Progress in Developing a Differential OSEM (DOSEM)

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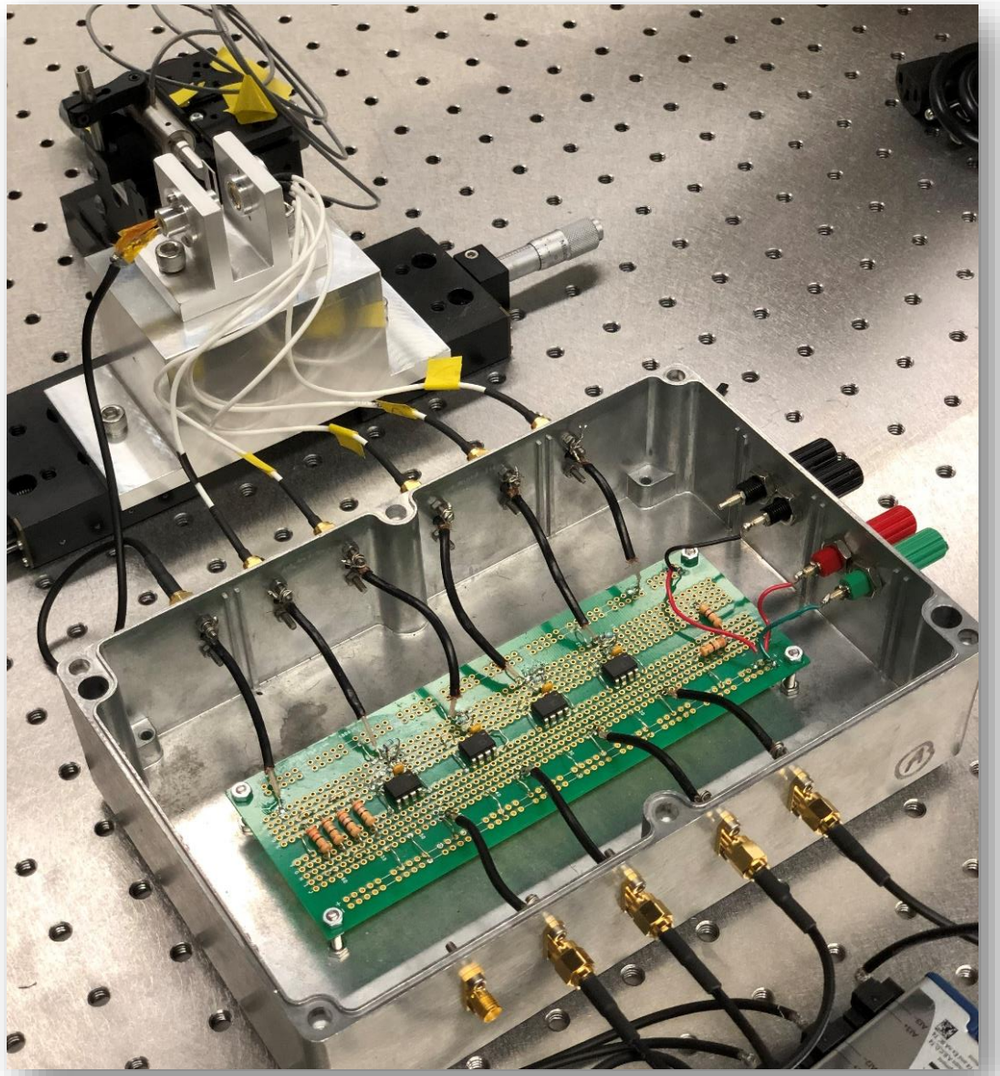
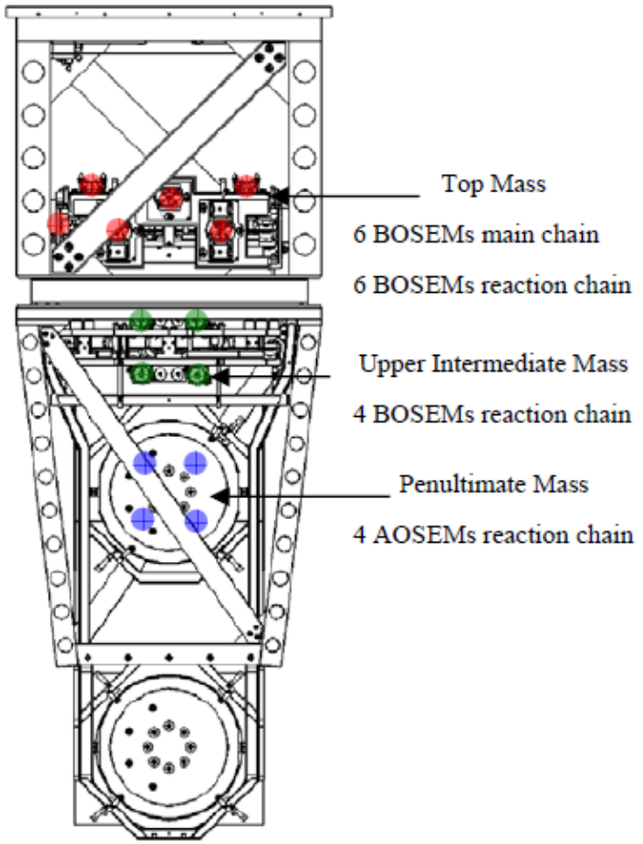
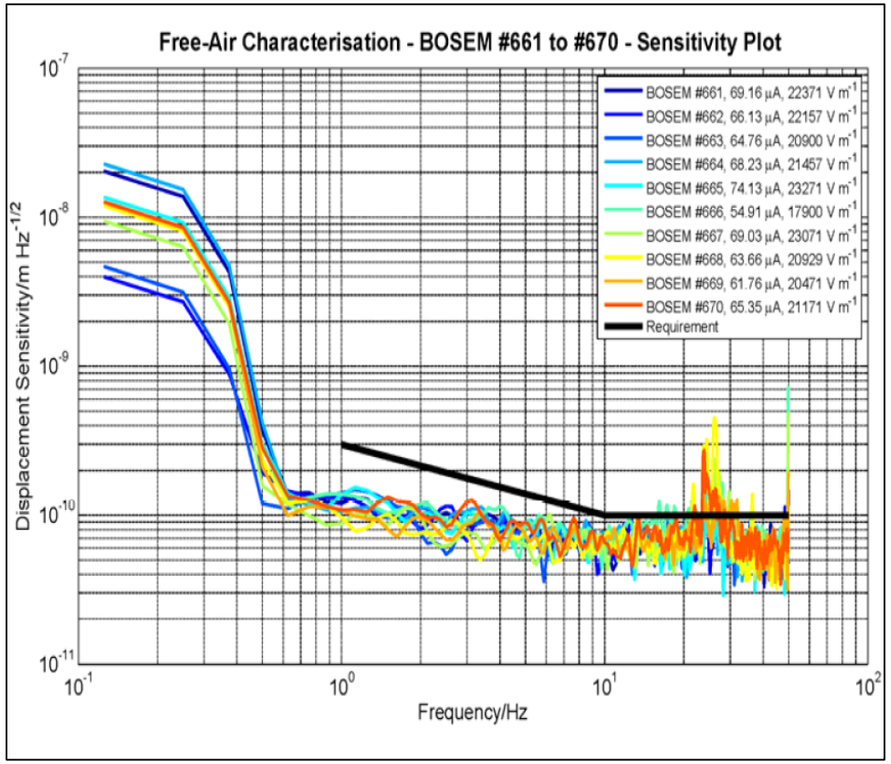
LIGO-G1900464-v1



