Tile Module Assembly for the CMS High Granularity Calorimeter at Fermilab
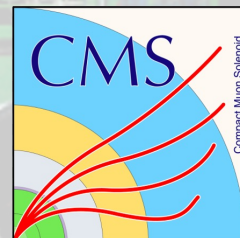
2023 US LUA Annual Meeting

Ryan S. Kim

Florida State University

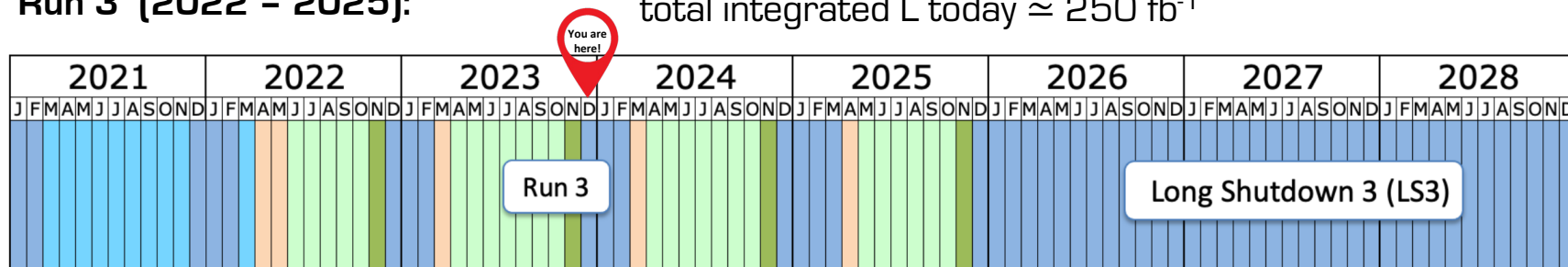On behalf of the CMS collaboration

December 14, 2023

Long Term LHC Schedule

- **Run 1 & 2 (2009 – 2018)**

- **Run 3 (2022 – 2025):**   total integrated L today $\simeq 250$ fb^{-1}

| 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 |

You are here!

Run 3

Long Shutdown 3 (LS3)

Shutdown/Technical stop
Protons physics
Ions
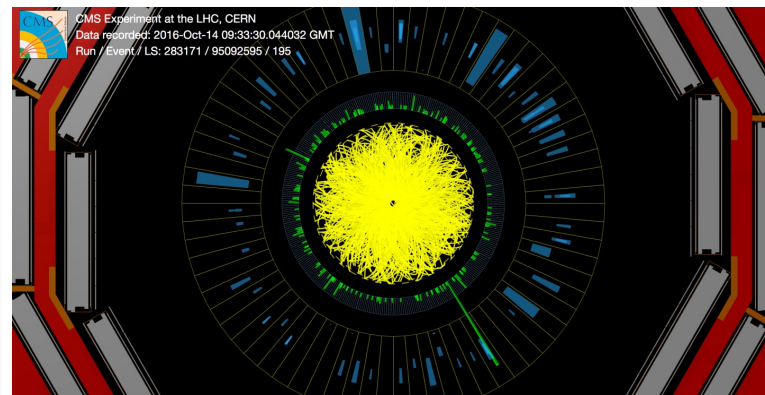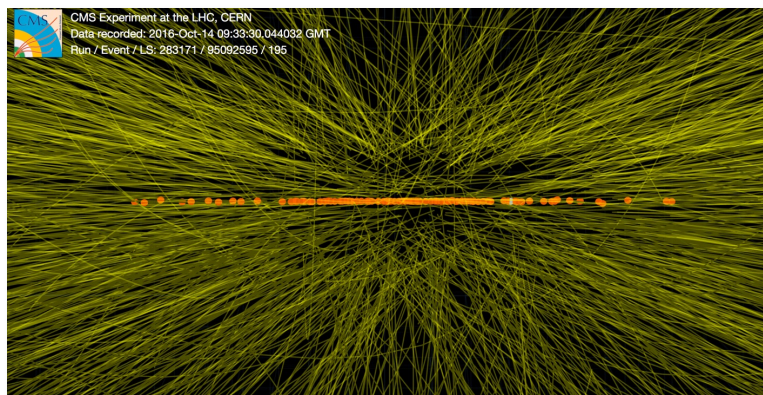Commissioning with beam
Hardware commissioning/magnet training

- **High Luminosity LHC   Run 4 & 5 (~ 2029 – 2040)**
  - Total expected integrated L $\simeq 3000$ fb^{-1}
  - Pile up of 200!
  - Detectors with higher radiation tolerance, better timing precision, and finer spatial granularity are needed
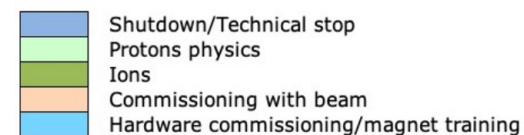
Special high pile up run in 2016

CMS High Granularity Calorimeter

- In CMS, **High Granularity Calorimeter** (HGCAL) is the new endcap calorimeter meeting these criteria for the HL-LHC, replacing current ECAL & HCAL endcaps

- 5D calorimetry:
  - **Energy measurement**
  - **Precise timing**: ~30 ps for particle showers
  - **Fine spatial granularity**: 22k -> 6M channels!

