The REM SDTO
First Use of Medipix in Space for Dosimetry and Space Radiation Measurements

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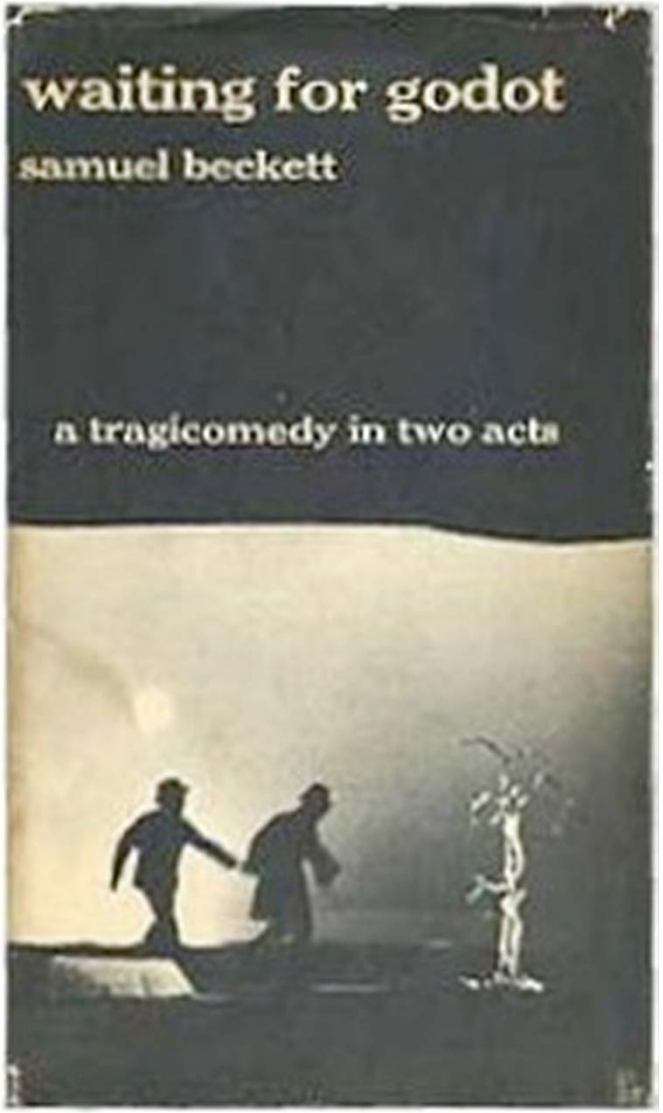
A. A. Bahadori, K. T. Lee, S. A. Wheeler, D. Turecek
S.Posposil, J. Jakubek, Z. Vykydal & J. Hauss

WRMISS – 2012 Austin, Texas
Pinsky – September 5, 2012.

OR…



- **August 2, Launched to ISS on Progress 48**
- **August 10, Scheduled for Deployment… (Postponed)**
- **August 20, Scheduled for Deployment… (Postponed)**
- **This Past Weekend Alerted for Deployment Support (No Deployment Yet)**

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[3] National Institute for Radiological Sciences, Chiba, Japan.
[4] @NASA/JSC, USA

Last year in Prague…

With Support From:

Michael Campbell, (Medipix Collaboration Spokesperson)

&

Ian McGill & Allan Honma, (CERN Bonding Lab)

The Medipix2 Consortium—CERN-Based

- 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, USA
- University of Houston, Houston, Texas USA

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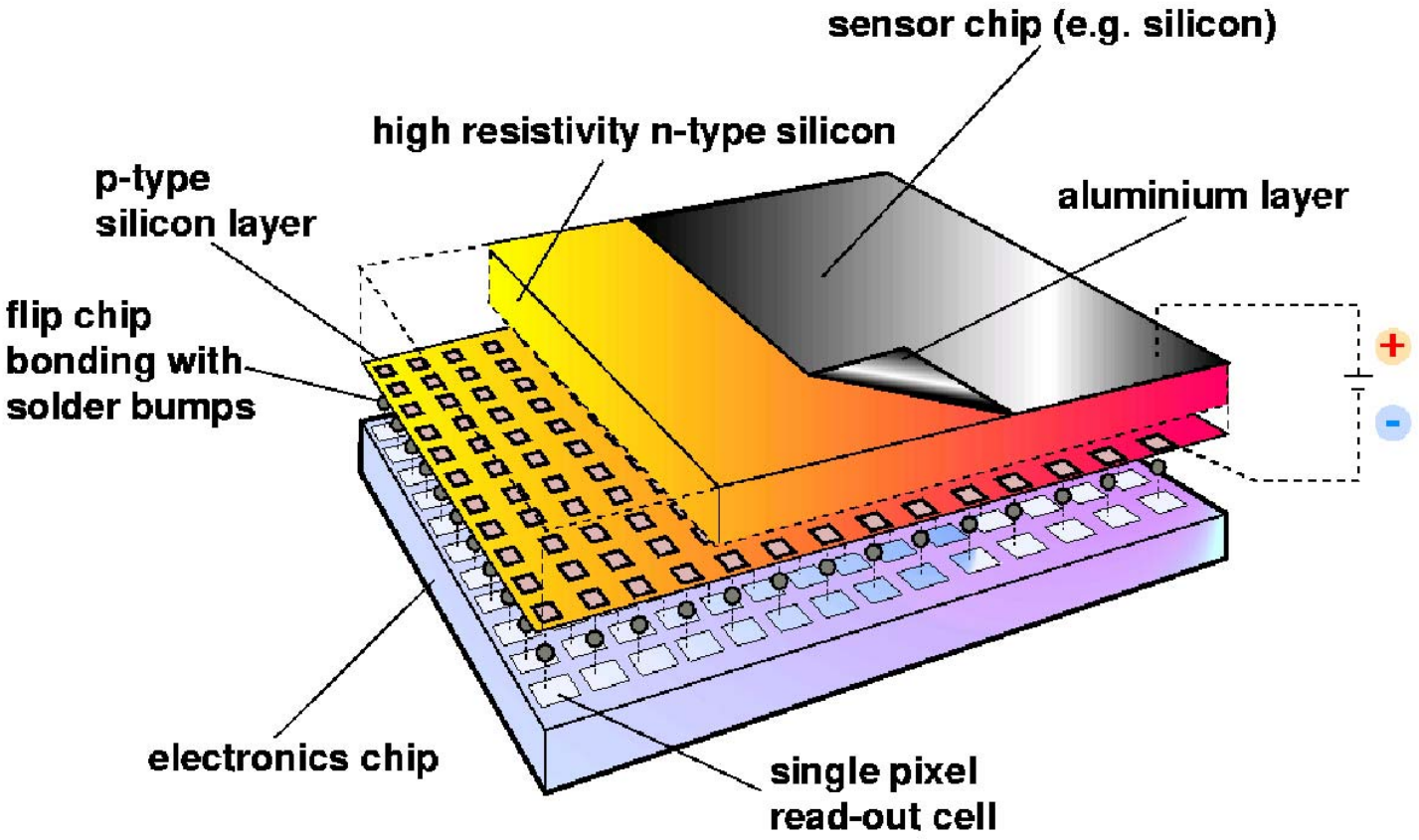
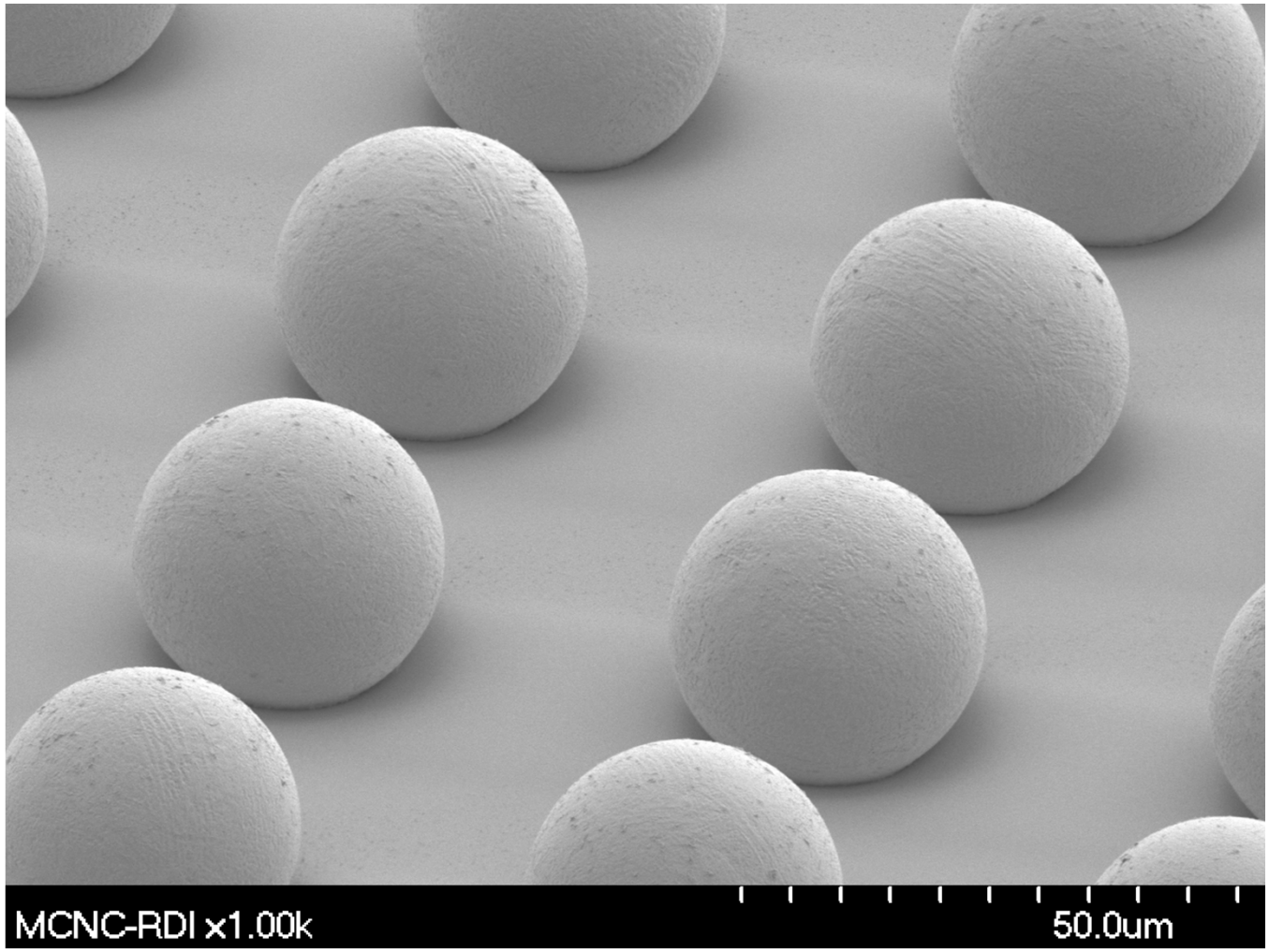
Medipix—A Hybrid Pixel Detector



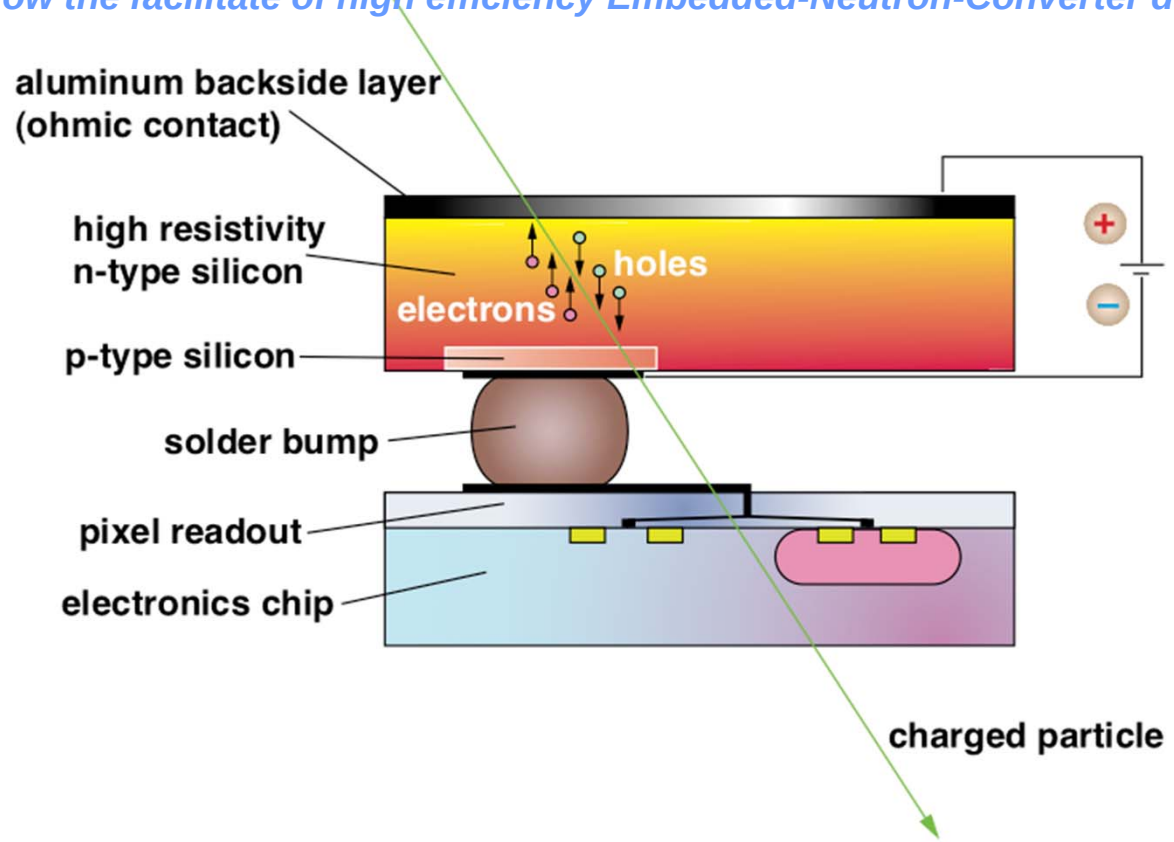
Detector and electronics readout are optimized separately

