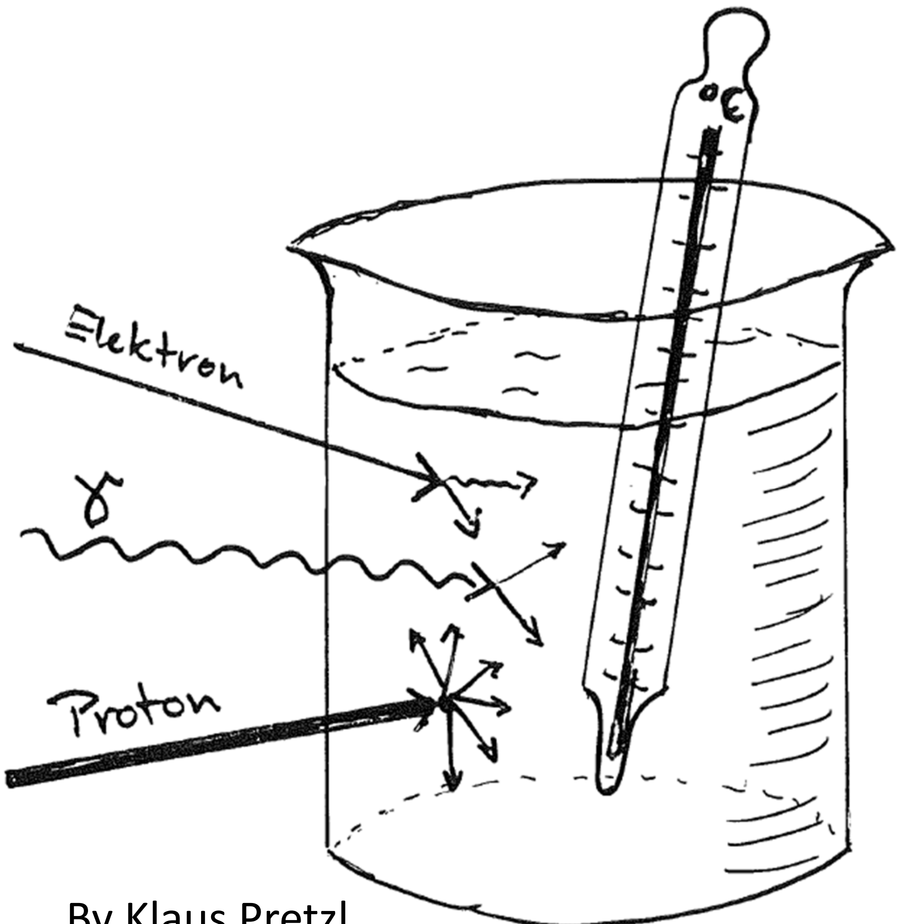
Calorimeter and jet reconstruction

M. Weber
(knowledgeable… but not expert)

Jet energy measurement with the ATLAS detector in proton-proton collisions at $\sqrt{s}$ = 7 TeV, arXiv:1112.6426v1



By Klaus Pretzl

Temperaturänderung:

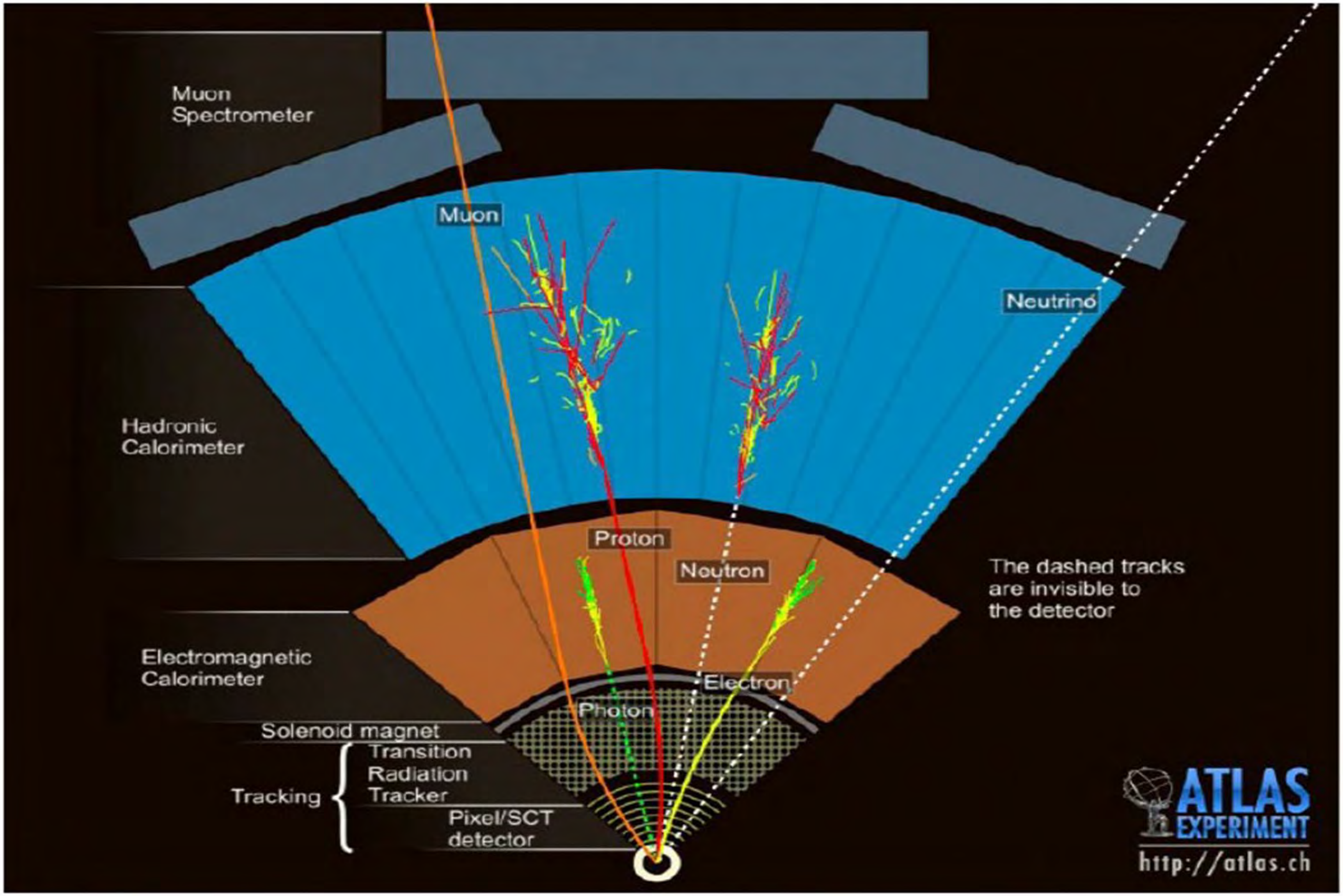
$$\Delta T = \frac{\Delta E}{C}$$

mit ΔE = Energieverlust des einfallenden Teilchens

C = Wärmekapazität von Wasser

Man braucht 1 kCal, um 1 Liter Wasser um 1° zu erhöhen.

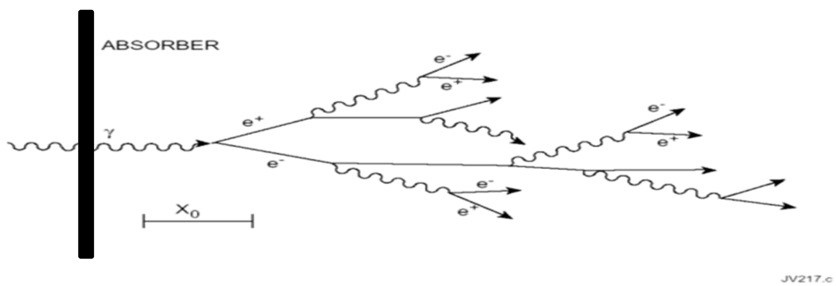
$$1\ \text{kCal} \mathrel{\hat{=}} 1000 \times 2.61 \times 10^{19}\ \text{eV}$$
$$\mathrel{\hat{=}} 2.61 \times 10^{22}\ \text{eV}$$
$$\mathrel{\hat{=}} 2.61 \times 10^{13}\ \text{GeV} = 2.61 \times 10^{10}\ \text{TeV}$$


Muon Spectrometer
Hadronic Calorimeter
Electromagnetic Calorimeter
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector
Muon
Neutrino
Proton
Neutron
Electron
Photon
The dashed tracks are invisible to the detector
ATLAS EXPERIMENT
http://atlas.ch

