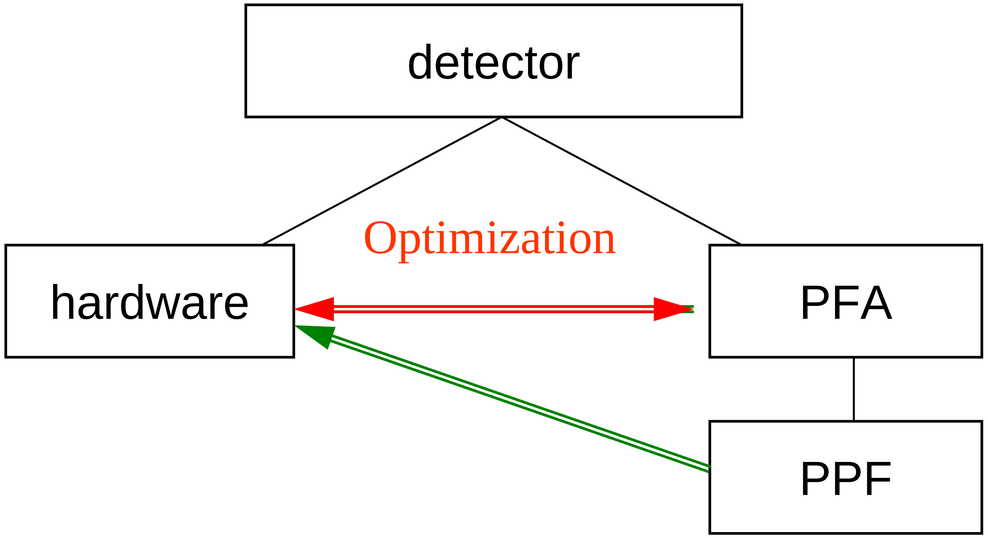
Particle flow performance and detector optimization

Introduction

- Physics based requirement for jet energy resolution of 30%
- Initial design on the base of general requirements – to have best possible sub-detectors (if affordable ☺)
- All designs made with intention to be suitable for particle flow algorithm (PFA)



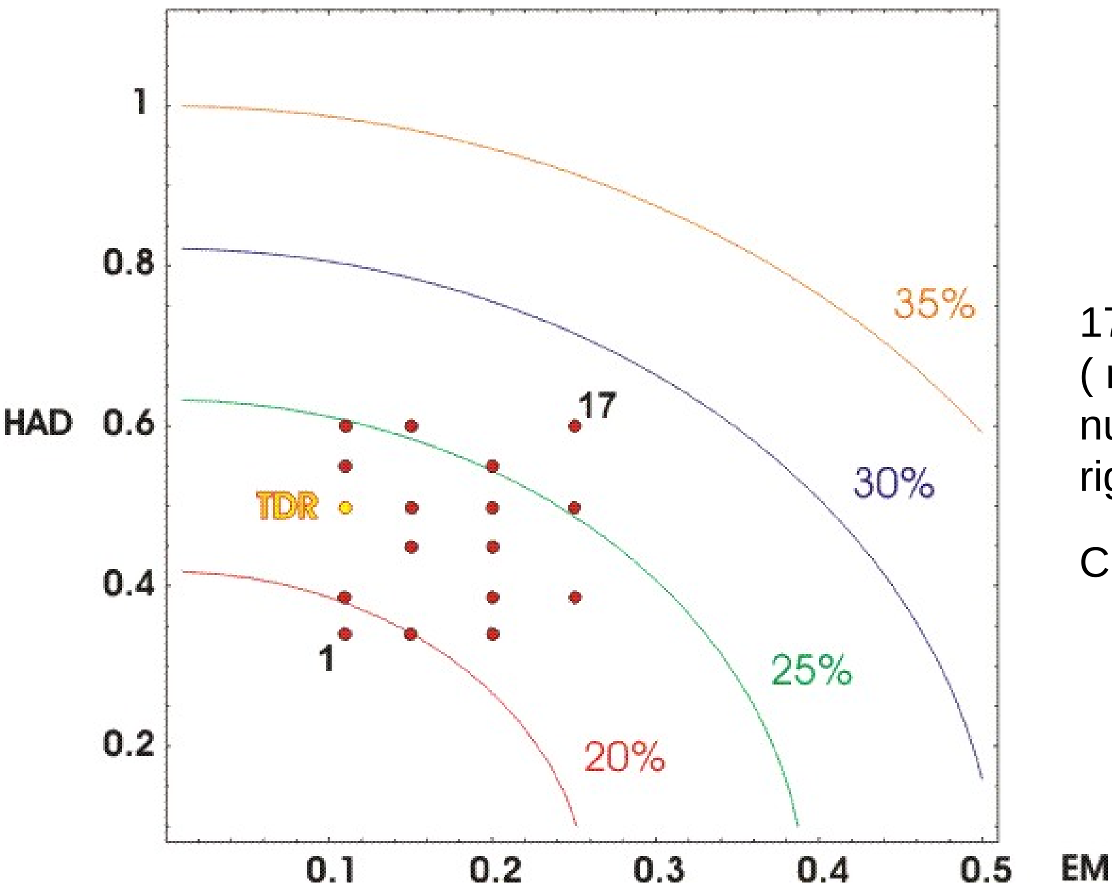
- Performance estimates made with different level of idealization – perfect particle flow (PPF)

- In order to estimate real performance and (or) to optimize the detector we can make two side approach – from the final reconstruction performance and from calorimeter performance estimate

