

# HCAL Optimisation Studies – Towards ILD –

**Angela Lucaci-Timoce**



## Overview

- 1 Introduction
- 2 Optimisation Studies
- 3 Conclusions and Overview



## 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  $K_L^0$ 's events (stdhep files provided by Mark Thomson)
- **Analysis sample:**  
10 000  $Z \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$  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)

## $RMS_{90}$

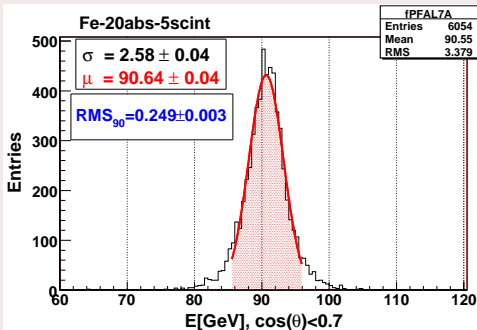
- Jet energy resolution:

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

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



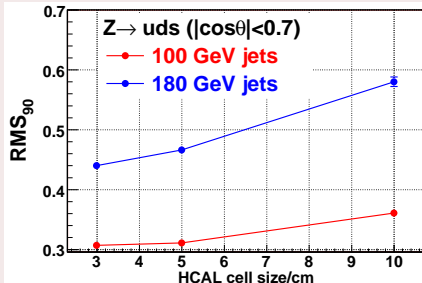
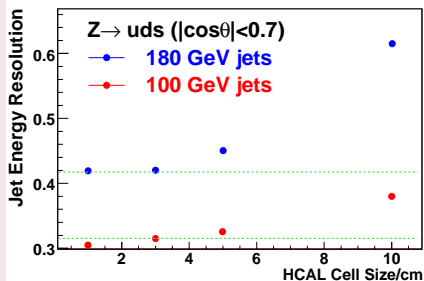
# Cross-checks of Results

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

$RMS_{90}$  and jet energy resolutions for default configuration

$E_{jet}$	$RMS_{90}$		$\sigma_E/E_j$	
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



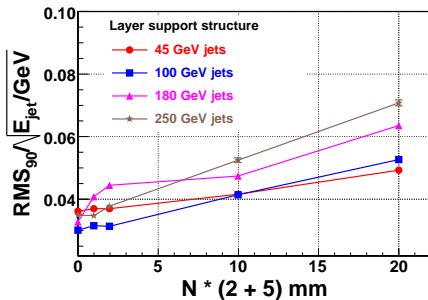
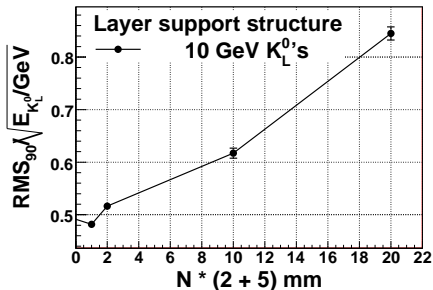
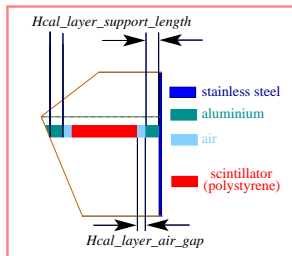
# Dead Zones: Layer Support Structure

- Support structures for the HCAL layers introduced few months ago  $\Rightarrow$  additional gaps and dead zones

- In default configuration:

$Hcal\_layer\_support\_length = 5 \text{ mm}$  (Al)

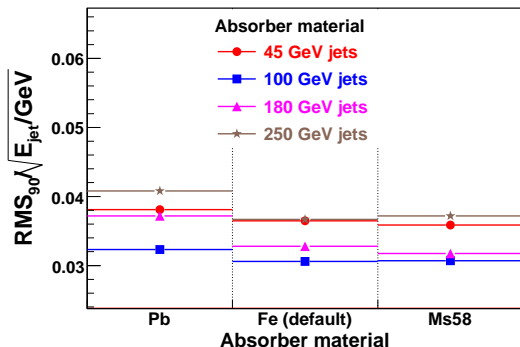
$Hcal\_layer\_air\_gap = 2 \text{ mm}$  (air)



# Absorber Material

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

Material	Nuclear interaction length $\lambda$ [cm]	Density [g/cm <sup>3</sup> ]	Moliere radius [cm]	Radiation length $X_0$ [cm]	$\lambda/X_0$
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

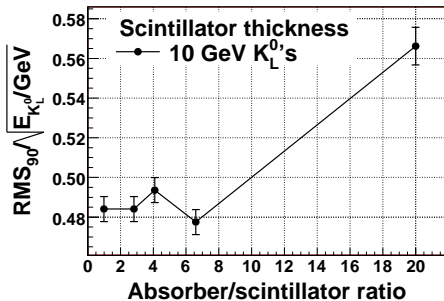


- For low energy jets: choice of material has a minimal influence on energy resolution
- For high energy jets: differences less than 1%

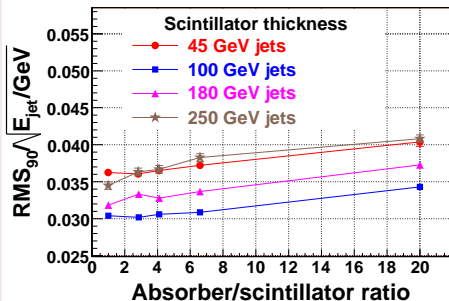
# Scintillator Thickness with PFA

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

For  $K_L^0$ 's used for calibration:



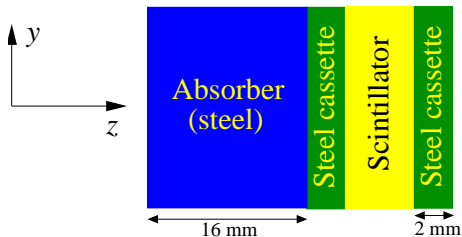
For  $Z \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$ :



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

# 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 ( $\lambda_I \sim 5.5$ )
- **3mm thick cintillator:**
  - 50 modules
  - total length: 135 cm ( $\lambda_I \sim 6$ )
- Incident particles:  $\pi^+$ , energies 10 - 150 GeV, hitting the center of calorimeter

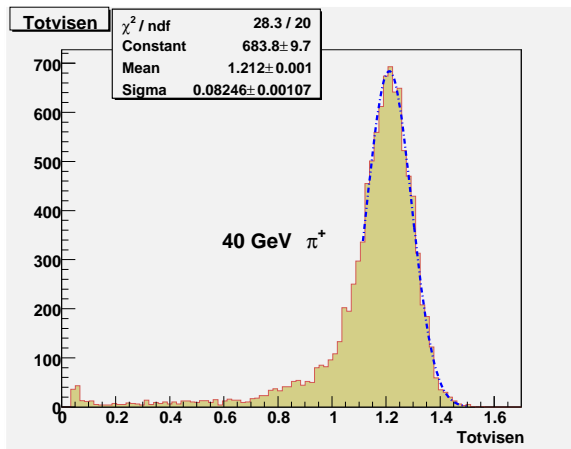


# Scintillator Thickness in GEANT3 - continued

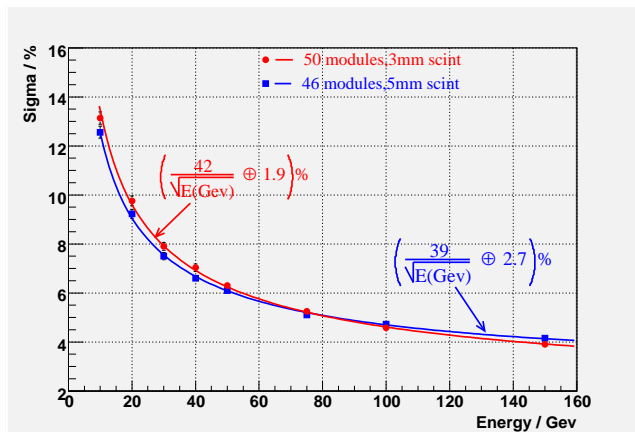
- Energy resolution from fit of total visible energy spectrum:

$$\frac{\sigma E}{E} = \frac{\sigma_{\text{Gaussian fit}}}{\text{mean}_{\text{Gaussian fit}}}$$

- Example for 40 GeV pions:



# Scintillator Thickness in GEANT3 - continued

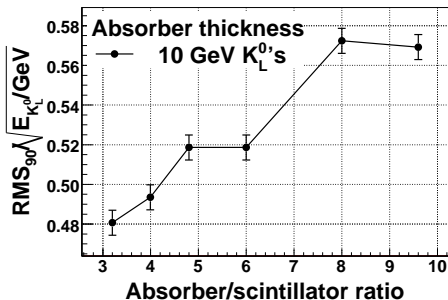


- **3 mm scintillator:** loss in stochastic term, but gain in constant term, because of containment

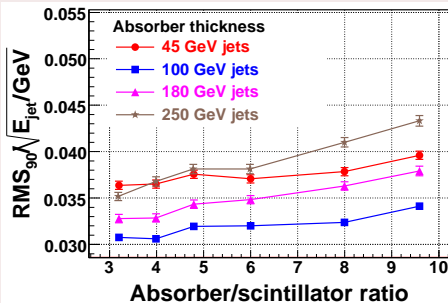
# Absorber Thickness

- 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  $K_L^0$ :



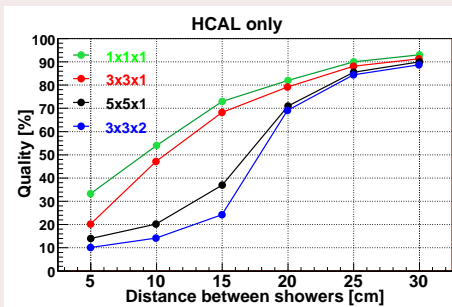
For  $Z \rightarrow u\bar{u}, d\bar{d}, s\bar{s}$ :



# Absorber Thickness - continued

## Word of caution

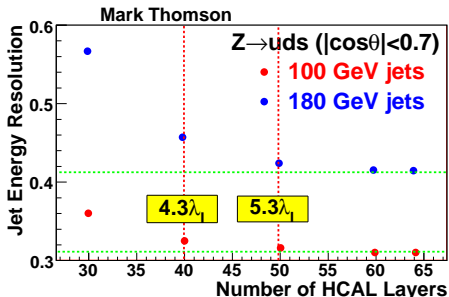
- Absorber thickness results need verification and must be interpreted with care
- Previous studies (2004) of A. Raspereza and V. Morgunov show that longitudinal (and transversal) segmentation is decisive



- **3x3x1** vs **3x3x2** (layers joined in depth): separation quality drops drastically with distance between showers  
⇒ 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.  $7 \lambda_I$ )



- HCAL leakage significant for high energies  $\Rightarrow$  optimum of approx.  $5 \lambda_I$  HCAL

# Saturation Effects: Birks Law

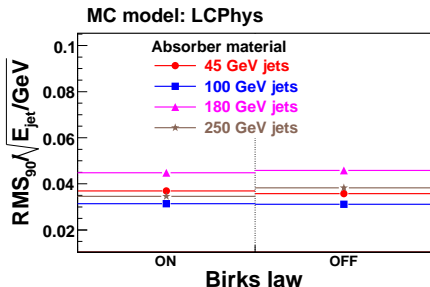
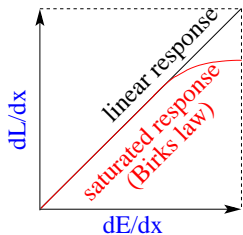
- Response of organic scintillators not linear with particle energy
- Primary excitation quenched by high density of ionized and excited molecules
- Saturation effects described by semi-empirical **Birks law**

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

$L$  - scintillator response

$k_B$ - Birks constant (material dependent)

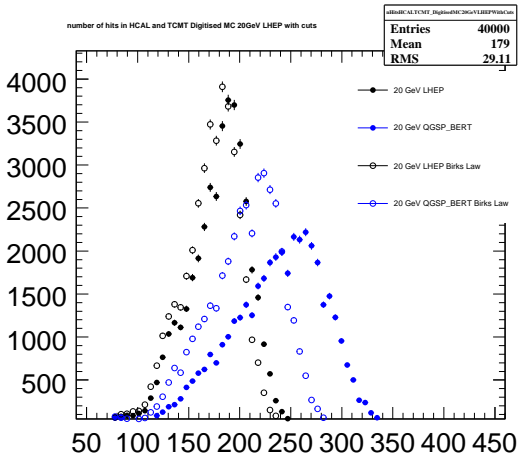
For polystyrene:  $k_B = 0.07943$  mm/MeV



- 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  $\rightarrow$  stronger effect in QGSP\_BERT, which has largest numbers of neutrons



## 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)
  - Ratios absorber/scintillator  $< 7$  give similar results

## Overview

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