

Project Update

n-type Gallium Arsenide / SNSPDs for Direct Dark Matter Detection

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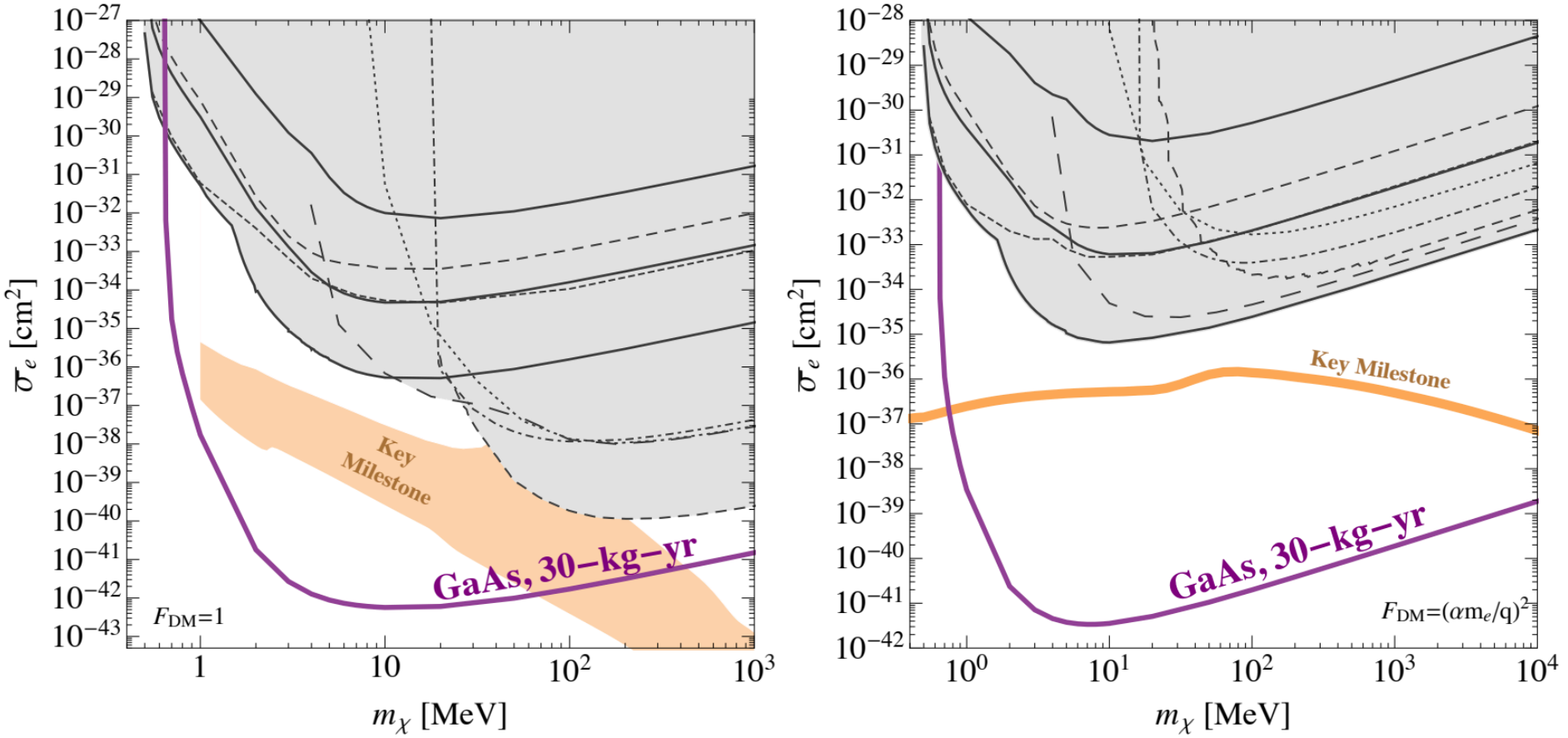
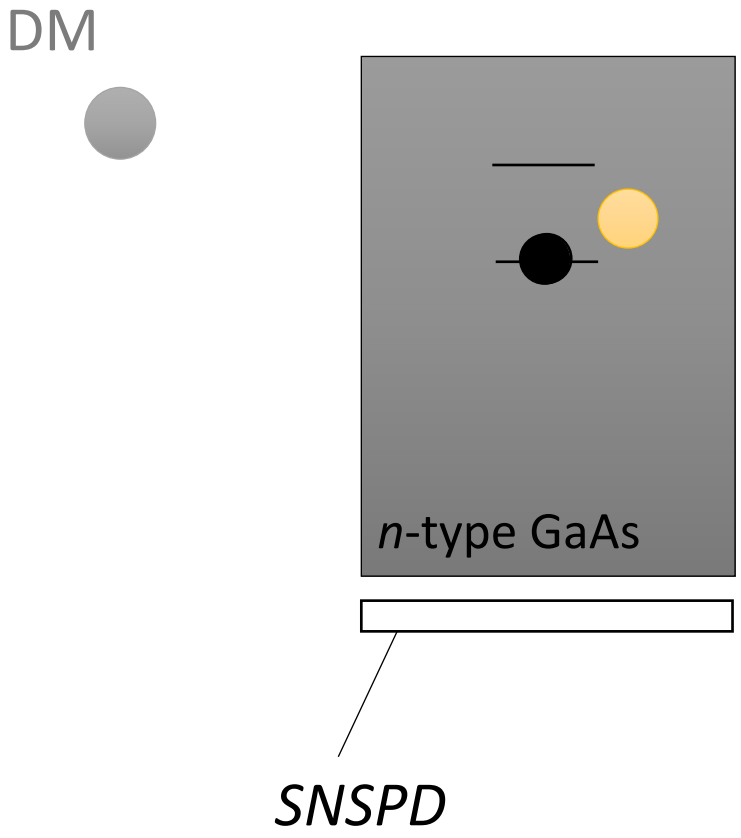


