Prototype and Test beam simulations for Digital Hadron Calorimeter

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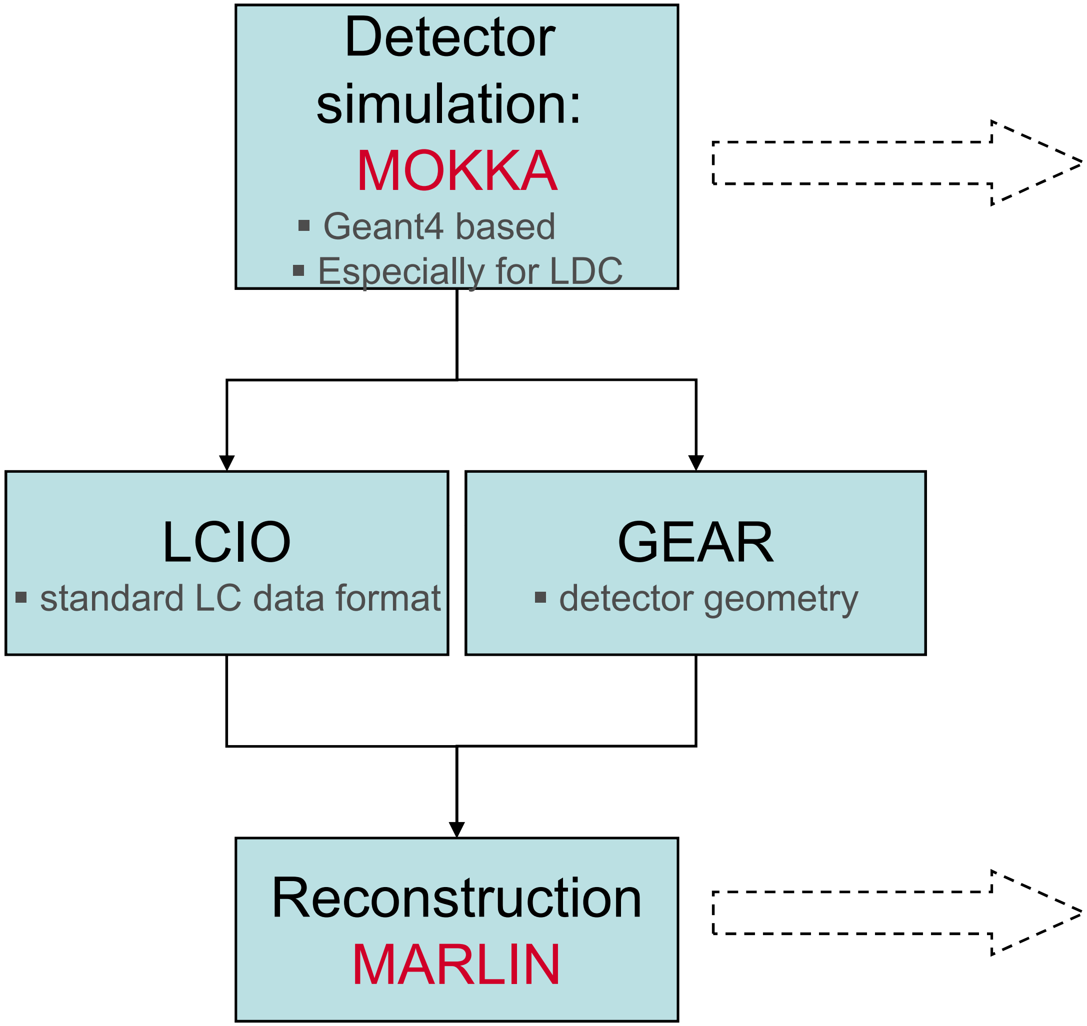
and thanks to Gabriel Musat, Paulo de Freitas, Gérald Grenier

Calorimeter for ILC

EDHCAL meeting at CERN, June 13th 2008

Highly simplified view of simulation in ILC

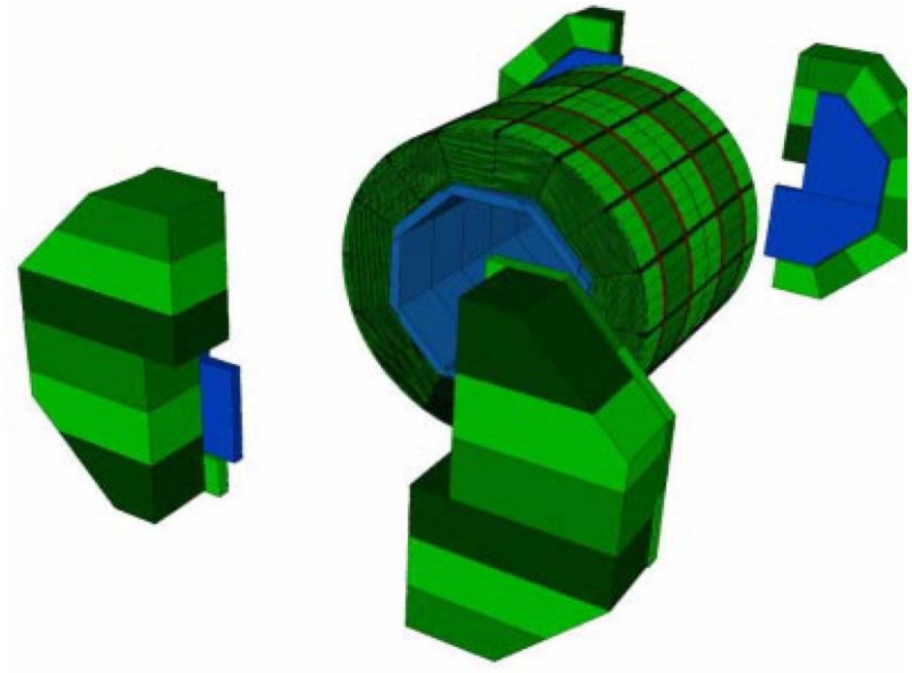


- Full DHCAL
- Test beam prototype

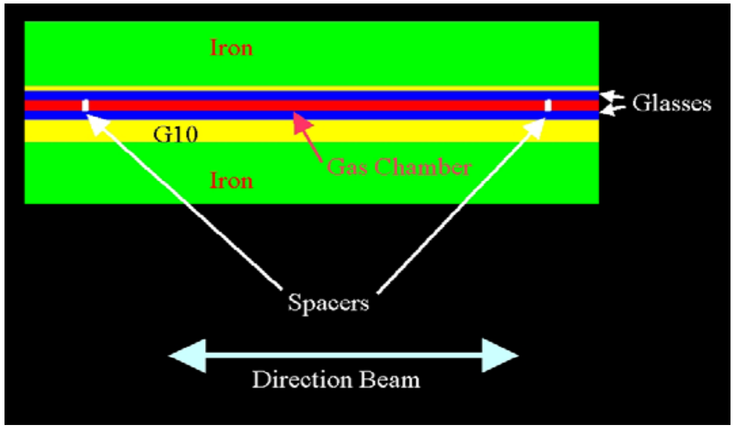
- Performance studies:
  - *Between concepts (AHCAL/DHCAL, SiD/ILD)*
  - *Optimization*Uses PFA
  - Used for LOI
- Uses PFA

⇨ Need for best detector description possible

Previous HCAL in MOKKA



- Based on Tesla TDR
- Used both for AHCAL and DHCAL
- In Mokka:
  - Included in models03
  - Driver= hcal03

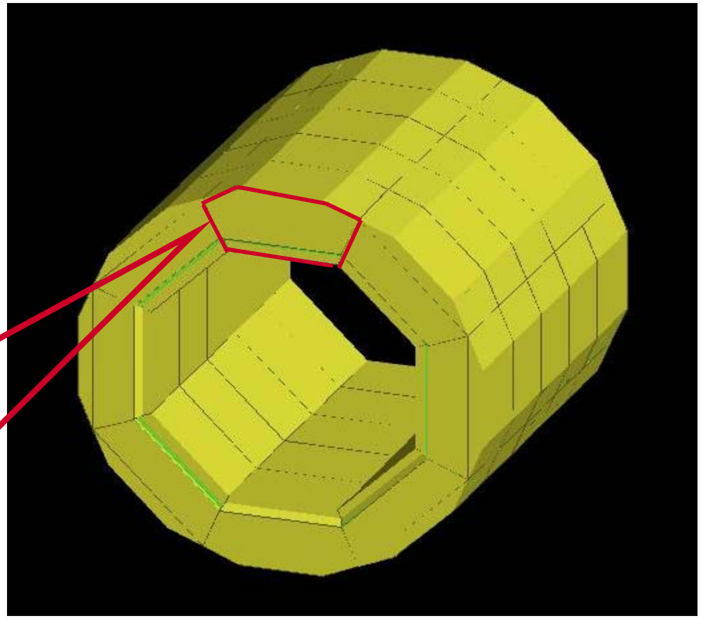


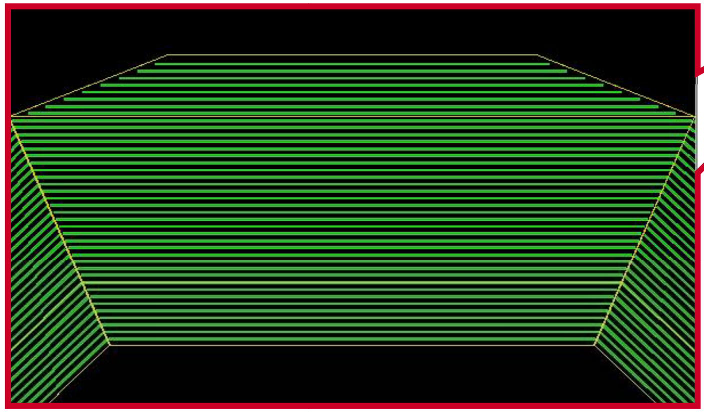
<u>RPC:</u>
gas=TFE+isobutane+N
1×1cm cells

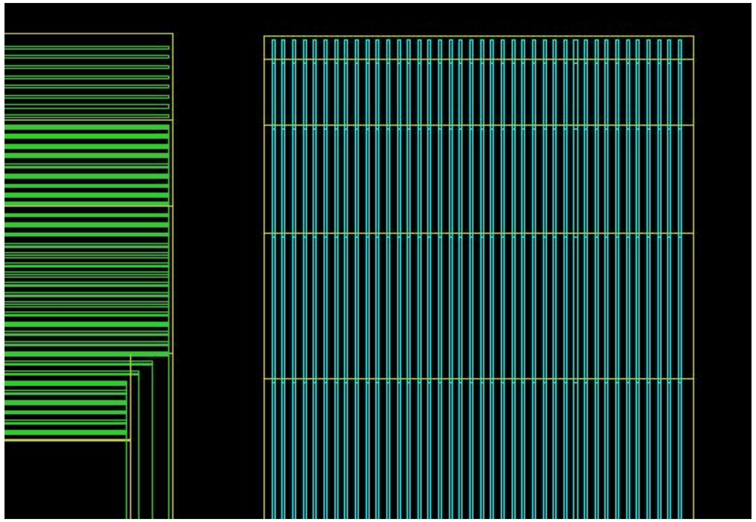
http://polywww.in2p3.fr/activites/physique/geant4/tesla/www/mokka/hcal/hcal.html

Previous HCAL in MOKKA

- Barrel:
  - *8 staves, 5 modules*
  - *40 layers: 18 mm absorber (Fe), 6.5 mm sensitive material*

