Reconstruction of Jets in Top Events at ATLAS.

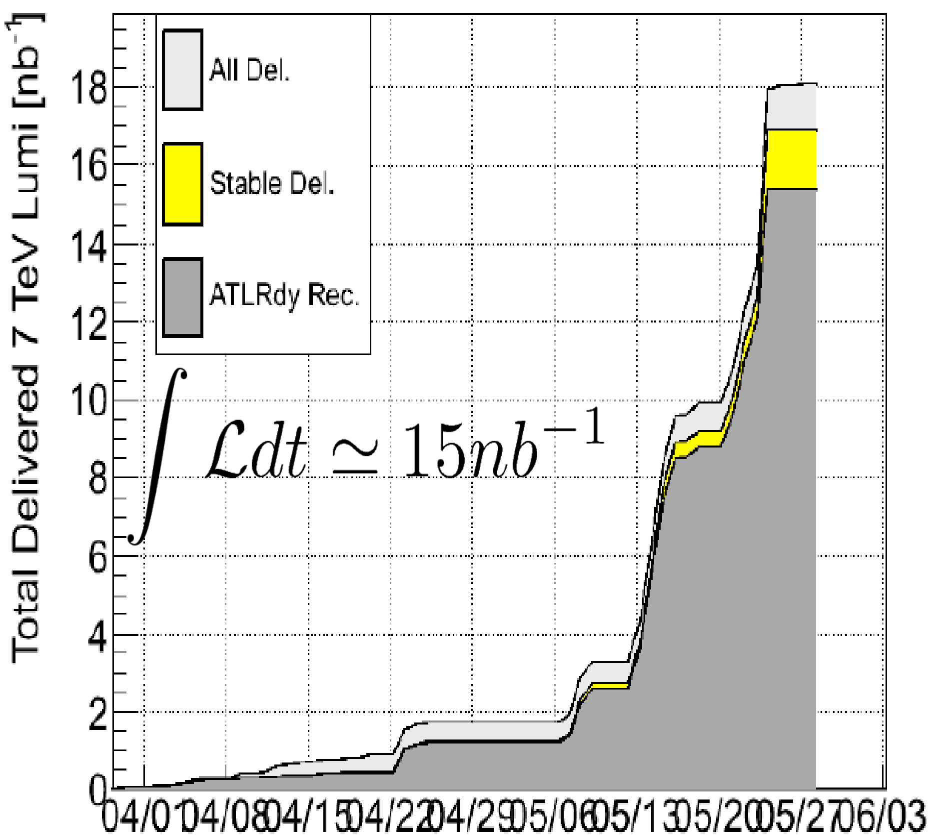
Nabil Ghodbane

(for the ATLAS Collaboration)

- ❑ Motivations
- ❑ The ATLAS calorimeter system
- ❑ Jet algorithms in use
- ❑ Inputs for jet algorithms
- ❑ Jet algorithm choice
- ❑ Jet calibration strategies
- ❑ In-situ based calibrations
- ❑ Conclusions

Motivations

- ATLAS is finally collecting data, thanks to the LHC accelerator division impressive work...
- We're a few hundred submitting GRID jobs to analyze these data, thanks to the robust distributed analysis framework... and the analysis model and tools developed in the past.



- Number of **top pair events probably produced**, assuming a reconstruction efficiency of 100%...:

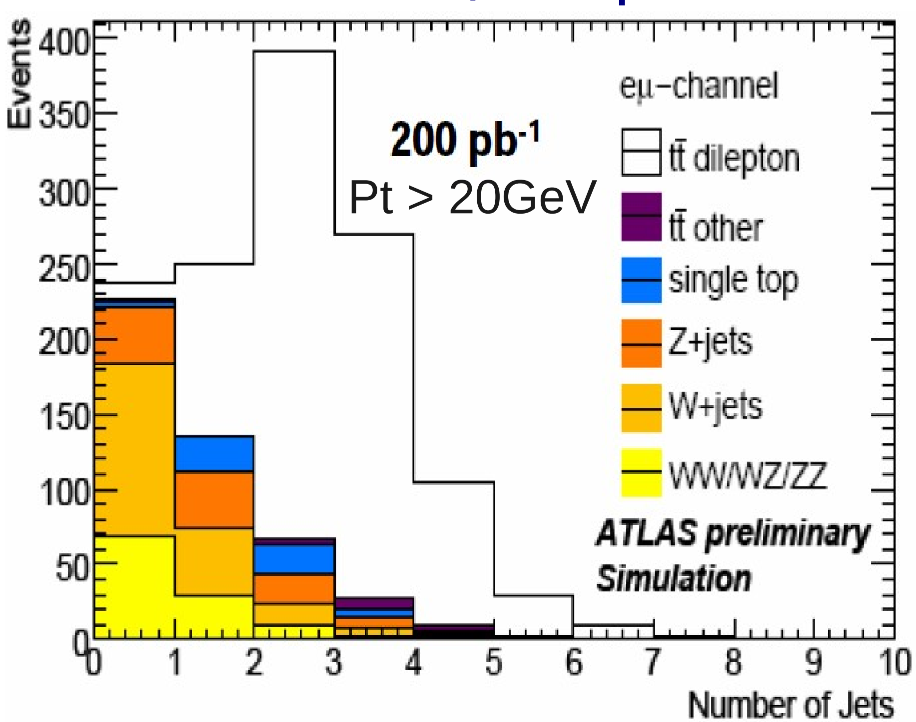
σ x $\mathscr{L}$ ~ 144 x 0.015 ~ **2**

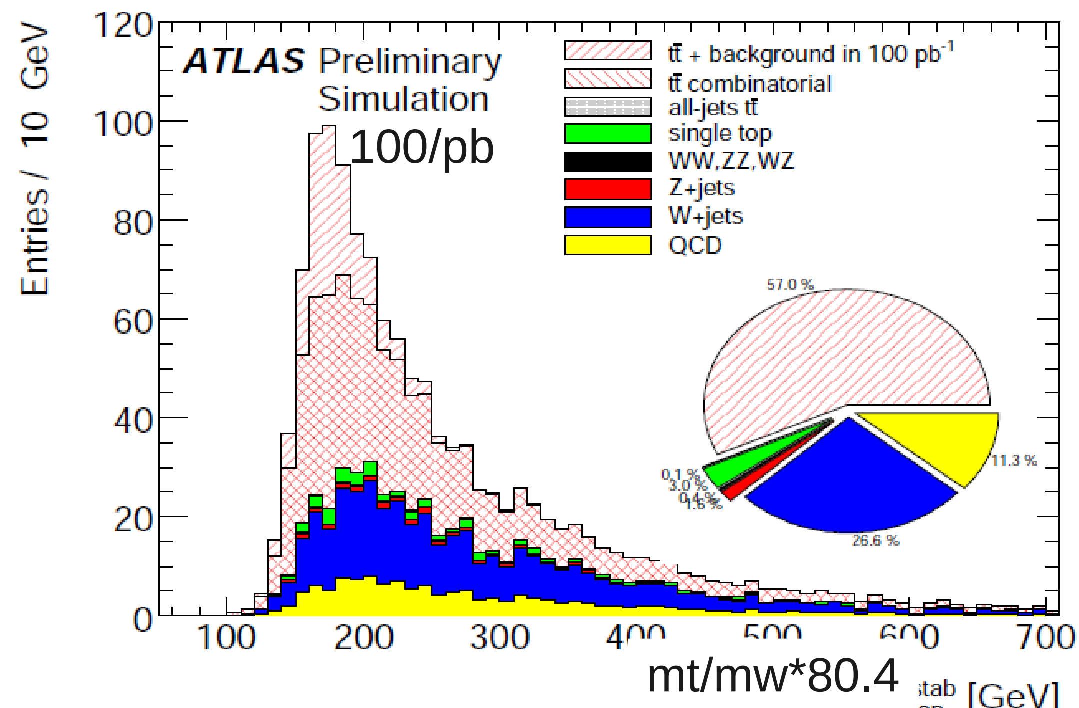
But reco efficiency, etc...

Motivations

- What can we report about today for the top?
rather sorry,NOT much here, next year surely more material. Moreover what is shown here is preliminary

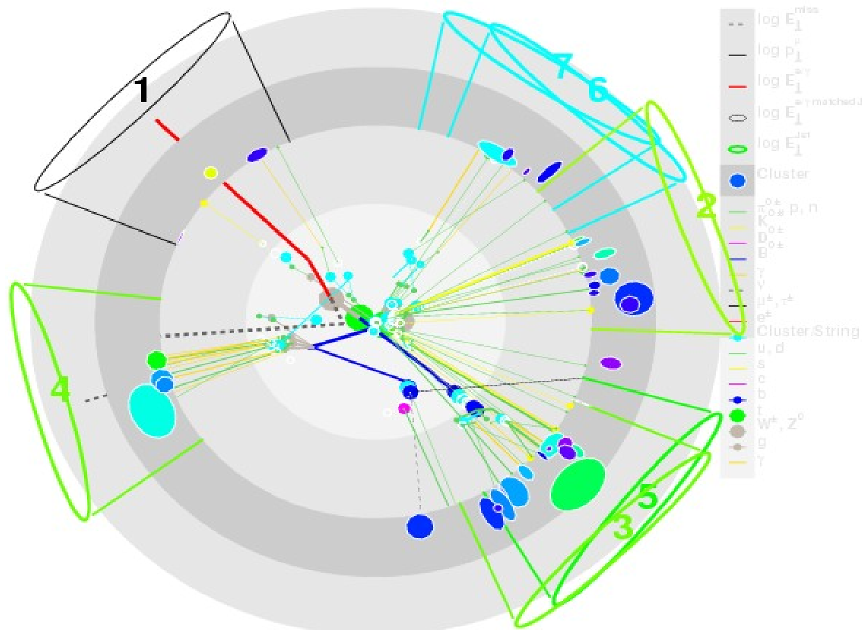
- Several analysis are being redone, but not much blessed material to be used here for jets in the top case, like below, the distribution for the number of jets for the di-lepton analysis or the reconstructed top mass distribution reconstructed in the muon+jets
(see poster session from G.Cortiana)



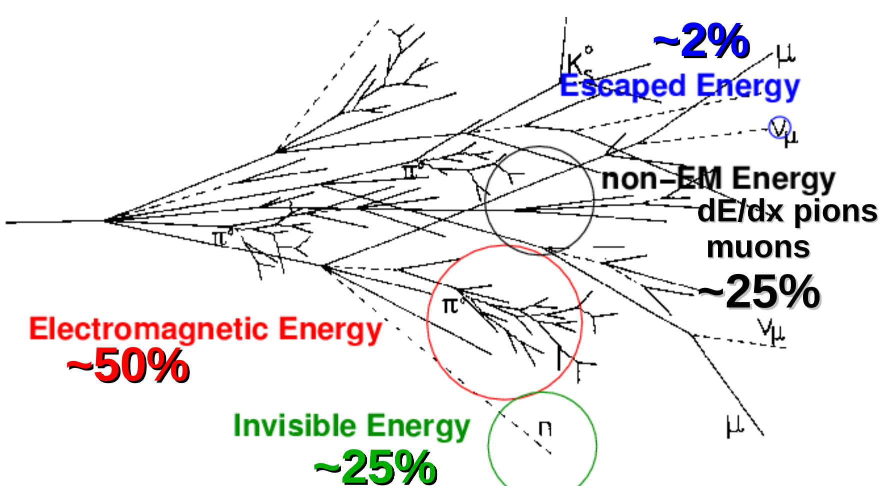


Motivations

In order to reconstruct the top quark and achieve the best precision, several issues need to be tackled from the experimental point of view.



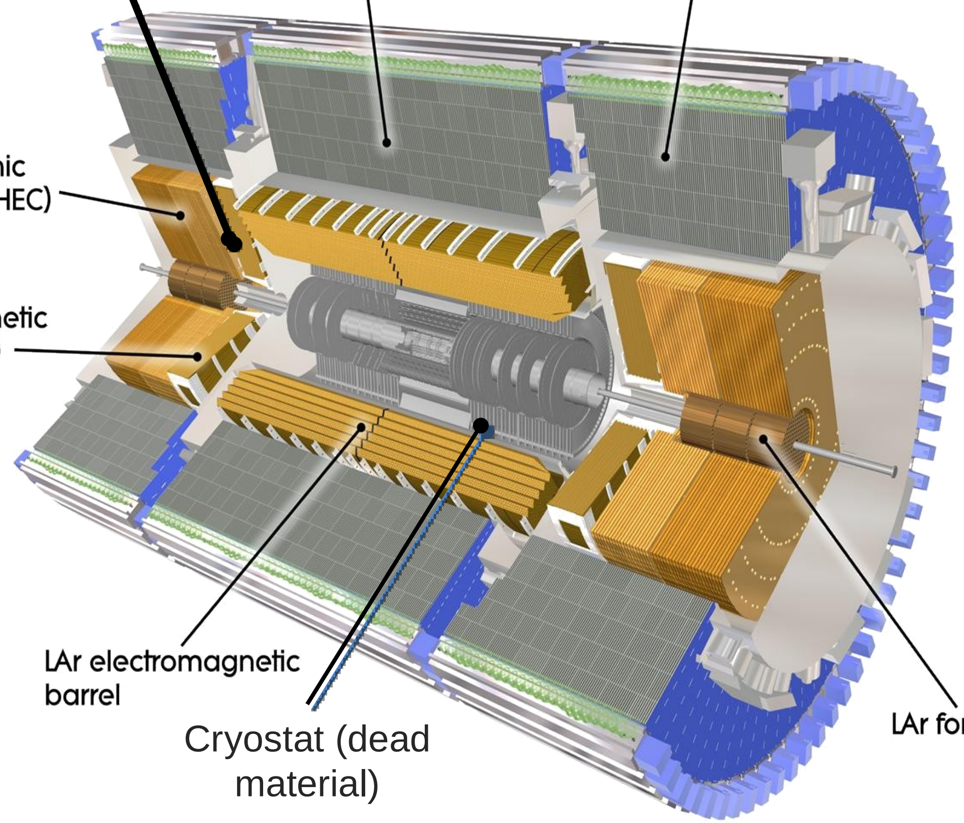
A typical ttbar event topology



- Understand the **detector response** for:
  - non compensation,
  - dead (or inactive) material,
  - electronic noise,
  - energy leakage,
- Choose/tune the appropriate **jet algorithm**:
  - (SIS)Cone, Kt, anti-Kt
  - out of cone energy losses
- Include and understand the **physics effects**:
  - jet types (light, b, gluons)
  - parton shower/fragmentation
  - ISR/FSR
  - underlying events
  - Pile-Up

The ATLAS Calorimeter System

Main features of the ATLAS Calorimeter system for reconstruction and calibration:



☑ Non compensating (e/h >1) :
Response to hadrons is lower than that to electrons and photons
Developed specific calibrations

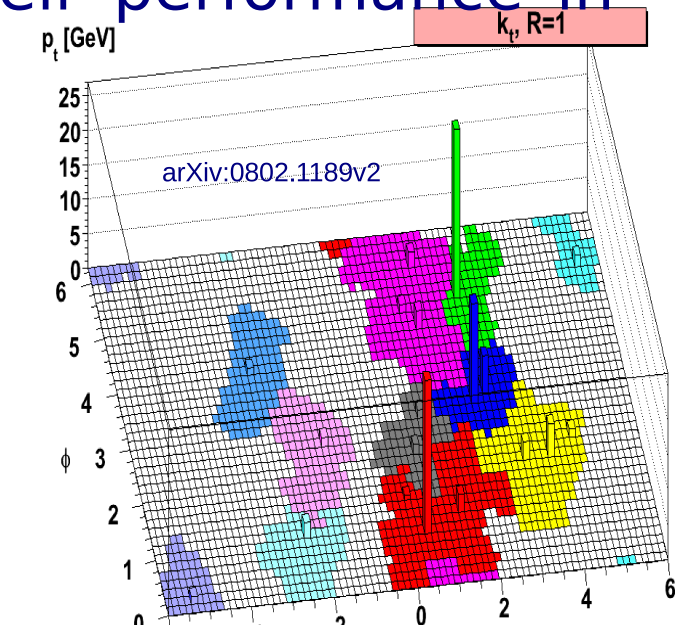
☑ Dead material:
Energy loss before and between the different calorimeters.

