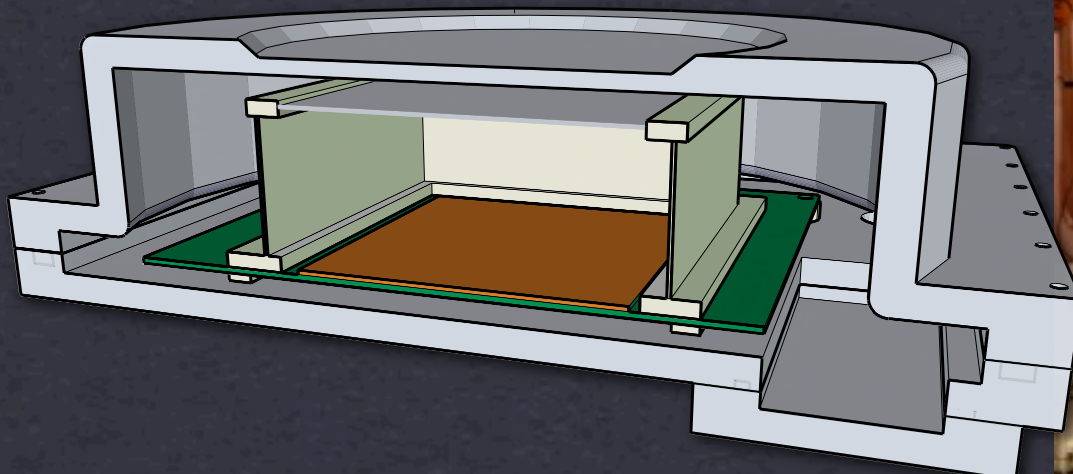
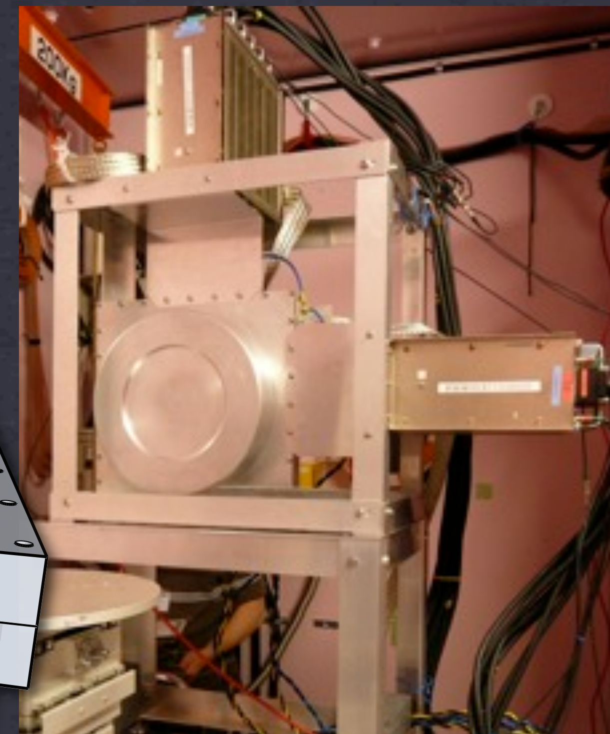




Neutron Imaging Detector based on the μPIC

Joe Parker
Cosmic Ray Group, Kyoto University

MPGD2011, 30 Aug 2011

KYOTO UNIVERSITY, COSMIC RAY GROUP

J.D. Parker, K. Hattori, S. Iwaki, S. Kabuki, Y. Kishimoto, H. Kubo, S. Kurosawa, K. Miuchi, H. Nishimura, T. Sawano, T. Tanimori, K. Ueno

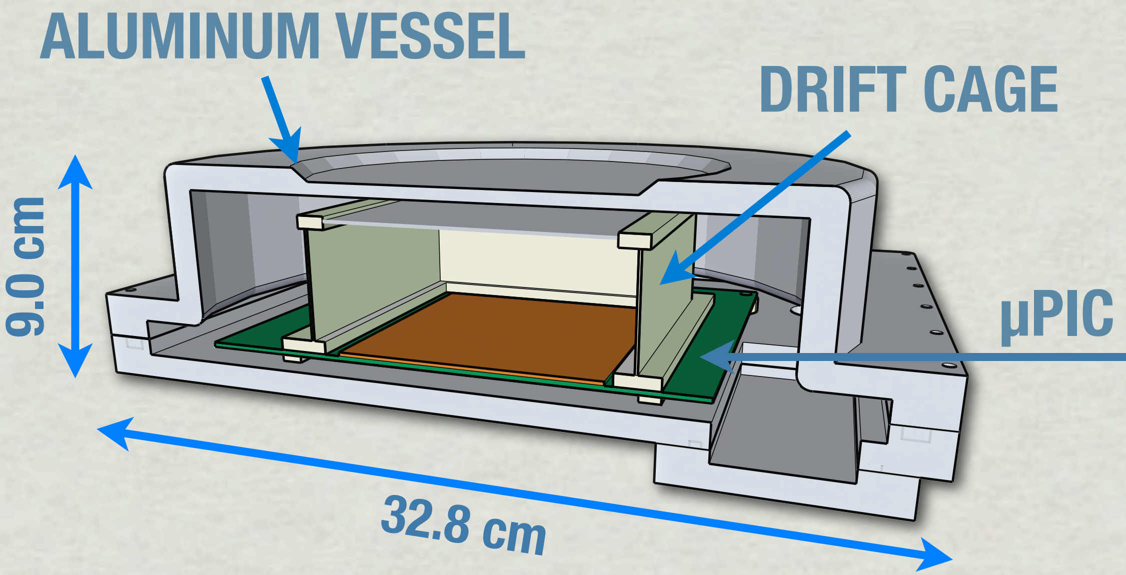
JAPAN ATOMIC ENERGY AGENCY, MATERIALS AND LIFE SCIENCE FACILITY DIVISION

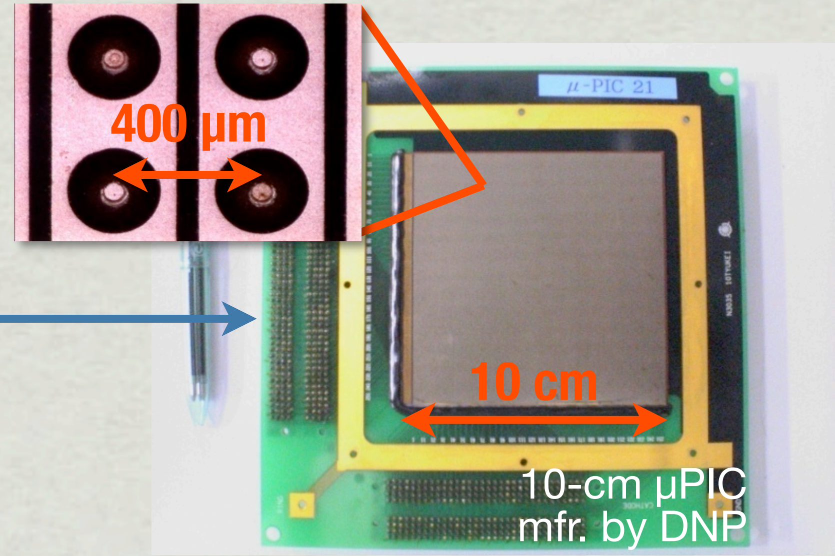
M. Harada, T. Oku, T. Shinohara, J. Suzuki

Neutron Imaging Detector based on the μPIC

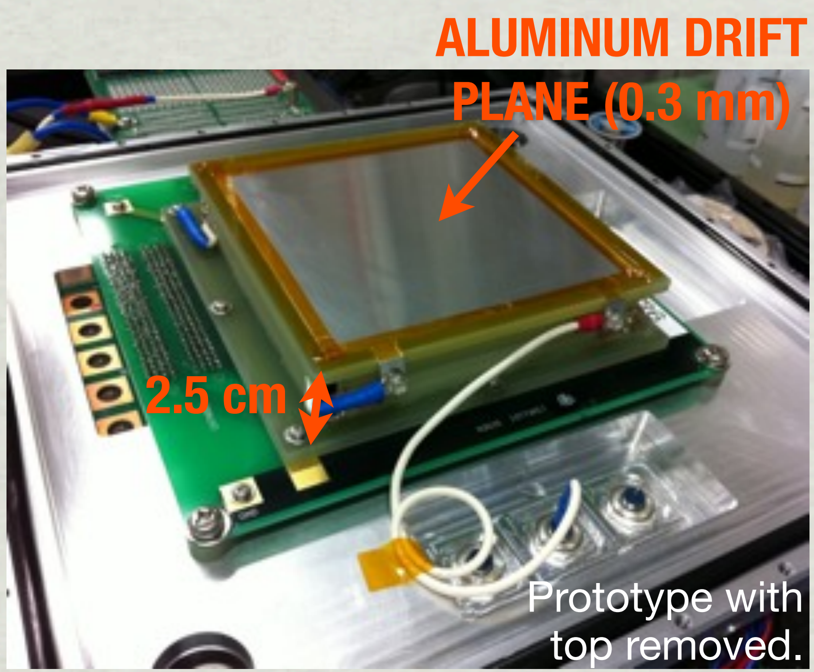
- Prototype system and basic operation.
- Demonstration measurements.
- Future improvements.

Neutron imaging detector prototype (μNID)

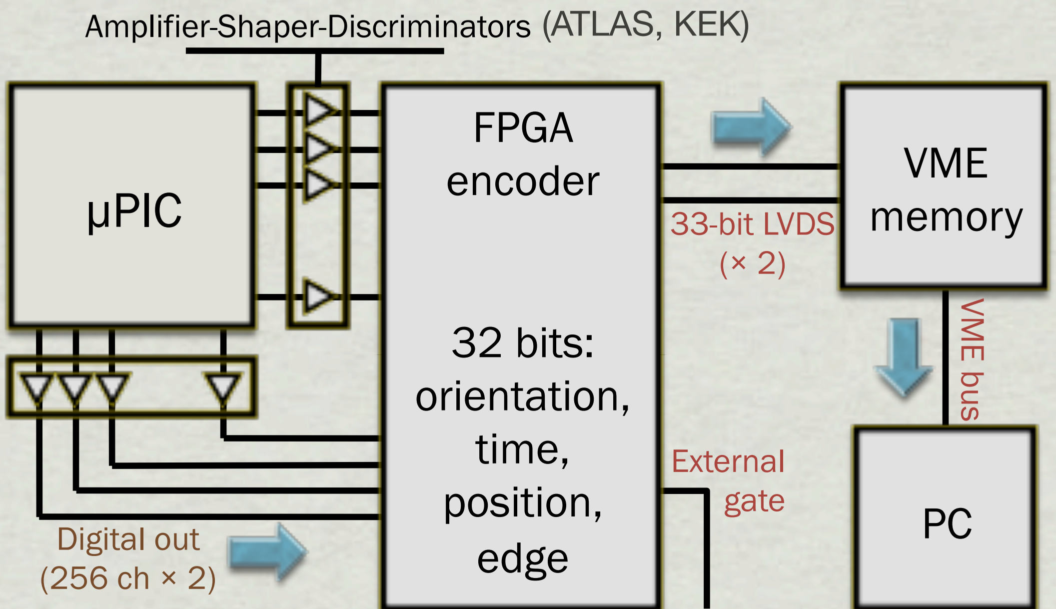




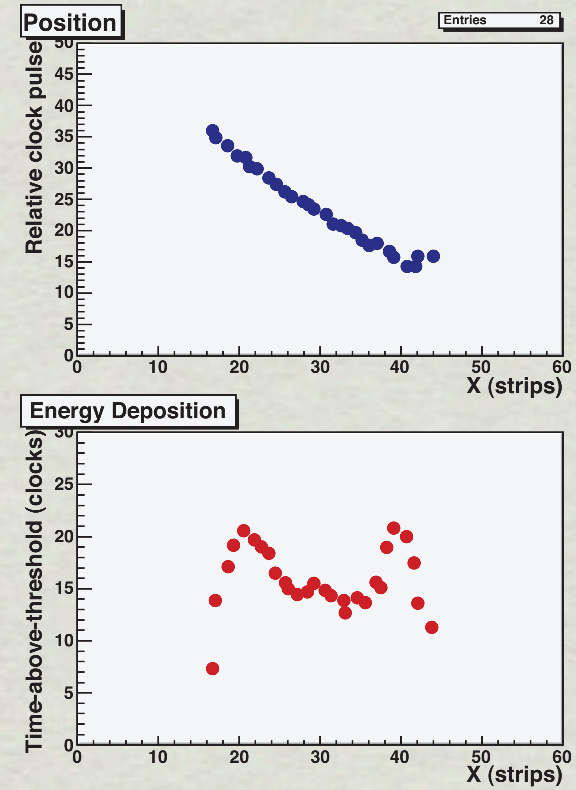
- Ar-C_2H_6-He^3 (up to 2 atm total pressure).
- Gas gain < 1000 for neutron imaging.
- TPC measures 3D proton-triton tracks.
- Compact, high-rate FPGA-based DAQ.
- Energy deposition estimated by time-above-threshold method.
- Efficiency up to ~30%, position res. of ~120 μm, time res. of ~1 μs.



