The Fastest Calorimeter

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The copy of this talk one can find at the http://www.desy.de/˜morgunov

Problem Description

The physical overlap of signals from different events

in the same calorimeter cells in time

will lead to deteriorate of energy resolution of any calorimeter

independently of it’s type.

How much?

Could be easily modeled at the test–beam CALICE data;

or any other test–beam calorimeter data that were collected years ago. *(it will not be discussed in this talk)*

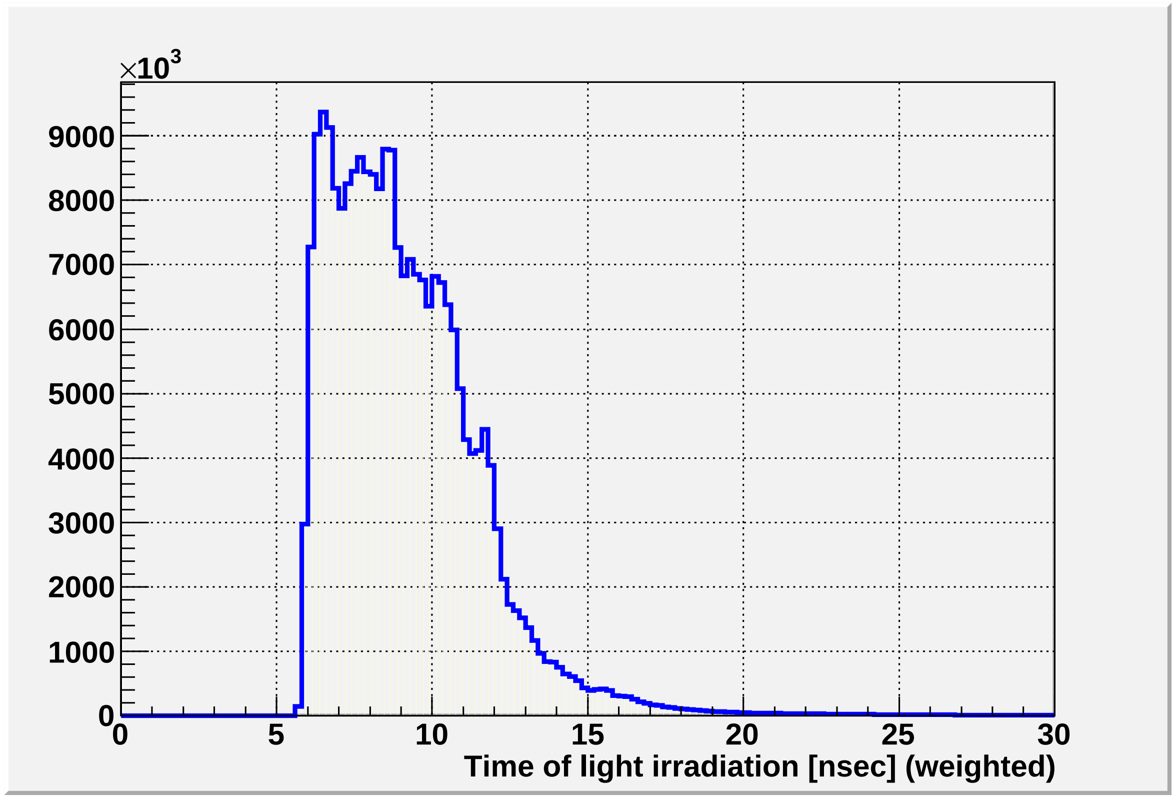
All LHC calorimeters at the nominal luminosity will get such kind of overlap without any chance to escape it.

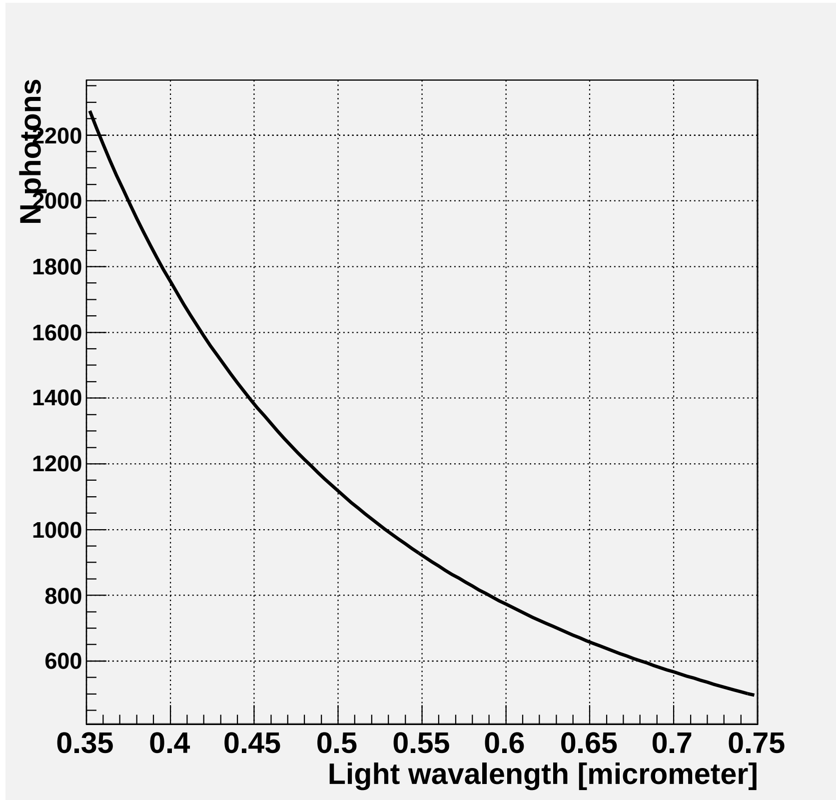
I never saw the numbers that describe such kind of overlap.

Is it helpful to build the fastest possible calorimeter for CLIC to escape overlap in time? Or at least to minimize of its effect ?

Here is a proposal of design of the fastest possible calorimeter.

Cherenkov light: time and spectrum





$e^+e^- \rightarrow t\bar{t}$ 500 GeV

Typical spectrum in visible range.

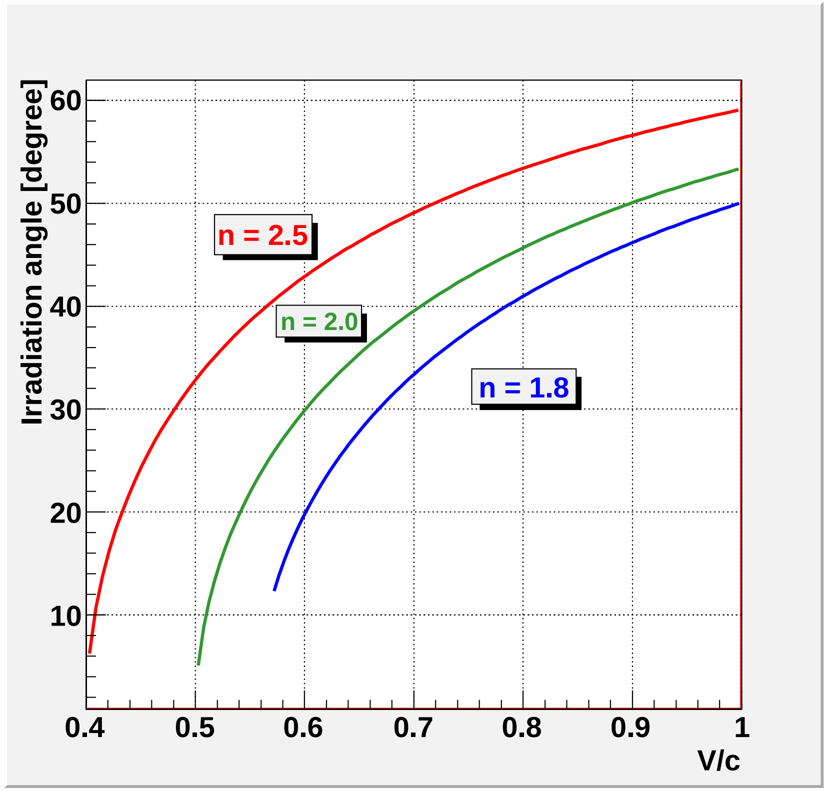
Particles need of about 6 nsec to reach a calorimeter face (no light in calorimeter, tracker radius = 2 m).

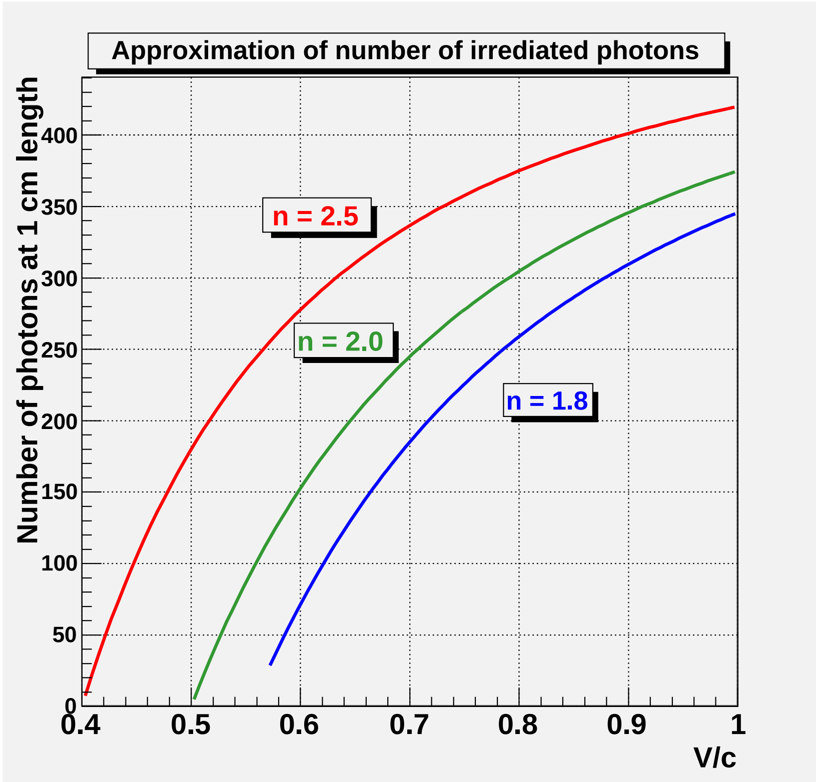
Main showers development takes of about 12 nsec in whole calorimeter (1.5 m in depth).

Tail is produced mainly during neutrons moderation and $n\gamma$ reactions in the detector volume; that is much larger than main hadron shower volume.

Light traveling time in tiles to reach SiPM is of about 1 nsec (tiles are small enough).

Cherenkov light: angular distributions and number of photons





Let us make a comparison of number of photons at CALICE scintillator tile and tile made of lead glass:

Number of emitted photons at scintillator is of about 10^4 for 5 mm scintillator tile thickness

BUT: number of photons reached SiPM "face" is of about 100 photons for one particle crossed tile.

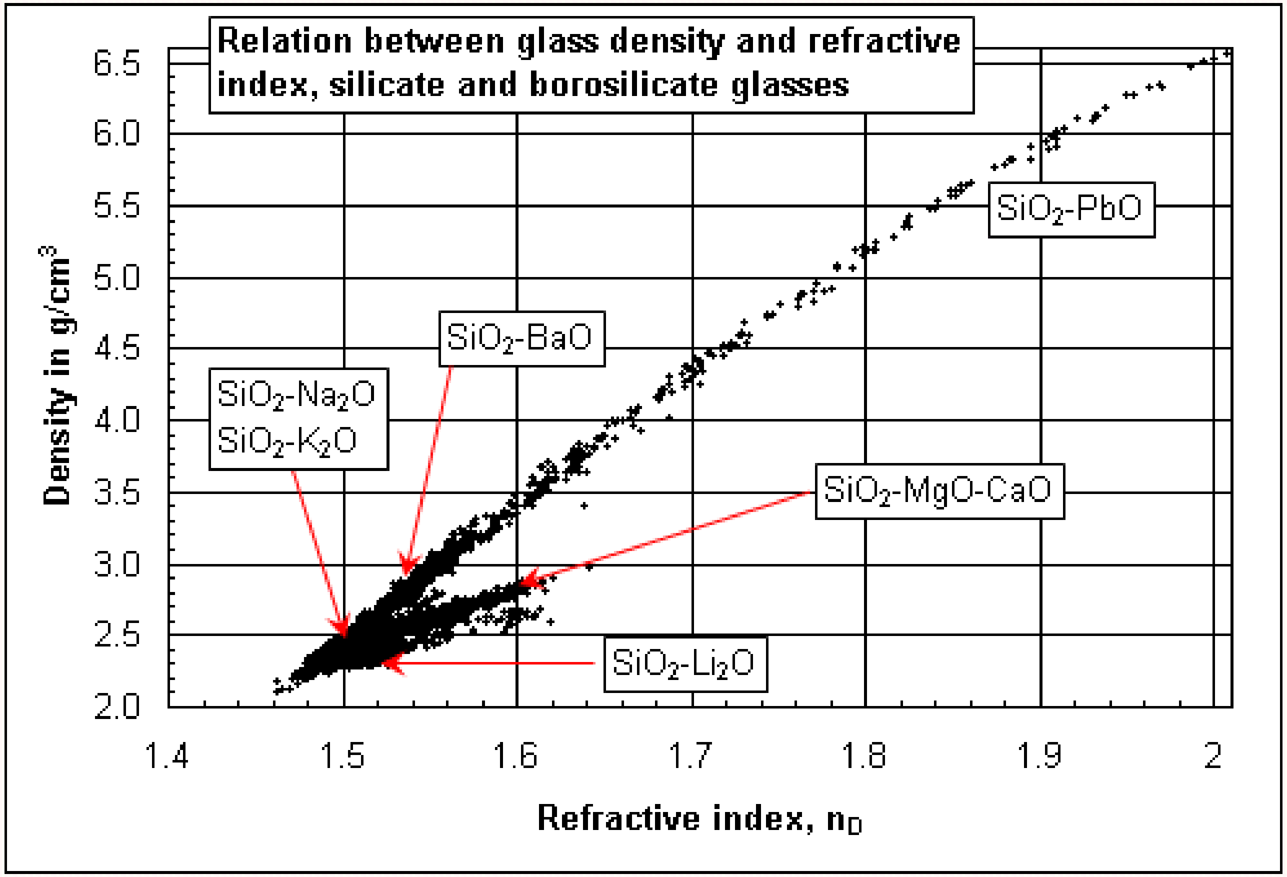
This is mainly due to light collection efficiency inside of WLS fiber, that is of about 6%.

In Lead glass we will have hundreds photons per cm track length (integrated in visible wavelength range).

Efficiency of light collection could be up to 80%. Geometry of the tiles will be shown later.

Lead glass properties

As large will be a refractive index as large will be a calorimeter response.



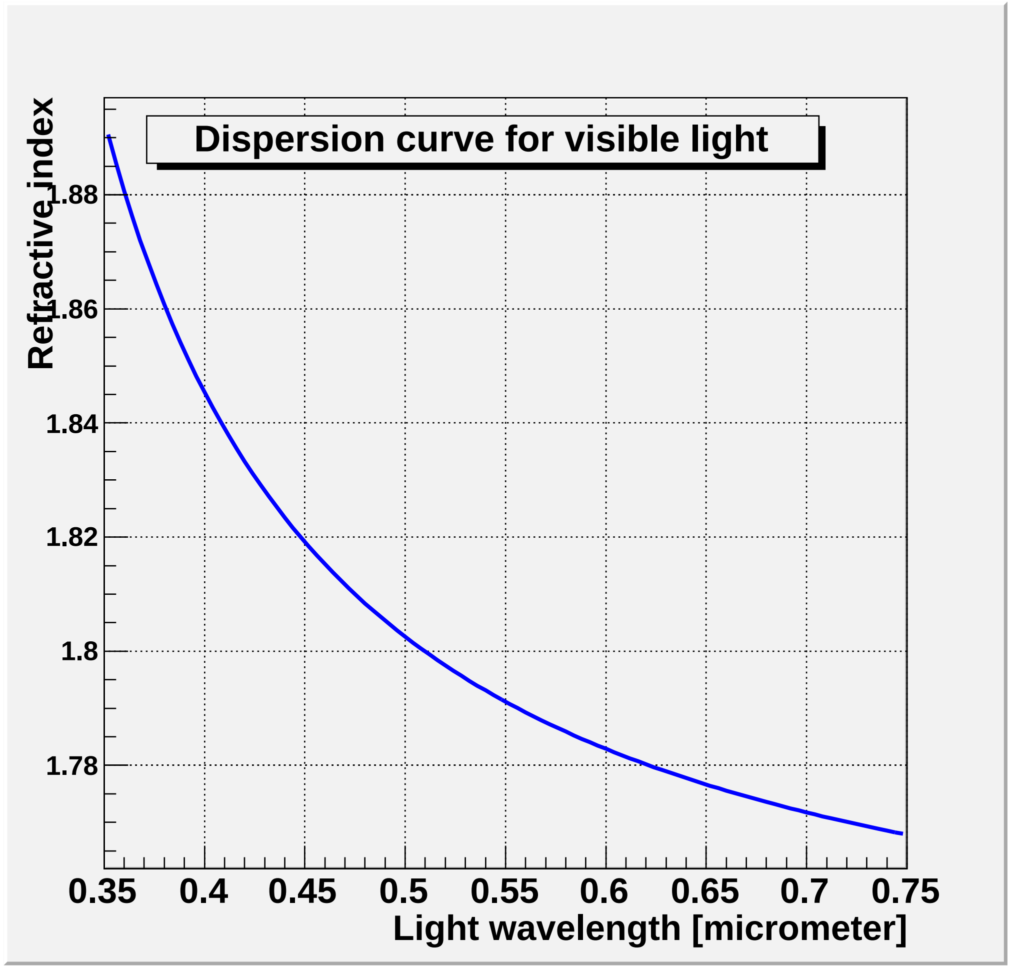
Experimental points on this picture show a possibility to reach a refractive index near by 2;

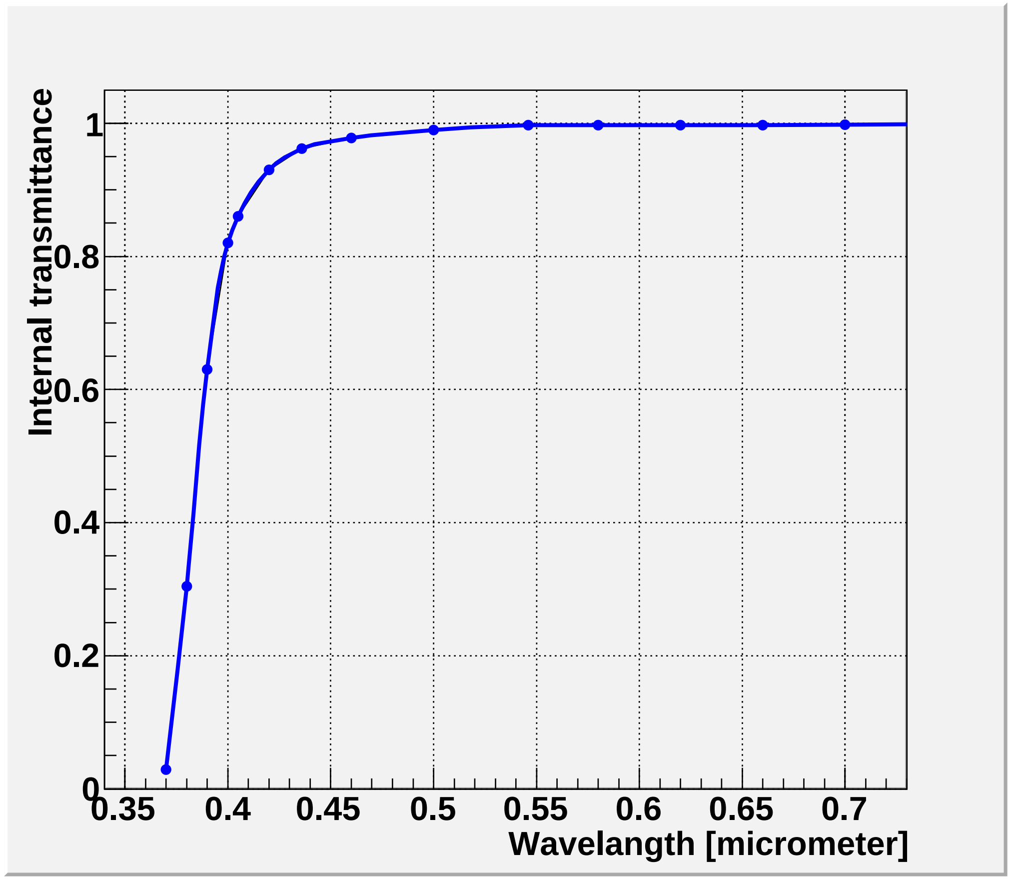
with density more than 6 g/cm^3

So, a lead glass is able to register the Cherenkov light from particles moving down to a half of speed of light.

see: http://glassproperties.com/refractive_index/

Typical lead glass dispersion curve and transmittance





For some type of existing lead glass.

see: http://www.schott.com/advanced_optics/english/abbe_datasheets/datasheet_n-sf11.pdf

G4_GLASS_LEAD

GEANT4 knows about Lead Glass with needed properties. Such a material exists in NIST database.

```
        Material: G4_GLASS_LEAD:
    density:  6.220 g/cm3;    Imean: 526.400 eV
  RadL:   1.266 cm ;    Nucl.Int.Length:  25.734 cm;
Element:O,  Z = 8.0, N = 16.0, A = 16.00 g/mole, MassFraction: 15.65 %
Element:Si, Z = 14.0, N = 28.1, A = 28.09 g/mole, MassFraction:  8.09 %
Element:Ti, Z = 22.0, N = 47.9, A = 47.87 g/mole, MassFraction:  0.81 %
Element:As, Z = 33.0, N = 75.0, A = 74.92 g/mole, MassFraction: 0.27 %
Element:Pb, Z = 82.0, N = 207.2, A = 207.22 g/mole, MassFraction: 75.19 %
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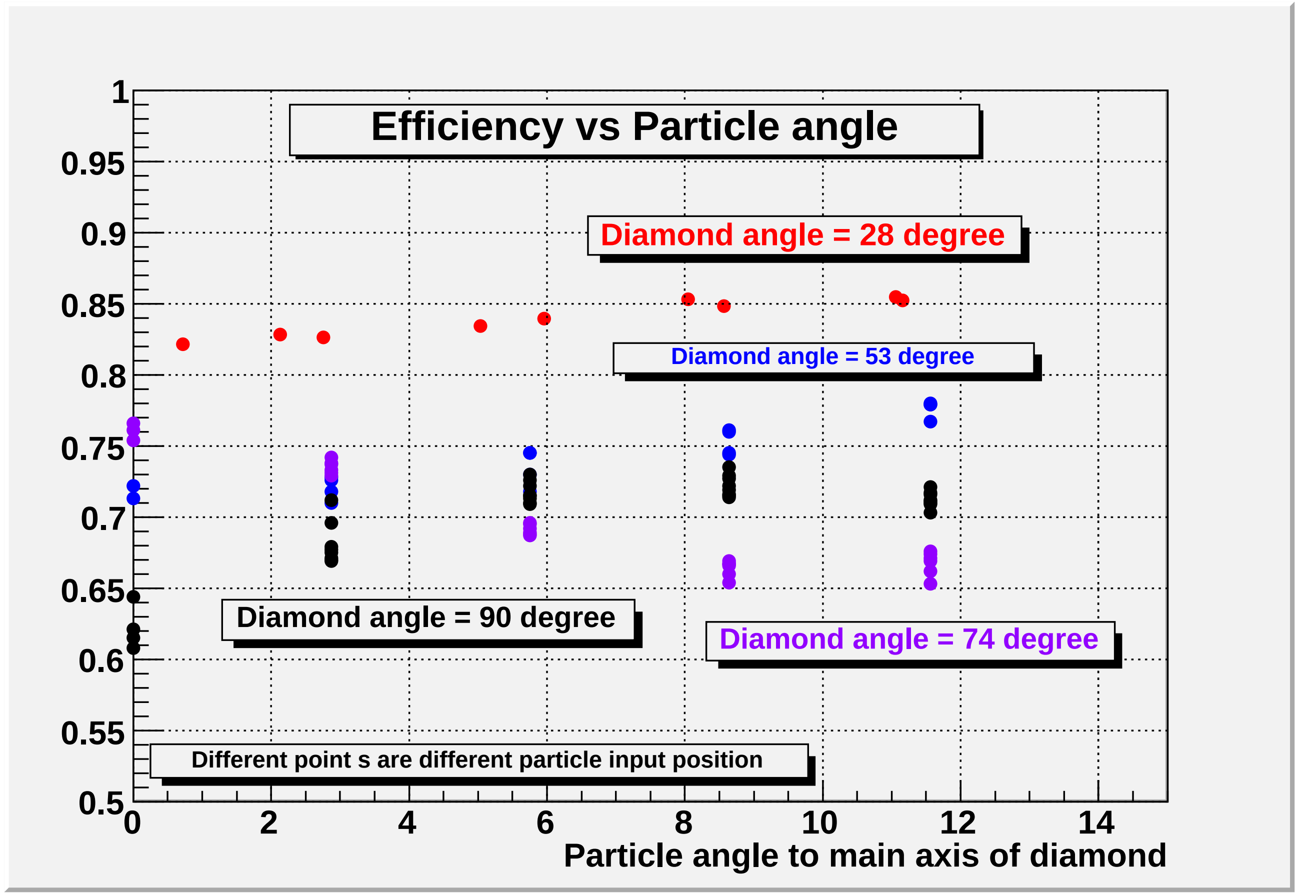
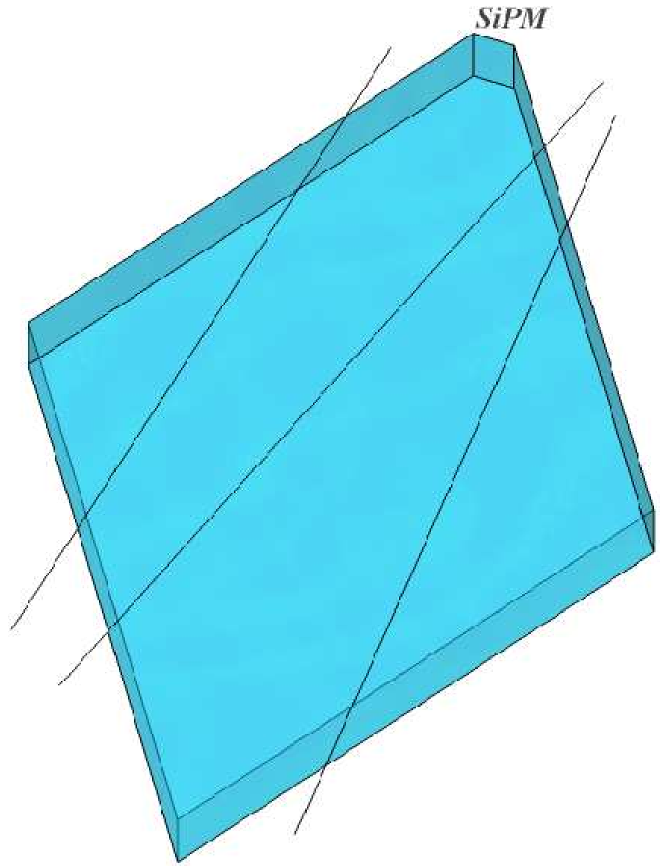
Factory for mass production that consists of oven and few automates for tile forming will be much cheaper than to buy crystals from Swarovski.

Cherenkov light collection efficiency is at the rhombus shape tile





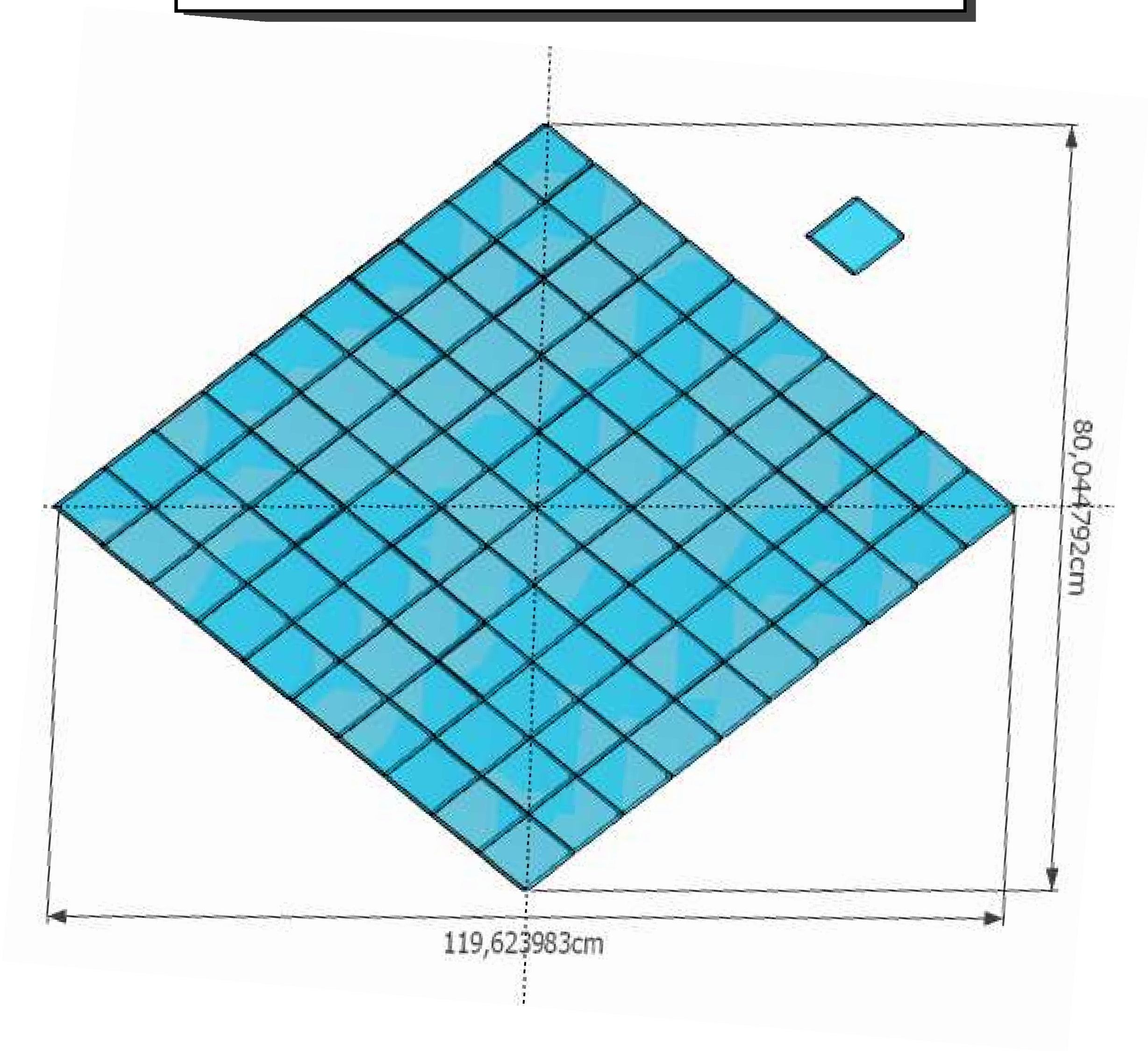
Many thanks to Eugeny Tarkovsky (ITEP) for light transport calculations.

Efficiency is stable and reasonable good in wide range of angles as for tile angle as for incident angle of particle.

It has a nontrivial dependency on the tile angle (for big angles).

These calculations should be carefully repeated using more accurate optical properties data for particular type of lead glass.

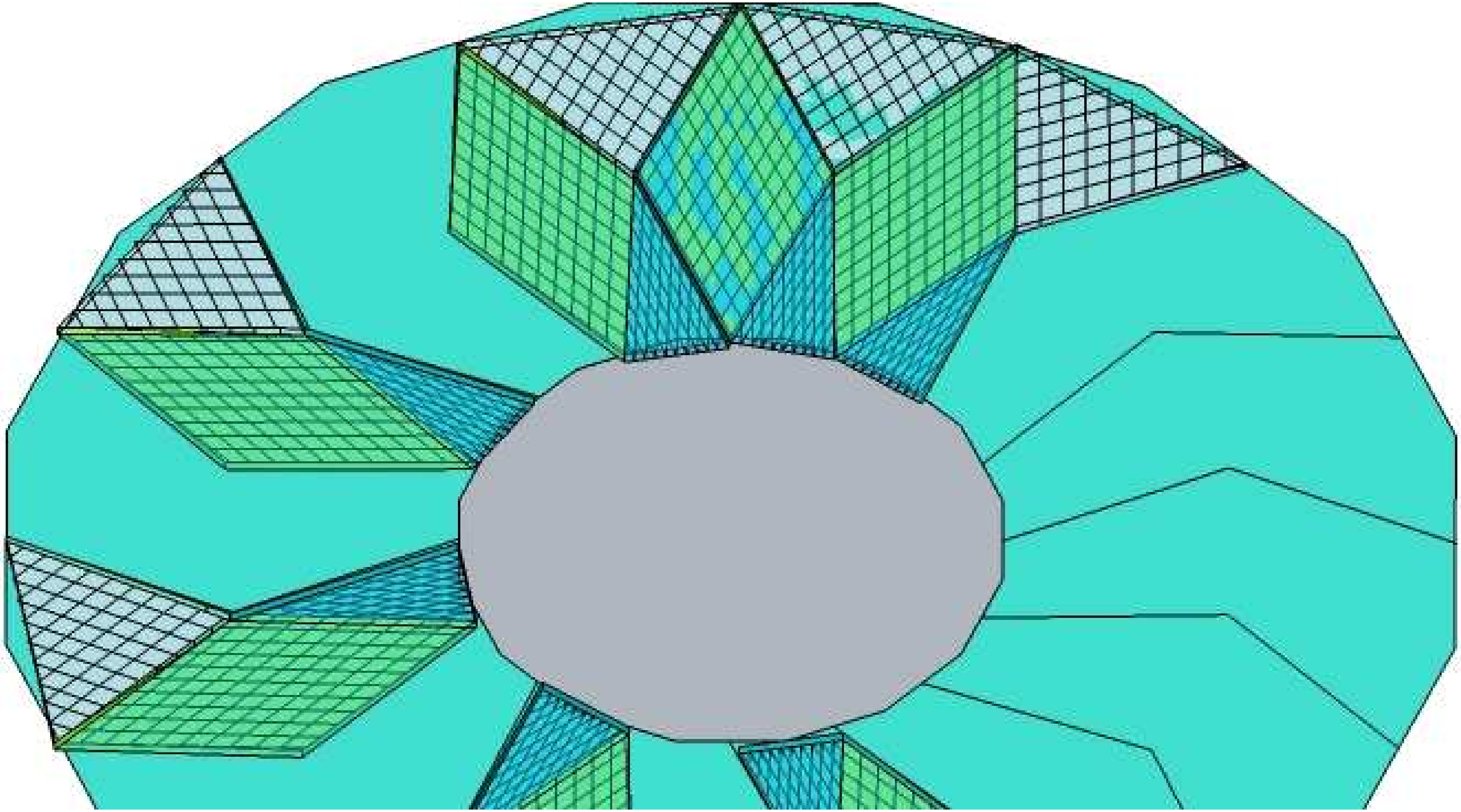
Calorimeter Barrel Design



One plate with 100 tiles; (1200 mm by 800 mm; plate thickness is 10 mm).

Calorimeter Barrel Design

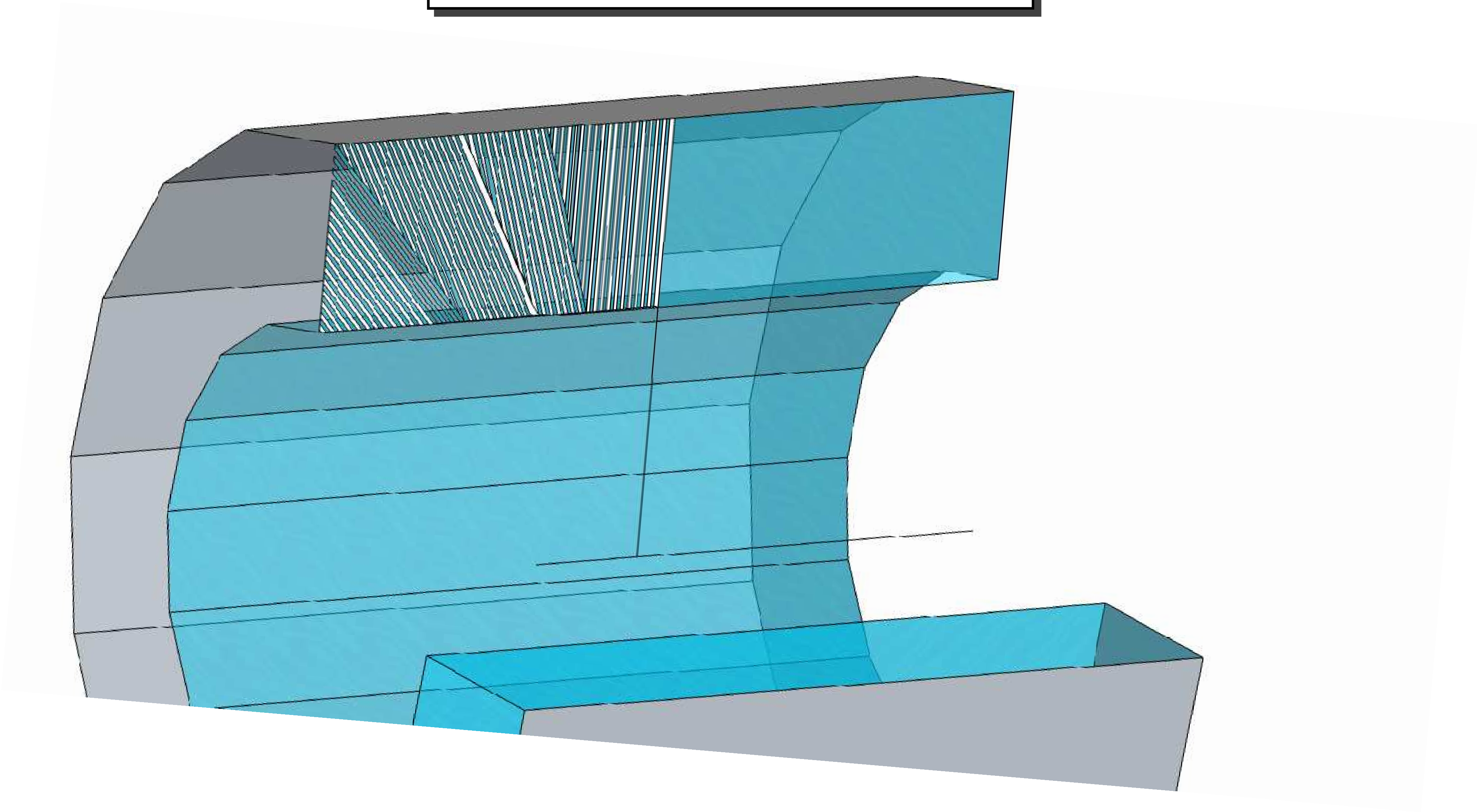
Vertical cut of the sketch of the calorimeter Barrel.



Main axis of every tile "looks" at IP with less than 10 degree spread.

It is almost 100% coverage of the disc (very small dead zone).

Calorimeter Barrel Design



Cut of calorimeter Barrel. (polygonal pyramids surfaces with vertexes near by IP.) see back–up slides

Calorimeter Design

ECAL and HCAL could be made in the same style, only rhombus pad sizes should be different.

Proposed sizes for ECAL barrel: 30 mm in radial (projective) direction, 15 mm across and thickness = 10 mm.

Estimated number of rings are of about 10; disks are of about 600; tiles at one disk are of about 16 000.

Whole estimated number of tiles at ECAL barrel are of about 10 000 000;

If ECAL endcap will be made with the same pad sizes than:

Estimated number of rings are of about 110; disks are of about 20; tiles at one disk are of about 160 000.

Whole estimated number of tiles at both ECAL endcaps is of about 3 000 000;

——————— *ECAL 13 000 000 channels; depth is of about 0.3 m; 24 X_0 and 1 λ_{nucl}* ———————-

Proposed sizes for HCAL barrel: 100 mm in radial (projective) direction, 40 mm across and thickness = 10 mm.

Estimated number of rings are of about 15; disks are of about 660; tiles at one disk are of about 13 000.

Whole estimated number of tiles at HCAL barrel of about are 8 500 000;

If HCAL endcap will be made with the same pad sizes than:

Estimated number of rings are of about 80; disks are of about 30; tiles at one disk are of about 190 000.

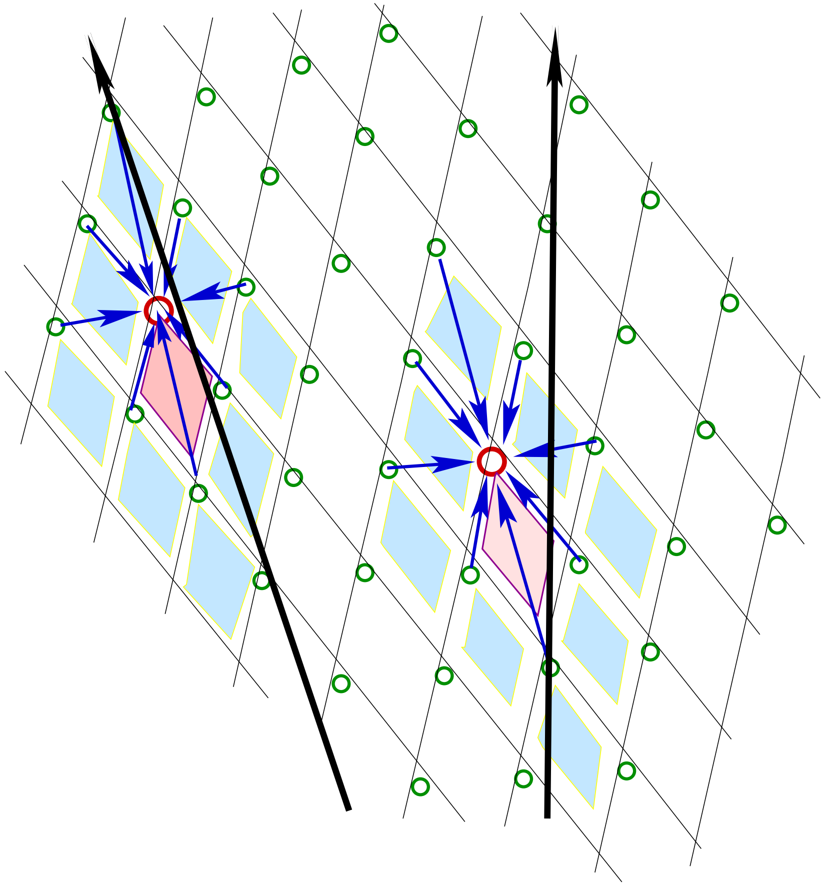
Whole estimated number of tiles at both HCAL endcaps are of about 6 000 000;

——————— *HCAL 14 500 000 channels; depth is of about 1.5 m; 6 λ_{nucl}* ———————

Number of channels is less than in any proposal for digital hadron calorimeter.

Such sizes of tiles will allow to apply Particle Flow Algorithm, if needed.

Trigger for every tile and zero suppression scheme



Sum of neighbors signals should be added to the signal of each tile and then send to discriminator of each tile.

Such a triggering scheme is needed to get zero suppression and it will allow significantly reduce a SiPM noise.

Particle tracks are in black.

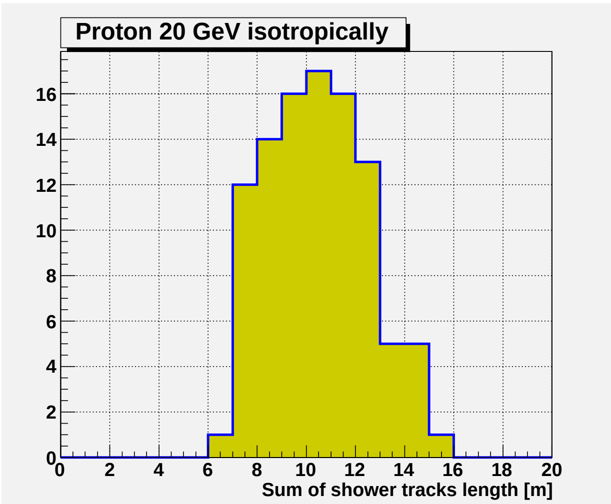
Green circles show position of photodetectors at each tile.

Tile neighbors are shown in light blue.

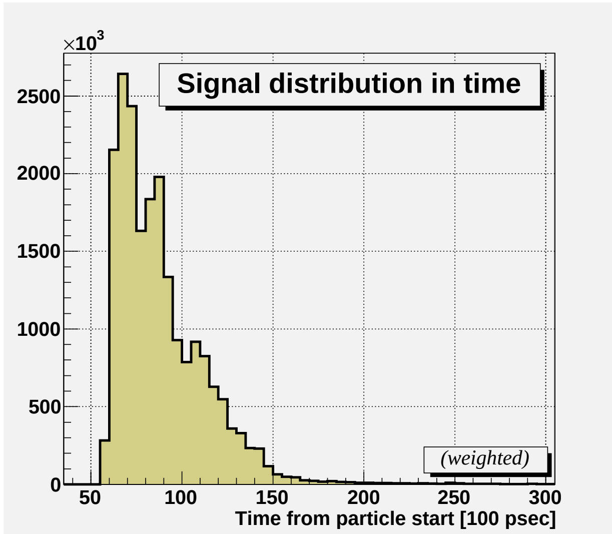
Some examples and numbers

Program to simulate any kind of events in such a type of calorimeter with simplified geometry is ready.

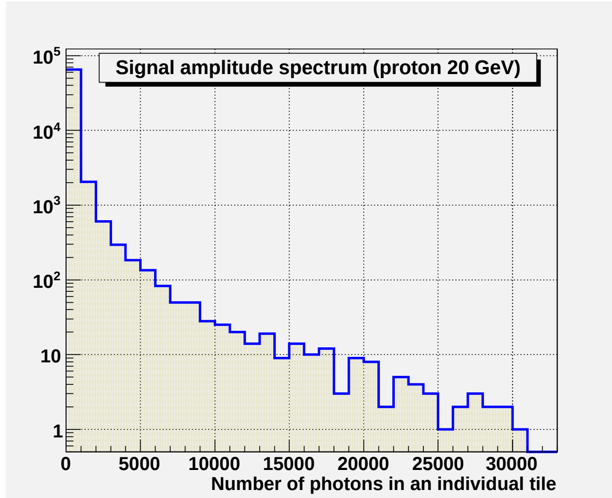
Program is able to record of signal histogram in time for all touched tiles with accuracy of 100 pico–seconds.



Average track length is of about 10 meter in the calorimeter tiles



Average arrival time is 10 nsec; small tail after 20 nsec



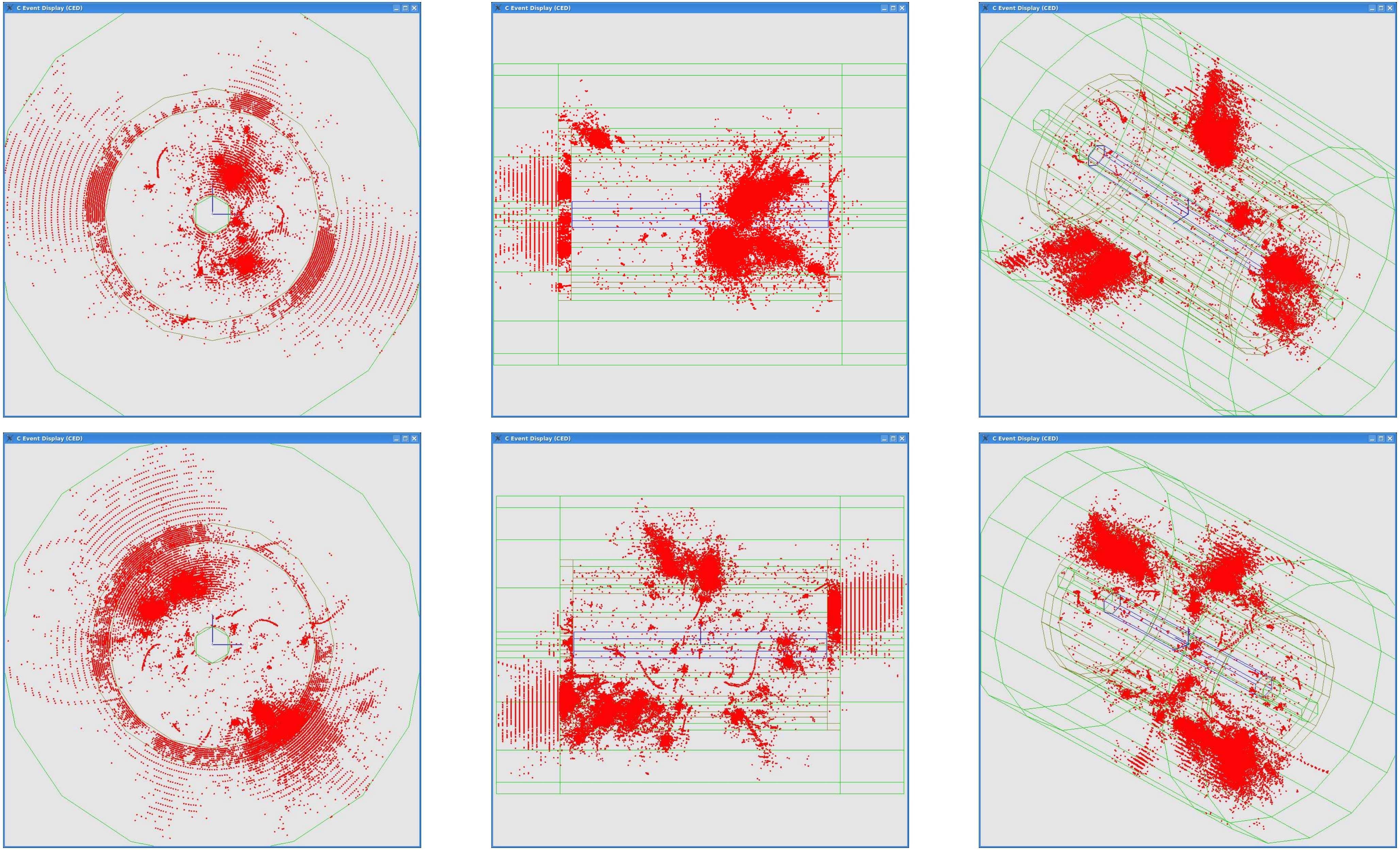
Amplitude spectrum of individual tile up to 30 000 photons per tile

20 GeV proton isotropically in angle each event is one individual shower

Light irradiation thresholds (E_{kin} for refractive index = 2.0) are: electron – 79keV; pion – 21MeV; proton – 150MeV.

Fast SiPM exists. Whole recovery time for some Hamamatsu MPPC = 4 nsec; i.e. tau in exponent is $\approx$ 1 nsec.

One should not forget that the hadronic shower development time in terms of cherenkov light is of about 12 nano second; for ionization energy deposition it will be bigger. If one will use scintillator as an active detector then one will get an additional time due to scintillator decay time (that is of about factor two even for the fastest scintillator). And, one should not forget about time for electronics to treat signals.



Two events of $e^+e^- \longrightarrow t\bar{t}$ 3 TeV; number of hits 56 641 in first event and 65 663 in second one.

Conclusion

The fastest calorimeter design is proposed.

The main axis of each rhombus shape tile in this design “looks” at the point of interaction with spread of less than 10 degree.

GENT4 program for simulation with recording of time histograms of every tile is ready.

To do:

Analise of the event overlap in time for CLIC timing of beam.

Need stdHEP file with all type of events, including $\gamma\gamma$ background.

Each event should have a time stamp when it was occurred inside a train (realistic model of event flux in time for several trains at CLIC).

Test beam to show efficiency of light collection in rhombus lead glass tile is underway.

A huge engineering challenge for support structure design.

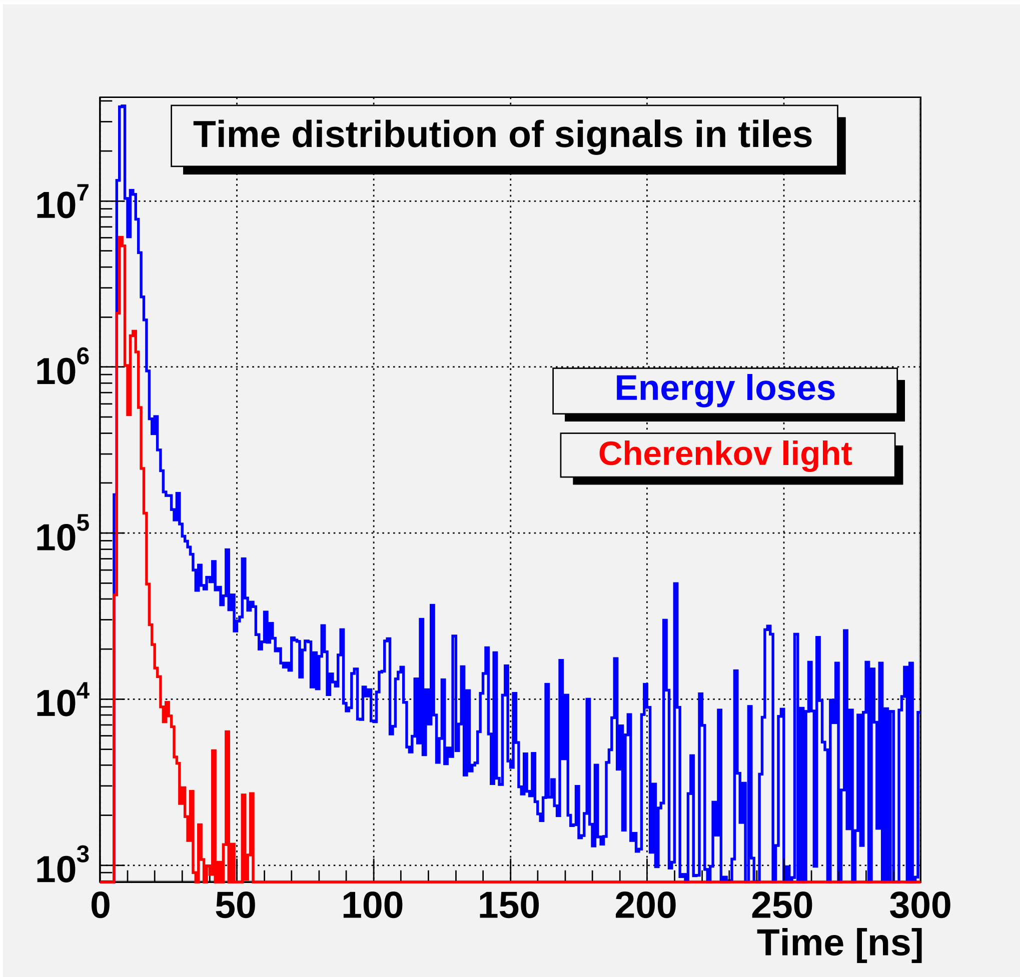
A big engineering challenge for electronics design.

And, of course, a rather big cost, but we will need a perfect jet energy measurement.

BACKUP SLIDES

Comparison with usual energy loses in calorimeter

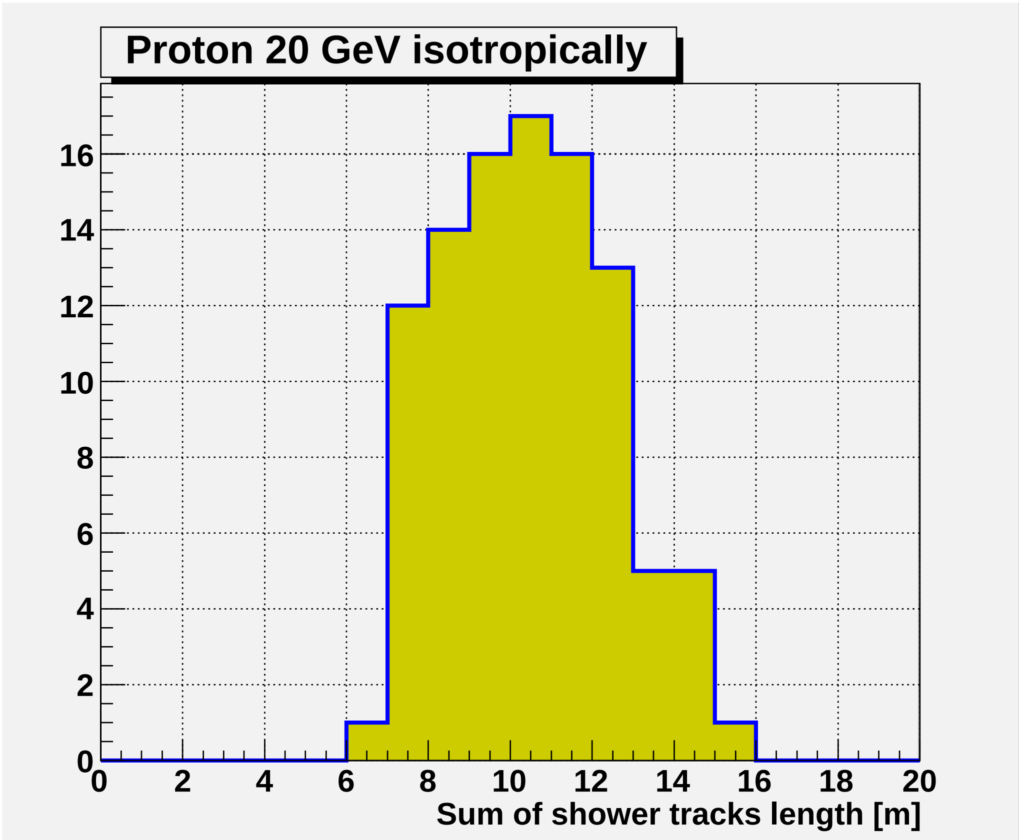
20 GeV proton isotropically in angle each event is one individual shower

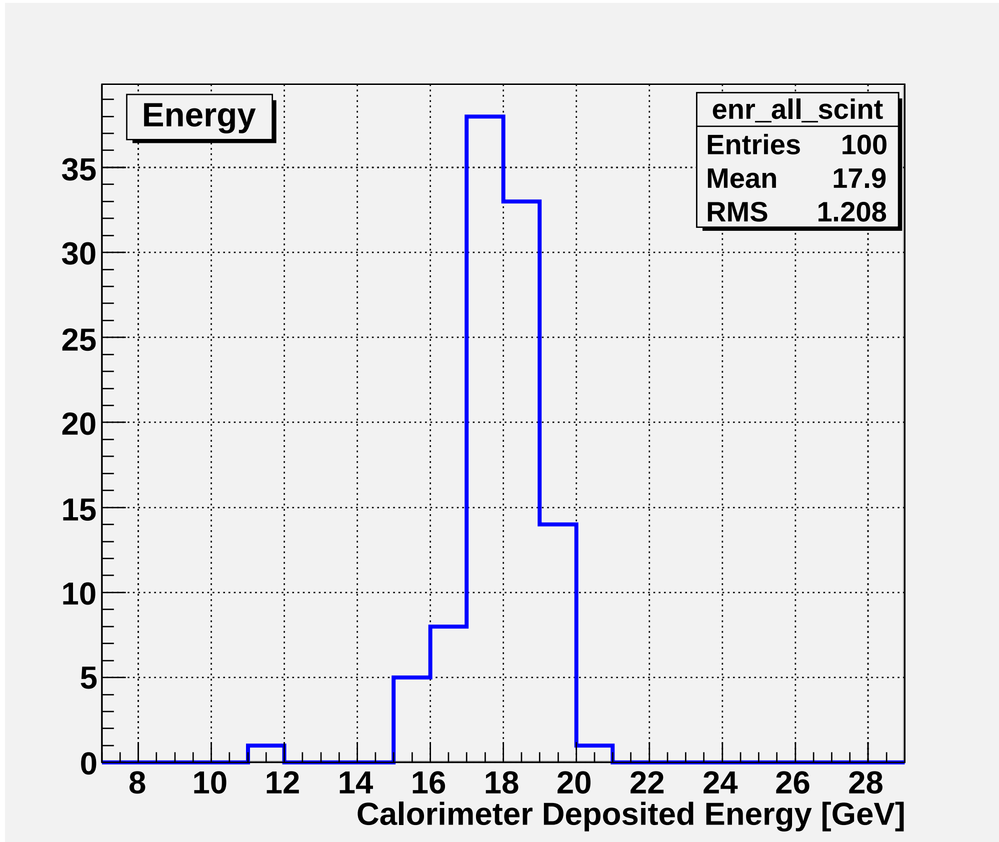


Do not forget than energy loses should be convoluted with a decay time of scintillator (that was not done here).

Comparison with usual energy loses in calorimeter

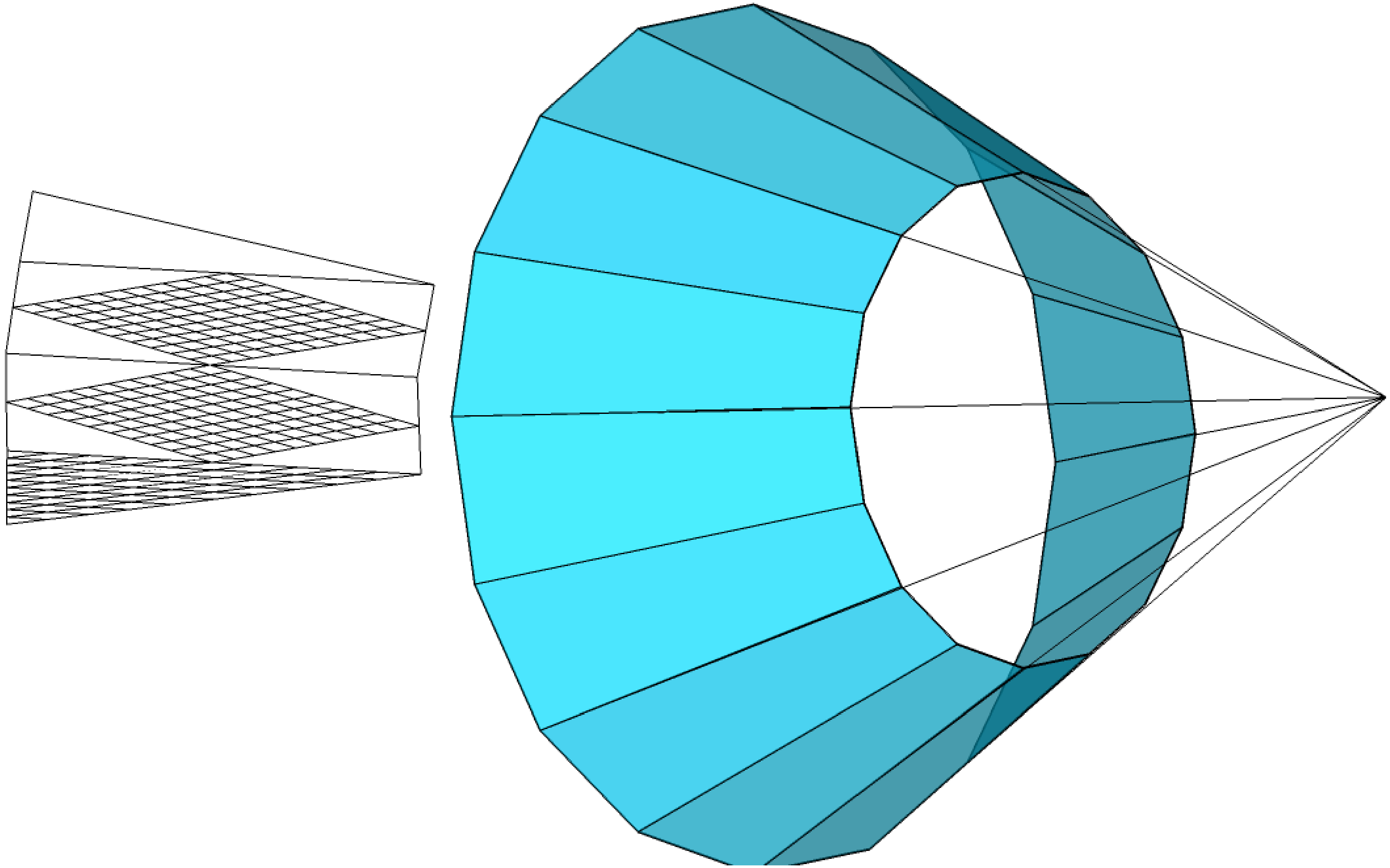
20 GeV proton isotropically in angle each event is one individual shower





Do not forget than this is a homogeneous calorimeter with much better resolution as it is.

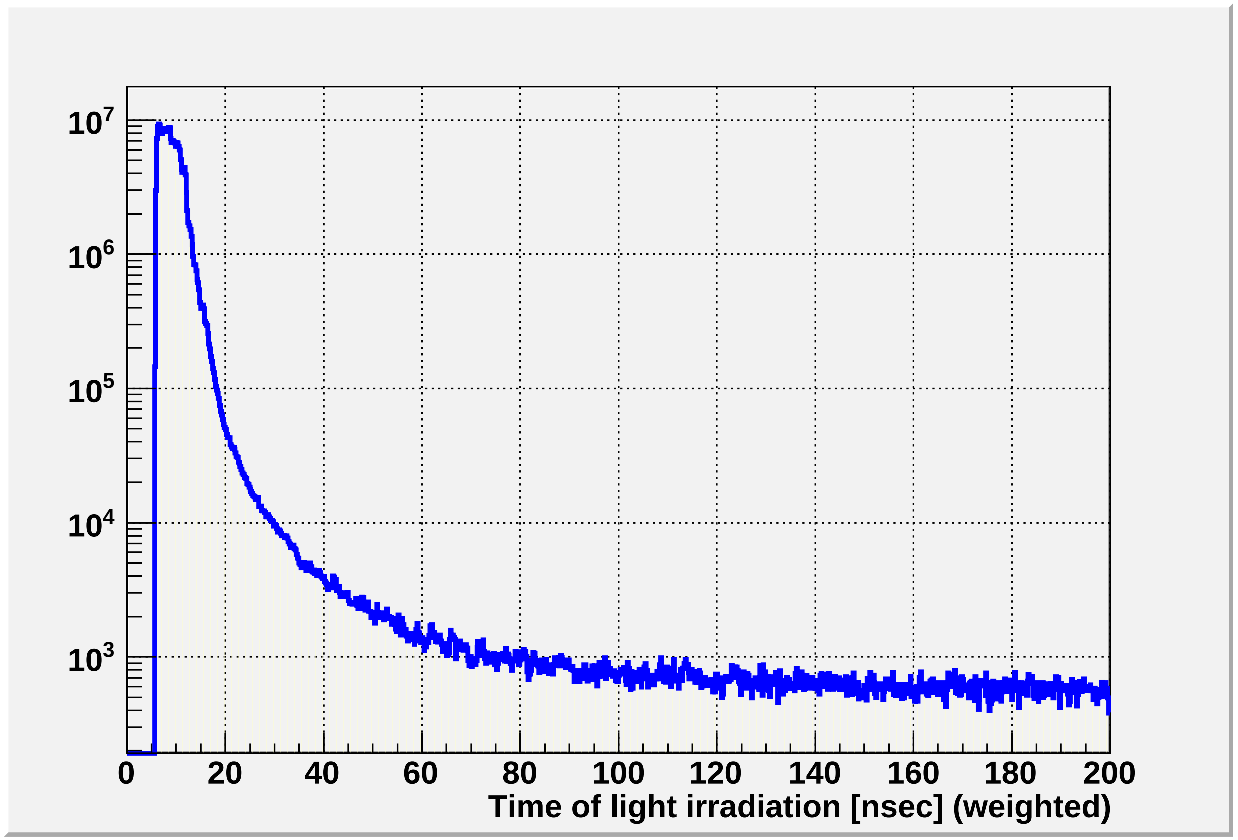
EndCap Design



One polygonal pyramid surface. Thickness is 1 cm.

Each plane is made of rhombus shape tiles.

Log scale histogram from transparency #3



The tail of this curve does not belongs to the concrete shower, or better say, it could not be assigned to concrete shower because the moderated neutrons travel a few meter distance from its origin before they initiate $n\gamma$ reactions; that will produce gammas and later on the cherenkov light from electrons, either from photo–effect or from Compton scattering.

Neutron's "cloud" will create an additional background during the train.

The depth of ECAL could be shorted, because of HCAL will/should work as a tail catcher for any long electromagnetic shower.

ECAL needs a fine structure at the first 15–20 X_0.

I did not say: It is the best calorimeter in terms of resolution I said: IT IS THE FASTEST.

The main good feature of the Silicon Photomultiplier is that it has an intrinsic gain of about 10^6; this will allow to make very fast readout easier.

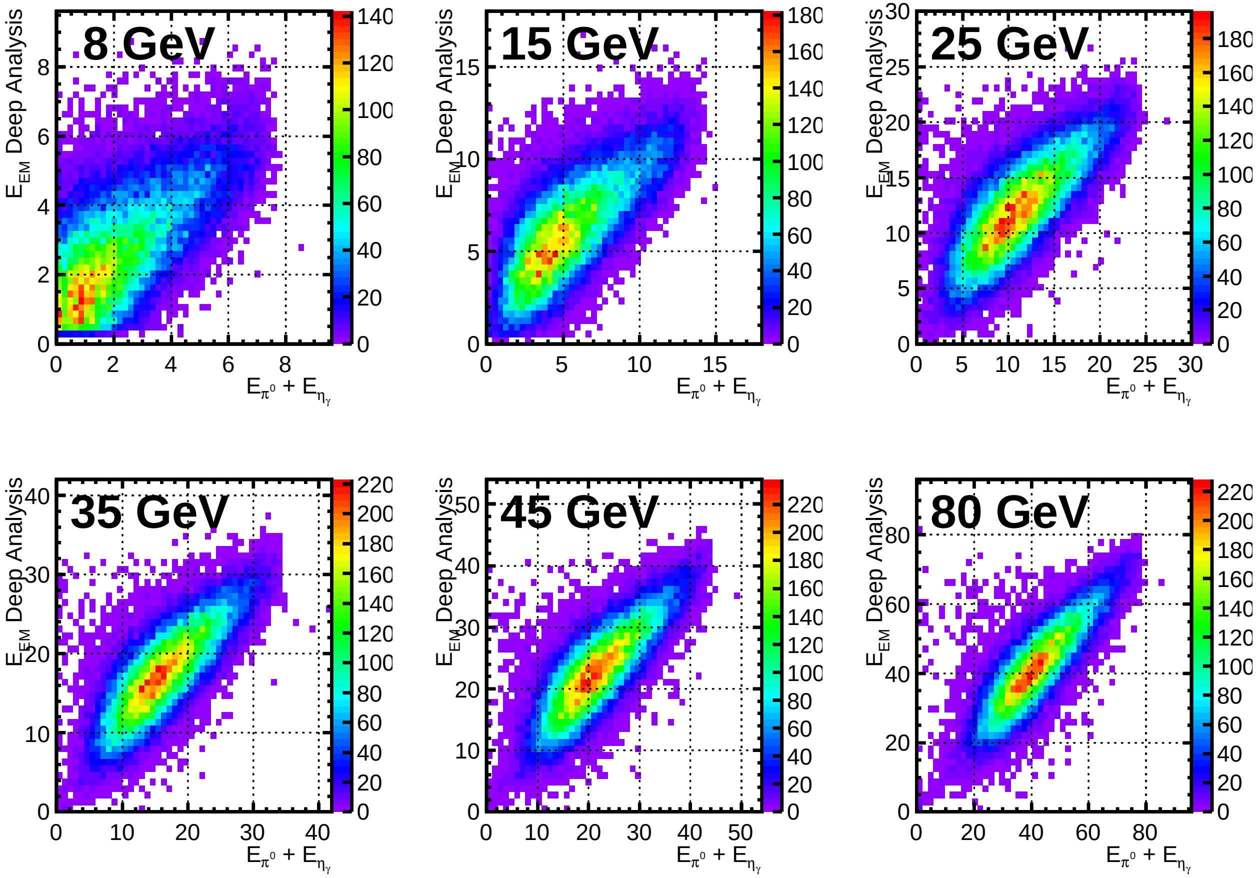
Si W calorimeter (without scintillator) could be as fast as this one, if it is possible to make very fast electronics (preamplifier) for each channel; SiPM is able to work without preamplifier.

Do not forget than the shower development takes at least 12 nano second!

Quality of DeepAnalysis clustering algorithm

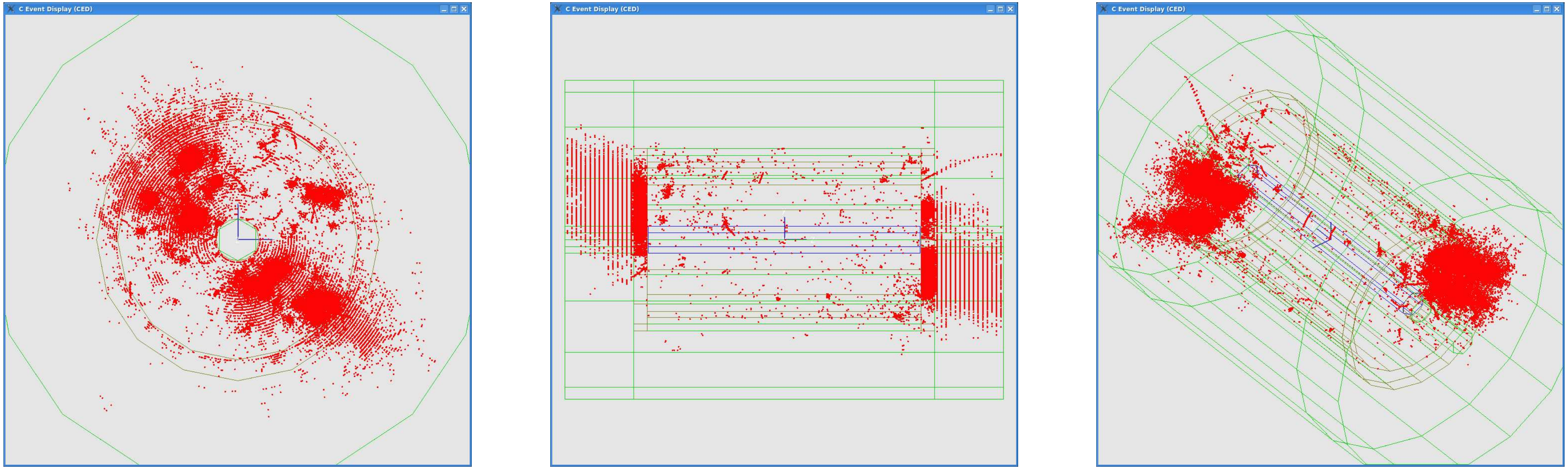
This method could be applied as software compensation technique for the fastest calorimeter.

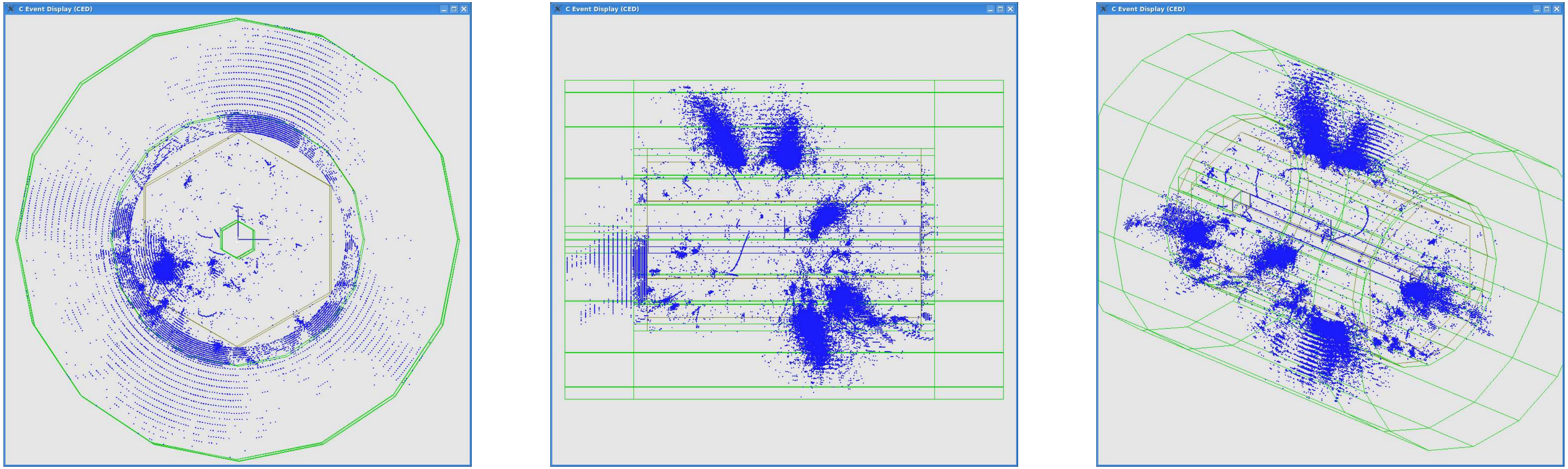
How well can we find an electromagnetic part of hadronic shower in highly granulated calorimeter?



Correlations between found electromagnetic part of hadronic shower and true Monte Carlo value of it.

Many thanks to Alex Kaplan (Hidelberg Univ.) for calculations.





Event of $e^+e^- \rightarrow t\bar{t}$ 3 TeV, number of hits 57920.

Event of $e^+e^- \rightarrow W^+W^-$ 3 TeV, number of hits 69922.