Electron identification with help of silicon transition radiation detector based on DEPFET pixel matrices

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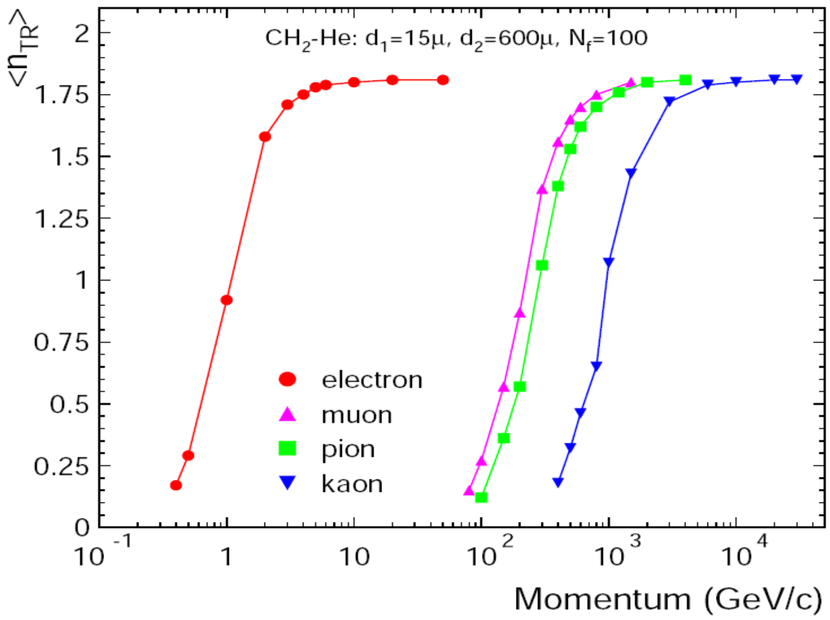
4th Workshop on Advanced Transition Radiation Detectors
for Accelerator and Space Applications
Bari, Italy, September 14-16, 2011

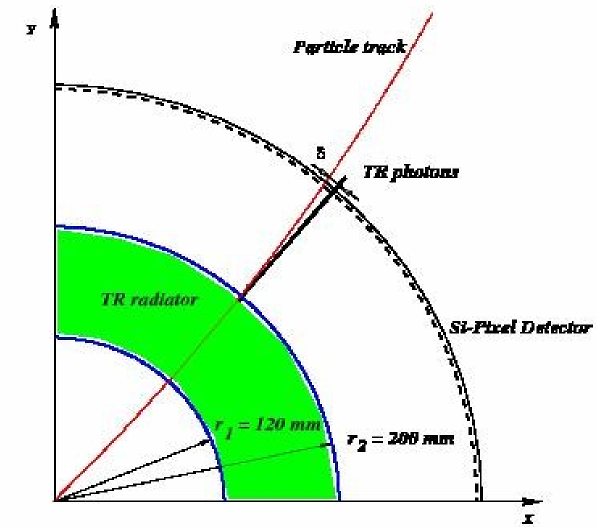
Outline

- *Introduction*
- *TR registration method in Si pixel detector DEPFET*
- *DEPFET concept*
  - DEPFET readout
- *Test Beam*
  - TB setup at CERN SPS and DESY
  - Results
- *Geant4 Monte Carlo*
  - Comparison with experimental data
- *Electron identification technique*
- *Outlook*

TR registration

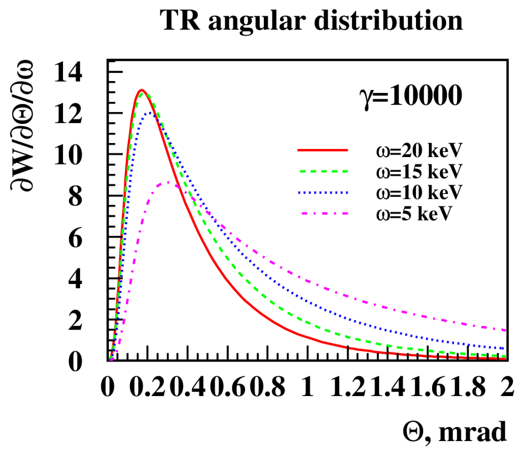
- *The basic problem in detection of transition radiation photons (TR) is the discrimination of TR from dE/dx energy loss of charged particles.*
- *The classical TRD is based on gaseous detectors filled with Xenon gas mixture to efficiently absorb transition radiation photons, with energy 5-30 keV over 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 particle dE/dx in 300-700µm of silicon - about 100-300keV.*
- *Another approach to detect TR is to separate particle dE/dx and TR in magnetic field. In this case, in silicon detectors TR photons and dE/dx are registered in different strips or pixels.*
  - In 2000 B.Dolgoshein has 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
- *Also natural angular distribution of transition radiation was investigated*





Early measurements of TR angle

- *For single surface yield typical angle is $\theta = 1/\gamma$*
- *B.Dolgoshein*
  - NIM 180 (1981) 409
  - NIM A 326 (1993) 434



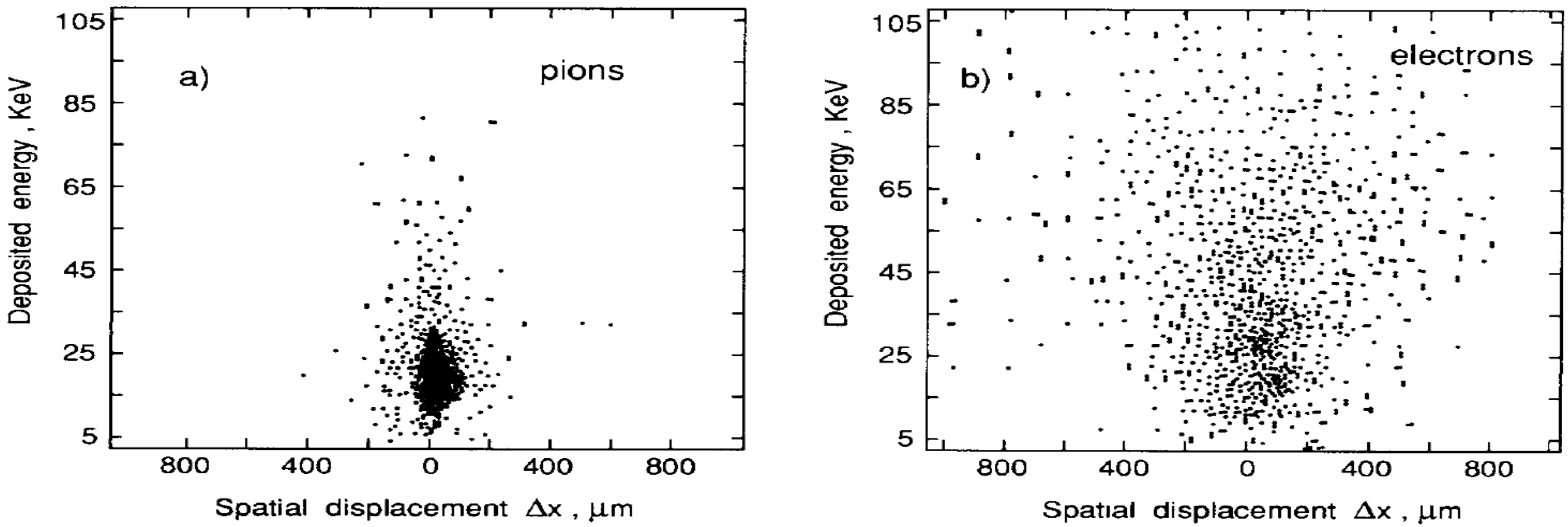
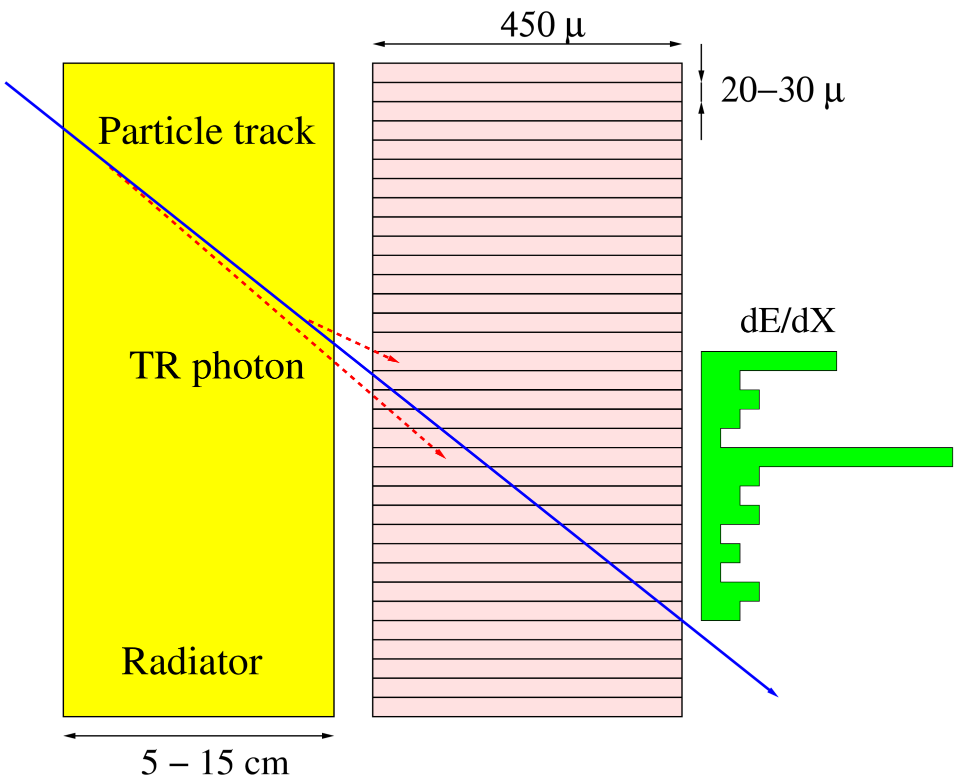
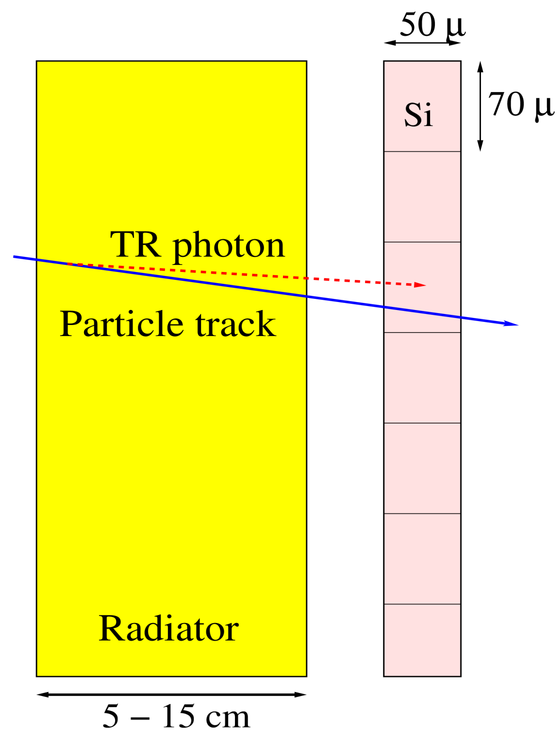


Fig. 7. Two-dimensional distributions of the events: energy deposition E in the detector vs spatial displacement of the center of gravity of the charge Δx for pions (a) and electrons (b). Smearing is enhanced in the case of electrons (b) due to the detection of TR photons.

TR registration with DEPFET



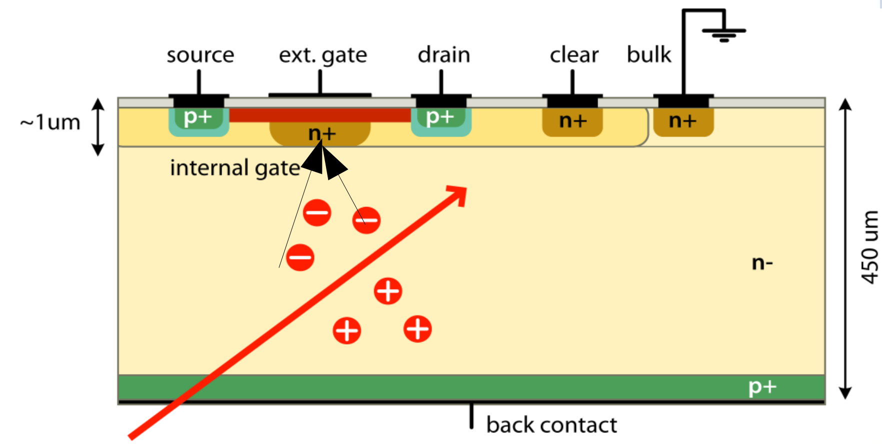


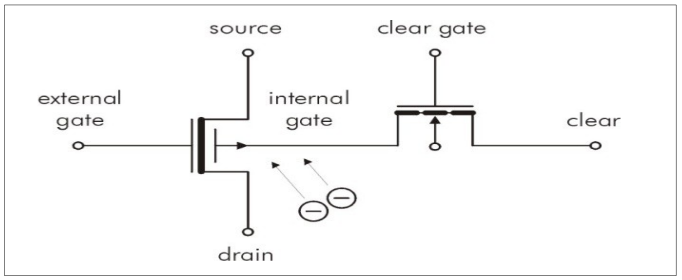
- *by turning the Silicon detector at 30-50° the full path of the particle in one pixel is about 30 µm and therefore dE/dx is a factor 10 less (~10 keV) and compatible with transition radiation energy.*
- *in addition 10-30 points of dE/dx measurement on the particle track. TR photons are absorbed in the first 2-7 bins (pixels) along the track.*
- *this fact of additional ionization from TR photons in the first pixels could be used for particle identification (separation).*

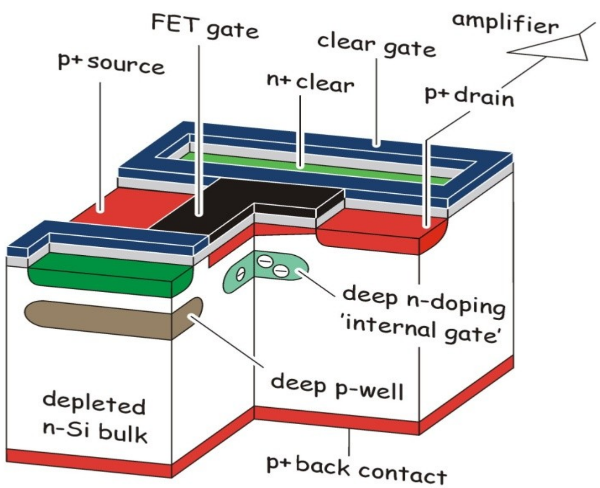
- *Nowadays the DEPFET substrate can be thinned down to 50 µm .*
  - dE/dx will be lower.
  - The drawback of this method is that the TR registration efficiency will be also lower.
  - The advantage is that pixel size could be much lager.

DEPFET principle

- *The DEPFET is an active pixel sensor which integrates a MOSFET into the high resistivity silicon substrate*
  - ➨ in-pixel amplification
- *Provides fast charge collection in fully depleted bulk*
  - ➨ fast signal rise time (~ns), small cluster size
- *Electrons are collected in "internal gate" - potential minimum for electrons - and modulate transistor current*
  - ➨ charge-to-current conversion
- *Transistor can be switched off by external GATE – charge collection is still active !*
  - ➨ potentially low power device
- *Low readout capacitance – reduces the noise*
- *no stitching, 100% fill factor*
- *no charge transfer is needed*
  - ➨ faster read out
  - ➨ better radiation tolerance
- *Charge from internal gate is removed by the CLEAR contact*

