PIP-II Managing Technology Obsolescence – RF Systems at FNAL

Victor Grzelak

PIP-II Technical Integration

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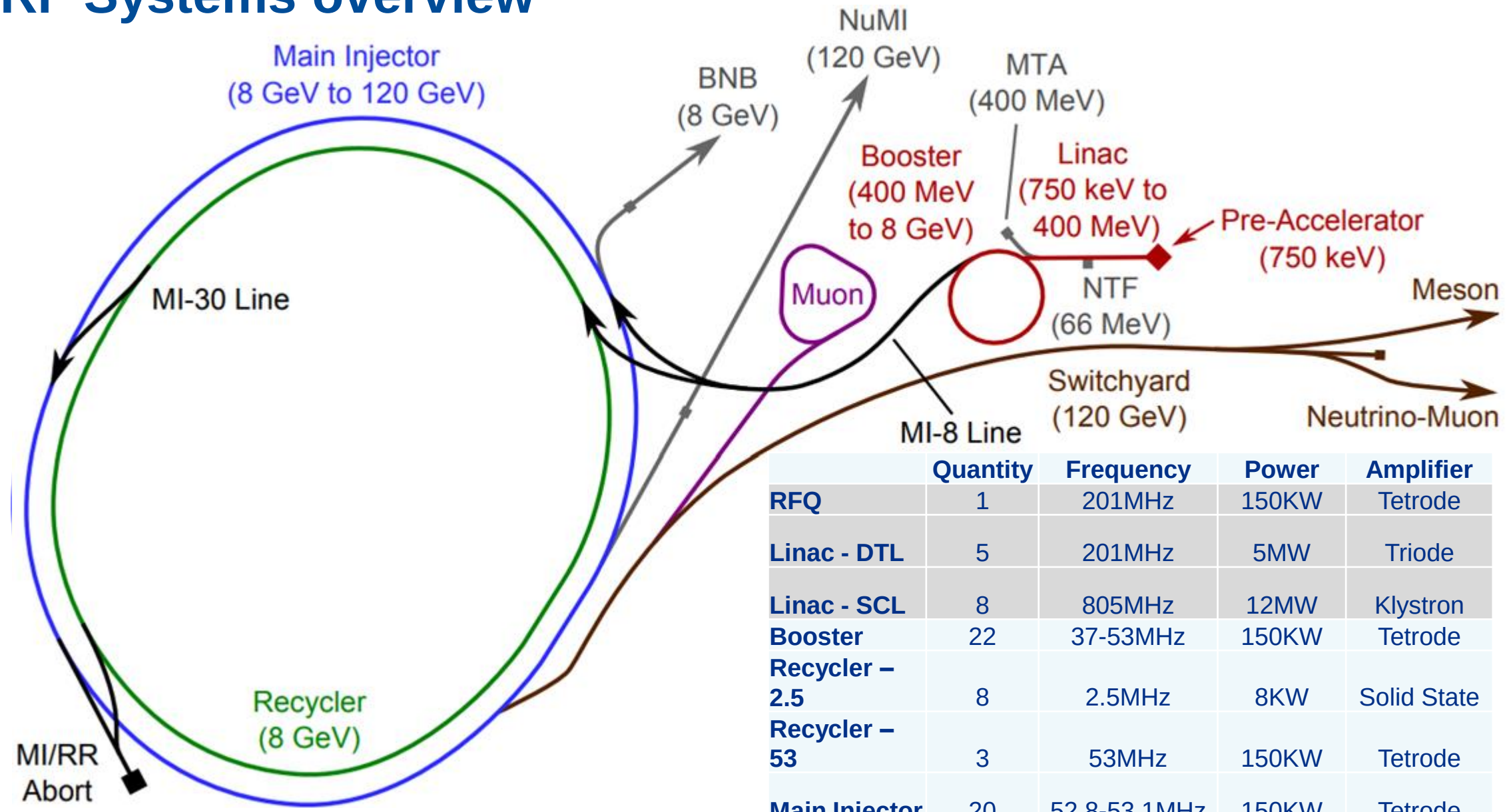
A Partnership of:

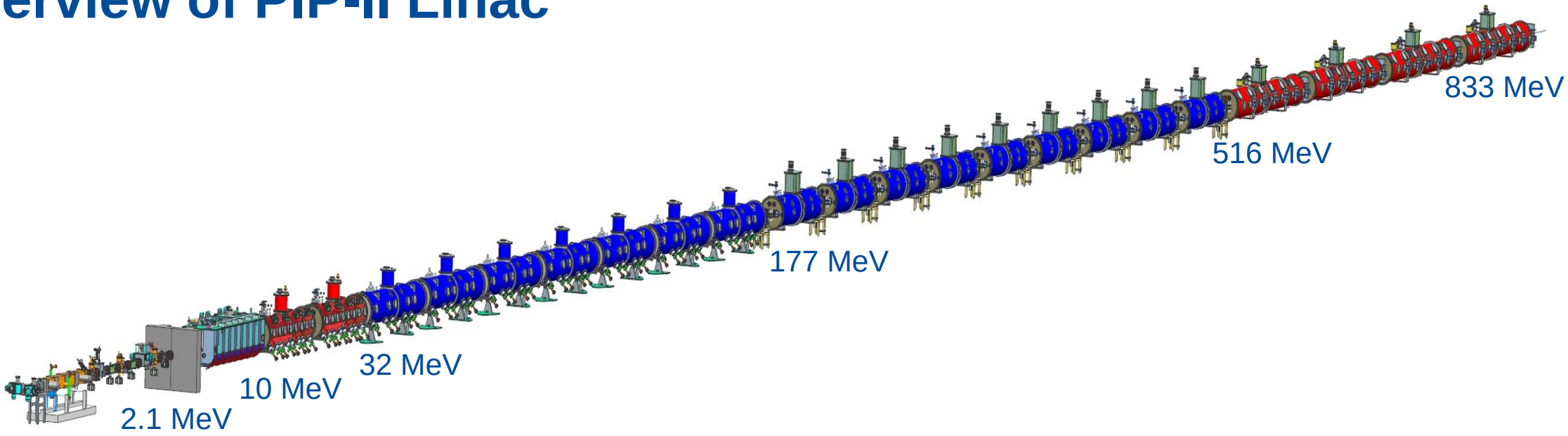
US/DOE
India/DAE
Italy/INFN
UK/UKRI-STFC
France/CEA, CNRS/IN2P3
Poland/WUST

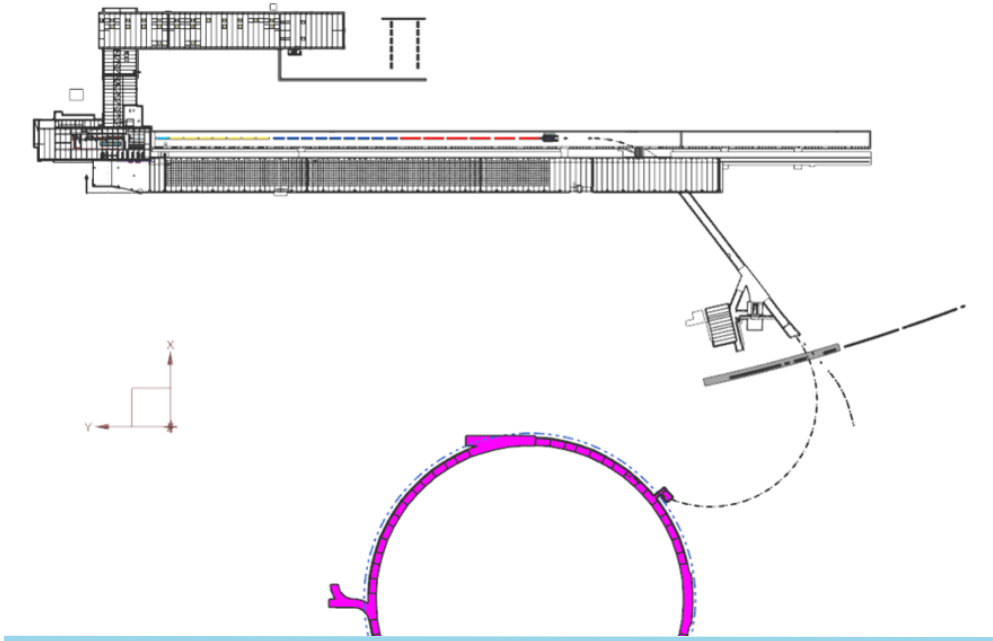
RF Systems overview



	Quantity	Frequency	Power	Amplifier
RFQ	1	201MHz	150KW	Tetrode
Linac - DTL	5	201MHz	5MW	Triode
Linac - SCL	8	805MHz	12MW	Klystron
Booster	22	37-53MHz	150KW	Tetrode
Recycler – 2.5	8	2.5MHz	8KW	Solid State
Recycler – 53	3	53MHz	150KW	Tetrode
Main Injector	20	52.8-53.1MHz	150KW	Tetrode

