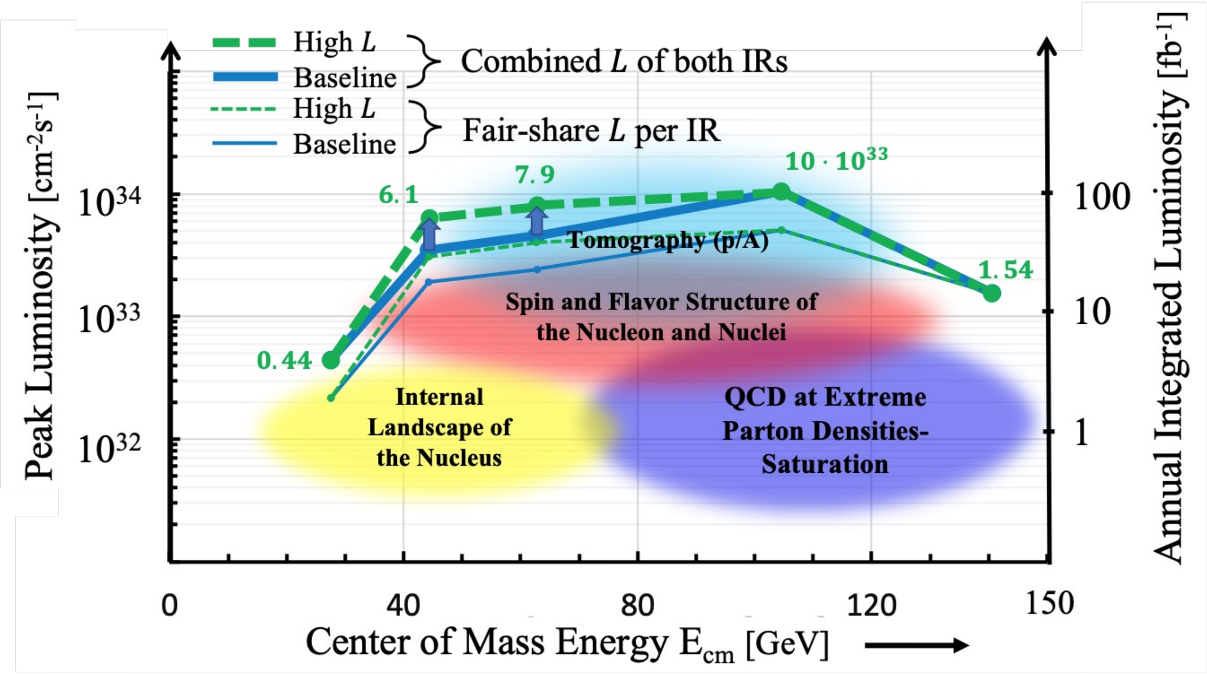
HRPPDs for ePIC Cherenkov detectors

Alexander Kiselev (BNL)

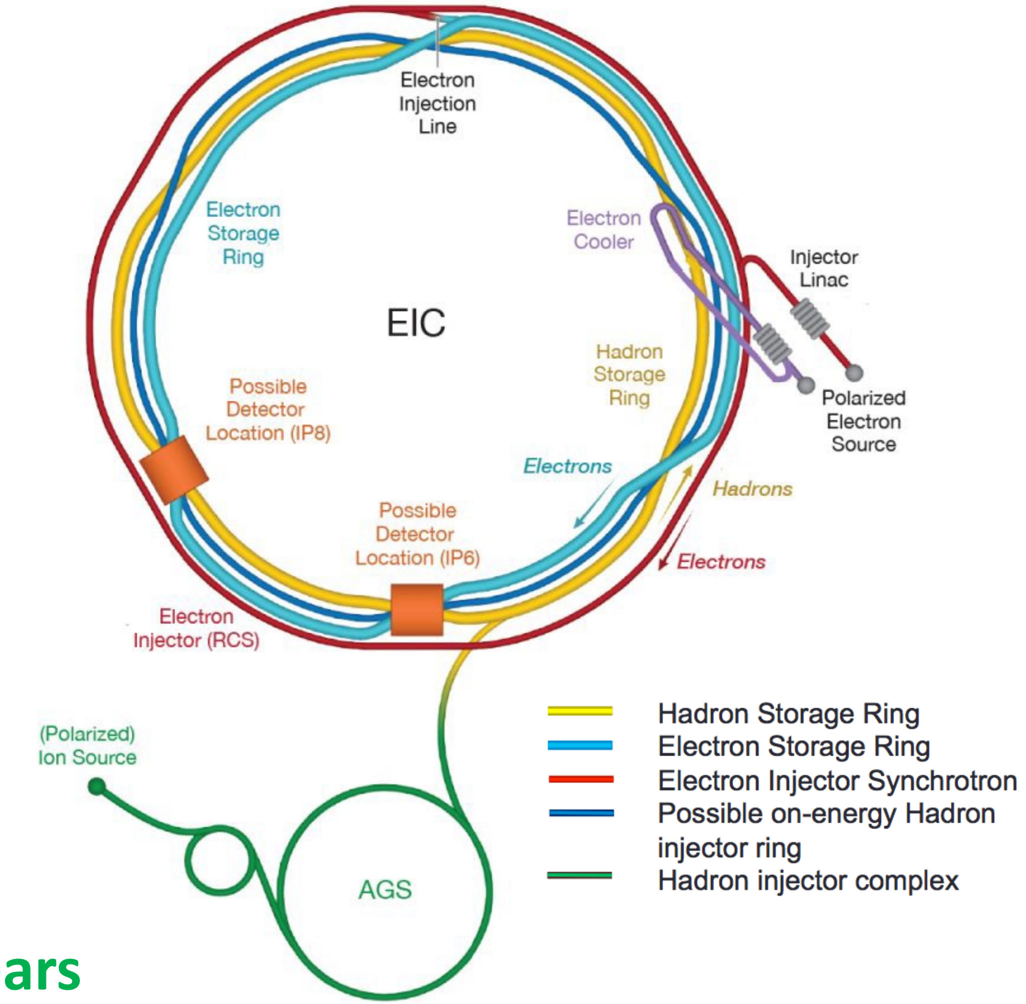
LAPPD Workshop #3, April 20, 2023

EIC, ePIC & HRPPDs

Electron-Ion Collider at Brookhaven



- Re-use one of the RHIC hadron rings
- Build a new general purpose detector in IP6



- Electron & proton beams with >70% polarization
- Ion beams, up to U
- Center-of-mass energy range $\sqrt{s}$ ~ 20 – 140 GeV
- Luminosity 100 … 1000 times compared to HERA
  - up to 100 fb^{-1} / year

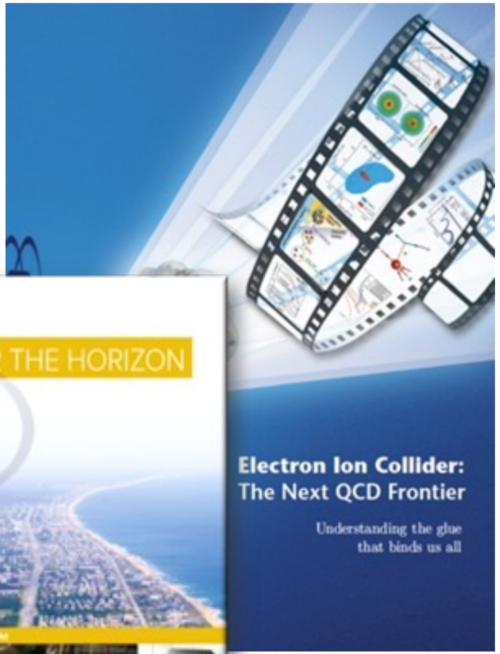
Start of construction in ~2 years

EIC science case

Assessment of US-based Electron-Ion Collider:
(National Academy of Science Report, 2018)

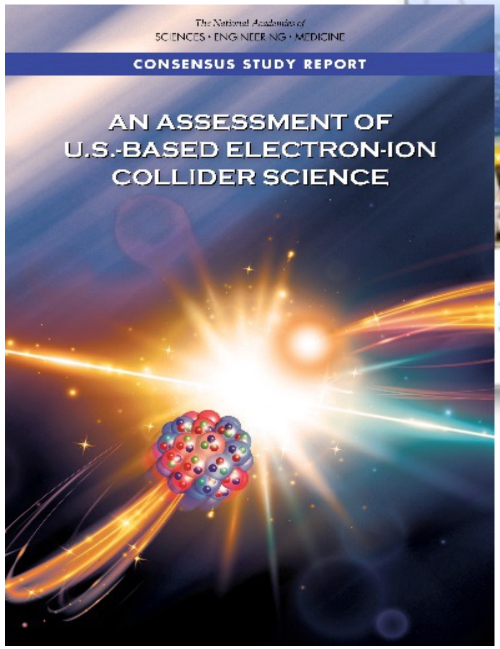
“An EIC can uniquely address three profound questions about nucleons - neutrons and protons - and how they are assembled to form the nuclei of atoms:

- ***How does the mass of the nucleon arise?***
- ***How does the spin of the nucleon arise?***
- ***What are the emergent properties of dense systems of gluons?”***



