the ATLAS Experiment

ATLAS実験におけるジェット及び消失横運動量測定のパフォーマンス

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Jet and Missing ET at ATLAS

- Jets and MissET are copiously produced at hadron colliders
- We would like them to represent
  - Jet : quarks and gluons
  - MissET: non-interacting particles (neutrinos, SUSY LSP, ...)
- Most challenging physics objects to reliably measure
  - Theoretically not unique (jet)
  - Detector and environmental limitations

Aim:

How do we measure jets and MissET at ATLAS?

→ *Expected performance and validation with real data*

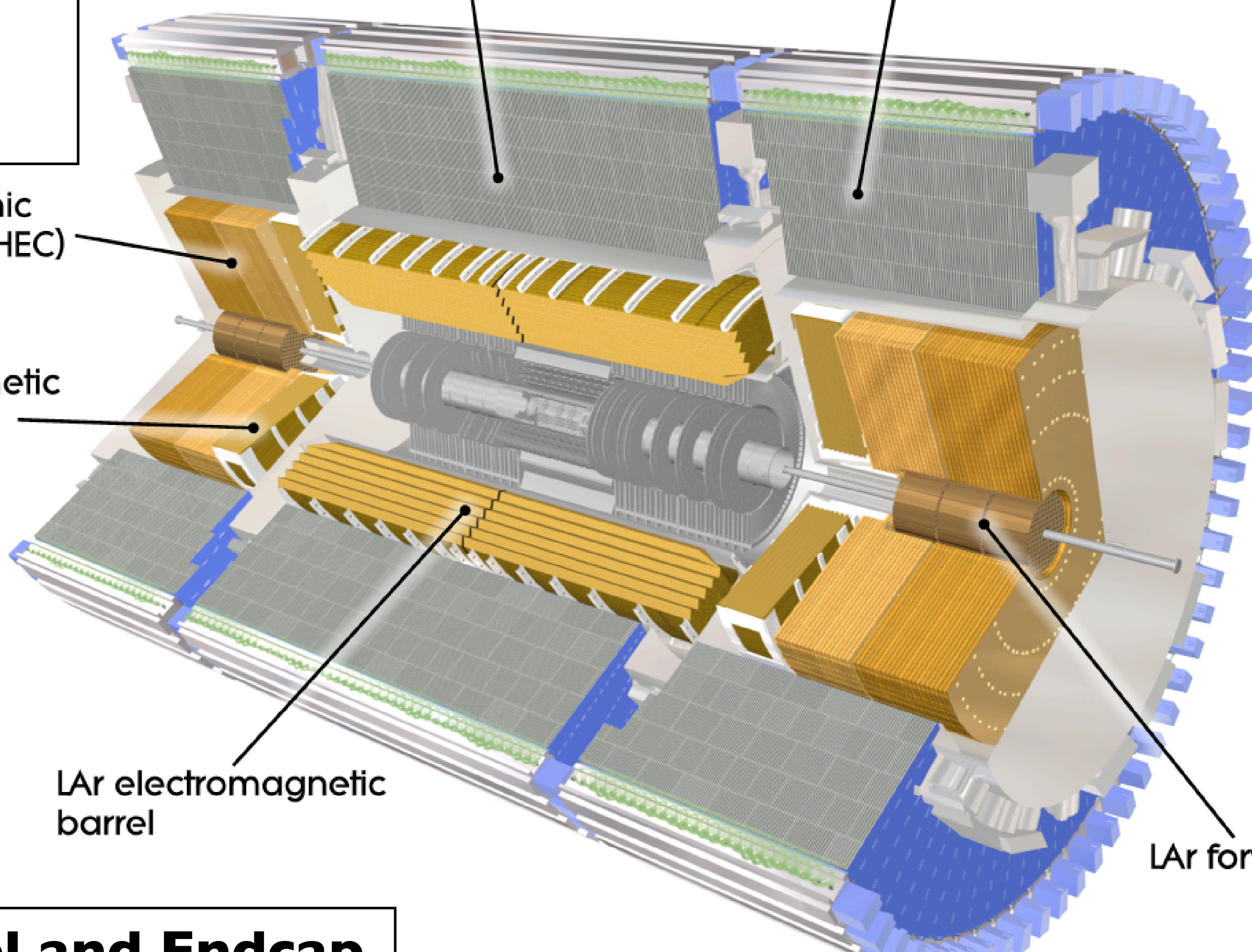
How do we calibrate jets in unprecedented regime?