☑ Different technologies and many transition regions:

	Structure	η range	Resolution	Channels
LAr EM	Pb-LAr accordion	$\lvert\eta\rvert < 3.2$	$e/\gamma\ \sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$	170k (98.6%)
FCAL	W-LAr accordion	$3.2 < \lvert\eta\rvert < 4.9$	$\sigma(E)/E = 100\%/\sqrt{E} \oplus 10\%$	3500 (100%)
HEC	Cu-LAr structure	$1.5 < \lvert\eta\rvert < 3.2$	$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\%$	5600 (99.9%)
TILE	Fe - scintillating	$\lvert\eta\rvert < 1.7$	$\sigma(E)/E = 50\%/\sqrt{E} \oplus 3\%$	9800 (98%)

Jet Algorithms in Use at ATLAS:

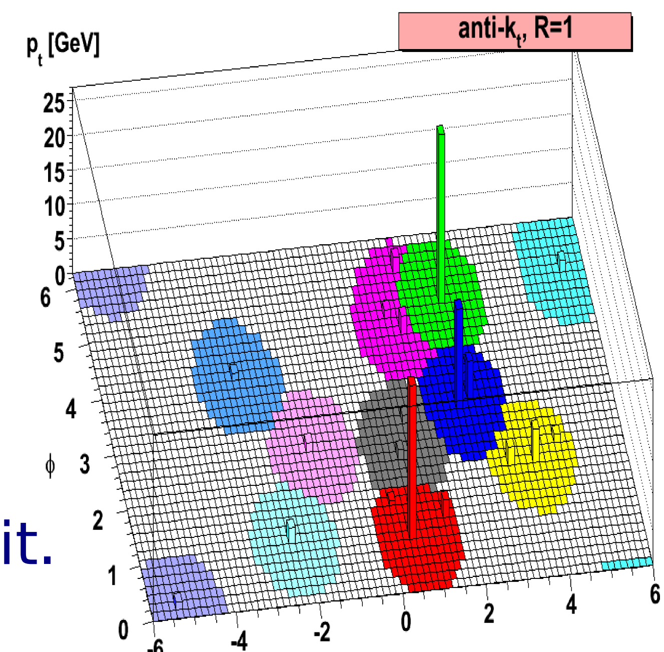
Several jet algorithms are in use within ATLAS and have been intensively studied in terms of their performance in the context of hadron collisions.



- **FastJet** (*p*=+1), **Anti-Kt** (*p*=-1)
  - Infrared & collinear safe (IRC)
  - Iterative combination of the input proto-jets $\{k_T\}_i$

  By comparing the distances d_{ij} and d_i

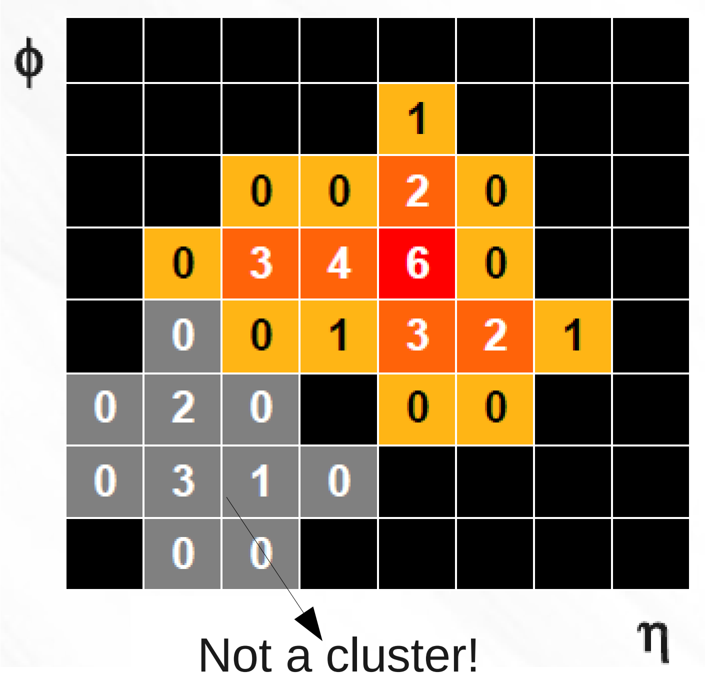
$$d_{ij} = min(k_{T,i}^{2p}, k_{T,j}^{2p})\Delta R_{i,j}^2/R^2 \quad d_i = k_{T,i}^{2p}$$



  - E recombination scheme,
  - Anti-Kt shapes more circular.
  - R=0.4, 0.6 mainly.
- **Seed-less Infrared Safe Cone**
  - split/merge (75%), IRC
- **Iterative seeded ATLAS cone**
  - used in the past, slowly moving from it.
  - split/merge (75%), not IRC

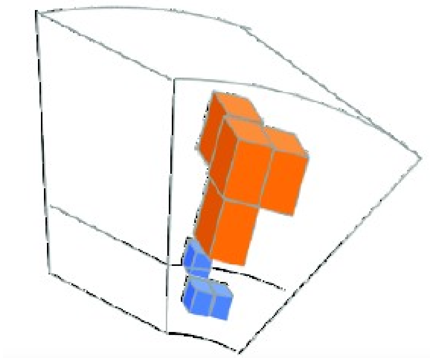
Input Signal to Jets

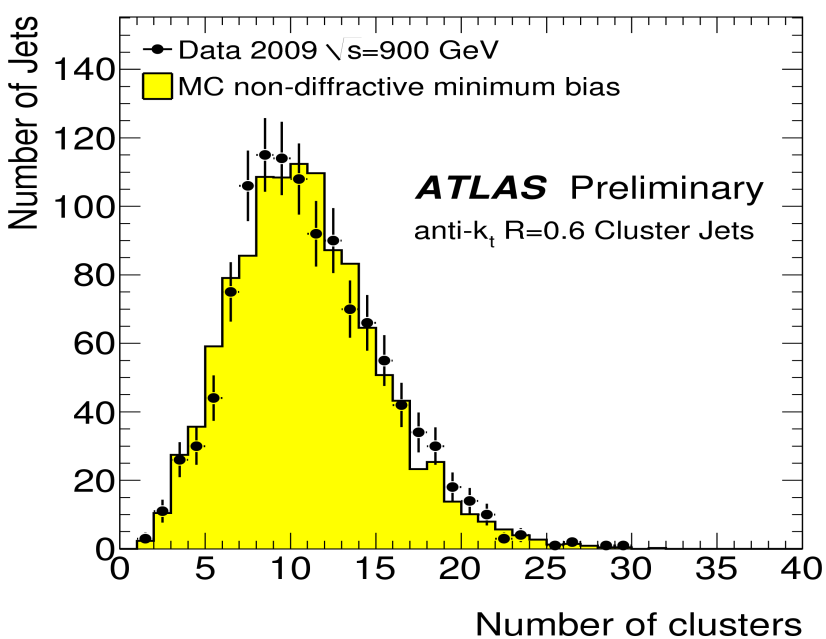
ATLAS uses two primary inputs to jet reconstruction algorithms:



- **topological clusters:**
  group of calorimeter cells topologically interconnected and selected by energy significance:
  - -seed cell: $|E_{cell}| > 4\sigma$ noise
  - -neighbor cells: $|E_{cell}| > 2\sigma$
  - -cells surrounding the cluster added.

Tries somehow to match the shape of the shower.

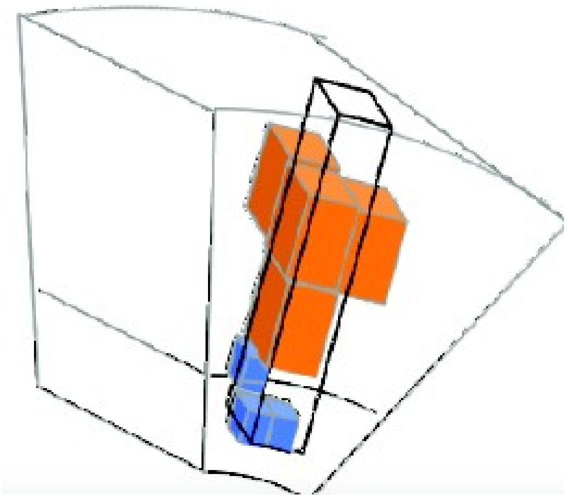




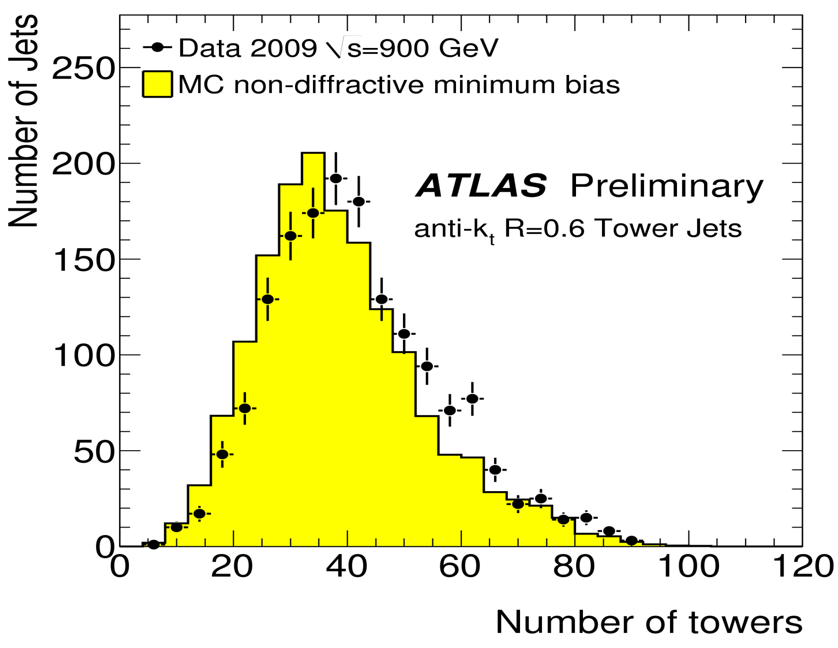
- comparison MC-Data at 900GeV shows a good description.

Input Signal to Jets

ATLAS uses two primary inputs to jet reconstruction algorithms:



- **topological towers:**
  select from the reconstructed cluster a tower (thin radial of calorimeter of fixed geometry 0.1x01 in ηxϕ) containing only cells with significant signal.

