HEP DIVISION BRAINSTORMING WORKSHOP
WEDNESDAY 6 NOVEMBER 2019

Argonne NATIONAL LABORATORY

HEPD DETECTOR R&D GROUP PROGRAMS, STATUS, AND DISCUSSION TOPICS

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OVERVIEW OF DETECTOR R&D PROGRAM

- **Detector R&D Group:**
  - Superconducting Detectors — identified as major focus of Detector R&D. Development of lower Tc materials, MKIDs, and testing of same
  - Q-Pix — promoted as other major initiative of Detector R&D, needs plan for work with defined objectives and goals; charge of Detector R&D Task Force
  - Ring Resonator — Development of optical notch filter to remove OH background lines in near infrared. FY2020 is last year of multi-year program with goal of on-sky tests of optical ring filter in NIR
  - Microchannel Plate Photodetector — scaled down from major program of last decade (LAPPD) to ongoing targeted improvement of MCP-PMT performance in timing resolution, magnetic field tolerance, and pixel readout; also support for 3D printed MCP development
  - CMOS Silicon Pixel — mainly irradiation and testing of pixel devices developed by collaborators (led by U. Geneva group); mandated to conclude Detector R&D program in FY2020
  - Nanoparticle Wavelength Shifters — to date has developed WLS materials outside of Detector R&D support. Plan to support work in FY2020 as part of Q-Pix UV photodetection program

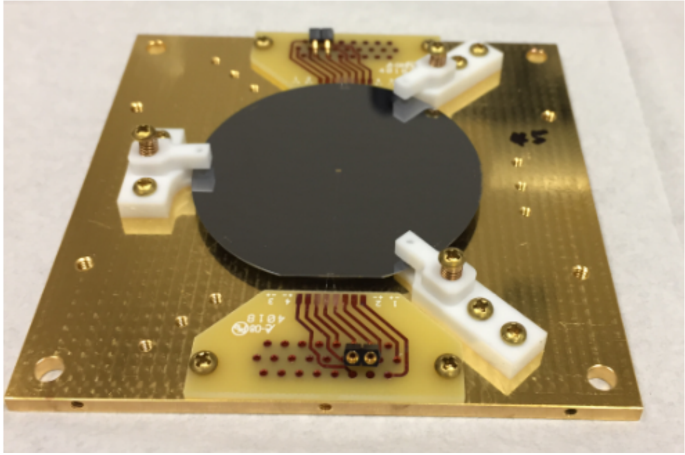
SUPERCONDUCTING DETECTORS

Well-defined program that includes development of lower Tc TES & Resonator materials for dark matter, neutrino physics, and light detection. MKIDs for higher frequency bands in CMB and on-chip spectroscopy for Line Intensity Mapping

- Detector R&D work concentrates on development of
  - Lower Tc TES devices (~20mK): Vlod Yefremenko
  - Low Tc TES development & testing: Gensheng Wang, Jianje Zhang
  - New materials for TES and resonators: Yefremenko
  - Current amplifier for readout: Wang
  - ADR TES+Resonator testing: Tom Cecil
  - Resonator development: Pete Barry
    - materials characterization
    - OMT-coupled KIDs
    - KID array
- Physics Impacts: enable light dark matter search with very low threshold (~10eV), low energy neutrino physics, improving CMB readout and detection in higher frequency bands

LOW-TC TES LIGHT DETECTOR

- The energy resolution of a TES detector can be improved by lowering its operational temperature
- A Low-Tc TES light detector with low-threshold energy (a few tens of eV) is required to measure scintillation (or Cherenkov) light for a zero background cryogenic Neutrino-Less Double Beta Decay (NLDBD) search experiment
- The developed technology will also be a critical technology for
  - Low mass Dark Matter searches
  - High resolution light detectors in high energy physics



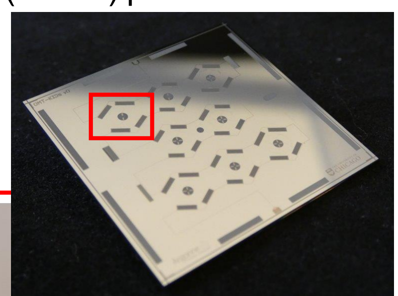
A low-Tc TES detector measuring light has three components: a surface-engineered thick silicon wafer (2-inch in diameter) as a light absorber, a TES thermometer in the middle measuring the absorbed energy, and a weak thermal link to a cold bath.