DAQ and FPGA logic

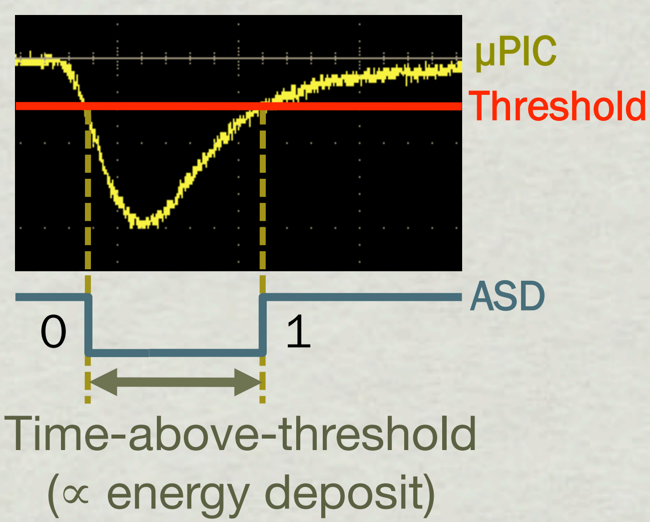


PROTON-TRITON TRACKS



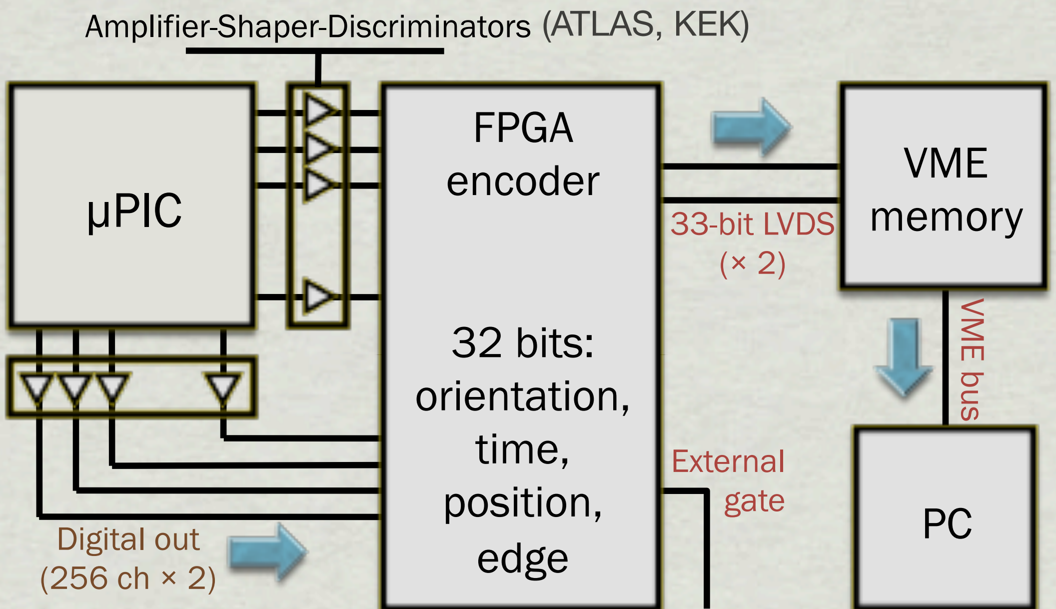
DATA ENCODING

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

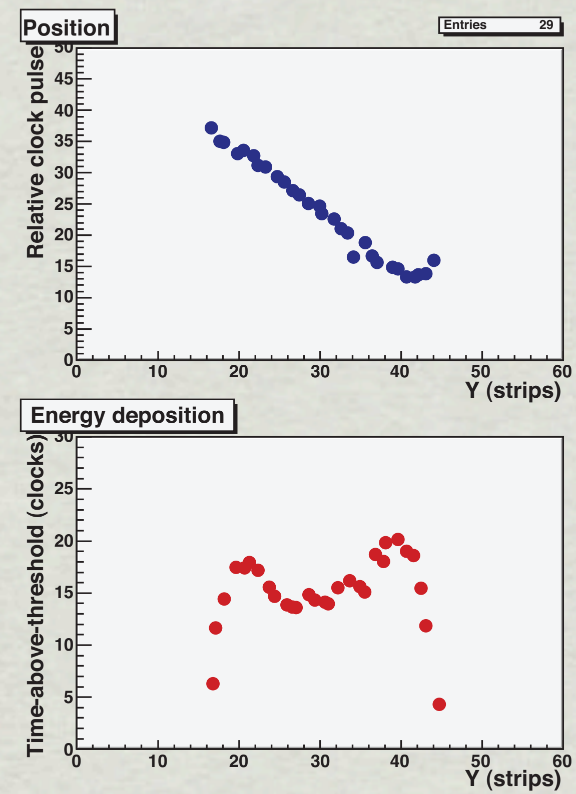


Simultaneous measurement of position and 'energy deposition' at high rates.

DAQ and FPGA logic



PROTON-TRITON TRACKS



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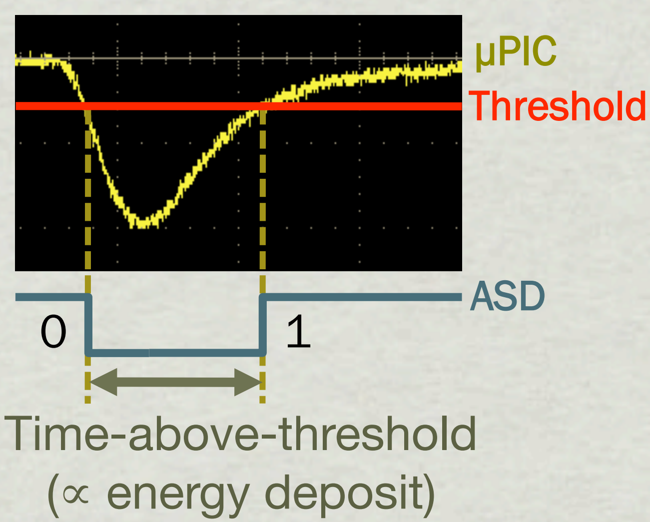

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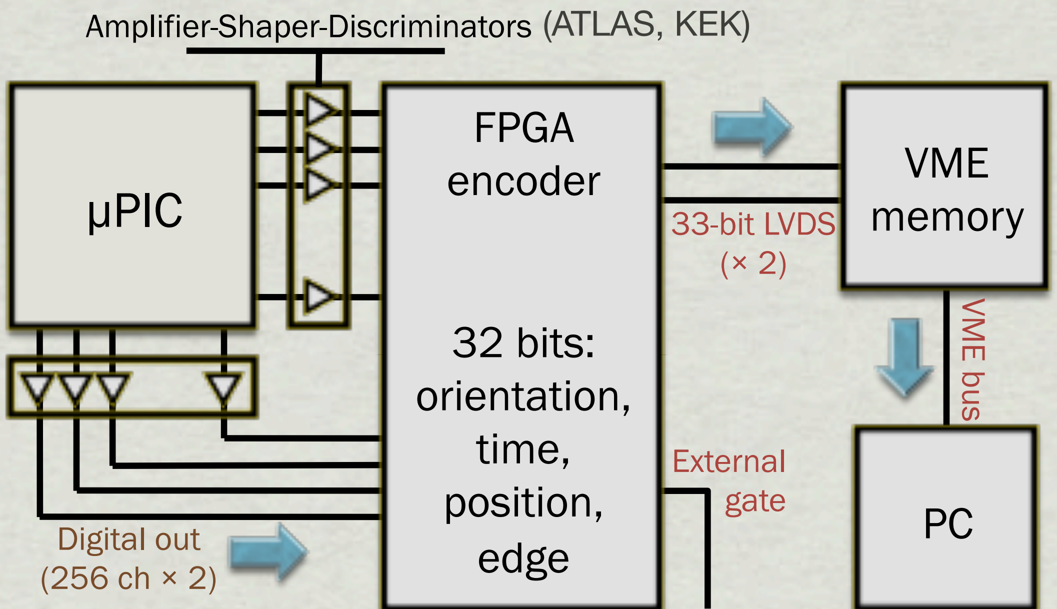
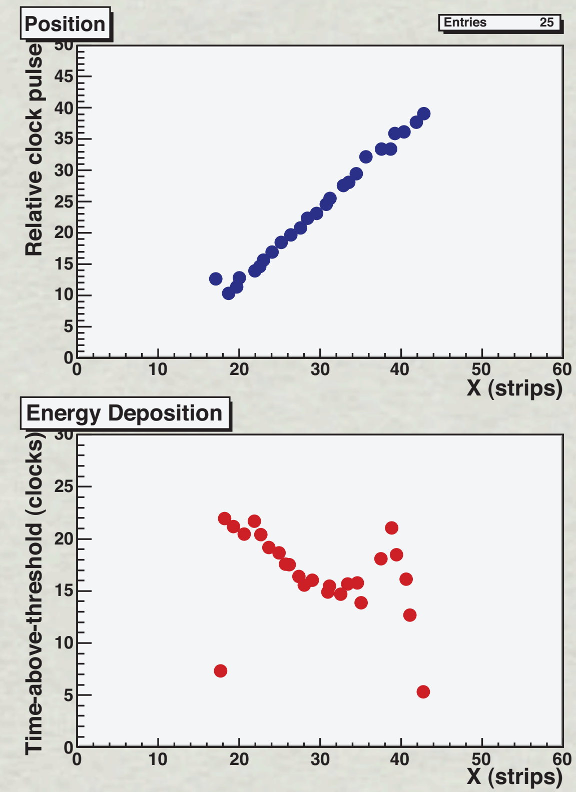
DAQ and FPGA logic



PROTON-TRITON TRACKS



DATA ENCODING

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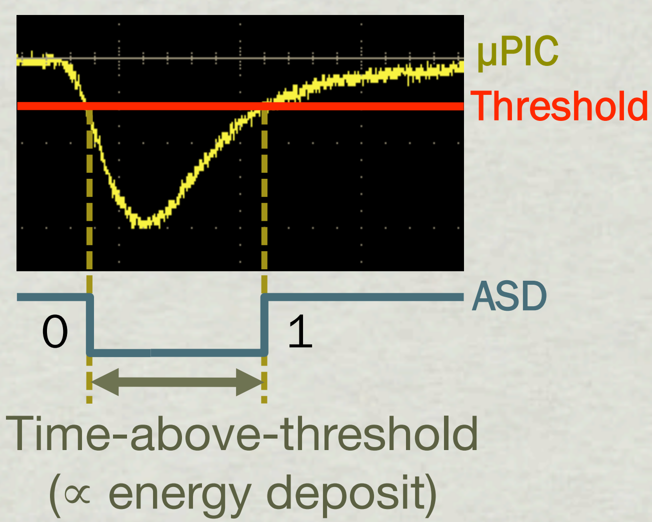
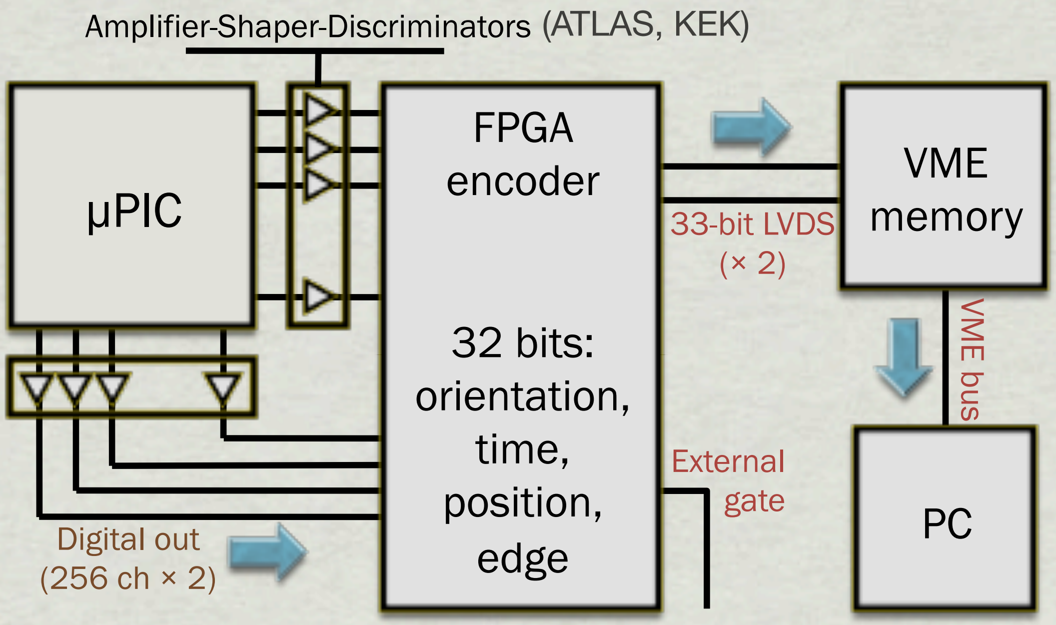
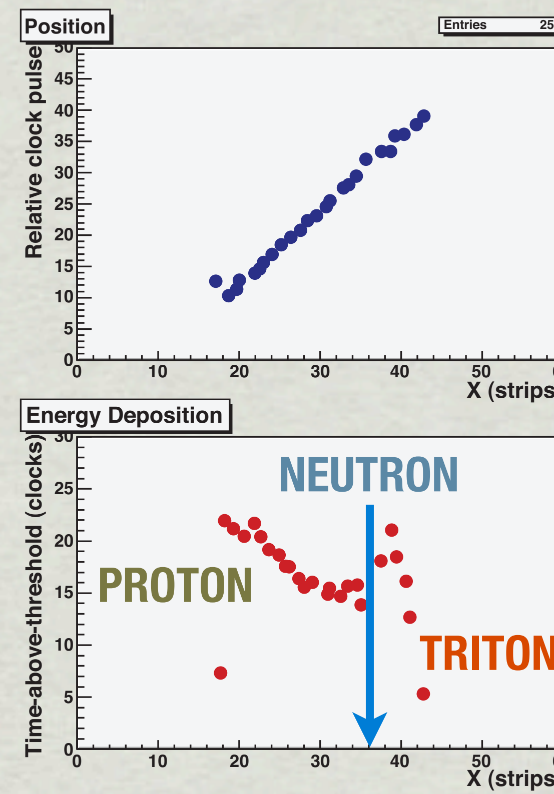


