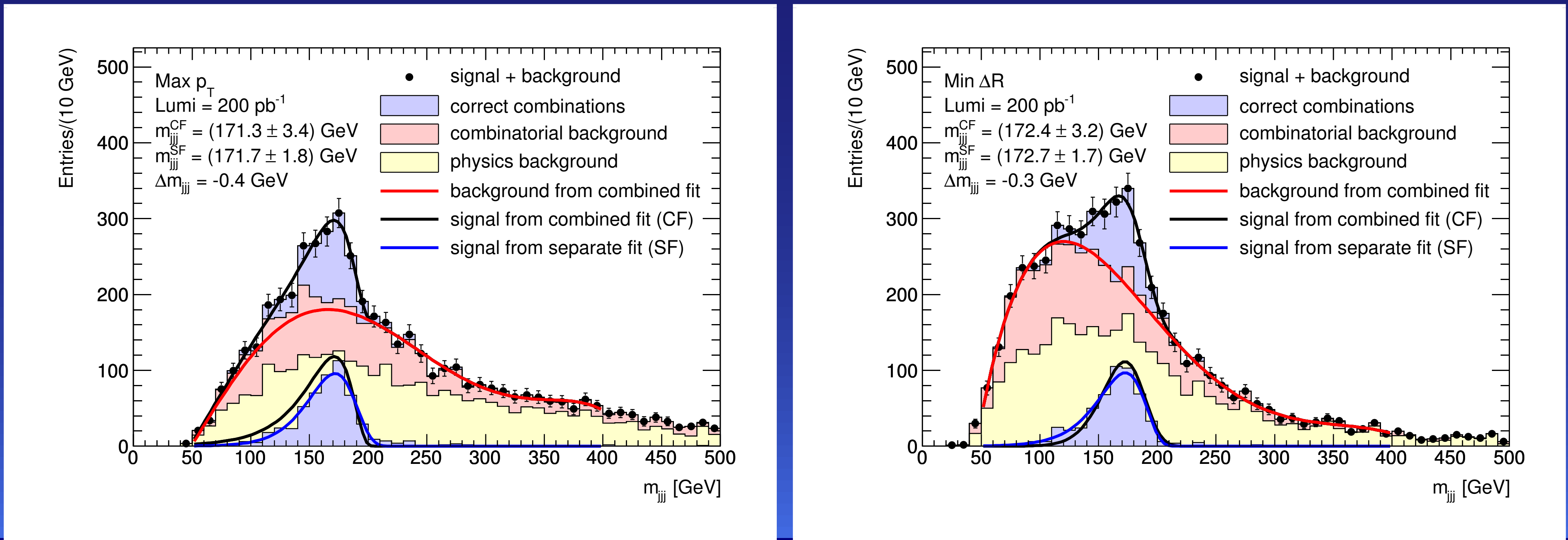


- energy fraction caried by low energetic clusters inside jet is correlated with lost energy
- compute correction weights based on this quantity
- left plot shows the weights as function of the low energy fraction and the jet energy
- right plot shows linearity for jets before any calibration (black), after cluster calibration (red) and after final jet calibration (blue)

