DEPFET as a Transition Radiation Detector

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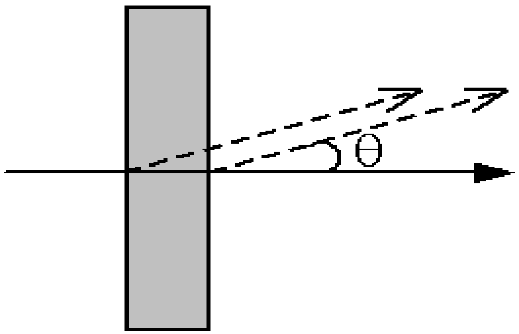
Outline

Introduction to TR
New technique for TR detection
Test Beam at CERN
Test Beam at DESY
Monte Carlo

Short history of the Transition Radiation

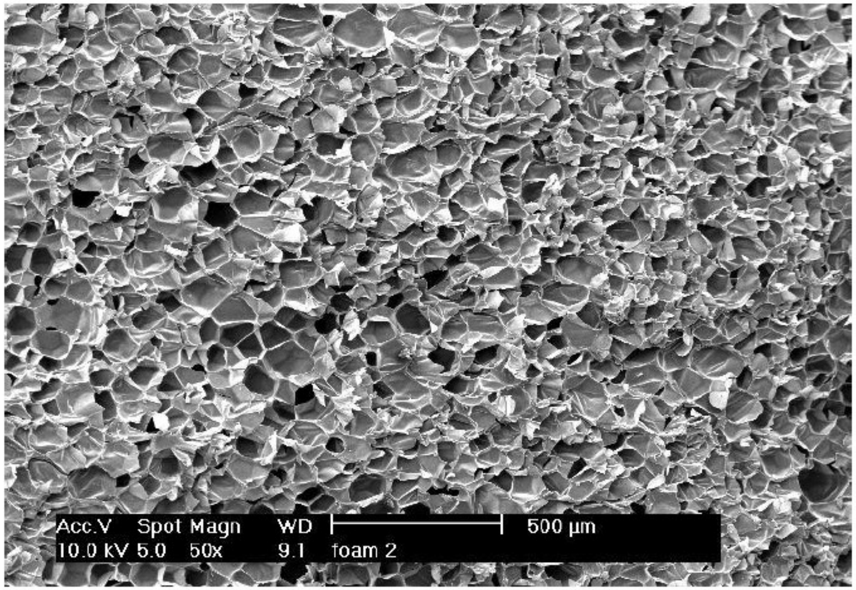
- *Transition radiation is produced by a charged particles when they cross the interface of two media of different dielectric constants.*



- *V.I.Ginzburg and I.M.Frank predicted existence of transition radiation in 1946.*
- *TR in optical region was observed in 1959 by Goldsmith and Jelly.*
- *TR in X-ray region for relativistic particles is shown by G.M.Garibian in 1958.*
- *X-ray TR observation and investigation by A.I.Alikhanian in 1961-1970.*
- *Here we will discuss only relativistic particles and X-ray Transition Radiation.*

Radiator

- *Due to electrodynamic nature of TR the probability to emit one photon per boundary is order of $\alpha \sim 1/137$*
- *Therefore a multilayer dielectric radiators are used to increase the transition radiation yield, typically few hundreds of mylar foils.*
- *Another possible materials for radiators are polyethylene foam and fibers (fleece)*
- *The latter one was used for tests*



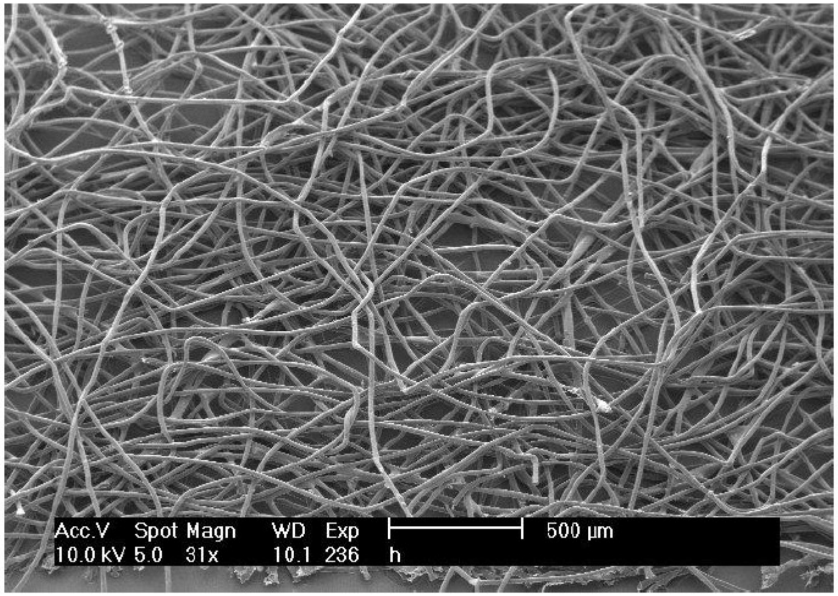
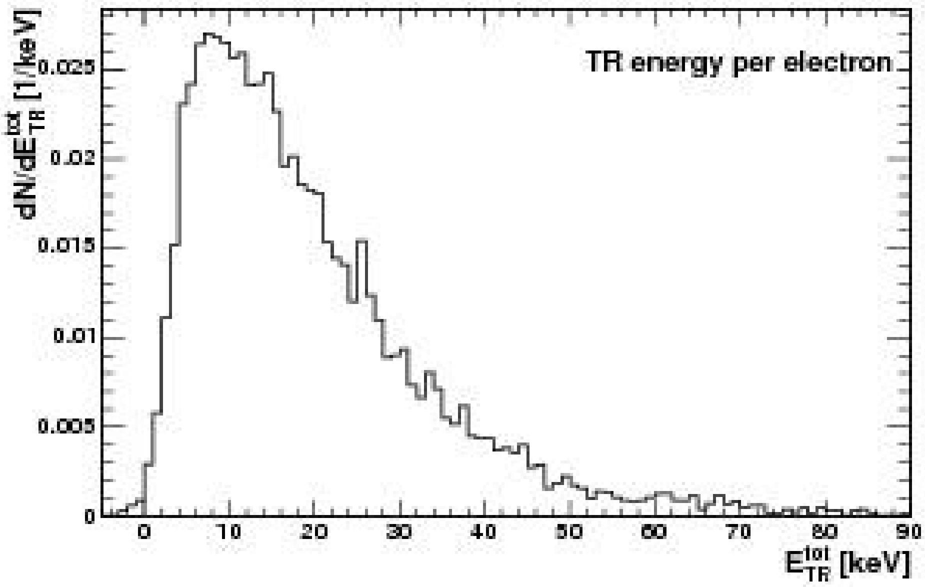
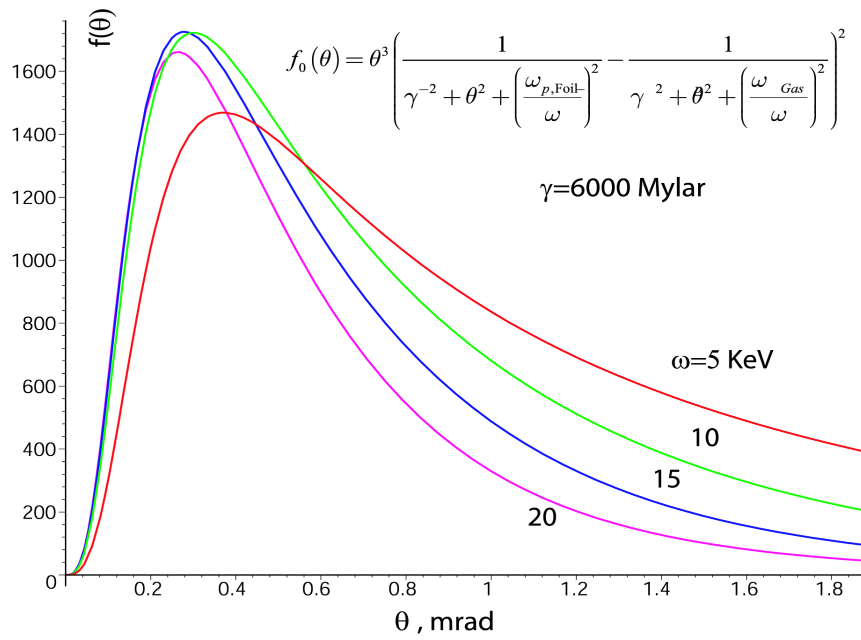


