# Detector Development at APS

Antonino Miceli (for the Optics & Detector Group/XSD)

SRI 2010 – Detector Workshop

September 21, 2010

# Outline

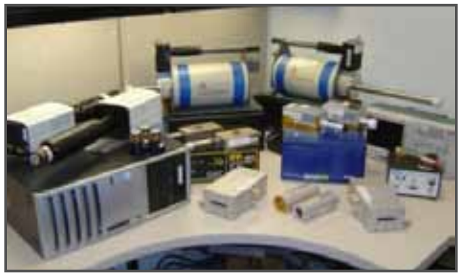
- **APS Detector/Equipment Pool**
  - General Overview & Activities
- **Detector R&D Activities**
  - Fast CCD (LBL + ANL)
  - Real-time Data Processing with FPGAs
  - Superconducting Detectors
  - Partnerships with Industry and Universities
- **Needs for APS Upgrade**
- **Conclusions**

# Optics & Detectors Group in XSD

- Led by Patricia Fernandez
- Detector Side consists of an R&D and Detector/Equipment Pool section
- Detector Staffing:  5 Engineers, 2 Physicists, 2 Scientific Associates, 2 Technicians
  - + 1 new hires!

# APS Detector/Equipment Pool

- Provide support for ~ 50 detector systems for temporary loan
  - ~ 300 requests per year.
- We are the outlet for new detectors for the beamlines.
- Centralized source for detector information.
- Characterization of current and new detectors.
  - New Optics and Detectors Beamline
- Detector-driven technique development
  - "Pushing detectors to the limit!"



# Major Detectors/Equipment

- GE & PE Amorphous Silicon Flat Panel (2) (>100%)
- Pilatus 100K Pixel Array Detector (2) (>100%)
- Mar 345 Image Plate (2) (100%)
- Mar 165 CCD (3) (100%)
  - Frameshift/Kinematics Mode
- Bruker 6500 CCD Detector (1)
- PI CoolSnap & Zeiss/Mitutoyo Optics (2) (75%)
  - Including scintillators
- Other Microscopy CCDs: Sarnoff, Prosilica, etc.
- APS-in-house Avalanche Photodiodes (APDs)
- Ketek Silicon Drift Diode (6)
- SII Vortex Single-element SDD (4) (75%)
- SII 4-element Vortex SDD (2) (80%)
- Single & multi - element Germanium (3)

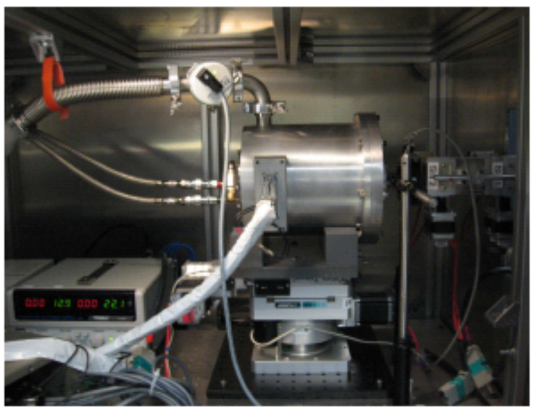
GE a-Si Flat Panel

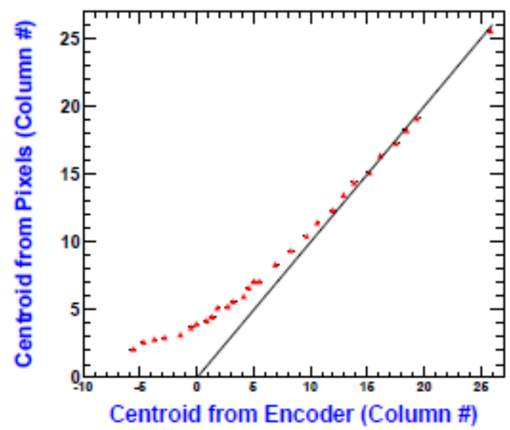
Pilatus 100K

4-element Vortex SDD

# Beyond the Detector Pool -- X-ray Test Facilities

- **Copper X-ray tube in 401-L0111**
  - Testing of FCCD (John Weizeorick)
  - "Narrow-Beam X-Ray Tests of CCD Edge Response" (submitted 2010)
    - S. Kuhlman et. al. (HEP/ANL)
    - Support by Beyer, Gades, Miceli, and Spence






**Evidence of E-field distortions at CCD edges!!!**

- **Phillips High-Energy X-Ray Tube (W anode)**
  - In operation.
  - Flat field Calibration of large area detectors (e.g., GE/PE flat panel)
  - ***Need to develop testing protocols!!***

# New Optics & Detectors Beamline at APS (6-BM)

- **Will enable systematic and careful detector characterization and re-calibration**
  - For example, energy-dependent threshold re-calibration of pixel detectors
  - Flat-fields for various large area detectors (e.g., GE and PE a-Si Detectors)
- **Will enable testing with synchrotron timing structure**
  - Dead-time corrections with various bunch structures (e.g., hybrid singlet) *(See Don Walko et. al. Poster)*
- **Will enable detector-driven technique development**
  - Novel uses of detectors.

