First Measurements of Jet Substructure in ATLAS

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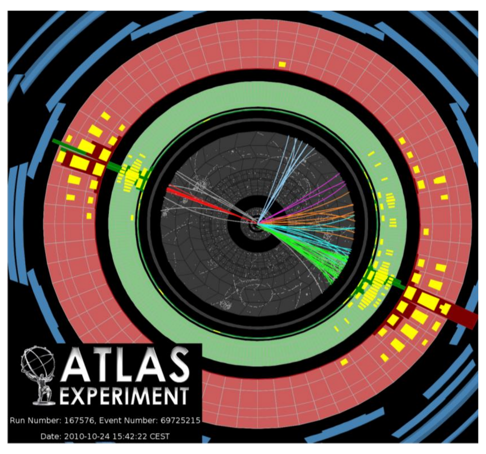
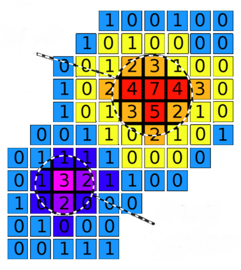
2011 Europhysics Conference on High-Energy Physics

JET CONSTITUENTS



Jets are 4-vector summations of clusters of calorimeter cells which have significant signal to noise ratio.

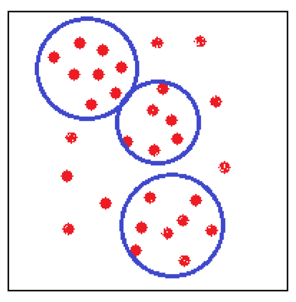
Clusters are classified as EM or hadronic based on shape, depth and energy density.



Signal to noise threshold for calorimeter cells of two clusters

Type-specific **cluster calibration** applied to account for non-compensating calorimeter.

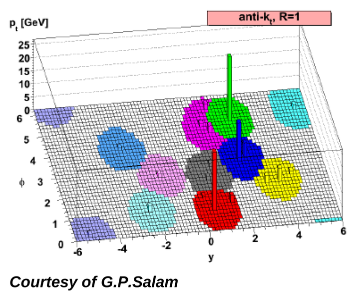
JET FORMATION



Jet algorithms combine the clusters into jets, according to their p_T and relative separation [1].

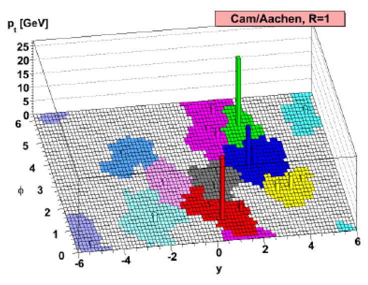
The resulting jets are formed with a pre-defined radius, R, in η-φ space.

Two types of jets have been used for substructure studies to date:



Courtesy of G.P.Salam

Anti-k_T, R = 1.0 [2]
Hardest constituents combined first. Gives circular jets resilient to soft radiation.



Cambridge-Aachen, R =1.2 [3]
Closest constituents clustered first.

SUBSTRUCTURE VARIABLES

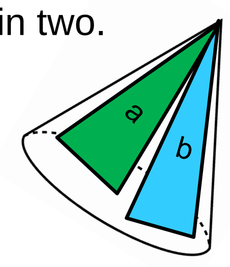
Jets are complicated composite objects!

Key properties currently studied in detail:

1. **Jet mass:** *powerful for identification of the parent particle.*

$$m_{jet}^2 = \left(\sum E_i\right)^2 + \left(\sum p_i\right)^2 \quad \text{(sum over constituents)}$$

