An iris diaphragm e-beam apparatus series (IDEAS) detector for beam halo measurement

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Deputy Director of Research, Euclid Techlabs
on behalf of the team

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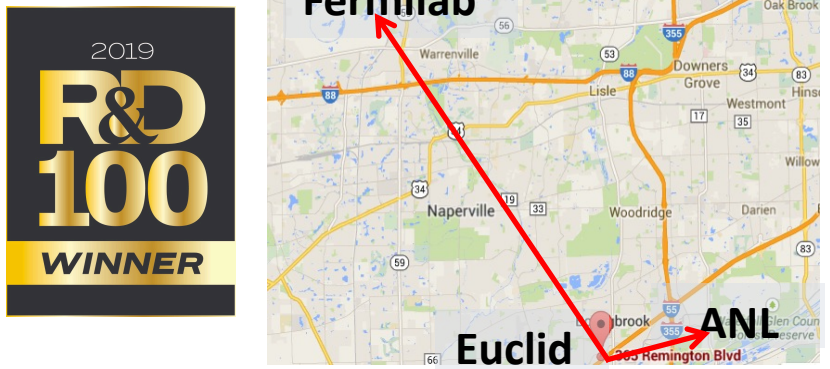
About Euclid Techlabs

- Euclid TechLabs LLC, founded in 1999 is a company specializing in the development of advanced accelerator technologies, new designs for beam physics and high power/high frequency applications. Recently, Euclid has rapidly expanded our list of capabilities (Company Link):
  - Particle Accelerator Development
  - Ultrafast Pulser for TEMs
  - Sputtering Thin Film Deposition
  - Femtosecond Laser Machining of Exotic Materials including Diamond
  - Advanced Ceramic Sintering and Treatment
  - RF and Beam Simulations
  - Mechanical and Thermal Engineering
  - Fabrication and Prototyping
  - Low Level RF System Design

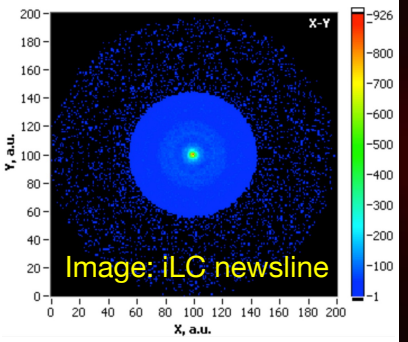


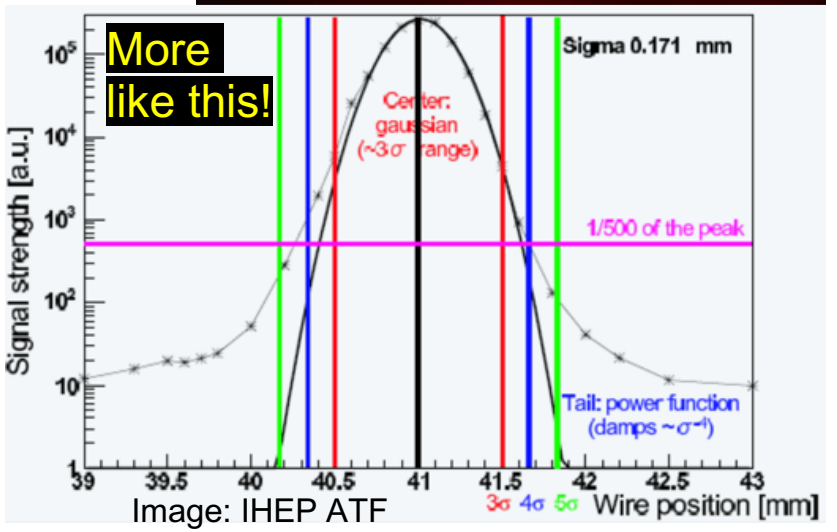
About our team on this project

- Ao Liu, Ph.D., PI
  - Deputy Director of Research
  - Degree from Indiana U & Fermilab on beamline R&D for muon and neutrino programs, lattice design, simulations and optimization algorithms
  - Current research interest: multidisciplinary: novel beam physics and technology; thin-film applications, machine automation applications in accelerators; software
- 3 more Ph.D., 3 engineers and 1 intern.
  - All with diversified background and knowledge

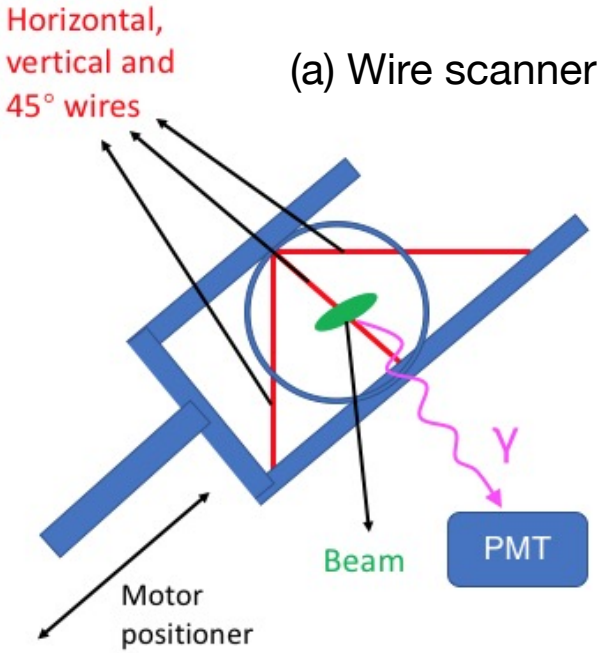
Background

- Beam halo
  - Non-Gaussian beam distributions around the beam core
  - Does many bad things: uncontrolled loss, radiation, etc.
- Multiple destructive or non-destructive techniques have been developed and tested
  - Non-destructive, *cons*: expensive, complicated setup, multiple copies not feasible; e.g. gas sheet, digital micromirror arrays
  - Destructive, *cons*: well, destructive…, interrupts the normal beam operations; e.g. wire scanner, a YaG…

