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# UPDATE on the Status of the Development of a New Active Dosimeter for Use in Space Radiation Environment Based on the MEDIPIX2 Technology


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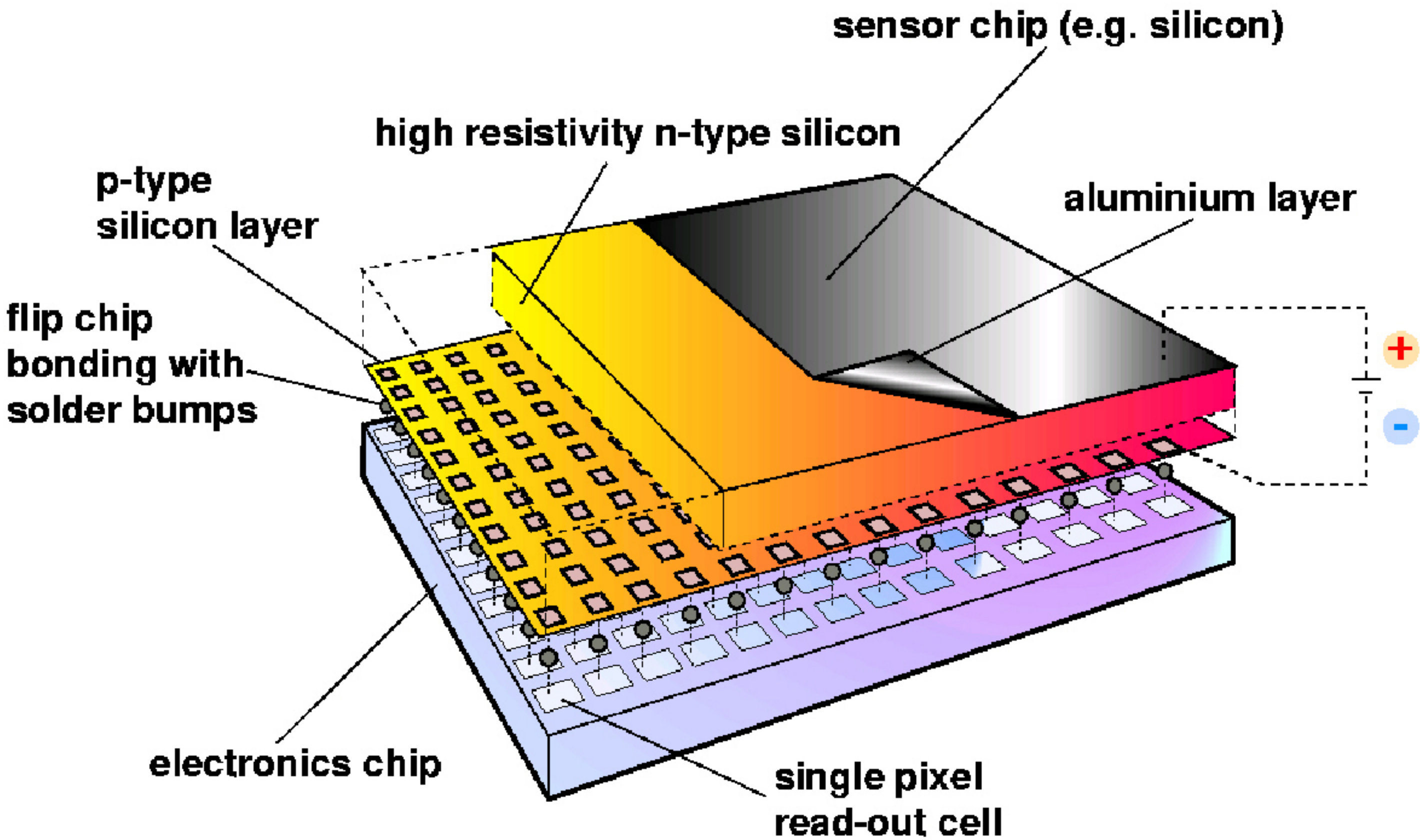
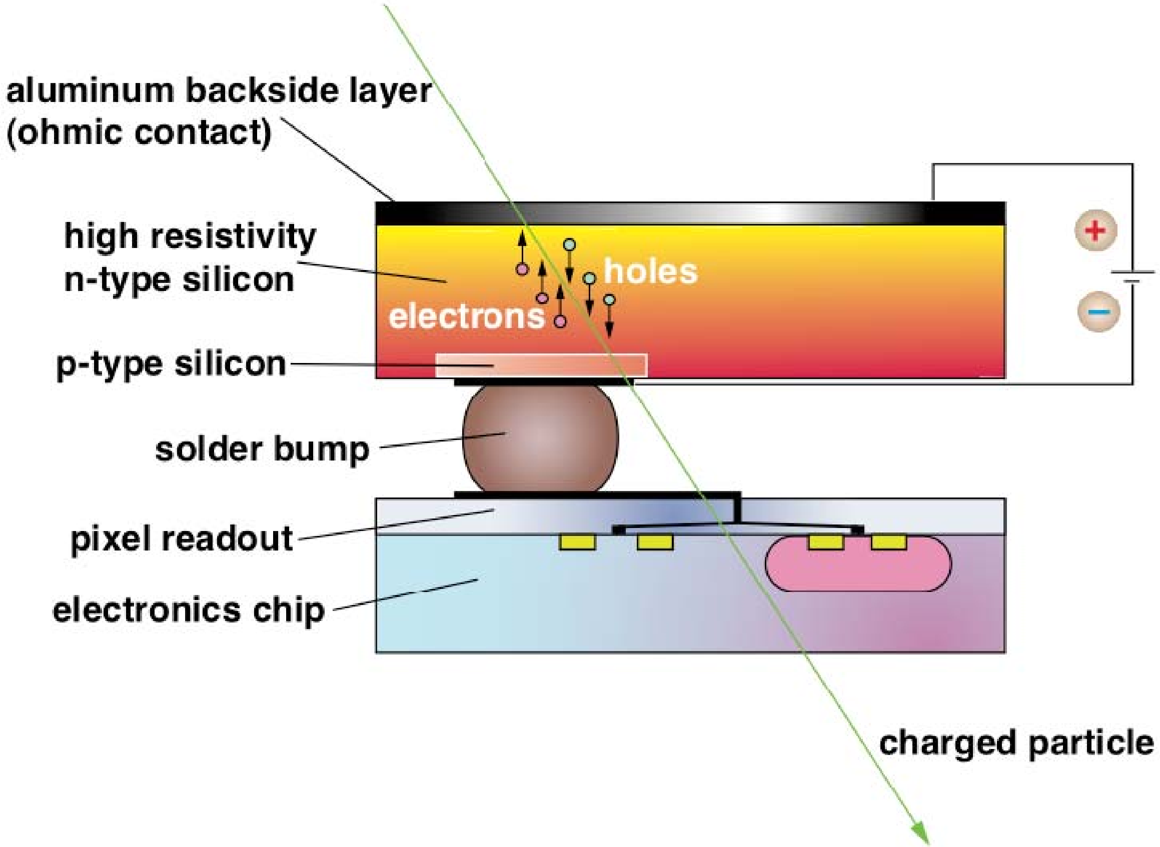
# Hybrid Pixel Detector




**Detector and electronics readout are optimized separately**

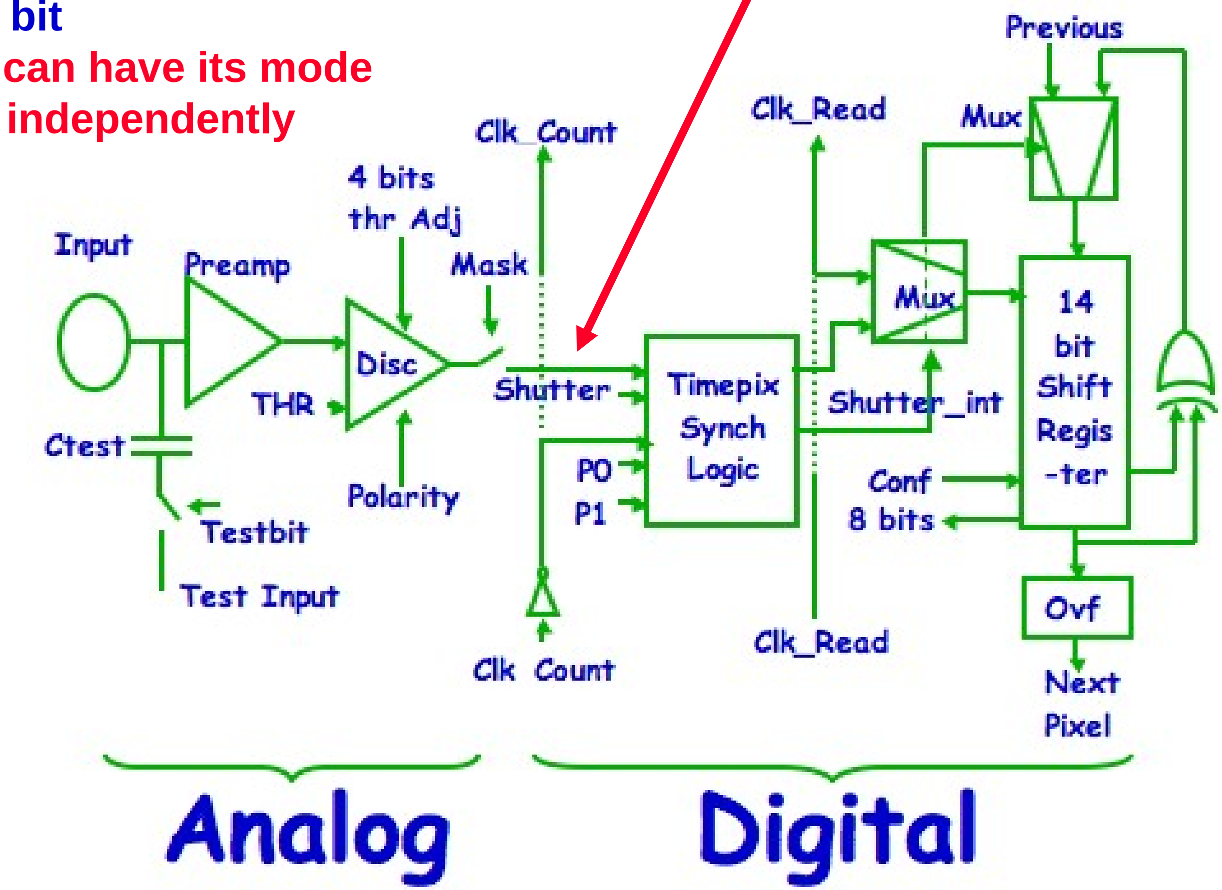
# Hybrid Pixel Detector - Cross Section

***UH is currently working on epitaxial deposition techniques that will facilitate the creation of high efficiency Embedded-Neutron-Converter detectors***