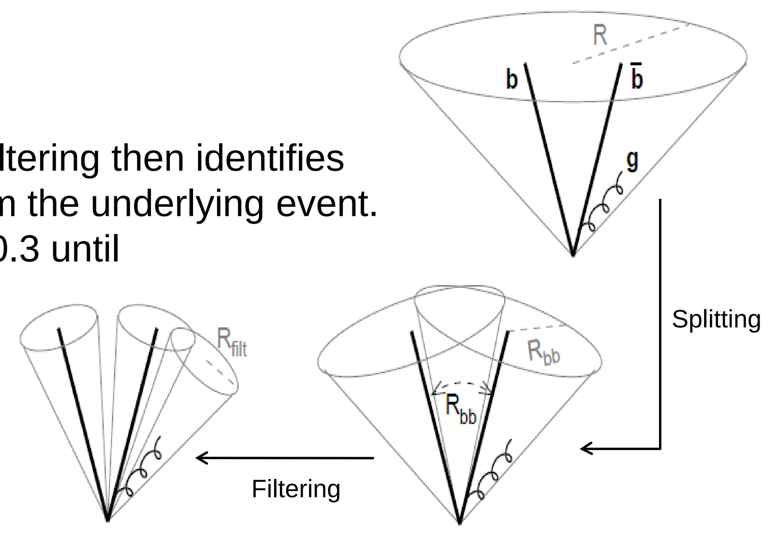
2. **Splitting scale**: energy at which the jet splits in two. *Distinguishes heavy particle decays from asymmetric QCD splittings.*



$$\min(p_{Ta}, p_{Tb}) \times \delta R_{a,b}$$

3. **Effect of splitting and filtering**
Splitting creates two sub-jets with significantly lower mass. Filtering then identifies three smaller hard jets and hence removes contamination from the underlying event. Minimum allowed separation of the split jets will be limited to 0.3 until greater understanding of the detector resolution is achieved.

Particularly effective for Higgs identification with symmetric decay (e.g. b quark pair)



CALIBRATION

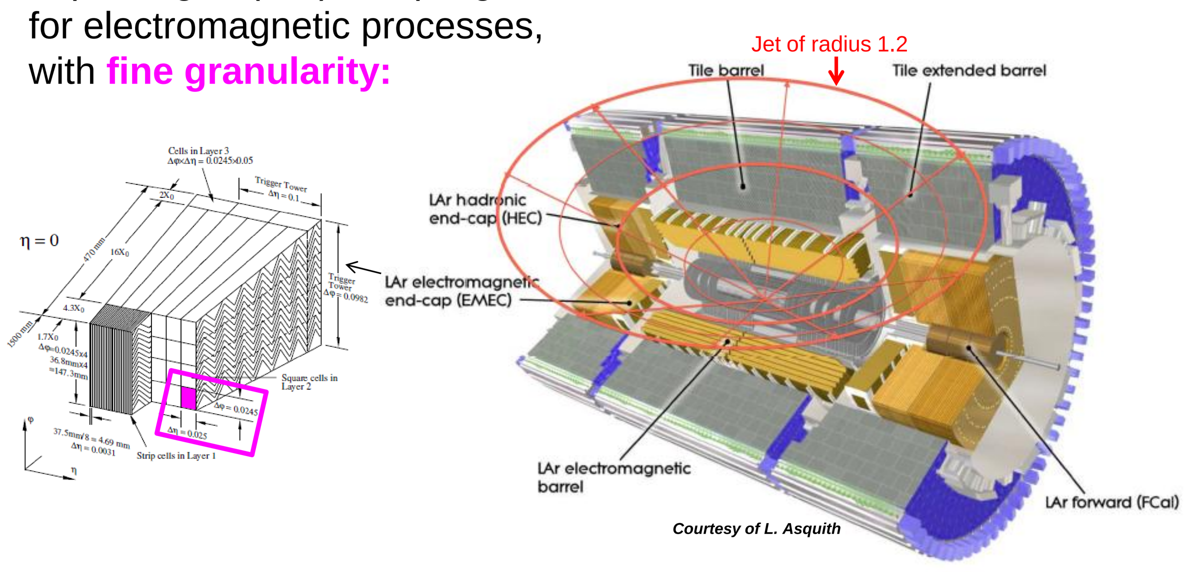
- Additional correction required to restore the true *jet* energy scale, additional to that applied to the jet *constituents*.
- ATLAS uses Monte Carlo simulations to derive corrections to jet energy and pseudorapidity, for standard jet sizes.
- **Additional correction factors calculated for mass of these large jets,** due to the importance of their mass for particle identification.

UNDERSTANDING SUBSTRUCTURE WITH THE ATLAS DETECTOR

THE ATLAS CALORIMETERS

Jets measured with the calorimetry system in | η | < 3.2. These large radius jets encompass a significant proportion of the calorimeters.