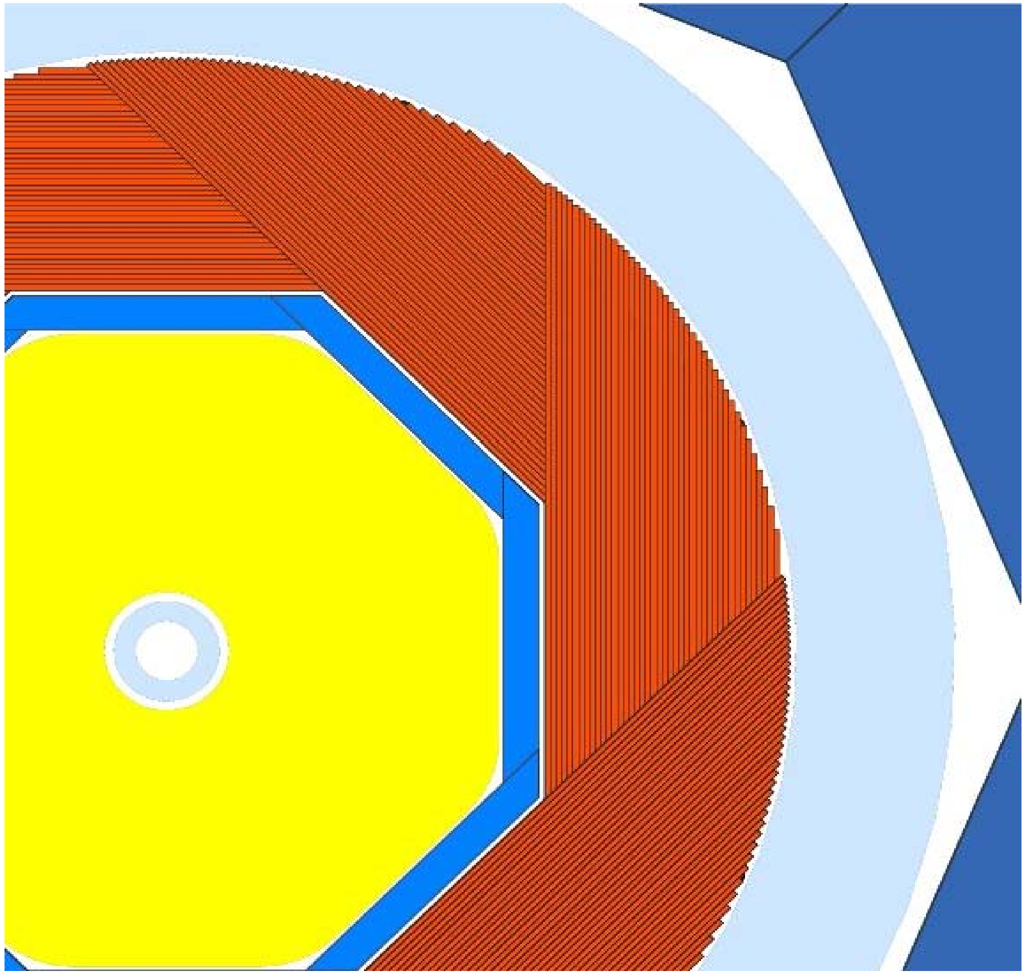






- End-caps:
  - *32 side polyhedra*
  - *40 layers: 18 mm absorber (Fe), 6.5 mm sensitive material*

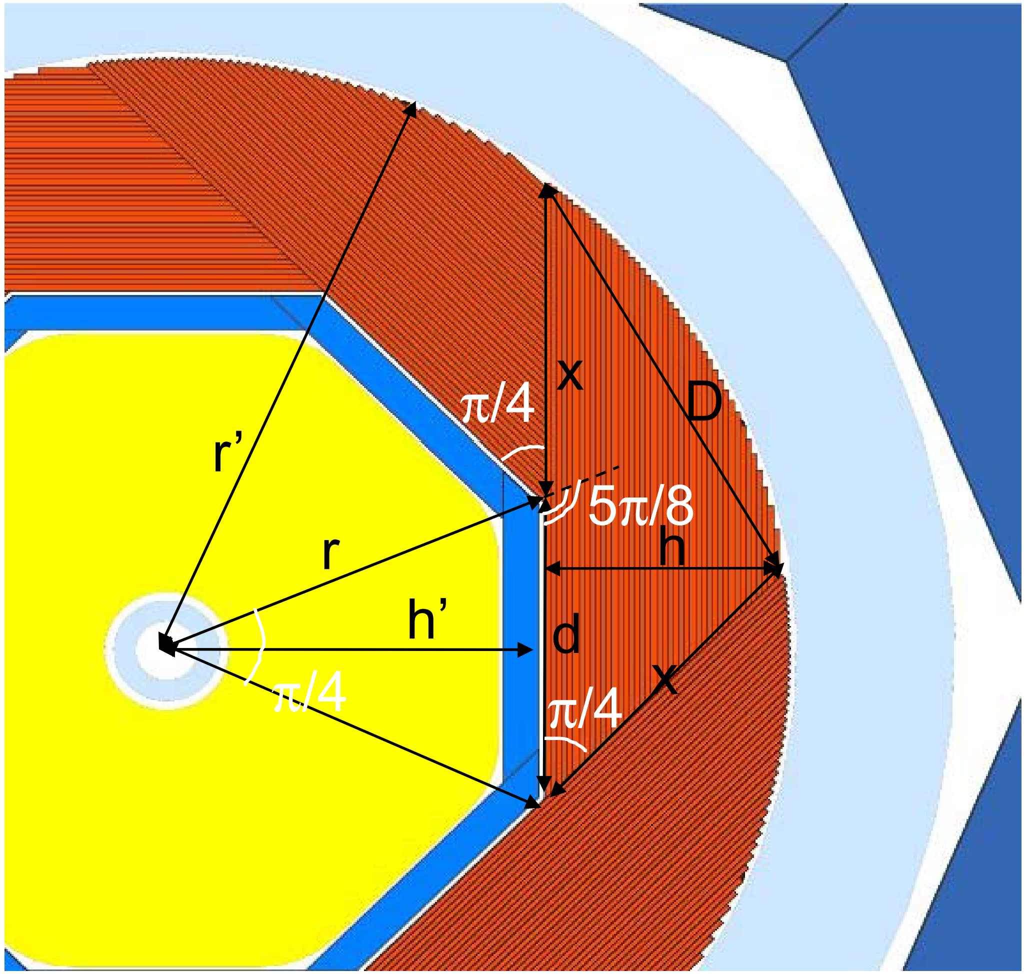
The new DHCAL



4 interaction lengths

- Barrel:
  - *Geometry proposed by Henri Videau*
  - *5 modules, 8 staves*
  - *40 layers: 20 mm absorber (stainless steel), 6 mm RPC*
- Convenient:
  - *No crack*
  - *Solves gas/electrical supply issues*
  - *Need mechanical studies*
- End-caps:
  - *No new proposal*
  - *Kept as Tesla TDR*
  - *Use old Tesla RPC*

The new DHCAL



- 2 parameters + number of layers define all geometry:

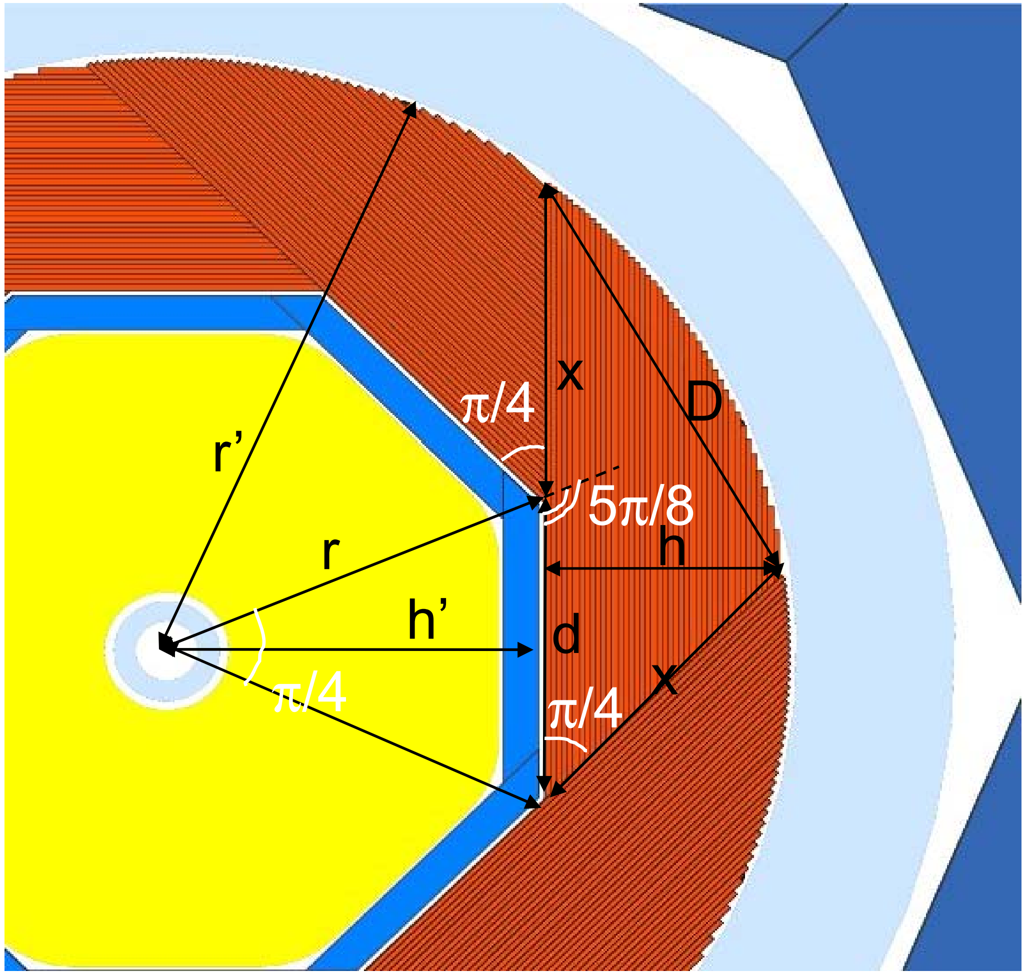
$$d = kr \qquad D = kr' \qquad \text{avec} \qquad k = \frac{\sin(\pi/4)}{\sin(3\pi/8)}$$