Bumps on the readout side – close up



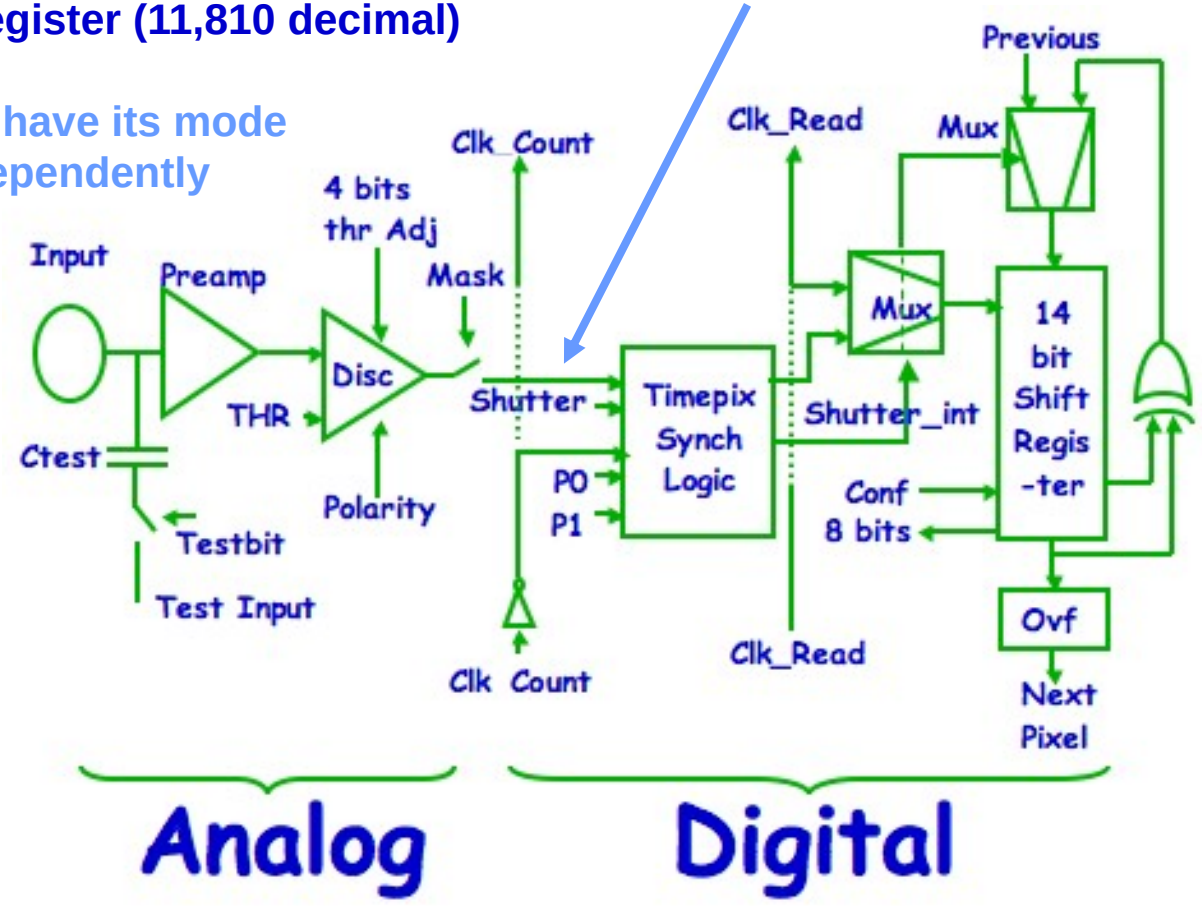
Hybrid Pixel Detector - Cross Section

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

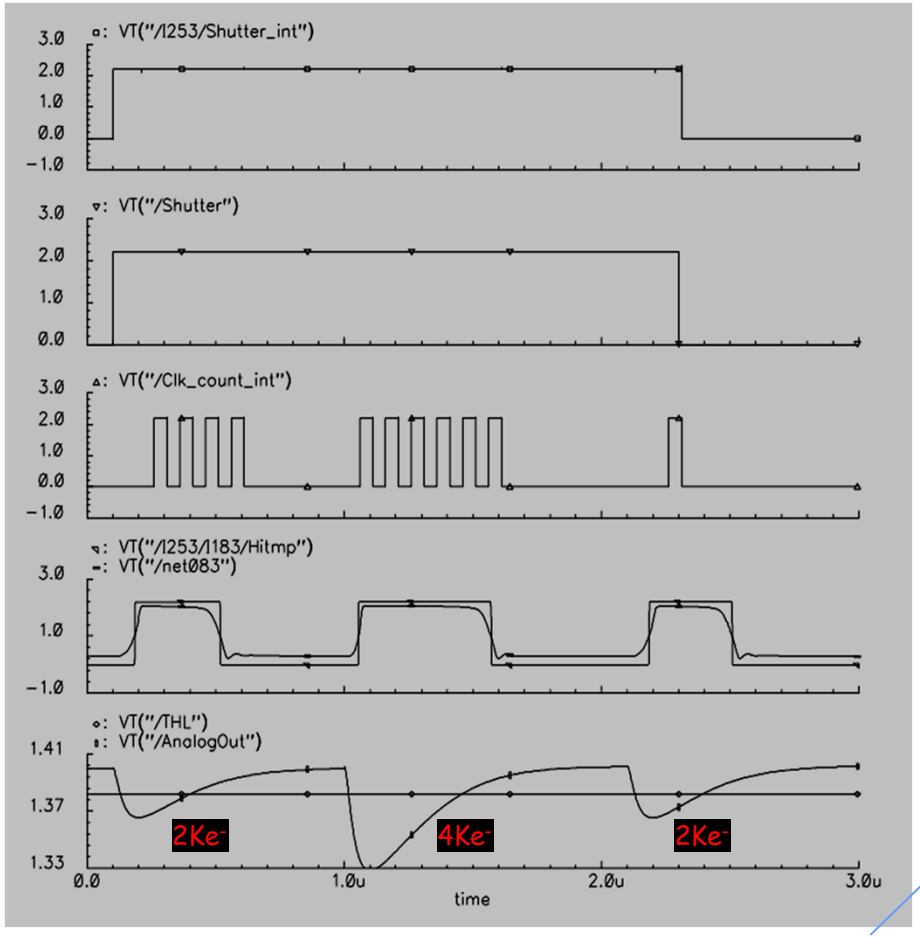


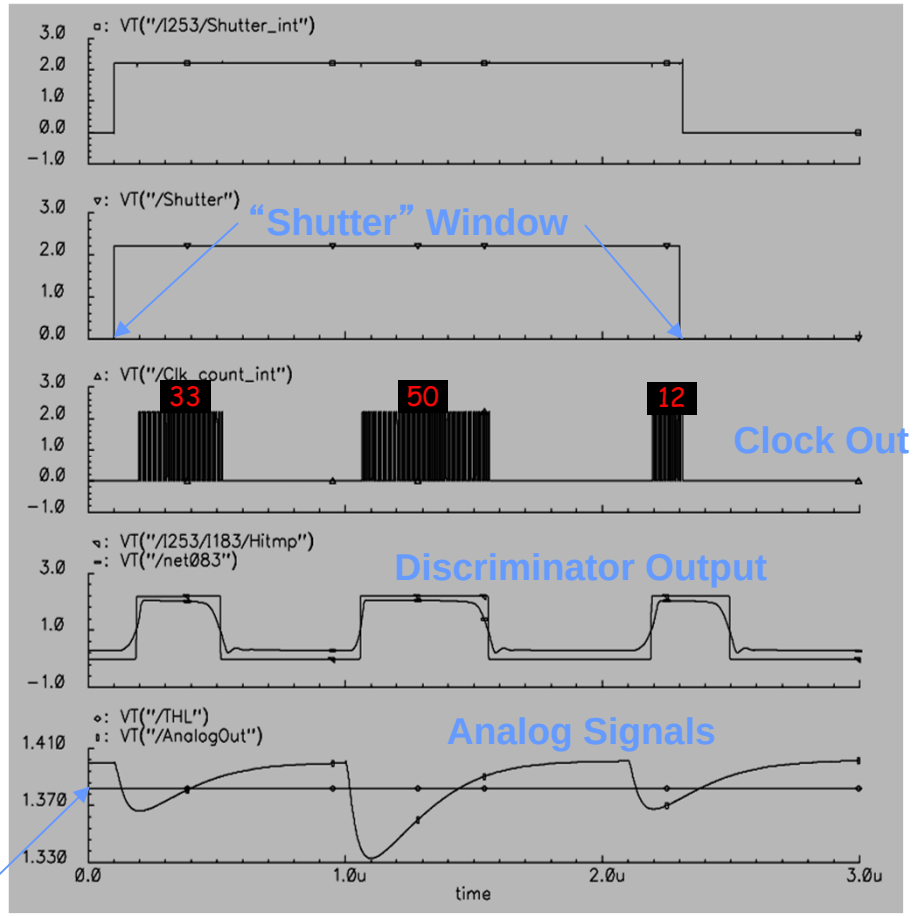
TimePix Version Logic Schematic

- **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**



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



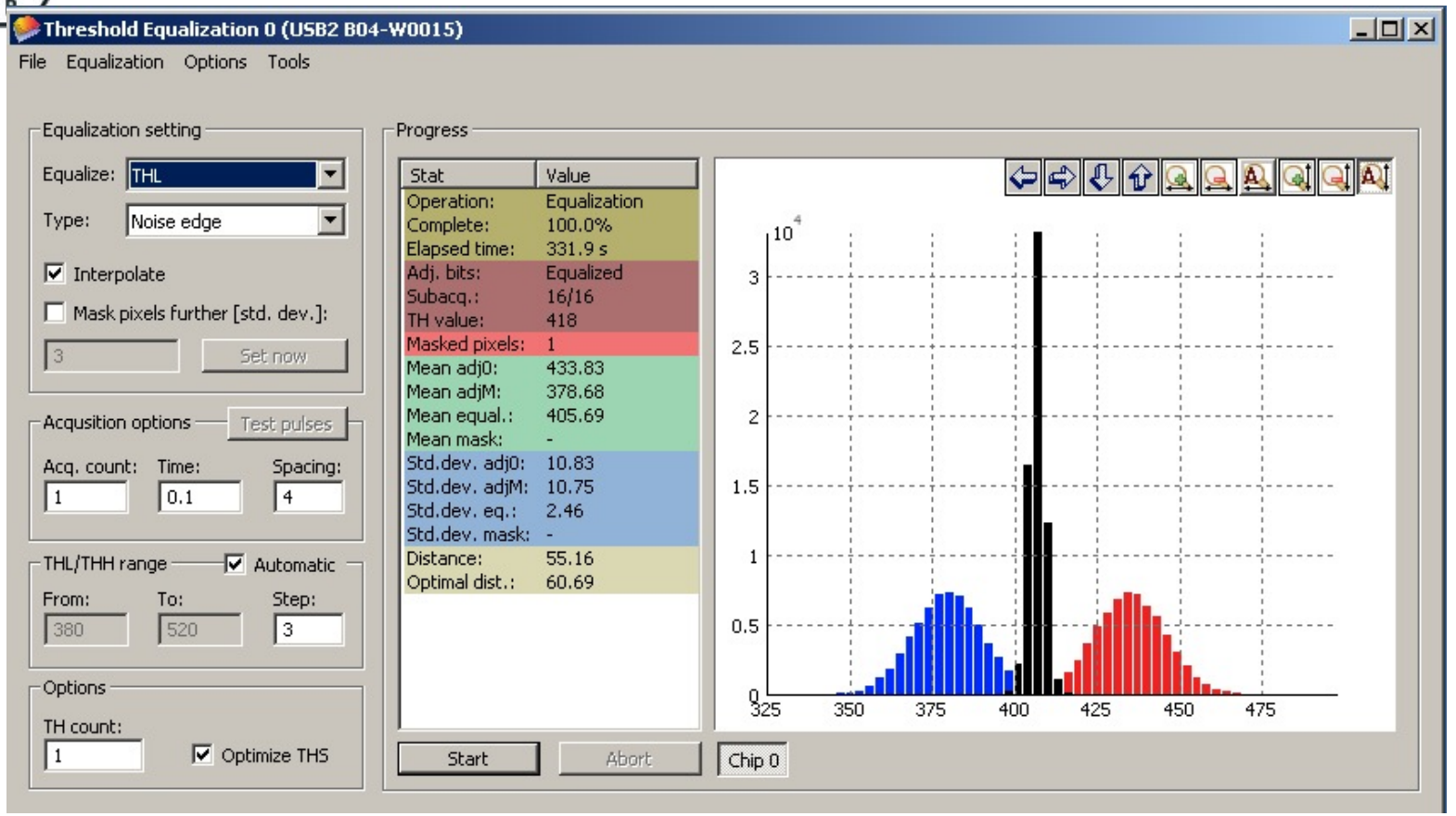


10MHz

Threshold

100MHz

TimePix Threshold Calibration

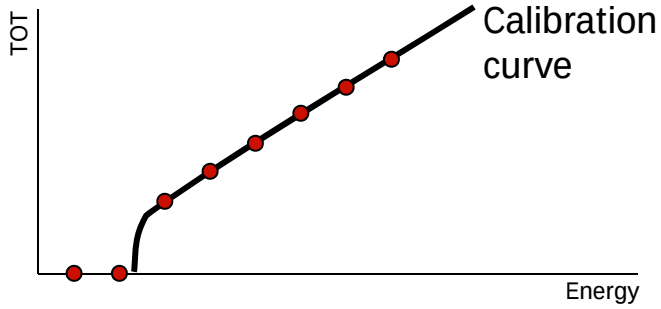


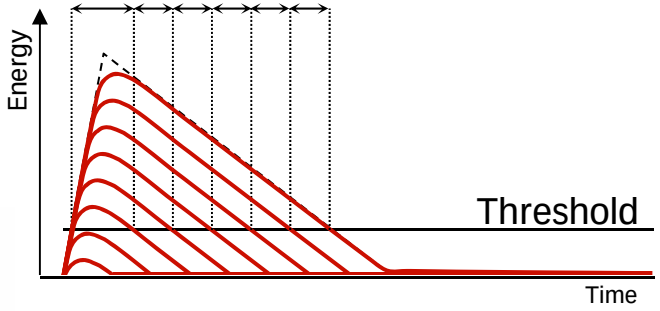
- **Calibrates the 4-bit (16 level) Threshold Offsets for each pixel. The RED histogram is the distribution of noise turn-on points with all bits set to high. The BLUE histogram is the corresponding low setting. The BLACK histogram is the corrected result. Each channel is ~20 e^-…**

