
# Application of the Medipix2 Technology to Space Radiation Dosimetry and Hadron Therapy Beam Monitoring



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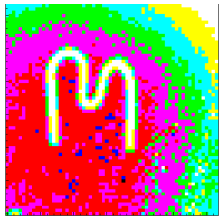
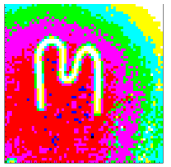


# The Full Author List



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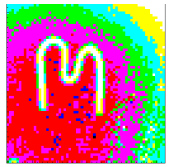
# The Medipix2 Consortium—CERN-Based



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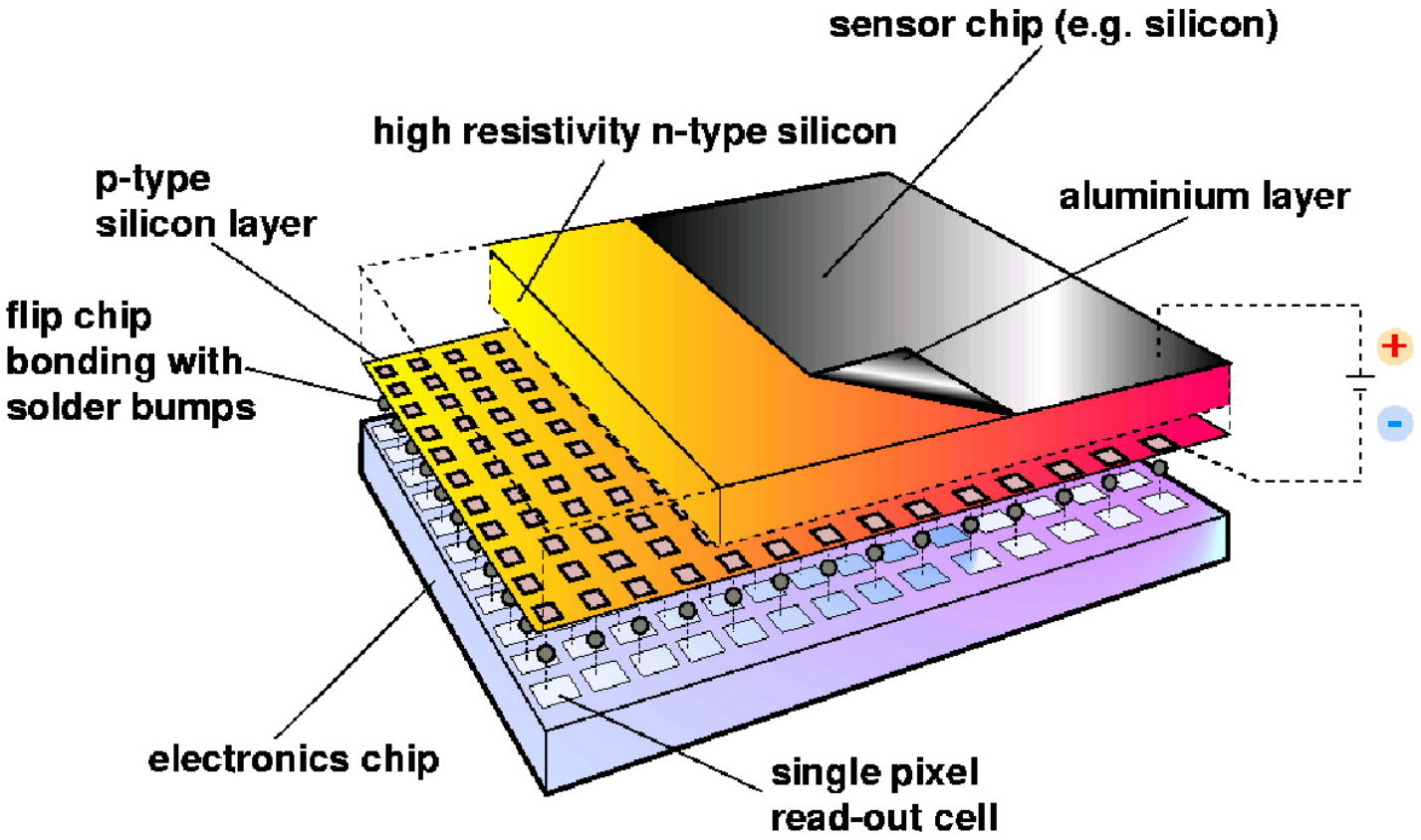
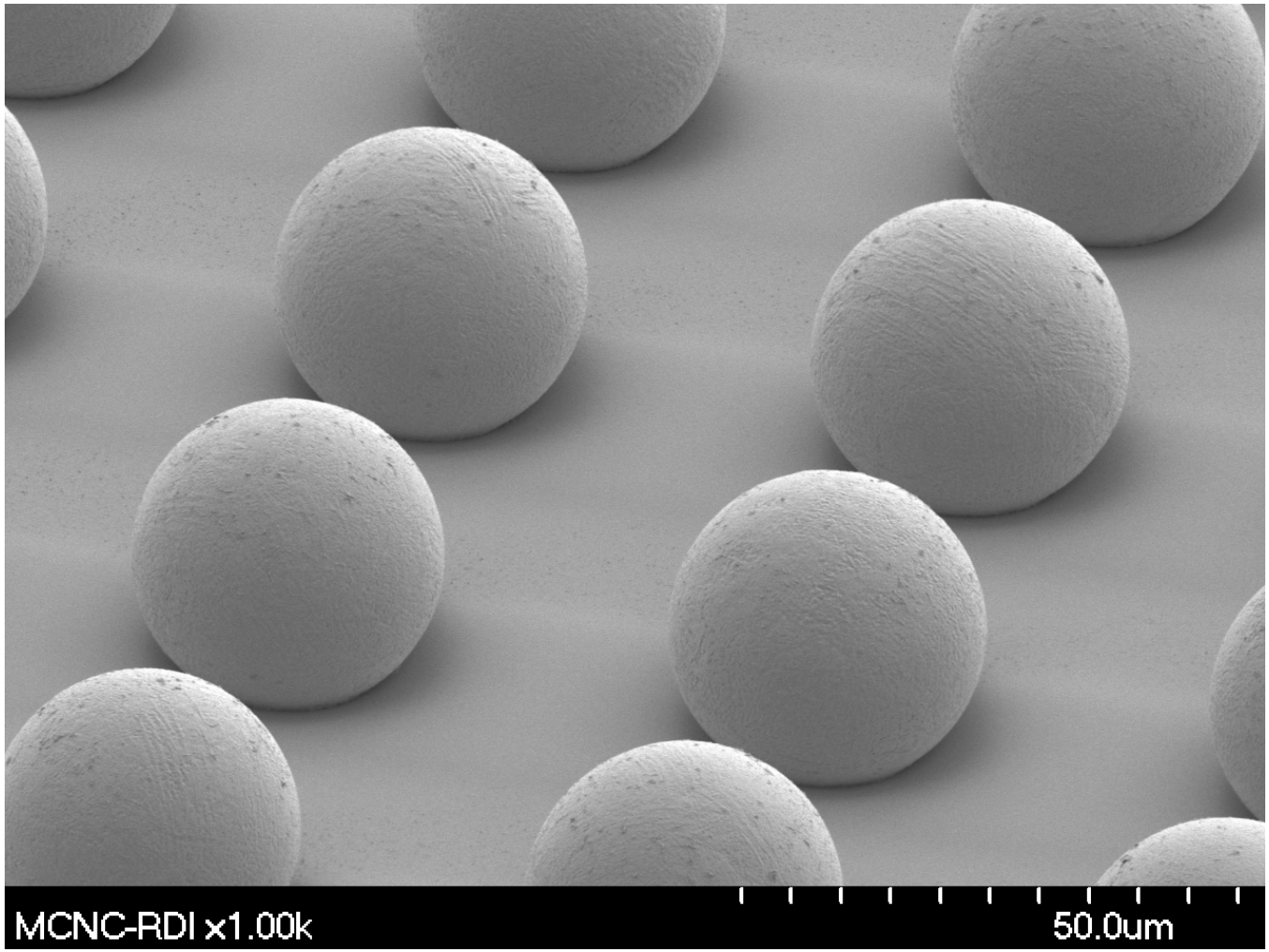
# Medipix—A Hybrid Pixel Detector

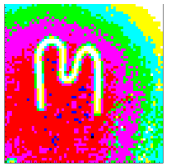



**Detector and electronics readout are optimized separately**

# Bumps on the readout side – close up

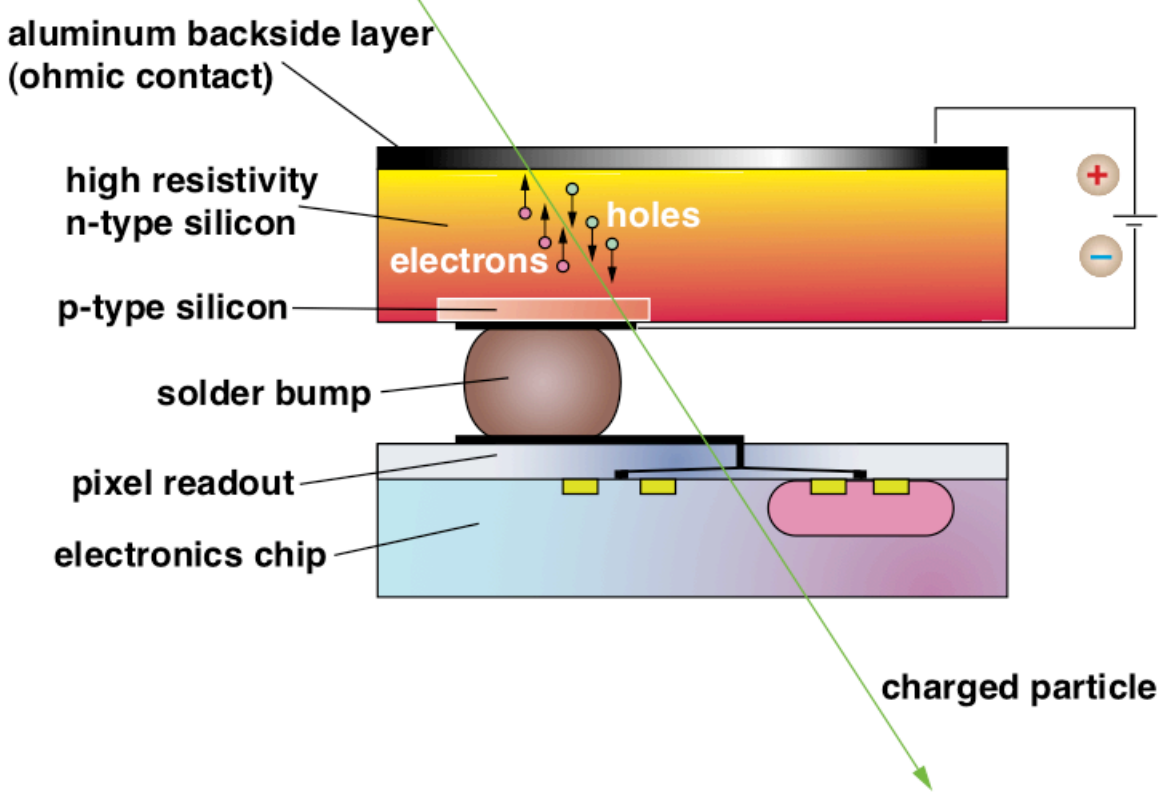


# Hybrid Pixel Detector - Cross Section



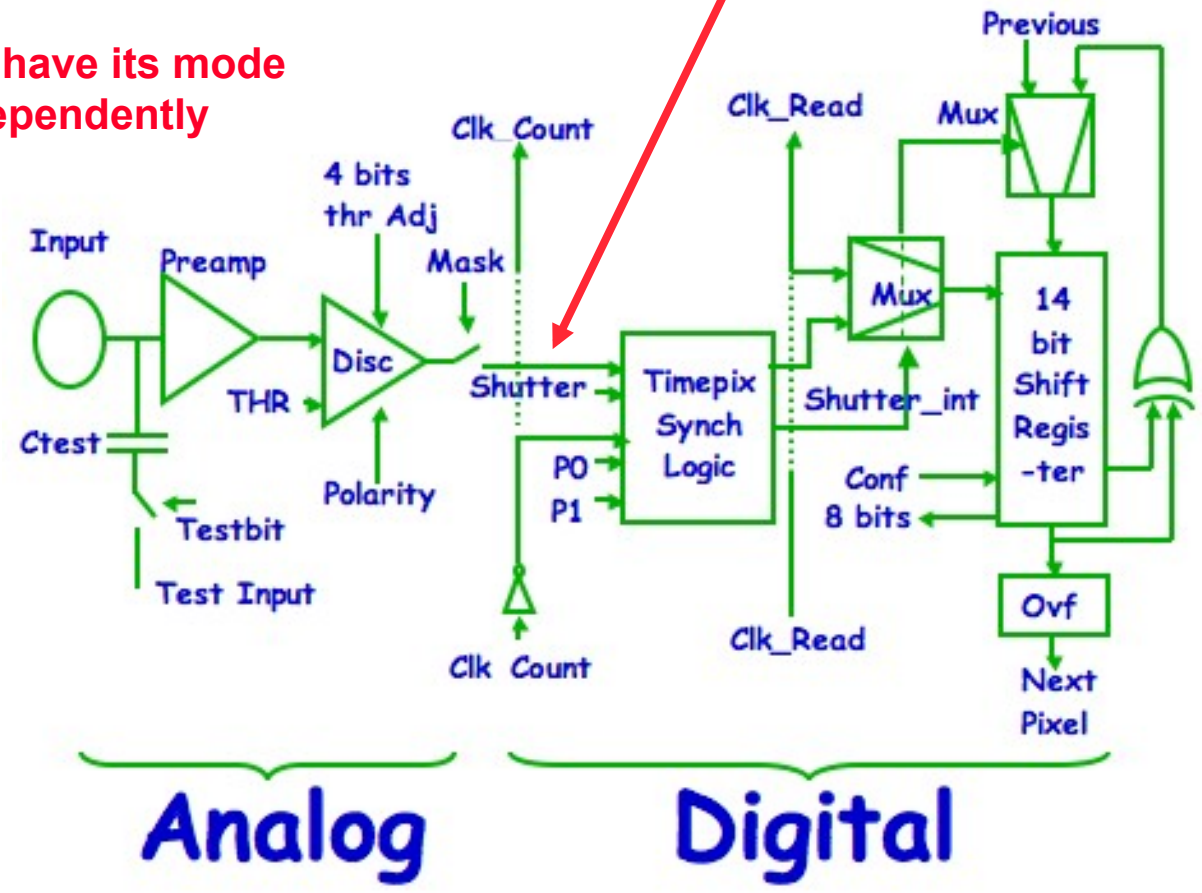
***UH is currently working on direct epitaxial deposition techniques that will allow the direct deposition of the detector layer onto the electronic chip wafer…***

