The Level-2 calorimeter status

SLAC ATLAS Forum

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Outline

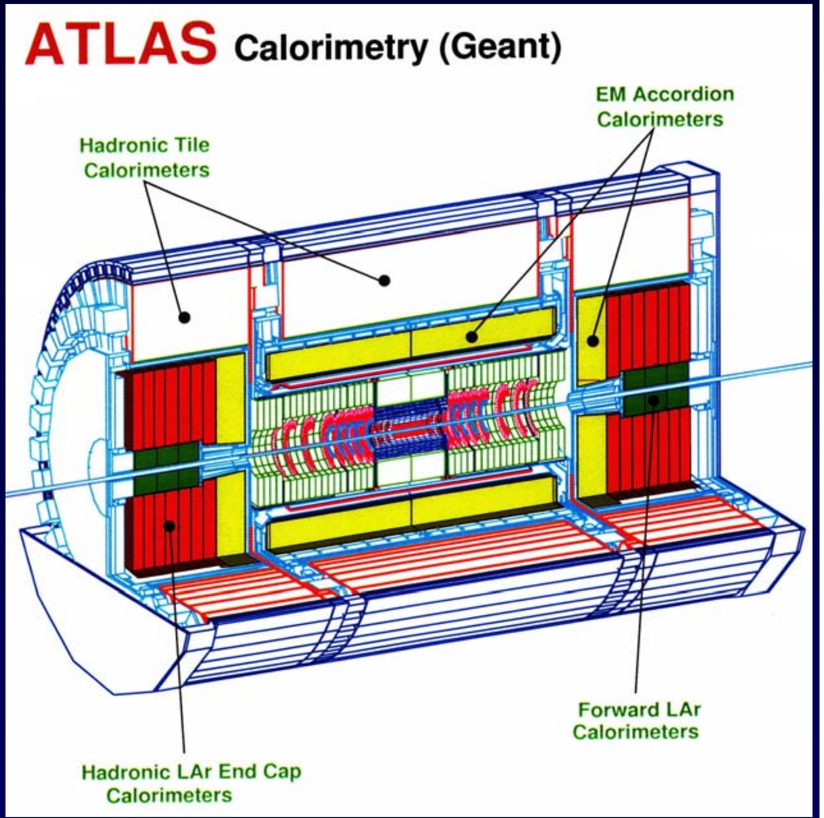
- Introduction
- The ATLAS calorimeter
- The ATLAS trigger system
- The Level-2 jet trigger
- The missing E_T in the High-Level trigger
- Summary

Introduction

- At the LHC many processes contain high-pT objects in the final state: e/γ, μ, τ, jets, E_T^{miss}.
- At the Level-2 trigger the full calorimeter granularity is available $O(10^5)$ cells.
- At Level-2 the average processing time per event is ~10ms.
- The challenge of Level-2 Calorimeter algorithms is quick access to the necessary calorimeter data
- This is most crucial for the Jets and missing E_T triggers.
- In this talk I will present the current status of the Level-2 jet trigger missing ET trigger in the High-Level Trigger (=Level-2 + Event Filter).

The ATLAS calorimeter

- **EM calorimeter**
  - Liquid Ar/Pb
  - 3 longitudinal samplings (+ presampler)
  - Barrel region ($|\eta|<1.475$)
  - End-caps ($1.375<|\eta|<2.5$)
  - Accordion-shape
- **Hadronic Calorimeter**
  - Tiles/Iron plates in barrel ($|\eta|<1.7$)
  - End-caps ($1.5 < |\eta|$ 3.2) use LAr/Cu sampling
- **Forward Calorimeter**
  - $3.1 < |\eta| < 4.9$
  - 1 EM module, 2 HAD modules



The ATLAS trigger

Level 1 (hardware):

Identifies *Regions of Interest (RoI)*

e/γ, μ, τ, jet candidates above E_T threshold

Uses Calorimeters and Muon chambers with reduced granularity.

2.5μs latency

Level 2 O(500PCs):

Seeded by LVL1 RoI

Full granularity of the detector available

Performs calo-track matching

<latency> ~ 10ms

Event Filter O(1900PCs):

Offline-like algorithms

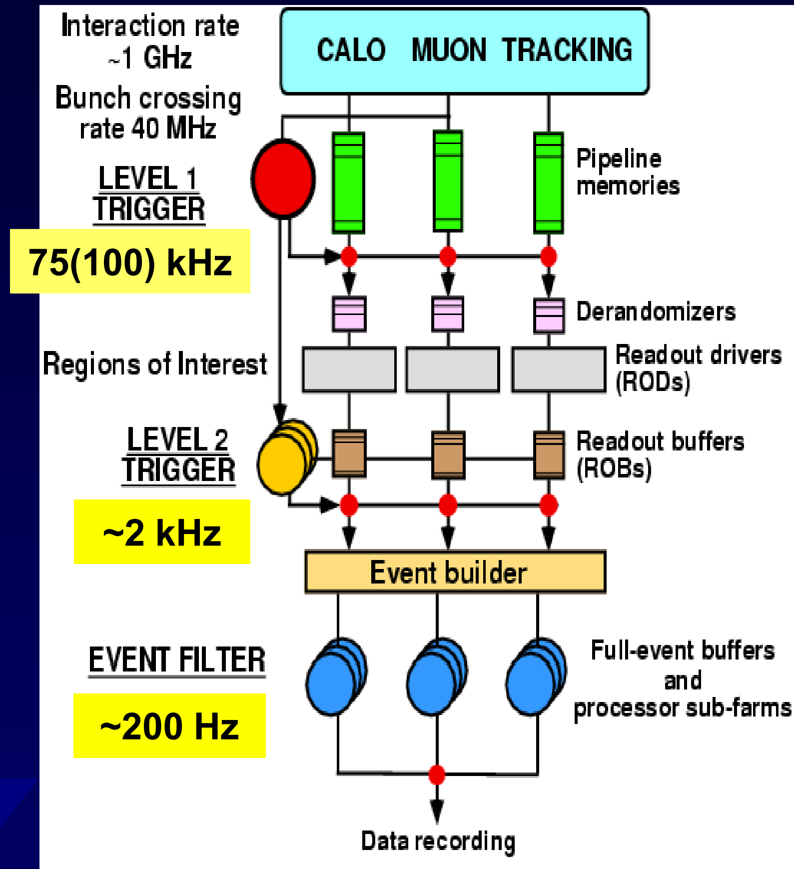
Refines LVL2 decision

Full event building

<latency> ~1s

High Level Trigger (PC farm)

Execution time



The Level-2 jet trigger

The algorithm

Uses Level-1 jet RoI as seed (in $|\eta| < 3.2$)

– Sum of trigger towers (2x2, 3x3 or 4x4) with E_T and (η,φ) position

(trigger towers ≡ sums of calorimeter cells in $\Delta\varphi x \Delta\eta \approx 0.2x0.2$)

Top algorithm (T2CaloJet) executes three tools:

1. Data preparation (T2CaloJetGridFromCells or T2CaloJetGridFromFEBHeader):

– Read out selected calorimeter region around the Level-1 jet RoI position.

2. Cone algorithm (T2CaloJetCone):

– Assume cone-shaped jet with defined R_{cone}.

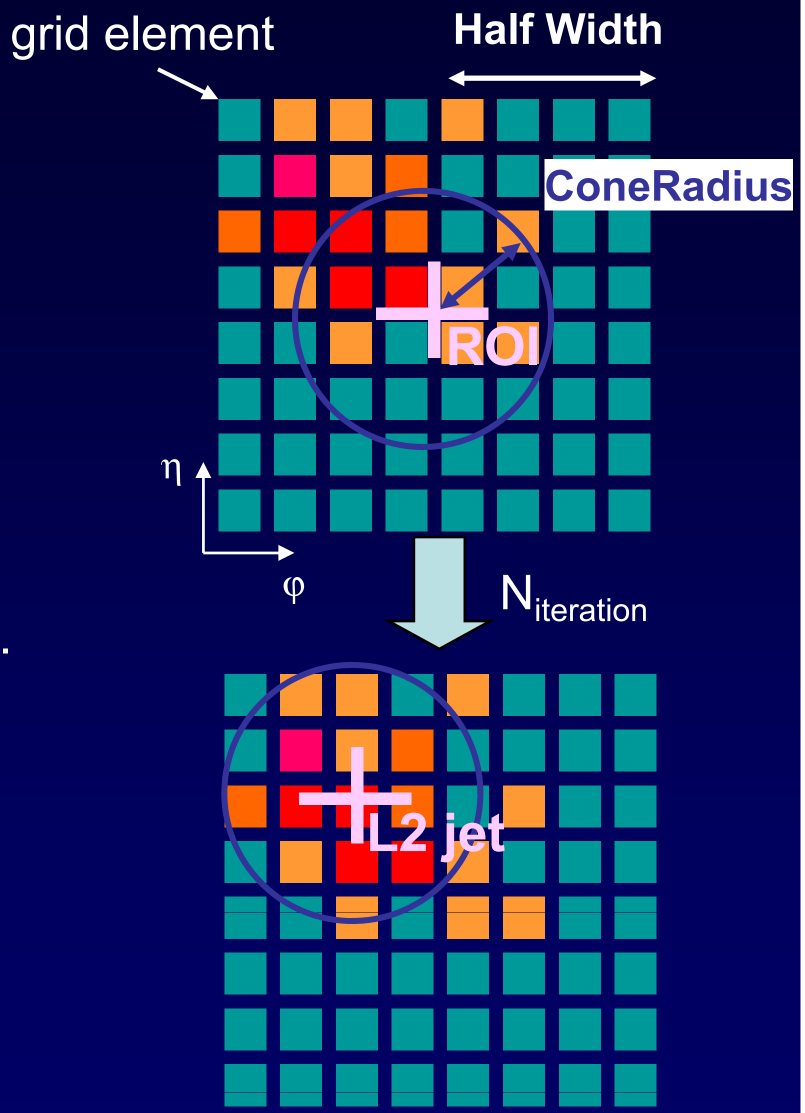
3. Calibration (T2CaloSampling):

– Apply calibration weights.