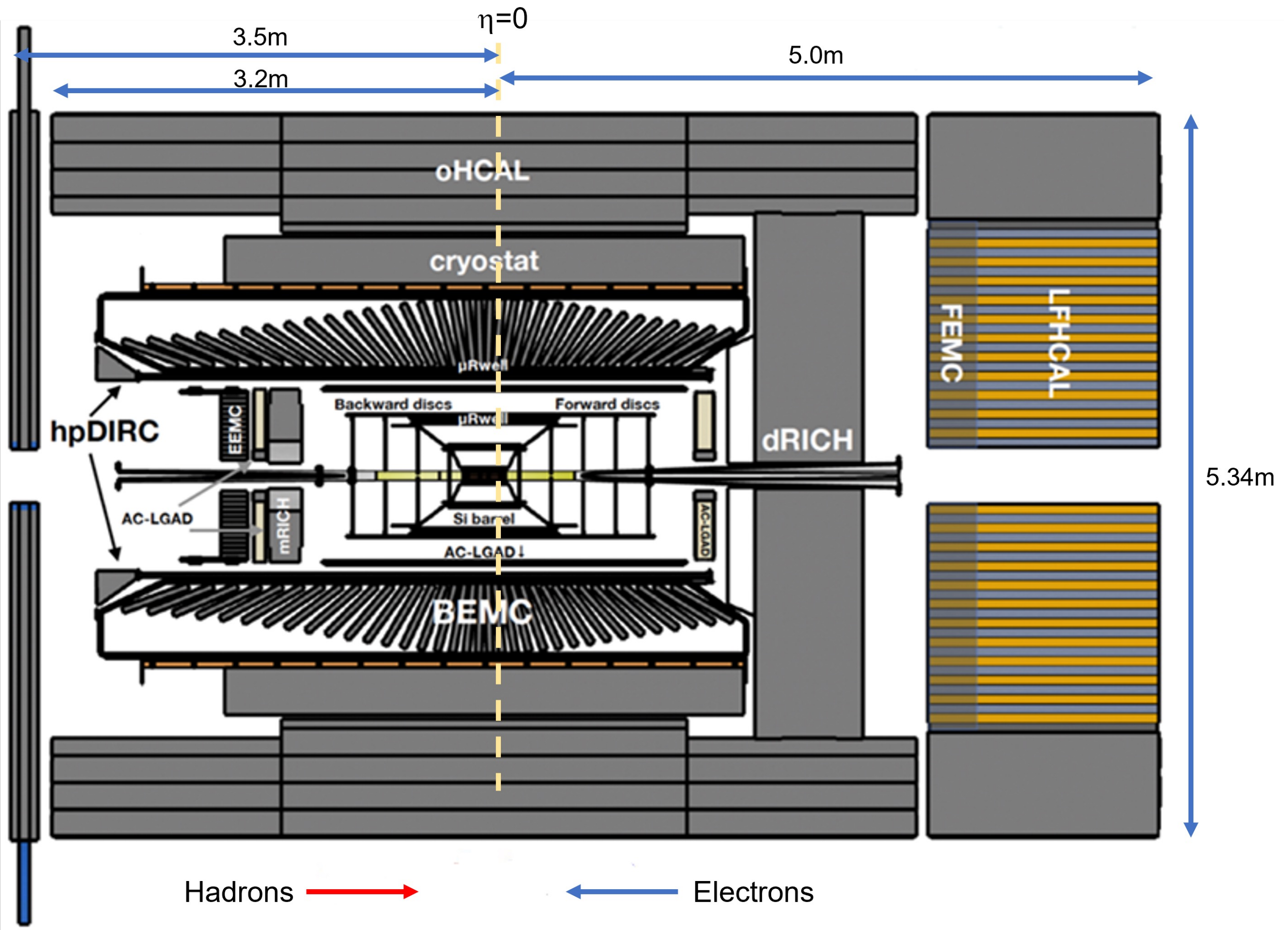
2012

2015



2018

ePIC: EIC general purpose detector @ IP6



Tracking:
- New 1.7 T solenoid magnet
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

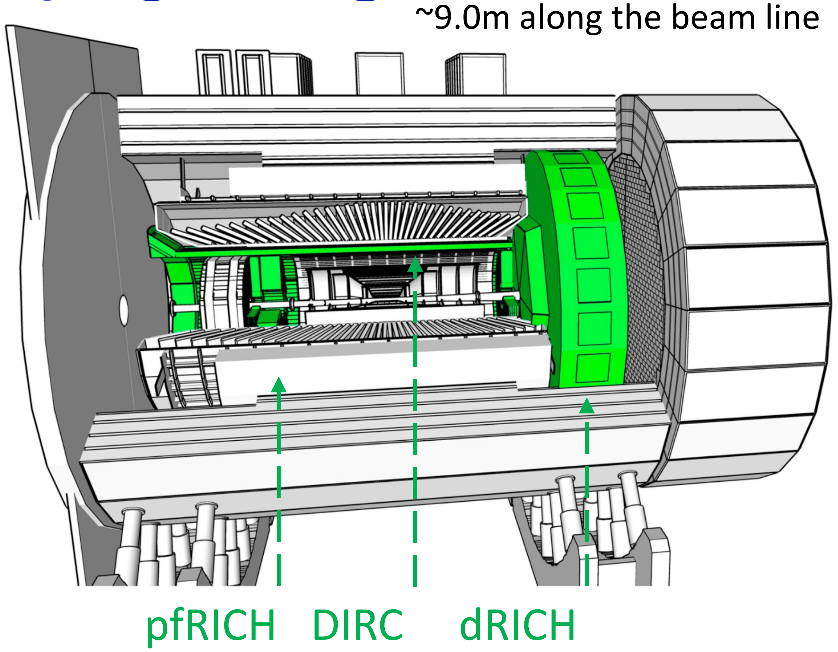
Calorimetry:
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal + HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

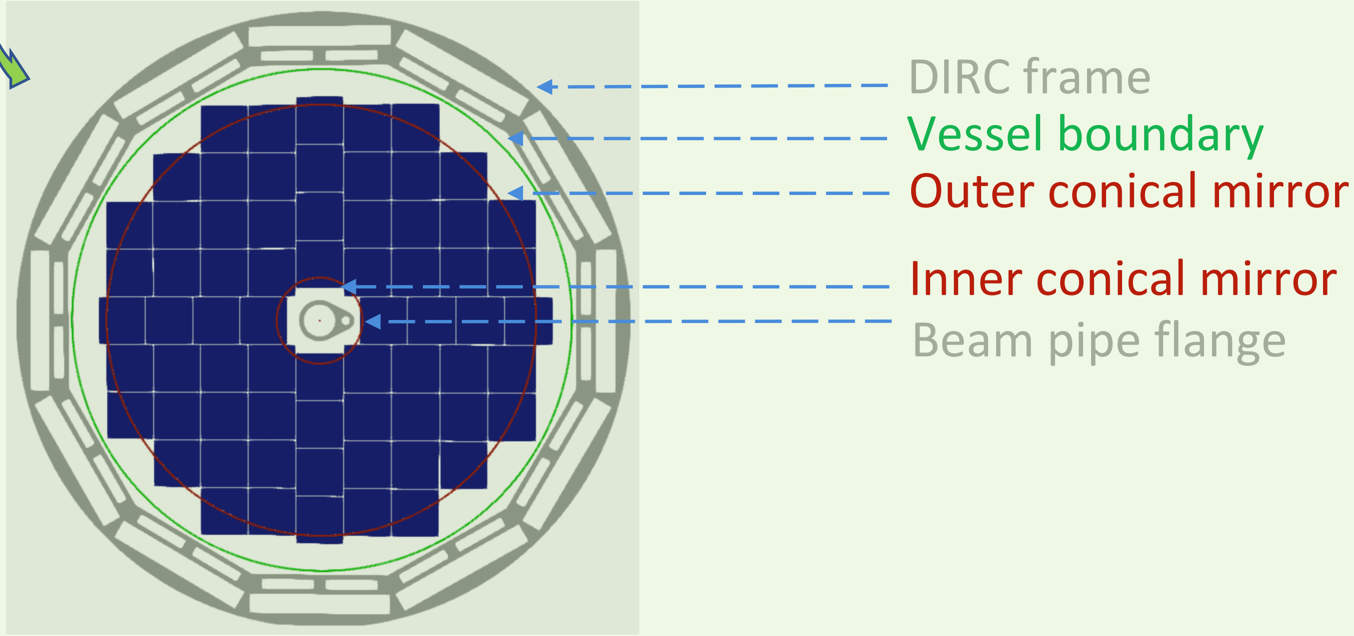
- A compact central detector with several subsystems
  - <9 m along the beam line
  - (Almost) hermetic coverage in tracking, calorimetry & PID $-3.5 < \eta < +3.5$

Possible LAPPD applications for the EIC

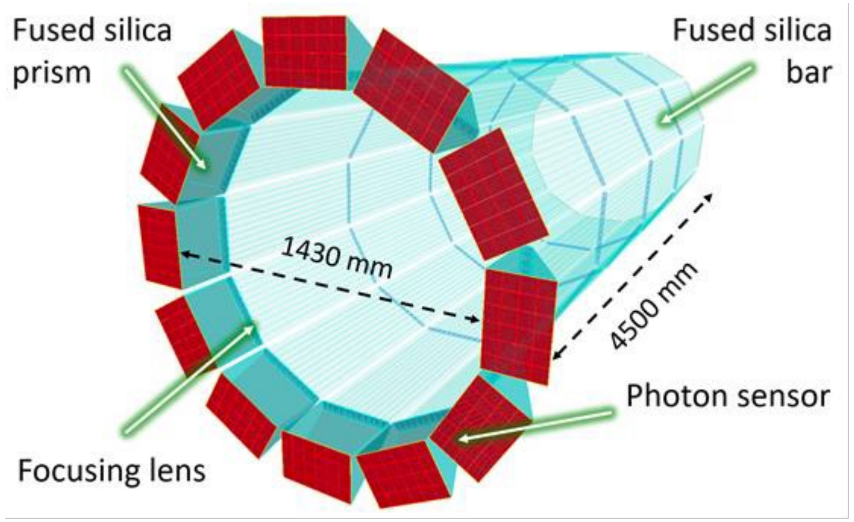
- Backward RICH: low dark noise, ToF capability (vs SiPMs)
  - LAPPD is a baseline photosensor as of November 2022
- DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- dRICH: problematic, because of the magnetic field orientation

