MEDIPIX: A CERN Technology That Can Be Developed Into An Active Real-time Space Radiation Dosimeter

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Important Disclaimers

- **Note that ALL DISCLOSURES regarding the Design and Performance of the MEDIPIX technology made in this presentation is to be considered CONFIDENTIAL to the extent that subsequent patent applications may be submitted.**
- **The University of Houston is NOT presently a member of the Medipix Consortium, but rather we have been formally invited by that Collaboration to join for the purpose of pursuing the adaptation of this technology to Space Radiation Dosimetry…**

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, USA

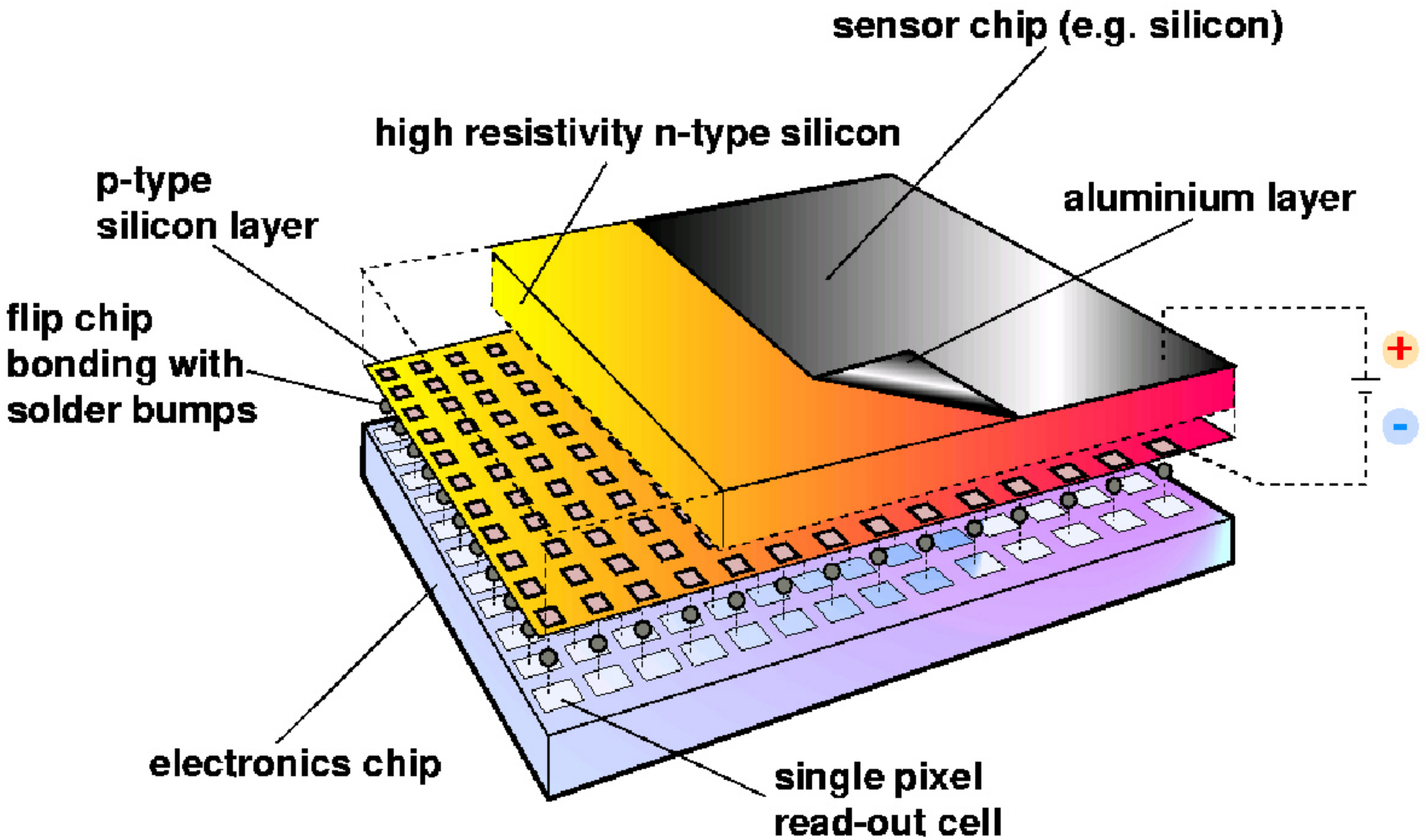
WHAT IS MEDIPIX2 DETECTOR?

Medipix2 is a pixel-based detector technology that can be employed to measure charged particles, photons (visible 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

- The Medipix2 Chip and Readout System
- Recent Heavy Ion Beam Medipix Exposures
- Timepix—An Evolution Within Medipix2
- Medipix3—The Next Generation of Medipix
- Where Do We Go From Here With Medipix

Hybrid Pixel Detector

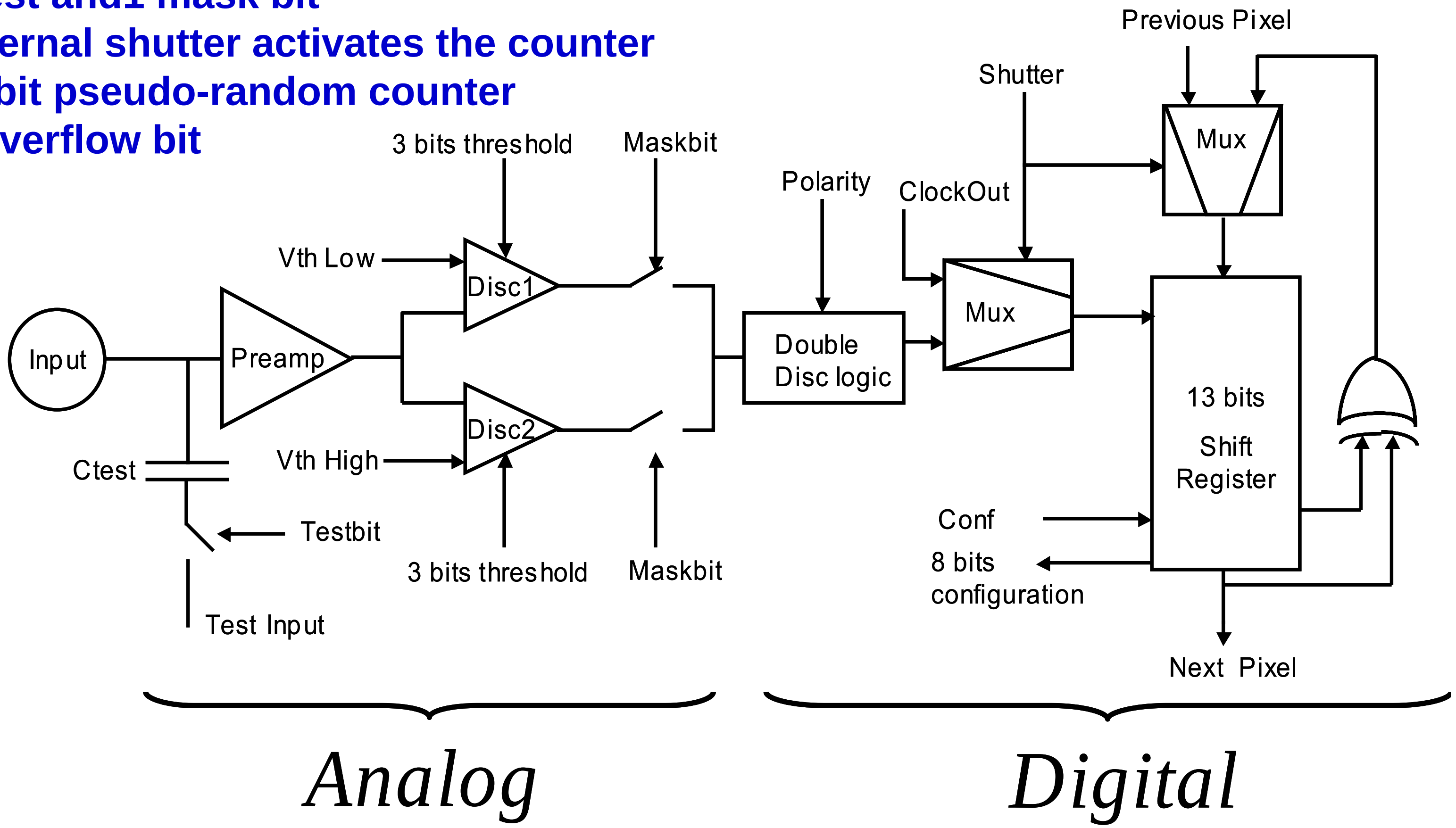


Detector and electronics readout are optimized separately

Hybrid Pixel Detector - Cross Section

Current Medipix2 Cell Schematic

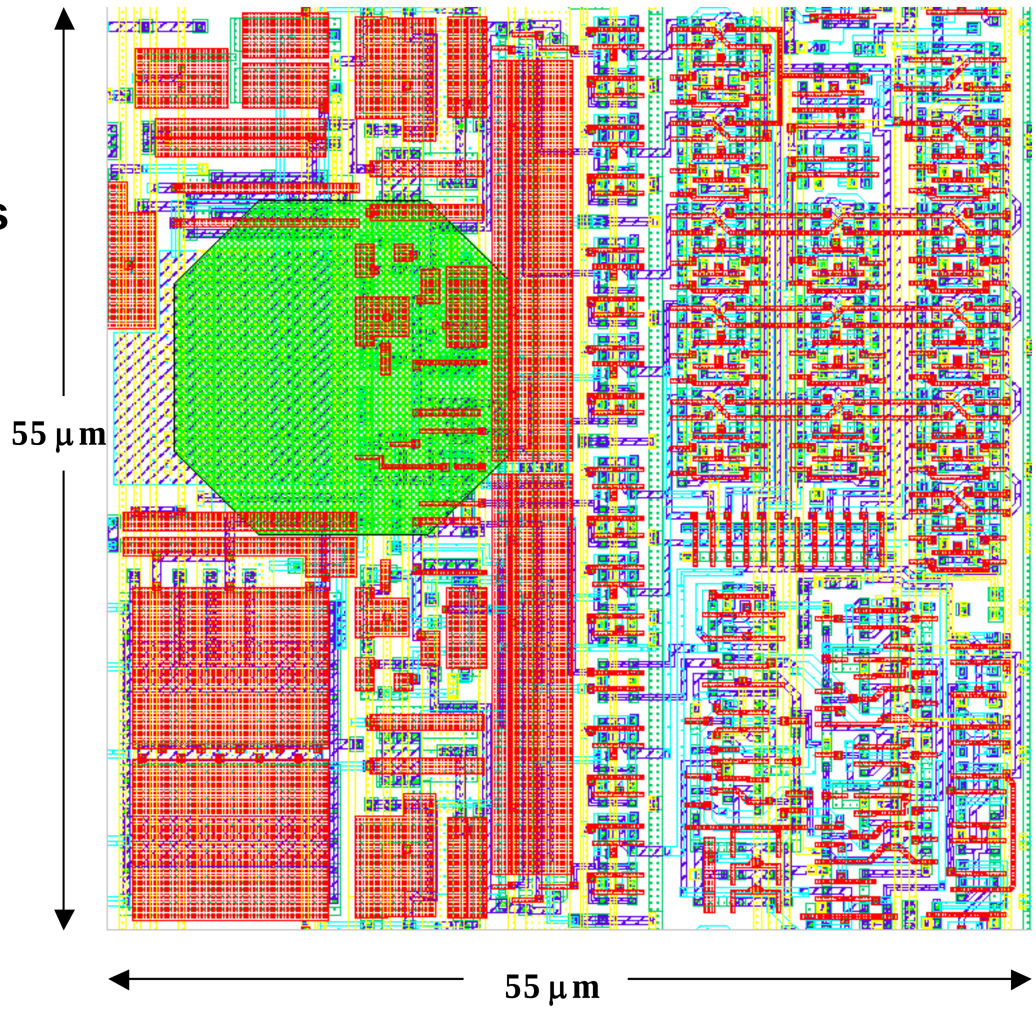
- Charge sensitive preamplifier with individual leakage current compensation
- 2 discriminators with globally adjustable thresholds
- 3-bit local fine tuning of the threshold per discriminator
- 1 test and1 mask bit
- External shutter activates the counter
- 13-bit pseudo-random counter
- 1 Overflow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



