LCLS-II

High Power RF–Solid State Amplifiers

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LCLS-II Collaboration

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SLAC NATIONAL ACCELERATOR LABORATORY

BERKELEY LAB Lawrence Berkeley National Laboratory

Argonne NATIONAL LABORATORY

Cornell University

Fermilab

Jefferson Lab

U.S. DEPARTMENT OF ENERGY Office of Science

Acknowledgments: High Power RF (HPRF) Systems

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Darren Marsh	Quality Assurance
Howard Wilson	Procurement
Geoff Zender	Project planning
Partner Laboratories	Cryo Module Test SSAs operation

And Many others

Groups involved in High Power RF (HPRF) Systems Design

Project Management

System Engineering

RF Engineers

Operations Engineers

Controls Engineers

Mechanical Engineers & Designers

Cable Plant Engineers

Facilities

Space Allocation

Equipment Removal and Installation

Safety

Quality Assurance

Procurement

Project planning

Partner Laboratories (Including LLRF) – FNAL, JLAB, LBNL

Introduction

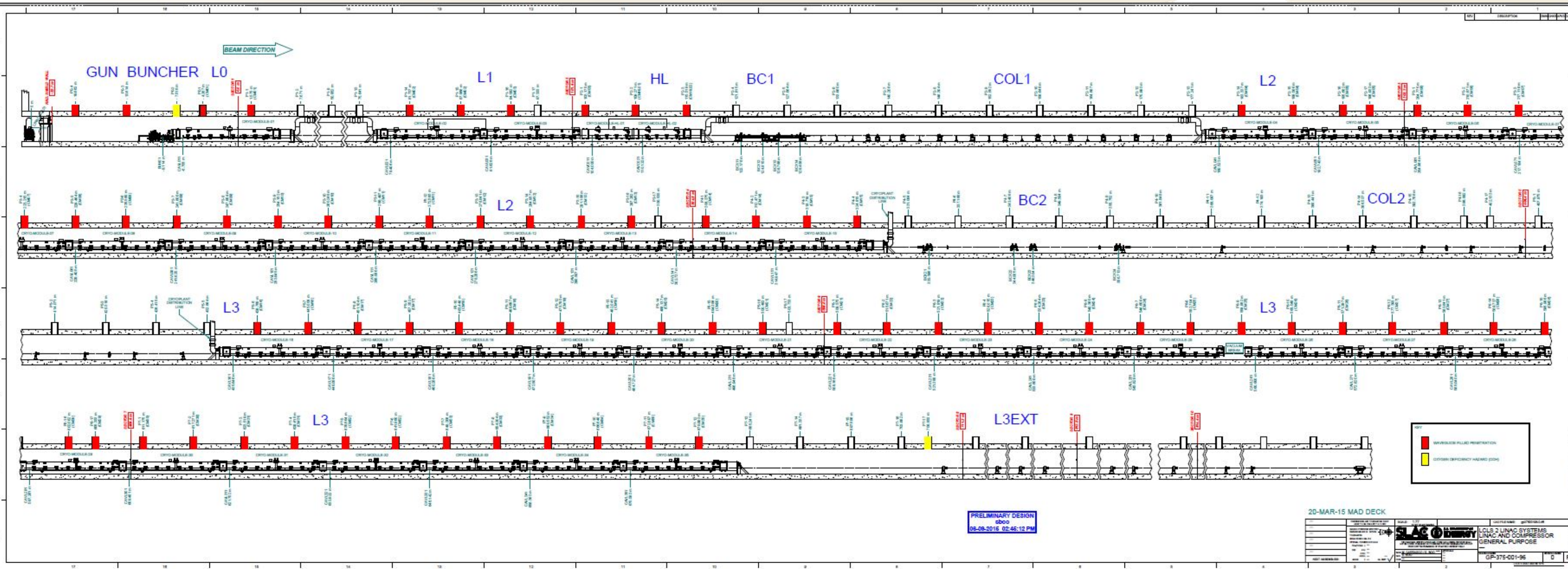
- **LCLS-II Bird's Eye View**
- **HPRF on LCLS II**
  - **SSAs**
  - **Waveguide Systems**
  - **NIRP**
- **Summary**

LCLS II – Second Linac Coherent Light Source at SLAC

•A second Generation CW X-ray free electron laser facility,

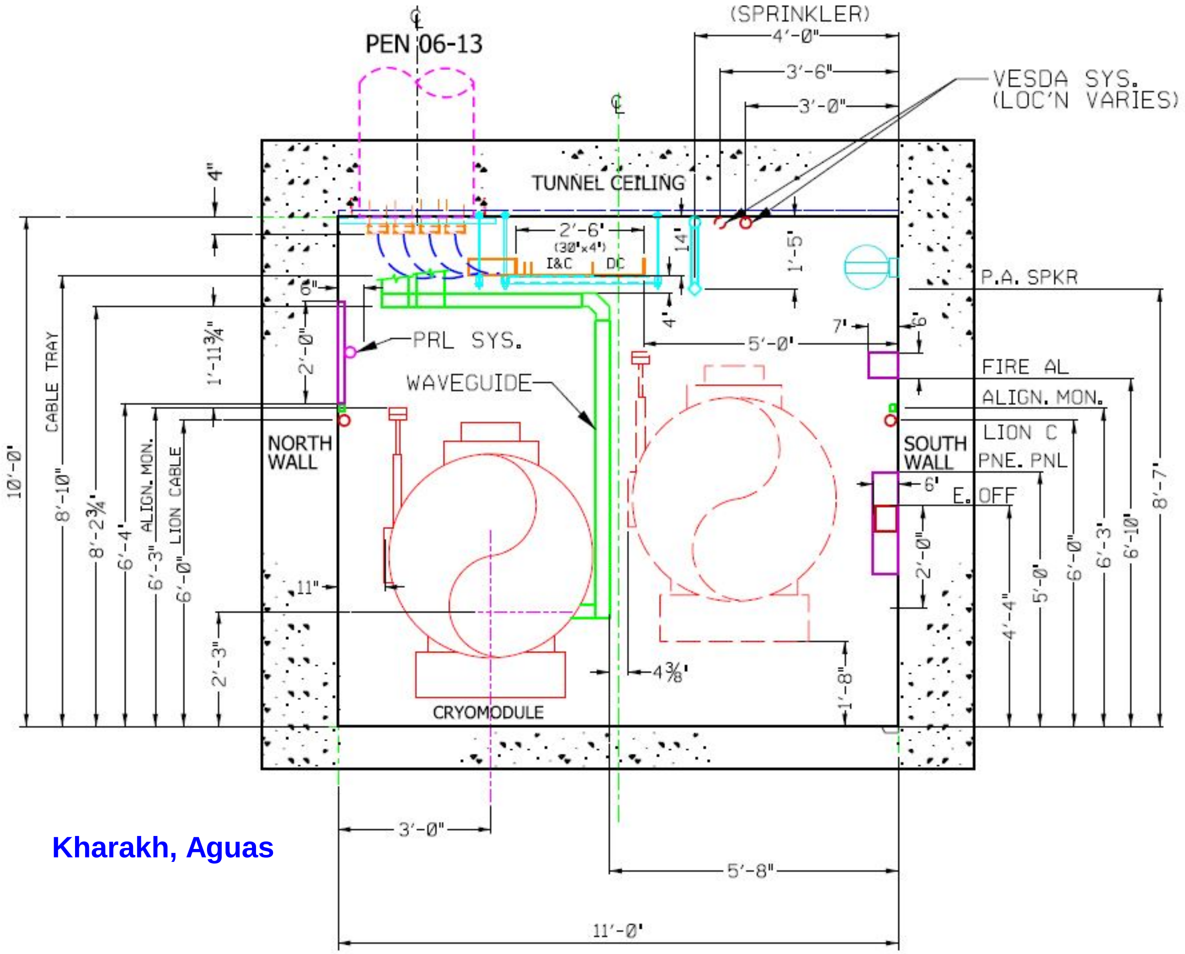
- based on a 1.3 GHz, continuous-wave (CW) superconducting linear accelerator.
- 4 GeV 100 μa cw delivered to the undulator hall (possible future upgrade to 300)
- Using the first kilometer of the existing SLAC Gallery and Tunnel

SLAC Gallery to Tunnel Penetration Allocations HPRF in Red



- **Total of 74 HPRF penetrations**
  - **70 for the main linac**
  - **2 for the Harmonic Linac**
  - **1 for the Buncher**
  - **1 for the RF Gun**

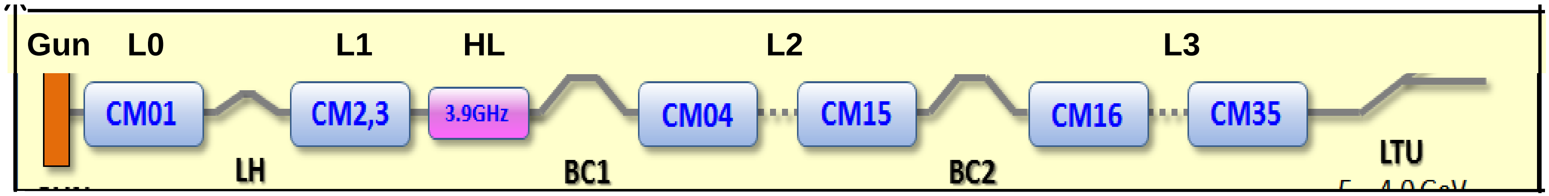
Tunnel Cross Section Near HPRF Penetrations Interferences with other systems Resolved



Kharakh, Aguas

ACCELERATOR TUNNEL
(TYP. CRYO-WAVEGUIDE & TRAY AT PENETRATION)

High Power RF (HPRF) Systems on LCLS II



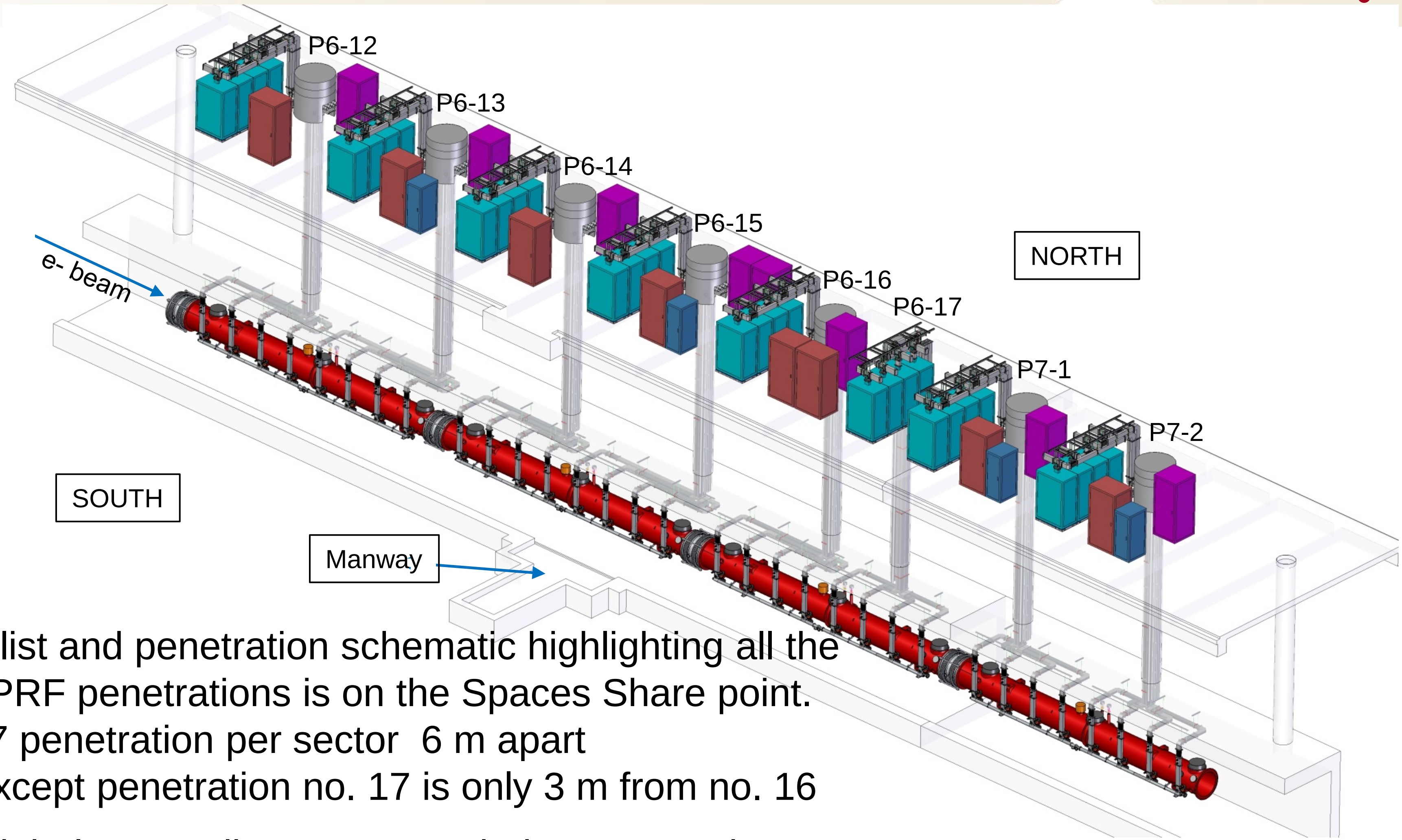
- Gun, Buncher and Cryogenic Cavities in L0, L1, HL, L2, L3