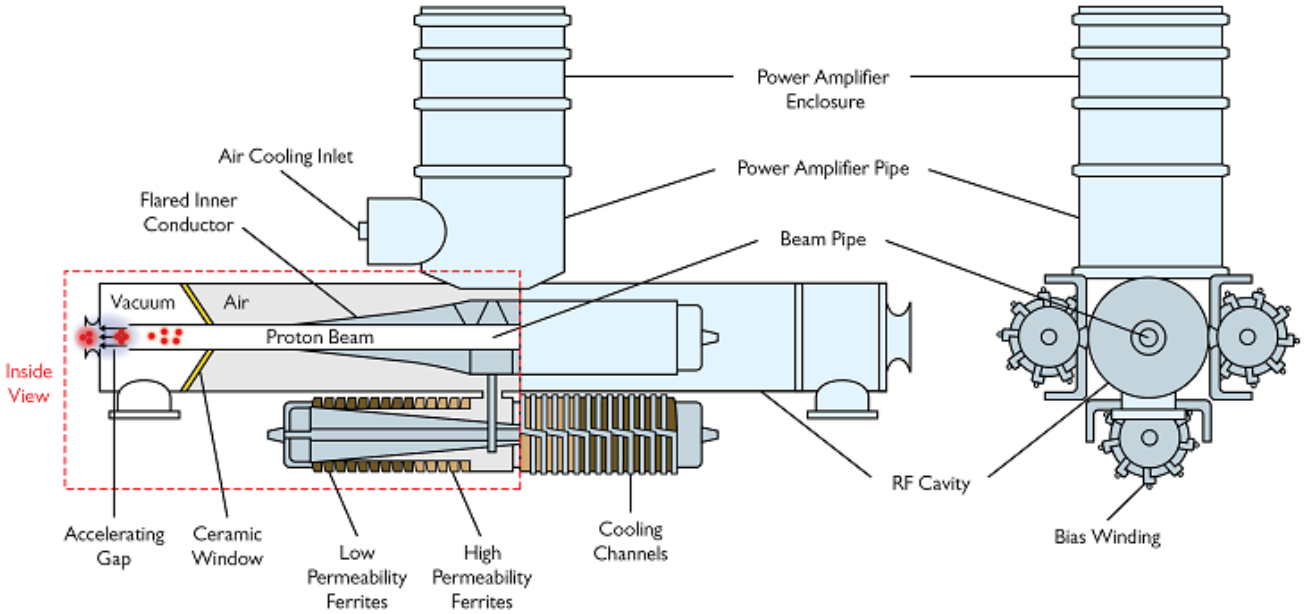
Overview of PIP-II Linac



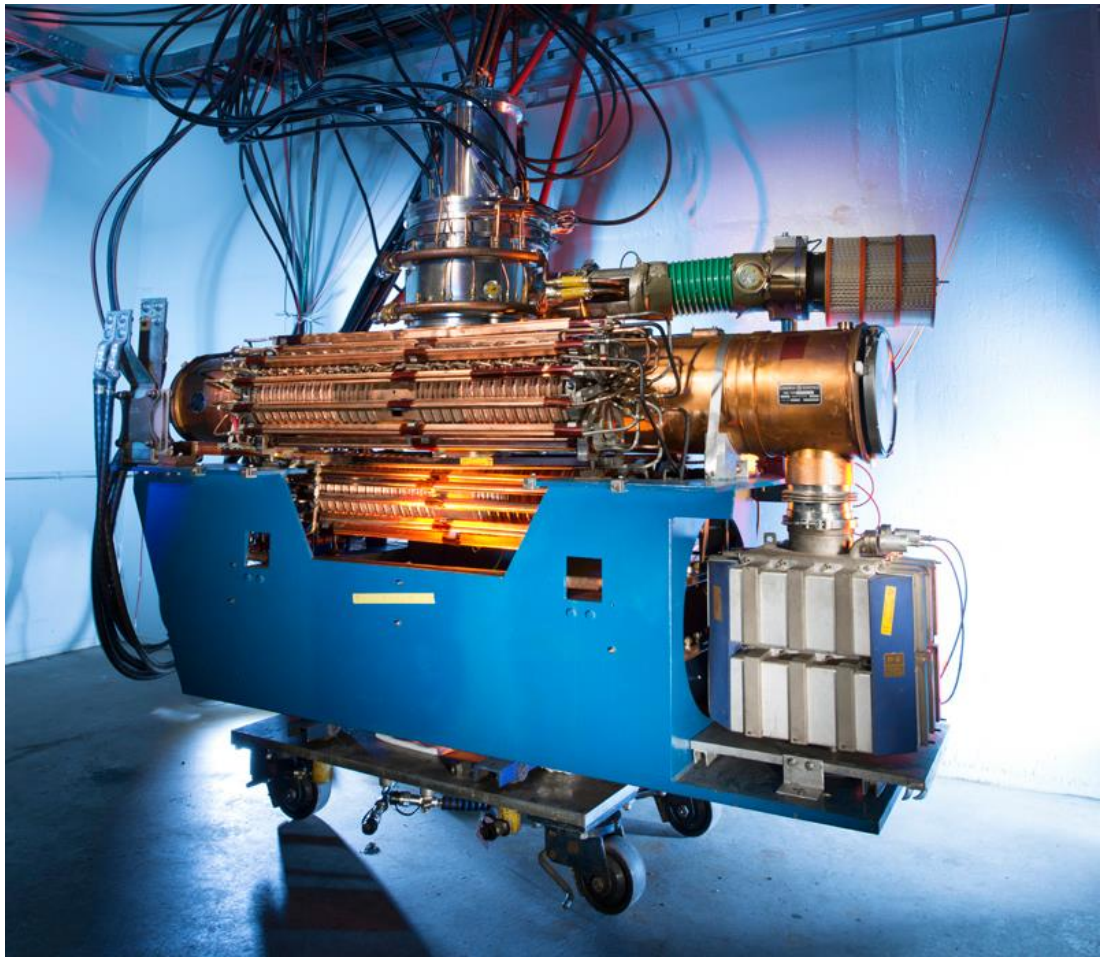


	Quantity	Frequency	Power	Amplifier
RFQ	2	162.5MHz	75KW	Solid State
HWR	8	162.5MHz	8kW	Solid State
SSR1	16	325MHz	8kW	Solid State
SSR2	35	325MHz	20KW	Solid State
LB650	36	650MHz	40KW	Solid State
HB650	24+12	650MHz	70KW	Solid State

Booster RF System



Injection Energy	400 MeV
Extraction Energy	8 GeV
Circumference	474.2 m
Periods	24
Lattice	FOFDOOD
Revolution Period (at 400 MeV/8 GeV)	$2.2\mu s/1.6\mu s$
RF Stations	19
RF Frequency	37.77 MHz to 52.8 MHz
Harmonic Number	84
RF Voltage Gain Per Turn	920 kV/turn



