First Engineering Balloon Flight Experiment Using a Liquid Argon Time Projection Chamber

ICEPP Symposium

Feb. 19 2023

Waseda Univ. Yorita Lab

1st Year Masters

Riki Nakajima

Outline

1. GRAMS intro
2. GRAMS Schedule
3. JAXA Taikicho
4. Application Process
5. GRAMS Engineering Balloon Flight
6. Experiment Design
7. LAr Operation
8. LArTPC
9. Cryogenic Amplifier
10. Summary & Prospects

GRAMS Experiment

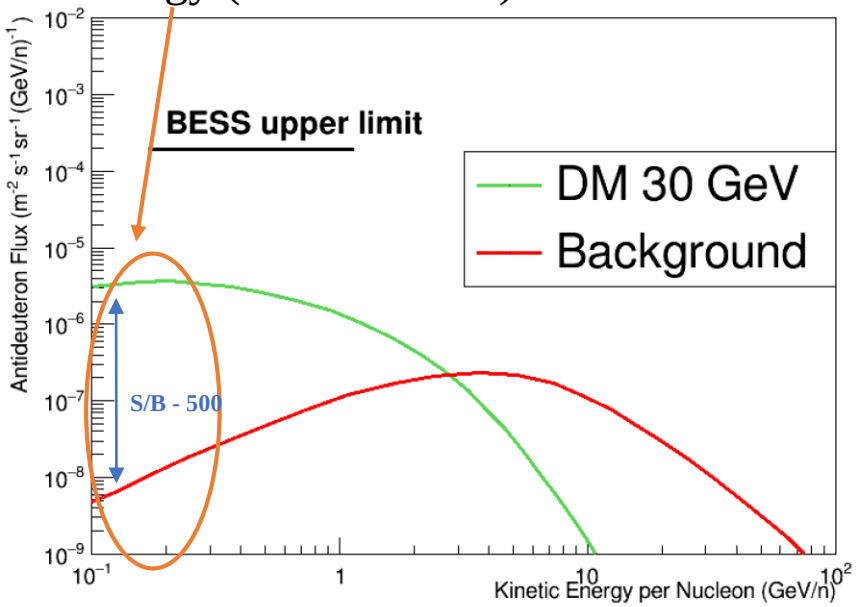
Gamma-**R**ay and **A**nti**M**atter **S**urvey

- Long Duration Balloon Experiment @ South Pole

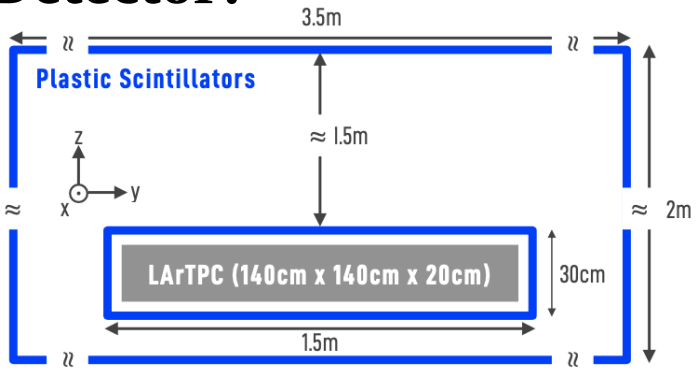
Objectives:

Indirect Dark Matter Search with Antimatter

- Anti Proton, **Anti Deuteron**, Anti Helium
  - Dark Matter Annihilation (Primary)
  - Cosmic Ray Interaction (Secondary)
    - Background-Free DM Search at Low-Energy (100-300MeV)

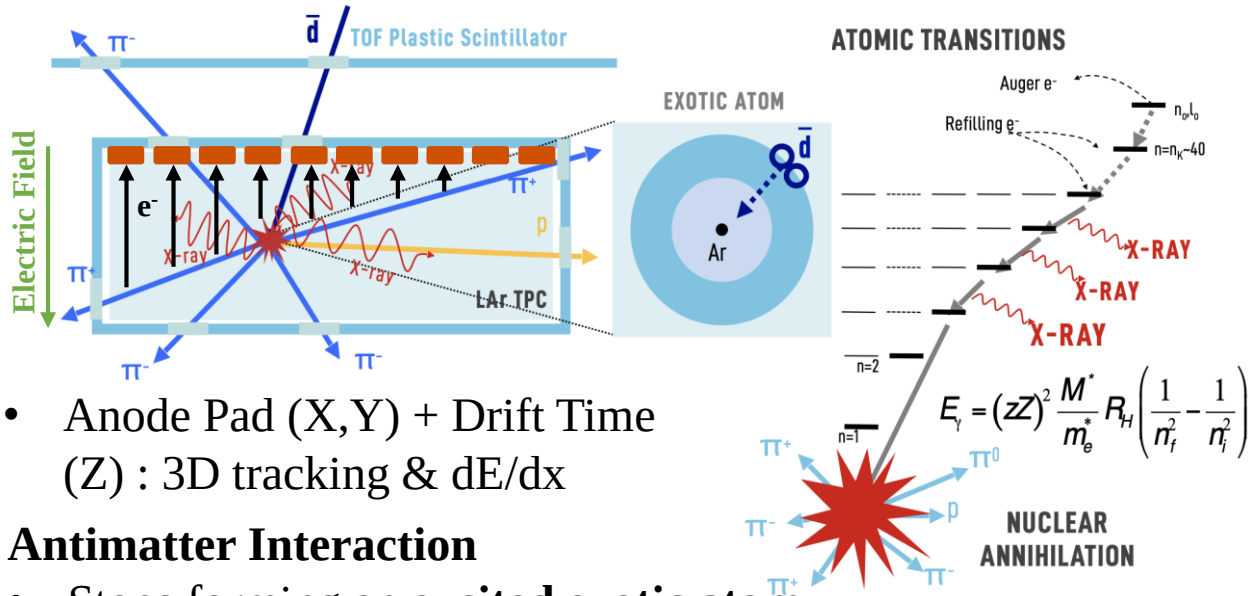


Detector:



- 2 Plastic ToF layers
- Single Phase LArTPC

LArTPC -> cost effective, expandable and no dead volume



- Anode Pad (X,Y) + Drift Time (Z) : 3D tracking & dE/dx

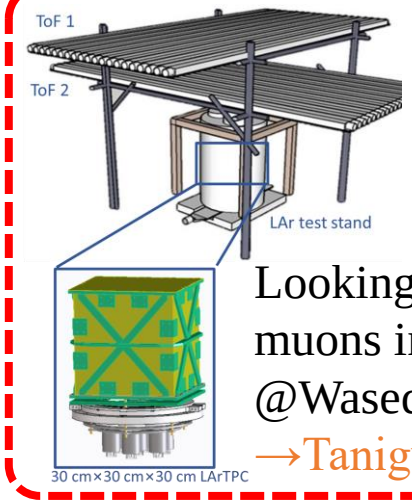
Antimatter Interaction

- Stops forming an **excited exotic atom**
- Deexcitation releases signature X-Rays
- Ends in a nuclear annihilation releasing **pion/protons**

GRAMS Schedule

- **Milestones for Cosmic AntiMatter Detection**
  - Verification of Matter/AntiMatter identification
  - Quantification of particle identification capability using Antimatter Beam Line
  - Establishment of stable LAr operation at balloon altitudes

Cosmic muon test



Looking for stopped muons in LAr @Waseda
→Taniguchi's talk

Beam test @J-PARC

Verification of antimatter capture process in LAr
→ K1.8BR @ J-PARC →Shimizu's talk

Engineering Balloon Flight

First Balloon Experiment using a LArTPC
→ @JAXA Taikicho ~ June 2023

Sep. 2022 — Mar. 2023 — Sep. 2023 — Mar. 2024

30 x 30 x 30 cm^3 LArTPC Cosmic Muon test

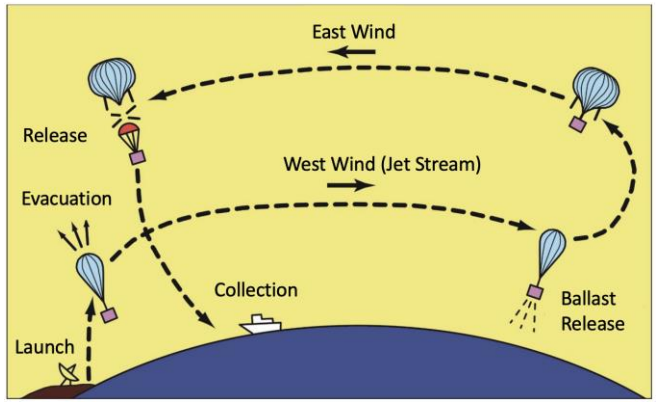
J-PARC Phase 1 Beam test

J-PARC Phase 2 Beam test

Engineering Balloon flight @ JAXA TARF

JAXA Taikicho (TARF)

- Since 2008 domestic balloon campaigns have been held at JAXA Taikicho
- Flight Season : May to September
- Recently rapid climate change has reduced chances for balloon flights



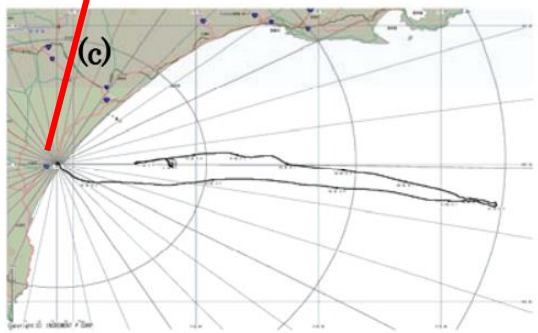
Boomerang Flight

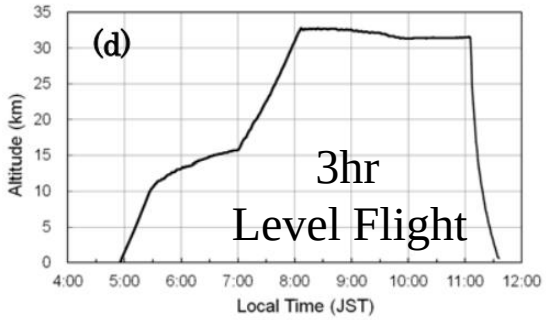
- Enable longer flight duration
- Low Altitude : West Wind
- High Altitude : East Wind

- Hangar: Balloon filling with He & Operational checkup
- Control Tower: Telemetry control of balloon flight

Previous Balloon Experiment (an example):

- **GAPS** has conducted engineering flights : pGAPS (Prototype GAPS) in 2012

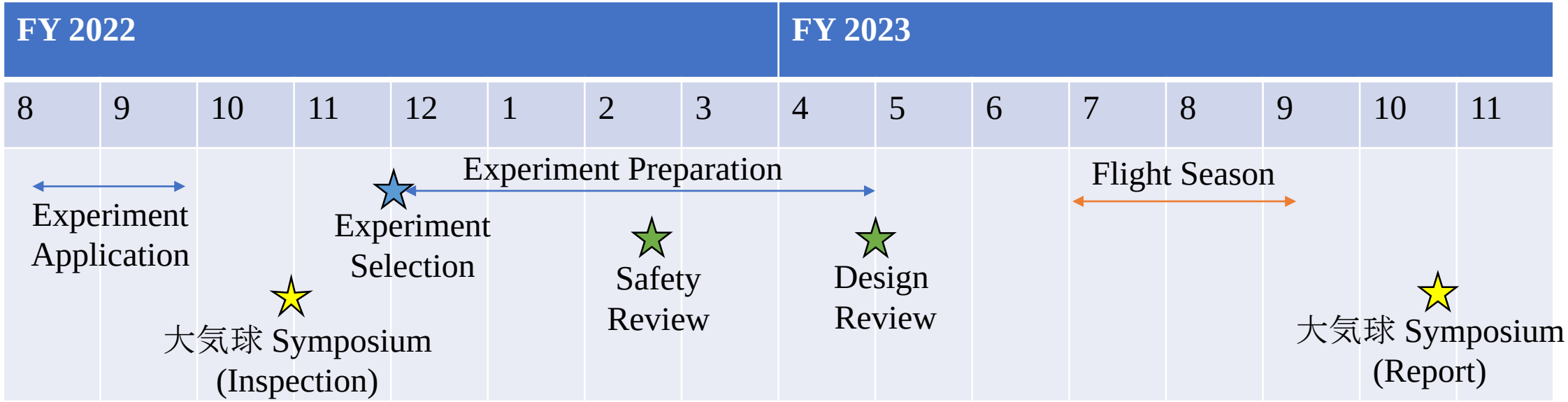




https://www.isas.jaxa.jp/j/researchers/symp/2012/image/1016_balloon_proc/isas12-sbs-018.pdf

Application Process

Schedule for Proposed Experiments



- Proposal submission during summer, further inspection at 大気球 Symposium
- Based on the payload, flight conditions differ (lighter experiments will have more chances)
  - Start off with small scale prototype of GRAMS (similar to pGAPS)
- GRAMS Proposal was accepted by JAXA (With a few other Piggyback experiments) and currently we are in the preparation process