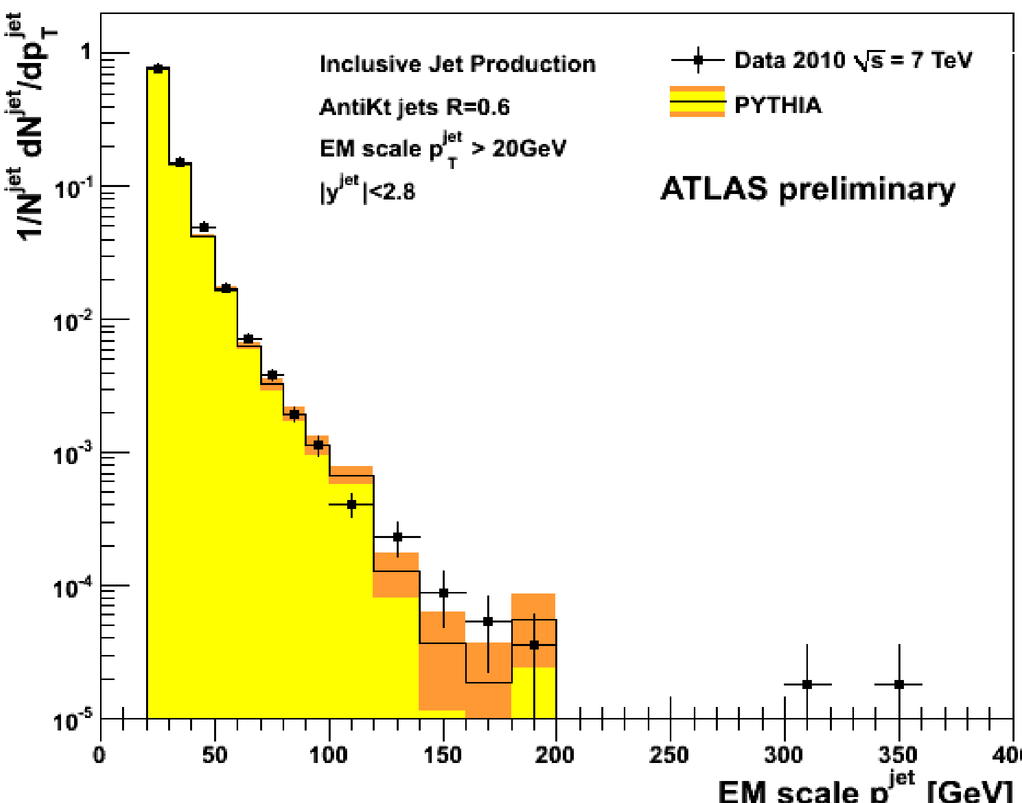


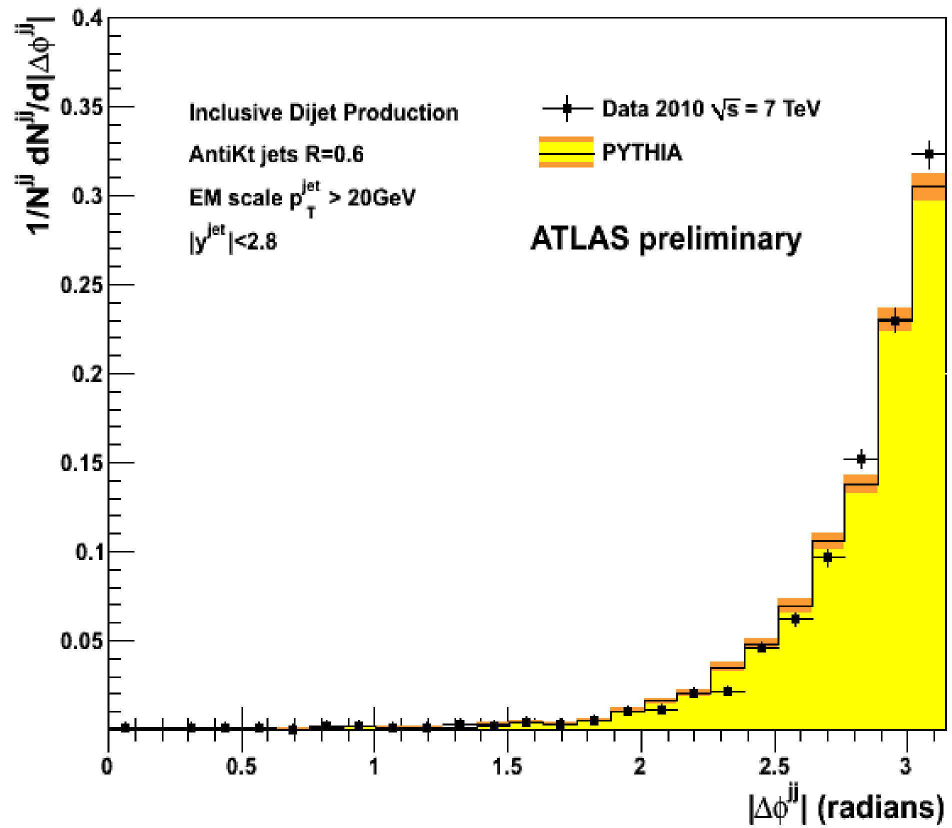
Comparison MC-Data at 900GeV shows
A slightly larger number of towers in the data.
-> noise description in MC.

Jet Algorithm: Anti-Kt, R=0.6

- ATLAS uses the infrared and collinear safe **Anti-Kt**, inclusive, E-recombination scheme, **R=0.4**, **0.6** as main algorithm for jet reconstruction. R=0.4 is required for top, in order to resolve the jets.

- Bottom plots: data/MC for pt, $|\Delta\Phi|$ distributions at the EM scale for di-jet event candidates at 7 TeV.
  - Jet P_T (EM scale) > 20 GeV, $|\eta|<2.8$.

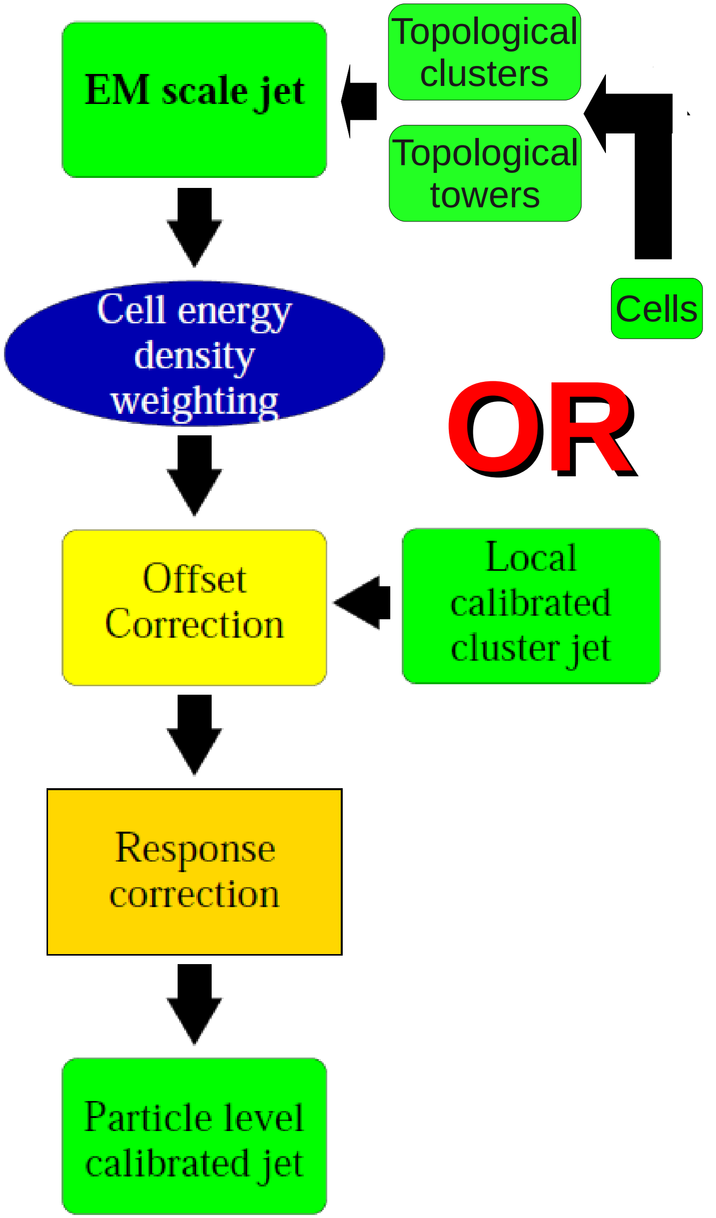




Jet Calibration Flow

ATLAS has a complex calorimeter system and thus developed a factorized multi-step approach for the jet calibration, flexible enough to understand the different corrections individually.

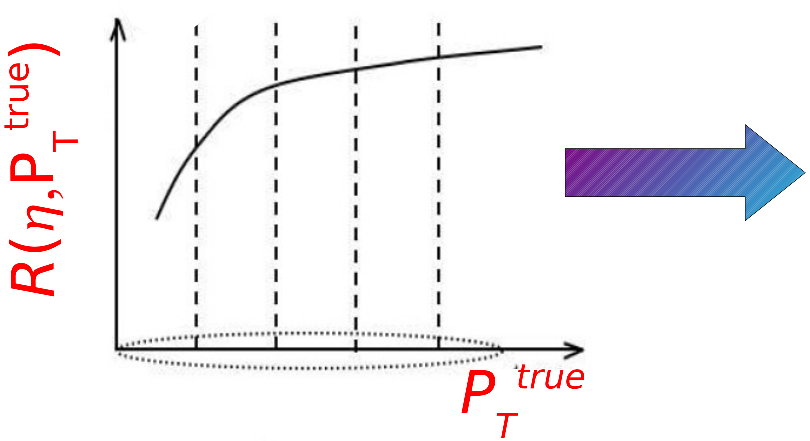
- **EM scale jets:**
  - jets are built from cluster or towers at the EM scale.
- **Offset correction**:
  - subtract the jet energy not originating from the hard scatter process (pile-up).
- **Response correction**:
  - relative η inter-calibration of jet energy response.
  - correction of the absolute energy scale back to particle level in the central barrel
  - ☞ see next slides.
- **Additional corrections**:
  - jet vertex fraction, track-based response
  - correction for configurations with close jet
  - flavor dependent correction (b, light, gluor

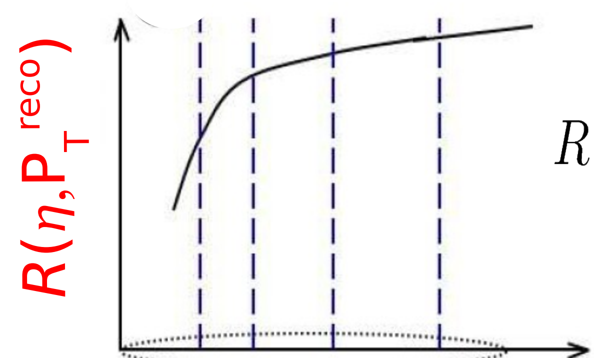


Jet Calibration Schemes: Numerical Inversion

ATLAS has developed several calibration schemes with different levels of complexity and sensitivity to systematic effects.

- **EM +JES**: simple P_T, $|\eta|$ dependent correction extracted from MC for P_T>20GeV and $|\eta|$<2.8.
  - Corrections are derived from matched true jets to MC reconstructed jets at EM scale to derive the response function $R(\eta,P_T^{reco})$ used to estimate the calibrated jet P_T.





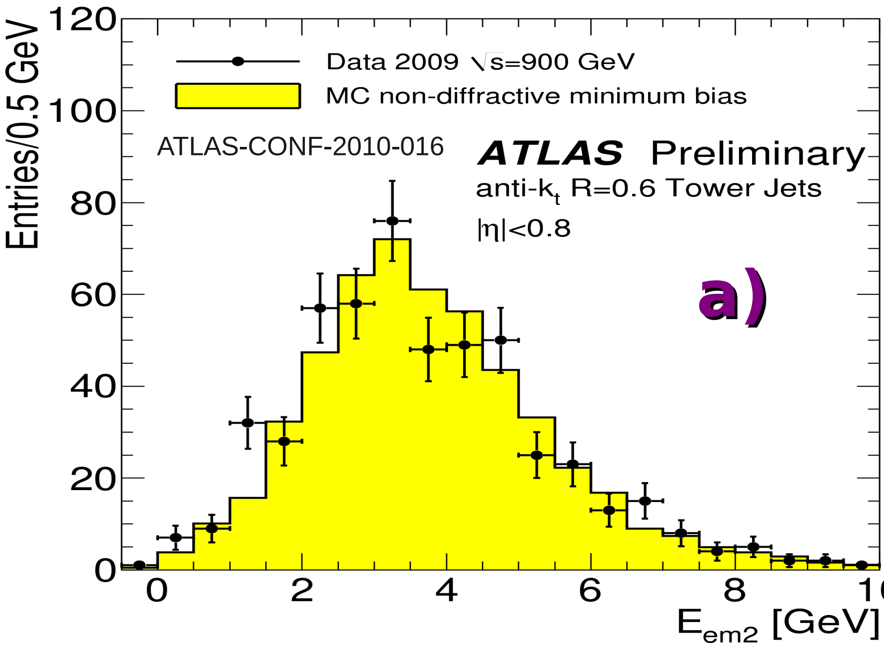
$$P_t^{reco} = R(\eta,P_T^{true}).P_T^{true}$$

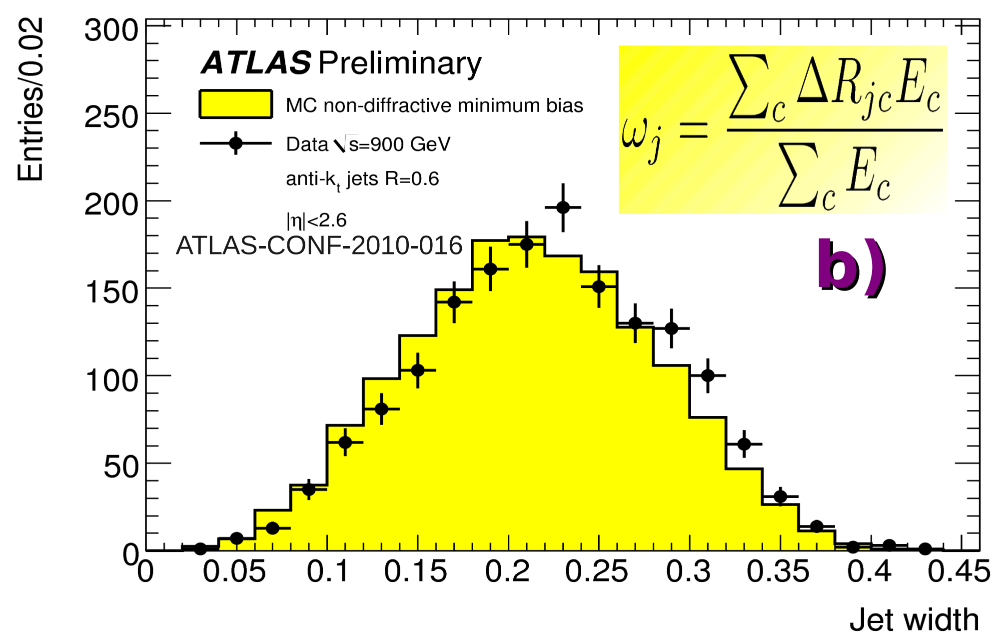
$$R(\eta, P_T) = \sum_{n=0,..,4} \frac{a_n(\eta)}{log(P_T))^n}$$