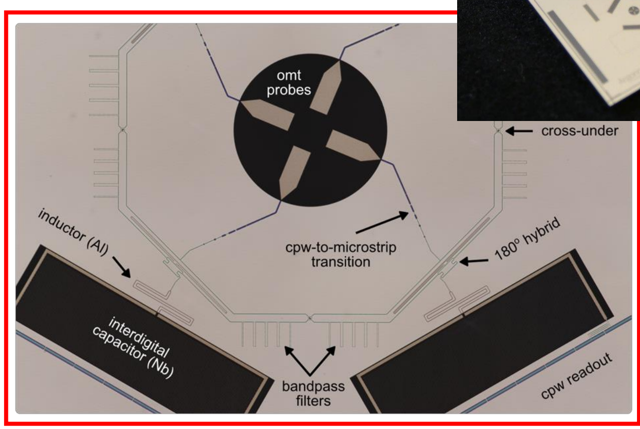
slide courtesy of Gensheng Wang, Argonne HEPD

SUPERCONDUCTING RESONATOR R&D

OMT-coupled MKIDs

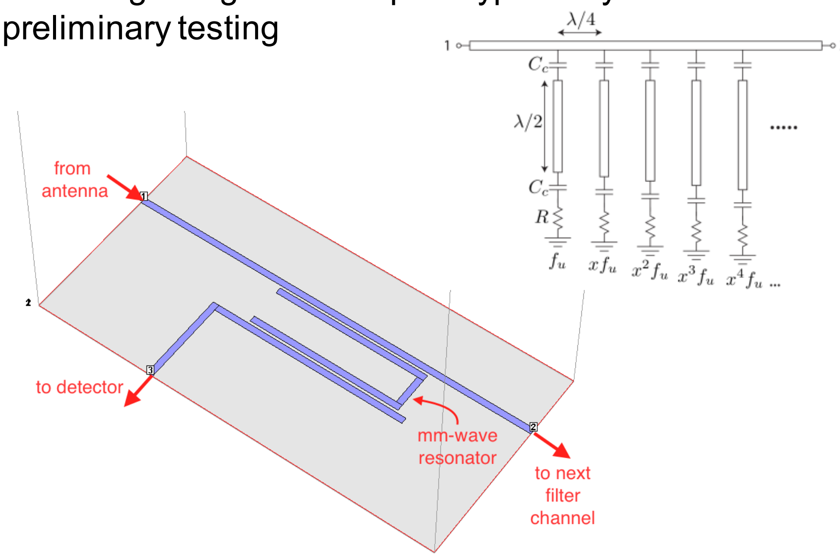
- Work at CNM (ANL) + PNF (UChicago) to develop high frequency (>200 GHz) planar OMT-coupled kinetic inductance detector arrays
- Prototype devices successfully fabricated and laboratory testing on-going
- Now scaling to full-wafer (6 inch) process