# TimePix Cell Schematic

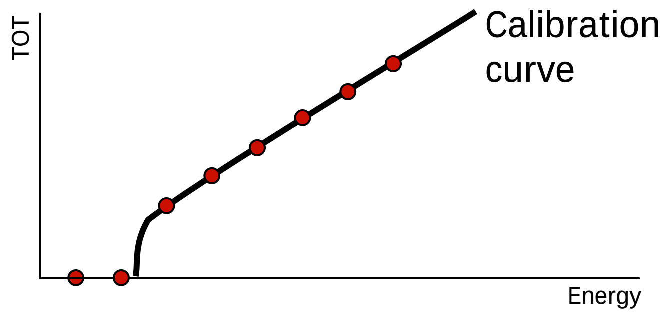
- Charge sensitive Preamp/Shaper w/ individual leakage current compensation
- Discriminator with globally adjustable thresholds & individual 4-bit fine tuning offset
- Individually settable test and mask bits for each pixel
- External shutter activates the counter (can be set as short as 10 ns)
- 14-bit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

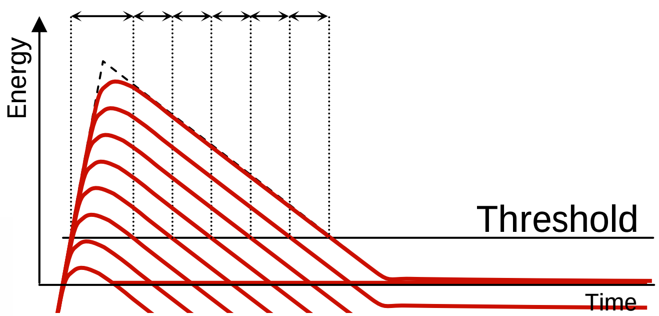


# TimePix and its TOT mode

Counter in each pixel can be used as

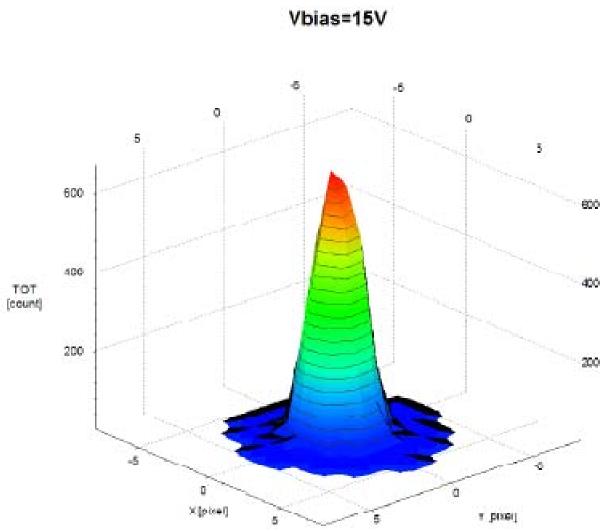
- **Timer** to measure detection time => TOF experiments, TPC detectors, ...
- Wilkinson type **ADC** to measure energy of each particle detected.



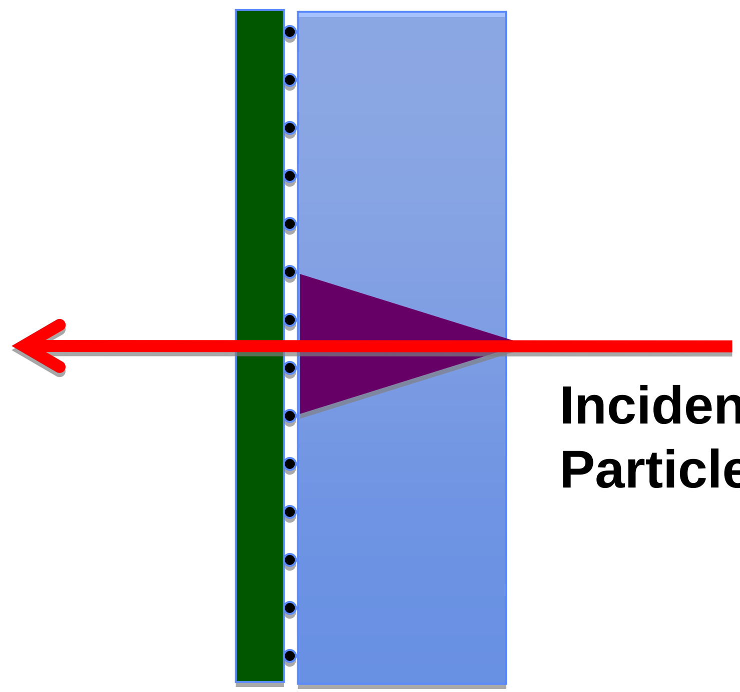

- **If the pulse shape is triangular then Time over Threshold is proportional to collected charge i.e. to energy.**
- **Due to limited bandwidth the pulse can be NEVER perfectly triangular.**
- **Non-linear TOT to energy dependence**

# Charge Clusters



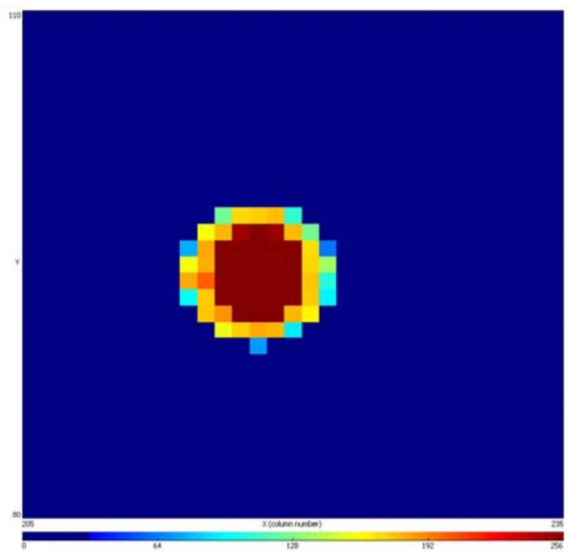

**The electron-hole pairs liberated by traversing moving charges drifts in the bias voltage and also diffuses during the process, creating a multi-pixel cluster.**

**TimePix**



**Incident Particle**

**"PIXELMAN" Image**



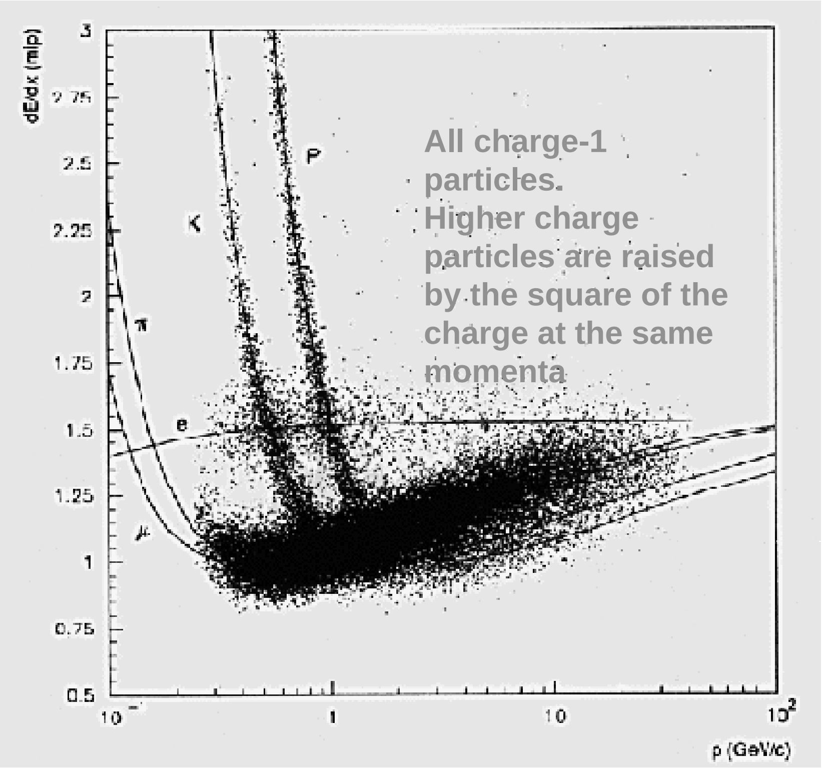
# Dosimetry in Space

- **Our approach is to try and Characterize the Radiation Field as precisely as possible as a function of time.**
- **To do that, we need to assess the radiation environment in terms of the Charge AND Energy of the individual particles that are present.**
- **…HOWEVER, because of the “$Z^2$ effect” and the shape of the energy-loss curves, it is possible for different ions to have the same dE/dx in a thin detector…**
- **Slow lower-Z particles seen in the dosimeter will not penetrate deeply into the body, and can be mimicked by higher-Z faster particles, which CAN penetrate deeply…**
- **SO, again, “Our approach is to try and Characterize the Radiation Field as precisely as possible as a function of time.”**

# Measuring Charge AND Energy

- **If you know β then measuring the charge is reasonably simple because of the $Z^2$ dependence.**
- **In accelerator experiments the interaction fragments from the projectile particle is generally moving at close to the projectile's original velocity, at least for forward fragments.**
- **However, if you have no *a priori* velocity information, the problem is the BETHE-BLOCH Equation…**

$$-\frac{dE}{dx} = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$



# Same dE/dx, BUT, Different Z

## Some “Standard” HIMAC Beams

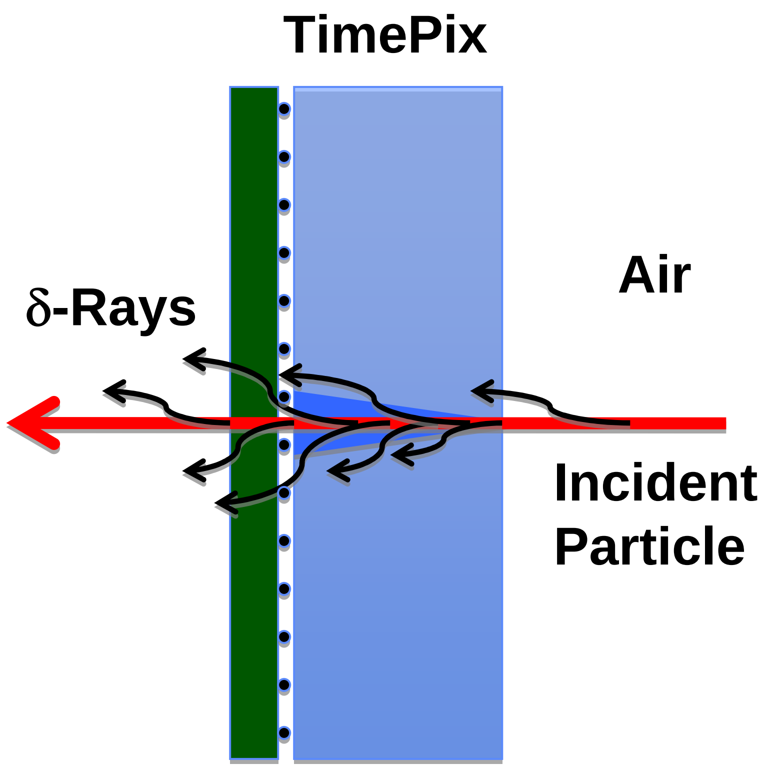
| KE (MeV/u)=> | 100.00 | 180.00 | 230.00 | 290.00 | 350.00 | 400.00 | 430.00 | 500.00 | 600.00 | 650.00 | 800.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| He (KeV/μm) | 5.42 | 3.60 | 3.09 | | | | | | | | |
| He (KeV) | 231.14 | 433.00 | 566.81 | | | | | | | | |
| C (KeV/ μm | 48.74 | 32.43 | 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/ μm | 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/ μm | 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/ μm | 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/ μm | 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/ μm | | *608.92 | | *456.68 | | 387.48 | | 351.51 | | | |
| Fe (KeV) | | 433.13 | | 735.39 | | 1066.15 | | 1391.58 | | | |