  - 284 3.8 kW, 1.3 GHz Solid State Amplifiers (SSA)
    - 280 for L0, L1, L2, L3
    - 4 for buncher after gun (not shown on drawing)

  - 16 2 kW, 3.9 GHz Sources for Harmonic Linac, HL

  - 2 60 KW, 185.7 MHz Sources for Gun (LBNL scope)

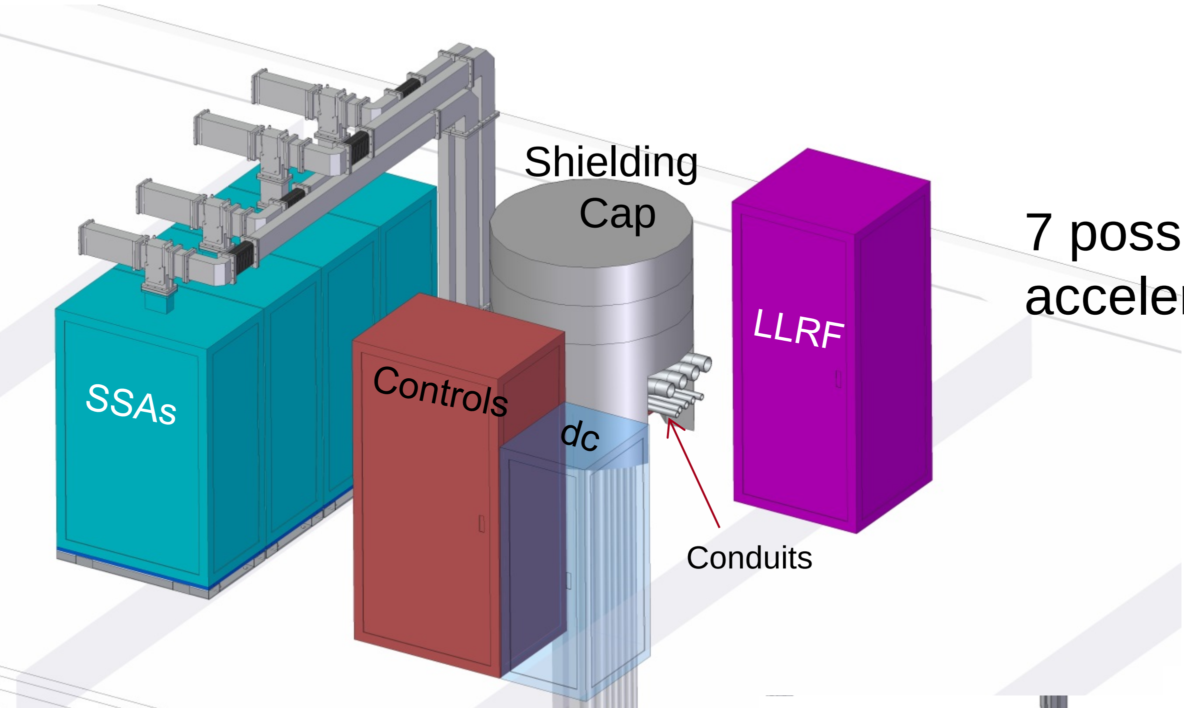
Layout at Eight HPRF Penetrations in L3 Includes all Variations of the LCLS II 1.3 GHz



- A list and penetration schematic highlighting all the HPRF penetrations is on the Spaces Share point.
- 17 penetration per sector 6 m apart except penetration no. 17 is only 3 m from no. 16
- Slight layout adjustment needed at penetration 16 & 17
- A section of L3 has every possible variation included

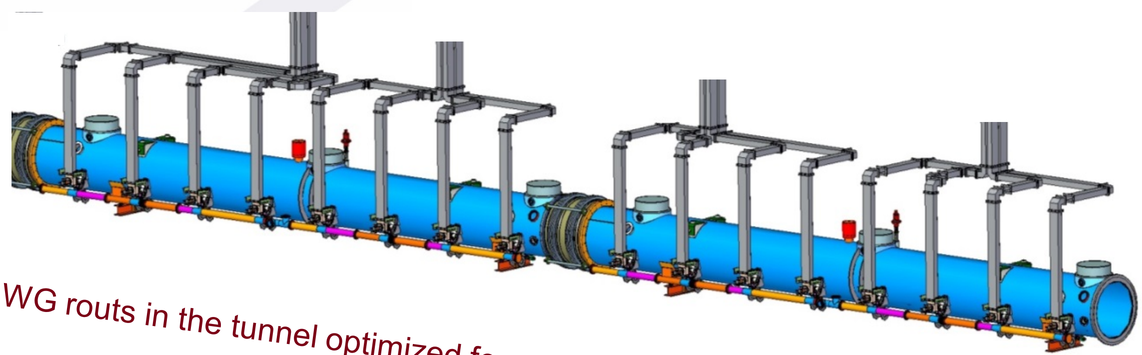
Nantista, Stewart w/ team input

Basic Layout at a typical LCLS-II 1.3 GHz HPRF Penetration Installation Level Waveguide Layout 80% Complete



7 possible variations at the accelerator housing ceiling.

Nantista, Stewart w/ team input



WG routs in the tunnel optimized for proximity of penetration to the Cryomodule.

LCLS II SSA unit is self sustained and self protected

Basic SSA Units include

- Control Module
- Power supplies
- Heat Exchanger
- Amplifier Modules
- Power combiner
- Internal Isolator
  Directional Coupler
- Rectangualr Wave guide output at a specified location

Front and Side

Back

The R&K 1.3 GHz SSA Rack for LCLS II

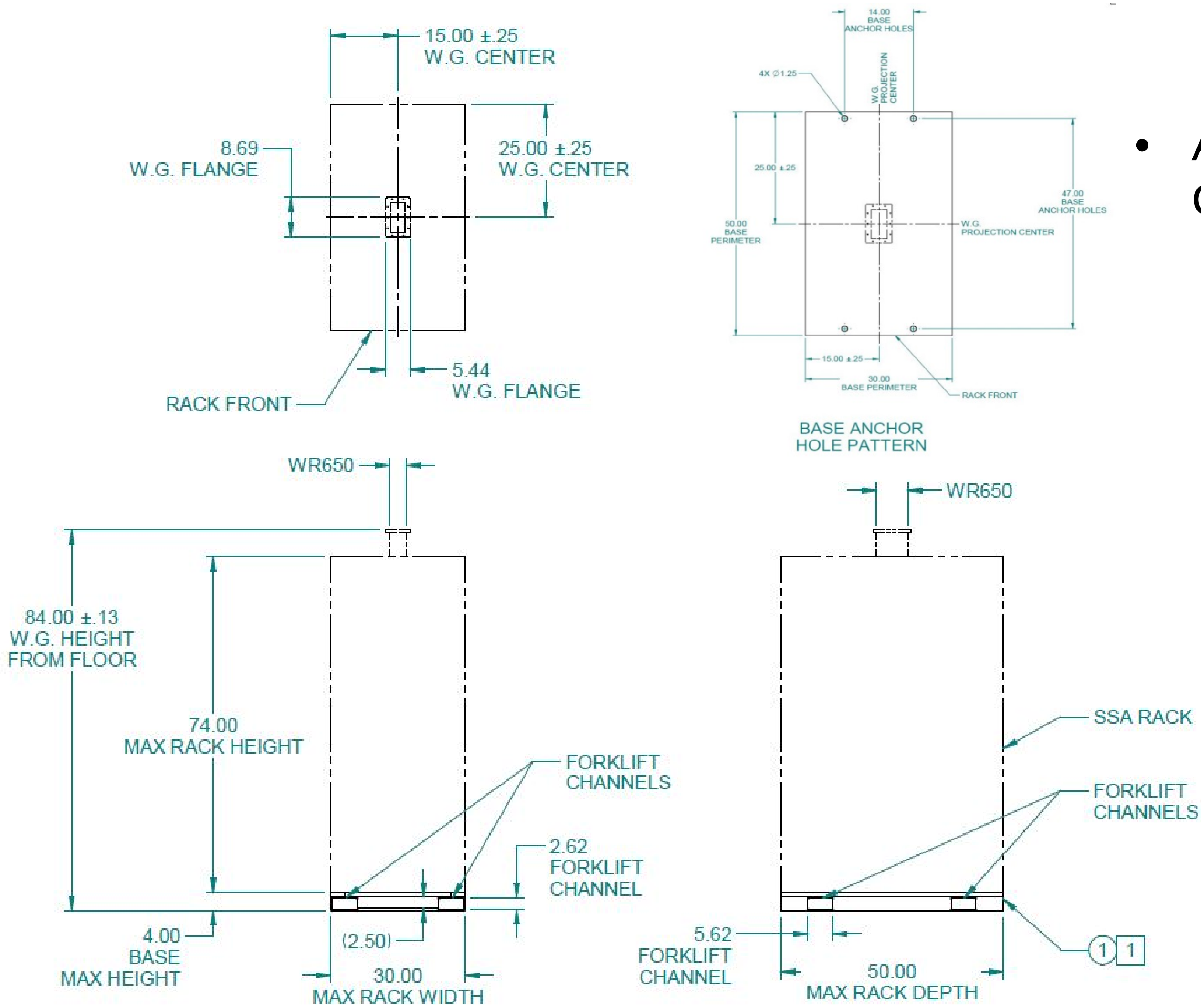
LCLS II Modular Nature of LCLS II SSAs

- The Modular Nature of the SSAs facilitates

  - Repairs with minimal impact on operation.

  - Possible upgrade to higher power if transistor technology improves considerably to improve efficiency.

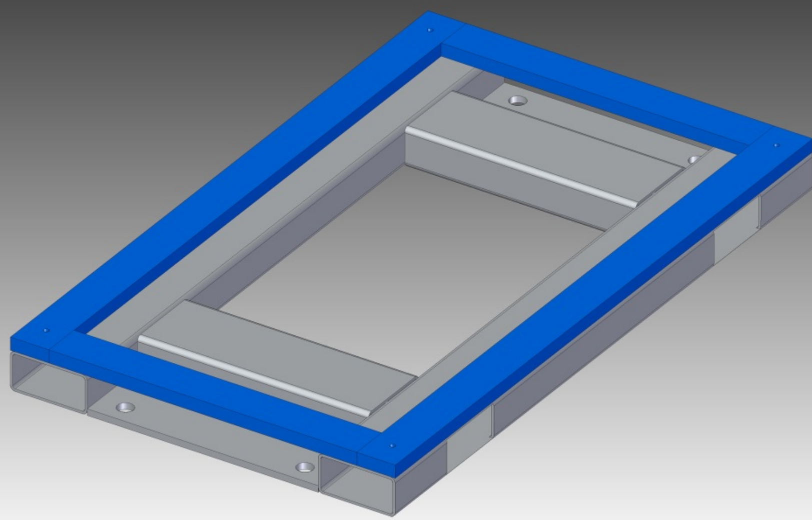
SSA Rack Geometry Assures Interchangeability of SSAs from Different Vendors.



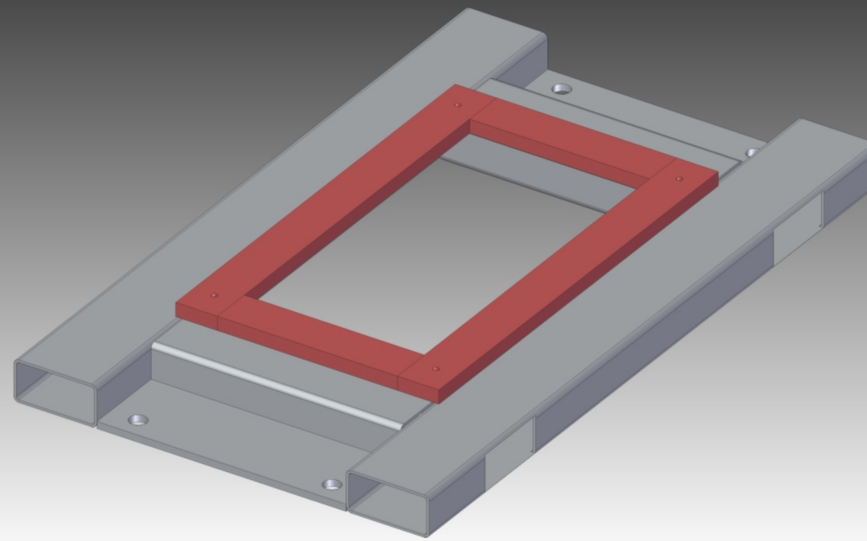
- All vendors Required to Comply with:
  - Base anchor bolt pattern
  - Output Waveguide orientation and relationship with anchor bolt pattern, and height from floor.
  - Maximum perimeter specifications.
  - Slots for forklift lifting from either direction
  - Eyebolts on top for lifting with crane.

SSA Rack Common Base Geometry allows Interchangeability of SSAs from Different Vendors. On the Gallery Floor

Blue and Red indicate Vendors choice of rack sizes to fix to the base.