Export final result (transverse jet energy E_T, η and φ position).

Level-2 jet trigger algorithm

- The Level-1 RoI is passed to Level-2 ≡ "jet0".
- Data preparation access data around jet0 position with given HalfWidth.
- Creates grid of detector readout elements
- Cone algorithm iteration:
  - Set coneRadius $R_{cone}=(\Delta\eta^2+\Delta\varphi^2)^{1/2}$ and use grid elements inside cone
  - Calculate energy-weighted position (η,φ).
  - Update jet E_T, η, $\varphi \equiv$ "jet1"
  - Iterate $N_{iteration}$ times: jet1 ➡ … ➡ jetN
- Apply calibration weights.
- Export final values $E_{T,L2}$, η_{L2}, φ_{L2}



Study jet trigger performance as a function of:

HalfWidth, $N_{iteration}$, R_{cone}, calibration

Data preparation

The data preparation is the most critical step in terms of timing performance ($O(10^5)$ calorimeter cells)

Choice between two data preparation methods:

- **cell-based method**:

  Uses full granularity (cells) of the ATLAS calorimeters

  – uses E_T, η, φ for each calorimeter cell

- **LArFEB-based method**:

  Uses information from the *liquid argon front end boards* (*LArFEB*s)

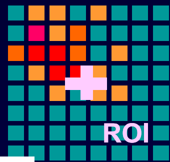
  – One LArFEB receives signals from 128 calorimeter cells.

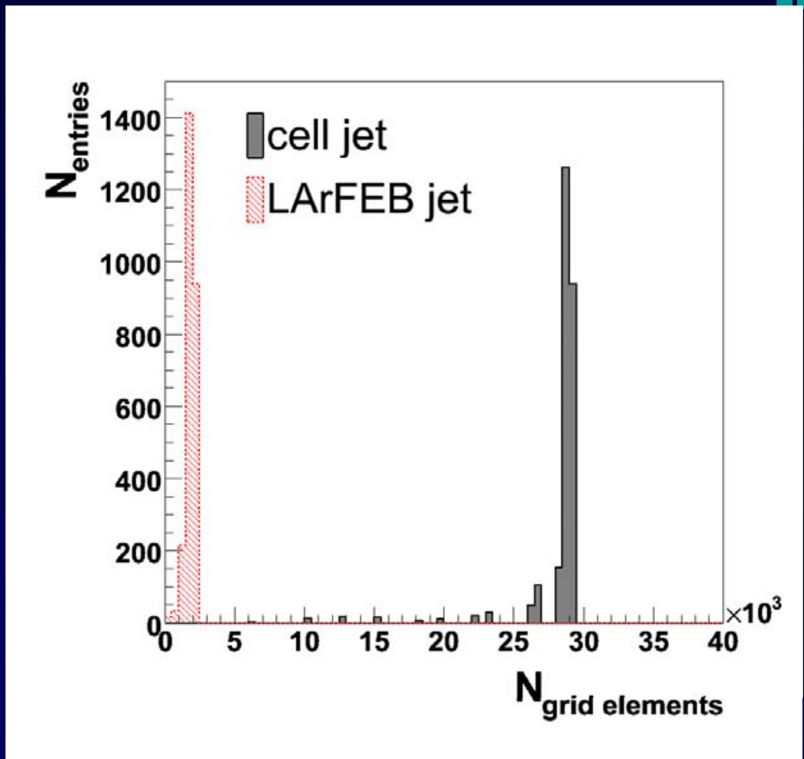
  – Uses E_T, η, φ for each LArFEB

Choice between two different kind of jets: **cell-based jets** *or* **LArFEB-based jets**!

System performance

Number of grid elements read out by the data preparation methods.





Timing performance (in ms)
2.8GHz CPU

	Cells	LArFEBs
Half Width	1.0	1.0
R_{cone}	0.7	0.7
RegionSelector	2.92	2.16
LAr ByteStreamConv	9.38	0.44
Tile ByteStreamConv	3.15	2.95
Prepare Grid	12.79	11.34
Cone algo ($N_{iteration}$ = 1)	16.63	1.08
Total	45.54	12.85

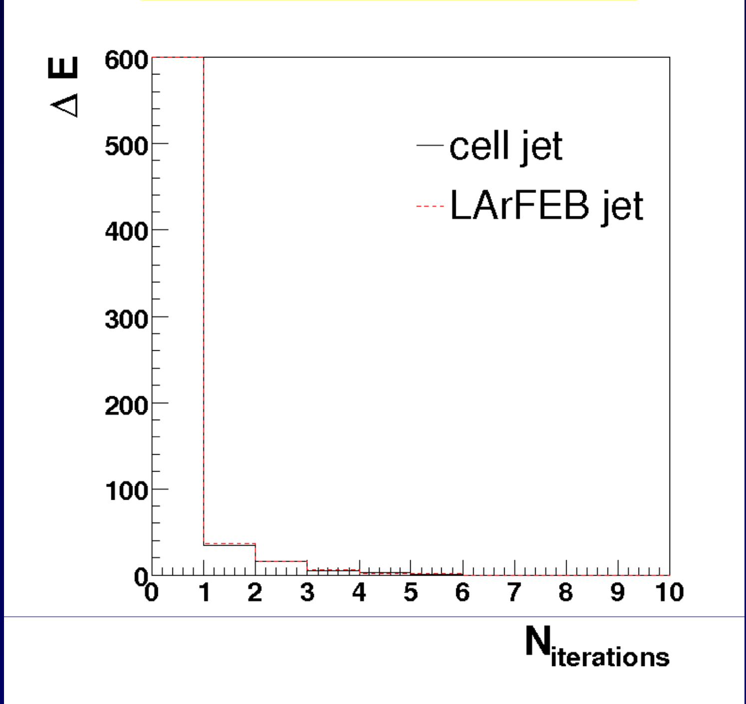
x4 faster!

LArFEB method reduces the amount of data by one order of magnitude.
LArFEB-based method is ~4 times faster than cell-based method!!

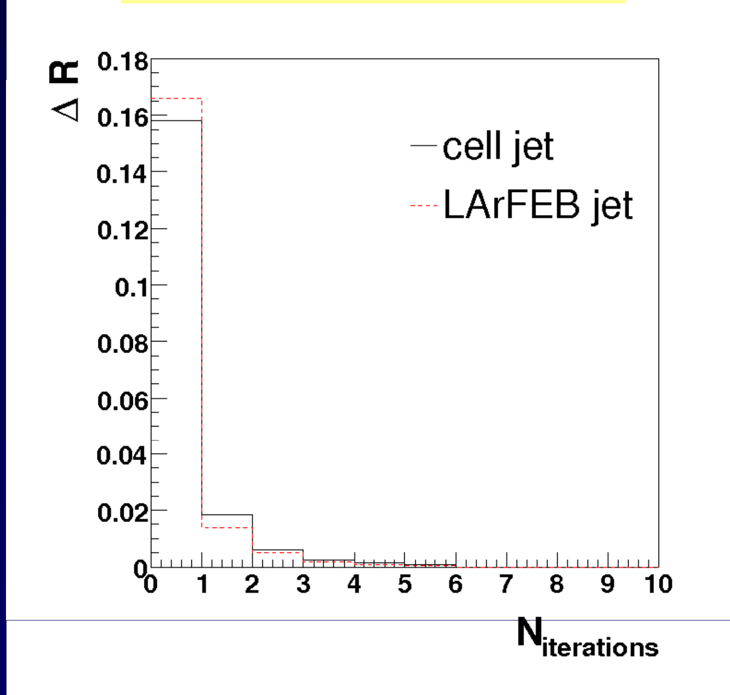
L2 jet system performance

Difference between two consecutive iterations of T2CaloJetConeTool
(Using 1000 dijet events pt>2240GeV)

ΔE=jetN(E)−jetN-1(E)



ΔR=jetN(R)−jetN-1(R)



The cone algorithm converges after 3-4 iterations for both data preparation methods

Data samples

Use QCD dijet samples:

Name	pT range (GeV)	σ (pb)
J3	70-140	$5.884 \cdot 10^6$
J4	140-280	$3.084 \cdot 10^5$
J5	280-560	$1.247 \cdot 10^4$
J6	560-1120	360.4
J7	1120-2240	5.707
J8	>2240	0.0244

Data files

From CSC production:

- events generated with Pythia 6.323
- simulation & digitization with Athena 11.0.42

→ files distributed on the GRID (LCG, OSG)

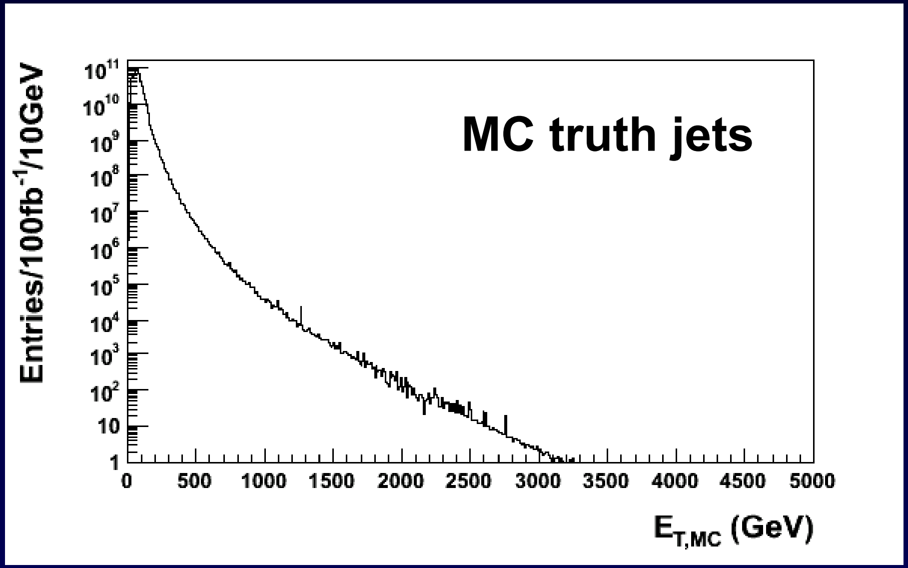
Private production:

- offline and Level-2 jet trigger reconstruction with Athena 12.0.3 (+private code).