**The Numbers in BLACK are the dE/dx values in Si, and the “*” are Non-Standard Beams (KeV/μm).**
**The Numbers in RED are the maximum kinematically allowed δ-Ray energies (KeV).**

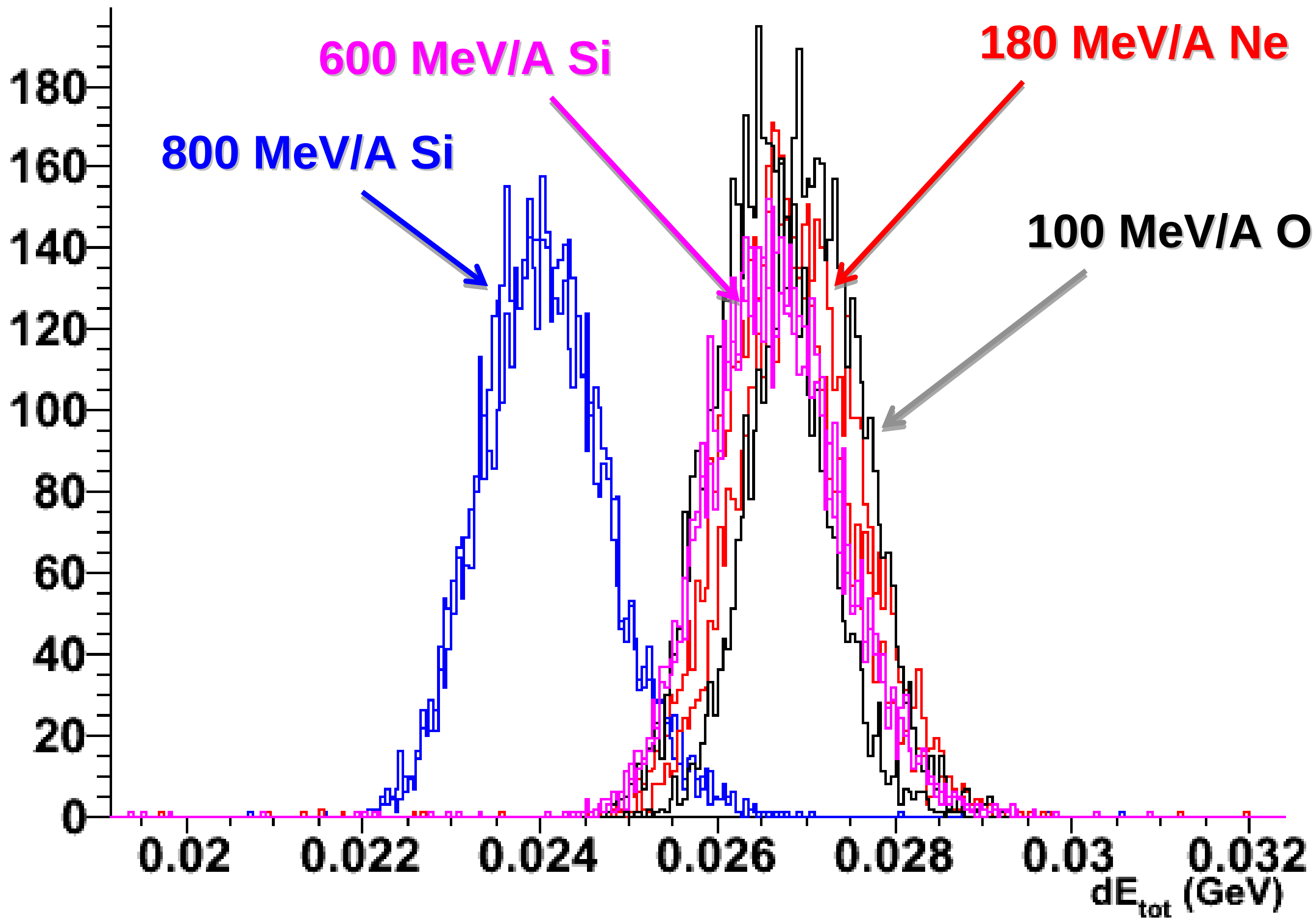
**Remember, these dE/dx values are from the Bethe-Bloch Equation!**
**AND… They represent STOPPING POWER, not Deposited Energy!**

# 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 δ-rays that offer the prospect of telling the difference between the different particle velocities with the same dE/dx…



# dE/dx vs. Energy Deposited FLUKA Simulations

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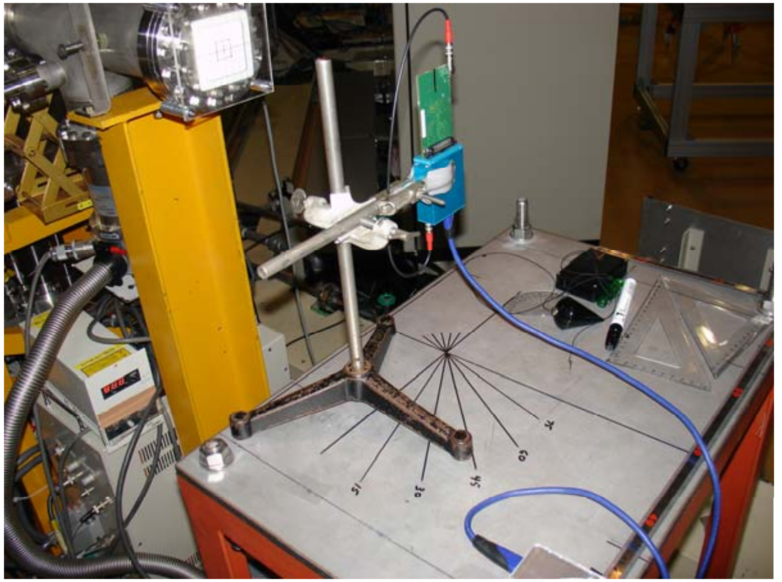
Slides courtesy of Michael Campbell, Stanislav Posposil & Jan Jakubek

# TimePix in the HIMAC Beams

- Data were taken in a parasitic mode with Fe @ 500 MeV/A, N @ 290 & 180 MeV/A and Si @ 400 MeV/A
- The primary beams were:
  - Si @ 600 & 800 MeV/A,
  - Ne at 180 MeV/A and
  - O @ 100 MeV/A,
  - all at Incident angles of 0°, 15°, 30°, 45°, 60°& 90°
- …With a TimePix clock of 20 MHz, IKRUM's of 3, BUT, with a Bias Voltage of ONLY 3 V!



| 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 |
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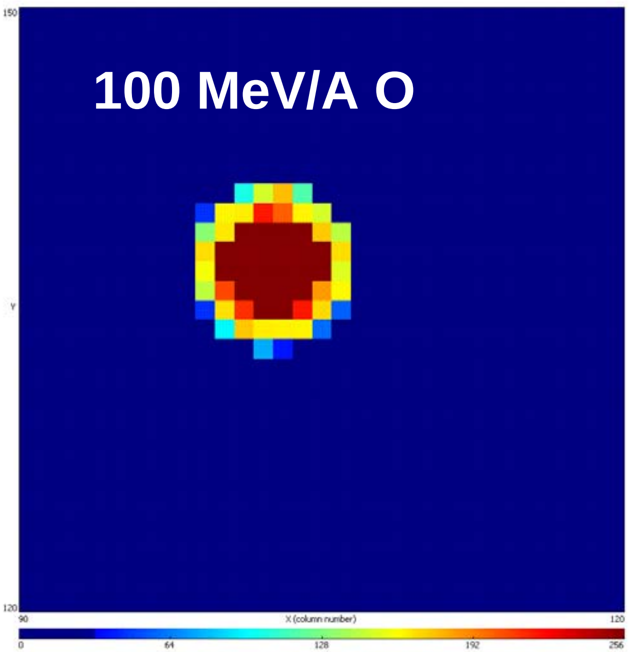
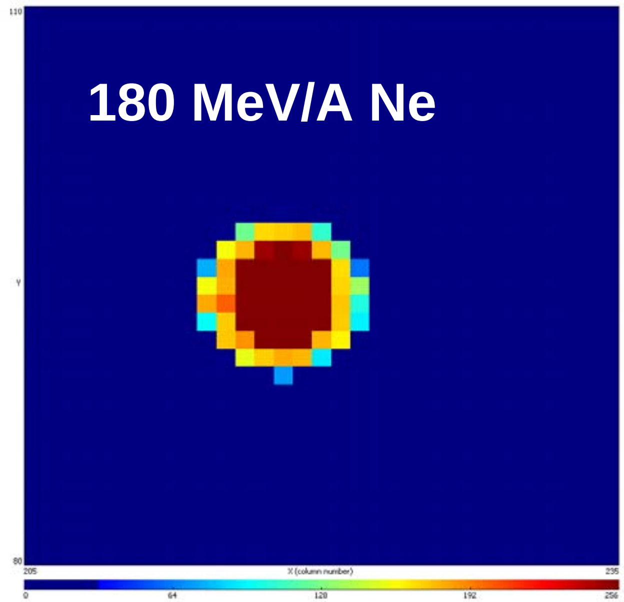
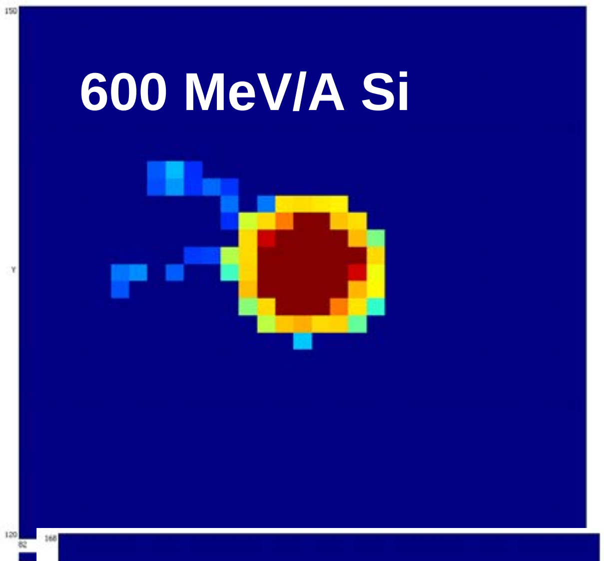
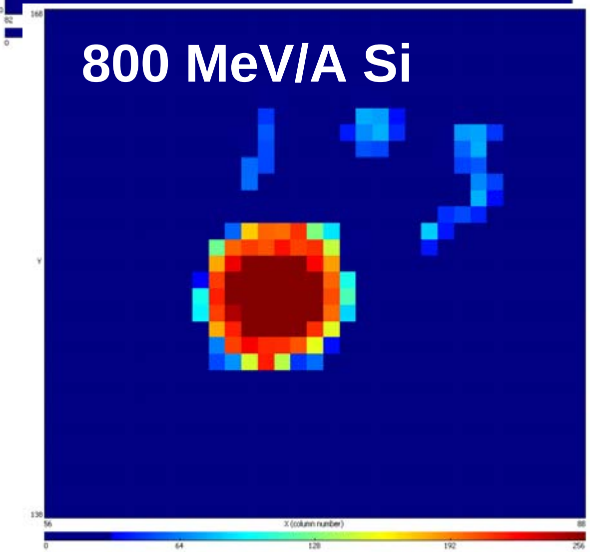
| Fe (KeV) | | 433.13 | | 735.39 | | 1066.15 | | 1391.58 | | | |

