JLC Detector Calorimeter

OFFLINE CLUSTERING

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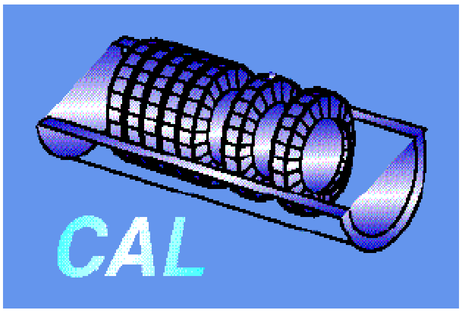


July 27^{th}, 2001

- Introduction
  - The calorimeter geometry
  - Simulated energy response
  - Prototype measurements
- Clustering procedures
  - The hits + utility routines
  - The cells
  - The clusters + more utility routines
  - The jets
- First results
  - Single particles (μ,e,π)
  - e^+e^- events
- Conclusions

Introduction

..

or

why

is

calorimeter

clustering

important

?

Calorimeter Geometry

The basic unit of the *calorimeter* is the *tower*. Each tower contains one electromagnetic and one hadronic *section*. Each section is divided in *layers*. The smallest unit in each layer of each section is the *cell*.

Calorimeter	Barrel	End Cap	
		Backward	Forward
#layers	7	3	3

Presampler	√	√	√
EM 1	√		
EM 2	√		
HD 1	√	√	√
HD 2	√	√*	√*
HD 3	√		
HD 4	√		

θ-range			
.. in EM cells	93	46	46
.. in HD cells	31	23	23
ϕ-range			
.. in EM cells	192	168	168
.. in HD cells	64	84	84

Notes: silicon strips (at shower maximum) are foreseen but not yet in the simulation. *Lateral segmentation??

Simulated Energy Response

Test of energy resolution using pions.

Energy $[GeV]$	Raw E	Raw σ	Cut E	Cut σ	$\frac{\sigma}{\sqrt{E}}$
2	1.923	0.588	1.916	0.586	42%
10	9.53	1.66	9.17	1.40	46%
25	24.88	2.81	24.65	2.58	52%
100	106.4	8.67	105.4	6.07	59%
200	212.8	13.95	210.9	10.54	73%

A containment cut of 98% was applied by requiring less than 2% of the total energy in the last tower layer (HD4).

The nominal $\frac{\sigma}{\sqrt{E}}$ resolution is 40%.

The shower resolution needs to be tuned:

- sampling?
- calibration?
- shower terminators?
- comparisons with prototype data?

Simulated Energy Response

Test energy resolution using electrons and pions.

Energy $[GeV]$	Electrons $\frac{\sigma}{\sqrt{E}}$	Pions Raw	Pions Cut
2	16%	42%	42%
10	17%	54%	46%
25	18%	56%	52%
100	18%	84%	59%
200	19%	96%	73%
Nominal	15%		40%

A pion containment cut of 98% was applied by requiring less than 2% of the total energy in the last tower layer (HD4).

The hadron shower resolution needs to be tuned:

- sampling?
- calibration?
- shower terminators?
- comparisons with prototype data?

Prototype Measurements

Apparently no simulation exists that would correspond to the calorimeter prototype data with the geometries set as in the actual experimental setups.

A "poor man"'s simulation was attempted in order to understand the simulation by tuning it to the extensive prototype calorimeter data:

- start from the current Barrel Cal. simulation
- set the magnetic field to zero (not easy!)
- tilt calorimeter towers back to perpendicular (to the origin, i.e. as if to the beam)
- ...

The effort was not pursued because:

- modifications are not always obvious (to me)
- many incompatibilities and/or bugs
- ALL files were lost after one infamous week... (code and data)
- priority is given to clustering

Nevertheless:

- much was learned about JIM *et al.*
- most remains relevant for clustering work

Calorimeter Clustering

The calorimeter data is available as *hits* from the event data banks.

The current clustering work proceeded as follows:

Step 1: check the validity and range of the hits.

Step 2: transform the hits into *cells*.