- No results with data will be shown in this presentation

Jet Calibration Schemes: Global Sequential

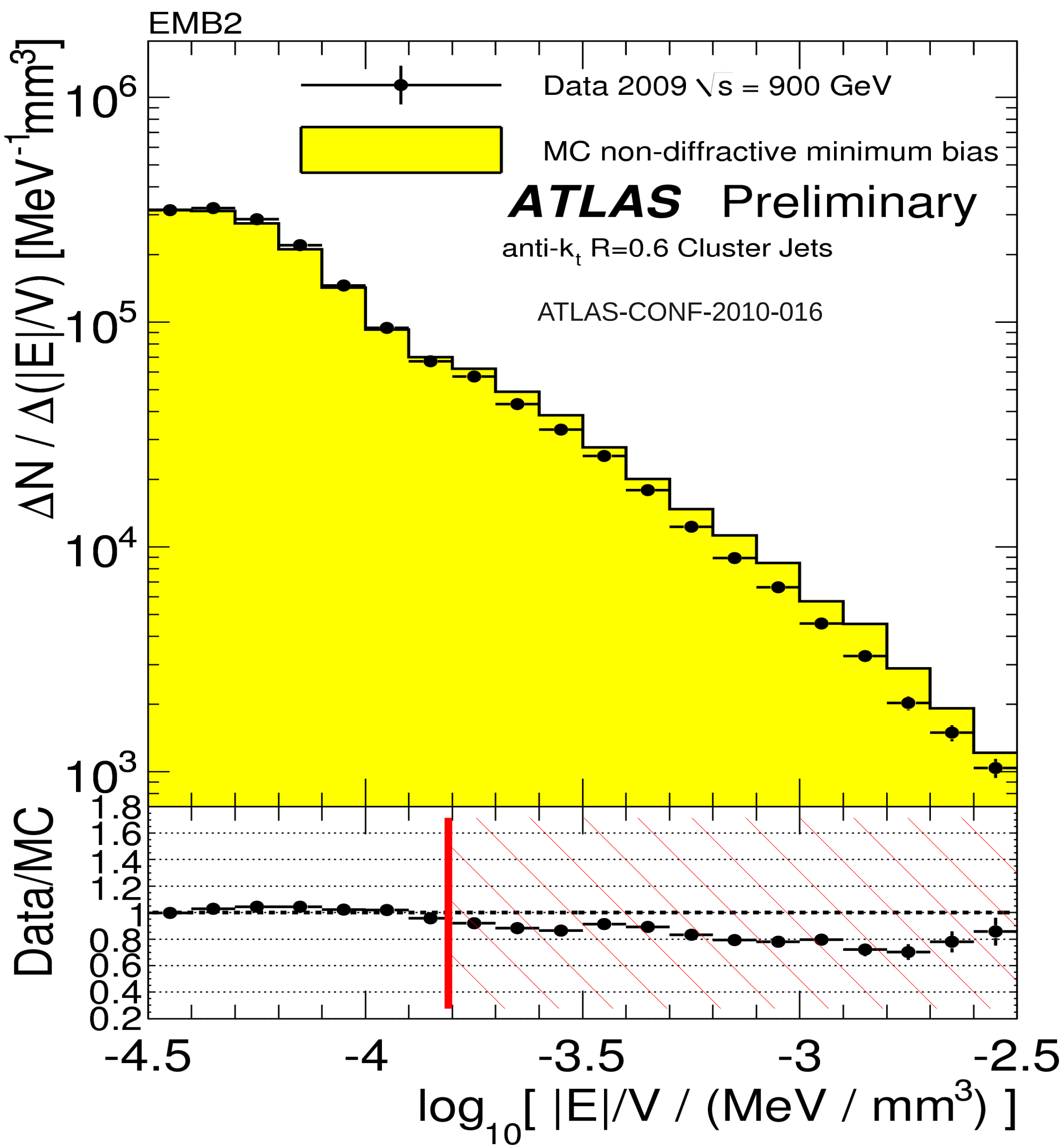
- **G**lobal **S**equential calibration scheme:
  - starts from jet response calibrated with **EM+JES**
  - uses the longitudinal and transverse properties of the jet structure to reduce response fluctuations.
  - Plots from the 900 GeV collision data:
    - **a)**: energy deposited in the second layer of the endcap of the EM calorimeter (reasonable agreement)
    - **b)**: weighted average distance of the jet constituents to the jet direction: wider jets in the data.





Jet Calibration Schemes: Global Cell Weighting

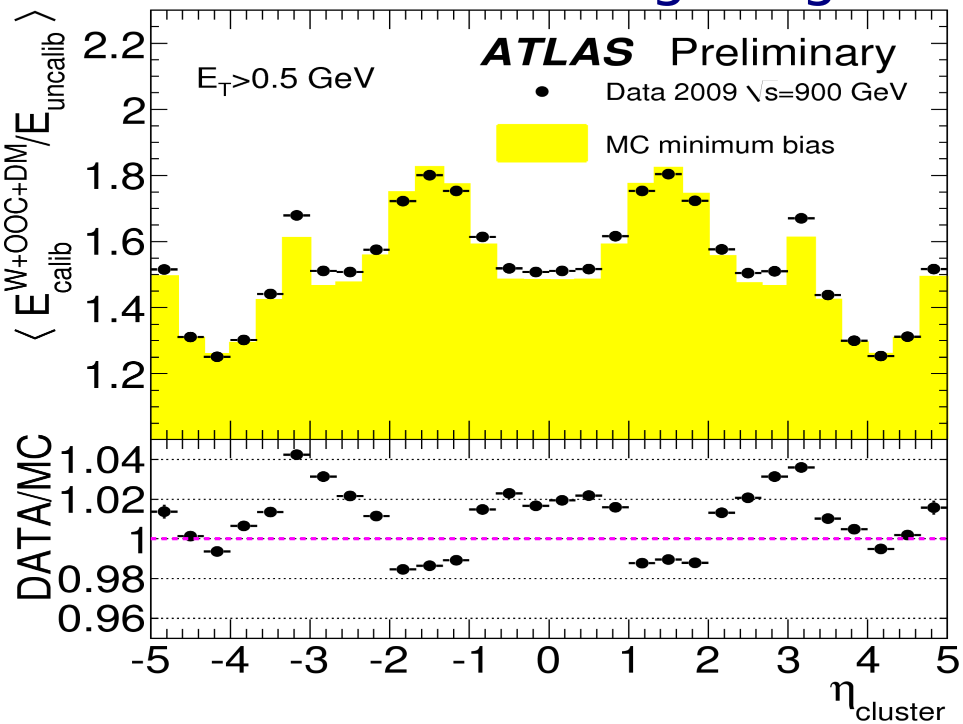
- **G**lobal **C**ell energy density **W**eighting:

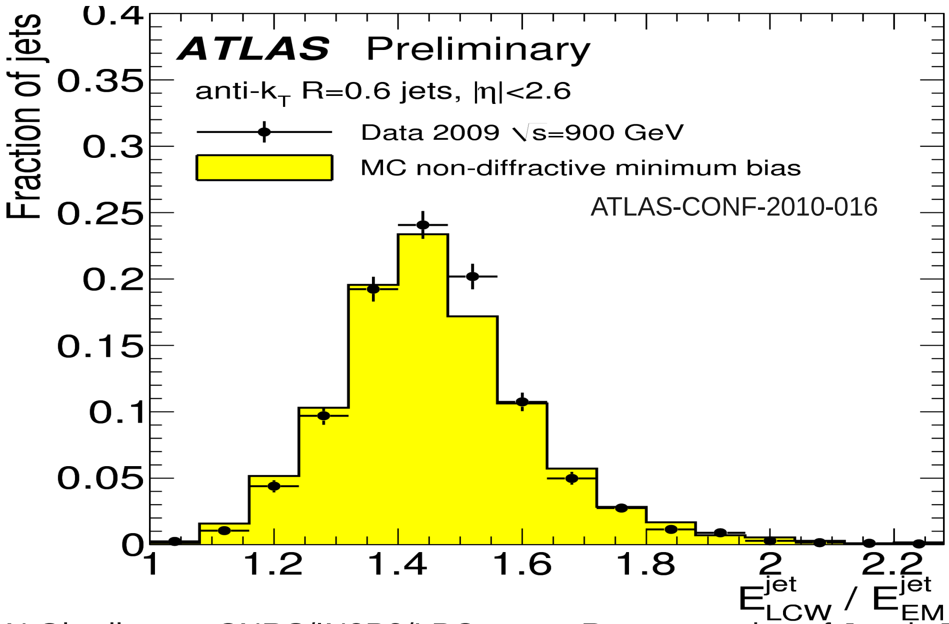


- starts from jet response at EM scale.
- apply a multiplicative correction factor to the calorimeter cells contained in the jet as a function of the cell location and energy density.
- Plot: energy density in EM barrel, second layer, shows a good agreement, expect for large energy densities (> 159eV/mm^3), for which MC overestimates data.

Jet Calibration Schemes: LCW

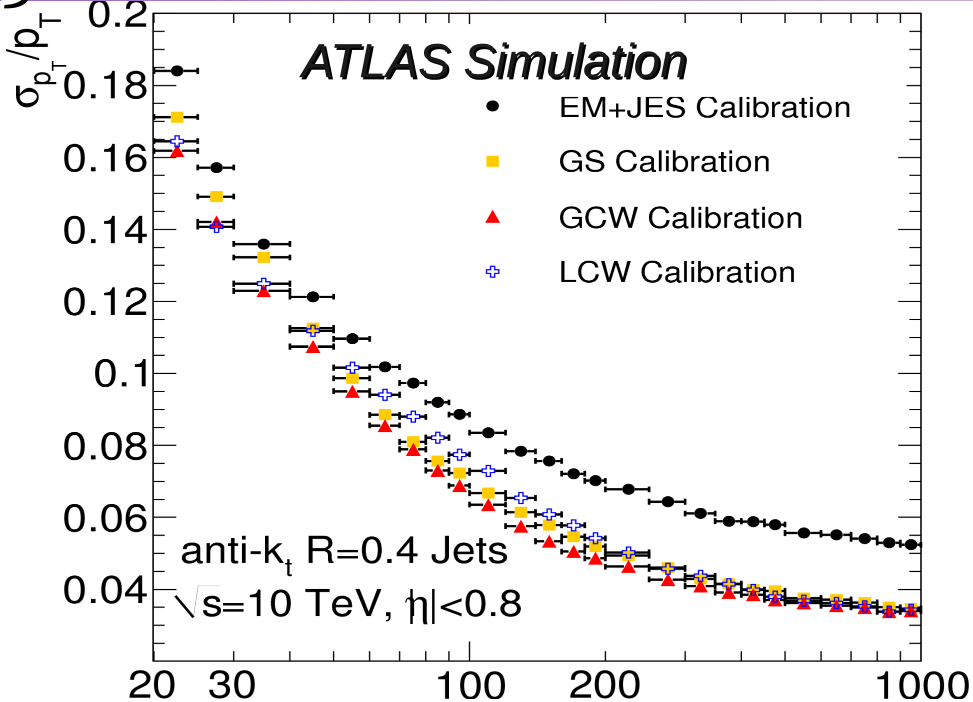
- **L**ocal **C**luster **W**eighting calibration scheme:

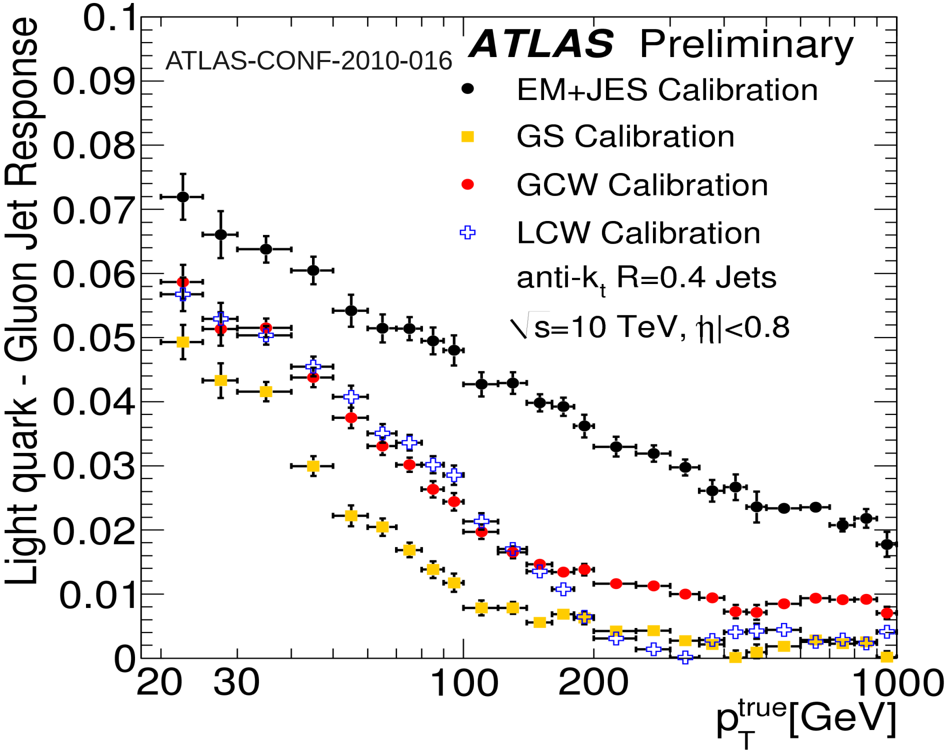




- uses the properties of the topological clusters to calibrate them individually to the hadron level in several steps:
  - cluster classification(EM, Had) according to their topology.
  - energy density based correction for cells in the Cluster (**W**).
  - out of cluster corrections (**OOC**) to account for cells not picked-up by the clustering algorithm.
  - dead material correction.
- Data/MC comparison at 900 GeV Agree within 4%, which translates into jet distributions.

Jet Calibration Schemes Comparison





- Jet transverse momentum resolution for the different jet calibration schemes at 10 TeV Monte-Carlo with respect to the true jet P_T:

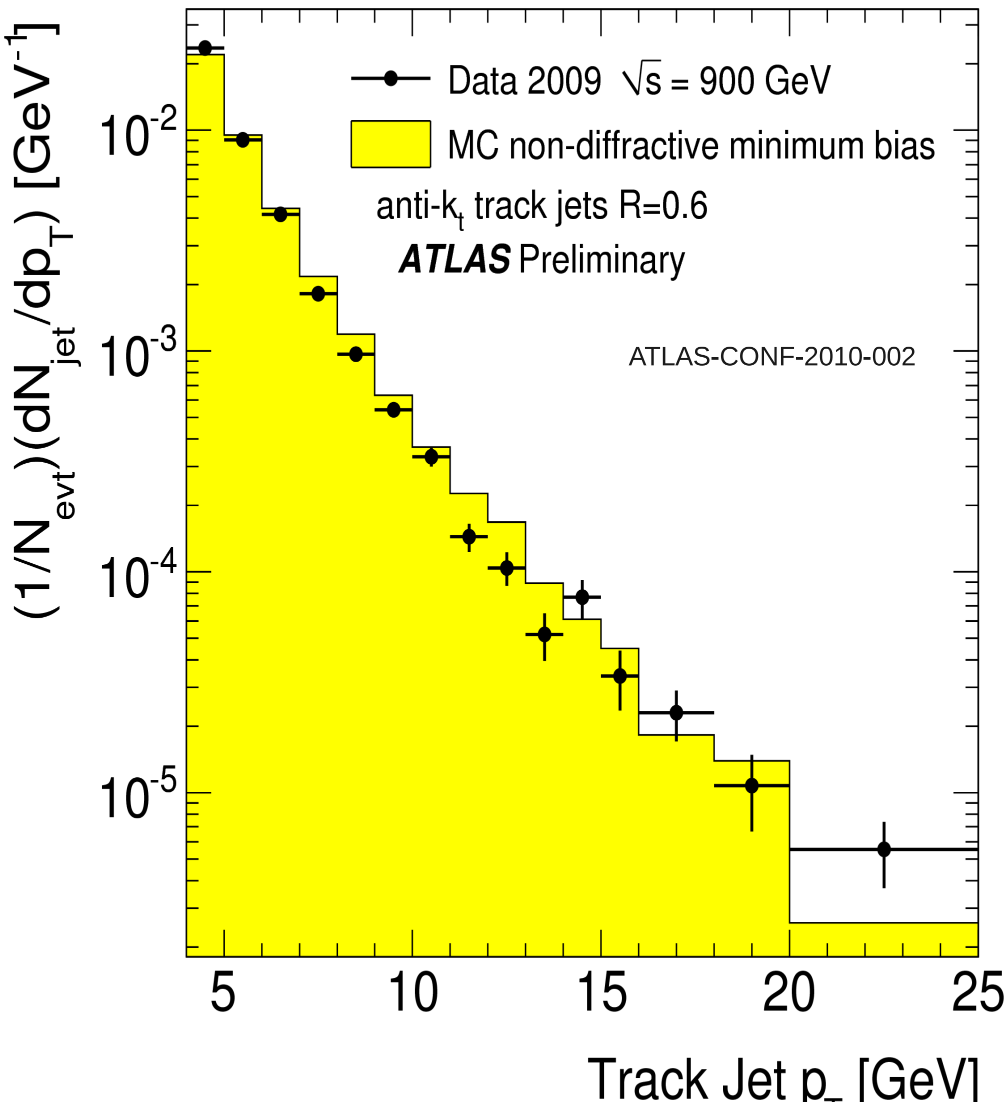
GS, **GCW** and **LCW** show similar performances whereas **EM+JES** has a reduced jet resolution at high P_T.

