Northeastern University

Indirect Dark Matter Searches with GAPS and GRAMS

Jan 3rd, 2024,

Jiancheng Zeng(NEU)

About me

Northeastern University

- Physics Undergrade at Sun Yat-sen University(China)
- Fifth year grad student at Northeastern department of physics.
- Worked on Bio-Physics for 2 years, designing electronics readout(FPGA).
- Currently working on cosmic antinuclei analysis, payload assembly and TPC hardware design with prof Tsuguo Aramaki(And every tedious small thing related …)

Outline

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- Dark matter and indirect dark matter search
- GAPS
- GRAMS

What is Dark Matter

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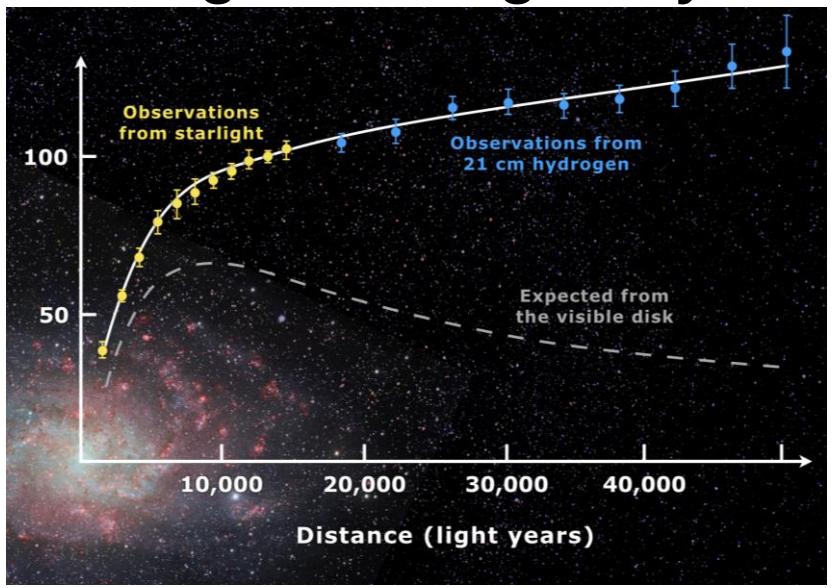
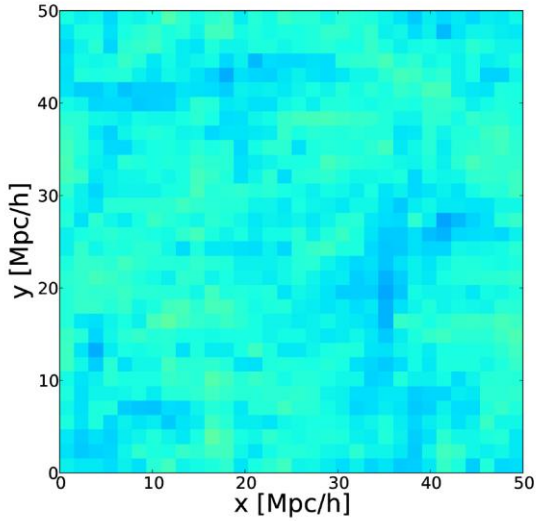
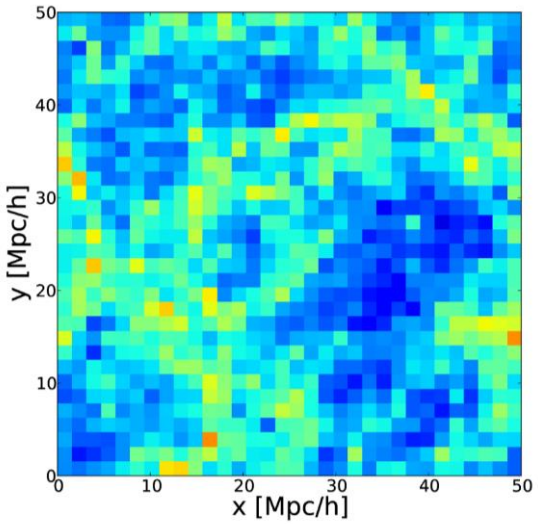
- Evidence we saw
  - Galaxy rotation curve
  - Bullet Cluster gravitational lensing
  - Large scale galaxy structure







Dark matter particles exist!

http://wwwmpa.mpa-garching.mpg.de/gadget/

WIMP Searching game

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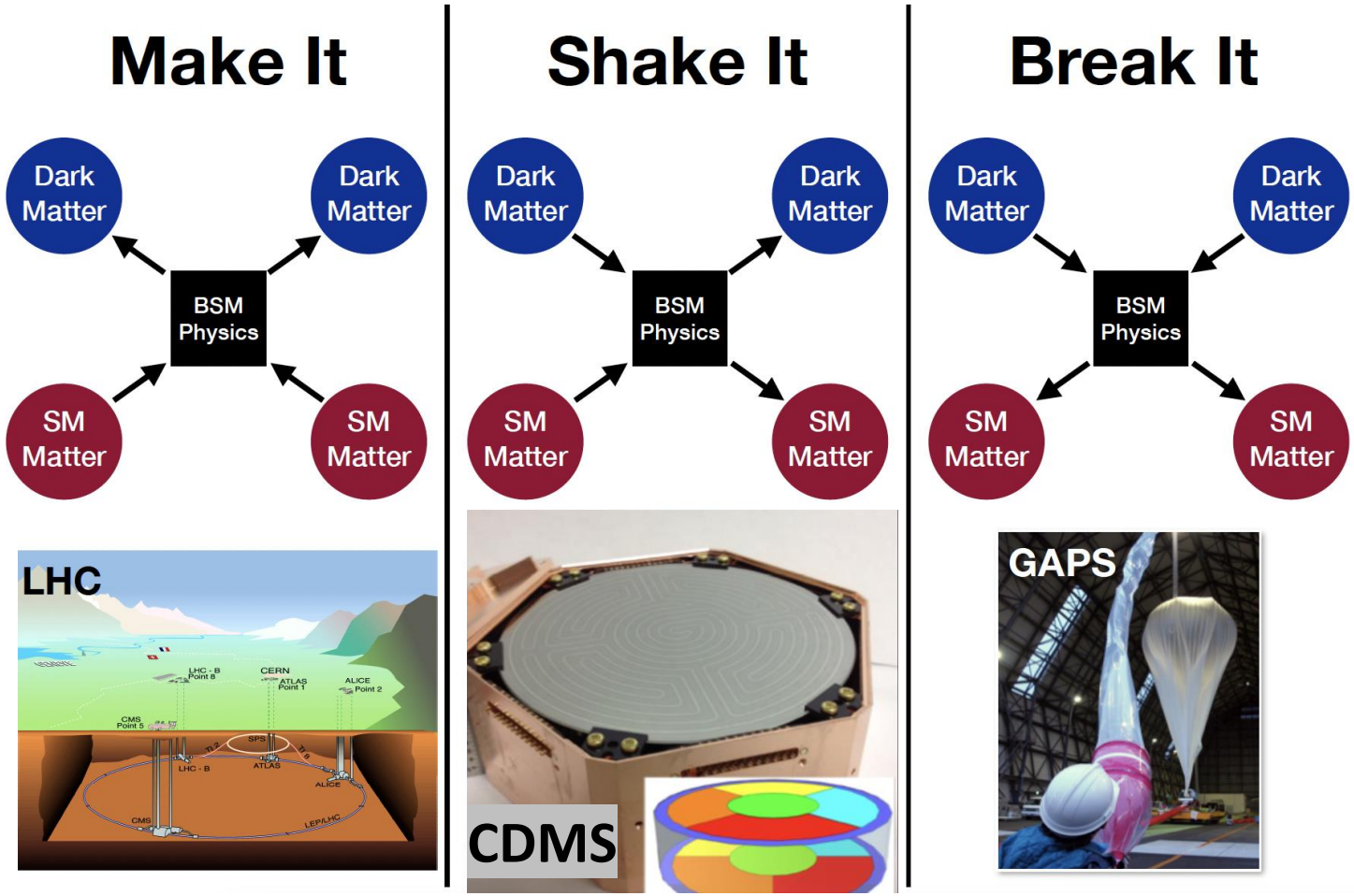
- Production in the lab
- Direct detection
- Indirect detection(What I worked on)



Cr: Gabriel Bridges

All methods give valuable info

Indirect Searches

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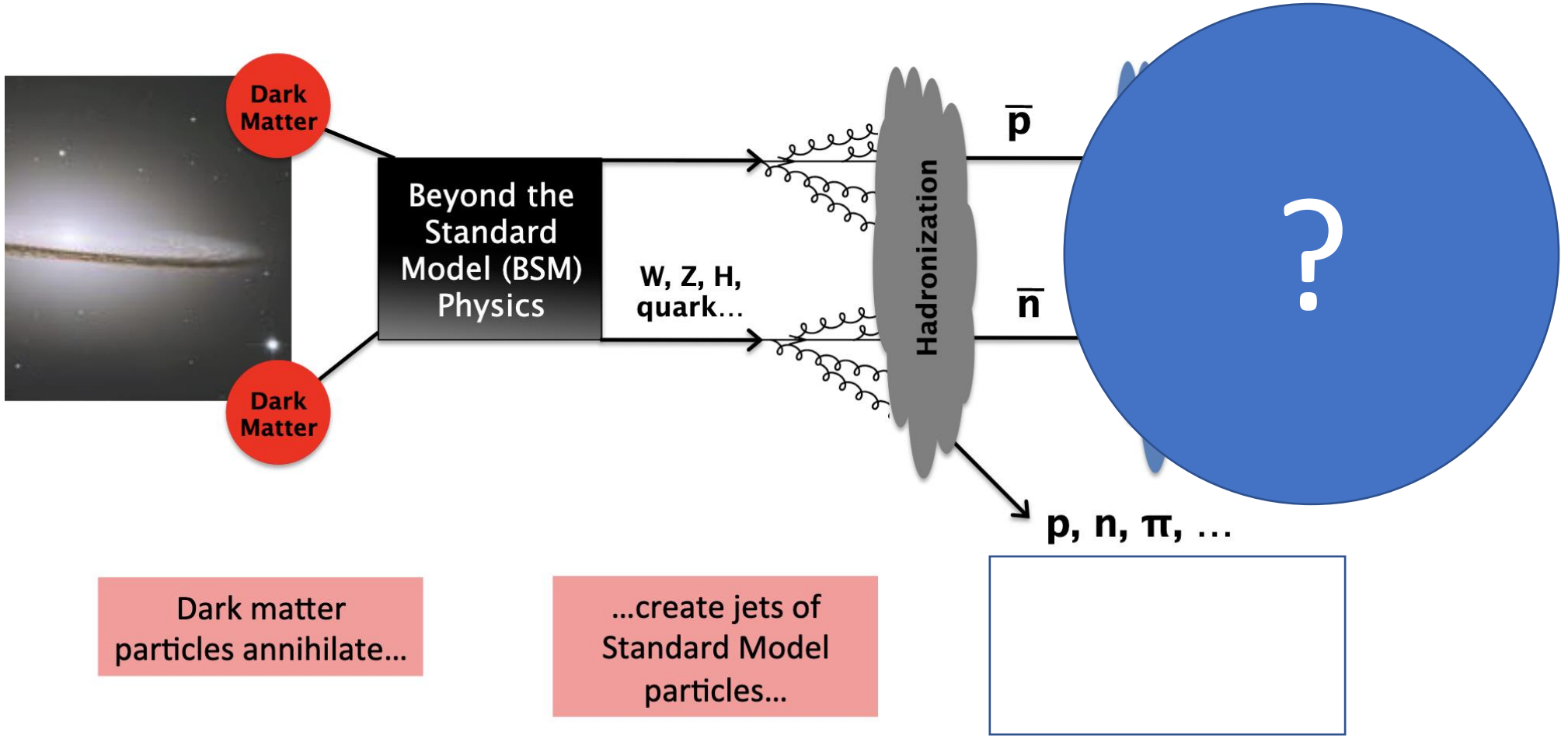

Finding products generate by DM self interaction

Indirect Searches

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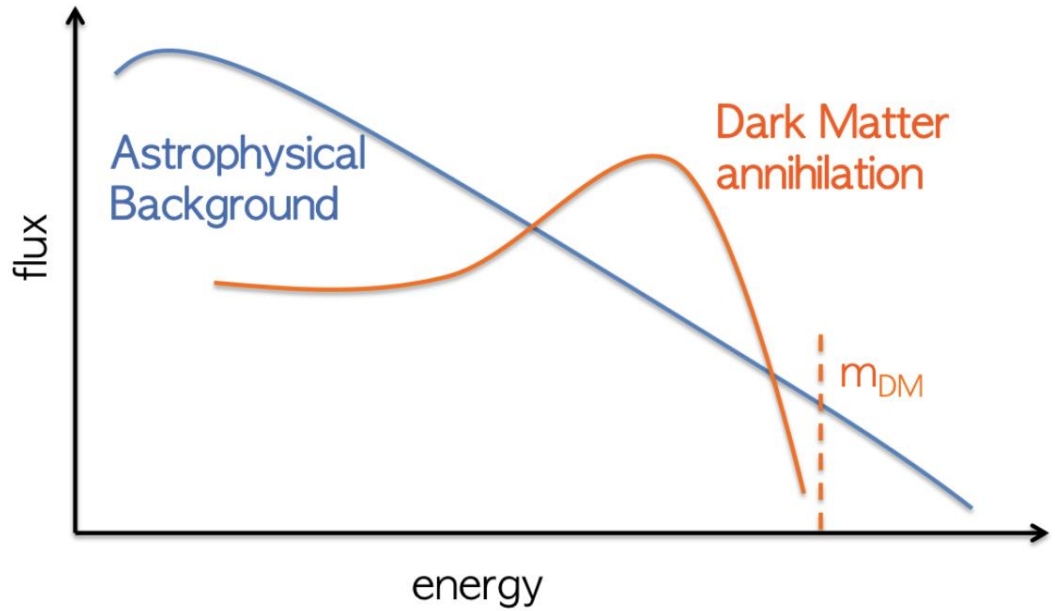
- Indirect searches focus on detecting an anomalous flux of photons, neutrinos or cosmic rays produced in annihilations or decay of dark matter particles gravitationally accumulated in heavy objects, like galaxies, or the sun



Detect what stand out of the background

Indirect Searches

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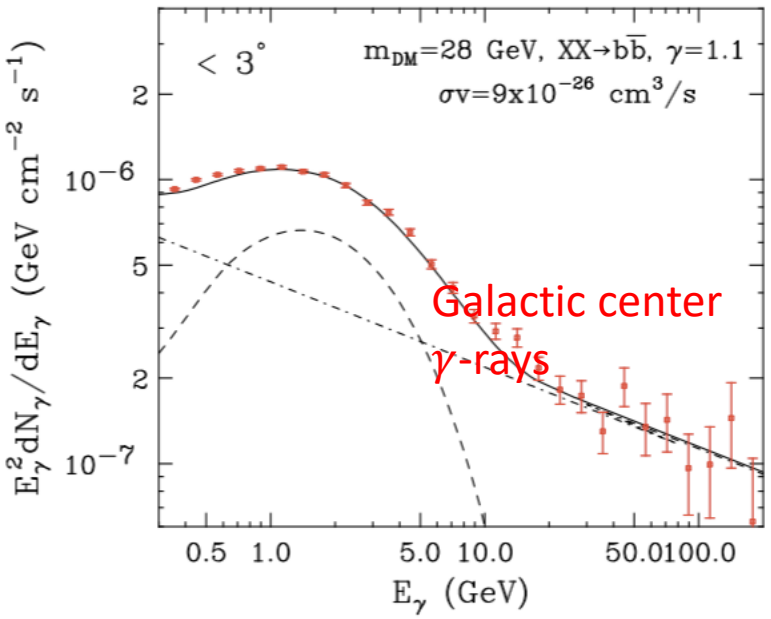
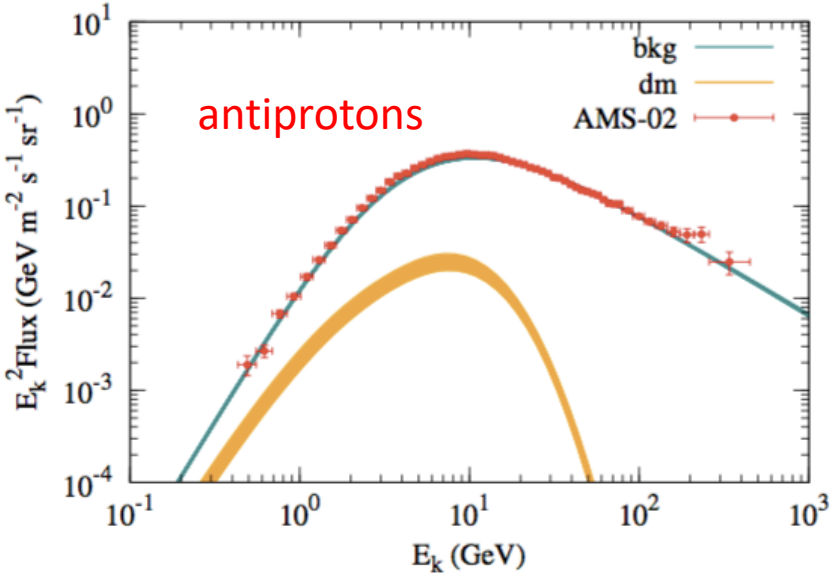
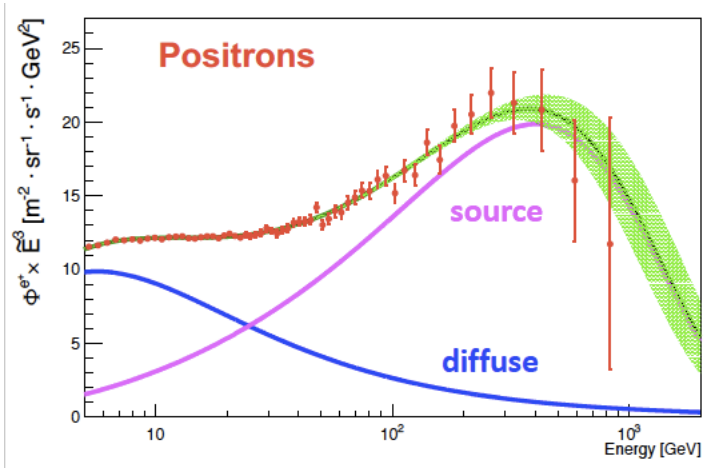
- Uncertain astrophysical backgrounds make indirect searches harder







We need background-free searches!

Indirect Searches

Northeastern University

- Low energy antideuteron give an essentially astrophysical background-free new physics signature

Antiproton Production:

$$p + p \rightarrow p + p + \boxed{p + \bar{p}}$$

Anti-deuteron Production:

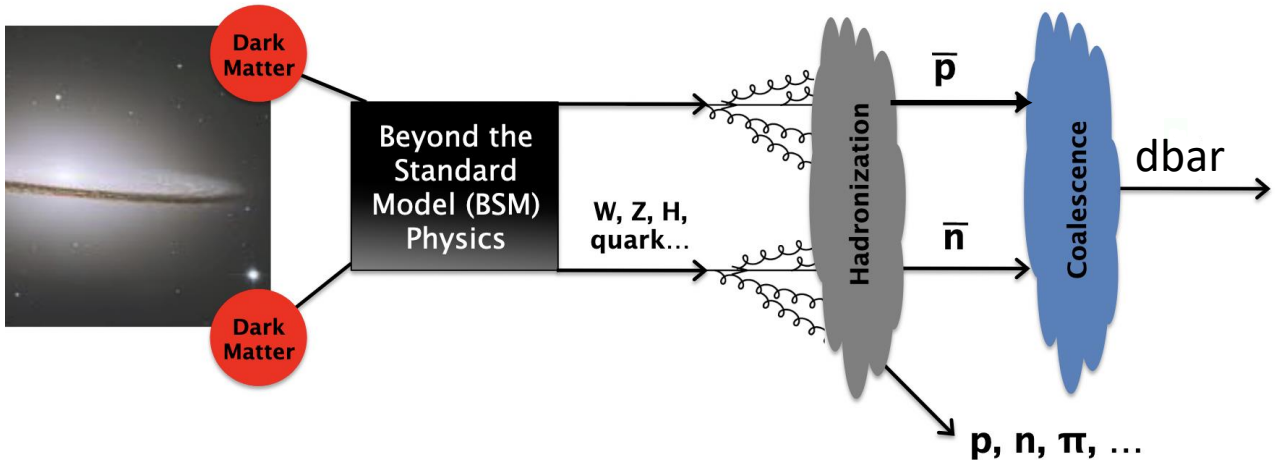
$$p + p \rightarrow p + p + \boxed{p + \bar{p} + n + \bar{n}} \rightarrow \bar{d}$$

- Threshold exist• Expect most antideuteron to come out with a few GeV
- **Almost impossible to produce low energy anti-deuterons from standard astrophysics**

Indirect Searches

Northeastern University

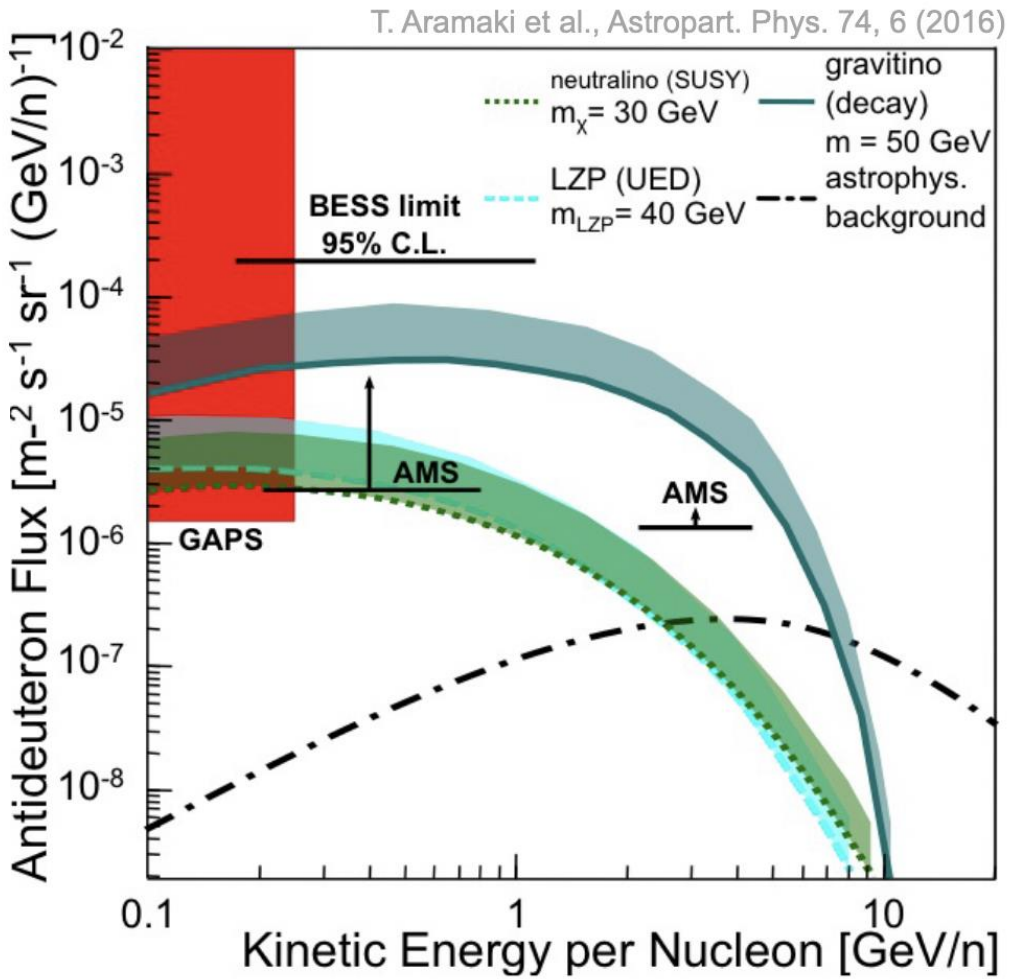
- Low energy antideuteron give an essentially astrophysical background-free new physics signature