Simultaneous measurement of position and ‘energy deposition’ at high rates.

DAQ and FPGA logic



PROTON-TRITON TRACKS



DATA ENCODING

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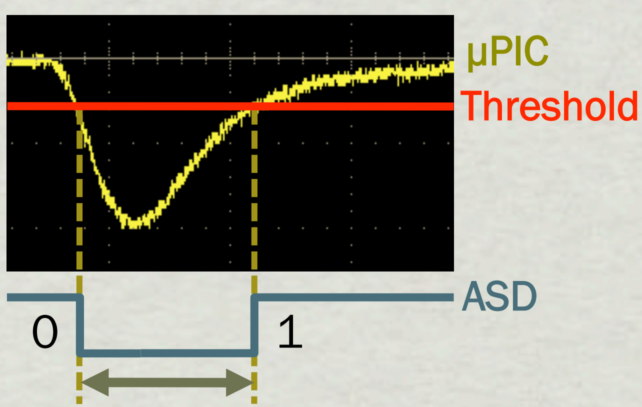
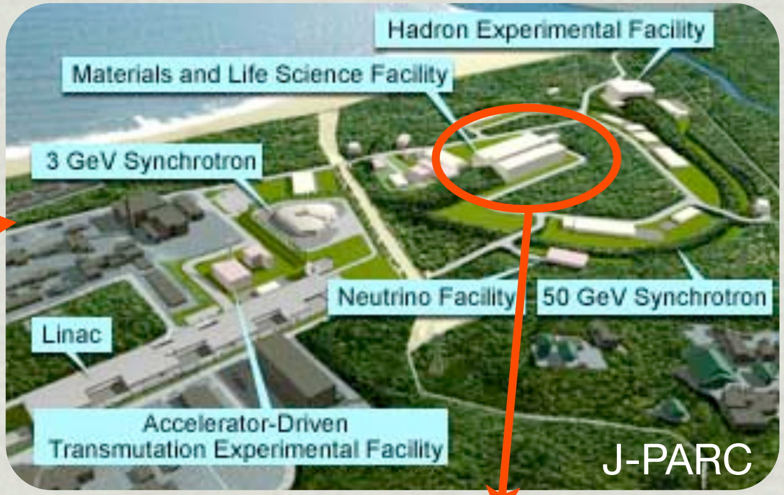


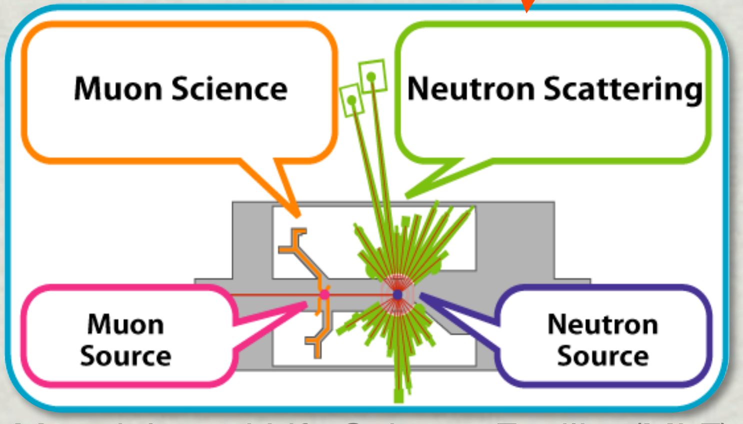
Time-above-threshold
(∝ energy deposit)

Simultaneous measurement of position and ‘energy deposition’ at high rates.

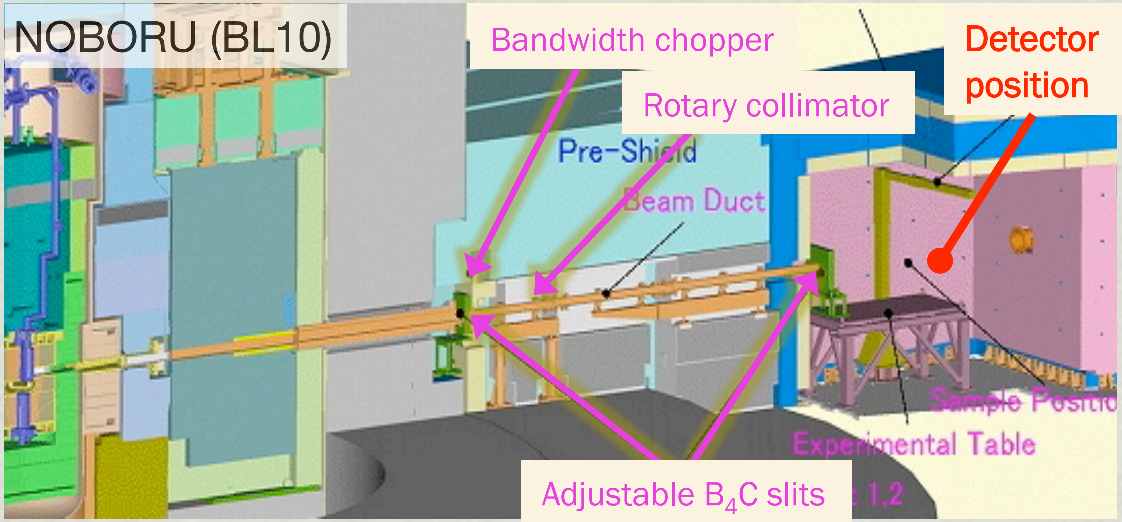
Test experiments at J-PARC



- Experiments in Nov. 2009, June 2010, and Feb. 2011.
- Beam power ~120 kW.
- Carried out at NOBORU beam line.
- Fill gas: Ar-C_2H_6-^{3}He (63:7:30) at 2 atm, efficiencies ~28%(5 cm), ~13%(2.5 cm).



Materials and Life Science Facility (MLF)

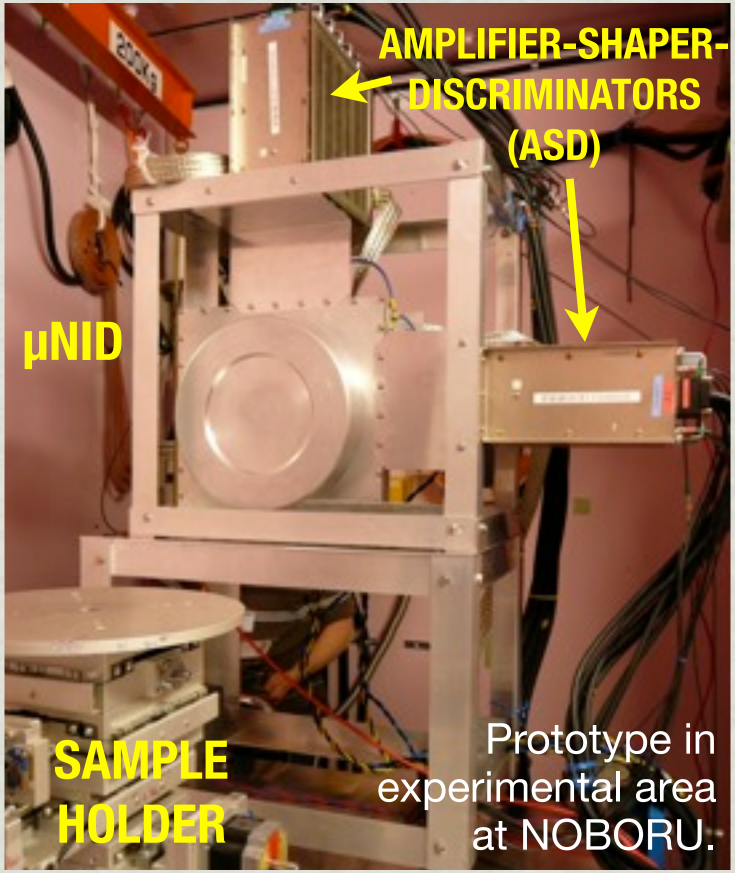


NOBORU BEAM LINE

- Moderator-to-detector distance of ~14.5 m.
- Max. beam size: 10 × 10 cm^2.
- 25 Hz pulse rate, 10 Å band-width.

Long term operability and ^{3}He usage

- Same gas filling used for first two experiments (separated by 8 months).
- No degradation in performance seen in June experiment.
- Gain recovered by increasing anode voltage.
- Detector remained operable after more than 1 year on single gas filling.



	Time after filling	Gain (% of initial)
1st Exp (2009)	0 months	100
2nd Exp (2010)	8 months	67
Dec 2010	13 months	30

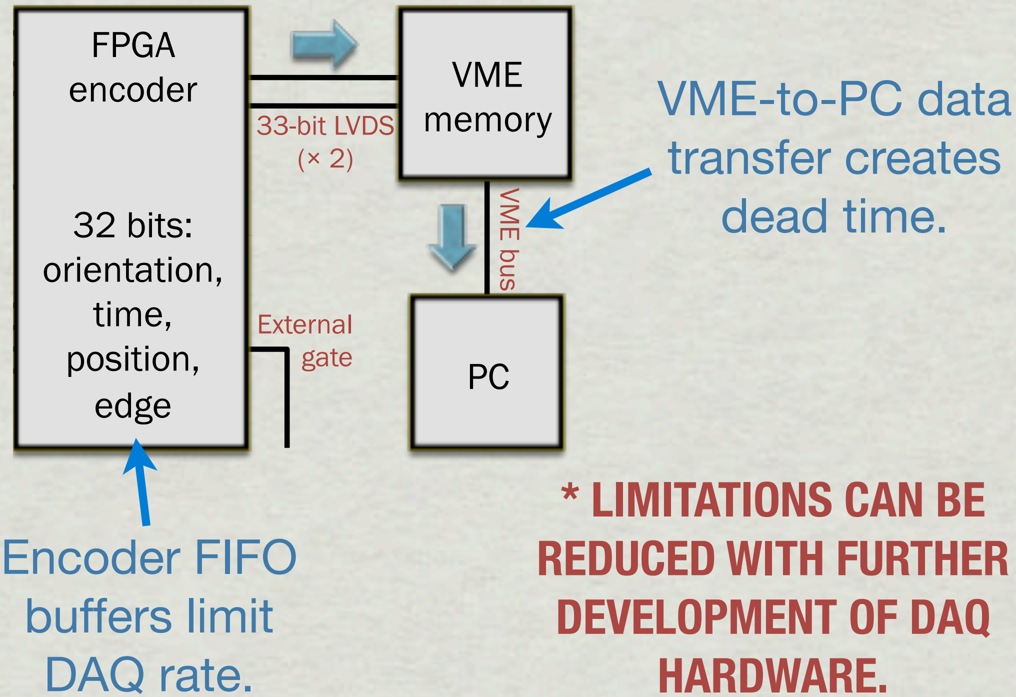
Strategies to extend operation

- Annealing of vessel and μPIC against outgassing.
- Careful selection of materials.
- Gas purification system (c.f. Nakamura's talk, 16:45 today).

