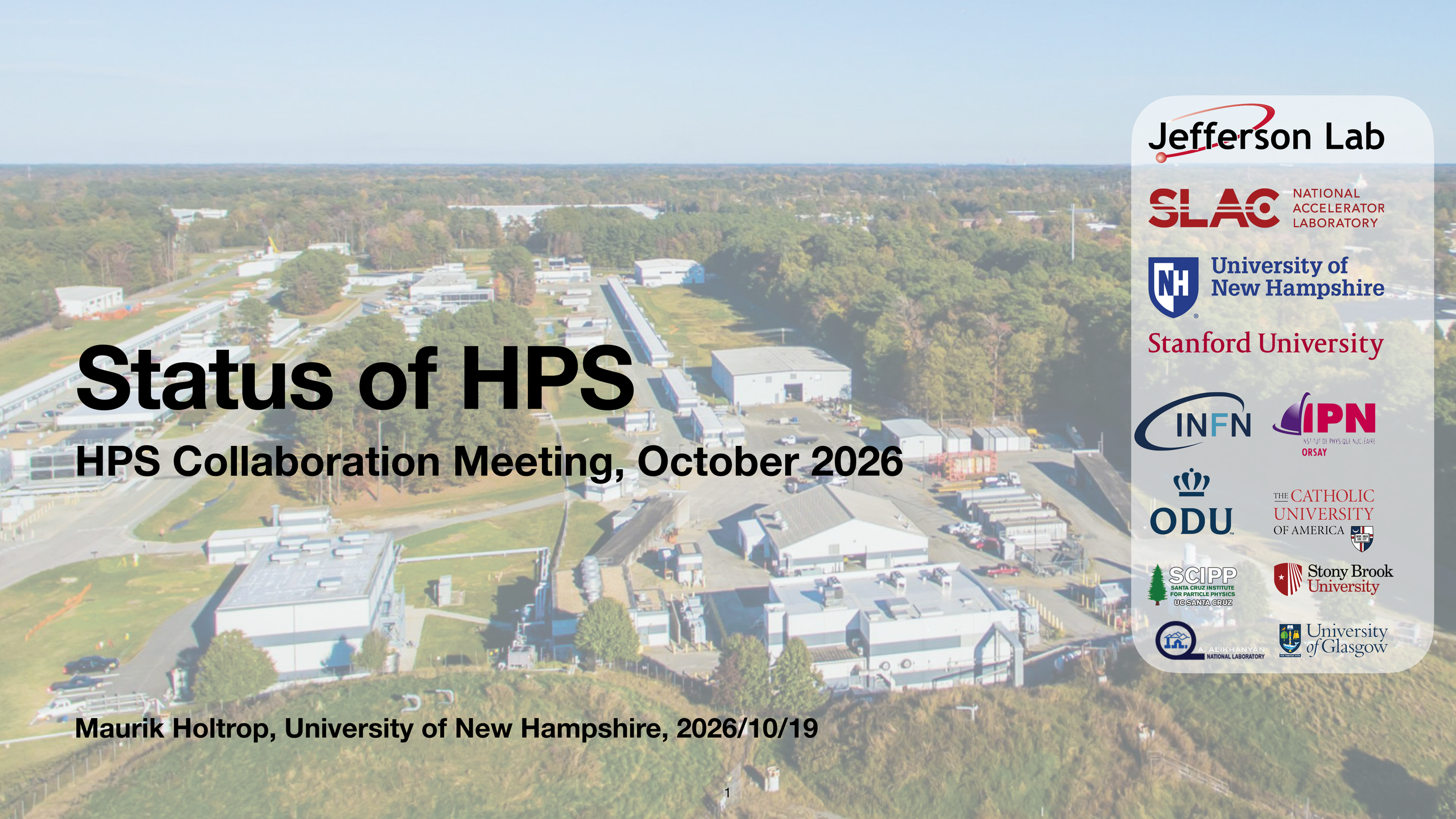


Status of HPS

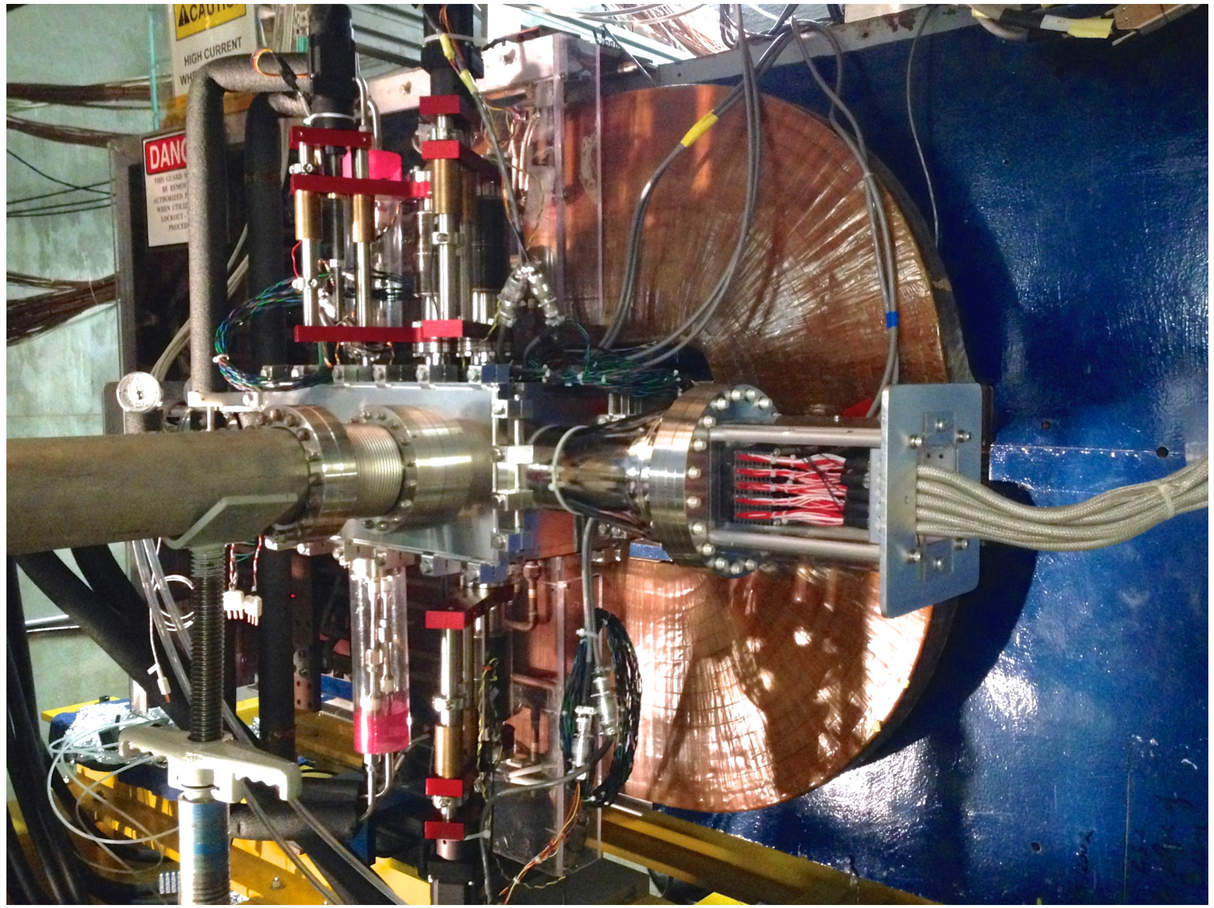
HPS Collaboration Meeting, October 2026

Maurik Holtrop, University of New Hampshire, 2026/10/19

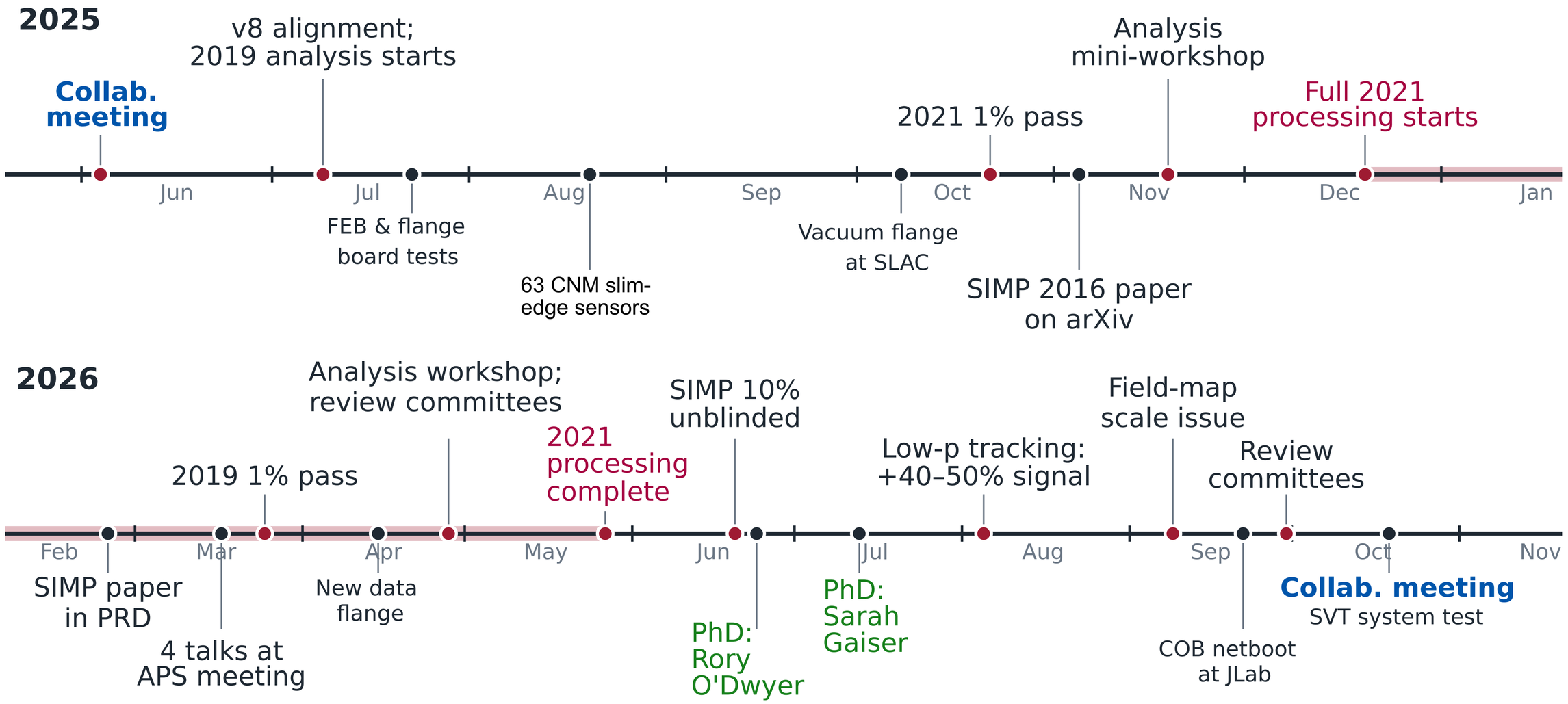
Overview

- I used the weekly meeting talks and analysis notes to summarize where we were recently. Talks in this meeting will give the updates of where we are **now.**

  - HPS, landscape, publications, presentations
  - Calibration Status, Data Processing, Monte Carlo
  - Analysis Progress, 2021, 2019
  - Bump Hunt, Nominal A’, SIMPs
  - ML/AI, Detector Updates
  - People
  - Future Running



