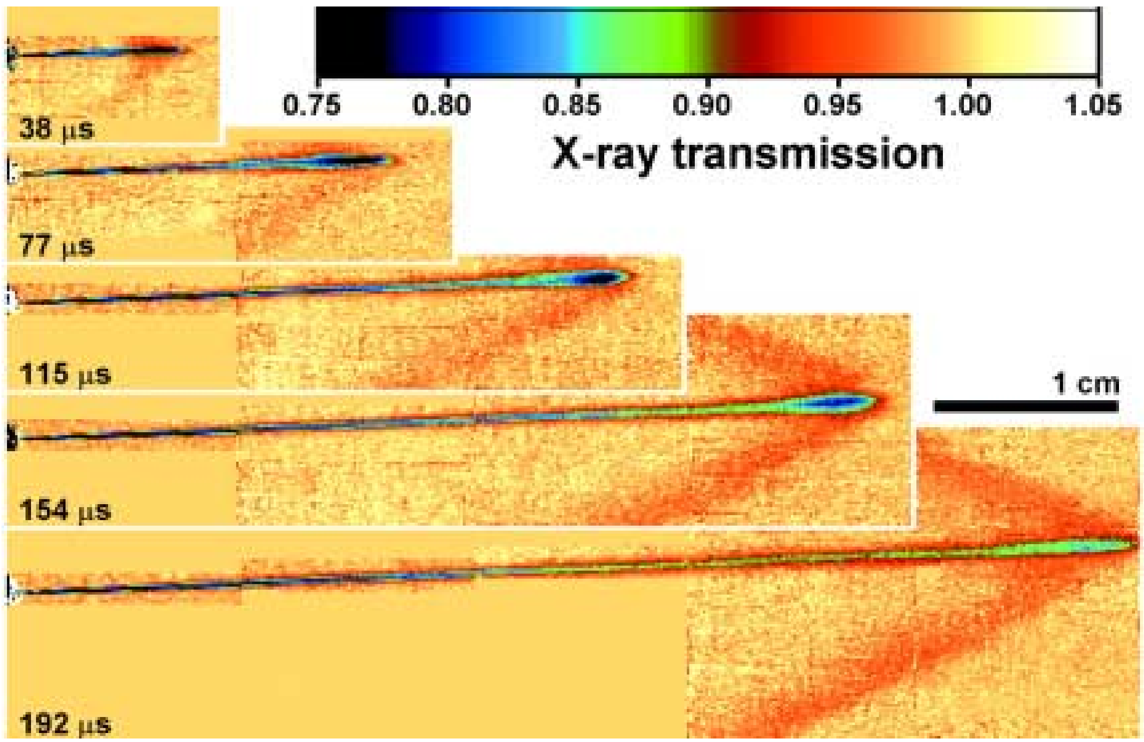
Pixel Array Detector (PAD)

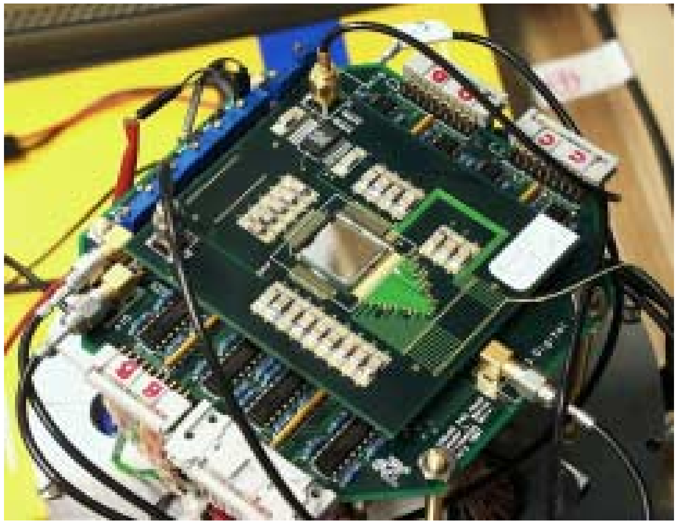
" There is a strong emphasis in our group on the development of instrumentation and techniques to provide additional handles for the exploration of the physical properties of specimens, such as high pressure x-ray methods and new types of x-ray detectors." (Prof. Sol M. Gruner)



a diesel fuel injector 5 μs exposure. Note the shock-wave

from Science, "X-ray Imaging of Shock Waves Generated by High-Pressure Fuel Spray", 15 Feb 2002, Vol. 295, pp. 1261-1263.