Backward RICH	either DC-coupled or Gen II, 10cm formfactor
DIRC	DC-coupled, 10cm



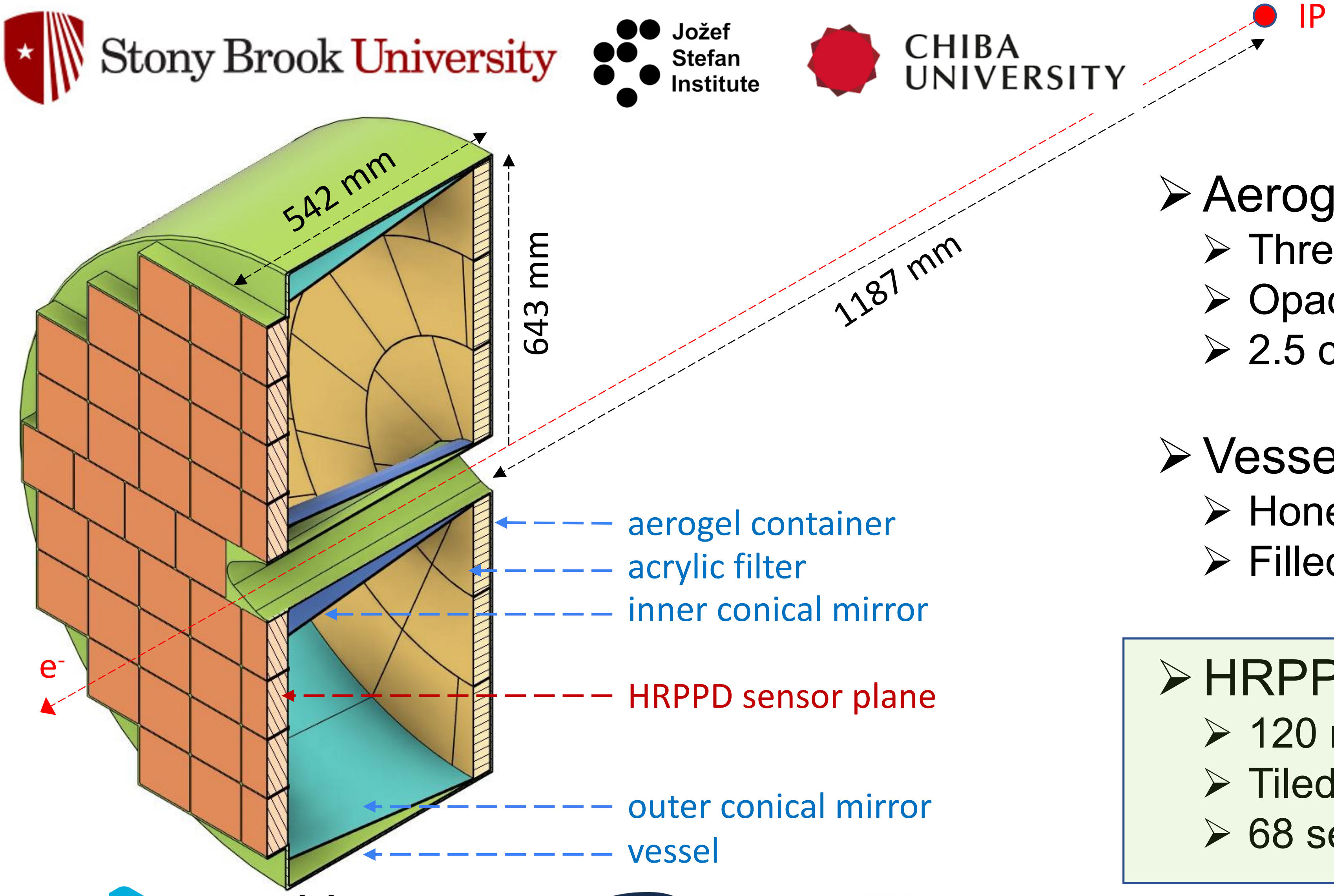


pfRICH sensor plane: 68 HRPPDs total



DIRC: 12*3*2 = 72 HRPPDs total

e-endcap RICH for ePIC detector



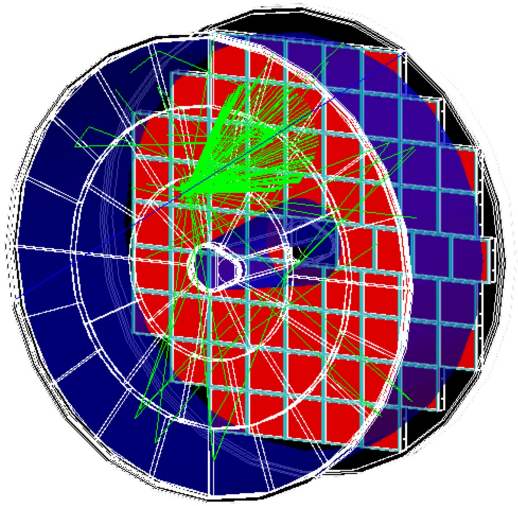
- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Honeycomb carbon fiber sandwich
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 1.5 mm gap
  - 68 sensors total

e-endcap RICH for ePIC detector

- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation above 3σ up to ~ 9.0 GeV/c and ~10-20ps t_0 reference with a ~100% geometric efficiency in one detector

- Will hopefully become a baseline detector for ePIC soon

A Proximity-Focusing RICH for the ePIC Experiment
– Conceptual Design Report –
(Draft 1.1)



Babak Azmoun[1], Deb Sankar Bhattacharya[2], Daniel Cacace[1], Helen Caines[3], Chandradoy Chatterjee[2], Jaydeep Datta[4], Abhay Deshpande[4], Christopher Dilks[5,6], James Dunlop[1], Alex Eslinger[6], Prakhar Garg[4,3], Tom Hemmick[4], Alexander Jentsch*,[1], Alexander Kiselev*,[1], Henry Klest[4], Samo Korpar[7], Peter Križan[7], Jeffery Landgraf[1], Saverio Minutoli[8], Charles-Joseph Naïm[4], Mikhail Osipenko[8], Brian Page*,[1], Sanghwa Park[9], Matt Posik[10], Rok Pestotnik[7], Andrej Seljak[7], Prashanth Shanmuganathan[1], Nikolai Smirnov[3], Bernd Surrow[10], Makoto Tabata[11], Silvia Dalla Torre[2], Zhoudunming Tu*,[1], Thomas Ullrich*,[1,3], Jan Vanek[1], Anselm Vossen[5,6], Craig Woody[1], and Zhengqiao Zhang[1]

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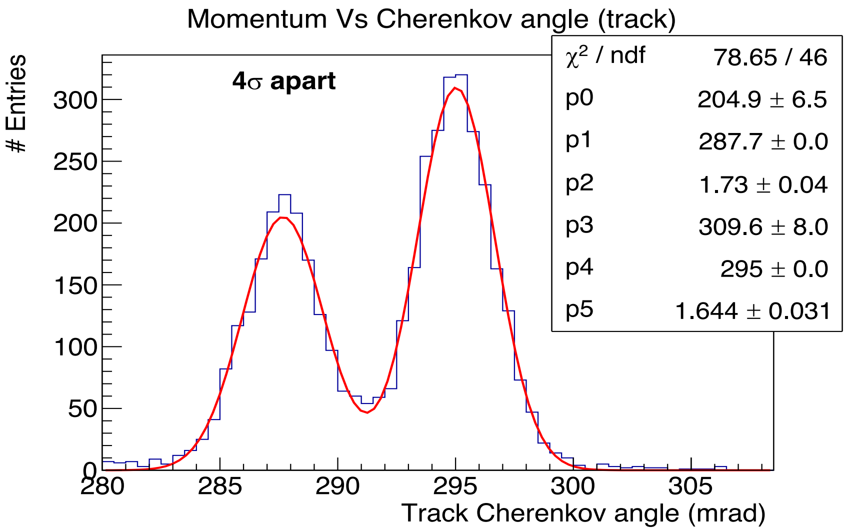
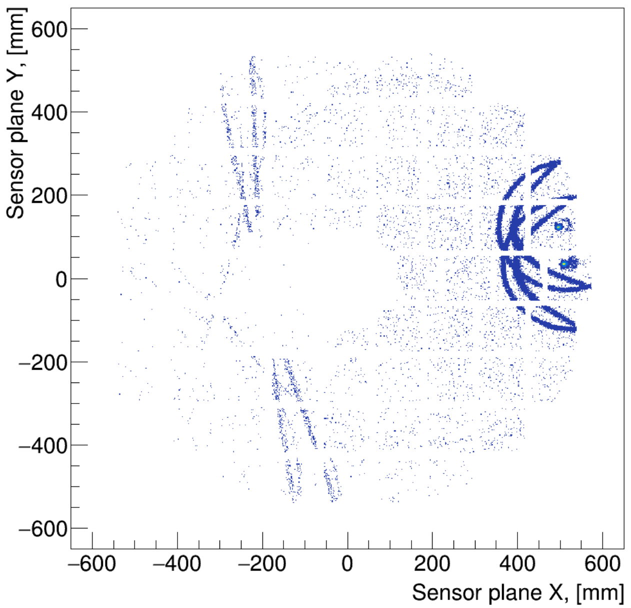
April 5, 2023



π & K: 7.25 GeV/c



7 GeV/c π and K @ η = -1.9: <5% misidentification rate
(plot accumulated over 1000 two-track events)

Open LAPPD R&D questions before CD-3

- We need to come up with a detailed assessment of the current state of the art and projected LAPPD photosensor performance, evaluate their potential use in various EIC PID detector subsystems, and assist Incom in modifying their existing product line to meet EIC requirements
  - Spatial resolution for Cherenkov imaging applications in a variety of fine pixellation schemes
  - Timing resolution in a single photon mode, for a selected subset of pixellation scenarios
  - Timing resolution for Time-of-Flight purposes
  - Performance in a strong (inhomogeneous) magnetic field

  - QE spectrum tuning and evaluation for ePIC detectors
  - Overall PDE and gain uniformity tuning and measurement
  - Geometric formfactor optimization

  - Prospects of integration in particular ePIC detector subsystems (together with the respective groups and / or consortia), as well as the on-board electronics integration

slide from the EIC Detector Advisory Committee review in October 2022

EIC leadership meeting with Incom Inc.

