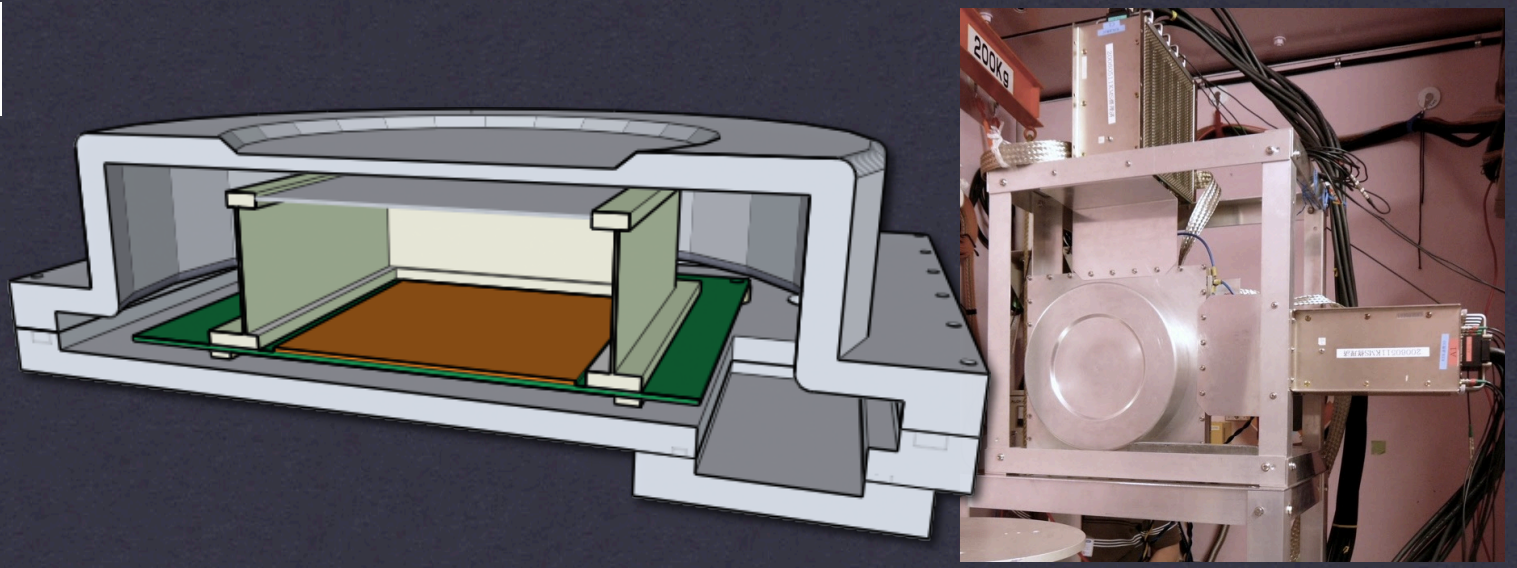
第9回 Micro-Pattern Gas Detectors 研究会　2012年12月8日



Neutron Imaging Detector Based on the μPIC Micro-Pixel Chamber

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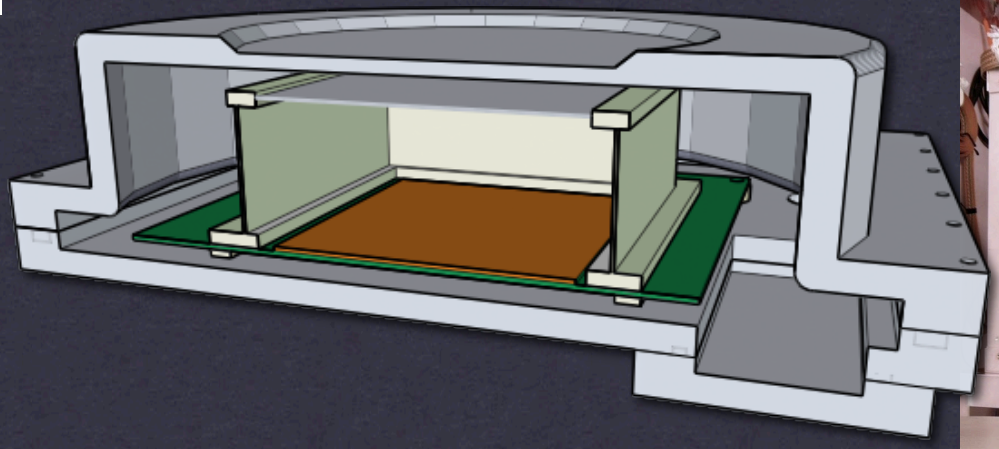
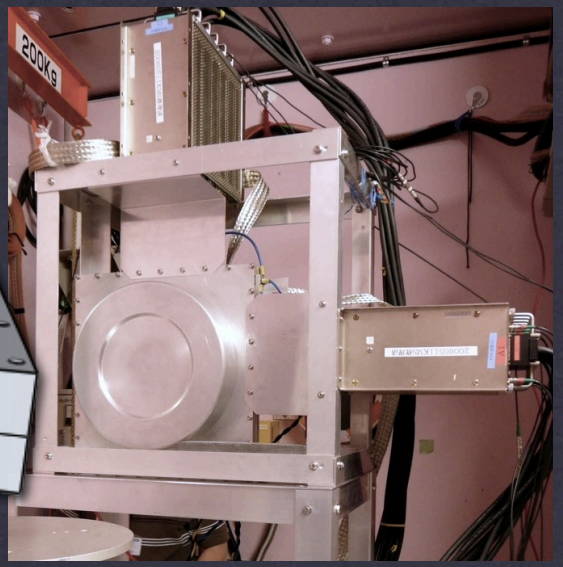
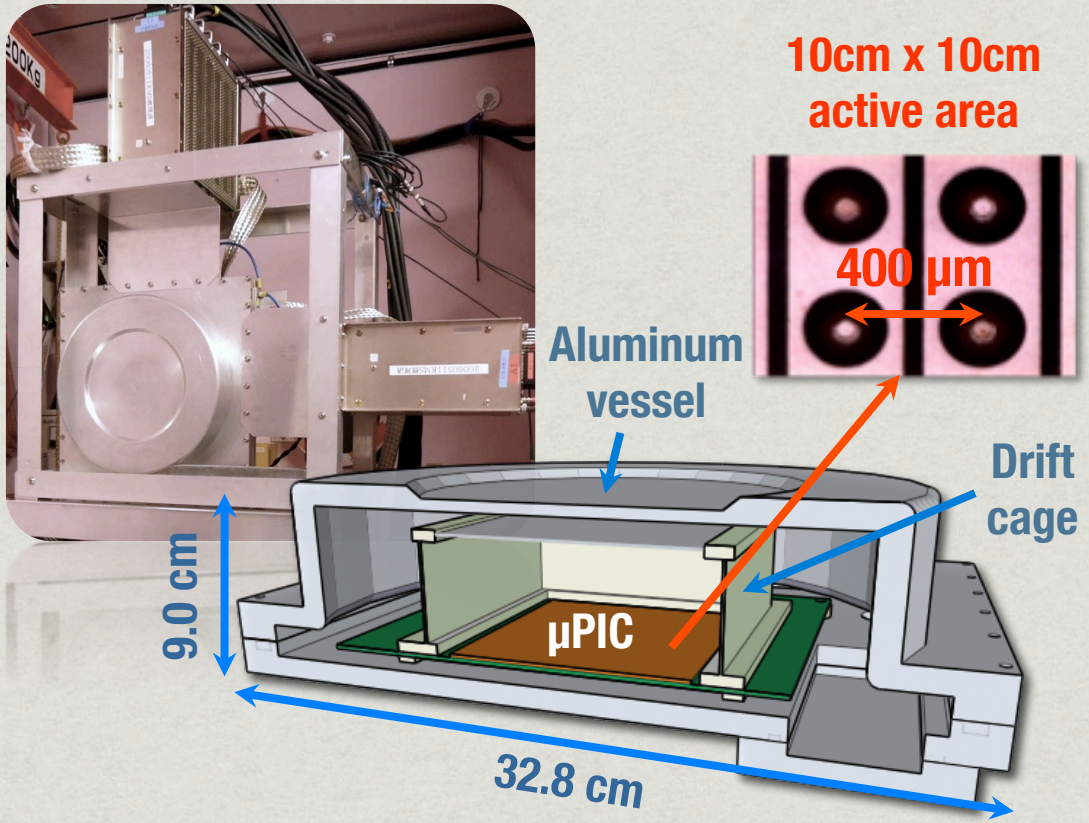




Contents

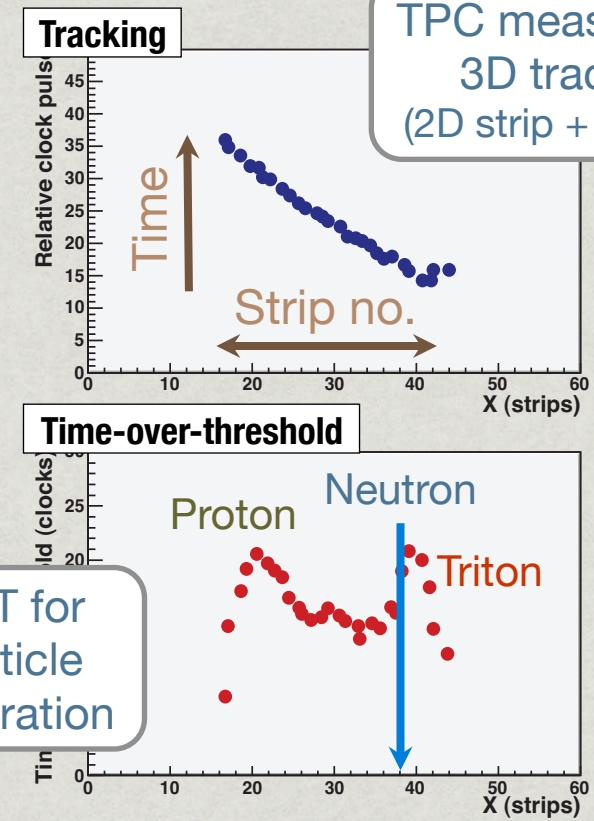
- Basic operating characteristics.
- Spatial resolution study.
- Future detector improvements.
- Recent demonstration measurements.