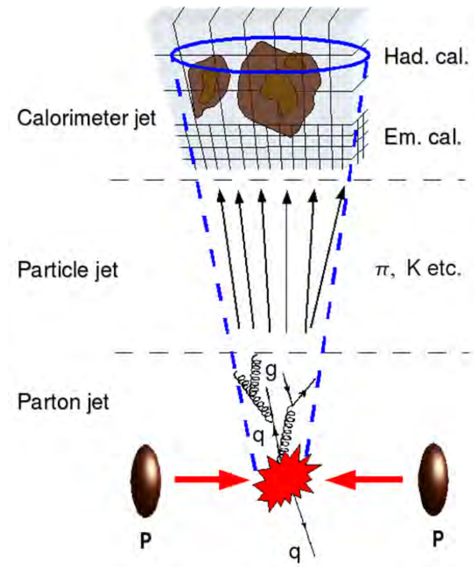
Jet reco basics

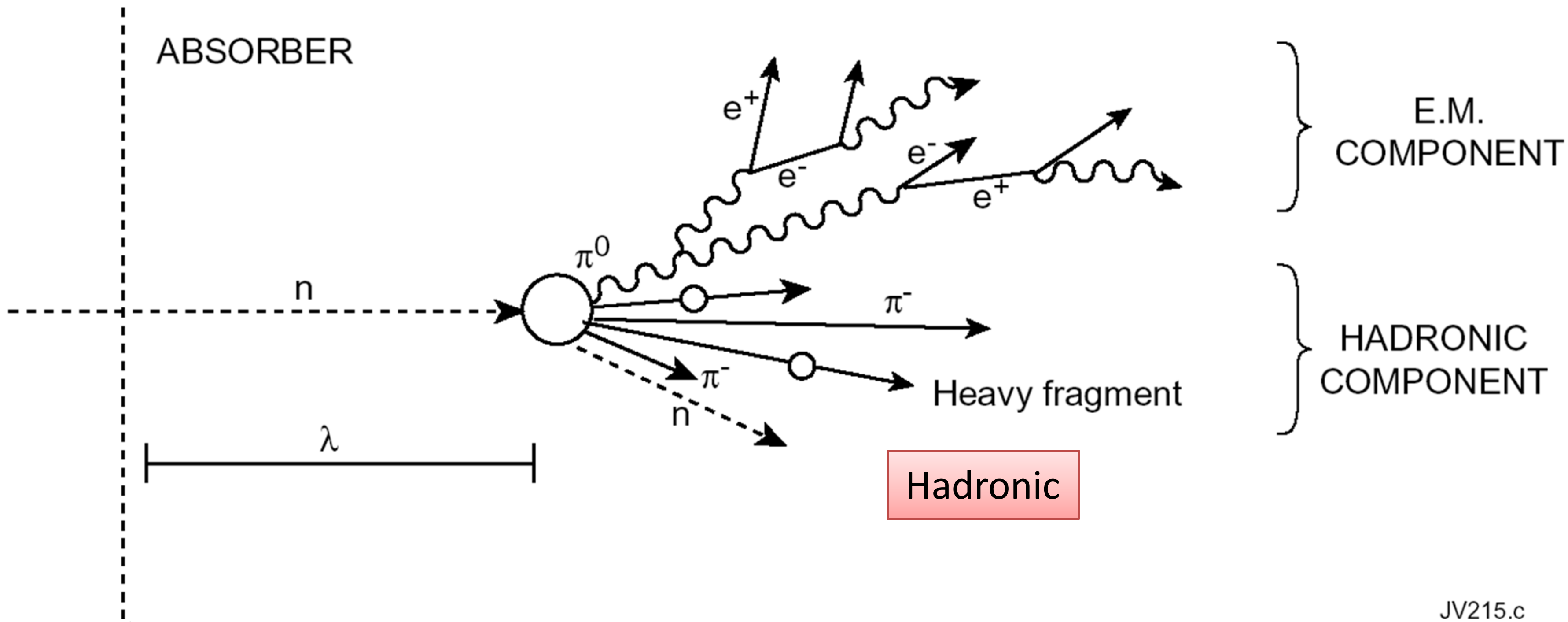
- **Jets** used for ATLAS physics analyses are reconstructed by a jet algorithm starting from the energy depositions of **electromagnetic and hadronic** showers in the **calorimeters**
- The jet Lorentz four-momentum is reconstructed from the corrected energy and angles with respect to the primary event vertex

EM and Hadronic showers



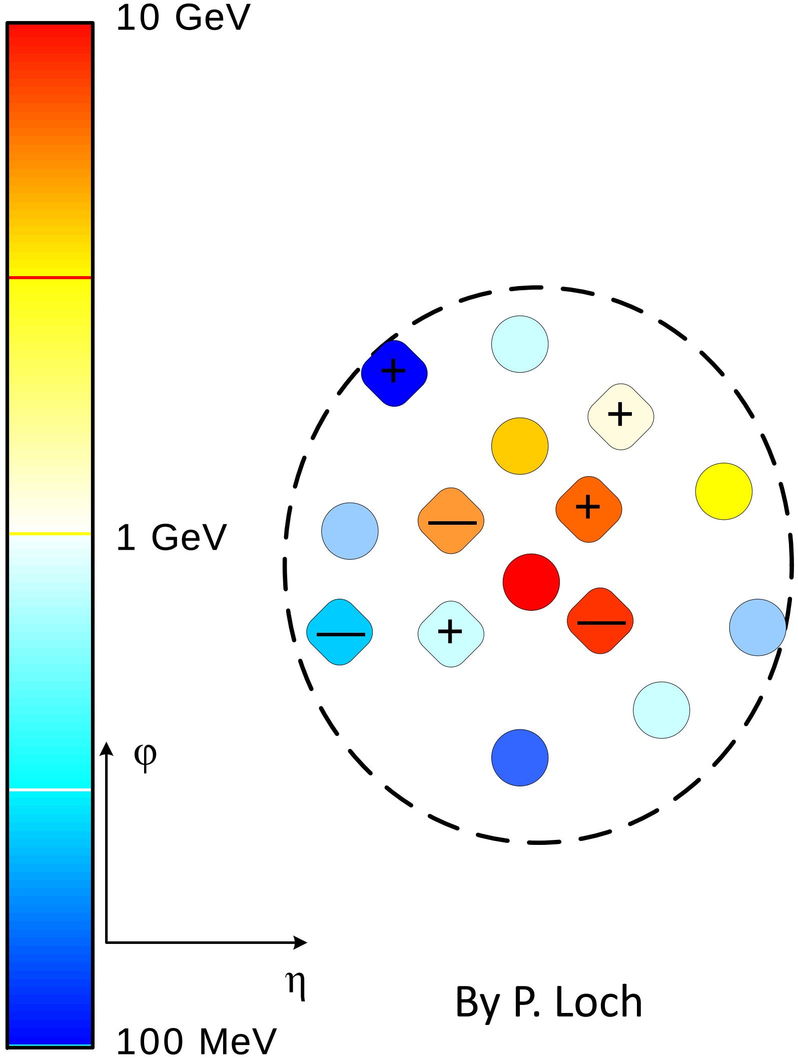
EM





Hadronic

Detector Effects On Jets



By P. Loch

Change of composition

- Radiation and decay inside detector volume
- "Randomization" of original particle content

Defocusing changes shape in lab frame

- Charged particles bend in solenoid field

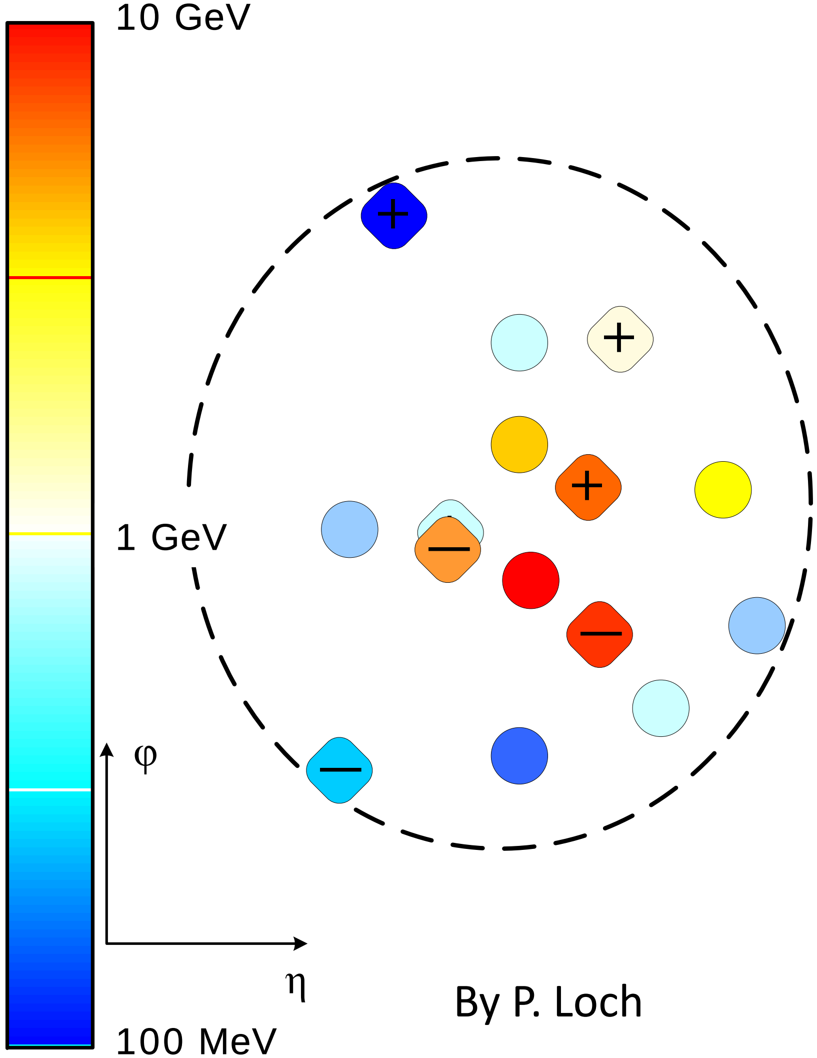
Attenuation changes energy

- Total loss of soft charged particles in magnetic field
- Partial and total energy loss of charged and neutral particles in inactive upstream material

Hadronic and electromagnetic cacades in calorimeters

- Distribute energy spatially
- Lateral particle shower overlap

Detector Effects On Jets



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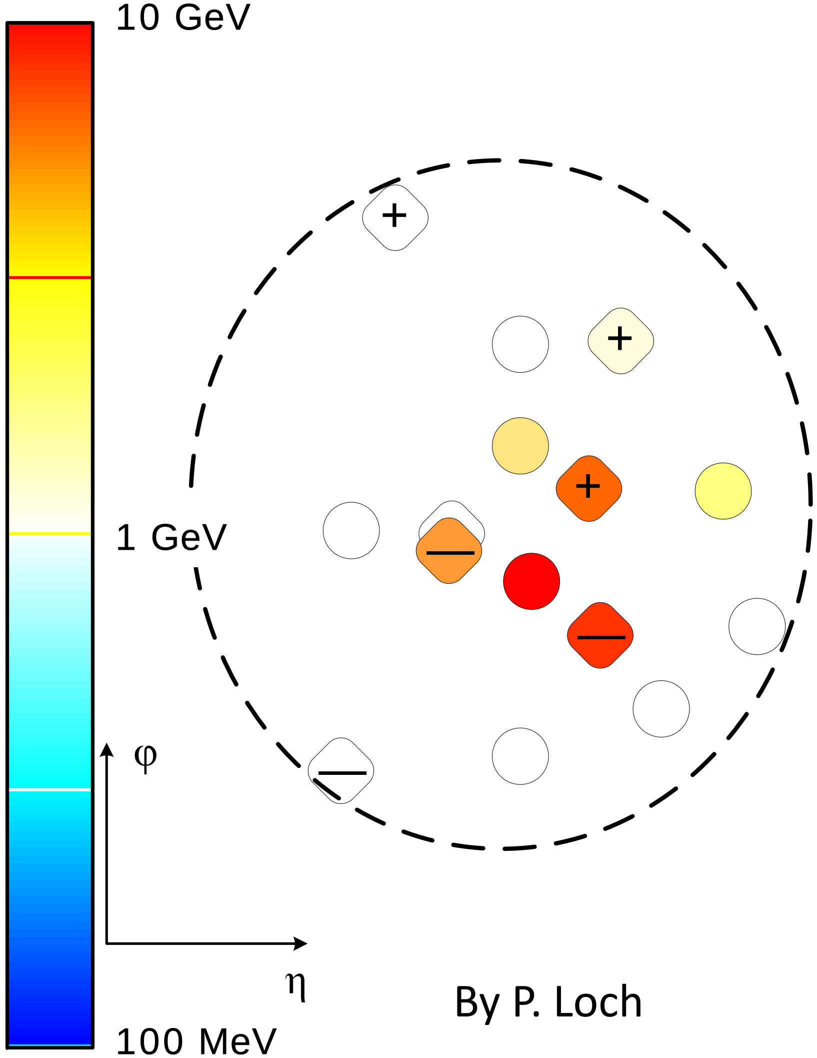