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**

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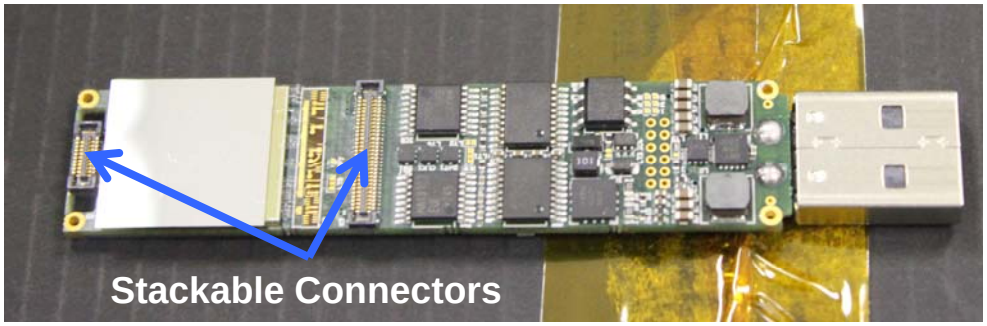
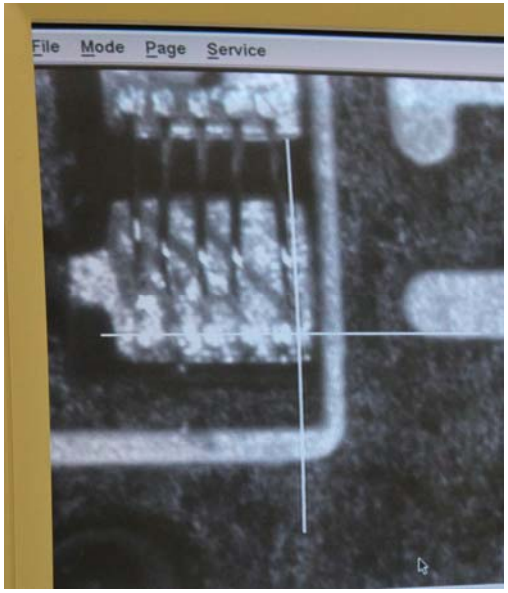
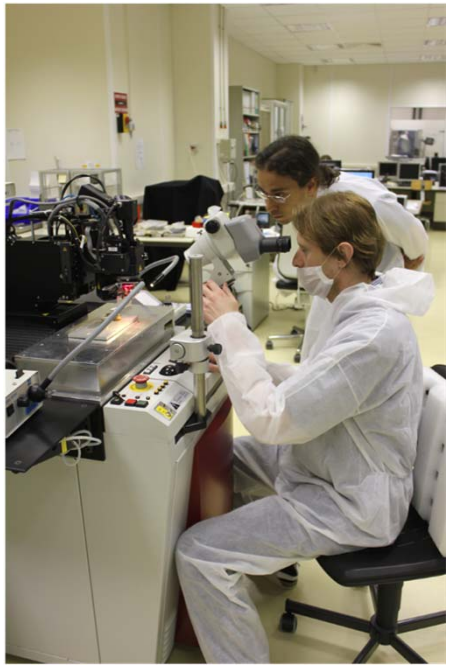
Development of Flight Hardware & Software for NASA @ IEAP, CERN & UH

- **IEAP**
  - Designed USB Lite Interface…
  - Calibrated Flight Units…
  - Provided the Core Flight Software…
- **CERN**
  - Medipix2 Collaboration Provided Timepix Detector Assemblies…
  - CERN Bond-Lab attached the Detector Assemblies to USB Boards.
- **UH**
  - Managed Overall Project…
  - Develop Analysis Software and Flight Software Algorithms…
  - Conformal Coating…







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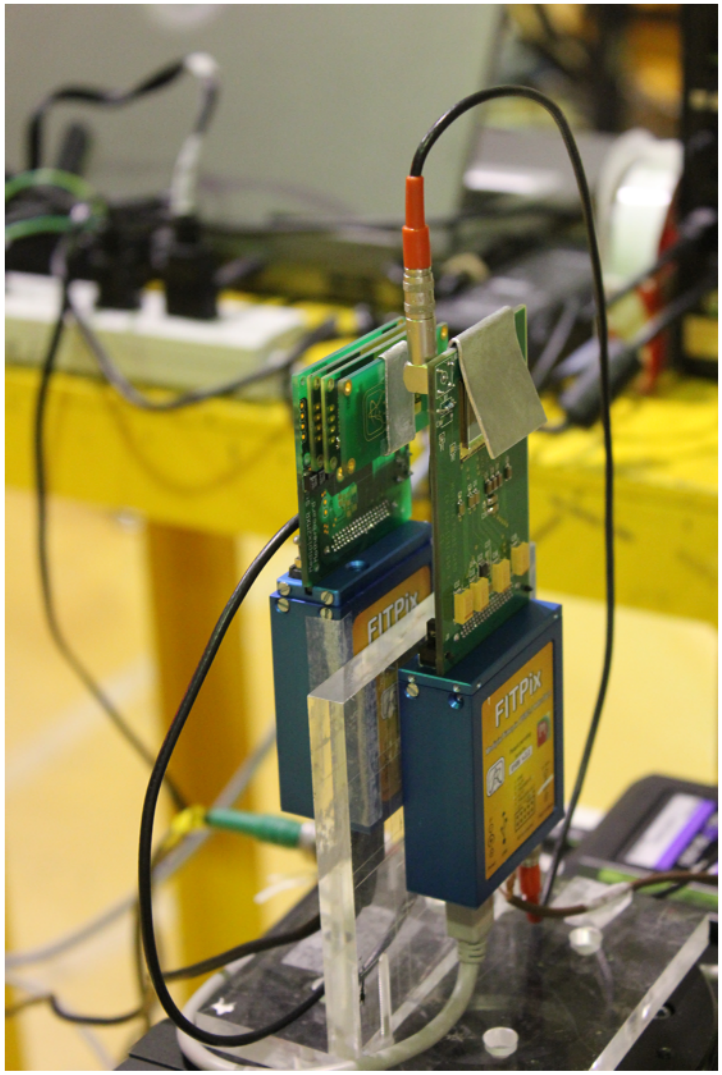
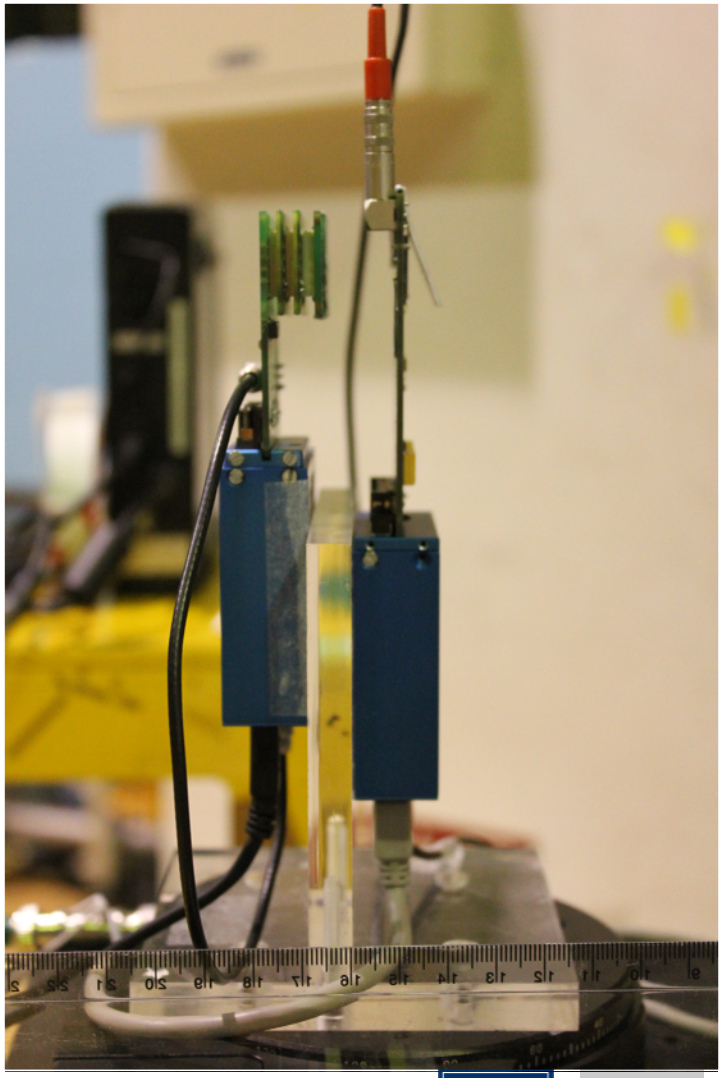
Radiation Environment Monitor ("REM")
NASA ISS SDTO Flight Hardware!

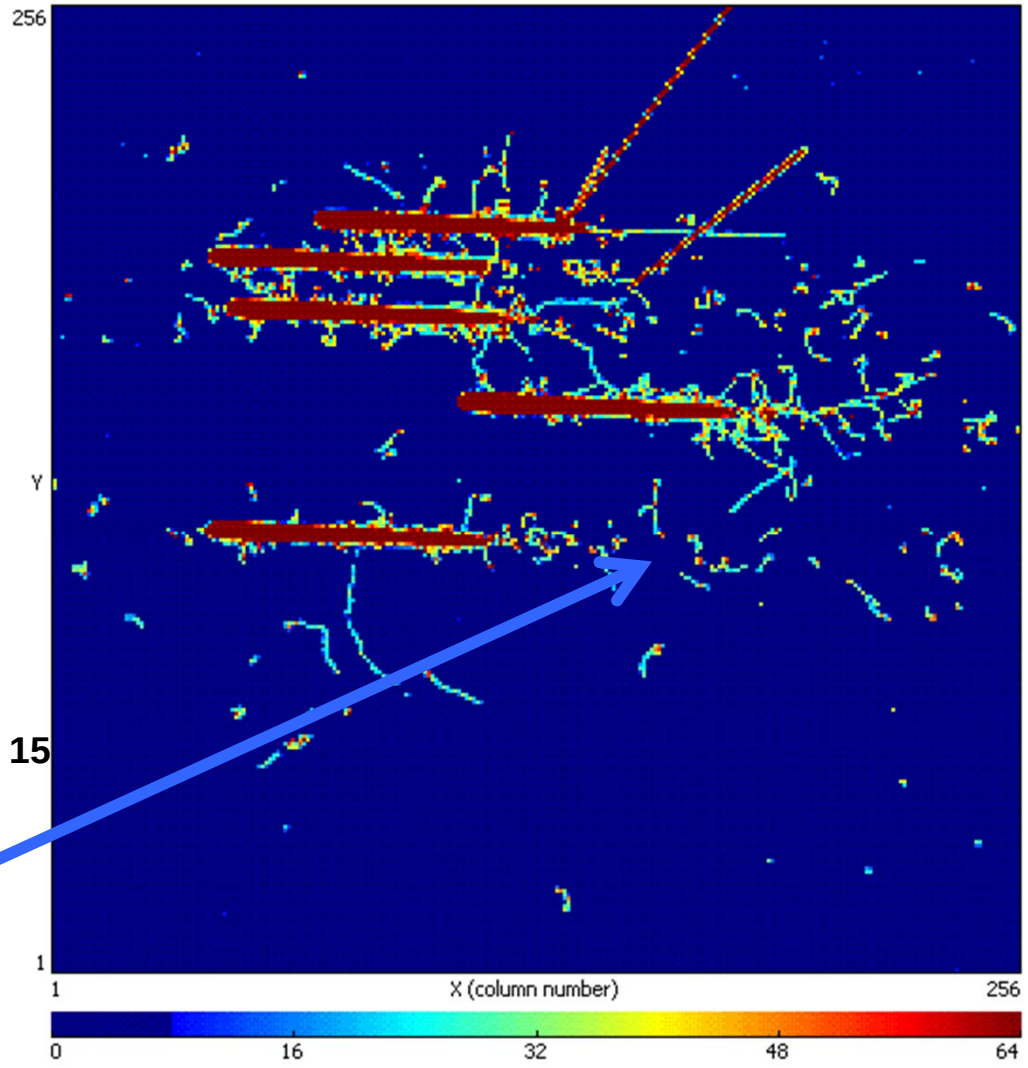
Each USB Interface Can Support Up To 4 Detectors, Enabling Stacks