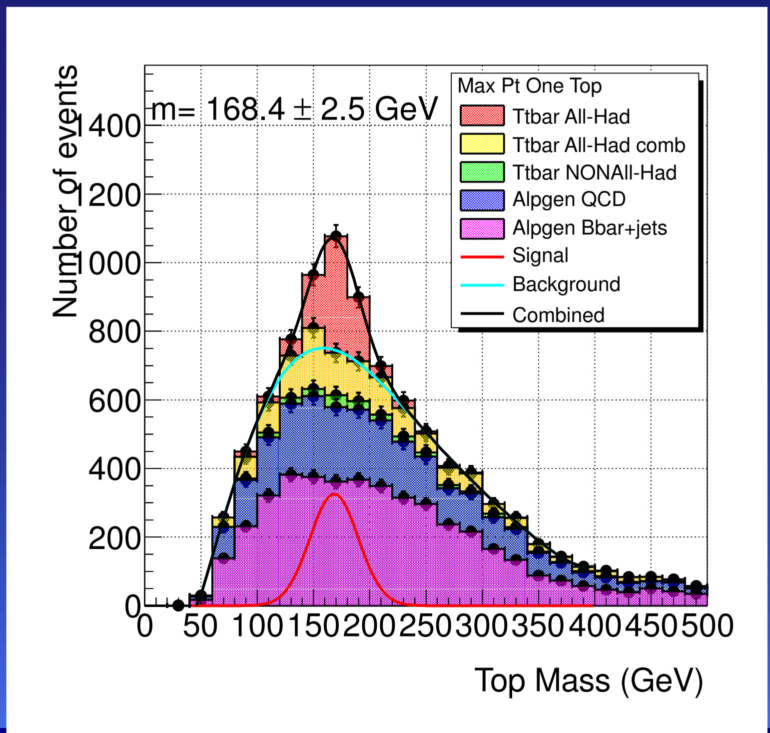


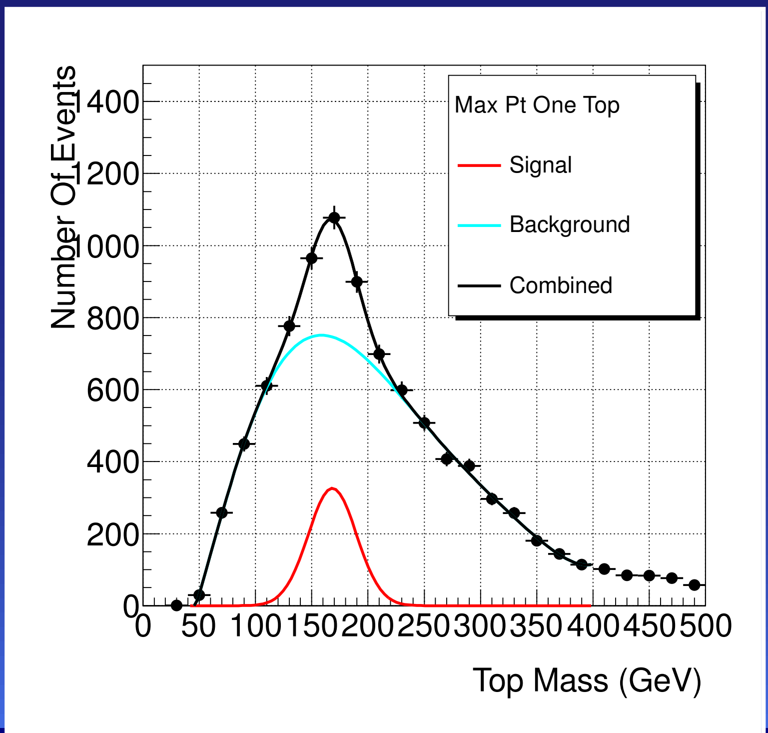


- $t\bar{t}$ Analysis in the semileptonic channel (A. Jantsch)
  - based on simulations at $\sqrt{s} = 10$ TeV
  - Signal produced with `MC@NLO`
  - QCD background with `Alpgen`
  - Jets from the `AntiKt` jet algorithm with local hadron calibrated clusters and jet-level-corrections as input
  - Exactly one good electron or muon with $p_\perp > 10$ GeV and $|\eta| < 2.5$
  - At least 4 good jets with $E_\perp > 20$ GeV and $|\eta| < 2.5$
  - $E_\perp^{\text{miss}} > 10$ GeV
  - combine 3 jets to hadronic top quark candidate by either maximizing $p_\perp$ of the tripplet (left) or by minimizing ΔR of the tripplet (right)
  - fit Gaussian with exponential left side tail plus polynomial to obtain top quark mass