- State-of-the-art detector technologies:
  - Radiation-hard **silicon sensors** closer to the p-p interaction point
  - Plastic **scintillator tiles** with "SiPM-on-Tile" readout toward the back in the lower radiation regions

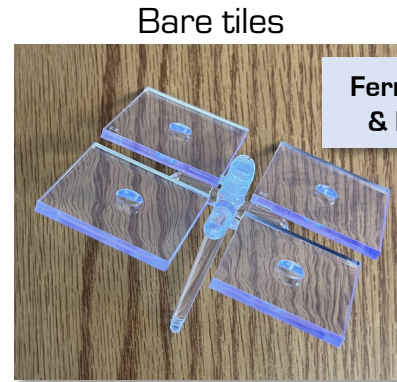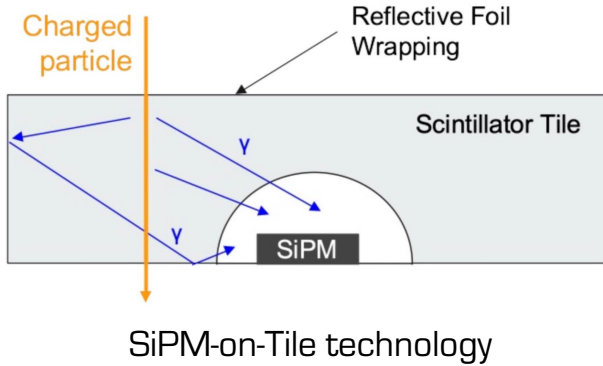**Lateral view of HGCAL**
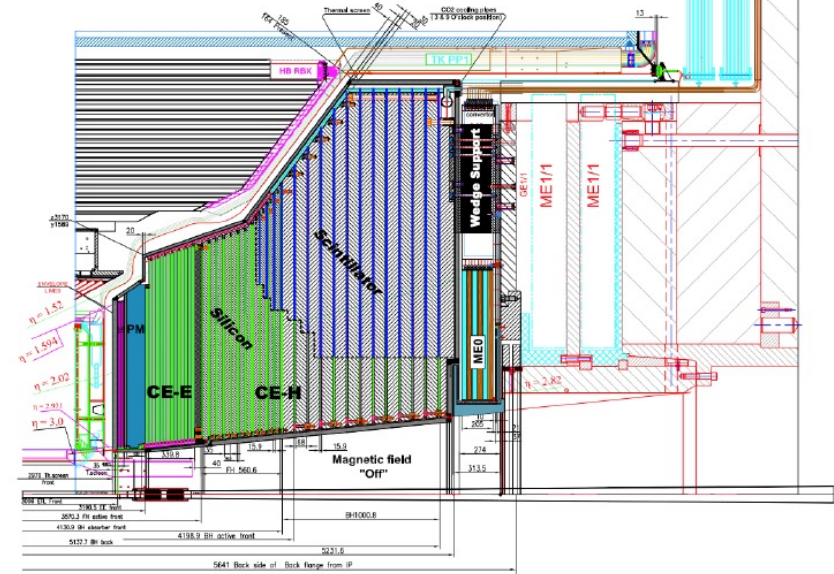
Cross-sectional view of HGCAL
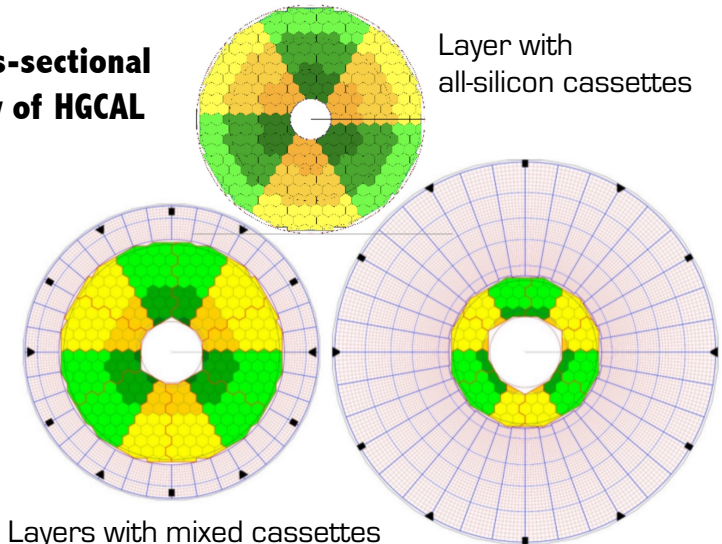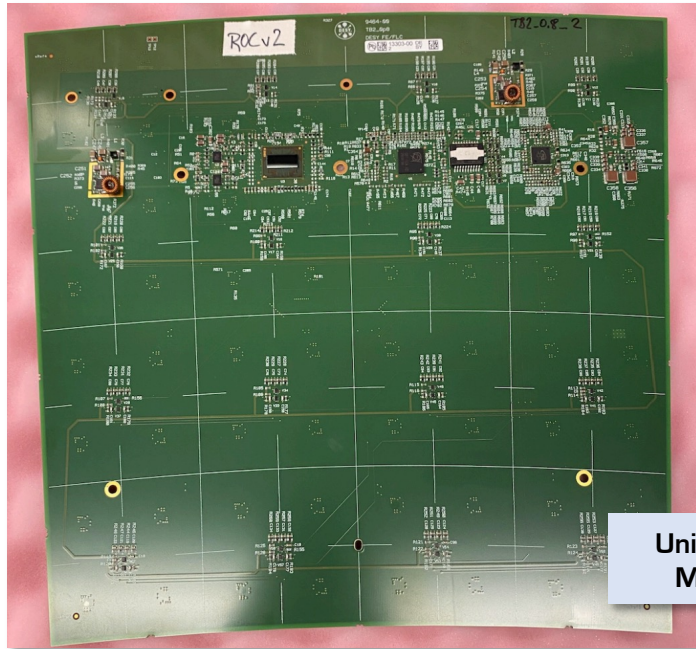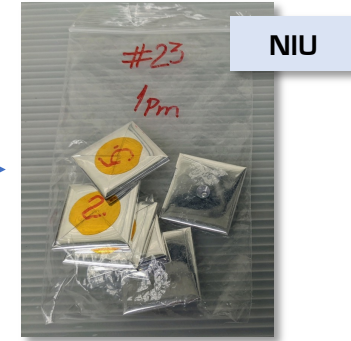