~300K events → use the GRID (LCG)!

Final analysis on CBNTs produced from ESDs

MC truth vs. Level-2 jets



MC truth jet definition:

- R_{cone}=0.4, E_{seed} > 2GeV, E_{cone} > 10GeV

Level-2 jet definition in this analysis:

- R_{cone}=0.4, HalfWidth=0.7, $N_{iteration}$=3

Compare L2 jets with MC truth jets |η| < 3.2: match MC truth – L2 jet: ΔR_{match} < 0.08

compare MC truth jets with Level-2 jets → Cell-based / LArFEB-based

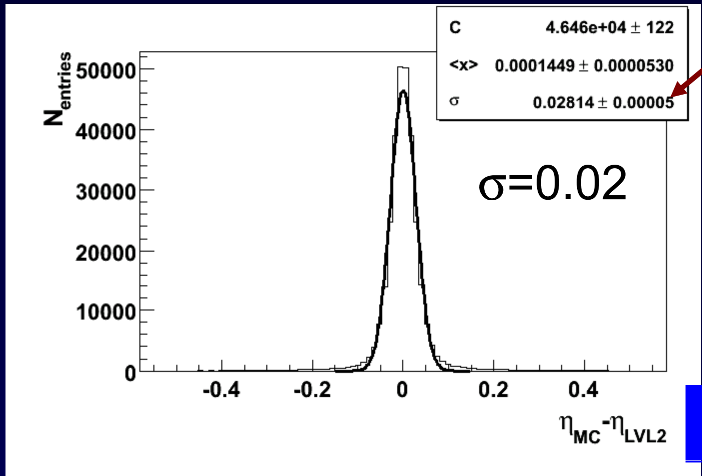
Two kind of LVL2 jets!!

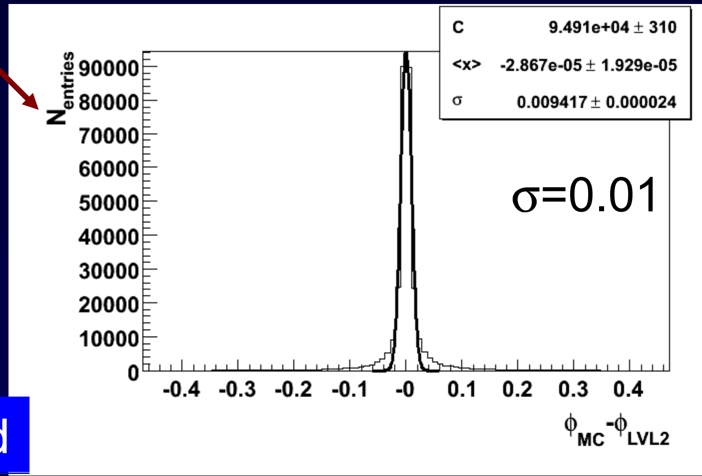
Position resolution

η resolution

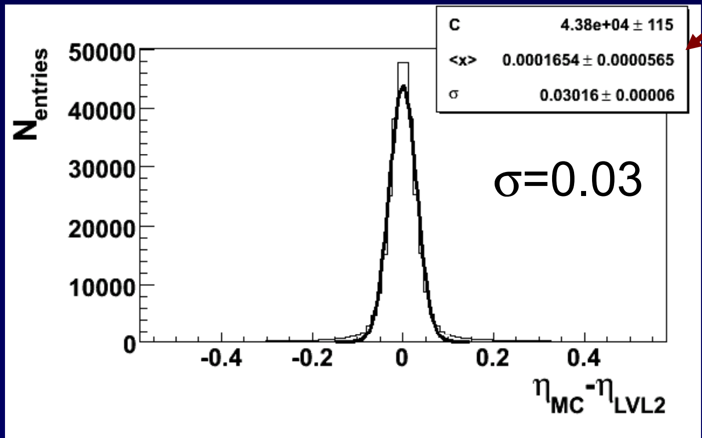
φ resolution

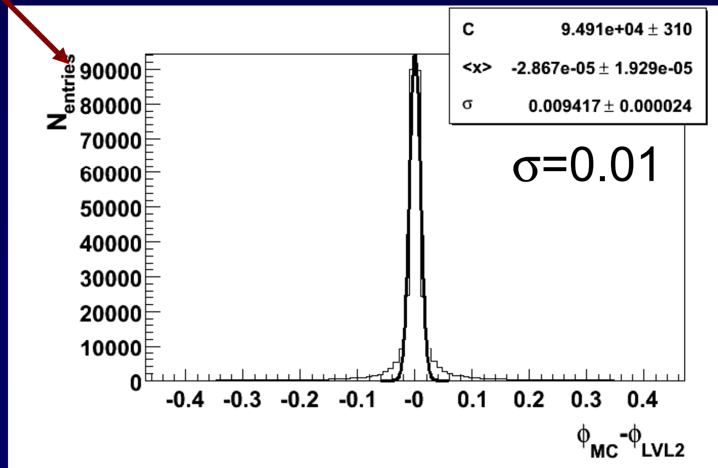
Cell-based





LArFEB-based





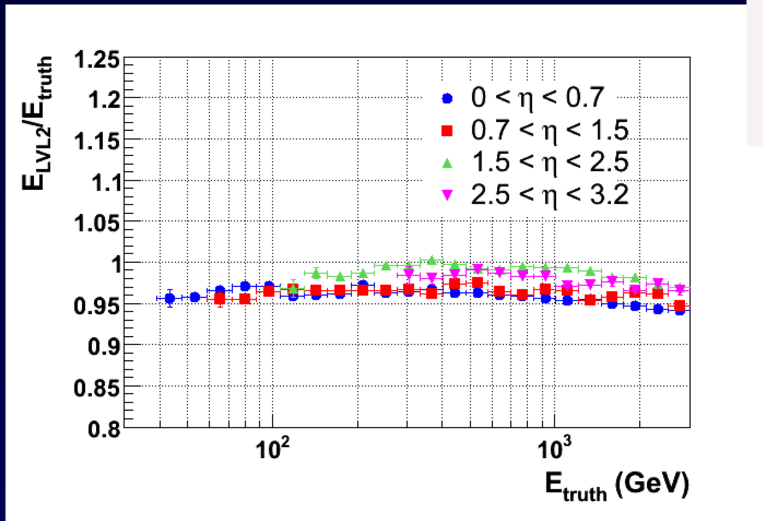
Compatible position resolution for cell- and LArFEB-based methods.

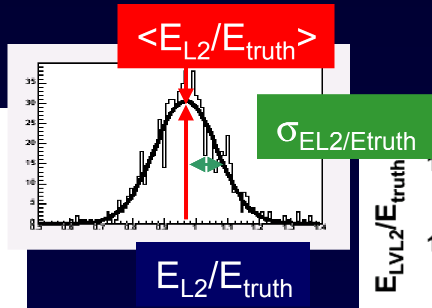
LVL2 jet energy - Calibration

- Calibration weights applied to LVL2 jet are derived using sampling technique.
- $E(rec)=E(em)+w_{had}(\eta)E(had)$
- $w_{em,had} = a+b\log(E)$
- Estimate weights by minimizing $S^2 = \sum_{m\ jets} (E_{jet}^{true} - E_{jet}^{rec})^2$
- So far calibration weights only derived based on cell-jets.
- Apply computed weights to both cell-based and LArFEB-based jets.
- Compute weights for bins in η with $\Delta\eta(bin)=0.1$

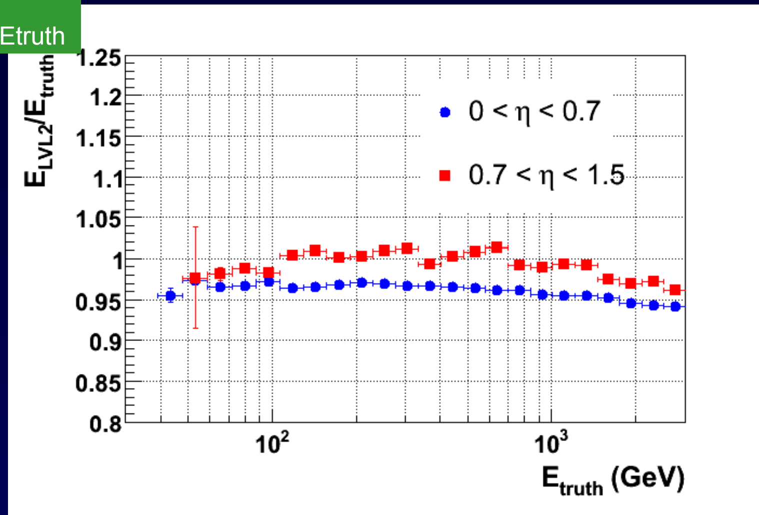
LVL2 jet energy scale

cell jets





LArFEB jets



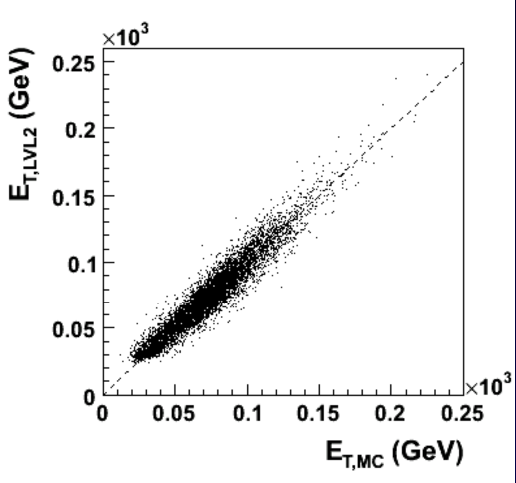
energy scale <1 due to difference in tile geometry in Athena 11.0.42 and 12.0.3

Fit only converges in central region $|\eta|<1.5$
remember: weights derived from cell-based approach! See following slides

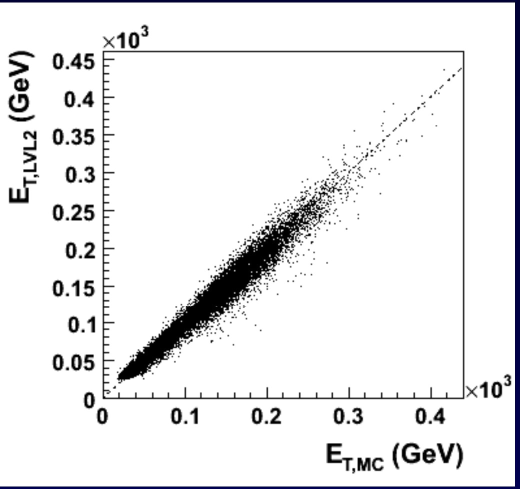
In the central region ($|\eta|<1.5$) the cell-based and the LArFEB-based jets have compatible performance (but LArFEB is faster!!).

