Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

PIP II SRF Program

Slava Yakovlev

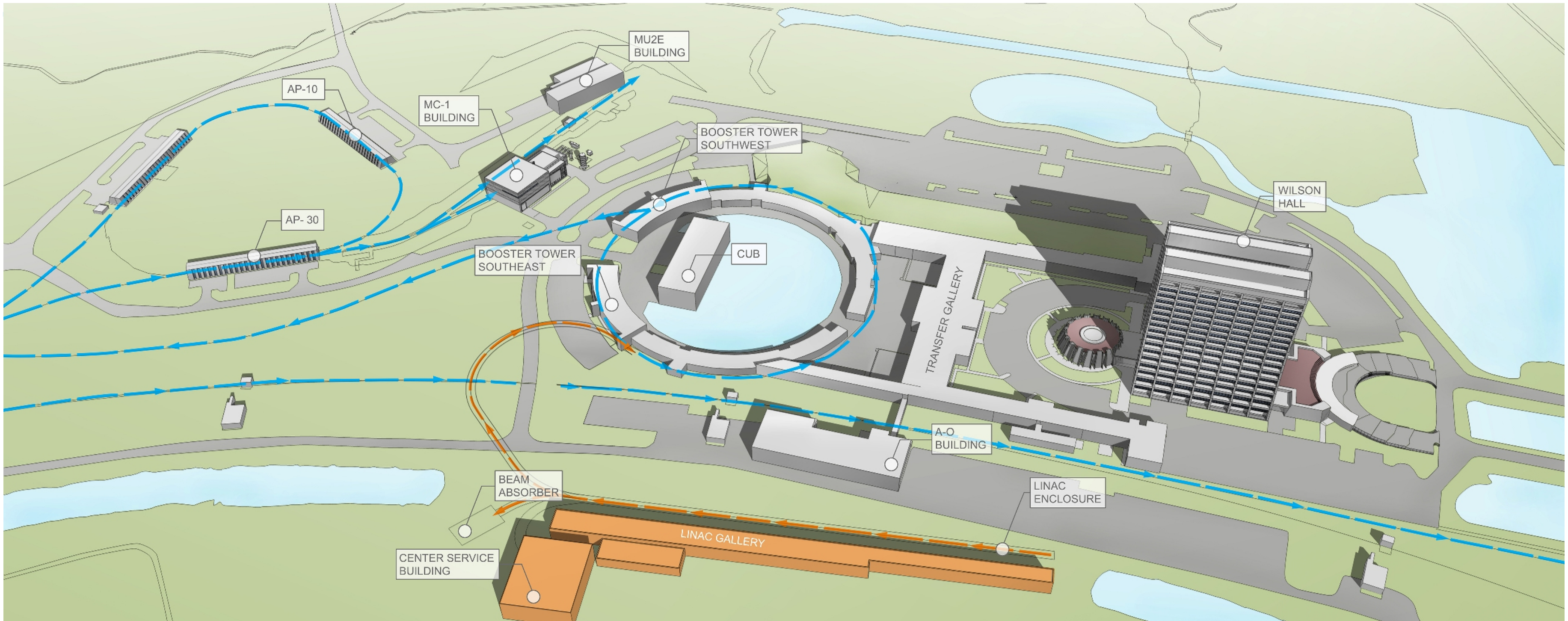
DOE Independent Project Review of PIP-II

16 June 2015

Outline

- The linac reference design;
- The main challenges and technical risks;
- Relevant R&D;
- The reference design of critical components;
- Status of RF and mechanical design of CMs;
- TD organization, staffing and facilities;
- LCLS II activity;
- Summary

PIP II SC Linac Requirements



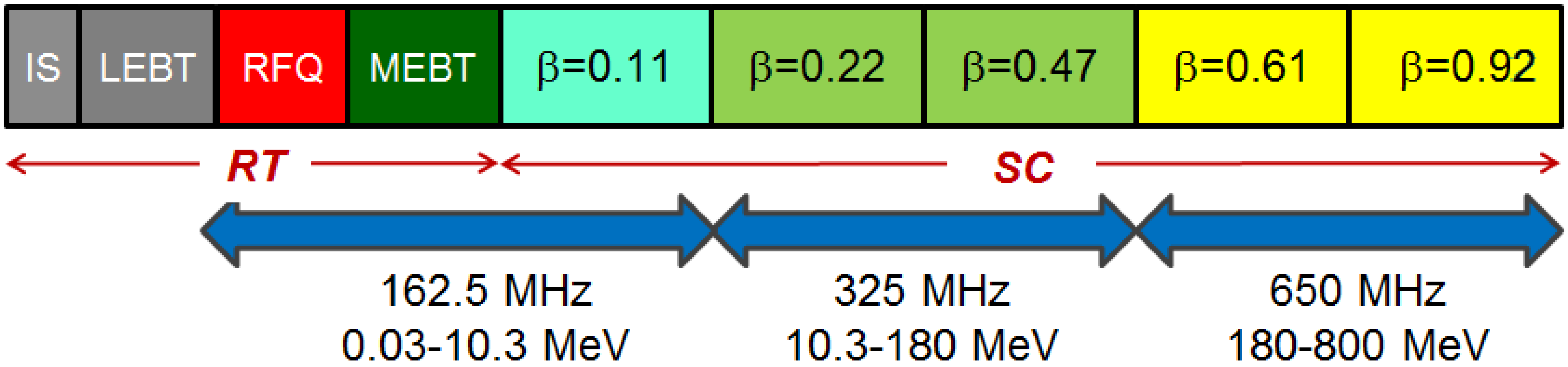
Performance Parameter	PIP-II	
Linac Beam Energy	800	MeV
Linac Beam Current	2	mA
Linac Beam Pulse Length	0.55	msec
Linac Pulse Repetition Rate	20	Hz
Linac Beam Power to Booster	18	kW