# Examples of Individual Tracks



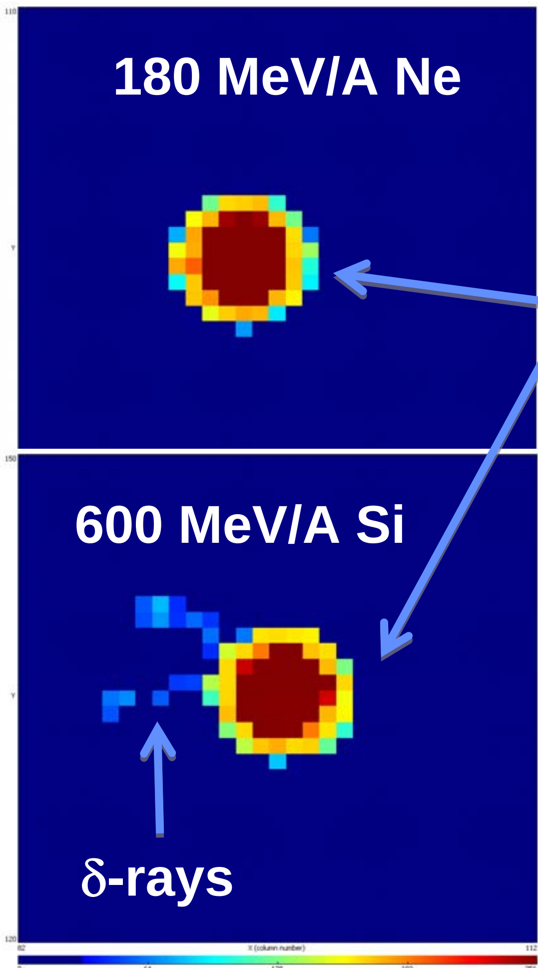




**The high energy δ-rays are clear in the higher energy tracks. These are not yet calibrated, and the study to be preformed is to explore the detailed resolution possible when all the information is included…**

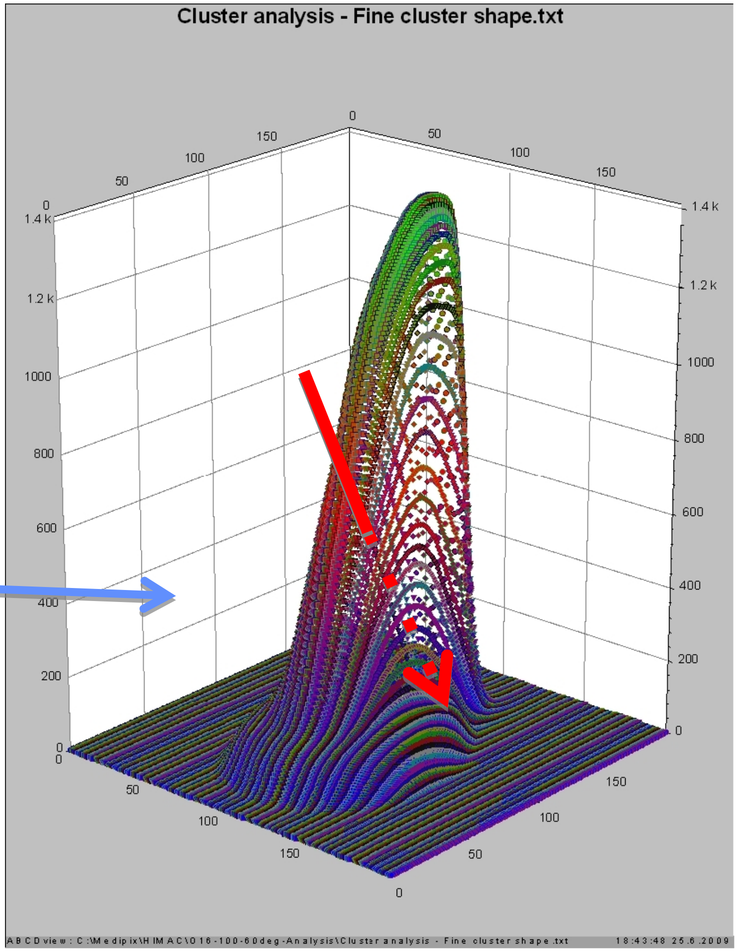
**The next goal is to be able to model these tracks in the FLUKA Monte Carlo code…**

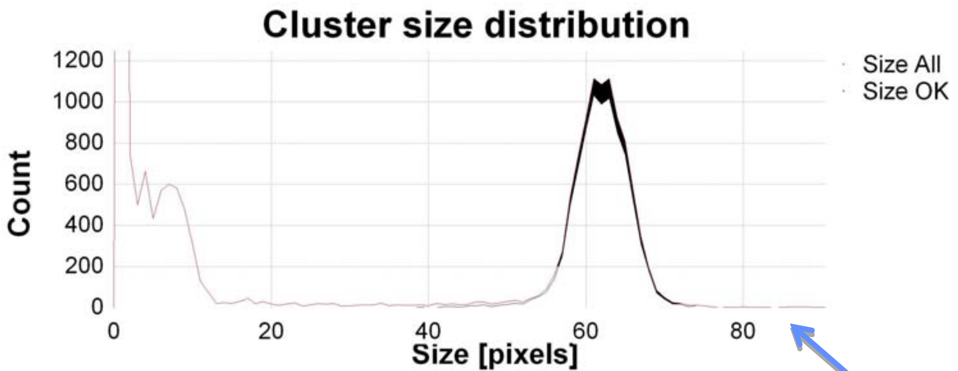
# Typical Heavy Ion "Tracks" as seen in the TimePix TOT Mode

