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MEDIPIX: Status Update For An Active Real-time Space Radiation Dosimeter

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All TimePix Results Courtesy of Stanislav Pospisil and Jan Jakubek
Czech Technical University, Prague, Czech Republic

Medipix Slides Courtesy of Michael Campbell
CERN, Geneva, Switzerland

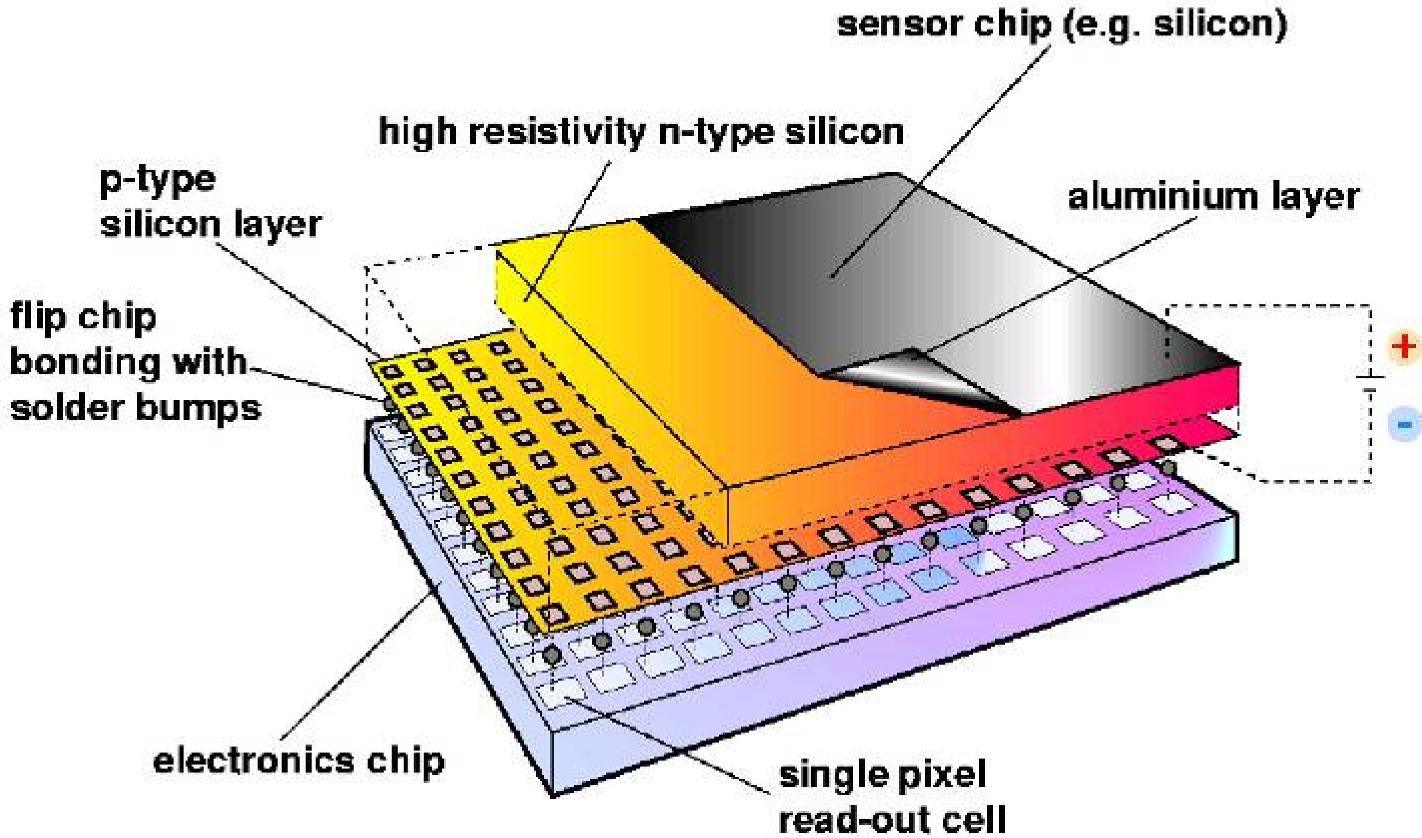
WHAT IS MEDIPIX2 DETECTOR?

Medipix2 is a pixel-based detector technology that can be employed to measure charged particles, photons (IR through gammas), and neutrons. It is based on a read-out chip that embeds the electronics for each pixel within the pixel's footprint!

Outline of This Talk

- Review of The Medipix2 Chip and Readout System…
- Timepix—First Results From the Next generation of Medipix2 Devices
- Where Do We Go From Here With Medipix…

Hybrid Pixel Detector

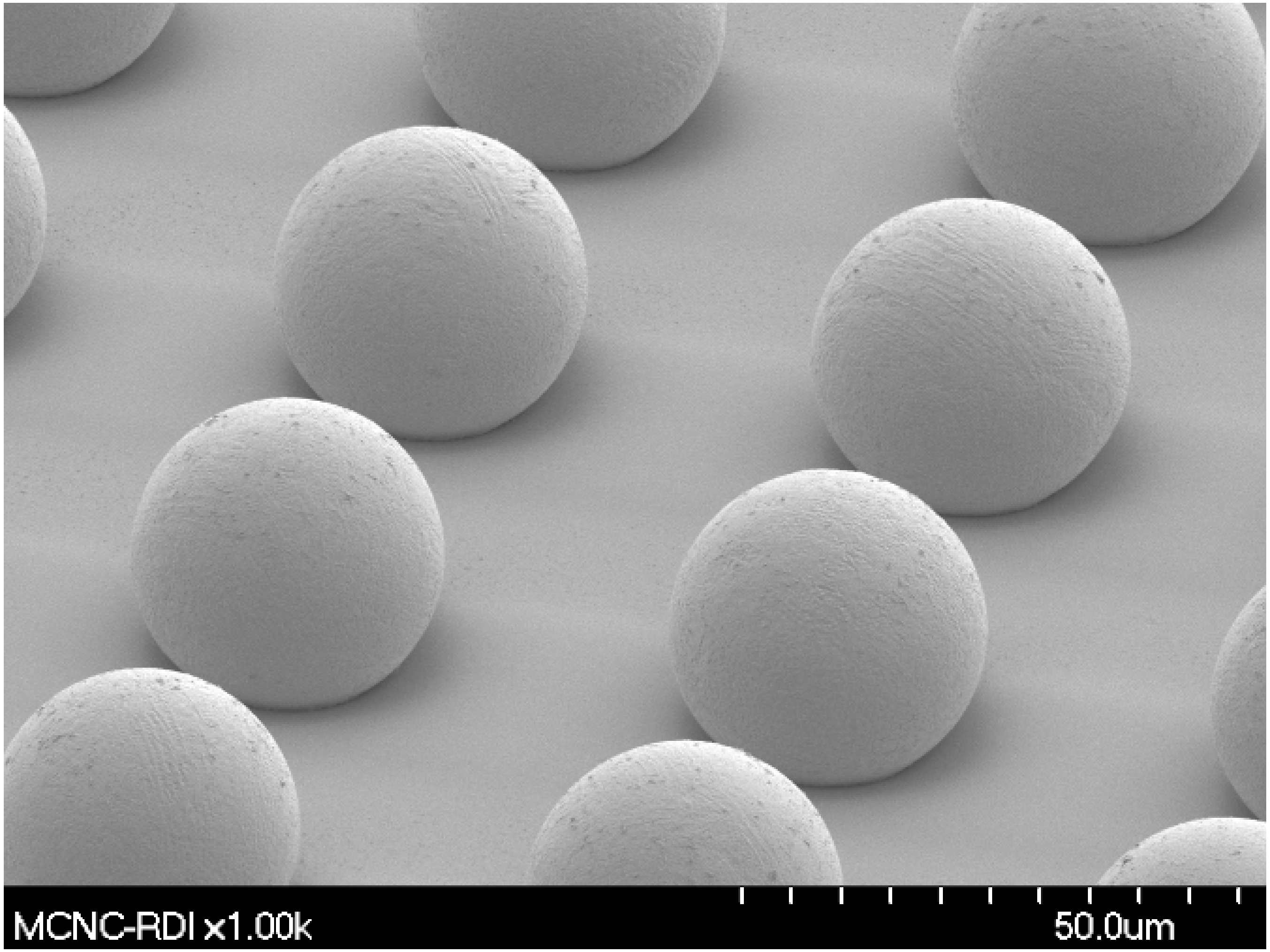


Detector and electronics readout are optimized separately

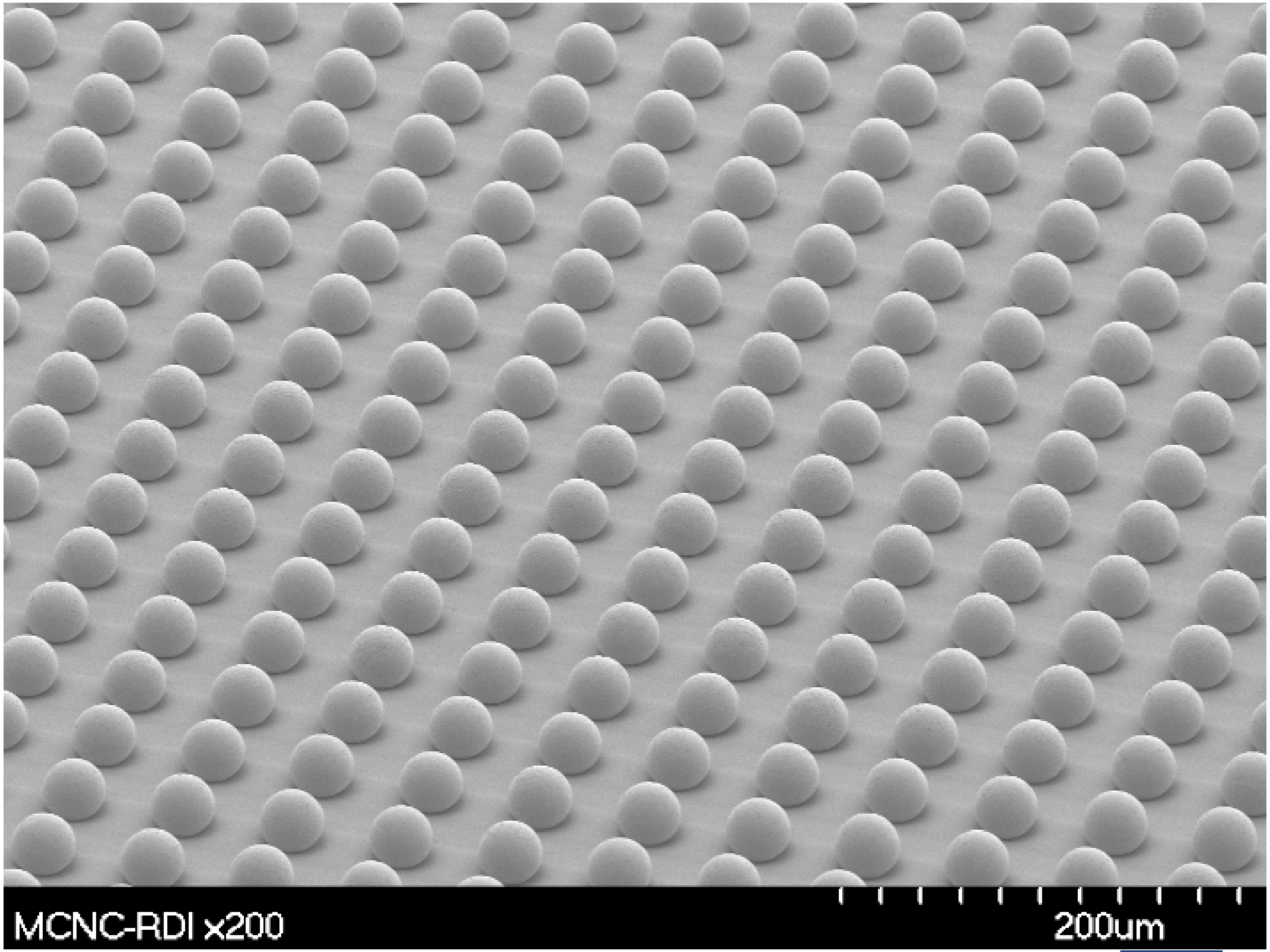
Hybrid Pixel Detector - Cross Section

This technology is an extension of designs originally developed for use in the CERN LHC Central Trackers

Bumps on the readout side – close up

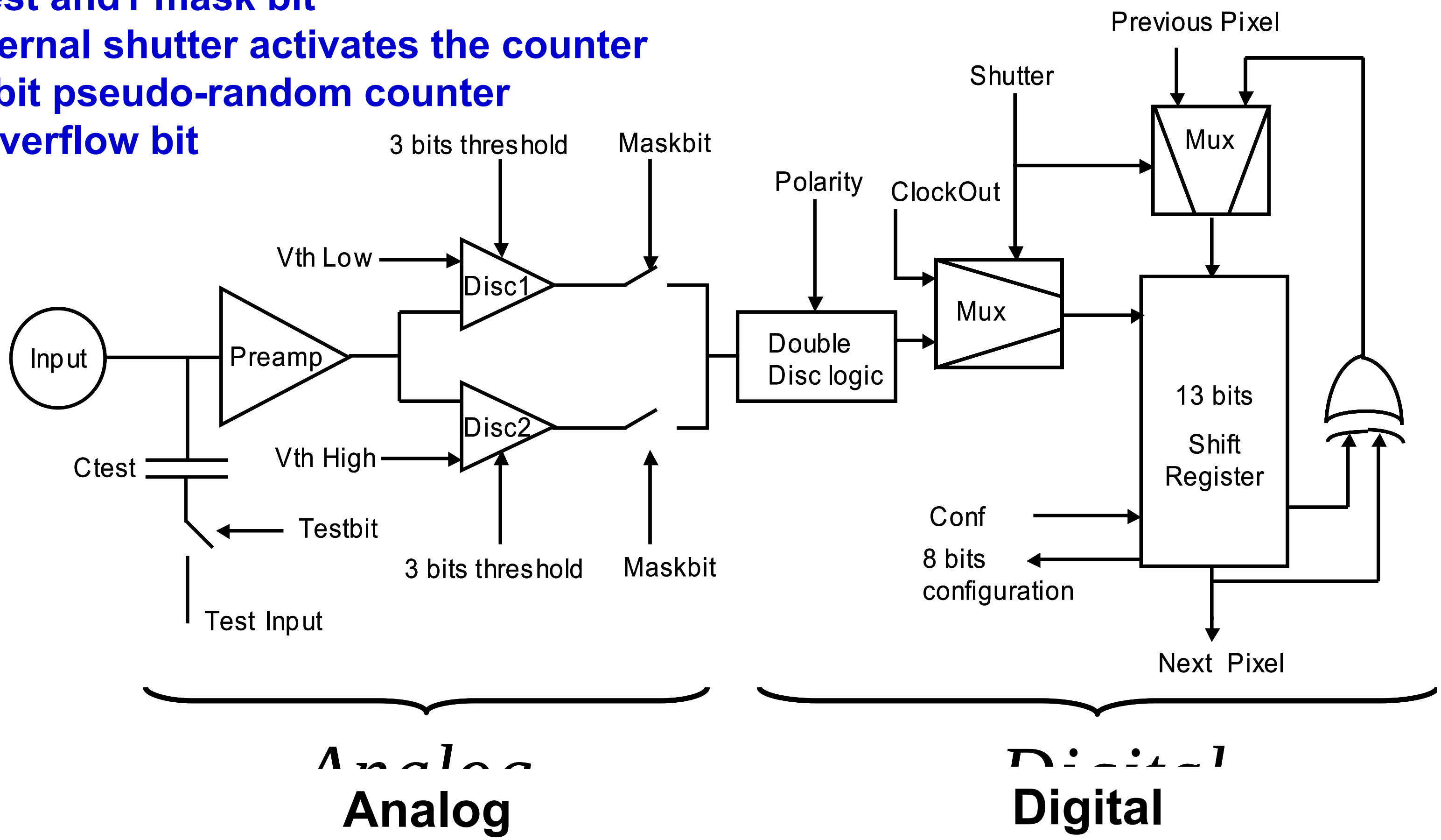


Bumps on the readout side

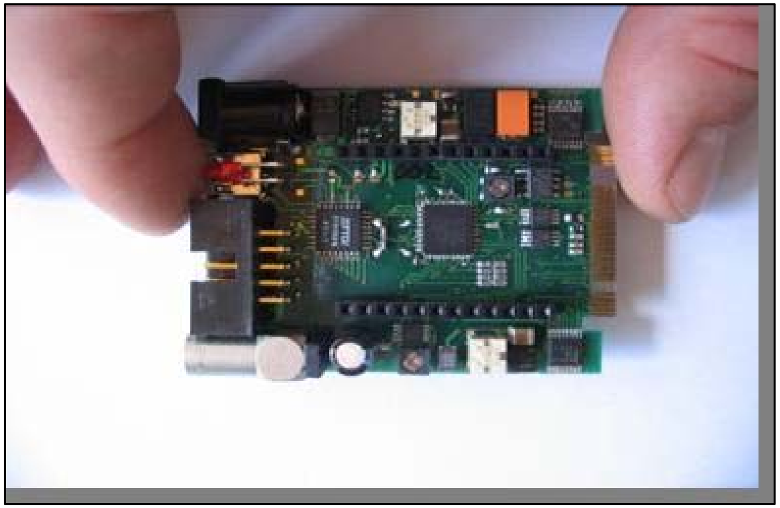


Basic Medipix2 Cell Schematic

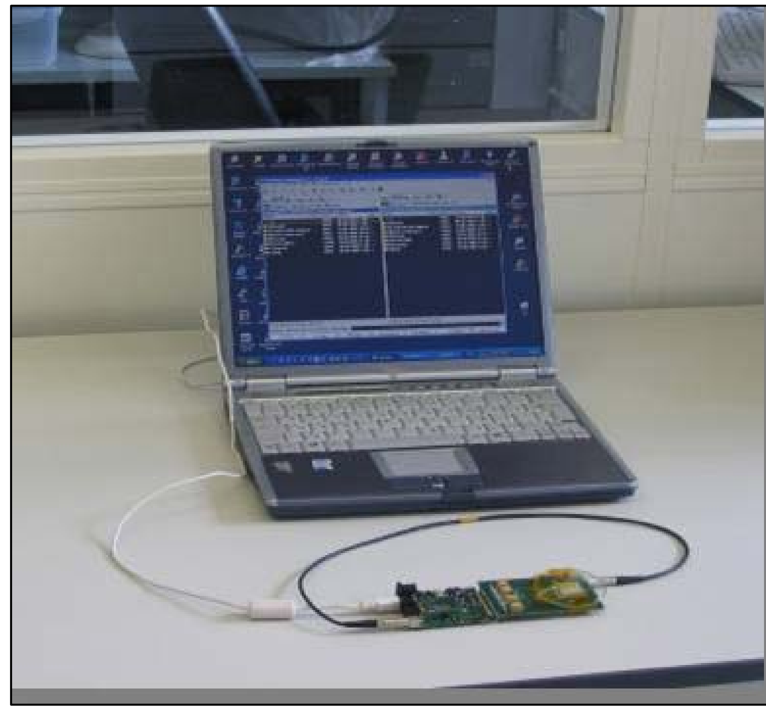
- Charge sensitive preamplifier with individual leakage current compensation
- 2 discriminators with globally adjustable thresholds
- 3-bit local fine tuning of the threshold per discriminator
- 1 test and1 mask bit
- External shutter activates the counter
- 13-bit pseudo-random counter
- 1 Overflow bit

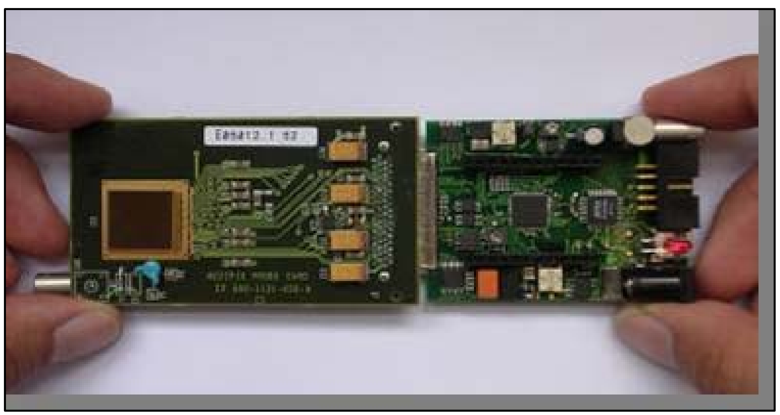


A new USB based Medipix2 Readout System

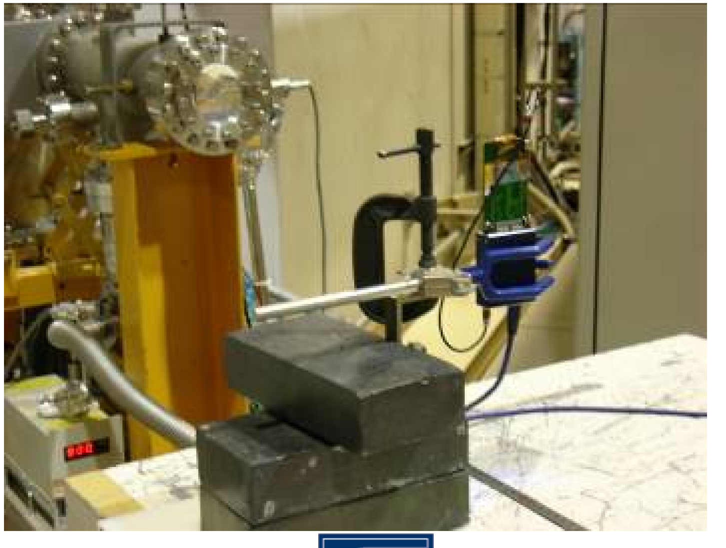


USB1 compatible
Developed by S. Pospisil et al.
CTU, Prague





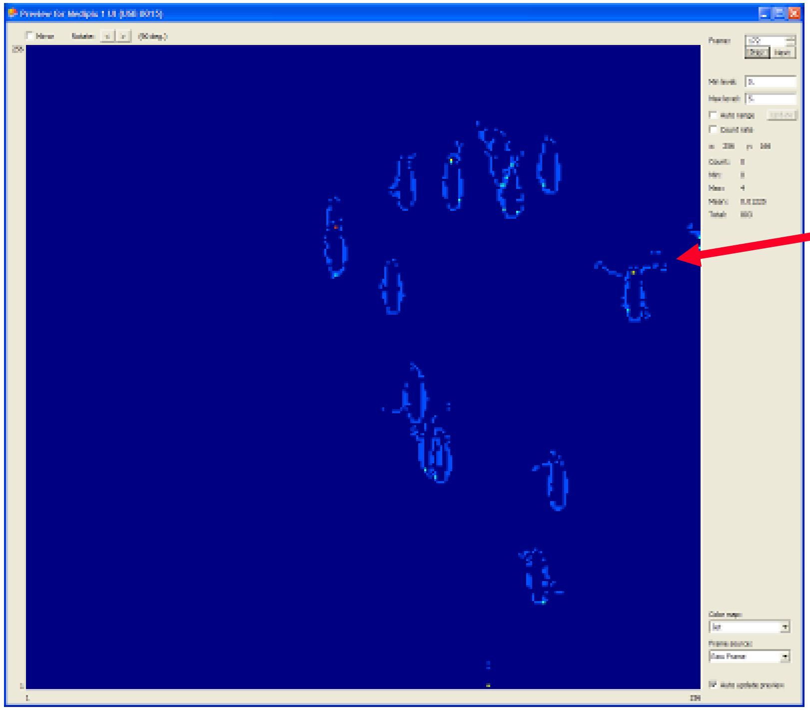
2006 Heavy Ion Measurements with Medipix2 (@ HIMAC & TAMU)



- **In collaboration with Jack Miller's Group at LBL, and Eric Benton, we made measurements @ HIMAC in 2006 with a Medipix2 of tracks in beams of:**
  - **Fe @ 500 Mev/A**
  - **O @ 290 MeV/A**
  - **Si @ 800 MeV/A**
  - **Ne @ 390 MeV/A**
- **Also in 2006, in collaboration with NASA/JSC/SRAG, measurements were made at Texas A&M's cyclotron in beams of:**
  - **Xe @ 12 & 24 MeV/A**
  - **p @ 20, 30 & 40 MeV**

Heavy Ion Images in Medipix2

- Pixels indicate above lower threshold & below upper threshold…
- These are effectively the energy slices through the track structure…