Provide a platform supporting a high duty factor/CW operation for future intensity frontier experiments

The Linac Reference Design

- The reference design is ready:
- Frequency choice: sub-harmonics of 1.3 GHz
  - 162.5 MHz, 325 MHz and 650 MHz;
- RF cavity types and betas:
  - one section of 162.5 MHz HWR type, $\beta = 0.11$ cavity,
  - two sections of 325 MHz spoke-cavity type, SSR1 and SSR2 with $\beta = 0.22$ and $\beta = 0.47$; and
  - two sections of elliptical 650 MHz cavities with $\beta = 0.61$ and $\beta = 0.92$;
- Break points are optimized in order to minimize the number of the cavities;
- CM concept:
  - separate CMs,
  - solenoids for HWR and SSR,
  - no focusing elements for elliptical.
- Operating regimes – both pulsed and CW;
- No HOM dampers.

The Linac Reference Design



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
RFQ	162.5	0.03-2.1		
HWR (β_{opt}=0.11)	162.5	2.1-10.3	8/8/1	HWR, solenoid
SSR1 (β_{opt}=0.22)	325	10.3-35	16/8/ 2	SSR, solenoid
SSR2 (β_{opt}=0.47)	325	35-185	35/21/7	SSR, solenoid
LB 650 (β_g=0.61)	650	185-500	33/22/11	5-cell elliptical, doublet*
HB 650 (β_g=0.92)	650	500-800	24/8/4	5-cell elliptical, doublet*

*Warm doublets external to cryomodules

All components CW-capable

The Linac Reference Design

Name	β	Freq (MHz)	Type of cavity	B_{peak} (mT)	E_{peak} (MV/m)	E_{acc} (MV/m)	ΔE (MeV)
HWR	0.11	162.5	Half wave resonator	48.3	44.9	9.7	2.0
SSR1	0.22	325	Single-spoke resonator	58.1	38.4	10	2.05
SSR2	0.47	325	Single-spoke resonator	64.5	40	11.4	5.0
LB650	0.61	650	Elliptic 5-cell	72	38.5	15.9	11.9
HB650	0.92	650	Elliptic 5-cell	72	38.3	17.8	19.9

- Operating gradients ($E_{peak} \precsim 40$ MV/m – field emission; $B_{peak} \precsim 70$ mT);

The main challenges and technical risks

- Future CW operation → cryo-losses → high Q_0 is desired;
- Low beam loading → narrow bandwidth;
  - Pulsed regime → Lorentz Force Detune (LFD);
  - CW regime → microphonics;
- High-Order Modes → “to damp, or not to damp?”

R&D approach:

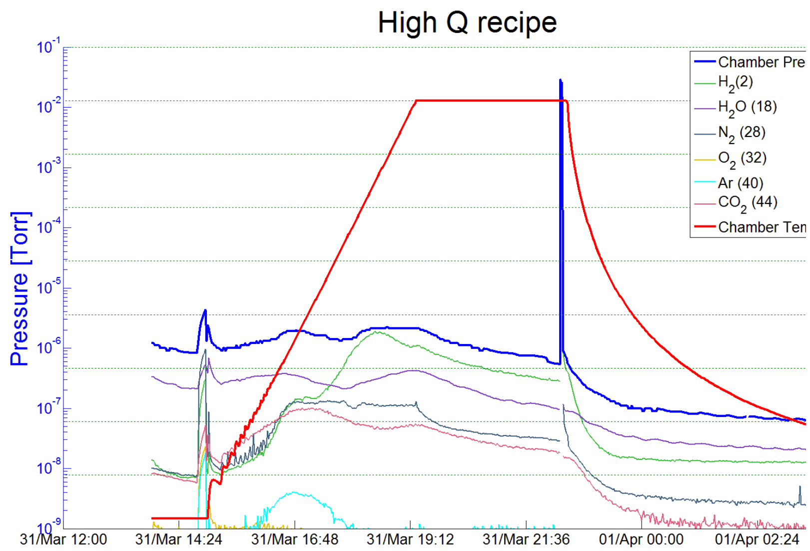
- High-Q0 program was initiated and is running successfully;
- Resonance Control program is underway in order to mitigate both microphonics and LFD;
- “Passive” mitigation of the cavity detune – improvement of cavity mechanical properties is underway;
- Detailed HOM analysis is performed.