Current Medipix2 Cell Layout

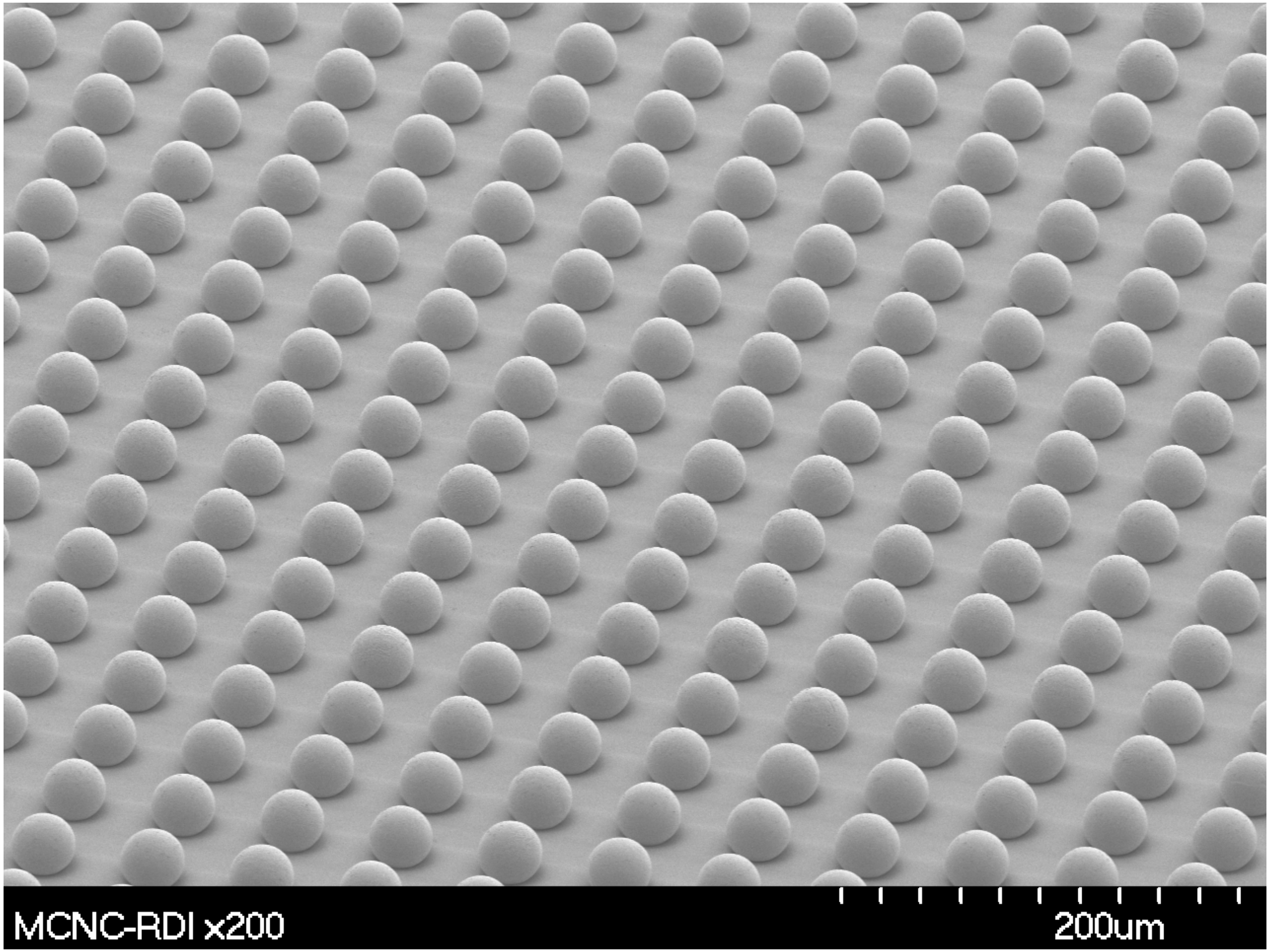
503 transistors per pixel

33M per Chip

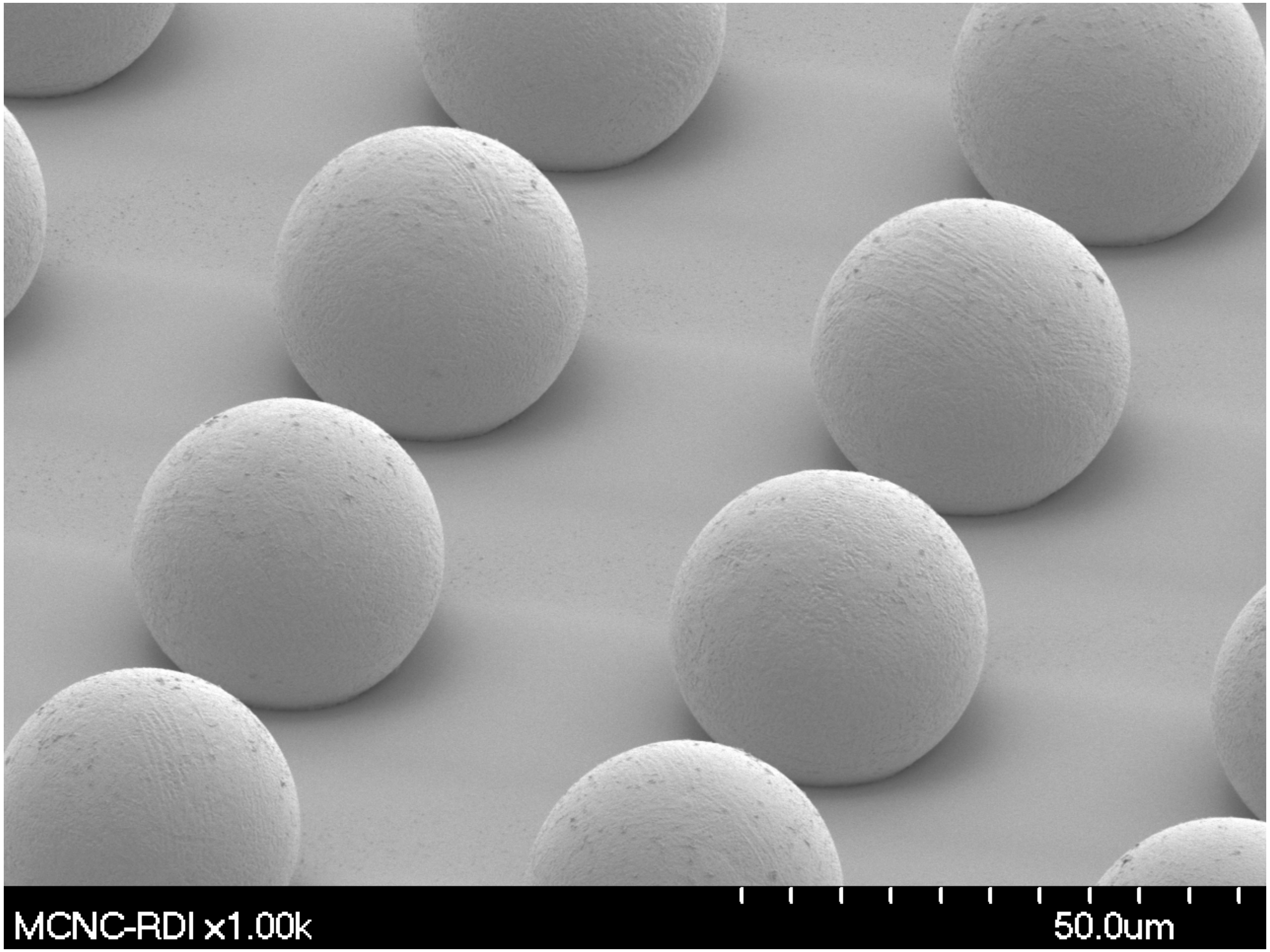


55 µm

Bumps on the readout side

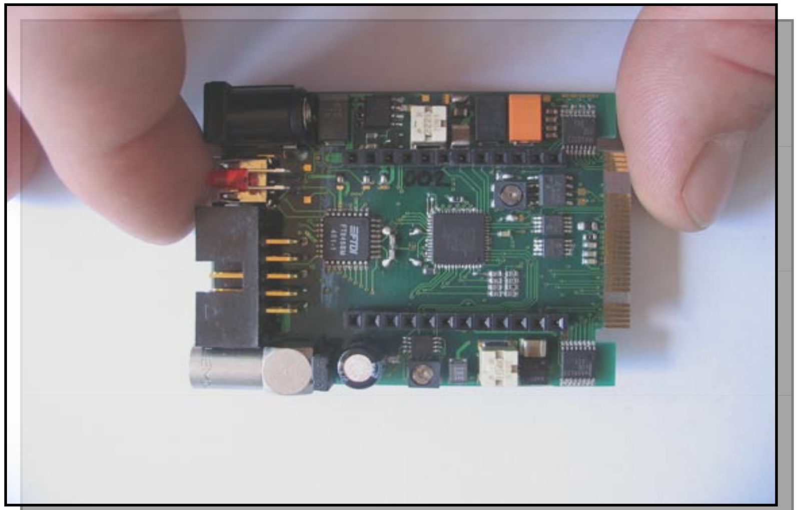


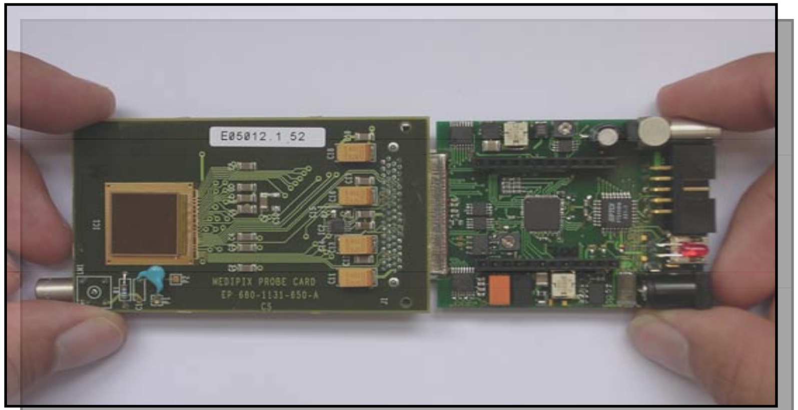
Bumps on the readout side – close up



Medipix2 Si Assembly

A new USB based Medipix2 Readout System





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

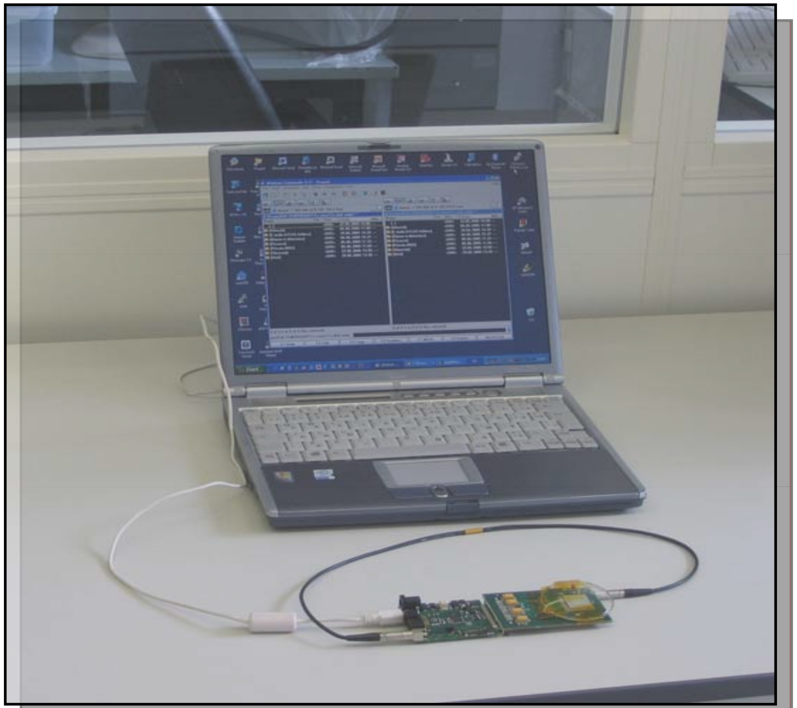


Image of a dried anchovy

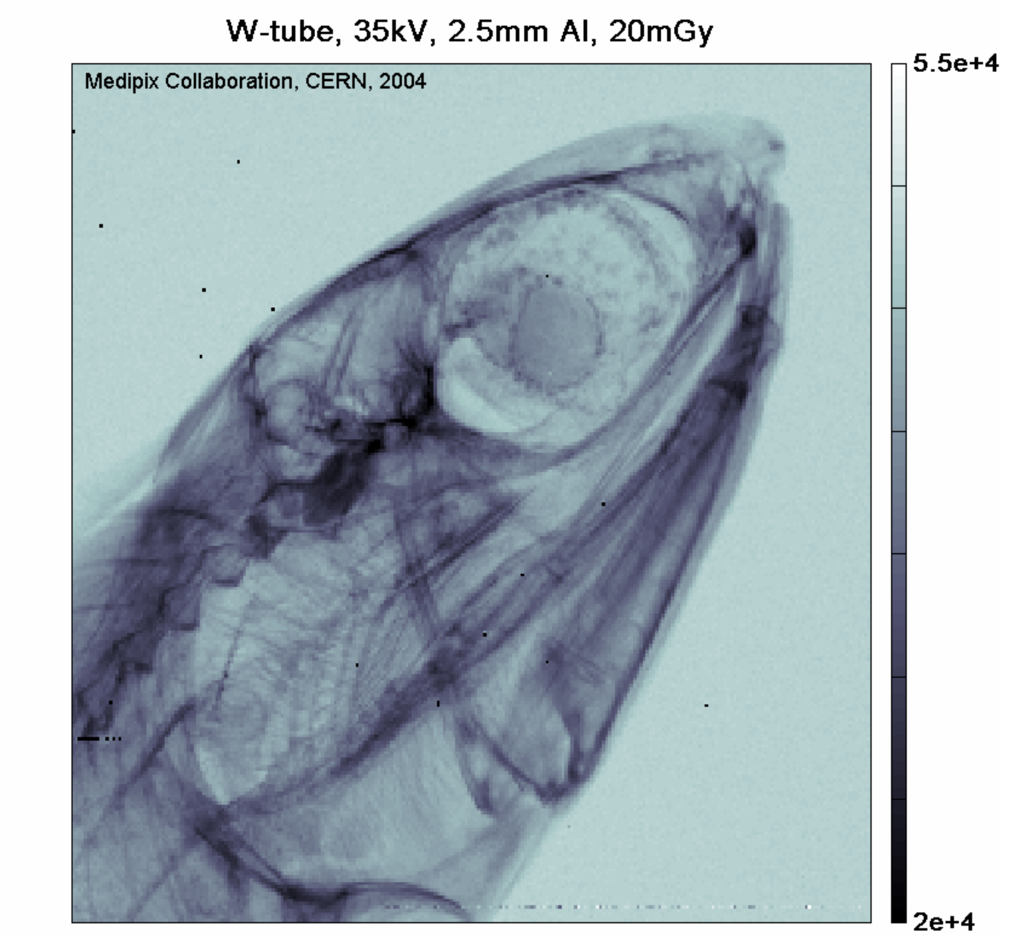


Image of a fly

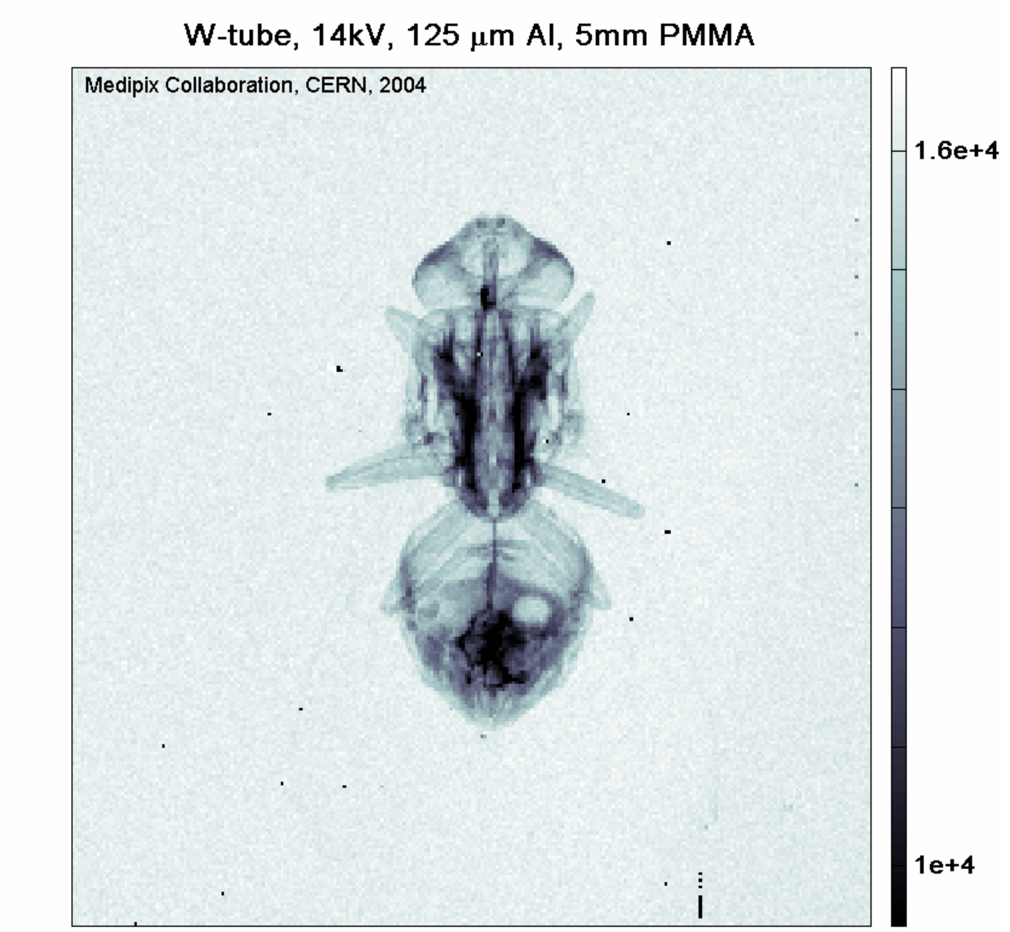
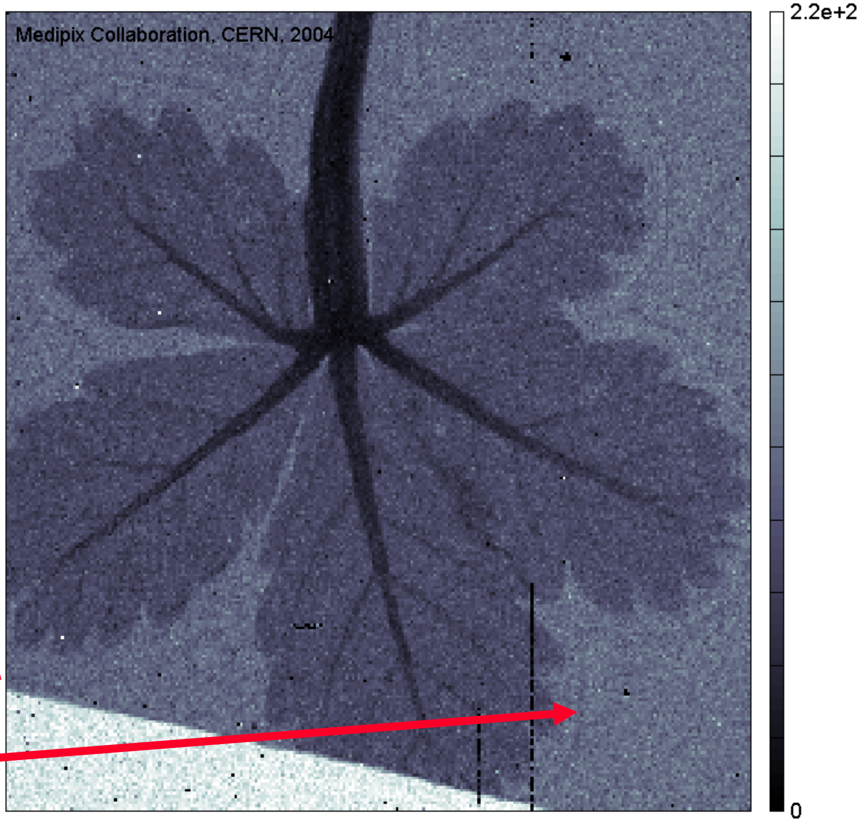


Image of a leaf (^{55}Fe)

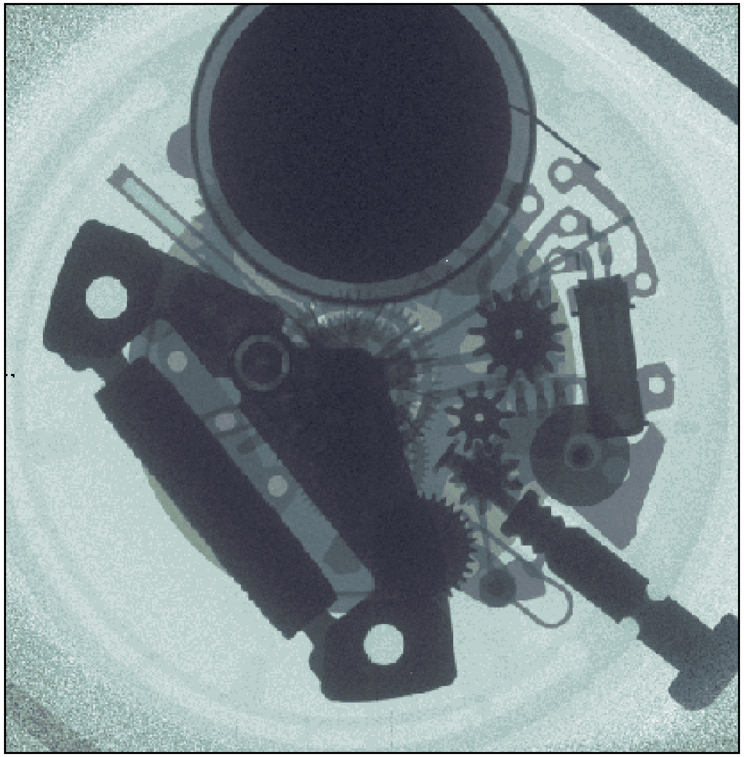
Image taken over 14 Hours (5.9 KeV e^-)

