First Results Using the Medipix2 Photon Counting ASIC as Readout for a Micro-Channel-Plate Detector - Proposal for a New Wavefront Sensor for Adaptive Optics

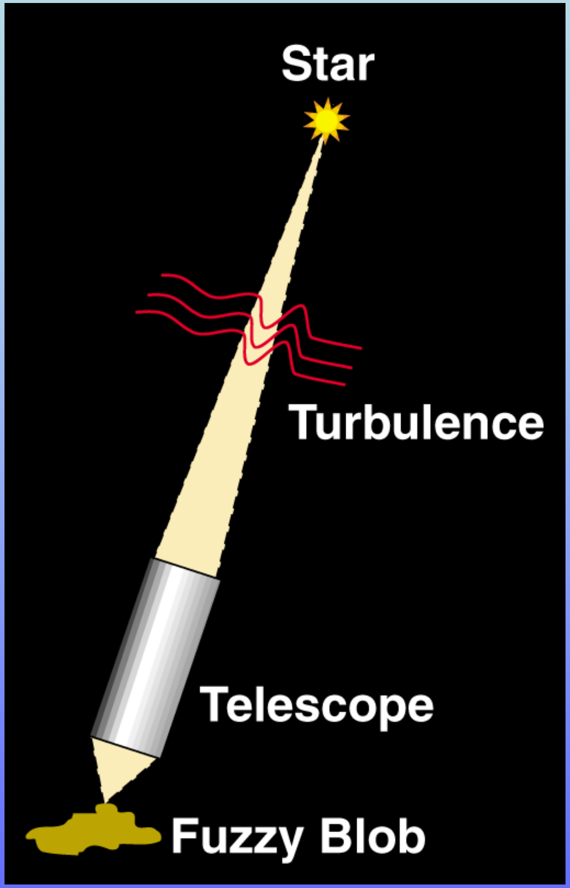
Allan Clark, Bettina Mikulec

John Vallerga, Jason McPhate, Anton Tremsin, Oswald Siegmund

(Space Science Laboratory, Univ. of Berkeley)