Note:
δ-rays

60 Degree Incidence O @ 290 MeV/A

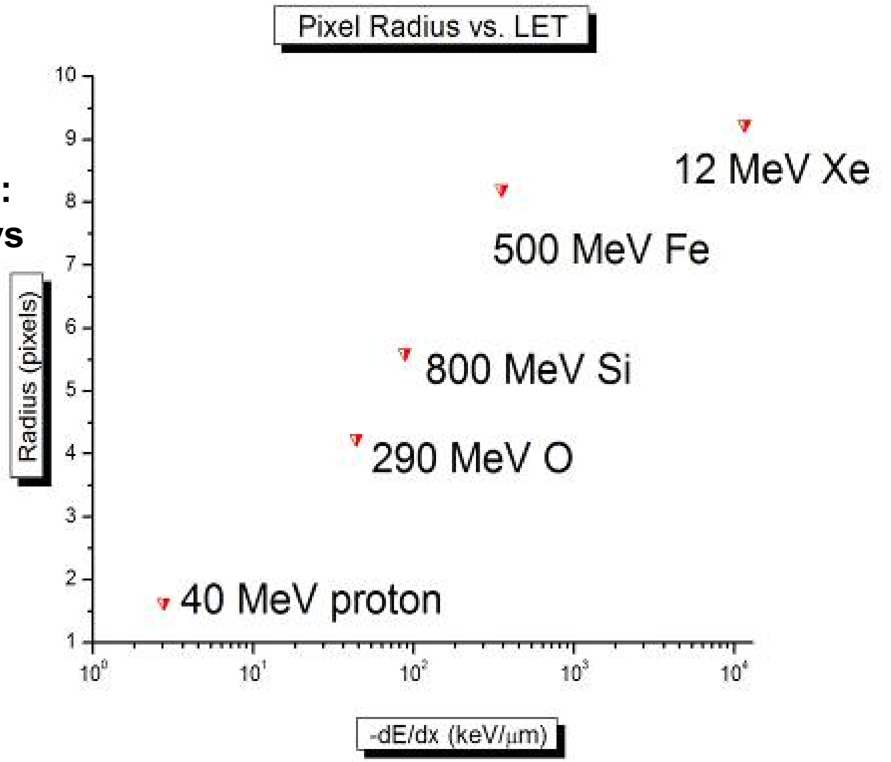
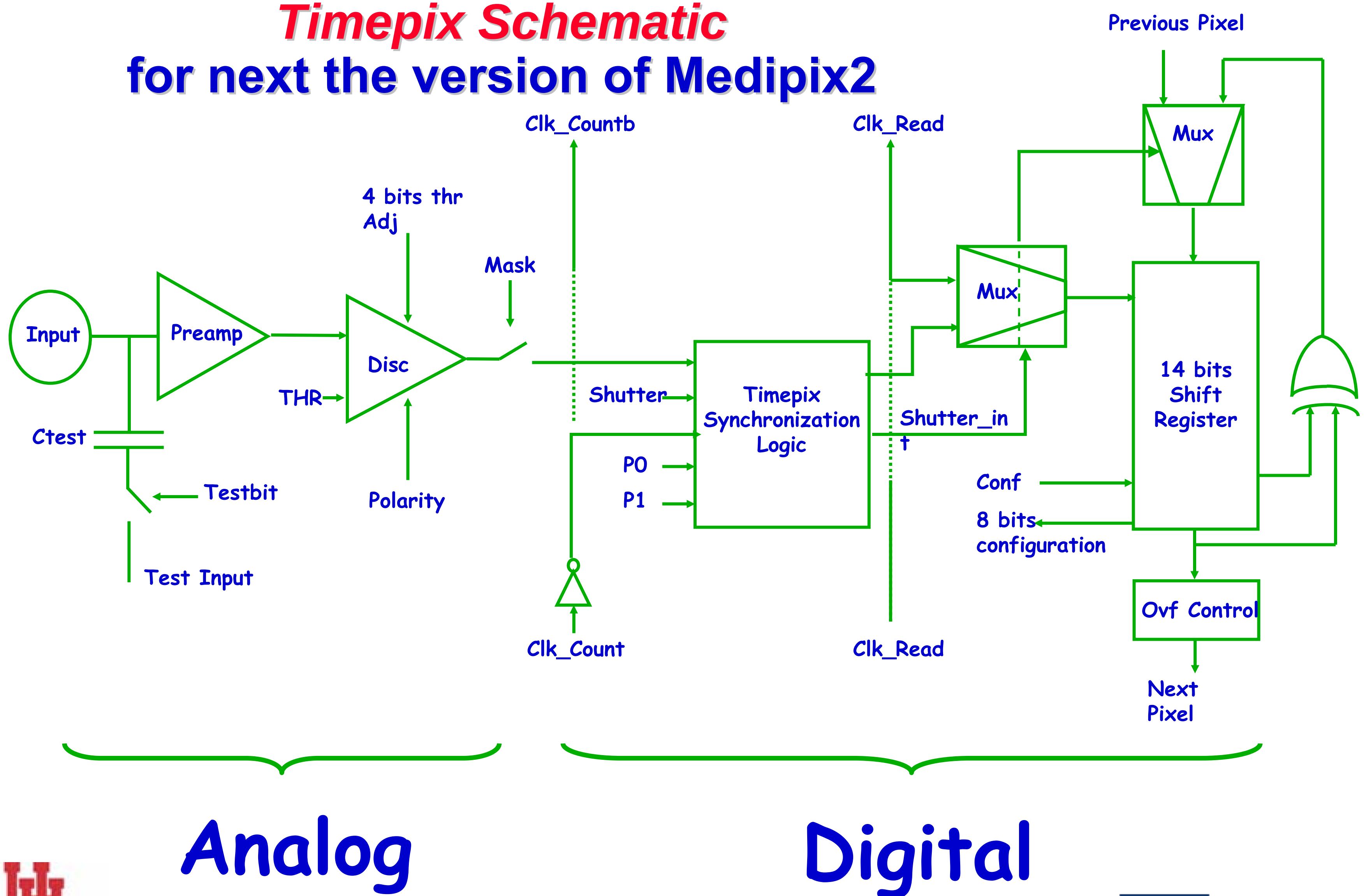
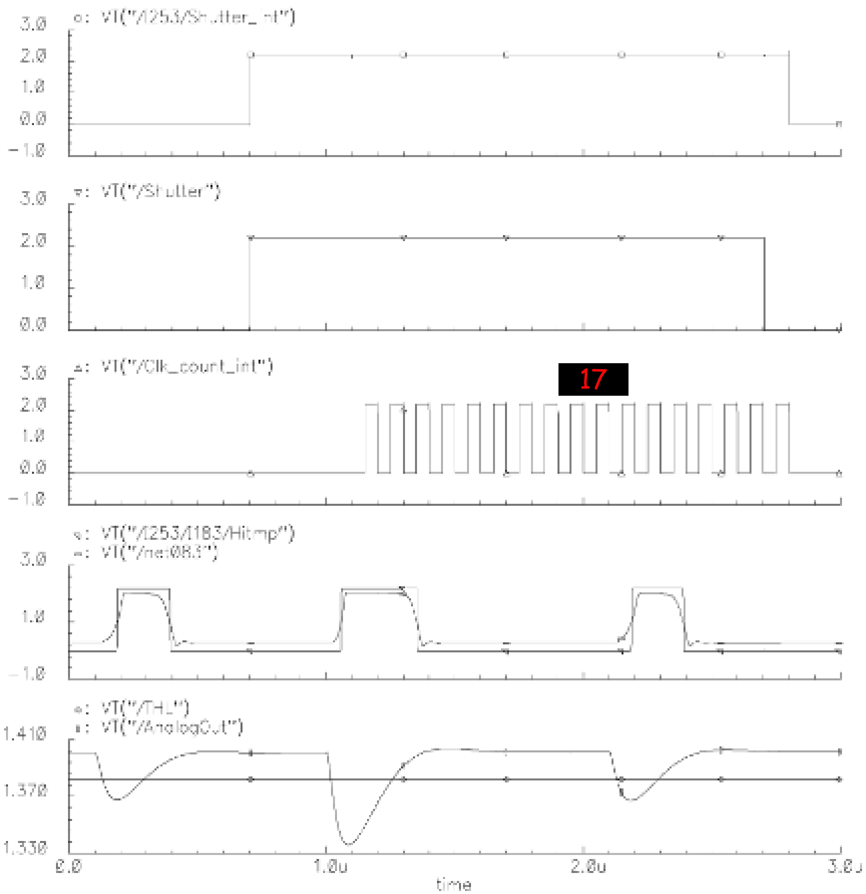


Image Slice Size v. LET for beams taken

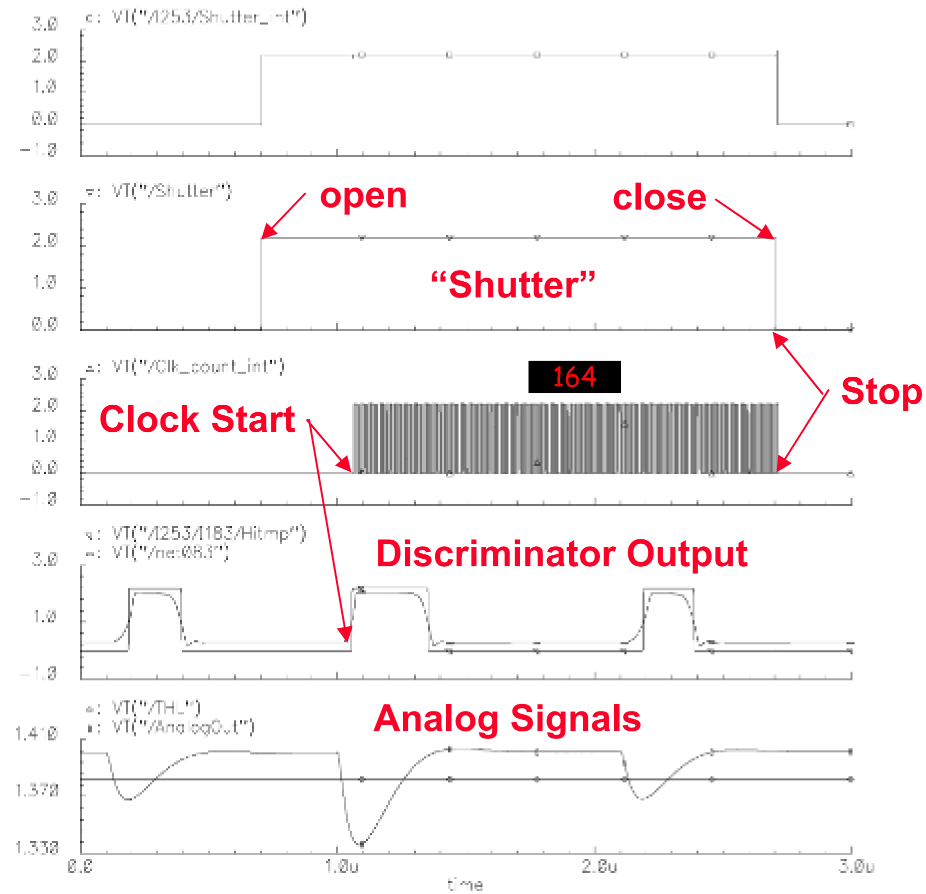
Adding ADC or TDC Capability, PIXEL BY PIXEL…
Timepix Schematic
for next the version of Medipix2



Timepix ("TDC") Mode (P0=1,P1=1)

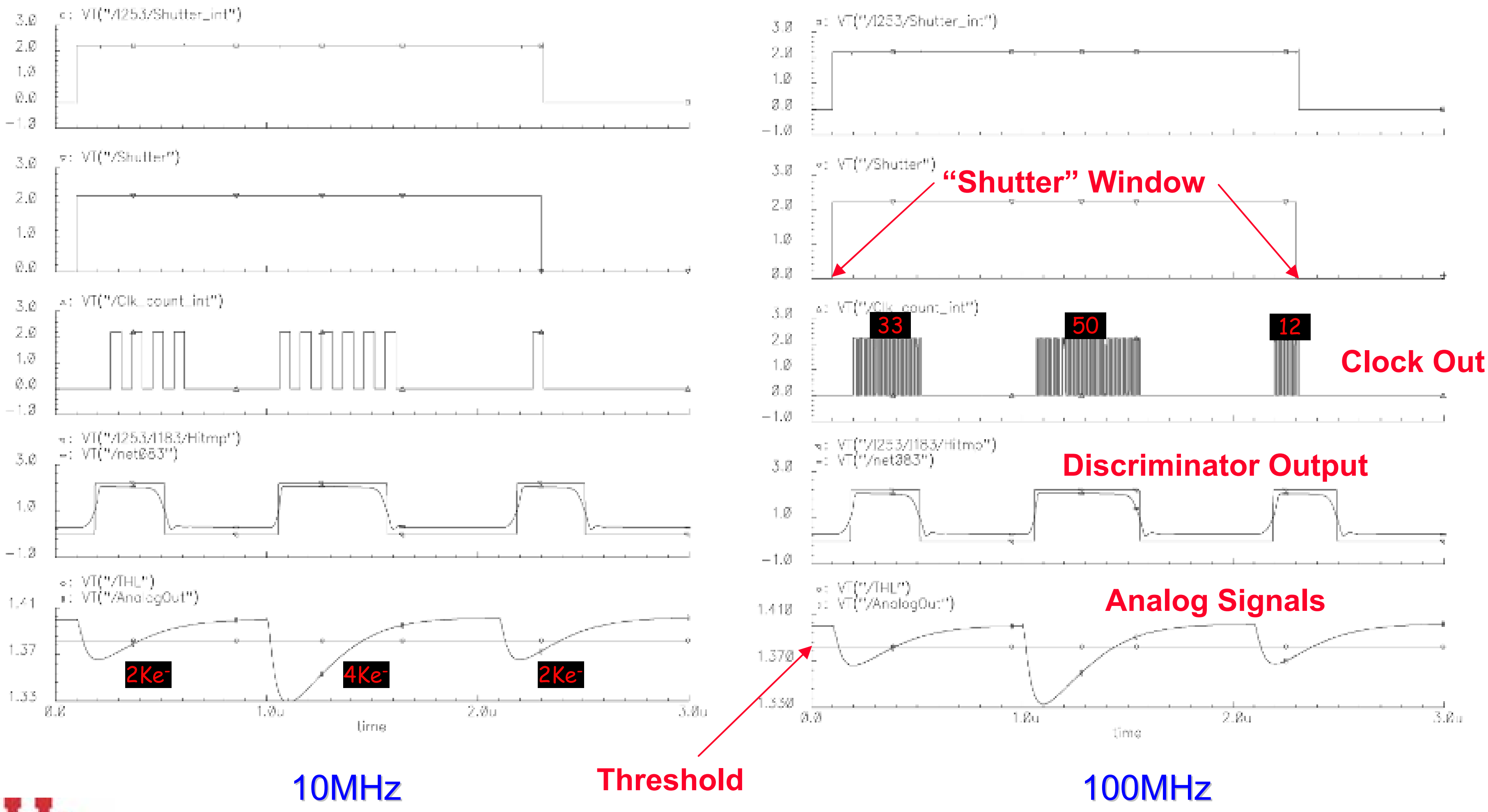


10MHz

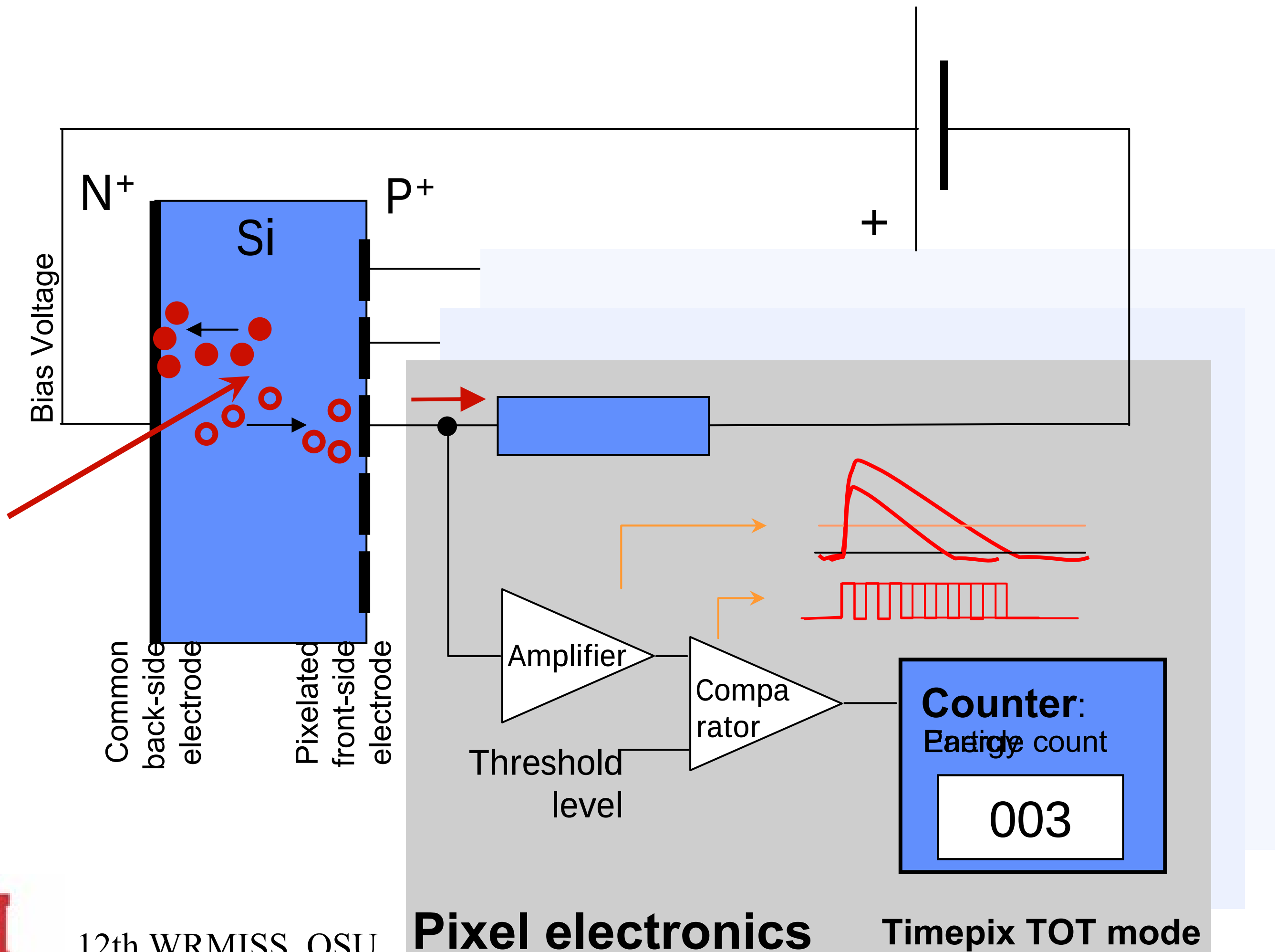


100MHz

Time-Over-Threshold (“ADC”) Mode (P0=1,P1=0)



TimePix TOT (ADC) Mode with Silicon Detector Layer



Threshold level above electronic noise
⇒No false counting.

Digital integration (counting)
⇒ No dark current.

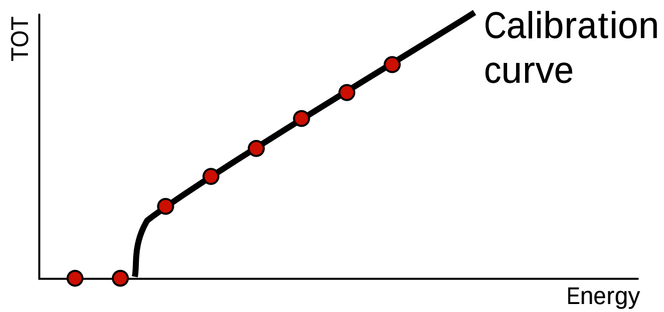
Unlimited dynamic range and exposure time.

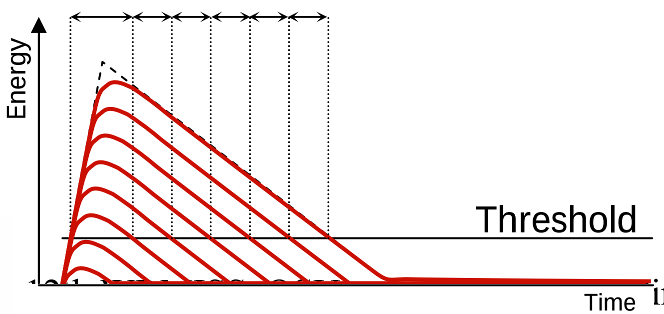
Detected count obeys poissonian distribution

TimePix and its TOT mode

Counter in each pixel can be used as

- **Timer** to measure detection time => TOF experiments, TPC detectors, ...
- Wilkinson type **ADC** to measure energy of each particle detected.





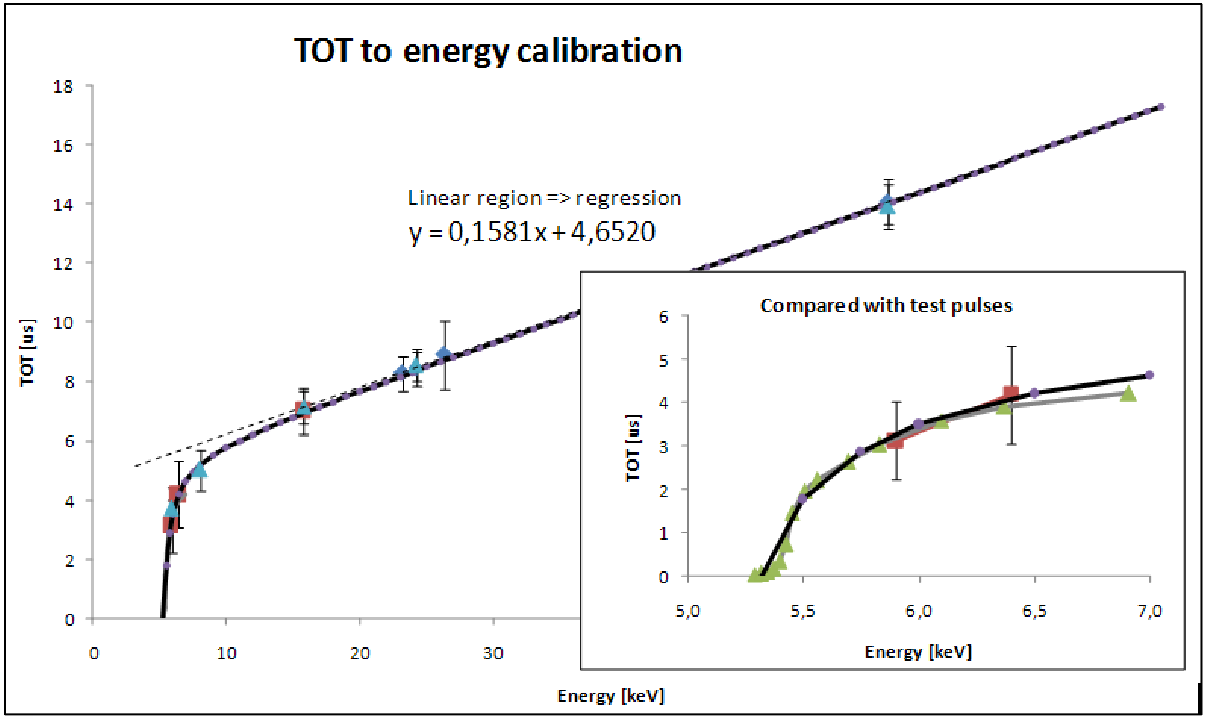
- **If the pulse shape is triangular then Time over Threshold is proportional to collected charge i.e. to energy.**
- **Due to limited bandwidth the pulse can be NEVER perfectly triangular.**
- **Non-linear TOT to energy dependence**

TOT mode calibration:
Surrogate calibration function

$$f(x) = ax + b - \frac{c}{(x-t)^d}$$

Meaning of parameters:

a,b – linear regression in high energy range
c,d – curvature (extent and symmetry)
t – threshold



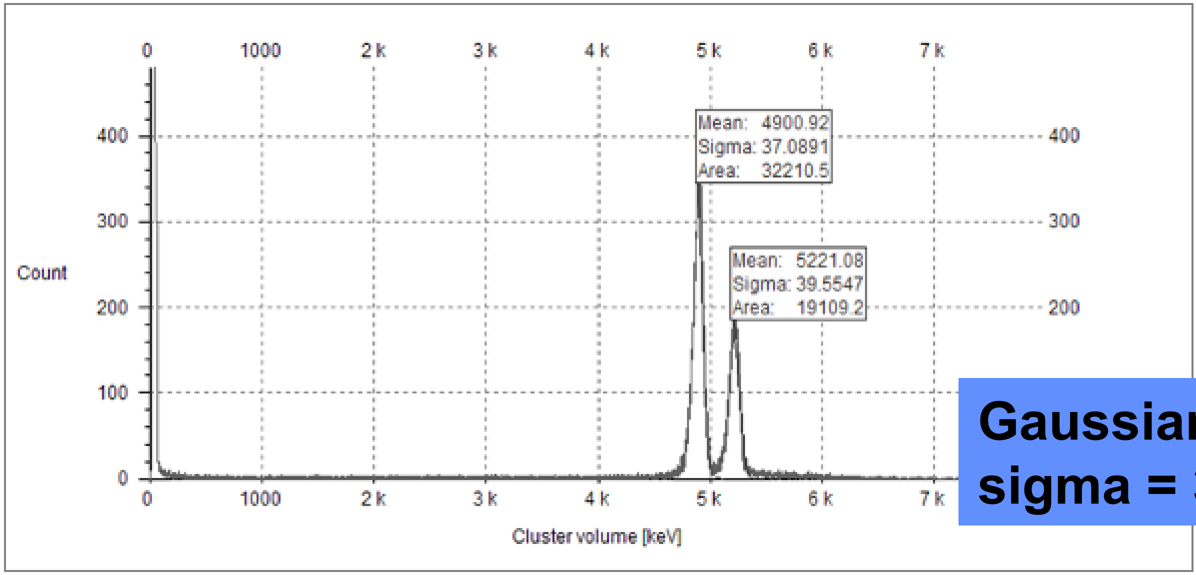
Parameters computed
Using global calibration
data:

a=0.158
b=4.65
c=2.4
d=1
t=4.86

Stopping Heavy Charged Particles
Total Energy Resolution

- Am241+ Pu239 combined source
- 5.2 and 5.5 MeV alphas
- "Heavy" calibration extrapolation

Cluster volume (energy) spectrum (measured in air)



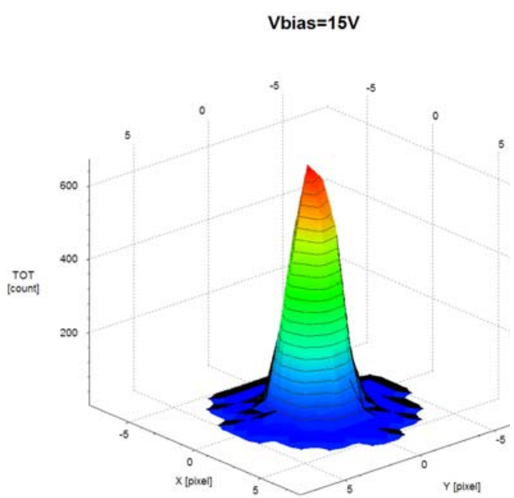
0.67%

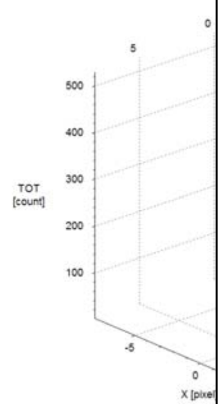
Gaussian fit sigma = 37 keV

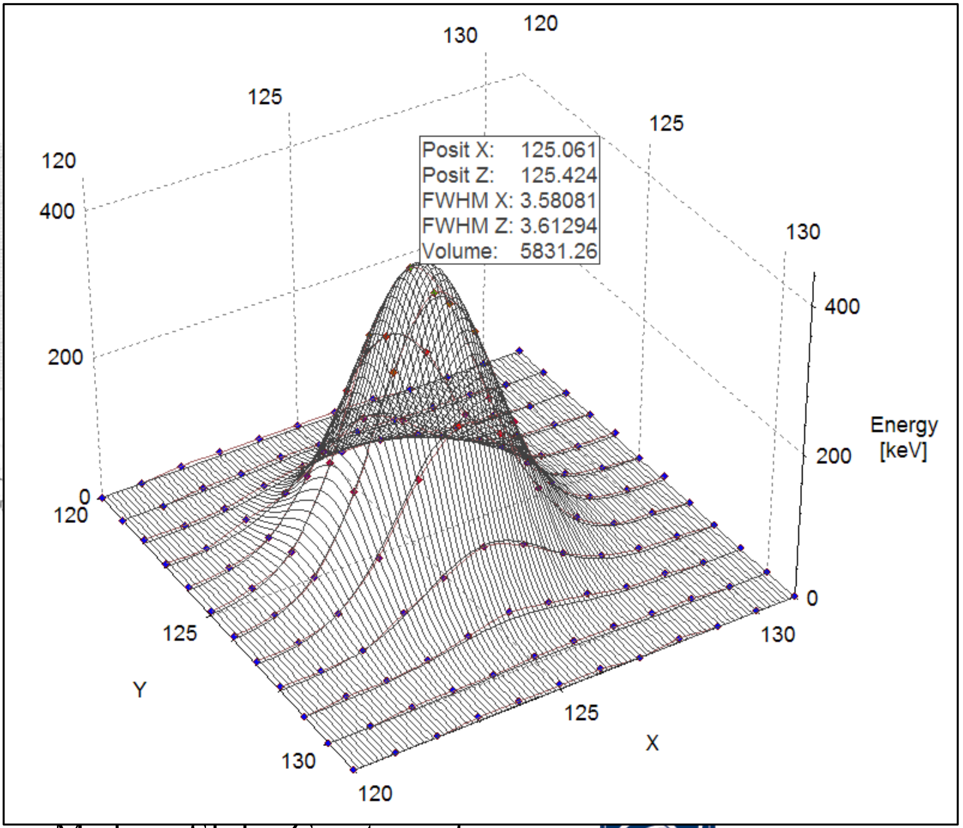
First results with TimePix:

Subpixel resolution

- **Cluster shape depends on detector bias voltage.**
- **Gaussian shape for low bias voltages (diffusion dominates)**



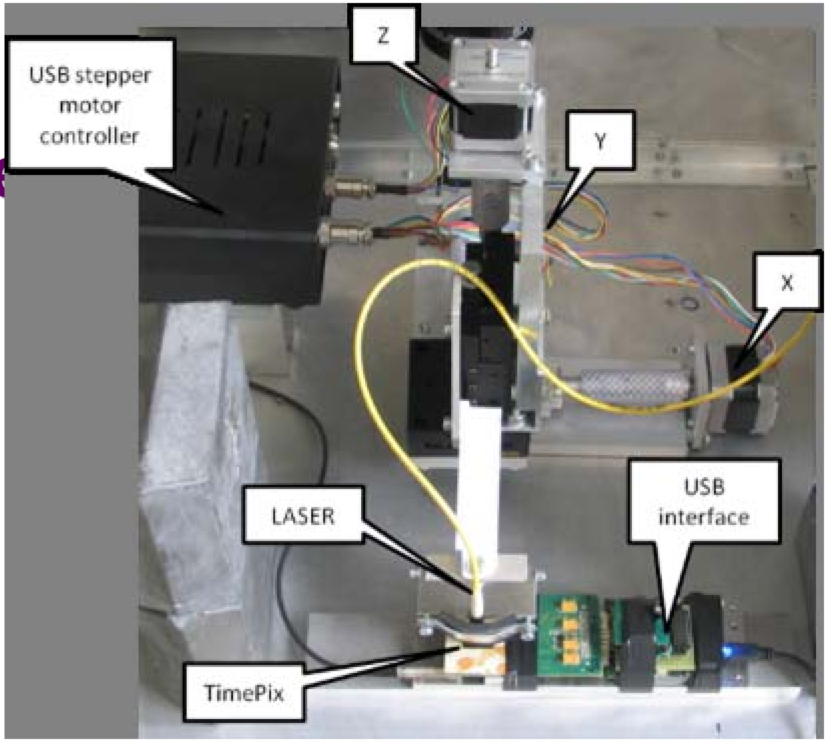




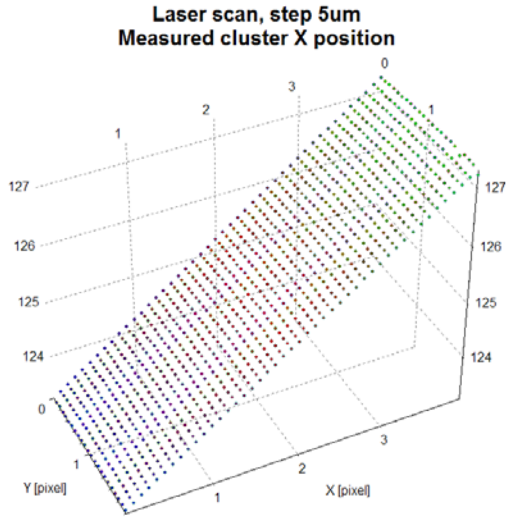
=> Subpixel resolution can be reached by Gaussian fit.