Dark matter particles annihilate…

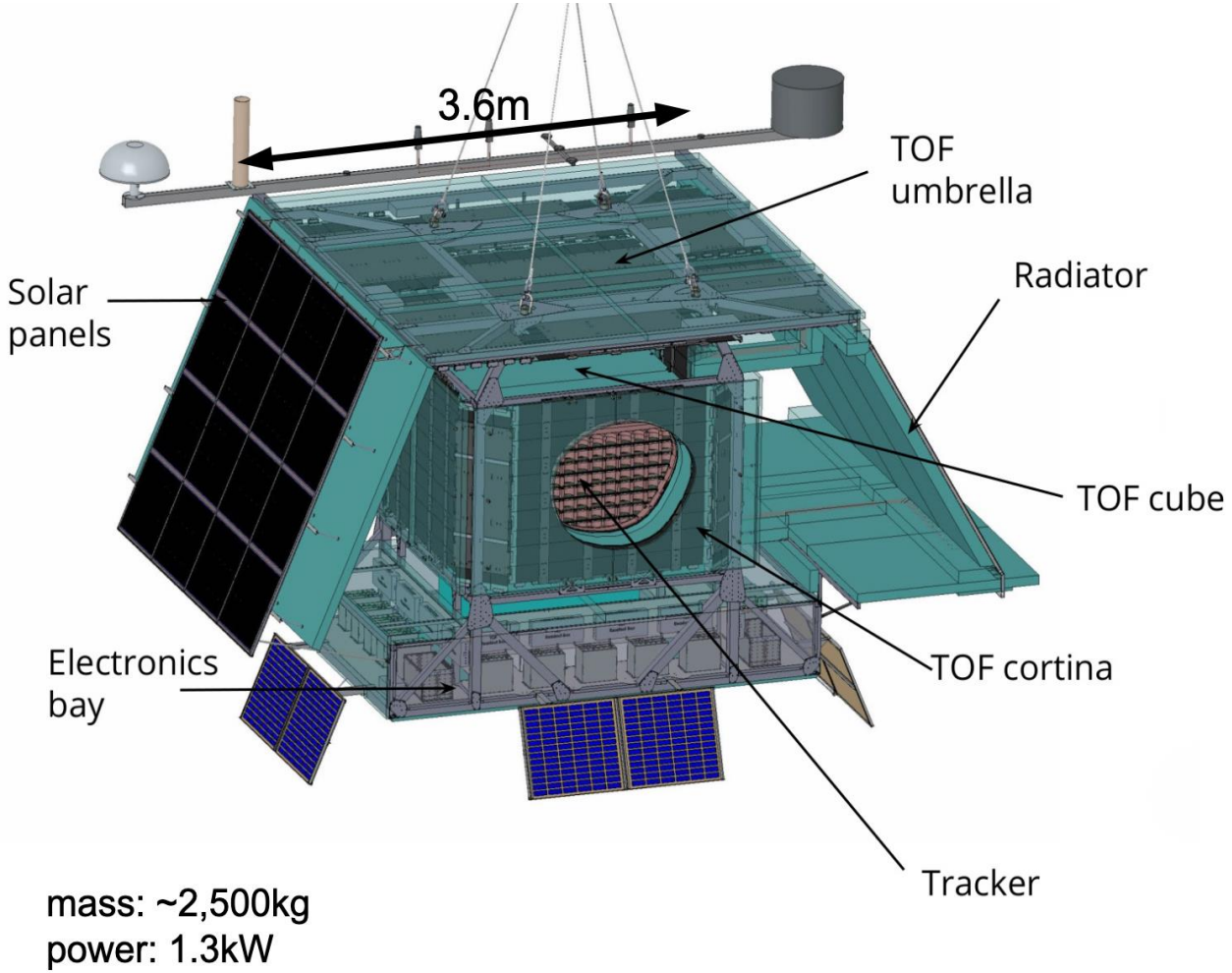
…create jets of Standard Model particles…

…some of which can make an antideuteron…



So let's targeting on antideuterons!

GAPS

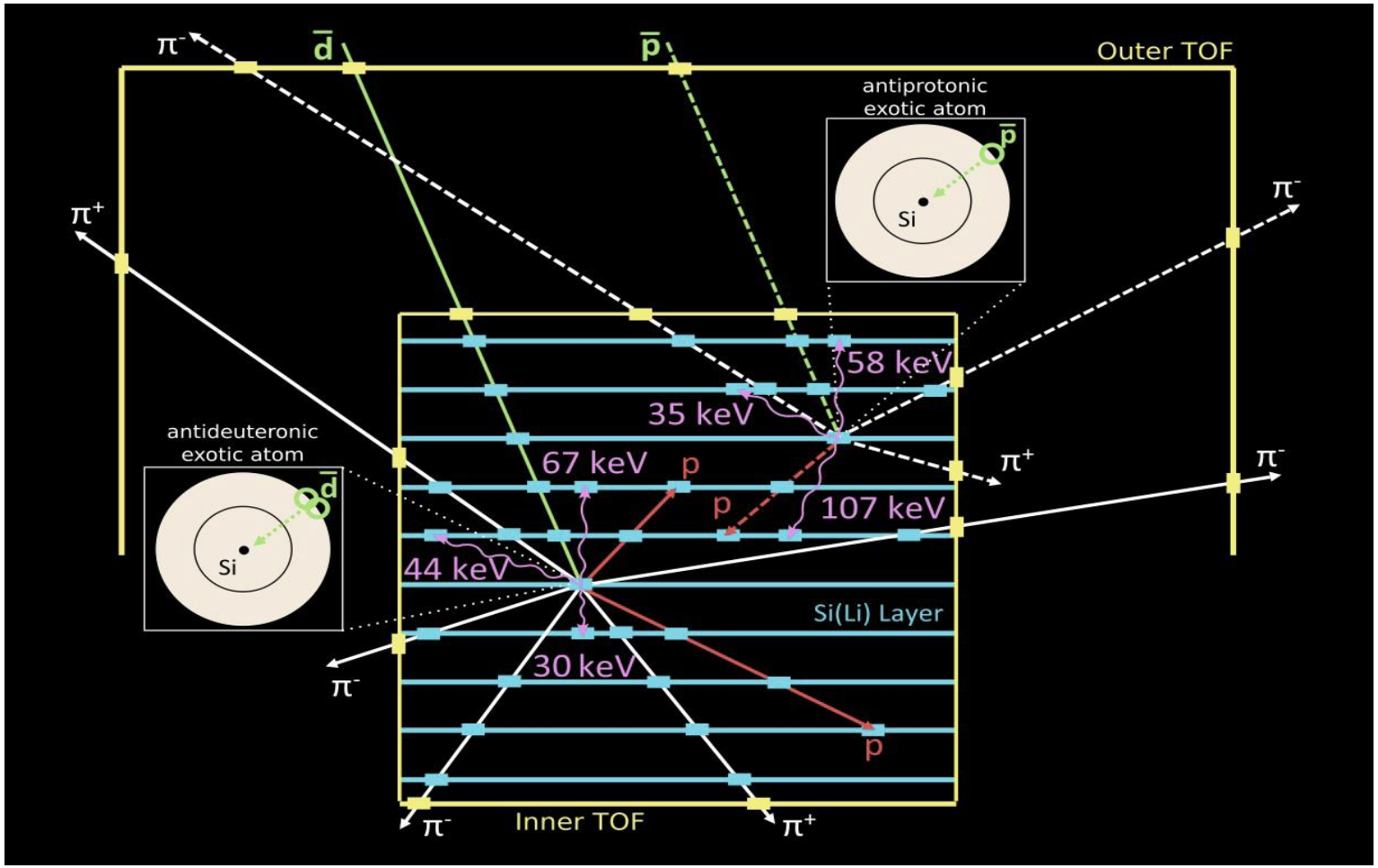


- General Antiparticle Spectrometer
  - GAPS is the first experiment dedicated and optimized for low-energy cosmic-ray antinuclei search
- GAPS will deliver:
  - antiproton measurement <0.25 GeV/n
  - antideuteron sensitivity 2 orders of magnitude below the current best limits
  - cosmic antihelium nuclei

GAPS

Detection Technique

- Identification
  - X-Ray
  - Pions/protons
  - Depth
  - dE/dx
  - …
- Main background is antiproton!



dE/dx identification

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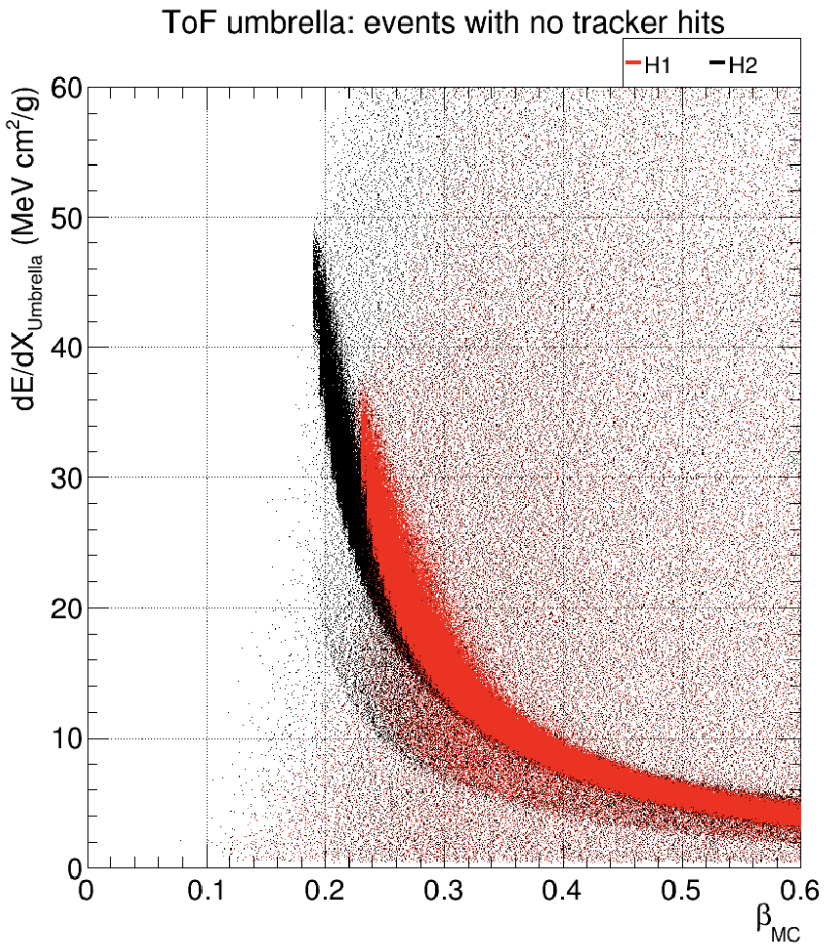
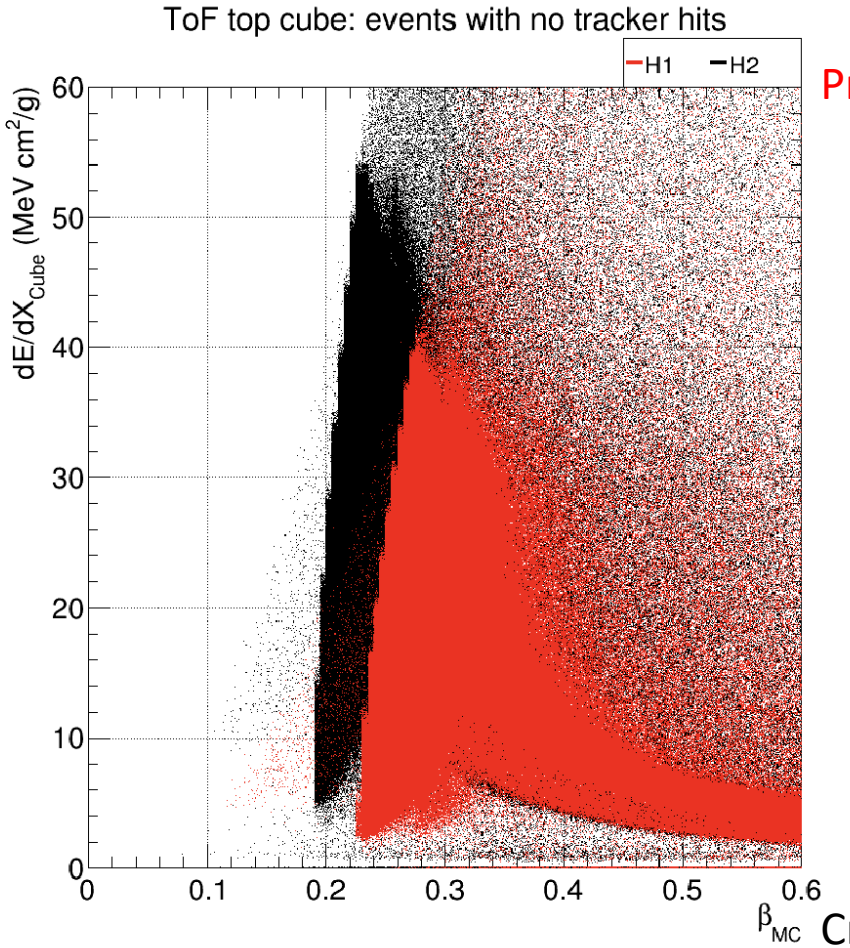
Deuteron identification

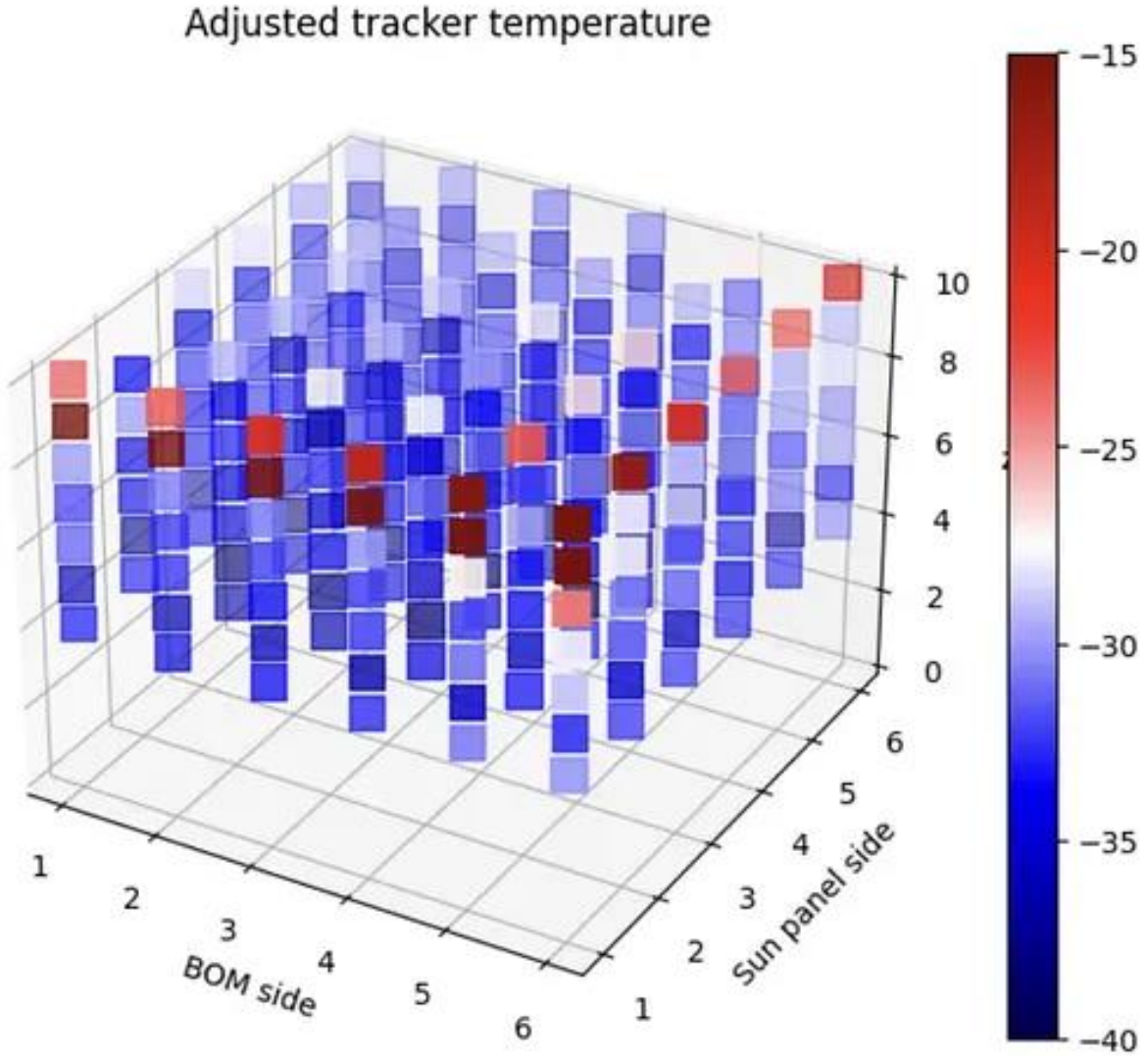




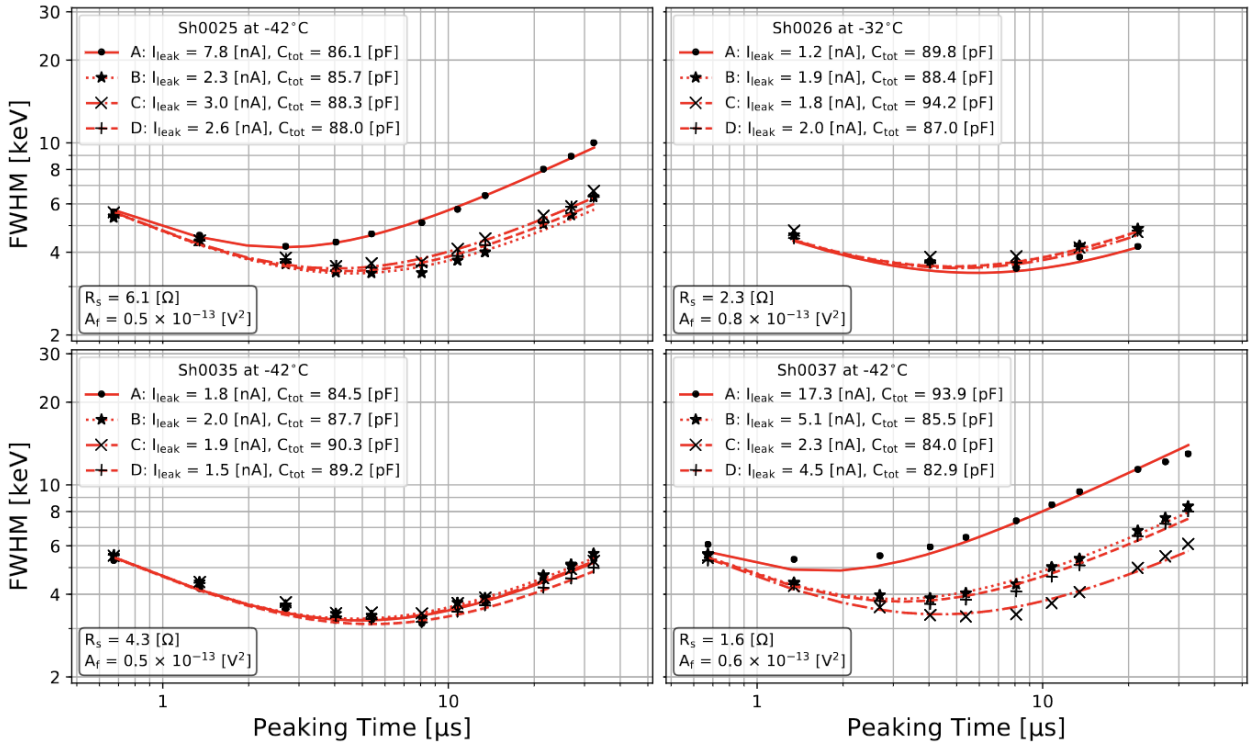
Preliminary result

Cr: Alex Lenni

Detector T requirement

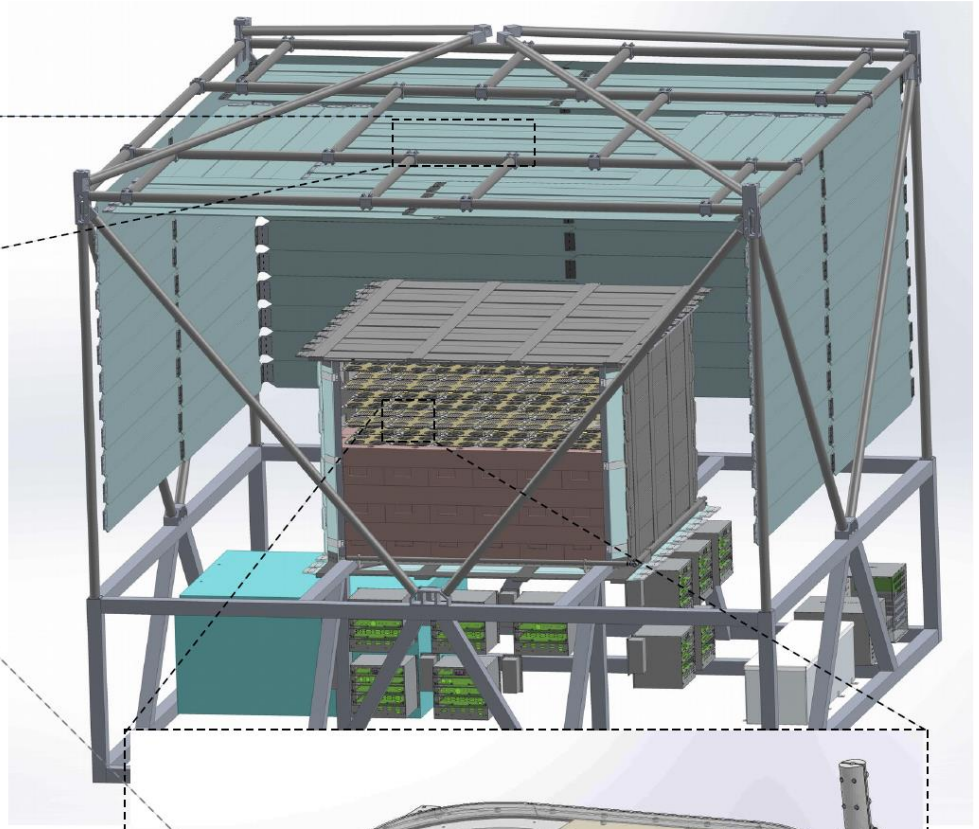


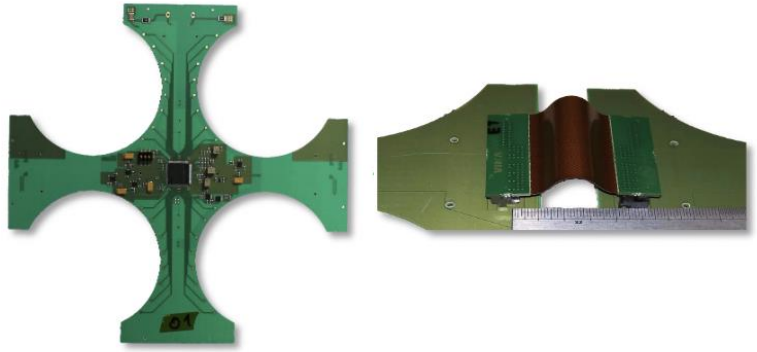
$$\mathrm{ENC}^2 = \left(2qI_{\mathrm{leak}} + \frac{4kT}{R_p}\right)\tau F_i + 4kT\left(R_s + \frac{\Gamma}{g_m}\right)\frac{C_{\mathrm{tot}}^2}{\tau}F_v + A_f C_{\mathrm{tot}}^2 F_{vf}$$