On-chip spectroscopy

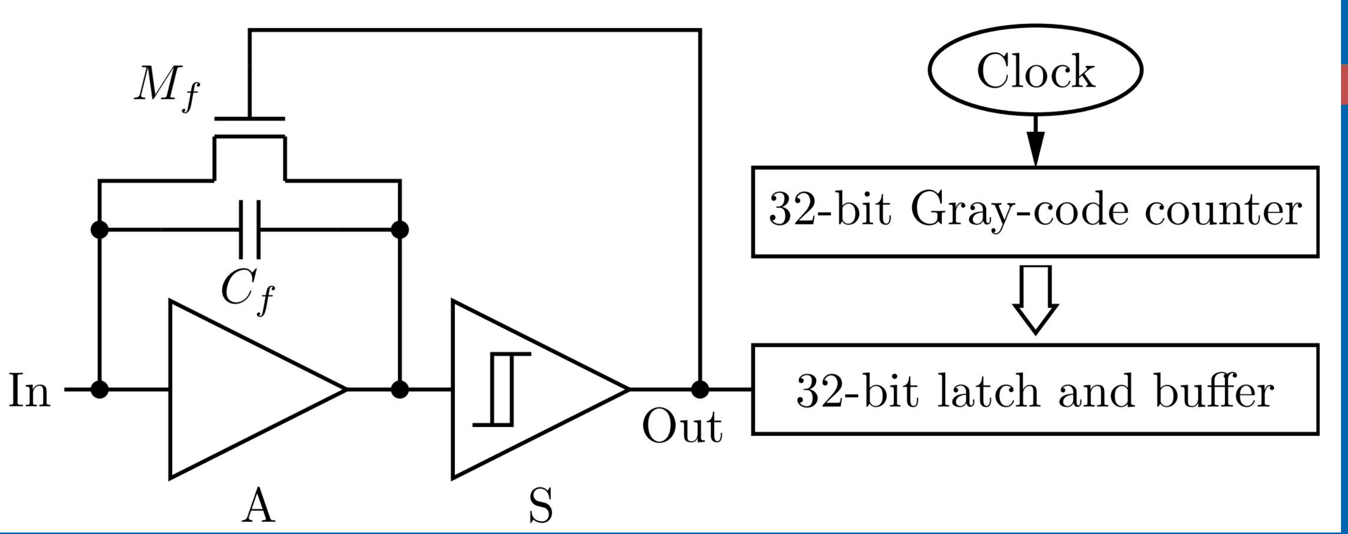
- Current mm-wave spectroscopy limited by scale-limited technology (e.g. grating)
- Instead, use miniature on-chip superconducting circuits to disperse incoming radiation
- Enable new instruments such as multi-object spectrometers and mm-wave IFUs
- Finalizing design of initial prototype arrays for preliminary testing

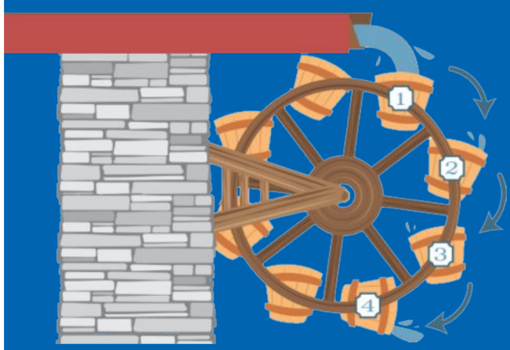


slide courtesy of Pete Barry, Argonne HEPD

WHAT IS Q-PIX?