Photo from TDR of ALICE TRD

Transition Radiation for relativistic particles

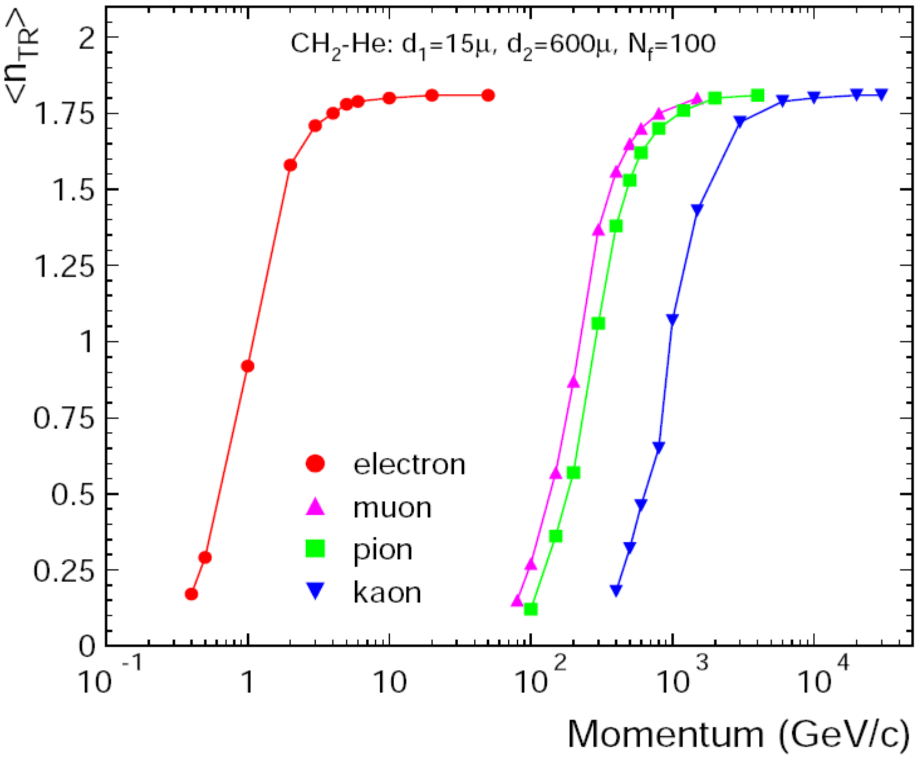
- *Energy of TR photons are in X-ray region (2-40keV)*
- *X-ray TR has remarkable features:*
  - TR in X-ray region is extremely forward peaked within an angle of $1/\gamma$
  - Total TR Energy E_{TR} is proportional to the γ factor of the charged particle

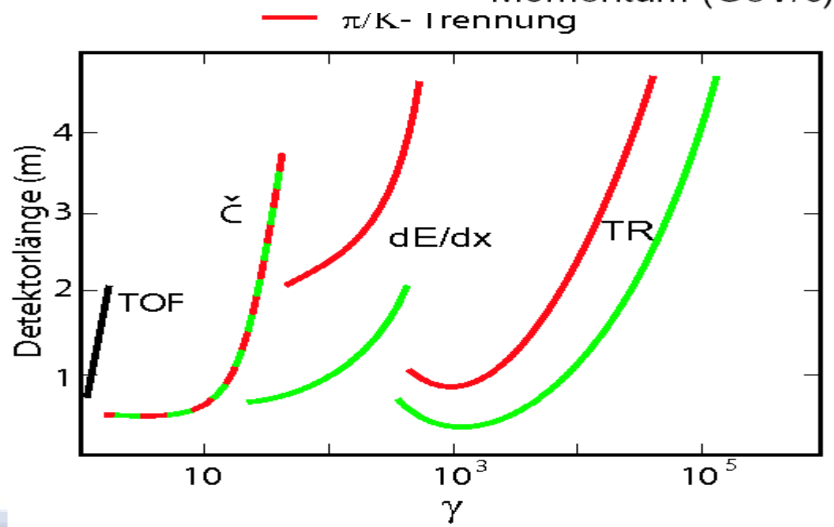




Why we are interested in measuring TR ?

- *Transition Radiation Detectors (TRD) has 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 "on the flight": without scattering, deceleration or absorption.*
- *Application of TRD in collider experiments:*
  - ZEUS, H1, HERMES at HERA (DESY), D0, PHENIX, ATLAS, ALICE...
- *TRD in space missions – AMS, PAMELA.*



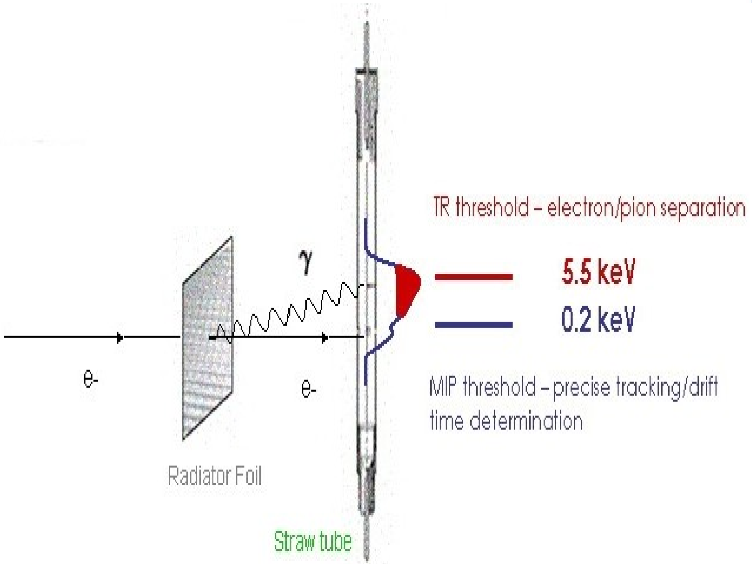


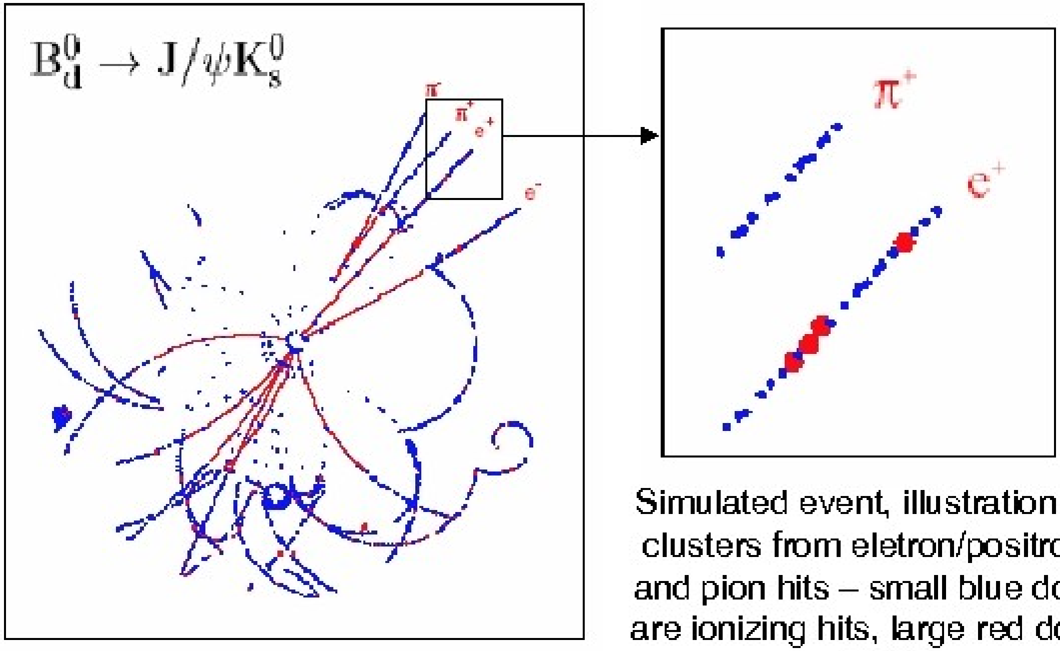
Detection of Transition Radiation

- *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.*
  - 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.

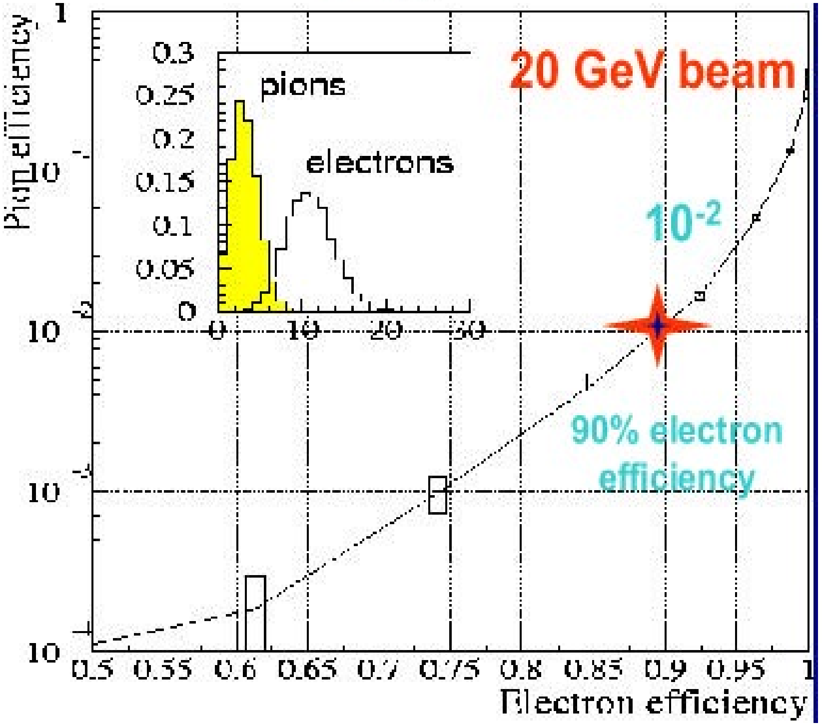
Transition Radiation Detectors

- *Typically in high energy physics TRD are used for electron identification and to reject hadron background.*
- *ATLAS TRT uses proportional gas chambers (straws) filled with Xe gas mixture:*
  - dE/dx +TR, Cluster discrimination by threshold method.