Time-resolved neutron imaging detector



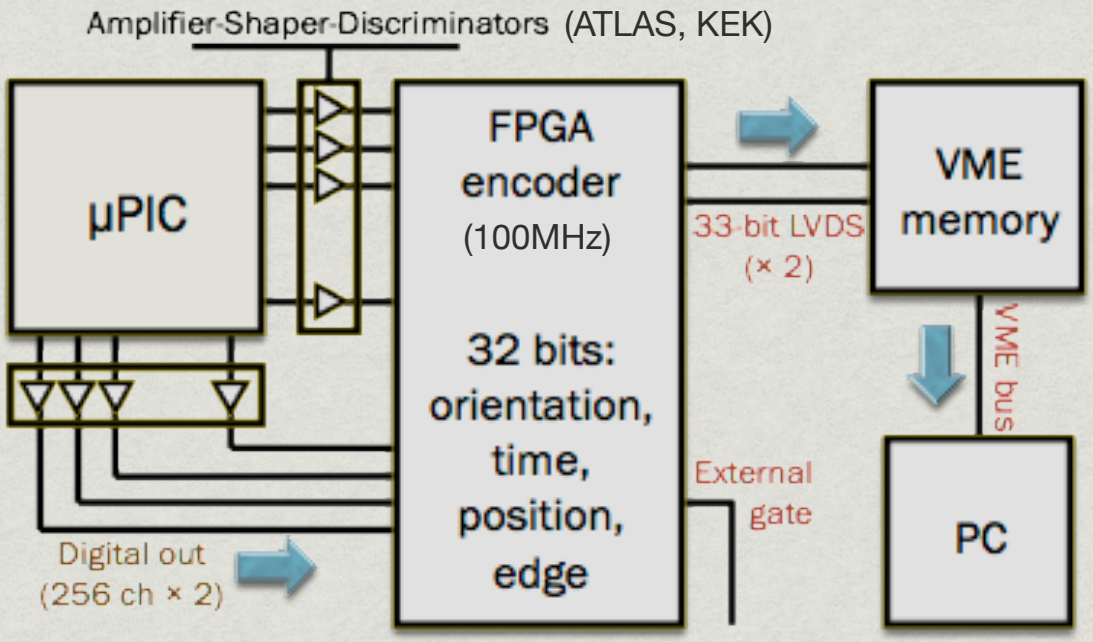
- Ar:C_2H_6:^{3}He gas mixture at 2 atm.
- Gas gain < 1000 for neutron imaging.
- Efficiency of 18% at 25.3 meV and up to 65% at 0.35 meV (2.5-cm gas depth).
- ~105 μm spatial resolution; 0.6 μs time resolution; <10^{-12} gamma sensitivity.
- 2 years operation or more on single gas filling.

FPGA encoder with time-over-threshold (TOT)



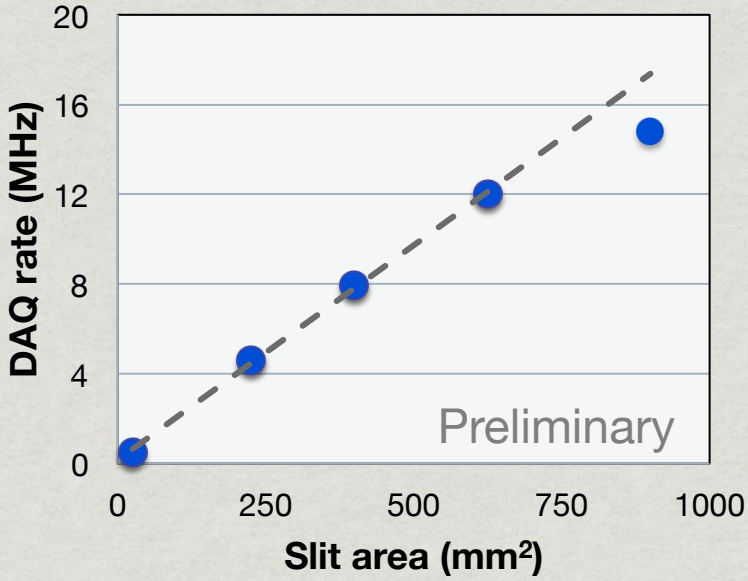
Improved position accuracy and background rejection via detailed tracking.

DAQ and FPGA logic



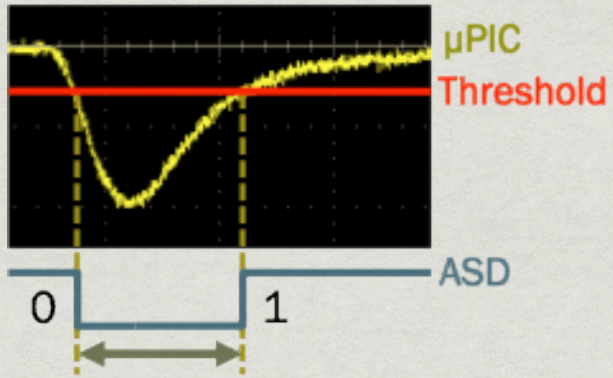
Rate test at NOBORU, J-PARC (2012)

Neutron intensity varied by adjusting size of slit opening



Data encoding

- Two words per pulse.
- 'Edge bit' saved with each data word.



Time-above-threshold
(∝ energy deposit)

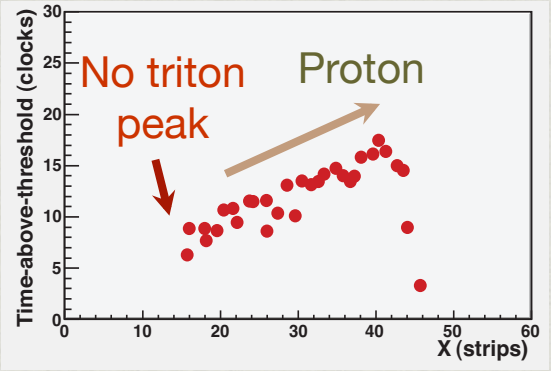
DAQ shows good linearity up to a data rate of 10~12MHz (neutron rate of ~200kcps).

Deviation due to internal FIFO overflows in FPGAs.

Fast neutron and gamma rejection

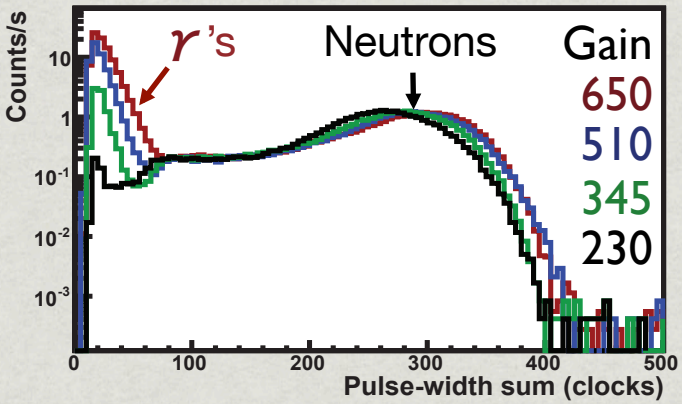
TOT distribution for scattered proton

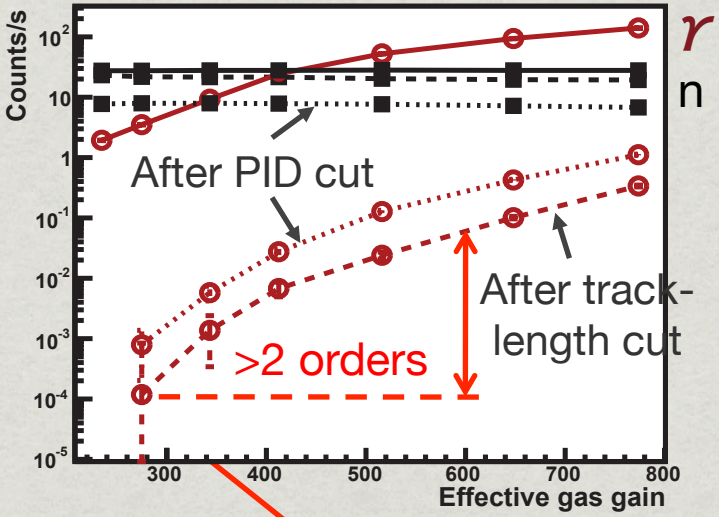
Fast neutrons from ^{252}Cf source



- Track length and total energy can be similar to neutron events.
- Distinguished by shape of TOT distribution.

