Ionizing particle beam fluence and position micro-pattern detector array with multi-coordinate readout

DOE SBIR Phase II project update and the outlook

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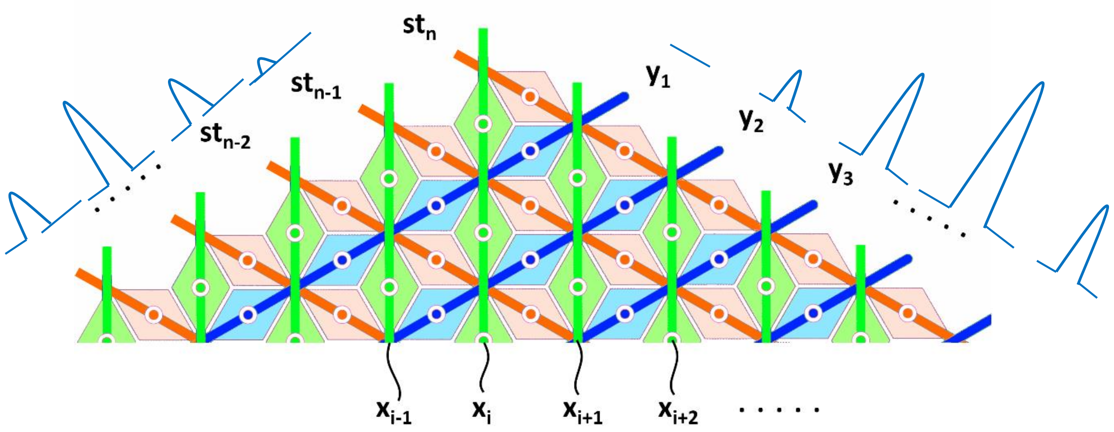
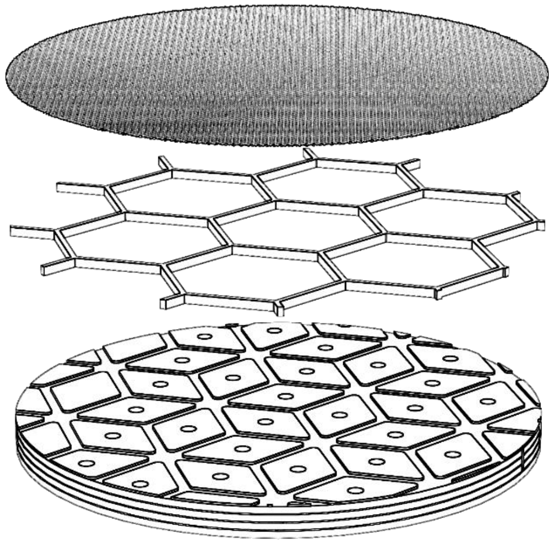
Introduction and recap of the project & team RDI

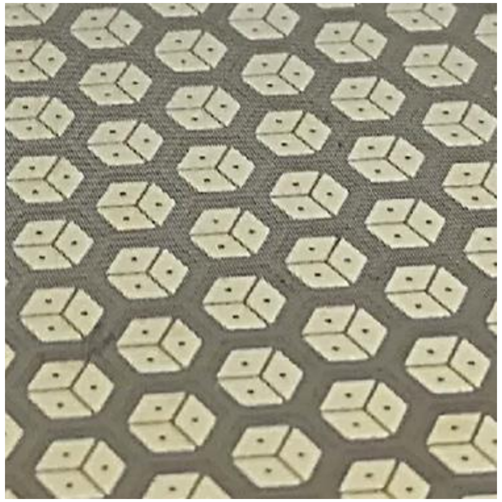
"High-density ionizing particle beam fluence and position detector array using the Micromegas technology with multi-coordinate readout" - DOE STTR Phase I (2016) / Phase II (2017-2019)

- Micro-pattern gas ionization array

… with a few new twists:







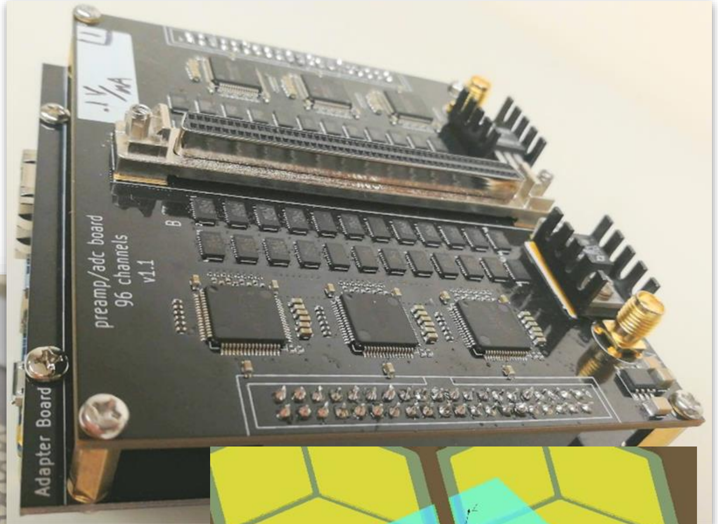
- A dedicated, focused, versatile team

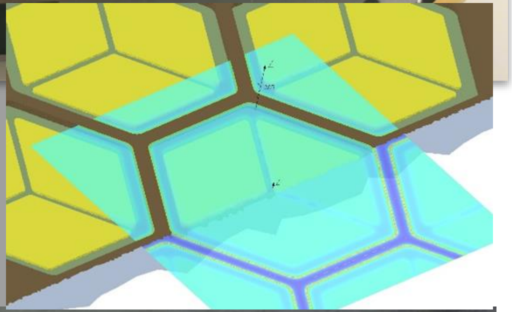
Project core since 2014, with few key additions!

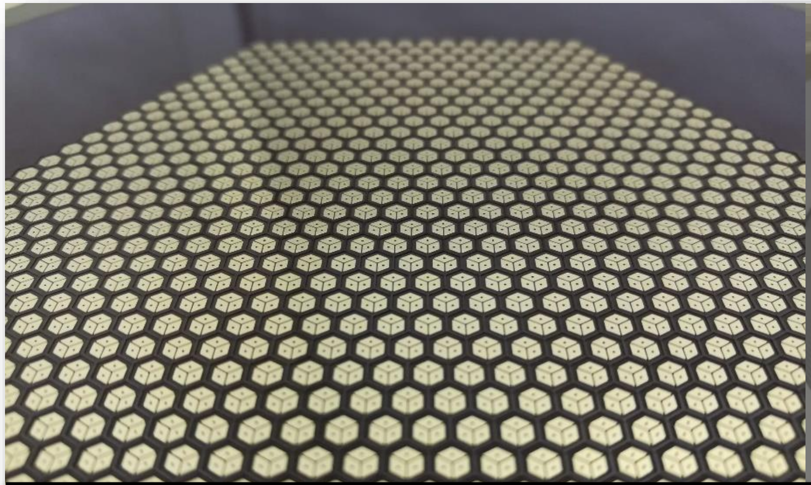
- Partners: ASU, United States Department of Energy, Mayo Clinic, ATM, St. Jude Children's Research Hospital

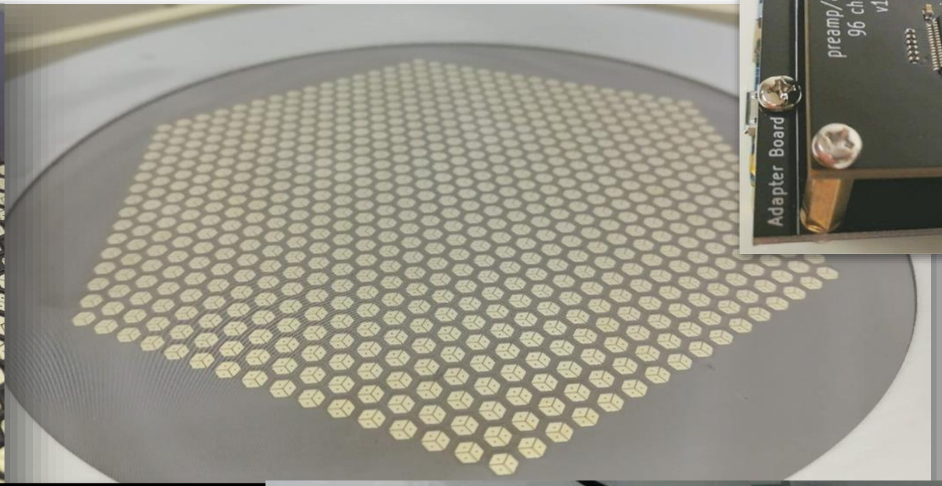
Making the RDI Micromegas detector arrays work