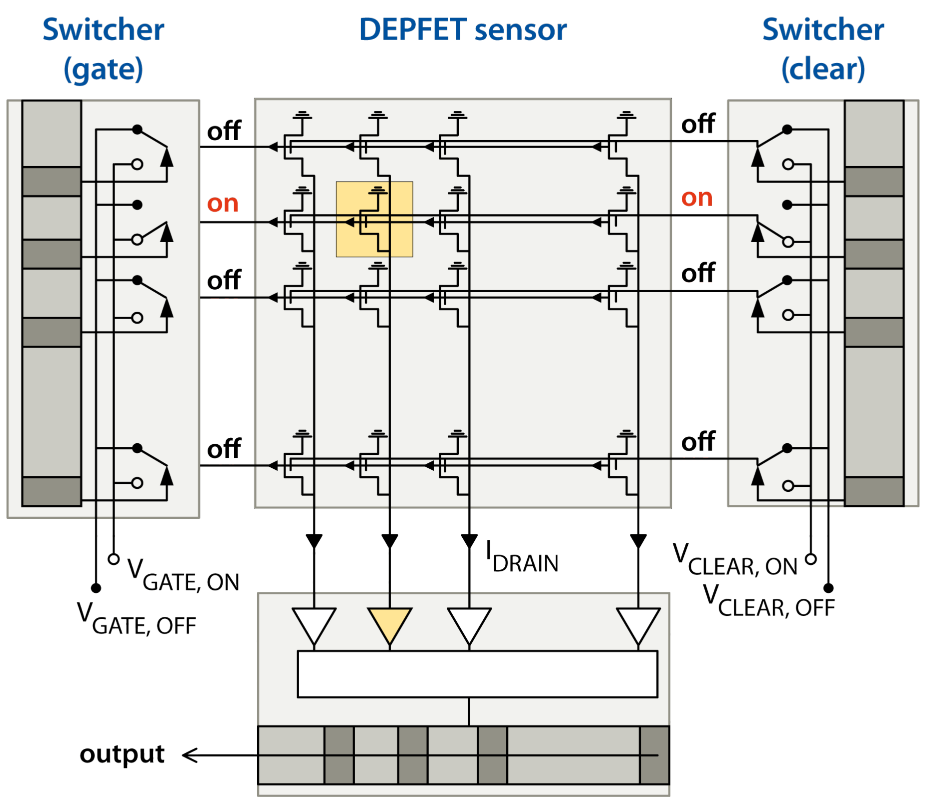


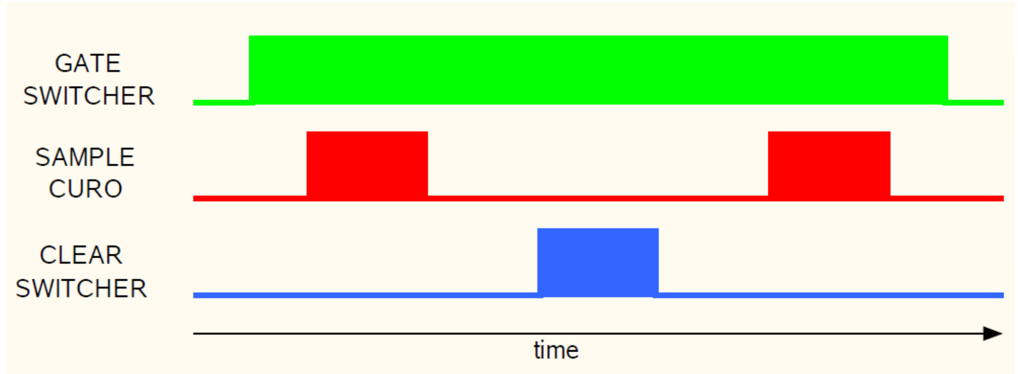




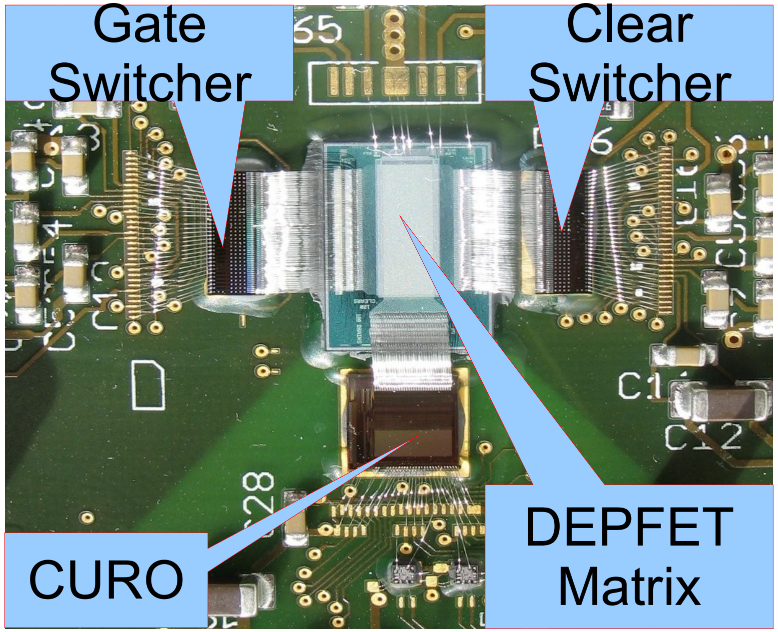
DEPFET readout sequence

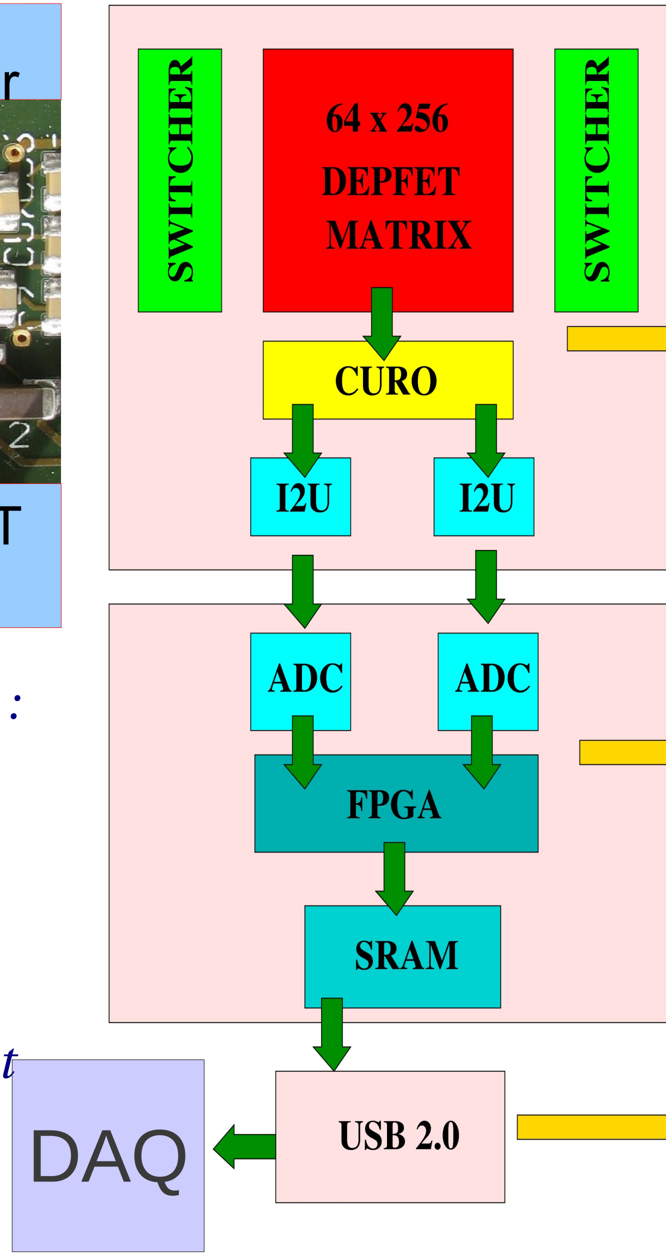
- *Sources of transistors are connected to common potential*
- *Gates are connected row-wise*
- *Drains are connected column-wise*
- *Readout chip CURO processes all columns in parallel*
- *The SWITCHER chip generates the steering signals for the rows - GATE and CLEAR.*
- *DEPFET readout sequence :*
  - select row with external gate
  - readout transistor current : I_sig + I_ped
  - clear charge from internal gate
  - again readout transistor current: I_ped
  - subtract pedestal current
  - select next row

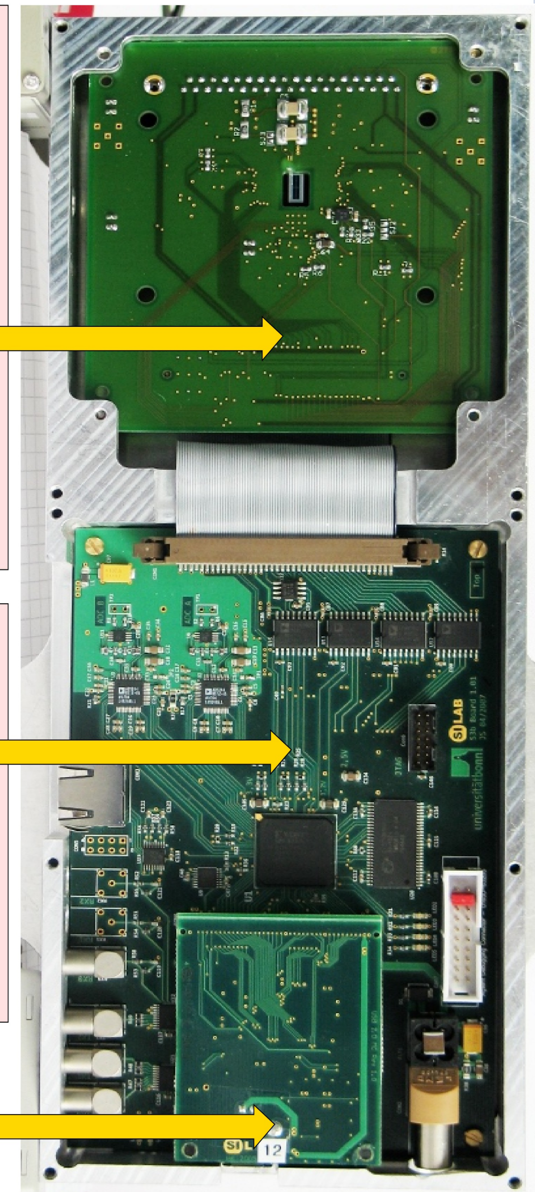




DEPFET test system



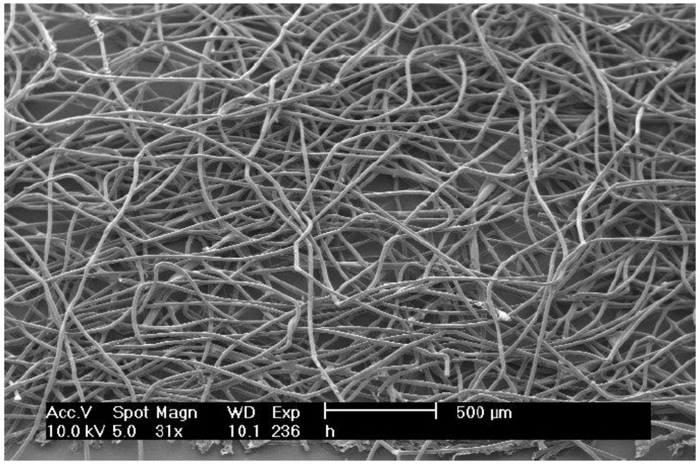




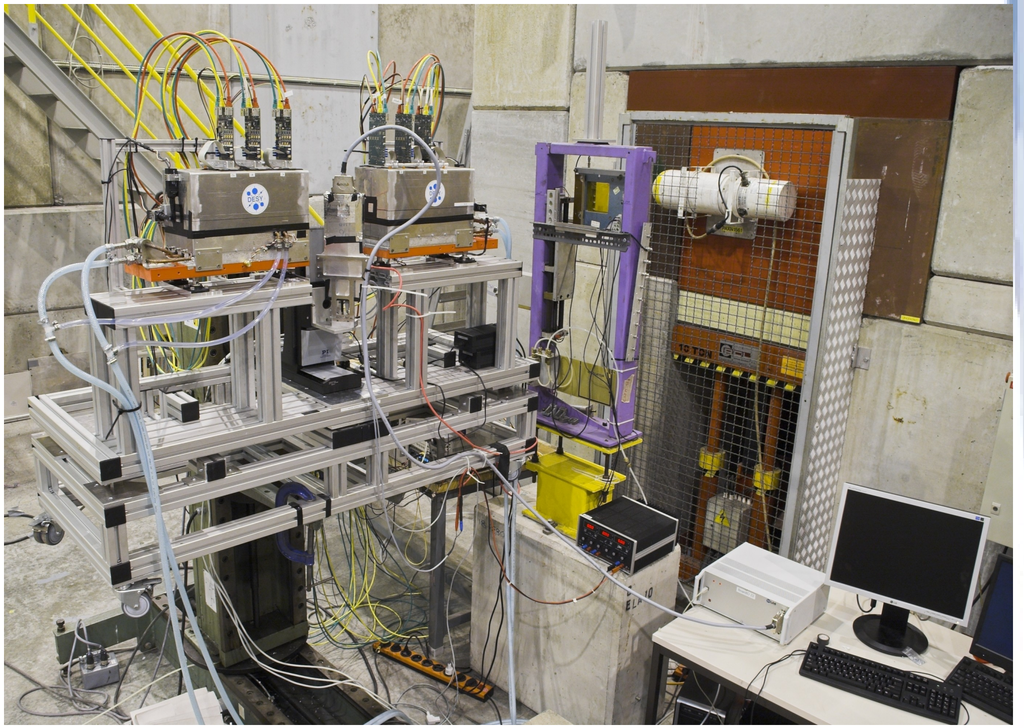
- *The second board (S3B) contains :*
  - FPGA
  - ADCs
  - buffer RAM
  - USB2.0-PC interface.
- *S3B board provides the read out rate up to 130 Hz*

Test Beam at CERN

Radiator



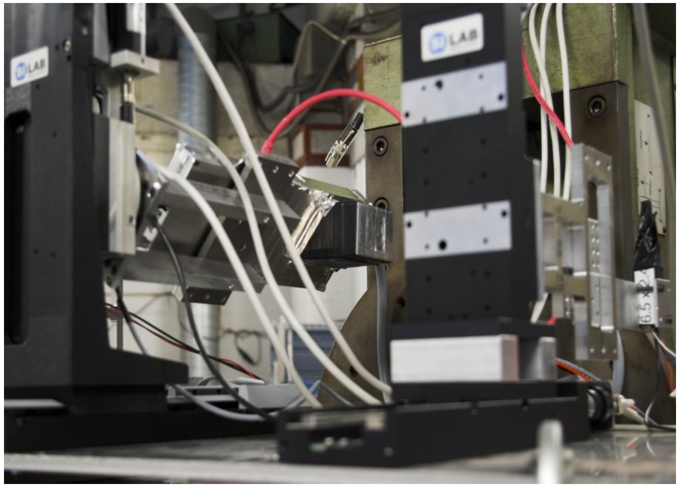
EUDET + DEPFET setup



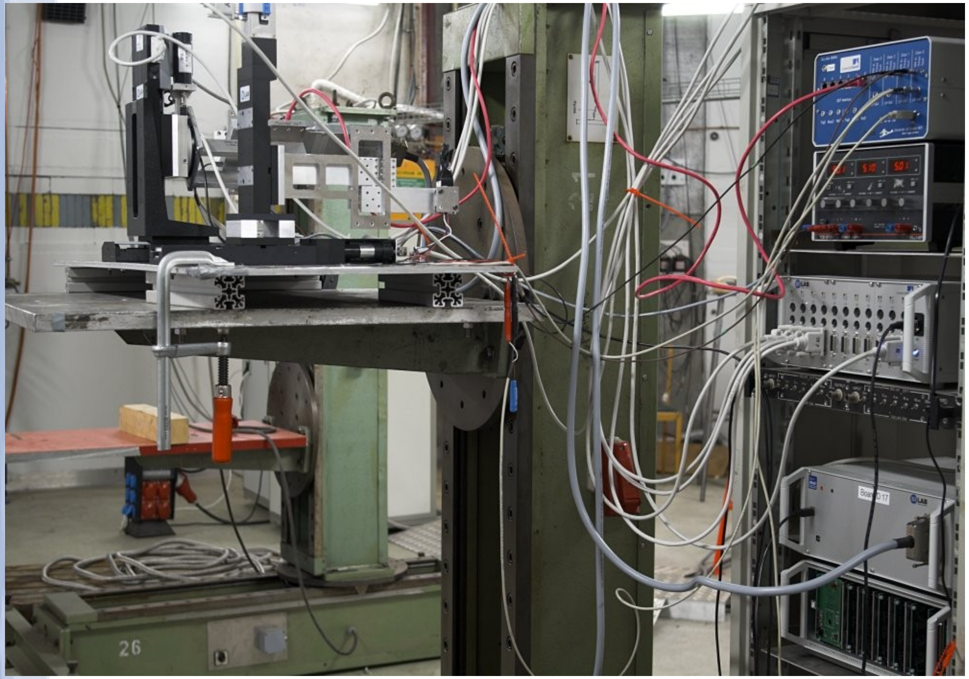
- *DEPFET module was installed in EUDET telescope as DUT.*
- *Matrix: DEPFET 24x24 µm rotated at 26˚ and 41˚.*
- *Radiator: fibers (fleece) 4 cm placed in front of the sensor.*
- *Beam: π (120,100,80..) e(100,80,60,40)*
- *Problems:*
  - in e-beam the number of electrons is unknown in range of 10-60%
  - 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.*

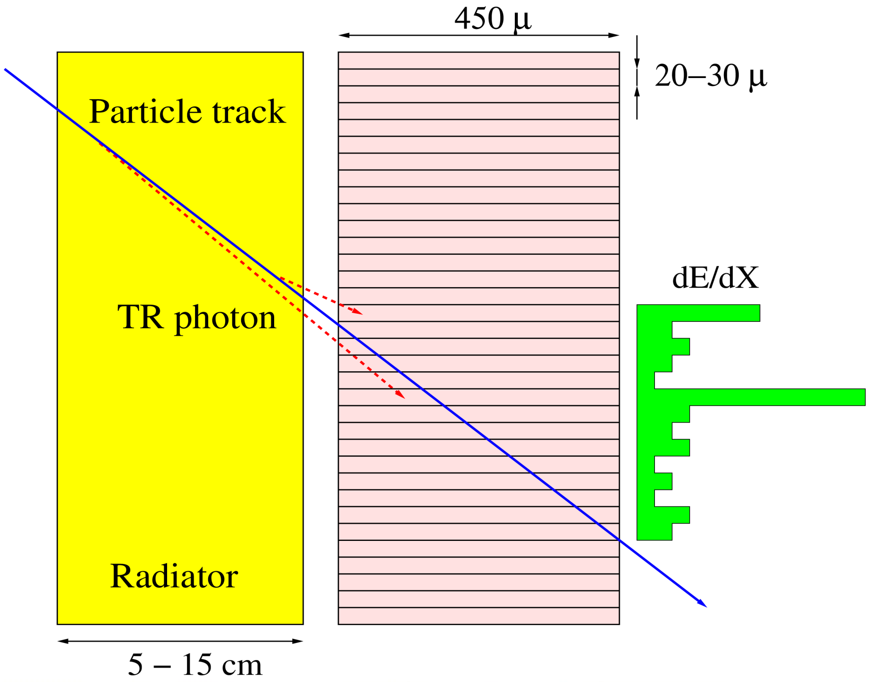
Test beam at DESY

- *Beam: pure electrons 5 GeV , γ~10000*
- *Sensor: DEPFET 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.*