- Difference in the response of light quark and gluon jets:
  - largest in **EM+JES** calibration. for EM+JES, corrections are sample dependent.
  - Response below 2% for **GS**, **GCW** and **LCW**.

Jets from Tracks

- ATLAS makes use of the robust inner detector system to reconstruct jets from track particles.

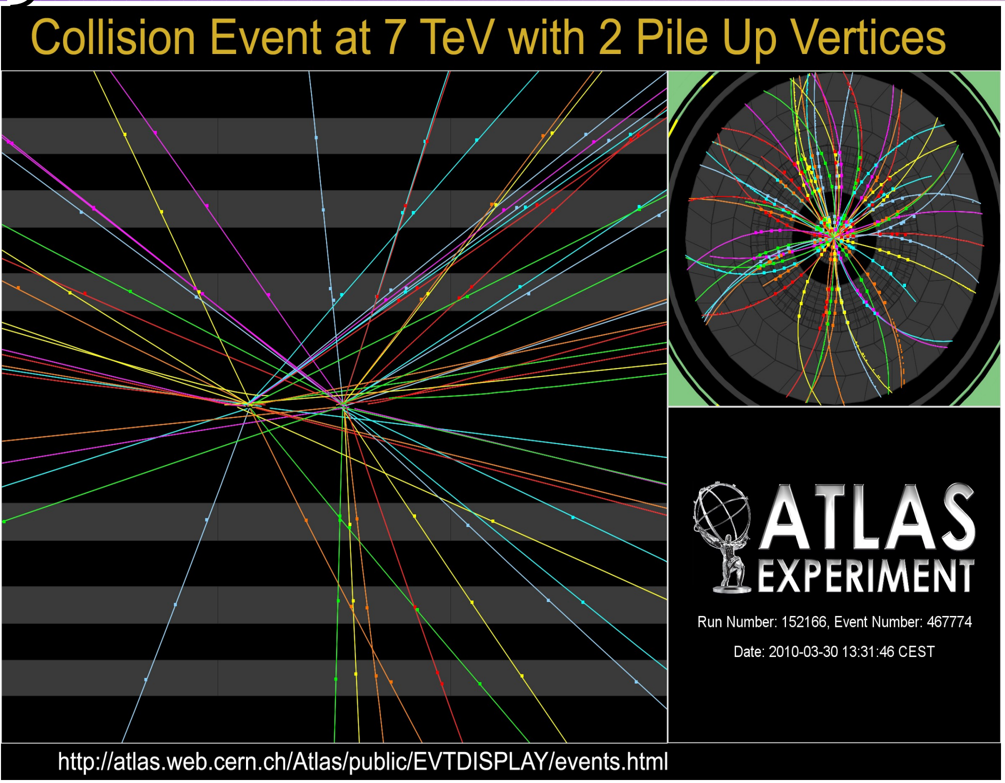
Track jets are complementary to the calorimeter jets, since:

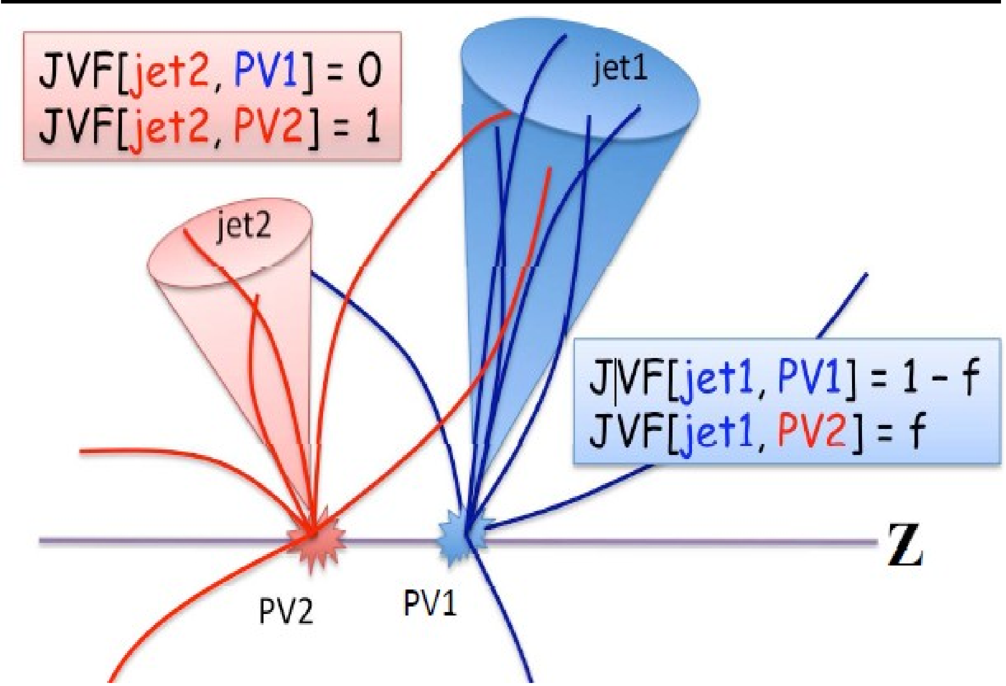


- allow to reconstruct jets at low momentum,
- introduce independent detector-related systematics
- useful to tackle pile-up.
- Calo. jet reconstruction efficiency can be based on the matching to track-jets.
- Plot: Pt distribution for jets reconstructed from tracks. Spectrum seems softer in data

☞ **work in progress for the 7TeV data.**

Jet Vertex Fraction Discriminant





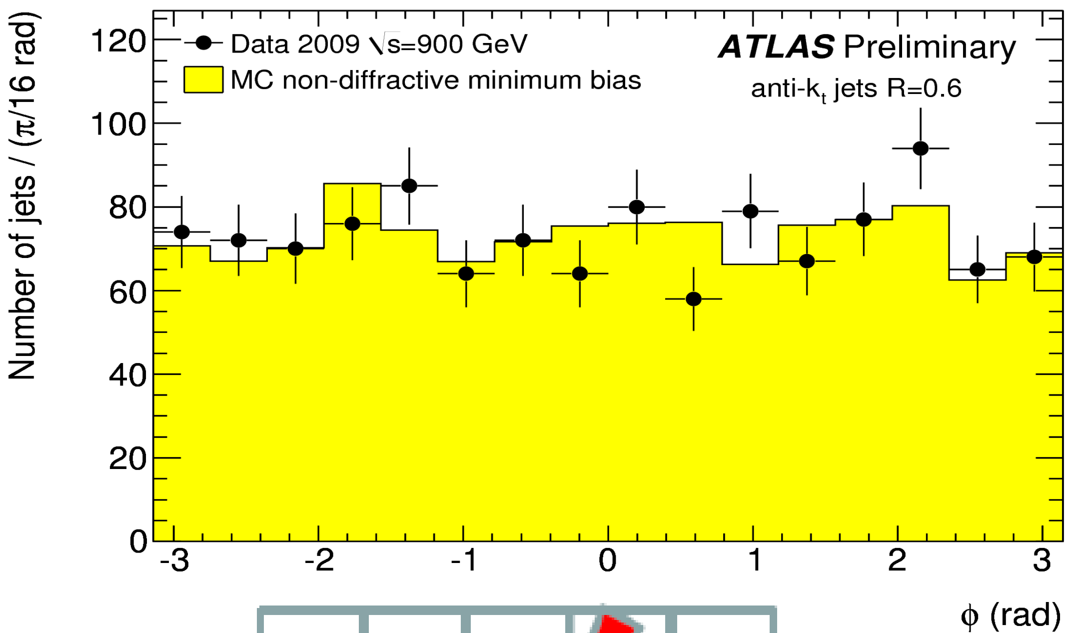
Multiple-Interaction will induce:

- higher charged particle multiplicity,
- the presence of several primary vertices (~2.3 @10^{11}p/b, β*=5m)
- event display of a reconstructed event with two primary vertices.
- Ideally associate each jet to Its corresponding primary Vertex:

$$JVF(\text{jet}_i, \text{vtx}_j) = \frac{\sum_k p_T(\text{trk}_k^{\text{jet}_i}, \text{vtx}_j)}{\sum_n \sum_l p_T(\text{trk}_l^{\text{jet}_i}, \text{vtx}_n)}$$

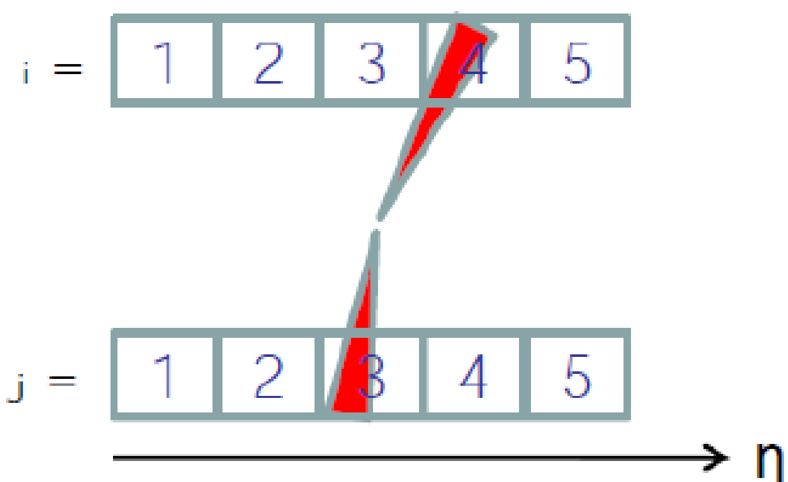
- cut on JVF to extract the Jets from the same collision.

Di-jet events with a large cross-section are useful for inter-calibration and jet resolution determination:



- inter-calibration in Φ v.s. different jet P_T>thresholds allows to check the sensitivity to the jet energy scale.

  ☞ **work in progress**



$$B_{ij} = 2 \times \frac{P_{T,jeti} - P_{T,jetj}}{P_{T,jeti} + P_{T,jetj}}$$

- inter-calibration in η using the balance between the two jets:

  take one well understood central η region and transport scale to other η regions.

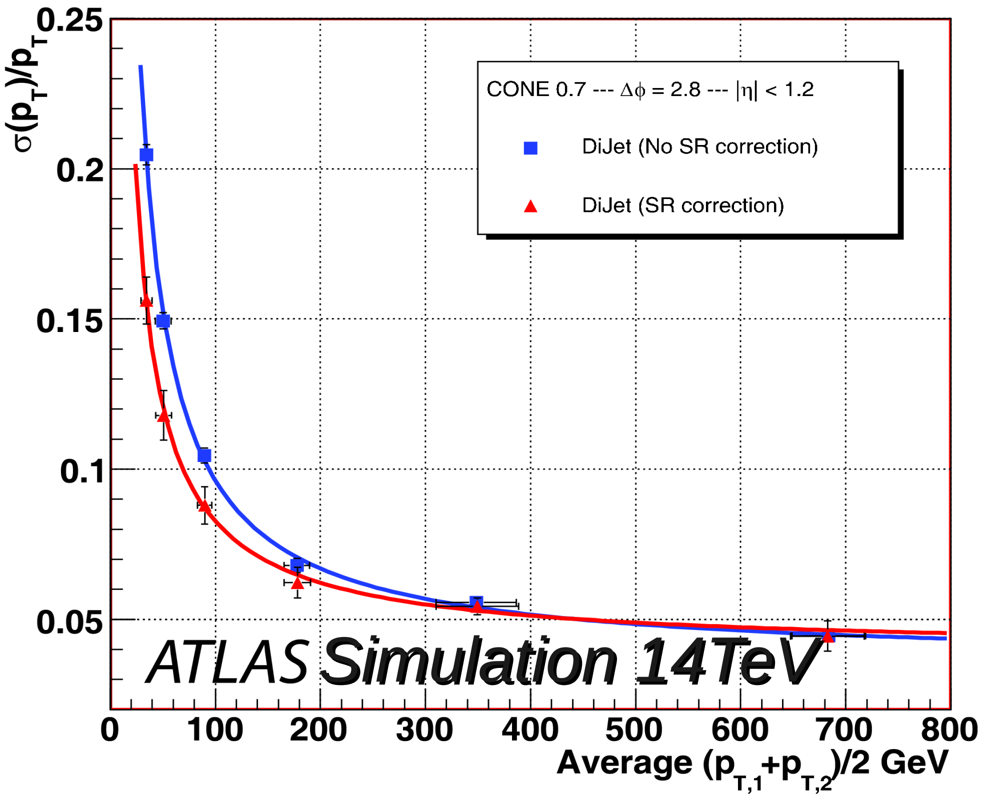
  ☞ **work in progress**

Strategy for Jet Calibration: Jet Resolution

- di-jet balance asymmetry based technique with the correction for an additional soft radiation (SR):

$$A = \frac{P_{T,1} - P_{T,2}}{P_{T,1} + P_{T,2}} \qquad \frac{\sigma_{P_T}}{P_T} = \sqrt{2}\sigma_A$$

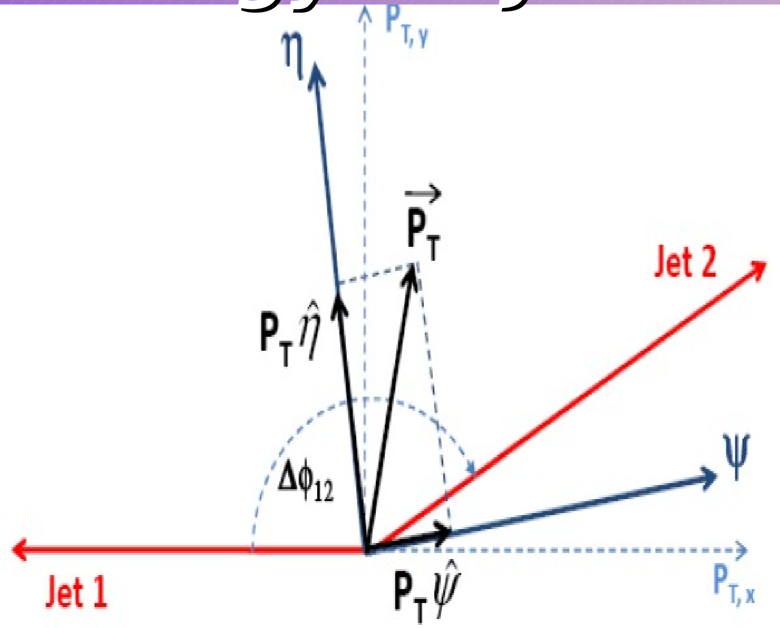
A is measured as a function of different $P_{T,3}$ thresholds and the obtained P_T resolution is then extrapolated to $P_{T,3}$ =0.