Using the full 50" x 30" footprint

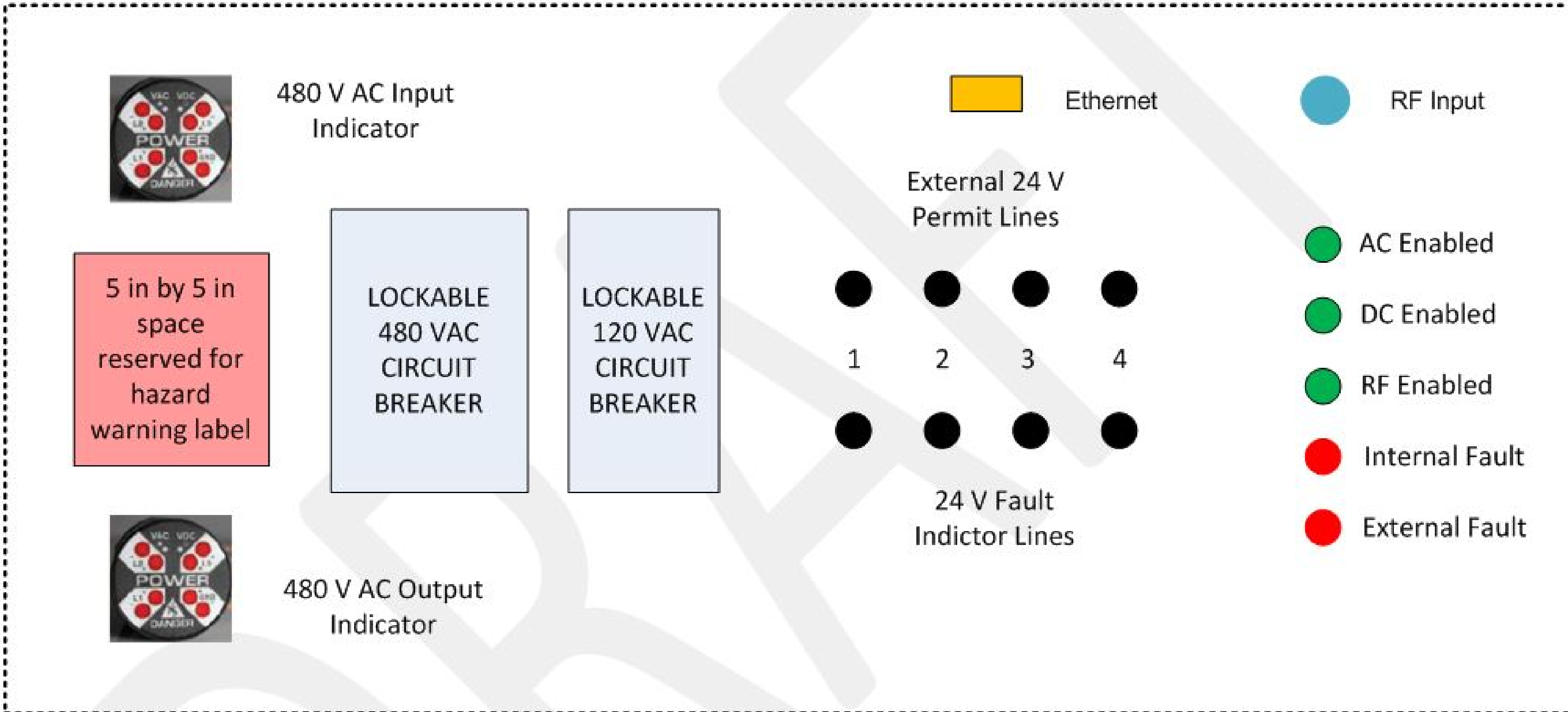


Using only portion of 50" x 30" footprint

Even SSA Rack Power and Water Connections are SLAC Defined and as you can see Touch safe

LCW inlet and outlet connectors Swagelok SS-12-AN-1-12: stainless steel pipe fitting adapter, 1 1/6 – 12 Male JIC thread ¾ in. male NPT.
480 V AC connecter: Meltric 480VAC 30A 3P+N+G PN: 63-38047 male
120 V AC connector: Meltric 120VAC 20A 1P+N+G PN: 63-18165 male.
SLAC provides the female counterparts on its power lines.

The SSA Control Panel Defined by SLAC for All Vendors.



The Control System has the following Features.

- Control Unit front panel has the following features –
  - RF and Ethernet input
  - AC, DC, RF enable lights,
  - 120 and 480 VAC status lights,
  - Internal and external fault lights
  - and 24 V Input and output permits via BNC.

- Self protecting - SSA will trip on internal Fault and remove all output 24 V permits to alert the LLRF system if
  - external or internal reflected power exceeds threshold
  - Input water temperature is not in range
  - Input water pressure is not in range

- Trip on command due to External faults - other problems on the Machine can require the SSA to trip
  - 4 external enable signals (24 V) let the SSA know all is OK
    - One will be dedicated to LLRF to command SSA to trip
    - One will be dedicated to Non Ionizing Radiation Protection diagnostics
    - Other two can be used for any other system on the machine to command the SSA to trip or if more than two then those signals will go into a sum box.

LCLS II 1.3 GHz SSA Basic Specifications

Requirement	
Frequency	1.3 GHz
Power (< 1 dB Compression)	3.8 kW with < 10 dBm input
Bandwidth (1 dB)	> 1 MHz centered about 1.3 GHz
Open Loop RF Stability	< 0.1 % amplitude, < 0.1 deg on one second time scale
Small Signal Delay	< 300 ns
Phase Variation (1 to 3.8 kW)	< 10 Degrees
Noise Figure	< 10 dB
Harmonic Content	< 30 dBc
Spurious Content	< 60 dBc
Drain Voltage Operation Range	30%-100%, user adjustable
Efficiency at 3.8 kW (< 1 dB Compression)	> 40%
Power Factor	≥0.9
Reliability/Maintainability	< 3 % transistors fail/year (but can still run with 1 failure)
	> 30,000 hr MTBF (for items that disable system)
Cooling	Low Conductivity Water (LCW) 4 GPM at 30^{o} C plus internal air heat exchanger (air temp < 45 degC)

LCLS II 3.9 GHz SSA Basic RF Specifications Needed

Requirement	
Frequency	3.9 GHz
Power (< 1 dB Compression)	900 W with < 10 dBm input
Bandwidth (1 dB)	> 2 MHz centered about 3.9 GHz
Open Loop RF Stability	< 0.1 % amplitude, < 0.1 deg on a one second time scale
Small Signal Delay	< 300 ns
Phase Variation (0.1 to 1 kW)	< 10 Degrees
Noise Figure	< 10 dB
Harmonic Content	<- 30 dBc
Spurious Content	< -60 dBc
Drain Voltage Operation Range	30%-100%, user adjustable
Efficiency at 1 kW (< 1 dB Compression)	> 25%
Reliability/Maintainability	> 15,000 hr MTBF (for items that disable system)
Cooling	Low Conductivity Water (LCW) 4 GPM at 30^{o} C plus internal air heat exchanger (Air temp < 45 degC)

Full specification of rack geometry and environment still in progress but will be similar to 1.3 GhHz with lessons learned applied.

R&K 7 1.3 GHz SSAs at R&K Prior to Shipment

- **6 of these were shipped to FNAL and JLAB (3 each) in Januarry, 2016 for Cyro Cavity Tests.**
- **1 of these was left at R&K for 2.5 months for long term tests**
  - **Continuous running for 2 months.**
  - **PA Module Swap tests from SSA to SSA show remarkable compatability – important for operations when swapping w/spares**
- **4 more delivered to FNAL and 5 more to JLAB in April 2016 for full complement to test one Cryo Module with 8 Cavities. (Note FNAL already had one SSA capable of 3.8 KW output.)**

Minimizing Chance for a Blow UP! But will Definitely let you know at CWRF18 and 20!

- **All 15 R&K SSAs have undergone thorough EEIP and passed after minor corrections in the first batch which were applied to the second batch and will be applied to future batches.**

LCLS II SSA Electrical Equipment Inspection Plan

- Each and Every SSA must pass the following EEIP inspection at the factory or at delivery location.
  - Rack as a whole –
    - ground bonding of all the walls
    - are all terminals >50 V covered and touch safe?,
    - All wire harnesses,
      - wire size,
      - is insulation in tact?
      - Routing - do all the 480V wires have bend radii ≥6 times radius,
      - Colored according to Code (important for safety of maintenance techs)
      - lugs of distribution lines,
  - Open every single chassis
      - check for the same things as above inside the chassis
      - Are fans easy to remove and install safely?

LCLS II SSA Factory Acceptance Tests

- Each and Every SSA undergoes the following Rigorous tests and more at the factory:
  - Electrical Equipment Inspection Plan (EEIP)
  - Output power (w/1dB compression) vs. input power for various drain voltages.
  - Δ Phase (Output – Input) vs. input power for various drain voltages.
  - Efficiency vs. input power for various drain voltages.
  - Gain curves at each Amplifier state and for the entire system.
  - Output Power and Phase vs. Frequency at 3.8kW and 1.5 kw
  - Spurious and Harmonic Spectrum Analysis
  - Operate unit in 45^{O}C environment for 24 hrs. at 3.8 KW and 2 hrs. at 1.5 KW and record (~ per min.)
    - Output power
    - Reflected power back to the SSA
    - Δ Phase (Output – Input)
    - rms power variation (over a ~ 1 second interval)
    - rms phase variation (over a ~ 1 second interval)
    - Cooling water temperature
    - Inside-the-rack air temperature
    - Outside-the-rack air temperature

    Unit should operate without a fault during this test
- Long term tests at Vendor site or at SLAC and of course at the Partner Labs.

LCLS II: SSAs AT FNAL

Courtesy for John Reid

LCLS II: AT FNAL During R&K SSA Acceptance Tests

LCLS II: R&K at AT JLAB During Acceptance Tests

Documentations left at FNAL and JLAB

R&K provided a complete set of hard copy and electronic documentation including

- Operation manual,
- Drawings and schematics
- Factory Acceptance Test Data,
- Source codes (electronic only),
- R&K's Modbus interface (electronic only),
- R&K's software for changing IP address and instructions (electronic only)

LCLS II - SSA Reliability Specifications

The SSA reliability is Specified in the Engineering Specification Document for the 1.3 GHz SSAs and will be also for the 3.9 GHz sources.

- Less than 1% of the transistor pallets fail per 2000 hours

- System continues to operate with one transistor failed.

- Systems that inhibit operation that take more than 1 hour to repair do not occur more than once on average per 30,000 hours

- An internal interlock system is to be provided that shuts off the SSA under various failure conditions (overheating, large rf reflection, etc)

LCLS-II SSA Availability Calculation Assumptions

- Consider a pessimistic case where repairs are made during machine operation only after a unit fails and its takes 12 hours to restore operation of the unit, ignoring redundancy.
  - Note 1 of 20 transistors and 2 of 6 PSs can fail and the unit will continue to operate.
- There will be up to 8% beam energy overhead – assume only ~ 2% available to compensate for failed SSAs (i.e., 6 units).
- Using the component MTBFs for every component provided by R&K for their SSAs, reliability/availability is as follows.

C. Adolphsen

LCLS II 1.3 GHz SSA Availability – Not a Limiting Factor

Failure	MTBF (khr.) (R&K units)	Average Number of Failed Units (12 hr. repair period)
Main Amplifier (Can run with 6 failed)	68.5	0.05
Pre Amplifiers	273	0.01
Main Power Supply (Can run w/ 2 out of 6 failed)	88	0.04
Controller	79.2	0.04
Heat Exchanger Fans	244	0.01
Flow Meter	66.9	0.05
TOTAL PER SSA RACK	**17.4**	**0.21**

With an average of 0.21 failed, probability of exceeding 6 failures = 2.6 x 10^{-9}

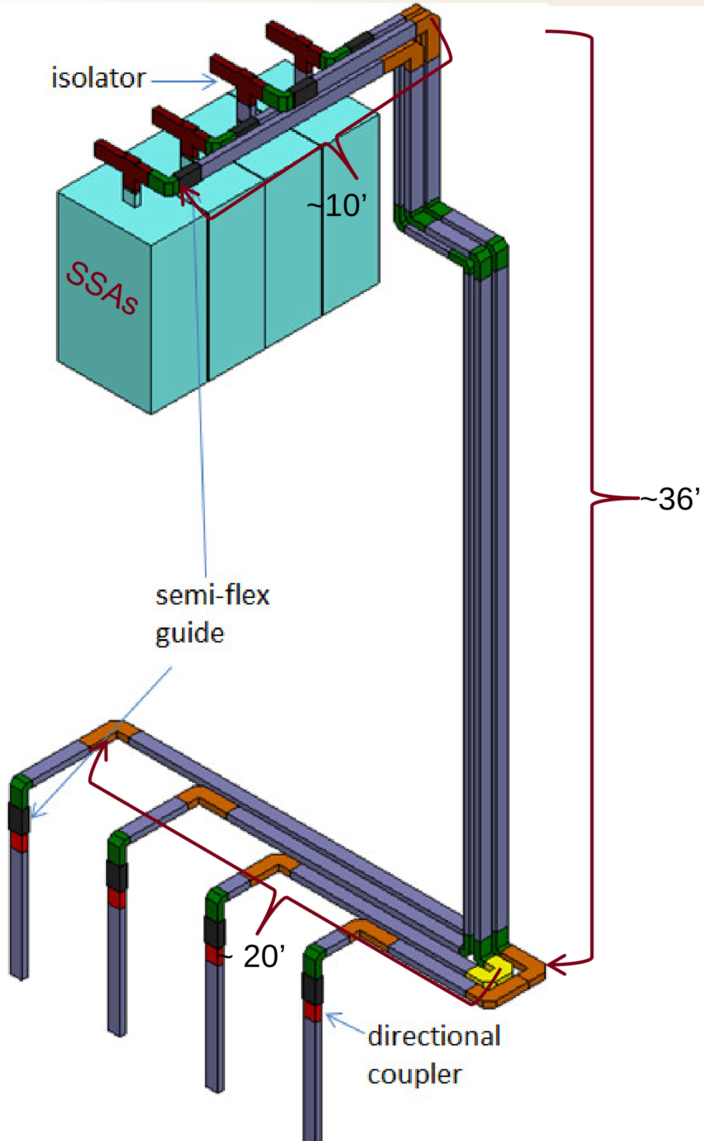
Thus Uptime for LCLS II SSA System is 99.99999974%