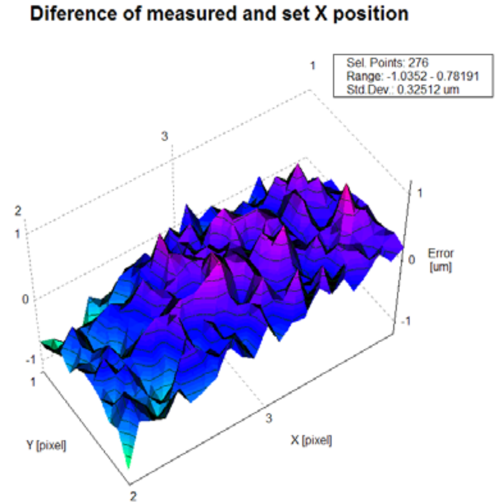
Spatial resolution

Subpixel re



- Alpha particles simulated by red LASER pulses
- Laser spot positioned with 1um accuracy
- Area of 3 x 2 pixels scanned with step of 1.25 um. Just single shot evaluated in each position.





Standard deviation of position determined by fit is **0.32 μm**

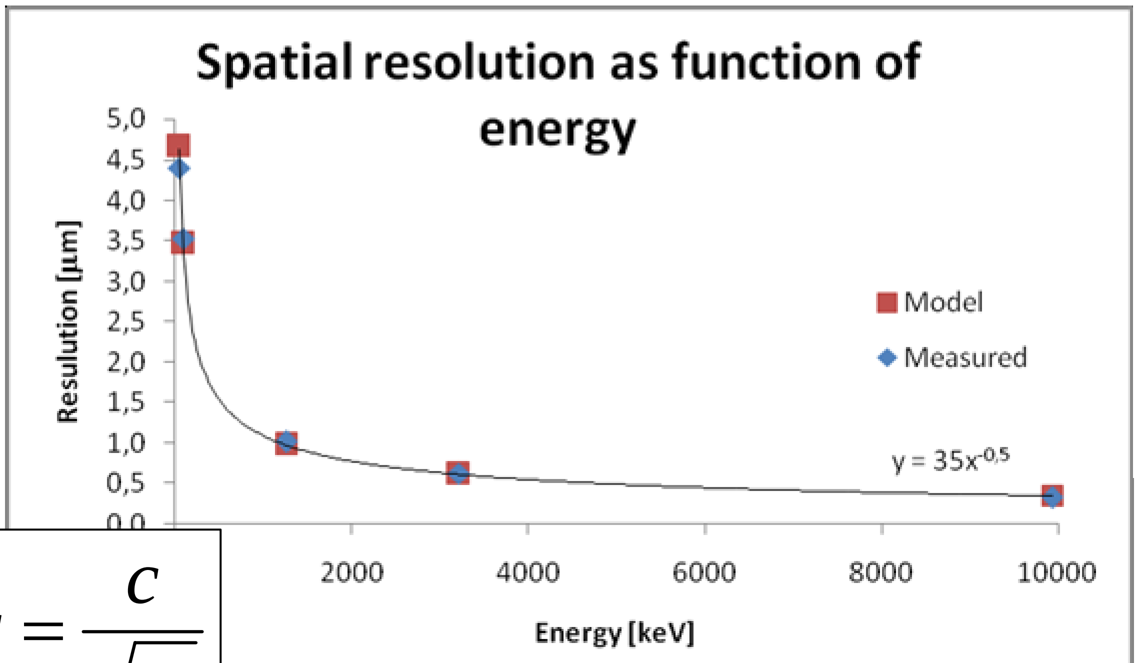
⇒ Each pixel can be divided to 100 x 100 subpixels

⇒ **655 Megapixels!**

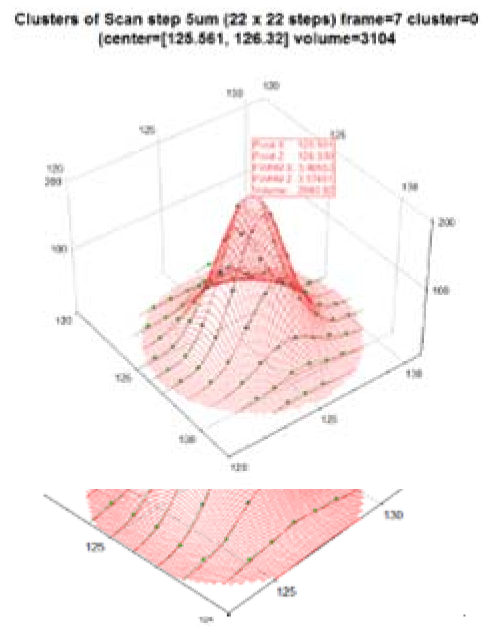
If center of gravity is used then Std.Dev. is **0.63 μm**.

Spatial resolution determination:
Spatial resolution as a function of energy

- LASER test performed for different equivalent energies of 50keV, 120keV, 1.2MeV, 3.2MeV and 9.9MeV

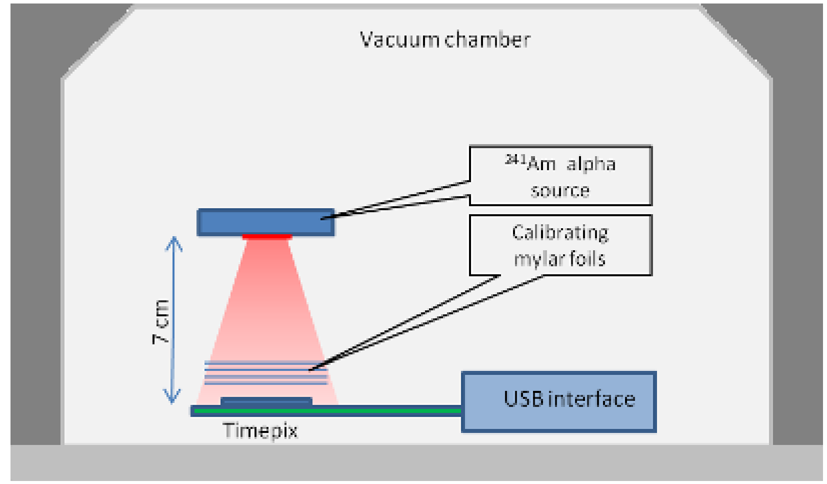


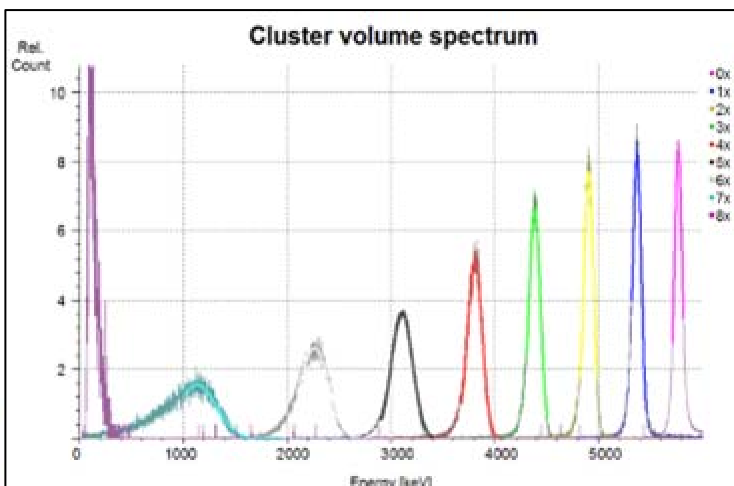
$$r = \frac{c}{\sqrt{E}}$$

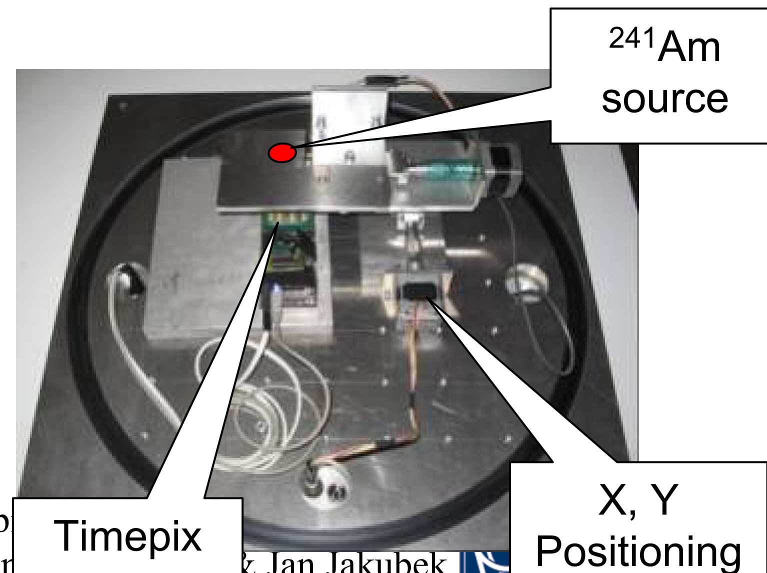


Radiography with heavy charged particles:
Example with TimePix

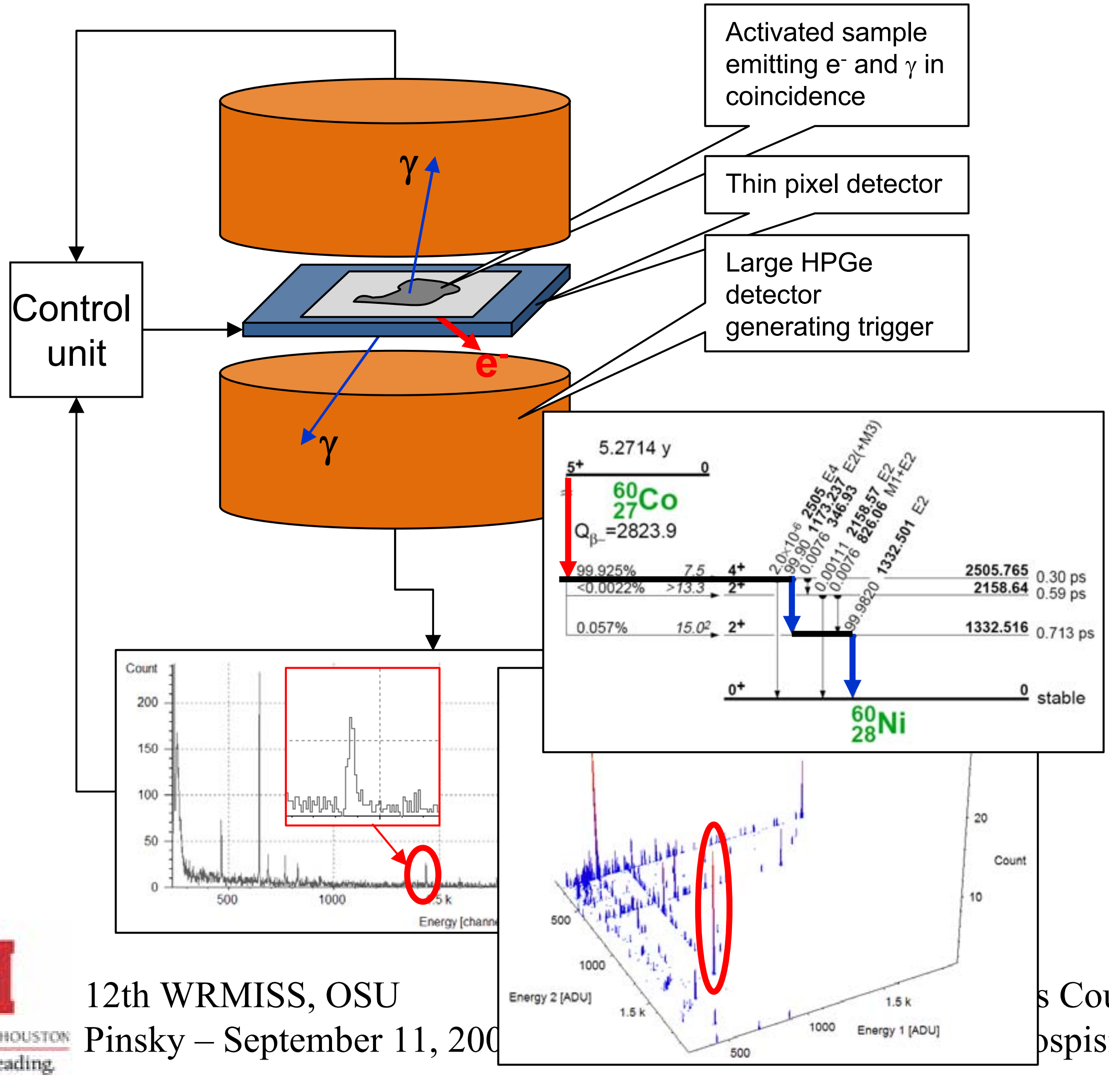
- ^{241}Am alpha source used
- Set of Mylar foils used to attenuate energy
- Measurement performed in vacuum







Coincident imaging:



Application field:

- Imaging in Activation Analysis
- Prompt gamma imaging
- …

Activation analysis:

- Excited nucleus emits radiation
- Energy of emitted gamma is typical for each element => direct measurement of element concentration
- Very sensitive method (<ppm)
- To improve selectivity several detectors can be used in coincidence
- Electrons are often present de-excitation in cascades

=> Chance for thin Si pixel detector

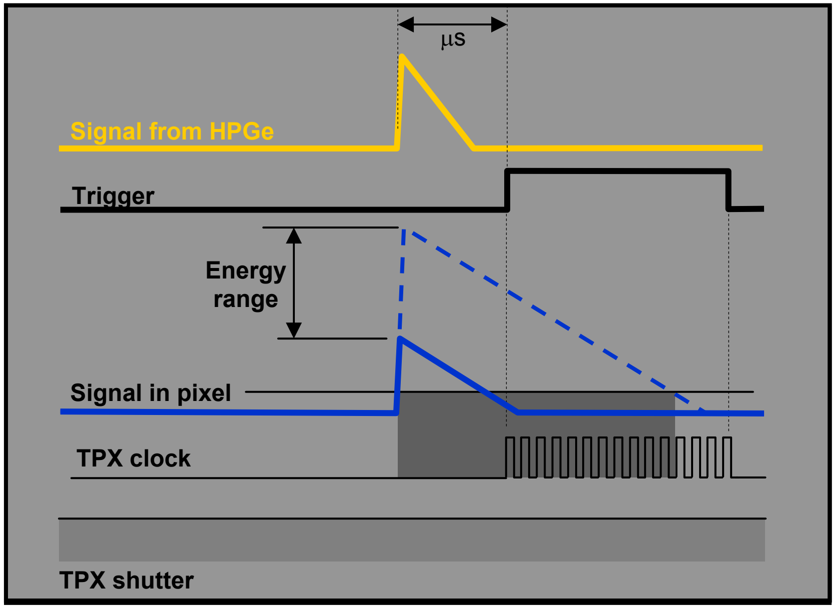
Coincident imaging:

Triggered image integration with TimePix

Situation:

- Just electrons emitted in coincidence with right gamma photon have to be counted.
- Detection of electron in the pixel detector and detection of gamma in HPGe is simultaneous.

=> When trigger from HPGe comes the detection in pixels is already finished.



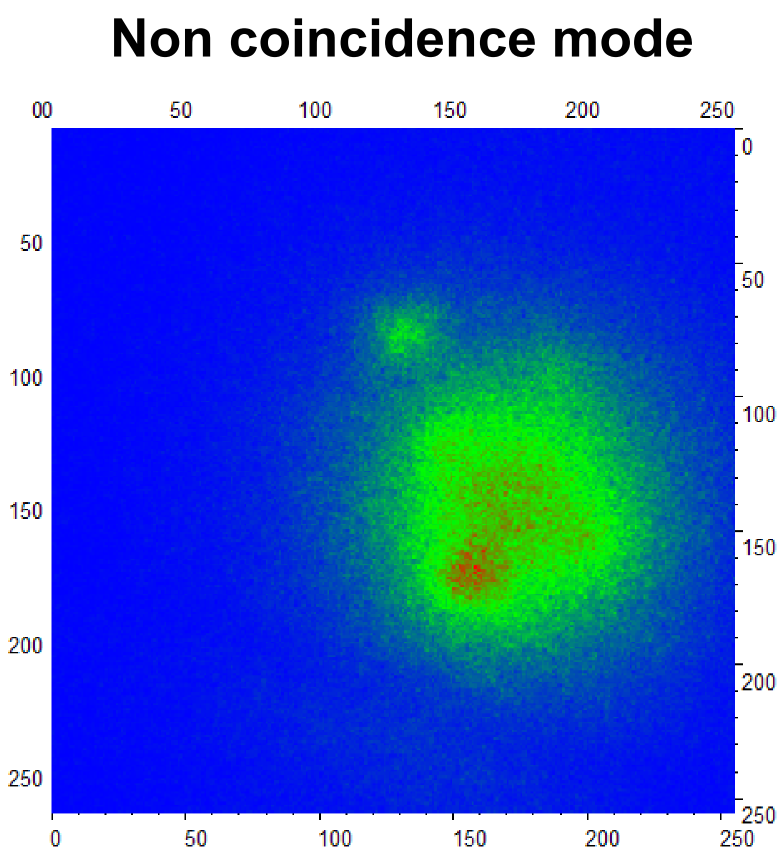
Solution 1 (not elegant):

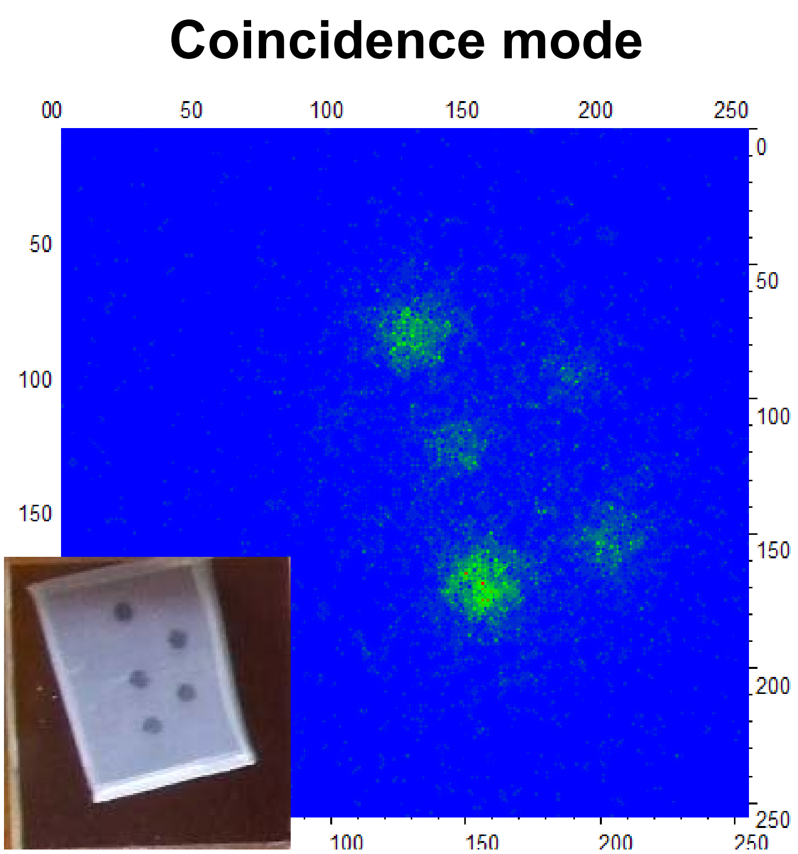
- Shutter is opened for certain (very short) time period
- If trigger from HPGe comes then frame is read, otherwise it is erased.
- Integration is performed in a computer
- Image has to be transferred for each trigger => **Very long dead time**

Solution 2 ("smarter"):

- Shutter is opened all the time, TPX is set to TOT mode. Shaping is set to be very long.
- Clock is generated just if trigger appears.
- In non-coincident case there is no clock => pulses are not counted.
- Integration is performed directly in the chip => **negligible dead time**

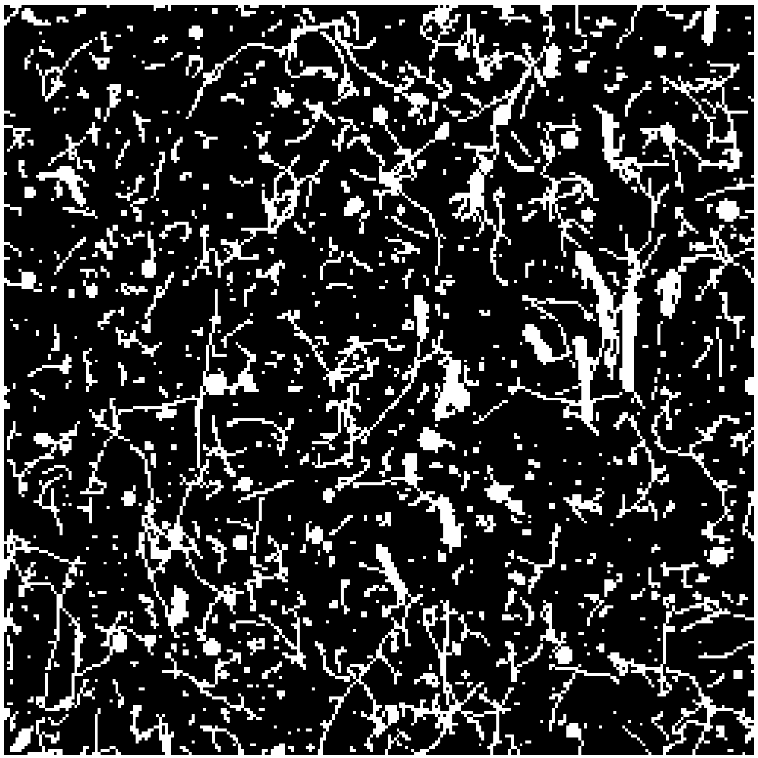
Coincident imaging:
Results

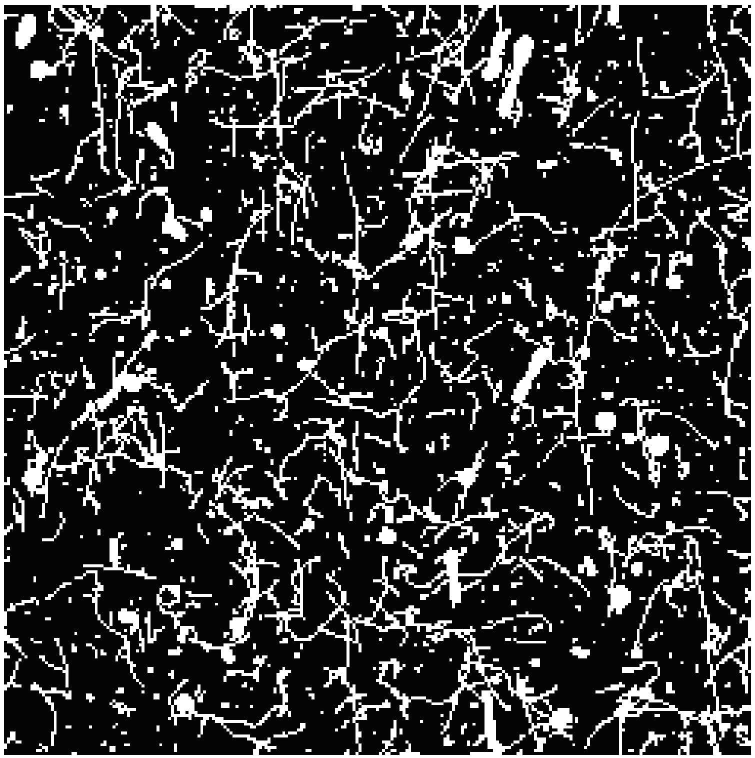




Exposure time was in both cases 1 minute. All dots clearly resolved.

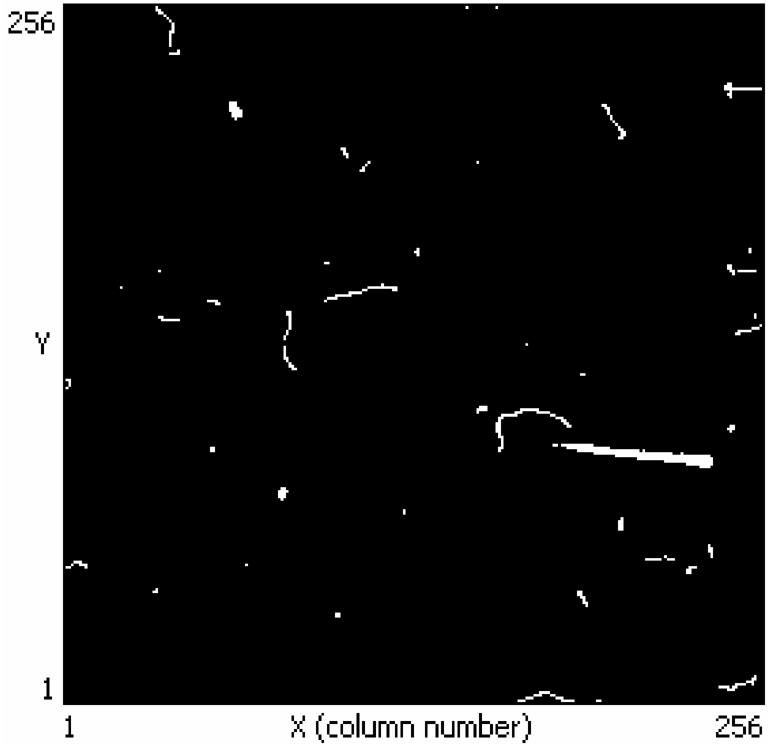
Examples of response of MEDIPIX to fast monochromatic neutrons (17MeV neutrons, flux about 10^4 n/(s.cm^2)) Also, we have a CERF run from last Fall

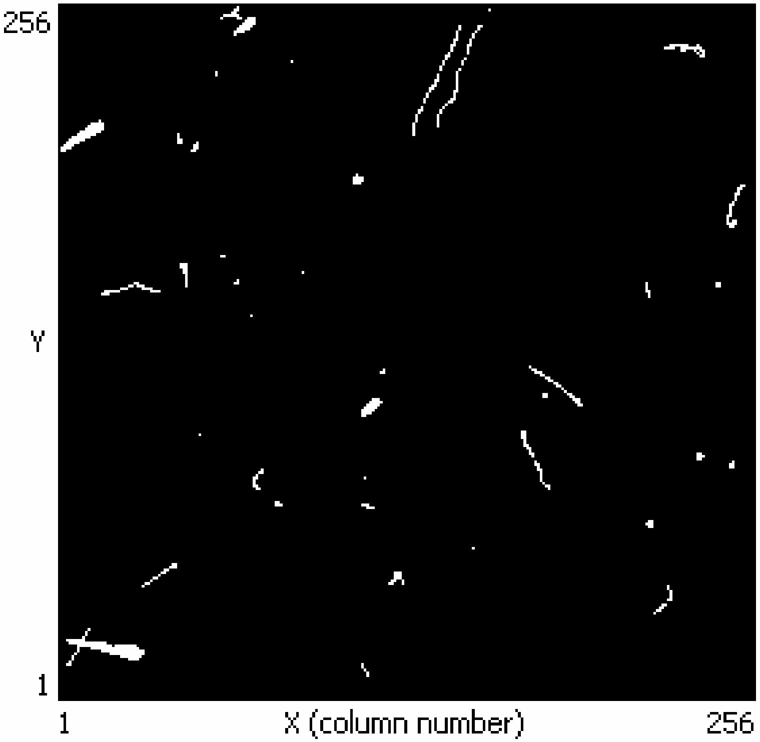




- The direction of the neutrons with respect to the image was upstream (from bottom to top). The huge background is due to gamma rays which accompany neutrons. Half of the sensor (the right-hand side) was covered with a CH2 foil about 1.3 mm thickness.
- One can clearly recognize long and rather thick tracks of recoiled protons (up to 2 mm, vertically oriented) and big tracks and clusters generated via 28Si(n,α)25Mg, 28Si(n,p)28Al nuclear reactions in the body of the silicon detector. These events are displayed on the dense background caused by tracks and traces of electrons from interactions of gamma rays. One can even recognize that proton tracks shapes follows a Bragg law.