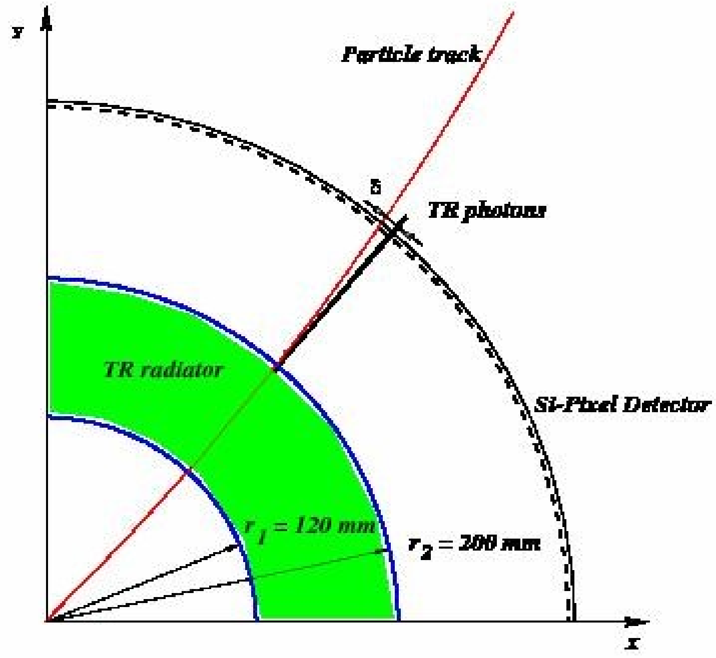


Simulated event, illustration of clusters from eletron/positron and pion hits – small blue dots are ionizing hits, large red dots are TR hits



Silicon Transition Radiation Detectors

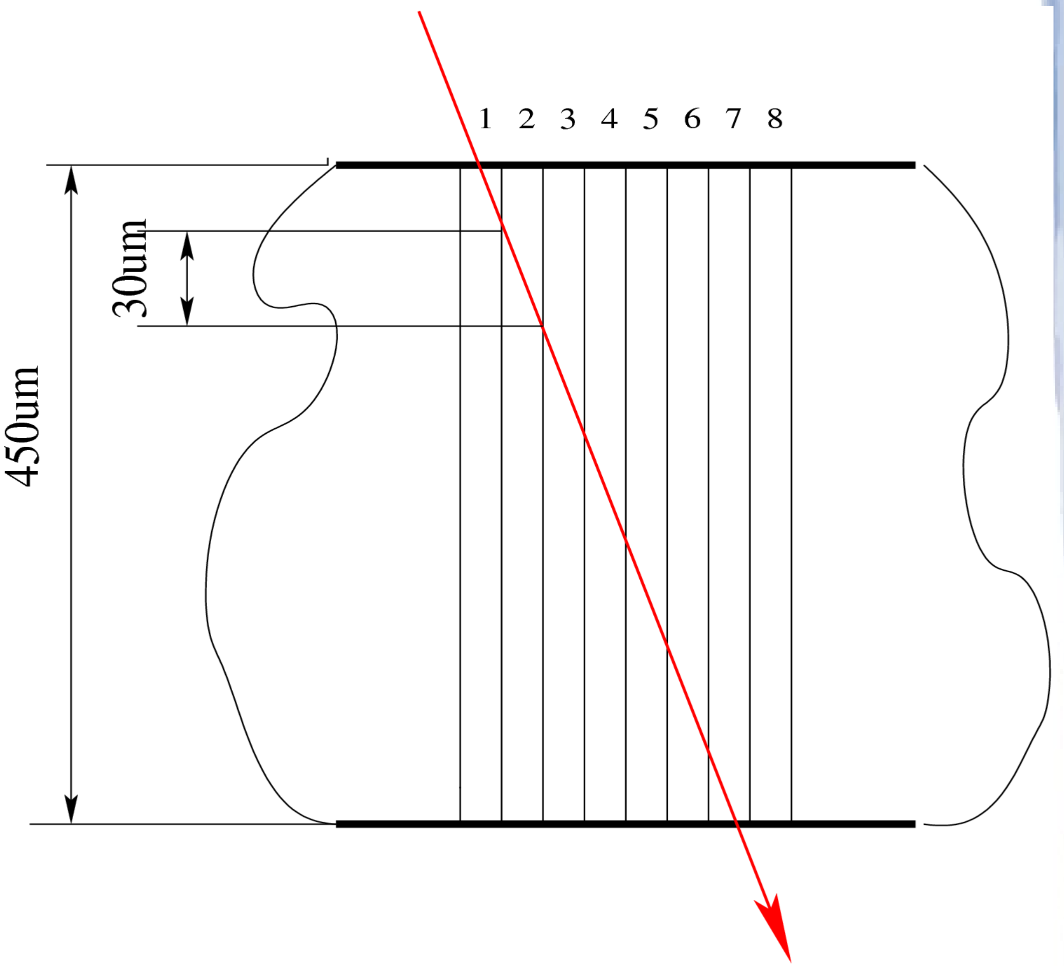
- *In 2000 was proposed design of TRD based on silicon, with separation of particle and TR in space by magnetic field. (see proposal for ILC/TESLA detector LC-DET-2000-038)*
- *Due to a number of limitation this method up to now is tested only in test beams.*



- *DEPFET has features which allows to use another detection technique to overcome the existing limitation on detecting TR photons with particles in the same pixel.*

A new Transition Radiation detection technique

- *by turning the Silicon detector at 30-50° the full path of the particle in one pixel is about 30 µm and therefore dE/dX is a factor 10 less (~10 keV) and compatible with transition radiation energy.*
- *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 addition ionization from TR photons in the first pixels could be used for particle identification (separation).*



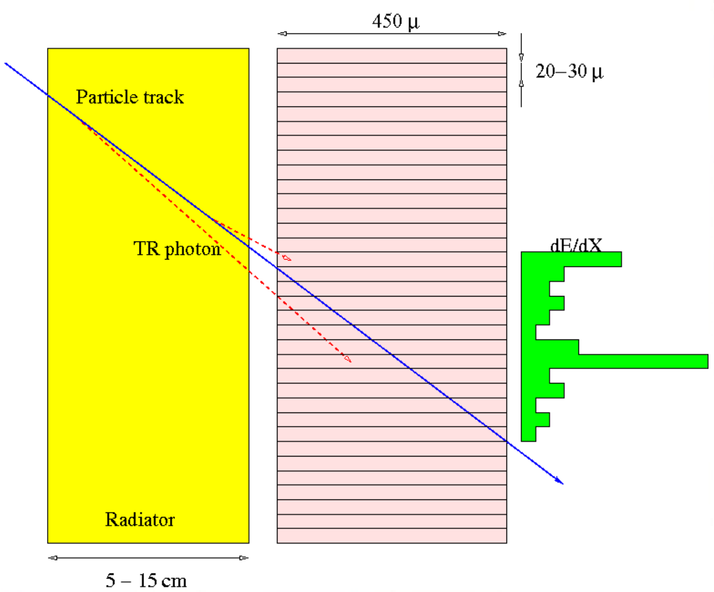
Test Beam at CERN in 2009

EUDET + DEPFET setup

- *S3B module was installed in EUDET telescope as DUT.*
- *Matrix: DEPFET (COCG SE H3.0.03) 24x24 μm rotated at 26° and 41°.*
- *Radiator: fibers (fleece) 4 cm placed in front of the sensor.*
- *Beam: π (120,100,80..) e(100,80,60,40)*
- *Problems:*
  - in e-beam the number of electrons is unknown in range of 10-60%
  - Low gain and high noise of this particular matrix not allow to set the cluster search threshold at level of TR
  - As result we have low efficiency for TR
- *Data analysis still ongoing.*

Test Beam at DESY in December 2009

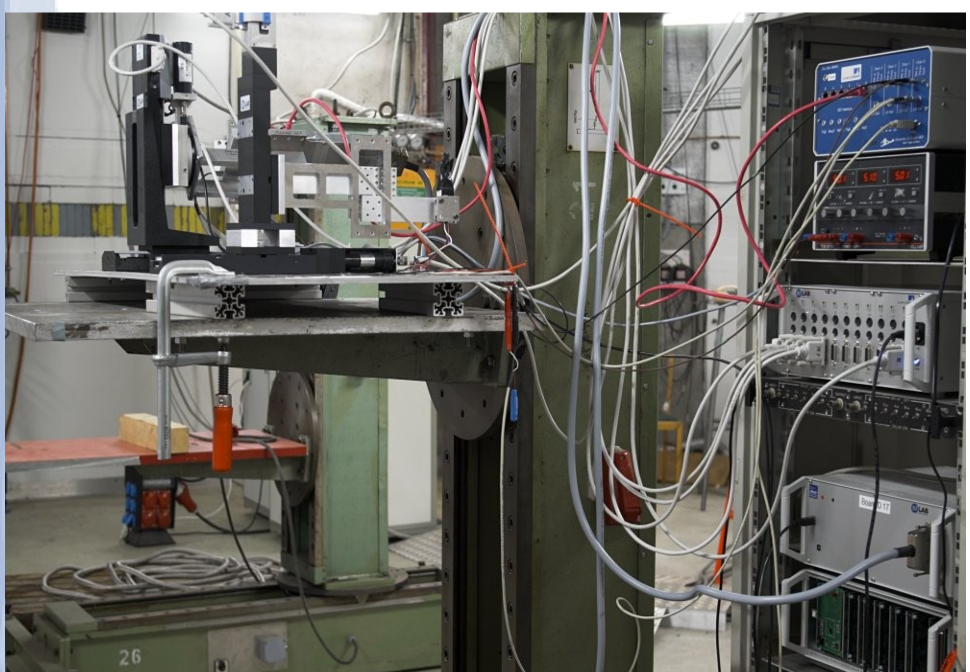
- *In December we have got from Prague matrix COCG SE H3.0.07 with higher gain and smaller pixel size - 20x20µ*
- *After characterization in lab with laser and Am source we decided also to repeat the tests with Transition Radiation at DESY.*
- *Test beam at DESY is pure electrons (or positrons)*
- *The maximum electrons energy is 6-7 GeV*
  - Gamma of electrons about 10,000 - much higher than transition Radiation threshold (~1000)
  - Also we have higher multiple scattering
  - And wider angular distribution of Transition Radiation