C. Adolphsen

SLAC Involvement in the LCLS II SSA Vendor Effort Process to Maximize Success and Minimize Blowups ☺

- Review vendor detailed design report and work with them until all specifications are assured.
- Bi weekly Reviews with all disciplines present from both sides
- Release Production process
- Receive and review Factory Acceptance Test Procedure (30 days in advance)
- Factory Acceptance Tests and Electrical Equipment Inspection Plan (EEIP) at vendor site with SLAC presence
- Receive and review installation and operating manual (30 days in advance of shipment)

On to Basic LCLS-II Waveguide System

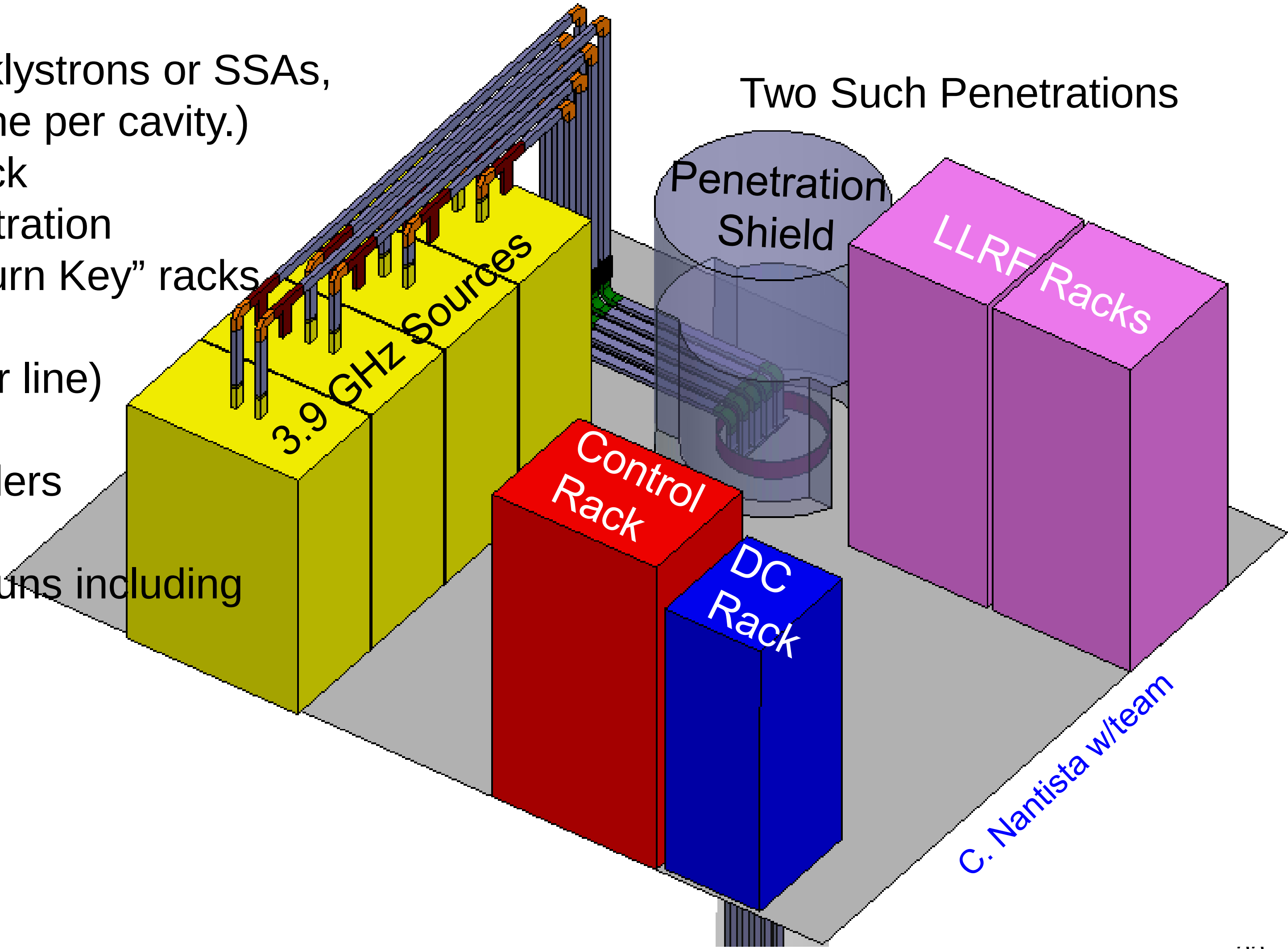


- Waveguide system consists of
  - Isolator immediately after the SSA output
  - Straights
  - E, H and U bends
  - 2 Flex Guides (downstream of Isolator and final E-bend in the housing
  - Directional Coupler after second flex guide
- Identical layouts for
  - SSA to cryomodule (slight support variations possible)
  - in penetration
  - cryomodule to accelerator housing ceiling
- Accelerator Housing Ceiling one of 5 Variations mentioned above
- The bottom of the penetration is sealed for with a plate and foam to prevent He_2 escape, in case of an accident.

3.9 GHz Source Basic System on LCLS-II

Critical RF Source Components

- 16 HPRF sources (klystrons or SSAs, one per cavity.)
  - 2 sources per rack
  - 4 racks per penetration
  - Self contained "turn Key" racks
- 16 Isolators (one per line)
- 16 Directional Couplers
- 16 RF waveguide Runs including
  - E & H Bends
  - Straights
  - Flex guides
  - Purge spacers
  - Gaskets



L-Band Wave Guide Components (S-band to Follow Soon)

Part Number	Description	Units
SC-375-461-02	1.3GHz E-BEND MITER WR650	1128
SC-375-459-15	PENETRATION BUNDLES	71
SC-375-461-03	1.3GHz H-BEND MITER WR650	640
SC-375-461-06	FLEXIBLE WAVEGUIDE, WR650	1124
SC-375-461-13	WR650 E-PLANE JOG	10
SC-375-461-14	U-BEND, H-PLANE, WR650	75
SC-375-461-01	1.3GHz-BAND ISOLATOR	284
SC-375-461-05	PURGE SPACER, WR650	568
SC-375-461-10	DIRECTIONAL COUPLER	280
SC-375-461-00	WR650, .125 WALL	1564
SC-375-461-08	WR650 GASKET AND BOLT KIT	5700

Penetration bundles include
4 lengths of WR650 and 4 E-bends

2.676 miles, 310 types of spool (not counting penetration Bundles)

kit includes: 1 gasket, 10 bolts, 10 nuts, 20 washers

A. Haase

Isolator Specifications for 1.3 GHz (3.9 GHz)

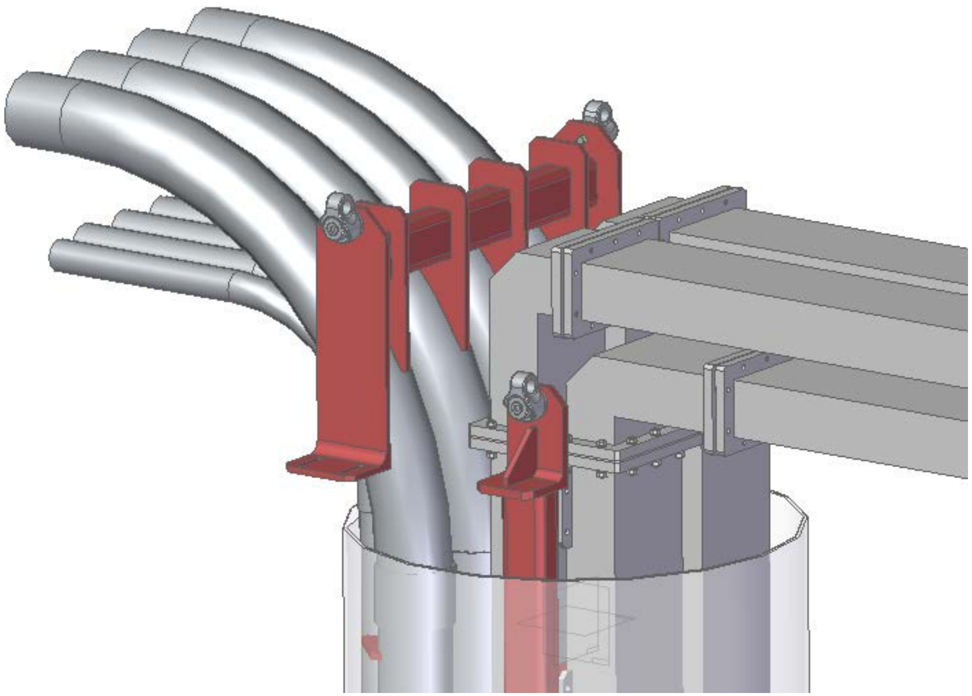
PARAMETER	SPECIFICATION
operating center frequency (f_0)	1,300 MHz (3,900 MHz)
bandwidth (BW)	10 MHz (30 MHz)
RF source operating power range	0–4 kW or 0–7 kW (0–1 kW) CW, w/ up to full reflection @ any phase
additional beam induced RF into the output port	≤ 430 W or 3.75 kW (≤ 190 W or 1.7 kW)
isolation ($-S_{12}$)	≥ 25 dB across BW
return loss (S_{11} & S_{22})	≤ -27 dB across BW; VSWR < 1.094)
insertion loss ($-S_{21}$)	≤ 0.15 dB (≤ 0.3 dB) across BW
RF body leakage	< -50 dB
waveguide	WR650 (WR284), corrosion resistant
flange type	WR650 (WR284) standard, flat, smooth to few mil level
angle between input and ouput ports	90°
cooling	low conductivity water cooled
pressurizability	airtight and performance stable to 4 psig
proximity	must work at 30” (12”) spacing w/o magnetic interference

Directional Coupler Electrical Specifications for 1.3 GHz (3.9 GHz)

PARAMETER	SPECIFICATION
operating center frequency (f_0)	1,300 MHz (3,900 MHz)
bandwidth (BW)	10 MHz (30 MHz)
operating power range	0–7 kW (0–2 kW) CW, w/ up to full reflection @ any phase
coupling (@ f_0)	-50 dB (-40 dB) ± 0.5 dB (forward & reverse, w/ factory cal.'s labeled)
coupling flatness	0.1 dB across 200 kHz (600 kHz) around f_0, 0.3 dB across BW
directivity	> 40 dB across BW
return loss (S_{11} & S_{22})	< -40 dB across BW; VSWR < 1.02
insertion loss ($-S_{21}$)	< 0.01 dB (< 0.02 dB) across BW
coupling ports	dual broad wall (same side) loop couplers
RF body leakage	< -50 dB
waveguide	WR650, corrosion resistant
flange type	WR650 standard, flat, smooth to few mil level
connectors	non-Teflon, precision Type N female, 50 Ω
pressurizability	gas tight and performance stable to 4 psig
radiation	radiation resistant materials (e.g. Rexolite windows, non-Teflon connectors)
length	12″

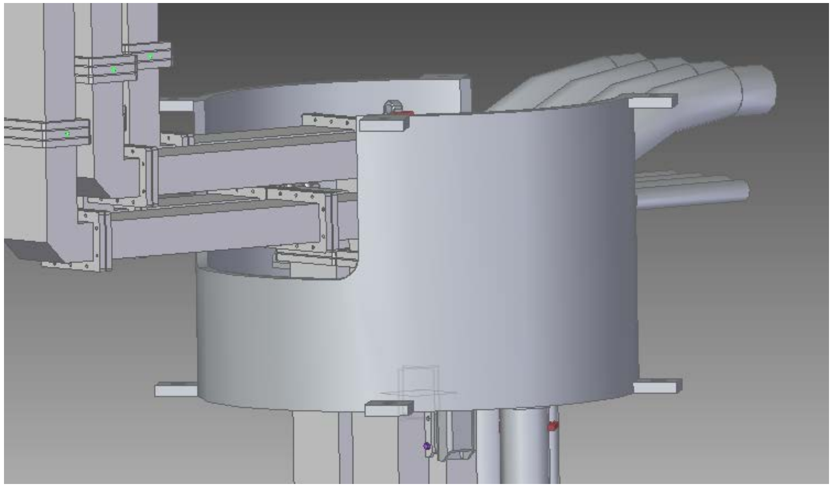
HPRF Penetration Configuration

- Service shafts to contain 4 waveguides, 9 conduits (ranging in size from 1.5 to 4”), and potentially a penetration cooling duct or baffel between the Waveguide and conduit bundle.

