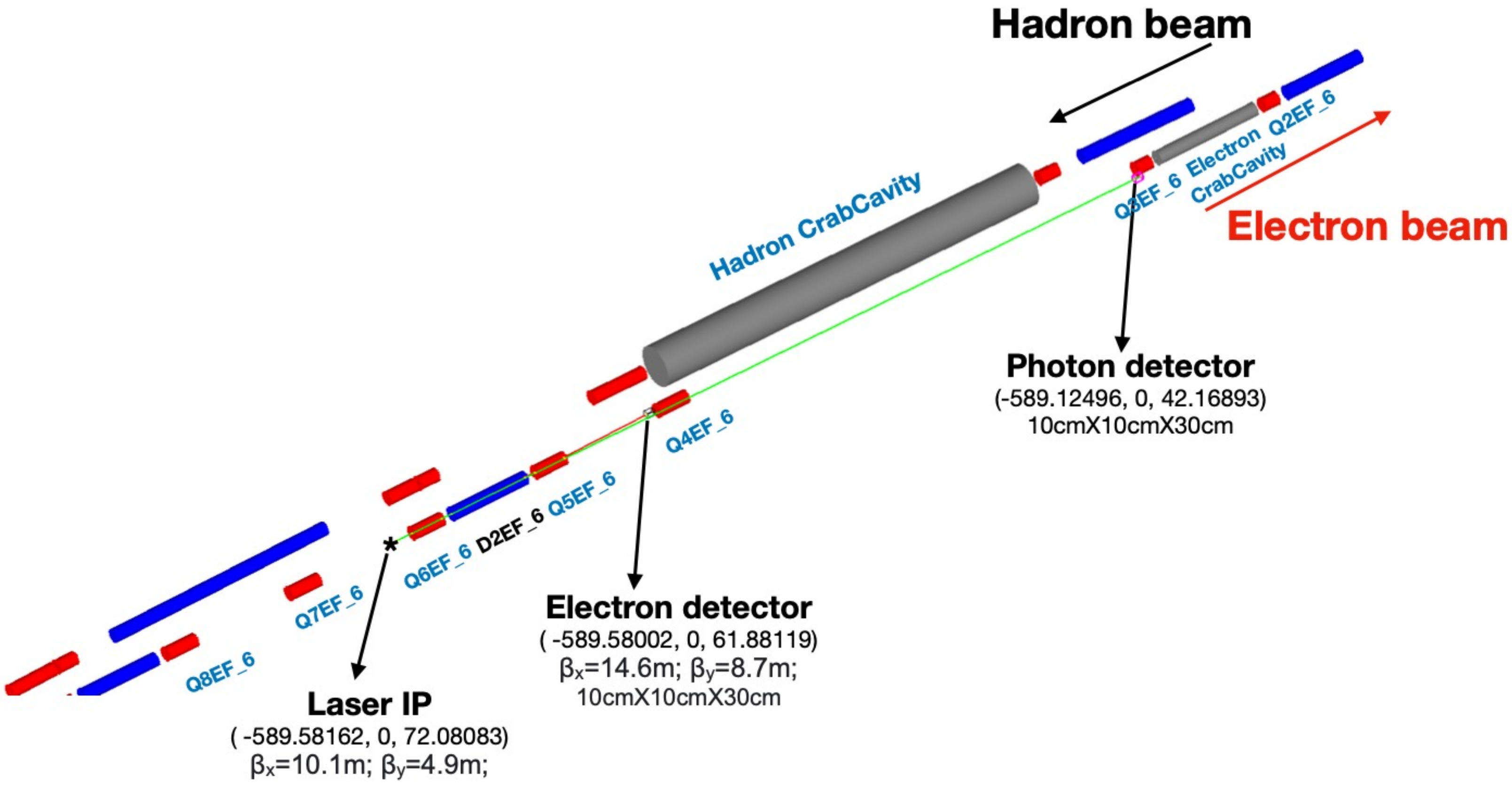
# Compton Polarimeter Detectors for the EIC