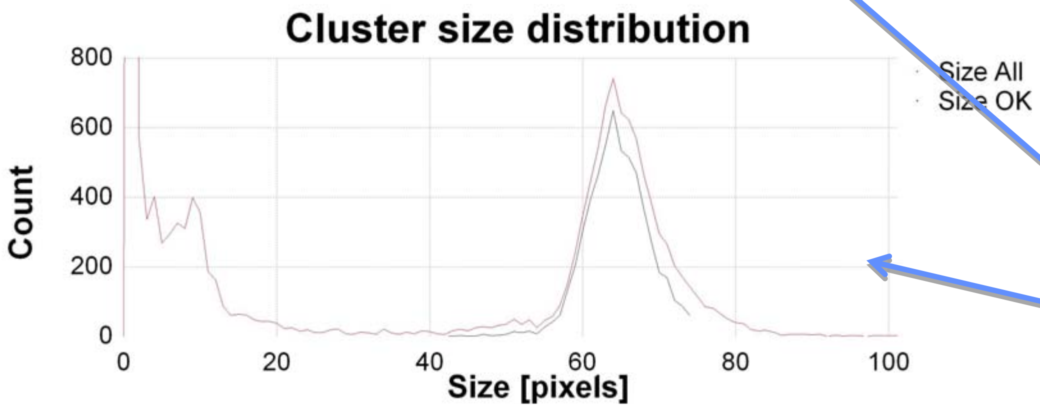


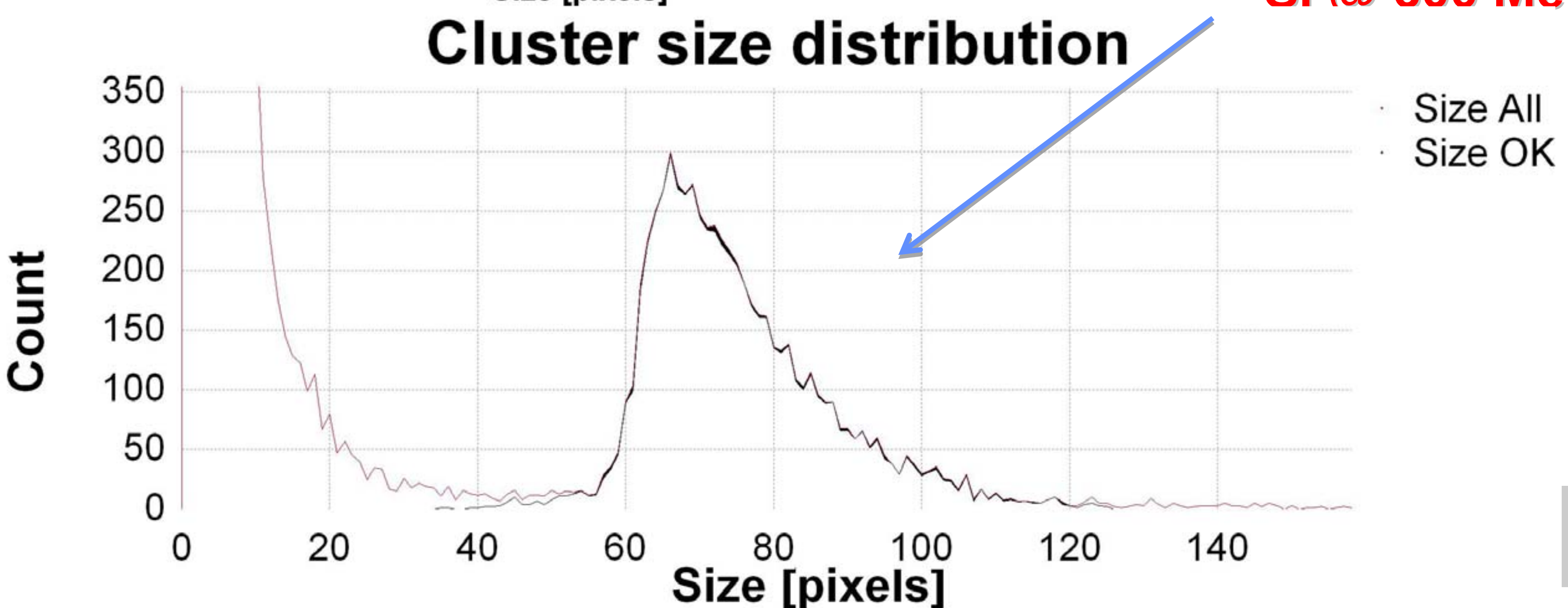

**Normal incidence Pixelman "tracks" from 2 different beams with the SAME dE/dx…**

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



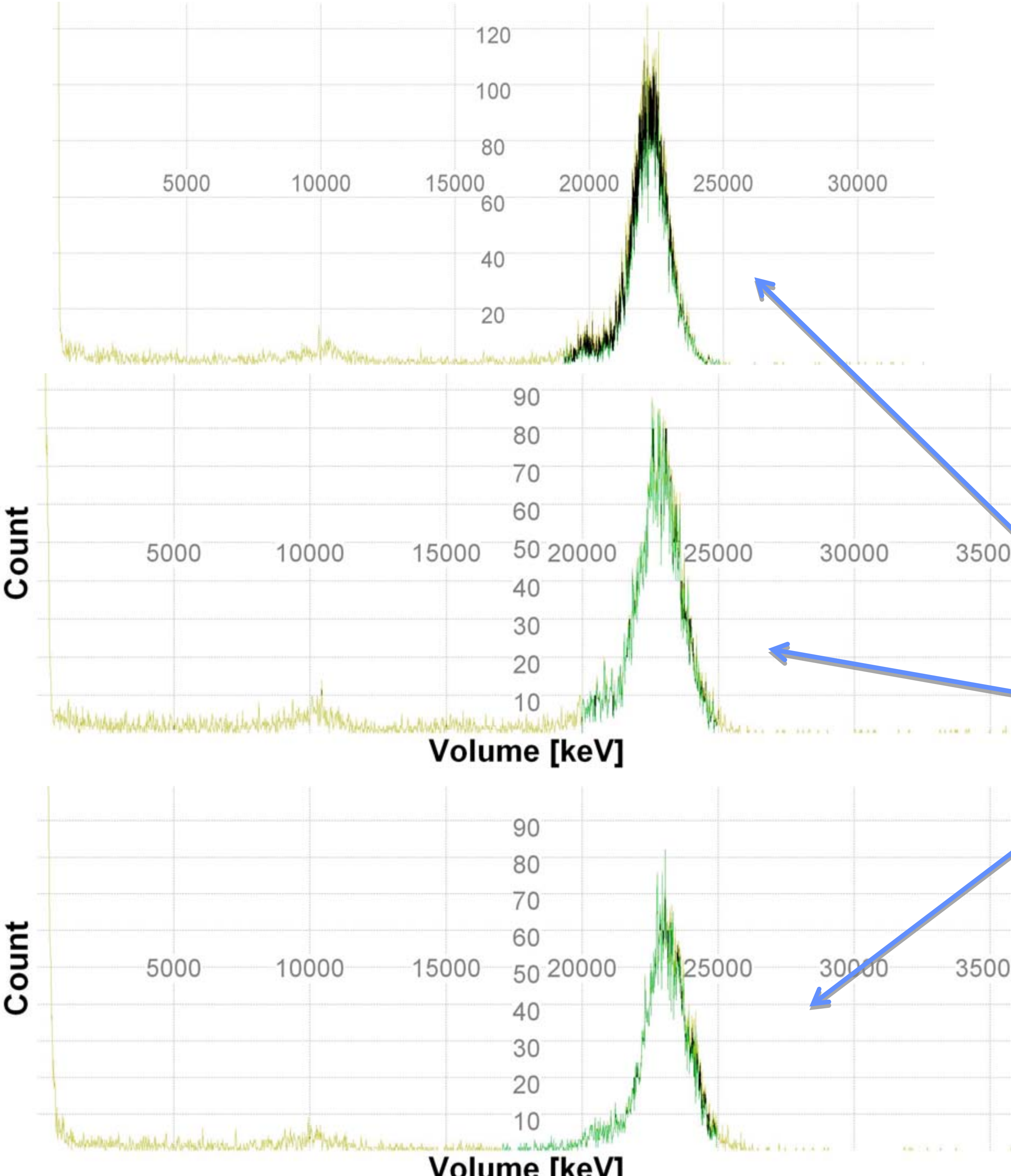



# Normal Incidence Cluster Size Distributions for:

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

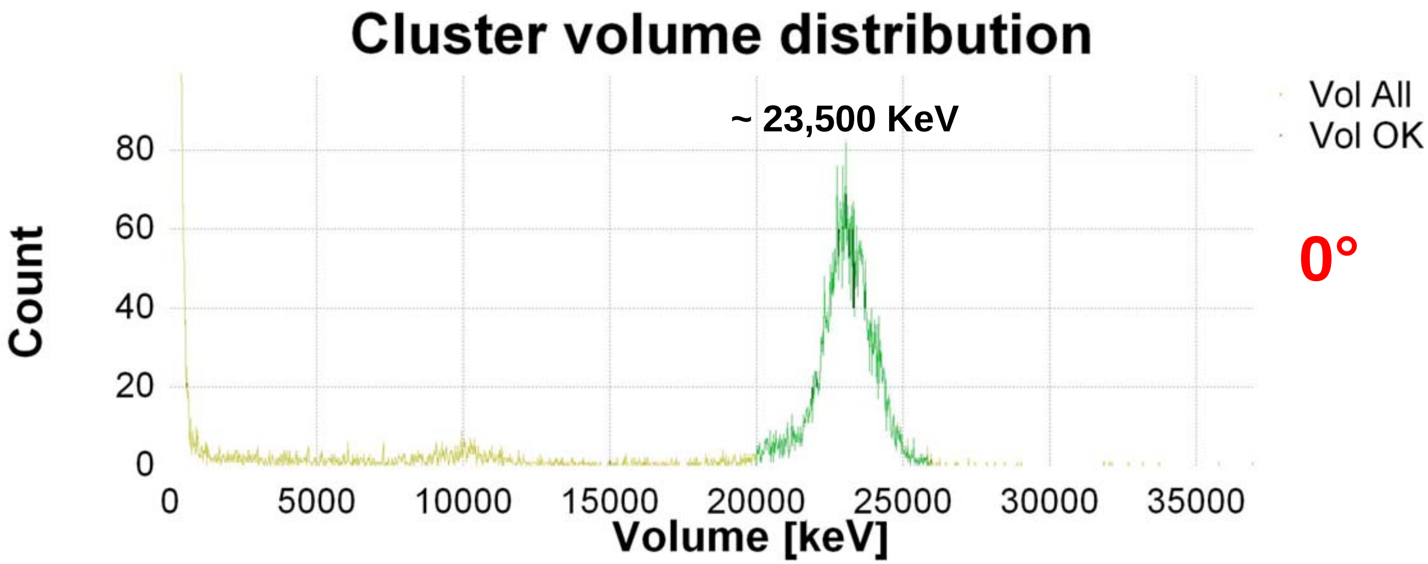



**Energy (KeV) Deposited in the 300 mm Si Detector Layer by:**

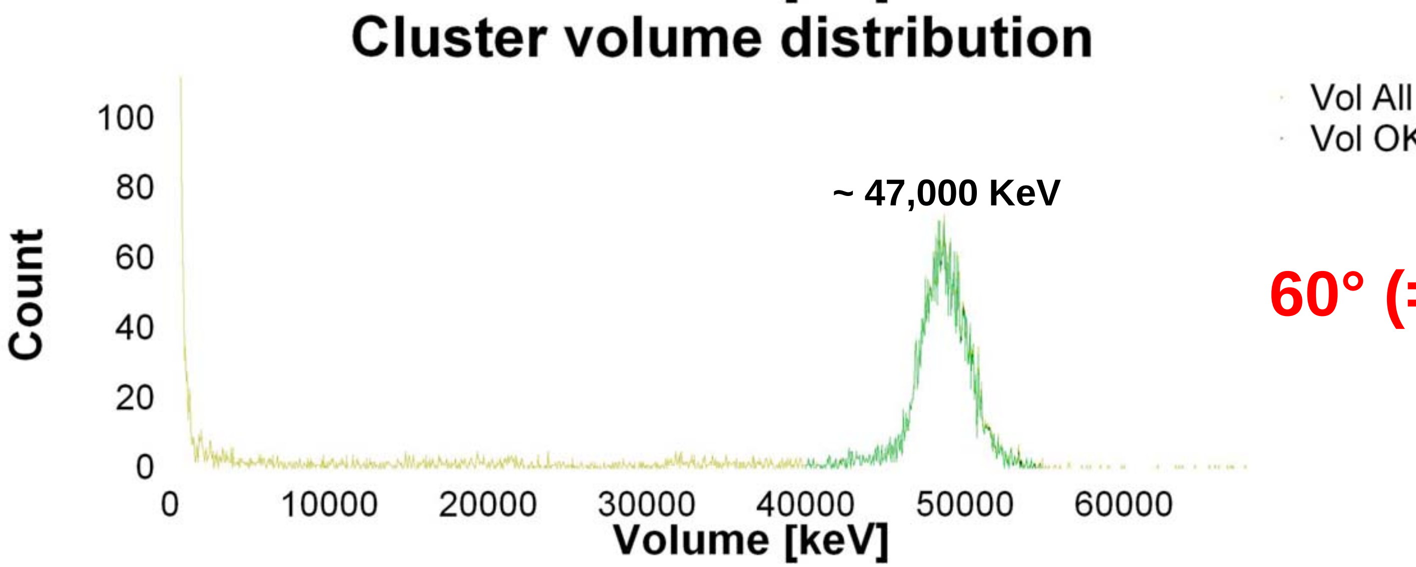
**O at 100 MeV/A**
**Ne @ 180 MeV/A and**
**Si @ 600 MeV/A**