Reset Time Difference





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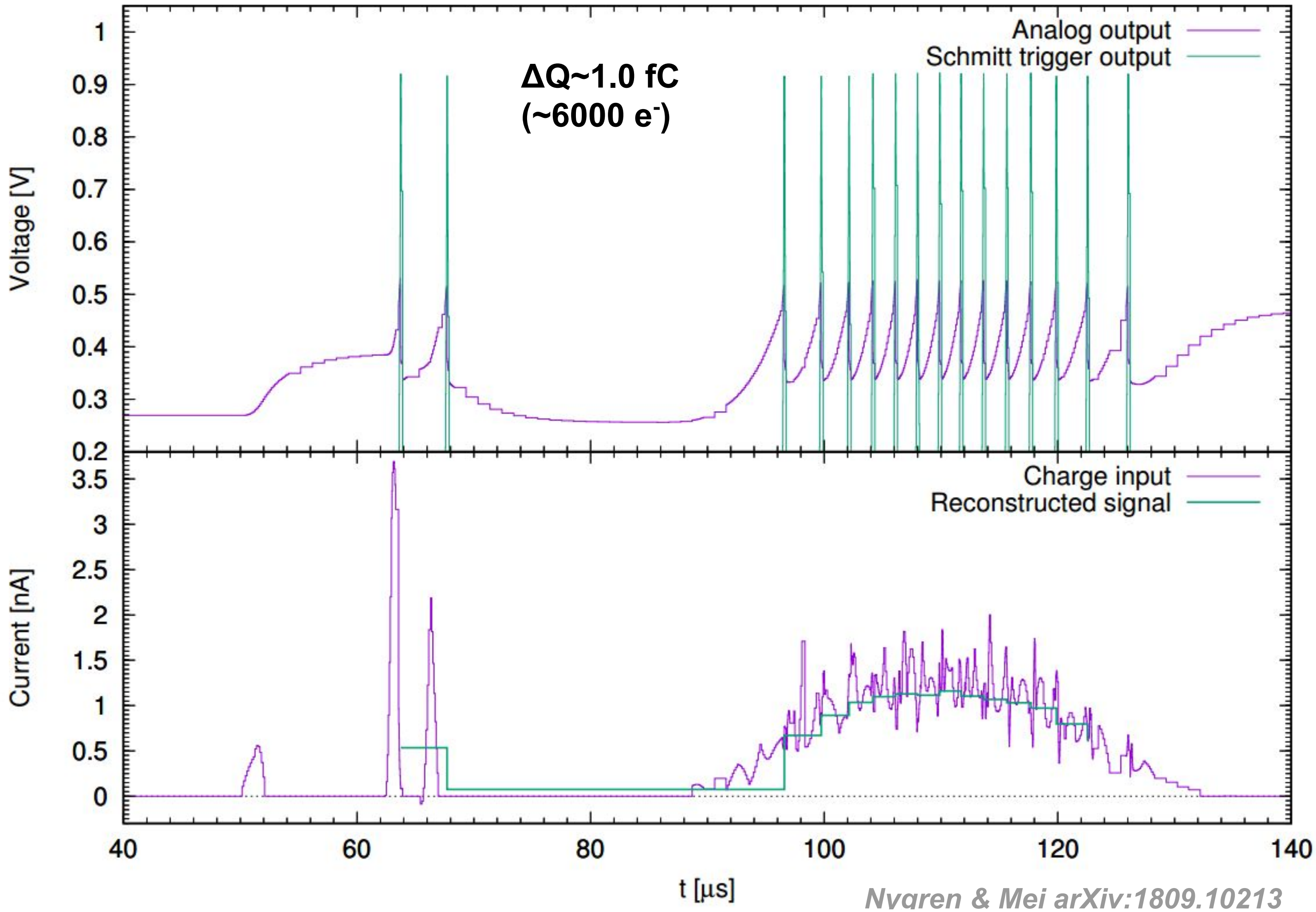
slide courtesy of Jonathan Asaadi, UTA

Q-PIX CONCEPT

What is new here?

- Take the difference between sequential resets
  - Reset Time Difference = RTD
- Total charge for any RTD = ΔQ
- RTD's measure the instantaneous current and captures the waveform
  - Small average current (background) = Large RTD
    - Background from ^{39}Ar ~ 100 aA
  - Large average current (signal) = Small RTD
    - Typical minimum ionizing track ~ 1.5 nA
- Signal / Background ~ 10^7
  - Background and Signal should be easy to distinguish
  - No signal differentiation (unlike induction wires)