TOT sum with no cuts and n and γ event rates (^{137}Cs + ^{252}Cf)

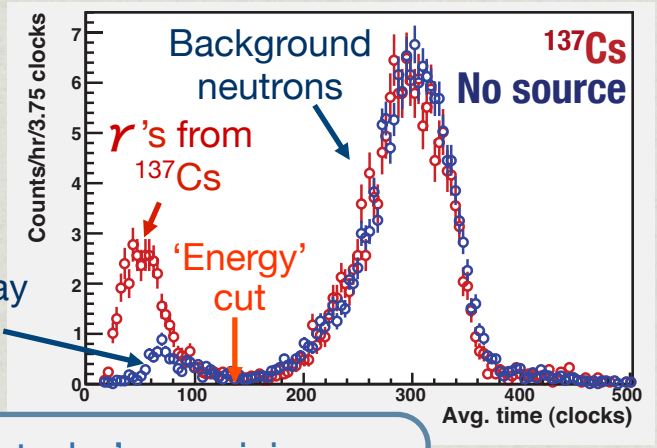




Event-by-event TOT sum (1-MBq ^{137}Cs)

Gas gain ~600, track-length cut applied

Gamma efficiency $<10^{-3}$ at gain of 600.



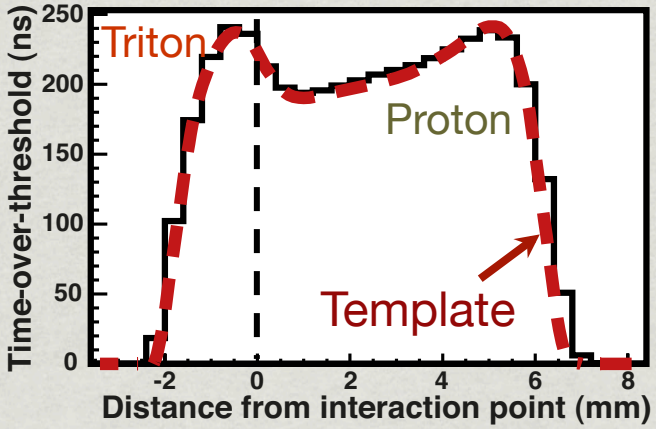
Fraction of detected γ's surviving neutron cuts < 10^{-6} (effective gamma sensitivity of < 10^{-9} at gain of ~600).

Sensitivity of order 10^{-12} or less can be achieved at reduced gain without loss of neutron efficiency.

Spatial resolution

- Proton-triton separation essential for spatial resolution.
- Proton direction, neutron position determined by 'template' fit.

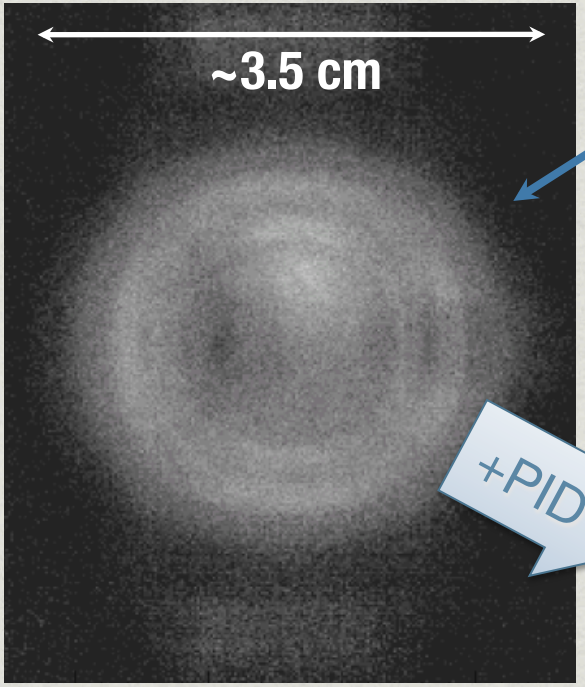
Measured TOT distribution



$$TOT(x,m) = A\ \mathrm{Template}_m[\hat{x} f_w(x - x_N)]$$

Templates generated with GEANT4 simulation of detector.

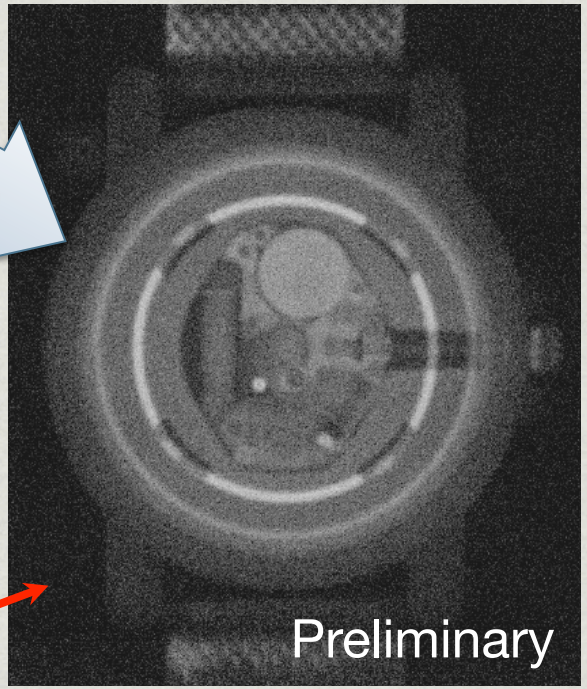
Image taken at NOBORU, J-PARC in Feb. 2011.
Gas gain ~470, Exposure time 29 mins.



Bin size: 200 μm × 200 μm.

Position from mid-point of track.
Resolution: ~1mm(σ)

+PID



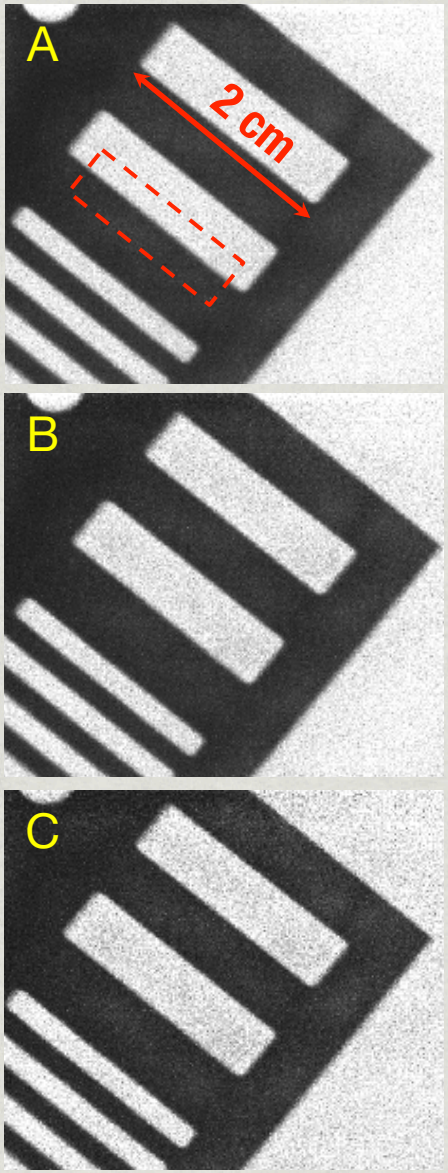
Bin size: 80 μm × 80 μm.

Preliminary!
Resolution with PID:
104 to 124μm(σ)
(Final resolution depends on tracking cuts.)

Spatial resolution: Characterization

Resolution from knife-edge test

Cadmium test chart, gas gain ~470



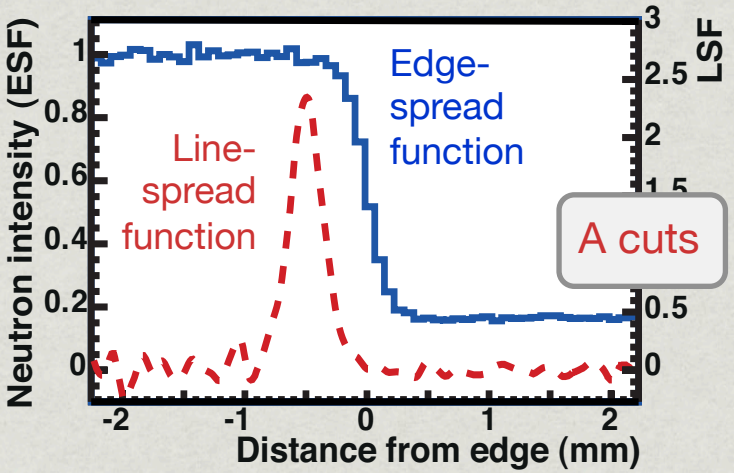
	Res(μm)	Eff(%)
A	131 ± 3	100
B	125 ± 3	66
C	111 ± 4	32

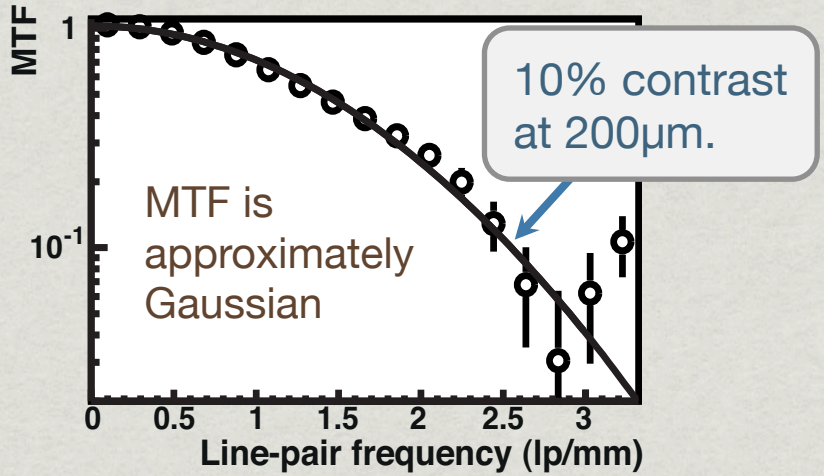
A. Gamma-rejection cuts on track-length/energy deposition.

