# Optimisation of the BeamCal Design (simulation studies)

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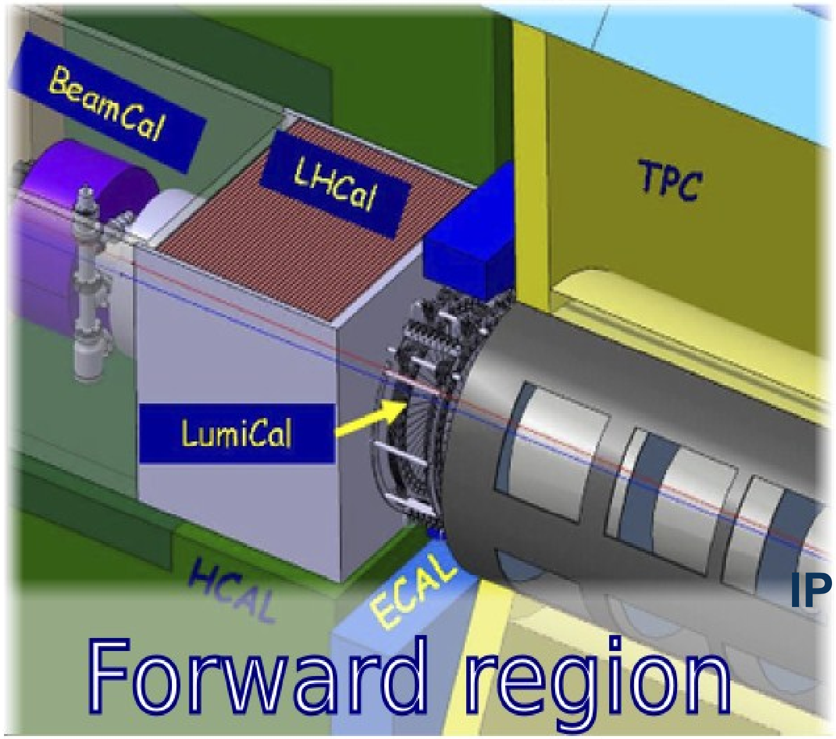
# The Aim and Content

**The Aim:** compare performance of BeamCal for 2 types of segmentation, investigate signal digitization

**Content:**

- Introduction
- Simulation studies
  - reconstruction algorithm
  - fake rate
  - efficiency
  - energy resolution
  - spatial resolution
- Signal digitization
- New BeamCal design proposal based on sapphire sensors
- Conclusion

# Beam Calorimeter at ILC

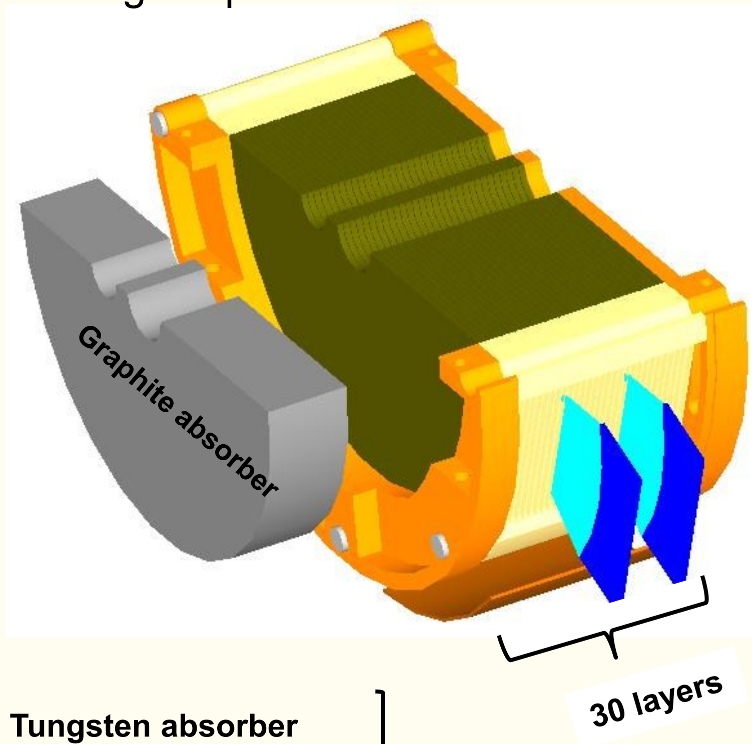



**Beam parameters from the ILC Technical Design Report (November 2012)**

- Nominal parameter set
- Center-of-mass energy 1 TeV

**BeamCal aimed:**

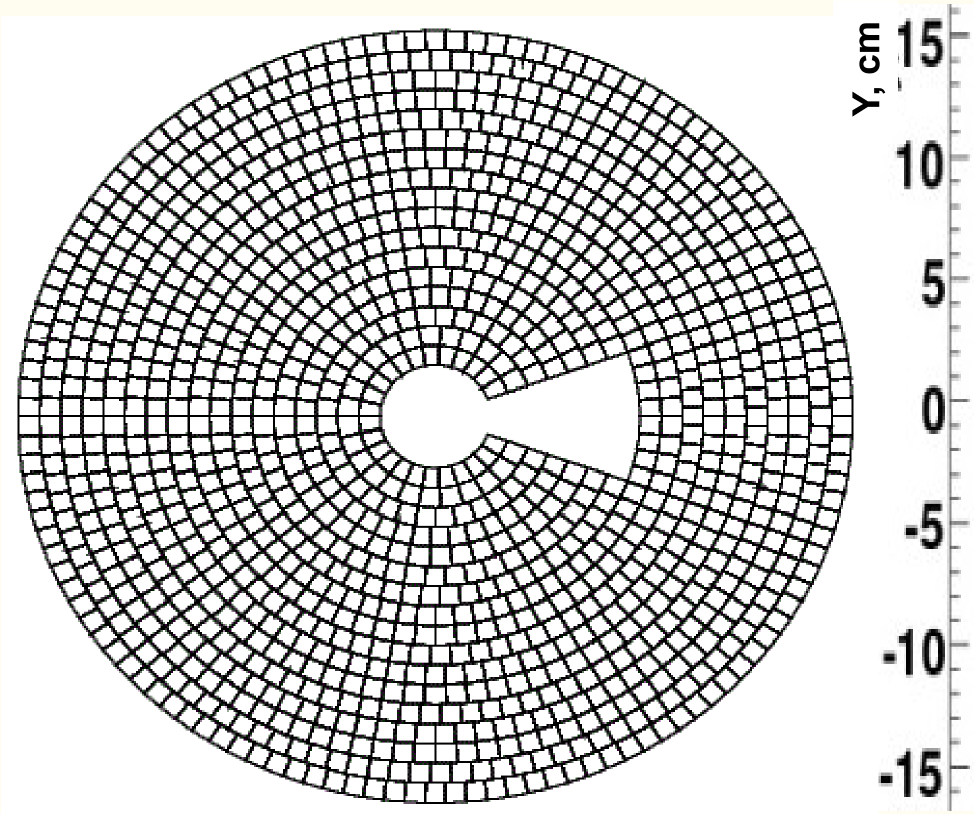
- Detect sHEe on top of BG
- Determine Beam Parameters
- Masking backscattered low energetic particles