$$h = x/\sqrt{2}$$

$$h' = \sqrt{r^2 - d^2/4}$$

$$x = \frac{\sqrt{2D^2(2+\sqrt{2}) - d^2(3+2\sqrt{2})} - d}{2}$$

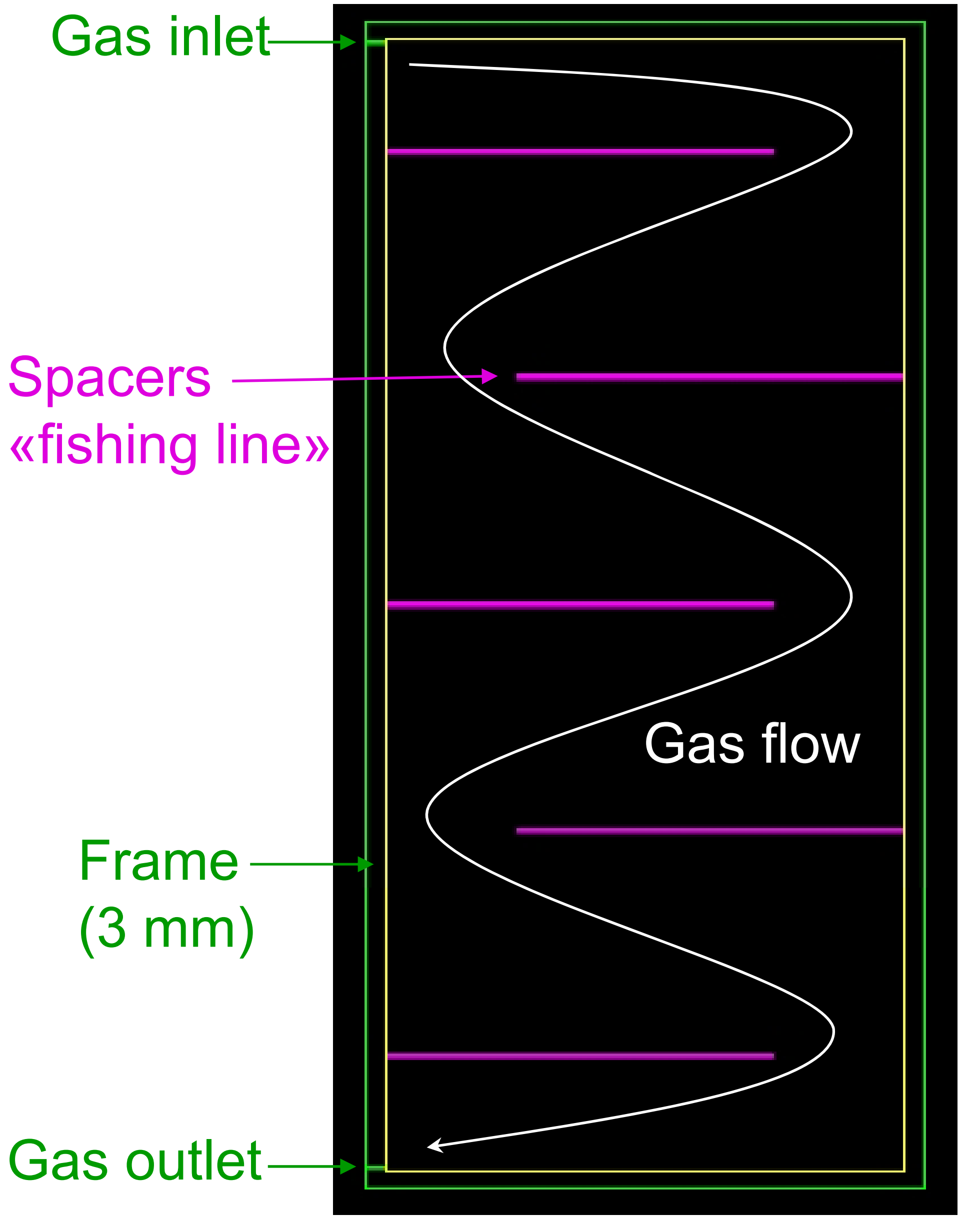
The new DHCAL



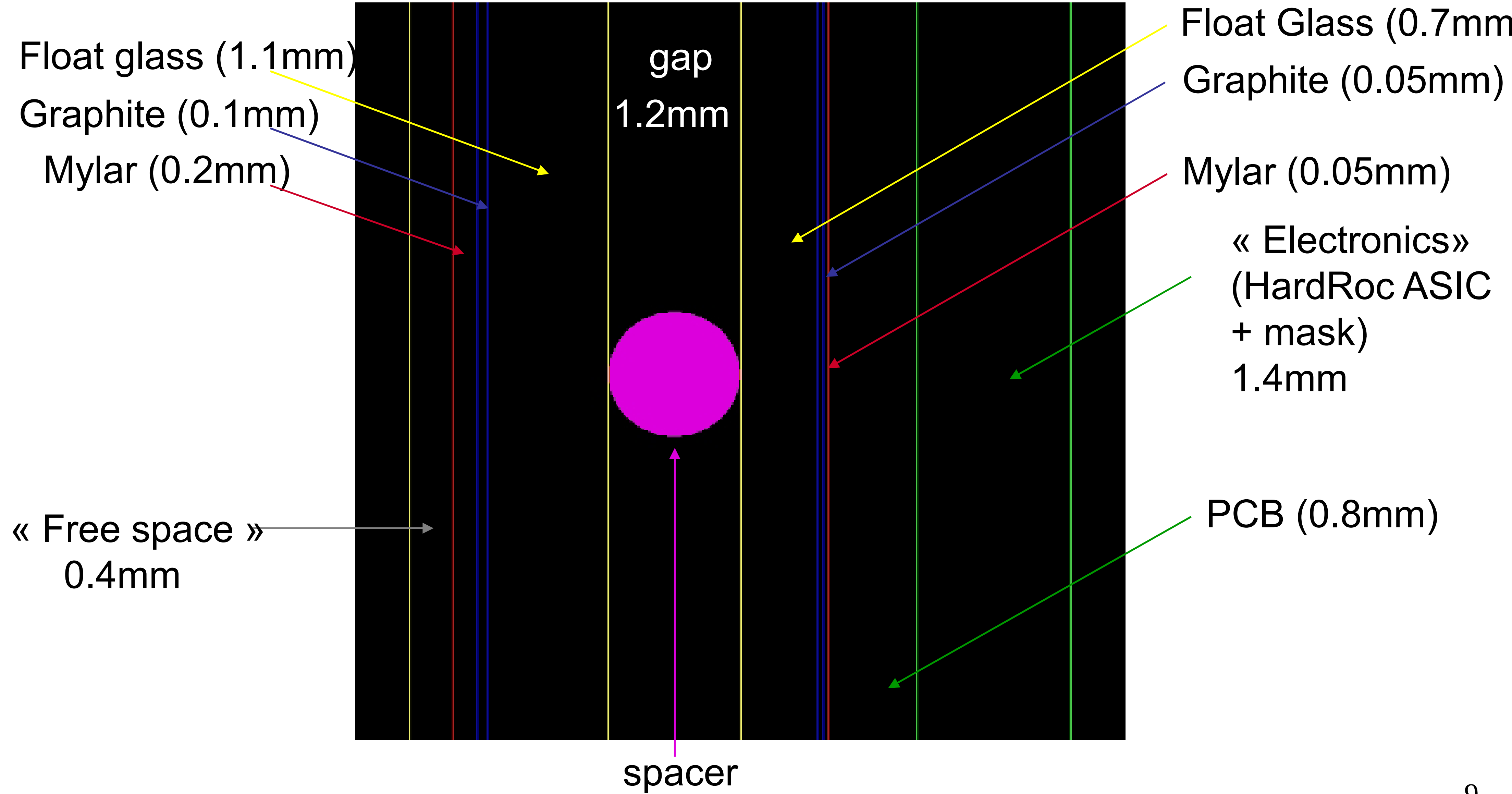
- Barrel dimensions:
  - *r'=2989.71 mm*
  - *z_max= 3030.42 mm*
  - *Hcal-Ecal gap = 29 mm*
  - *h'-δ=1910 mm (Ecal outer radius)*
- Staves dimensions:
  - *Largest RPC: 3030.41   878.4 mm*^{2}
  - *Smallest RPC: 16   878.4 mm*^{2} *(layer 39=256.236   878.4 mm*^{2}*)*

RPC Overall design

- Inspired by current R&D developments on large dimensions RPC
- Structure more detailed compared to previous MOKKA's RPC
- 40 different sizes (length)
- 6 mm of material budget



RPC section


Float glass (1.1mm)
Graphite (0.1mm)
Mylar (0.2mm)
« Free space »
0.4mm
gap
1.2mm
spacer
Float Glass (0.7mm
Graphite (0.05mm)
Mylar (0.05mm)
« Electronics»
(HardRoc ASIC
+ mask)
1.4mm
PCB (0.8mm)

Materials used

- Absorber =stainless steel
- New RPC materials required added to materials02 DB

Component	Material	Name of material in DB
PCB+Electronics	G-10/FR4 epoxy	g10
mylar	mylar	mylar
graphite	graphite	graphite
glass	quartz+soda+Mg0+CaO	FloatGlass
gas	Mixture: TFE(93%)+SF_6 (2%)+isobutane (5%)	RPCGAS2
spacers	nylon	nylon
frame, gas inlets	PEEK-GF30 (PolyEtherEtherKetone+30% glass fiber	PEEK
free space	air	air

Code overview

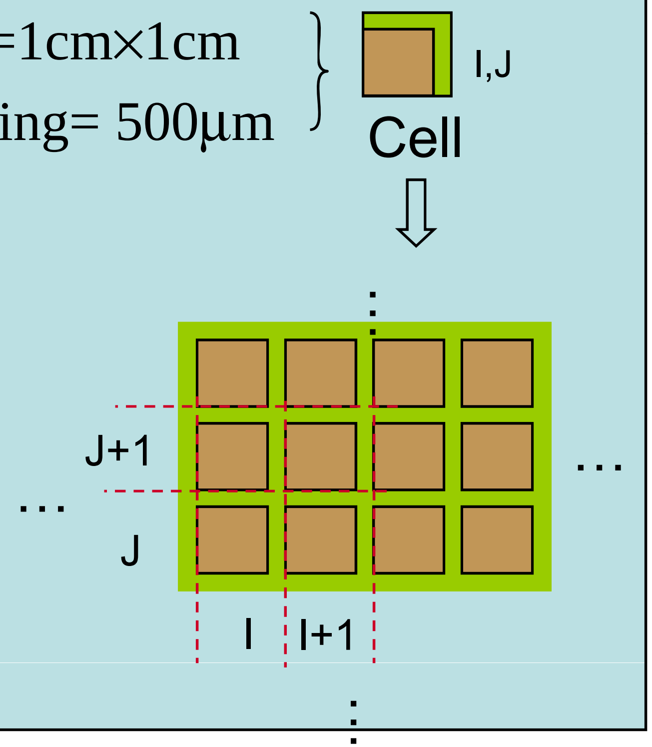
- Available in source/Geometry/LDC

New superdriver : SHcal04

- **Barrel**
  - Boolean solid: Tube-Octogon,
  - Filled with steel
- **Modules**: *SHcal04::BarrelVirtualModules*
  - Builds 1 **layer** (for one stave)
  - Fills layer with RPC
  - Builds **staves** by rotating layer
  - Builds modules applying z-offset
  - Loops on 40 layers
- **RPC**: *SHcal04::BuildRPC2Box(…)*

New sensitive detector: SDHcalSD01

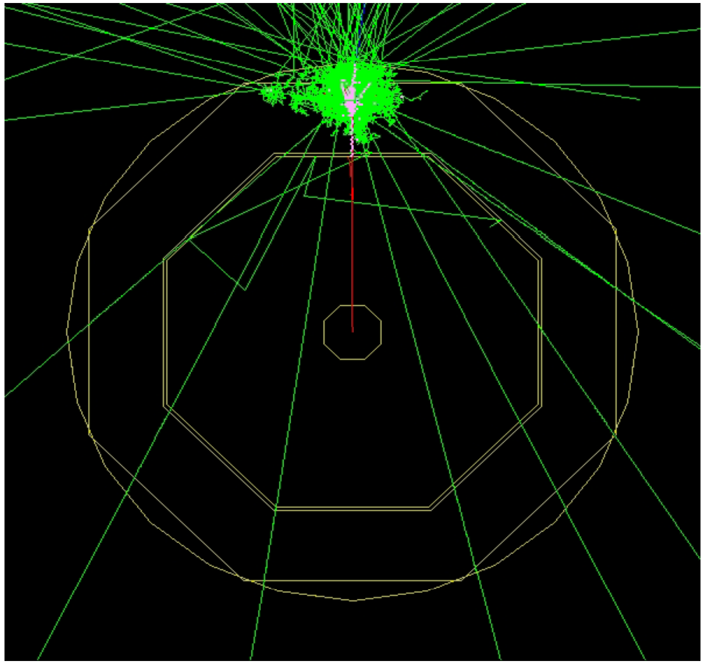
- Sensitive volume=gas gap (without spacer)
- Pad size=1cm×1cm
- Pad spacing= 500µm



- Geometry debugged, cell ID recovery tested with ≠ method

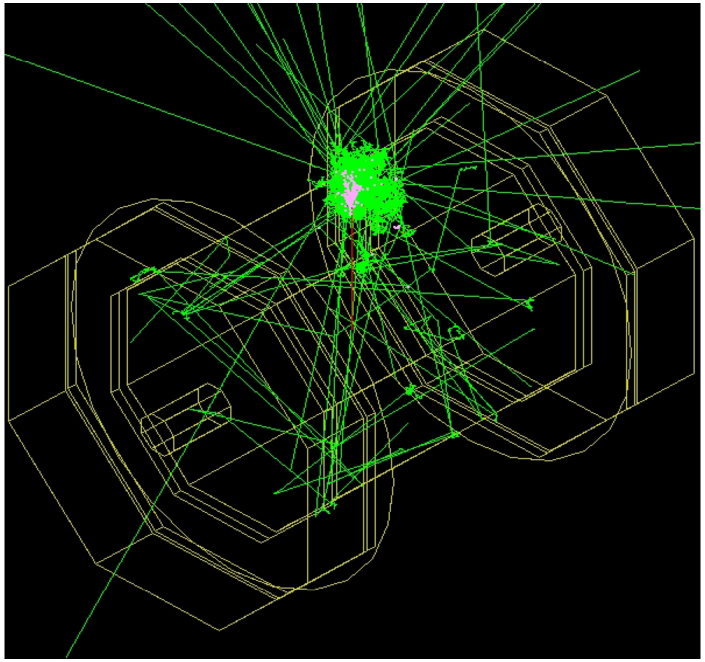
How to use this geometry?