B. + Z-consistency of proton direction between anode and cathode.

C. + Two peaks (proton and triton) in TOT distribution.

Modulation transfer function



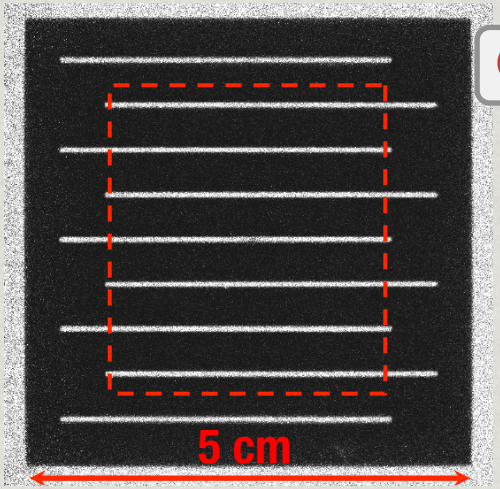


Line-pair: one light and one dark line.

Image taken at NOBORU, J-PARC in March 2012.

Spatial resolution: Uniformity

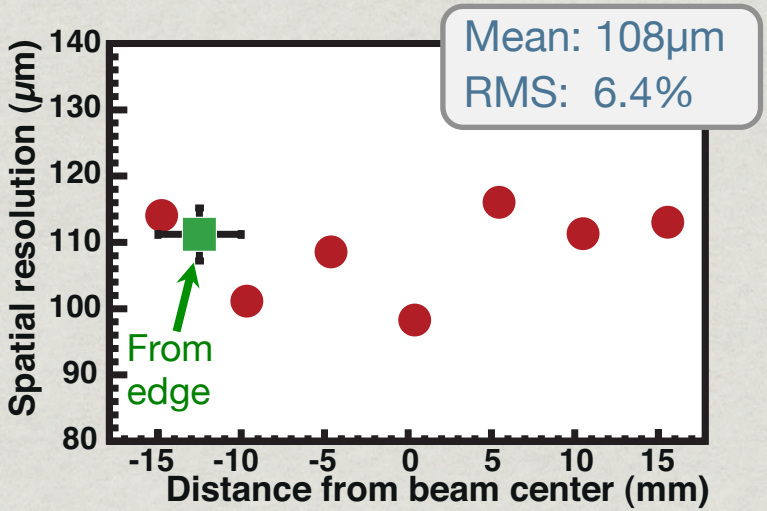
Uniformity of resolution



C cuts

Image taken at gas gain of ~470.

Uniformity evaluated over 3cm × 3cm area.

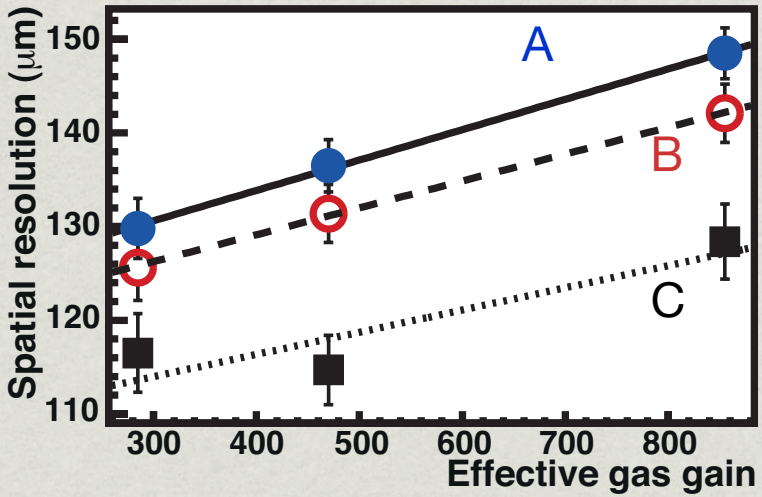


Mean: 108μm
RMS: 6.4%

After correcting for beam divergence:

Mean: 104μm
RMS: 5.3%

Resolution vs gas gain



A. Gamma-rejection cuts.
B. + Z-consistency.
C. + Two peaks in TOT.

- Resolution improves by ~3μm per 100 decrease in gain.
- Optimum gain 250~300 (neutron efficiency decreases below gain of ~200).

Data taken at NOBORU, J-PARC in March 2012.

Improvement of spatial resolution

Gas properties

- Shorten proton-triton track lengths.
- Reduce electron diffusion.

Improvements to μPIC

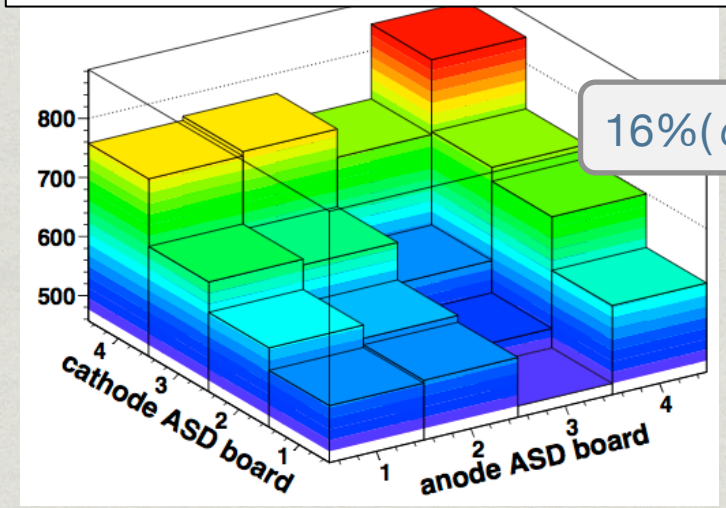
- Improve gain variation (better manufacturing controls).
- Reduce pixel pitch.

Simulation results for different gas mixtures

	Pressure (atm)	Transverse diffusion ($\mu m/cm^{1/2}$)	p-t track length (mm)	Expected improvement in resolution
Ar:C_2H_6:^{3}He (63:7:30)	2	273	7.9	(105μm~)
Ar:C_2H_6:^{3}He (63:7:30)	3	231	5.3	~15%
Xe:C_2H_6:^{3}He (50:20:30)	2	183	5.0	~15%
Ar:CO_2:^{3}He (50:20:30)	2	107	7.4	~15%

Gas parameters determined by MAGBOLTZ.
Resolutions estimated with GEANT4.

Measured gain variation of prototype



- Reducing gain variation improves spatial resolution by 5~10% and uniformity by 15~30%.
- In low gain operation, pixel pitch can be reduced to ~200μm.
- GEANT4 studies are ongoing.

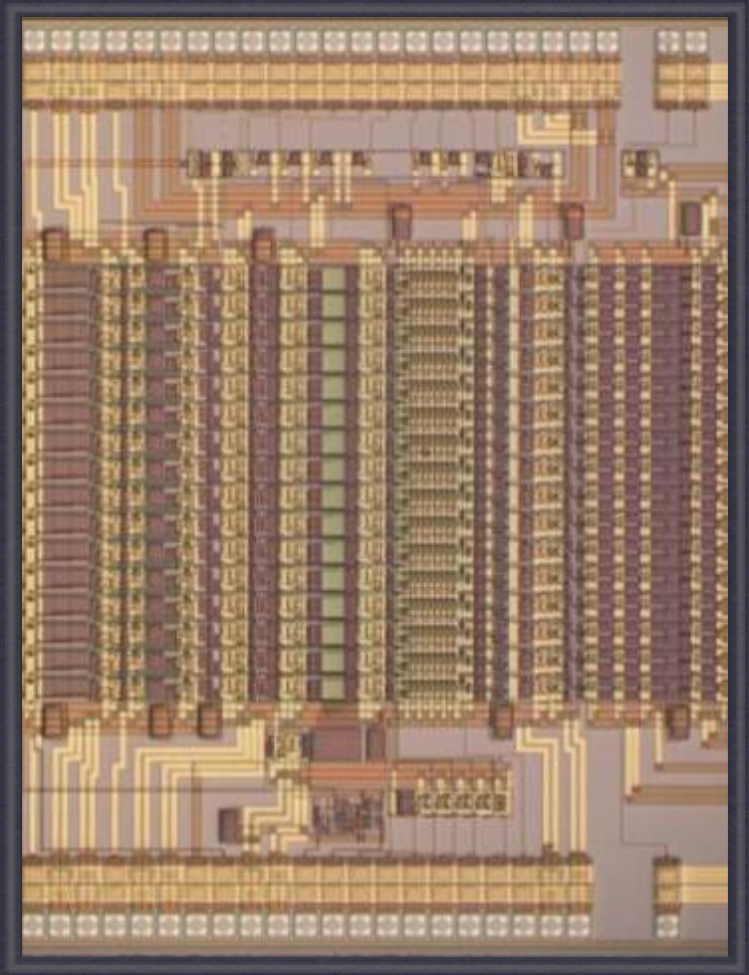
Resolution after diffusion and gain variation improvements: 80~90μm.

