Jets energy calibration in ATLAS

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Jets energy calibration in ATLAS

- Jets are present in many signatures of interest in ATLAS
  - Top quark physics, Higgs, susy, compositness...
  - QCD is the background for many analysis

- Knowledge of the Jet Energy Scale is a crucial issue for
  - inclusive jet cross section
  - missing energy
  - top quark mass (at Tevatron : most relevant systematic error on the top mass)

- Goal of the collaboration
  - calibration of the Jet Energy Scale at 1% with the best possible resolution.
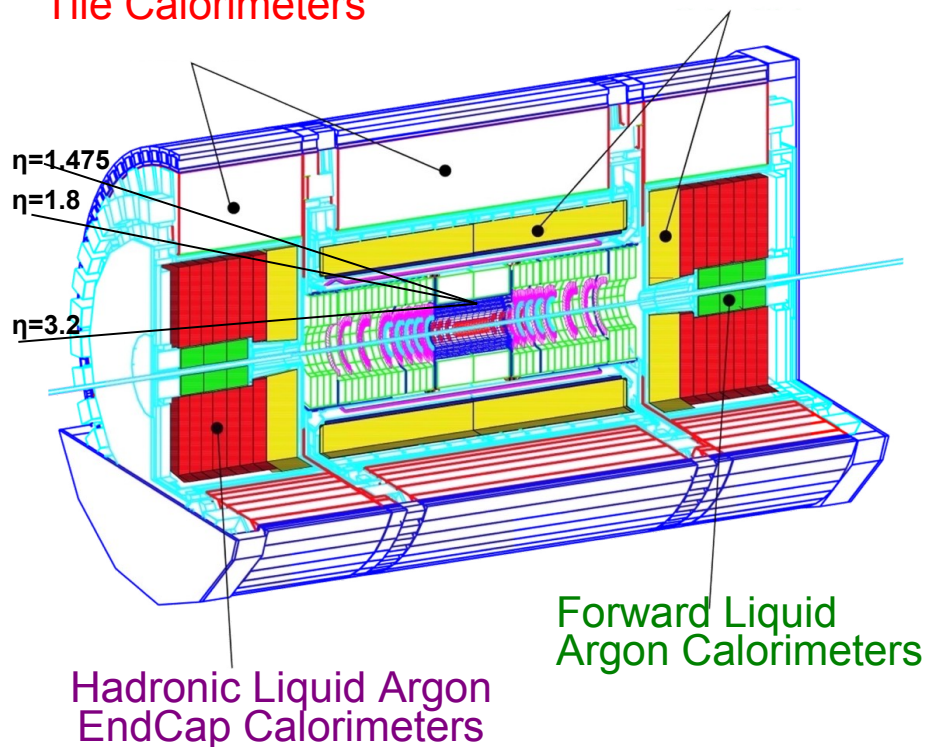
Outlines

- The calorimetry in ATLAS

- Strategy for jets energy calibration

- Reconstruction and calibration scheme

- Check of the jet energy scale

Calorimetry in ATLAS

Tile Calorimeters

Electromagnetic Liquid Argon Calorimeters

η=1.475
η=1.8
η=3.2

Forward Liquid Argon Calorimeters

Hadronic Liquid Argon EndCap Calorimeters

EM accordion |η| < 3.2
- Pb/LAr 3 longitudinal sections 1.2 λ
- Δη×Δφ = 0.025 × 0.025 and higher

Central Hadronic |η| < 1.7
- Fe/scintillator
- 3 longitudinal sections 7.2 λ
- Δη×Δφ = 0.1 × 0.1 and higher

End Cap Hadronic 1.5 < η < 3.2
- Cu/LAr
- 4 longitudinal sections
- Δη×Δφ < 0.1 × 0.1

Forward calorimeter 3.1 < η < 4.9
- EM Cu/LAr – HAD W/Lar
- 3 longitudinal sections – 9 λ
- Δη×Δφ = 0.2 × 0.2

Strategy for the jets energy calibration

General idea
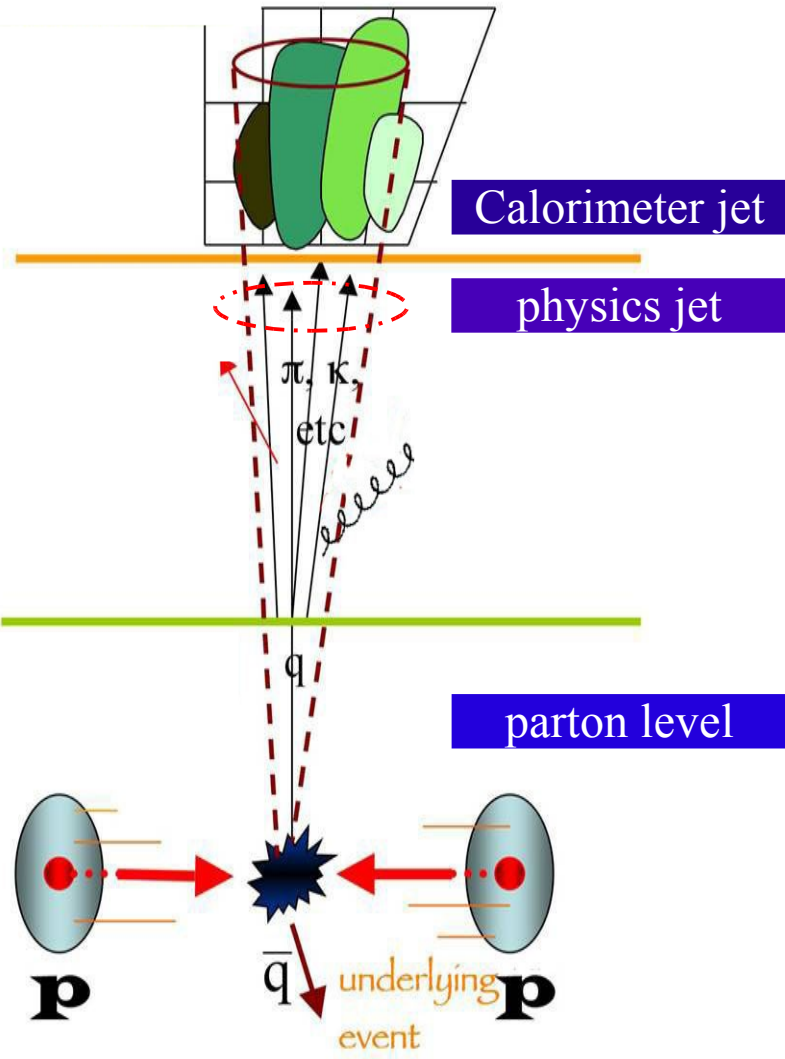
Before calibration
- jets @ electromagnetic scale (does not mean that e and γ are correctly calibrated)