- **Tungsten absorber**
- **Diamond sensor**
- **Readout plane/air gap**

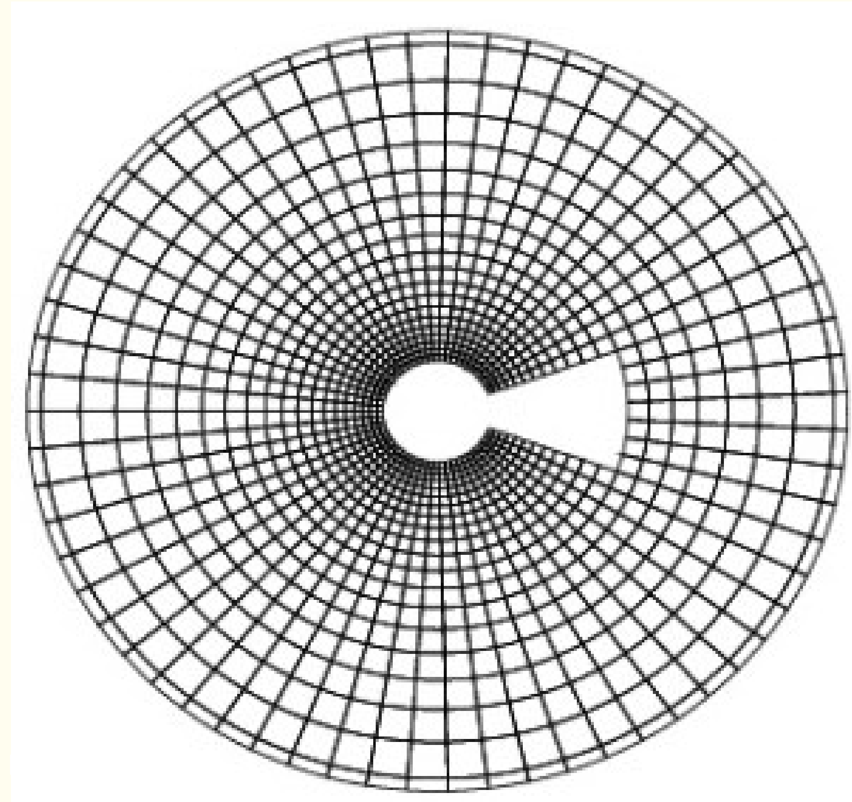
$\left.\right\}$ **1** $X_0$

# BeamCal Segmentation




**Uniform Segmentation (US)**

pads size are the same



**Proportional Segmentation (PS)**

pads size are proportional to the radius

**Similar number of channels**

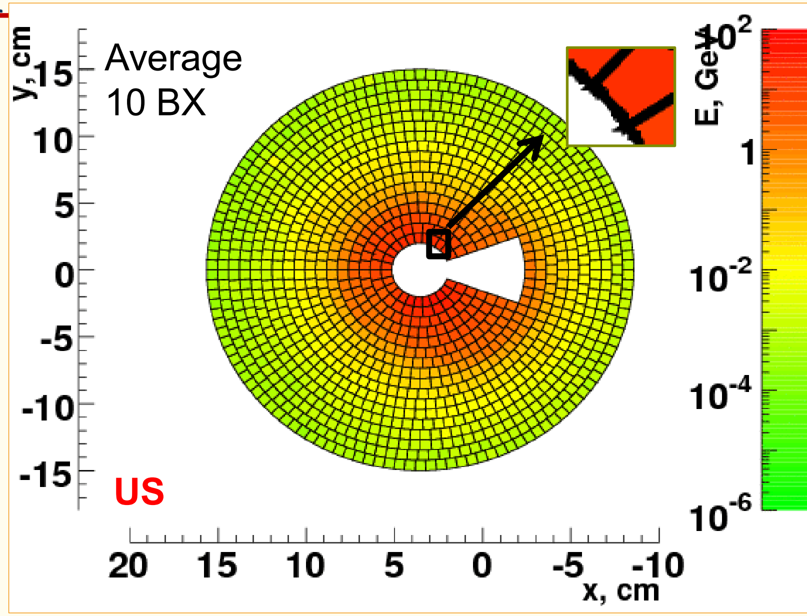
# Energy Deposition due to Beamstrahlung

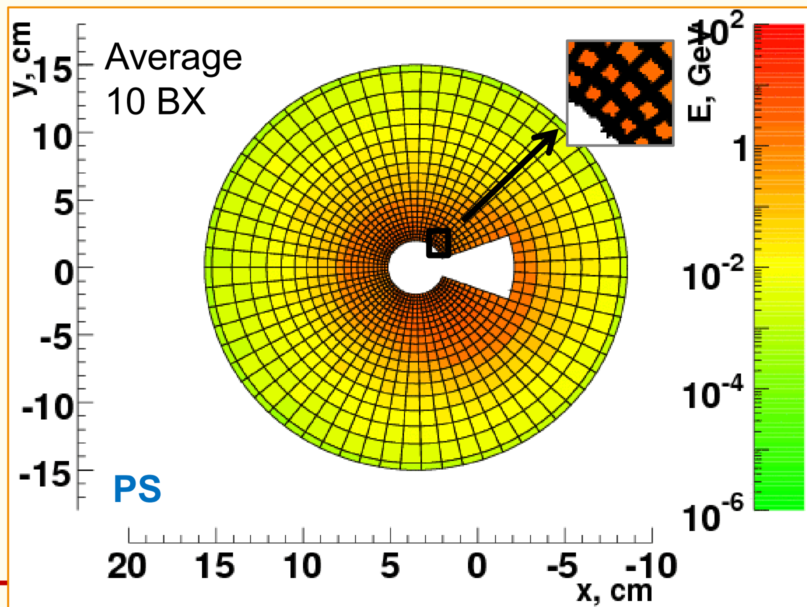
- **Beamstrahlung (BS) pairs generated with Guinea Pig**
- **Energy deposition in sensors from BS simulated with Geant4**

  **⟶ *considered as Background (BG)***
- **RMS of the averaged BG**

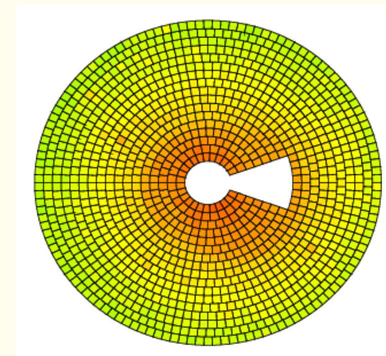
  **⟶ *considered as energy threshold***

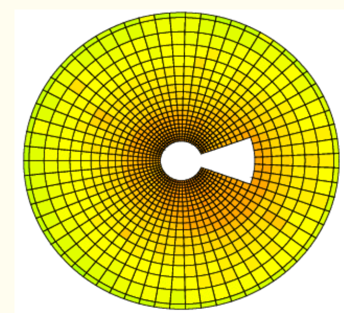
**$E_{dep}$ is the same, but $E_{dep}$/pad is different!**