- Use Mokka *LDC06-06*
- In your Mokka steering file: /Mokka/init/subDetector SHcal04
- SHcal04 is a superdriver: scaling included



Normal to z-axis

Event with a 20 GeV π^-



Normal to (1,1,1) axis

Physics list used

- LCPhysics list:

« contains the best-guess selection of electromagnetic and hadronic physics processes required to run a linear collider detector simulation »

Dennis Wright

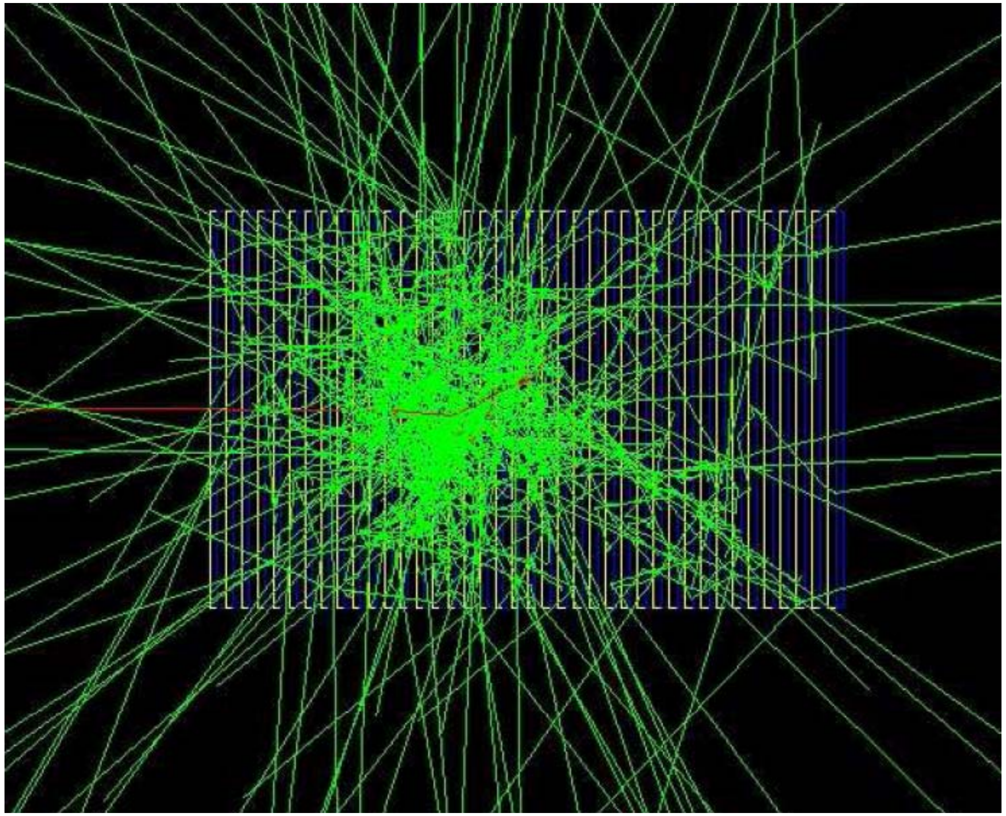
Modular structure

- Boson physics
- Lepton physics
- Hadron physics
- Decays physics
- Light ions physics

Hadronic processes

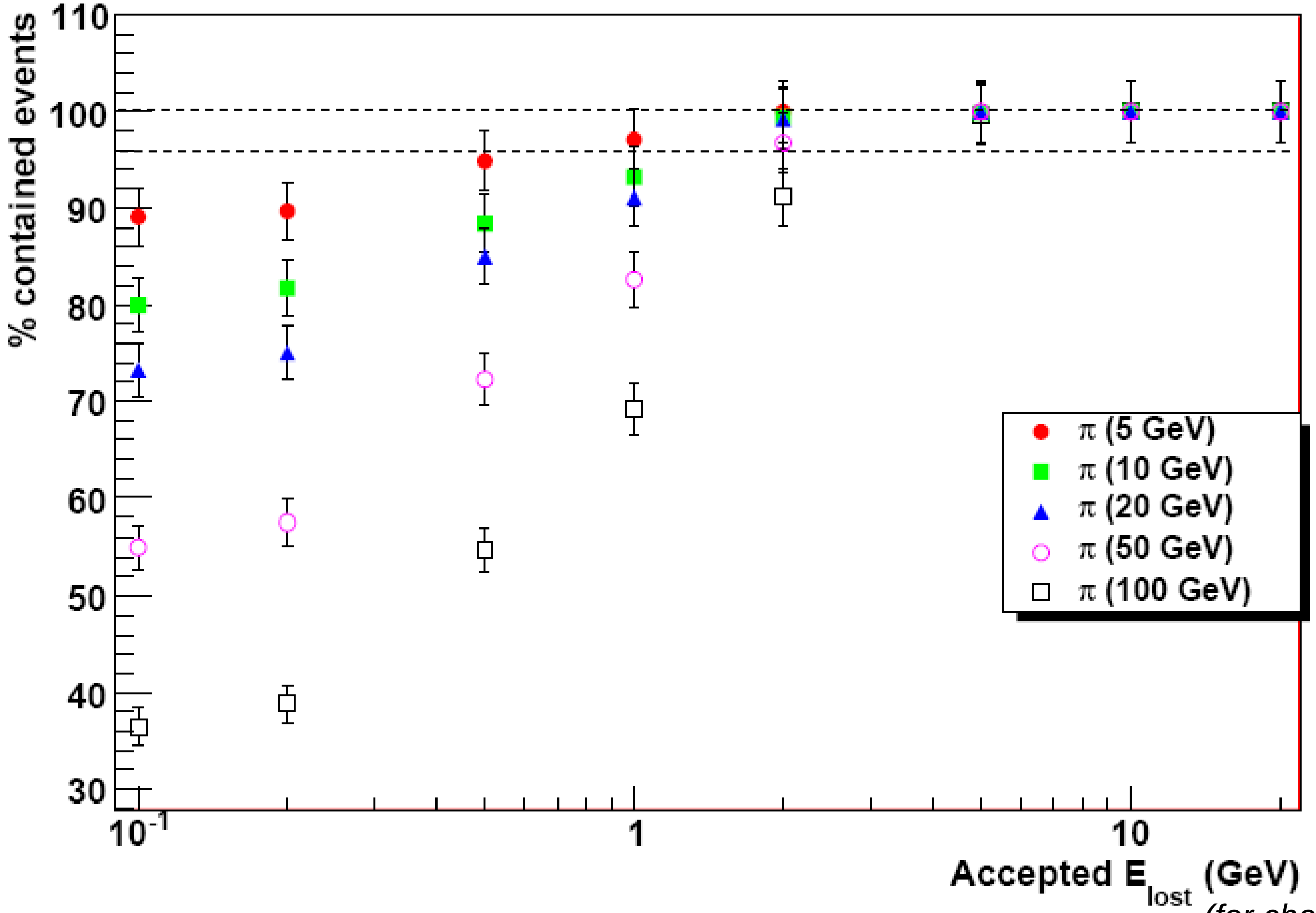
- *Multiple scattering (charged hadrons only)*
- *Hadron ionization (charged hadrons only)*
- *Elastic scattering*
- *Inelastic scattering*
- *Absorption at rest (π^- and K^-)*
- *Annihilation at rest (antiprotons, antineutrons)*
- *Neutron capture*

Simplified geometry



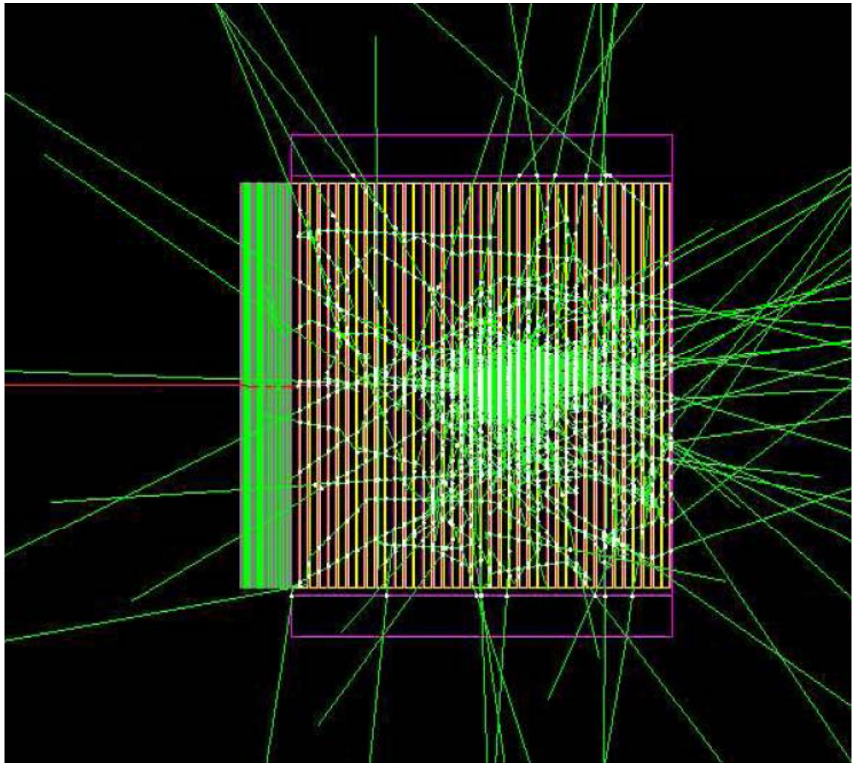
- Sampling sandwich with Geant4
  - *40 layers*
  - *Absorber: 2 cm of Fe*
  - *Sensitive material: 2 cm of air*
  - *1×1 m^2 section*
- Goal:
  - *First Geant4 exercise*
  - *Have a first idea of hadronic shower spread*

Shower containment



(for charged tracks)