- *Very high p_T jets*
- *Pile-up of real jets in physics event*

ATLAS Calorimeters

Hadronic Endcap

- Liquid Argon/Cu parallel plate structure
- $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ $(1.5<|\eta|<2.5)$
- $\Delta\eta \times \Delta\varphi = 0.2 \times 0.2$ $(2.5<|\eta|<3.2)$
- 4 samplings



Hadronic Barrel

- Scintillator/Fe in tiled readout
- $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
- 3 longitudinal samplings
- Coverage $|\eta|<1.7$

Electromagnetic Barrel and Endcap

- Liquid Argon/Pb accordion structure
- Highly granular readout (~170,000 channels)
- $0.0025 \leq \Delta\eta \leq 0.05$, $0.025 \leq \Delta\varphi \leq 0.1$
- 2-3 longitudinal samplings
- Coverage $|\eta|<3.2$, pre-sampler up to $|\eta|<1.8$

Forward

- Liquid Argon/Cu or W absorbers
- Non-projective geometry
- $\Delta\eta \times \Delta\varphi \approx 0.2 \times 0.2$ $(3.2<|\eta|<4.9)$
- 3 samplings

Jet in ATLAS

Input to Jet

Calorimeter Tower

- $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
- Sum of all cell signals (no cell cuts)

Calorimeter Cluster

- Topologically connected cells in 3-D
- Based on cell energy significance relative to noise

Jet Algorithm

Seeded cone

- Iterative cone finder starting from seeds
- Free parameters:
  - seed E_T threshold (typically 1 GeV)
  - cone size R (=0.4 or 0.7)

Kt algorithm

- Combines proto-jets if relative p_T is smaller than p_T of more energetic proto-jet
- No seeds needed

Calibration

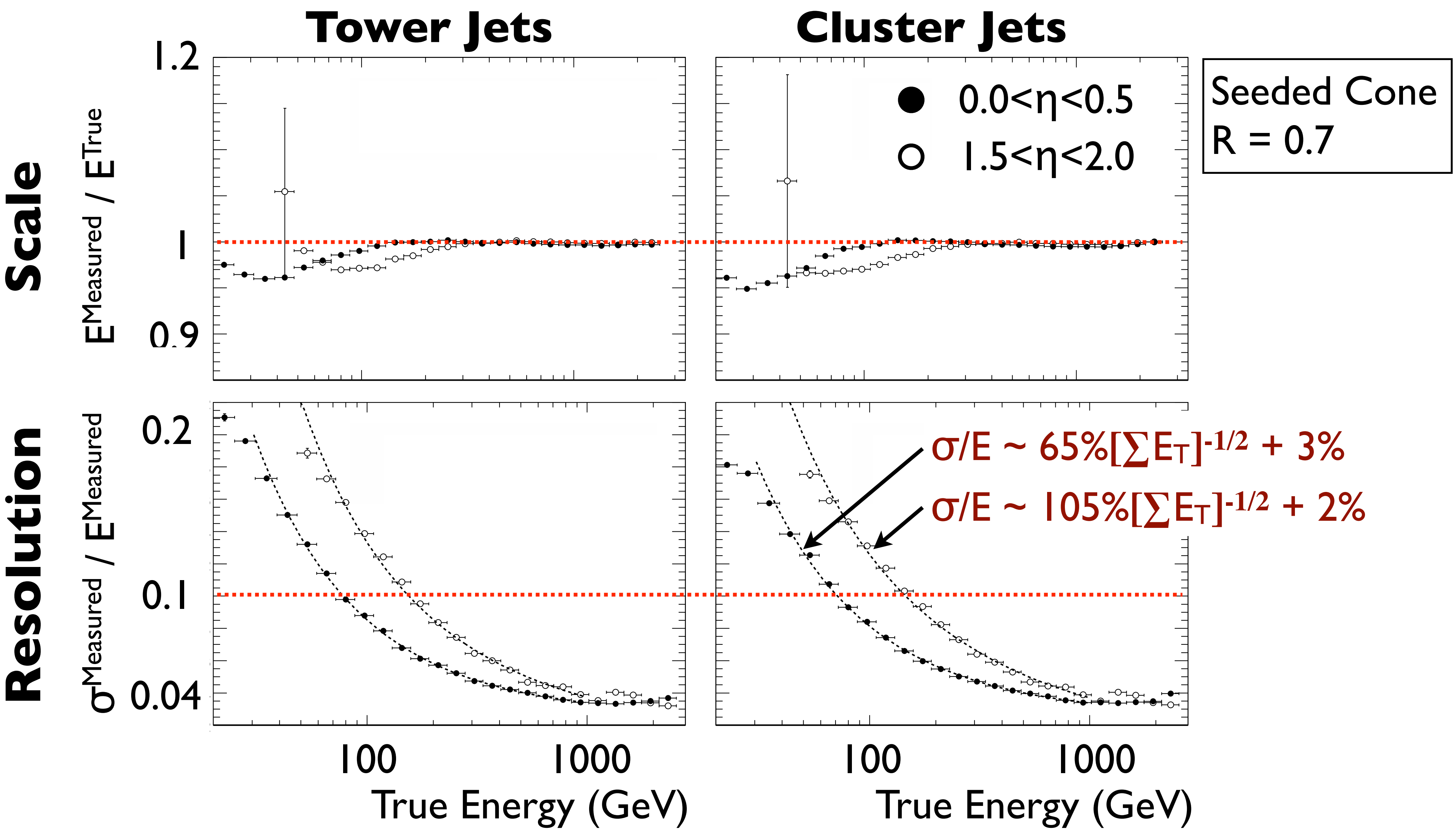
"Global" cell-level calibration

- Based on QCD dijet Monte Carlo simulation
- Bring calorimeter jet scale to particle jet