***This will allow the facilitate of high efficiency Embedded-Neutron-Converter detectors***

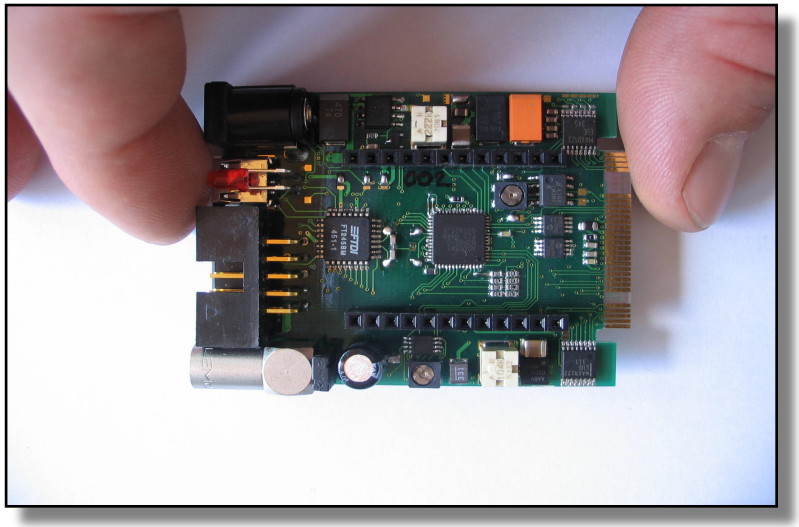


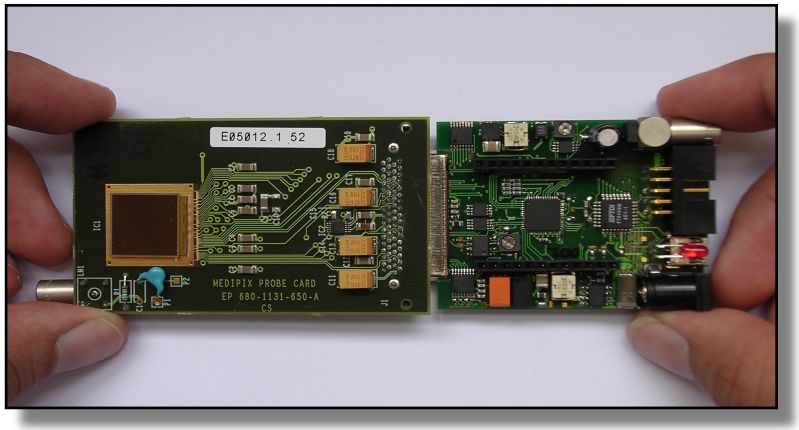
# TimePix Version Logic Schematic

- Charge sensitive Preamp/Shaper w/ individual leakage current compensation
- Discriminator with globally adjustable thresholds & individual 4-bit fine tuning offset
- Individually settable test and mask bits for each pixel
- External shutter gates the clock (can be as short as 10 ns but 1 μs is the practical limit)
- 14-bit output register (11,810 decimal)
- 1 Overflow bit
- Each pixel can have its mode set independently

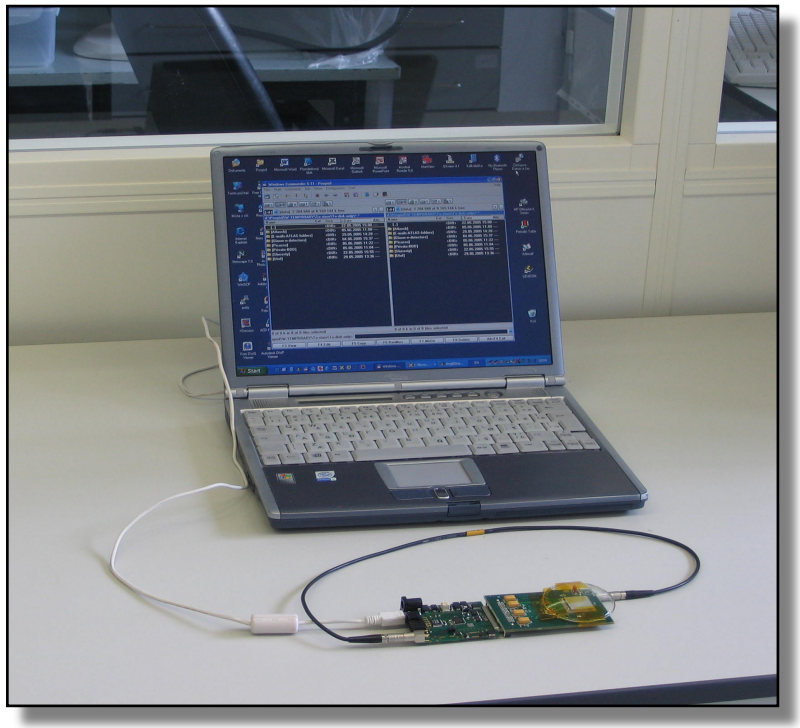


# A USB based Medipix2 Readout System Is Available

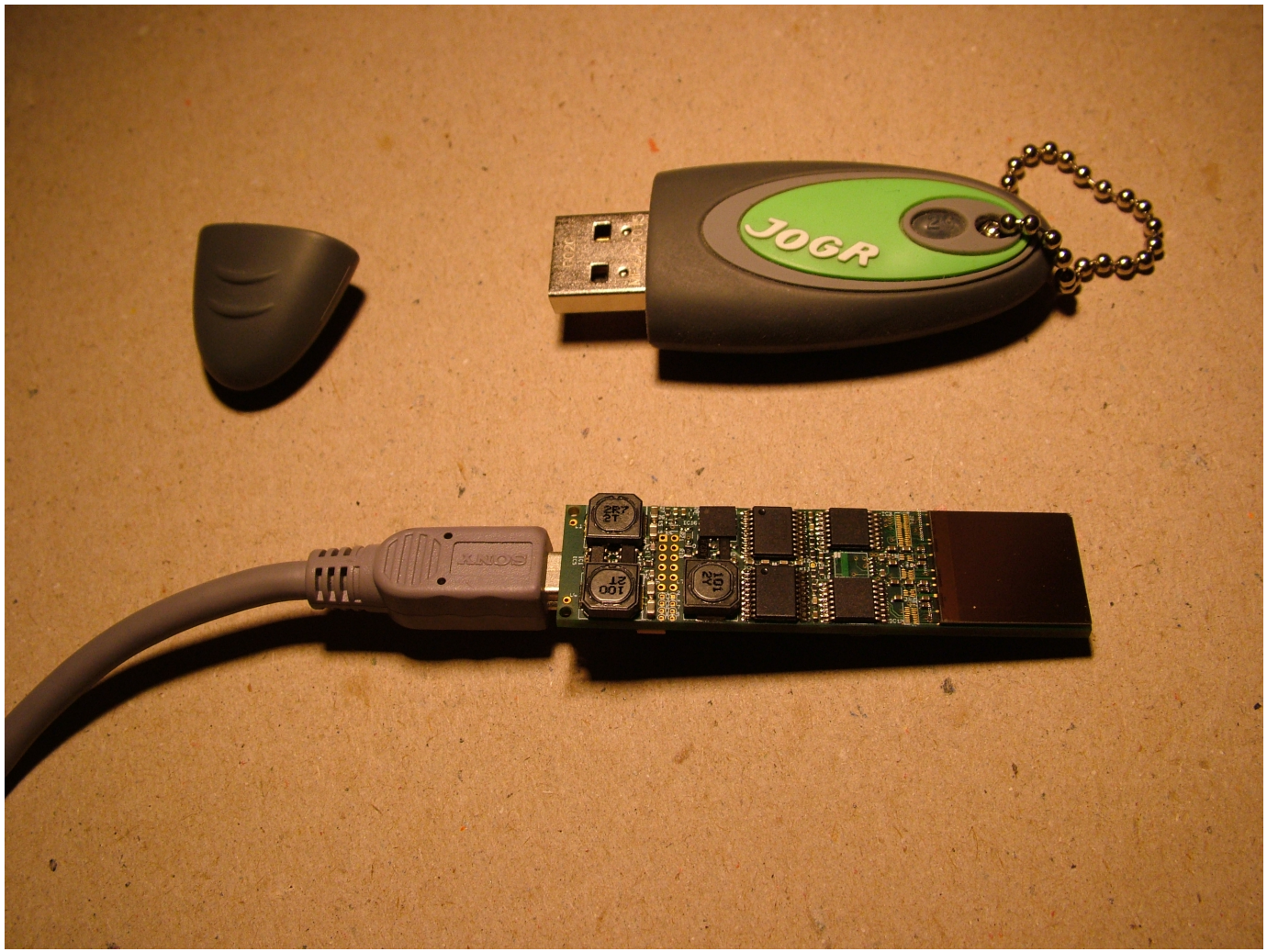


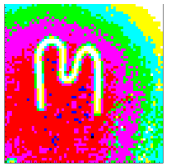



**Existing USB-1 compatible**
**Developed by S. Pospisil et al.**
**CTU, Prague…**
**USB-2 Version-Hardware IS Ready**
**( and waiting for the software…)**



# Also—A "USB Lite" Interface is Available for (an earlier) "MXR" version of the Chip

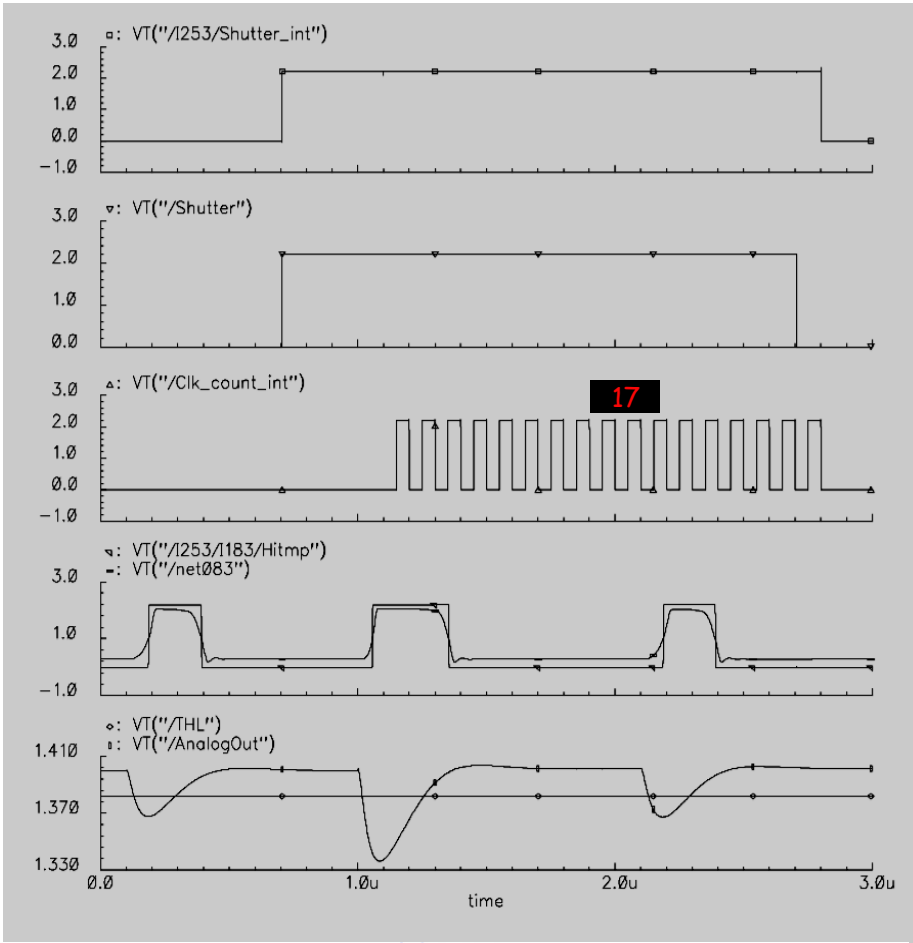




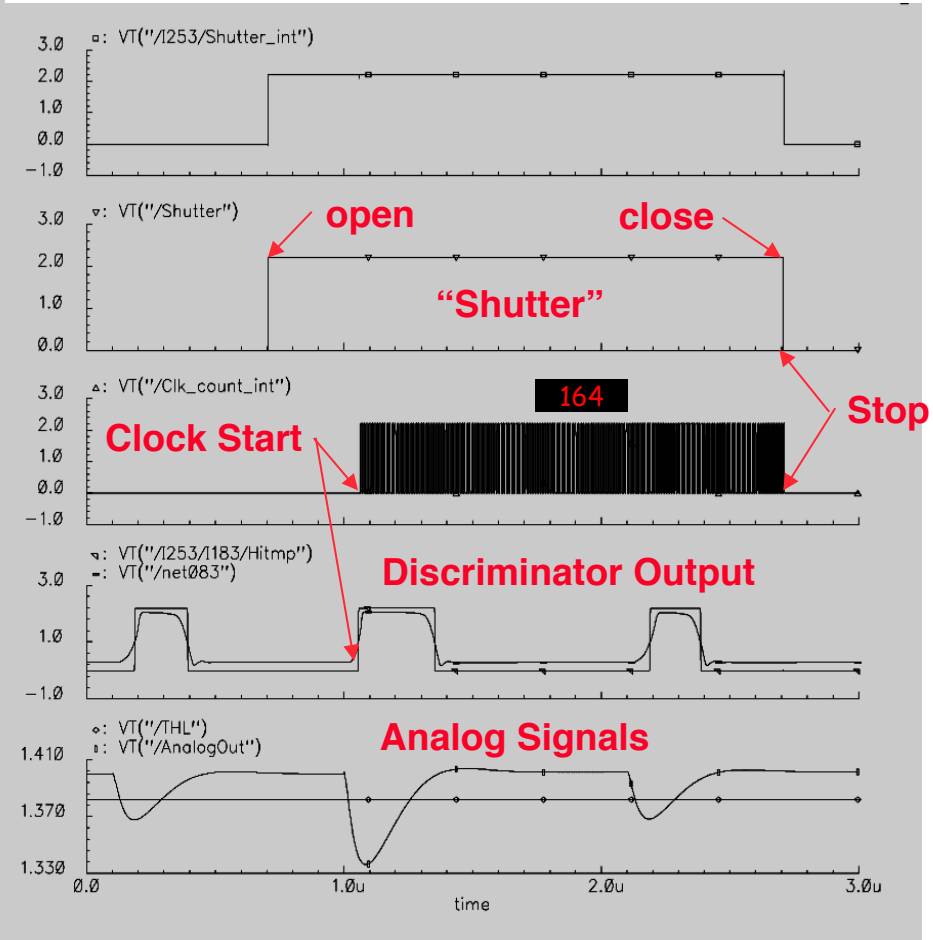
# TimePix Modes

- **Time-Over-Threshold (TOT) >>> "ADC" Mode**
  - During Shutter Open, Counter Clock pulses are added to Output Register while shaped input pulse exceeds Threshold value.
- **TimePix >>> "TDC" Mode**
  - During Shutter Open, Counter Clock pulses are added to Output Register starting when shaped input pulse first exceeds Threshold value.
- **Medipix >>> "Hit" Counter Mode**
  - While the Shutter is Open, the Output Register is Incremented every time the shaped input pulse leading edge crosses the Threshold value.

