LHCal MC simulations. Updated results

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Overview

Introduction: Goals

- Understand how to work with software DD4Hep, lcgeo, etc.
- LHCal geometry modification according to calorimeter requirements
- Perform MC simulations for different types of particles
- Simulation data analysis

Introduction: Previous steps

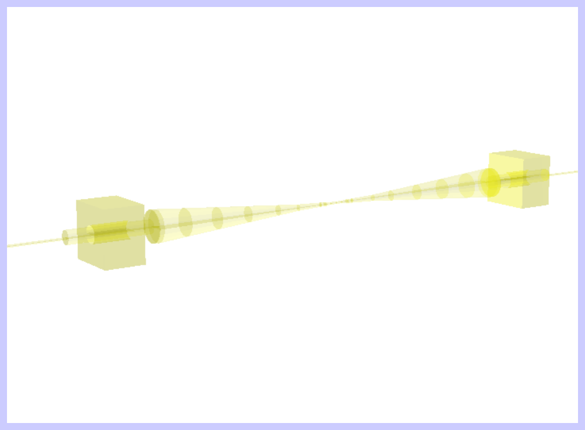
The following soft have been installed on the local computers:

- ROOT 5.34.24 with proper options
- Geant 4.9.6
- GDML v03-01-01
- LCDD v04-00-00
- ILCUTIL v01-02
- GEAR v01-04-01
- LCIO v02-05
- DD4HEP in two variants:
  1. with tinyxml parser;
  2. with xercesc (needed for Geant simulation)
- LCGEO

So now we can work without direct connection to the DESY resources

Introduction: Current status

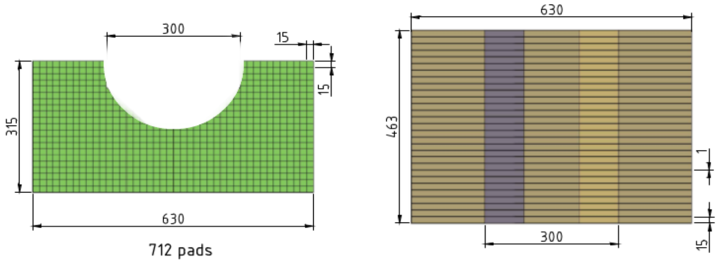
- Geometry of *LHCal + BeamPipe* configuration has been modified, using as basic composition of the whole *ILD detector (o1 _ v05)*
- Set of simulation have been done both for negatively and positively charged particles: *electrons, muons, pions and kaons* having energies: *1, 3, 5, 20 and 50 GeV*
- *LHCal + BeamPipe*



MC simulation features: ILD LHCal structure

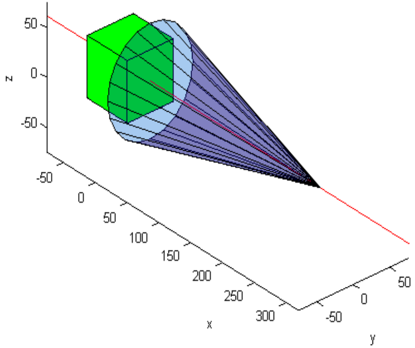
Tested variant:

- 29 layers of 16 mm thickness
- Total thickness: $29 \cdot 16 - 1 = 463$ mm
- Half size in XY-plane: $L_{XY} = 315$ mm



MC simulation features: Model parameters

- Simulation tool: DD4HEP (based on Geant4.9.6) and LCGEO
- Particles: $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}$
- Initial momenta: 1, 3, 5, 20, 50 GeV
- Initial particle directions covered the whole solid angle for LHCal

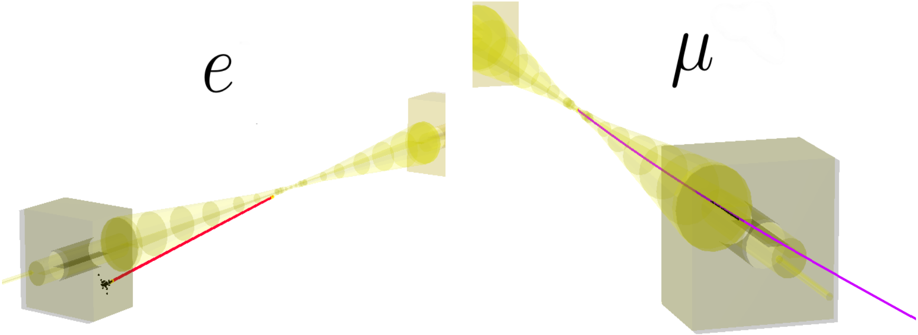


MC simulation features: Model parameters

- XY-plane divided on 25 $\times$ 25 bins from $-L_{XY} - 60 = -375$ mm to $+L_{XY} + 60 = 375$ mm.
- Two types materials of layers have been used:
  - Layer thickness = 16 mm = 12 mm (W) + 0.1 mm (Air) + 1 mm (Si) + 1.9 mm (Cu) + 1 mm (Air gap)
  - Layer thickness = 16 mm = 13.8 mm (Fe) + 0.1 mm (Air) + 1 mm (Si) + 0.1 mm (Cu) + 1 mm (Air gap)

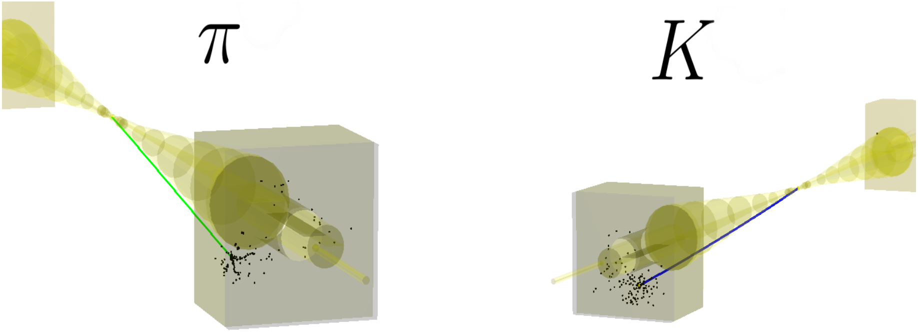
- The following simulations have been done for layers with tungsten:
  - Types of particles: $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}$
  - Initial particle momentums: 5, 20, 50 GeV
  - **Number of events:** $2 \cdot 10^4$ (but in some cases 10^5)
- The following simulations have been done for layers with ferrum:
  - Types of particles: $e^{\pm}, \mu^{\pm}, \pi^{\pm}, K^{\pm}$
  - Initial particle momentums: 1, 3, 5 GeV
  - **Number of events:** $4 \cdot 10^4$