OSEMs & Motivation

- Optical Sensor and Electro-Magnetic actuators (OSEMs)
  - Measures, actuates multiple DOF of Top Mass, UIM, PUM
- As-installed performance of BOSEMs (thanks Arnaud)
  - 30-200 pm/Hz$^{1/2}$ @ 10 Hz
  - 150-2000 pm/Hz$^{1/2}$ @ 1 Hz
- May limit low frequency performance of aLIGO via control system
- Goal: Improve sensitivity and reduce systematics

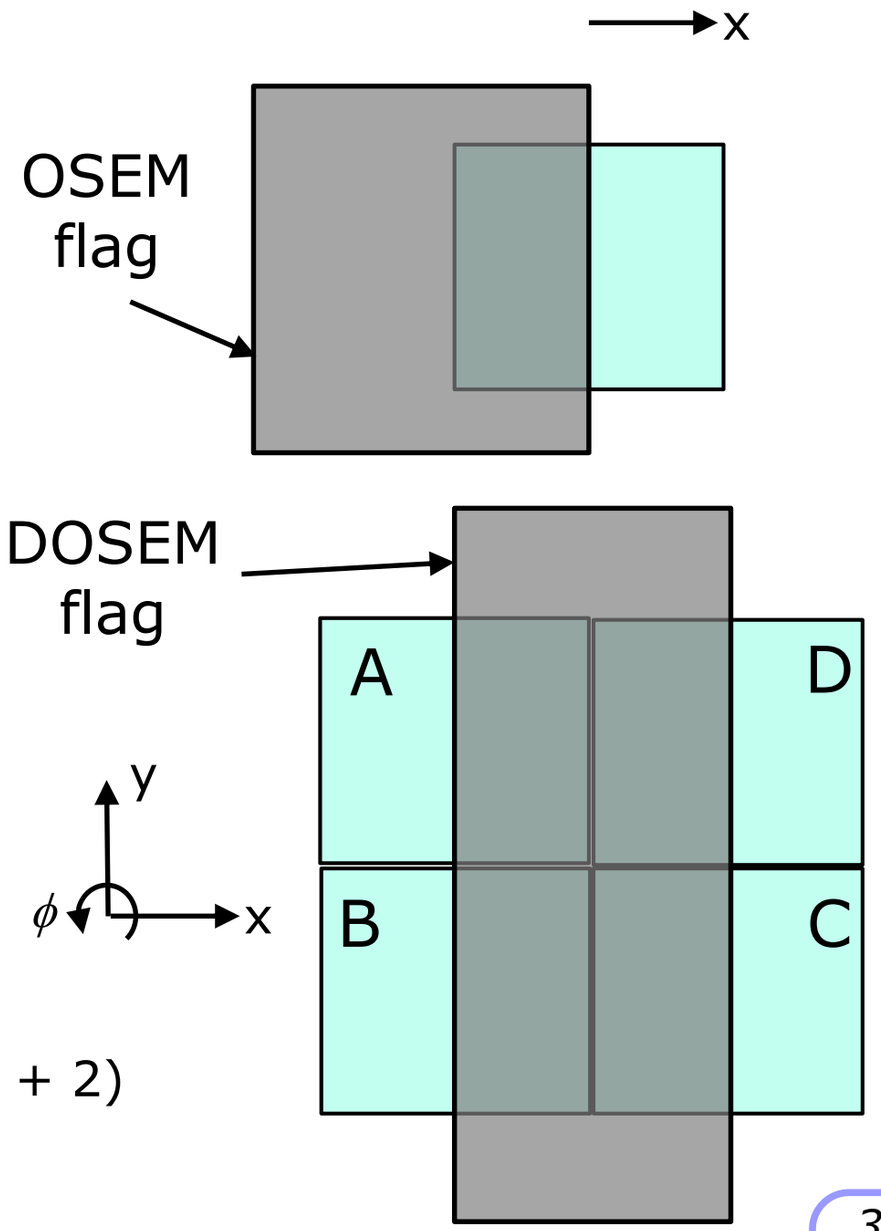




[SM Aston 2011]