Q-PIX SIGNAL



Nygren & Mei arXiv:1809.10213

slide courtesy of Jonathan Asaadi, UTA

Q-PIX WORK AT ARGONNE

Argonne is recognized as collaborator in developing Q-Pix concept

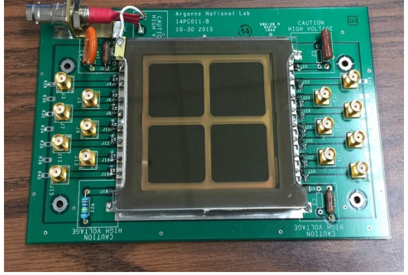
- Actual work to date has focussed on pixel board mechanical design and support structure
  - Mainly work performed by Vic Guarino in EOF
  - Enthusiastic support from Q-Pix leadership
- Area of interest for Argonne work is UV light detection scheme compatible with presence of pixel boards vs. wire anode readout (transparent for UV)
  - Work has begun but needs coherent plan acceptable to HEPD and Q-Pix collaboration
  - UV sensitive materials to directly absorb UV and produce signal electrons
    - amorphous selenium
    - perovskites
    - nanoparticle WLS or nanoplatelets for direct conversion
    - Leverages abilities and resources in Materials Science and/or Applied Materials Divisions
      - Alex Martinson (MSD) supported one day per week to work on materials for UV conversion
      - Steve Magill has scheme for nanoplatelets to WLS UV to visible or directly to electrons
  - Another possibility is electronics integration and readout of ASICs
- Need to identify who does the work at Argonne and who leads the program

MICROCHANNEL PLATE PHOTODETECTORS

Argonne is recognized leader in development of ALD functionalized MCP-PMTs

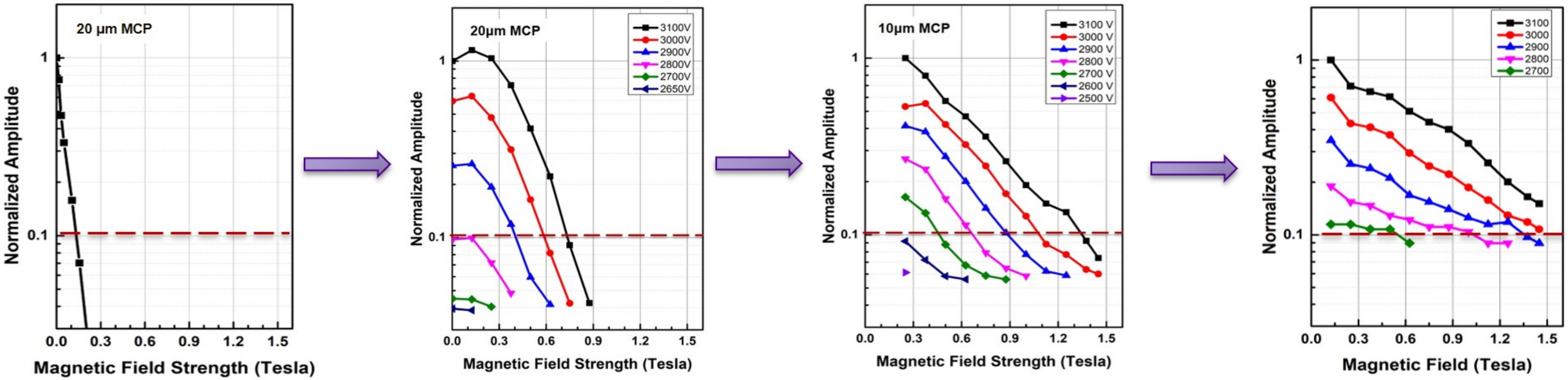
- OHEP supports low level of work continuing for MCP-PMT development; specifically:
  - Continued collaboration with Incom, Inc mainly through SBIR
  - Improved magnetic field performance and timing resolution by use of smaller diameter pore MCPs and optimized spacing of detector components
  - lifetime testing: based at U. Texas-Arlingtion; collaborative work with Incom and HEPD
- Physics Division is pursuing fabrication of new processing system for $10{\times}10cm^2$ MCP-PMT for use in MEP program; especially for future EIC RICH detectors
  - HEPD should be a collaborator on using this system to produce MCP-PMTs
  - Would require increased effort from HEPD physicists
- 3D MCP fabrication via Nanoscribe printer located in Bldg 241.
  - Owned by MSD but main work is for HEP (MCPs) and APS (X-ray lenses)
  - limited by time and configuration to structures $\mathcal{O}(1mm^3$ or $1mm \times cm^2)$
  - Have concept for scaled printer for m^2 structures and filed for patent
  - Promised funding (~$2M) from NNSA-NA22 in Feb. 2019 withdrawn due to priority change. Continuing to seek alternative funding sources.