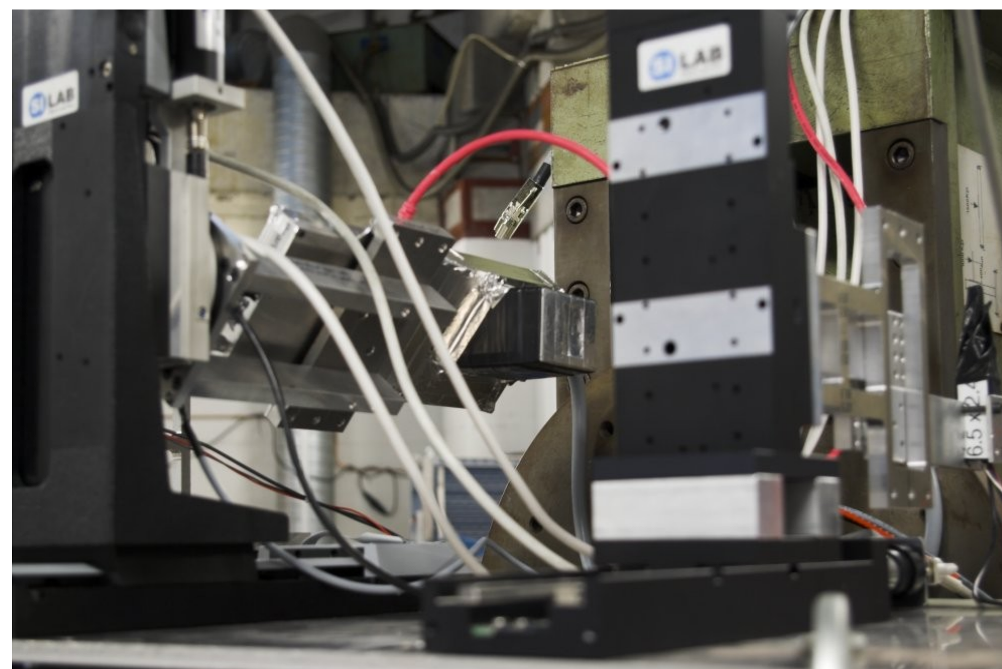


Test beam at DESY in December 2009

- *Beam: pure electrons 5 GeV , γ~10000*
- *Sensor: DEPFET (COCG SE H3.0.07) 20x20μm rotated at 26° and 41°*
- *Radiator: fibers (fleece) length of 5,10,15 cm, is placed in front of the sensor*
- *DEPFET module and trigger scintillator are installed on 2 motor stages*
- *Power Supply, TLU, DAQ PC.*

