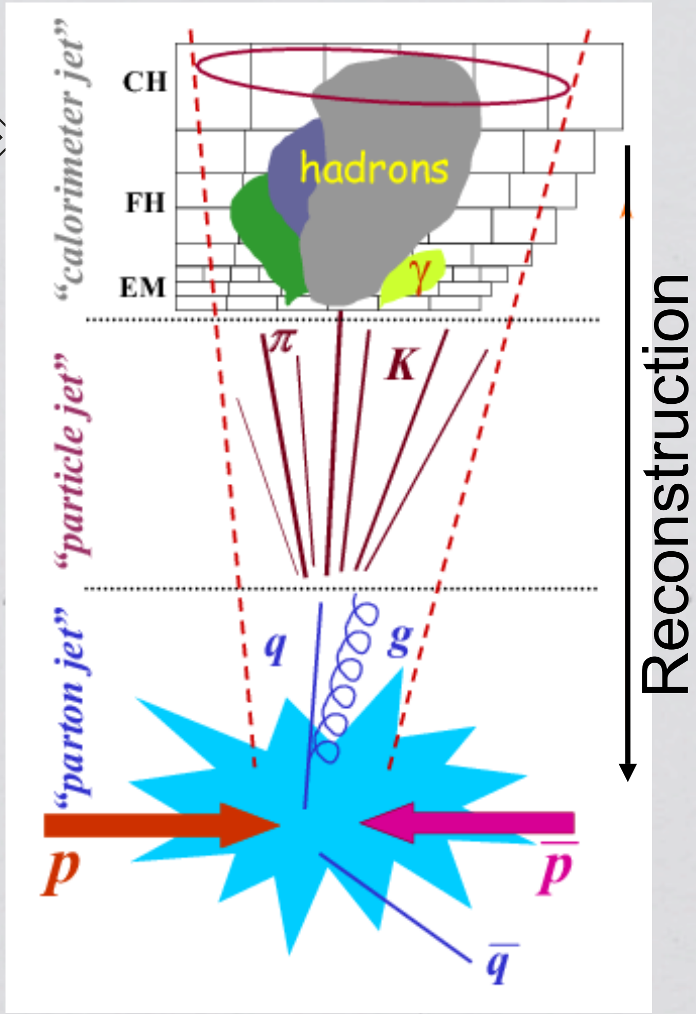
JET RECONSTRUCTION AND CALIBRATION

Additional material from: S. Menke, P. Francavilla and Z. Zenonos

1st ARTEMIS annual meeting, 27-28 September 2007 - Chalkidiki, Greece

Outlook

- Introduction: jet calibration strategy in ATLAS
- Additional material provided by ARTEMIS members:
  - Z. Zenonos: "TileCal simulation studies: first results on validation of hadronic physics simulation"
  - S. Menke: "Local hadron calibration"
  - P. Francavilla: "Effect on inclusive jet cross section measurement of systematic uncertainties: first approach"



* Jet reconstruction consists in obtaining from the calorimeter hadronic signals the kinematics of the particle jet or of the parton jet depending on where we want to have Theory-Data comparison.

Parton jet, Particle jet, Calorimeter jets are obtained running the same jet clustering algorithm on:

- Partons
- stable particles after fragmentation
- calorimeter signals

Jet Reconstruction Algorithms

* Jet clustering algorithms must be applicable at any level: calorimeter signals, particles, partons (jet components).

Various jet clustering algorithms have been implemented in ATLAS. Brief description of the two that are mostly used for physics analysis:

- Iterative seeded cone algorithm
- k_T algorithm

Once the jet components have been obtained the jet kinematics is calculated from the components applying the "recombination scheme": the recombination scheme used in ATLAS is the 4-momentum sum of the jet components.

Jet clustering: iterative seeded cone algorithm

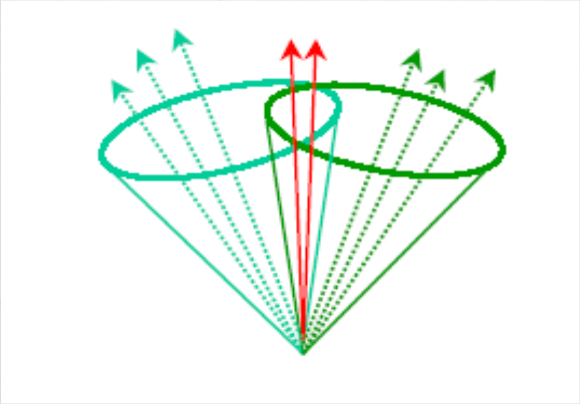
1. All jet components in (η,φ) having $E_T > E_t seed$ are considered as seeds for the jets

2.For each seed (η^s,φ^s) all components lying at distance $<\Delta R$ are associated to the jet

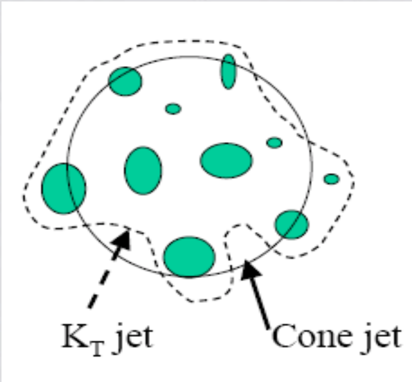
3. if the seed position (η^s,φ^s) coincide (<0.05) with the jet centroide (η^c,φ^c), the jet is considered stable otherwise $(\eta^s,\varphi^s) = (\eta^c,\varphi^c)$.

4. two jets sharing a percentual of energy energy > Δ**S** of the least energetic jets are combined, otherwise the shared components are associated to the closest jet.

	Δ**R**	$E_T$seed	Δ**S**
ATLAS	0.4/0.7	1 GeV	50%
CMS	0.5	2 GeV	-
CDF	0.4/0.7	1 GeV	75%



Jet clustering algorithm : k_T



Jet components are clustered considering closness in ΔR and transverse momentum (k_T). k_T jets do not have predefined geometrical shape.

For each couple of components i,j

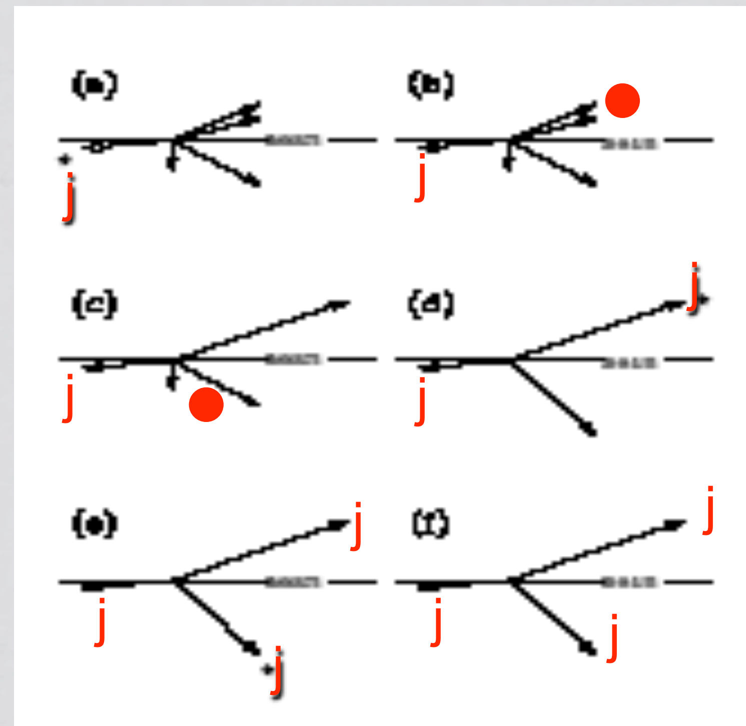
$$d = \begin{cases} d_{ii} = p_{T,i}^2 \\ d_{ij} = \min(p_{T,i}^2, p_{T,j}^2)\dfrac{\Delta R_{ij}^2}{D^2} \end{cases}$$

Collinear (if $\Delta R << 1$)