Figure 1: Projected sensitivity (thick magenta line) to dark-matter-electron scattering mediated by a heavy mediator (**left**) or light mediator (**right**) of a GaAs target assuming a 30 kg-year exposure. We assume zero background events for events with one or more photons, a radiative efficiency of 1, and a photon detection efficiency of 1. Existing constraints are shown in gray from SENSEI, DAMIC at SNOLAB, XENON10, XENON100, XENON1T, DarkSide-50, EDELWEISS, and CDMS-HVeV [10–21]. Orange regions labelled "Key Milestone" are from [4].

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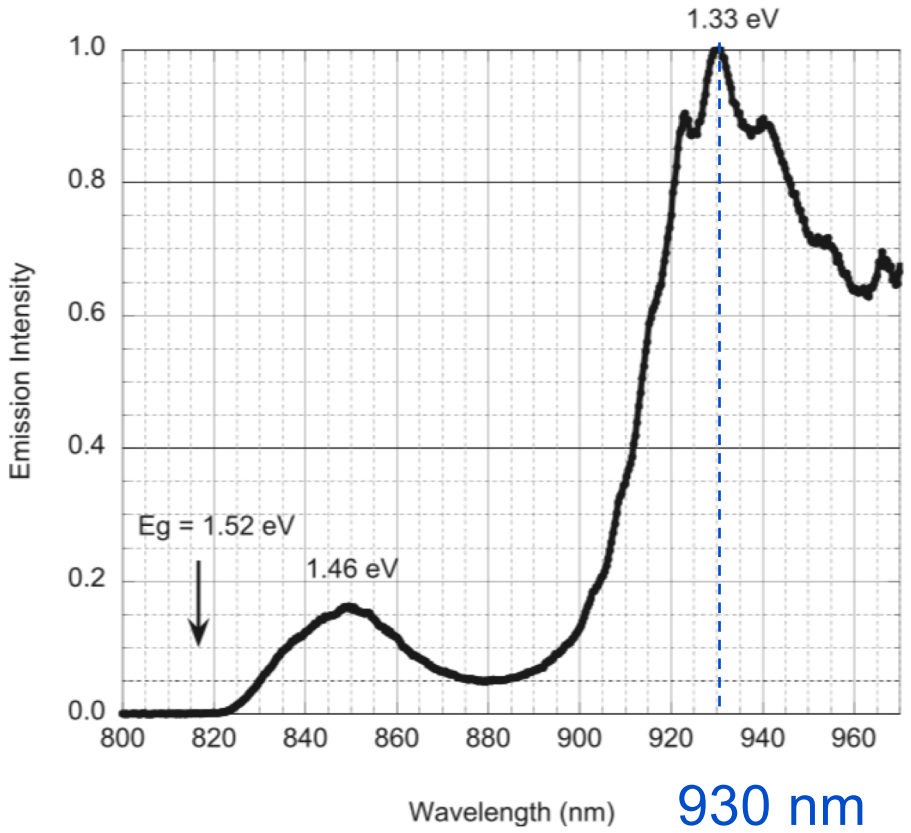
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Detection Principle