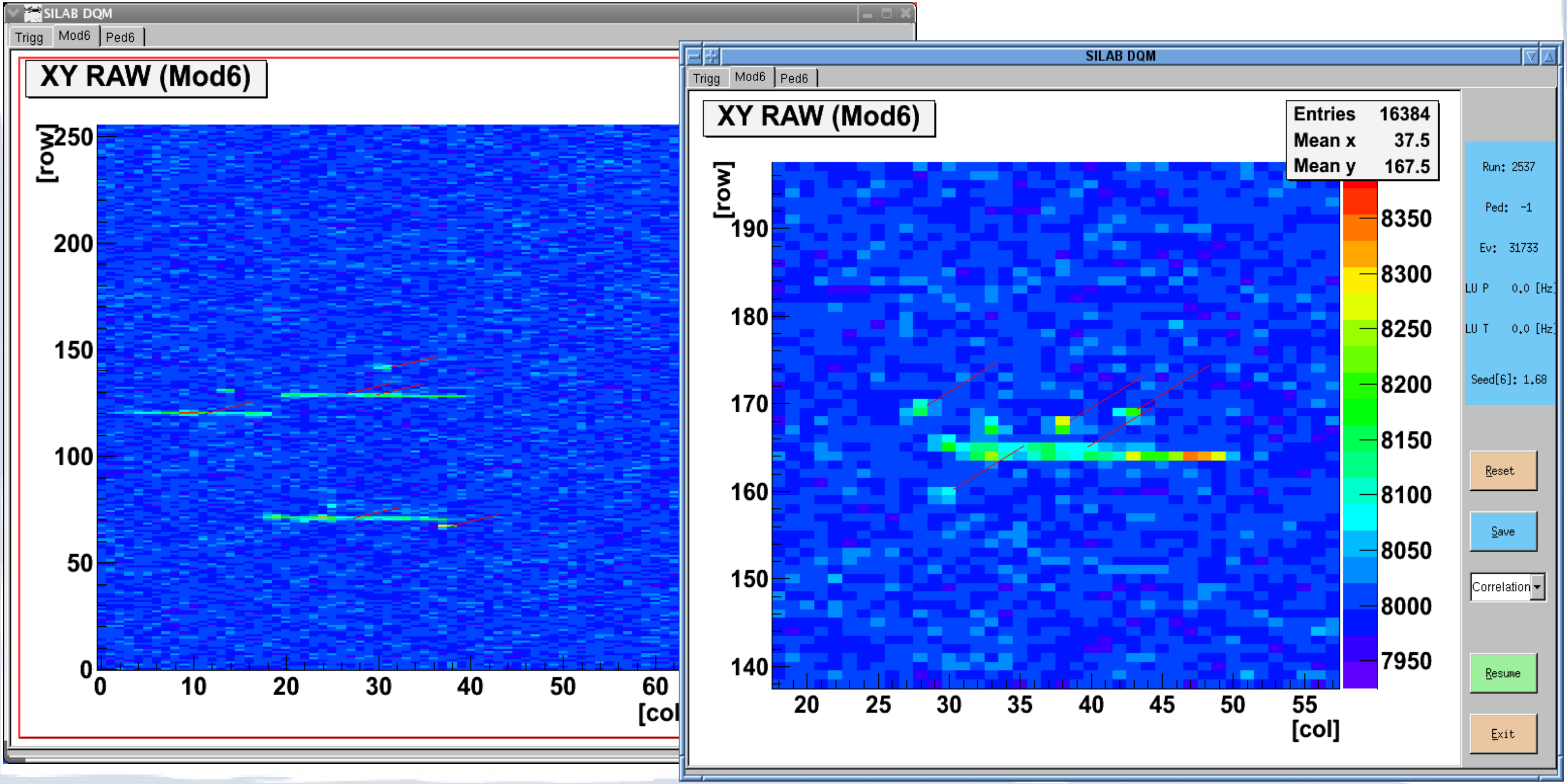
DESY Setup



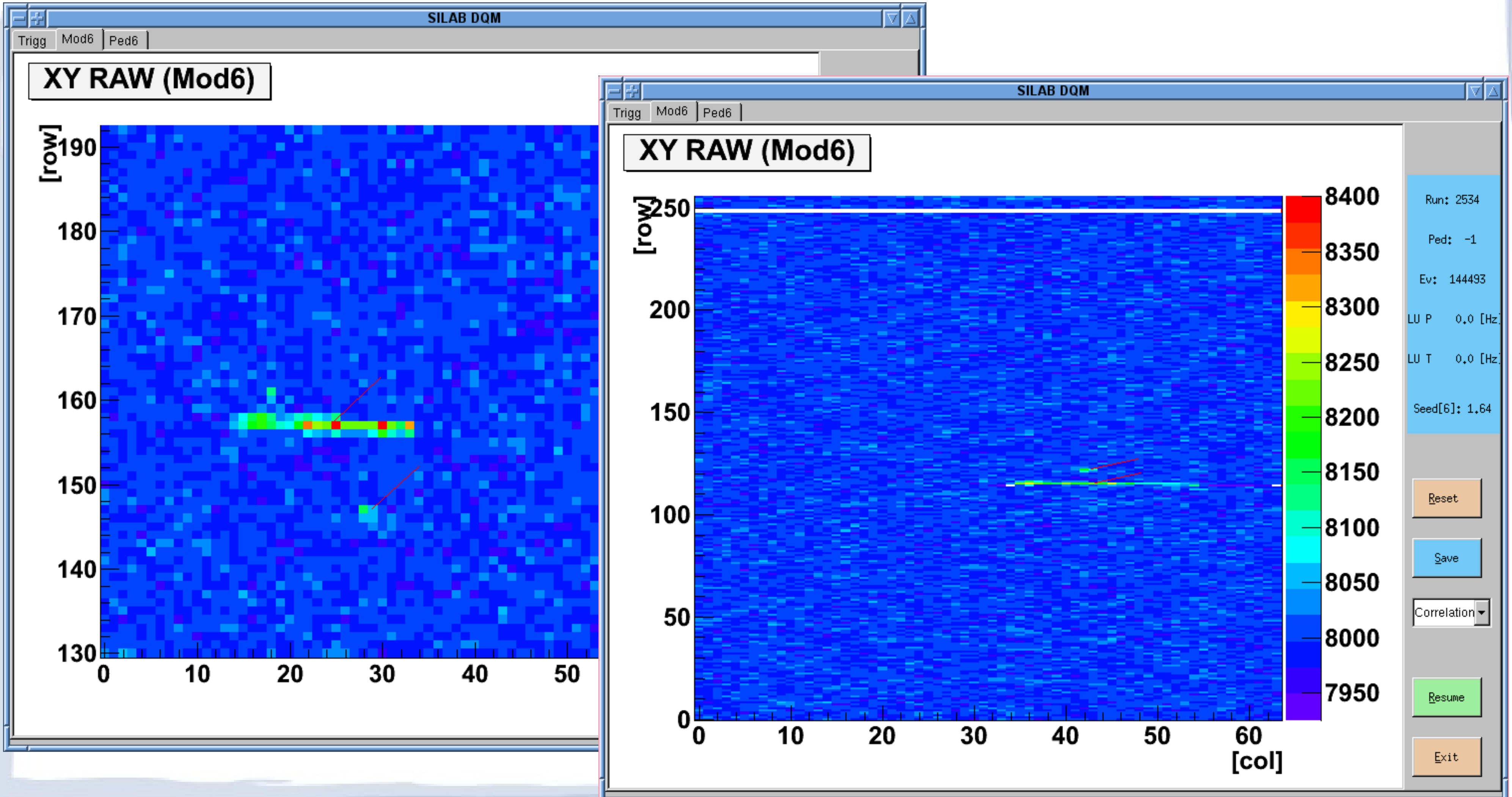


Event Display

- *Matrix 20x20 μ, beam angle 41° , length of cluster from particle ~20 pixels.*
- *TR photons are clearly visible and separated from track by few pixels !*
    - red lines shows the center of found cluster

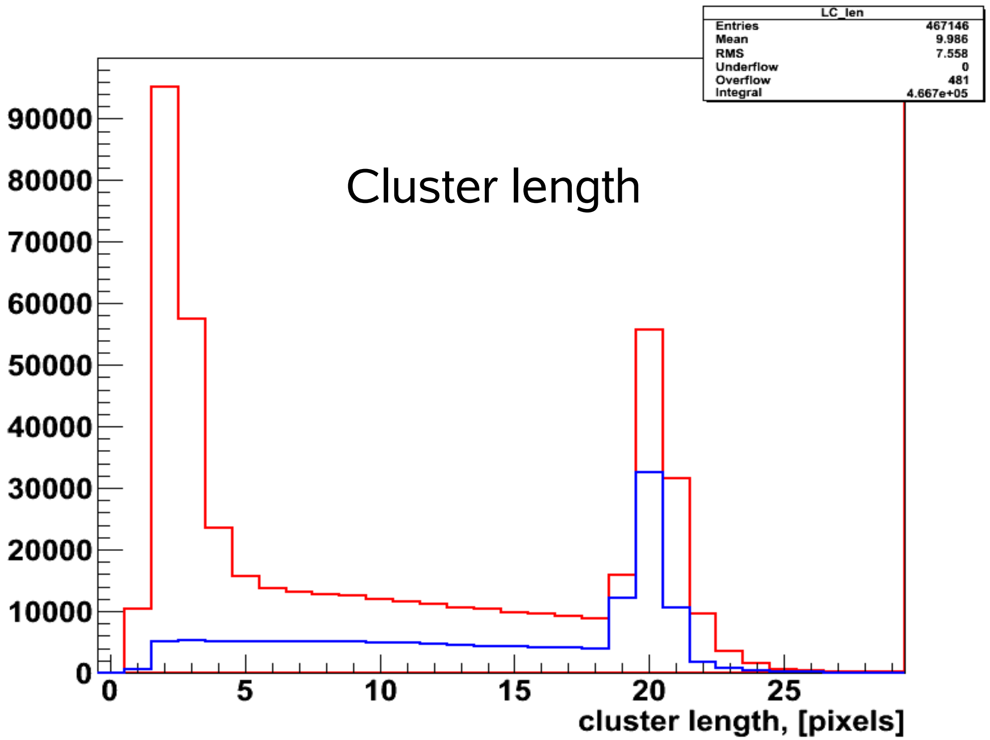


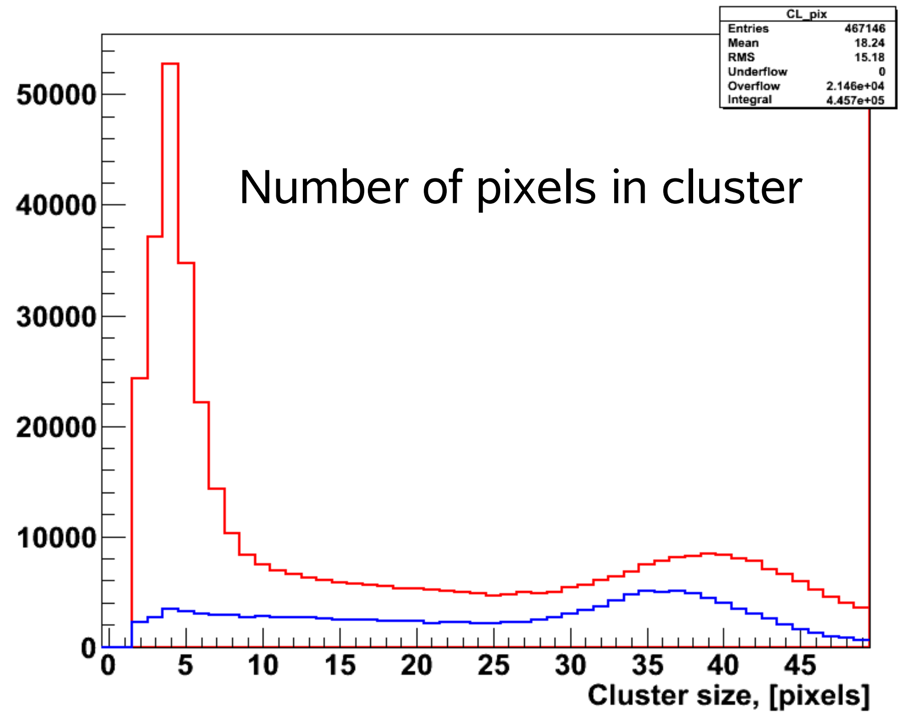
Event Display



Cluster size

- *Clusters are evaluated by 4 parameters:*
  - Cluster length
  - Cluster width
  - Number of pixels in cluster
  - Cluster energy
- RED line – with radiator
- BLUE line – without radiator
- (histograms are not normalized)
- *Runs with radiator has an excess in small cluster size*