# Timepix (“TDC”) Mode (P0=1,P1=1)

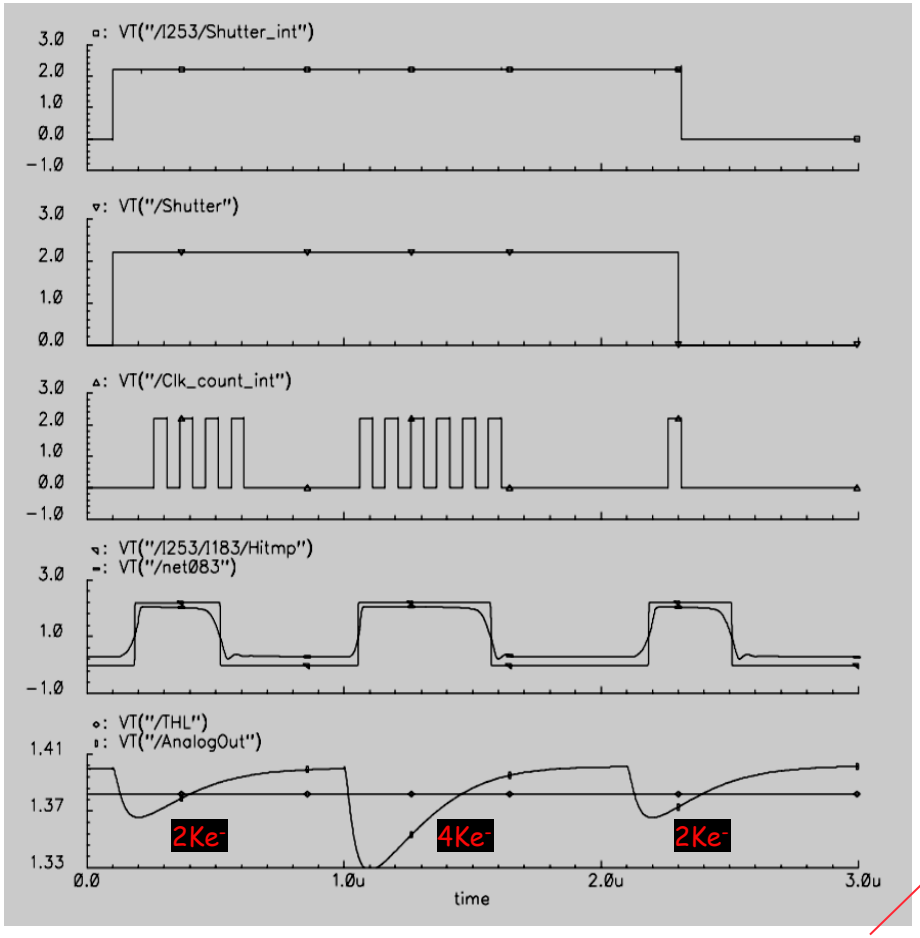


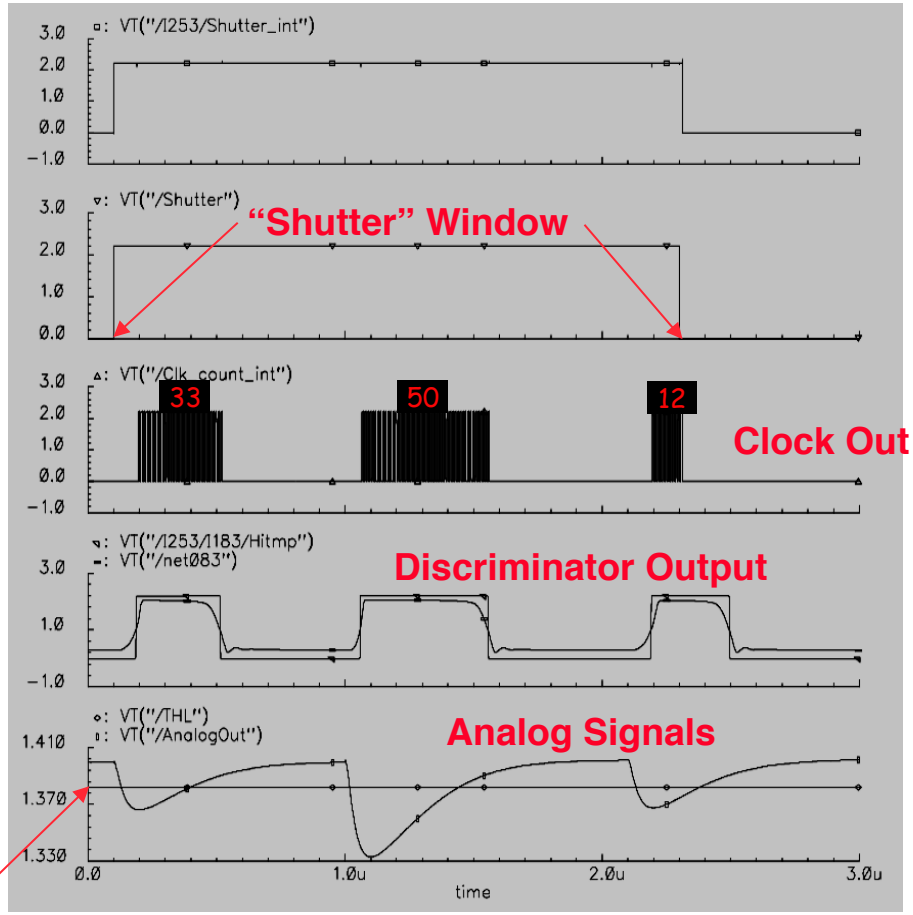

10MHz




100MHz

# Time-Over-Threshold ("ADC") Mode (P0=1,P1=0)

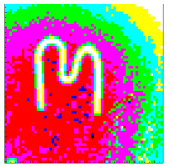



10MHz

Threshold

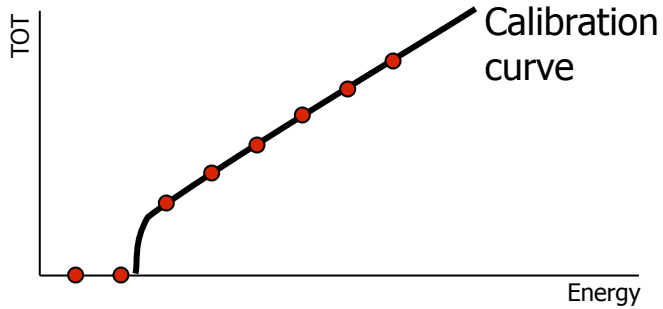
100MHz

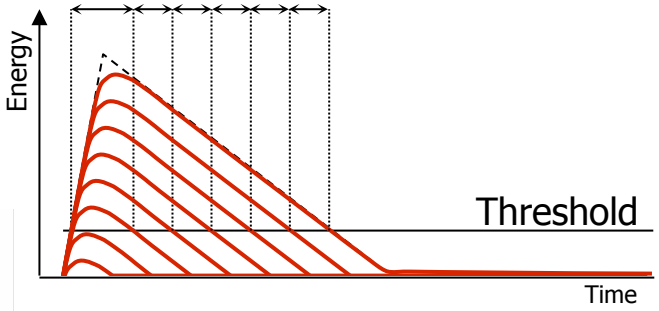


# TimePix and its TOT mode

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.



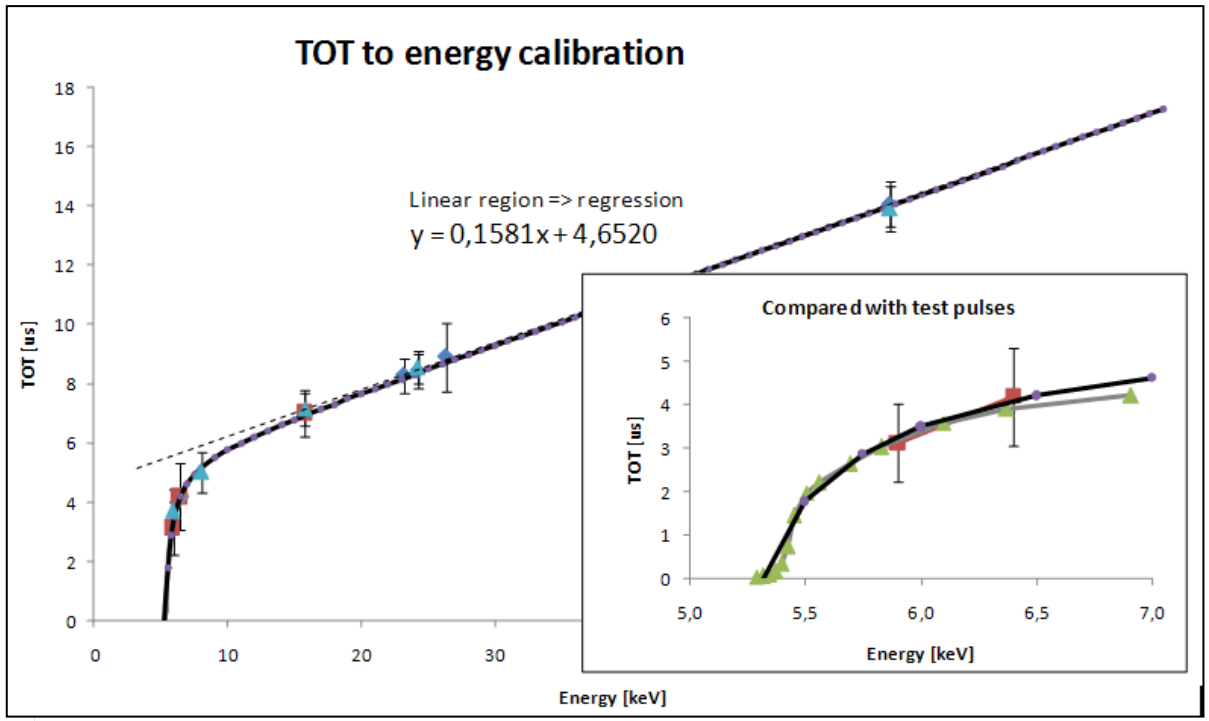

- **If the pulse shape is triangular then Time over Threshold is proportional to collected charge i.e. to energy.**
- **Due to limited bandwidth the pulse can be NEVER perfectly triangular.**
- **Non-linear TOT to energy dependence**

## 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:

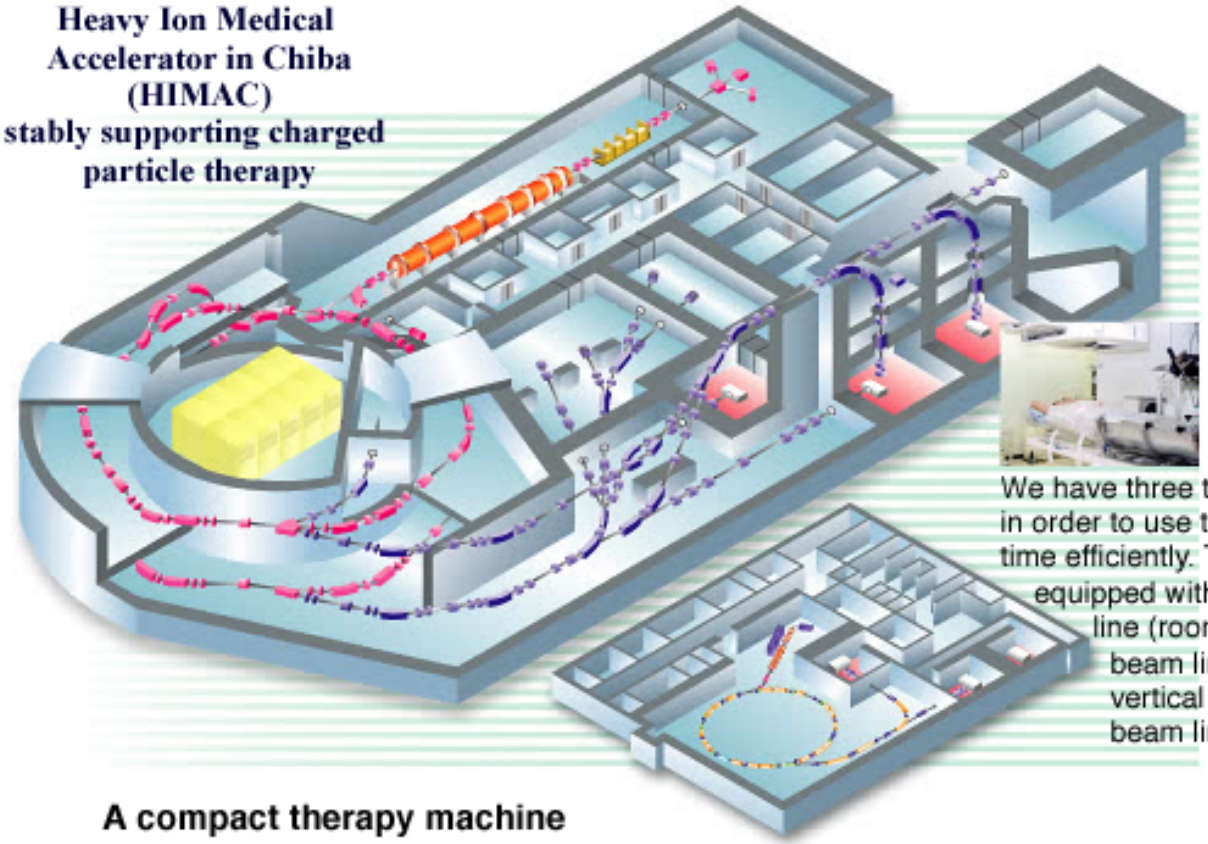
a=0.158
b=4.65
c=2.4
d=1
t=4.86

# HIMAC @ NIRS in Japan

- HIMAC - (Heavy Ion Medical Accelerator Center) @ NIRS (National Institute for Radiological Sciences) in Chiba, Japan.
- Primarily a Cancer Therapy Center, but they give us free beam time to do physics and detector development research…

# HIMAC Layout

**Heavy Ion Medical Accelerator in Chiba (HIMAC) stably supporting charged particle therapy**





We have three treatment rooms in order to use the HIMAC beam time efficiently. These rooms are equipped with a vertical beam line (room A), a horizontal beam line (room C) and vertical and horizontal beam lines (room B).

**A compact therapy machine**

The NIRS completed research and development on a compact carbon therapy machine in FY 2005. Gunma University has adopted our proposal and will start construction of a new therapy facility in FY 2006. The NIRS is giving technical support to this project at Gunma University.

