Scintillator HCAL Optimisation Studies
– Towards ILD –

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Overview

1. Introduction
2. Optimisation Studies
3. PFA: Conclusions and Overview
4. HCAL Engineering Answers

Introduction

Why?

Try to answer basic (and not so) basic questions:

- which material to use as absorber?
- optimum dimension of scintillator tiles?
- optimum absorber thickness?
- effect of dead zones?
- effect of Birks law?
- etc

How?

- Studies done with **PandoraPFA** algorithm
- **Calibration sample**:
  10 000 **K^0_L's events** (`stdhep` files provided by Mark Thomson)
- **Analysis sample**:
  10 000 **$Z \to u\bar{u}, d\bar{d}, s\bar{s}$ events** at $\sqrt{s} = 91, 200, 360$ and 500 GeV
- LDC model: **LDCPrime_02Sc**
- Mokka version: **mokka-06-06-p03**
- ILC software version: **v01-04**
- Physics list: **LCPhys**

Results: RMS_{90}

- **Disclaimer**: presented PFA measurements are not direct measurement of HCAL performance (only 6 - 10% neutral energy in HCAL, the rest in trackers + ECAL)

RMS_{90}

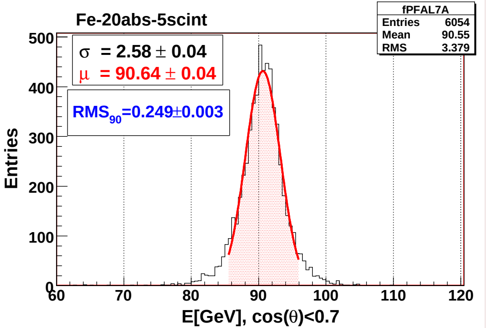
- Jet energy resolution:

$$RMS_{90} = \left(\frac{\sigma_E}{E}\right)_{90\%} \cdot \sqrt{E_{jet}/\mathrm{GeV}}$$

i.e. for the part of energy distribution which contains 90% of the events

Example

- $Z \rightarrow u\bar{u},\ d\bar{d}, s\bar{s}$ at $\sqrt{s} = 91$ GeV, default configuration of `LDCPrime_02Sc` model



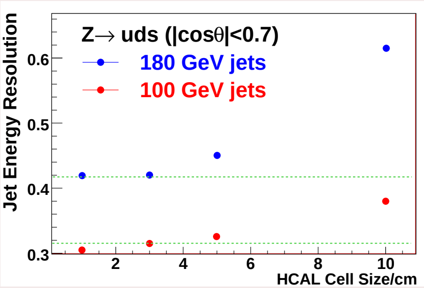
Cross-checks of Results

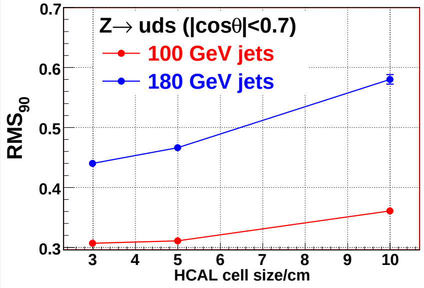
- Comparison of results from Mark Thomson (left) and me (right)

RMS_{90} and jet energy resolutions for default configuration

E_{jet}	RMS_{90}		σ_E/E_j	
45 GeV	24.9%	24.9%	3.7%	3.7%
100 GeV	30.7%	31.4%	3.1%	3.1%
180 GeV	43.0%	44.8%	3.2%	3.3%
250 GeV	52.2%	54.7%	3.3%	3.5%