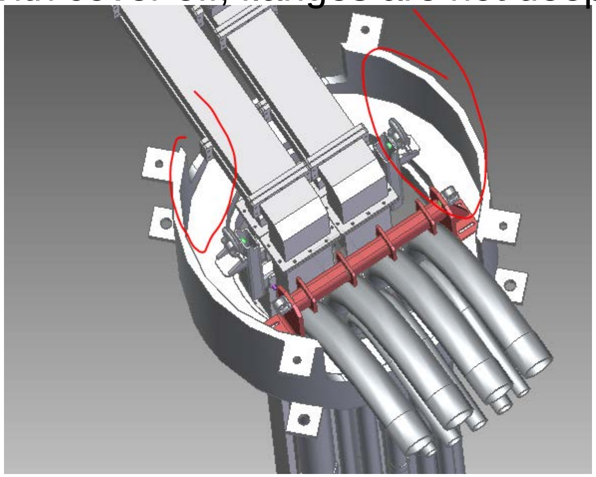


Gallery/Penetration Waveguide Assembly Access

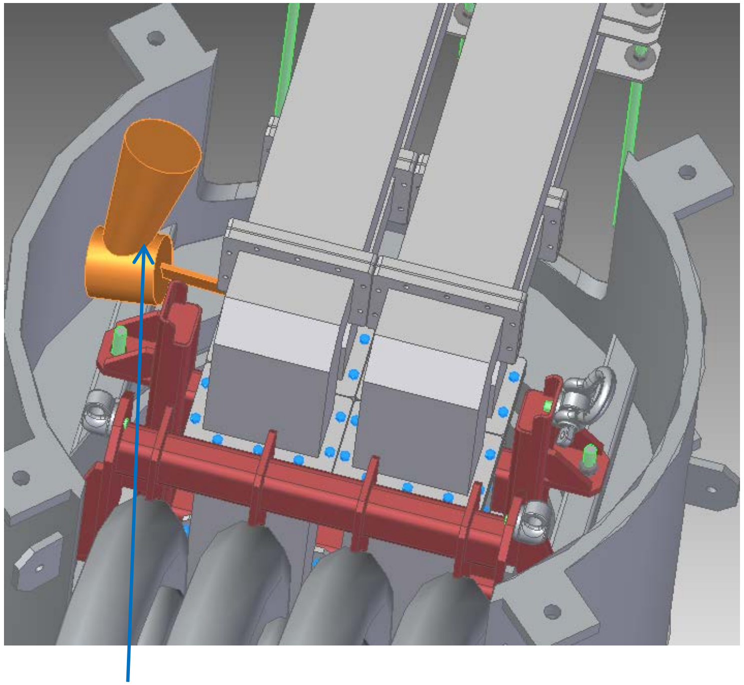
Access to connections “inside” shield support base:



With cover off, flanges are not deeply recessed

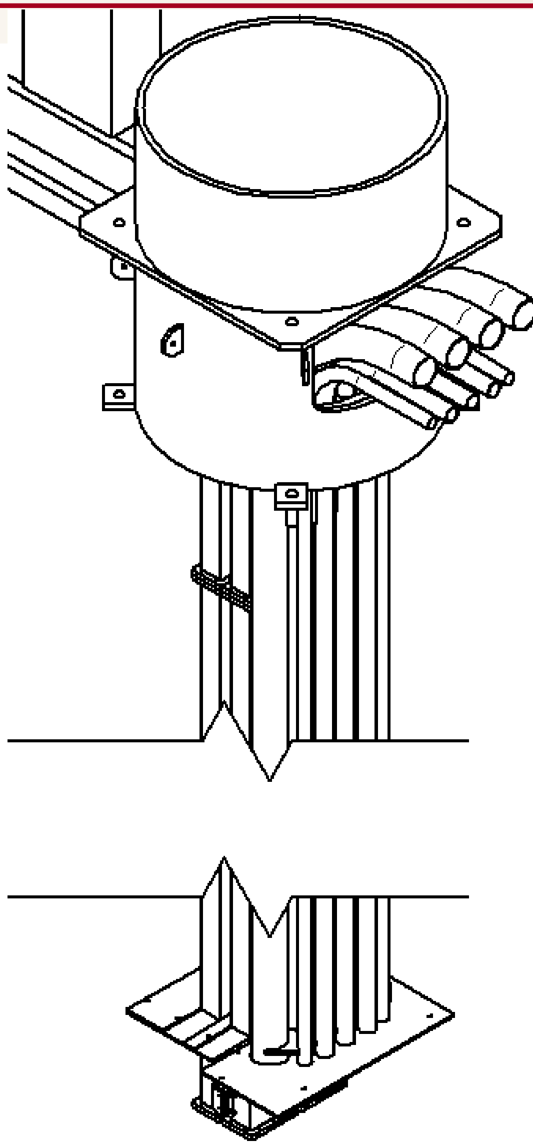


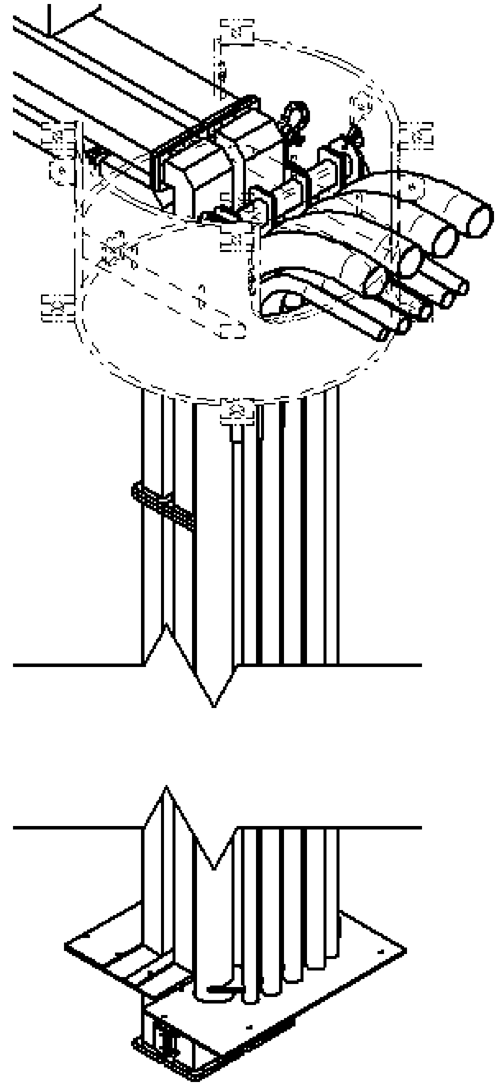
A. Haase



- Orange Ensemble represents Hand/Arm/Wrench on most difficult bolt (hand is 4”x4” cylinder)
- There is Considerable space to the sides

Penetration Waveguide and Conduit Bundles Inside Shielding Cap

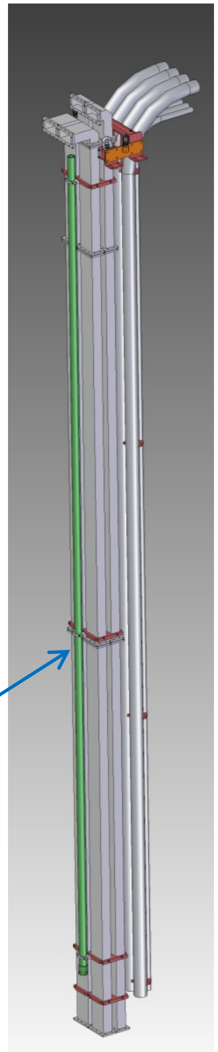




A. Haase

Installation Scenarios in Discussion Already
Waveguide Bundles share Penetration with Conduit Bundles.

28.5 ft.



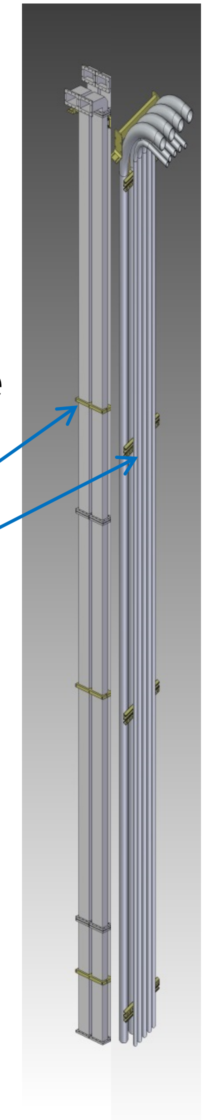
Air cooling pipe in case needed

Waveguide and conduits in penetration

- Installed in bundles from the roof
  - Together then separated or
  - WG and Conduit bundles lowered separately.

Waveguide supports designed for the weight and lever Arms associated with the waveguide system

Guards to hold each bundle together



Haase, Stewart, Rodrigues, Aguas

HPRF Penetration Heat Loads

For G=16 MV/m, Q_L= 4.1e7 and WR650 loss =0 .00839 dB/m

I_b = 0

Pforward = 2.62 kW, Preflected = 2.56 kW, Ptot = 5.18 kW
Heat per WG: 9.99 W/m

I_b = 100 μA

Pforward = 3.67 kW, Preflected = 1.93 kW, Ptot = 5.60 kW
Heat per WG: 10.8 W/m

I_b = 300 μA

Pforward = 6.48 kW, Preflected = 1.46 kW, Ptot = 7.94 kW
Heat per WG: 15.3 W/m

Approximate length in the penetration: 25 ft. = 7.62 m
From 4 waveguides, the total heat in the penetration load is:

I_b = 0:	40.0 W/m	or	304.8 W	+	30W Conduit
I_b = 100 μA:	43.2 W/m	or	329.2 W	+	30W Conduit
I_b = 300 μA:	61.2 W/m	or	466.3 W	+	30W Conduit

C. Nantista

HPRF Penetration Temperature

Assumptions:

Gallery ambient T = 40° C
Accelerator housing ambient T = 25° C

No Cooling With Bottom of Penetration Covered.

Case	100µA	300 µA
Calculated WG T	74°C	91°C
Calculated Conduit T	71 - 73°C	86-88C

Water Cooled Baffle With Bottom of Penetration Covered.

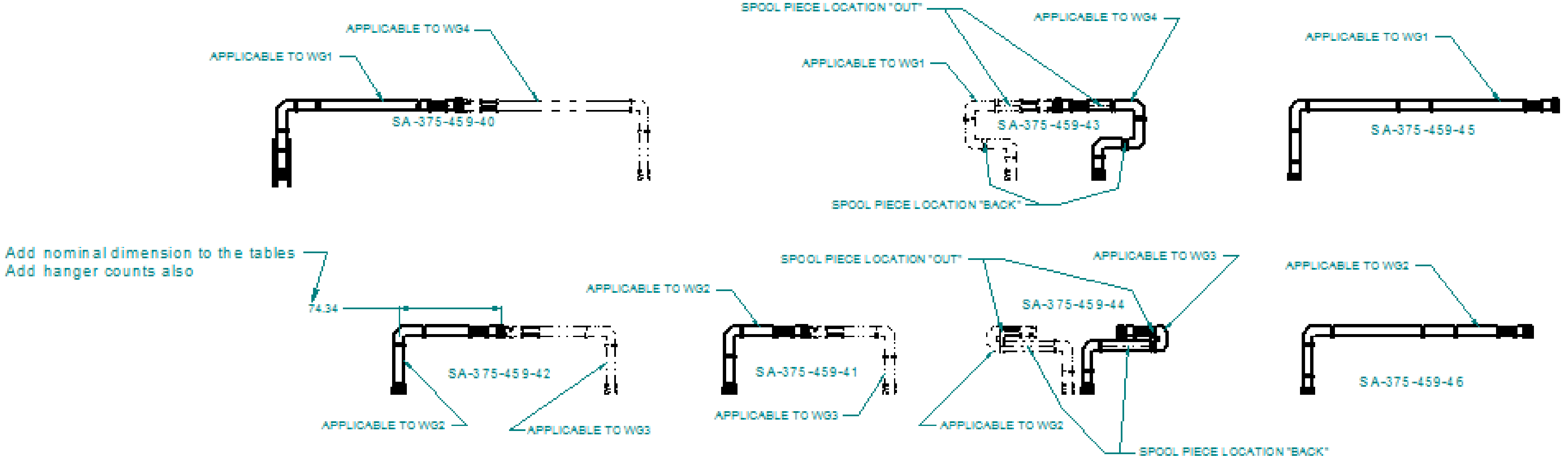
0.25 inch ID tubing down and back the Baffle (600 inches)
Input Water Conditions: Flow = 0.5 GPM, dP = 5 to 10 PSI, H_2O Tin = 45°C
SSA and isolator cooling water exhaust meets the necessary input water conditions for the Penetration Cooling Baffle.

Case	300 µA
Calculated WG T	65°C
Calculated Conduit T	**54-59°C**
H_2O ΔT	1.5°C

E. Jongewaard

- Adding a thermocouple on the waveguide bundle is recommended.
- Air Cooling simulation is difficult and less accurate and requires an additional 80 hr.