**Normal Incidence**

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

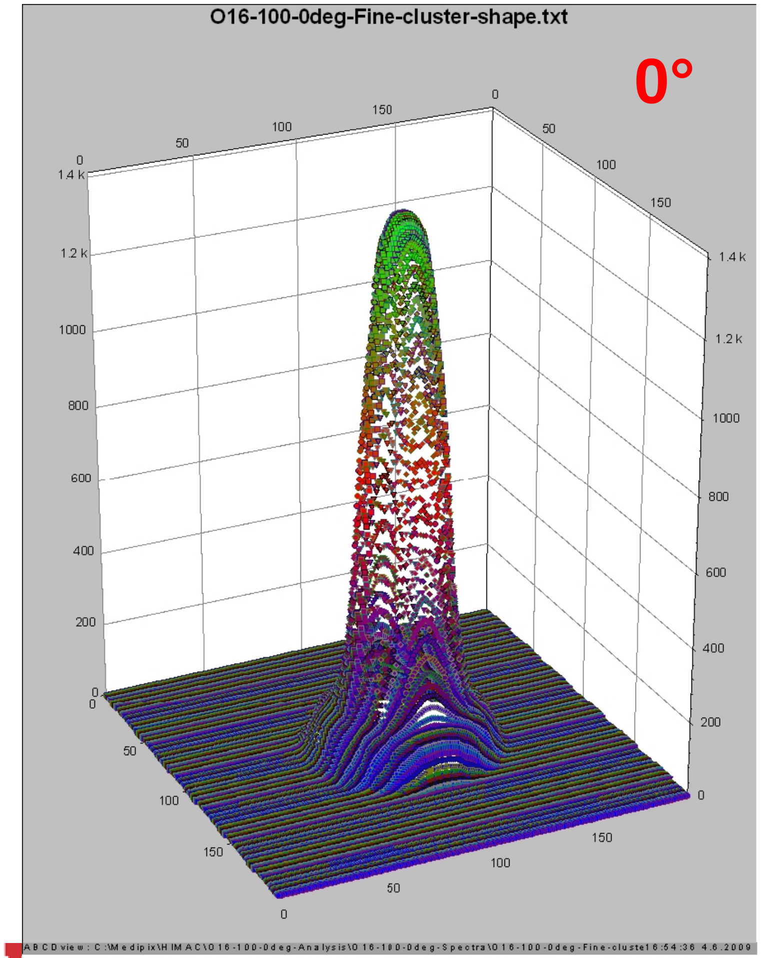


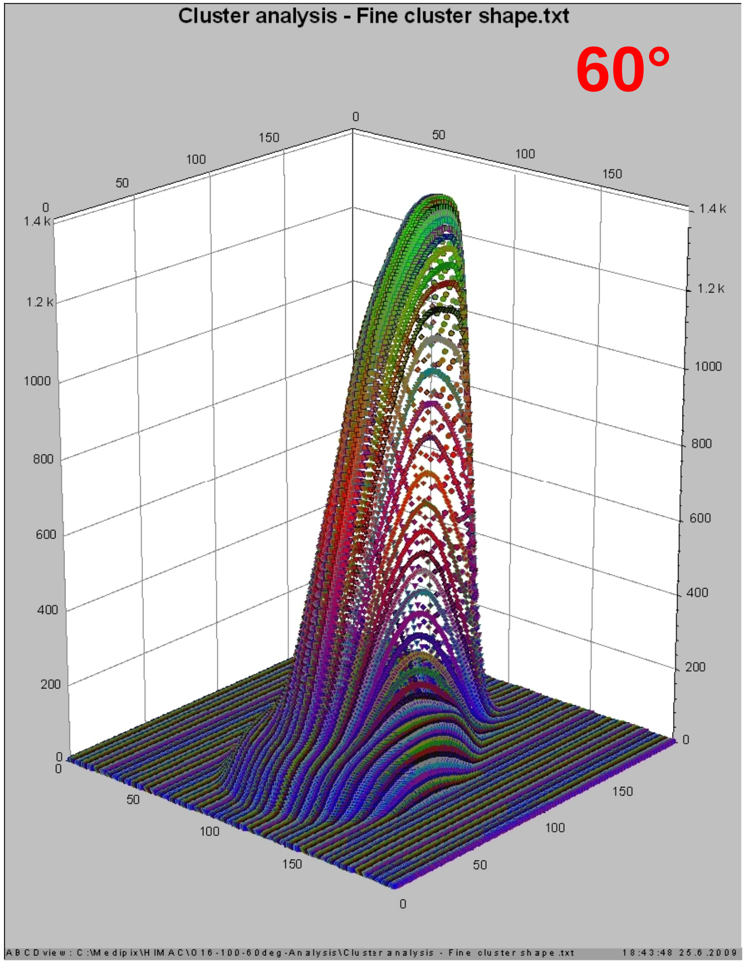

**0°**




**60° (= 2 x 0°)**

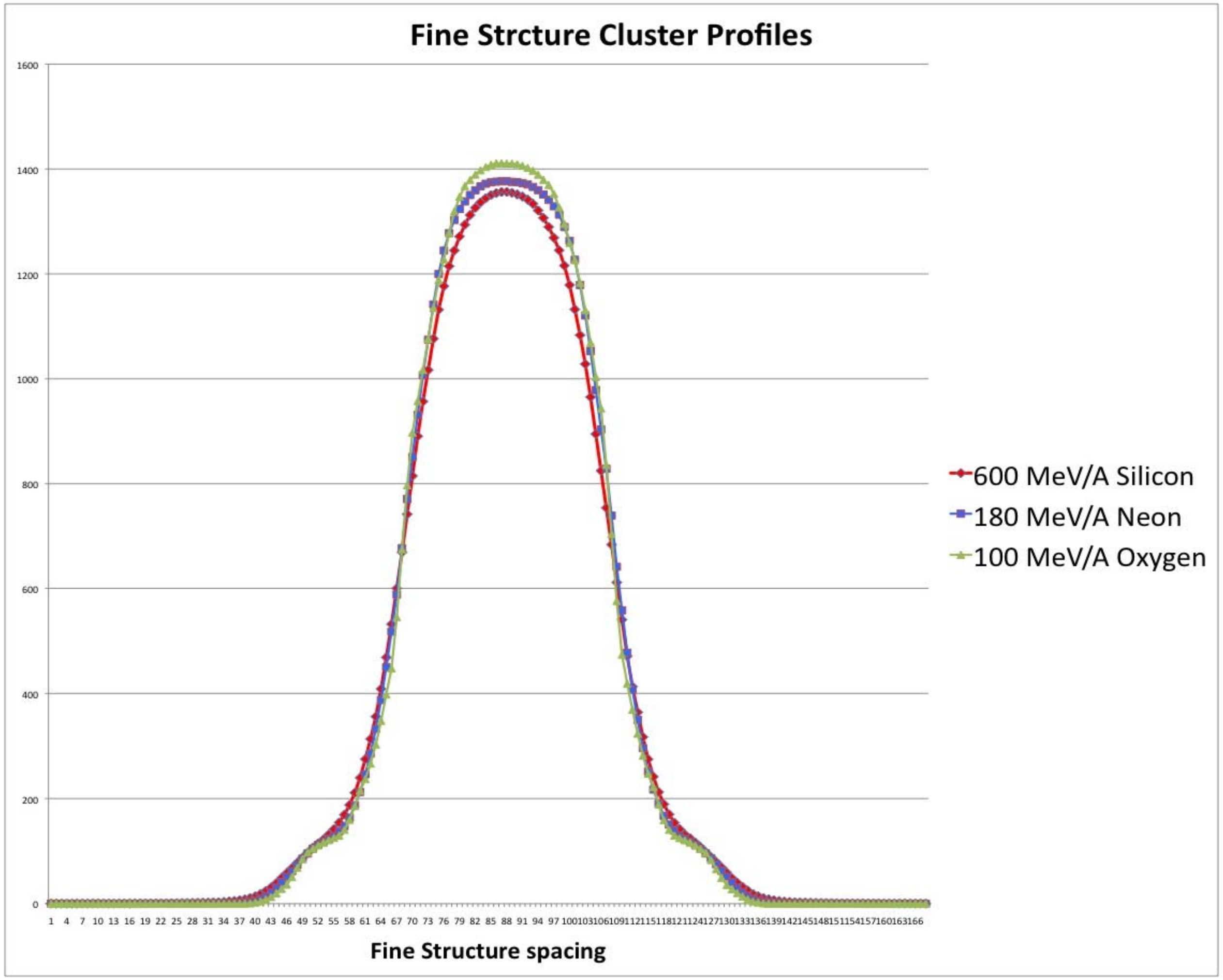
# $^{16}O$ @ 100 MeV/A—Averaged Cluster Shapes @ 0° & 60°



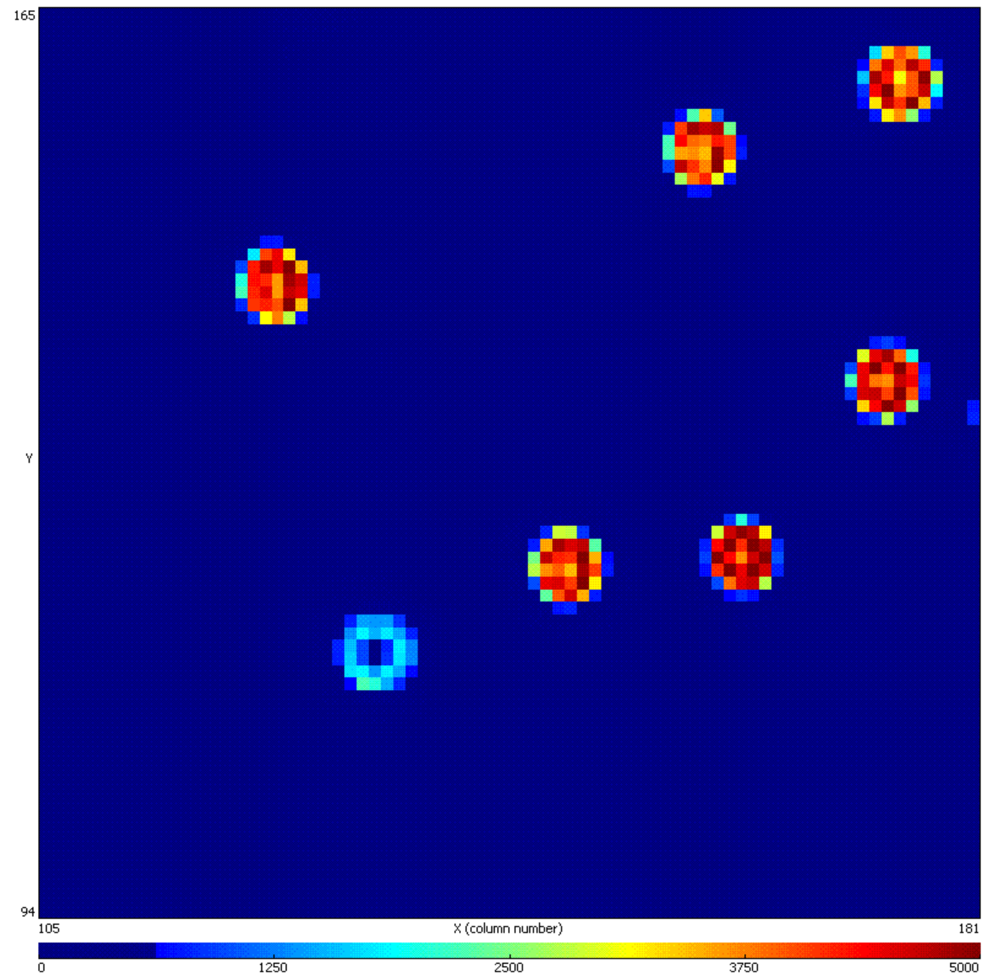
# Using Differences in Cluster Shapes to Discriminate Particles with Similar dE/dx's

- Even with a accidental ~3 V Bias Voltage, the difference is noticeable.
- This is NOT a fit, but the calibrated Data!
- The higher energy $\delta$-rays cause the higher energy particles to increase the net width of their profiles…
- …While, the net total energy is the same…