Cartigny, 2 July 2004

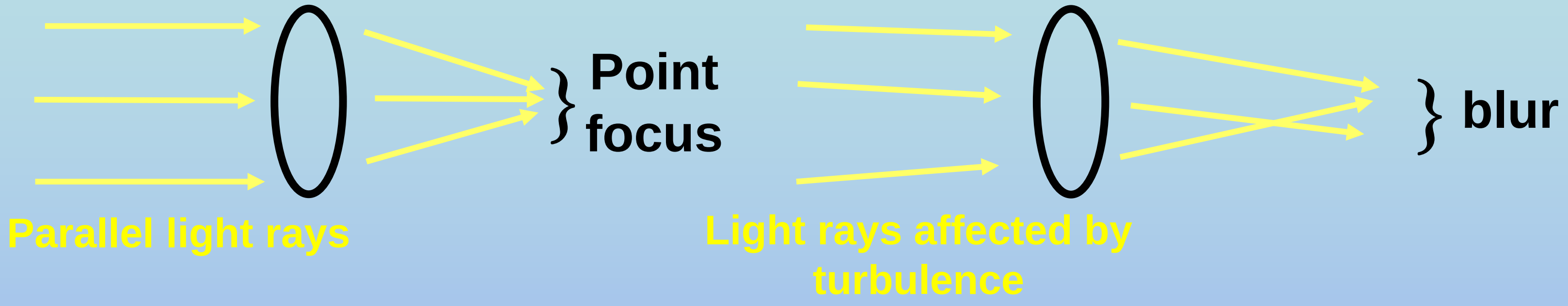
Introduction

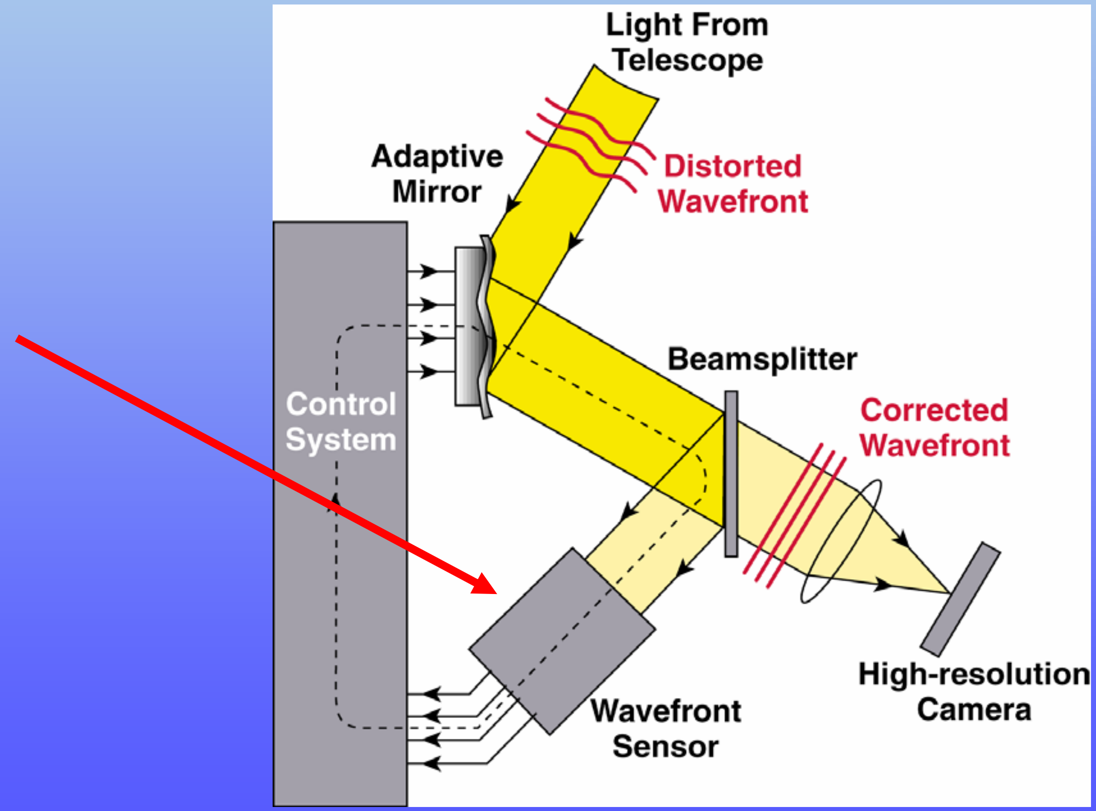


- Turbulence in the earth’s atmosphere makes stars twinkle
- More importantly, turbulence spreads out the star light making it a blob rather than a point

Even the largest ground-based astronomical telescopes have no better resolution than an 8" telescope!