## Some conceptual ideas

Jim Fast



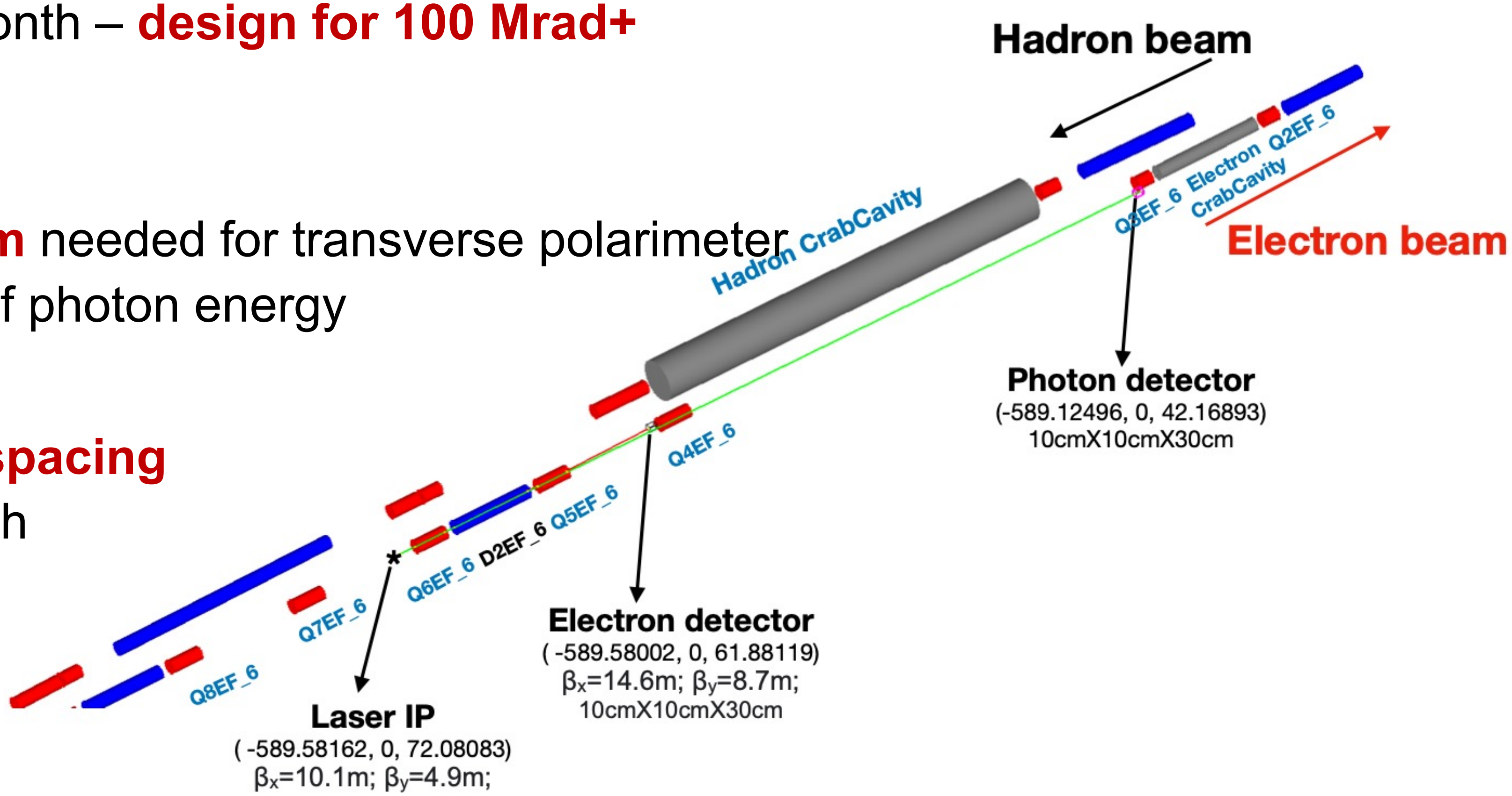
**Photon detector**
(-589.12496, 0, 42.16893)
10cmX10cmX30cm