DAQ performance at NOBORU

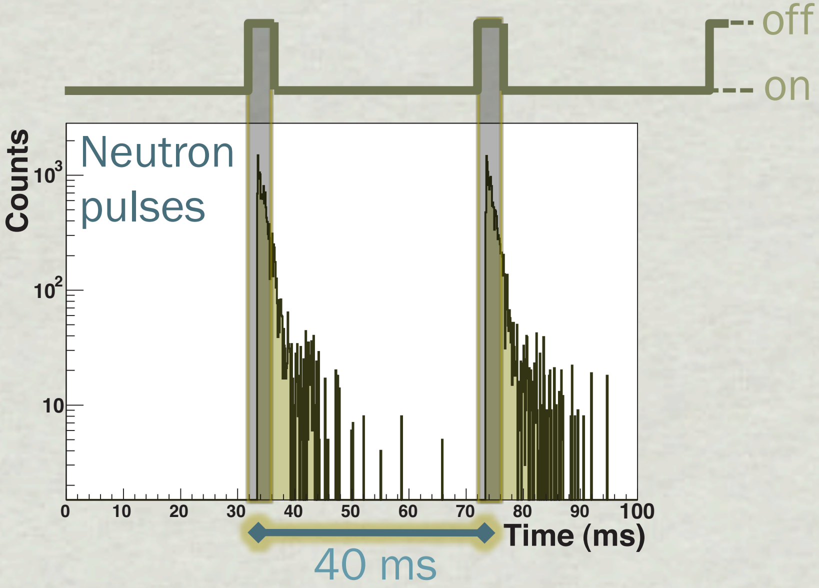
- Time-averaged data rates from 200 kHz ~ 9.4 MHz.
- Neutron rate of 80~100 kHz.
- Large dead time (40 ~ 85%).

DAQ BOTTLENECKS



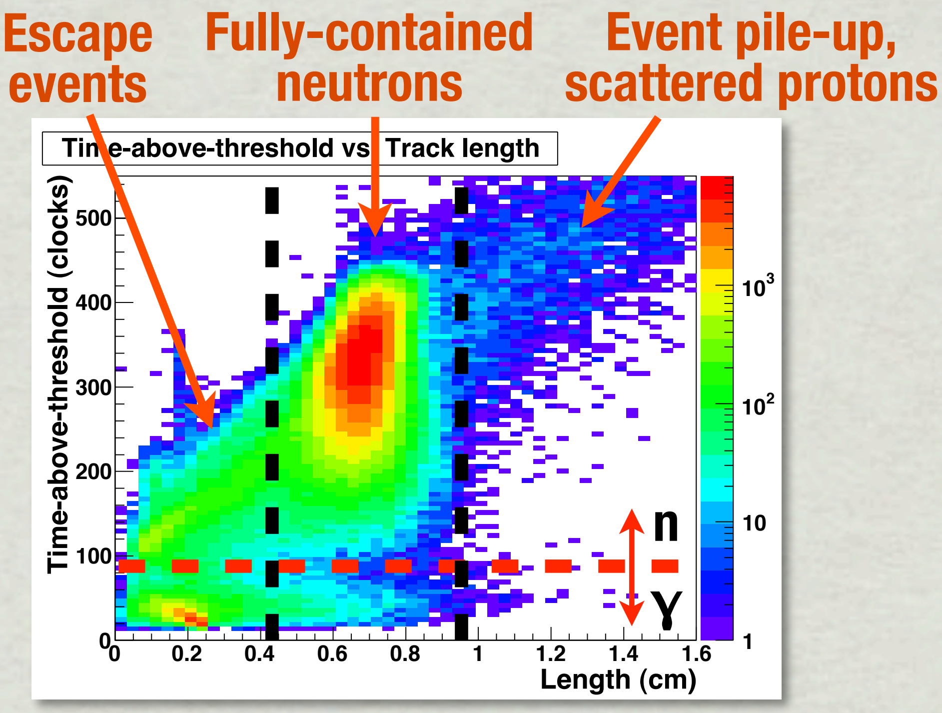
*** LIMITATIONS CAN BE REDUCED WITH FURTHER DEVELOPMENT OF DAQ HARDWARE.**

EXTERNAL TOF GATE

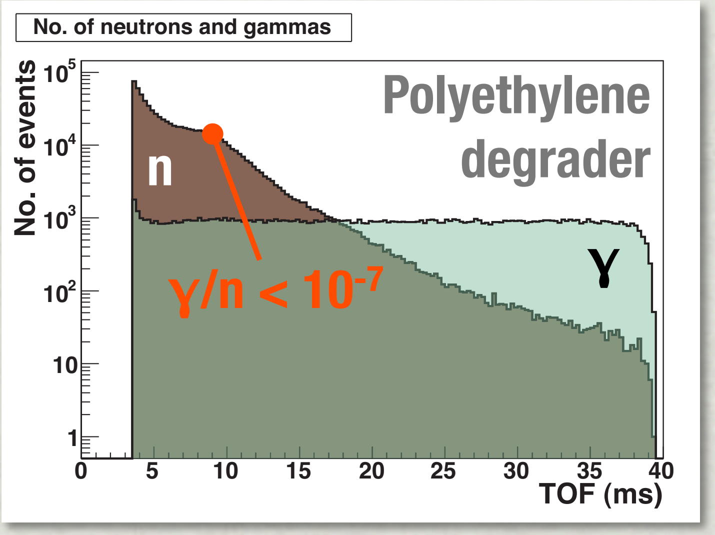


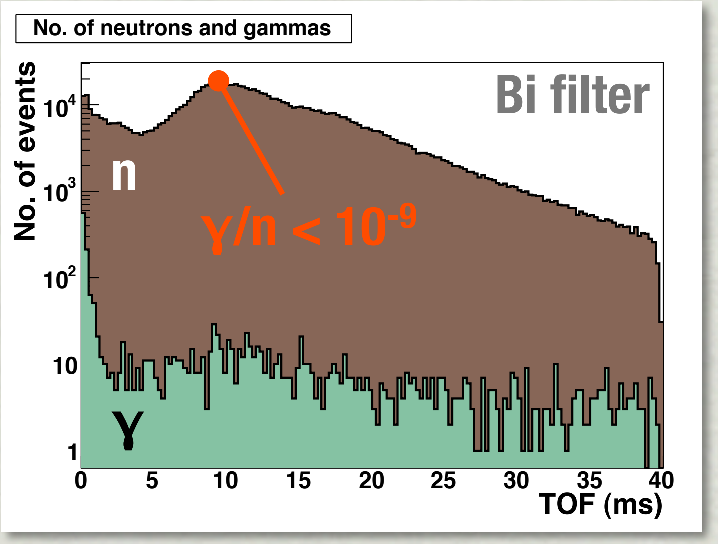
- Reduction in incoming data means fewer VME readouts.
- Effectiveness depends on details of TOF distribution and gate.
- Useful for Bragg transmission, resonance absorption.

Neutron-gamma separation



SAMPLE TOF DISTRIBUTIONS



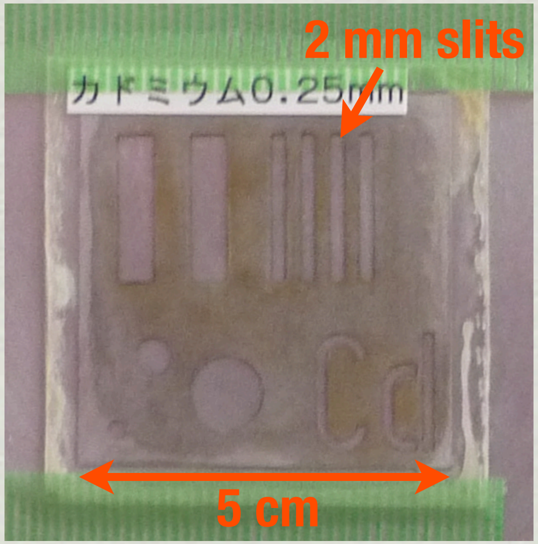


- Both neutrons and γ's are detected (γ efficiency ~10^{-3}).
- Neutrons selected by cuts in total time-above-threshold and 3D track length.
- Fraction of detected γ's surviving neutron cuts < 10^{-6} (effective gamma sensitivity of < 10^{-9}).

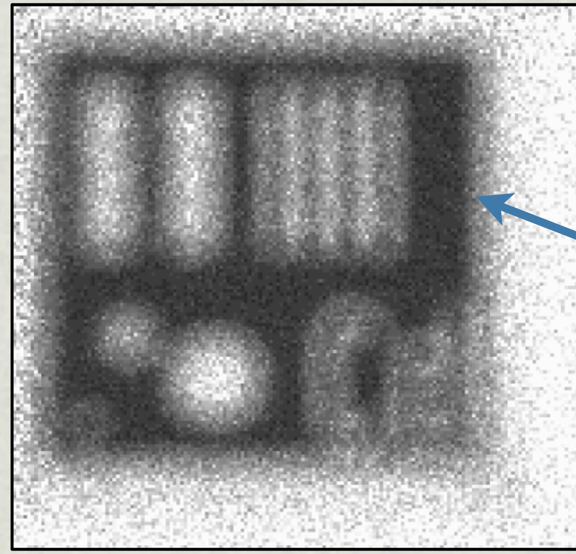
Data taken at NOBORU, J-PARC in June 2010.

Position resolution with PID

Cd TEST CHART



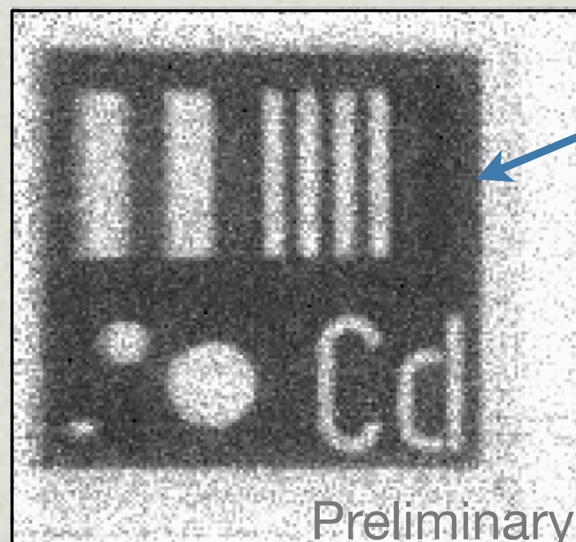
No PID



Position from mid-point of track.

Resolution: ~1 mm (σ)

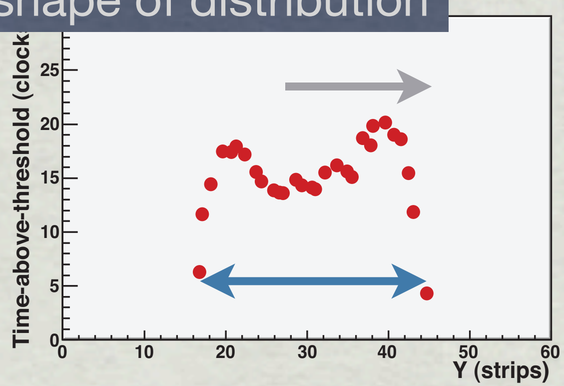
With PID



Resolution with PID: 349 ± 36 μm (σ)

(Includes beam dispersion.)