GAPS
Design

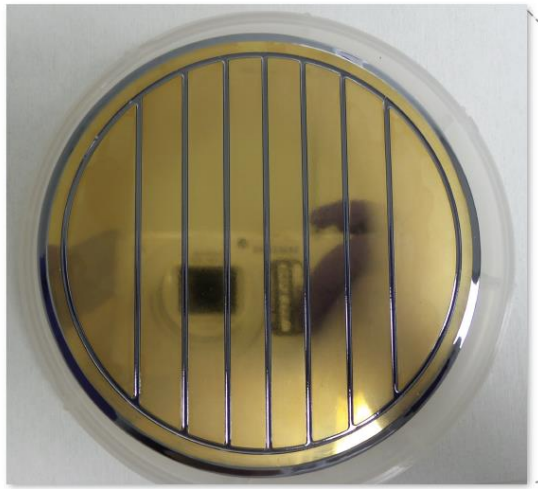
Time of flight system

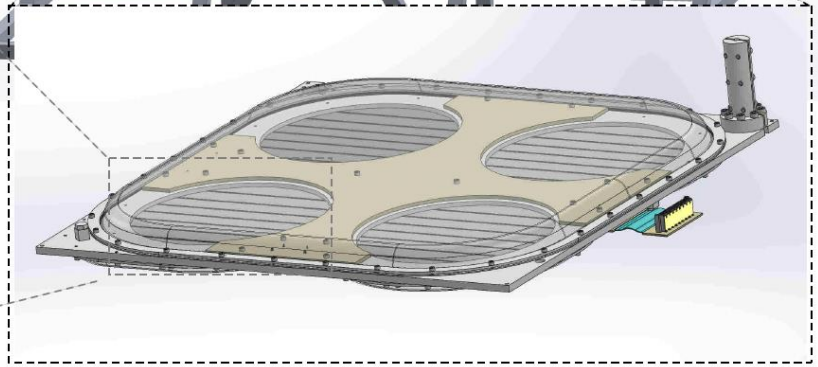




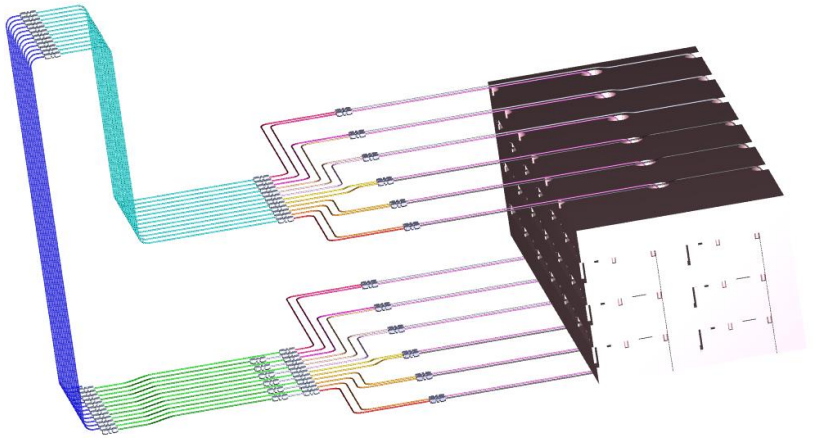
Electronic system

SiLi detector



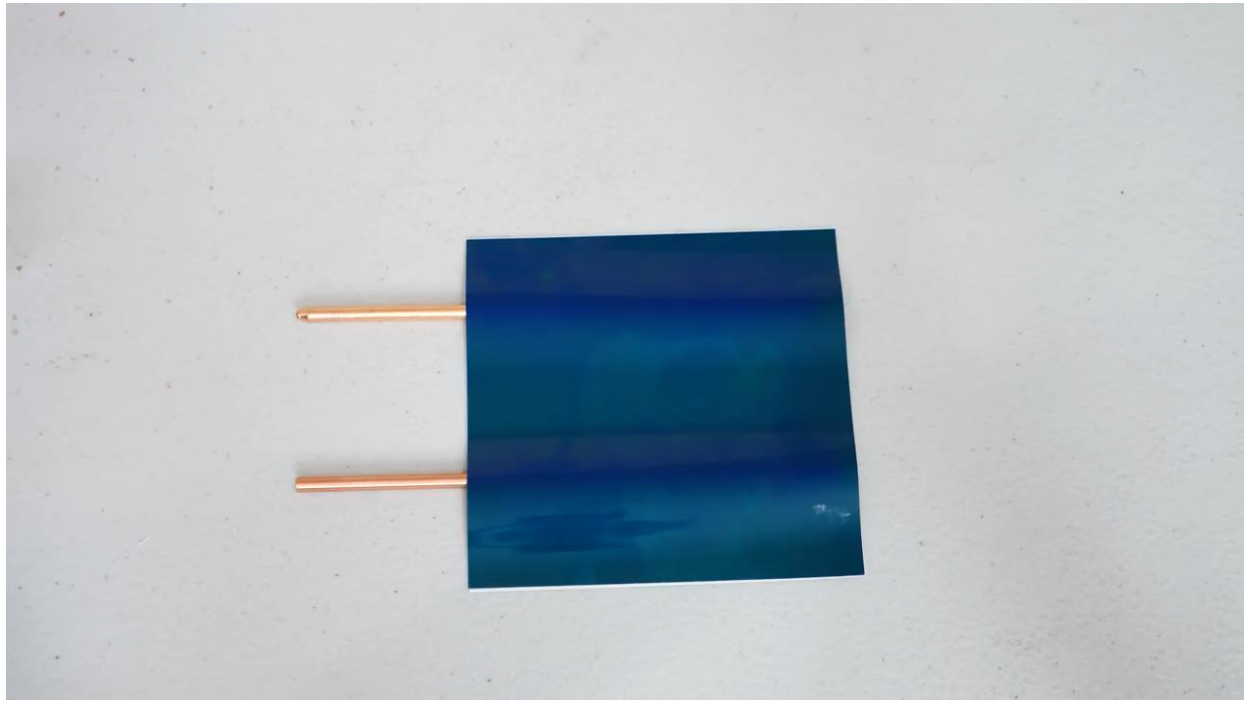


SiLi detector module



OHP cooling system

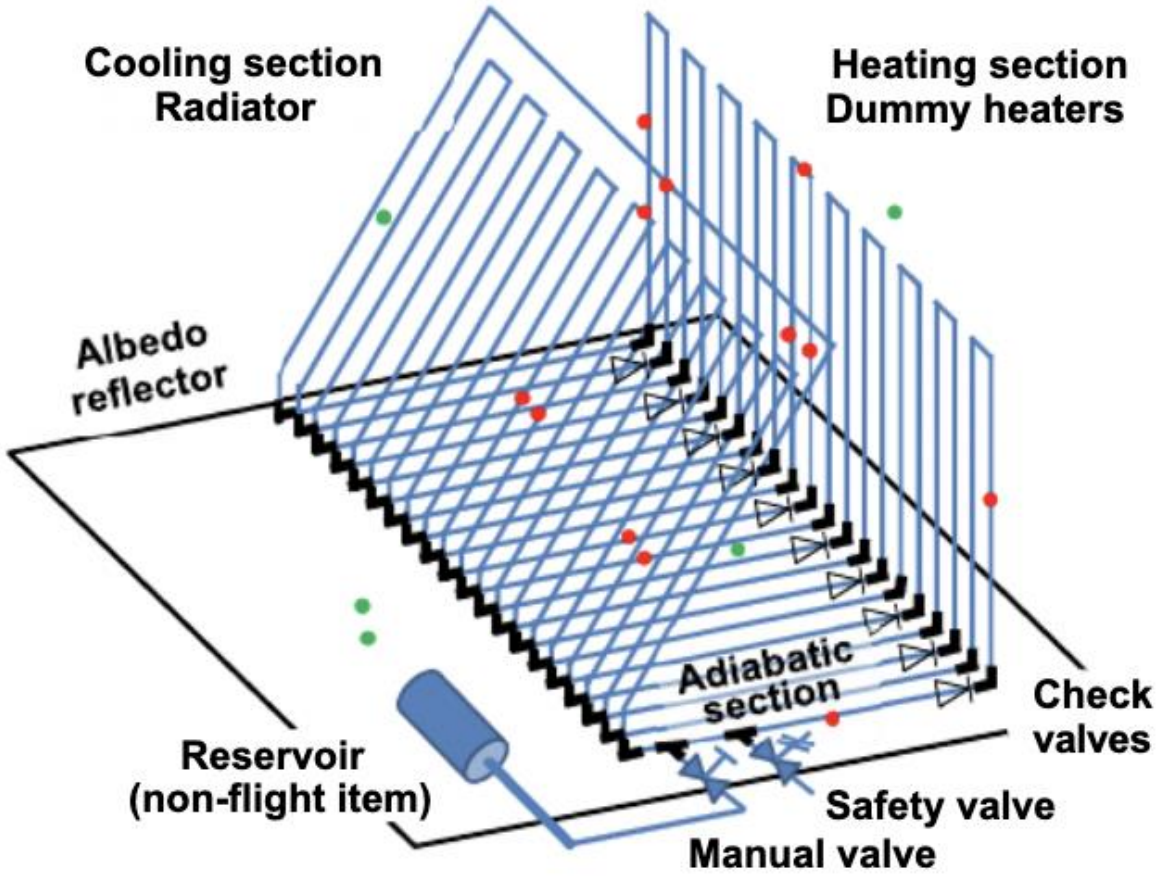
- Mass limited, OHP don't need pump and there is no moving part while cooling

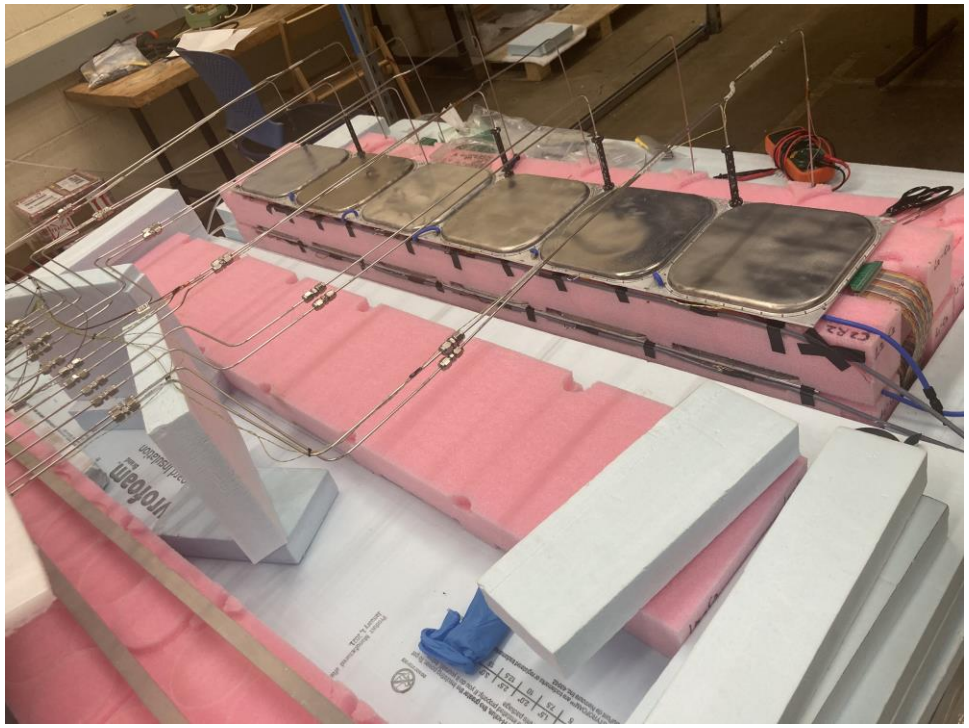


Youtube college: What's Inside the Worlds' Fastest Heat Conductor?

GAPS

Cooling system

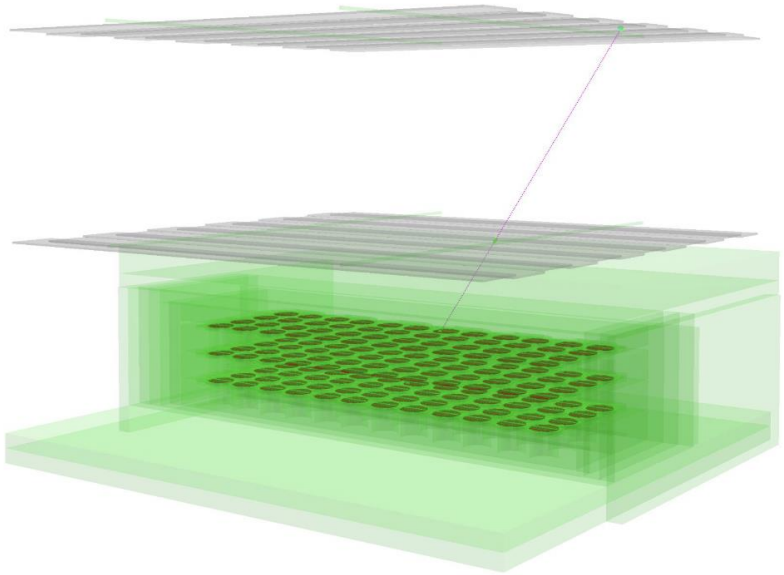




GAPS

Functional prototype

Feb 2021

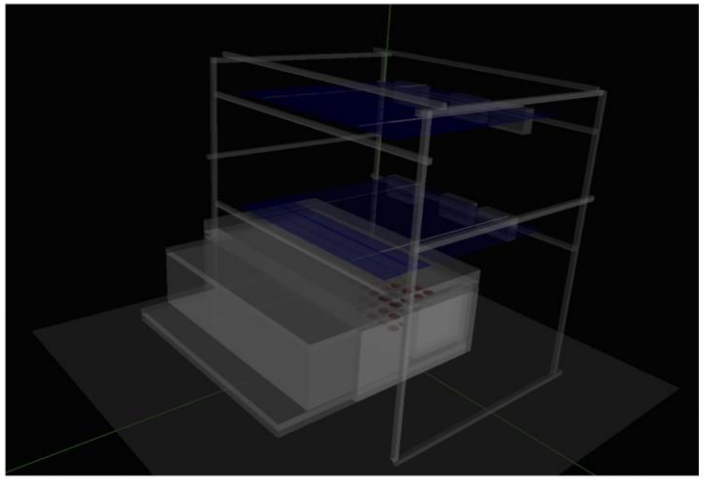


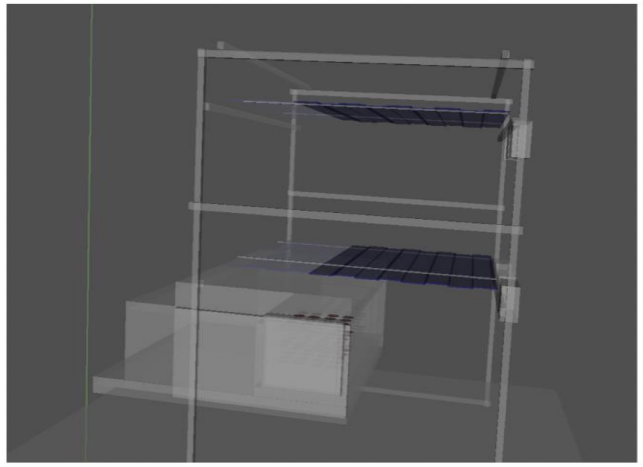
- From Jan 2021, we built GFP from scratch and took massive cosmic muon data!

Nov 2021

GAPS

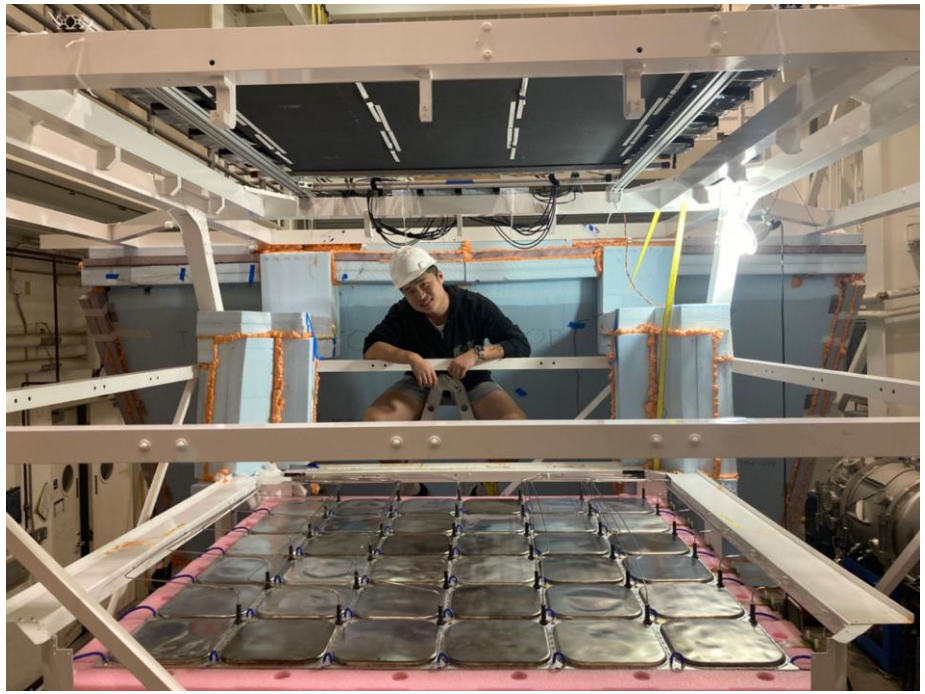
Functional prototype

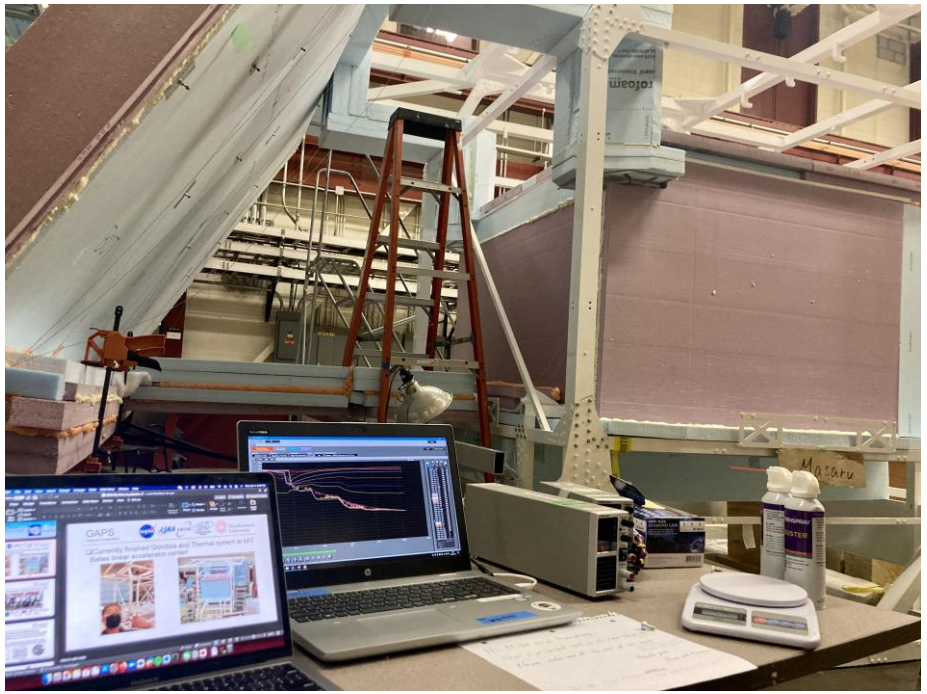




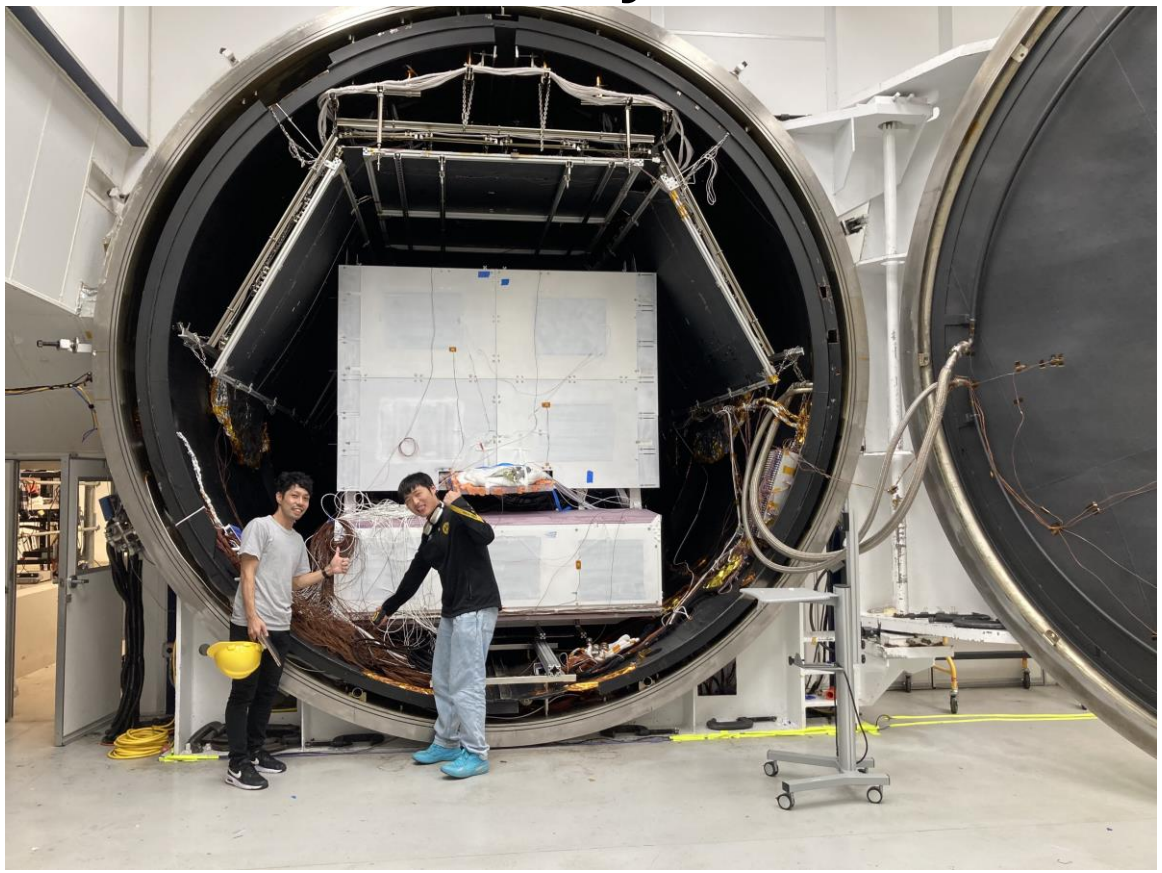
- Validated detector performance and installation procedure
- Validated cooling system performance
- Validated software(data acquisition, trigger logic and track reconstruction)
- We are done with doing small scale! Ready to go for real deal!!