# Same dE/dx, BUT, Different Z

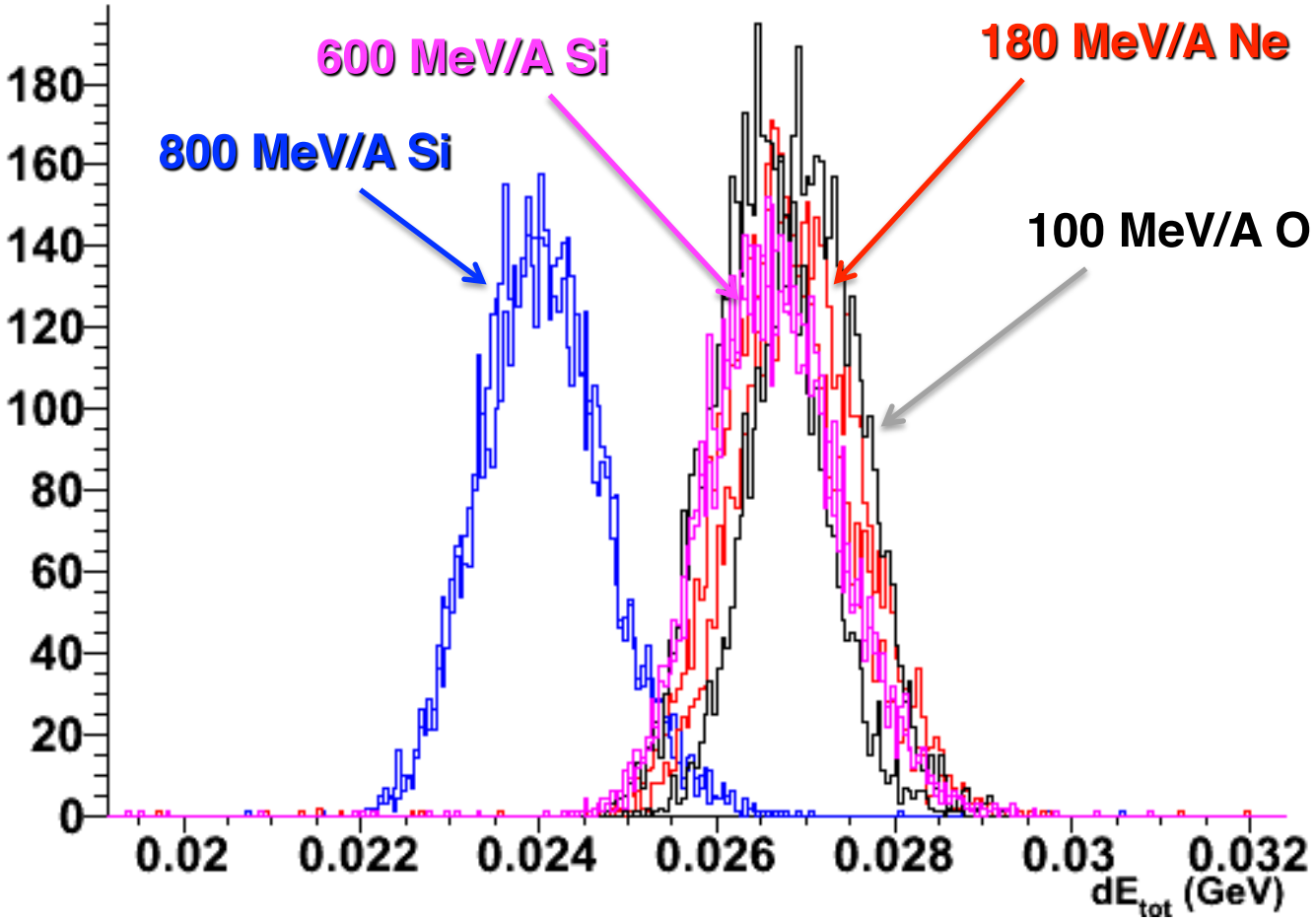
**Black Values are dE/dx in KeV/μm**

**Red Values are the δ-rays Kinematic Maximum Energy in KeV**

| KE (MeV/u)=> | 100.00 | 180.00 | 230.00 | 290.00 | 350.00 | 400.00 | 430.00 | 500.00 | 600.00 | 650.00 | 800.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| He (KeV/μm) | 5.42 | 3.60 | 3.09 | | | | | | | | |
| He (KeV) | 231.14 | 433.00 | 566.81 | | | | | | | | |
| C (KeV/mm) | 48.74 | 32.43 | 27.81 | 24.32 | 22.02 | 20.63 | 19.96 | | | | |
| C (KeV) | 231.19 | 433.09 | 566.94 | 735.32 | 912.18 | 1066.04 | 1161.19 | | | | |
| N (KeV/mm) | 66.34 | 44.14 | 37.85 | 33.10 | 29.97 | 28.09 | 27.17 | | | | |
| N (KeV) | 231.19 | 433.10 | 566.95 | 735.33 | 912.20 | 1066.06 | 1161.21 | | | | |
| O (KeV/mm) | 86.85 | 57.65 | 49.43 | 43.24 | 39.15 | 36.68 | 35.49 | | | | |
| O (KeV) | 231.19 | 433.10 | 566.95 | 735.34 | 912.21 | 1066.08 | 1161.23 | | | | |
| Ne (KeV/mm) | 135.38 | 90.08 | 77.24 | 67.56 | 61.17 | 57.32 | | | 48.55 | | |
| Ne (KeV) | 231.20 | 433.11 | 566.96 | 735.36 | 39.65 | 1066.10 | | | 1740.46 | | |
| Si (KeV/mm) | 265.35 | 176.55 | 151.39 | 132.41 | 119.89 | 112.35 | | | 95.15 | | 87.18 |
| Si (KeV) | 231.20 | 433.12 | 566.97 | 735.37 | 912.25 | 1066.12 | | | 1740.51 | | 2509.10 |
| Ar (KeV/mm) | | *291.85 | | 218.88 | | 185.71 | | | | 153.11 | |
| Ar (KeV) | | 433.13 | | 735.38 | | 1066.14 | | | | 1923.86 | |
| Fe (KeV/mm) | | *608.92 | | *456.68 | | 387.48 | | 351.51 | | | |
| Fe (KeV) | | 433.13 | | 735.39 | | 1066.15 | | 1391.58 | | | |

**Remember, these dE/dx values are from the Bethe-Bloch Equation!**

# dE/dx vs. Energy Deposited

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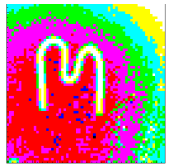
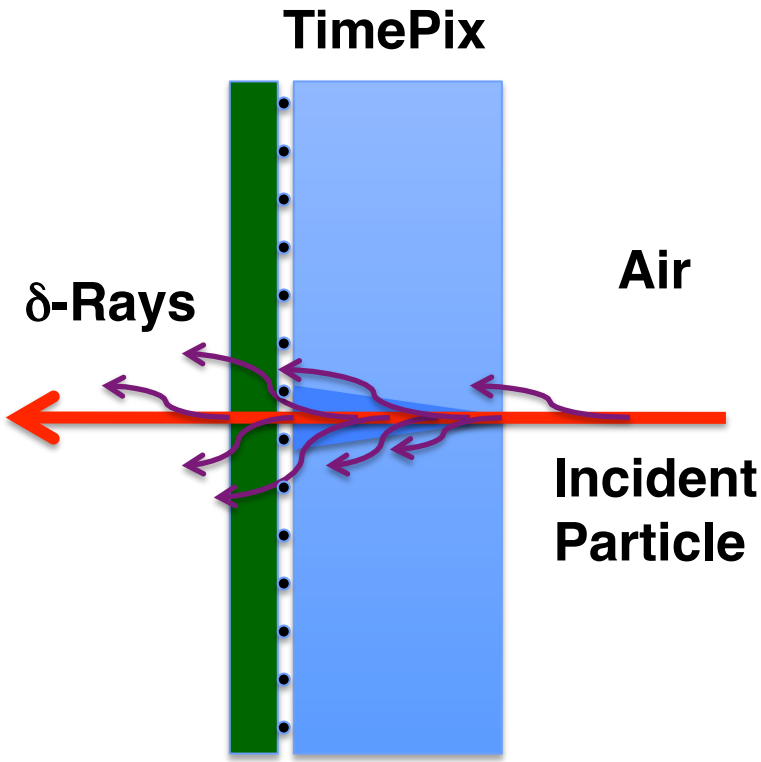
# High Energy δ-Rays



- Because the number of δ-rays produced per unit track length in the Air prior to entering the Si is much less than in the the Si…
- …The highest energy δ-rays carry away more energy from the Si than enters from the air.
- HOWEVER—It is the High Energy d-rays that offer the prospect of telling the difference between the different particle velocities with the same dE/dx…



# Heavy Ion Beam Runs To Date

- The TimePix at HIMAC in the beam…

So far data were taken @ (MeV/A):

$^{1}$H (p) 160

$^{4}$He 180 & 230

$^{12}$C 230

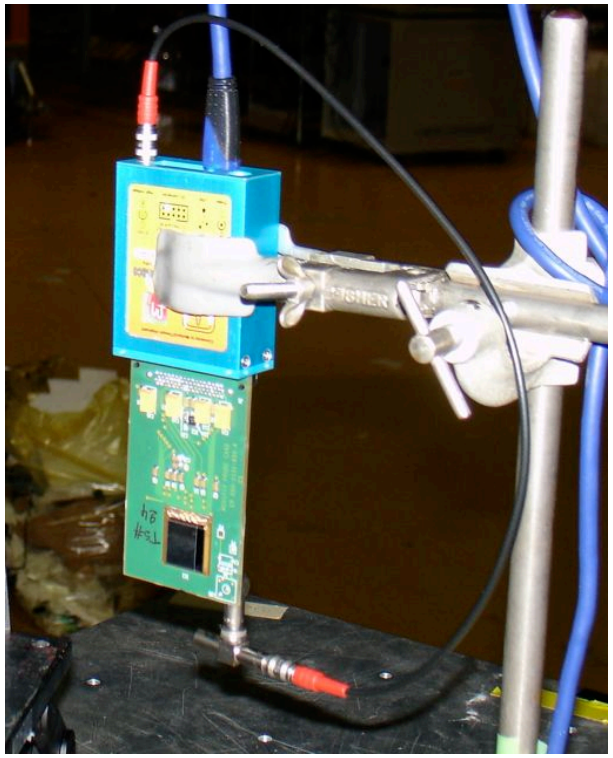
$^{14}$N 180 & 290

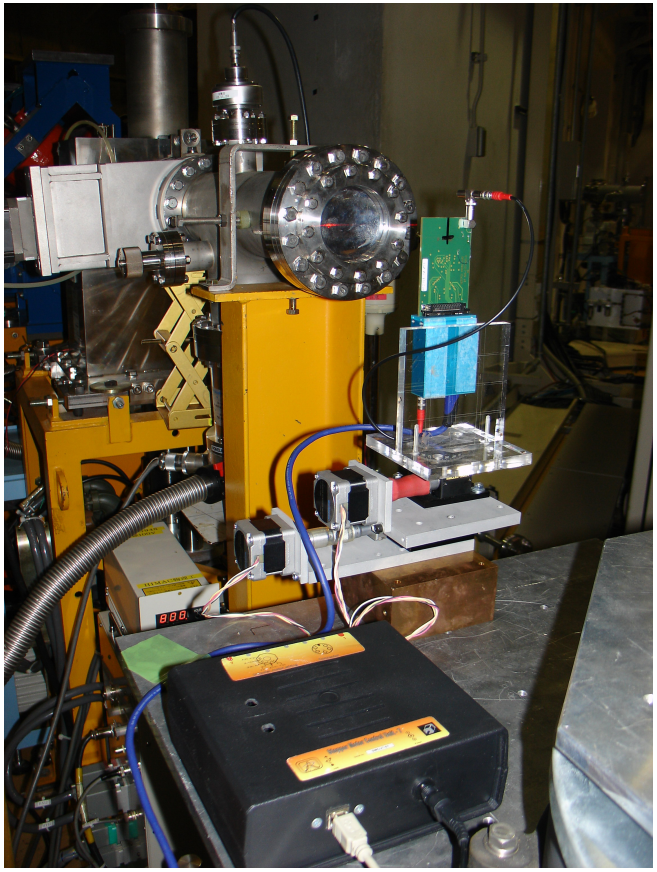
$^{16}$O 100 & 230

$^{20}$Ne 180, 430 & 600

$^{28}$Si 400, 600 & 800

$^{56}$Fe 500





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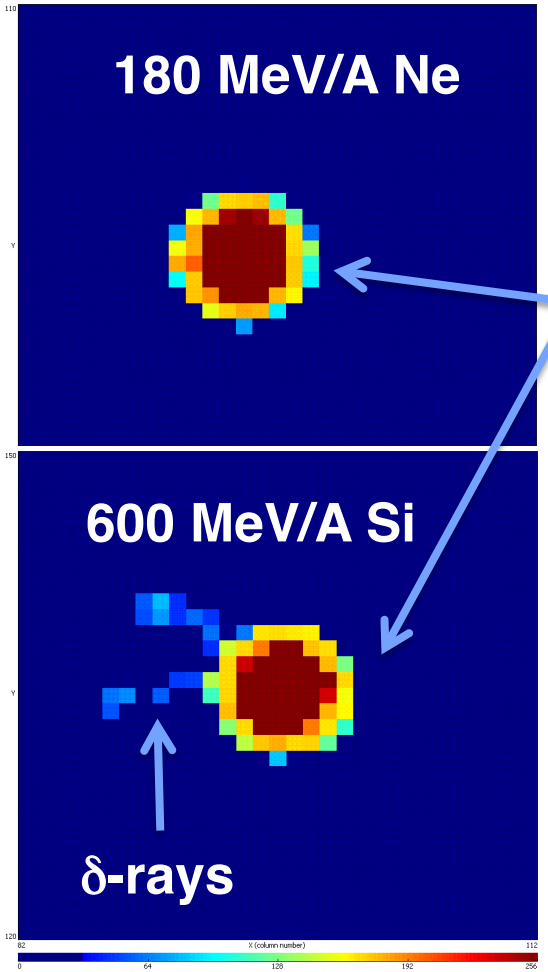
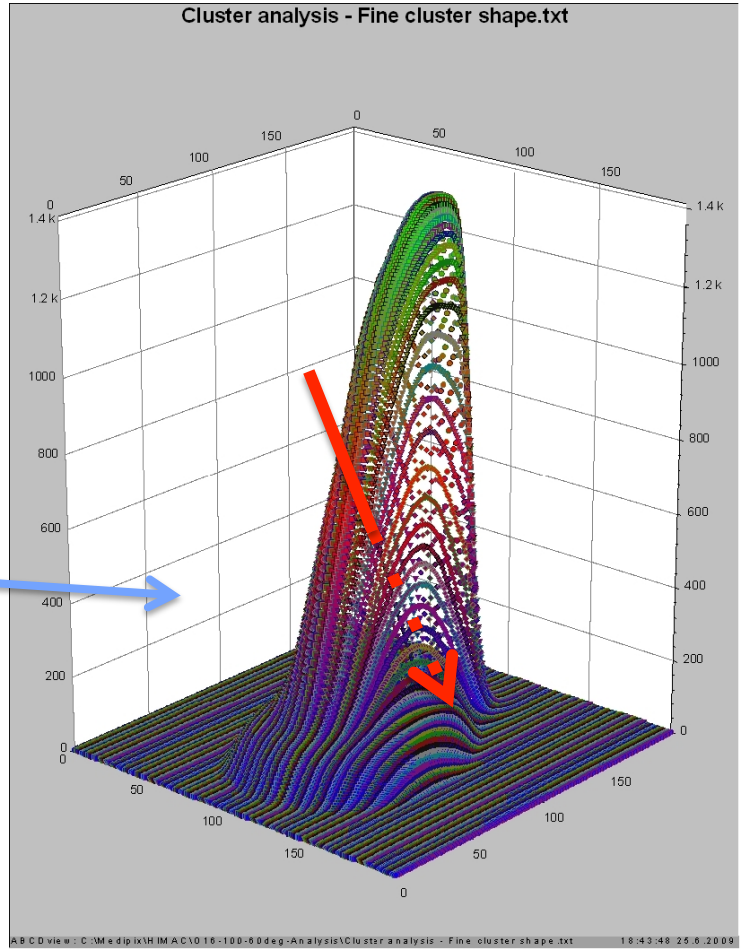
# Typical Heavy Ion "Tracks" as seen in the TimePix TOT Mode