Booster cavities in operation since start of lab

Booster RF System

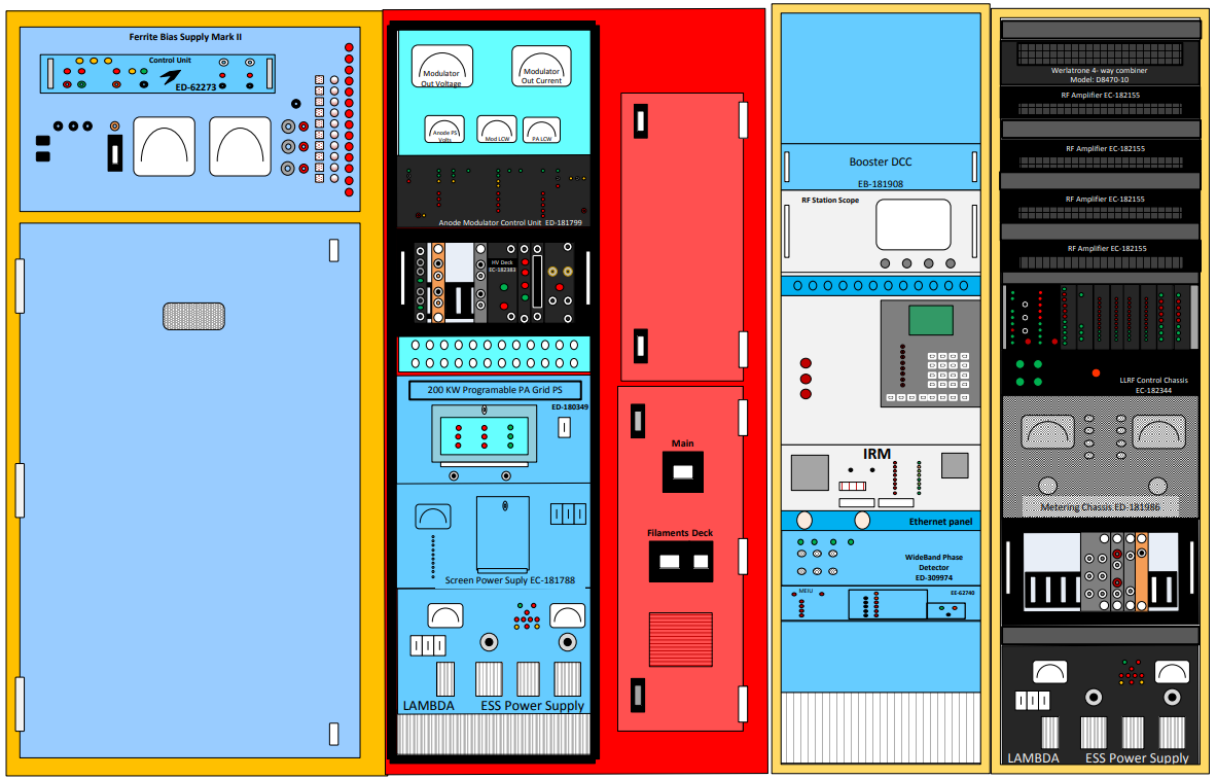
