Machine Development – Sector 20 Stability

FACET-II

Facility for Advanced Accelerator Experimental Tests

FACET-II Planning Meeting, March 2023

Glen White / FACET-II Optics Designer/ AD-ARD Beam Physics

March 14, 2023

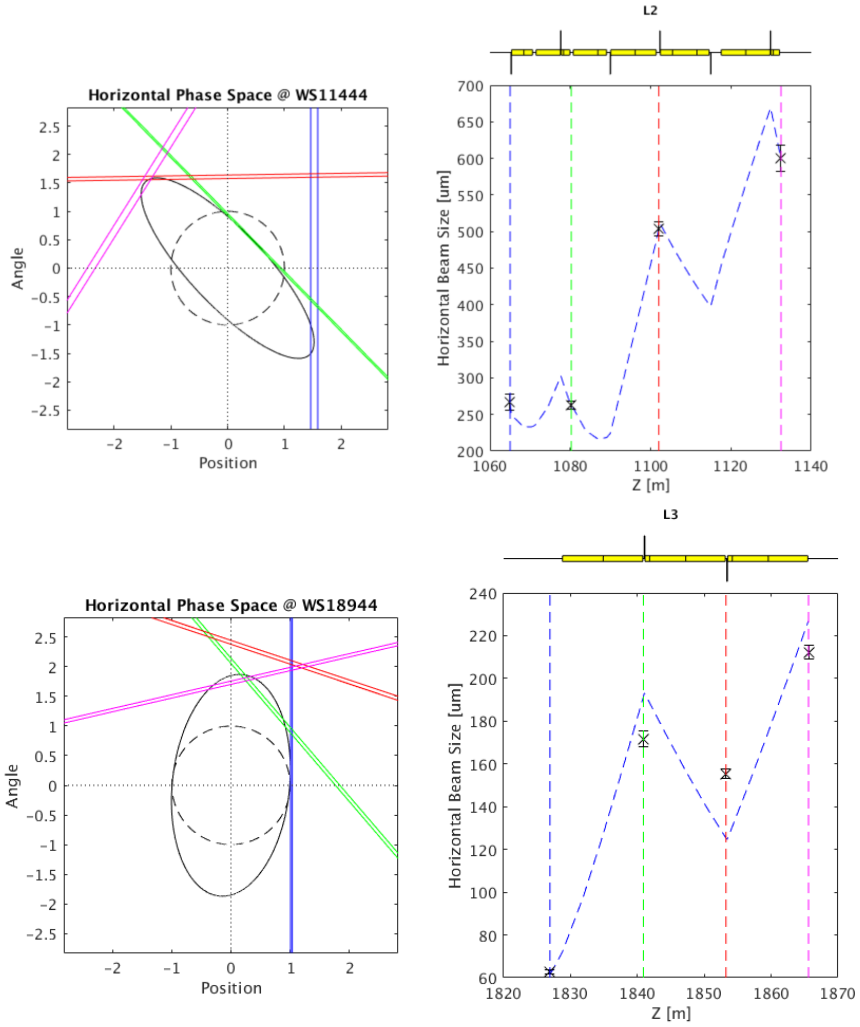
SLAC NATIONAL ACCELERATOR LABORATORY

Stanford University

U.S. DEPARTMENT OF ENERGY

Linac Operational Measurements – 8/7/22 (pencil beam)

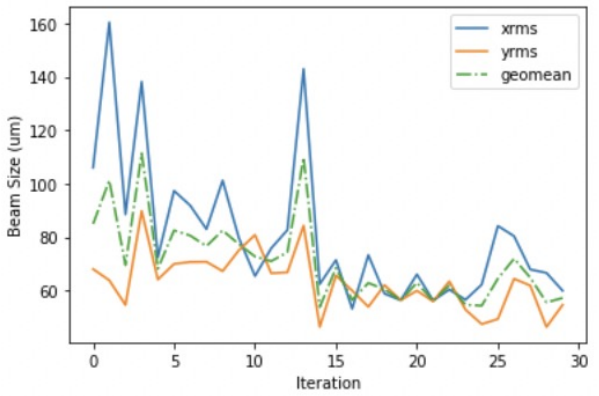
- Measurements taken 8/7/2022
  - Multi-wire (4 wirescanners)
- L2 *(LI11/12)*
  - $\gamma\varepsilon_x$ = 8.2 µm-rad, BMAG = 1.1
  - $\gamma\varepsilon_y$ = 4.5 µm-rad, BMAG = 1.9
- L3 *(LI18/19)*
  - $\gamma\varepsilon_x$ = 12.6 µm-rad, BMAG = 1.2
  - $\gamma\varepsilon_y$ = 8.8 µm-rad, BMAG = 1.4
- Operational issues affecting emittance & stability
  - Fast orbit excursions during wirescans
    - Improvements to control system links to SCP over downtime to enable jitter-subtraction
  - Extreme sensitivity to orbit in L1 / beginning of L2
    - MD studies scheduled to further investigate
  - Diurnal variation in klystron phases (see next slide)

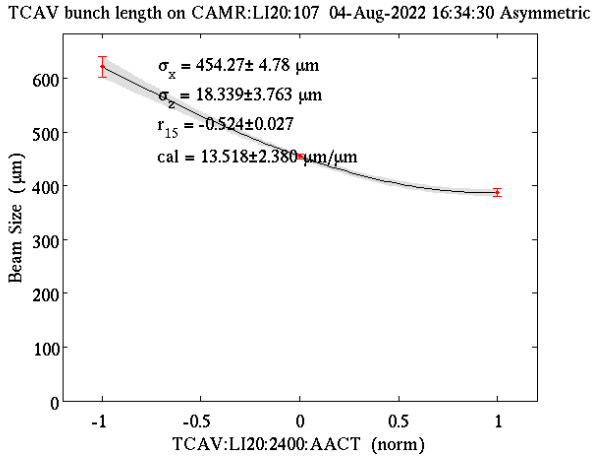


Emittance growth in Linac (L1-L3) typically 2X-3X after tuning

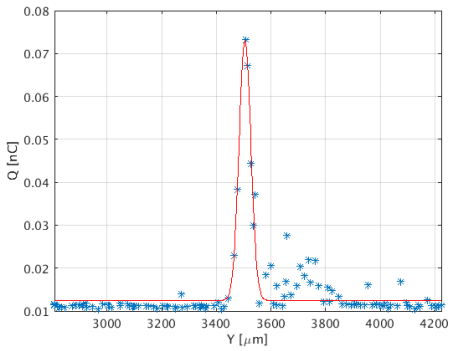
Sector 20 Operational Measurements – 8/7/22 (pencil beam)

- Measurements taken 8/7/2022 (wirescanner), 8/4/2022 (XTCAV)
- Wire-scanner measurements (IPWS1) with $\beta^* = 0.5$ m
  - **$\sigma_x^* = 23.2$ µm**
  - **$\sigma_y^* = 21.5$ µm**
  - **$\sigma_z = 18.3$ µm**
- Wire breakage
  - ongoing problem due to high charge density
- Similar sensitivity to dispersion leakage seen in FACET
  - Use sextupole movers in BC20 to control
- First checkout of "ML tuning"
  - Bayesian optimization tool applied to Sextupole mover system for S1 & S2 sextupoles (L & R)

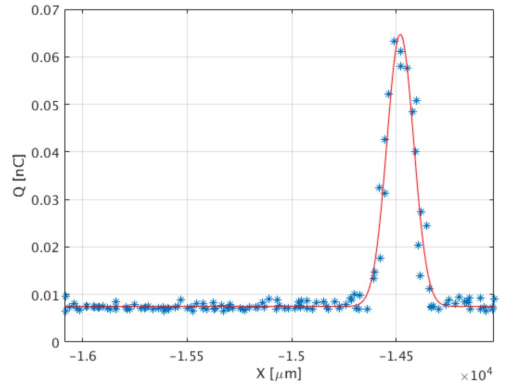




Scan showing signs of broken wires on card

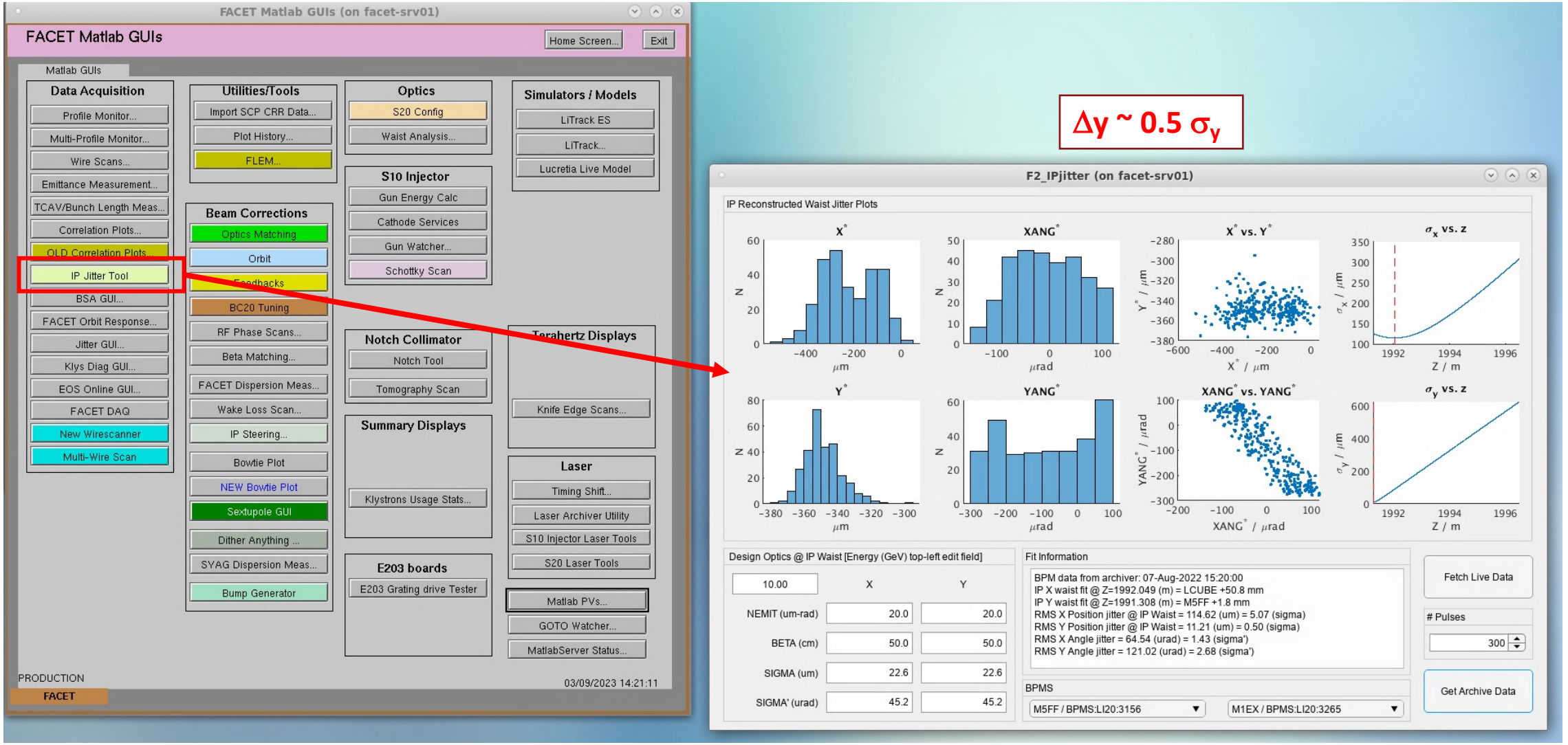


Newly fixed card



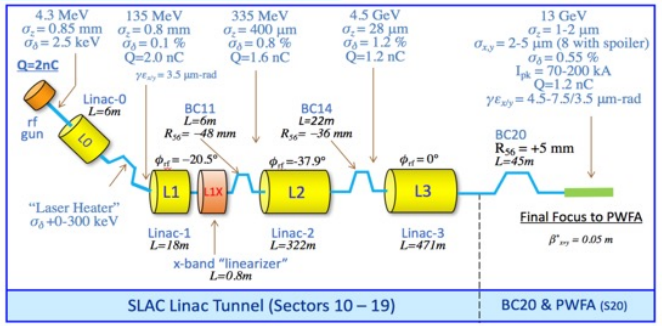
Efforts ongoing to address phase stability in Linac

IP Jitter Tool



Model / Other Machine Jitter Levels ~ **X2 larger than expect**

FACET-II @ SLAC



Monte Carlo Simulation Parameters

Property	Unit	FACET	Upgraded
Source Charge Fluctuation	%	1	0.1
Source Electron Position Fluctuation (laser spot jitter on cathode)	% $\sigma_{x,y}$	3	3
Initial Electron Laser Timing Error	fs	200	10
L1 Phase Jitter	degS	0.1	0.01
L2/L3 Phase Jitter	degS	0.25	0.01
L0P Phase Jitter	degS	0.1	0.01
L1 Amplitude Jitter	%	0.1	0.01
L2/L3/L0P Amplitude Jitter	%	0.25	0.01
BC0 & BC11 Magnet Strength Jitter	dB/B	1e-5	1e-6
BC14 & BC20 Magnet Strength Jitter	dB/B	1e-4	1e-6
L1/L2/L3/S20 Magnet Vibration (x/y), rms	μm	1.5/0.5	0.02/0.02
e- injector Magnet Vibration (x&y), rms	μm	0.1	0.02

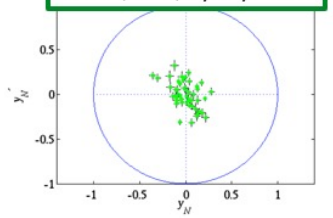
Upgraded: Engineering estimates of max performance given unlimited R&D scope (assuming no technology breakthroughs)

Beam Parameter	Symbol	Unit	Design	rms Jitter: FACET	rms Jitter: Upgraded
Horizontal position	x	μm	0	5.5	0.36
Vertical position	y	μm	0	1.6	0.12
Horizontal angle	x'	μrad	0	103	8.0
Vertical angle	y'	μrad	0	8.6	4.5
Arrival time	t	fs	0	103	6.7
Horizontal rms beam size	σ_x	μm	8	1.4	0.13
Vertical rms beam size	σ_y	μm	8	0.05	0.02
rms Bunch length	σ_z	μm	1	2.5	0.13
Peak current	I_{pk}	kA	70	20.9	4.4

FELs

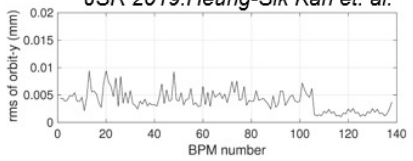
FEL 2008: F Decker et. al.

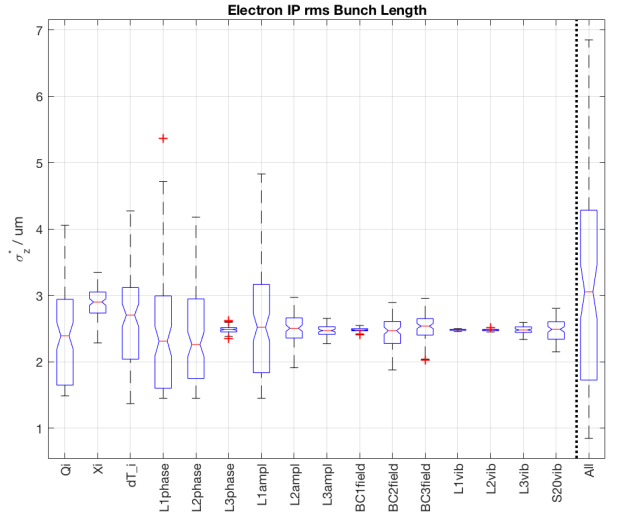
LCLS (2008) Δ_y / σ_y ~10%



PAL-XFEL (2019) Δ_y / σ_y ~10%

JSR 2019:Heung-Sik Kan et. al.



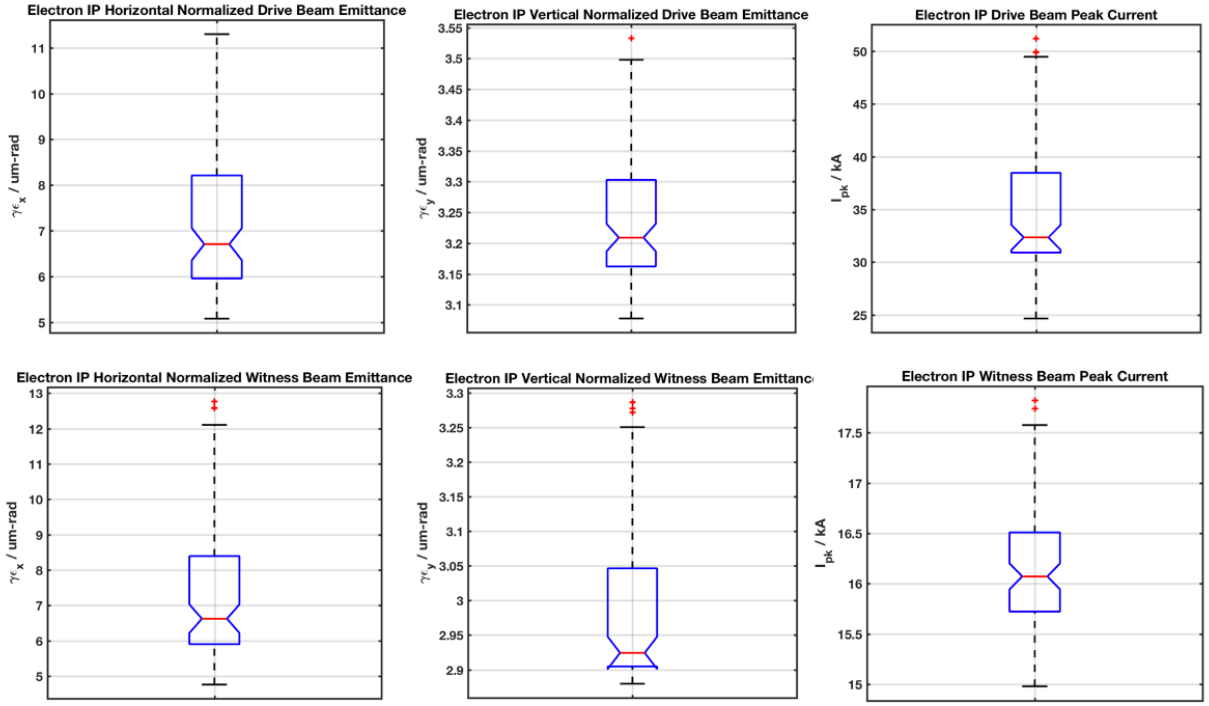


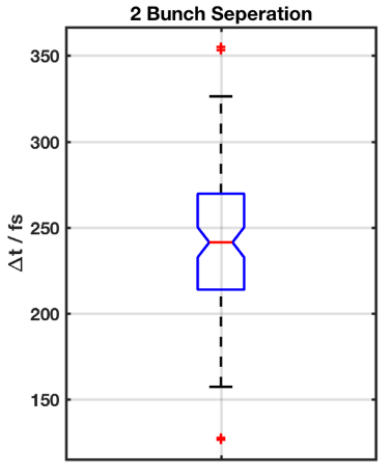
Expect ~1.5um bunch length jitter
-> Currently measure ~3.5um

Expect ~2um vertical jitter @ β*=5cm (say 6um @ 50cm)
-> Currently measure ~11um

Many existing Linac-based accelerators exhibit ~10% beam size jitter
FACET-II I_{pk} >> FEL's: expect ~20% y jitter, or down to 1.5% with cost-no-object upgrades

2-Bunch Jitter – Modeled Expectations





Δz =13 μm (rms)

Parameter @ IP	Drive Bunch	Witness Bunch
ε_x (μm-rad) (90%)	7.2 +/- 1.6	7.4 +/- 2.0
ε_y (μm-rad) (90%)	3.2 +/- 0.1	3.0 +/- 0.1
Δt (fs)	243 +/- 45	
I_{pk} (kA)	35.5 +/- 6.6	16.1 +/- 0.6

MD Options Currently Being Considered

- Introduction of further transverse feedbacks
  - L1 launch
  - L2 launch
  - S20 launch
- Other Feedbacks?
  - Currently only “slow” feedbacks to fix ~temperature drifts, consideration of faster feedbacks requires more work and possibly hardware
- Improvements to BL measurements
  - Expect microbunching to pollute BL feedback signals
    - Observed in past that bunch length changes even if BC14 BLEN signal remains fixed
  - Laser heater helps?
  - Investigate optical filtering for edge radiation
  - More complex BLEN detector? (Frisch/Maxwell special) – definitely helpful for S20
- Upgrade BC11 & BC14 energy feedback low-level RF
- Incorporate BC20 BLEN windowing into S20 wirescans
- XTCAV SLED
- S15 Tcav
- S17/S18 fast phase shifter hardware
- SCAV beamline