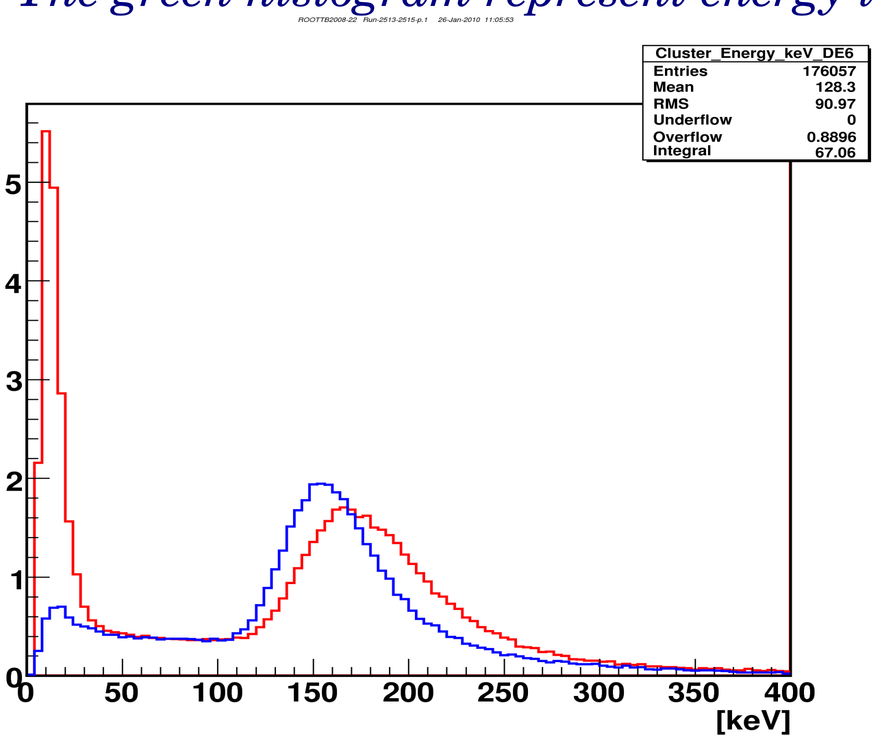
Transition Radiation absorbed spectrum

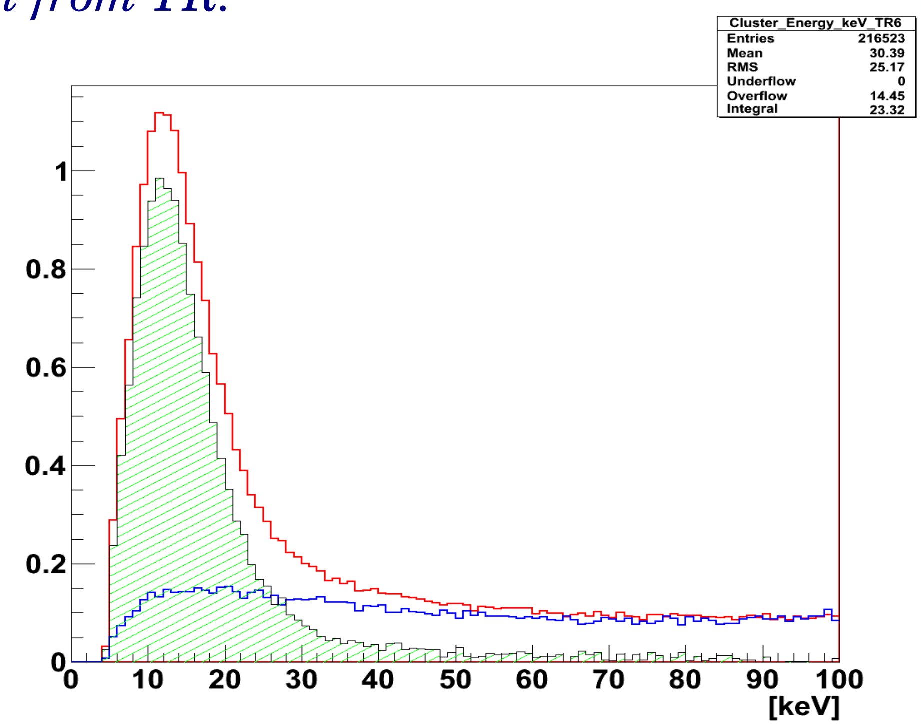
- *On the two pictures below are shown cluster energy distribution for 2 cases – with radiator and without radiator*
- *I case with radiator we have a lot of low energy clusters – Transition Radiation photons.*
- *On the right picture are shown zoomed area*
- *The green histogram represent energy input from TR.*

With radiator

Without radiator

TR spectrum

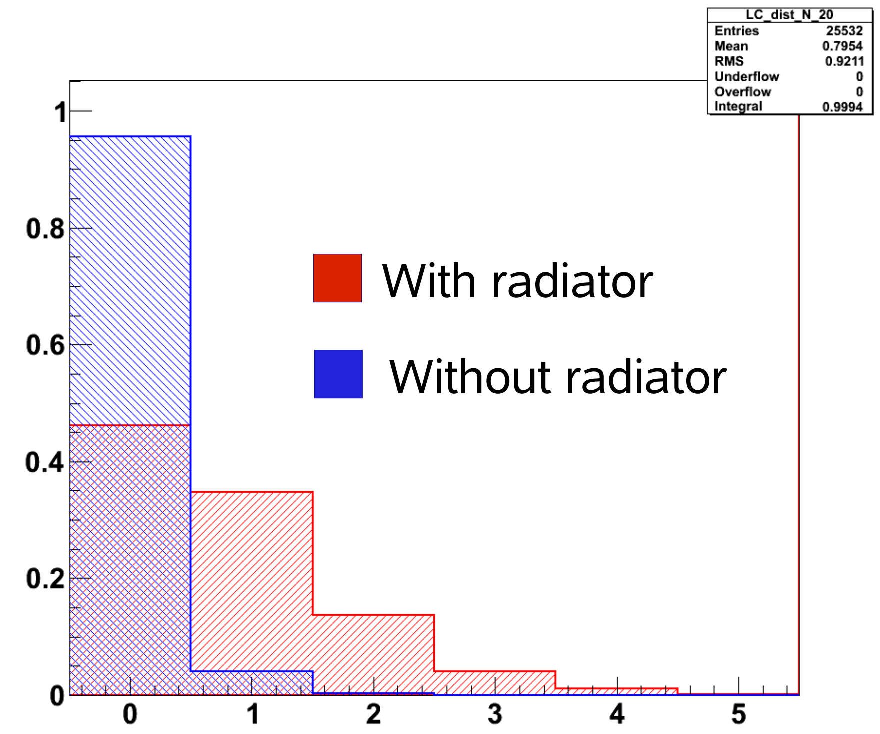




TR clusters efficiency

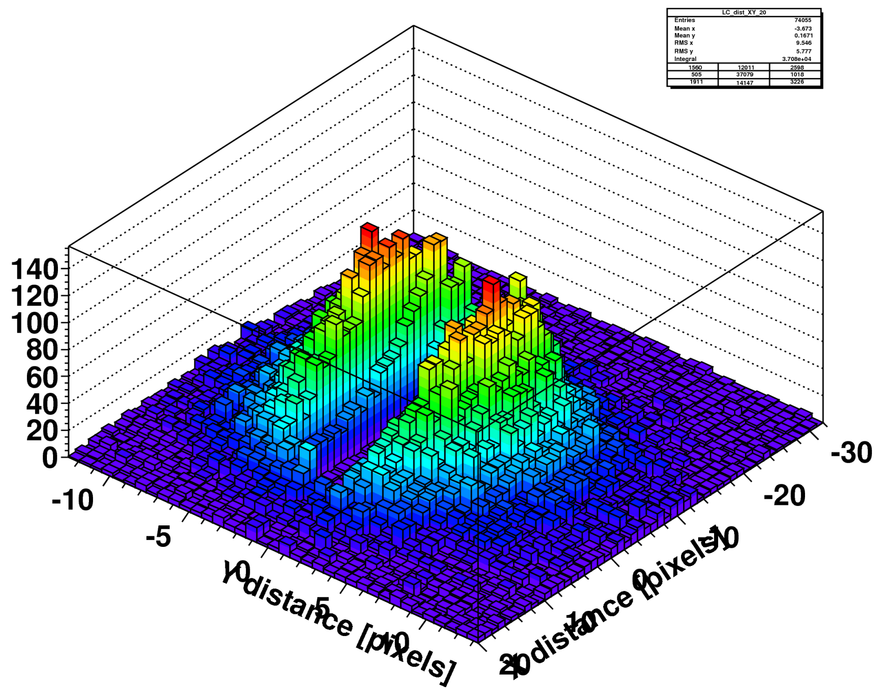
- *The probability to find TR photon near the track is 53% with radiator and 5% without radiator.*
- *In 47% of inefficiency included :*
  - Inefficiency cluster search algorithm
  - Overlapping TR cluster with track
  - TR cluster too far from track
  - TR photon energy too high – not stopped in silicon
  - No TR photon for this track

Number of TR photons found per track

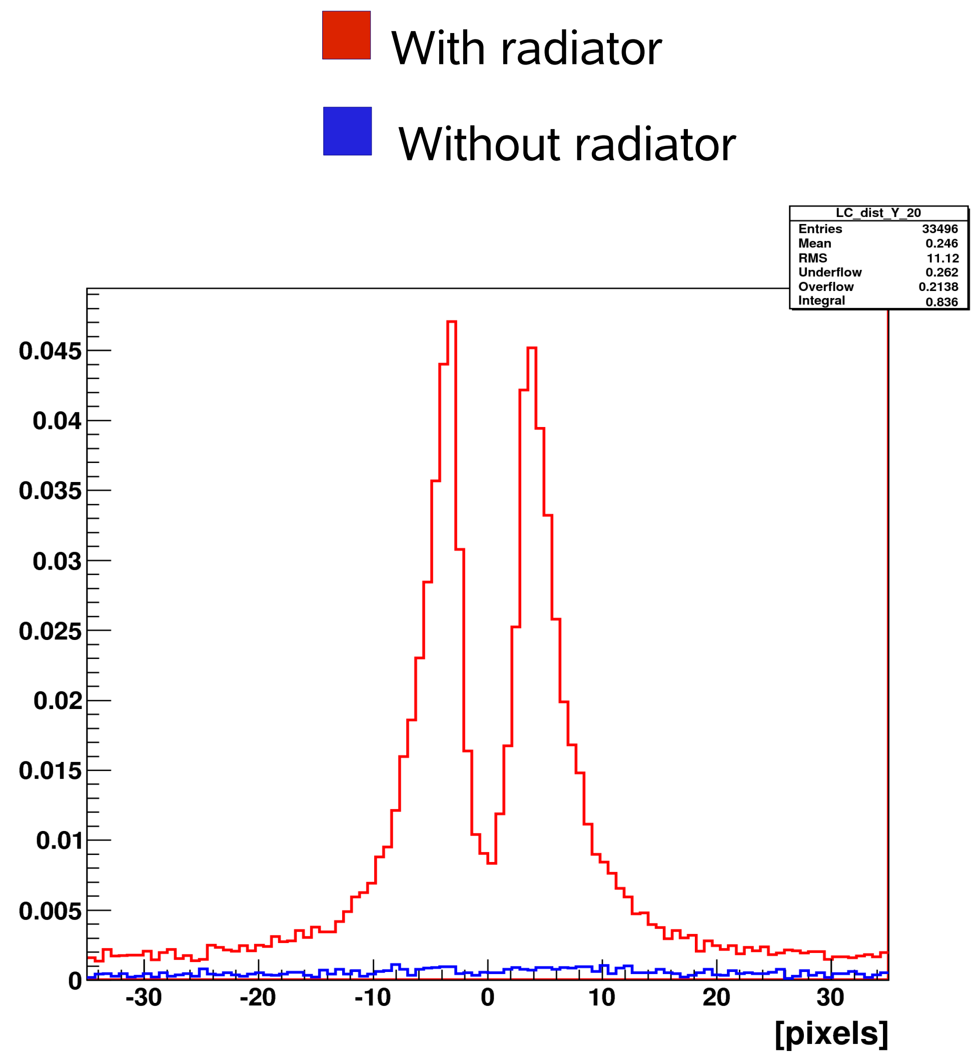


[number of photons found]