Particle Flow Performance

Initial estimate – highest level of idealization (taking into account only component resolutions)

$$\sigma_{jet}^2 = w_{ph} \cdot \sigma_{ph}^2 + w_{had} \cdot \sigma_{had}^2 + w_{ch} \cdot \sigma_{ch}^2 + \sigma_{conf}^2$$



$$w_{ch} = 0.62$$

$$w_{ph} = 0.26$$

$$w_{had} = 0.10$$

17 points chosen (red dots in the plot numerated from left to right)

Curves- jet resolution

$$\sigma_{ch} = 7 \cdot 10^{-5}$$

	EM %			
HAD %	11	15	20	25
34	12.12 case 1 12.94	13.19 13.96	14.82 15.50	
38	13.26 14.29		15.76 16.58	17.52 18.21
45		16.15 17.08	17.51 18.39	
50	16.77 TDR 17.97	17.56 18.76	18.81 19.77	20.31 21.21
55	18.27 19.70		20.16 21.55	
60	19.79 21.42	20.46 21.83		22.86 case 17 24.06

Jet energy resolution ($\frac{x}{\sqrt{E}}$)
Expected (from the average energy fractions and the formulae) in blue
Red rms of the calculation on the event by event basis for WW 500GeV

Particle Flow Performance

- **Jet energy resolution :**

$$\sigma_{Ejet} = \sigma_{PPU} \oplus \sigma_{JFU} \oplus \sigma_{DG} \oplus \sigma_{PFA}$$

- **PPU Pure Physical Uncertainties:**

$$\sigma_{PPU} = \sigma_{\Gamma} \oplus \sigma_{Elumi} \oplus \sigma_{ISR} \oplus \sigma_{E\nu}$$

- **JFU Jet Finder Uncertainties:** $\sigma_{JFU} = \sigma_{\mathrm{JetFinderAlgorithm}}$

- **DG Detector Geometry Term:** $\sigma_{DG} = \sigma_{toBeamTube} \oplus \sigma_{DeadZones}$

Above sum depends on the particular physics process; on quality of accelerator; in particular on the beam spot size and crossing angle;on the jet finder chosen for analysis; on the detector geometry ; all of them have no deal with PFA
Particle-Flow Algorithm (PFA) quality is a function of sub-detector resolutions.
For PFA quality estimation one should first of all split of independent terms or remove them from analysis.
Goodness of Particle-Flow or it's comparison is possible ONLY after such splitting

Particle Flow Performance

$$\sigma_{Ejet} = \sigma_{PPU} \oplus \sigma_{JFU} \oplus \sigma_{DG} \oplus \sigma_{PFA}$$

$$\sigma_{PPU} = \cancel{\sigma_{\Gamma}} \oplus \cancel{\sigma_{Elumi}} \oplus \cancel{\sigma_{ISR}} \oplus \sigma_{E\nu}$$

$$\sigma_{JFU} = \cancel{\sigma_{\mathrm{JetFinderAlgorithm}}}$$

$$\sigma_{DG} = \sigma_{toBeamTube} \oplus \sigma_{DeadZones}$$

Full mass of the event is used to avoid jet finder algorithm, thus natural width doesn't influence the result, events were generated without ISR and we don't take into account luminosity spectrum.

Sub-detector resolutions

TPC (with angular and momentum dependence)

ECAL $12\%/\sqrt{E}$

HCAL $50\%/\sqrt{E} \oplus 4\%$

Beam tube < 5degrees

Minimal transverse momentum to reach TPC 0.36 GeV

Exact mass assignment for hadrons or Mcharged=M(pi+)
Mneutral=M(KL)