Cavity – Ferrite loaded coaxial cavity

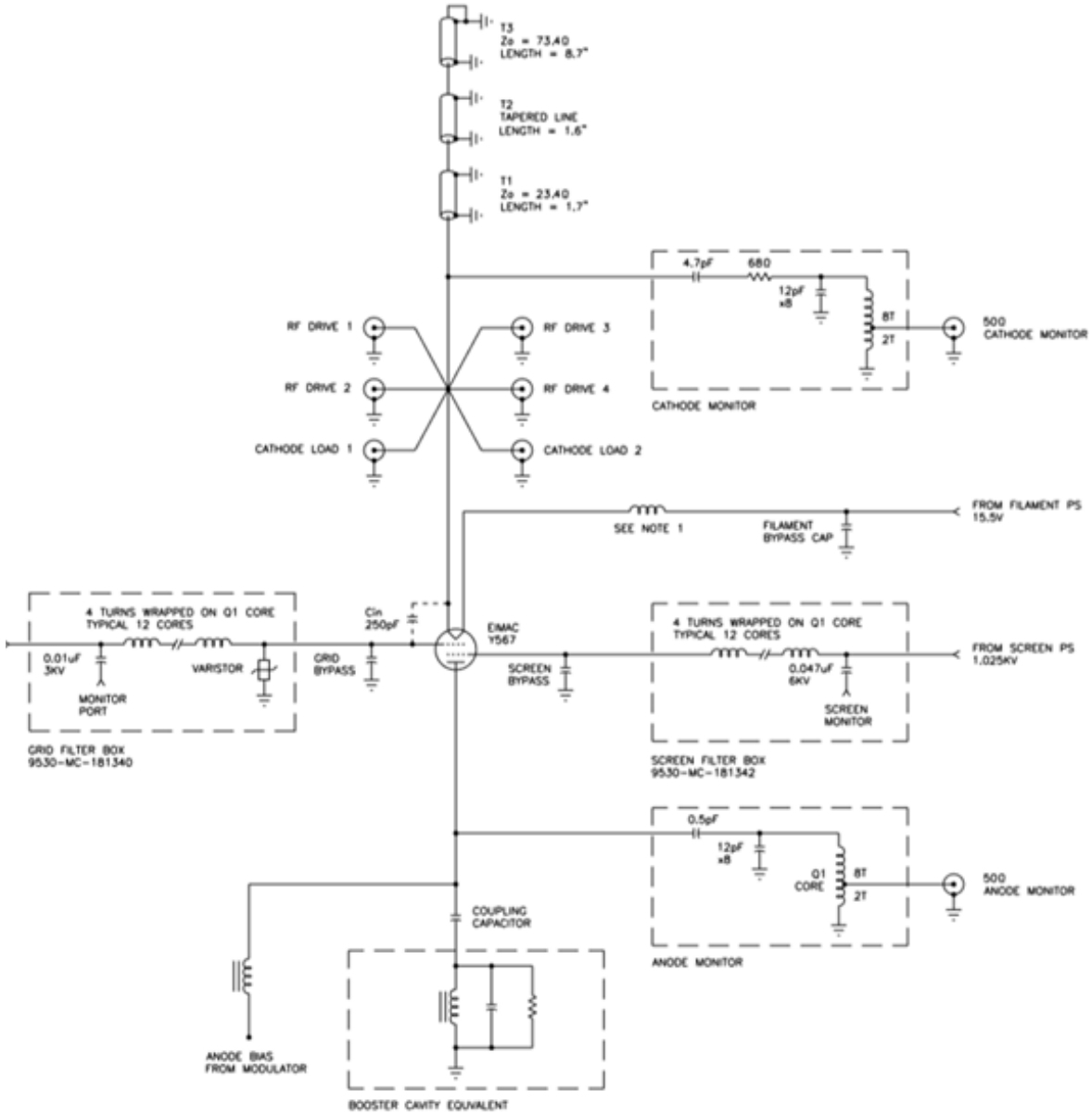
Ferrite Bias Supply – Precision tuning of cavity