Engineering Balloon Flight

- First ever balloon experiment using LArTPC
- Plan to finish preparation by June and flight in July to Sep

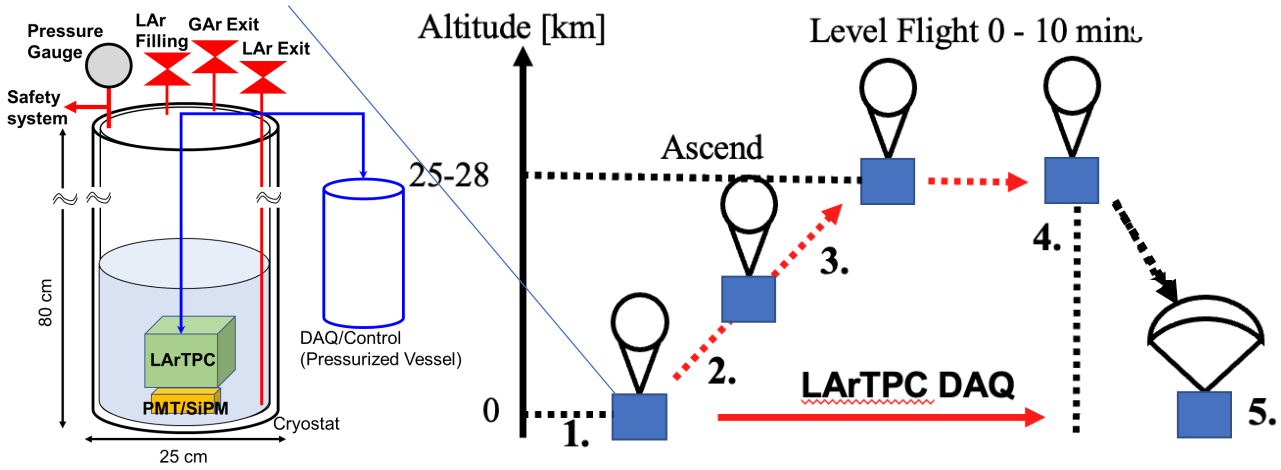
Objectives:

Minimum Success	Full Success
1. Monitor vacuum vessel environment and **safely operate LAr.** 2. Obtain data from LArTPC during ascend.	1. Obtain environmental data and LArTPC data during level flight.

Proposal:

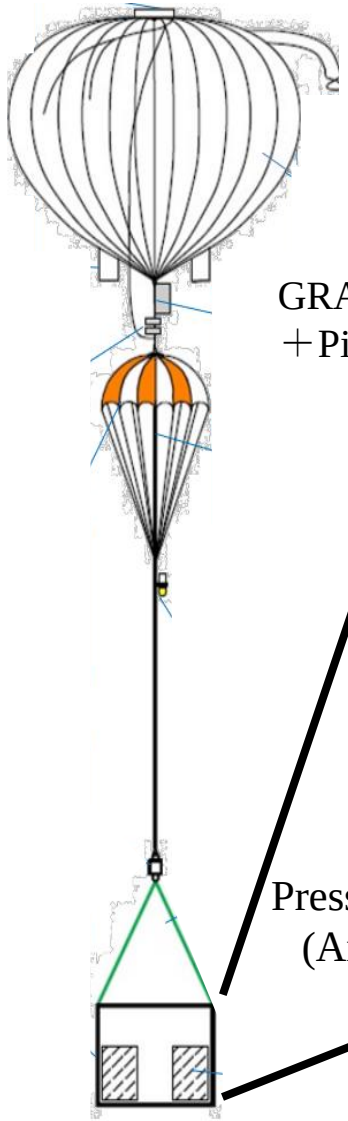
	Require	If Possible
Max Altitude	25km	28km
Flight @ Max Altitude	0 min	10min

Experiment Plan:

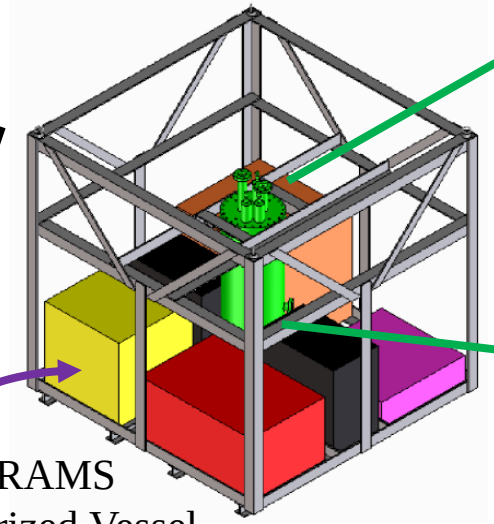


1. **Before Launch:**
   Fill LAr into vessel & check Detector operation
2. **After Launch:**
   Stabilization of Vessel Pressure & detector operation test
3. **During Ascend:**
   Continue to control inner pressure, start DAQ.
4. **Before Release:**
   Stop DAQ & evacuate LAr into atmosphere
5. **Collection:**
   Retrieve detector and data (stored in SSD and MicroSD)

Experiment Design



GRAMS LAr Vessel（Around 70 kg）
＋Piggyback Experiment etc（Around 60kg）

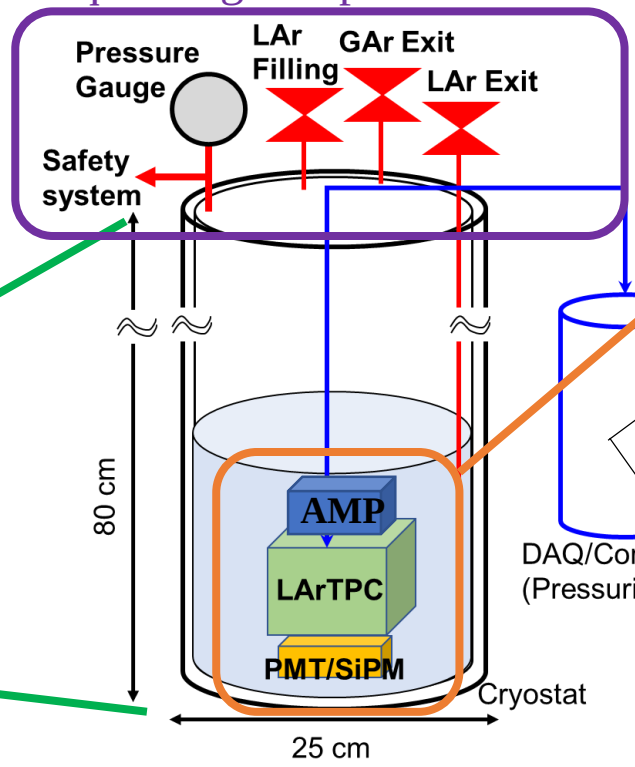


GRAMS
Pressurized Vessel
(Around 10kg)

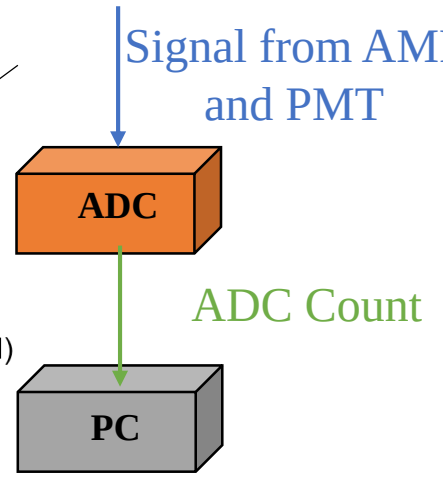
Gondola Design:
Launch：XYZ Direction 3G
Release：Z Direction 7.5G

Gondola Total Weight: Around 200kg

Liquid Argon Operation

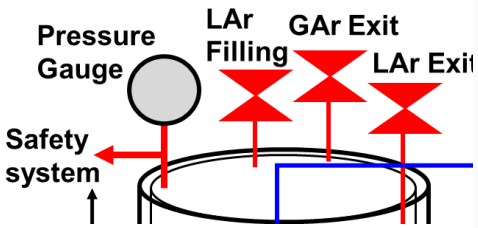


My Research Area:
TPC design and
Signal Readout System



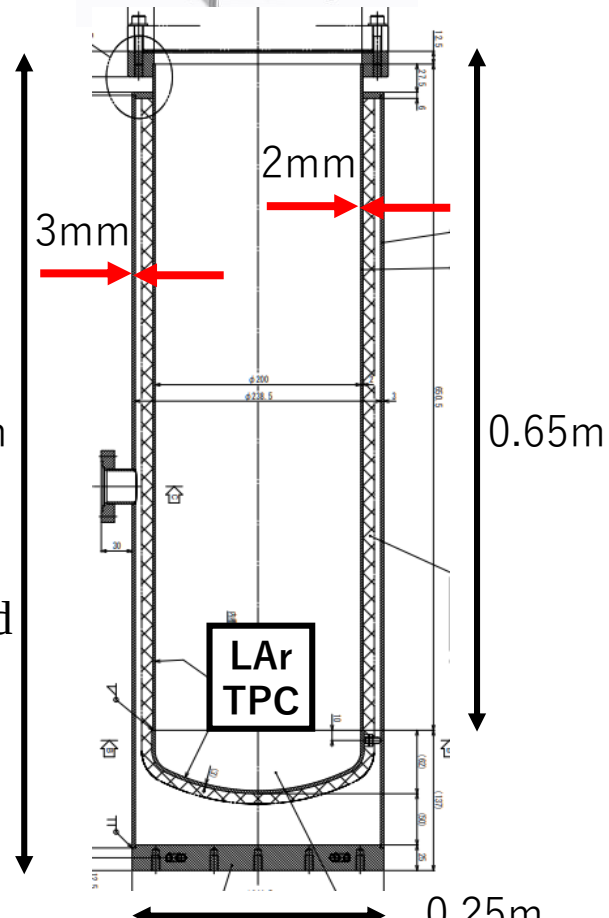
- LAr Vessel: Vacuum Insulated + SuperInsulation
  250mm diameter, Height 800mm
- GRAMS Pressurized Vessel: Lithium primary batteries, Power Supply Unit, Detector Control, HV supply, DAQ, PC.

LAr Vessel

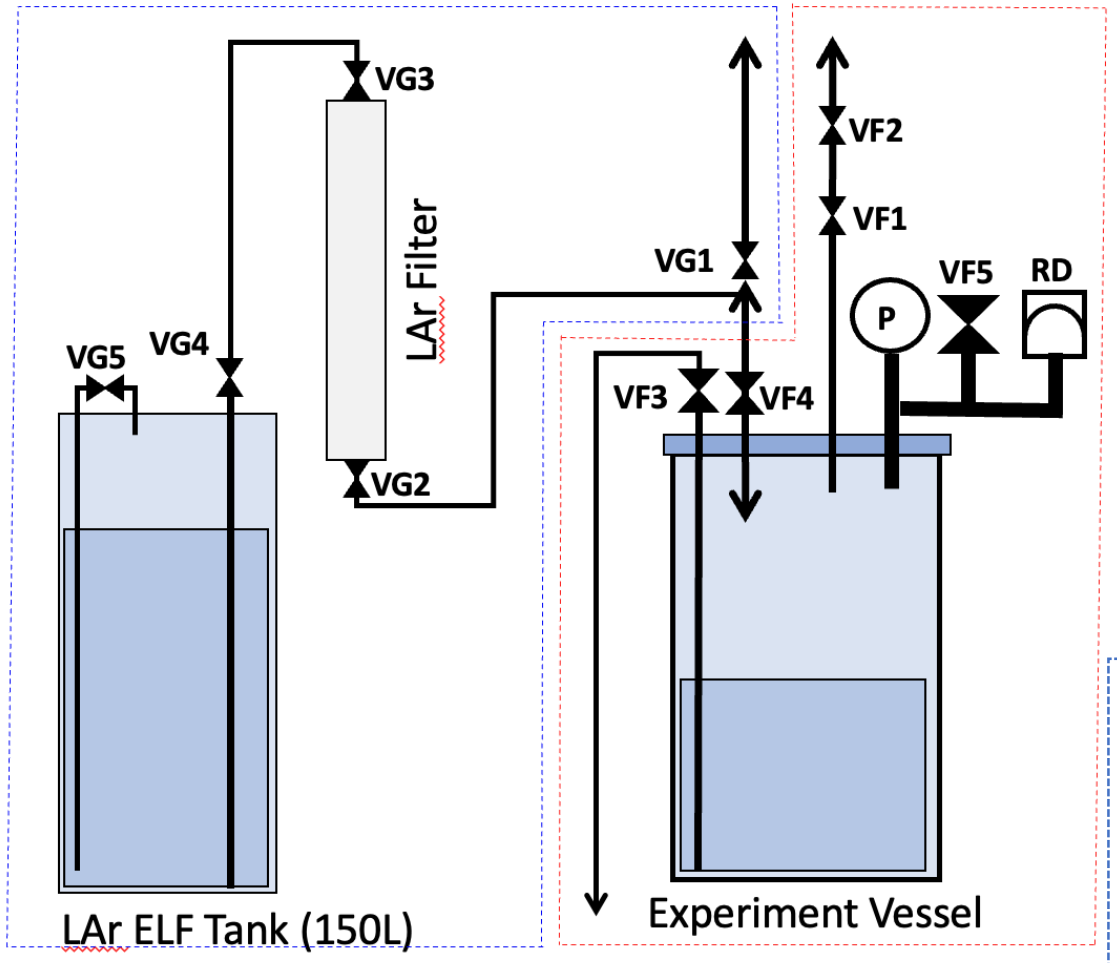


Design Considerations

1. Mountable Top flange for detector
   with M8 Holes for stainless rod to connect LArTPC
2. Minimize Heat Inflow :
   - Vacuum Insulation + Super Insulation
   - Vertically Long
     →Reduce explosive evaporation (LAr contact with top flange)
3. Low Weight : 46kg
4. Inner Pressure Resistance: 9.8 atm
5. Top Flange: 3 x VCR (LAr Filling, GAr Exit, LAr Exit)
   & 2x ICF 70 (Safety System, LArTPC Input/Output)
6. Endure 5G (during release) : 3 points of connection between inner and outer layer.