Note celophane tape used to hold leaf in place…

And air bubble Surrounding leaf…



High rate images

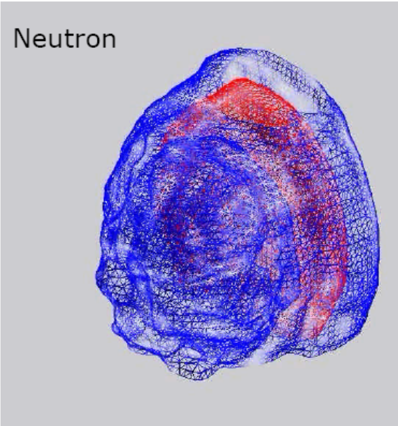


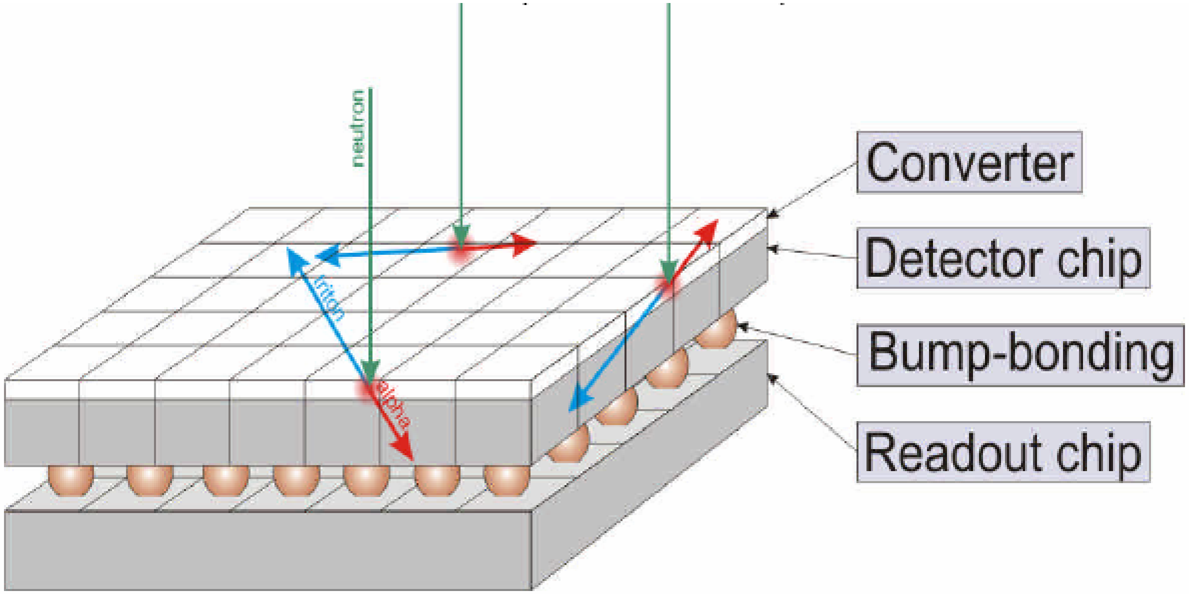
X-Ray movie at 5.5fps 512x512 pixels
Uses 4-chip Quad detector

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: $^6Li + n \rightarrow \alpha$ (2.05 MeV) + ^3H (2.72 MeV)**
  Cross section: 940 barns (0.0253 eV)





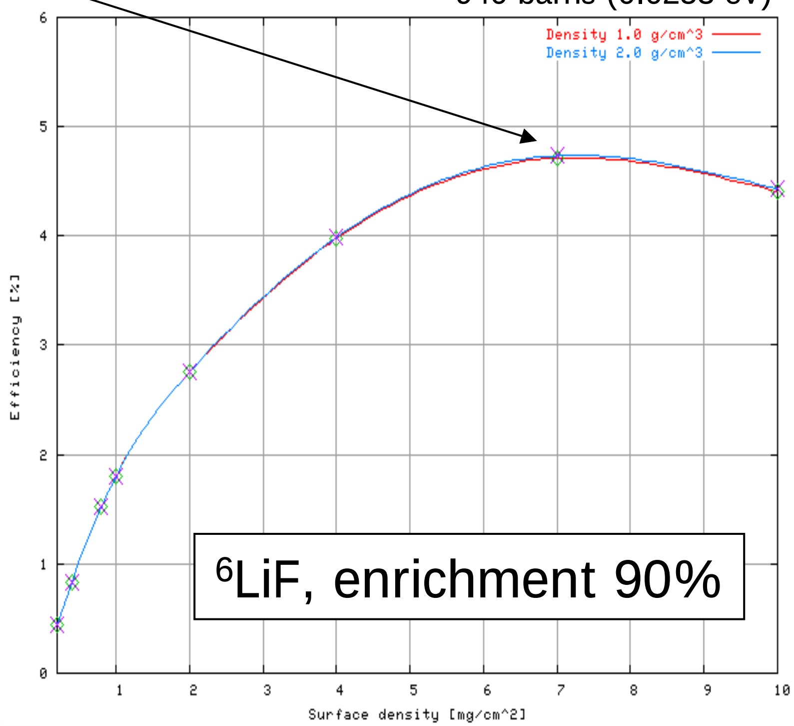
Monte-Carlo efficiency simulations

Detection efficiency was simulated in dependence on the converter thickness

- The neutron transport simulated using MCNP
- Energy deposition and ionization computed by TRIM/SRIM

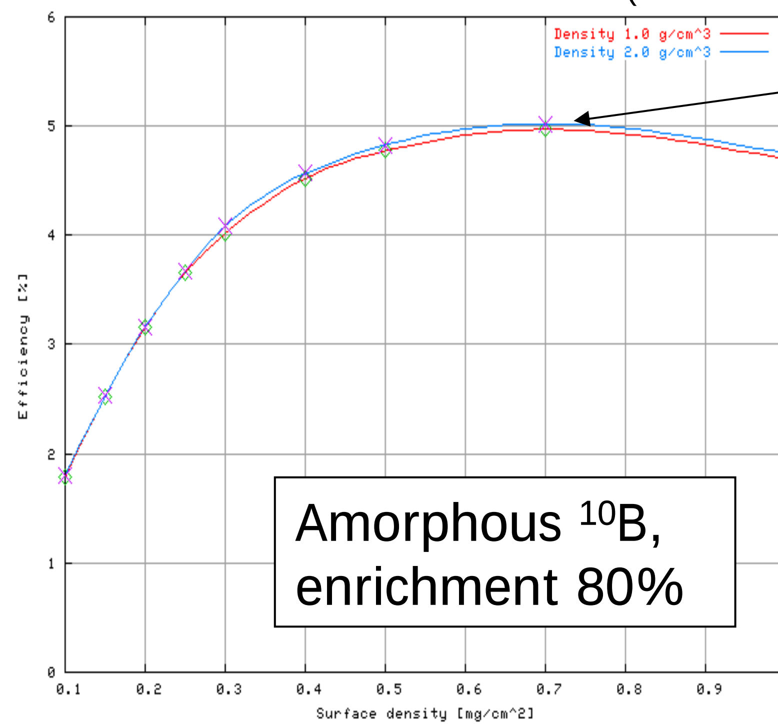
~4.7%

940 barns (0.0253 eV)

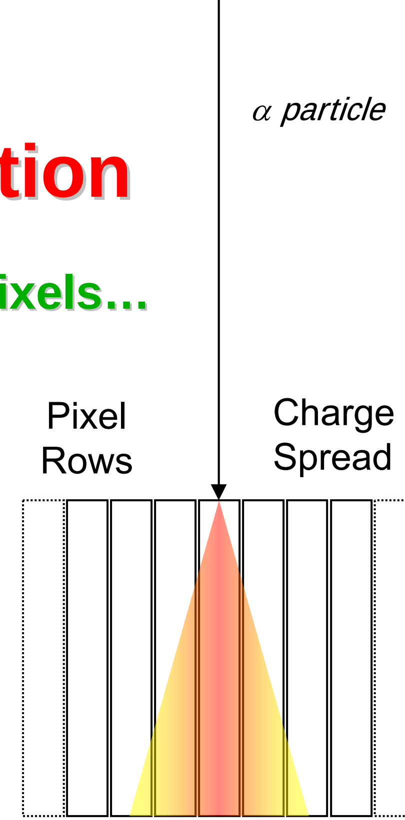


3840 barns (0.0253 eV)

