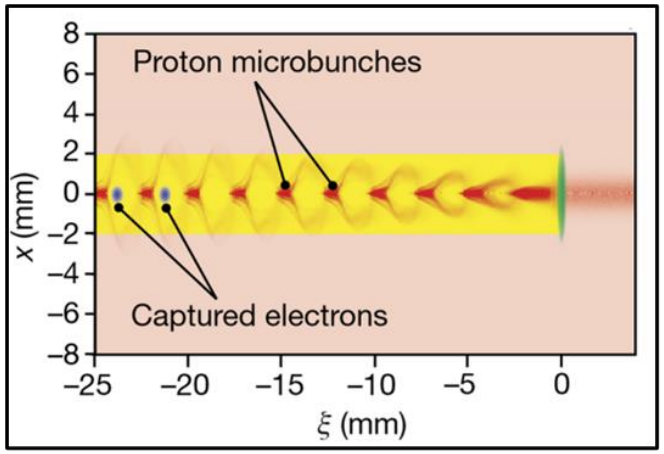
Lancaster University

Timing & Synchronisation Updates for Run 2c

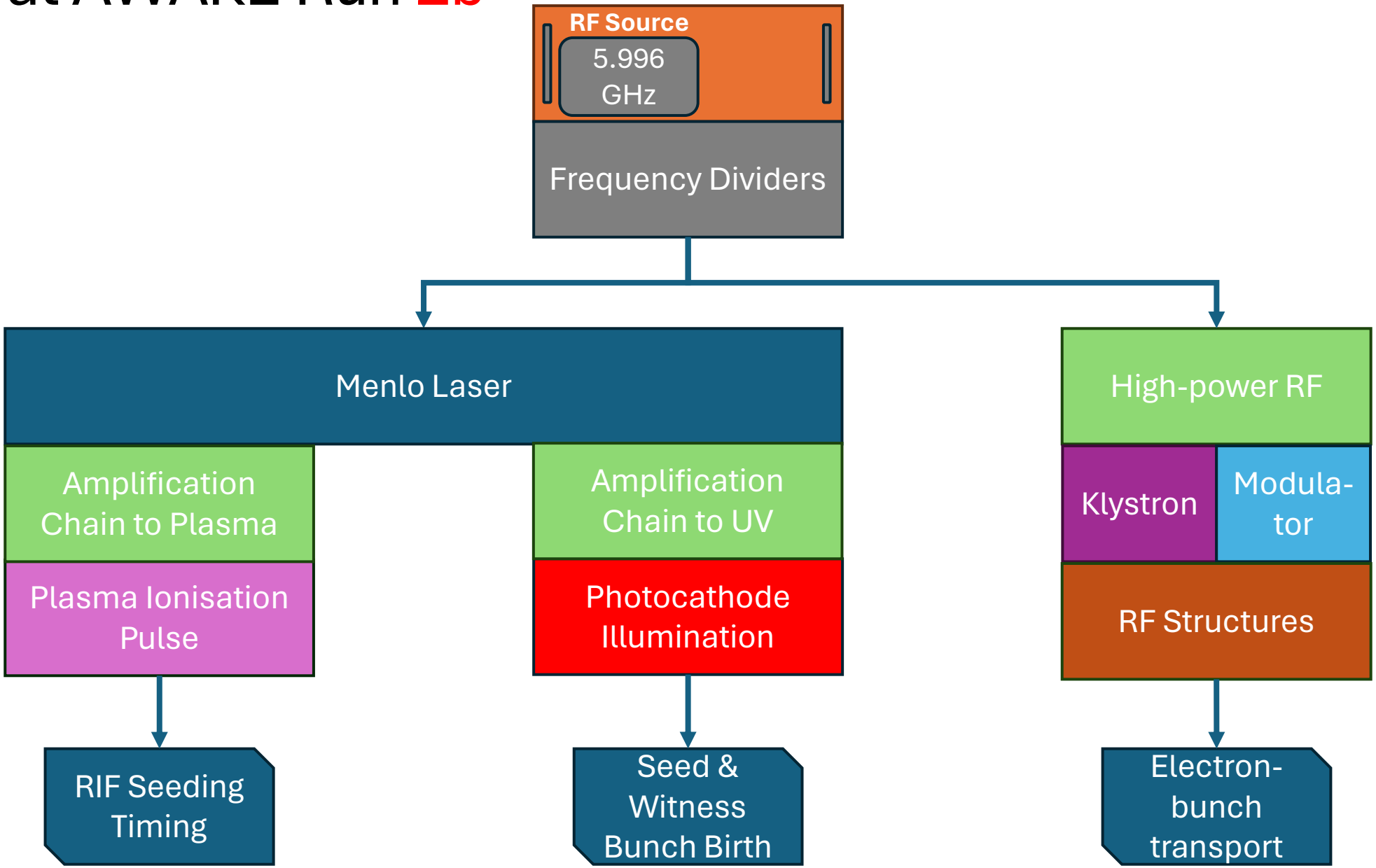
Joshua Gregory

Timing at AWAKE Run 2c

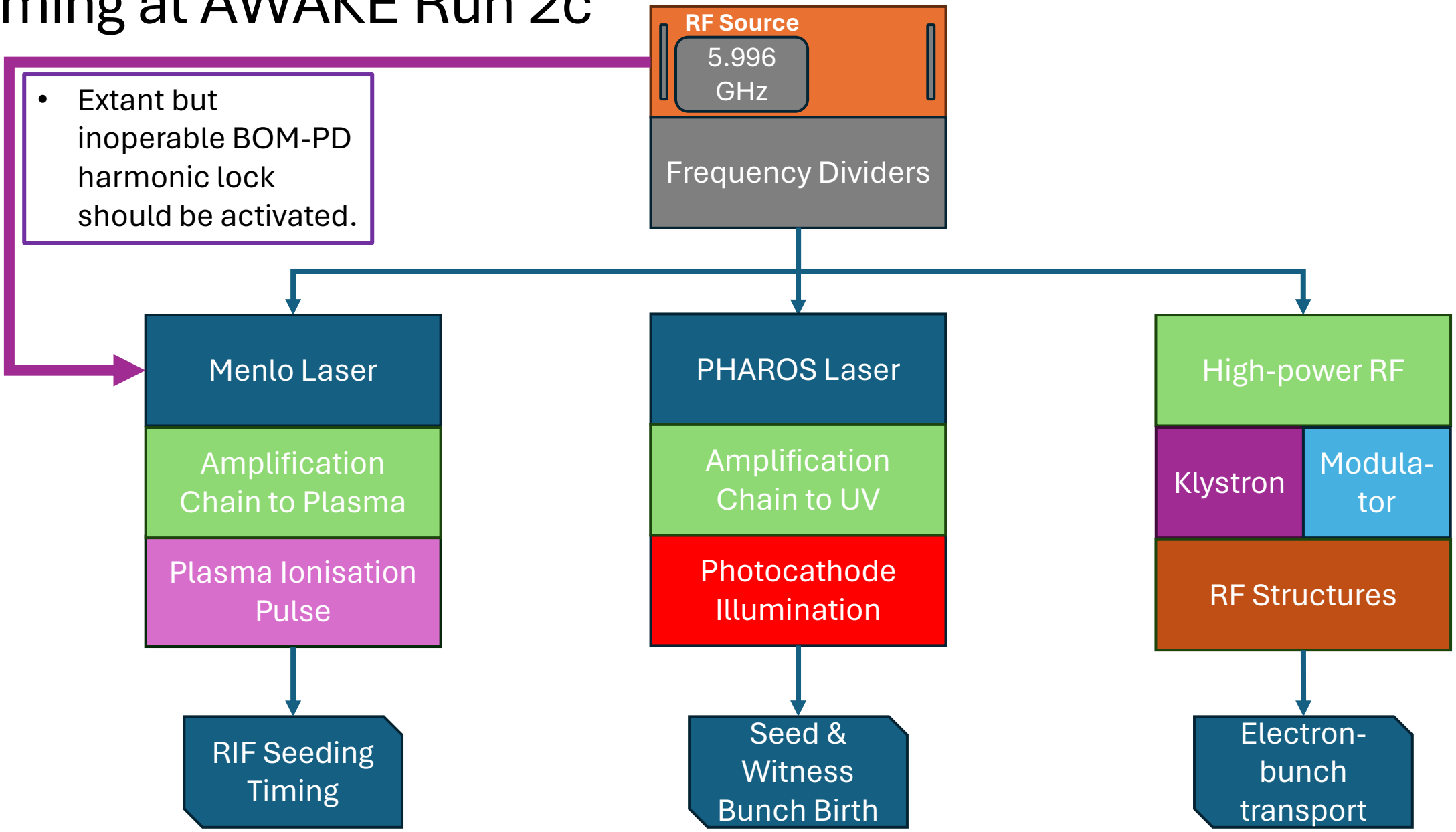
- Basic graphic shows three avenues of timing distribution which ought to be stable.
  - RIF Seeding Laser Pulse
  - Electron injection times.
  - (Lesser degree) electron-bunch acceleration and transport.



Timing at AWAKE Run 2b



Timing at AWAKE Run 2c

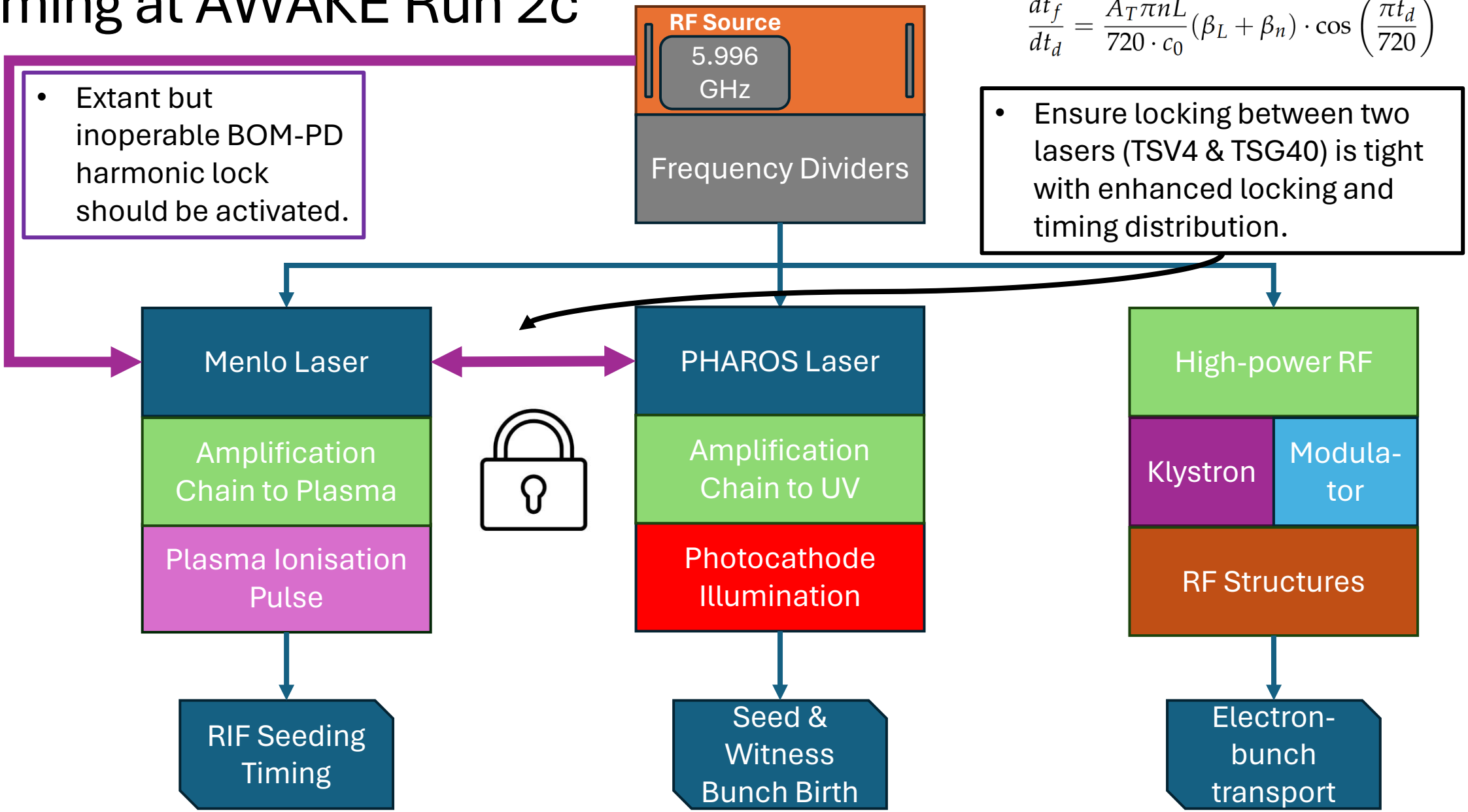


Timing at AWAKE Run 2c

$$\frac{dt_f}{dt_d} = \frac{A_T \pi n L}{720 \cdot c_0}(\beta_L + \beta_n) \cdot \cos\left(\frac{\pi t_d}{720}\right)$$

- Extant but inoperable BOM-PD harmonic lock should be activated.

- Ensure locking between two lasers (TSV4 & TSG40) is tight with enhanced locking and timing distribution.



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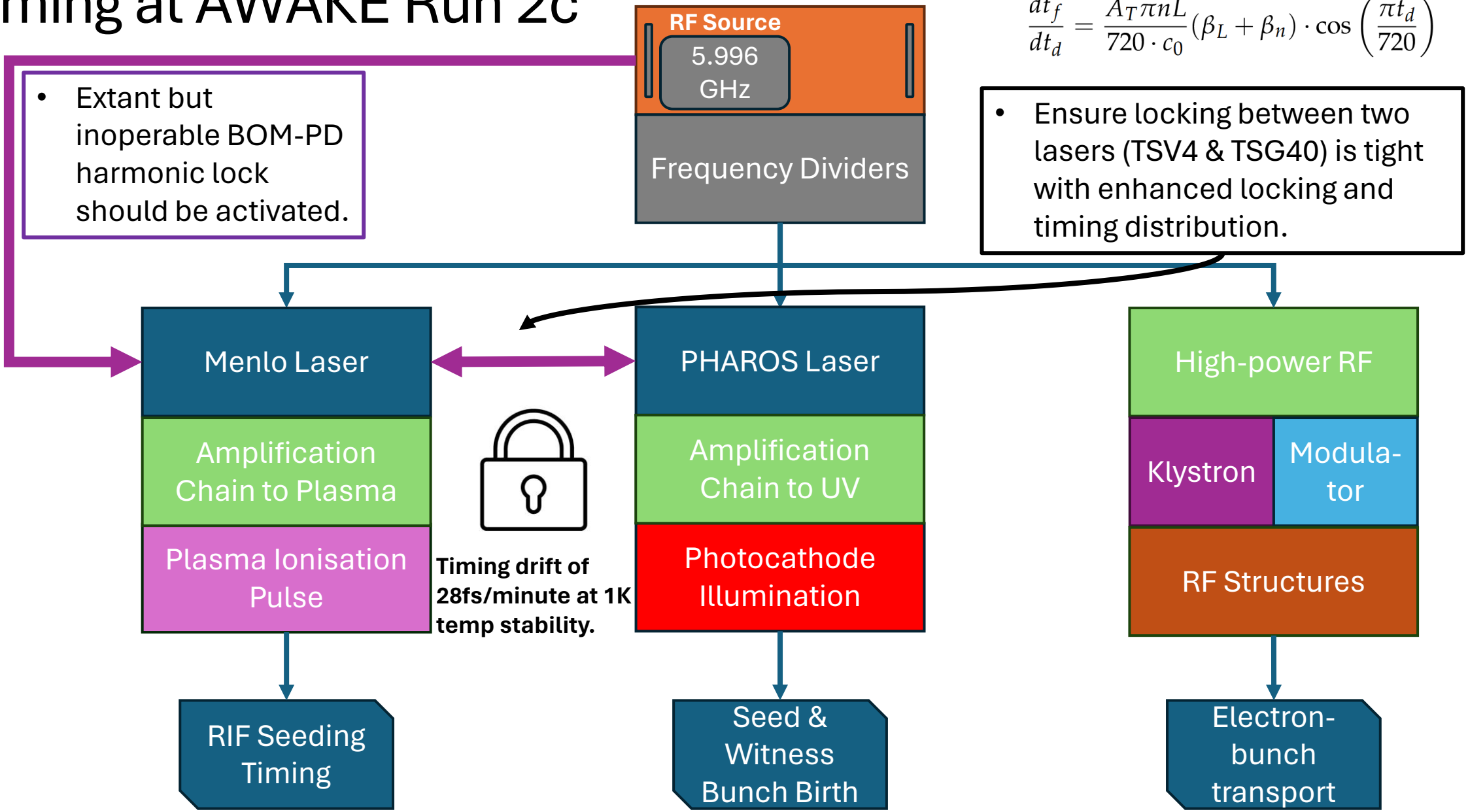
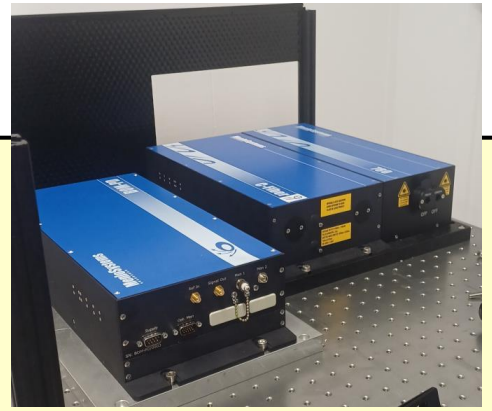
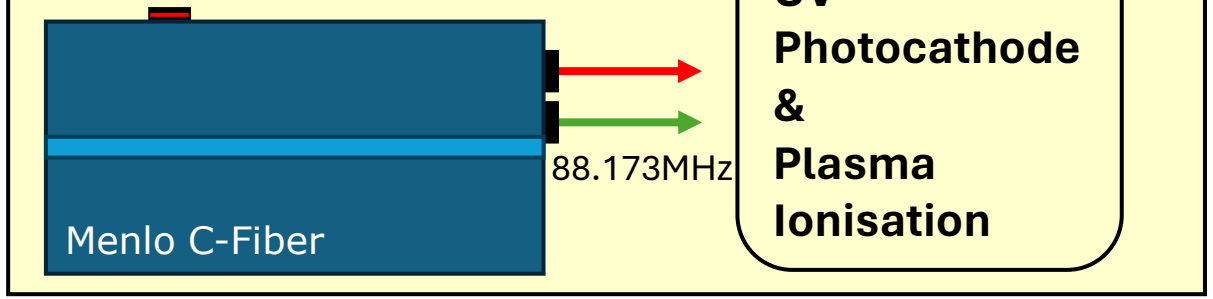
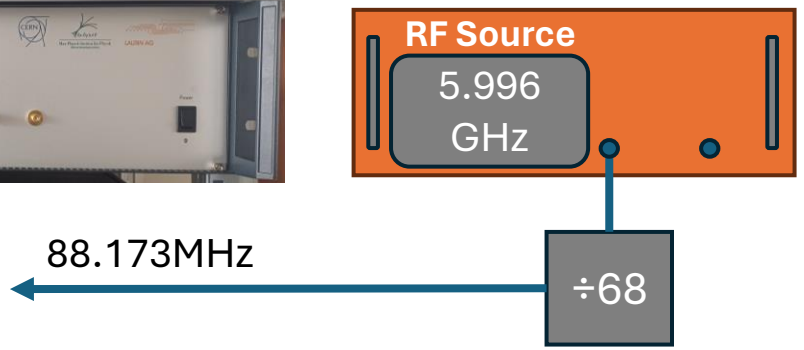


AWAKE Optical Sync - Tunnel

- Menlo LASER oscillates with 88MHz rep-rate.
- RF Oscillator oscillates at 5.996GHz, but is divided by 68 to obtain 88MHz by VME crate card. (Actually ÷2, ÷2, ÷17). Division adds phase noise!







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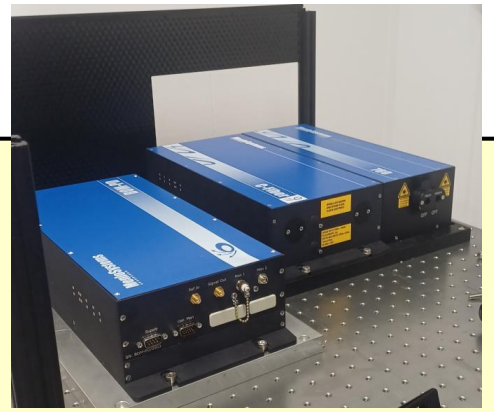
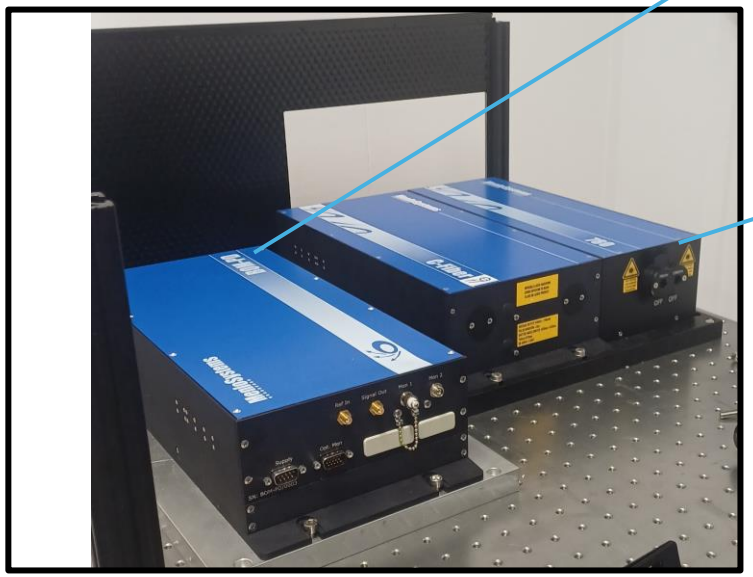
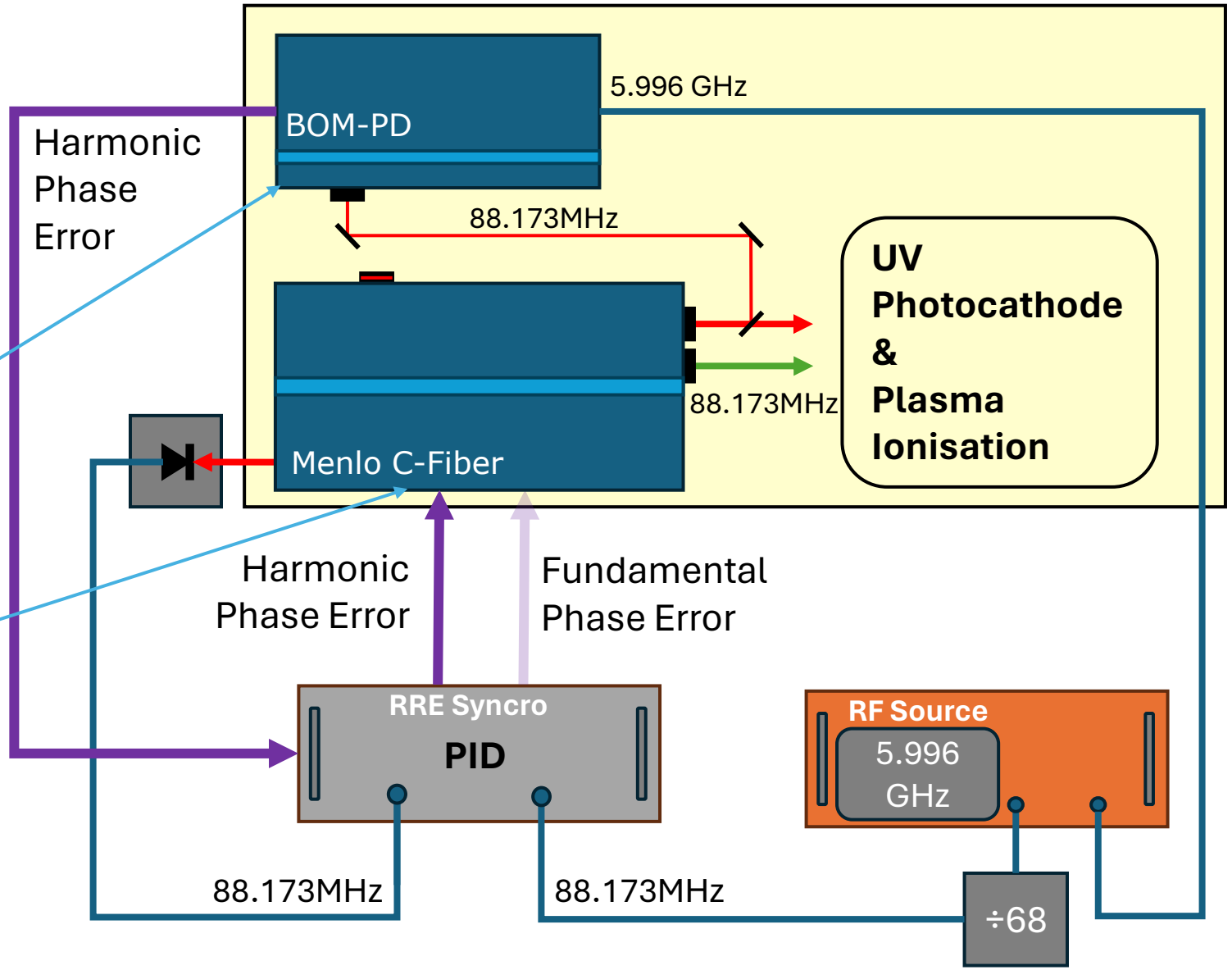
- LASER fundamental harmonic tapped from oscillator and phase-error is measured by MENLO RRE Synchro phase-locked-loop system.
- Attains 870fs (measured) / <200fs (advertised) RMS jitter (0.1Hz – 500kHz).
- Setup used throughout Run 2b.



AWAKE Optical Sync – Tunnel

- Max performance obtained with BOM-PD, as installed in 2015(?) but never used during Runs.
- Advertises <10fs RMS jitter (3Hz – 1MHz), but locking lost frequently, and dubious power coupling.





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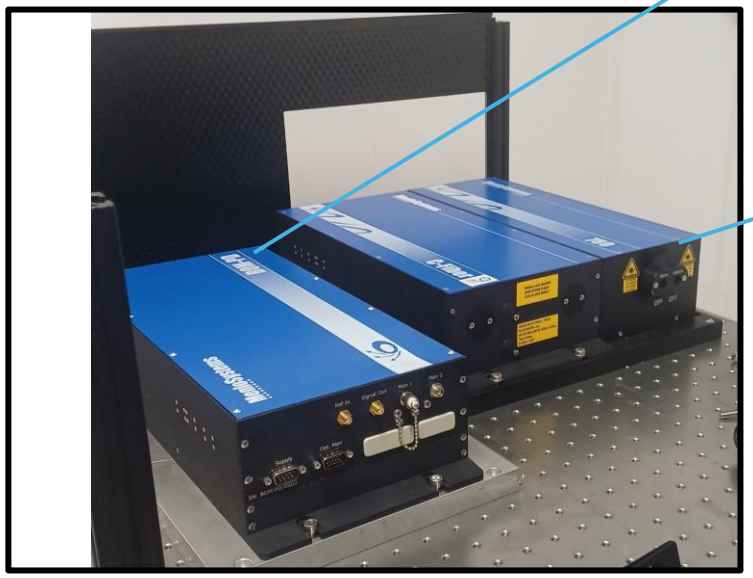
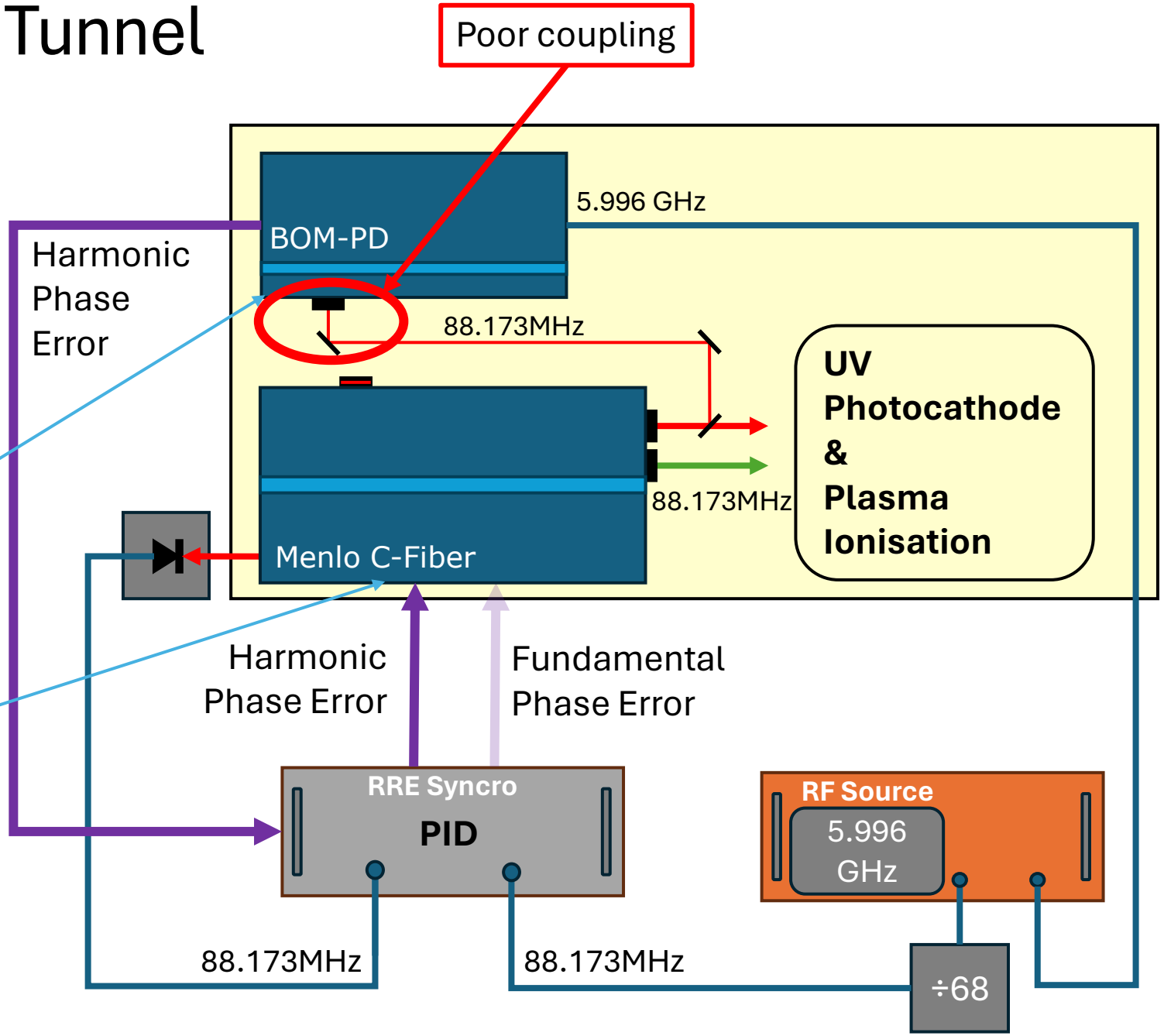
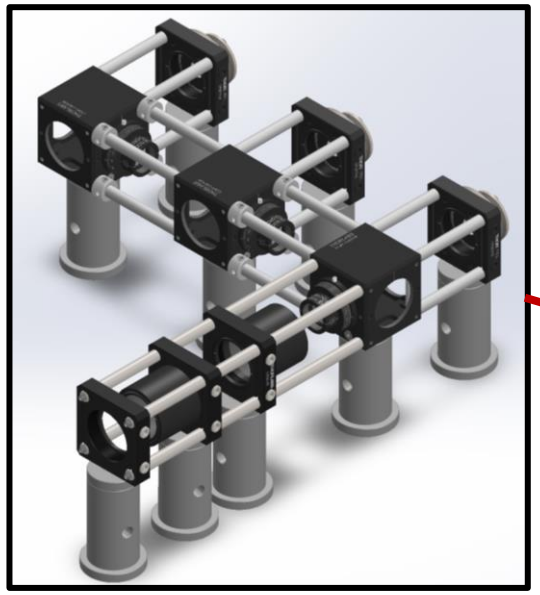


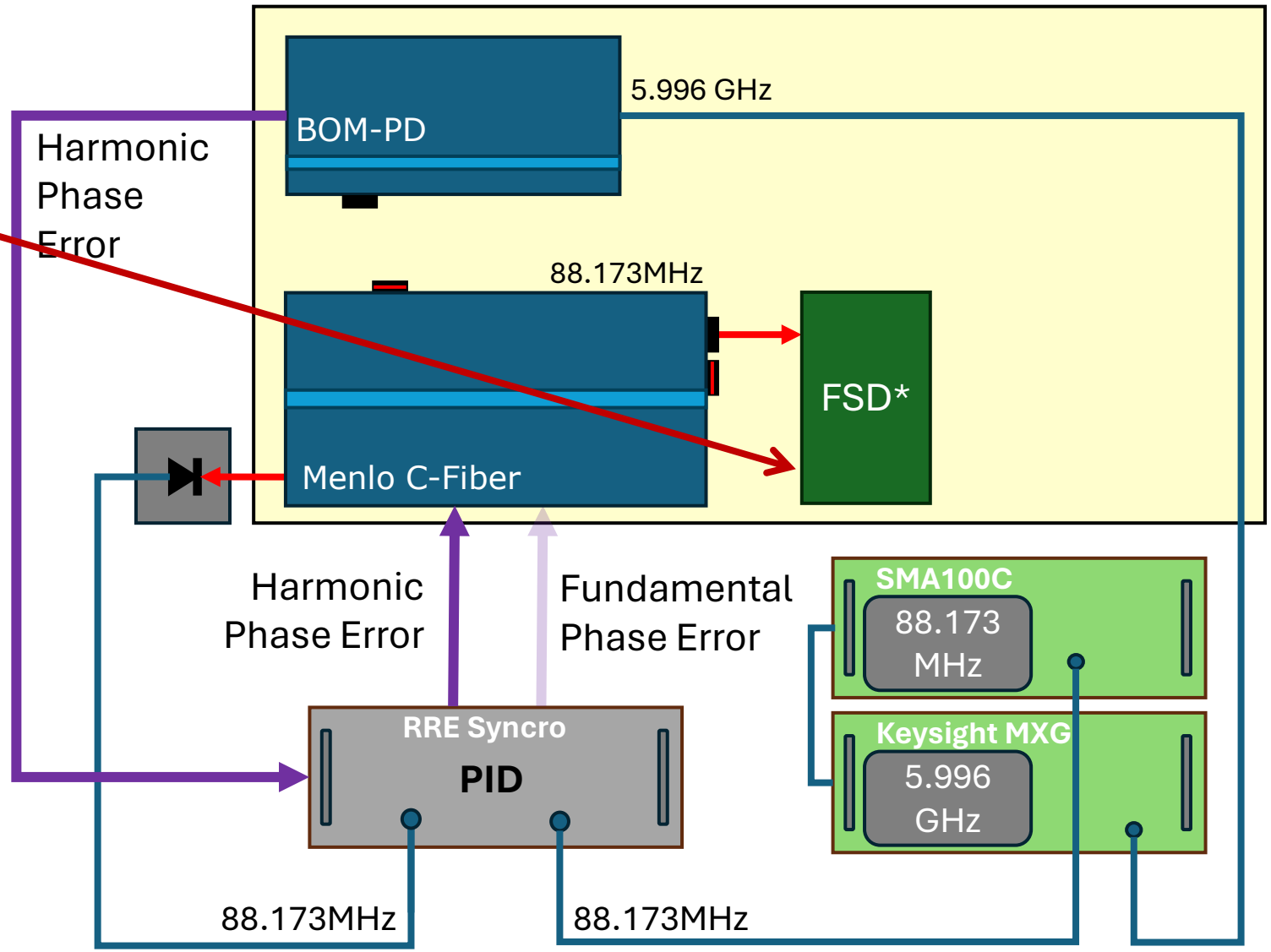


AWAKE Optical Sync – **DEV LAB**



FSD*: Free-Space Distribution

- RF Sources swapped from single oscillator (AWAKE Custom Design); to Keysight MXG, and SMA100C oscillators coupled at the 10MHz reference. (MXG drives SMA100C).
- Superior performance to existing frequency divider (÷68 chain). More closely represents performance in Run 2c, where frequency synthesis will be improved – NEW FELLOW in RF-LL.
- Residual phase-noise between MXG and SMA100C TBD.



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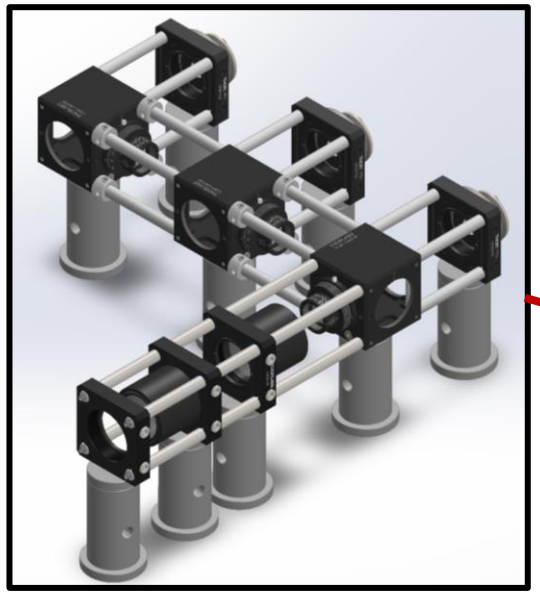
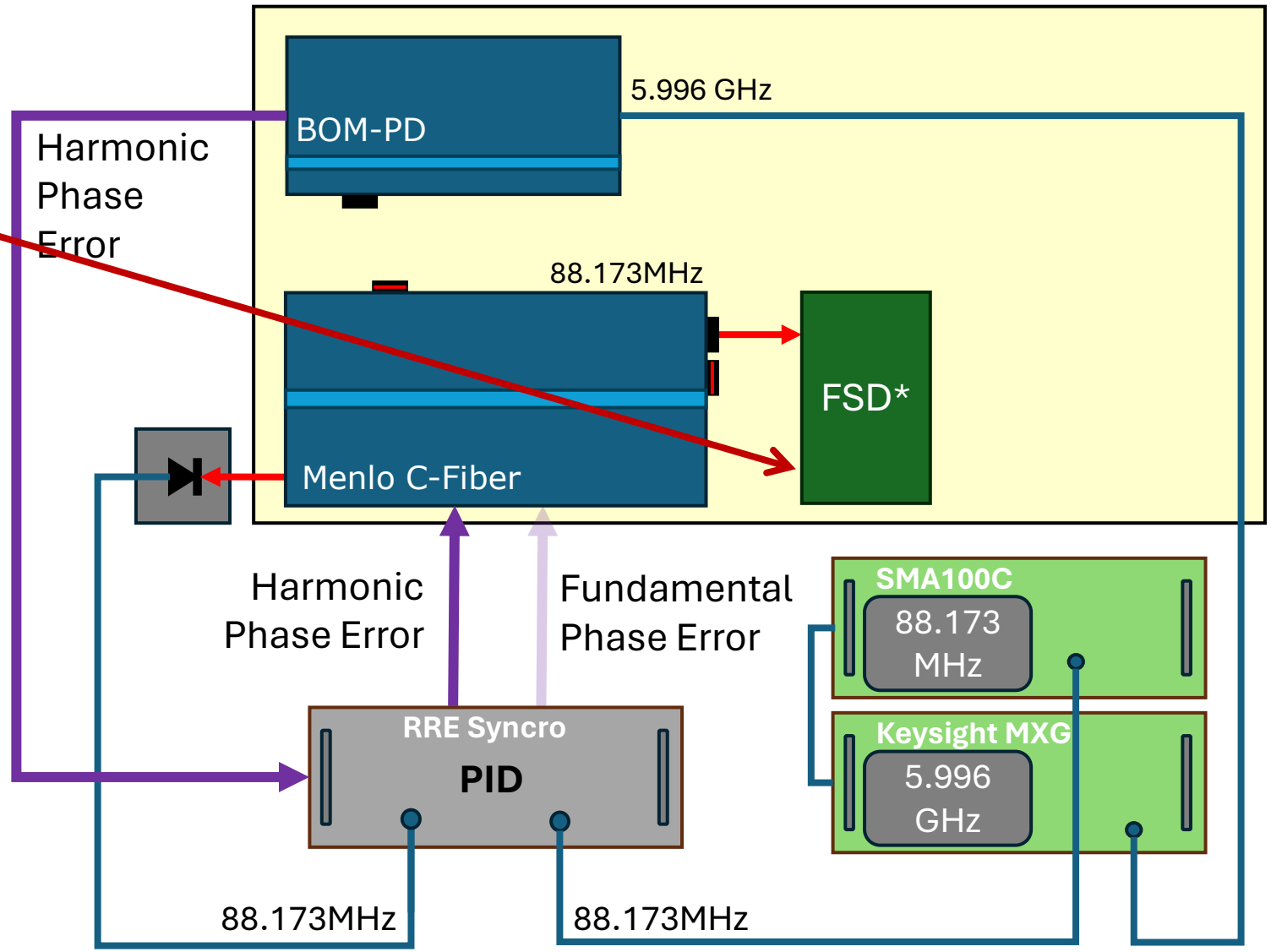


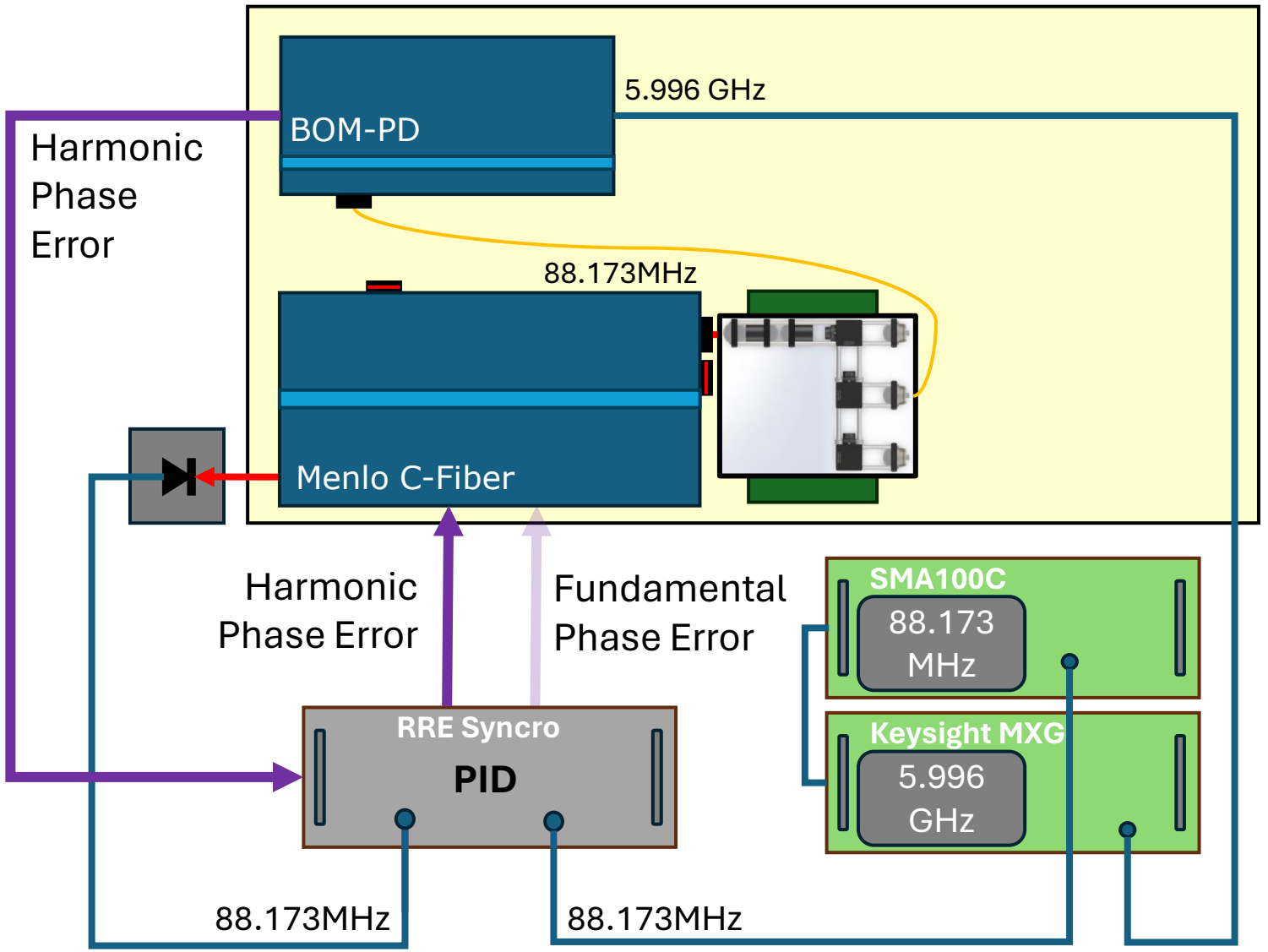
FSD*: Free-Space Distribution

- OEM coupler is bypassed using own fiber-coupler in a free-space distribution unit. (ABOVE)
- HWP & PBS pairs allow remaining 1560nm power to be variably diverted for other uses.
- Telescope designed in Zemax adjusts beam to FiberPort dimensions.
- Optimising power-in allows recommissioning of BOM-PD & Harmonic Lock.



AWAKE Optical Sync – **DEV LAB**

- BOM-PD power coupling fix.
  - Improve system resilience; rapid recommissioning in TSG40.
  - Polarisation-maintaining patch-cable preserves s-polarisation for internal optics.
- BOM-PD recommissioning will attempt to achieve and preserve advertised harmonic locking performance.
- Measurements:
  - Residual Jitter between the SMA100C and Laser for fundamental lock performance.
  - Residual Jitter between MXG RF Source and Menlo Laser for harmonic lock performance.
  - Additive jitter of laser system established by driving PNA and LASER with MXG Osc.
  - Absolute jitter of MXG TBC.
- PID gains of the two channel RRE Syncro unit to be optimised.
- Isolation chamber option if harmonic lock remains unstable.

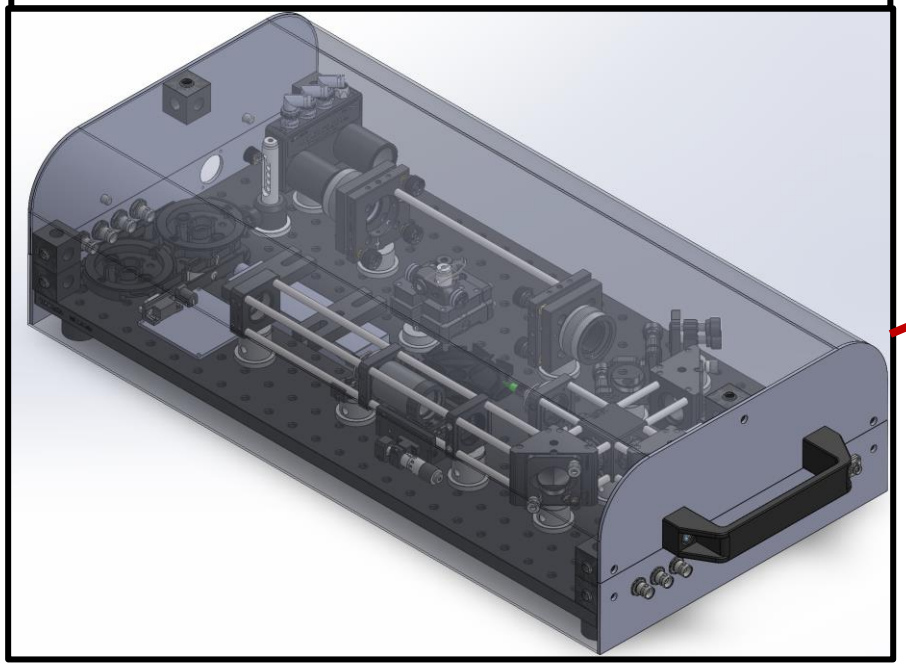


FSD*: Free-Space Distribution

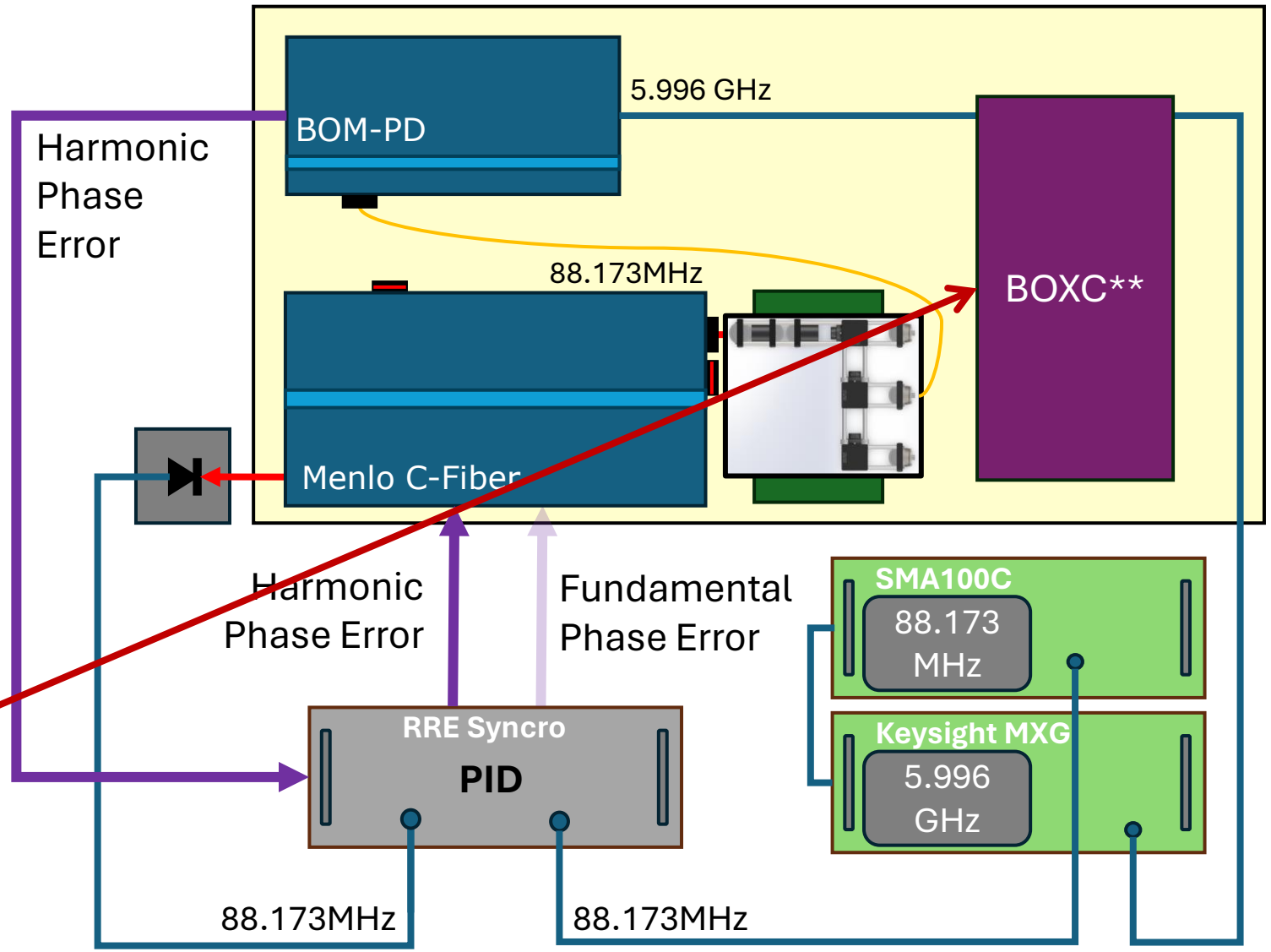
AWAKE Optical Sync – **DEV LAB**

- LASER customers to be supplied with TOF-stabilised 1560nm optical pulses.
  - PHAROS Laser Sync Distribution
  - Optical Arrival-Monitoring(?)
  - Bunch Arrival-Monitoring(?)
  - EOS Measurement(?)

- Stabilised optical distribution to be developed using Menlo LASER outputs.
  - Design Complete!
  - Procurement Underway (~8 Weeks).
  - Anticipated testing in January.



BOXC = Balanced Optical Cross Correlator**



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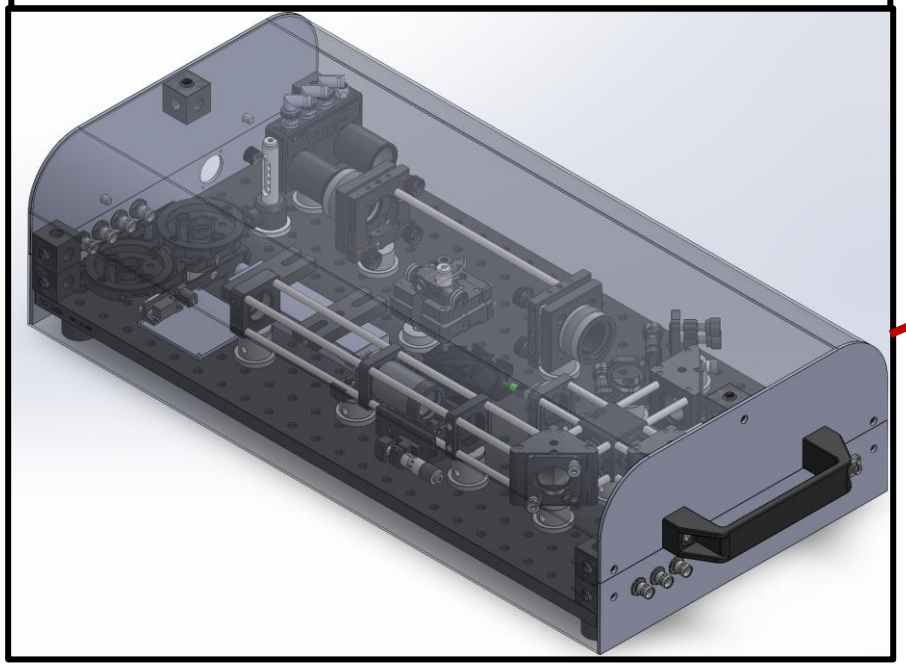

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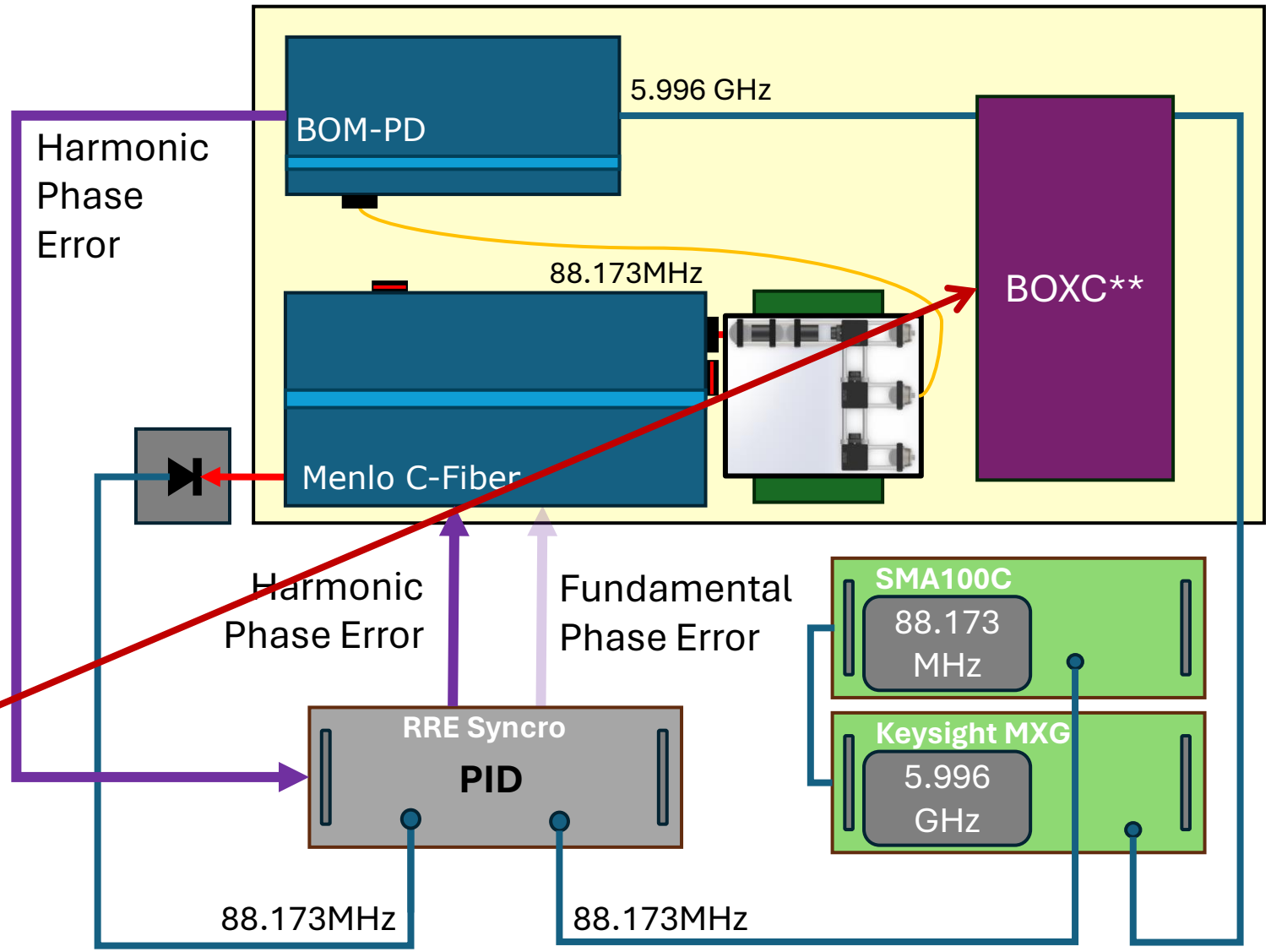
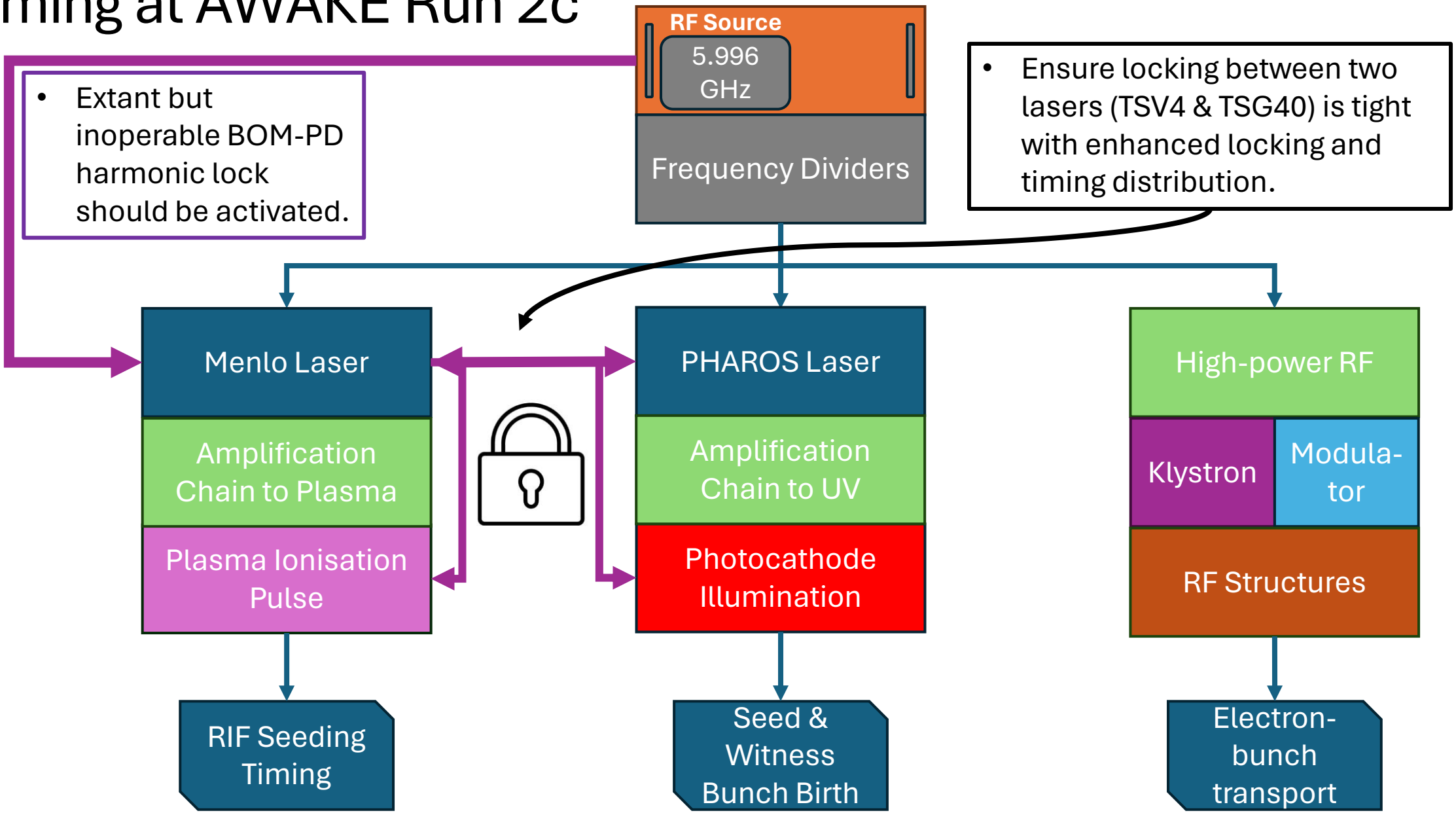
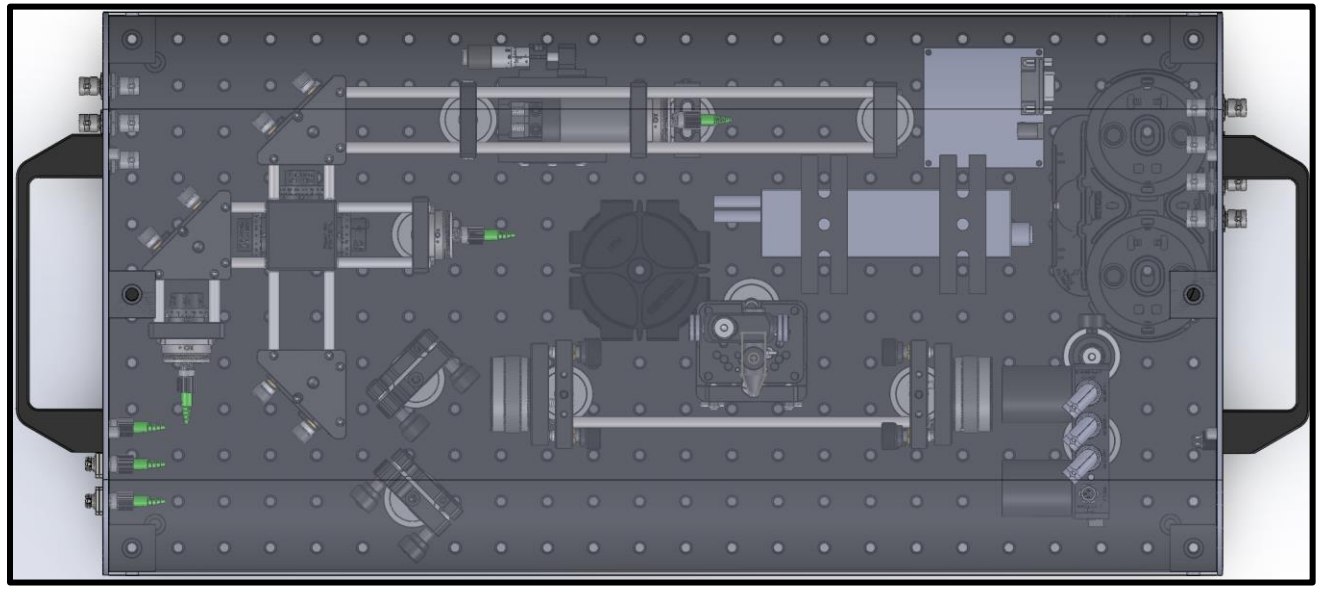


FSD*: Free-Space Distribution

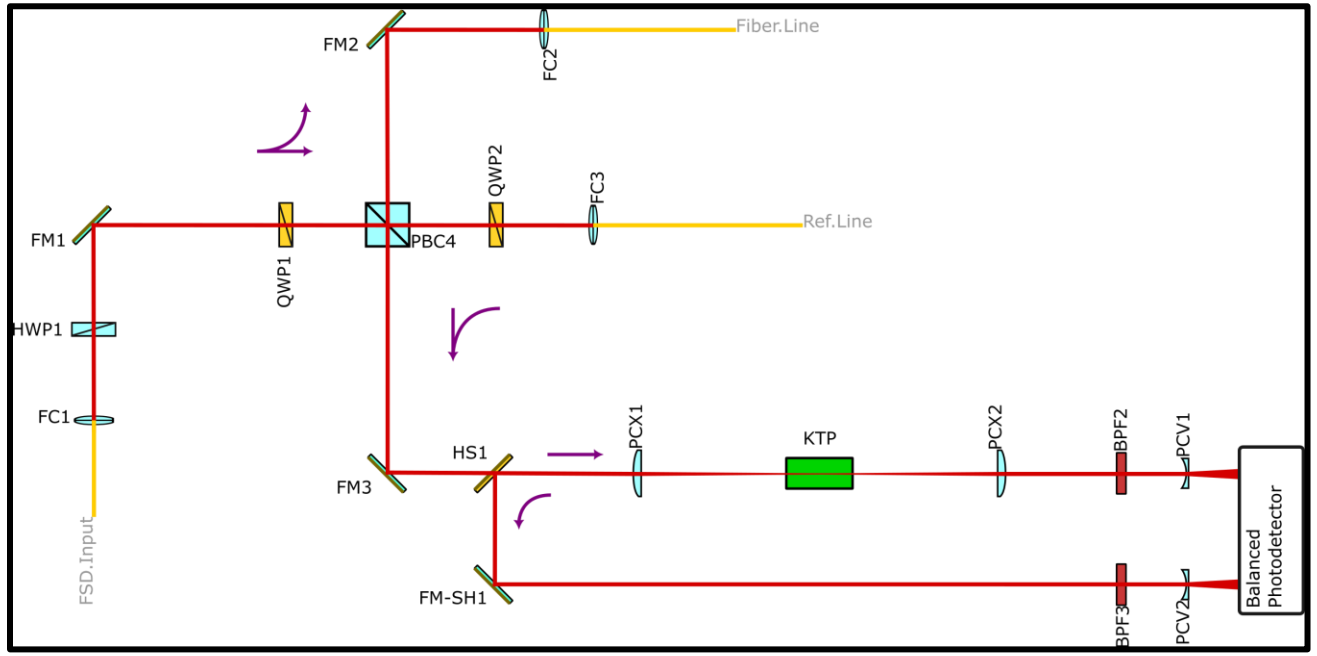
Timing at AWAKE Run 2c



AWAKE Optical Sync – **DEV LAB**



- Balanced Optical Cross-Correlator (BOXC) design finalised – in particular crystal choice.
- Periodically-poled KTP crystal selected for harmonic media.
  - 2mm x 1mm Aperture.
  - 45um Poling Period.
  - 2mm length.
  - BBAR front-face coating.
  - Harmonic-separator back-face coating.



FC – Fiber-coupler
HWP – Half-wave plate
QWP – Quarter-wave plate
FM – Fast Mirror
PBC – Polarising Beam Cube
PCX – Plano-Convex Lens
PCV – Plano-Concave Lens
BPF – Bandpass Filter
HS – Harmonic Separator

AWAKE Optical Sync – **DEV LAB**

- Construction awaiting delivery of components from suppliers. Long-lead items 6-weeks from current date. Gantt chart overleaf.
- Stages are integrated – only single 4u rack to be added to system in addition to light-table equipment.
- Uses ‘wasted’ 1560nm light.
- Up to 150mW distributable power to end-stations should this be needed – fiber nonlinearities need to be examined.
- Optimised for 100m fiber-links to end-stations.
- Testing
  - Phase-noise analyser tests.
  - Drift testing.
  - Possible to design own RF synchronisation monitor at distance – resynthesis of frequencies at distance.
- Arrival-monitoring integrable.

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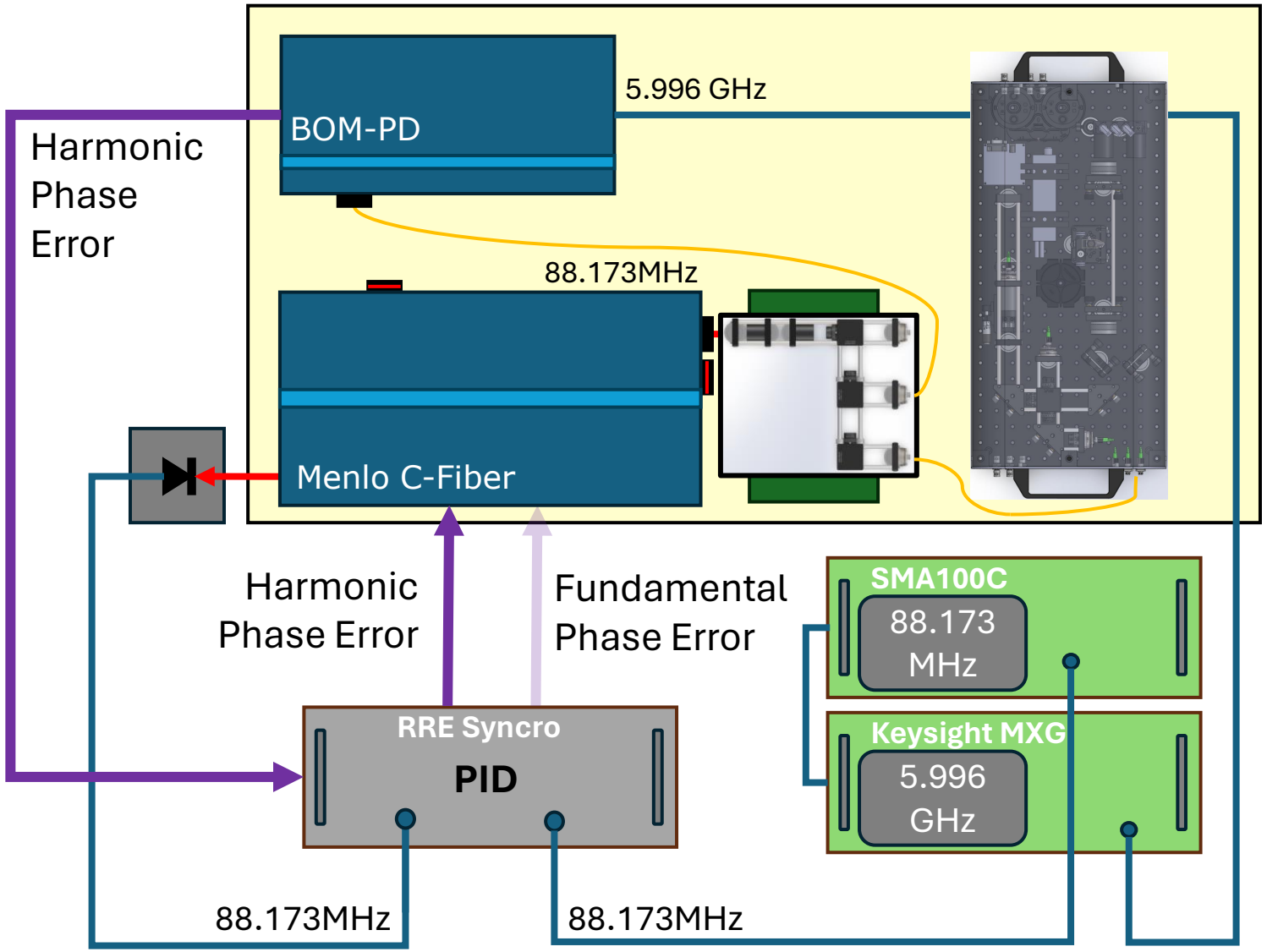

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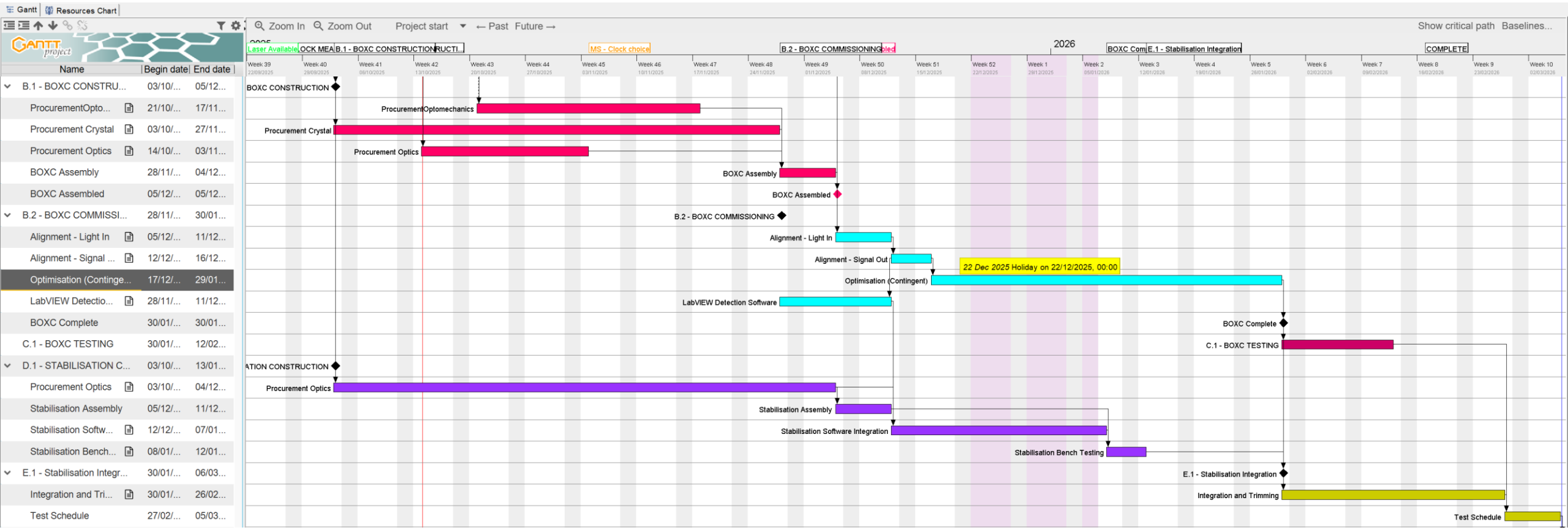
DEV LAB - Schedule



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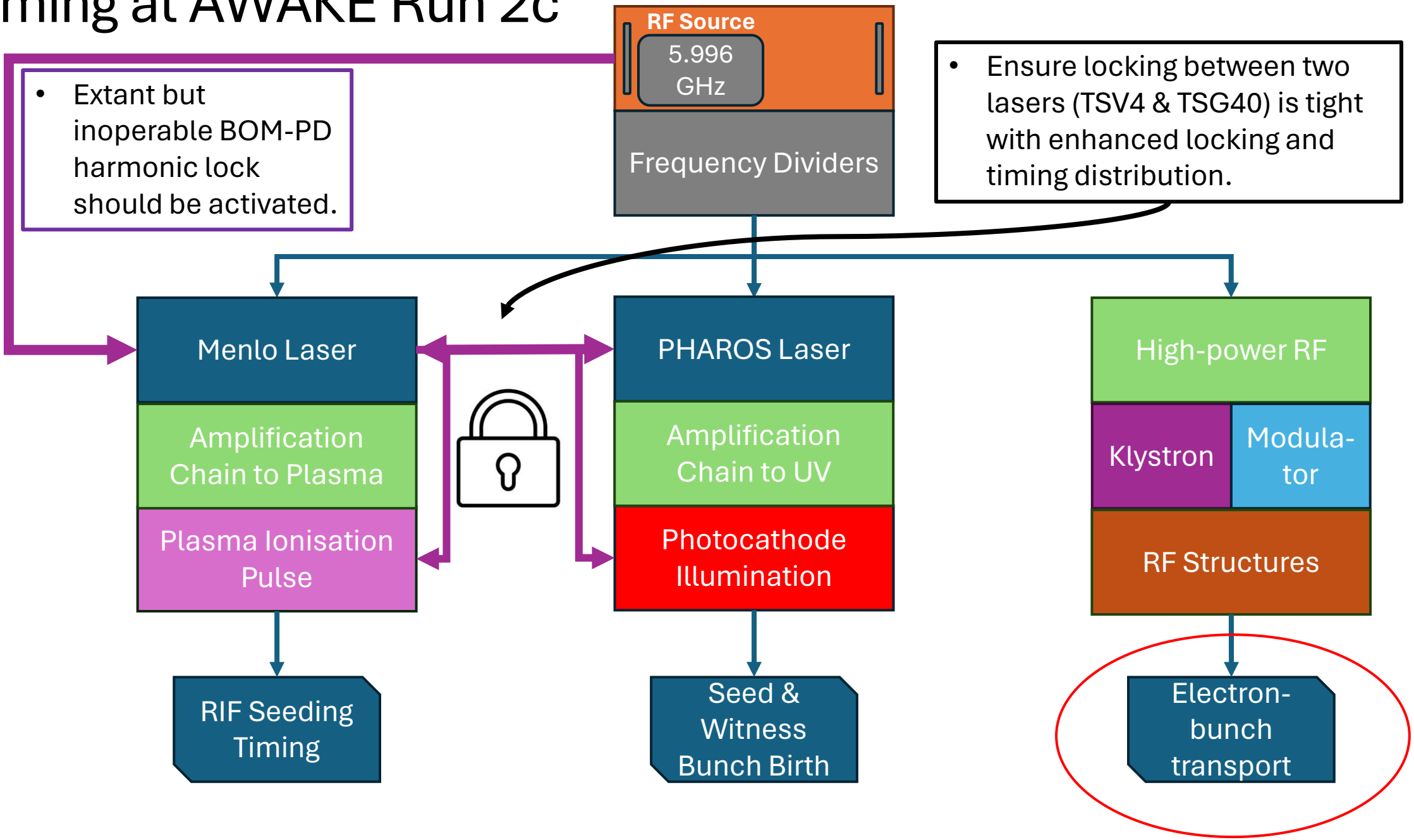

Electron-Bunch Transport

- XSuite particle tracking codes used to design Run 2c beamlines by **Eleonora** can be augmented to extract timing jitter from trajectory errors.
- Allows investigation of dipole/quad/sextupole field errors, magnet misalignments and particle distributions.
- Allows assessment of intrinsic time-of-flight variances shot-to-shot, which constitutes an unavoidable timing-error source.
- ***Example*** calculation includes 10ppm field (gradient) errors for dipoles (quads), and 10um quad misalignment is shown right. Code to be developed further with additional errors and specific tolerances.
- Beamline design is not yet complete – subject to changes and additions.