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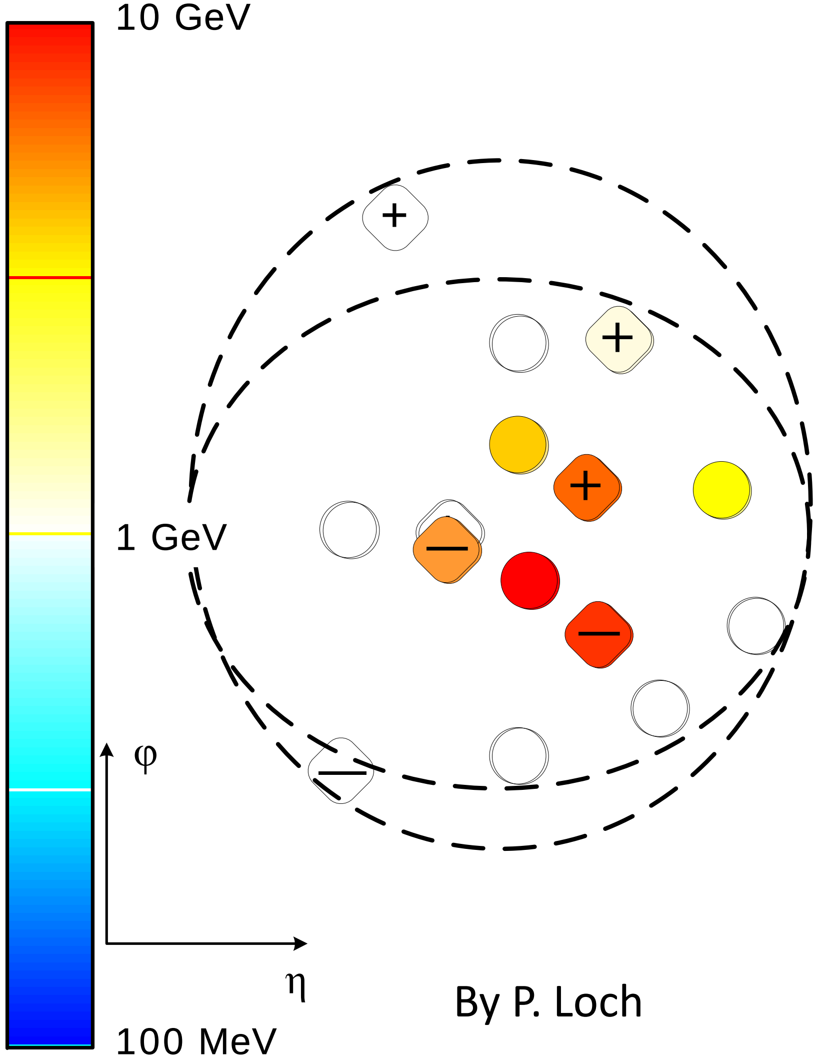

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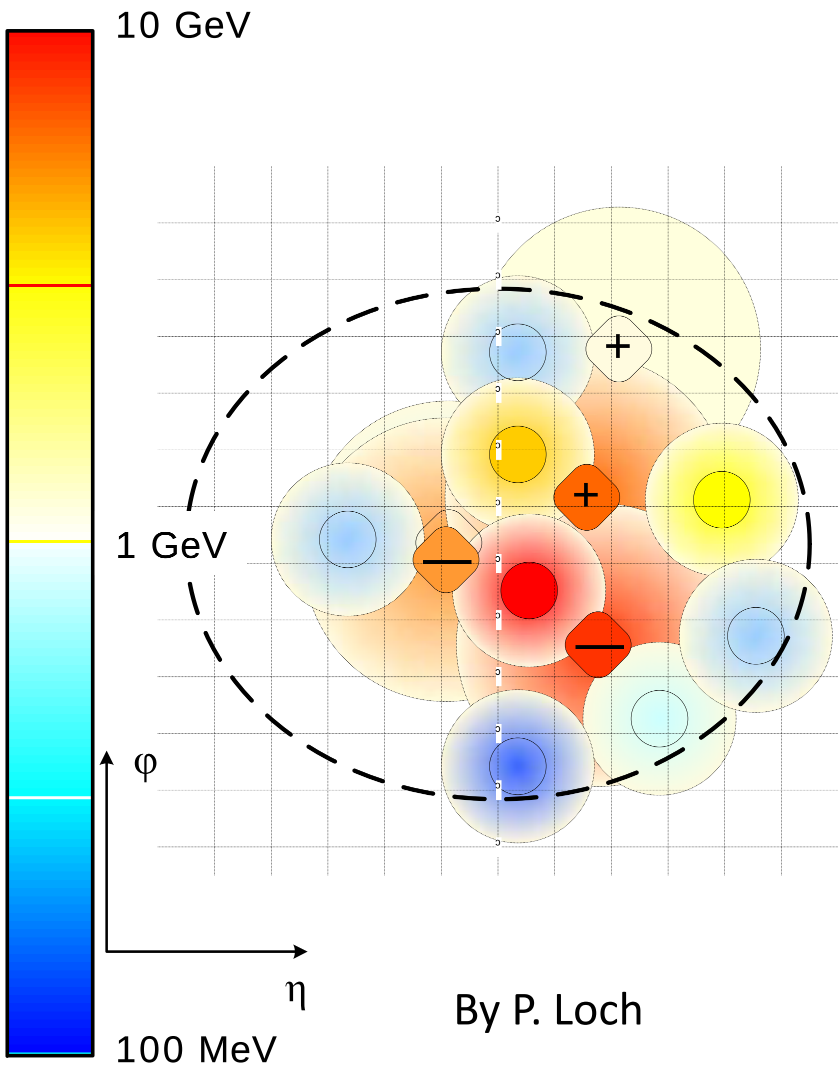