Particle Flow Performance

$e^+ e^- \to W^+ W^- \to q\bar{q}q\bar{q}$ at 500GeV

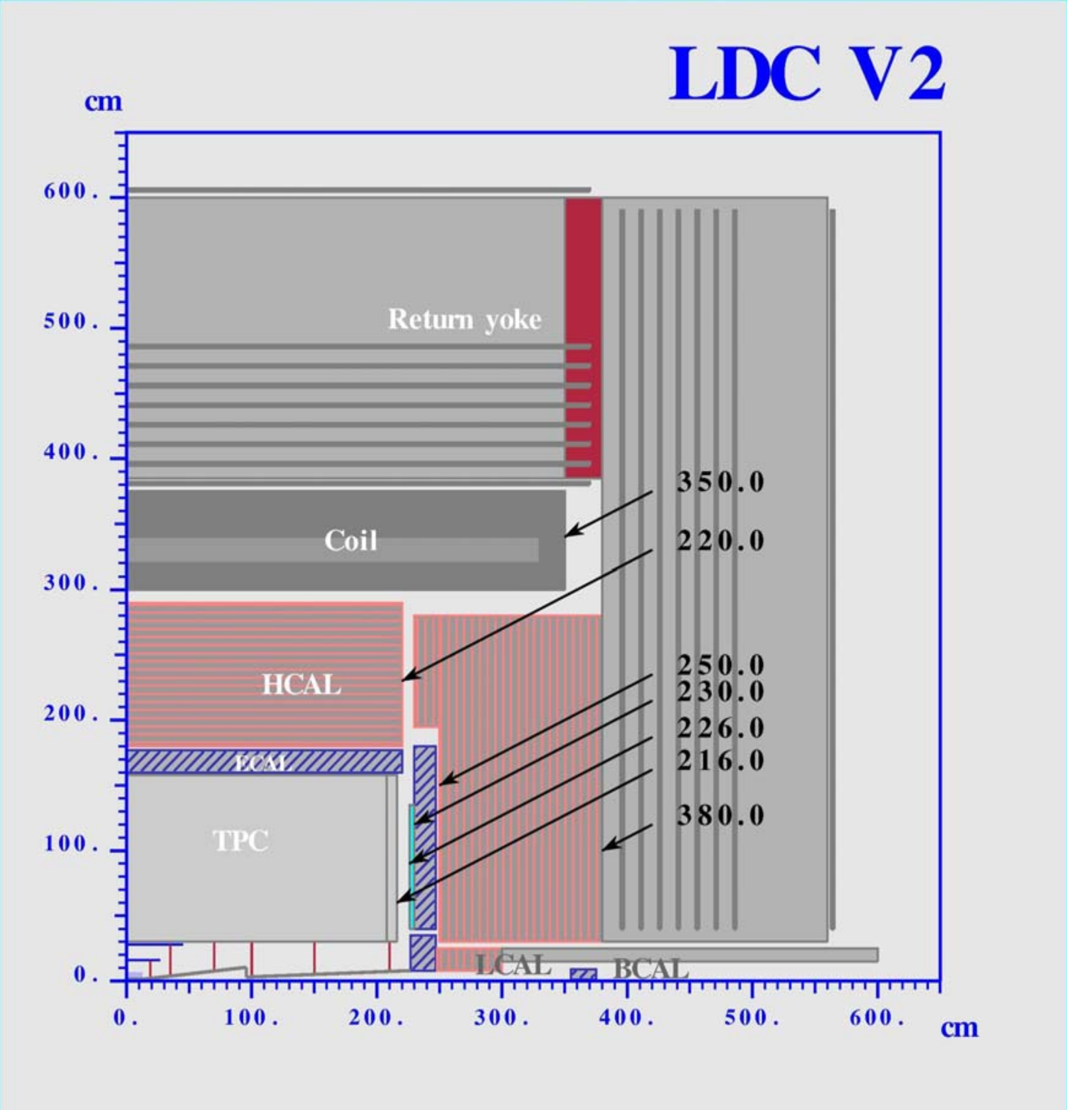
Effect	σ[GeV] separate	σ[GeV] not joined	σ[GeV] total ($\% / \sqrt{E}$)	σ % to total
$E_\nu > 0$	0.70	0.70	0.70 (3.13%)	1.50
$Cone < 5^o$	2.73	2.82	2.82(12.60%)	22.78
$P_t < 0.36$	1.36	3.13	3.13(13.99%)	5.65
σ_{HCAL}	4.10	4.10	5.16(23.07%)	51.39
σ_{ECAL}	2.17	4.64	5.60(25.02%)	14.40
M_{neutral}	1.02	4.75	5.69(25.44%)	3.18
M_{charged}	0.60	4.79	5.72(25.58%)	1.10

Particle Flow Performance

Whole event resolution

		500 GeV		
Effect	Z_{pole}	Z	W^+W^-	$t\bar{t}$
$\sigma_{DETECTOR}$ [GeV]	1.76	2.76	3.13	3.01
σ_{PPF} [GeV]	1.63	3.94	4.79	4.38
σ_{total} [GeV]	2.40	4.81	5.72	5.31
$\sigma_{total}\ \%/\sqrt{E}$	25.1%	21.5%	25.6%	23.7%

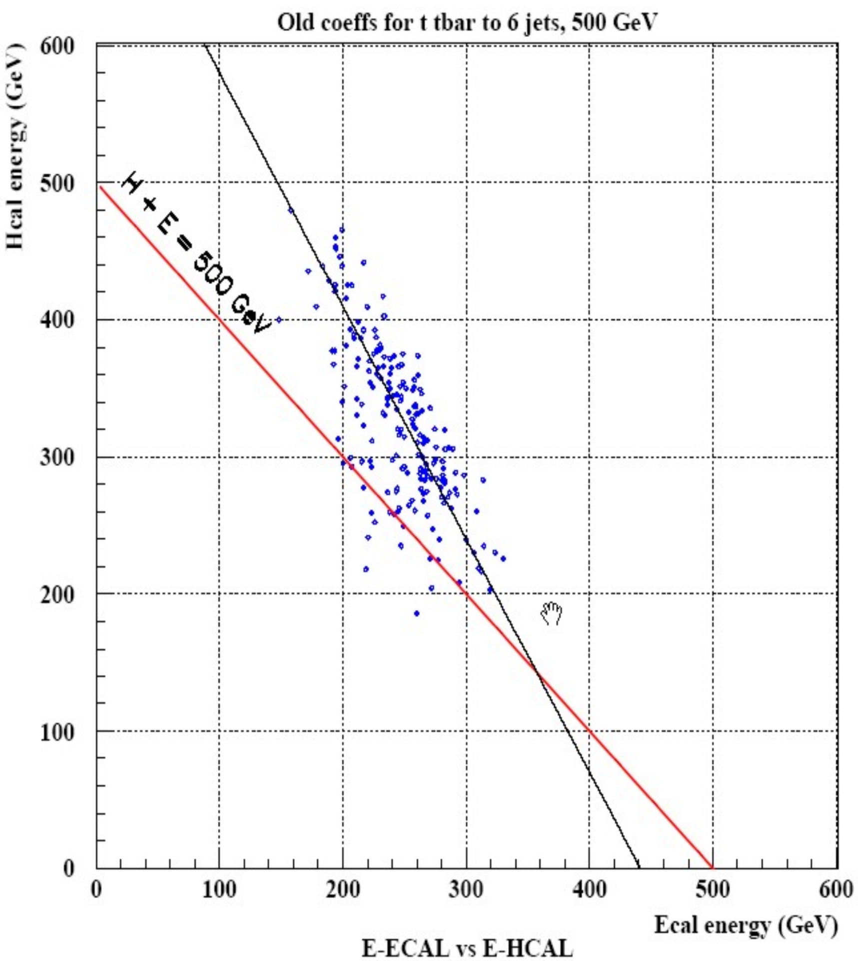
Detector



- View of the detector quadrant
- Two major versions implemented in G4 simulation MOKKA