MC simulation features: Tracks of particles



- Muons are going through all layers of calorimeter
- Electrons $\longrightarrow$ absorbed $\longrightarrow$ electromagnetic shower

MC simulation features: Tracks of particles

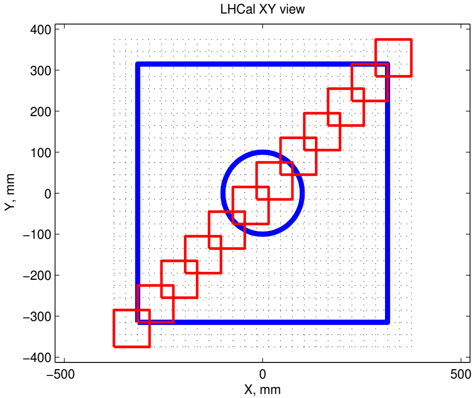


- LHCal absorbs pions and kaons
- Pions and kaons hadron showers are bigger compared to electrons

MC simulation features: Binning

The following partition have been used:

- LHCal dimensions: 630×630 mm, Radius of beam tube: $150 mm$
- XY-plane divided on 25×25 bins
- Each 9 bins combine into one group (red squares at the picture).
- Central bins are empty (beam tube location)

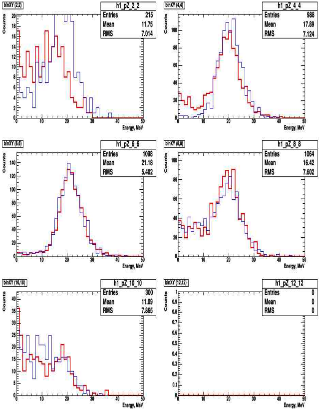


Momentum 1 GeV: e^+, e^-

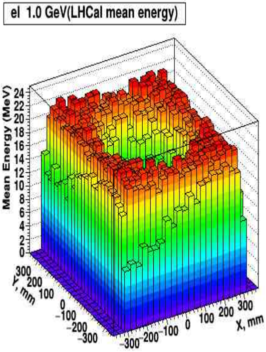
- Material: ferrum
- Number of events: $4 \cdot 10^4$

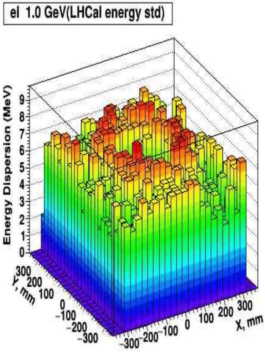
- Mean Energy $\approx$ 16 MeV
- Energy Dispersion $\approx$ 7 MeV

Energy distribution, red line for e^+, blue — e^-:



Mean energy and energy dispersion:



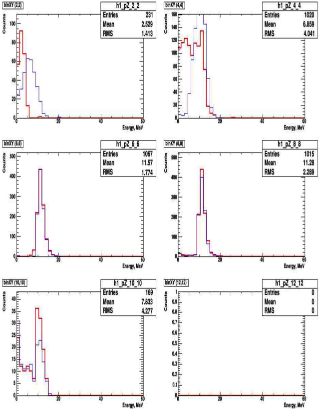


Momentum 1 GeV: μ^+, μ^-

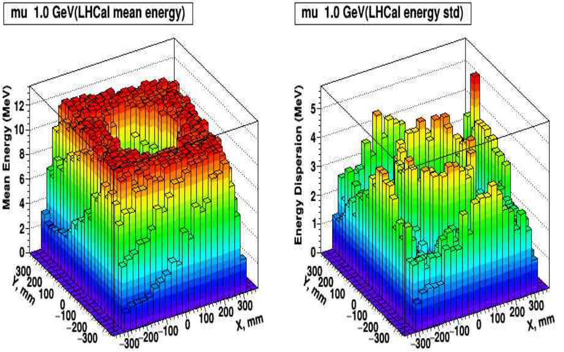
- Material: ferrum
- Number of events: $4 \cdot 10^4$

- Mean Energy $\approx$ 10 MeV
- Energy Dispersion $\approx$ 3 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:

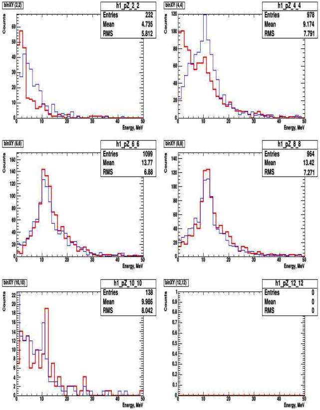


Momentum 1 GeV: π^+, π^-

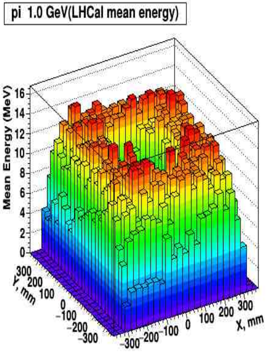
- Material: ferrum
- Number of events: $4 \cdot 10^4$

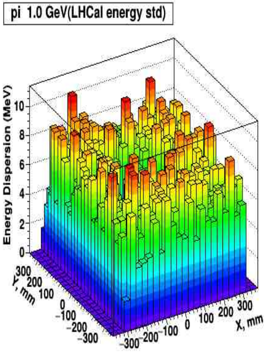
- Mean Energy $\approx$ 12 MeV
- Energy Dispersion $\approx$ 7 MeV