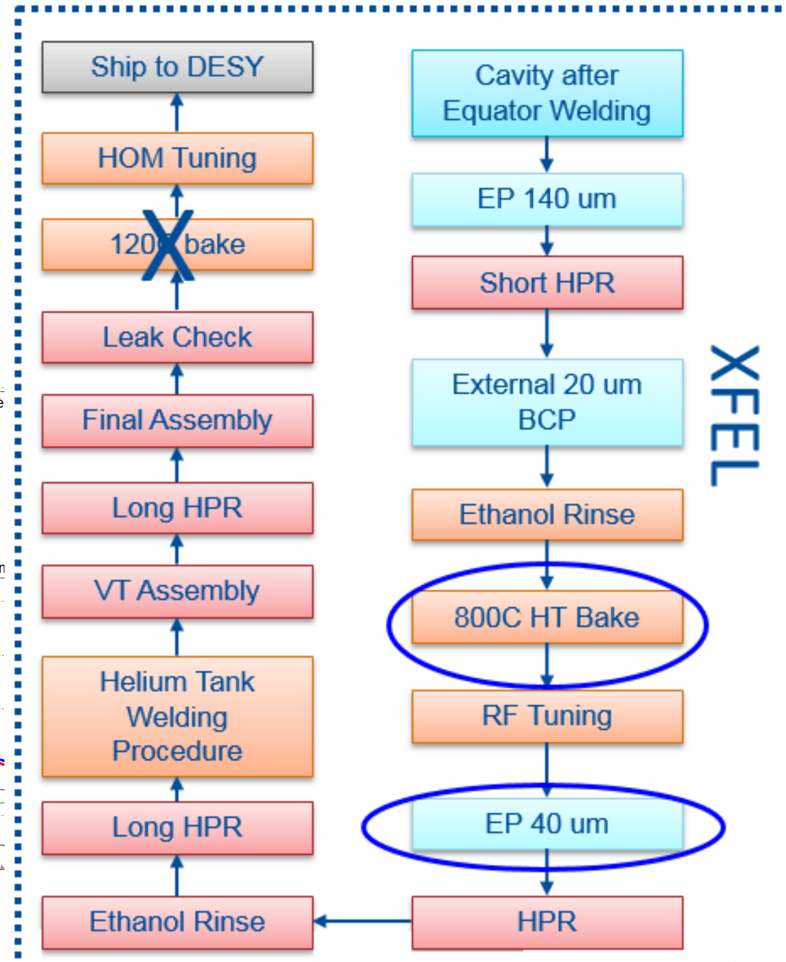
High Q0 R&D program

N Doping – small variation from standard ILC treatment

Example from FNAL 2/6 doping process:

- Bulk EP
- 800 C anneal for 2 hours in vacuum
- 2 minutes @ 800C nitrogen diffusion
- 800 C for 6 minutes in vacuum
- Vacuum cooling
- 5 micro