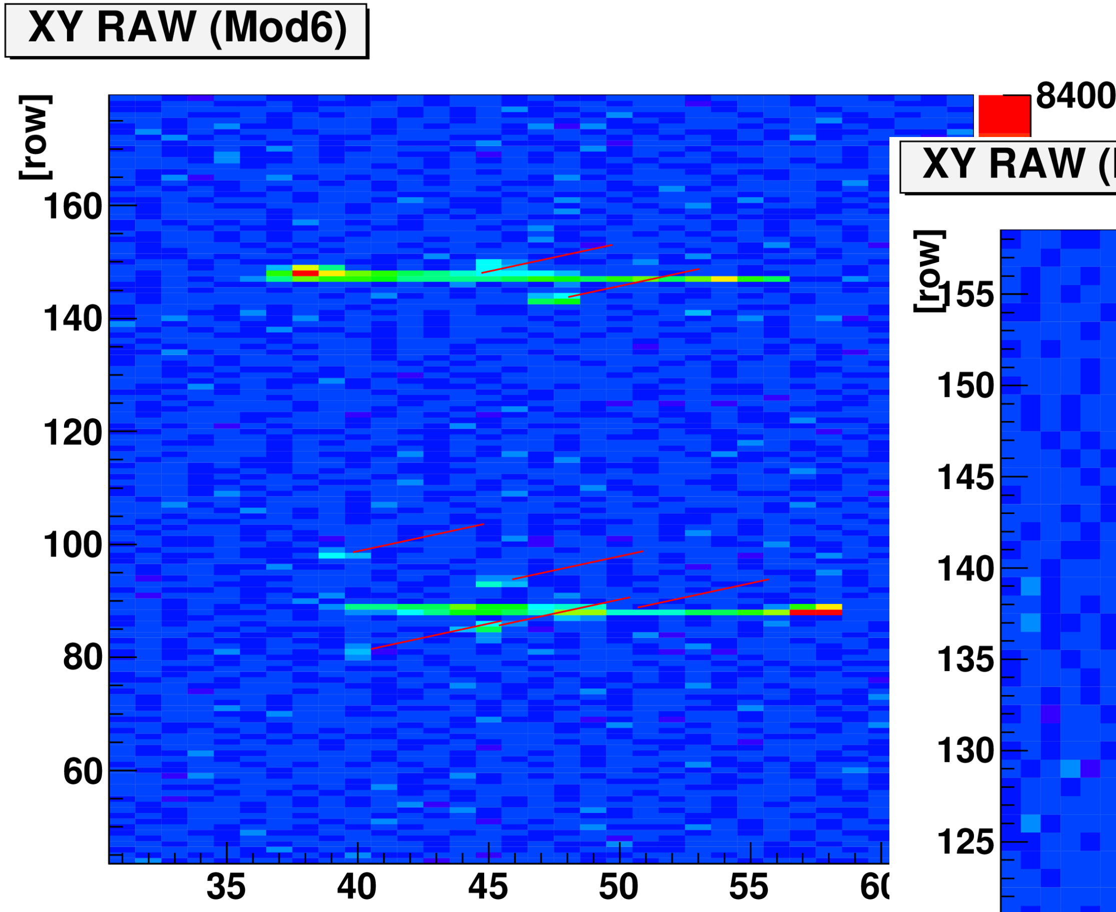
DESY Setup

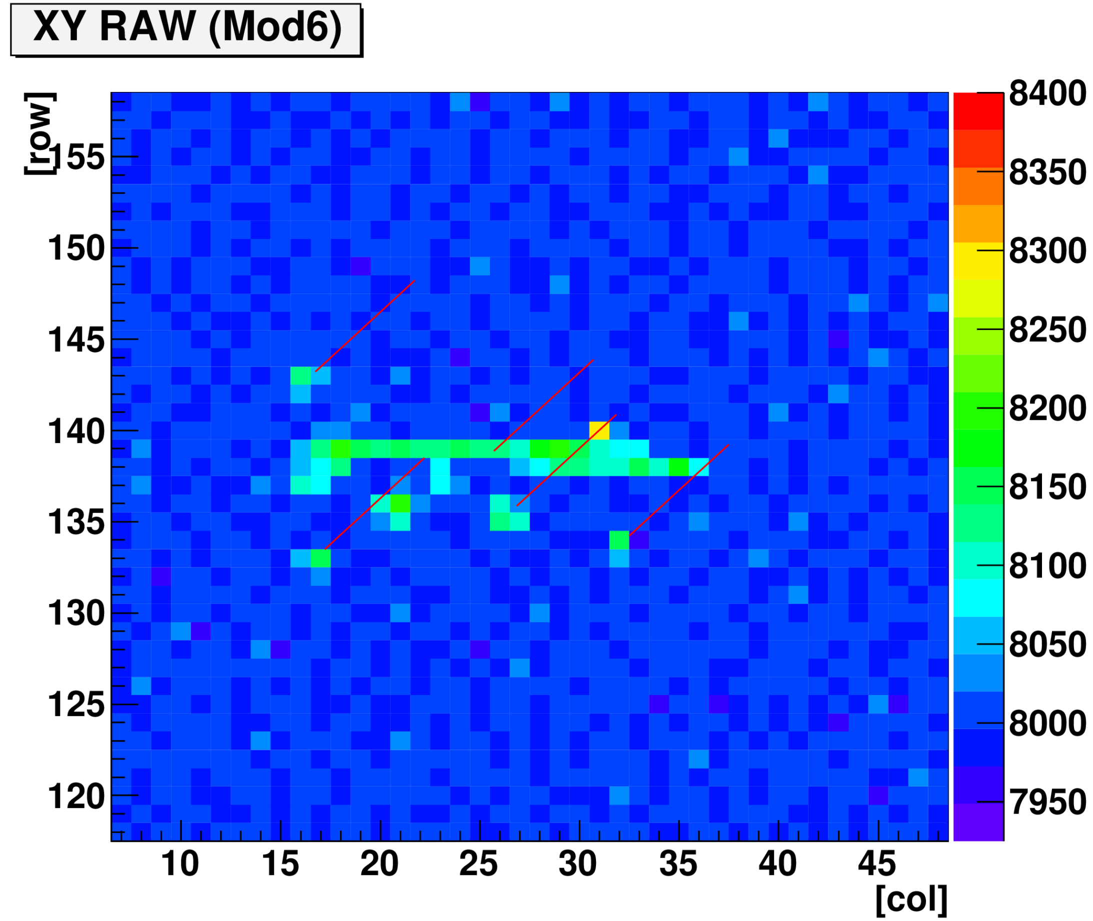




Event Display

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





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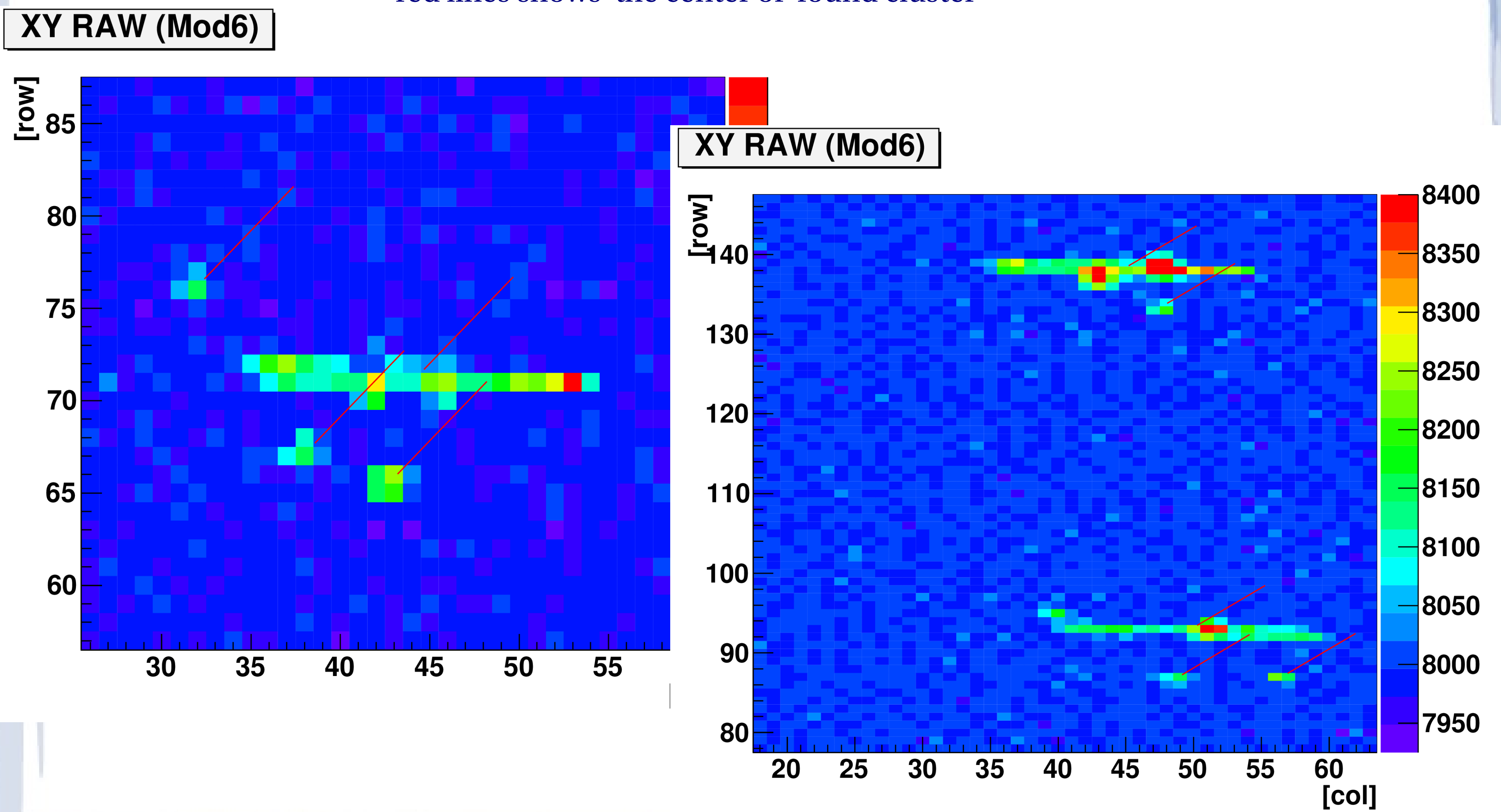
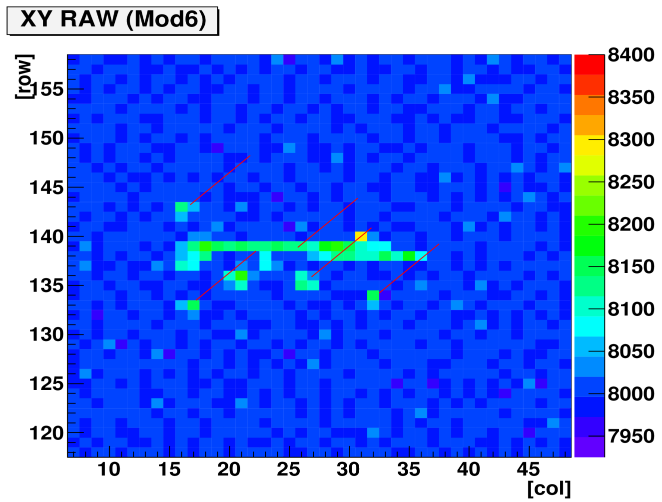
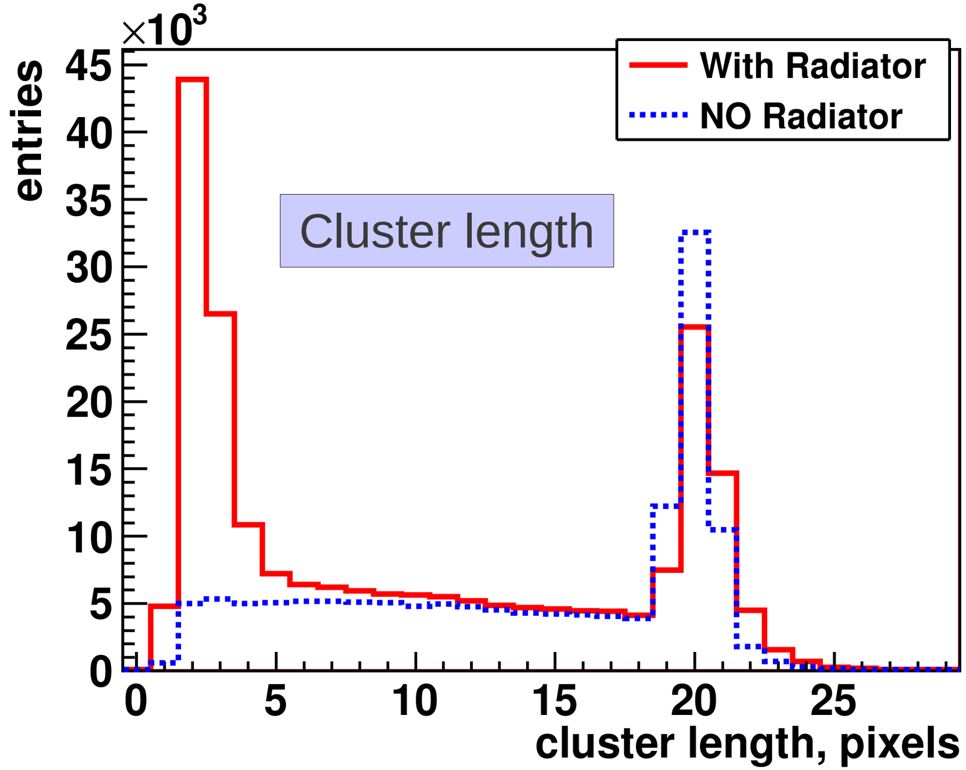
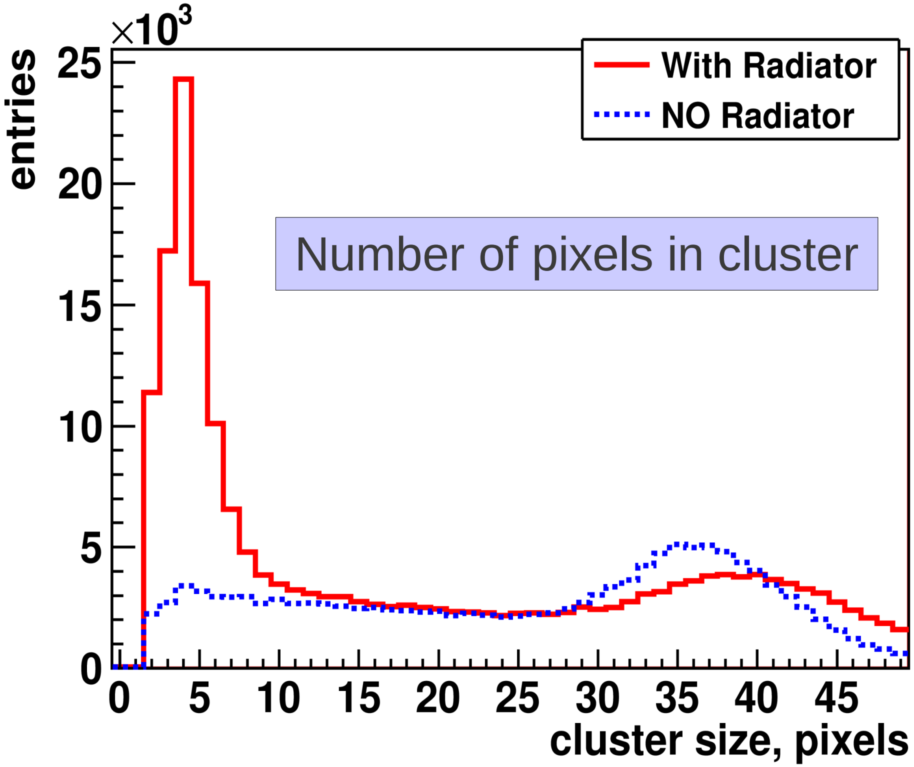


Cluster size

- *Clusters are evaluated by 4 parameters:*
  - Cluster length
  - Cluster width
  - Number of pixels in cluster
  - Cluster energy
- *Runs with radiator has an excess in small cluster size*