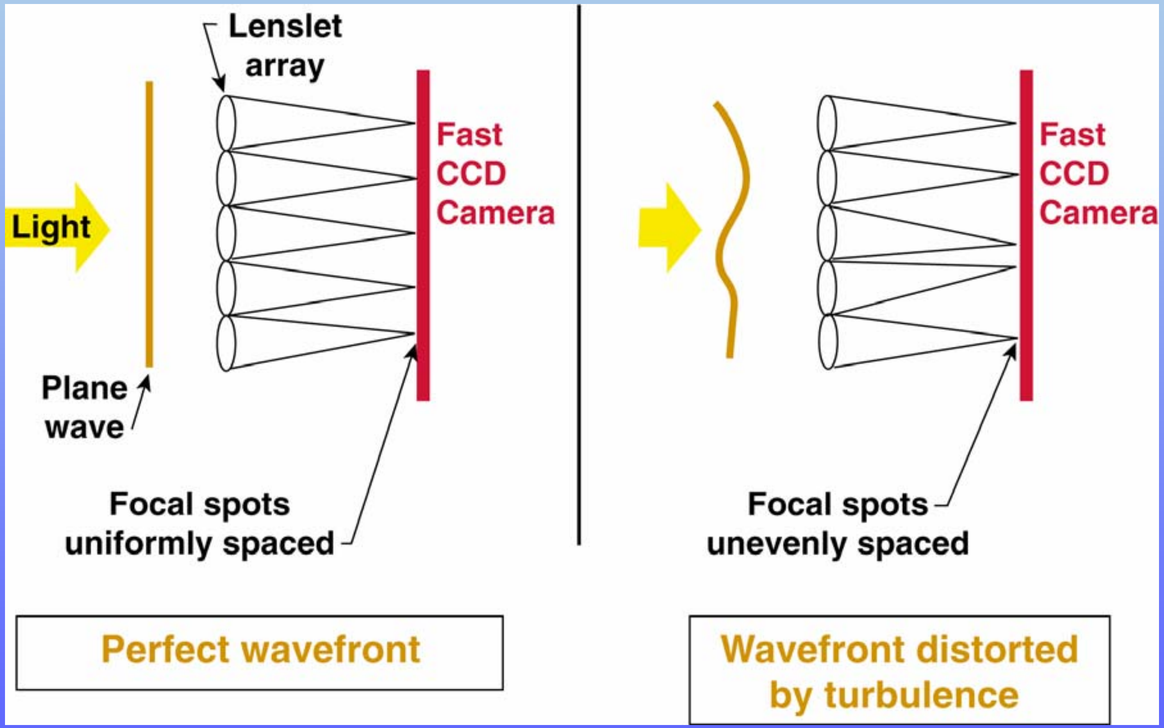
Adaptive Optics



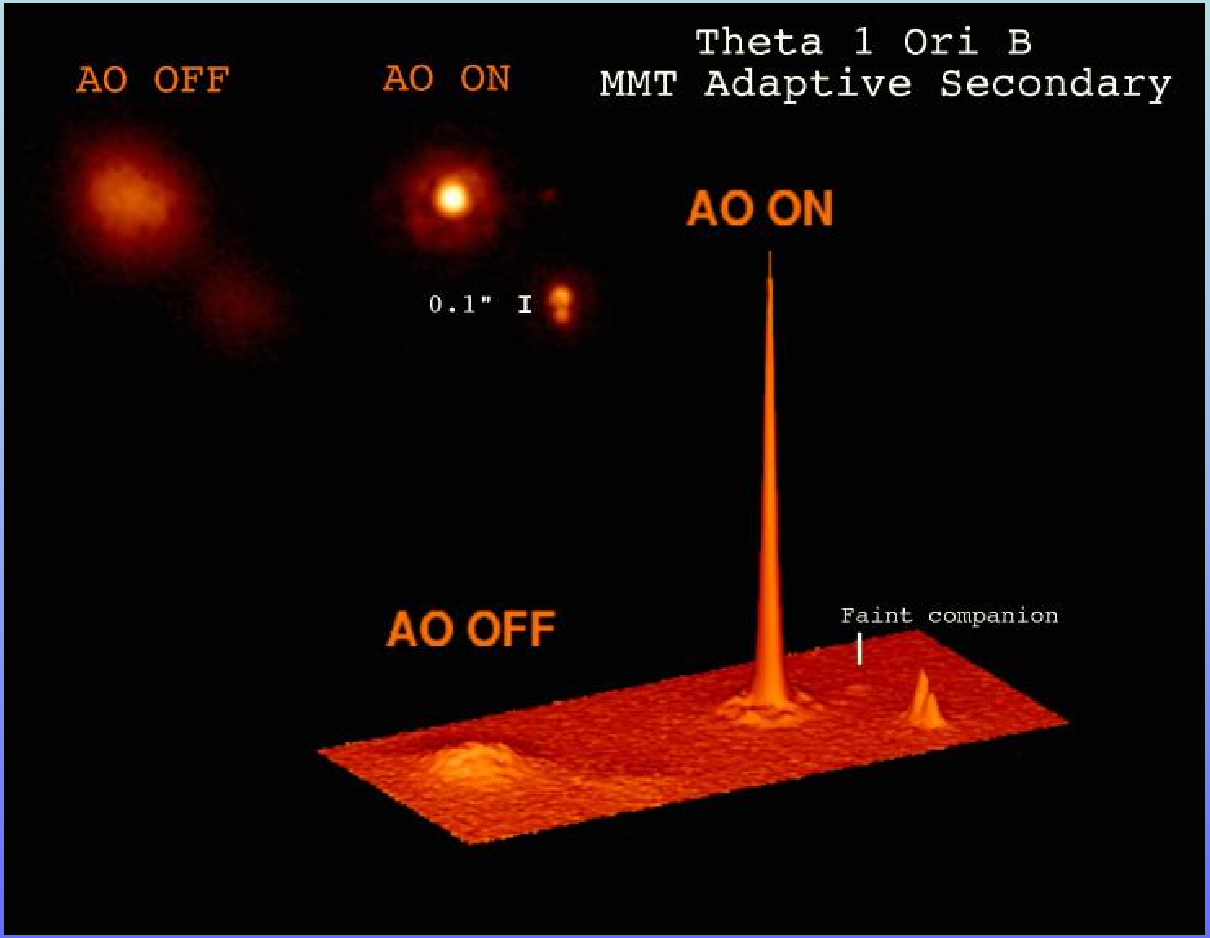


Adaptive Optics

- Determine the distortions with the help of a natural or laser guide star and a lenslet array (one method among many). Deviations of the spot positions from a perfect grid is a measure for the shape of the incoming wave-front.