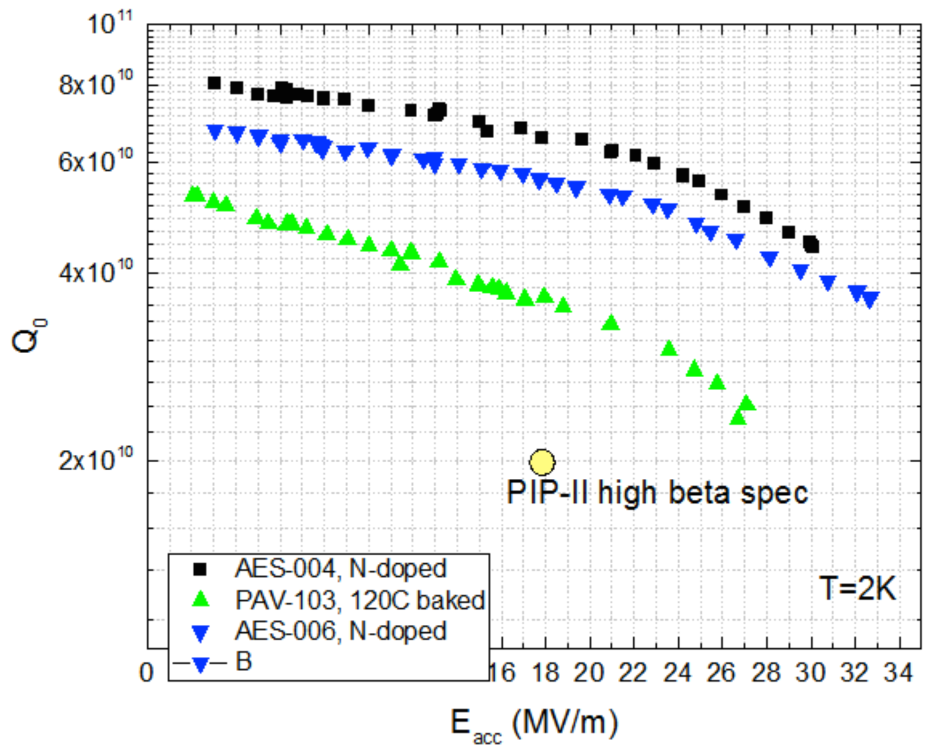




A. Grassellino et al, 2013 Supercond. Sci. Technol. **26** 102001

High Q0 R&D program

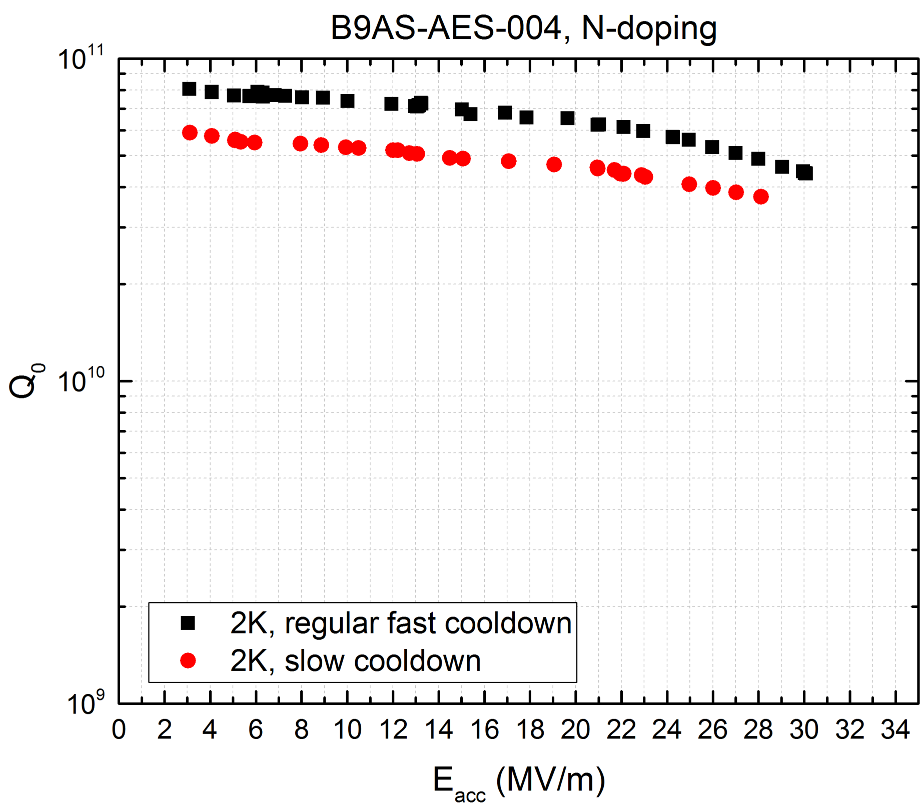
- Results – highlights – 120C bake versus N doping
  Q~ 7e10 at 2K, 17 MV/m – world record at this frequency!
- Applying N doping to 650 MHz (beta=0.9) leads to double Q compared to 120C bake (standard surface treatment ILC/XFEL)



A. Grassellino, MOYGB2, IPAC15, Richmond

High Q0 R&D program

Results on 650MHz – cooling studies – fast vs slow cooling



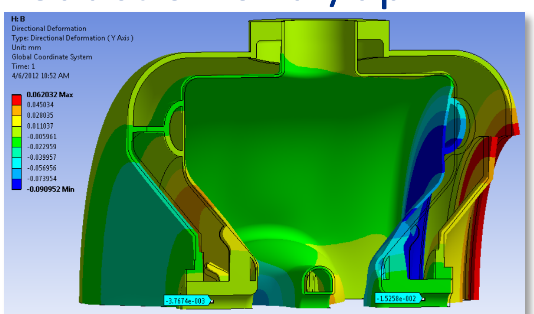
- Cooling details have been shown to play an important role in Q retention
- Slow cooling through Tc shown to severely deteriorate Q for 1.3 GHz cavities
- At 650 MHz we find a weaker effect, likely due to smaller impact of trapped flux at lower frequency
- Very promising for Q retention in cryomodule

A. Romanenko, A. Grassellino, O. Melnychuk, D. A. Sergatskov, J. Appl. Phys. ***115****, 184903 (2014)*
A. Romanenko, A. Grassellino, A.Crawford, D. A. Sergatskov, Appl. Phys. Lett. 105, 234103 (2014)

Resonance Control R&D program

Section	Freq MHz	Maximal detune (peak, Hz)	LFD at operating gradient, Hz	Minimal Half Bandwidth (Hz)	Max Required Power (kW)
HWR	162.5	20	-122	33	6.5
SSR1	325	20	-440	43	6.1
SSR2	325	20	-	28	17.0
LB650	650	20	-192	29	38.0
HB650	650	20	-136	29	64.0

Reduction of df/dp



- A self-compensating design was developed allowing low sensitivity to Helium pressure fluctuations, without increasing the stiffness to frequency-tuning.
- Prototype cavity ~ **150 Hz/torr** -> New design ~**4 Hz/torr** (~40 times less)
- Ease of tuning virtually unchanged: 39 N/kHz (bare), 40 N/kHz (with He vessel)

D. Passarelli, L. Ristori, IPAC12

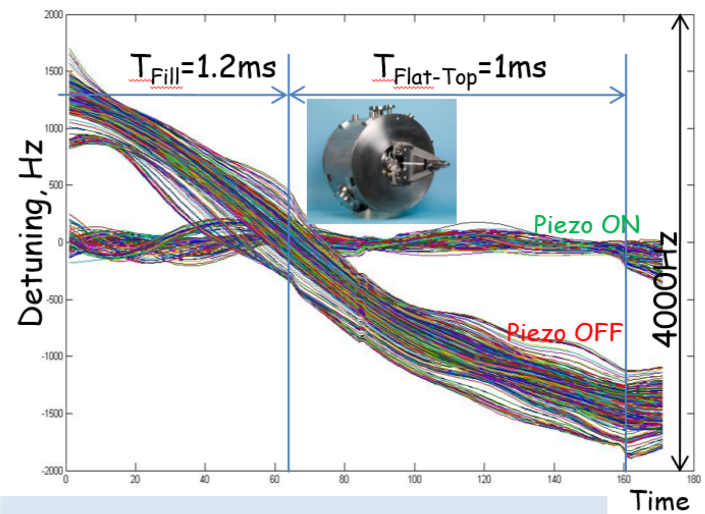
FNAL's Adaptive Least Square LFD Compensation Algorithm.