1. DM particle scatters off an electron in the valence band of a scintillating crystal target
2. Generation of an electron-hole pair
3. Emission of scintillation photon(s) from relaxation of the electron to the ground state
4. Detection by sensitive photodetector

n-type GaAs Emissions: ***measurements from LBNL***



930 nm

X-ray excited emission spectrum at 10K

TABLE III
THE LIGHT OUTPUT OF GALLIUM ARSENIDE SAMPLES FOR DIFFERENT SPECTRAL REGIONS AND PHOTODETECTORS

Crystal	PD	Region (nm)	Bands	LY (%)	LY (ph/keV)
GaAs:(Si, B)	InGaAs	800-900	A	1	1.2
		900-1000	B	33	42
		1000-1150	C	28	35
		1150-1700	D	38	47
		800-1700	Total	100	125.2 ± 6
GaAs:(Si, B)	Si	800-900	A	2	1.6
		900-1000	B	48	39
		1000-1140	C	49	40
		800-1140	Total	100	80.6 ± 4

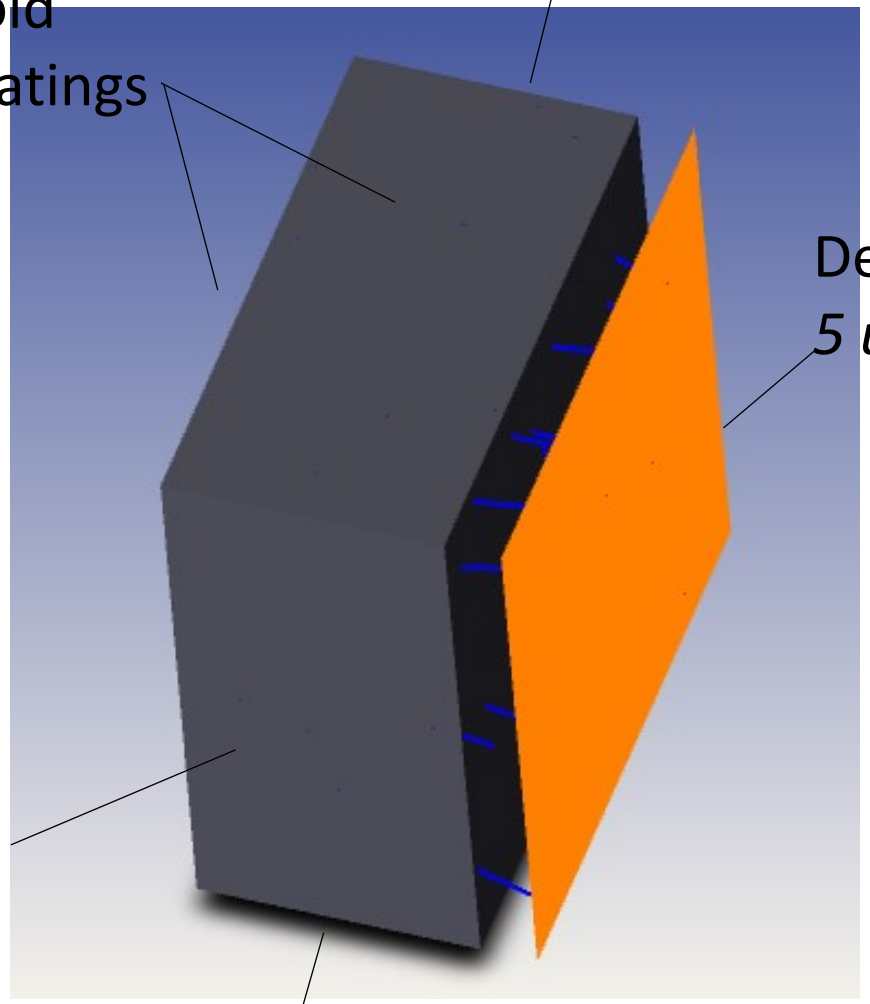
Sample number	Supplier	Si ppm (wt) atoms/cm^3	B ppm (wt) atoms/cm^3	P ppm (wt) atoms/cm^3	*n*-type free carriers/cm^3
13316	AXT[a]	8.9 1.02×10^{18}	9.7 2.87×10^{18}	0.008 8×10^{14}	5.5×10^{17}