Adaptive Optics



example for the enormous improvements using AO

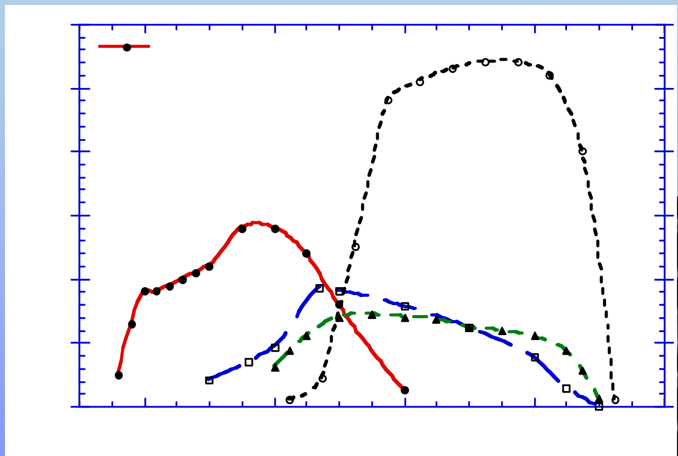
Wavefront Sensor Requirements

- High QE for dimmer guide stars (~80% optical QE)
- Many pixels in the order of 512 x 512; future large telescopes will have about 5000 actuators (controlled via 70 x 70 centroid measurements)
- 1000 photons per spot to get a 3% centroid rms error with respect to the stellar image size.
- 1 kHz frame rate (light integration, readout, calculations, send out 5000 signals and ready for new frame) corresponding to the timescale of the atmospheric turbulences
- Very low readout noise ($< 3e^-$)
- Gate the detector in 2-4 μs range for operation with laser guide stars

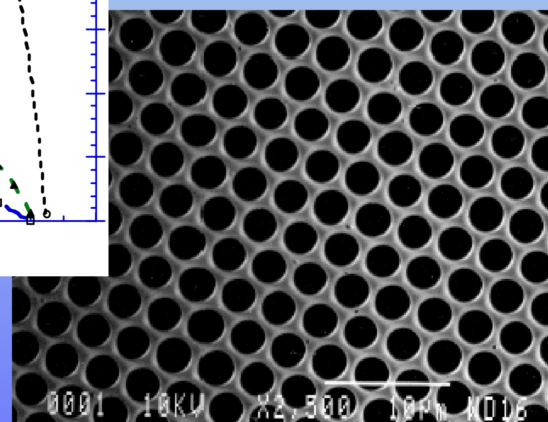
Large pixel array, high frame rate and no readout noise not simultaneously achievable with CCDs!

Proposal for a New Wavefront Sensor

high-QE photo-cathode
+ MCP + Medipix2



GaAs photo cathode



2 µm pores on 3 µm centers *(Burle Industries)*

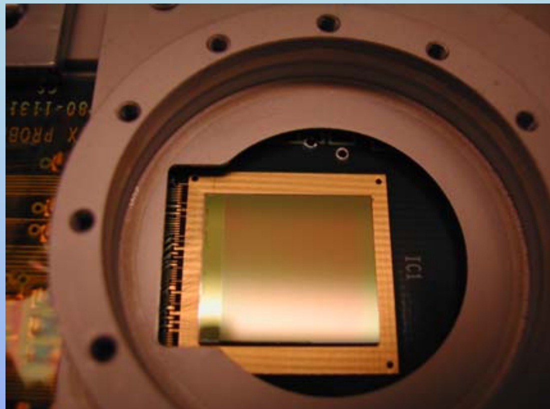
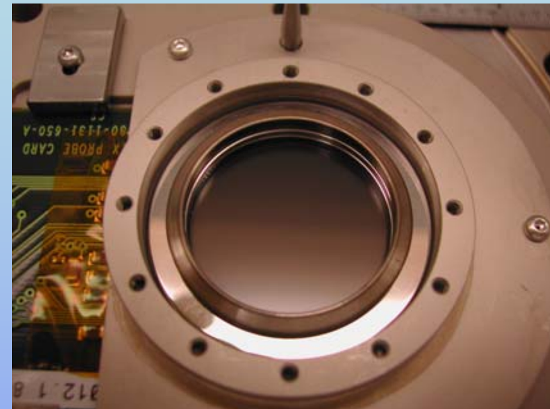
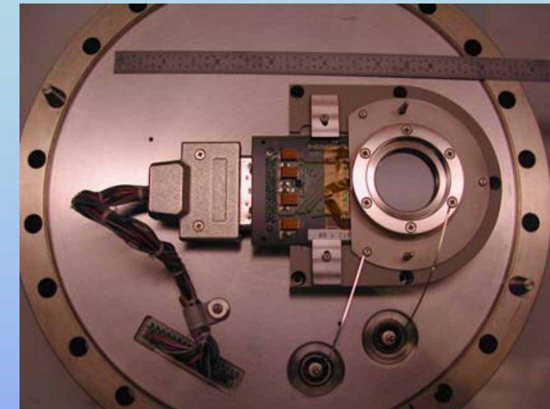
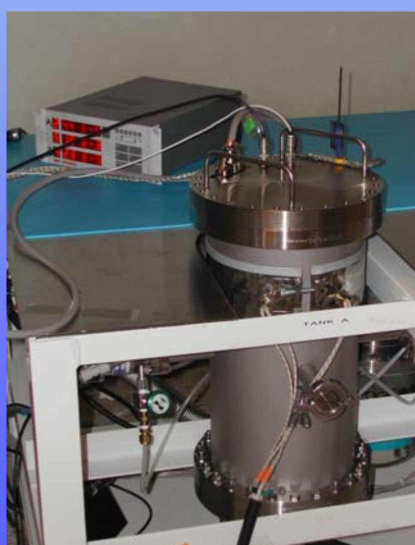
Medipix2 photon counting ASIC