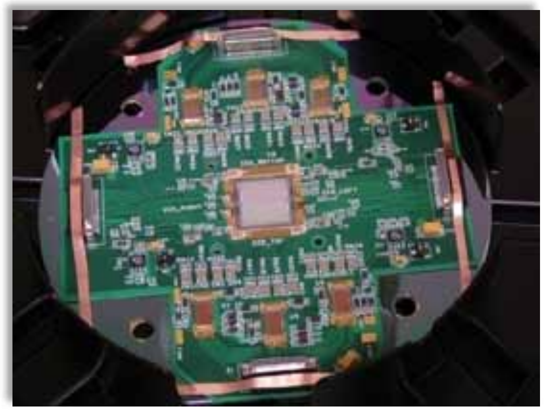
# Detector R&D Examples

- **Detector R&D at synchrotrons is a dizzying task!**
  - Lots of people to please! (Science or Detector focused?)
- **Fast CCD Project (LBL & ANL)**
- **Real-time Processing of XPCS Data in an FPGA**
- **Superconducting Detectors**
- **This is an incomplete list….**
  - Bernhard Adams' talk: "Hard-X-Ray Streak Camera at APS" (Thursday @ 1:50pm)
  - Klaus Attenkofer's Poster – "Sub-ns  Resolving Area Detector for X-ray Photons"
    - Leveraging UChicago/ANL "Large Area Picosecond Photo Detector" Project
      - Picosecond timing for water cherenkov neutrino experiment
  - APS Users: e.g., G. Seidler (Seattle) "miniXS" x-ray emission spectrometers
    - Short working distance x-ray optics + Pilatus
    - http://faculty.washington.edu/seidler/minixs.html

# FastCCD -- Quasi-Column Parallel, Thick CCD

- LBNL CCD Sensor
  - 480 x 480 pixels, 30µm x 30 µm pixel size
  - 200µm Thick Fully Depleted (High QE)
    - Direct Detection
  - Readout Time = 5.1 msec
  - 96 Analog outputs - Almost column-parallel readout
  - XPCS applications at 8-ID
- LBNL fCRIC Readout ASIC
- APS DAQ System
  - Dalsa X64-CL Full Frame Grabber
    - Original Frame Grabber collecting raw data
    - Too Much Data! ~100 MB/sec continuous
  - Dalsa Anaconda Frame Grabber
    - User Programmable FPGA
    - Allows real time data compression

SEE DIONISIO 'S TALK



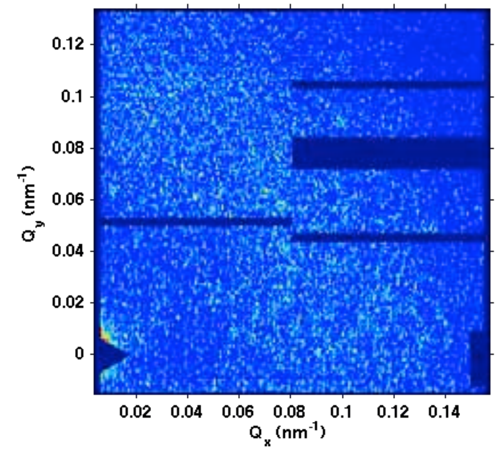
FCCD 6" wafer holder

John Weizeorick

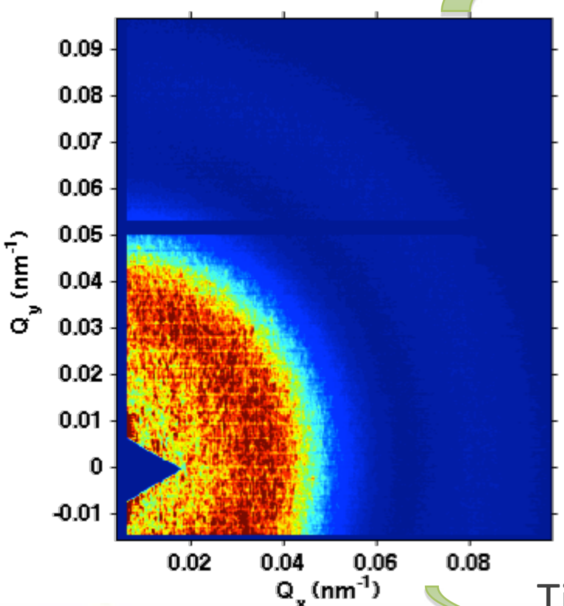
# FCCD Science - Speckle & XPCS at 8-ID

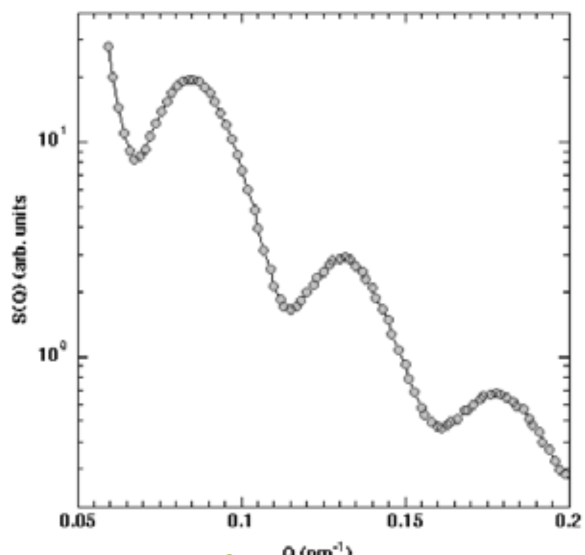
- **Static and dynamic speckle measurements**
  - **Aerogel – static speckle**
  - **Dynamics of latex spheres (R=260 nm) in glycerol**
    - **Bread and butter XPCS experiment– performed for NX summer school – know answers**