Plus smaller pixel pitch: < 70μm.

Preliminary!

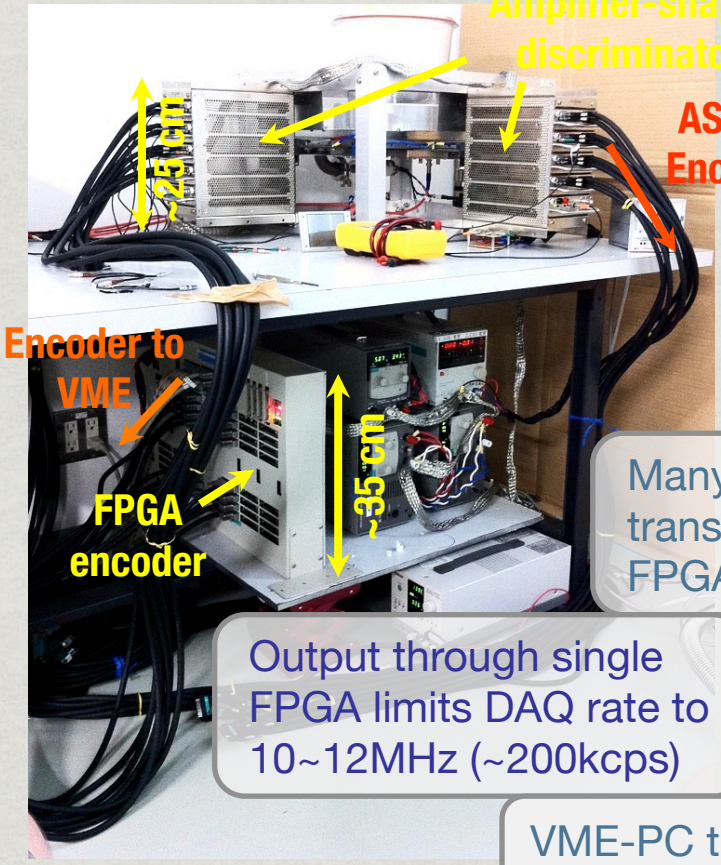
DAQ upgrade

- New ASICs and encoder for higher rate DAQ.



DAQ upgrade

Current DAQ



Many cables transfer signals to FPGA encoder

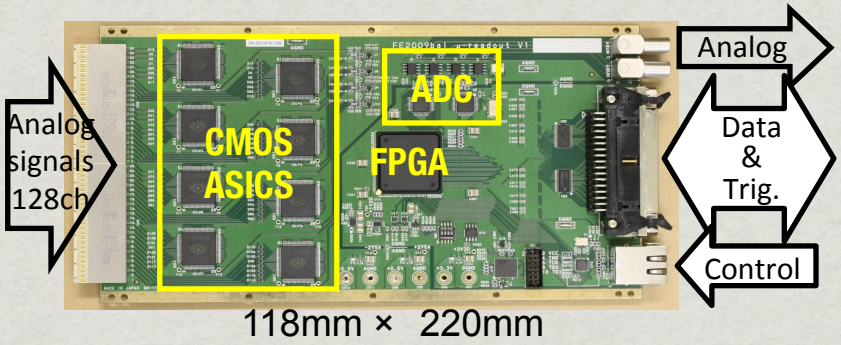
Output through single FPGA limits DAQ rate to 10~12MHz (~200kcps)

VME-PC transfer limits live-time

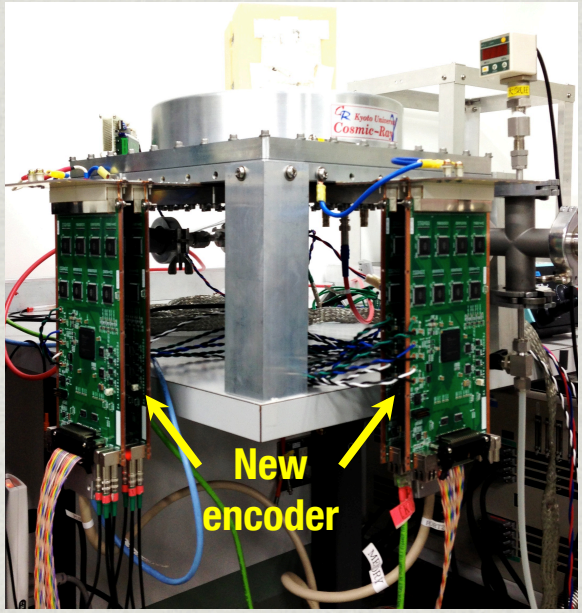
VME-PC transfer

- Implement faster VME readout (block transfer, double-buffer).
- Block transfer gives 1.5X increase; double-buffer not yet tested.
- For future, switch to SiTCP.

New encoder module



- 128 channels per board.
- ASICs and FPGA on single board.

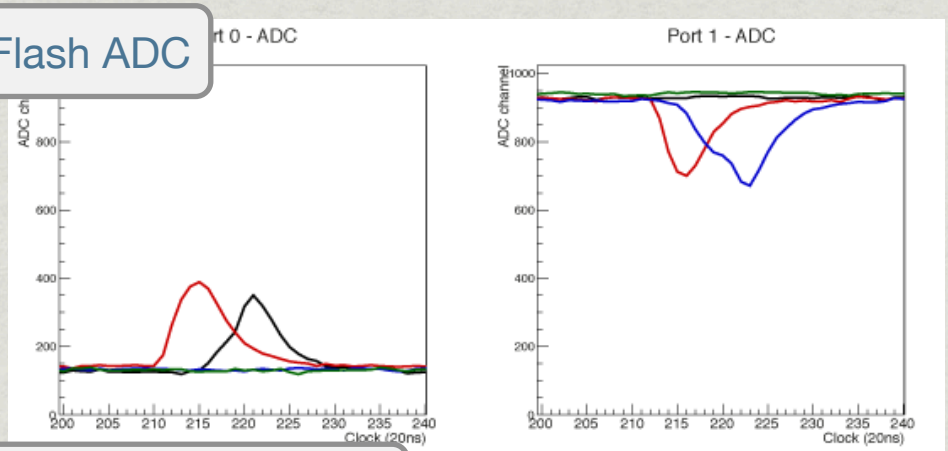


Expect rate increase by factor of 4 or more.

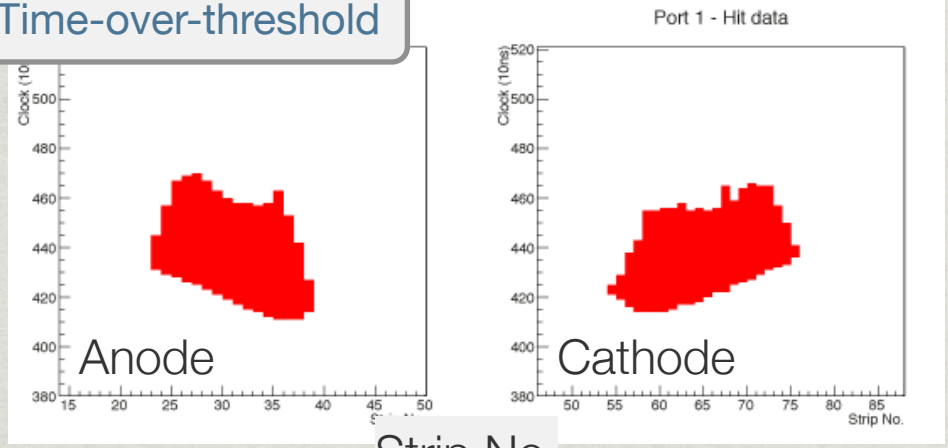
DAQ upgrade

Neutron event
(proton-triton track)

Flash ADC



Time-over-threshold

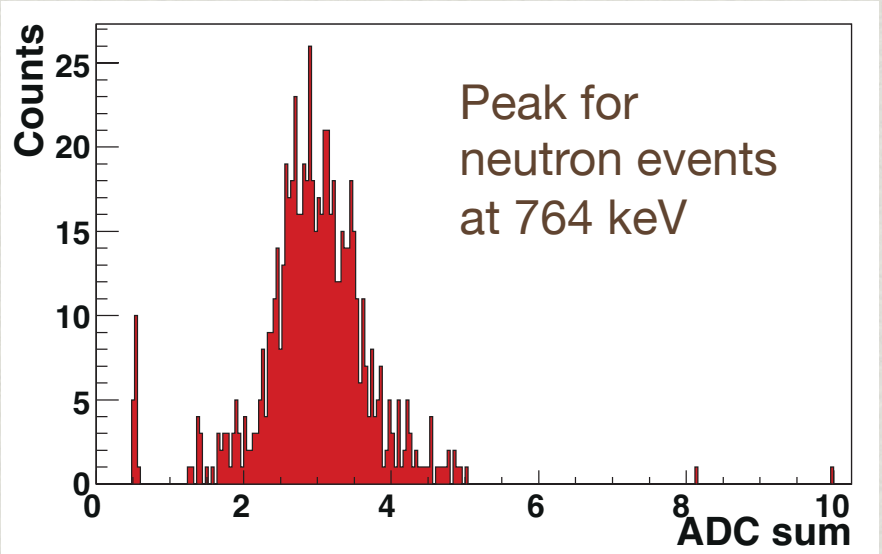


Time

Strip No.