Status and Required R&D

Gallium Arsenide Targets

- ***For a real DM experiment***: targets on the order of a few kg
- LBNL has sent us 1 x 1 x 0.5 mm test systems (~0.27 g)
- *R&D* Goals: Optimize GaAs crystal size, surface roughness, and dopant density to maximize photon production and detection efficiency
  - Optical simulations with Zemax – ongoing

Proposed Design

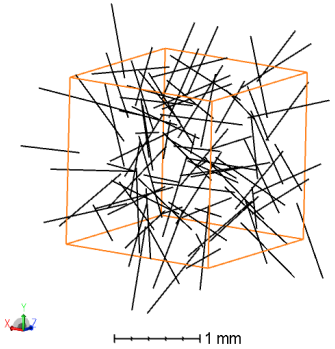


exploded view

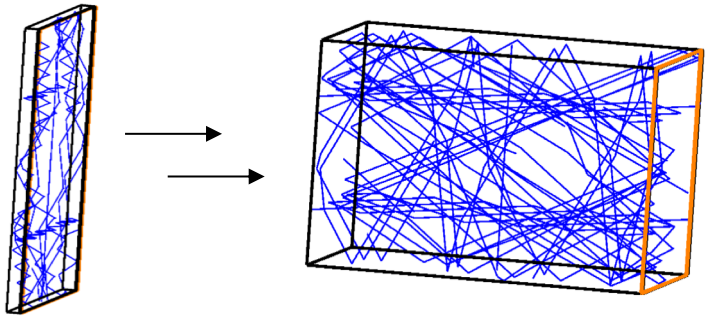
- ***Design***: coat target with gold everywhere except for face adjacent to detector
- ***Simulation*:** vary the target thickness
- Simulated with and without AR coating on detector-adjacent face and diffusive and polished GaAs
- *What is the largest target thickness we can get away with for a given detector area?*

Parameter	
Index of Refraction	3.4 at 930 nm
Emission Spectrum of GaAs	930 nm
Mean free path for absorption	10 cm
Reflectivity of gold coating	98% at 930nm
Thickness of gold coatings	1 um
Detector Material	Ideal absorber
Diffuse crystal surface	Lambertian
Input power	1W