Step 1 : corrects for instrumental effects
- Goal : bring reco jet energy to the total energy of MC jet particles stable (physics jet)
- Calorimeter and physics jets reconstructed using the same clustering algorithm
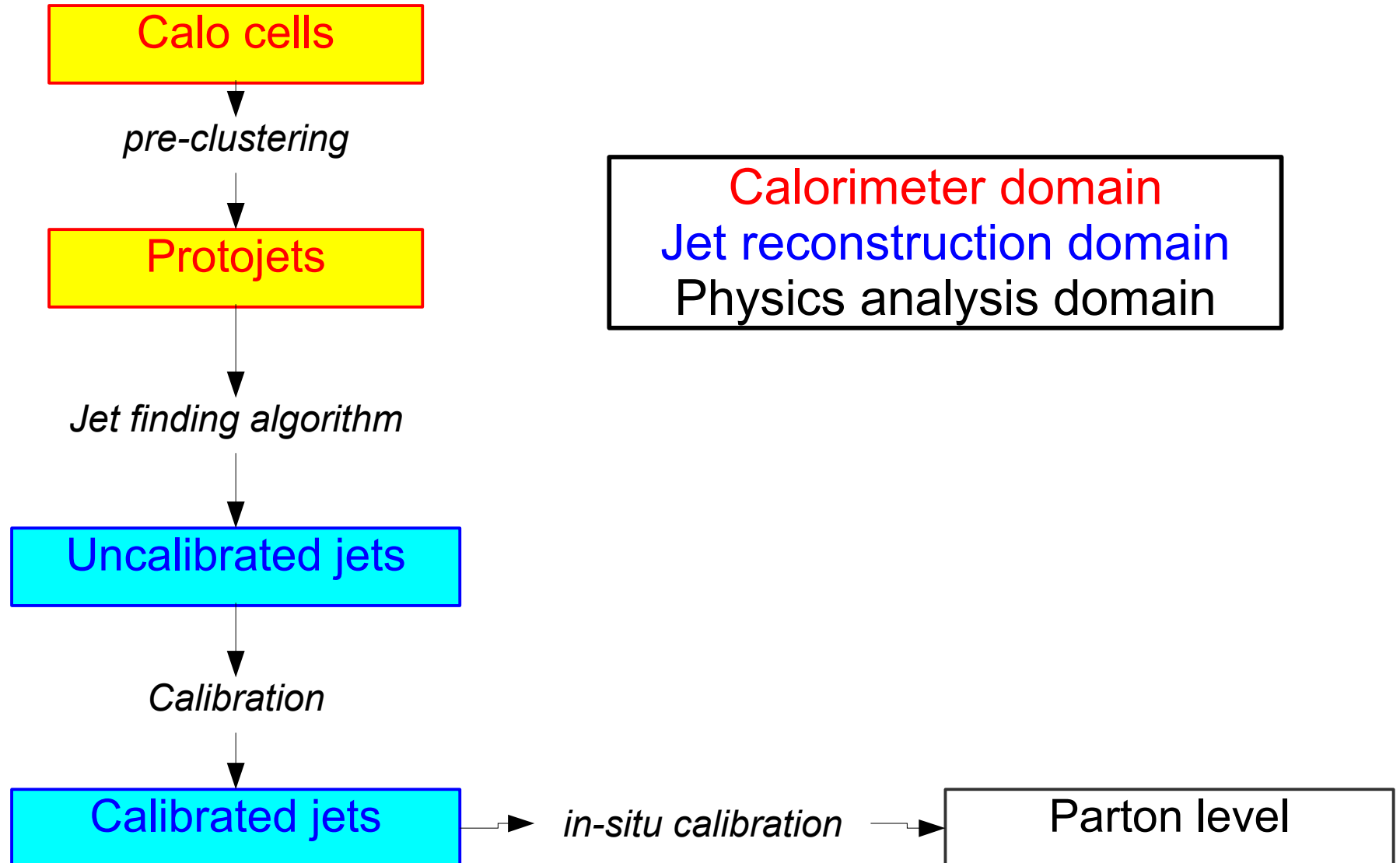- corrects for instrumental effects (gap, dead material, non-compensation)

JES is now independent on detector effects

Step 2 : go back to initial parton energy
- correction for Underlying events, out-of-cluster energy...
- using data (in situ studies)
- using simulation

Strategy for the jets energy calibration

Different steps of the calibration

Reconstruction and calibration scheme

From calo cells to protojets

▶ <u>Input :</u> calorimeter cells (uncalibrated signal)
- Clusters are built grouping cells in :
  - Projective towers $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$ (no longitudinal information)
  - 3D topological clusters : groups nearest-neighbor cells around a seed with significant signal, rejects cells with insignificant signal
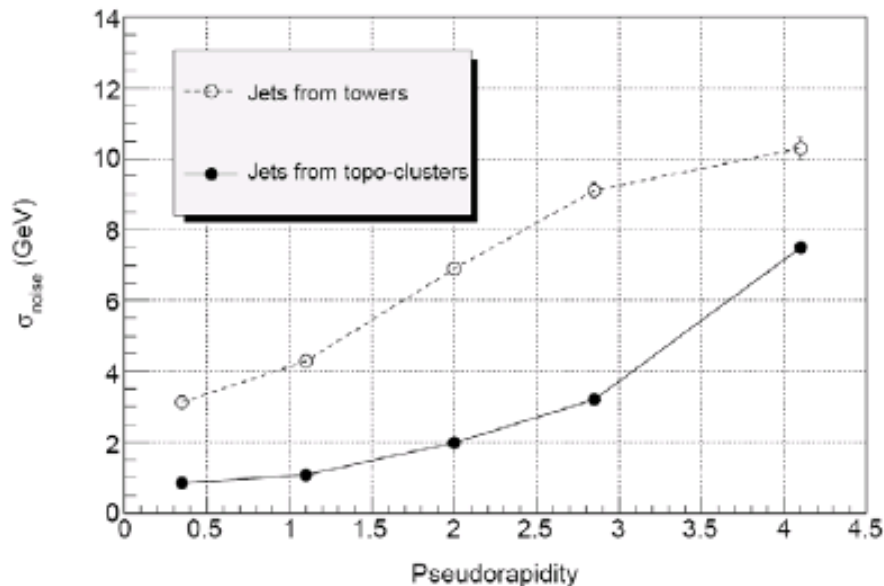
- Better noise reduction / less cells in clusters using the 3D topological clustering

▶ <u>Output :</u> uncalibrated protojets (towers/clusters)

Reconstruction and calibration scheme

From protojets to uncalibrated jets

▶ <u>Input :</u> uncalibrated protojets

- Jet finding algorithm applied on protojets.

- Default algorithm for ATLAS
    - Seeded cone algorithm
        - iterative cone finder starting from seeds
        - Parameters : seed threshold (typically p_T=1 GeV), cone radius (in $\eta\varphi$)
    - Kt algorithm
        - Merge protojets which are close in space and in p_T
        - Parameter : distance D between protojets

- Default parameters in ATLAS :
    - Seeded cone : ΔR=0.4 (W and top physics), ΔR=0.7 (QCD, jet cross-section)
    - Kt : D=0.4 (W and top physics), D=0.6 (QCD, jet cross-section)

▶ <u>Output :</u> uncalibrated jets

Reconstruction and calibration scheme

From uncalibrated to calibrated jets

▶ <u>Input :</u> uncalibrated jets

- Jets need to be calibrated in order to correct for
  - η dependence of the reconstructed energy (gap, dead material)
  - non-linearity (non-compensation, inter-calibration between calorimeters)
  - effect of the magnetic field on soft charged particles

- Calibration based on simulation : reference = truth jet energy E(truth)
  - Truth jets obtained running *the same jet finding algorithm* as reco jets on final state particles from the event generator (except muons, neutrinos and non interacting particles)
  - Each reconstructed jet is associated to the nearest truth jet

Reconstruction and calibration scheme

From uncalibrated to calibrated jets

- Default in ATLAS : H1-style method

- Calibrated jet energy calculated as : $E_{jet}^{reco} = \sum_{i\,cells\,\in\,jet} w_i(\rho_i) E_i$

  - E_i = energy deposited in i-th cell of the calorimeters
  - ρ_i = energy density in cell i (energy over cell volume)
  - w_i = weighting function depending on ρ_i

- Weights obtained minimizing the quantity : $\chi^2 = \sum_{jets} \left(\dfrac{E_{jet}^{reco} - E_{jet}^{truth}}{E_{jet}^{truth}} \right)^2$

- Weights are computed on QCD jets sample

▶ <u>Output :</u> calibrated jets : JES do not depend any more (in principle) on the calorimeter characteristics