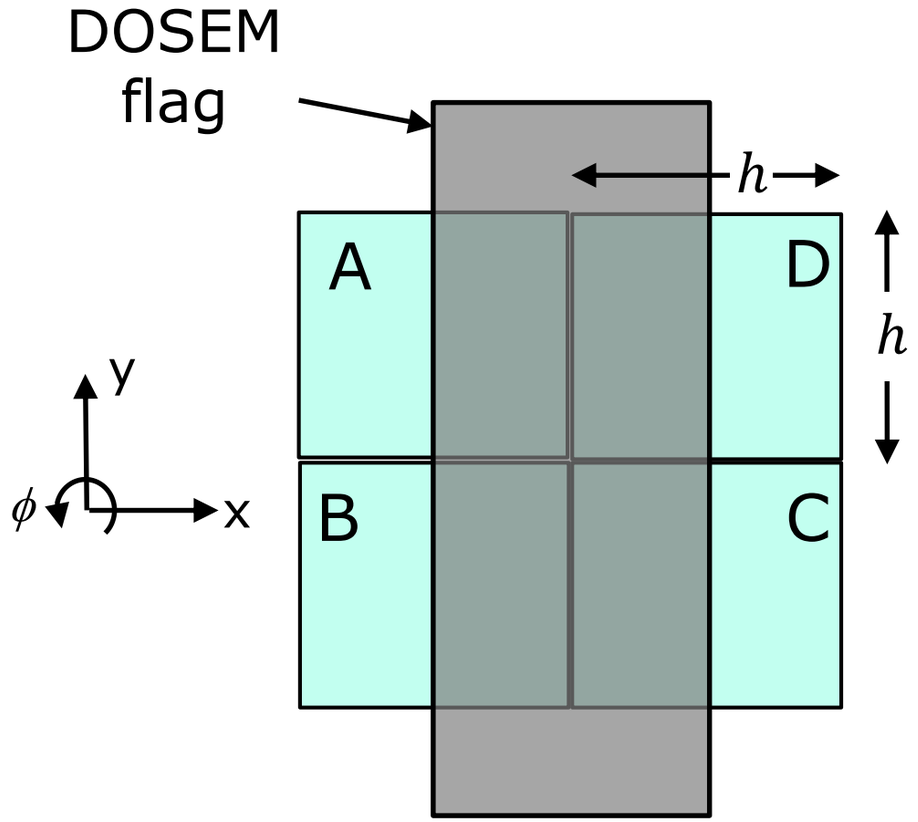
Basic idea behind DOSEM

- Replace BOSEM photodiode with a quadrant photodiode
- Replace BOSEM flag with one with a thin vertical plate
- Keep everything else the same
- Advantages
  - Increases sensitivity (could be 4x)
  - Eliminates some systematics via common mode rejection (more important)
  - Improved linearity
- Disadvantages
  - More complex flag (machined one at UF fairly easily)
  - Four vac feedthrough wires (2 + 2) → Seven wires (5 + 2)



(over)Simplified Sensor Model

- Output voltage for quadrant i
  - $V_i = g_i P_i(x) + b_i$
  - g_i = gain, $P_i(x)$ = integrated power, b_i = bias
- For perfectly uniform light distribution, optimal flag width = $h + \text{gap}$ and
  - $P_i(x) = P_0 h \left(\frac{1}{2} h \pm x\right)$
- Then, can model output voltage as
  - $V_i = \pm A_i x + B_i$
- After calibration (fitting for A_i, B_i)
  - Construct $s_i = (V_i - B_i)/A_i$
  - $x = \frac{(s_A + s_B) - (s_C + s_D)}{s_A + s_B + s_C + s_D}$
- This combination insensitive to fluctuations in g_i, P_0, b_i



Emitter and Detector

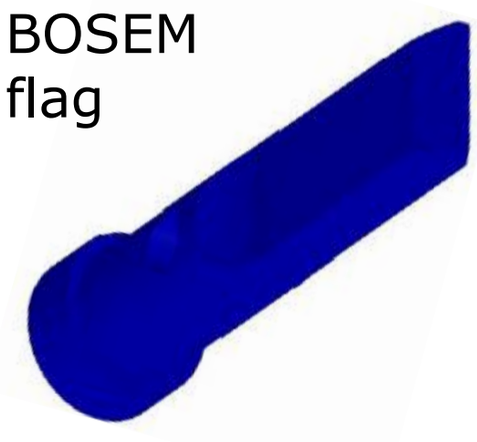
- Quadrant photodiode: First Sensor GP5-6 TO

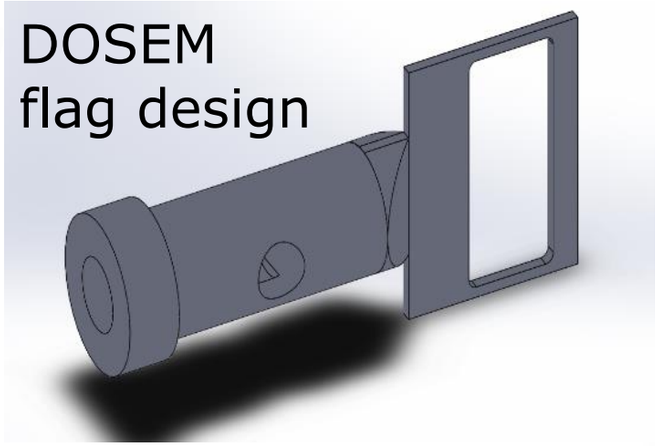
	QPD GP5-5 TO (DOSEM)	**BPX65 (BOSEM)**
Active area side length	1.10 mm square + 0.024 mm gap	1.0 mm square
Responsivity @ 900nm	0.64 A/W	0.55 A/W
Dark current	0.2 nA	5 nA
Package (diam)	TO5 (8.1 mm)	TO-46 (4.7 mm)
Cost	$35	cheap