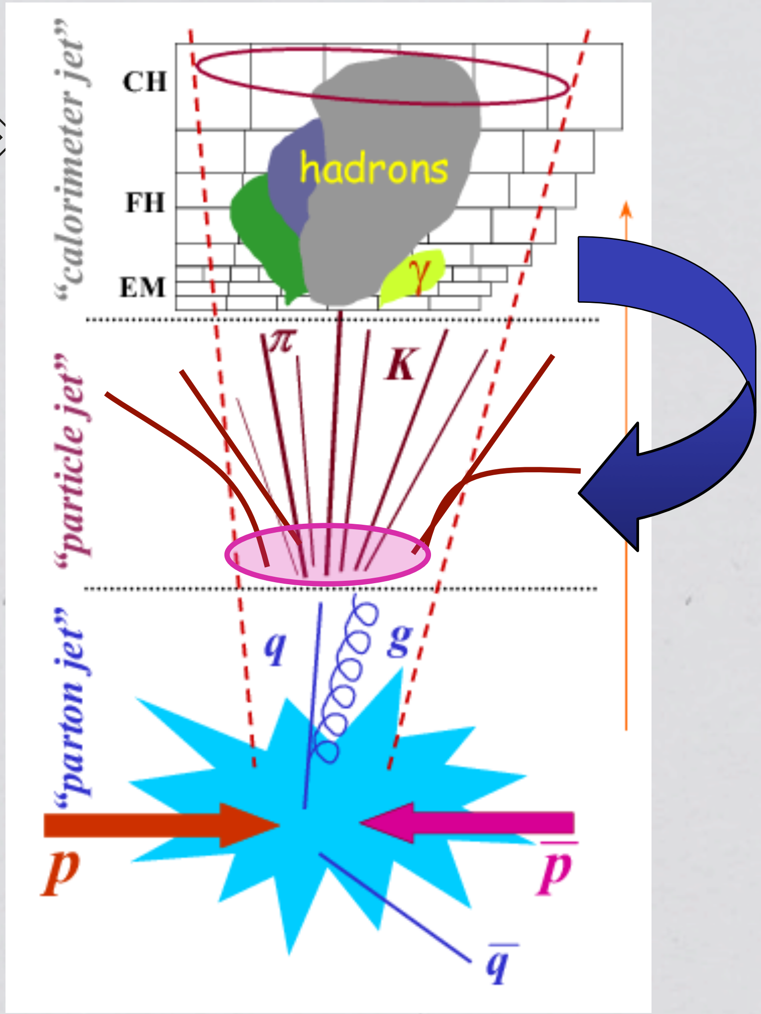
Angular resolution

If ($d_{min} = d_{ii}$) $\Rightarrow$ jet

else if $d_{min} = d_{ij} \Rightarrow$ ij (4-vector sum) in a new d_{ii}



kT algorithm is infrared and collinear safe



* After jets have been reconstructed we need to correct energy measurement for detector effects:
  * calorimeter non compensation (e/h)
  * effect of cracks, dead material, losses in front of calorimeter, longitudinal leakage, magnetic field effect
* Jet calibration methods discussed here:
  * H1 -> I. Vivarelli
  * Local Hadron Calib -> S. Menke
  * Energy Flow -> M. Hodgkinson

MC validation studies: TileCal sampling fraction
Zenonos Zenonas

- Many jet calibration schemes rely on how well Monte Carlo simulation (Geant4) predicts interacting particles with ATLAS calorimeters
- Need to validate in detail Geant4 hadronic physics lists comparing results with test beam data
- Just an example is shown here: evolution of TileCal sampling fraction with respect to different physics lists
- Ongoing activities: Geant4 had. physics validation with CTB data (V. Kazanine, I. Vivarelli), Geant4/Fluka comparison with TileCal TB data (M.Cascella, I. Vivarelli, T. Del Prete, A.D.)

TileCal Sampling Fraction Studies

ATLAS Hadronic Calorimeter: *a sampling calorimeter*

→ absorbsion of energy in high-density material (steel)
→ scintillating tiles periodically sample the energy deposited
→ infer the total energy of the original particle shower

TileCal Sampling Fraction: *a constant parameter*

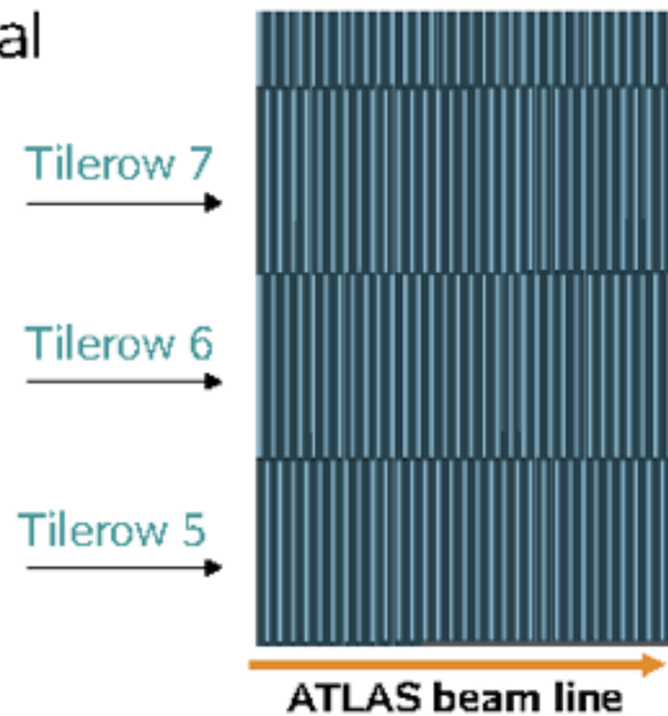
→ is used in the digitization step of MC simulation
→ multiplies the energy deposits in the scintillators
to get the calibrated energy released in TileCal

$$TSF = \frac{E_{vis}^{scint}}{E_{beam}}$$

E_{vis}^{scint} → energy deposited only in sensitive parts of cells -scintillators

E_{beam} → energy deposited in TileCal cells

The periodical iron – scintillator TileCal structure



Physics List: *MC particle physics data sets*

→ QGSP: Quark Gluon String-Model
→ upgraded production cross-sections
+ theory driven model for final state

Details of electron simulation in ATLAS

→ Pseudoprojective and $\theta=\pi/2$ configuration: the beam is impinging “unnaturally” (parallel to the ATLAS beam line) on TileCal; a configuration possible only at TBs.

→ The beam is always a square - 20 GeV electrons – no beam divergency simulated.

→ **ATHENA 13.0.10** and **G4.83** using different physics lists:

- **QGSP_EMV:** it is supposed to be the same as G4.7 concerning electromagnetic showers.
- **QGSP:** modified multiple scattering.
- **QGSP_BERT:** model for intra-nuclear nucleon-nucleon scattering

(concerning electrons, we expect an energy release very similar to QGSP)

→ **ATHENA 12.0.07** and **G4.7**:

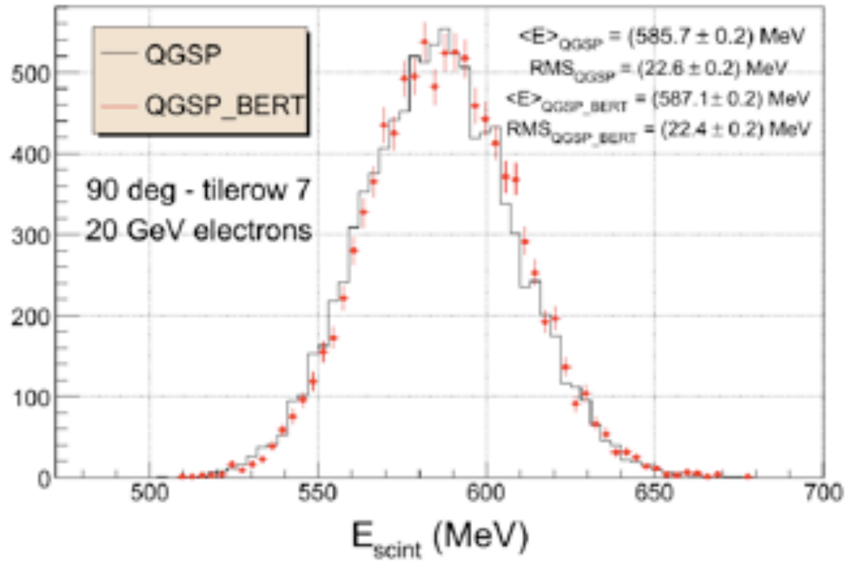
- **QGSP** physics list

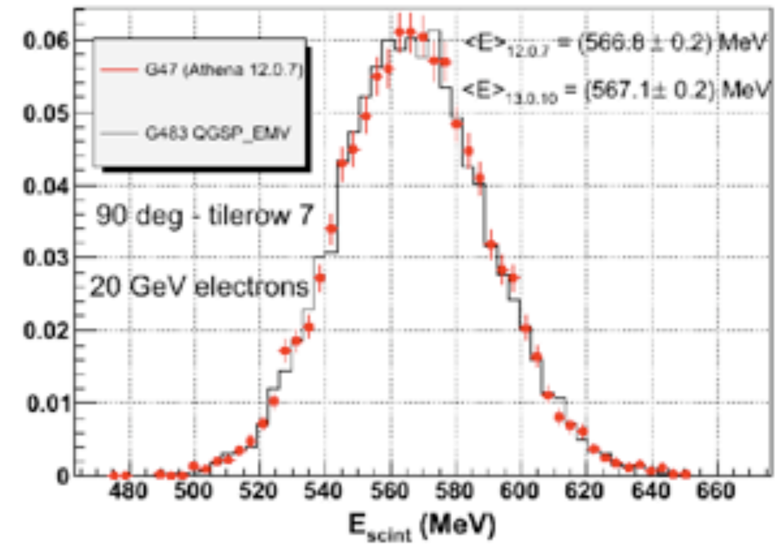
→ All the results are at the hits level: no electronics noise, no photostatistics, no digitization is applied.

→ For all the configurations the setup is TileCal standalone TB.

Given the new multiple scattering, it is expected to be different for **G4.7** and **G4.8**.

We want to estimate this difference.



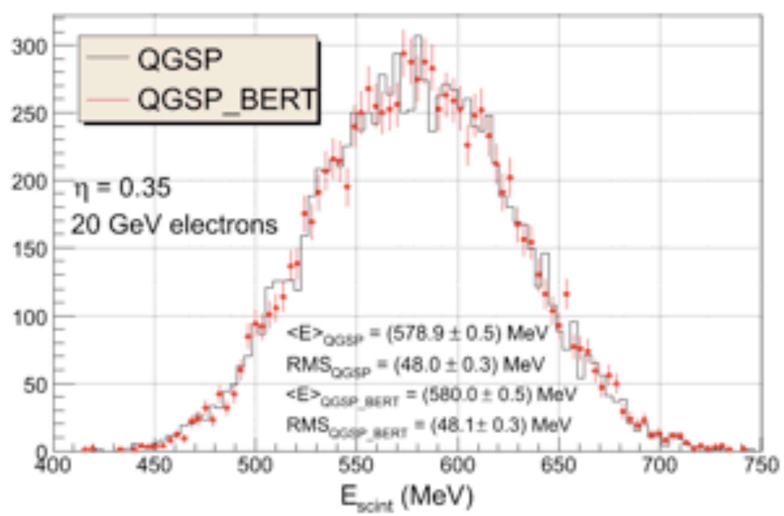


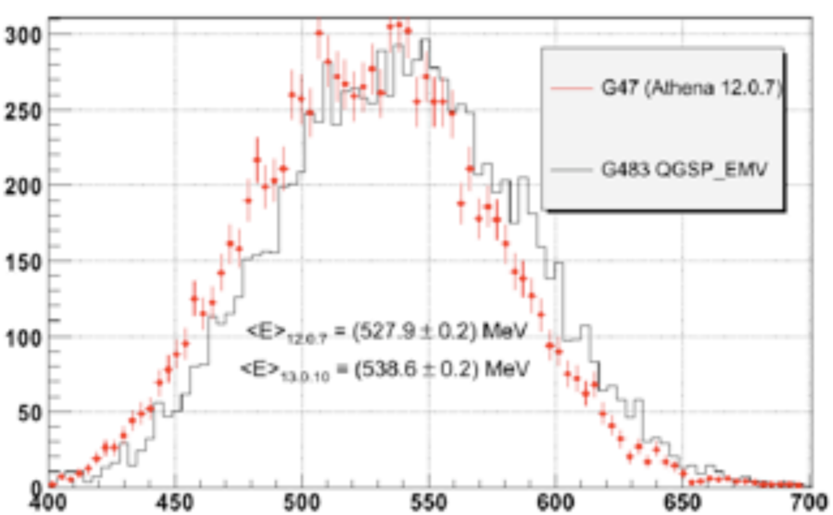
QGSP and **QGSP_BERT** expected to be the same concerning electrons energy release:

- confirmed for θ=π/2 – discrepancies on the mean values at 3 permille.
- confirmed also in pseudoprojective runs

QGSP_EMV:

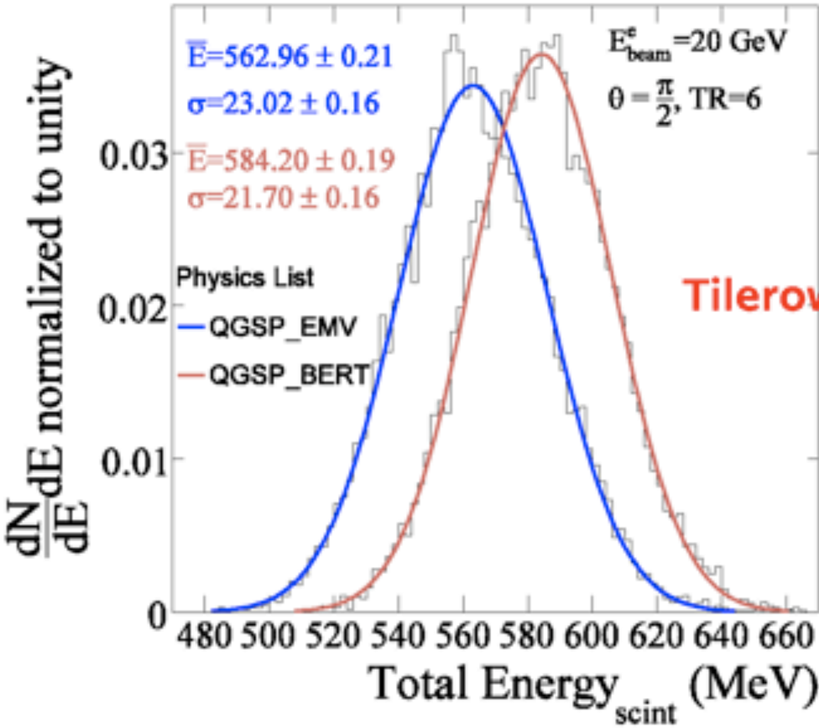
- expected to reproduce G4.7 – confirmed for θ=π/2 – the mean values agree within the errors
- is **2%** higher with respect to G4.7 for η = 0.35



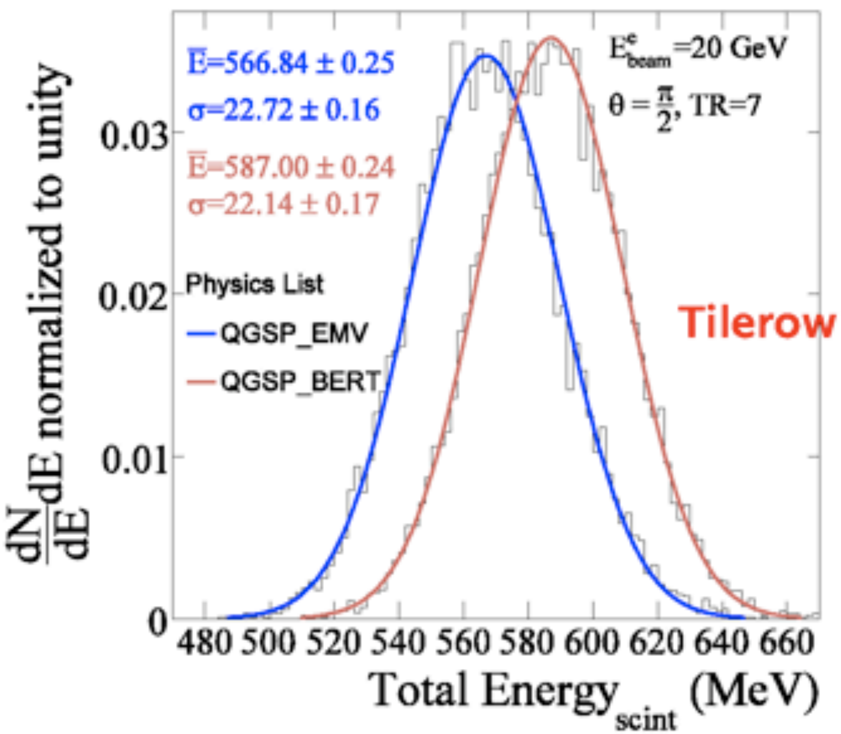


Comparison of the energy distributions of QGSP_BERT and QGSP_EMV for two different tilerows