Reconstruction and calibration scheme

Performance of the calibration on QCD jets
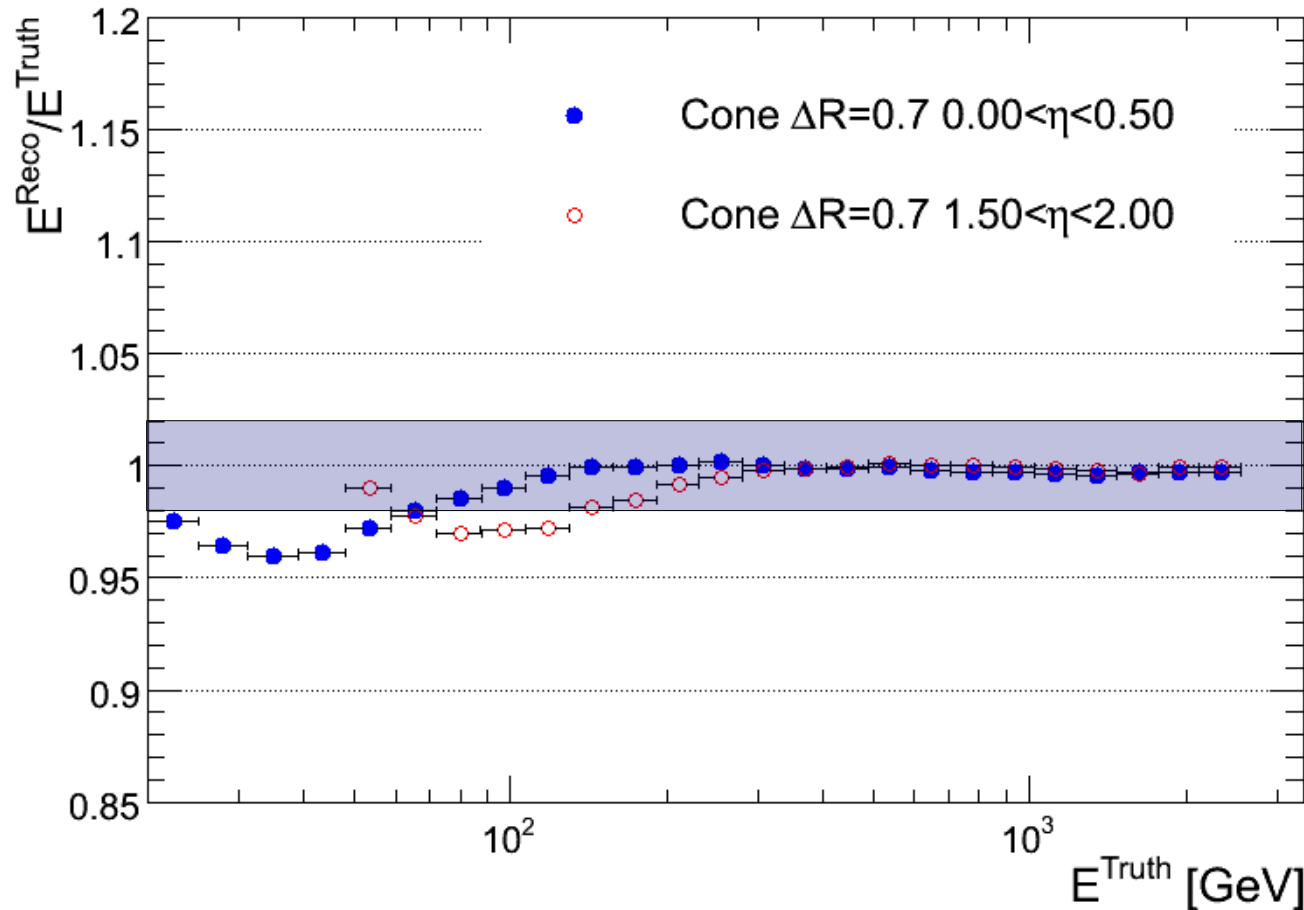
- Non-linearity <2% between 50 GeV and 2 TeV

- Energy resolution :

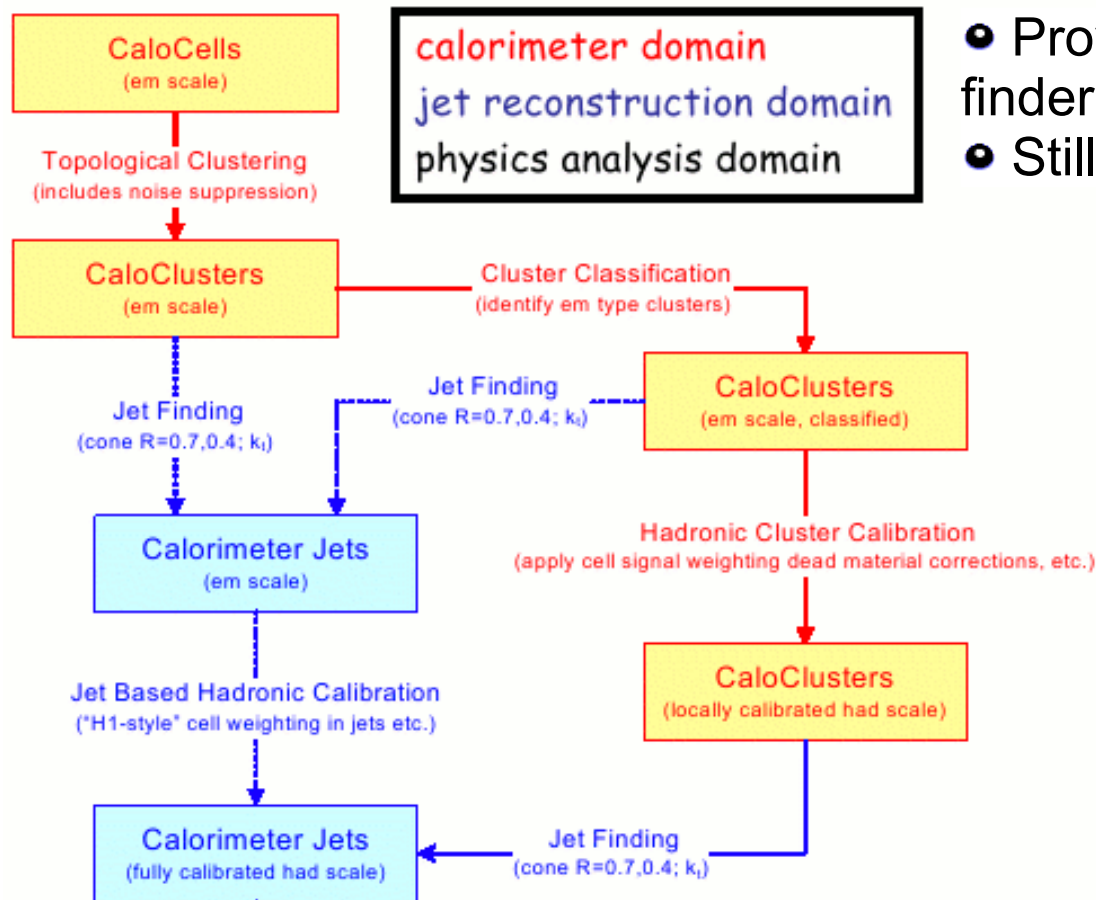$$\frac{\sigma(E)}{E} = \frac{0.64}{\sqrt{E(GeV)}} \oplus 0.026 \oplus \frac{4.9}{E(GeV)}$$

- NB : Estimation based on the simulation of the detector

Alternative scheme for calibration

Local hadron calibration

Use calorimeter information (energy density) to distinguish between e.m. clusters and more hadronic clusters

- Apply a different weight depending on the type of cluster
- Apply the jet finding algorithm on the weighted clusters

calorimeter domain

jet reconstruction domain

physics analysis domain

- Provides better calibrated input to jet finder algorithms
- Still under development...