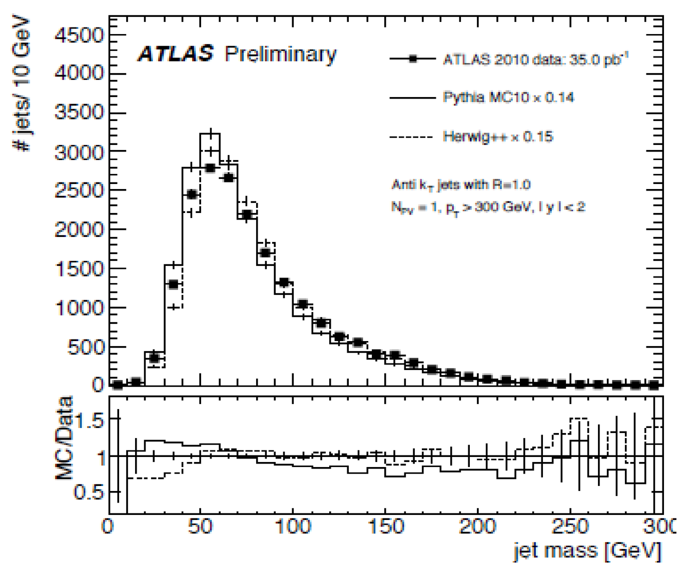
Scintillating-tile design for hadronic processes.
Liquid argon (LAr) sampling calorimeter for electromagnetic processes, with **fine granularity:**

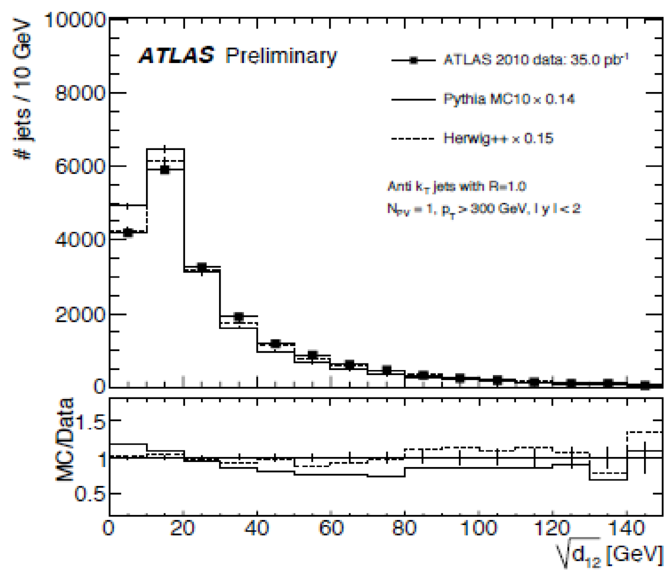


Courtesy of L. Asquith

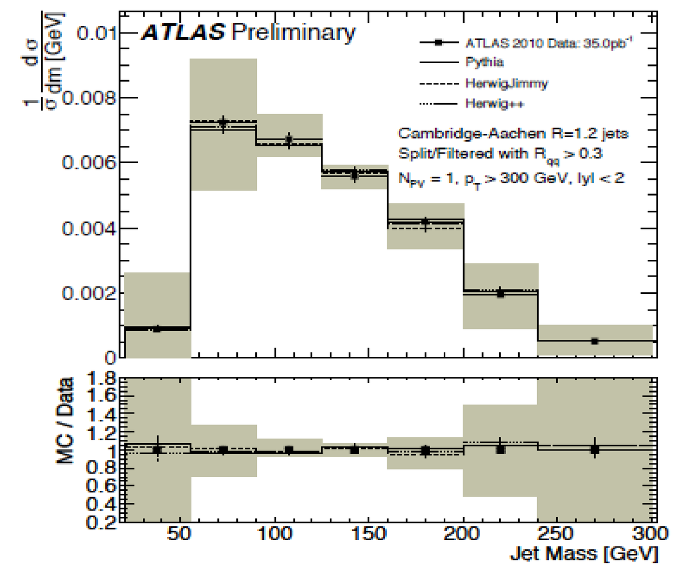
COMPARISONS TO THEORETICAL MODELS

A sample of inclusive jets was collected from a 35 pb^{-1} of proton-proton collisions at $\sqrt{s}$ = 7 TeV [4]. Predictions from leading order parton shower Monte Carlo generators are in agreement with data, indicating that jet substructure generated by QCD radiation is well understood.