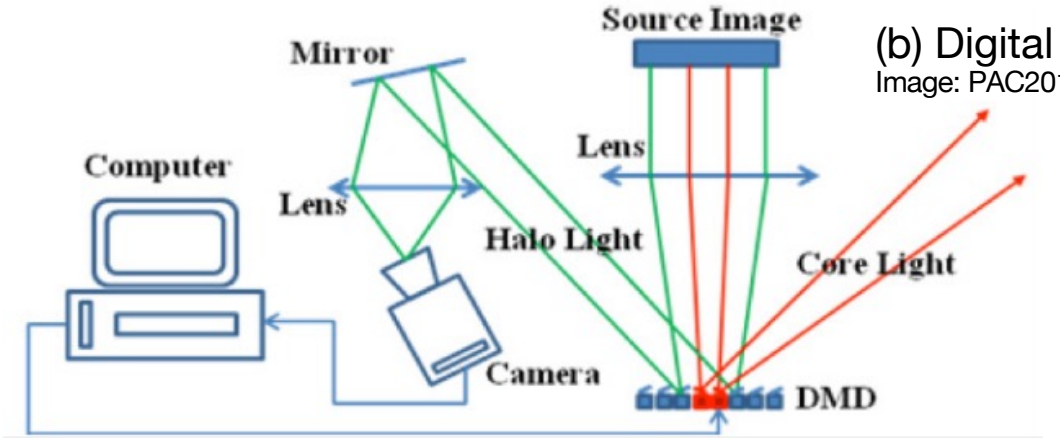




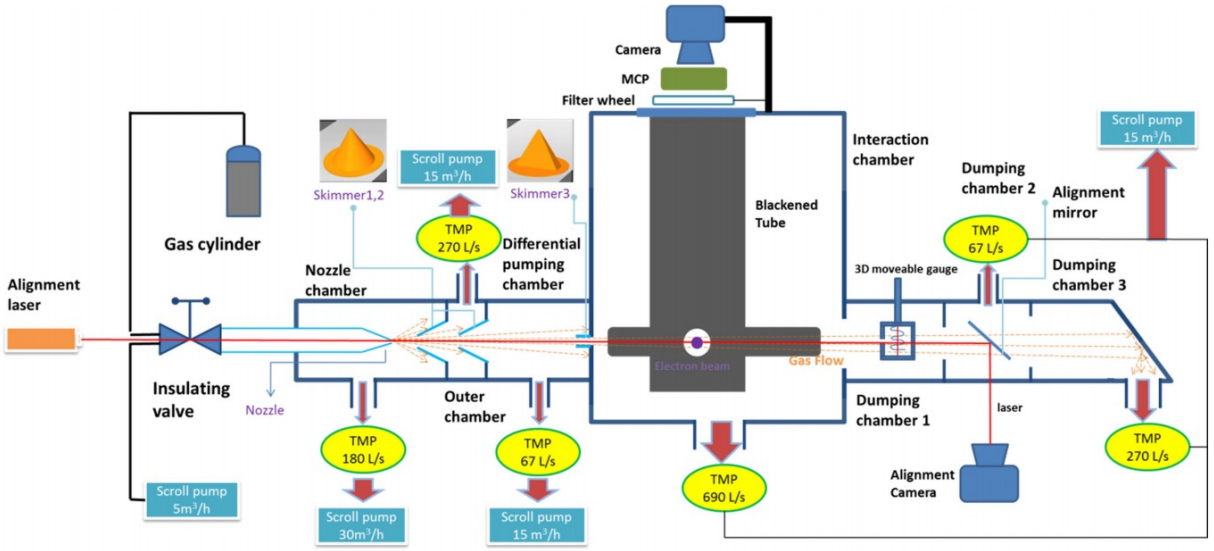
Three examples of halo measurement techniques



(a) Wire scanner



(b) Digital micromirror array device (DMD)
Image: PAC2011, WEOCN5, Zhang, et al.



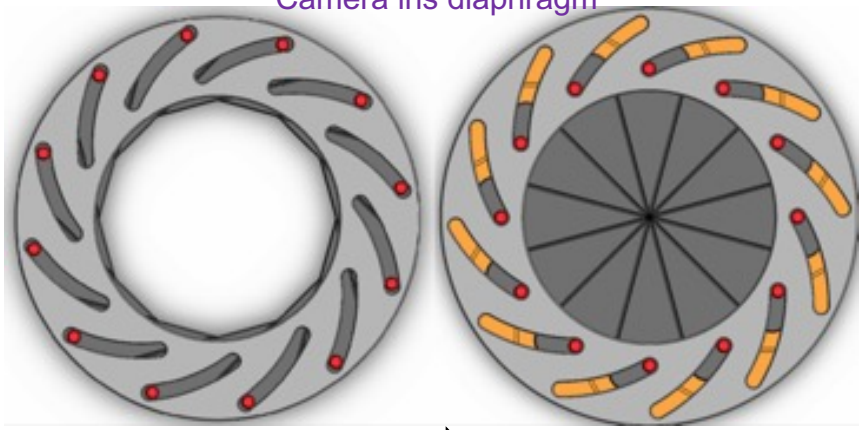
(c) Gas jet profile monitor
Image: IPAC2017, MOPAB139, Zhang, et al.

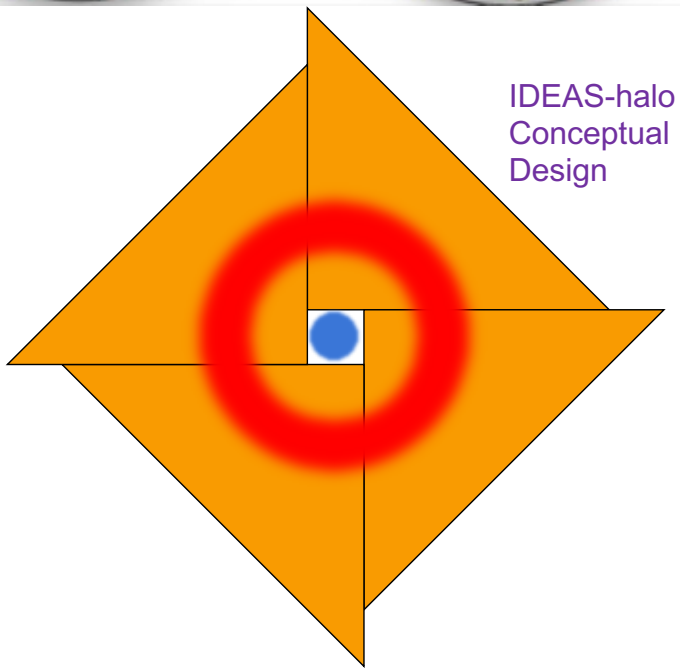
Is there a cost-effective device that can combine the pros and avoid the cons?

Introducing the IDEAS-halo

- Iris diaphragm e-beam apparatus series (IDEAS)
- IDEAS-halo was inspired by…
  - An actual iris diaphragm! (for cameras)
- Concepts:
  - Use iris blades to intercept outlier charges, which generate current signals;
  - Use non-conductive thin-films to isolate blades for independent signals;
  - Iris opens to let more beam pass and closes to intercept more;
  - Iris is actuated by a vacuum linear actuator;
    - UHV-compatible piezoelectric positioners can be used, too