**Electron detector**
( -589.58002, 0, 61.88119)
$\beta_x$=14.6m; $\beta_y$=8.7m;
10cmX10cmX30cm

**Laser IP**
( -589.58162, 0, 72.08083)
$\beta_x$=10.1m; $\beta_y$=4.9m;

# Electron polarimeter layout for IP6

- Electron detectors
  - ~10 meters from laser
  - 1-D segmentation (electron stripe <1 mm tall after dipole)
  - Location of stripe dependent on electron beam energy
  - Expected dose ~15 Mrad/month – **design for 100 Mrad+**
- Photon detectors
  - ~30 meters from laser
  - **Spatial resolution of <1 mm** needed for transverse polarimeter
  - Calorimetric measurement of photon energy
- Common requirement
  - Fast timing – **10 ns bunch spacing**
  - Need to measure each bunch



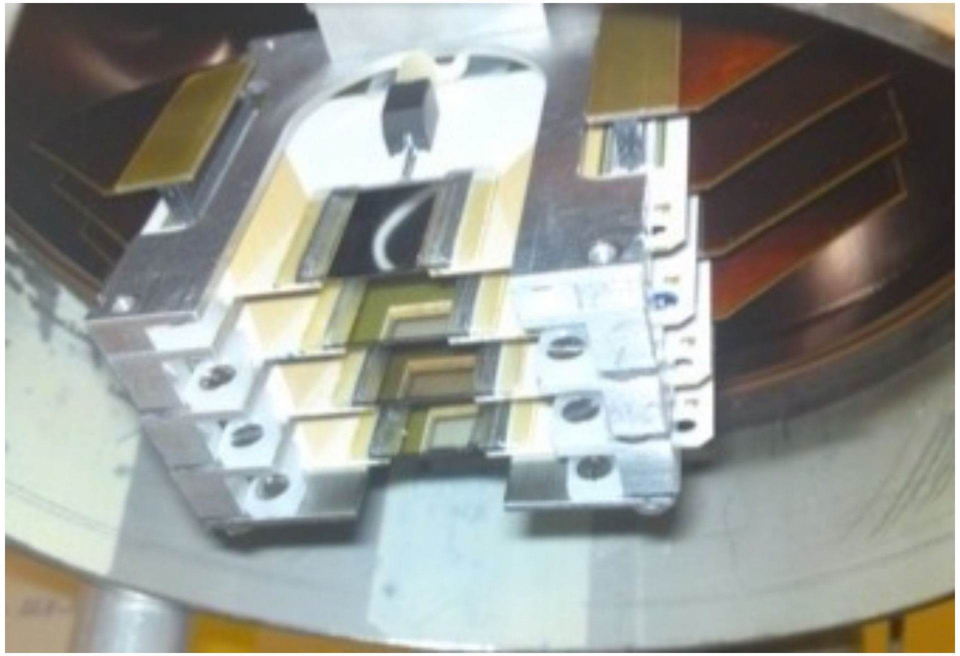
**Photon detector**
(-589.12496, 0, 42.16893)
10cmX10cmX30cm

**Electron detector**
( -589.58002, 0, 61.88119)
$\beta_x$=14.6m; $\beta_y$=8.7m;
10cmX10cmX30cm

**Laser IP**
( -589.58162, 0, 72.08083)
$\beta_x$=10.1m; $\beta_y$=4.9m;

# Electron detectors

- Planes of strip or pixel detectors
  - Diamond is best option for radiation tolerance **(>100 Mrad)**
    - Practical limit of ~250μ charge collection distance
    - Signal size is ~9,000 electrons (compared to 22,000 for 300μ Si)
  - MAPS (TowerJazz 180 nm) only good to ~1 Mrad
    - 65 nm process under development now (100 Mrad?)
  - Four planes good for efficiency/redundancy
  - Detectors over 3 cm are more difficult to obtain
    - Natural detector width of 6 cm; probably best to use 2 sensors
  - Of order 1 mm guard ring (dead area) on sensors
    - Overlap sensors (scattering) or have ~ 2 mm dead strip at center of detector plane?
    - Dead area along edge near primary beam – what is acceptable?
- On-board ASICs for good S/N ratio (S/N>15 at installation)
  - Transmission of low-level diamond signals over long flex significantly impacted JLab detector performance
  - More on options later…
  - Dose at end of active volume (where ASICs sit) needs to be understood
- In accelerator vacuum
  - Low outgassing PCBs (ceramic) and cabling (Kapton)
  - Packaged die (e.g. VMM3) need to be checked for vacuum compatibility
- Alignment requirements and retraction capability
  - At JLab, detectors can be retracted for beam tuning to avoid damage from mis-steering, halo etc.