Step 3: study the detailed data distributions and define the clustering algorithm.

Step 4: merge the cells into *clusters*.
1) adjacent cells only
2) first layer by layer
3) within each calorimeter only
4) starting from behind (deepest layers)
5) highest-energy cells as seeds

Step 5: further merging (still no physics)
5) also adjacent clusters
6) layers within EM or HD sections
7) EM with HD with boundary binning

Step 6: debug & "polish", then go for *jets*.

The Calorimeter Hits

_C	Hit	#	BC	EM	The	Phi	Etot	PS/H1	E1/H2	E2/H3	--/H4
BC	88	1	1	1	18	181	0.001	0.001	0.000	0.000	
BC	88	2	1	1	26	73	0.011	0.011	0.000	0.000	
BC	88	3	1	1	31	123	0.014	0.014	0.000	0.000	
BC	88	4	1	1	31	12	0.001	0.001	0.000	0.000	
BC	88	5	1	1	45	23	0.150	0.013	0.108	0.030	
BC	88	6	1	1	45	24	0.049	0.008	0.007	0.035	
BC	88	7	1	1	46	21	0.047	0.007	0.027	0.014	
BC	88	8	1	1	47	23	18.116	0.027	0.166	17.923	
BC	88	9	1	1	47	21	0.225	0.142	0.083	0.000	
BC	88	10	1	1	51	23	0.010	0.002	0.008	0.000	
BC	88	57	1	1	55	191	0.021	0.000	0.000	0.021	
BC	88	58	1	1	56	191	0.030	0.000	0.000	0.030	
BC	88	59	1	1	56	24	0.002	0.000	0.000	0.002	
BC	88	60	1	2	14	5	0.011	0.011	0.000	0.000	0.000
BC	88	61	1	2	14	9	0.214	0.214	0.000	0.000	0.000
BC	88	62	1	2	14	6	0.139	0.139	0.000	0.000	0.000
BC	88	63	1	2	14	7	0.035	0.035	0.000	0.000	0.000
BC	88	64	1	2	15	8	2.176	1.130	0.274	0.365	0.407
BC	88	65	1	2	15	5	0.025	0.025	0.000	0.000	0.000
BC	88	66	1	2	15	7	0.993	0.843	0.135	0.014	0.000
BC	88	67	1	2	15	9	0.253	0.163	0.000	0.000	0.091
BC	88	68	1	2	15	6	0.116	0.116	0.000	0.000	0.000
BC	88	69	1	2	16	8	56.838	24.449	25.070	5.975	1.343
BC	88	70	1	2	16	9	1.575	0.321	0.712	0.543	0.000
BC	88	71	1	2	16	7	3.889	1.303	1.721	0.825	0.041
BC	88	72	1	2	16	6	0.313	0.313	0.000	0.000	0.000
BC	88	73	1	2	16	10	0.004	0.002	0.000	0.002	0.000
BC	88	74	1	2	17	7	0.618	0.019	0.372	0.227	0.000
BC	88	75	1	2	17	8	2.897	0.315	1.979	0.437	0.166
BC	88	84	1	2	20	10	0.119	0.000	0.119	0.000	0.000
BC	88	85	1	2	13	6	0.101	0.000	0.000	0.101	0.000
BC	88	86	1	2	13	5	0.113	0.000	0.000	0.113	0.000
BC	88	87	1	2	18	9	0.019	0.000	0.000	0.000	0.019
EC	88	88	2	1	-8	58	0.016	0.016			