CaloCells
(em scale)

Topological Clustering
(includes noise suppression)

CaloClusters
(em scale)

Cluster Classification
(identify em type clusters)

Jet Finding
(cone R=0.7,0.4; k_t)

CaloClusters
(em scale, classified)

Jet Finding
(cone R=0.7,0.4; k_t)

Calorimeter Jets
(em scale)

Hadronic Cluster Calibration
(apply cell signal weighting dead material corrections, etc.)

Jet Based Hadronic Calibration
("H1-style" cell weighting in jets etc.)

CaloClusters
(locally calibrated had scale)

Calorimeter Jets
(fully calibrated had scale)

Jet Finding
(cone R=0.7,0.4; k_t)

Validation of the calibration scheme

Simulation of the calorimeters

Jet calibration procedure relies on simulation of calorimeters response to jets. Confrontation between MC and data is a crucial step to validate the calibration scheme

- Many standalone and combined test-beams with calorimeters
  - hadronic and electromagnetic end-caps
  - Forward
  - electromagnetic and hadronic central barrels

- Different types of particles : π, e, p, μ

- Large range in energy (from 1 to 350 GeV) and pseudo-rapidity

Validation of the calibration scheme

Simulation of the calorimeters

- Systematic comparison between TB data and MC : how well can simulation reproduce :
  - total energy distribution, linearity, energy resolution
  - shower profile (longitudinal and lateral), e/π
  - ...

- Comparison between different versions of GEANT4

- Comparison between physics lists (QGSP, + Bertini cascade, + quasi-elastic scattering...) depending the energy range

- Interact and iterate with physics simulation experts until required precision is achieved

- Define one or more "optimized and recommended" physics lists and parameters (e.g. range cuts, etc...)

Validation of the calibration scheme

Simulation of the fragmentation

Calibration designed to bring the JES to the total energy of particles composing the jets. Going back to the parton level requests
- *good description of fragmentation*
- *good description of the underlying event activity*

- A powerful tool : use the conservation of transverse impulsion in events with back-to-back objects : *Pt balance*

- Provides many informations extracted from data that can be compared with simulation
  - effect of the jet finding algorithm
  - jet calibration
  - underlaying event

- Several strategies under study
  - Z/γ + jet : relate the hadronic scale of the jets with the well calibrated em objects
  - QCD back-to-back di-jets (higher statistics)

Validation of the calibration scheme

Simulation of the fragmentation

Pt balance in γ + jet system
Select the leading γ and the leading jet in the opposite hemisphere

- Analysis can be performed at various levels of the calibration procedure :
  - Before the jets calibration to disentangle physics effects from calibration effects
    - validate the fragmentation model
    - study the underlying events
  - After the jets calibration
    - study of the out-of-cluster energy, underlying event
    - jets radial profile
    - comparative studies on jet finding algorithm

- Should also be possible to extract correction factor on data to bring the jet energy to the initial parton energy

Validation of the calibration scheme

*Simulation of the fragmentation*

QCD di-jet balance
Select events with 2 jets back-to-back (higher statistics that Z/γ + jet)

- Can be used to check of the uniformity vs pseudo rapidity
  - First jet in a reference region (central region : smaller amount of dead material)
  - Second jet as a probe for eta regions where detector geometry is more complex (gap, cracks)

Validation of the calibration scheme

An interesting test on TB data

- Attempt to transfer MC calibration to real data
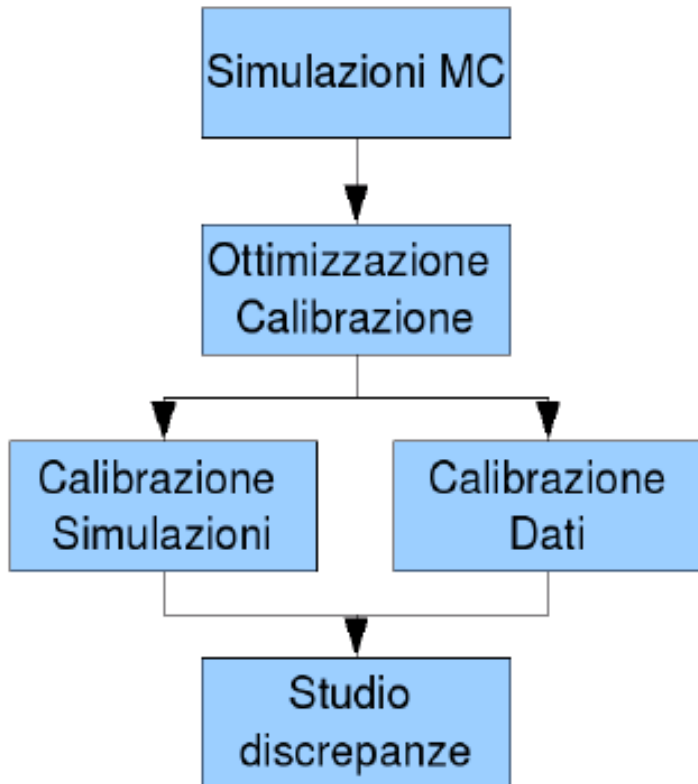
- Calibration factors (H1 weights) computed with MC, for pions in the TB configuration

- Application of these weights to real TB data

- after calibration read data ~3% off wrt simulation

Summary

- In ATLAS, jets calibration performed in two steps :
  - Correction of instrumental effects (calibration to the jets particles level)
  - Correction for detector independent effects (out-of-cluster energy, UE, ...)

- Both steps are based on simulation : a good MC description is crucial
  - detector response : use of the TB results
  - physics : use on in-situ calibration (eg Pt balance)

- The validation of the calorimeters simulation is in progress
  - MC/data comparison for electrons and pions on a large energy range
  - comparisons between different physics lists and versions of G4

- Pt balance : a tool to extract informations from data
  - This will be used to check and validate the second step of the calibration procedure

- More sophisticated calibration schemes based on local hadron calibration are under development/validation.

Backup slides

Clustering

At present, cells are clusterized in two ways w.r.t. jet reconstruction:

-Consider calorimetric towers (2D)

-3D clustering accordingly to energy deposits in neighbouring cells (Topological Clusters)

TopoClusters – some details:

• Cells with $|E/\sigma_{noise}|>T_{seed}$ are used to generate a TopoCluster. The adiacent cells are checked to be associated to the cluster. Default:
$$T_{seed} = 4\sigma_{noise}$$

• Cells with $|E/\sigma_{noise}| > T_{neigh}$ are used to expand the cluster. The adiacent cells are checked to be associated to the cluster. Default:
$$T_{neigh} = 2\sigma_{noise}$$

• Cells with $|E/\sigma_{noise}| > T_{used}$ can be used to expand the cluster. Default $T_{used}=0$
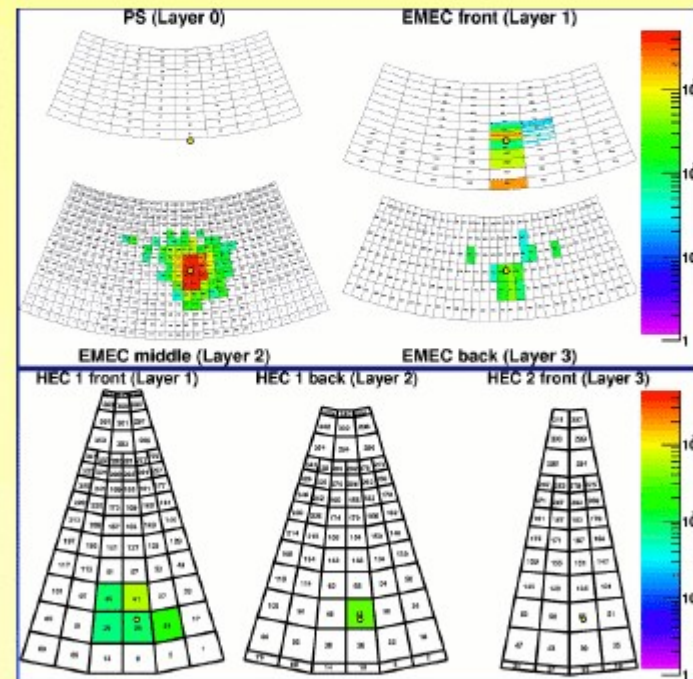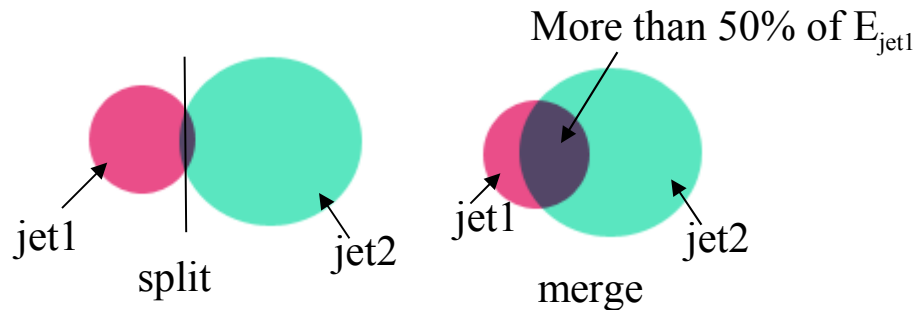
Cluster for 120 GeV pion in EMEC and HEC (2002 Test Beam data)