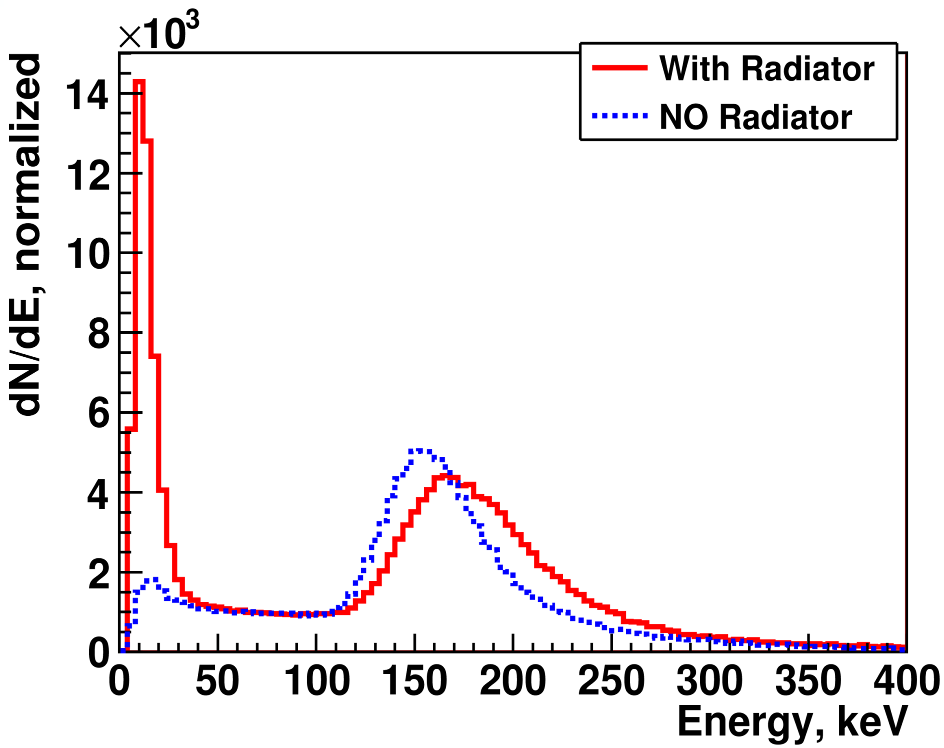


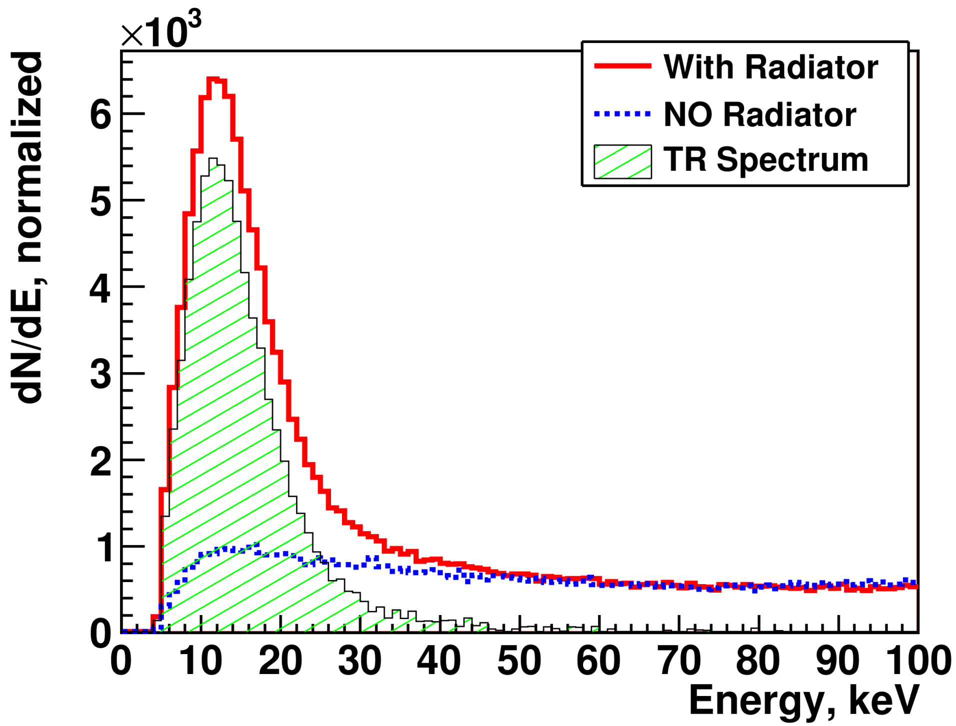




TR absorbed spectrum

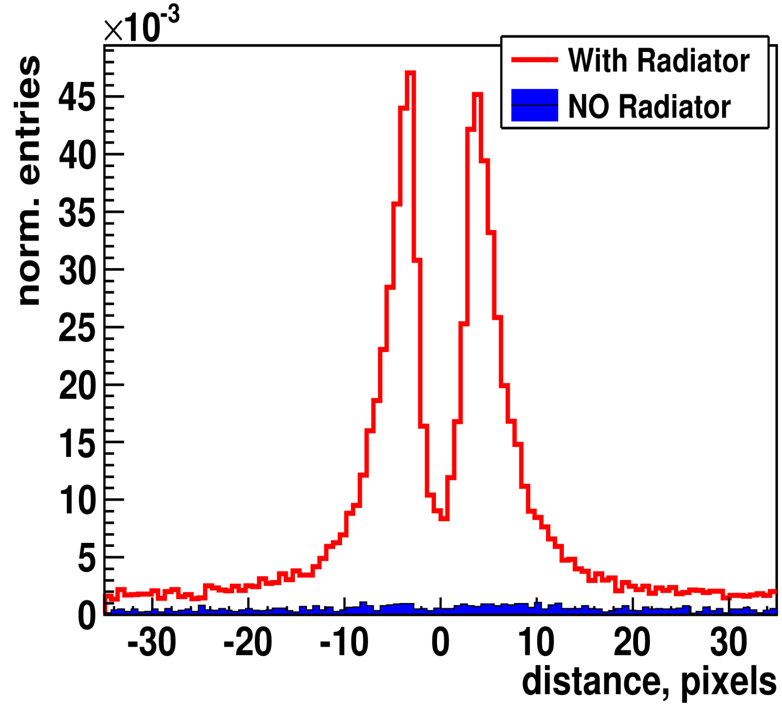
- *On the two pictures below cluster energy distribution are shown for 2 cases – with radiator and without radiator*
- *In case with radiator we have a lot of low energy clusters – Transition Radiation photons.*
- *On the right picture zoomed area is shown*
- *The green histogram represent energy input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

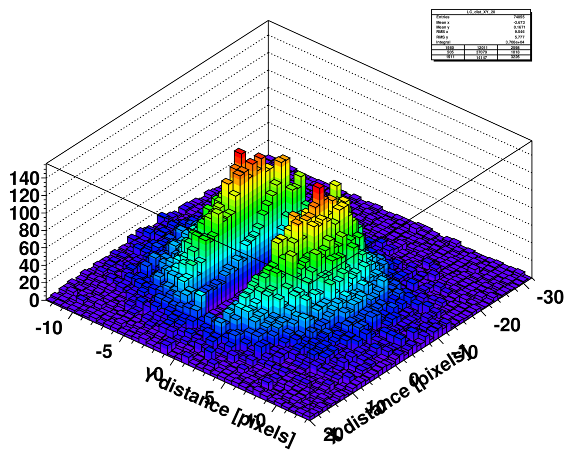


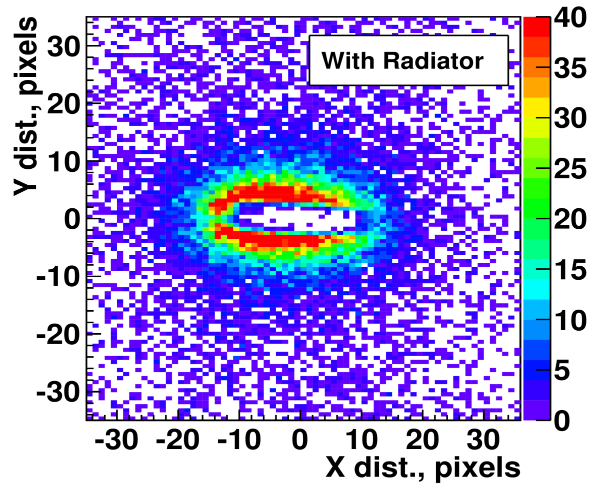


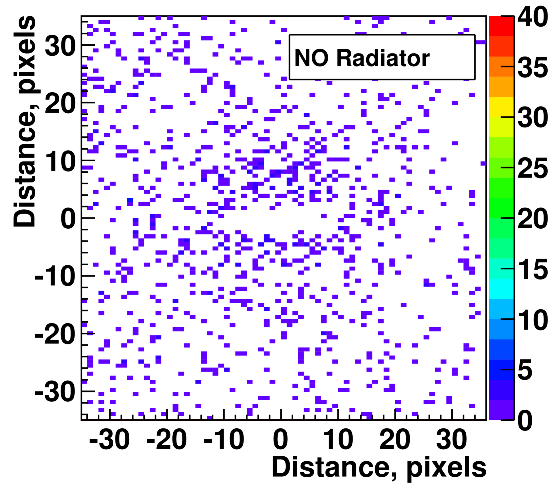
TR angular distribution

- *On the right plot is shown the distance of TR clusters from the particle tack in Y-projection, which represent angular distribution and multiple scattering of TR photons and particles*
- *On the lower left plot is shown the same in 3D*
- *Two lower right plots represent 2D angular distributions of TR clusters (which are defined as compact cluster with size of 1-4 pixels) for electron with radiator and without radiator.*
    - Even without radiation there some clusters are reconstructed. (see next slide)



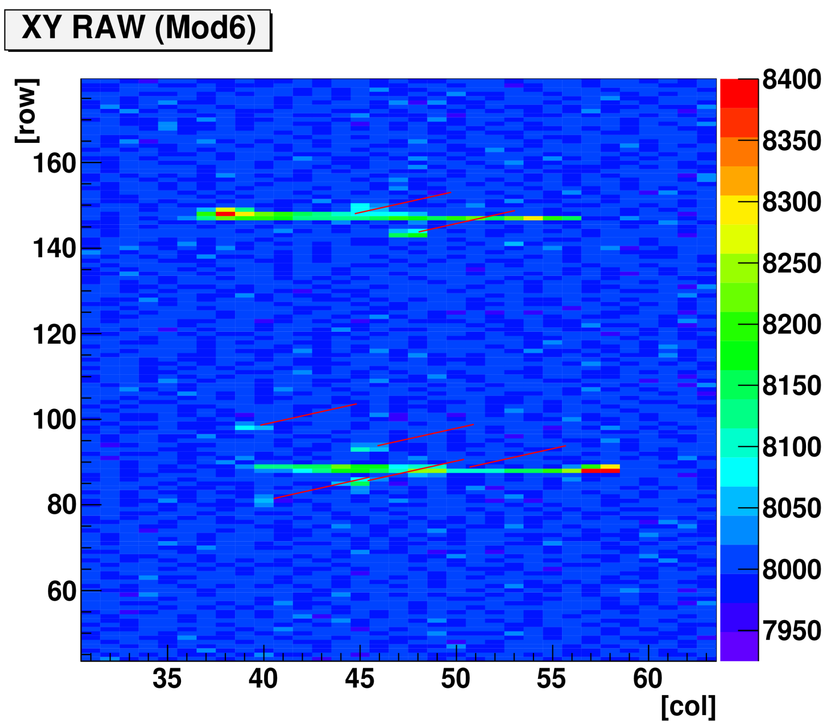




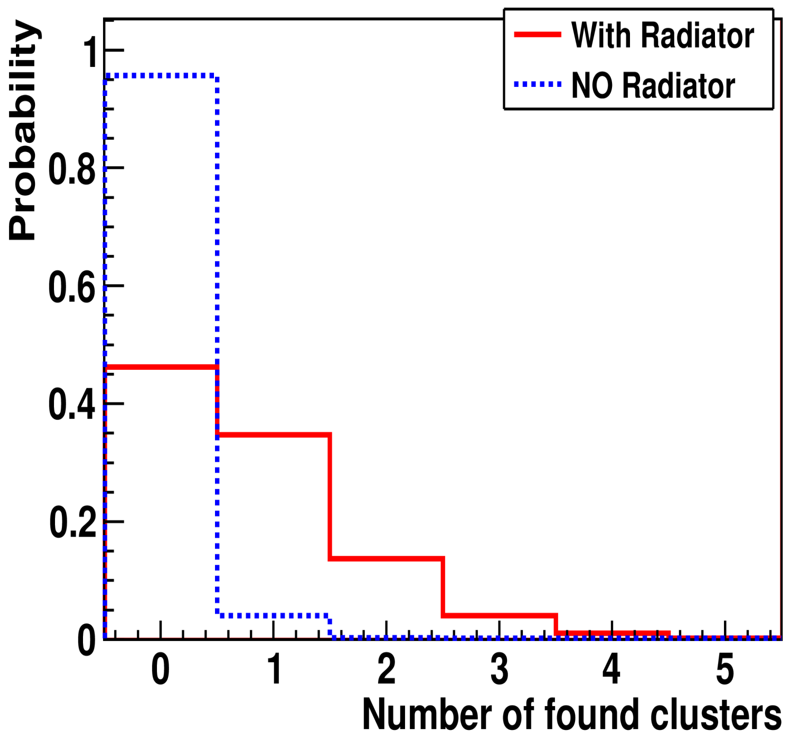


TR clusters efficiency

- *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

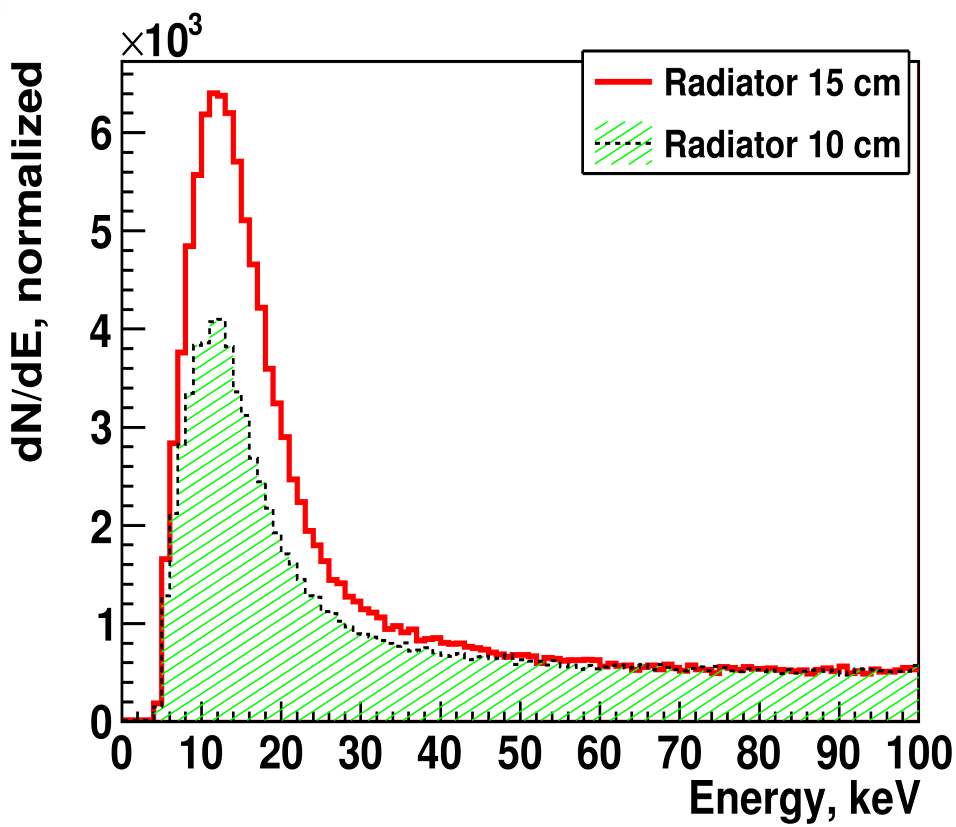


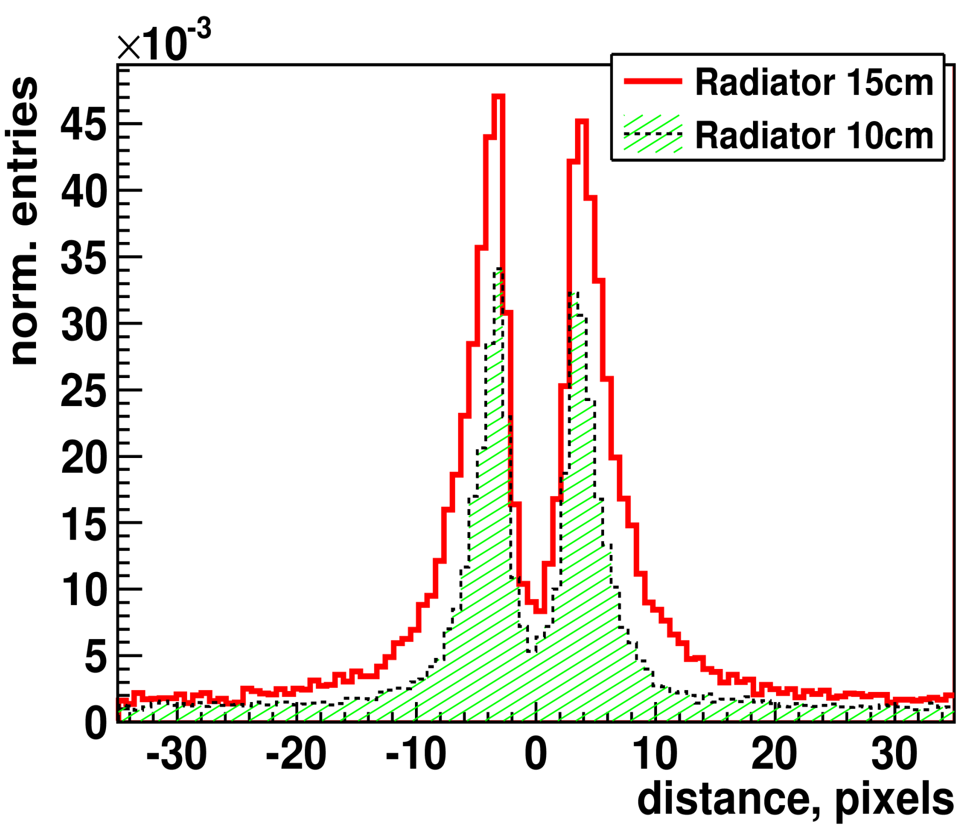
Number of TR photons found per track



Radiator length

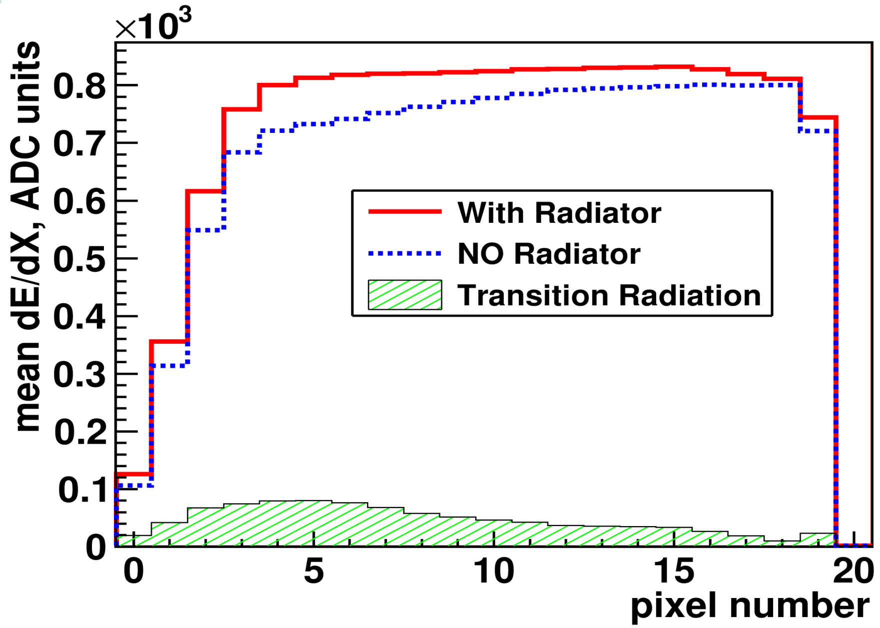
- *The number of TR photons increased with radiator length.*
- *2 pictures represent TR yield for 2 radiator length 10 cm and 15 cm.*
  - The typical density of radiator 0.05 g/cm^3