Cell jets - calibrated

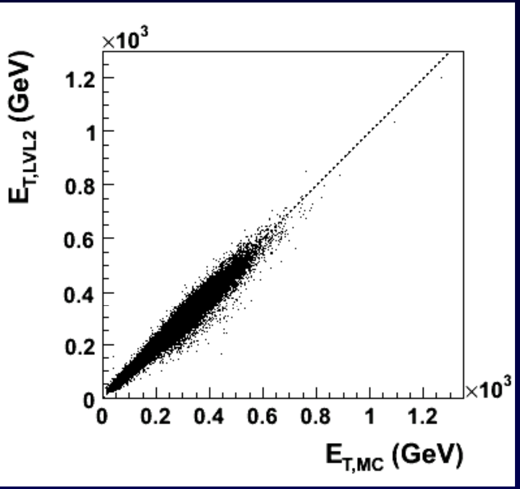
J3



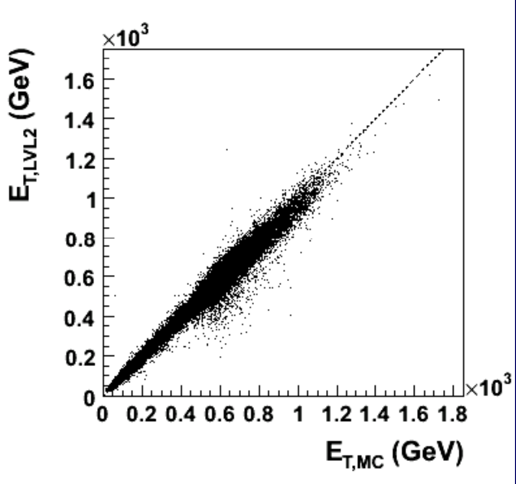
J4



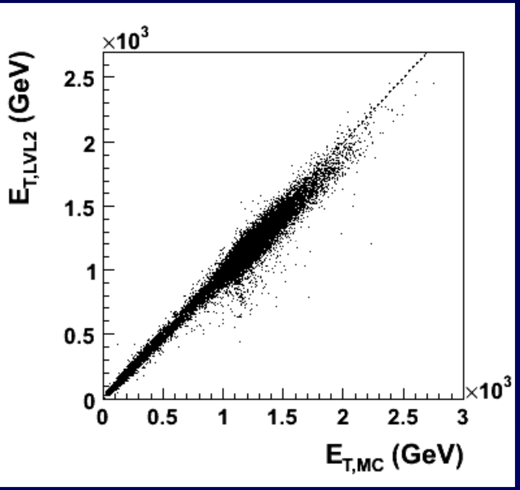
J5



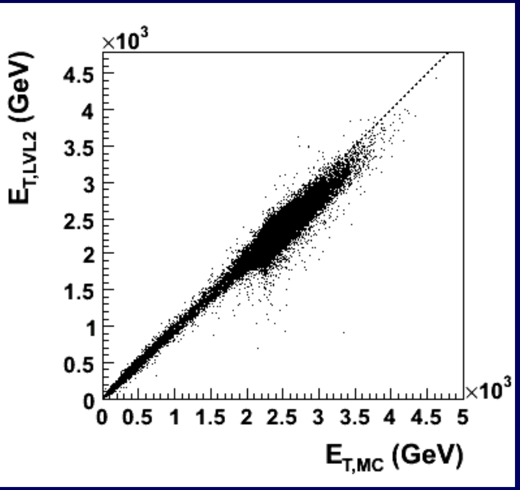
J6



J7

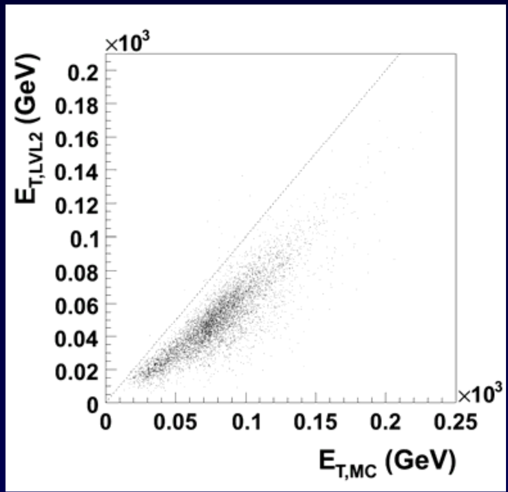


J8



LArFEB jets - uncalibrated

J3



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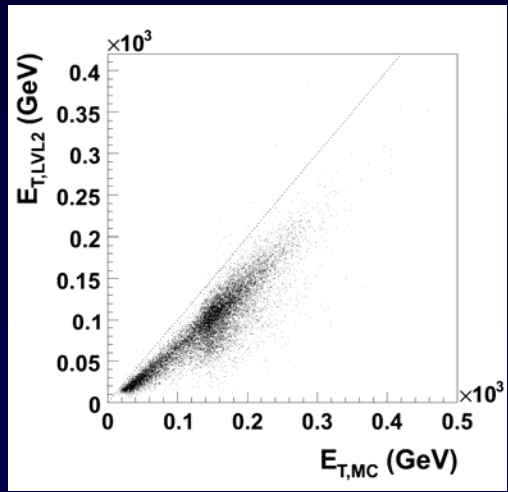

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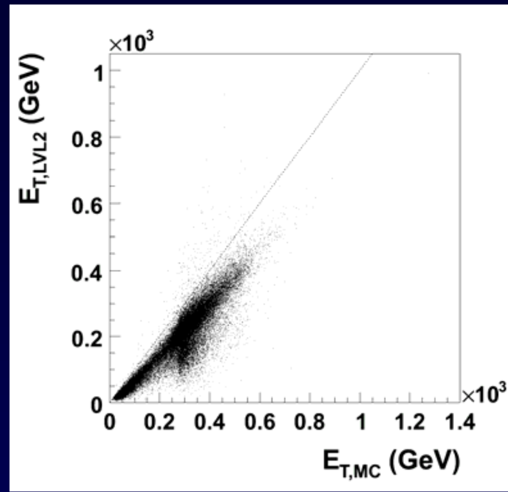

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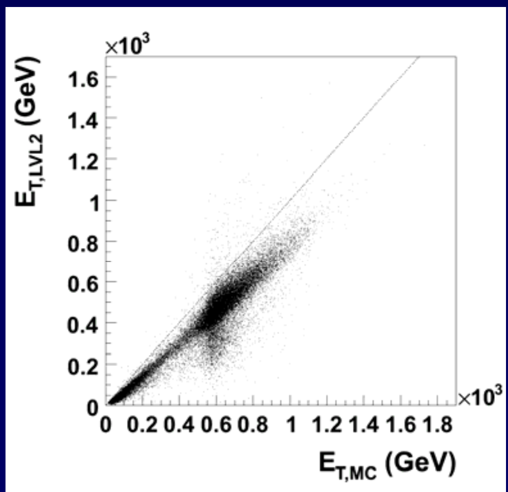

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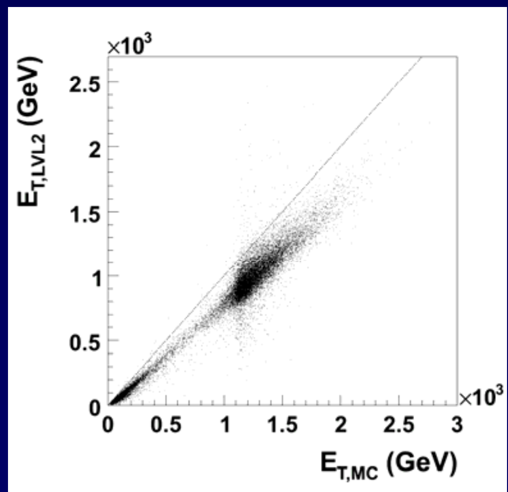

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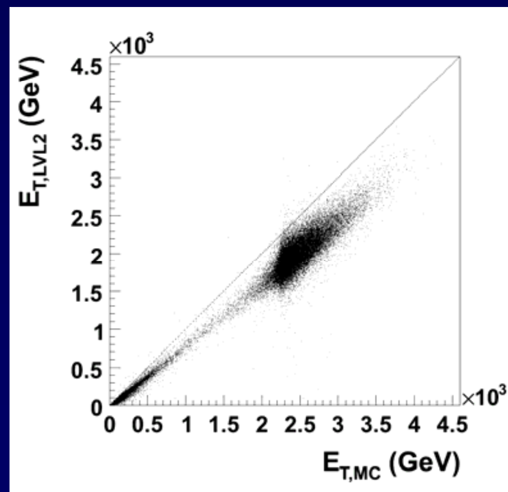
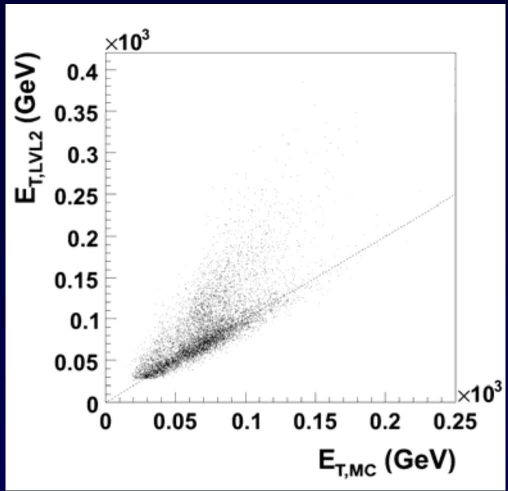
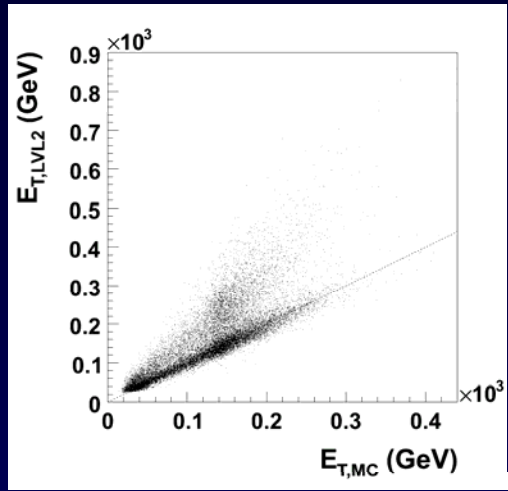