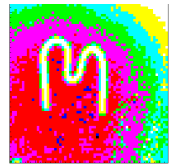



**Normal incidence "tracks" from 2 different beams with the SAME dE/dx…**

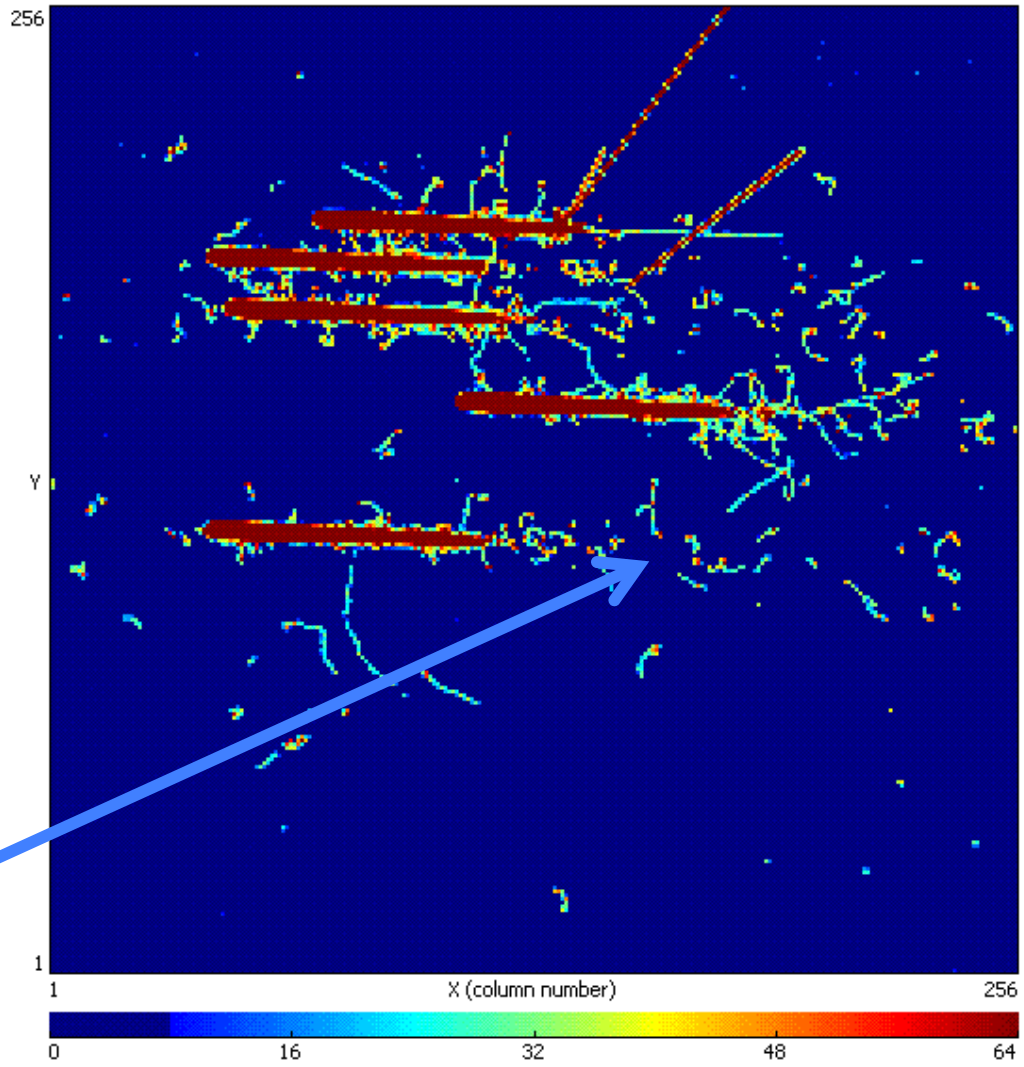
**Integrated cluster shape from ~5000 100 MeV/A Oxygen ions incident at 60 degrees, which have the same dE/dx as the other 2 tracks…**



# 800 MeV/A Si 85 degree Tracks

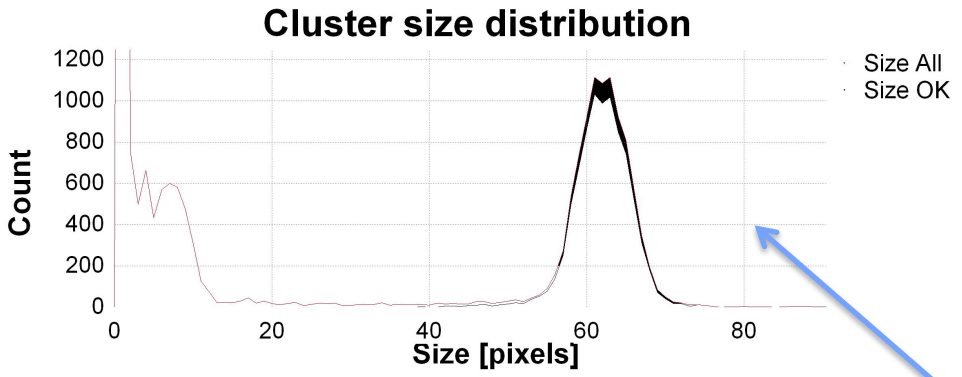


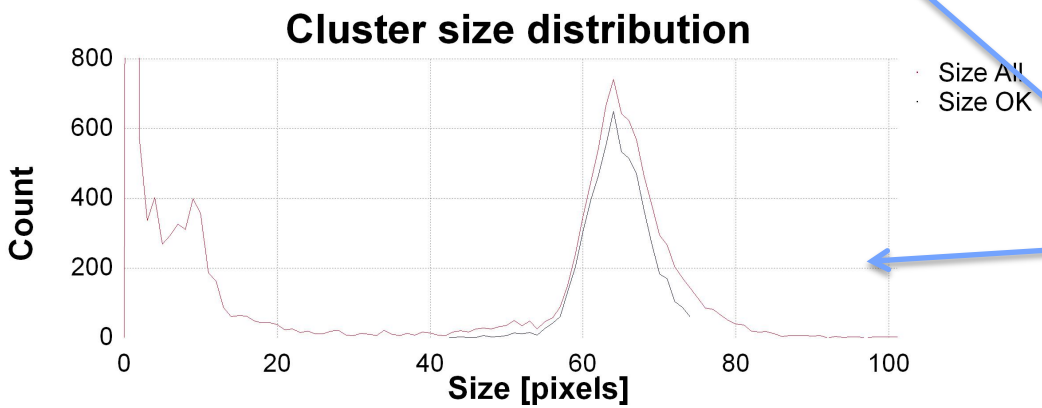
- The tracks are from particles diving downward from left to right.
- As they pass though the solder-bumps and into the underlying chip after leaving the Si detector layer.
- Some of the high energy δ-rays from the chip enter the overlying detector layer…

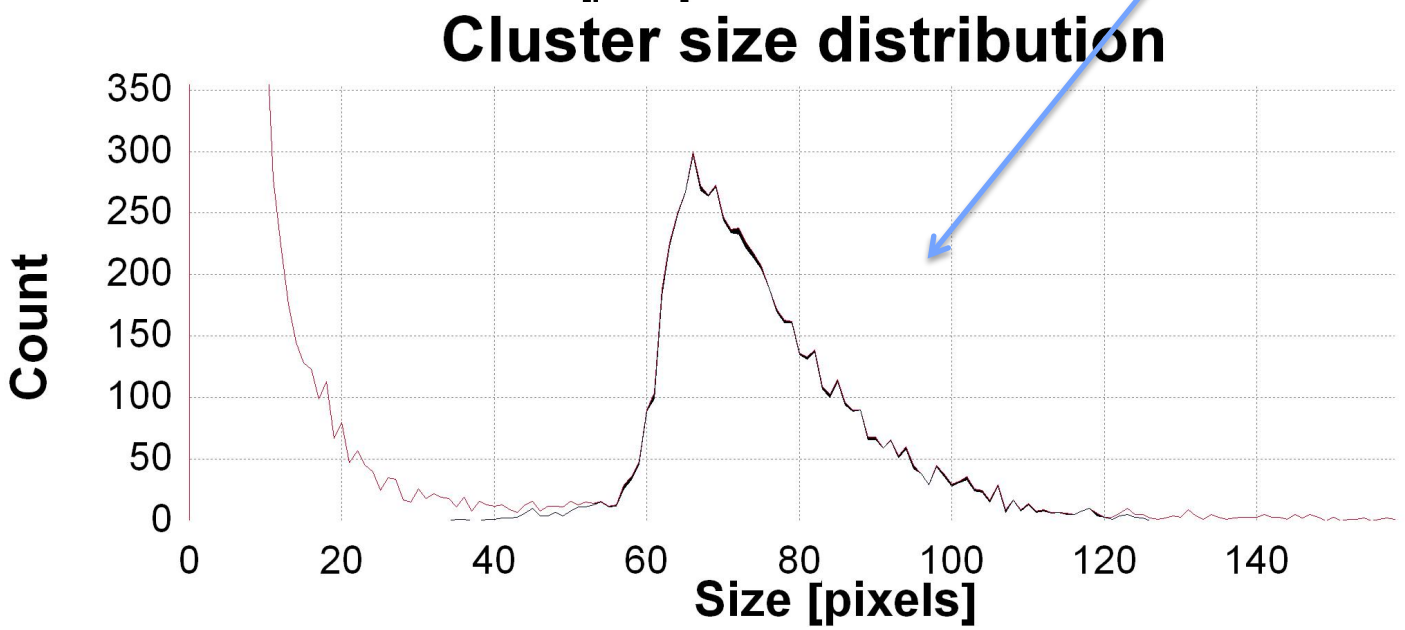


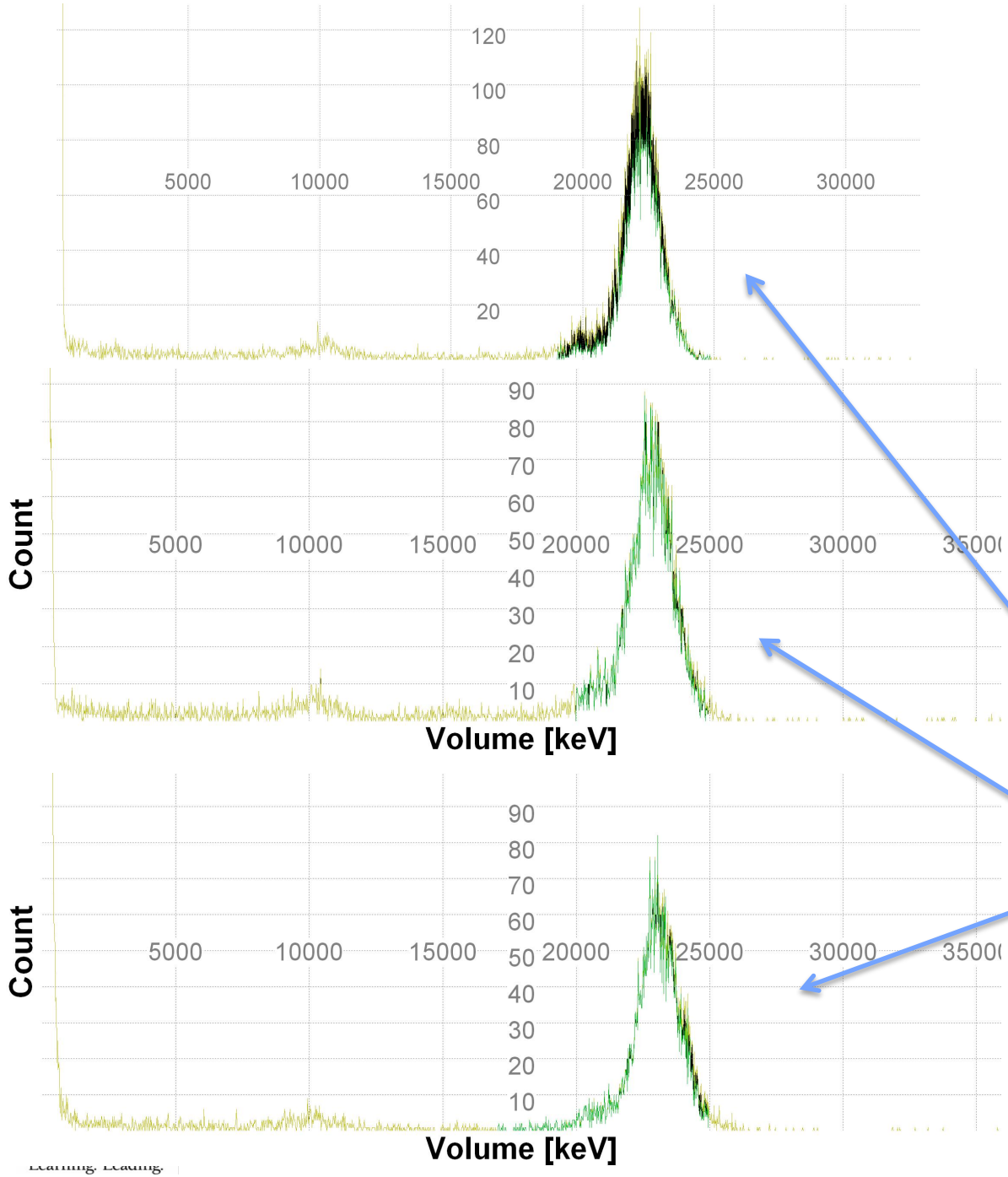
# Normal Incidence Cluster Size Distributions for:

**O at 100 MeV/A**
**Ne @ 180 MeV/A and**
**Si @ 600 MeV/A**



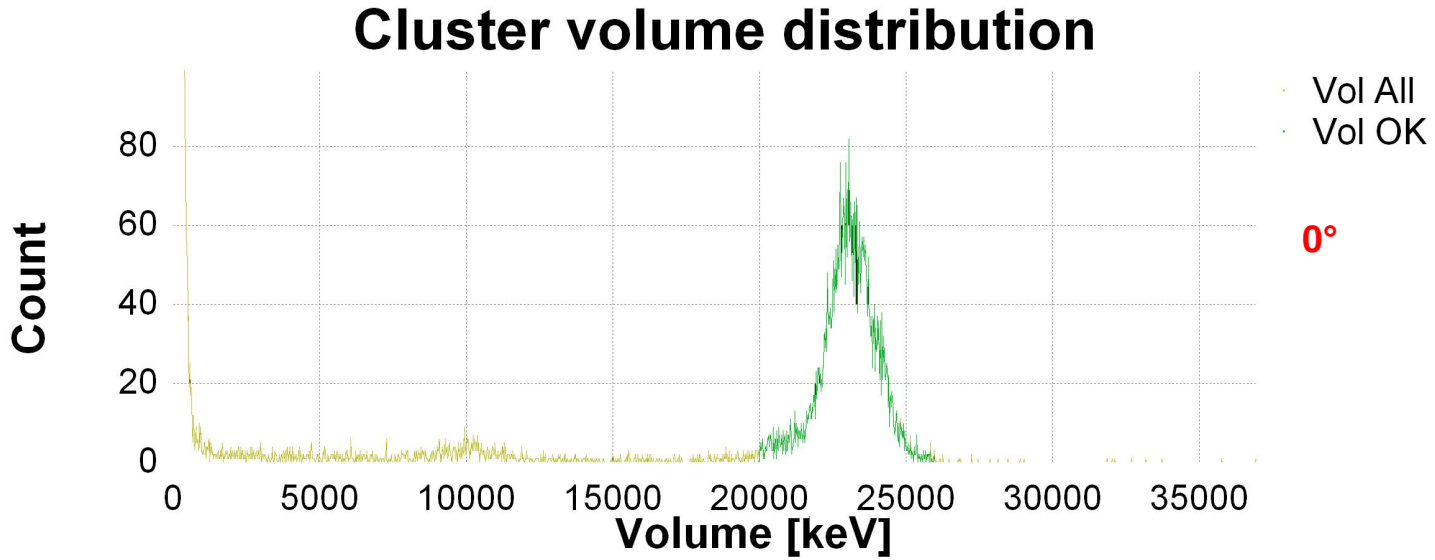



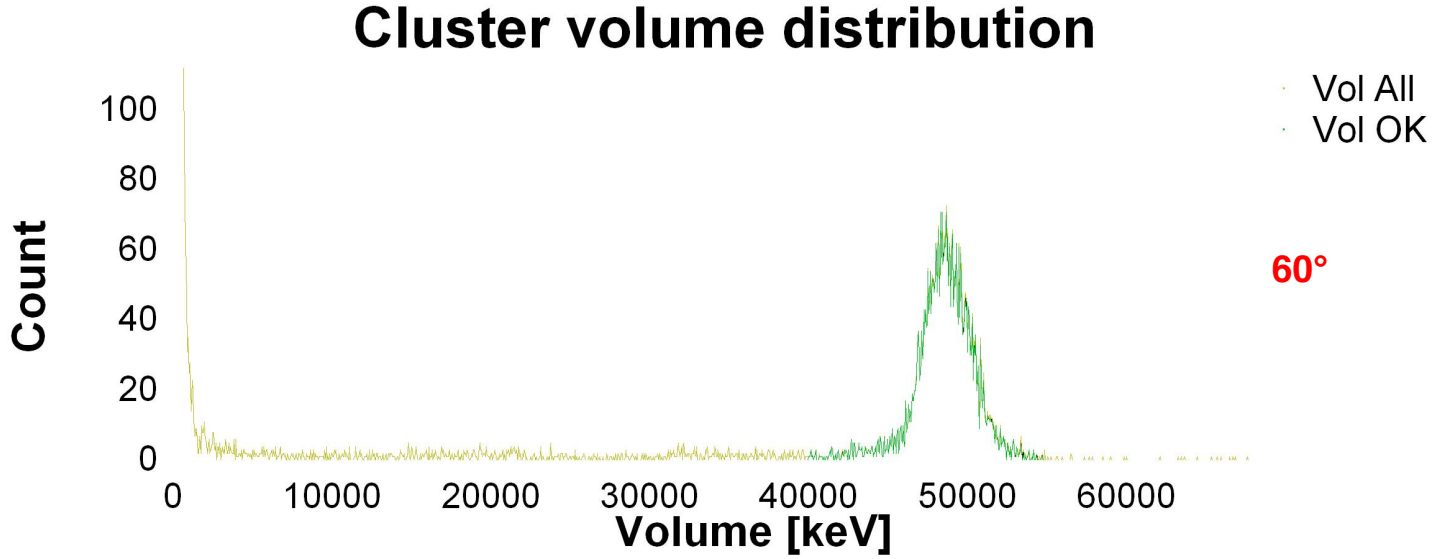



# Energy (KeV) Deposited in the 300 mm Si Detector Layer by Norman Incidence:

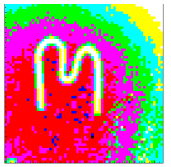
**O at 100 MeV/A**
**Ne @ 180 MeV/A and**
**Si @ 600 MeV/A**

# 600 MeV/A $^{28}$Si Energy Deposition @ 0° & 60°

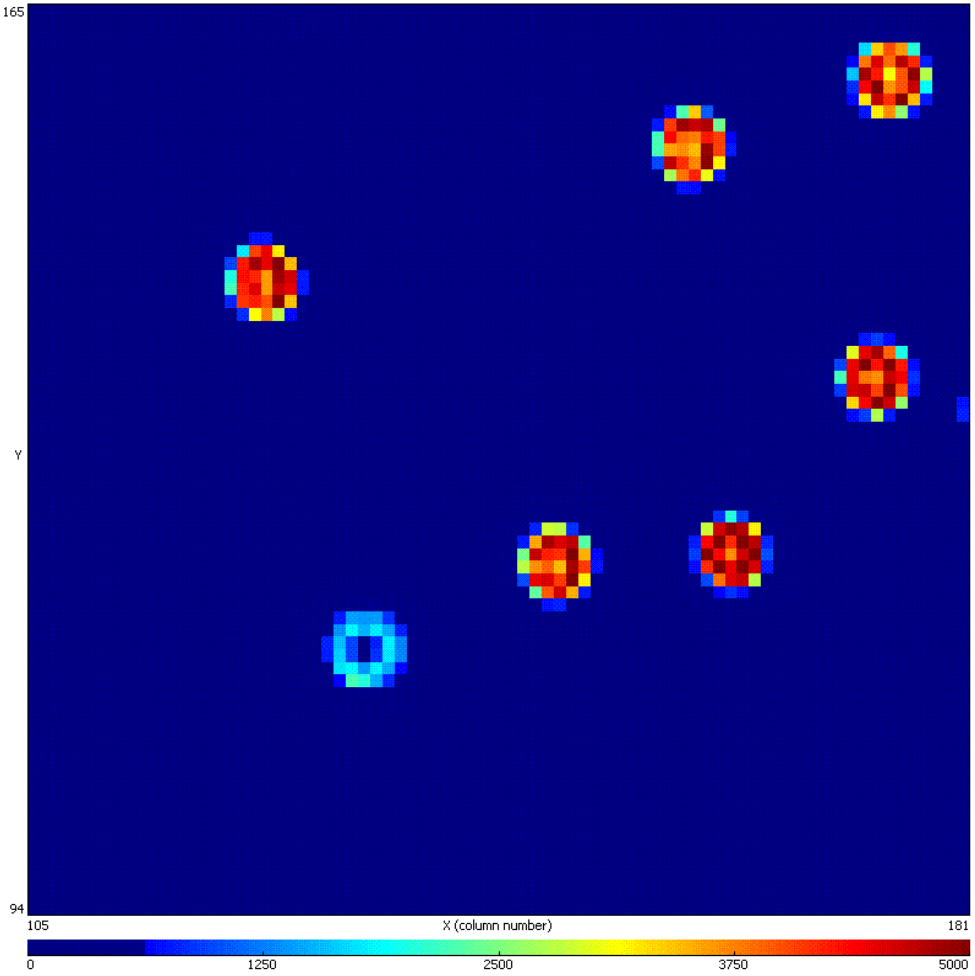


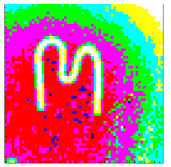
# The "Volcano" Effect



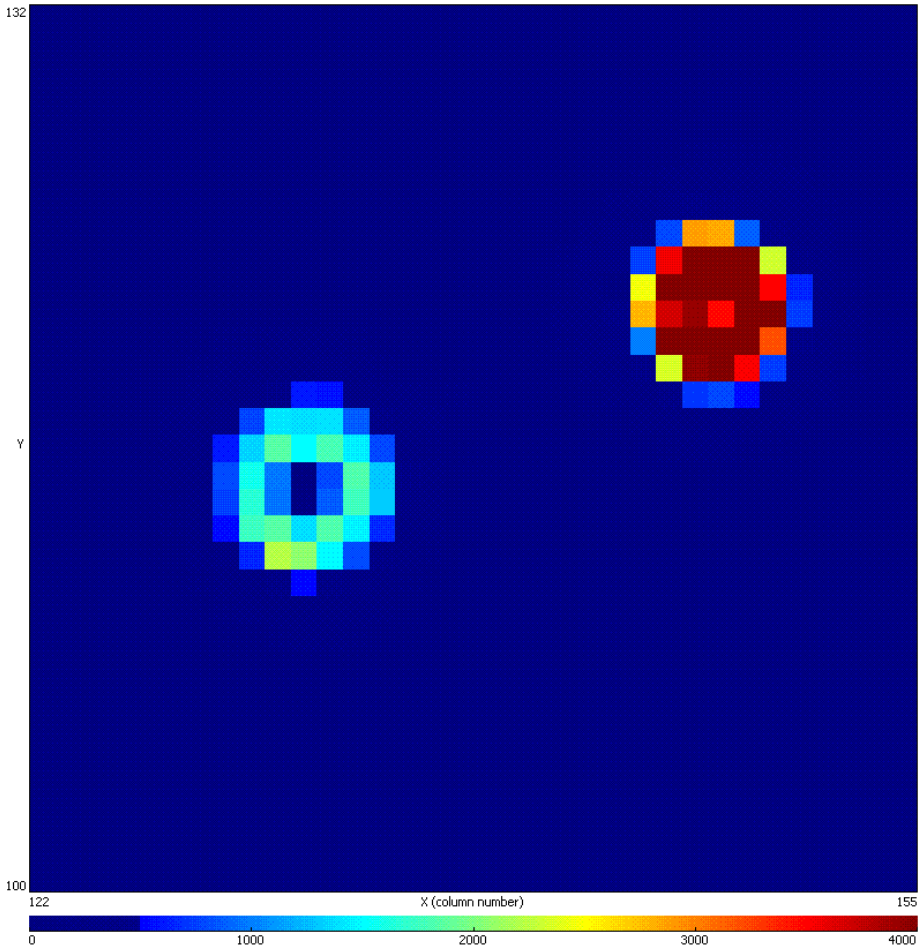
- We see a dip in response for the highest charge deposition rates…
- This may be due to detector saturation effects…
- …Or to a plasma effect that causes high recombination rates…
- So far we see this only in the Fe tracks…



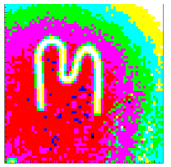
# Close Up of the "Partial" Event



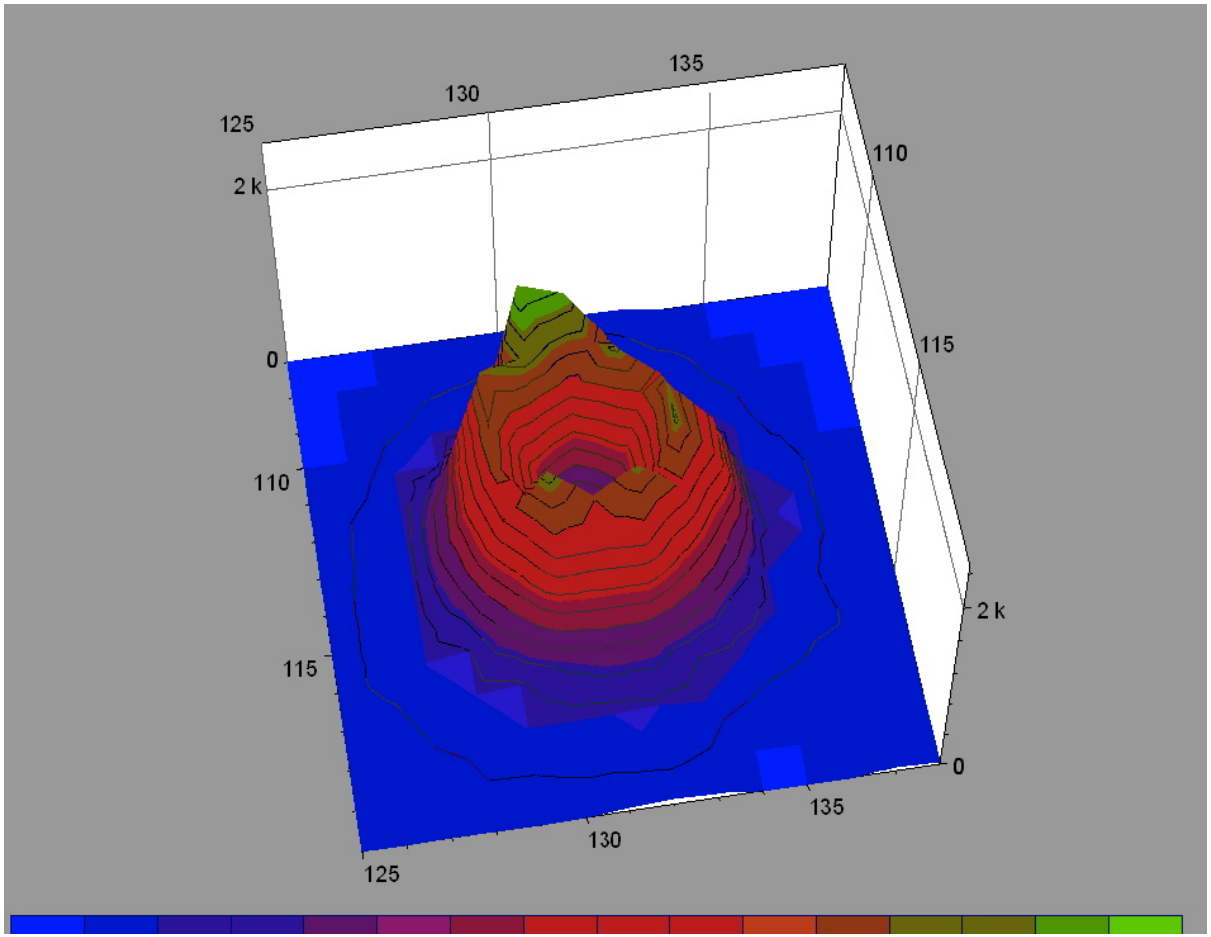
- The right-hand event is a "normal" iron event, which does show a clear "Volcano" Effect. The scale is so high that the δ-rays are not visible.
- The left-hand event is a "Partial-Event." One that was partially cutoff by the "Shutter."
- Because the central hole essentially goes to zero, it would appear that this event occurred at the end of the Shutter window and was only the early part of the drift image…



# “Partial” Event



- This is an event where the Shutter cut off the the ADC counter early in the charge collection process.
- Note that the attenuation is essentially total in the center.
- This may be due to electronic saturation effects or massive recombination

