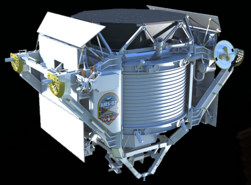


Status of the AMS Experiment

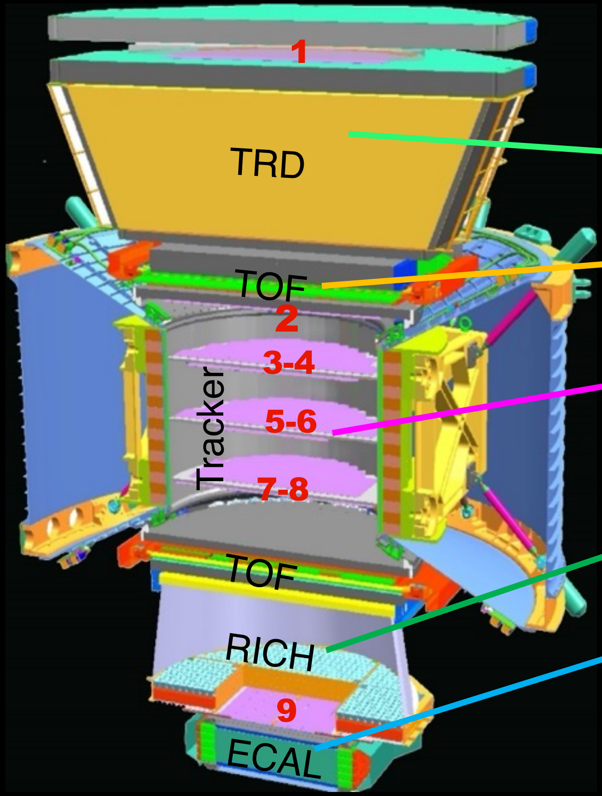
Hsin-Yi Chou

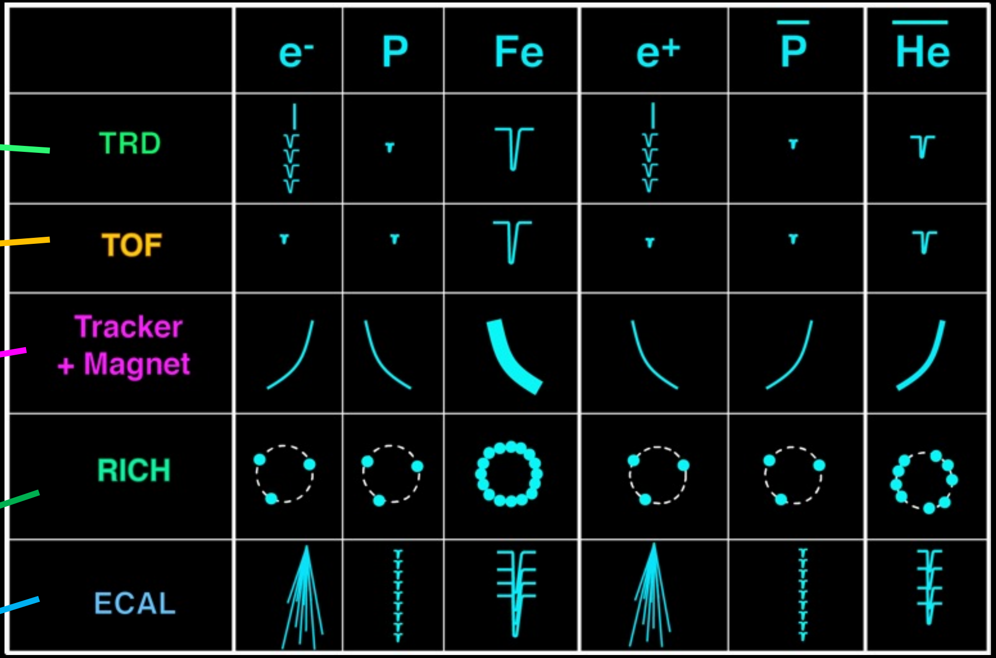
Institute of Physics, Academia Sinica

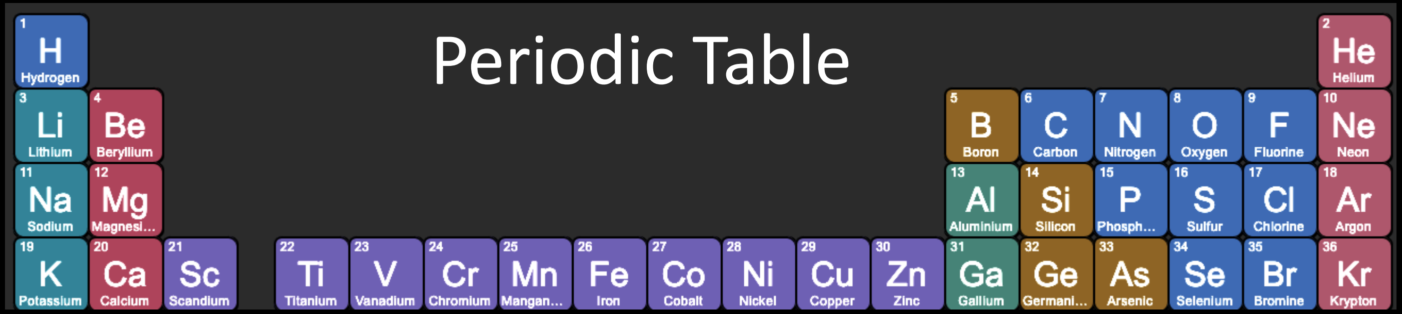
2024 CHiP Annual Meeting

Nov 21st, 2024

The AMS detectors provide essential information on cosmic rays





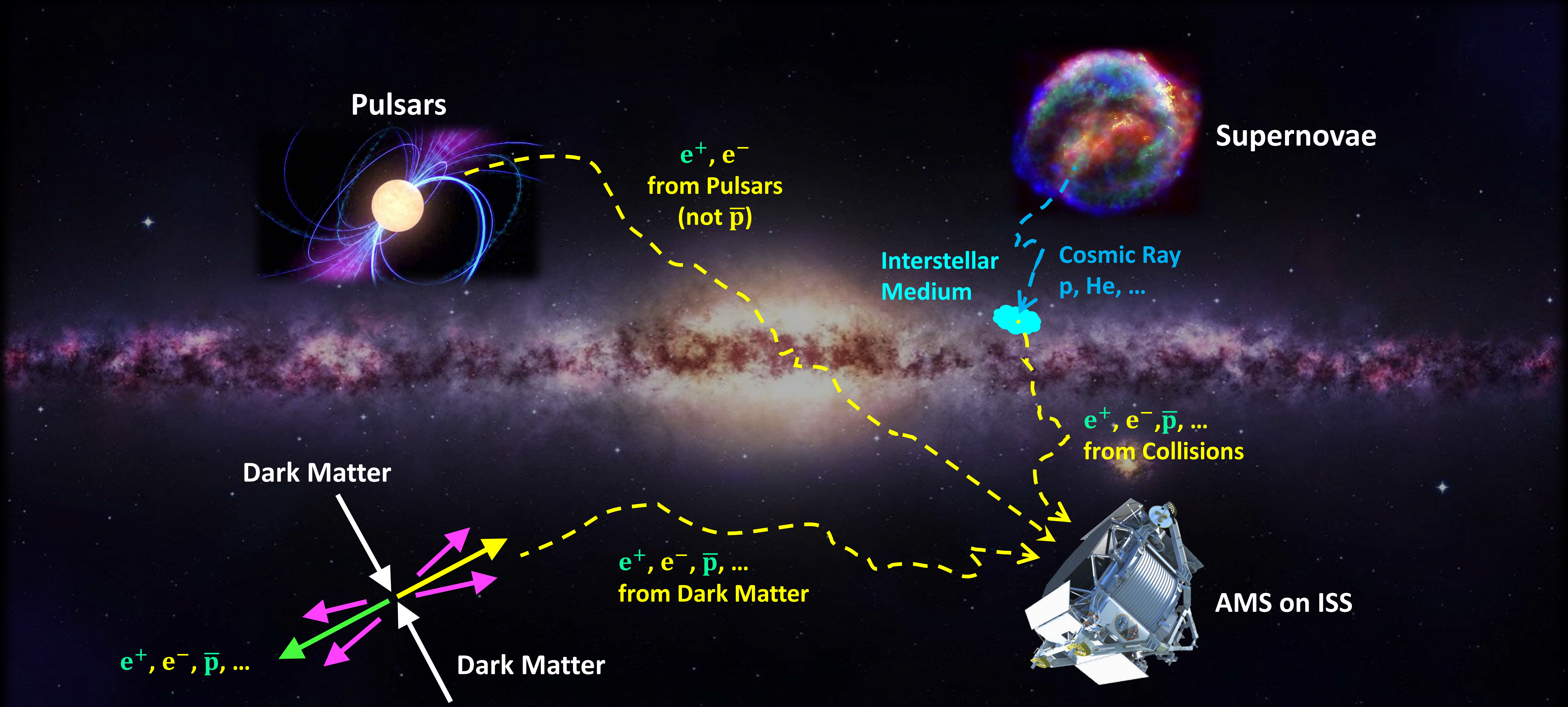


With high accuracy, AMS measures

Momentum (P, GeV/c)
Charge (Z)
Rigidity (R=P/Z, GV)
Energy (E, GeV/A)
Flux (signals/(s sr m^2 GeV))

for all the charged cosmic rays, e^+, e^-, p, and $\bar{p}$, and the nuclei in the Periodic Table

Latest Results on cosmic elementary particles: e^+, e^-, p, and $\bar{p}$

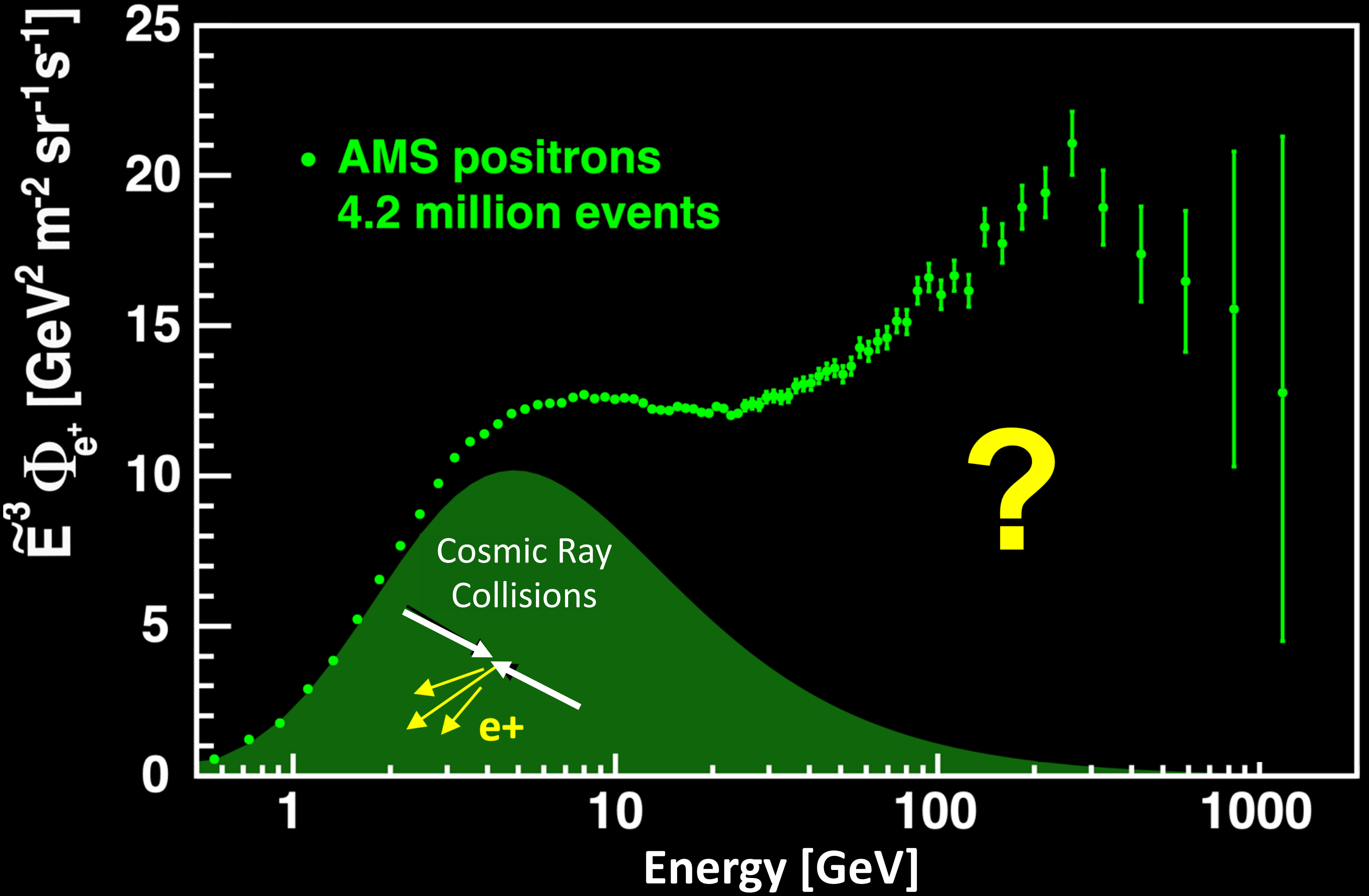


Measurement of these elementary particles (e^-, e^+, p, $\bar{p}$)
is a major tool to study new physics in space