ARGONNE MCP-PMT R&D STATUS



Magnetic field tolerance and timing improvement

ANL version 1	ANL version 2	ANL version 3	ANL version 4
Internal resistor chain	IBD design 20 μm MCP	IBD design 10 μm MCP	IBD design 10 μm MCP reduced spacing

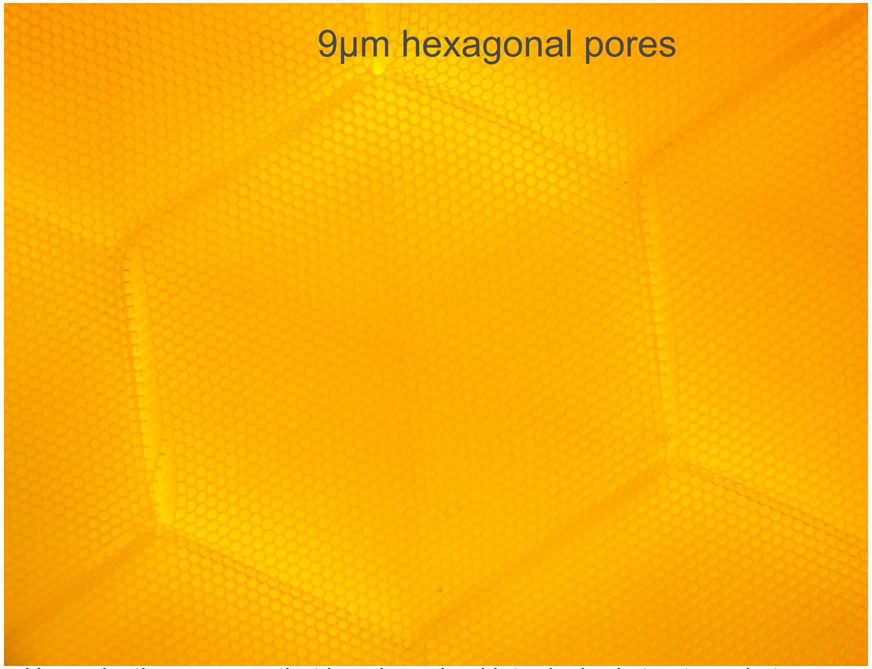


		ANL Version 2 Standard 20 μm MCP-PMT	ANL Version 3 10 μm MCP-PMT without reduced spacing	ANL Version 4 10 μm MCP-PMT with reduced spacing
Gain Characteristic	Gain	1.35×10^7	3.05×10^6	2.0×10^7
Time Characteristic	Rise time	536 ps	439 ps	390 ps
	Timing distribution RMS	**204 ps**	**106 ps**	**109 ps**
	System resolution	70.0 ps	37.2 ps	41 ps
	Time resolution	**63 ps**	**20 ps**	**28.5 ps**
	Differential time spread	11 ps	7 ps	5 ps
	Spatial resolution	0.83 mm	0.53 mm	0.38 mm
Magnetic Field	Magnetic field tolerance	**0.7 Tesla**	**1.3 Tesla**	**> 1.5 Tesla**