- Currently finished Gondola and Thermal system at Nevis Laboratory



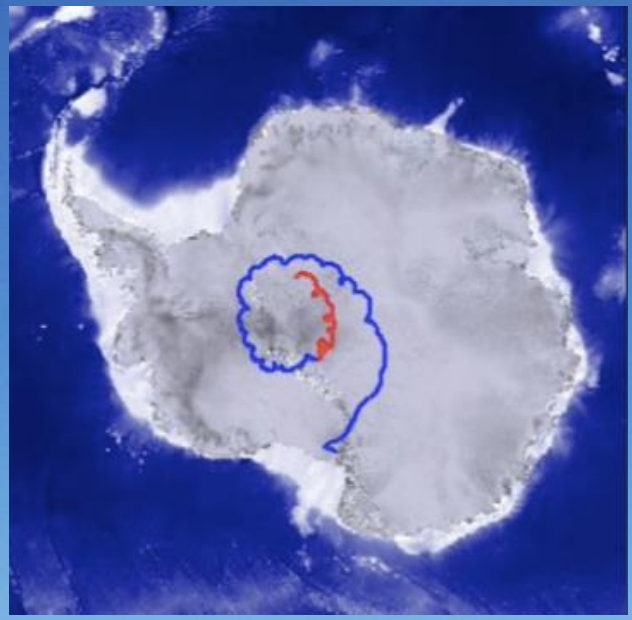


- Currently finished Gondola and Thermal system at Nevis Laboratory



GAPS
history

- 2002: First idea
- 2004-2005: Beam test
- 2012: p-GAPS flight
- 2018: detector and system design
- 2018: TOF and Si(Li) fabrication
- 2021-2023:GAPS payload integration
- 2023: GAPS TVAC test
- 2024/2025 :**First flight!** 2 follow-up flights planned



GAPS
Collaborators

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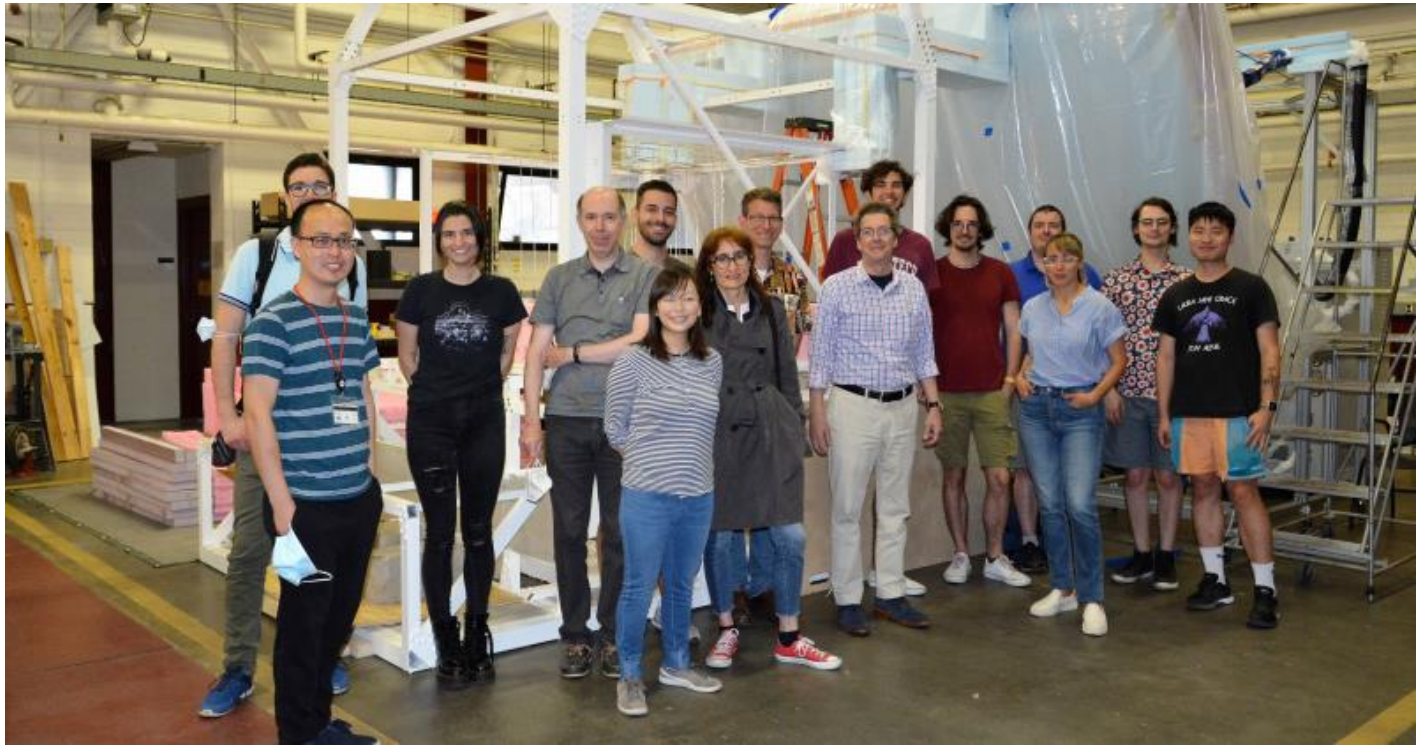
- In-person collaboration meeting back at MIT in June, 2022



JAXA Japan Aerospace Exploration Agency

INFN Istituto Nazionale di Fisica Nucleare

科研費 KAKENHI

HEISING-SIMONS FOUNDATION

NSF

NASA

Columbia University

MIT Massachusetts Institute of Technology

UCLA

University of Hawai'i Mānoa

Northeastern University

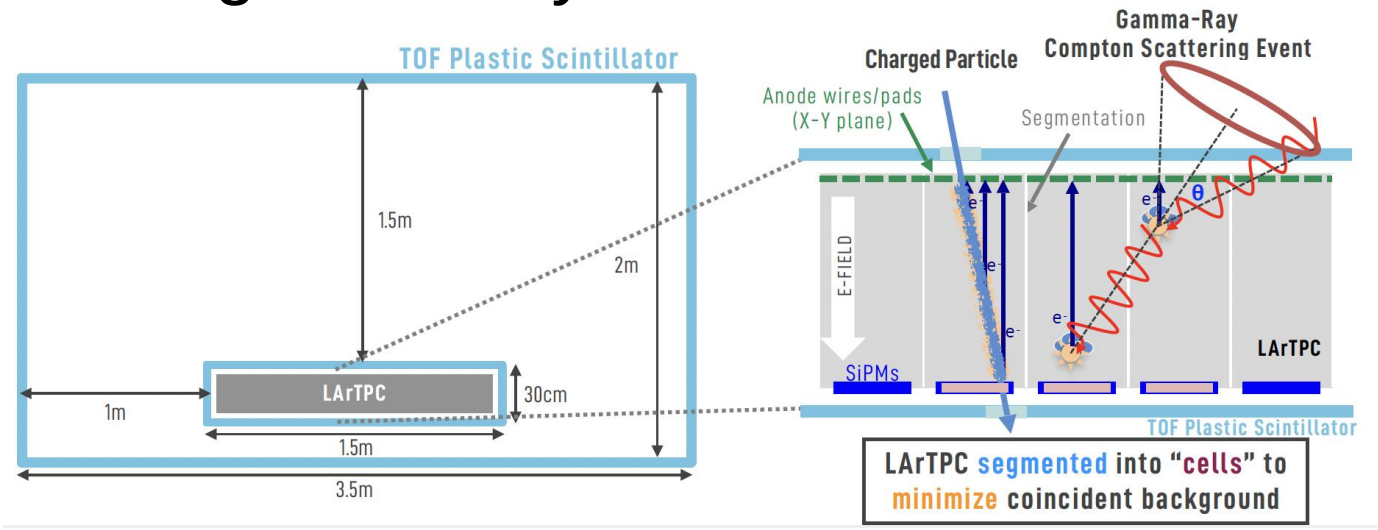
UC San Diego

SLAC

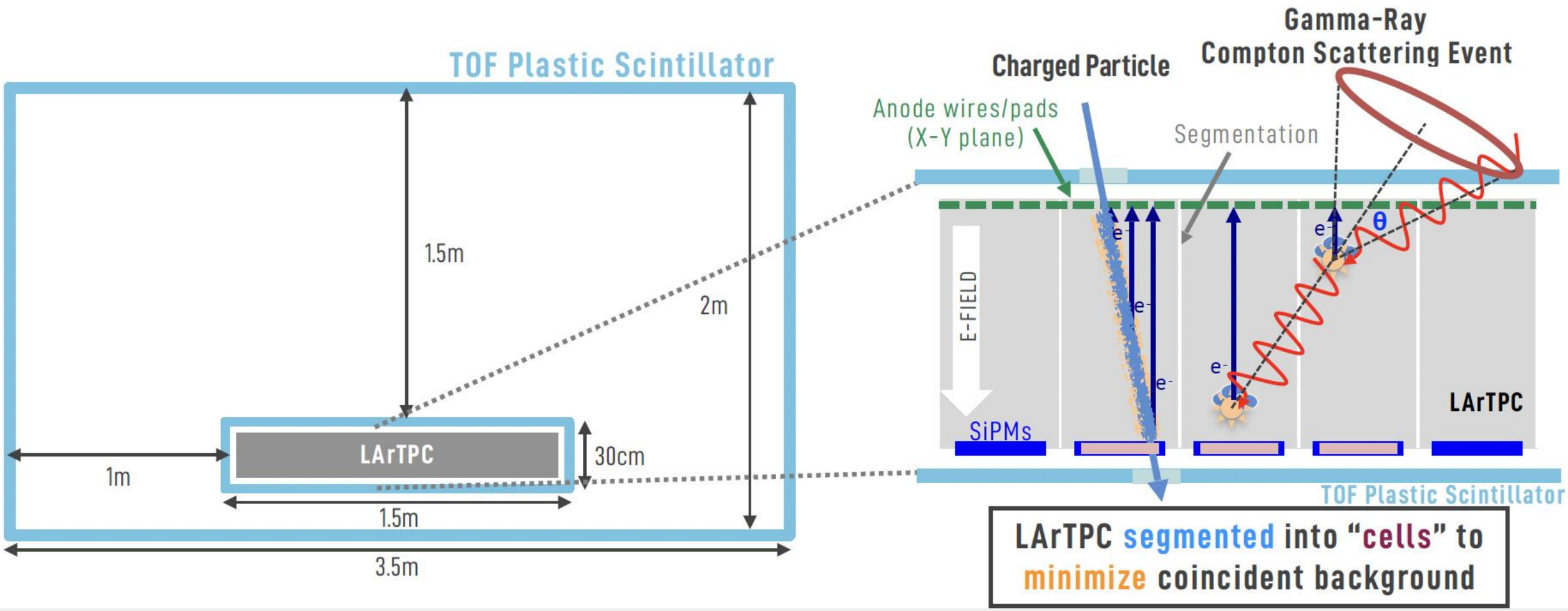
Oak Ridge National Laboratory

GRAMS

- GRAMS = Gamma-Ray and AntiMatter Survey
  - A newly funded project with an international collaboration
  - **First balloon/satellite mission with a low-cost, large-scale LArTPC detector!**
  - First experiment for both astrophysical observations with MeV gamma rays and dark matter searches with antimatter



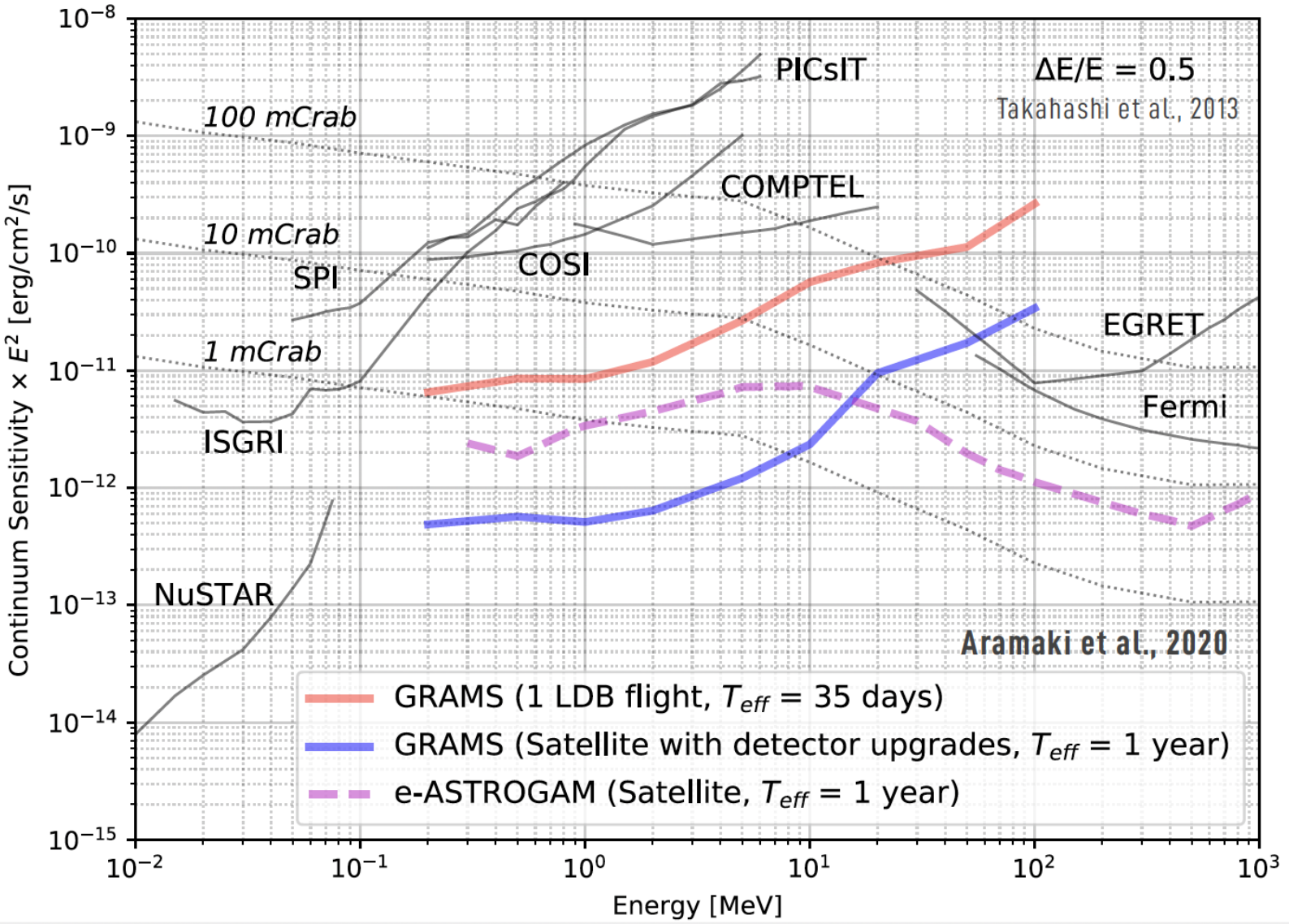
GRAMS First Paper: (1901.03430, Astropart. Phys)


TOF Plastic Scintillator
1.5m
2m
LArTPC
30cm
1m
1.5m
3.5m
Gamma-Ray
Compton Scattering Event
Charged Particle
Anode wires/pads
(X-Y plane)
Segmentation
E-FIELD
SiPMs
LArTPC
TOF Plastic Scintillator
θ
e-
LArTPC segmented into "cells" to
minimize coincident background

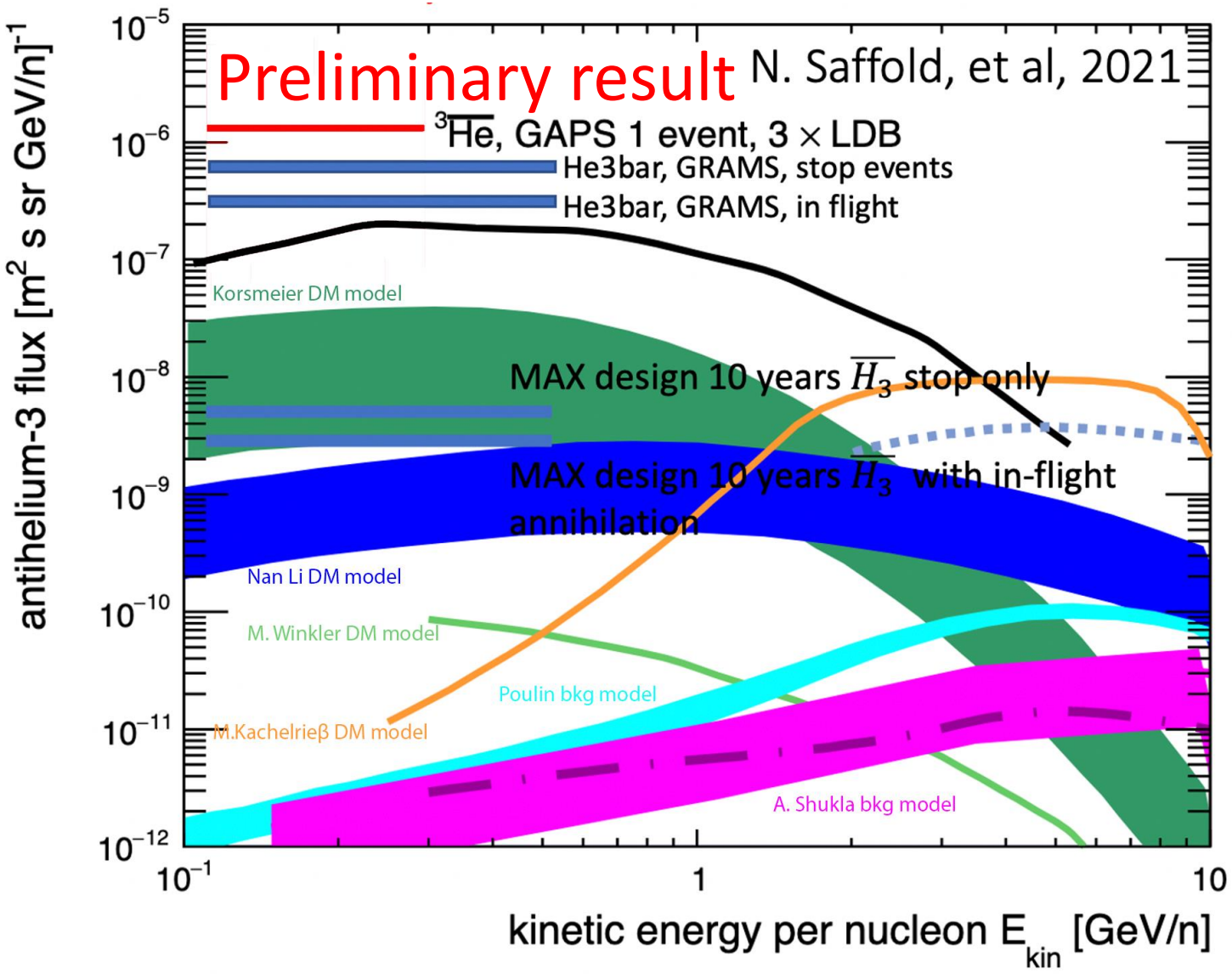
GRAMS science

- Gamma-Ray
  - Sensitivity order of magnitude increase
  - Using Gamma-Ray to do indirect dark matter searches
- Antiparticles
  - Antiproton, antideuteron, antihelium(AMS detected antihelium-like events)