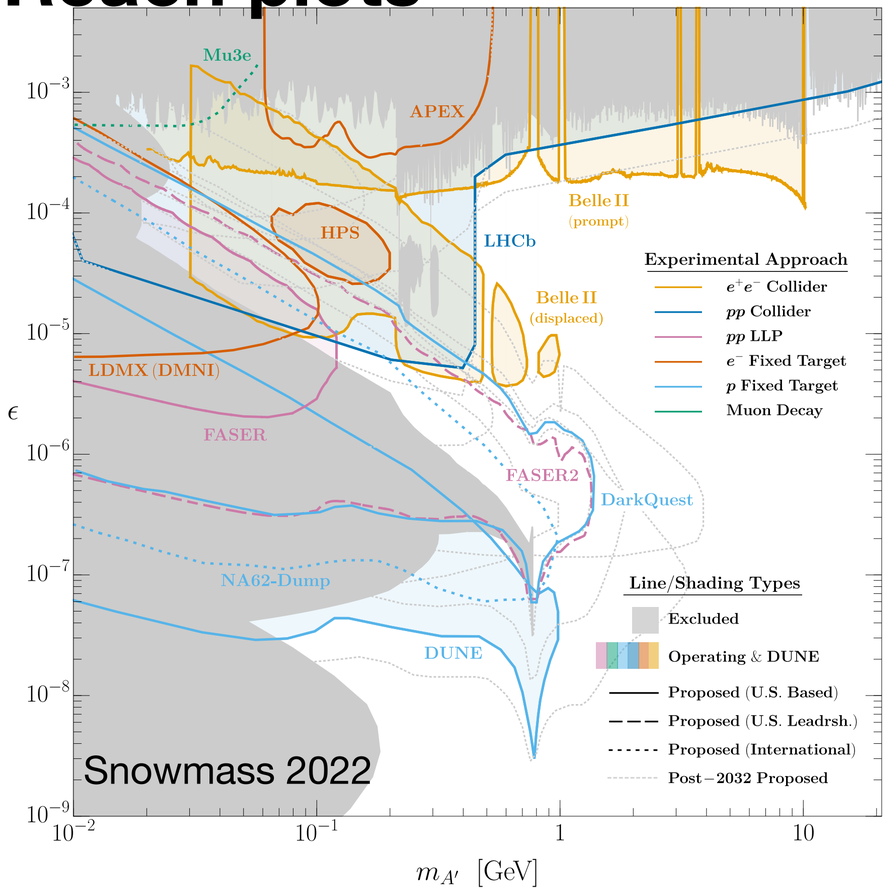
Since the last meeting…

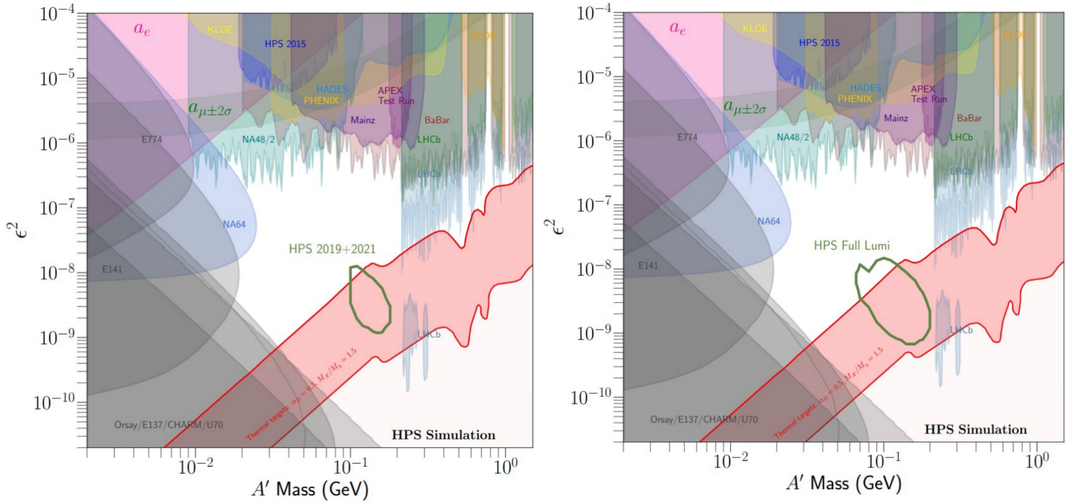


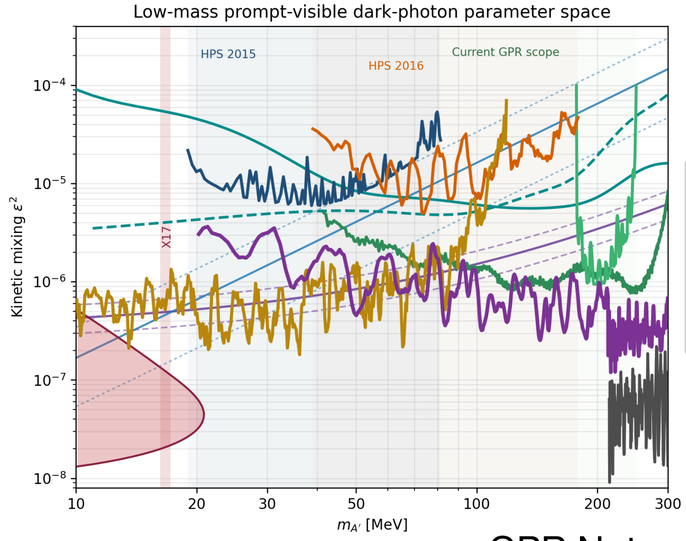
* Information extracted from Wednesday meeting talks.

HPS in the landscape

Reach plots







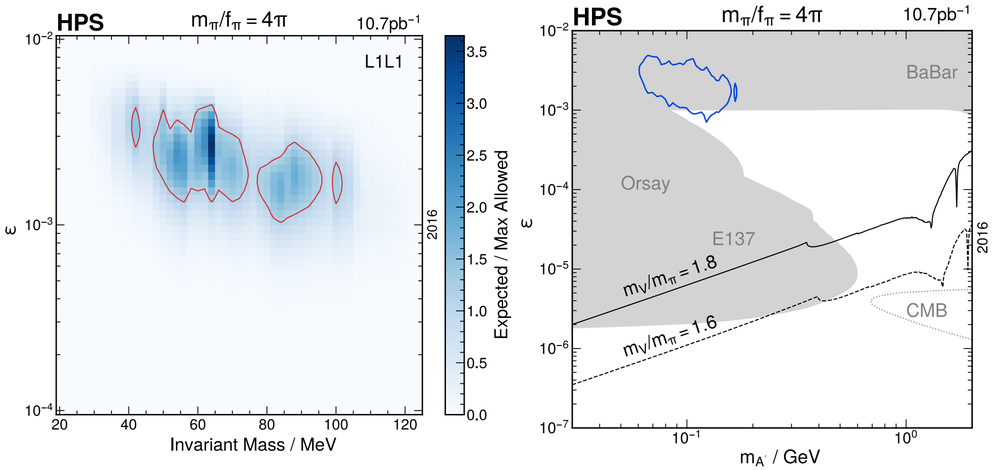
GPR Note

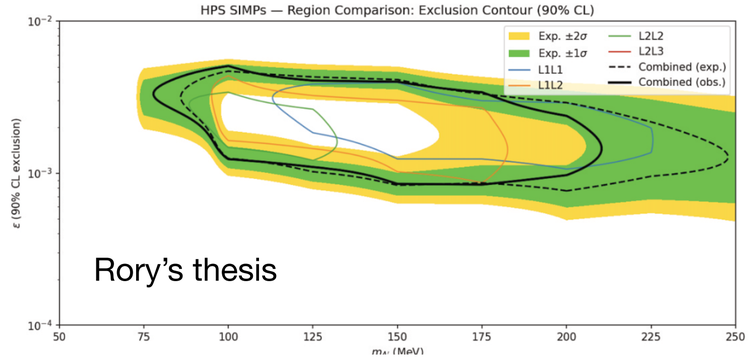
- Our reach for displaced vertex is still competitive.
- Emrys showed that with improved analysis, the Bump Hunt may also be competitive.
- See next talk “Overview of Dark Sectors” - Stephania Gory

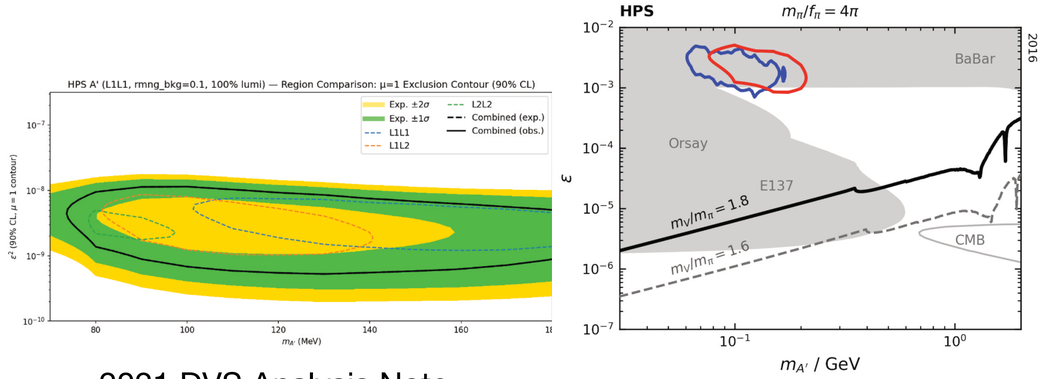
Recent Publications

- **PRD 113, 032019 (2026)**, arXiv:2511.02695, HPS Collaboration, “First displaced vertex search for electroproduced dark-sector strongly interacting massive particles by the HPS experiment”, 2016 engineering run, VD →e⁺e⁻, significant exclusion region.
- PhD theses (2026):
  - R. O’Dwyer (Stanford), “Searching for Mesonic Dark Matter With the Heavy Photon Search Experiment”
  - S. Gaiser (Stanford), “Searching for Long-Lived Dark Photons with the HPS Experiment”
- Internal notes under review:
  - 2021 Displaced Vertex Search Analysis Note v2.1 (June 2026)
  - GPR Resonance Search Analysis Note v2 (June 2026).
- In preparation:
  - SVT NIM paper (30-page draft, effort restarted August 2026);
  - 2021 SIMP paper (target early 2027?).
  - Bump Hunt & Displaced Vertex papers (?)