Tilerow 6

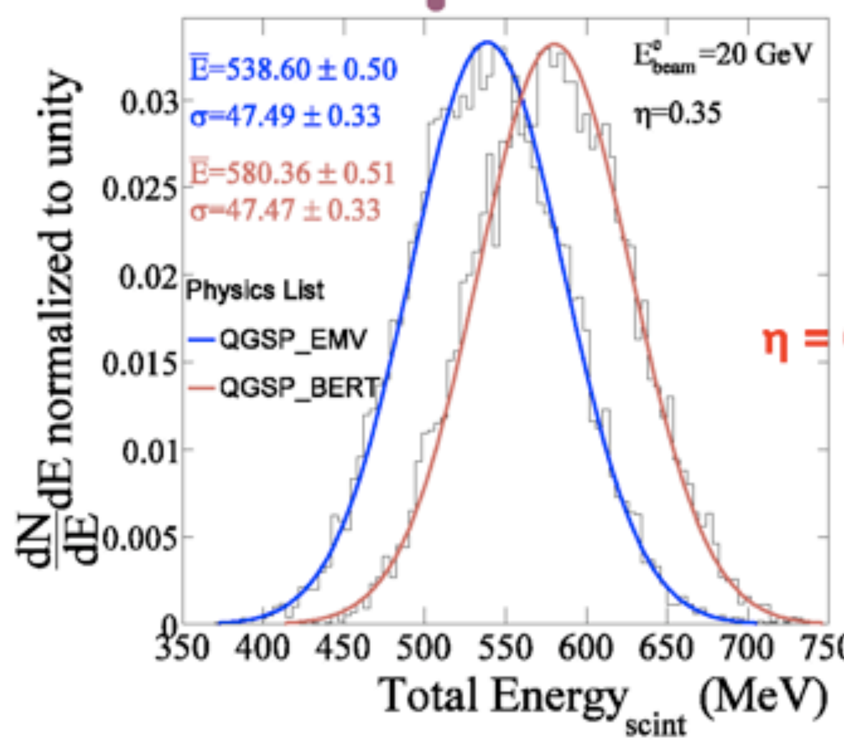


Tilerow 7



Comparison on the mean value bewteen QGSP and QGSP_EMV shows a *different ratio* between sampling fractions w.r.t. the 90 deg configuration (left plots)

η = 0.35



Summarizing on sampling fraction

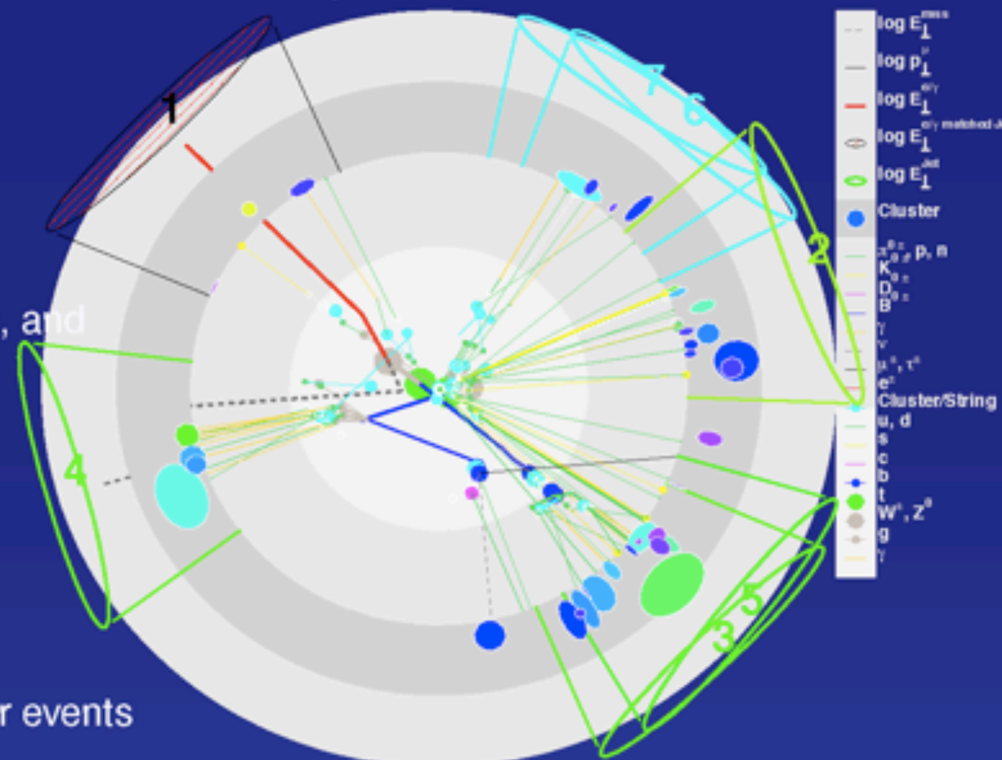
Physics list	**θ = π/2**	**η = 0.35**
$QGSP_{EMV}$ and **G4.7** predict the same mean energy in the scintillators?	yes	no $QGSP_{EMV}$ is higher w.r.t. G4.7 by 2%
$QGSP_{EMV}$ and $QGSP_{BERT}$ predict the same mean energy in the scintillators?	yes	yes
Ratio $\frac{\langle E \rangle_{QGSP}^{EMV}}{\langle E \rangle_{QGSP}^{BERT}}$ where the error is the maximum spread between tilerows :	0.965 ± 0.002	0.928 ± 0.002
The G4.7 sampling fraction is 1/35.9		
Simulating $QGSP_{EMV}$ with the same sampling fraction might result in a 2% excess in energy (projective result).		
$QGSP$ and $QGSP_{BERT}$ sampling fraction is the same within 1% level at 90◦ and at η = 0.35. More eta points can shed light to the pseudorapidity dependence.		
Our present results show that $QGSP_{BERT}$ sampling fraction is 1/(34.3 ± 0.2), where the error indicates the spread 90◦ - η = 0.35.		

Local Hadron Calibration
Sven Menke

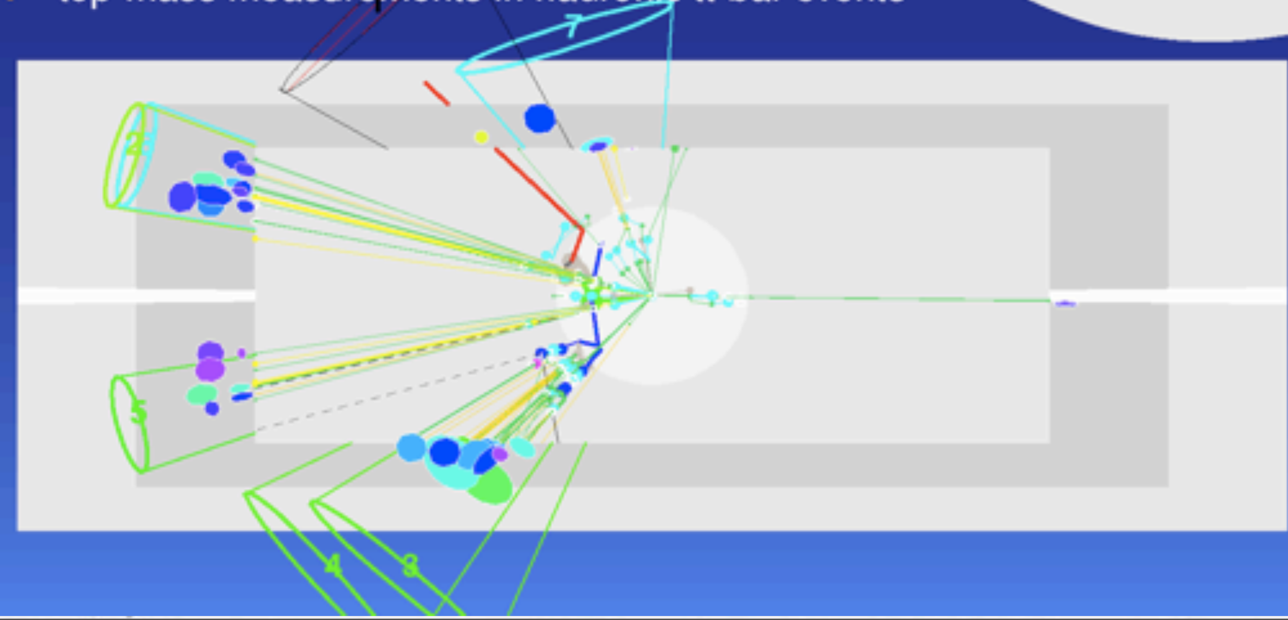
- Use clusters (instead of towers) as input to jet clustering algorithms
- Clusters are corrected for:
  - "Hadronic energy losses" (i.e. clusters originating from charged pions) corrected for non-compensation
  - Energy losses in dead material (between and in front of calorimeters)