Proton direction from shape of distribution

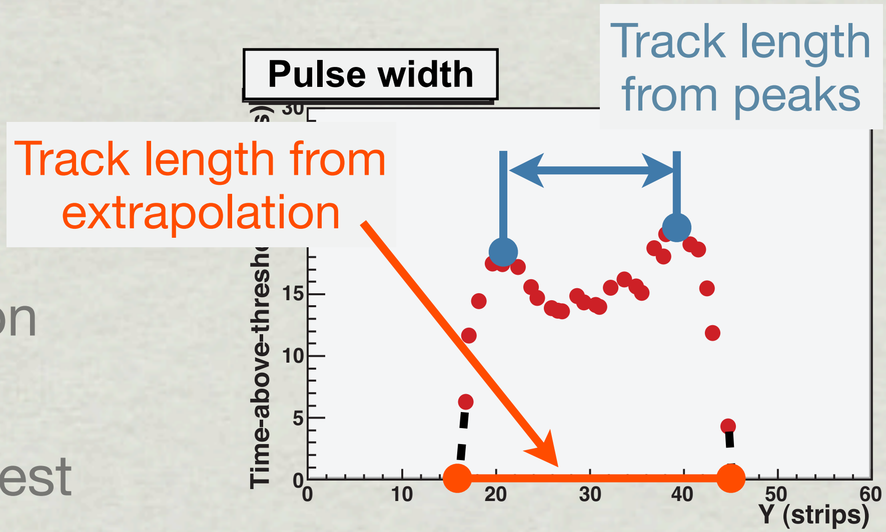


Track length from end-points

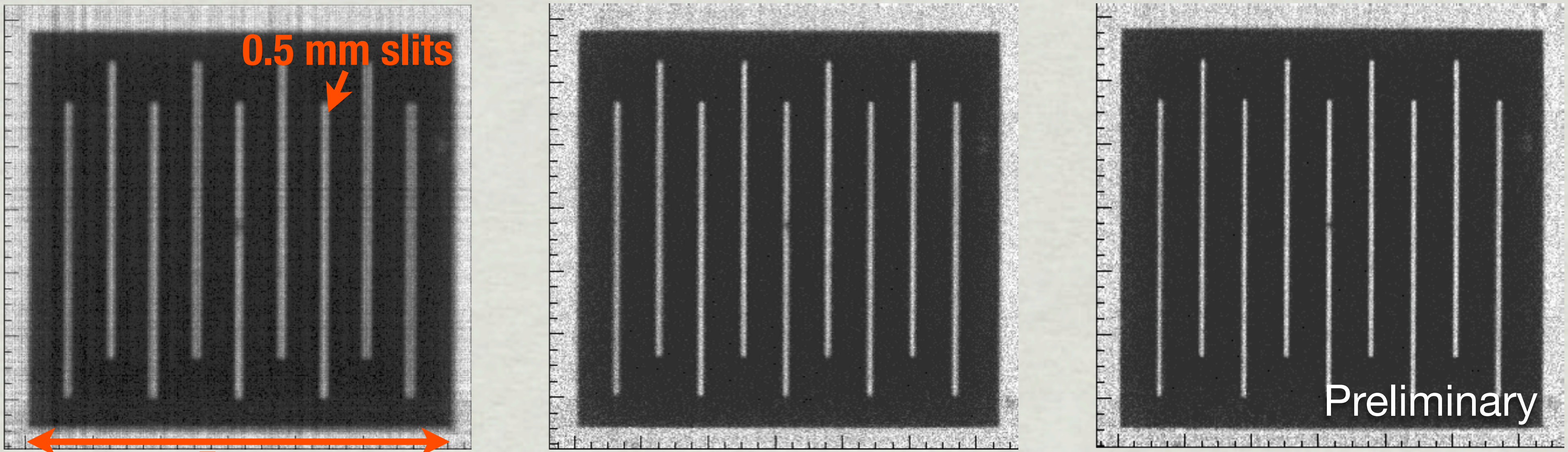
Data taken at NOBORU, J-PARC in Nov. 2009.

Refining position resolution

- Two methods: End-Point Extrapolation (EPE) and Peak Interpolation (PI).
- Combining both methods produces best result of σ = 118.4 ± 0.2 μm.



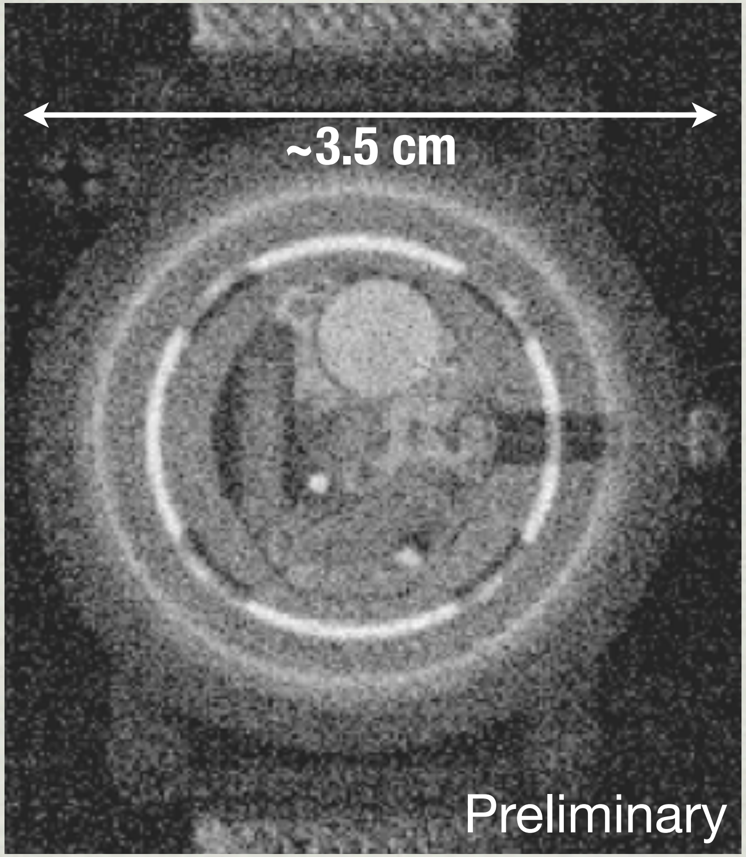
NO REFINEMENT (σ = 315 μm) → **EPE ONLY** (σ = 182 μm) → **EPE + PI** (σ = 118 μm)



Data taken at NOBORU, J-PARC in Feb. 2011.

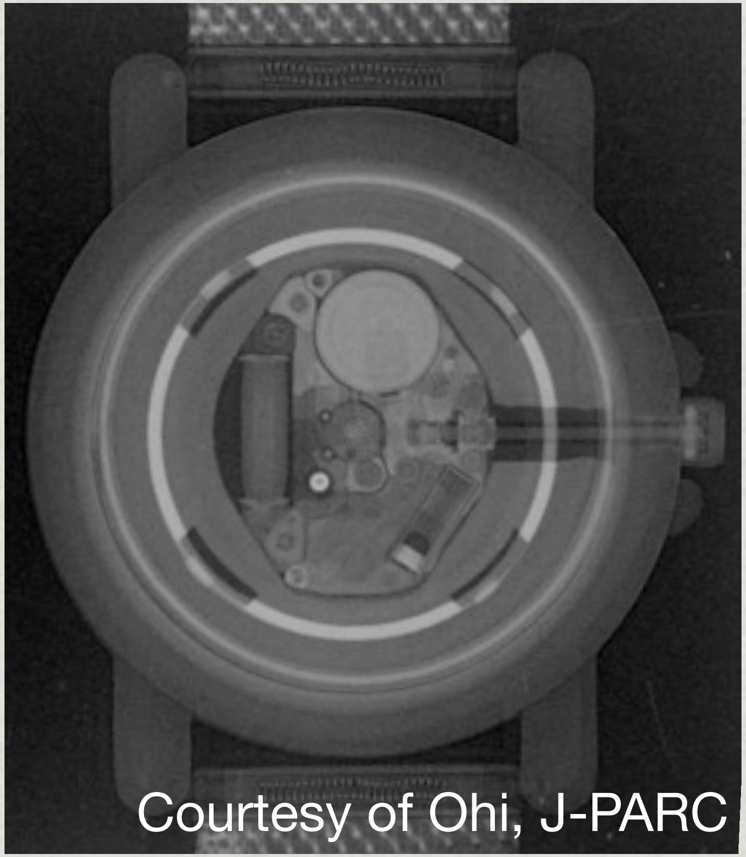
Image of a wristwatch

μPIC (29 MIN.)



Bin size: 200 μm × 200 μm.

IMAGING PLATE (200 MIN.)

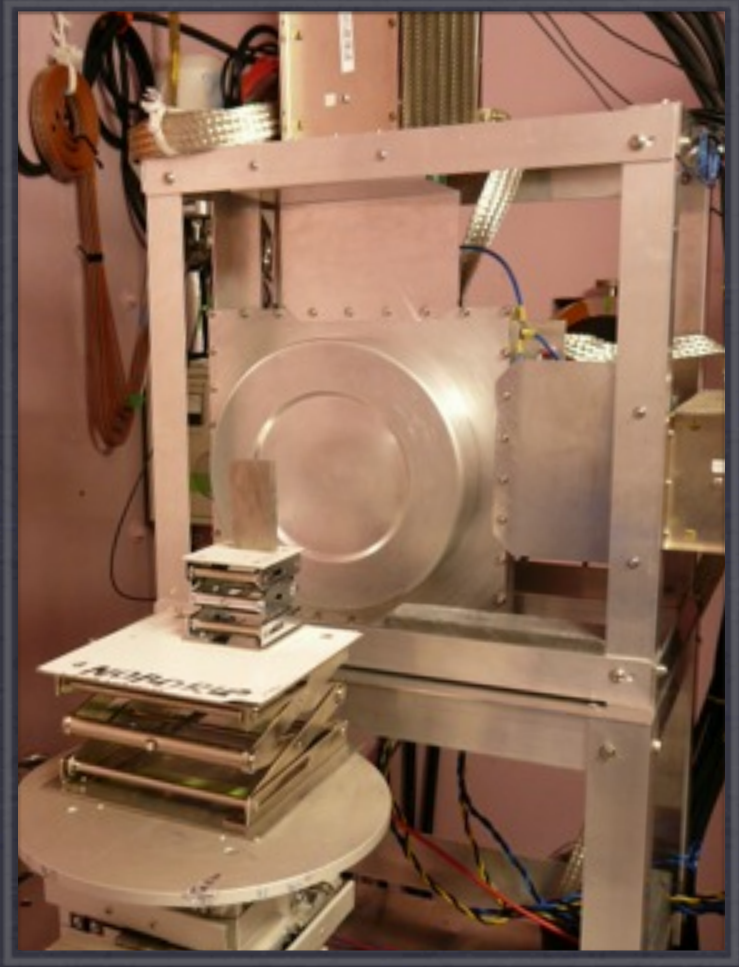


- Bin size can be decreased with higher statistics.
- Image processing techniques could improve image.

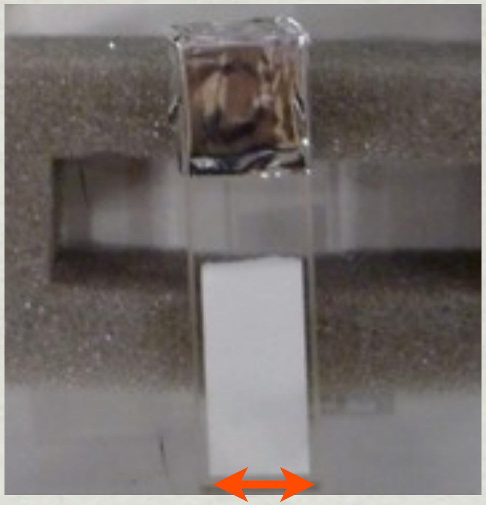
Data taken at NOBORU, J-PARC in Feb. 2011 (μPIC).

Demonstration measurements

- Small-angle neutron scattering.
- Resonance imaging.
- Bragg-edge transmission.

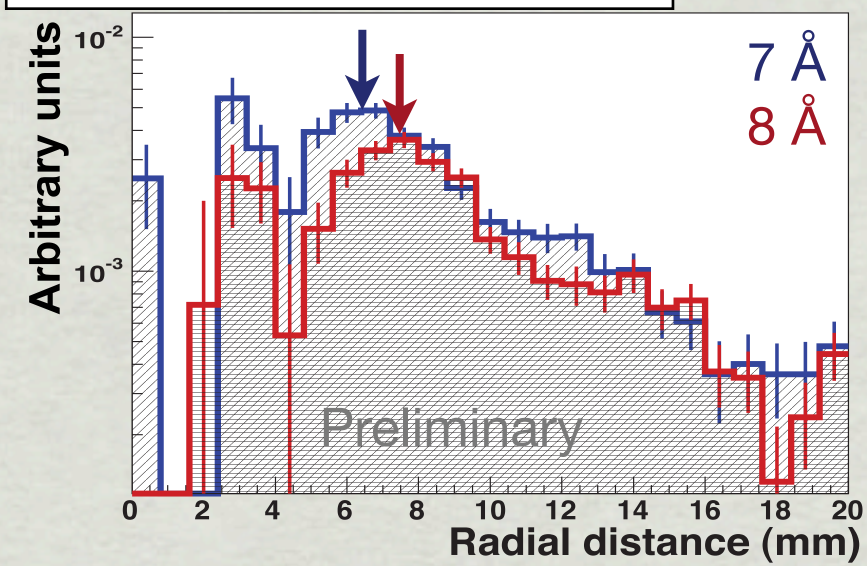


Small-angle neutron scattering

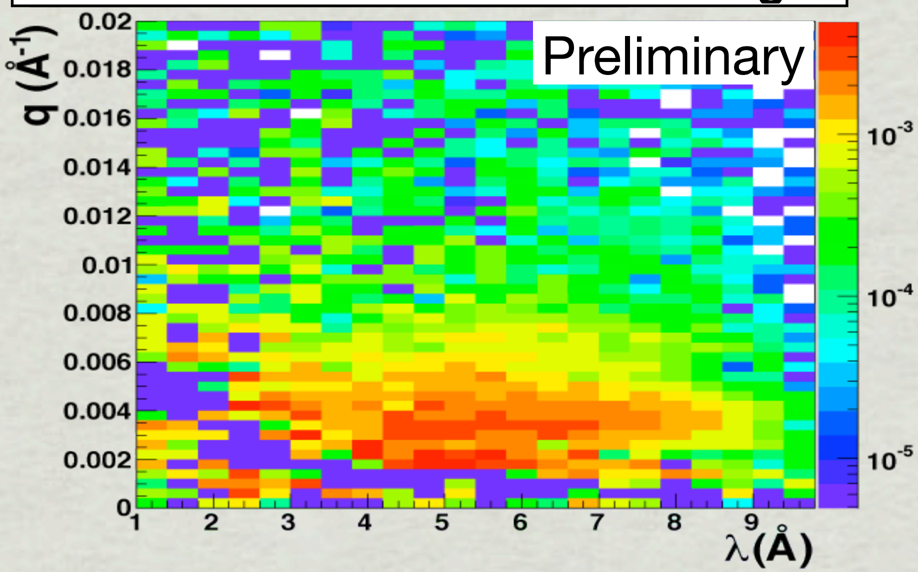


- Spherical SiO_2 nanoparticles (diameter ~200 nm).
- Sample-to-detector distance of 1666 mm.
- Exposure time of 35 min.
- Radial position of peak depends on wavelength but is constant in momentum transfer, q.
- Expected pattern for spherical particles seen in q.