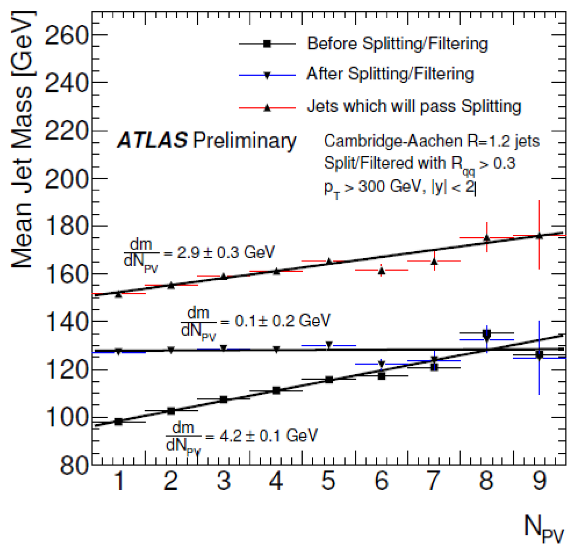


Anti-k_T R = 1.0 jet mass and first splitting scale, *at detector level.*



Cambridge-Aachen R = 1.2 split / filtered jets. Jet mass *unfolded to particle level.*

EFFECT OF MULTIPLE INTERACTIONS

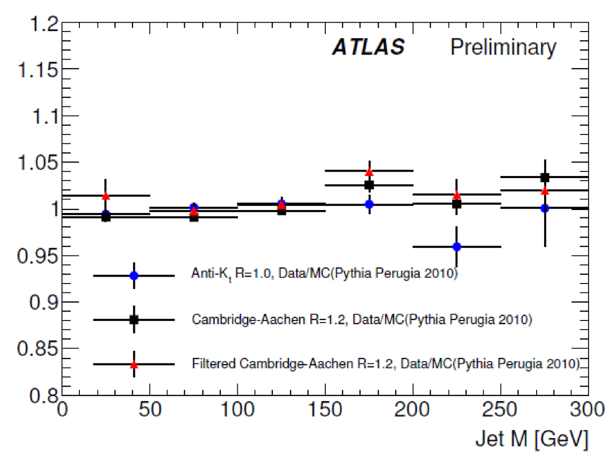


Larger jets found to have a greater dependence on number of interactions in the event, N_{PV}.

Splitting / filtering reduces this dependence. The application of other jet grooming techniques is being investigated.

SYSTEMATIC UNCERTAINTIES

In order to use the mass and substructure characteristics for particle identification, an estimation of the systematic uncertainty associated with these measurements has been performed. A comparison of jets reconstructed using energy deposits in the calorimeter and tracks in the inner detector enables an estimation of this uncertainty, since these sub-detectors have largely uncorrelated systematic effects.

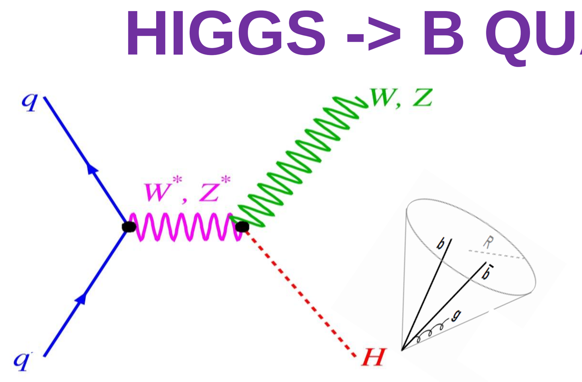


The ratios of masses of the two types of jets are compared between data and Monte Carlo. Maximum discrepancy sets the systematic uncertainty, in this case, on the anti-k_T R = 1.0 jet mass scale.

Jet algorithm	Energy scale	Mass scale	Energy resolution	Mass resolution	Scale of splitting scale	Resolution of splitting scale
Anti-k_T R = 1.0	5 %	7 %	20 %	30 %	15 %	30 %
Cam-Aachen R = 1.2	5%	6 %	20 %	30 %	n/a	n/a
Cam-Aachen filtered R = 1.2	6%	7 %	20 %	30 %	n/a	n/a

WHEN CAN KNOWLEDGE OF JET SUBSTRUCTURE HELP?

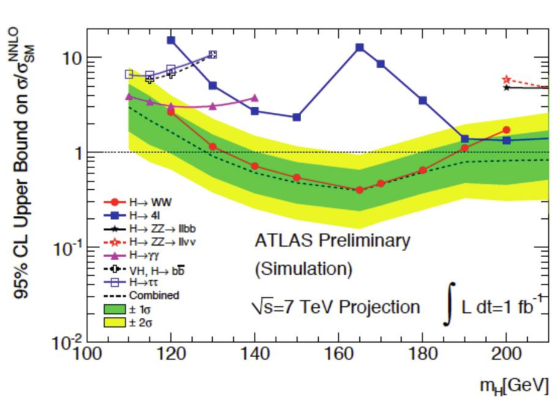
HIGGS -> B QUARK PAIR SEARCH



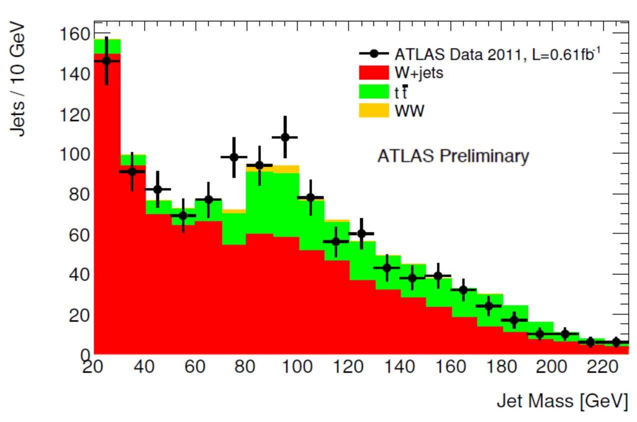
Extremely promising search channel for boosted Higgs:

- Central decay products are within detector acceptance
- Reduced ttbar background

Boosted Higgs decay produces one jet composed of two merged b-jets.



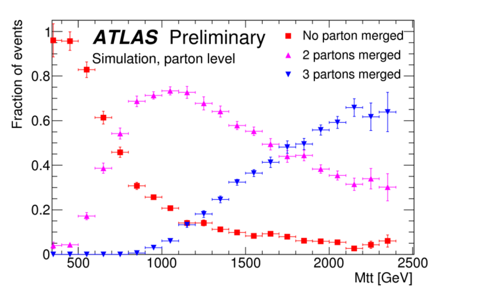
Split and filtered Cambridge-Aachen R = 1.2 jets are used to identify the Higgs decay within the jet and thus provide discrimination from background processes.



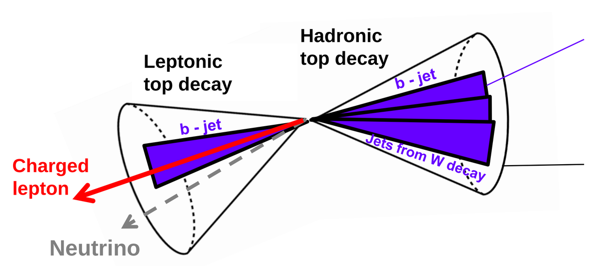
Jet mass distribution of split and filtered C – A, R = 1.2 jets, with p_T > 180 GeV and $d\varphi_{W,jet}$ > 1.2. Event selection requires a leptonically decaying W boson with p_T > 200 GeV [5].

BOOSTED TOP IDENTIFICATION

As mass of top pair increases, decay products merge to ΔR < 0.8:



For Mtt = 1 TeV, a 70% probability that two partons will merge to a cone with R = 0.8

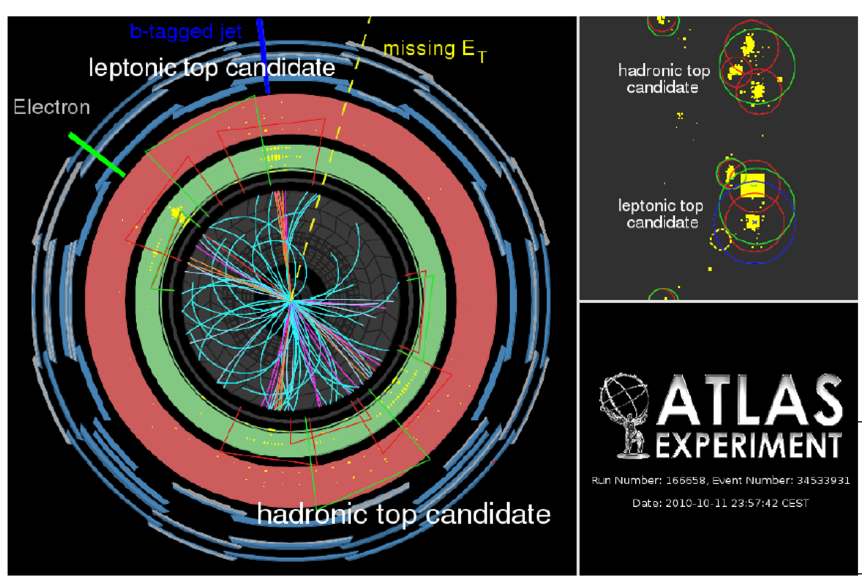


Conventional approach: resolve the decay products using jets with R=0.4

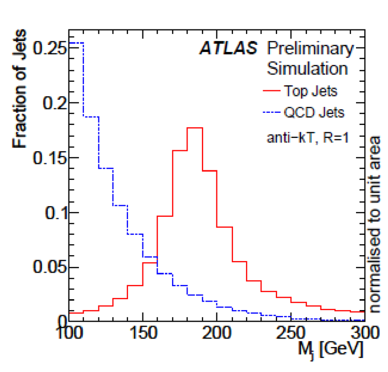
Boosted approach: use a large jet (e.g. anti-k_T R=1.0) to contain all decay products, and probe the substructure.

The use of jet substructure is important for top measurements at LHC energies and vital for ttbar resonance searches.

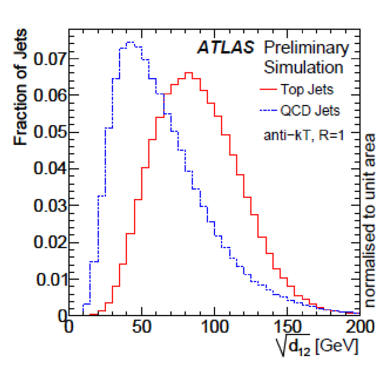
Key variables for discrimination of top against QCD background processes [6]:



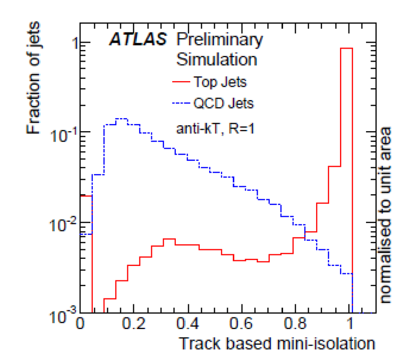
Boosted tops in 2011 data
Red: anti-k_T R = 0.4 jets
Green: anti-k_T R = 1.0 jets



Jet mass: top jets' masses peak at top mass



Splitting scale: top jets split at energy ~ W mass



Lepton mini-isolation: p_T of lepton divided by energy in cone ΔR around the lepton, where $\Delta R < \frac{15 GeV}{p_T^l}$

[1] G. P. Salam, *Towards Jetography*, arXiv:0906.1833v2 [hep-ph]
[2] M. Cacciari, G. P. Salam, and G. Soyez, *The Anti-k_T Jet Clustering Algorithm*, JHEP 04 (2008) 063, arXiv:0802.1189 [hep-ph]
[3] Y. L. Dokshitzer, G. D. Leder, S. Moretti, and B. R. Webber, *Better Jet Clustering Algorithms*, JHEP 08 (1997) 001, arXiv:hep-ph/9707323
[4] ATLAS Collaboration, *Measurement of Jet Mass and Substructure for Inclusive Jets in $\sqrt{s}$ = 7 TeV pp Collisions with the ATLAS Experiment*, Tech. Rep. ATLAS-CONF-2011-073, CERN, Geneva, 2011
[5] ATLAS Collaboration, *Search for the Standard Model Higgs Boson Decaying to a b-quark Pair with the ATLAS Detector at the LHC*, in preparation
[6] ATLAS Collaboration, *Prospects for Early ttbar Resonance Searches in ATLAS*, Tech. Rep. ATL-PHYS-PUB-2010-008, CERN, Geneva, 2011