LAr Operation



On Ground
Detach from Experiment Vessel after filling

For Flight
Place in Gondola

LAr operation (Current Plan)

All Offline (No electronics)
Except Solenoid Valve (VF3)

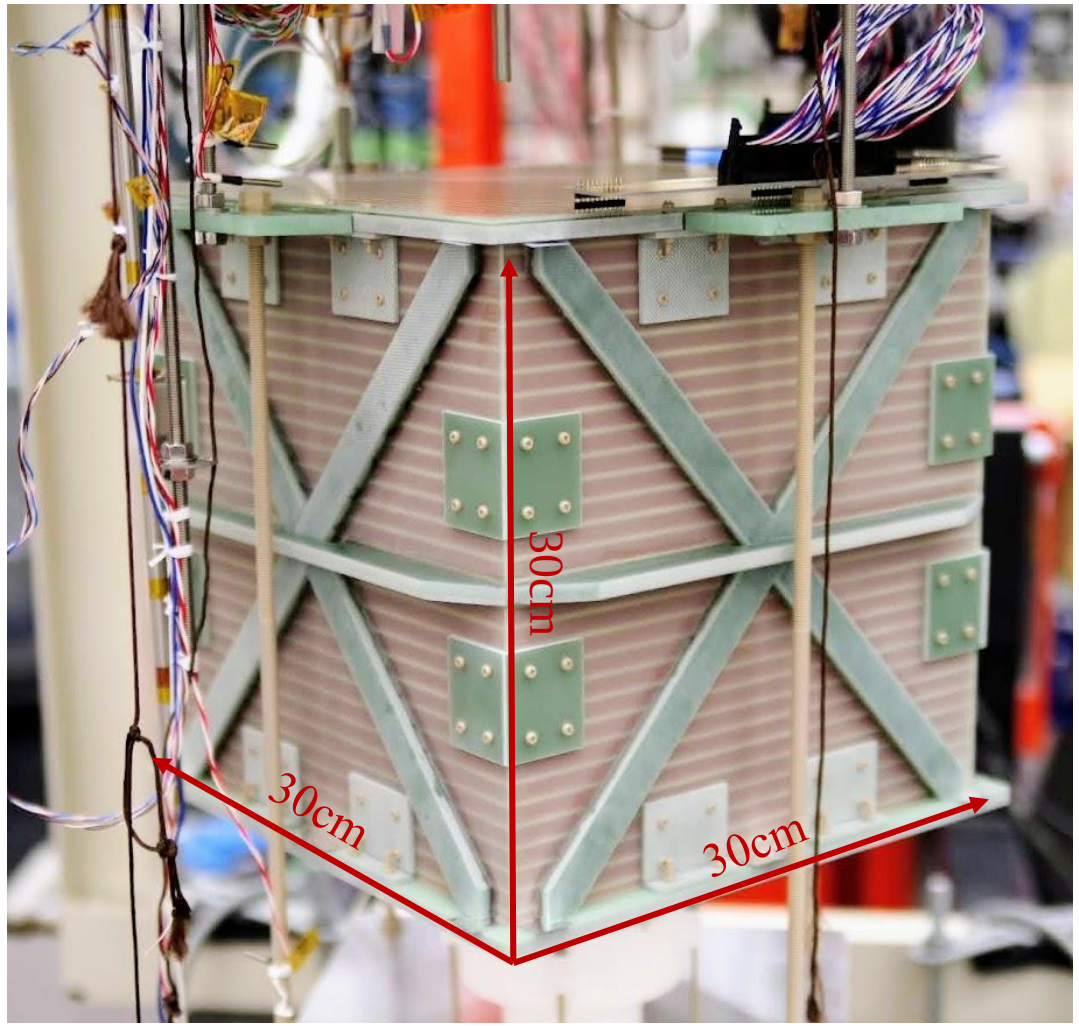
- **Filling**
  From ELF Tank (Pass through Filter)
- **Control LAr Volume :** Sufficient for LArTPC to operate
  Low Heat Inflow Open Bath Vessel with Top Flange
- **Stabilize Vessel Pressure :** Increased Pressure due to evaporation
  → Absolute Pressure Safety Valve (VF1)
- **Evacuation of LAr**
  → Solenoid Valve (VF3)
  Differential pressure (outside vessel 0atm, inside vessel 1atm)

VG1: Filter Cooling Manual Valve
VG2: Filter Output Manual Valve
VG3: Filter Input Manual Valve
VG4: ELF Tank LAr Output Manual Valve
VG5: ELF Tank Pressurization Valve

VF1: Absolute Pressure Valve
VF2: Flow Control Manual Valve
VF3: LAr Evacuation Solenoid Valve
VF4: LAr Filling Manual Valve
VF5: Differential Pressure Valve
RD: Rupture Disc
-> Ultimate Safety Measure

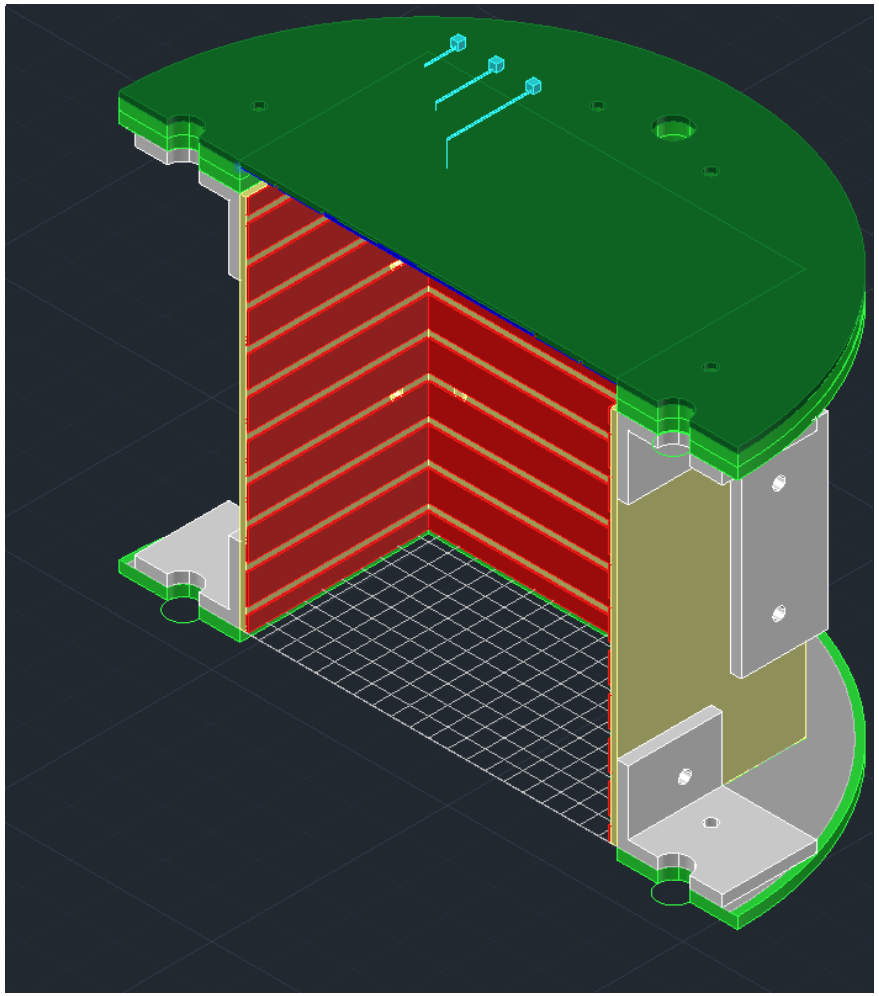
LArTPC Design

Run 22.1 LArTPC



Engineering Balloon Flight LArTPC

- Scaled down design of Cosmic muon test LArTPC



Layers:

Anode

Anode Reinforcement x2

Anode Grid

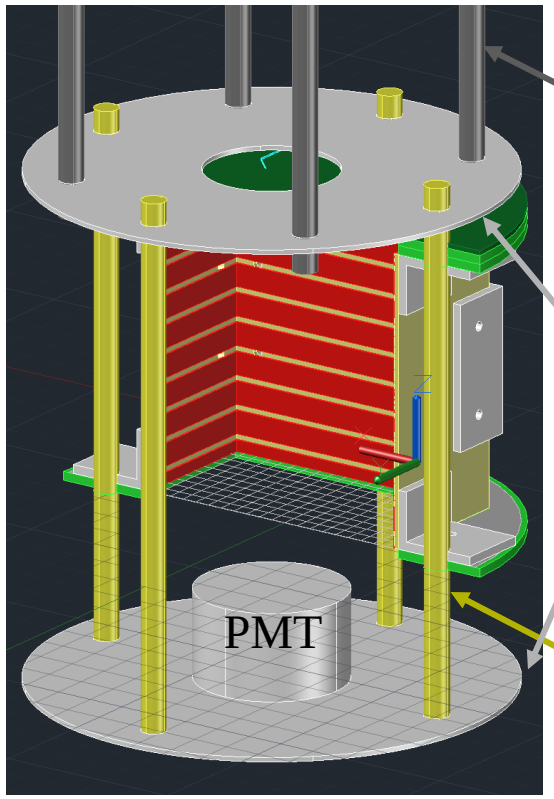
Side Plate

Cathode Grid

Cathode Reinforcement

Detector Parts

Inside Vessel



M8 Stainless Rod to Top Flange

1.5mm thickness Baffle Plate

M8 PEEK Rod

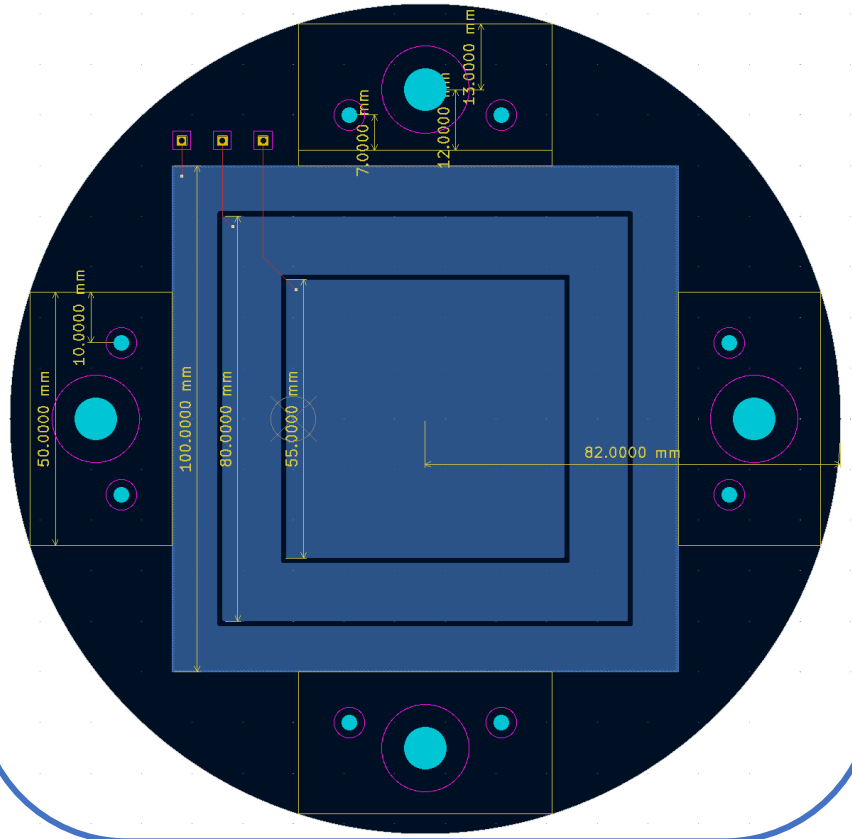
PMT

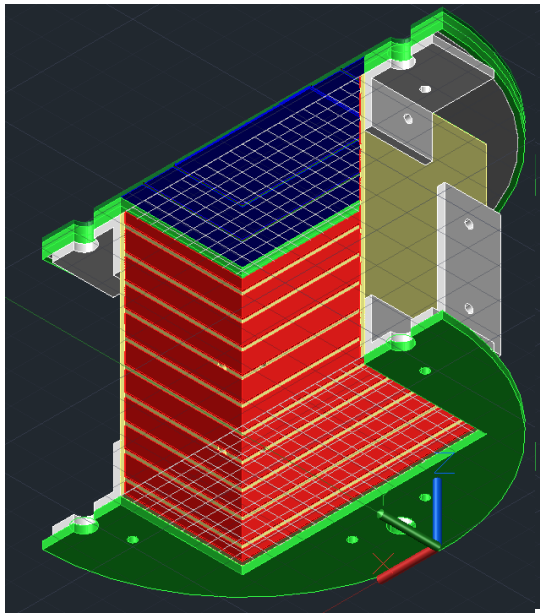
- R6041-06 (Hamamatsu)
- Input: +700V 40uA
- Tube Diameter : 51mm
- Typ Gain 1 x 10^6