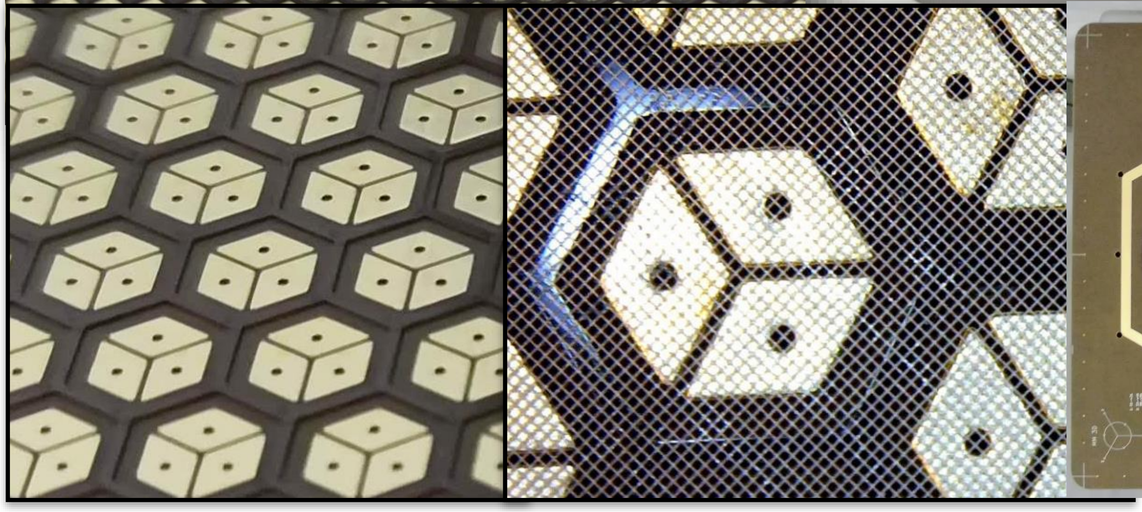
- Optimization through simulation
- Reliably and reproducibly building the arrays
- True multi-channel capability: own DAQ system