Y. Pischalnikov and W.Schappert, "Adaptive Lorentz Force Detuning Compensation" Fermilab Preprint-TM2476-TD

W.Schappert *et. al.*," Resonance Control in SRF Cavities at FNAL", PAC2011, New York, USA

Successfully applied to different cavities/tuner configurations

325MHz SSR1 cavity



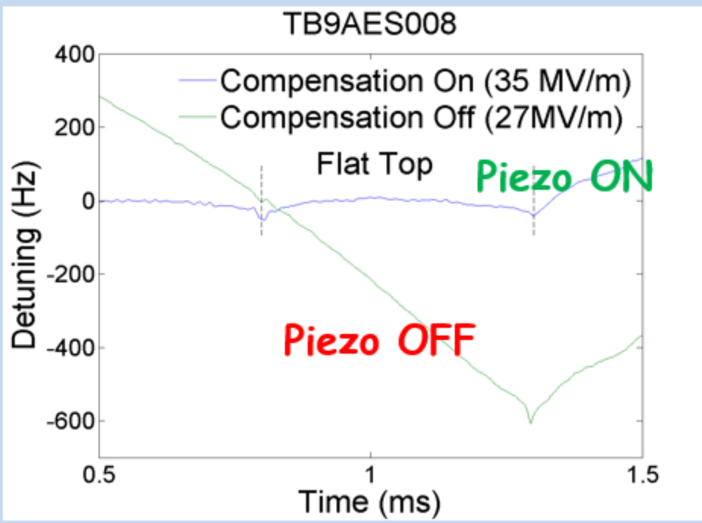
Eacc	Piezo OFF	Piezo On
23MV/m	3500Hz	75Hz

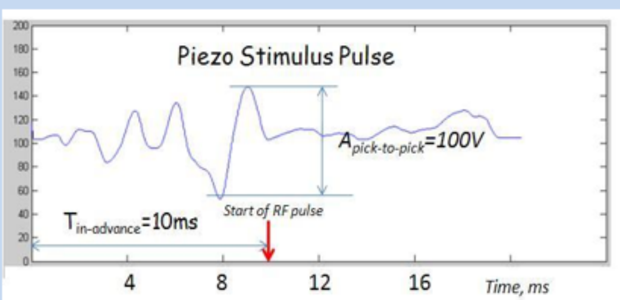
$\Delta F=-kE_{acc}^2$ K~2.7Hz/(MV/m)^2

Resonance Control R&D program

1.3GHz for ILC/XFEL pulse operation

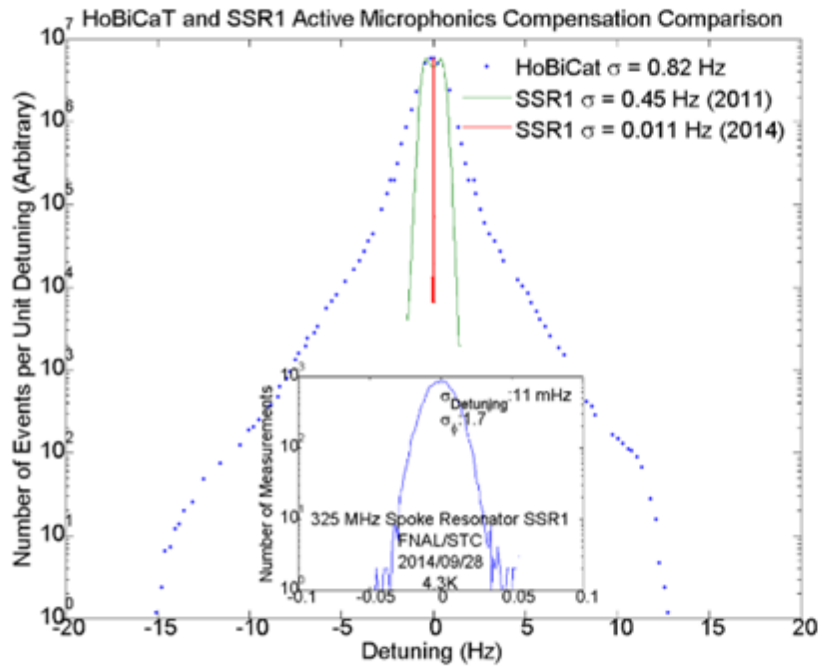
LFD during 1,3ms RF-pulse (Fill+FlatTop) ~2300Hz
After LS LFD compensation -- to less than 20Hz during 1,3ms pulse





SSR1 Active Microphonics Control

Feed forward compensation of the ponderomotive effects & active resonance stabilization using feedback



Studies of HOMs in the PIP II

- Small beam current
- Small bunch population

Detailed simulations show:

- Beam Break Up (BBU) should not be a problem;
- “Klystron-type” longitudinal instability does not look to be a problem as well.
- Resonance excitation of the dipole modes does not look to be an issue;
- Accidental resonance excitation of the 2d monopole band in beta=0.9 section may lead to longitudinal emittance dilution, but probability is very small. However, v.2 of the cavity was designed which is free of this issue.