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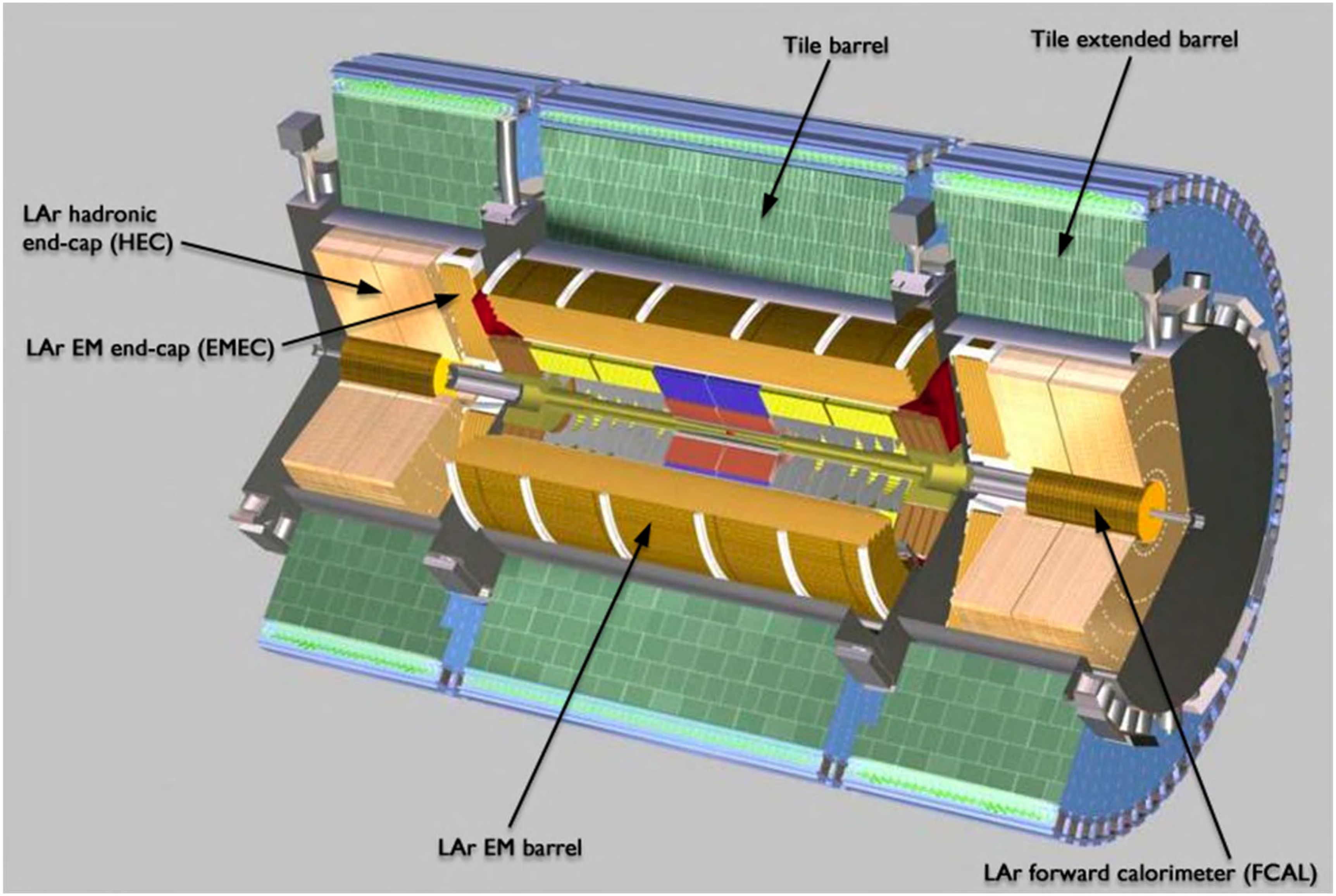
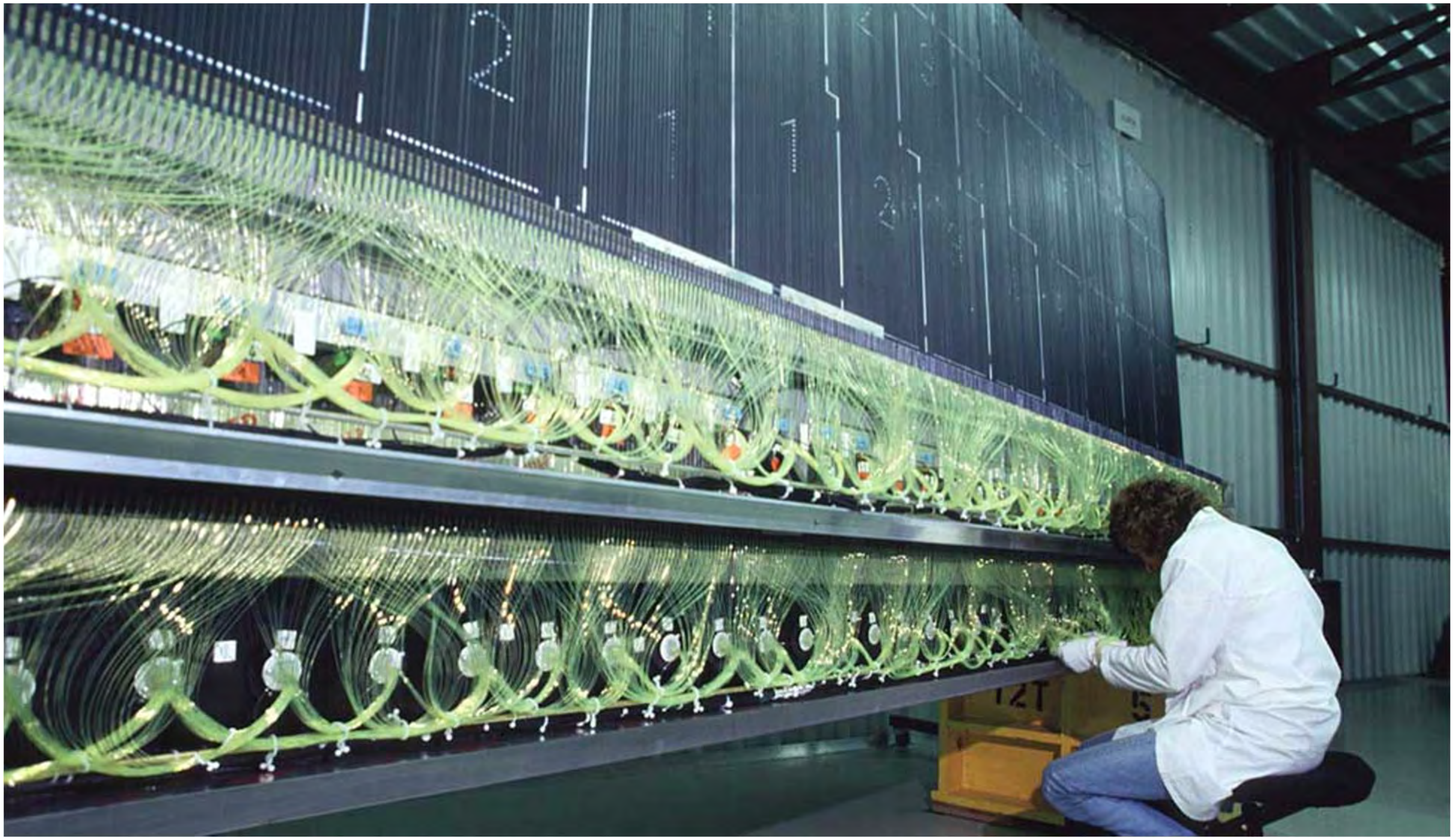
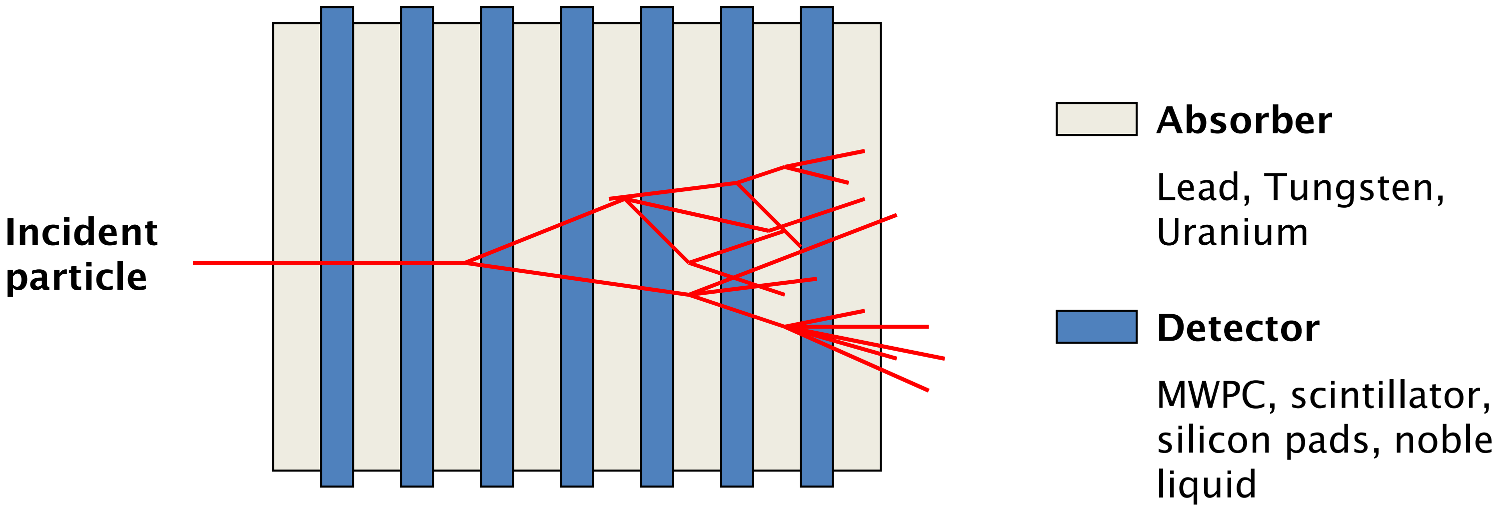
Particle jets

- The **jet** energy calibration relates the jet energy measured with the ATLAS calorimeter to the true energy of the corresponding **jet of stable particles** entering the ATLAS detector
- "Track jets": for systematic studies and calibration purposes, built from charged particles using their momenta measured in the inner detector
- "Truth jets": jet algorithm applied to MC simulated stable particle jets


Tile barrel
Tile extended barrel
LAr hadronic
end-cap (HEC)
LAr EM end-cap (EMEC)
LAr EM barrel
LAr forward calorimeter (FCAL)



Sampling Calorimeters



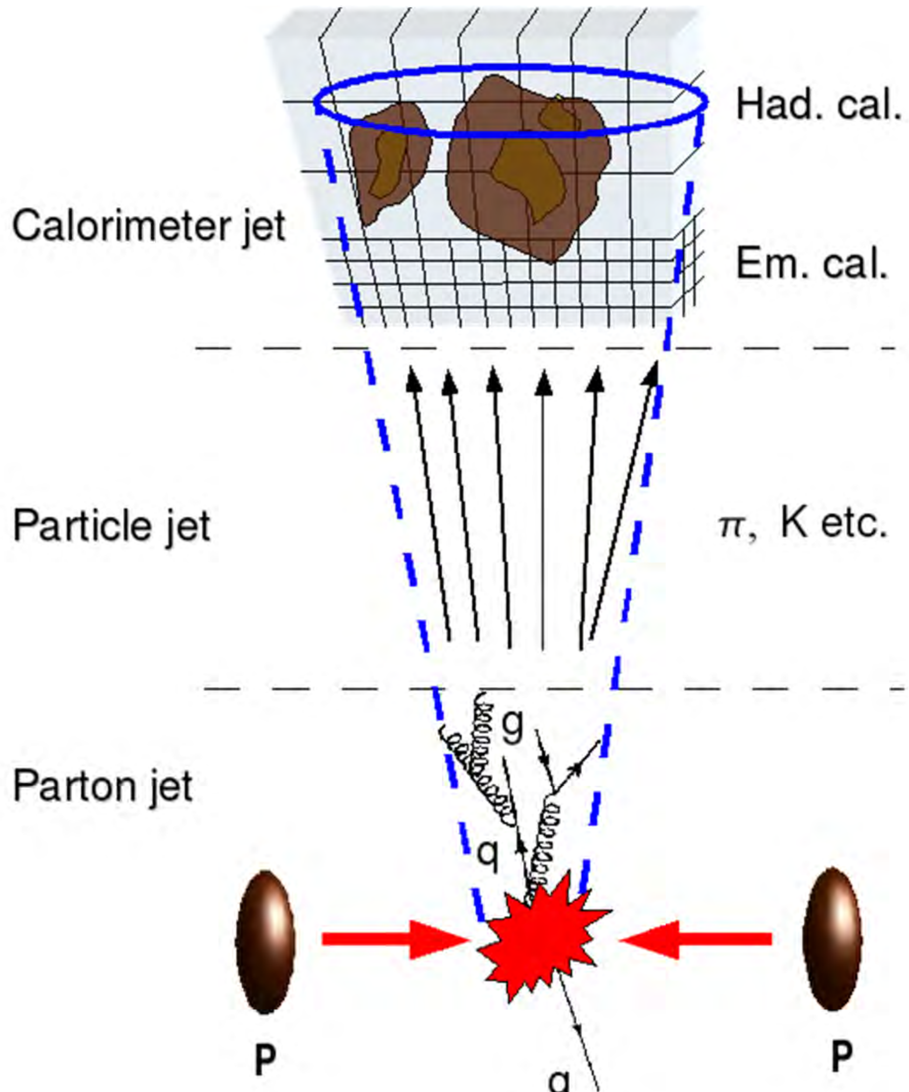
- Absorber (passive) and detector (active) layers
- Fluctuations in visible energy: "sampling fluctuations" due to variation of the nnumber of charged particles in the detector

Energy resolution

- Statistical fluctations
  - In the number of particles in the shower
  - In the number of escaping or undetected particles
- Noise
  - Electronic noise
  - Pile up
- Constant
  - Dead material
  - Calibration errors
  - Mechanical imperfections

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus \frac{\sigma_n}{E} \oplus \text{constant}$$

- **Higher energy -> better resolution**

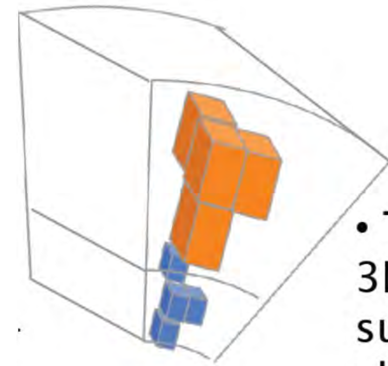

Had. cal.
Calorimeter jet
Em. cal.
Particle jet
π, K etc.
g
Parton jet
q
P
P
q

ATLAS jets

- Use **Anti-kt** with R=0.4 or R=0.6
- M. Cacciari and G. P. Salam, *Dispelling the N*3 *myth for the kt jet-finder*, Phys. Lett. B **641** (2006) 57
- M. Cacciari, G. P. Salam, and G. Soyez. http://fastjet.fr/

- Jet finding is done in *y*-phi coordinates
- Corrections are often done in eta-phi coordinates
- Jet *p*T reconstruction threshold is *p*T > 7 GeV
- **Inputs are: topological clusters or towers** (next slide)