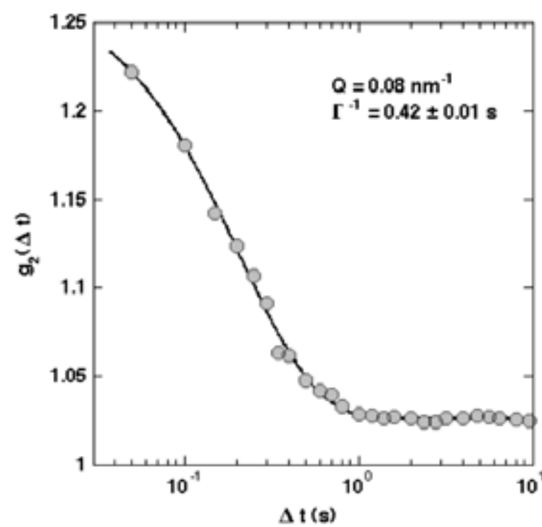
    **[L. Lurio, et al., Phys. Rev. Lett. 84, 785 (2000)]**
  - **Fast CCD works for speckle and XPCS measurements!**




Time autocorrelation



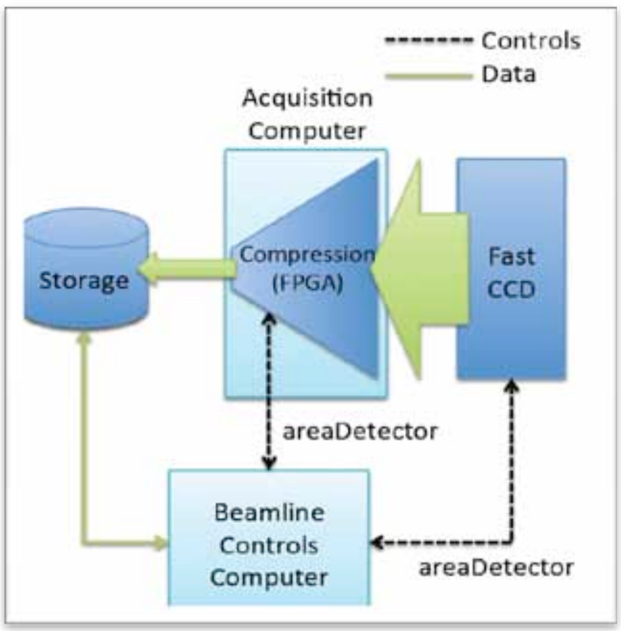

Time average

10 ms exposures

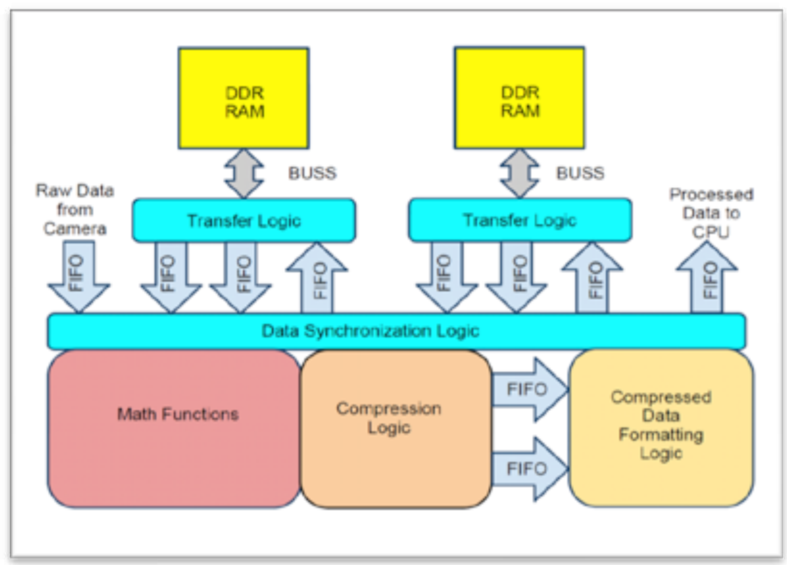
A. Sandy & L. Lurio

# Real-time Processing of XPCS Data in an FPGA (Tim Madden)

- Real-time processing with FPGA
  - Image averaging
  - Noise measurements
  - Dark subtraction
  - Compression
  - EPICS interface
  - Allows the fast camera to collect XPCS data continually




Hardware setup for XPCS

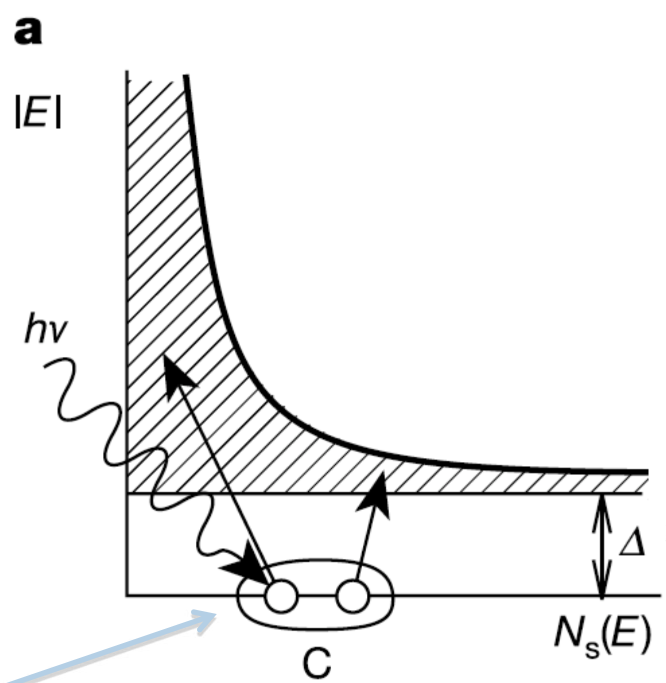



FPGA firmware/hardware.