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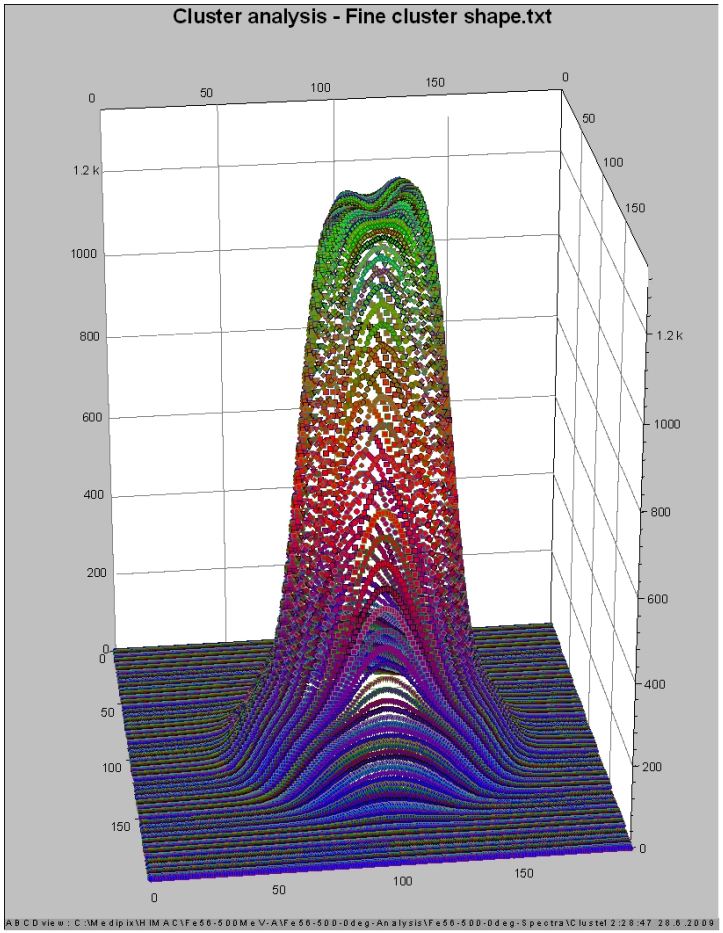
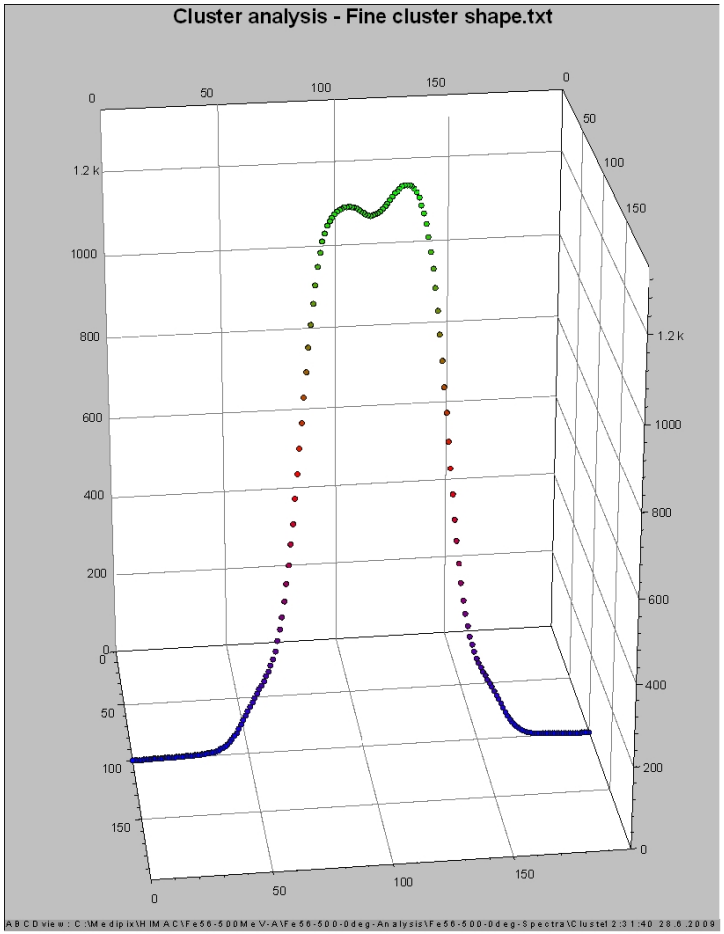
# $^{56}$Fe @ 500 MeV/A Saturation/Recombination

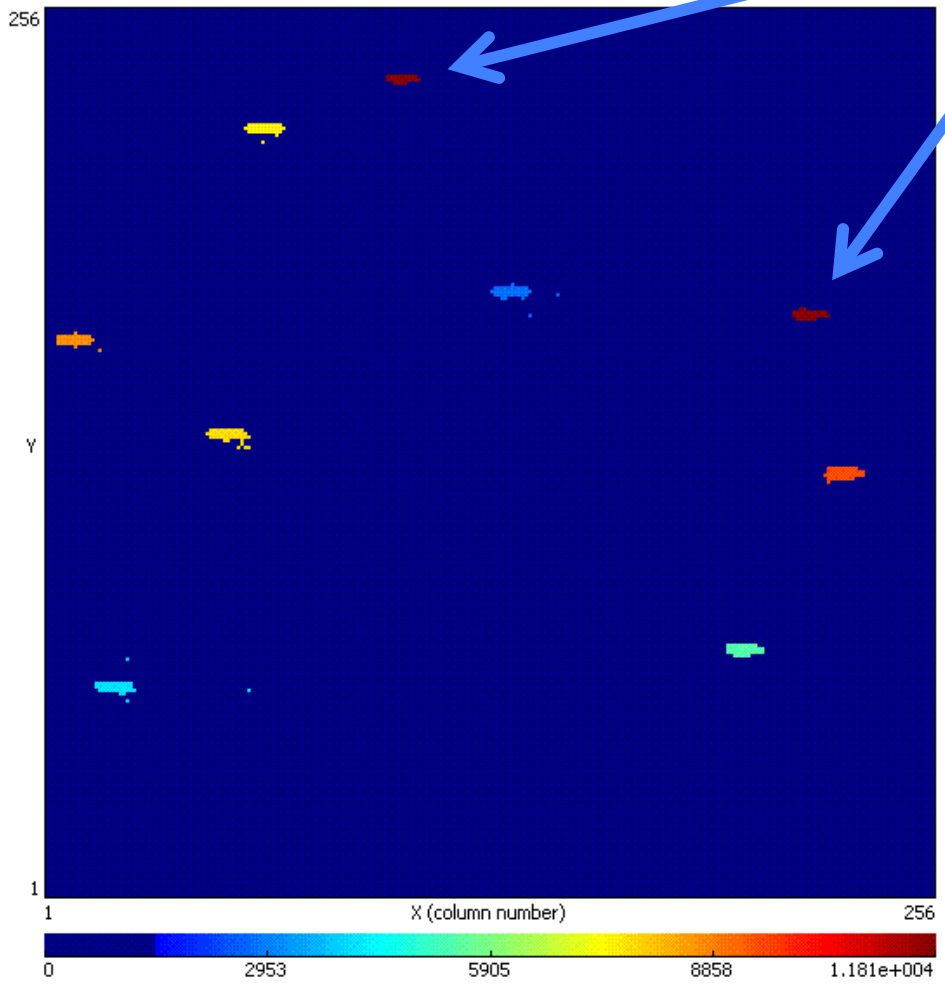


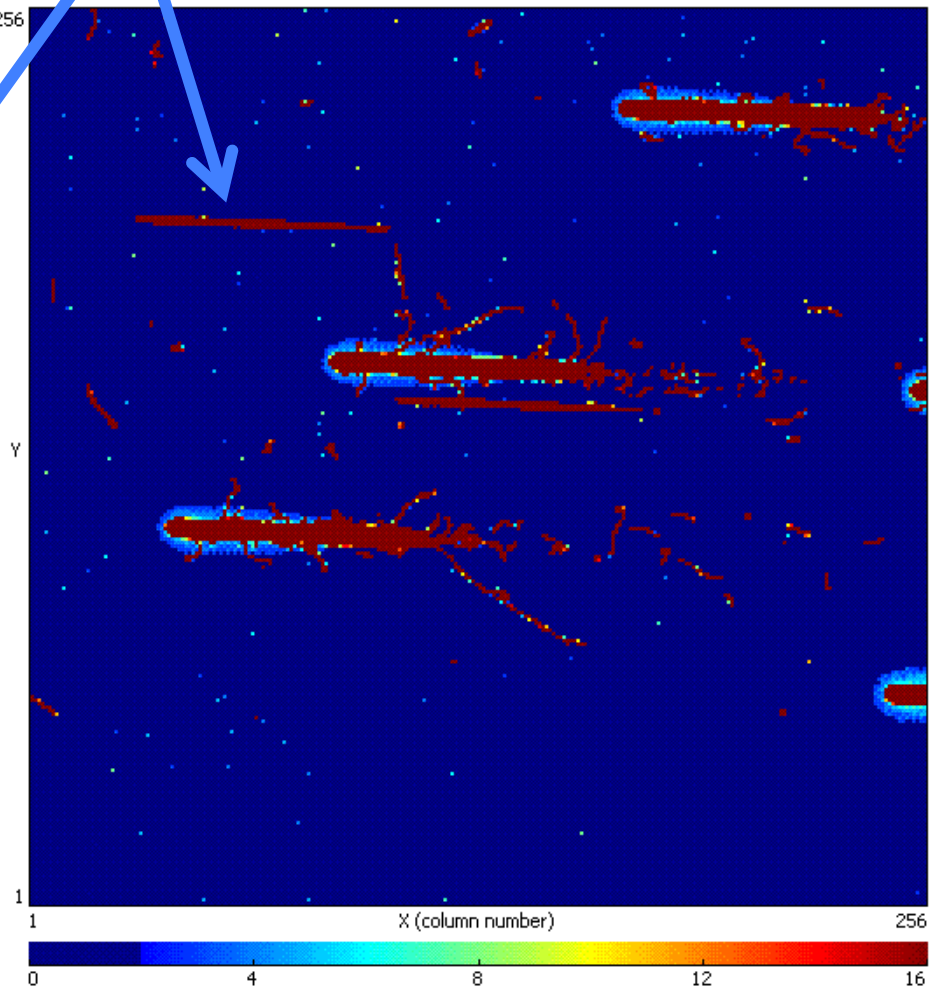



# Latent Track "Ghosts"

**60 degree Tracks in TDC Mode…**

**85 degree Tracks in ADC Mode…**

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# ATLAS Area Neutron Monitors
# Detector Configuration

**Medipix2 ASIC with 300$\mu$m Si sensor + USB interface**

**Neutron conversion structures:**

**1)LiF+50$\mu$m Al foil area**

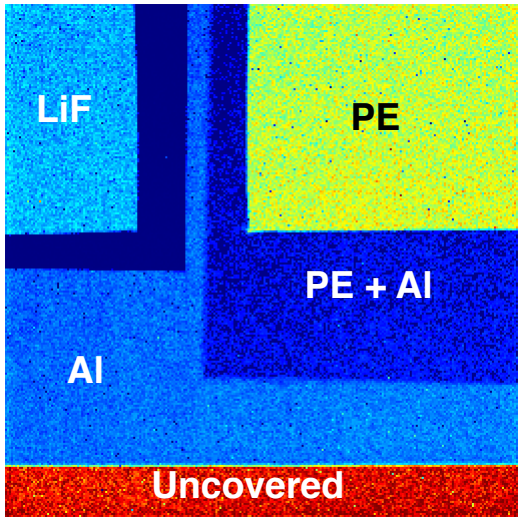
**2)100$\mu$m Al foil area**

**3)PE area**

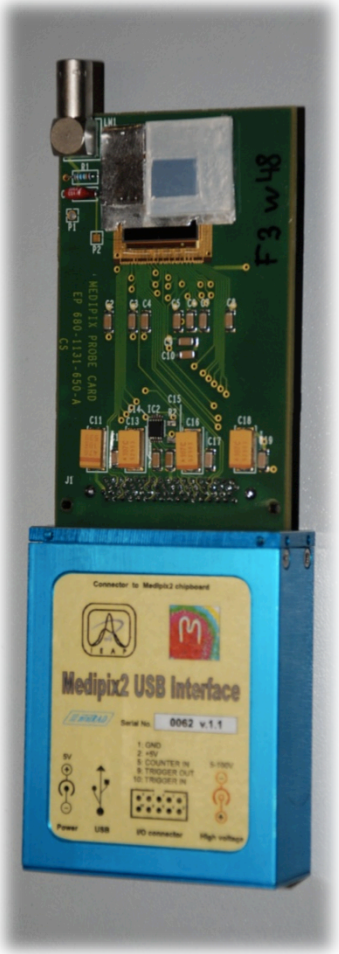
**4)PE+50$\mu$m Al foil area**

**5)Uncovered area**

**X-ray image of conversion layers**





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# Neutron efficiency calibration

(see also poster 3.2.4 of Dominic Greiffenberg)

**Calibrated efficiency:**

Thermal: 1.41E-2 ± 7.11E-4 $cm^{-2}s^{-1}$

252Cf: 1.19E-3 ± 1.89E-5 $cm^{-2}s^{-1}$

AmBe: 2.86E-3 ± 5.46E-5 $cm^{-2}s^{-1}$

VDG: 7.23E-3 ± 5.81E-4 $cm^{-2}s^{-1}$

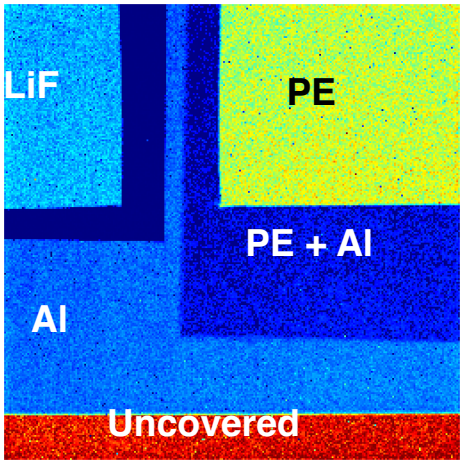
**PE / PE+Al cluster count ratio:**

252Cf: 10.70 ± 0.04

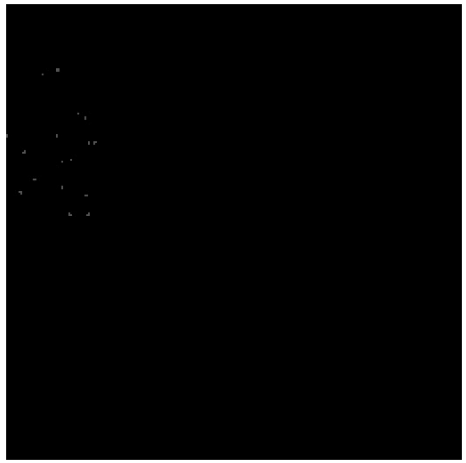
AmBe: 5.18 ± 0.03

VDG: 2.51 ± 0.03

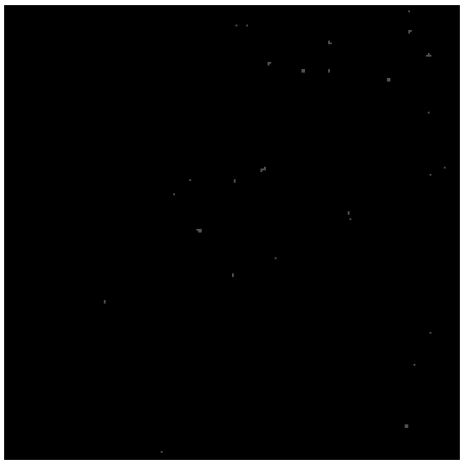
X-ray image of conversion layers



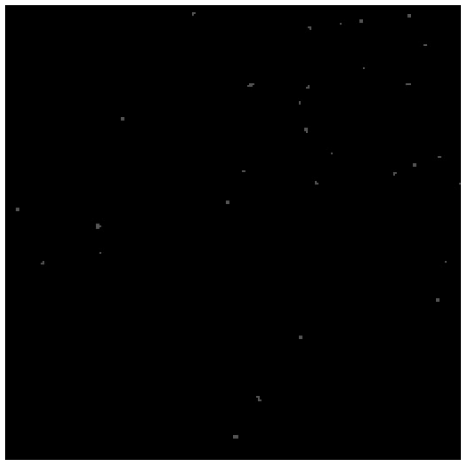

Thermal neutrons – 500s,



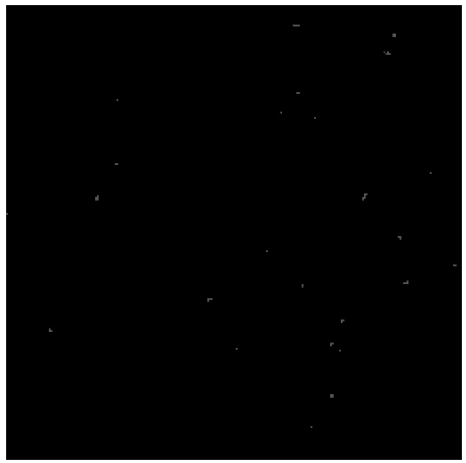
252Cf – 2000s, 2MeV (mean)



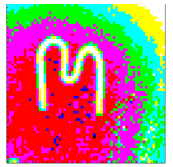
AmBe – 2000s, 4MeV (mean)