**RMS**

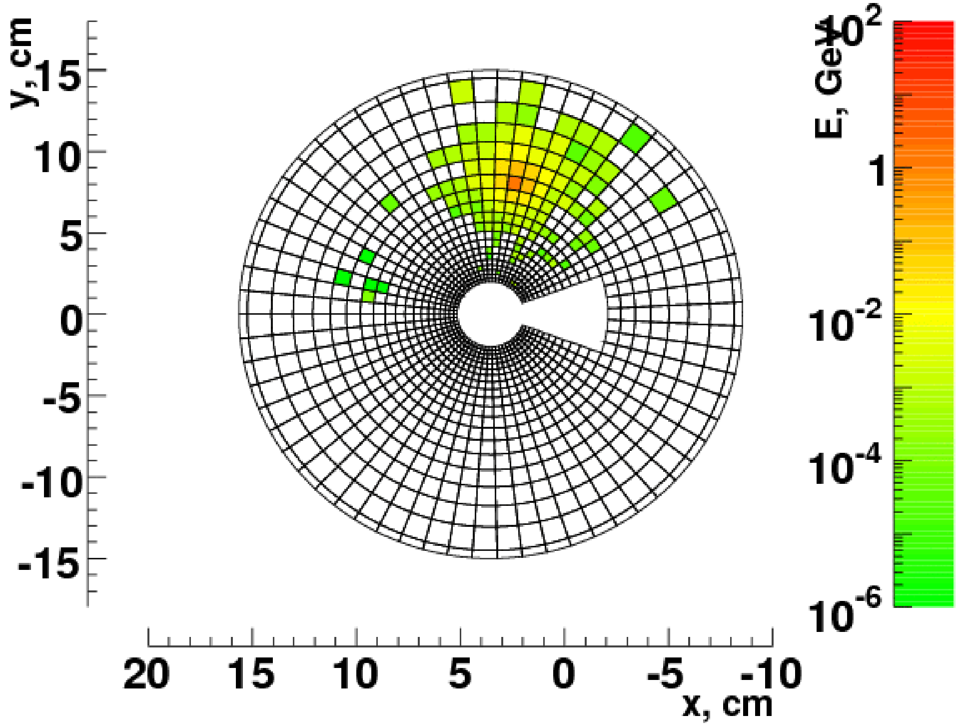




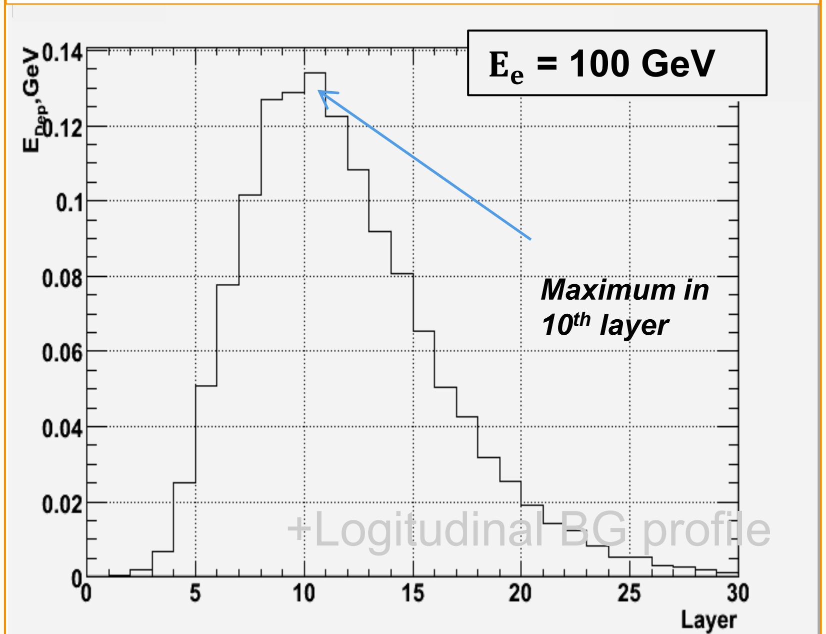
**Figures show sum of all layers**

# Example of Shower from 500 GeV Electron

Shower from 100- GeV electron




Longitudinal **distributions of energy deposition** in calorimeter




*(average over 10 showers)*

- At some areas BG energy deposition is several times higher than deposition from the electron.
- But due to the relatively low energy of BS pairs, the background and a high energy electron have different longitudinal distributions

# Reconstruction Algorithm

With BG

Without BG

1. SH + BG – average by 10th previous BXs BG
2. Select layers from **5th** to **20th**
3. Applying energy threshold **3** RMS
4. Combine to towers, calculate its energy
5. Search shower core (max number of pads)

   * if there ≥ **9** pads (not necessarily sequent), search for neighbor towers

     * if in neighbor ≥ **6** pads & at least 1 neighbor

   => shower defined

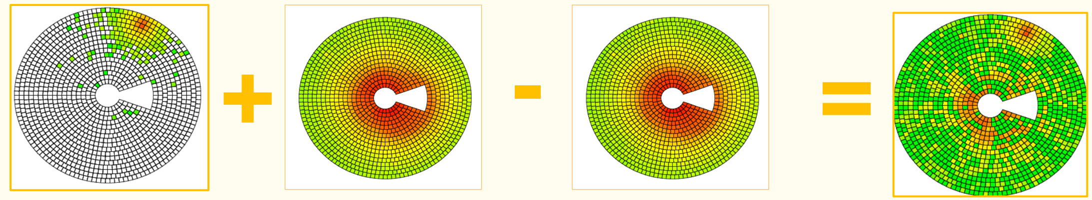
   * Candidate towers are considered to shower within Rm=1.2 cm or inside 8 neighbor towers

   => shower created
6. Next shower: repeat step 5
7. For each shower calculating

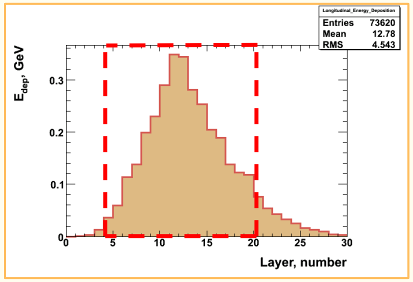
   - $R_{COG}$, $\varphi_{COG}$, $E_{sh}$

SH BG Average BG

1

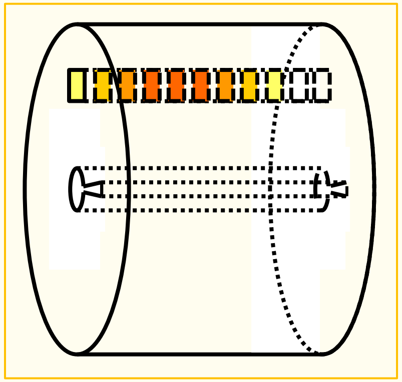


2



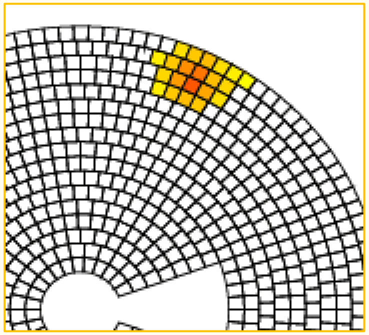

Tower

4



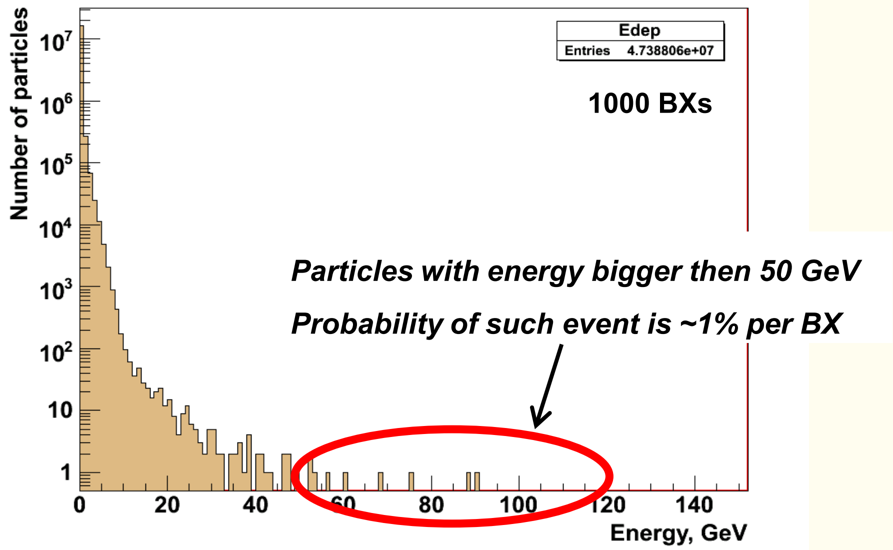
Reconstructed SH

5

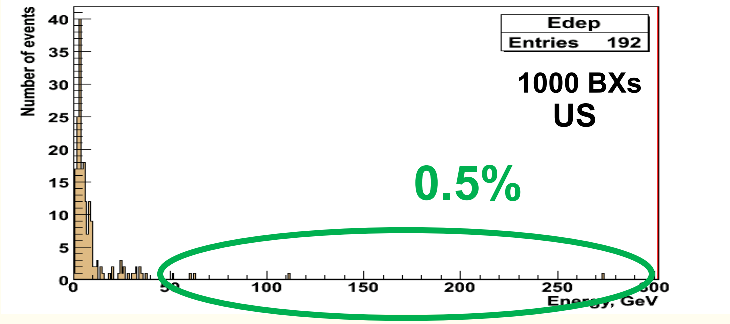


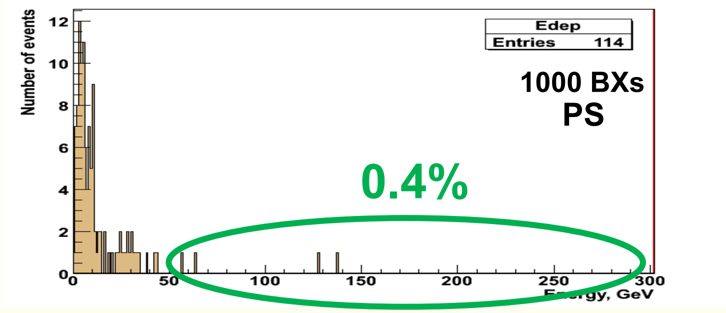
# Beamstrahlung (BS) Energy Distribution. Fake Rate