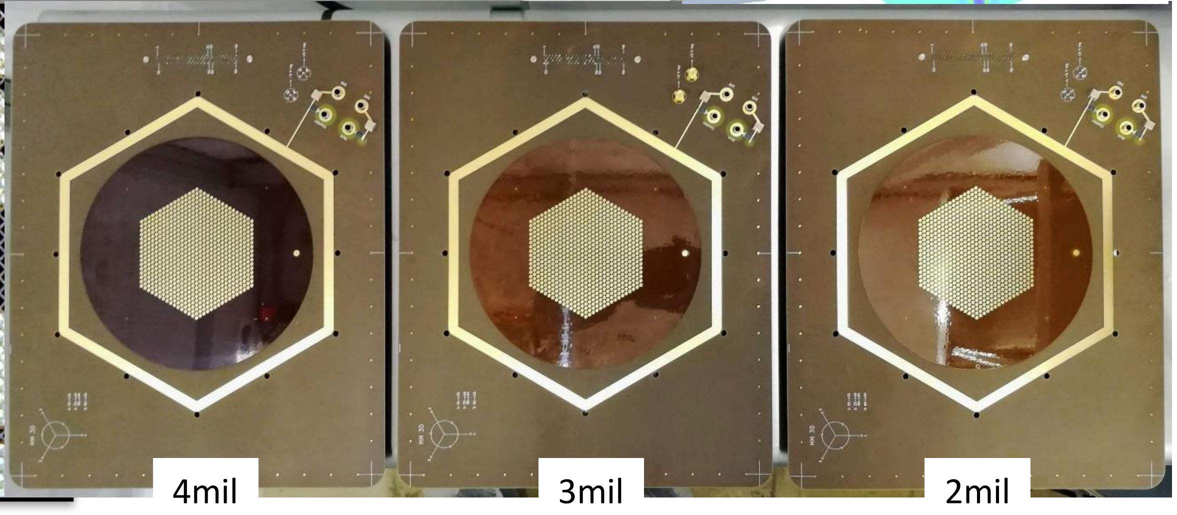






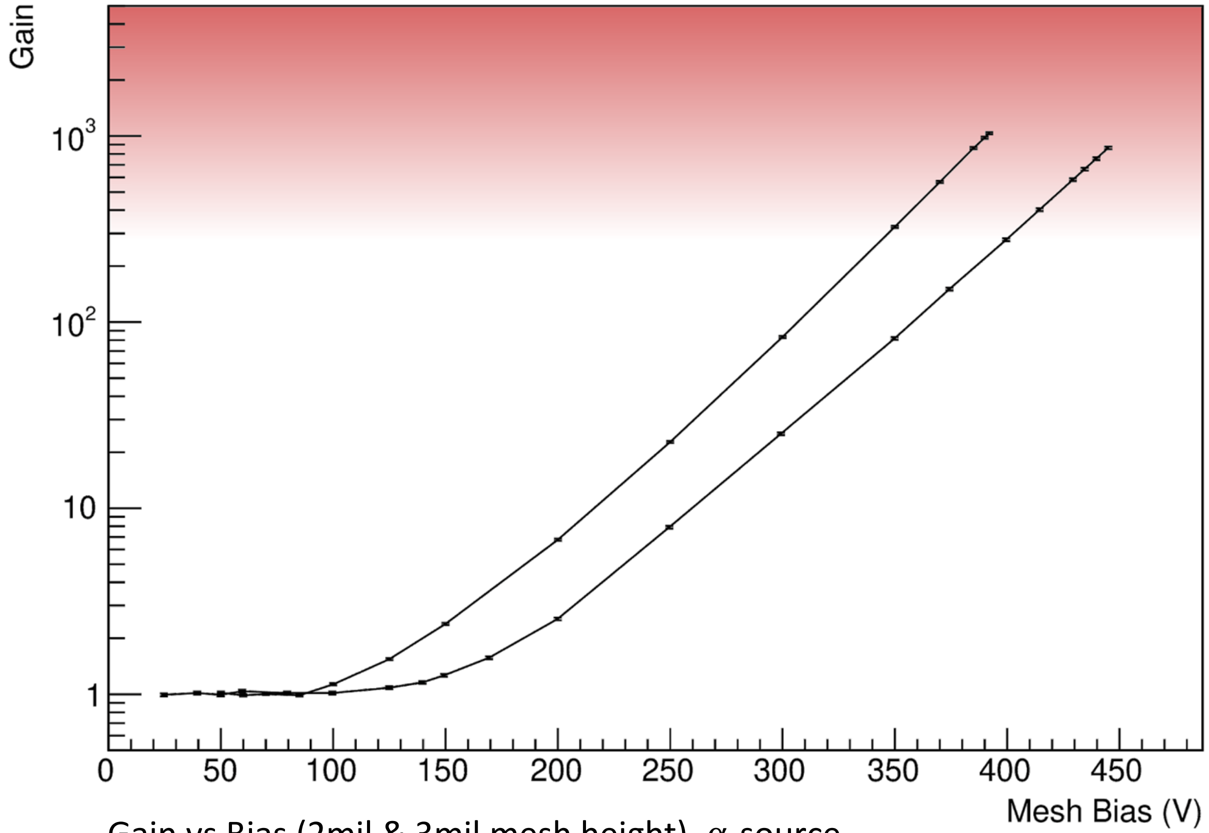




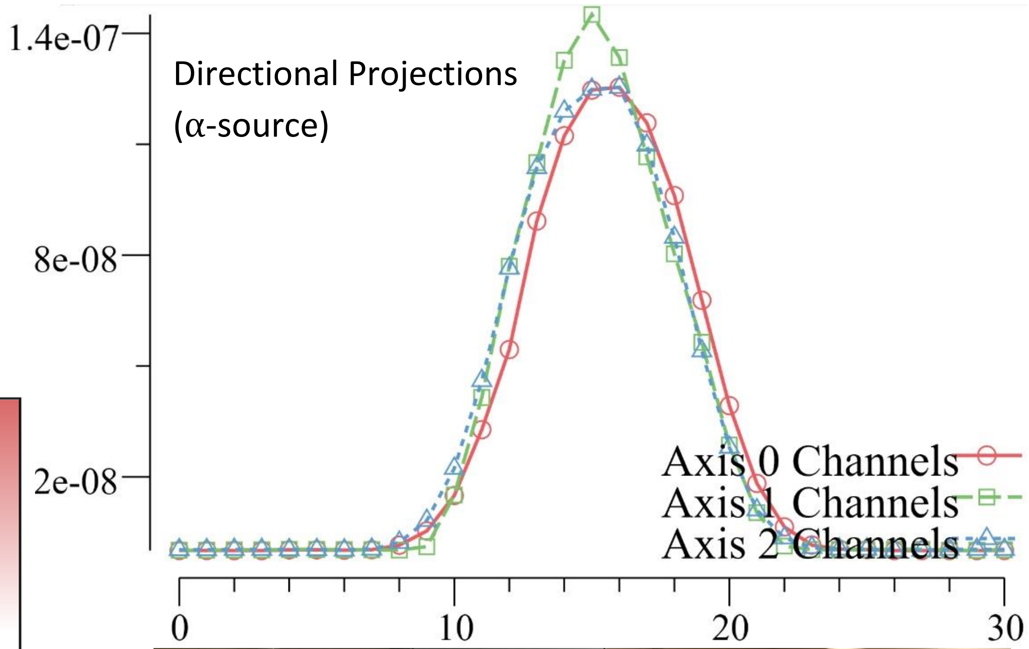


Experimental milestones for the RDI Micromegas (1)

- Achieved stable high-gain operation
- High-performance multi-channel readout
- New, versatile data handling and processing
- Position and shape reconstruction
- Test bed for the future product integration



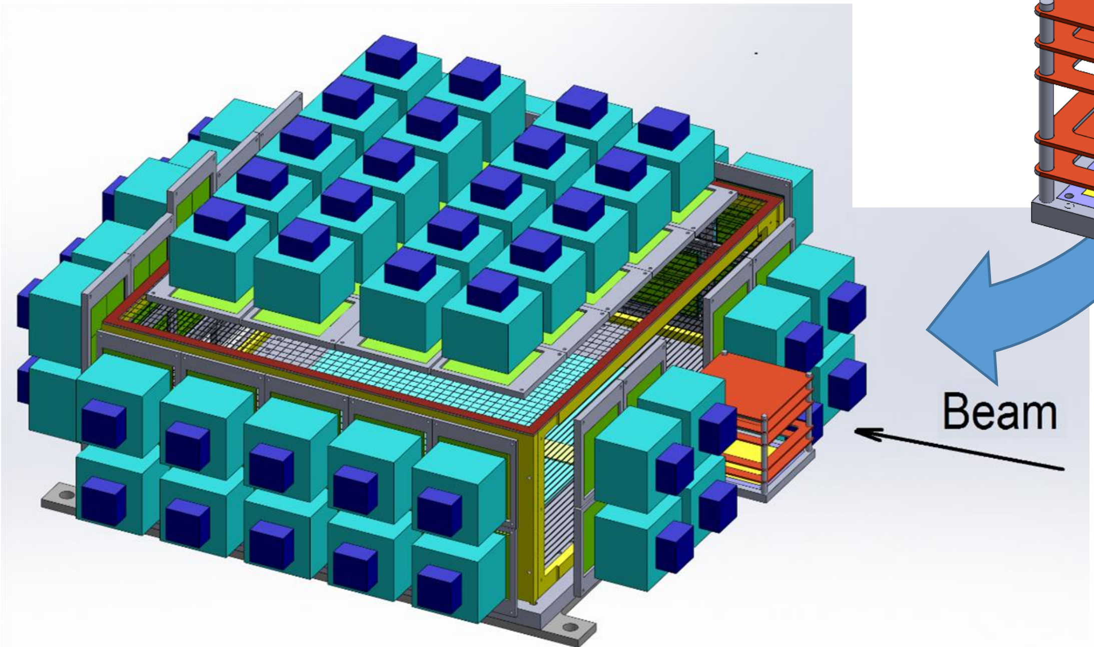
Gain vs Bias (2mil & 3mil mesh height), α-source

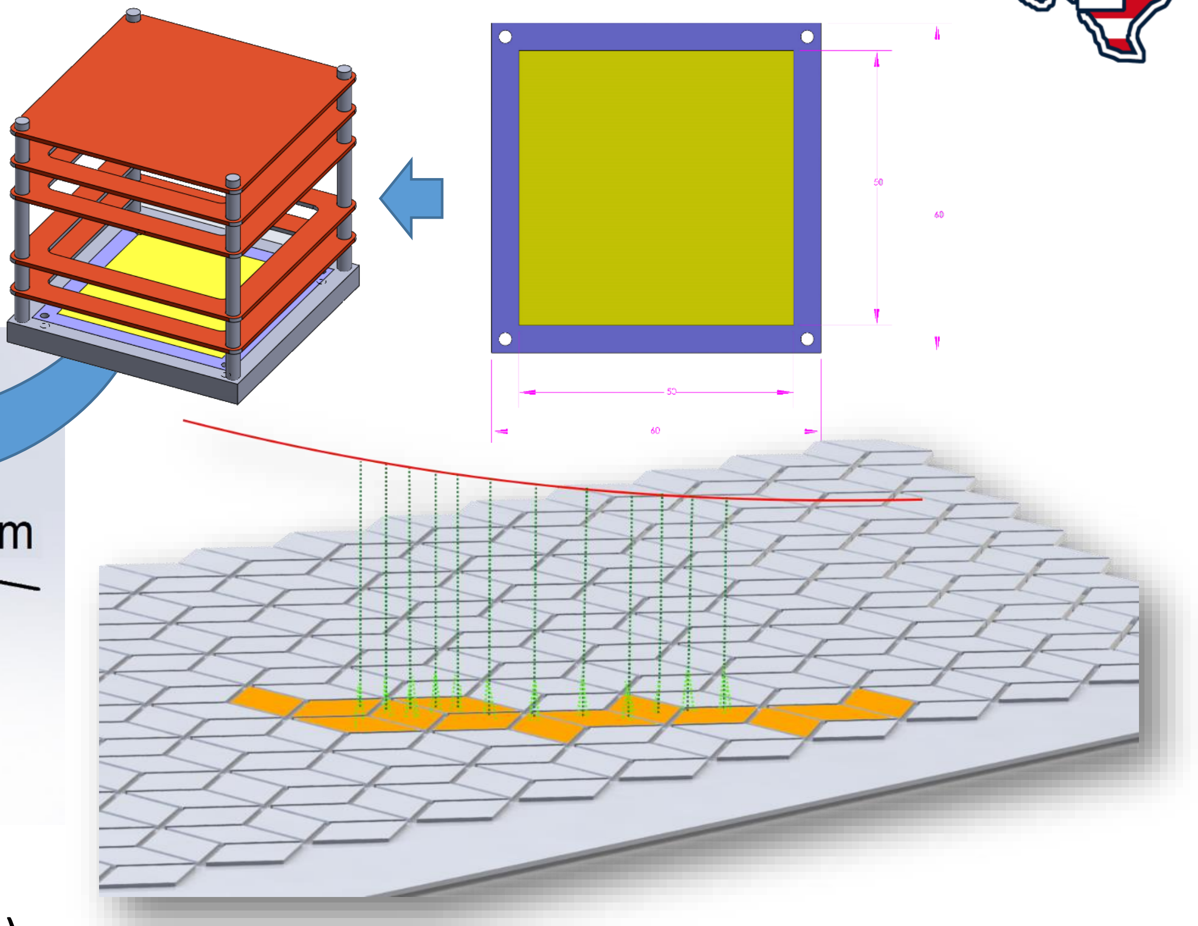


A set-up of the technology tester detector in an x-ray beam

Planned validation in a physics experiment

- TexAT TPC:

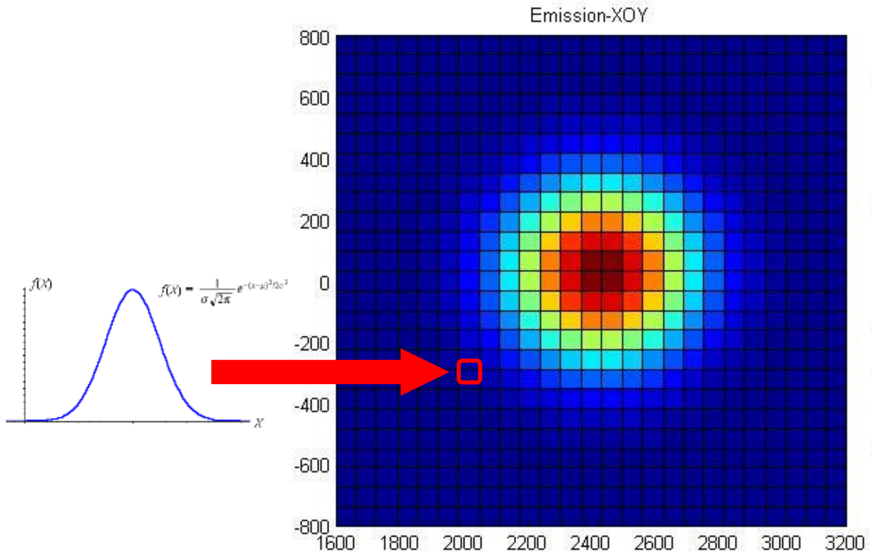


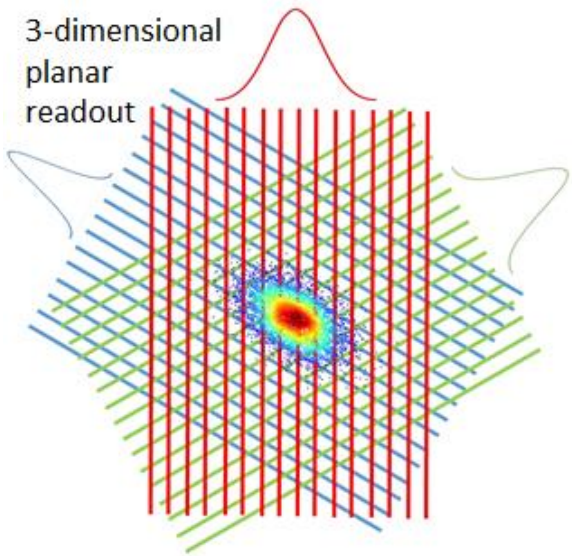


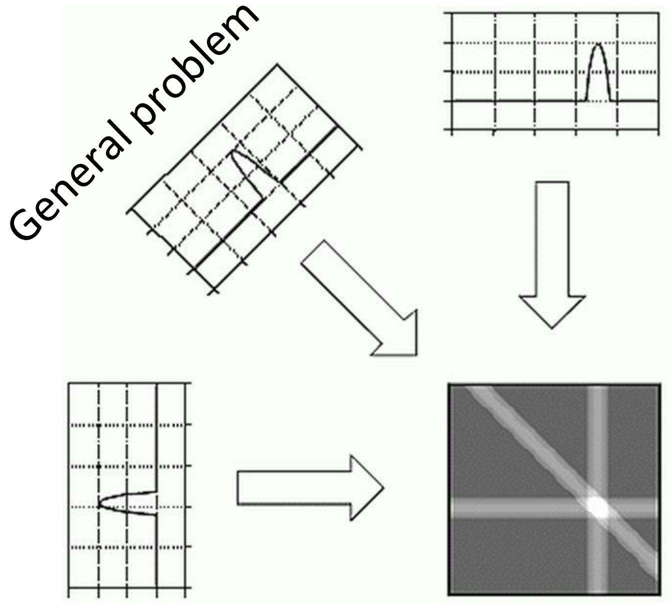
- Adding entry beam position and orientation tracking
  - Requires fine spatial resolution (≤ 200um)
  - Integrated with TAMU DAQ electronics (GET)
  - RDI is to help with position reconstruction
  - RDI to try ‘pulsed’ own DAQ system when ready
  - Excellent compact testing platform

- The project now is in active design phase
- No additional funds from the DOE (NCE)
- RDI is to supply the Micromegas Oct-2019
- Experimental validation with TAMU
- Future plan to supply a full-area array

Real-time tomography







Ill-conditioned Non-Negative Least Squares Problem: Many more pixels than readout channels ⇒ non-invertible rank-deficient matrix. Additionally, unphysical negative pixel intensities must be avoided.

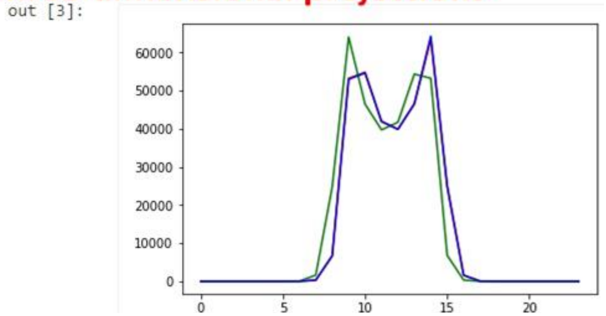
Regularization: A Bayesian **prior** estimate for the image pixel probability distribution to resolve rank deficiency ⇒ Gaussian covariance between the pixel values. **Calculated ahead of time for all measurements.**

Real-Time Application: In real time, apply pre-computed, regularized linear estimator while enforcing inequality constraints.

The method **allows to carry out tomography in real time!**

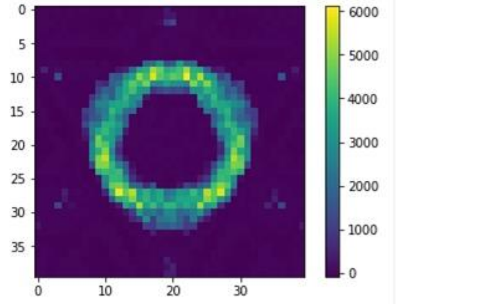
See also T. Wang et al https://doi.org/10.1063/1.5023162

Three-dimensional projections



Application example to our exact array geometry (simulated)