Setup for the First Measurements

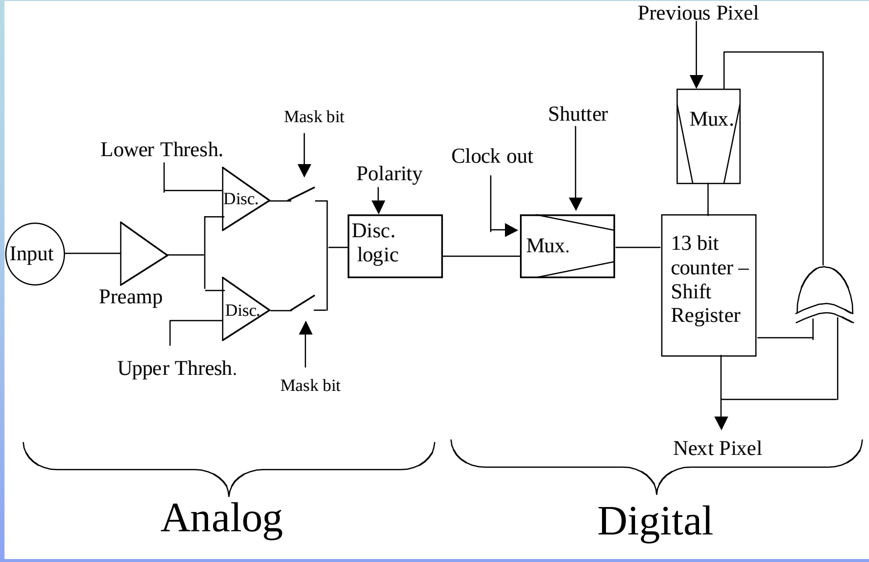
- A Medipix2 photon counting chip
- A matched pair of MCPs:
  - Photonis MCPs with 33 mm diameter
  - 10 μm hole diameters, L/D = 40/1
  - low resistivity (~22 MOhms per plate)
  - gain was varied between 20k and 200k (1430 - 1680 V)

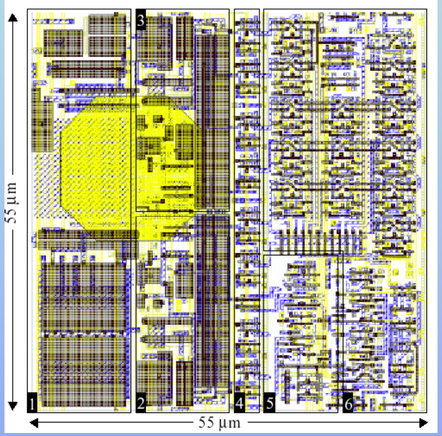
- Vacuum tank pumped down to ~10^{-6} torr
- Hermetic feed-throughs (50-pin connector for Medipix signals)
- A standard UV Hg pen-ray lamp with collimator (~10 counts/s -500M counts/s)
- A Muros2 readout board
- Medisoft 4.0 software modified for electron readout