Double-peak from stopping proton and triton in ADC and TOT.

ADC spectrum

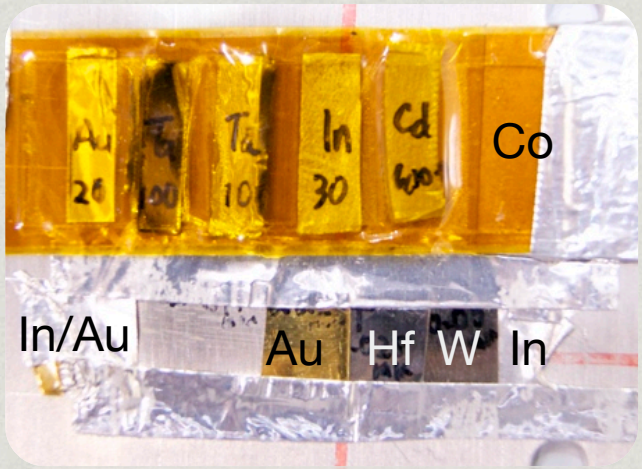


- Preliminary check OK.
- Determine threshold for optimum TOT behavior.
- Write FPGA code specific for neutron imaging.

Recent measurements

- Resonance absorption.
- CT test measurement.

Neutron resonance absorption



Exposure: 5 hrs
Rate: ~10 kcps
Live time: 60%

External TOF gate applied (0 – 2.2ms)

- Measurement of neutron TOF allows selective imaging of nuclides via resonance absorption.
- Good time resolution is essential.

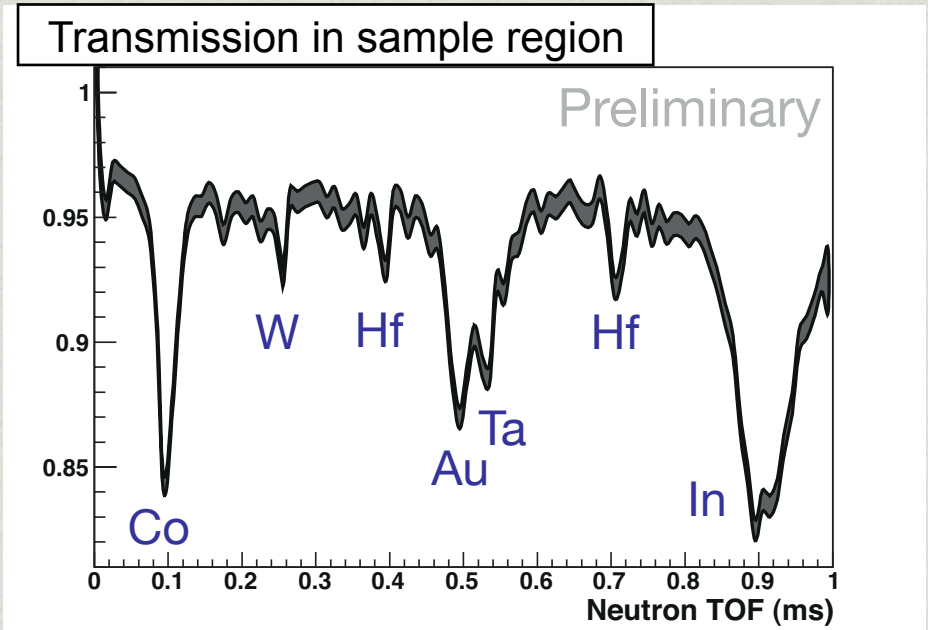
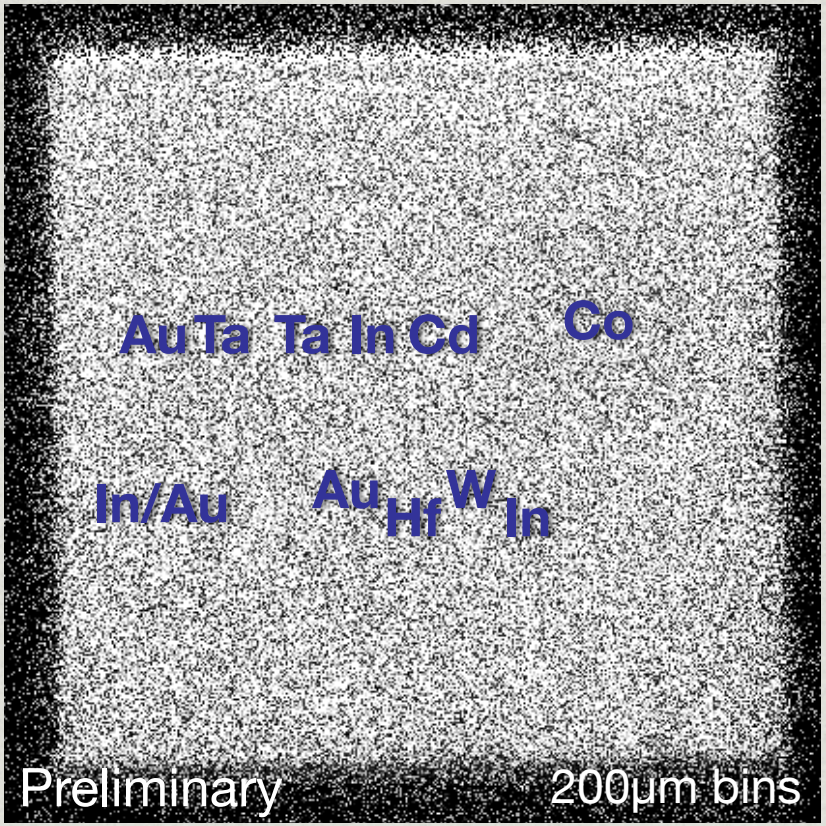
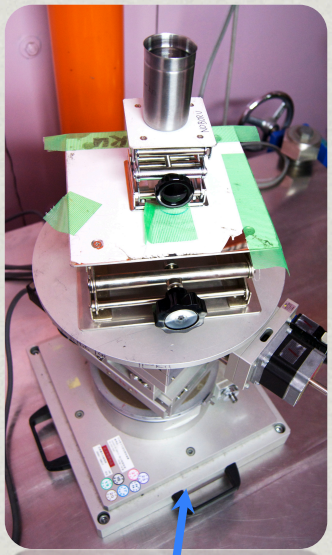


Image vs. TOF (0 ~ 1 ms)

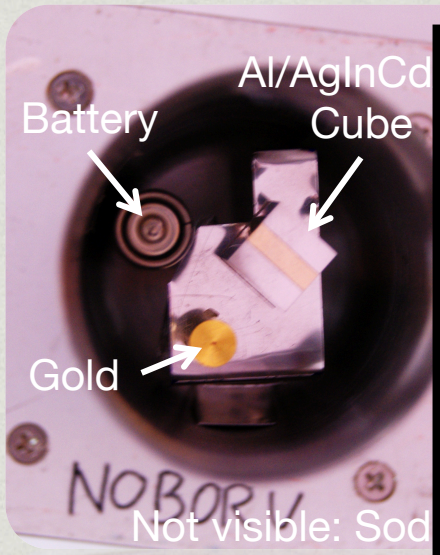


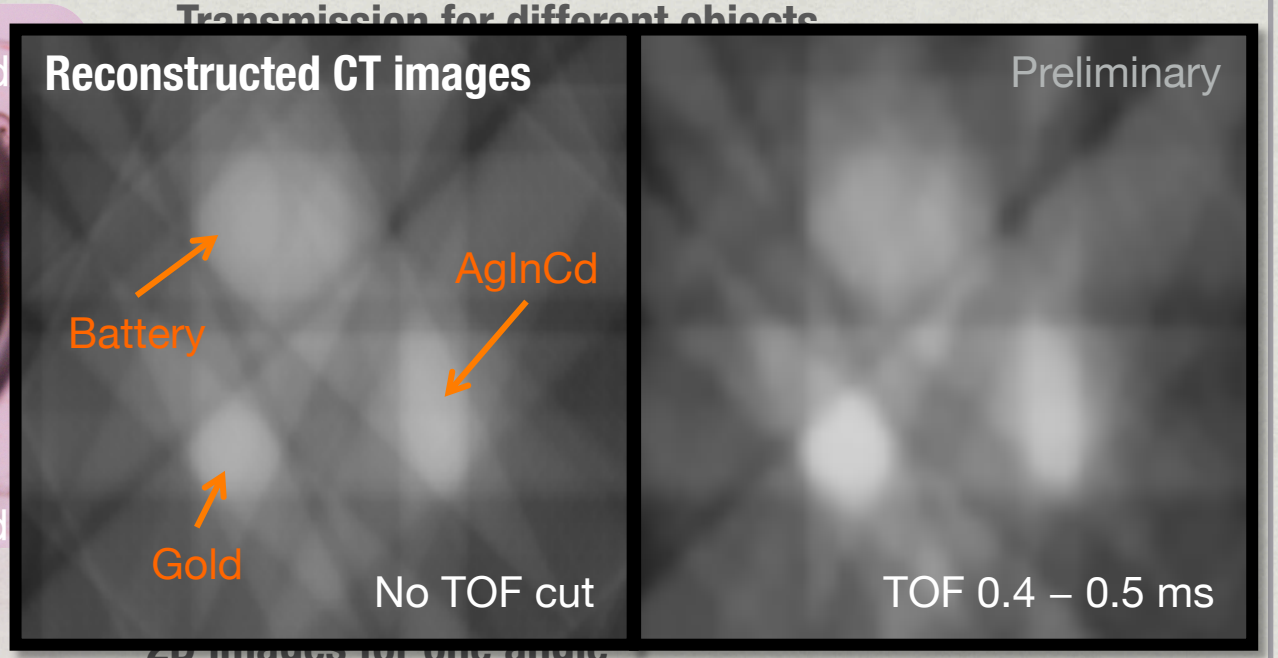
Data taken at NOBORU in March 2012.