Modulator – Programable RF envelope shaping

PA – RF Amplification

SSA – Drive signal amplification





Booster Upgrades

1. Solid State amplifier upgrade replaced tube drivers
   - Replaced cascode amplifiers (CW800F) with SSA greatly improving reliability
   - Reducing operating cost, transitioning away from tube amplifiers

2. Modulator HV MOSFET program upgrade replaced tube
   - Replaced Eimac CW800F tube, was replaced with High voltage FET
   - Removal of FET allowed for simplification of design
   - Reducing operating cost, transitioning away from tube amplifiers

3. LLRF fanout system upgraded from analog system to FPGA based system
   - Phase stability greatly increased, allowing for more accurate paraphrasing

4. Booster cavities operated in a 20+2 redundancy scheme
   - When a cavities' RF system went out of service, 2 viable spares were available minimizing downtime

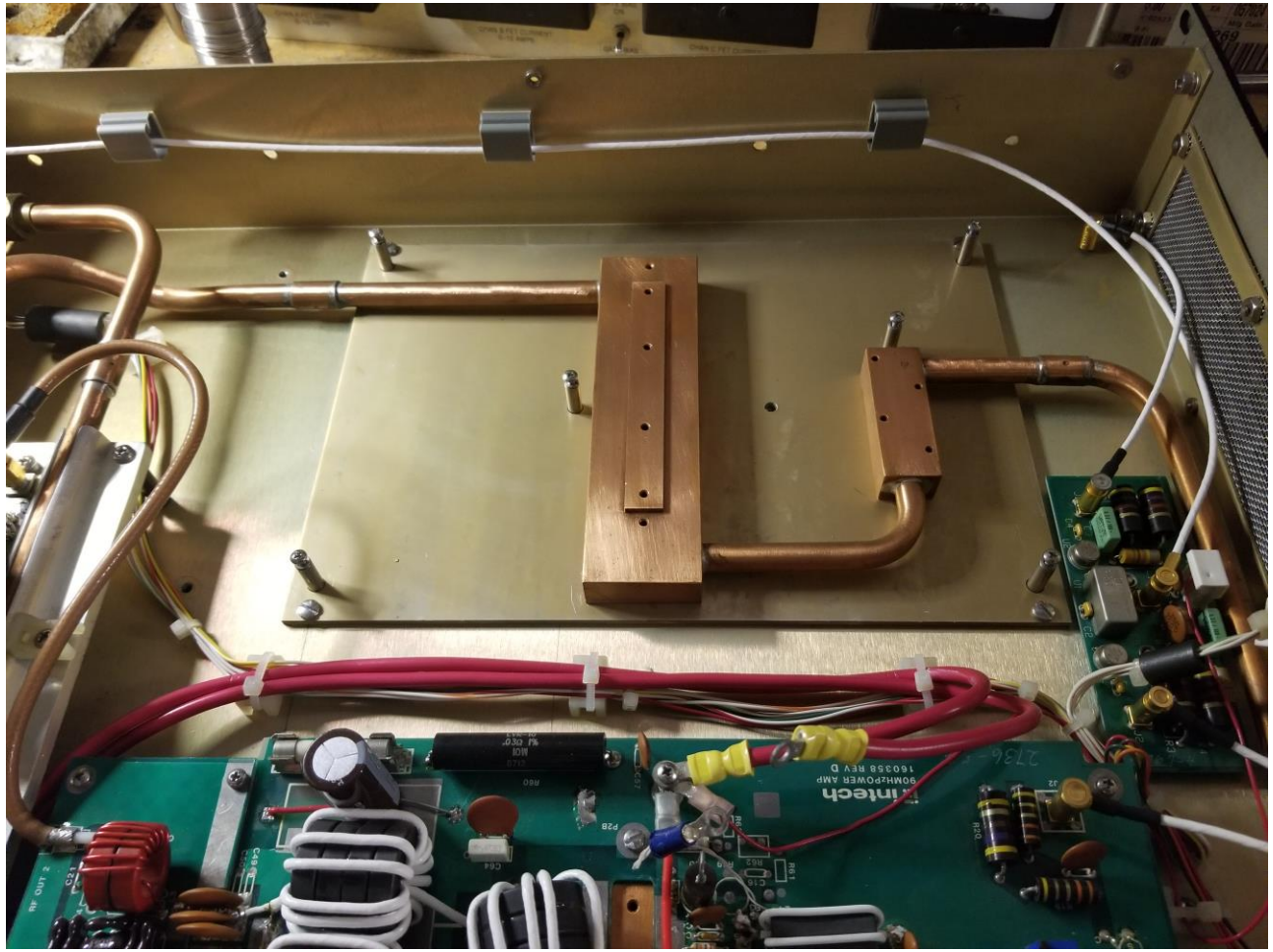
Solid State Drivers

1. RF modules arranged in rack mountable “Slices”
   - Optimize architecture for upgradability
     - Each slice composed of 4 FETs
   - Optimize production from multiple vendors
     - Amplifier slices have been manufactured in house and through various vendors
   - Utilize rack mountable solution fits 19” relay rack
   - Standardize instrumentation for scalable solution
2. DC power supplies
   - Utilize off the shelf components available from multiple vendors
3. Cabinet layout
   - Optimize cabinet layout to allow for upgradability and additional components