The people and some history.



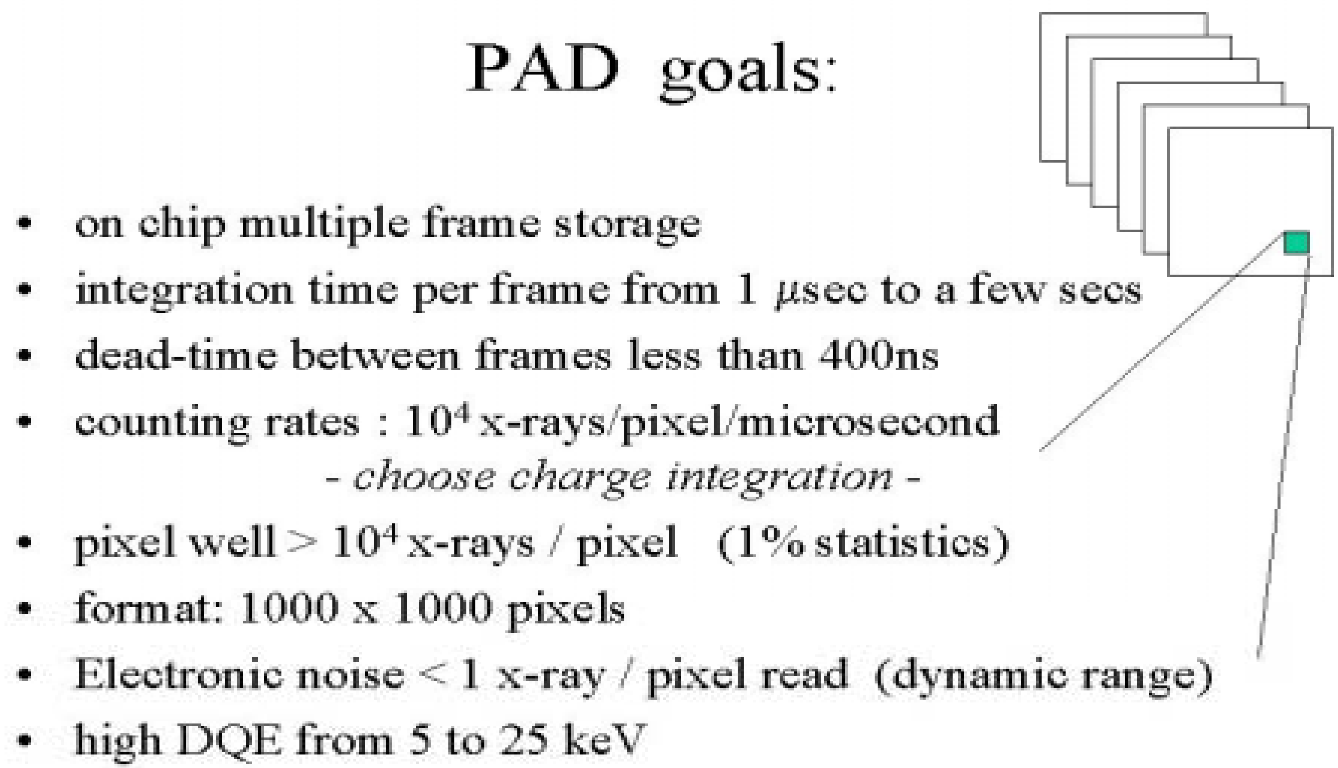
The 100x92 PAD prototype

A Pixel Array Detector (PAD) for Time resolved X-ray Diffraction is being developed at Cornell University under the supervision of Sol M. Gruner. Three members of our group are affiliated with the project: Matt Renzi and Alper Ercan, currently doing their Ph.D. on this subject, and Mark Tate, senior research associate with many years of experience in X-ray detector development. The list of people previously involved in this project includes: Eric Eikenberry from Robert Wood Medical School, NJ (now at the Swiss Light Source); Robert Wixted, formerly at Princeton University , and Paul Seller from University of Surrey, UK, Giuseppe Rossi of Photobit and Sandor Barna of Photobit. Eric, Bob and Sandor were involved on the PAD project in its early stage. Eric worked on designing the controller of the detector. Bob has been our guru for VLSI design of CMOS ASIC chip. Dr. Rossi was a postdoc here at Cornell. Most of the detector performances have been demonstrated at CHESS with the priceless support of Don H. Bilderback and Ernie Fontes.