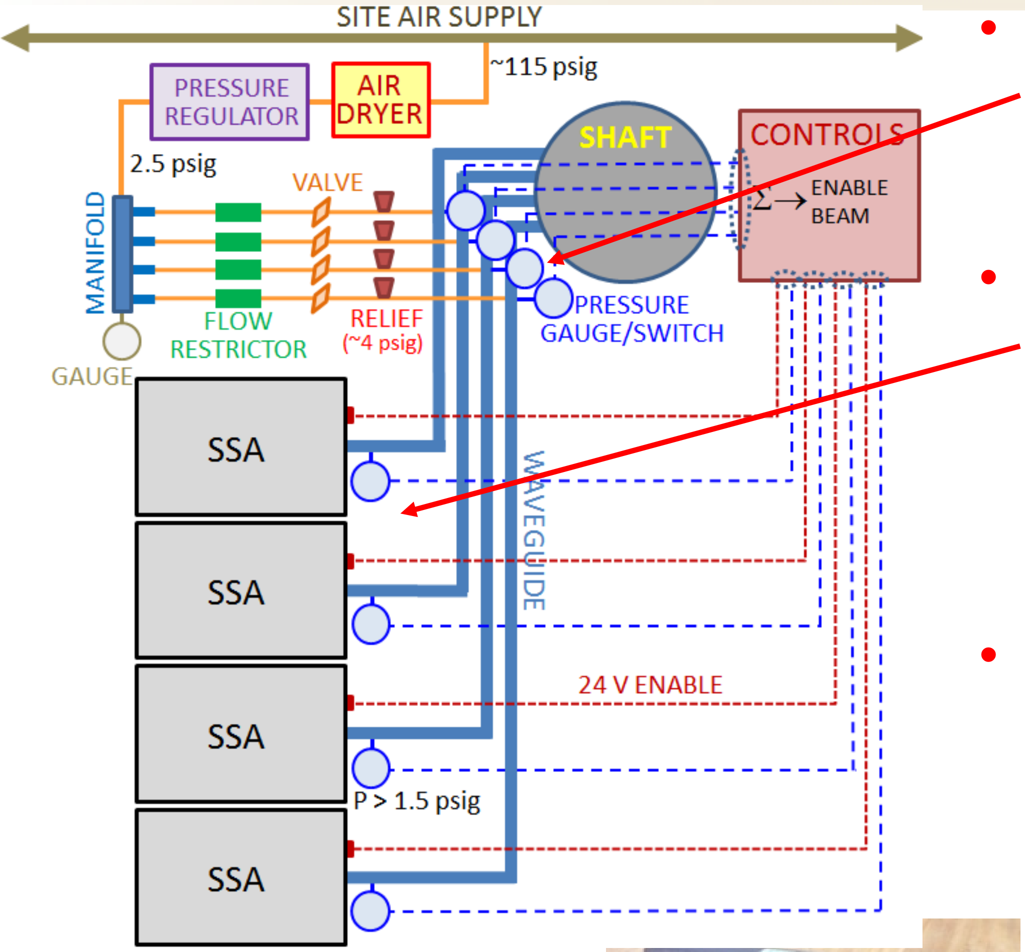
Waveguide Installation at the Tunnel Ceiling (ID-375-459-00)



A. Haase

All 280 horizontal runs at the tunnel Ceiling utilize one of the 7 configurations (5 of them are also used in a mirror image configuration.

LCLS-II: On to NIRP Scenario



- Each SSA Pressure Gauge is only interlocked to associated RF Source and is travels with the SSA
- WG Penetration Pressure Gauges from each RF source are Interlocked to turn off the beam and the SSA. (Beam loading or forward power activate)
- If SSA needs to be removed for an extend period
  - SSA Pressure Gauge can be removed with SSA
  - RF Shorting Plate shall be added to the Waveguide
  - Waveguide shall be re-pressurized

An RF Test Stand at SLAC for Risk Mitigation and to Discover as many Blow Ups as Early as Possible

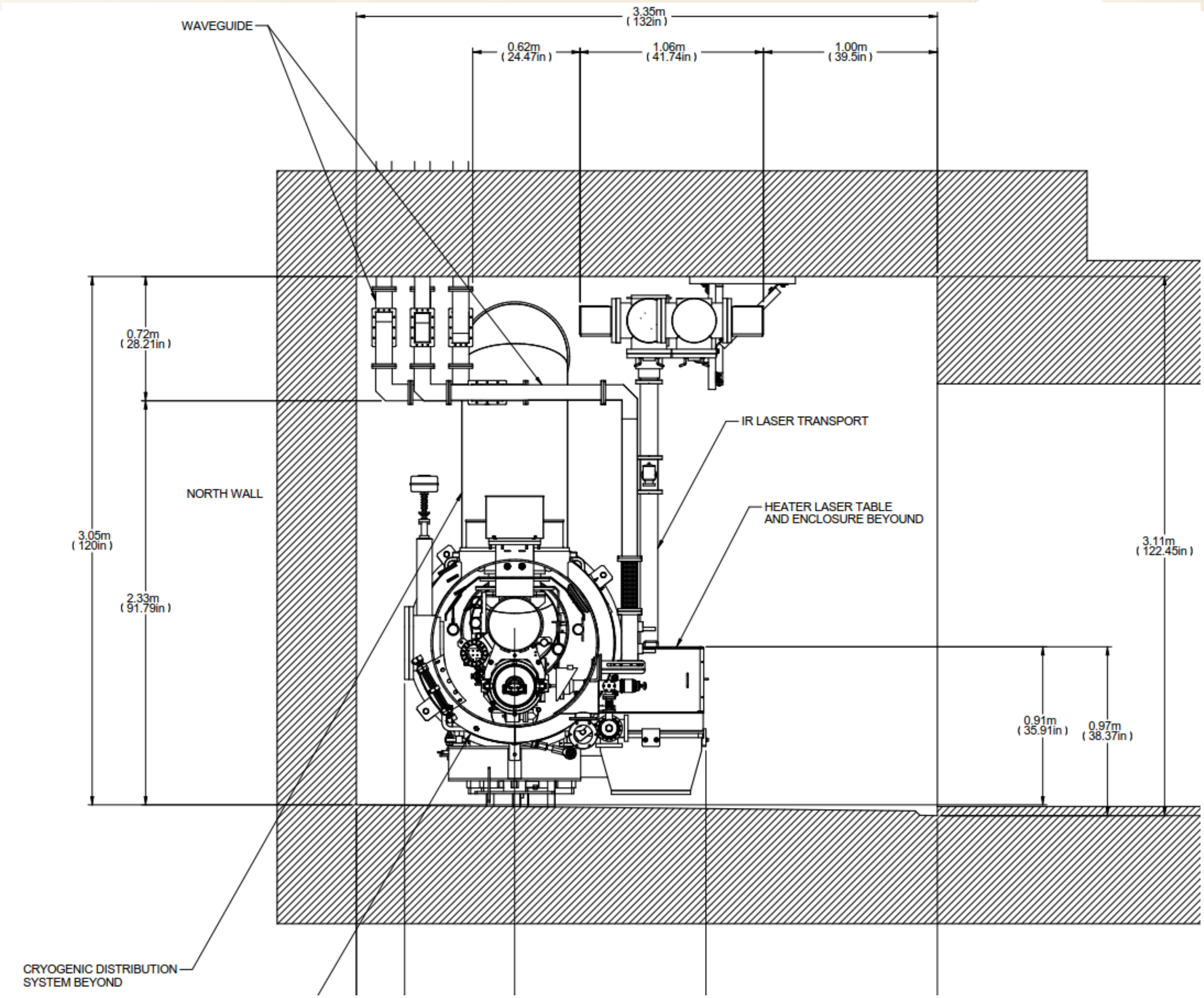
- A test stand to accommodate 3 SSA stations is nearly completed at SLAC and will be used to
  - Qualify SSAs
  - Test SSA control software
  - Qualify Waveguide components
    - Isolators
    - Directional couplers
    - Straights, bends and flexes
  - Test Non Ionizing Radiation Plan scenarios.
  - Provide experience for operations.
  - Maybe learn about Blowups (hopefully non) and make corrections to apply on LCLS II

LCLS II HPRF Summary

- RF component specification are very detailed not only about RF performance but quality as well. We hope we will have no blow ups to report at CWRF18 and beyond, but promise we will if they happen.
- Enough SSAs on hand for testing 1.3 GHz Cryo Modules at FNAL and JLAB on Schedule.
- A HPRF Tests stand at SLAC is nearly complete for thorough evaluation all HPRF components.
- Deliver from Second vendor is delayed, but expect no impact on Installation schedule. All vendors required to meet same quality and performance specifications.
- All other HPRF systems are progressing on schedule to meet the Installation Plan.
- Suggestions from the floor or in the hallways for imporivment are welcomed !

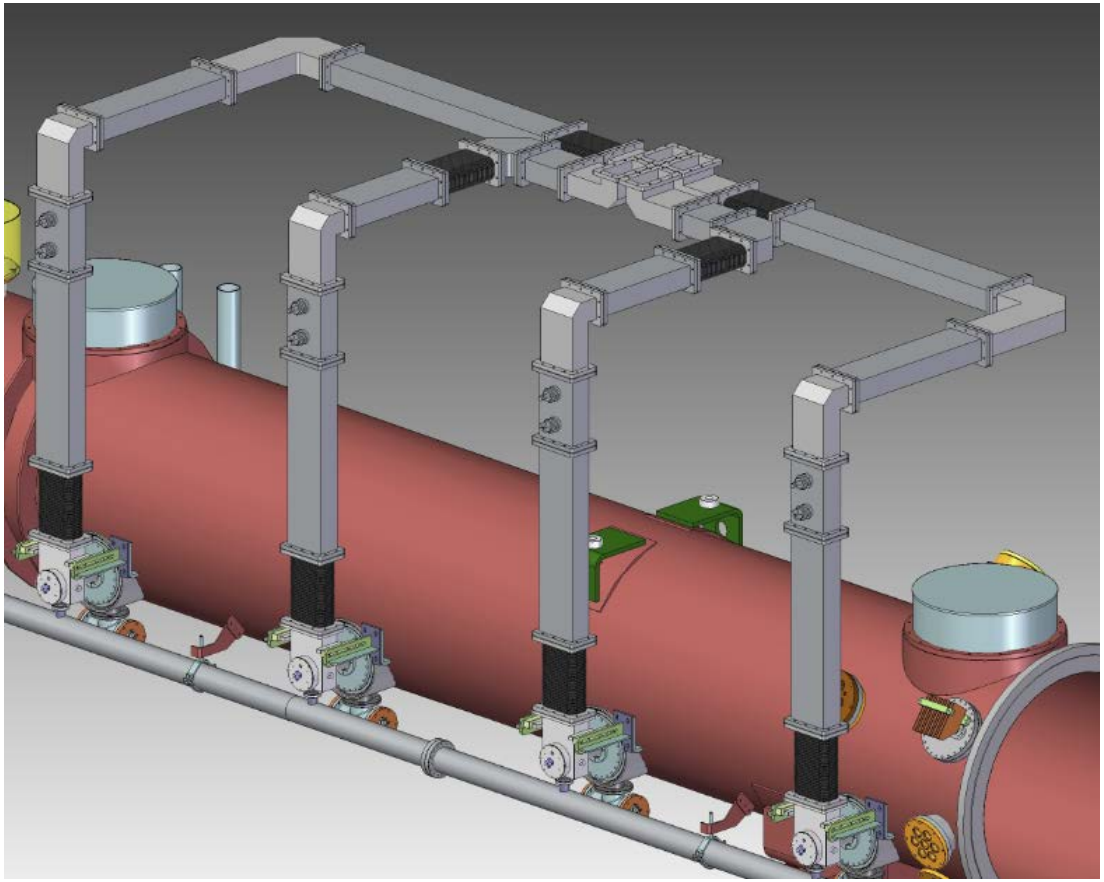
End
Backup Slides below

Tunnel Cross Section Near HPRF Penetrations in L0
Interferences with other systems Resolved



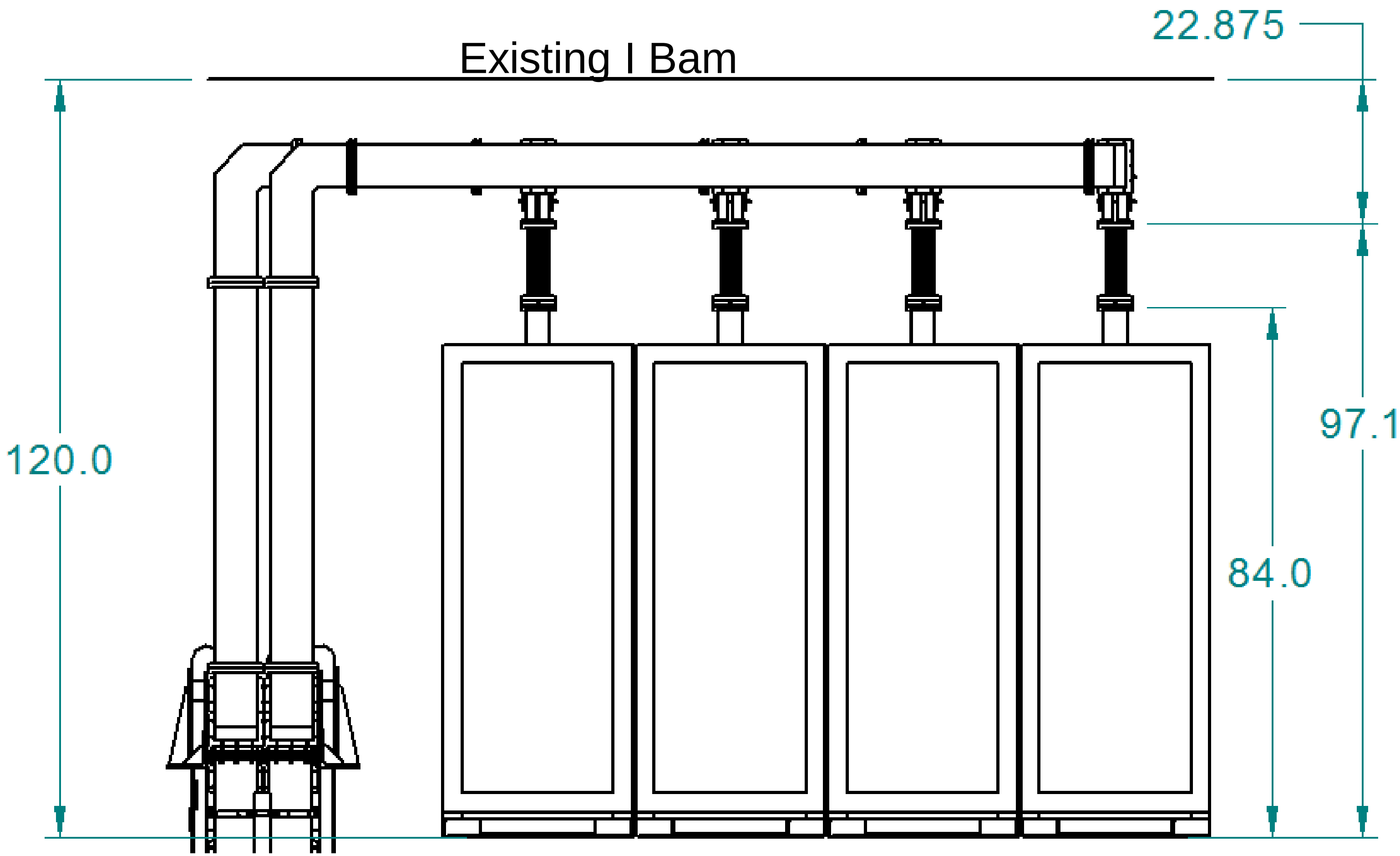
Accelerator Housing HPRF Distribution

- Representative waveguide configuration
  - supports not shown but described below
- Base of penetration waveguides constrained laterally but free to expand/contract vertically
  - 40°C excursion results in nearly .4” delta length. The adjacent flex guide is rated at just over 1” of E-plane offset
- Guide weight is supported periodically from simple hangers
- The guide is anchored to the housing approximately above the coupler box
- The flex connected immediately to the coupler box decouples residual misalignment, waveguide to cryo-module thermal expansion, and seismic displacements