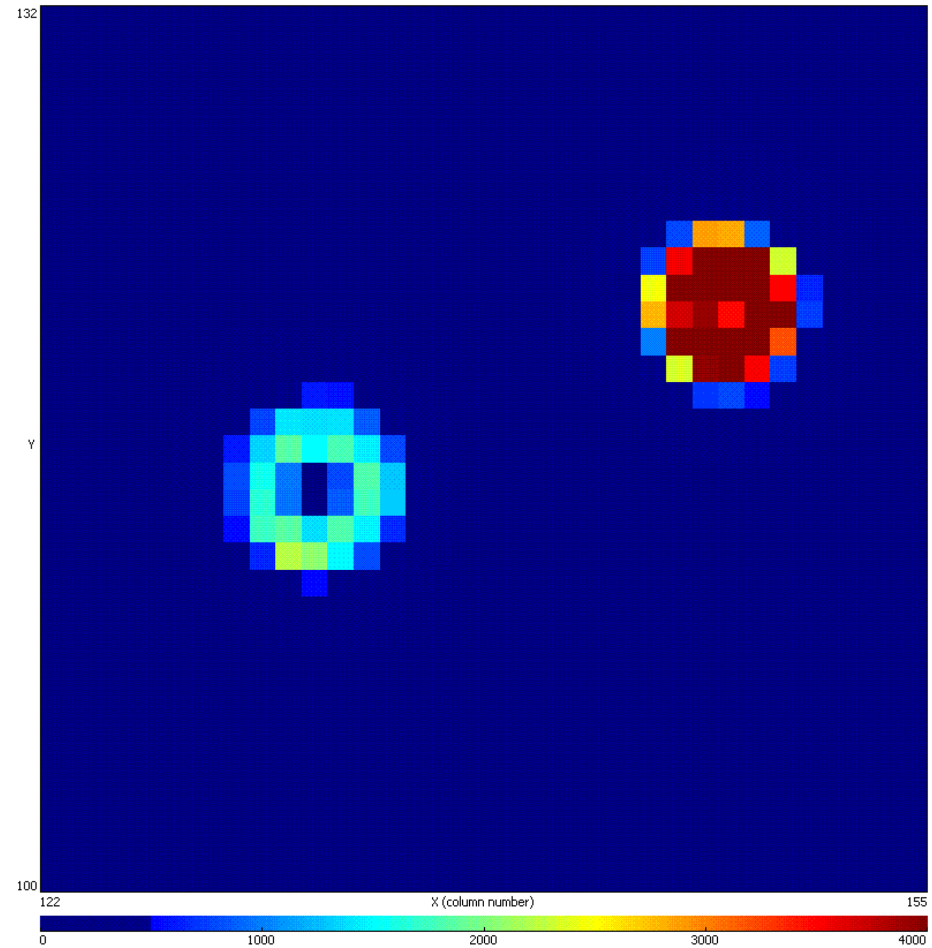
# The “Volcano” Effect

- 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…

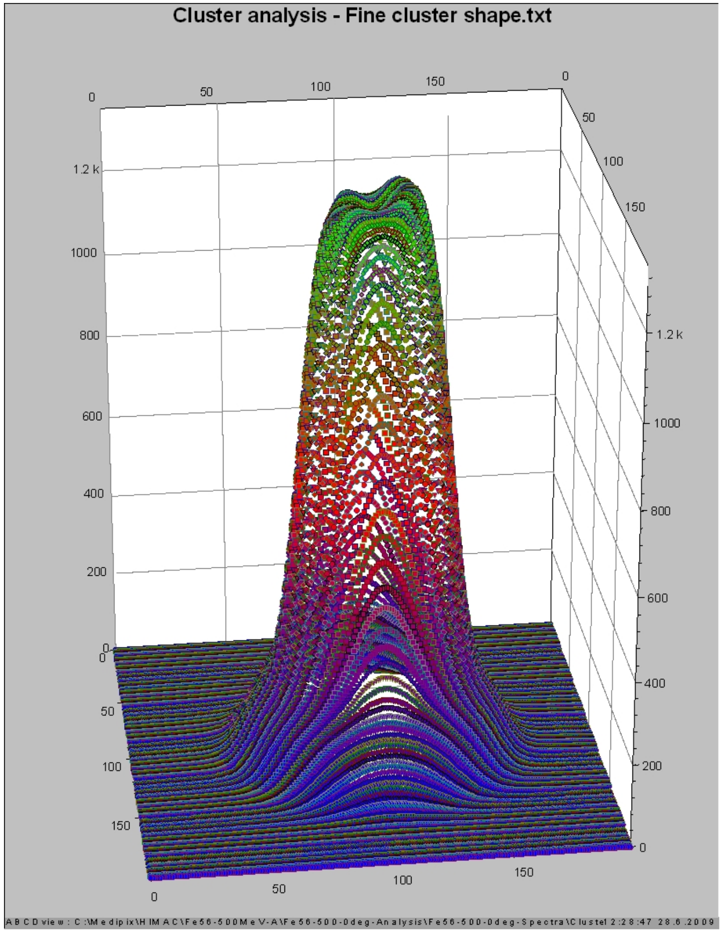


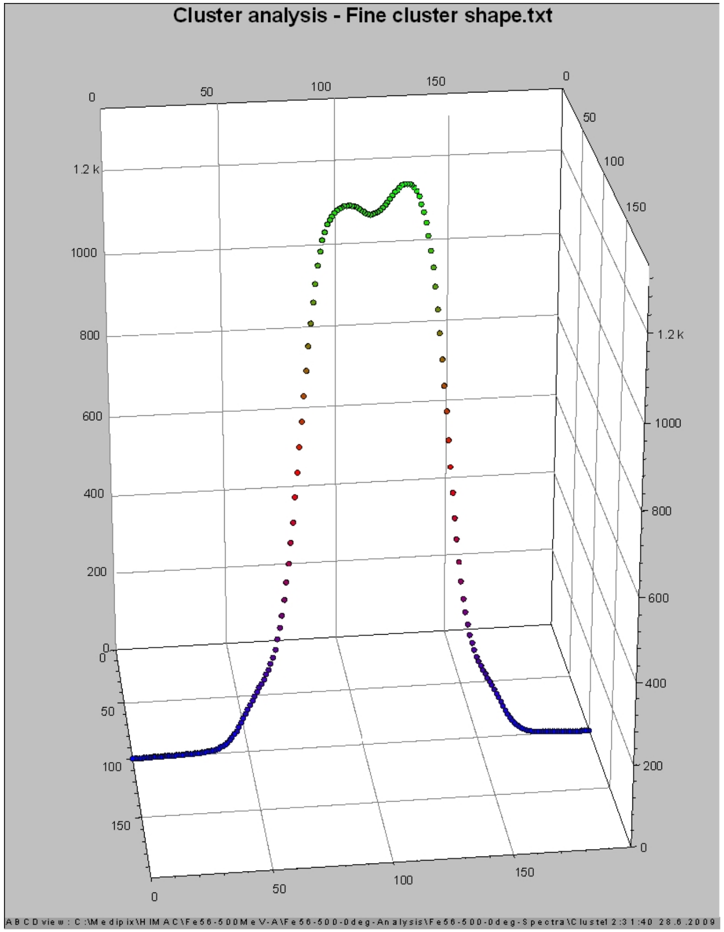
# Close Up of the "Partial" Event

- The right-hand event is a "normal" iron event, which does show a clear "Volcano" Effect.  The scale is so high that the $\delta$-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…