Layer with all-silicon cassettes

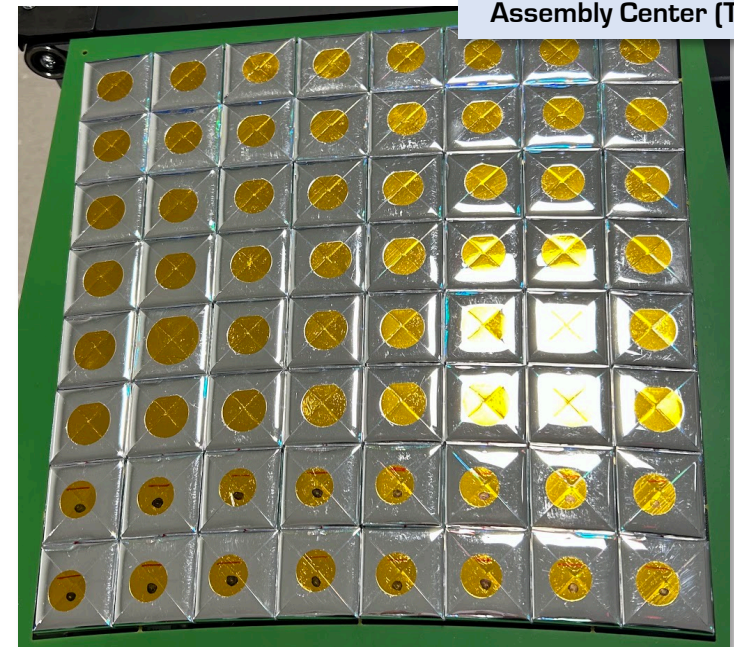Layers with mixed cassettes

SiPM-on-Tile Modules

U.S. workflow!

SiPM-on-Tile technology

Bare tiles

Fermilab & NIU

Wrapped tiles

NIU

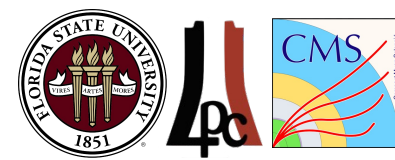**Fermilab Tile Module Assembly Center (TAC)**

University of Maryland

Tileboard with electronics

Wrapped tiles assembled on tileboard ≡ "tile module"

Fermilab Tile Module Assembly Center

Assembly of ~2000 tile modules to be carried out by pick-and-place (PnP) machines

Fermilab TAC tasks leading up to production:

- Construction and maintenance of PnP machines
- Preparation for the assembly of different tile module types
- Development of quality control (QC) procedures for completed tile modules including thermal cycling and electrical QC