AMS positron flux measurement

Low-energy positrons come from cosmic ray collisions

High-energy positrons must come from a new source

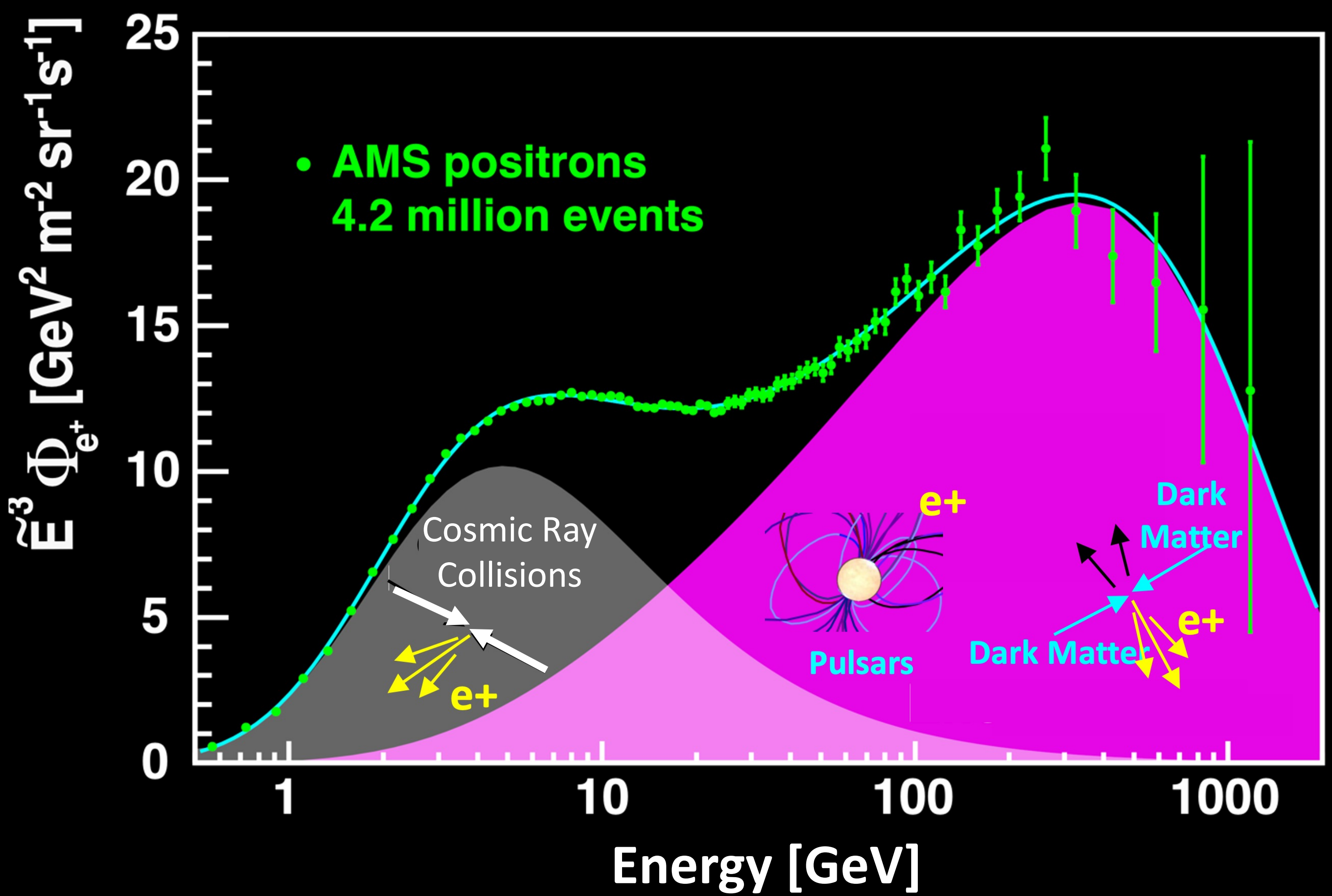


The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter with a cutoff energy

Empirical model: $\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right]$

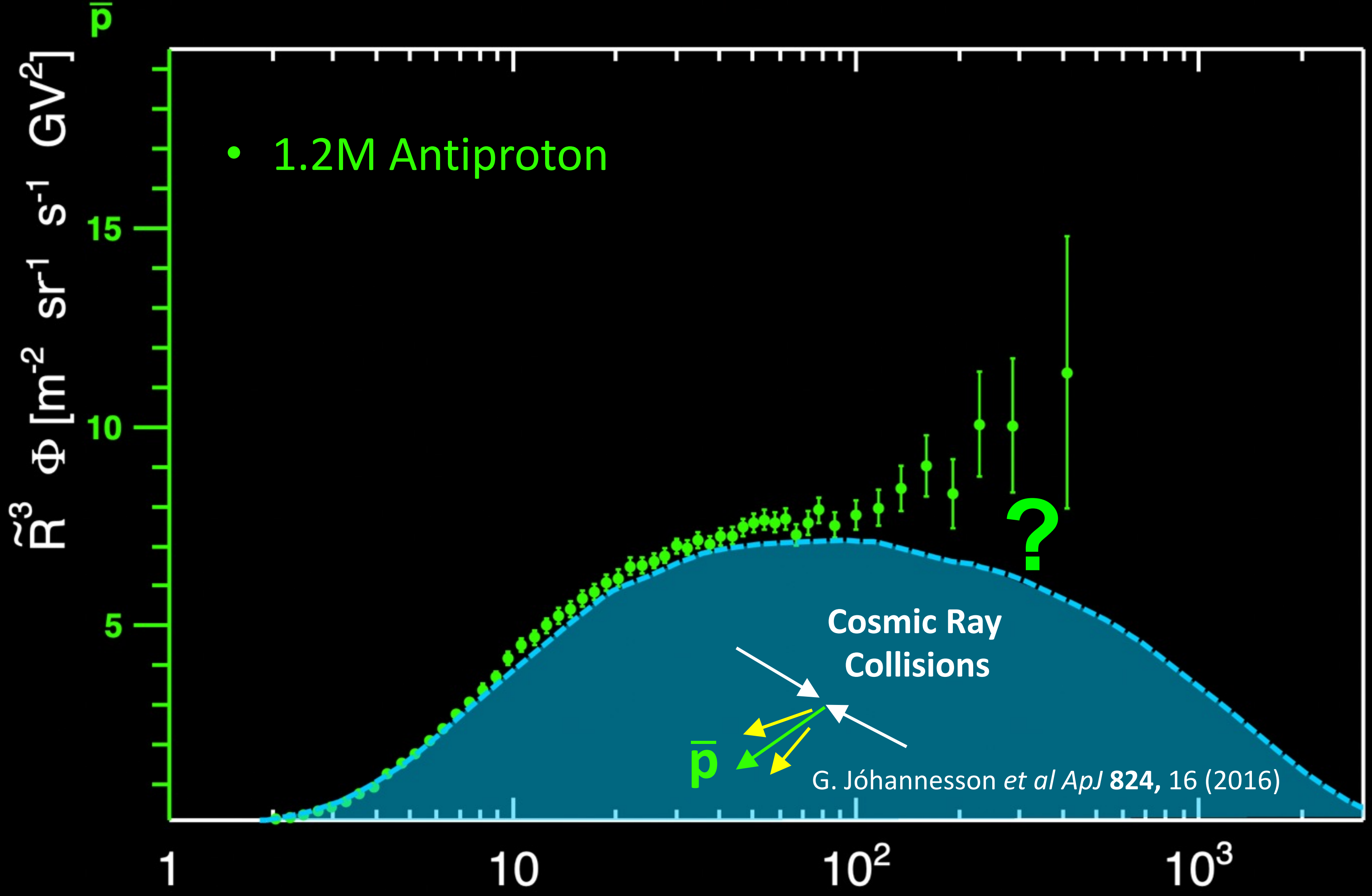
$\chi^2/\text{dof} = 63/66$

Solar Collisions Pulsars or Dark Matter



E_S = 778 GeV at 4.8 σ

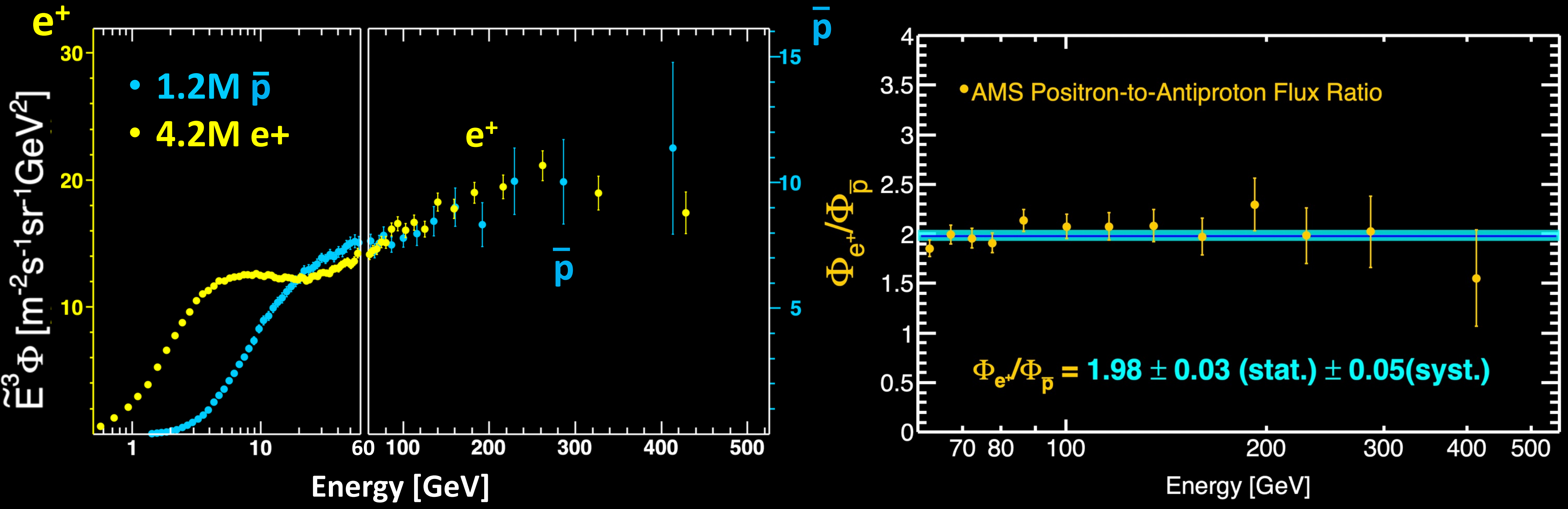
Cosmic Antiprotons



p̄ are not produced by pulsars nor by cosmic ray collisions above 60 GV

Cosmic Antiprotons and Positrons

Above 60 GeV, the $\bar{p}$ and e^+ fluxes have identical rigidity dependence

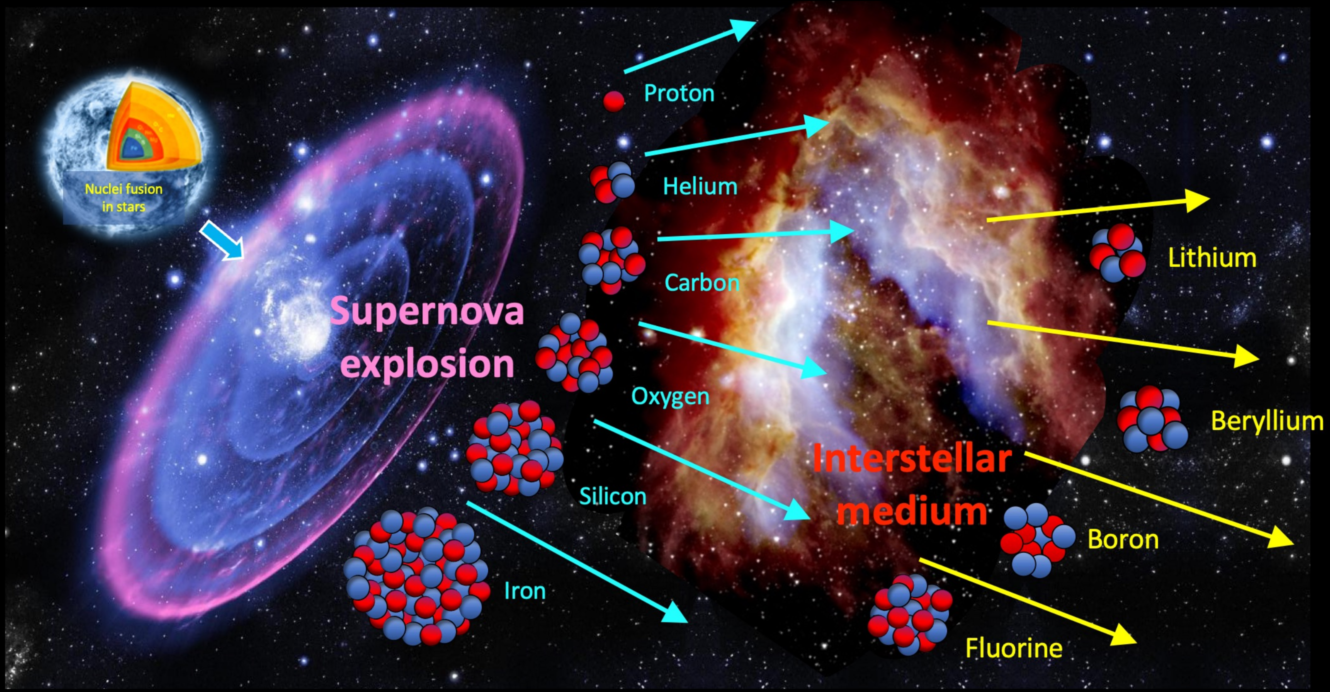


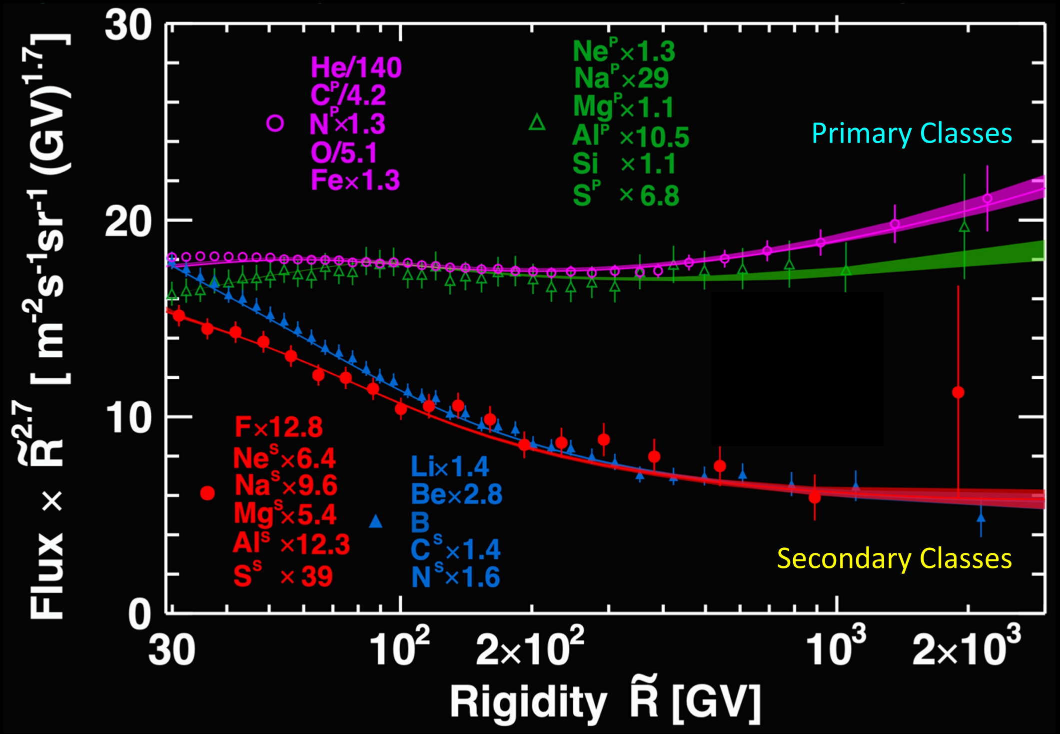
The positron-to-antiproton flux ratio is independent of energy.

Latest Results on cosmic ray nuclei

Primary cosmic rays p, He, C, O, ..., Si, ..., Fe
are produced during the lifetime of stars and accelerated by supernovae.
They propagate through interstellar medium before they reach AMS.

Secondary Li, Be, B, and F nuclei in cosmic rays are produced by the collision of primary cosmic rays with the interstellar medium.





Measurements of primary and secondary cosmic ray fluxes are fundamental to understanding the origin, acceleration, and propagation processes of cosmic rays in the Galaxy.

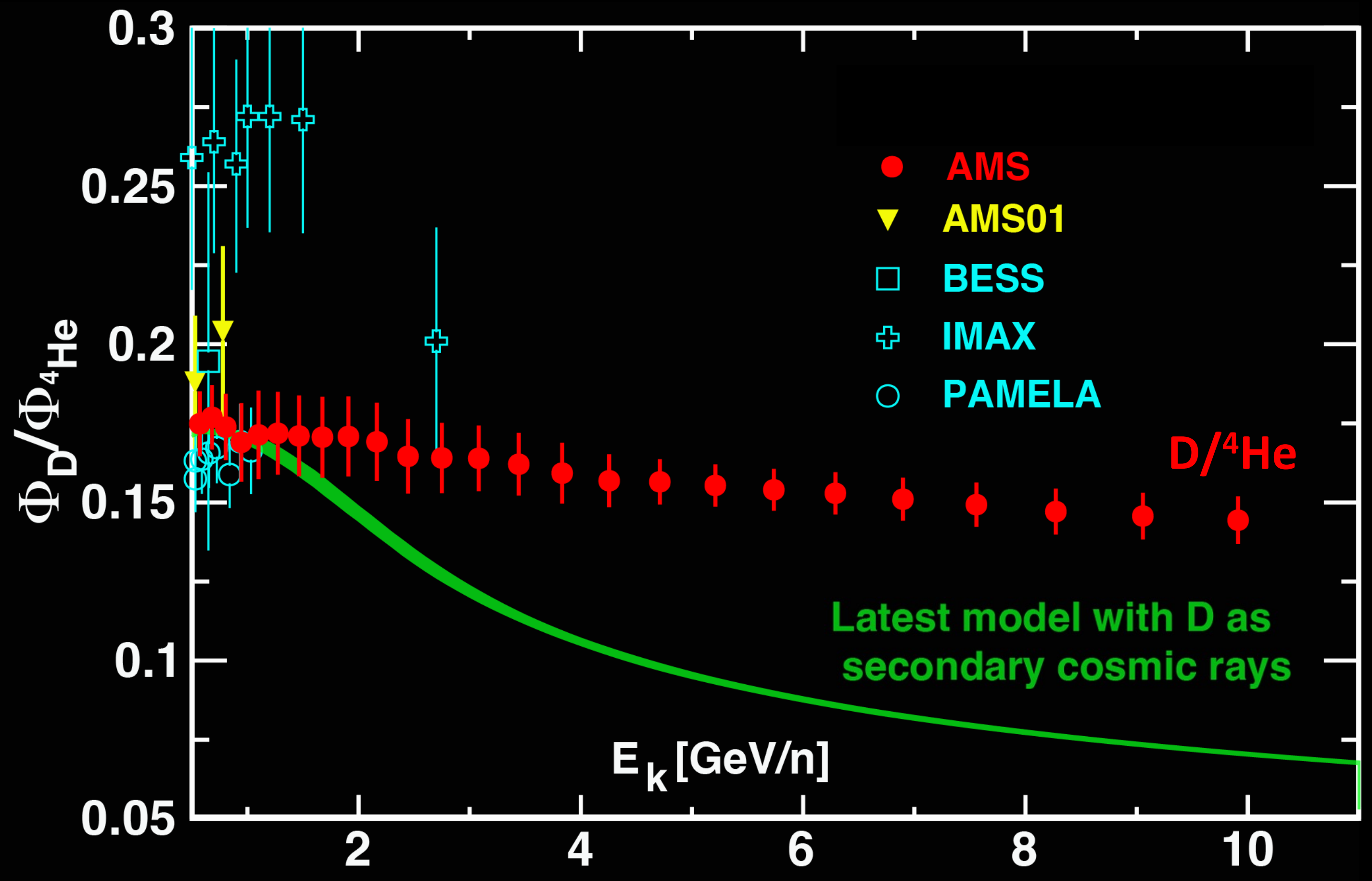
Measurement of Isotopes: Cosmic rays with *same Z, different m*

Origin of Cosmic Deuterons D

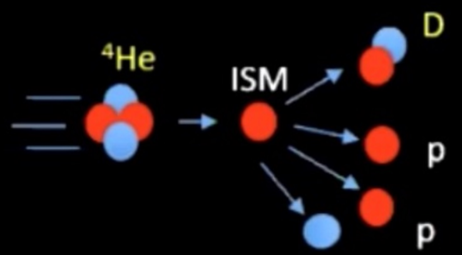
(He, C, O, …) + Interstellar Medium → (D, ^{3}He) + *X*

D and ^{3}He are both considered to be secondary cosmic rays

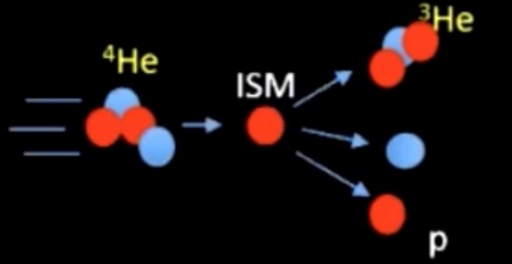
B. Coste, L. Derome, D. Maurin, and A. Putze, A&A **539**, A88 (2012)
I. A. Grenier, J. H. Black and A. W. Strong, Annu. Rev. Astron. Astrophys. **53**, 199 (2015)