Camera iris diaphragm

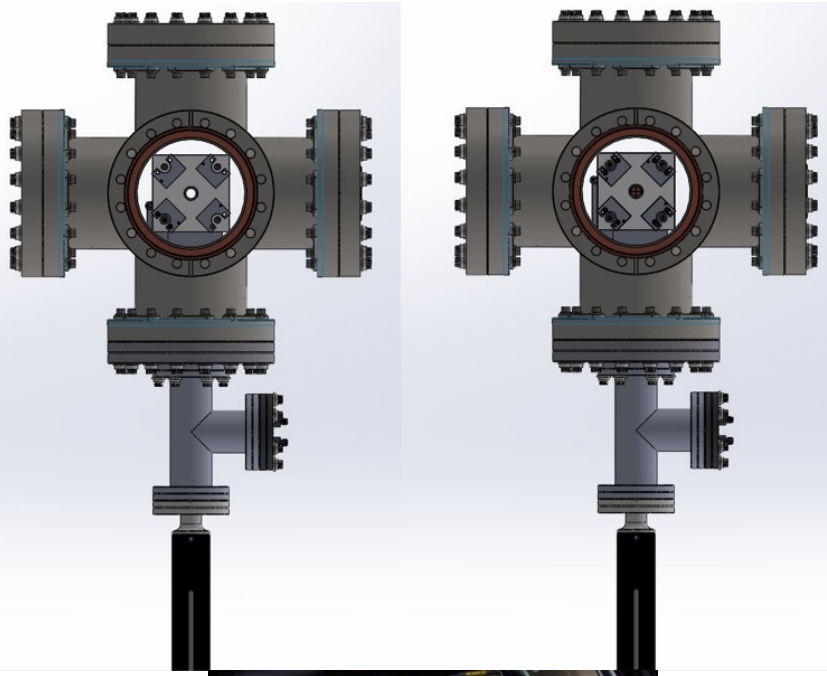




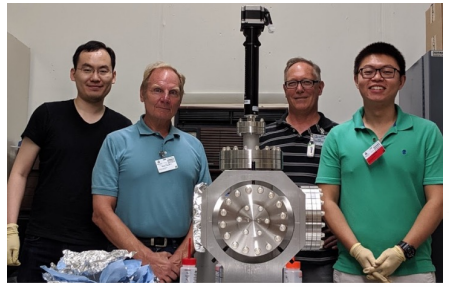
IDEAS-halo Conceptual Design

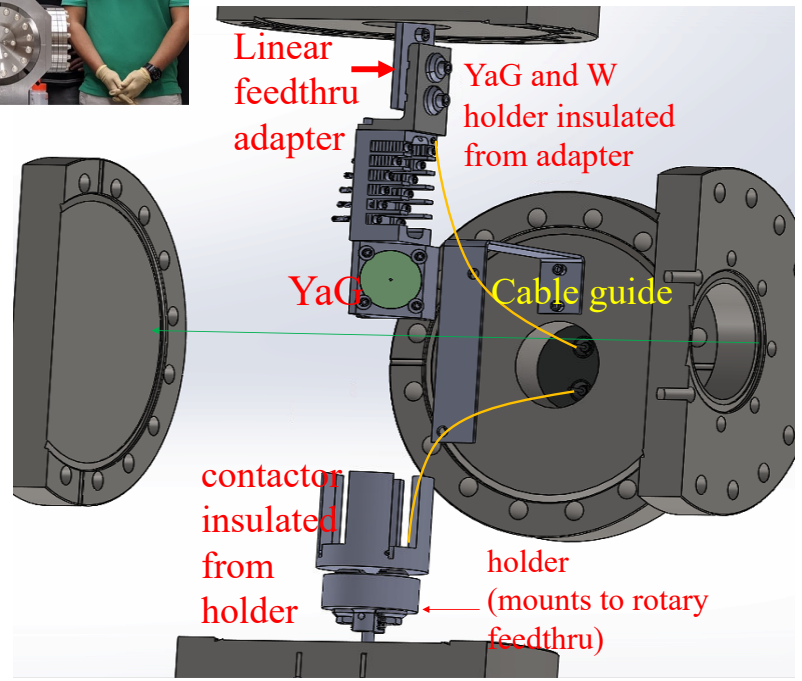
Advantages of IDEAS-halo

- Cost-effective
  - Modular design significantly brings the cost down
- Dual-purpose
  - Beam halo/profile measurement
  - Beam collimator – a variable collimator
- High portability
  - All mounted on a 6” CF 6-way/4-way cross
  - You can transport it in the trunk of your car
- Fast signal response
  - Measured signals largely preserve timing structures of the beam

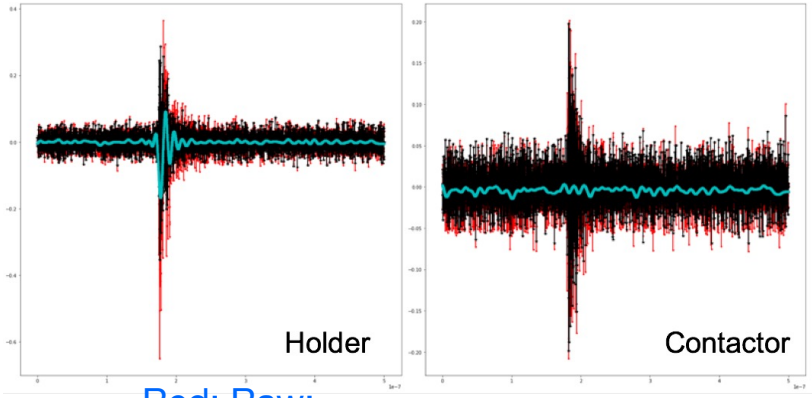


Proof-of-principle version-alpha

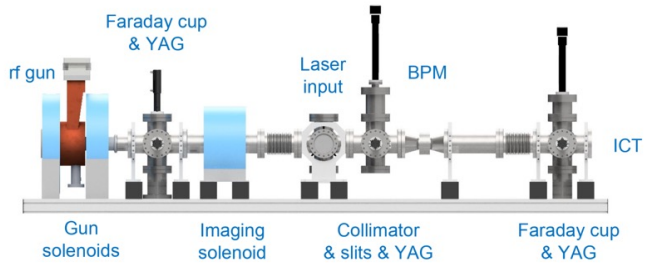


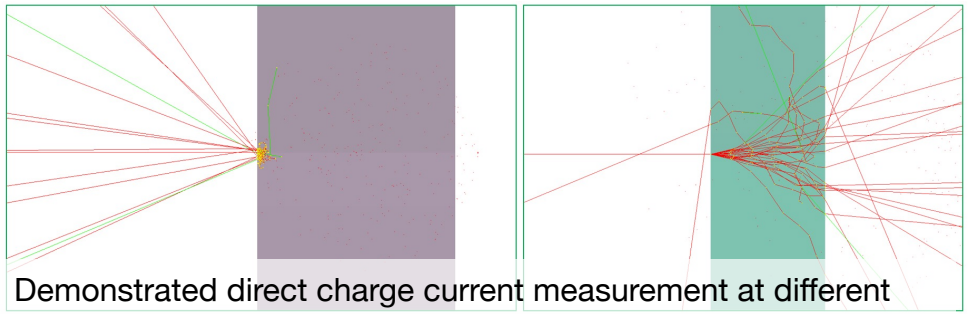


- AWA cathode testbed (ACT) @ ANL
- 1-2 MeV electron beam bombarding metal blades at various thickness made of different materials;
- Current signal extracted from the blades to SMA ports;
- Ceramic insulation of signals from conductors;
- UHV compatibility