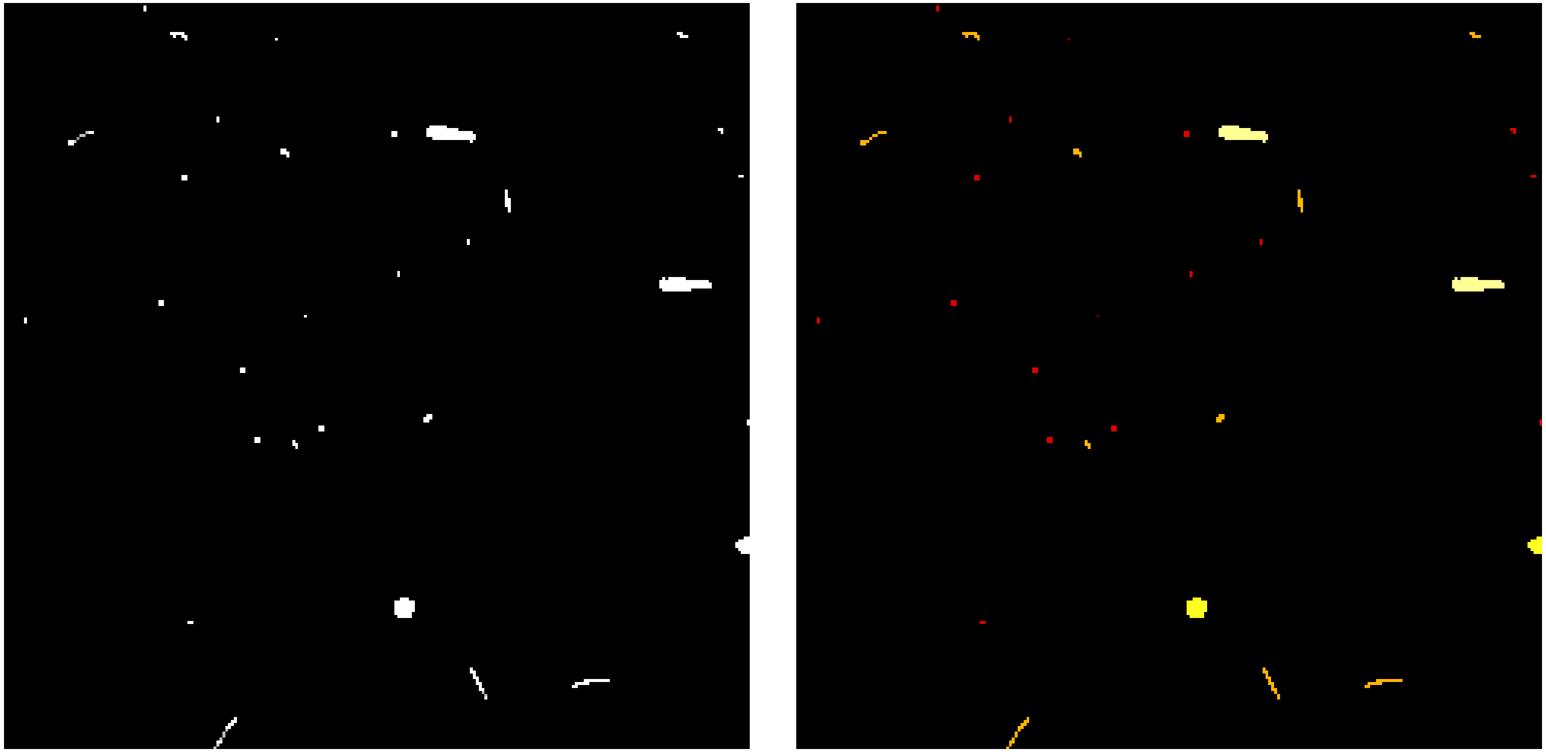
Track visualization: recognition of interacting quanta and its energy





Medipix2 device with 700 μm thick silicon sensor illuminated by fast neutrons (up to 30 MeV)

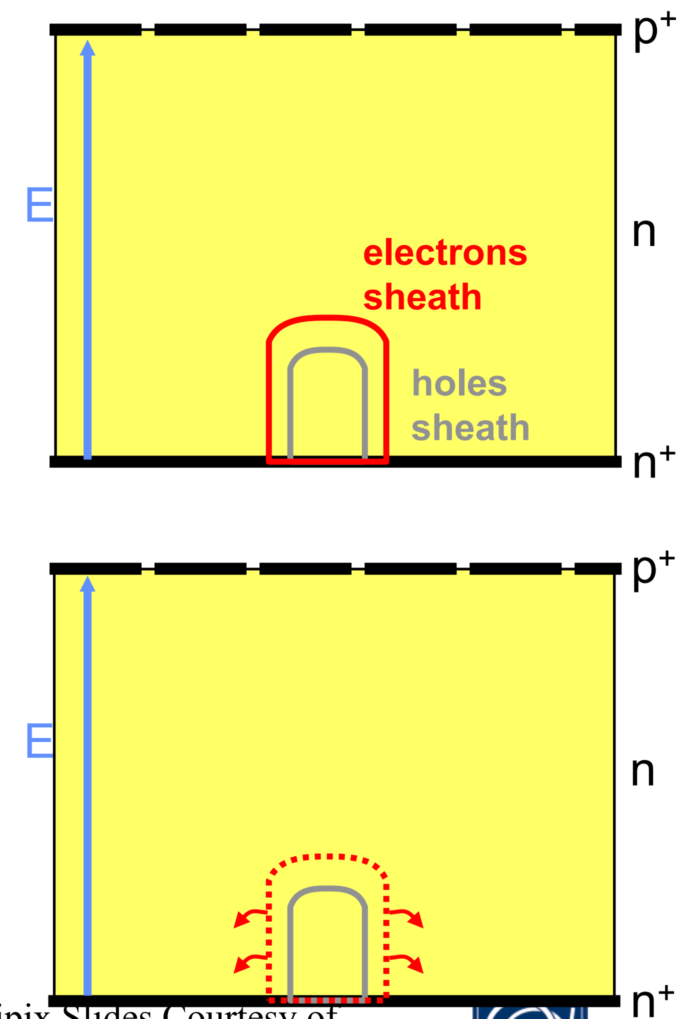
Track pattern recognition



200 frames recognized in 1 sec on standard PC

In conditions of high applied electric field (over full depletion)

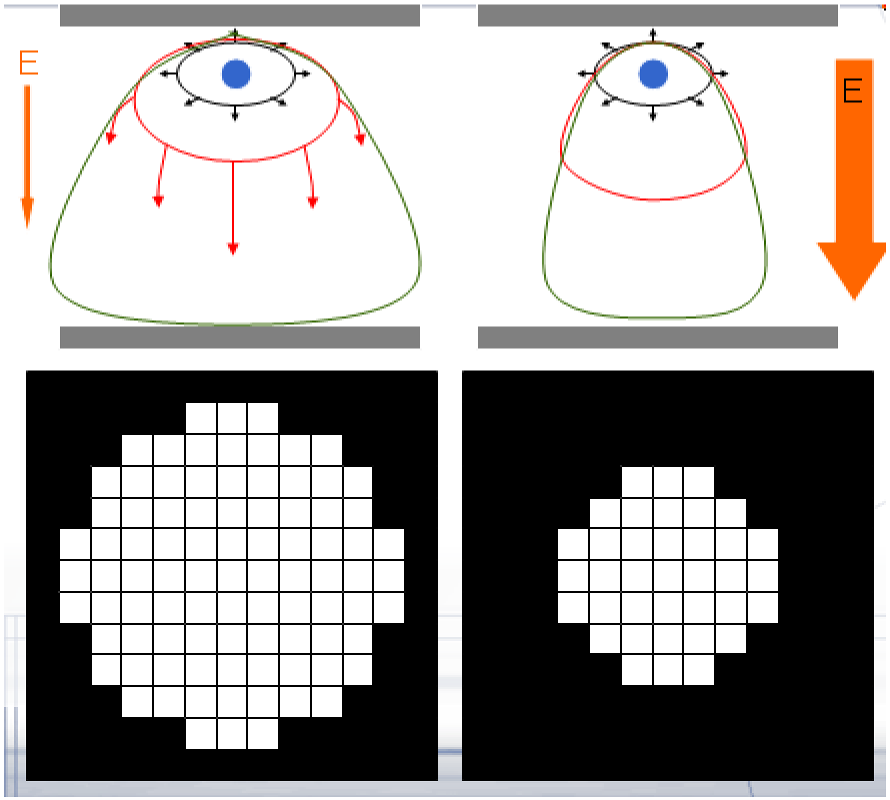
- **Electrons move faster than the holes:**
  - **Negative and positive sheaths are created in the column**
- **Carriers inside the column are shielded from the electric field but the electrons on the outside of the column feel it**
  - **Erosion begins**
- **Diffusion processes change as the hole density transitions from greater than the doping density to less than that value**
- **We are modeling this complex process…**



Cluster Size as function of V_{bias}

$$E_r(r) = \frac{-n_{lin}}{2\pi r \epsilon_0} \exp\left(\frac{-r^2}{4D_a t}\right)$$

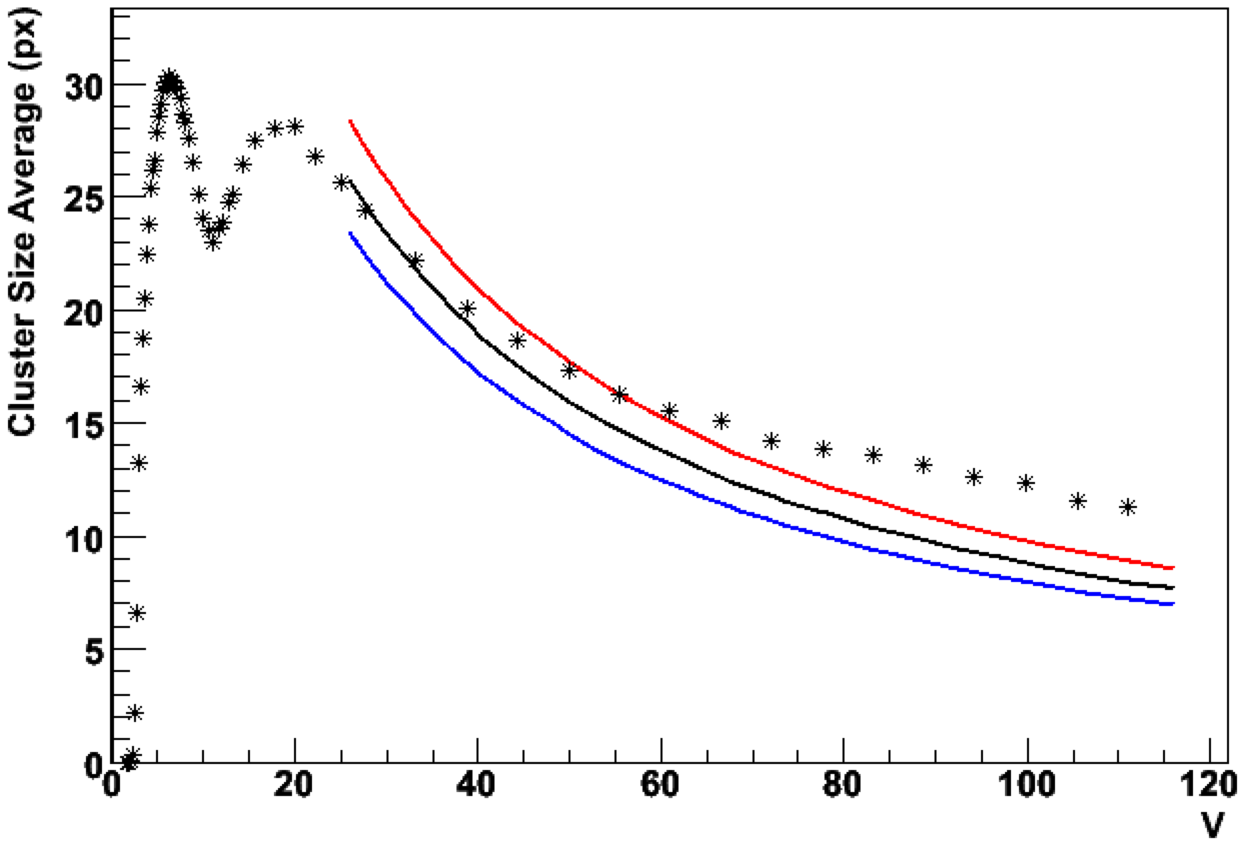
$$E_z(z) = \frac{2V_{fd}}{w^2}(z-w) - \frac{V - V_{fd}}{w}$$



n_{lin} is the linear density of electrons,
D_a is the ambipolar diffusion koefficient,
W is the detector thickness,
Vf_d is the full depletion voltage

The used values for calculations:
- Full depletion voltage: 25 V
- Initial plasma column length for alpha particles (12 μm for 3 MeV and 19 μm for 4.2 MeV) and radius (2.2 μm μm for 3 MeV 1.85 μm for 4.2 MeV)

The influence of plasma column radius on charge sharing effect in case of alpha particles



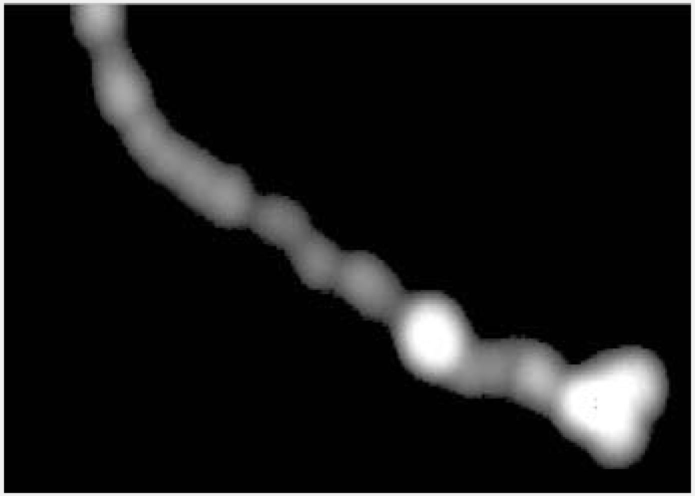
The plasma column size has a stronger influence since the radial field varies as 1/r * exp(-r^2). The influence of the plasma column radius on alpha particle cluster size: red: 2 µm, black: 2.2 µm, and blue 2.4 µm.

New devices of Medipix family

Timepix

Counter in each pixel can be used as

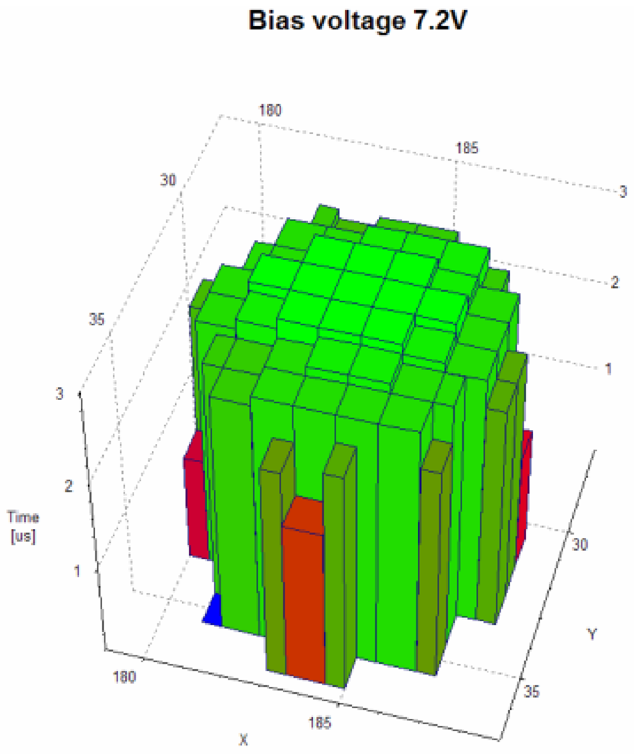
- Timer **to measure detection time => TOF experiments, TPC detectors**
- **Wilkinson type** ADC **to measure energy of each particle detected. Integral mode is also possible**

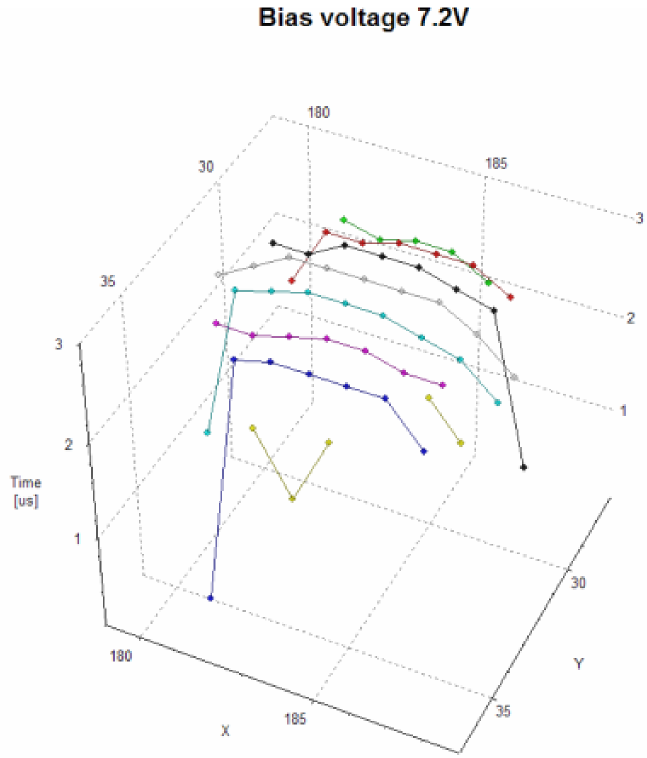


Medipix3

- **Two counters in each pixel** enabling
  - Continuous acquisition (no deadline due to data transfer)
  - Two “colors” imaging (two energy channels)
- **Charge summing scheme** => improved energy sensitivity
- **Four adjacent pixels can share their resources** => 8 counters allows 8 energy channels
- First “proof” chips exists so far

Charge collection time in individual pixels - single alpha event





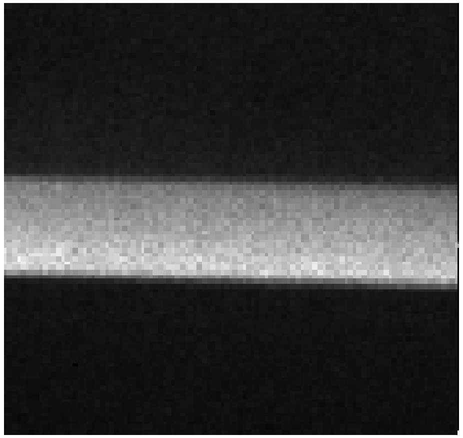
See also talk of Jan Jakubek on this conference!

Charge sharing effect:

Dependence of cluster size on depth of interaction

How to create defined charge in single point defined depth?

- Charged particles are creating tracks of statistical nature
- Photo-effect is localized, amount of charge is well defined



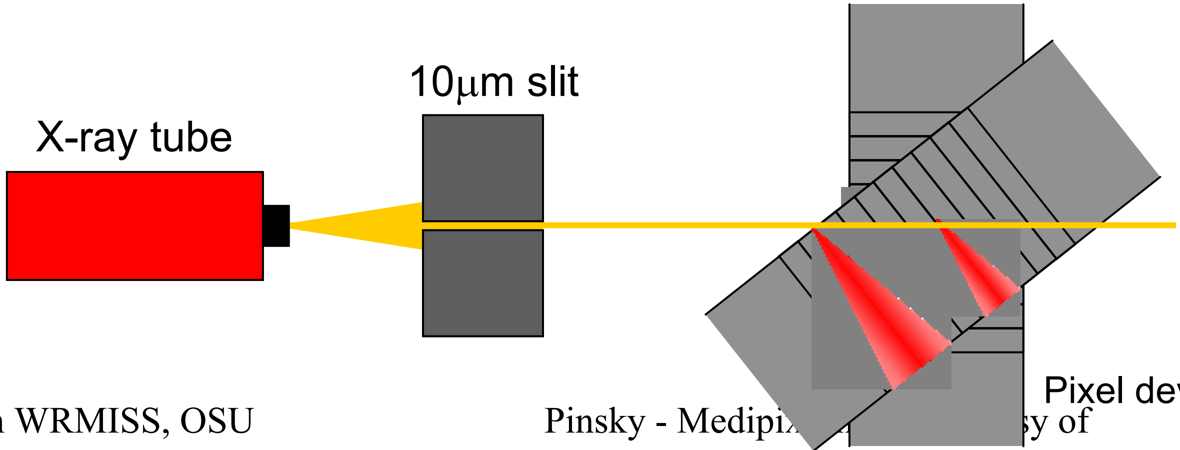
Direct slit projection:

All cluster sizes are overlapping.

Projection under angle:

Depth of photon interaction can be determined easily.

=> Hard to process data

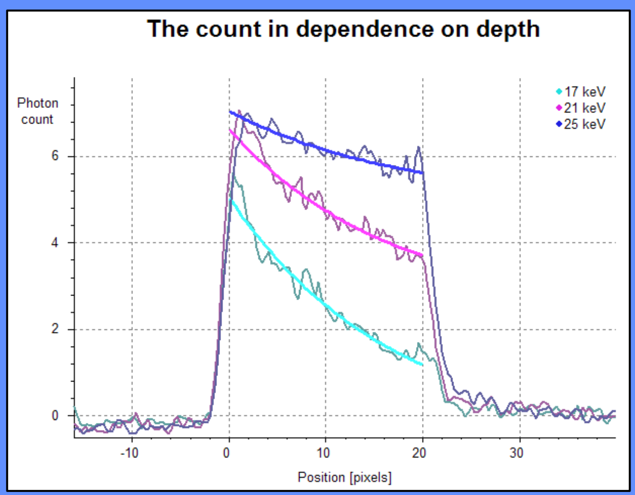


Charge sharing effect:

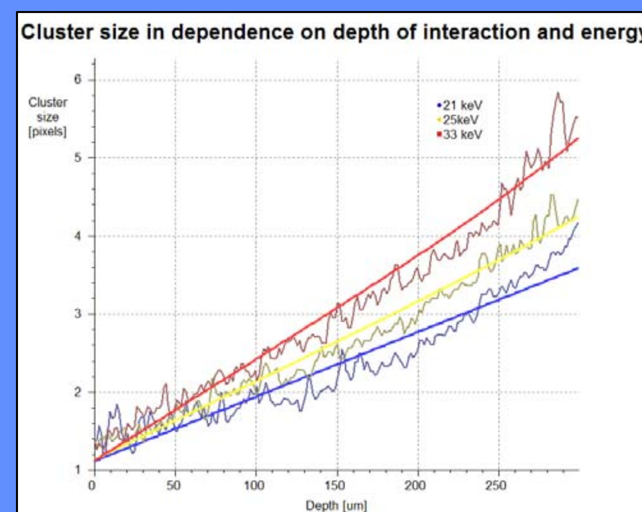
Dependence of cluster size on depth of interaction

Measurement:

- X-ray tube settings: 60kV, 1μA
- 5069 frames with short exposure time were taken by **TimePix** device in TOT mode (to see individual clusters). Threshold is set just above the noise (~3keV).
- 570 663 clusters identified.
- Volume of each cluster reflects the photon energy
- Just clusters of given energy are processed.



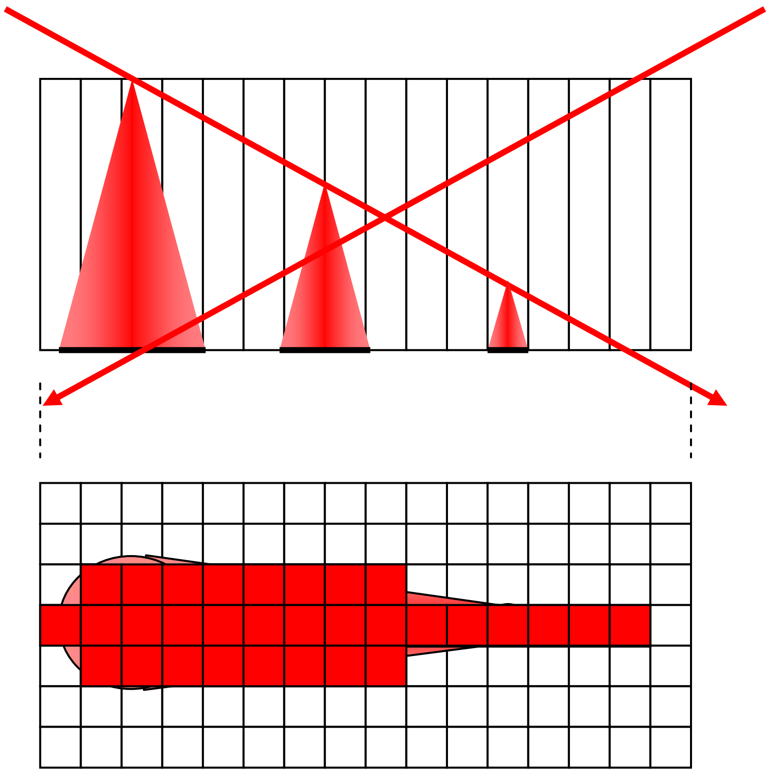
Exponential attenuation confirms method of energy determination using cluster volume (The device has to be calibrated)



Dependence of cluster size on the depth is almost linear. Cluster size can be even 8 pixels and more for higher photon energies.

Charge sharing effect:

Tracks of MIP particles

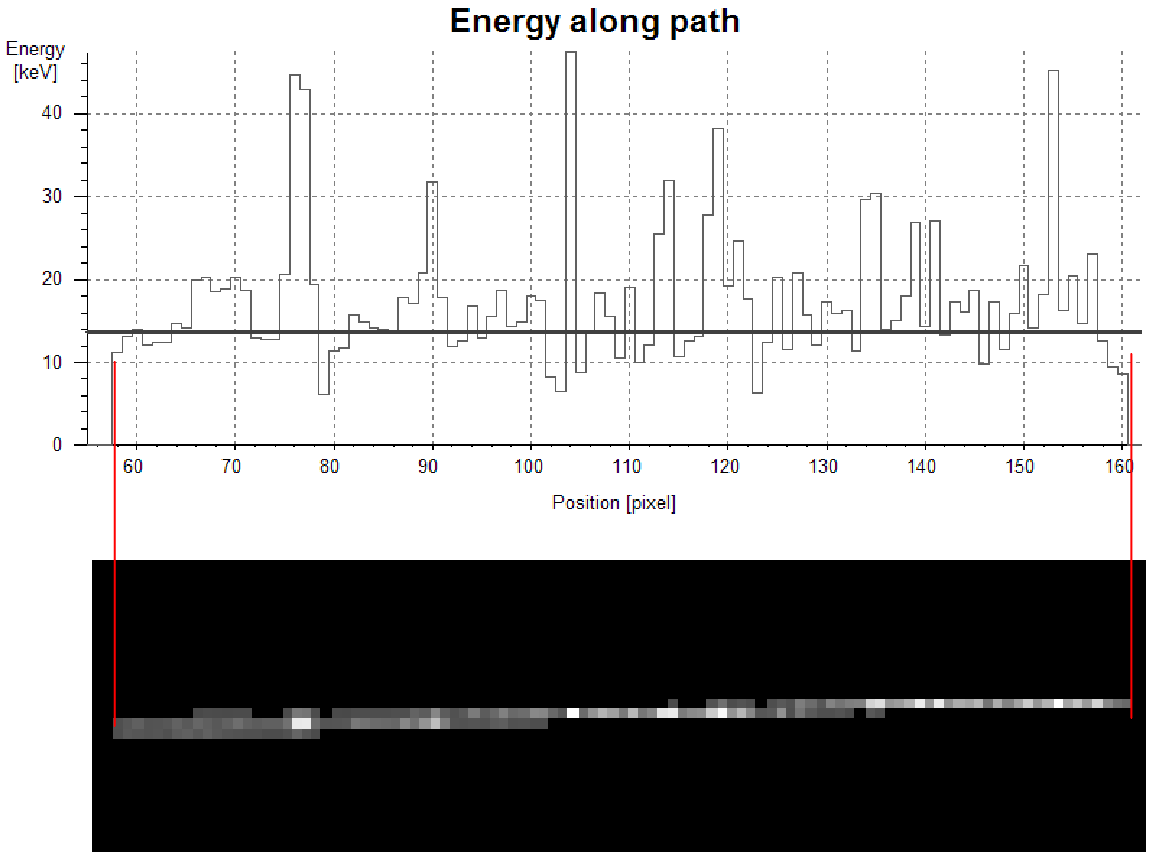


- Ionization by MIP particles doesn’t depend on depth and follows Landau distribution
- Charge sharing effect is more significant if charge is generated near the surface

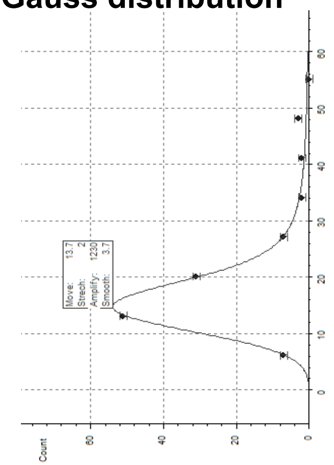
=> Charge sharing brings more information in tracking mode

Charge sharing effect:

Tracks of MIP particles – Cosmic muons



Energy distribution fit by convolution of Landau and Gauss distribution



The muon track recorded by TimePix device

Where Do We Go From Here?