**Energy distribution of BS pairs that hit BeamCal**




**Energy distribution of reconstructed from pure background electrons**




⇒ *Some part of high energetic particles from Beamstrahlung, which hit BeamCal, can cause "fake showers"*

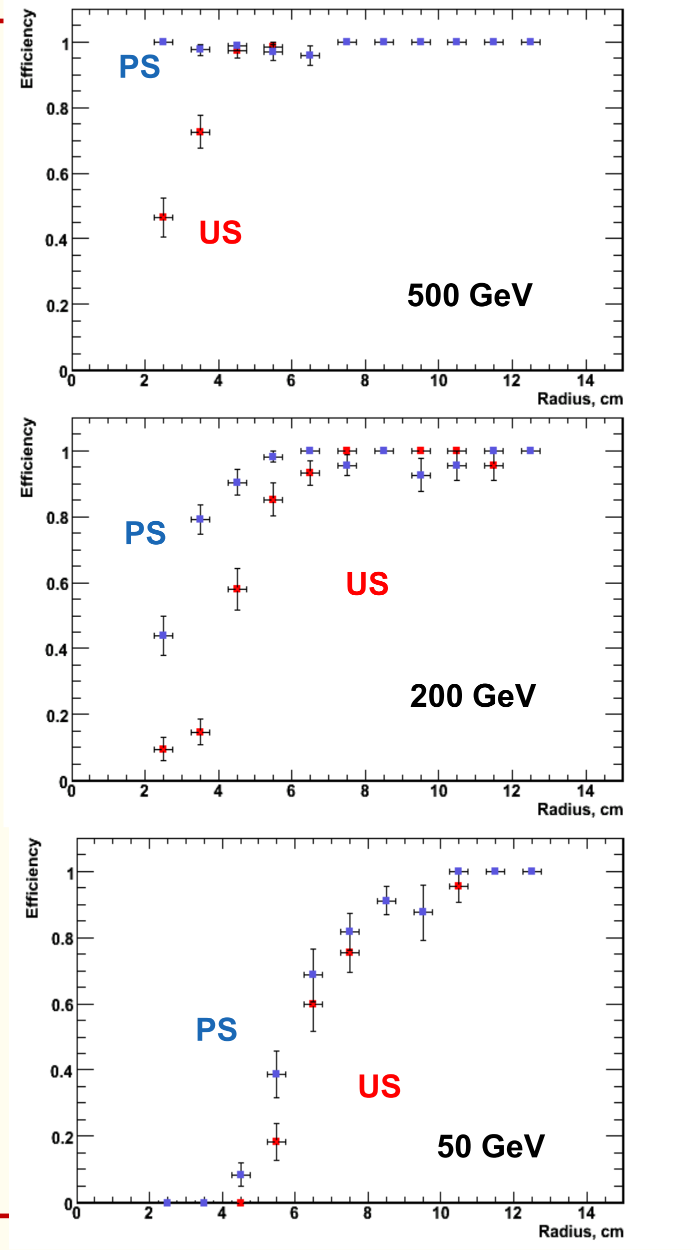
⇒ *Also fluctuations of background can be recognized as a shower by clustering algorithm.*

# Efficiency of shower reconstruction as a function of radius

Shower is considered as reconstructed correctly if:

- distance

$$| (X,Y)_{true} - (X,Y)_{reco} | \leq R_{moliere}$$

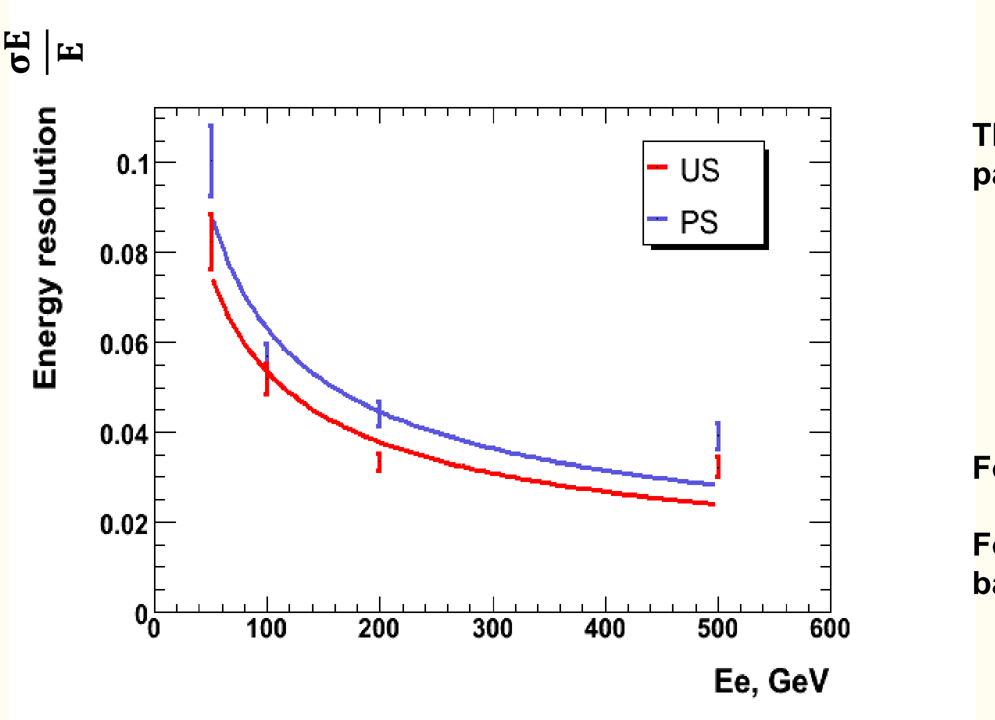



*Number events 500*

- 500 GeV electrons detected with 100% efficiency by PS even at high background area, while US detects efficient, but concede at radii smaller then 4 cm
- 200 GeV electrons can be efficiently detected only at radii larger then ~4 cm, while PS performs better efficiency
- 50 GeV electrons can be detected only at R ≥ 7cm

# Energy resolution vs Energy of Electron for low BG area

7<R<14 [cm]




The relative energy resolution can be parameterized as

$$\frac{\sigma E}{E} = \frac{A}{\sqrt{E}}$$

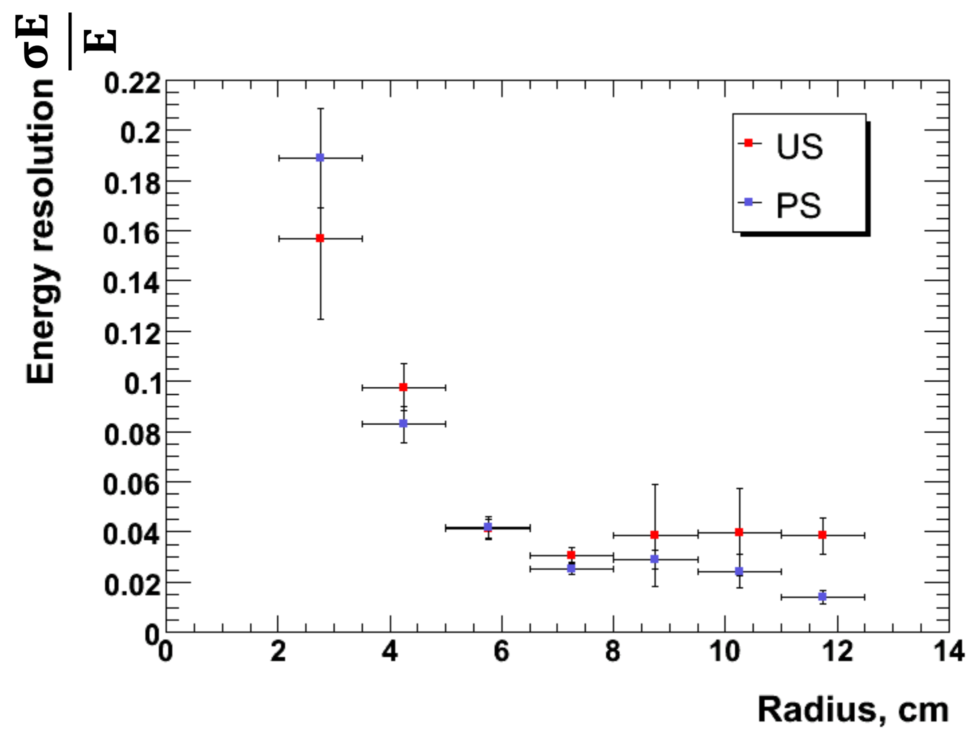
For the ideal case (without BG) A~0.2

For reconstructed showers on top of the background :

$$A_{US} \sim 0.5$$
$$A_{PS} \sim 0.6$$

The energy resolution for PS is worse on low BG area because pads are bigger there