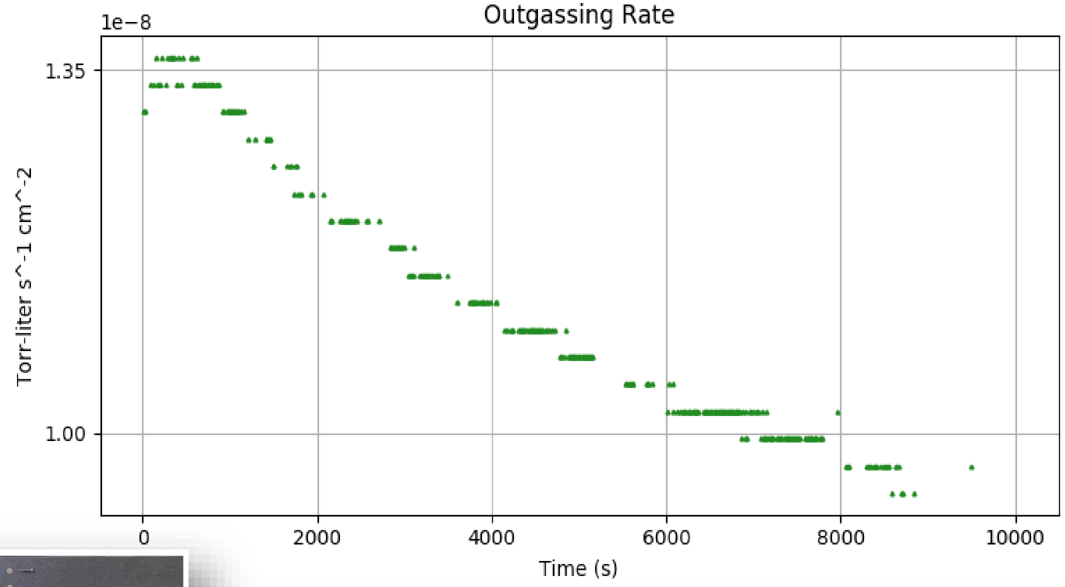
Reconstructed shape

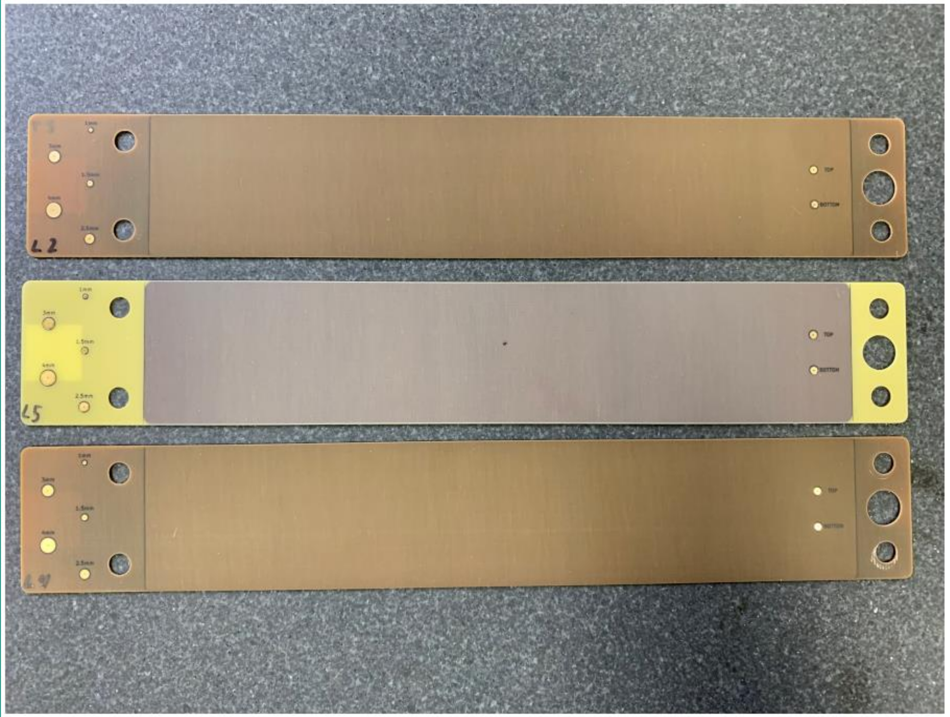


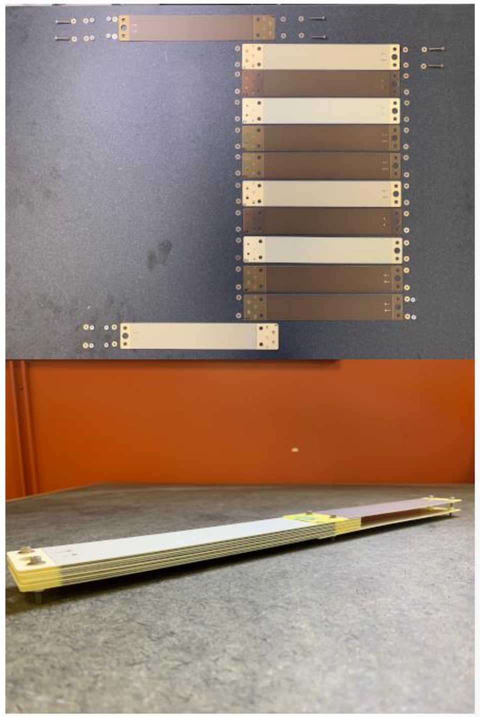
Supporting R&D: radiation hardness, outgassing, etc.

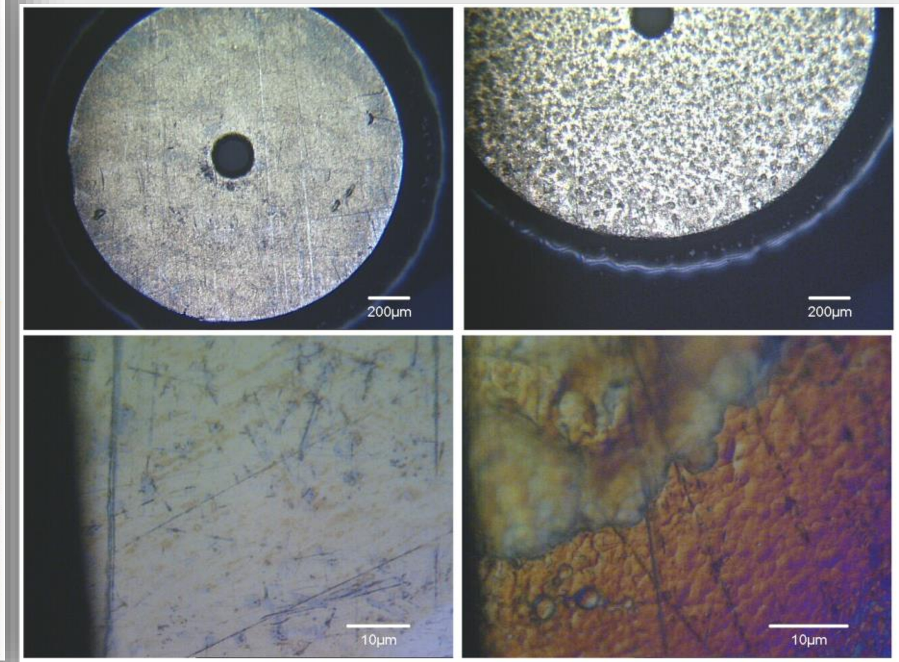
Understanding PCB characteristics

- Outgassing rates
- Evidence of radiation damage
  - Discoloration
  - ENIG Copper pad degradation
  - Changes in electrical & mechanical properties