PRD 113, 03219



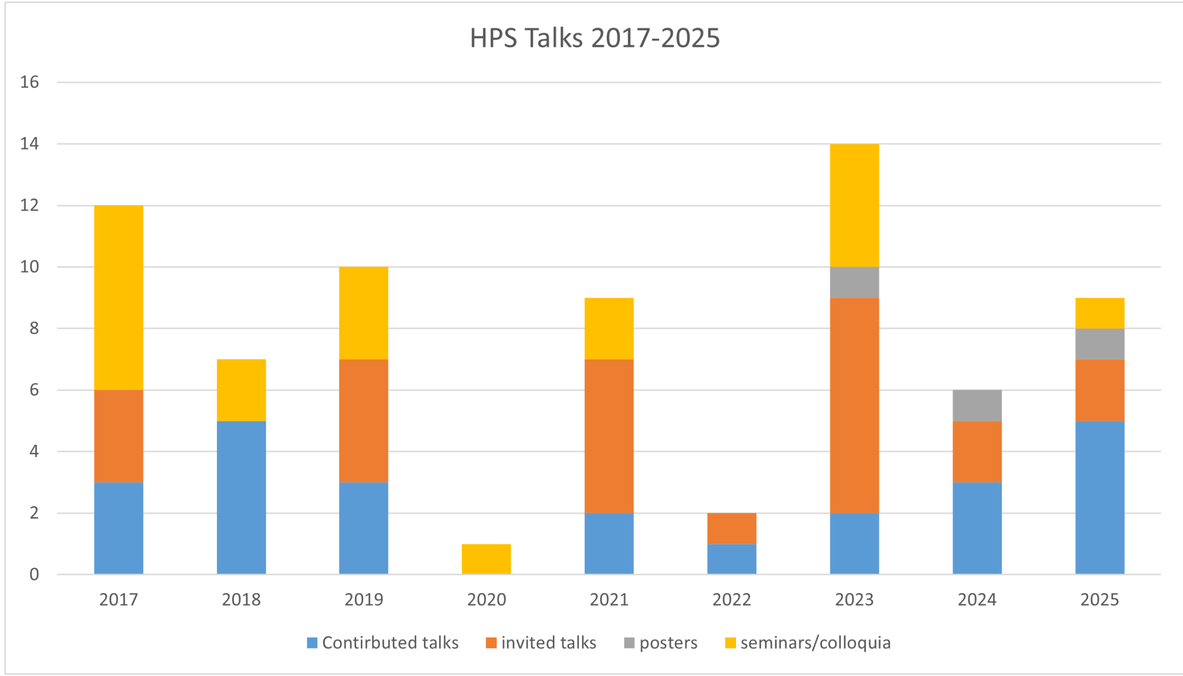




2021 DVS Analysis Note

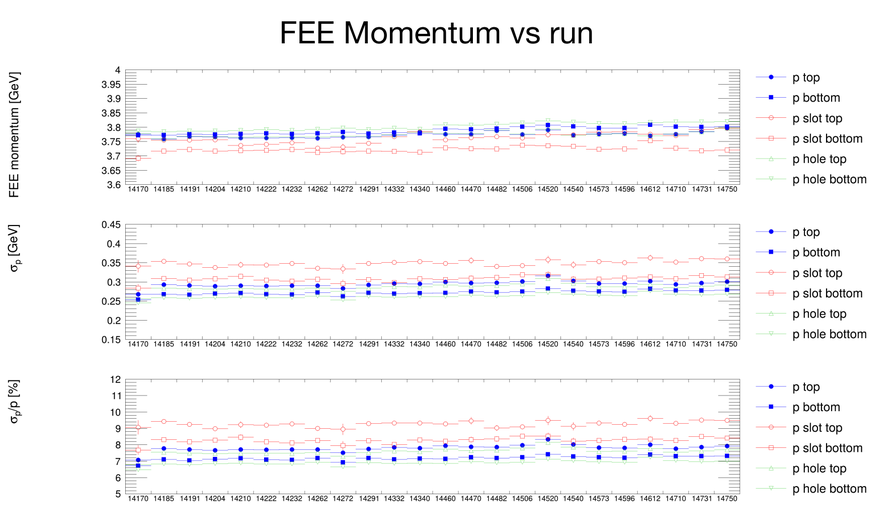
Presentations

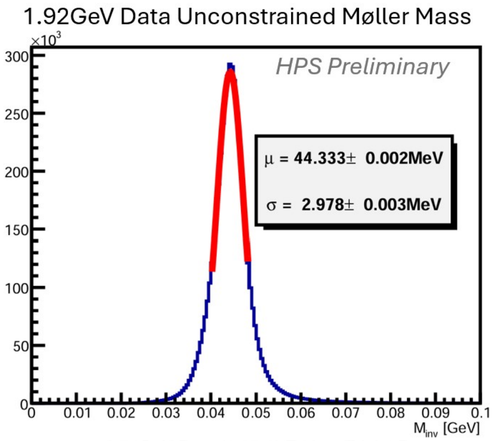
- APS Global Physics Summit, March 2026, session “Dark Matter I”:
  - S. Gaiser, “Searching for long-lived dark photons with the Heavy Photon Search experiment”
  - R. O’Dwyer, “Applying an Adversarial Neural Network to probe the 2021 HPS SIMP Search”
  - L. Wolf, “Møller electrons and radiative tridents for determining the HPS detector resolution”
  - E. Peets, “Resonance Searches using Gaussian Process Regression in the Heavy Photon Search Experiment”
- JLab Users Meeting 2025, N. Baltzell
- Only Sarah posted her slides to Confluence!!!
- Number of talks fluctuates year to year, but 2026 seems low.
- Show recent results in invited talks in 2027!

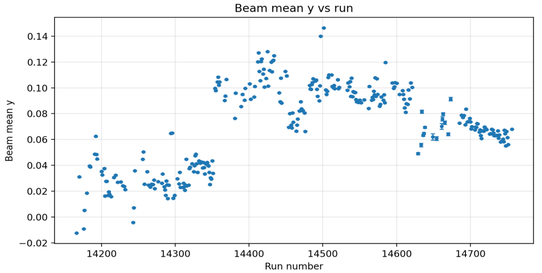


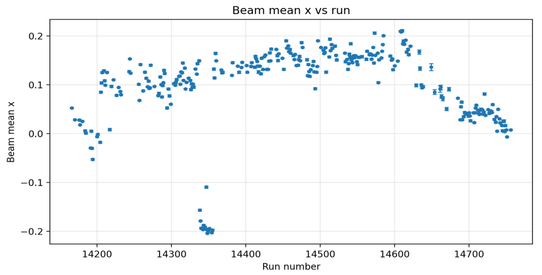
Calibration 2021 v9

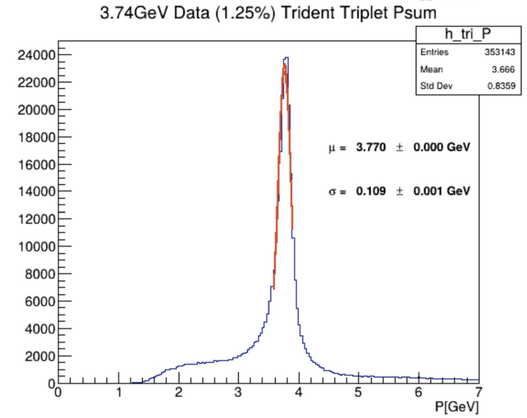
- Millepede alignment with FEEs; local and global rigid-body motions; run-by-run constants from 25 runs, interpolated to all runs; iterated v4→v9 (v10 in progress)
  - Detectors also at https://nuclear.unh.edu/HPS/Detectors/
- FEE momentum within a few percent of 3.74 GeV
  relative momentum resolution 6-9%
  E/p within ~5% of unity, stable vs run.
- Unconstrained Møller mass 44.35±0.02 MeV vs 44.31 MeV expected at 1.92 GeV.
- Fully resolved tridents: p_{sum} peak at beam energy, width ~110 MeV.
- Beam spot from HARP/wire scans and V_0 fits stored run by run in a conditions database; target at
  z~ -0.75 → -1 mm.











Calibration 2021 v10

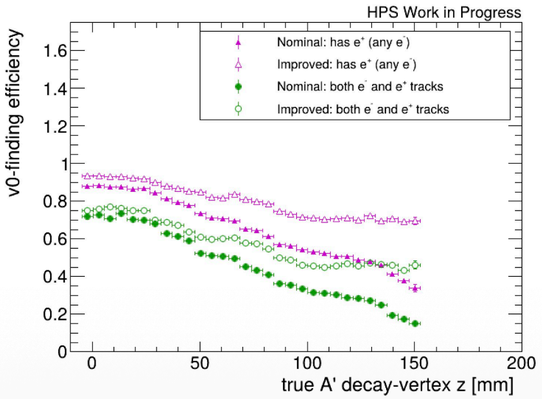
- Momentum scale is a few percent high.
  The 2021 field maps were built from readback rather than setpoint magnet current.
  (2021: setpoint 1307.8 A, readback 1321.6 A);
  (2019 maps already used setpoint)
  - Regenerated maps lower the scale; vertex z mean and width unchanged (WED 2026-09-09).
- Relaxed tracking parameters and extending seeding strategies increases reconstruction of highly displaced vertexes. (WED 2026-08-05).
- Low momentum tracking update, increases efficiency ~40%, but costs 3x the CPU.
- Isolation fixes.
- Recoil hit finding to seed low p tracks (Elizabeth analysis note)
- Vertexing fix: vertexing code used incorrect z (?) causing target constraint (?) invariant mass to shift.

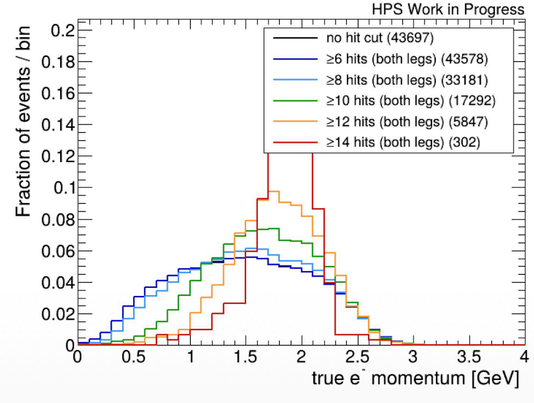
Field map studies

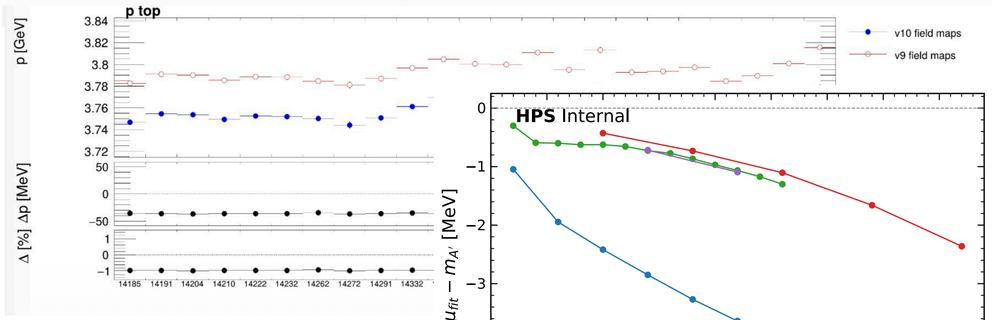
- Prompted from the systematically high momentum scale in the 2021 dataset, I began an investigation into field maps in for the 2021 dataset
- Readback runs consistently a few percent

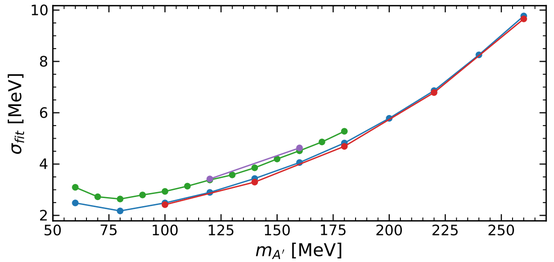
	Energy	Setpoint	Readback	Ratio
2015	1058.57	369.6	372.7	0.9917
2016	2306.64	806.4	814.5	0.9901
2019	4556.66	1592.4	1609.5	0.9894
2021	3741.97	1307.8	1321.6	0.9896









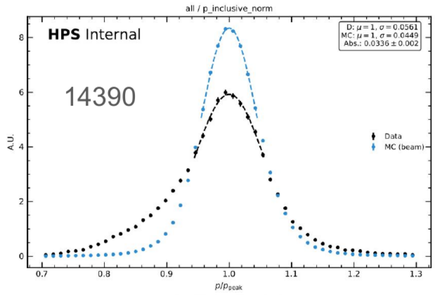


Calibration 2021 v10

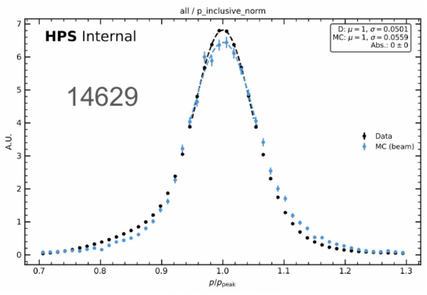
- Still outstanding questions?
  - FEE resolution in data is much worse than MC at 3.74 GeV but agrees at 1.92 GeV; larger radiative tail in the 3.74 GeV data. Not yet understood (?) (WED 2026-07-01).
  - Møller width in MC still below data after hit and curvature smearing;~2 mrad angular smearing per electron needed to match. (WED 2026-07-01).
  - **See updates Wednesday morning!**

FEE: momentum resolution

- Momentum resolution significantly worse in data than MC in 3.74 GeV dataset but NOT in the 1.92 GeV dataset
- Significant radiative tail (?) in 3.74 GeV dataset that's not present in Moller runs? Effect of target thickness? Purity issue?