Readout

Anode

- Radius 82mm, circular 1.6mm thick Double-Sided board
- 10 x 10 cm^2 3ch anode pad





Layers:

Anode

Anode Reinforcement x2

Anode Grid

Side Plate

Cathode Grid

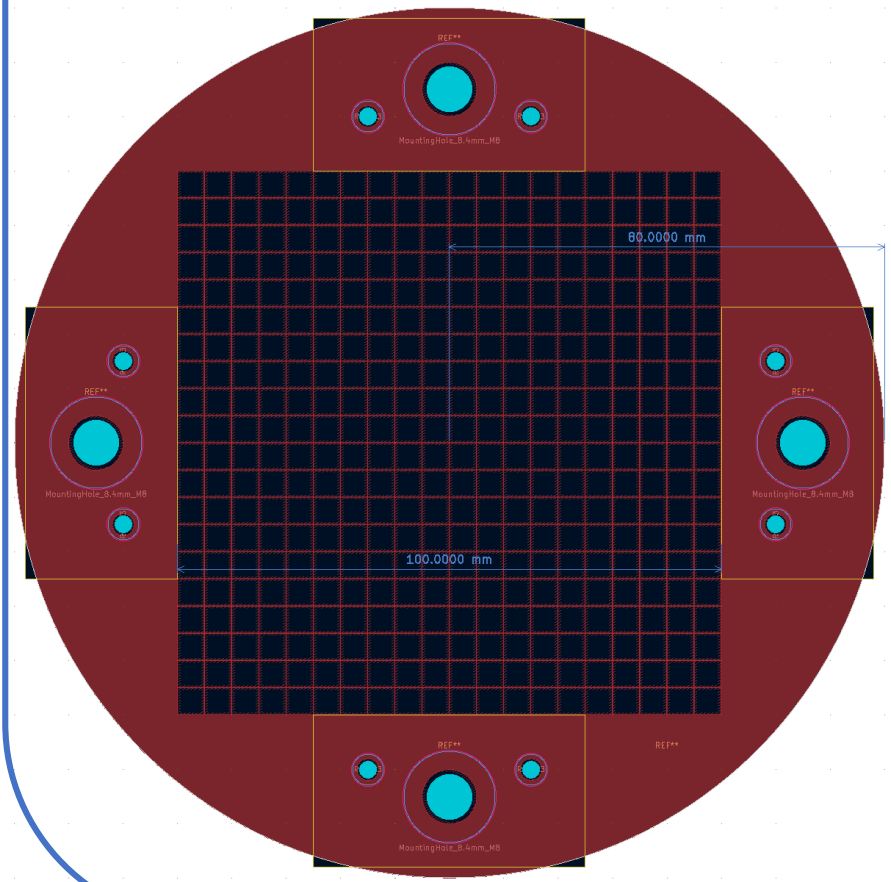
Cathode Reinforcement

Detector Parts

Field Shaping

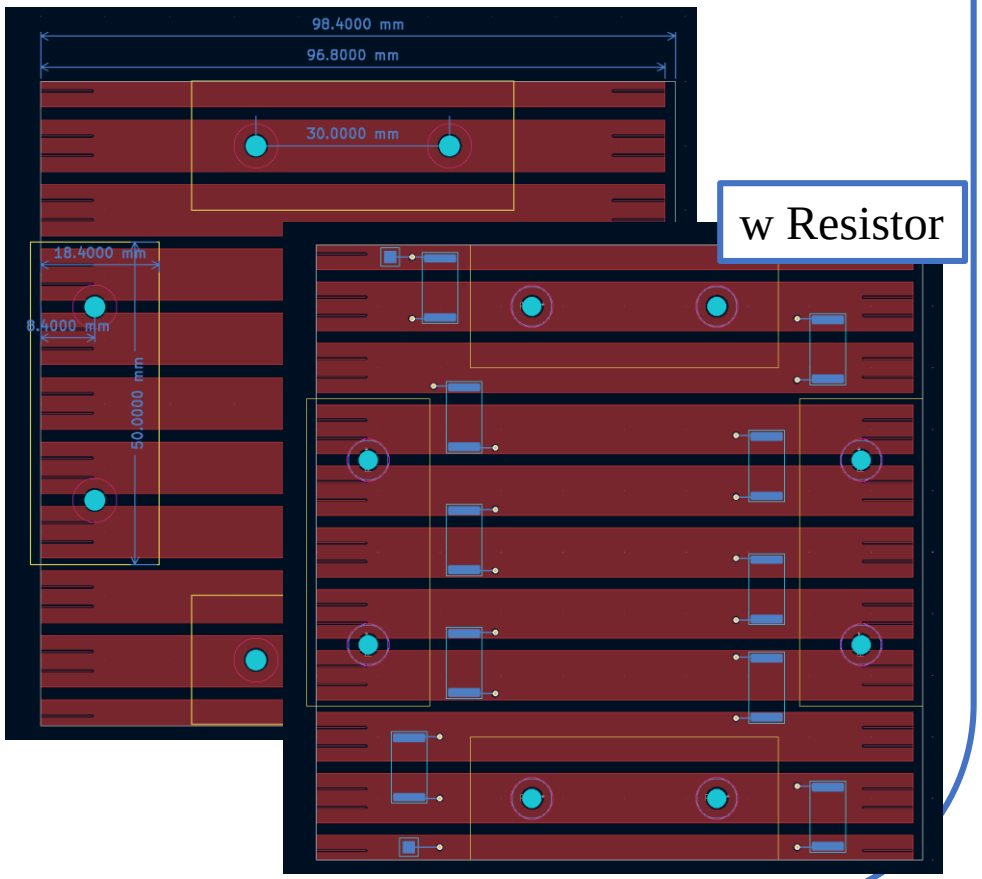
Grid (for Anode Grid & Cathode Grid)

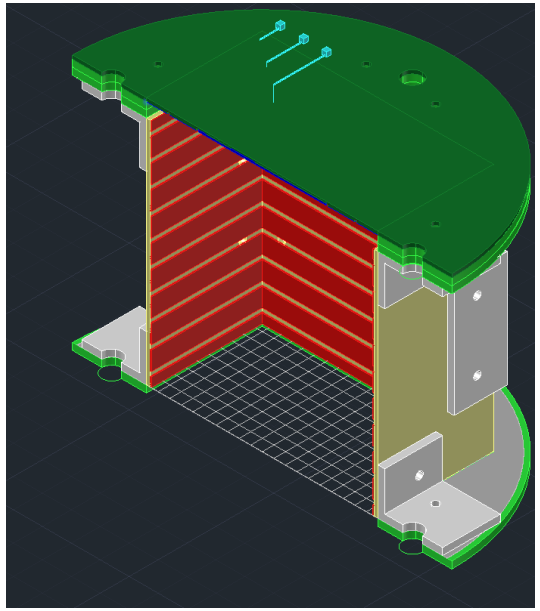
- 0.1mm thickness, 5mm pitch, 0.1mm wide stainless-steel mesh



Side Plate

- 1cm interval, 8mm height electrodes
- 100MΩ resistor between electrodes
- 1.6mm thick Double-Sided board





Layers:

Anode

Anode Reinforcement x2

Anode Grid

Side Plate

Cathode Grid

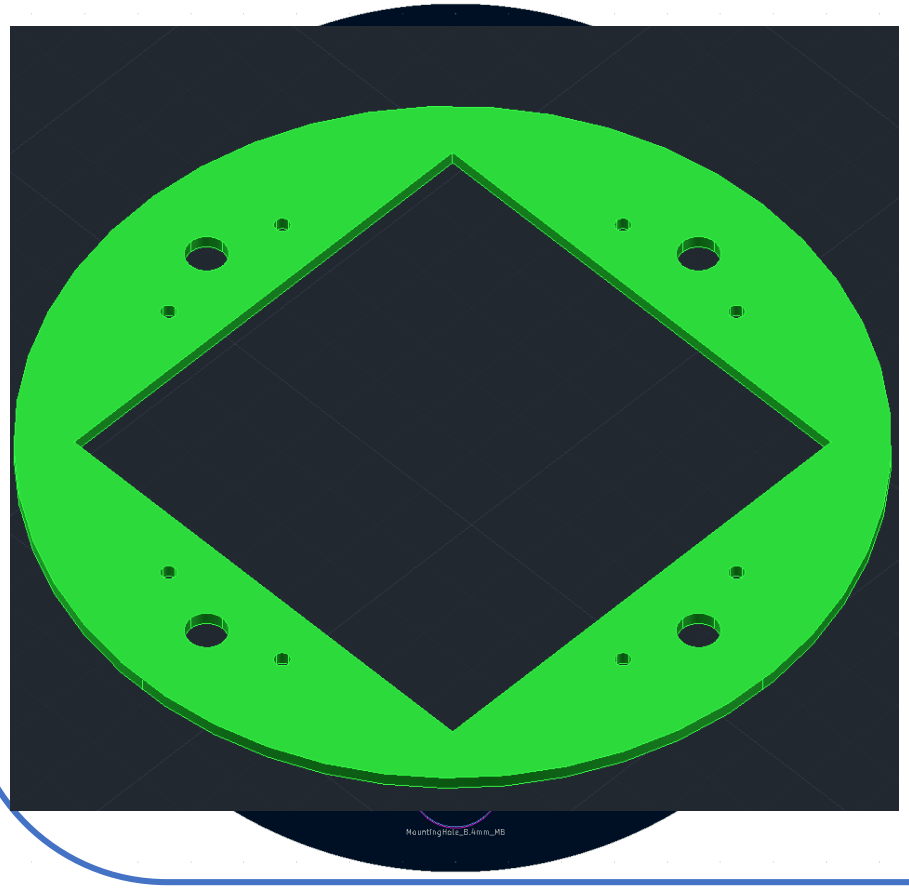
Cathode Reinforcement

Detector Parts

Reinforcement

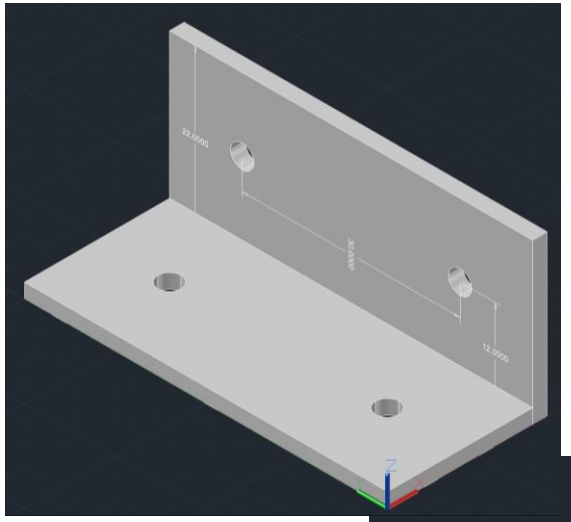
For Anode Grid & Cathode Grid

- 3mm thickness, FR-4 Plate
- 2 between anode grid and anode
- 1 below Cathode



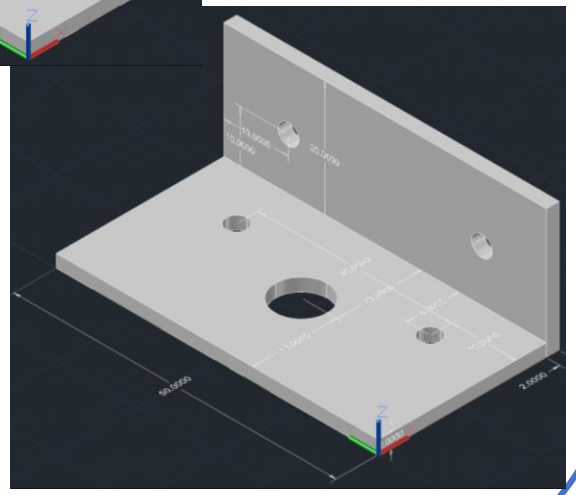
For Side Plate

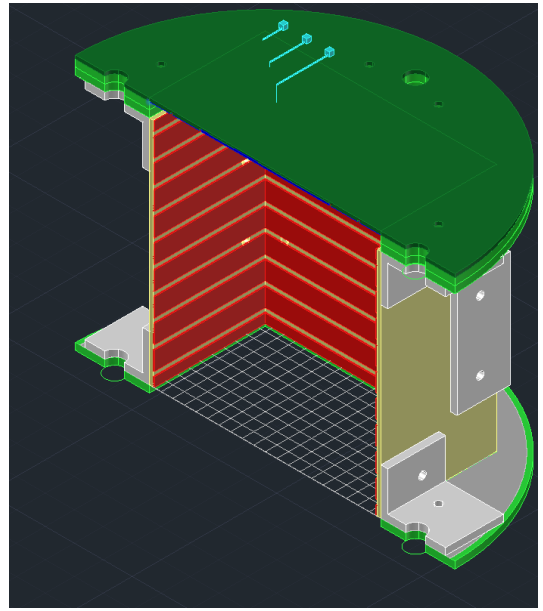
- 3D Printable @ Waseda (ABS or PLA)