- The University of Houston has been admitted to the Medipix2 Consortium for the purpose of developing a Space Radiation Dosimeter based on the Medipix Technology.
- The Timepix version of the Medipix2 chip offers an immediate opportunity to develop prototype flight hardware for evaluation.
- UH is proposing (via and SBIR proposal) to develop a directly deposited detector layer to avoid the necessity of "Bump-Bonding."
- Our intention is to try and fly a prototype within the next few years… This requires NASA funding in the near future… (Hopefully via a new NRA opportunity)
- Longer term, we would like to also join the new Medipix3 Consortium to participate in the continued development of a robust versatile portable personal active Space Radiation Dosimeter…

Thank You For Your Attention..

Backup Slides

Effects to be considered to explain charge sharing in case of strongly ionizing particles (alpha particles)

- **Plasma effect**
  - High free carriers density
    1. Carriers diffuse outwards of the column to reach equilibrium
    2. Electrons are faster than holes
       - Creation of two walls: outside negative, inside positive
    3. Distortion of the local electric field
- **Erosion**
  - Walls created by the plasma effect are removed faster than by pure diffusion under the influence of the electric field in the detector
- **Funneling**
  - Electric field distortion pushes the carriers towards their electrodes
    - More charge than expected is collected

Important with high applied field

Important for low applied fields

Plasma Effect

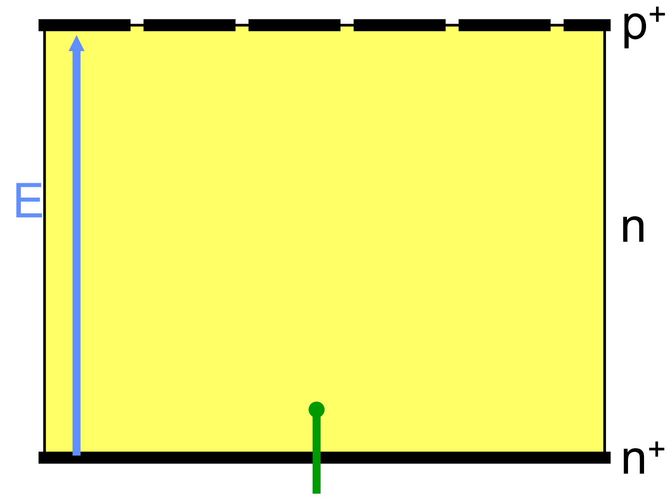
- **Ionization along the track is sufficient to have a radius greater than the Debye length**
  - **Screening of the outside electric field**
  - **Conditions correspond to a plasma**
- **The plasma time is expressed as:**

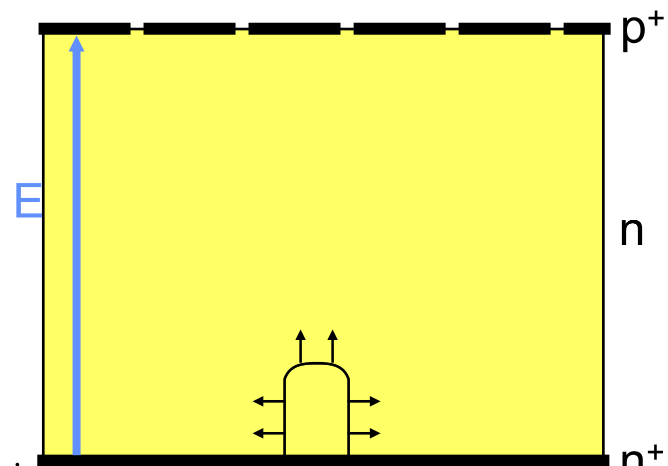
$$t_p = \frac{n_{lin}^2}{(4\pi\varepsilon_0 E)^2 D_a}$$

where n_{lin} is the linear ionization density, E is the applied electric field and D_a is the ambipolar diffusion constant.

In conditions of high applied electric field (over full depletion)

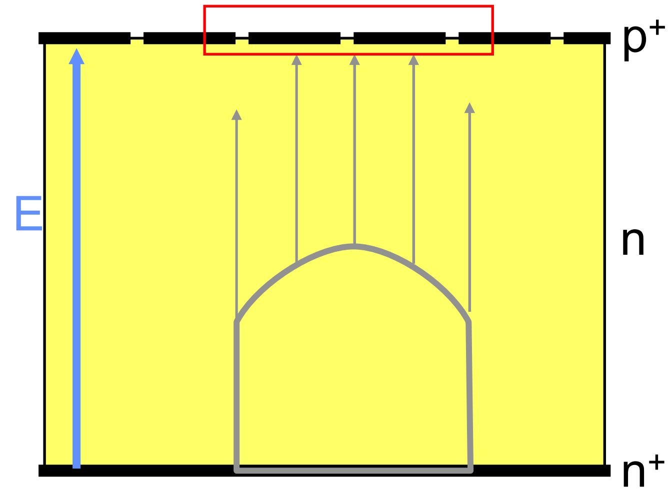
- **The heavy charged-particle enters the detector through the back side:**
  - **Plasma of electrons and holes is created along the path**
- **The charge density is much higher in the column, the particles diffuse to less dense areas**
  - **Ambipolar diffusion**





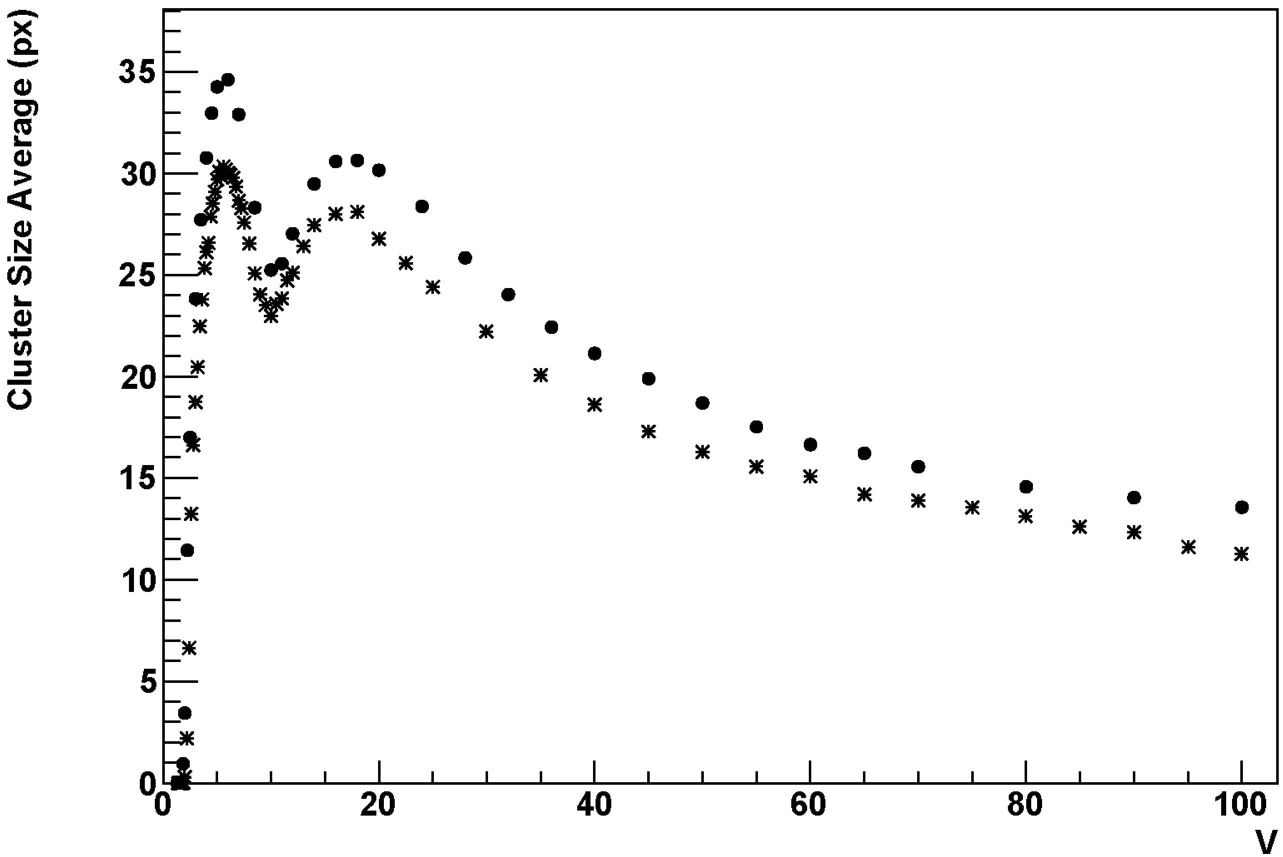
In conditions of high applied electric field (over full depletion)

- **Outside electrons are constantly removed. The column of holes expands up to a point where the plasma conditions no longer apply.**
  - **Lateral expansion stops, charge is collected through drifting.**



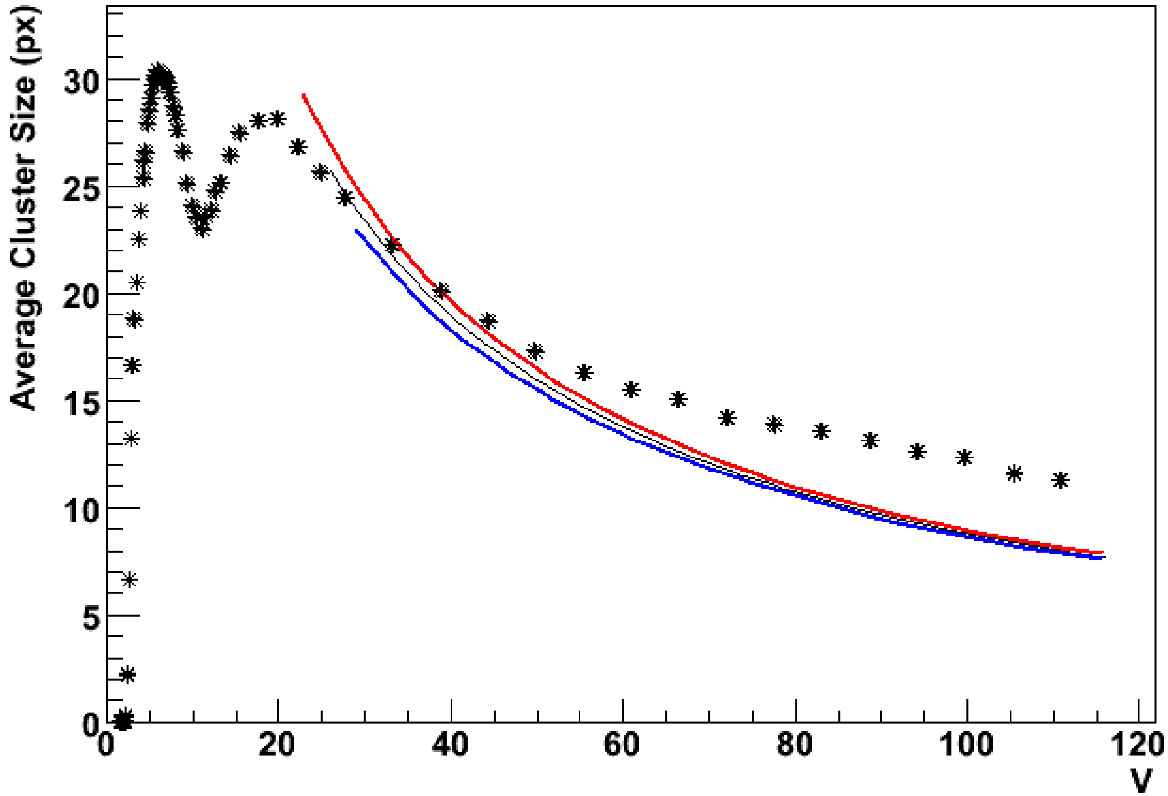
For low applied fields, the funneling effect, which pushes more carriers to the electrode than by pure diffusion, must be added. This case will not be discussed further.

Variation of alpha particle cluster size on applied bias



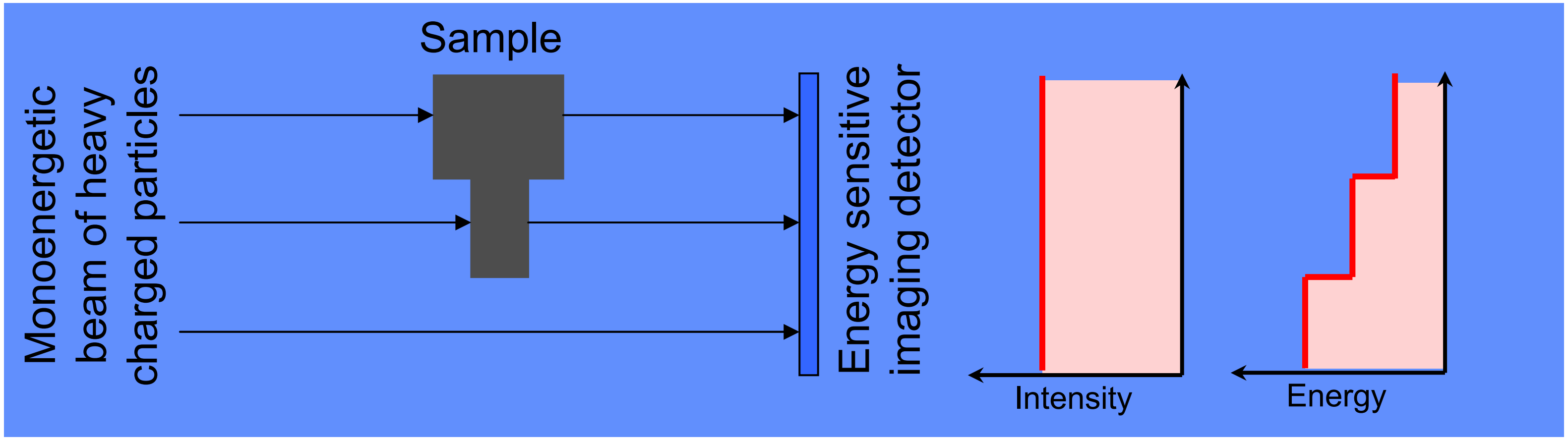
● for 4.2 MeV, * for 3 MeV

Variation of alpha particle cluster size as a function of applied bias for different V_{fd}



In red, Vfd =22 V, in black Vfd = 25 V and in blue, Vfd = 28 V.

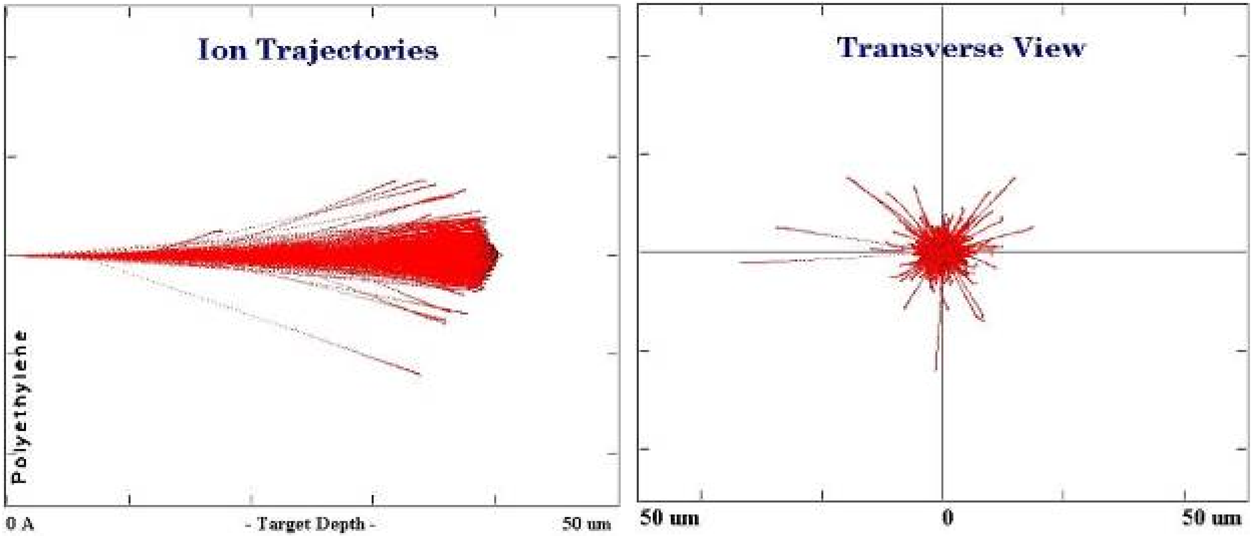
Application:
Radiography with heavy particles



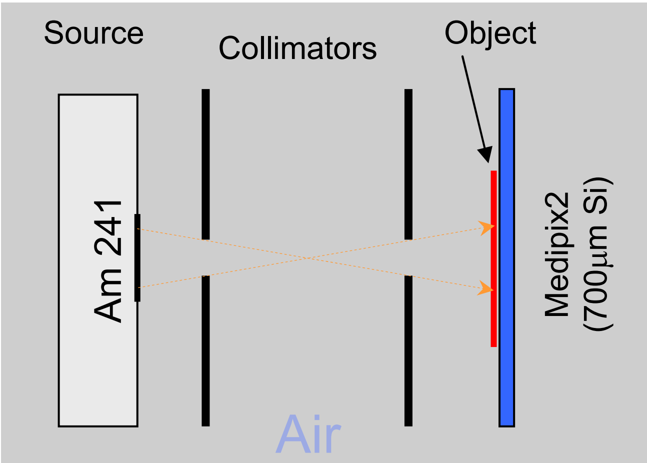
- Heavy charged particles **(protons, deuterons, tritons, alphas, ions) can be used (impossible with photons, difficult with electrons due to huge change of direction).**
- **Instead of transmitted beam intensity the** energy losses **of individual particles are measured.**
- **Just single particle is needed to measure material "density".**
- **With common sources of heavy charged particles (isotopes, ion beams) it is feasible to inspect just small (thin) objects (thin layer, foils, cellular structures)**
- Precision of thickness measurement can be in nanometer scale.

Radiography with heavy charged particles:
MC simulations

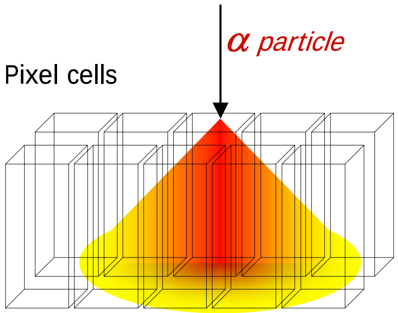
- Simple simulation performed for 5.5 MeV alphas and polyethylene
- Mean range is 39.1 μm
- Straggling is at the end of track about 500 nm (longitudinal and transversal)



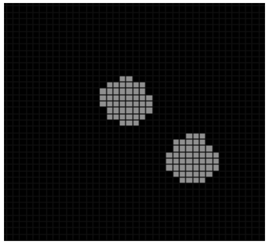
Radiography with heavy charged particles:
Simple example with Medipix2



High energy (5.5MeV) of alpha particle produces signal in several adjacent pixels forming **cluster**.
Cluster size depends on particle energy.

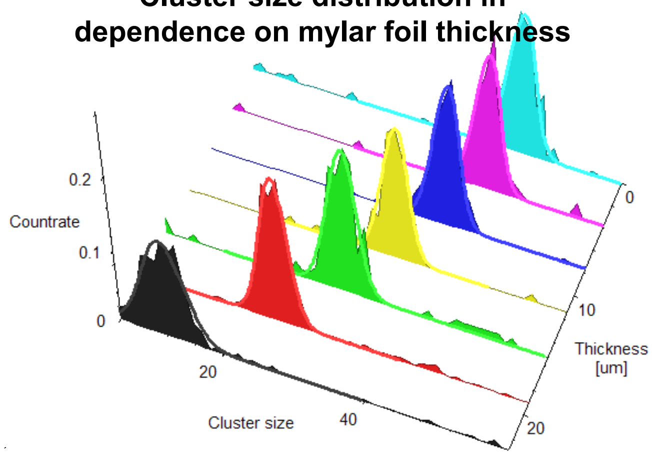


2 detected clusters

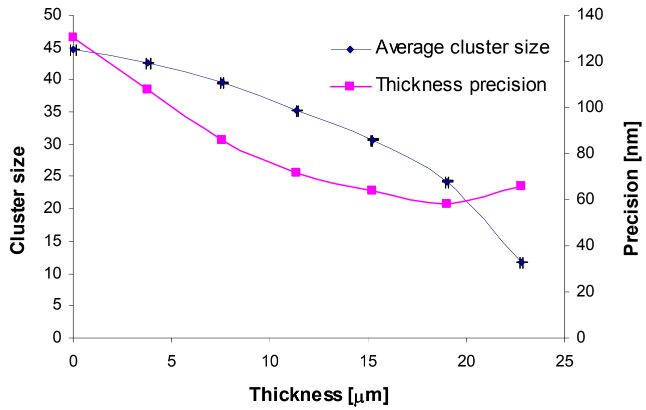


Cluster size up to 100!

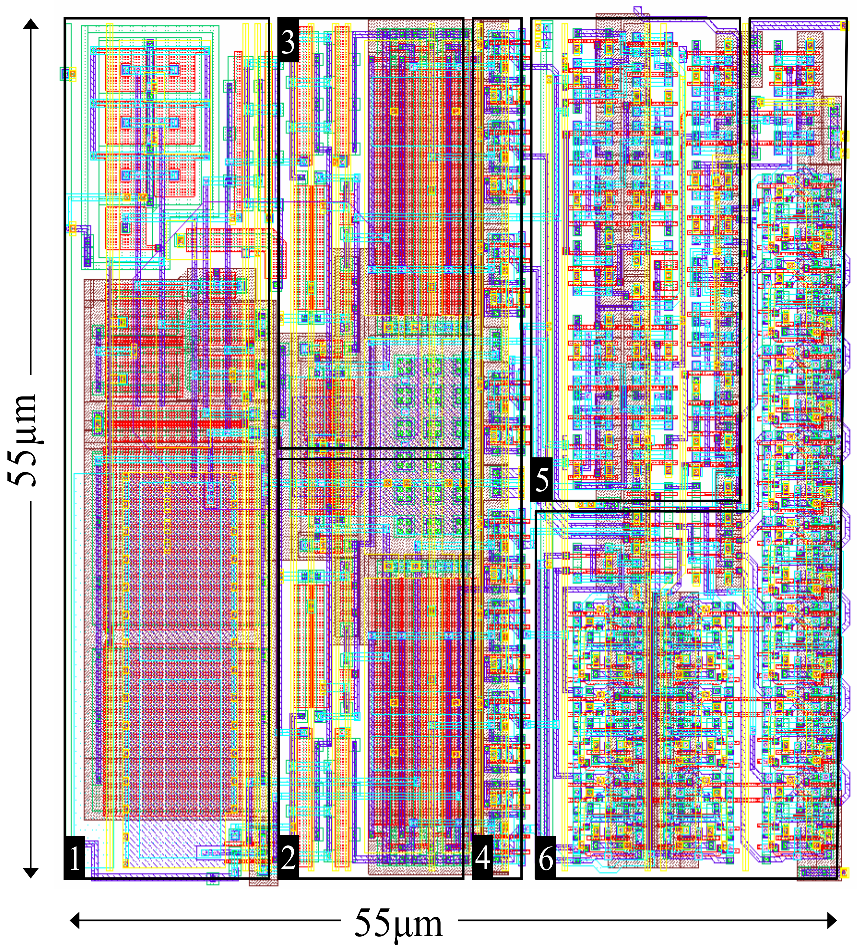
Cluster size distribution in dependence on mylar foil thickness



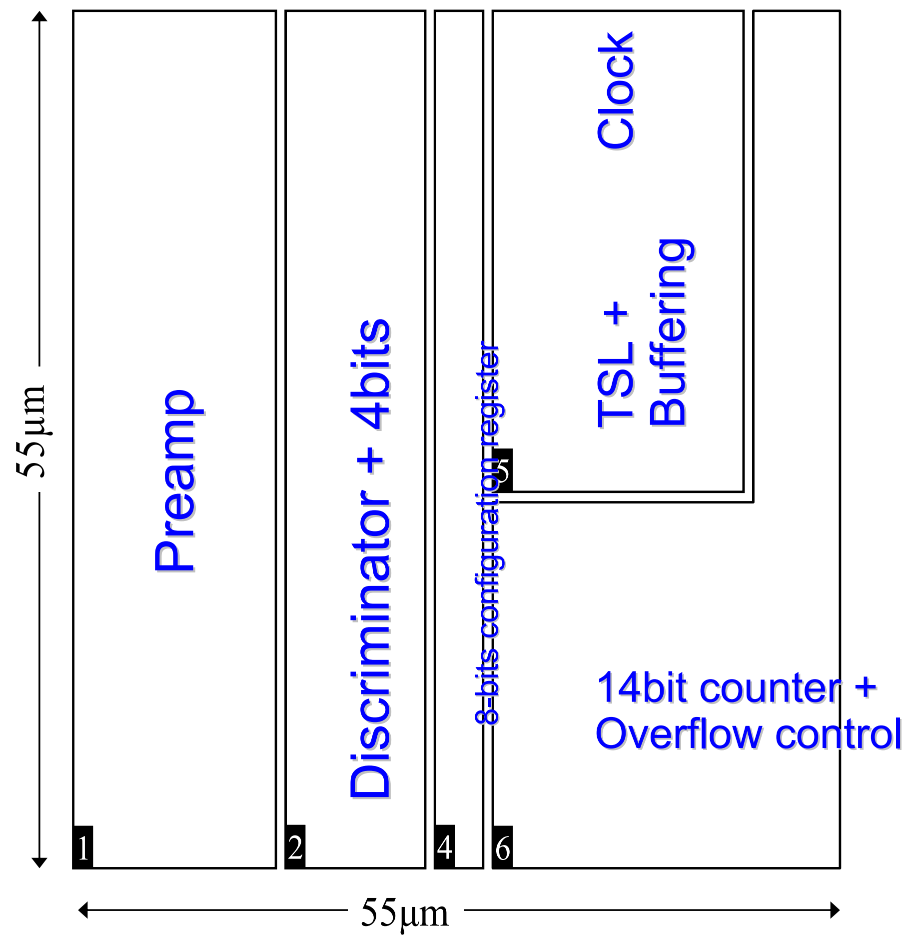
Dependence of average cluster size on foil thickness (1000 clusters analyzed)



Timepix Floorplan



Mpix2MXR20 layout



Timepix floorplan

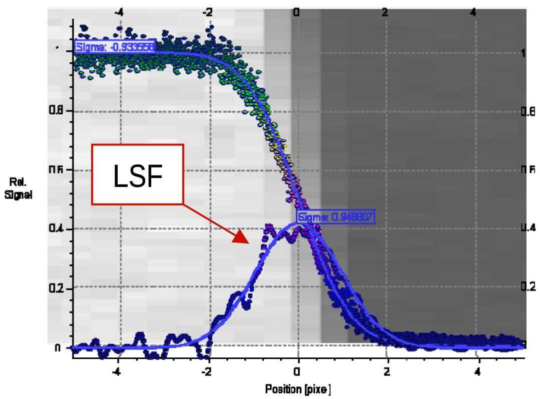
Tests with Thermal Neutrons

- **NEUTRA station of spallation neutron source SINQ in Paul Scherrer Institute, Villigen, Switzerland**
  - Intensity about $3 \cdot 10^6$ neutrons/cm^{2}s at proton accelerator current of 1mA and proton energy of 590 MeV
  - Beam Cross section: 40 cm in diameter

- **Horizontal channel of the LVR-15 nuclear research reactor at Nuclear Physics Institute of the Czech Academy of Sciences at Rez near Prague.**
  - Intensity is about 10^7 neutrons/cm^{2}s (at reactor power of 8MW)
  - Beam Cross section: 4 mm (height) x 60 mm (width)
  - The divergence of the neutron beam is < 0.5°

^{6}LiF converter
Spatial resolution – Edge response

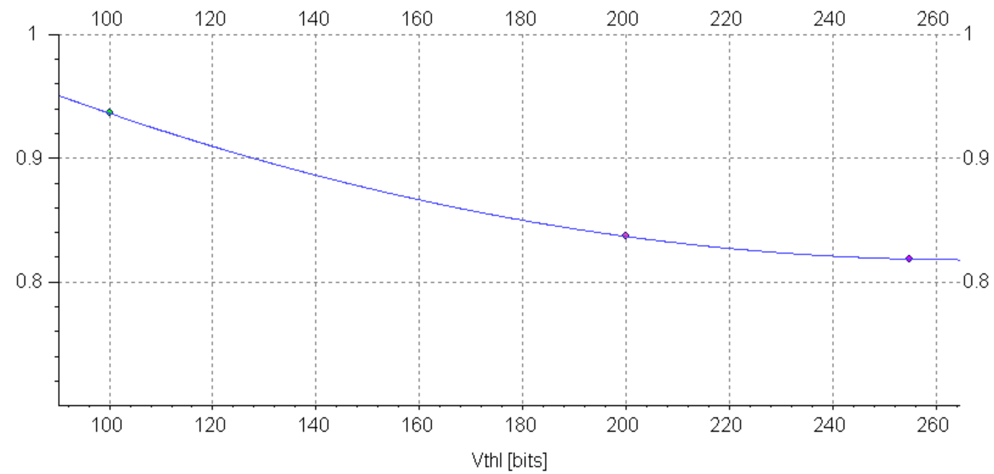
Tilted cadmium edge profile



Edge blurring is caused by clusters => Spatial resolution is dependent on the threshold level

Fit by ERF: σ=0.83 pixel
=> LSF FWHM=107 μm

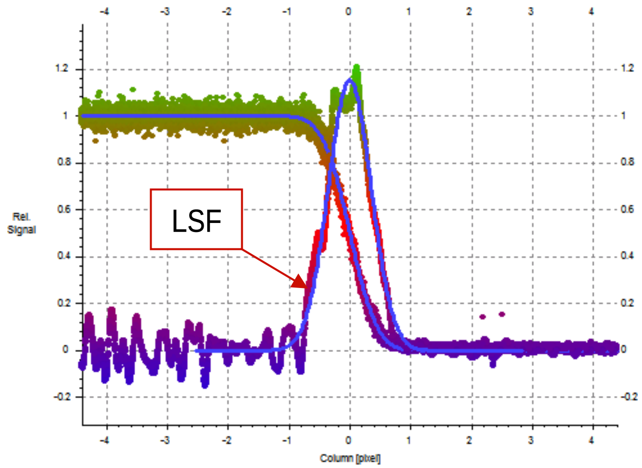
Dependence of edge profile sigma on Vthl



Spatial resolution is limited by size of clusters and range of product particles in silicon (R_{Triton}=44μm, R_{α}=8.9μm)

^{10}B converter
Spatial resolution – Edge response

Tilted cadmium edge profile



Fit by ERF: σ=0.35 pixel
=> LSF FWHM=45 μm

Heavy charged particles emitted by ^{10}B converter have shorter ranges then in case of ^{6}Li. Their energies are also lower so charge sharing is less important.