SRI Poster

# High resolution fluorescence detectors using superconducting sensors…

- Use Cooper Pairs as detection mechanism (like electron hole pairs in a semiconductor) ….
  - Quasiparticle detector.
  - Not Bolometers or Transition Edge Sensor devices.
- The goal is moderate energy resolution (< 20eV) with good count rate capabilities (> 200kcps)




Cooper Pair

SC Energy Gap

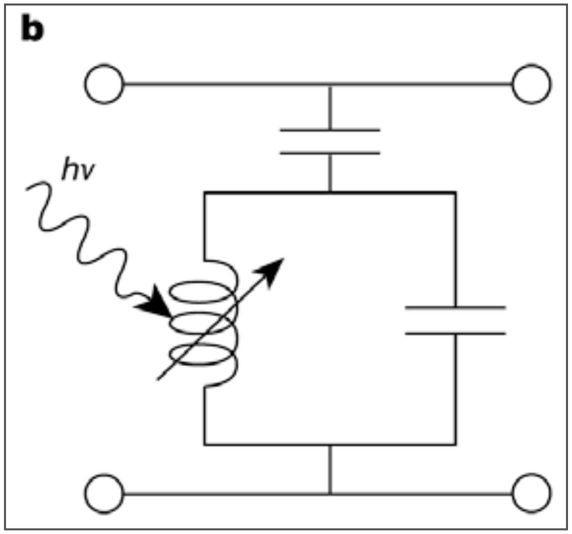
Silicon – 1.10000 eV

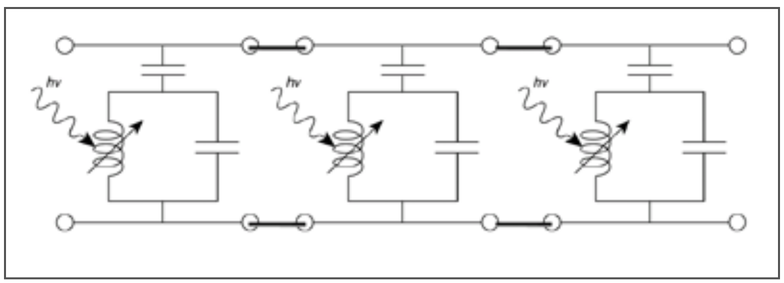
Aluminum – 0.00018 eV

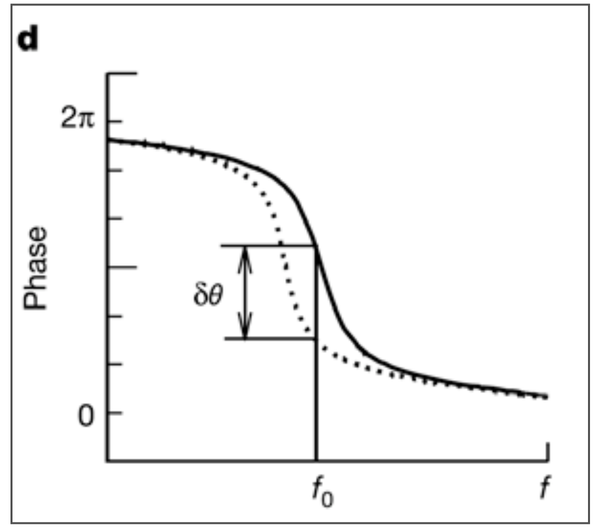
Energy resolution:

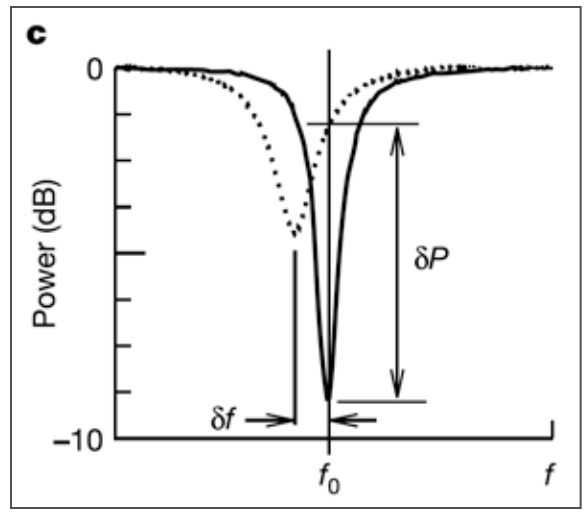
$$R = \frac{1}{2.355}\sqrt{\frac{\eta h\nu}{F\Delta}}$$