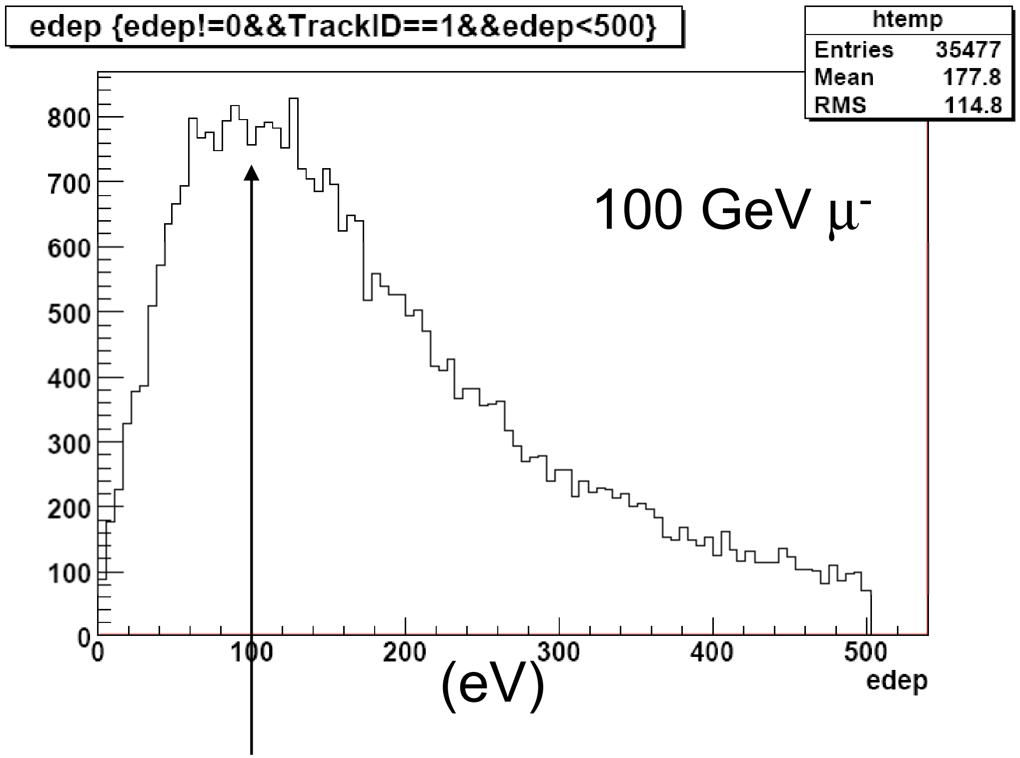
Calice Test Beam configuration



- Ecal of 40 layers:
  - *Absorber: tungsten (1.4 mm thick for 30 first layers, 4.2 mm thick for last 10 layers)*
  - *Sensitive material: Si layer (0.5 mm) sandwiched between 2 epoxy PCB (0.8 mm)*
- Hcal of 40 layers:
  - *Absorber: Fe (2 cm)*
  - *Sensitive material: 6mm RPC (same one as new DHCAL in MOKKA)*
- Why not MOKKA?
  - *Problems with big events having bad_alloc* (no more memory) (http://forum.linearcollider.org/index.php?t=tree&goto=1055&rid=0&S=3fbba2fe86b9a5bd12f094f1c4af7a1f&srch=new#msg_1055)
  - *Simulations done at CCIN2P3: Mokka version= mokka-06-00 (Patch mokka-06-04P2)*
  - *Installing our own soft on IPNL machine (see slide before conclusion)*

Calice Test Beam configuration

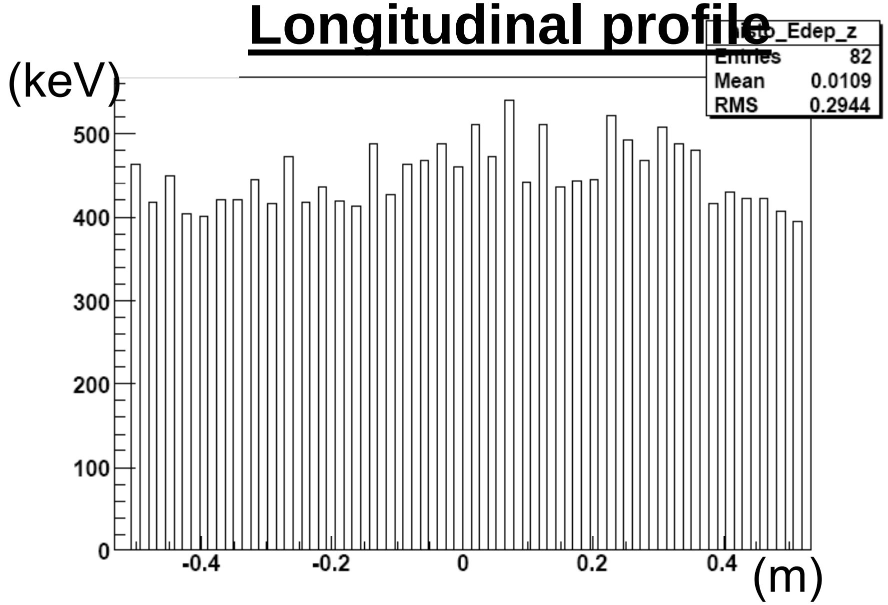
Distribution of energy deposited by incident μ⁻