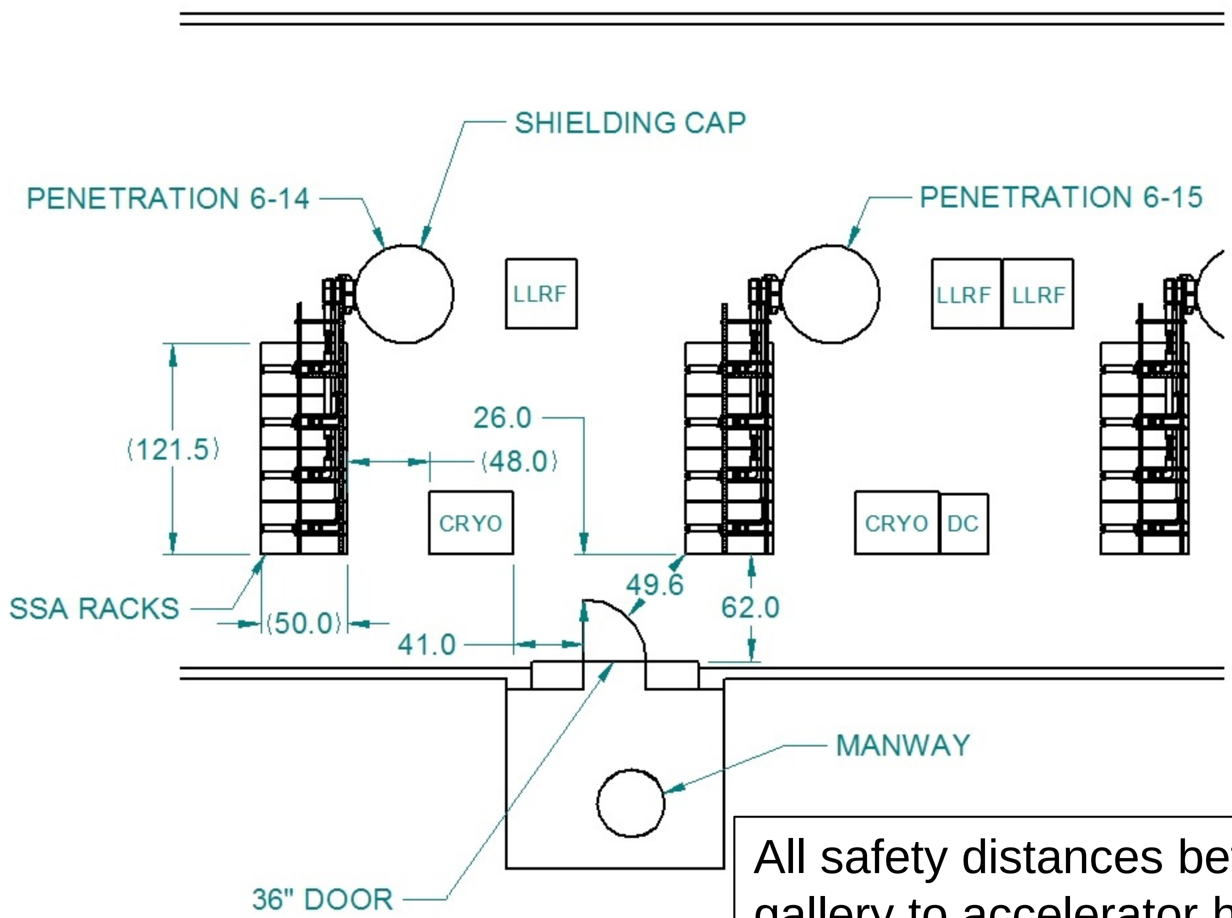
Elevation View at Penetration in the Gallery

North is to the left, looking at the front of the SSA



Gallery Floor Plan Near the Gallery-to-Accelerator-Housing Manway

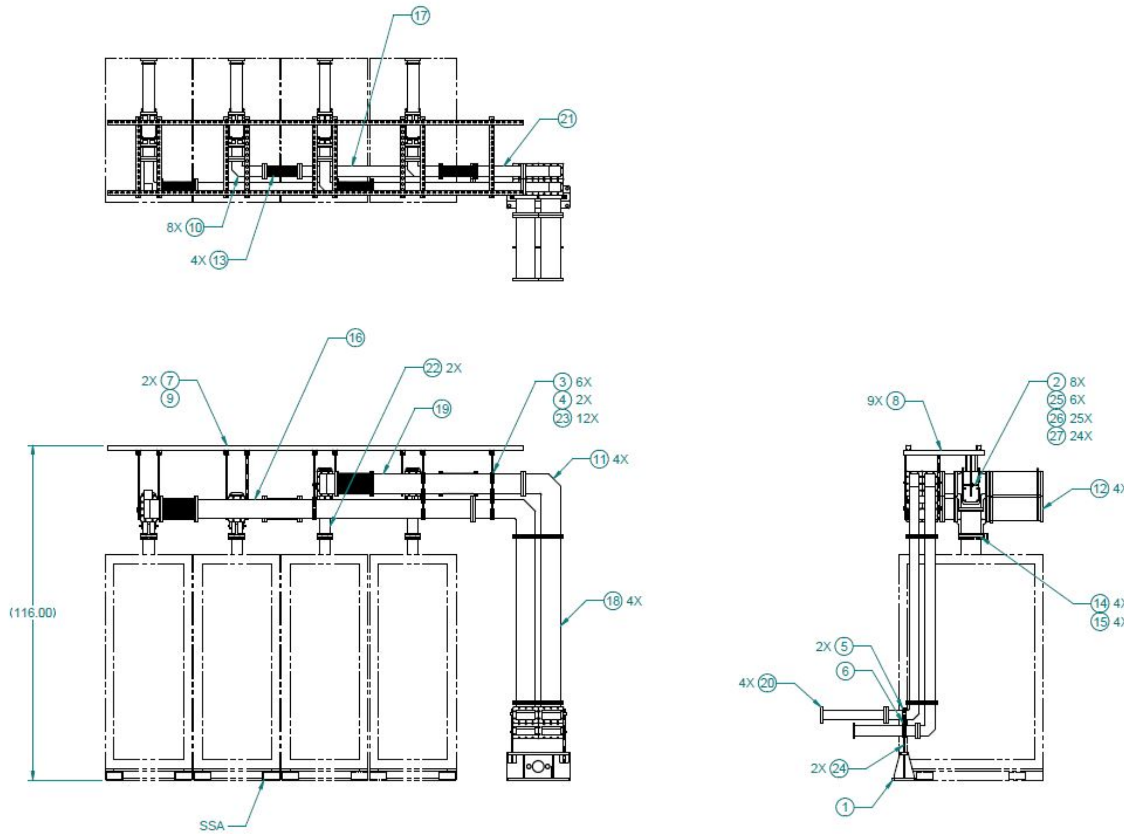
N. Stewart w/ team input



All safety distances between racks and gallery to accelerator housing manway area and door are respected.

Waveguide and Supports Layout From SSA to Top of Penetration Identical for all LCLS-II 1.3 GHz Penetrations (71)

CHECK-PRINT
nstewart
10-08-2015 08:25:47 AM



ITEM	STOCK OR PART NO	TITLE OR DESCRIPTION	QTY
27		NUT, HEX, 1/2-13 UNC-2B, STEEL	24
26		WASHER, FLAT RGLR, .50 ID, STEEL	25
25		THREADED ROD, 1/2-13 UNC-2A X 16.00 L	6
24		THREADED ROD, 1/2-13 UNC-2A X 18.00 L	2
23		THREADED ROD, 1/2-13 UNC-2A X 24.00 L	12
22		WR650, .125 WALL, 8.63 L	2
21		WR650, .125 WALL, 16.38 L	1
20		WR650, .125 WALL, 22.50 L	4
19		WR650, .125 WALL, 52.38 L	1
18		WR650, .125 WALL, 57.50 L	4
17		WR650, .125 WALL, 59.88 L	1
16		WR650, .125 WALL, 95.88 L	1
15	McDaniel Controls Q3BC	PRESSURE GAUGE, 1/4 NPT,0-30 PSI, SST, CENTER BACK CONNECTION	4
14		PURGE SPACER, .75 THK, WR650	4
13		FLEXIBLE COUPLING, WR650	4
12		ISOLATOR	4
11		H-BEND MITER, WR650, .125 WALL, ASYMMETRIC	4
10		E-BEND MITER, WR650, .125 WALL, ASYMMETRIC	8
9	UNISTRUT P1010	CHANNEL NUT, 1/2-13 UNC	12
8	UNISTRUT P1000T	UNISTRUT, T-SERIES, 1.63 X 1.63 X 28.00 L	9
7	UNISTRUT P1000T	UNISTRUT, T-SERIES, 1.63 X 1.63 X 144.00 L	2
6	PF-375-520-26	DOUBLE SPACER HORIZONTAL	1
5	PF-375-520-25	DOUBLE WAVEGUIDE HORIZONTAL	2
4	PF-375-520-24	DOUBLE SPACER VERTICAL	2
3	PF-375-520-23	DOUBLE WAVEGUIDE VERTICAL	6
2	PF-375-520-21	ISOLATOR SUPPORT BRACKET	8
1	SA-375-520-01	WAVEGUIDE FLOOR SUPPORT	1

SA-375-549-03
NEXT ASSEMBLIES:

SCALE: 1:20 DO NOT SCALE DRAWING
ESTIMATED MASS: .000 LB
CAD FILE NAME: sa37545911-0.dft

SLAC NATIONAL ACCELERATOR LABORATORY — U.S. DEPARTMENT OF ENERGY

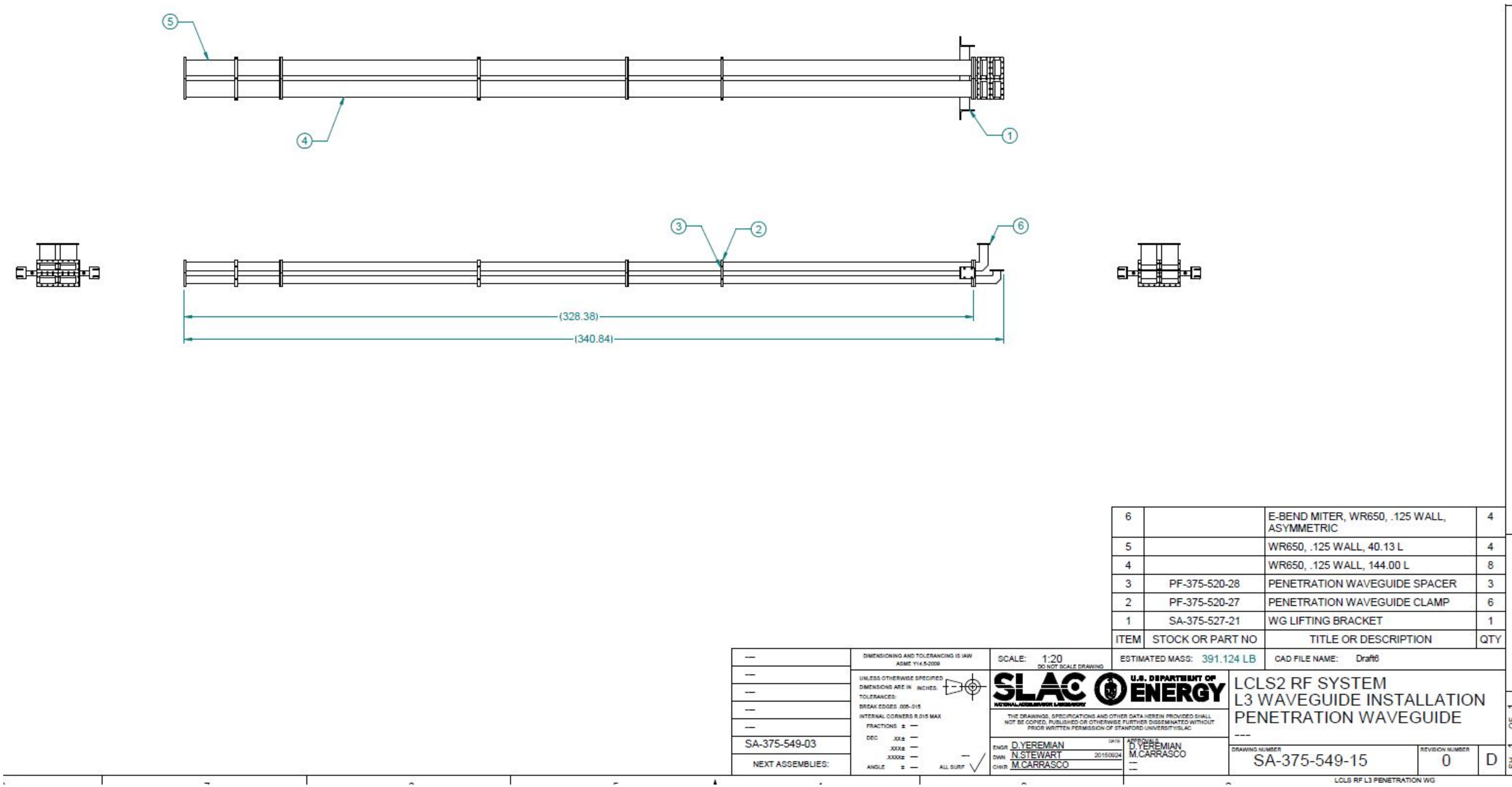
LCLS RF SYSTEMS
L3 WAVEGUIDE INSTALLATION
GALLERY WG