Between
Side Plates

Between
Side Plate & Grids





Layers:

Anode

Anode Reinforcement x2

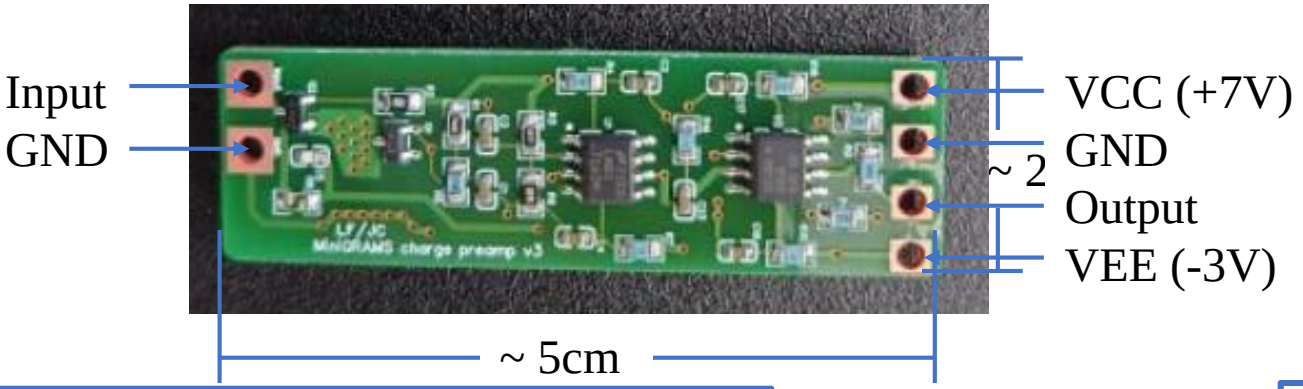
Anode Grid

Side Plate

Cathode Grid

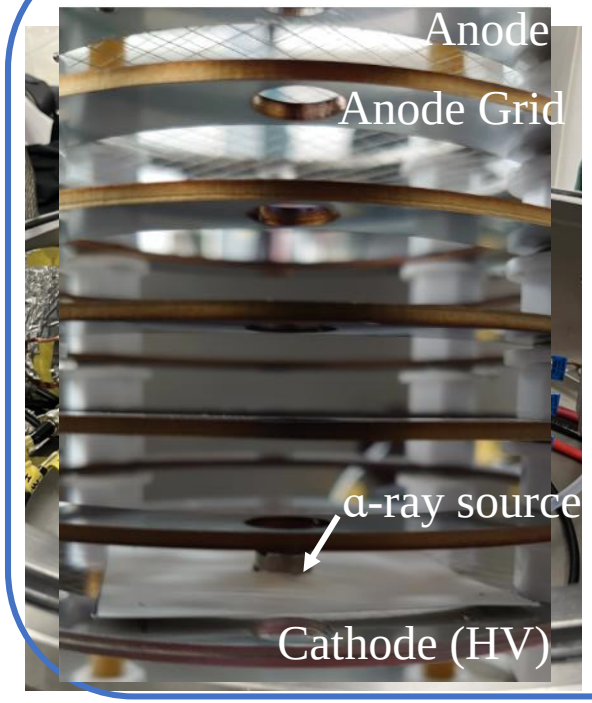
Cathode Reinforcement

Cryogenic Amplifier

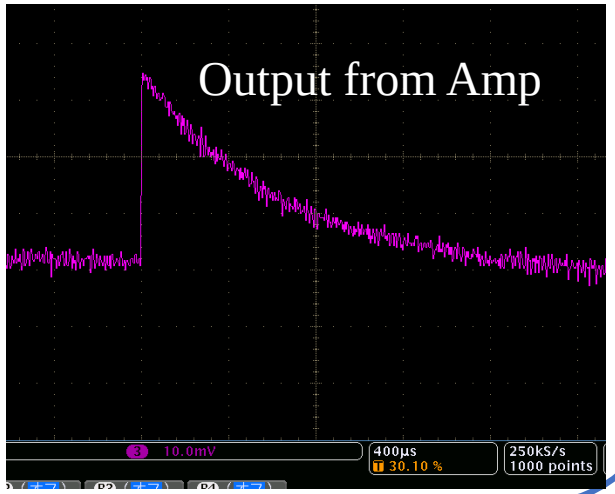


- Cryogenic amplifier made in northeastern Univ.
- Operates in liquid argon
- $\tau \approx 500\ \mu s$
- Gain : 10fC → 15mV
- 1 module connects to each output channel on anode

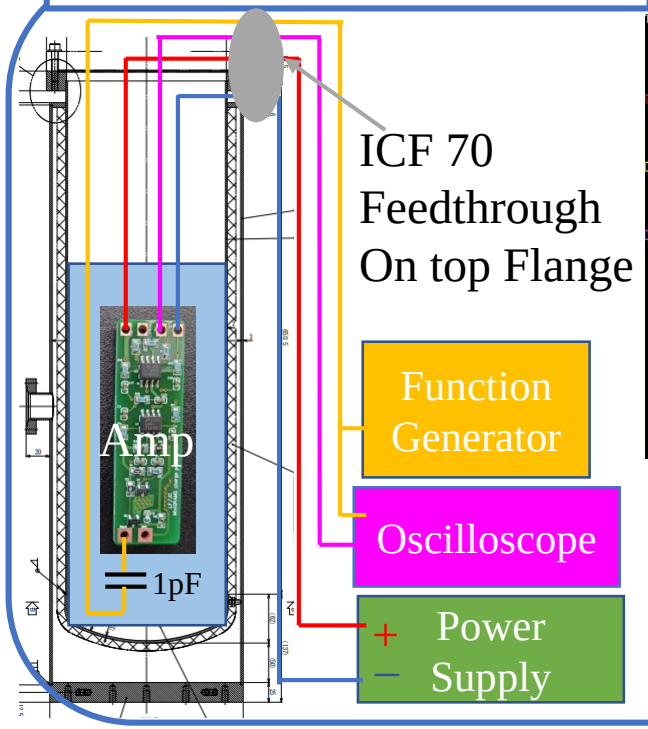
GAr test with 1ch output Field Shaper

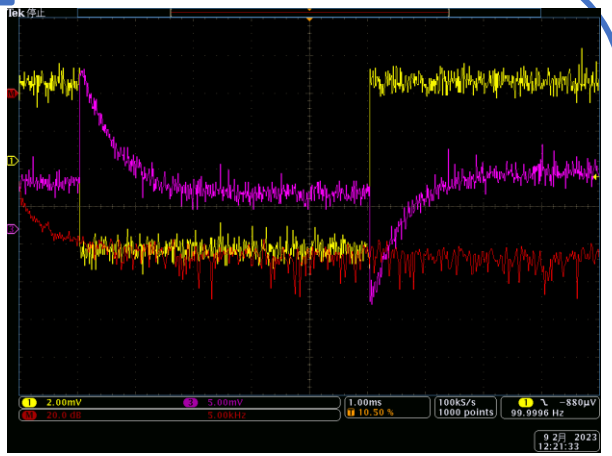


Verification of potential divider field shaping with single High voltage input @ Cathode



LAr test with input test pulse





-- Square wave input (10mV =10fC)
-- Amp Output (~15mV)
-- FFT

Summary & Prospects

Summary

- GRAMS is a proposed Long Duration Balloon Experiment with one of its goals to indirectly search for dark matter
- This year we have submitted a proposal to JAXA which was **accepted**.
- Our goal is to **safely operate LAr** at balloon altitudes and obtain data from vessel components and prototype TPC
- Currently we are in the preparation phase for the upcoming engineering balloon flight at JAXA TARF (Summer 2023)

Prospects

Next 6 months

- Construct the TPC & conduct operation test with full setup
- Hopefully conditions will be met, and our balloon experiment will be conducted @ JAXA TARF

Future

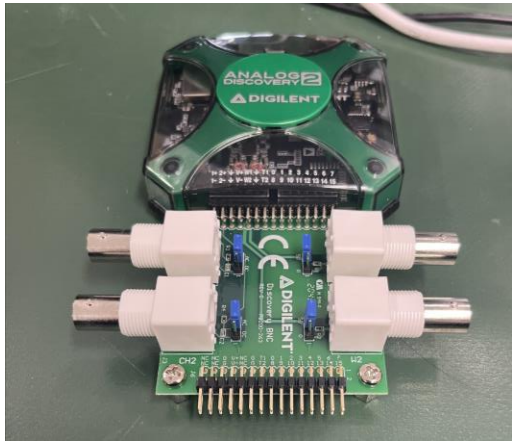
- Upgraded balloon / satellite experiment for particle tracking & particle identification

Back Up

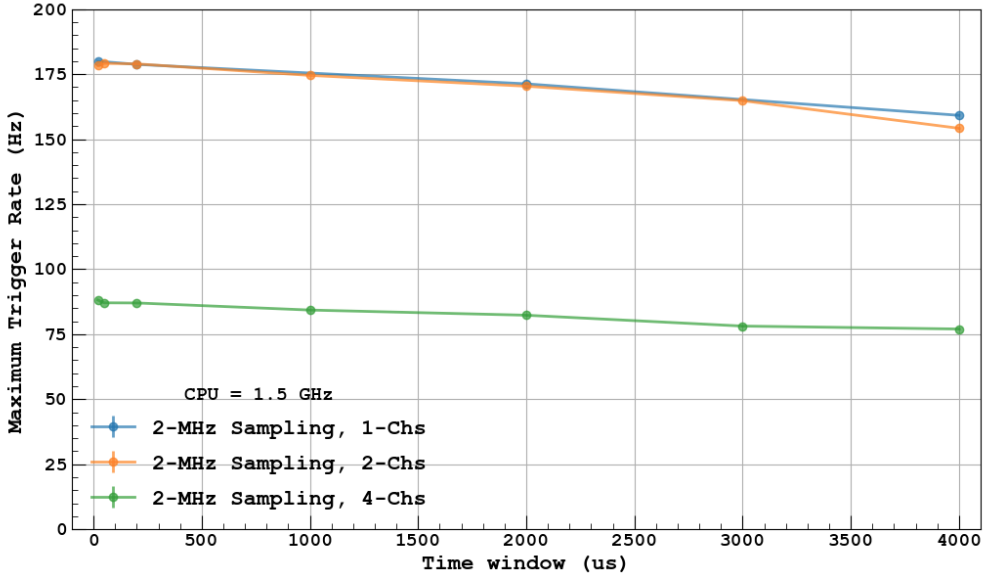
DAQ (In Pressurized Vessel)

Anode
PMT

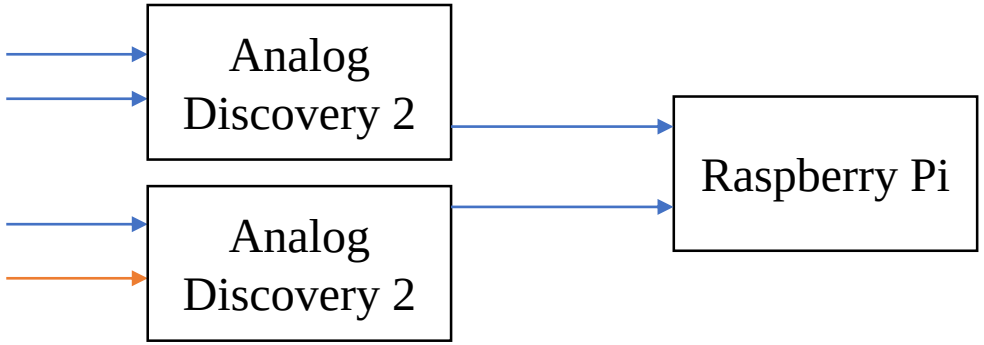
ADC



- Product: Analog Discovery 2
- 2 channel USB Oscilloscope
- Max : 100MHz Sampling Rate
  8192 Samples
- DAQ Rate : Max 80Hz
- Connect to PC via USB 2.0
- USB connection to PC : both power and data transfer
  (External power supply also possible)