LArFEB jets calibrated |η|<3.2

J3



J4



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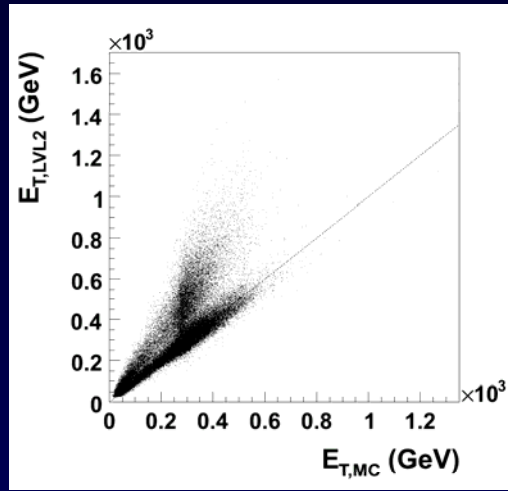

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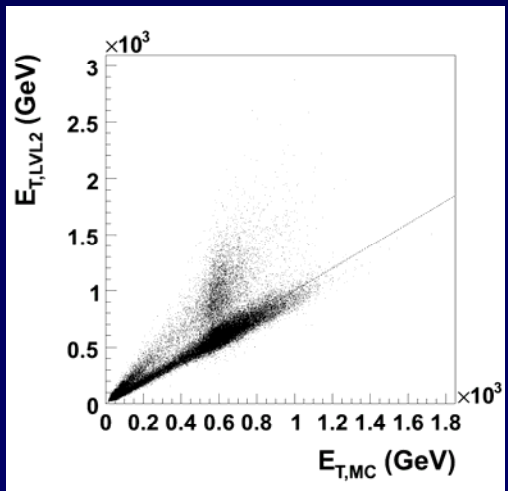

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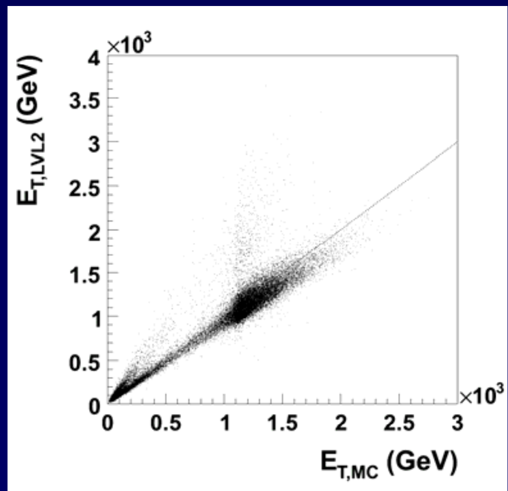

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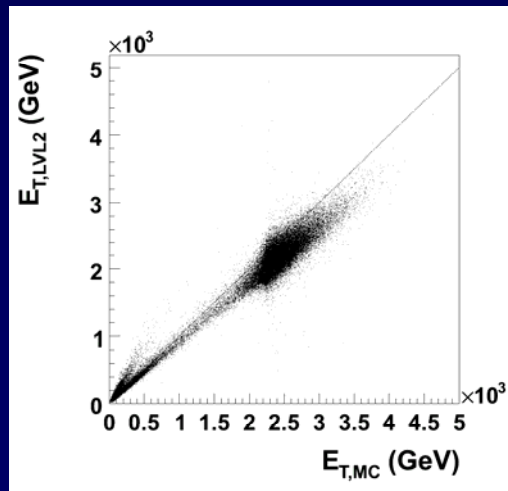
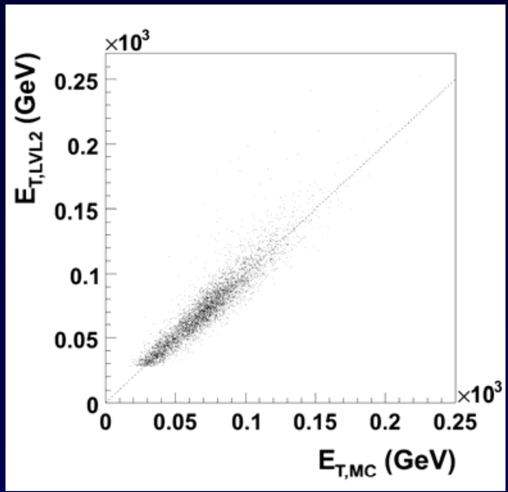


LArFEB jets $|\eta|<1.5$

J3



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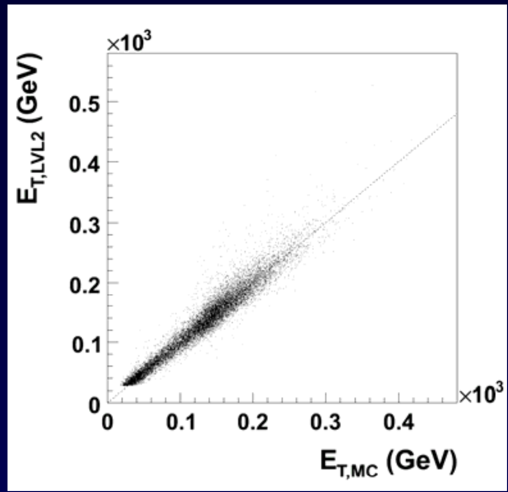
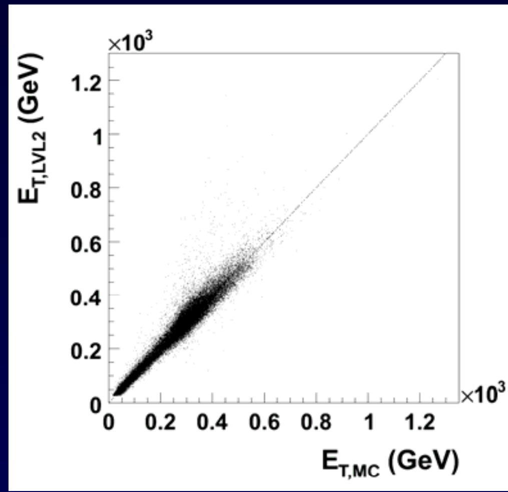


J5



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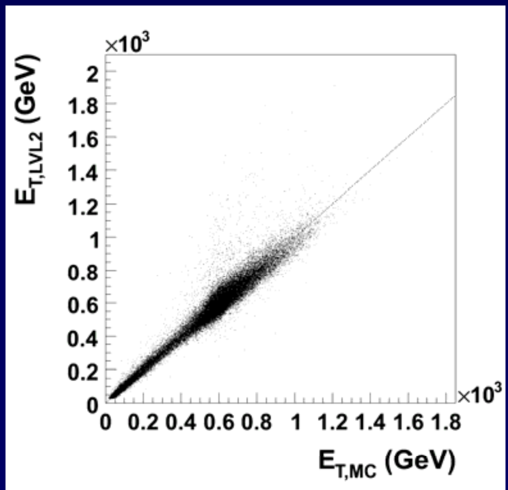
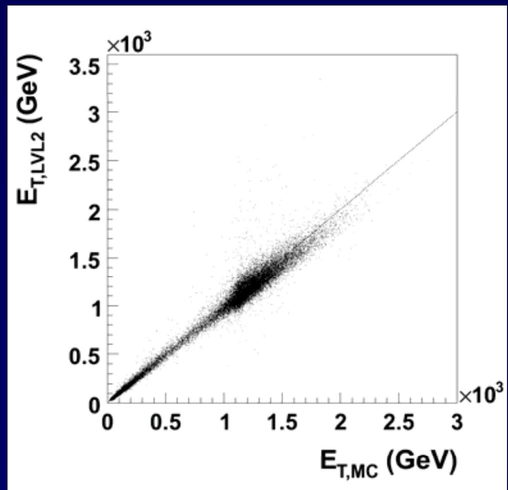
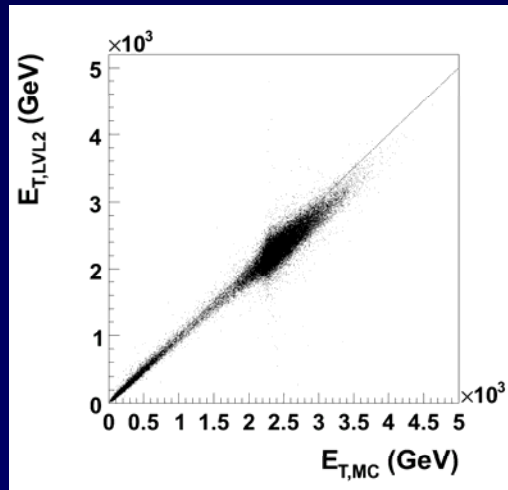


