

# HFCC R&D needs

Caterina Vernieri, Carl Haber for HFCC

Su Dong

LESA workshop

SLAC, September 5, 2025

# Physics benchmarks for FCC-ee

■ ■ ■ FCC@ZH Bunches 1  $\mu$ s apart

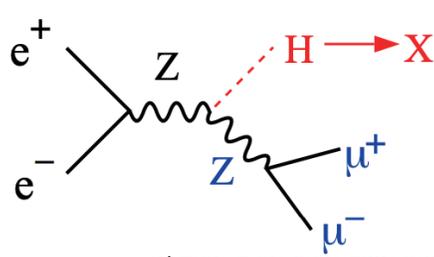
■ ■ ■ ■ ■ FCC@Z Bunches 20 ns apart

## Higgs boson physics at 240-250 GeV

- Measurement of the total ZH cross section with  $<1\%$  uncertainty
- Measure Higgs boson mass to 0.01% accuracy and branching ratio to invisible particles using Z recoil, with 0.1% or better uncertainty.

## Z pole run, TeraZ program, WW threshold

- Precision measurement of electroweak parameters:  $\sin^2\theta_W$ , Z and W masses and widths, ...
  - Track angular resolution  $< 0.1$  mrad



Initial state	Physics goal	Detector	Requirement
$e^+e^-$	$hZZ$ sub-%	Tracker Calorimeter	$\sigma_{p_T}/p_T=0.2\%$ for $p_T < 100$ GeV $\sigma_{p_T}/p_T^2 = 2 \cdot 10^{-5} / \text{GeV}$ for $p_T > 100$ GeV 4% particle flow jet resolution EM cells $0.5 \times 0.5 \text{ cm}^2$ , HAD cells $1 \times 1 \text{ cm}^2$ EM $\sigma_E/E = 10\%/\sqrt{E} \oplus 1\%$ shower timing resolution 10 ps
	$hb\bar{b}/hc\bar{c}$	Tracker	$\sigma_{r\phi} = 5 \oplus 15(p \sin \theta^{\frac{3}{2}})^{-1} \mu\text{m}$ 5 $\mu\text{m}$ single hit resolution

Arxiv:2209.14111 Arxiv:2211.11084 DOE Basic Research Needs Study on Instrumentation

# General R&D needs

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Several technology under development for each sub-detector

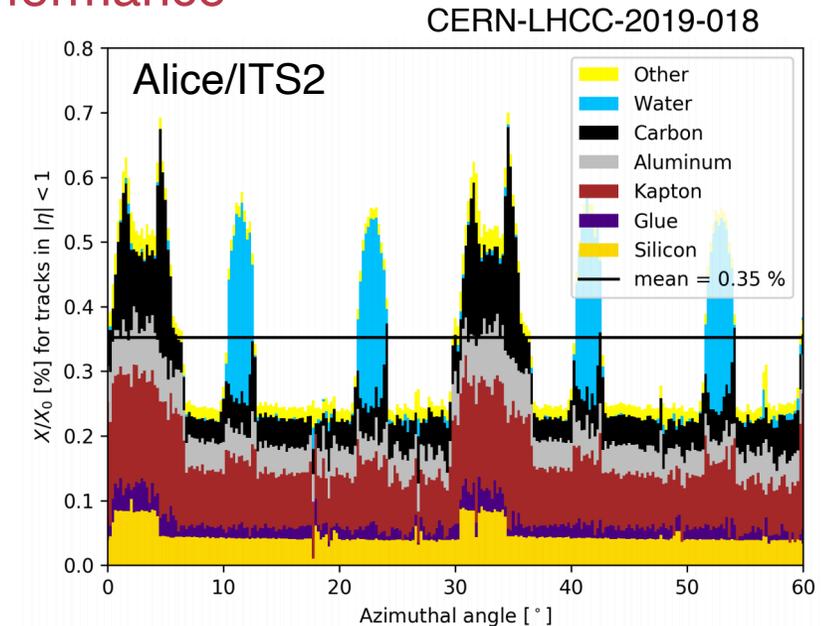
- Tracking
  - Straw tracker
  - Drift chamber
  - Silicon: MAPS based approach (see later), smart pixels.
- Calorimetry
  - silicon based approach
  - dual-read out (see Ariel's talk)
- Timing (see also Simone's and Carl's talks)