^{4}He + ISM → D + X

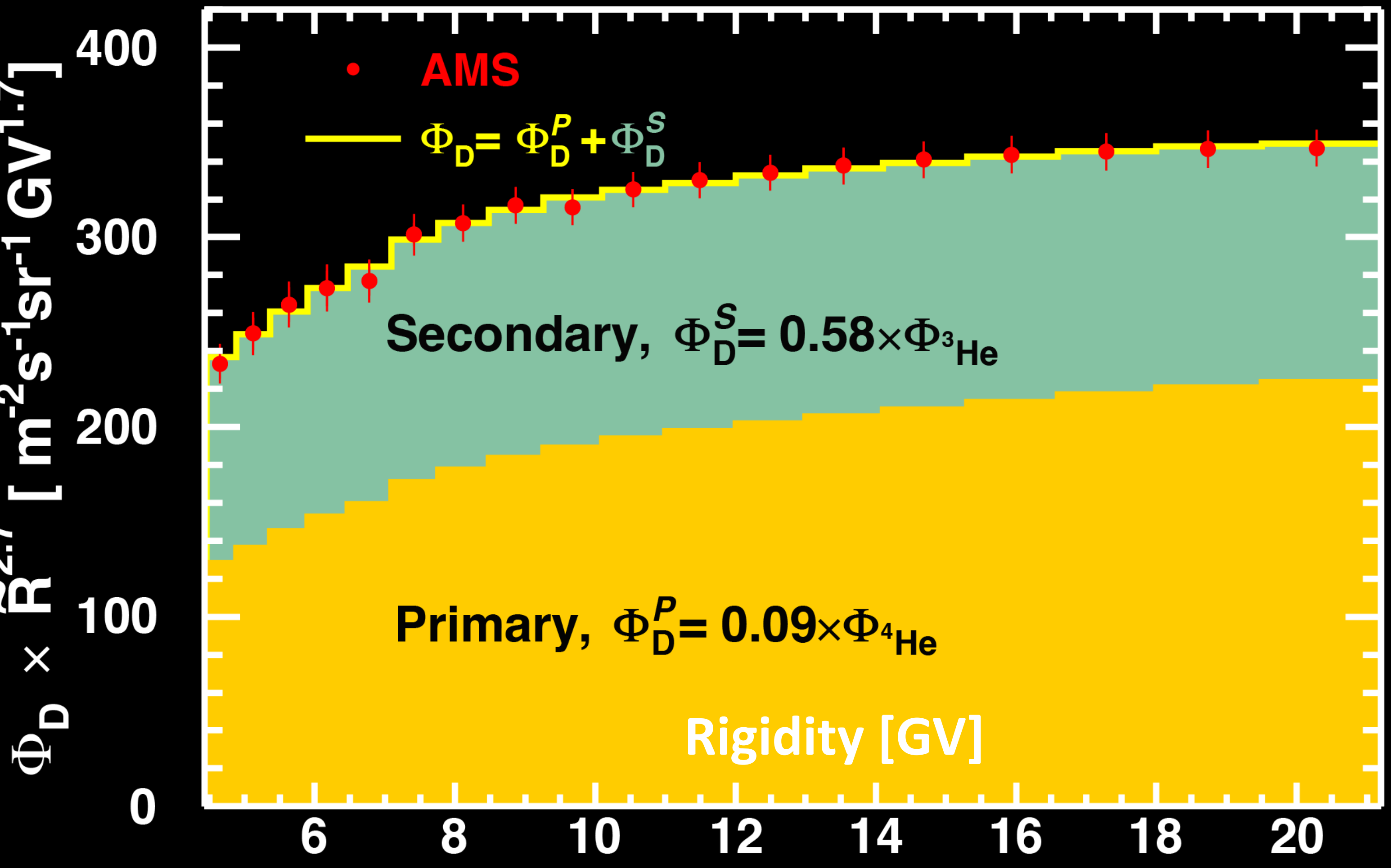


^{4}He + ISM → ^{3}He + X

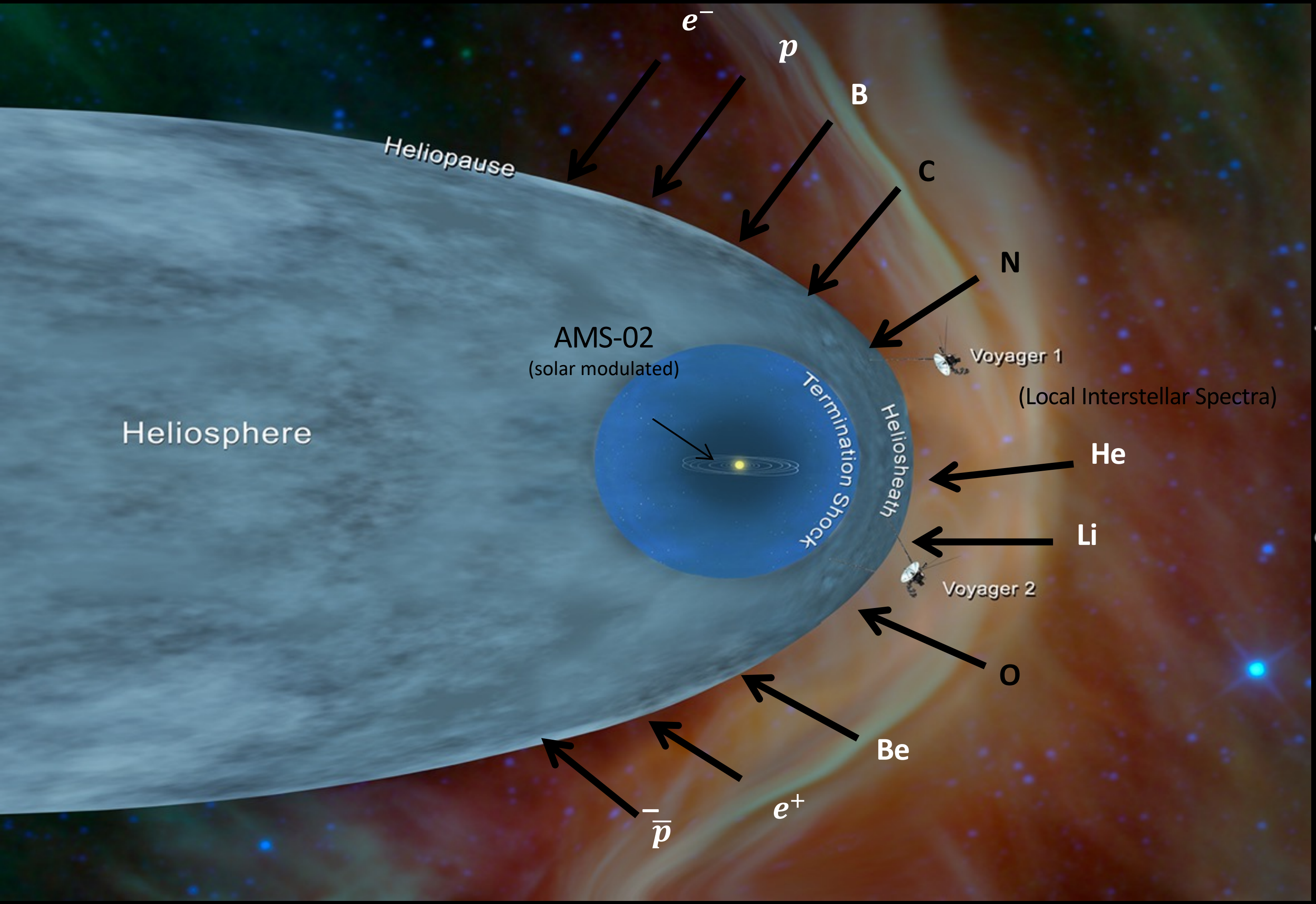


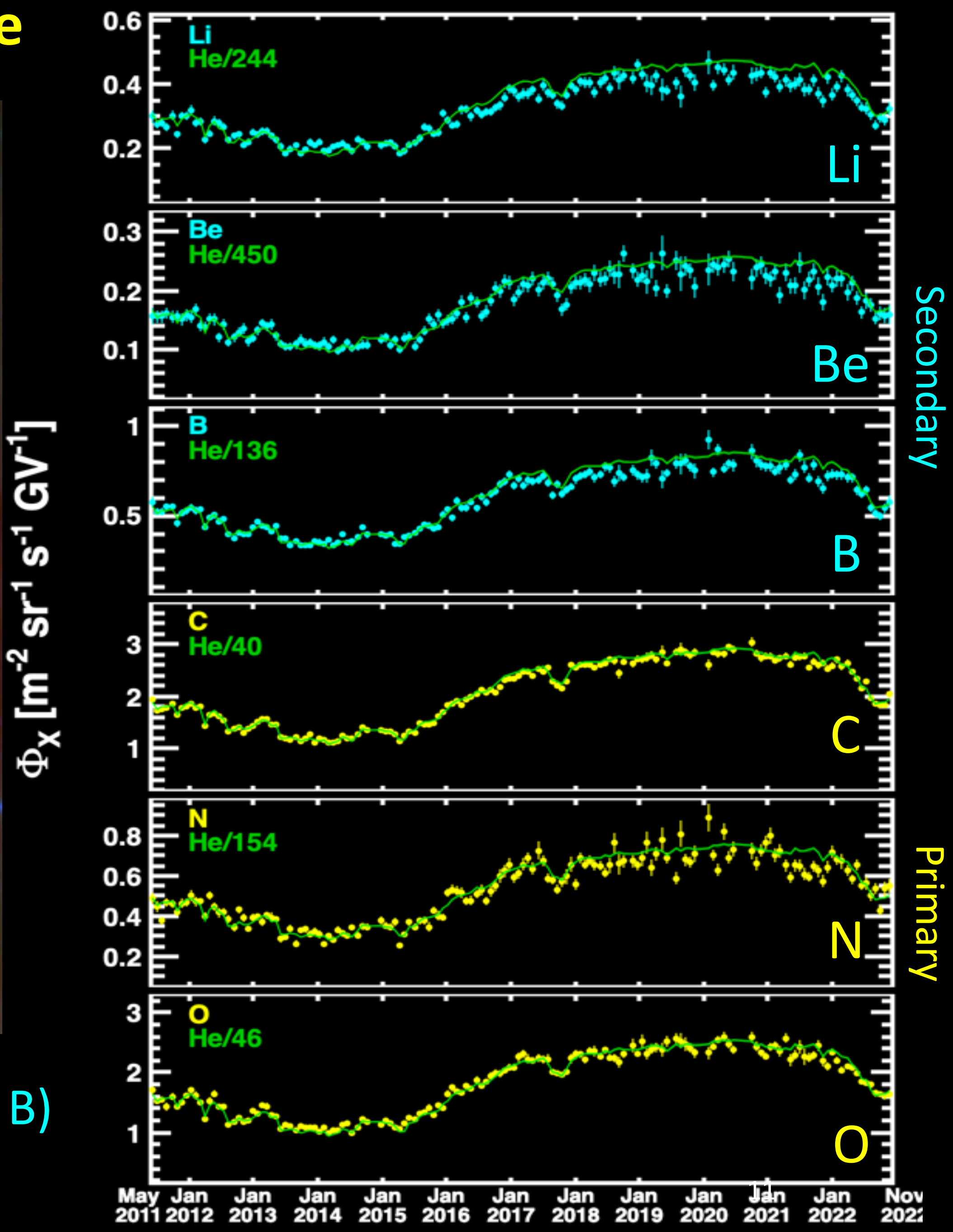
Deuterons have a significant primary component

From 5 to 20 GV, the precision deuteron flux Φ_D is a composition of
a primary part Φ_D^P identical to the ^{4}He flux $\Phi_{^4He}$ and
a secondary part Φ_D^S, identical to the ^{3}He flux $\Phi_{^3He}$



Temporal variation of light nuclei in the Heliosphere

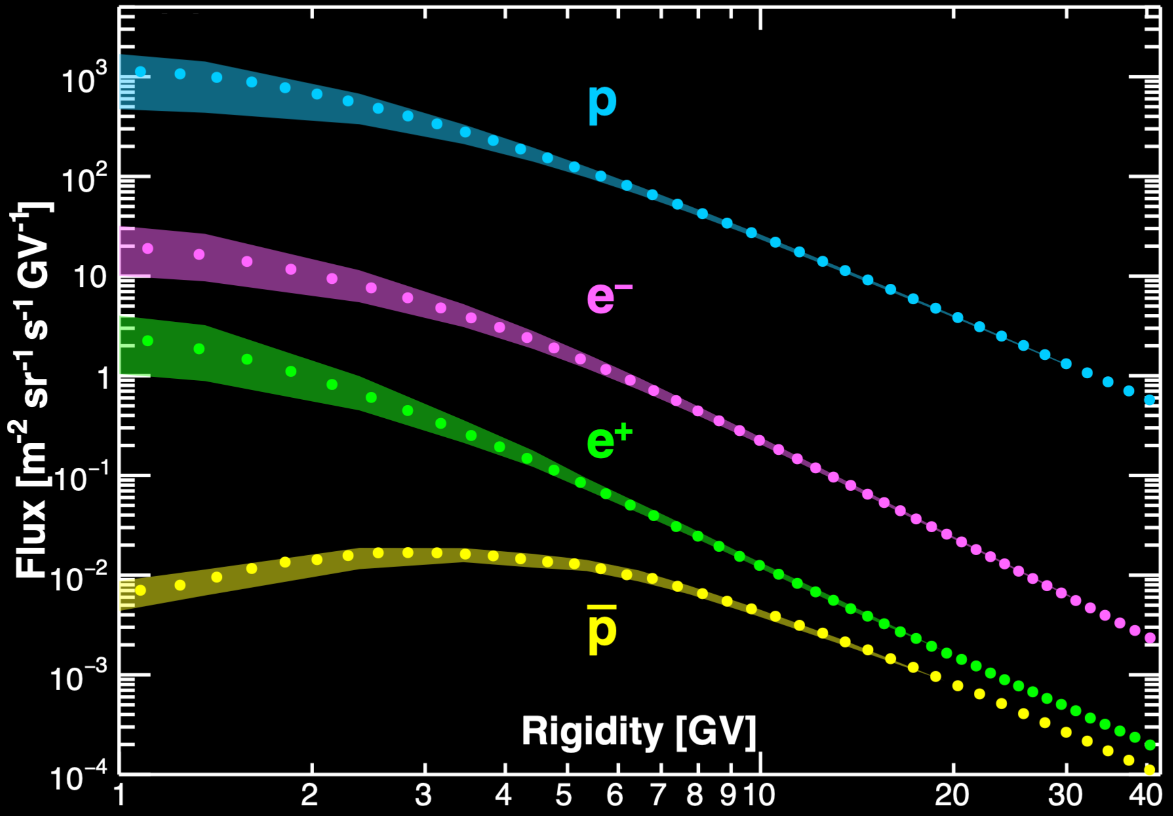




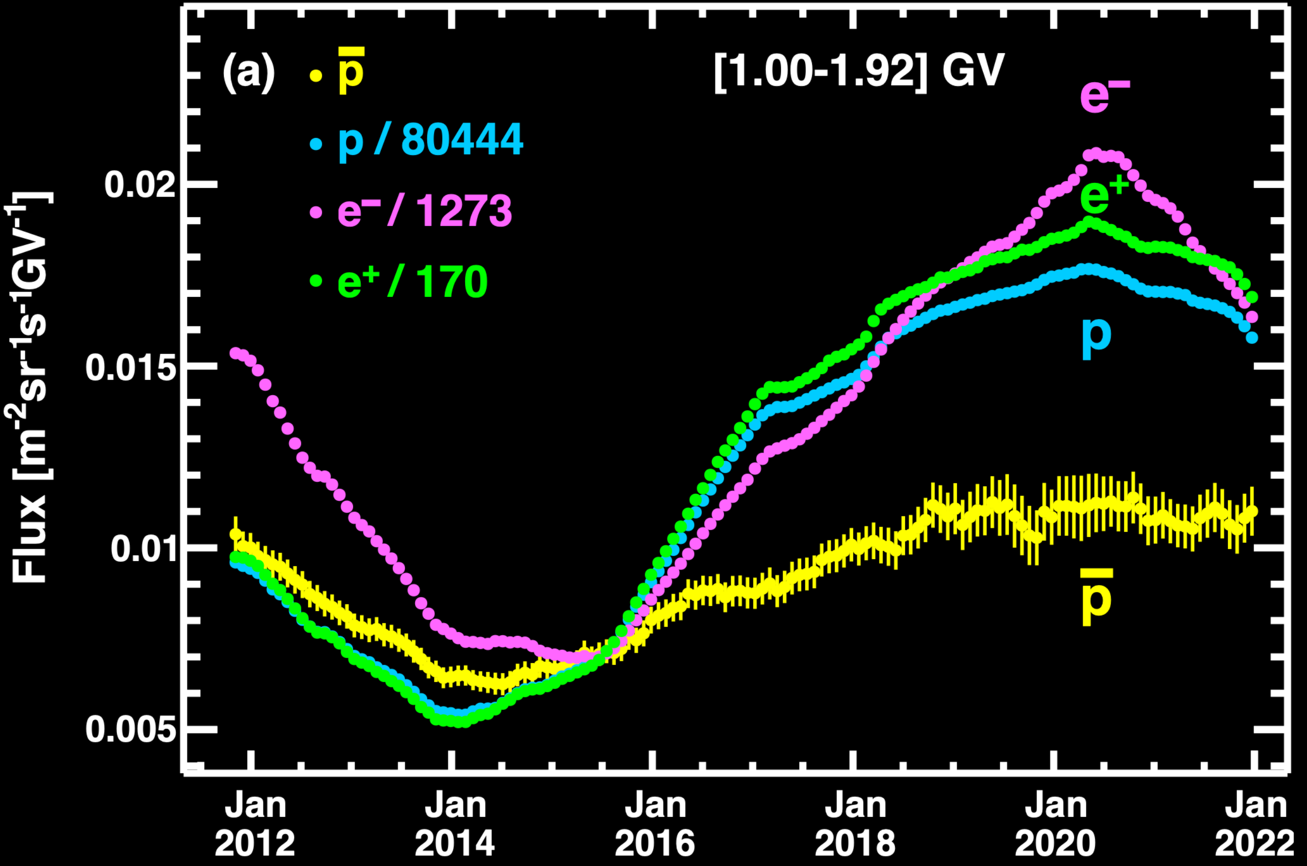
Primary light nuclei (C, N, O) and secondary light nuclei (Li, Be, B) show similar temporal variations as He.

Elementary Particles (e^+, e^-, p, $\bar{p}$) in the Heliosphere over an 11-year Solar Cycle (2011-2022)

The ranges of the flux temporal variation during this period are shown as shaded bands.

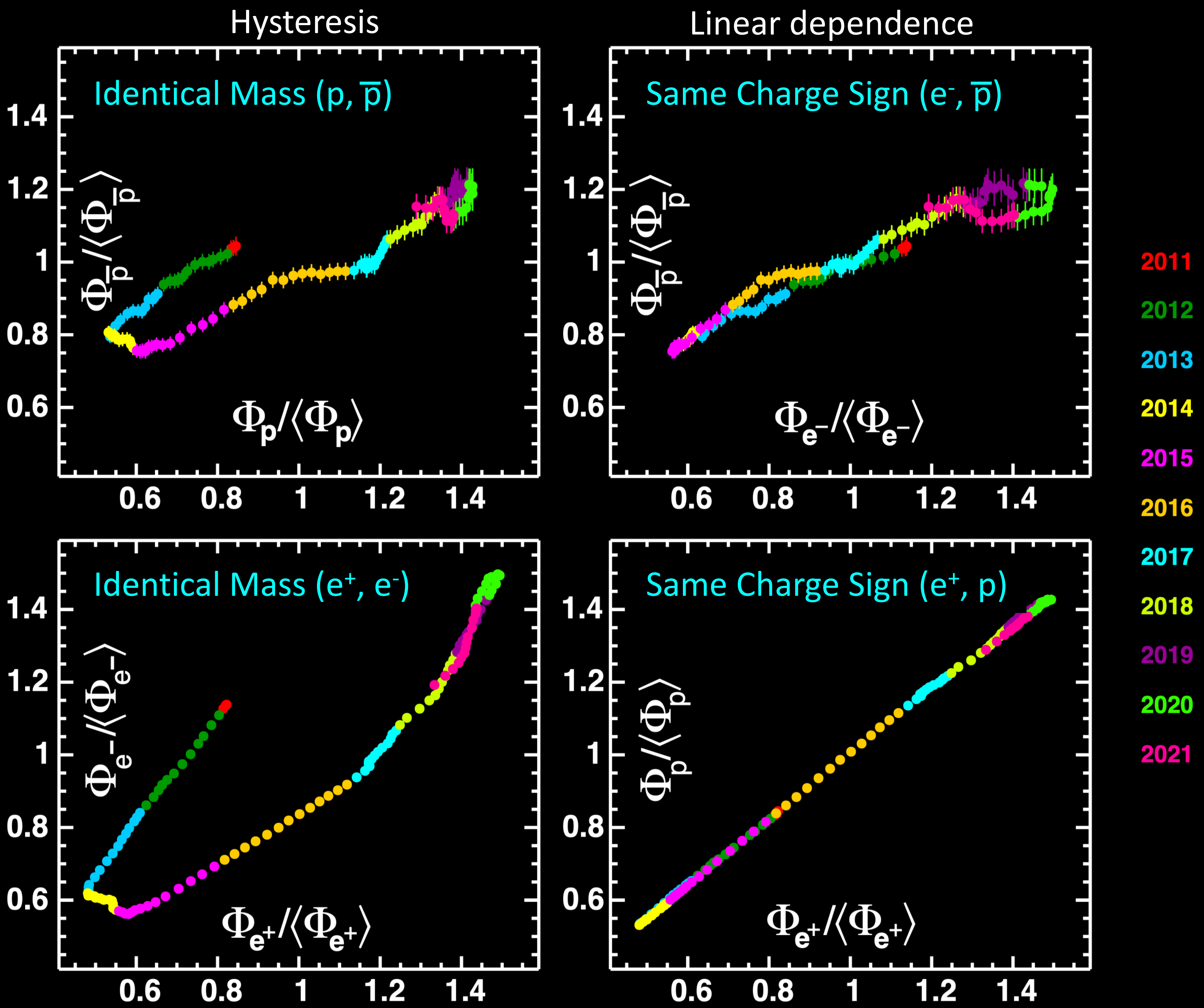


Each data point represents the 13-Bartels rotation (BR: 27 days) moving average flux.

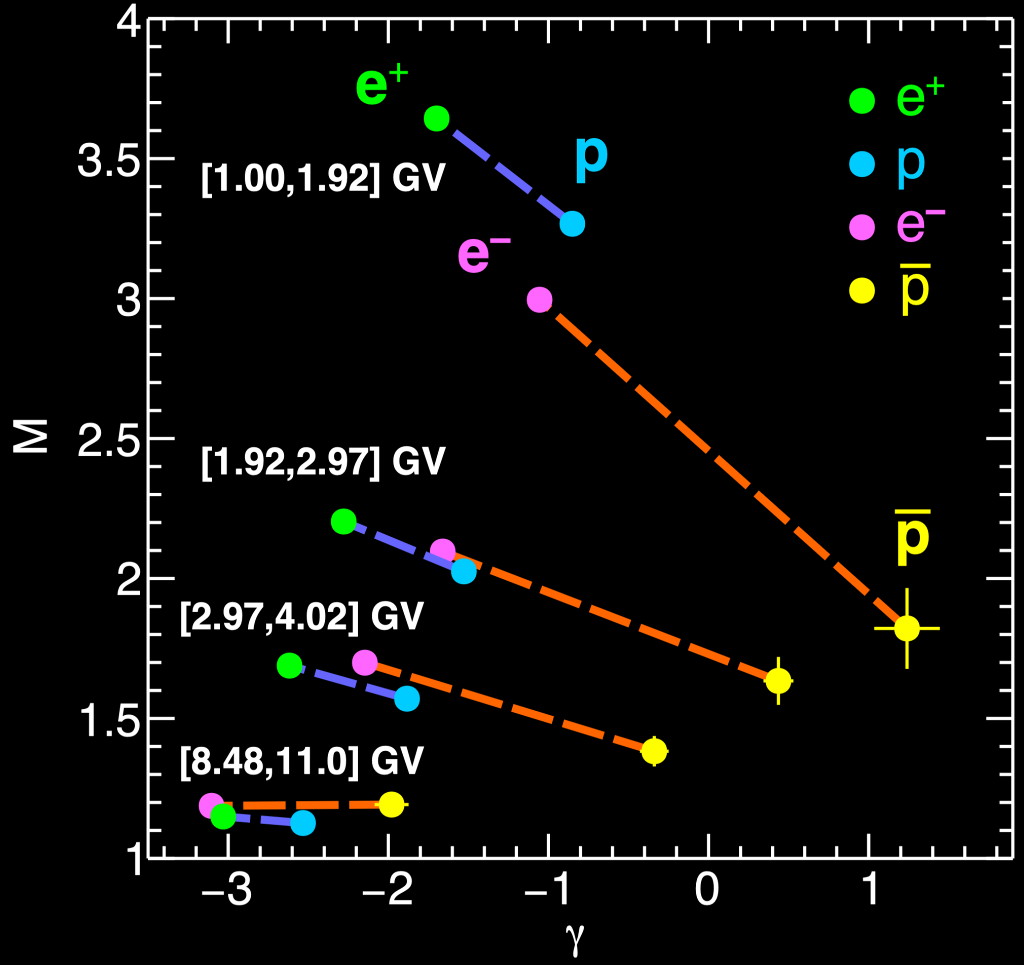


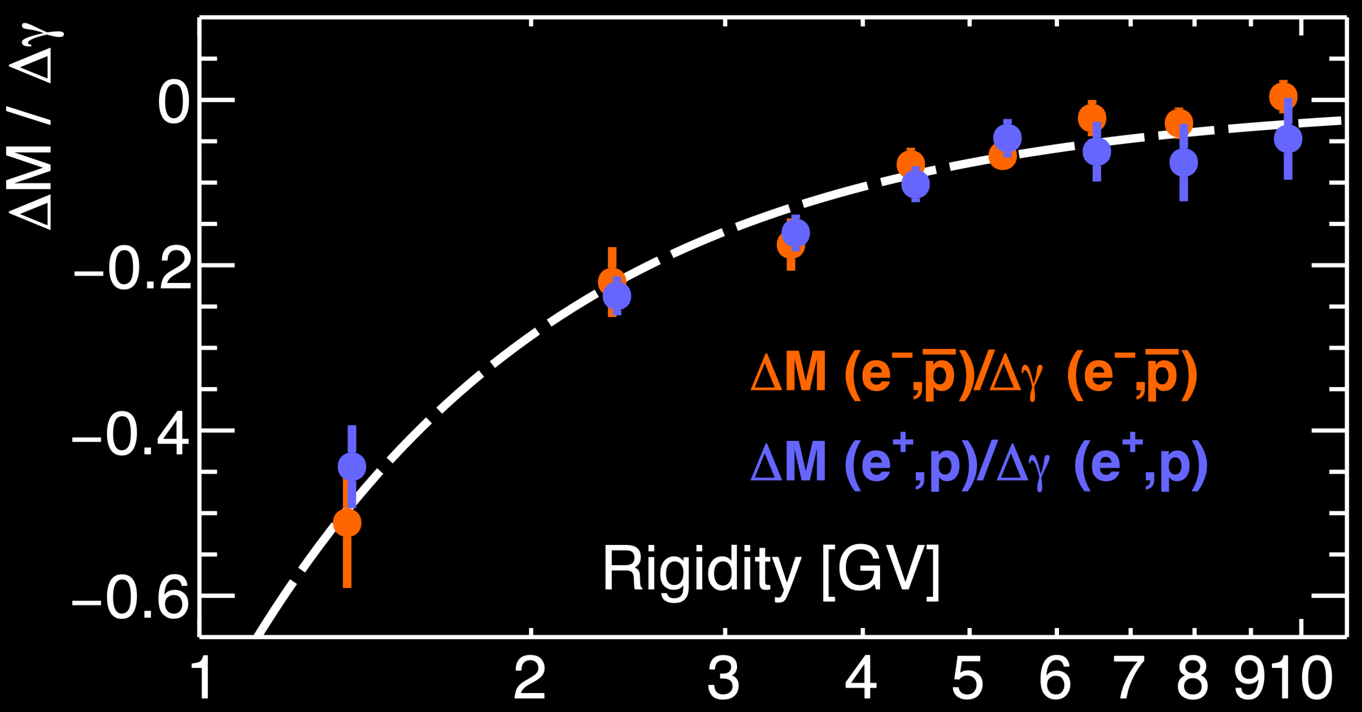
All four fluxes show complex temporal structures, and $\bar{p}$ is distinctly different from all other elementary particle fluxes.