- LED emitter: OP232 (same as BOSEM)
  - TO-46 can
  - Max forward current 100 mA (35 nominal)
- Procured and testing alternate LEDs: OPT132

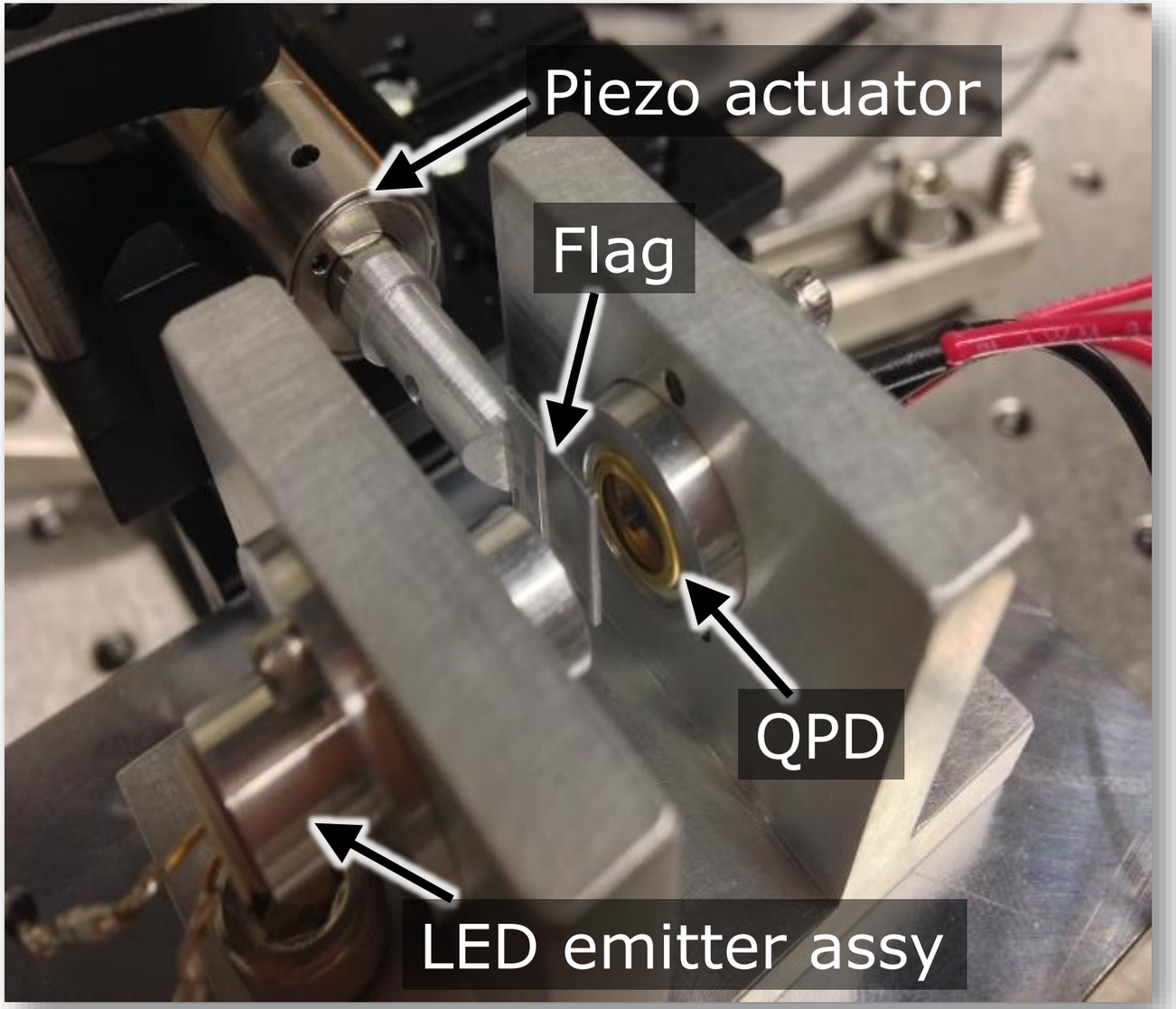
BOSEM LED (left), PD (right)
[SM Aston 2011]