Transition Radiation angular distribution

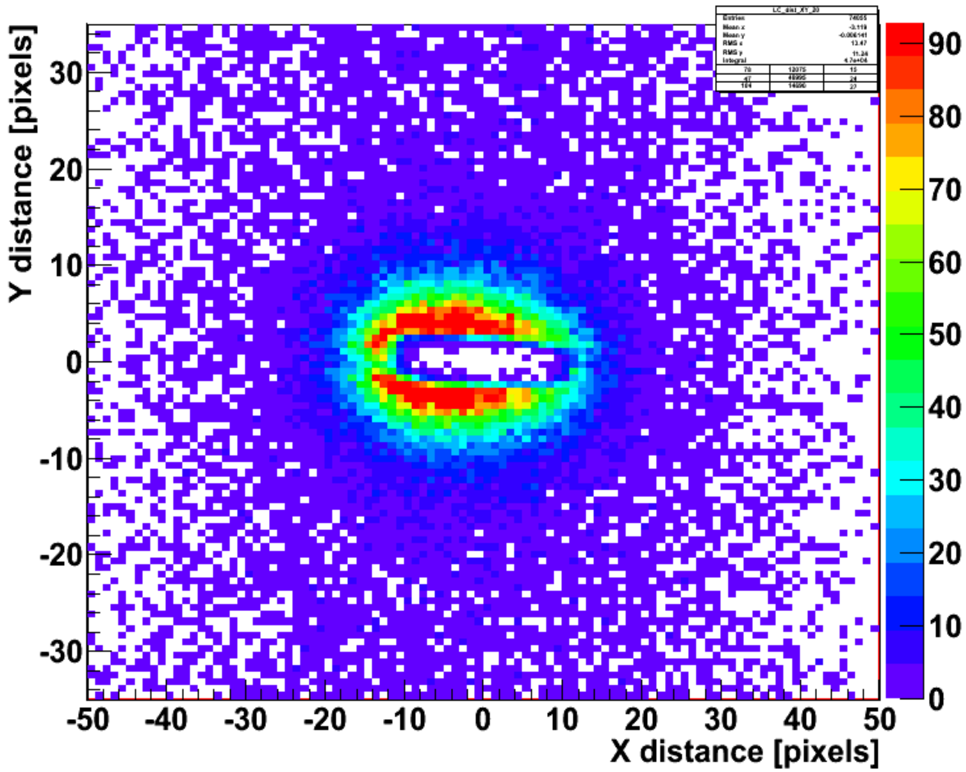


Y-projection

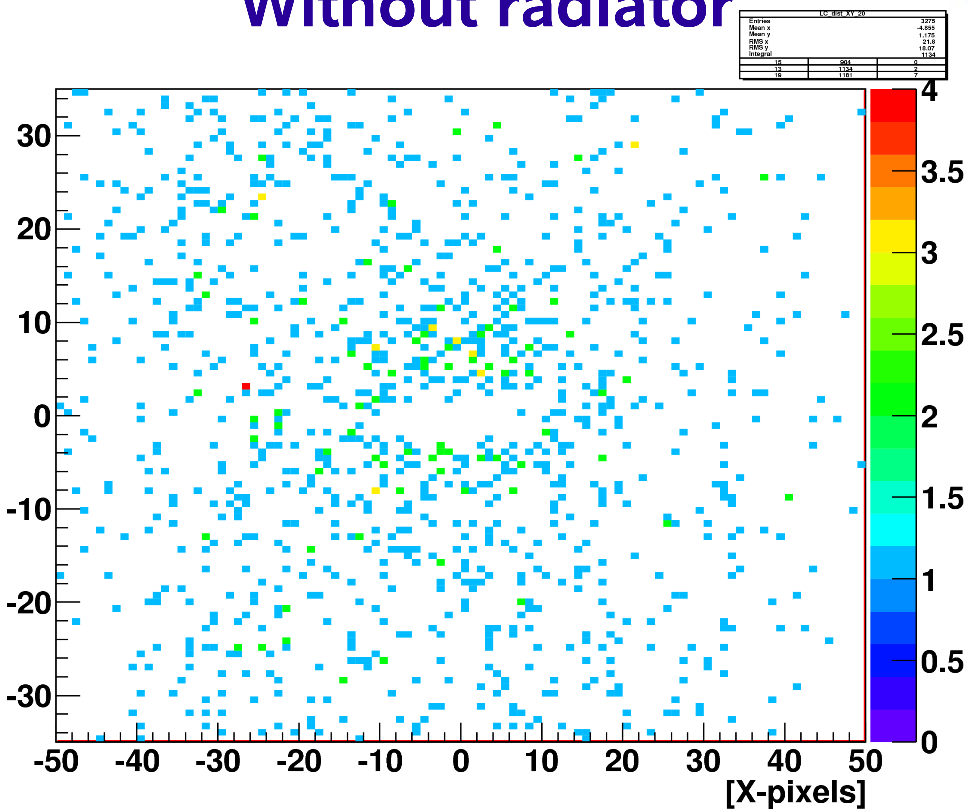


Angular distribution

With radiator

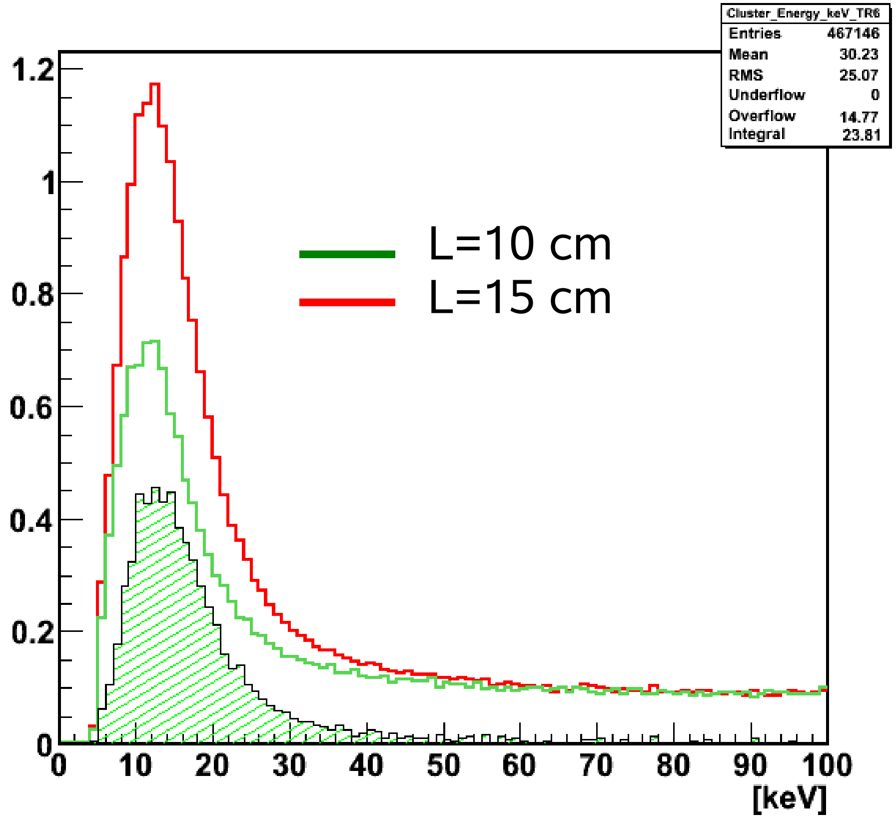


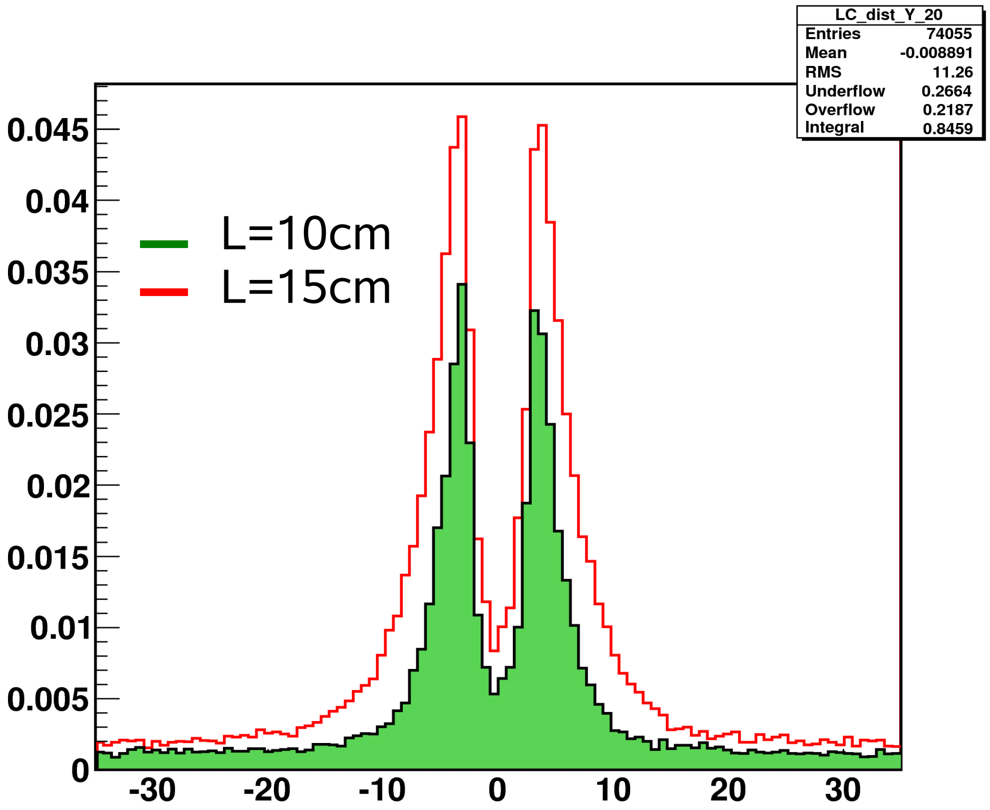
Without radiator



Radiator length

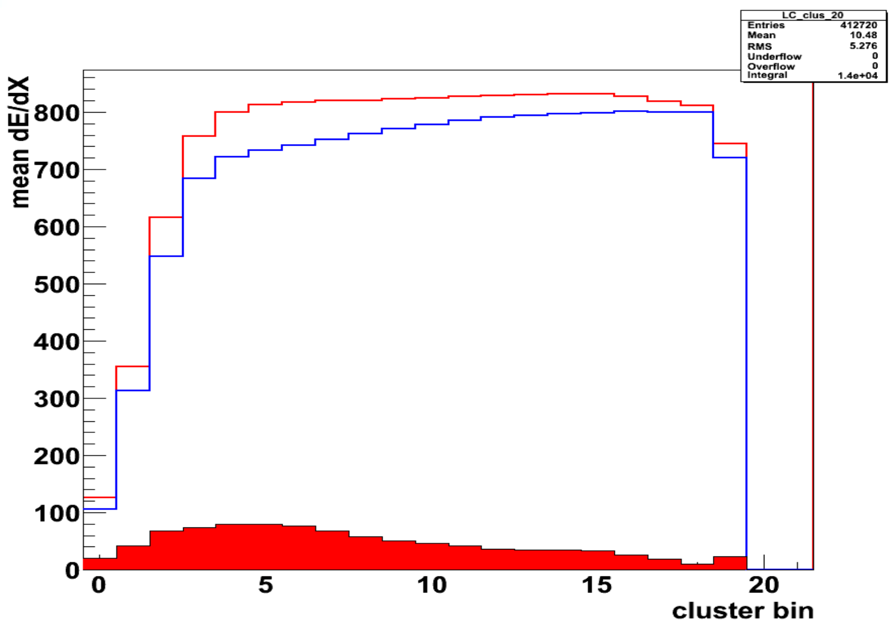
- *The number of TR photons increased with radiator length.*
- *2 pictures represent TR yield for 2 radiator length 10 cm and 15 cm.*
- *We can improve the efficiency just by adding more radiator in front of detector !*
  - The typical density of radiator 0.05 g/cm^3

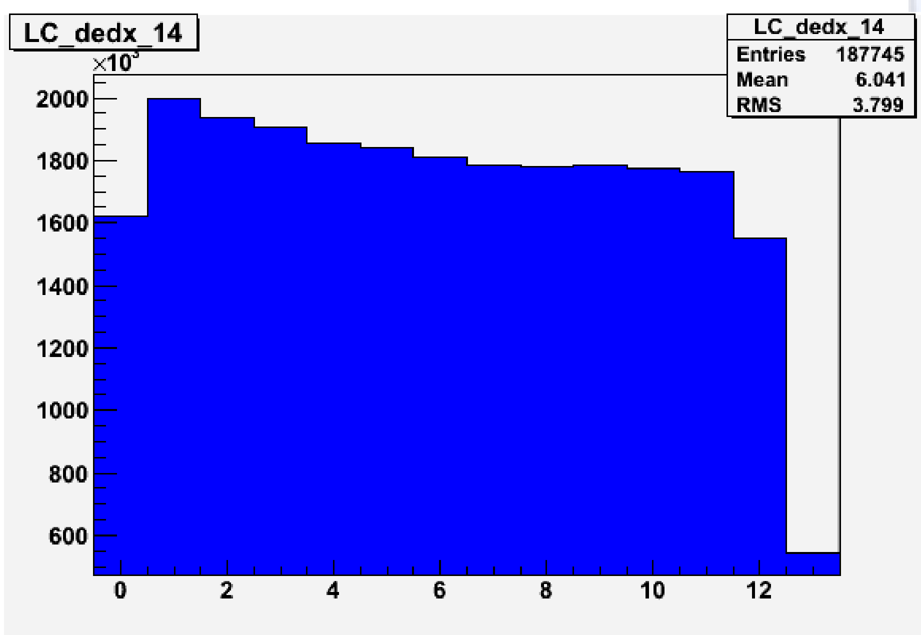




dE/dX vs cluster length

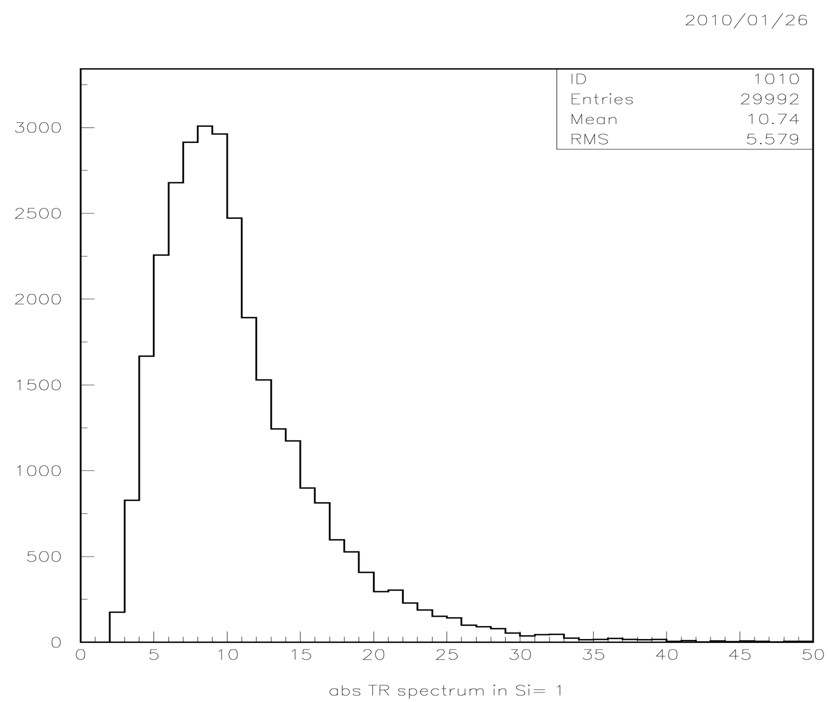
- *Now we return to the original idea – discrimination of TR photons on the top of dE/dX from particle.*
- *Left histogram below shows average dE/dX for each of 20 pixels (20x20µ 41°)*
- *Red line – with radiator, Blue line– without radiator, Red filled area - TR.*
- *dE/dX along track without radiator non uniform for each bin.*