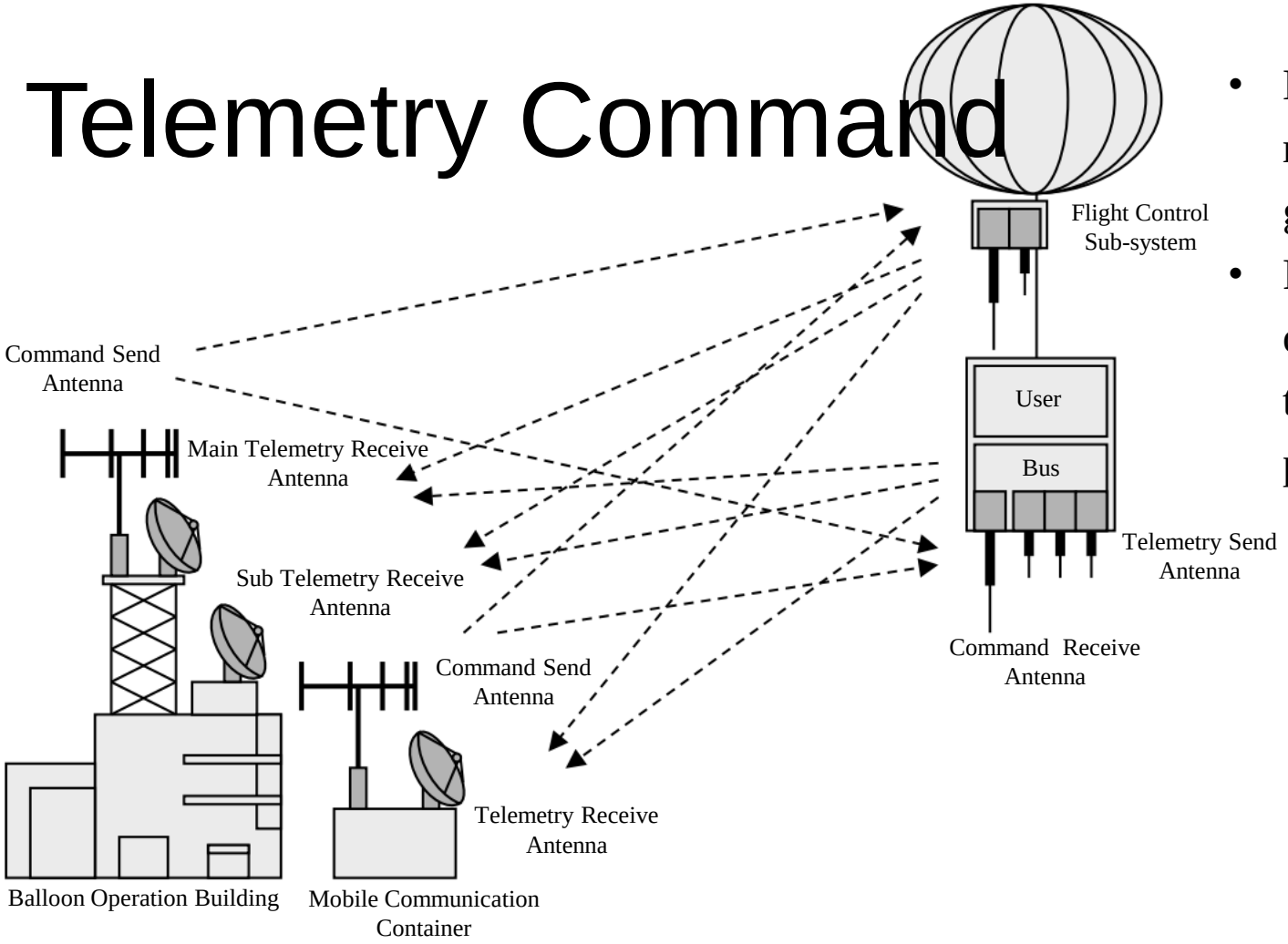
Setup (simplified)



PC

- Product: Raspberry Pi 4B
- Run DAQ by telemetry command
- USB Connection:
  2 x Analog Discovery 2, SSD, (Maybe Camera)
- GPIO Connection:
  Couple of sensors and telemetry command input

Telemetry Command

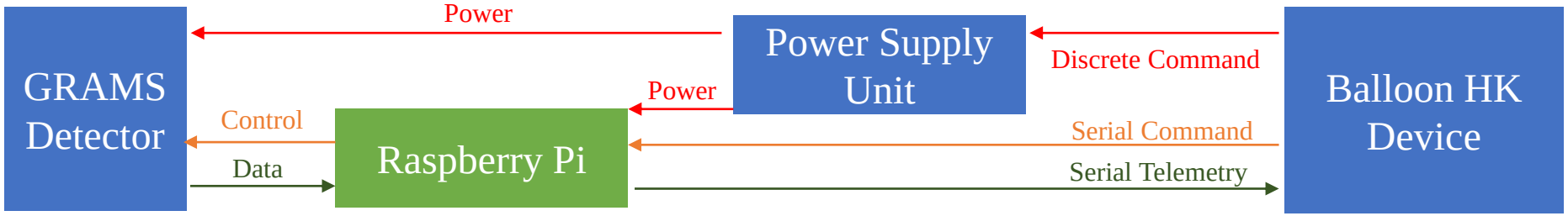


- Bus System (Balloon HK Device) for transmission and reception of command/telemetry must be installed in the gondola
- For users, by connecting the experiment device or PC to the Bus System, communication between the experiment from the ground is possible

GRAMS Operation

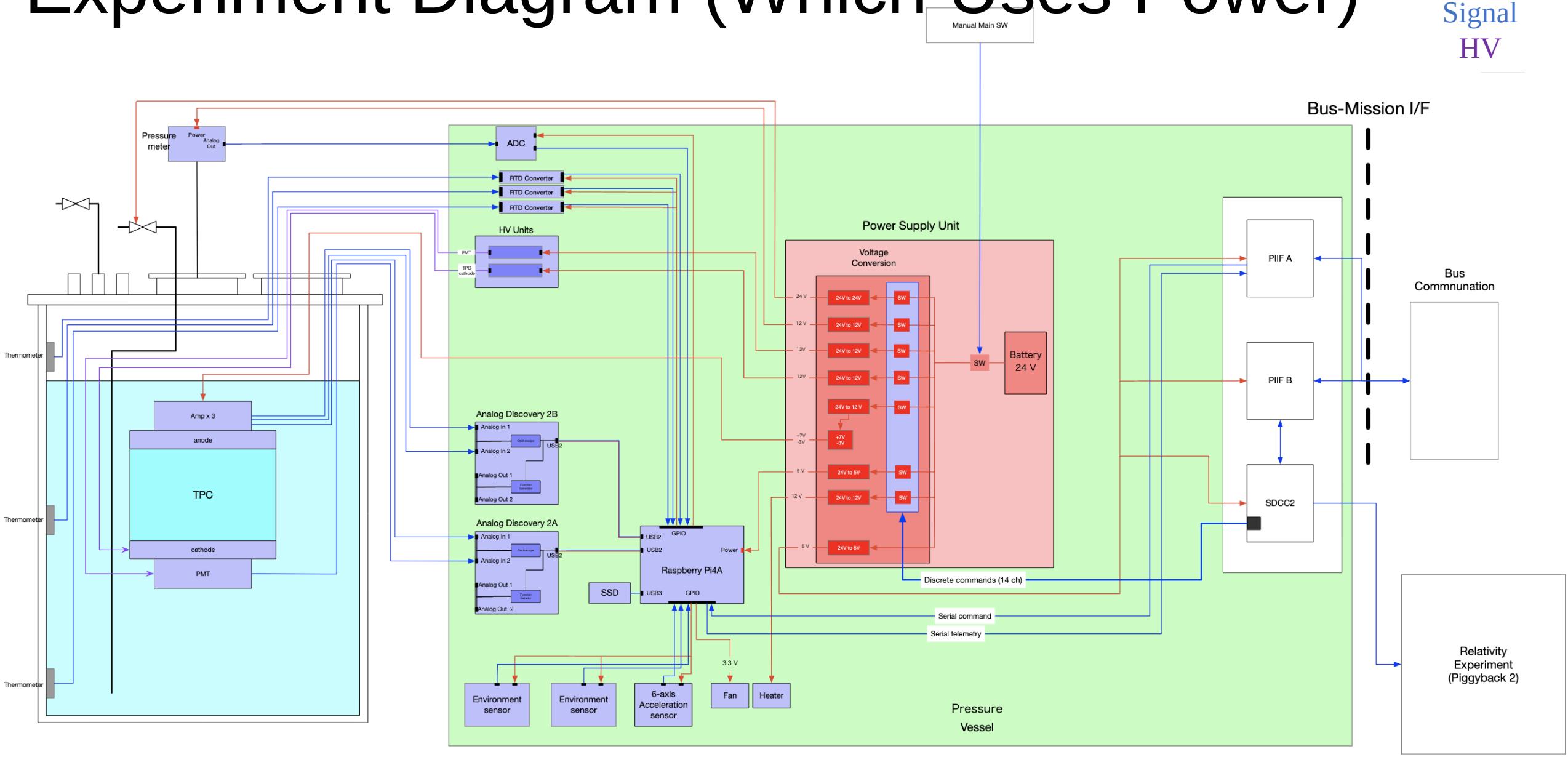
- Critical Operations such as turning on Raspberry Pi are all done through discrete commands
- Other operations such as changing detector settings are done through serial commands.

GRAMS Command Line



Experiment Diagram (Which Uses Power)