The Setup at SSL - Photos

The Medipix2 Photon Counting Chip

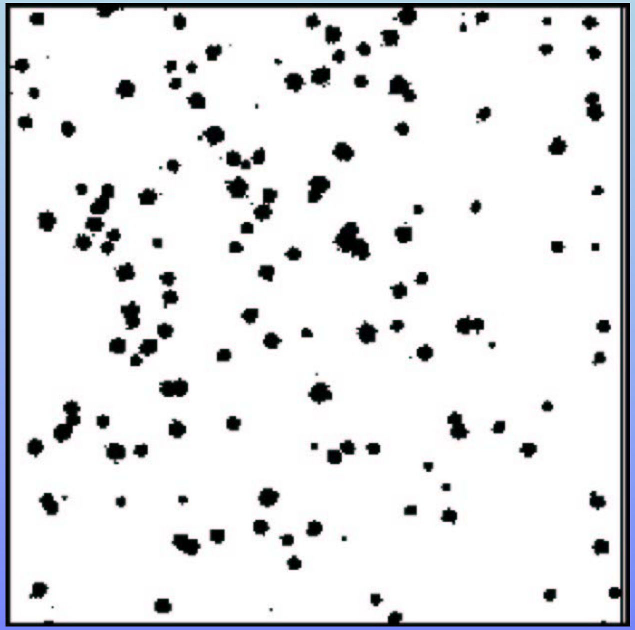




- **0.25 μm CMOS technology (33M transistors/chip)**
- **square pixel size of 55 µm**
- **256 x 256 pixels**
- **sensitive to positive or negative input charge (free choice of different detector materials)**
- **pixel-by-pixel detector leakage current compensation**
- **window in energy**
- **discriminators designed to be linear over a large range**
- **13-bit counter per pixel**
- **count rate: ~1 MHz/pixel (0.33 GHz/mm^2)**
- **3-side buttable**
- **serial or parallel I/O (min. readout time of full matrix 266 µs)**

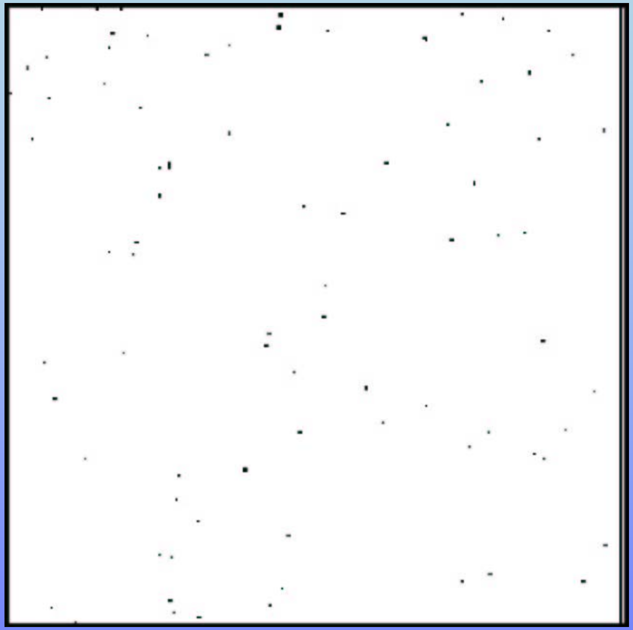
Feasibility Tests

06 April 2004



gain 10^6, rear field 427 V

single photon events



gain 50k, rear field 980 V

It works!

Investigating the Parameters…

- Spot area [no. of pixels] is a function of
  - MCP gain (voltage across MCPs):
    decreases with decreasing gain (threshold effect)
  - Rear field (voltage between MCP exit and Medipix chip):
    decreases with increasing rear field