- *Right picture shows the same for matrix 24x32µ and 36° angle (TB2008)*
    - Note – on the right picture is mirrored - the particles coming from rigth to left

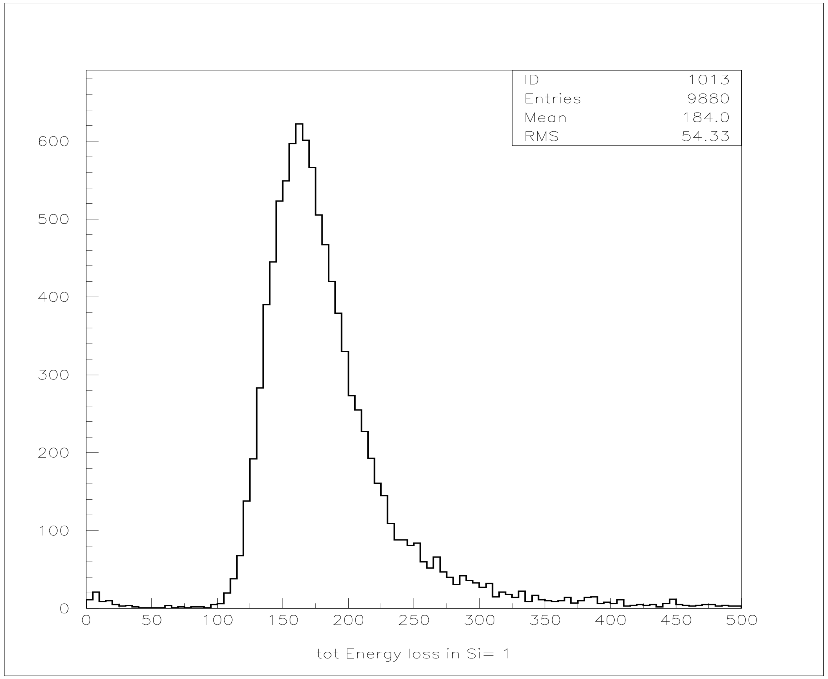




Monte Carlo

- *Monte Carlo simulation is based on GEANT 3 - ATLSIM*
    - ATLSIM originally was developed for simulation of ATLAS detector
- *for dE/dX simulation is used PAI model*
- *for Transition Radiation generation and absorption is used custom software, developed for simulation of ATLAS TRT*





Conclusion

- *First tests of DEPFET for transition radiation detection shows very promising results.*
- *In comparison to traditional gaseous wire chamber detectors DEPFET has advantages:*
    - High granularity allow to build tracker and identificator in one .
    - Does not require magnet, gas and gas equipment – easy to build light weighted and compact detector - especially important for space missions.
- *The work is just started and there still a lot of open questions*