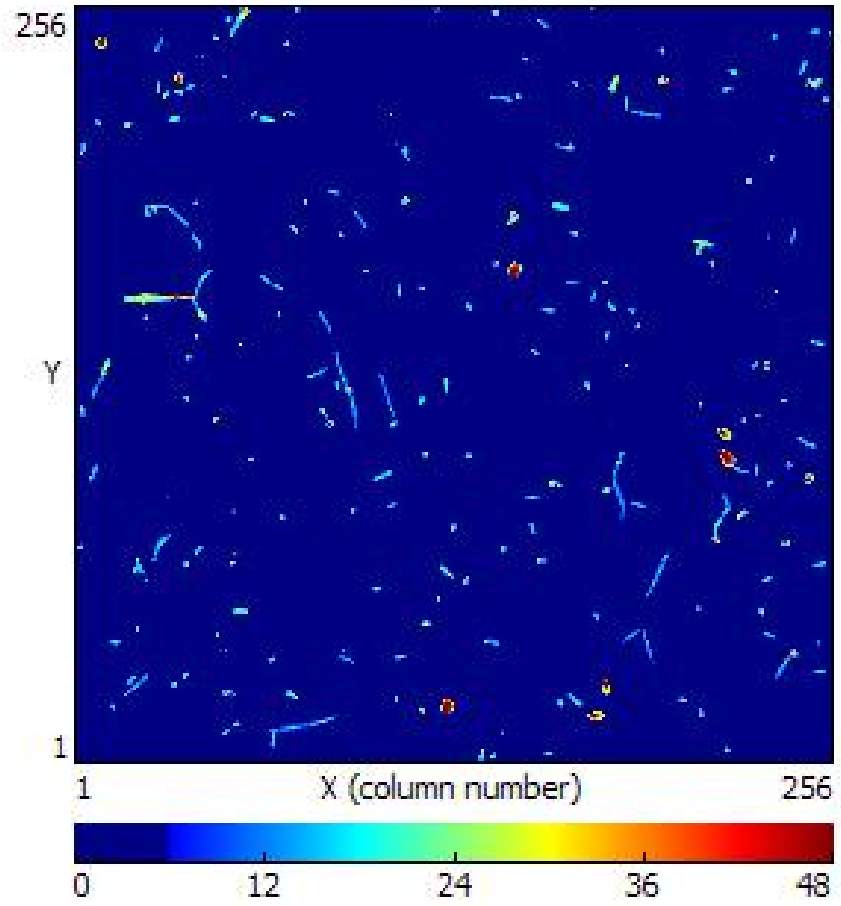
800 MeV/A Si 85 degree Tracks

- 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…

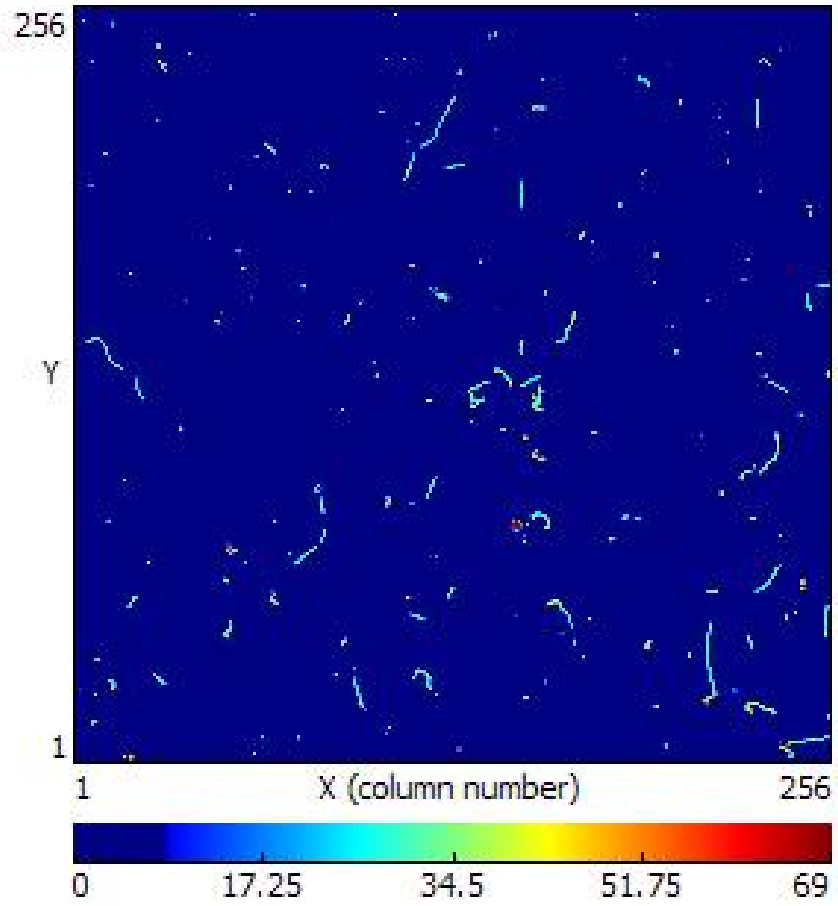


"Film-Badge" Equivalent Dosimetry

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

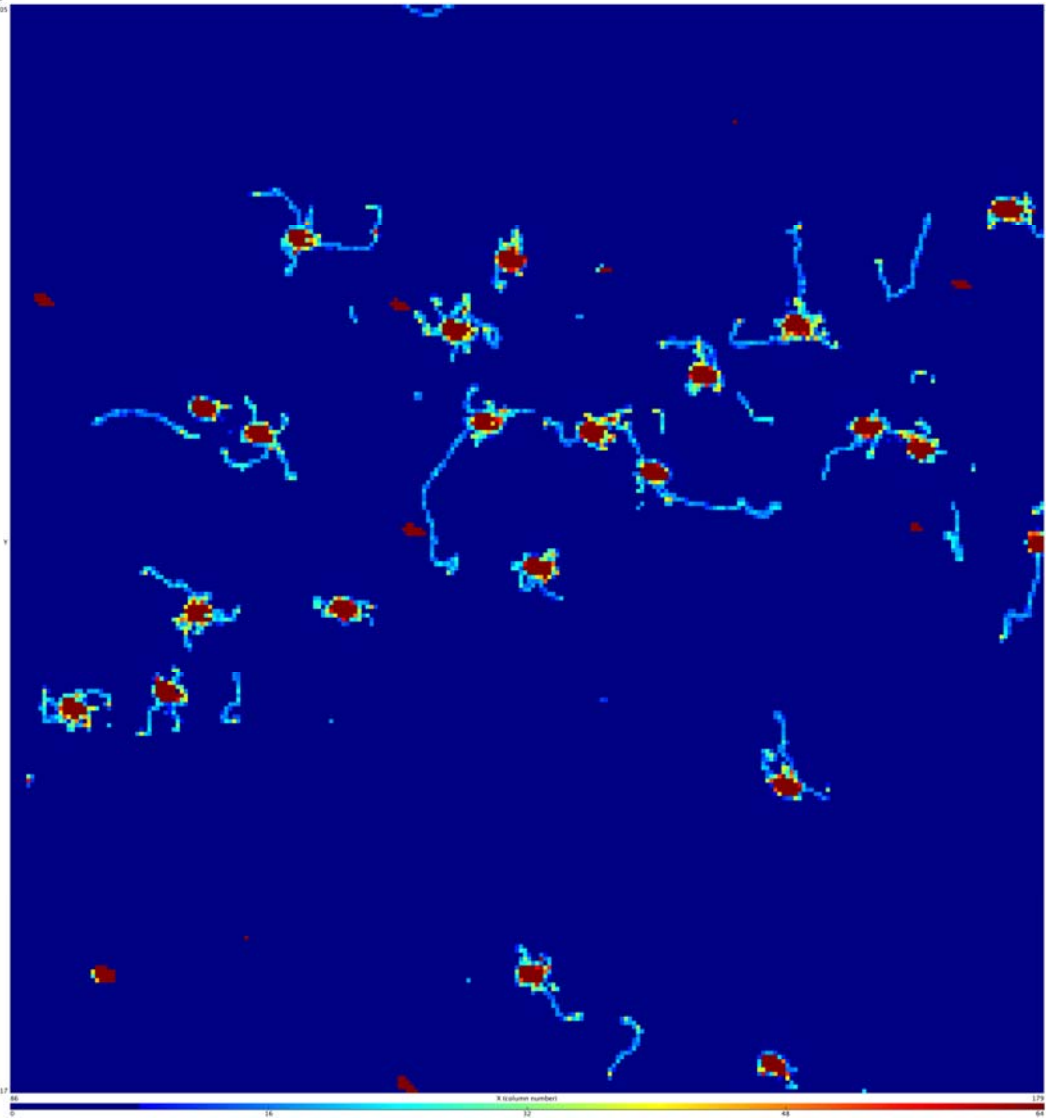


***1000 Sec* in my office in Houston**



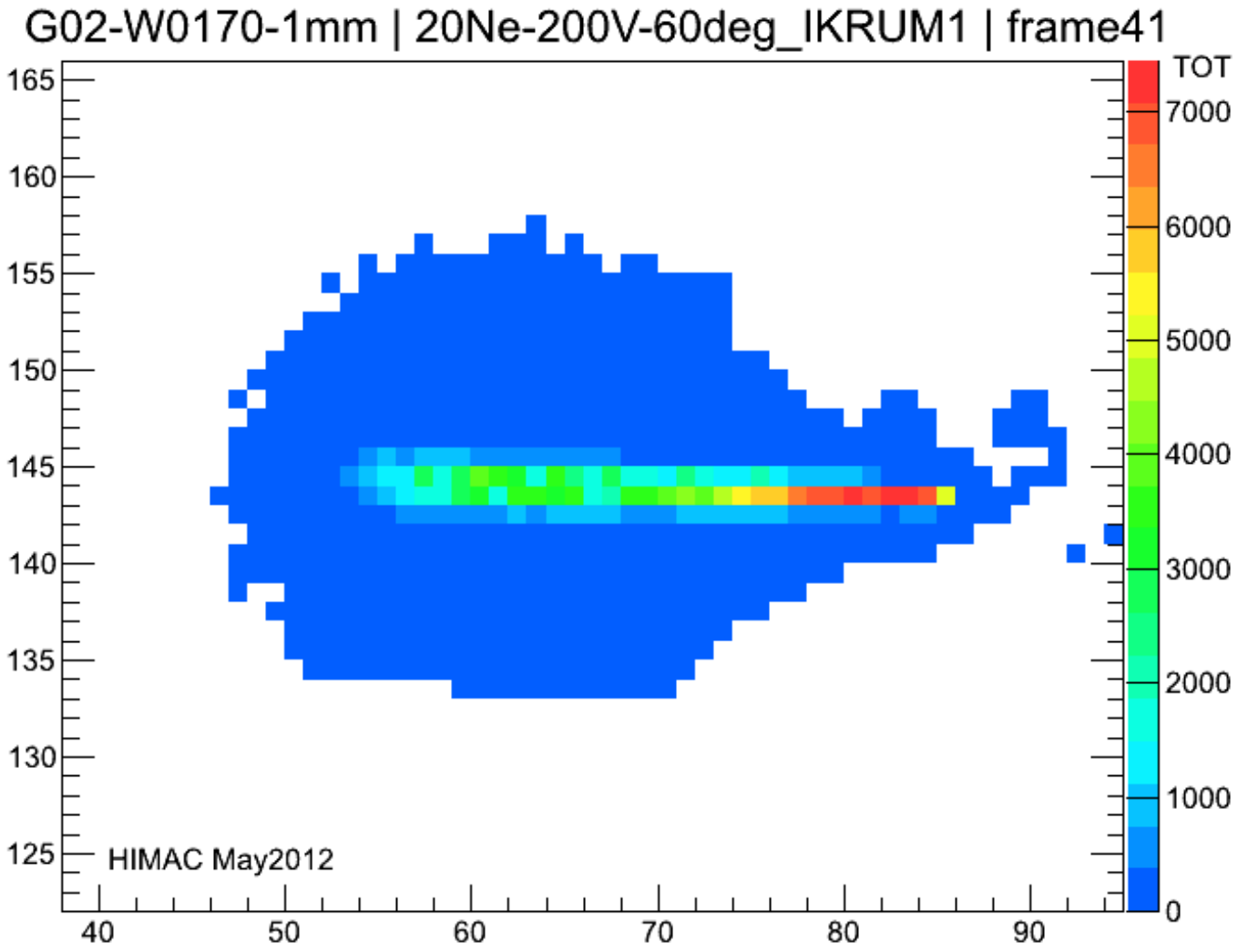
This in flight Dose Rate is 50 to 100 times that in my office…

^{20}Ne @ 600 MeV/A & 15° w/ IKRUM = 5



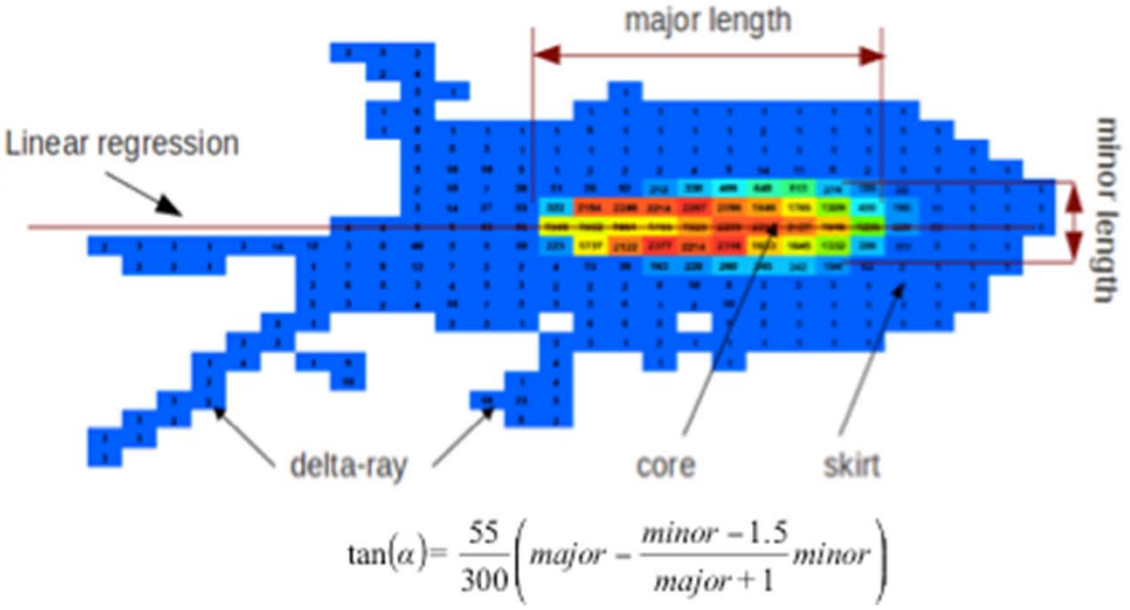
- Note that even at an IKRUM of 5 there are "Ghost" tracks…
- Note also that the "Normal" Tracks ALL have clearly visible δ-rays…
- Also the asymmetry of the cluster is clearly pronounced at 15 degrees from normal incidence…