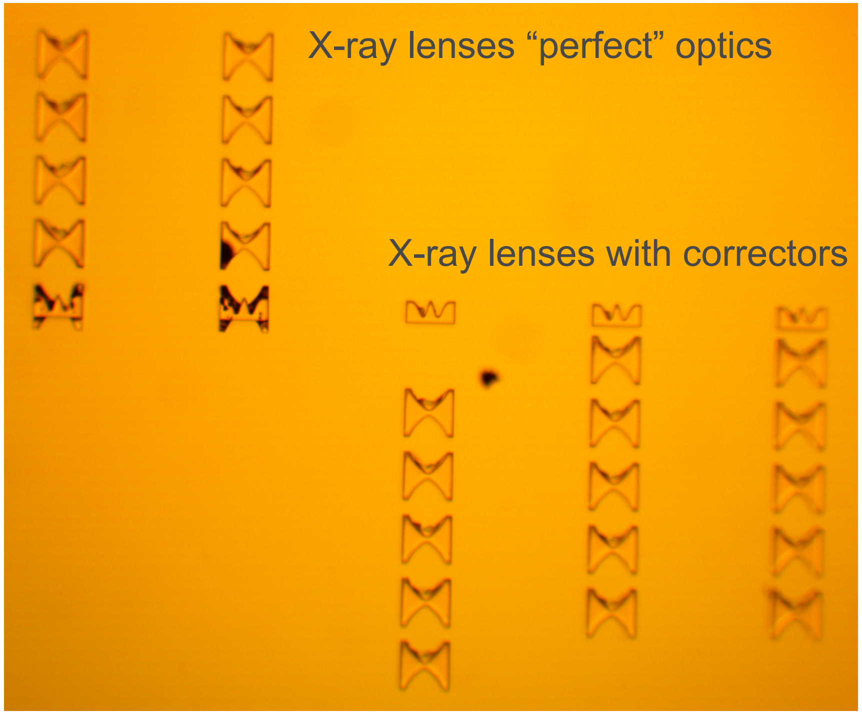
slide courtesy of Junqi Xie, Argonne Physics Div.

3D PRINTED CAPILLARY ARRAYS AND X-RAY LENSES

Ultra-high resolution 3D printer enables printing capillary arrays in polymer structure for ALD functionalization into MCPs for very low cost



- Uses plastic monomer that is polymerized into desired structure via two-photon absorption
- Photoresist is UV sensitive; two photons at 780nm provide energy for polymerization
- Probability for two photon absorption only significant at laser focus which allows sub-micron resolution
- Turning to development using organically modified ceramic material that allows much higher temperatures for baking and ALD



- 3D printed lenses for focussing beams at Advanced Photon Source
- Replaces very expensive commercial lenses at cost of few $'s

SILICON PIXEL WORK AT ARGONNE

- Hardware/firmware/software updates to correlate FELIX for RD53A and FELIX for FEI4/ATLASPix/MIMOSA modules (saw first RD53A beam spot with FELIC in May!)
  - Writing paper on telescope performance (need data from one more test beam run)
- Improving the performance and efficiency of the Argonne Pixel Telescope
  - Telescope plane FEI4 Quad modules need to be cooled to work efficiently
    - Implementing peltier cooling blocks w/ TPG material to telescope planes
  - Add remote controlled stages for faster alignment in beam
  - Improve heat transfer in DUT box. Current: -25℃ Goal: -45℃
- Plans:
  - study radiation damage effects in CMOS using H35demo samples irradiated at Los Alamos last year (H35demo comprised of several pixel blocks with different radiation tolerance schemes implemented)
  - Commission edge-TCT setup to study E-field profile changes
  - Perform test beam and irradiation studies on ATLASPix-v2 when available