BC							98.555				
EC							0.016				
							98.571				

Calorimeter Cells

#Cell	Cell#	Calo	Layer	Hit#	Item#	Energy	Value	Order
133	1	1	1	1	3	0.001	1100.001	133
133	2	1	1	2	3	0.011	1100.011	96
133	3	1	1	3	3	0.014	1100.014	117
133	4	1	1	4	3	0.001	1100.001	85
133	5	1	1	5	3	0.013	1100.013	121
133	6	1	2	5	4	0.108	1200.108	113
133	7	1	3	5	5	0.030	1300.030	91
133	8	1	1	6	3	0.008	1100.008	103
133	9	1	2	6	4	0.007	1200.007	132
133	10	1	3	6	5	0.035	1300.035	95
133	11	1	1	7	3	0.007	1100.007	102
133	12	1	2	7	4	0.027	1200.026	116
133	13	1	3	7	5	0.014	1300.014	99
133	14	1	1	8	3	0.027	1100.027	112
133	15	1	2	8	4	0.166	1200.166	84
133	16	1	3	8	5	17.923	1317.923	109
133	17	1	1	9	3	0.142	1100.142	131
133	18	1	2	9	4	0.083	1200.083	130
133	19	1	1	10	3	0.002	1100.002	120
133	89	1	6	66	5	0.014	1600.014	46
133	90	1	4	67	3	0.163	1400.163	13
133	91	1	7	67	6	0.091	1700.091	51
133	92	1	4	68	3	0.116	1400.116	48
133	93	1	4	69	3	24.449	1424.449	65
133	94	1	5	69	4	25.070	1525.070	69
133	95	1	6	69	5	5.975	1605.975	57
133	96	1	7	69	6	1.343	1701.343	72
133	97	1	4	70	3	0.321	1400.321	77
133	98	1	5	70	4	0.712	1500.712	64
133	99	1	6	70	5	0.543	1600.542	47
133	100	1	4	71	3	1.303	1401.302	39
133	127	1	5	82	4	0.092	1500.092	5
133	128	1	5	83	4	0.121	1500.121	2
133	129	1	5	84	4	0.119	1500.119	8
133	130	1	6	85	5	0.101	1600.101	11
133	131	1	6	86	5	0.113	1600.113	19
133	132	1	7	87	6	0.019	1700.019	1
133	133	3	1	88	3	0.016	3100.016	4

						98.571		

Utility Routines

Event energy sums for Barrel Cal. and EndCap Cal:

- Energy per layer/section/calorimeter
- .. idem per opening angle θ
- .. idem per azimuthal angle ϕ
- options: θ-ϕ-E distribution plots per event
- options: N-tuple of θ,ϕ,E,.. for all events

Clustering parameters

```
Flag#     Value   Comment
-----     -----   -------
    1         F   info. from cells (vs from clusters)
    2         F   apply energy threshold cuts (vs not)
    3         F   angle info. from cells (vs sections)
    4         F   .. from within each cell (vs front face)

Para#     Value   Comment
-----     -----   -------
    1     0.005       N/A  threshold Barrel Presampler
    2     0.050       N/A  .         .      EM
    3     0.100       N/A  .         .      HD
    4     0.005       N/A  .         EndCap Presampler
    5     0.050       N/A  .         .      EM
    6     0.100       N/A  .         .      HD
    7     0.000       depth in cell [0,1]=[front,back]
    8   250.000       jet algorithm scale
    9     0.020       jet algorithm 'ycut'

 Name     Value   Comment
 ----     -----   -------
MBCELL     1500       max. number of cells
MBCLUS      200       .    .         .  clusters
MBCLCE      120       .    .         .  cells per cluster
```

Calorimeter Clusters

Clus	Calo	Layer	#Cell	Energy	Order	Cells..					
----	----	-----	-----	------	-----	-------					
1	3	1	1	0.016	1	133					
2	1	7	108	96.662	2	96	85	113	117	121	..
						116	99	112	84	109	..
						101	98	115	108	83	..
						87	97	110	104	90	..
						86	107	119	125	123	..
						16	31	36	34	62	..
						49	58	50	56	66	..
						10	59	54	7	29	..
						13	51	48	65	69	..
						35	15	6	28	33	..
						37	41	9	17	14	..
3	1	6	2	0.214	3	131	130				
4	1	5	1	0.119	5	129					
5	1	5	2	0.197	4	126	127				
6	1	3	1	0.134	6	74					
7	1	3	2	0.050	7	76	75				
8	1	3	1	0.000	8	47					
9	1	2	1	0.191	11	27					
10	1	2	1	0.122	9	45					
11	1	2	4	0.691	10	23	20	22	19		
12	1	2	1	0.005	12	26					
13	1	2	1	0.002	13	32					
14	1	1	1	0.094	14	25					
15	1	1	1	0.025	15	24					
16	1	1	1	0.023	16	21					
17	1	1	1	0.014	17	3					
18	1	1	1	0.011	18	2					
19	1	1	1	0.001	19	1					
20	1	1	1	0.001	20	4					
			---	------							
			133	98.571							
			133	98.571	(cross-check)						