"Local" cluster-level calibration

- Based on single particle Monte Carlo simulation
- Bring cluster energy scale to hadronic energy

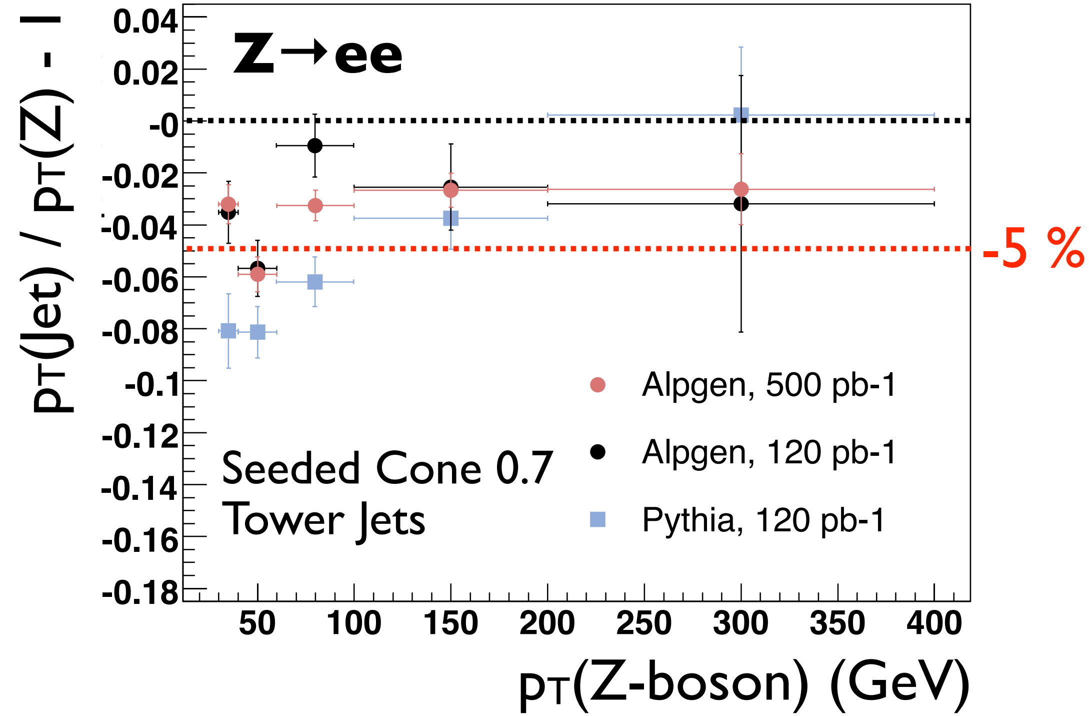
Jet Performance at ATLAS



- Similar stochastic and constant terms between two jet types
- Cluster jets have ~13%(23%) smaller noise term than tower jets