~5%



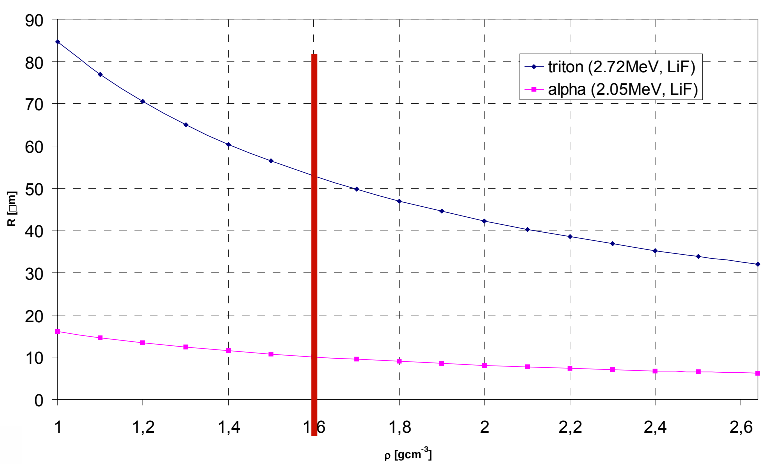
Spatial resolution estimation

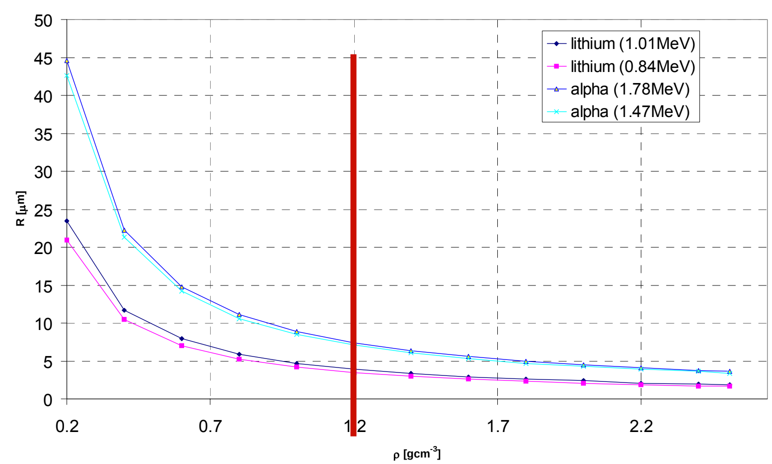


Note: 700μm Si with 55 μm Square read-out collection pixels…

Spatial resolution is affected by:

- Range of heavy charged particles in converter material – density dependant
  ^{6}LiF (ρ=1.6 g/cm^{3}): R_{Triton}=52μm, R_{α}=10μm
  ^{10}B (r=1.2 g/cm^{3}): R_{Li}=5μm, R_{α}=7μm
- Range in silicon
  ^{6}LiF: R_{Triton}=44.1μm, R_{α}=8.6μm.
  ^{10}B: R_{Li}=3μm / 2.7μm, R_{α}=5.4μm / 5.2μm
- Charge sharing effect ?



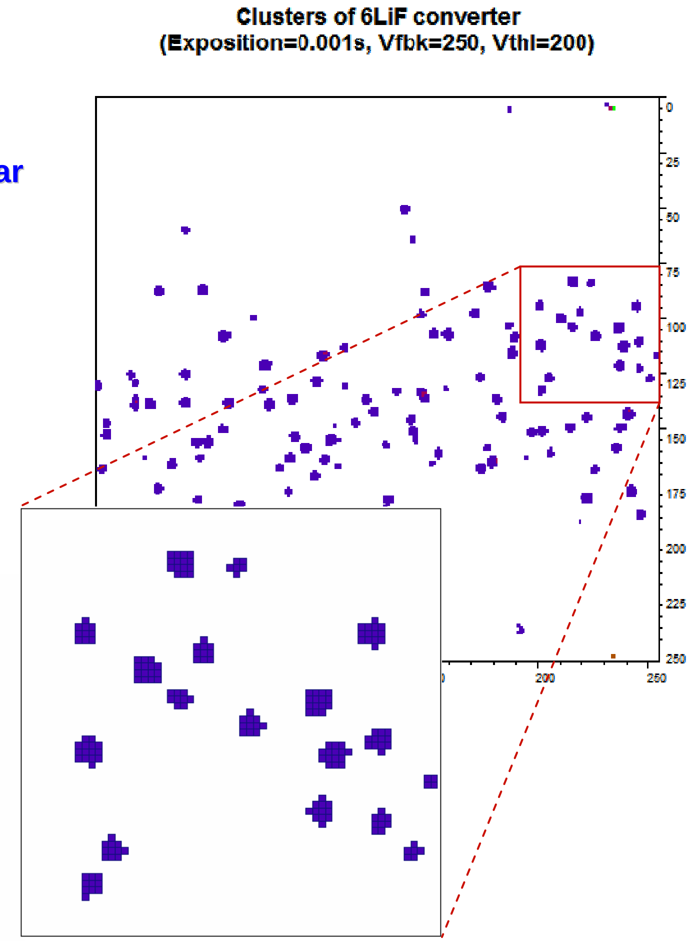


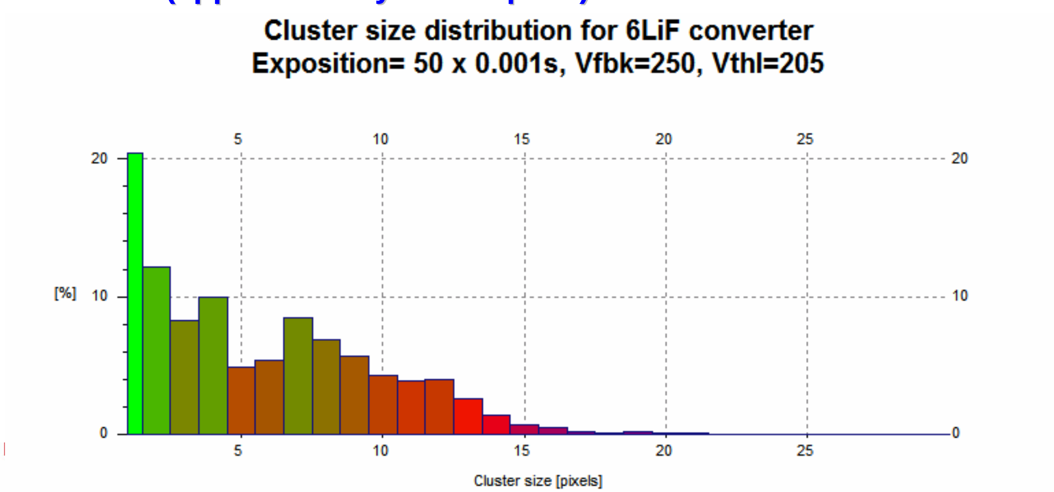
^{6}LiF converter (Cluster Sizes)

- Sensor covered by ^{6}LiF layer (3mg/cm^{2}). Detection efficiency is about 3%.
- High energy of alpha particles and tritons is deposited near 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.

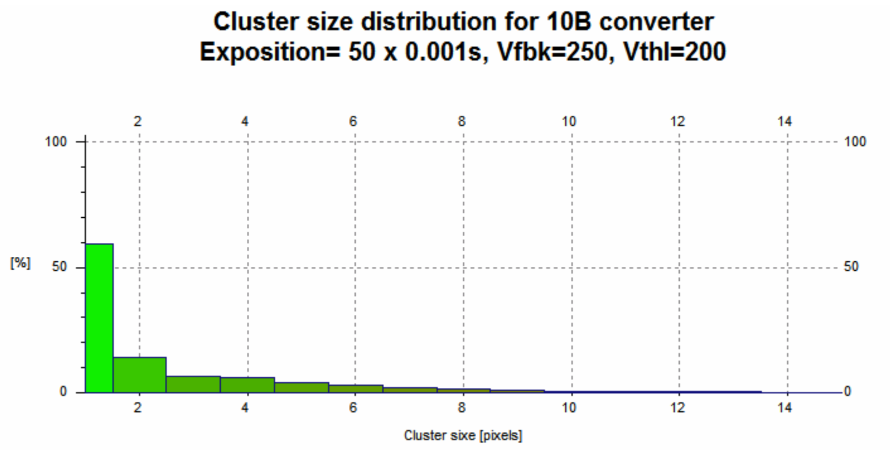
- Using event-by-event acquisition and finding centroids of clusters it is possible to reach subpixel spatial resolution (approximately half of pixel)

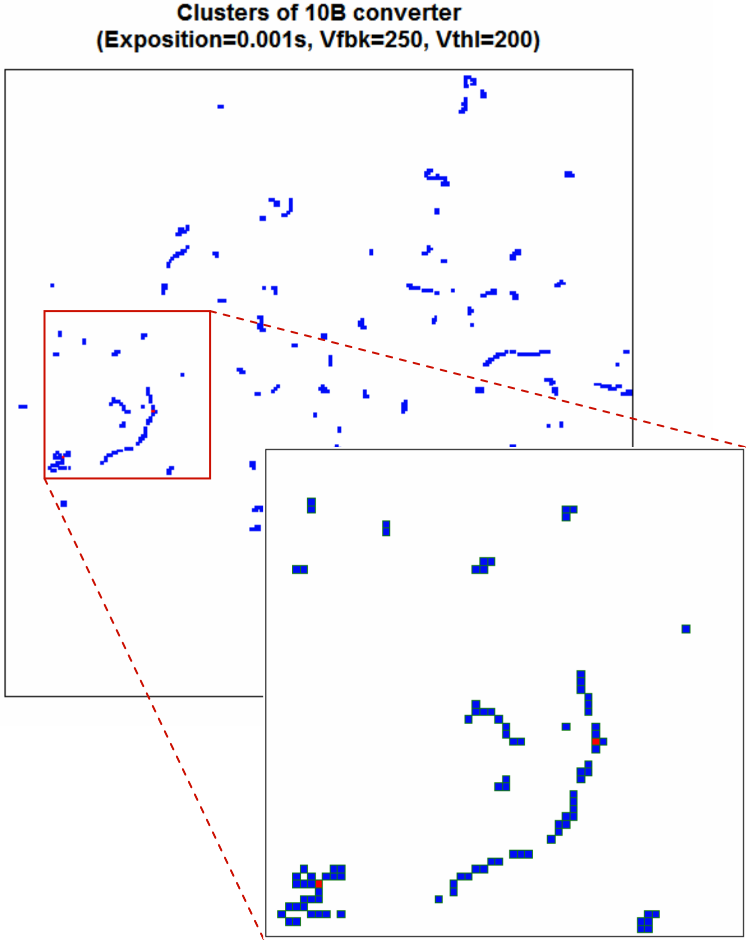




Amorphous ^{10}B converter (Cluster Sizes)

- 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.





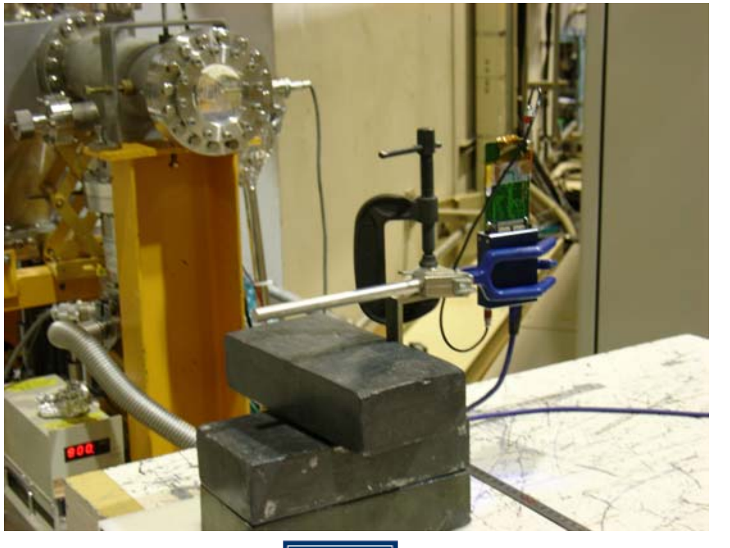
Future Evolution of Medipix Neutron Sensitivity

- We are collaborating with the Medipix Group in Prague (Stanislav Posposil).
- Considerable monoenergetic neutron response data are available and will be taken…
- CERF Run Scheduled for Oct. 29…
- Future PROPRITARY Techniques may be applicable to raise the neutron efficiency in the 1-100 MeV range to over 35%
- Simulations confirm the potential…
- May be tested soon…
- Unable to say more at present…

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

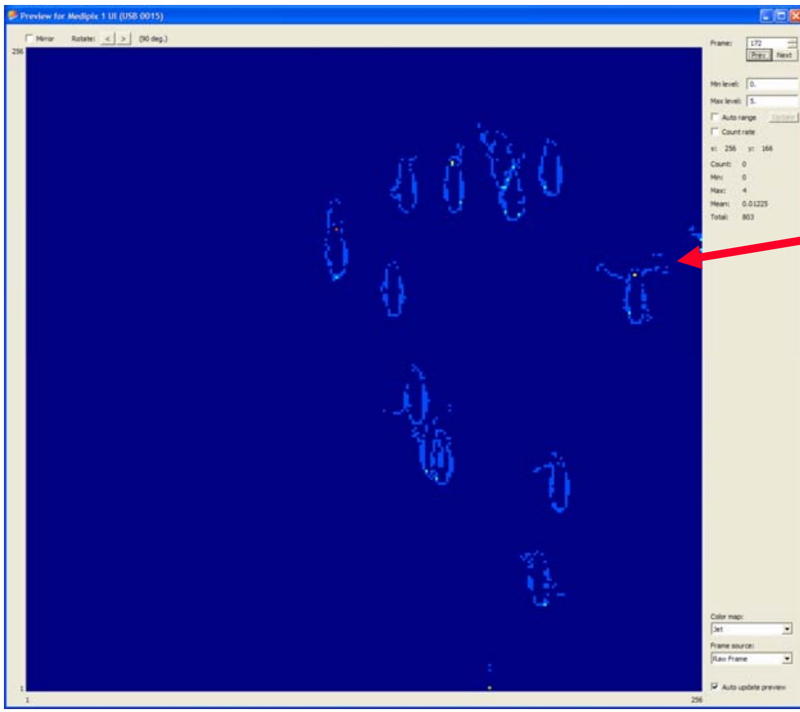
- **In collaboration with Jack Miller's Group at LBL, and Eric Benton, we recently made measurements with a Medipix2 of tracks in beams of:**
  - **Fe @ 500 Mev/A**
  - **O @ 290 MeV/A**
  - **Si @ 800 MeV/A**
  - **Ne @ 390 MeV/A**