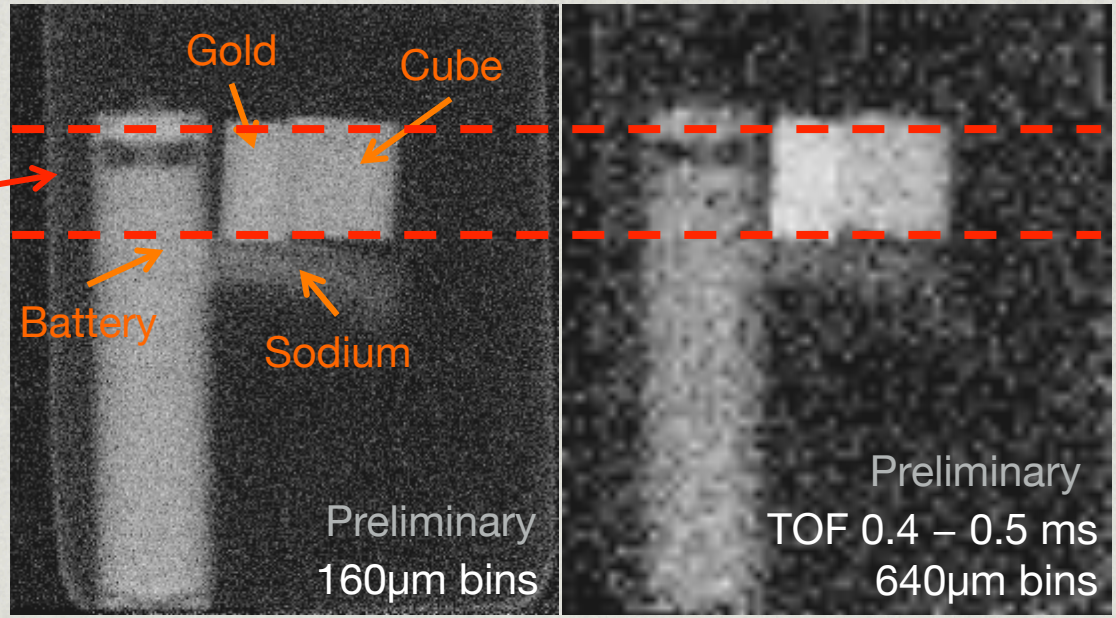
CT test measurement



Goniometer with θ -rotation from -155° to 155°.







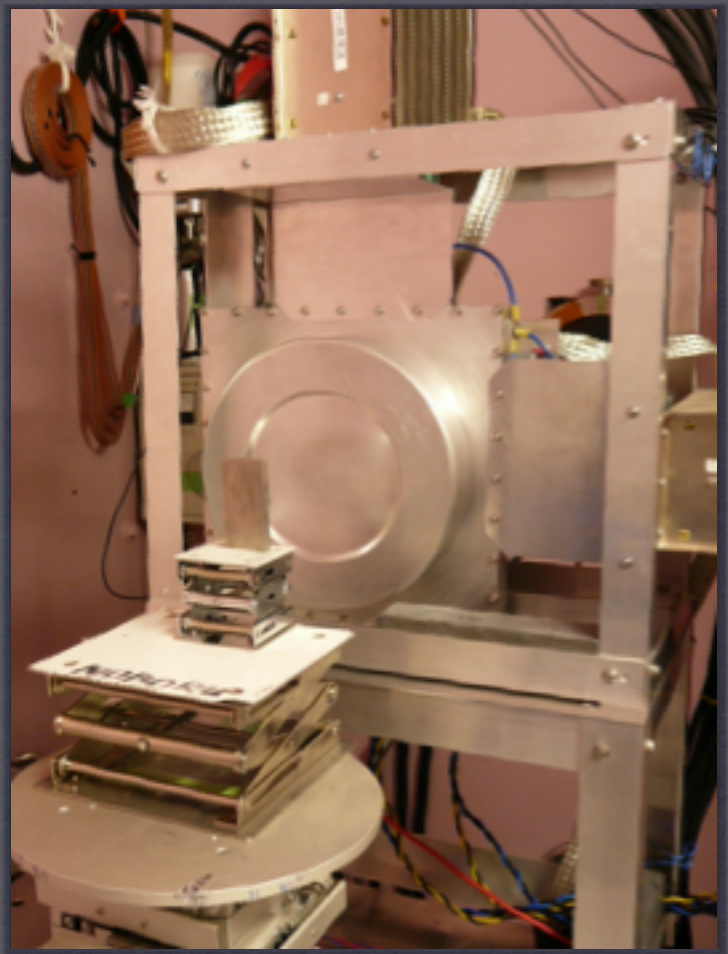
- 9 angles (6 independent), 54 minutes/angle.
- TOF: 0 – 3 ms
- Neutron rate ~10 kcps, Live time 60%.
- CT reconstruction using simple back-projection method.

Data taken at NOBORU in March 2012.

Summary

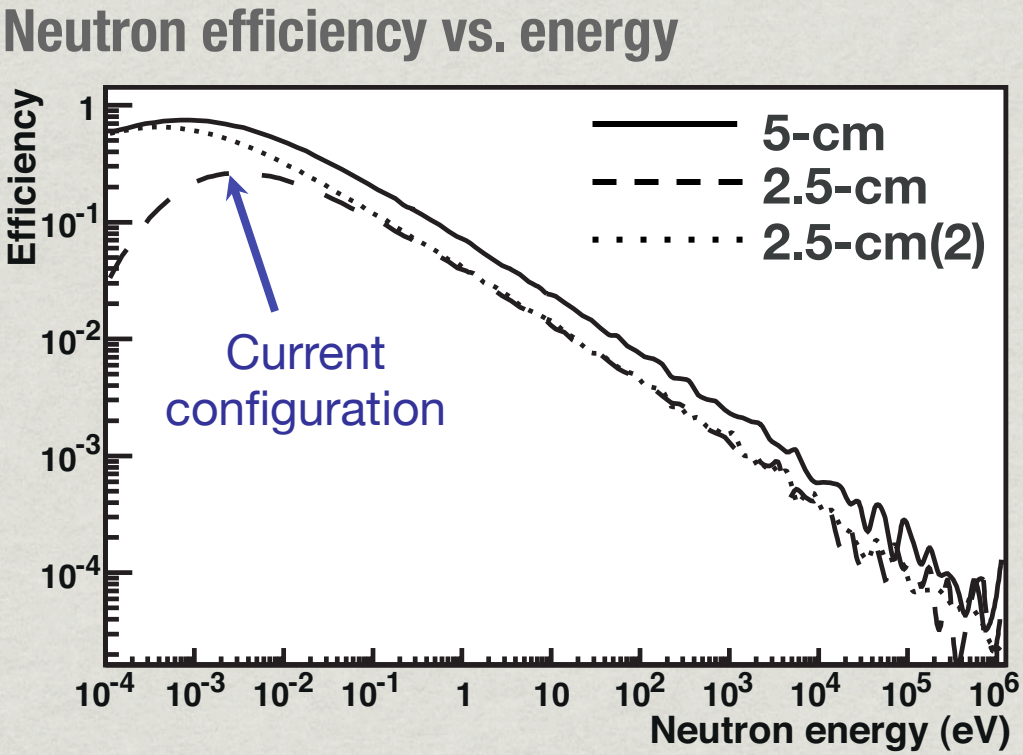
- μPIC-based time-resolved neutron imaging detector.
  - For radiography, neutron resonance absorption imaging/spectroscopy, Bragg-edge transmission, CT imaging, SANS.
- Detector performance.
  - Spatial resolution of 104 μm (100% reconstruction eff.) to 124 μm (32% reconstruction eff.).
  - Time resolution ~0.6 μs; very small effective gamma sensitivity $< 10^{-12}$.
  - Can operate for ~2 years on a single gas filling.
  - After upgrading DAQ and optimizing gas, maximum neutron rate on order of 1 Mcps and spatial resolution <100 μm.
- Next
  - Develop and test new FPGA code for neutron imaging.
  - Beam test of new DAQ at NOBORU this February.