Relationship between the four elementary particles (e^+, e^-, p, $\bar{p}$)



Variation Magnitudes ($M = \Phi_{max}/\Phi_{min}$) and Flux Spectral Indices ($\gamma = d[\log\Phi]/d[\log R]$)

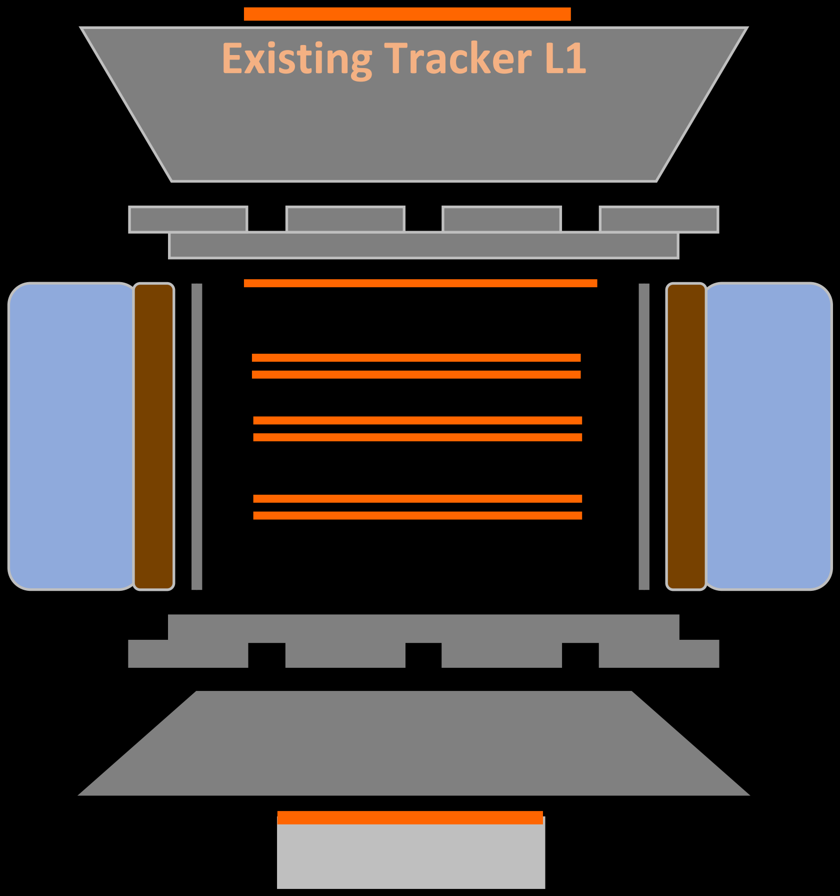




The $\Delta M/\Delta\gamma$ ratios for positive and negative particles are consistent.
At high rigidity, this ratio tends to zero.

AMS 2011-2026

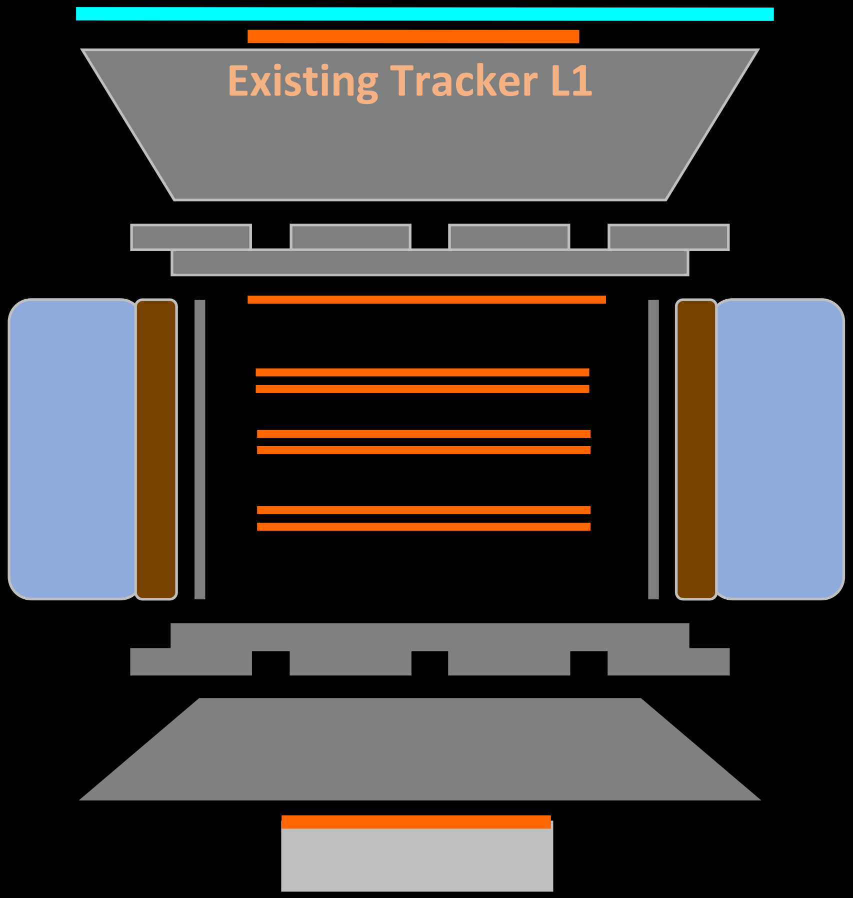
Continuous data-taking



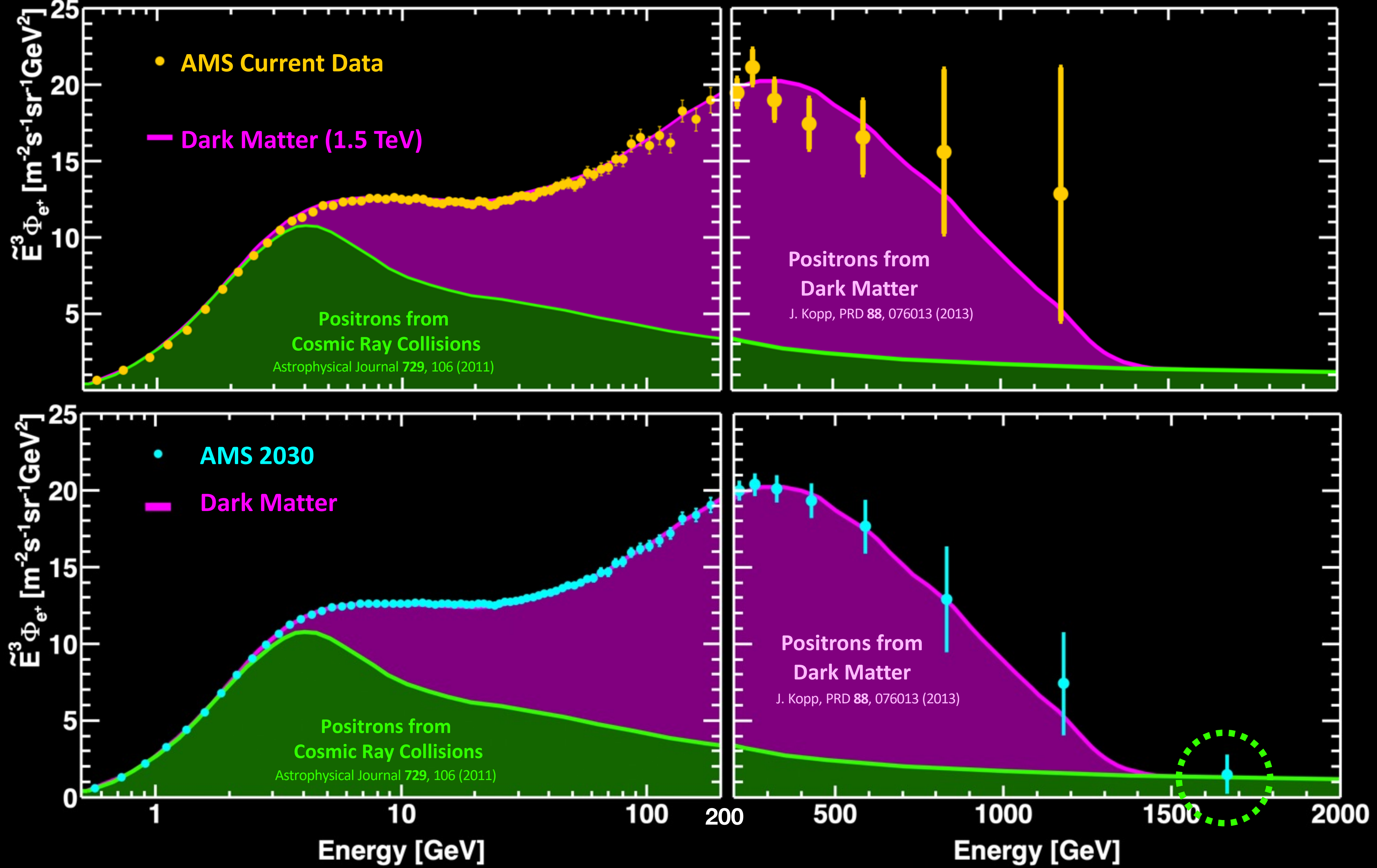
AMS 2026-2030+

New 4+4m² Silicon Tracker Planes

Acceptance increased to 300%

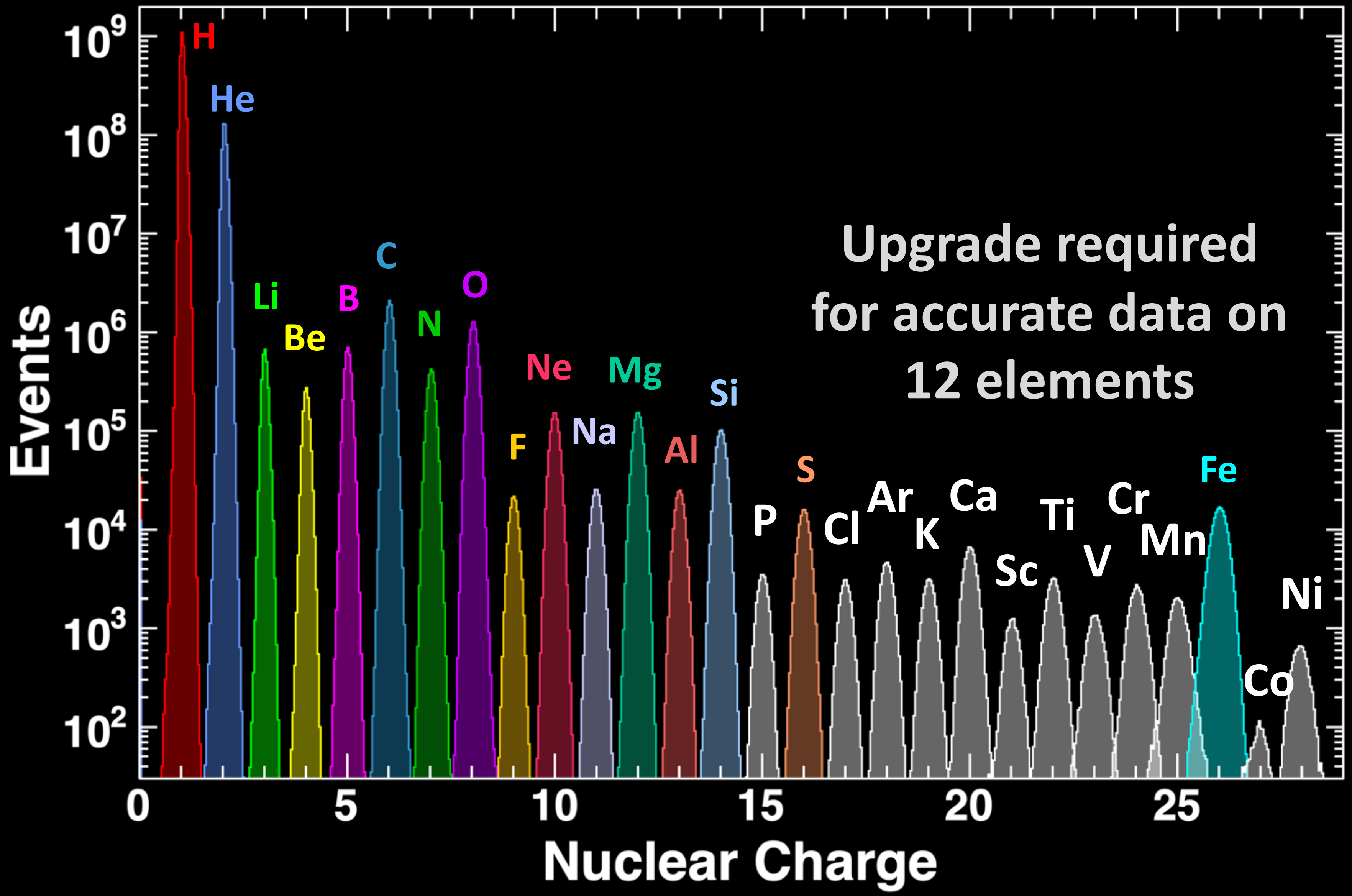


Positron spectrum to 2030



By 2030, AMS will ensure that the high energy positron spectrum drops off quickly in the 0.2-2 TeV region and the highest energy positrons only come from cosmic ray collisions as predicted for dark matter collisions

Current AMS Cosmic Ray Data

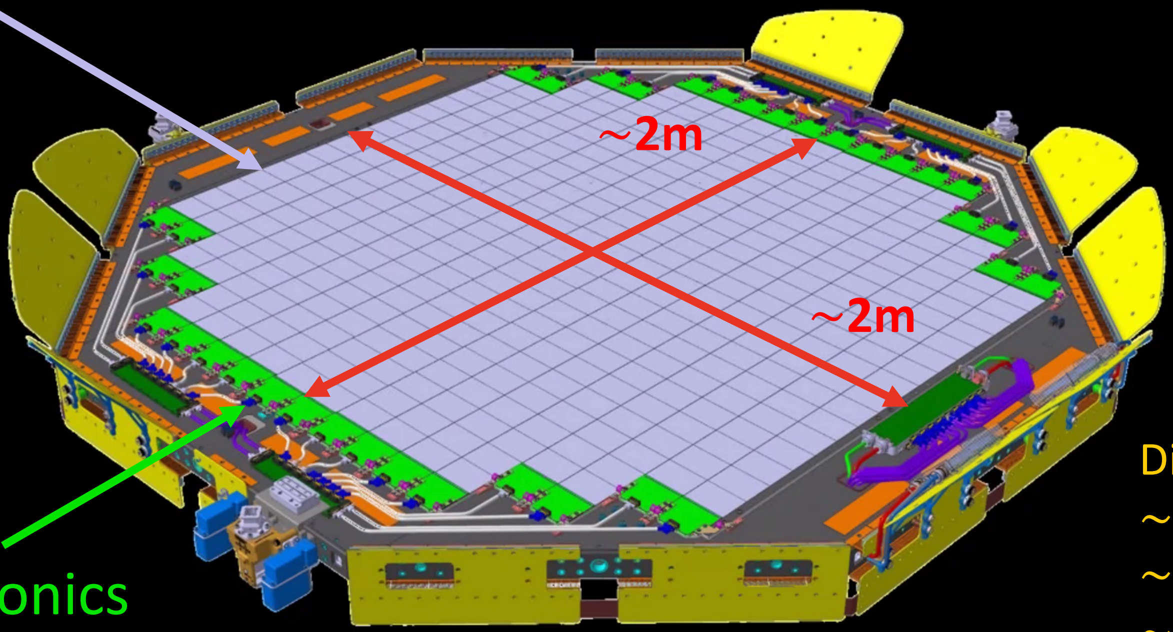


By 2030, AMS will provide complete and accurate spectra for the 28 elements and will provide the foundation for a comprehensive theory of cosmic rays.

Upgrade with New 4+4m^2 Silicon Tracker Planes

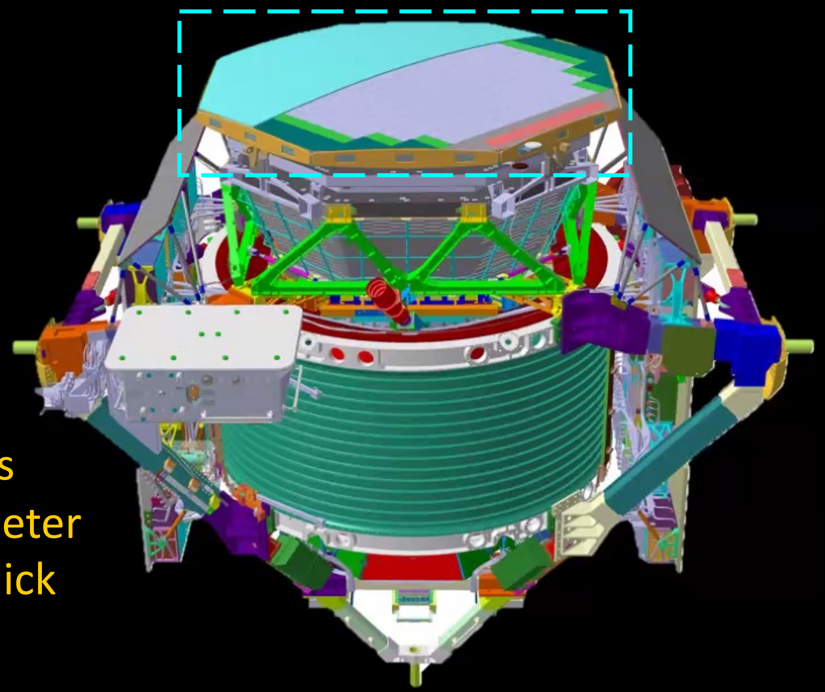
Layer-0 Assembly and Integration

Silicon Strip Detectors
(IHEP, INFN Perugia)



Electronics
(AS, NCSIST, MIT, INFN Perugia)

Layer-0



Dimensions
~ 2.8 diameter
~ 45 cm thick
~326 kg

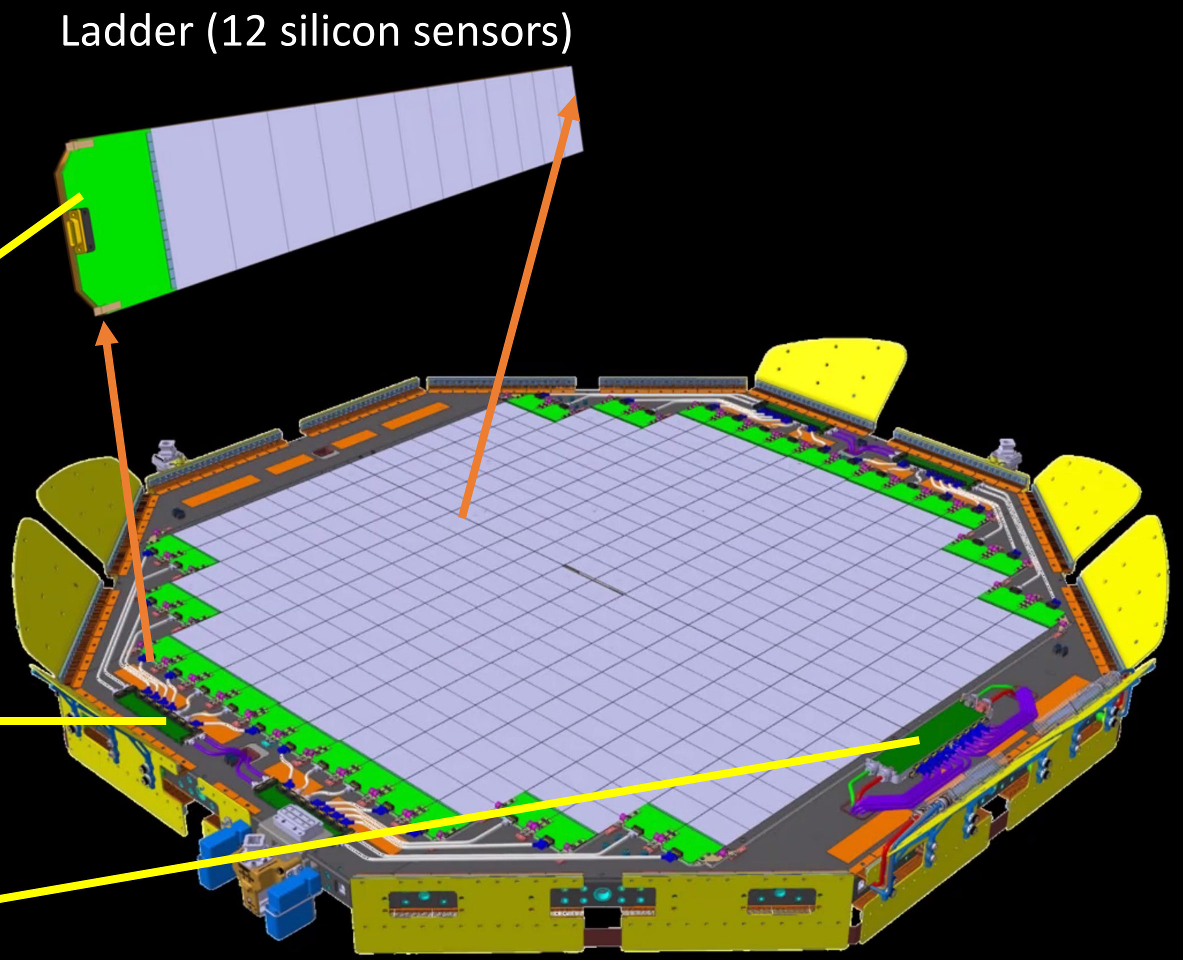
The production procedure follows the process established for the AMS-02 electronics on board of ISS, which have been working smoothly in space for 13 years.