J7

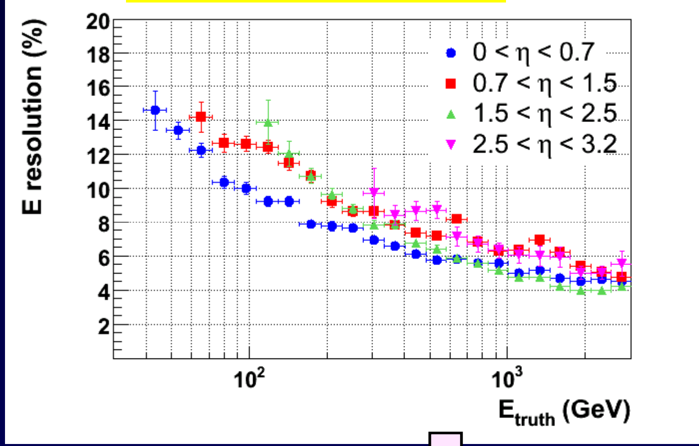


J8

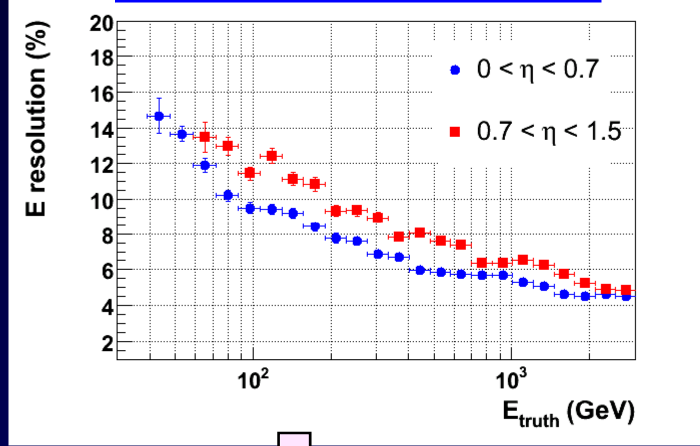


Level-2 jet energy resolution

cell-based jets



LArFEB-based jets



$$\frac{\sigma}{E} = \frac{A\%\ \mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus B\%,$$

η-range	A (% GeV)	B (%)
0 < |η| < 0.7	64.9 ± 2.2	3.2 ± 0.1
0.7 < |η| < 1.5	94.7 ± 4.1	3.3 ± 0.2

η-range	A (% GeV)	B (%)
0 < |η| < 0.7	66.9 ± 2.1	3.2 ± 0.1
0.7 < |η| < 1.5	93.2 ± 3.3	3.3 ± 0.1

Similar energy resolution in |η|<1.5 for both methods, cell-based and LArFEB-based!!

Status of the LVL-2 jet algorithm

In release 13.0.X

- Level-2 jet algorithm adapted to new steering
- Migration to configurables

Next steps:

- Need LArFEB-jet calibration to access $|\eta|>1.5$
- Data-driven calibration.
- Validation with more complex event signatures (e.g. mSUGRA).
- Test the Jet trigger slice with the SLAC TDAQ farm.
- New measurements during upcoming Technical Run in May (21-25).
- Improve speed, resolution (using tracks?).

Missing E_T in the High-Level Trigger

Missing E_T trigger

- Missing E_T trigger is the most challenging in terms of speed.
- Missing E_T is crucial for many physics scenarios
  - SUSY, taus, $W \rightarrow e\nu$
- Focus on rejecting events with fake E_T (from shower leakage, noisy/hot cells, dead material) !
- The missing E_T slice is the least advanced slice of the High-Level Trigger
- So far only missing E_T trigger at the Event Filter is implemented.

MET trigger at Level-2

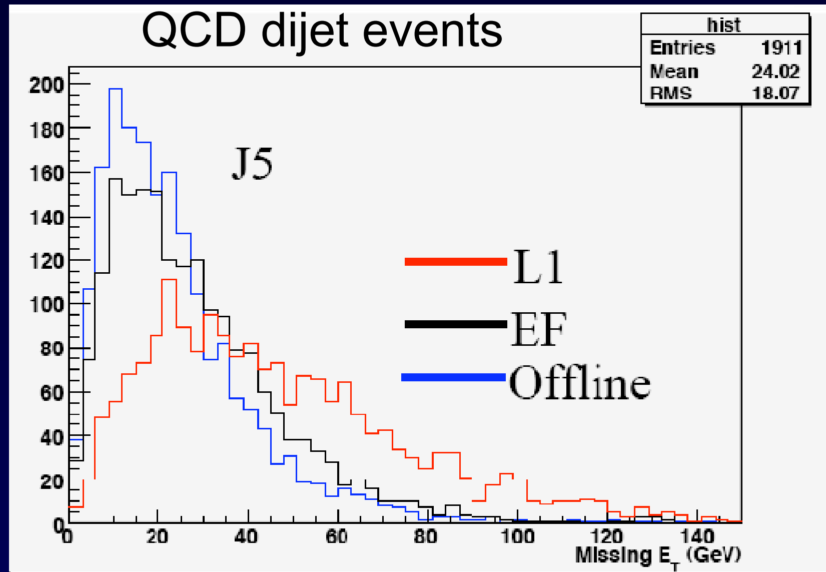
- Level-2: RoI-based approach is not adequate, cannot read out the full calorimeter data
- possibility 1: refine LVL1 E_T^{miss} by including muons at LVL2
- possibility 2: use **MHT trigger**
- **Missing Hadronic Transverse Energy MHT = $|\Sigma P_T(\vec{jets})|$**
  - Use Level-2 jets with $P_T \gtrsim$ 20GeV ?
  - Could implement this using the current LVL2-jet algorithm
  - Study performance of MHT trigger
    - as function of minimum jet P_T
    - calibration
    - em fraction
    - tracker

MET at the Event Filter – cells

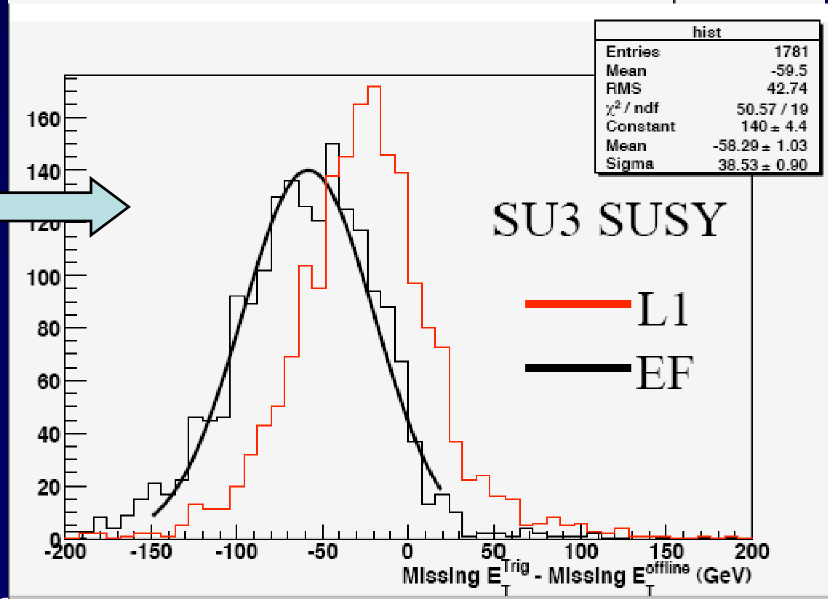
Currently two strategies implemented for missing E_T in the Event Filter

(i) **cell-based**: read out all cells from the calorimeter

• Recent results with 12.0.X using dijet events (top) and SUSY events (bottom).



shift of ~60GeV
for SUSY events



Kyle Cranmer, March 20 T&P week

MET at the Event Filter – LArFEB based

Currently two strategies implemented for missing E_T in the Event Filter

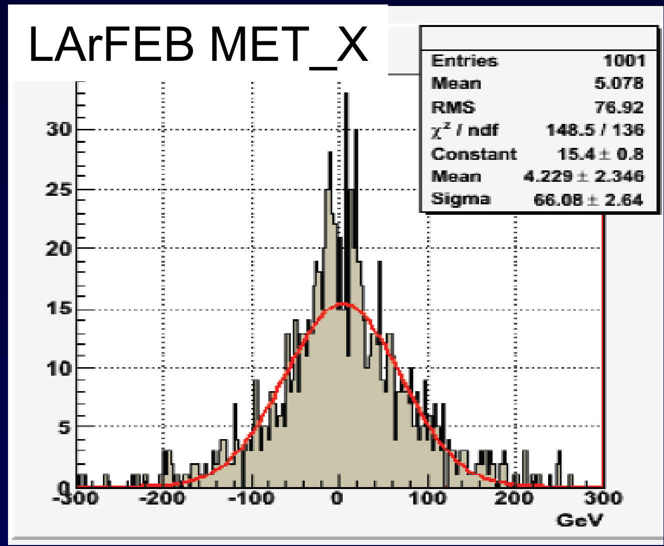
(ii) **LArFEB-based**: read out all Ex, Ey from LArFEB; cell from tile calorimeter

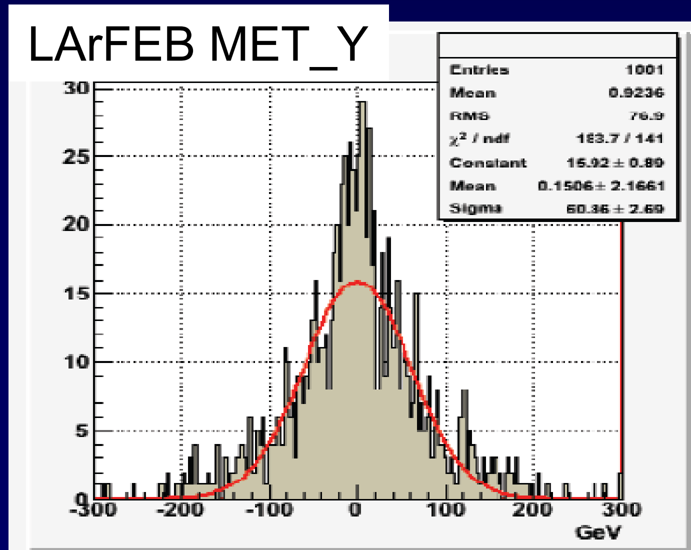
- Only results with release 11.0.5 available
- Worse resolution than cell-based:

cell: s(MEx) ≈ 42GeV; s(MEy) ≈ 37GeV

LArFEB: s(MEx) ≈ 66GeVl s(MEy) ≈ 60GeV

- no calibration





Missing ET in the HLT – status

- Missing E_T only running at the Event Filter so far. Missing items:
  - noise suppression
  - hadronic calibration
  - muon and cryostat correction term
- Work for ET miss at LVL2 has only started recently!
  - development stalled due to migration to configurables and new steering