This development started at Princeton University where Sol and the Biophisics Group were formely based. Sandor Barna, former member of this group, graduated from Princeton in 1997 with a thesis based on the development of the first PAD prototype. Much of the today results are a direct outcome of his terrific work.

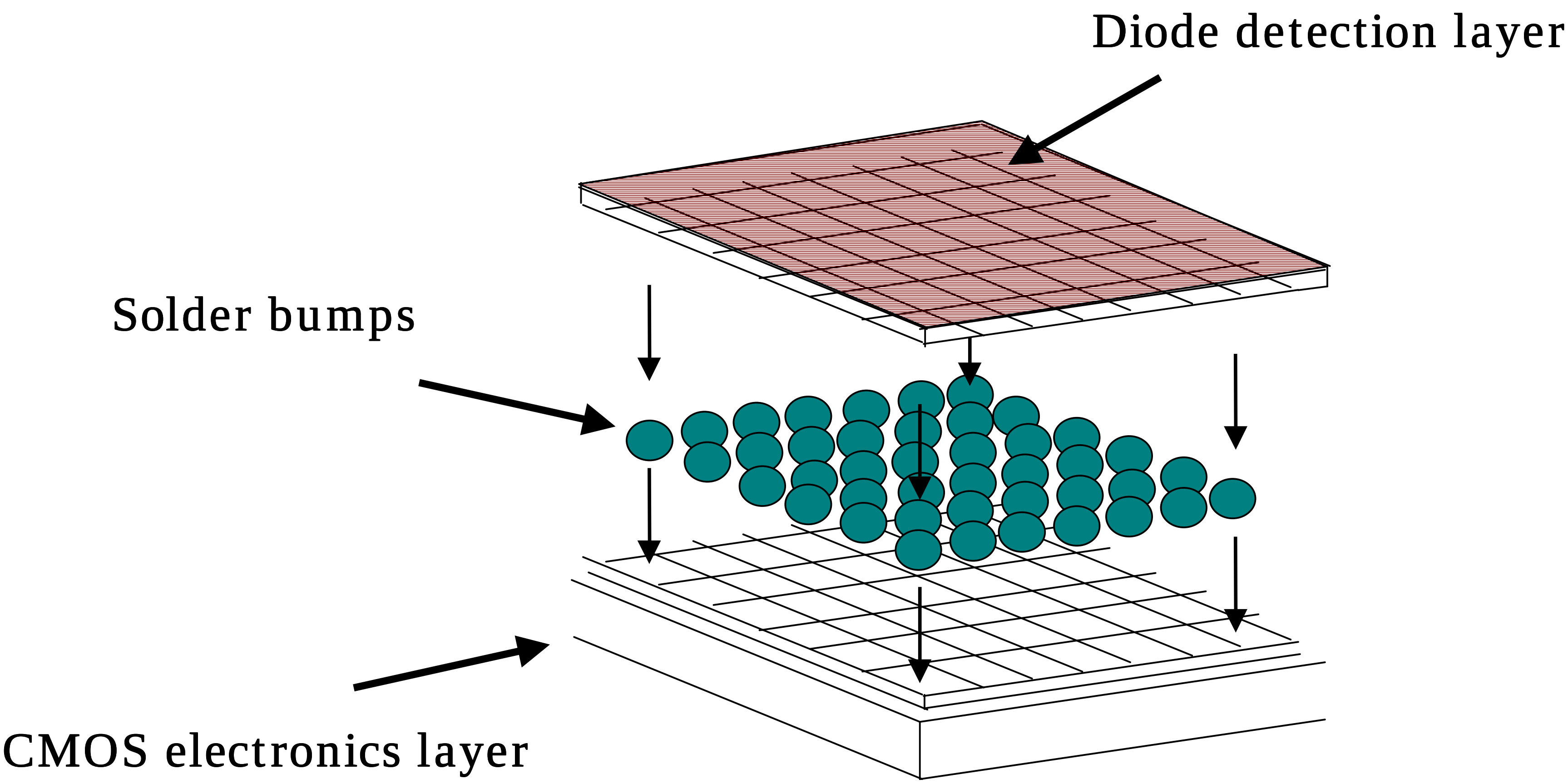
The PAD detector : a short overview.