Layer-0 electronics (~74k channels)

Quantity	
	Silicon Detector with 1024 silicon strips
	Frontend chips (VA)
72	**Frontend board (LEF)** • Digitization, serialization • Data compression • Assemble and transfer
8	**Intermediate board LINF (L, R)** • Collect data from 9 LEF • Assemble and transfer
1	**Interface board (LINJ)** • Collect data from 8 LINF • Assemble and transfer
2	**Power Dist. Box (LPD)**

To existing AMS system

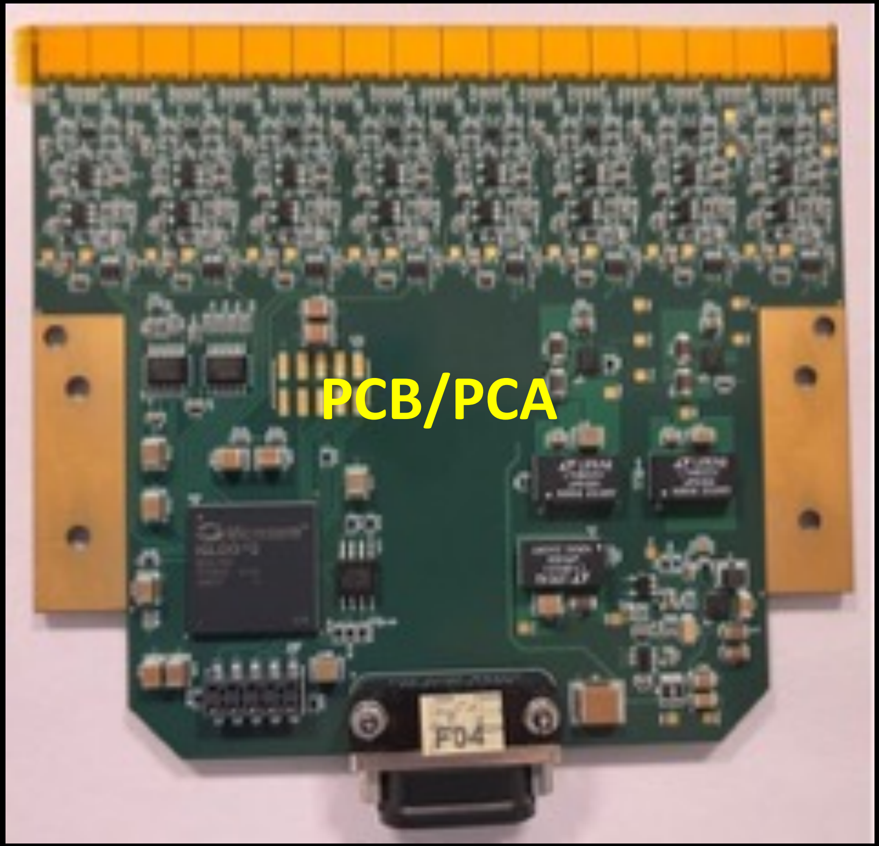
ISS Power



Frontend board (LEF) Production

1. Design Gerber File
2. Design Rule Check
3. PCB Production
4. PCB Assembly (PCA)
5. 1st Function Test (No VA)
6. 1st Thermal Cycle Test (20 cycles, not powered)
7. 2nd Function Test (No VA)
8. Conformal Coating
9. 3rd Function Test (No VA)
10. VA gluing
11. Wire Bonding VA
12. Function Test (with VA connected)
13. **Acceptance Test** (10 thermal cycles, with power + function test)
14. Shipping

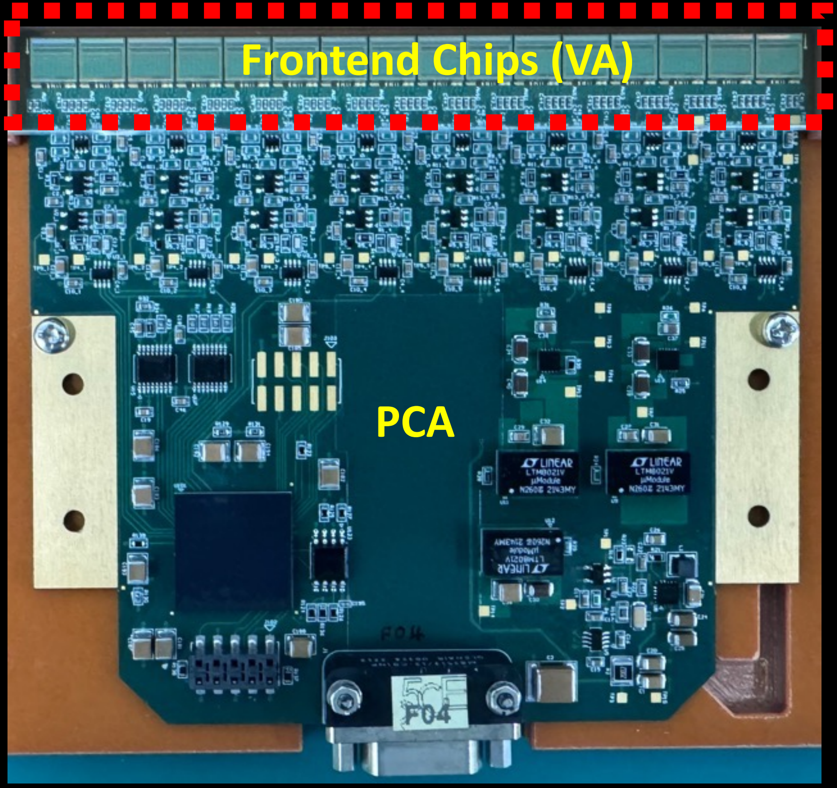
Frontend board (LEF)



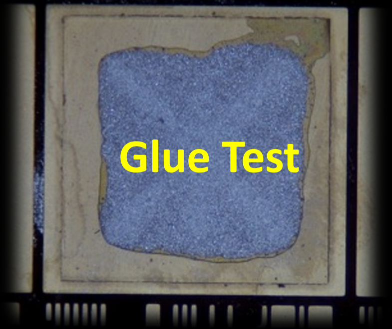
PCB/PCA Production @ NCSIST

Frontend board (LEF) Production

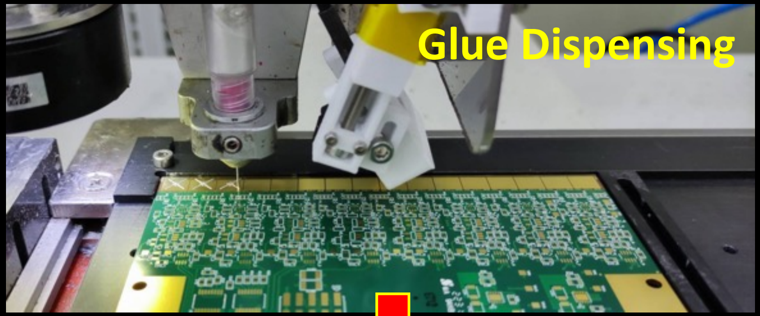
- Design Gerber File
- Design Rule Check
- PCB Production
- PCB Assembly (PCA)
- 1st Function Test (No VA)
- 1st Thermal Cycle Test (20 cycles, not powered)
- 2nd Function Test (No VA)
- Conformal Coating
- 3rd Function Test (No VA)
- VA gluing
- Wire Bonding VA
- Function Test (with VA connected)
- **Acceptance Test** (10 thermal cycles, with power + function test)
- Shipping

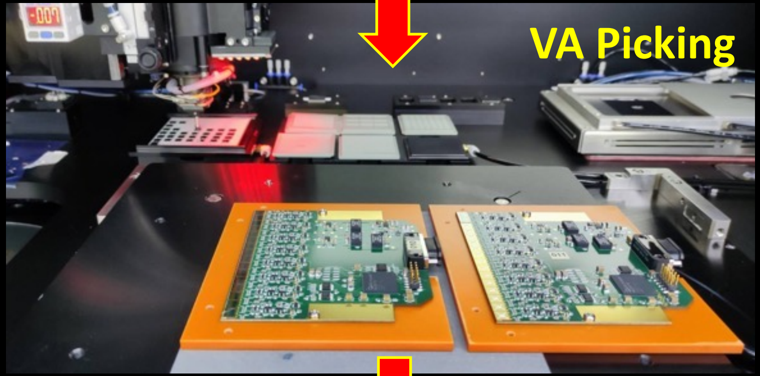


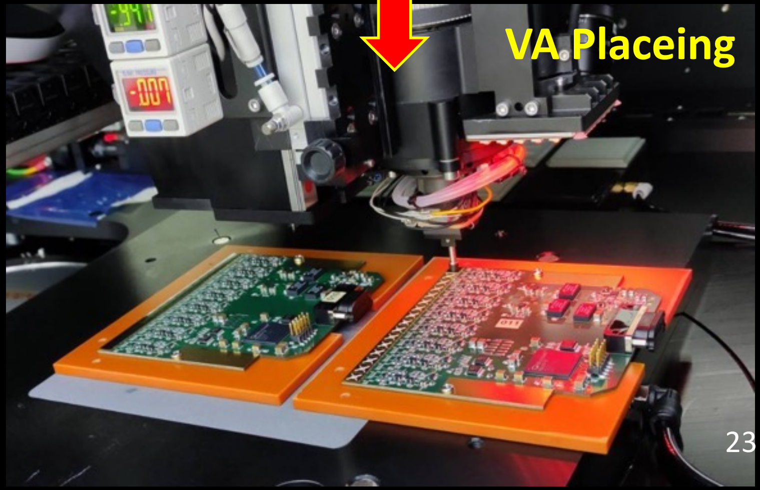
Die Bonding (VA gluing) @ iST



EPO-TEK® EJ2189 is an electrically conductive, silver-filled epoxy paste.

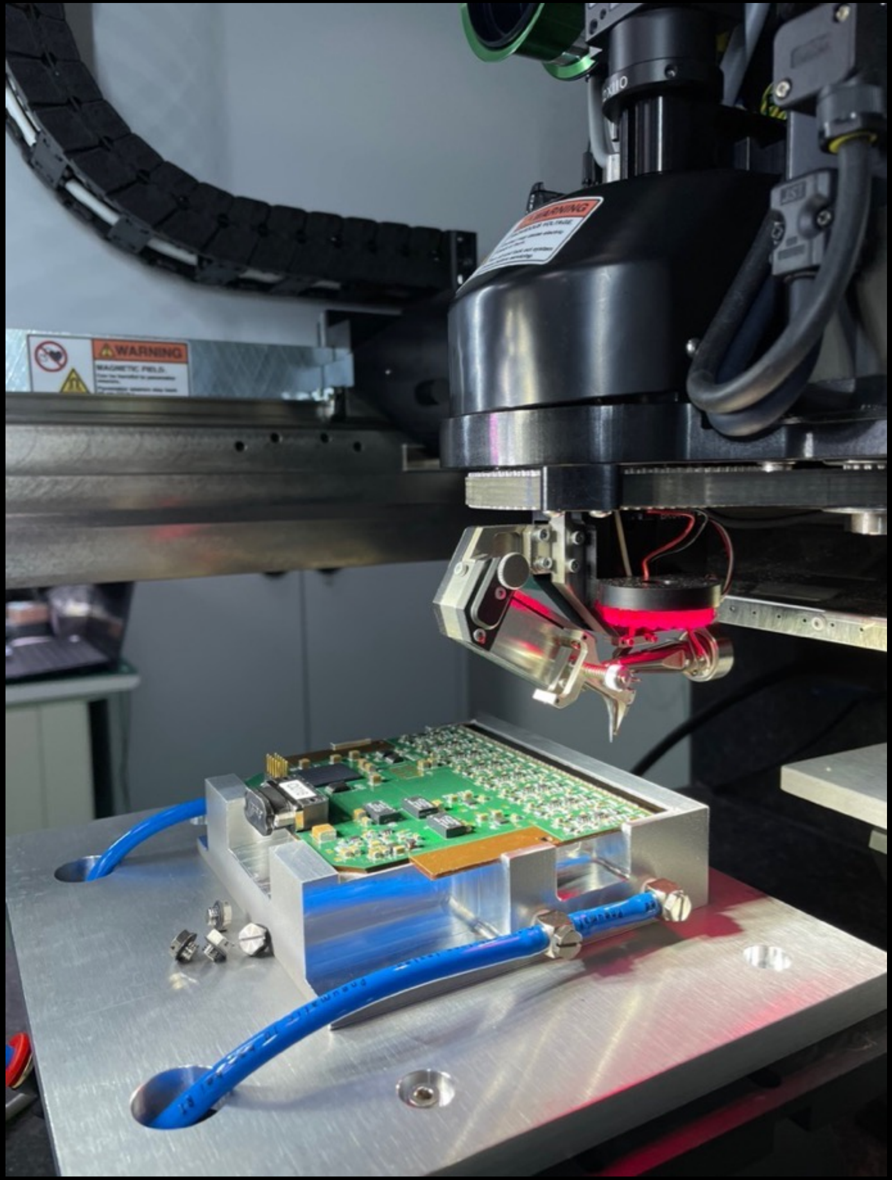


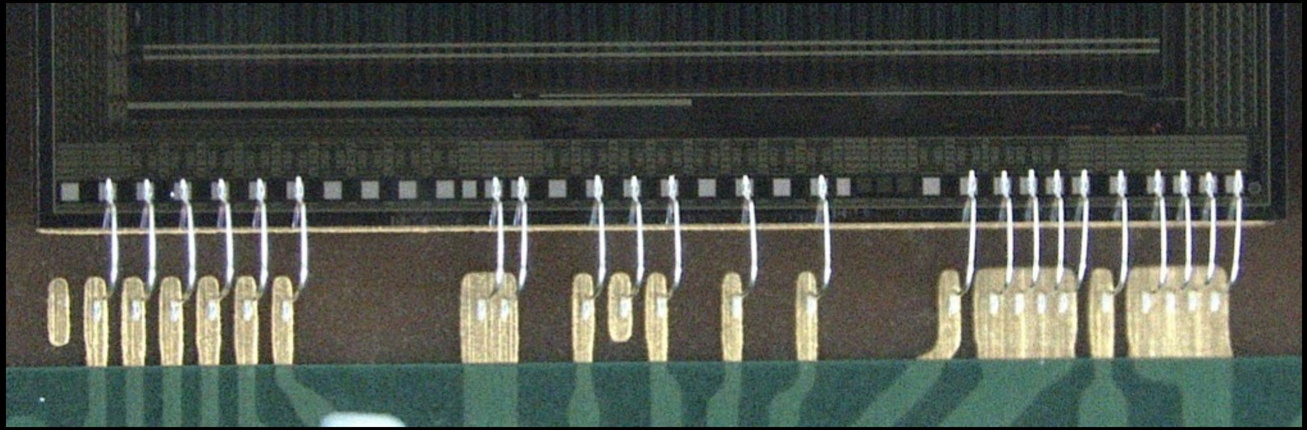


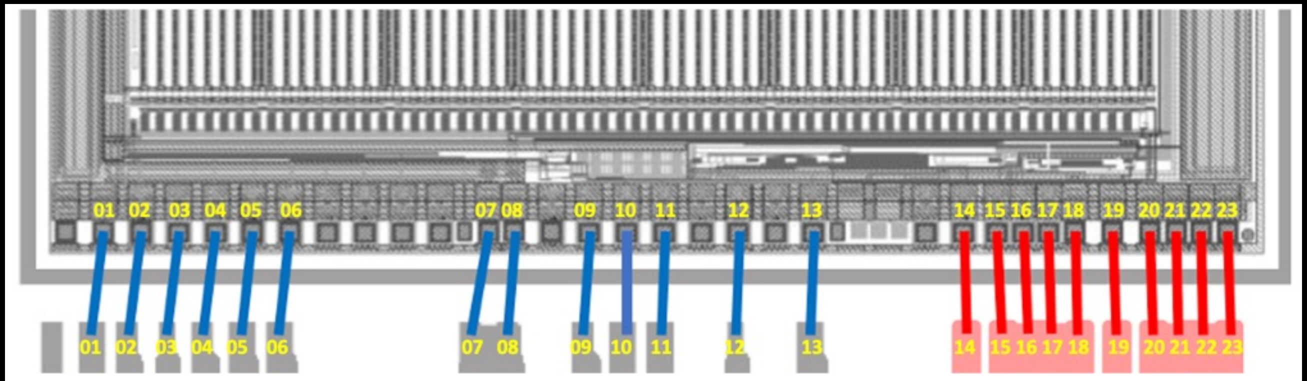


- (IDE1140) Die bond with EPO-TEK EJ2189
  cure condition 80˚C / 3 hours.
  1) Do the glue test by pseudo die (glass).
  2) Do the visual inspection before the die bonding.
  3) The glue cannot be out of the die area region.

Wire Bonding @NTU

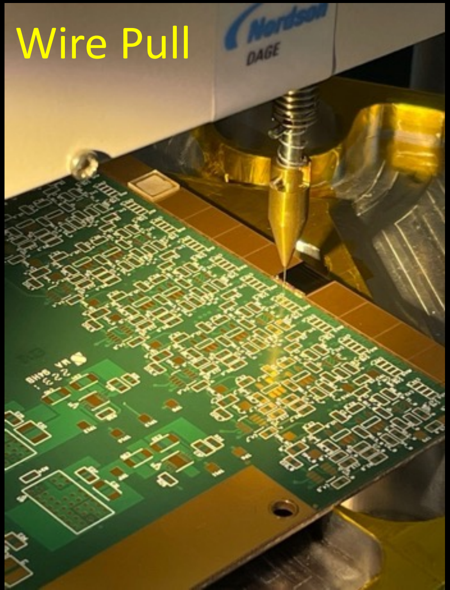


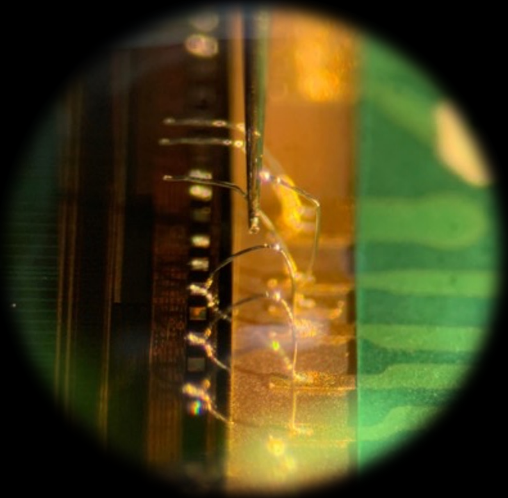


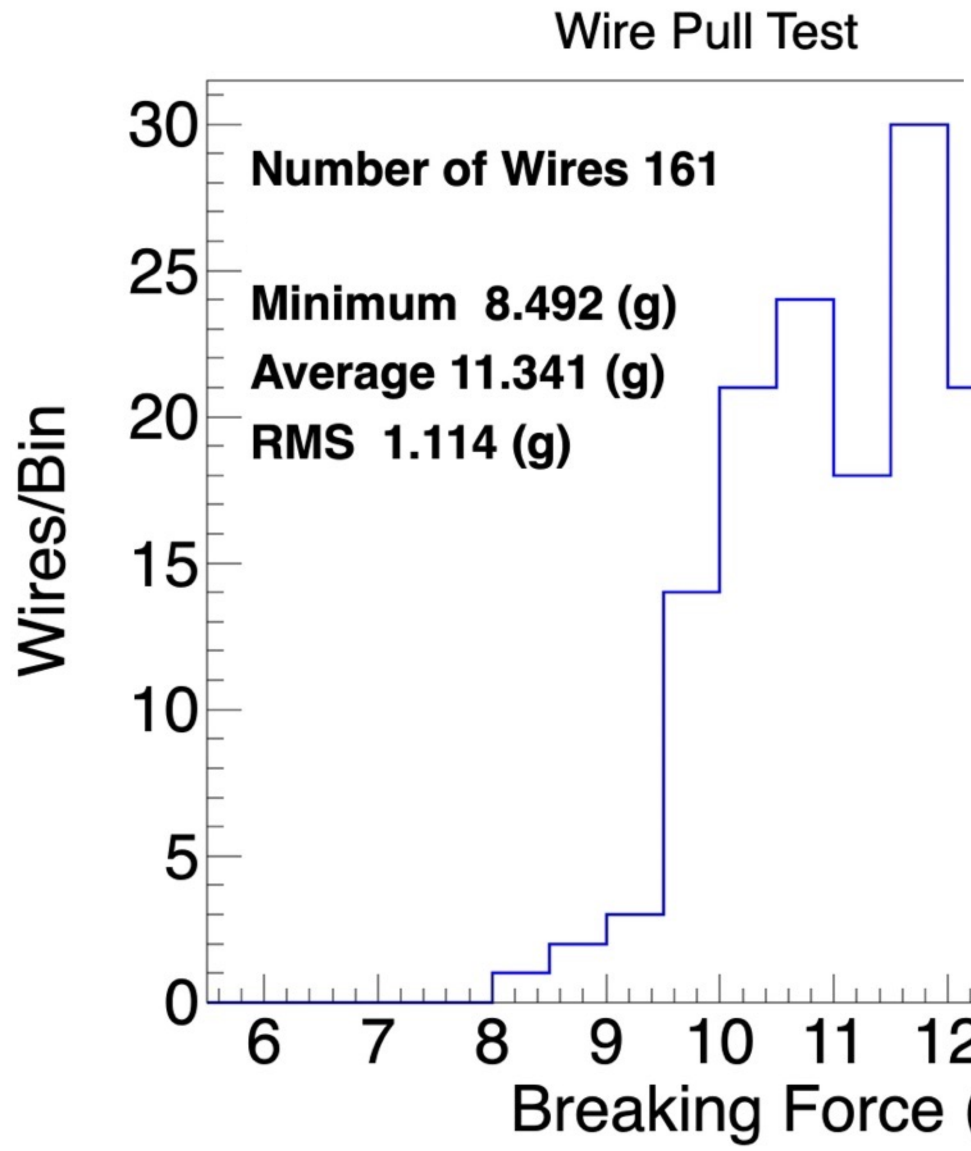


6mm

Wire Pull Test during production





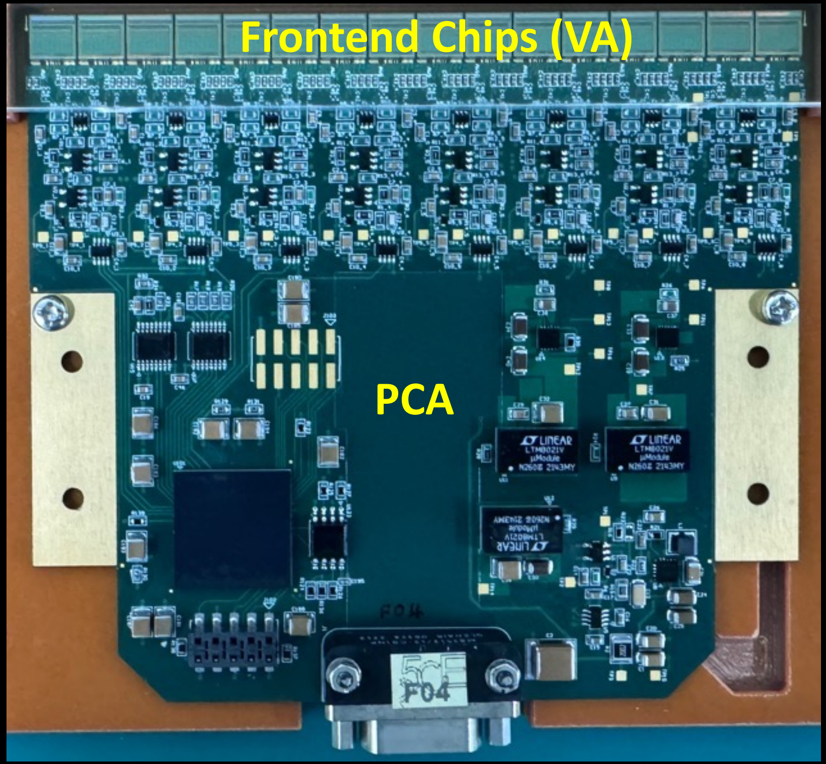


Wire Pull Test Acceptance Criteria

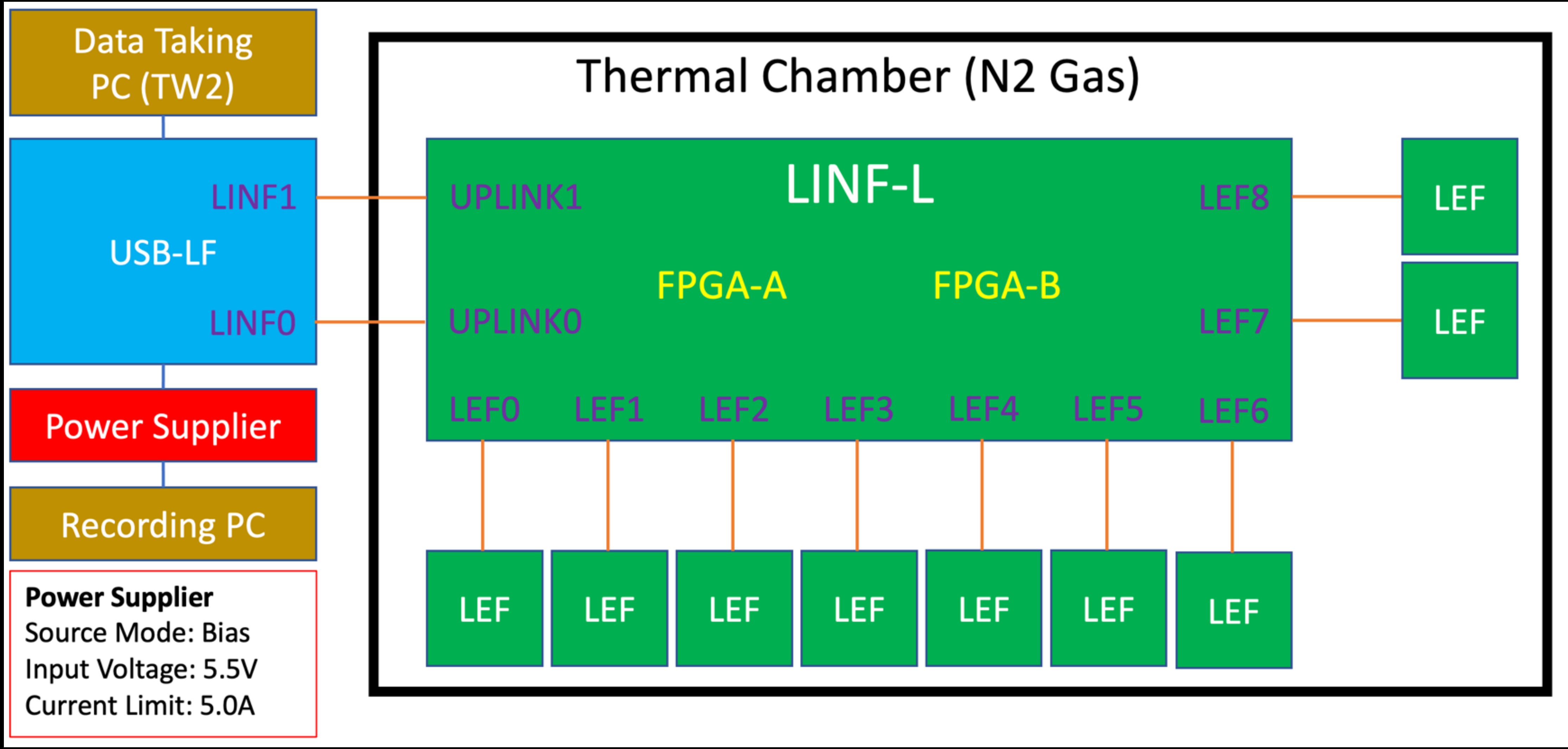
Minimum (g)	> 5 g
Average (g)	> 9 g
RMS (g)	< 2 g

Frontend board (LEF) Production

Design Gerber File
↓
Design Rule Check
↓
PCB Production
↓
PCB Assembly (PCA)
↓
1st Function Test (No VA)
↓
1st Thermal Cycle Test (20 cycles, not powered)
↓
2nd Function Test (No VA)
↓
Conformal Coating
↓
3rd Function Test (No VA)
↓
VA gluing
↓
Wire Bonding VA
↓
Function Test (with VA connected)
↓
Acceptance Test (10 thermal cycles, with power + function test)
↓
Shipping

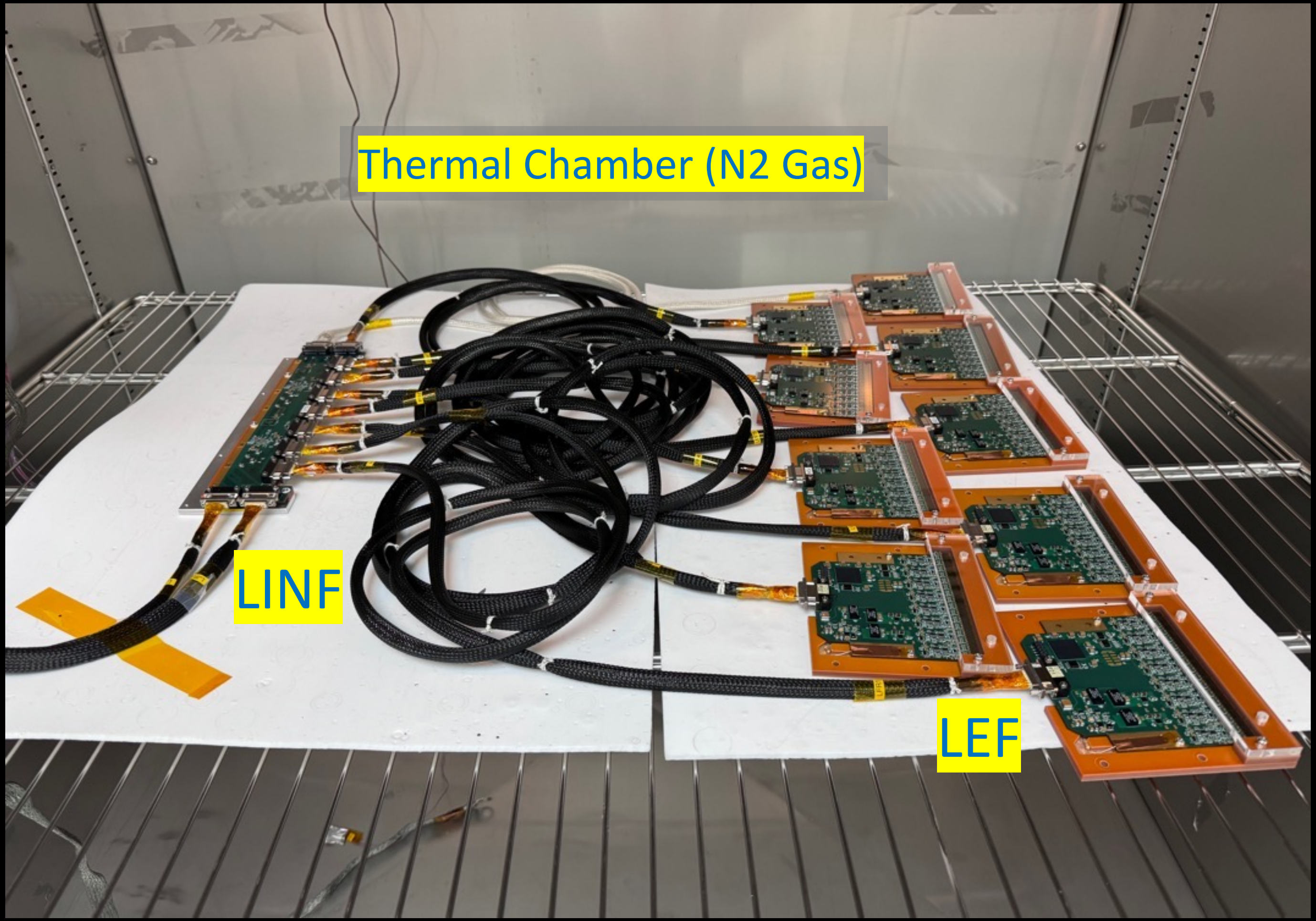


Acceptance Test



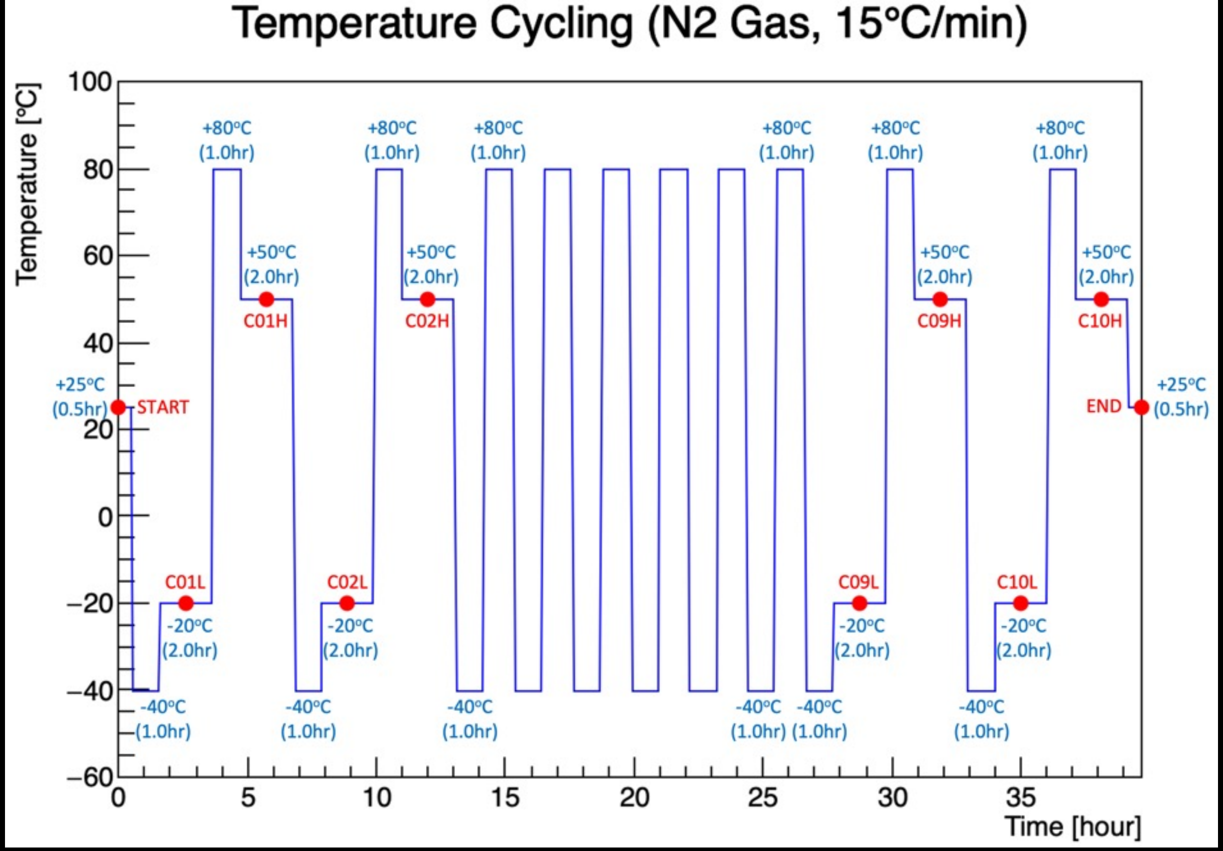
- Test 9 pcs FM LEF and LINF-L with USB-LF and existing software

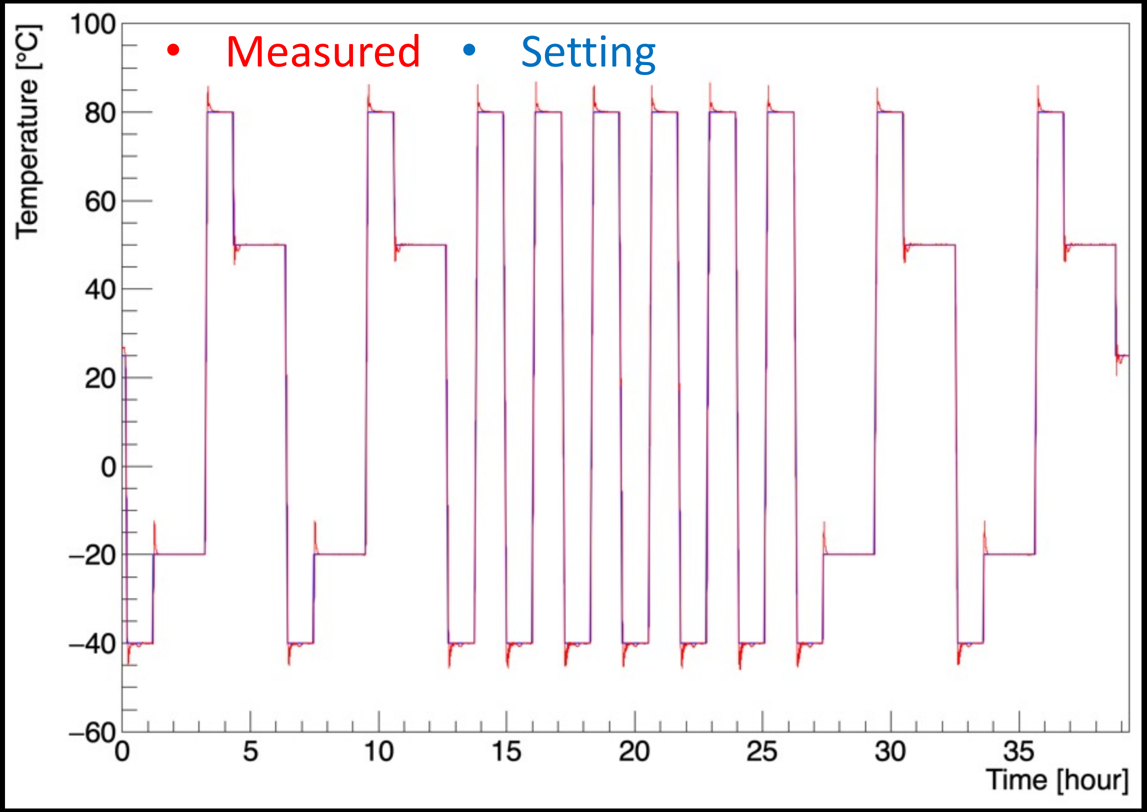
Acceptance Test



Readout chain arranged the same way as will be in the Layer-0: 1 LINF reads 9 LEFs.

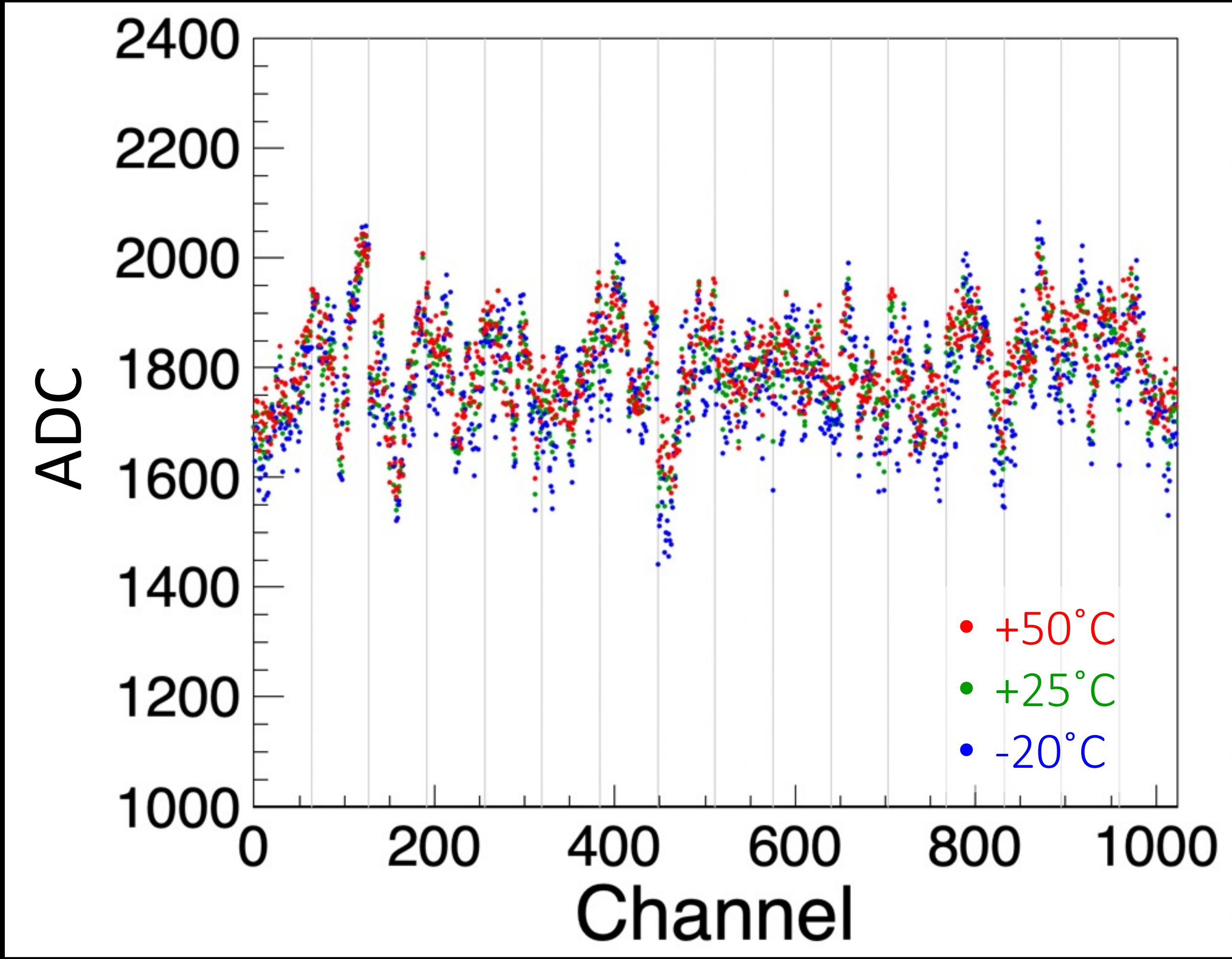
Acceptance test temperature profile

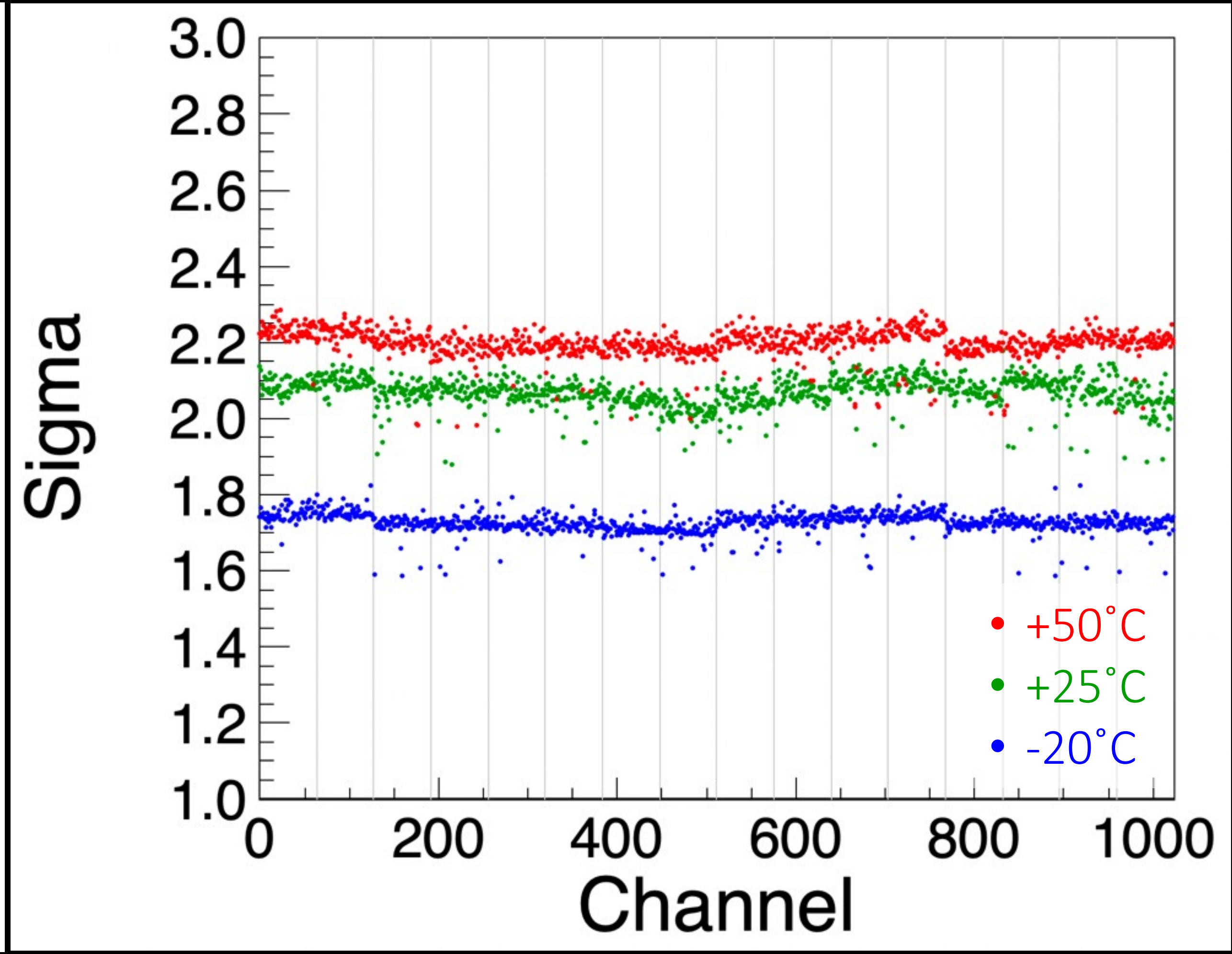




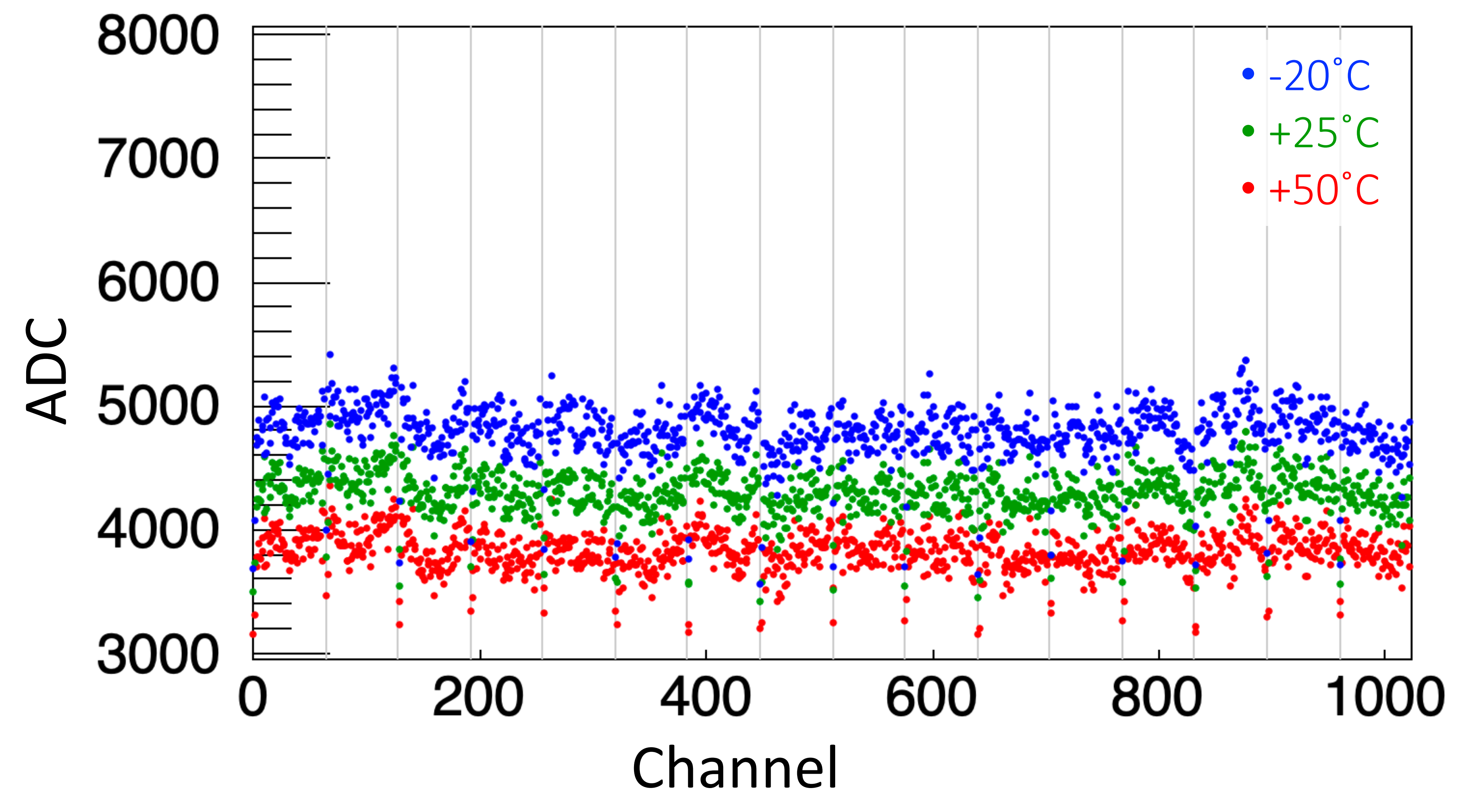
- The chamber filled with Nitrogen (N_2).
- Totally 10 cycles should be taken. (NOTE: $\pm 15^{o}C$/min)
- Power up and test at the first two cycles and the last two cycles.
- **Tests: (1) Bias voltage, (2) Pedestal and noise without signal, (3) Gain test with injected signal.**

Pedestal and sigma during thermal cycle (LEF F04)

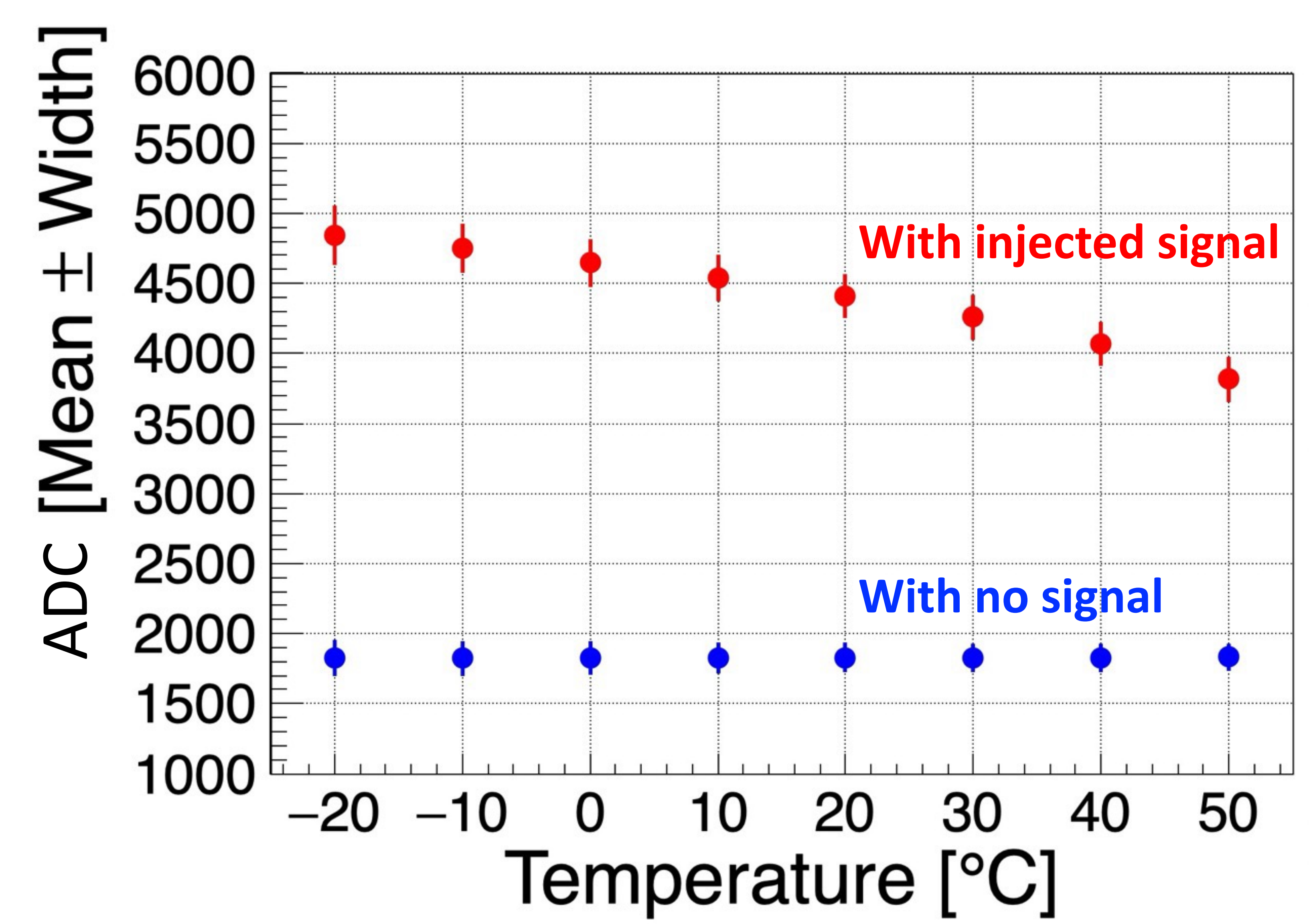




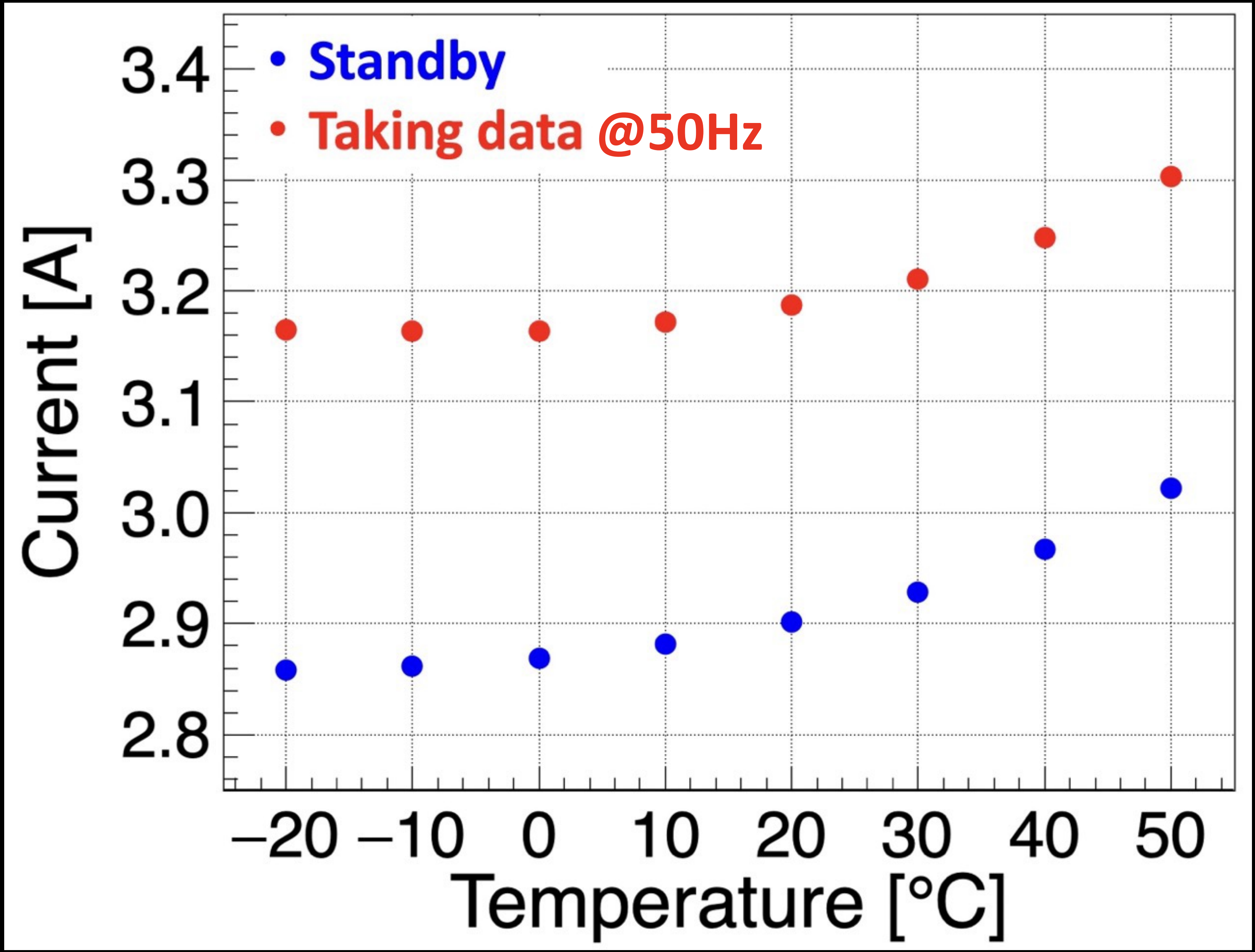
Gain test (with injected signal) during thermal cycle (LEF F04)



Gain test result versus temperature



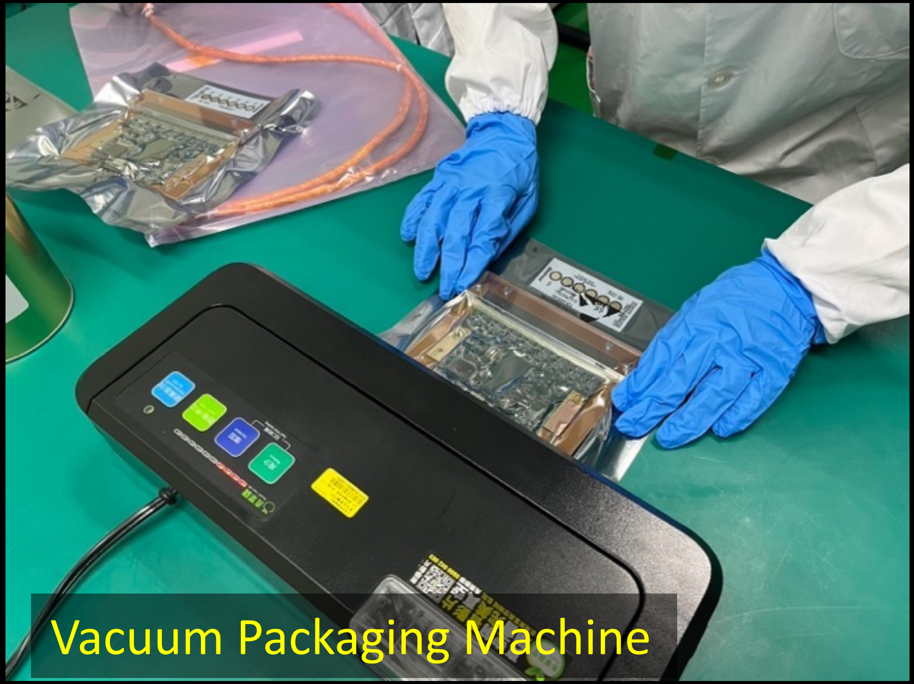
5.5V current for 1 LINF + 9 LEFs

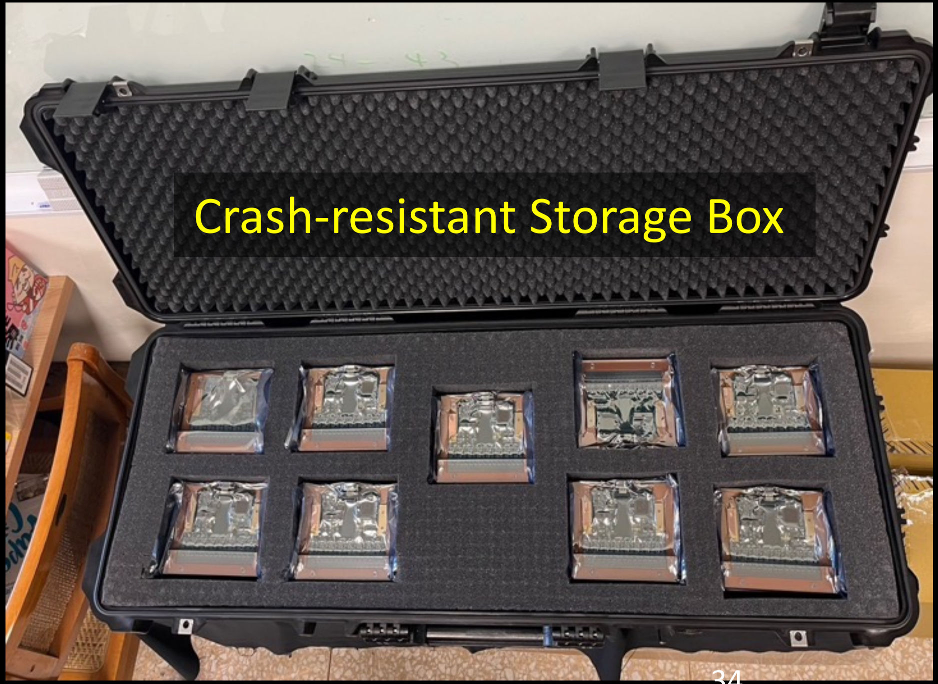


LEF Shipping

- Packing procedure

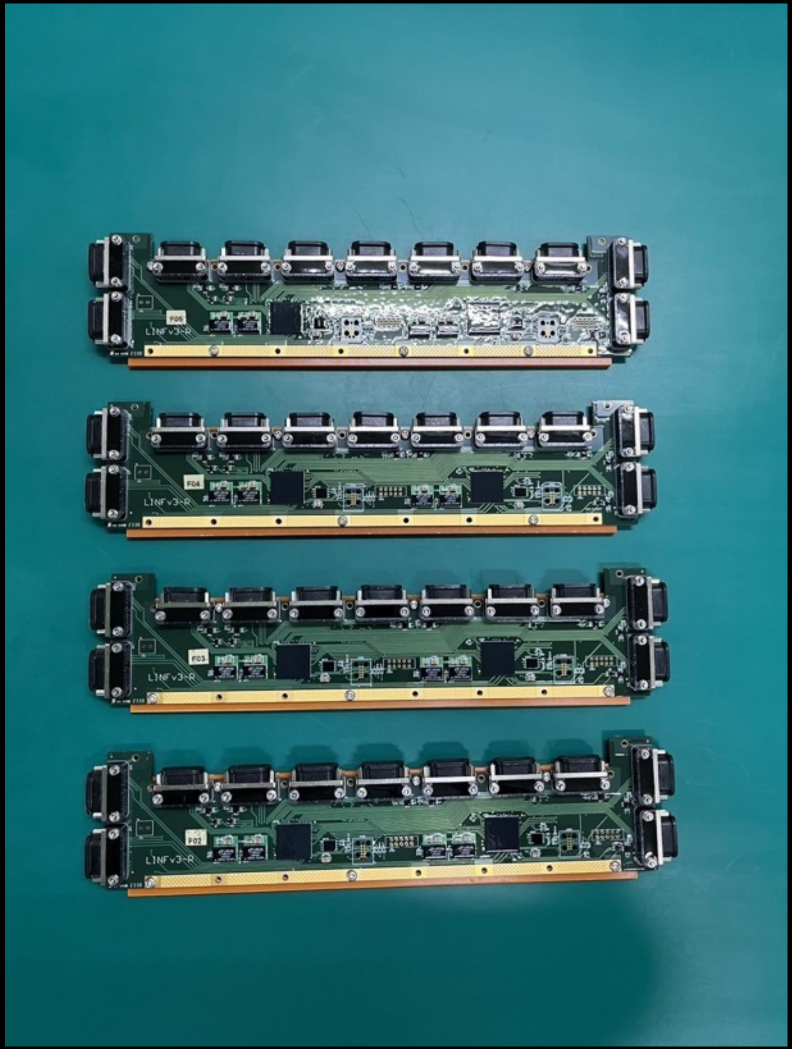
  1) Put and fix a humidity indicator card in a static shielding bag.
  2) Put a LEF with a jig in the same static shielding bag.
  3) Seal the bag with the vacuum packaging machine.
  4) Put all LEFs in the crash-resistant storage box.



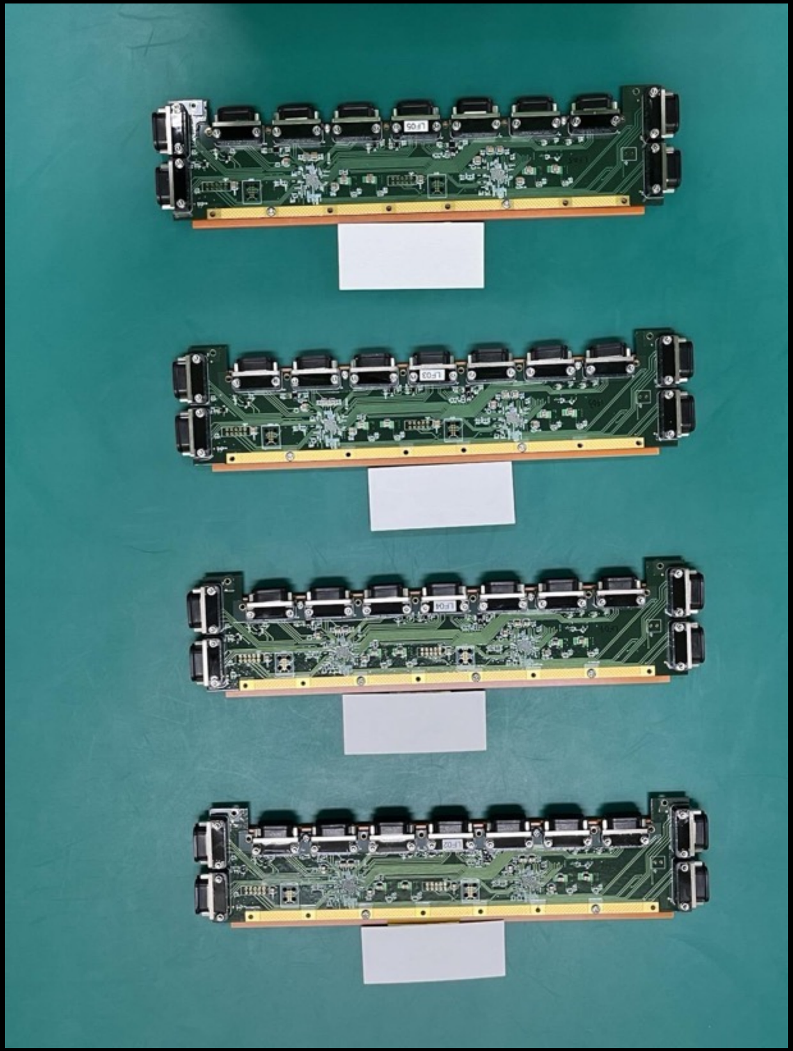


Intermediate board (LINF)

LINF-R



LINF-L



Silicon Detector with 1024 silicon strips

Frontend chips (VA)

Frontend board (LEF)

- Digitization, serialization
- Data compression
- Assemble and transfer

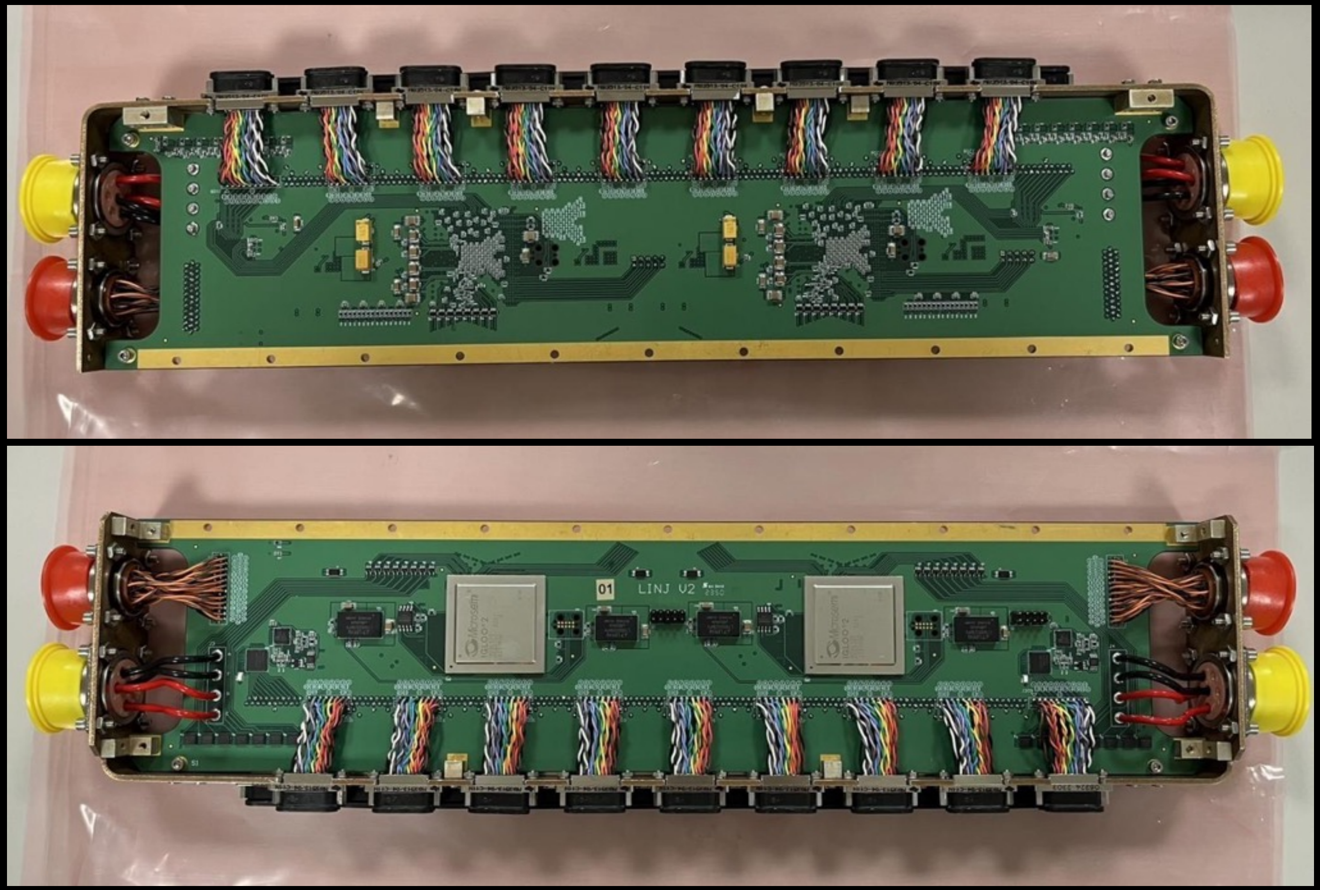
Intermediate board LINF (L, R)

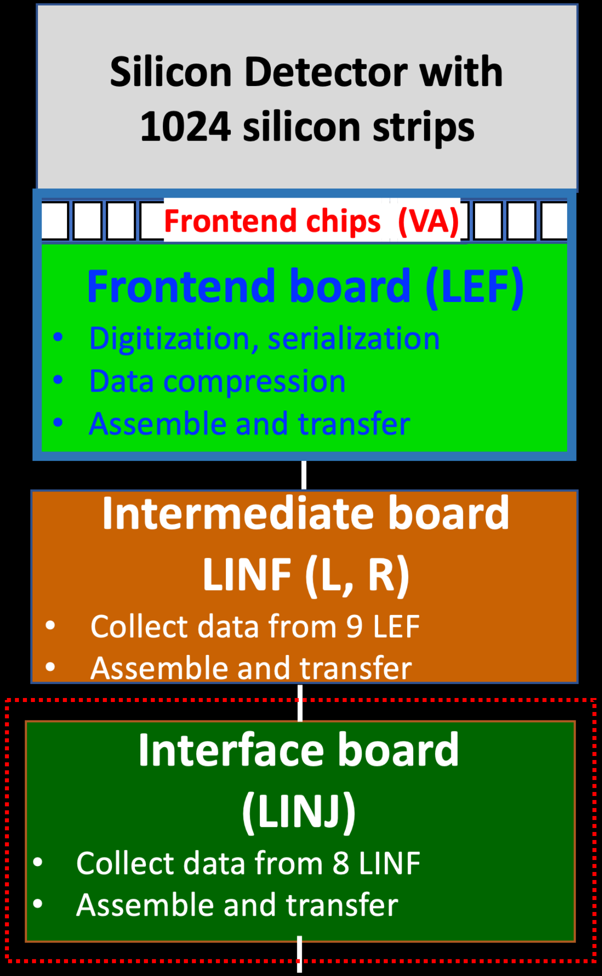
- Collect data from 9 LEF
- Assemble and transfer

Interface board (LINJ)

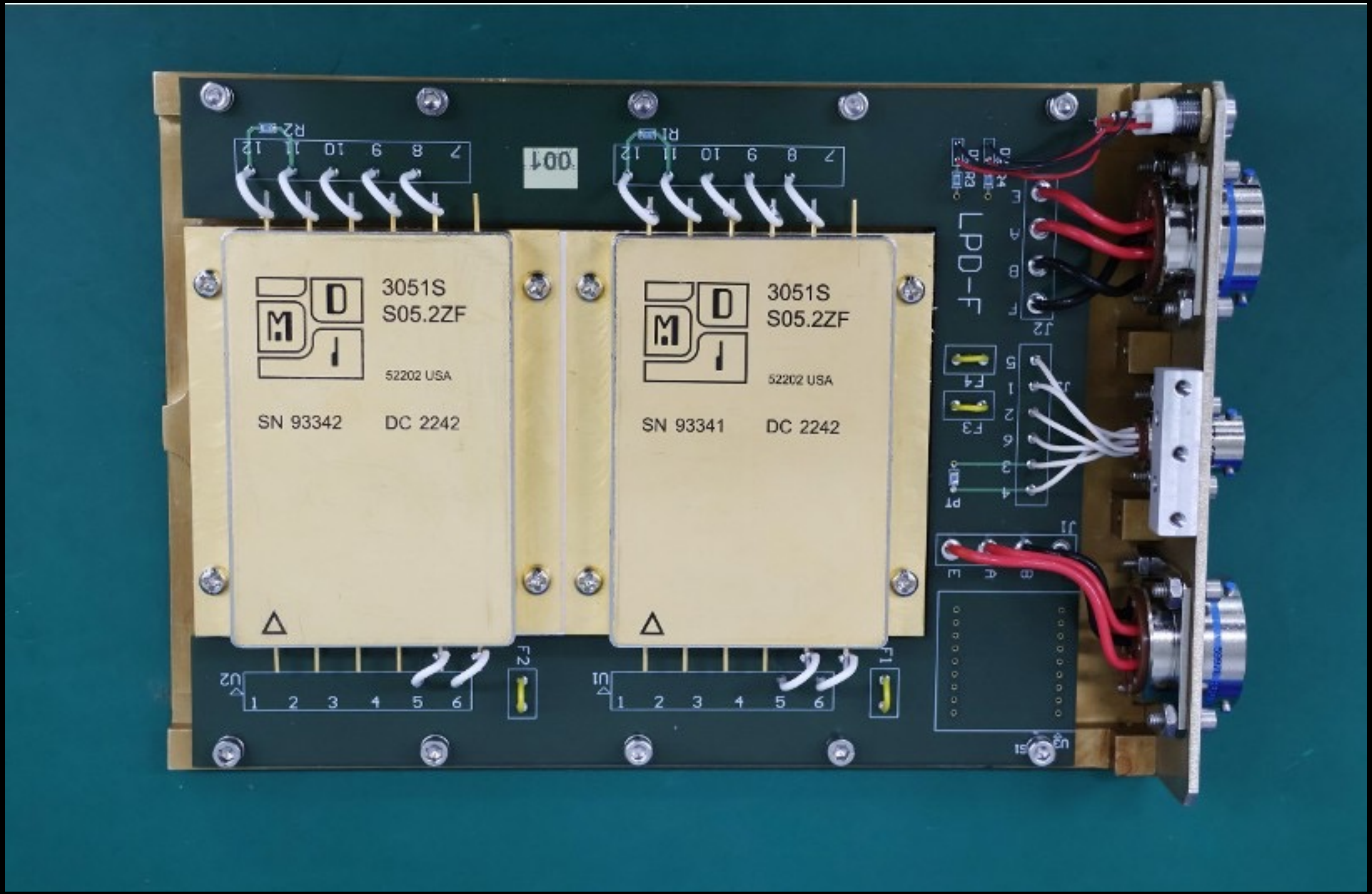
- Collect data from 8 LINF
- Assemble and transfer

Interface board (LINJ)





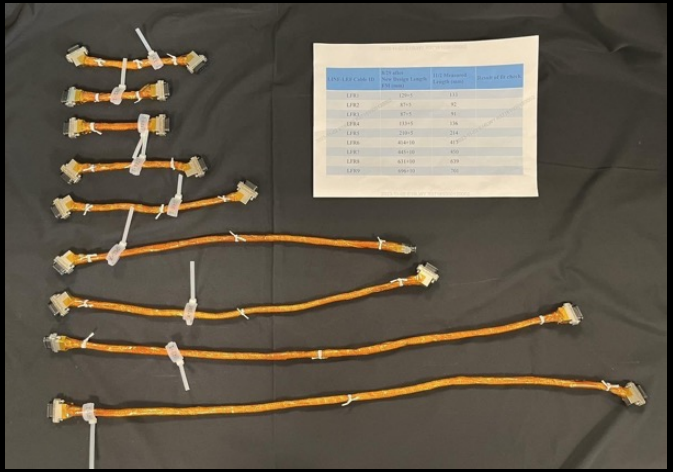
Power supply board LPD



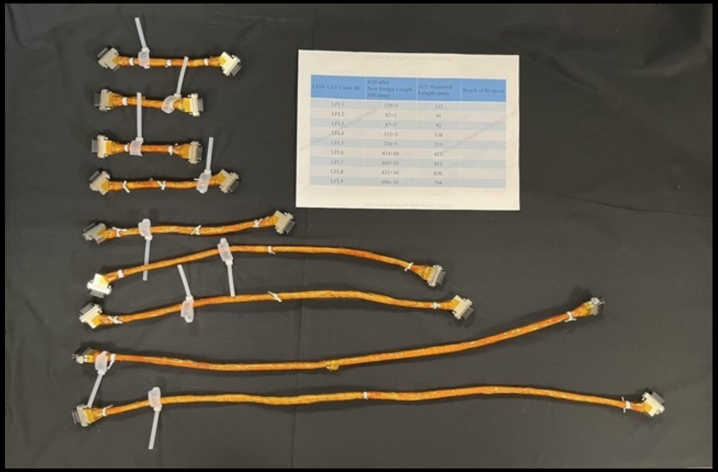
Cable Production

- LINF-LEF cables (18 types, 72 cables)

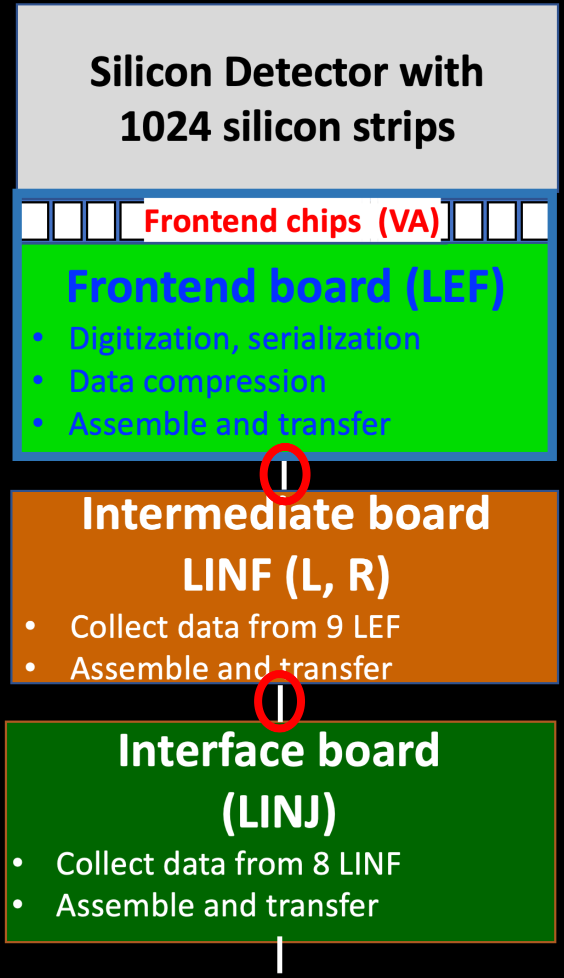
LINF-LEF-R cables



LINF-LEF-L cables

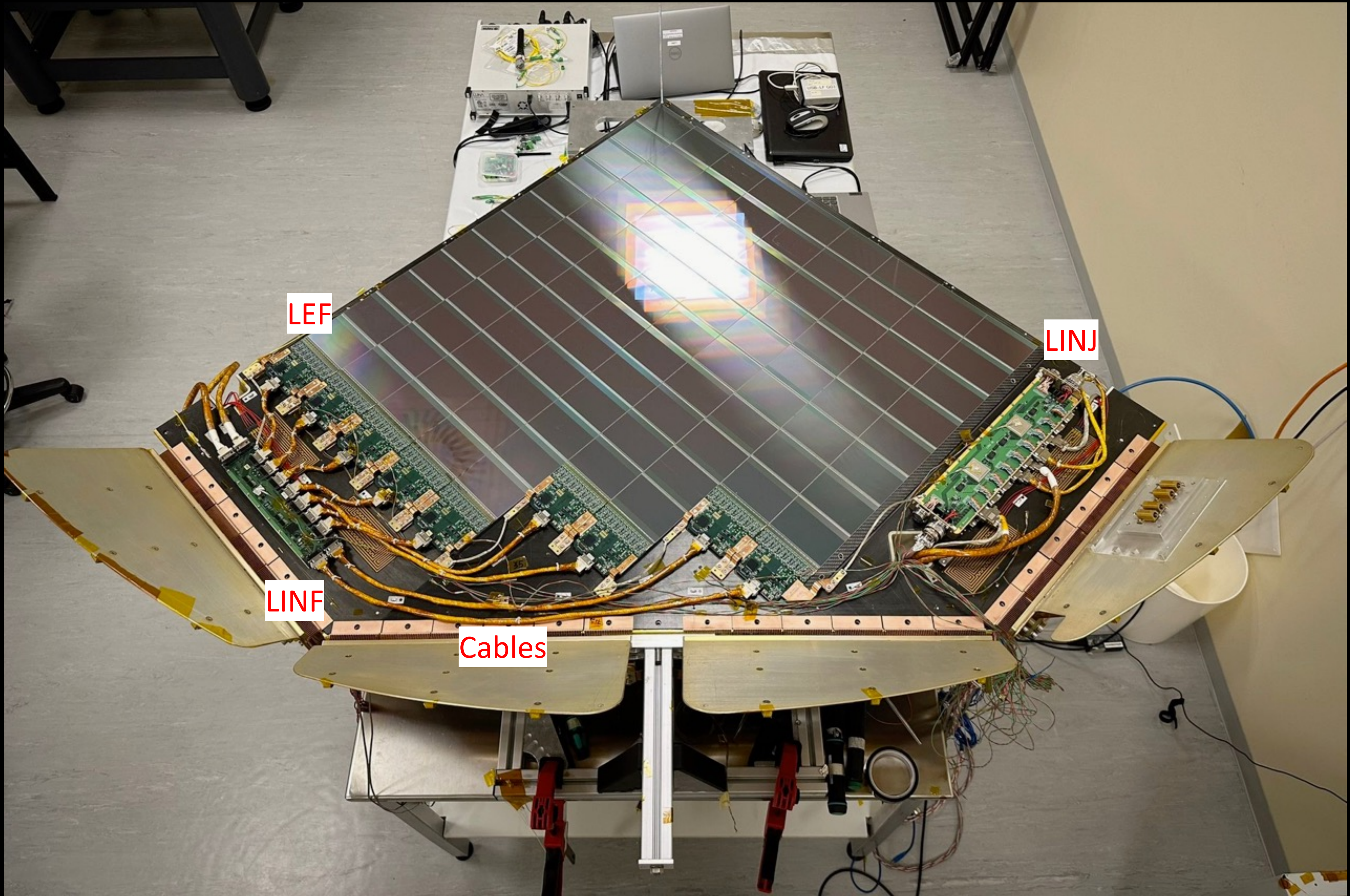


- LINJ-LINF cables (16 cables with different lengths)



Cable Production @NCSIST

QM electronics assembled in the 1/4 plane



Summary

- AMS is providing cosmic ray information with ~1% accuracy. The measurement results on elementary particles, nuclei, and antimatter offer comprehensive insights into understanding the universe.

- With the upgrade, spectral measurements will be significantly improved, including those of heavy nuclei and positron spectra.

- The electronics for the new silicon tracker plane are produced and tested in Taiwan.