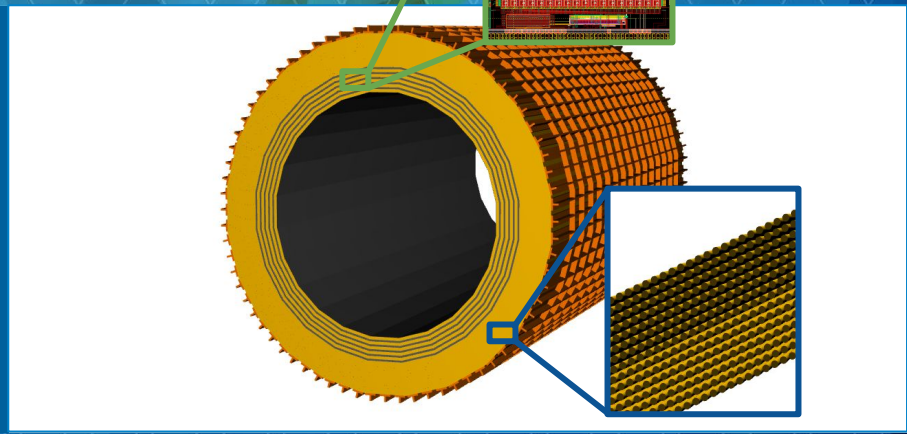
ePIC Collaboration Meeting

January 10, 2024



Barrel Imaging Calorimeter (BIC)
INTRO AND FORMAT

Sylvester Joosten
Argonne National Laboratory

Why electromagnetic calorimetry at EIC is hard

From the EIC Yellow Report: stringent barrel ECal requirements

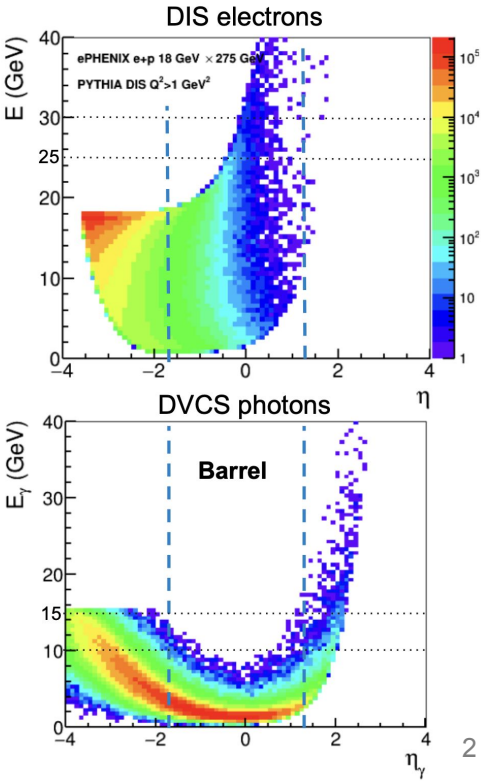
EIC is an **electron scattering** machine and identifying scattered electrons mainly depends on the electromagnetic calorimetry.

The electromagnetic calorimeter is the main detector for **electron-pion separation**. The inclusive physics program requires up to 10^4 pion suppression at low momenta in the barrel.

The exclusive program requires **decent energy resolution** (< $7\%/\sqrt{E} \oplus$ 1-3%) **for photon energy reconstruction, and also the fine granularity for good** π^0-ɣ separation up to 10 GeV.

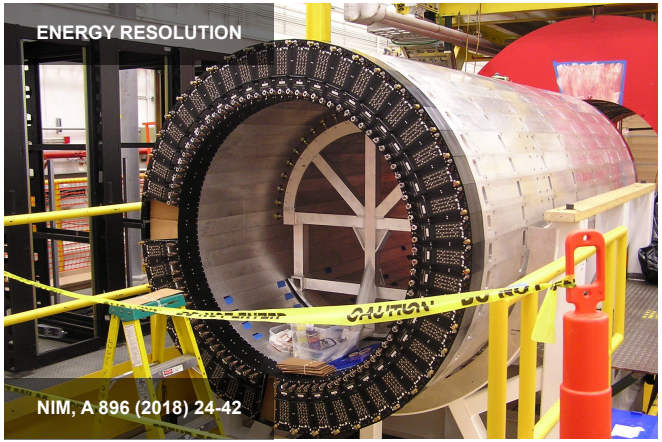
The bECal should be capable of measuring **low energy photons** down to 100 MeV, while having the range to measure energies well above 10 GeV