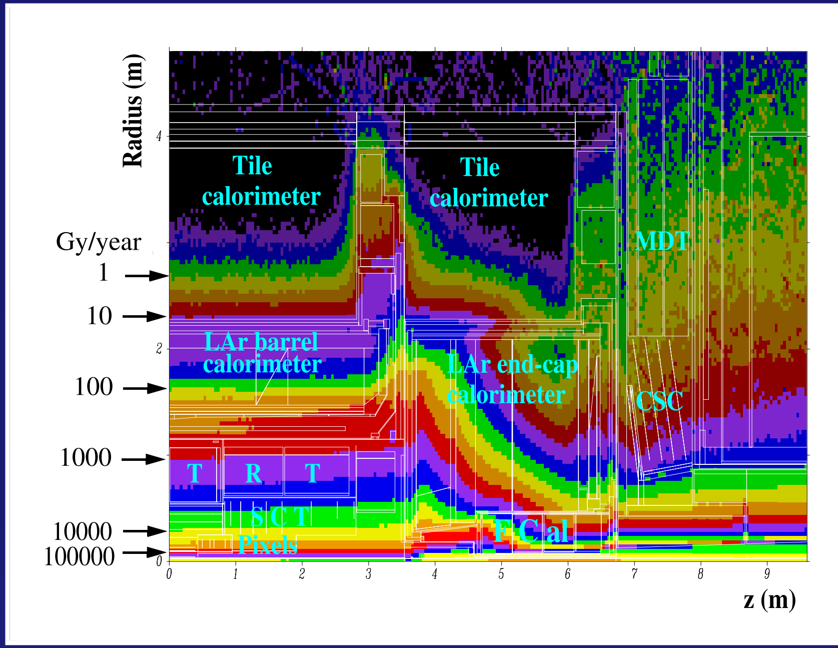
- $t\bar{t}$ Analysis in the all-hadronic channel (P. Giovannini)
  - same $\sqrt{s} = 10$ TeV simulation as semi-leptonic analysis
  - No good electron or muon with $p_\perp > 10$ GeV and $|\eta| < 2.5$
  - At least 6 good jets with $E_\perp > 20$ GeV and $|\eta| < 2.5$
  - $E_\perp^{\text{miss}} / 0.5\sqrt{\sum E_\perp} < 6.5$ (no significant missing transverse energy)
  - 2 jets tagged as b-jets
  - Event shape cuts on centrality $\sum E_\perp / m_{\text{jets}} > 0.6$ and $\sum E_\perp - E_\perp^{\text{max}} - E_\perp^{\text{2nd}} > 170$ GeV help reduce QCD bckgd.
  - sub-leading jet cuts: $p_\perp^{\text{4th}} > 40$ GeV; $p_\perp^{\text{5th}} > 30$ GeV
  - ΔR(b-jets) > 1.5 ► S/B improves from $1/10000$ before to $1/3.6$ after all cuts