$\Rightarrow$ Spatial resolution is better

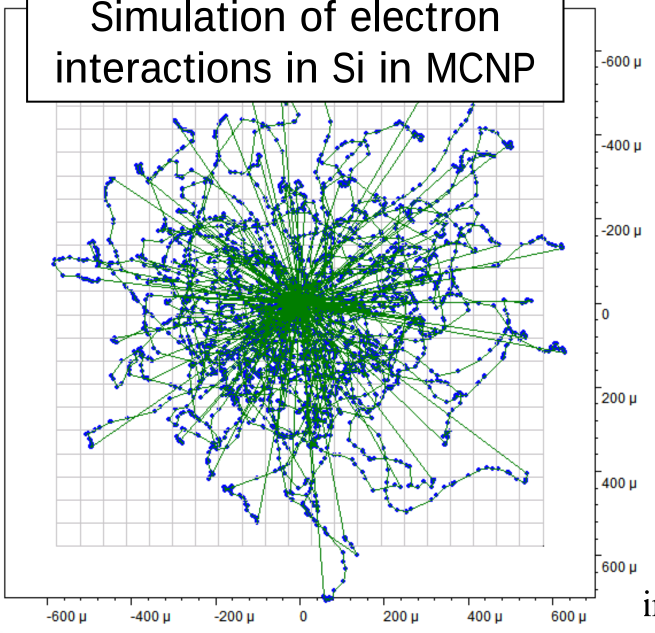
But lower number of particles can penetrate to depleted volume of the detector.

$\Rightarrow$ Efficiency is lower (approx. 2 times)

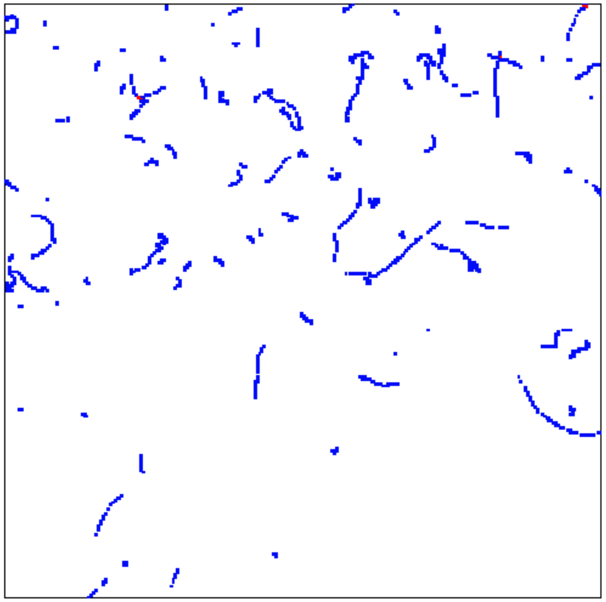
^{113}Cd converter

- Only conversion electrons are usable for imaging.
- Resolution highly deteriorated
- Using event-by-event acquisition and robust track analyzing algorithm it is probably possible to increase resolution.

Simulation of electron interactions in Si in MCNP

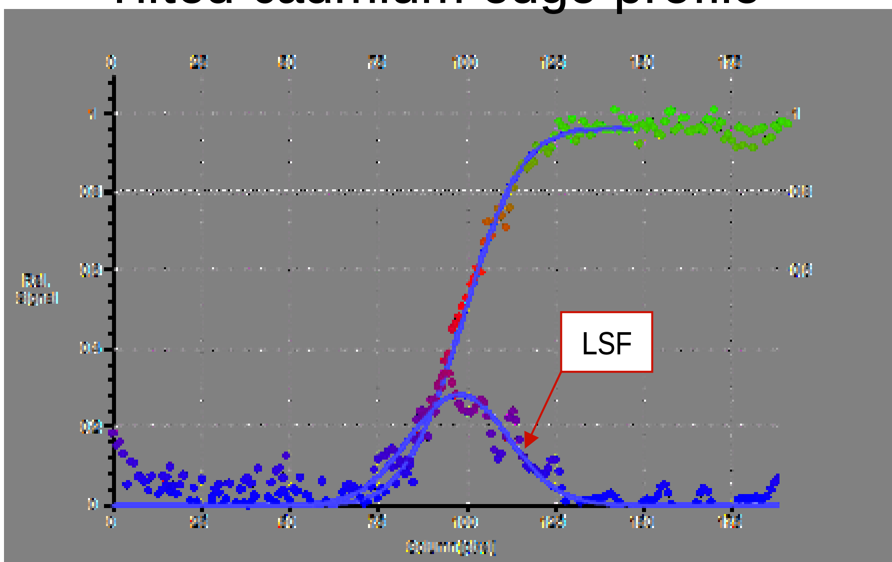


Tracks from 113Cd converter
Exposition=0.001s, Vfbk=250, Vthl=200



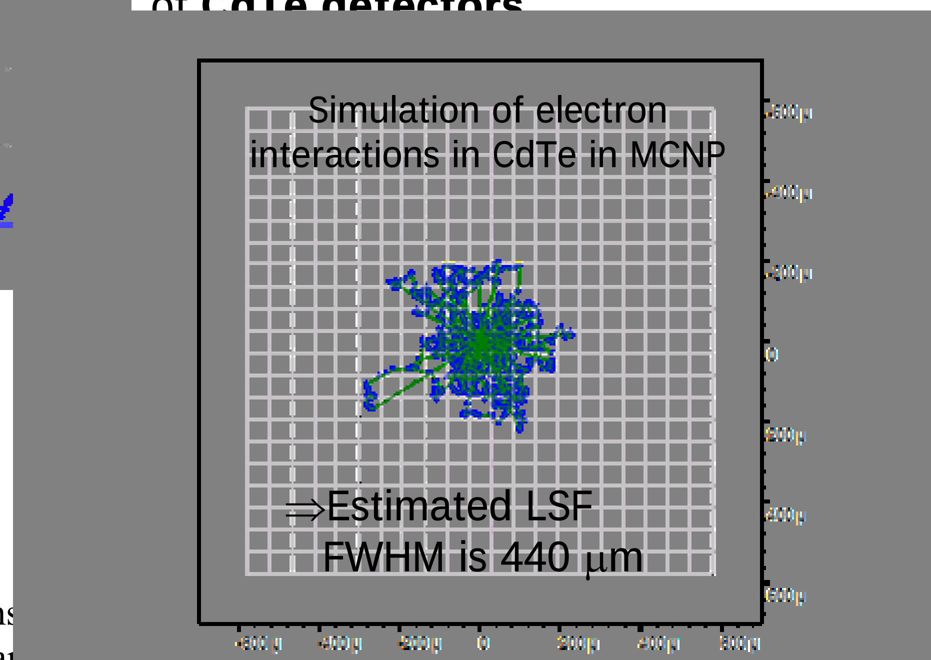
^{113}Cd converter
Spatial resolution – Edge response

Tilted cadmium edge profile



Fit by ERF: σ=13.1 pixel
=> LSF **FWHM=1.7 mm**

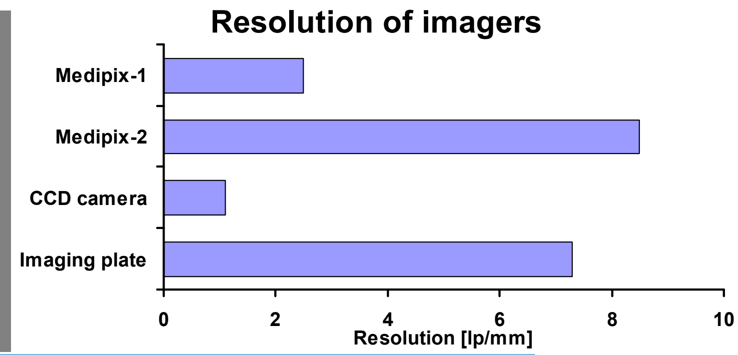
^{113}Cd as converter in combination with Si detector is not good choice for position sensitive detection of neutrons. But thanks to the large cross section it can reach good detection efficiency especially in case of **CdTe detectors**

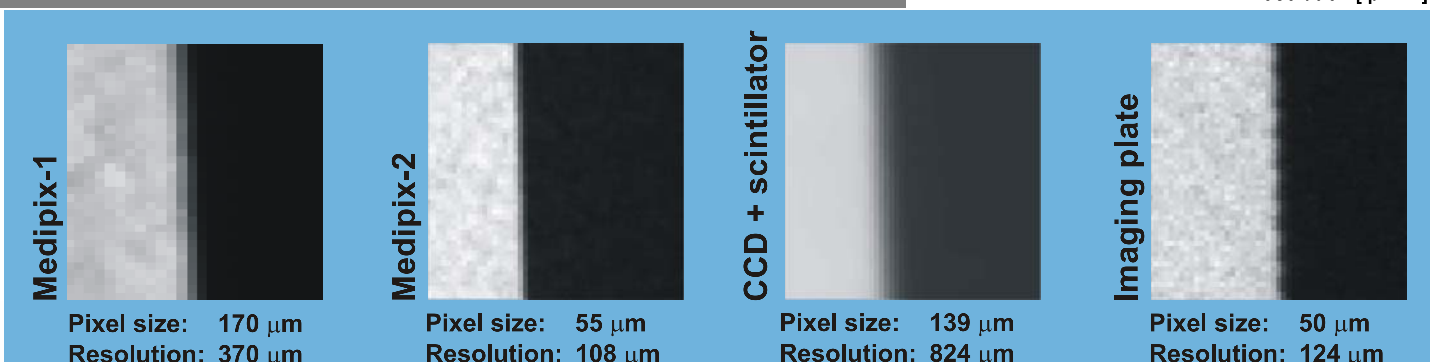


Comparison of Medipix-2 with other neutron imaging detectors

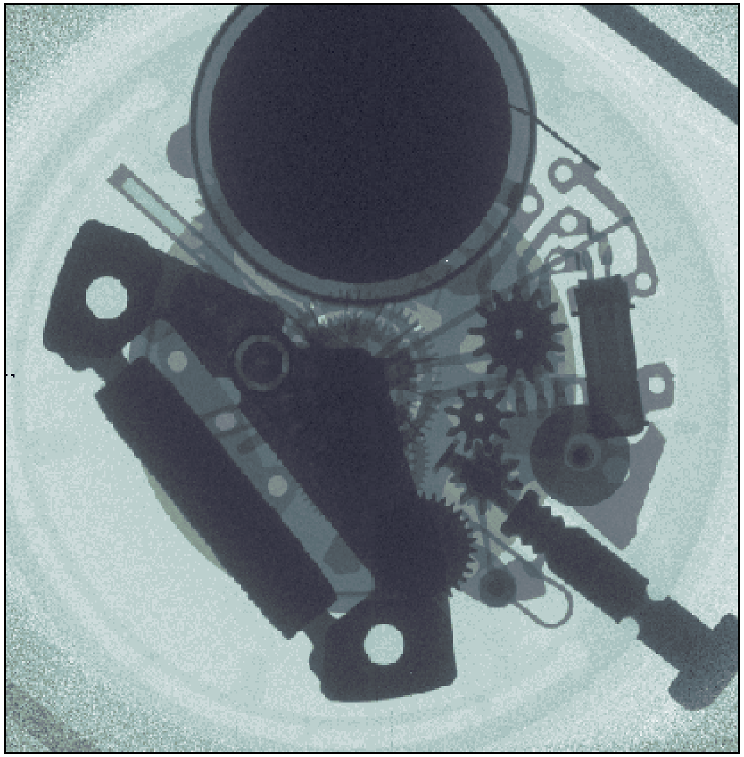
Tested:
- **CCD camera** with scintilator containing ^{6}Li (pixel size 0.139 mm)
- **Imaging plate** (excitation by neutrons, deexcitation by laser scanner followed by light emission, scanner pixel size 50μm)
- **Medipix-1** device with ^{6}LiF converter
- **Medipix-2** device with ^{6}LiF converter

Imager	Resolution (FWHM[1] of LSF[2]) [μm]	Resolution[3] [lp/mm]
Medipix-1 device	370	2.5
Medipix-2 device	108	8.5
CCD camera	824	1.1
Imaging plate	124	7.3





High rate images

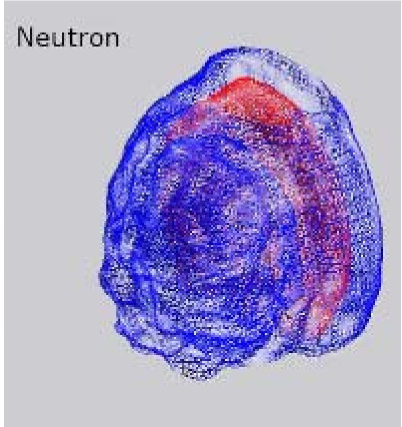


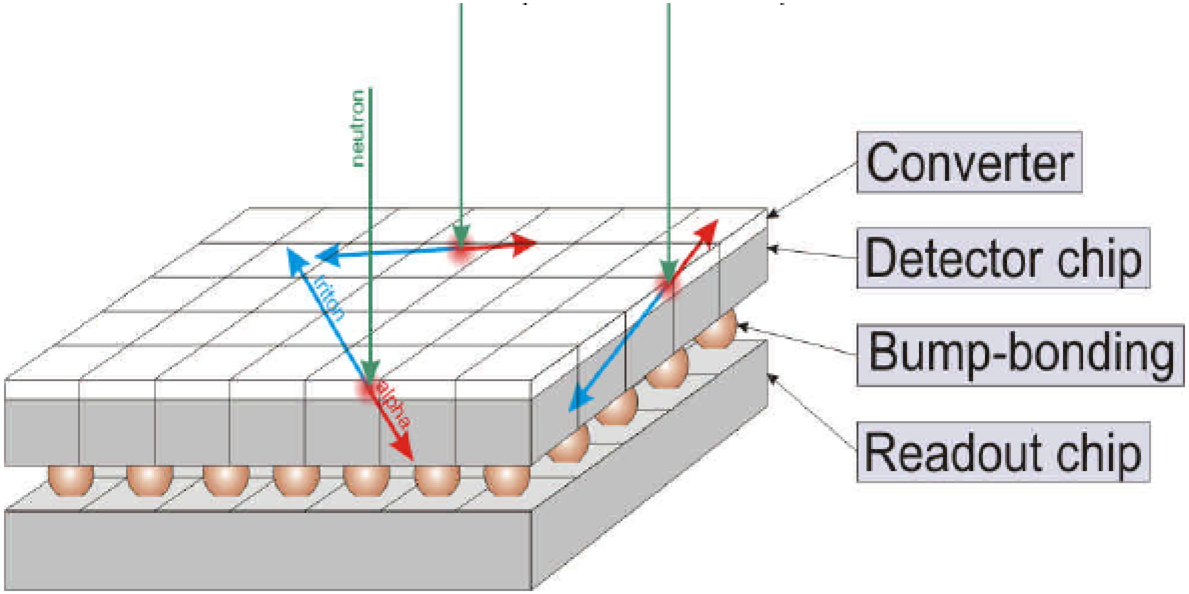
X-Ray movie at 5.5fps 512x512 pixels
Uses 4-chip Quad detector

Neutronography & Neutron Dosimetry

Lukas Tlustos, Czech Technical University, Prague *(To be developed by the University of Houston)*

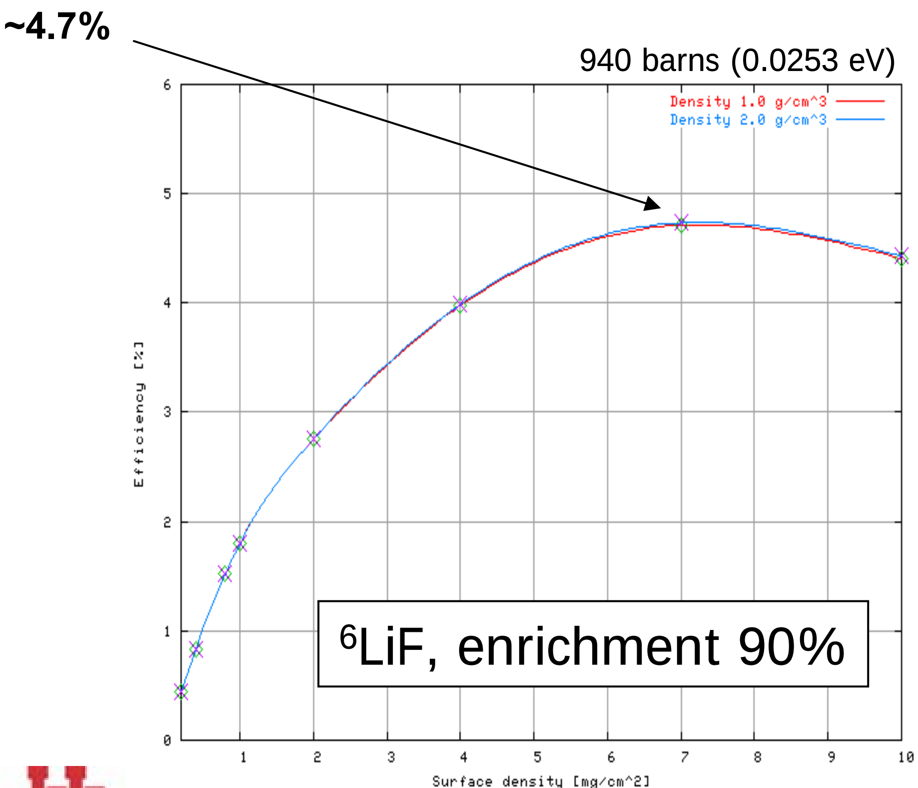
- **Detection of light elements due to different attenuation of neutrons in matter, strong attenuation by H -> organic materials**
- **Conversion of thermal neutrons to heavy charged particles in ^{6}Li converter layer**
- **Reaction: $^{6}Li + n \rightarrow \alpha$ (2.05 MeV) + ^{3}H (2.72 MeV)**
  Cross section: 940 barns (0.0253 eV)

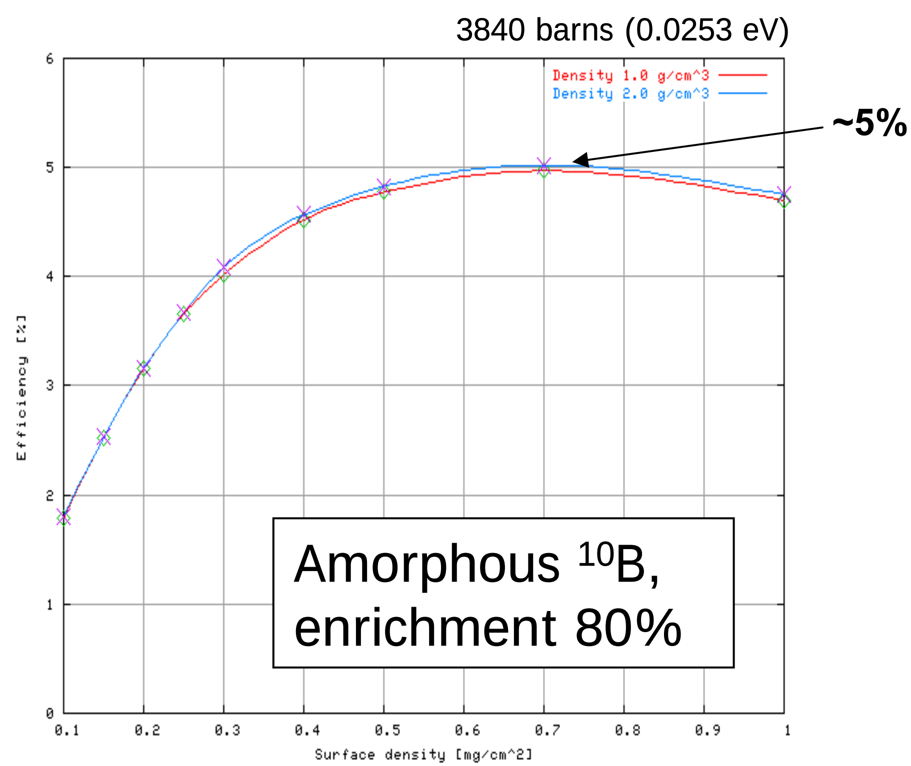




Monte-Carlo efficiency simulations

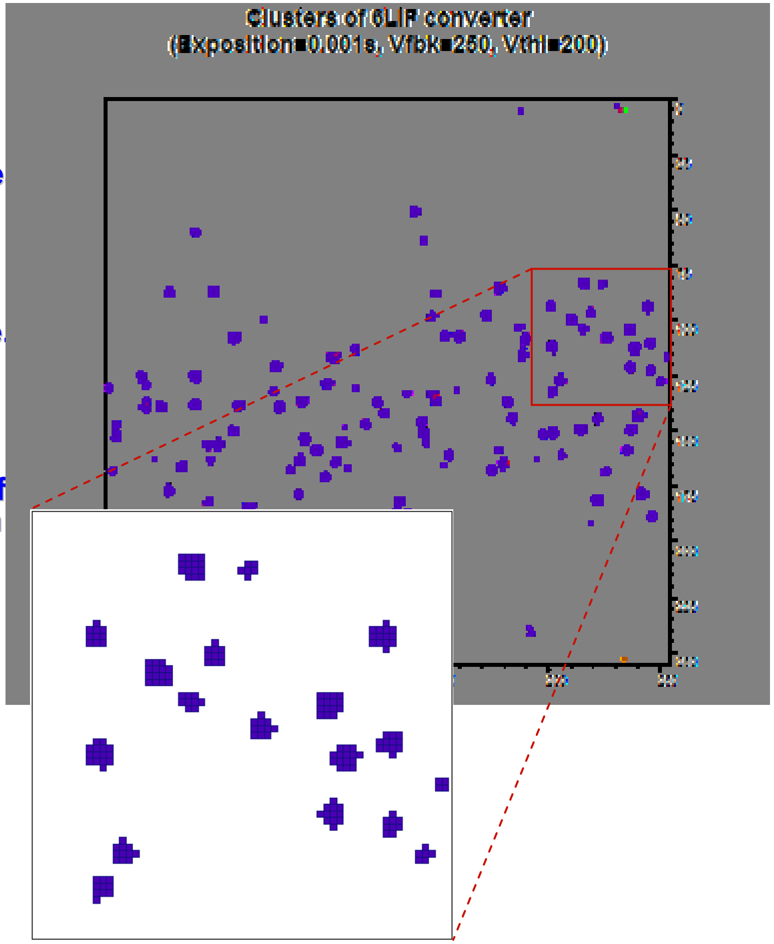
Detection efficiency was simulated in dependence on the converter thickness
- The neutron transport simulated using MCNP
- Energy deposition and ionization computed by TRIM/SRIM



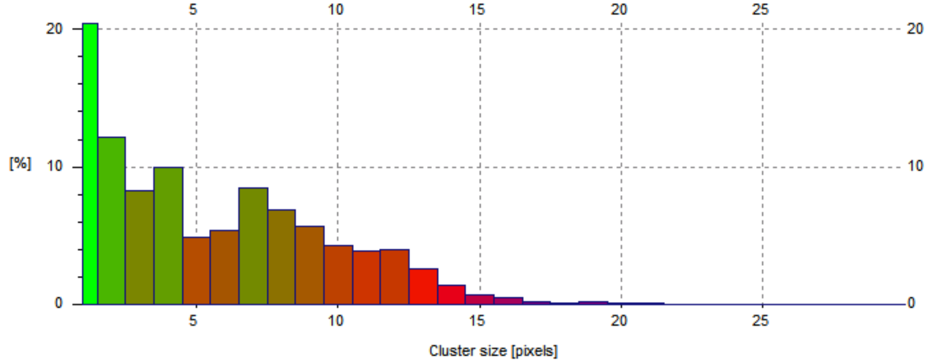


^{6}LiF converter (Cluster Sizes)

- Sensor covered by ^{6}LiF layer (3mg/cm^{2}). Detection efficiency is about 3%.
- High energy of alpha particles and tritons is deposited ne detector surface => charge sharing is significant.
- Each hit creates signal in cluster of pixels.
- Cluster size limits spatial resolution in integrating regime.
- Cluster size can be decreased by high threshold at the expense of efficiency.
- Using event-by-event acquisition and finding centroids of clusters it is possible to reach subpixel spatial resolution (approximately half of pixel)



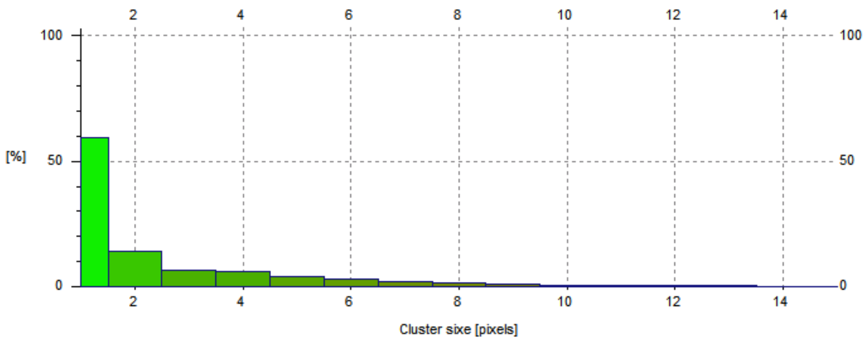
Cluster size distribution for 6LiF converter
Exposition= 50 x 0.001s, Vfbk=250, Vthl=205



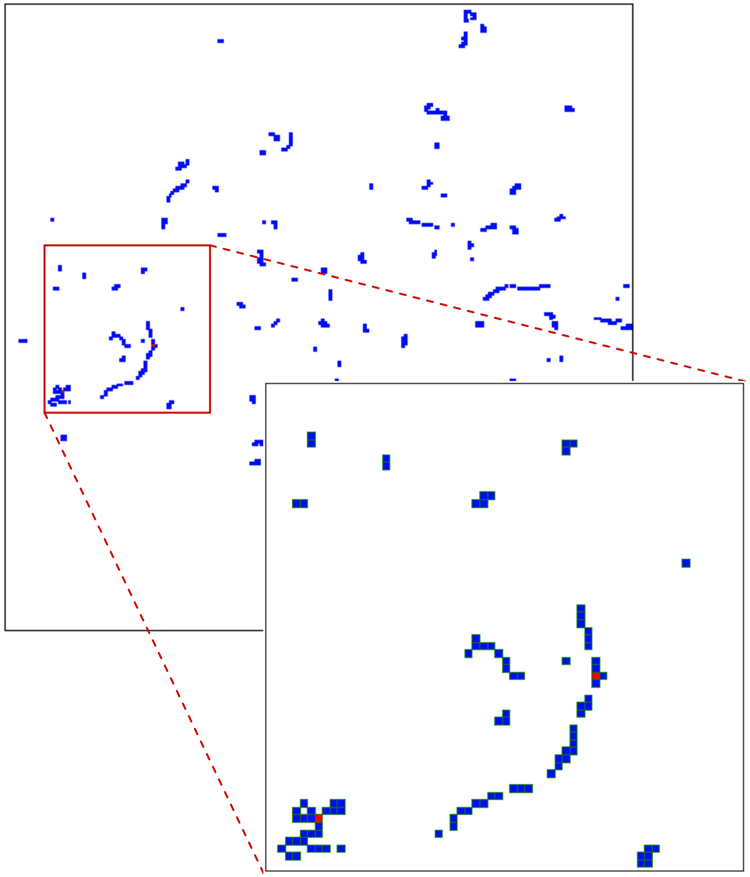
Amorphous ^{10}B converter (Cluster Sizes)

- Energy of heavy charged particles is lower than in case of ^{6}Li converter => smaller clusters are produced.
- From γ interactions electrons are generated => electron tracks are present. Spatial resolution is deteriorated by electron tracks.
- Energy of electrons is lower then energy of heavy particles => electron tracks can be suppressed by suitable threshold selection.