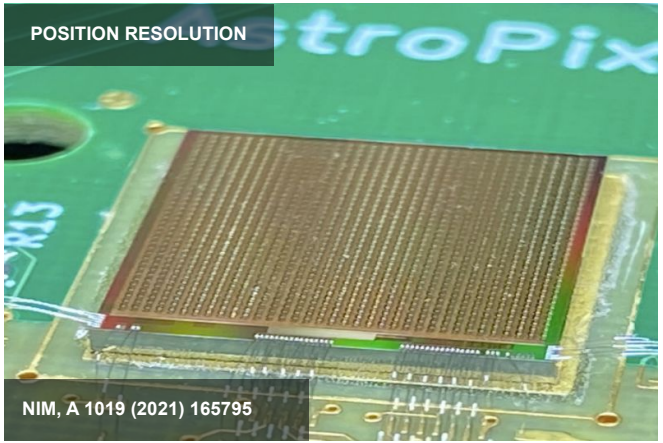
The system is space-constrained to very **limited space** inside the solenoid.



CONCEPT: A HYBRID IMAGING CALORIMETER

Combination of a high-performance sampling calorimeter with inexpensive silicon sensors for shower profiling



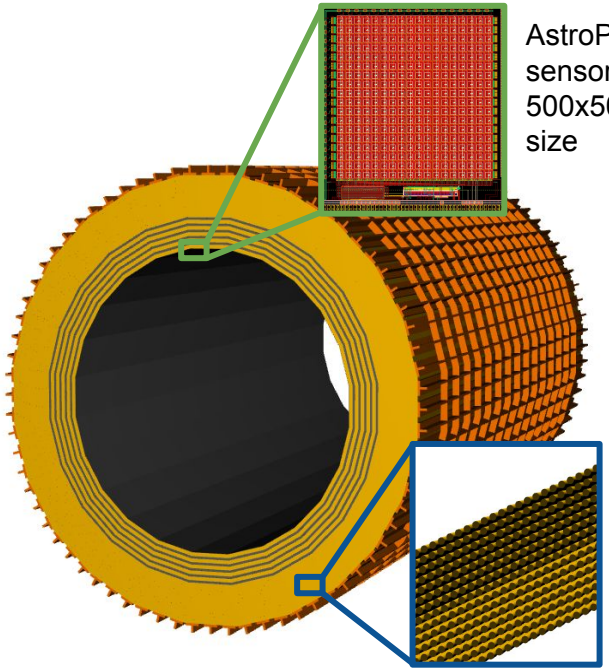


Start from mature layered Pb/ScFi technology with side-readout (same as the GlueX calorimeter) for state-of-the-art sampling calorimeter performance

Insert layers of monolithic AstroPix sensors (inexpensive ultra-low-power silicon sensor developed for NASA) in the first half of the calorimeter to capture a 3-D image of the developing shower

General Overview

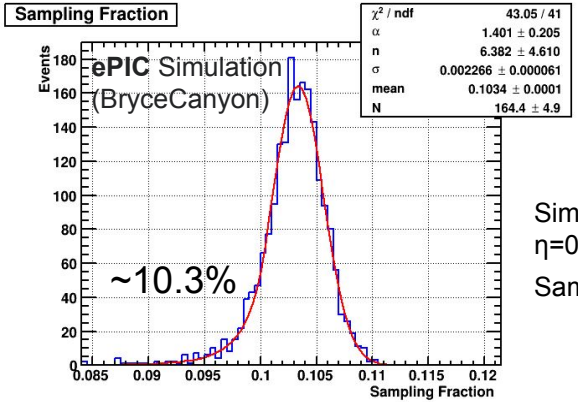
BARREL IMAGING CALORIMETER (BIC)



AstroPix: silicon sensor with 500x500μm^2 pixel size

ScFi Layers with two-sided SiPM readout

- **4(+2) layers of imaging Si sensors** interleaved with **5 Pb/ScFi layers**
- Followed by a **large section of Pb/ScFi section**
- Total radiation thickness > 17.1 X_0
- Sampling fraction ~ 10%