3.74 GeV



1.92 GeV

9:00 AM → 10:30 AM **Reconstruction: Status of 2019 and 2020 reconstruction**
Convener: Dr Rafayel Paremuzyan (Jefferson Lab)

- 9:00 AM **Low momentum reconstruction** 30m
  Speaker: Matthew Gignac (SLAC)
- 9:30 AM **Third track reconstruction** 30m
  Speaker: Elizabeth Berzin (SLAC)
- 10:00 AM **Three Track Vertexing** 30m
  Speaker: Mathew Graham (SLAC National Accelerator Laboratory)

10:30 AM → 11:00 AM **Coffee break** 30m

11:00 AM → 12:30 PM **Reconstruction: Reconstruction Improvements**
Convener: Mathew Graham (SLAC National Accelerator Laboratory)

- 11:00 AM **Target Constraint Bias** 20m
  Speaker: Matthew Gignac (SLAC)
- 11:20 AM **Mass resolution updates & summary** 30m
  Speaker: Lewis Wolf (University of New Hampshire)
- 11:50 AM **Status of 2019 Alignment and Detector Performance** 30m
  Speaker: Elizabeth Berzin (SLAC)

Calibration 2019

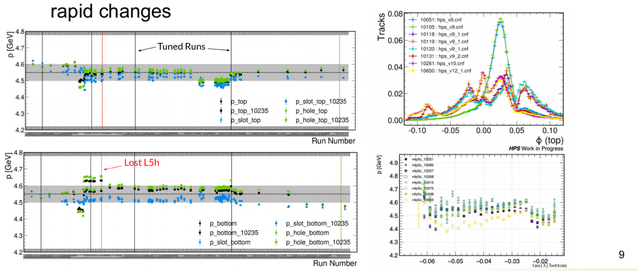
Alignment

- Alignment follows the 2021 strategy (E. Berzin). Harder: rapid changes in detector response through the run, changing FEE prescales; several detector models plus run-by-run constants for transition periods.
- Track seeding changed to skip problematic layers; tracking efficiency now stable run by run.
- Mass-resolution probes: Møller acceptance is zero for 2019; fully resolved tridents show a clear peak; ϕ→K+K– under study.
- Open: ECal calibration, alignment of the second transition period. (WED 2026-04-22).
- **Update on Wednesday morning - Elizabeth.**

Alignment in 2019

SLAC

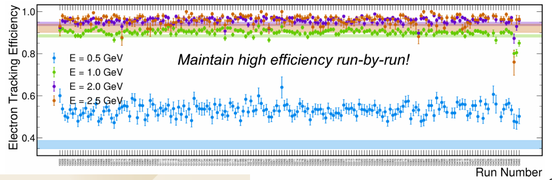
- Elizabeth has made excellent and rapid progress on the 2019 alignment model, following the 2021 strategy
  - Extremely challenging: rapid changes in detector response throughout dataset, changing pre-scales in FEE trigger, etc…
  - Planning 3-4 major detectors, and run-by-run for periods of rapid changes



Seeding strategy for 2019

SLAC

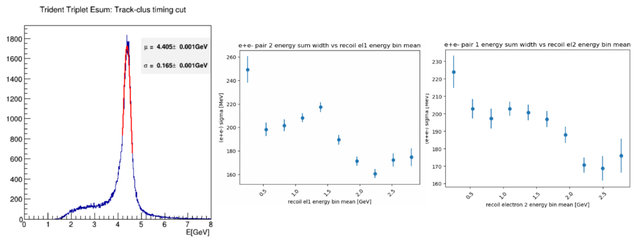
- Run dependent track reconstruction inefficiencies originally observed in the bottom detector
- Checked all KF parameters & code: no issues. Track seeding strategy primary source of inefficiency
- Changed seeding strategy to skip problematic layers



Mass resolution in 2019: Fully resolved tridents

SLAC

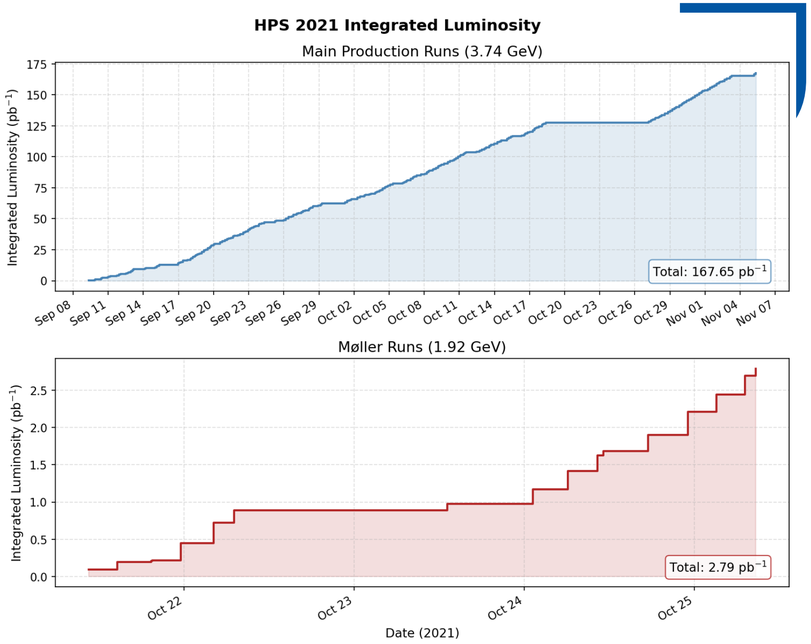
- Fully resolved tridents provide one other promising alternative to study mass resolution in 2019 dataset
  - Observe clear trident peak, but overall scale is low



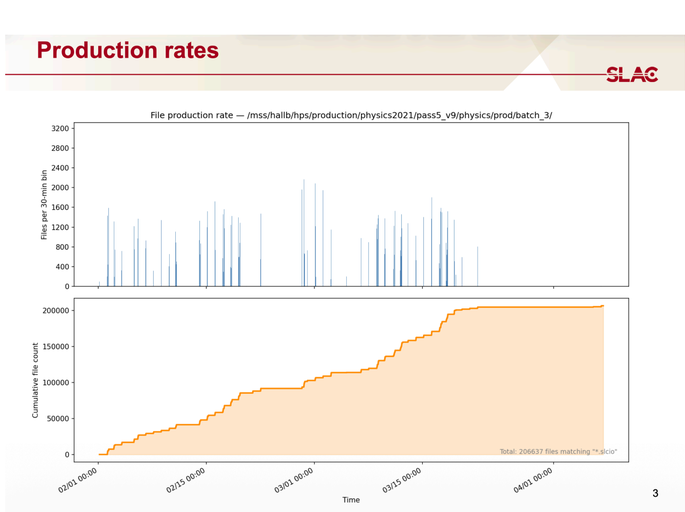
Data Processing

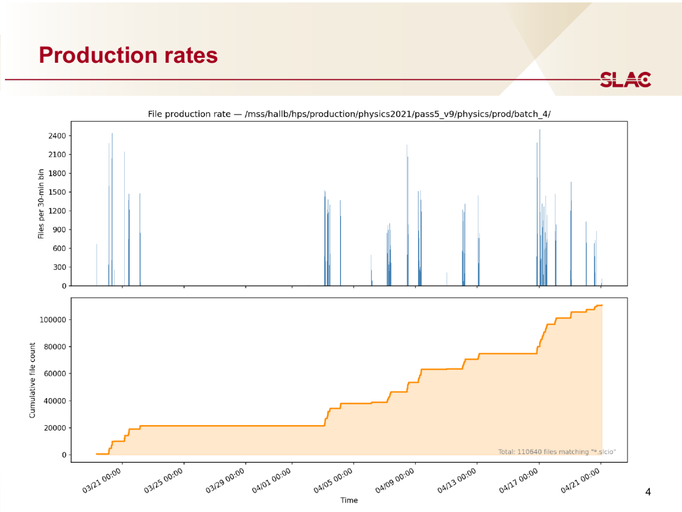
2021 and 2019

- 2021 physics run: 3.74 GeV, 20 μm W target, 167.65 pb^{-1}, 8 Sep – 7 Nov 2021. Møller runs: 1.92 GeV, 8 μm W, 2.79 pb^{-1}.
- Full 2021 reconstruction, pass5_v9 started Christmas 2025, finished May 2026; >400k jobs in~5 months, failure rate 0.29%
- Staged unblinding samples: 1% ➡ 10% ➡ 100%
- 2019: first 1% pass (“pass2”) with a full-dataset alignment, spring 2026.
- Will we need a pass6 for 2021?
  - Start with a 1% pass6, re-evaluate.



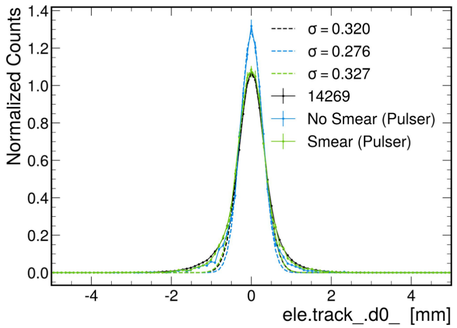
DVS Analysis Note Fig. 14

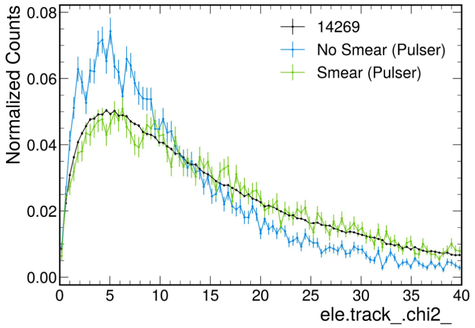


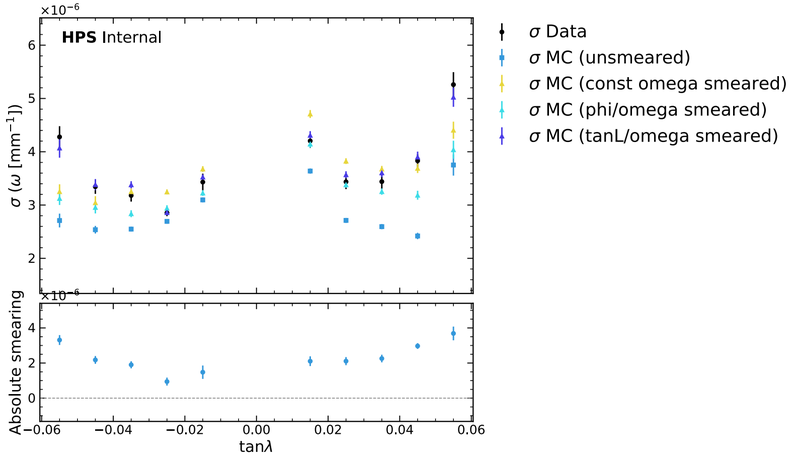


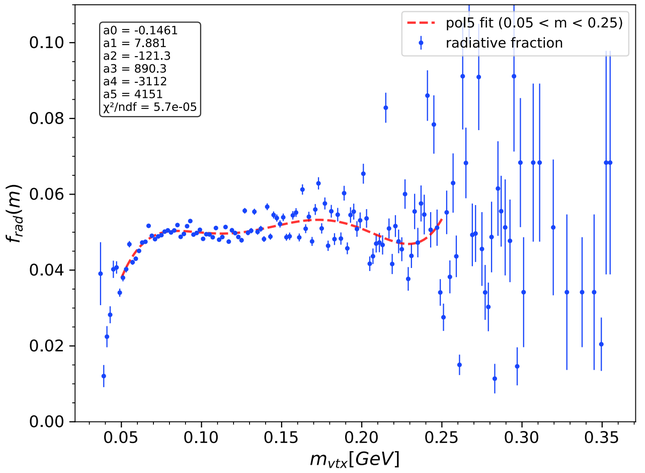
Monte Carlo Status

- 2021MC: pass5_v9 with pulser-data overlay: two run-period detectors (early run 14272, late run 14596), split near run 14320 where the beam y position moves (WED 2026-08-12).
- Hit smearing and curvature smearing needed to reproduce resolution. (Plus angle for Møller?)
- Data/MC: shapes agree; 2021 data rate~10% above MC; 2019 data/MC~1.5–2 after preselection. (WED 2025-11-19)
- 2021: Radiative fraction ≈5%, nearly flat in mass. (DVS Analysis note)
- MC production now run by M. Graham.
  Erbaz is testing MC on AlmaLinux 9 (UNH & Jlab).
- Update on Tuesday Morning (Matt & Elizabeth)