Cone algorithm : slide from Michiru Kaneda

Cone Algorithm (Seeded Algorithm)
- E_T Seed::2GeV
- Collect neighbors around a seed in $\Delta R = \sqrt{(\Delta \eta^2 + \Delta \phi^2)}$
  - ☛ $\Delta R = 0.7$::To avoid fragmentation loss for low Pt jets
  - ☛ $\Delta R = 0.4$::Necessary at high luminosity and to separate overlapping jets
- Split and Merge
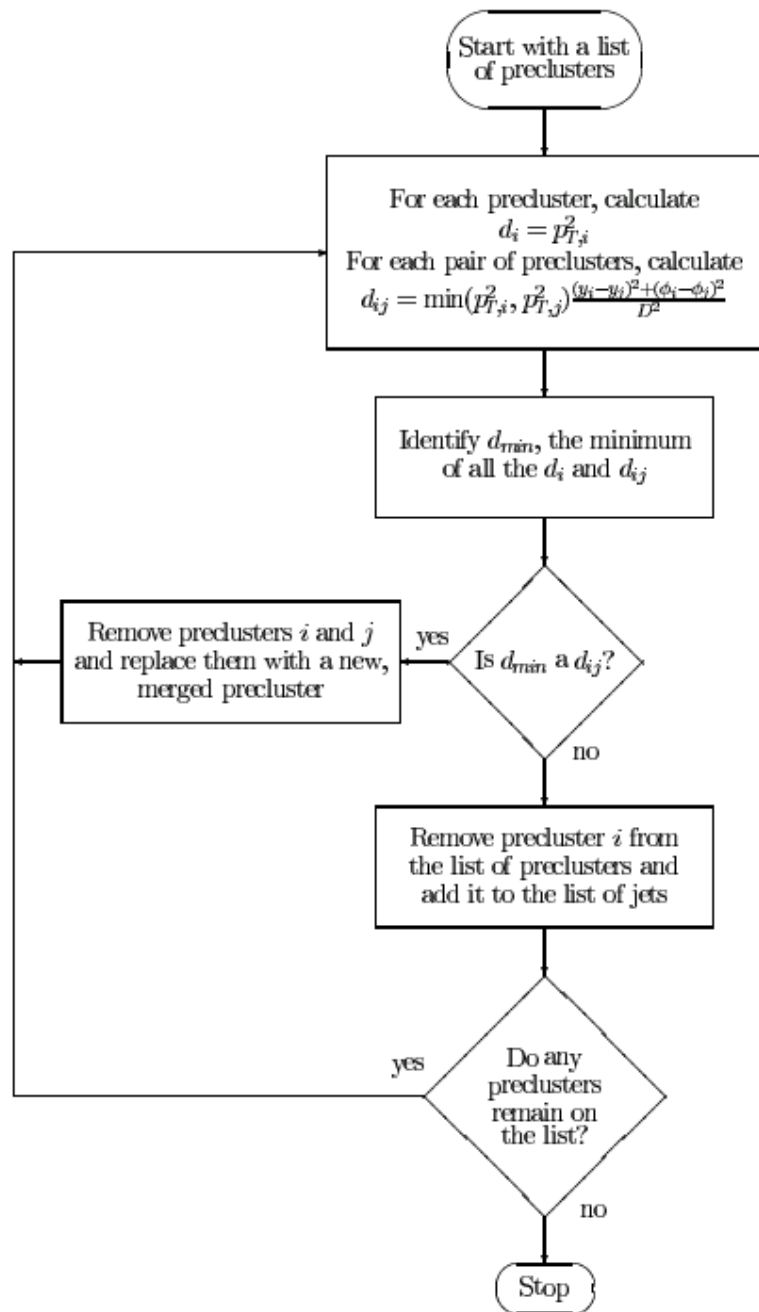 - – Merge two jets if overlapping energy is more than 50% of the least energetic jet energy.

More than 50% of E_{jet1}

jet1   split   jet2   jet1   merge   jet2

Kt algorithm

Start with a list of preclusters

For each precluster, calculate
$$d_i = p_{T,i}^2$$
For each pair of preclusters, calculate
$$d_{ij} = \min(p_{T,i}^2, p_{T,j}^2)\frac{(y_i - y_j)^2 + (\phi_i - \phi_j)^2}{D^2}$$

Identify d_{min}, the minimum of all the d_i and d_{ij}

Is d_{min} a d_{ij}?

yes → Remove preclusters i and j and replace them with a new, merged precluster

no

Remove precluster i from the list of preclusters and add it to the list of jets

Do any preclusters remain on the list?

yes

no

Stop

(a)

(b)

(c)

(d)

(e)

(f)