Detector version	LDC	
Tag	00	01
Ecal R_{inner}	160cm	170cm
TPC Z/2	200cm	250cm
	Ecal design	
N×W[mm]	30 × 1.4	20 × 2.1
N×W[mm]	10 × 4.2	10 × 4.2

Calibration



- In LDC detector there are three structures with different sampling fractions
- Coefficients defined by muon run in the simulation for each sampling structure

$$c_i = \frac{E^i_{whole}}{E^i_{visible}}$$

- The simple formula should give us an answer $E_{Ecal} + E_{Hcal} = E_{CM}$

  but events are of , and we need to "rotate" the black line to fit the energy conservation
- These "rotated" coefficients consist of all "properties" of whole LDC calorimeters as wall as flavor's containment of the jets plus convoluted angular and field dependencies

Method proposed by V.Morgunov at LCWS06

Calibration

- The black line equation is: $a_0 E_{Ecal} + E_{Hcal} = a_0 (c_1 E_{vis1} + c_2 E_{vis2}) + c_3 H_{vis} = E_0$

Where c_1, c_2 and c_3 are initial energy conversion coefficients, a_0 is the slope which gives us the minimal energy width. E_0 is some constant – the line should come through the most probable value of initial energy sum.

- The red line equation is: $E_{Ecal}^{calib} + E_{Hcal}^{calib} = E_{CM}$ energy conservation law
- Let us require $E_0 = E_{CM}$ and $a_0 = 1$

then we got the new coefficients

$$c_1^{calib} = f\, a_0 c_1 \ , \ c_2^{calib} = f\, a_0 c_2 \ \text{and} \ c_3^{calib} = f\, c_3$$

Where $f = \frac{E_{CM}}{E_0}$ and

$c_1^{calib} E_{vis1} + c_2^{calib} E_{vis2} + c_3^{calib} H_{vis} = E_{CM}$ along the most probable line

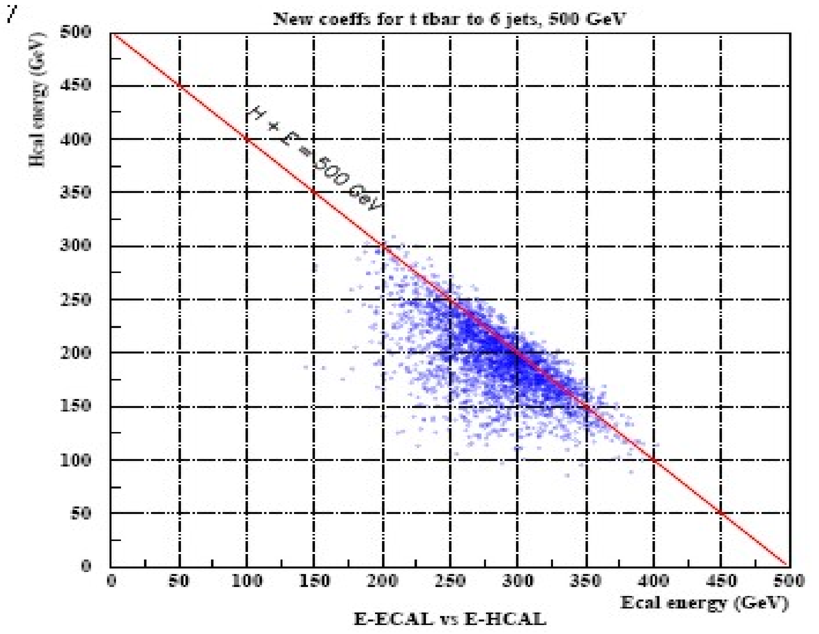
c_1^{calib} , c_2^{calib} and c_3^{calib} will be applied on to each hit the the particular sampling regions of the calorimeter.