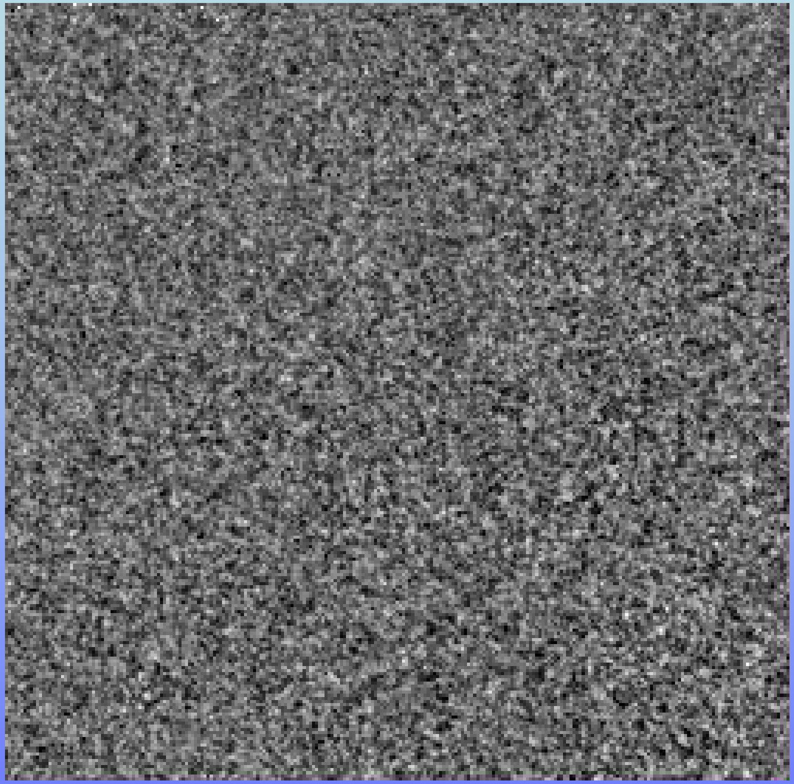
- Increasing VTH_{low} over the available range at MCP gain of ~200k results in a decreasing spot area size, but the number of spots stays approximately constant.

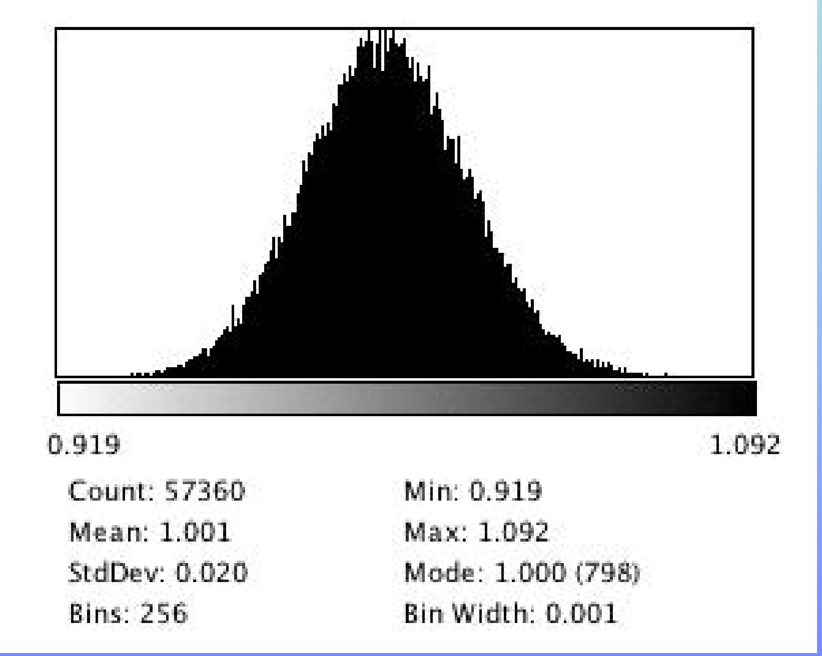
Flat Fields

- Take image at 50ke gain and 1600 V rear field (~5000 counts/pixel). Average single spot area: 2.4 pixels

fixed pattern noise mostly from dead spots on the MCPs and MCP multifibres

Flat Fields





The division of 2 flat fields shows only Gaussian noise (no residual fixed pattern noise).

Histogram of the division of 2 flat fields; average=1, rms=0.02 consistent with variance of the division of two 5000 count images.

Air Force Test Pattern - Centroiding

- The Air Force test pattern was used to demonstrate the imaging properties of the detector, in particular the resolution.

  The pattern provides different groups of horizontal and longitudinal lines; 6 elements of different line width (and line separation) per group. In the standard Air Force 1951 target, the number of lines per mm doubles with every 6th target element.