- Site visit on January 12, 2023
  - Facility tour
  - Half a day of discussions

- A “staged” EIC / Incom contract for the next ~12 months is in preparation:
  - Phase I: finalize remaining R&D to the extent needed (by September 2023)
    - Will be critical for the rest of the contract [some details given in Alexey’s talk]
    - Will to a large extent depend on the success of the “configurable LTCC pixellation” exercise
  - Phase II: procure 5 HRPPDs (September - February 2023)

  - “Phase III”: perform bench tests and beam test evaluation well ahead of the EIC CD-2 review
    - Winter 2023/2024: an optional “sensor-only” test at Fermilab
    - Late spring 2024: a pfRICH prototype test at Fermilab

ASIC choice and HRPPD / FEE integration model

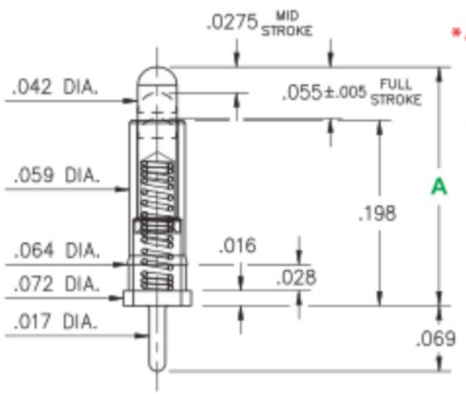
Integration attempt #1: pogo pins

Signal pogo pins: Mill Max 0908 series

#72 SPRING LOW FORCE SPRING	Full Stroke Capability : .055"± .005" [1,4 ± 0,127]
Spring Material : Beryllium Copper Alloy 172	Force @ Mid. Stroke : 45 g ± 20 g
Mid. Stroke : .0275" [0,7]	Initial Force (Pre-Load) : 15 g

0908-X-15-20-7X-14-11-0

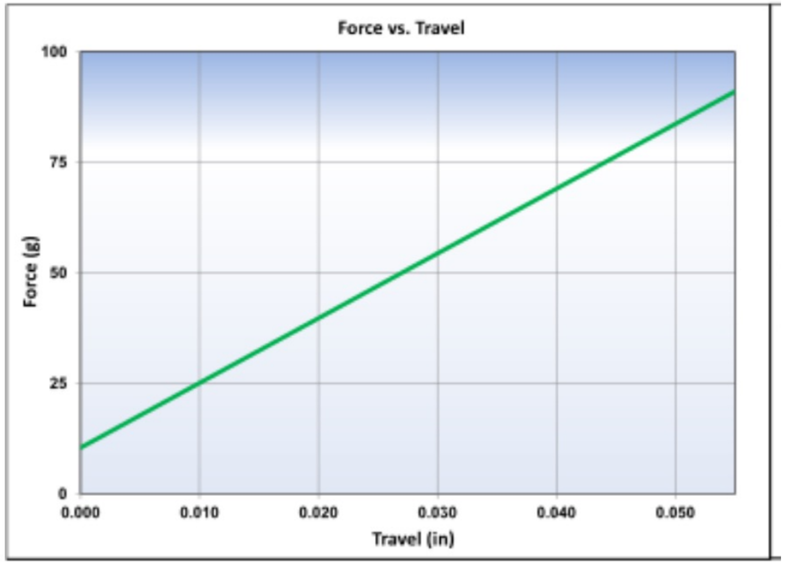
Standard stroke, Solder mount in .020 min. mounting hole

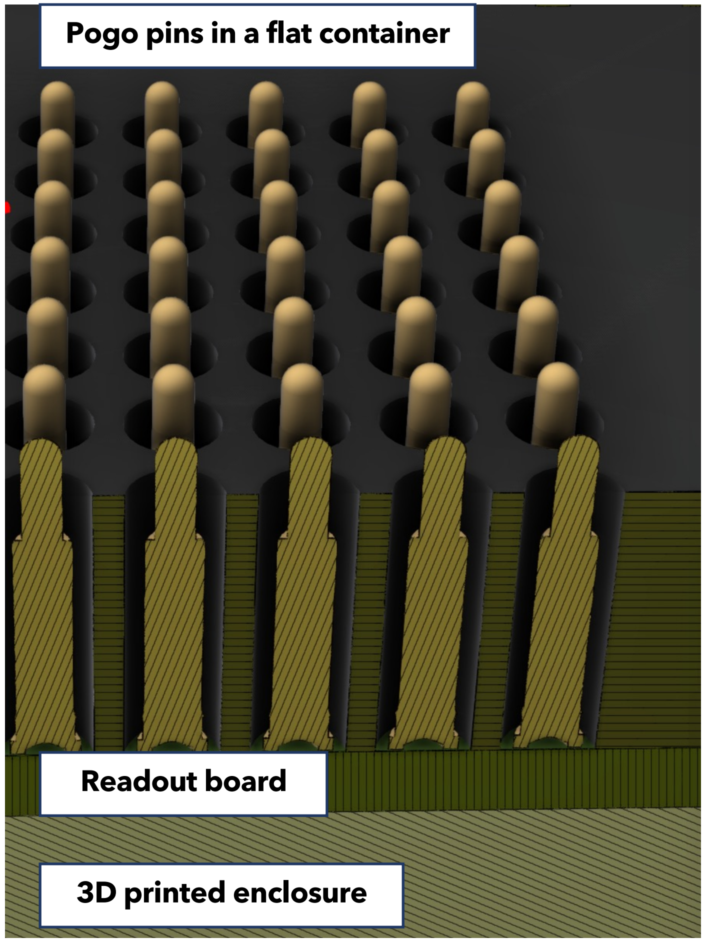


*Available packaged on Tape & Reel

Basic Part Number	Length (A)
0908-0	.255
0908-1	.275
0908-2	.295
0908-3	.315
*0908-4	.335
0908-5	.350
0908-6	.370
0908-7	.390
0908-8	.410
0908-9	.430

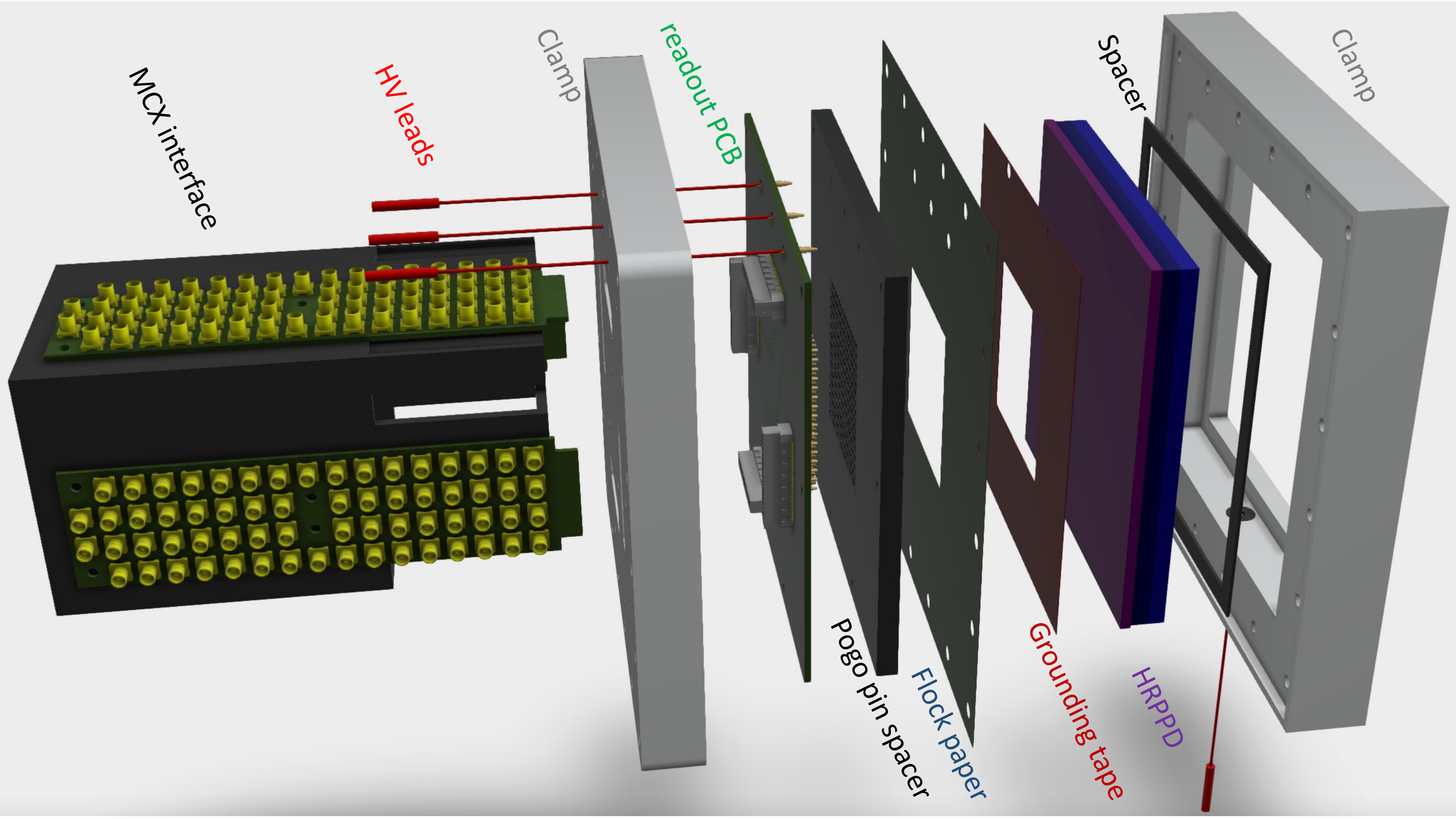
Standard Tolerances:
Lengths: ± .006
Diameters: ± .002
Angles: ± 2°