Collaborators:
- **Myself (FSU)**
- **Daniel Guerrero (FNAL)**
- **Jim Freeman (FNAL)**
- **Harry Cheung (FNAL)**
- **Don Lincoln (FNAL)**
- **Vishnu Zutshi (NIU)**
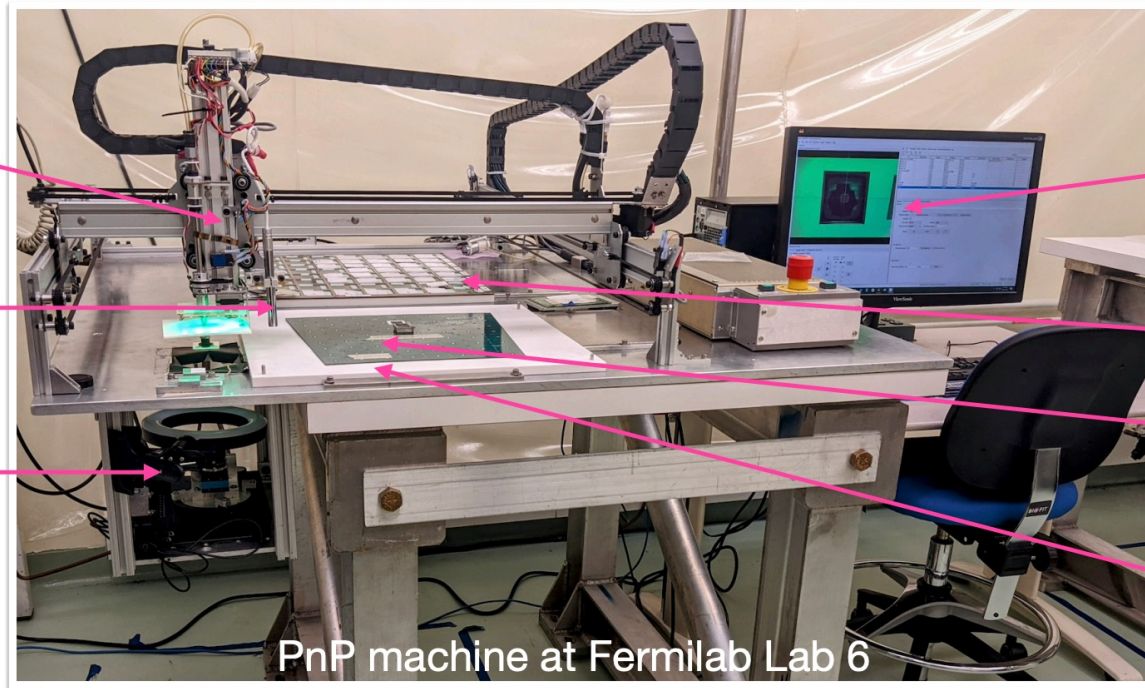
Robot gantry (Pick and place)

Down-facing camera (Position calibration)

Up-facing camera (Vision system)

PC running openPnP software

Tile Tray

Tileboard PCB

Tileboard carrier

PnP machine at Fermilab Lab 6
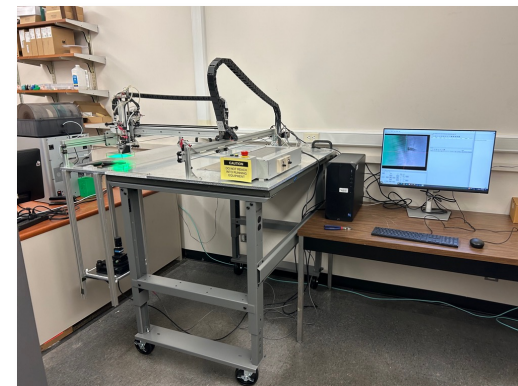
PnP Machine Hardware & Software