No HOM dampers for PIP II

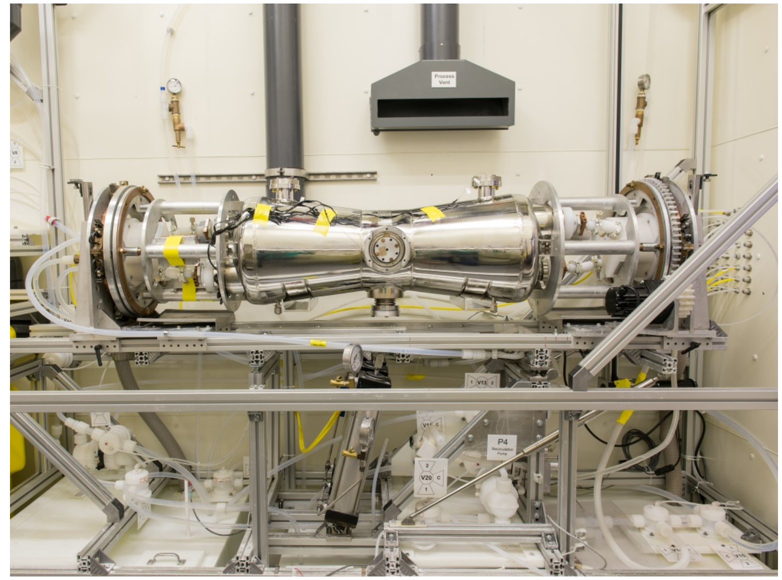
General design approach

- Most components (couplers, tuners, etc.) should be of the same or similar type;
- Cryomodules should be preferably of the same type and contain mostly the same parts;
- Two types of CMs are to be prototyped,
  - spoke-cavity CM for SSR1 and
  - elliptical cavity CM for HB 650.
- Other CMs will be developed basing on the lessons learned for these CMs.

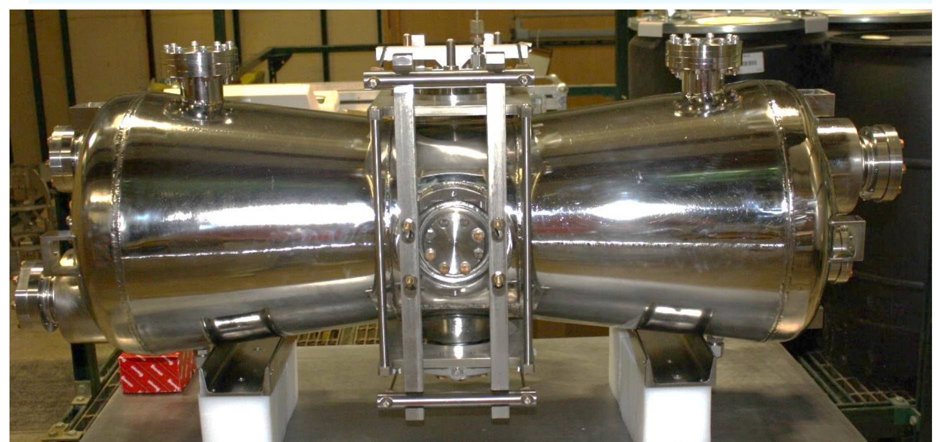
Status of development of critical components

HWR Fabrication Status

- The first two HWR cavities were tested at 2 K.
- HWRs were electropolished after all fabrication was complete.
- Niobium work in all remaining 7 cavities is nearly complete.