- Topological clusters
  - groups of calorimeter cells that are designed to follow the shower development
  - Start from a seed cell with S/N>=4, iteratively add cells with S/N>=2
  - A splitting procedure exists
  - E = Sum(Ecell), M=0 GeV,
- Towers
  - static, eta × phi = 0.1×0.1, grid elements built directly from calorimeter cells



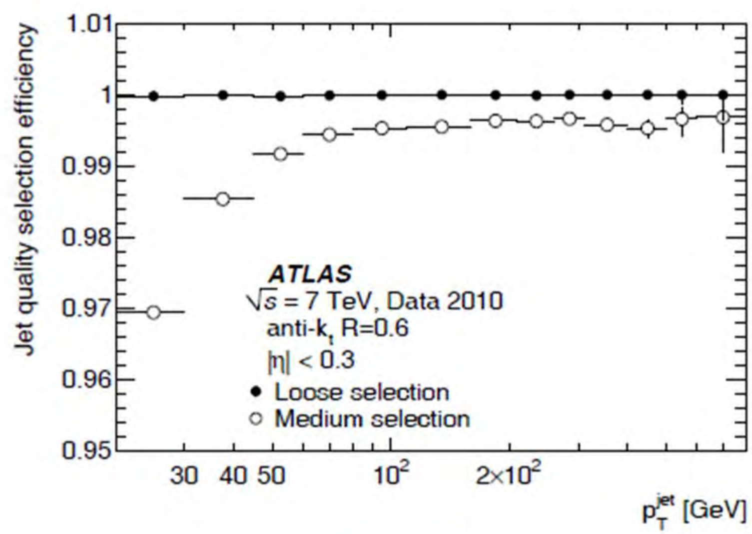
• **TopoClusters**: 3D noise-suppressed clusters of cells

• **Towers**: 0.1x0.1 calorimeter towers

Efficiency

	Loose	Medium
HEC spikes	$(f_{HEC} > 0.5$ and $\mid f_{HECquality} \mid > 0.5)$ or $\mid E_{neg} \mid > 60$ GeV	Loose or $f_{HEC} > 1 - \mid f_{HECquality} \mid$
Coherent EM noise	$f_{EM} > 0.95$ and $f_{quality} > 0.8$ and $\mid \eta \mid < 2.8$	Loose or $f_{EM} > 0.9$ and $f_{quality} > 0.8$ and $\mid \eta \mid < 2.8$
Non-collision background	$\mid t_{jet} \mid > 25$ ns or $(f_{EM} < 0.05$ and $f_{ch} < 0.05$ and $\mid \eta \mid < 2)$ or $(f_{EM} < 0.05$ and $\mid \eta \mid \geq 2)$ or $(f_{max} > 0.99$ and $\mid \eta \mid < 2)$	Loose or $\mid t_{jet} \mid > 10$ ns or $(f_{EM} < 0.05$ and $f_{ch} < 0.1$ and $\mid \eta \mid < 2)$ or $(f_{EM} > 0.95$ and $f_{ch} < 0.05$ and $\mid \eta \mid < 2)$

Table 1: Selection criteria used to reject fake jets and non-collision background.

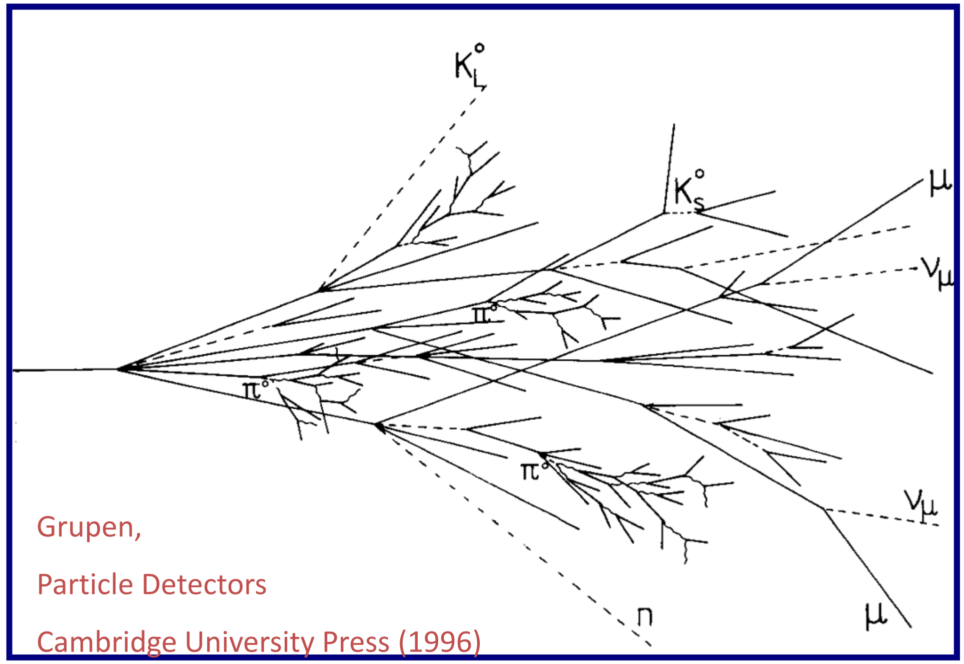


(a) $|\eta| < 0.3$


Sky over Florida, 24.4.2007
Here the ‘fun’ begins…
JES

Calibration

– **Calorimeter non-compensation** partial measurement of the energy deposited by hadrons



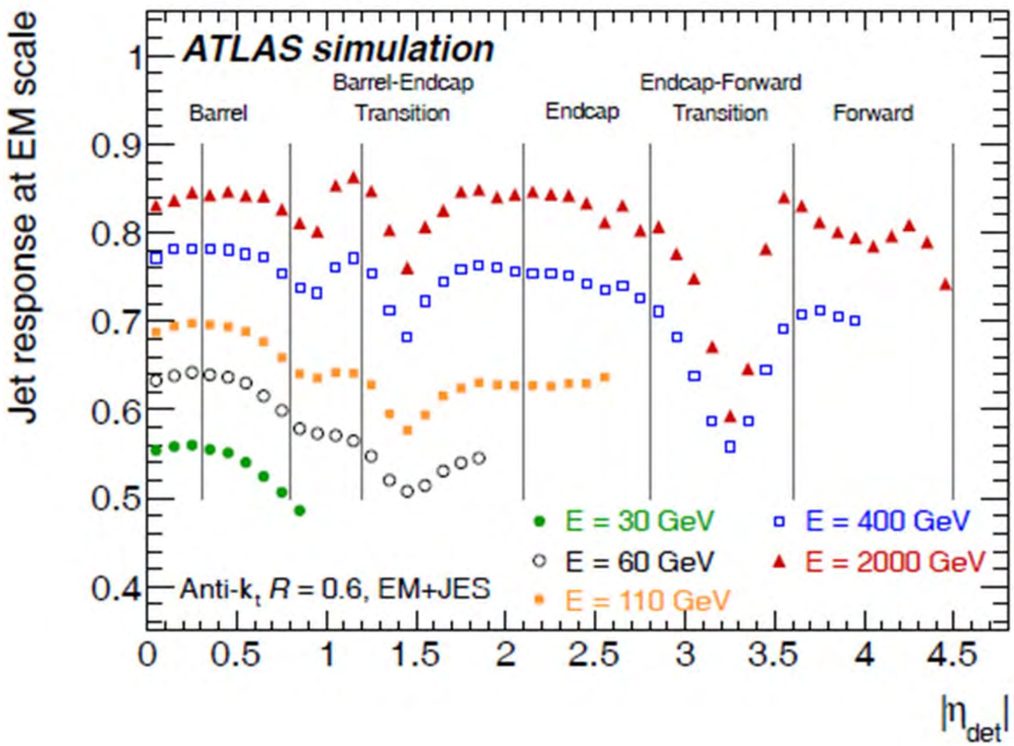
Grupen,

Particle Detectors

Cambridge University Press (1996)

– **Dead material** energy losses in inactive regions of the detector
– **Leakage** energy of particles reaching outside the calorimeters
– **Out of calorimeter jet radiation** energy deposits of particles inside the truth jet entering the detector that are not included in the reconstructed jet
– **Noise thresholds and particle reconstruction efficiency** signal losses in the calorimeter clustering and jet reconstruction

Jet response



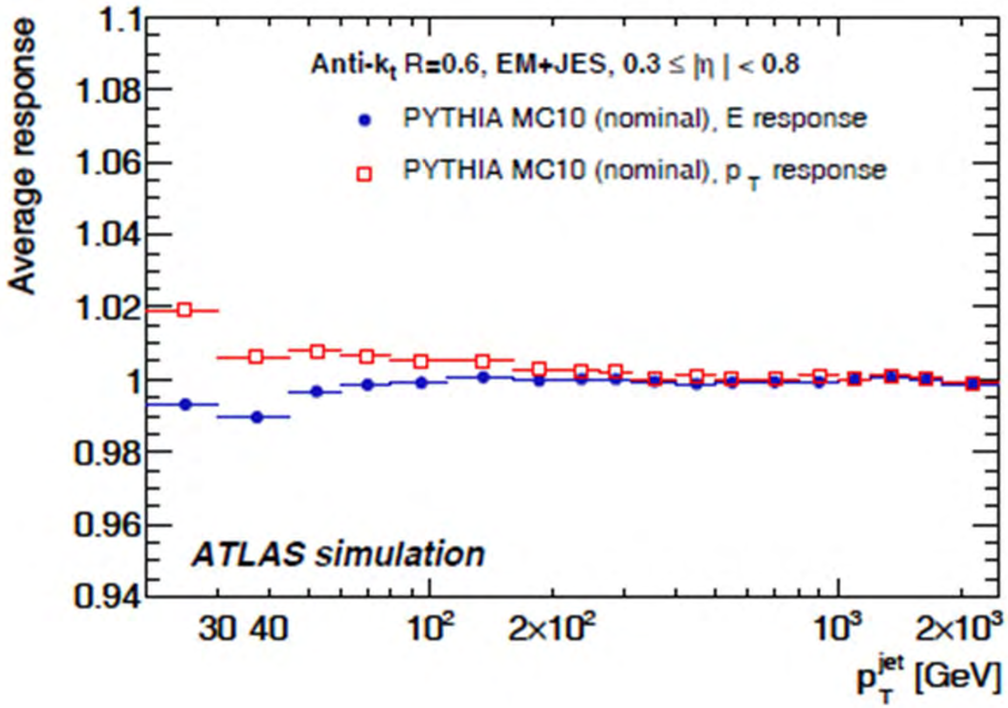
NOT A SMALL CORRECTION…

- Based ok MC (without MPI, as offset already corrected)
- Lines depicts the eta boundaries for the **corrections, which will be averages**

ATLAS knows several correction ‘levels’