JLAB HALL C DIAMOND PLANES

# Diamond substrate supply concerns

- Several companies have come and gone in this arena
  - There is some science and some art to this
  - Harris Kagan at Ohio State is world expert on substrate processing to make detectors
    - Harris has trained people at several companies over the past 30 years
    - Successful until key personnel leave or profit margins drive process changes
- II-VI is the primary supplier of detector-grade material currently
  - Have had processing issues lately leading to high leakage currents (for ATLAS and JLab)
    - Essentially the issue is sub-surface damage
    - Subcontracting post-growth processing; deviations from established process
  - Problems seem to be understood, but production is still struggling to recover

# ASICs for diamond strip readout – two best candidates

- FLAT-32 (under development by SenseIC)
  - 32-channel evolution of CALYPSO chip developed for ATLAS BCM-prime
  - Outstanding noise performance (~200 $e^-$, S/N~50 for diamond)
  - 10 ns analog pulse full width
  - Dual gain for single MIP (high gain) in diamond and beam abort events (low gain)
  - Designed for low capacitance input from diamond strips/striplets/pads
  - On-board logic provides start time and time-over-threshold output as LVDS pulse
  - Manufactured in 65 nm bipolar CMOS (highly radiation tolerant)

JLab preferred solution for next generation detectors in Halls A and C

- SAMPA (developed for ALICE TPC)
  - 32-channel
  - Gain of 20 mV/fC; noise of 600 $e^-$ with load of 18.5 pF
    - In principle sufficient for diamond strips (S/N~15 prior to irradiation)
  - 160 ns peaking time
    - Probably not sufficient for EIC timing requirements/bunch spacing
  - 10-bit ADC, 10 MSPS (up to 20 MSPS)
  - Ten 320 Mbps eLinks to transmit ADC outputs
  - Fabricated in 130 nm CMOS (radiation tolerant, but less so than 65 nm bipolar)
  - Being considered for use elsewhere in EIC so DAQ compatibility should be OK

JLab is building a test board for SAMPA plus diamond strip sensor

# ASICs for semiconductor strip readout – other options we've looked at

- VMM3 (designed for ATLAS MPGD)
  - 64-channel chip packaged in BGA package
    - Signal routing adds capacitance/noise
    - Is package vacuum compatible?
  - Gain adjustable (4-16 mV/fC)
  - 300 $e^-$ noise measured at 30 pF load and 16 mV/fC gain (400 $e^-$ at 6 mV/fC)
  - Adjustable peaking time 25-200 ns
  - Manufactured in 130 nm Global Foundries 8RF-DM process (rad tolerant design)
  - Being considered for use elsewhere in EIC so DAQ compatibility should be OK