Timeline compatible with when LESA will become online

# Sensors technology requirements for Vertex Detector

Several technologies are being studied to meet the physics performance

- **Sensor's contribution to the total material budget is 15-30%**
  - Services cables + cooling + support make up most of the detector mass
- Sensors will have to be less than  $75 \mu\text{m}$  thick with at least  $3\text{-}5 \mu\text{m}$  hit resolution ( $17\text{-}25 \mu\text{m}$  pitch) and low power consumption
- Beam-background suppression
  - FCC, continuous r/o integrated over  $\sim 10 \mu\text{s}$  with  $O(1)$  ns timing resolution for beam background suppression



## Physics driven requirements

$\sigma < 3 \mu\text{m}$

Material budget  $0.1\% X_0/\text{layer}$

r of the Inner most layer  $12\text{-}14 \text{ mm}$

## Running constraints

Cooling

Beam-background

Radiation damage

## Sensor specifications

Small Pixel  $\sim 15 \mu\text{m}$

Thinning to  $50 \mu\text{m}$

Low Power  $20\text{-}50 \text{ mW}/\text{cm}^2$

Fast Readout  $\sim 1\text{-}10 \mu\text{s}$

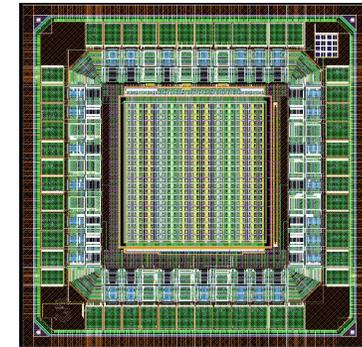
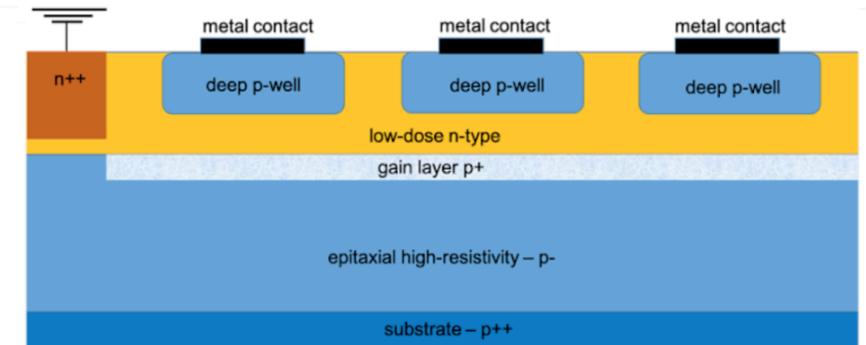
Radiation Tolerance  $10 \text{ MRad}, 10^{14} \text{ n}_{\text{eq}} / \text{cm}^2$