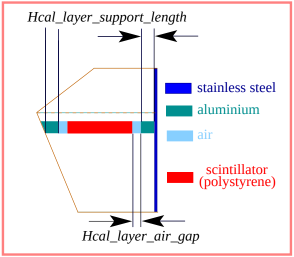
HCAL tile size

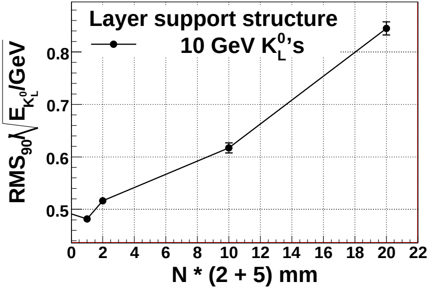


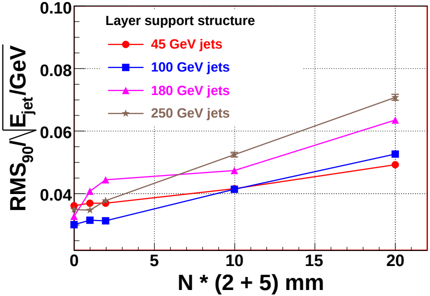


Dead Zones: Layer Support Structure

- Support structures for the HCAL layers introduced few months ago $\Rightarrow$ additional gaps and dead zones
- In default configuration:
  $Hcal\_layer\_support\_length = 5\ \mathrm{mm}$ (Al)
  $Hcal\_layer\_air\_gap = 2\ \mathrm{mm}$ (air)



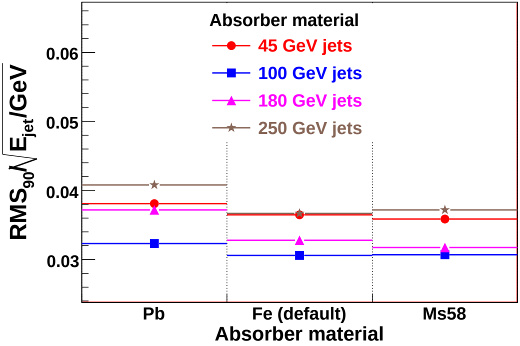




Absorber Material

- Comparison between Fe, Pb and Ms58 (non-magnetic material)
- Ms58 = 58% Cu + 39% Zn + 3% Pb

Material	**Nuclear interaction length** λ [cm]	**Density** $[\mathrm{g/cm^3}]$	**Moliere radius** [cm]	**Radiation length** X_0 [cm]	λ/X_0
Fe	16.77	7.87	1.719	1.757	9.65
Pb	17.59	11.4	1.602	0.5612	31.34
Ms58	16.46	8.6	1.7	1.43	11.52

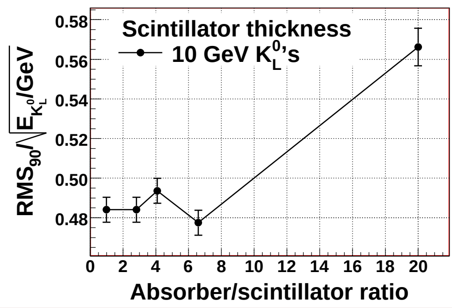


- For low energy jets: choice of material has a minimal influence on energy resolution
- For high energy jets: differences less than 1%

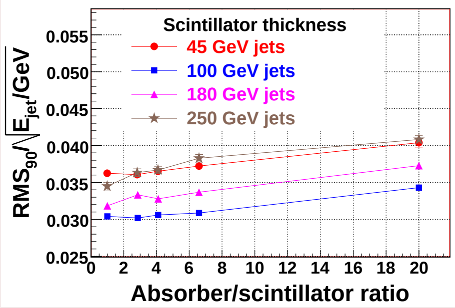
Scintillator Thickness with PFA

- Default configuration: 20 mm absorber + 5 mm scintillator
  i.e. $\mathrm{absorber/scintillator} = 4$
- Modify scintillator thickness (everything else unchanged)

For K_L^0's used for calibration:



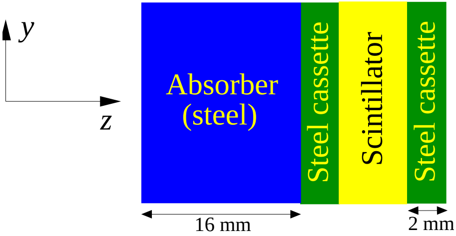
For $Z \to u\bar{u},\ d\bar{d},\ s\bar{s}$:



- $Z \to u\bar{u},\ d\bar{d},\ s\bar{s}$: $\Longrightarrow$ Small differences ($< 5\%$) in jet energy resolution for $\mathrm{absorber/scintillator} < 7$

Scintillator Thickness in GEANT3

- Yuri Soloviev: GEANT3 simulation (FLUKA) of the **test beam** HCAL



- **5 mm thick scintillator**:
  - 46 modules
  - total length: 133.4 cm ($\lambda_I \backsim 5.5$)
- **3mm thick cintillator**:
  - 50 modules
  - total length: 135 cm ($\lambda_I \backsim 6$)

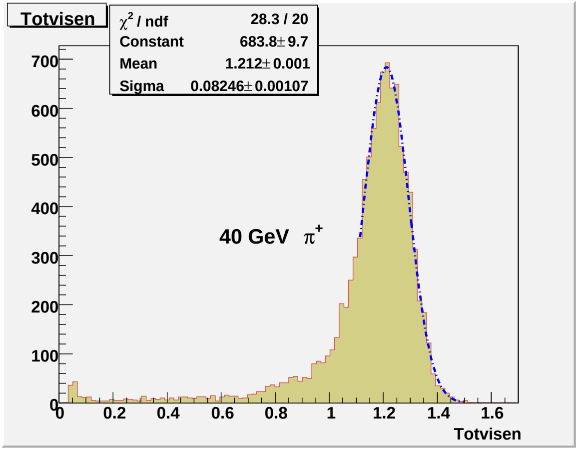
- Incident particles: π^+, energies 10 - 150 GeV, hitting the center of calorimeter

Scintillator Thickness in GEANT3 - continued

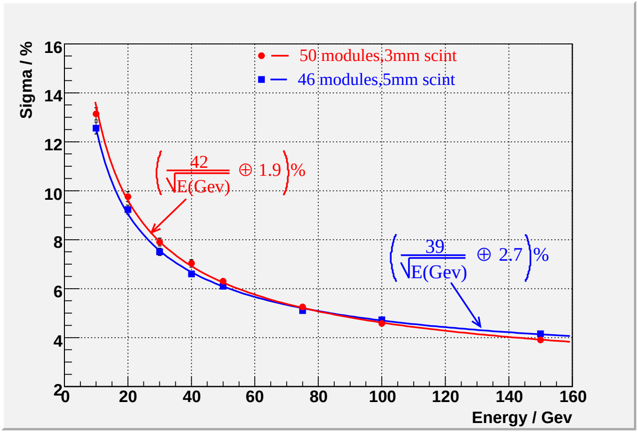
- Energy resolution from fit of total visible energy spectrum:

$$\frac{\sigma_E}{E} = \frac{\sigma_{Gaussian\ fit}}{mean_{Gaussian\ fit}}$$

- Example for 40 GeV pions:



Scintillator Thickness in GEANT3 - continued

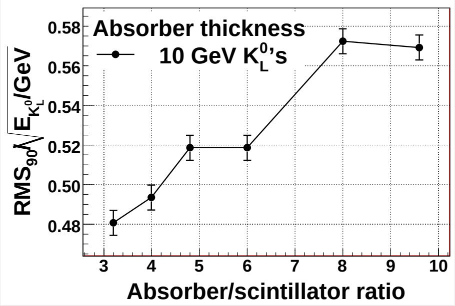


- **3 mm scintillator**: loss in stochastic term, but gain in constant term, because of containment

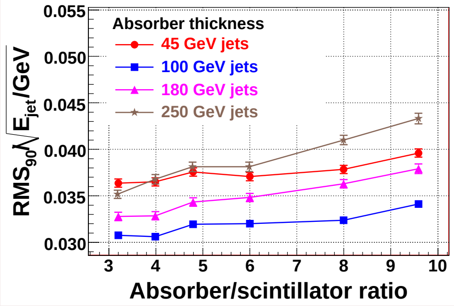
Absorber Thickness

- Change absorber thickness to see sampling effects (modify number of HCAL layers accordingly, to keep total thickness approximately constant; range: 20 - 60 HCAL layers)

For K_L^0:



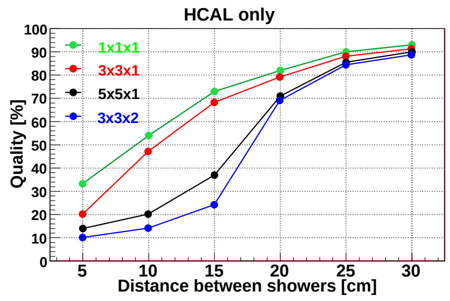
For $Z \rightarrow u\bar{u},\ d\bar{d},\ s\bar{s}$:



Absorber Thickness - continued

Word of caution

- Absorber thickness results need verification and must be interpreted with care
- Previous studies (2004) of A. Raspereza and V. Morgunov show that longitudinal (and transversal) segmentation is decisive

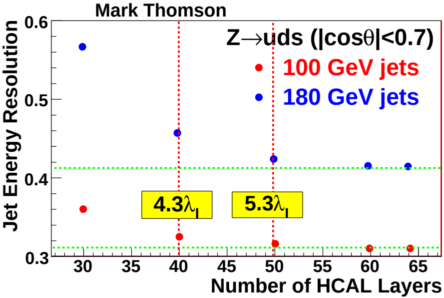


- **3x3x1** vs **3x3x2** (layers joined in depth): separation quality drops drastically with distance between showers
  $\Rightarrow$ longitudinal segmentation is important!
- Can be tested with test beam data!

- Maybe PFA does not use the full potential of the HCAL imaging capabilities

HCAL Depth and Transverse Segmentation

- Investigation of HCAL depth (interaction lengths) by **Mark Thomson** with PFA algorithm
- Generated $Z \rightarrow uds$ events with large HCAL: 64 layers (approx. 7 λ_I)



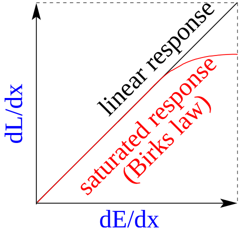
- HCAL leakage significant for high energies ⇒ optimum of approx. 5 λ_I HCAL

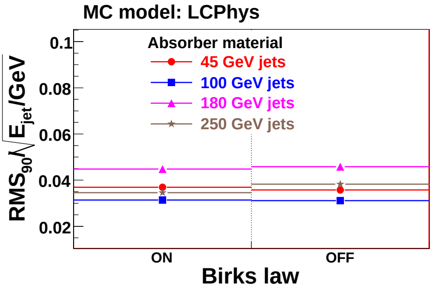
Saturation Effects: Birks Law

- Response of organic scintillators not linear with particle energy
- Primary excitation quenched by high density of ionized and excited molecules
- Saturation effects described by semi-empirical **Birks law**

$$\frac{dL}{dx} \propto \frac{dE/dx}{1 + k_b \cdot dE/dx}$$

L - scintillator response
k_B- Birks constant (material dependent)
For polystyrene: $k_B = 0.07943$ mm/MeV

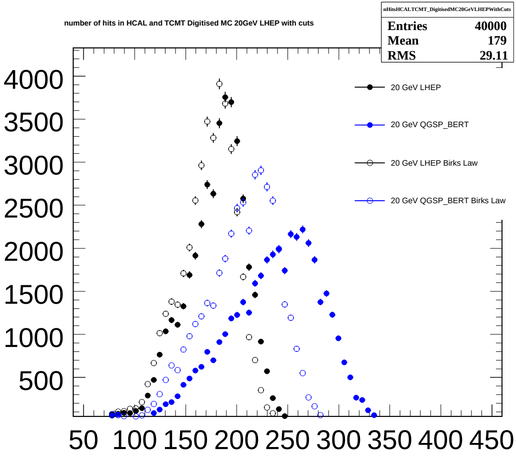




- Expect visible effects for physics lists in which neutrons play important roles, e.g. QGSP_BERT

Saturation Effects: Birks Law - continued

- Example from test beam models: **LHEP** vs **QGSP_BERT**
- Birks law: on vs off → stronger effect in QGSP_BERT, which has largest numbers of neutrons



PFA: Conclusions

1. PFA algorithm gives stable results for the performed studies
2. With respect to jet energy resolution:
    - Dimension of HCAL layer support structure not as important as originally thought
    - Choice of absorber material is not decisive (at least for low energy jets)

Overview

- Investigate reasons for (in)sensitivity of PFA algorithm
- Move z-gaps
- Results for different physics lists and 500 GeV jets
- Single particle resolutions

HCAL Engineering Answers

- First results of engineering work (design, mechanics, costs...) from K. Gadow and colleagues, but most of works still ahead

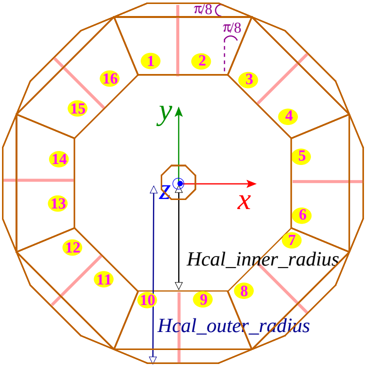
Caution: not final numbers, likely to evolve!

HCAL Absorber Material

- Should have an optimized Z, λ_I and X_0 for hadronic interactions $\rightarrow 5 - 7\ \lambda_I$
- Possibilities: Fe, Cu, Pb, W, Ms
- Decision: **stainless steel**
- Arguments: strength, strain, antimagnetic, treatment, costs

Engineering Answers: HCAL Barrel Dimensions

- HCAL mounted inside solenoid to get homogenous and straight fiels
  - barrel should fit into cryostat
  - space should be left for installation and fixation points



Inner radius: (2000 ± 50) mm

- Decision arguments: absorption length, stability, deflection, type of sensitive detectors, barrel shape design

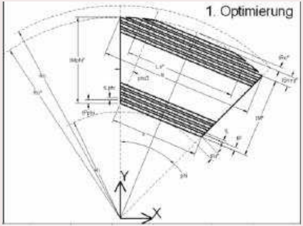
Outer radius: (3200 ± 50) mm

- Decision arguments: solenoid costs, HCAL-, ECAL-, TPC- performed calculations, barrel shape design, supply volumes

Engineering Answers: HCAL Shape

Barrel shape: octogonal

- Maximum use of the given HCAL volume: optimal shape is cylindrical
- But: sensitive detector layers will be from flat panels (production reasons)
  → **octogonal shaped structure**, split in the middle of the total volume



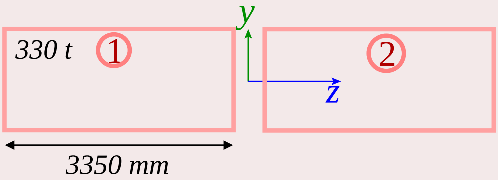
Module shape: Tesla design

- 2 modules will build one octant
  → **16 modules** in total
- **Non-sensitive areas** between sensitive volume: **30 mm** wide, **pointing** in the detector center
- Arguments: size of commercially available steel plates, machining possibilities, module stabitlity, installation process

Engineering Answers: HCAL Length and Weight

HCAL length: (6700 ± 100) mm

- Barrel made of 2 parts, will be slide from both ends of the coil into the cryostat
- One half barrel will have on both sides 2 sliding feets
- The feets will rest on rails which will be fixed on the inner wall of the cryostat



HCAL weight: (660 ± 10) t

Engineering Answers: HCAL Cables Lengths; Tail Catcher

HCAL cross sections per end face (half barrel)	
Cooling pipes	$2 \times 16 \times d = 60$ mm incl. insulation ± 10 mm
Power cables	$16 \times 48 \times d = 10$ mm ± 2mm
CCC/data cables	$16 \times 48 \times d = 12$ mm ± 2 mm

- Electrical power consumption: $2 \times 16 \times 48 \times 50$ W $= (76800 \pm 5000)$ W

Tail Catcher

- Requirements not yet established
- Based on optimization studies for the test beam system, assume a system with several active layers, with 10 cm thick absorber
- The gap can be made as thin as 10 mm, if needed (14 mm in test beam)

Conclusions

- Preliminary engineering answers to:

  - HCAL absorber material

  - barrel dimensions

  - shape, length, weight

  - Tail Catcher

- Subject to change!