ENGR D.YEREMIAN
DWN N.STEWART 20150924
CHKR M.CARRASCO
APPROVALS D.YEREMIAN M.CARRASCO

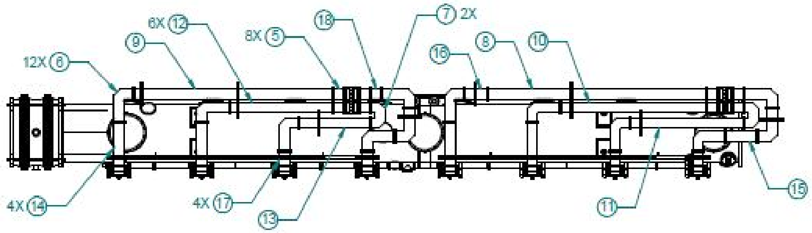
DRAWING NUMBER SA-375-459-11
REVISION NUMBER 0
D

LCLS RF L3 WG INSTALL

Waveguide and Supports Layout in Penetration Identical for all LCLS-II 1.3 GHz Waveguides (71 times)

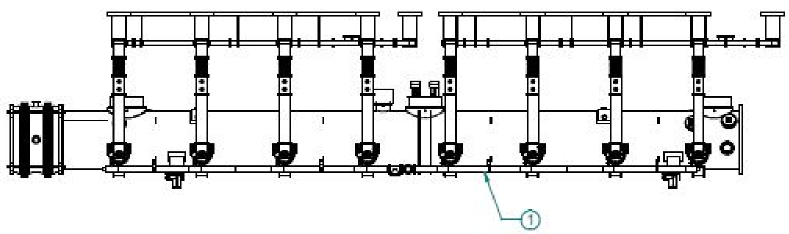


Waveguide and Supports Layout in Accelerator Housing for LCLS-II 1.3 GHz Waveguides



5 possible variations at the accelerator housing ceiling:

- 4 upstream
- 4 downstream
- 2 upstream, 2 downstream
- 3 upstream, 1 downstream
- 1 upstream, 3 downstream



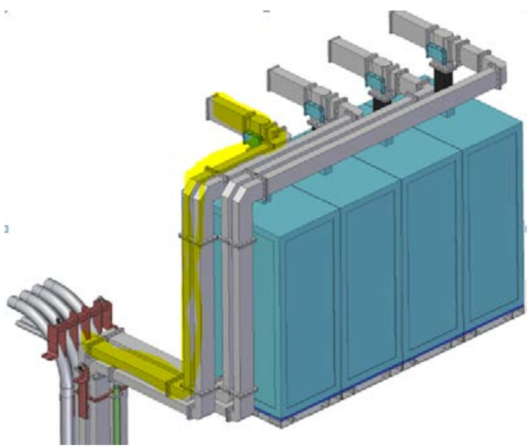
Identical vertical assemblies from cryomodule to ceiling (35 times).

ITEM	STOCK OR PART NO	TITLE OR DESCRIPTION	QTY
18		WR650, .125 WALL, 7.11 L	1
17		WR650, .125 WALL, 13.22 L	4
16		WR650, .125 WALL, 15.15 L	1
15		WR650, .125 WALL, 20.74 L	1
14		WR 650, .125 WALL, 32.40 L	4
13		WR650, .125 WALL, 47.09 L	1
12		WR650, .125 WALL, 72.45 L	1
11		WR650, .125 WALL, 75.18 L	1
10		WR650, .125 WALL, 96.03 L	1
9		WR650, .125 WALL, 131.17 L	1
8		WR650, .125 WALL, 144.00 L	1
7		U-BEND, H-PLANE, WR650, .125 WALL	2
6		H-BEND MITER, WR650, .125 WALL, ASYMMETRIC	12
5		E-BEND MITER, WR650, .125 WALL, ASYMMETRIC	8
4	SA-375-520-05	FRONT CRYO WG SUPPORT	2
3	SA-375-520-03	DOUBLE WAVEGUIDE SUPPORT	2
2	SA-375-520-02	SINGLE WAVEGUIDE SUPPORT	6
1	SA-375-459-10	CRYO WAVEGUIDE	1

SA-375-459-03
NEXT ASSEMBLIES
SCALE: 1:40
ESTIMATED MASS: .000 LB
CAD FILE NAME: sa37546027-0.dft
SLAC U.S. DEPARTMENT OF ENERGY
LCLS RF SYSTEMS
L3 WAVEGUIDE
CM027 WG INSTALL
D.YEREMIAN
N.STEWART
M.CARRASCO
D.YEREMIAN
M.CARRASCO
SA-375-460-27
0
D
LCLS RF L3 CM027 WAVEGUIDE

Gallery HPRF Layout Evaluation Short Waveguide Run

- Worst case positional errors in X,Y,Z of ~.75” require no more than .25” of waveguide flex to locate the flex guide flange within acceptable limits.
- Expect installation/mounting procedure to flex the guide enough (~1/2) so that the initial/static displacement of the isolation flex is small.

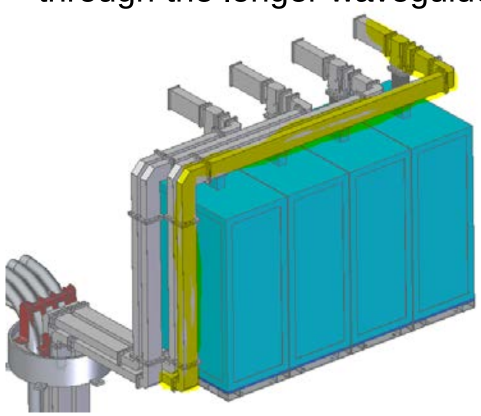


Gallery Short Run	Nominal End Position X, N-S, T (in)	Y, U-D, V (in)	Z, W-E, L (in)	Length (in)	Direction	Error Position X, N-S, T (in)	Y, U-D, V (in)	Z, W-E, L (in)
Penetration Flange	**0**	**0**	**0**	**0**		0	0	0
Spool 1	0	0	38	38	L	0.099484	0.0994837	38.057
E-bend 1a	0	0	42.125	4.125	L	0.110283	0.1102829	42.18819
E-bend 1b	0	9.625	42.125	9.625	V	0.135481	9.7497204	42.21339
Spool 2	0	69.625	42.125	60	V	0.29256	69.83972	42.37047
H-bend 1a	0	87.875	42.125	18.25	V	0.340339	88.117095	42.41824
H-bend 1b	9.5	87.875	42.125	9.5	T	9.854589	88.141966	42.44311
Spool 3	36.5	87.875	42.125	27	T	36.89509	88.212652	42.5138
E-bend 2a	46.125	87.875	42.125	9.625	T	46.53453	88.23785	42.539
E-bend 2b	46.125	87.875	46.25	4.125	L	46.54533	88.248649	46.67019
Isolator a	46.125	87.875	56.25	10	L	46.57151	88.274829	56.68519
Isolator b	46.125	96.875	56.25	9	V	46.59507	97.288329	56.70875
Variation in Run	**0.470067**	**0.413329**	**0.458748**					
Anchor position	0.25	0	0.25					
Floor height	0	0.25	0					
SSA Flange height	0	0.13	0					
Total Fixed Error	**0.720067**	**0.793329**	**0.708748**					
Thermal Expansion	0.042435	0.089125	0.05175					
Flex Guide Range	1.1	0.66	0.57					
Additonal Flex R'qd	**-0.3375**	**0.222454**	**0.190498**					

Nominal Errors		
Roll/Pitch/Yaw	0.15	deg
Length	0.0015	in/in
Thermal excursion	40	°C

Gallery HPRF Layout Evaluation Long Waveguide Run

- Worst case positional errors in X,Y,Z of ~1” require no more than ~.5” of waveguide flex to maintain flex guide within limits.
- Expect installation/mounting procedure to flex the guide enough (~3/4”) so that the initial/static displacement of the isolation flex is small.
- This additional flex/displacement is realized through the longer waveguide



Gallery Long Run	Nominal End Position X, N-S, T (in)	Y, U-D, V (in)	Z, W-E, L (in)	Length (in)	Direction	Error Position X, N-S, T (in)	Y, U-D, V (in)	Z, W-E, L (in)
Penetration Flange	**0**	**0**	**0**	**0**		0	0	0
Spool 1	0	0	50	50	L	0.1309	0.1308995	50.075
E-bend 1a	0	0	54.125	4.125	L	0.141699	0.1416988	54.20619
E-bend 1b	0	9.625	54.125	9.625	V	0.166897	9.7811363	54.23139
Spool 2	0	69.625	54.125	60	V	0.323976	69.871136	54.38847
H-bend 1a	0	87.875	54.125	18.25	V	0.371755	88.148511	54.43624
H-bend 1b	9.5	87.875	54.125	9.5	T	9.886005	88.173382	54.46111
Spool 3	124.5	87.875	54.125	115	T	125.0585	88.474451	54.76218
E-bend 2a	134.125	87.875	54.125	9.625	T	134.6979	88.499649	54.78738
E-bend 2b	134.125	87.875	58.25	4.125	L	134.7087	88.510448	58.91857
Isolator a	134.125	87.875	68.25	10	L	134.7349	88.536628	68.93357
Isolator b	134.125	96.875	68.25	9	V	134.7585	97.550128	68.95713

Variation in Run	**0.633483**	**0.675128**	**0.707131**
Anchor position	0.25	0	0.25
Floor height	0	0.25	0
SSA Flange height	0	0.13	0
Total Fixed Error	**0.883483**	**1.055128**	**0.957131**
Thermal Expansion	0.123395	0.089125	0.06279
Flex Guide Range	1.1	0.66	0.57
Additonal Flex R'qd	**-0.09312**	**0.484253**	**0.449921**

Nominal Errors		
Roll/Pitch/Yaw	0.15	deg
Length	0.0015	in/in
Thermal excursion	40	°C

Rigid Guide Flex

As previously noted it is quite unreasonable to expect all the errors to accumulate, as random variation in orientation should result in significant cancelation. This particular installation does not have quite enough components to support a full statistical analysis.

For purposes of bracketing the problem the worst case of +/-2" of error will be considered.

The Rated offset capability of the flex guide is:

- H-offset, .66"
- E-offset, 1.08"
- Length, .57"
- Twist, .55°

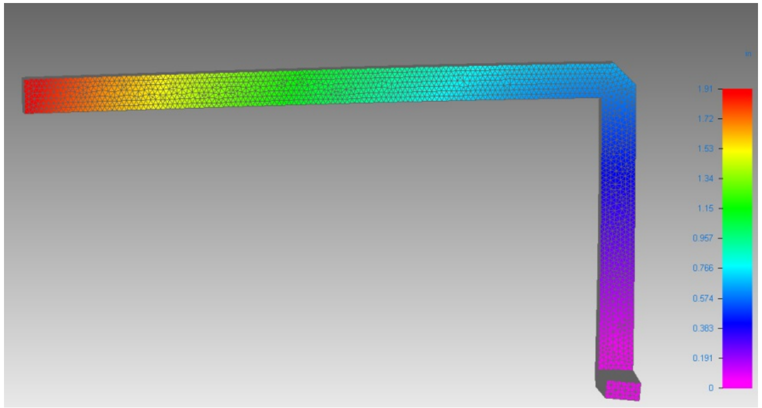
The rated flex guide displacements require ~60 Lbs for the lateral offsets and 1,300 in-lbs torque for the twist.

If these same forces are applied to the "rigid" length of waveguide the resulting elastic deflection is approximately the entire 2" required.

This flexibility of the rigid guide will allow the flange position to be adjusted into the range of the bellows by the hanger/support system.

The flex guide would then be used to make up any remaining misalignment and decouple the SSA flange from the rigid waveguide system.

The combination of a single flex guide section plus adjustable waveguide supports can accommodate the worst case required displacement of 2"



- Displacement of rigid waveguide with 60Lbs load at end of run ~2"
- This force will be easily generated by the support system and adjustable hangers

1.3 GHz and 3.9 GHz Isolator Physical Constraints