GRAMS sensitivity



GRAMS sensitivity

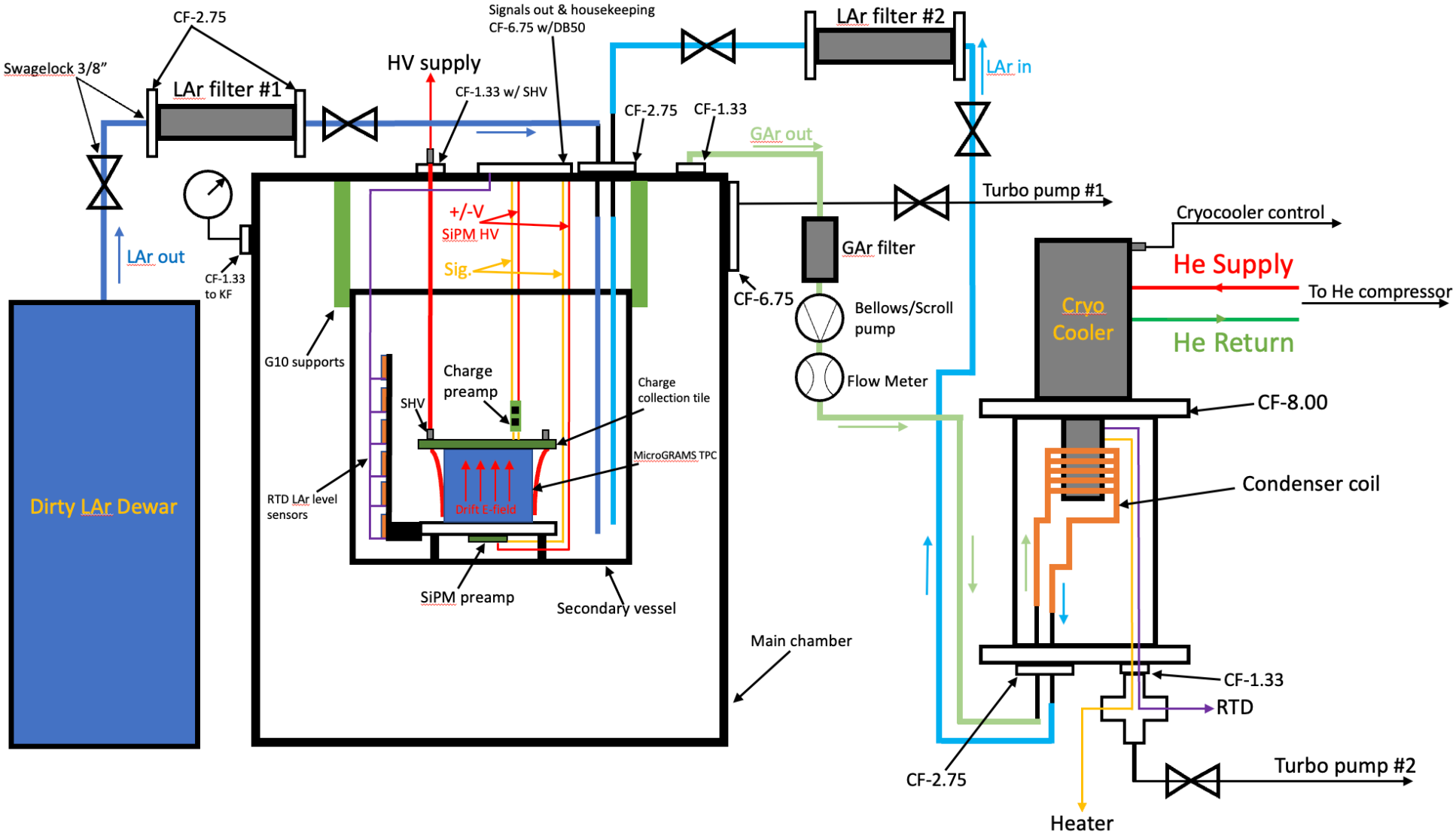


GRAMS

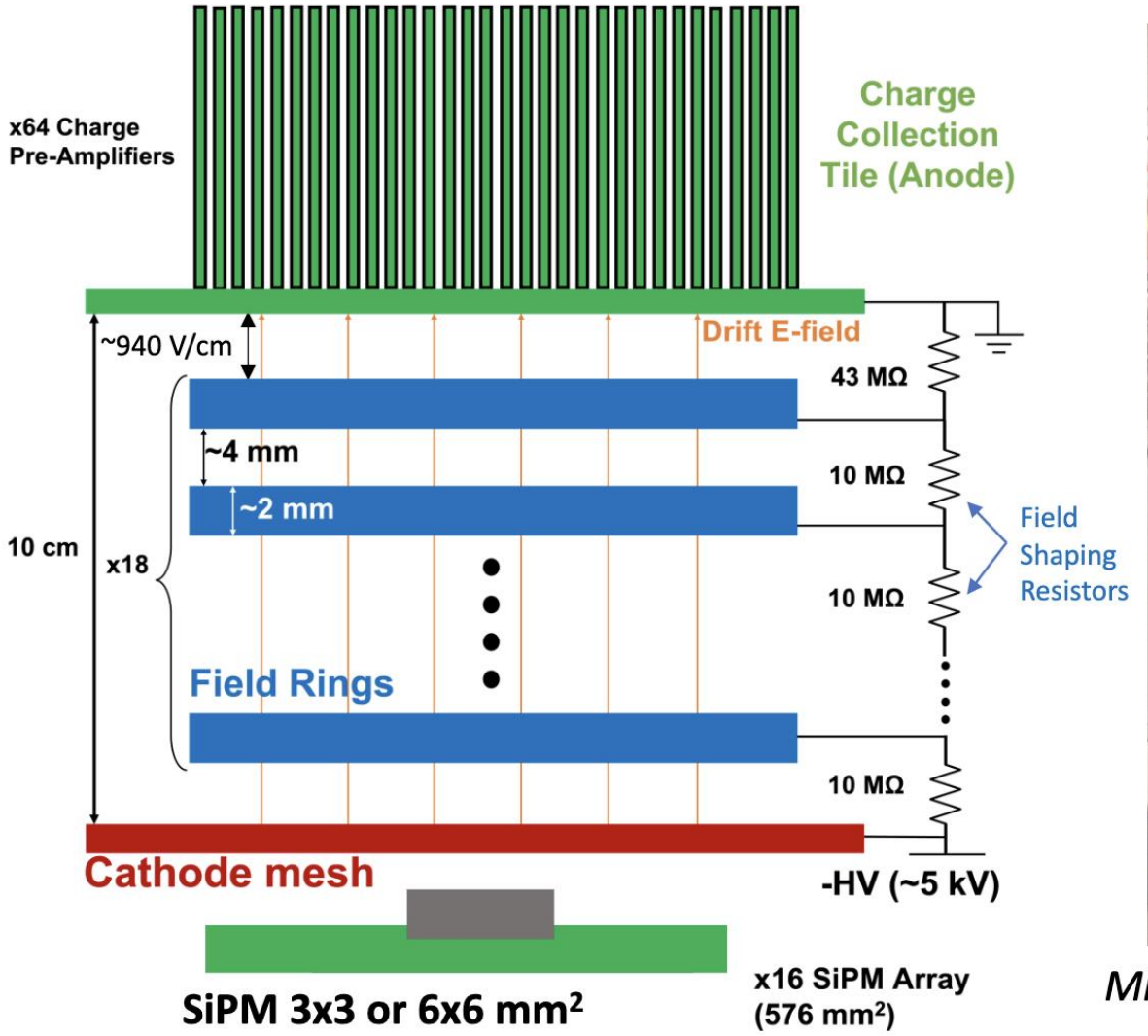
- GRAMS status(early stage, led by Northeastern)
  - Hardware:
    - Finished engineer flight in Japan July 2023
    - TPC development at NEU(SiPM, CSP)
    - Readout electronics adopted from MicroBooNE at Nevis
    - TOF and Gondola R&D happened at NASA Goddard
  - Software:
    - Flight trigger system under development
    - Telemetry system developed by Japanese collaborator
    - Simulation and analysis group led by Columbia

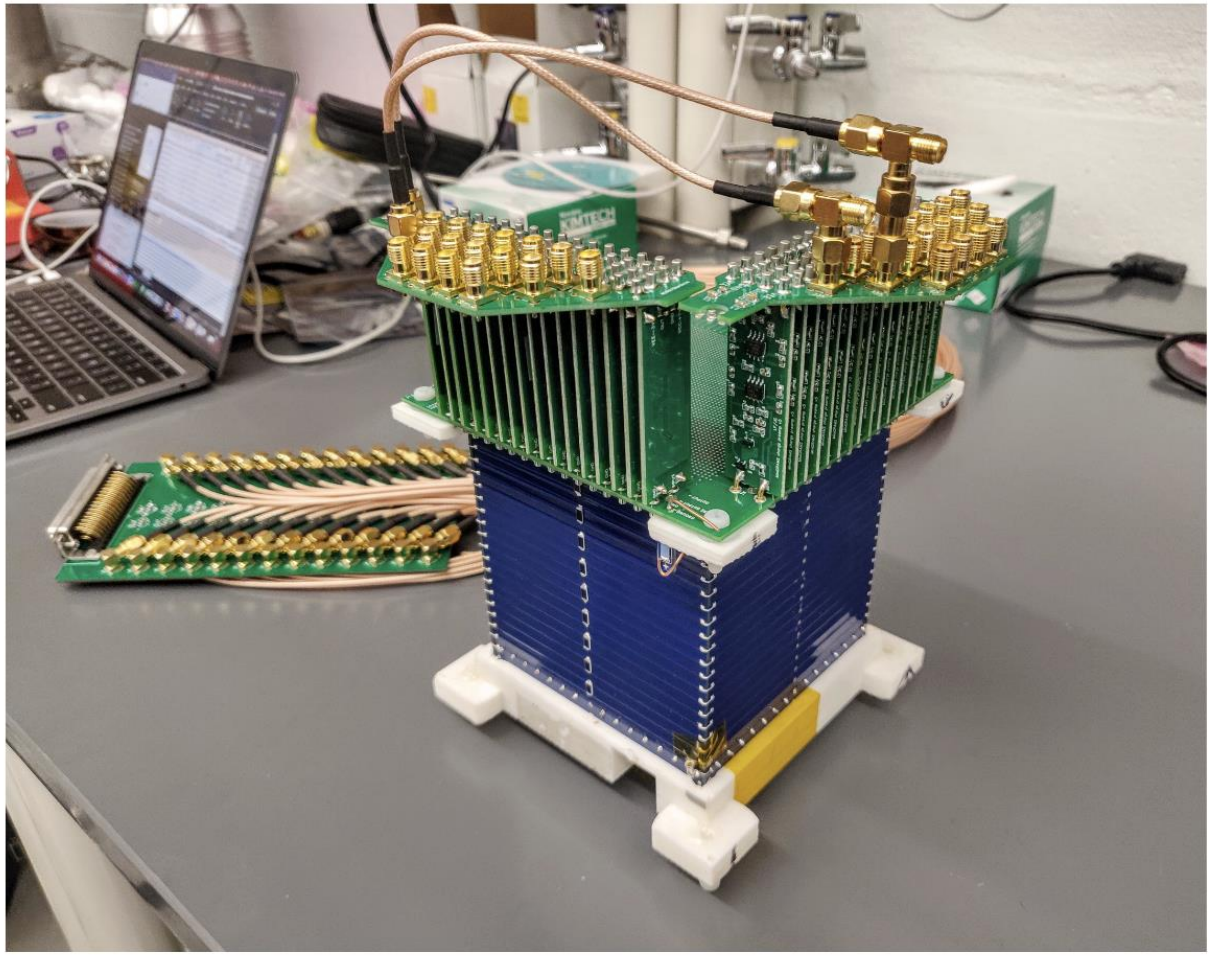
miniGRAMS

Northeastern University



miniGRAMS TPC

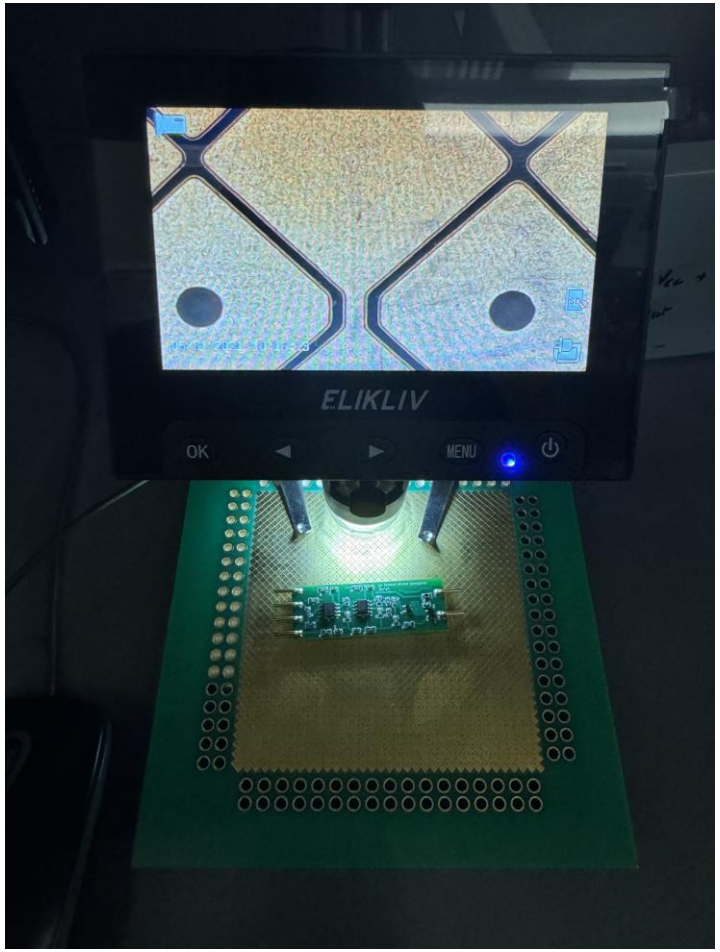


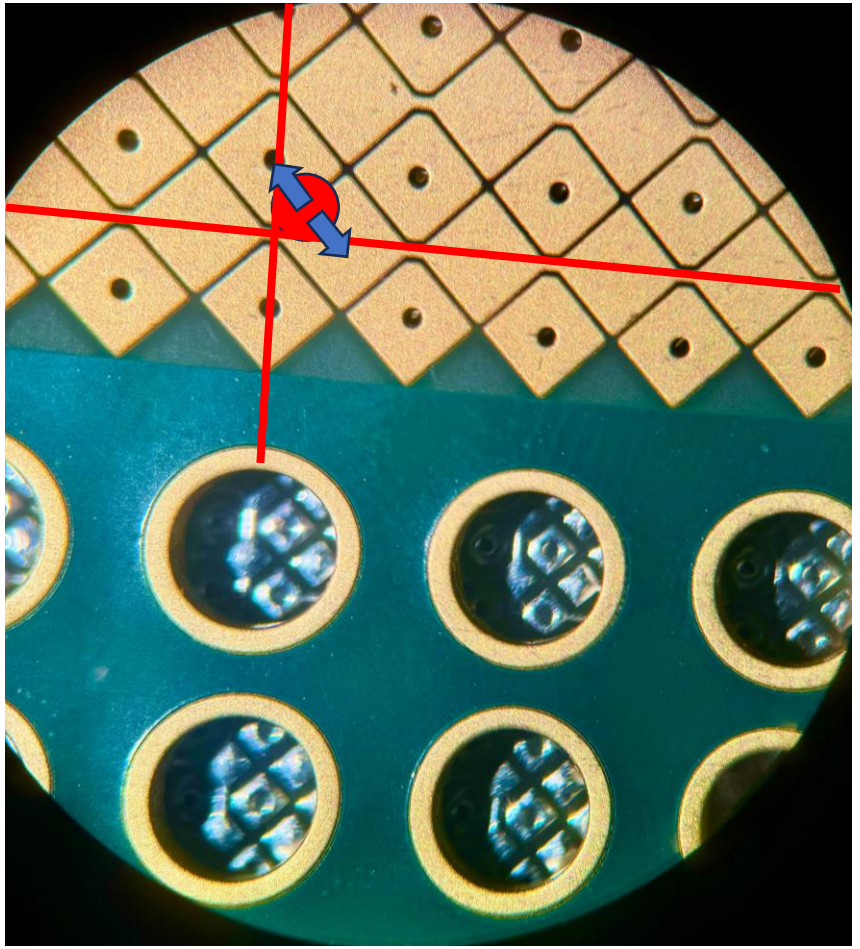


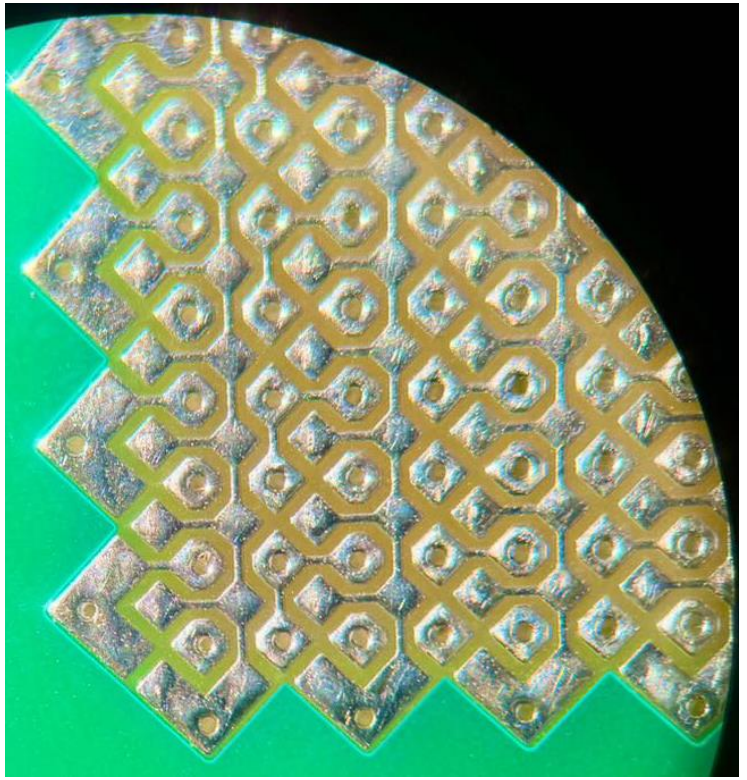
MicroGRAMS TPC prototype with 32/64 charge channels active

Charge readout tile

- 2D readout with smaller channels



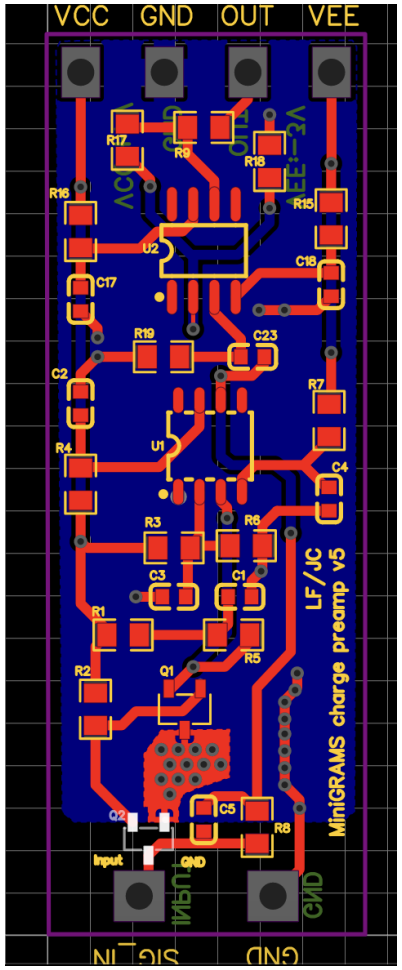


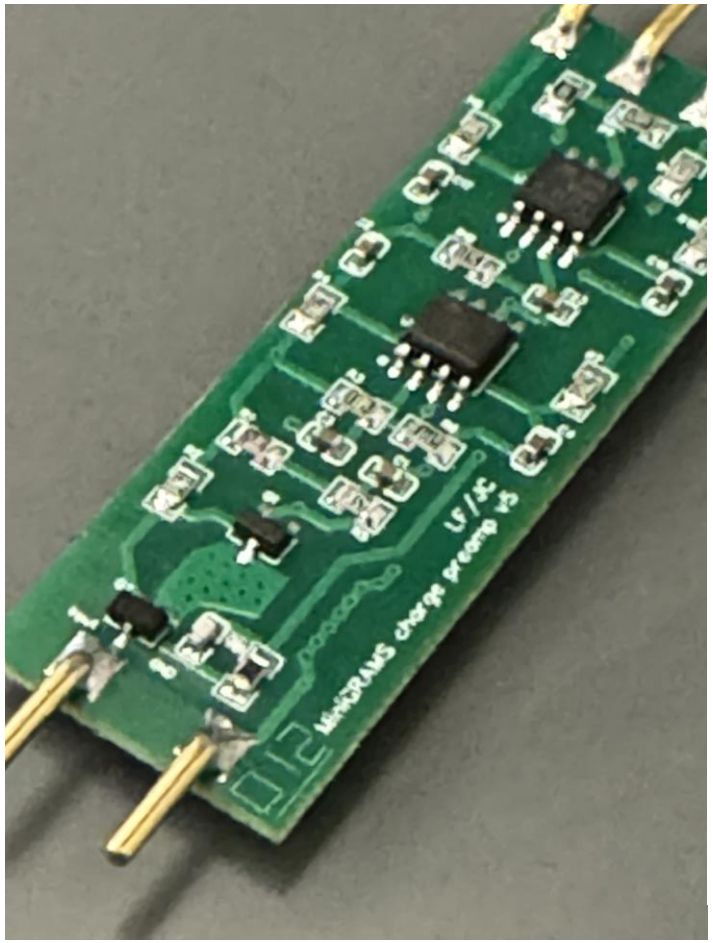


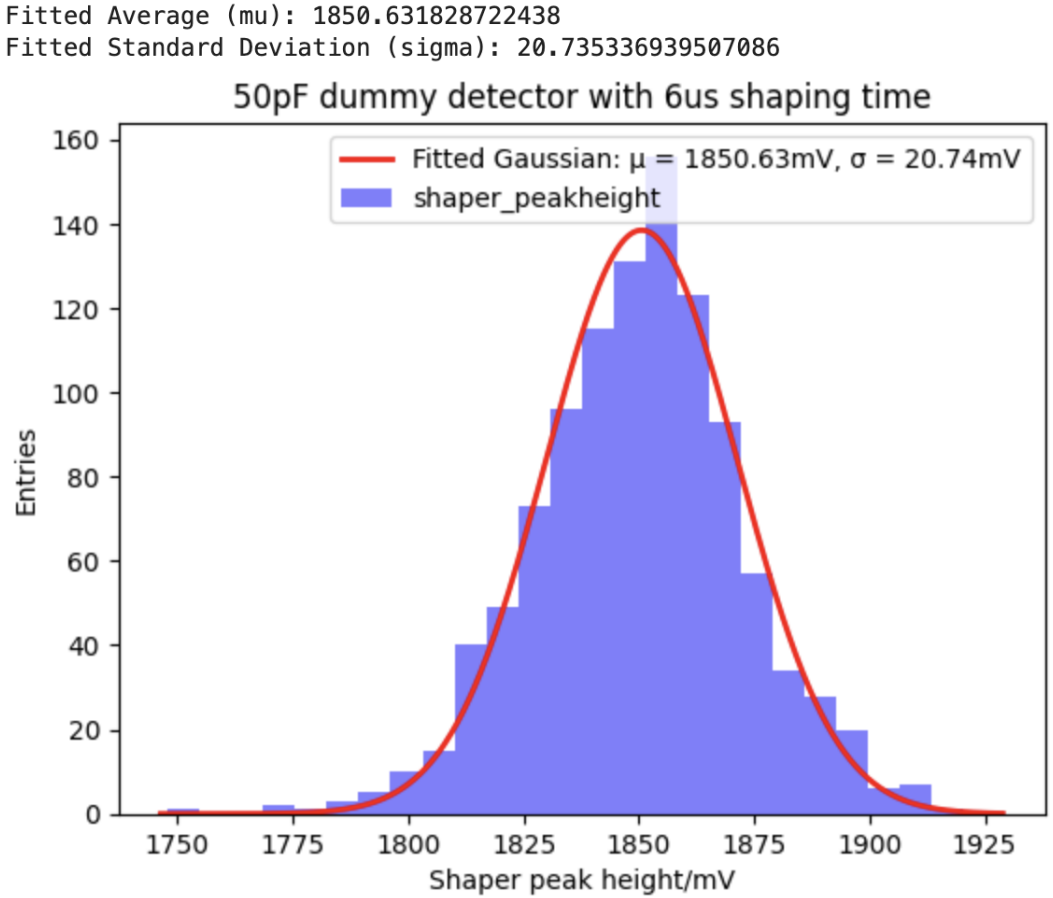
To reduce the chance of only 1D triggering