DOSEM Sensor Testbed

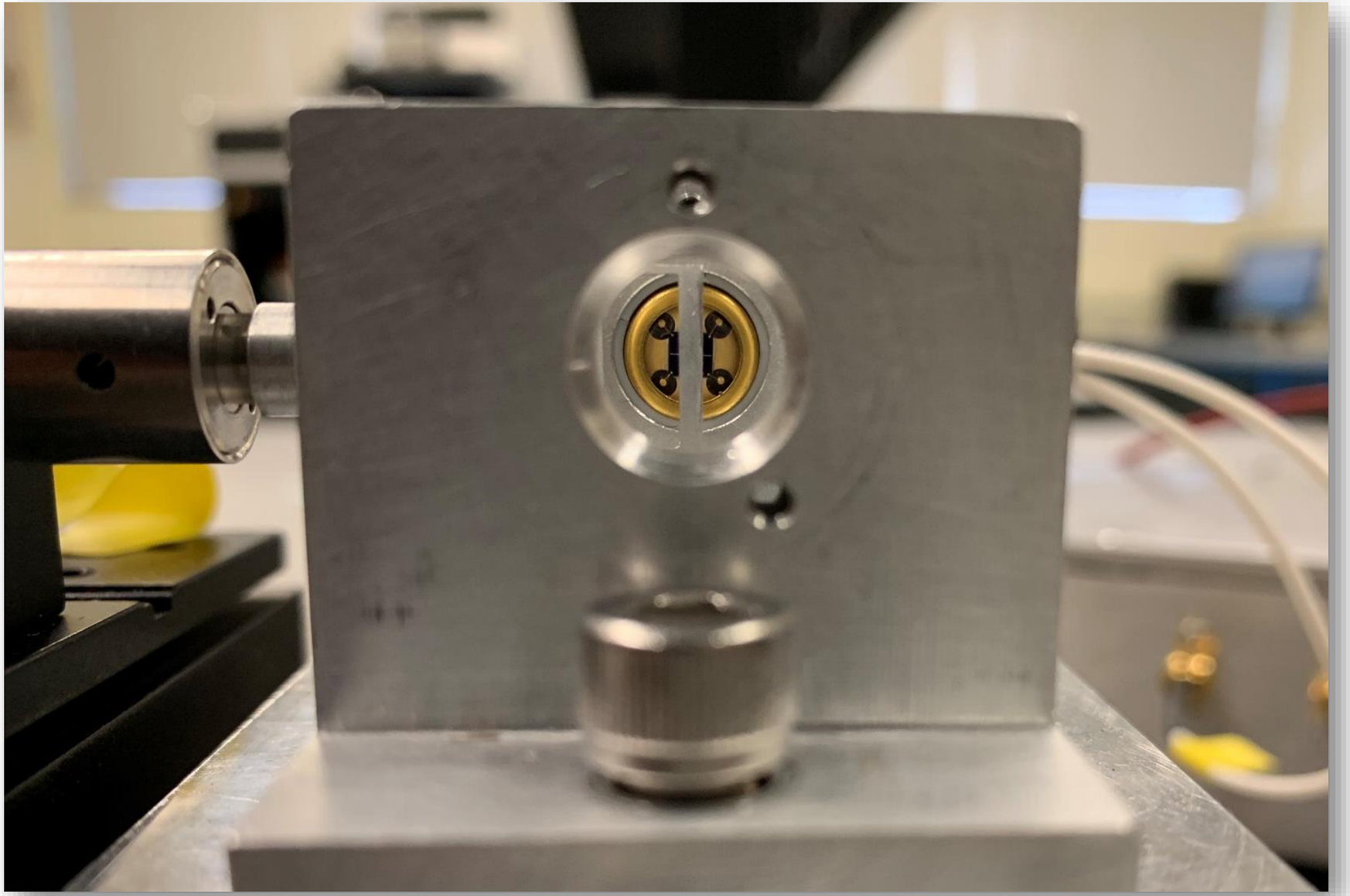




- Mount side of flag same as BOSEM
  - Mounted to piezo stage on top of 3-axis micrometer stage
- Aluminum mount holds LED & QPD with spacing equal to that of BOSEM
- LED holder same as BOSEM
- QPD holder is modified BOSEM design (larger diameter)