20℃ improvement observed with peltier operated in lab at room temp

RING RESONATORS

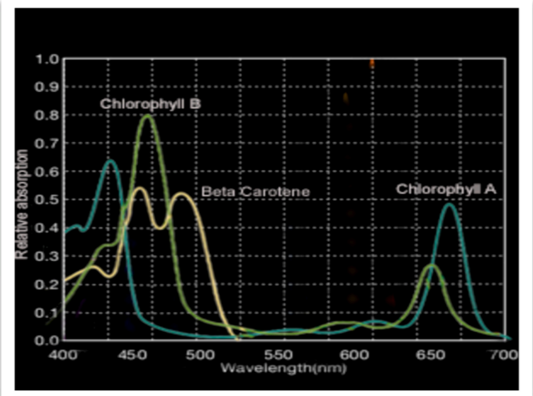
Ring resonator chip on-sky tests will begin in Dec., 2019 with 4 iterations at AAO Australia and 3 at Lowell in Flagstaff AZ planned for FY2020

- Preparations for on-sky tests in Australia (Simon Ellis) and Lowell Obs. (Kyler Kuehn) are in progress.
  - Australia planned for December, 2019 using setup debugged by Kuhlmann in 2017 test
  - Lowell initial test planned for January, 2020 using existing spectrograph and new equipment for resonators funded by $20k grant from Lowell. Purchased their own foundry resonator chip using Argonne designs
  - Cycle: 1) new chips from foundry, 2) test and retune resonant wavelengths at Argonne requires ~2 months $\Longrightarrow\Longrightarrow$ 4 tests in Australia, 3 tests at Lowell in FY2020
  - Results of tests plus roadmaps for how to use ring resonators in future for SNe and other science to be published late FY20 or early FY21.
- Argonne work part of decadel survey white paper on astrophotonics
- Dave Underwood at Argonne making progress on inexpensive NIR detector for SNe follow-up demonstrator using notch filters.
  - Commercial detector with 30% QE in J-band with low noise; plus cooling and readout electronics available for ~$30k
  - Underwood's custom electronics uses photodetectors with 90%QE and potentially lower noise. Needs cooling and FPGA engineering
  - Trade-offs between alternatives being studied at present
- In separate application, Simon Ellis has $50k grant to develop RR for positronium point sources from DM and bkgd sources using ground-based telescopes
  - Large fraction of free positrons spend time in positronium state which emits a strong line very near at strong atmospheric OH line.
  - If Ring Resonator can precisely remove nearby OH line, then detecting positronium point sources from ground would be possible for first time

NANOPARTICLE-ENHANCED PHOTODETECTION

- SBIR – CapeSym, Inc. (8/19 – 4-20)
  - Identify nanoparticle candidates for detection of 128 nm light from Argon and 175 nm light from Xenon (Neutrino and Dark Matter experiments)
  - ANL role – test candidates and characterize in terms of absorption, wavelength-shift size, emission
  - Filter-based testing to low wavelengths in vacuum, nitrogen

- Submitted Technology Commercialization Fund Proposal Declaration – 10/11/19
  - Enhanced plant growth using nanoparticle films on greenhouse panels
  - Tuned to absorb near UV, visible light and sized to emit at the dual peaks of chlorophyll absorption
  - Initial tests yield up to 3X growth rate with nanoparticle film



SUGGESTED TOPICS FOR DISCUSSION

- What will be our plan for Q-Pix Work within HEPD?
  - Being discussed/formulated within Detector R&D Task Force. Input from today's workshop will be valuable. Invite anyone interested to attend Task Force meetings to help us.
- What are the opportunities for HEPD Detector R&D to pursue new ideas that that advantage of the facilities and expertise available throughout Argonne
  - Need to consider what physics HEPD is doing or would like to do
  - What technology would enable and/or support studies that wouldn't happen without it
- Given the HEPD ATLAS group work on silicon pixels, what work, if any, is there for collider pixel detectors for Detector R&D group
  - OHEP has mandated phase out silicon Detector R&D work. We will follow this directive
  - Thin film detector development is a possible alternative
- Is electronics integration/readout work that we want to pursue for Q-Pix?
  - Would require hire of electronics engineer to carry out work
- What skill set would we want for an electronics engineer hire?
  - Other areas where opportunities exist if we had an engineer skilled in …