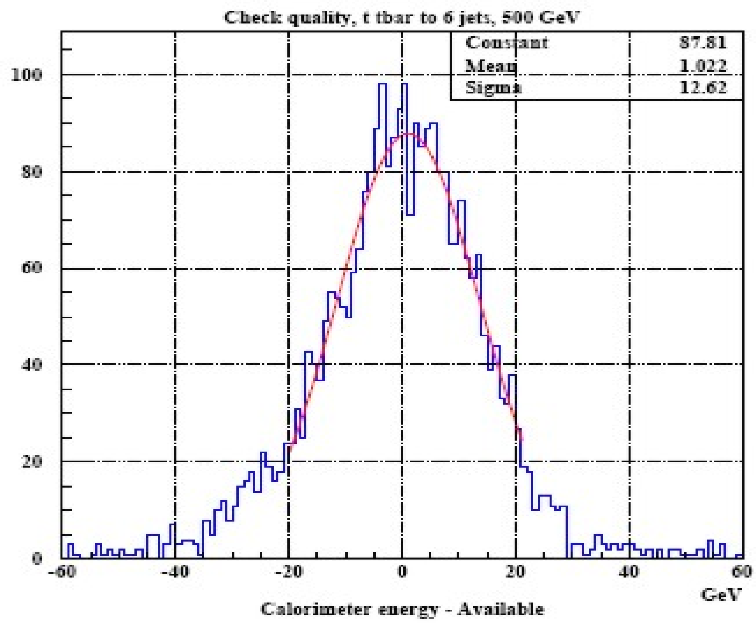
Calibration

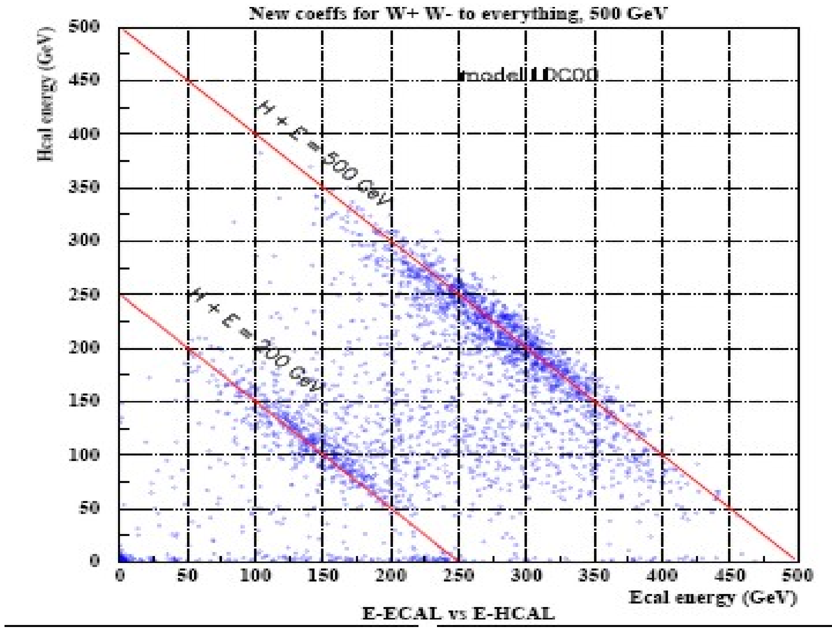
- Events were generated without luminosity curve and without ISR so the whole sum of energy in HEP record is equal of the center mass energy exactly
- To calculate available energy for calorimeters one should subtract the neutrino energies as well as the energy of particles that are lost due to the acceptance, and also muon energies in cases when they pass through the calorimeter leaving about 1.6GeV per muon.
- Estimated energy to be measured by calorimeters for each event is

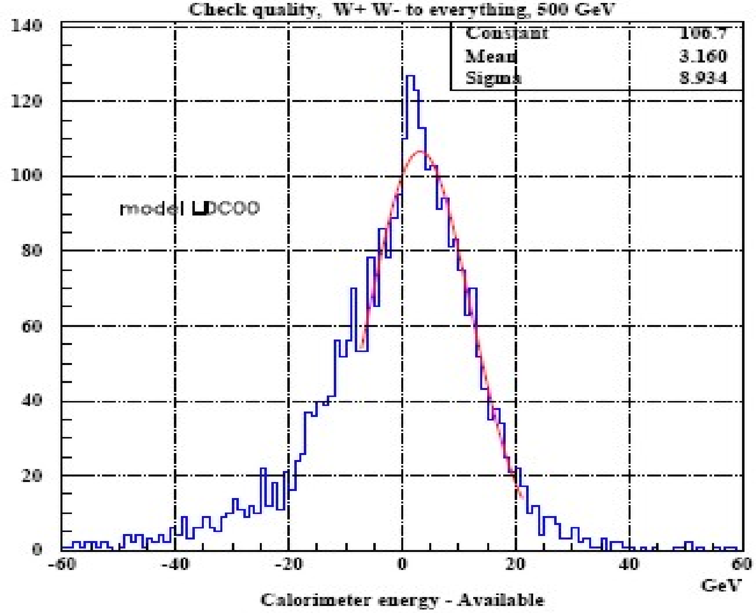
$$E_{available} = E_{CM} - E_{neutrinos} - E_{acc} - E_{muon} + N_{muons} \times 1.6GeV$$

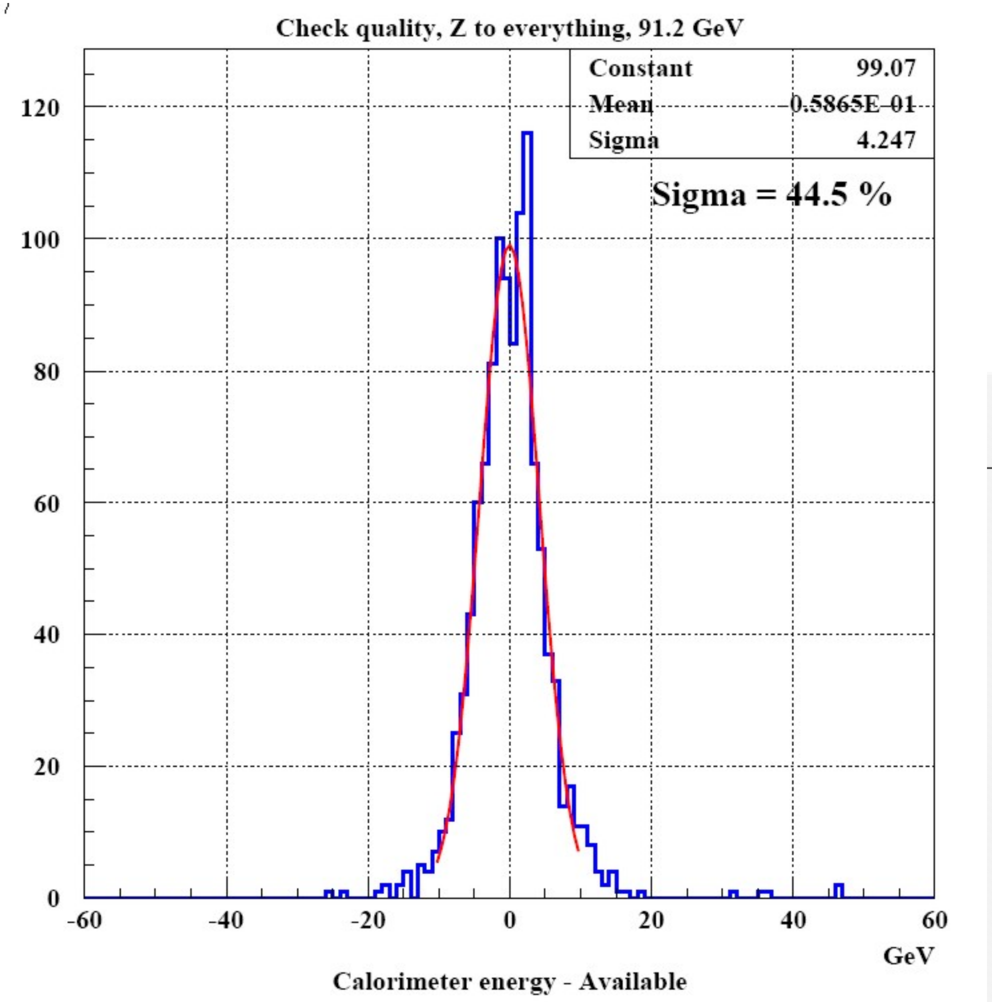
- Using this reference energy it's possible to make the check plots – distributions of total calorimeter energy after calibration minus available energy
- Events were processed using Geant 4.7.1p1