# Microwave Kinetic Inductance Detectors



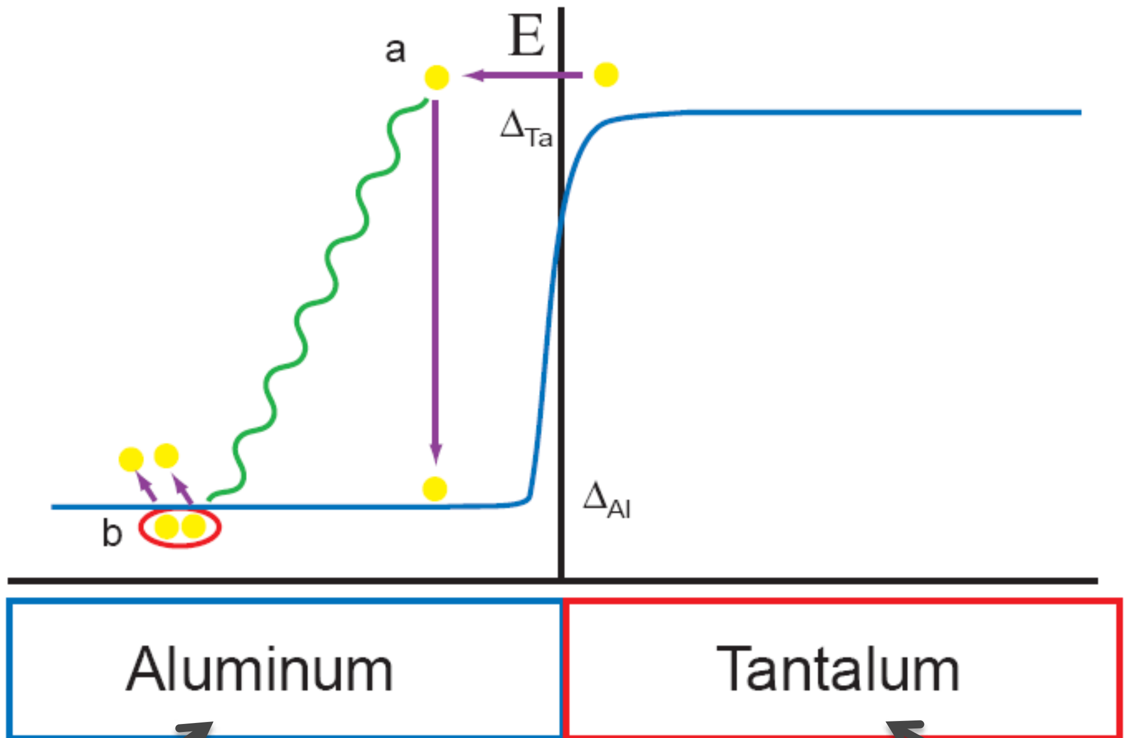

**Ben Mazin et. al.**

UCSB
University of California, Santa Barbara

JPL
Jet Propulsion Laboratory
California Institute of Technology

‘Microwave’ refers to the readout frequency!
(e.g., 3-10 GHz)

# MKIDs – Quasiparticle Trapping



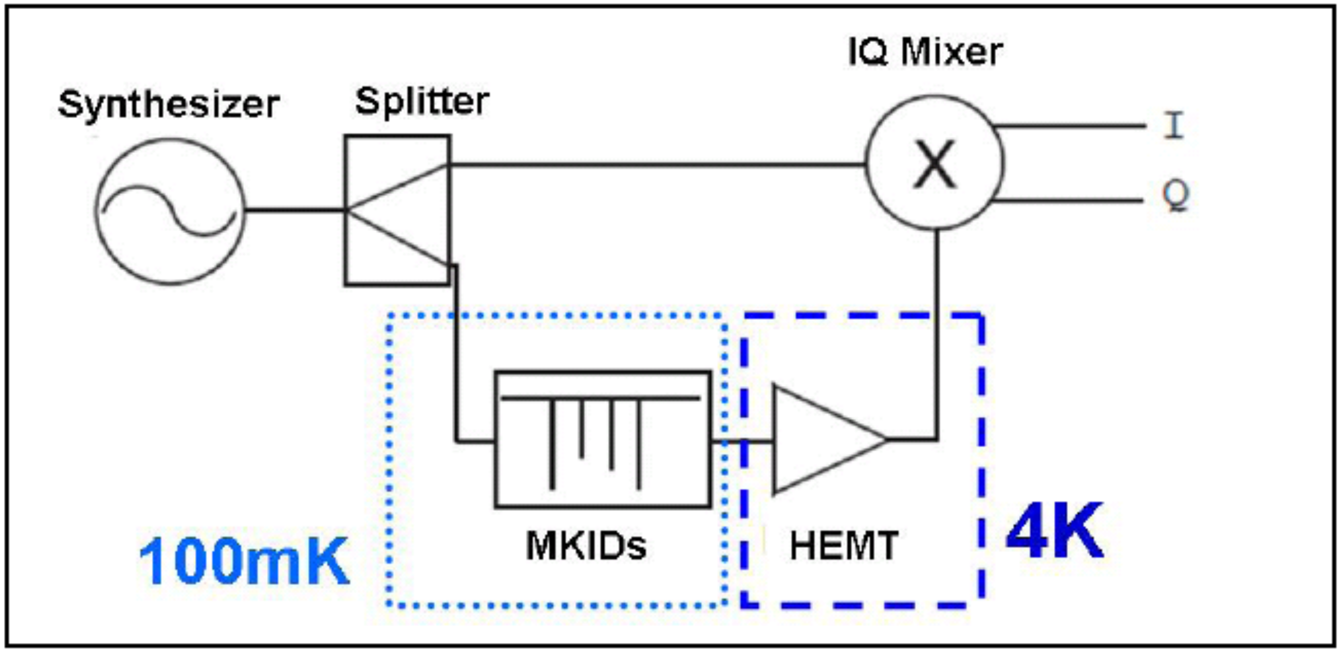

Co-Planar Waveguide Resonator

X-ray Absorber (quasiparticle diffusion)

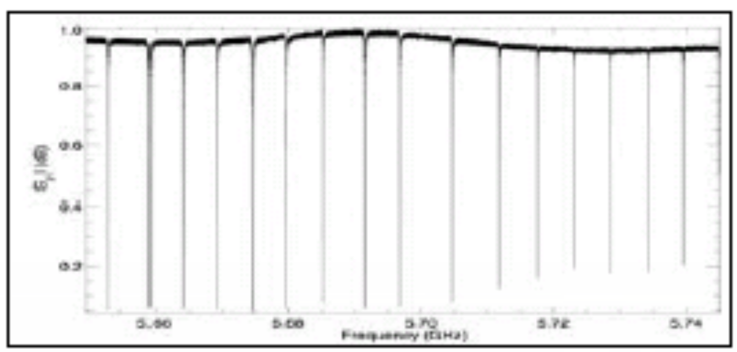
# MKIDs – Count-Rate

- The maximum count rate is roughly the inverse of the combined quasiparticle lifetime in the absorber ($t_a$ ) and the resonator ($t_r$ ).
  - Rise time → Absorber diffusion time
  - Fall time → Quasiparticle lifetime in the resonator
  - e.g., tantalum absorber and aluminum resonator
    - the measured lifetimes are: $t_a$ ~ 40 ms and $t_r$ ~ 190 ms
    - This yields a maximum count rate of ~ 4000 Hz per element.