# E resolution vs Radius




For showers from 500 GeV electrons

The large values of the energy resolution in the first 2 cm of calorimeter ( R<4cm) are caused by the high background energy density and the shower leakage

Within errors both segmentations give same resolution as function of radius for the 500 GeV electrons

# Spatial Resolution

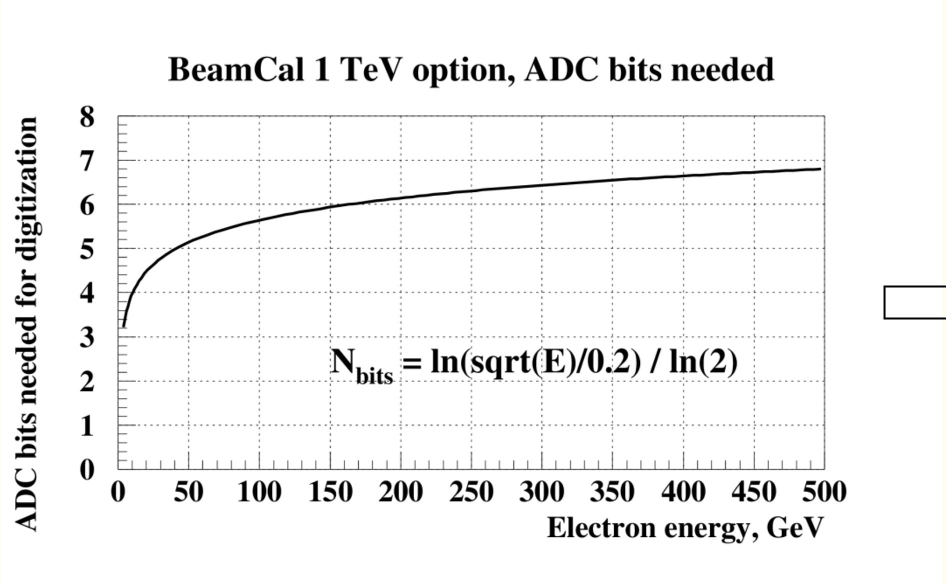
$\frac{\sigma R}{R}$

For showers from
500 GeV electrons

# ADC bits needed for shower energy measurement

- **Energy resolution of the sampling calorimeter:** $\frac{\sigma E}{E} = \frac{A}{\sqrt{E}}$
- **For the BeamCal for ideal case (no BG) A ~ 0.2:** $\frac{\sigma E}{E} = \frac{0.2}{\sqrt{E}}$
- **Ratio of the signal $E$ to the absolute error $\sigma E$ gives number of bits $N_{bits}$ that are necessary for charge measurement:** $\frac{E}{\sigma E} = 2^{N_{bits}}$

$$N_{bits} = \frac{\ln\frac{\sqrt{E}}{0.2}}{\ln 2}$$




- **7-bit number gives enough precision even at high energies**
- **Max $E_{dep}$ from BG similar to 500GeV electron $E_{dep}$ => need factor of 2 extension of the energy range => 8-bit**

# Charge Range Estimates

**GaAs sensors, 300 micron thickness:**

| | | Max collected charge per pad |
|---|---|---|
| MIP | | 4.3 fC |
| 500 GeV electron | | 20 pC |
| BG | PS | 20 pC |
| | US | 120(!) pC |

$$\frac{Q_{max}}{Q_{min}} = \frac{Q_{500GeV\ electron}}{Q_{MIP}} \sim 4500$$

=> 12-13 –bit ADC is needed

*Note: this inner area of calorimeter with US is useless!*

- **We want to calibrate sensors by MIPs during ILC operation**
- **Also MIPs can be used for estimation of degradation of sensors after irradiation**

**Electronics should be sufficiently precise for low signals**

Solutions

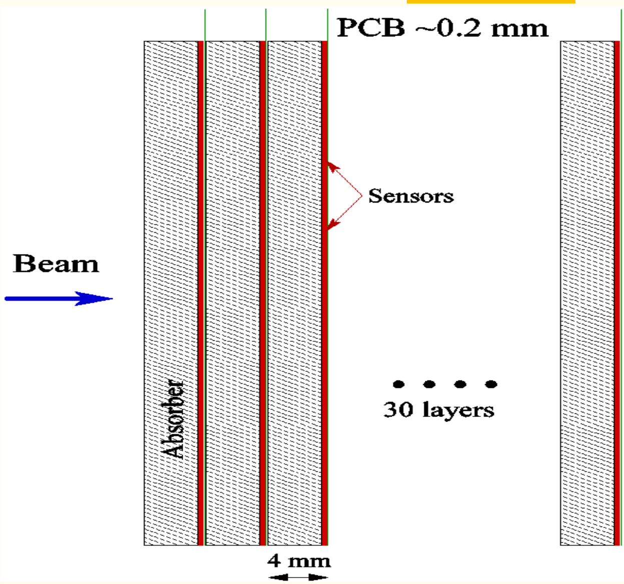
**2 channels from each pad: with low and high gain.**
**Reading either both together or only one channel chosen by threshold energy**

**to turn sensors along beam direction (see next slides)**

# Proposal of new BeamCal design based on sapphires

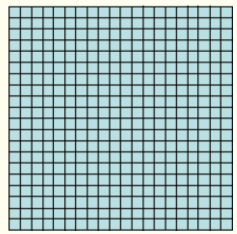
**2 designs of BeamCal model are considered:**

**baseline**



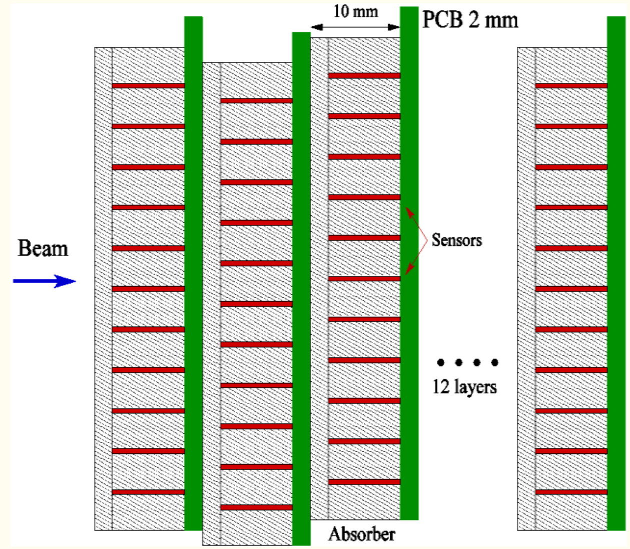

Transverse view:

15 x 15 cm



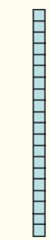
pads 7.5 x 7.5 mm

**new**




Sensor strip in depth:

7.5 x 15 cm



pads 7.5 x 7.5 mm

- **The main idea of the new design is to increase response of sensors to the MIPs, shifting calibration signal up in the “physical” working range, thus additional calibration mode is not needed anymore**
- **Total number of pads(readout channels) is 12000 for baseline design and 8880 for new one, while longitudinal and transverse sizes for both designs are kept the same**
- **Note: new design leaves much more space for electronics between layers ~10mm compare to 4mm at baseline design and fanout PCB could be made using standard multilayer technology**