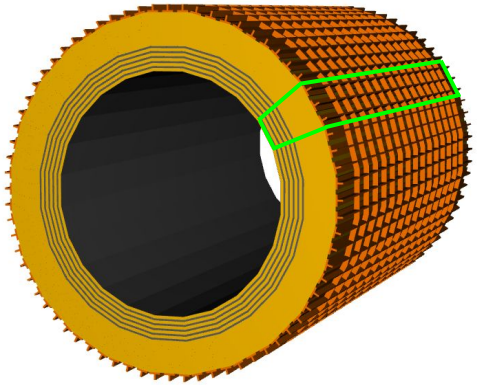
Simulation of **single photons** at η=0 (~17.1 X_0)

Sampling fraction = ΣE_{fibers} / E_{thrown}

Energy resolution - Primarily from Pb/ScFi layers (+ Imaging pixels energy information)
Position resolution - Primarily from Imaging Layers (+ 2-side Pb/ScFi readout)

Components

BARREL IMAGING CALORIMETER (BIC)

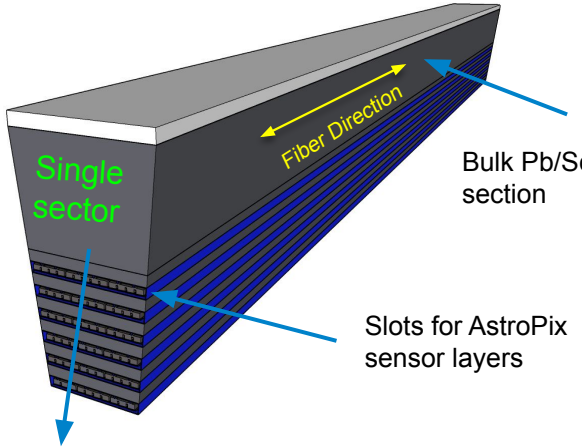


Length: 432.5 cm

Radius: ~ 80 cm radius,

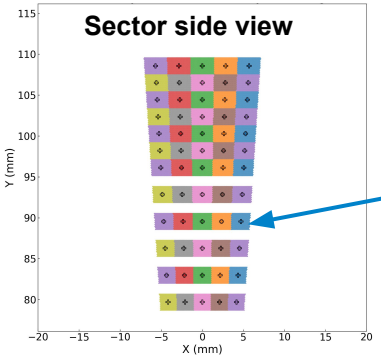
Structure: 48 sectors

η Range: -1.71 < η < 1.31



Bulk Pb/SciFi section

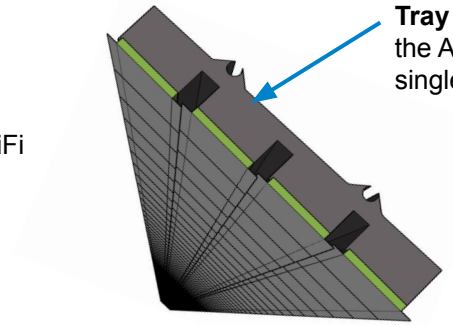
Slots for AstroPix sensor layers



Pb/SciFi **Layer** - 12 layers per sector

Structure: 5 readout cells (one light-guide per readout cell)

Construction: 17 rows of fiber

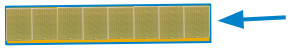


Tray - Structure holding the AstroPix staves for a single layer

Length: ~ 200 cm (half length)

Structure: 6-7 “turbofanned” staves per tray

Stave Structure: ~ 13 **Modules** per stave



Length: ~ 16 cm

Width: ~ 2 cm

Gaps: < 200 μm

Structure: ~ 8 chips/module

Module - Several AstroPix chips daisy-chained together on Flex PCB

AstroPix Development Schedule

Not shown:
Early CD4 (Oct 2032)
CD4 (Oct 2034)

We are here

FY19 FY20 FY21 FY22 FY23 FY24 FY25 FY26 FY27 FY28 FY29

Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3

- AstroPix v1: Design & Fabr. | Test
- AstroPix v2: Design & Fabr. | Test
- AstroPix v3: Design & Fabr. | Test | Test
- AstroPix v4: Design & Fabr. | Test
- AstroPix v5: Design & Fabr.
- AstroPix v5 (production): Production Fab.

v3 has comprehensive test program: benchtop and testbeam, irradiation, quad-chip readout for NASA payload mission (A-STEP), integration with Pb/SciFi for ePIC (R&D studies and test article production)

first v5 wafers used for preproduction

Start of production driven by project fund availability (estimated ~ 1 year after CD2/3)

EIC Project Milestone
New AstroPix version

ePIC BIC Timeline

- Design and generic R&D
- Final design and EIC R&D
- BIC Preproduction
- BIC Production