Charge readout CSM

- Adopted from nEXO, modified for cryo usage



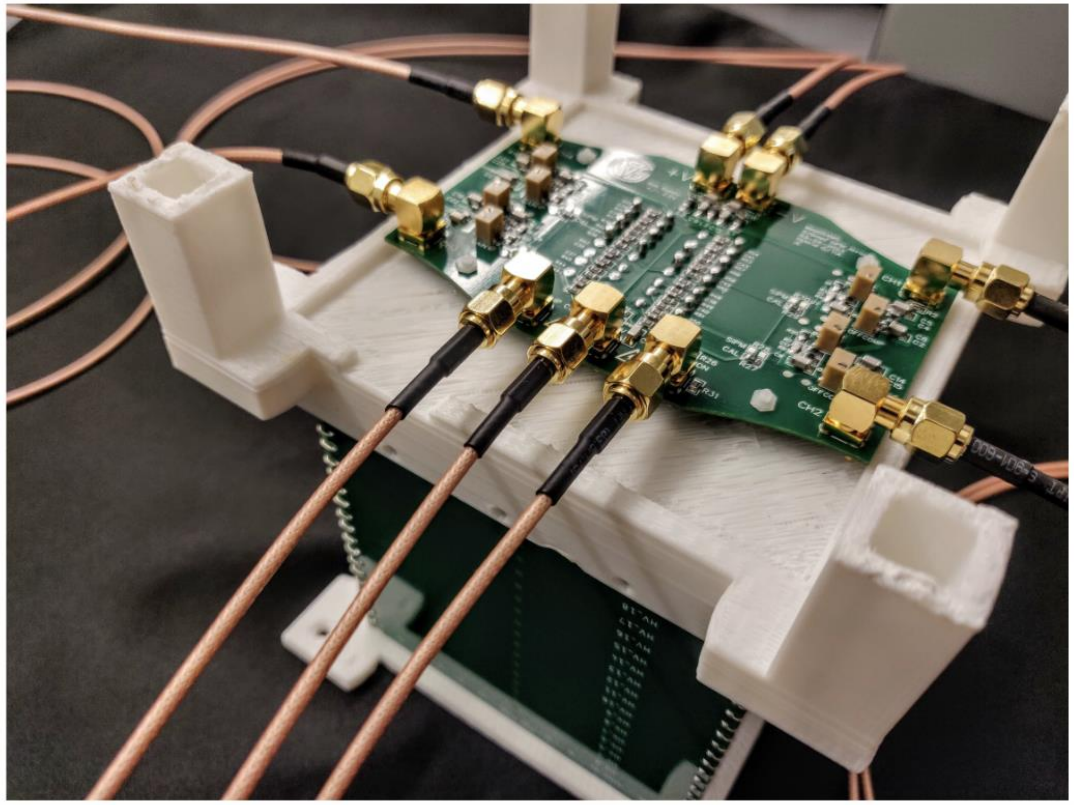


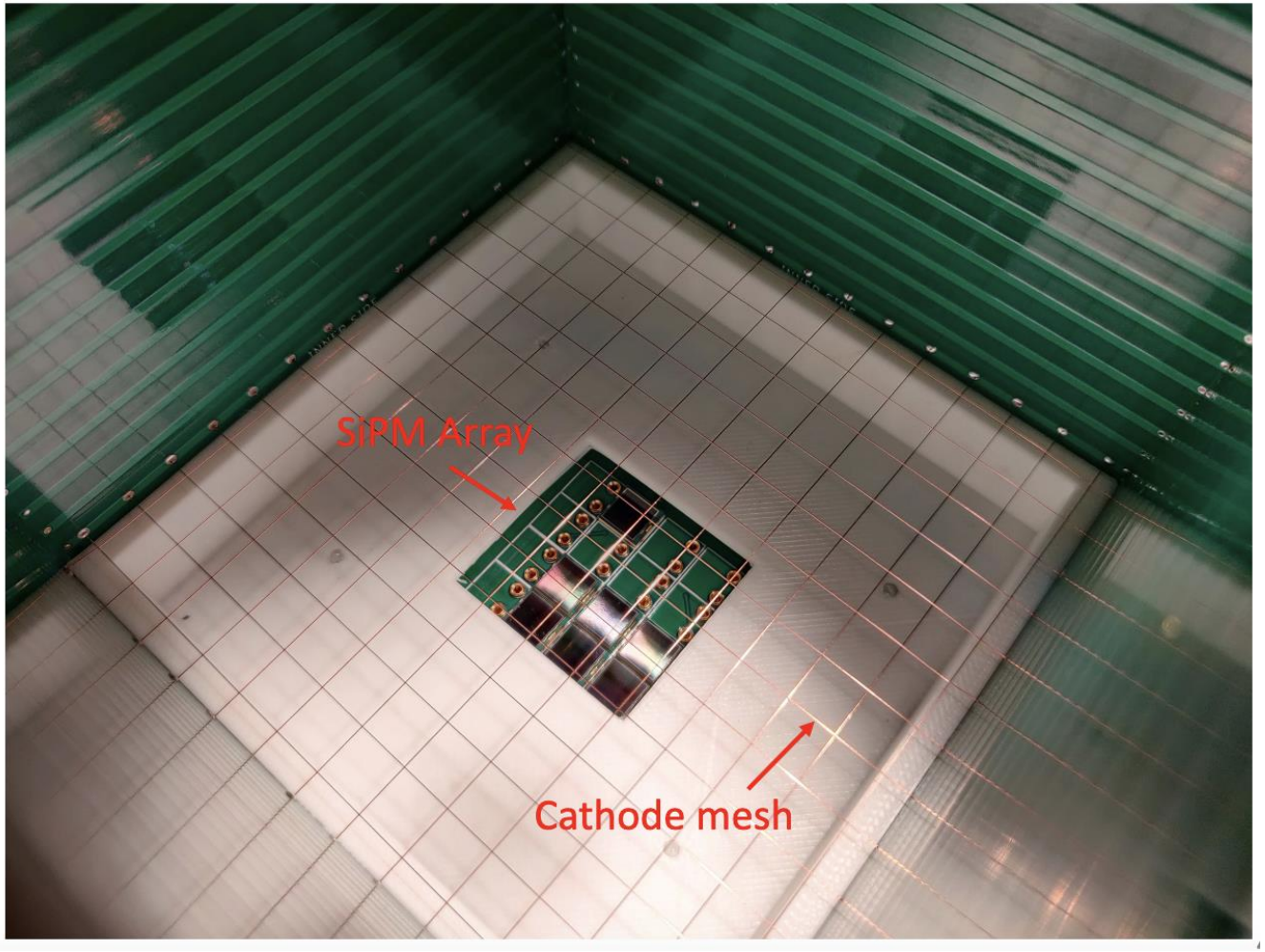


Reached 10keV resolution!!

Light readout SiPM

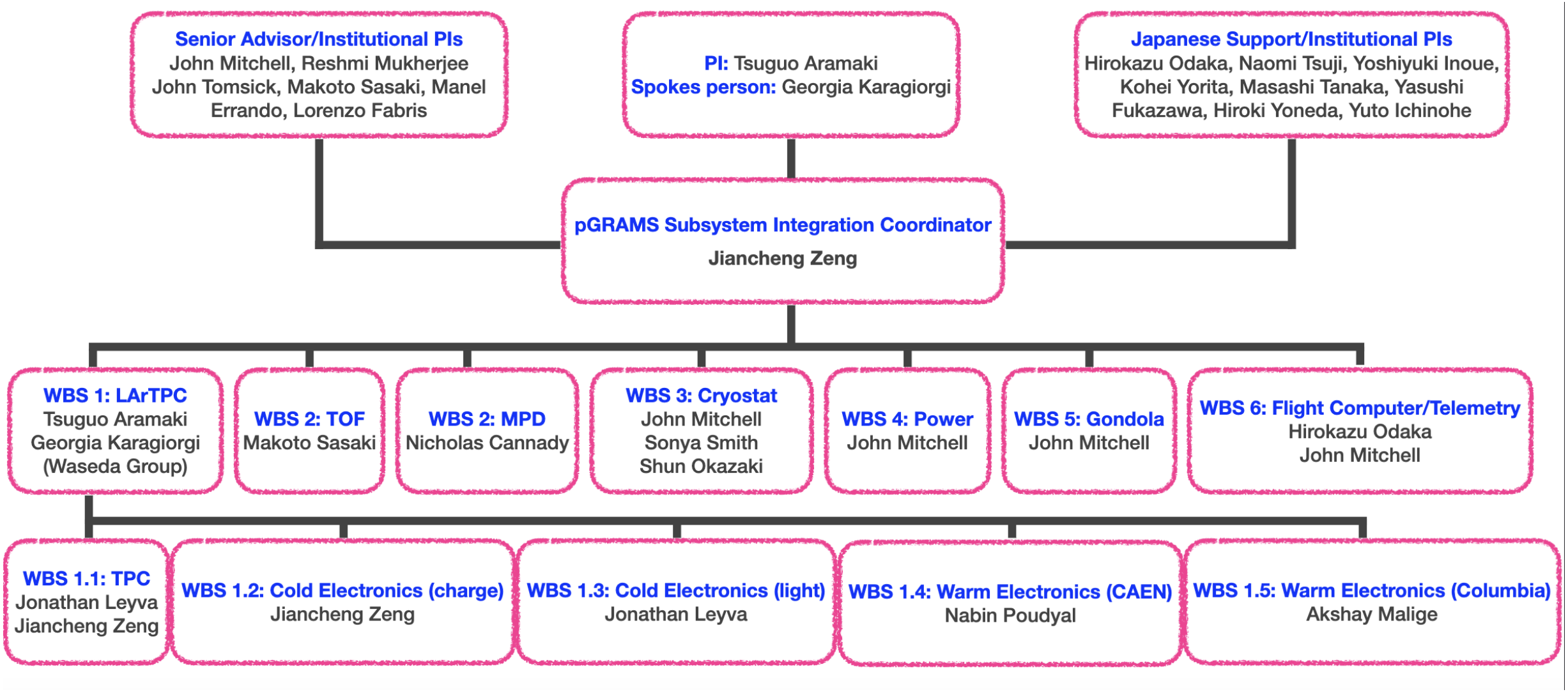
- TPB wavelength shifter not shown





Other systems

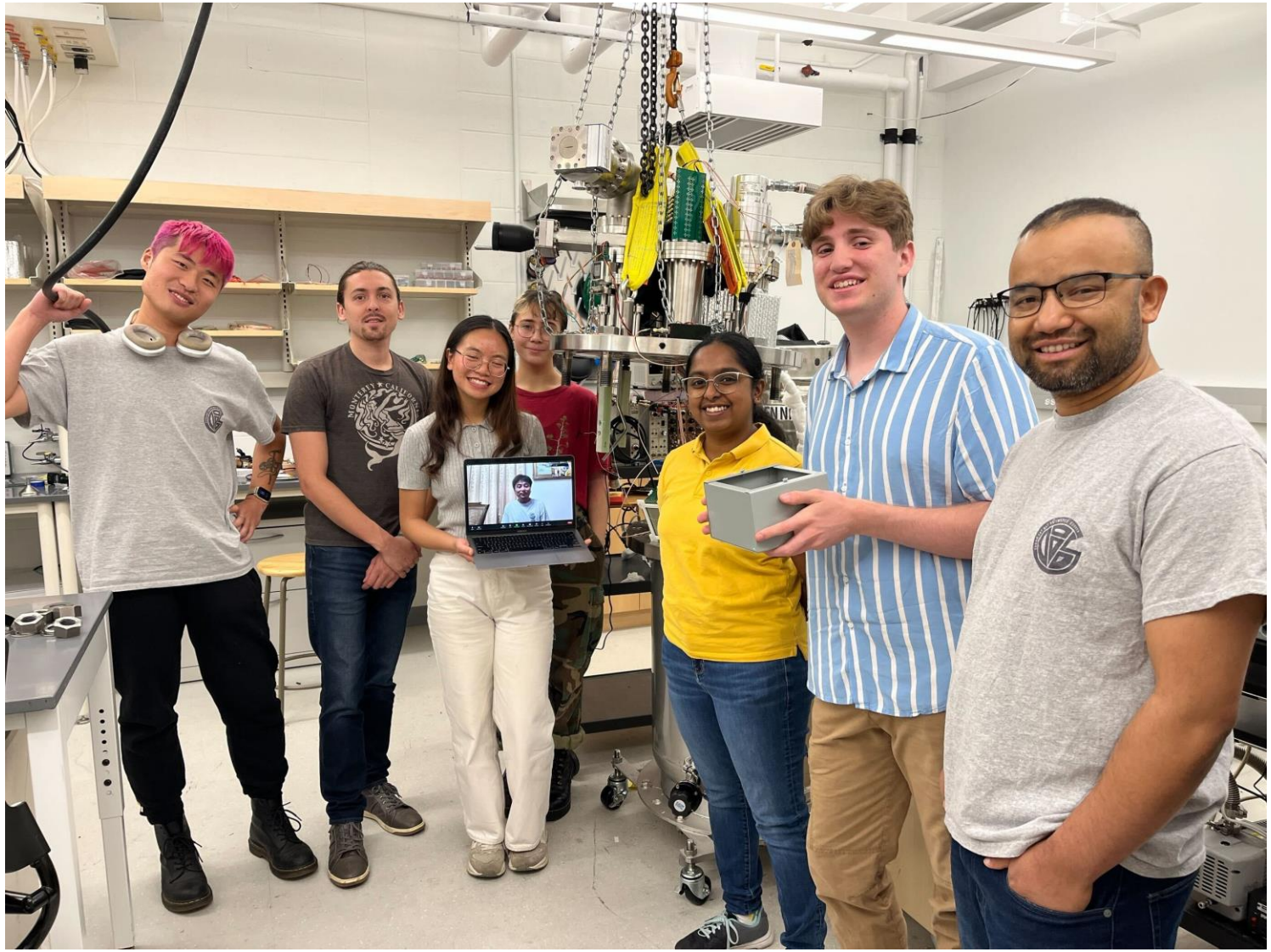
- TOF/ACD
- DAQ system
  - CAEN digitizer, MicroBOONE electronics
- Gondola
- PDU
- Thermal system


Senior Advisor/Institutional PIs
John Mitchell, Reshmi Mukherjee
John Tomsick, Makoto Sasaki, Manel
Errando, Lorenzo Fabris
PI: Tsuguo Aramaki
Spokes person: Georgia Karagiorgi
Japanese Support/Institutional PIs
Hirokazu Odaka, Naomi Tsuji, Yoshiyuki Inoue,
Kohei Yorita, Masashi Tanaka, Yasushi
Fukazawa, Hiroki Yoneda, Yuto Ichinohe
pGRAMS Subsystem Integration Coordinator
Jiancheng Zeng
WBS 1: LArTPC
Tsuguo Aramaki
Georgia Karagiorgi
(Waseda Group)
WBS 2: TOF
Makoto Sasaki
WBS 2: MPD
Nicholas Cannady
WBS 3: Cryostat
John Mitchell
Sonya Smith
Shun Okazaki
WBS 4: Power
John Mitchell
WBS 5: Gondola
John Mitchell
WBS 6: Flight Computer/Telemetry
Hirokazu Odaka
John Mitchell
WBS 1.1: TPC
Jonathan Leyva
Jiancheng Zeng
WBS 1.2: Cold Electronics (charge)
Jiancheng Zeng
WBS 1.3: Cold Electronics (light)
Jonathan Leyva
WBS 1.4: Warm Electronics (CAEN)
Nabin Poudyal
WBS 1.5: Warm Electronics (Columbia)
Akshay Malige

GRAMS timeline

- June 2023: Engineer flight in Japan
- Sep 2023: Selected by NASA for a flight in 2025/2026
- 2024: Sub system R&D and integration
- Spring 2025: Flight hardware manufacture and testing
- Winter 2025/Spring 2026: integrate at NASA goddard and prepare for flight(location not decided yet)

GRAMS NEU group



GRAMS Collaboration

Northeastern University

大阪大学 OSAKA UNIVERSITY

東京大学 THE UNIVERSITY OF TOKYO

立教大学 RIKKYO UNIVERSITY

COLUMBIA UNIVERSITY

WASEDA University 早稲田大学

広島大学 HIROSHIMA UNIVERSITY

Massachusetts Institute of Technology

RIKEN

Northeastern University

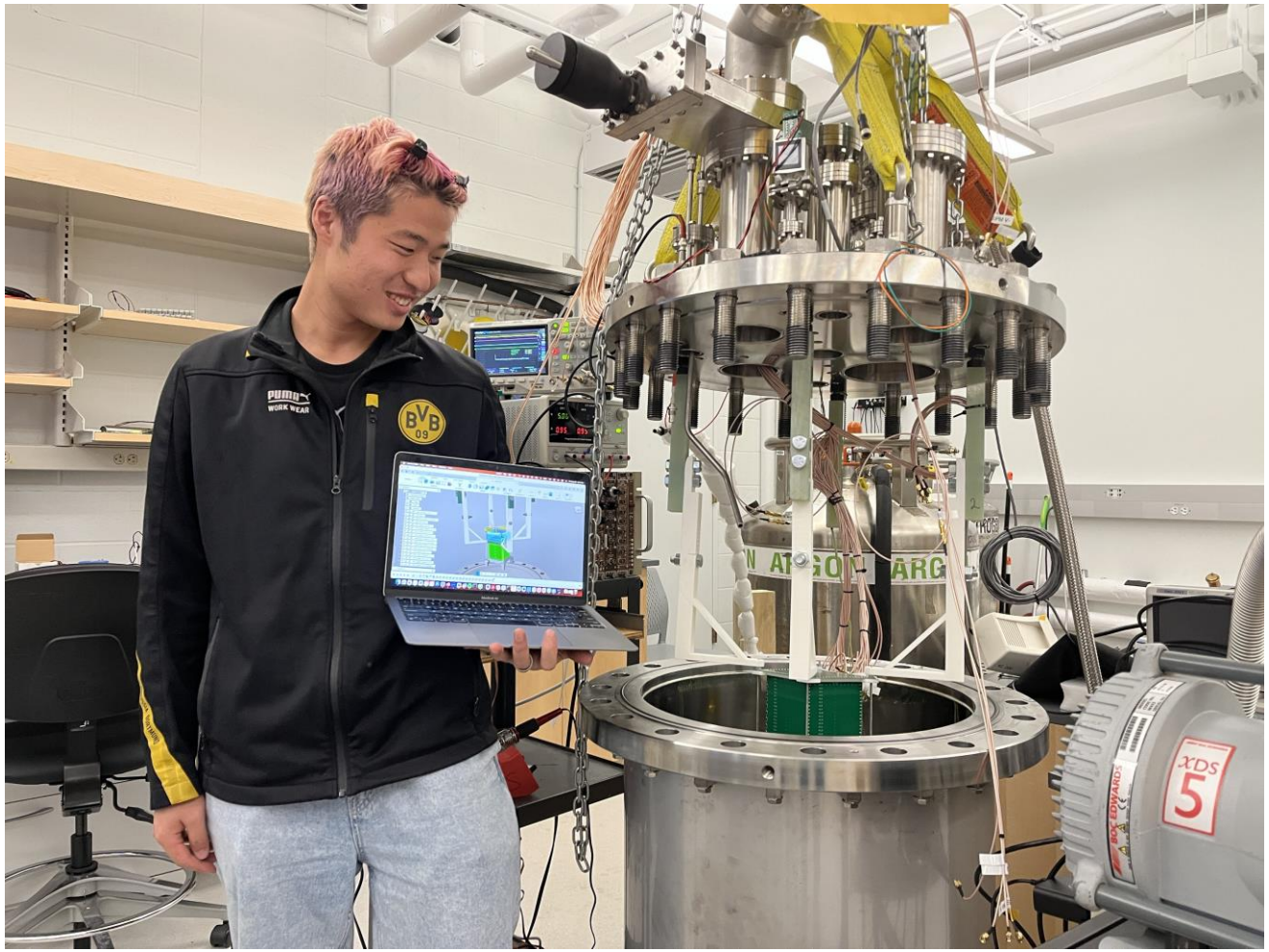
Thanks!