Solid State Drivers

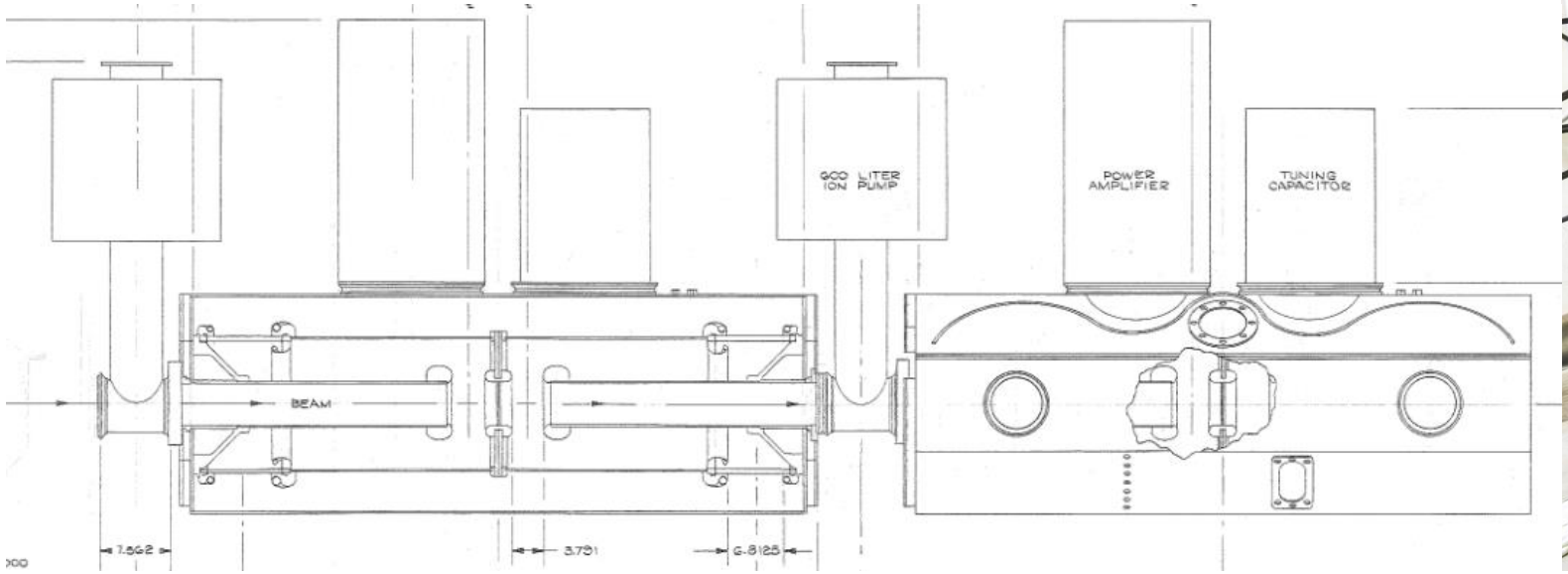
1. Heatsink design
   - Optimized for surface area
   - Quality control process implemented to maintain proper thermal connections