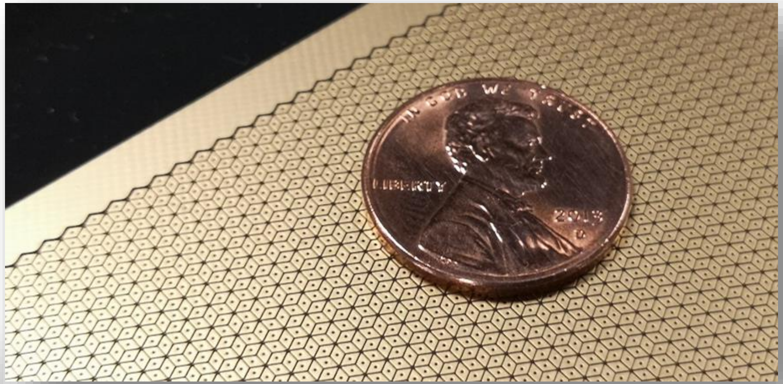


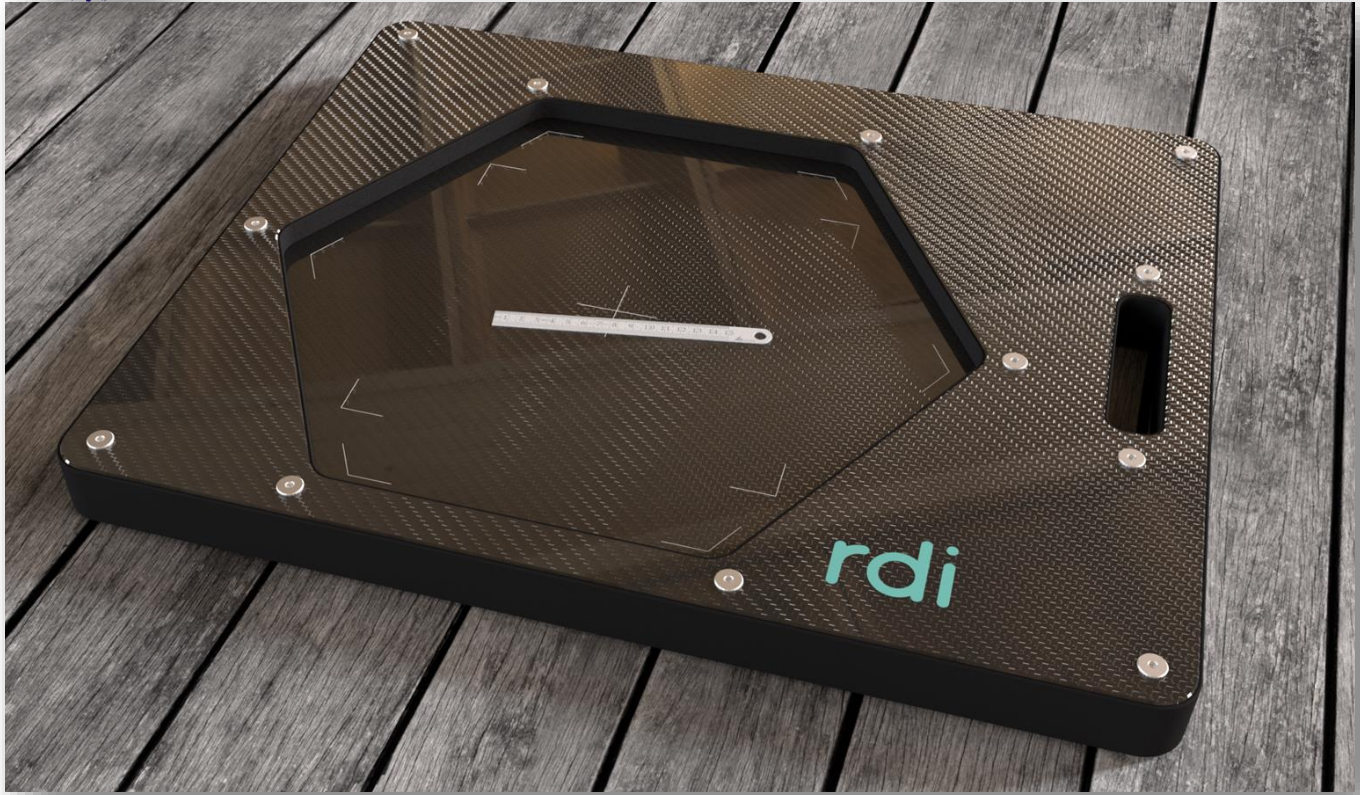


Proton fluence and position detector
for clinical radiotherapy QA

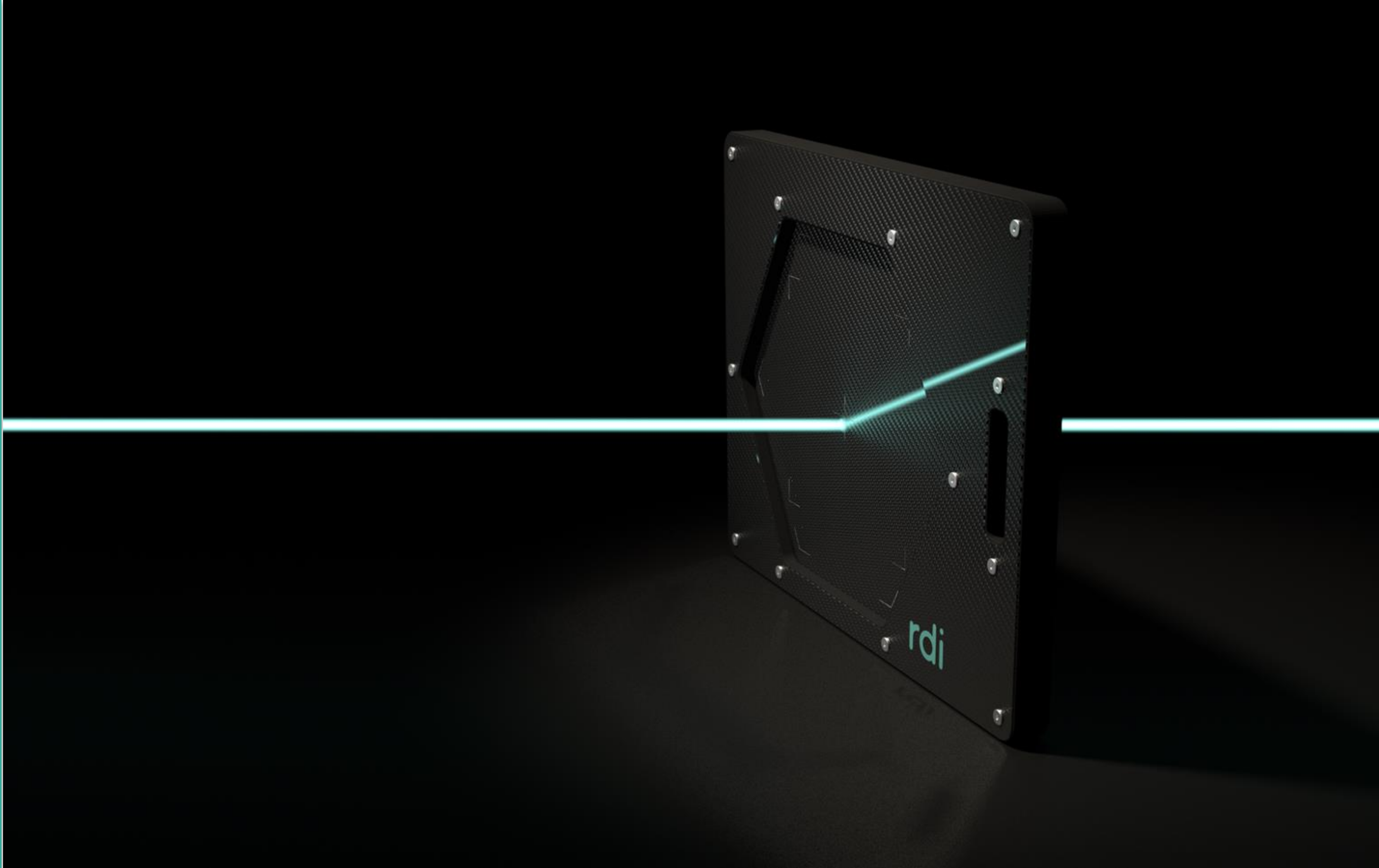
- Parallel-plate air ionization detector with highly segmented anode
  - Three-directional readout
  - Uniformity of response across the array
- Innovative detector product design
  - Carbon fiber construction
  - Modular architecture

PATENT PENDING

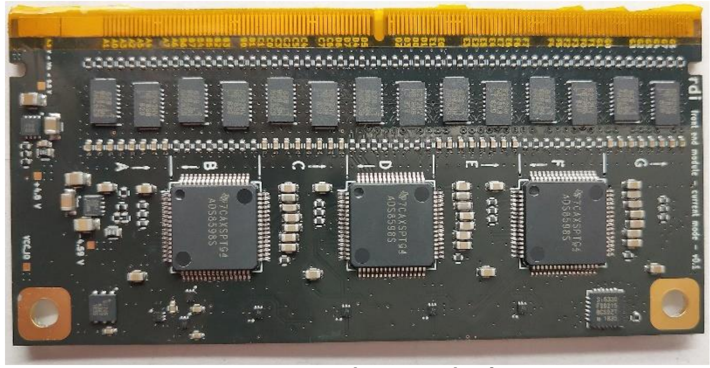




- Cutting-edge software tech
  - Versatile, efficient, modular
  - Cloud-capable
  - Highly scalable
- All done in-house
  - Working with our future customers directly
  - True flexibility of product R&D
- PTCOG-NA presentation