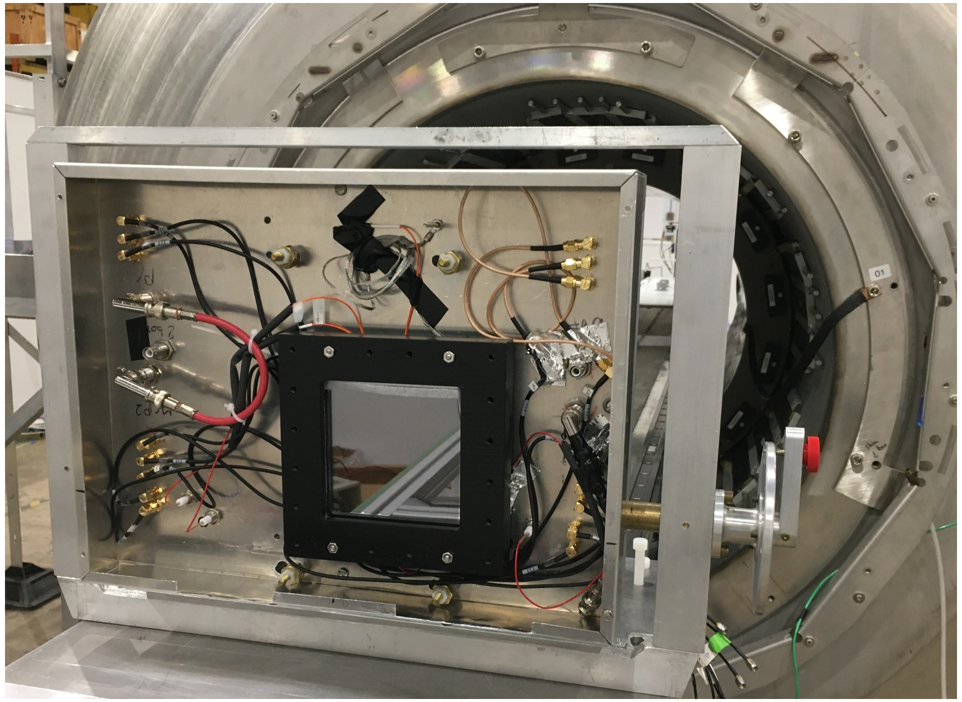


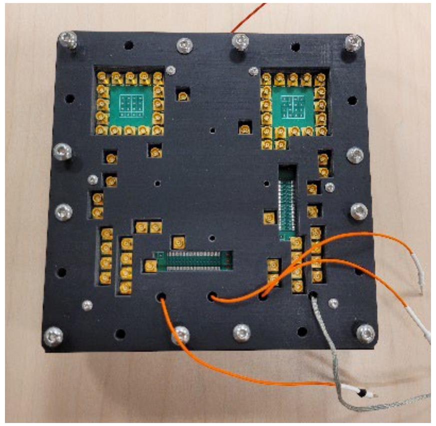


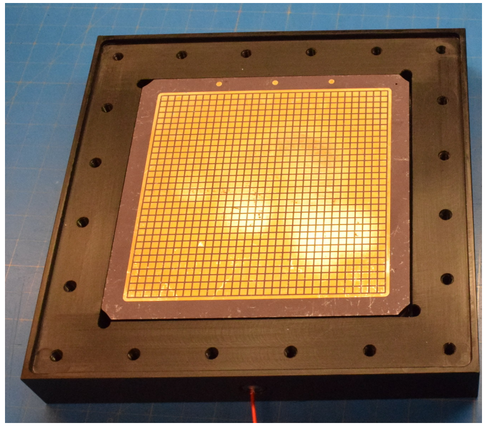
- Should suffice for a basic performance evaluation

Integration attempt #1: pogo pins









- Was implemented (and used in Argonne B-field tests)
    - See presentation by Mark
- Looks suitable for the TOF PET prototype
- Drawings and spare PCBs can be shared with other groups

ASIC considerations

- **A standard requirement list**
  - Provide timing resolution <20ps and amplitude measurement
  - Work with collected charge from few dozens to few hundred fC
  - Work with a relatively high detector capacitance up to 10 pF
  - Have high channel density (64 channels per ASIC and more) and few mW/ch power dissipation
  - Streaming mode (either this or that way)

Waveform digitizer (e.g. by Nalu Scientific)

- Pros
  - Expect higher timing resolution overall
  - Performance less affected by signal shape
- Cons
  - Higher expected power dissipation
  - None is readily available with a high channel density
    - Therefore, realistically, one should consider more space

TOA/ADC (EICROC by OMEGA group)

- Pros
  - Supported by the EIC project
  - HGCROC3 is available as a starting point
  - Expected power dissipation ~1-3mW/ch
  - Should work with HRPPDs at a lower gain
- Cons
  - Assumes signals have a “regular” shape

ASIC considerations

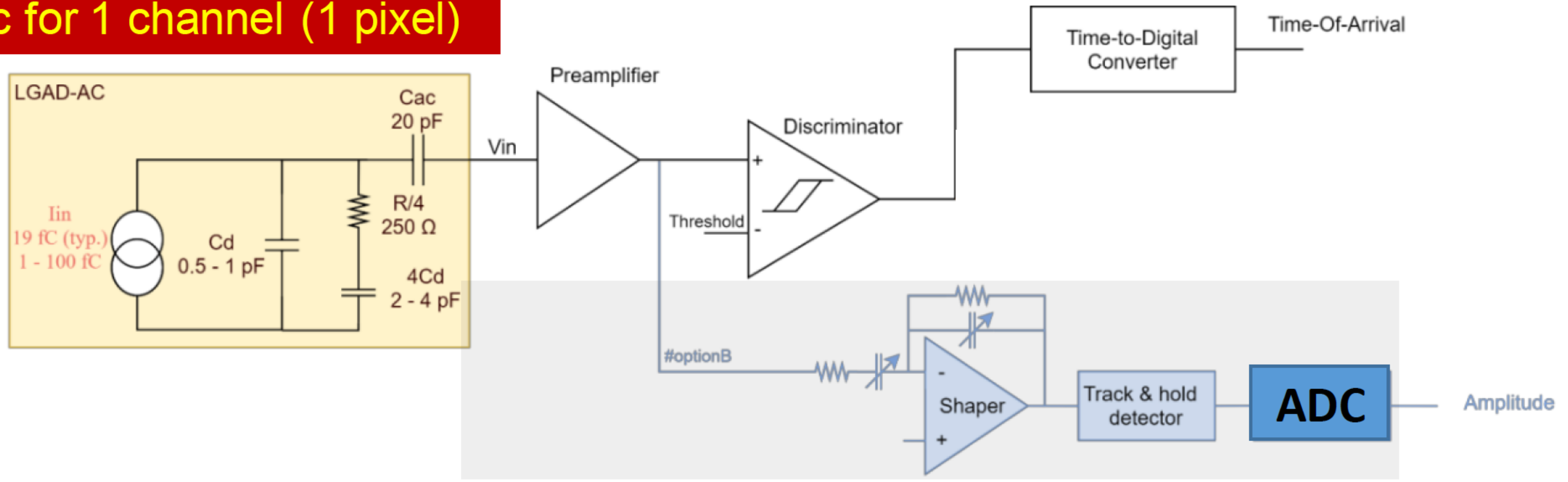
EICROC0 design: 16 channels (4x4)

Requirements:
- pixel size **0.5 x 0.5 mm²** ***(HGTD 1.3x1.3 mm²)***
- low power consumption < **2 mW/channel**
- low jitter **~ 20 ps**
- low noise **~ 1 mV/channel**
- sensitivity to low charge **(2 fC)**

Charge sharing studies (simulation + β source)

EICROC0 design:
- TZ Preamplifiers from ALTIROC
- TDC from HGCROC (CMS, CEA/Irfu/DEDIP)
- 8 bit ADC for time-walk correction (AGH Krakow, adapted from HGCROC)

Schematic for 1 channel (1 pixel)



Compared to ALTIROC, ToT TDC (non-linear behavior as a function of deposited charge) replaced by an ADC

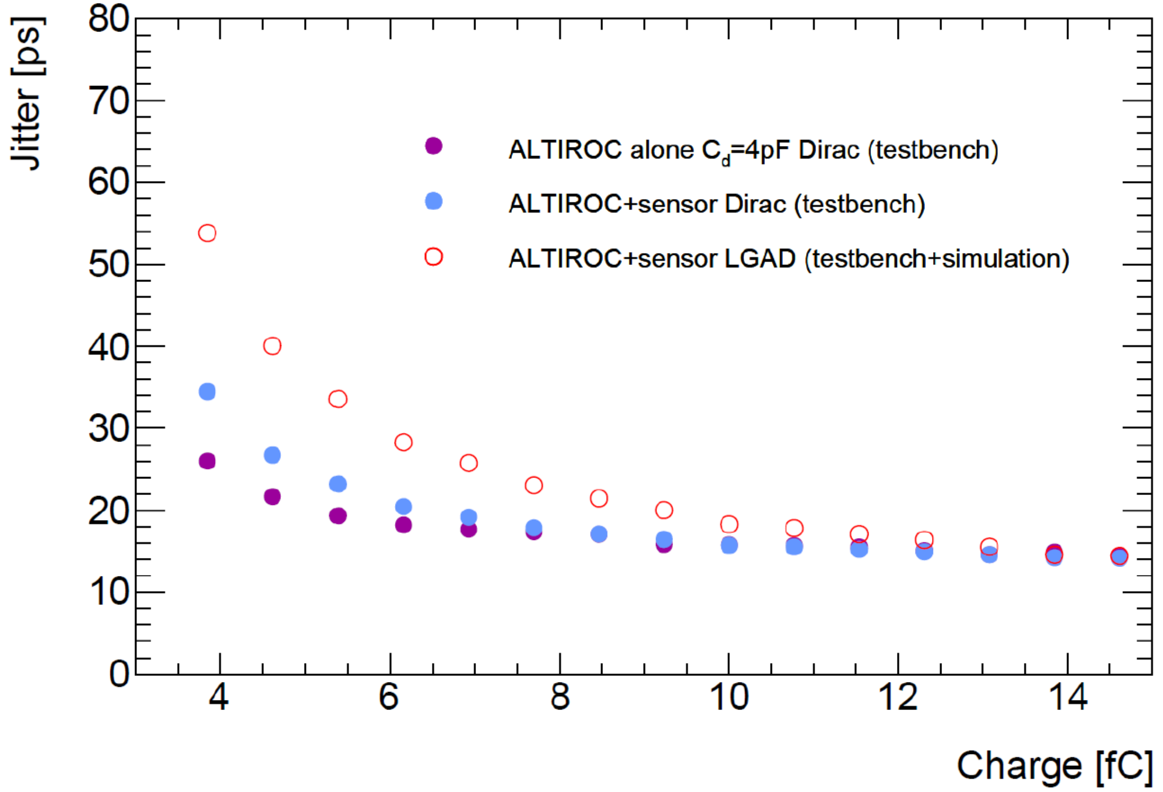
ASIC considerations

- Together with eRD109 consortium we set up a meeting with MCP-PMT experts, m(pf)RICH and DIRC representatives and EICROC ASIC designers: https://indico.bnl.gov/event/18539/
- Conclusions:
  - EICROC meets the overall requirements
  - Will be available in 256+ channel configuration
  - Will be developed for ePIC AC-LGADs anyway