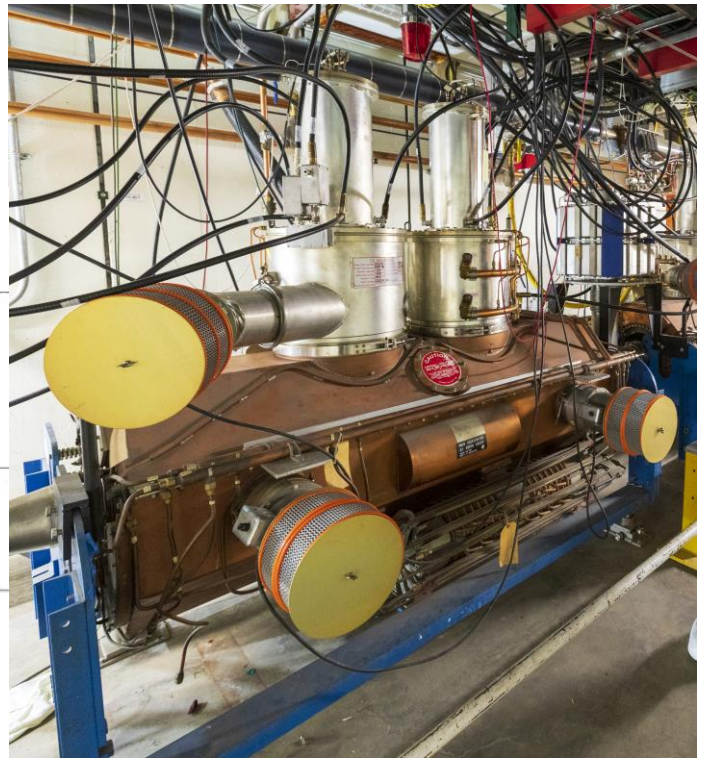
2. Rack mount design allowed for implementation in numerous other locations
   - Booster Synchrotron (88 slices)
   - Booster 2nd harmonic (4 slices)
   - Main injector 53MHz system (160 slices)
   - Recycler 53MHz system (24 slices)
   - Recycler 2.5MHz System (36 slices)



Main Injector Cavity Design

1. Design of the cavity was built with upgradability in mind
   - Second amplifier could be installed to increase current capability
   - Prototype was installed in push-pull configuration (PIP-II Accelerator upgrade)
   - 3 years of operation allowing for proof of concept





Planning upgrades

1. Failure tracking
   - Serialize components
   - Log failures in database
   - Bi-annual review of largest issues
2. Annual technology obsolescence analysis
   - Review availability of parts list for each major system
   - Identify no-longer supported devices
   - As tubes become more obsolete, is moving to solid state an option?
3. Industry and lab communication
   - What is the availability of components needed?
   - Who else is driving the supply?
     - Fore example BNL, LANL, and FNAL used the 7835 Triode tube
   - Is there legacy technology involved?
     - Staggering procurements helpful?

Planning upgrades - Failure tracking

Task Entry Form

Entry Date	Machine	Equipment	Station	Serial Number	Task	Priority	Est Task time	Personnel +	Complete	Completed Date	Notes	Uploads	Task Time (Hour)
									No				

Save New

All | Booster | FAST | LB650 | **Main Injector** | PIP-II | Recycler | Recycler 2.5MHz | Single Spoke Resonator 1

ID	Entry Date	Machine	Equipment	Station	Serial	Task	Priority	Est Task Time	Personnel	Complete	Complete Date	Notes	Uploads	Task Time (Hour)	Delete
Active Repairs															
Offline Repairs															
415	02/18/2022	MI	SSD	12		The station won't run. SSD Amp 4 keeps tripping. Suspect it needs replacement.	High	1	E Cortez (x2719) J Holm (x5604) R Pfaff (x4306)	Offline Repair					
417	02/17/2022	MI	MOD	13	MIM-14	Swapped out St. 13 Mod. Removed MIM-13, installed MIM-14. Offline repairs.	High	3	J Holm (x5604) R Pfaff (x4306)	Offline Repair		Pulse test indicated a bad series tube, however, this tube has only 6 months run time. Investigation continues, suspect tube socket.			
Log															
432	05/05/2022	MI	SSD	14		Yuriy found a puddle under the cabinet and it was traced to the hose barb for Amp 6 Supply IN...	High	0.5	E Cortez (x2719) R Pfaff (x4306)	Yes	05/05/2022	Replaced the hose barb with a new one and an extended hose as well.		0.5	
431	05/05/2022	MI	MOD (HV Cabinet)	08	MIM-23	Station kept tripping, Ops bypassed it and found a puddle on the floor coming from the modulator...	High	1	E Cortez (x2719) J Holm (x5604) Y Koval (xn/a) R Pfaff (x4306)	Yes	05/05/2022	There is a pinhole on the supply line copper elbow at the S.T.. We swapped the modulator with a spare (MIM-17) and will repair this one offline.		1	

Design takeaways

1. Each system and subsystem is designed modularly
    1. Rack mountable designs – Serviceable, maintainable and upgradable
    2. Multiple source options for primary components – Prevent sole source issues
    3. Precise specifications on the component level
    4. Choose architecture with prospect of upgradability

2. Prototyping and advanced testing
    1. Implementing a new system into the machine is the best mechanism for proof of concept
    2. “Beam is boss”
    3. Early design flaw detection

3. Vendor communication an industry collaboration
    1. Communicate with industry and verify technology support
    2. Communicate with other labs to learn their design insights
    3. Prevent re-inventing the wheel when possible

Thank you for your attention!