Hardware

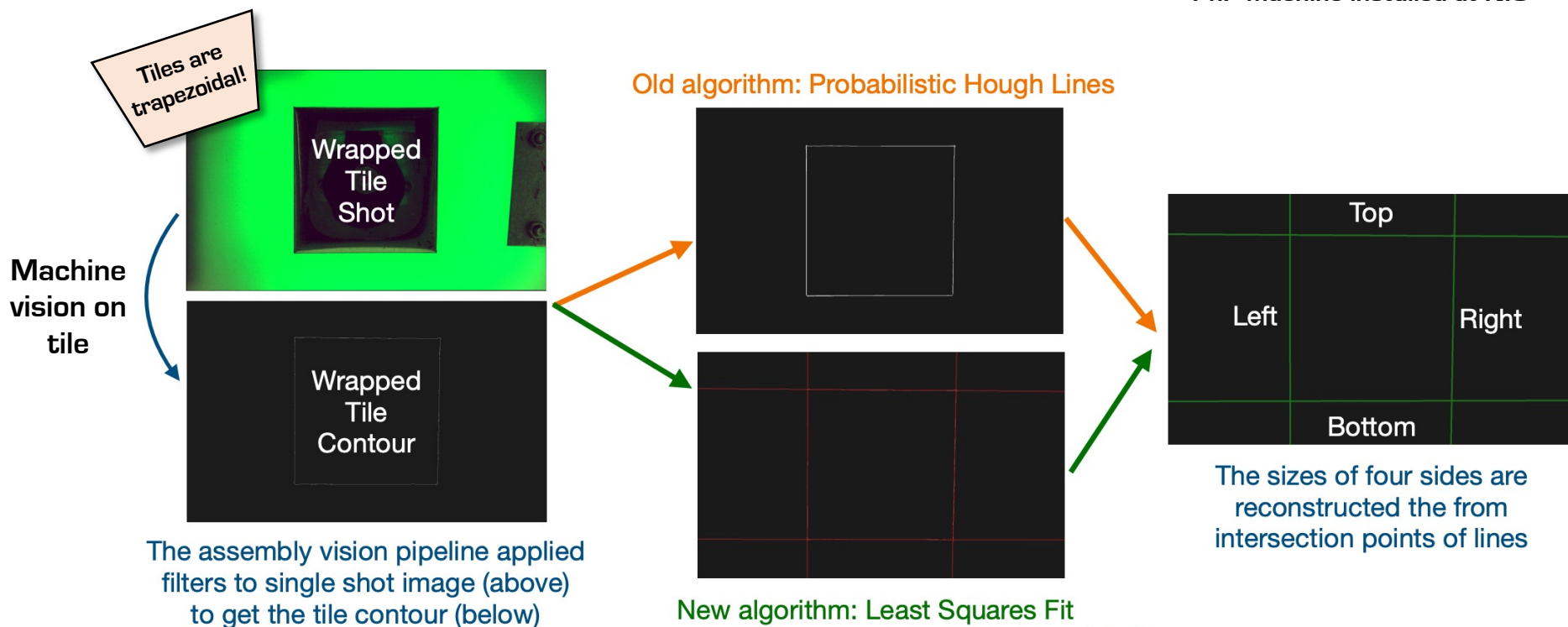Construction of three total PnP machines

- Two machines at Fermilab for **tile module assembly**
- One machine recently installed at NIU for **wrapped tile QC**

Software

- Open-source program called openpnp optimized for our use
- Contours from tile images taken and *least-squares fit* applied

PnP machine installed at NIU

Tiles are trapezoidal!

Wrapped Tile Shot

Wrapped Tile Contour

Machine vision on tile

Old algorithm: Probabilistic Hough Lines

New algorithm: Least Squares Fit

The assembly vision pipeline applied filters to single shot image (above) to get the tile contour (below)

Top

Left   Right

Bottom

The sizes of four sides are reconstructed the from intersection points of lines

Quality Control Procedures

Visual inspection and robustness
- Verify labeling and numbering
- Thermal cycling: +30 C to -30 C
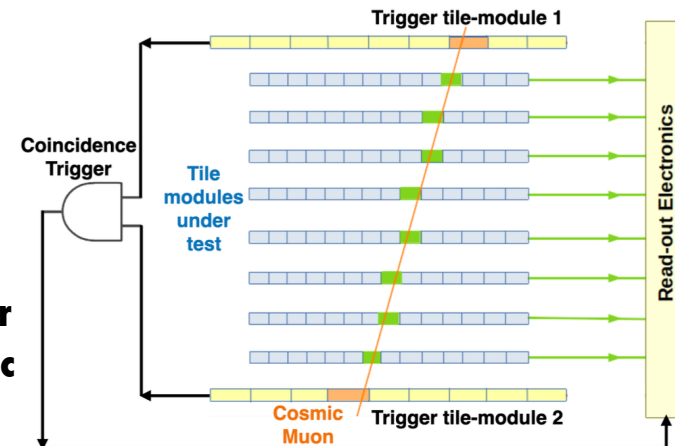- Perform handling tests before and after thermal cycling

Electrical validation
- Verify registers and pedestals
- Verify charge injection functionality
- Verify SiPM response to LED light
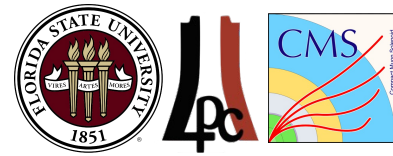- Cosmic ray runs of 24-48 hours using multi-module test stand at room temperature
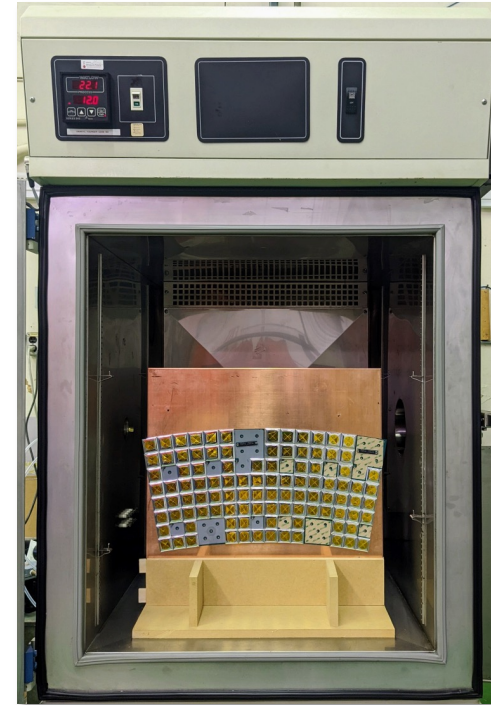
Thermal cycling trial in the oven

**Schematic sketch for multi-module cosmic ray test stand**

Summary & Outlook

- The HGCAL is first of its kind "imaging calorimeter" using state-of-the-art technologies, promising high performance for the HL-LHC era with 5D calorimetry of particle energy measurement, precise timing, and fine spatial granularity

- Fermilab has leading roles in building this detector, including in tile module assembly

- The pick-and-place machine hardware and machine vision software that will be used for assembly, as well as post-assembly QC plans, are being developed & optimized

- Production is expected to begin in 2024!