Performance Validation

Validation with real data is crucial as ATLAS calibration scheme is MC based



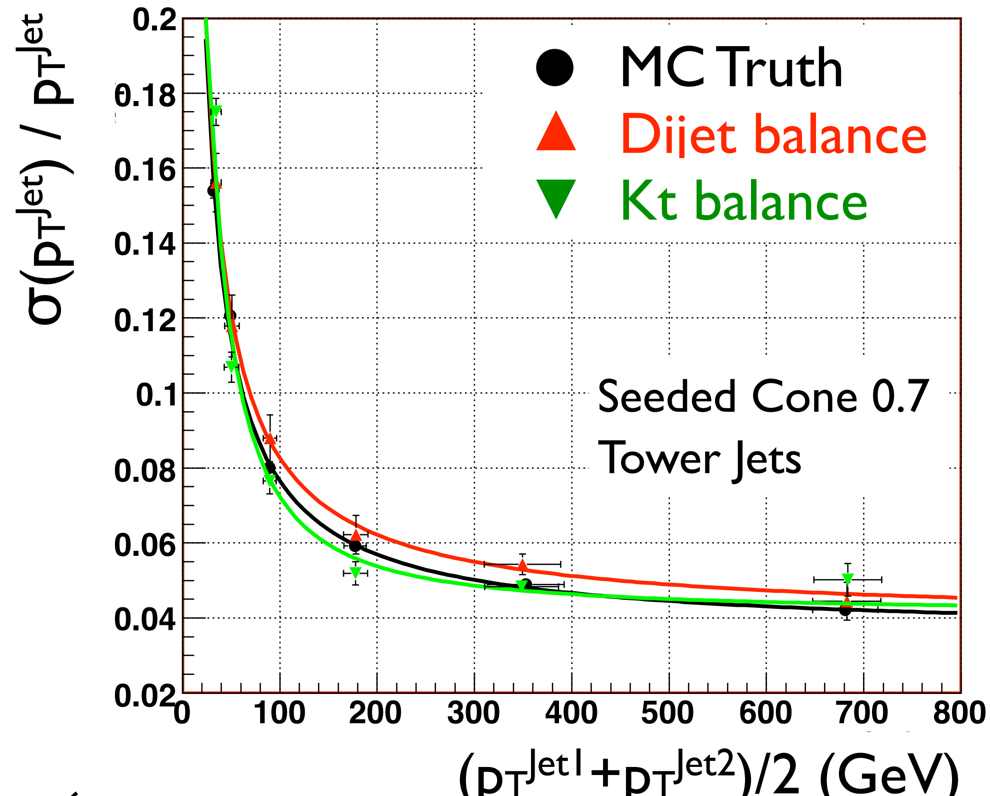
<u>Jet Energy Scale</u>

- γ/Z - jet p_T balance
- W→jj using M_W in tt (light quark)

<u>Jet Energy Resolution</u>

- Dijet balance
- Kt balance

- Based on Tevatron experience
- Utilize p_T balance between 2 jets
- Soft radiation effects taken into account



MissET in ATLAS

Missing ET is an event variable representing E_T of "invisible" particles

$$\Rightarrow \text{MissET} = \sum_{i=1}^{\nu,\tilde{\chi},\tilde{G},\ldots} E_T^{\,i} = -\sum_{i=1}^{\text{detected particles}} E_T^{\,i}$$

(concept is simple...)

Experimentally measured from calorimeter signals above noise threshold;

$$\text{MissE}_{X(Y)} = -\sum_{i=1}^{\text{CaloCells}} E_{X(Y)}^{\,i}, \quad \text{MissET} = [\text{MissE}_X^{\,2} + \text{MissE}_Y^{\,2}]^{1/2}$$

⇒
- Need to correct for muons and energy loss in dead materials
- Calorimeter cells calibrated at electromagnetic energy scale (e=1)
  → Need to calibrate hadronic energy to the correct scale (as e/h > 1)

Global Calibration

- Apply global cell-level weights to all signal at once

Refined Calibration (default)

- Identify physics objects in an event
  - e, γ, τ, jets, muons, unused topological clusters
- Decompose objects into constituent cells
- Calibrate cells with object calibration weights