New coeffs for t tbar to 6 jets, 500 GeV
Hcal energy (GeV)
H + E = 500 GeV
Ecal energy (GeV)
E-ECAL vs E-HCAL

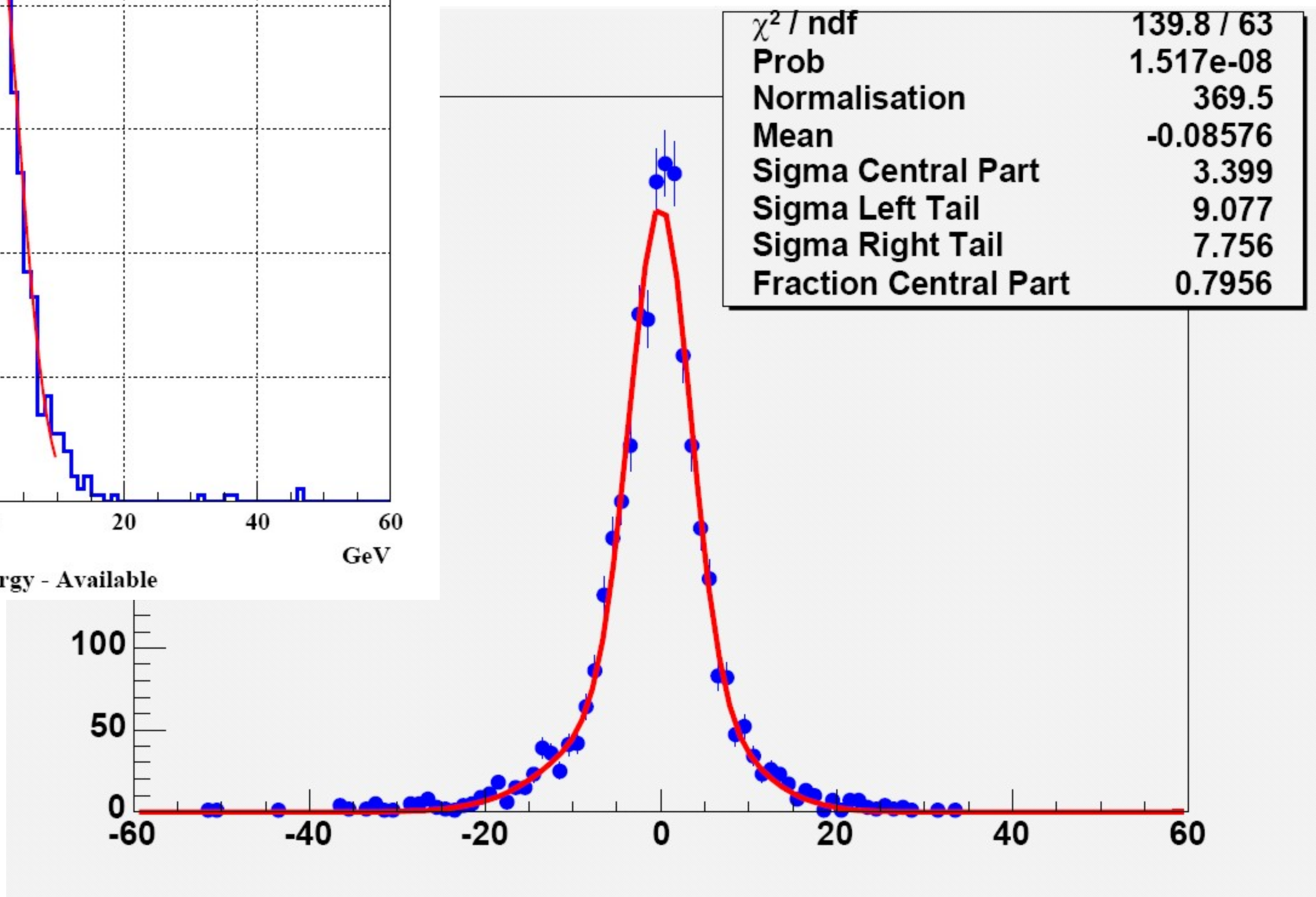

Check quality, t tbar to 6 jets, 500 GeV
Constant 87.81
Mean 1.022
Sigma 12.62
GeV
Calorimeter energy - Available