Cluster size distribution for 10B converter
Exposition= 50 x 0.001s, Vfbk=250, Vthl=200



Clusters of 10B converter
(Exposition=0.001s, Vfbk=250, Vthl=200)



Analog pixel summary

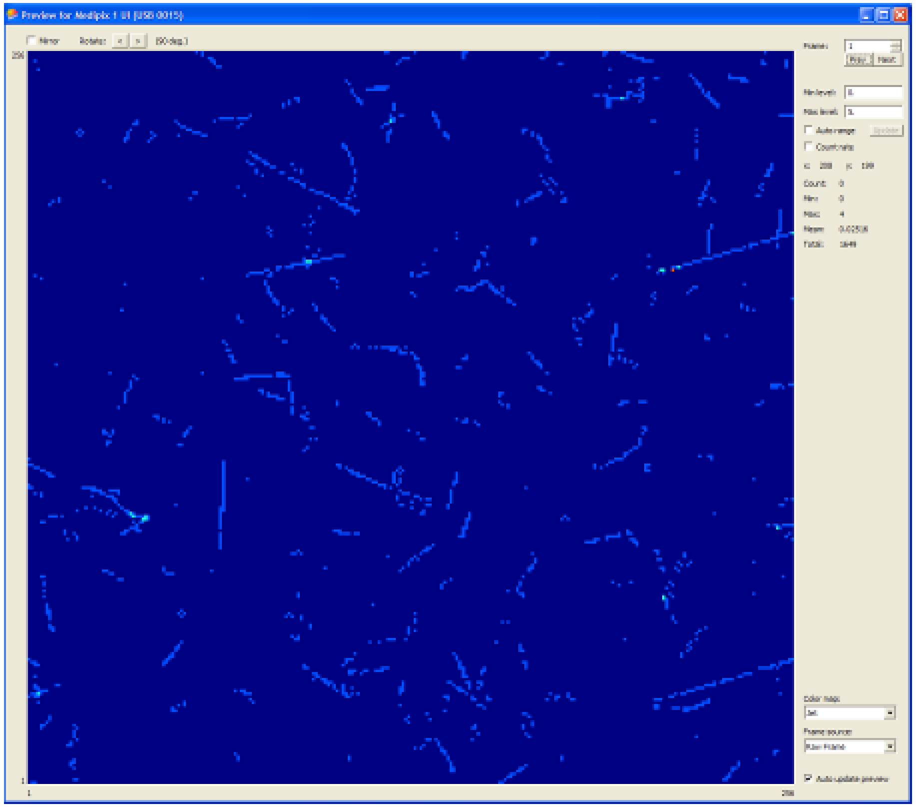
Amplifier Gain	~18mV/Ke	
Peaking Time	90ns…140ns (IPreamp)	
Pixel noise	~75e^-_{rms}	
Preamp DC Level (FBK)	800mV (e^-)	1.4V (h^+)
Threshold dispersion	~170e^-	
Adjusted Threshold dispersion	~25e^-	
Voltage linear range	0 to 50 Ke^- (< 2%)	
TOT linear range	>200Ke^-	
Time Walk	~25ns (2Qth to ∞)	
TOTgain	~55ns/Ke^- (Ikrum=5nA)	
Analog Pixel consumption (Max)	2.9μA x 2.2V = 6.38 μW (30% less than Mpix2MXR20)	

All these values are extracted from simulations !!!

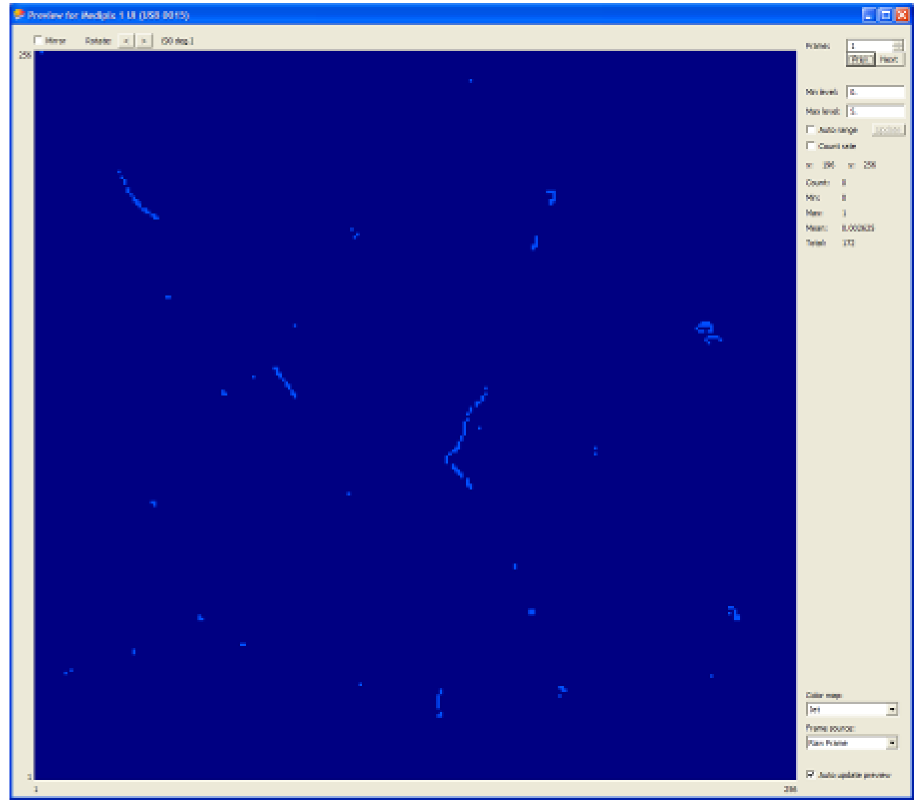
The Medipix2 Consortium

- Institut de Fisca d'Altes Energies, Barcelona, Spain
- University of Cagliari and INFN Section thereof, Italy
- CEA, Paris, France
- CERN, Geneva, Switzerland,
- Universitat Freiburg, Freiburg, Germany,
- University of Glasgow, Scotland
- Universita' di Napoli and INFN Section thereof, Italy
- NIKHEF, Amsterdam, The Netherlands
- University of Pisa and INFN Section thereof, Italy
- University of Auvergne, Clermont Ferrand, France,
- Laboratory of Molecular Biology, Cambridge England
- Mitthogskolan, Sundsvall, Sweden,
- Czech Technical University, Prague, Czech Republic
- ESRF, Grenoble, France
- Academy of Sciences of the Czech Republic, Prague
- Universität Erlangen-Nurnberg, Erlangen, Germany
- University of California-SSL, Berkeley, CA, USA
- University of Houston, Houston, Texas, USA

100 Sec Integrated Medipix2 Images

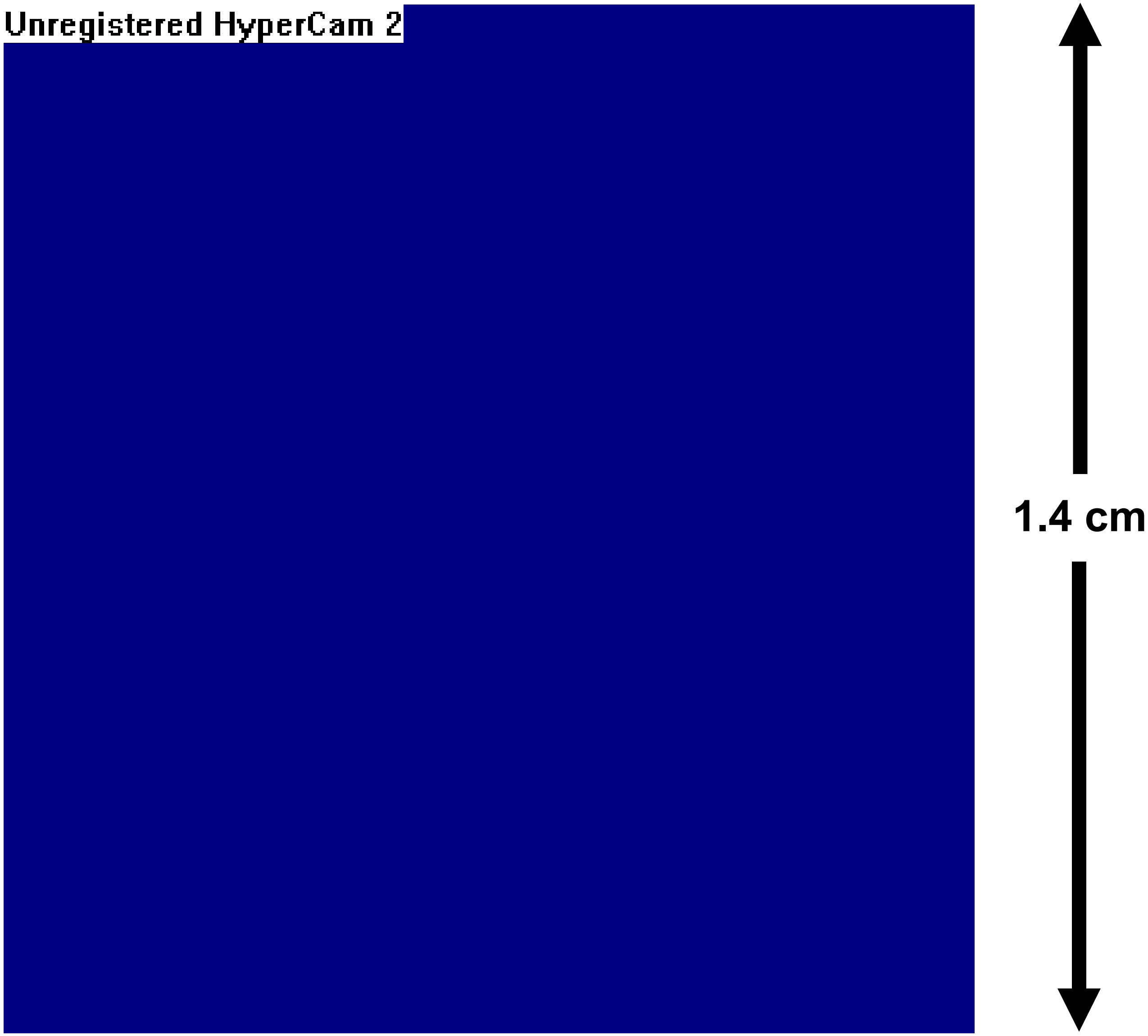


On my lap in a 777 airliner at 34,000 Feet over Anchorage, Alaska on the flight to Japan…



On the 15th floor of the Mitsui Garden Hotel in Chiba, Japan…

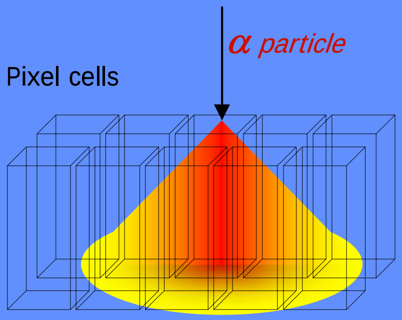
α Source



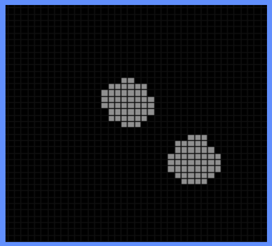
Charge sharing for position and energy sensitive detection of heavy charged particles with pixel detectors

Several adjacent pixels can be incremented when a single particle is detected due to charge diffusion during charge collection.

Pixels incremented by a single particle form a **cluster.**



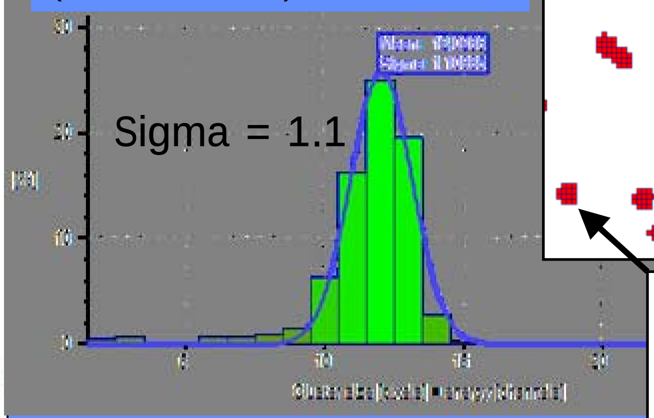
2 detected clusters

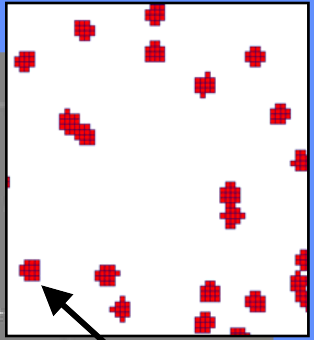


Cluster size up to 90!

Cluster size depends on particle energy

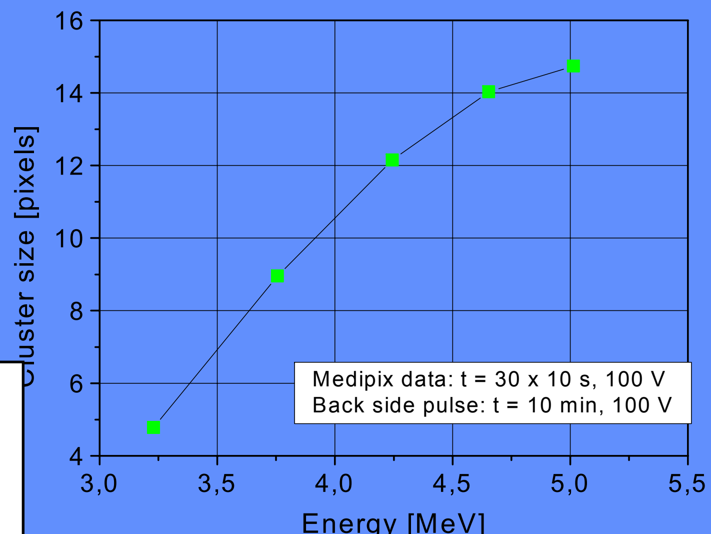
5.4 MeV alpha source at 24 mm (measured in air)





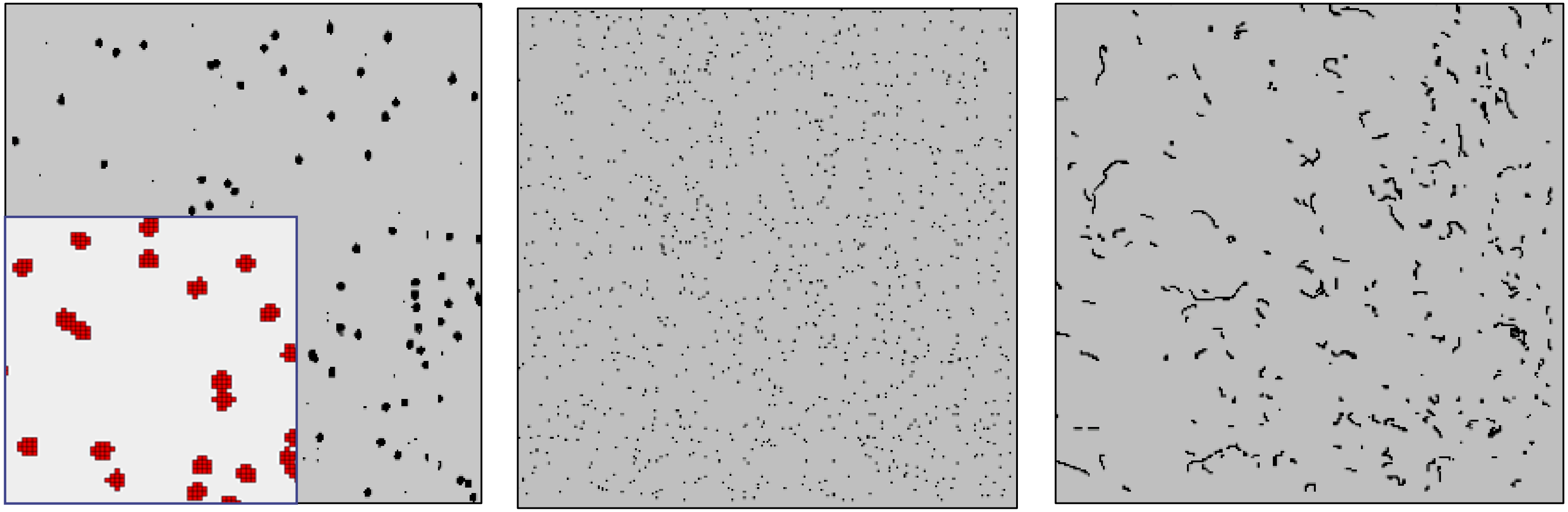
Signal by one alpha particle = cluster

Dependence of **cluster size on alpha particle energy**



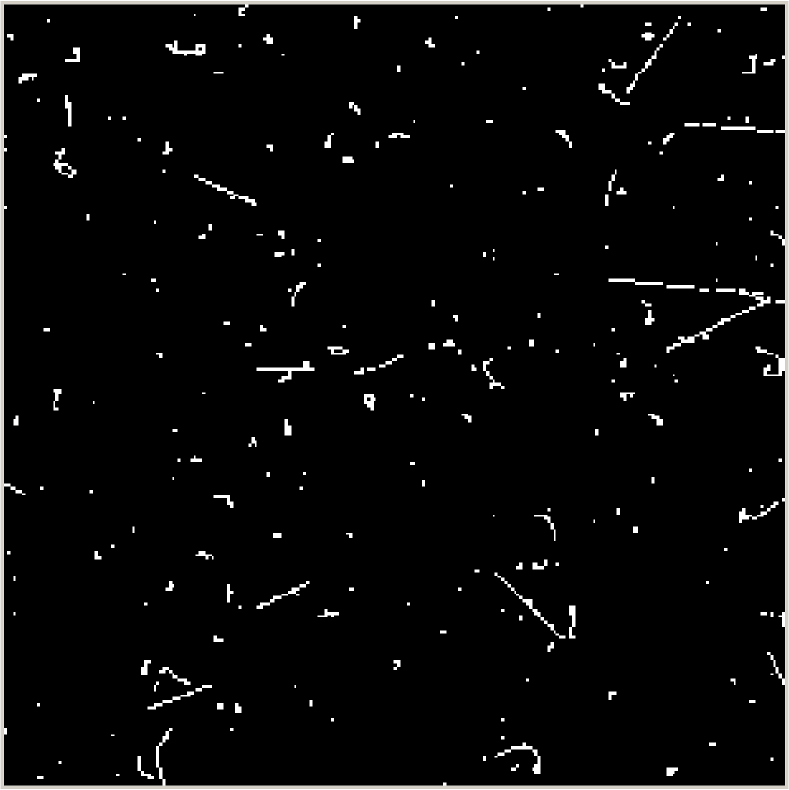
Tracking mode of pixel detector

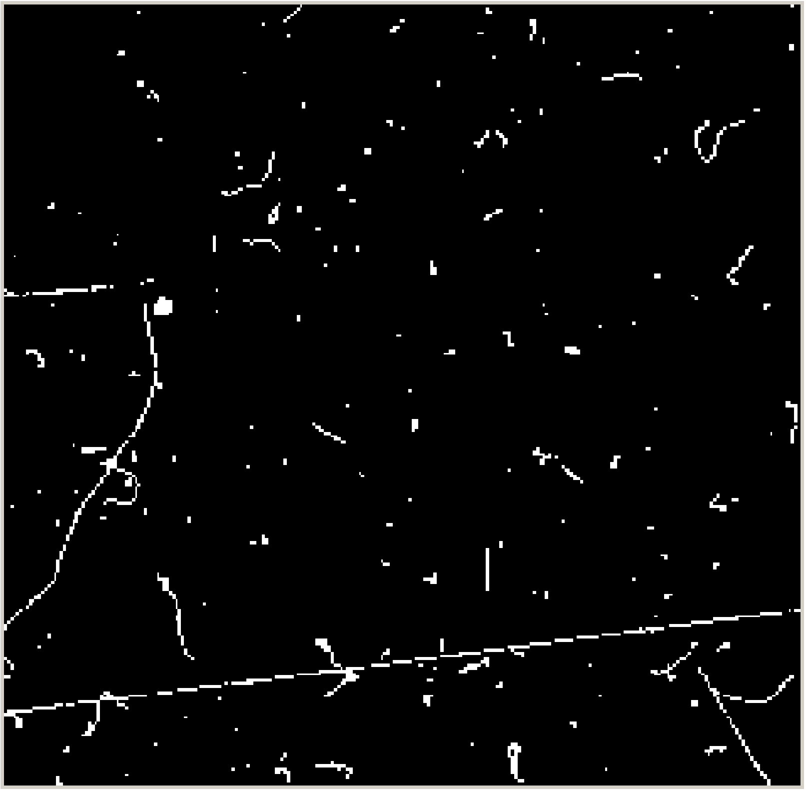
(on-line imaging of tracks and traces of single radiation quanta)



- **241Am alpha source gives clusters of ~5x5 pixels measured with the MEDIPIX-USB device and a 300 μm thick silicon sensor. The clusters are shown in detail in the inlet. The cluster sizes depend on particle energy and threshold setting.**
- **Signature of X-rays from a 55Fe X-ray source. Photons yield single pixel hits or hits on 2 adjacent pixels due to charge sharing.**
- **A 90Sr beta source produces curved tracks in the silicon detector.**

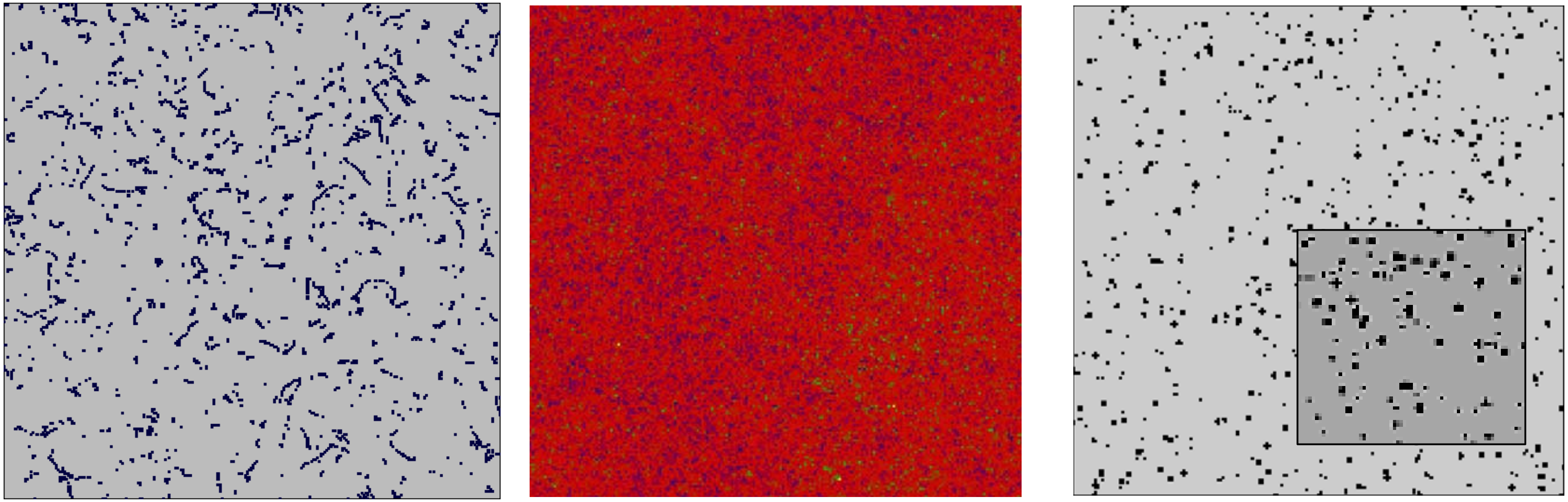
Natural background radiation





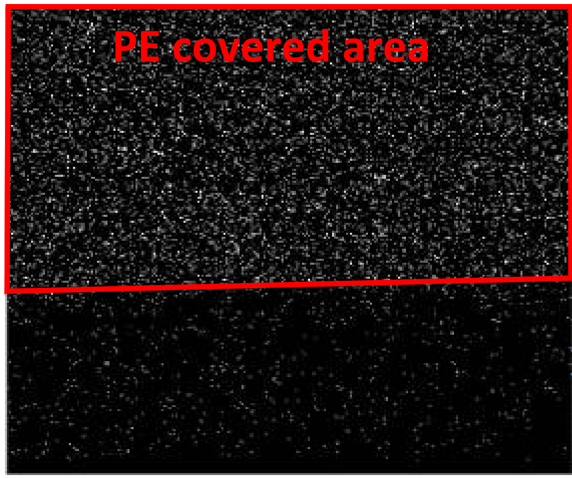
Clearly recognizable tracks and traces of X-rays, electrons generated mostly by gamma rays, alpha particles, muon, …

Measurements inside the “low power” light water reactor LR-0 (close to the active zone). The silicon sensor covered with a ^{6}LiF converter 5 mg/cm^2 thick. The thermal neutron flux ~10^9 n/(s.cm^2)



- The measurements were done at different threshold settings to demonstrate the capability of the device to operate at extremely high count rate and to discriminate different components of radiation.
- Left: The reactor was off, image obtained at low threshold settings.
- Middle: The reactor was on – low threshold settings. Total count rate ~10^9 counts/s.
- Right: The reactor was on – high threshold settings. One can clearly recognize, that all signals induced by gamma rays and electrons are discriminated (by corresponding tracks disappearance) and only neutrons are detected. It shows that the extremely high background contribution can be very effectively suppressed! *See posters 10.9 – Josef Uher and 10.10 – Celine Lebel!*

Background suppression by means of threshold high settings



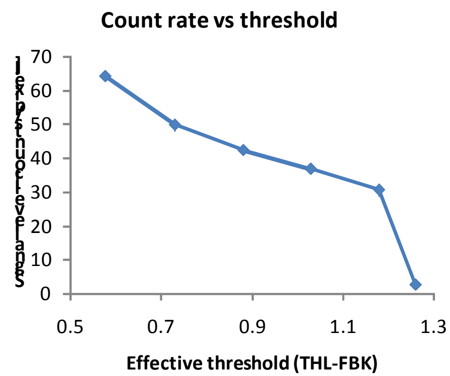
1 mm thick PE sheet was mounted on Medipix2 device

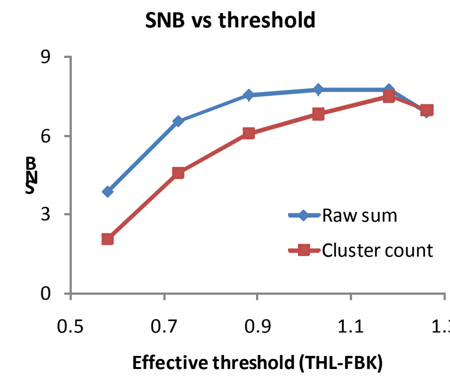
See also Poster 10.9 of Josef Uher!