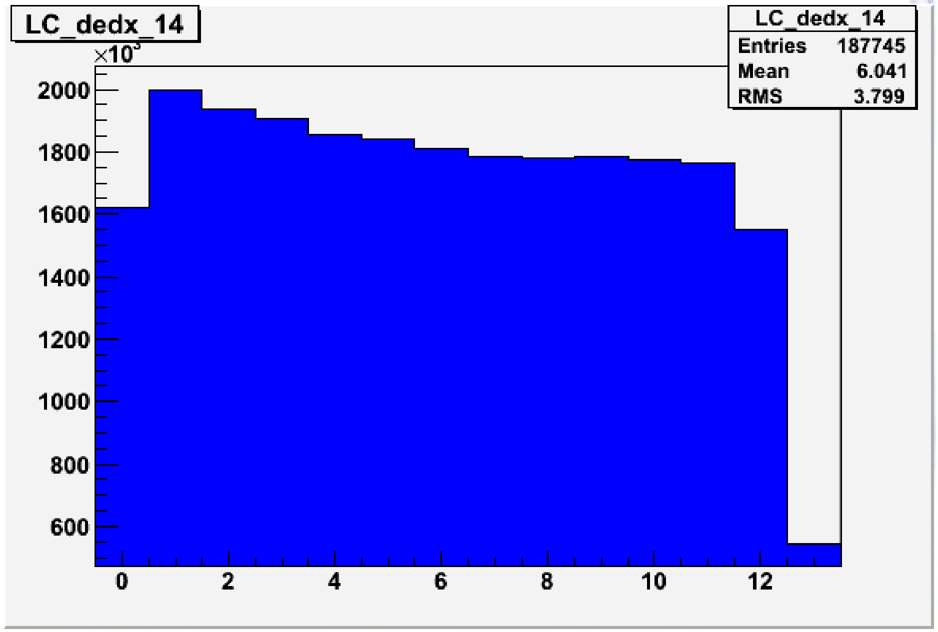




dE/dx vs cluster length

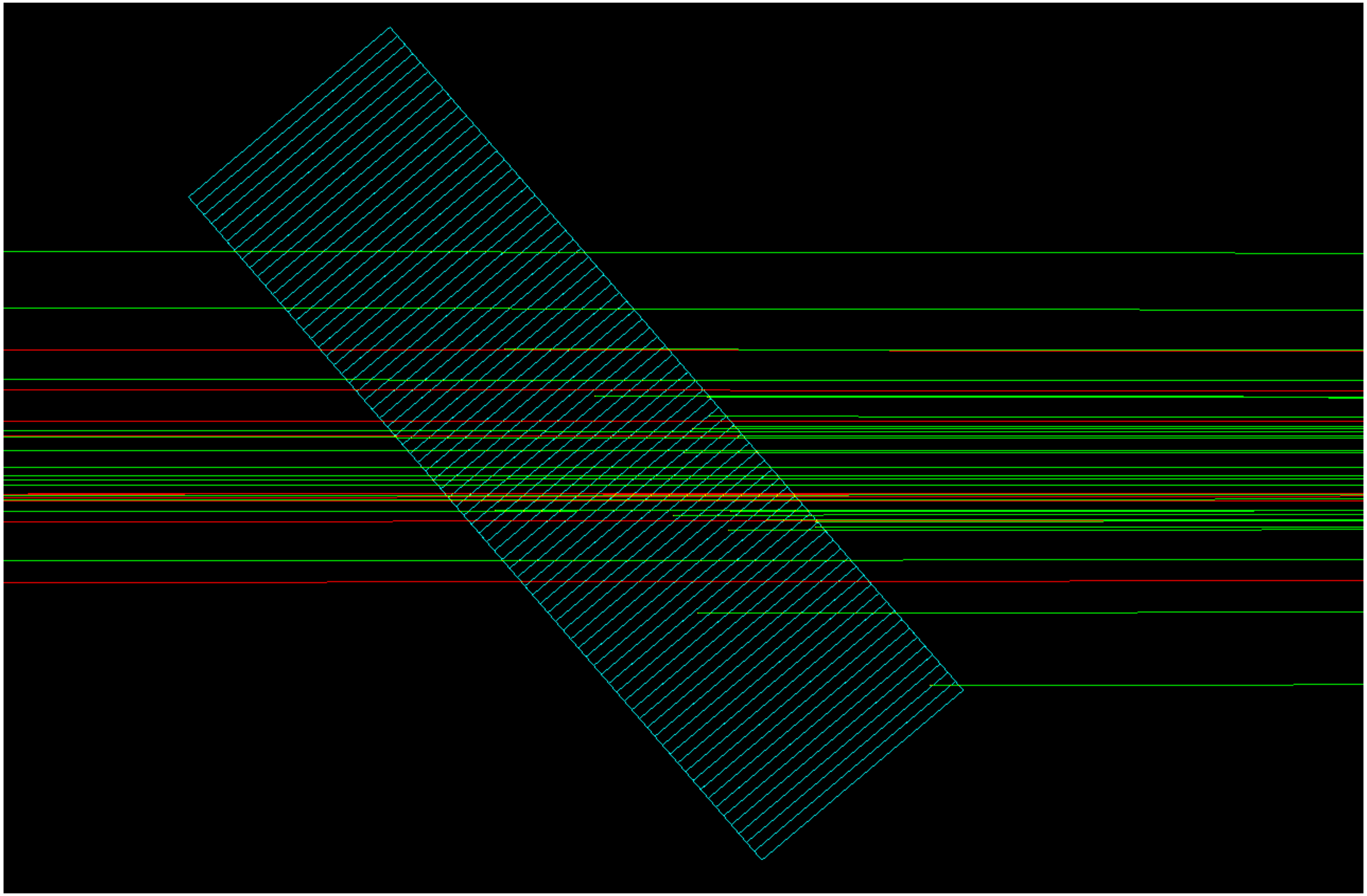
- *Now we return to the original idea – discrimination of TR photons on the top of dE/dx from particle.*
- *Left histogram below shows average dE/dx for each of 20 pixels (20x20µ 41°)*
- *Red line – with radiator, Blue line– without radiator, Red filled area - TR.*
- *dE/dx along track without radiator is non-uniform due to diffusion and also depends on pixel size and geometry of DEPFET. Since the energy in each pixel is compared independently , the bin uniformity is not important.*
    - Right picture shows the same for matrix 24x32µ and 36° angle
        - Note – on the right picture is mirrored – the particles coming from right to left



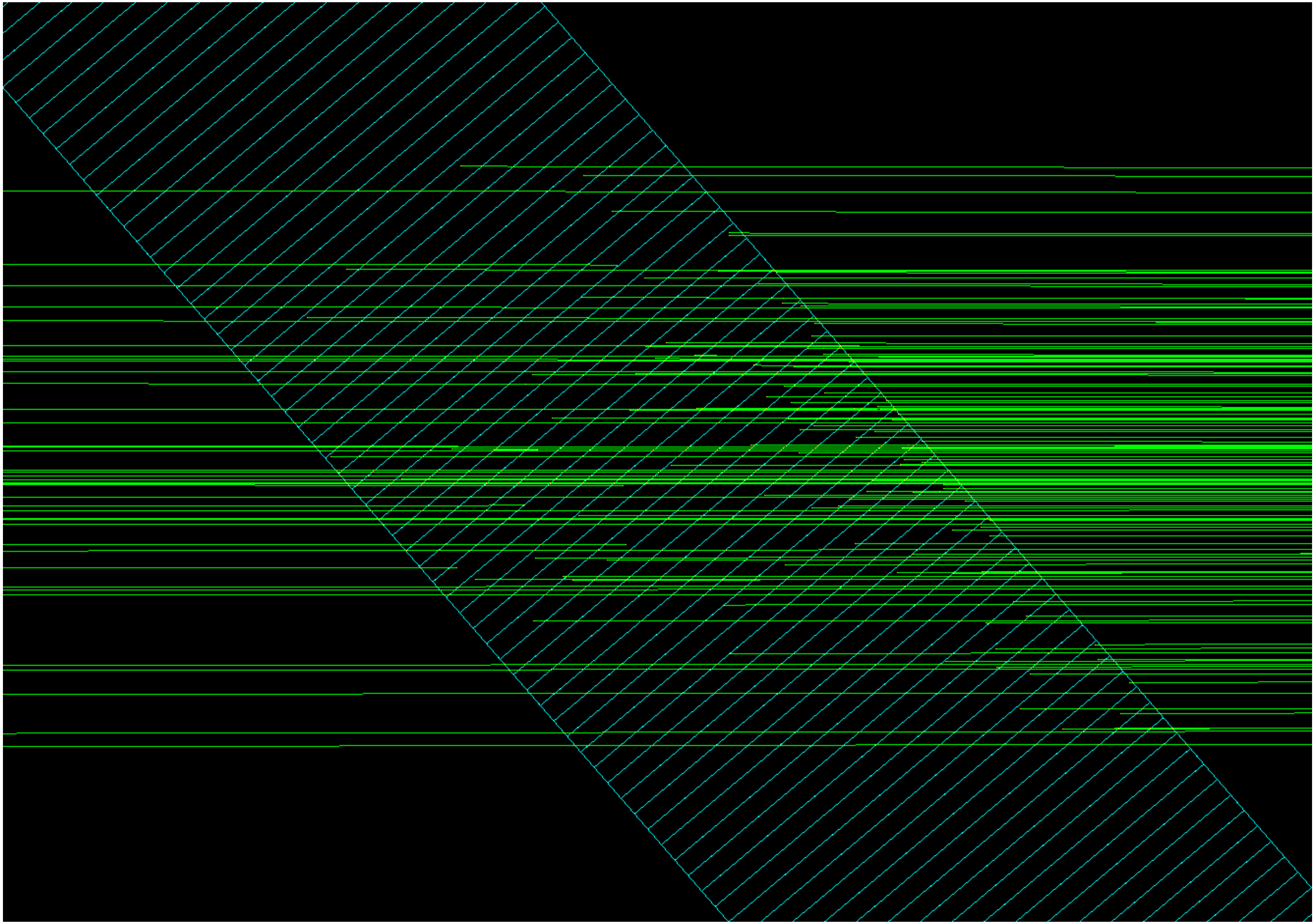


Geant4 simulation

- *Red – electrons tracks*
- *Green: TR photons*

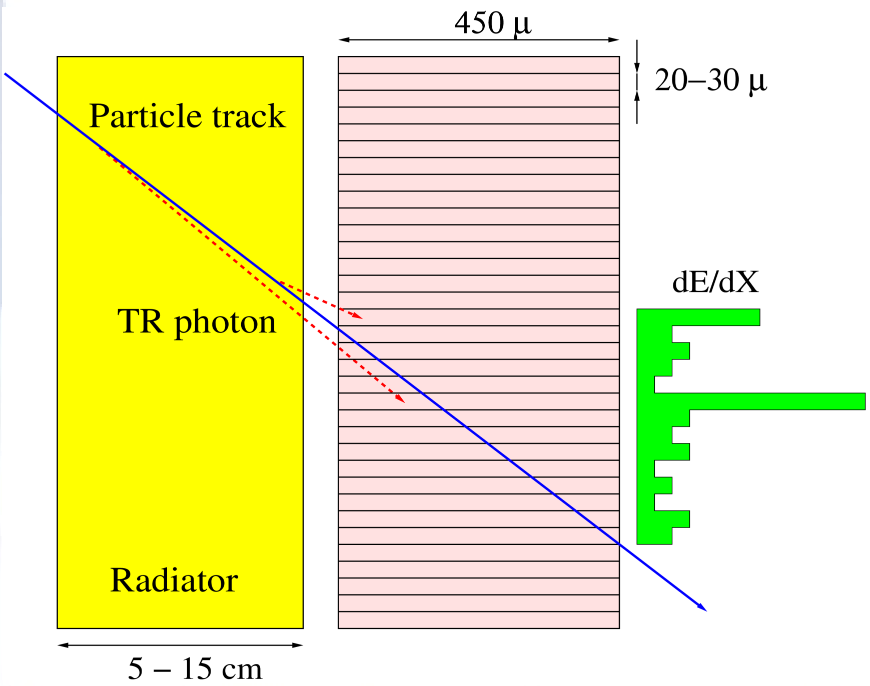


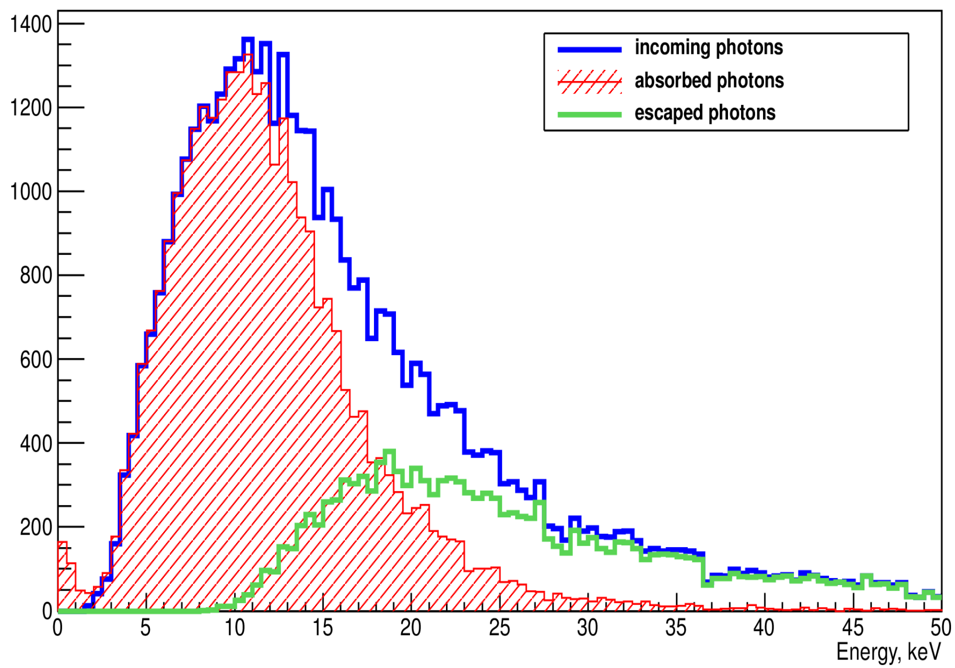
Geant4 simulation



TR photons absorption

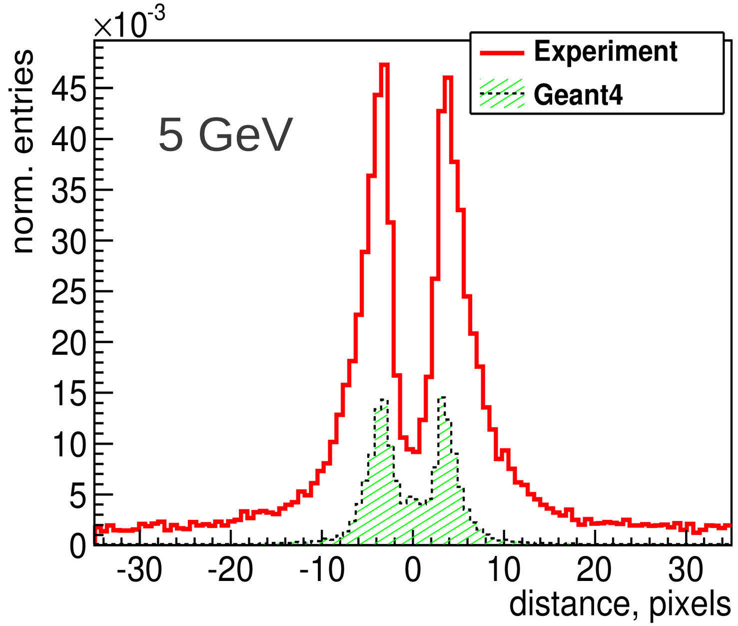
- *DEPFET shows good efficiency for TR photons absorption*
- *DEPFET thickness of 450 um at 41 degree gives a total path in silicon about 600 um*
  - Almost 100% efficiency for photon energy up to 15 keV