- **This past weekend, 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

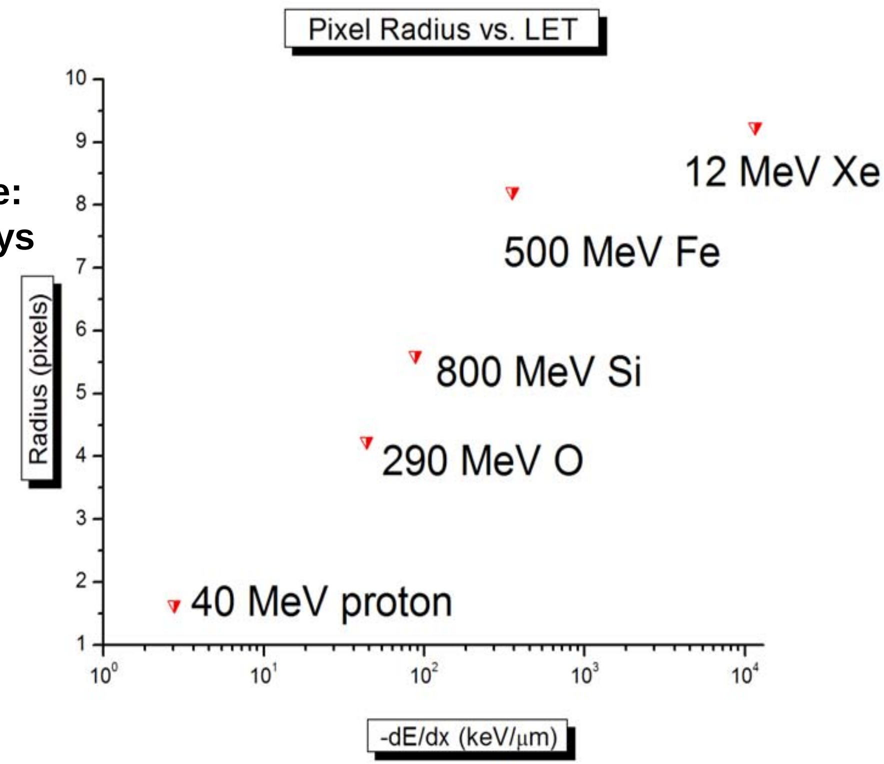
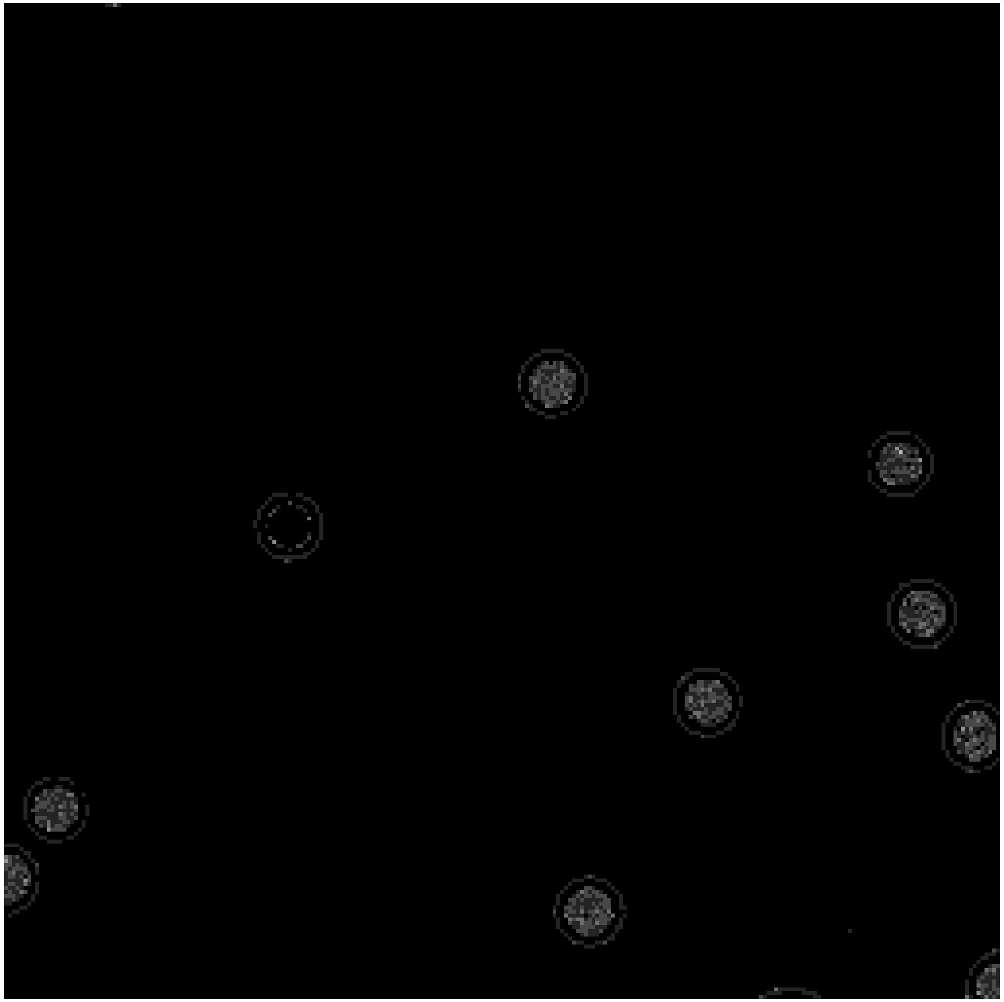
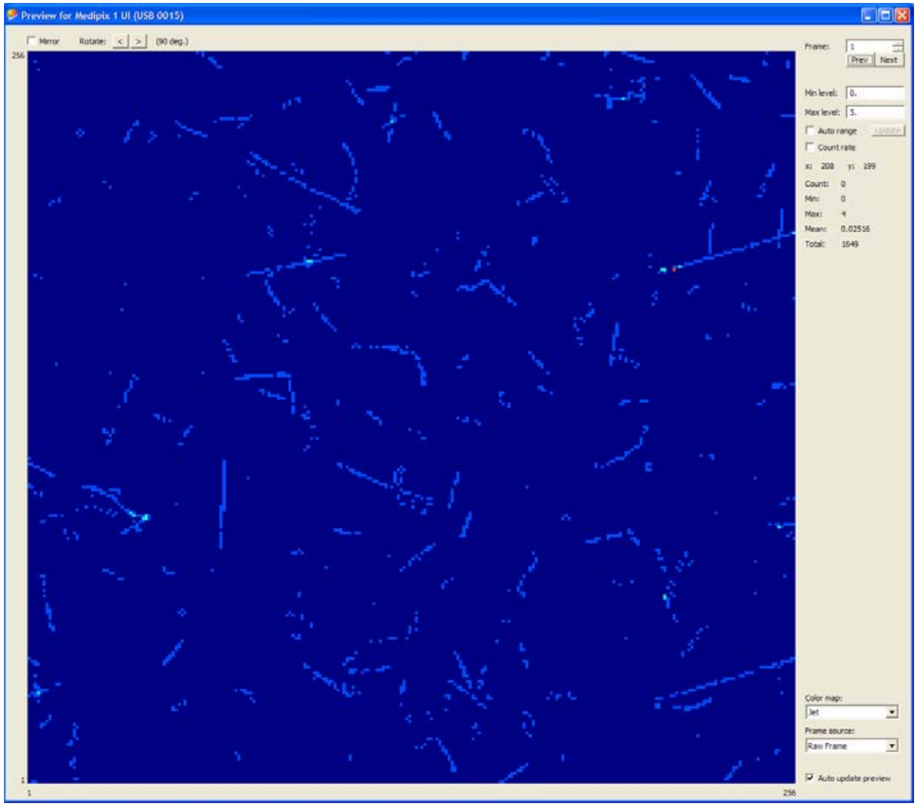


Image Slice Size v. LET for beams taken

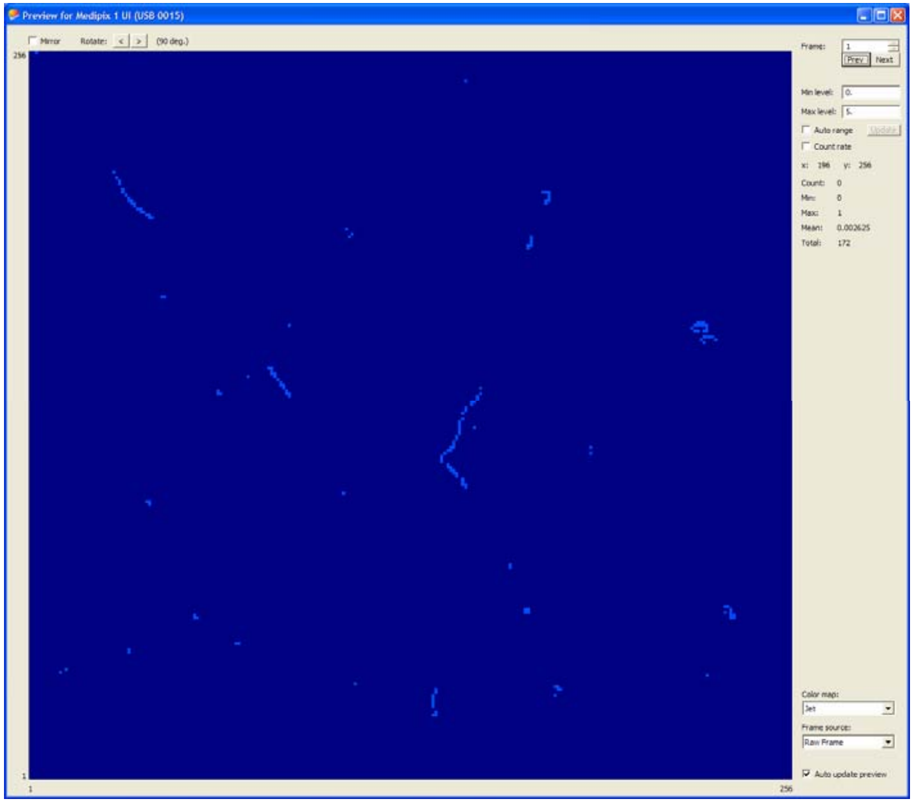
Medipix Movie of Xe Beam from This Past Spring at A& M Cyclotron



100 Sec Integrated Medipix2 Images

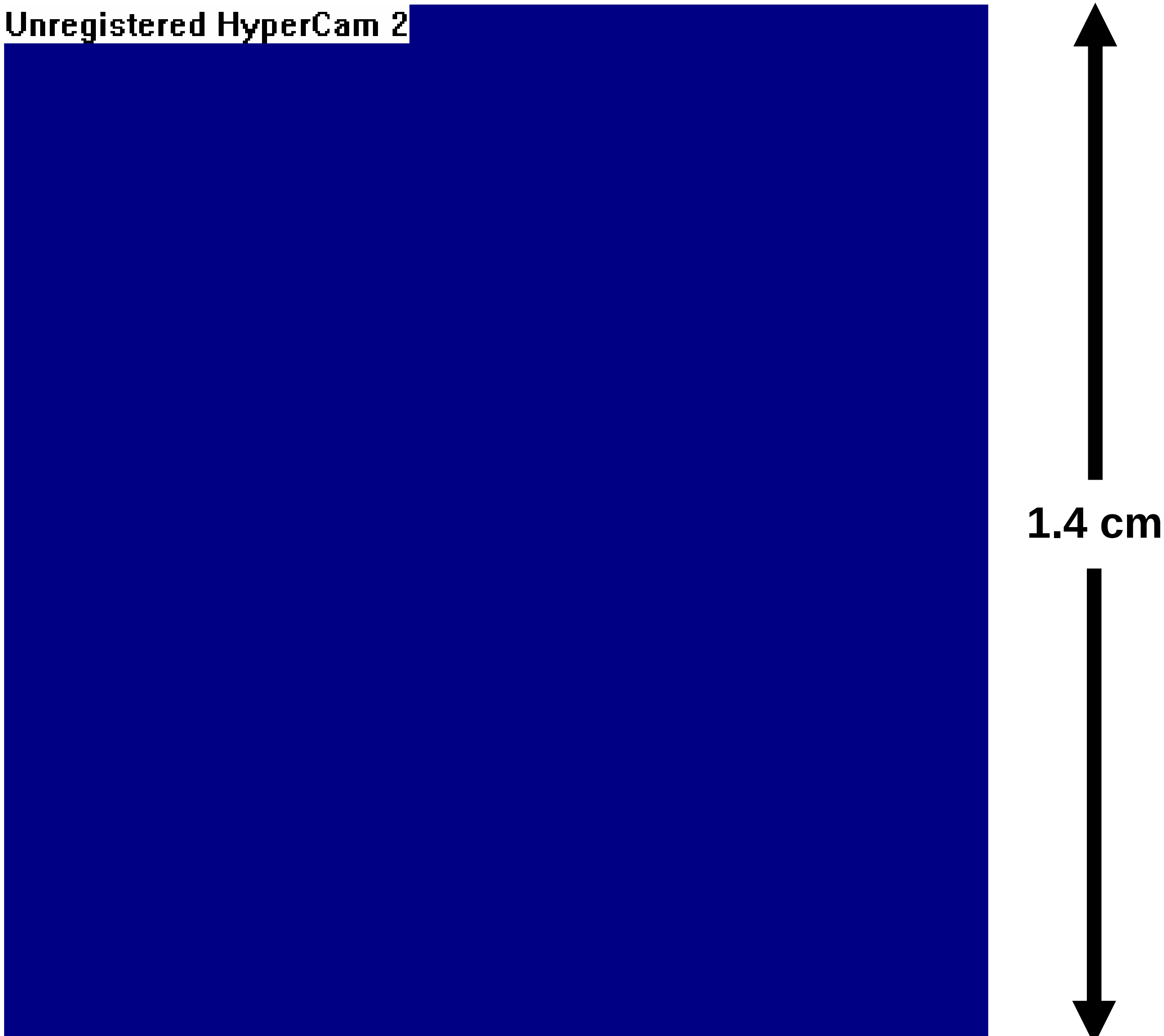


On my lap in a 777 airliner at 34,000 Feet over Anchorage, Alaska on the flight to Japan…