MissET Performance

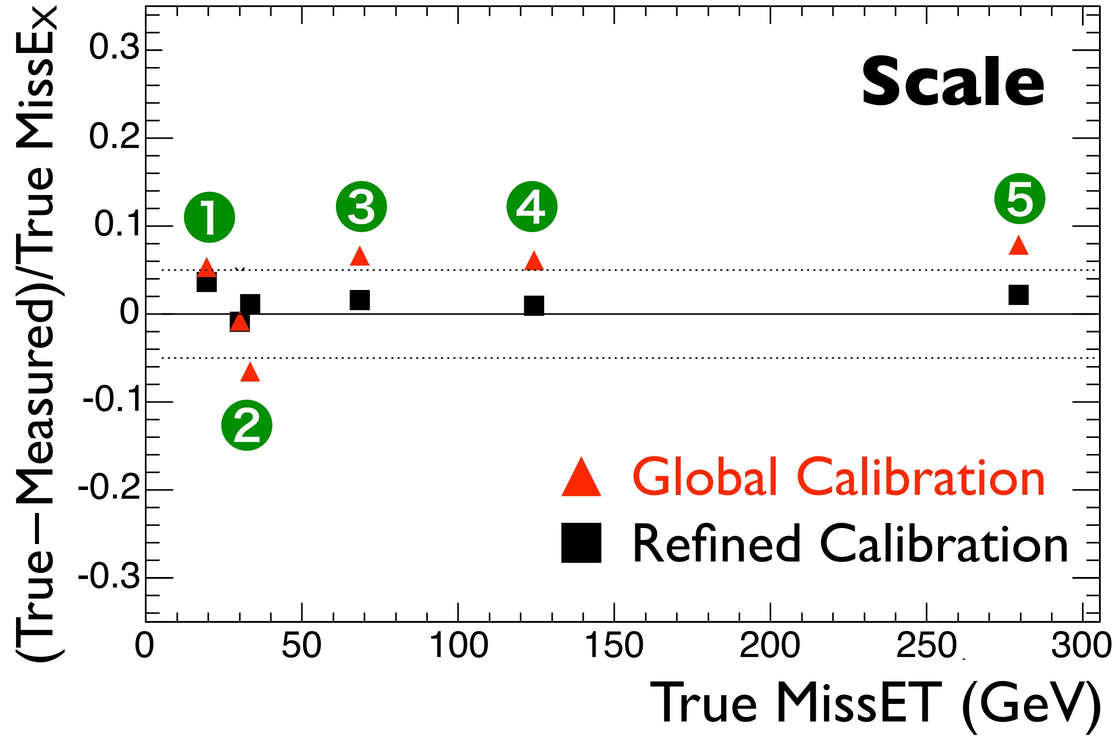
MissET Scale

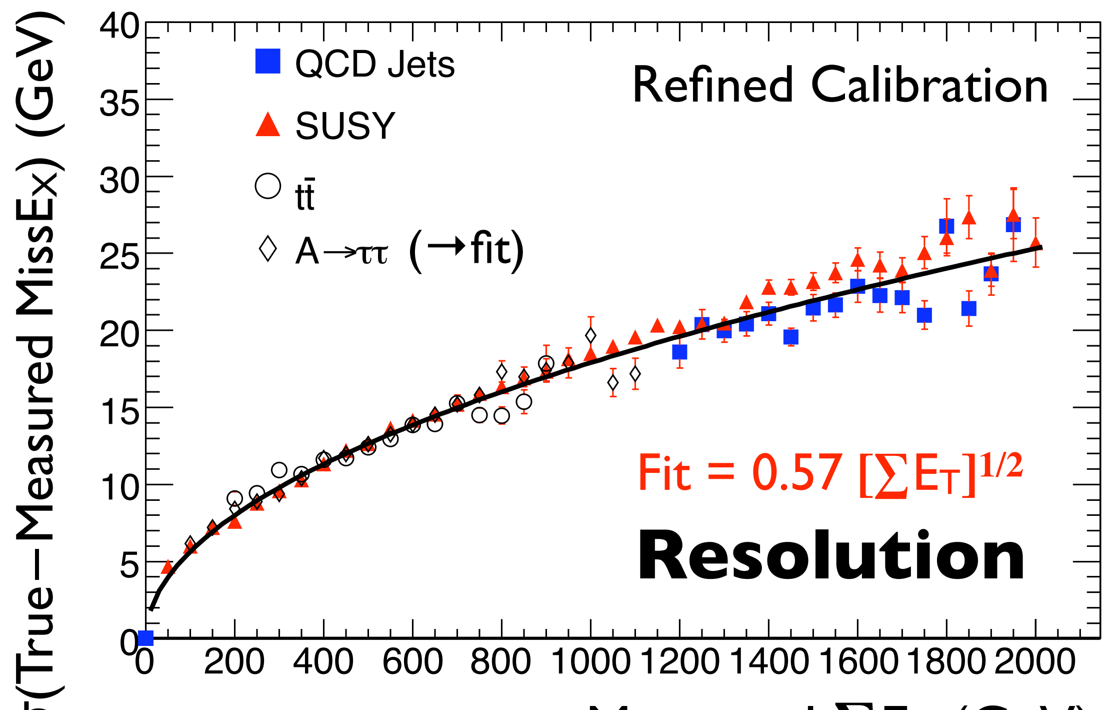
Fairly robust around a few % over wide MissET range and different processes

- ❶ $Z \rightarrow \tau\tau$
- ❷ $W \rightarrow e\nu, \mu\nu$
- ❸ $t\bar{t}$ semi-leptonic
- ❹ $A \rightarrow \tau\tau$ (m_A = 800 GeV)
- ❺ SUSY (~1 TeV mass)

MissET Resolution

Follow $\sigma = a\,[\sum E_T]^{1/2}$ over a very wide range of $\sum E_T$



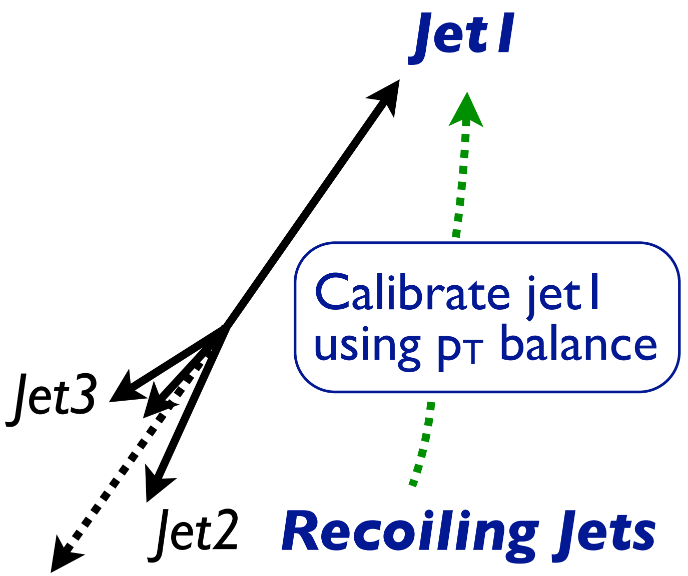


Challenge : Very High p_T Jets

- Very high p_T jet in a TeV range is an unexplored territory at collider experiment
- Calibration challenging as O(TeV) p_T is too high to use γ/Z - jet balance method