Thank you!

Additional Material

Tile Module Assembly Procedure
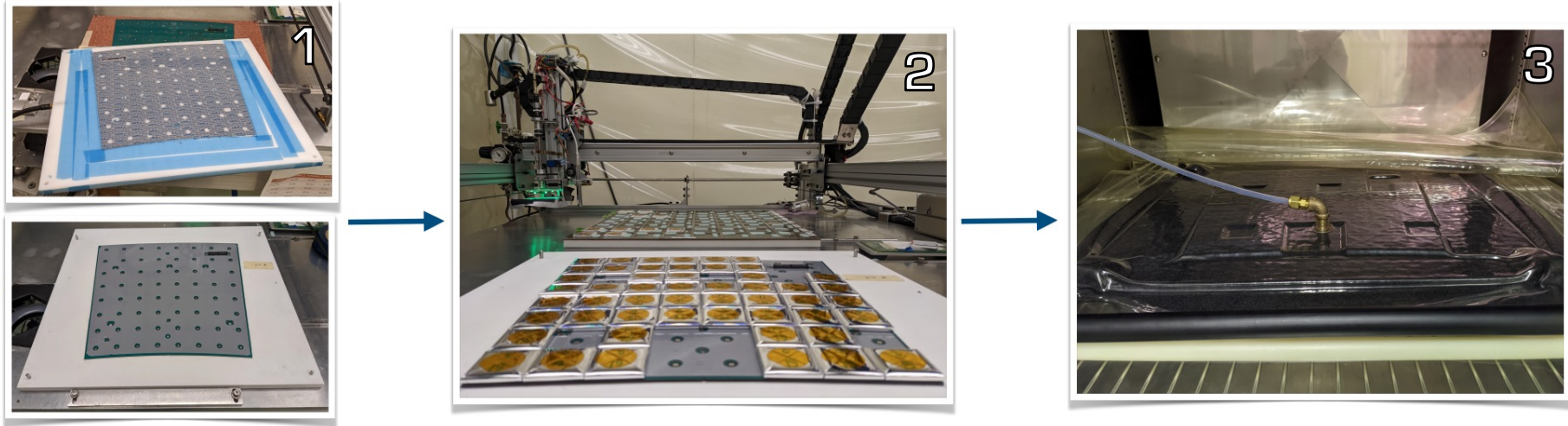
1) Adhesive material is placed on tileboard using a vacuum jig
2) Pick-and-place machine places tiles on the tileboard
- Tiles are taken from tile tray
- Correct size & orientation are verified using the vision system
- Tiles are placed on the tileboard with an accuracy of ~50 μm in its assigned location

3) The tile module is transferred to a vacuum bag and cured in an oven for bonding strength of the adhesive material
4) Completed tile modules are then protected by cover plates

(Old) Video of PnP Machine in Operation
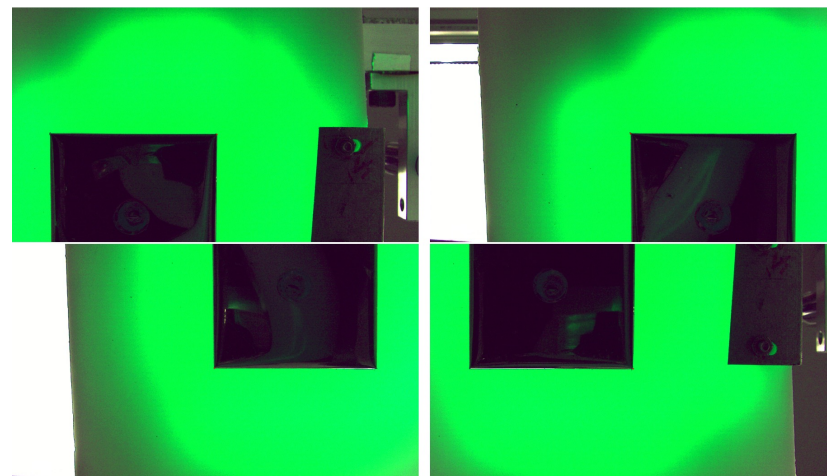
Pick-and-Place Machine Software

- Our forked [repository](#) is based on OpenPnP software — branches for testing & optimizing
- We take contours from tile images and apply *least-squares fit*
- Single-shot quick in-situ tile dimension & orientation check
- Multi-shot takes shot of each corner, better precision expected but slower
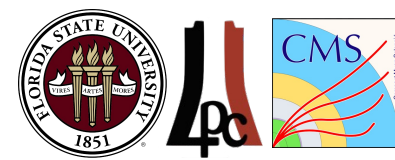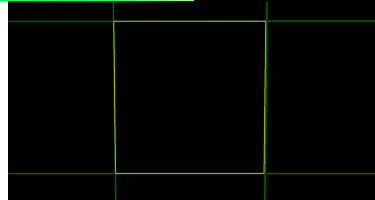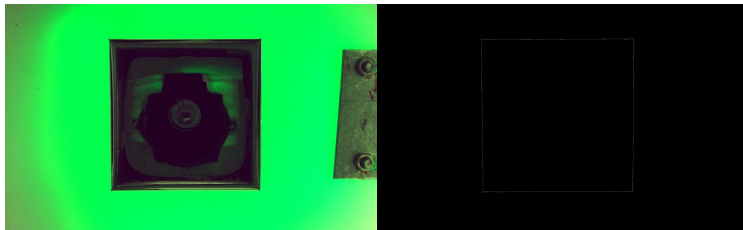
Single-shot machine vision on tile