Distance from beam center



Momentum transfer vs. wavelength



Data taken at NOBORU, J-PARC in Nov. 2009.

Small-angle neutron scattering

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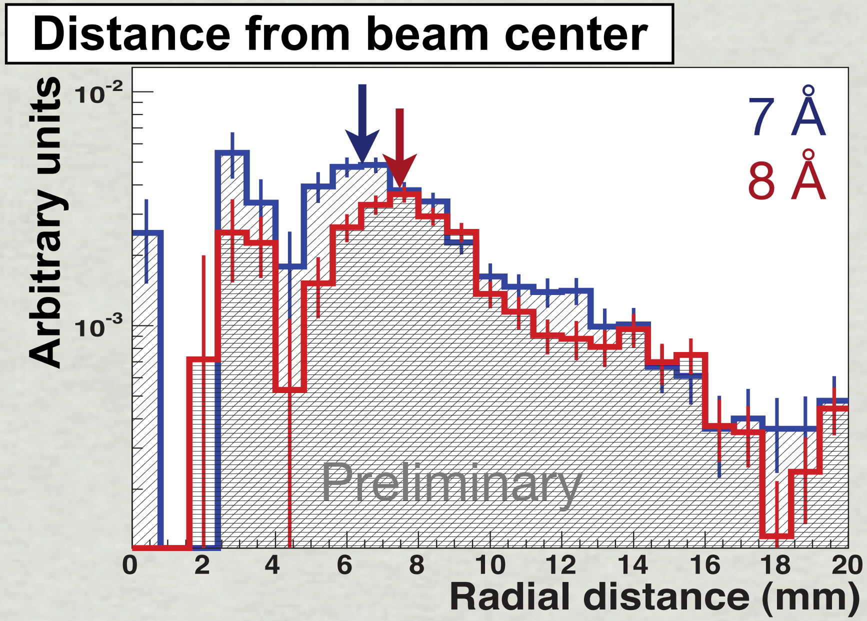
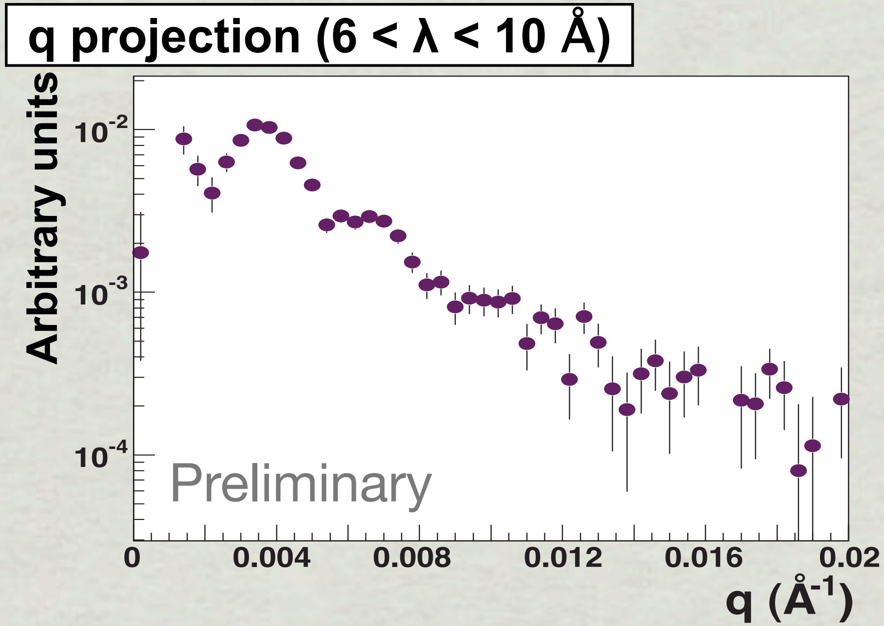


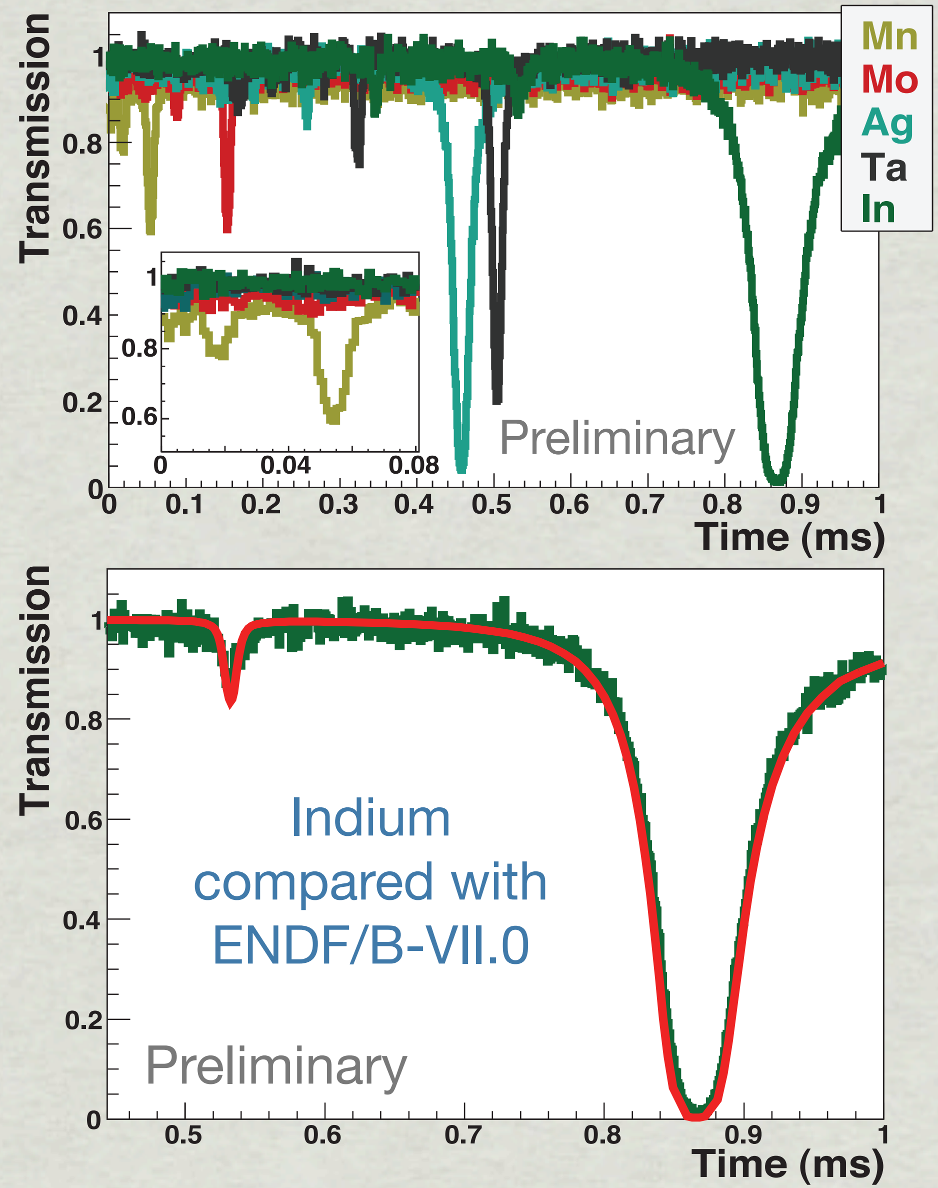


Data taken at NOBORU, J-PARC in Nov. 2009.

Resonance absorption

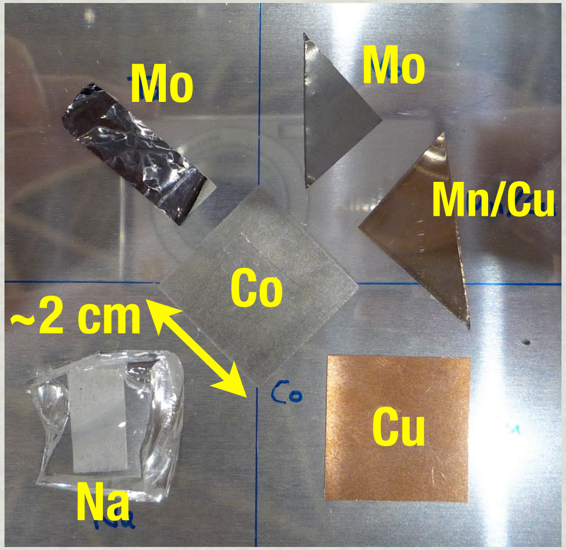
- Sheets of In, Ta, Ag, Mo, and Mn.
- Typical area of 10 cm × 10 cm.
- Thicknesses from 10 μm to 1 mm.

- Large samples to accumulate statistics quickly (~16 min/sample).
- Good time resolution and background rejection allows us to see resonances near beginning of pulse.

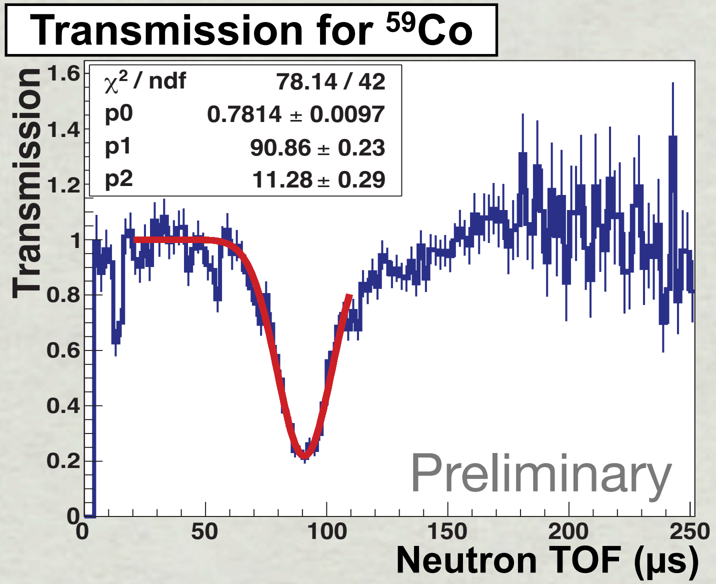


Data taken at NOBORU, J-PARC in Feb. 2011.

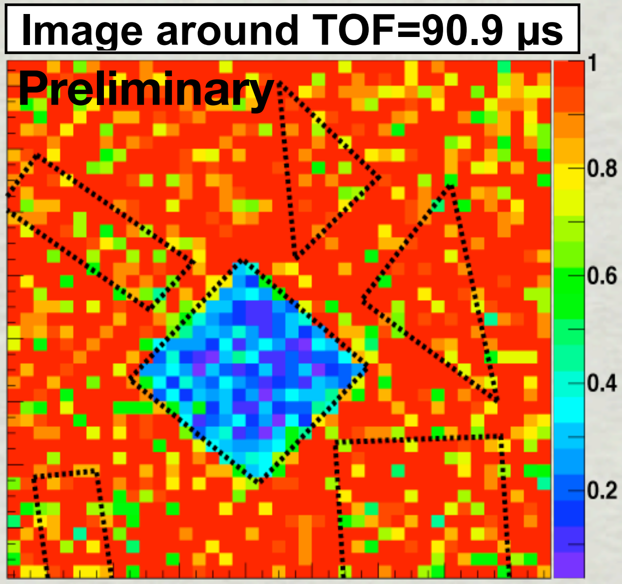
Resonance imaging



- Assorted metals.
- DAQ rate of 2.96 MHz (neutron rate of ~30 kHz).
- Exposure time of 5.5 min.
- ^{59}Co resonance observed at 90.86 ± 0.23 μs.
- Matches known resonance at 132 eV (TOF of 90.9 μs).