The PAD detector is a 2-dimensional imager capable of storing subsequent frames in less than 0.5 microsecond. It will be used for time resolved experiments where speed is a critical factor. Some of the main PAD goals are:



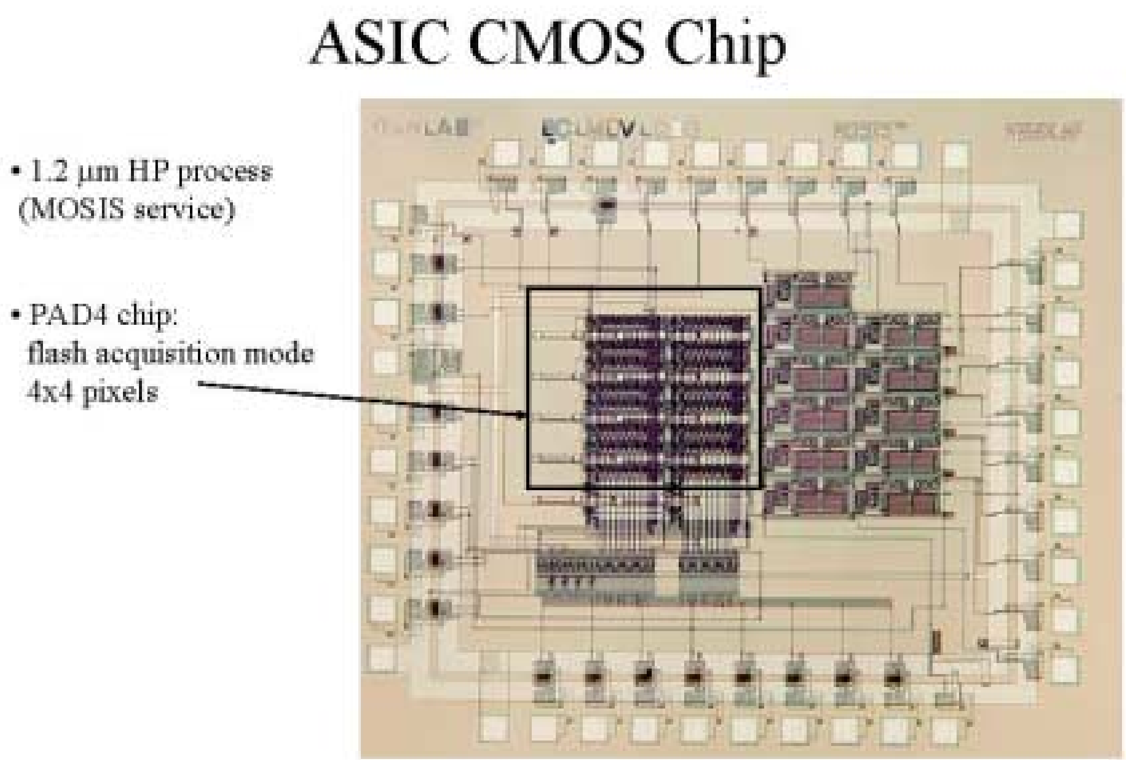
PAD Composition

A PAD detector is composed of a high resistivity pixellated silicon layer bump bonded to an ASIC CMOS chip.   The high resistivity pixellated silicon layer is also called diode detection layer: this is the place where X-rays are absorbed and converted into an electrical signal. This signal is then sensed and collected by individual pixels. Each pixel is connected to a specific read-out electronics channel laid-out on an ASIC CMOS chip by a solder bump bond.