→ Exploring the technique to calibrate jets at TeV range

Option 1. **Multi-jet Balance**

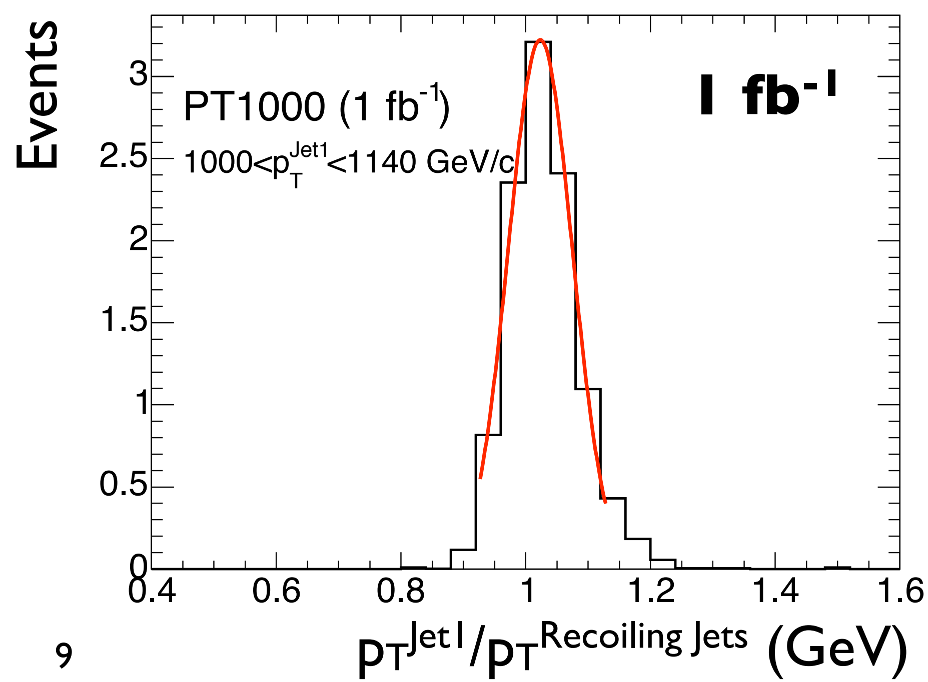


- Use QCD multi-jet events
  - ≥4 jets with p_T>40 GeV
  - Jet p_T cuts : e.g, $1000<p_T^{Jet1}<1140$ GeV, $p_T^{Jet2}<470$ GeV
  - $\Delta\phi$(Jet1, Recoiling jets) > 160 degree
- Evaluate jet1 energy scale from $p_T^{Jet1}/p_T^{Recoiling\ Jets}$
- Possible to extend p_T range by iteration

Potential accuracy of 1 TeV jet scale at 1 fb^{-1}

➡ **< 10%**

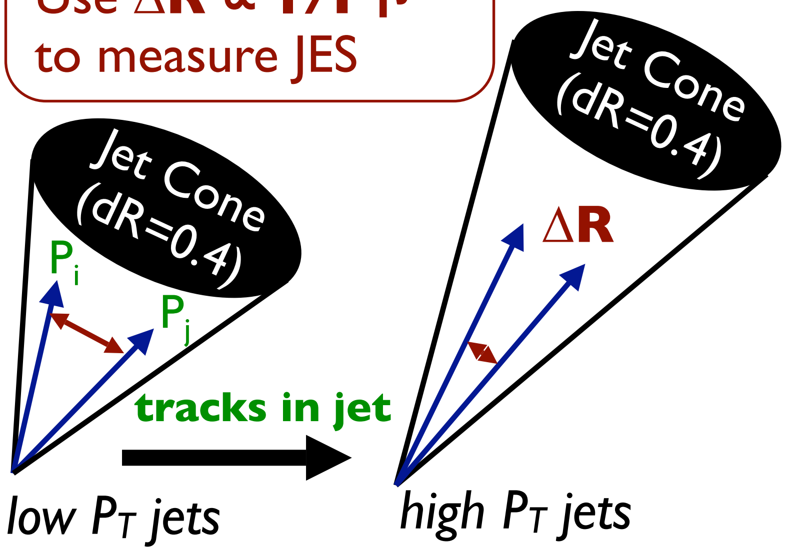
(comparable to low p_T jets)