# Interest from US FCC community

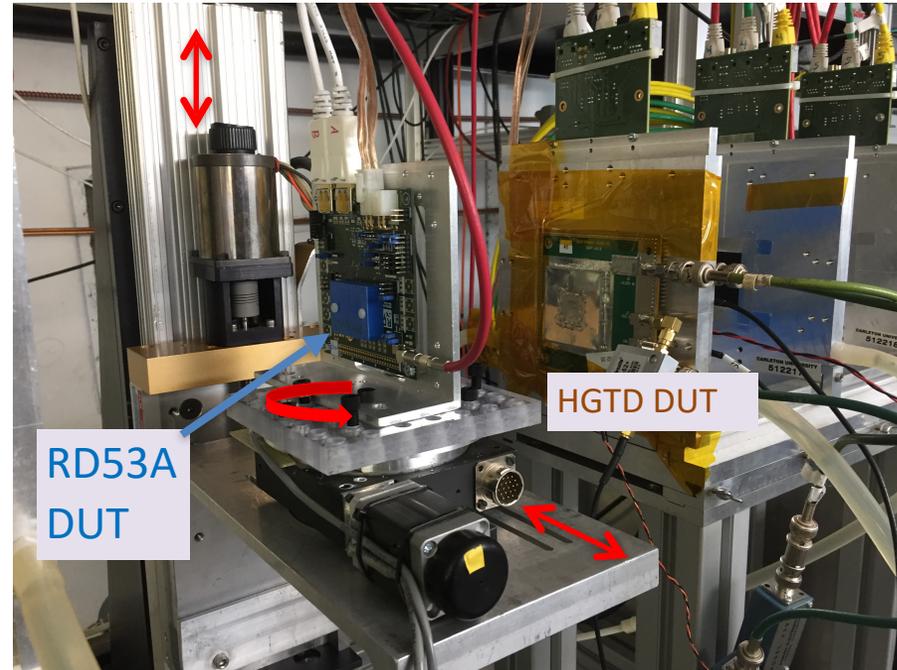
1. **LGAD-based detectors, for timing layer (FNAL/BNL)**  
few kHz particle rates
2. **MAPS sensors with spatial resolution  $< 3\mu\text{m}$**   
(Interest also from Alice ITS3, for large stitched sensors)
  - **NAPA MAPS sensors with ns timing capability (SLAC)**  
1.5mmx1.5mm test structure
3. **ETROC, Future Precision Timing Detectors (FNAL)**
  - **1x1cm size, highest intensities**
4. **Scintillator based detectors** for radiation protection studies  
< 1 particle per pulse at different rep rates

## Common needs:

- Large band-width oscilloscope with multi-channels, fast digitizers, fast triggering systems
- Remote controlled motion table, dry air supply, chillers, low and high voltage power supplies
- tracking telescope - see next slide