CD0 CD1 CD3a CD3b CD2/3

Start of BIC installation at BNL

AstroPix v1

HV-CMOS MAPS based on ATLASPix3, designed for the AMEGO-X NASA mission, optimized for power dissipation and energy resolution
Nucl.Instrum.Meth.A 1019 (2021) 165795

0.45 x 0.45 cm^2 chip, 175 µm pixel pitch
18 x 18 pixel matrix
Power dissipation 14.7 mW/cm^2

AstroPix v2

1 x 1 cm^2 chip, 250 µm pixel pitch
35 x 35 pixel matrix
Row/column readout
Power dissipation 3.4 mW/cm^2

AstroPix v3

First full-size chip

2 x 2 cm^2 chip, 500 µm pixel pitch
Row/column readout
Power dissipation <1 mW/cm^2
2.5 MHz timestamp, 200 MHz ToT

AstroPix v4

Final design but smaller size

1 x 1 cm^2 chip, 500 µm pixel pitch
Individual pixel readout
3 timestamps, 3.25ns time resolution
TuneDAC for pixel-by-pixel thresholds

AstroPix v5

Full-size production chip

2 x 2 cm^2 chip, 500 µm pixel pitch
Design identical to v4 (with bug fixes)

PB/SCFI TECHNOLOGY

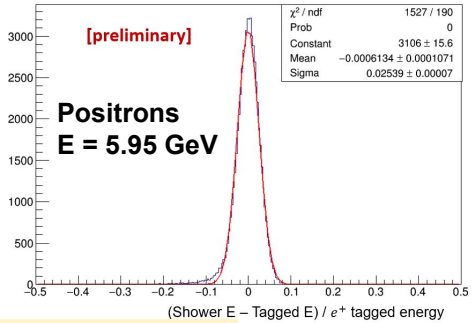
Our Pb/ScFi layers follow the GlueX Design

- Mature Technology: **GlueX**, KLOE electromagnetic calorimeters
  - Detailed studies on **calorimetry performance**, including the light collection uniformity in fibers, light collection efficiencies, etc.
  - **Module construction** (lead handling, swaging, Pb/ScFi layers assembly, module machining) fully developed for GlueX
    Z. Papandreou, https://halldweb.jlab.org/DocDB/0031/003164/
  - Assembly and installation of self-supporting barrel based on GlueX experience
- Tested extensively for electromagnetic response in energies $\mathbf{E_\gamma < 2.5\ GeV}$
- **Energy resolution:** $\sigma = 5.2\% / \sqrt{E} \oplus 3.6\%$ [1)]
  - 15.5 X_0, GlueX could not constrain the constant term due to low energies
  - New results from Hall D beam tests show that constant term < 2%

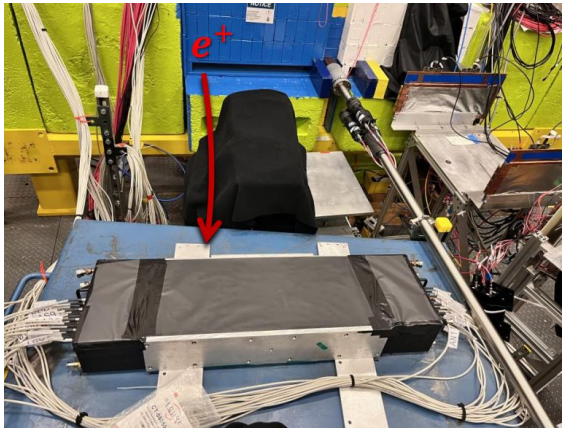
March 2023 beam test

Measured Resolution: ~ 2.5%

Extrapolated GlueX NIM[1)]: ~4.2%



Trends well below a 2% constant term!



