HPS Overview

Tim Nelson - SLAC

HPS Collaboration Meeting

November 15, 2020

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

HPS Overview

Collaboration News

Operations: past, present, future

Analysis and Physics

HPS Membership News

SLAC

new Ph.D. student Emrys Peets: Emrys deferred some classwork to do significant work on rebuilding and installing and helping with operations (including first SVT Expert duties.)

Stanford

new Ph.D. student Rory O'Dwyer: Rory joined just in time to help prepare and install the SVT at JLab and take some shifts before fall classes started.

As per the HPS bylaws, will soon need to define dissertation topics for Emrys and Rory.

NP Institutions

Collaborators supported by nuclear physics funding in the US and Europe are under pressure to reduce effort on HPS, and some collaborators lost in lead up to the 2021 run.

The best way to combat this is to deliver more physics results!

HPS Organizational News

Spokespeople:

Maurik Holtrop (UNH), Tim Nelson (SLAC), Stepan Stepanyan (JLab)

Executive Committee: (two seats to be elected at this meeting)

Marzio De Napoli (INFN Catania), Norman Graf (SLAC), Maurik Holtrop (UNH), John Jaros (SLAC - emeritus), Omar Moreno (SLAC), Tim Nelson (SLAC), Rafayel Paramuzyan (JLab), Stepan Stepanyan (JLab)

Nathan Baltzell

Cameron Bravo

Omar Moreno

Rafayel Paremuzyan

Matt Solt

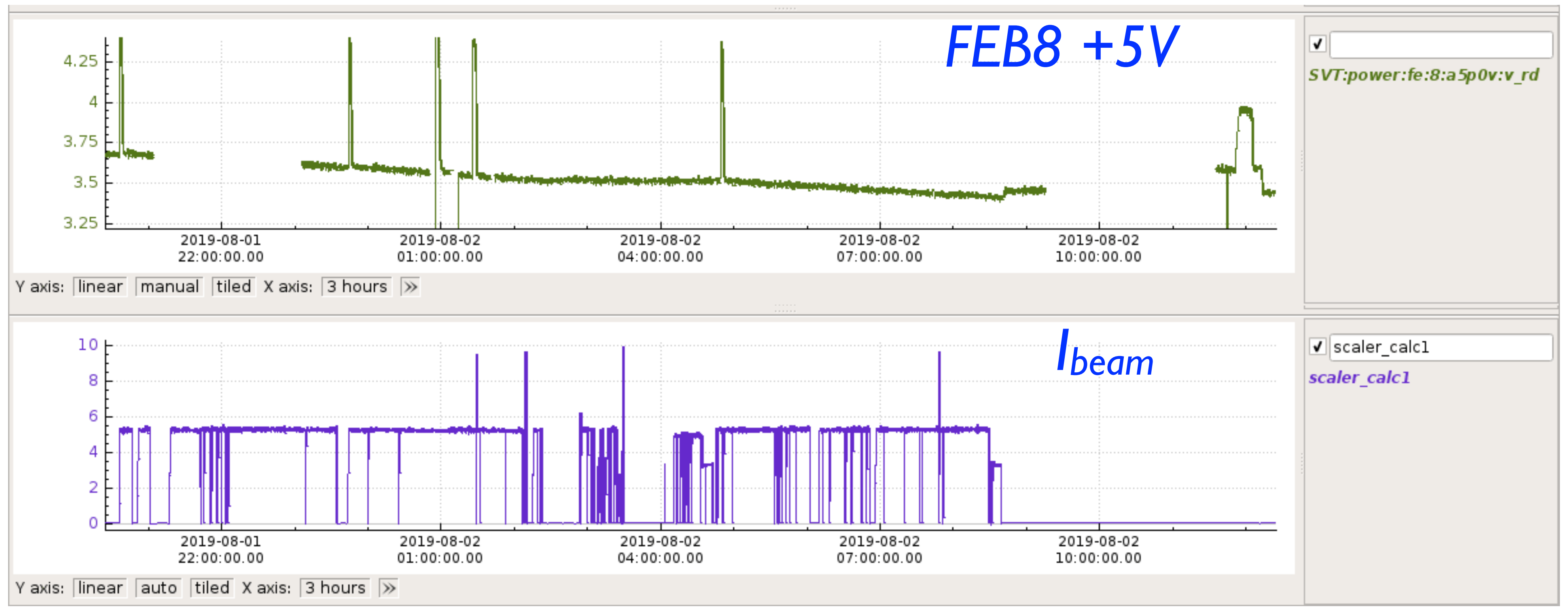
Don't forget to vote your two selections!

Publications and Presentations Committee:

Gabriel Charles (Orsay), Rouven Essig (Stony Brook), Alessandra Filippi (INFN Torino), Norman Graf (SLAC), Matt Graham (SLAC)

Recap of 2019 operations

After relatively smooth engineering runs in 2015 & 2016, operations in 2019 were beset by problems:



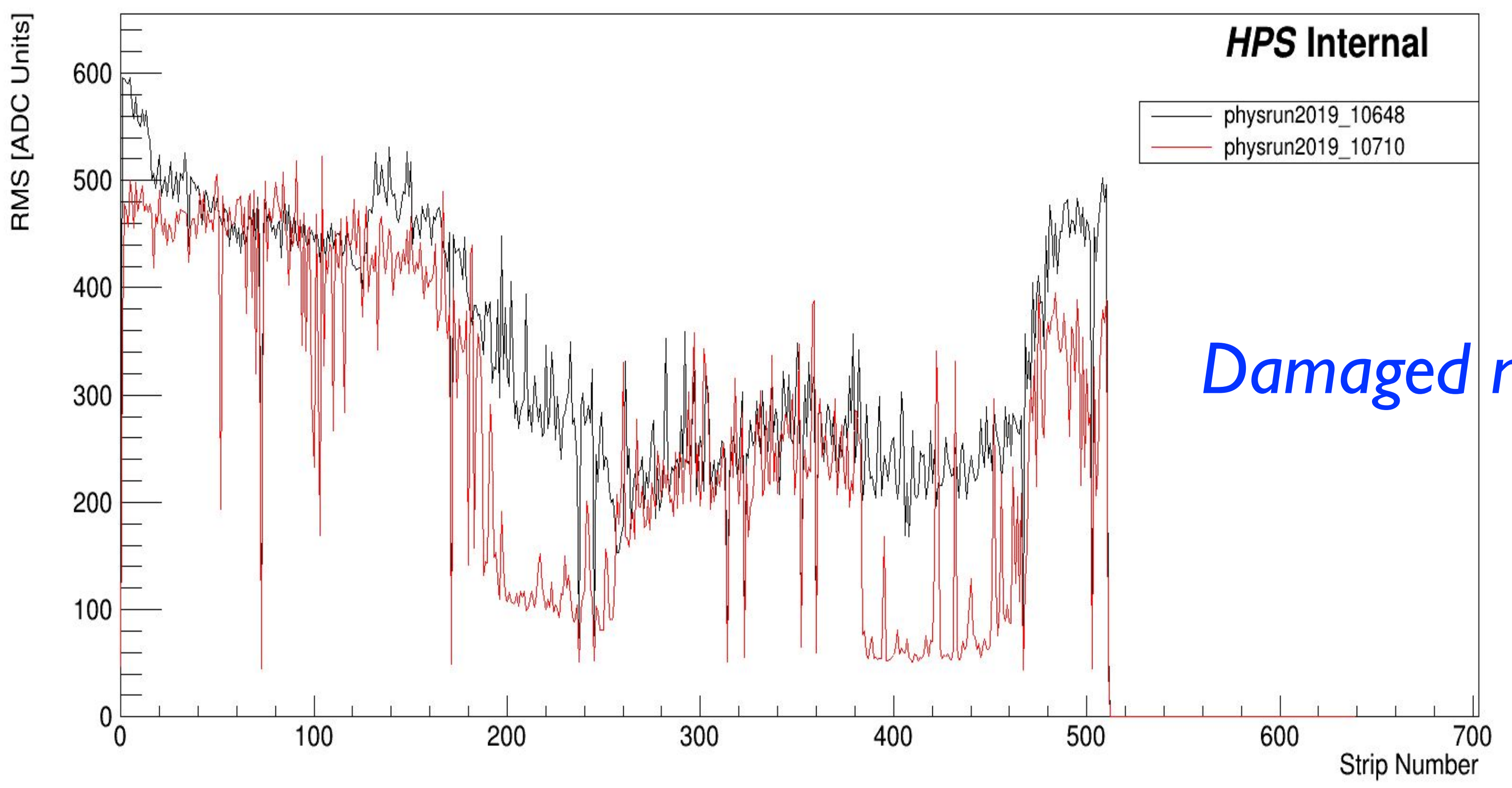
- CEBAF tuning / radiation

➡ SVT FEB damage

➡ SVT L1/L2 damage

Displaced SVT

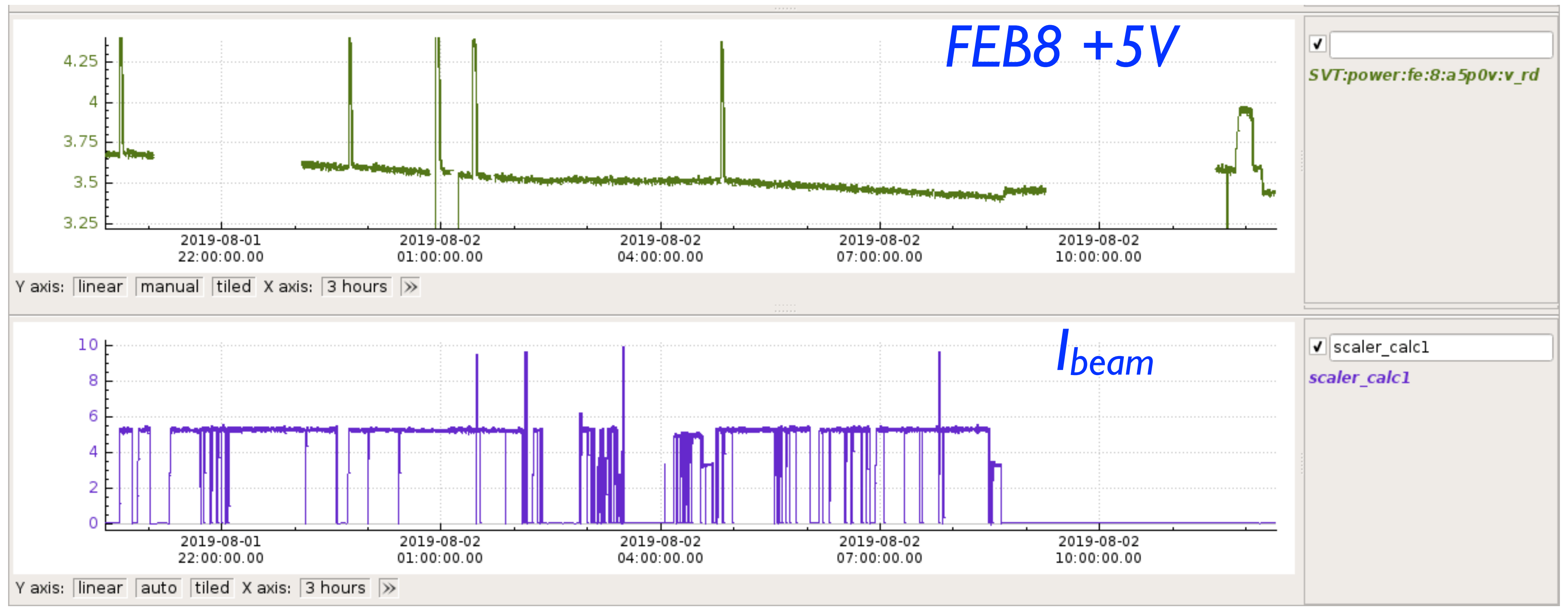
- Power outage / magnet trip (moved SVT out of position)
- Cooling: SVT/ECal chiller malfunctions, SVT HFE loss
- Issues with new TI and corresponding SVT DAQ changes



These lessons gave us a list of important improvements for 2021

Recap of 2019 operations

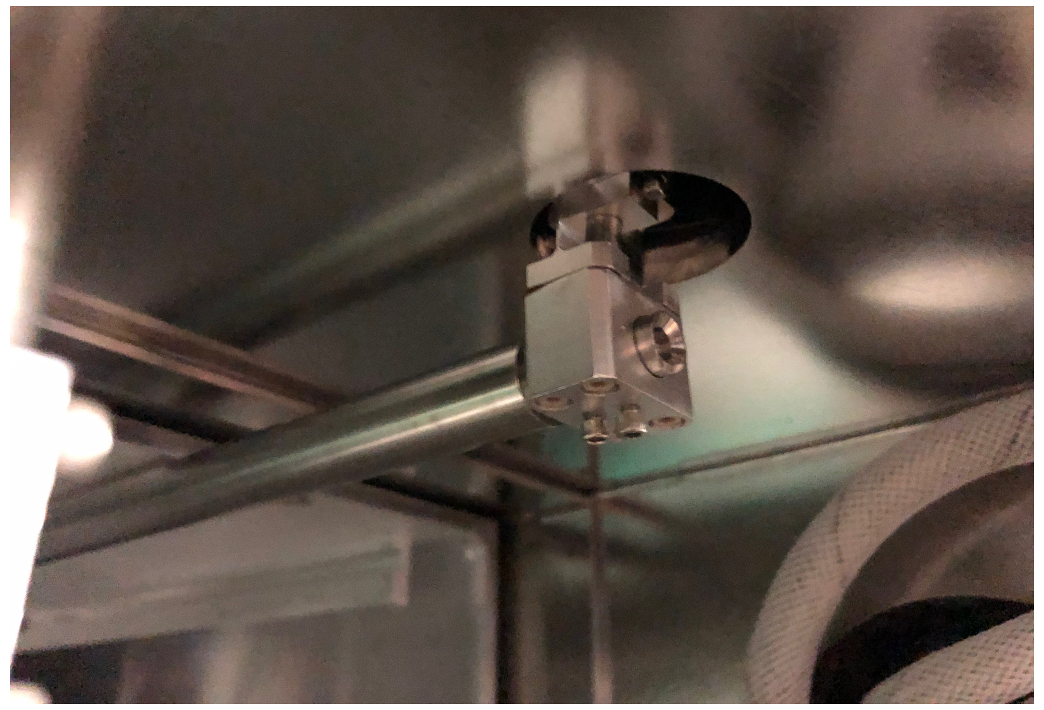
After relatively smooth engineering runs in 2015 & 2016, operations in 2019 were beset by problems:



- CEBAF tuning / radiation

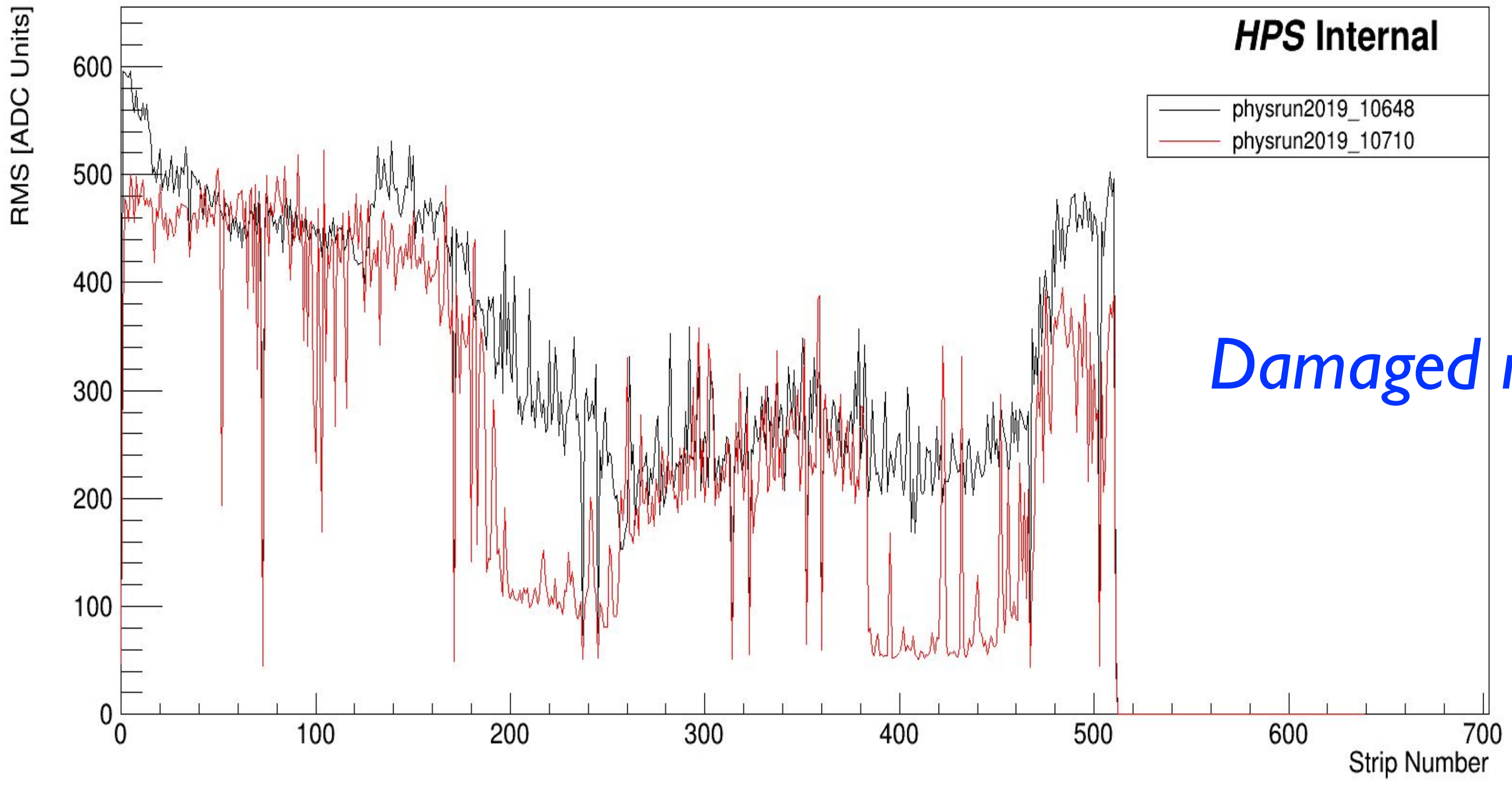
  ➡ SVT FEB damage

  ➡ SVT L1/L2 damage



Displaced SVT

- Power outage / magnet trip (moved SVT out of position)
- Cooling: SVT/ECal chiller malfunctions, SVT HFE loss
- Issues with new TI and corresponding SVT DAQ changes



Damaged module

These lessons gave us a list of important improvements for 2021

2021 Run prepararations

SLAC

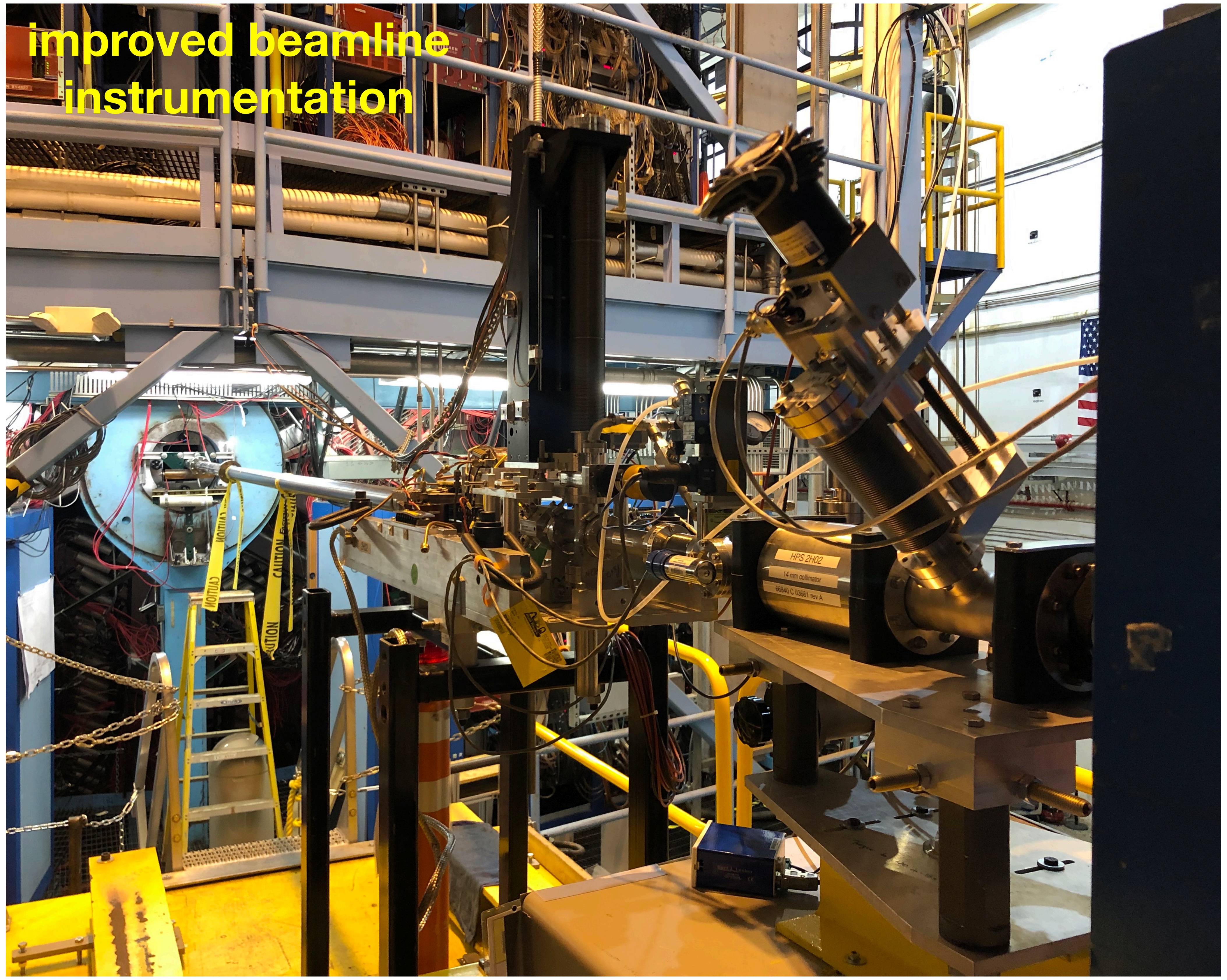
Improvements to beamline instrumentation
- Refined tuning strategy for bringing beam through HPS
- Larger collimator for tuning (2.82 mm ⟶ 8 mm)
- Fiducialization of collimator and beamline elements

New, redesigned FEBs
- more radiation-tolerant 5V regulators, small refinements
- more robust board construction (HT FR4 ⟶ polyimide)

New L1/L2 modules with improved slim-edge sensors
- new dielectric processing to reduce pinholes
- new features for better slim-edge cleaving

SVT cooling system maintenance
- SVT chiller maintenance and cooling system rebuild
- leak identified in vacuum-interlock shutoff valve: rebuilt

Early setup and shakedown of combined DAQ
- Full system setup at SLAC before moving to JLab



The cornerstone of the plan was removal of the SVT to the EEL, full rebuild of the SVT and DAQ, and full system testing prior to installation

2021 Run prepararations

Improvements to beamline instrumentation

- Refined tuning strategy for bringing beam through HPS
- Larger collimator for tuning (2.82 mm ⟶ 8 mm)
- Fiducialization of collimator and beamline elements

New, redesigned FEBs

- more radiation-tolerant 5V regulators, small refinements
- more robust board construction (HT FR4 ⟶ polyimide)

New L1/L2 modules with improved slim-edge sensors

- new dielectric processing to reduce pinholes
- new features for better slim-edge cleaving

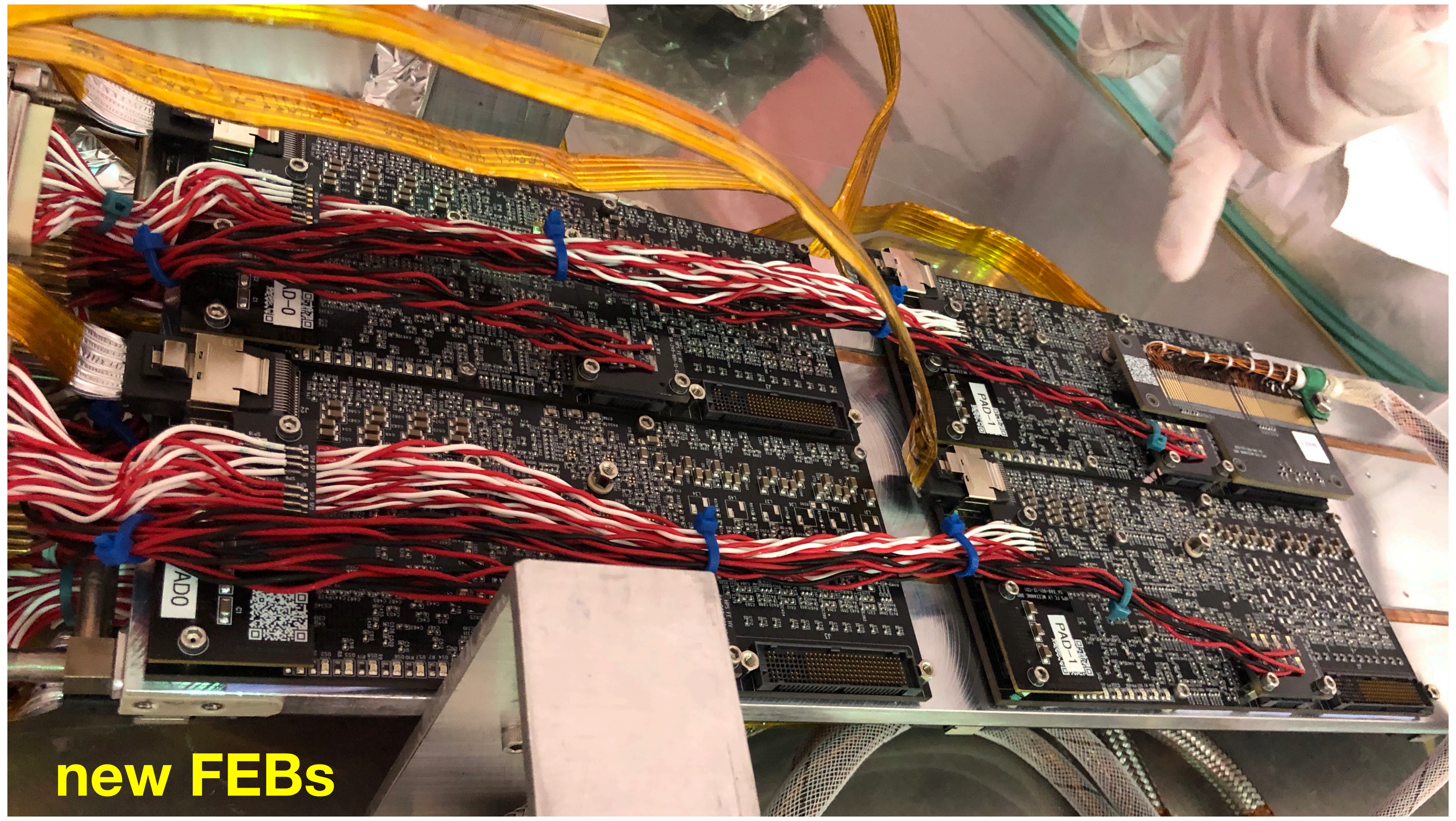
SVT cooling system maintenance

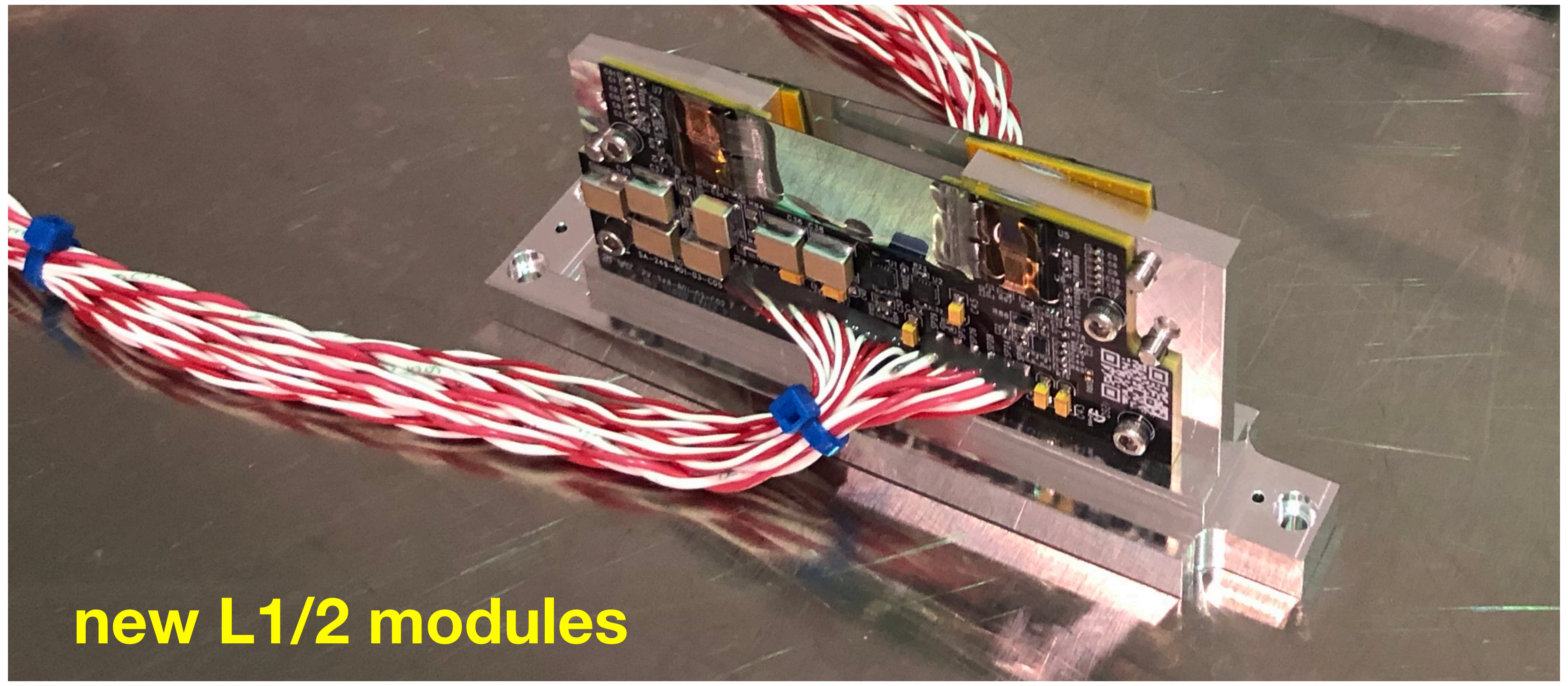
- SVT chiller maintenance and cooling system rebuild
- leak identified in vacuum-interlock shutoff valve: rebuilt

Early setup and shakedown of combined DAQ

- Full system setup at SLAC before moving to JLab

The cornerstone of the plan was removal of the SVT to the EEL, full rebuild of the SVT and DAQ, and full system testing prior to installation





2021 Installation and Commissioning

SLAC

Original plan: remove SVT and begin work in Summer 2020 with 4 trips totaling ~6 weeks to JLab interspersed with work at SLAC in advance of operations in June 2021.

Travel prohibitions compressed work plan to ~9 weeks in June-August 2021, leaving little margin for error or surprises:

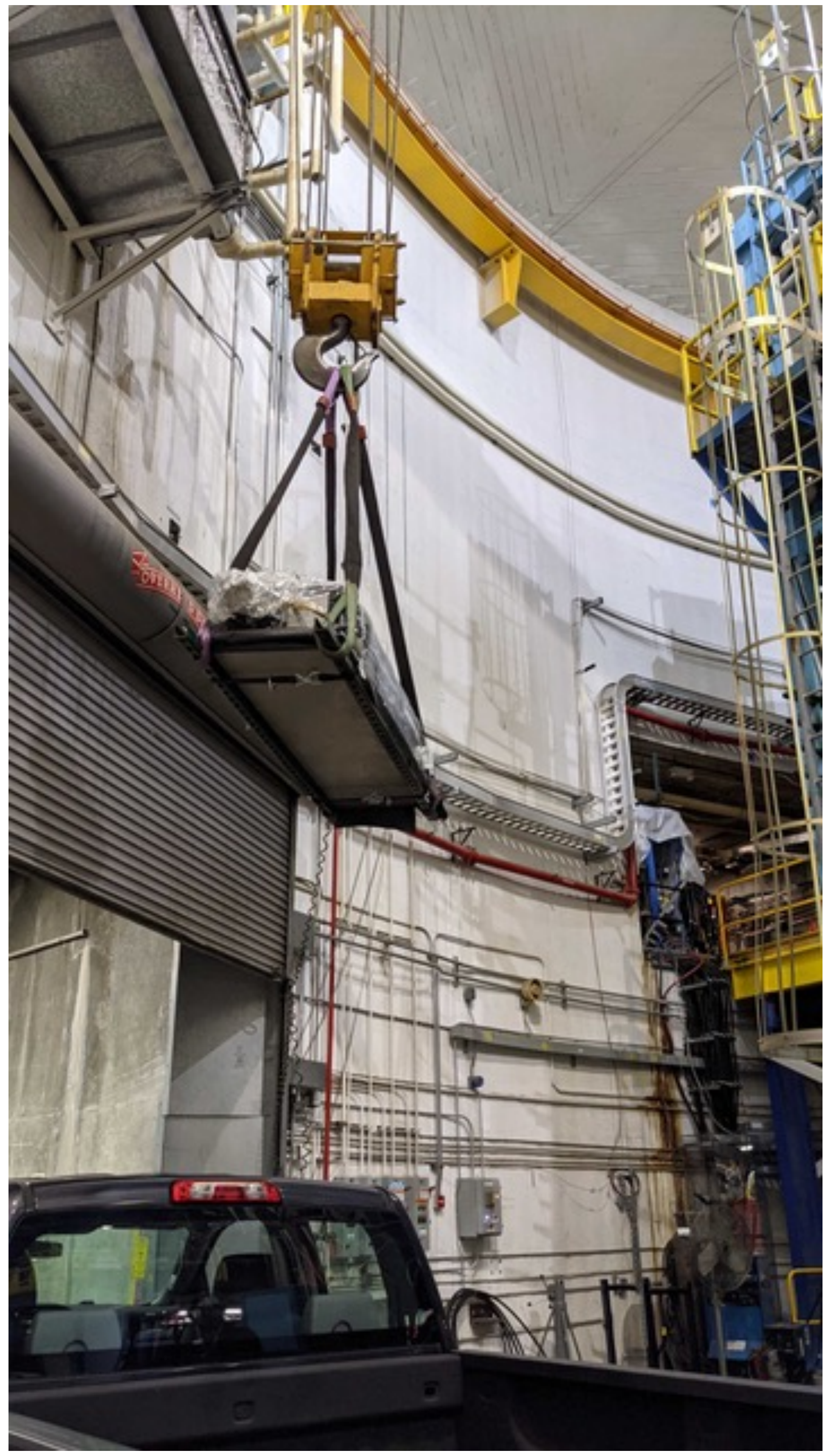
- The new FEBs turned out great, but changes revealed a latent design error dating back to 2014. A few extra weeks were required to investigate and mitigate impact. A major success amidst worldwide chip shortage.
- New sensors have excellent pinhole rate (≪1%) and near-perfect alignment and positioning of the slim edge, but new processing for slim-edge cleaving compromises breakdown voltage.
- Issues in L5-7 “long modules” stored cold and under vacuum at JLab (but not in spares stored in EEL or at SLAC!)
  - Broken wire bonds / dead chips in several devices: SVT was reconfigured to marginalize these problems: 97% channels working, 100% of acceptance in critical first 4/7 layers.
  - ~50% developed low impedances between analog rails, either inside APV25 chips or the PCBs, but work fine (!?)
- Discovered new damage to one of the SVT/target motors, motivating full overhaul of all three motors.
- New TIPCIe cards were delayed by chip shortages, no spares for the only two older cards in existence.

Overall, rebuild of the SVT and DAQ with new components was successful and went as planned, running about 1 week over.

Repairs to ECal to eliminate a few dead channels were also successfully performed.

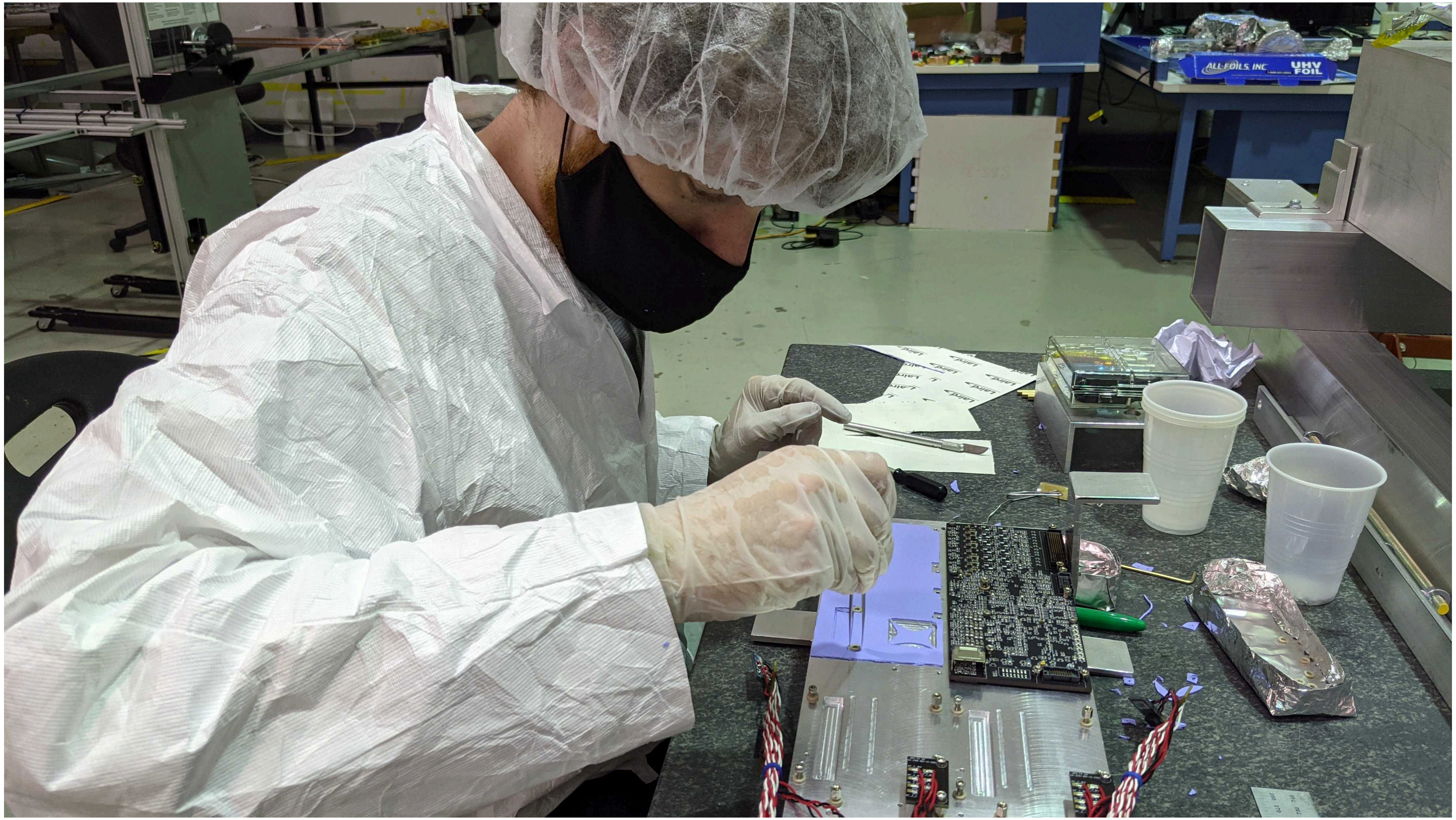
SVT Rebuild Gallery - detector moves

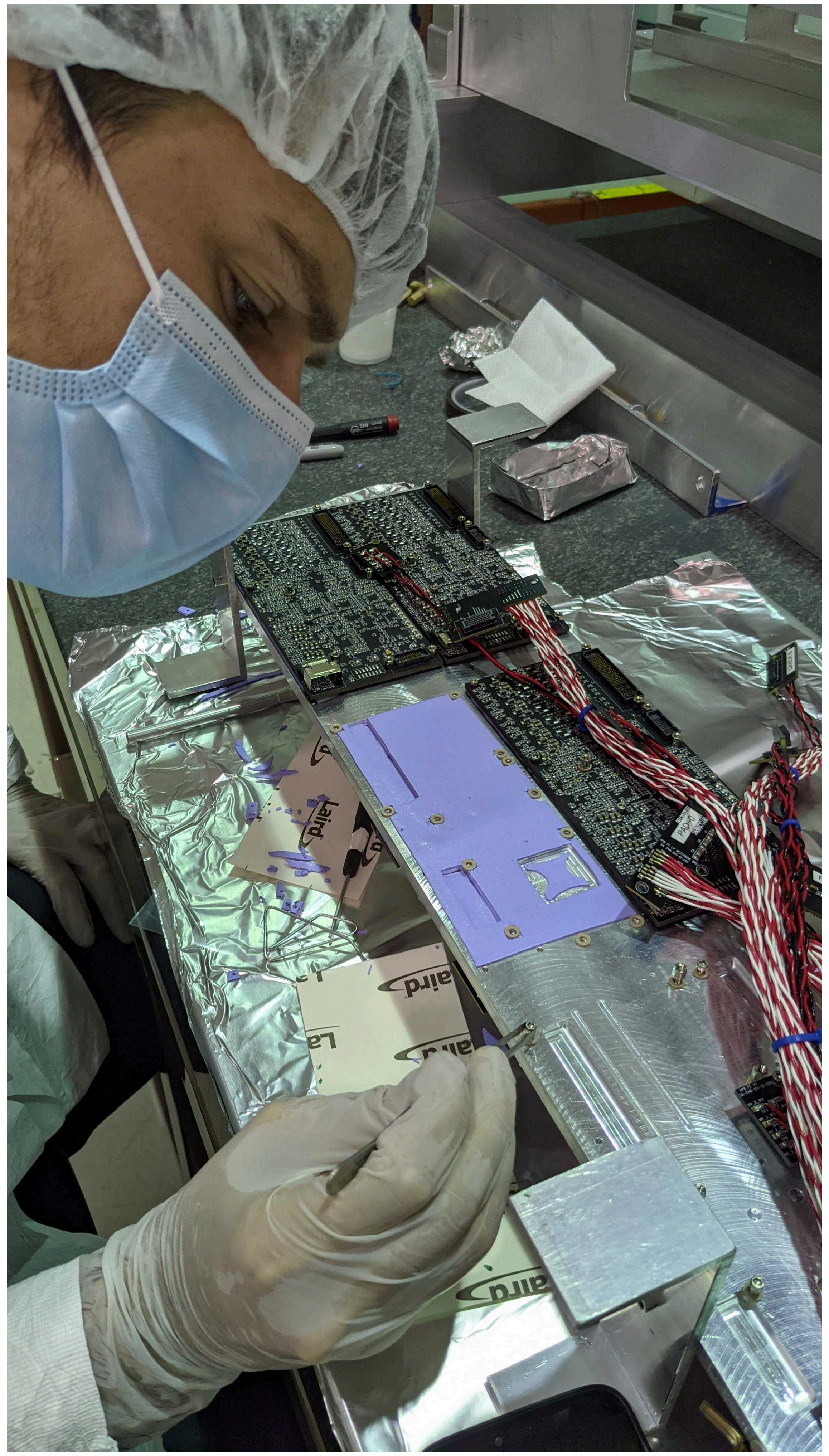
Moving SVT from/to Hall B (7/29 & 8/24)



SVT Rebuild Gallery- EEL

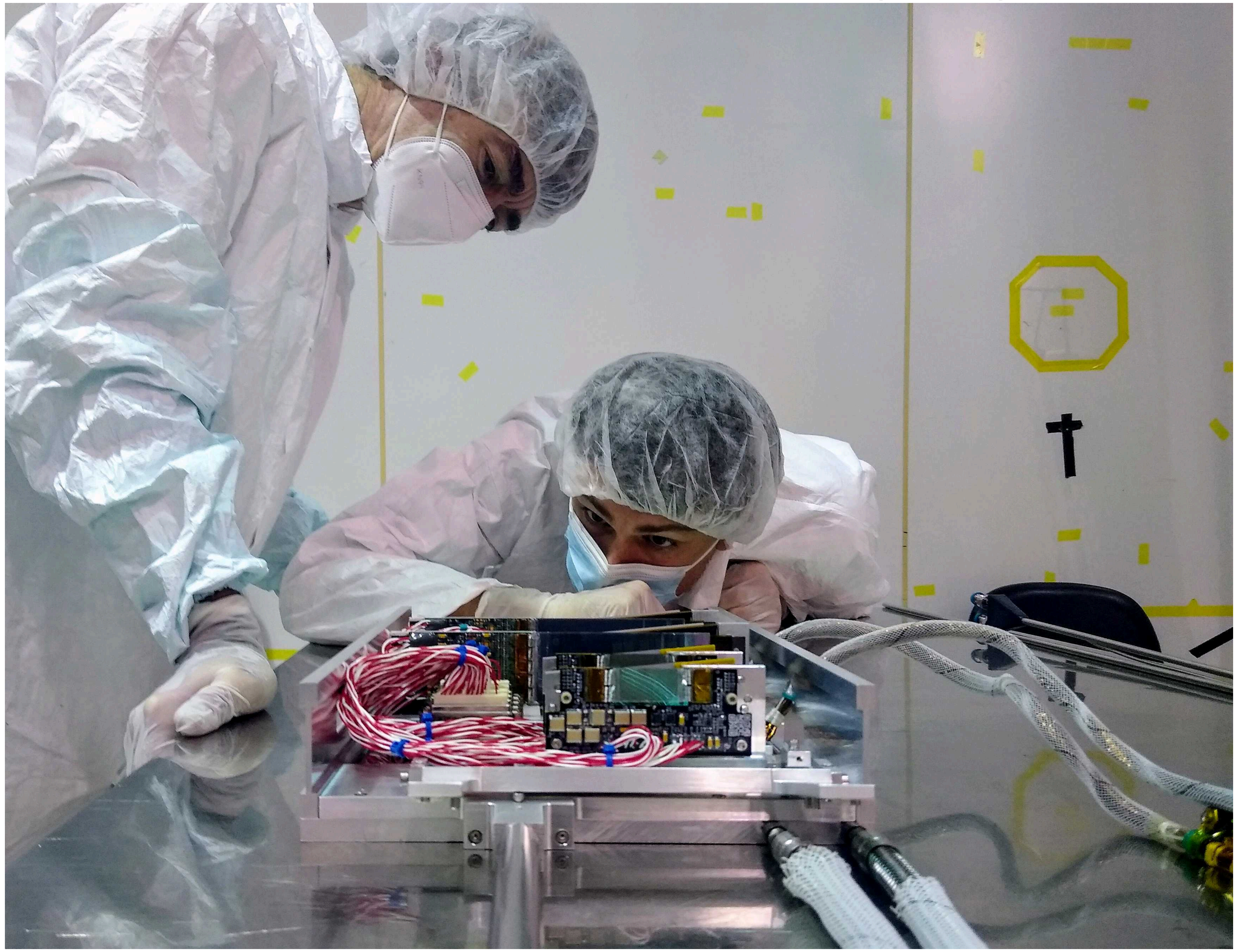
Alic and Emrys take turns installing FEBs (8/1)





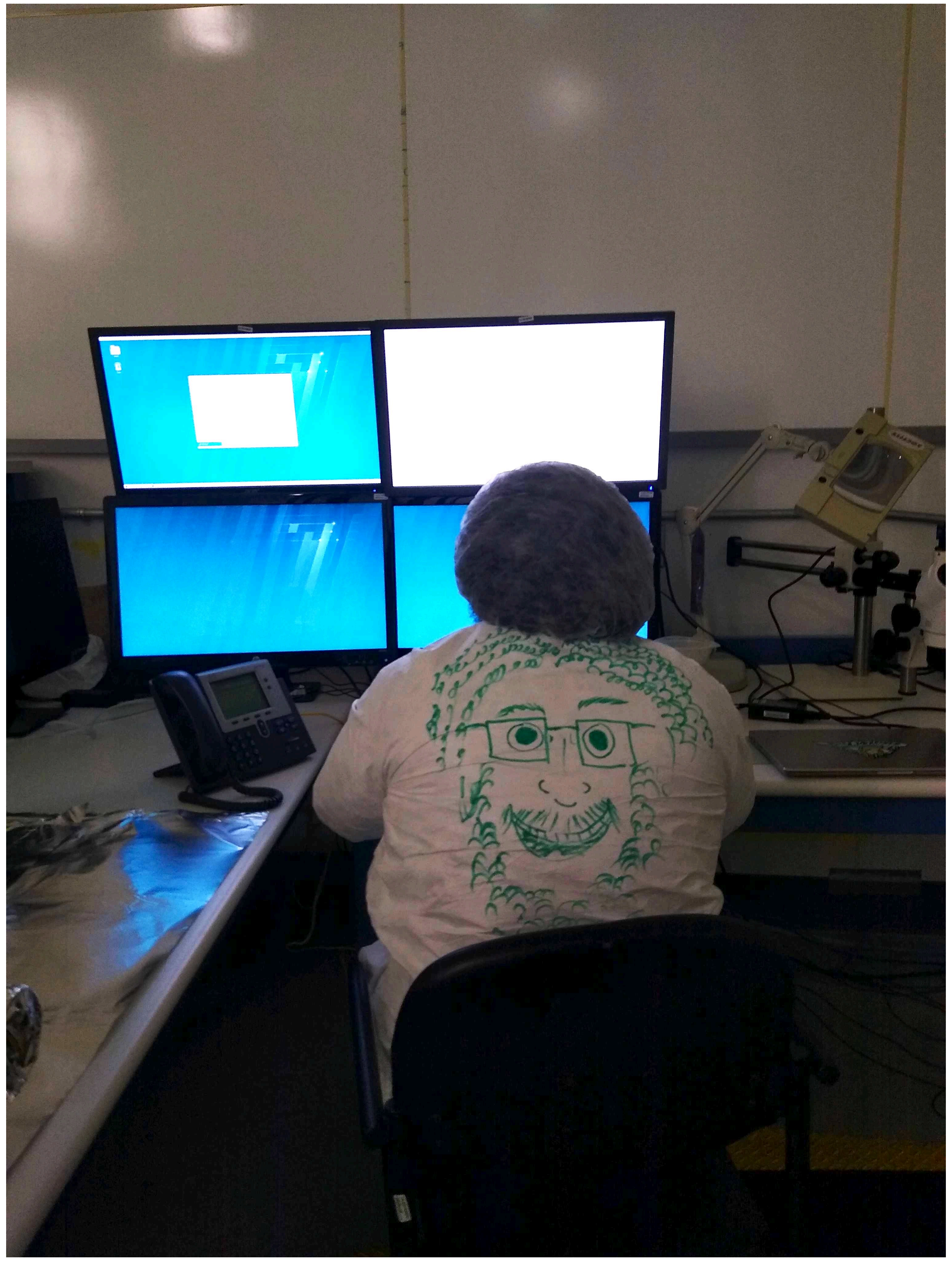
SVT Rebuild Gallery- EEL

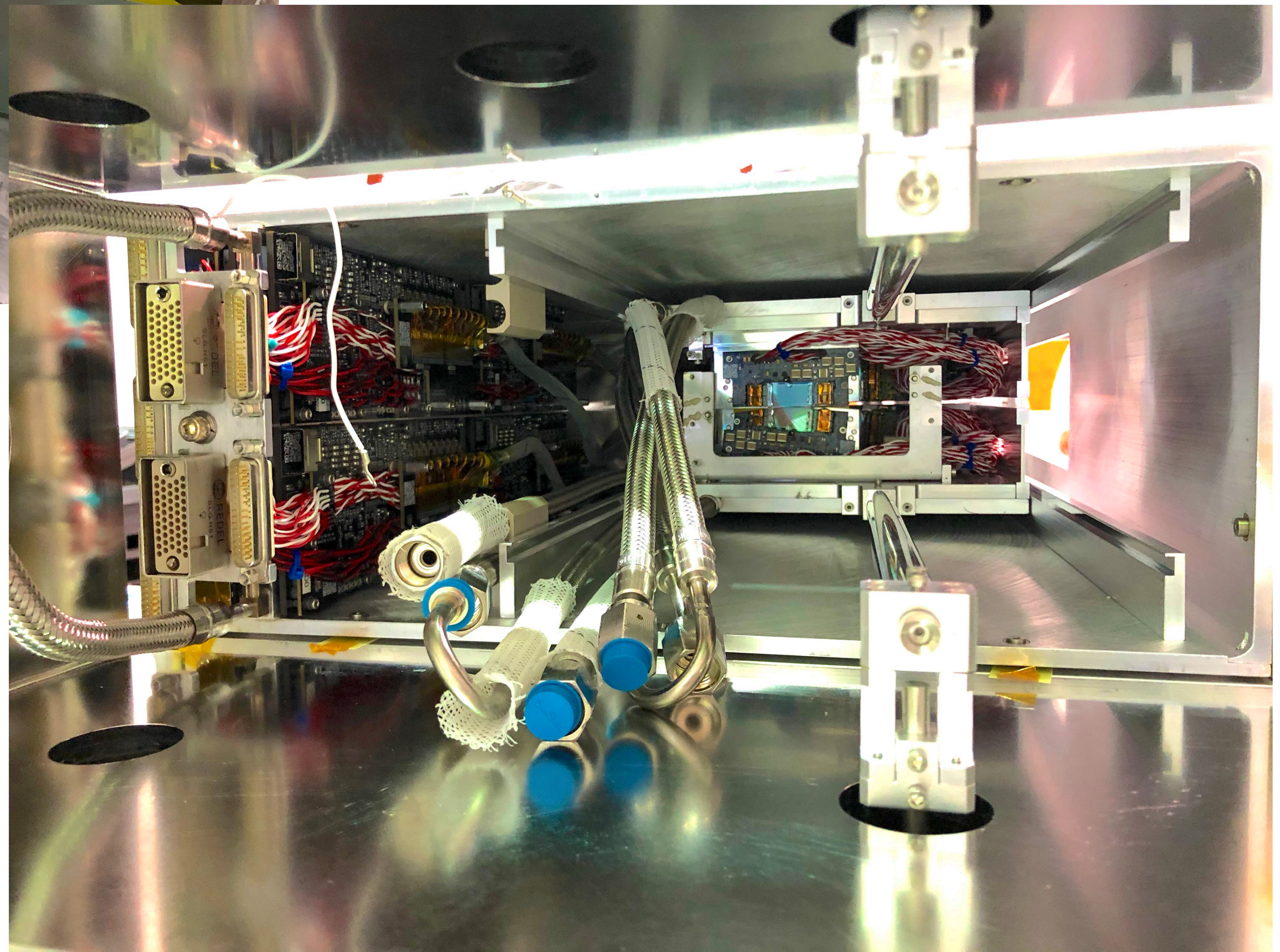
Investigating new issues with SVT modules (8/3-8/26)



SVT Rebuild Gallery- EEL

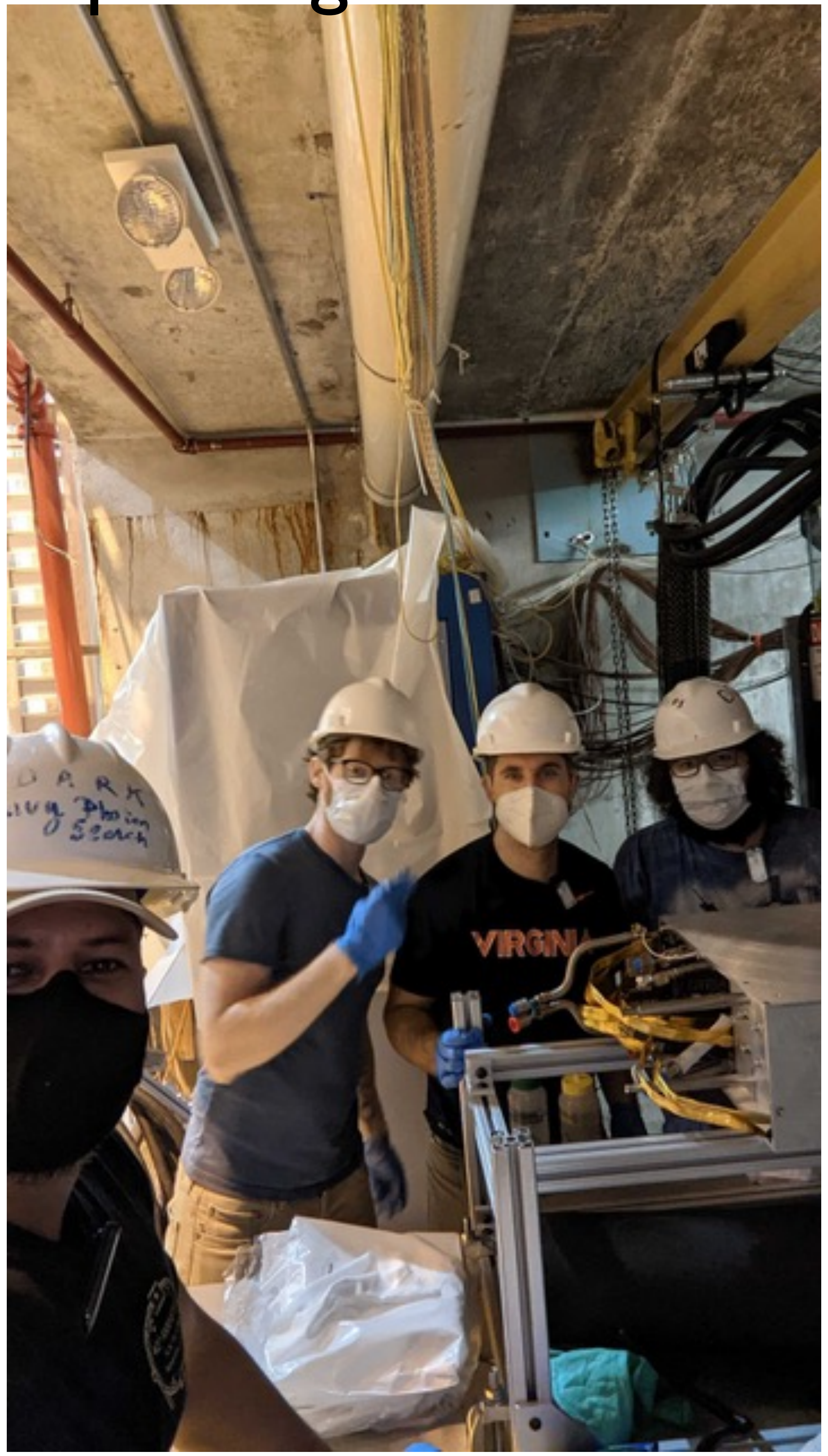
System Testing (8/5-8/26)





SVT Rebuild Gallery- Hall B

pushing in the SVT



"MC Fiber"

Tim spots a dark photon

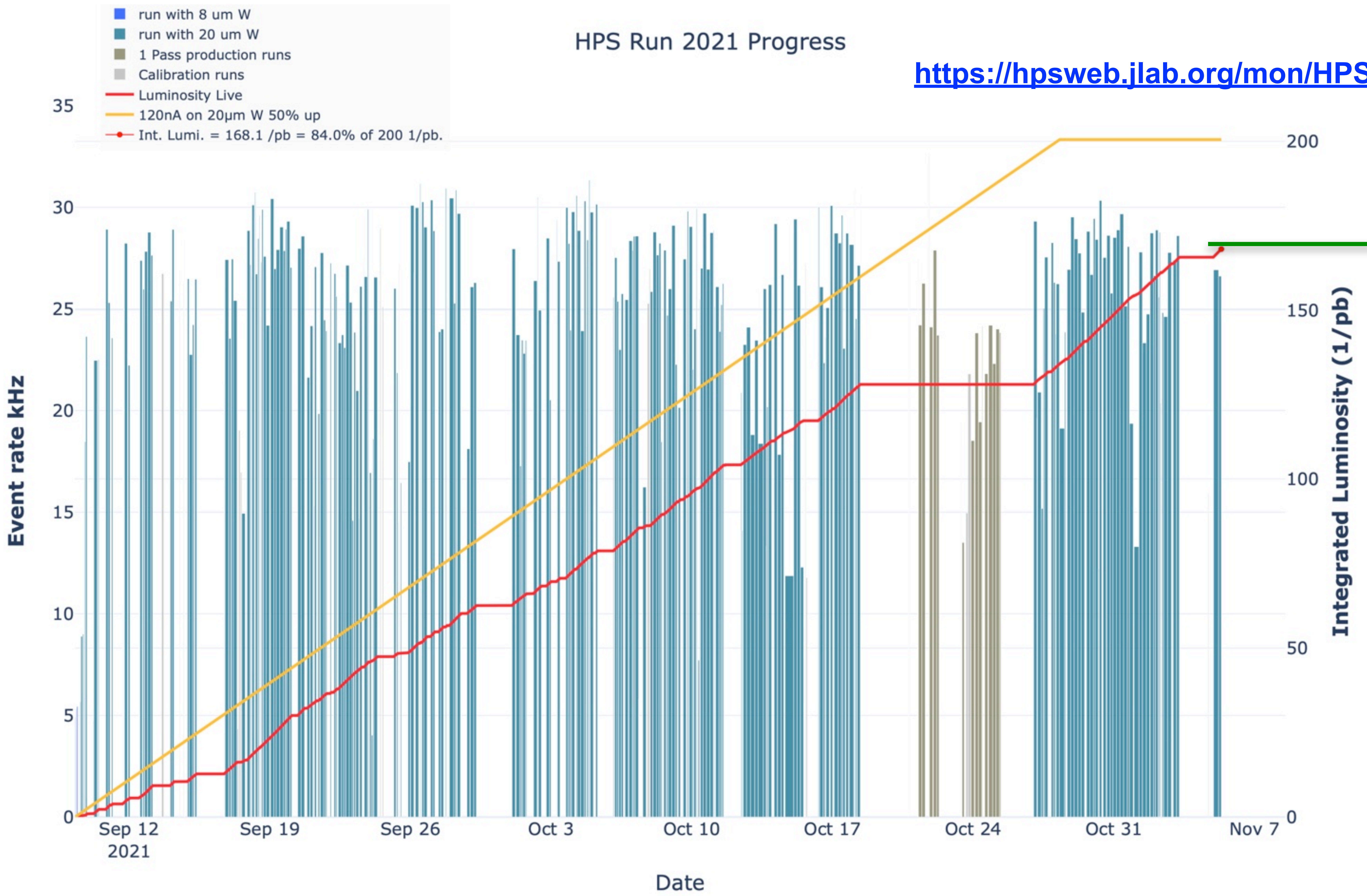
2021 Operations

HPS installation was completed on 8/30, saw first beam on 9/2, and took first physics data on 9/9. Despite being a week late to start, we were ready before experiments in the other halls.

- After our planned week of commissioning, problems tuning beam for HPS were few and far between.
- New FEBs performed extremely well: no serious issues of any kind.
- Slim-edge sensors behaved better than previous generation (surface currents during long runs) but we struggled to increase V_{bias} for high charge collection efficiency after irradiation due to low $V_{breakdown}$.
- None of the surprises in L3-7 of the SVT became significantly worse during the run.
- SVT cooling and SVT/target motor systems had few problems and performed well.
- A clock coordination issue between TIPCIe and SVT DAQ during transitions was a nuisance, but risk of modifying the TIPCIe firmware to resolve it was deemed unacceptable, so we developed workarounds.
- Chiller issues and nuisance HV trips in ECal kept shifters busy but efficiency loss was small.
- Magnet trip caused by lightning storm successfully tested new lockdown for SVT inside vacuum chamber.

2019 seemed like all bad luck. In 2021 we were luckier than not, and executed well on good plans with a lot of hard work by many people. (Cameron wins the SVT prize by a wide margin with 79 days at JLab!)

2021 Data



https://hpsweb.jlab.org/mon/HPSRun2021_progress.html

Run Total = 168 pb^{-1}
84% of goal

HPS Operations Program

Review of HPS by PAC 48 in 2020 secured future run plans

approved: 180 days
pre-2021: 45 days
2021 run: 33 days (planned 30)
remaining: 102 days (planned 105)

Number	Contact Person	Title	Hall	Days Req'd	Days Awarded	Scientific Rating	PAC Decision	Topic
E12-12-002 (GlueX-II)	M. Shepherd	An update on the GlueX II and Jefferson Lab Eta Factory experiments	D	220		A	Remain Active	1
E12-13-008 (Pion polarizability)	R. Miskimen	Measuring the Charged Pion Polarizability in the gamma gamma -> pi+ pi- Reaction	D	25		A-	Remain Active	2
RG-A	L. Elouadrhiri	CLAS12 Run Group A (RG-A)	B	200		A	Remain Active	4
RG-B	S. Niccolai	CLAS12 Run-Group B: Electroproduction on deuterium with CLAS12	B	56		A	Remain Active	3
RG-C	S. Kuhn	CLAS12 Run Group C	B	200	120	A	Remain Active	4
RG-D	L. El Fassi	Study of Color Transparency in Exclusive Vector Meson Electroproduction off Nuclei	B	60	30	B+	Remain Active	5
RG-E	W. Brooks	Quark Propagation and Hadron Formation	B	60		A-	Remain Active	5
RG-G	W. Brooks	The EMC Effect in Spin Structure Functions (CLAS Run Group G)	B	55		B+	Upgrade Rating A-	4
RG-H	M. Contalbrigo	Run Group H Jeopardy Update Document. CLAS12 Experiments with a Transversely Polarized Target	B	110		A	Remain Active	4
RG-I	T. Nelson	Search for Massive Photons at Jefferson Laboratory (HPS)	B	180		A	Remain Active	6
RG-K	A. D'Angelo	RG-K Quark-Gluon Confinement & Strong QCD	B	100		A-	Remain Active	5

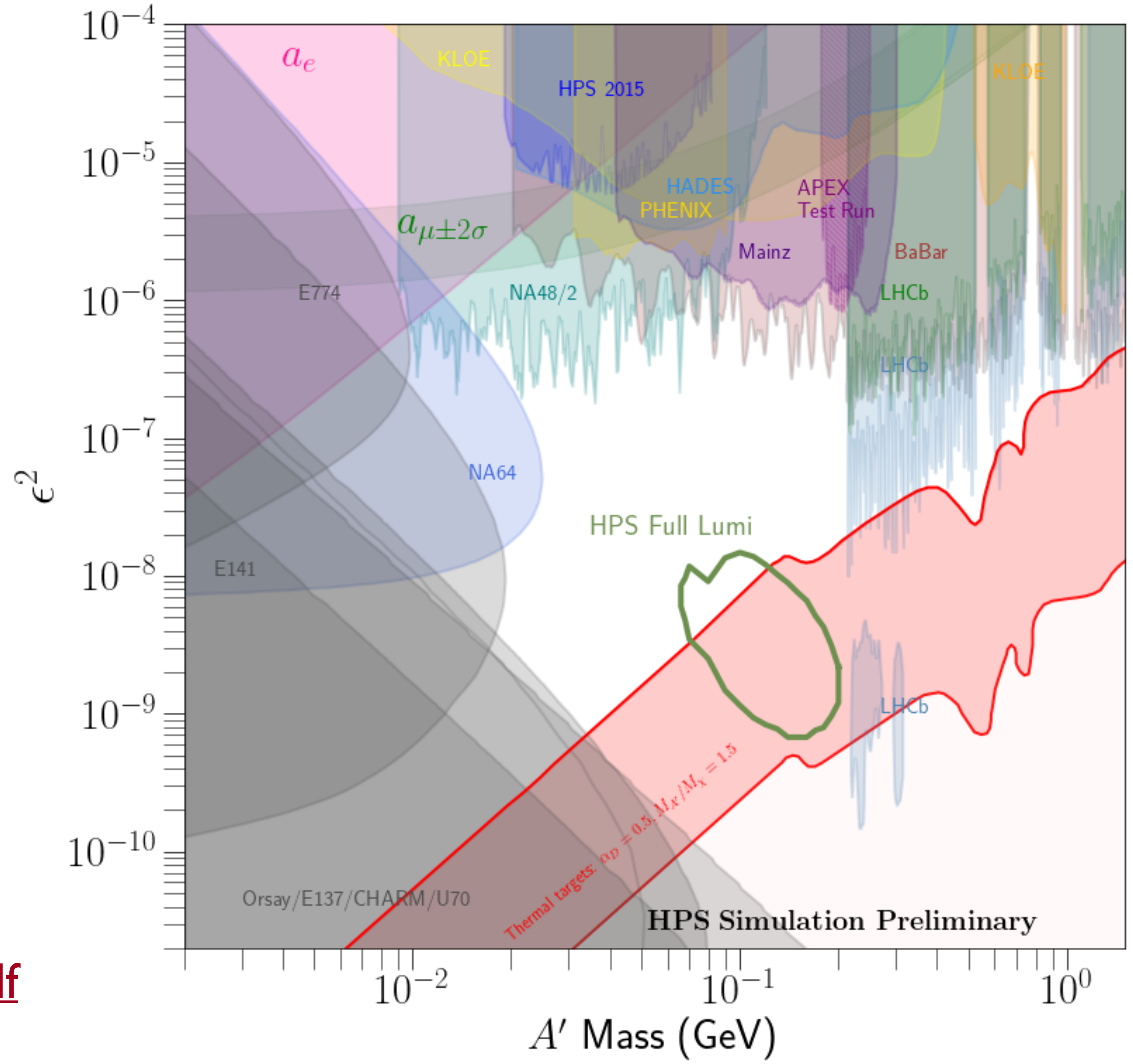
3) Should the remaining beam time allocation and experiment grade be reconsidered?

The collaboration proposes that future physics operations include 10 PAC weeks at ≈ 4 GeV and 6 PAC weeks at ≈ 2 GeV. The PAC endorses this scenario and recommends maintaining the remaining time allocation (135 days) as well as the experiment grade A.

Summary: The PAC recommends the approval of 135 PAC days of beam time for running with beam energies from ≈ 2 GeV to ≈ 4 GeV.

https://www.jlab.org/indico/event/401/

https://www.jlab.org/exp_prog/PACpage/PAC48/PAC48_PrelimReportPlus_FINAL.pdf



Operations Future

A few projects should be undertaken before another run: some contingency funds are left over to get us started.

L1/L2 modules: we completed and tested 27 readout hybrids, but only completed 11 with sensors (8 in SVT). We should build the rest with a third generation of sensors to resolve the problem of low $V_{breakdown}$.
Status: in discussions with sensor vendor (CNM in Spain) for another run.

L5-7 modules: we should identify the issue with anomalous impedances and build additional modules.
Status: have inventoried parts at SLAC, can make 8 more half-modules (12 in SVT) using more sensors available at FNAL and minimal additional M&S. Will investigate possibility for more (carbon fiber).

FEBs: The design error from 2014 has left us with few spares. We should update the design and obtain more.
Status: should complete design process, where FPGA shortages will probably make this a very long-lead item.

Flanges: We used the spare SVT data flange for this run (copper - optical conversion across the vacuum barrier) because original flange no longer had enough good channels (two spares when new). We should consider building another data flange.

Status: locating tooling at SLAC for flange assembly. Need to quote a small run of boards (4 in SVT).

HPS is unlikely to run until at least 2023, so we have time to do these in a deliberate way if we begin now. In the meantime we should focus our efforts elsewhere….

Physics!

For our small collaboration, it takes 100% effort both to operate the experiment and to do the physics. We need to pivot strongly to producing physics results before another run can appear on the horizon.

2016 Engineering Run (5.4 days @ 2.3 GeV)

- resonance search and displaced vertex search: complete, in publication review
- SIMPs - ongoing effort that we should try to complete ASAP, sensitivity to new physics

2019 Physics Run (~14 days @ 4.55 GeV)

- initial calibration and alignment work complete
- some SVT alignment improvements still needed
- ready to begin cornerstone resonance and displaced vertex searches when effort is available

2021 Physics Run (~24 days @ 3.74 GeV)

- first looks at data are encouraging
- a lot of work to do in order to understand the key issues for calibration and reconstruction
- it could be that 2019 and 2021 analyses proceed in parallel

We have as many analyses to pursue as we have active analyzers, so this will be a very busy period!

2016 Engineering Run Analyses

The 2016 resonance and displaced vertex results were complete by early summer, but review and approval process were interrupted by the run.

- Discussions last week between the analysis team and the review committee identified the path forward on approval of the internal note and completion of the paper
- Questions about possible additions to the paper are being referred to the EC

Although the 2016 data is quite old at this point and lacks strong physics reach, those attributes make it especially interesting for new developments:

Tools: Kalman Filter pattern recognition, hit/cluster reconstruction, alignment

Physics: ALPs, SIMPs, iDM

The 2016 data will likely remain a touchstone until 2019/2021 analyses are complete.

Snowmass

The Snowmass process is ramping up again with final in-person meetings planned for next summer

HPS submitted an LOI aimed at expanding the physics case for the experiment.

- Axion-like particles (ALPs): a re-cast of the resonance search that motivates improvements (no hadronic couplings in e^--coupling dominant regime)
- Strongly interacting massive particles (SIMPs): displaced vertex + missing energy, already underway
- inelastic dark matter (iDM): similar to SIMP signature, but much work needed to understand what parts of parameter space where HPS has sensitivity.

Need to decide soon what can be achieved for Snowmass.

Snowmass Letter of Interest —Topical Group: RF6

The Heavy Photon Search Experiment

Nathan Baltzell[17], Marco Battaglieri[17], Mariangela Bondi[6], Sergei Boyarinov[17], Cameron Bravo[13], Stephen Bueltmann[11], Volker Burkert[17], Pierfrancesco Butti[13], Tongtong Cao[10], Massimo Carpinelli[12], Andrea Celentano[6], Gabriel Charles[4], Chris Cuevas[17], Annalisa D'Angelo[8], Domenico D'Urso[12], Natalia Dashyan[20], Marzio De Napoli[5], Raffaella De Vita[6], Alexandre Deur[17], Miriam Diamond[18], Raphael Dupre[4], Hovanes Egiyan[17], Latifa Elouadrhiri[17], Rouven Essig[15], Vitaliy Fadeyev[1], R. Clive Field[13], Alessandra Filippi[9], Nerses Gevorgyan[20], Norman Graf[13], Mathew Graham[13], Keith Griffioen[19], Ryan Herbst[13], Maurik Holtrop[10,+], John Jaros[13], Robert Johnson[1], Gregory Kalicy[2], Valery Kubarovsky[17], Dominique Marchand[4], Luca Marsicano[6], Takashi Maruyama[13], Kyle McCarty[10], Bryan McKinnon[3], Omar Moreno[13], Carlos Munoz-Camacho[4], Timothy Nelson[13,*], Silvia Niccolai[4], Rafayel Paremuzyan[17], Sebouh Paul[16], Nunzio Randazzo[5], Benjamin Raydo[17], Benjamin Reese[13], Philip Schuster[13], Stanislava Sevova[14], Youri Sharabian[17], Gabriele Simi[7], Valeria Sipala[12], Daria Sokhan[3], Matthew Solt[13], Alic Spellman[1], Stepan Stepanyan[17,x], Holly Szumila-Vance[17], Lauren Tompkins[14], Natalia Toro[13], Maurizio Ungaro[17], Hakop Voskanyan[20], Bogdan Wojtsekhowski[17], and Bradley Yale[19]

[1] *University of California, Santa Cruz, CA 95064*
[2] *The Catholic University of America, Washington, DC 20064*
[3] *University of Glasgow, Glasgow G12 8QQ, United Kingdom*
[4] *Institut de Physique Nucleaire d'Orsay, IN2P3, BP 1, 91406 Orsay, France*
[5] *Istituto Nazionale di Fisica Nucleare, Sezione di Catania e Dipartimento di Fisica dell'Università, Catania, Italy*
[6] *Istituto Nazionale di Fisica Nucleare, Sezione di Genova e Dipartimento di Fisica dellÚniversita, 16146 Genova, Italy*
[7] *Istituto Nazionale di Fisica Nucleare, Sezione di Padova, Padova, Italy*
[8] *Istituto Nazionale di Fisica Nucleare, Sezione di Roma-TorVergata e Dipartimento di Fisica dell'Università, Roma, Italy*
[9] *Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Torino, Italy*
[10] *University of New Hampshire, Department of Physics, Durham, NH 03824*
[11] *Old Dominion University, Norfolk, Virginia 23529*
[12] *Università di Sassari e Istituto Nazionale di Fisica Nucleare, 07100 Sassari, Italy*
[13] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025*
[14] *Stanford University, Stanford, CA 94305*
[15] *Stony Brook University, Stony Brook, NY 11794-3800*
[16] *Tel Aviv University, Tel Aviv, Israel*
[17] *Thomas Jefferson National Accelerator Facility, Newport News, Virginia 23606*
[18] *University of Toronto, Toronto, ON M5S, Ca*
[19] *The College of William and Mary, Department of Physics, Williamsburg, VA 23185*
[20] *Yerevan Physics Institute, 375036 Yerevan, Armenia*
[+] *maurik.holtrop@unh.edu*
[*] *tknelson@slac.stanford.edu (contact person)*
[x] *stepanya@jlab.org*

ABSTRACT

The Heavy Photon Search (HPS) experiment is designed to search for a new vector boson A' in the mass range of 20 MeV/c^2 to 220 MeV/c^2 that kinetically mixes with the Standard Model photon with couplings $\varepsilon > 10^{-10}$. After short engineering runs in 2015 and 2016, HPS took first physics data in 2019. Future operations in 2021 and beyond are planned, with the potential to discover dark photons in highly-motivated regions of the mass-coupling parameter space. In addition to the minimal Dark Photon, HPS has the ability to search for strongly interacting dark sectors (SIMPs) and potentially also other dark sector scenarios.

1

2019 Analysis

2019 data is ready for analysis effort to begin

Calibration and alignment are nearly complete

- ECal energy fully calibrated
- Vertex resolution is in good shape
- Momentum resolution uniformity needs work

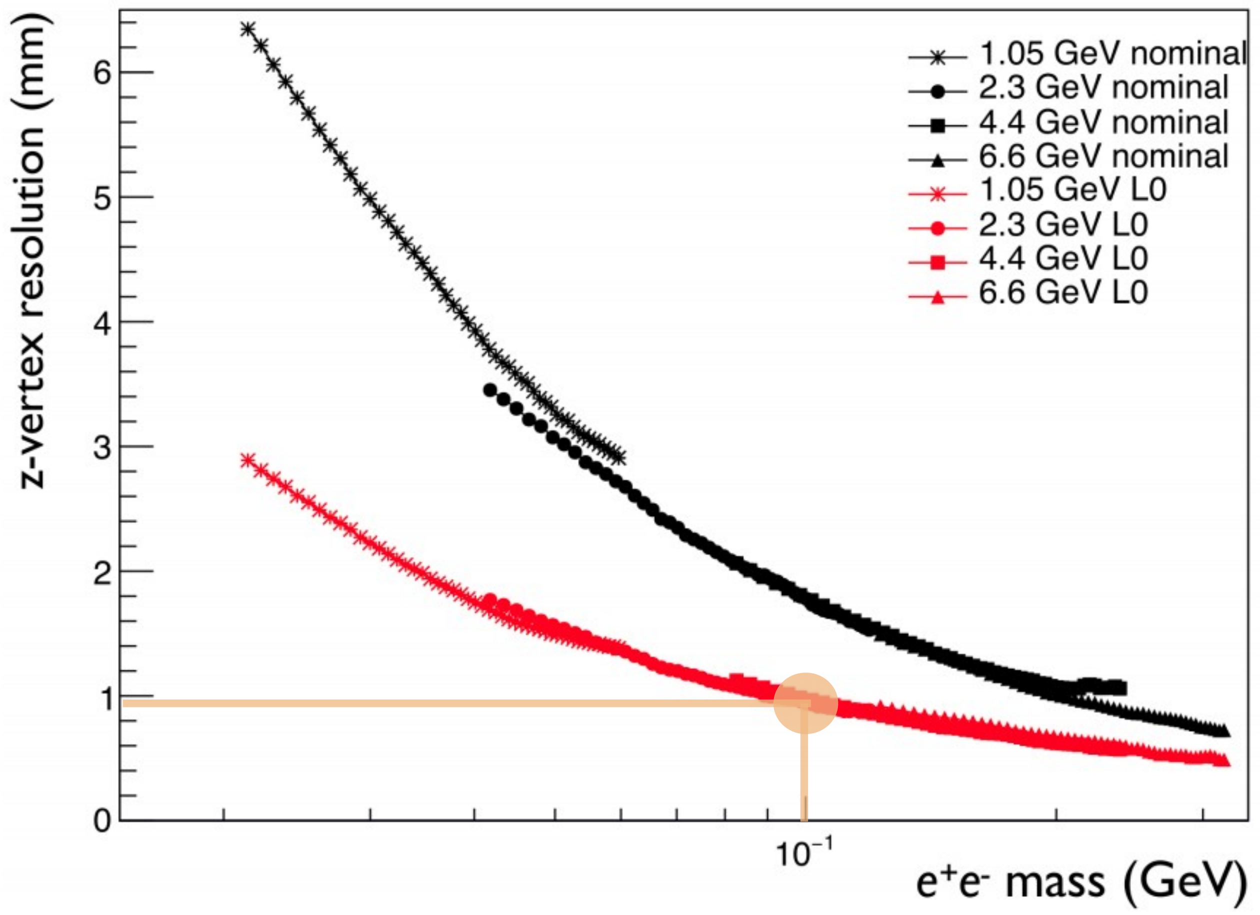
Significant improvements to reconstruction techniques are ready.

- Kalman Filter track finding
- ECal cluster matching
- Improvements to hit and cluster reconstruction are underway, but more to do.

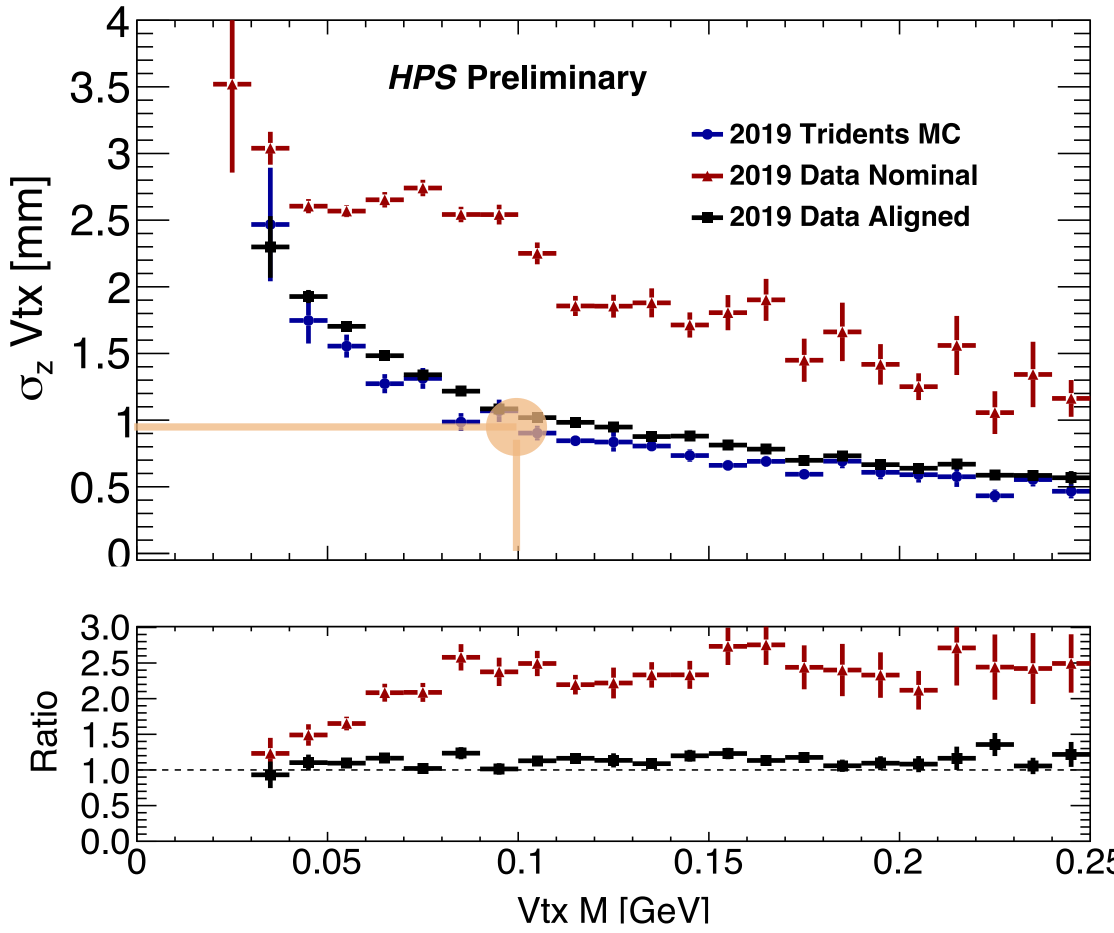
The way to speed further improvements is to push into the analysis tasks in parallel.

proposal studies

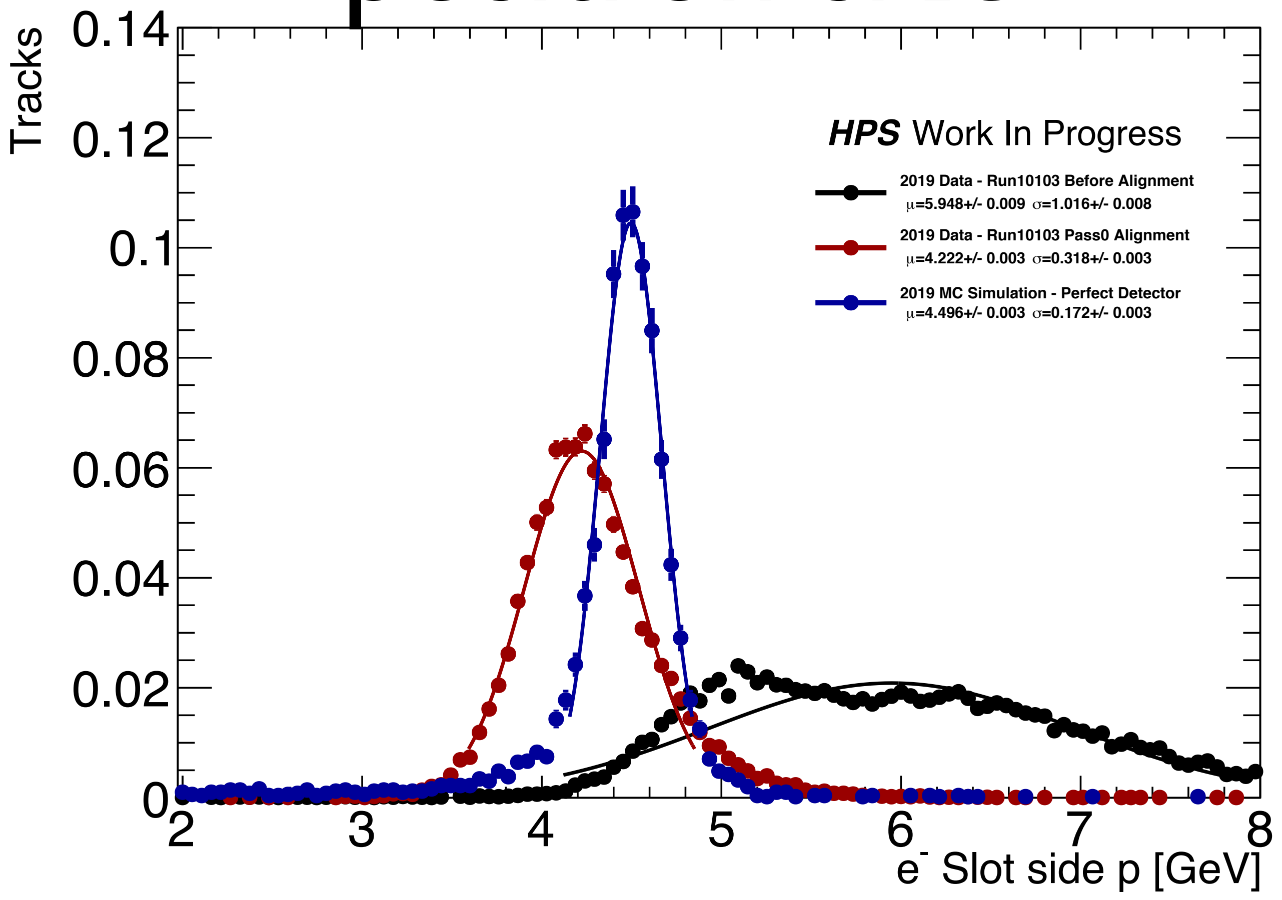
decay length resolution vs. mass



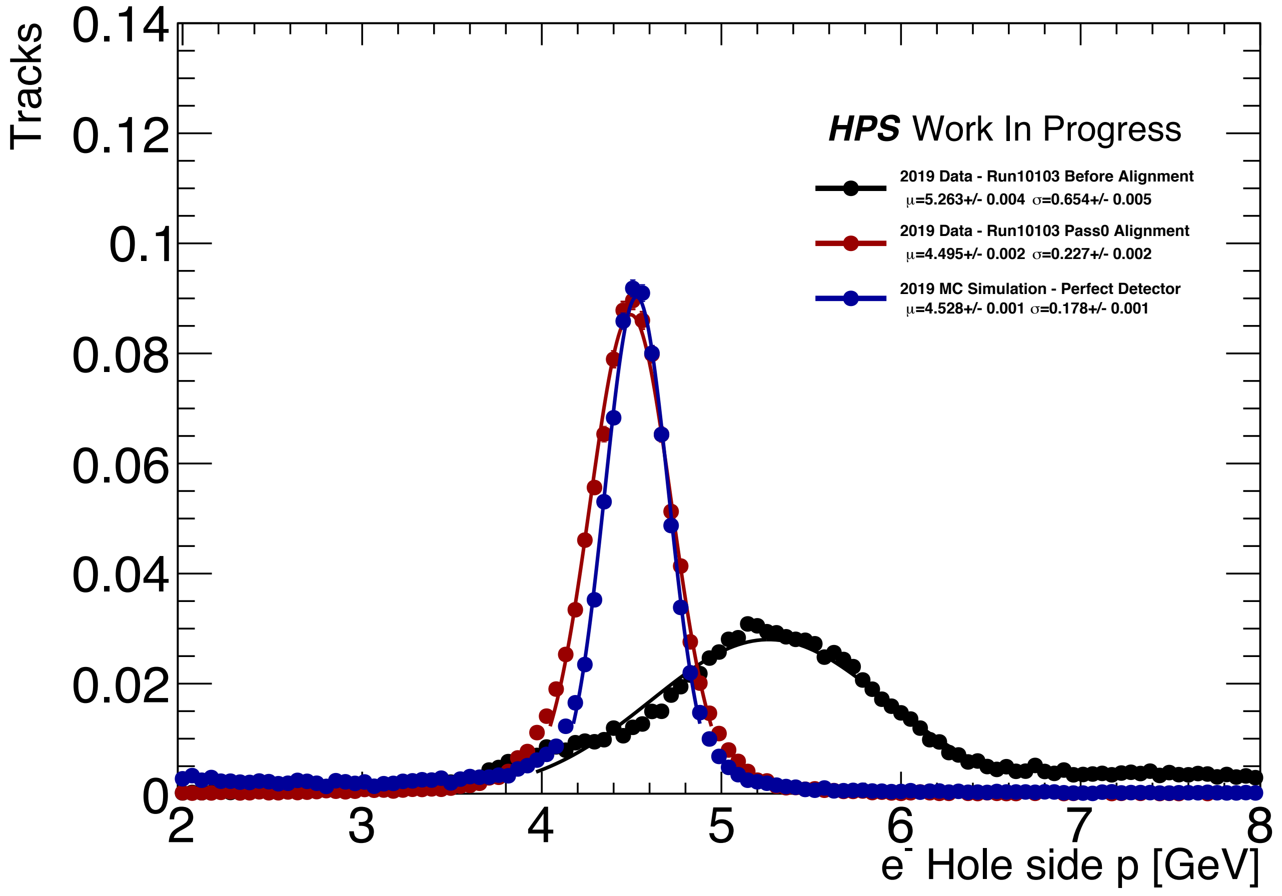
2019 data / MC



positron side



electron side



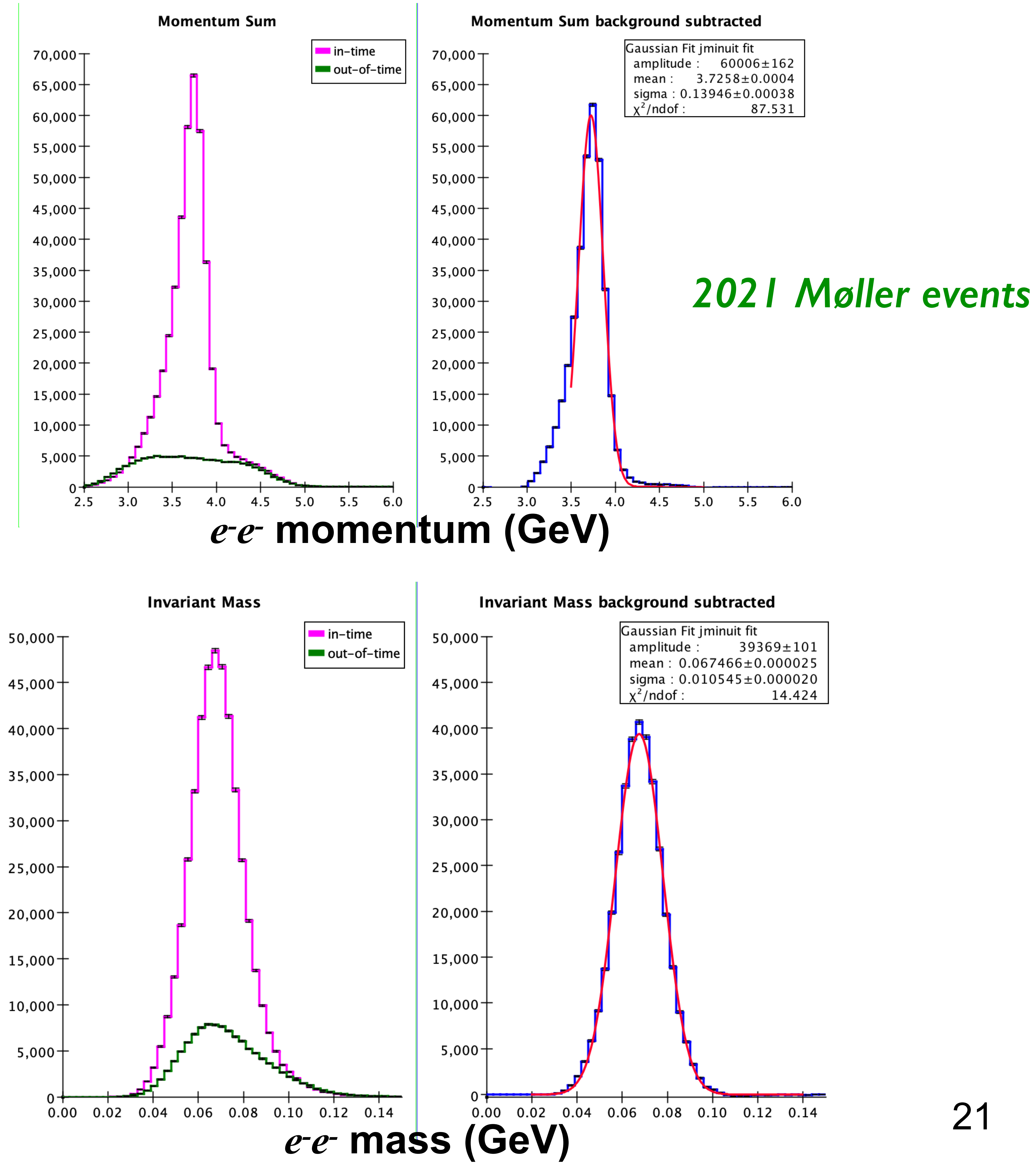
2021 Analysis

First looks at the 2021 data are encouraging.

There are still many issues to deal with before we will be ready to process the data for analysis

- Identifying good runs / blocks
- Filtering of APV25 crosstalk events
- ECal and SVT calibrations
- SVT alignment
- L1/L2 charge collection efficiencies

Although the data is cleaner than 2019 and we have much better tools now, we still don't know what's in this can of worms and it will take time to sort out.



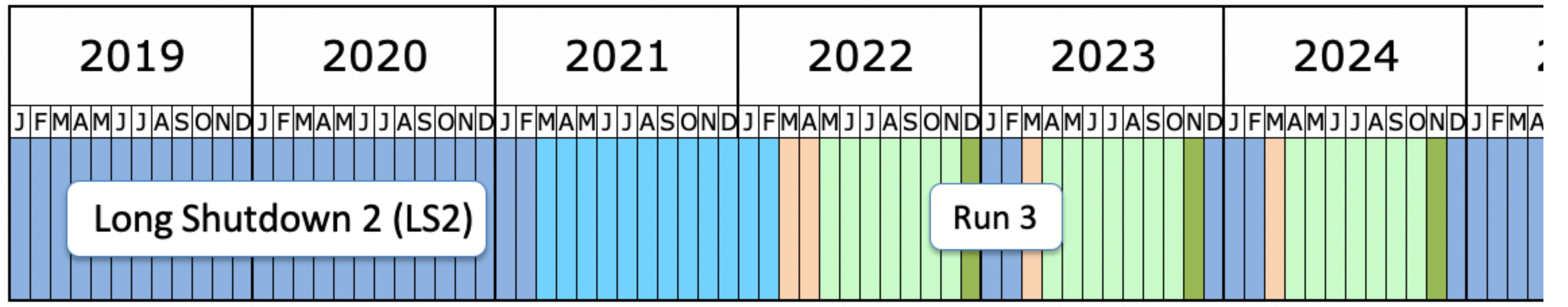
Worldwide Landscape

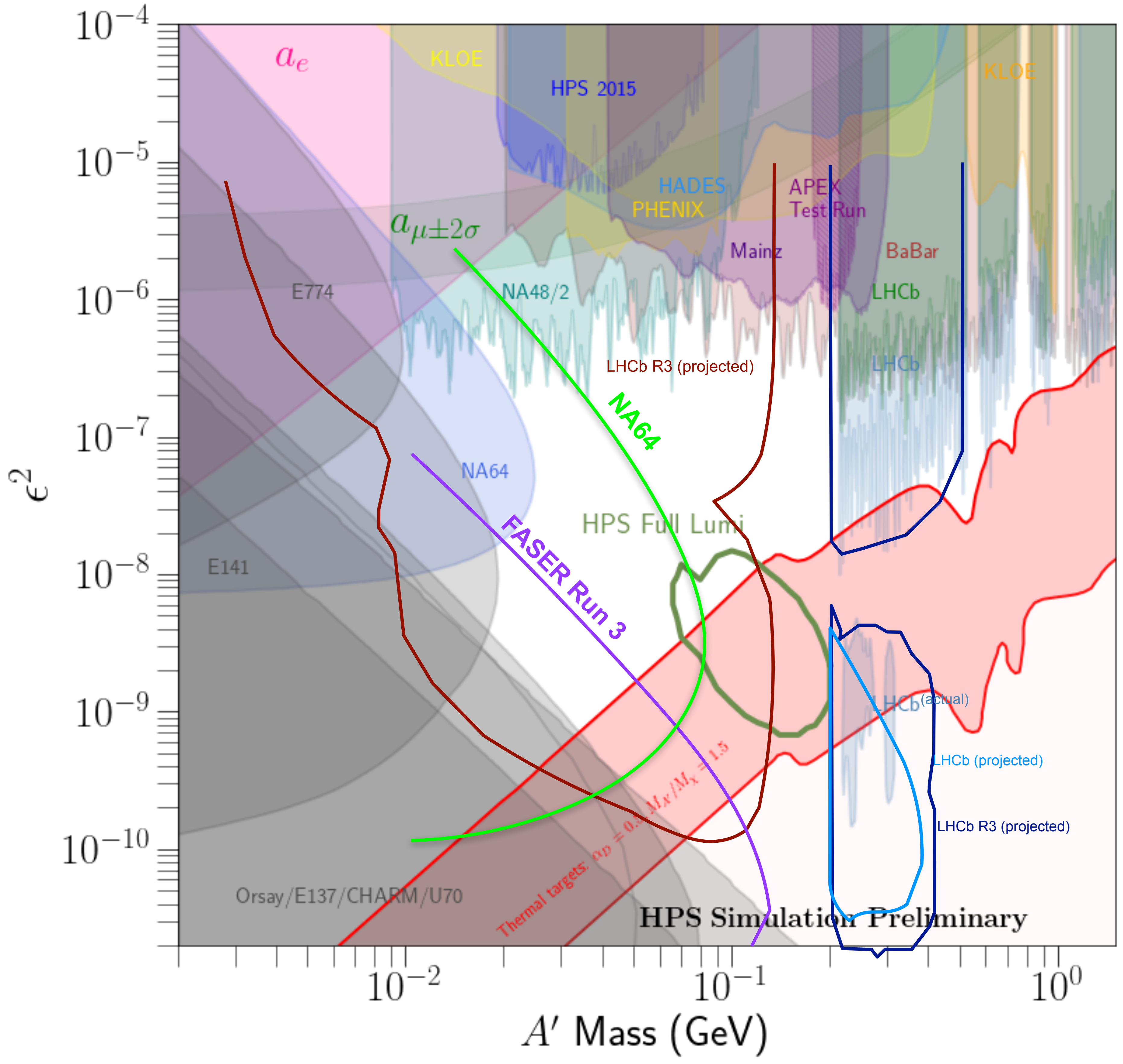
The interesting competition in the next few years is from LHCb and NA64.

With the 2021 run, we gained some time, as LHC Run 3 has been delayed by the pandemic.

We should try to get 2019/2021 results out by early 2023 for greatest impact.

On that schedule, analysis efforts will not be interrupted by more operations and will be timely relative to other efforts worldwide.





Summary/Conclusion

We did a good job preparing for and operating our run this fall. Pandemic notwithstanding we had reasonably good luck, and have been rewarded with a dataset worthy of the effort.

HPS now sits on data with serious physics potential, where a lot of effort is now needed to mine it for our key results.

In the next period, before another run appears on the horizon to distract us, we need an intense focus to deliver timely results.

In parallel, we should work to expand our physics case to include other dark sector scenarios, where Snowmass provides a target.