New coeffs for W+ W- to everything, 500 GeV
Hcal energy (GeV)
model LDC00
H + E = 500 GeV
H + E = 200 GeV
Ecal energy (GeV)
E-ECAL vs E-HCAL


Check quality, W+ W- to everything, 500 GeV
Constant 106.7
Mean 3.160
Sigma 8.934
model LDC00
GeV
Calorimeter energy - Available



- using the explained calibration procedure and Marlin based [reconstruction software]() we obtain following result



Calibration

The same three calibration coefficients were used for all energies and processes

		Whole calorimeter sum		Check plots	
$e^+ e^- \to$		Mean [GeV]	Sigma[GeV]	Mean[GeV]	Sigma[GeV]
$t\bar{t}$	1TeV	982.3	24.6	0.19	18.7
W^+W^-	1TeV	992.6	25.5	2.7	17.4
$t\bar{t}$	500GeV	488.8	16.9	1.8	12.6
W^+W^-	500GeV	496.6	16.9	1.6	10.9
$b\bar{b}, c\bar{c}$	500GeV	495.0	14.8	-0.5	12.8
$u\bar{u}, d\bar{d}, s\bar{s}$	500GeV	497.9	14.9	-1.1	14.3
$t\bar{t}$	360GeV	356.4	14.0	5.5	10.0
Z pole	91.2GeV	90.4	4.67	-0.06	4.25

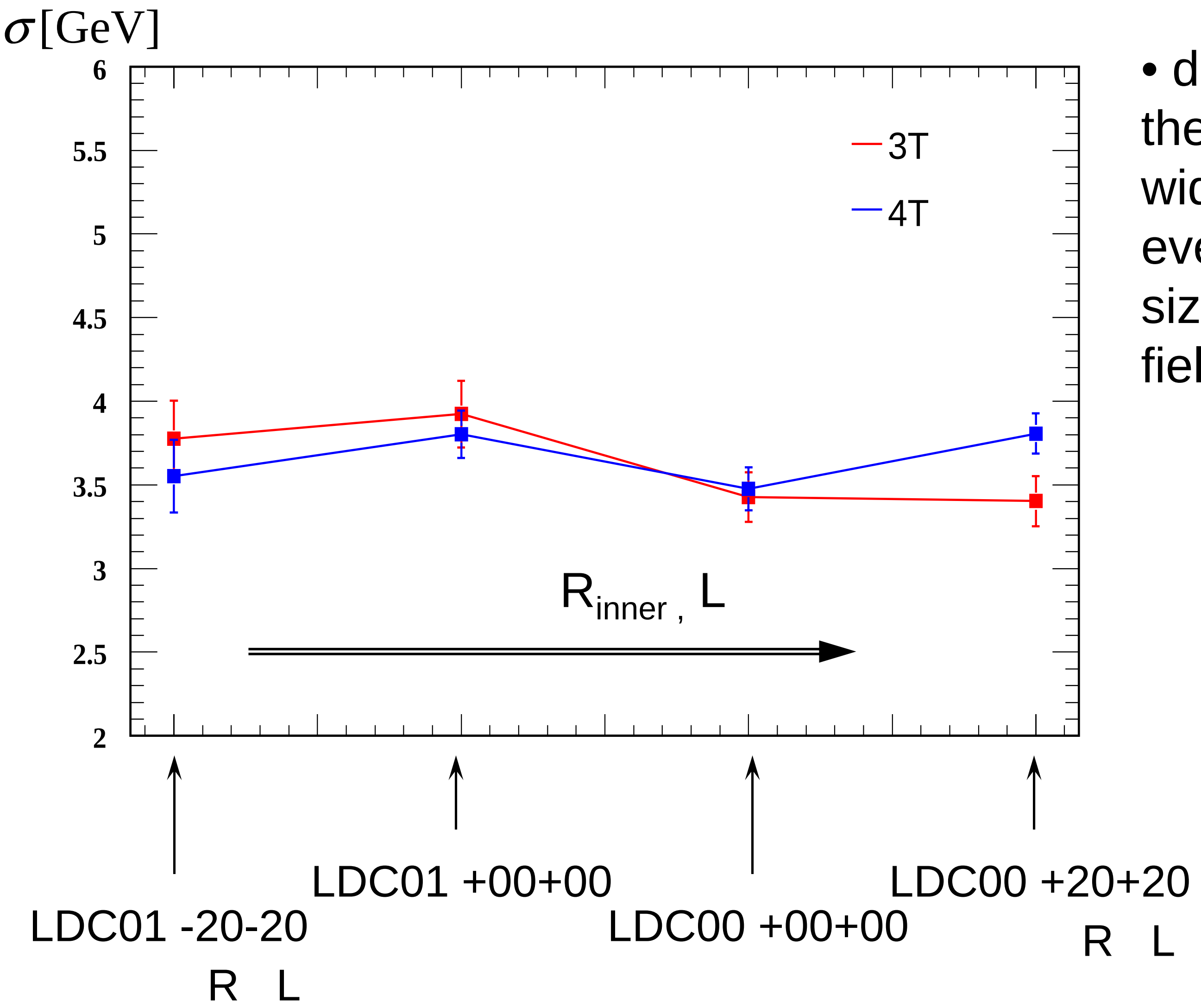
Optimization

Shift of energy distribution peak from the center of mass energy

	3Tesla				4 Tesla			
	LDC01		LDC00		LDC01		LDC00	
$e^+ e^- \rightarrow$	-20 -20	+00 +00	+00 +00	+20 +20	-20 -20	+00 +00	+00 +00	+20 +20
W^+W^- 500GeV	-3.4	-2.1	+3.1	+2.4	-0.8	-0.4	+4.2	+3.1
$t\bar{t}$ 500GeV	-6.9	-7.0	-3.1	-4.6	-6.2	-5.0	-1.9	-3.0
$t\bar{t}$ 360GeV	-6.7	-6.3	-3.6	-4.6	-5.8	-6.5	-3.2	-5.0