# MKIDs – Readout Scheme




***Multiplexing is main advantage of MKIDs over STJs and TES***




**Should be able to readout ~4000 pixels**

# MKIDs @ Argonne for synchrotrons

- Fabrication is completely in-house
- Relatively "simple"… patterning of metal (deposition, photolithography, etching)
  - Film quality is very important!
- Funded for 5 years
- ***Leverages Argonne's micro/nano-fab facilities (CNM) and superconductivity expertise (MSD); Astronomical TES bolometer program (MSD & UChicago); and the APS RF expertise.***

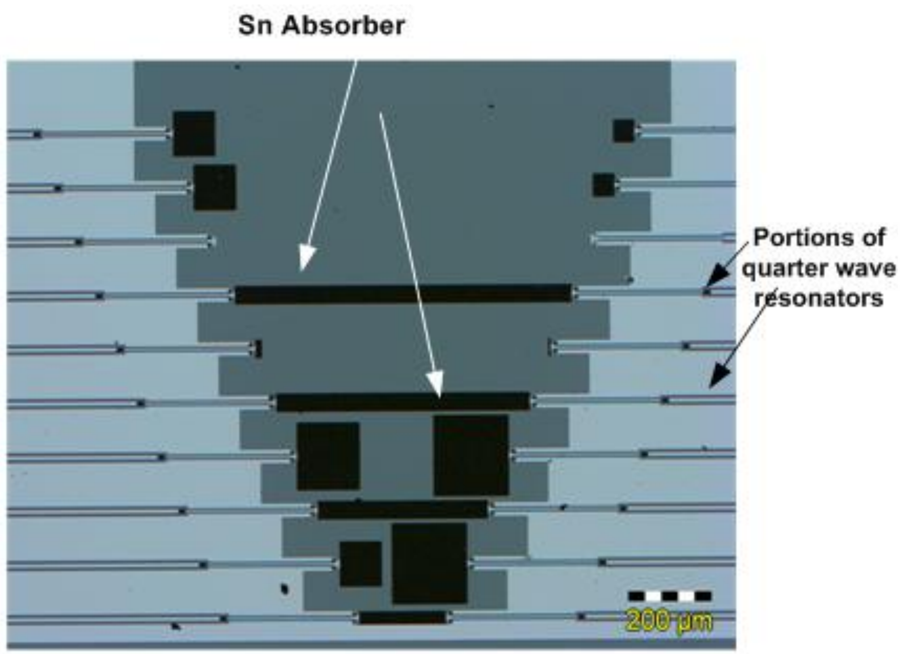



**Table 1:** Fano Limits for Various Absorber Materials

| Material | Atomic Number Z | Transition Temperature | Theoretical Energy Resolution at 6 keV | Attenuation Length at 6 keV |
|---|---|---|---|---|
| Lead | 82 | 7.2 Kelvin | 3.53 eV | 1.86 μm |
| Tantalum | 73 | 4.5 Kelvin | 2.79 eV | 1.79 μm |
| Tin | 50 | 3.7 Kelvin | 2.53 eV | 2.60 μm |
| Indium | 49 | 3.4 Kelvin | 2.43 eV | 2.77 μm |
| Rhenium | 75 | 1.7 Kelvin | 1.72 eV | 1.31 μm |
| Molybdenum | 42 | .92 Kelvin | 1.26 eV | 2.94 μm |
| Osmium | 76 | .66 Kelvin | 1.07 eV | 1.18 μm |

# Partnerships with with Industry & Universities (Steve Ross)

- **SBIR Collaborations**
  - **Voxtel Inc**. -- Pixel array detector (2 counters / pixel, 2 energy levels, for pump-probe applications, 12-100 ns shaping times, silicon sensors)
  - **RMD Inc**. -- Silicon avalanche photodiode array detectors (sub-ns response times, fast timing, photon counting, ultra low dark counts.
- **University Collaborations**
  - **Georgia Tech EE (Prof. J. Cressler) → Ultra-Fast ps Photon Counting Detectors**
    - Measure time of arrival of x rays (probe) wrt to laser (pump) with precision < 10 ps.
    - Using state-of-art silicon-germanium IC design, IBM8HP process.
    - First ASIC run sent out 6/2010; expect to have first pixels by 2011.
  - **Northern Illinois University's Cleanroom Partnership**
    - 8000 ft2 class 100 facility
    - Building capabilities not available internally at ANL/CNM
    - Aimed at semiconductor device fabrication

SRI Poster

# Needs for APS Upgrade
## (from Beamline Staff)

- **Expansion of APS Detector Pool**
  - Expand inventory
  - Procure custom or non-commercial items
  - Expand services
- **Fast Detectors**
  - Fast Radiography & Pump-Probe PX → Analog pixel array detectors with "analog pipeline" (e.g., Cornell, XFEL, etc)
- **Small Pixels**
  - e.g., Coherent Diffraction Imaging (CDI) limited by direct detection CCDs dynamic range!!
    - Need Pilatus-like detector with 30 microns pixels!
    - 3D-ASICs?
- **"Hard X-ray Detectors" ( E > 20keV)**