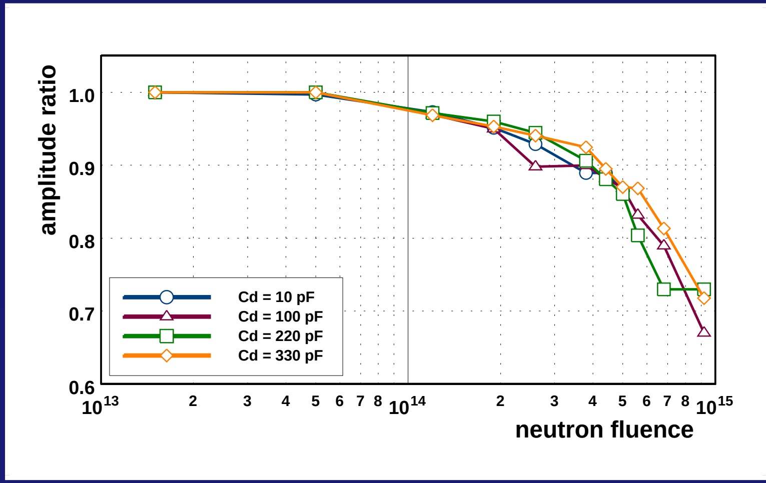
Upgrade Activities for sLHC

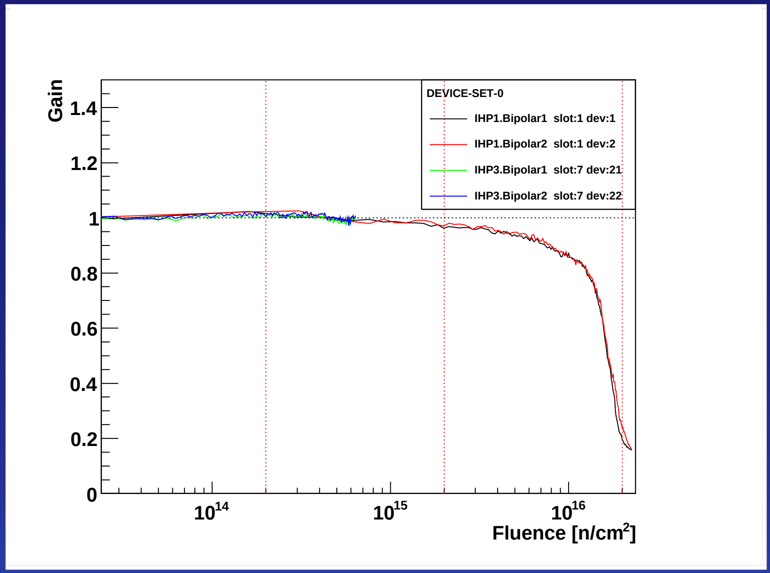
- MPP contributed two hardware components to the exisiting HEC
  - Cold readout electronics based on GaAs pre-amplifiers
  - Low Voltage Power Supplies sitting just outside the cryostats
- The current cold electronics withstand 1.5 times the expected radiation dose of 10 years running with LHC including safety factors
- Thus a factor 10 increase as anticipated by the sLHC upgrade scenarios (see plot) brings the electronics at its limits and eliminates any safety factor.



Upgrade Activities for sLHC ► Electronics

- The LV PS would not withstand the radiation conditions at sLHC and provide not enough redundancy
  ► the need to be exchanged at sLHC even if the cold electronics stays the same
- Exact radiation levels for LHC have to be established until end of 2011
  ► only then we know for certain if the cold electronics have to be exchanged
  ► current numbers including safety factor of 10 for 10 years running: LHC = $2 \times 10^{14}\ \mathrm{n/cm^2}$; sLHC $2 \times 10^{15}\ \mathrm{n/cm^2}$
- The R&D for a possible upgrade has started already (2012 would be too late)
- Amplitude loss after irradiation for the exisiting cold electronics and 4 bipolar transistors tested for sLHC (bottom)
- SiGe bipolar, GaAs FET and Si COMOS FET transistors are currently tested. So far all technologies tested would tolerate the sLHC radiation levels
- for cost reasons the Si based CMOS option is currently prefered
- a modified transistor design for further tests in the cold and under irradiation (in Rez/Prague) is in progress





- The operation of the endcap calorimeters under high radiation levels is tested at the IHEP 70 GeV synchrotron in Protvino, Russia
- Small test modules corresponding to the electromagnetic (EMEC), hadronic (HEC) endcap and forward (FCal) calorimeters are exposed to beams of 10^{13} protons per spill
- Main objective is if the ion-buildup in the LAr expected at sLHC can still be tolerated
- A degradation of the pulse shape is expected in the EMEC and HEC (upper plot shows pulse shape in the EMEC at low radiation rates; lower plot at high rates)
- Tests so far indicate that the EMEC and HEC can be operated with possibly modified electronics
- The FCal needs to be either replaced by a device with smaller LAr gaps or a new detector has to be placed in front of the existing FCal to withstand the sLHC radiation levels