^{20}Ne at 600 MeV/A Drift Image



Determining the Projected Track Length

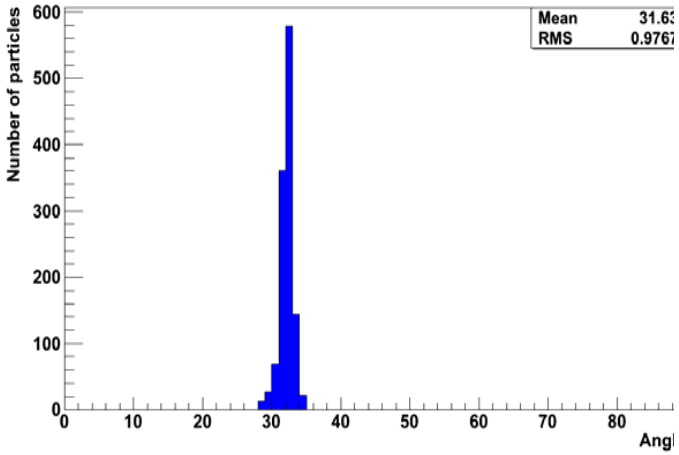
- In order to determine the LET that a particle had from its track image, we need to estimate the projected track length. We know the thickness of the sensor and we can measure the energy loss by summing the pixels in the cluster…
- The method chose for real-time processing is to do a selective subtraction of pixels to determine the "core" length and "skirt" width. An empirically-based algorithm has bee developed using a wide variety of beams and energies at the HIMAC facility in Japan.



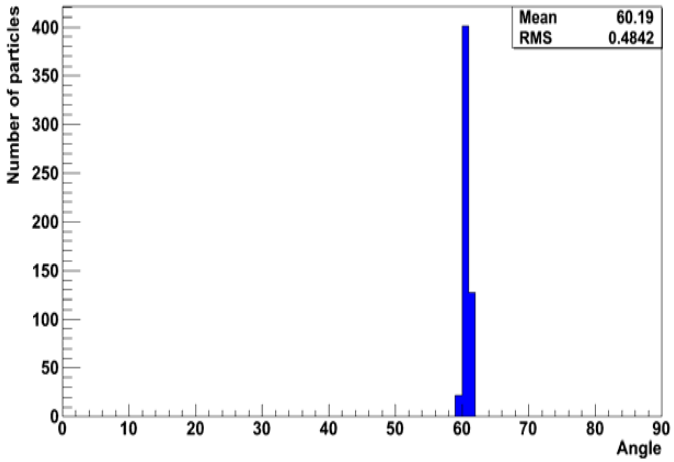
$$\tan(\alpha) = \frac{55}{300}\left(major - \frac{minor - 1.5}{major + 1} minor\right)$$

Real-Time Angular Resolution

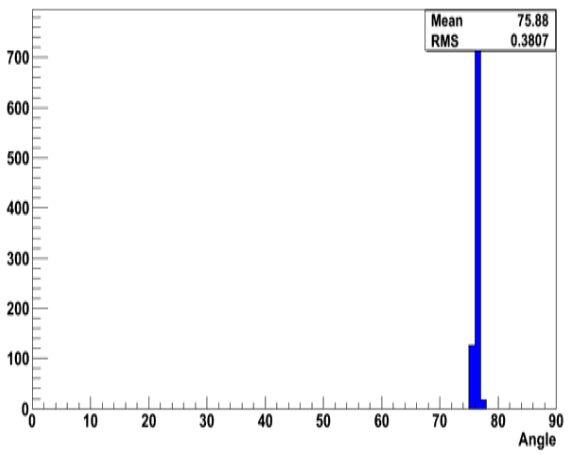
- The algorithm described on the previous slide has a reasonable resolution for angles above 15° with a 300μm thick sensor as Thicker sensors (500 μm to 1 mm) have good angular resolutions down to < 5° , and the error introduced to the LET estimate are still dominated by the Landau fluctuations. The figures below are for 160 MeV/A He with 1 mm sensors…
- For ground-based analysis a global cluster-fitting routine is under development and offers even better resolution…



30°



60°



75°

f,#" *%7#+*%%$L' ,)+D"

- HB+' " #F4#$<%%. ^B(+(%%4_B)()F' /%" *%' %#.)#F' /%' /.)F' /(
- H$L' ,)+D" %*4). *(%%44' ,.)/L%' %*3*,#$%,)+*,)#%[(B- c,' BF/*(\X
  - :)2*$%' B/+
  - &*$+#%1)2*$%' B/+%[%,#" *(\
  - :)2*$%' $B" *
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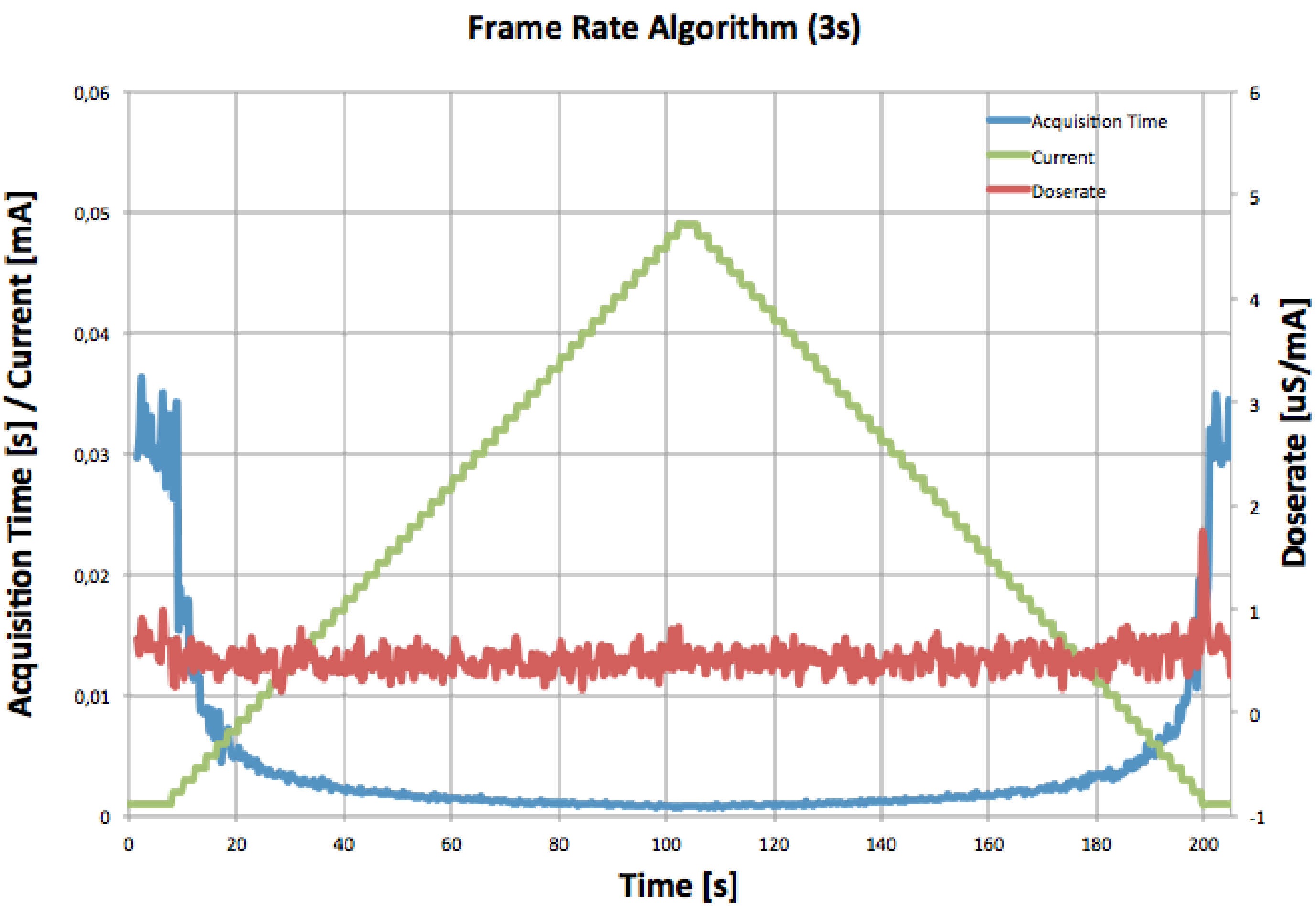
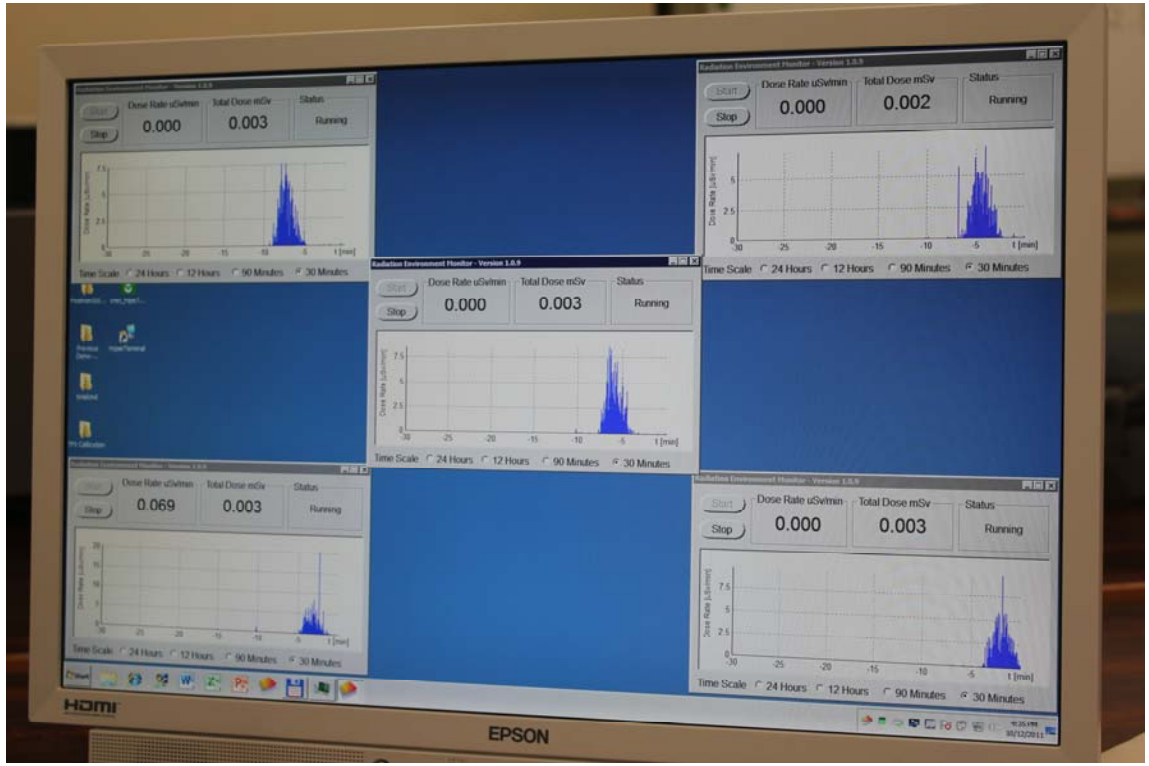
  - l $B(+*,%<1*
  - px%a,).
- G#4D%(B- c,' BF/*%/. %$%1#,#" *+*,(%,*%' /VLB,#- $*%,' " %%$*

fTH%0*(F/L%9)+D%þcT#<%4B-*

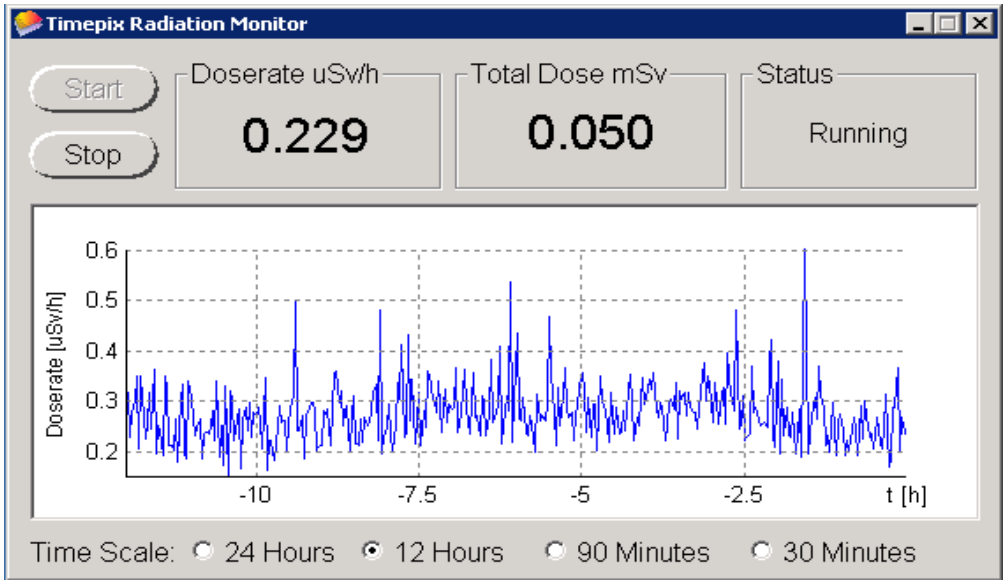


Simulating an SAA Pass with the Flight Units @ HIMAC



Five Flight Units were translated laterally through the beam while running the Flight Software. The display above contains the Flight interface for each unit.