Baby BCAL
60 cm long
15.5 X0

tested with e+
E ~ 3.6-6 GeV

1) GlueX, Nucl. Instrum. Meth. A, vol. 896, pp. 24–42, 2018

USA

Argonne National Laboratory

NASA Goddard Space Flight Center

Oklahome State University

University of Connecticut

University of California Santa Cruz

Canada

University of Manitoba

University of Regina

Mount Allison University

NSERC

Canada Fund for Innovation

Korea

Kyungpook National University

Yonsei University

University of Seoul

Pusan National University

Korea University

Sungkyunkwan University

Hanyang University

Gangneung-Wonju National University

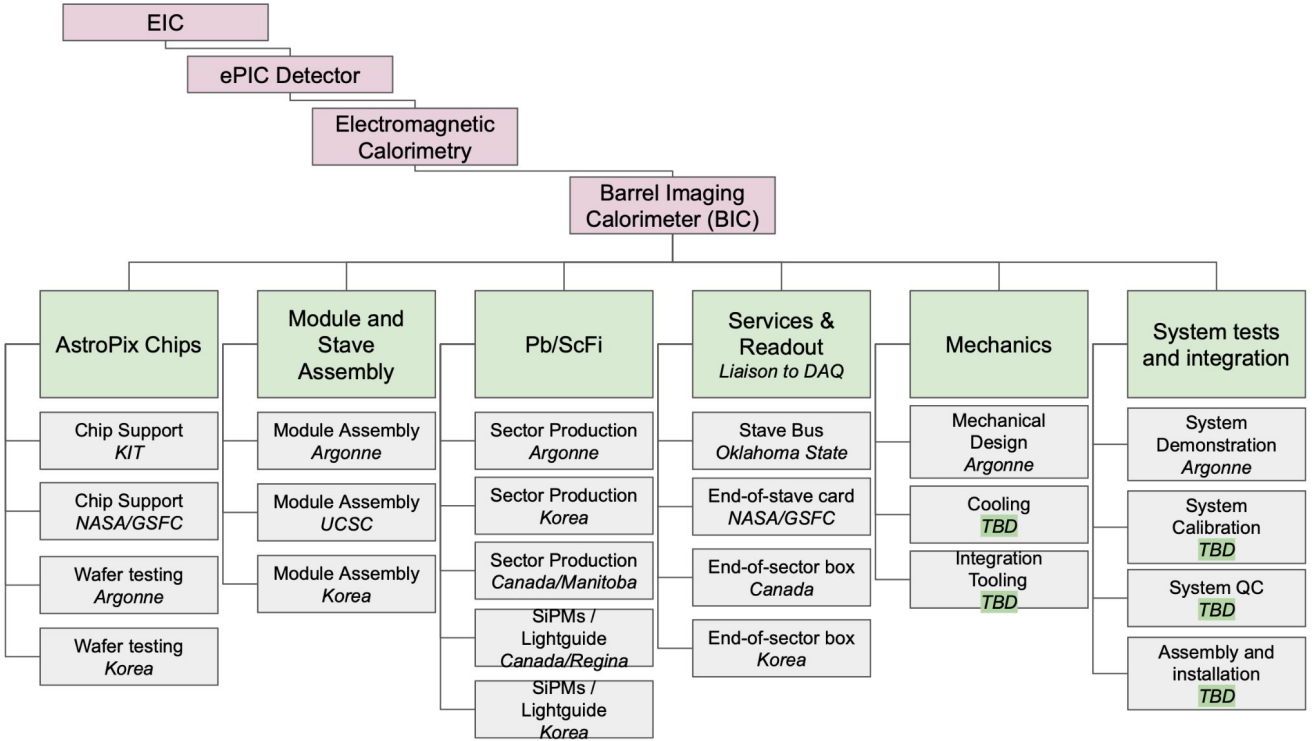
Germany

Karlsruhe Institute of Technology

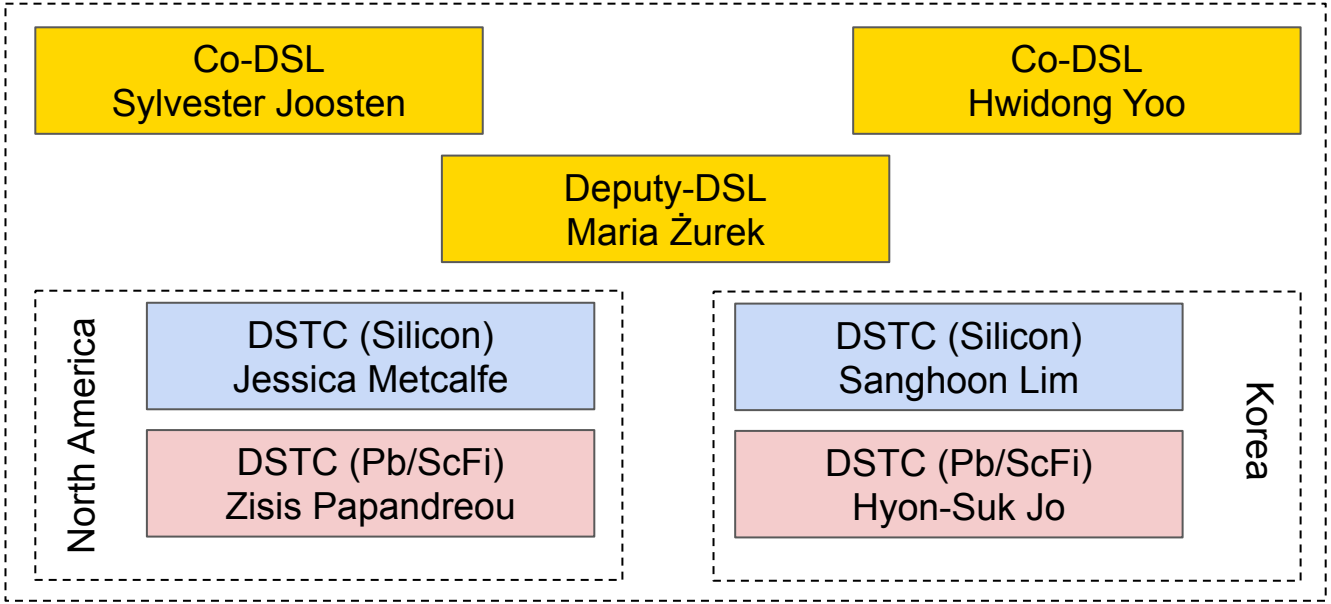
University of Giessen

ePIC BIC Detector Subsystem Collaboration

WBS ORG CHART



BIC DETECTOR SUBSYSTEM COLLABORATION