Local Hadron Calibration

1st Artemis Annual Meeting   Sven Menke, MPI München   27. September 2007, Chalkidiki, Greece

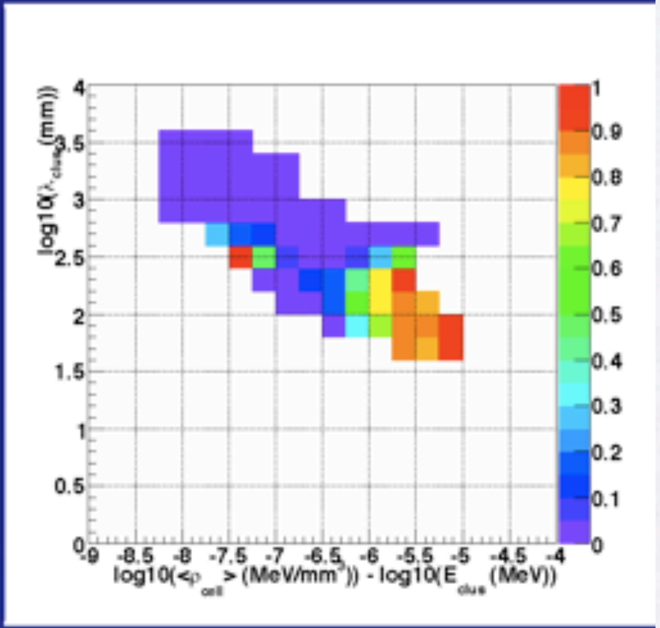


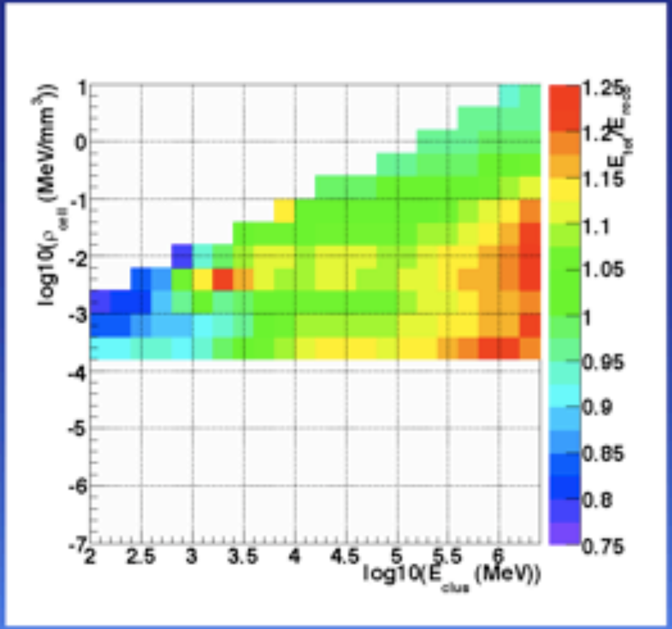
- **Local Hadron Calibration**
  - cluster moments and classification
  - energy weights, dead material corrections, and out-of-cluster corrections
- **Application to jets**
  - jet level corrections
- **Plans**
  - top-mass measurements in hadronic tt-bar events



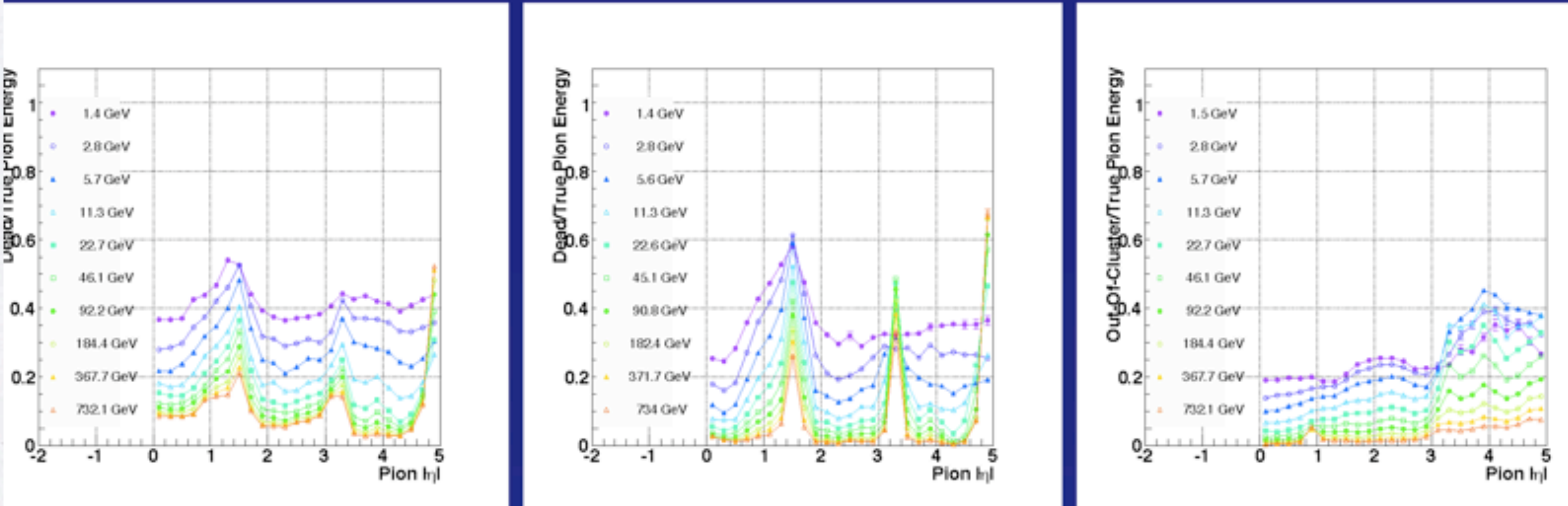
Local Hadron Calibration

- Classify and calibrate topo clusters to hadron-level
- Classification
  - use shower shape variables (cluster moments) like shower depth and (weighted) energy density of the cell constituents normalized to cluster energy
  - em showers are less deep and have higher average energy density than had showers
  - derive phase space population in energy-depth-density space for charged and neutral pions
  - make a cut on probability to observe a neutral pion with a-priori neutral-to-charged pion ratio of $1:2$ (example plot shows endcap and $8\ \mathrm{GeV} < E_{\mathrm{clus}} < 16\ \mathrm{GeV}$)