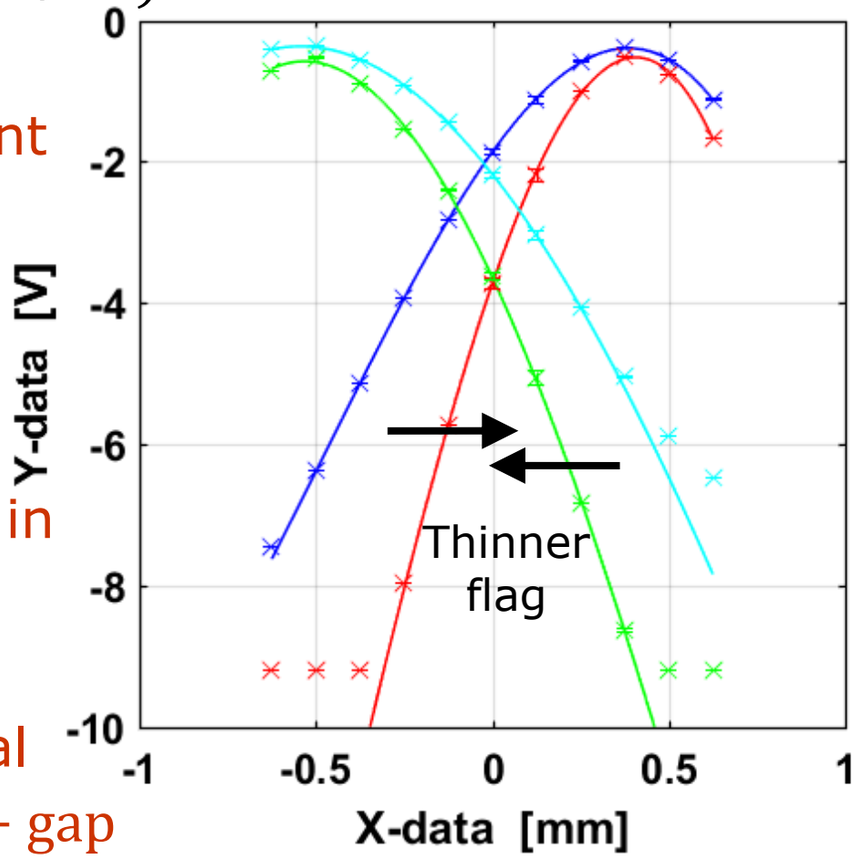


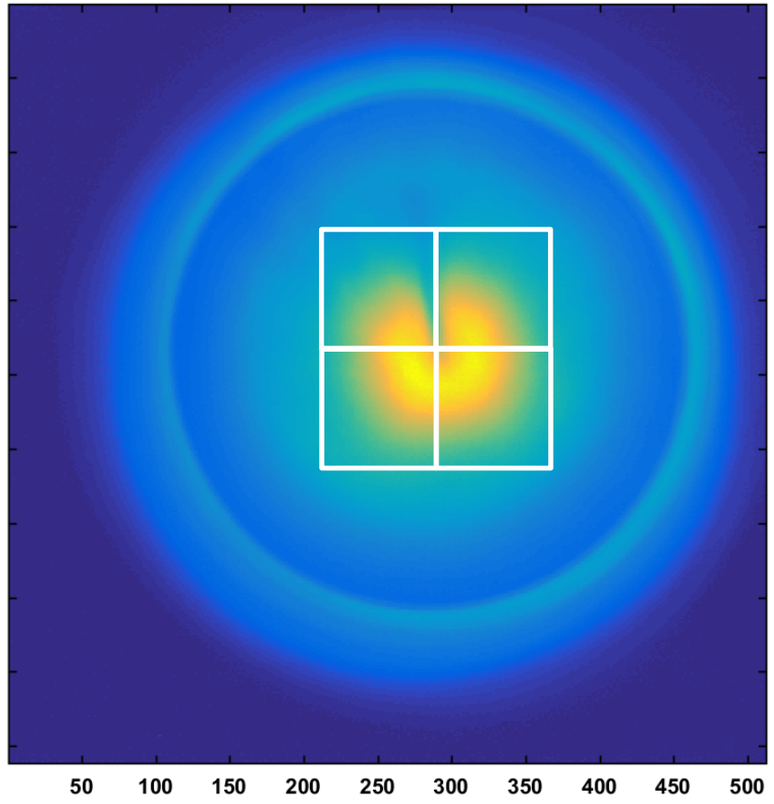
View from LED



Dealing with Non-uniform Light Distribution

- LED power on QPD is non-uniform, leads to polynomial model for integrated power
  - $P_i(x) = P_0(a_0 + a_1 x + a_1 x^2 + \cdots)$
- Calibration involves fitting polynomials for each quadrant
- x channel combination still insensitive fluctuations in
  - LED power, PD gain & bias
  - Axisymmetric LED distribution
- Still sensitive to fluctuations in
  - Right-left beam deflection
  - Right-left asymmetric dist.
- For ~Gaussian beam, optimal flag width is thinner than $h + \text{gap}$

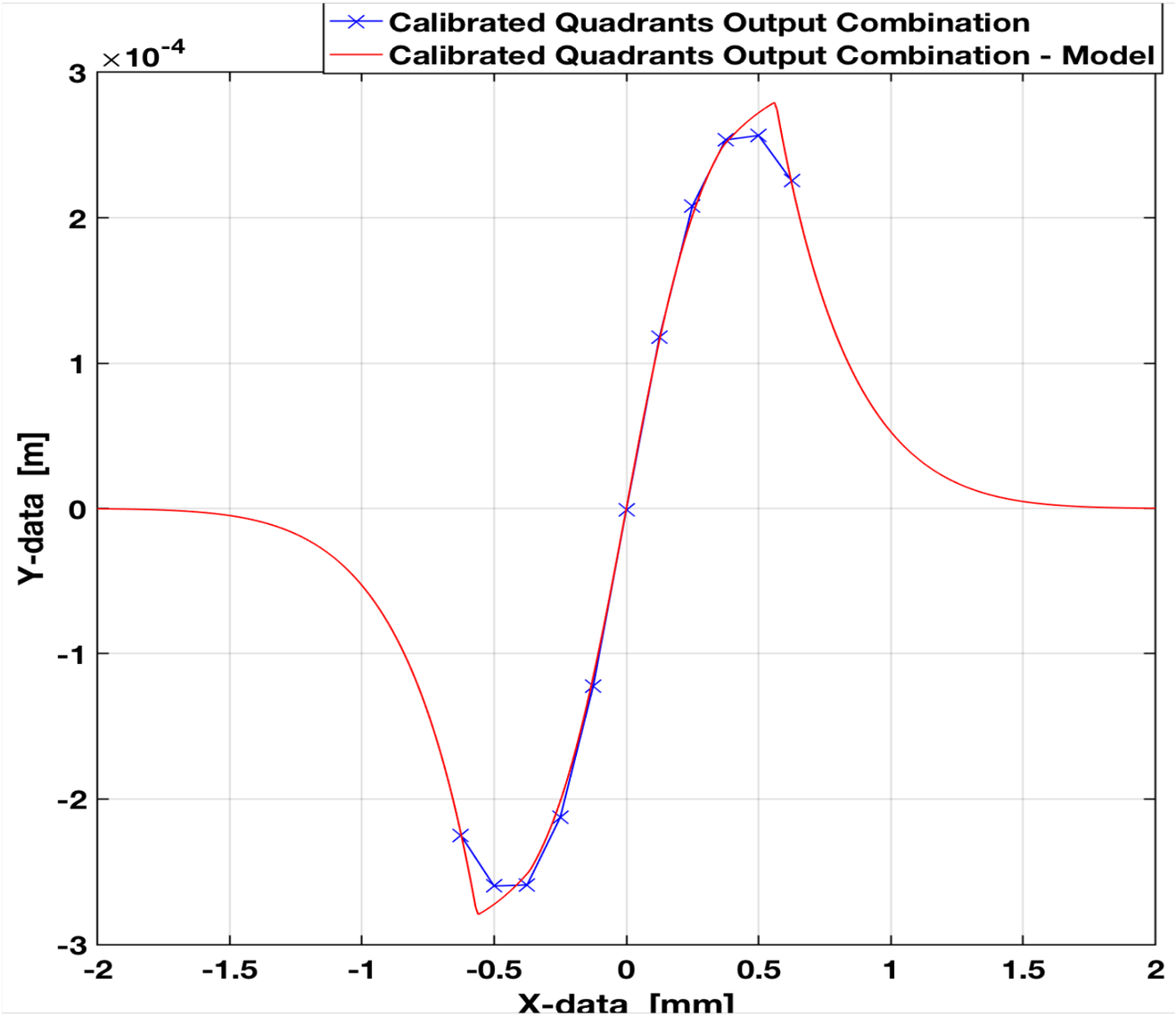




Beam profile with QPD overlay (approx)