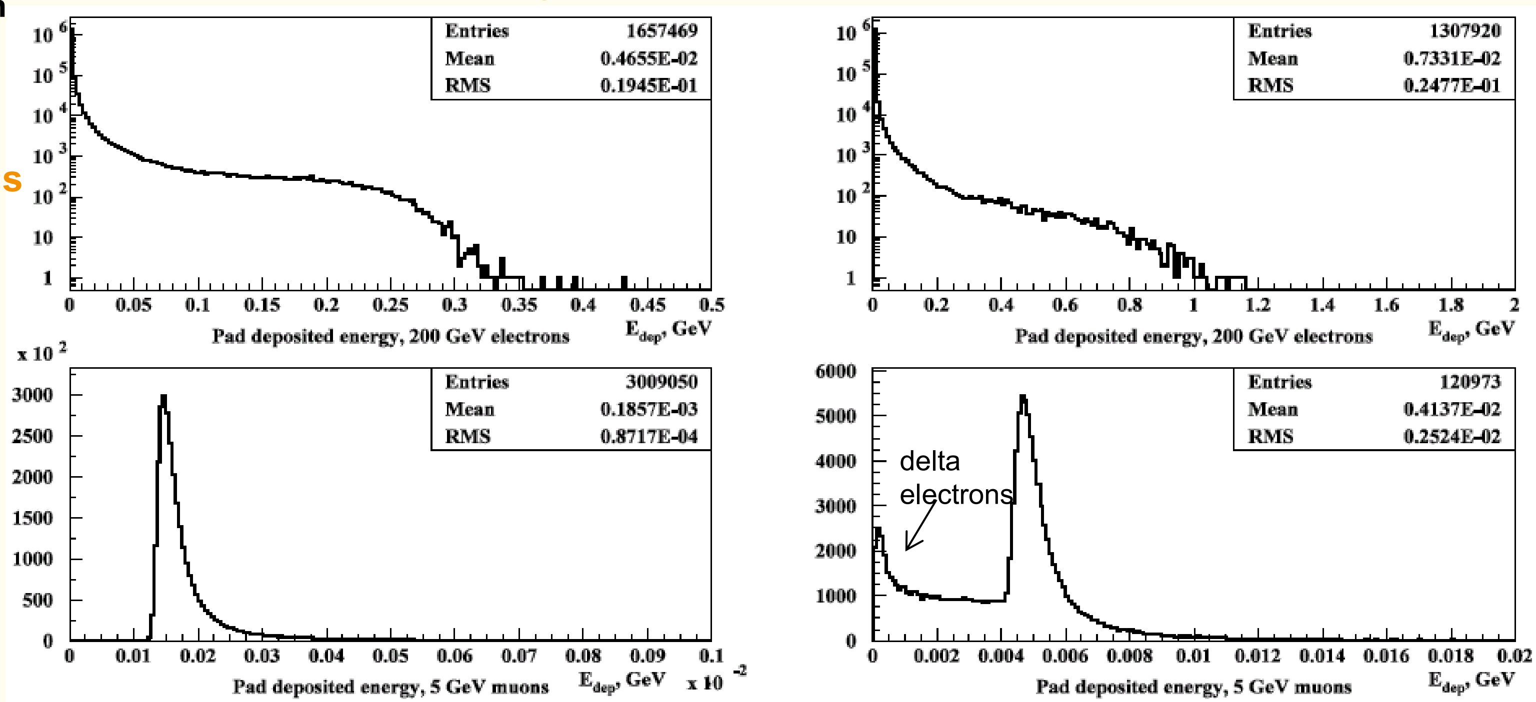
# Testing new design: energy deposition in pads

Distribution of pad energy deposition from:

**Baseline design** | **New sapphire design**

**200 GeV electrons**

**5 GeV muons (MIPs)**



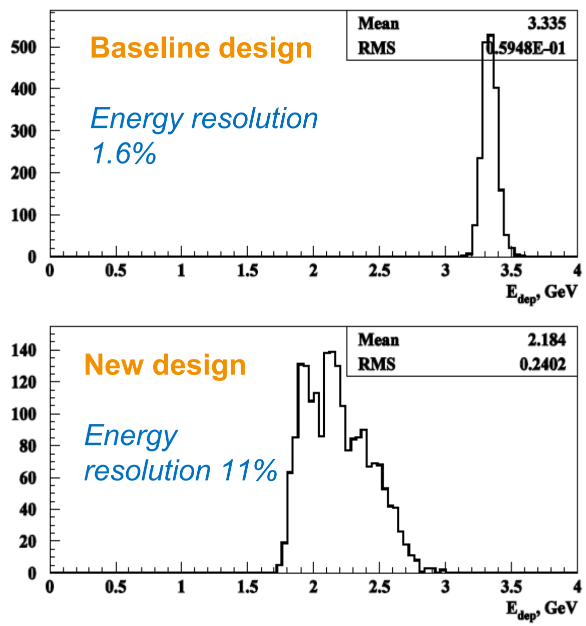

**2300** | **220**

*Dynamic range of the readout* $= \dfrac{\textit{end point of 200 GeV } e^{-} \textit{ spectra}}{\textit{MPV of MIPs peak}}$

- *Because of sensors orientation for new design for the calibration is 15 times more statistics is needed*
- *From the other side, for new design no special runs are needed*

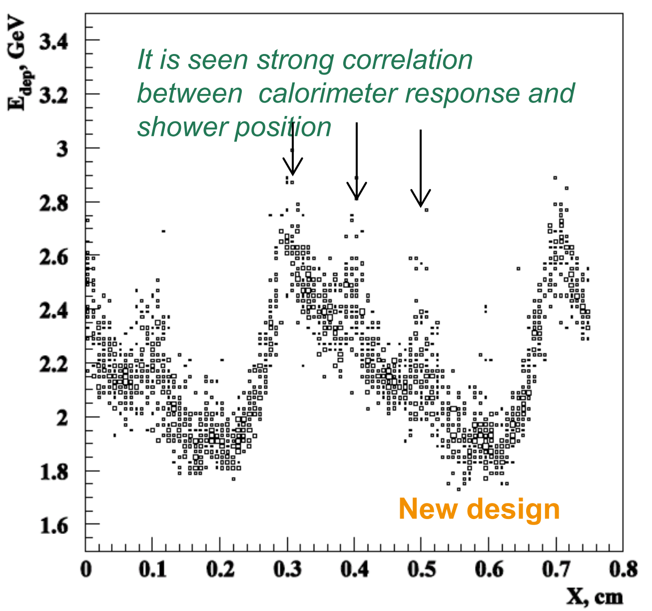
# Testing new design: energy and spatial resolution

Distribution of total sensors energy deposition for 200 GeV electrons:




*Poor energy resolution for new design is caused by highly non-uniform sensors distribution in the transverse direction*

Sensor energy deposition sum for 200 GeV electrones as a function of trnansverse coordinate X, which is perpendicular to sensor strips:




- ***Further optimization should include hardware compensation of non-uniformity (optimization of layers displasment) and software correction of the measured energy, based on the shower position determination.***
- ***Spatial resolution of the new design is expected to be similar to the baseline one along the strips, and could be higher in perpendicular strips direction(higher sampling frequency)***

# Conclusion

- Performance of BeamCal for two different sensor segmentations was compared
  - Number of readout channels is kept similar
  - Signal from sHEe nearly independent of the segmentation
  - Energy deposition per pad from Beamstrahlung differs significantly
  - Proportional segmentation improves the signal-to-noise ratio
  - Proportional segmentation gives better reconstruction efficiency
- The charge range has been estimated
  - Collected charge per pad from sHEe nearly independent of the segmentation
  - Collected charge per pad from BS for US in 6 times more than for PS
- Energy deposition was investigated
  - Dependence between energy of electron and deposited in calorimeter energy is good linear

    Coefficient of linearity 59.
  - Dependence energy resolution vs energy of electron is calculated and parameterized.