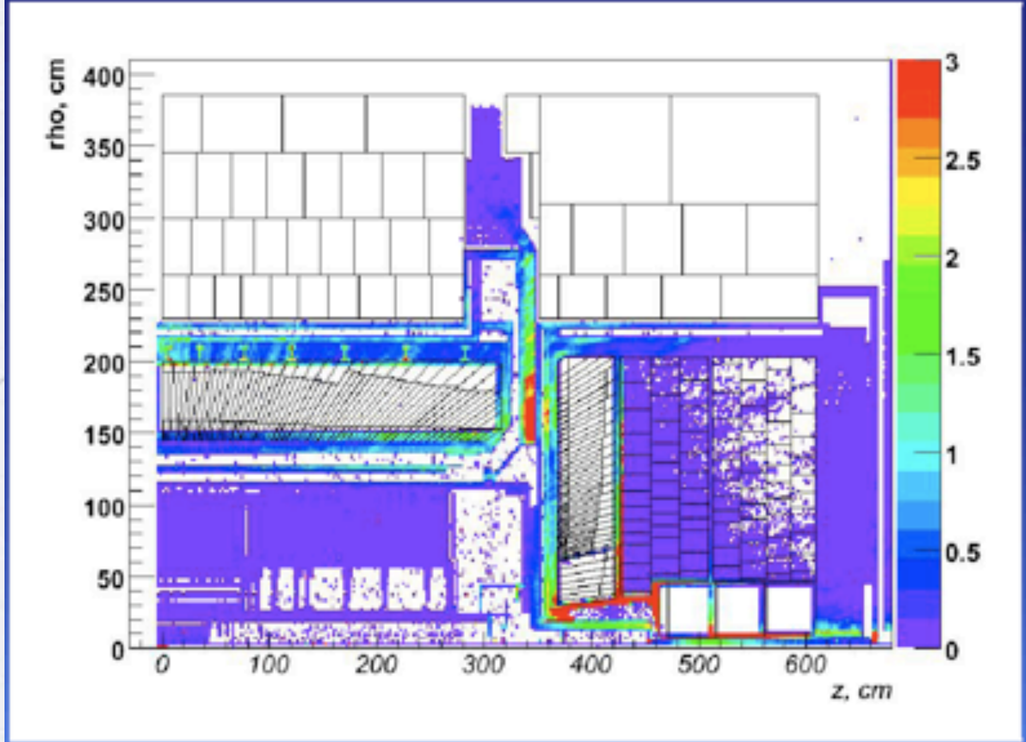


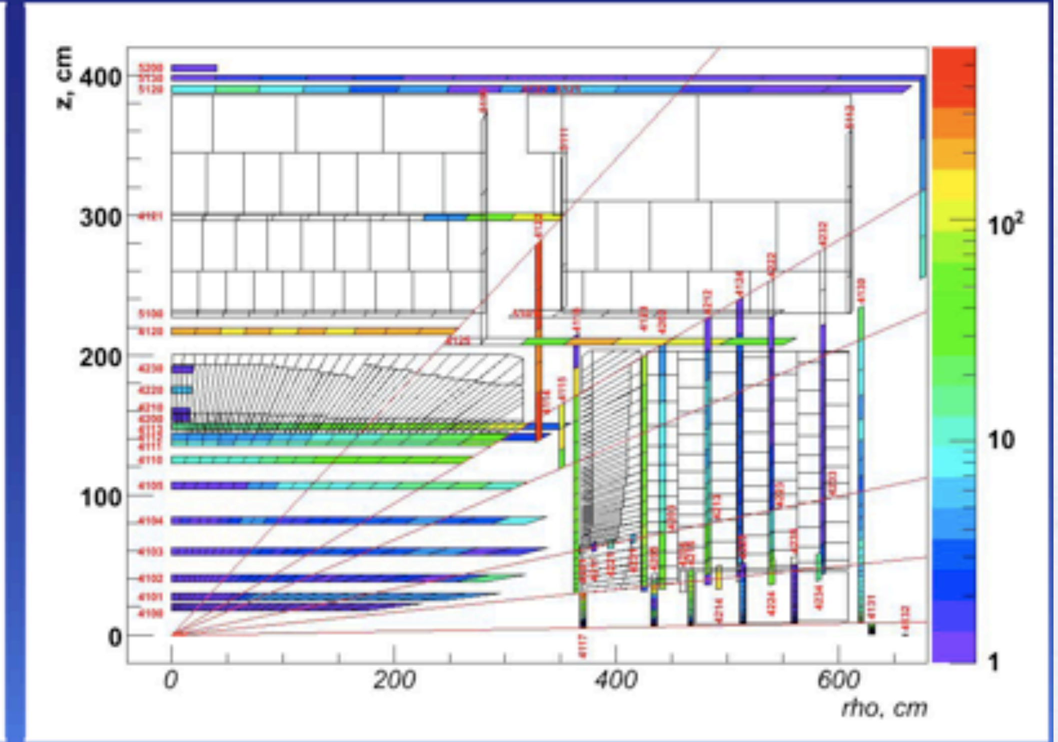
- Calibration
  - treat only clusters classified as hadronic
    - except for dead material corrections which are available also for em clusters
  - derive cell weights from Geant4 true energy (calibration hits) including invisible energy and absorber deposits and reconstructed cell energy for each η region and layer: $w_i = \langle E_{\mathrm{true}}/E_{\mathrm{reco}} \rangle$, $i = \mathrm{bin\#}(E_{\mathrm{cluster}}, E_{\mathrm{cell}}/V_{\mathrm{cell}})$
  - example weights in main sampling of EM calorimeter for $2.0 < |\eta| < 2.2$
- Apply dead material and out-of-cluster corrections



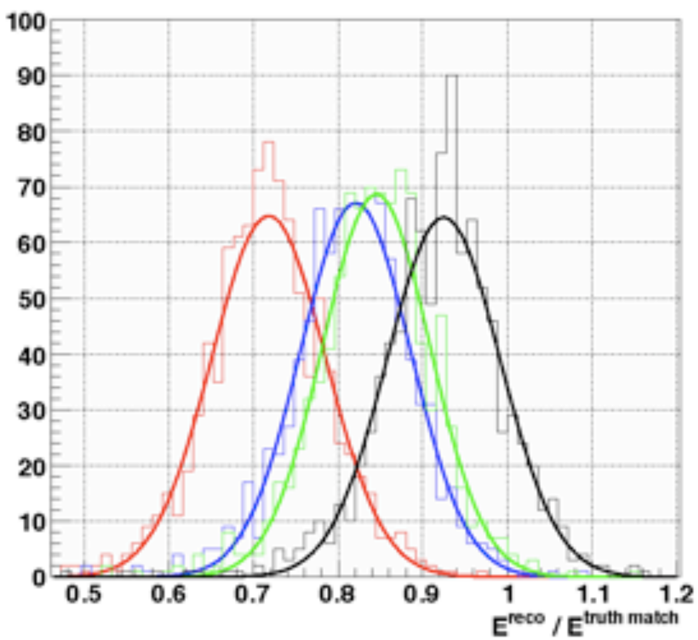
- Dead material corrections
  - account for deposits in material in front of and between calorimeter systems overlapping in $\eta \times \phi$ with cells from the cluster
  - for charged pions (left plot)
  - for neutral pions (right plot)
- Out-Of-Cluster corrections
  - account for all the rest
  - mainly deposits in calorimeter cells left out by the cluster algorithm
  - weighted with degree of isolation of the cluster to avoid double-counting

- Average G4Hit's energy deposited in dead material for 100 GeV pions (left)
- Dead Material Hits are saved in 53 separate areas with granularity $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ (right)
- corrections are derived from cell energies inside topo clusters close to the DM areas
- task is to find correlations of measured energies with expected (predicted) DM deposits





- Use two leading jets ($K_\perp$ with $R = 0.4$) in di-jet MC samples in the region $0.2 < |\eta| < 0.4$
- Energy of the leading jets in this sample and region is about 150 ± 40 GeV
- plot shows the ratio of total energy of the reconstructed jet over the energy of a matched truth jet (also $K_\perp$ with $R = 0.4$) with $\Delta R < 0.05$ for EM-scale (red); weighted (blue); weighted+OOC (green); weighted+OOC+DM (black)



	EM	W	W+OOC	W+OOC+DM
mean (%)	71.8	82.0	84.5	92.5
σ (%)	6.7	6.5	6.3	6.7
σ / mean (%)	9.4	7.9	7.5	7.2

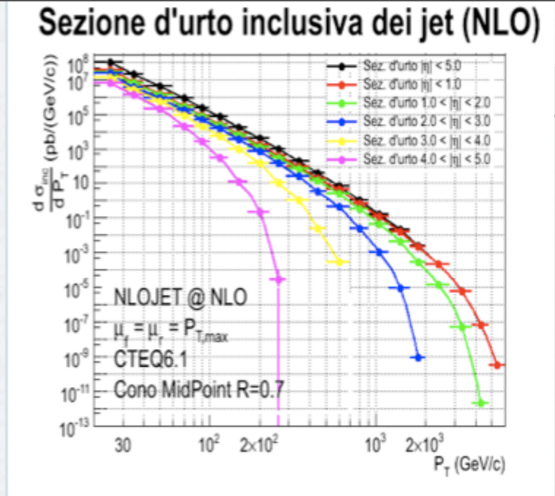
- mean and relative resolution improve in every step
- final deviation from truth jet energy is only 7.5 % consistent with expected out-of-jet corrections ($\sim$ 3% cluster inefficieny; $\sim$ 3% misclassification; $\sim$ 2% magnetic bending)