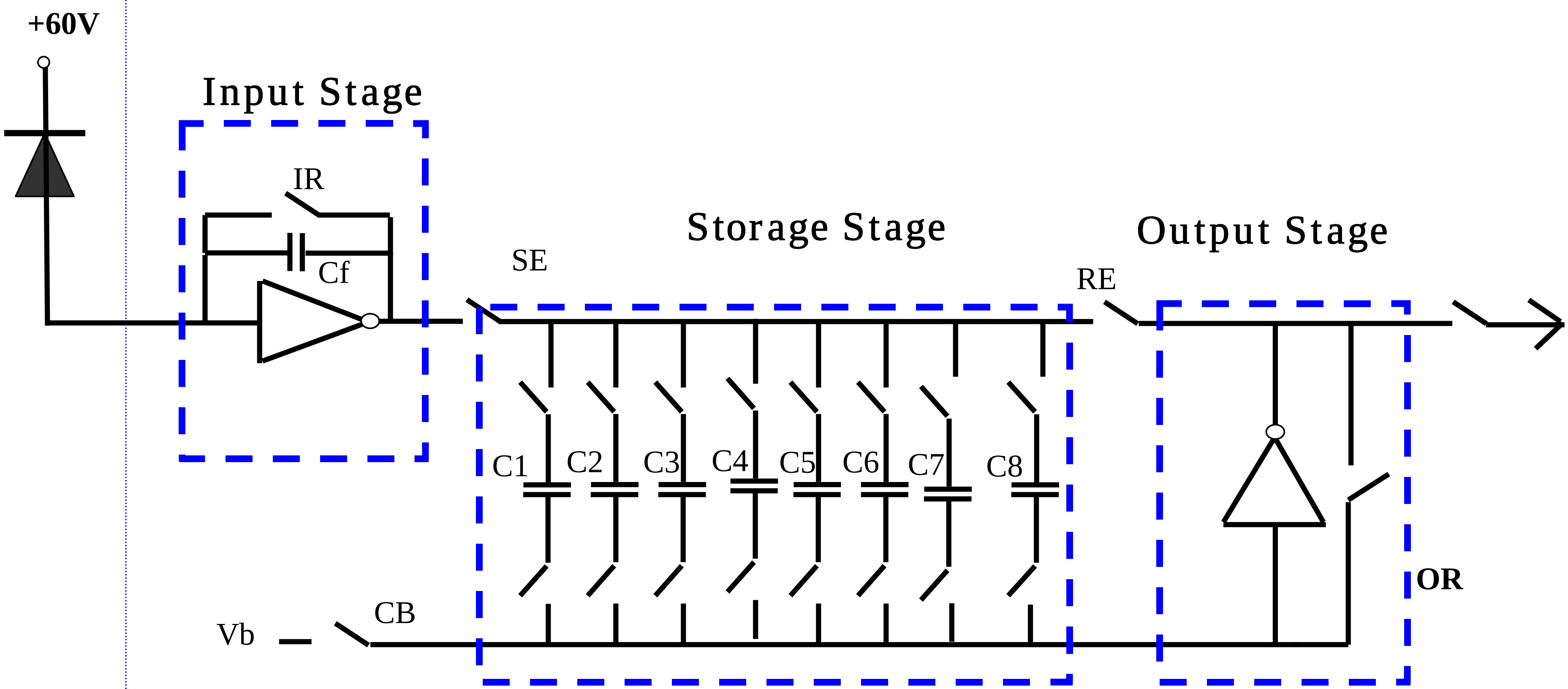


The ASIC

This is an example of the ASIC CMOS chip designed for the first detector build at Princeton. The ASIC is designed in house and then sent for fabrication. The true benefit of a pixel array detector is its flexibility. The function of the detector is determined by the ASIC, i.e. how to process the charge coming from the silicon diode layer. Therefore we can think of many ways to process the data, either integrating the charge or counting pulses of charge due to each x-ray.



A Pixel Schematic for Ultra-Fast Data Collection



This schematic represents a rapid fire storage system.
Eight capacitors store eight frames of x-ray information.
These are stored at a variable rate of up to >1Mhz.
After storage of eight frames, the detector is read out.
It's the **fastest** framing detector around!