Challenge : Very High p_T Jets

Option 2. **Track-based Method**

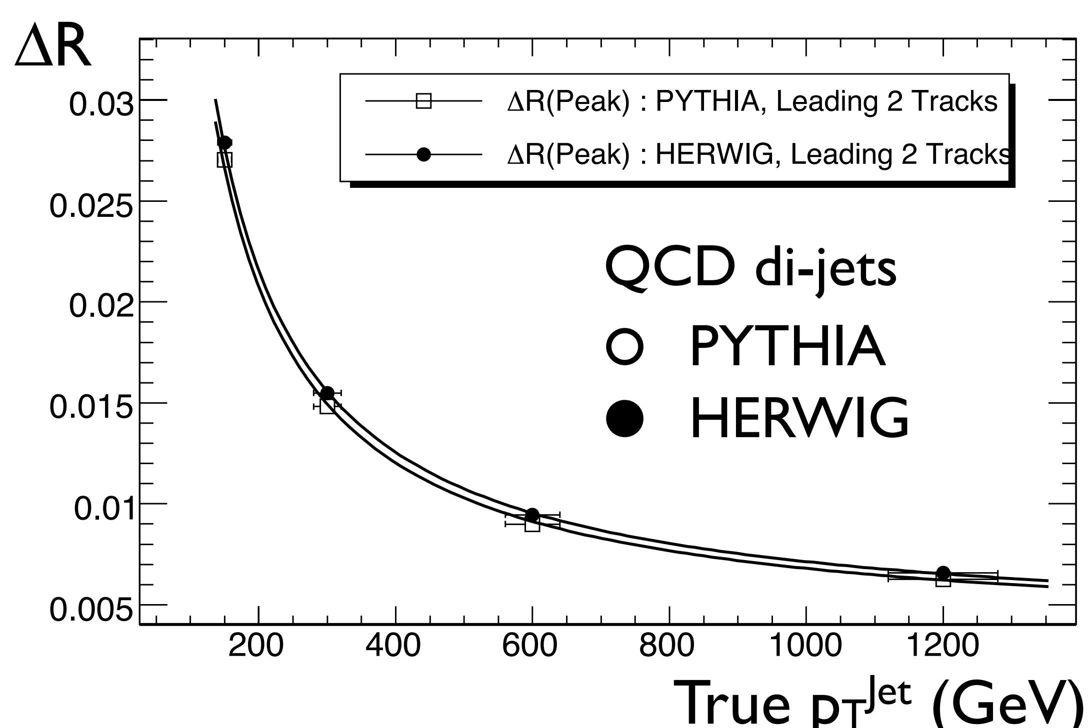
Use $\Delta R \propto 1/P_T^{Jet}$ to measure JES



- Use QCD di-jet events
  - count all tracks inside the leading jet cone
  - calculate ΔR values over all combinations for leading *N* tracks and take mean value
- Complementary to multi-jet balance method
- Need to study flavor (in)dependence

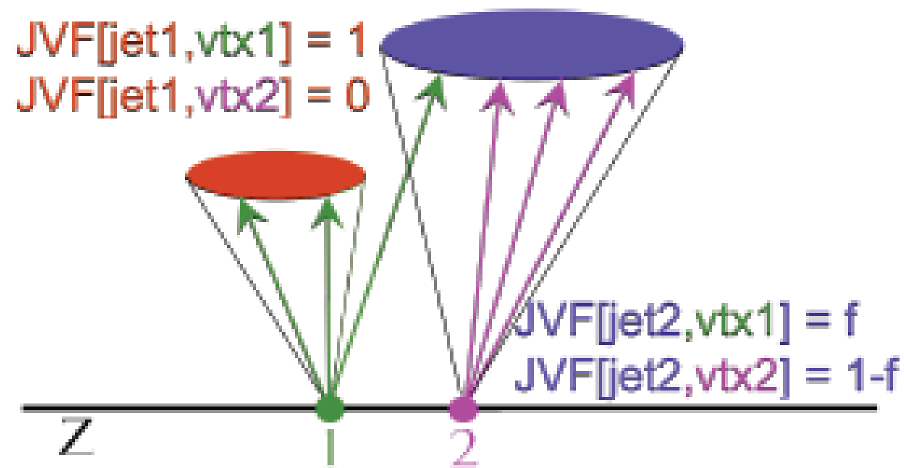
Potential accuracy of 1 TeV jet scale at 1 fb^{-1}