Energy distribution, red line for π^+, blue — π^-:



Mean energy and energy dispersion:



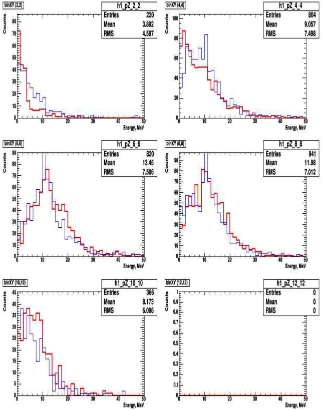


Momentum 1 GeV: K^+, K^-

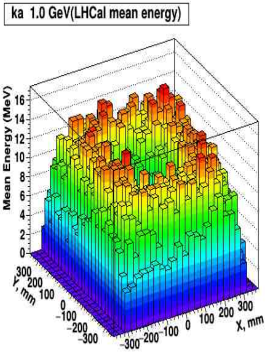
- Material: ferrum
- Number of events: $4 \cdot 10^4$

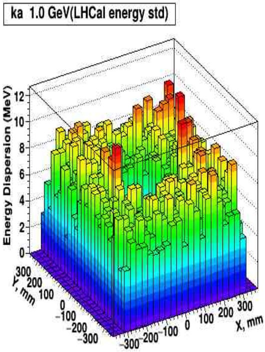
- Mean Energy $\approx$ 11 MeV
- Energy Dispersion $\approx$ 7 MeV

Energy distribution, red line for K^+, blue — K^-:



Mean energy and energy dispersion:



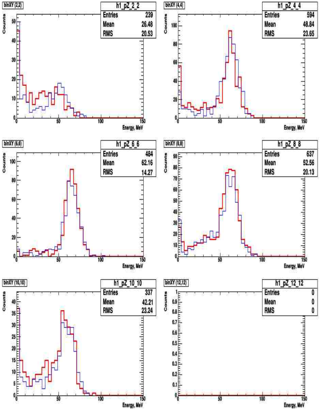


Momentum 3 GeV: e^+, e^-

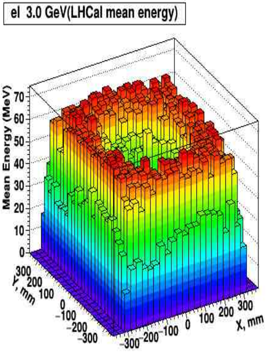
- Material: ferrum
- Number of events: $4 \cdot 10^4$

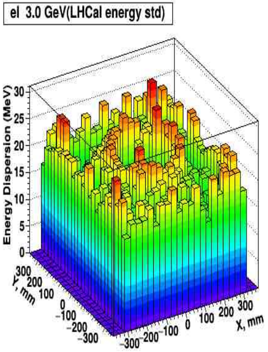
- Mean Energy $\approx$ 52 MeV
- Energy Dispersion $\approx$ 23 MeV

Energy distribution, red line for e^+, blue — e^-:



Mean energy and energy dispersion:



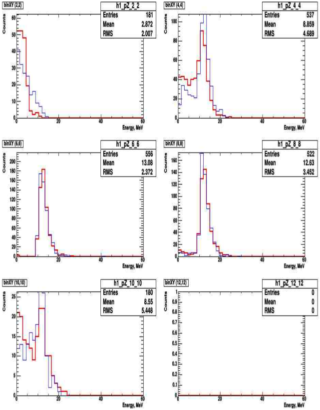


Momentum 3 GeV: μ^+, μ^-

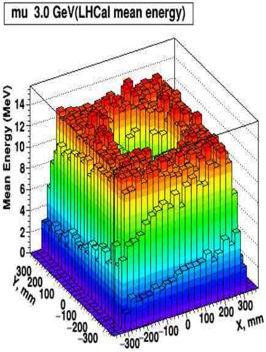
- Material: ferrum
- Number of events: $4 \cdot 10^4$

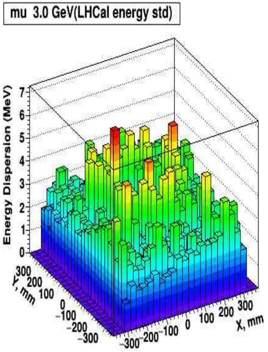
- Mean Energy $\approx$ 11 MeV
- Energy Dispersion $\approx$ 4 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:



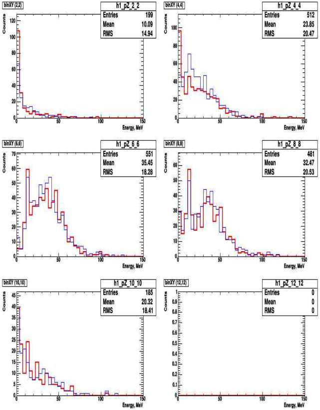


Momentum 3 GeV: π^{+}, π^{-}

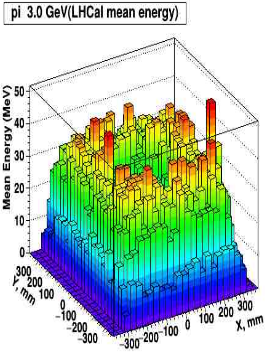
- Material: ferrum
- Number of events: $4 \cdot 10^{4}$

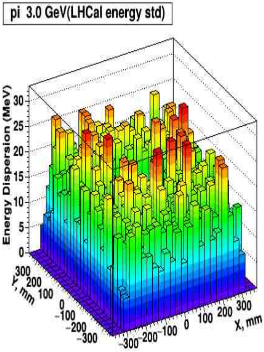
- Mean Energy $\approx$ 29 MeV
- Energy Dispersion $\approx$ 22 MeV

Energy distribution, red line for π^{+}, blue — π^{-}:



Mean energy and energy dispersion:



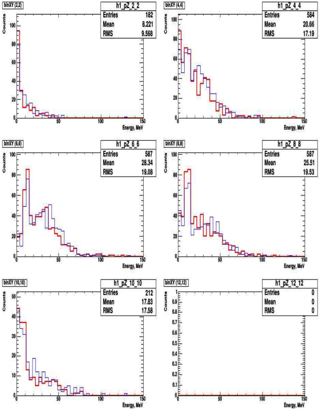


Momentum 3 GeV: K^+, K^-

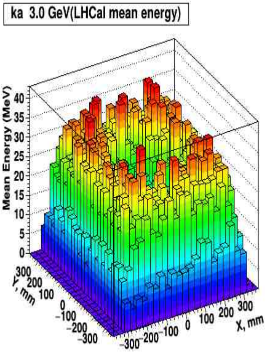
- Material: ferrum
- Number of events: $4 \cdot 10^4$

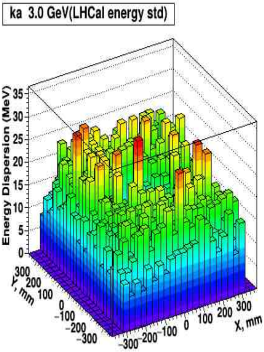
- Mean Energy $\approx$ 24 MeV
- Energy Dispersion $\approx$ 22 MeV

Energy distribution, red line for K^+, blue — K^-:



Mean energy and energy dispersion:



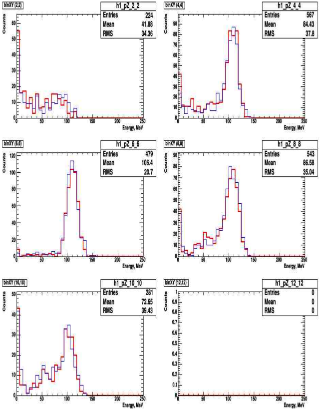


Momentum 5 GeV, ferrum: e^+, e^-

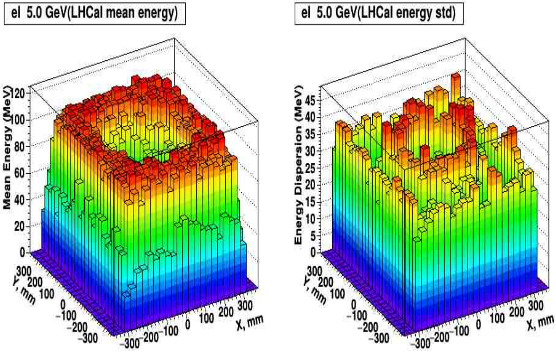
- Material: ferrum
- Number of events: $4 \cdot 10^4$

- Mean Energy $\approx$ 88 MeV
- Energy Dispersion $\approx$ 35 MeV

Energy distribution, red line for e^+, blue — e^-:



Mean energy and energy dispersion:

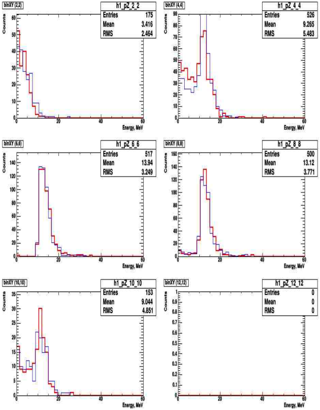


Momentum 5 GeV: μ^+, μ^-

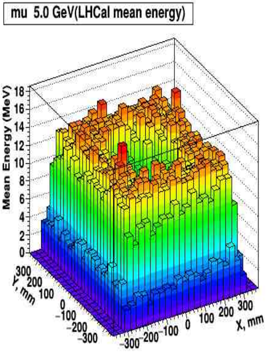
- Material: ferrum
- Number of events: $4 \cdot 10^4$

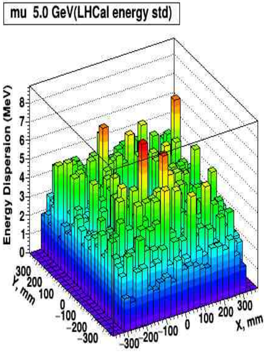
- Mean Energy $\approx$ 12 MeV
- Energy Dispersion $\approx$ 4 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:



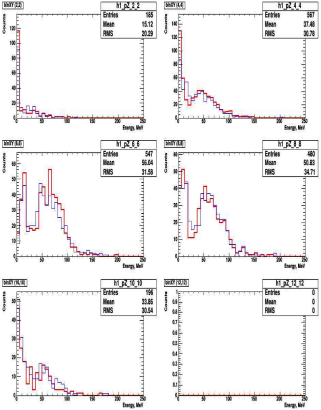


Momentum 5 GeV: π^+, π^-

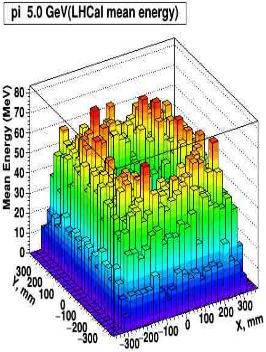
- Material: ferrum
- Number of events: $4 \cdot 10^4$

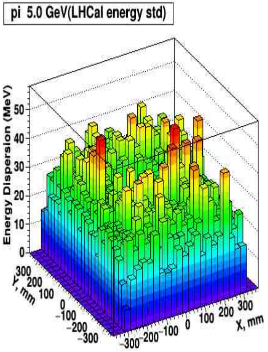
- Mean Energy $\approx$ 40 MeV
- Energy Dispersion $\approx$ 30 MeV

Energy distribution, red line for π^+, blue — π^-:



Mean energy and energy dispersion:



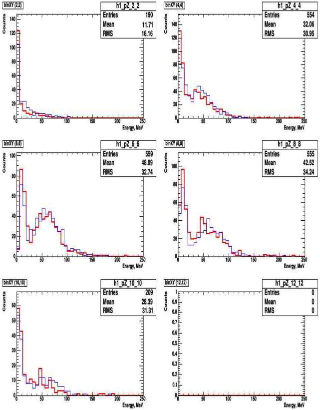


Momentum 5 GeV: K^+, K^-

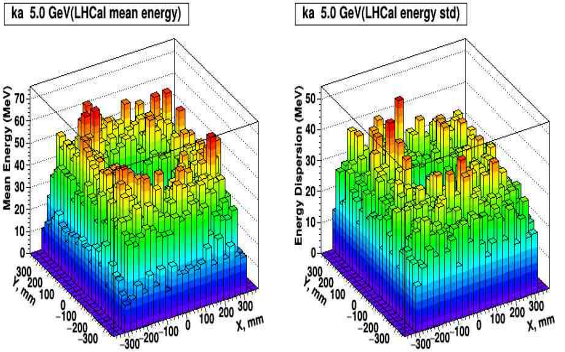
- Material: ferrum
- Number of events: $4 \cdot 10^4$

- Mean Energy $\approx$ 45 MeV
- Energy Dispersion $\approx$ 30 MeV

Energy distribution, red line for K^+, blue — K^-:

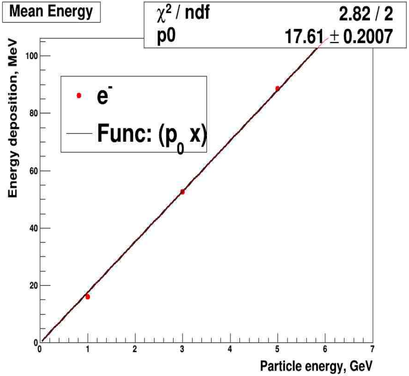


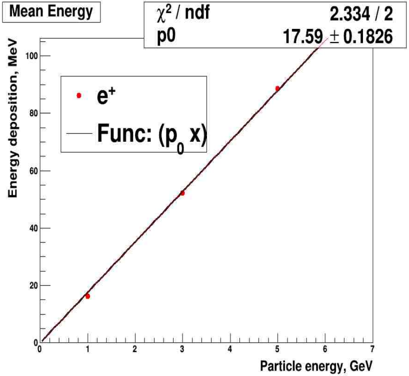
Mean energy and energy dispersion:



Linearity of LHCal: e^+, e^-

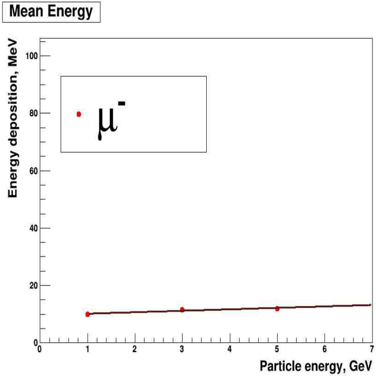
- Material: ferrum
- Number of events: $4 \cdot 10^4$

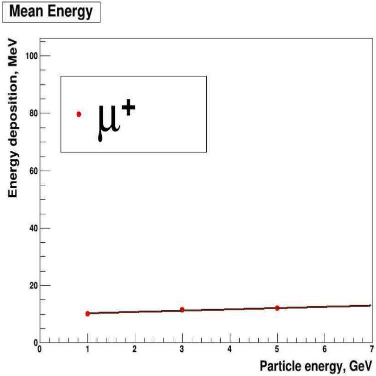




Linearity of LHCal: μ^+, μ^-

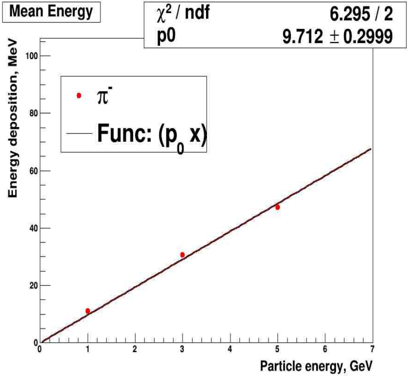
- Material: ferrum
- Number of events: $4 \cdot 10^4$

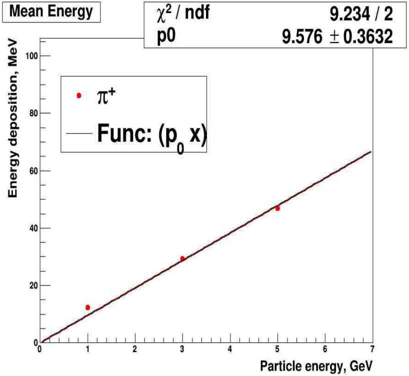




Linearity of LHCal: π^+, π^-

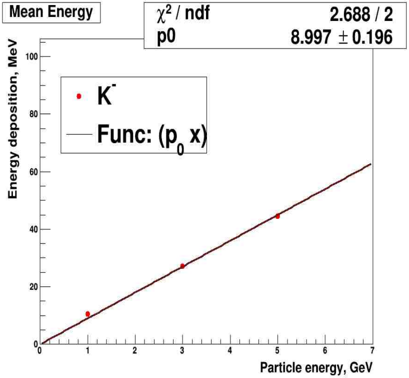
- Material: ferrum
- Number of events: $4 \cdot 10^4$

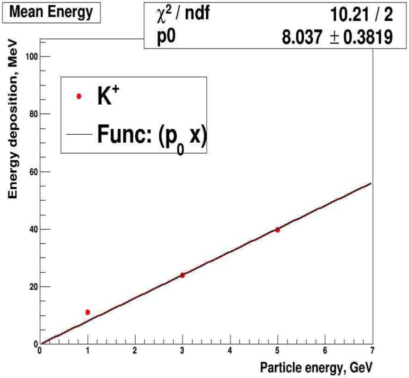




Linearity of LHCal: K^+, K^-

- Material: ferrum
- Number of events: $4 \cdot 10^4$





Conclusions:

Conclusions

- ILC soft has been installed on the local computers. Advantages:
  - quick test in Kyiv
  - routine simulations using NAF
- Deposition energy and energy distribution have been studied for electrons, muons, pions, kaons for $1, 3, 5, 20, 50$ GeV
- Different types of material have been used
- MC simulations have been done for tungsten for each type of particles with initial energy: 5, 20, 50 GeV and number of events: $2 \cdot 10^4$
- MC simulations have been done for ferrum for each type of particles with initial energy: 1, 3, 5 GeV and number of events: $4 \cdot 10^4$
- Linear response of calorimeter is observed

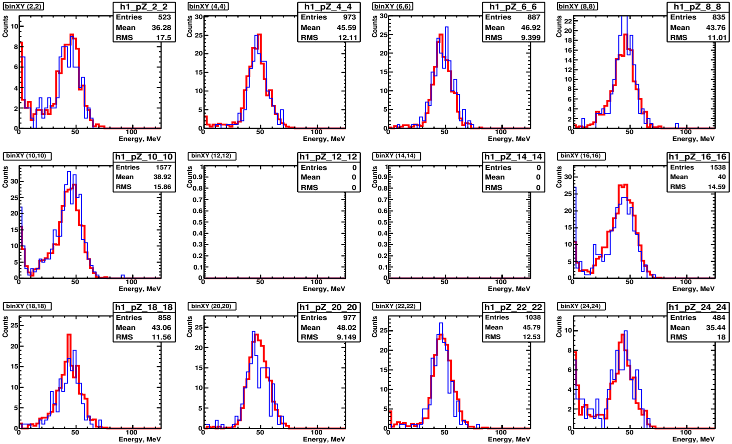
Next steps

- Extending the energy range
- Comparing calorimeter response for different materials
- Simulations with/without LumiCal

Back-up

Back-up: Momentum 5 GeV, e^+, e^-

- Material: Tungsten
- Number of events: $2 \cdot 10^4$
- Each energy distribution in (i, j)-bin: summarised within 9 neighbour bins (3×3)
- Central bins: (12,12) and (14,14) — empty (beam tube location)
- Red line for e^+, blue — e^-
- *Well, distributions match, but, also, some edge effects for the marginal bins are observed.*

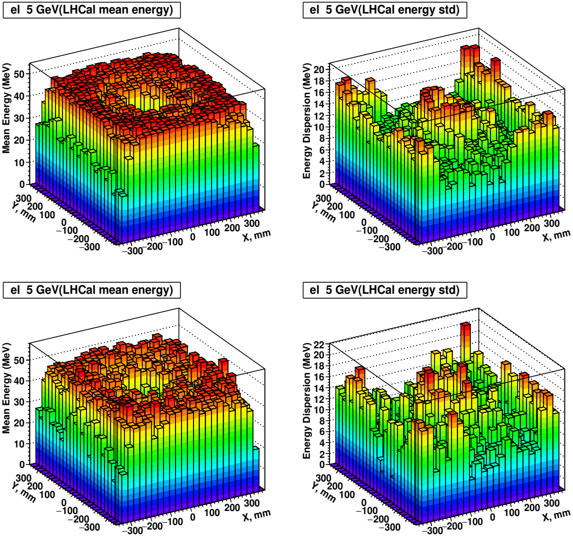


Back-up: Momentum 5 GeV, e^+, e^-

Mean Energy $\approx$ 48 *MeV and Energy Dispersion* $\approx$ 15 *MeV*

e^+

e^-



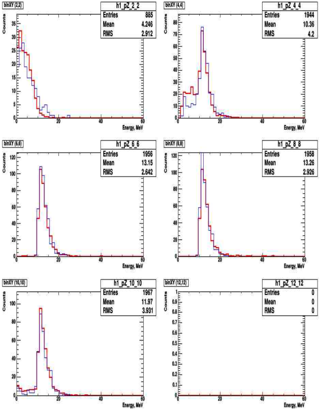
'Beam tube' effect in dispersion is observed

Back-up: Momentum 5 GeV, μ^+, μ^-

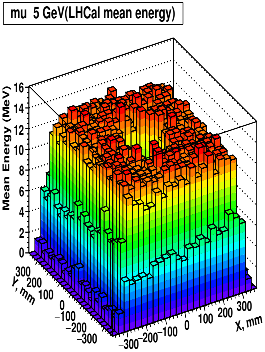
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

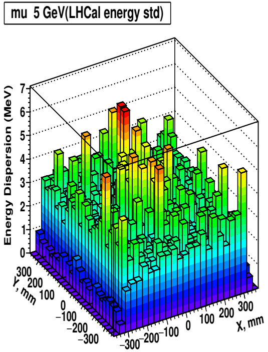
- Mean Energy $\approx$ 13 MeV
- Energy Dispersion $\approx$ 3 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:



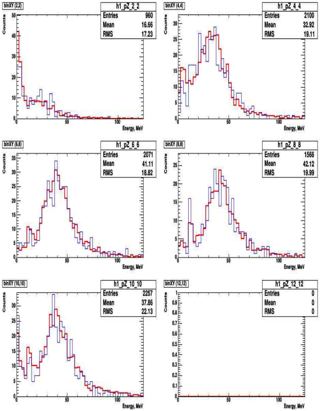


Back-up: Momentum 5 GeV, π^+, π^-

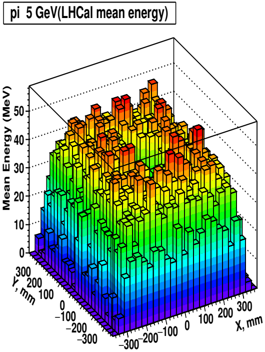
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

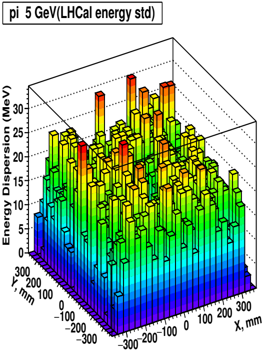
- Mean Energy $\approx$ 40 MeV
- Energy Dispersion $\approx$ 20 MeV

Energy distribution, red line for π^+, blue — π^-:



Mean energy and energy dispersion:

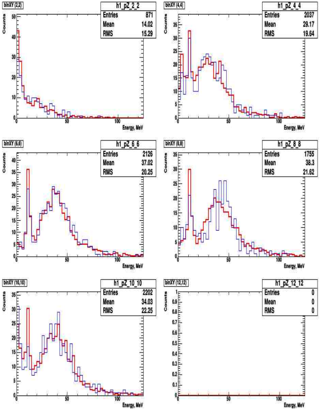




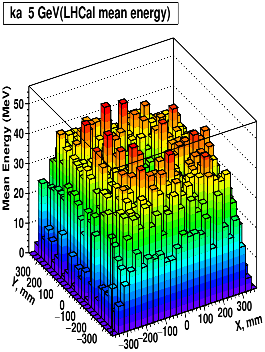
Back-up: Momentum 5 GeV, K^+, K^-

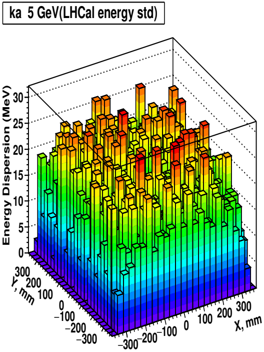
- Material: Tungsten
- Number of events: $2 \cdot 10^4$
- Mean Energy $\approx$ 38 MeV
- Energy Dispersion $\approx$ 23 MeV

Energy distribution, red line for K^+, blue — K^-:



Mean energy and energy dispersion:



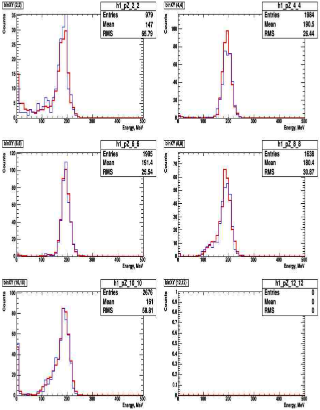


Back-up: Momentum 20 GeV, e^+, e^-

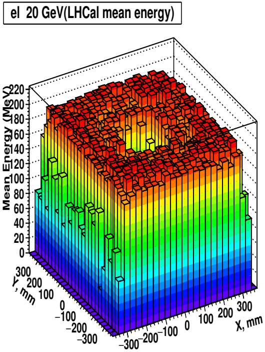
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

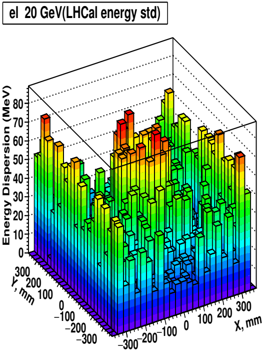
- Mean Energy $\approx$ 190 MeV
- Energy Dispersion $\approx$ 45 MeV

Energy distribution, red line for e^+, blue — e^-:



Mean energy and energy dispersion:



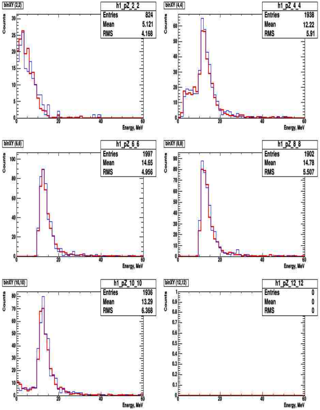


Back-up: Momentum 20 GeV, μ^+, μ^-

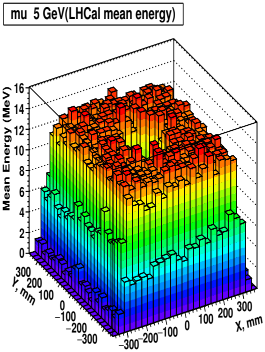
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

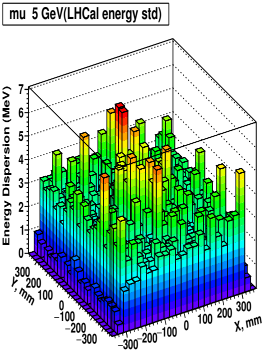
- Mean Energy $\approx$ 14 MeV
- Energy Dispersion $\approx$ 5 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:



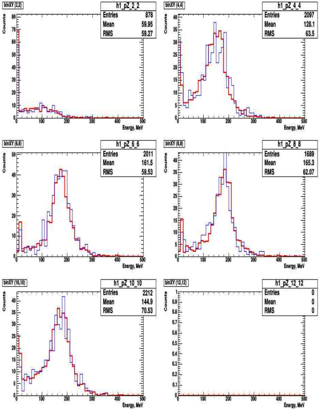


Back-up: Momentum 20 GeV, π^+, π^-

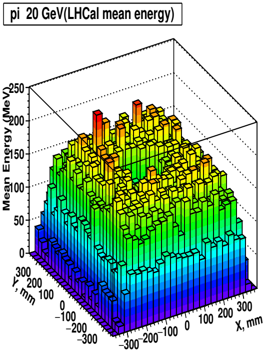
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

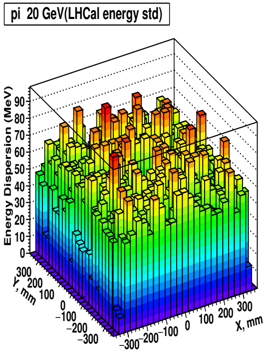
- Mean Energy $\approx$ 150 MeV
- Energy Dispersion $\approx$ 60 MeV

Energy distribution, red line for π^+, blue — π^-:



Mean energy and energy dispersion:



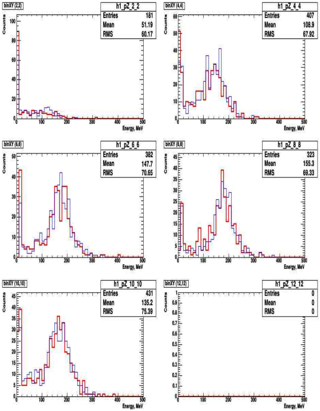


Back-up: Momentum 20 GeV, K^+, K^-

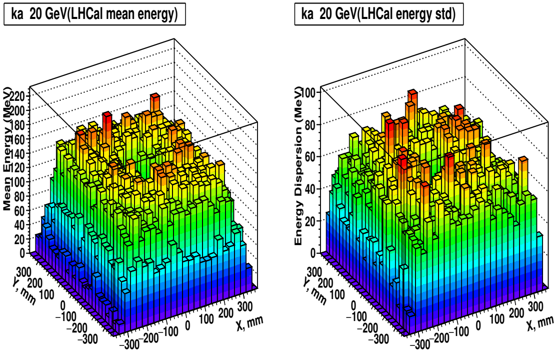
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

- Mean Energy $\approx$ 140 MeV
- Energy Dispersion $\approx$ 60 MeV

Energy distribution, red line for K^+, blue — K^-:



Mean energy and energy dispersion:

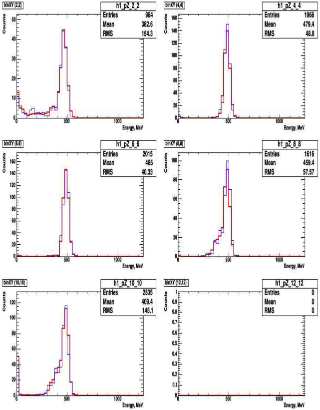


Back-up: Momentum 50 GeV, e^+, e^-

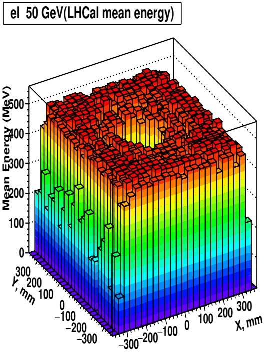
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

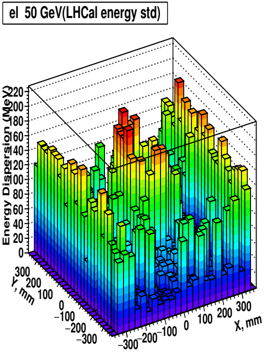
- Mean Energy $\approx$ 480 MeV
- Energy Dispersion $\approx$ 120 MeV

Energy distribution, red line for e^+, blue — e^-:



Mean energy and energy dispersion:



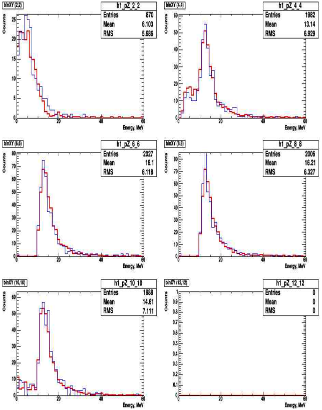


Back-up: Momentum 50 GeV, μ^+, μ^-

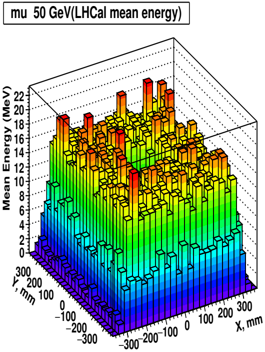
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

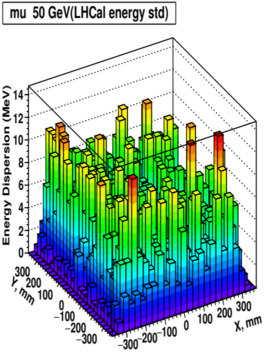
- Mean Energy $\approx$ 16 MeV
- Energy Dispersion $\approx$ 7 MeV

Energy distribution, red line for μ^+, blue — μ^-:



Mean energy and energy dispersion:



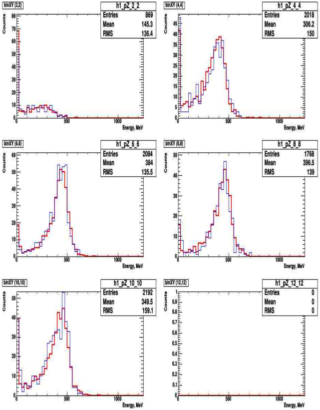


Back-up: Momentum 50 GeV, π^+, π^-

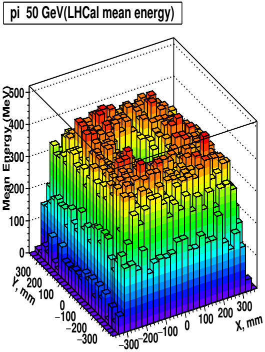
- Material: Tungsten
- Number of events: $2 \cdot 10^4$

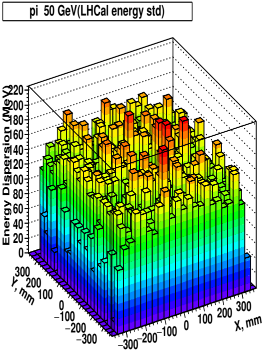
- Mean Energy $\approx$ 350 MeV
- Energy Dispersion $\approx$ 140 MeV

Energy distribution, red line for π^+, blue — π^-:



Mean energy and energy dispersion:



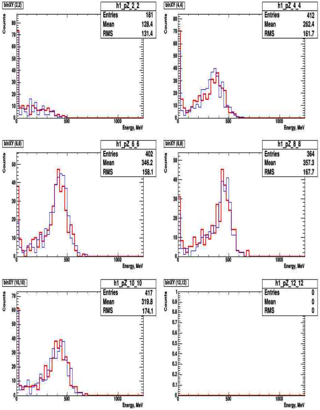


Back-up: Momentum 50 GeV, K^+, K^-

- Material: Tungsten
- Number of events: $2 \cdot 10^4$

- Mean Energy $\approx$ 360 MeV
- Energy Dispersion $\approx$ 160 MeV

Energy distribution, red line for K^+, blue — K^-:



Mean energy and energy dispersion: