New transition radiation detection technique based on DEPFET silicon pixel matrices

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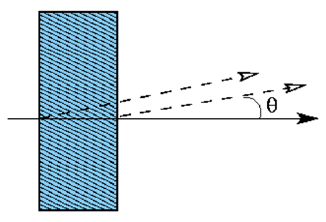
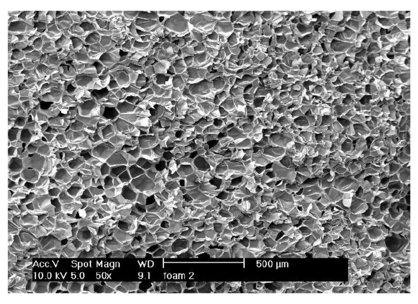
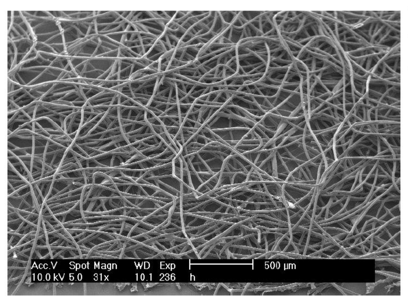
Transition Radiation



- Transition radiation is produced by charged particles when they cross the interface between two media with different dielectric constants.

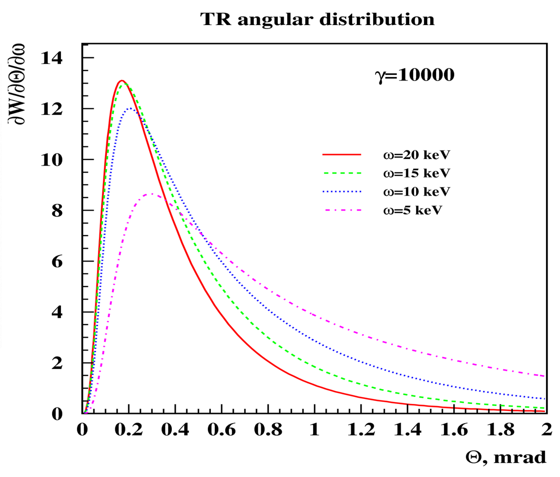
- The probability to emit one photon per boundary is order of α~1/137
- Therefore multilayer dielectric radiators are used to increase the transition radiation yield, typically few hundreds of mylar foils.
- Other materials for radiators are polyethylene foam and fibers (fleece):

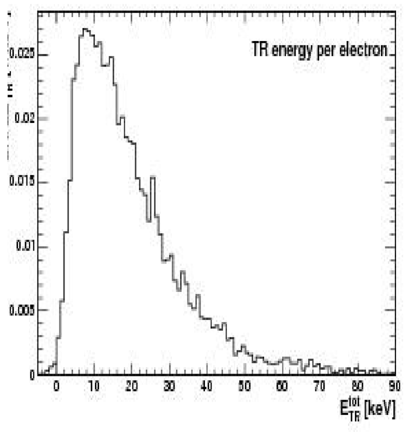
Photos from ALICE TRD Technical Design Report CERN /LHCC 2001-021

Transition Radiation for relativistic particles

- Energies of TR photons are in X-ray region (2-40keV).
- TR in X-ray region is extremely forward peaked within an angle of 1/γ.
- Total TR Energy E_{TR} is proportional to the γ factor of the charged particle.

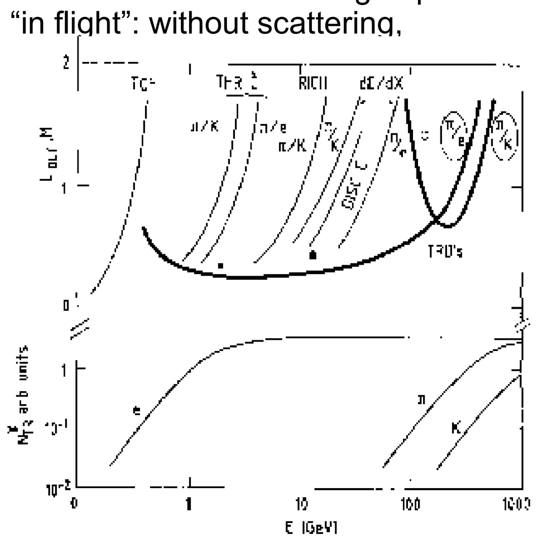


Energy distribution of TR photons



Why we are interested in a measurement of the TR?

- Transition Radiation Detectors (TRD) have the attractive features of being able to separate particles by their gamma factor.
- e/π separation in high γ region, where other methods are not working anymore.
- Identification of the charged particle "in flight": without scattering.

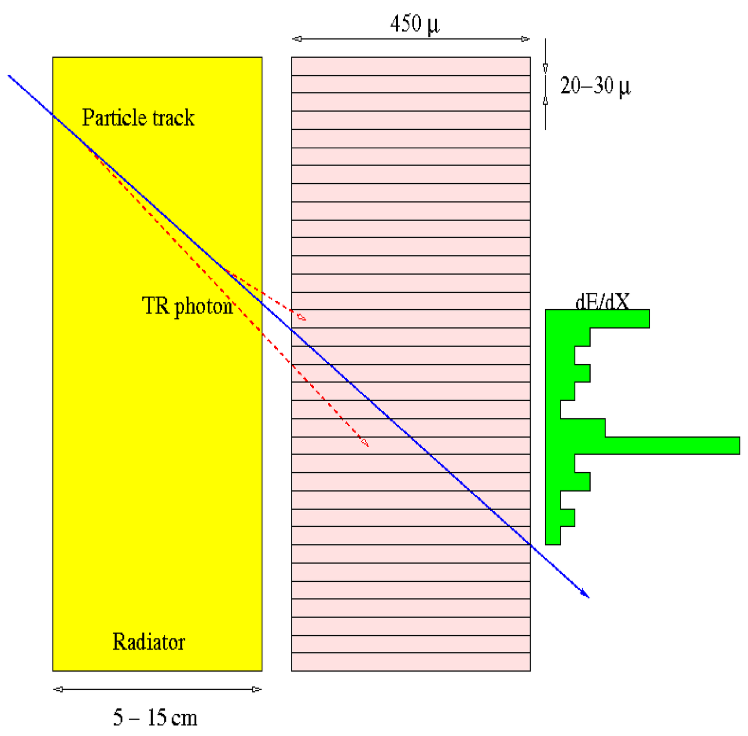


Existing methods of the transition radiation detection

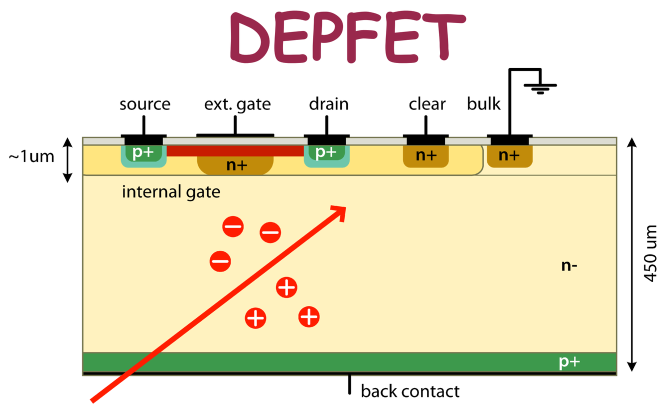
- The basic problem in detection of transition radiation photons (TR) is the discrimination of TR from dE/dX energy loss of charged particles.
- The classical TRD is based on gaseous detectors filled with xenon gas mixture to efficiently absorb transition radiation photons, with energy 5-30 keV over a background of dE/dX with energy about 2-3 keV.
- Replacing the xenon based gaseous detectors with modern silicon detectors is complicated by the huge dE/dX of particles in 300-700μm of silicon - about 100-300keV.
- Another approach to detect TR is to separate dE/dX of particle and TR in magnetic field. In this case, in silicon detectors TR photons and dE/dX are registered in different strips or pixels.(see proposal for ILC/TESLA detector LC-DET-2000-038)
- This method requires a large and heavy magnet and additionally is limited by particle momentum: the magnetic field should be able to move a particle from TR by at least one pixel of a silicon detector.

New transition radiation detection technique

- By turning the silicon detector at 30-40° the full path of the particle in one pixel is about 30 μm and therefore dE/dX on a pixel is a factor 10 less (~10 keV)
- In addition 10-30 points of dE/dx measurement on the particle track. TR photons are absorbed in the first 2-7 bins (pixels) along the track.
- This fact of additional ionization from TR photons in the first pixels could be used for particle identification (separation).