Reconstructed trapezoid

Multi-shot machine vision on tile
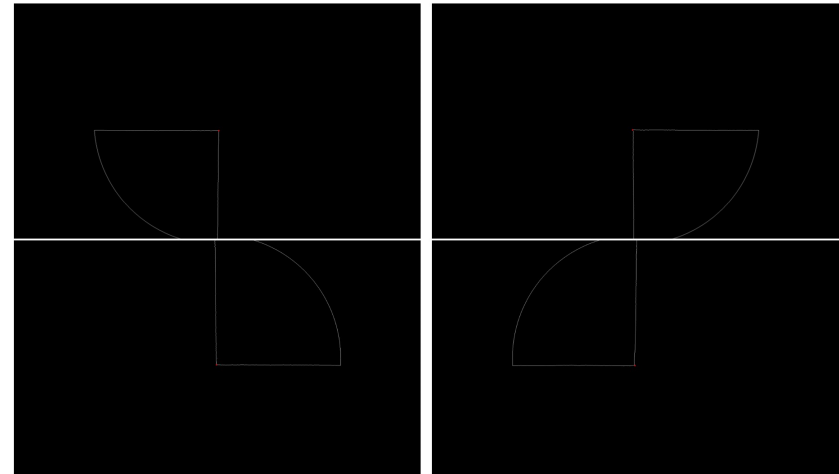
Pick-and-Place Machine Software

- Our forked [repository](#) is based on OpenPnP software — branches for testing & optimizing
- We take contours from tile images and apply *least-squares fit*
- Single-shot quick in-situ tile dimension & orientation check
- Multi-shot takes shot of each corner, better precision expected but slower
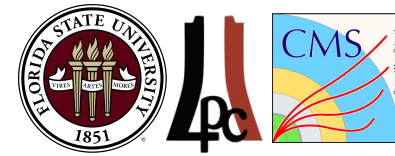
Single-shot machine vision on tile

Reconstructed trapezoid

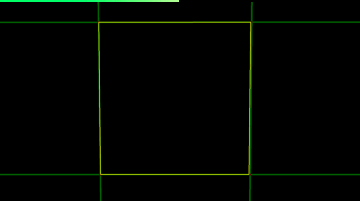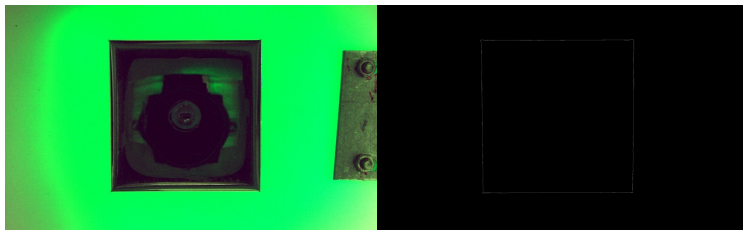**Multi-shot machine vision on tile**