Power
Signal
HV

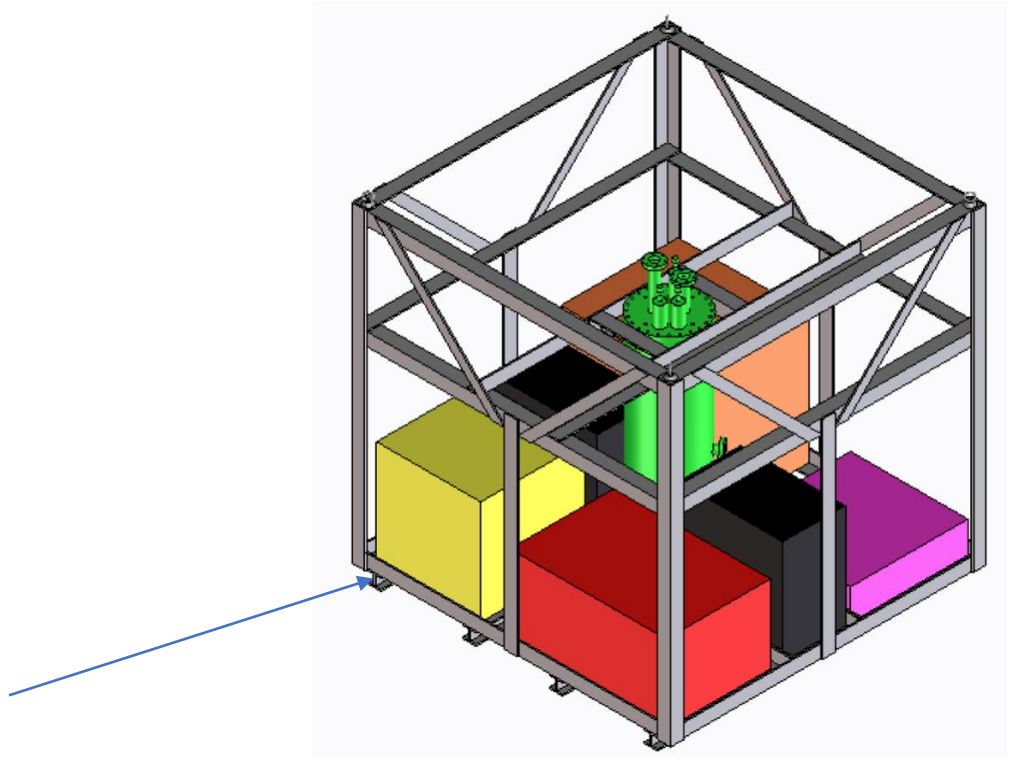


Gondola

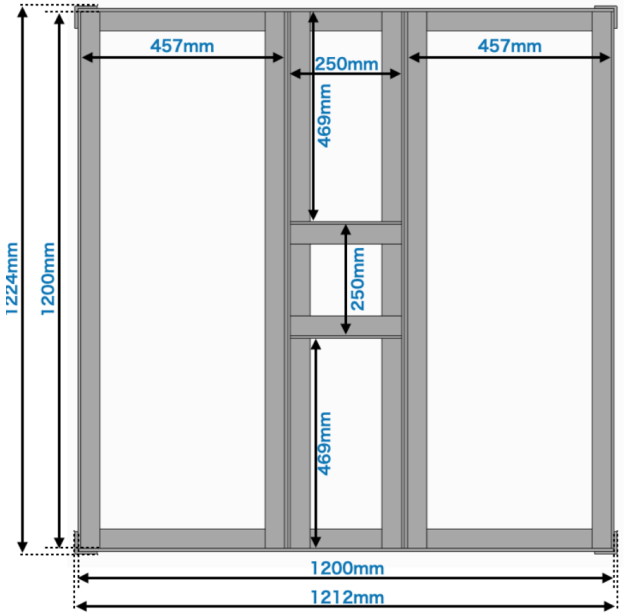
Design

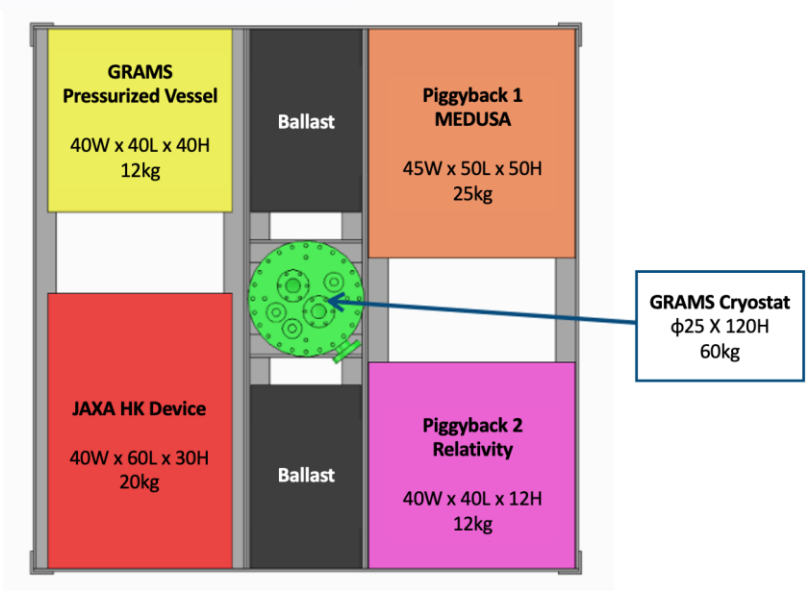
- 120cm Width x 120cm Length x 120cm Height
- Based on the “standard” model from B22-07
- Made from A6063 L-shaped Aluminum Plates

  Thickness 6mm Width 50mm



- H- shaped frame on the bottom for extra support
- Total Weight : 60kg + bolts
- For connection with the balloon, M16 eyebolts on each corner
- Each experiment device/vessel will be connected to the gondola on the bottommost layer





Cosmic Particle Rate Simulation Study

Motivation:

- Rate of particles entering TPC needs to be studied
  → Simulate Current in TPC
- Important for study on pile up rate
- To understand which altitudes has enough cosmic flux for obtaining data that we want.

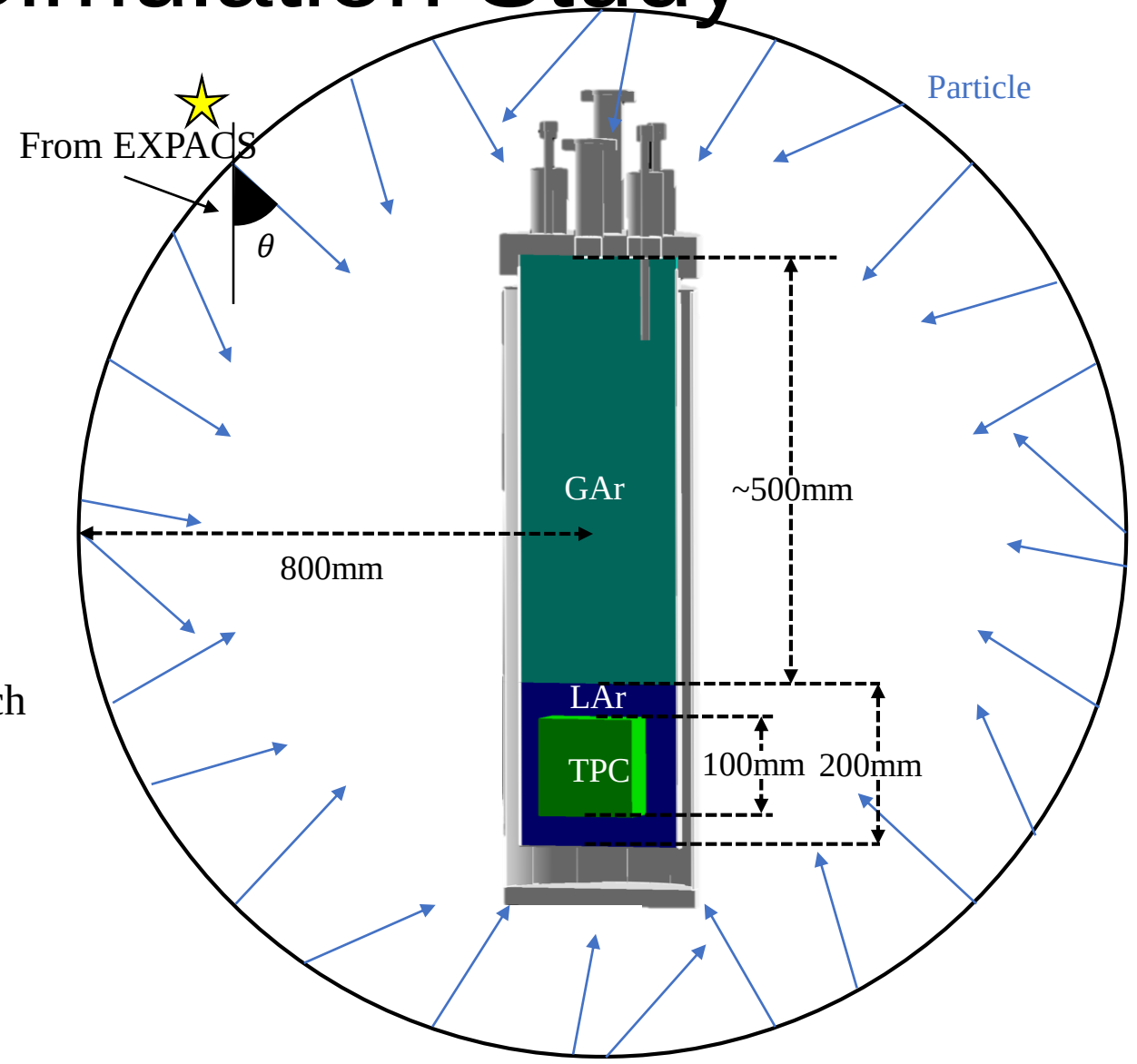
Setup:

EXPACS + Geant4 → Rate of CR entering TPC at various altitudes

- EXPACS: Obtain <u>energy + angle distribution</u> and flux of each cosmic particle at given altitude above Taikicho
- Geant4: Setup detector and obtain particle interaction info
  (Use EXPACS output for particle generation)

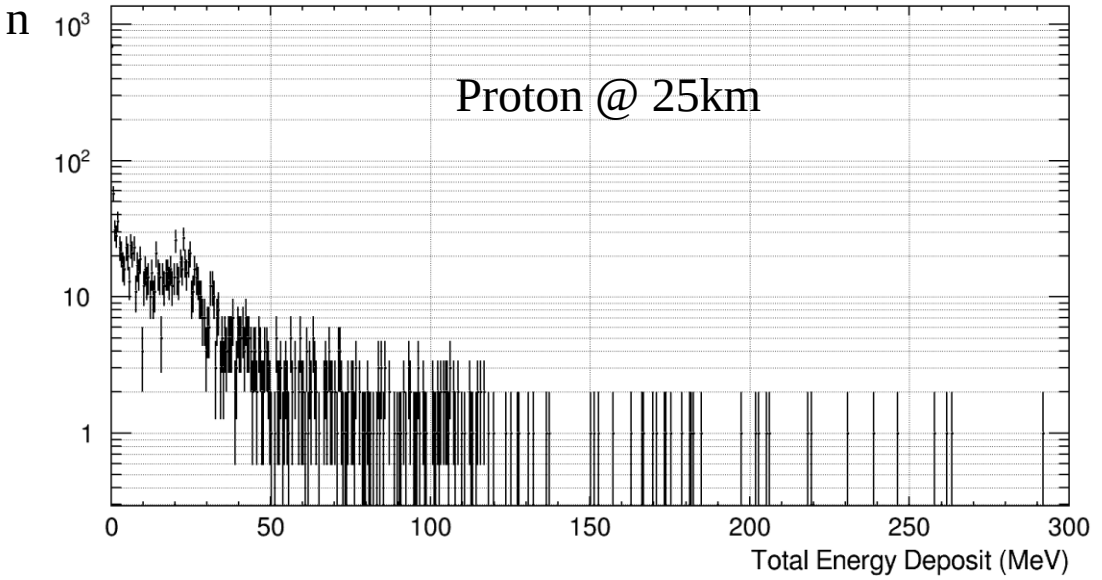
Variables:

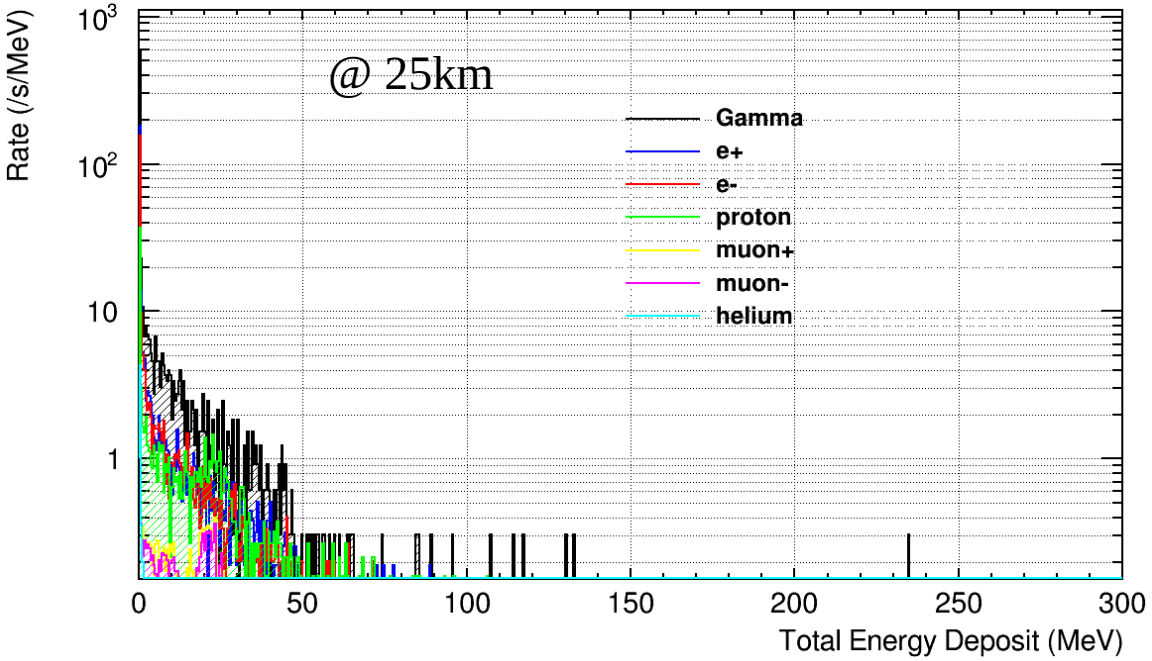
- Particle: gamma, muon±, e±, proton, helium
- Altitude: 0km ~ 30km (per 5km)