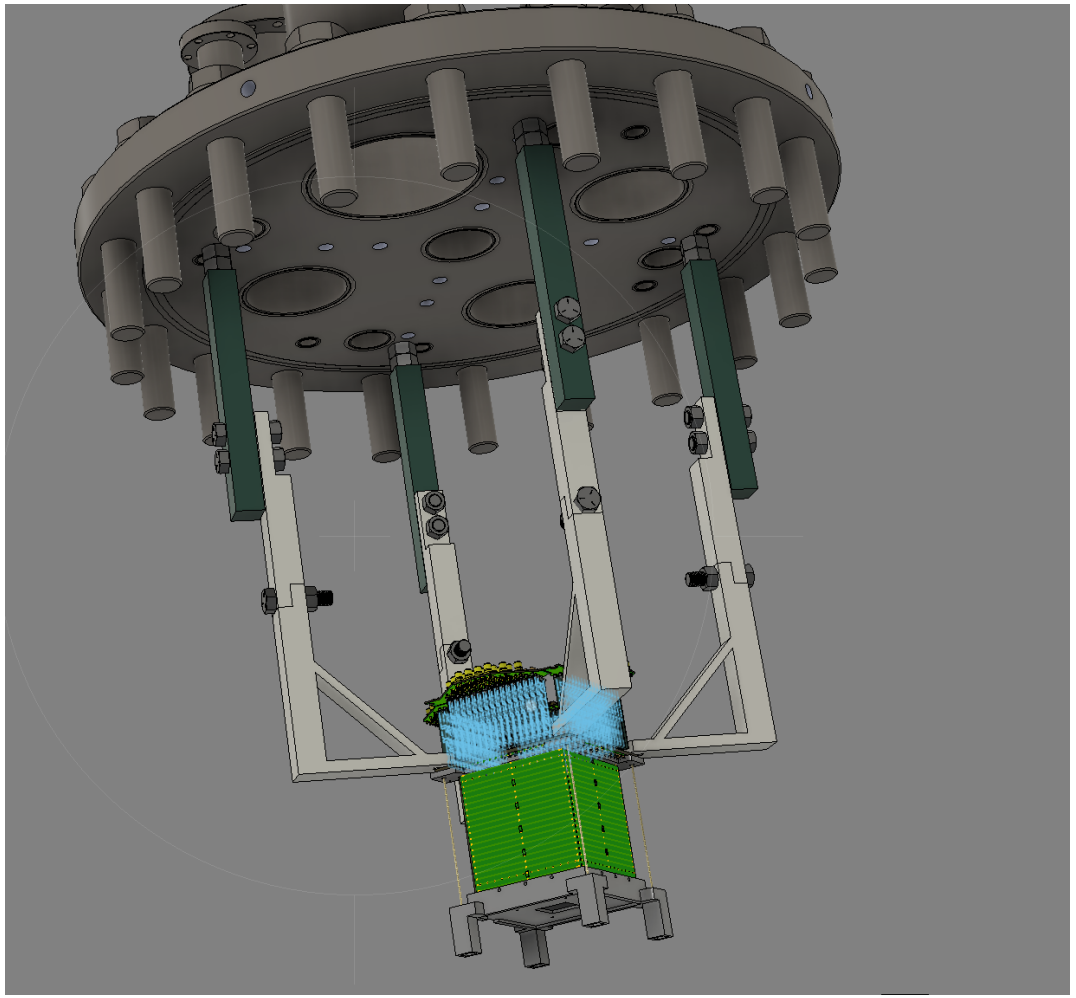
Feel free to contact me if you are interested in what we are doing!

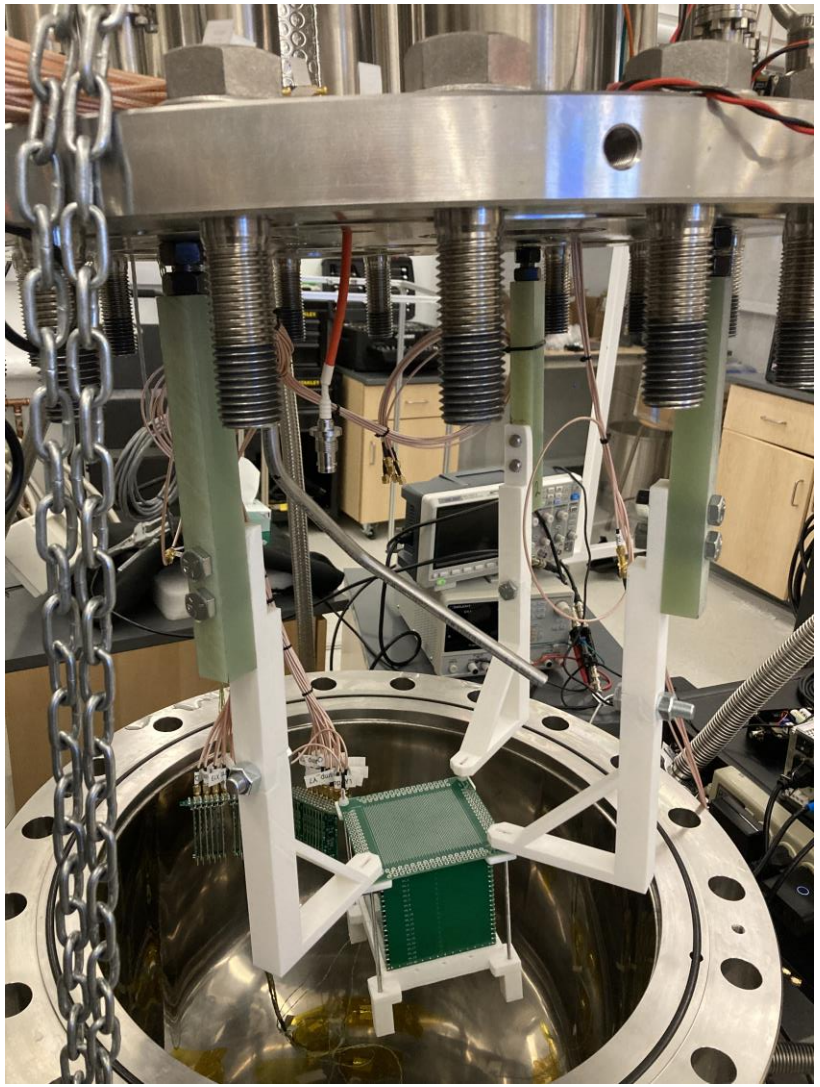
zeng.jia@northeastern.edu

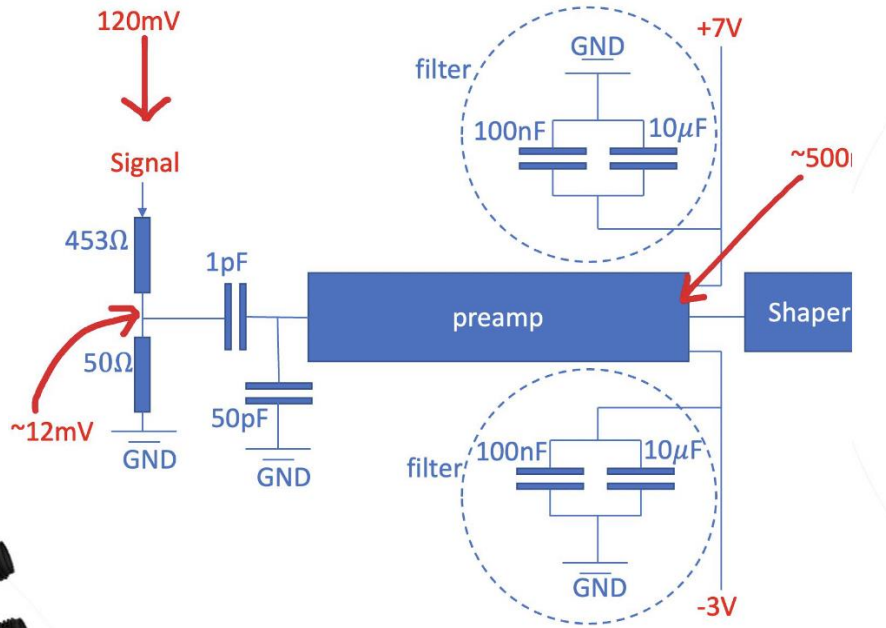
Backup slides

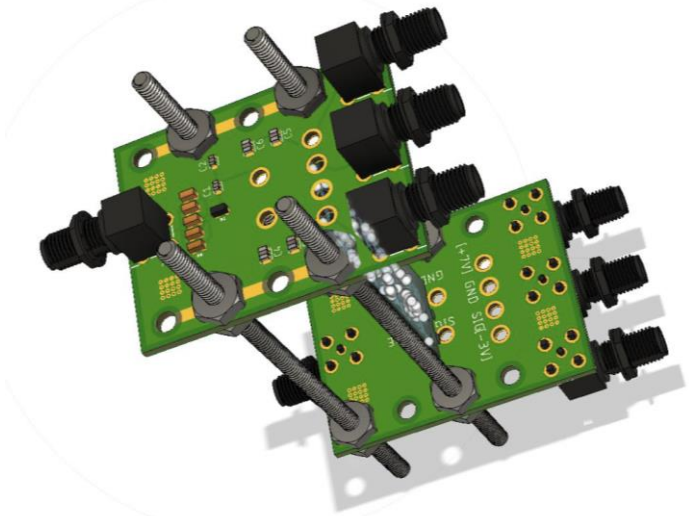
Northeastern University








120mV
Signal
453Ω
50Ω
~12mV
GND
1pF
50pF
GND
preamp
Shaper
GND
+7V
filter
100nF
10μF
~500
filter
100nF
10μF
GND
-3V



NEU Housekeeping

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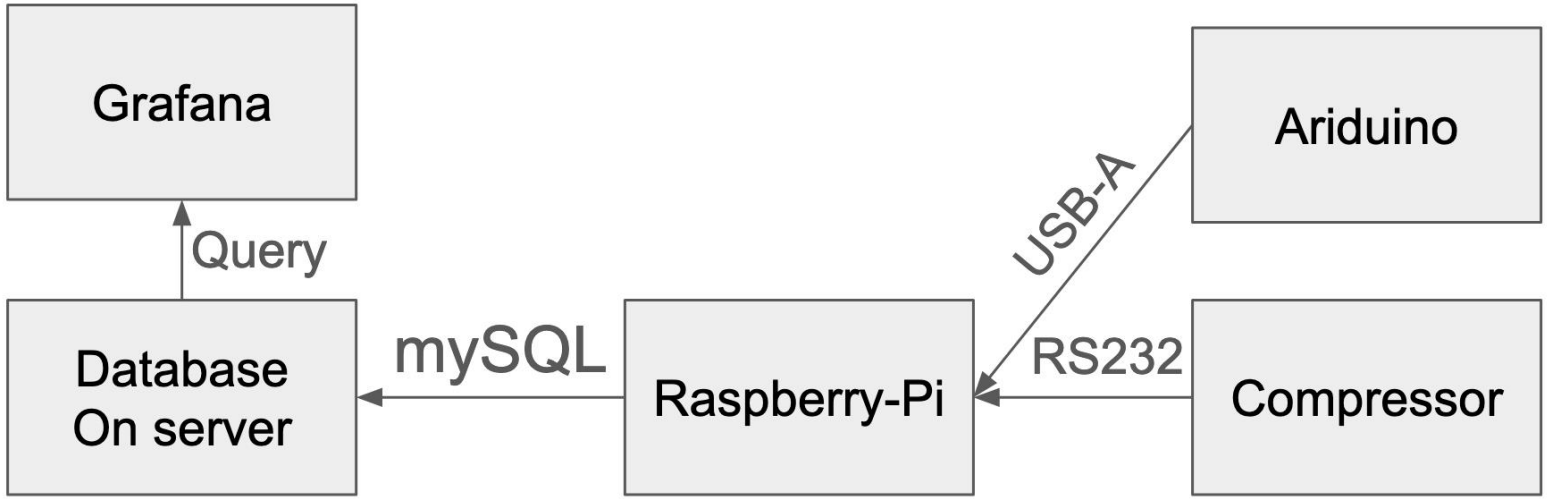
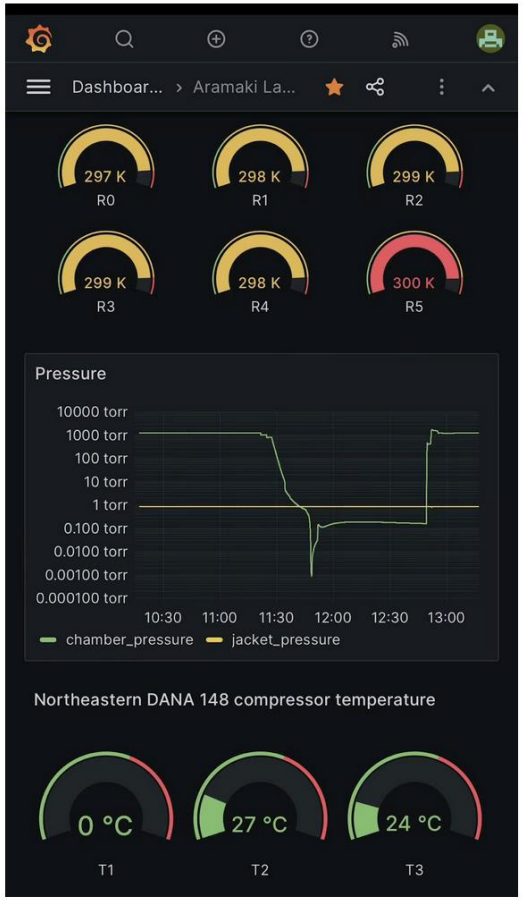
- Github page:https://github.com/Eclipsedclaw/ALAB_housekeeping
- Grafana based GUI
  - Run on our ubuntu server: http://jianchengjc.com:3000/d/f12ea01c-2b65-43c9-bd97-90bd0ddd0dfb/aramaki-lab-housekeeping?orgId=1&refresh=auto&from=now-1h&to=now





CSP sensitivity

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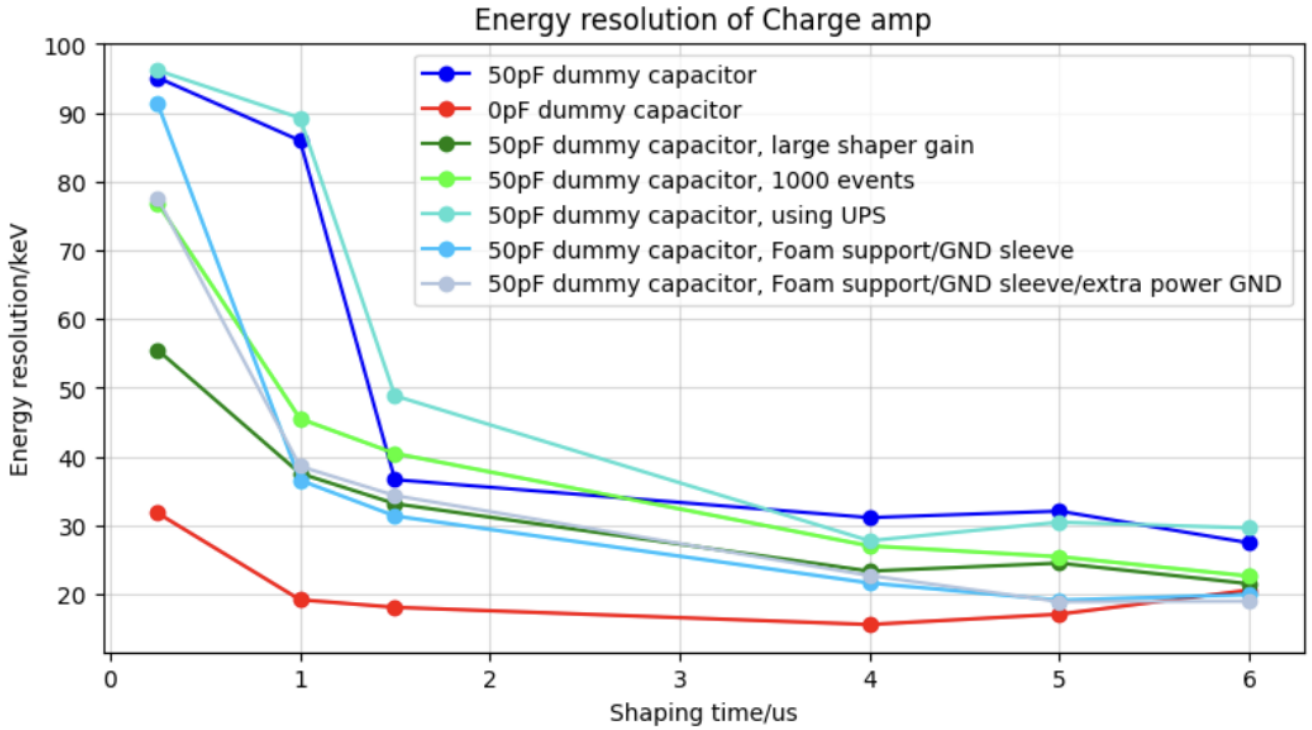

	0.25us/keV	1us/keV	1.5us/keV	4us/keV	5us/keV	6us/keV
0pF dummy	31.8	19.2	18.1	15.6	17.1	20.6
50pF dummy	55.517	37.58	33.165	23.363	24.528	21.523
50pF 1000 events	76.872	45.527	40.48	27.033	25.46	22.642
50pF no pump	185.83	43.64	47.49	25.89	21.3	21.35
50pF UPS	96.17	89.26	48.86	27.78	30.48	29.64
50pF celling GND	66.66	37.06	NaN	22.53	24.7	22.71
50pF foam/sleeve/celling GND	91.32	36.58	31.38	21.64	19.13	19.95
50pF extra power GND	77.54	38.6	34.35	22.72	18.92	18.98

SiPM board

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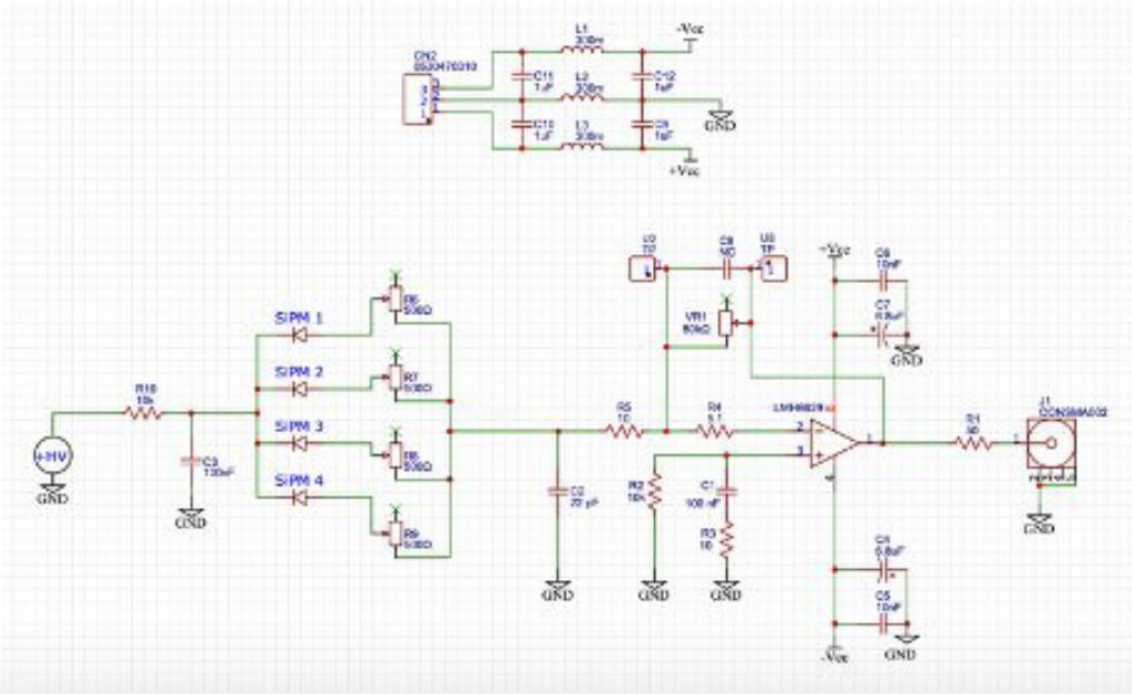
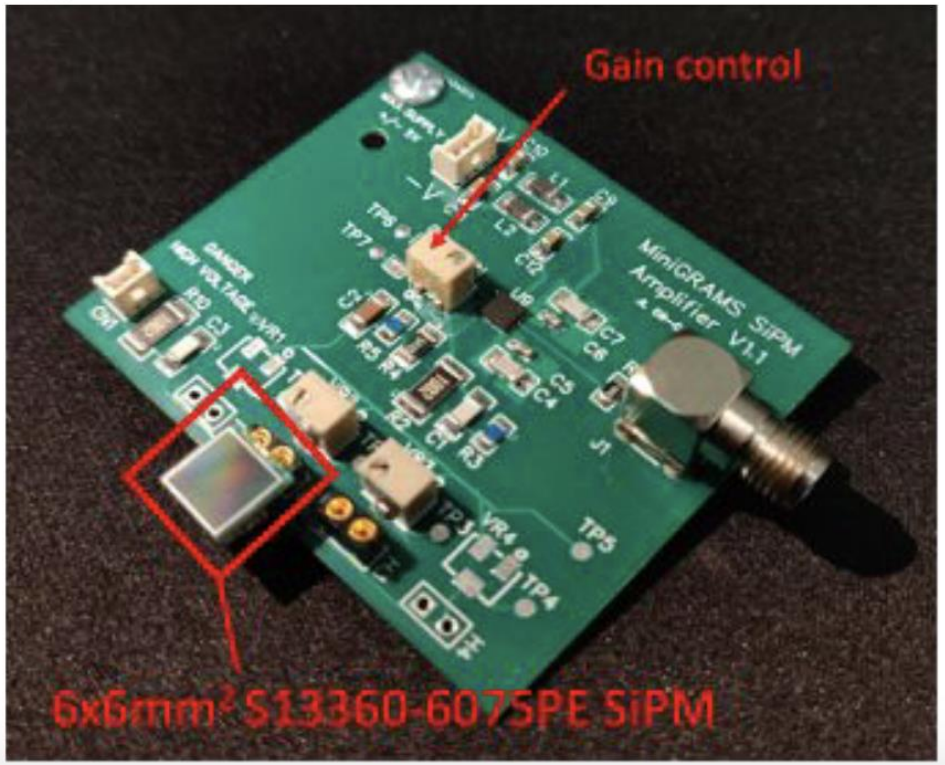
- Texas Instruments LMH6629
  - Input noise: 0.69 nV/√Hz and 2.6 pA/√Hz
  - 900 MHz bandwidth (includes controllable compensation feature that sacrifices bandwidth for improved stability at gains as low as 4V/V)
  - 1600 V/μs slew rate
  - Hetero-junction BJT, good for low temp stability
  - Typical power consumption with 3.4V (+/- 1.7V) of dynamic range → ~30 mW @ T=87K





eGRAMS photos

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launching

landing at sea

eGRAMS payload

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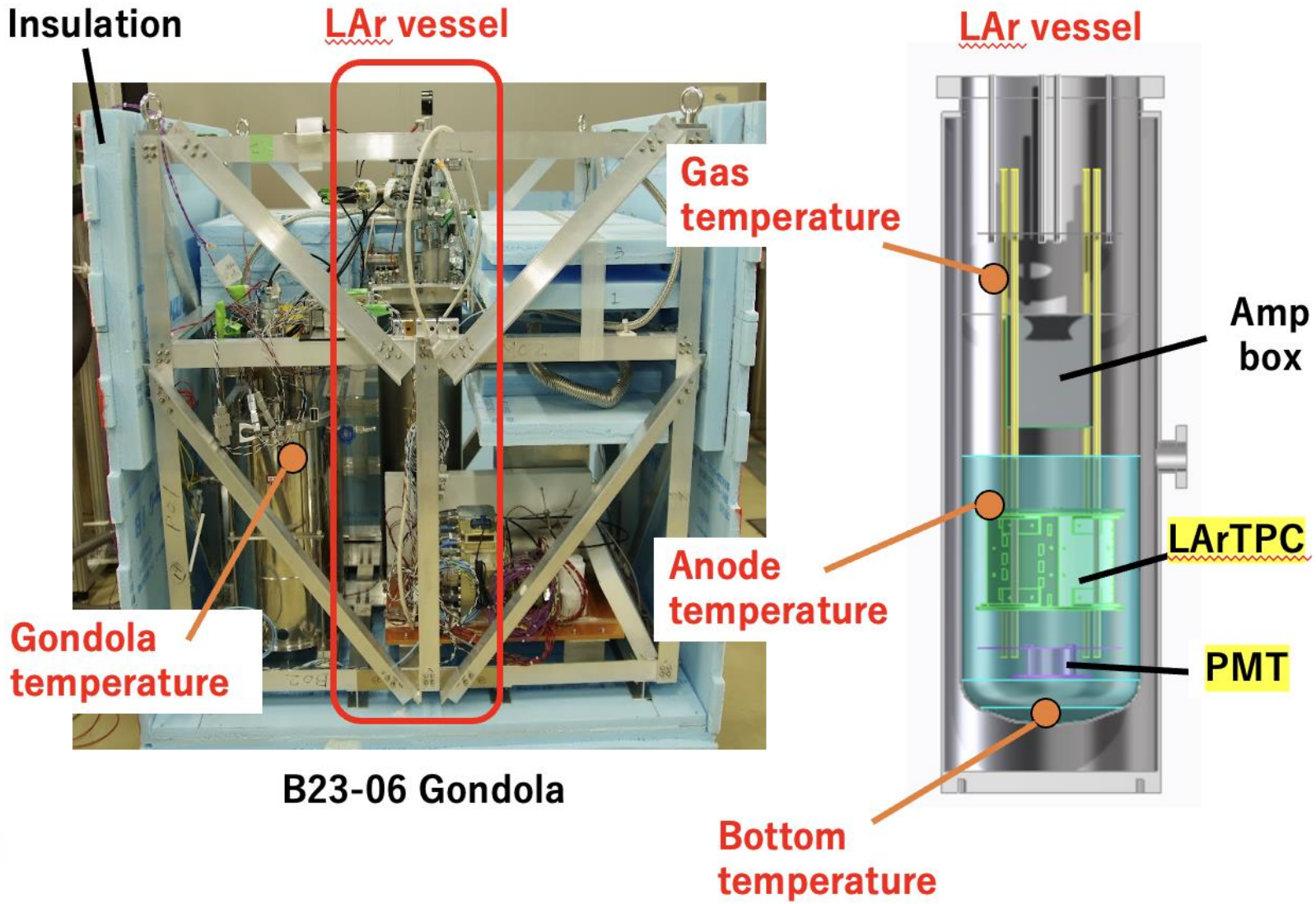