The multiplicative soft correction factor is applied to the raw P_T resolution.

Illustrative plot for 14TeV showing the improvement in the resolution While including the SR.

☞ **work in progress**



- di-jet bi-sector technique based on the definition of an imbalance vector

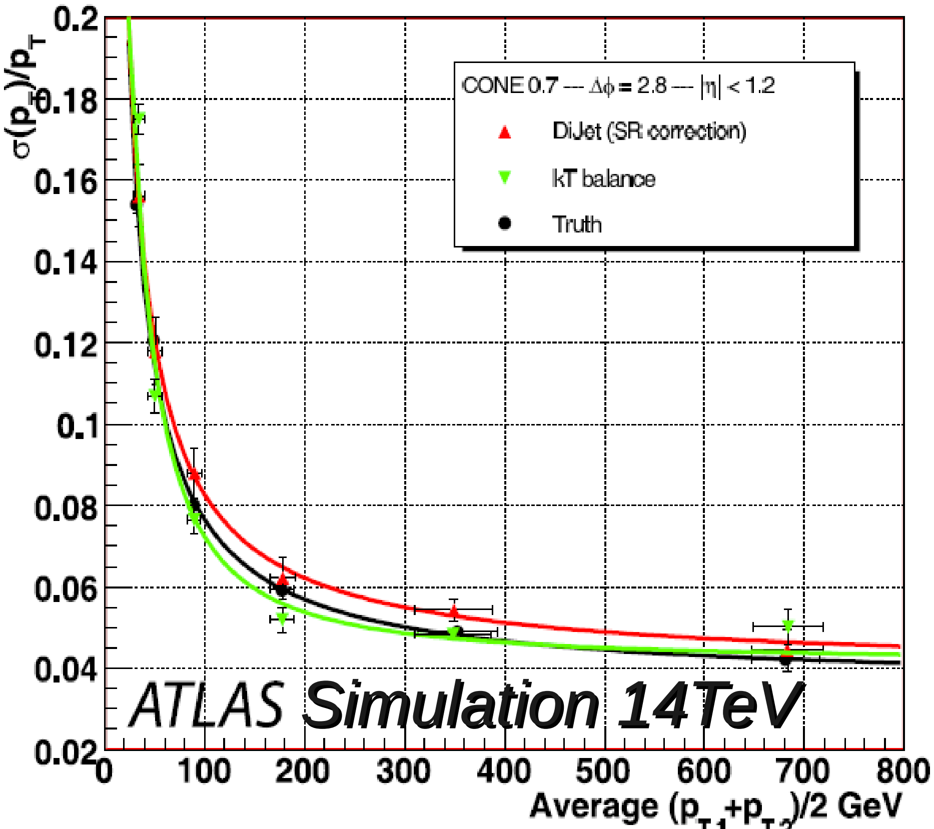
$$\vec{P}_T = \vec{P}_{T,1} + \vec{P}_{T,2}$$

η = direction that bisects ϕ_{12}

ψ = orthogonal direction to η.

Resolution:

$$\frac{\sigma(P_T)}{\langle P_T \rangle} = \frac{\sqrt{\sigma_\psi^{2\ \mathrm{calo}} - \sigma_\eta^{2\ \mathrm{calo}}}}{\sqrt{2}\,\langle P_T \rangle\,|\cos\Delta\phi_{12}|}$$



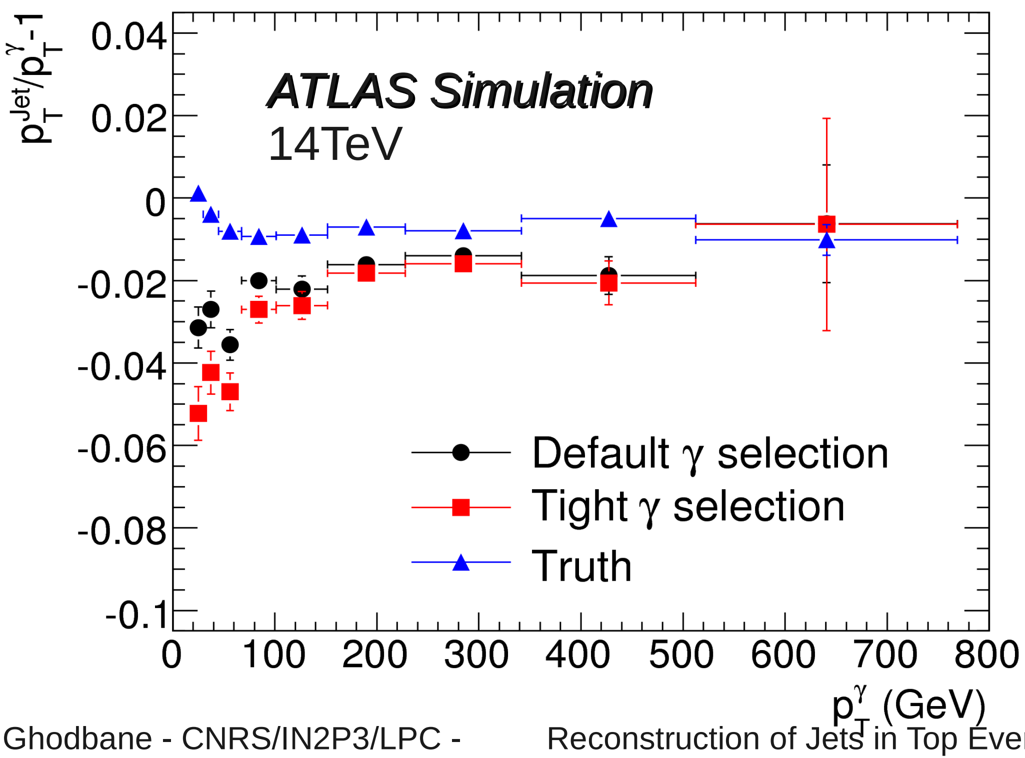
Plot from 14 TeV comparing the two methods:

☞ **work in progress**

Strategy for Jet Calibration: in-situ Approaches

Several in-situ approaches, currently under investigation, make use of the P_T balance between a particle at the EM scale against the leading jet:

- **γ + jets**:
  - balance the leading well reconstructed photon against the leading jet.
  - large statistics, but QCD background.

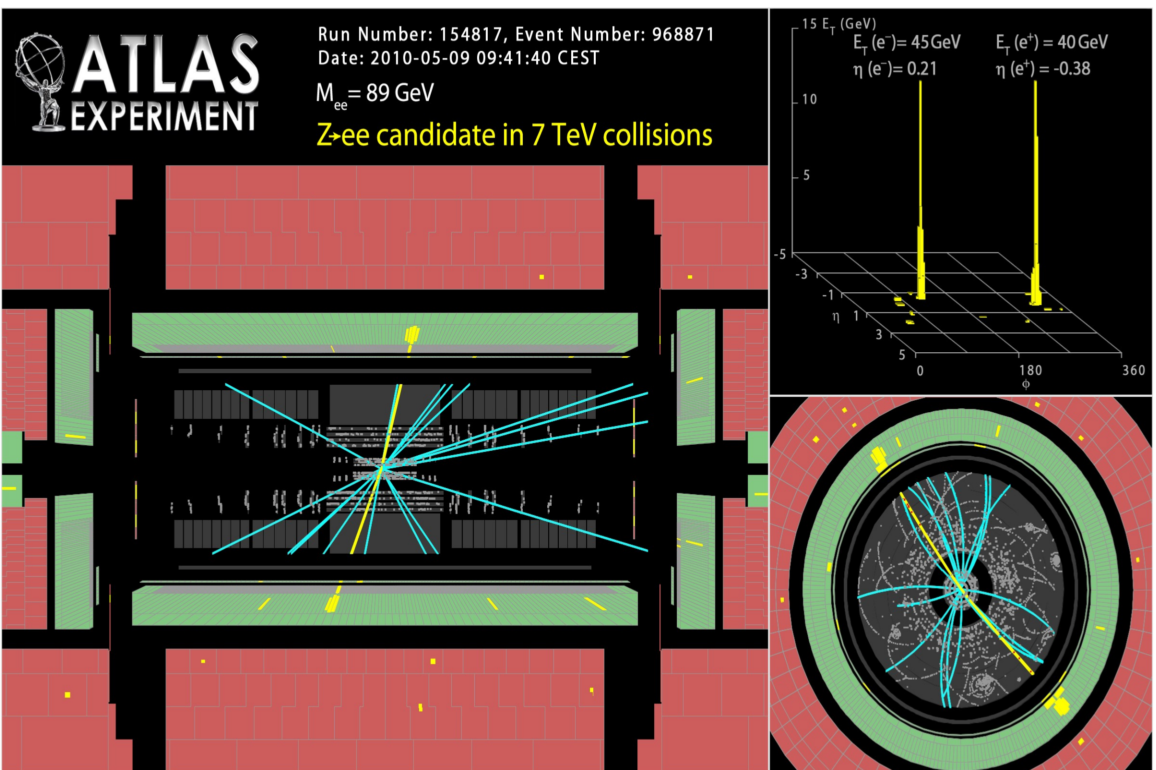


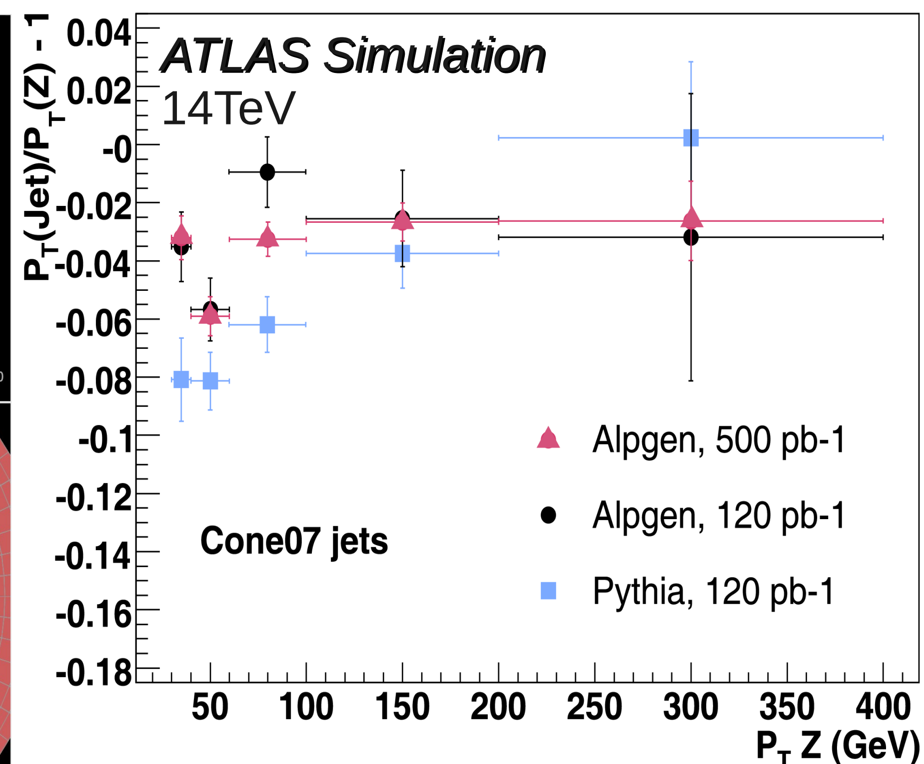
- calibration to 5% above P_T> 20GeV seems to be achievable with 100/pb

☞ **work in progress with the 7TeV data**

Several in-situ approaches, currently under investigation, make use of the P_T balance between a particle at the EM scale against the leading jet:

- **$Z^0(\rightarrow e^+e^-, \mu^+\mu^-)$ + jets**: clear identification, but low statistics.
- Plots: a **Z^0** candidate and balance method for a few hundred /pb (@ 14TeV...)