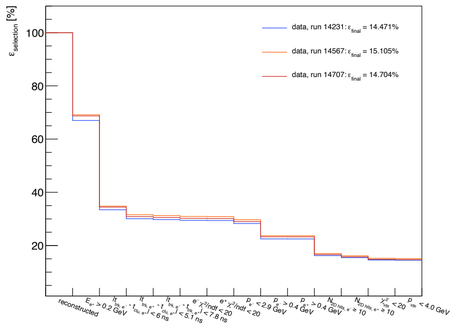




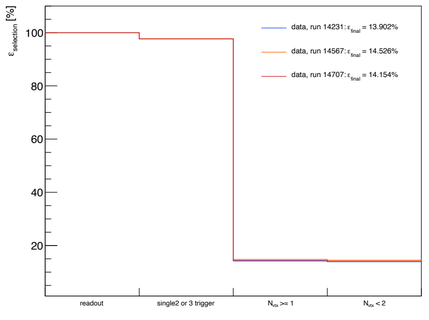
Analysis progress 2021

Pre-selection

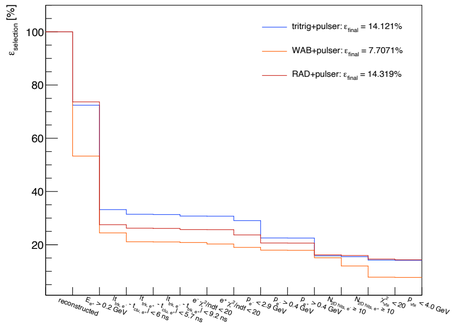
- Preselection reduces the data size for further analysis
- Common preselection for SIMPs, nominal A′and bump hunt (DVS Analysis note Table 38)
  - Trigger single2 or single3
  - FEE veto: p_{e^-} <2.9 GeV
  - p_{vtx} <4.0 GeV
  - $E_{e+\ cluster}$ >0.2 GeV, p_{trk} >0.4 GeV
  - N2D hits ≥10; χ2 trk/ndf <20; χ2 vtx <20
  - Track–cluster and track–track timing within 3σ
  - Exactly one good vertex
- Efficiency:
  - data~14%
  - tritrig MC 13.6%
  - **A′MC 10.6% (60 MeV) to 16.4% (180 MeV)**
  - **Needs improvement!**



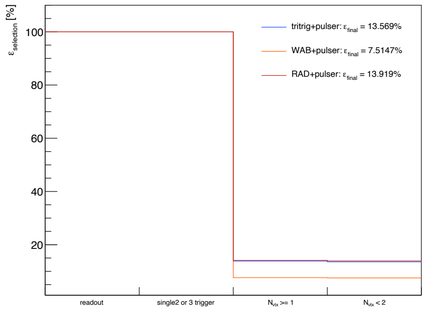
(a) Vertex cutflow – data from selected runs.



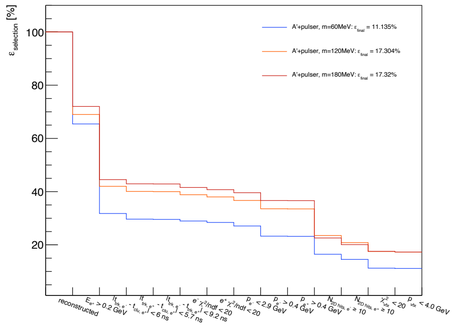
(b) Event cutflow – data from selected runs.



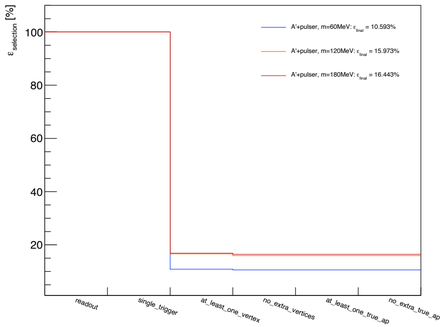
(c) Vertex cutflow – background MC.



(d) Event cutflow – background MC.



(e) Vertex cutflow – A' signal MC.

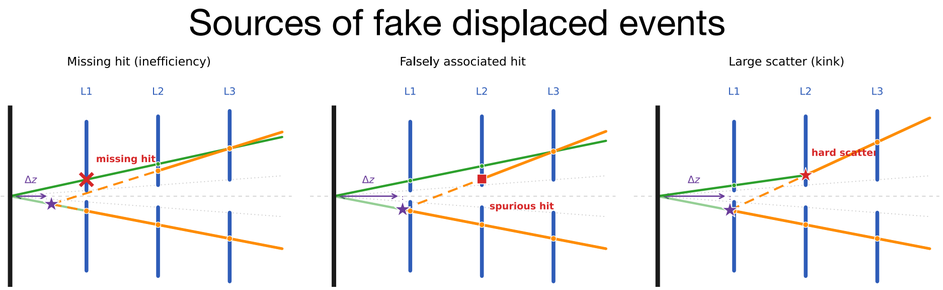


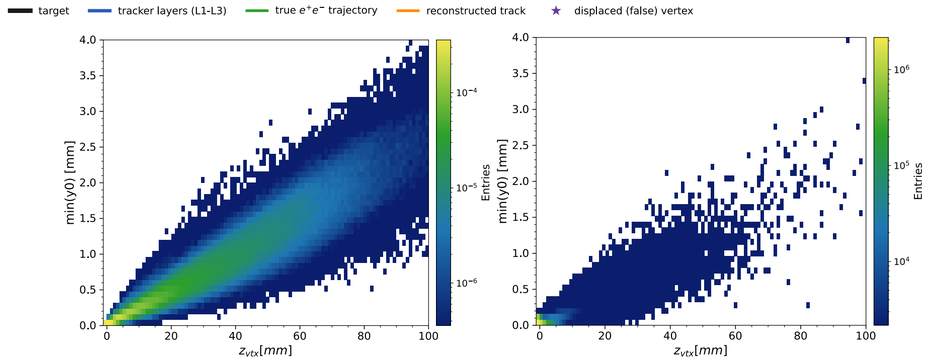
(f) Event cutflow – A' signal MC.

Analysis progress 2021

Tight-selection

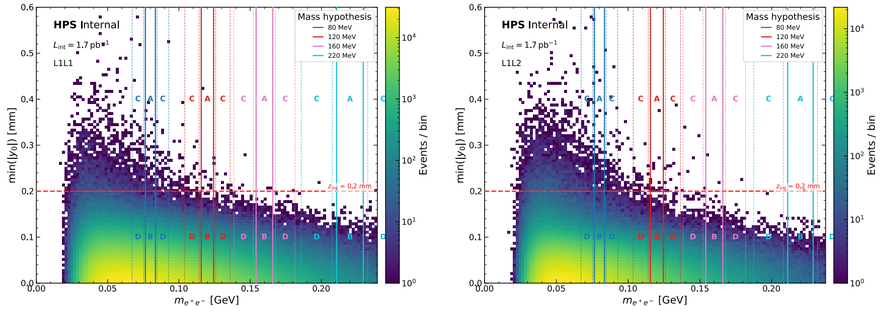
- For DVS: Every surviving background is a falsely displaced vertex: missing hit, wrongly associated hit, or hard scatter in L1–L3 (DVS Analysis note, fig 109).
- Events split into exclusive hit categories (L1L1, L1L2, L2L2, L2L3).
- Key variables: min(|y0|) of the two tracks, vertex projection significance, psum, recoil angle.
  - Look into combined variables?
- Background in the signal region from the data-driven ABCD method in (me+ e–, min |y0|); validated on 1% and on selected blinded 10% mass points (80, 120, 180 MeV).
- **Needs improving! Too little signal survives!**
- Expected signal-yield systematic ≈14% (target position 9%, mass resolution 6.5%, cross section 3.5%, preselection 3%, tight selection 2–4%) (DVS Analysis note table 60).





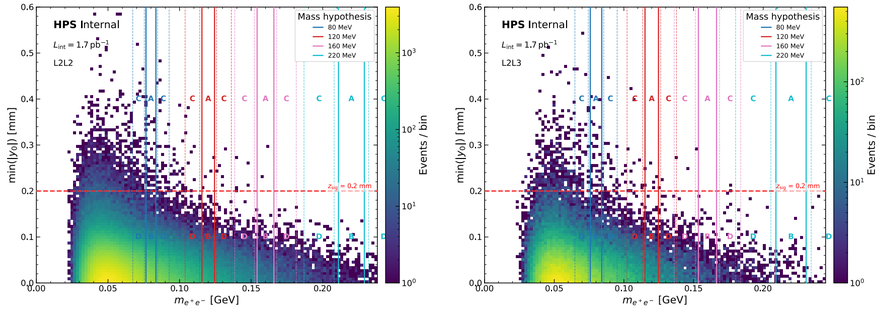
(a) $y0_{\min}$ in 120 MeV, $\varepsilon^2 = 10^{-10}$ A' signal

(b) $y0_{\min}$ in 1 % data sample



(a) L1L1

(b) L1L2



Analysis progress 2021

Unblinding

- Staged unblinding 1% →10% →100%; same pre-selection & tight selection for all 3 stages
- Review committees determine readiness for next level unblinding:
  - Bump hunt: Nathan, Majd, Rafo.
  - Displaced vertex & SIMPS: Maurik, Tongtong, John
- June ’26: SIMP 10% unblinded, nominal A′ 10% unblinded, Bump Hunt ?