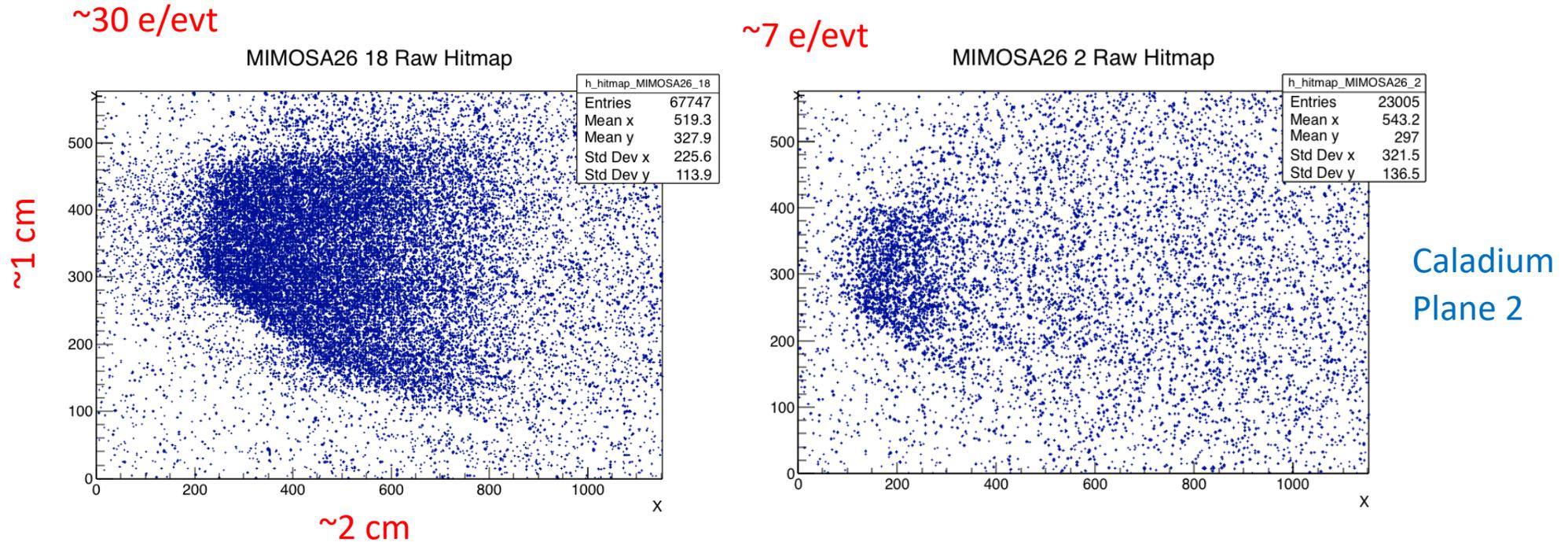


# Current setup: Caladium EUDET Telescope + DUT



- **Caladium EUDET telescope** resident at ESTB since Dec/2015,
- Loan from Carleton University, **Thomas Koffas**, supporting/operating the telescope
- EUDET: 6 planes of CMOS MIMOSA-26 (up to ~10KHz trigger)
- 18.5x18.5 $\mu\text{m}$  pixels, X\*Y aperture ~2x1 cm and ~3 $\mu\text{m}$  spatial resolution.
- Augmented by remote controlled movers
- Overall XY stage for telescope+DUT
- dedicated DUT XY & rotation stage (new: mounting electrical insulation)

# Beam Spot (from Su Dong, 2017)



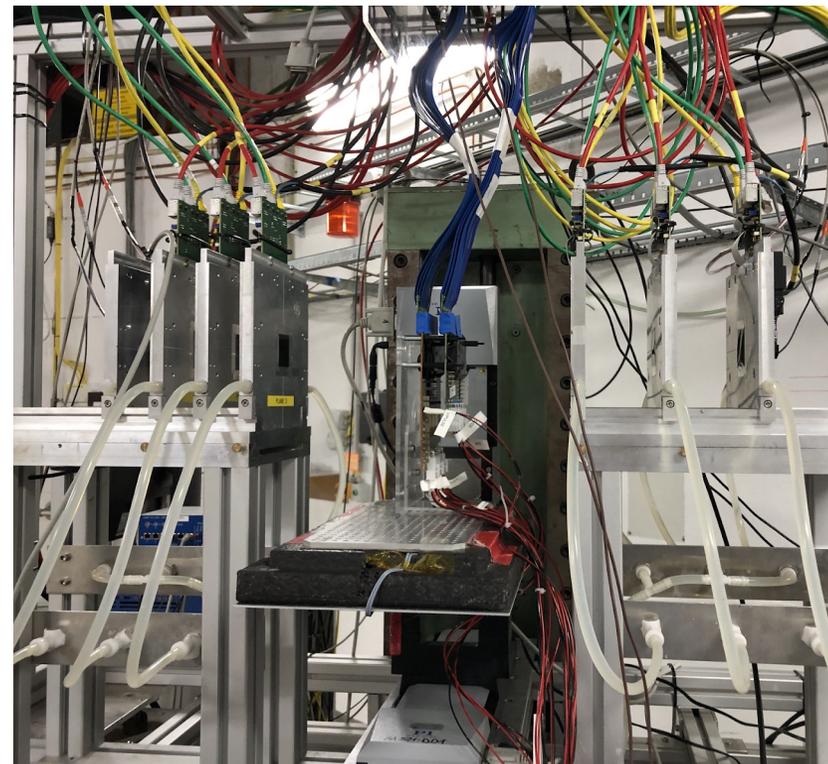
- Requested MCC to uniformly spread beam in 2x1 cm aperture
- Bulk of quality data taken at  $\sim 7$  e/event to keep track density within reconstruction capability
- Rate and beam position can jump when LCLS changing primary beam energy

# Needs cont'd

Telescope - possible updates - SBU interested in a MALTA update

- Malta ( $36\mu\text{m}$  pitch, 25 ns) plane (3 available) as timing reference to improve track finding at higher intensities
  - Open to collaborating on an HFCC telescope with new technologies: can help with test, integration, DAQ/TLU, operations.

- 6-8 campaigns a year with possible optimization across different efforts within HFCC & DRDx
  - As early as end of 2026.
- 1-2 weeks each