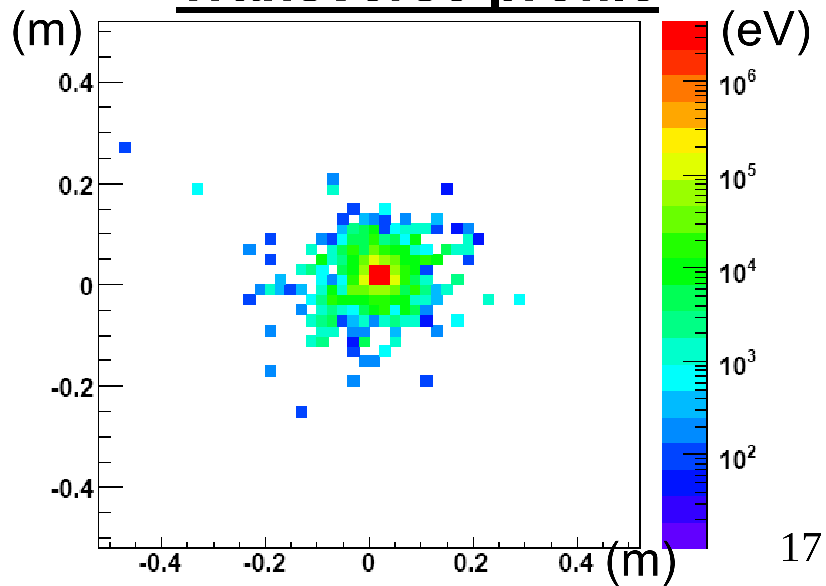
mip ≈ 100 eV

1000 events

Longitudinal profile

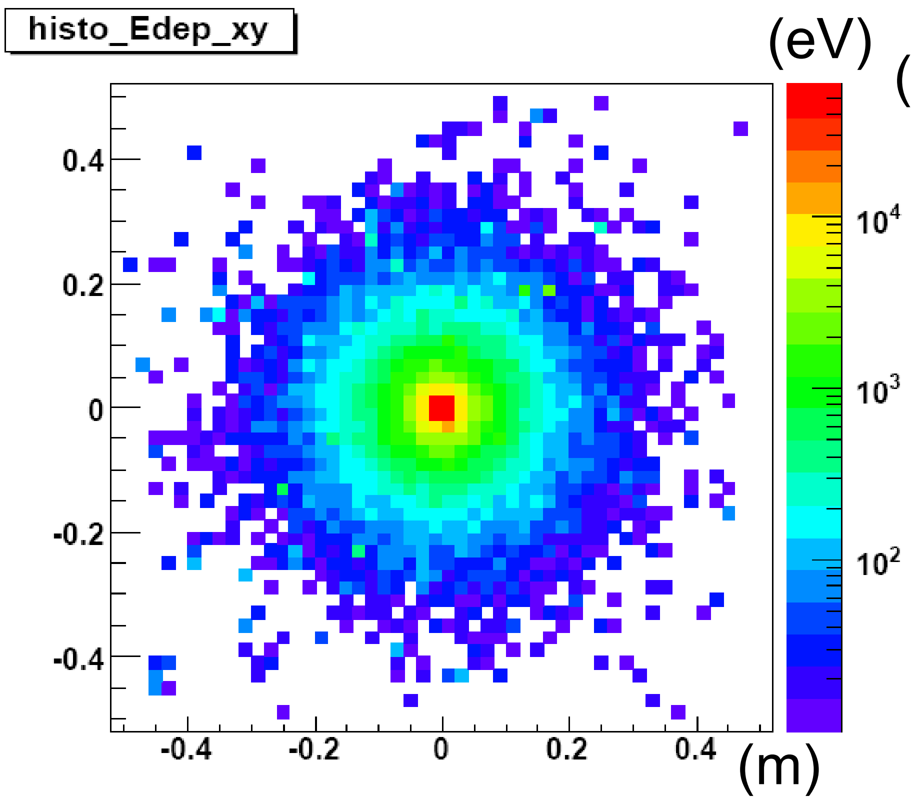


Transverse profile

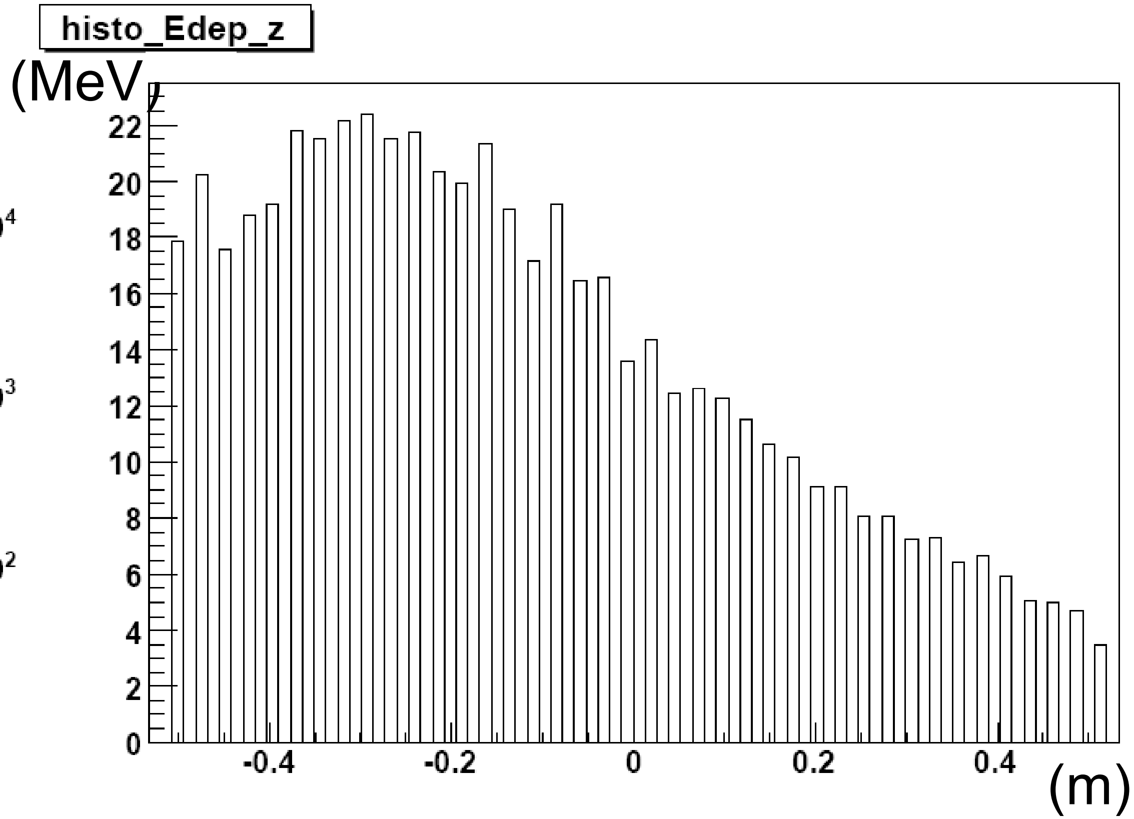


Calice Test Beam configuration

Transverse energy profile



Longitudinal energy profile

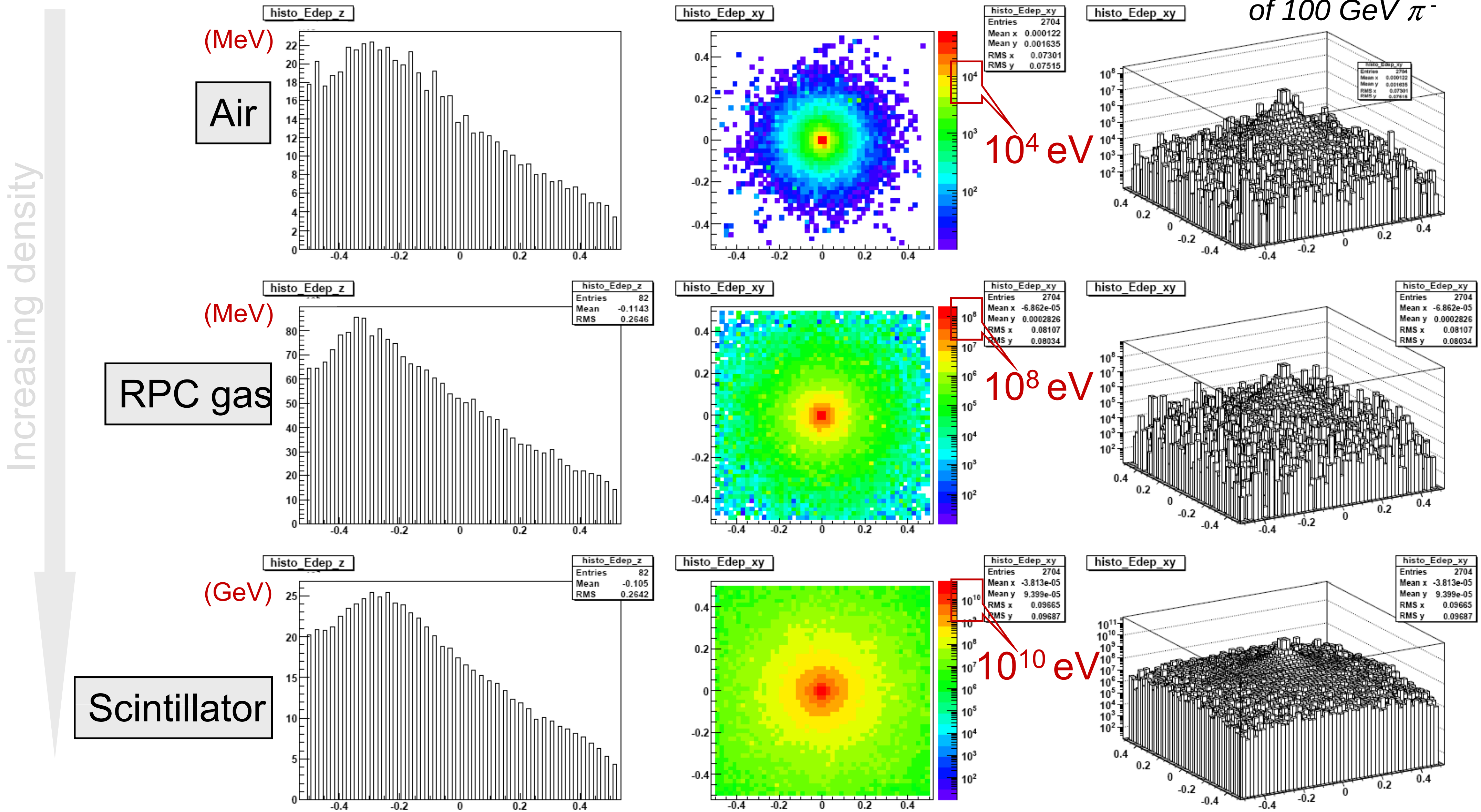


100 GeV π^- (1000 evts)

Influence of sensitive material

Longitudinal energy profile | Transverse energy profile

Based on 1000 evts of 100 GeV π^-



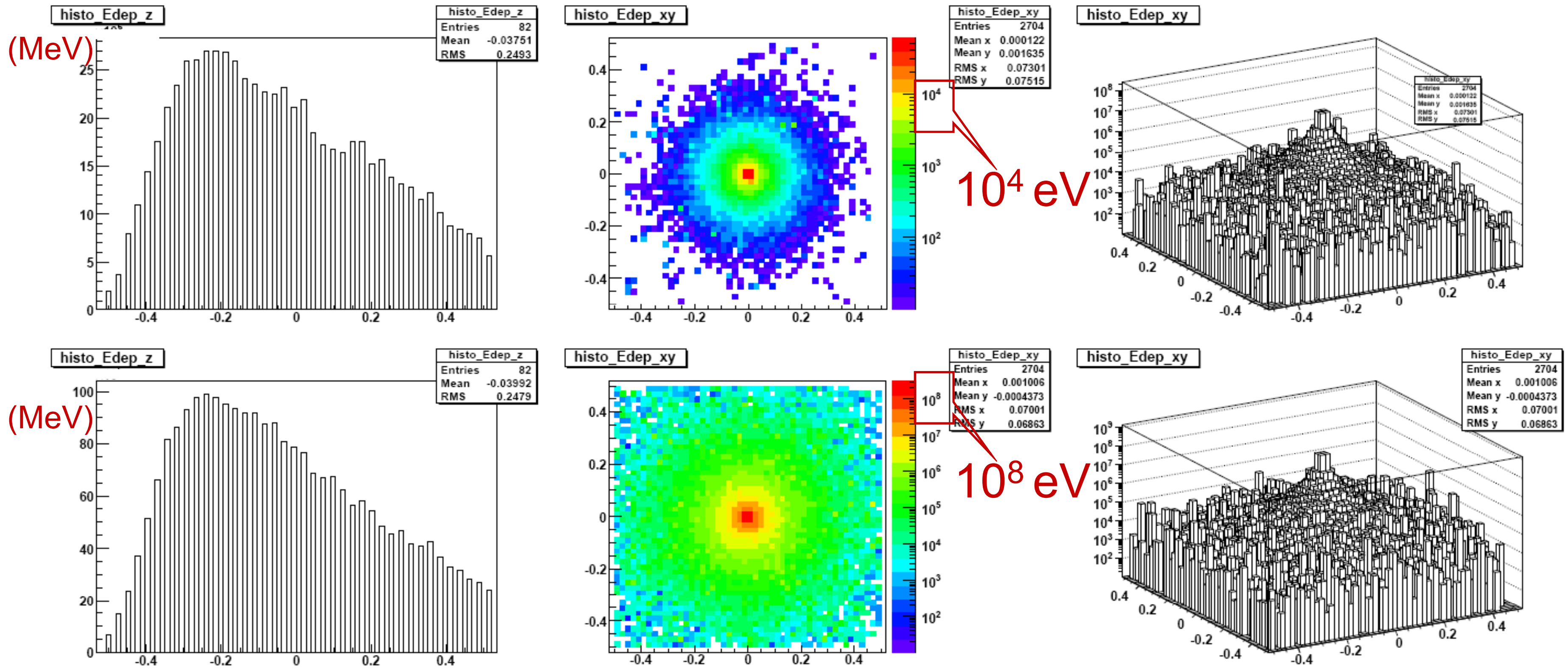
Influence of sensitive material

Sensitive material	density (g/cm^3)	mip energy	Number of hits depositing more than 0.5 mip	Box containing 95% of deposited energy	Cell percentage with less than 10 hits
Air	1.205×10^{-3}	100 eV	1672432	68×68 cm^2	36
RPC Gas	4.13×10^{-3}	100 eV	3829917	72×72 cm^2	23
Scintillator	1.060	45 keV	5178984	76×76 cm^2	1

Based on 1000 evts of 100 GeV π^-

- Beware: scintillator and gas thickness identical: not an AHCAL config!
- With ECAL in front of DHCAL: need a 72×72 cm^2 prototype

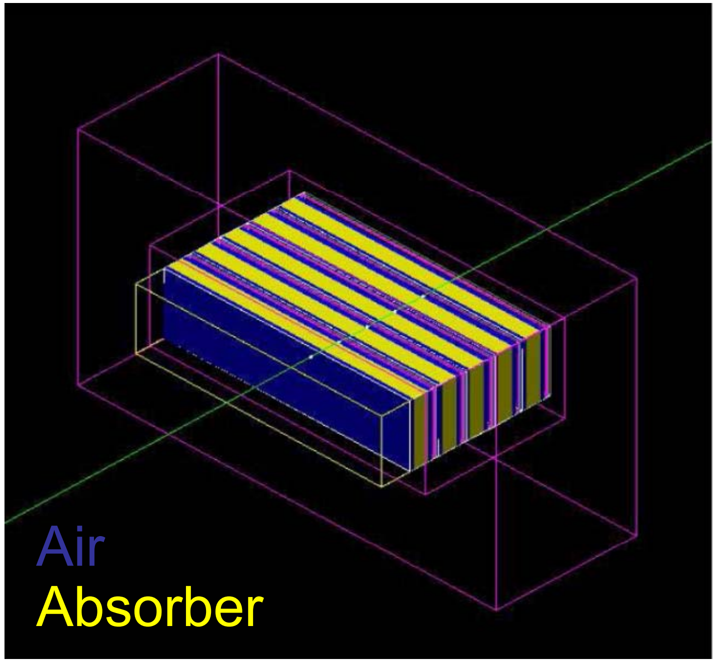
Removing ECAL



Sensitive material	density (g/cm^3)	mip energy	Number of hits depositing more than 0.5 mip	Box containing 95% of deposited energy	Cell percentage with less than 10 hits
Air	1.205×10^{-3}	100 eV	2151631	66×66 cm^2	40
RPC Gas	4.13×10^{-3}	100 eV	4947556	68×68 cm^2	26

PS test beam configuration

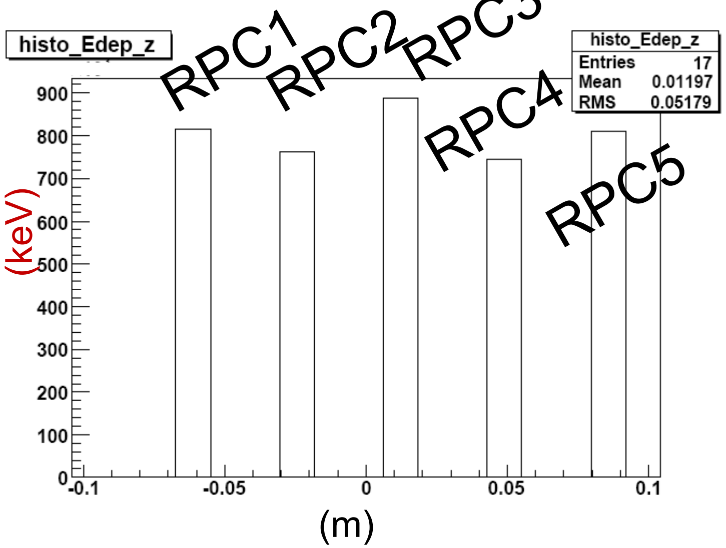
- Configuration:
  - *5 RPC (as in new DHCAL model presented before + 2×3 mm aluminium plate for box)*
  - *Stainless steel absorber between RPC*
  - *Variable thickness of additional absorber*
  - *Dimensions taken on real TB device*
  - *5mm layer of air between absorber and RPC*