Summary – Level-2 jets

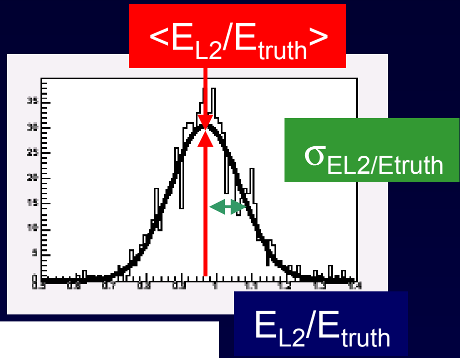
- The Level-2 jet trigger has been tested
  - LArFEB-based jets vs. cell-based jets give compatible resolution in $|\eta|<1.5$, but LArFEB is 4x faster than cell-based!!
  - Need to understand LArFEB in the end-caps, compute calibration constants for LArFEB.
  - Further improvements possible, e.g. mask hot/noisy cells, use Level-2 tracks, ...
  - Run online tests on SLAC TDAQ farm.
  - Test Level-2 jet with more complex event signatures (SUSY).

Summary – Missing E_T in the HLT

- The missing E_T in the HLT
  - In the Event Filter: choice between cell-based and LArFEB-based method.
  - Shift of approx. 60GeV observed in SUSY events.
  - Work at Level-2 has started only recently.
  - Plan: Implement MHT trigger using Level-2 jets.

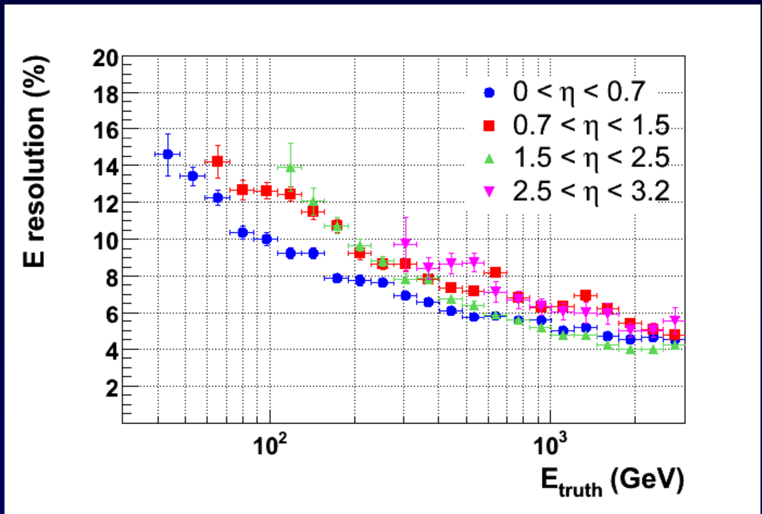
Back-Up

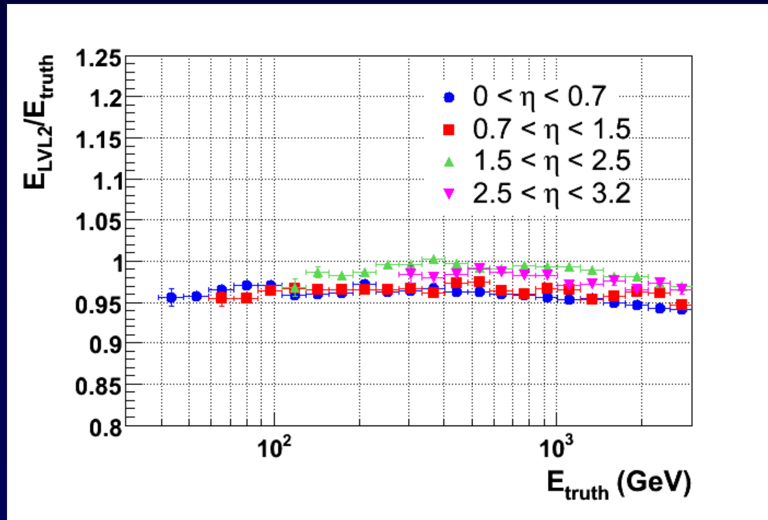
Level-2 jets – cells



Compare Level-2 jet energy to MC truth jet energy

Fit E_{LVL2}/E_{truth} for different bins in E_{truth} and η

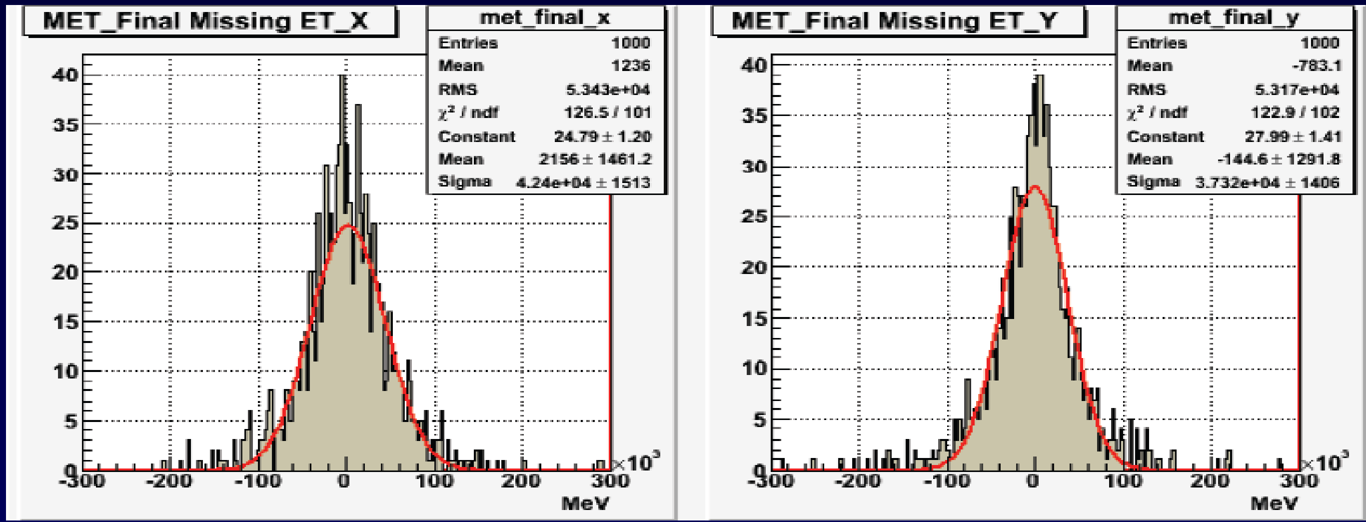




$$\frac{\sigma}{E} = \frac{A\%\ \mathrm{GeV}^{1/2}}{\sqrt{E}} \oplus B\%,$$

η-range	fit region (GeV)	A (% GeV)	B (%)
0 < |η| < 0.7	80 < E_{truth} < 3000	64.9 ± 2.2	3.2 ± 0.1
0.7 < |η| < 1.5	100 < E_{truth} < 3000	94.7 ± 4.1	3.3 ± 0.2
1.5 < |η| < 2.5	100 < E_{truth} < 3000	118.4 ± 4.8	1.4 ± 0.1
2.5 < |η| < 3.2	80 < E_{truth} < 3000	127.5 ± 15.1	2.4 ± 0.5

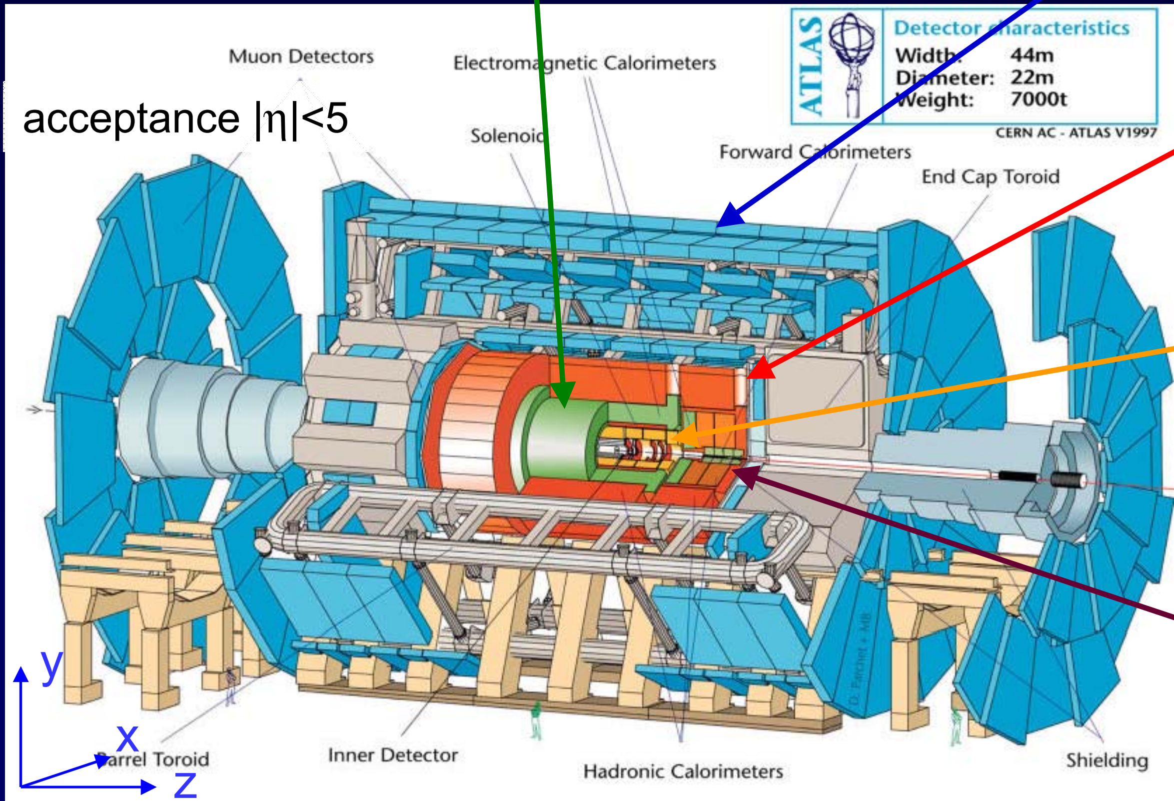
MET in Event Filter – cells with 11.0.5



ATLAS

Electromagnetic calorimeter $|\eta|<3.2$
liquid argon (LAr)/Pb accordion
$\sigma/E \approx 10\%/\sqrt{E} \oplus 0.7\%$
10^6 readout cells