Thresholds of individual pixel set higher.
Number of events in the uncovered area are significantly reduced.

Thresholds of individual pixel set low.
Events in the uncovered area are caused only by background.

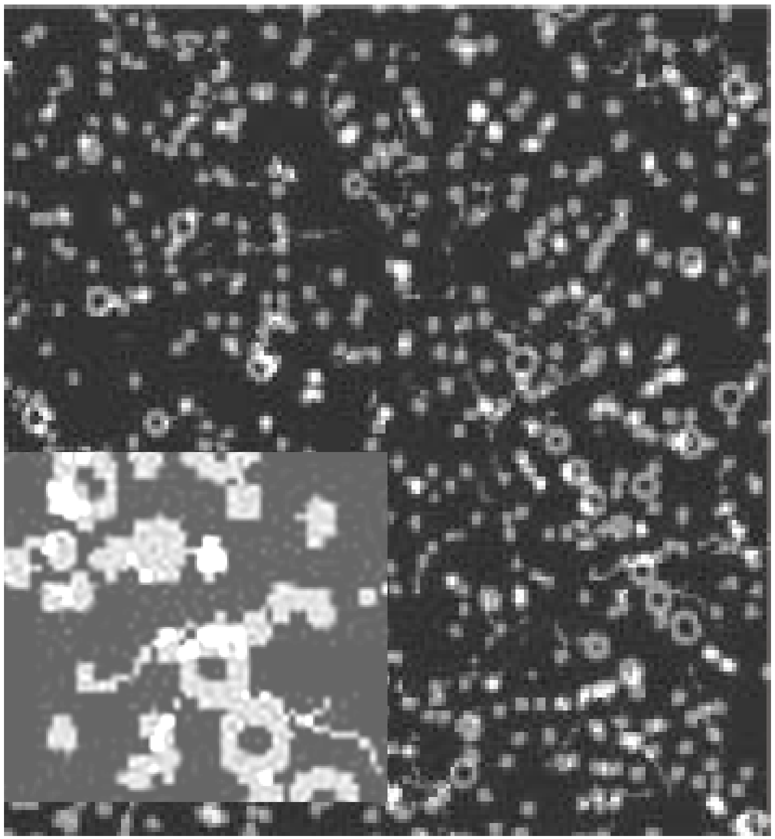
The measurements were performed at:
- neutron beam of the reactor Sparrow of the Czech Technical University in Prague
- neutron beam at Institut Laue-Langevin (ILL) in Grenoble

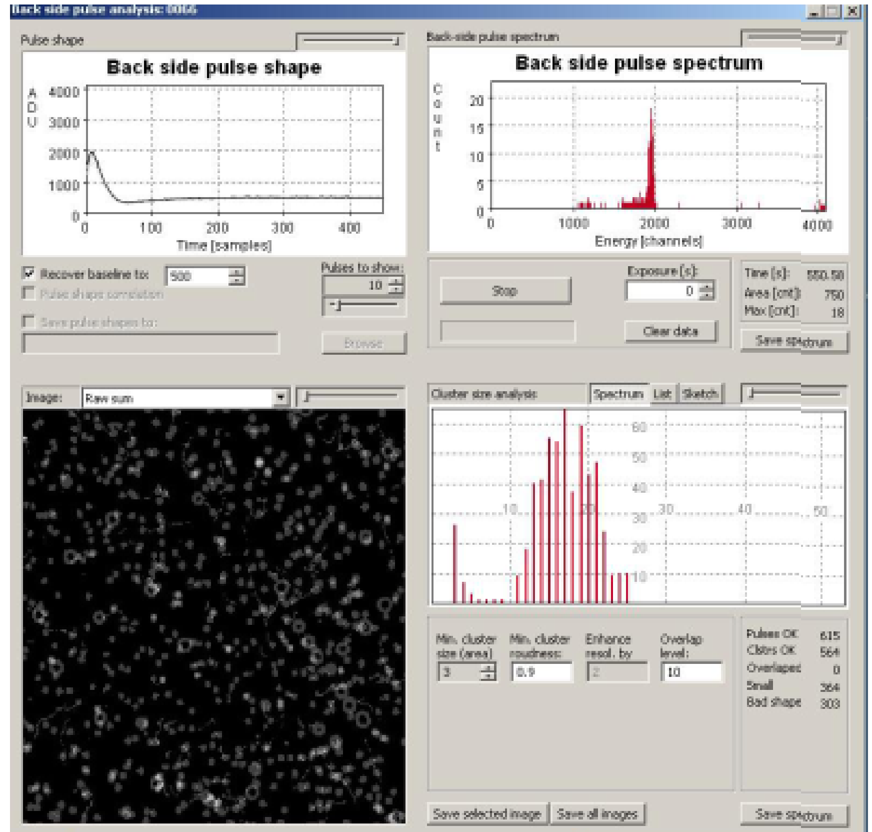




Measured count rate and SNB as functions of the effective threshold

Detailed view on structure of clusters of fission fragments



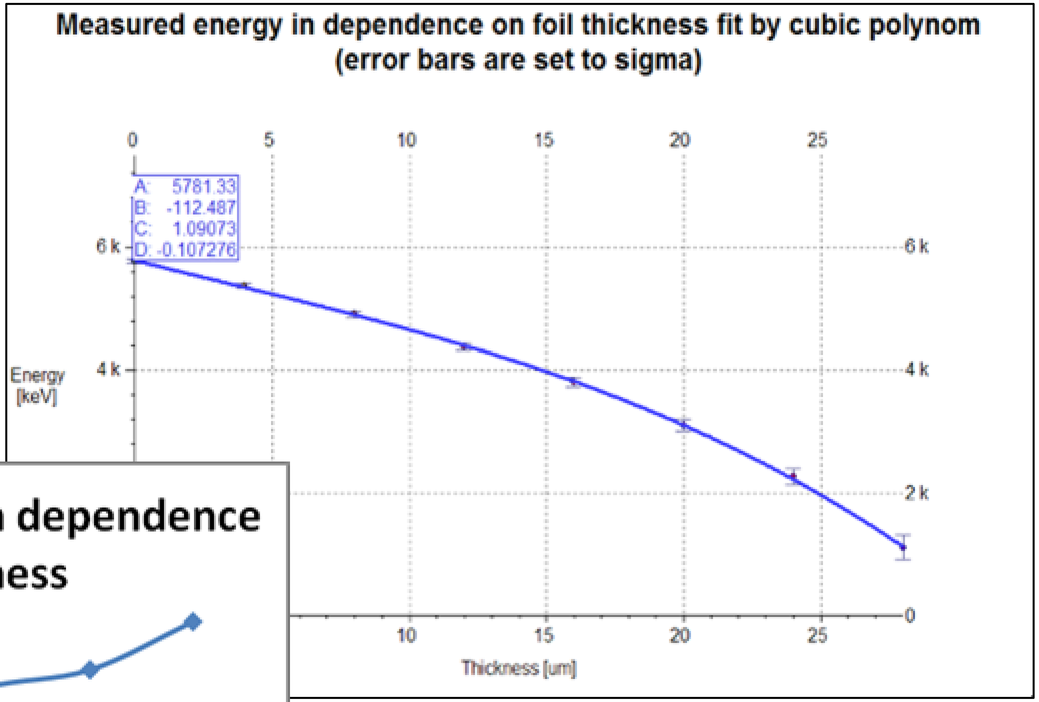


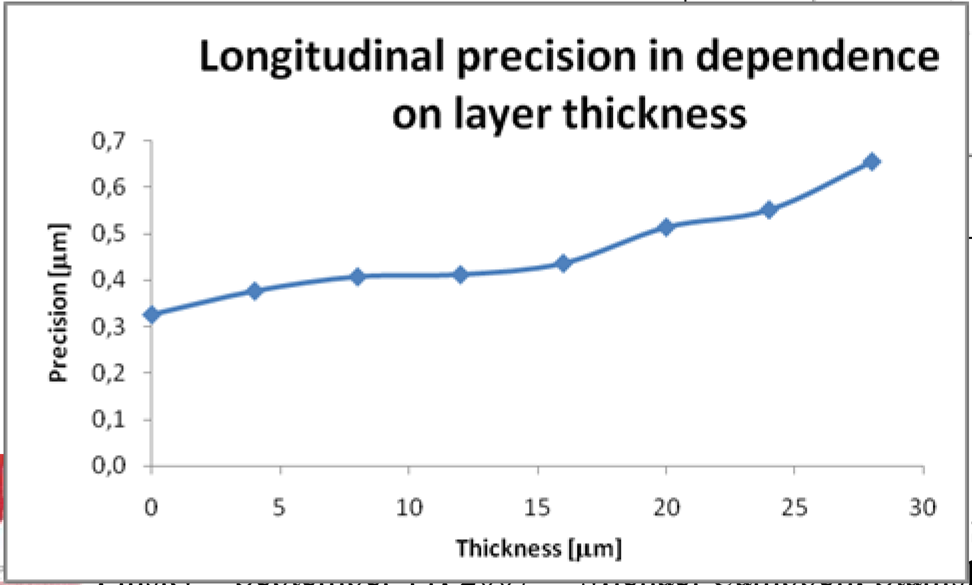
Clusters of alpha particles and fission fragments (up to 100 MeV energy) are clearly recognizable. Saturation of individual pixel electronics is displayed by a "ring" shape clusters. Pulse height spectrum (energy range > 3 MeV) obtained by the back-side pulse spectrscopy is also dispalyed (right).

Radiography with heavy charged particles:

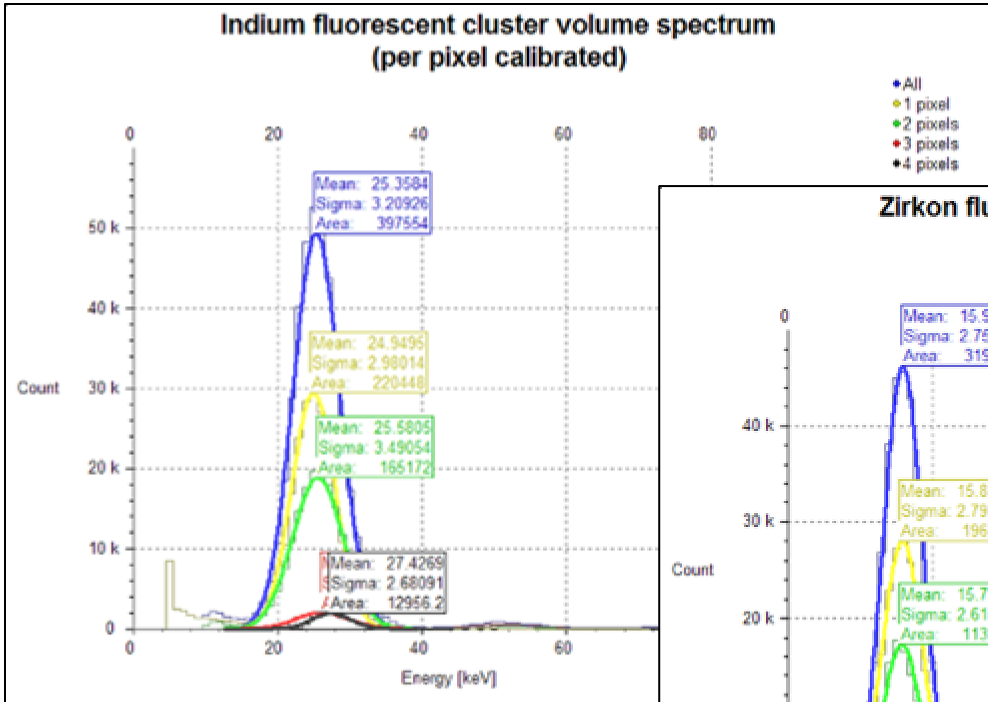
Determination of longitudinal precision

- Thickness of thin layer is measured with single alpha particle with precision of 320 nm
- If 50 particles are averaged then precision reaches 50 nm

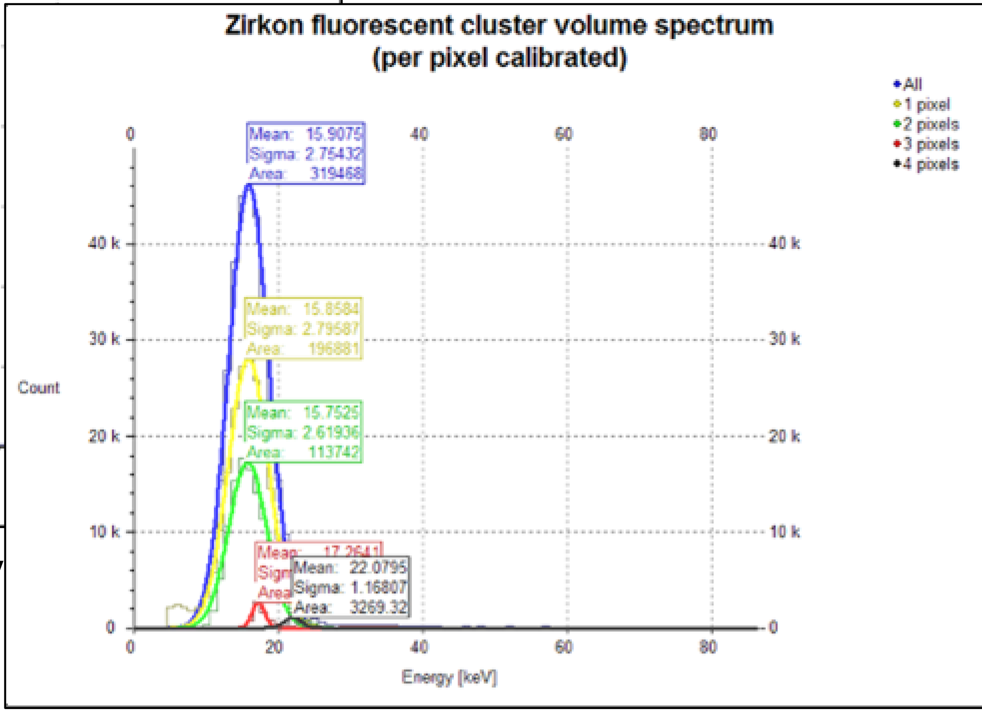




TOT mode calibration:
Zr and In fluorescence



In: 24.2keV peak sigma = 3.2keV



Zr: 15.8keV peak sigma = 2.7keV

Triggered image integration

TOT mode calibration:
Pixel by Pixel

If particle hits a border between pixels then:

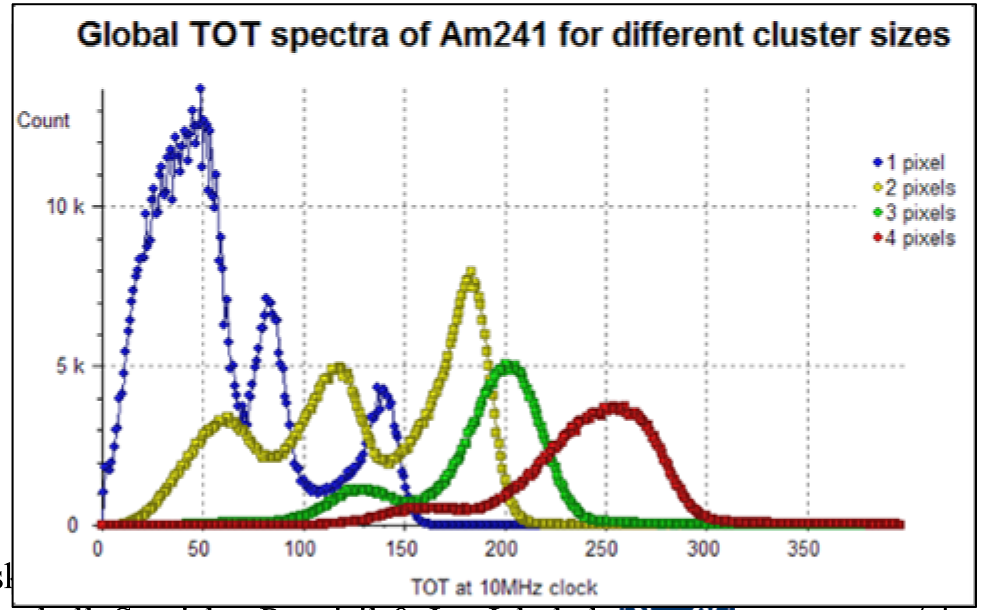
⇒ **charge is collected by more than one pixel**

⇒ **to recover original charge it is possible to sum energies measured by all hit pixels (compute cluster volume)**

Test without calibration:

^{241}Am: 59.5keV, 26.3keV

For 59,5keV are two and three pixel clusters more frequent then singles.



TOT mode calibration:
How to calibrate?

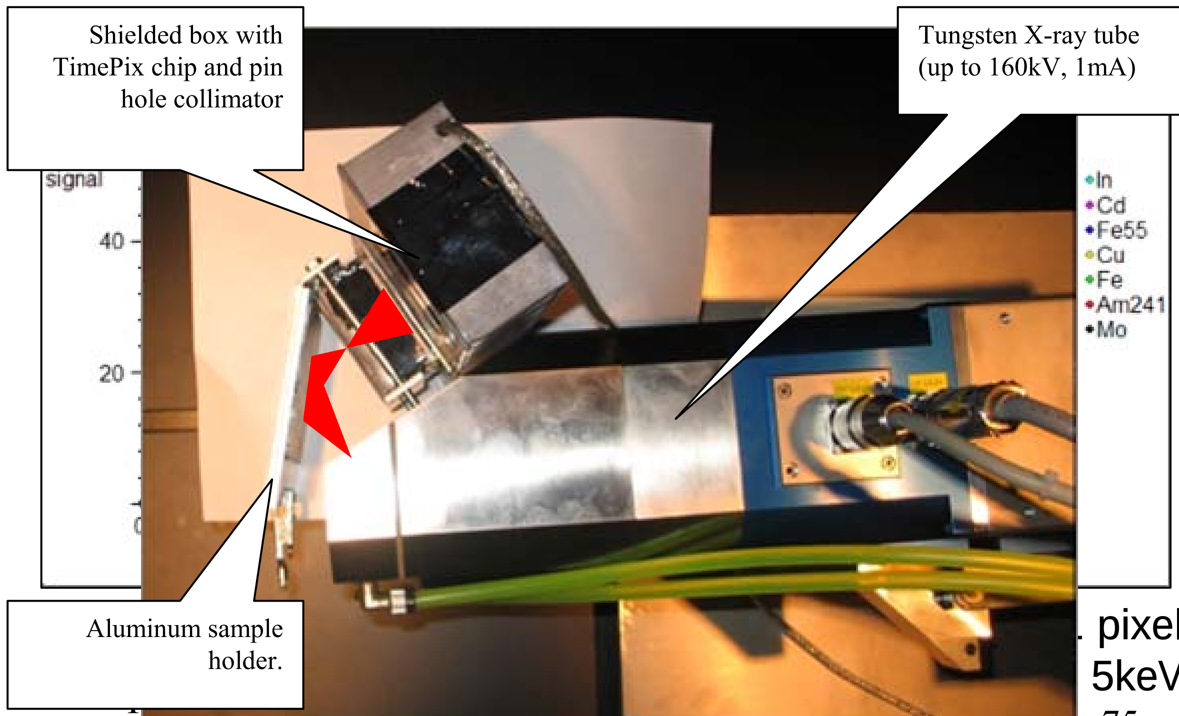
- **Test pulse**
- **Gamma or X-ray sources taking into account just** single pixel clusters.
  => charge leak to adjacent pixel is under threshold

Radioactive sources

^{55}Fe:	5.9	keV
^{241}Am:	59.5	keV

Fluorescence from

Fe:	6.4	keV
Cu:	8.0	keV
Zr:	15.8	keV
Mo:	17.5	keV
Cd:	23.2	keV
In:	24.2	keV

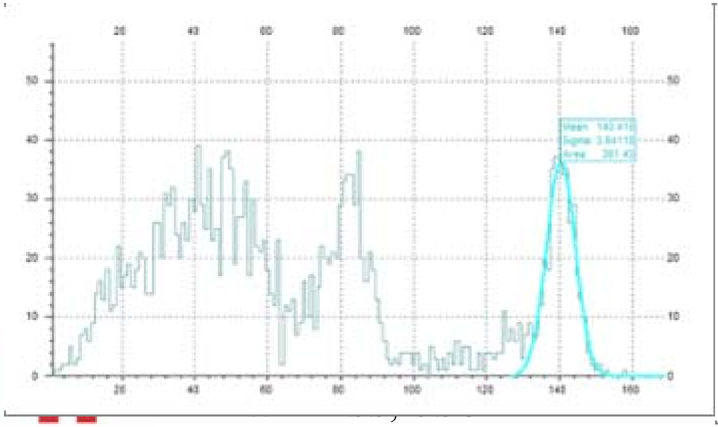


. pixel
5keV

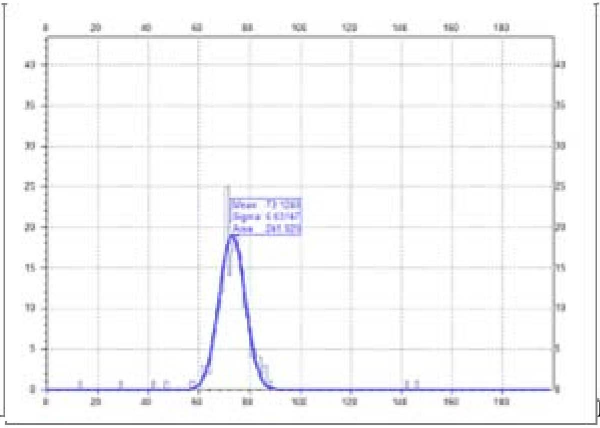
TOT mode calibration:
Per pixel calibration

- **To improve energy resolution per pixel calibration is needed.**
- **Calibration done using 5.9keV (Fe55), 15.8keV (Zr) and 59.5keV (Am241) using single pixel clusters.**
- **Good per pixel spectra of one pixel clusters needed =>** 200 000 000 clusters **analyzed in case of Am241.**
- **Gaussian fit done for each peak and each parameter =>** 200 000 gaussians
- **Just three parameters determined for each pixel:** *a*,*b* **and** *t*.
- **Parameters** *c* **and** *d* **were set constant to 2.4 and 1 respectively.**

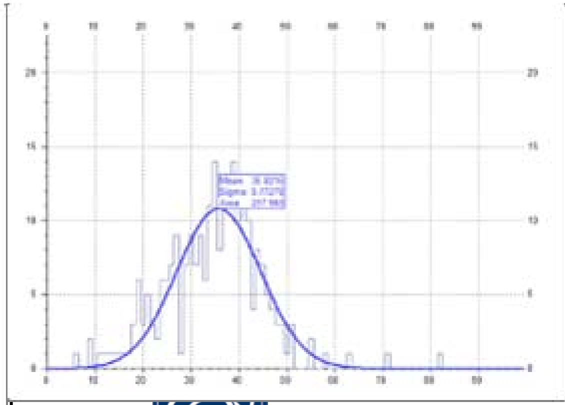
Am241 (59.5keV):



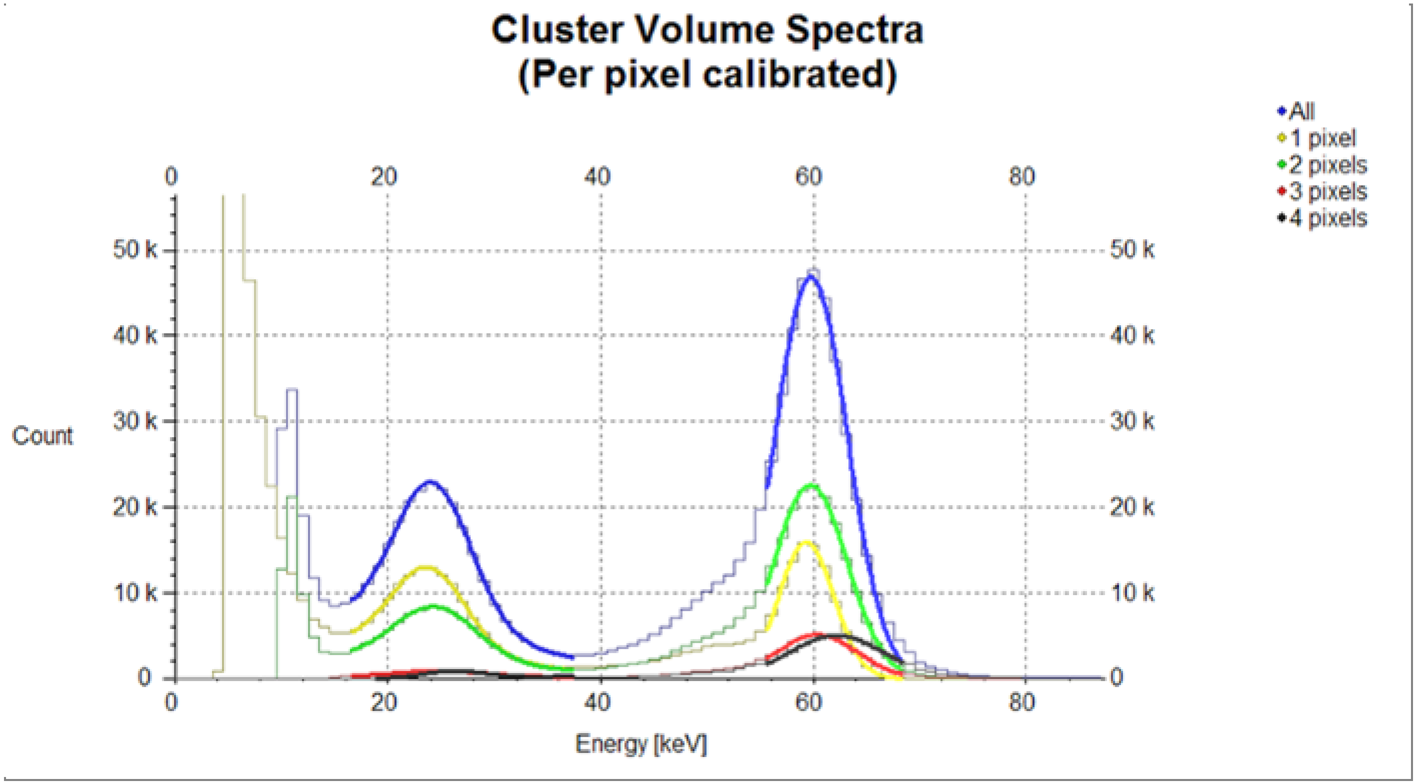
Zr (15.8keV):



Fe55 (5.9keV):



TOT mode calibration:
Tests with per pixel calibrated TimePix device



^{241}**Am**: 59.5keV peak sigma = 3.3keV