DEPFET



The Depleted P-Channel Field Effect Transistor (DEPFET):

- a **p-FET** transistor is integrated in every pixel
- **fully depleted** sensitive volume (high negative backplane voltage)
- electrons are collected by drift in the „internal gate" and **modulate the transistor current**
- Signal charge is removed from "internal gate" via a clear process

http://www.depfet.org

Test beam at CERN and DESY

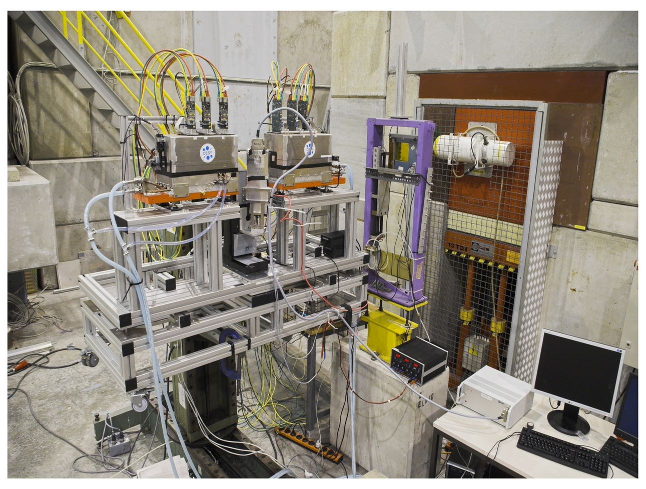
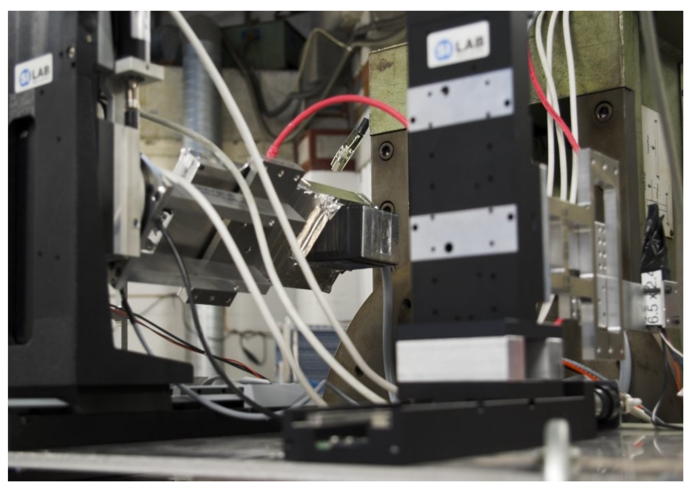
CERN Setup

- Beam: electrons (80-100 GeV), pions (40-120GeV)
- Sensor: DEPFET with a pitch 24x24μm² and thickness 450μm, rotated at 26° and 41° (EUDET telescope as an external tracker).
- Radiator: fibers (fleece) length of 5 cm, are placed in front of the sensor

DESY Setup

- Beam: pure electrons 5 GeV,γ~10⁴
- Sensor: DEPFET with a pitch size 20x20μm² and thickness 450μm, rotated at 26° and 41°.
- Radiator: fibers (fleece) length of 10,15 cm, are placed in front of the sensor

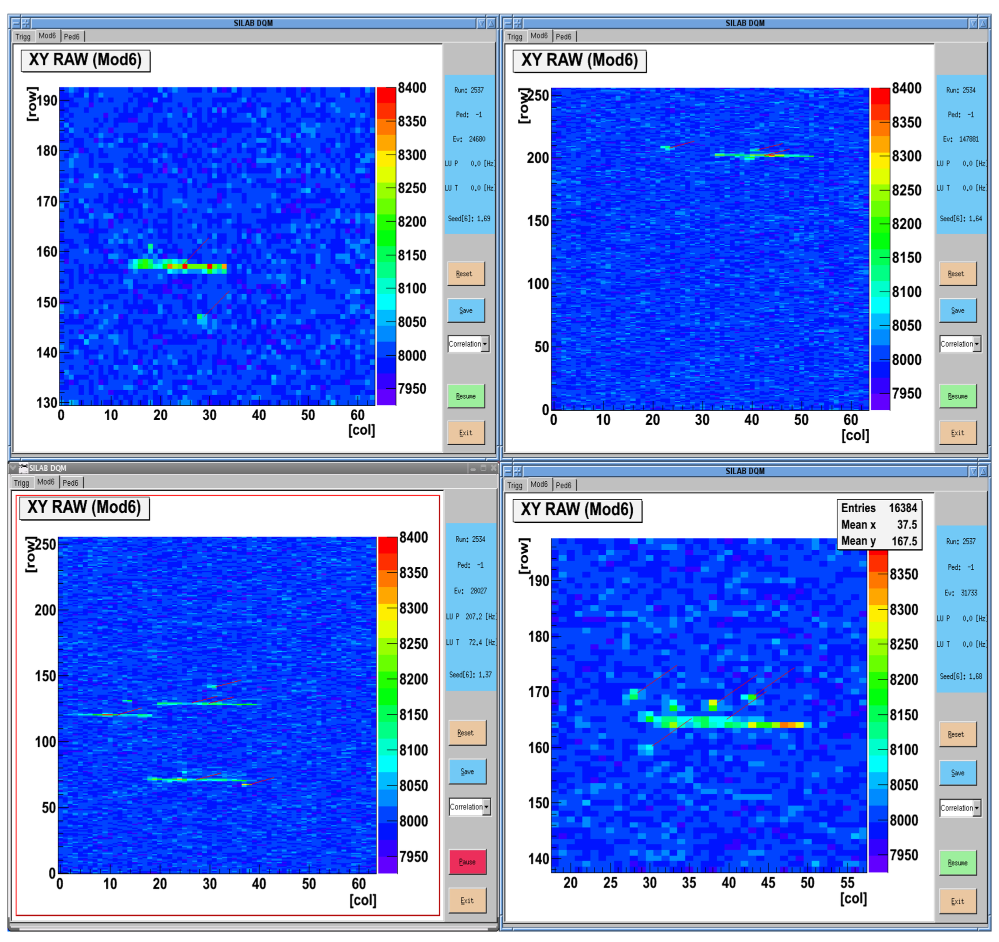
Problem: unknown percentage of electrons in the beam

Test beam results

Event display

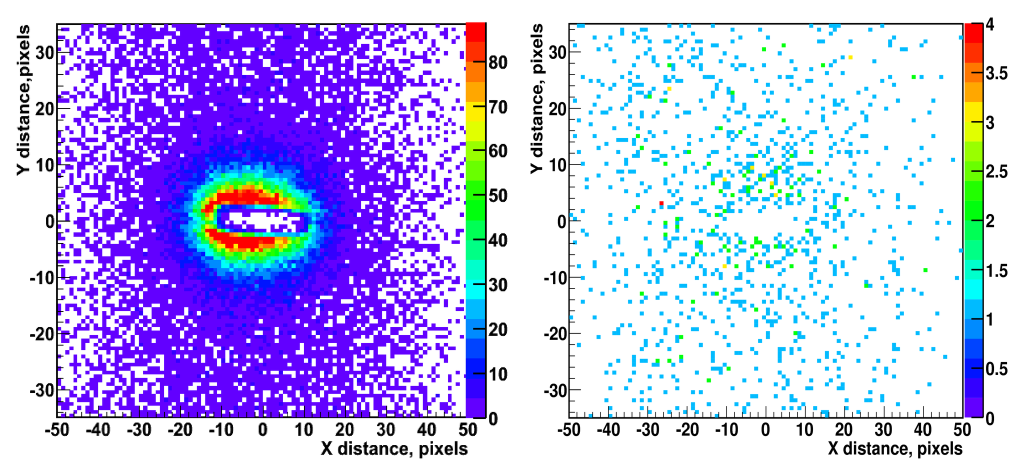
- A matrix with a pitch 20x20 μm², module rotated at the angle of 41°, the length of a cluster from a beam particle is about 20 pixels.
- TR photons are clearly visible and separated from track by few pixels.
- A red line shows a cluster founded by software



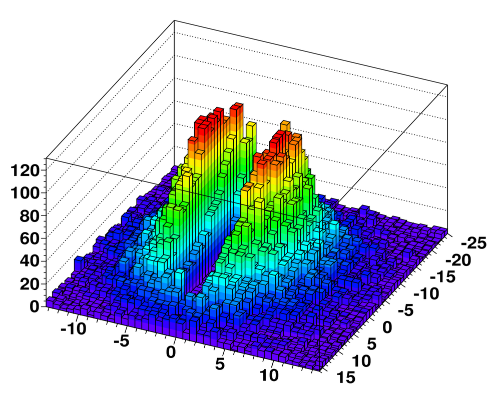
Transition radiation angular distribution

- As could be seen from plots TR photons are extremely forward.
- In the runs taken without radiator photons were not observed

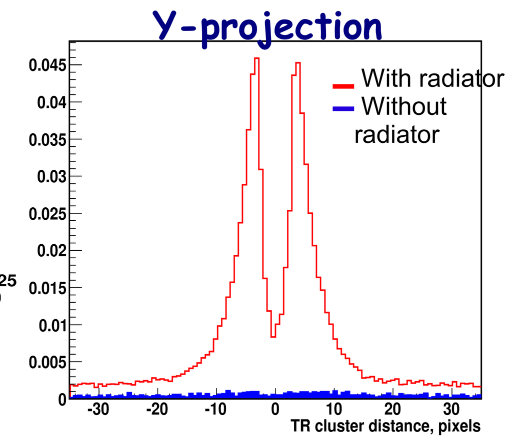
With radiator | Without radiator



With radiator 3D-view



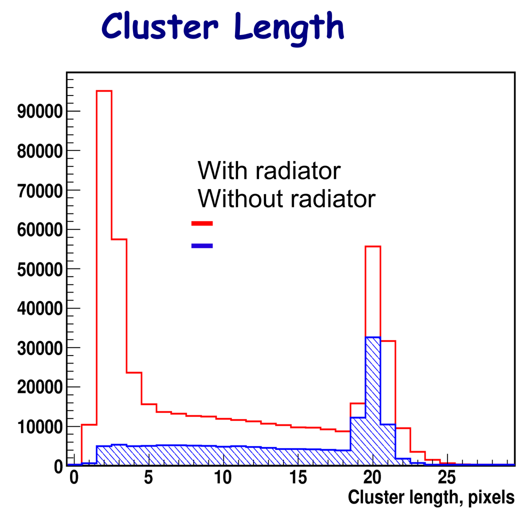
Y-projection



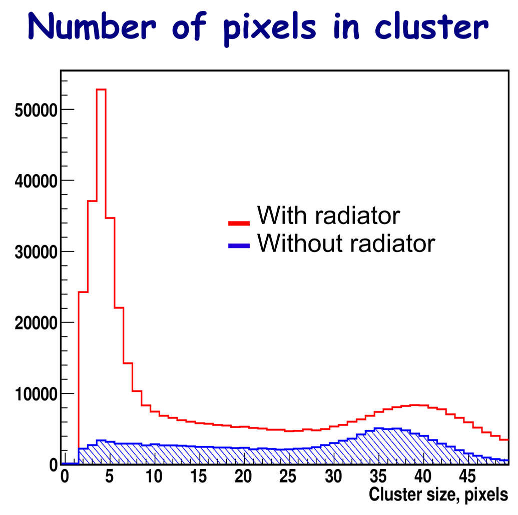
Cluster size

- Clusters were evaluated by 4 parameters: cluster length, cluster width, number of pixels in the cluster, cluster energy
- Runs with radiator have an additional contribution of the TR clusters in a small (3x3) cluster size region.

Cluster Length



Number of pixels in cluster

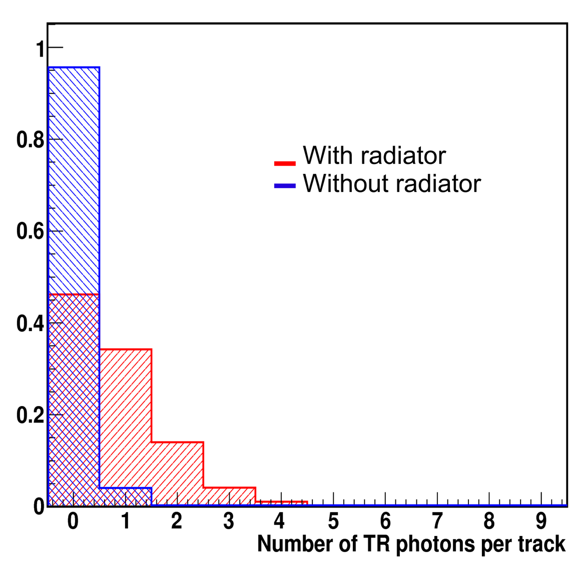


TR clusters efficiency

The probability to find TR photon near the track is 53% with radiator and 5% without radiator.