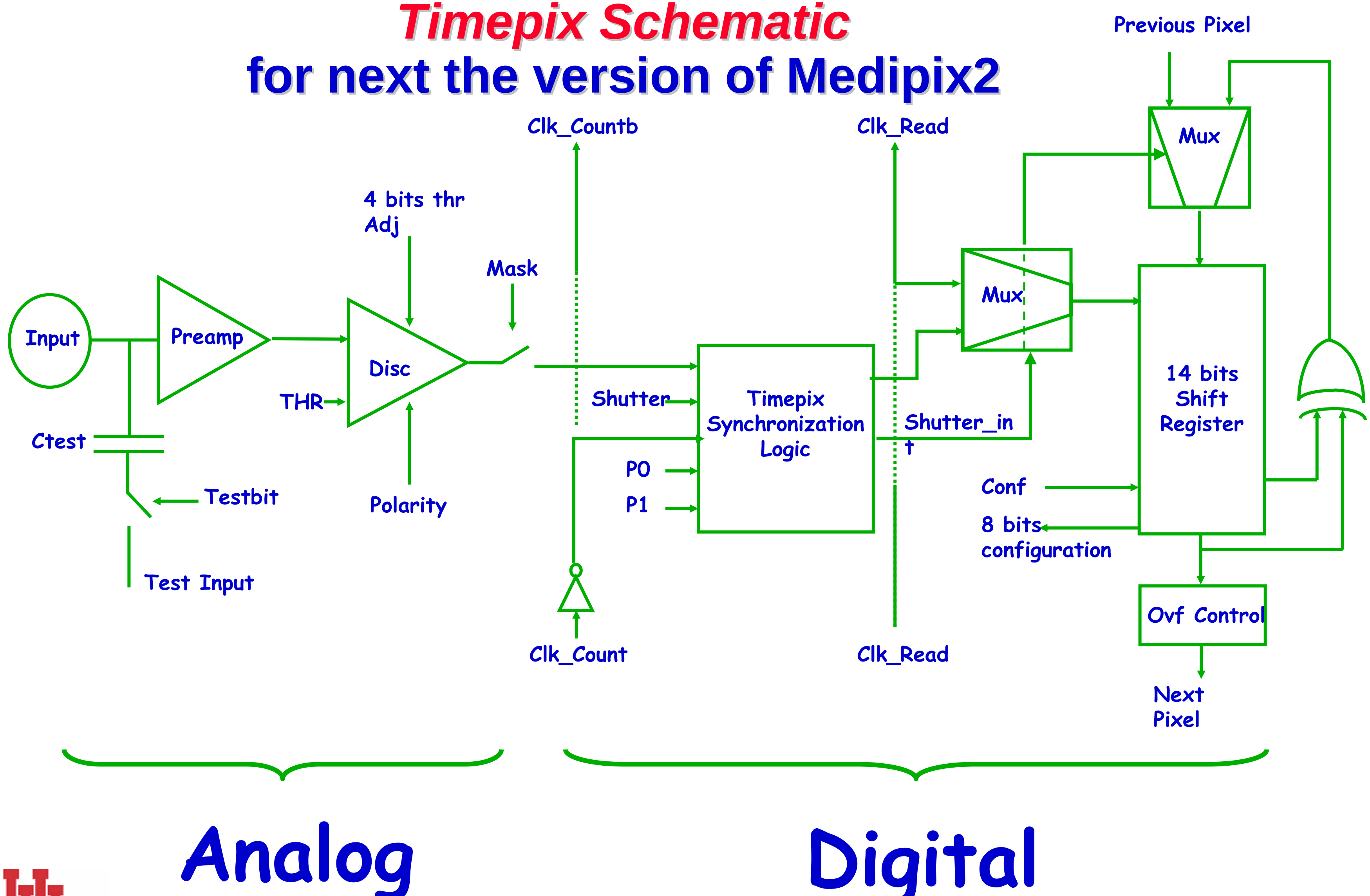


On the 15th floor of the Mitsui Garden Hotel in Chiba, Japan…

α Source



Adding Pulse Height Capability…
Timepix Schematic
for next the version of Medipix2



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)	

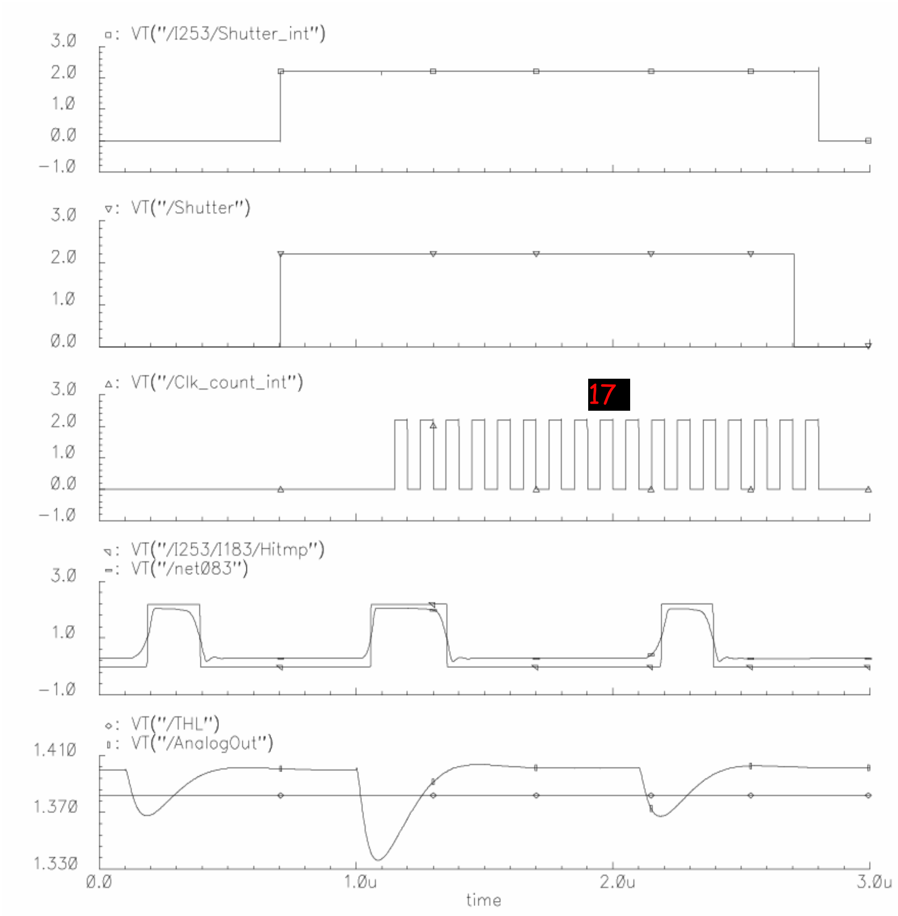
All these values are extracted from simulations !!!

Timepix Synchronization Logic control

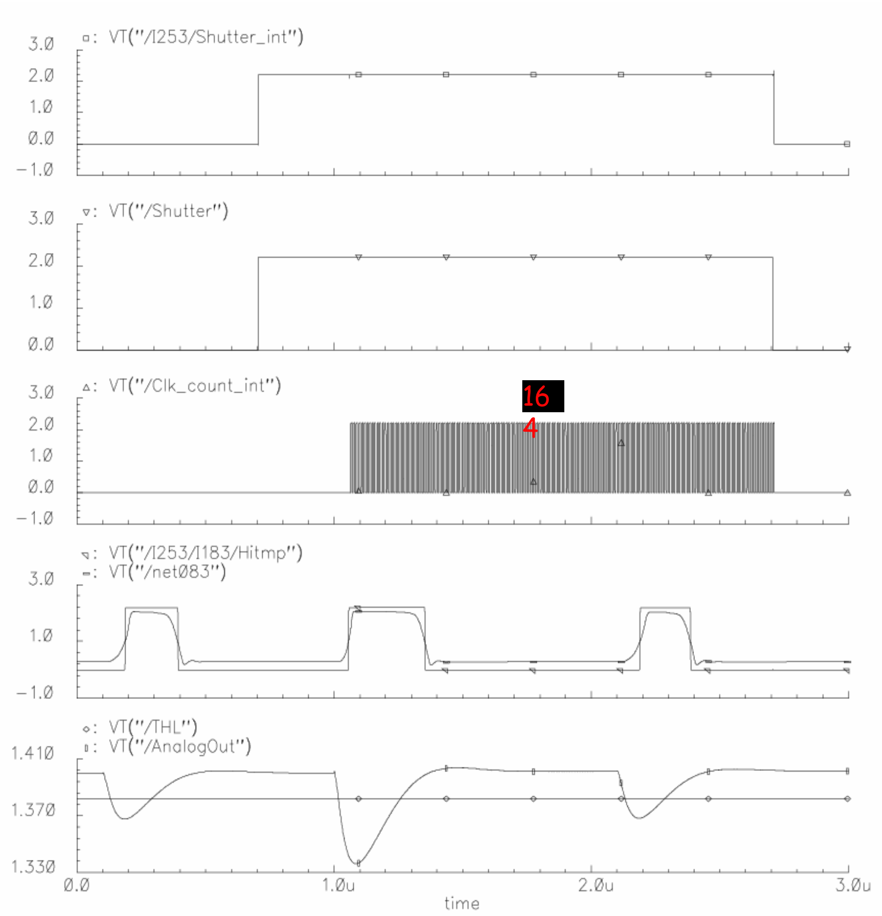
- Use of 3-bit High threshold adjustment bits for : 4th equalization bit and P0, P1.
- Each pixel can be configured independently in 5 different modes.
- This logic needs 104 Trts (Mpix2MXR20 had 92 Trts)
- Logic only consumes power only when a hit is present

Mas k	P 1	P0	Mode
0	0	0	Masked
0	0	1	Masked
0	1	0	Masked
0	1	1	Masked
1	0	0	Medipix
1	0	1	TOT
1	1	0	Timepix-1hit
1	1	1	Timepix

Timepix Mode (P0=1,P1=1)

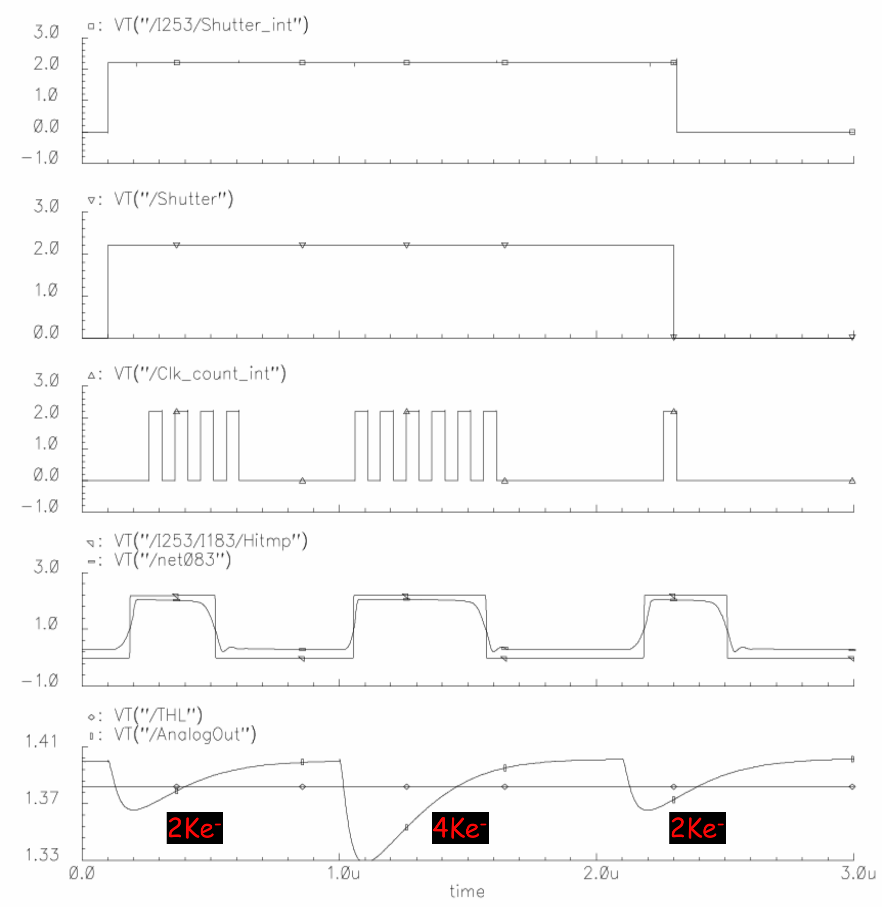


10MHz

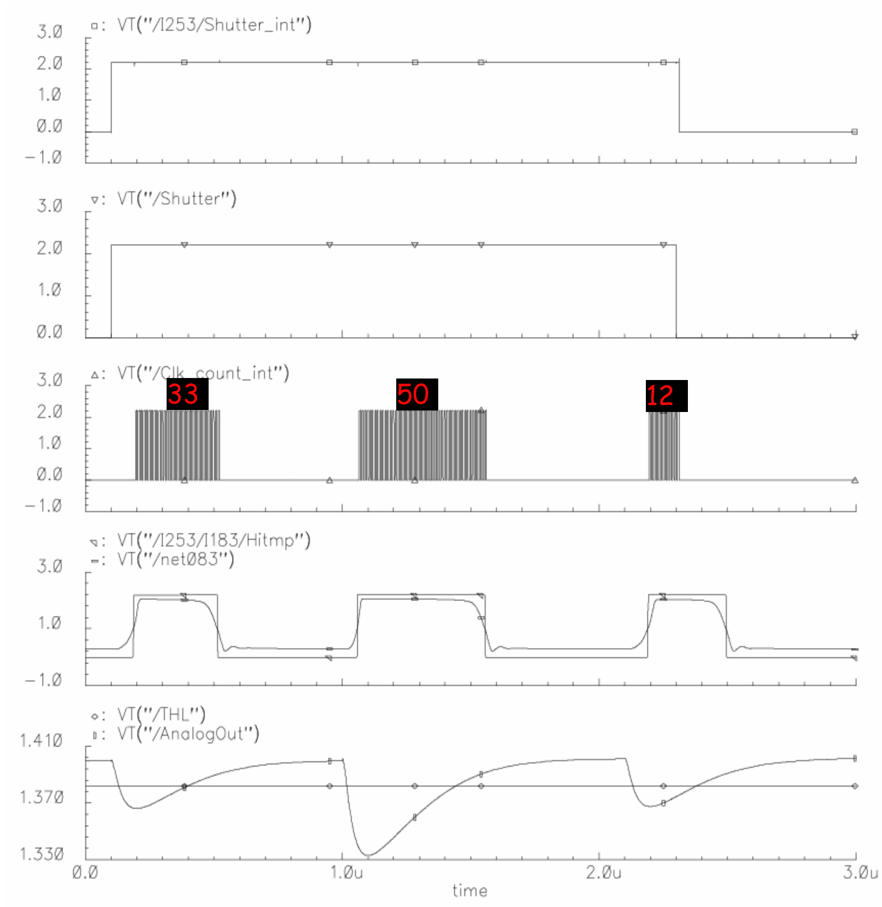


100MHz

TOT Mode (P0=1,P1=0)