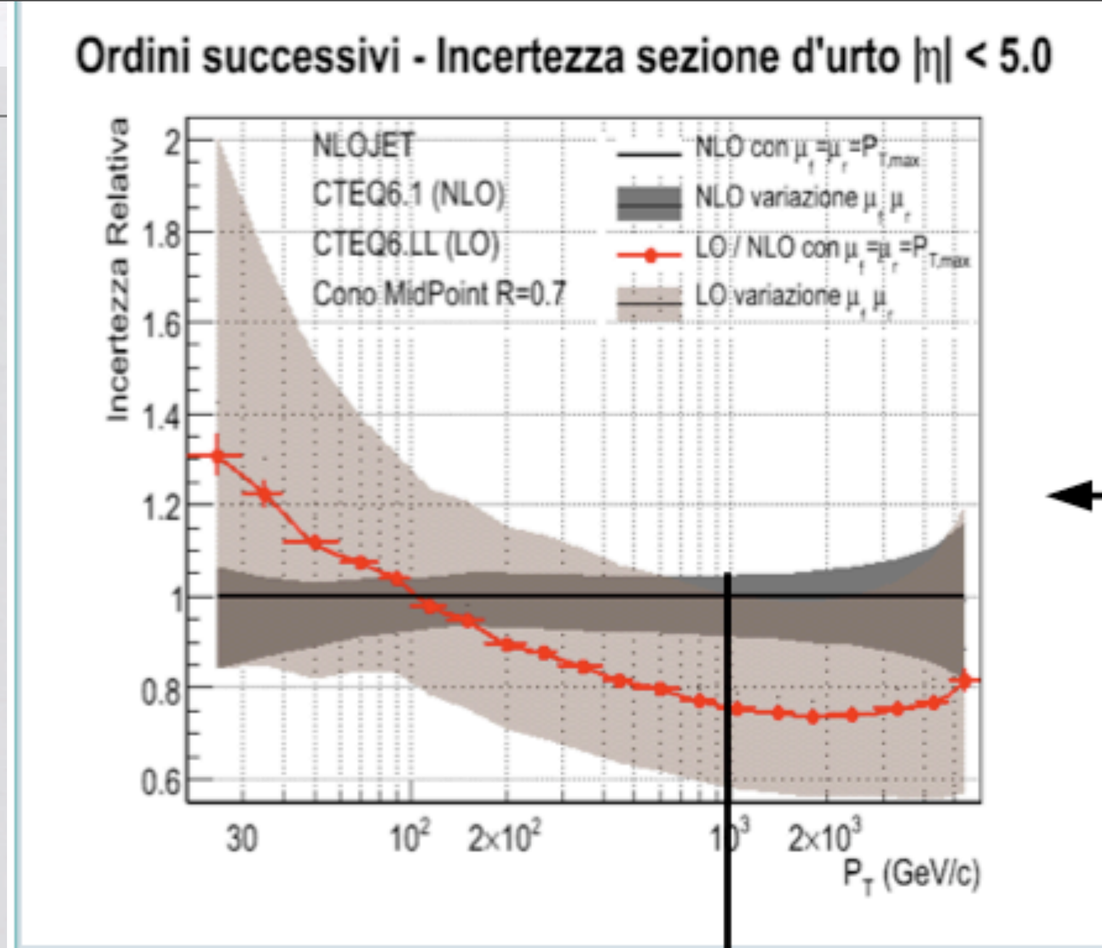
Plans

- Artemis PhD student (P. Giovannini) starts end of October
  - development of jet-level corrections on top of local hadron calibration
    - the final 7.5% for jet energy response
  - application of in-situ weighting to parton level in tt-bar events
    - the go from hadron to parton level
  - measurement of the top-mass in the all hadronic channel
    - this channel relies most on jet performance
- Maintenence and further improvements of local hadron calibration within the MPI/HEC group
  - especially the 3% due to misclassification need to be addressed
- Commissioning and top-mass measurement in the semileptonic top-pair channel within the MPI/HEC group
  - 2 more ongoing PhD studies

Towards first measurements: inclusive jet cross section Paolo Francavilla

- First attempt to study systematic uncertainties in inclusive jet cross section measurements:
    - Theoretical uncertainties: uncertainties on LO vs NLO calculations, renormalization and factorization scales, uncertainties on PDFs
    - Experimental uncertainties: effect of jet energy scale and of jet resolution
- Studies performed on parton jets only (generator level)

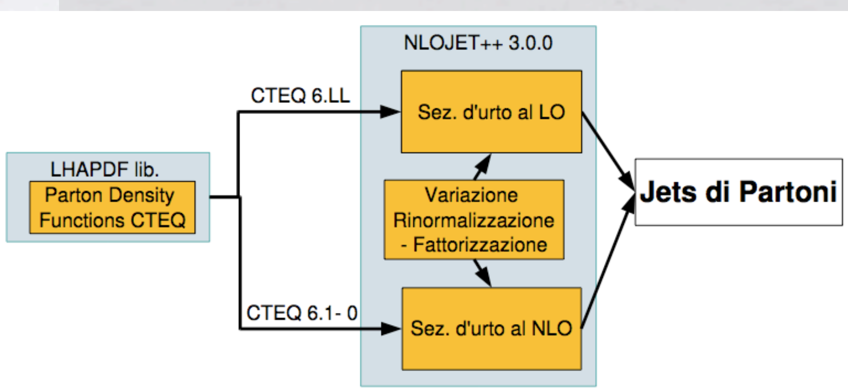




- Studied difference in predicted inclusive jet cross-section between LO and NLO calculations
- Renormalization (μ_r) and factorization (μ_f) scales have been varied and effect on cross section has been studied

Incertezze:
~30% @LO (1 TeV/c)
~7% @NLO (1 TeV/c)

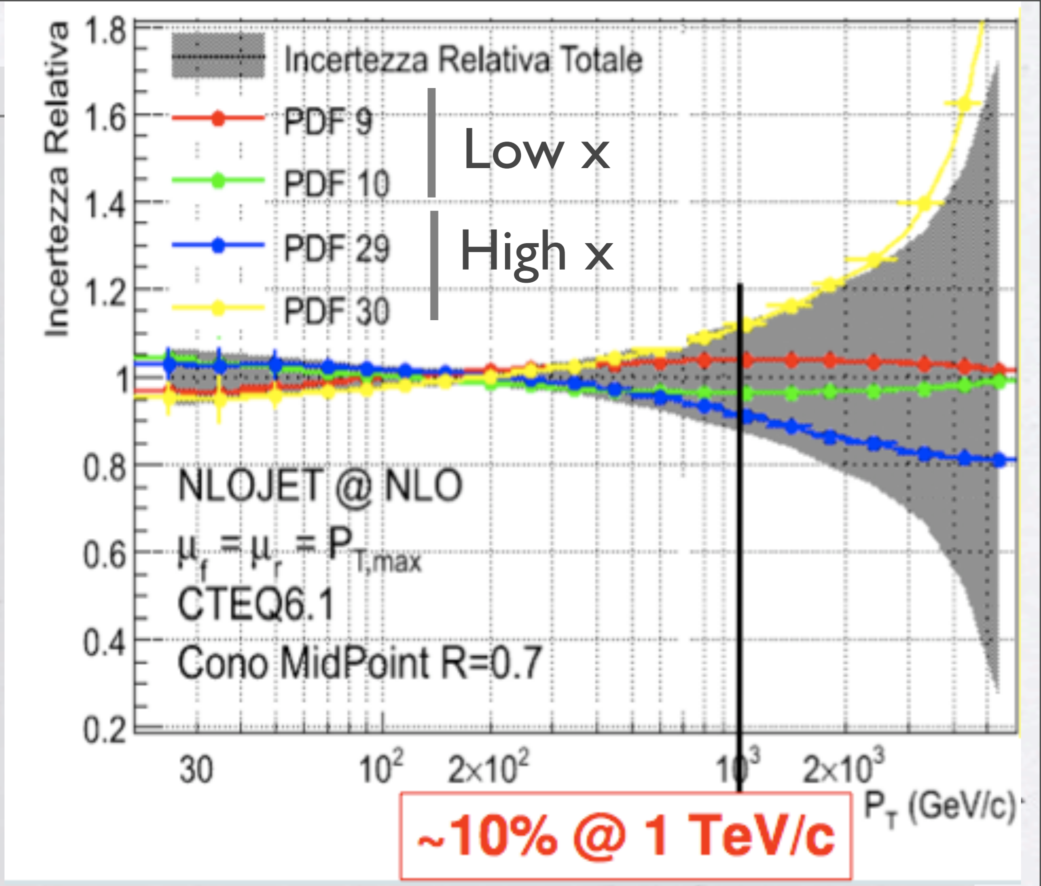
μ_r	μ_f
0.5 P_t^{jet} Max	0.5 P_t^{jet} Max
1.0 P_t^{jet} Max	1.0 P_t^{jet} Max
2.0 P_t^{jet} Max	2.0 P_t^{jet} Max