Figure 20. A simplified example of the final state of a hadron collision. The open arrows represent preclusters in the event, and the solid arrows represent the final jets reconstructed by the K_T algorithm. The six diagrams show successive iterations of the algorithm. In each diagram, either a jet is defined (when it is well separated from all other preclusters), or two preclusters are merged (when they have small relative $k_\perp$). The asterisk labels the relevant precluster(s) at each step.
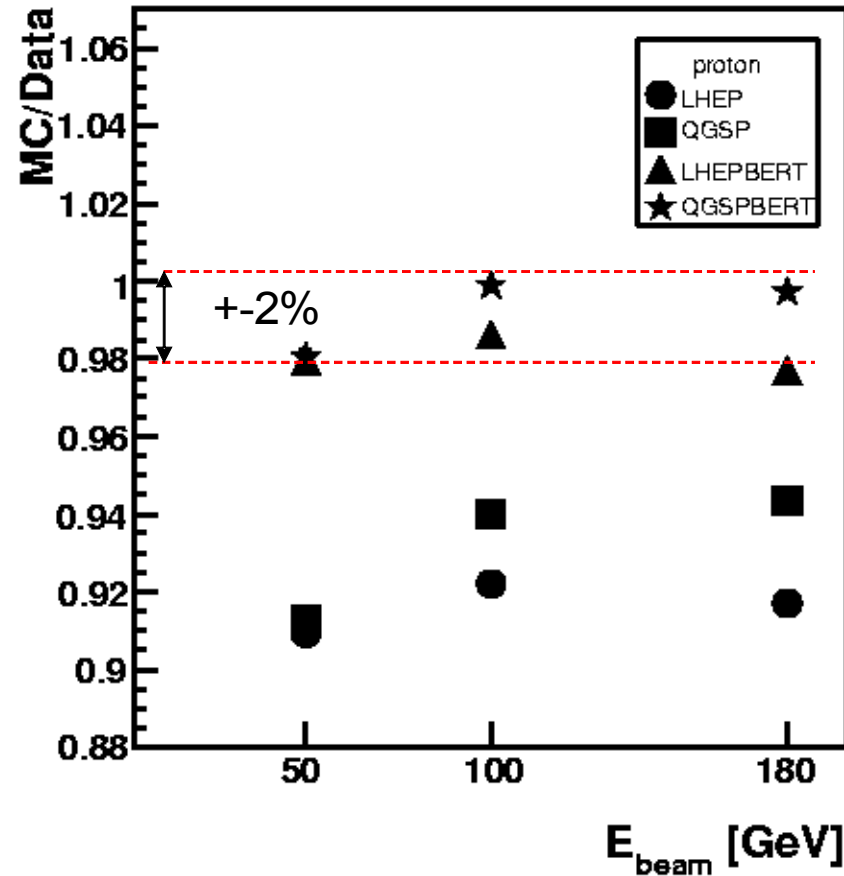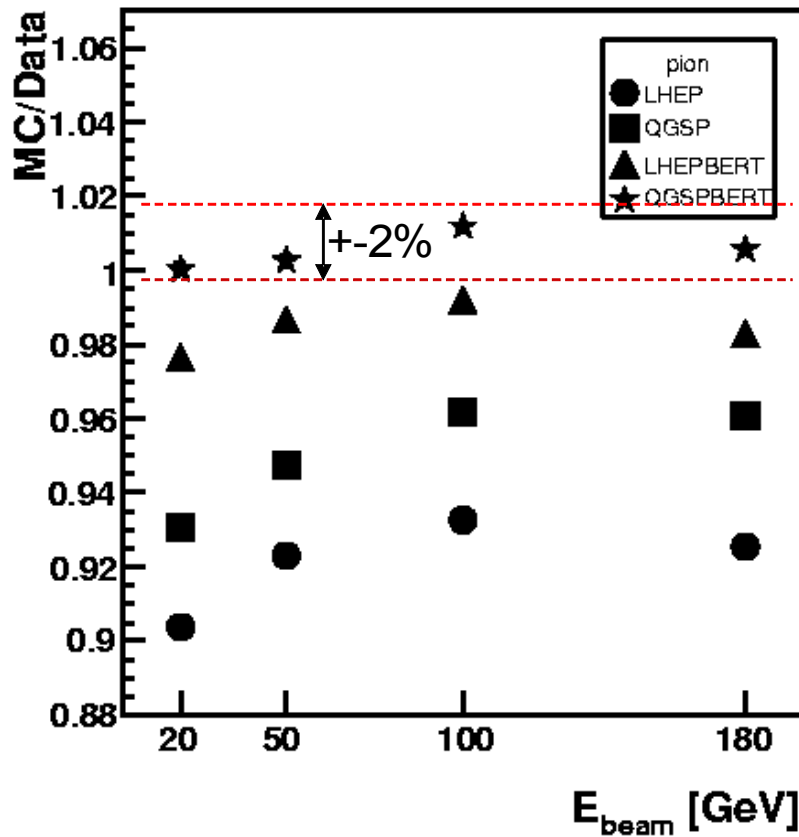
Some results from the Physics Validation Project

Pions and protons at 90° in TileCal

G49
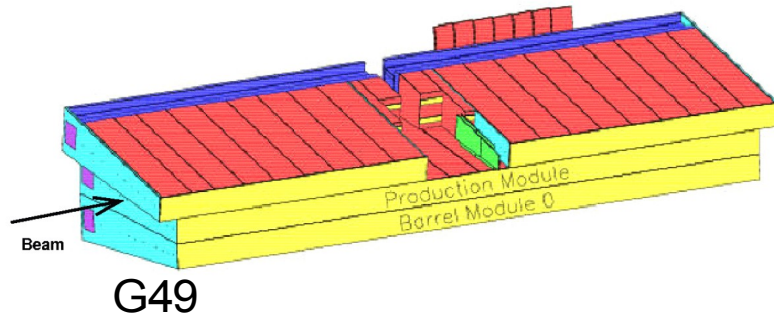
T.Carli, M.Simonyan
Physics Validation Meeting Oct 17, 2007

Erec/Ebeam

Some results from the Physics Validation Project

ATLAS Hadronic End-cap calorimeter

A.Kiryunin, P.Strizenec
Physics Validation Meeting Oct 17, 2007

New round of GEANT4 based simulations with version 9.0 was carried out for the HEC stand-alone testbeam. Comparison with experimental results and results of previous simulations is done.
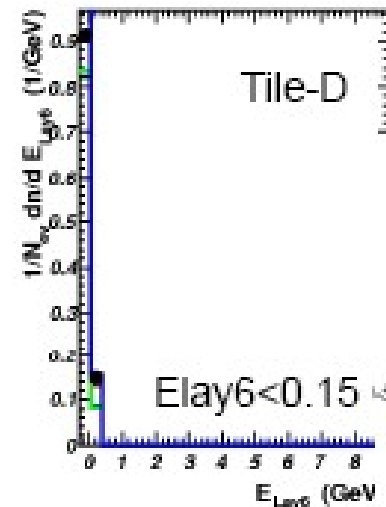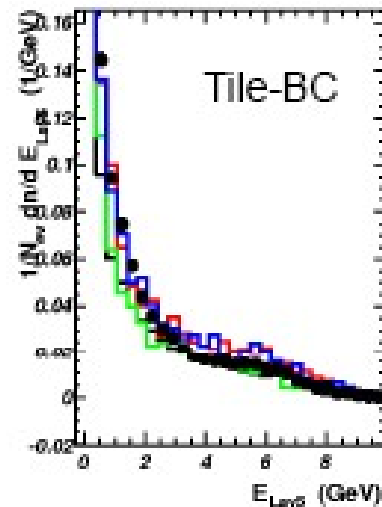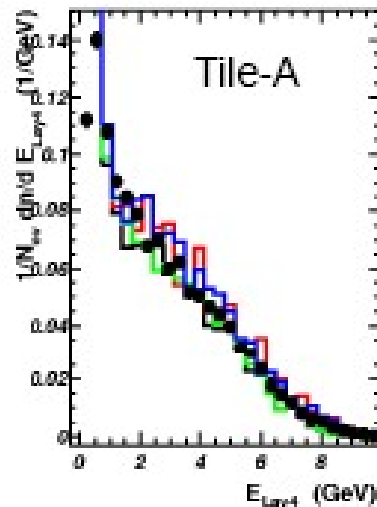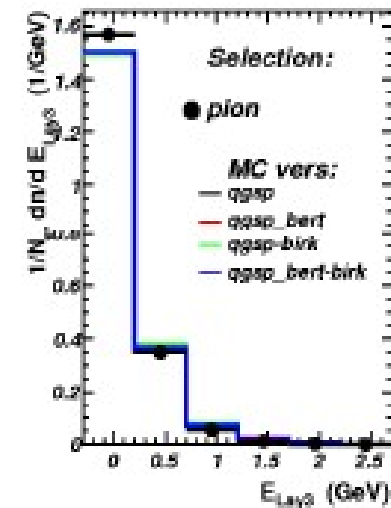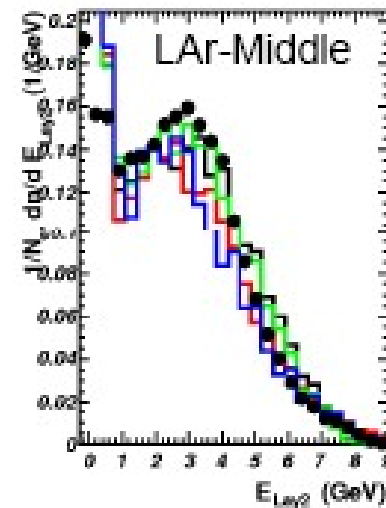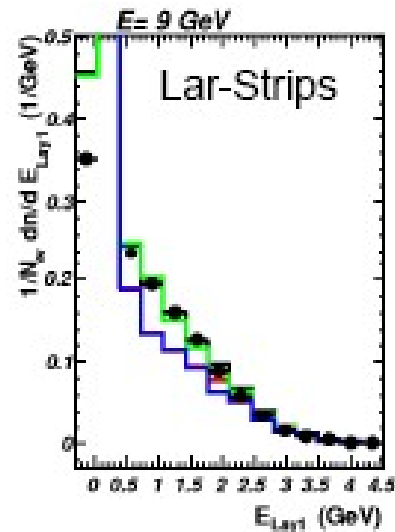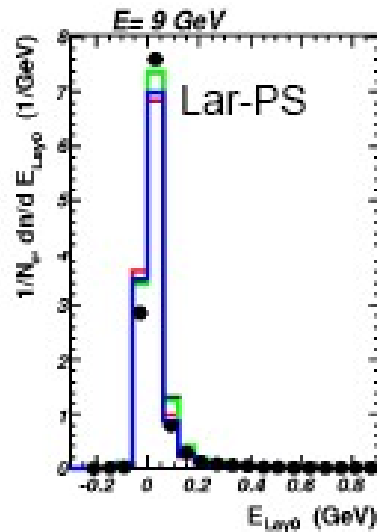
- Electron simulations:
    - predictions on EM-scale are in agreement with experimental data
    - electron energy resolution is still too optimistic
- QGSP hadronic physics list:
    - rather good predictions on e/π-ratio and pion energy resolution (problems appeared in version 8.2 are overcome)
    - problems in description of longitudinal shapes of hadronic showers
- Quasi-elastic model in QGSP:
    - no influence on pion energy resolution and e/π-ratio
    - small improvement of longitudinal profiles of hadronic showers
- Physics list QGSP-BERT with Bertini cascade model:
    - describes well longitudinal shapes of hadronic showers
    - predicts too low values of the pion energy resolution and too high values of the pion energy depositions