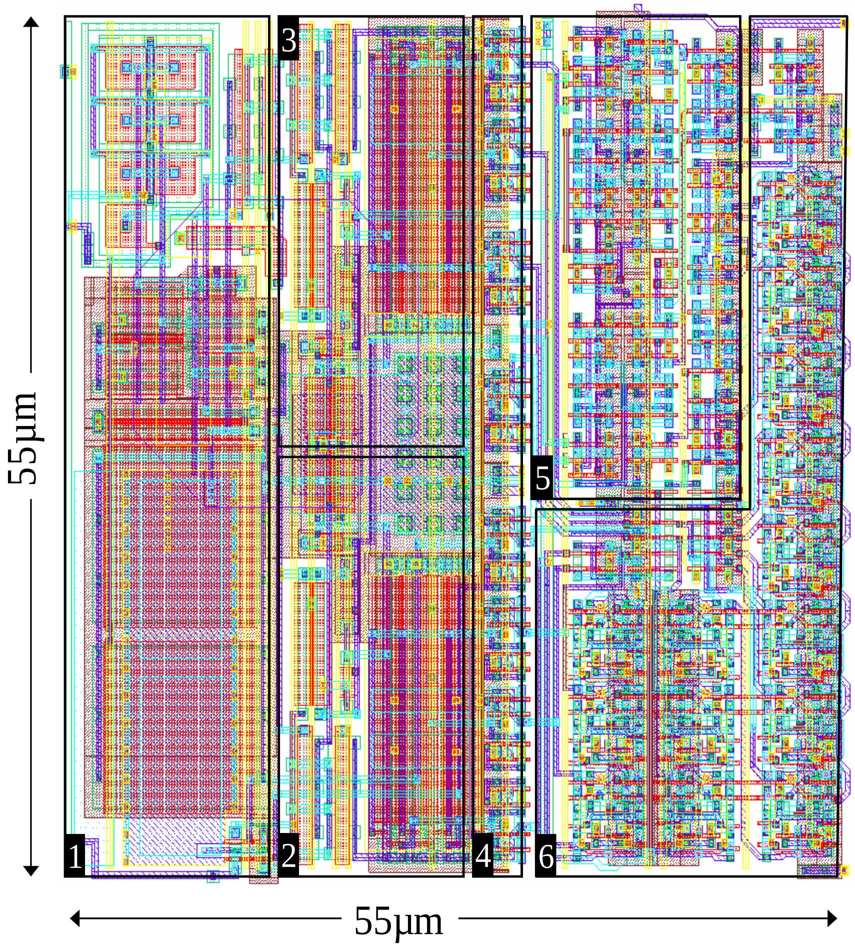


10MHz

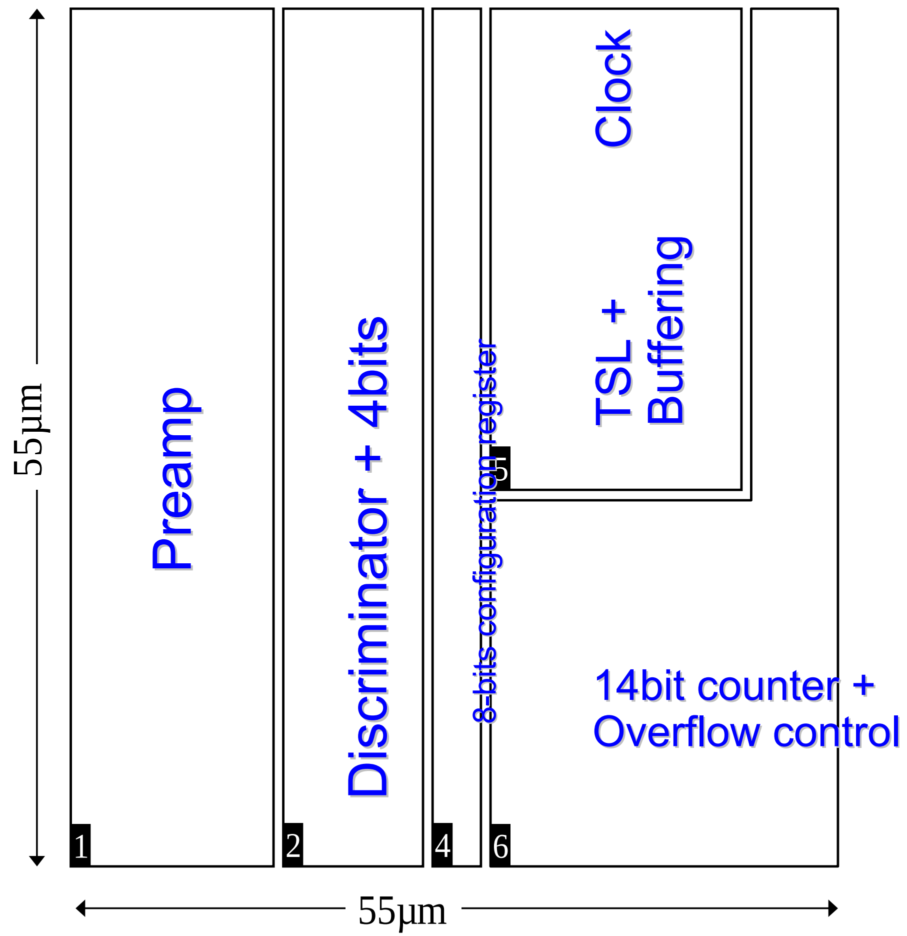


100MHz

Timepix proposed Floorplan



Mpix2MXR20 layout



Timepix proposed floorplan

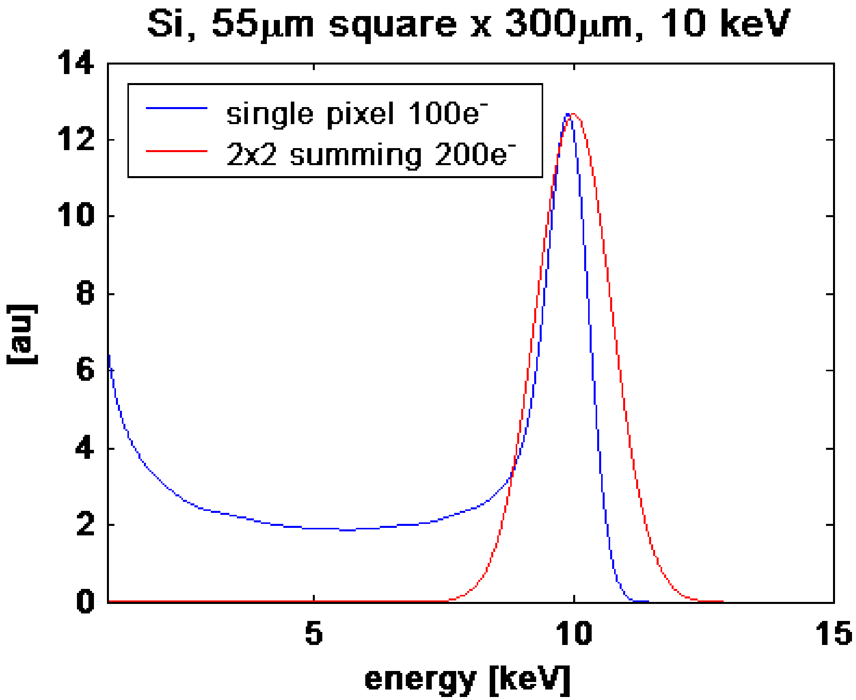
Timepix - Summary

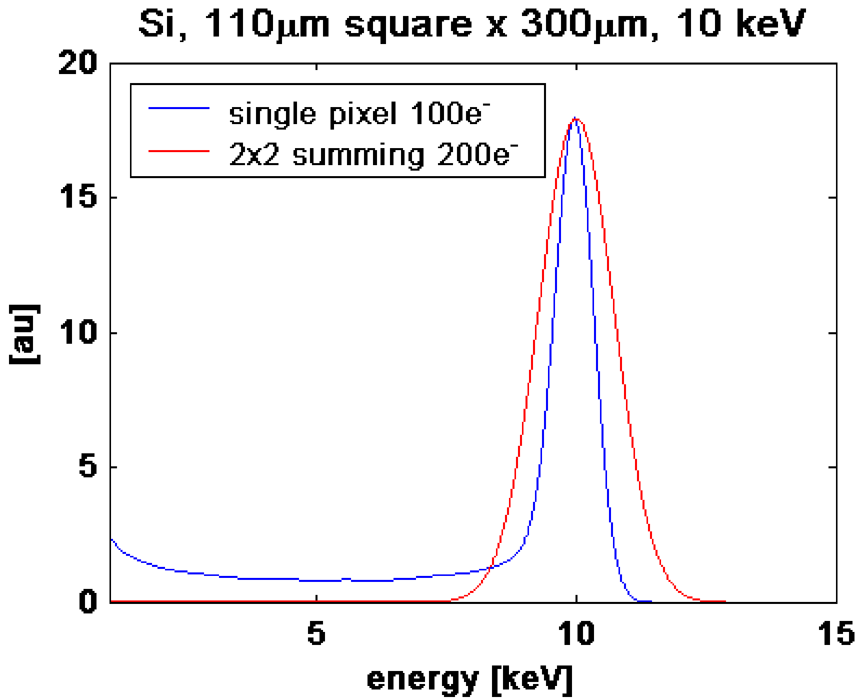
- Timepix development is driven by TPC readout for the ILC (EUDET consortium)
- Timepix will act as proof of principle for concept using existing Medixix2 readout system and software
- Initially foreseen for Time of Flight, the chip is now programable to measure Time over Threshold…
- Chip design is complete!
- Initial Foundary tests completed May, 2006
- Ready for Production (Awaiting NASA Funding)

Medipix3 – The Next Generation

- New pixel electronics taking care of charge diffusion – event-by-event clustering
- Flexible architecture – 2 counters per pixel
- Higher acquisition and frame rate with dead time free readout possible
- Small prototype just in testing
- Uses 0.13μm CMOS
- Medipix3 will attempt to resolve many of the limitations of the Medipix2 system
- Collaboration agreement ready for signature
- Could be made Rad-Hard…

Comparison Medipix2/Medipix3 - Si





$\mu\tau \sim 5.8e3$ cm

Vbias = 120V

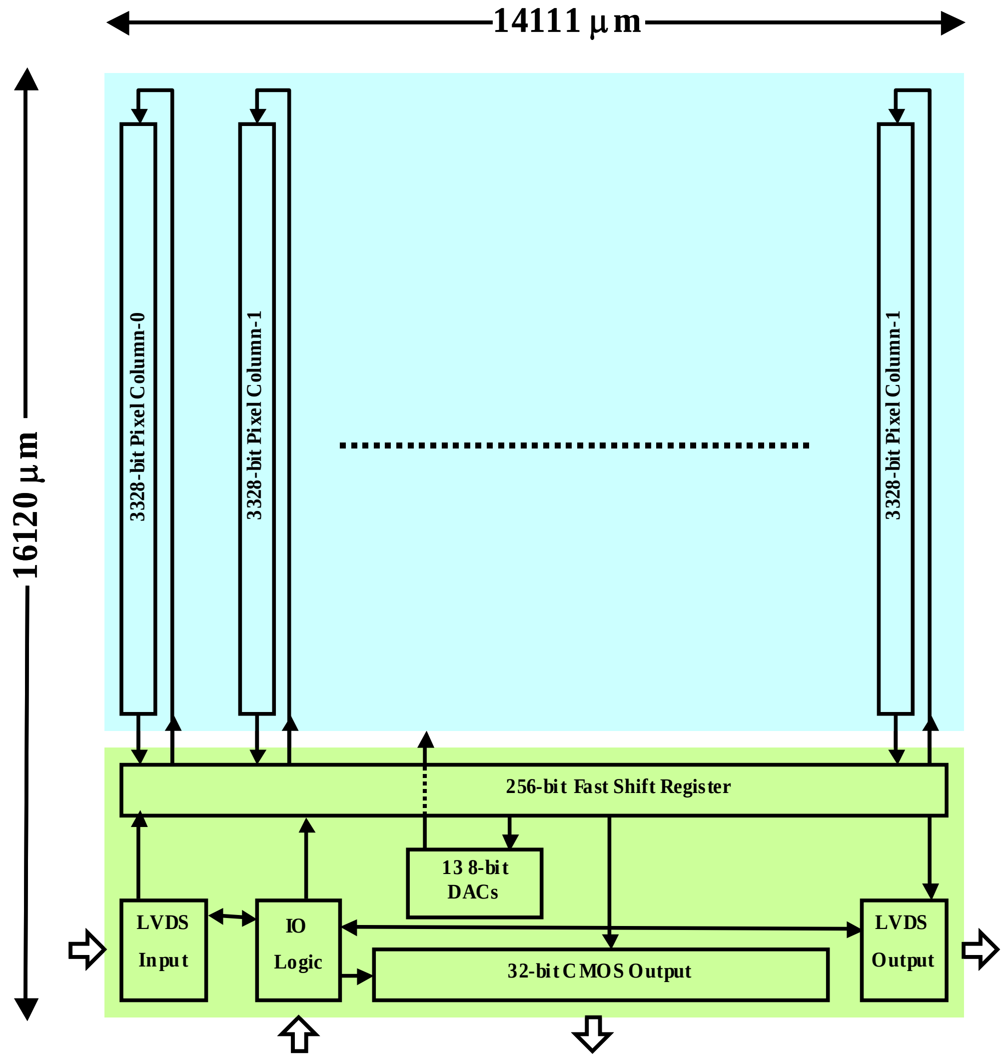
Where Do We Go From Here?