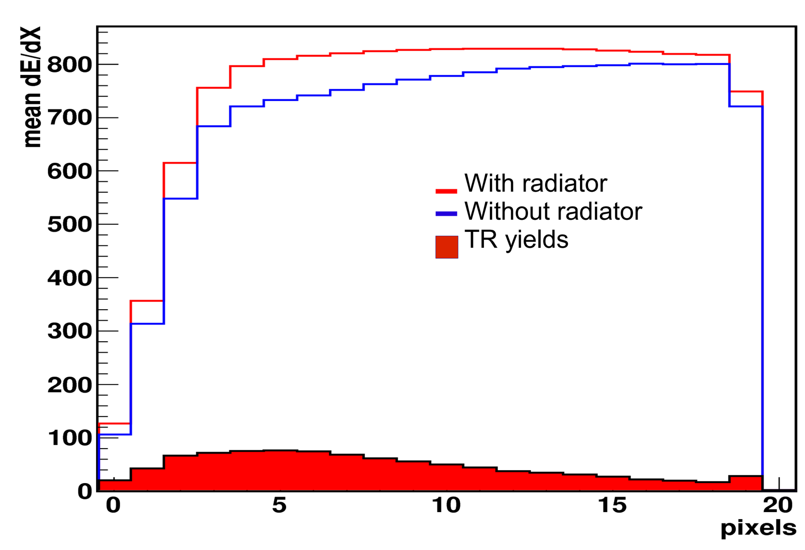
The inefficiency includes :

- Inefficiency of the cluster search algorithm
- Overlapping of the TR clusters with a cluster from track
- TR clusters are too far from track
- The energy of the TR photons are too high and they were not stopped in the silicon
- No TR photon for this track



dE/dX vs cluster length

The average dE/dX value for each of 20 pixels (20x20μm² pitch at the angle of 41°): red line – with radiator, blue line– without radiator, red filled area are the energy of the TR photons.
dE/dX along track without radiator non uniform for each bin.