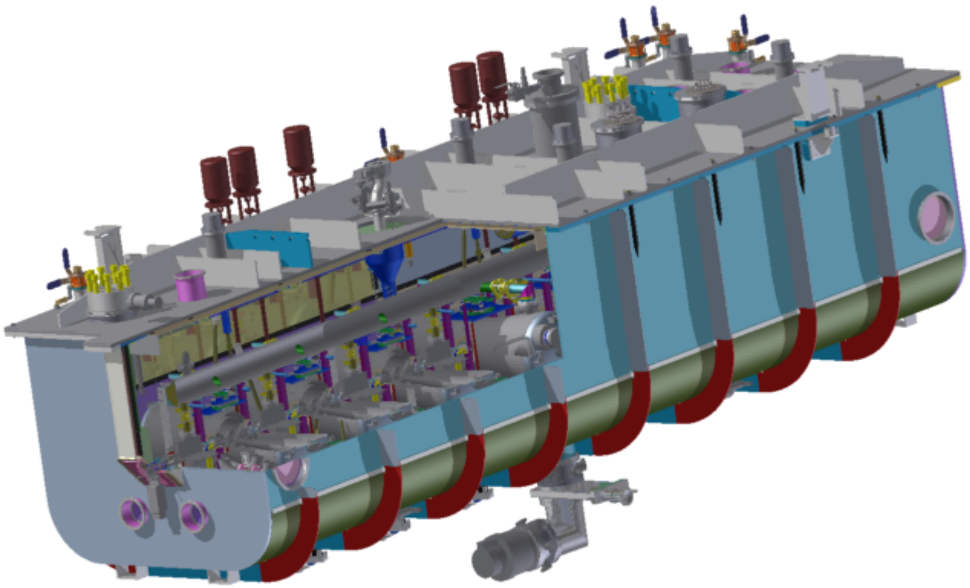


HWR Electropolish in Low-β EP Tool



Status of development of critical components

- HWR Cryomodule Vessel Assembly

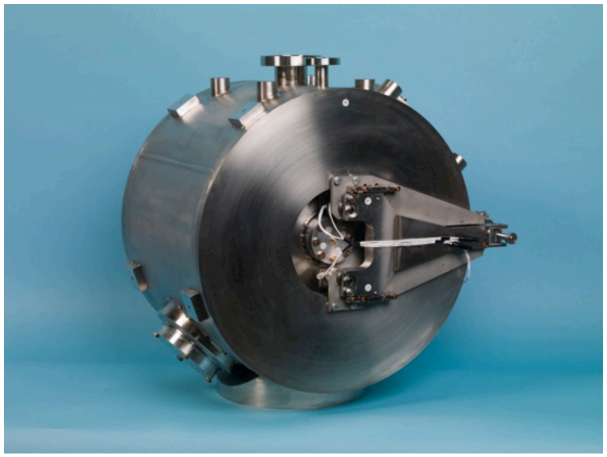


Titanium Strongback

Cryostat vessel in factory

Status of development of critical components

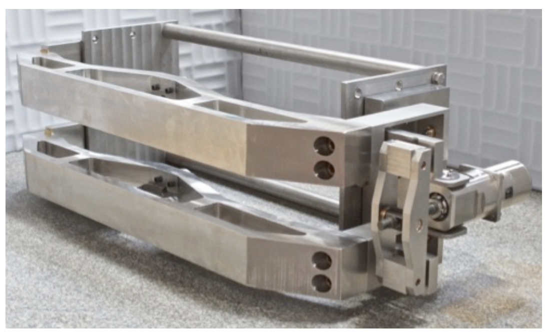
SSR1 development



First jacketed SSR1 prototype with prototype tuner for HINS (2010)

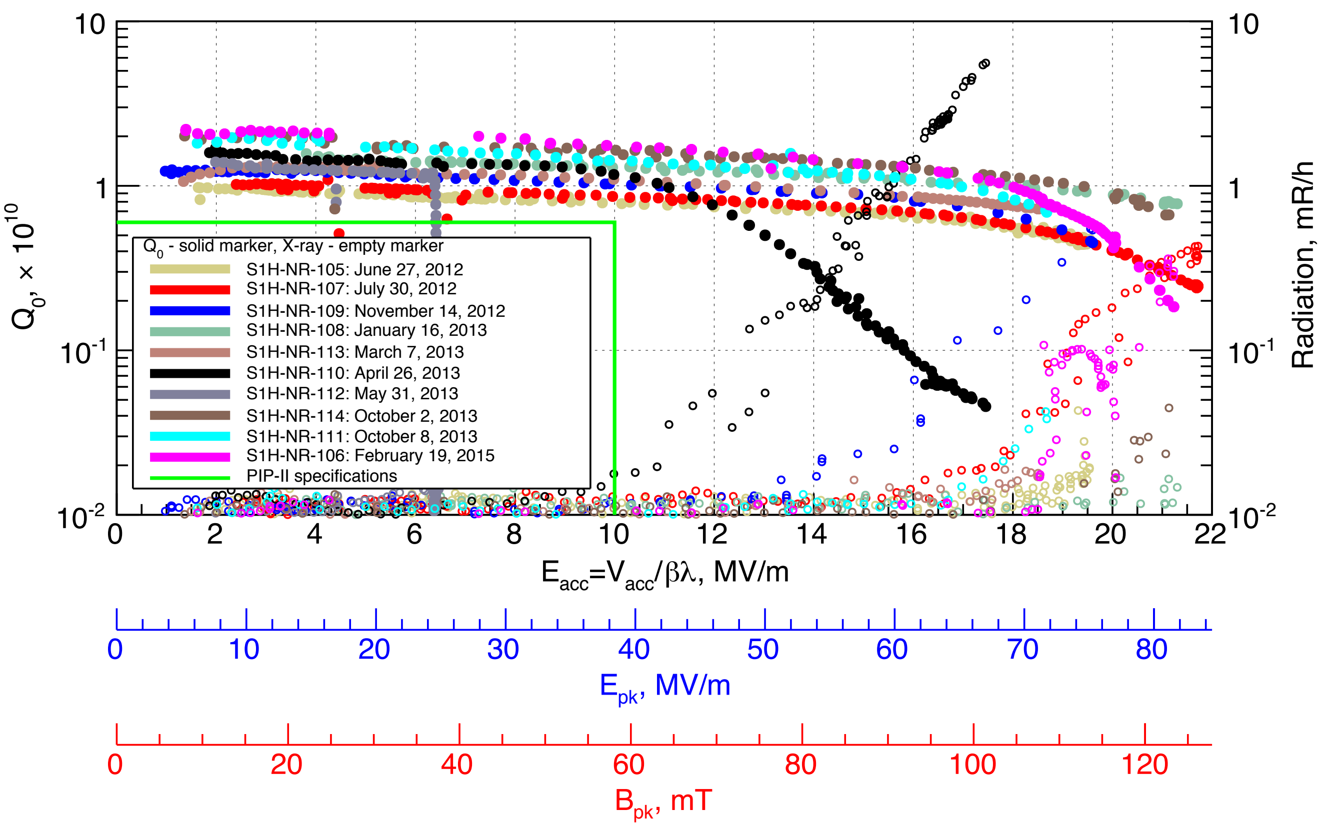
New generation SSR1 for PXIE with reduced df/dP (2013)