ATLAS

Some results from the Physics Validation Project

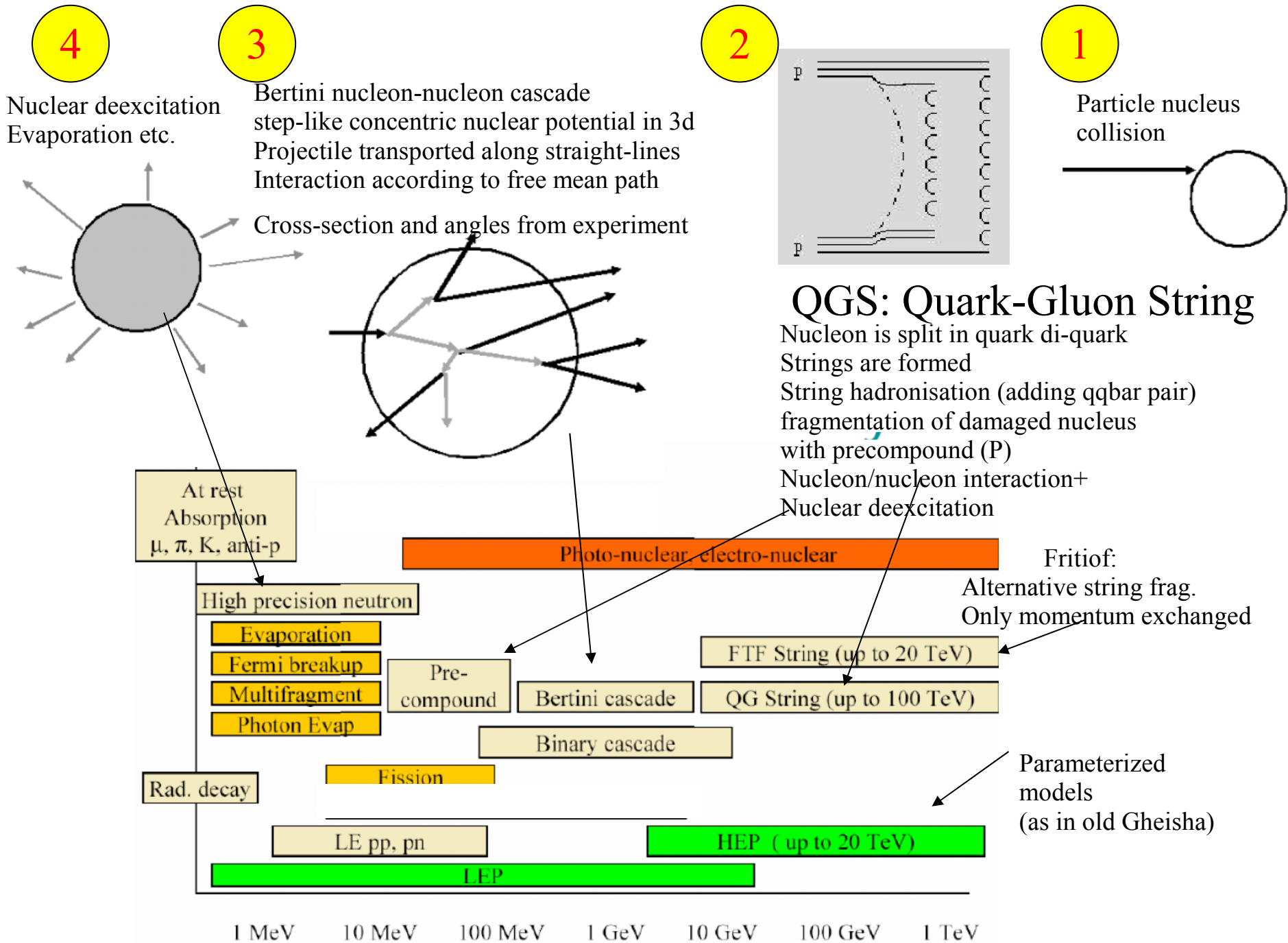*Combined central calorimetry – very low energy pions*

T.Carli
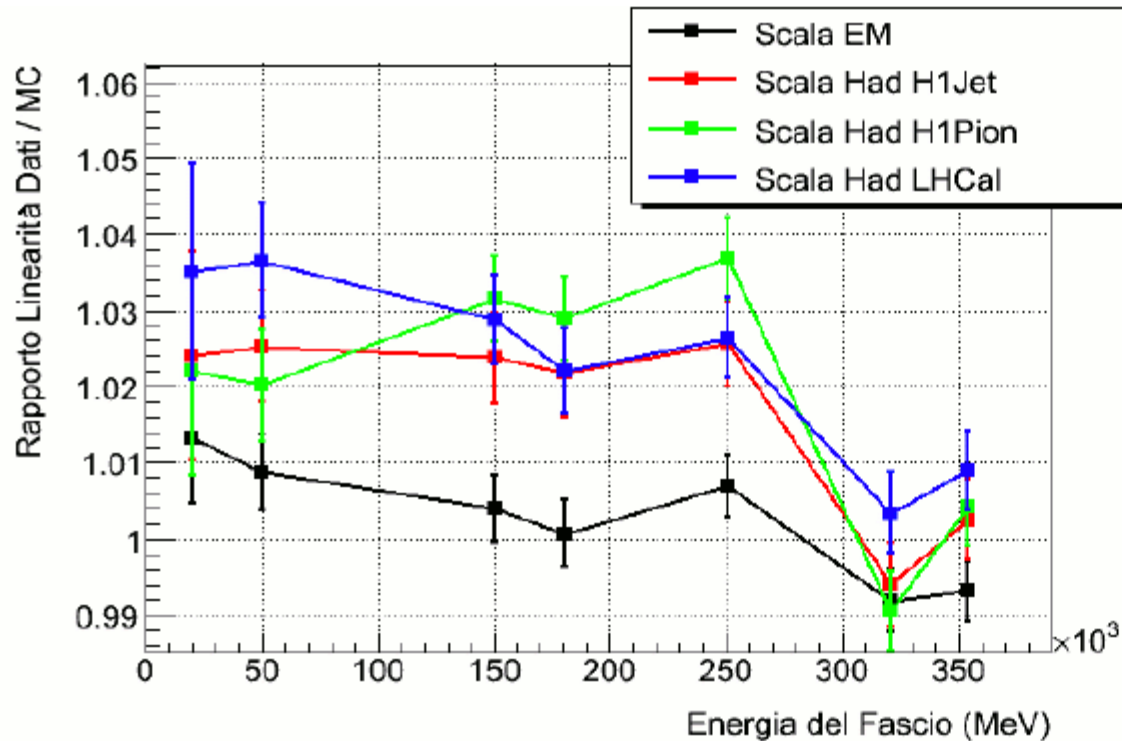Physics Validation Meeting Oct 17, 2007
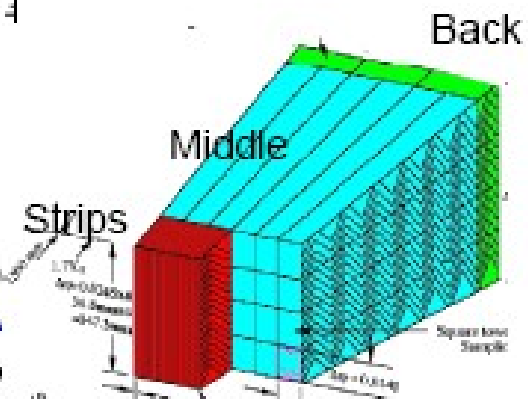
More about physics lists

