WP2: Update on high repetition rate developments for SCAPA

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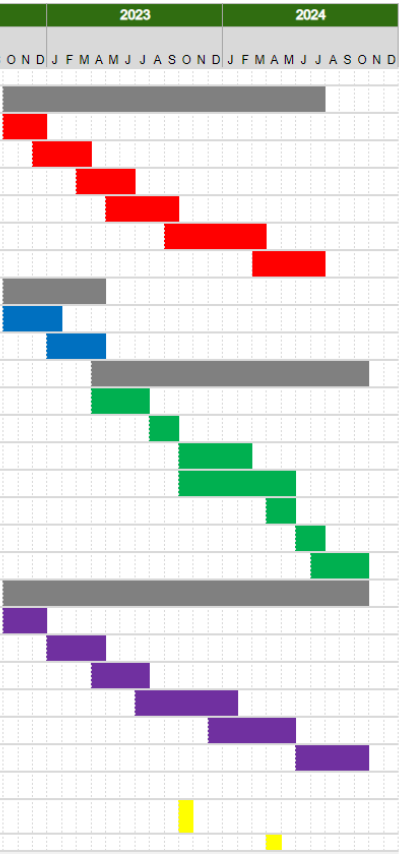
WP2 project plan…

LhARA WP2 Gantt Chart

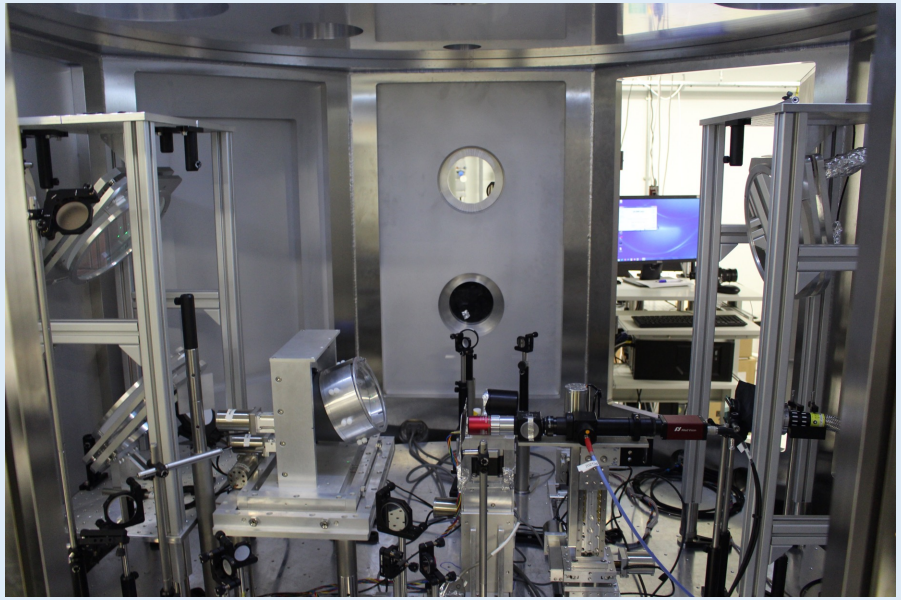
TASK DESCRIPTION	START	END	TYPE
O1 - Baseline Simulations (Lancaster)	01/10/2022	01/07/2024	
Convergence Testing and Benchmarking	01/10/2022	01/12/2022	R
Hydrodynamic modelling of laser contrast	01/12/2022	01/03/2023	R
2D PIC modelling of TNSA for proton acceleration on SCAPA	01/03/2023	01/06/2023	R
3D 'full scale' simulations for proton acceleration on SCAPA	01/05/2023	01/09/2023	R
2D PIC modelling of TNSA for heavy ion acceleration on SCAPA	01/09/2023	01/03/2024	R
3D 'full scale' simulations for heavy ion acceleration on SCAPA	01/03/2024	01/07/2024	R
O2 - Diagnostic Package (Strath/IC)	01/10/2022	01/04/2023	
Concept design for diagnostic platform	01/10/2022	01/01/2023	B
Testing preliminary ion diagnostics	01/01/2023	01/04/2023	B
O3 - Baseline SCAPA experiments (Strath)	01/04/2023	01/10/2024	
Experiment Planning, Design and Preparation	01/04/2023	01/07/2023	G
SCAPA ion source commissioning experiment	01/08/2023	01/09/2023	G
Data Processing and Analysis	01/10/2023	01/02/2024	G
Simulation Benchmarking and Iteration	01/10/2023	01/05/2024	G
Experiment Planning, Design and Preparation	01/04/2024	01/05/2024	G
SCAPA experiment on parametric optimisation of source	01/06/2024	01/07/2024	G
Data Processing and Analysis	01/07/2024	01/10/2024	G
O4 - Advanced targetry, debris and stablisation studies (IC/Lanc)	01/10/2022	01/10/2024	
Experiment Planning, Design and Preparation	01/10/2022	01/12/2022	P
Initial Baseline Experiment at IC for source characterisation and stability	01/01/2023	01/04/2023	P
Data Processing and Analysis	01/04/2023	01/07/2023	P
Experiment Planning, Design and Preparation	01/07/2023	01/01/2024	P
Base line experiment for debris and contaminant removal studies	01/12/2023	01/05/2024	P
Data Processing and Analysis	01/06/2024	01/10/2024	P
WP2 milestones			
M2.1: Prediction of optimised proton source for 100+ TW laser systems based on hydrodynamic and kinetic simulations	01/10/2023	01/10/2023	Y
M2.2: First SCAPA ion source simulations and experiment completed	01/04/2024	01/04/2024	Y



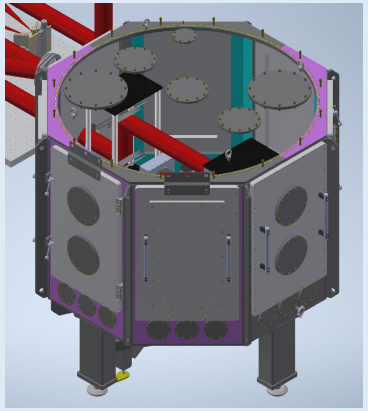
- Deliverables for the first two years are focused on early experiments and source benchmarking in simulations, as well as initial technology development in diagnostics and targetry.

- For the initial experiments we would ideally like to perform detailed, statistically significant parameter scans to establish and optimise the source performance.

SCAPA: Scottish Centre for Application of Plasma based Accelerators

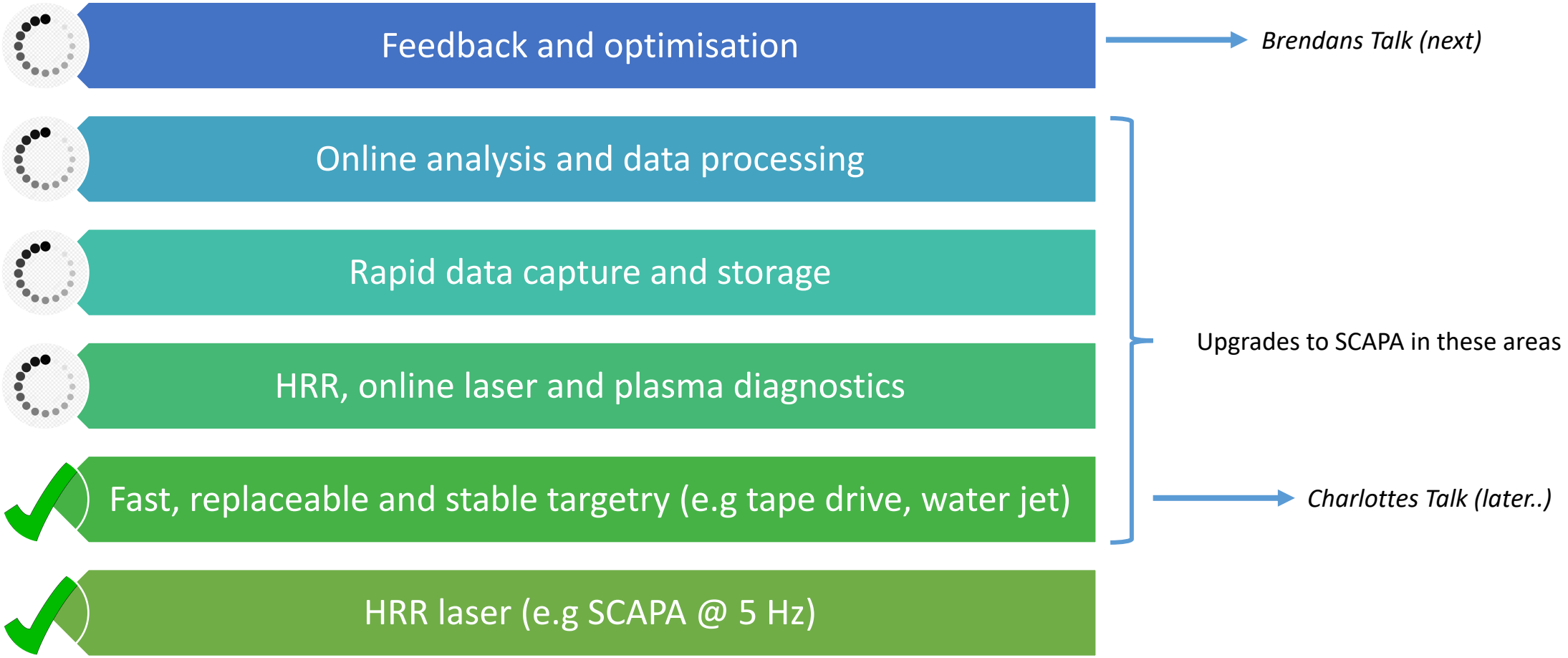


Laser-solid interaction beamline B1 in Bunker B.

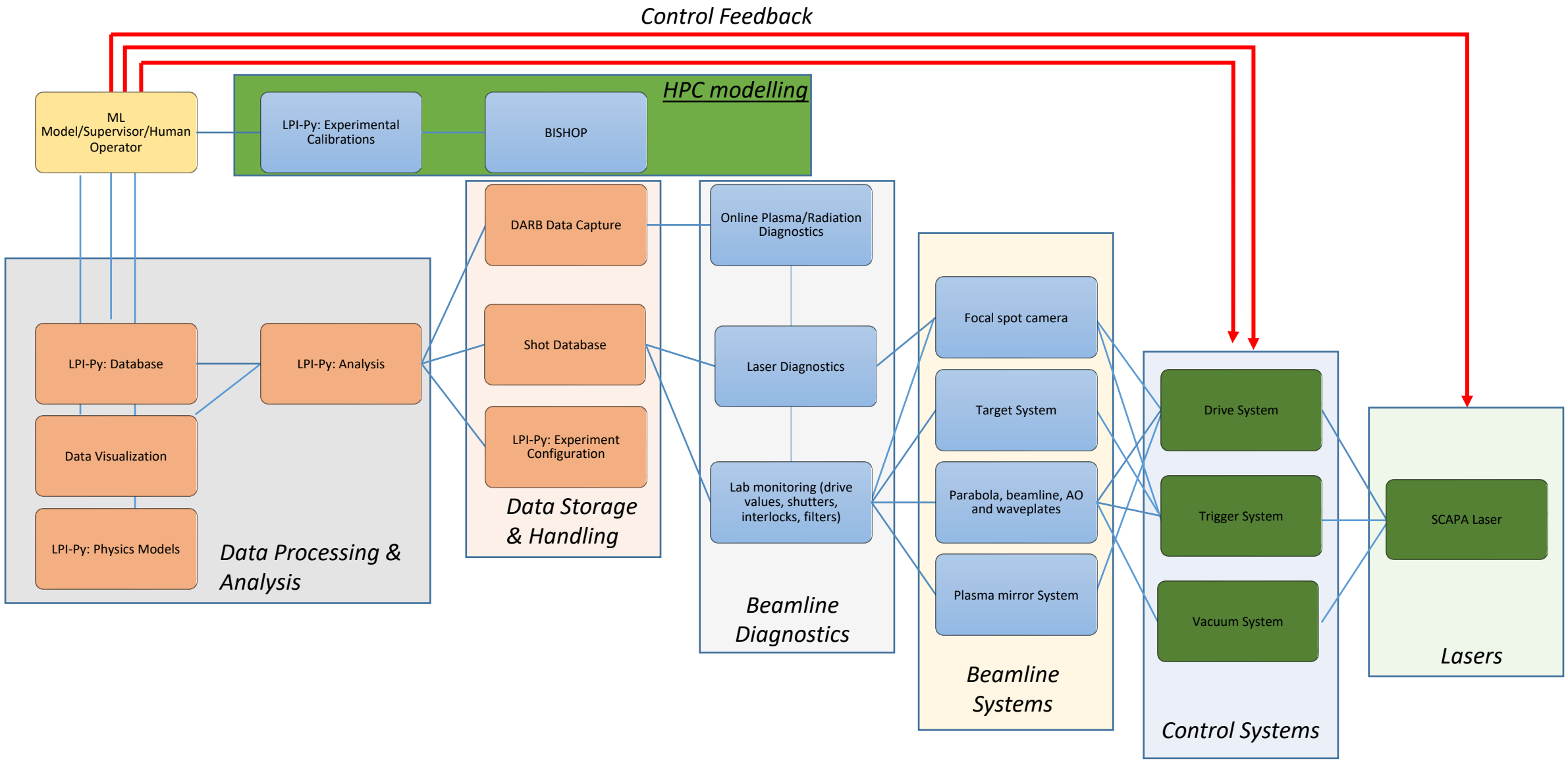


- 8 J, 25 fs at 5 Hz repetition rate up to ~10^{20} W/cm^2
- Three experimental areas (A,B,C) with Bunker B dedicated to ion acceleration

Achieving a continuous, optimised HRR source will require a set of integrated underlying technologies…

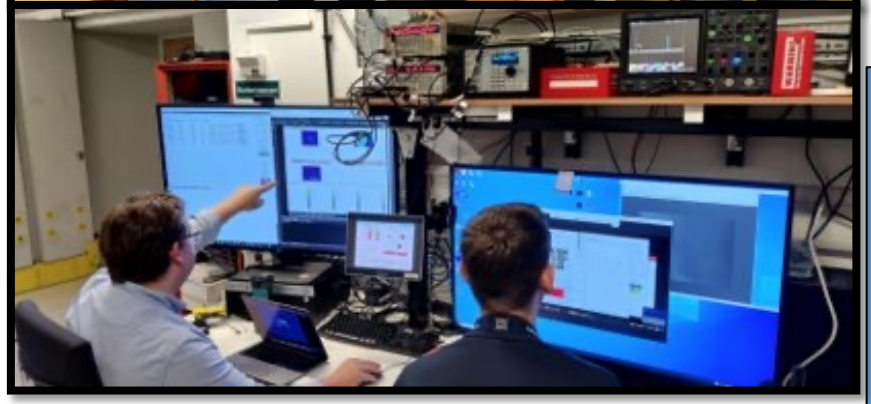


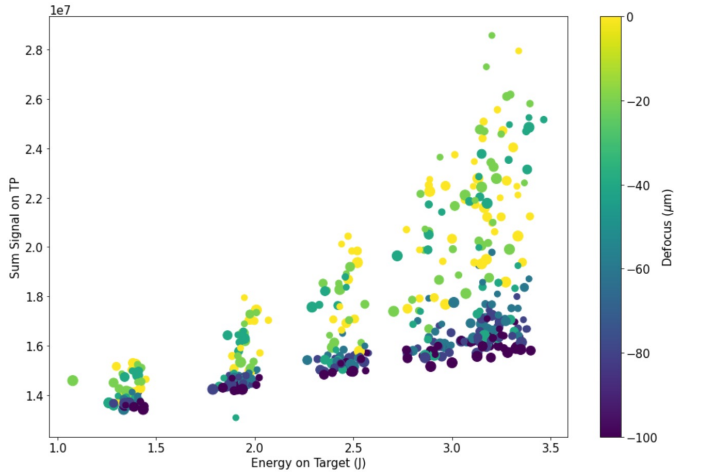
System diagram for HRR Scapa

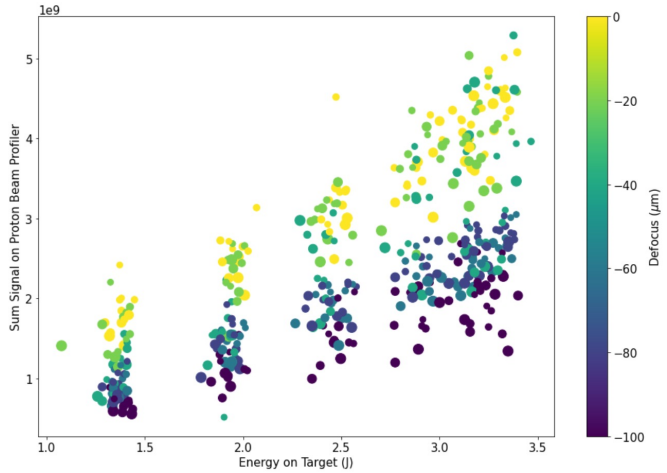


- Our ambition is to develop a highly integrated command and control system with high levels of automation

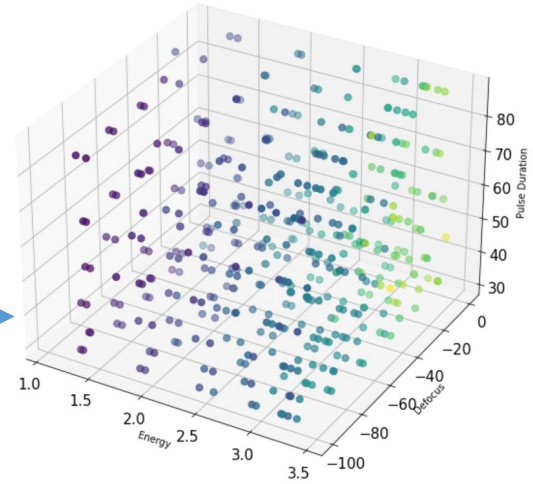
September SCAPA experiment (first beamtime in Bunker B)

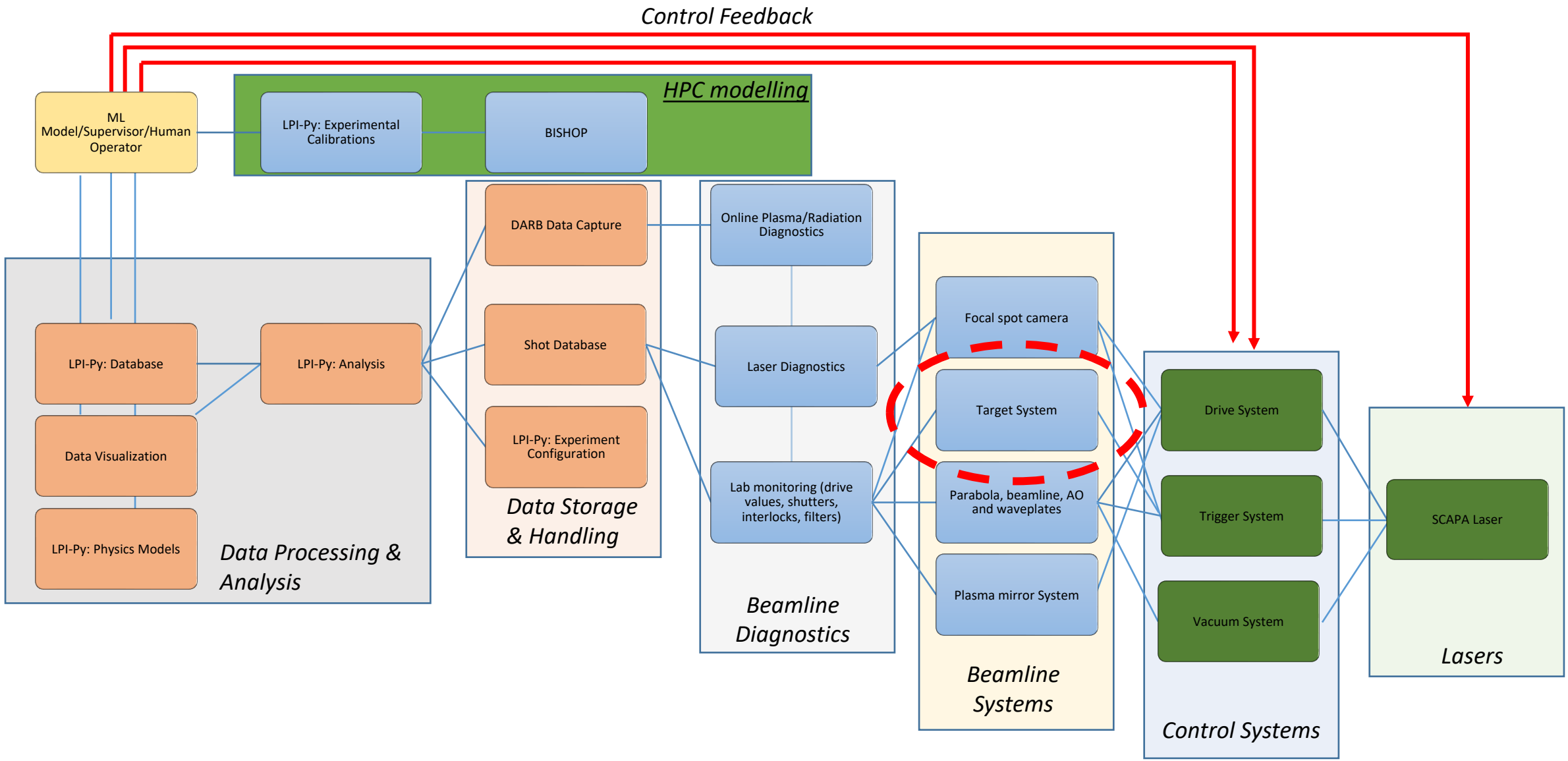






- 3D parameter space scan of pulse duration, laser energy and defocus measuring total proton energy
- ~450 shots taken over 4 hour period

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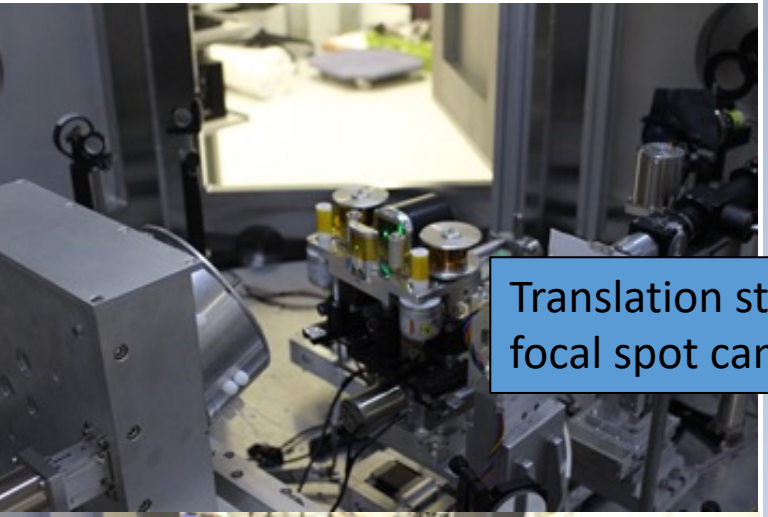
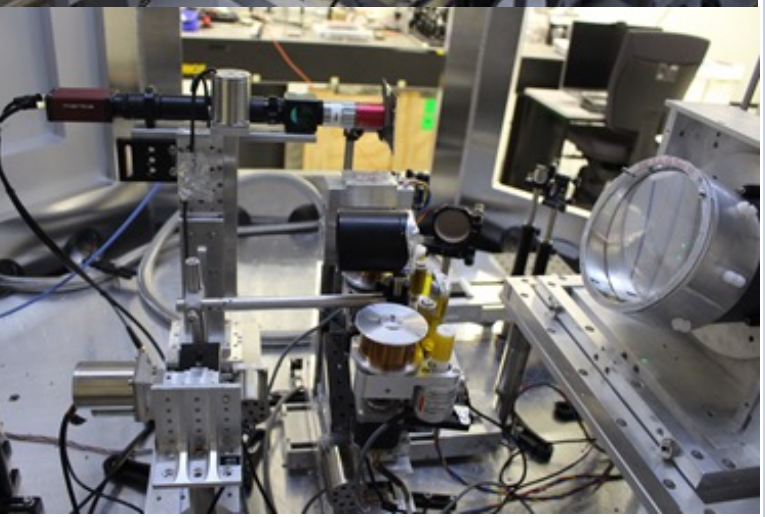
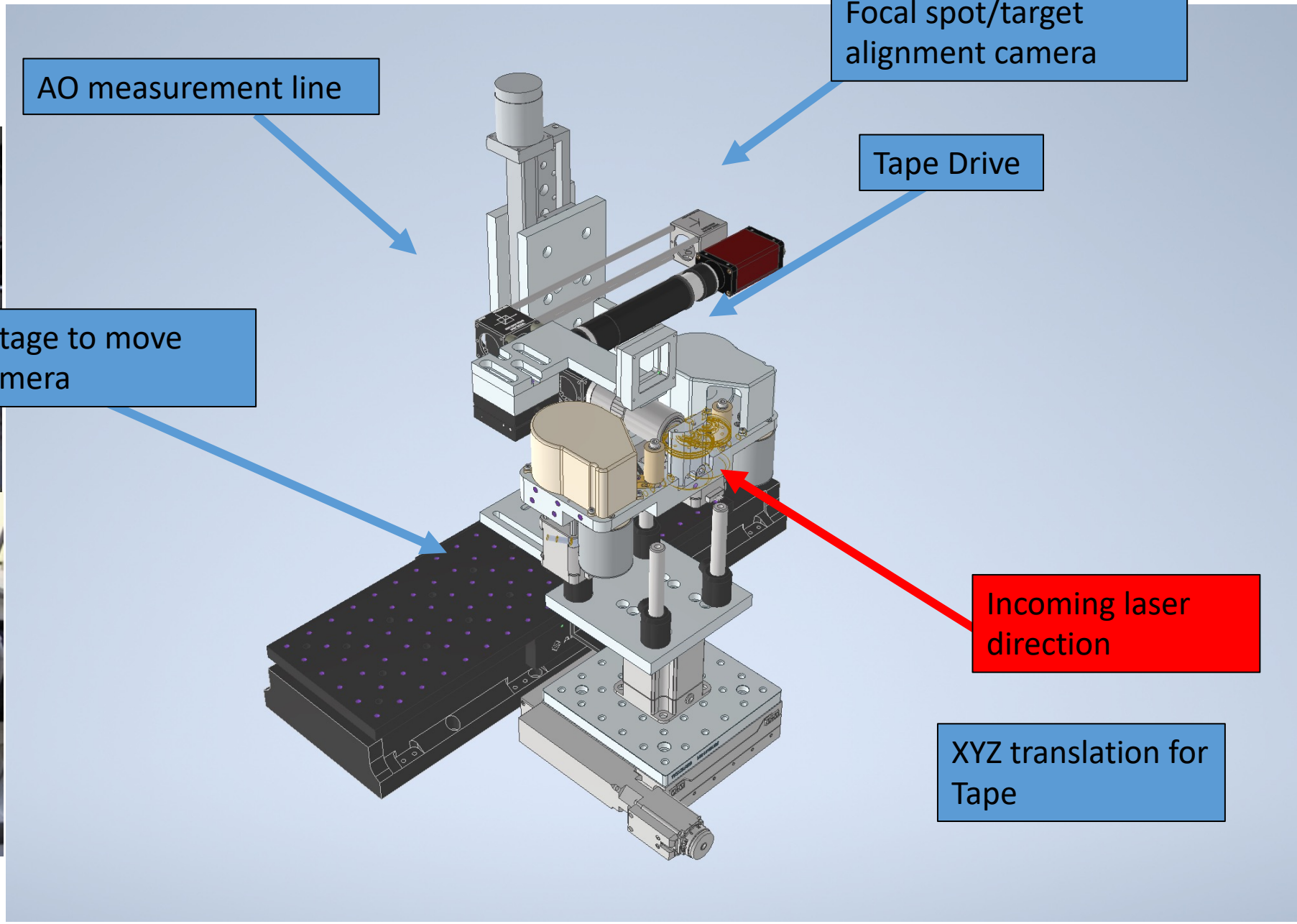
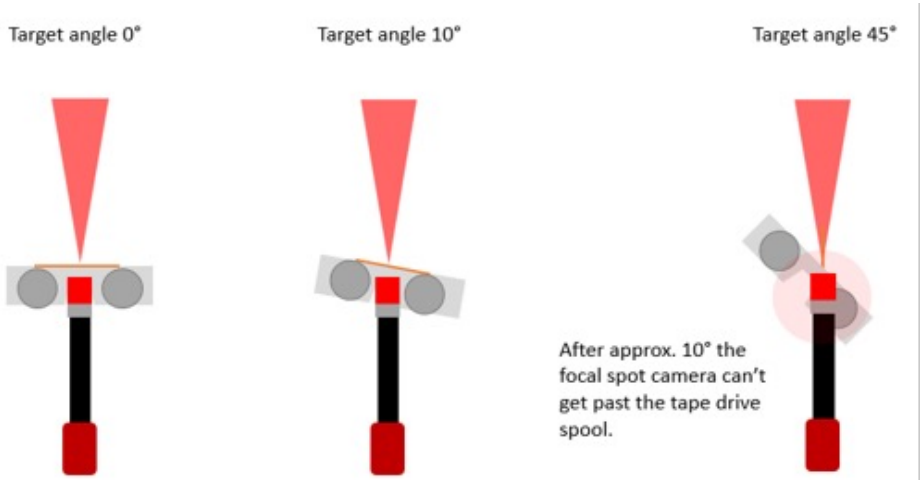
Update on tape targets



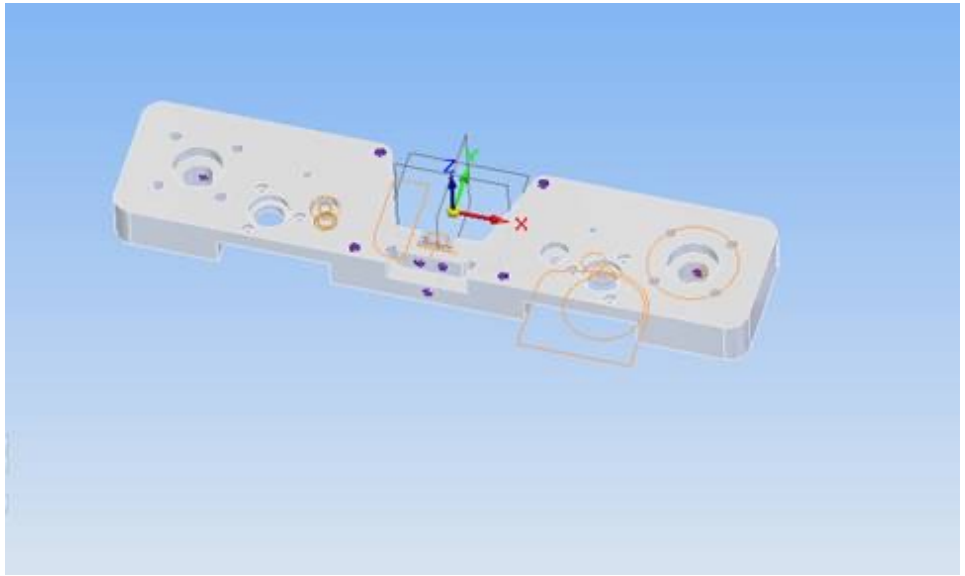




Update on tape targets



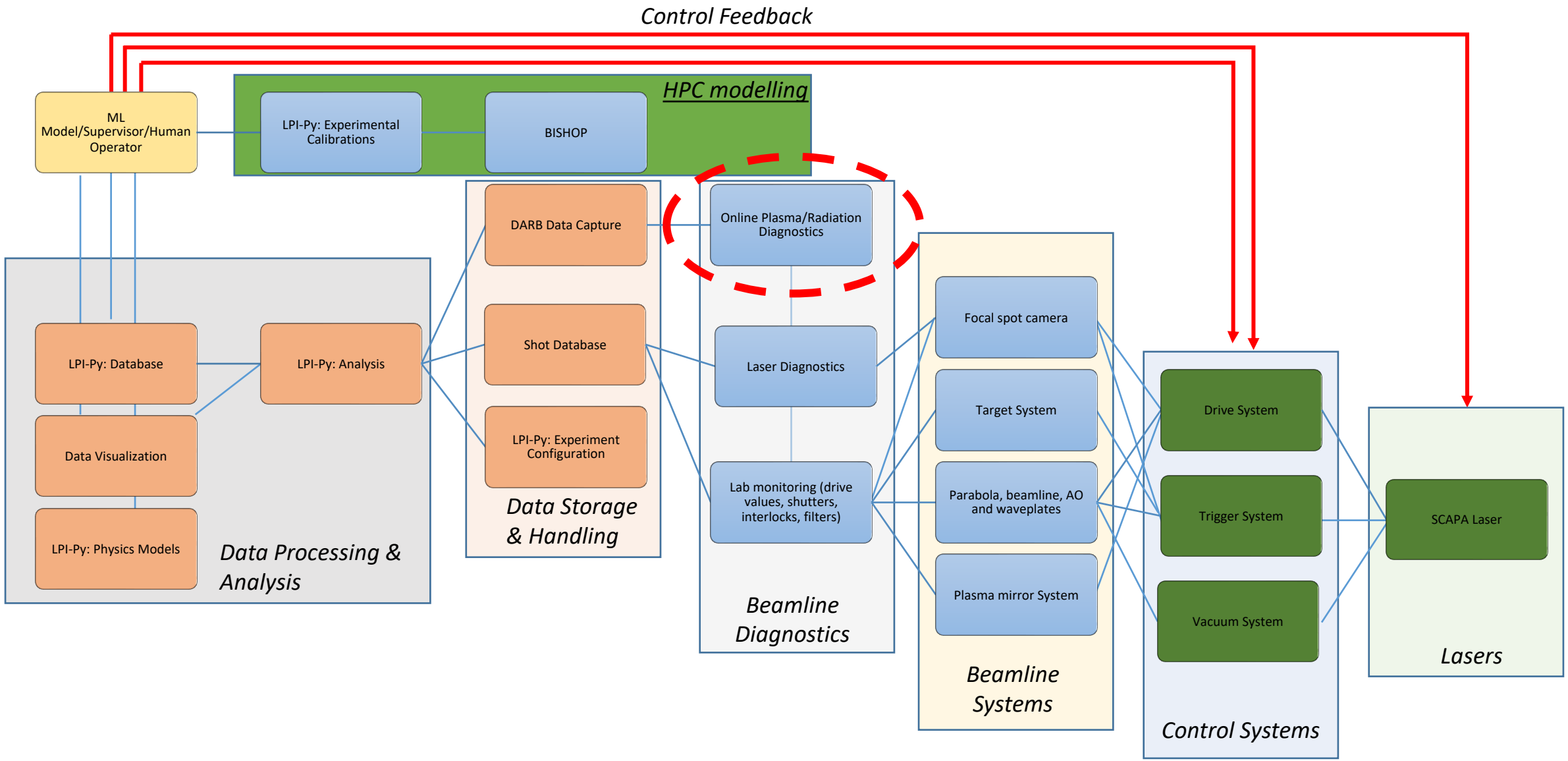
Target angle was limited by requirement for focal spot camera and tape reels



Updated base plate design

- Currently updating the base plate design increase the separation
- Some initial tests on thinned down targets worked but there are improvements needed for the horizontal stability of the tape, this is also being upgraded.
- We are also adding 'a triggered' mode to the controller so that the tape movement is synchronous with the laser

Debris and burn after 1000 shots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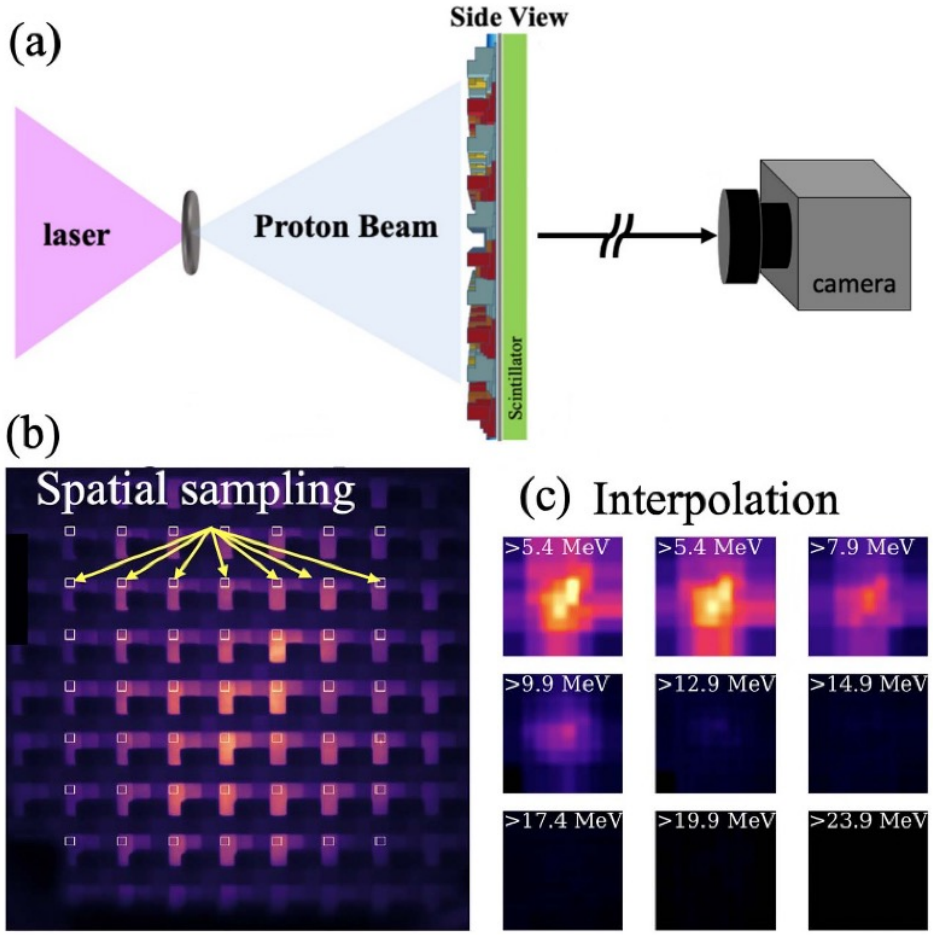
Update on beamline diagnostics

- Spatial-spectral profiler (pre-existing concept from LLNL)
- Repeating step filter units backed by a scintillator, uniformly sampling beam profile at varying energies
- Basic setup, positioned like an RCF stack and imaged from behind
- Interpolation of spatial samples reconstructs the beam profile at each energy bin

IOP Publishing
Plasma Physics and Controlled Fusion
Plasma Phys. Control. Fusion **63** (2021) 114003 (10pp)
https://doi.org/10.1088/1361-6587/ac234a

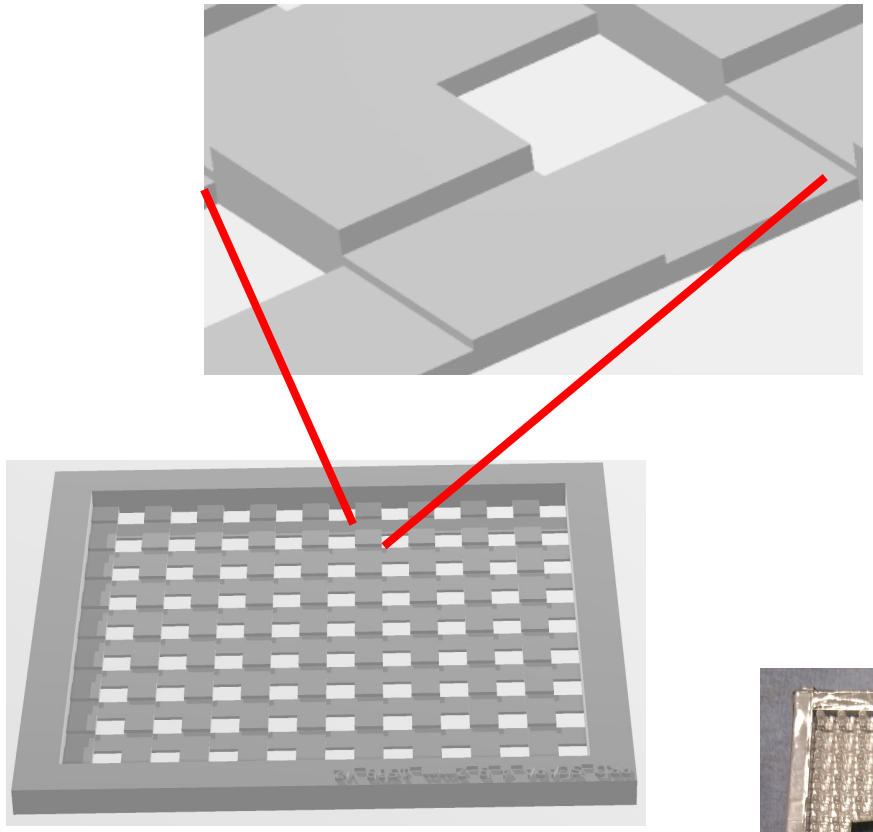
Design of flexible proton beam imaging energy spectrometers (PROBIES)

D A Mariscal[1,*], B Z Djordjević[1], E S Grace[2], R Hollinger[3], T Ma[1], G G Scott[1], H Song[3], R A Simpson[4], J J Rocca[3] and S Wang[3]

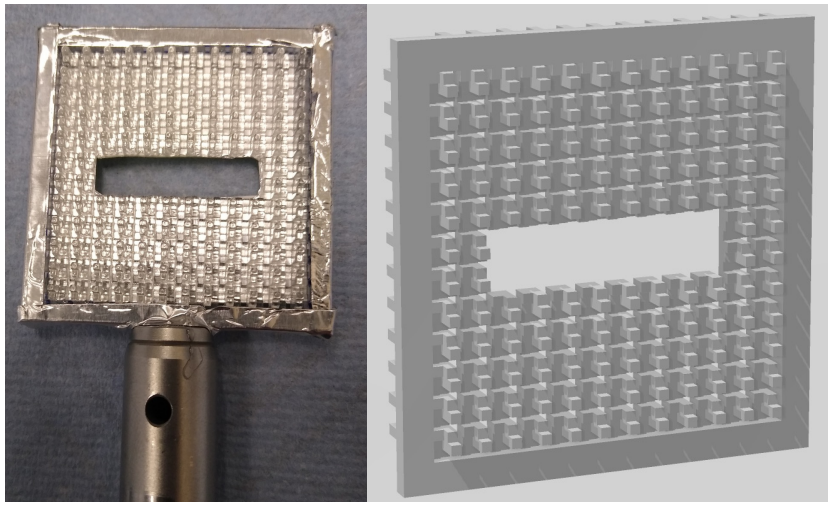


PROBIES

- Measurements are based on design of the filter
- Spatial and spectral resolution are inherently linked
- For example, altering the mask to boost spectral resolution means sacrificing spatial resolution



1000 um (1.1 MeV)	0 um (1.1 MeV)
750 um (9.6 MeV)	500 um (7.6 MeV)

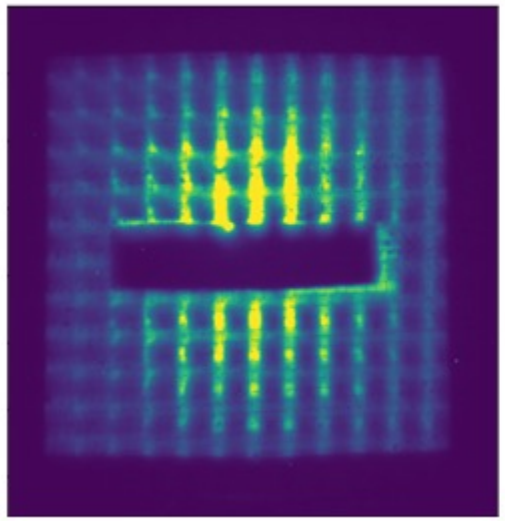


Upgraded design used on Gemini Nov/Dec 2022

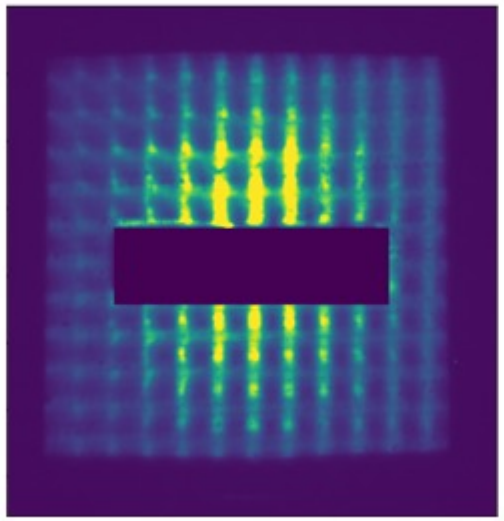
Gemini 2022

- Analysis of full spectrum still underway
- Reconstruction of the lowest energy bin shows the benefit of higher spatial sampling rate
- Diagnostic demonstrated as a high-repetition rate proton diagnostic

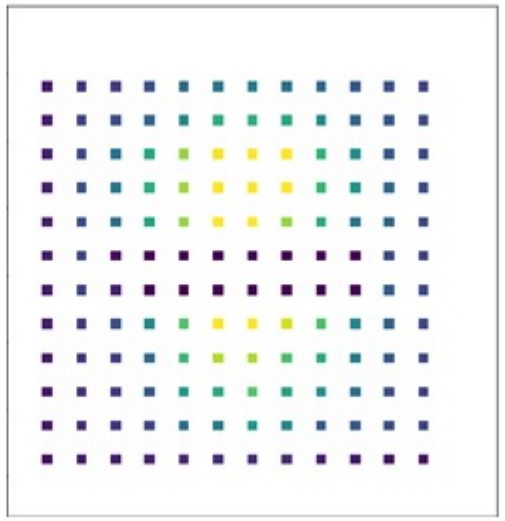
Raw Image



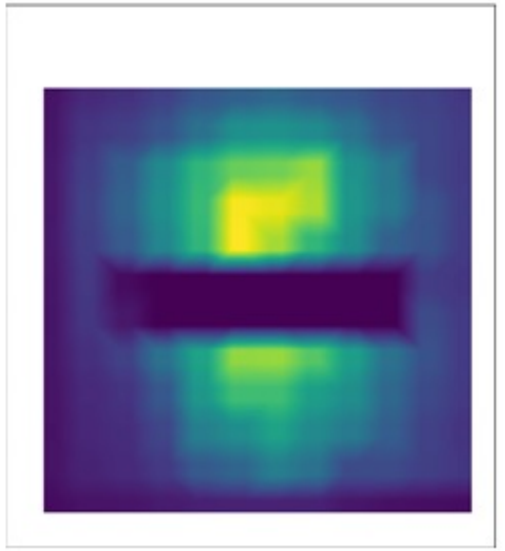
Filtered Image



Masked Pixels

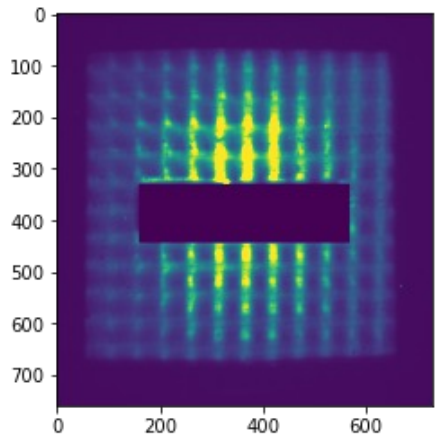


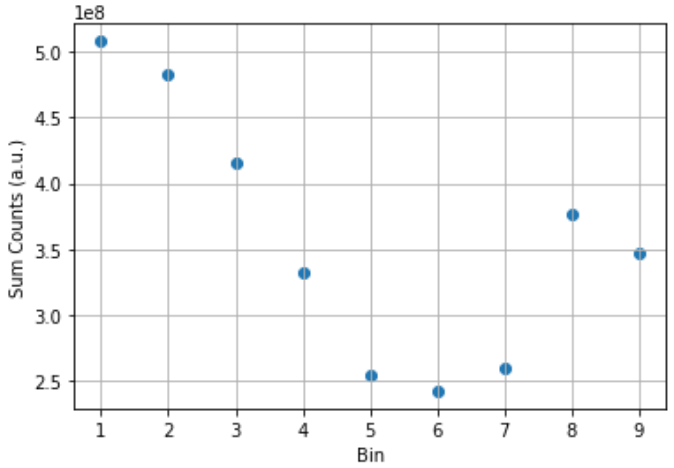
Interpolated Profile

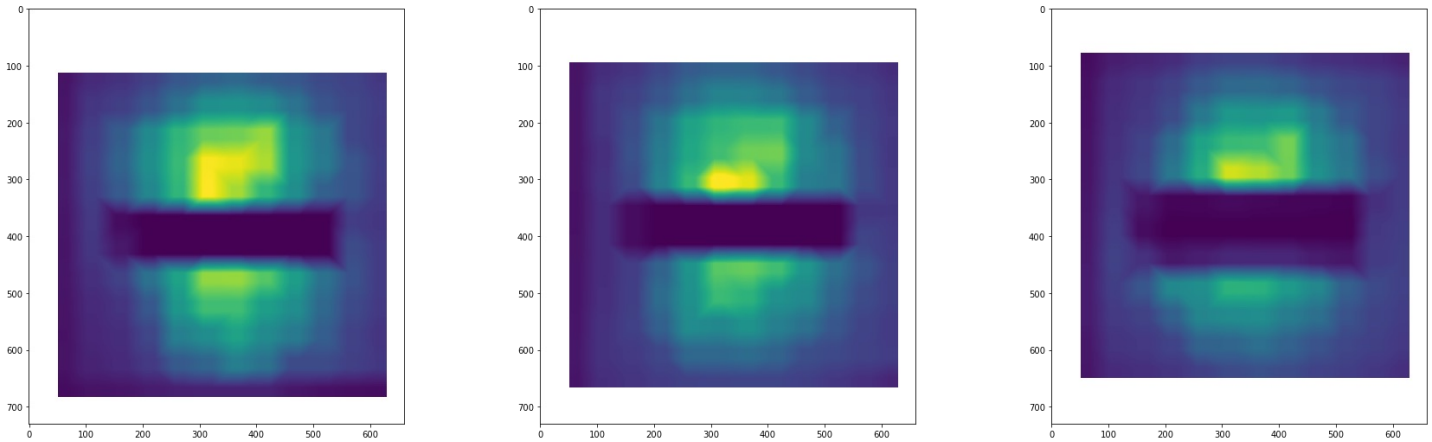


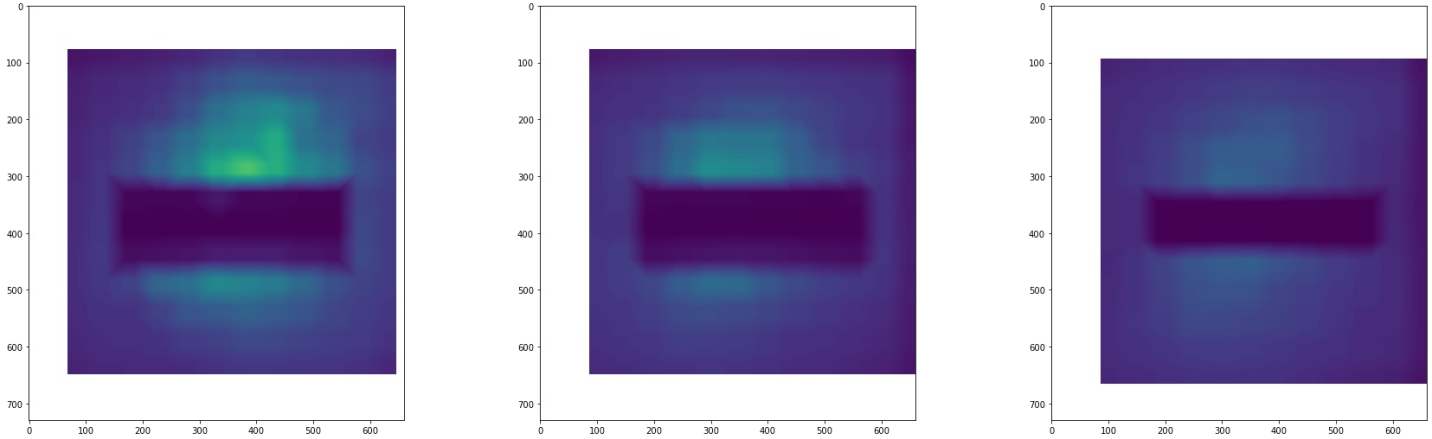
Gemini 2022

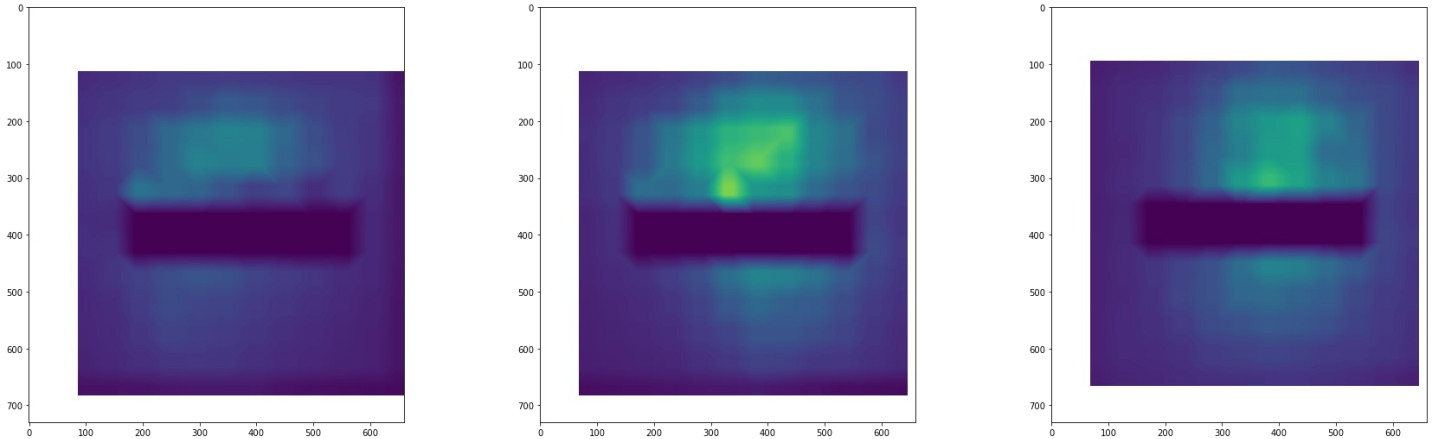
- Strong signal with small pixel size leads to signal bleeding across pixels







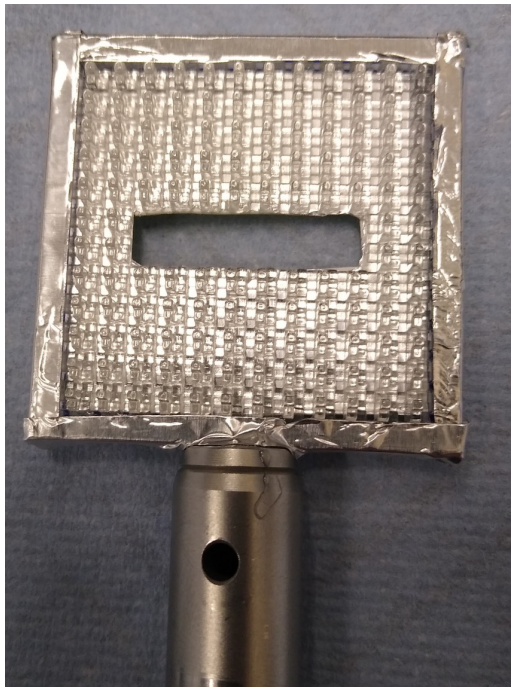


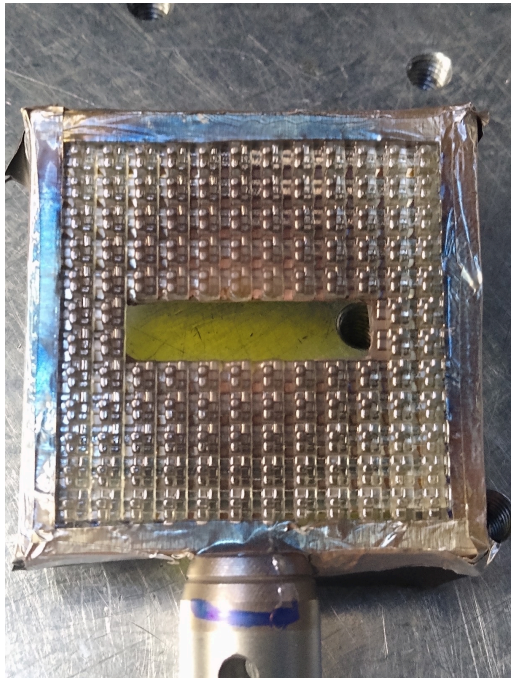


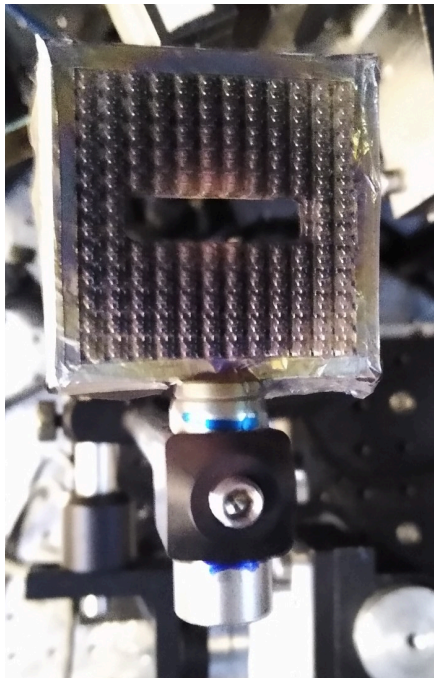
Potential Issues

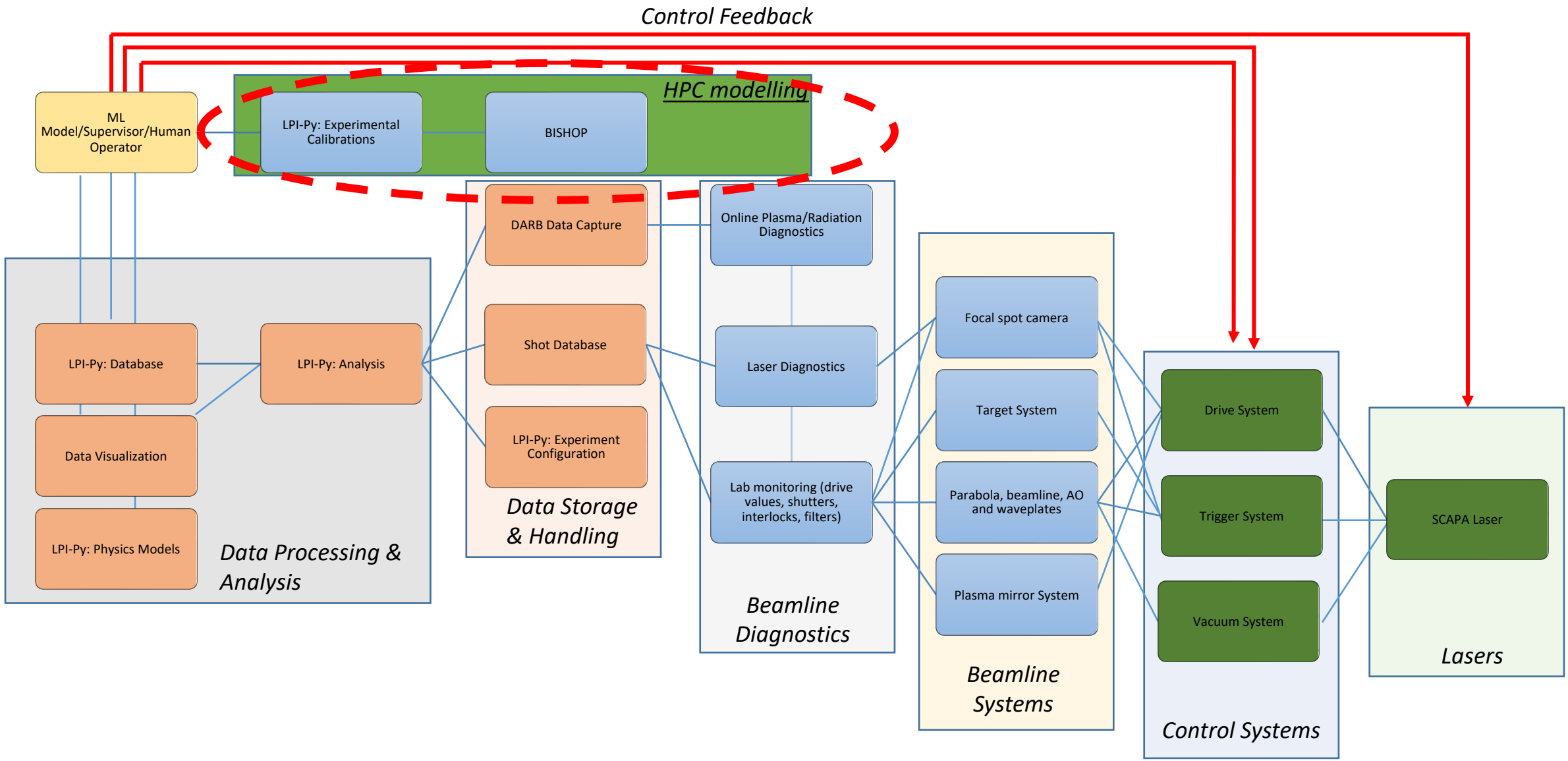
- Interpolation analysis is slow and not workable at 5 Hz – Neural network for analysis?

- Debris builds up quite quickly. The extent is not fully known and target dependent but worthy of further investigation





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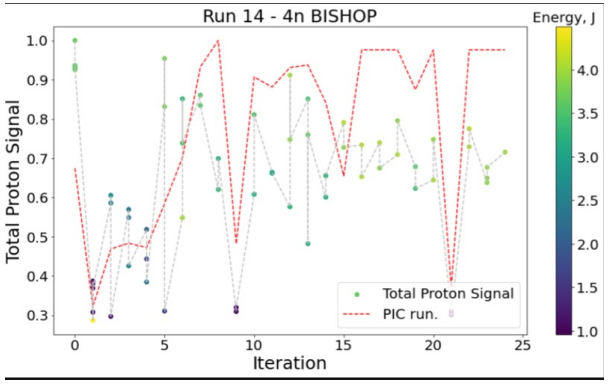
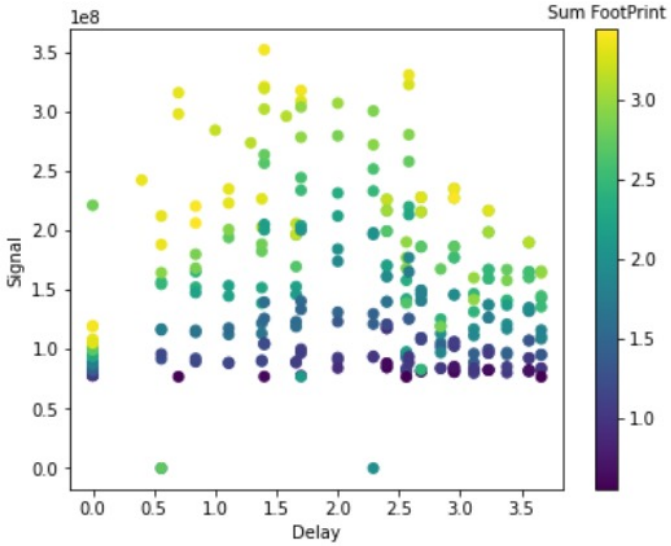
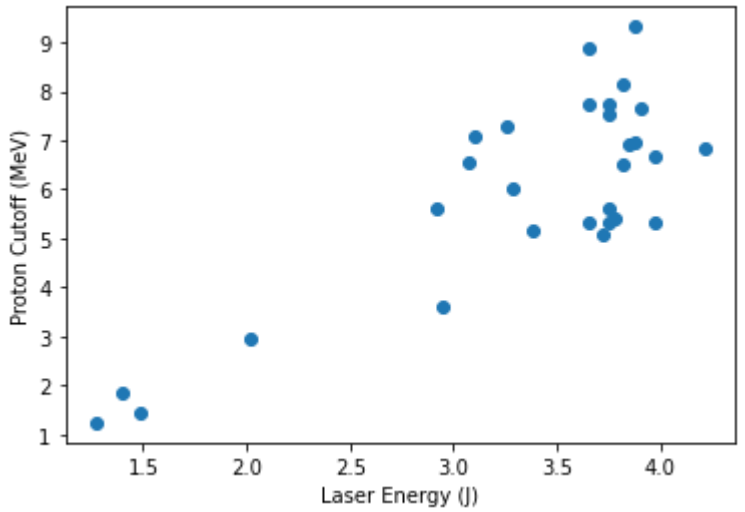
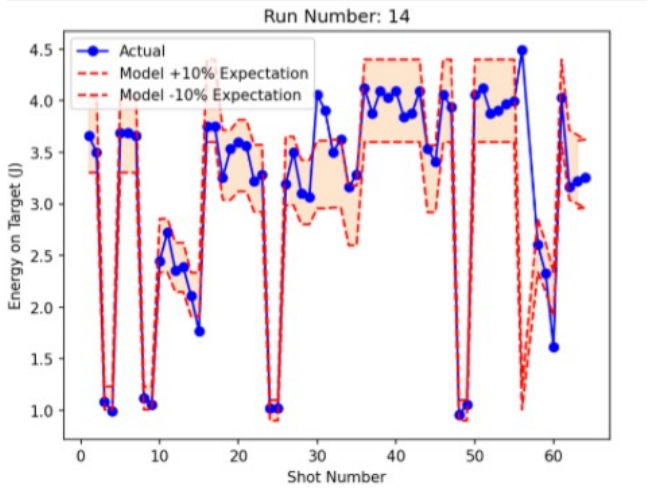
Gemini Nov/Dec 2022 - PIC guided Feedback

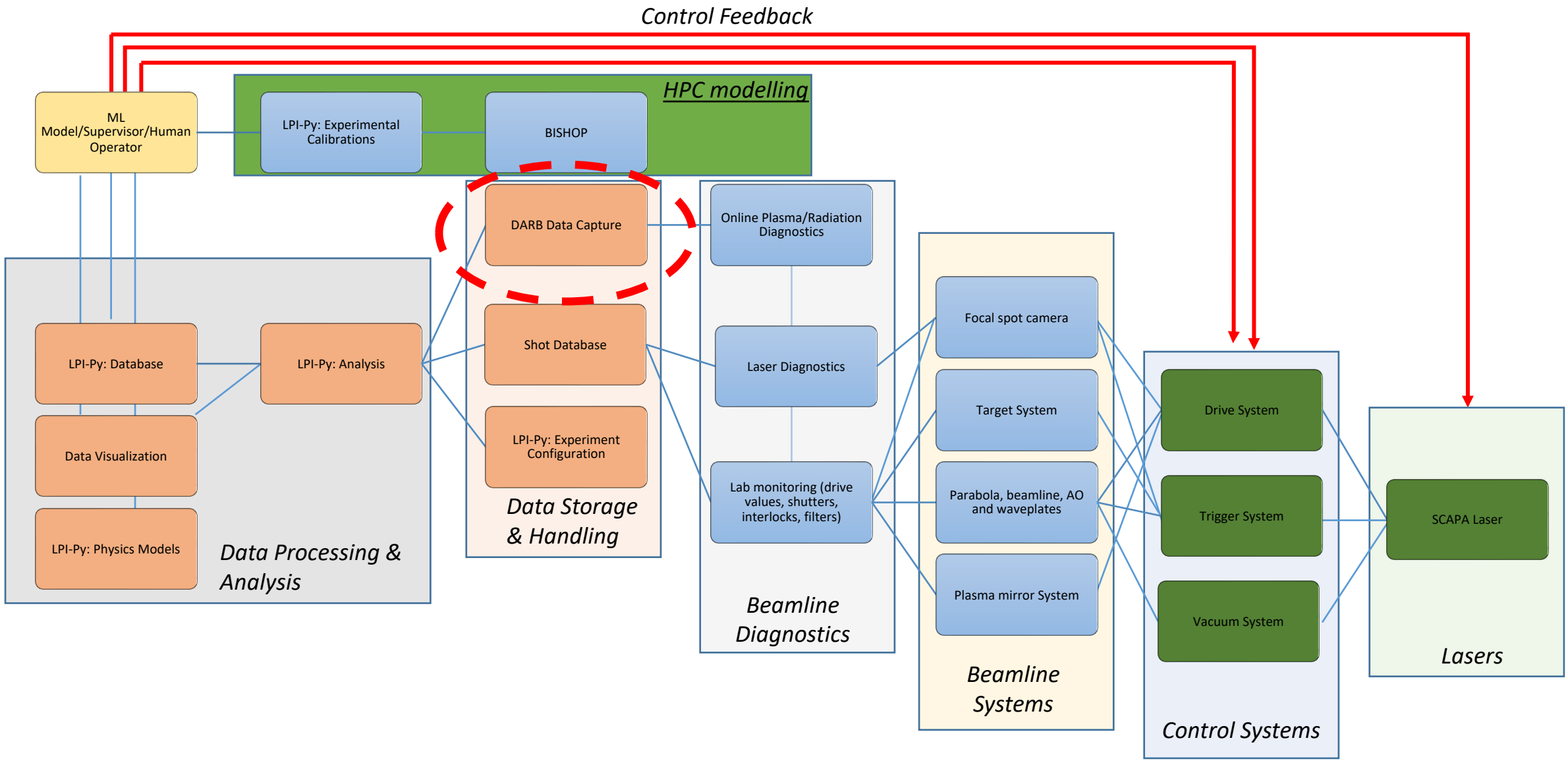








- Performed an experiment where input conditions and experimental settings were guided via Bayesian optimization of simulations
- Tuning of preplasma conditions is key and significantly helps with optimization
- Maximum cutoff energies of ~9 MeV at 4J suggest we might see >15 MeV at 8J on SCAPA but more to be done on target thickness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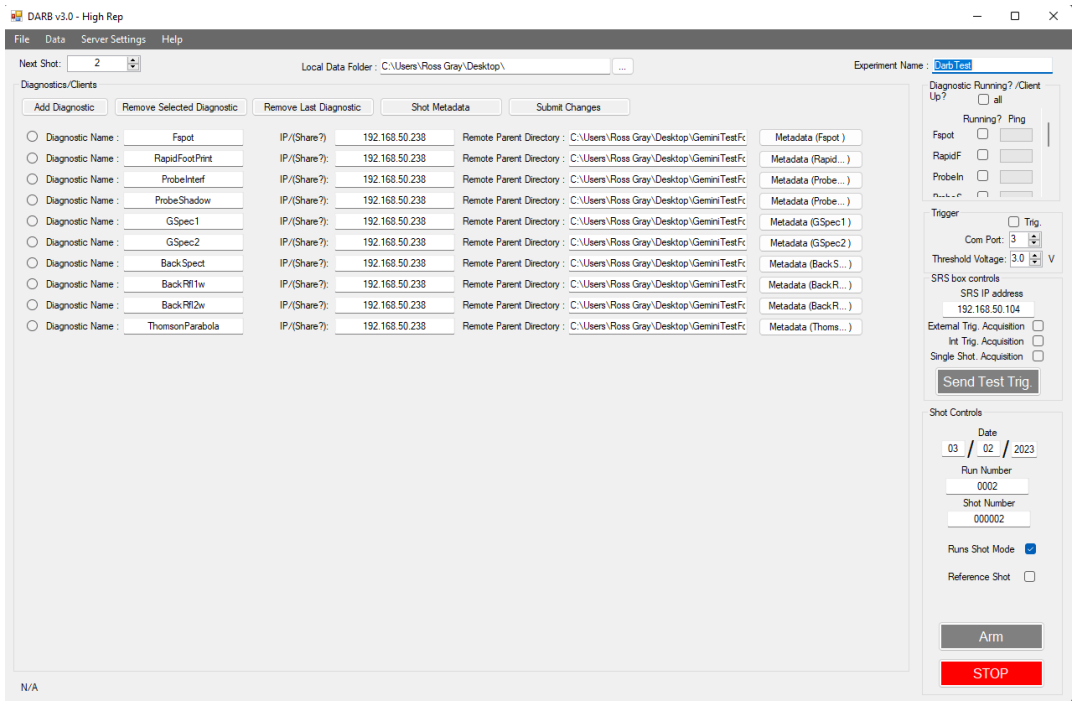
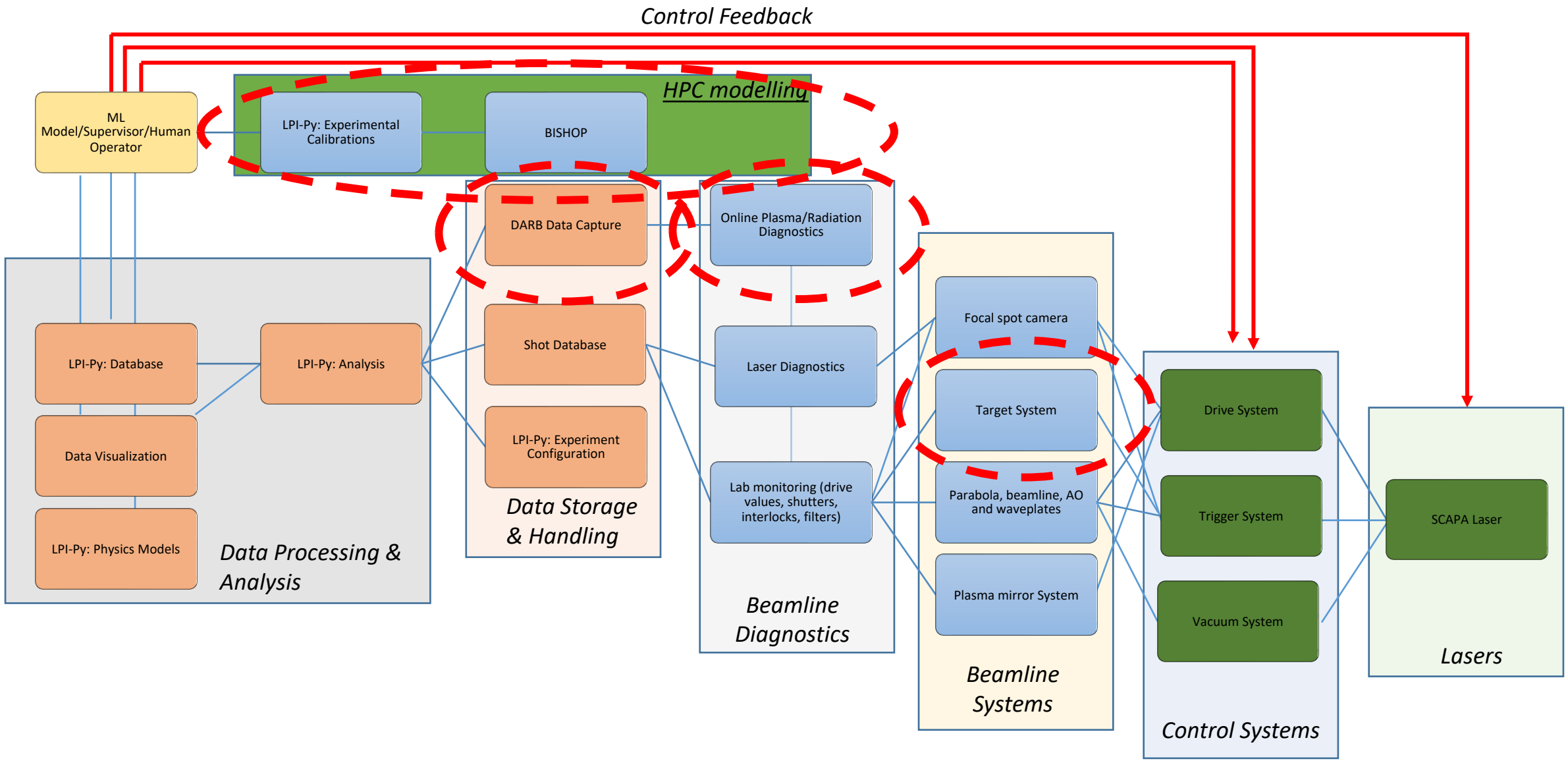
Data collection at 5 Hz – DARB V3.0



- Data collection system we developed at Strathclyde ~10 years go and have used on many different laser systems.
- Initially designed for high energy, low rep systems with a client-server model
- Complete rewrite of the backend and data transfer changed to “publisher-subscriber” model with data transfer that is asynchronous with shot.
- System is now hardware limited but >10 Hz demonstrated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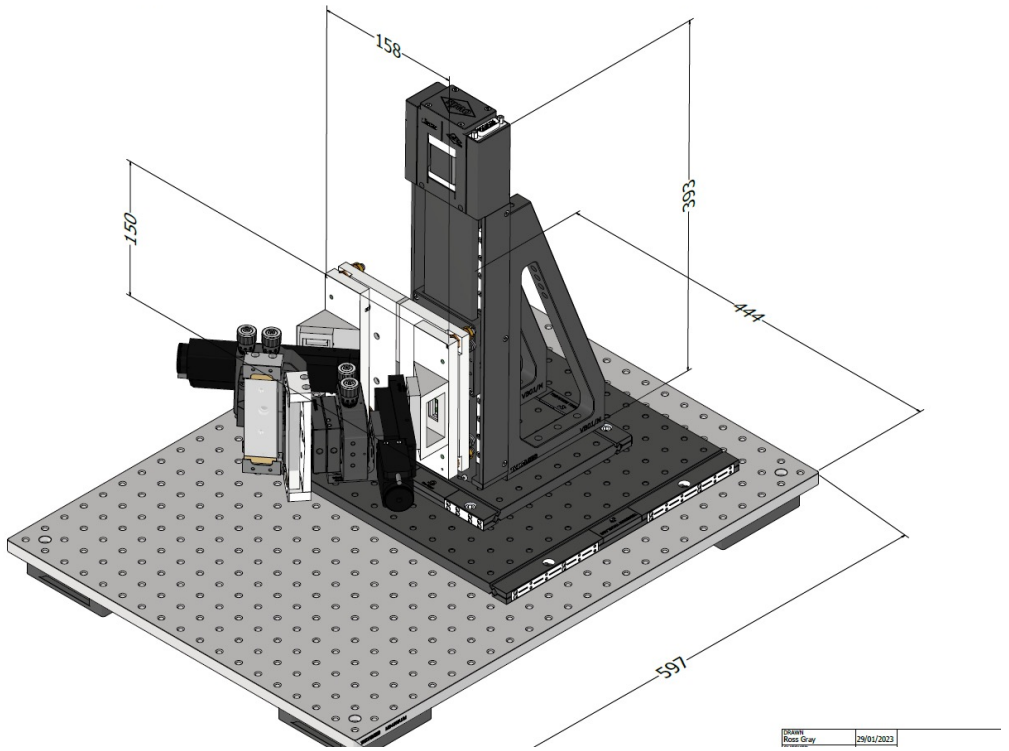
September SCAPA experiment (first beamtime in Bunker B)…main lessons

Issue	Action
1. Maximum proton energy measured up to 5 MeV with half laser energy	We need > 15 MeV. Higher laser energy (will double in next run) but thinner targets and contrast control likely required
2. High repetition rate (1 Hz +) possible but limited by data transfer/capture	Updated data capture system
3. Angle of incidence limited by tape drive design	Updated tape drive design
4. Tape drive horizontal stability needs to be improved	Adding position monitoring and updated drives
5. Laser contrast control required	Adding PM system in march and prepulser beamline
6. Online diagnostics operational but background subtraction and beam analysis needs to be improved	Working on a multichannel “two colour” design to improve electron background measurement

Upcoming Beamtime……Scheduling

SCAPA



- Short commissioning run now scheduled at end for March to bring the plasma mirror system online
- This will support the move toward thinner targets
- <u>W/B 17th July is now scheduled for the first LhARA beamtime</u>

Thanks To Our Collaborators

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LhARA Collaboration

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H. Ahmed and C. Armstrong

Target Fabrication, (CLF)

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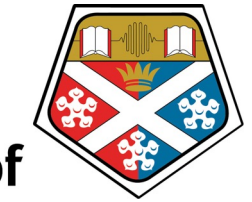

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The Cockcroft Institute of Accelerator Science and Technology