EICROC0 (2022)

Not yet measured, values fm ALTIROC

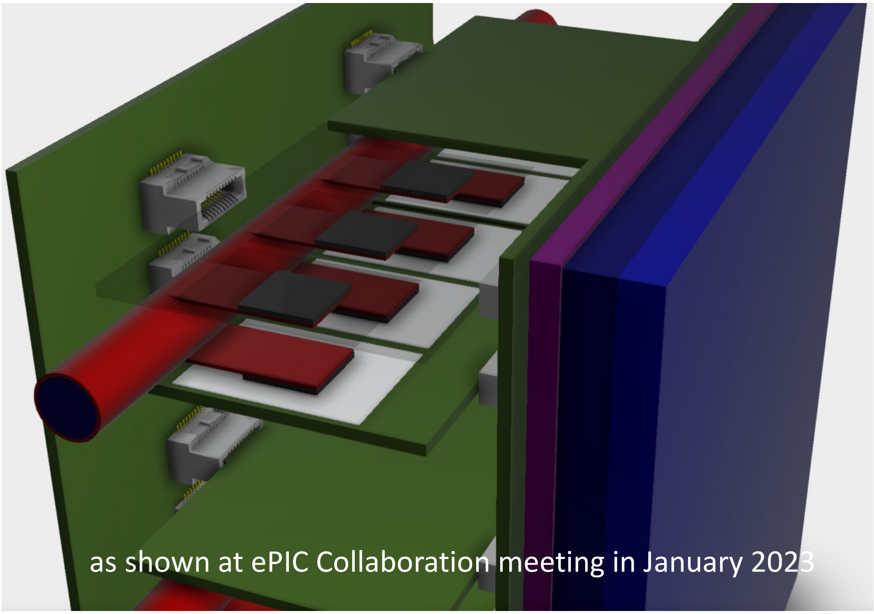
- 16 channels COB
- Sensor : AC LGAD Cd~1 pF
- Dyn range 0.3 fC to 100 fC
- Noise : 0.3 fC
- TOA Min threshold ~4 fC (Cd=4 pF)
- Time walk ~0.7 ns (Cd=4 pF)
- Jitter ~100 ps/Q(fC) (Cd=4 pF)
- Pd = 3 mW/ch

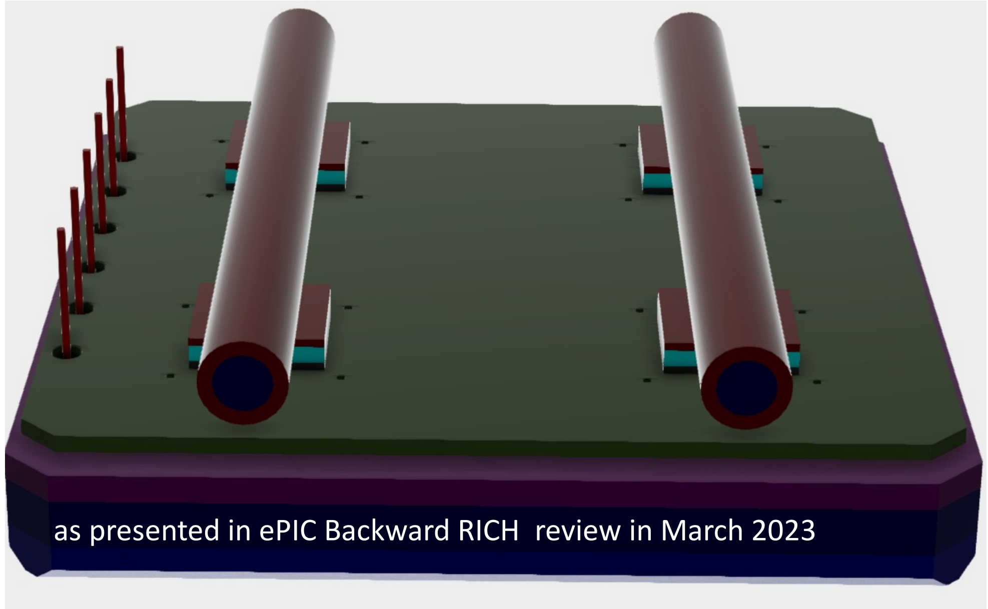


< 20 ps for Q > 6 fC dominated by clock/TDC/calib command

< 40 ps at Q=4 fC start to be dominated by noise

HRPPD / FEE integration model change



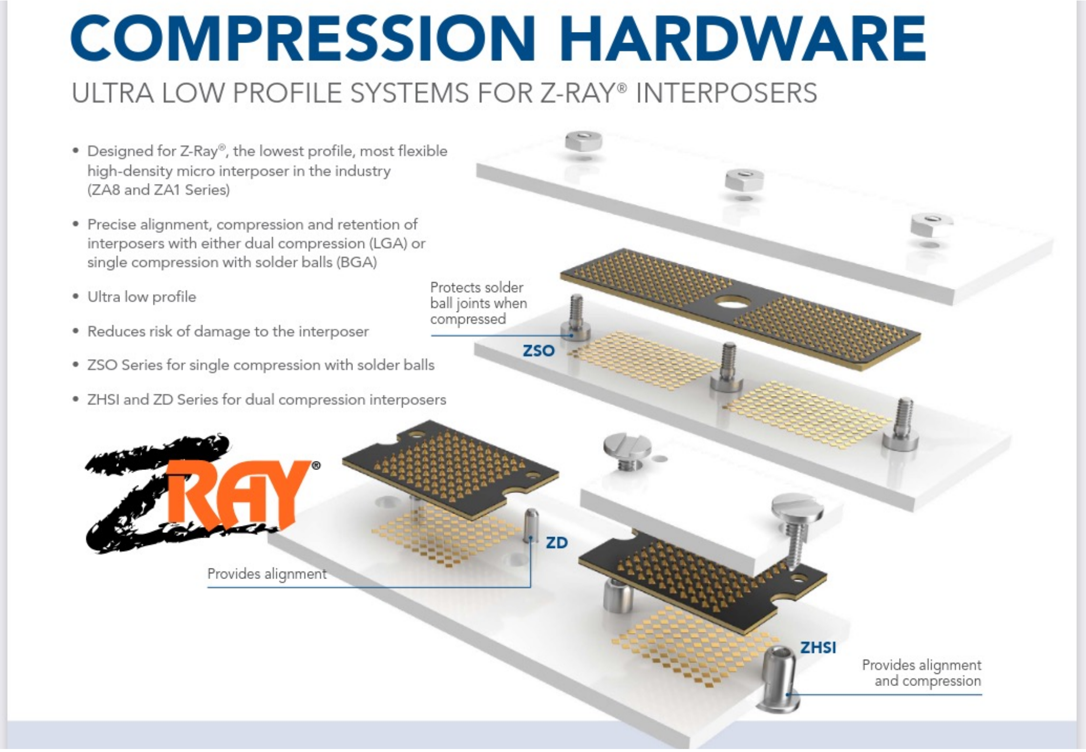


- Capacitively coupled HRPPDs
- 24x24 pad pixellation
- Waveform digitizer ASIC
- Vertical integration + a backplane

- DC-coupled HRPPDs
- 32x32 pad pixellation
- TOA / TOT(ADC) ASIC
- Flat integration

Integration attempt #2: compression interposers

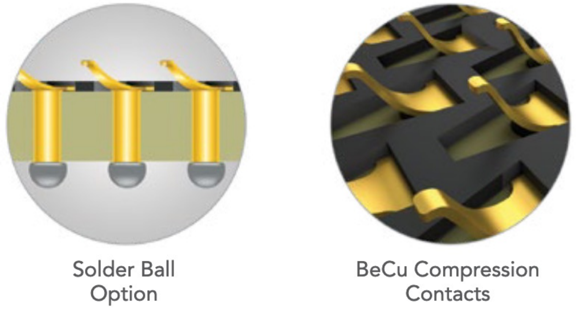
- Custom anode base plates are seemingly possible
  - Samtec compression interposers seem to be a reasonable option
  - Fallback option: conductive epoxy screen printing


COMPRESSION HARDWARE

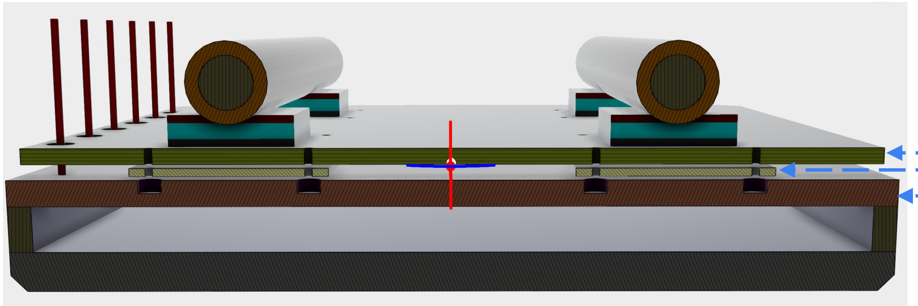
ULTRA LOW PROFILE SYSTEMS FOR Z-RAY® INTERPOSERS

- Designed for Z-Ray®, the lowest profile, most flexible high-density micro interposer in the industry (ZA8 and ZA1 Series)
- Precise alignment, compression and retention of interposers with either dual compression (LGA) or single compression with solder balls (BGA)
- Ultra low profile
- Reduces risk of damage to the interposer
- ZSO Series for single compression with solder balls
- ZHSI and ZD Series for dual compression interposers