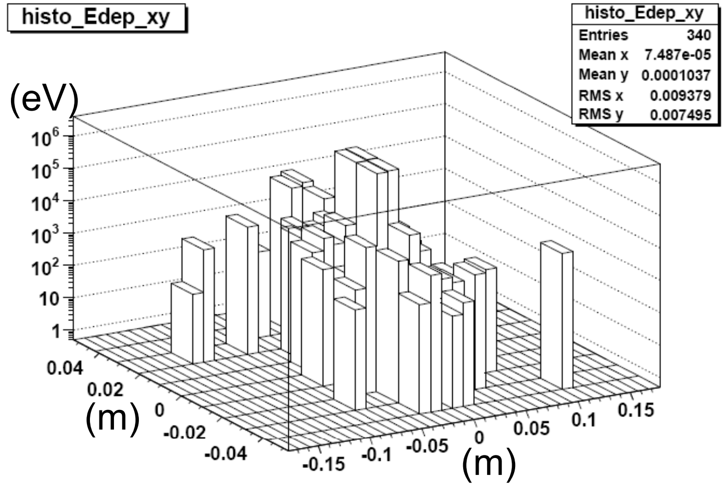
- Goal:
  - *Simulations for 1 GeV and 7 GeV and μ^- and π^-*
  - *Estimation of energy deposited (amount, spread)*
  - *Look at influence of absorber thickness*

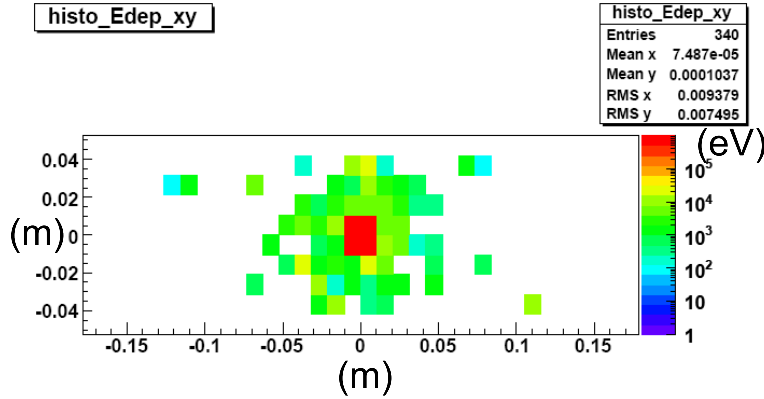
Simulations for 1 GeV muons

Longitudinal energy profile



Transverse energy profile



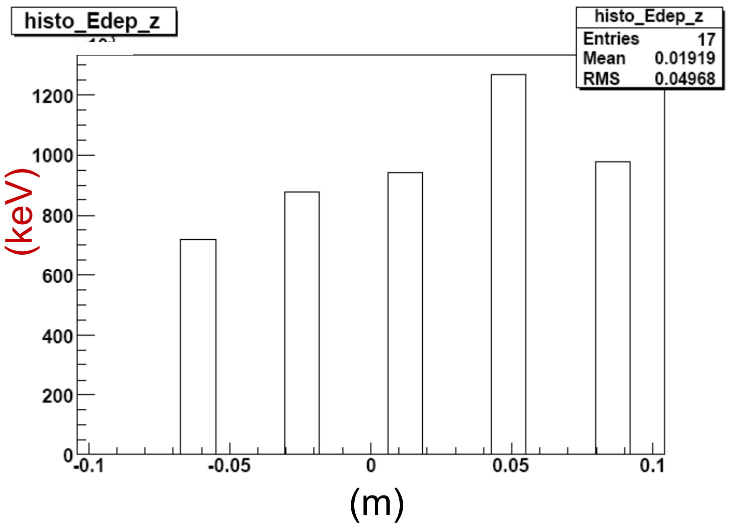


1 GeV μ^- (1000 evts)

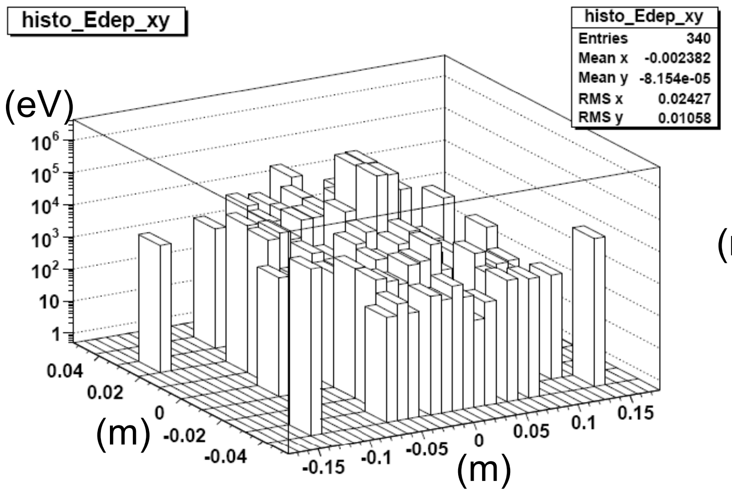
Absorber configuration	Total deposited energy in eV (E_{dep})	Total number of hits (E_{dep}>0.5mip)	Size of box with 95% E_{dep} (in m)
No absorber	4.01881e+06	11680	0.042
With absorber	3.98719e+06	11907	0.042
Additional 2 cm	4.10171e+06	11835	0.042
Additional 4 cm	4.10963e+06	11894	0.063
Additional 6 cm	4.13061e+06	11829	0.063
Additional 8 cm	4.20308e+06	11838	0.063
Additional 10 cm	4.02745e+06	11561	0.063

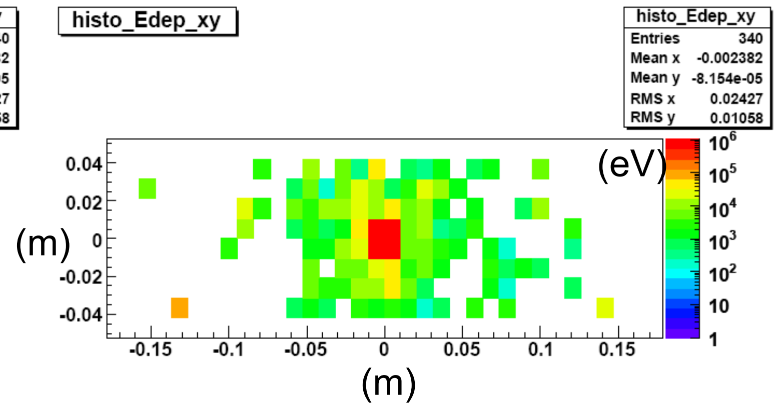
Simulations for 1 GeV pions

Longitudinal energy profile



Transverse energy profile



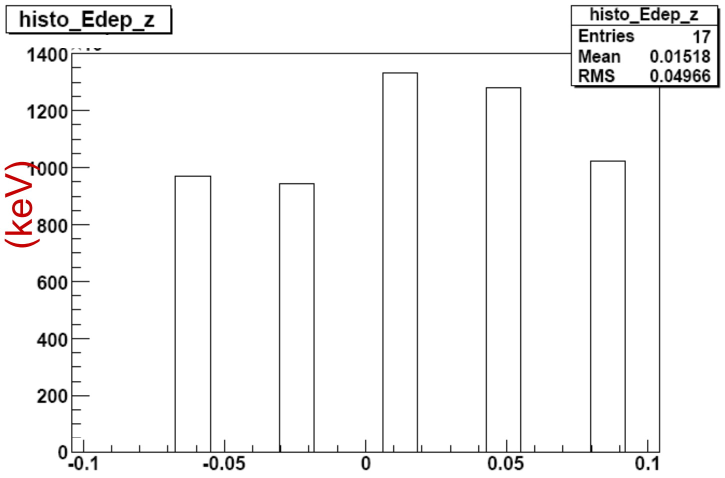


1 GeV π^- (1000 evts)

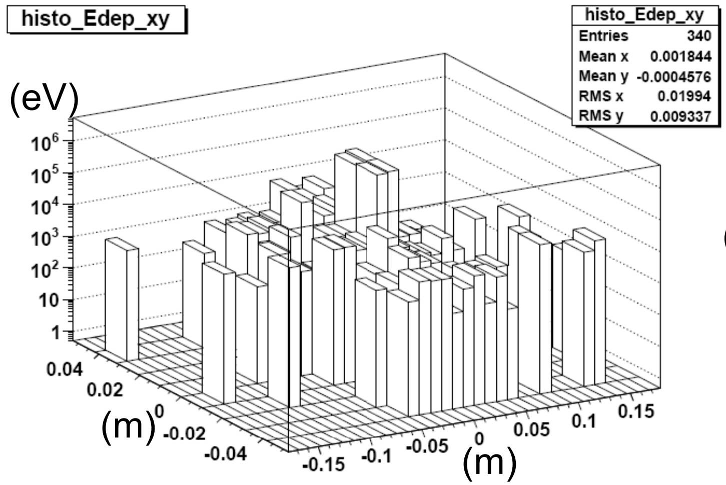
Absorber configuration	Total deposited energy in eV (E_{dep})	Total number of hits (E_{dep}>0.5mip)	Size of box with 95% E_{dep} (in m)
No absorber	4.78485e+06	11493	0.105
With absorber	6.18263e+06	12239	Not reached
Additional 2 cm	6.97507e+06	11433	Not reached
Additional 4 cm	7.6841e+06	11069	Not reached
Additional 6 cm	4.69574e+06	9266	Not reached
Additional 8 cm	4.40713e+06	8122	Not reached
Additional 10 cm	4.69204e+06	7989	Not reached