- The University of Houston has been invited to join the Medipix Consortium for the purpose of developing a Space Radiation Dosimeter based on the Medipix Technology. Funding from NASA is needed to initiate this effort.
- The imminent availability of the Timepix version of the Medipix2 chip offers an immediate opportunity to develop prototype flight hardware for evaluation.
- Our intention is to try and fly a prototype within 2 years… This requires immediate NASA funding ($120k to join plus operational funding)…
- Longer term, we would like to also join the new Medipix3 Consortium to participate in the development of a robust versatile portable personal active Space Radiation Dosimeter… ($40k/yr * 4 yrs)

Thank You For Your Attention..

Medipix2 Chip Architecture

256 x 256 pixels

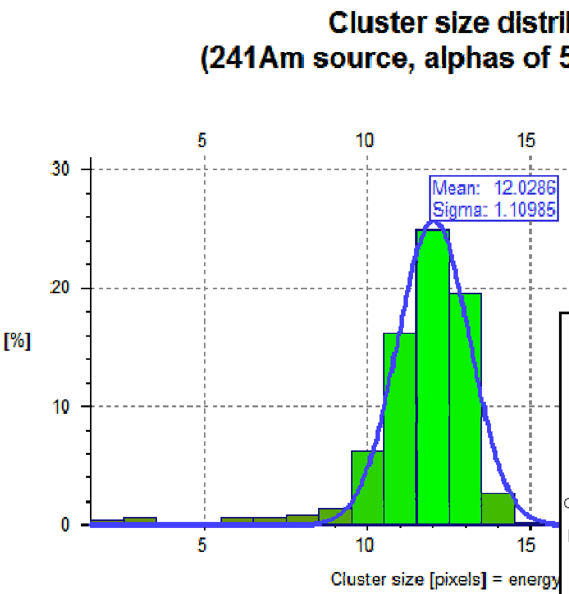


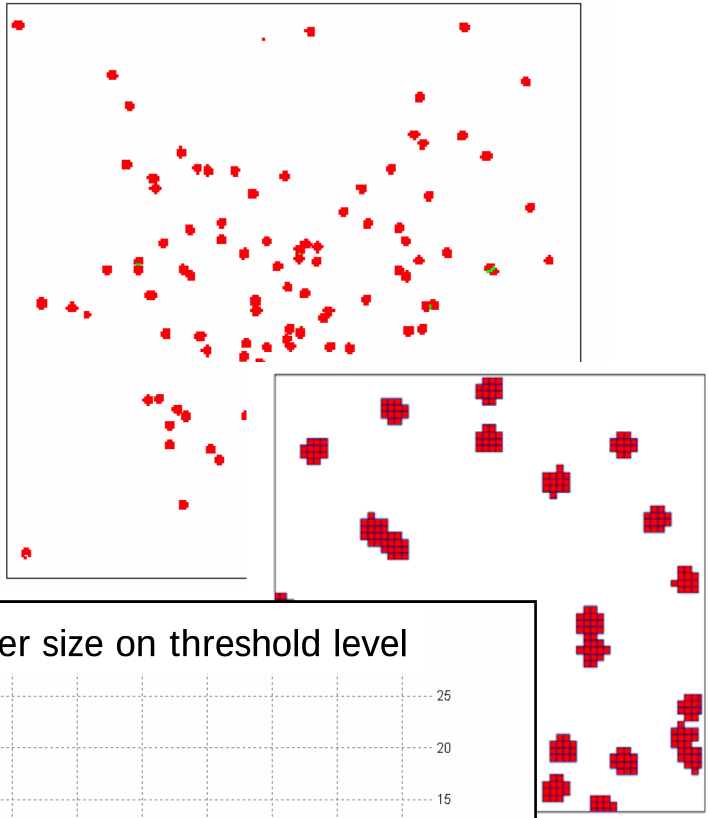
10 ms readout time

300 µs readout time

Tests of Medipix2 with alpha particles

- **Medipix-2 without converter layer**
- **Alpha particles: 5.6 MeV (^{241}Am)**
- **Short exposition time**
- **Circular clusters observed**



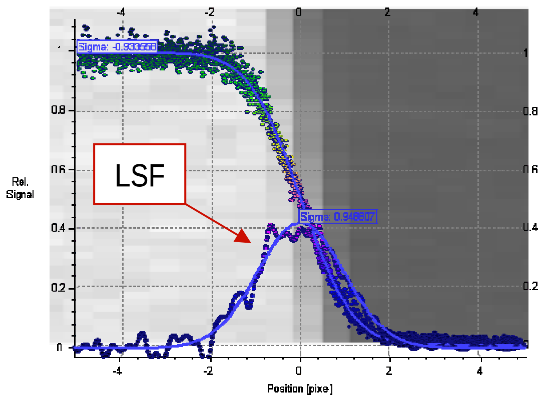


Tests with Thermal Neutrons

- **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

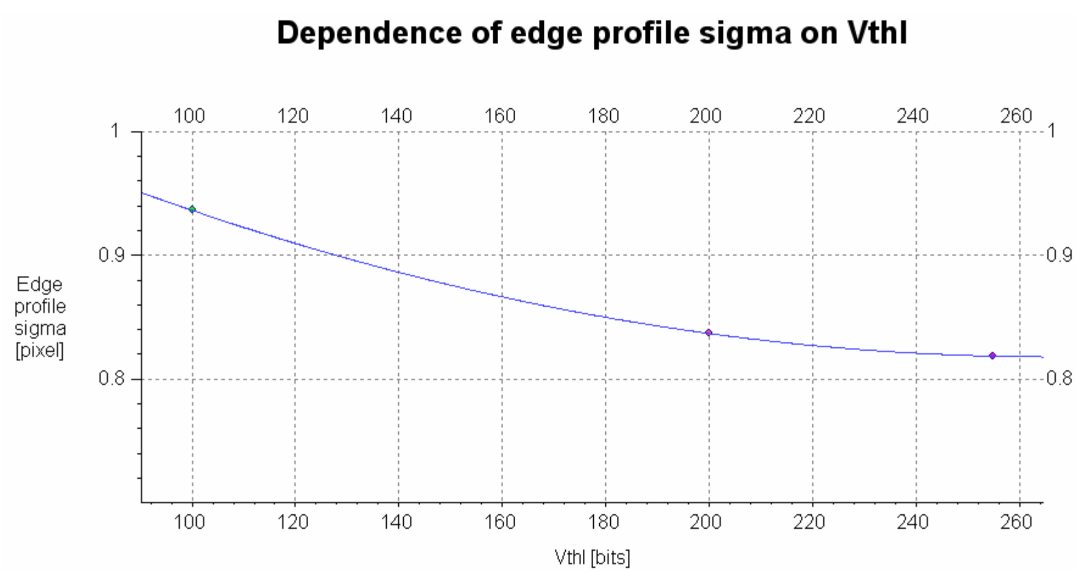
Tilted cadmium edge profile



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

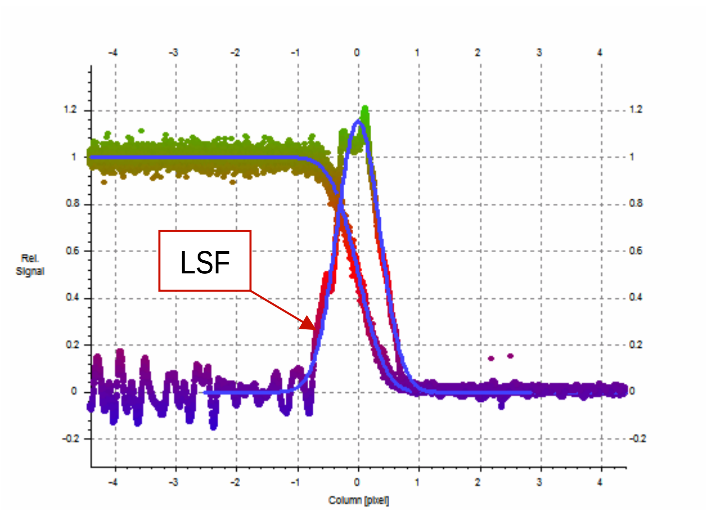
Spatial resolution is limited by size of clusters and range of product particles in silicon (R_{Triton}=44μm, R_{α}=8.9μm)

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



^{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.

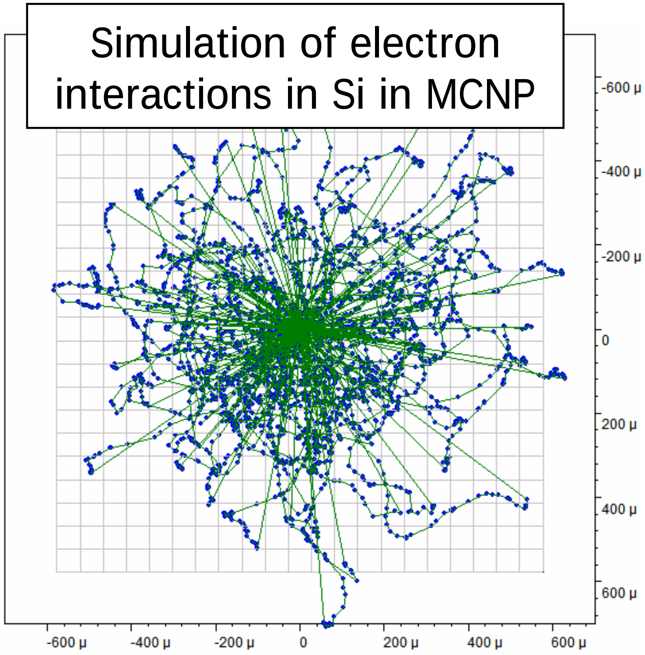
$\Rightarrow$ Spatial resolution is better

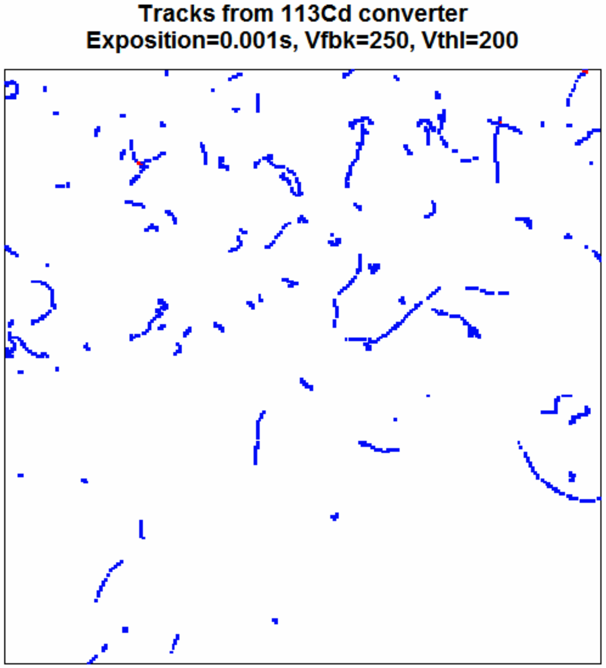
But lower number of particles can penetrate to depleted volume of the detector.

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

^{113}Cd converter

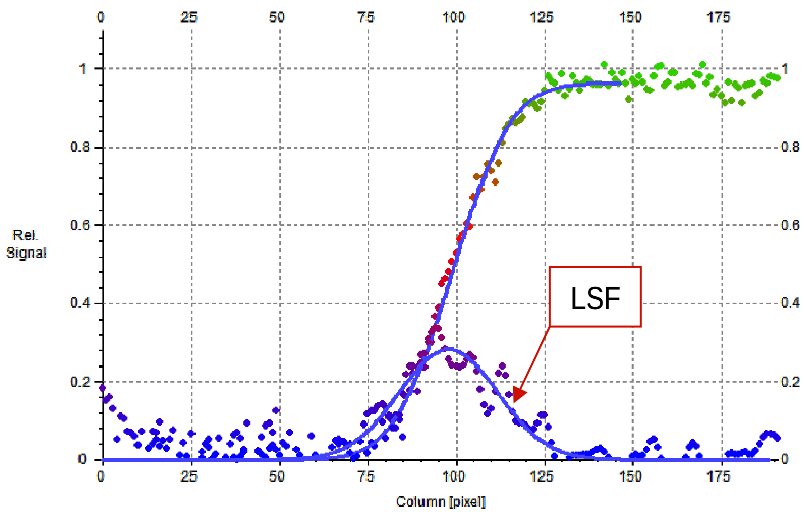
- Only conversion electrons are usable for imaging.
- Resolution highly deteriorated
- Using event-by-event acquisition and robust track analyzing algorithm it is probably possible to increase resolution.





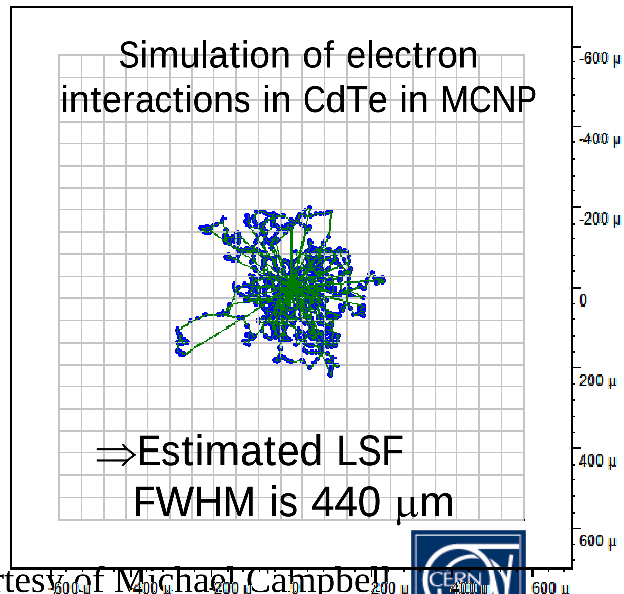
^{113}Cd converter
Spatial resolution – Edge response

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