- Start from ‘EM scale’
  - Apply an absolute calibration derived from test-beam measurements based on EM-showers
    - Test with muons (test-beam, MC, cosmics)
    - Test with Z-> ee
- Apply a ‘simple’ JES
  - Correct for lower detector response to hadrons
  - Cell based
- More ‘realistic’ scales
  - Cluster-by-cluster, jet-by-jet
  - Use in-situ calibrations

- Closure ?
- Uncertainties at the level of %
- -> Systematic



(a) $0.3 \leq |\eta| < 0.8$

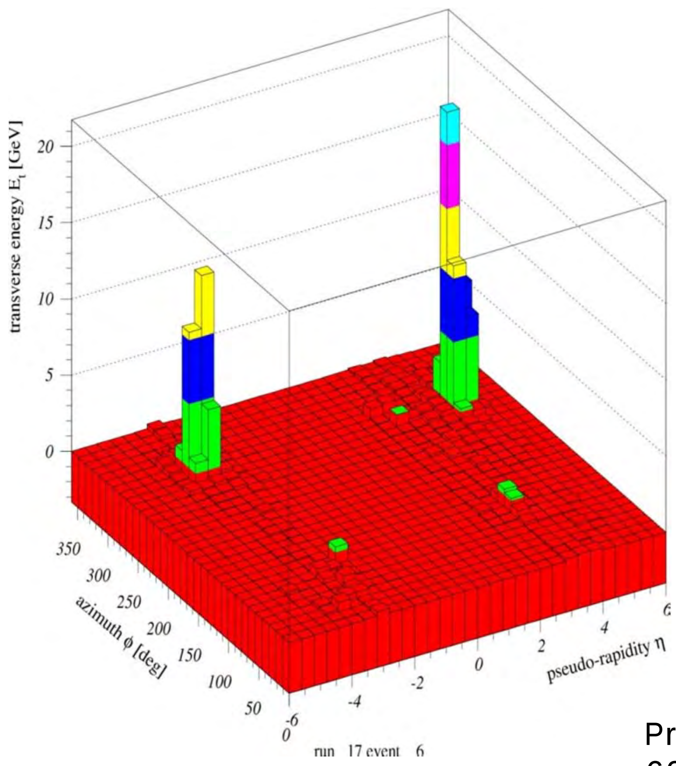
Measure the top quark mass to m_t = 173.2 +- 0.9 GeV (= 0.5%)… (arXiv:1207.1069)

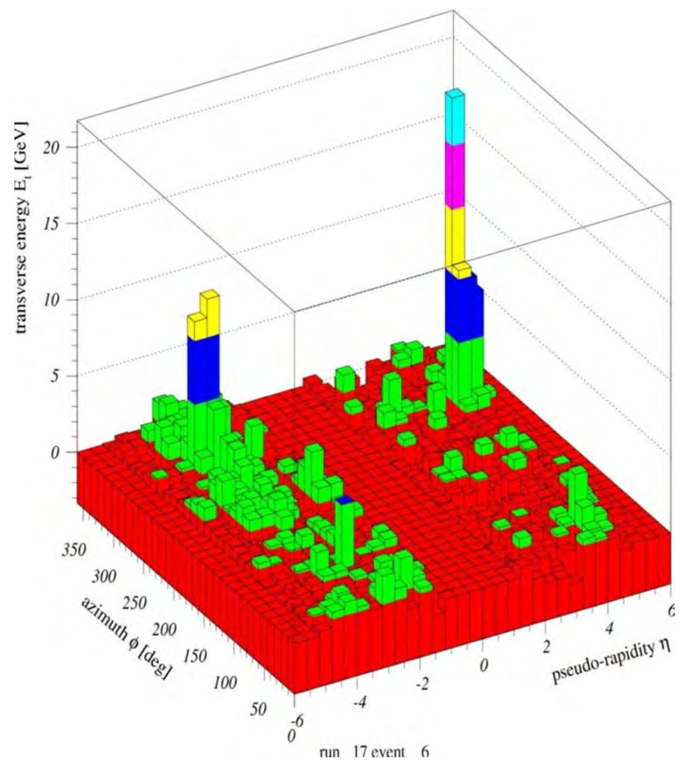
Other Corrections

- **Pile-up correction**:
  average additional energy due to additional proton-proton interactions (correction from *in situ* measurements)
- **Jet origin correction**:
  Correct the direction of the jet to originate from the primary vertex, no effect on energy
- **Jet energy and direction correction**:
  Correction based on constants derived from the comparison of the kinematic observables of reconstructed jets and those from truth jets (MC).

Off-set due to pile-up

- Actually corrected for before the hadronic energy scale is restored, such that the derivation of the jet energy scale does not depend on it





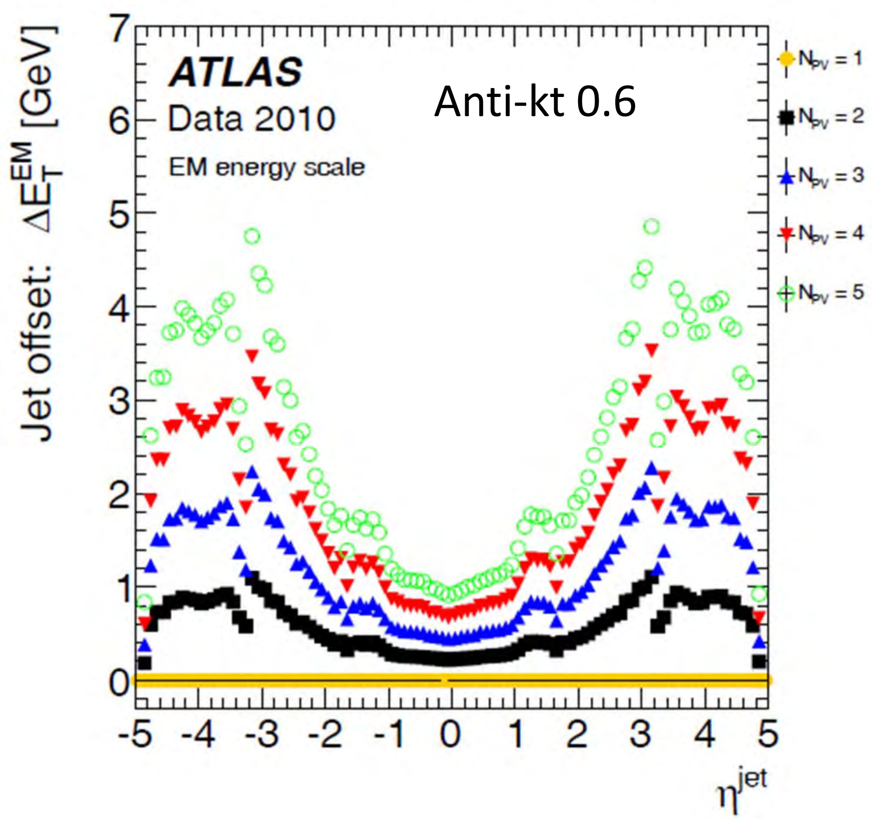
Prog.Part.Nucl.Phys. 60:484-551,2008

D0 Jet Energy Scale cake

Essentially valid for ATLAS too

Offset

- Depends on
  eta, NPV, bunch spacing
- Also depends on the number of towers in a jet (area, but not trivial depending on jet algorithm)
- Shown: jet offset, based on tower offset