Routine Overview

```
CALORIMETER CLUSTERING SUMMARY OF ANALYSIS ROUTINES
            (*) = mandatory    (_) = utility

  *BCFLAG:  set clustering flags and parameters (as above)

  *BCPOSI:  find geometrical positions for each cell

  _BCLIST:  print calorimeter hits and
            check for data consistency

  _BCSUMS:  calculate Barrel Cal energy sums
  _ECSUMS:  calculate EndCap Cal energy sums
            (with single event plots & N-tuples for all)

  *BCCELL:  calorimeter cells from calorimeter hits
            calls BCUNCO to unpack the hits

  *BCCLUS:  merge cells into clusters
            calls BCNEAR to check adjacency of cells
            calls BCANGL to assign cell attributes (angles+)

   BCJETS:  merge clusters into jets (try a JADE algorithm)

  _BCSHOW:  display the clustered data
            (with single event plots & N-tuples for all)


TYPICAL ROUTINE ARGUMENTS

   IBEC:    select one, all or no calorimeter
   ISTP:    select strips (not active yet)
   IPRI:    printing level [none, minimum, debugging]

   IEVH:    enable individual histograms event per event
   NTUP:    enable detailed N-tuples for all events
```

Single Particle Results

Only Barrel Cal. results are presented here

Muons:

5 muons $\rightarrow$ 5 clusters
0/42 cells "lost", i.e. 100% E-efficiency

Electrons:

5 electrons $\rightarrow$ 5 main clusters
75/308 cells "lost", but still 99.8% E-efficiency

Pions:

5 muons $\rightarrow$ 4 main clusters (one double, see plot)
99/459 cells "lost", but 98.3% E-efficiency

Some "almost adjacent" cells to work on:
add (some) diagonals?
consider shower sizes?

Unavoidable low-energy particles on first layers

e^+e^- Event Results

Still no jet algorithm, only clustering

1^{st} "Lund" 250 GeV event:

cluster#1: EC+, 174 cells, 43 GeV
cluster#2: EC+, 128 cells, 29 GeV
cluster#3: EC+, 97 cells, 26 GeV
cluster#4: EC−, 93 cells, 27 GeV
cluster#5: BC , 104 cells, 53 GeV
cluster#6: BC , 131 cells, 50 GeV
326/1053 cells elsewhere, 91% E-efficiency

2^{nd} "Lund" 250 GeV event:

cluster#1: BC , 173 cells, 84 GeV
cluster#2: BC , 108 cells, 60 GeV
cluster#3: BC , 44 cells, 7 GeV
95/420 cells elsewhere, 85% E-efficiency

E-efficiency is defined as the energy fraction in the main clusters compared to the total calorimeter energy.

Cell Positions

The hit banks contain the information of the front faces of either electromagnetic or hadronic section of each tower. What is needed is information on the front face of each cell.

Step 1: Produce 100 "Lund" events and study the production of hits in all parts of the calorimeters.