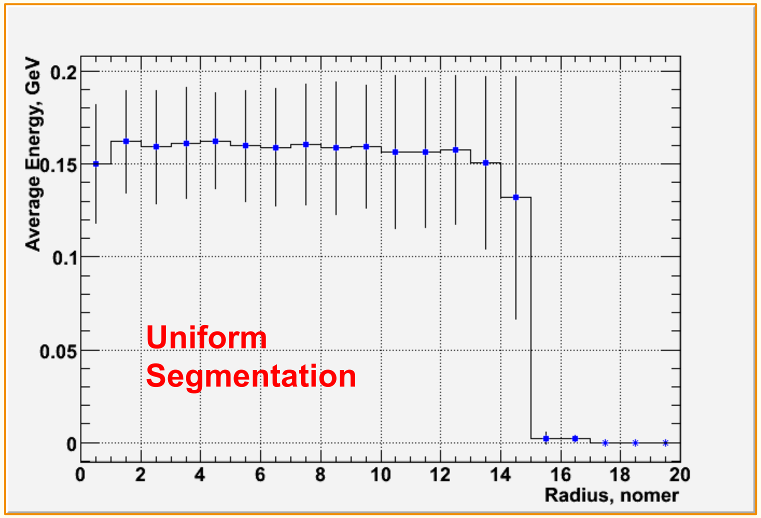
    Calorimeter gives good energy resolution: 3% ( for 50GeV HEe); 1,1% (500GeV)

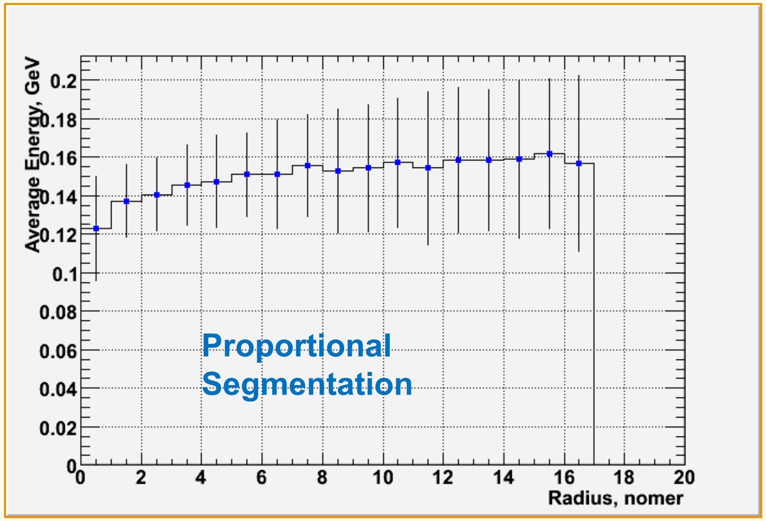
**Thank you for your attention!**

# Backup slides

# Signal and RMS for both Segmentations

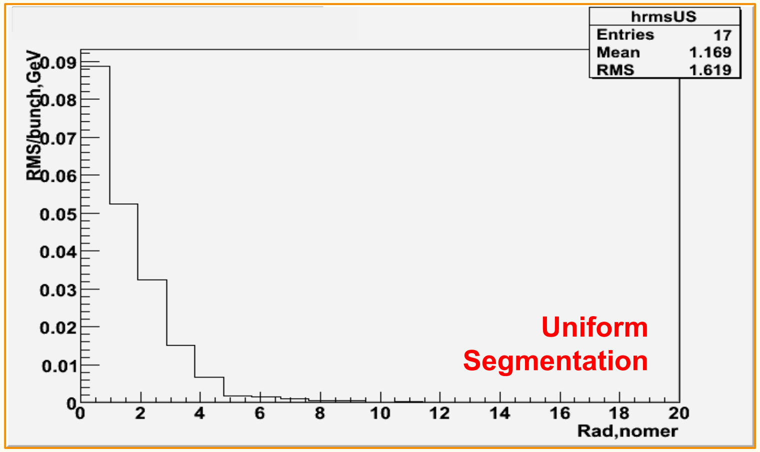
## Core signal in layer of shower maximum (10th layer for 100 GeV)

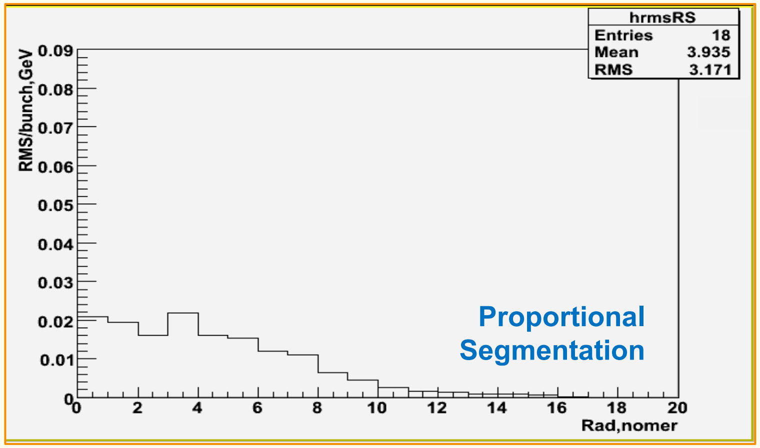



**Signal nearly segmentation-independent!**

## RMS from Background (in 10th layer)



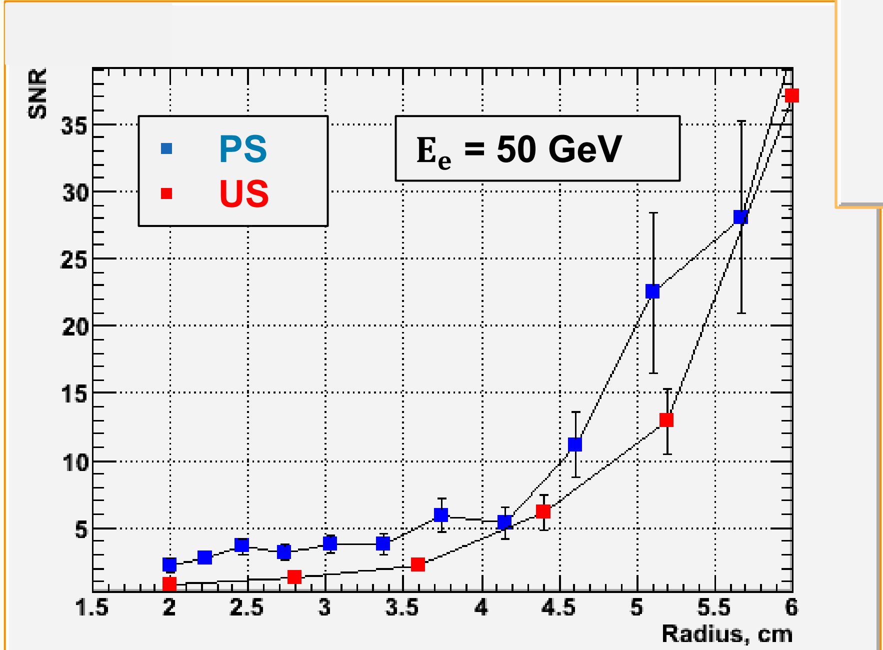

**Different distributions!**

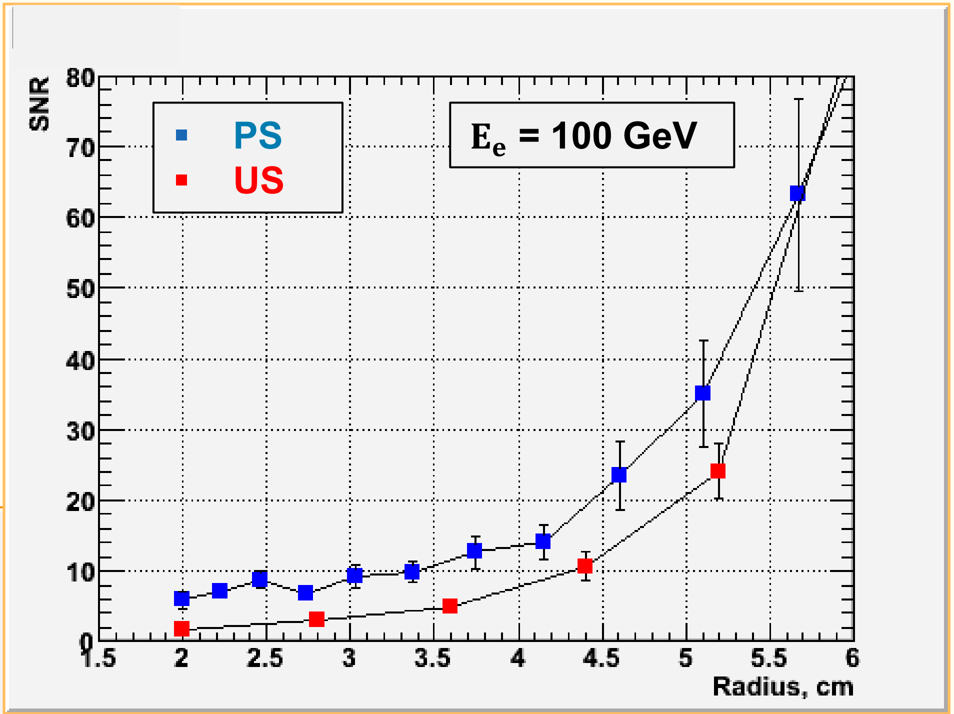
20 bunch crossings were given

# SNR in cell with maximum E_dep

- <u>Signal</u> – is maximum energy deposition in cell from sHEe *( in the core of shower and in the maximum energy deposition layer)*