Red: Raw;
Cyan: LP filtered; Black: HP filtered

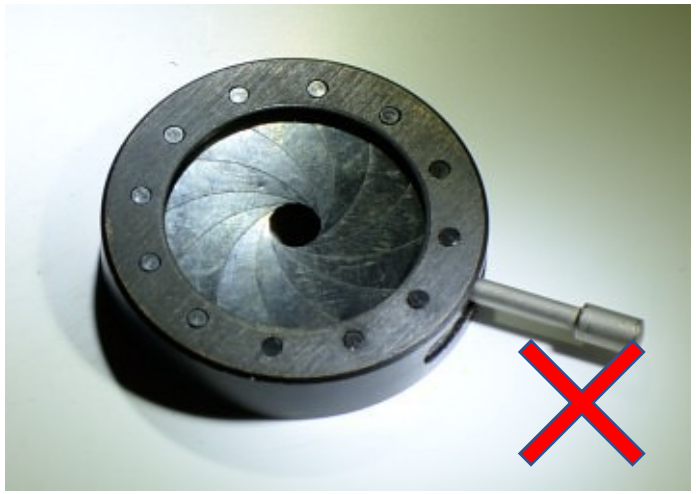


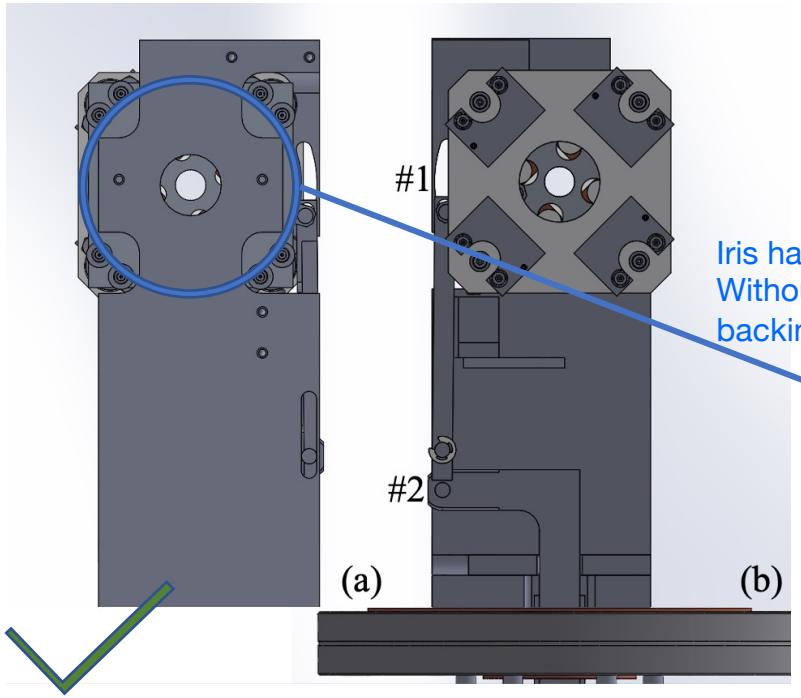


Demonstrated direct charge current measurement at different stopping power, agrees with Geant4 simulations

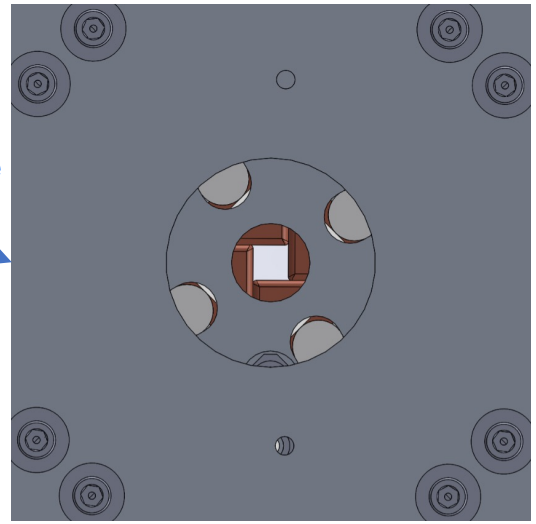
Iris structure – challenge #1

- Mechanical design of the iris structure
  - Mobility
  - Electrical properties
  - Vacuum compatibility