- observe ϕ-asymmetries?
- EndCap Hadronic section indeed segmented laterally
- azimuthal range: $-\pi < \phi < +\pi$

Step 2: Look at the MCBCPAR and MCECPAR banks

- azimuthal range: $-\pi < \phi < +\pi$ (OK?? see later)
- EndCap Forward: $+0.8 < \theta < +1.3$
- Barrel: $-0.8 < \theta < +0.8$
- EndCap Backward: $+1.8 < \theta < +2.3$
- some data bugs and inconsistencies

Step 3: Install (temporary) fixes

- EndCap Forward: $+0.2 < \theta < +0.7$
- Barrel: $+0.7 < \theta < +2.4$
- EndCap Backward: $+2.4 < \theta < +2.9$
- correct position tables for sections

Step 4: Make new positions tables for cells

- based on tables for sections
- still some geometrical inconsistencies
- depth fine tuning possible

Step 5: Fold the energy-weighted information into clusters

Jet Reconstruction

Try a JADE version from the H1 experiment

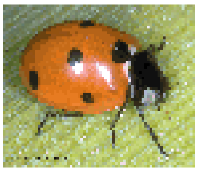
(tentative only: not tuned at all yet)

Param#	Value	Comment
8	250.000	scale
9	0.020	ycut

Jet#	#Clus	Energy	Clusters..									
1	76	104.433	10	65	35	64	110	77	68	30	75	111
			79	112	113	72	85	14	87	70	114	80
			36	37	42	116	82	118	119	83	122	84
			90	124	125	4	88	96	49	89	9	106
			92	126	93	50	94	127	128	51	129	95
			52	97	53	54	98	56	99	130	100	58
			101	102	103	104	105	17	59	107	60	131
			108	5	61	132	109	133				
2	18	70.711	11	40	69	31	15	38	39	81	24	57
			117	121	123	16	45	86	46	91		
3	35	17.555	13	41	19	26	28	62	33	21	1	55
			18	7	27	32	47	67	73	48	25	63
			71	78	23	6	66	43	74	44	2	3
			34	8	76	120	115					
4	3	4.131	20	12	22							
5	1	0.791	29									
	---	-------										
	133	197.619										
	133		(cross-check)									

Jet#	#Clus	Energy	Theta	Phi	Px	Py	Pz
1	76	104.433	1.568	-0.349	98.146	-35.686	0.334
2	18	70.711	1.609	2.669	-62.899	32.193	-2.704
3	35	17.555	1.499	-1.793	-3.853	-17.080	1.266
4	3	4.131	1.364	-0.128	4.010	-0.514	0.847
5	1	0.791	1.234	2.057	-0.349	0.660	0.262
	---	-------			------	-------	-------
	133	197.619			35.055	-20.428	0.006

List of Bugs



Simulation program: (noted)

- unclear limitation on number of particles per event
- how to set magnetic field to zero
- color coding and counting in source code
- display from sides XZ or YZ
- calorimeter hit bank inconsistent once
- EndCap calorimetry geometry unclear
- cell depths tilt-dependent in Barrel?
- cell depths varying in EndCap

Reconstruction program: ("fixed")

- in JLGBCP, NDIVBC = 0 !!
- MCECPAR bank is partly non-sense
- .. due e.g. to 2D array transfers in JLGECP
- in JLGECP, 23 not 46 for loop, confusing
- θ badly defined in JLGBCP & JLGECP

PAW: (noted)

- PAW colour code 4D is reversed

Suggestions:

- re-define azimuthal range: $0 < \phi < 2\pi$ as in binning
- add keyword to skip events at beginning

Conclusions

Clustering

- the first version works satisfactorily
- understanding for single particles
- first studies towards jet reconstruction

Done or almost done

- routine documentation
- ease code for any later add-ons
- list of bugs
- put magnetic field & tower tilts back
- get cell positions instead of tower positions
- develop jet algorithm(s)
- clustering across calorimeters

Still missing

- shower simulation tuning, e.g. terminators
- *also* simulation of prototype data
- longitudinal segmentation in had. EndCap's

Next to do

- fine tuning with shower size vs geometry
- compare with particle/event TRUE information
- add beam-induced & detector noises
- study response vs calorimetry geometry

Prospects

- good

Questions and Feedback
(some of them only)

Questions

- re-do single particle efficiencies with magnetic field and tilts back on?
  yes, should do
- fraction of particles rejected by containment cuts?
  would have to look it up
- sometimes enough information to keep clusters apart?
  yes, but not done yet

Feedback

- combine with tracking in 3D?
  must be done
- get directions from clusters?
  good idea!