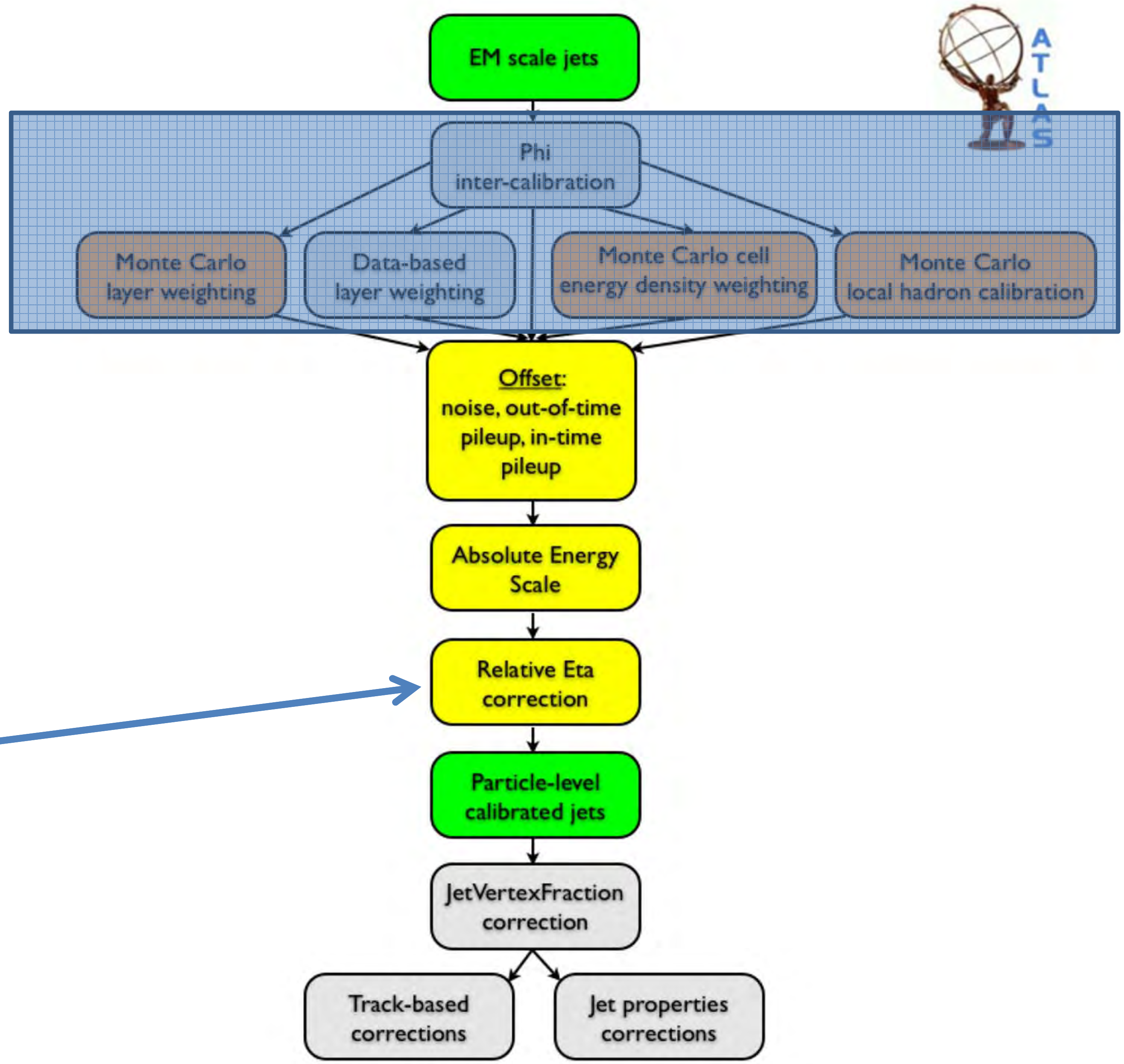


(b) Jet offset

optional

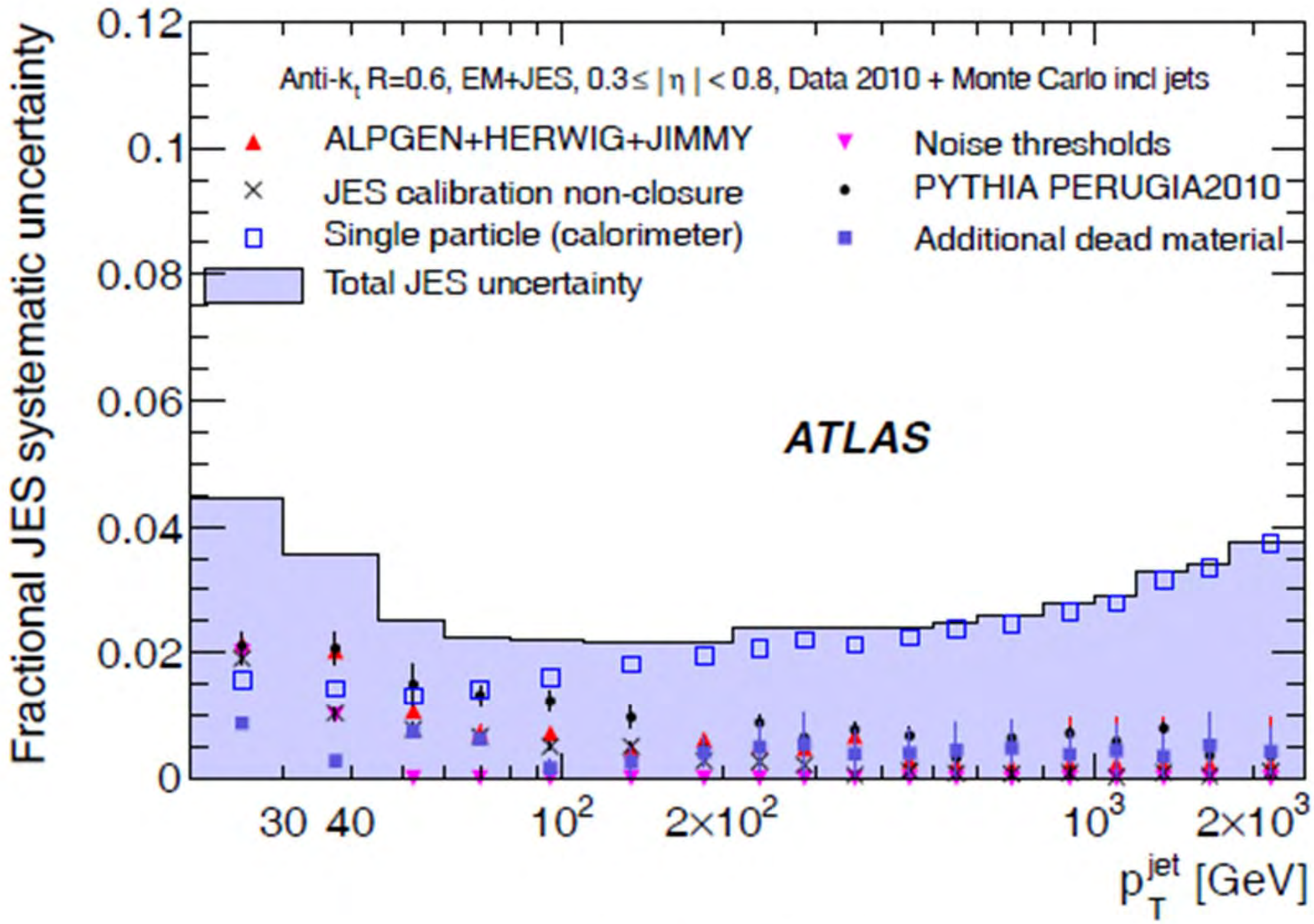
data driven

MC



NEXT

Uncertainty



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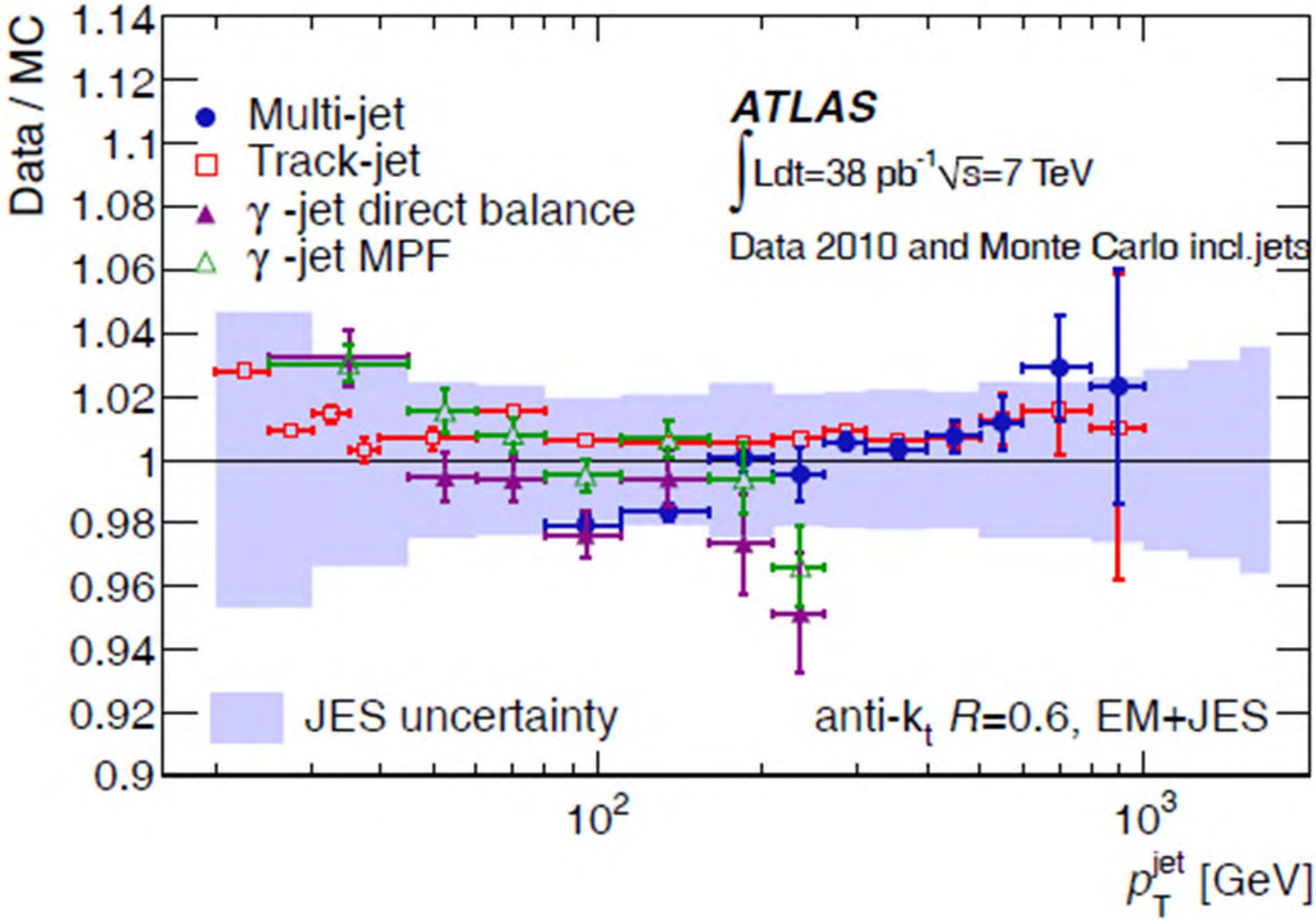
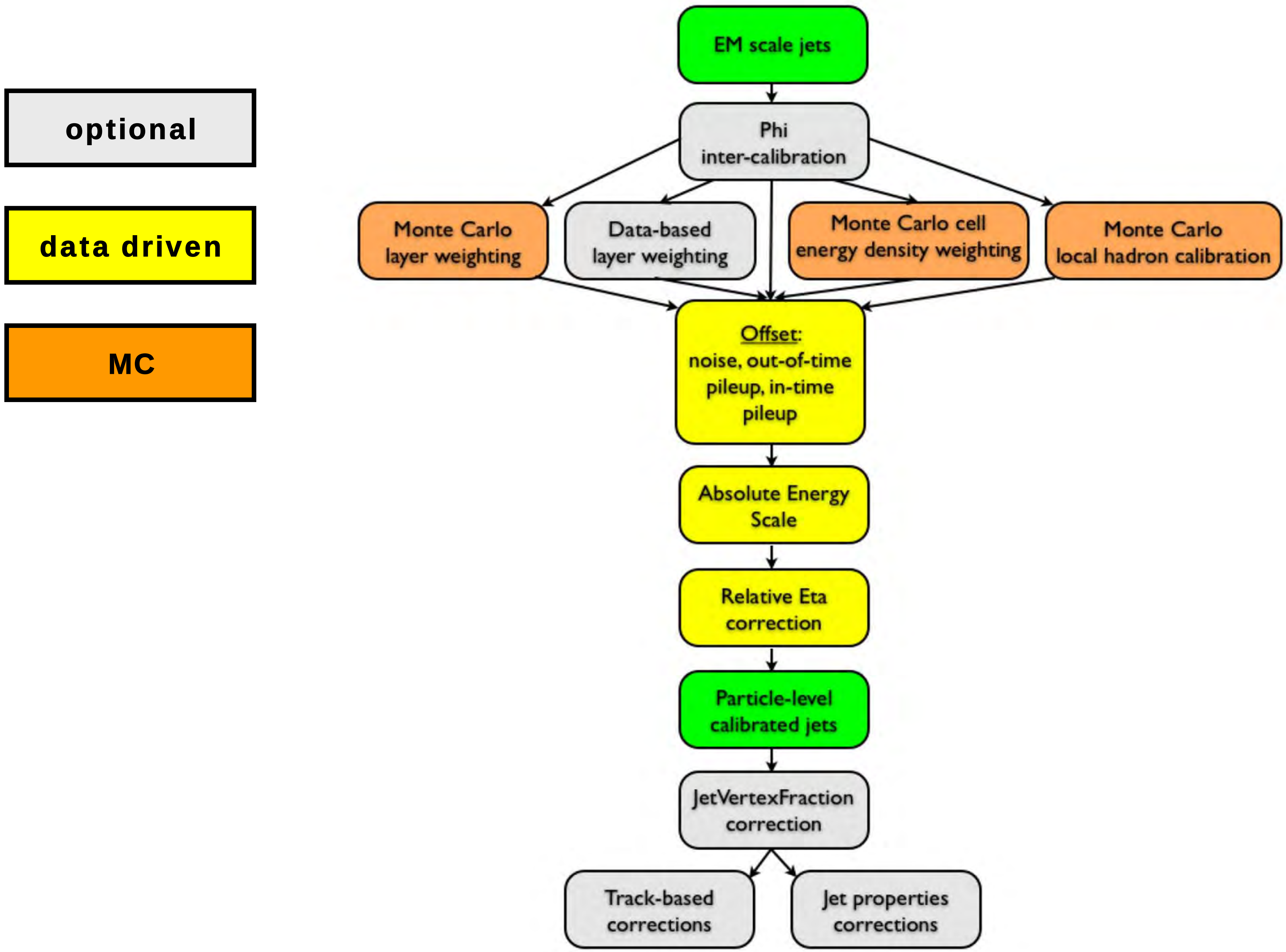