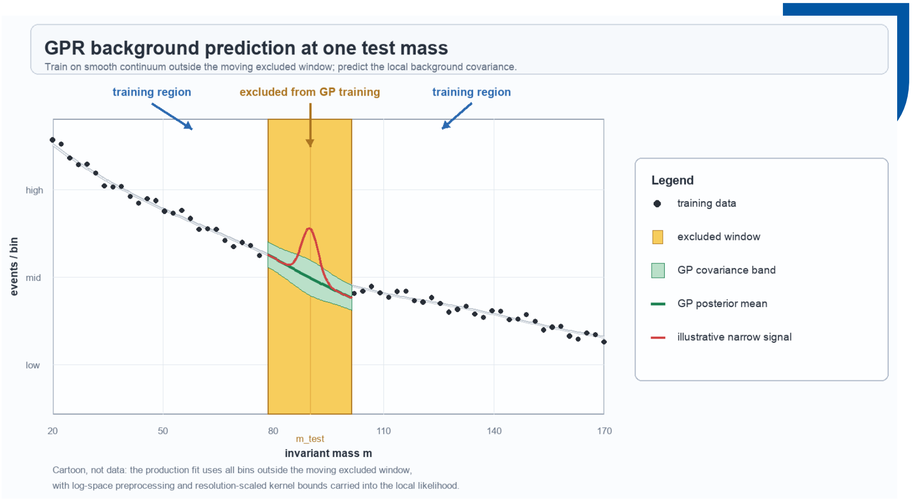
Analysis progress 2019

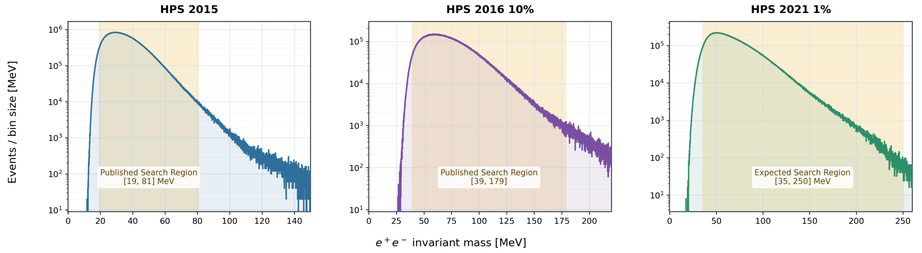
Mostly on pause again

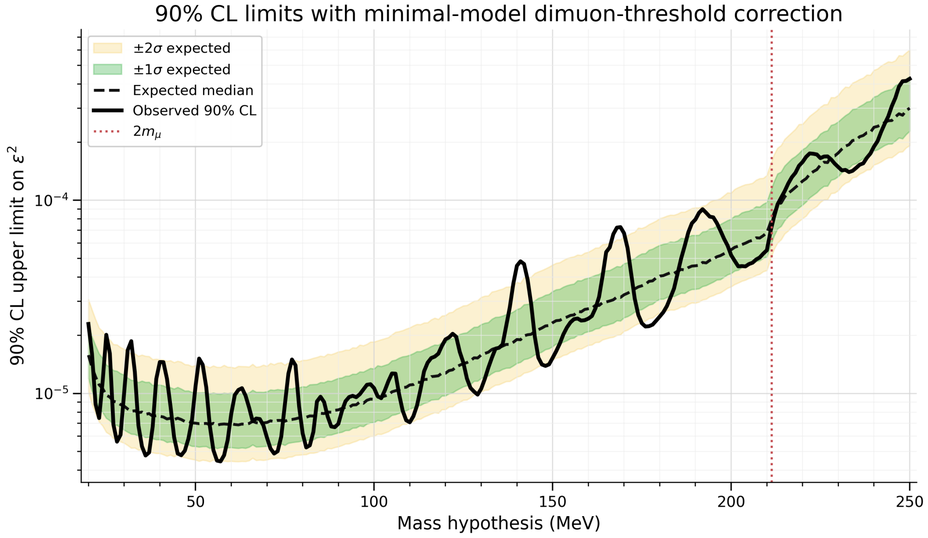
- The 2021 analysis is again taking precedence.
- First 1% pass of the full 2019 data set (spring 2026); data quality good.
- Preselection follows the 2021 scheme; distribution shapes agree between data and MC
- MC rate low by 1.5–2
- Mass resolution: fully resolved tridents and $\phi \rightarrow K^+K^-$; Møller acceptance too small.
- Update Wednesday morning, Elizabeth.

Bumphunt Status

- New method: global Gaussian-process fit to the full mass spectrum, trained in log-mass/log-counts, Constant×RBF
- kernel, length scale tied to mass resolution; test-mass window ($\pm 2.25\sigma_m$) removed from training; GP mean and covariance enter a profile likelihood; CLs limits (GPR Note §4).
- Validated with toys: spurious signal, pull, signal-injection recovery, for 2015, 2016 10% and 2021 1%.
- Current result: simultaneous fit of 2015 (100%), 2016 (10%) and 2021 (1%) in a shared $\epsilon 2$ (GPR Fig. 55)
- Projection to full statistics: median factor ≈9 improvement in ϵ^2 over the published 2016 limit (GPR Note §6.4).
- Open: reconstructed-mass offset that grows with mass in 2021 target-constrained vertices (WED 2026-09-30)
  - Fixed in recent code update?
- Next steps: freeze 2016/2021 inputs, radiative fraction and systematics; look-elsewhere toys.

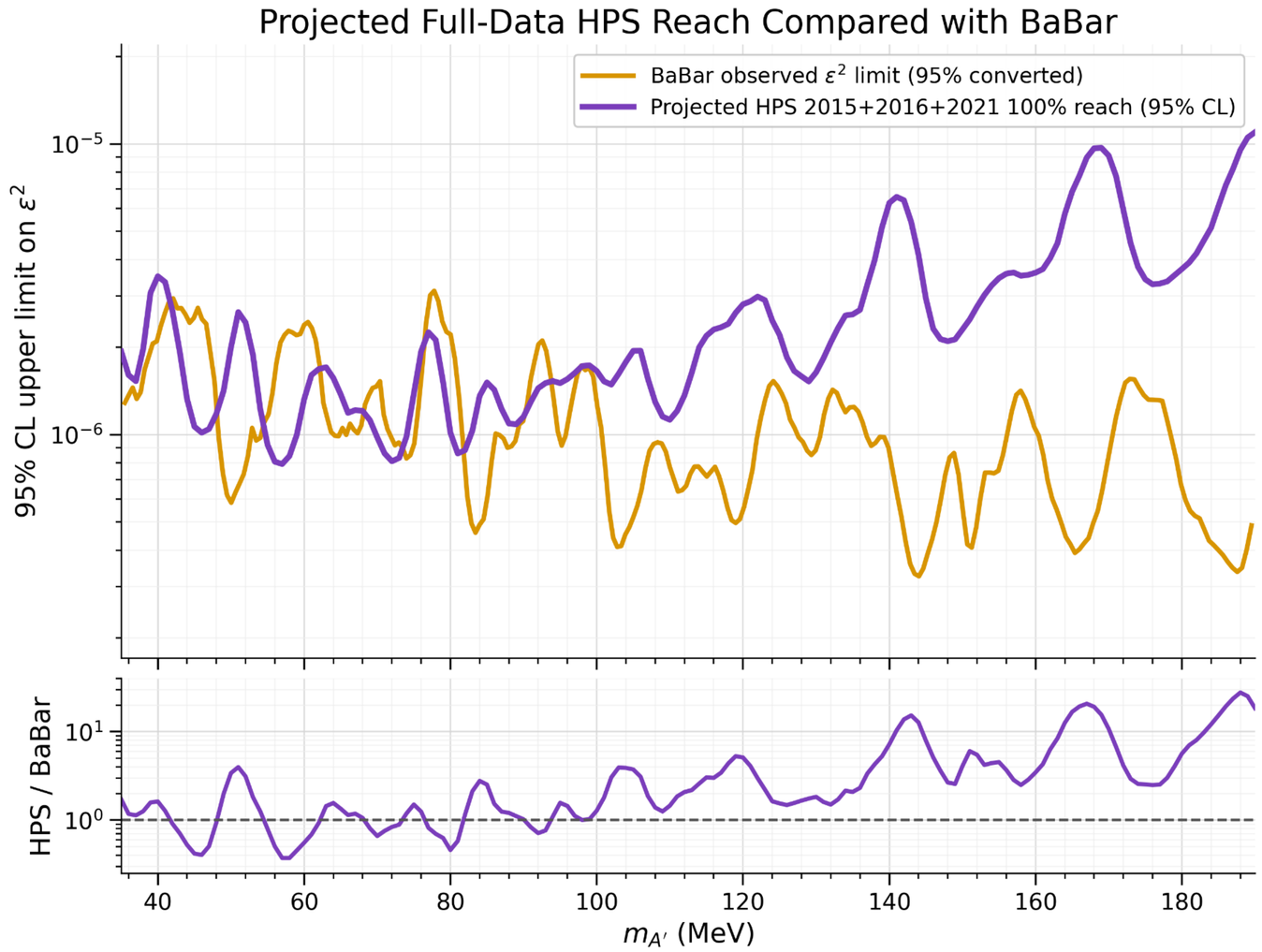






Bumphunt Status

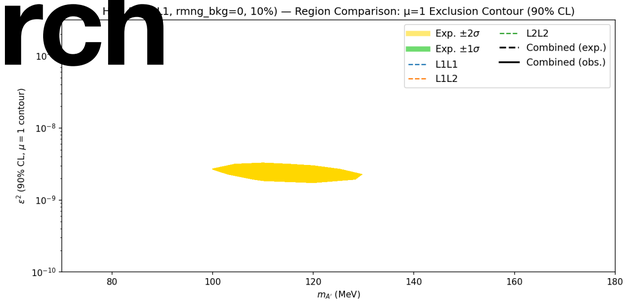
- Very promising results, which scaled to full data set may be competitive with Babar results.



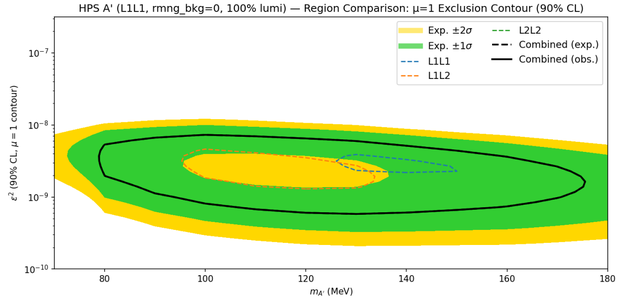
See talk Tuesday afternoon, Emrys

Detached Vertex A’ Search

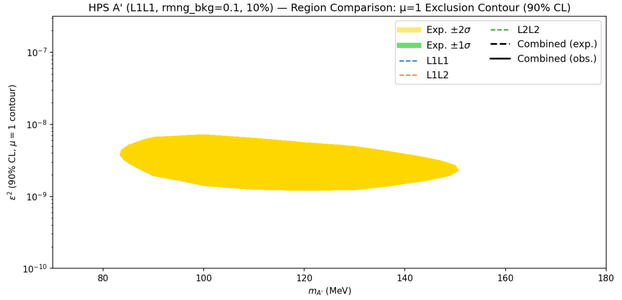
- High-psum selection; background-free signal region needed.
- At 10% no point is excluded:
  best μ_{up} ≈2.5 at mA′ ≈100 MeV near ϵ^2 ~3 ×10–9
  (rbkg = 0.1 optimization) (DVS Analysis note §10.3)
- The 100% projection gives a μ= 1 contour over mA′ ≈75–180 MeV,
  ϵ2 ≈6 ×10^{-10}–10^{-8} (DVS Analysis note).
- Needed: Improved pre-selection, improved tight selection, leading to more signal.
- See talk Tuesday morning, Elizabeth.



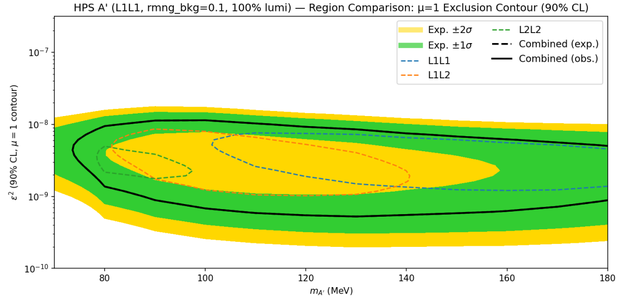
(a) $r_{bkg} = 0$, 10%



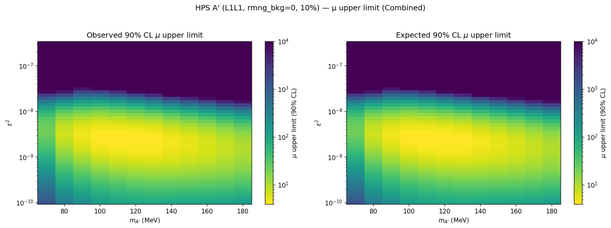
(b) $r_{bkg} = 0$, 100%



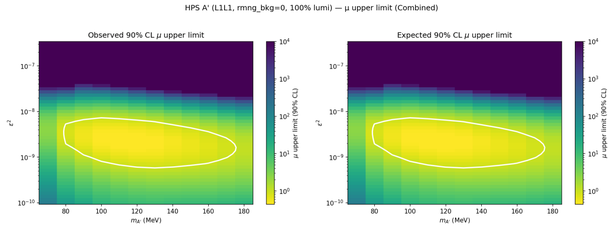
(c) $r_{bkg} = 0.1$, 10%



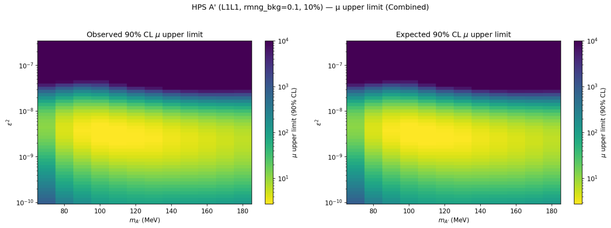
(d) $r_{bkg} = 0.1$, 100%



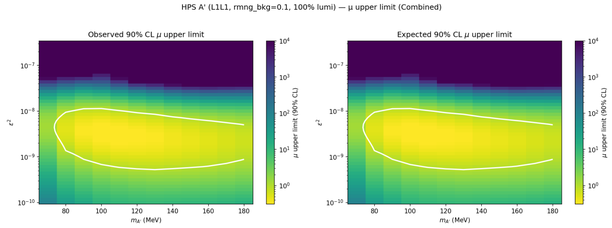
(a) $r_{bkg} = 0$, 10%



(b) $r_{bkg} = 0$, 100%



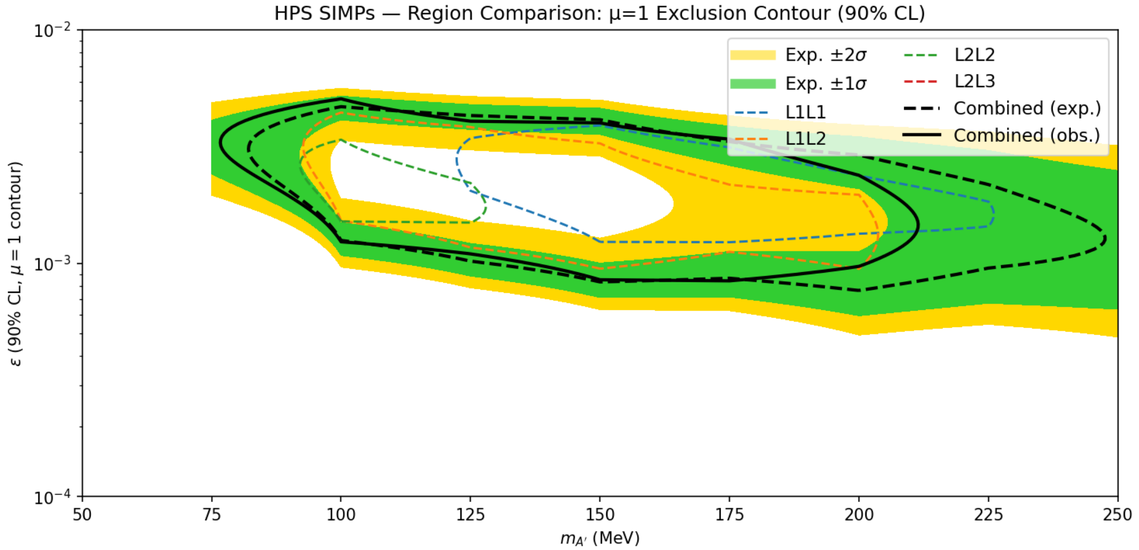
(c) $r_{bkg} = 0.1$, 10%

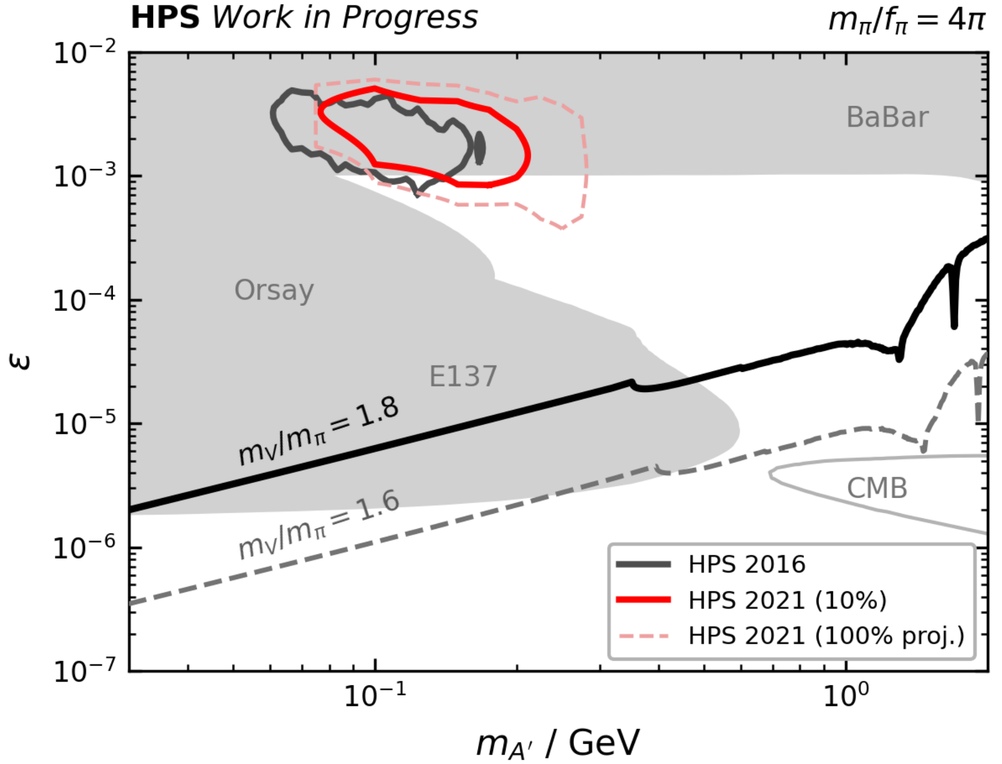


(d) $r_{bkg} = 0.1$, 100%

SIMPs

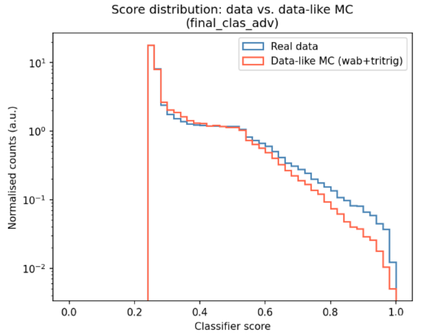
- Model: $m_{A'} : m_V : m_\pi = 3 : 1.8 : 1$, $m_\pi/f_\pi = 4\pi$, $\alpha_D = 0.01$.
- 10% sample; eight channels: four hit categories ×two min(y0) bins; ABCD background; CLs at 90%.
- Observed exclusion in ($m_{A'}$, ϵ): roughly mA′ ≈80–210 MeV and ϵ ≈1–5 ×10–3; observed within ±1σ of expected. Statistics dominated;
  background systematics ≲ 0.3% of the band.
- Publication early 2027?
- Update on Tuesday morning, Majd



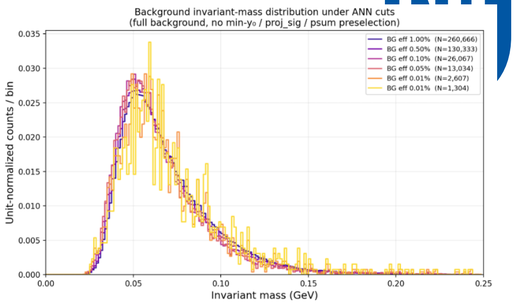


Using ML/AI for analysis

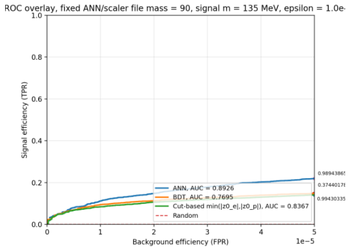
- Several uses of ML have been tried:
- SIMP tight selection: adversarial neural network (classifier plus adversary decorrelating from invariant mass) on p_{sum}, ye^{-}_{0} , ye^{+}_{0} , projection significance. ROC curves better than cut-based selection; little mass sculpting, compatible with ABCD; data/MC score agreement checked (DVS analysis note, App. J)
- Performance comparable to cuts in L1L1/L1L2, better in L2L2/L2L3; possible hybrid selection? ANN systematic 4% vs 2% for cuts.
- Gaussian-process regression for Bump Hunt background.
- Background discrimination WAB/BH/radiative with new variables (recoil angle, momentum asymmetry, y_0 products) and NN studies (E. Berzin, Majd; WED 2026-06-24)
- $\phi \rightarrow K^{+}K^{-}$ with ANN-selected sample: peak at 1020.55±0.03 MeV, width 7.9 MeV (E. Peets; WED 2026-06-24).



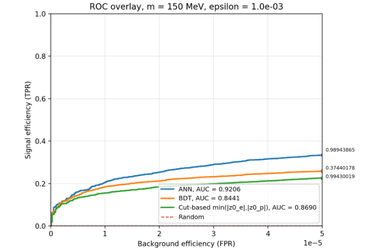
(a) ANN score distribution in data and MC. Demonstrates decent agreement between the two samples.



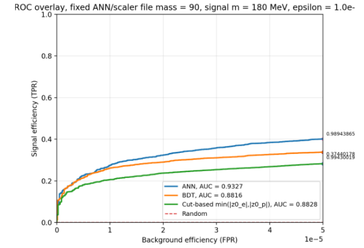
(b) ANN threshold cuts employed on the background distribution; demonstrates low shaping for the ANN classifier.



(a) Lowest mass range.



(b) Intermediate mass range.



(c) Highest mass range.

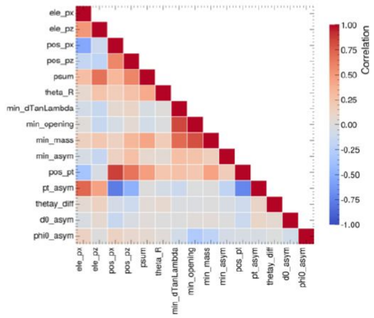
Discrimination between WAB/BH/RAD (EB)

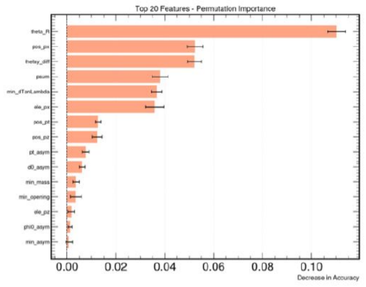
June 9 Talk; June 23 Talk

- Applying Sarah's most recent tight-selection, up to y0 product -2
- Signal efficiency increases relative to preselection, to 90-95%:
  - To be understood, maybe a reflection of reconstruction quality effects being factored out?
- Background rejection ~30-40%, increasing for more displaced hit categories.
- No significant change in signal efficiency seen when tightening 2016-style selection

Feature Importance/Correlation

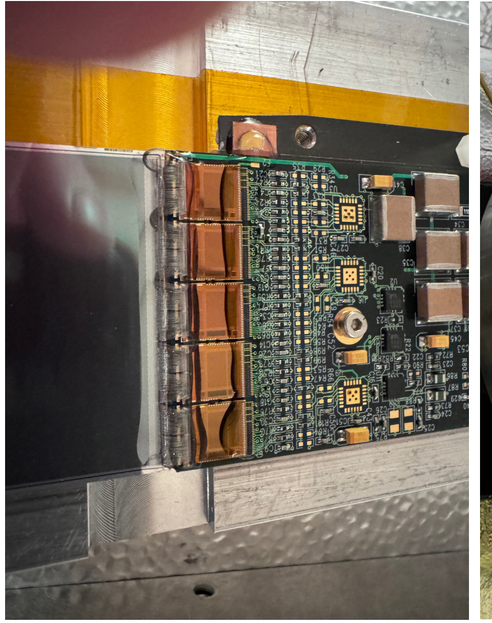
- Similar ranking to previous BDT:

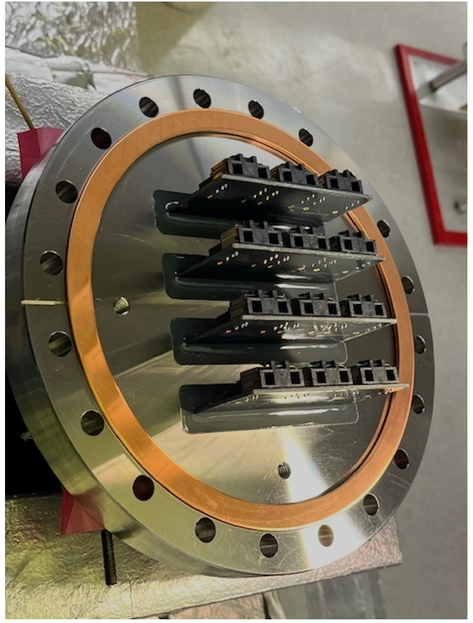


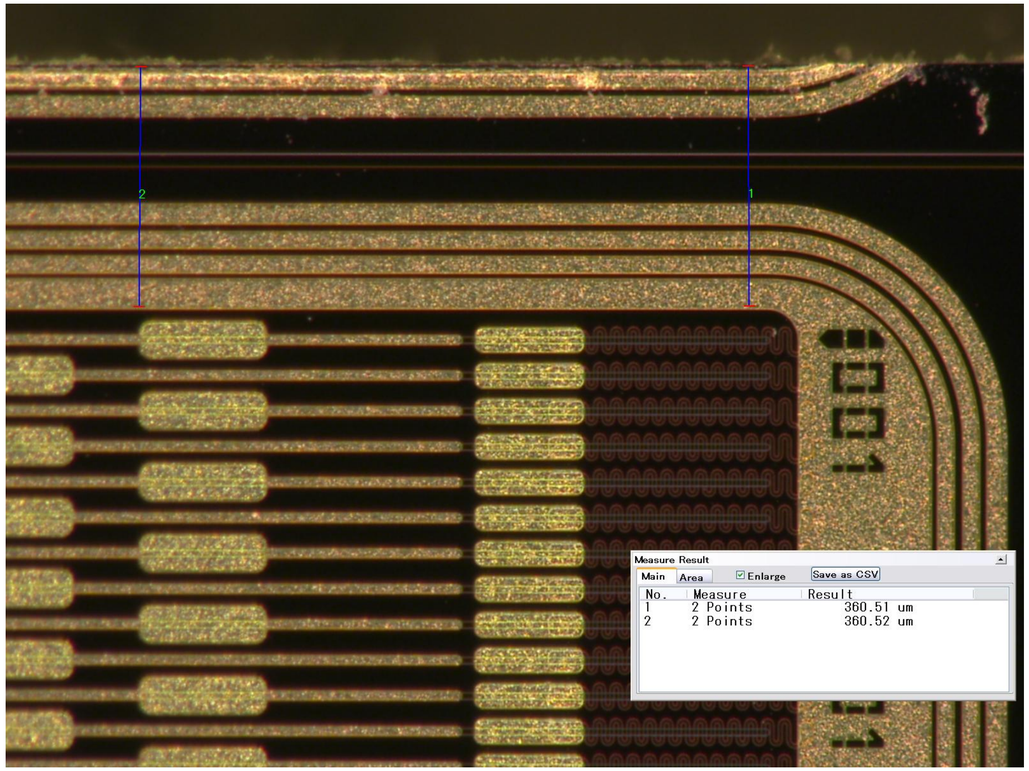


Detector Updates

- A lot of work done on the SVT:
- FEBs: 20 rad-tolerant C03 FEBs loaded and tested at SLAC: 14 without issues, 10 needed.
- Data flange: 10 new optical boards tested; new vacuum flange assembled April 2026; He leak check and cleanroom electrical test pending/under way.
- COBs: broken DPM replaced with an ex-ProtoDUNE spare; two COBs netbooting at SLAC. NFSv2 boot problem solved with TFTP + NFSv3; first COB netbooted at JLab in September 2026; 3 spare COBs.
- Sensors: 63 CNM slim-edge sensors received, IV-tested and imaged at UCSC; leakage~40% above CNM values, still O(100 nA); slim edge 250–350 μm.
- Modules: L1–2 rebuild (18 working hybrids; sensors ranked by slim-edge distance, slope and IV); L5–7 hybrids loaded and wire-bonded at UCSC.
- This week at JLab: end-to-end test
  COB →new flange →C03 FEBs →SVT.
- MPOD LV cards repaired; HV for the test borrowed from CLAS.
- See talk this afternoon, Matt Gignac







Former HPS Students

Name	Institute		Year	Advisor	Title
Emma Buchanan	Glasgow	MSc	2014	Daria Sokhan	Electromagnetic calorimeter for the Heavy Photon Search Experiment at Jefferson Lab
Luca Colaneri	Rome	PhD	2016	A. D'Angelo	The HPS experiment
Omar Moreno	UC Santa Cruz	PhD	2016	B. Schumm	Search for a Heavy Photon in the 2015 Engineering Run Data of the Heavy Photon Search Experiment
Sho Uemura	Stanford	PhD	2016	J. Jaros	Searching for heavy photons in the HPS experiment
Ani Simonyan	IPN Orsay	PhD	2017	S. Stepanyan, A. Denig	Dark Photon Search with the HPS Experiment at JLab
Holly Szumila-Vance	Old Dominion	PhD	2017	L. Weinstein	Searching for Heavy Photons With Detached Vertices in the Heavy Photon Search Experiment
Sebouh Paul	William & Mary	PhD	2018	K. Griffioen	Searching for A Dark Photon in the HPS Experiment
Bradley Yale	UNH	PhD	2019	M. Holtrop	Heavy Photon Displaced Vertex Search at 2.3 GeV with Prospects for True Muonium Discovery
Samantha McCarty	UNH	PhD	2020	M. Holtrop	Search for an A' Resonance in the Heavy Photon Search 2.3 GeV Data Set
Matthew Solt	Stanford	PhD	2020	P. Schuster	Searching for long-lived dark photons with the heavy photon search experiment
Alic Spellman	UC Santa Cruz	PhD	2024	R. Johnson	Searching for Strongly-Interacting Dark Matter with the Heavy Photon Search Experiment
Rory O'Dwyer	Stanford	PhD	2026	L. Tompkins, P. Burchat, T. Nelson	Searching for Mesonic Dark Matter With the Heavy Photon Search Experiment
Sarah Gaiser	Stanford	PhD	2026	P. Shuster, T. Nelson	Searching for Long-Lived Dark Photons with the HPS Experiment

Table added to Confluence page below dissertation list.

Current HPS Students

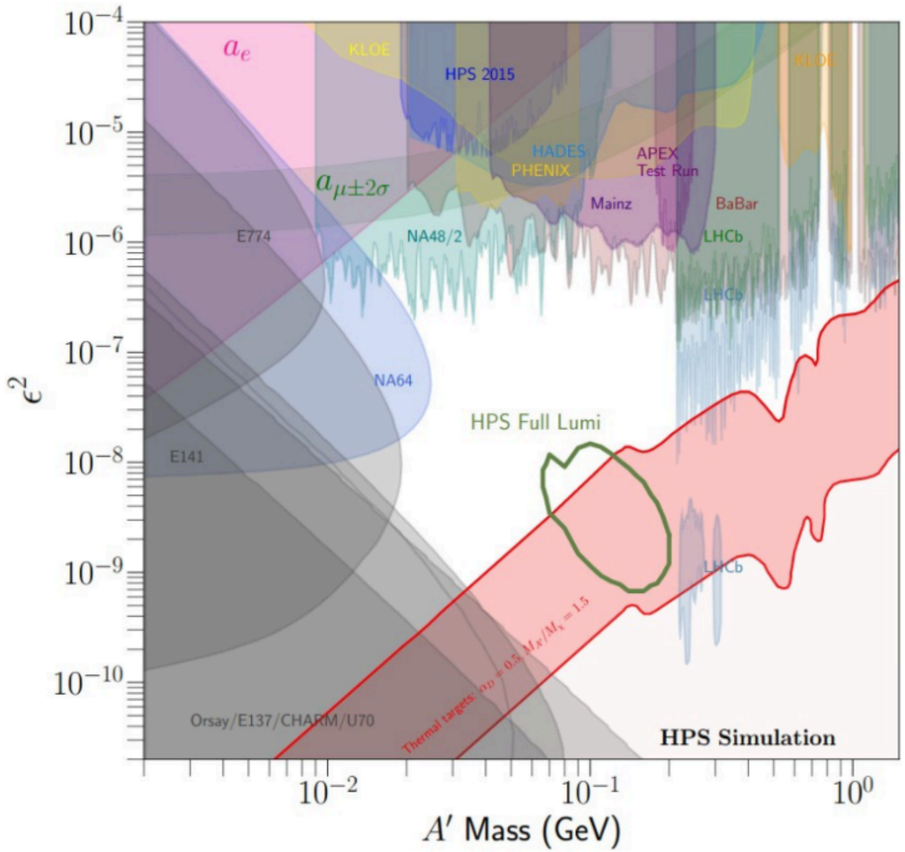
and post-docs and research scientists

- The people that are now doing the actual work…
- Students:
  - Emrys Peets (Stanford) Bump Hunt, GPR; defense pending
  - Elizabeth Berzin (Stanford) 2019 alignment, signal estimation, MC, 2021
  - Lewis Wolf (UNH) Møller and trident resolution, pre-selection & tight selection 2021.
  - Erbaz Khan (UNH) (starte Jan ’26) ECal calibration note, MC on AlmaLinux
  - Undergraduates on the GP effort (E. Hsu, J. Bailey, T. Britt).

- Post-doc & staff:
  - Majd Ghrear 2019 preselection, $\phi \rightarrow KK$
  - Matt Gignac (alignment, SVT + everything)
  - Matt Graham (analysis coordination, MC)
  - Nathan Baltzell (reconstruction software, review)
  - Tongtong Cao (MC, review)
  - Rafo Paremuzyan (beam, review)

Future Runs

- Possible long run in 2030
  Full AY beamtime ~ all remaining PAC days?
  - Sensitivity grows nearly linearly with additional running for the displaced A′search; the 2021 100% projections show the reach of the existing data.
- What do we need for this?
  - Need sufficient SVT spares.
    - Most vulnerable component in the detector, suffers radiation damage.
  - More students + postdocs + collaborators.
    - This will be *a lot* of shifts, RC week, SVT & ECal expert weeks.



Conclusions

- We finally have a good calibration for the 2021 data set, possibly getting even better.
  - Very exciting preliminary results for the SIMPs and Bump Hunt.
    - SIMP paper soon?
  - Nominal, detached vertex, A’ search needs work to keep more signal.
- Calibration for 2019 has a clear path forward.
- We found a number of bugs/software improvements that improve the data analysis. Enough for a 2021 pass6?
- There are promising initial expirations of ML, but it is more difficult than at first glance. Still a lot to learn.
- Possible long run in 2030 will need significant preparation.