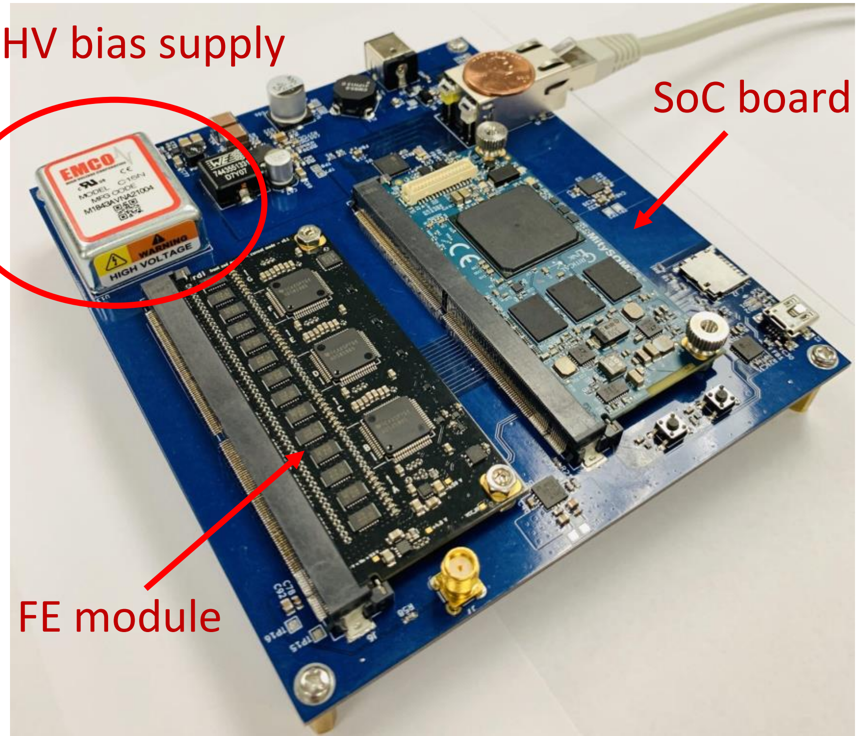

rdi

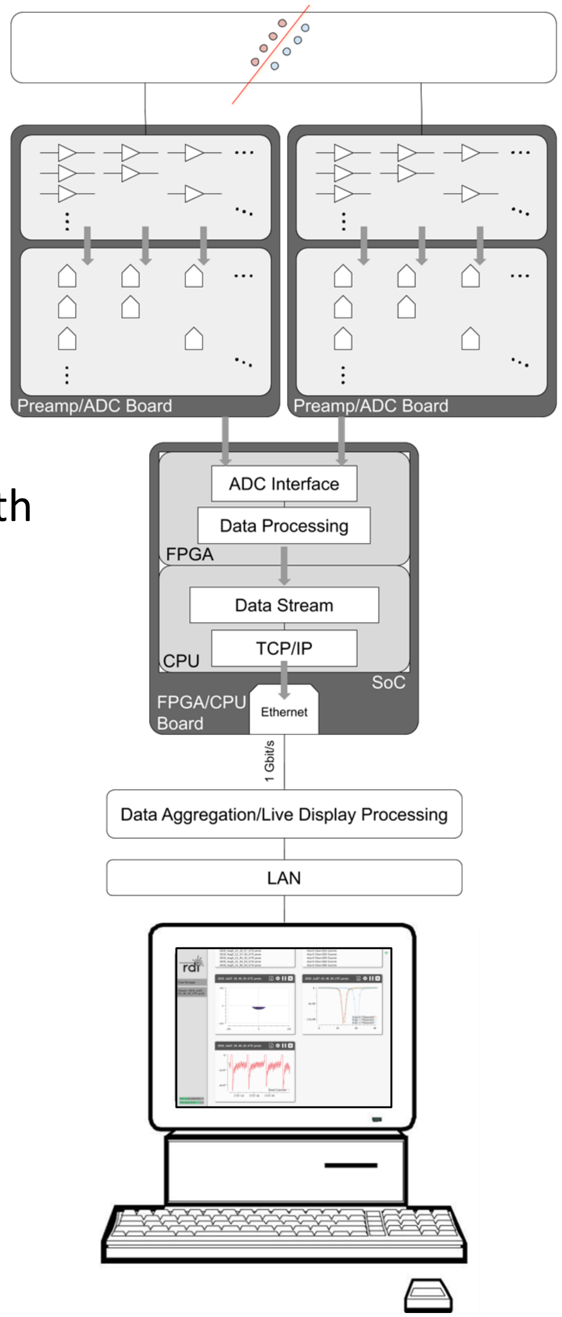
Readout electronics and data acquisition system



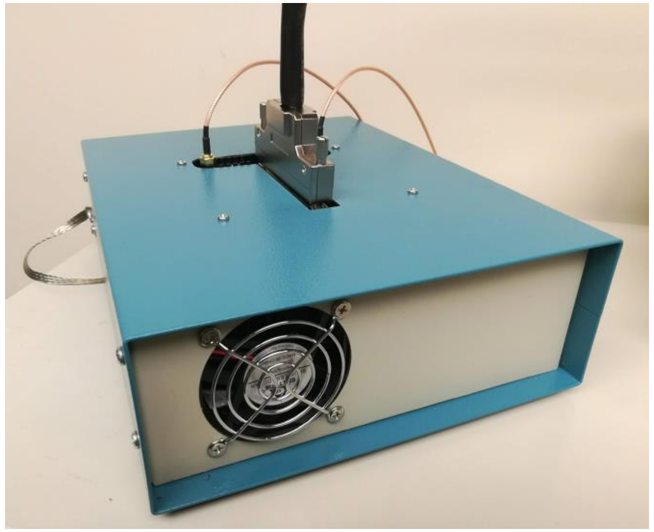
Front-end module

Power and communication design tester with the SoC main board installed



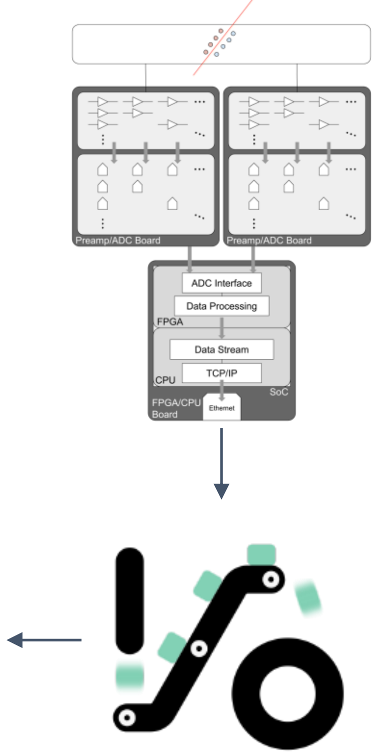


- Analog bandwidth is 10 kHz
- 18-bit ADC depth
- Altera FPGA/CPU-based system
- 96 channels / analog module
- Channel signal range < 100pA ~ 5μA