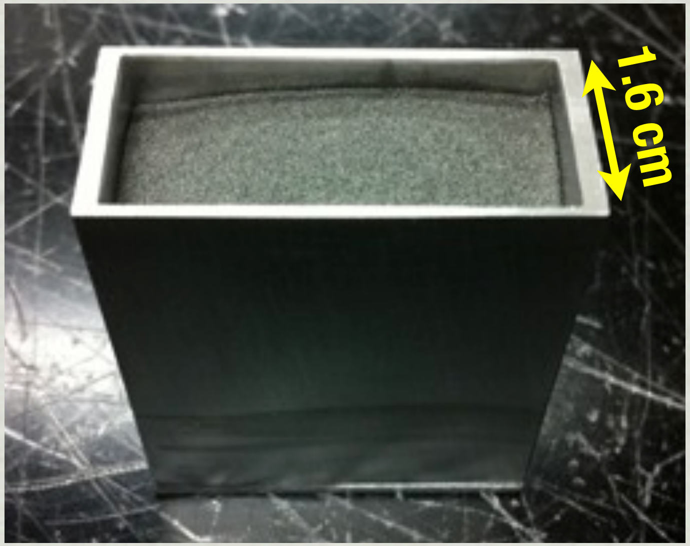


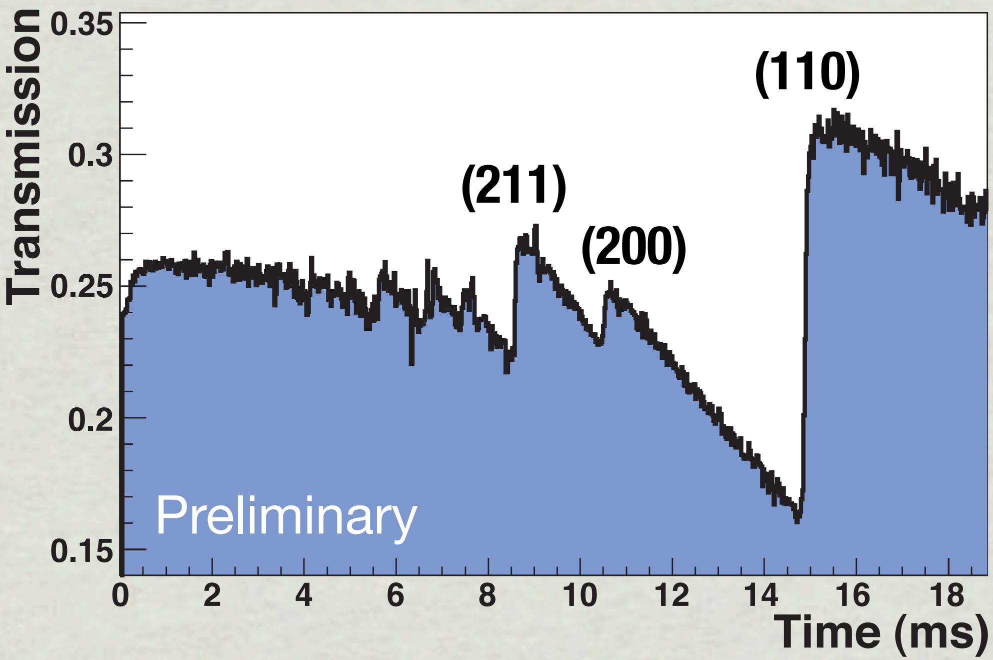
Neutrons at resonance energy for selective imaging.



Data taken at NOBORU, J-PARC in Nov. 2009.

Bragg-edge transmission





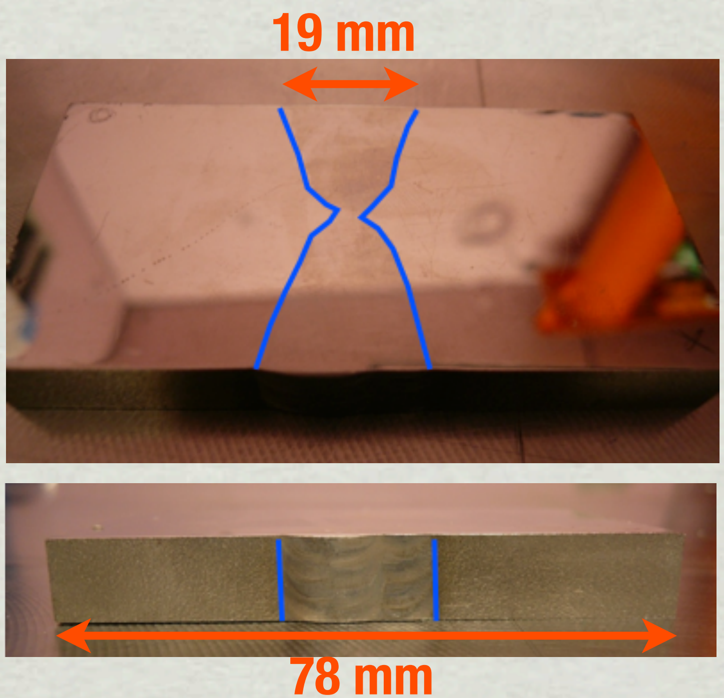
- Fe powder (>99% pure, grain size < 325 μm).
- Sample thickness of 1.6 cm.
- DAQ rate of 2.94 MHz (neutron rate of ~30 kHz).
- Exposure time of 40 min.

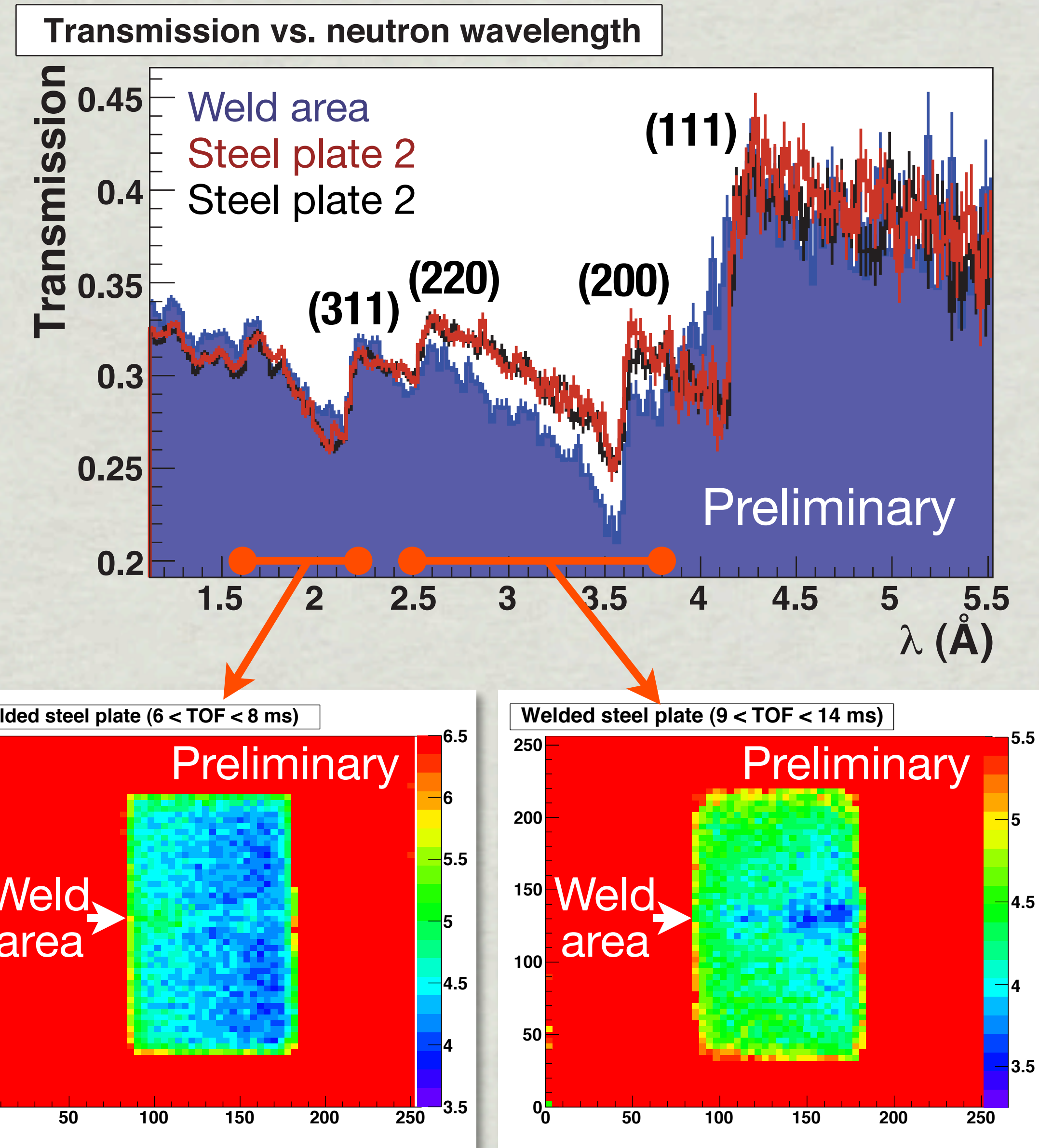
- Edge spacing is consistent with expected BCC crystal structure.
- Precise measurement of edge positions determines lattice parameter.

Data taken at NOBORU, J-PARC in Feb. 2011.

Bragg-edge transmission

78 × 40.5 × 10 mm^3 TIG-WELDED 316L STAINLESS STEEL PLATE

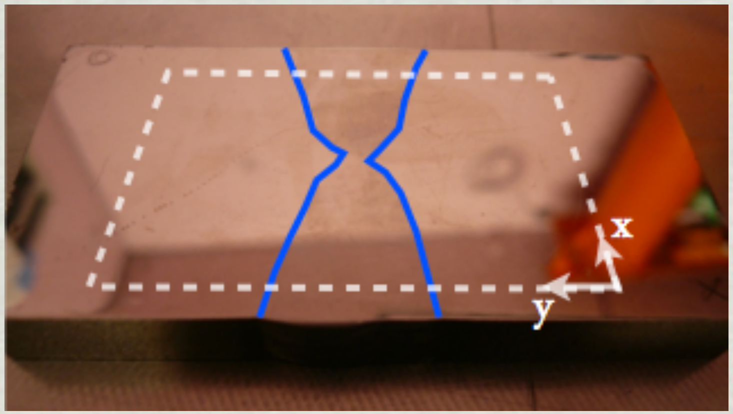




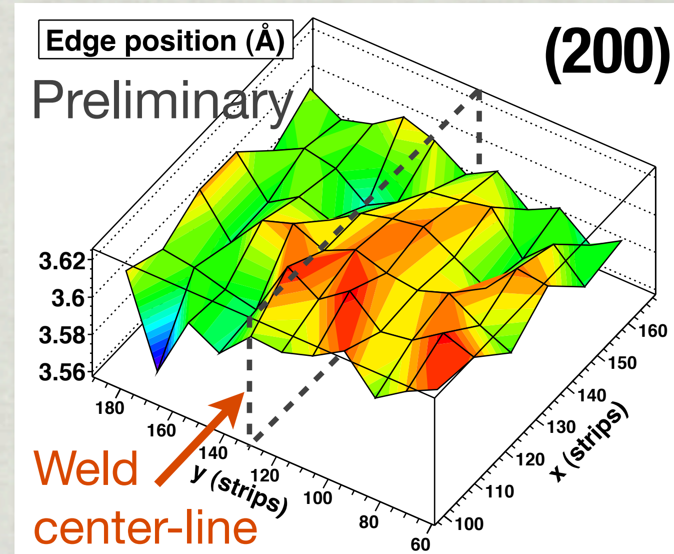
Edge spacing is consistent with FCC crystal structure.

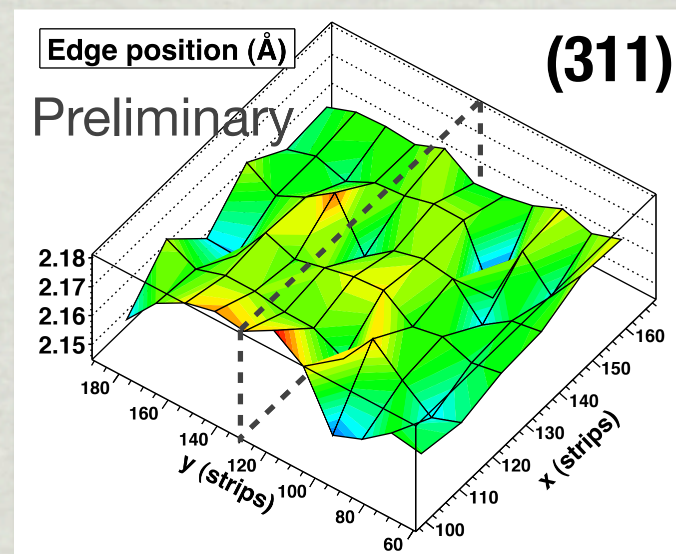
Data taken at NOBORU, J-PARC in June 2010.