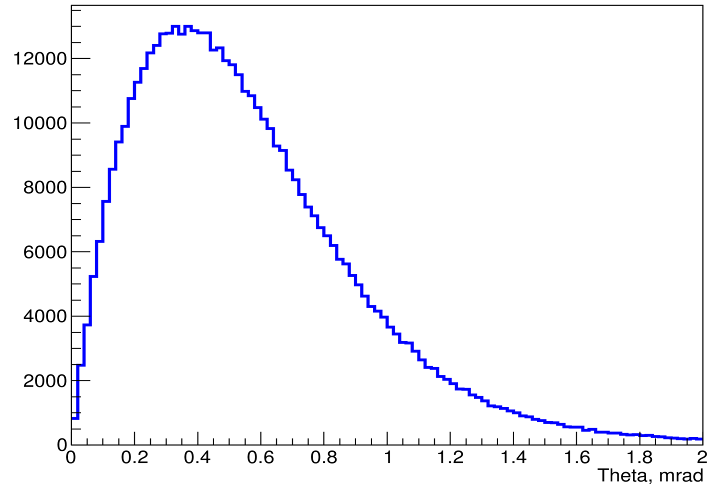




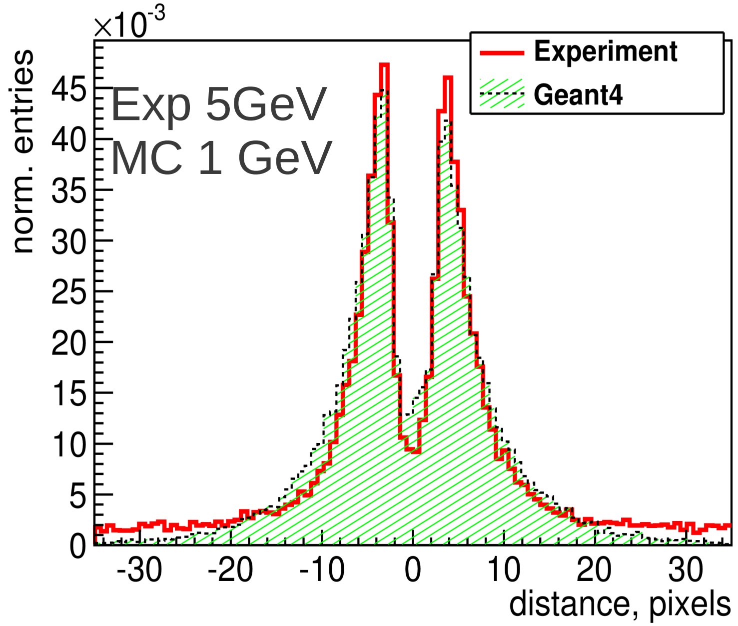
TR angular distribution in Geant4

- *On the right plot is shown the distance of TR clusters from the particle tack   in Y-projection, which represents angular distribution and multiple scattering of TR photons and particles*
- *The reasonable agreement we have in comparison of 5 GeV exp. data with 1 GeV Geant simulation.*
- *Simulation of angular distribution with Geant4 require additional studies to find the source of discrepancy between experimental data and the simulation.*





Angular distribution of TR photons, Geant4

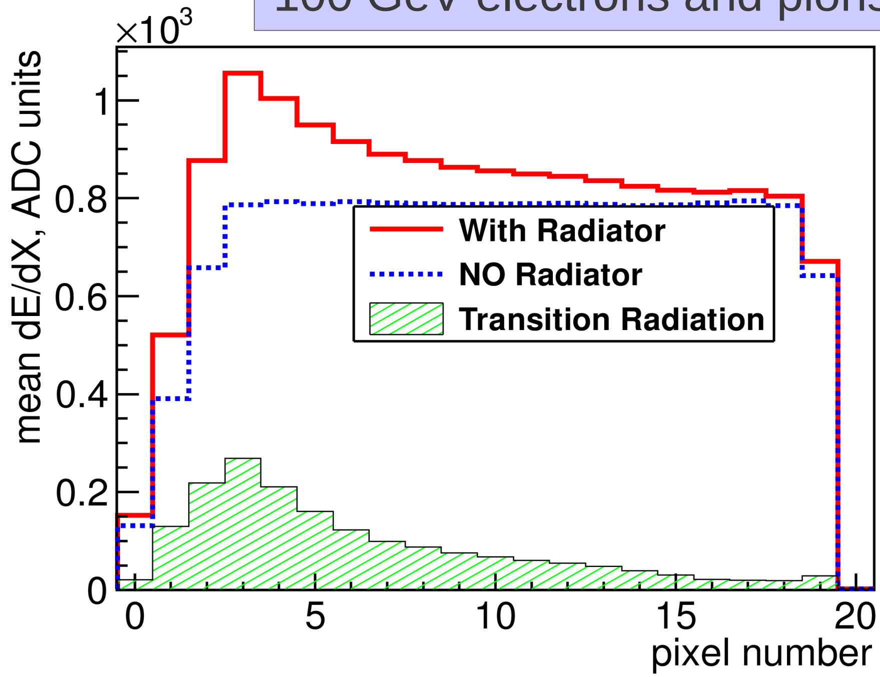


Geant4 results

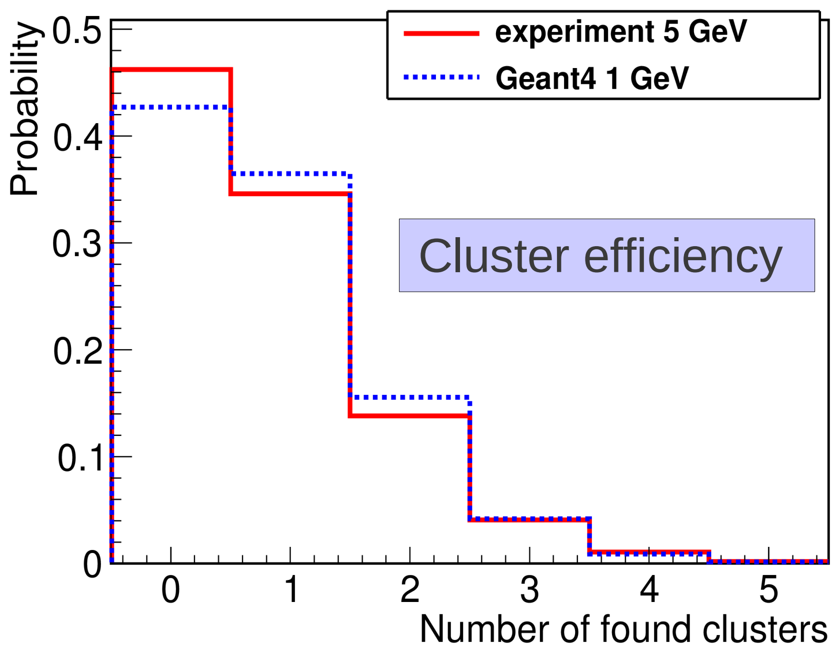
- *MC simulation for high energy electrons predicts more energy absorbed in the first pixels on the track*
- *A good agreement experimental data and Geant4 MC for cluster efficiency can be reached only with lower energy of electrons in Geant4*

dE/dx along the particle track

100 GeV electrons and pions

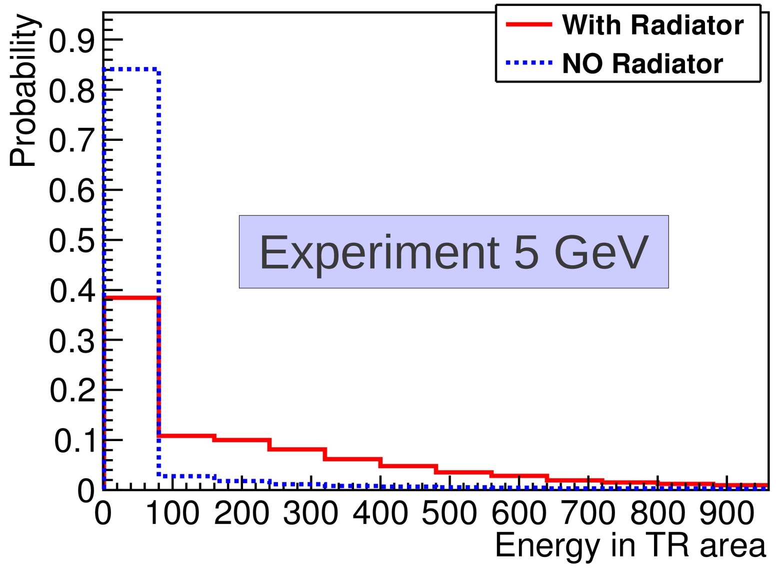


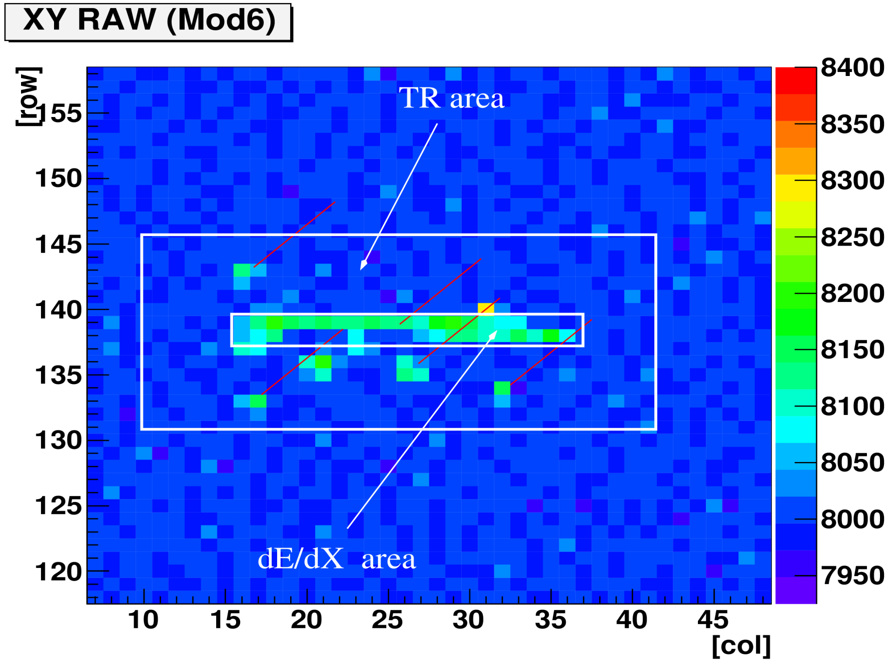
Comparison for
5 GeV experiment
1 GeV Geant

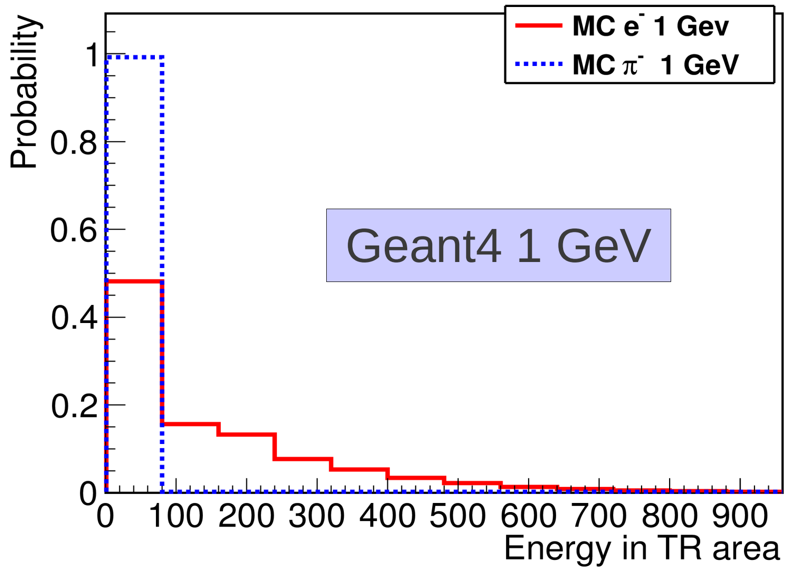


Identification with external track

- *If we have reconstructed track it is possible to calculate energy deposition in 2 areas :*
  - Particle area – here is particle dE/dx and TR photons overlapped with particle track
  - TR area – here is mainly TR photons, delta electrons and other particles in case of high occupancy
- *Energy in TR cluster area could be used for identification*
  - On the right plots are shown energy deposition in TR area for experiment and Geant4 MC

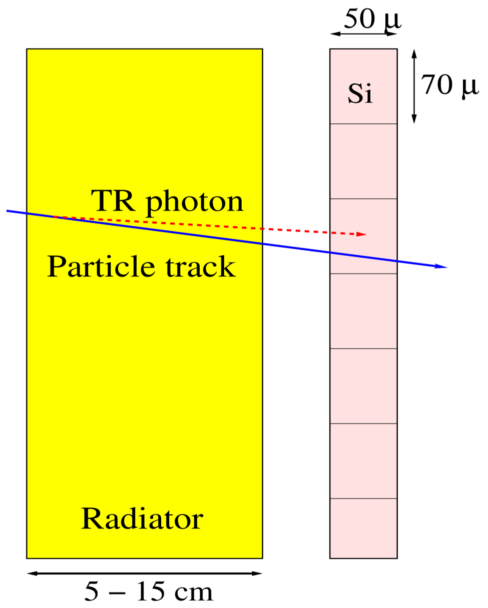


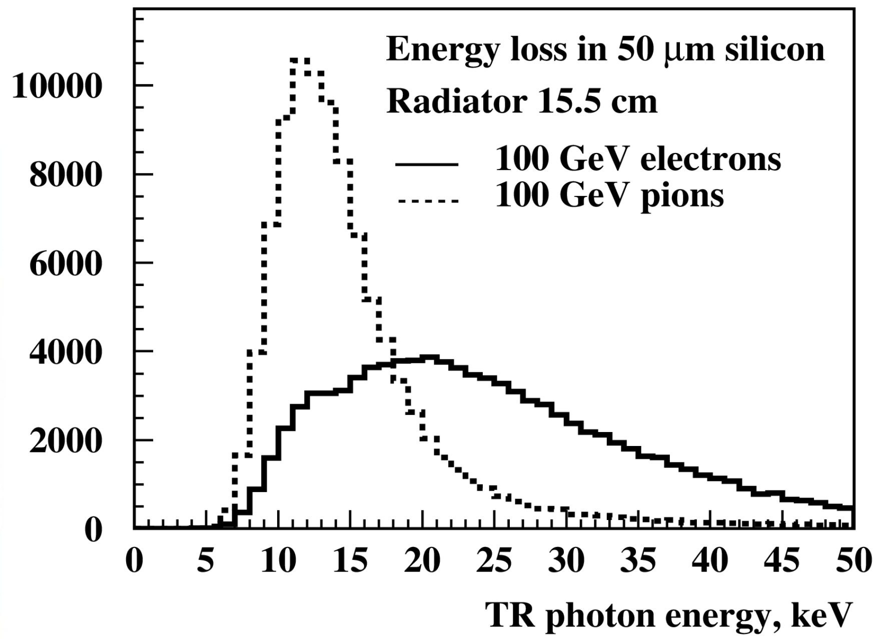


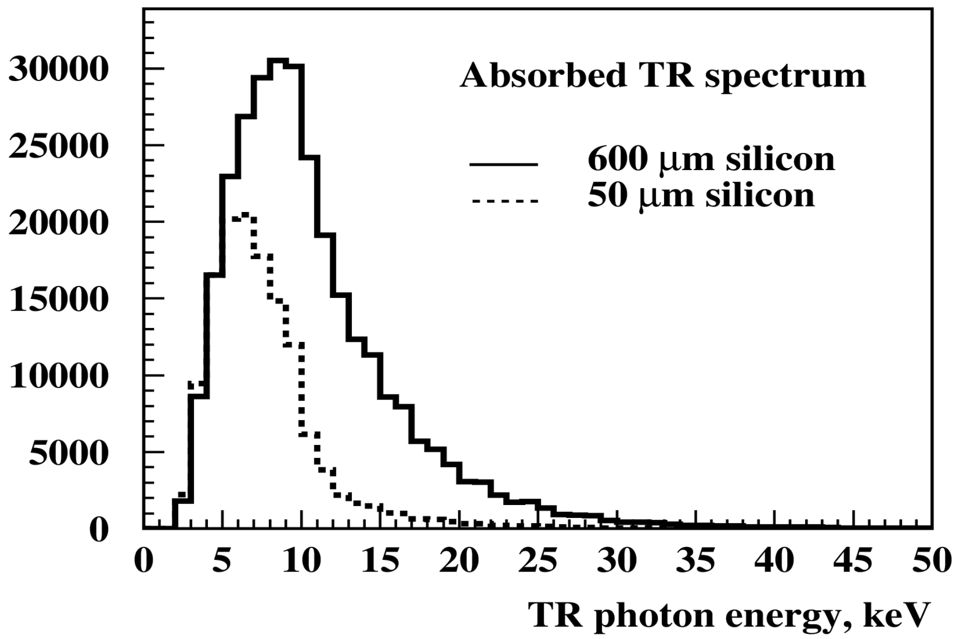


MC simulation for thin sensor

- *Here is some MC result for TRD option with thin DEPFET sensor*
- *The lower left plot show Geant simulation of energy deposition in 50 μm thin DEPFET sensor for 100 GeV electrons and pions.*
- *The main problem for identification is lower TR absorption efficiency*
  - Lower right plot shows comparison for 50 μm and 600 μm sensor
- *The real beam tests with thin DEPFET are planned for this October*