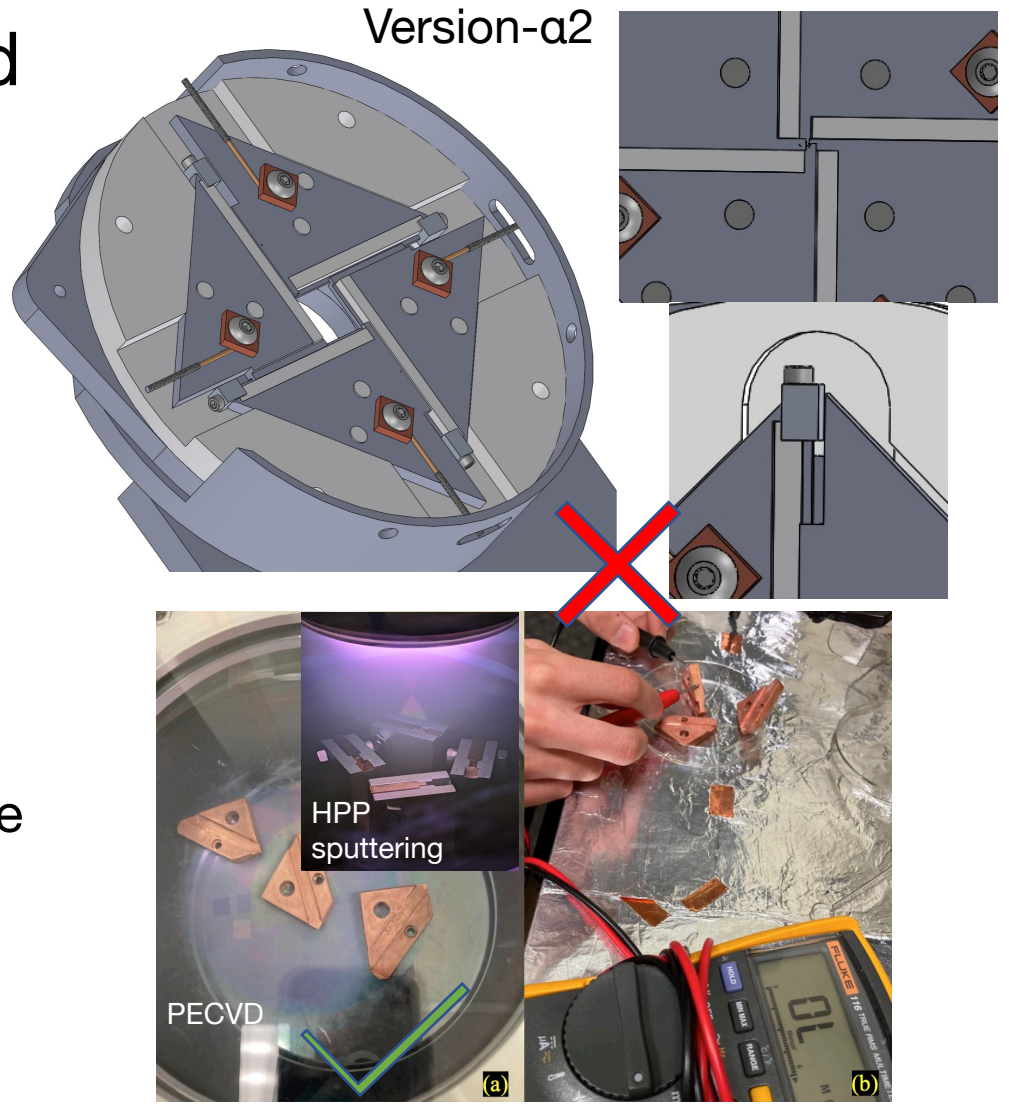


Iris half-open
Without the
backing plate

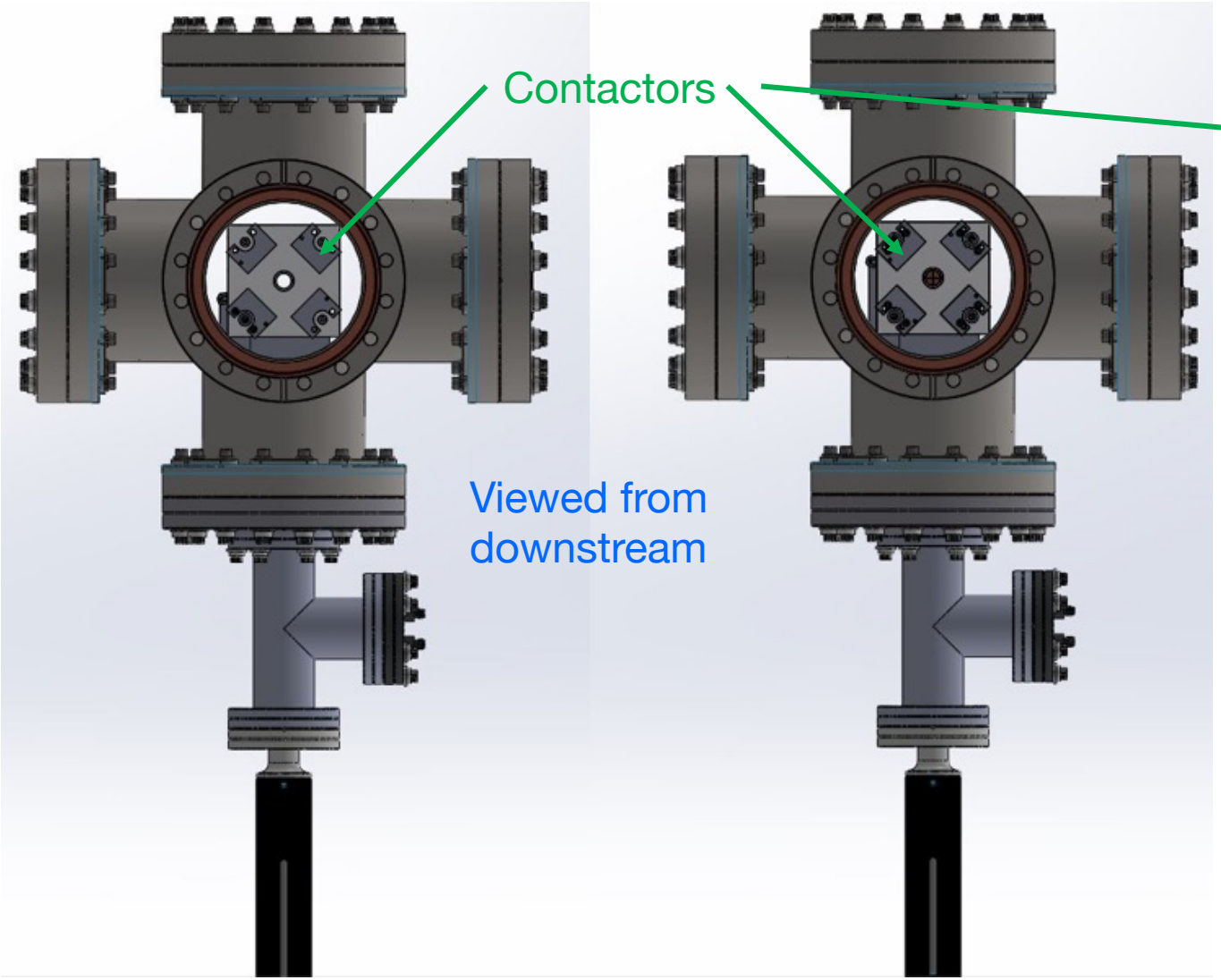


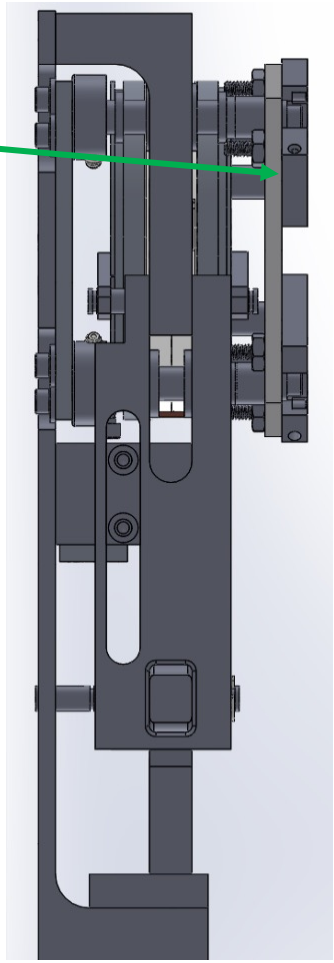
Iris structure – challenge #2

- Electrical insulation between blades and from the housing
  - ~~– Ceramic slabs~~
    - Charging issues
    - Mounting/Mechanical issues
    - Assembly issues
  - – Thin-film insulation
    - Choose the right materials
    - Polished surfaces on the sides
    - HPP RF Sputtering or PECVD
    - UHV-compatible lubricant for smoother slippage



Newest version – beta100



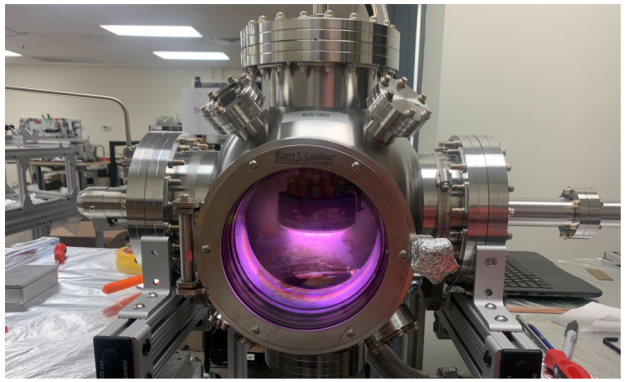


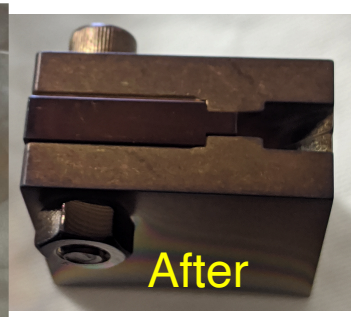
Sideview

- Apparatus on one 6” CF port (zero-length reducer)
- Small space occupied, portable
- 4 independent signal outputs (each contactor connects with a SMA feedthrough port)
- Thin-film between blades
- Ceramic guiding plates for insulation from ground
- Innovative mechanical structures to improve mobility