4

Nuclear deexcitation
Evaporation etc.

3

Bertini nucleon-nucleon cascade
step-like concentric nuclear potential in 3d
Projectile transported along straight-lines
Interaction according to free mean path

Cross-section and angles from experiment

2

p

C

p

C

QGS: Quark-Gluon String

Nucleon is split in quark di-quark
Strings are formed
String hadronisation (adding qqbar pair)
fragmentation of damaged nucleus
with precompound (P)
Nucleon/nucleon interaction+
Nuclear deexcitation

1

Particle nucleus
collision

Fritiof:
Alternative string frag.
Only momentum exchanged

At rest
Absorption
μ, π, K, anti-p

Photo-nuclear, electro-nuclear

High precision neutron

Evaporation

Fermi breakup

Multifragment

Photon Evap

Pre-compound

Bertini cascade

FTF String (up to 20 TeV)

QG String (up to 100 TeV)

Binary cascade

Rad. decay

Fission

Parameterized
models
(as in old Gheisha)

LE pp, pn

HEP (up to 20 TeV)

LEP

| 1 MeV | 10 MeV | 100 MeV | 1 GeV | 10 GeV | 100 GeV | 1 TeV |

Transfer of MC weights to TB data

Rapporti:
per capire le **discrepanze** introdotte dalla **non corretta descrizione** dei dati da parte del **Monte Carlo**.
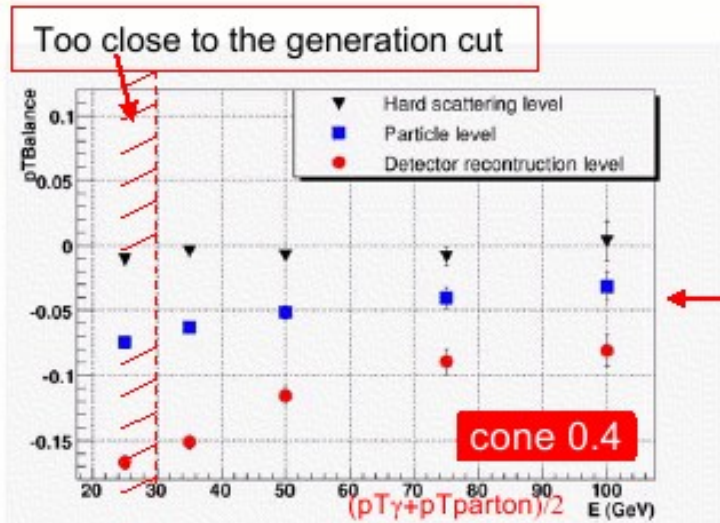
Incertezze:
- Scala elettromagnetica
- Introdotte nella calibrazione

Slide from Paolo Francavilla

Calib. Algo	Linearità	Risoluzione
Scala EM	1.3%	19.5%
Introdotti dalla calibrazione		
H1_Jet	2.1%	22.4%
H1_Pion	3.0%	11.7%
LHCal	2.8%	27.0%

Pt balance with gamma+jet

Slide from S.Jorgensen, CCW San Feliu Sept. 2006

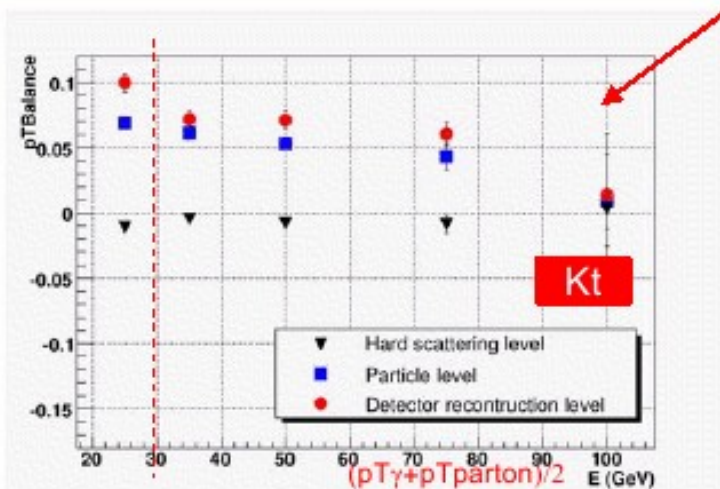Too close to the generation cut

- Cone 0.4 collects only the core of the jet

- Leakage out of cone and UE compensate in cone 0.7
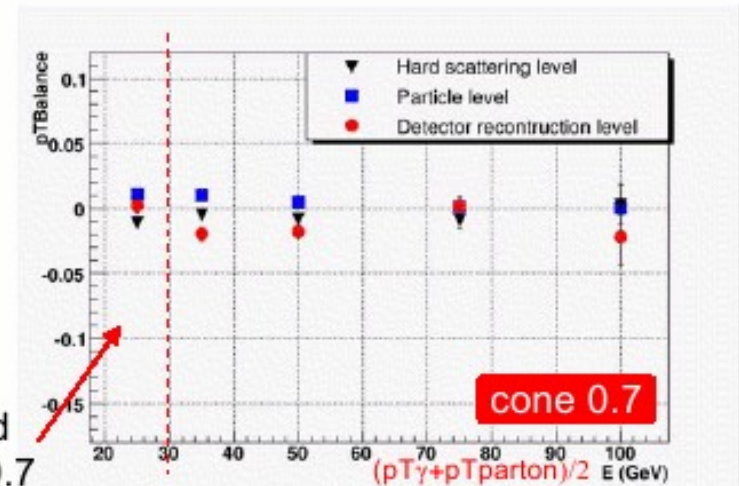
- Excess of energy in Kt jets (D=1) due to UE and noise

Differences between recon and particle levels related to the standard H1 weighting (calibrated for cone 0.7)

- Biases on pT balance MOP for the different jet algorithms:

Algorithms	Cone 0.7	Cone 0.4	Kt (D=1)
Parton level	-1 - 0%	-1 - 0%	-1 - 0%
Particle level	1 - 0%	-6 - -3%	6 - 1%
Recon level	-2 - 0%	-15 - -7%	7 - 2%

Pt balance with QCD jets

Example of studies realized by V.Lendermann, P.Weber, P.Hodgson