Electron identification

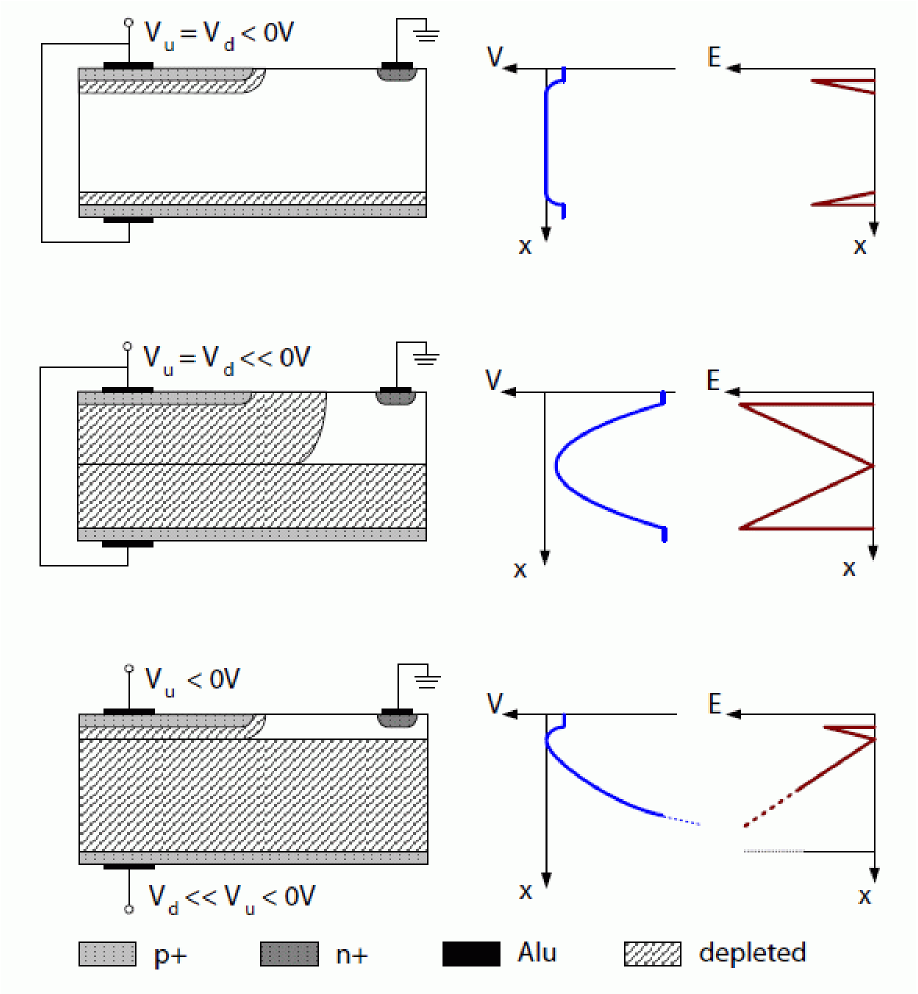
- *For electron identification we have two geometry options - thin and thick sensor, and two particle energy regions: high energy – without angular distribution of TR photons, and low energy where TR photons are separated from the particle track due to natural angle of generated photon and multiple scattering of particle.*
- *High energy electrons*
  - TR photons follow the particle track
  - TR photons absorbed in fist pixels of DEPFET sensor.
  - Additional ionization from TR photons is used for electron identification
- *Low energy electrons*
  - TR photons has large enough angular distribution to find TR cluster separated from track
  - Presence of TR cluster close to track could be used for particle identification
  - If we have reconstructed track – we can calculate the energy deposition in TR area around the particle pixels and to use it for identification.
- *Up to now the only high energy option are estimated with Monte Carlo, using likelihood method and artificial neural network for electrons and pions of 100 GeV both. (Likelihood shows the better result).*
  - Thick sensor: the pion rejection factor of about 100 is achieved with 4-5 layers of radiator+silicon
  - Thin sensor: 8-9 modules are needed to achieve a pion rejection factor of ~80.

Outlook

- *DEPFET as transition radiation detector shows promising results*
- *Additionally to identification it could also provide high accuracy tracking*
- *It has some advantages on gas detectors :*
  - better spacial resolution for tracking
  - no heavy equipment are needed – gas vessels and gas distribution system
  - no HV power
  - working time is not limited by gas volume in bottles (important in space)
- *Also silicon TRD has some drawback*
  - Higher dE/dx for charged particles
  - Low Z hence lower absorption of TR photons
  - Radiation tolerance
  - Price and availability
- *New Beam Tests at CERN SPS are planned for October 2011*
  - To have a pure electrons we plan to use external identificator
- *Also important to find the source of discrepancy between Geant4 and experiment for TR angular distribution*
- *As a long term plan: a detailed performance simulation of multilayer DEPFET / TRD for different methods of TR discrimination and energies of particles*

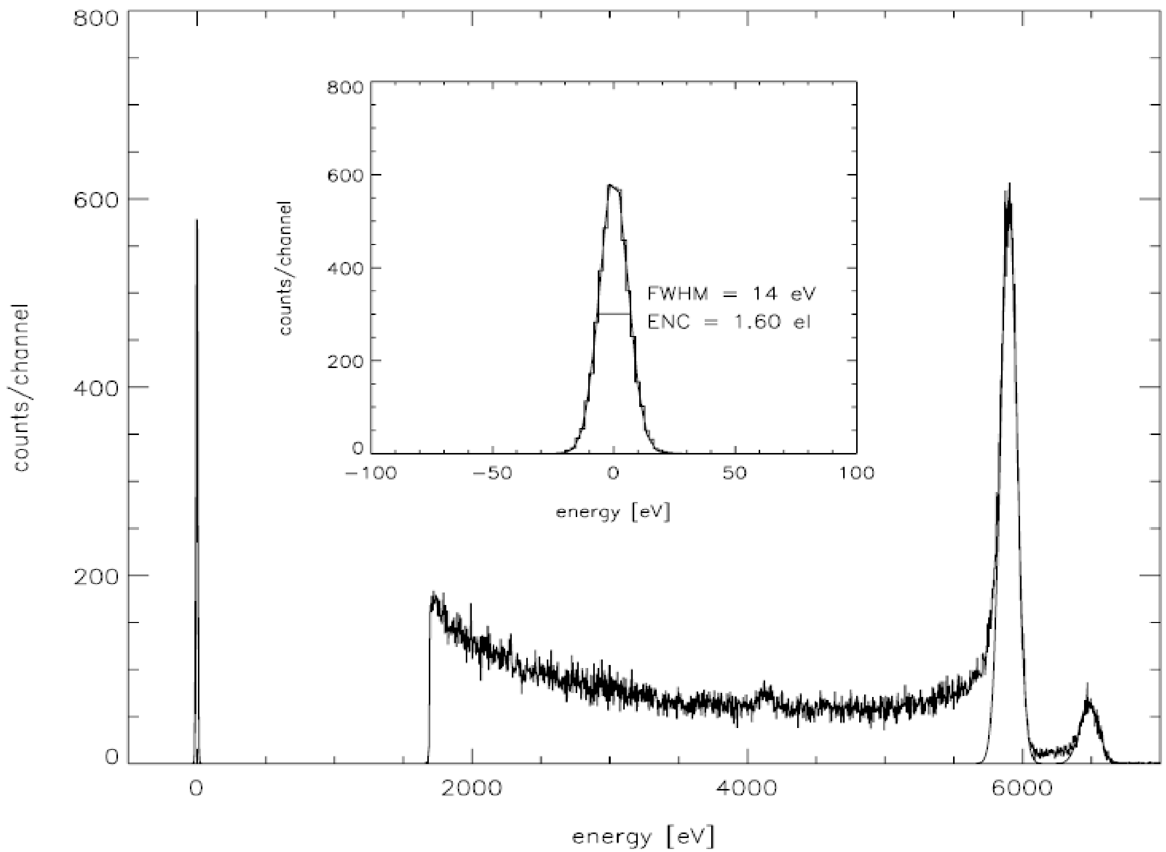
Backup Slides

DEPFET sidewards depletion



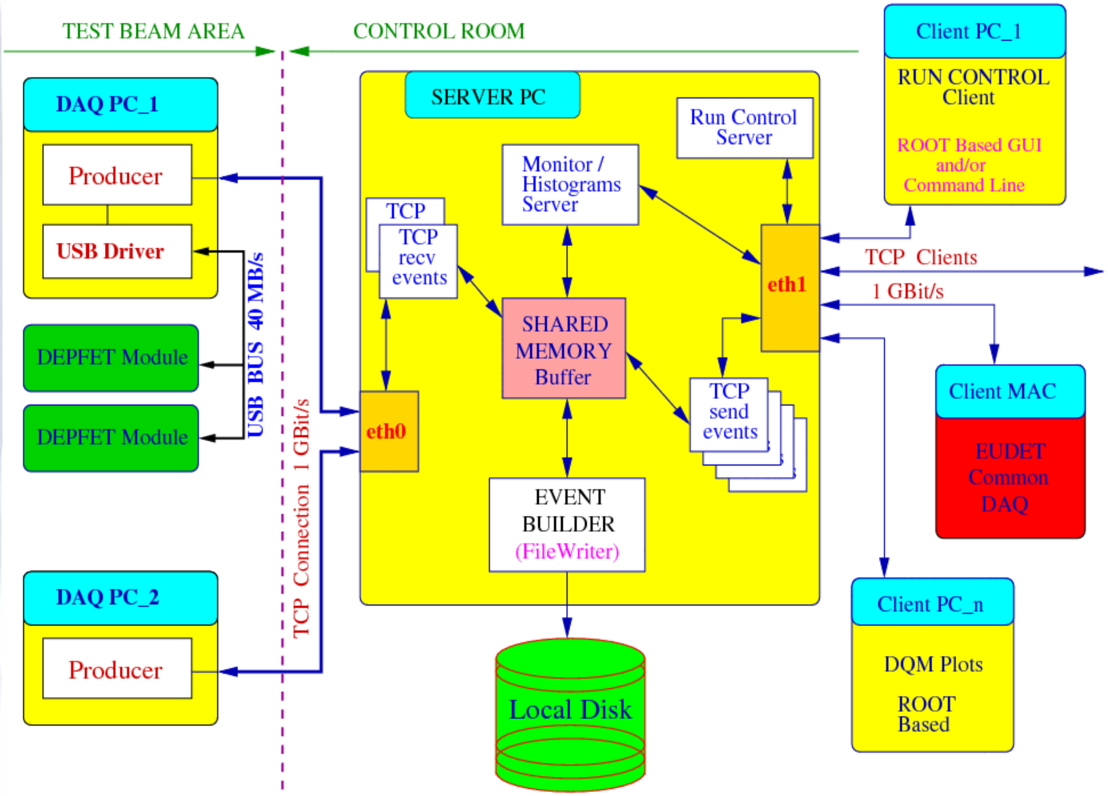
DEPFET noise

- *DEPFET shows a good noise performance:*
  - In lab tests an equivalent noise charge of ENC=1.6 electrons at root temperature has been measured



Network DAQ System

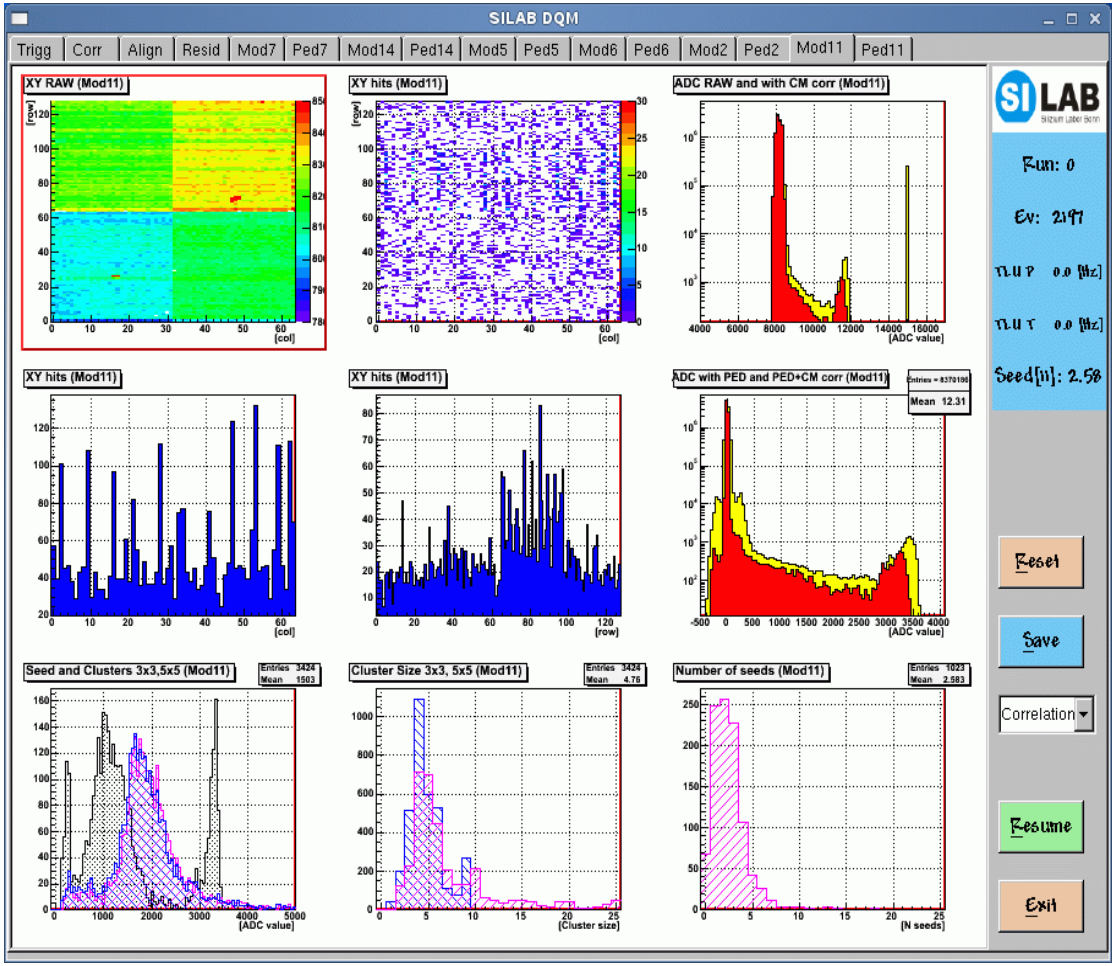
- *DAQ is based on Linux network distributed client/server architecture which allows :*
  - share resources and tasks
  - easy scale the system
  - remote control and monitoring
  - easy integration of other detectors



- *DAQ uses USB 2.0 for data transfer from DEPFET R/O board to PC and TCP/IP to send data to Event Builder .*
- *The DAQ components are:*
  - a LINUX based USB driver for the DEPFET DAQ board
  - a USB readout client transferring data to an event builder via network;
  - an Event Builder assembling complete events and storing in a shared memory buffer;
  - an event server send complete event to consumers (file writer, DQM, upper level DAQ, histogram server);
  - online Data Quality Monitoring (DQM) package based on ROOT.
- *Run control server can accept commands from different clients:*
  - Command line interface via Telnet
  - TCL/TK or Root GUI
  - Another program with TCP connection to Run Control

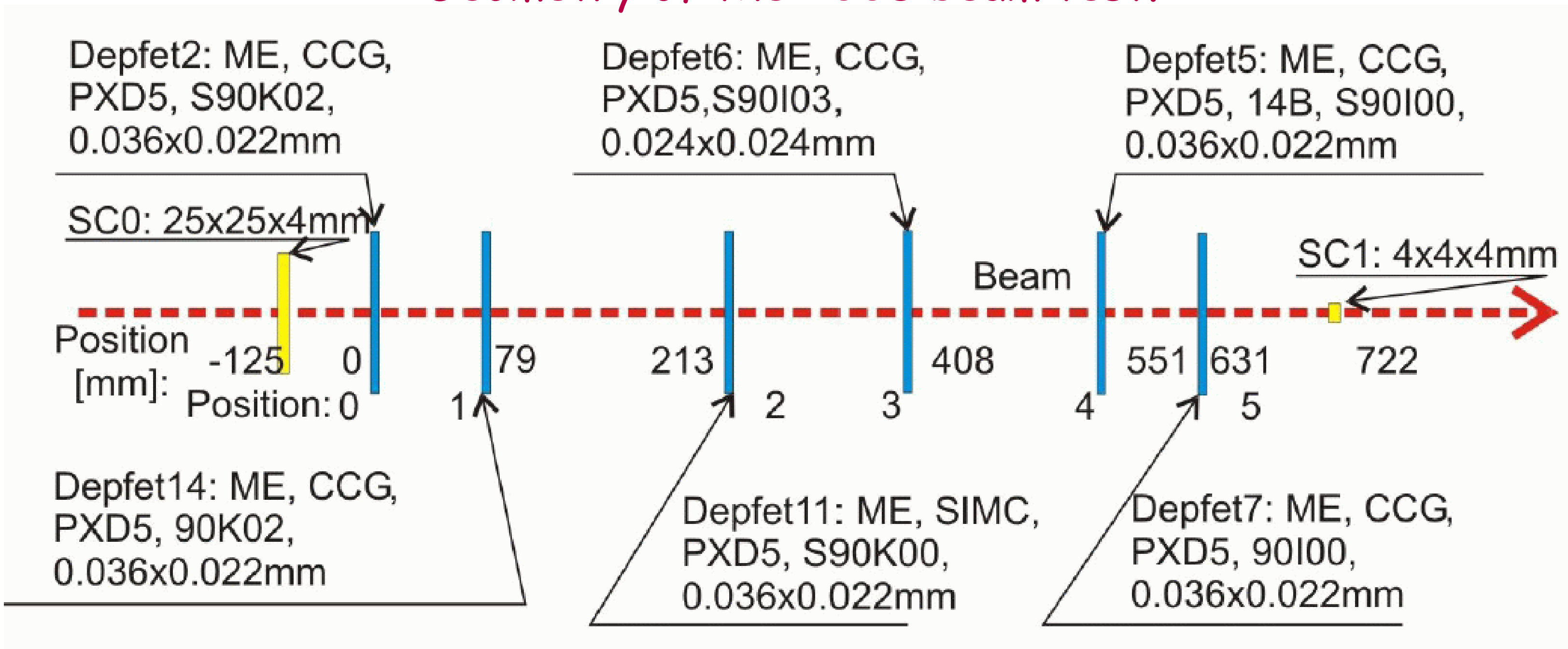
Data Quality Monitor

- *Network Data Acquisition system allows to run powerful Data Quality Monitor on dedicated PC in real time*
- *DQM is based on ROOT :*
  - includes various data access methods : file, shared memory, network
  - online data processing – pedestal and common mode calculation, cluster reconstruction and simple tracking.
  - can also act as network histogram server
- *advanced DQM functionality allows to find most of DAQ and DEPFET matrix problems during the run*
- *WEB interface for remote DQM*



Final TB 2008 resolution

Geometry of the 2008 beam test.