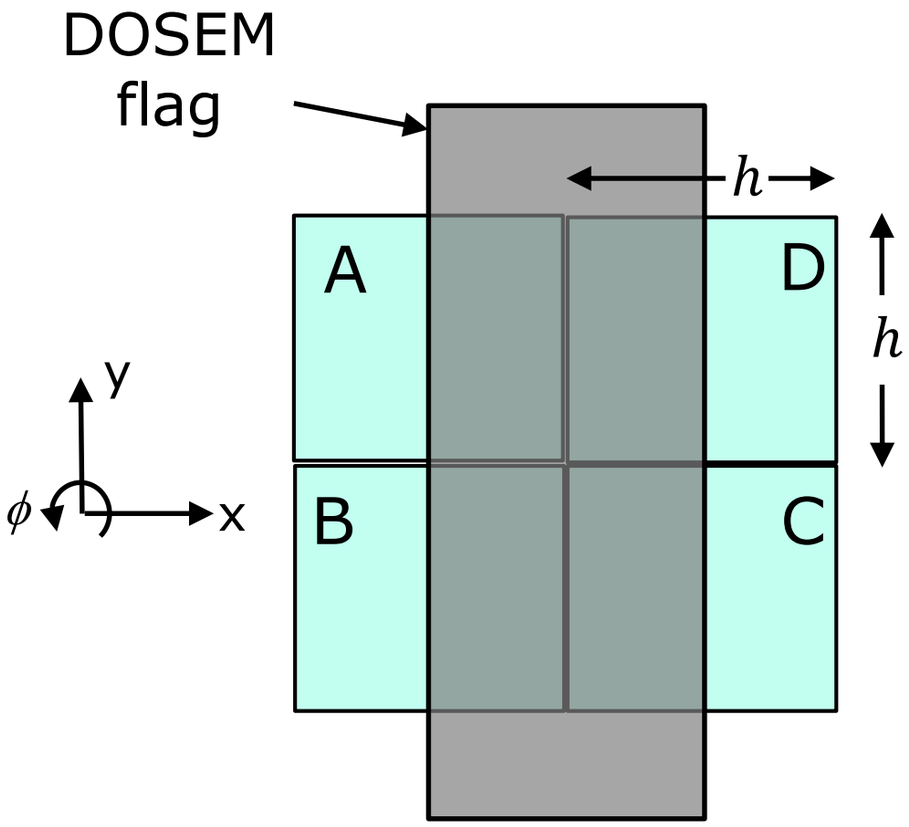
Modeled x Channel Signal

- Differential signal naturally reduces nonlinearity
  - Nonlinearity could be removed in digital output
- Linear range: ~ ±0.4 mm
- Equivalent sensitivity ~80kV/m (calibrated combined signal is unitless)