Viable performance parameters for diamond sensors

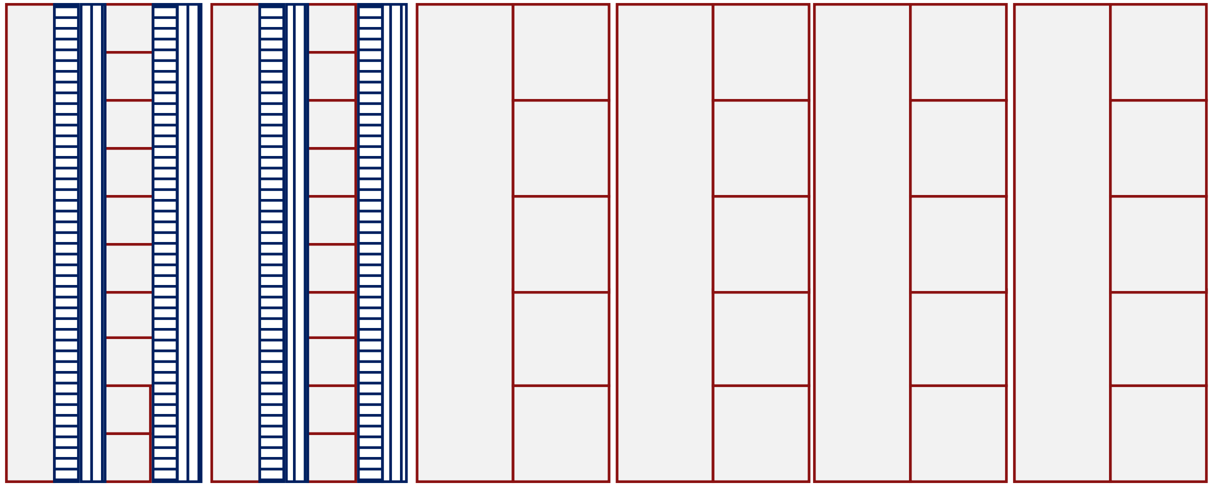
- SALT 3 (developed for LHCb VELO silicon)
  - S/N = 12 for silicon so expect S/N~6 for diamond
  - Chip run completed for LHCb – significant investment would be needed to produce chips

Inadequate performance for diamond sensors

# Photon Detectors

- Goals:
  - Good spatial resolution (mm-scale)
  - Excellent timing resolution (resolve 10 ns bunches)
  - Measure full photon energy
  - Areal coverage of order 10 cm x 10 cm
- General approach: pre-shower followed by EMCAL
  - Pre-shower could use silicon or diamond sensors (radiation levels?)
    - Number of layers and thickness need to be optimized for performance vs cost
      - Efficiency for getting photon position requires a significant thickness ($X_0$)
      - Position resolution favors thinner radiators and more tracking planes
      - Cost favors minimizing tracking planes
    - Calorimeter could be sampling type or crystal EMCAL
      - Energy resolution better with crystal EMCAL
      - Timing resolution and “afterglow” are concerns for most scintillators given 10 ns bunch spacing

# Some ideas for calorimetry



- Orient crystal calorimeter modules transverse to beam direction (alternating orientation) and use as an active radiator for the pre-shower
  - Minimal inactive material for optimal energy resolution
  - Active radiator in pre-shower allows for greater depth (more efficiency) without compromising calorimeter energy resolution
  - Modular design can be adapted for both electron and photon detectors
- Consider alternatives to $PbWO_4$ crystals for EMCAL
  - Short decay time is paramount to avoid impacts of pileup with 10 ns bunch spacing ($PbWO_4$ fast 6 ns, slow 30 ns)
    - Interesting newer result on $PbWO_4$ shows much faster response arXiv:2103.13106v2 (2 ns fast component, 6 ns slow component)
    - $CeBr_3$ (19 ns) , LYSO:Ce (36 ns), $BaF_2$:Y (0.5 ns @ 220 nm)
    - High light yield (e.g. $CeBr_3$ or LYSO) would allow for a longitudinally segmented calorimeter without compromising energy resolution
    - LYSO and $BaF_2$ are not hygroscopic while $CeBr_3$ is very hygroscopic and requires encapsulation
- Use wavelength difference between fast and slow components of scintillation light to select only the fast component if using $BaF_2$ or similar (wavelength cutoff filters)
  - Poisson fluctuations in slow component of light from pile-up events results in time-dependent baseline which will ruin resolution

# Some Project-related comments

- For EIC, these are small devices and full-scale device prototyping is reasonable
  - Recommend integrating significant prototyping in to project planning now
- Early definition of requirements and interfaces (size, mounting, cable routing etc.) would allow pursuing multiple (internal) technology options without increasing or delaying integration engineering effort
  - The more differences in implementation, the earlier a down-select has to happen
  - In this respect, competing ideas need to be collaborating now
- “Perfect is the enemy of good” (Voltaire)
  - Clearly defined goals (requirements) should be established as early as possible
- Pareto Principle: the last 20% of a task takes 80% of the effort
  - Detector R&D should transition to engineer design as soon as requirements are satisfied
- From a project perspective, risk is a significant driver
  - Cost and schedule risk will outweigh small performance benefits