Flight Software



Daniel Turecek, IEAP… with routines supplied by UH Graduate Students: Nic Stoffle (Physics) and Son Minh Hoang (Computer Science)…

- **Automatic frame integration time adjustment…**
- **Cluster-Finder…**
- **Track-Projection length estimator (needed to Calculate LET)…**
- **LET Calculator…**
- **Robust SEE and SEU recovery capability…**
- **Daily raw data downloads…**
- **Accessible input parameter file…**

Ground-Based Software

- To be ROOT-Based
- Initial versions are operational, but need concatenation…
- General Data & Software Repository at UH…
- CERN/LHC-based Analysis Procedure
  - Raw => DST => AOD
  - Standard Routines to produce DST and "Filters" to AODs…

- Standard Routines
  - Cluster Finder
  - Cluster Dis-Ambiguity
  - Cluster Angle Finder
  - Cluster Energy Total
  - Cluster δ-Ray Evaluation
  - LET Determination
  - Q-Factor Estimator
  - Dose Endpoint Estimators…

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…AND, This is Where They Are NOW!

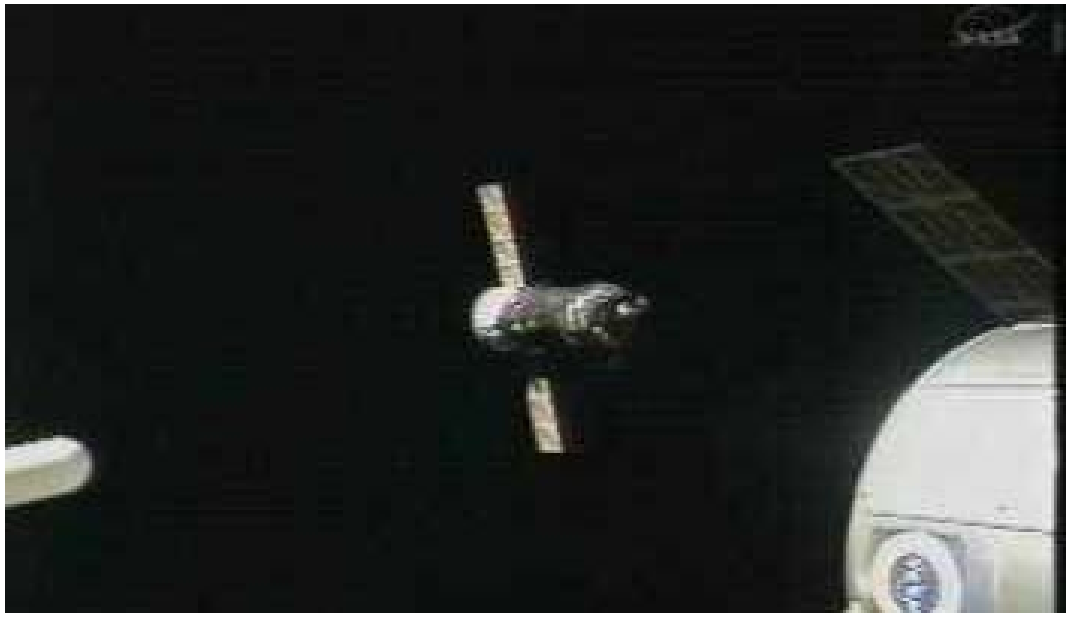
S114E7221

Progress 48 Being Assembled

Progress 48 On the Launch Pad in Baikonur

Progress 48 Liftoff…
August 2, 2012

…And, Same Day Arrival at the ISS (August 2)



Long Term Goals for Medipix in Space

- **We plan to use the SDTO to obtain experience with the current Timepix technology in space…**
  - **Both with the current USB interface where power and connectivity are available…**
  - **And, a stand-alone, battery-powered, wireless version in order to influence the design of a low-power (probably dedicated) Medipix3-based device…**
- **…With the ultimate goal of having several types of Medipix-based devices with both charged particle and neutron capability deployed operationally…**
  - **A stand-alone battery-powered, wireless personal dosimeter with local readout, and alarm capability, along with a ~30-day battery life and the size of a typical current smart-phone.**
  - **In-suit EVA radiation monitors coupled to existing spacesuit built-in power and data interfaces.**
  - **Wireless & wired area monitors for use in spacecraft and Planetary and Lunar habitats…**

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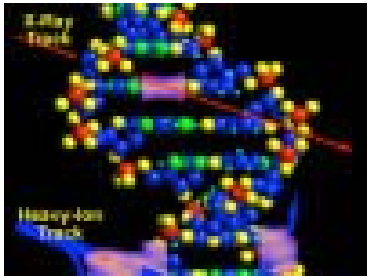
Thank You for Your Attention

Ongoing Development Projects: NASA Advanced Exploration Systems

AES Crew Systems Project:



Radiation Protection:

This project is developing radiation shielding, radiation analysis tools, and advanced dosimetry sensors to protect the crew against the harmful effects of space radiation.

Approval to fly on ETF-1 has been obtained and 2 Timepix units are planned to fly inside the First Test Flight of the new US Manned Orion Module

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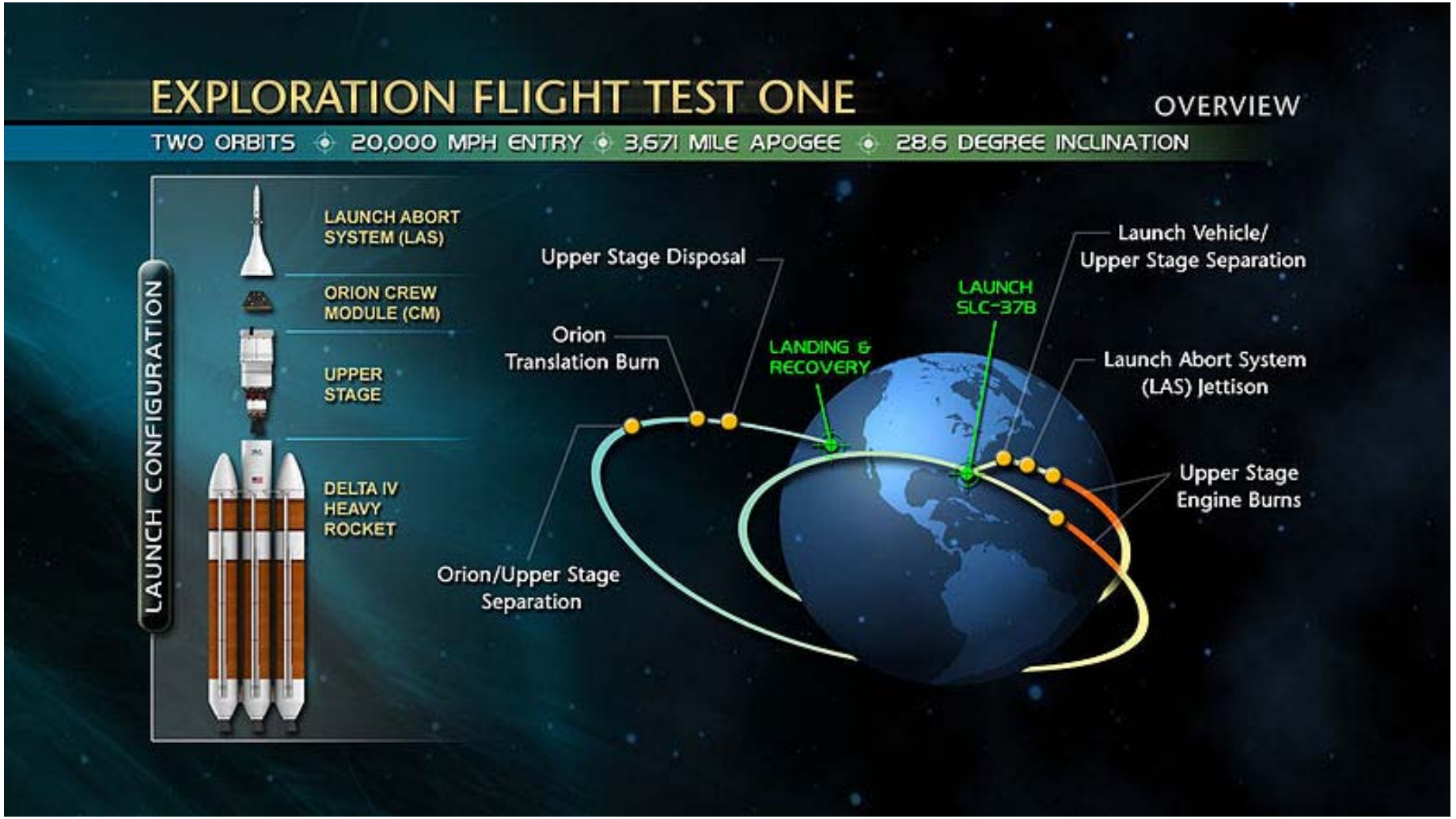
EFT-1

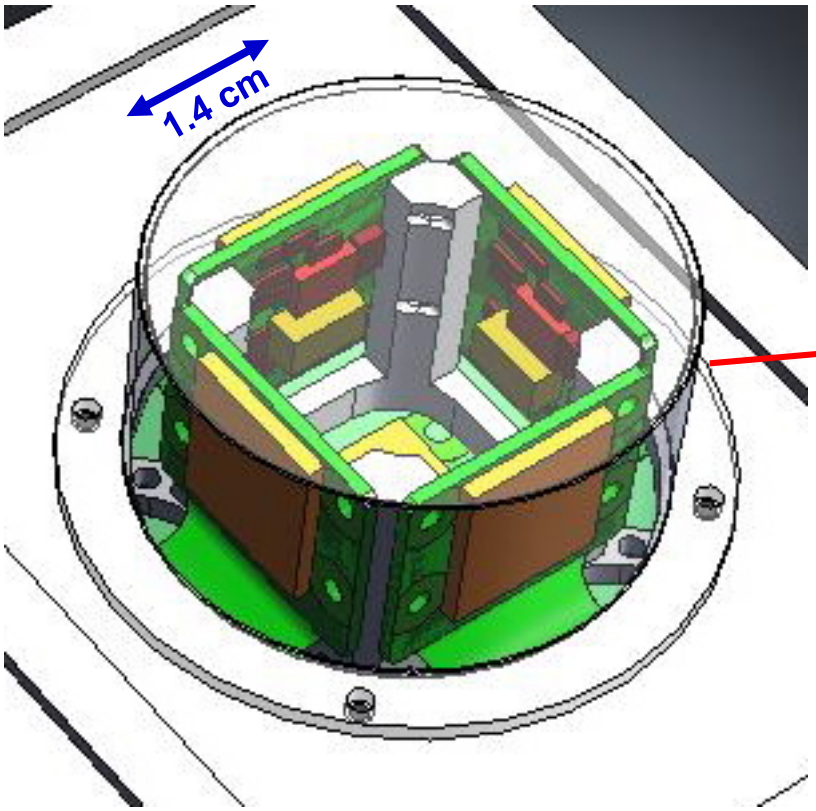

EXPLORATION FLIGHT TEST ONE
OVERVIEW
TWO ORBITS ◆ 20,000 MPH ENTRY ◆ 3,671 MILE APOGEE ◆ 28.6 DEGREE INCLINATION
LAUNCH CONFIGURATION
LAUNCH ABORT SYSTEM (LAS)
ORION CREW MODULE (CM)
UPPER STAGE
DELTA IV HEAVY ROCKET
Upper Stage Disposal
Orion Translation Burn
LANDING & RECOVERY
LAUNCH SLC-37B
Launch Vehicle/ Upper Stage Separation
Launch Abort System (LAS) Jettison
Upper Stage Engine Burns
Orion/Upper Stage Separation

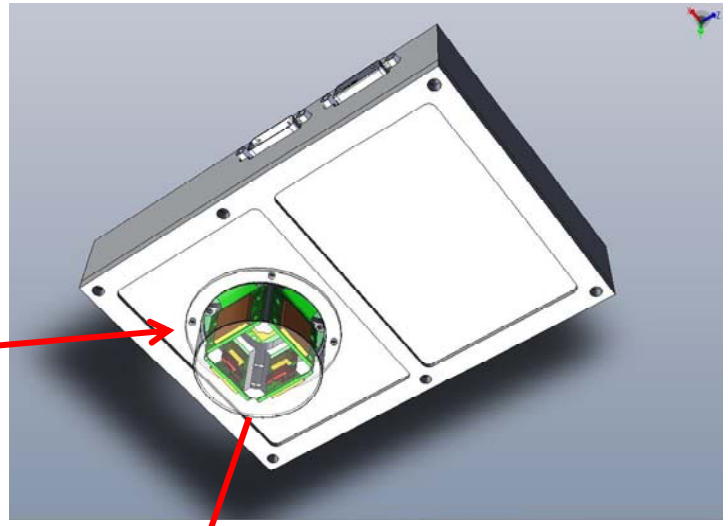
…AND in Habitats…

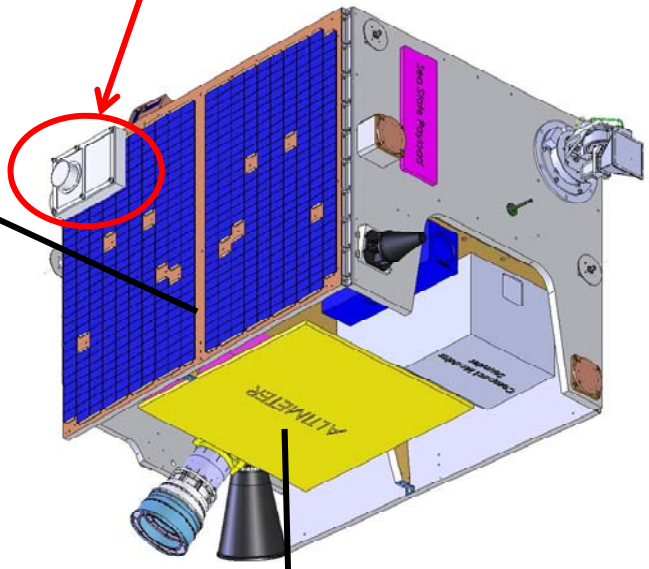
- **Bigelow Aerospace, a US Private Company is planning to deploy an "Inflatable" Habitat Module attached to the ISS, and NASA will evaluate its suitability for long term space and surface habitat technology… Current plans are to do radiation measurements existing Medipix technology (Laptops and USB interfaces)**