Potential PAD experiments

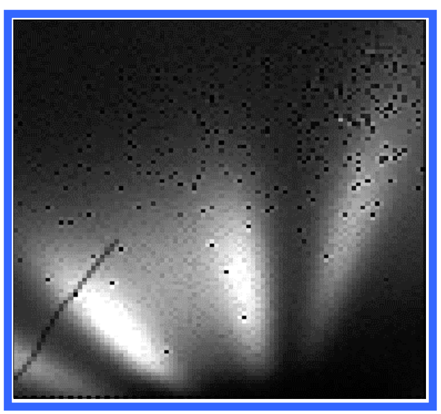
There are many high speed x-ray experiments that suit the Pixel Array Detector. Prime examples are time-resolved X-ray diffraction studies of biological and non-biological materials. Interesting biological diffraction studies include examination of enzyme-substrate interactions, polymerization, and contracting muscle. Time-resolved non-biological materials include substances undergoing elastic deformation under stress, phase changes in liquid crystals, fluid flows, and materials failure. Short time interval experiments often involve a combination of fast-optical imaging and fast-radiography, and frequently require data acquisition for very short time intervals (micro to nanosecs). Currently available area detectors cannot frame on these time scales. Therefore, a fast, large-area detector is needed.

The Solution: The Cornell **P**ixel **A**rray **D**etector

A few PAD Experiments already done

Diffraction Experiment:
Laue Diffraction at CHESS

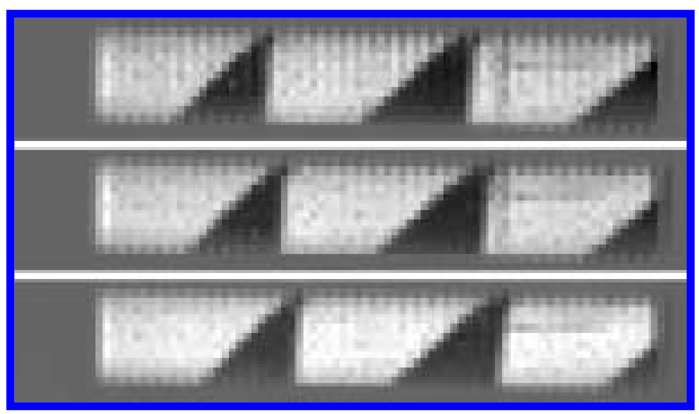
The detector. Ready for diffraction.



Al Diffraction Pattern, 100 µs exposure

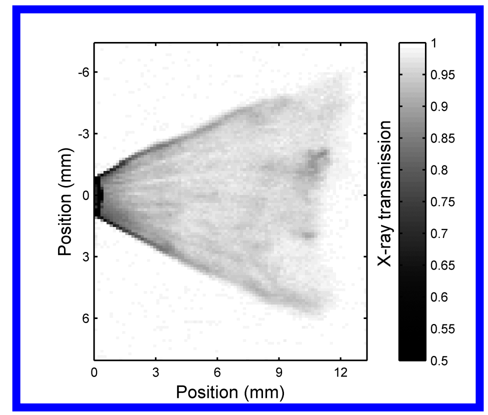
High-speed Imaging:
Moving Saw Blades!

Set-up of Sawblade apparatus. Live Dangerously.

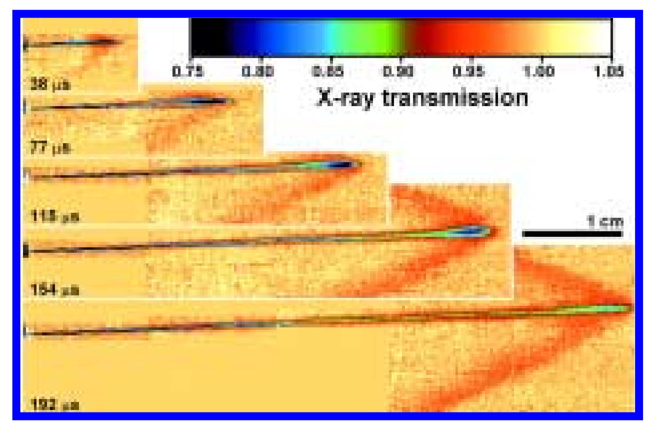


*5 µs exposures of a Sawblade, 1 µs frame spacing,
5000 RPM blade speed*

High-speed Radiography:
Looking at fuel sprays!



Spray from a car fuel injector



*Spray from a diesel fuel injector 5 µs exposure
Note the shock-wave*

Example: High speed imaging at the **APS** and **CHESS**: Experiments on fuel injector spray – radiography. This is a collaboration with Dr. Jin Wang's group at the **APS**.