UPDATES

What happened since our Workshop in June?

- **July**: BIC detailed bottom-up budget provided to Project
- **August**: Pb/ScFi cosmics at JLab, and ScFi/SiPM tests and simulations
- **September**:
  - SiPM and Pb/ScFi Final Design Reviews for CD3a
  - Notice of Decision for BIC formally signed and posted
  - Received AstroPix v4 chip
- **October - November**:
  - Global engineering and integration with Project engineers
  - EIC CD3a Director's and OPA reviews
- **December - January**
  - Organize Project Engineering and Design (PED) work, first SoWs sent to the Project last week
  - Simulation studies to support technology choices, prepare EIC R&D tests
  - Prepare for CD3a LLP
- … And much more!

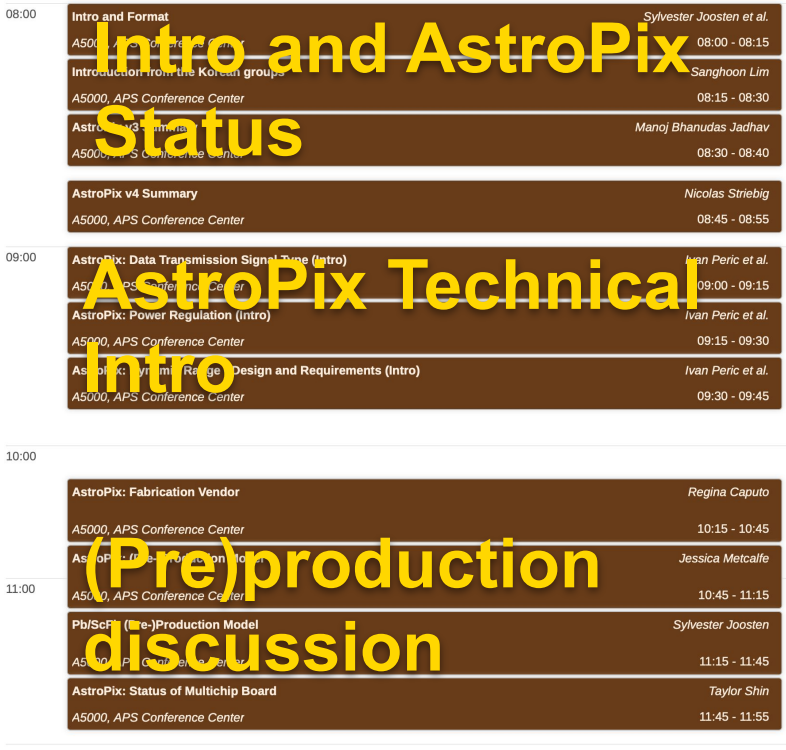
MEETING FORMAT

What do we want to accomplish with this meeting?