Insulating thin-film deposition

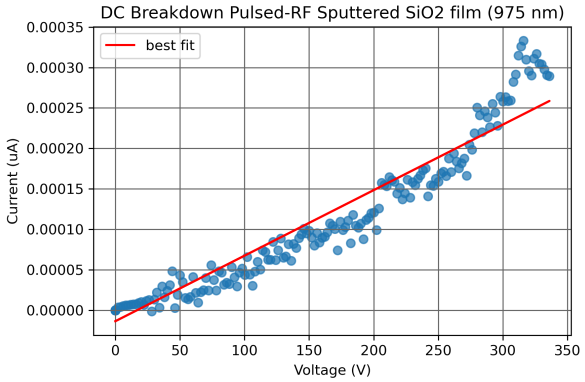
- Non-conductive SiO_2 thin-films
  - Wonderful electric and thermal properties
  - Stable in vacuum and at high temperatures
  - Well known deposition techniques
- "Paprika" RF sputtering system @ Euclid
  - Nominal CW RF sputtering
    - 200 Watt limited by target tolerance
  - Improved thin-film quality through high power pulsed (HPP) RF sputtering
    - 600 Watt limited by the RF source, 10% duty factor
    - DeFlesko PosiTest AT-A Adhesion Tester: 3000 kPa to lift
- PECVD @ CNM
  - Less strong thin-film but higher reliability
- Euclid supports young scientists
  - IPAC2021 THPAB278 – Mr. John Callahan (Fresh bachelor graduate from Illinois Institute of Technology)

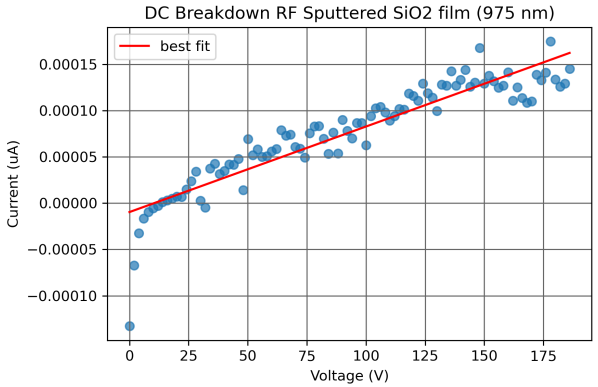




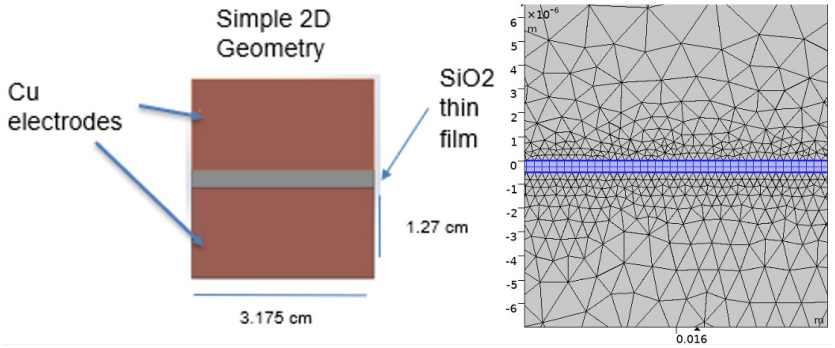
Insulating SiO_2 thin-film properties

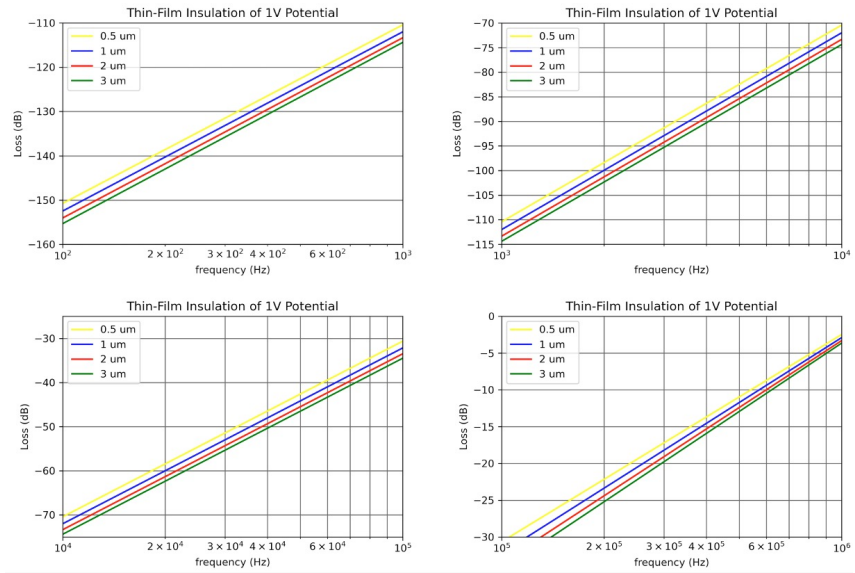
- High DC breakdown:
  - Up to **350 MV/m**!





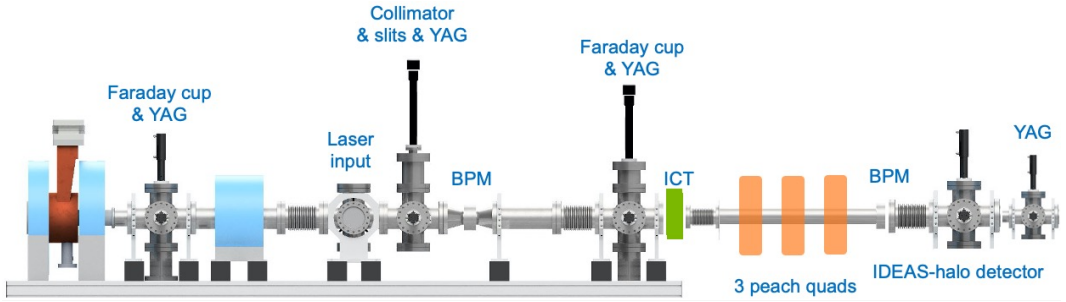
- Capacitive frequency response to AC – less insulating at higher *f*.