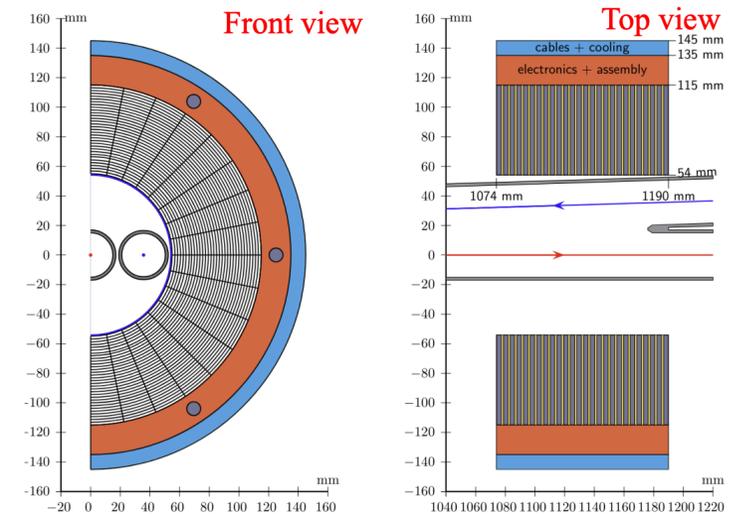
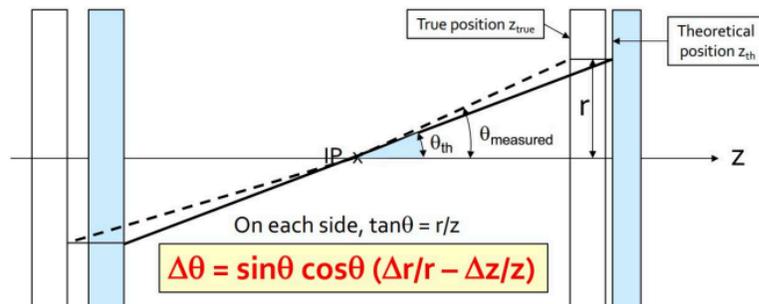
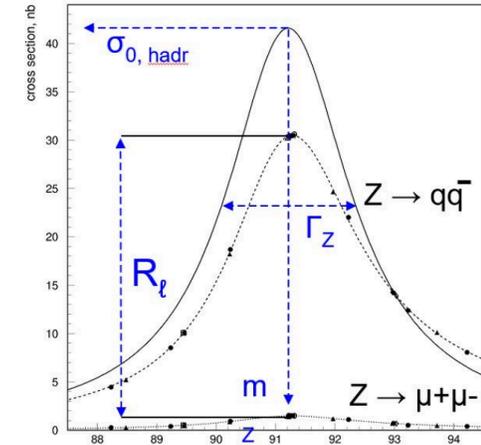
V. Dao, G. Piacquadio (SBU)

*Backup*

# (Z pole) physics requirements for detectors

## Z pole precision challenges even more detector design

- $\Gamma_Z$  is extracted from the Z lineshape
  - systematic uncertainty should be  $\sim 5$  keV to match statistical precision
    - requires exquisite **control and stability of the momentum scale**
    - $\delta\Gamma_Z \sim 20$  (40) keV and  $40 \text{ keV} / 90 \text{ GeV} < 1e^{-6}$
- $R_l$  demands precise knowledge of the geometrical acceptance
- Absolute luminosity measurement at Z pole, required by peak Z cross section
  - $\Delta\theta_{\min} \sim 10 \mu\text{rad}$  to match statistical precision ( $2 \times 10^{-5}$ )
    - equivalent to  $\Delta r \sim 30 \mu\text{m}$ ,  $\Delta z \sim 80 \mu\text{m}$  at  $\theta = 20^\circ$  and  $z = 2.6\text{m}$
- Luminosity Monitors centered around outgoing beam lines
  - $\delta R_{\min} \sim O(1 \mu\text{m})$ ,  $\delta z \sim O(100 \mu\text{m})$
  - **Ambitious goal: absolute normalization to  $10^{-4}$  note  $O(10^{-2})$  for LHC and relative (energy scan points) to  $10^{-5}$**
  - Current theoretical uncertainty:  $3.8 \times 10^{-4}$ , **major theory efforts also needed**