Pick-and-Place Machine Software

- Our forked [repository](#) is based on OpenPnP software — branches for testing & optimizing
- We take contours from tile images and apply *least-squares fit*
- Single-shot quick in-situ tile dimension & orientation check
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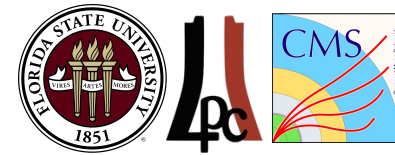
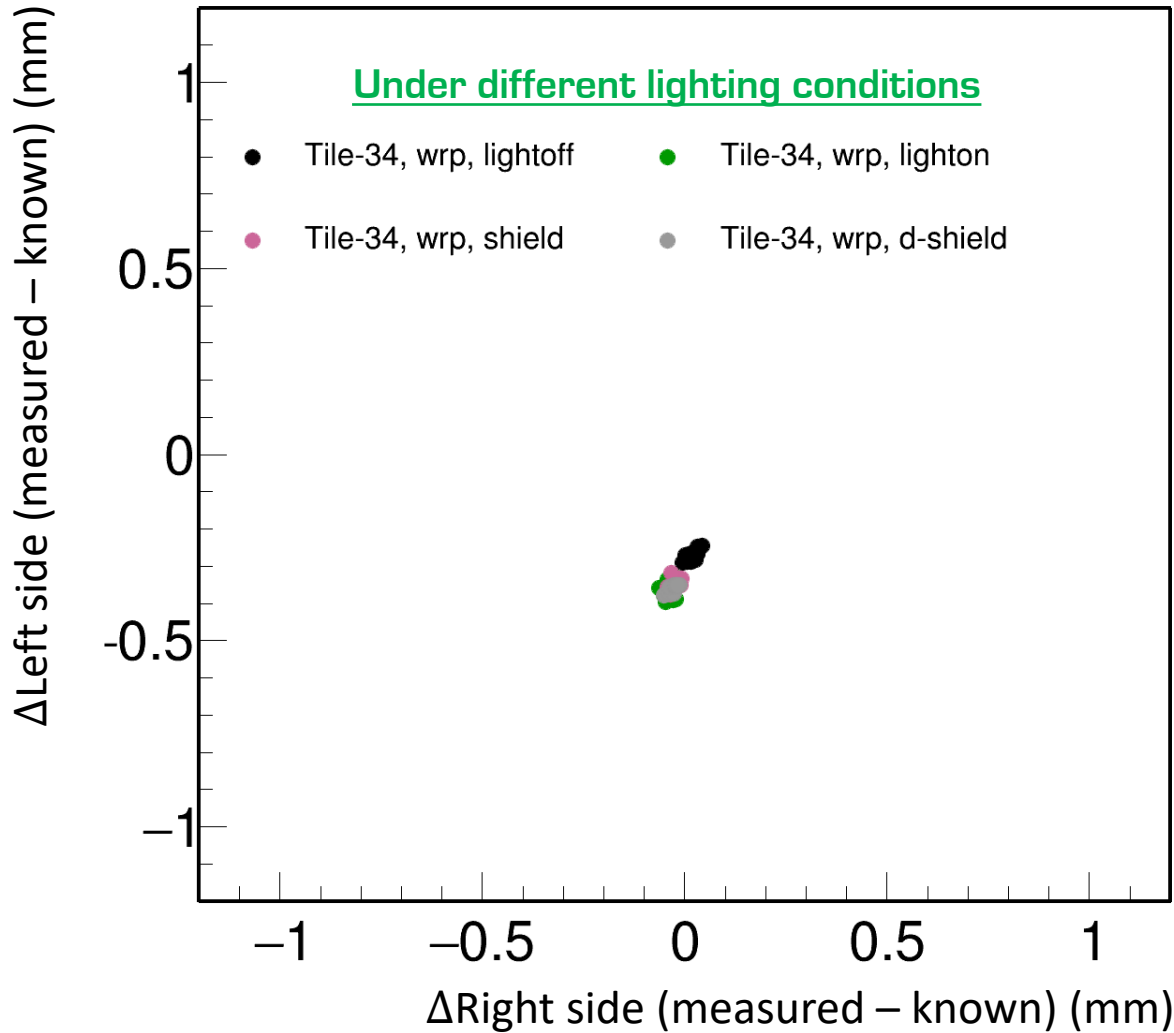**Single-shot machine vision on tile**

Reconstructed trapezoid

**Multi-shot applying least-squares fit
(y-axis flipped and not to scale)**
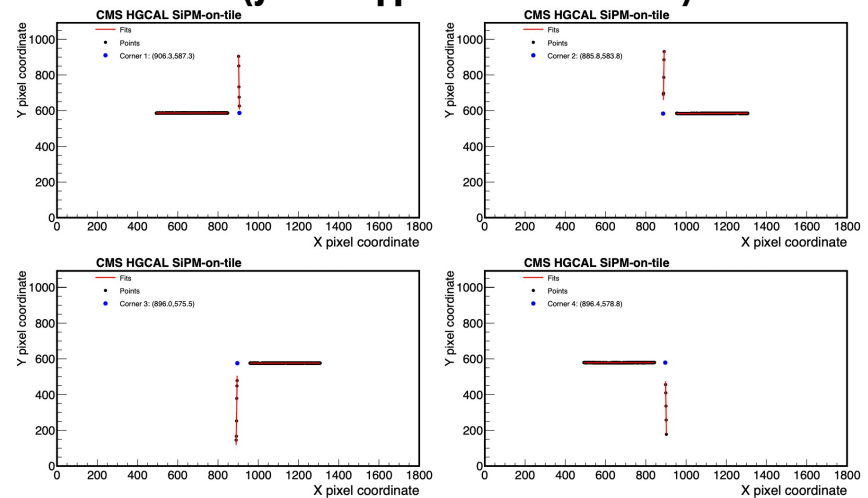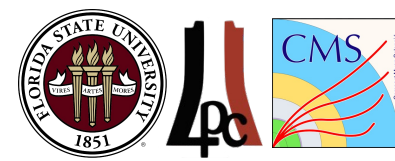
PnP Machine Vision Performance

CMS HGCAL SiPM-on-Tile

Our machine vision is very stable and reproducible!

Recent PnP Machine Move to NIU

- One machine at NIU not for tile module assembly, but for *wrapped tile size QC* — same vision system ensures no surprises before assembly!

- Constructed at Fermilab, with operational readiness clearance

- Moved to NIU on Nov 17; calibration & commissioning ongoing

The move in a few pictures...