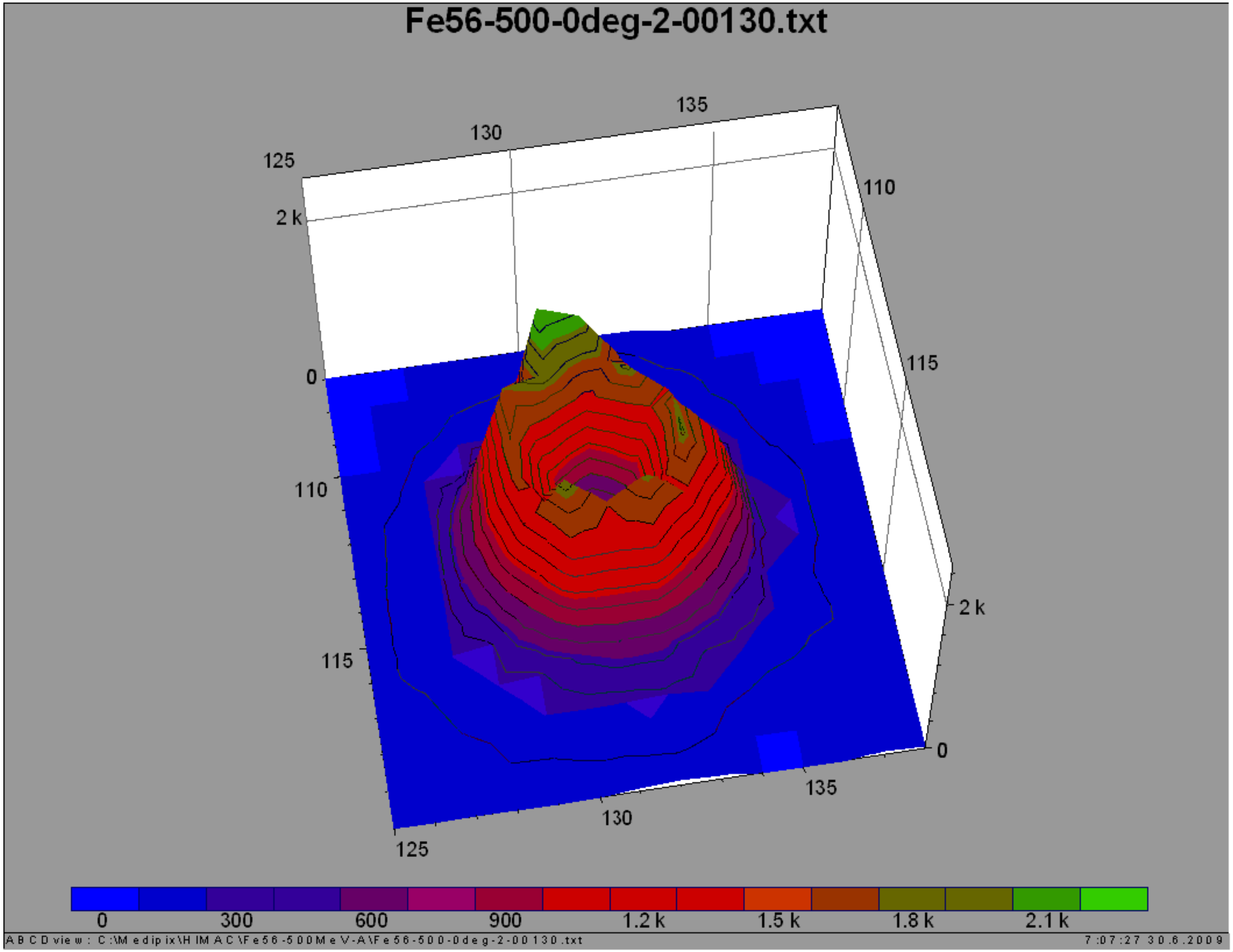


# $^{56}Fe$ @ 500 MeV/A

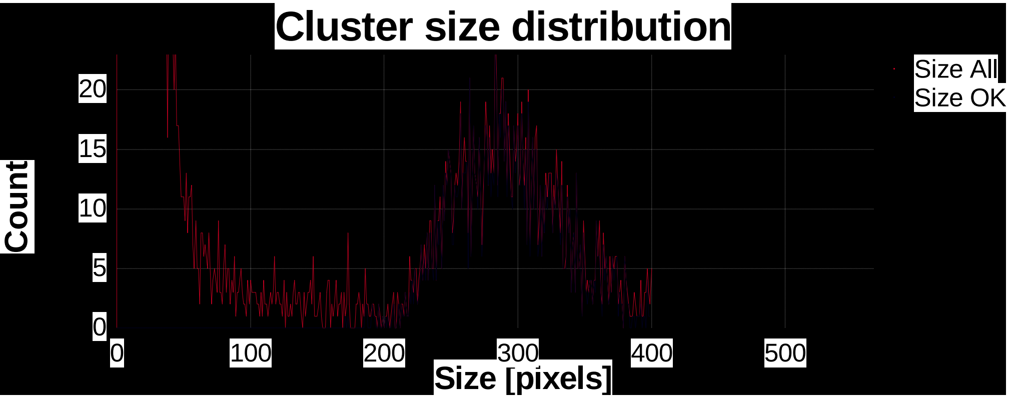


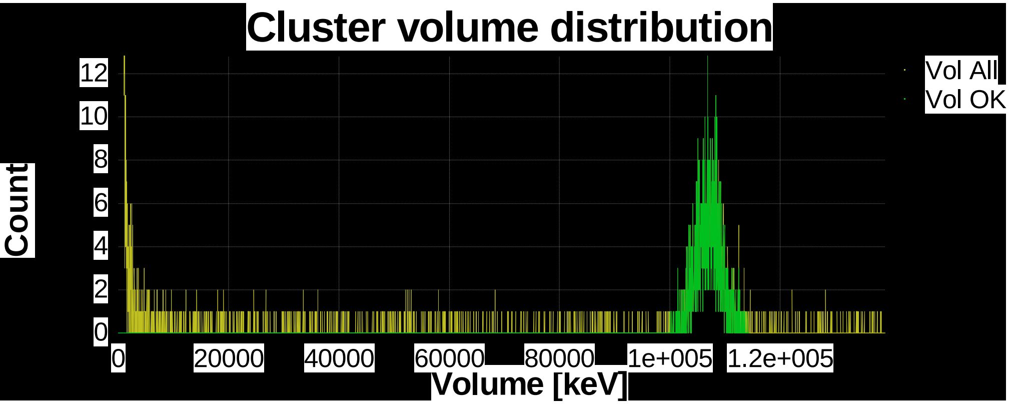



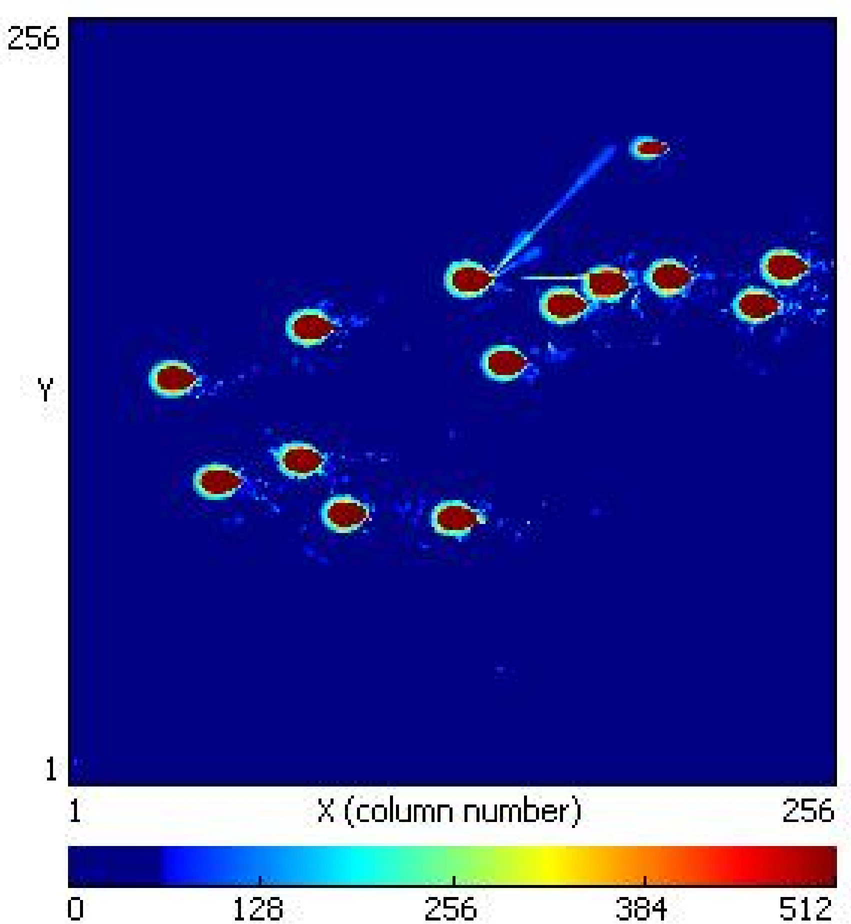
# Fe "Volcano" Event



# $^{56}Fe$ 60 degree Runs…

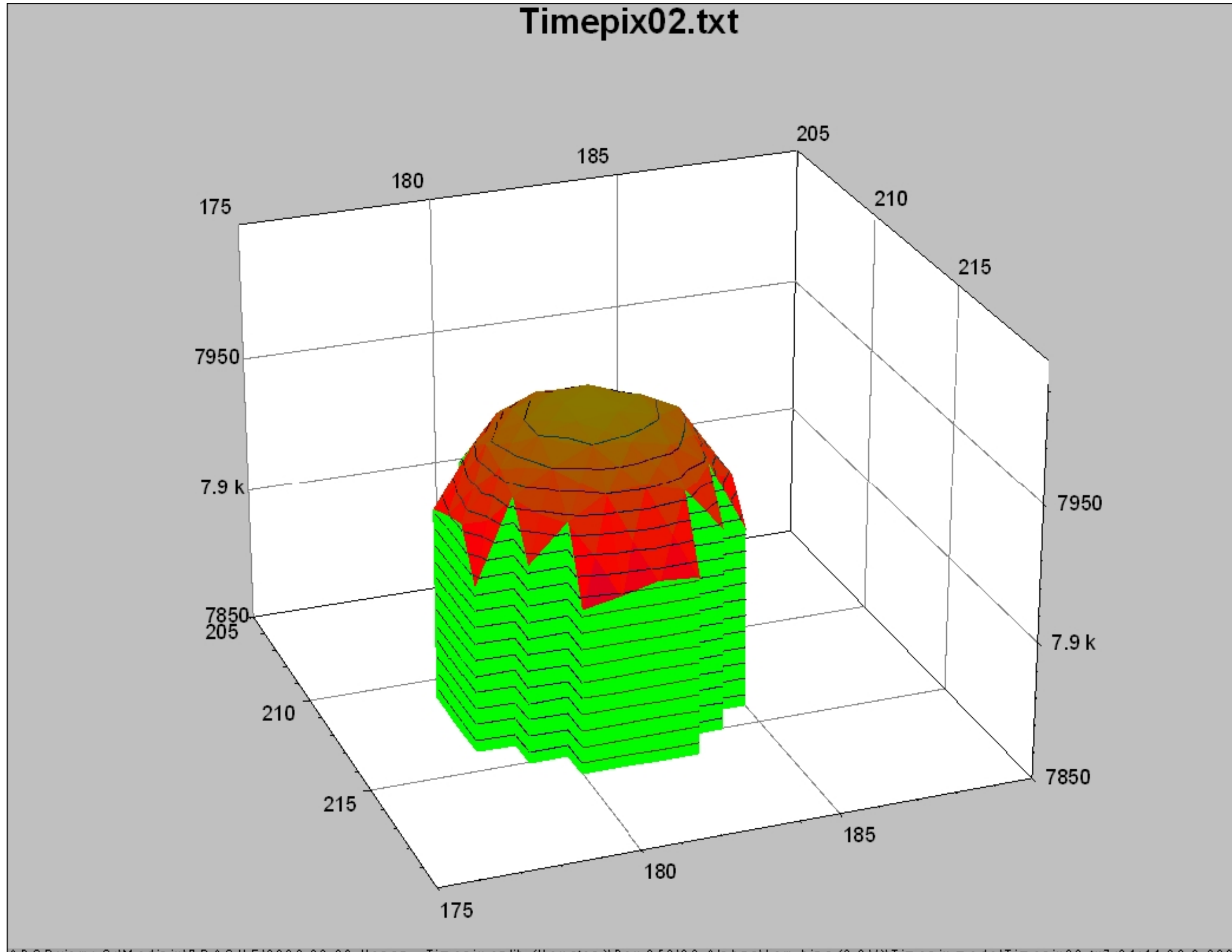


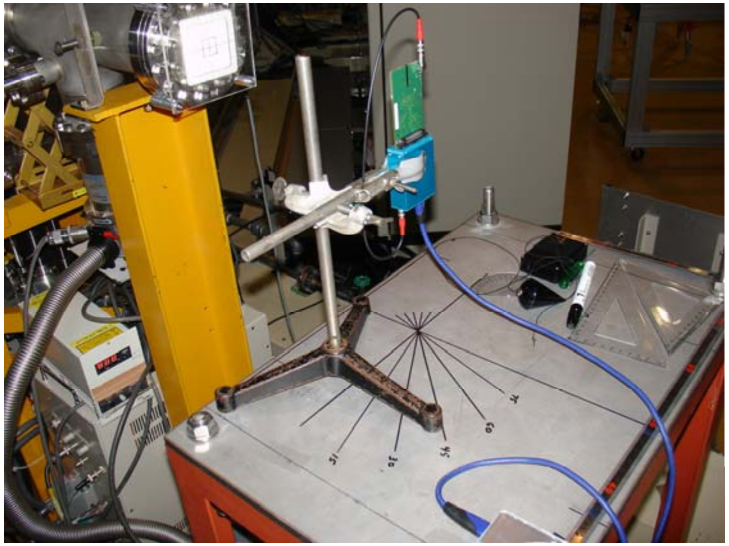
# Charge Drift Cloud Image ($^{241}$Am 5.5 MeV $\alpha$)

- ***Time of Arrival*** **image from a 5.5 MeV $\alpha$ from an $^{241}$Am decay.**
- **Common global threshold can be adjusted to get time (i.e. charge) contours through the drift cloud…**
- **(Single Event)**



# The Next Steps…

- We are starting a serious Monte Carlo (FLUKA) modeling effort to simulate the clusters from Heavy Ions..
- …And, we will also complete the measurement program at HIMAC… (Re-Do of the last runs NEXT WEEK—WITH reasonable bias voltages.
- Then we can simulate the Space Radiation TimePix response and develop the pattern recognition software needed for real-time dosimetry



# Thank You for Your Attention