# Conclusions

- **APS Detector/Equipment Pool**
  - Provide a centralized source for detector information and knowledge base
- **Detector R&D Activities**
  - Finding the right projects to work on is a challenge
    - Conflict between technology limitations and what people want.
  - Need to leverage local opportunities and form strategic collaborations

# Acknowledgements

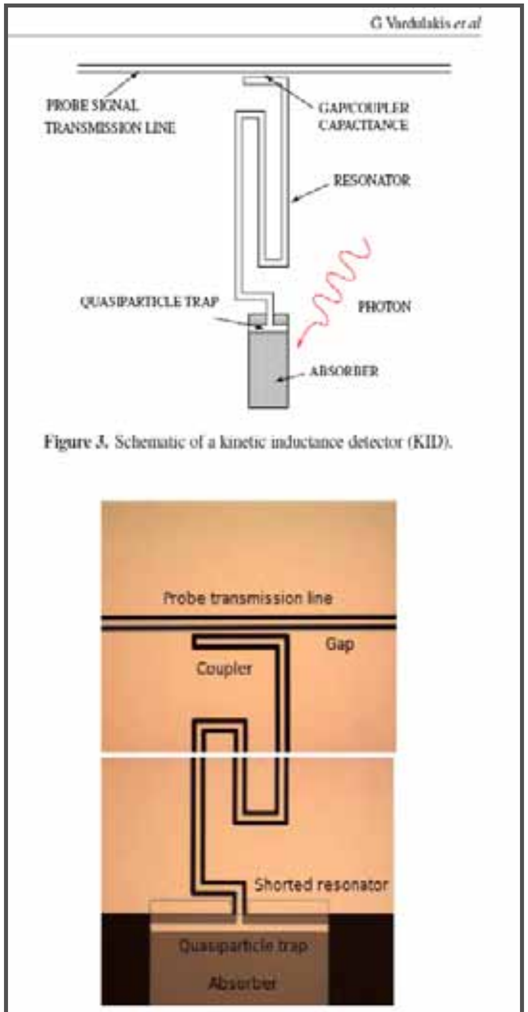

- Patricia Fernandez (ODG Group Leader)
- Steve Ross
- John Weizeorick
- Tim Madden
- John Lee
- David Kline
- Antonino Miceli
- Tom Cecil
- Lisa Gades
- Troy Lutes
- Jon Baldwin
- Chris Piatak

# Extra Slides

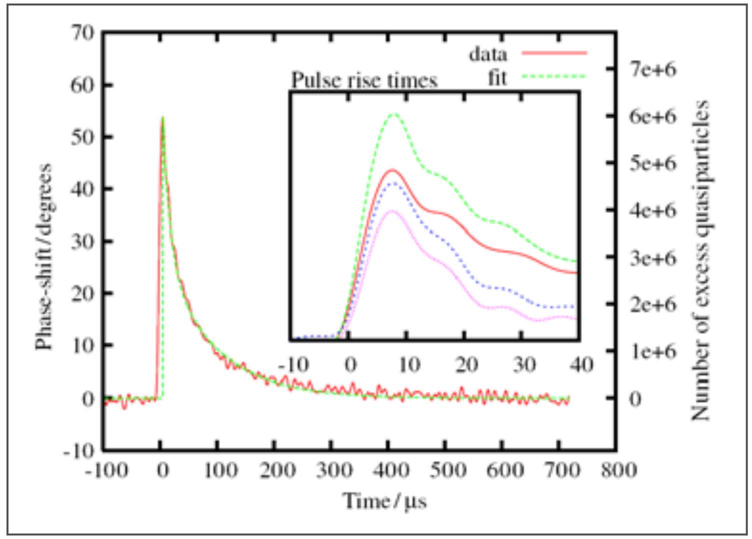
# MKIDs - How Cold?

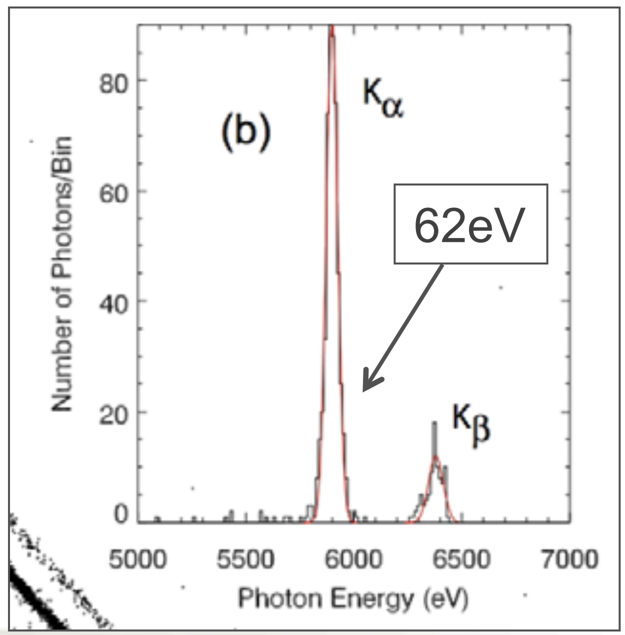
- **Want to operate T ~ Tc/10 ~ 100mK**
  - Minimize quasiparticle recombination noise (P/B)
- **How?**
  - He3/He4 Dilution Fridge (dry)
    - Lots of cooling power, expensive, difficult to operate
  - 2-stage Adiabatic Demag. Refrig. (ADR) (dry)
    - Fixed hold time (1-2 days, 2-3 hour recycle time)
    - Cheaper and less cooling capacity.