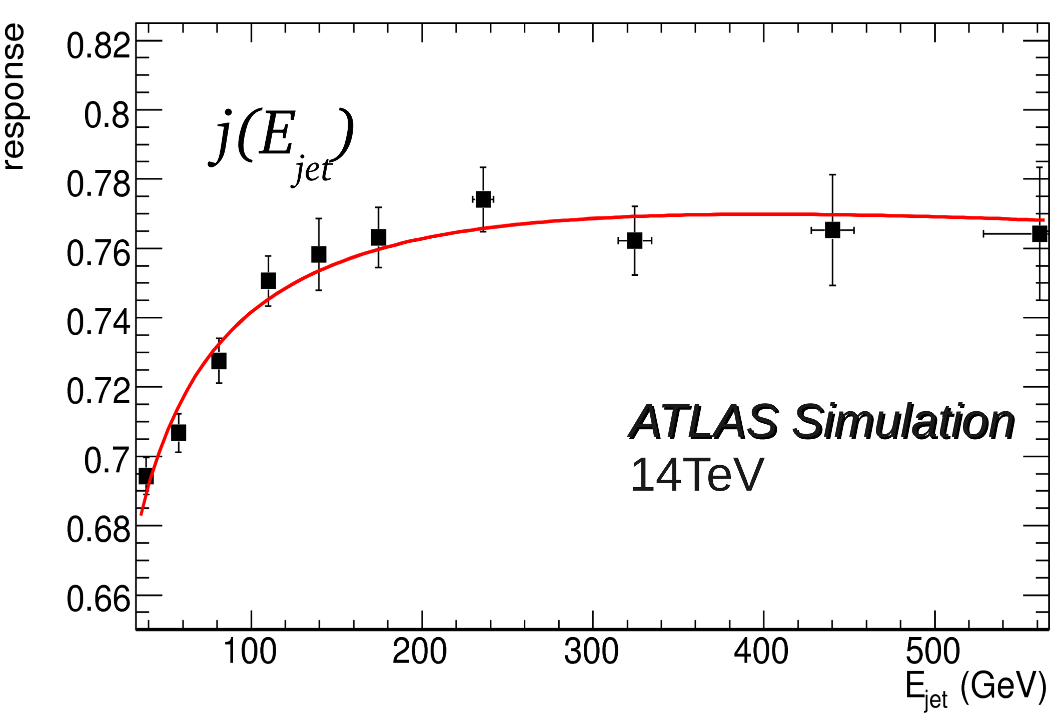


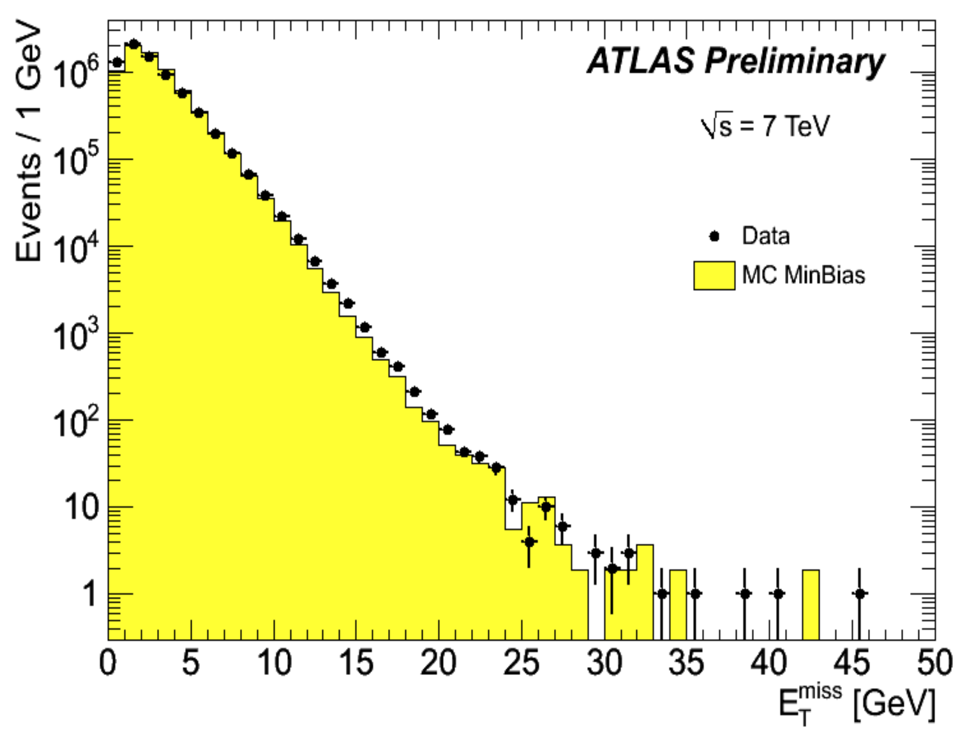
Strategy for Jet Calibration: in-situ Approaches

- Missing transverse energy Projection Fraction (MPF) balances the photon against the entire hadronic recoil to extract the jet response $j(E_{jet})$:

$$e\overrightarrow{E_T^{\gamma}} + j(E_{jet})\overrightarrow{E_T^{jet}} = -\overrightarrow{\not{E}_T} \quad \Rightarrow \quad j(E_{jet}) = 1 + \frac{\overrightarrow{E_T^{\gamma}} \cdot \overrightarrow{\not{E}_T}}{(E_T^{\gamma})^2}$$

- Advantage: less dependent on the jet algorithm.
- Plots: **a)** MPF based response in bins of jet energy.
  b) Missing Et data /MC comparison at 7 TeV.



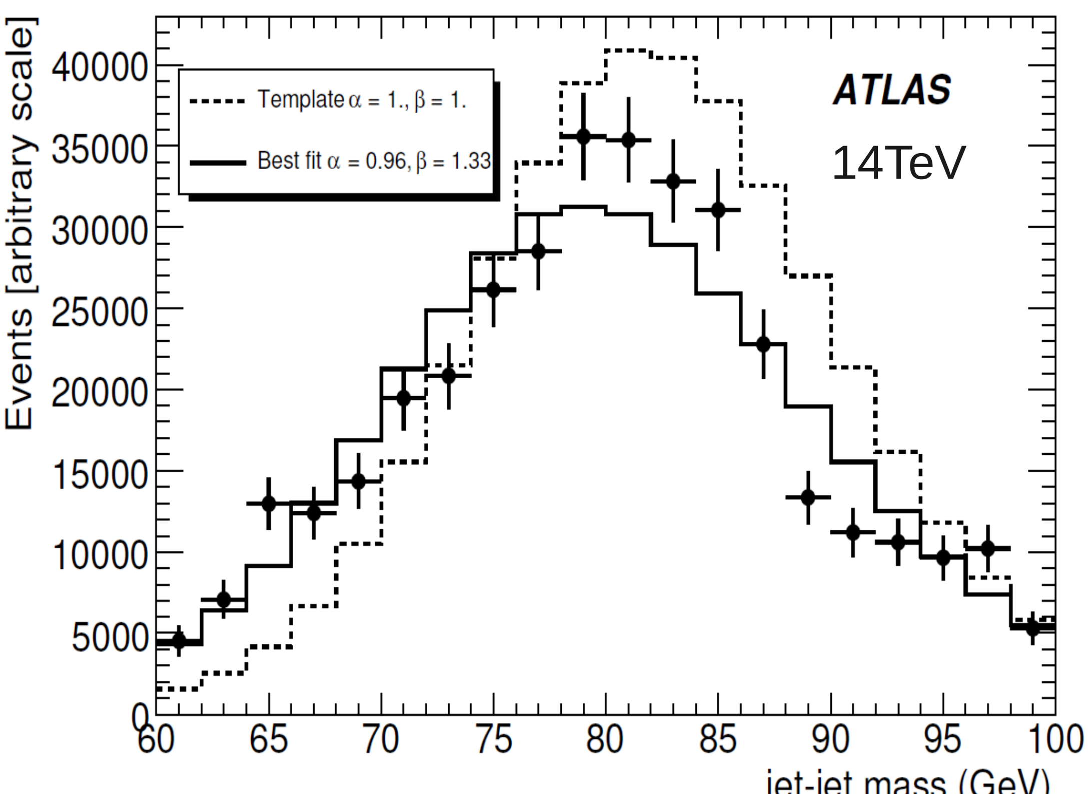


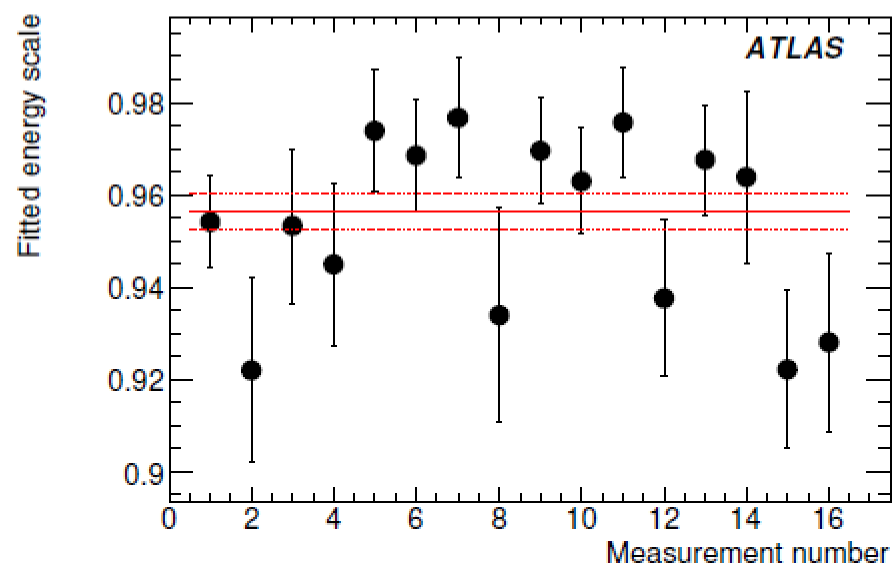
Strategy for Jet Calibration: in-situ Approaches

- **W→ j j** from top semi-leptonic events will be used for the light jet energy scale extraction: what we could do.

- The scale and the resolution are extracted by fitting the jet-jet invariant mass with template distributions with various energy scale α and resolution β for the jets.

- Stability of the method within 2% for 50/pb lumi samples.





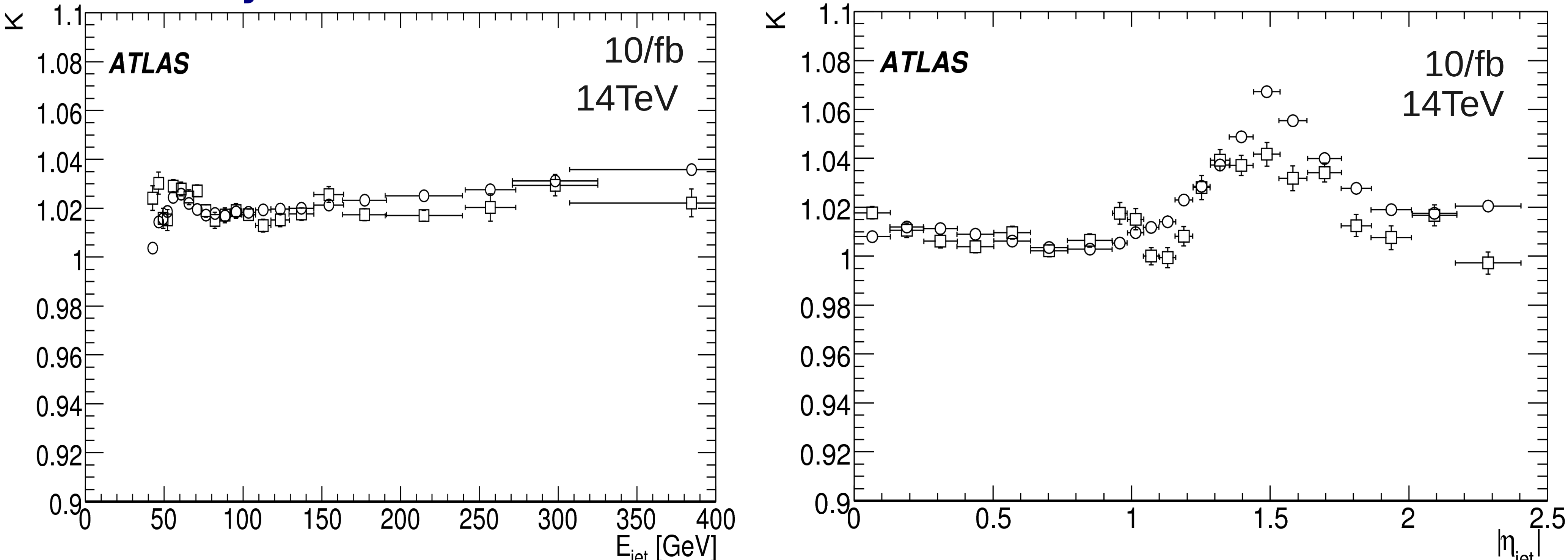
Strategy for Jet Calibration: in-situ Approaches

- **W→ j j** from top semi-leptonic events:

light jets are calibrated in bins of E_{jet} and pseudo-rapidity iteratively by constraining the di-jet mass to the PDG constraint:

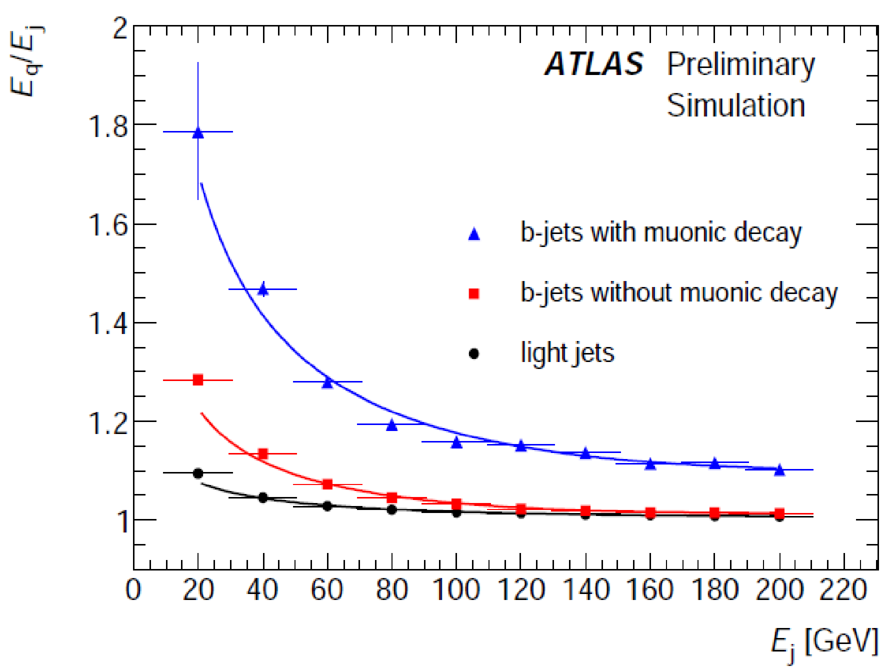
$$K = M_W^{PDG} / M_{jj,fit}$$

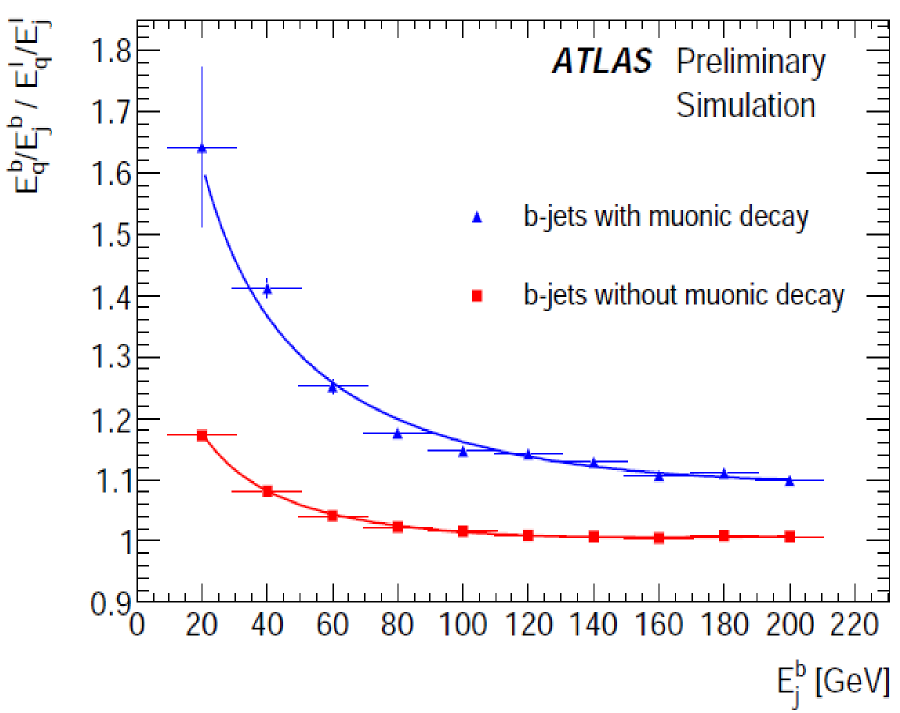
- Plots: calibration factor with respect to the jet energy and pseudo rapidity. This approach will requires a large luminosity.