Extra slides



Neutron efficiency

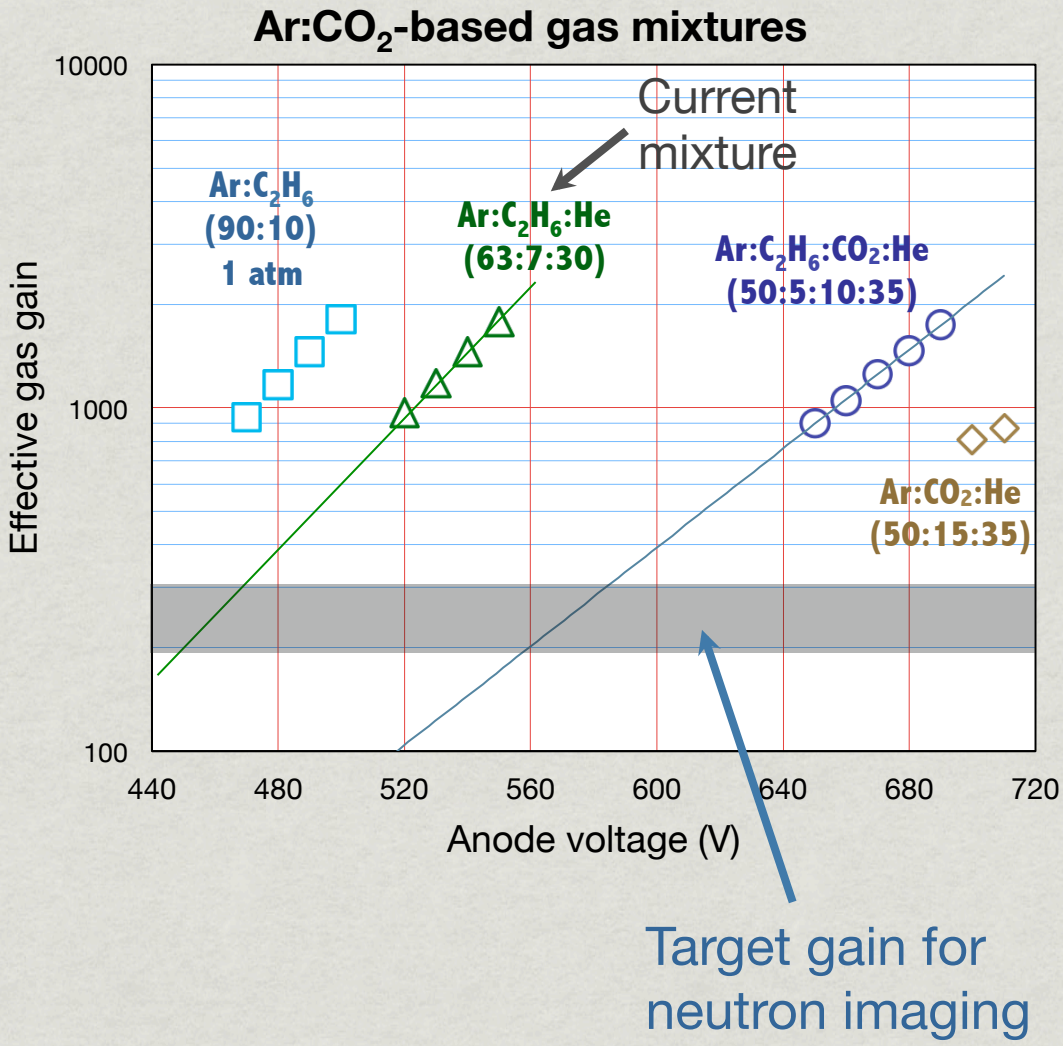
- Neutron efficiency as a function of neutron energy.
- Determined from GEANT4 simulation.
- Loss of peak efficiency due to large dead layer in current configuration (2.5-cm).



Drift cage configuration	Drift height	Dead layer	Efficiency at 25.3 meV	Peak efficiency
5-cm	5.0 cm	0.8 cm	0.35	0.75 (0.7meV)
2.5-cm	2.5 cm	3.3 cm	0.18	0.27 (3meV)
2.5-cm(2)	2.5 cm	0.8 cm	0.20	0.65 (0.35meV)

Gas study – Ar:CO_2-based mixtures

- Compared following mixtures at 2 atm:
  - Ar:C_2H_6:He (63:7:30)
  - Ar:CO_2:He (50:15:35)
  - Ar:CO_2:C_2H_6:He (50:10:5:35)
- C_2H_6 included to increase gain and stability.
- ^{4}He used in place of ^{3}He.

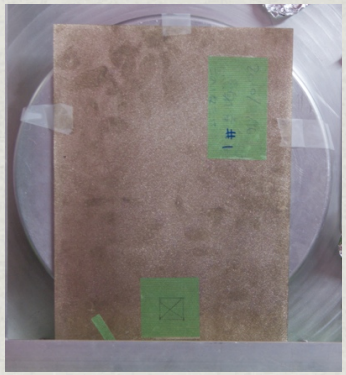


CO_2-based mixtures require higher anode voltages.

Next steps:

- Check gain variation.
- Add small amount of ^{3}He and measure proton-triton tracks.

Resonance absorption: Ag-In-Cd alloy



- Plate thickness: 3 mm.
- Exposure: 2 hrs.
- TOF gate: 0 – 3 ms.
- Neutron rate: ~10 kcps.
- DAQ live time: 70%.

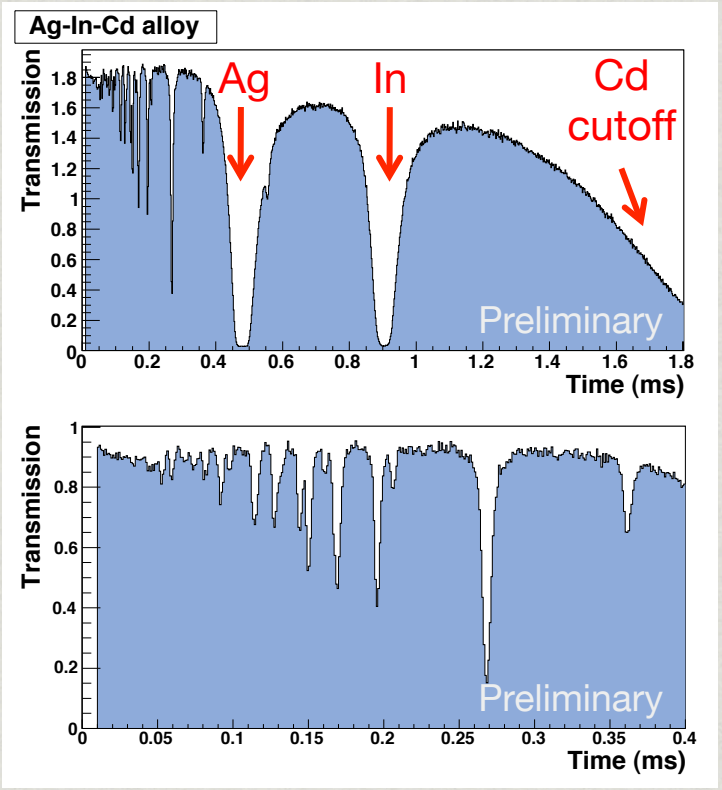
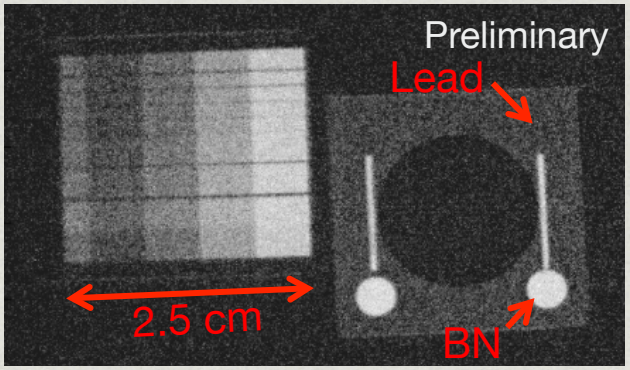


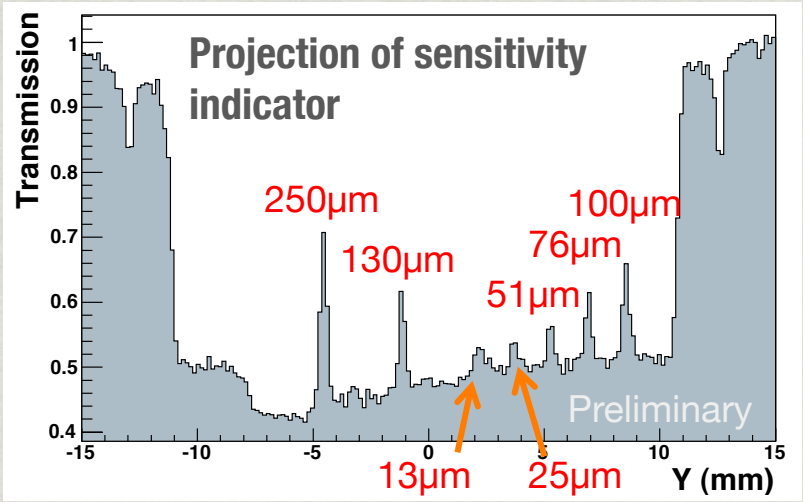
Image of ASTM indicator

Image taken with μPIC (100 μm bins)



- Exposure: 3 hrs.
- No TOF gate.
- ~120 kcps.
- Live time: 14%.

X-ray provided with sample



Data taken at NOBORU in March 2012.