Muon spectrometer $|\eta|<2.7$
$\sigma(p_T) \approx 10\%$ @ $p_T = 1$TeV



Hadron calorimeter
$|\eta|<1.5$ Tile; $1.5<|\eta|<3.2$ LAr

$$\frac{\sigma(E)}{E} = \frac{0.67}{\sqrt{E(GeV)}} \oplus 0.02 \oplus \frac{4.3}{E(GeV)}$$

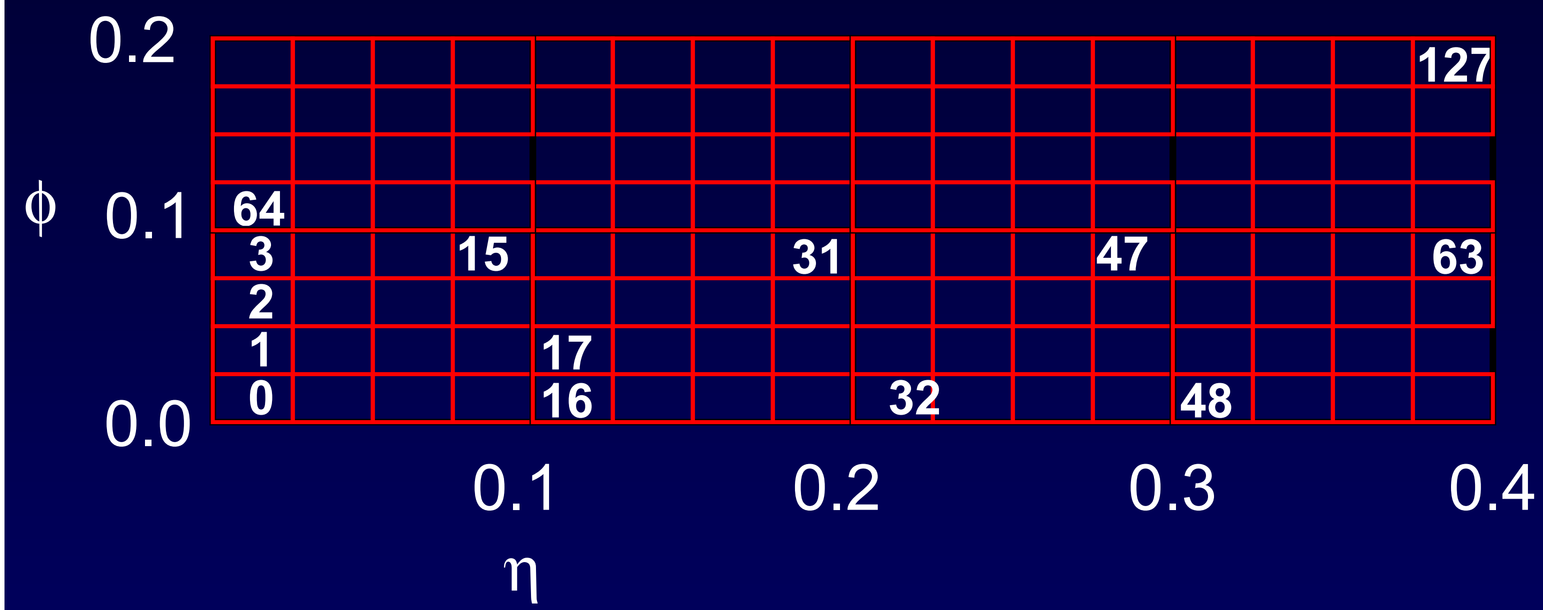
Inner detector $|\eta|<2.5$
Si pixel and strips (SCT)
Transition radiation tracker

$$\sigma(d_0) \approx 11 \oplus \frac{73}{p_T\sqrt{\sin\theta}} \ (\mu m).$$

Forward calorimeter $3.1<|\eta|<4.9$
$\sigma/E \approx 100\%/\sqrt{E} \oplus 7.0\%$

Supraconducting magnet system: solenoid (inner tracker) 2T; air-core toroids 0.5T

FEB cell organization in barrel middle sampling

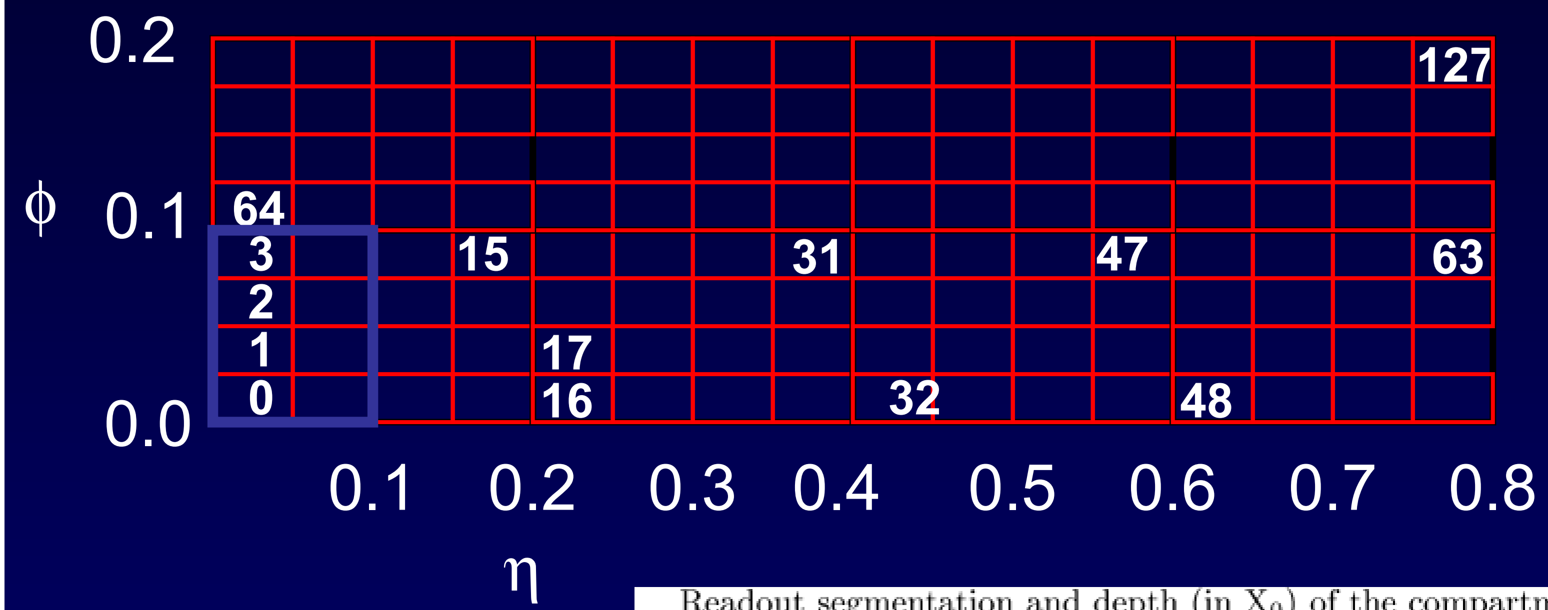


Readout segmentation and depth (in X_0) of the compartments of a barrel module and its associated presampler sectors for $\eta < 1.3$.

Compartment	$\Delta\eta$	$\Delta\phi$	X_0
Presampler	0.025	$2\pi/64$	0.08 to 0.15
Front	0.025/8	$2\pi/64$	2.5 to 4.5
Middle	0.025	$2\pi/256$	16.5 to 19
Back	0.050	$2\pi/256$	1.4 to 7

Middle
cell: $\Delta\phi \times \Delta\eta$ = 0.025 X 0.0
TT : $\Delta\phi \times \Delta\eta$ = 0.1 X 0.
→16 cells/TT

FEB cell organization in barrel back sampling



Back
cell: Δϕ x Δη = 0.025 X 0.05
TT : Δϕ x Δη = 0.1 X 0.1
→8 cells/TT
→ 16 TT/FEB

Readout segmentation and depth (in X_0) of the compartments of a barrel module and its associated presampler sectors for $\eta < 1.3$.

Compartment	$\Delta\eta$	$\Delta\phi$	X_0
Presampler	0.025	$2\pi/64$	0.08 to 0.15
Front	0.025/8	$2\pi/64$	2.5 to 4.5
Middle	0.025	$2\pi/256$	16.5 to 19
Back	0.050	$2\pi/256$	1.4 to 7

FEB cell organization in barrel front sampling

Front

cell: $\Delta\phi$ x $\Delta\eta$ = 0.1 X 0.025/8

TT : $\Delta\phi$ x $\Delta\eta$ = 0.1 X 0.1

→ 32 cells/TT

→ 4 TT /FEB

Readout segmentation and depth (in X_0) of the compartments of a barrel module and its associated presampler sectors for $\eta < 1.3$.

Compartment	$\Delta\eta$	$\Delta\phi$	X_0
Presampler	0.025	$2\pi/64$	0.08 to 0.15
Front	0.025/8	$2\pi/64$	2.5 to 4.5
Middle	0.025	$2\pi/256$	16.5 to 19
Back	0.050	$2\pi/256$	1.4 to 7