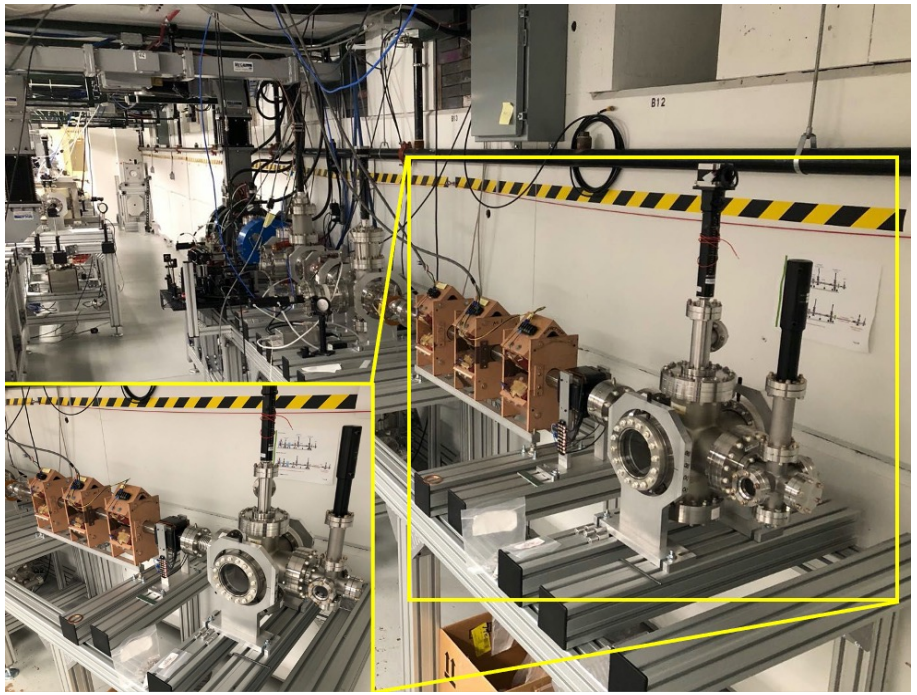




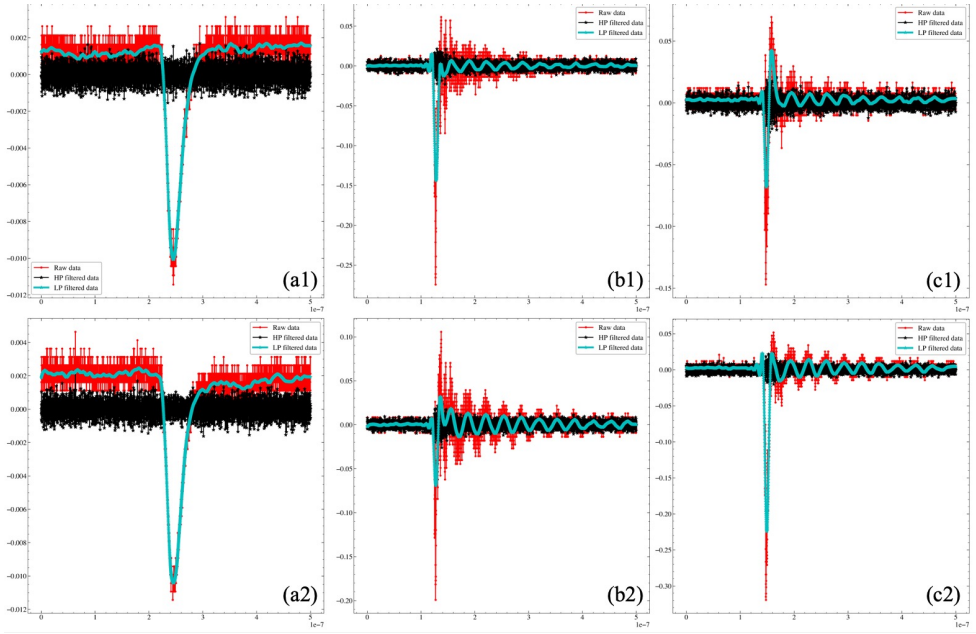
Experiments – AWA's ACT

- Tested version: beta004
  - Very similar to version-beta100 other than mechanical structure
  - Iris unfortunately immobile (half open)
  - Two output ports only (2 adjacent combined)
- Main objective: signal response

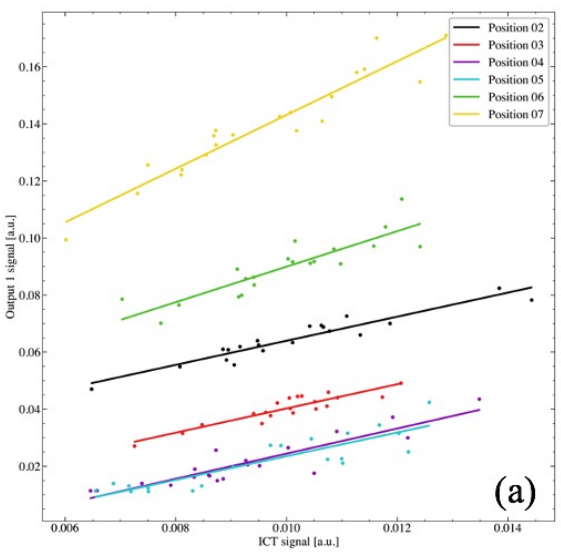


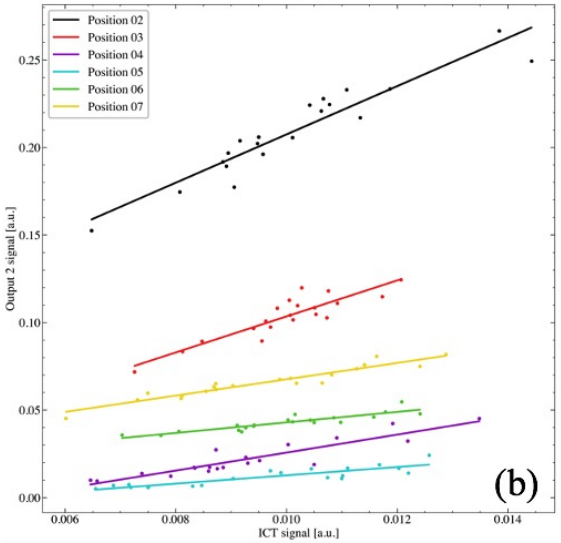


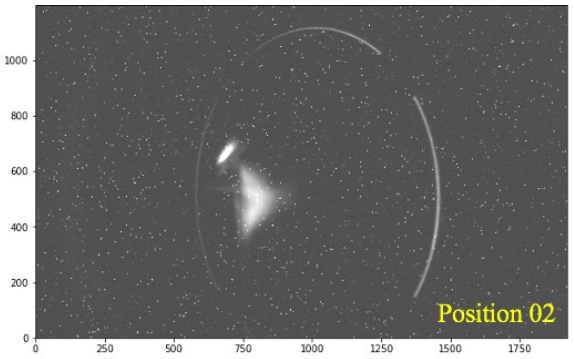
Similar to version-alpha: LP filter needed

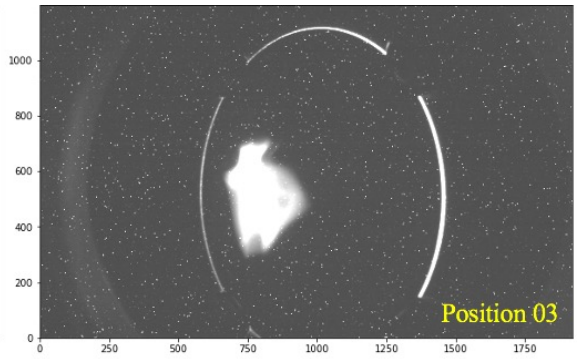


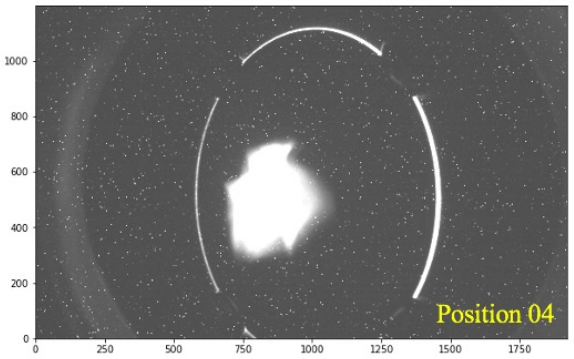
Version-beta004 signal response to positions