HRPPD anode plate side



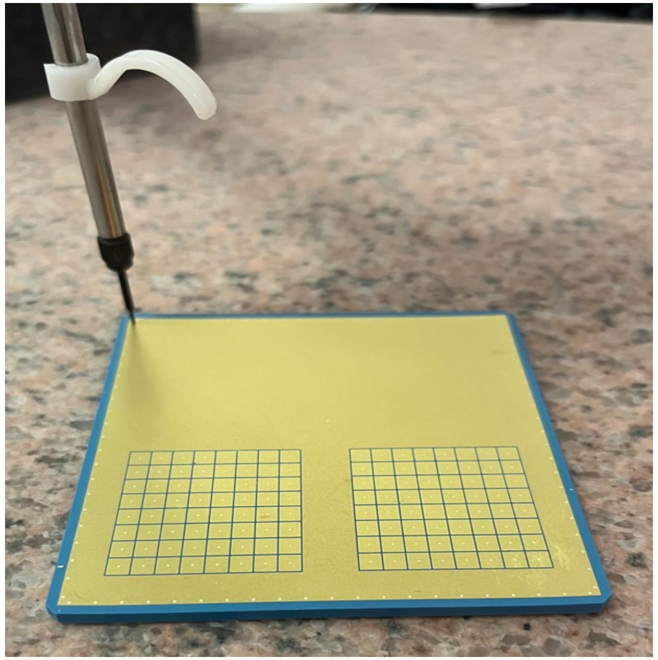
ASIC PCB side

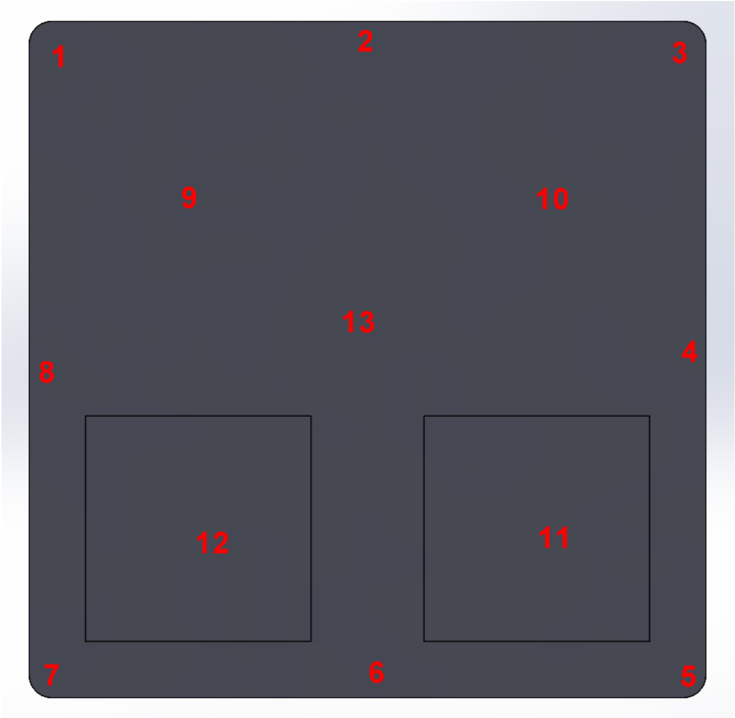


HRPPD face down

Small size multi-layer ceramic prototypes

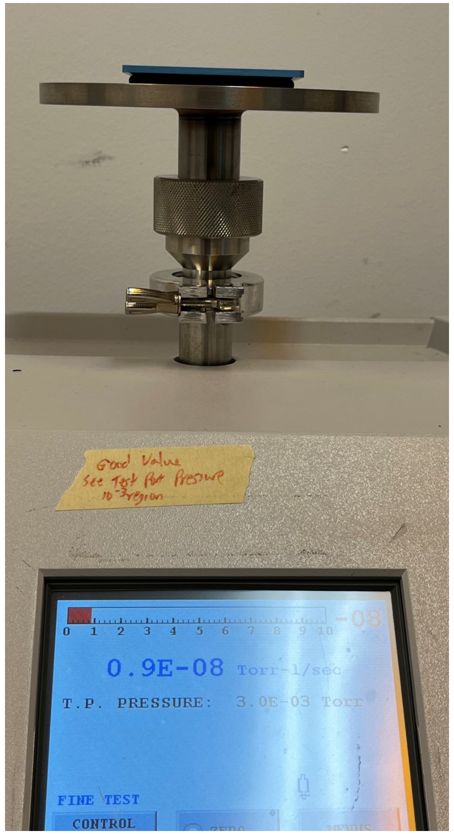
- First two 3” LTCC anode plates by Techtra (Poland) were examined <u>at Incom</u>
  - Flatness is tolerable on a 3.0mm thick plate, less so on a 2.5mm thick one
  - Vacuum tightness of the 3.0 mm plate confirmed





	Sample 1 TOP	Sample 1 Bot.
Point 1 is the datum and as such is considered "ground zero"	0	0
Min	0.00889	-0.00635
Max	-0.03556	0.0762
delta (pts 2 to 13)	0.04445	-0.08255
delta (pts 2 to 13)	0.0018	-0.0033
delta (pts 1 to 13)	-0.03556	0.0762
delta (pts 1 to 13)	-0.0014	0.0030

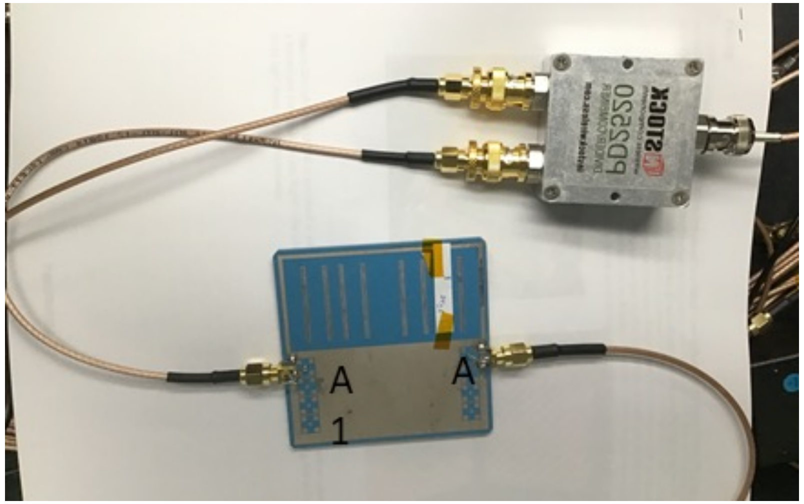
[mm]

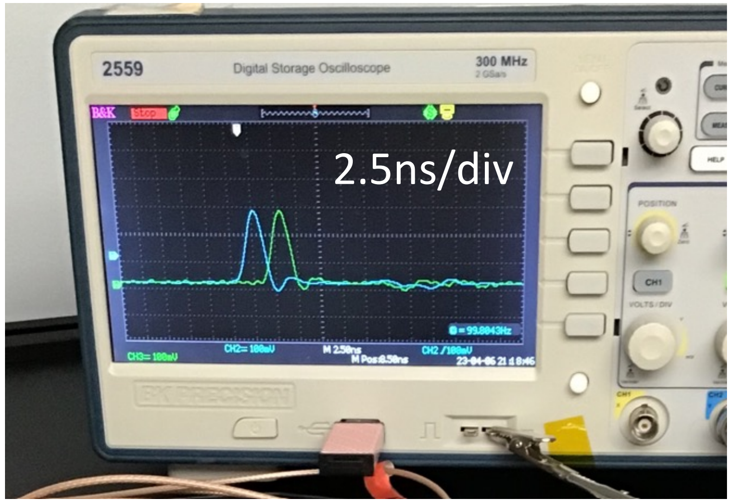


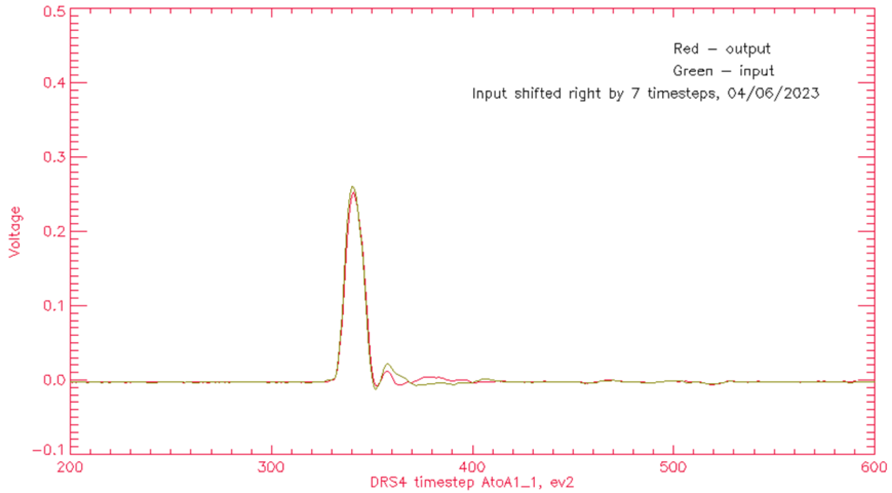
Small size multi-layer ceramic prototypes

- First two 3” LTCC anode plates by Techtra (Poland) were examined <u>at Incom</u>
  - No measurable cross-talk introduced in the ceramic stack
    - 50 Ohm impedance matched isolated coplanar waveguide trace configuration
  - Small trace capacitance (few pF) confirmed