Bragg-edge transmission



Divide image into 4.8 × 4.8 mm^2 'pixels' and fit edge positions*.





- Edge positions related to spacing of crystal planes perpendicular to beam.
- Variation in position may be related to internal strain.
- Full strain tensor requires measurements from multiple directions.

$$d = \frac{\lambda}{2}$$

d-spacing from wavelength

$$\varepsilon = \frac{d - d_0}{d_0}$$

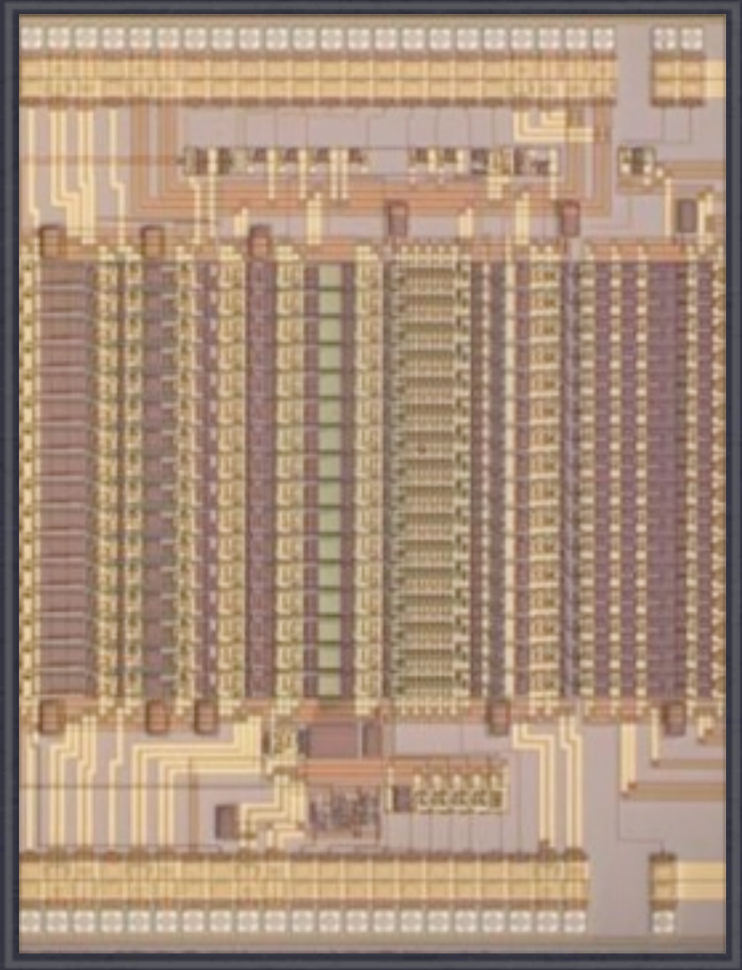
strain component in beam direction

* Fit procedure based on Santisteban, et al. (2001)

Data taken at NOBORU, J-PARC in June 2010.

Future improvements

- Optimization of gas mixture.
- Smaller pitch μPIC.
- New ASICs and encoder for more compact DAQ.

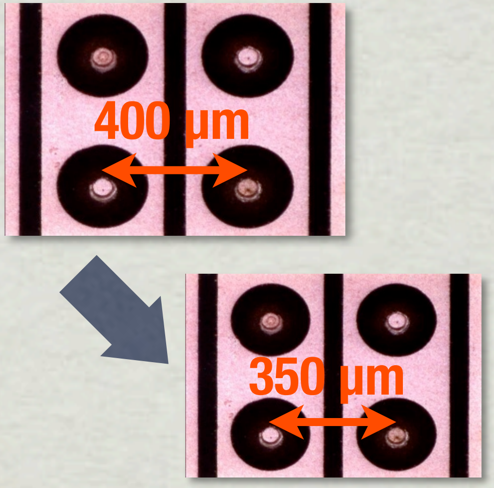


Gas optimization and pixel pitch

	Pressure (atm)	Drift velocity (µm/ns)	Transverse diffusion ($\mu m/cm^{1/2}$)	Longitudinal diffusion ($\mu m/cm^{1/2}$)	Expected improvement in resolution
$Ar:C_2H_6:{}^3He$ (63:7:30)	2	23.1	273	169	(118 µm)
$Ar:C_2H_6:{}^3He$ (63:7:30)	3	23.4	231	126	~15%
$Xe:C_2H_6:{}^3He$ (50:20:30)	2	29.4	183	125	~15%
$Ar:CO_2:{}^3He$ (50:20:30)	2	22.5	107	114	~15%

Gas parameters determined by MAGBOLTZ.
Resolutions estimated with GEANT4.

REDUCE PIXEL PITCH



- Shorten p-t track lengths by increasing pressure or changing to gas with higher stopping power.
- Reduce diffusion of drift electrons.
- Moderate reductions in pixel pitch produce corresponding reduction in position resolution.

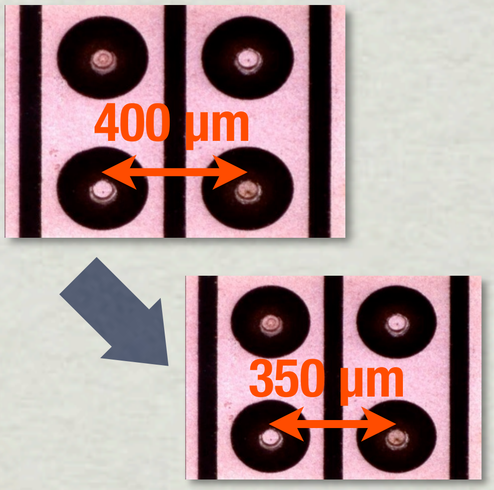
Gas optimization and pixel pitch

	Pressure (atm)	Drift velocity (µm/ns)	Transverse diffusion (µm/cm$^{1/2}$)	Longitudinal diffusion (µm/cm$^{1/2}$)	Expected improvement in resolution
$Ar:C_2H_6:{}^3He$ (63:7:30)	2	23.1	273	169	(118 µm)
$Ar:C_2H_6:{}^3He$ (63:7:30)	3	23.4	231	126	~15%
$Xe:C_2H_6:{}^3He$ (50:20:30)	2	29.4	183	125	~15%
$Ar:CO_2:{}^3He$ (50:20:30)	2	22.5	107	114	~15%

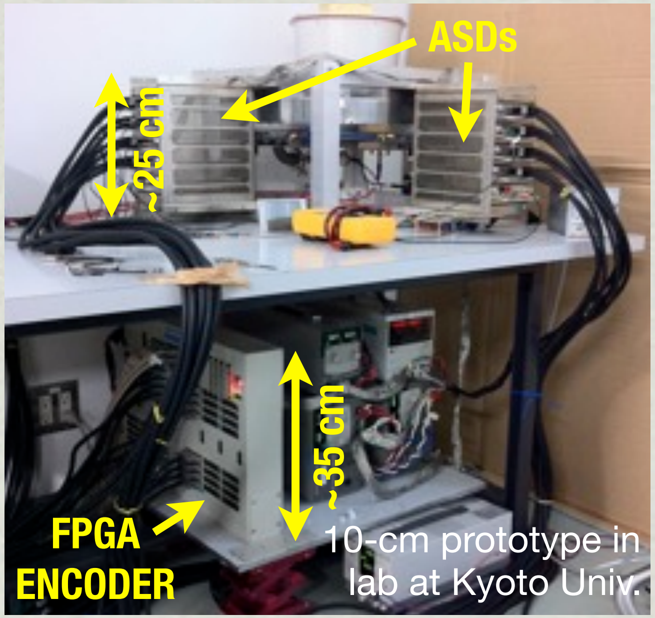
Gas parameters determined by MAGBOLTZ.
Resolutions estimated with GEANT4.

- Shorten p-t track lengths by increasing pressure or changing to gas with higher stopping power.
- Reduce diffusion of drift electrons.
- Moderate reductions in pixel pitch produce corresponding reduction in position resolution.

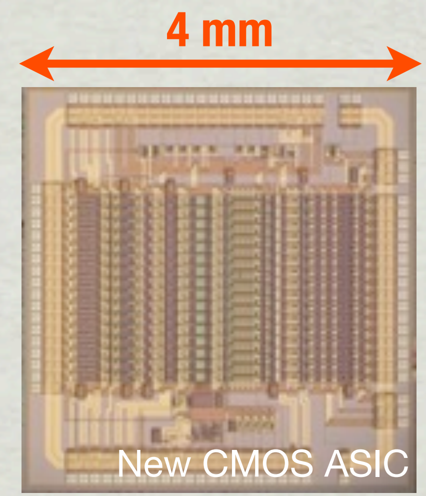
REDUCE PIXEL PITCH



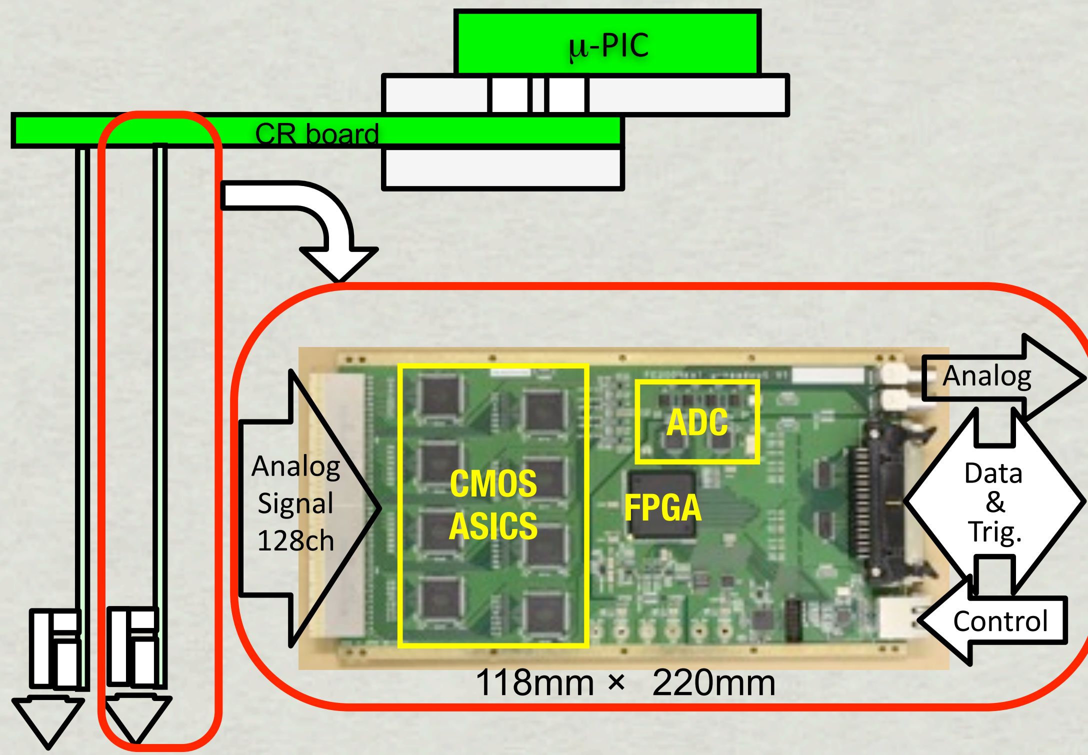
DAQ improvements



- Replace ASDs with CMOS chips (developed with KEK).
- 16 channels/chip (increased from 4).
- Power per channel reduced by factor of more than 3.



- Combine CMOS chips with FPGA on single board.
- Four boards replace ASD racks, encoder, cables.
- Each board writes to memory, increasing max. data rate.
- New boards now under testing (cf. Iwaki, poster 67).



Summary

- TPC based on micro-pattern gaseous detector and FPGA DAQ system.
  - Position resolution of 118 μm; time resolution of ~1 μs.
  - Compact DAQ with high data rates.
  - Strong rejection of gammas and fast neutrons.
- Detector remains operable over long time.
  - Annealing to reduce outgassing for increased long-term stability.
  - Gas filtration system could extend operation considerably.
- Continuing studies to improve detector performance with aid of GEANT4 simulation.
  - Gas mixture and pixel pitch optimization.
- Setting up 20-cm neutron imaging detector for use at Kyoto University.
  - μPIC sizes up to 30 × 30 cm^2 are currently available.