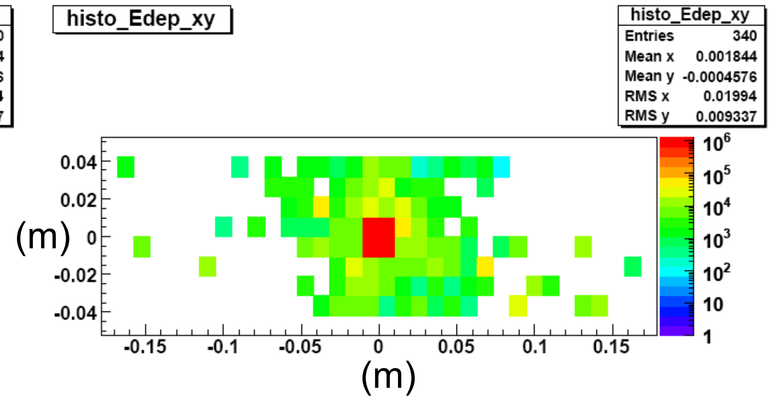
Simulations for 7 GeV pions

Longitudinal energy profile



Transverse energy profile

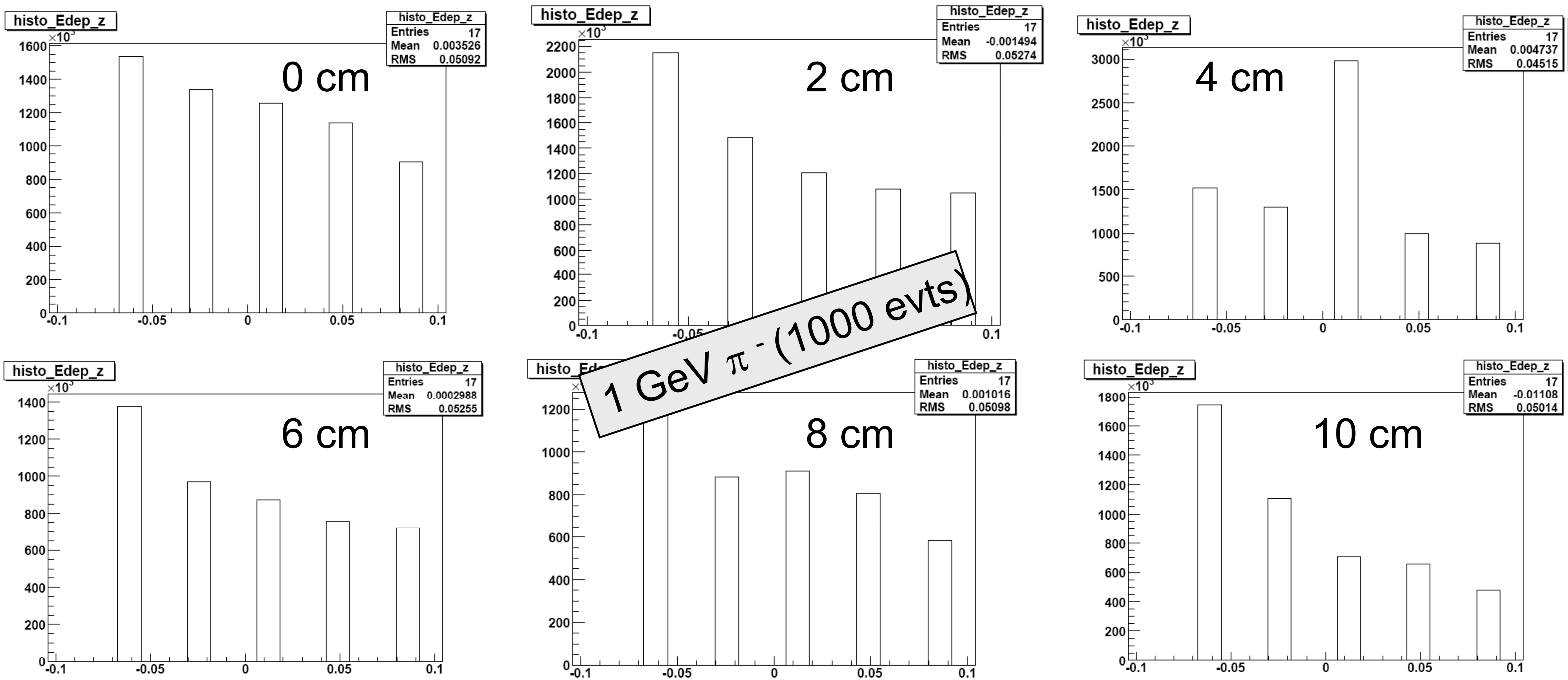




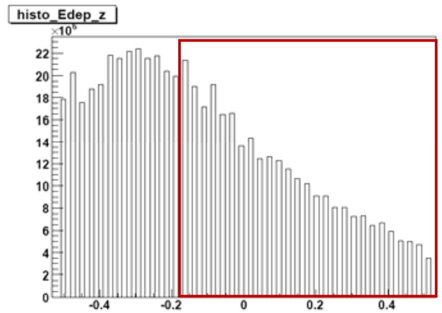
7 GeV π - (1000 evts)

Absorber configuration	Total deposited energy in eV (E_{dep})	Total number of hits (E_{dep}>0.5mip)	Size of box with 95% E_{dep} (in m)
No absorber	5.54832e+06	13670	0.084
With absorber	1.68663e+07	32140	Not reached
Additional 2 cm	1.74442e+07	37149	Not reached
Additional 4 cm	2.24866e+07	42890	Not reached
Additional 6 cm	2.09209e+07	43468	Not reached
Additional 8 cm	2.19416e+07	44929	Not reached
Additional 10 cm	1.98212e+07	41867	Not reached

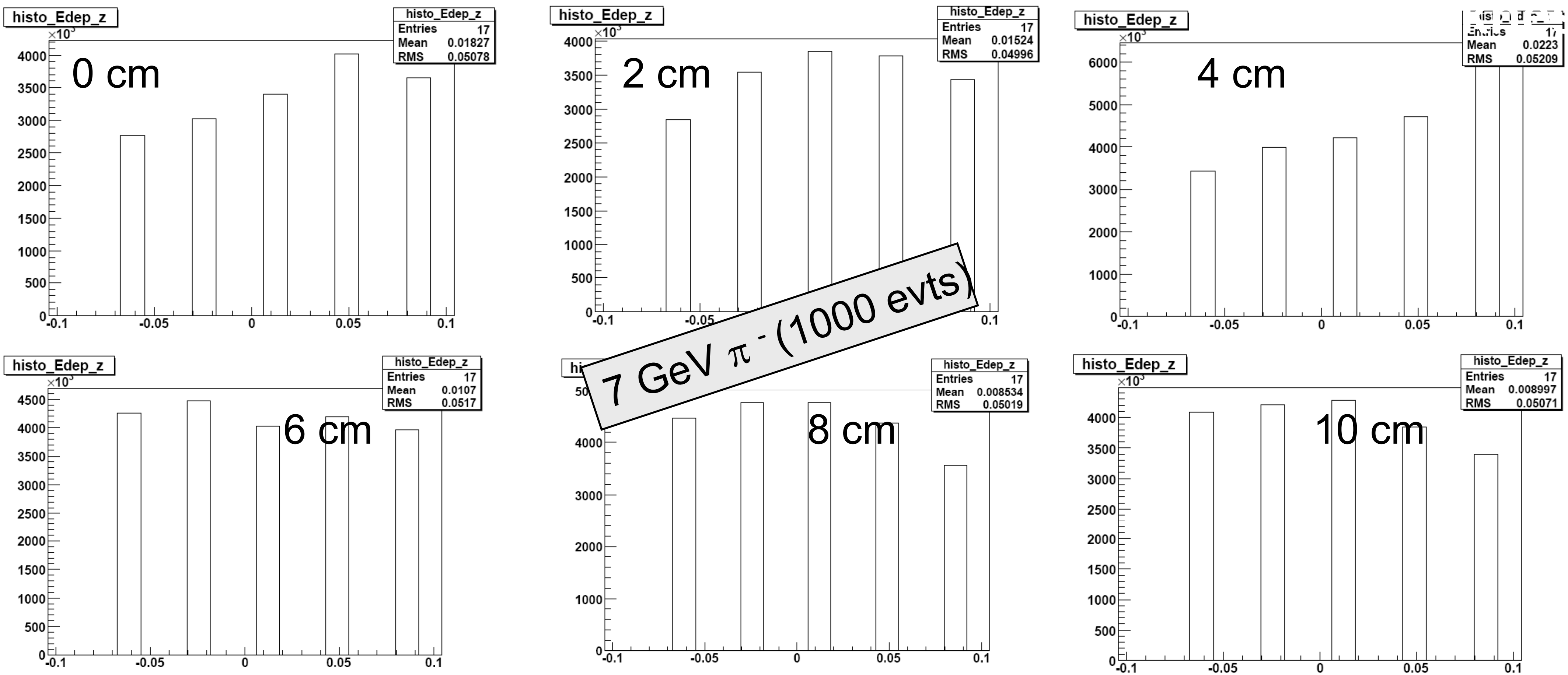
Longitudinal energy profile with increasing absorber

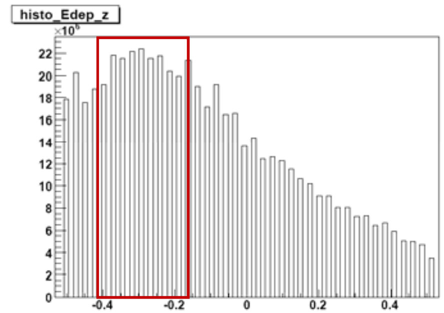


⇨ Enables to study tail of the shower



Longitudinal energy profile with increasing absorber





⇨ Enables to study core of the shower

A few words for the software for Test

- ILC software installed on lyogrid04
  - *Latest release for each ILC software package*
  - *Used **ilcinstall** script*
  - *Almost all packages installed*

- For PS test beam:
  - *EUTelescope included and compiled with EUDAQ*
  - *Possibility to browse slcio files with JAS3*

Conclusion

- New DHCAL model implemented in MOKKA
  - *Barrel « à la Videau »*
  - *New RPC model*
  - *End-caps unchanged*

- Test beam simulations:
  - *Full prototype confirm the possibility to restrict to ~70×70 cm^2*
  - *First idea of what we should expect at PS*

- Documentation:

  http://polzope.in2p3.fr:8081/MOKKA/detector-models/ldc/DHCALdoc.pdf

  https://lyosvn.in2p3.fr/ilc/wiki/Simulations

Back-up: Complete list of DHCAL parameters default

- ChipPackageThickness = 1.4
- Ecal_endcap_outer_radius = 1926.1
- Ecal_endcap_zmax = 2500.
- Ecal_endcap_zmin = 2329
- Ecal_outer_radius = 1910
- EdgeWidth = 3.0
- Gap_Thickness = 1.2
- GazInletInnerRadius = 0.4
- GazInletLength = 3.0
- GazInletOuterRadius = 0.5
- Graphite_ThicknessAnode = 0.05
- Graphite_ThicknessCathode = 0.1
- Hcal_Ecal_gap = 29
- Hcal_R_max = 2900.
- Hcal_barrel_number_modules = 5
- Hcal_cells_size = 10
- Hcal_chamber_thickness = 6.0
- Hcal_endcap_cables_gap = 214
- Hcal_endcap_center_box_size = 600
- Hcal_endcap_ecal_gap = 30
- Hcal_fiber_gap = 1.5
- Hcal_lateral_structure_thickness = 10
- Hcal_modules_gap = 2
- Hcal_nlayers = 40
- Hcal_outer_radius = 3000.
- Hcal_radial_ring_inner_gap = 50
- Hcal_radiator_material = stainless_steel
- Hcal_radiator_thickness = 20
- Hcal_ring = 1
- Hcal_stave_gaps = 3
- PCB_Thickness = 0.8
- PadSeparation = 0.5
- TPC_Ecal_Hcal_barrel_halfZ = 2200.00
- ThickGlass = 1.1
- ThinGlass = 0.7
- mylar_ThicknessAnode = 0.05
- mylar_ThicknessCathode = 0.2

Back-up: Description of DHCAL parameters

- Ecal_endcap_zmax: 2500 (Z boundary of the Ecal endcap to avoid overlap with the Hcal one.)
- Ecal_outer_radius: 1910 (Ecal outer radius)
- Hcal_Ecal_gap: 29 (Gap between the Ecal and Hcal barrels, it's used to modifie the Hcal inner radius depending on the Ecal outer radius.)
- Hcal_endcap_cables_gap : 214 (The gap between the barrel and the endcap)
- Hcal_endcap_center_box_size : 600 (The size of the central box whole in the hcal endcaps)
- Hcal_lateral_structure_thickness : 10 (Lateral support plate thickness)
- Hcal_modules_gap : 2 (Gap between the hcal modules in a stave)
- Hcal_outer_radius : 3000 (The Hcal outer radius, used by the Coil super driver.)
- Hcal_R_max : 2900 (Minimum radius limit to start the Coil)
- Hcal_stave_gaps : 3 (Gap thickness between the hcal staves)
- TPC_Ecal_Hcal_barrel_halfZ : 2200 (The Z half length of the TPC central chamber plus the electronics at the botton. It's also the Ecal barrel size.)
- Hcal_endcap_ecal_gap : 30 (Gap between the Ecal and the Hcal endcaps)
- Ecal_endcap_zmin : 2329 (Starting Z for Ecal endcap, used by Hcal rings)
- Ecal_endcap_outer_radius : 1296.1 (The Ecal endcap outer radius, used by Hcal rings to avoid overlaps)
- Hcal_radial_ring_inner_gap : 50 (The radial gap between the Hcal ring and the Ecal endcap)

Back-up: energy profile with 10 cm of absorber