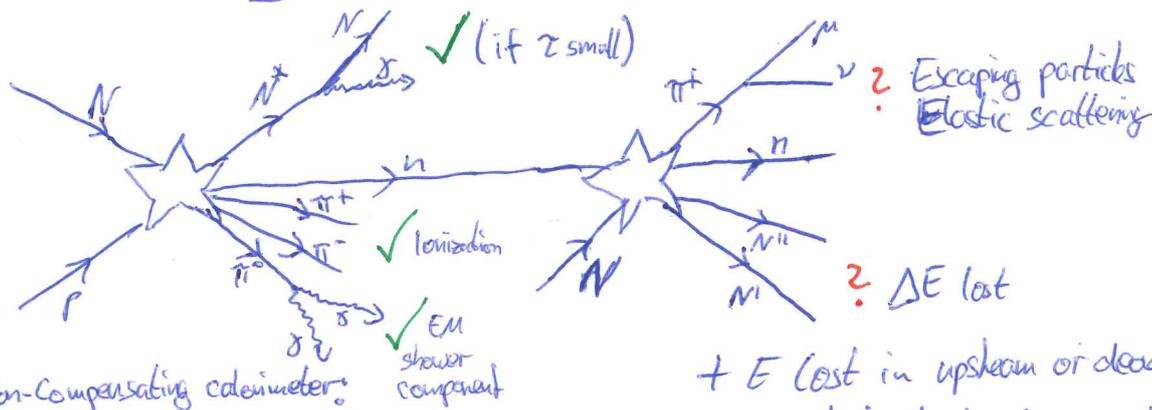


Set Energy Scale in ATLAS

Detectable energy in hadronic showers:



ATLAS: Non-Compensating calorimeter:

- Large Fraction of jet energy remains undetected (~30%)
 - Hadronic calorimeter response is non-linear with $\frac{EM}{HAD} > 1$ (clusters at EM scale)
- ⇒ Jets need to be calibrated

Jet calibration

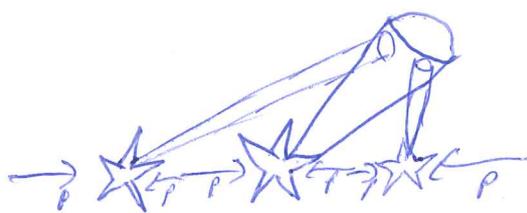
Reference object (ATLAS): Truth particle jets (MC)

Goal: Linearity: $R = \langle E_{reco} / E_{truth} \rangle = 1$

Resolution: σ_E / E as low as possible

Position Reconstruction: $\langle \eta - \phi_{reco} \rangle = \langle \eta - \phi_{truth} \rangle$

Step 1: Pile-Up offset correction:

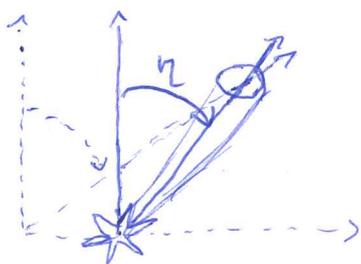


Derive from MC:

$$P_T^{cor} = P_T^{EM} - \rho \cdot A - \alpha (N_{PV} - 1) - \beta \langle \mu \rangle$$

ρ : avg. energy density in event
 A : Jet area
 α : # primary vertices
 $\beta \langle \mu \rangle$: Avg. interactions per bunch crossing

Step 2: Origin Correction:

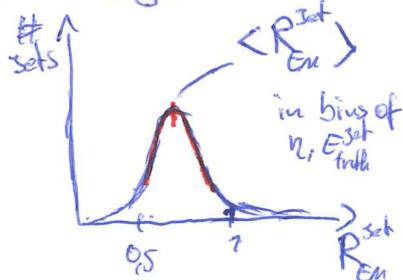


- Improves angular resolution of jet
- Does not affect E
- Small improvement (<1%) in P_T response

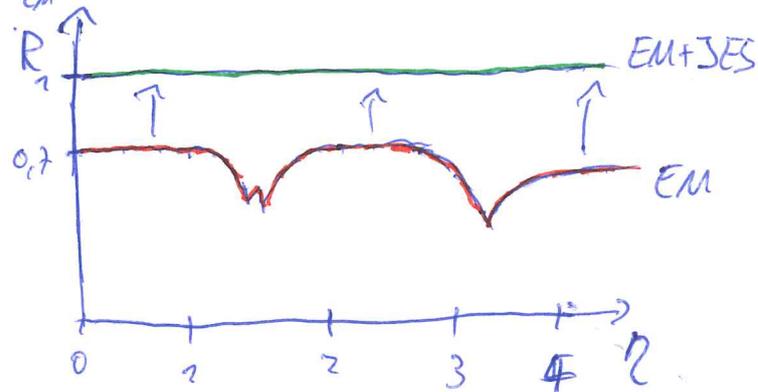
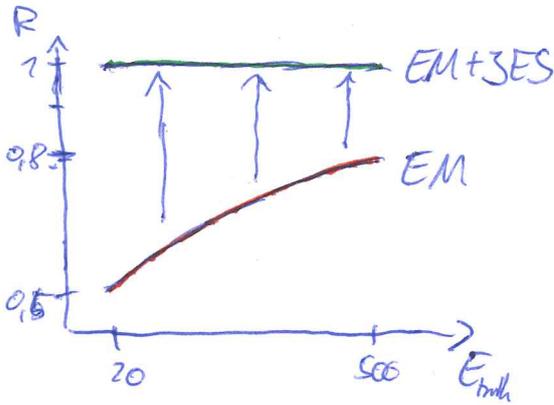
Step 3: McSES calibration:

Truth response of isolated EM scale jets:

$$R_{EM}^{set} = \frac{E_{EM}^{set}}{E_{truth}^{set}}$$



Corr = "Numerical Inversion" of $\langle R_{EM}^{set} \rangle$



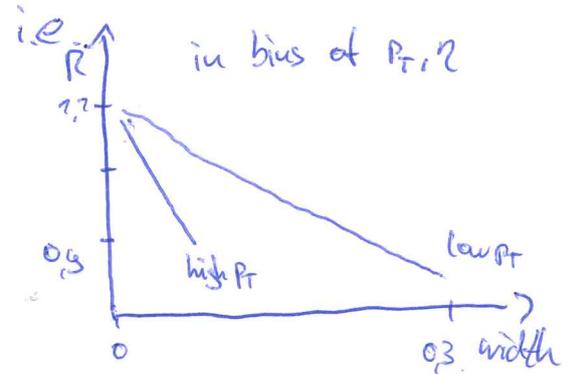
McSES is good in R , but not in terms of $\sigma_{E/E}$

Step 4: Global Sequential Correction:

GSC = EM+SES + additional corrections to improve $\sigma_{E/E}$

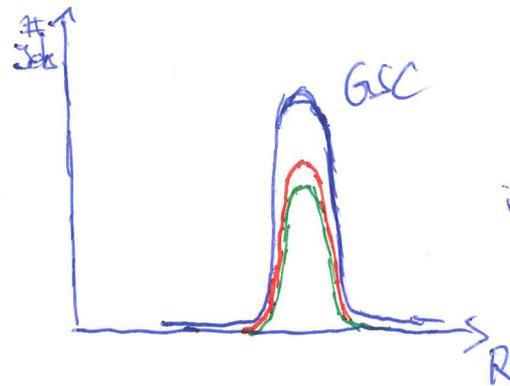
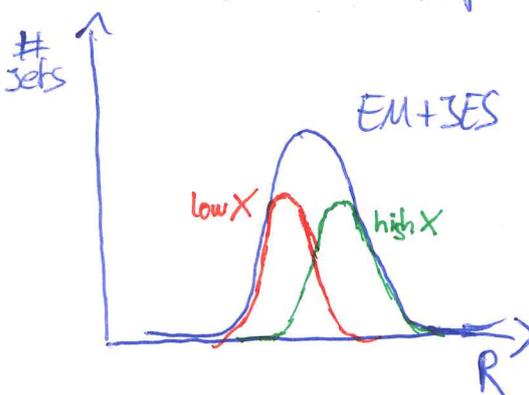
Response depends on jet variables X : (apart from p_T, η)

- Fraction of E deposited in last EM layer
- Fraction of E deposited in first HAD layer
- # tracks
- p_T weighted track width
- # active muon segments behind jet



GSC corrects for flavor response differences

- Gluon jets are softer, wider and contain more particles
 \rightarrow Lower response needs correction

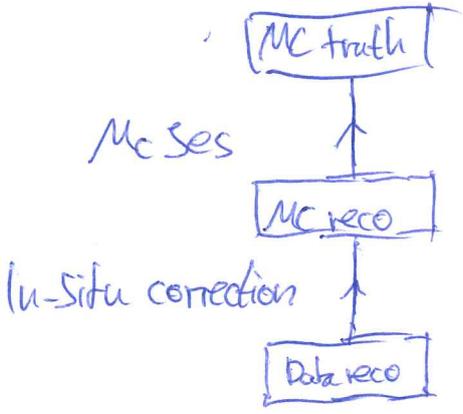


$\sim 30\%$ improvement in $\sigma_{E/E}$

Alternative: Local Cluster Weighting (LCW)

⇒ weight cluster based on: $\eta, E, f_{\text{cluster}}, S_E, \text{isolation}$

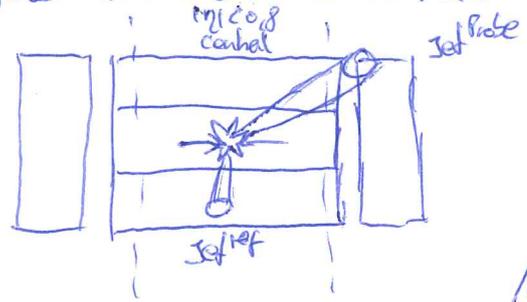
So far: calibration based on MC



- Differences in modelling of
- Underlying event, jet formation, pile-up
 - Physics of EM & HAD interactions with detector
 - Description of detector material
- (most discrepant in forward region)

Step 5: η -Intercalibration (relative in-situ):

Removes differences in relative response between forward and central jets in data and MC



$$A = \frac{p_T^{\text{probe}} - p_T^{\text{ref}}}{p_T^{\text{avg}}} \quad \text{in bias of } p_T^{\text{avg}}, \eta^{\text{probe}}$$

$$\frac{p_T^{\text{probe}}}{p_T^{\text{ref}}} = \frac{2 + A}{2 - A} = \frac{1}{c} \quad \text{corr} = \frac{c^{\text{data}}}{c^{\text{MC}}}$$

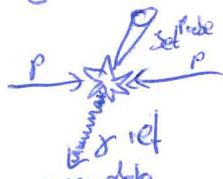
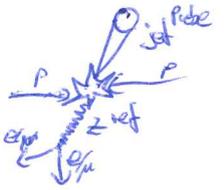
Motiv method: Generalize A for jets from arbitrary η regions

Step 6: Absolute in-situ calibration

Removes differences in absolute jet response between data and MC.

Low p_T : Z-Jet Balance

medium p_T : γ -Jet Balance



$$B = \frac{p_T^{\text{jet}}}{p_T^{\text{ref}}}$$

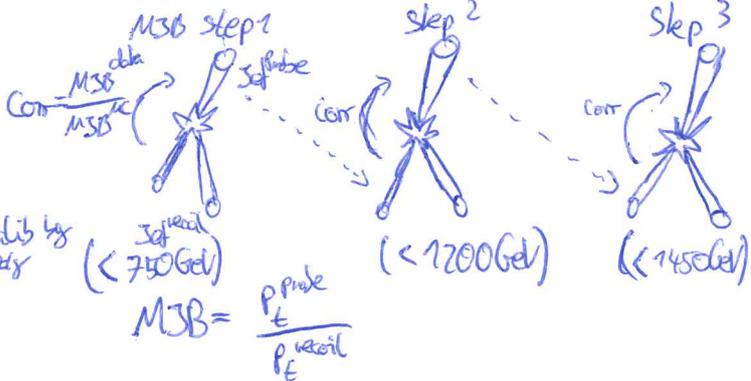
$$\text{corr} = \frac{\langle B^{\text{data}} \rangle}{\langle B^{\text{MC}} \rangle}$$

Affected by:

- Additional parton radiation, pile-up
- Out-of-cone radiation
- Uncertainty on p_T of reference object

$$\Rightarrow p_T^{\text{ref}} = p_T^{\text{obj}} \cdot |\cos \Delta\phi|$$

High p_T : Multi-Jet-Balance



$$MJB = \frac{p_T^{\text{probe}}}{p_T^{\text{recoil}}}$$

$$\text{Total corr} = \frac{\langle B^{\text{Z}}, MJB \rangle^{\text{data}}}{\langle B^{\text{Z}}, MJB \rangle^{\text{MC}}}$$

JES uncertainty 2016: 1-6%

Alternative: "Missing Projection Fraction" (MPF)