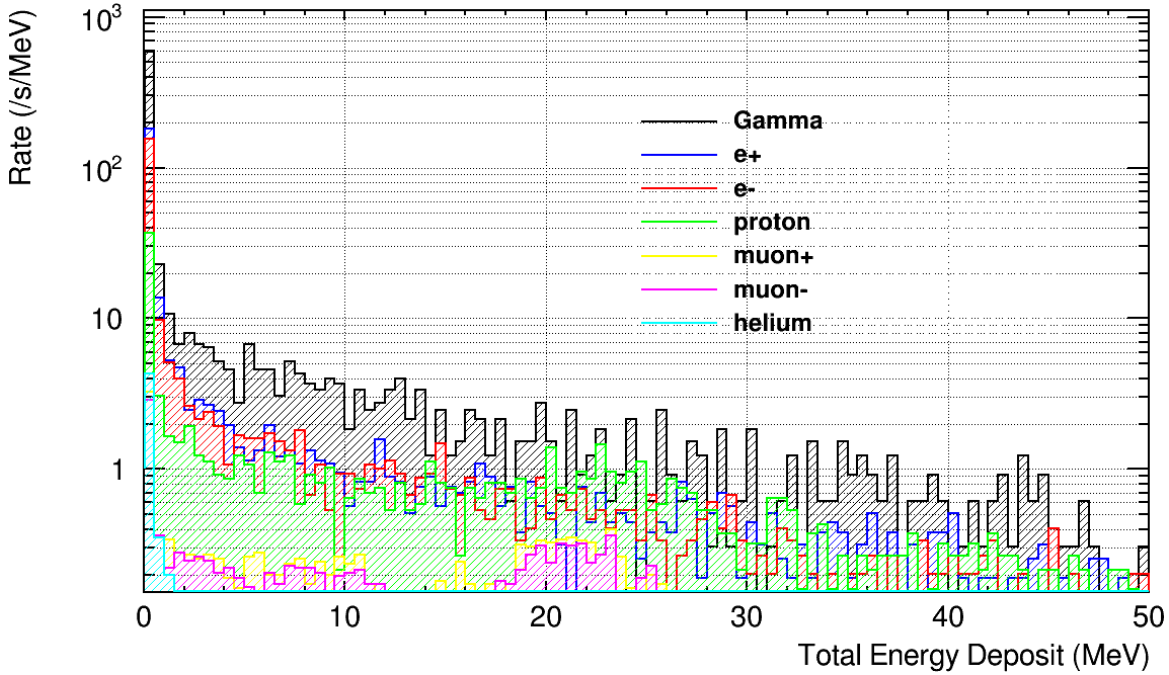


Simulation Results

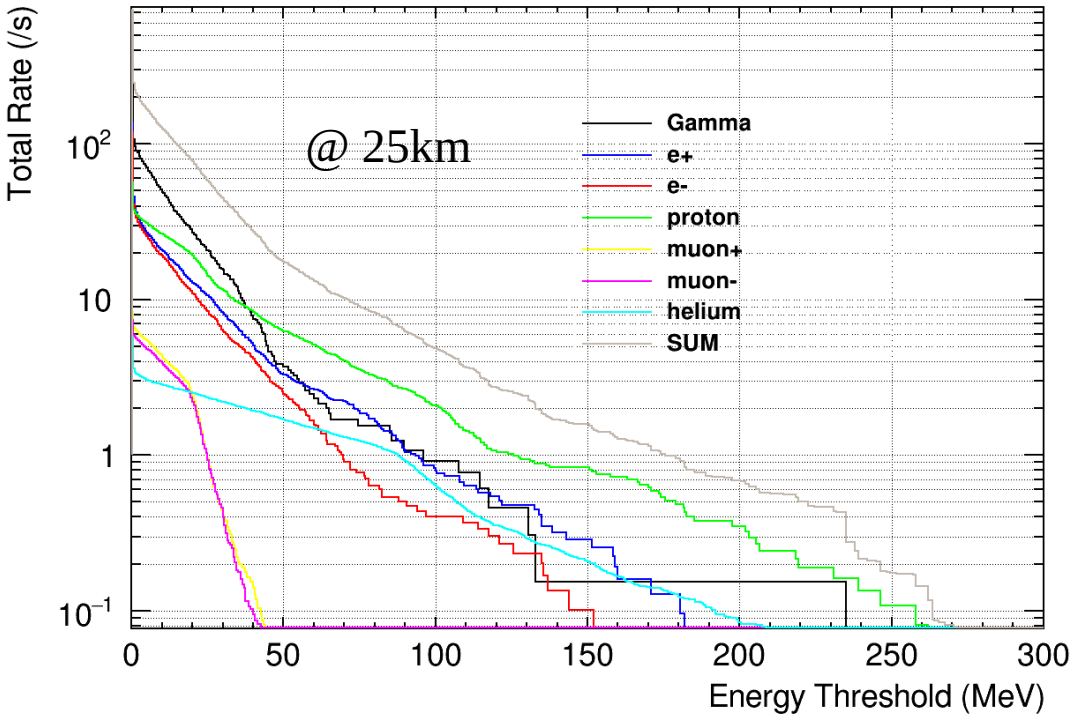
- $\boldsymbol{Rate(/s) = Flux(/cm^2/s) \times \frac{n}{N} \times Orthodrome\ Area}$
- $Flux(/cm^2/s)$ = Integral Flux between 10MeV ~ 10GeV (EXPACS)
- N = Total number of events generated in Geant4
- n = Number of events in each energy deposition bin (from Geant4)
- Orthodrome Area = 800mm X 800mm X π

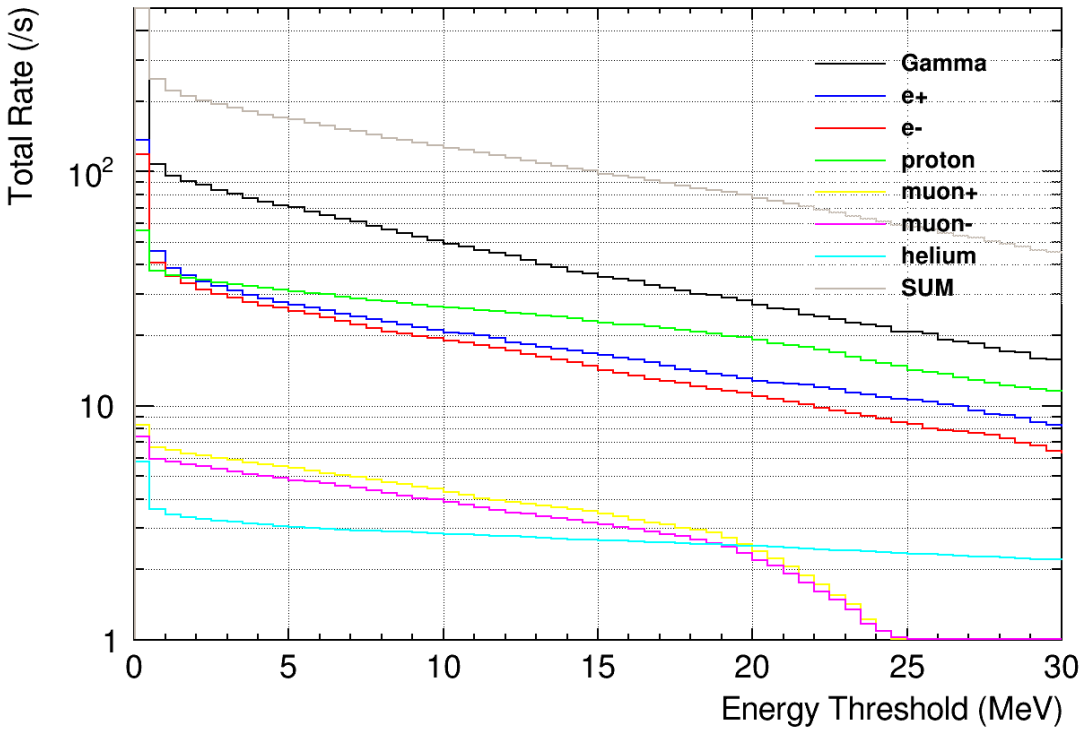




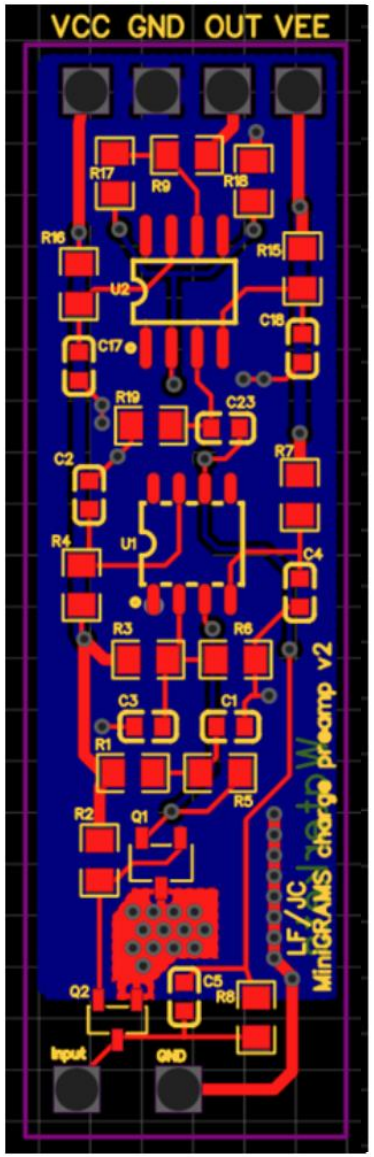


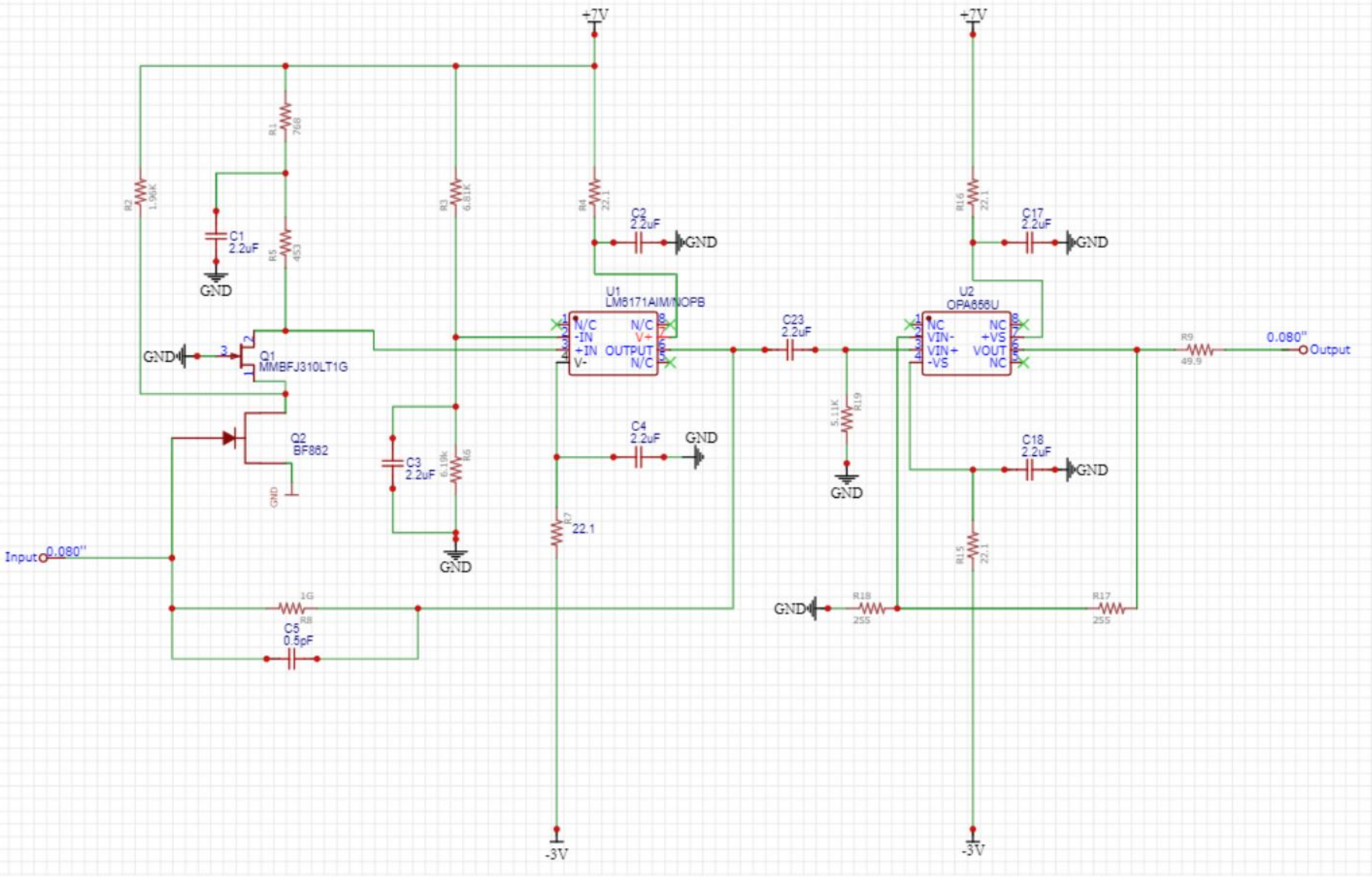
Simulation Results





Cryogenic Amplifier





Preparation Status

System	Finished	To do
Vessel	• Full System Design • Heat Inflow test • Pressure gauge tests	• LAr evacuation test • Design and Manufacture of Pressurized Vessel for Electronics
Detector	• PCB Electrode Design • Cryogenic Amplifier Manufacture • PMT operation test	• TPC Manufacture and operation test • Cryogenic Amplifier operation test • Full System operation test
DAQ	• Readout System for 3 channel TPC • Command/Telemetry system design	• Software Coding for • Command/Telemetry system operation test
Gondola	• 3D CAD Design including Piggyback interface	• Stress Calculation • Manufacture

B22-07 Scientific Balloon Experiment

- JAXA Engineering Balloon Flight to test new ballast system