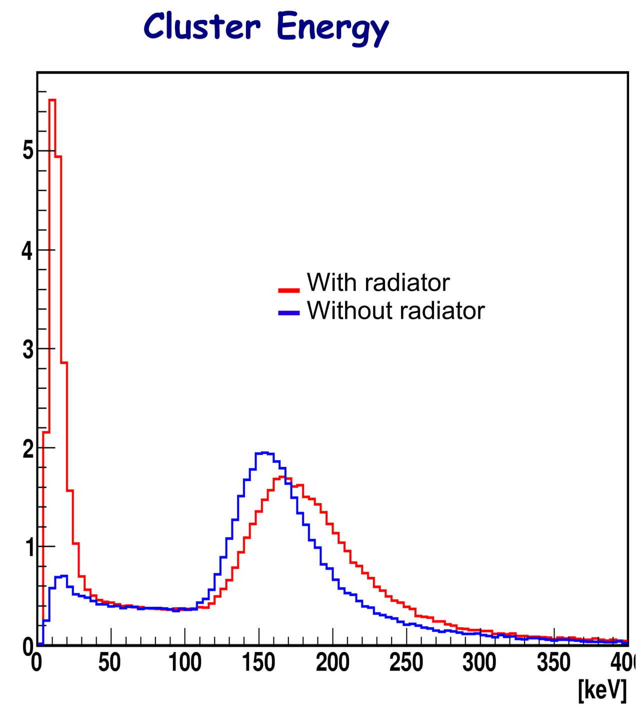


Transition radiation absorbed spectrum

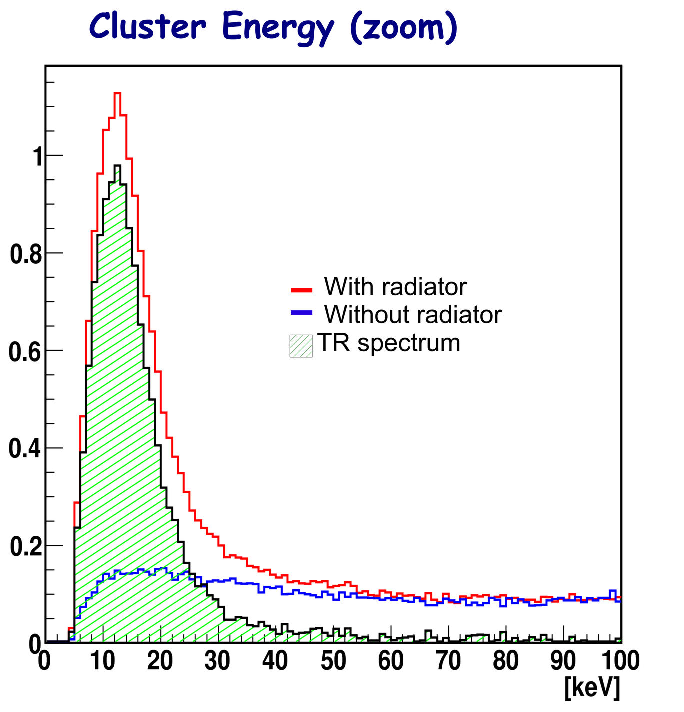
On the two pictures below are shown cluster energy distribution for 2 cases – with radiator and without radiator

- In case with radiator a lot of low energy clusters has been found, coming from transition radiation photons.
- On the right picture are shown zoomed area
- The green histogram represents absorbed transition radiation spectrum.

Cluster Energy



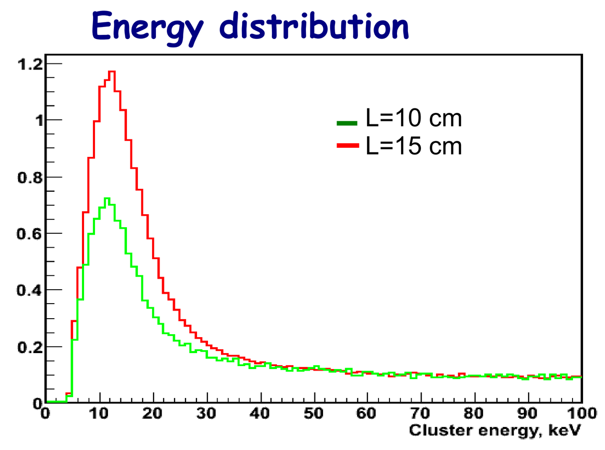
Cluster Energy (zoom)



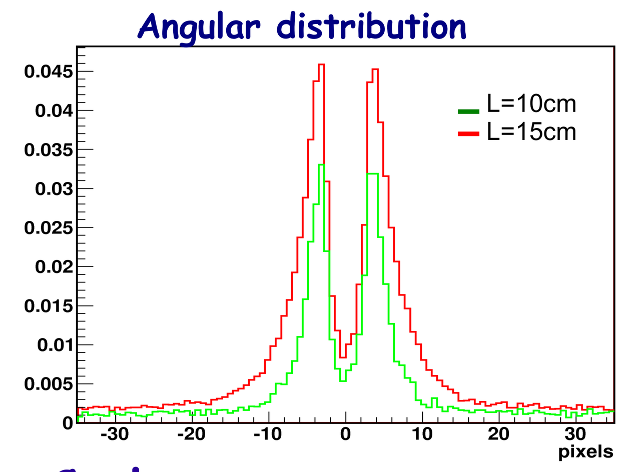
TR yields vs different radiator length

- The number of TR photons increased with radiator length.
- Pictures show TR yield for 2 radiator length 10 cm and 15 cm.
- The efficiency could be improved by just adding more radiator in front of detector

Energy distribution



Angular distribution



Monte Carlo

- Monte Carlo simulation is based on GEANT 3 (ATLSIM):
  ATLSIM originally has been developed for simulation of the ATLAS detector
- For dE/dX simulation a PAI (photoabsorption ionization) model has been used.
- For generation and absorption of the Transition Radiation a custom software,developed for the ATLAS TRT simulation, has been used.