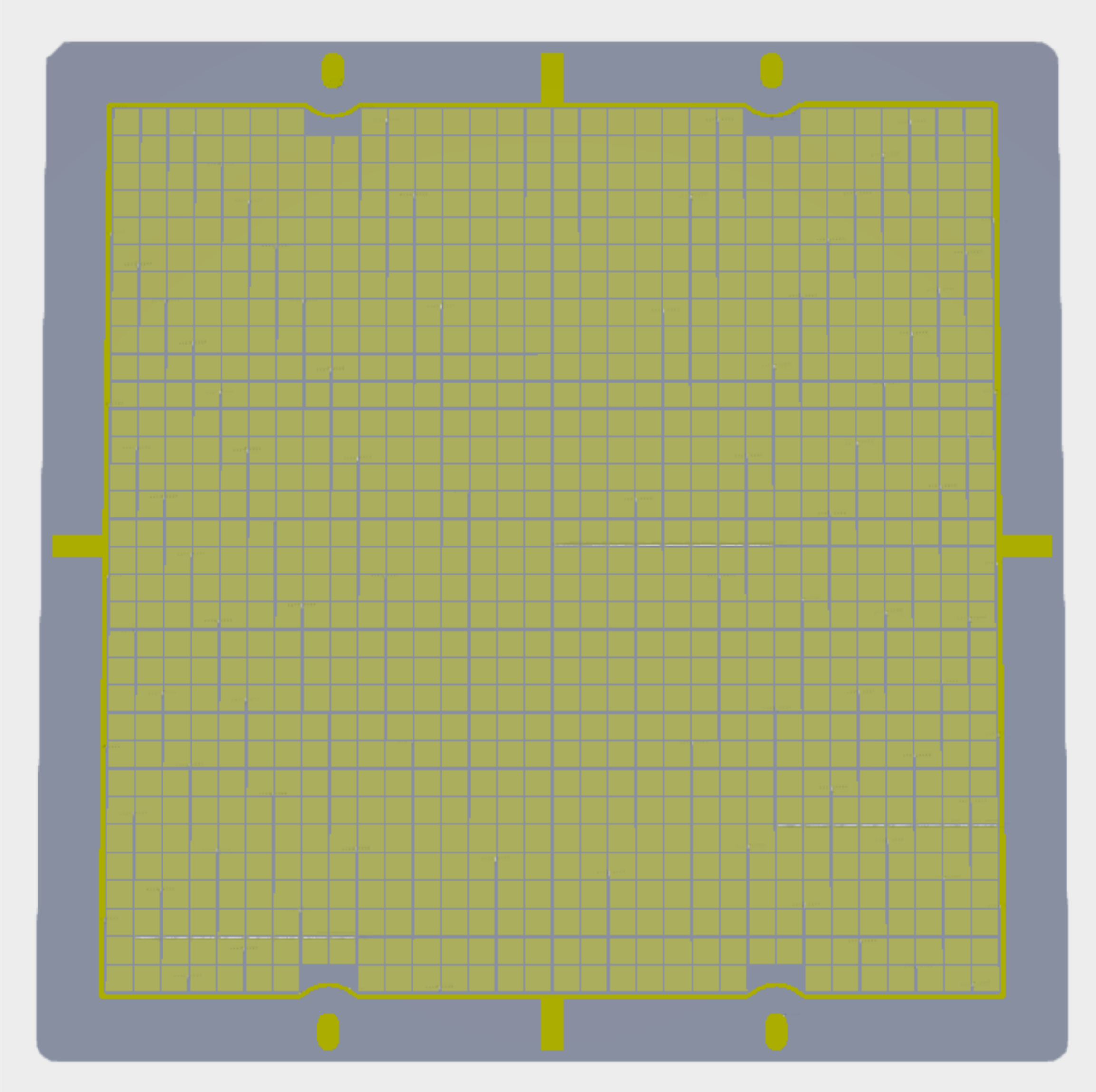
  - Certain signal degradation observed on the long (5 cm) traces





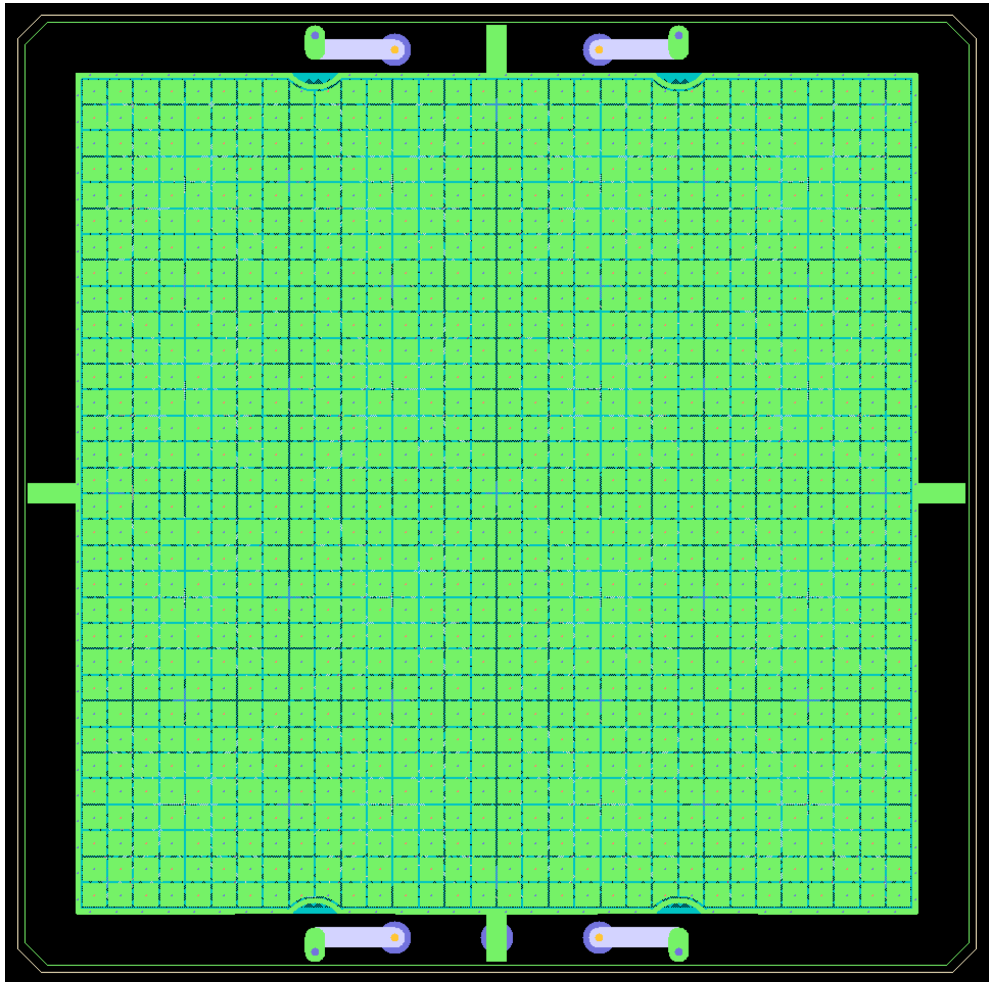


Full size HRPPD anode base plate: wish list

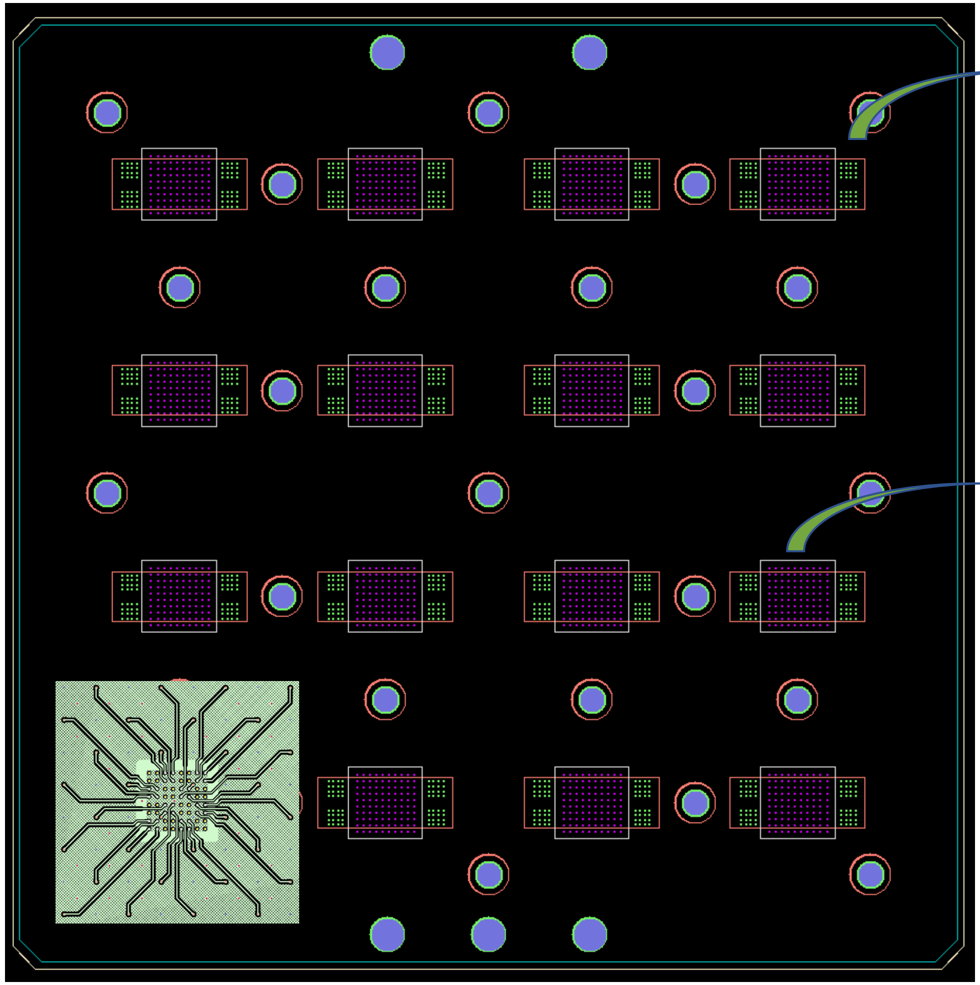


- Reproduce the updated HRPPD design
  - Outer dimensions: 120 mm
  - Independent HV connections for two MCPs
  - Pitch: 3.24 mm
  - ~75% OAR
- Route to 16 Z-Ray interposers (800 μm pitch)
- Be compatible with both 64-channel HGCROC (spring 2024 configuration) and 256-channel EICROC ASICs
  - No mechanical holes at ASIC locations
- Have first five tiles compatible with the final EIC order

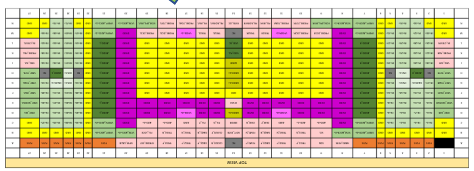
Full size anode base plate and a matching PCB



Inner side of a 32x32 pad ceramic base plate



Outer side overlaid with a 16x HGCROC PCB template



HGCROC ASIC

Samtec interposer

Solder Ball Option

BeCu Compression Contacts

- This 120mm x 120mm LTCC base plate is now being built by Techtra