# MKIDs – Speed and Resolution




G Vardulakis *et al* Meas. Sci. Technol. **19** (2008) 015509




**Mazin et al 2006**

# Recent Commercial Detector Acquisitions
## (from US Stimulus/ARRA Funding)

- **Dectris Pilatus Detectors**
  - 3x 100k (Surface Scattering (6, 33-ID) & XAFS/Diffraction (20-ID))
  - 1x 1M (GISAXS @8-ID)
  - 1x 2M (SAXS @ 12-ID)
- **Flat Panel (40x40cm) a-Si Detectors**
  - 4x GE a-Si for 1-ID
  - 1x PerkinElmer a-Si for 11-ID
  - 1x PE a-Si for Detector Pool
- 4x **SII Nano Vortex ME-4** (4-element SDD)
  - Microprobes (2-ID, 8-BM), XAFS (20-ID), and DP.
- 1x **Bruker Quad Annular Transmission** mode SDD array (2-ID microprobe)
- Funding for next-generation **Fast CCD** with LBL (1k Frame Transfer device)

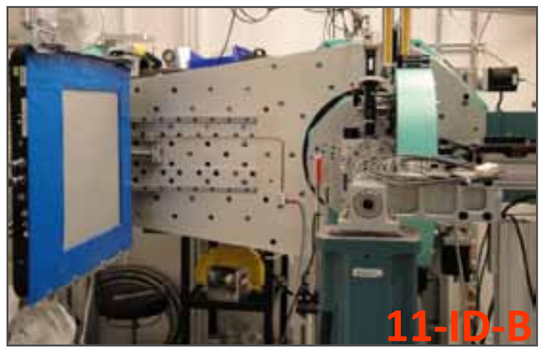
# a-Si Flat Panel Detectors at APS

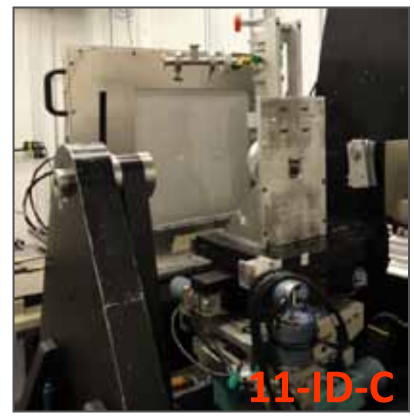
- GE Medical Systems & PerkinElmer
- CsI Scintillator (~400 microns)
- a-Si array of photodiodes
  - 2048 x 2048 (200 mm pixels)
- Frame Rates:
  - 8 Hz (2k x 2k)
  - 30 Hz (1k x 1k binned)
- High-Energy Diffraction ( >20keV)

# a-Si Flat Panel Detectors at APS

- **1x GE @ 1-ID/6-ID**
  - HE Diffraction
  - J. Almer, U. Lienert, P. Lee, D. Haeffner
- **1x PE at 11-ID-B**
  - Pair Distribution Function
  - Pete Chupas
- **1x PE at 11-ID-C**
  - HE Diffraction
  - Yang Ren, Chris Benmore
- **3x PE at 34-ID-E**
  - X-ray Laue Micro-diffraction
  - G. Ice, W. Liu, J. Tischler

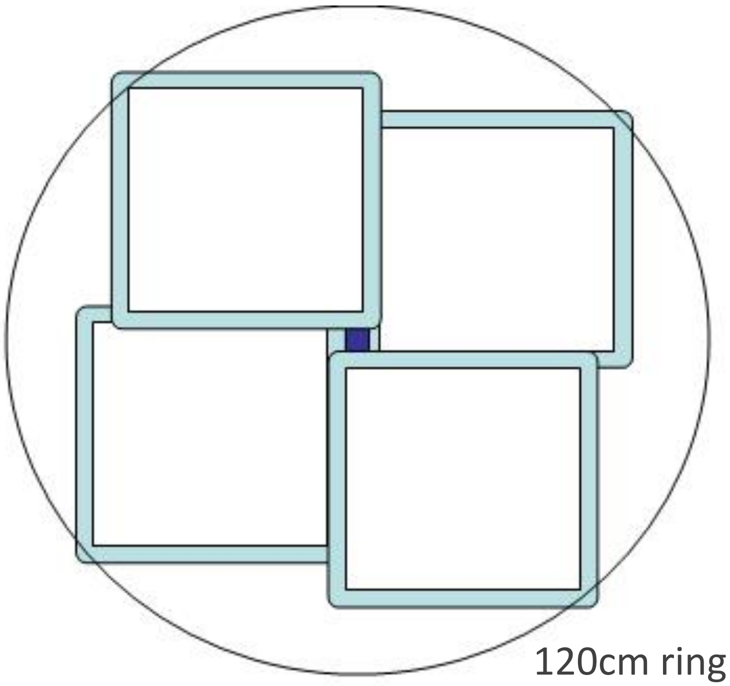
1-ID/6-ID





# Quad GE a-Si @ 1-ID for HE-SAXS/WAXS




## Operational modes at 1-ID

- Quad-paneled array for SAXS/WAXS
- 1 near-field, 2-3 far-field for HEDM
- 1-2 for powder/crystallography
    - fixed setup mounts, interchange detectors

## Technical gains

- Increase radial resolution to ~10-4
- Enable simultaneous SAXS/WAXS/(imaging)
- Scattering tomography
- Improved temporal resolution (up to 4) using offsets
- Improved signal/noise (fluorescence, 'hot' samples)

## Scientific gains

- Fundamental dislocation dynamics studies (HEDM)
- Nano-particle synthesis (SAXS/WAXS)
- Damage evolution under mechanical/thermo-mechanical deformation (SAXS/WAXS/HEDM)
    - Advanced nuclear energy systems *('hot' samples)*
    - Biomechanics *(temporal studies)*
    - Energy conversion devices - batteries and fuel cells
    - Tribology/coatings

**Jon Almer (1-ID)**