- Capitalize on having many key people here in person, so favor discussion over presentation
  - Targeted technical discussions on key items, such as technical discussions on the AstroPix sensor, the Pb/ScFi LLP items, Readout, Mechanical Design
  - For many of our technical discussion, we have short intro talks, followed by a discussion later, sometimes even the next day (to allow for homework)
  - Today we have an important conversation about our PED work and TDR readiness
- Secondary goal: Get everyone on the same page about the detector status and planning

We are time constrained so let's all try to keep the session on topic

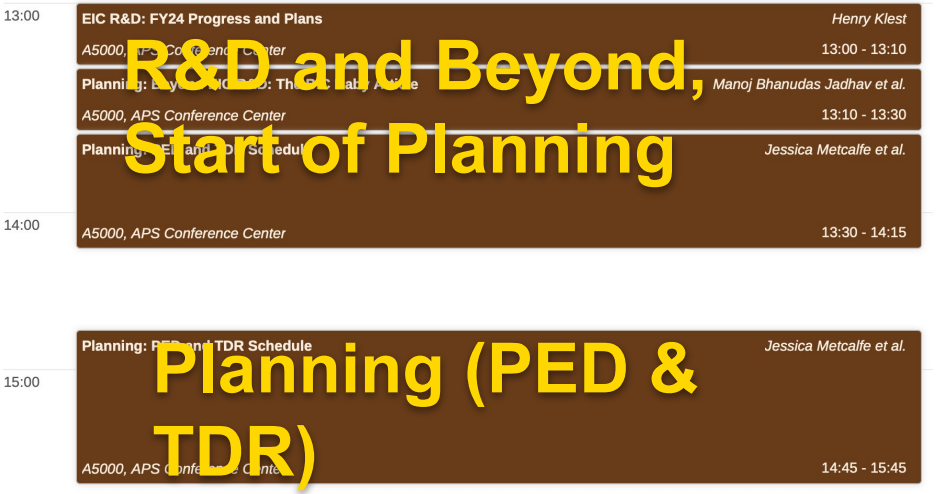
SCHEDULE: DAY 1 (WEDNESDAY)



Intro and AstroPix Status

AstroPix Technical Intro

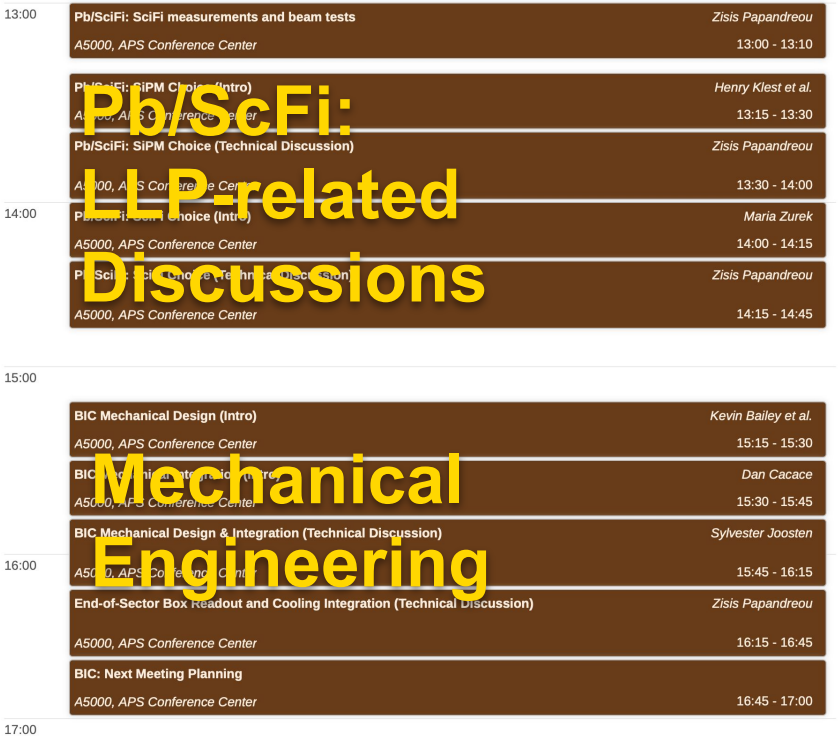
(Pre)production discussion



R&D and Beyond, Start of Planning

Planning (PED & TDR)

SCHEDULE: DAY 2 (THURSDAY)




Let’s have a productive BIC meeting!