Impact of LArTPC thickness

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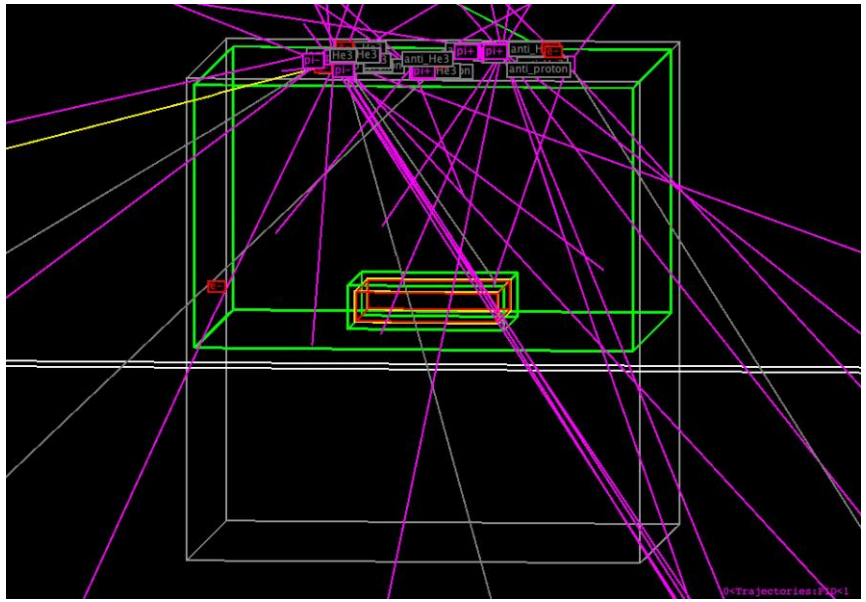
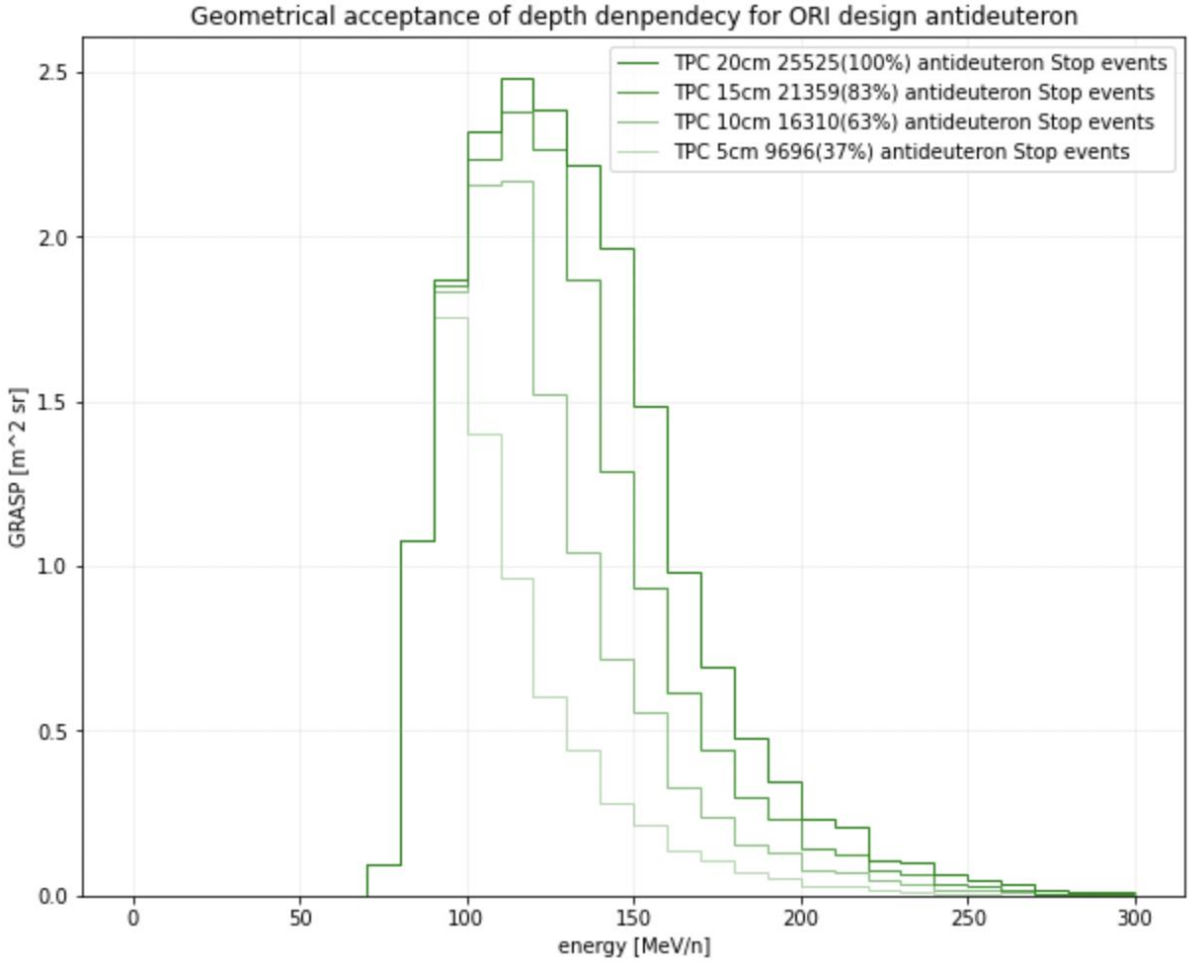
- Randomly generate antideuteron from the sky and collect events that stop and annihilate inside LArTPC.





Detector horizontally expand

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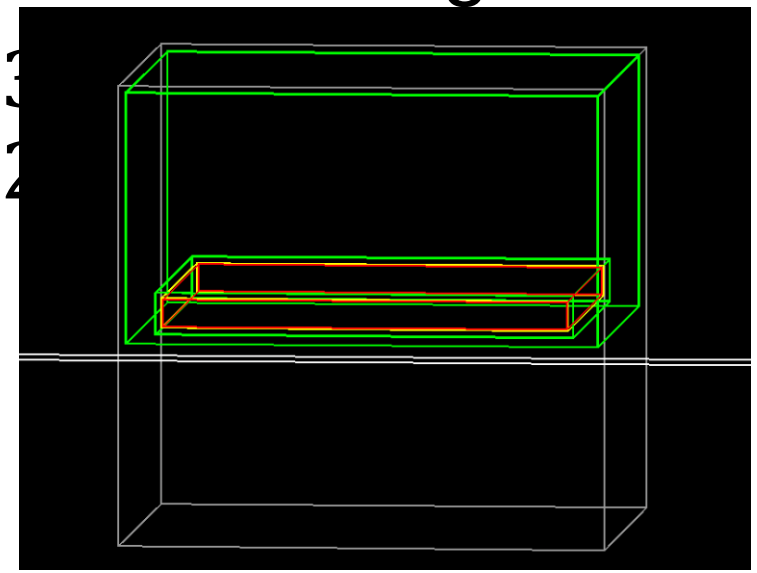
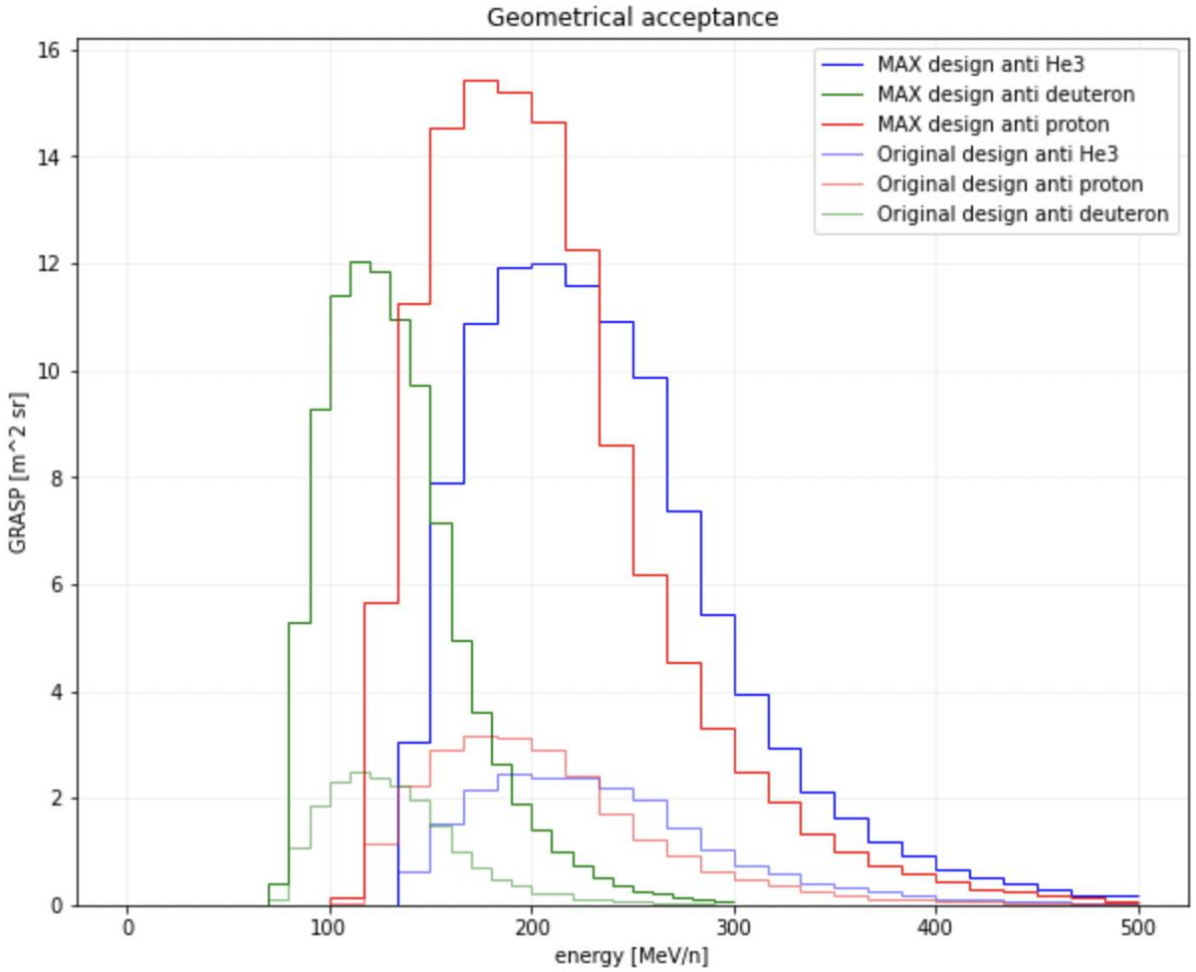
- Original design:

$140cm \times 140cm \times 20cm$

- MAX design:





TPC shape

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Tracker + TOF 900kg	TOF CONF 1424
TPC length [cm]	TPC thickness [cm]
50	88.2
60	62.8
70	46.2
80	34.8
90	26.6
100	20.7
110	16.2
120	12.7
140	7.8
160	4.6
180	2.3
200	0.8
300	-2.9
600	-4.8

Tracker + TOF 1100kg	TOF CONF 1424
TPC length [cm]	TPC thickness [cm]
50	130
60	93.7
70	69.9
80	53.5
90	41.8
100	33.1
110	26.6
120	21.6
140	14.4
160	9.7
180	6.5
200	4.1
300	-1.4
600	-4.4

Tracker + TOF 1300kg	TOF CONF 1424
TPC length [cm]	TPC thickness [cm]
50	171.7
60	124.6
70	93.6
80	72.2
90	56.9
100	45.6
110	37.1
120	30.5
140	21.1
160	14.9
180	10.6
200	7.5
300	0.2
600	-4

Tracker + TOF 1500kg	TOF CONF 1424
TPC length [cm]	TPC thickness [cm]
50	213.5
60	155.5
70	117.2
80	90.9
90	72
100	58.1
110	47.5
120	39.4
140	27.7
160	20
180	14.7
200	10.8
300	1.7
600	-3.7

TPC Shape

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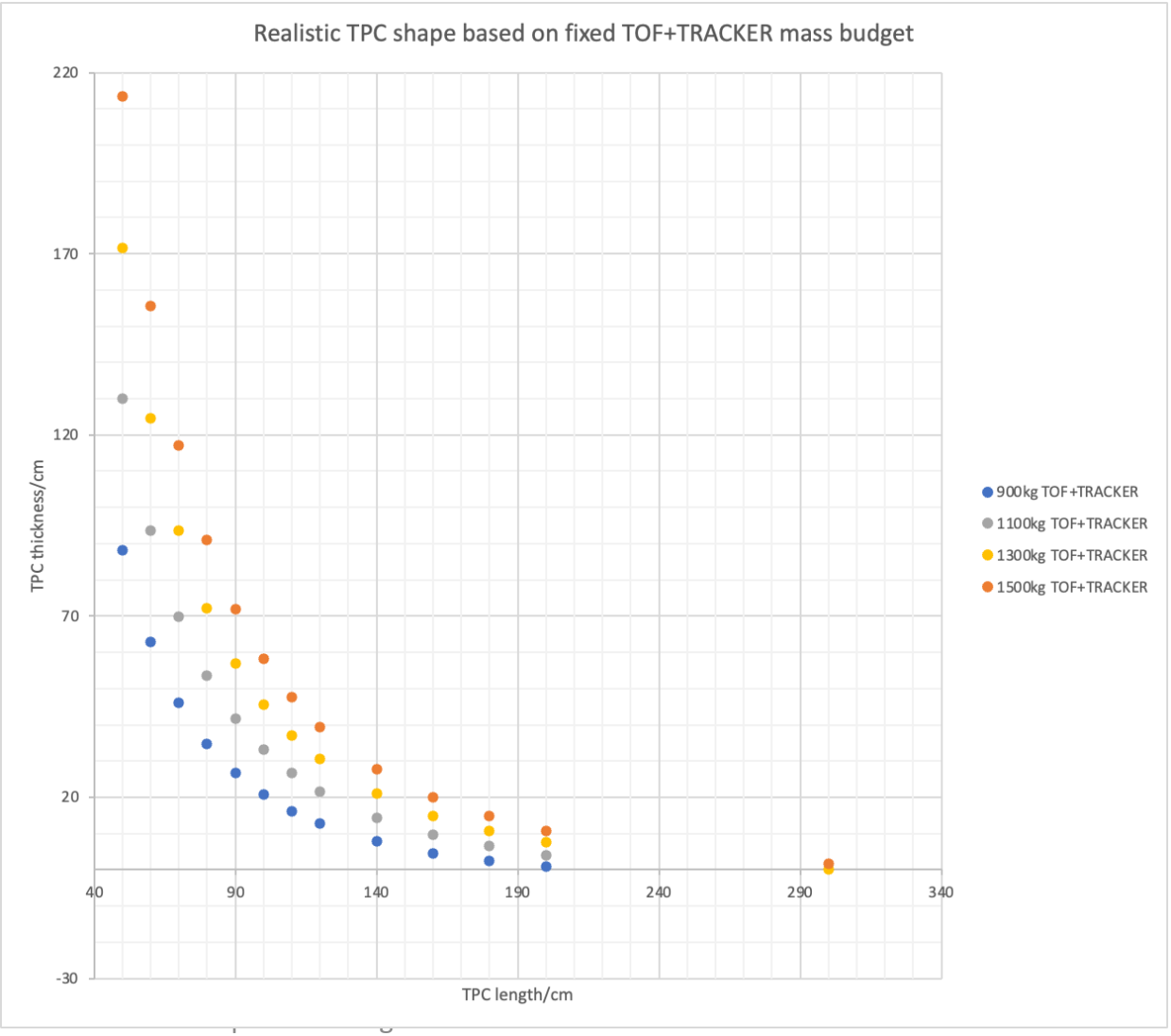

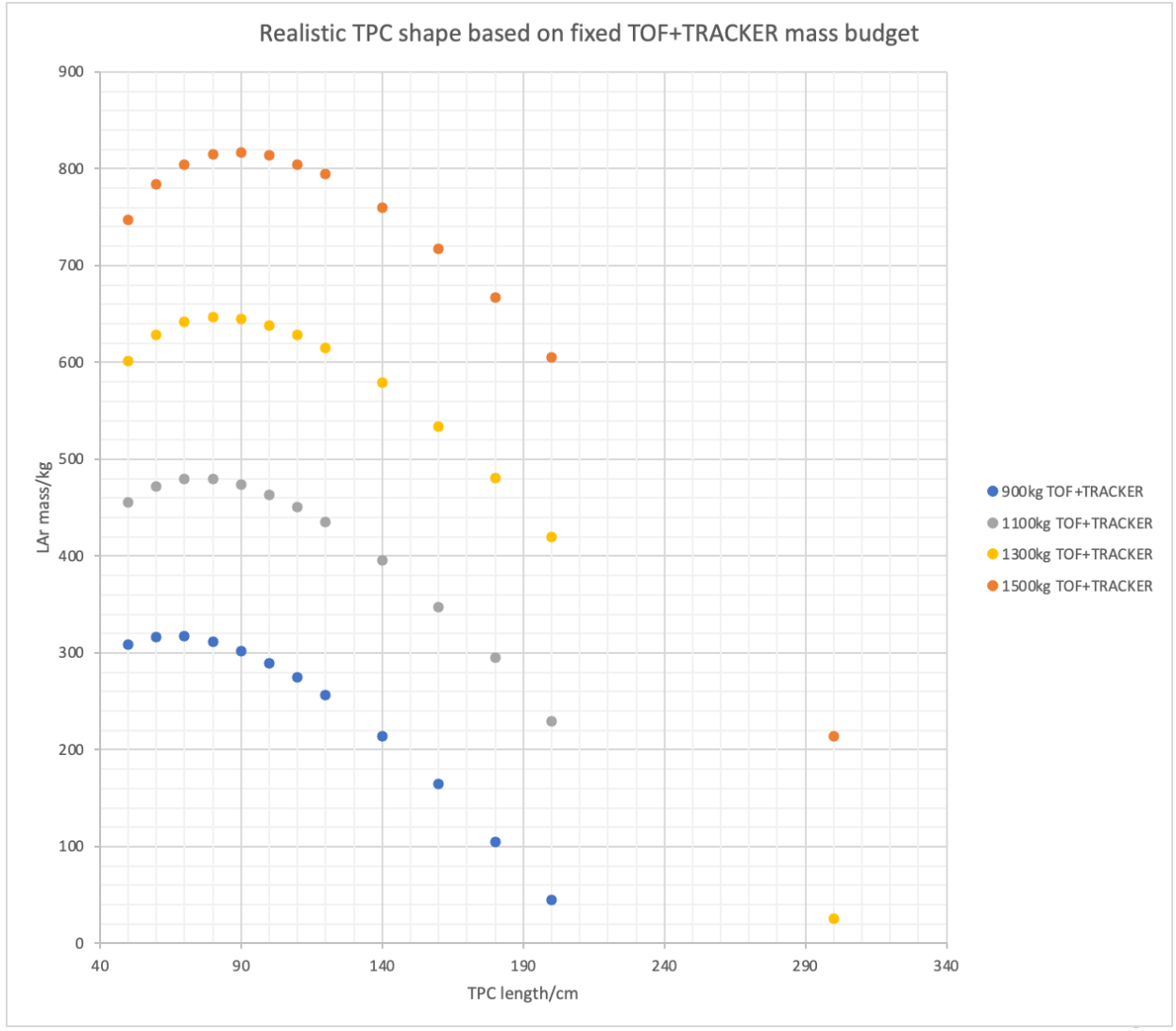

Mass budget comparison

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