Strategy for Jet Calibration: b-jet case

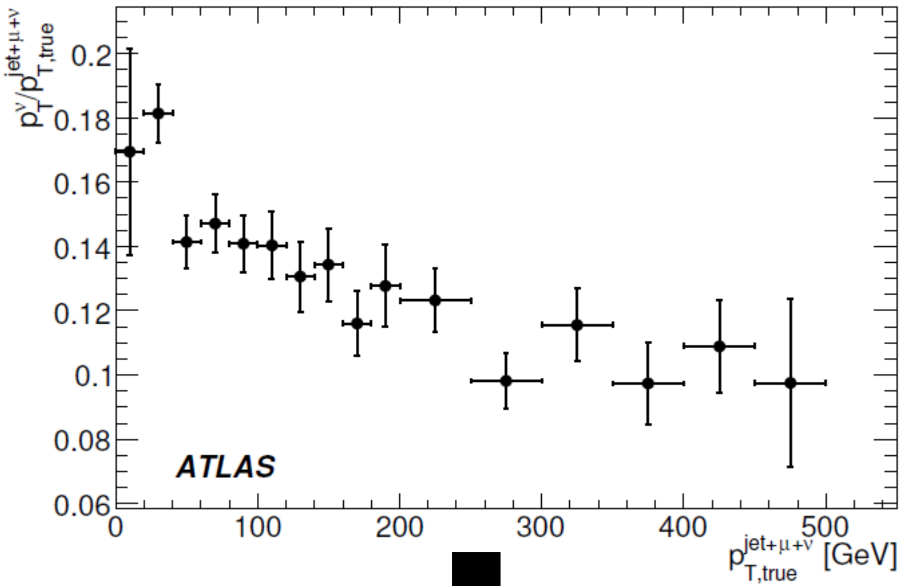
- b-jet identification with b-tagging (no slides shown here): see performance report by I.Van Vulpen.
- b-Jet response correction:
  - use the jet energy scale extracted from light jets
  - apply on top of it a correction factor MC dependent to correct for the remaining difference between the light and b-jet responses.
  - rely on the balance of Z(->leptons) + b events to cross check the method.





Strategy for Jet Calibration: b-jet case

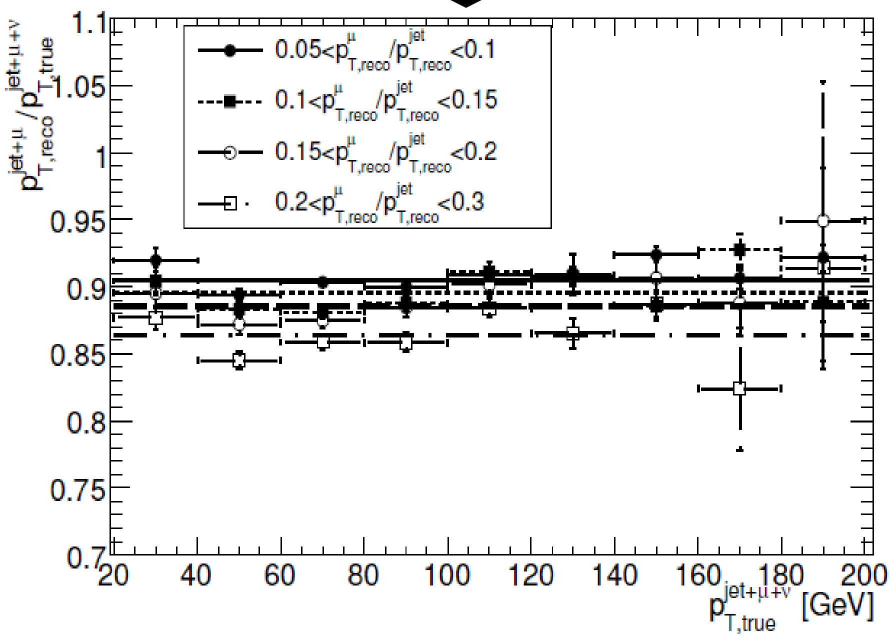
- b-Jet response correction for b-jets in case of muonic decay $(\sim 20\%)$ to account for the unmeasured neutrino:

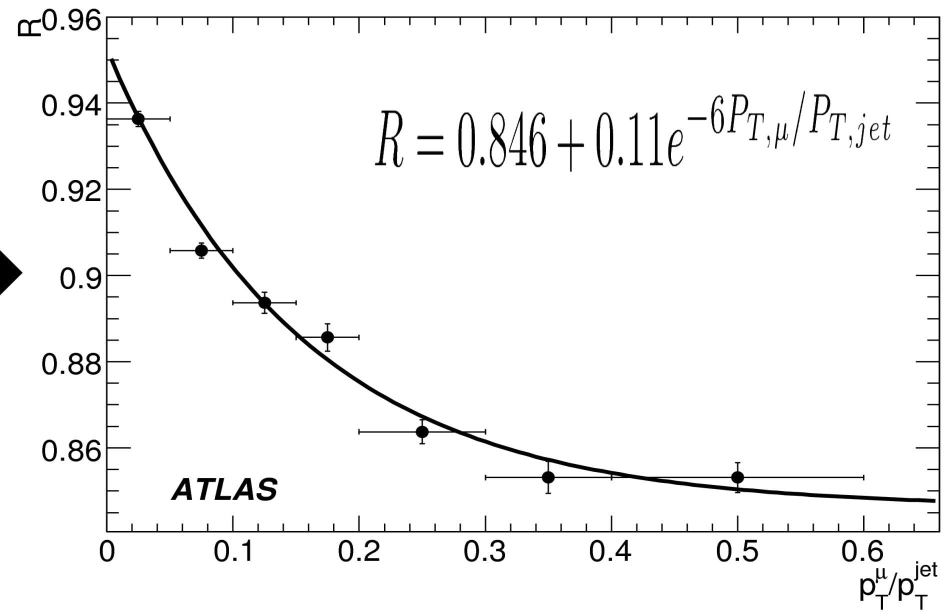


- Typically the response is lower by about 15% for a b-jet reconstructed with a P_T of 40GeV.

- Strategy entirely MC dependent
  Parametrise the response:

$$R = P_{T,jet+\mu} / P_{T,jet+\mu+\nu}$$





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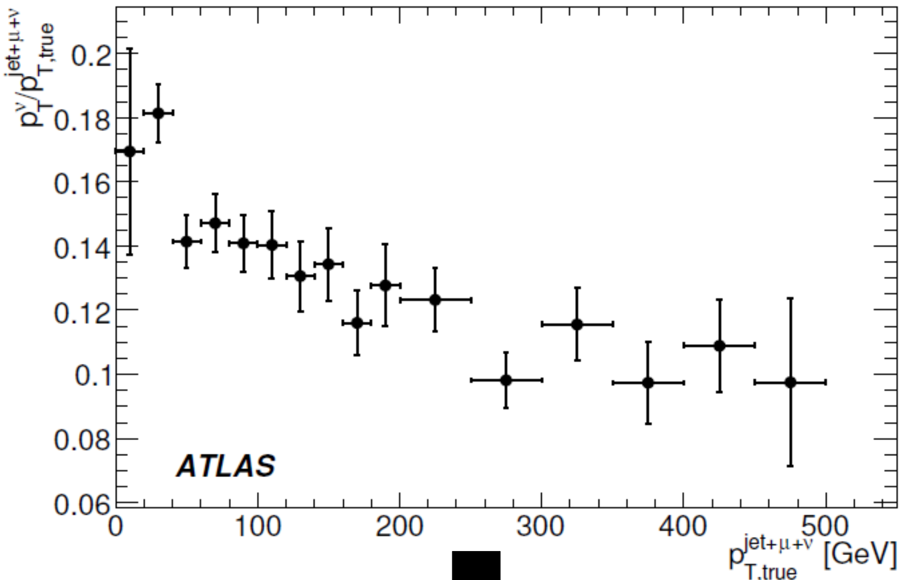

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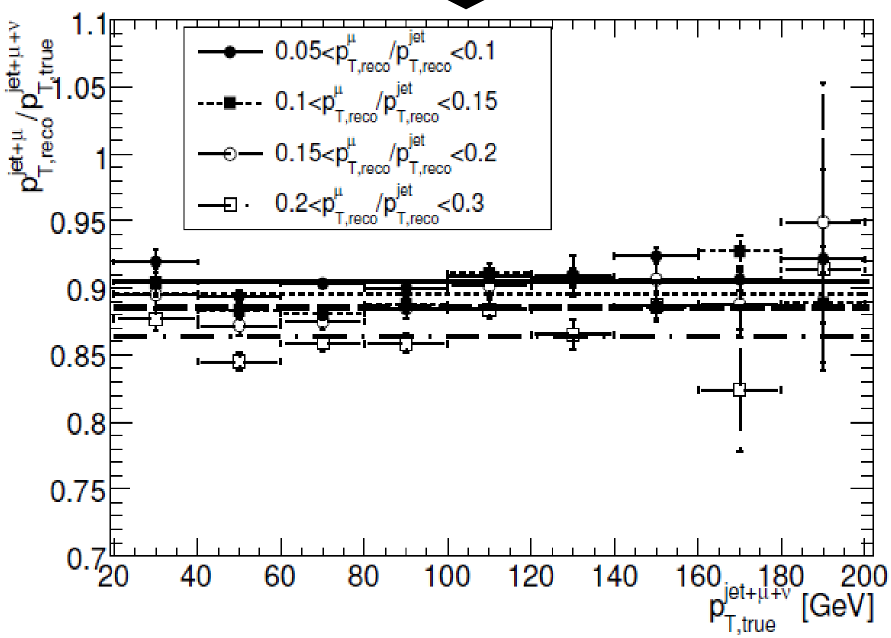

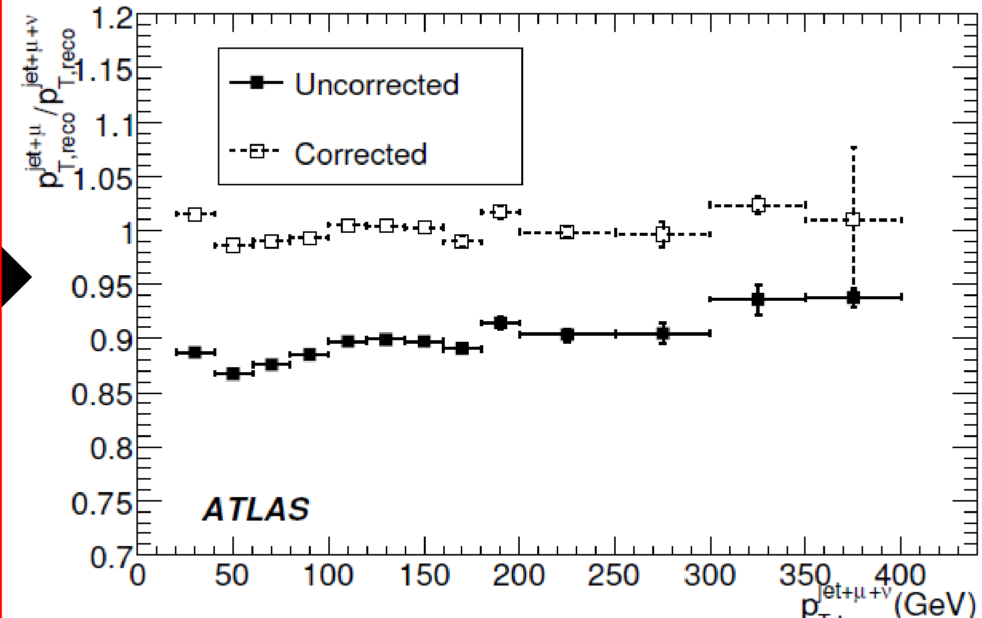

Conclusions

- The ATLAS detector is collecting data at high efficiency at 7 TeV center-of-mass energy, thanks to the impressive LHC accelerator division work!
- The Standard Model is being “rediscovered”. Step by step, W, Z and certainly soon top events are being produced.
- The early analysis shows that measured jet properties are well-reproduced by Monte Carlo detector simulation based on Geant4.
  We benefit from the extensive analysis from the past test-beams and cosmic based measurements.
- A set of cleaning variables have been defined for the jets selection and are being validated.
- Four different jet calibration schemes are under study and show good agreement between MC and data, which is somehow promising and for the top physics case.
- At this stage, it is too early to say something about the top case. Hopefully soon...