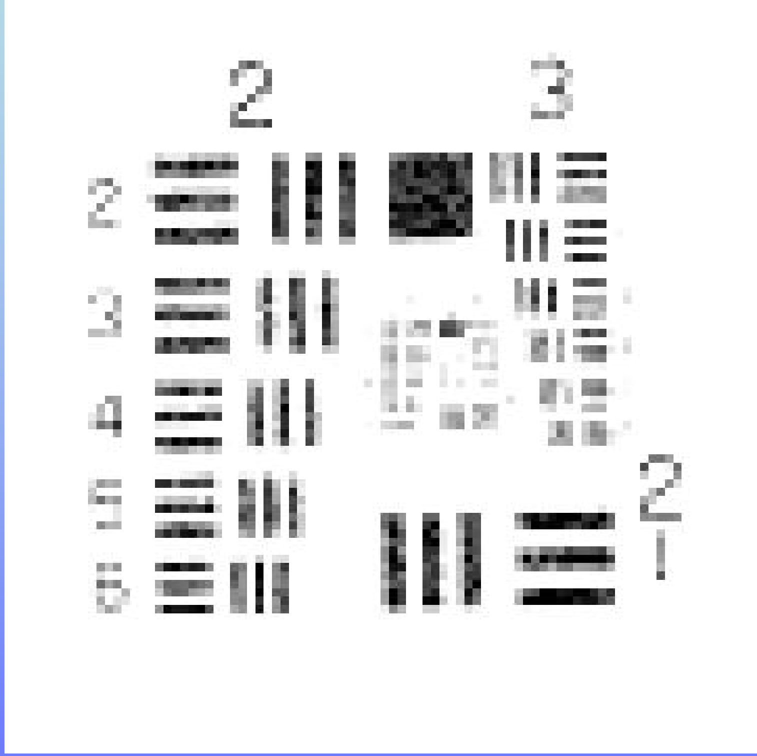
Centroiding individual photon events to achieve sub-pixel resolution:

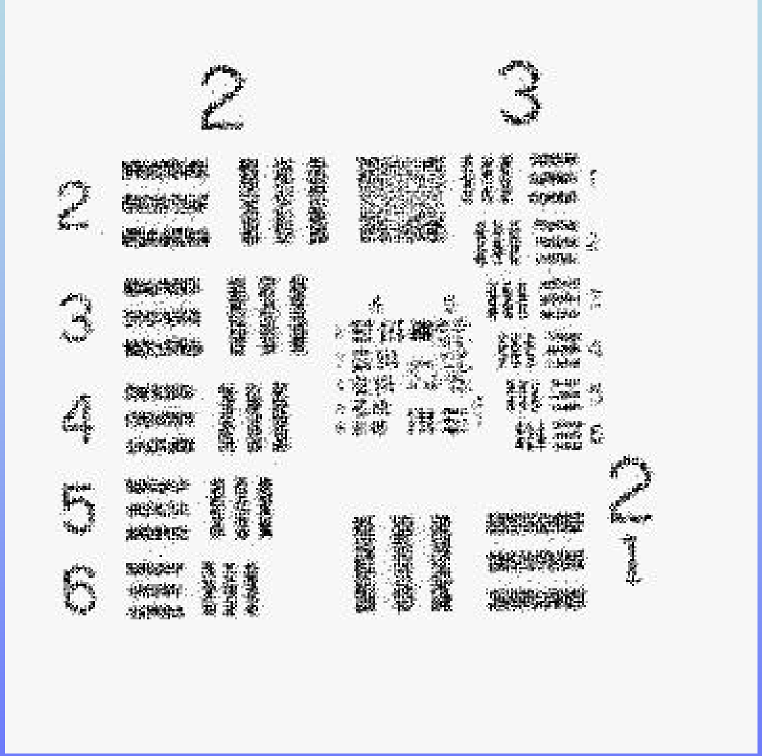
- Take many very low count rate images with larger spot area to avoid overlapping spots. (~100-150 counts/frame; 1000 frames)
- Special analysis software written to identify unique spots and reject overlapping events (counts $\geq$ 2), count spots, record their size and calculate the centroids.

Could be useful for low rate imaging applications!

Air Force Test Pattern - Centroiding

- Air Force test pattern:

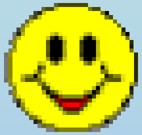




Standard Medipix readout with small spot sizes; 3-2 visible (8.98 lp/mm corresponding to the Nyquist limit with 55 μm pixels).

Sub-pixel centroiding using individual photon events with larger spot area of ~12 pixels; 1024 x 1024 binning. 4-2 starts to be resolved (17.95 lp/mm; 55.7 μm corresponding to ~28 μm pixels).

Conclusions



- Setup installed at Berkeley
- First feasibility tests very successful!
- Systematic tests varying different detector parameters underway
- No fixed pattern noise yet detectable except MCP imperfections
- Resolution at Nyquist limit and below (for event-by-event centroiding) demonstrated

Future Plans

- Prepare a setup in Geneva
- Evaluate different MCPs (L/D ratio, pore angle, resistivity etc.)
- Tests with metallised Medipix2 chips
- Evaluate process of metallised holes through wire bonding pads???
- Tube fabrication to be prepared
- Specific parallel readout board to be designed

- Possibility for Geneva to *gain experience* with pixel detectors and readout