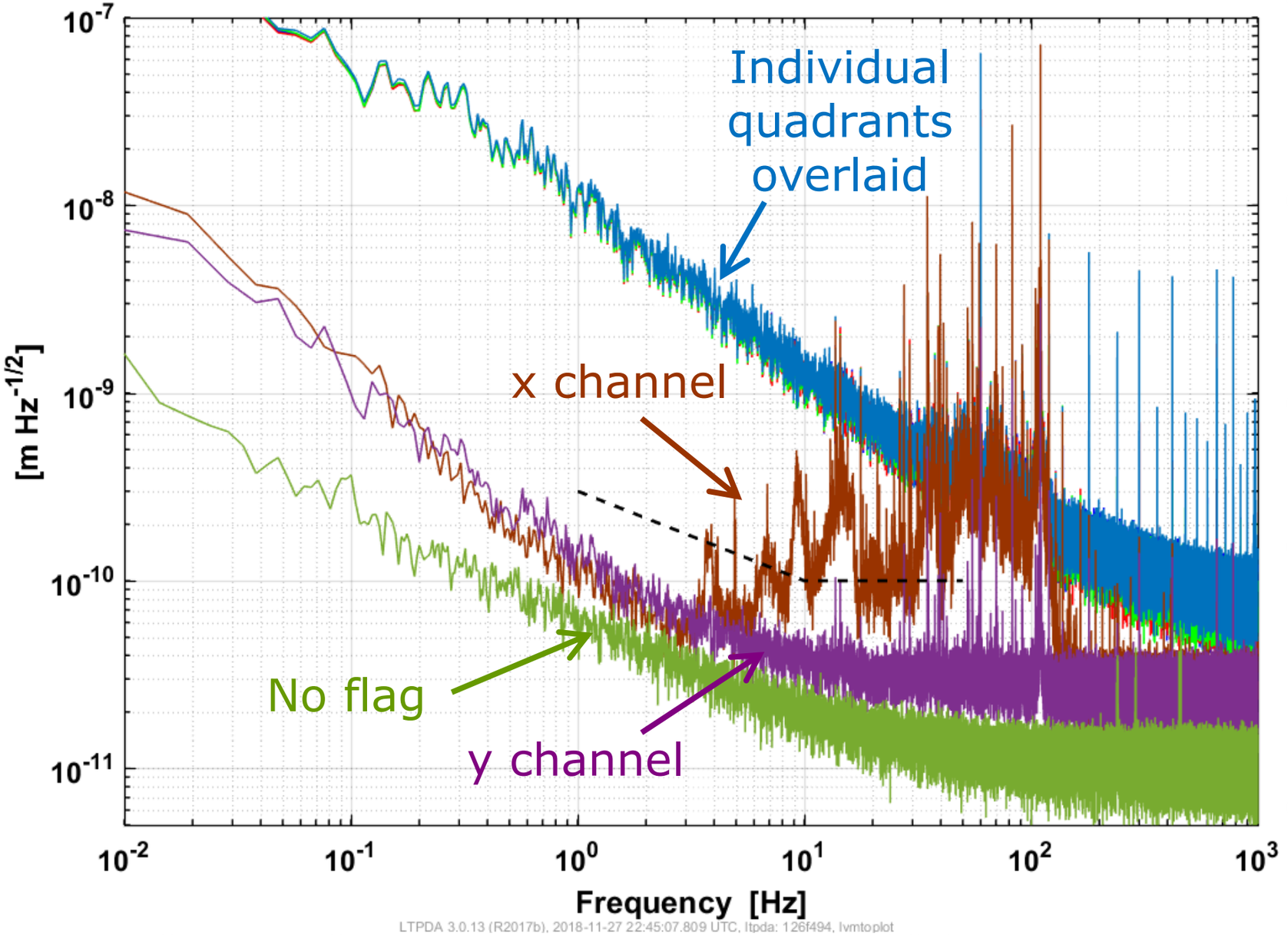
Three output channels

- Calibrated quadrant outputs can be combined to produce three channels
  - $x = \frac{(s_A+s_B)-(s_C+s_D)}{s_A+s_B+s_C+s_D}$
  - $y = \frac{(s_B+s_C)-(s_A+s_D)}{s_A+s_B+s_C+s_D}$
  - $\phi = \frac{(s_B+s_D)-(s_A+s_C)}{s_A+s_B+s_C+s_D}$



- y and ϕ channels are useful for:
  - Noise characterization
  - Alignment

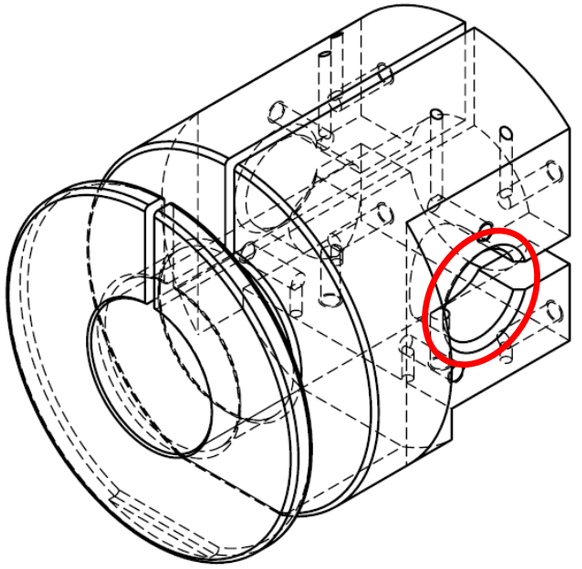
Early Results

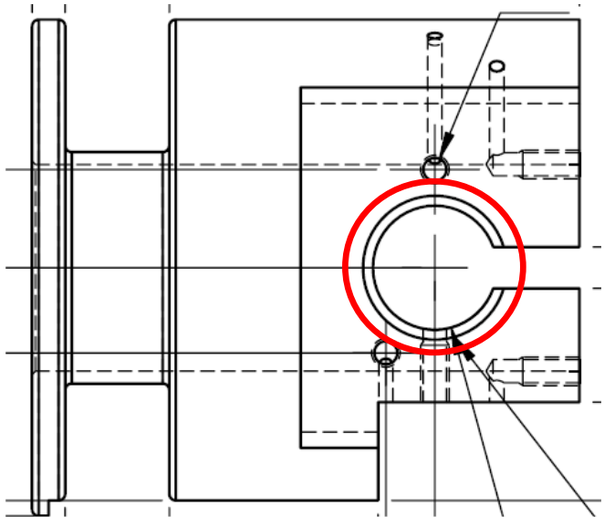


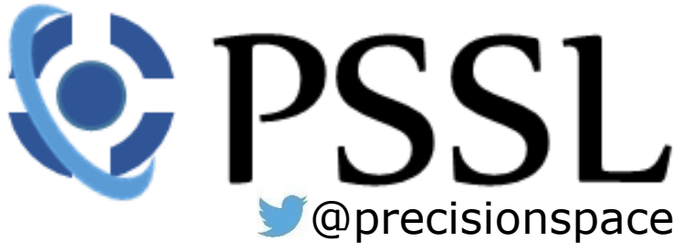
- Single quad sensitivity
  ~1 nm/Hz$^{1/2}$ @ 10 Hz
  (10x worse than BOSEM)
- Combined sensitivity
  ~40 pm/Hz$^{1/2}$ @ 10 Hz
  ~150 pm/Hz$^{1/2}$ @ 10 Hz
- Common mode rejection
  ~30x @ 10 Hz
- X channel signal
  (3 Hz to 100 Hz) above y channel is likely flag motion
- Shot noise appears to be limit above few Hz

Future Prospects

- Pathways to increase sensitivity:
  - Optimize flag width (reduce by ~0.2 mm)
    → ~2x increase in sensitivity (based on calibration slope)
  - Minimize vibration, air currents → vac chamber + vibe isolation
  - Improve analog electronics: Protoboard → PCB
  - Optimize light distribution on QPD: LED current, optics
- Work in progress:
  - Moving testbed to vacuum chamber (ion pump) on vibration isolation table (old LIGO HAM table)
- Future Work
  - Examine impact on BOSEM design; both for the sensor head, and analog/digital electronics
  - Seek out SWG interest, advice in DOSEM development
- Happy to evaluate alternate LEDs as part of this project







I arrive at LVC meeting in Wisconsin tomorrow night, depart Thursday afternoon

Happy to discuss further! – J.W. Conklin