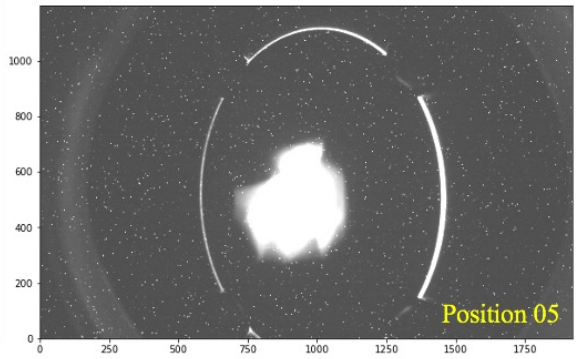


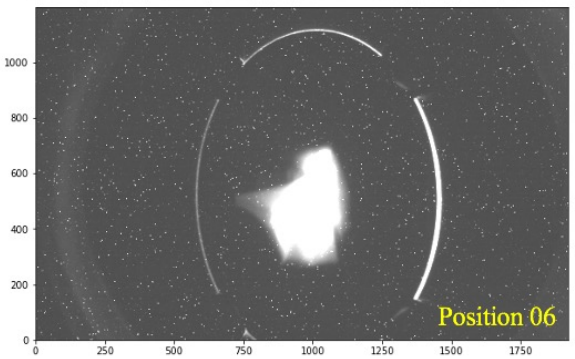


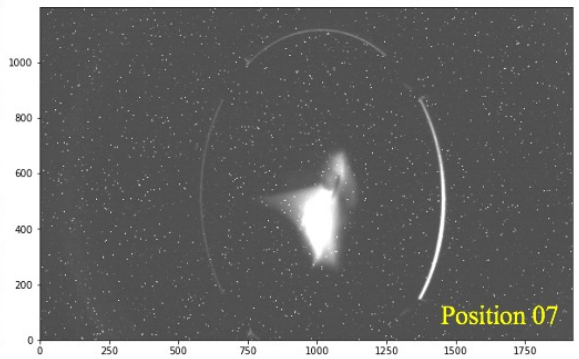








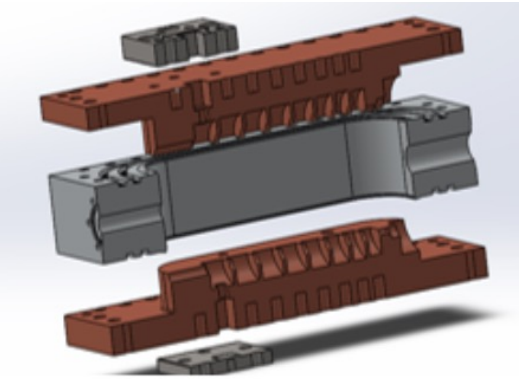




- Moved beam from left to right
- Signal transferred from left (b) to right (a)
- Beam distribution can be measured with mobile iris

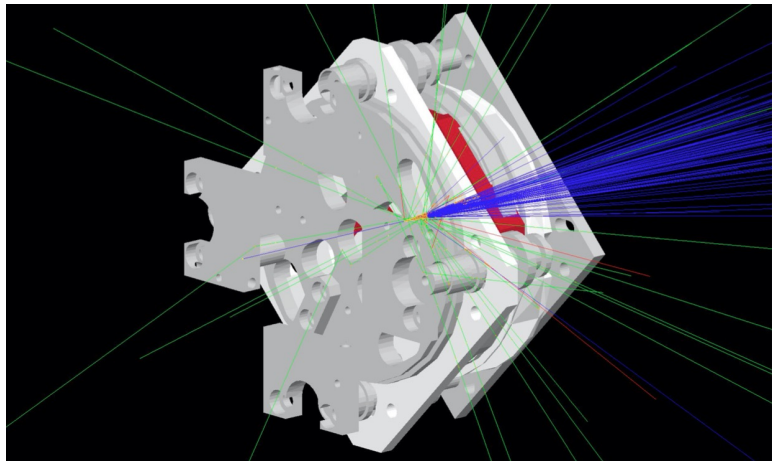
Version-004 – other experiments

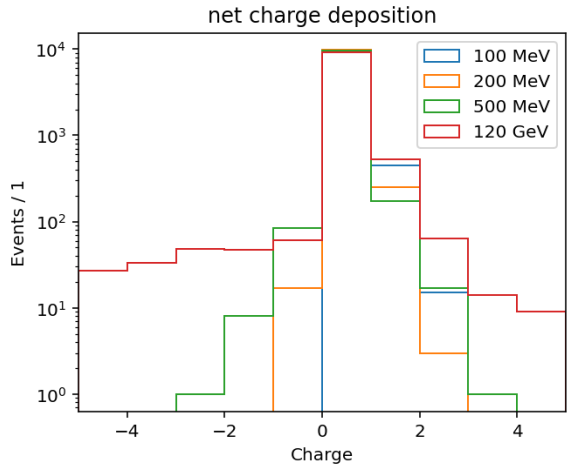
- Tested with pulsed e^- beam at Euclid
  - ~ 1 MeV pulsed beam with a novel “Brazeless” structure
  - Same signal response behavior as at the ACT experiment seen
- Tested with DC transmission electron microscope (TEM) beam
  - 200 keV beam from a thermionic gun (LaB_6)
  - SiO_2 insulation worked perfectly in the DC regime
    - Independent signals from 4 channels
  - Beam experiment opportunities open to lab collaborations



Version-beta100 plans

- Vacuum tested at high 10^{-8} Torr
- Iris mobile (see videos)
- Electron beam experiments:
  - ACT (End of Sep 2021)
  - Duke University FEL facility's linac beamline (~ 100 MeV), installation Sep 2021, experiment Oct 2021.
- Proton beam experiments
  - Geant4 simulations showed interesting charge deposition v.s. proton E





Planning:
NY proton center (~200 MeV);
Fermilab test facility (120 GeV)

Conclusions

- IDEAS-halo is a novel detector that serves for:
  - Beam halo/profile detection
  - Beam halo collimation
- IDEAS-halo is equipped with novel technologies:
  - Novel thin-film insulation scheme;
  - Vacuum linear actuator control scheme;
- IDEAS-halo is cost-effective, portable, customizable and it works
  - Demonstrated with pulsed or DC e^- beams
  - Tests with proton beams with various energies next
- IDEAS-halo is ready for more tests and usage!

Thank you!

Questions?