- <u>Noise</u> – is RMS of the averaged BG

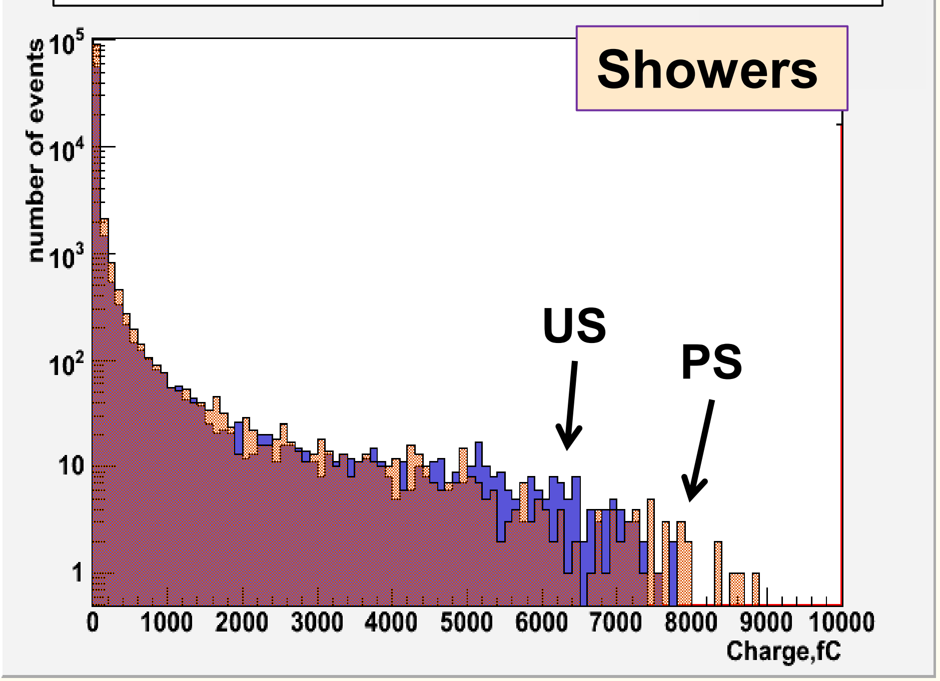


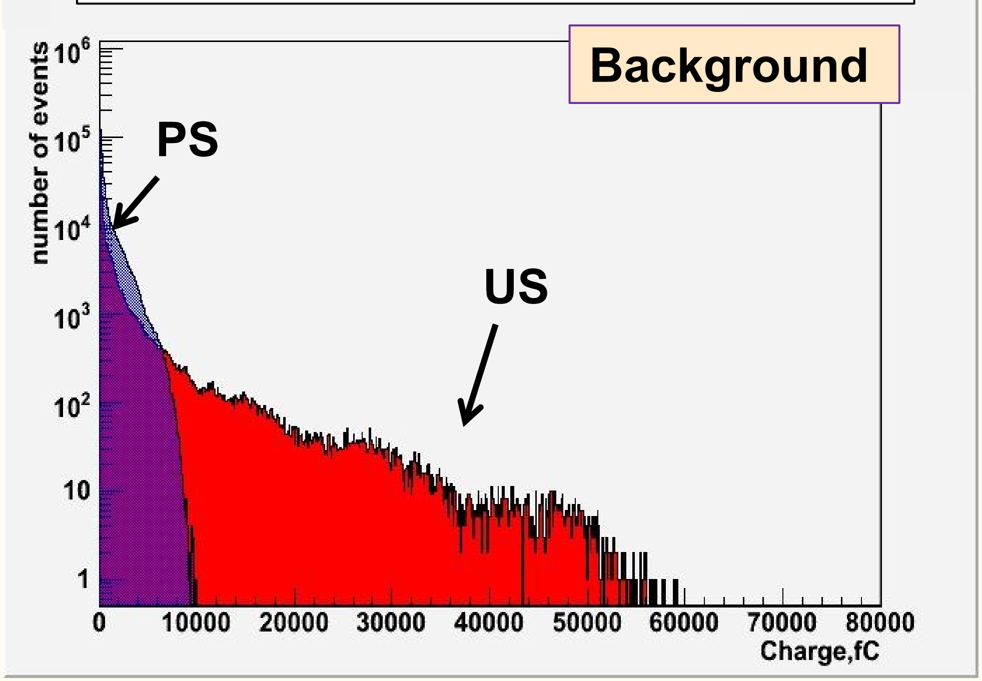

$$\text{SNR} = \frac{\text{signal from HE electron}}{\text{RMS from background}}$$

# Charge Range Estimate

Distribution of the collected charge per pad from 500Gev electron showers for Diamond




Distribution of the collected charge per pad from Background for Diamond



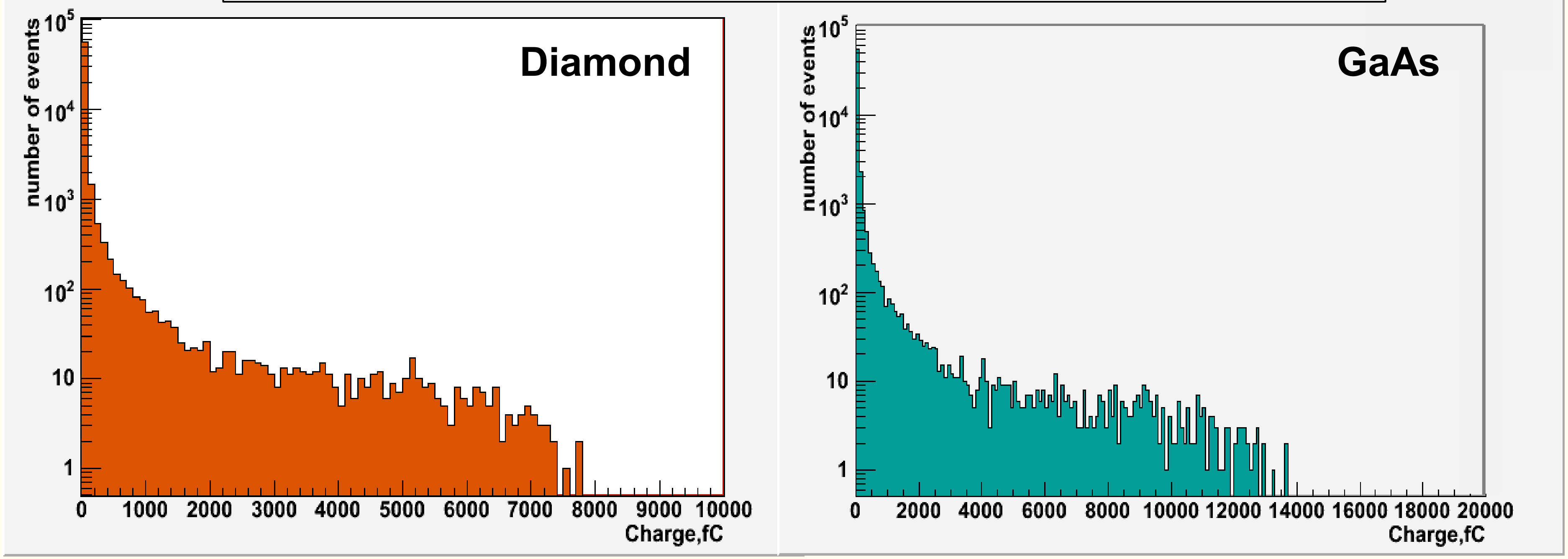

**For Diamond sensor pad thickness 300 µm:**

- **Charge collected from MIP: 2.44 fC**
- **Maximum charge collected – for shower from 500 GeV electron: 12214 fC**

**(correspond to about 5000 MIPs)**

# Charge range estimate

Distribution of the collected charge per pad for 500Gev electron showers

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