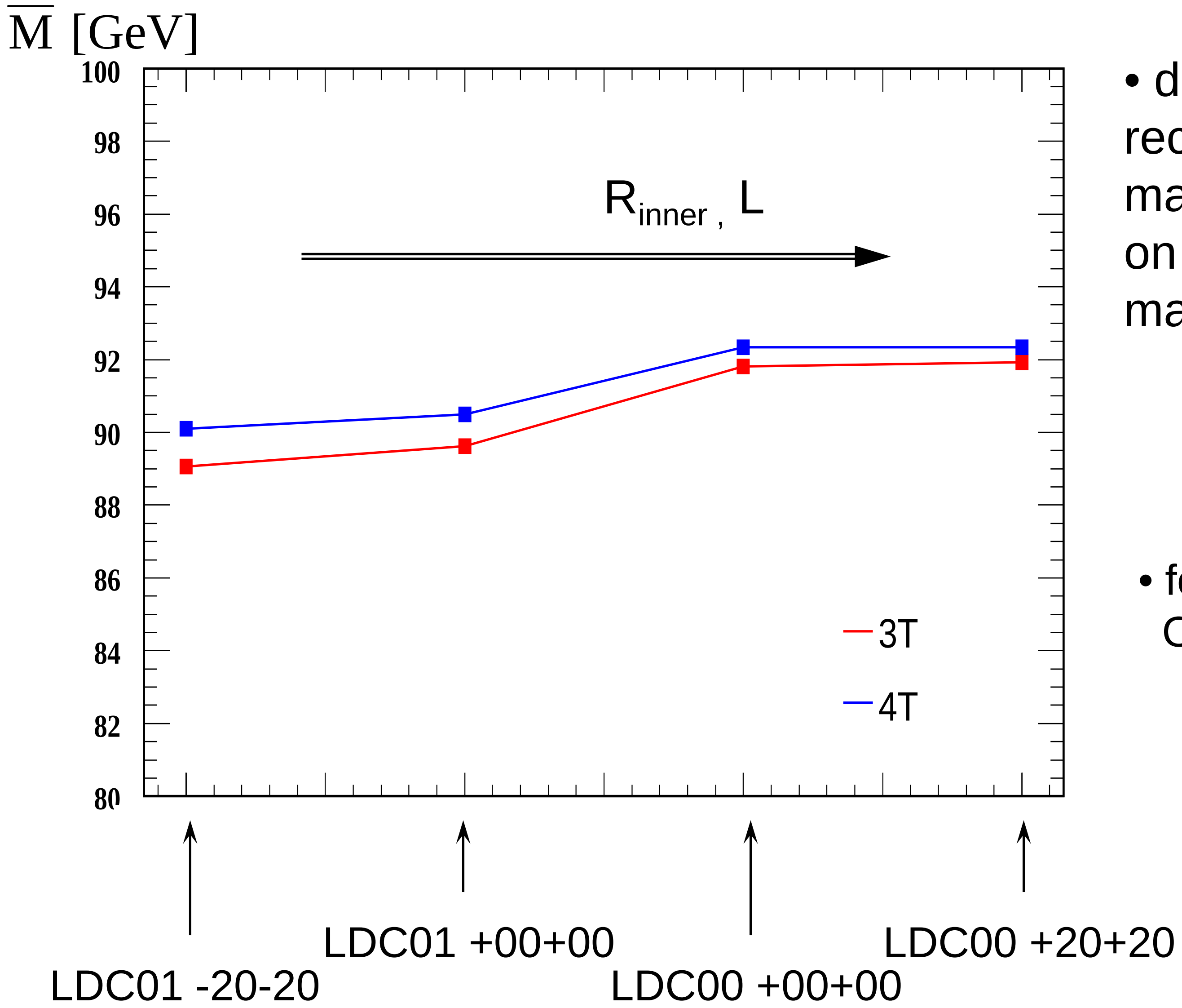
• tiny dependencies that are visible are on the percent level and can be fully explained by second order effects. All detector variations are equal in respect of the full calorimeter energy.

Optimization



- dependence of the reconstructed width of Z pole events on detector size and magnetic field.

Optimization



- dependence of the reconstructed mean mass of Z pole events on detector size and magnetic field.

- for further details see O.Wendt Cambridge

Conclusion

	PPF	Implementation of PFA	Calorimeter Sum
$e^+ e^- \to$	Sigma [GeV]		
Z pole 91.2GeV	$\approx$ 2.4	3.4	$\approx$ 4.67
$t\bar{t}$ 500GeV	$\approx$ 5.3	?	$\approx$ 12.6
W^+W^- 500GeV	$\approx$ 5.7	?	$\approx$ 16.9
$q\bar{q}$ 500GeV	$\approx$ 4.8	?	$\approx$ 14.8

- software performance was limiting factor in continuing the optimization since designed detector + software should give designed resolution in full range of energies up to 1TeV.
- On energies were it works there is no significant dependence on R, L or B to make any conclusions.
- Once you have software that is able to fill empty spaces in the table it's possible to optimize the detector