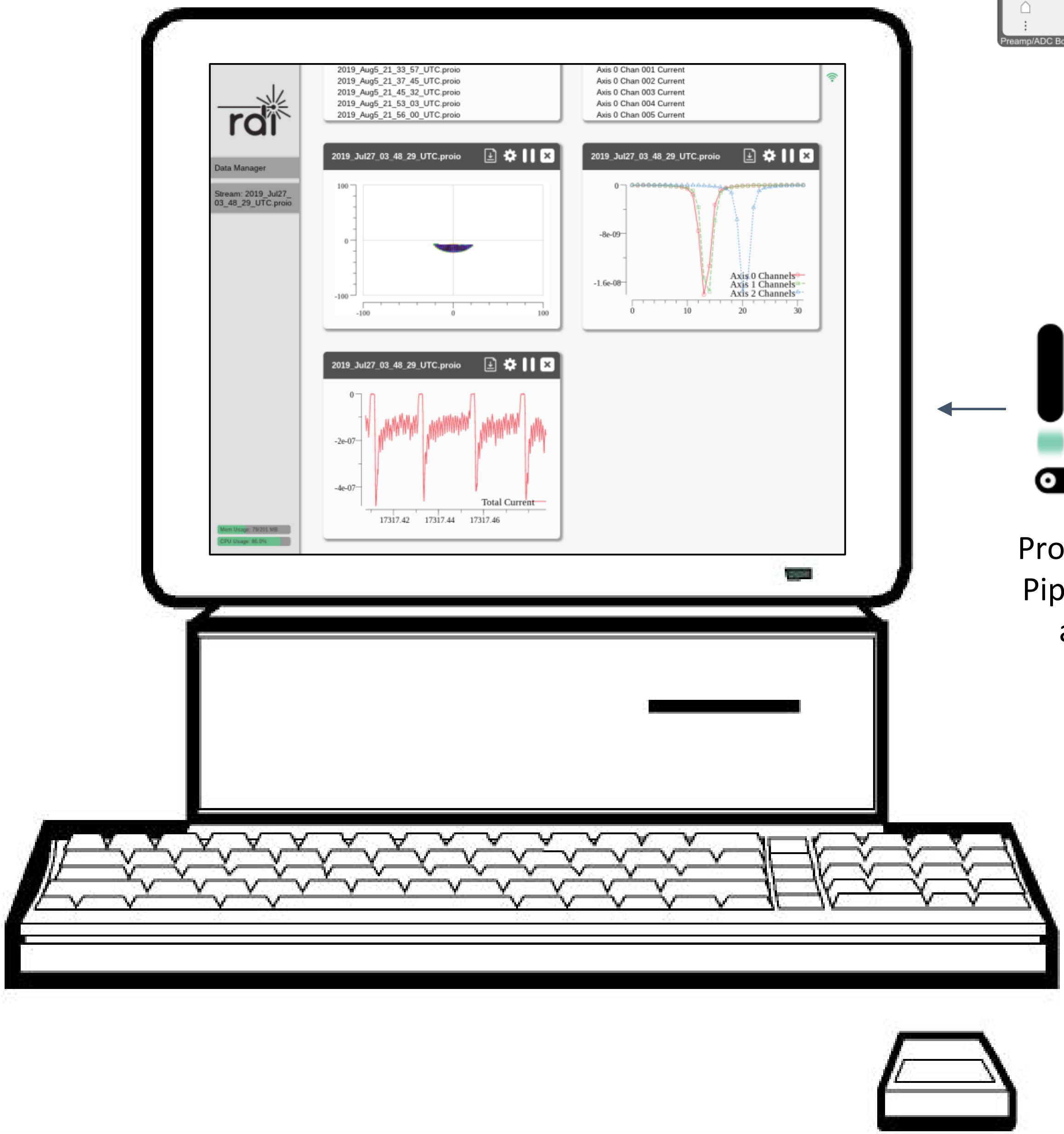


Software

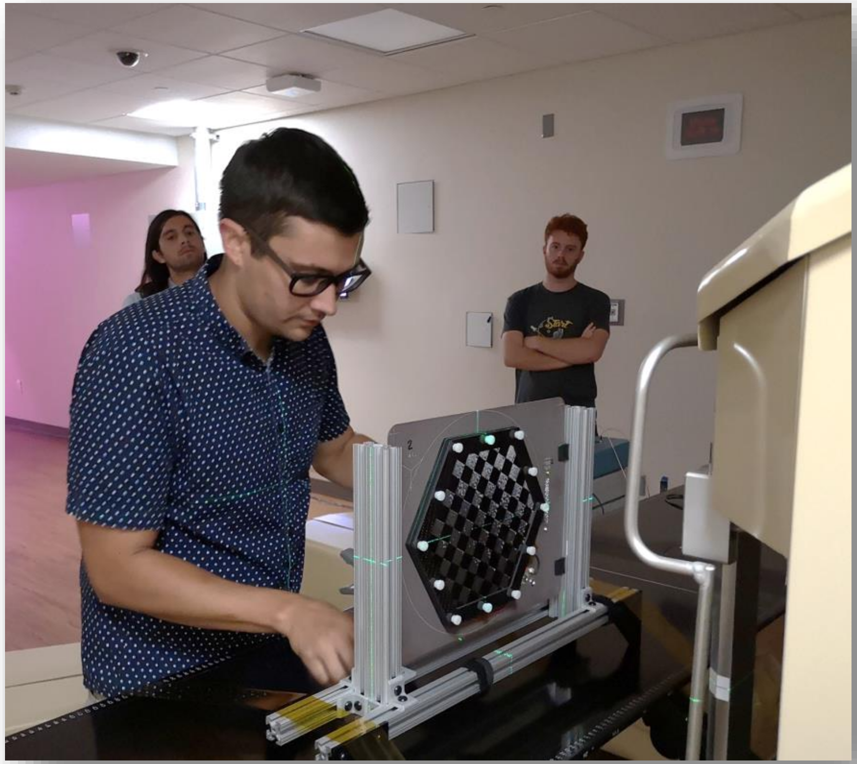
- **Data stream** from front-end modules to the aggregator, and are **processed live** on a pipeline.
    - DAQ uses a **triggerless** operation
    - Uses a streaming format (**ProIO**) developed for HEP and future Electron-Ion Collider physics
- Processing includes calibration and pedestal subtraction, tomography, etc.
- DAQ computer serves **live display** software to the user as a **browser application** served over LAN

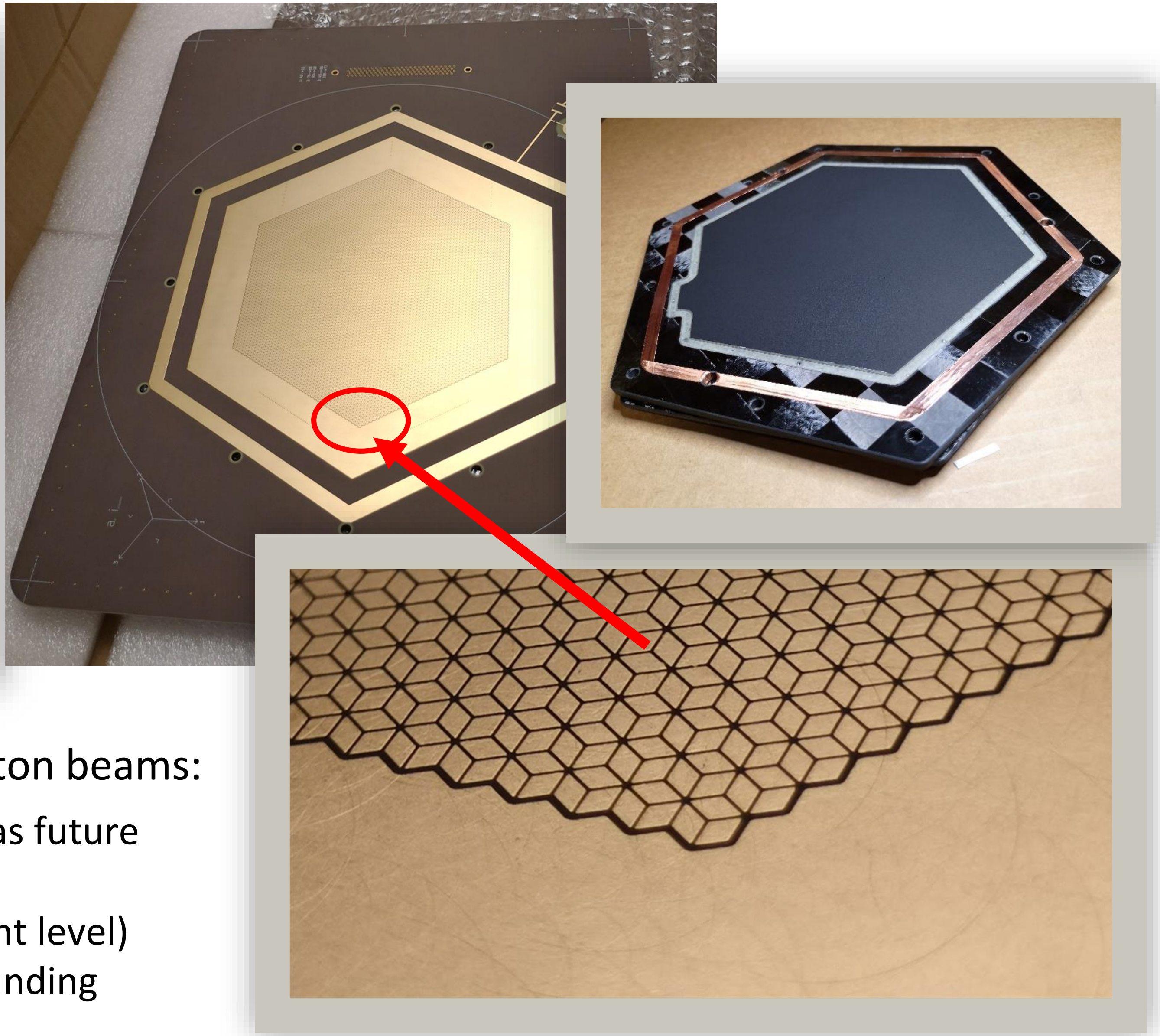


ProIO Processing Pipeline on data aggregator



Experimental highlights for the clinical device





The latest series of tests with Mayo proton beams:

- Same granularity and readout geometry as future clinical detector product
- Same front end electronics (on component level)
- Same cathode technology, biasing & grounding

SBIR project status - summary, conclusions and outlook

I. DOE SBIR program goals

- RDI develops the new tech
- Project goes far beyond the original planned scope
- Few goals are still outstanding

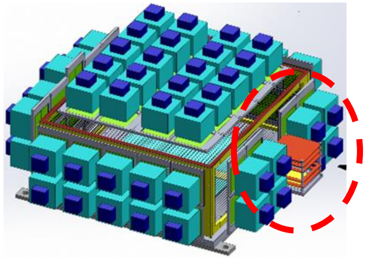
Multi-dimensional readout in a plane
A sub-type of a gas ionization gain detector
A novel way to do tomographic reconstruction

Building the Micromegas
Cost-efficient, high-performance modular DAQ
Design-through-simulation loop
New technologies in data format and analysis
Highly technological, scalable software tech

Publications (in the pipeline)
Scientific applications proof-of-merit (working on)
Pulsed-mode DAQ (now be just another module)

I. Aims at commercialization

- Medical device product(s)
- Scientific product(s)



I. Future of the project

- Micromegas at TAMU
- Micromegas in X-Ray fluence imaging

This project is **JUST GETTING STARTED!**

Thanks everyone at the U.S. DEPARTMENT OF ENERGY Office of Science

THANKS to EVERYONE!

QUESTIONS?