LUCID – *Langton* Ultimate Cosmic ray Intensity Detector

TimePix's First Space Mission—Educational Outreach (UK Satellite "TechDemo-1" to be Launched Q1—2013)



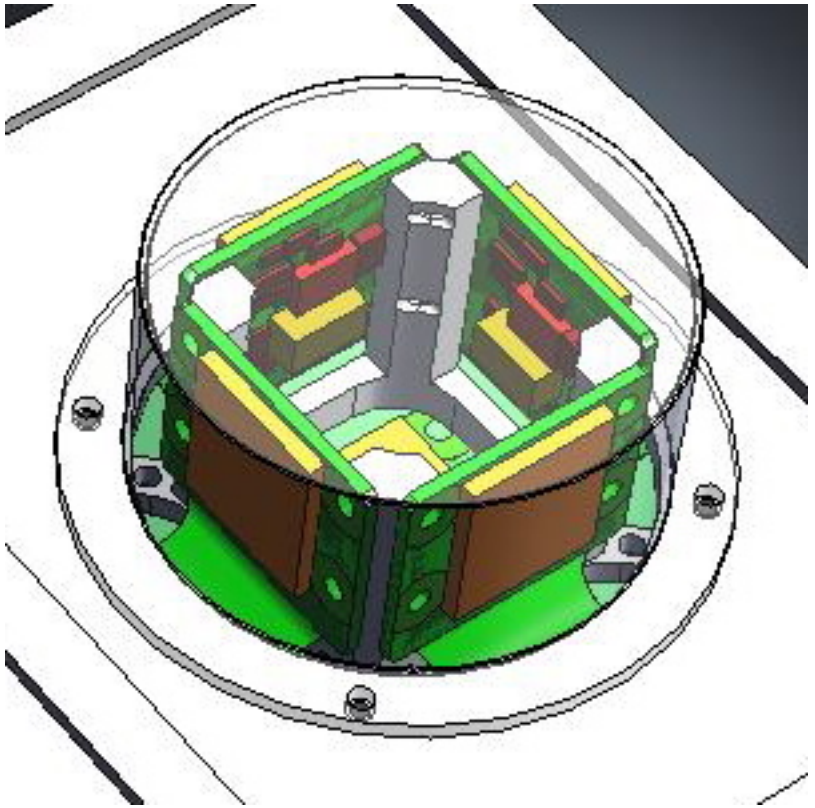




- 5 TimePix Detectors (0.7 mm Al dome)
- Sun-Synchronous Polar Orbit (98° @ 11:00)
- Programmable Signal Processor for on-orbit data analysis…

LUCID

- **Educational Outreach**
  - **PI is Becky Parker from the Langton School in Canterbury, UK.**
  - **Data will be available in Daily downloads to High School groups worldwide via the Web…**
  - **Online analysis tools will be provided…**
  - **Correlations with surface Cosmic Ray Detectors deployed in schools worldwide is possible…**
- **CERN@School**
  - **TimePix kits are being provided for laboratory use.**



LUCID is Planned to be Launched by an Indian Launch Vehicle

- The orbit will be Sun-Synchronous (at 11:00) with a 600 Km circular orbit at 98° .
- This will allow it to sample both the inner and outer trapped radiation belts.

NASA ISS Detailed Test Objective (SDTO) Status

- A special version of Pixelman (PixelmanISS) has been uploaded to the 21 ISS (Lenovo) Laptops… (Thanks to Daniel Turecek)
- 5 “Flight Units” have been transferred to Biakonur (Kazakhstan), and are waiting there for a (scheduled) July 31 Launch on the Progress-48 Supply Vehicle to the ISS.
- Within a few weeks, first one, then all five units will be plugged into 5 separate laptops and plans are to acquire data for 2-3 weeks.
- All raw frame data will be downloaded several times each day for analysis on the ground

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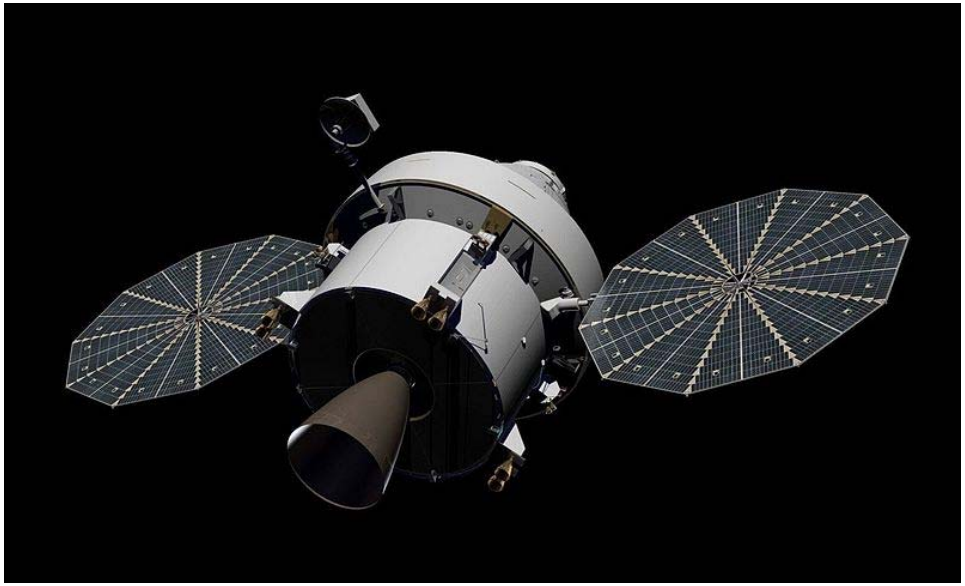
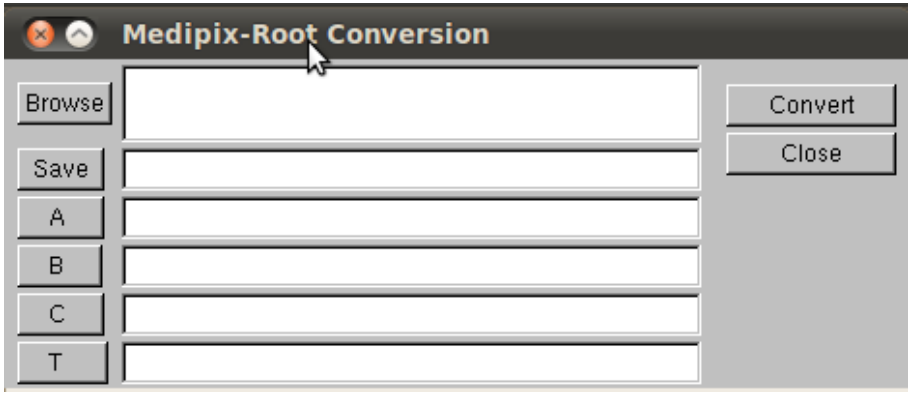
Summary

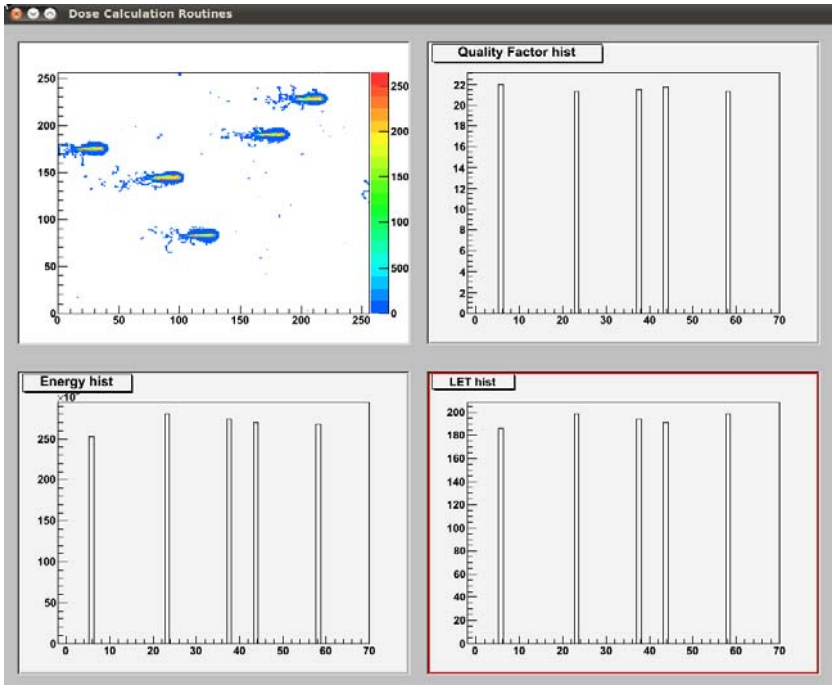
- The NASA Project has morphed into several separate projects…
- NASA is leaning towards using a dedicated design(s)…
- They are ready to begin acquiring detectors from the licensees as soon as they are able to supply them reliably…
- It appears that thicker Si sensors are preferable…



Offline (Ground-Based) Analysis Software To Be Available my mid-July (John Idarraga)

- **ROOT-Based…**
  - Maintained by CERN…
  - Free for Research applications…
  - Designed to handle massive data sets…
  - Uses "C" as the scripting language (allows scripts to be compiled for faster analysis execution!)
  - Runs on all platforms…
- **Hopefully will incorporate all existing routines and plug-ins from current IEAP "Pixelman" software…**
- **Can also be used as a DAQ software…**