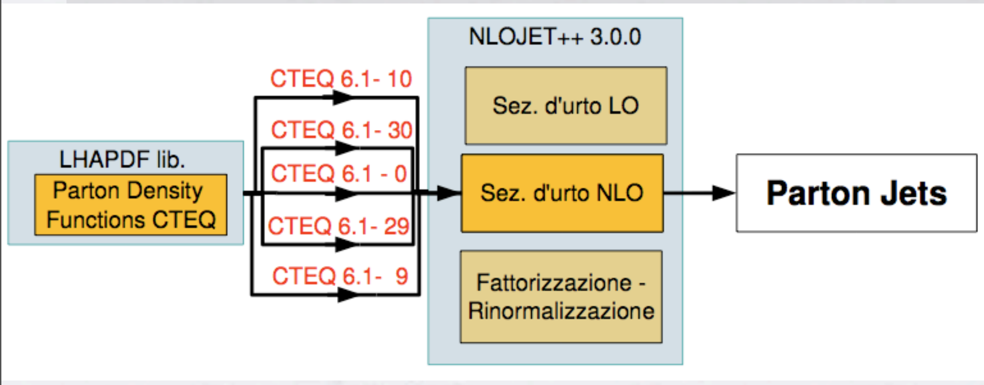
* Uncertainties in PDFs influence cross section measurement

* Total uncertainty dominated by gluon PDF contribution

* Effects of uncertainty at low x (9-10) and high x (29-30) have been studied

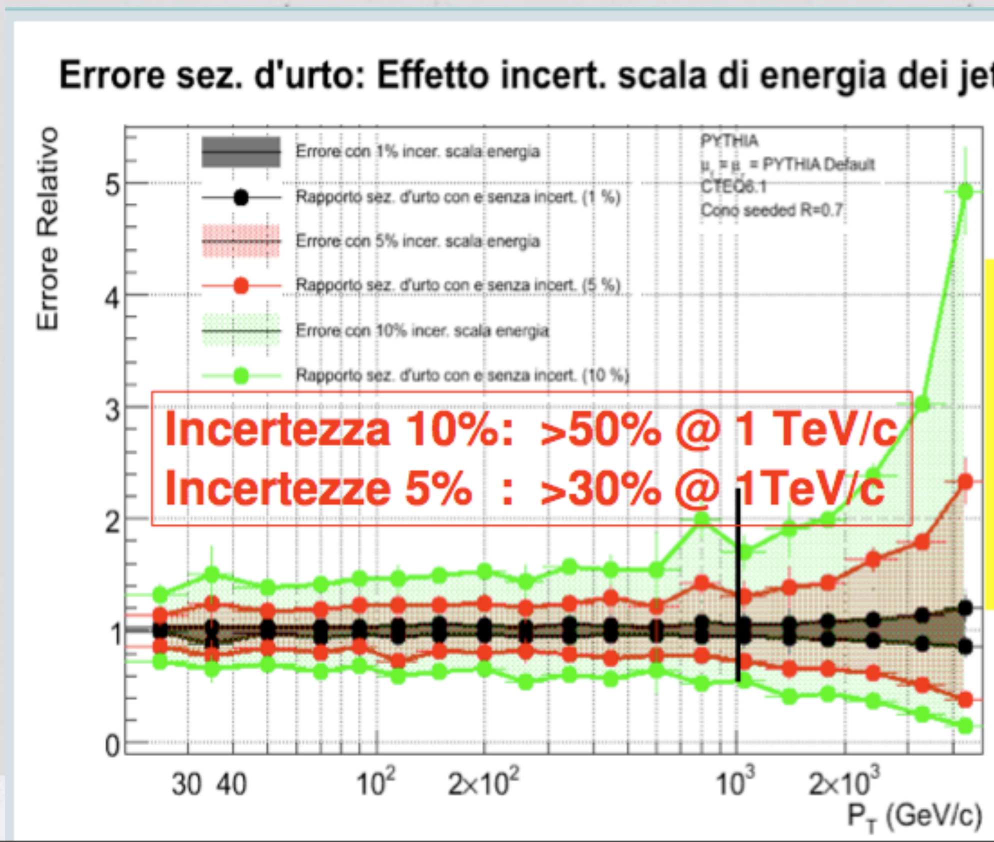


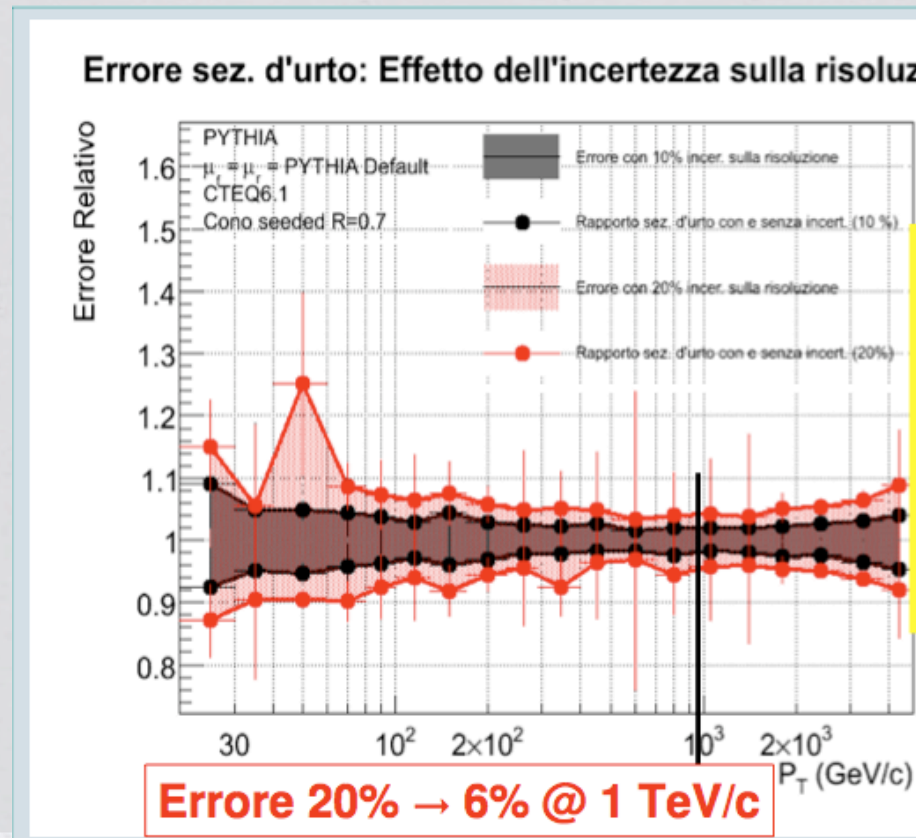
* At high transverse momentum uncertainties on high x gluon PDFs largely dominate



* Effect of jet energy scale:
* $P_T' = (1+x) P_T$
* $x = \pm 1\%, \pm 5\%, \pm 10\%$

* Effect of jet energy resolution:
* $\sigma(E)/E = a(1+x)/\sqrt{E} \oplus b(1+x)/E \oplus c(1+x)$
* $x = \pm 10\%, \pm 20\%$





source	P_T=1 TeV/c	P_T=200GeV/C
Jet Energy scale 10% (5%)	57% (29%)	43% (21%)
PDF	13%	2%
Renorm. and Fact. scales (NLO)	7%	6%
Jet Resolution 20% (10%)	4% (2%)	6% (3%)
Stat. (100 pb^{-1})	1.2%	2%

Calibration method (H1) verified on CTB data, O(5%) JES error seems reasonable.

See V. Giangiobbe talk

* Many thanks to Sven, Zenon and Paolo