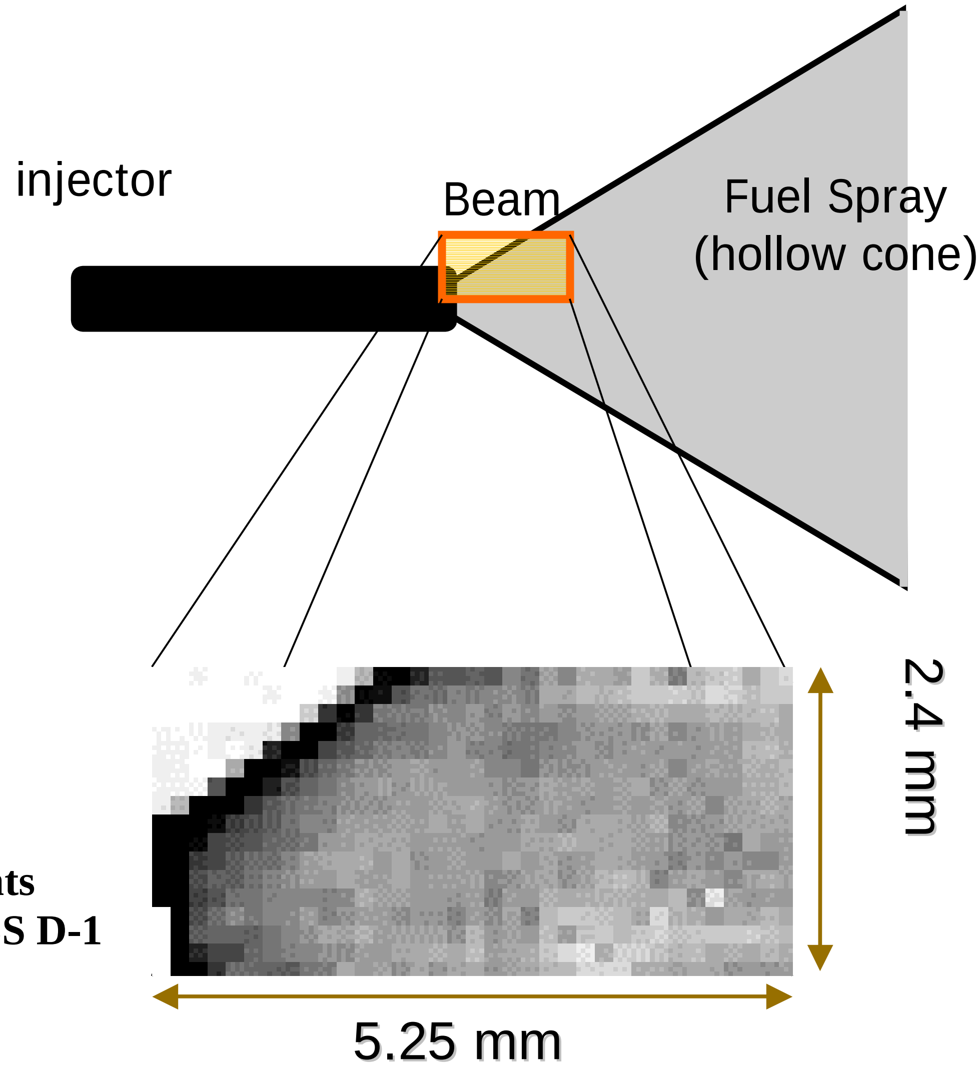
APS x-ray beam:

Beamline 1-BM
(bending magnet)
6 keV (Si monochromator)
2.4 mm x 5.25 mm
(step sample to tile large area)
10^8 x-rays/pix/s
7.4 μs integration (2x ring period)

Fuel injection system:

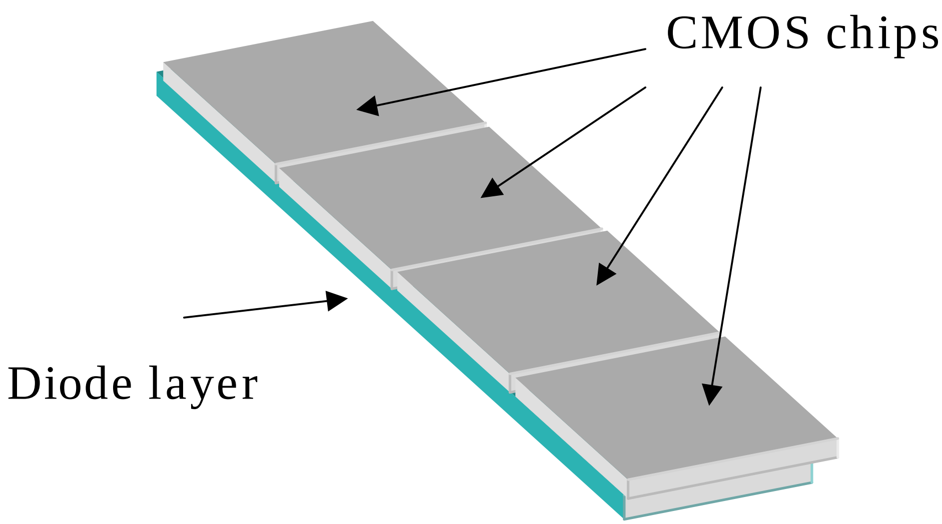
cesium added for x-ray contrast
1000 PSI gas driven
1 ms pulse

Other fuel injector imaging experiments have been performed at the CHESS D-1 station.



Plans for the Immediate Future

A new microchip is in the final stages of fabrication. The design is a new one: four ASICs will be bonded to a monolithic diode layer, thus creating a new “strip” detector. Each ASIC has 209x213 pixels, so a monolithic module contains 209x852 pixels, a huge leap in pixel number. It is a three side buttable design, such that the detector modules can be tiled to cover even larger formats and areas. The new chip has been designed with a 0.25 μm process, with 100 μm pixel.



Pixel Array Detector Papers

X-ray Imaging of Shock Waves Generated by High-Pressure Fuel Sprays
Andrew G. MacPhee, Mark W. Tate, Christopher F. Powell, Yong Yue, Matthew J. Renzi, Alper Ercan, Suresh Narayanan, Ernest Fontes, Jochen Walther, Johannes Schaller, Sol M. Gruner, and Jin Wang, **Science**,Vol 255, Number 5558, p1261, (2000).

Development of a pixel array detector for time resolved X-ray imaging
,G. Rossi, M.J. Renzi, E.F. Eikenberry, M.W. Tate, D. Bilderback, E. Fontes, R. Wixted, S. Barna, S.M. Gruner, **AIP Conf. Proc**, (2000).

Performance of semi-insulating gallium arsenide X-ray pixel detectors with current-integrating readout
Sellin, P.J.; Rossi, G.; Renzi, M.J.; Knights, A.P.; Eikenberry, E.F.; Tate, M.W.; Barna, S.L.; Wixted, R.L.; Gruner, S.M.**, Nuclear Instruments & Methods in Physics Research, Section A**, Volume 460, Issue 1, p 207, (2001).

Tests of a prototype pixel array detector for microsecond time-resolved X-ray diffraction
G. Rossi, M. Renzi, E. F. Eikenberry, M. W. Tate, D. H. Bilderback, E. Fontes, R. Wixted, S. Barna, and S. M. Gruner, **J. Synchrotron Rad**. **6**, p 1096 (1999).

A pixel-array detector for time-resolved X-ray diffraction
E. F. Eikenberry, S. L. Barna, M. W. Tate, G. Rossi, R. L. Wixted, P. J. Sellin, and S. M. Gruner, **J. Synchrotron Rad. 5**, p 252 (1998).

Characterization of a prototype pixel array detector (PAD) for use in microsecond framing time-resolved X-ray diffraction studies
S. L. Barna, J. A. Shepherd, M. W. Tate, R. L. Wixted, E. F. Eikenberry, and S. M. Gruner, **IEEE Trans. Nucl. Sci. 44**, p 950 (1997).

Development of a fast pixel array detector for use in microsecond time-resolved X-ray diffraction
S. L. Barna, J. A. Shepherd, R. L. Wixted, M. W. Tate, B. G. Rodricks, and S. M. Gruner, **Proc. SPIE 2521**, p 301 (1995).