➡ **~20% level**



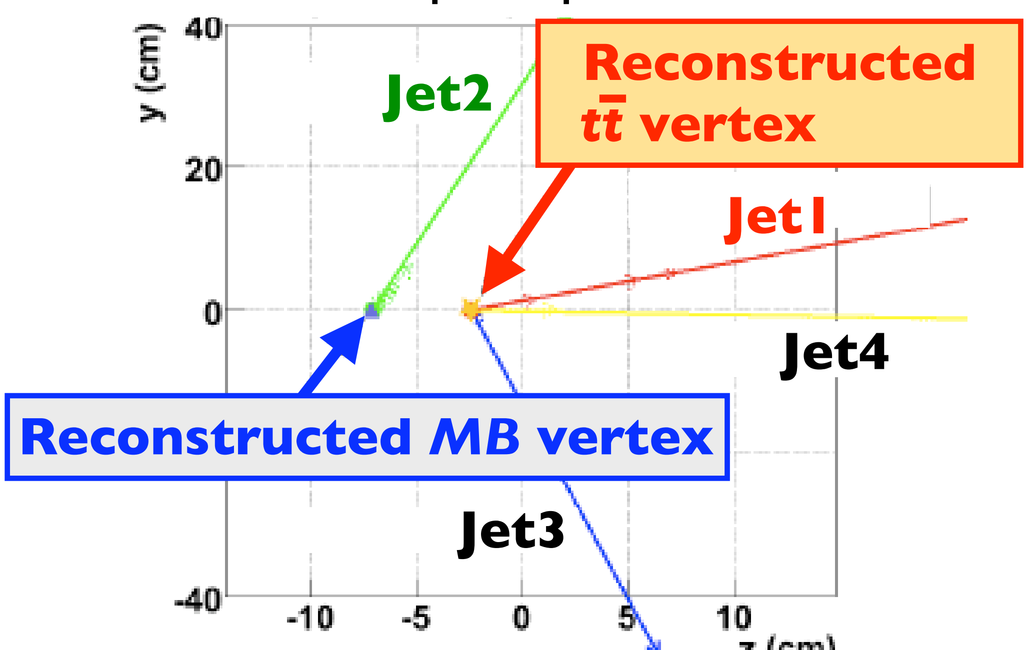
Challenge : Jet Pile-up

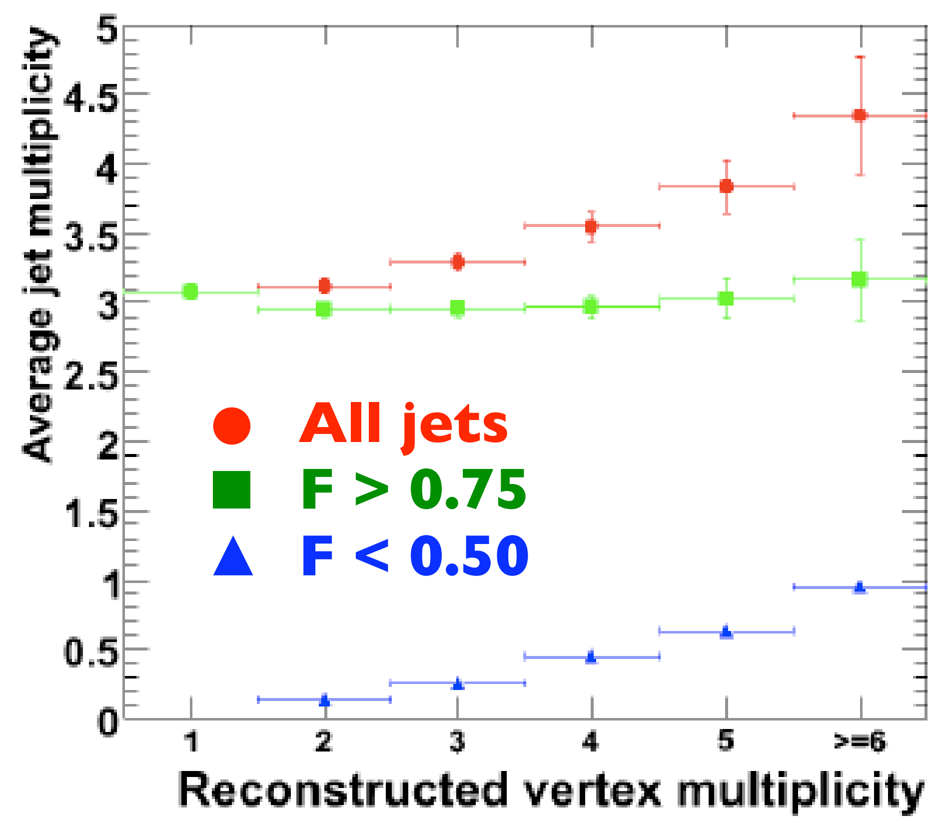
- Soft pile-up noise → Topological Clustering
- "Hard" (minimum bias jet) pile-up?
  - ➔ 3-D (η,ϕ,Z) jet finding using tracks
    - Associate jets to primary vertices
    - Evaluate fraction **F** of charged track energy in each jet originating in each identified primary vertex



Minimum bias events do make hard jets!

$t\bar{t}$ events with pile-up





Summary

- Jet and Missing ET performance studies at ATLAS are in good progress
- Most calibrations and corrections are based on Monte Carlo simulations
- Development of data-driven calibration and validation technique is crucial
- Many (unexpected) challenges ahead of us, but being ready to attack problems with useful tools