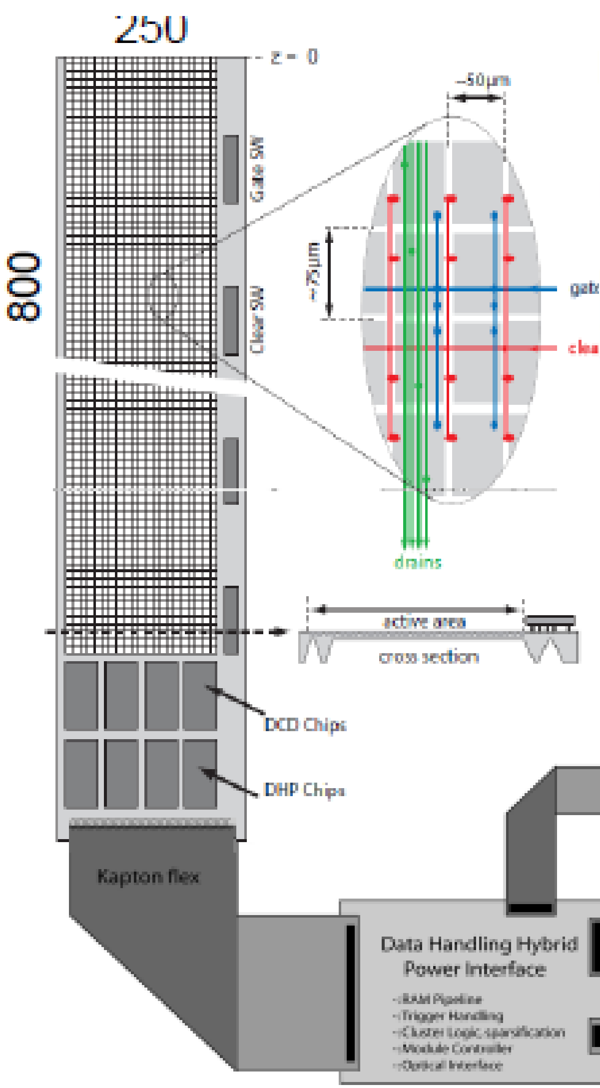
Final residuals and resolutions from Prague analysis

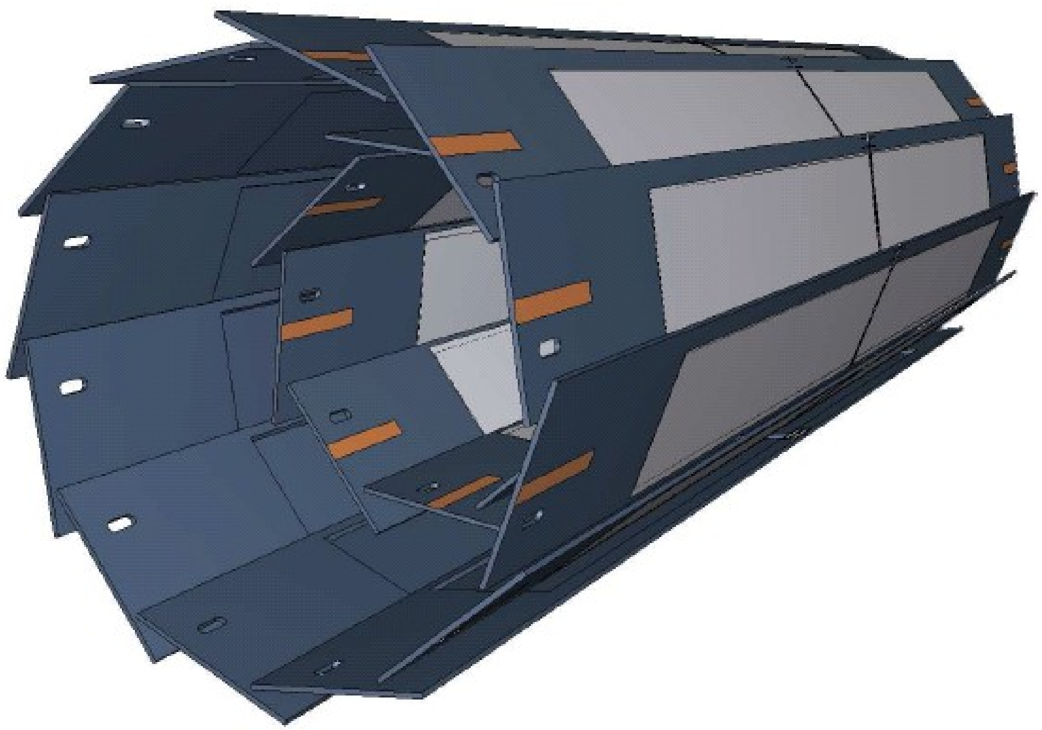
Y resolution [μm]	Module 0 CCGME- -S90K02 32x24 μm	Module 1 CCGME- -90K02 32x24 μm	Module 2 SIMCME- -S90K00 32x24 μm	Module 3 CCGME- -S90I03 24x24 μm	Module 4 CCGME- -S90I00 32x24 μm	Module 5 CCGME- -90I00 32x24 μm
X residual [μm]	2.9	2.2	2.3	2.0	3.1	3.4
Y residual [μm]	2.3	1.7	1.7	1.7	2.2	2.6
X resolution [μm]	2.1	1.6	1.9	1.3	2.6	2.4
Y resolution [μm]	1.5	1.3	1.2	1.2	1.8	1.7

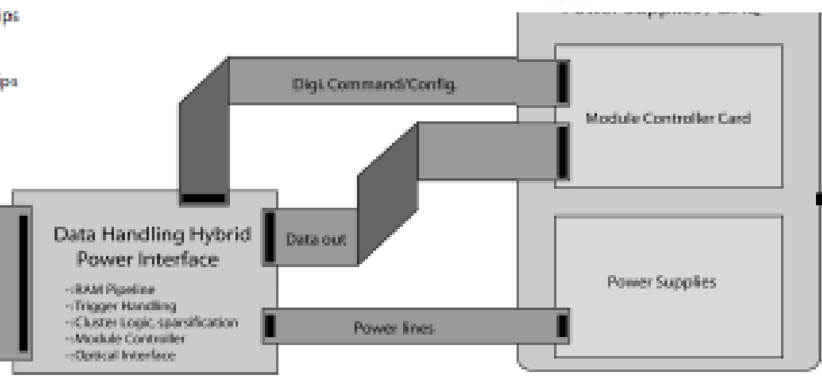
DEPFET for Belle II

2 layers: @1.4(2.2) cm

Pixels: 50 x 50(75) µm   75µm thick 0.18% X_0







2 MPixel

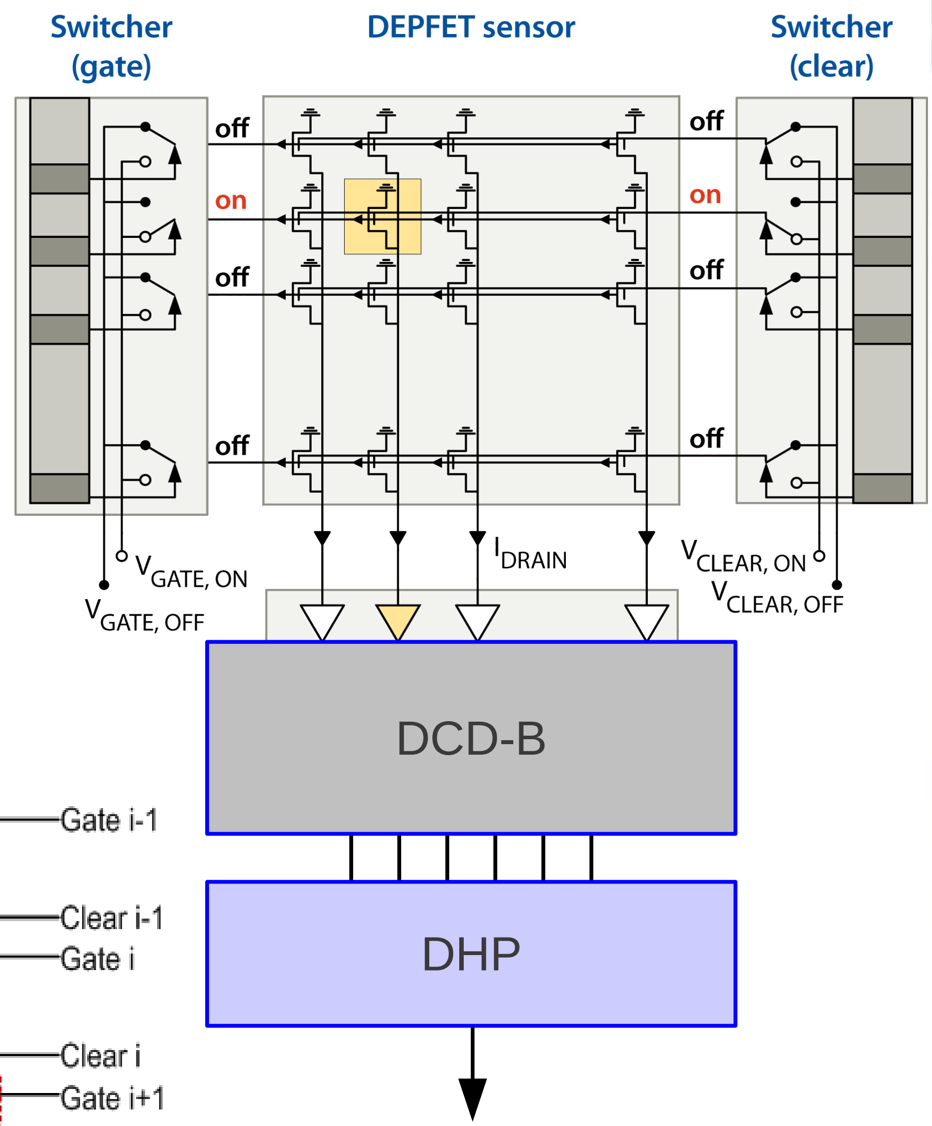
Optical links

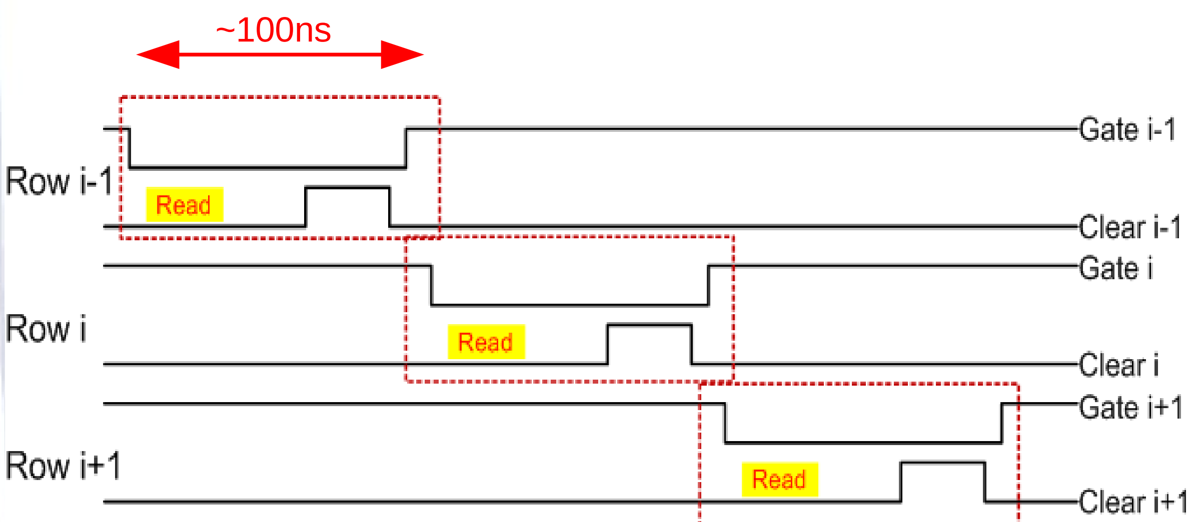
COMPUTE NODE

Power consumption in sensitive area: 0.1W/cm² => air-cooling sufficient

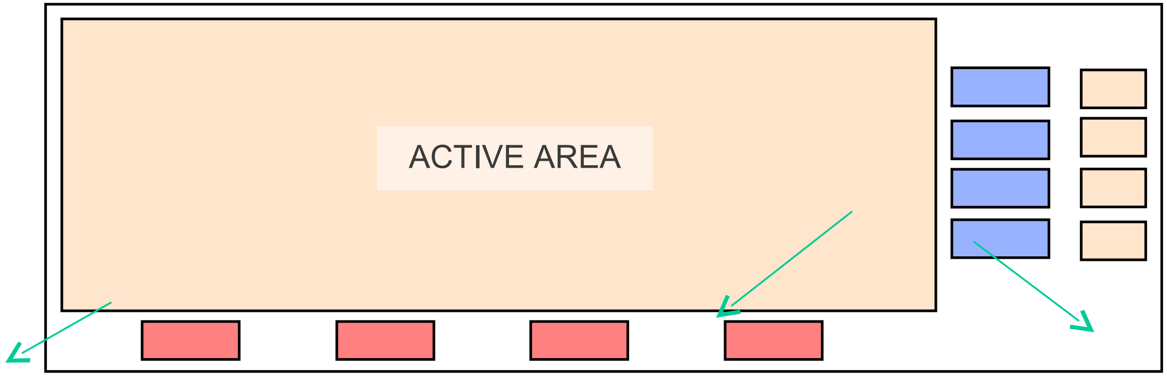
DEPFET readout sequence

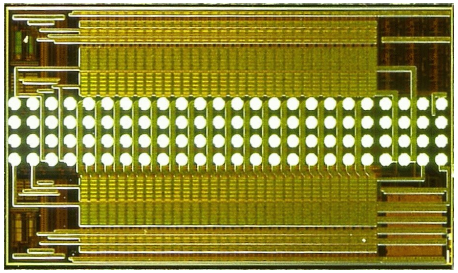
- *Row wise readout (Rolling Shutter)*
- *The SWITCHER chip generates the steering signals for the rows - GATE and CLEAR.*
- *Readout chip processes all columns in parallel*
- *DEPFET readout sequence (single sampling) :*
  1. select row with external gate
  2. readout transistor current
  3. clear charge from internal gate
  4. select next row

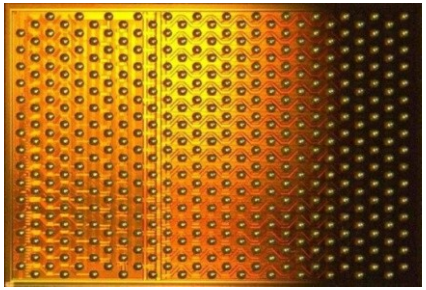


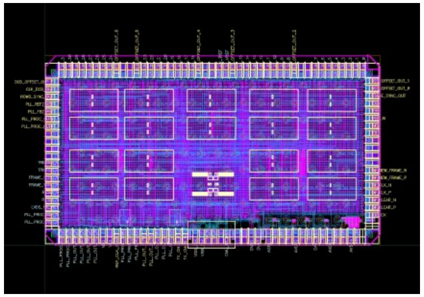


ASICs for control and readout









Switcher
Control of gate and clear
32 x 2 channels
Switches up to 30V
AMS 0.35 µm HV technology
Tested up to 36 Mrad

DCDB
Amplification and digitization of DEPFET signals
256 input channels
8-bit ADC per channel
92 ns sampling time
UMC 189nm
Rad hard desiign

DHP
Signal processor
Common mode correction
Pedestal subtraction
0-supression
Timing and trigger control
IBM 90 nm
Rad hard design
½ size (32 channel) test chip

All three chips fabricated and tested