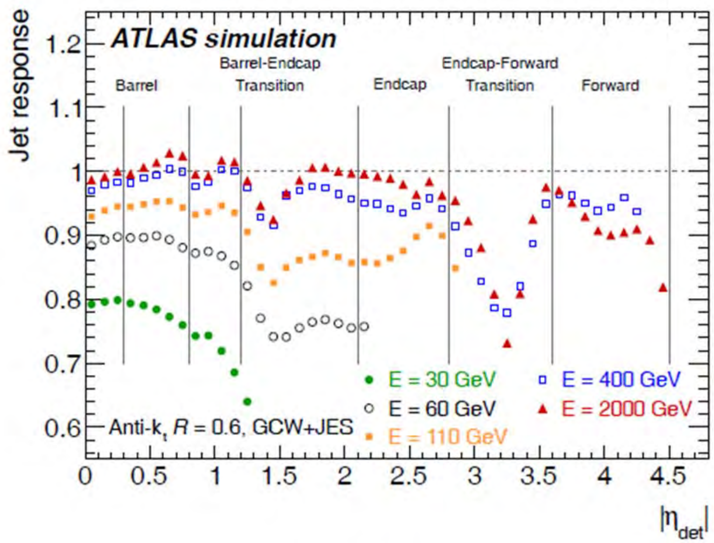
Data / MC
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
Multi-jet
Track-jet
γ -jet direct balance
γ -jet MPF
ATLAS
∫Ldt=38 pb-1 √s=7 TeV
Data 2010 and Monte Carlo incl.jets
JES uncertainty
anti-kt R=0.6, EM+JES
10^2
10^3
p_T^{jet} [GeV]


optional
data driven
MC
EM scale jets
Phi
inter-calibration
Monte Carlo
layer weighting
Data-based
layer weighting
Monte Carlo cell
energy density weighting
Monte Carlo
local hadron calibration
Offset:
noise, out-of-time
pileup, in-time
pileup
Absolute Energy
Scale
Relative Eta
correction
Particle-level
calibrated jets
JetVertexFraction
correction
Track-based
corrections
Jet properties
corrections

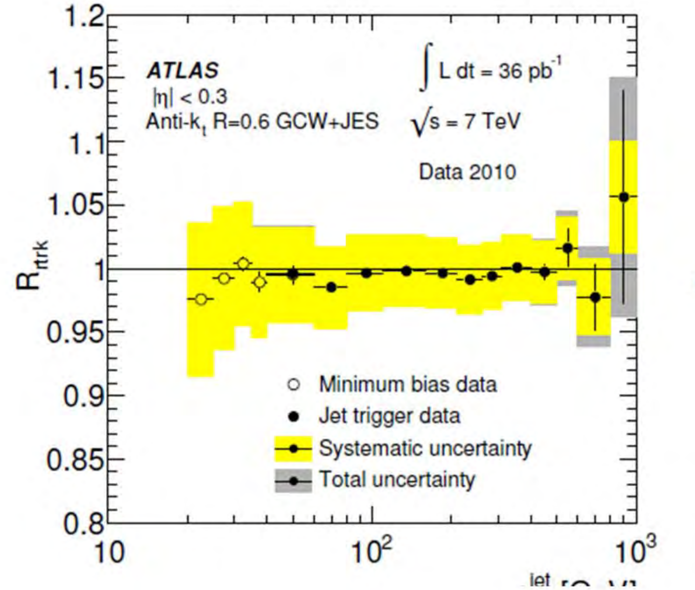
Beyond the simplistic EM+JES

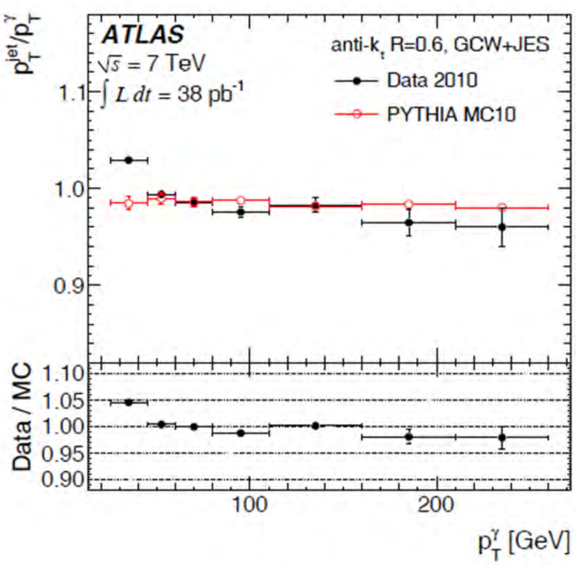
- The EM+JES calibration facilitates the evaluation of systematic, but the energy resolution is rather poor and it exhibits a rather high sensitivity of the jet response to the flavour of the parton inducing the jet

- Global calorimeter cell energy density calibration(GCW)
  - jet is calibrated as a whole, longitudinal weights
  - attempts to assign a larger cell level weight to hadronic energy depositions in order to compensate
- Local cluster calibration (LCW)
  - cluster shape variables characterize the topology of the energy deposits of electromagnetic or hadronic showers
  - "Local", from simulation, without considering the jet context

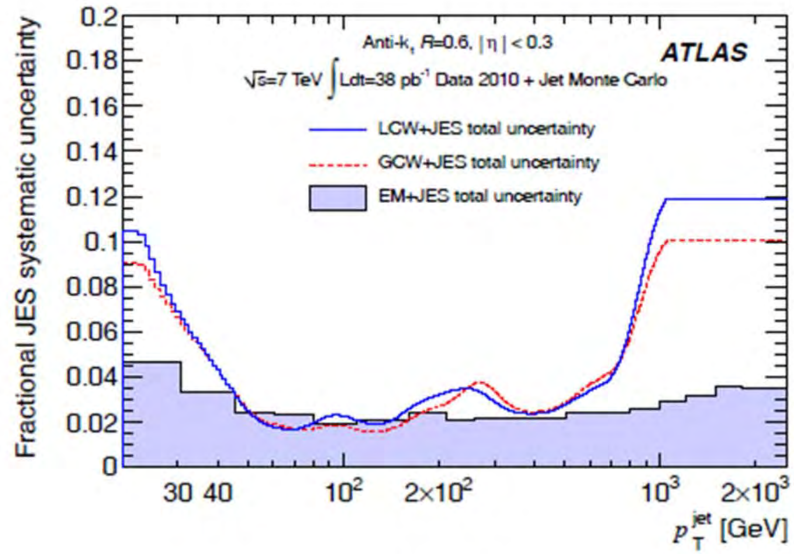


(a) GCW



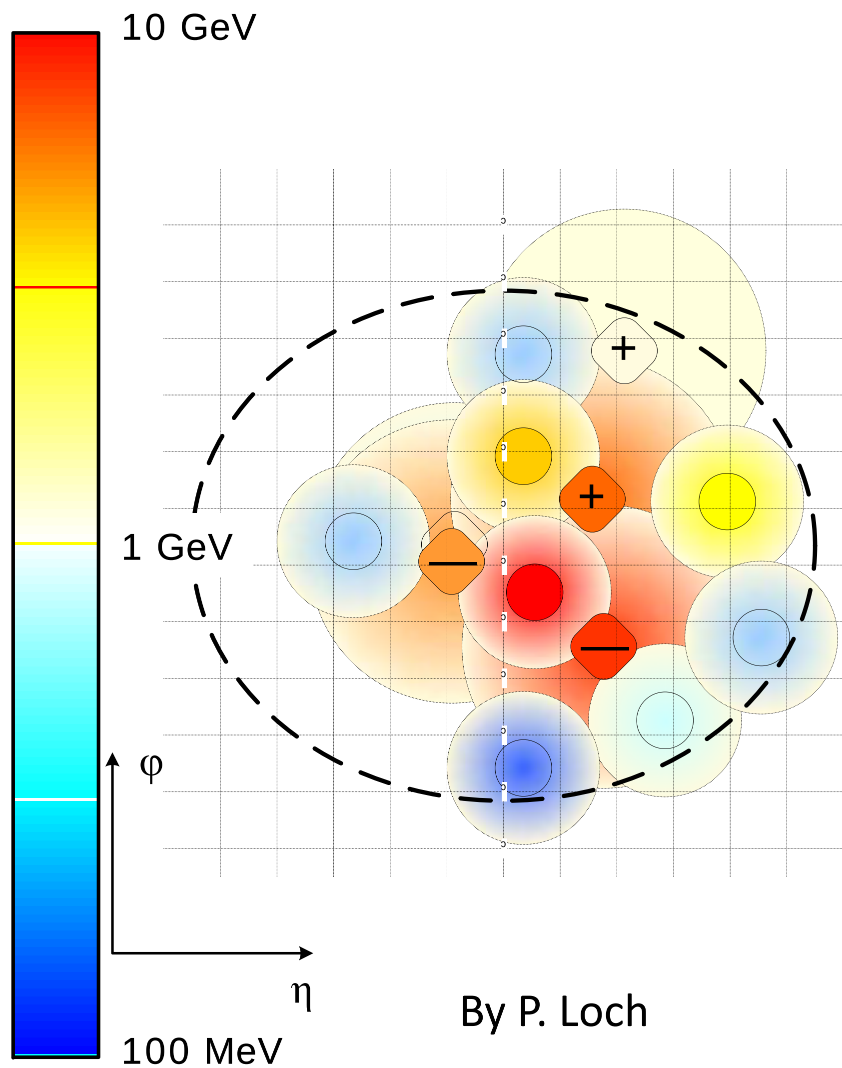


(a) GCW+JES



(a) $|\eta| < 0.3$

Next… Split the jet in sub-jets



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