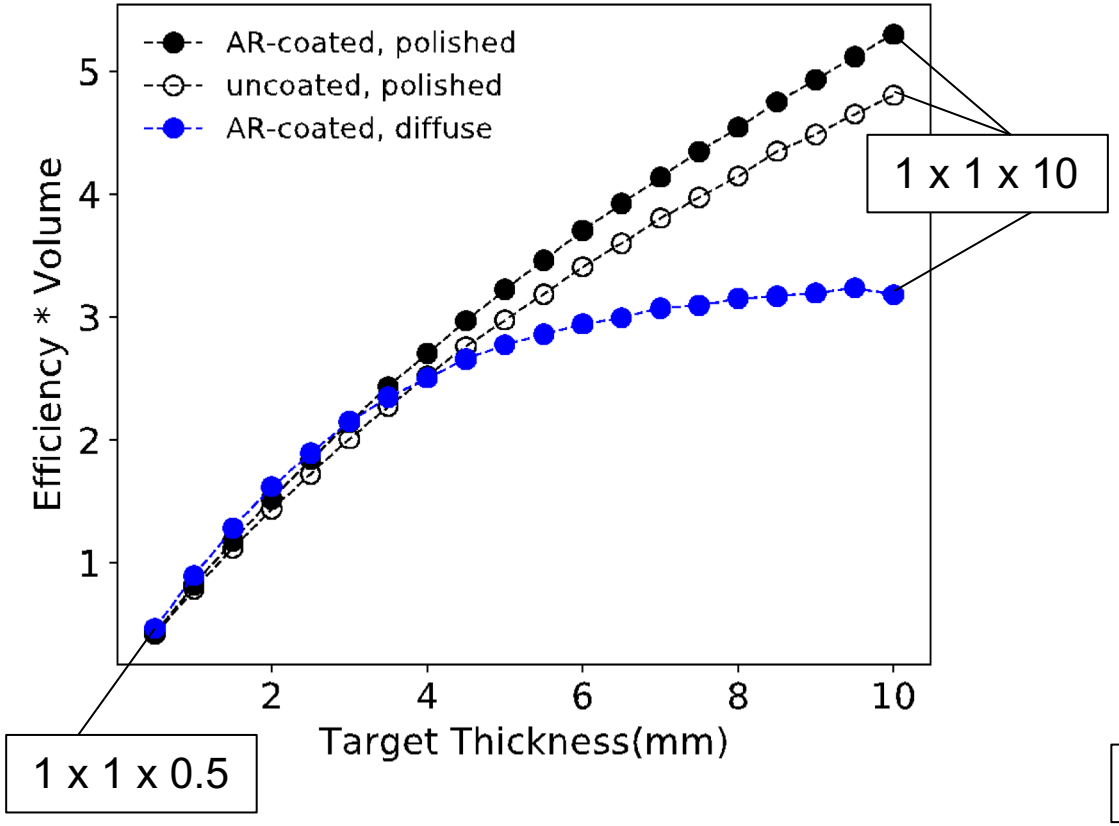
volume source



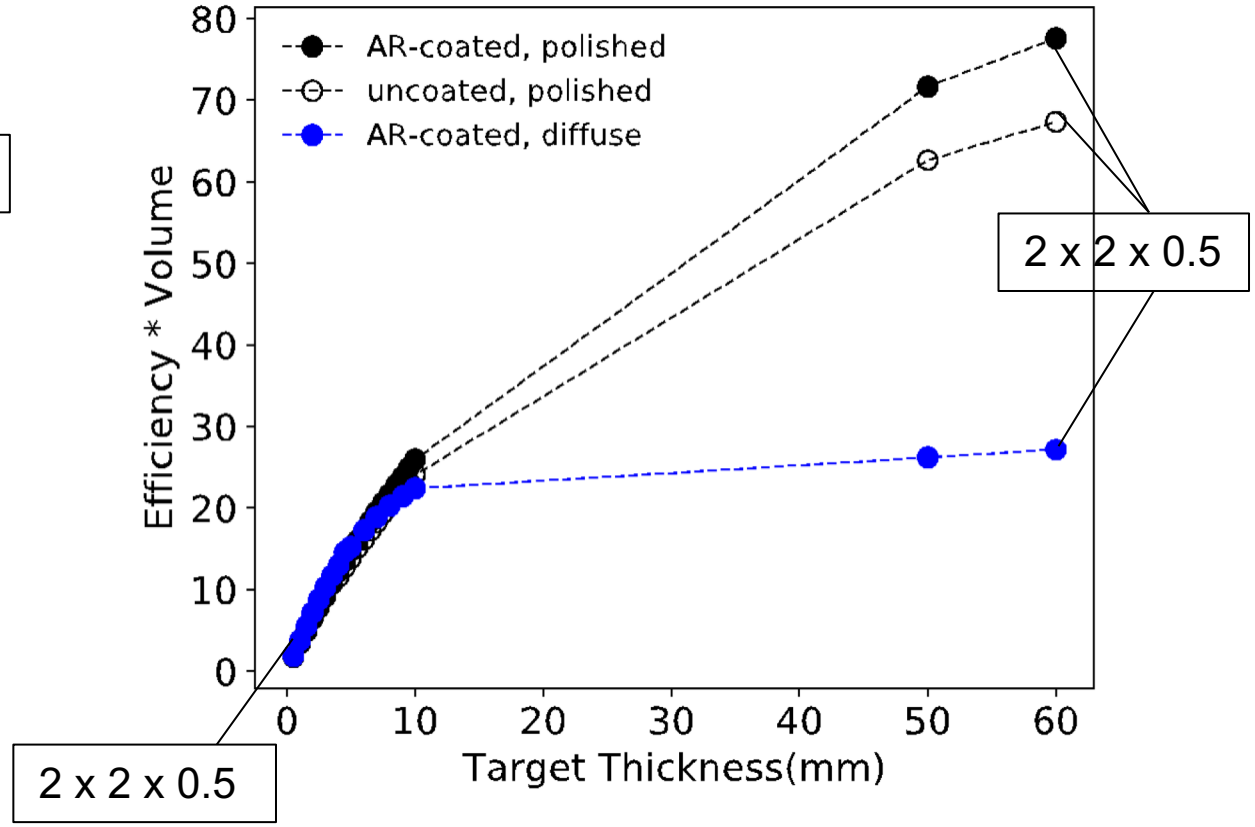
Target thickness



1mm x 1mm Detector



2mm x 2mm Detector



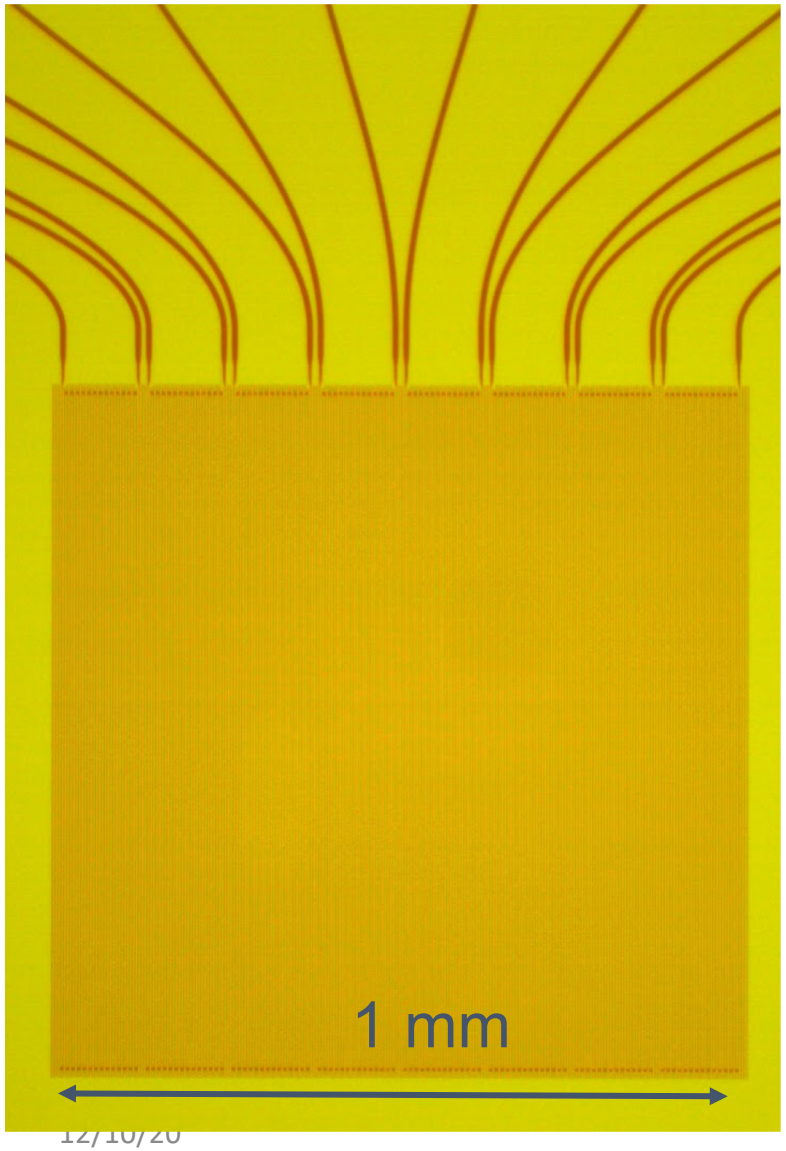
Upcoming Experiments

Cryogenic Measurements with test system: small GaAs targets (mm-scale) and 1 x 1 mm SNSPD

- UV-excited lifetime measurements – *soon*
- Precisely measure the luminosity
  - UV-excitation – *soon*
  - x-ray excitation – *future*

Status and Required R&D

Large Area SNSPDs



- ***Goal***: scale active area of SNSPDs from mm^2 to cm^2 and beyond to accommodate cm to m-scale targets
- Microwire architectures
  - Microstructures can be patterned by photolithography- less expensive and time consuming than electron or ion beam techniques used to fabricate traditional (nano-wire scale) devices
  - More robust to manufacturing issues
  - Significant reduction of the kinetic inductance by using micron-wide wires
- Arrays allow for the possibility of vetoing coincidence events if those arise due to noise or cosmic ray events depositing energy in the substrate

Large area WSi SNSPD arrays: preliminary results

1 x1 mm 8 pixel array with 0.5 um wires

- 1064 nm source
  - Close to saturated internal efficiency - limited by latching with AC-coupling
  - Promising preliminary results with DC-coupled readout showing higher switching currents.
- 0.9 Kelvin operation
- 0.5 - 3 um wire widths being studied
- Achieved 7/8 pixels on first arrays characterized

Fabricated devices from other WSi stoichiometries

- Tc range of 3.9 to 1.9 K being studied