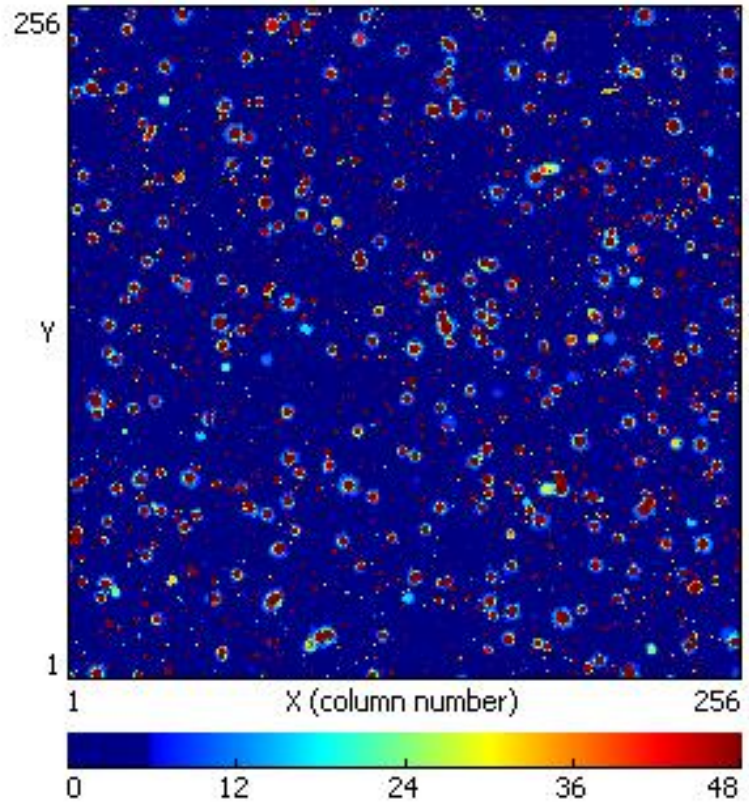
Van de Graaff – 1000s, 14MeV



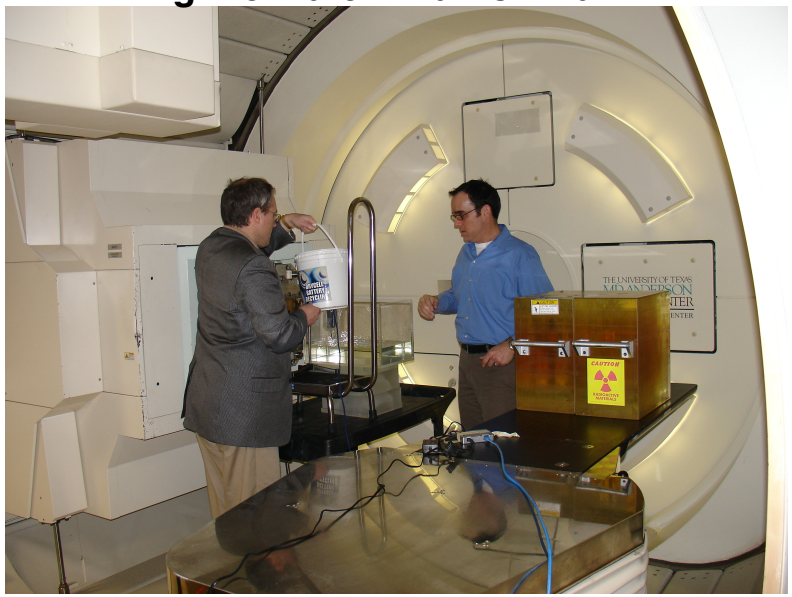
# A Recent Exposure at the M.D. Anderson Proton Therapy Center



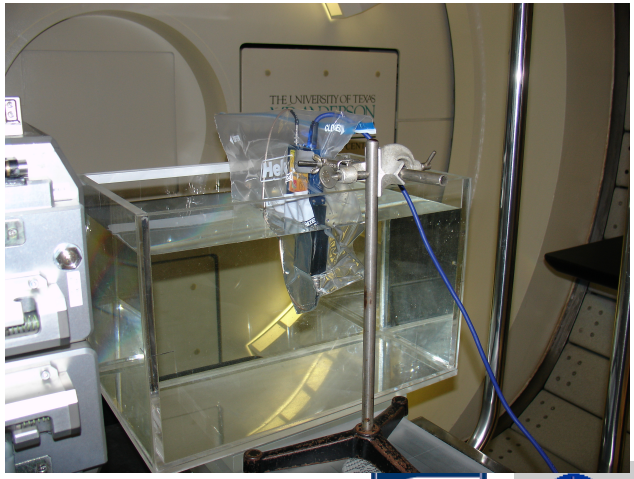
**A 10 μs snapshot of what the tumor cells see…**




**Filling the Water Phantom Tank**



**Water Phantom W/Timepix inside a plastic bag**



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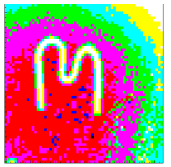
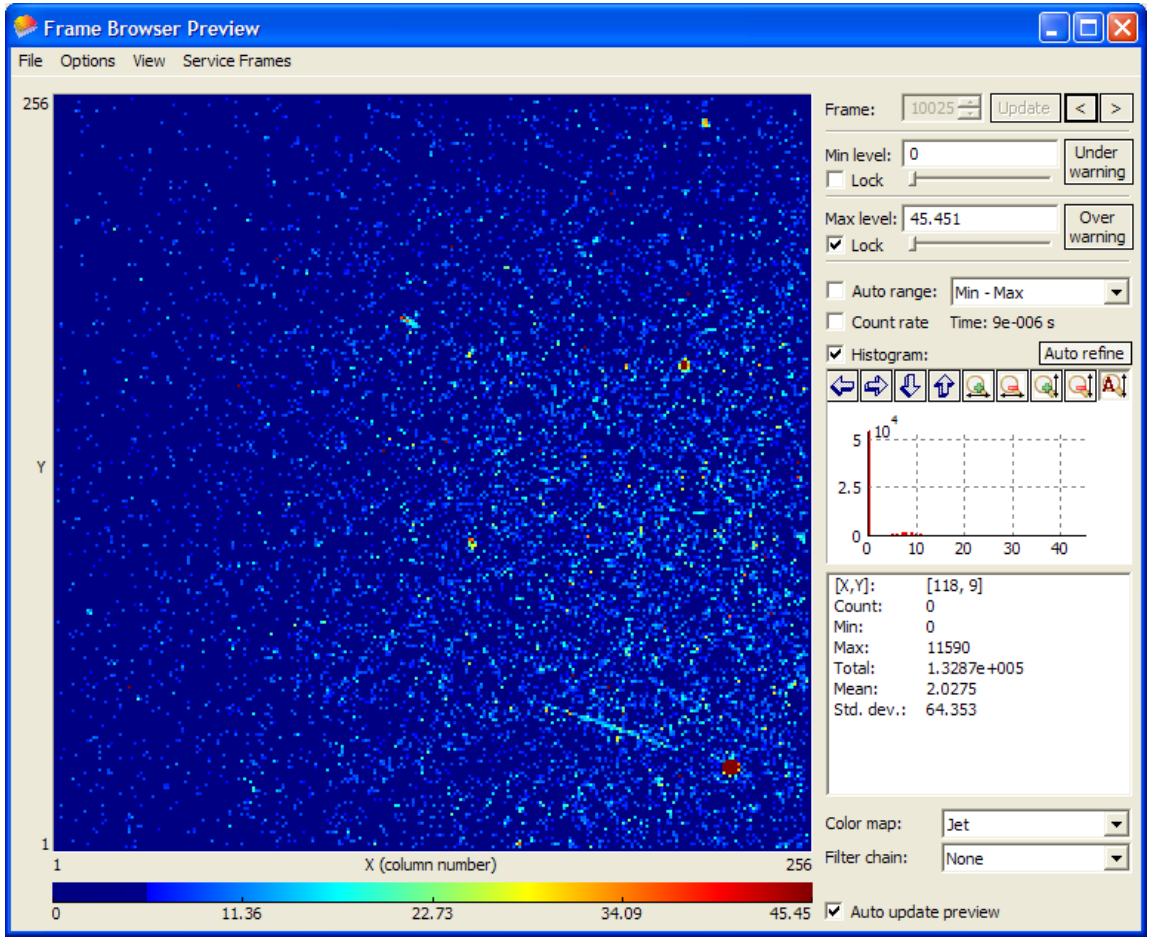
# M.D. Anderson Proton Therapy Center Scanning Beam Frame



- This 10 μs frame was taken in the high intensity scanning beam at the M.D. Anderson Proton Therapy Center in Houston, Texas.

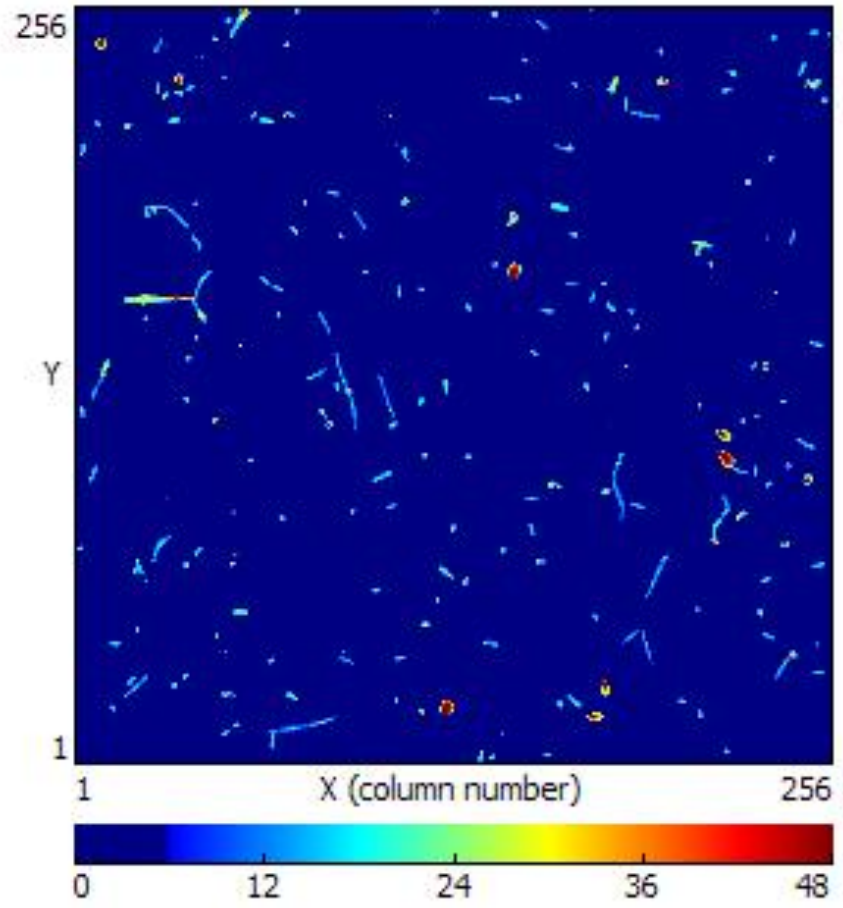
- The fluence is > $10^8$ protons/cm$^2$s. The beam is centered near the lower right edge of the frame and is nominally 1 cm in diameter. The frame is ~1.4 cm across.



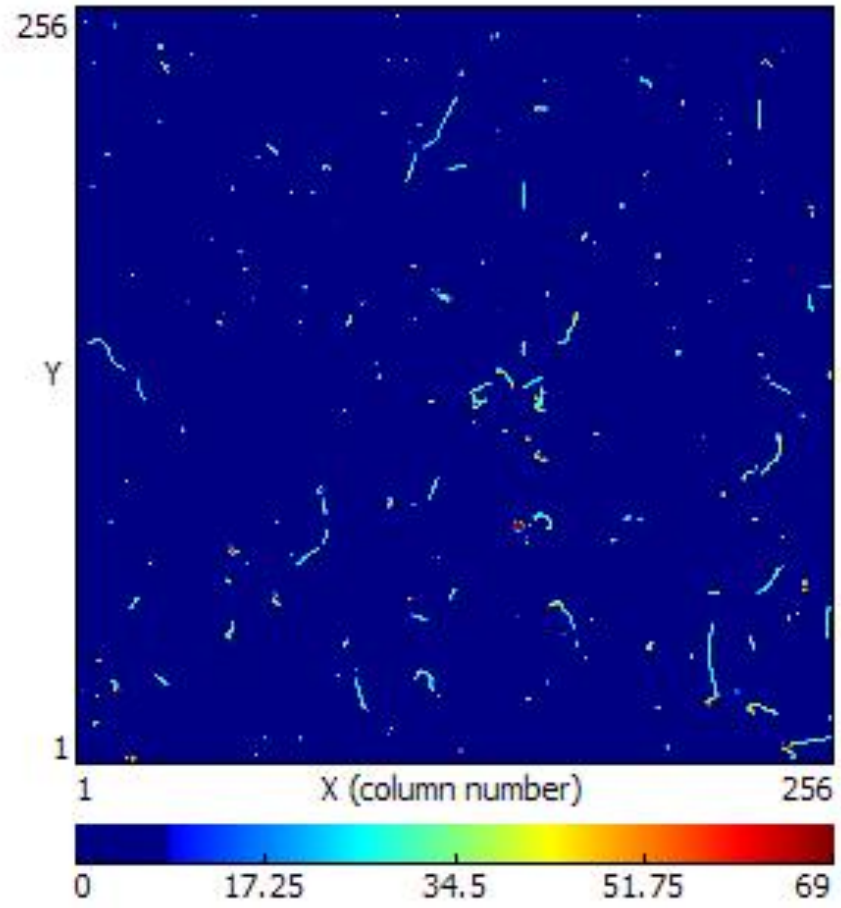

**Bias Voltage and ADC Feedback Current were reduced to avoid USB voltage sag.**

# "Film-Badge" Equivalent Dosimetry

***100 sec*** **@ 11,000 m in a 777 over the Bering Sea**




***1000 Sec*** **in my office in Houston**

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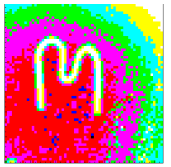
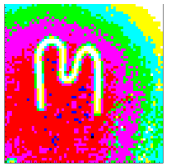
# Where Do We Go From Here?

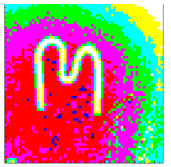


- The Medipix Technology is clearly capable of providing a tool to accurately map out and monitor the radiation field on a detailed level in Hadron Therapy Beams…
- There is a "Next Generation" (Medipix3) being designed at the present time, that will extend the capabilities of the current versions…
- We are developing detailed models of the response of the detector that will be available within the (CERN-Supported) FLUKA Monte Carlo Code, to simulate the anticipated data frames in all relevant cases…
- We are benchmarking the absolute performance of the TimePix to current Hadron Therapy Beam Monitors…
- And…Ultimately, we will install a signal processor on the device itself to calculate and output the dosimetric endpoints directly…
- A UK satellite is scheduled to be launched late next year with 5 TimePix detectors on board…



# Thank You for Your Attention

# Using Differences in Cluster Shapes to Discriminate Particles with Similar dE/dx's



- This is NOT a fit, but the calibrated Data!
- The higher energy δ-rays cause the higher energy particles to increase the net width of their profiles…
- …While, the net total energy is the same…