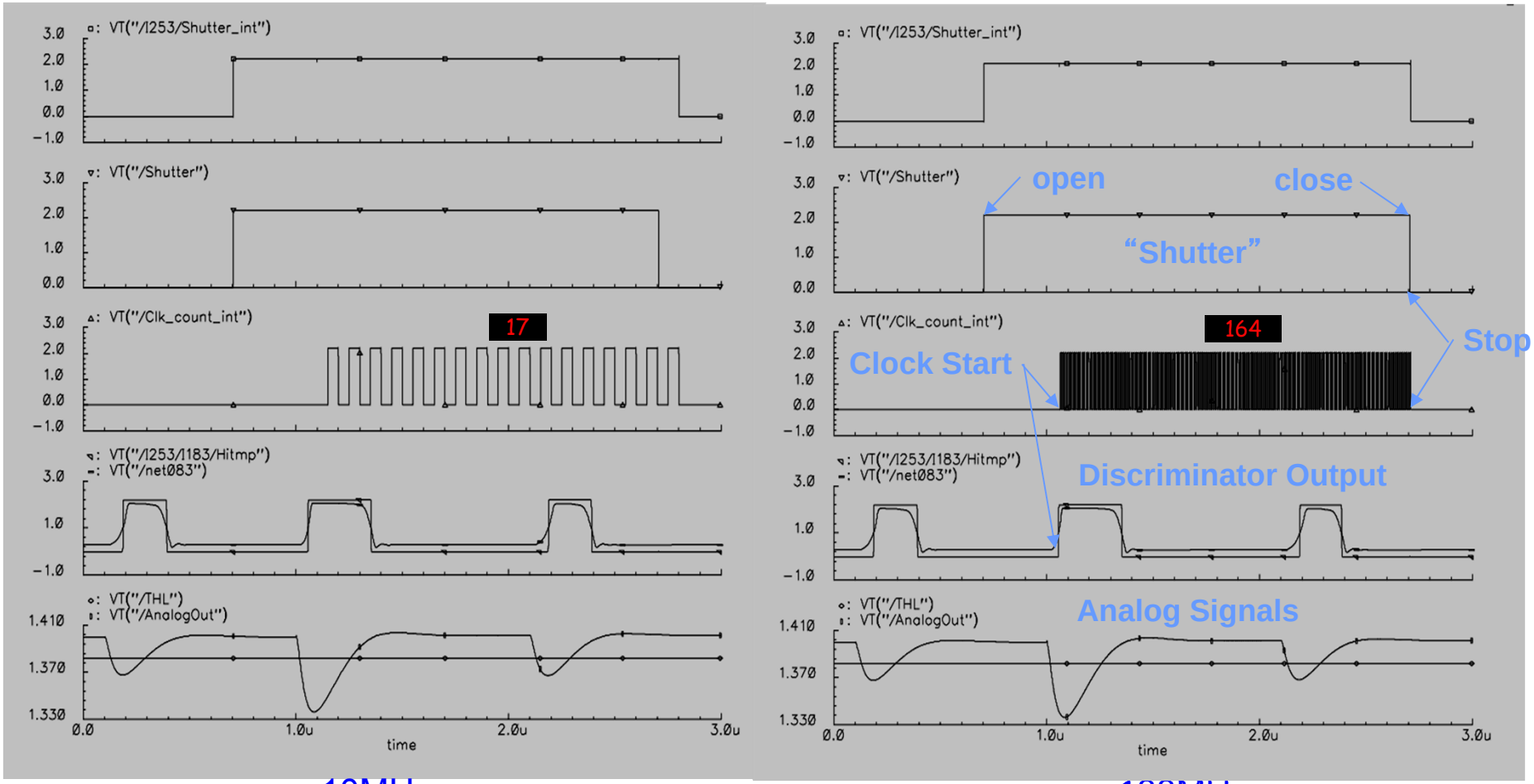




TimePix Modes

- **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

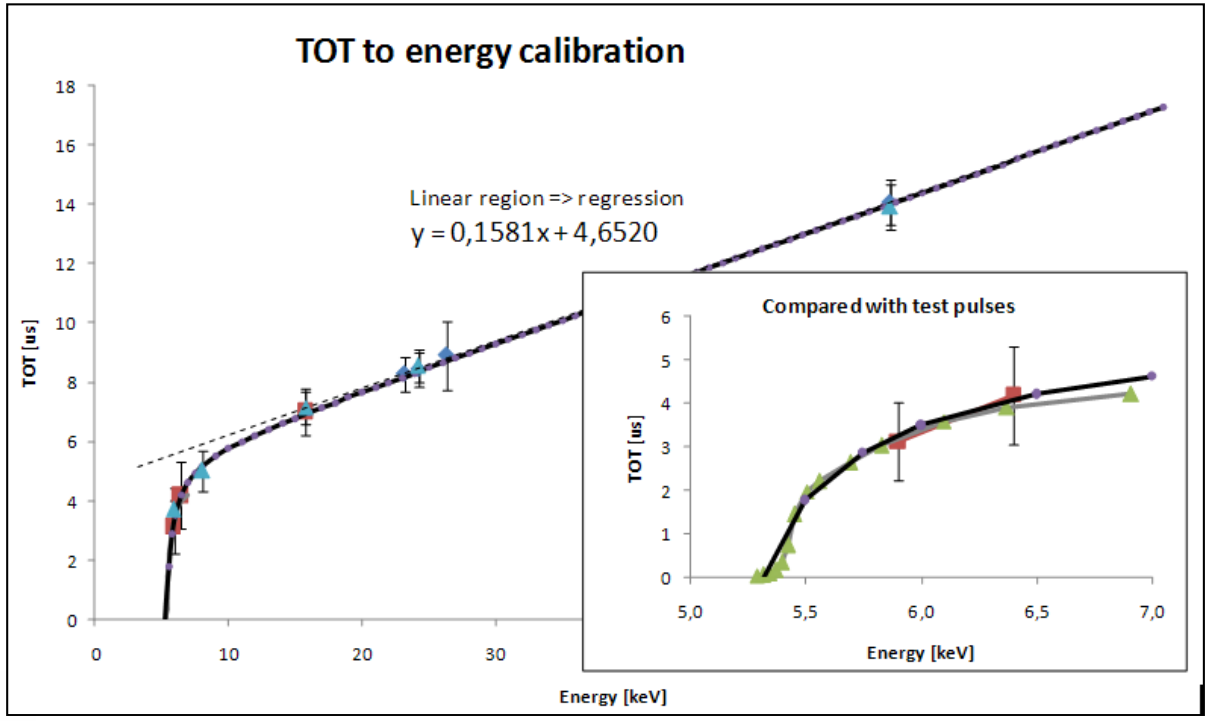
100MHz

Calibration Curves & Functional Form

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

Meaning of parameters:

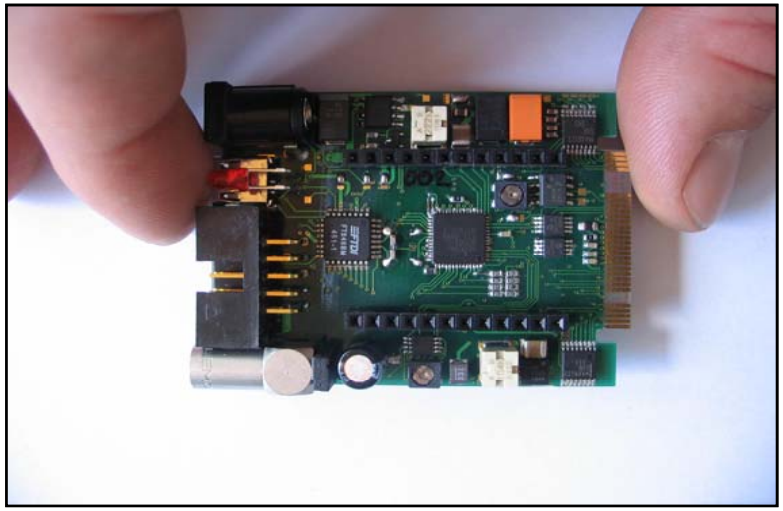
a,b – linear regression in high energy range
c,d – curvature (extent and symmetry)
t – threshold

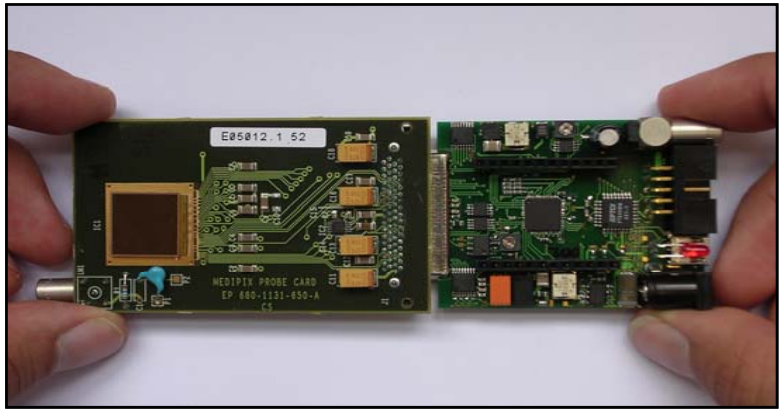


Parameters computed Using global calibration data:

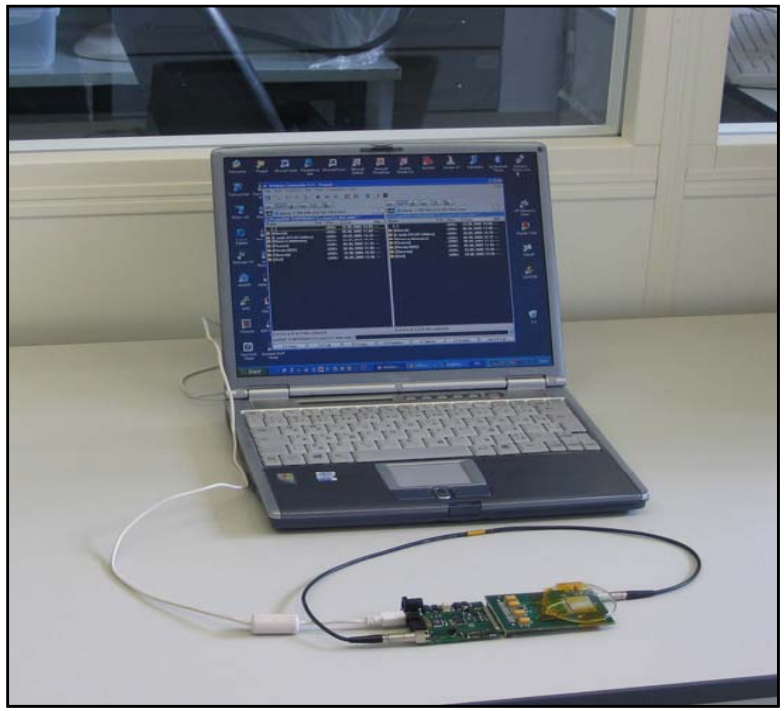
a=0.158
b=4.65
c=2.4
d=1
t=4.86

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…)



Credits

- Funding- SRAG (& Wyle) @ NASA/JSC…
- Timepix Design—Medipix Collaboration
- Timepix Fabrication—IBM
- Detector Layer Fabrication--Canberra
- Wire-bonding—CERN Bonding Lab
- USB-Lite interface Design and Development—IEAP, Czech Technical University in Prague
- USB-Lite Layout and Fabrication—Ales Burian
- Flight Software—IEAP, Czech Technical University in Prague & UH
- Heavy Ion Beam Testing—HIMAC @ NIRS
- Coordination NASA JSC…

ATLAS Area Neutron Monitors
Detector Configuration

Medipix2 ASIC with 300μm Si sensor + USB interface

Neutron conversion structures:

1)LiF+50μm Al foil area

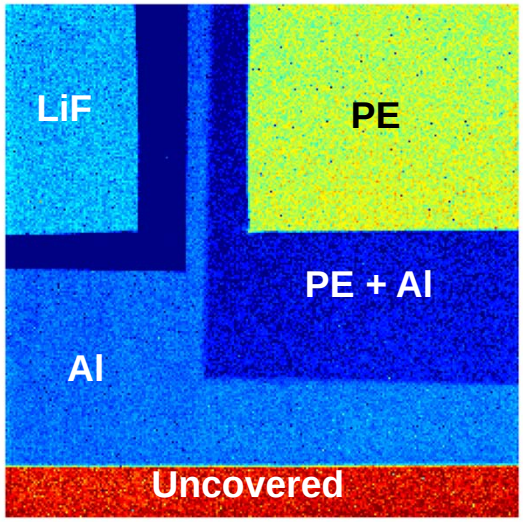
2)100μm Al foil area

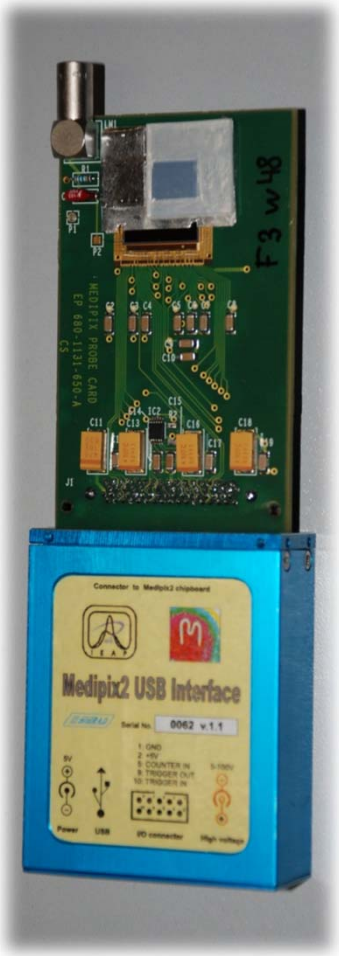
3)PE area

4)PE+50μm 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 $cm^{-2}s^{-1}$

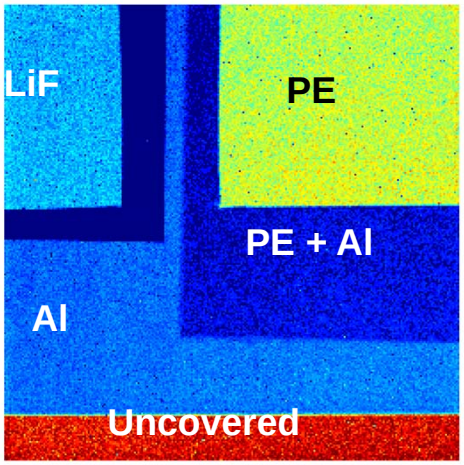
PE / PE+Al cluster count ratio:

252Cf: 10.70 ± 0.04

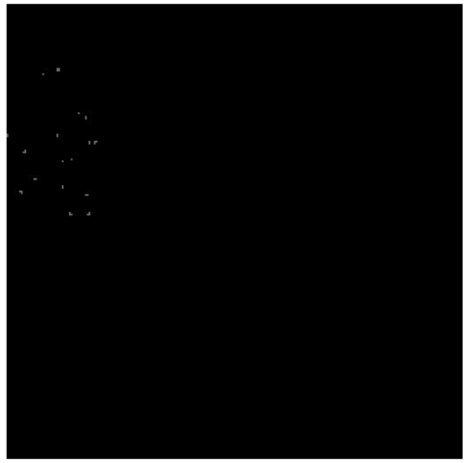
AmBe: 5.18 ± 0.03

VDG: 2.51 ± 0.03

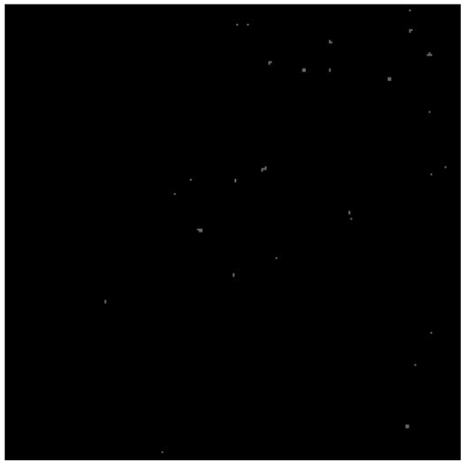
X-ray image of conversion layers



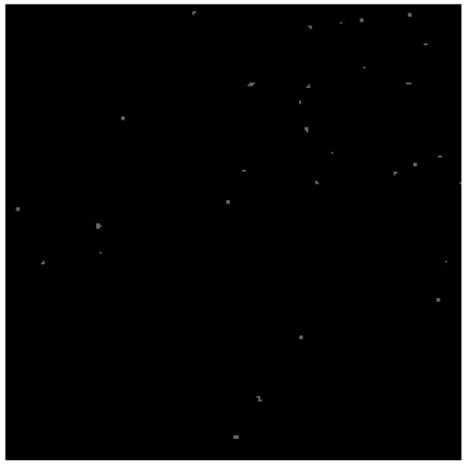
Thermal neutrons – 500s, 25meV



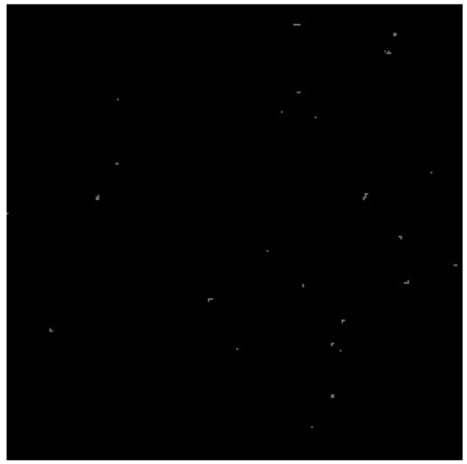
252Cf – 2000s, 2MeV (mean)



AmBe – 2000s, 4MeV (mean)



Van de Graaff – 1000s, 14MeV



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