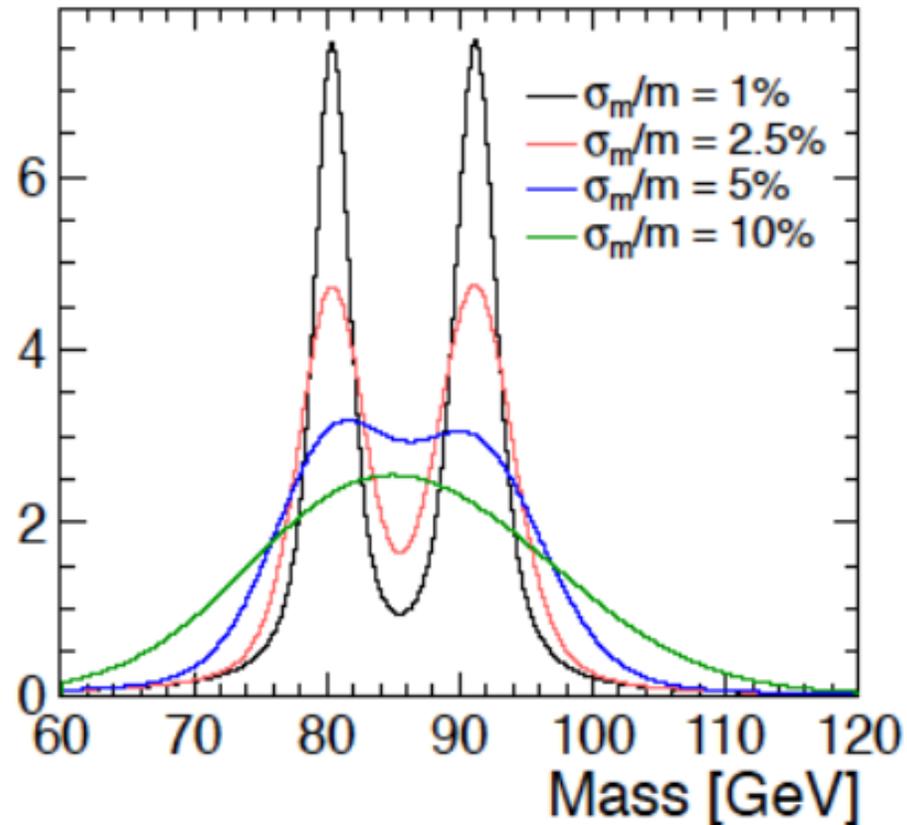


**This in-situ calibration technique could be used to determine lumiCal acceptance**

# One more: W/Z separation

Precision challenges detector design

## W-Z separation



Drives the requirement on jet resolution

**hadronic jet energy resolution  $\sigma_E/E \sim 3 \rightarrow 5\%$  over wide energy range**  
→ distinguish W, Z, H

- ECAL target resolution of 10-15%  $1/\sqrt{E}$  for photons
  - ECAL granularity resolution needed for efficient photon bremsstrahlung recovery
    - 3% $1/\sqrt{E}$  EM resolution improves  $m_H$  by 22%**
- HCAL target resolution of  $\sim 30\% / \sqrt{E}$  for neutral

# ESTB infrastructure

EPICS supported by SLAC Test Facilities

The screenshot shows the Beckhoff 26 control interface for B061 Caladium. It features five motor control panels, each with a status indicator (Stopped), absolute position (Abs pos [mm]), and relative position (Rel pos [mm]) controls. The motors are: Motor 1: X coarse (98.00 mm), Motor 2: Y coarse (0.00 mm), Motor 3: Y fine (46.20 mm), Motor 4: X fine (0.00 mm), and Motor 5: Rotation (180.00 mm). A 'noError' status is displayed at the top left and bottom left.

XY stage control & temperature probes

The screenshot shows the T-539 Specific control interface. It includes sections for 'Caladium Beckhoff (Motors, ADC, Temp.)', 'Caladium Power Strip', and 'Webcams'. Under 'Webcams', three cameras are listed: EsaCam02: DUT DAQ, EsaCam03: Power supplies, and EsaCam05: DUT Overhead.

Web  
cams

The screenshot shows the APC Power Strip control interface for B061 Caladium. It displays a load of 4.50 Amp and an IO State of Good. A table shows the status of various components across three banks.

Bank 1 Status and Control			
	Name	State	reBoot
1		Good	Stop
2	Telescope PSU	Good	Stop
3	DUT LV + HV	Good	Stop
4	Sun Server	Good	Stop
5	NI Crate	Good	Stop
6	TLU	Good	Stop
7	HSIO-II	Good	Stop
8	Gbit cam switch	Good	Stop

Remote  
power  
control