The new Double-Lever tuner (left) and piezo encapsulations (right)



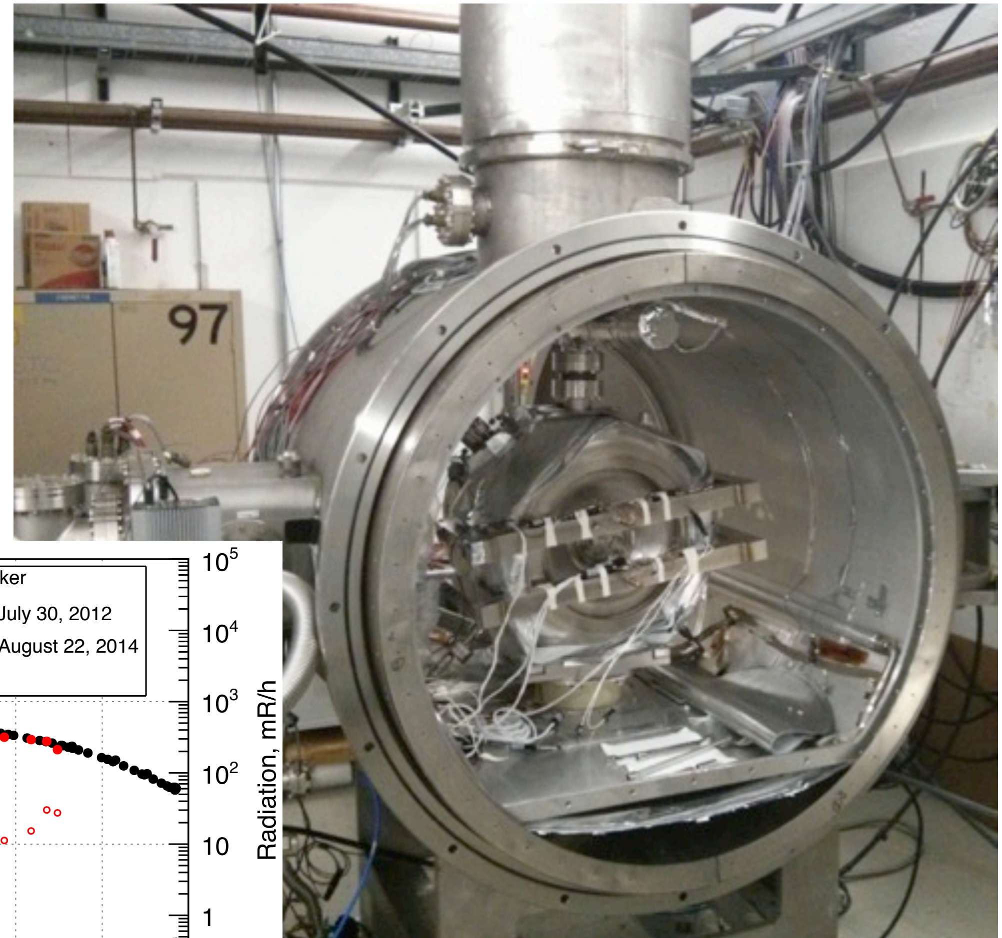
Status of development of critical components

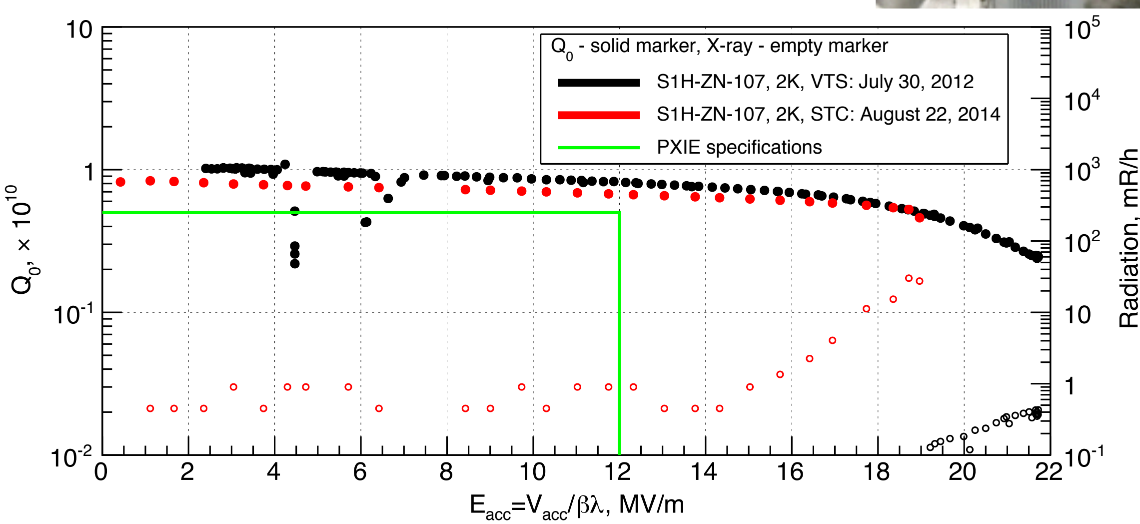
- Successful qualification of 9 production SSR1 cavities for PXIE cryomodule (A. Sukhanov)



Status of development of critical components

Spoke Test Cryostat (STC) – S107 (A. Hocker, A. Sukhanov)



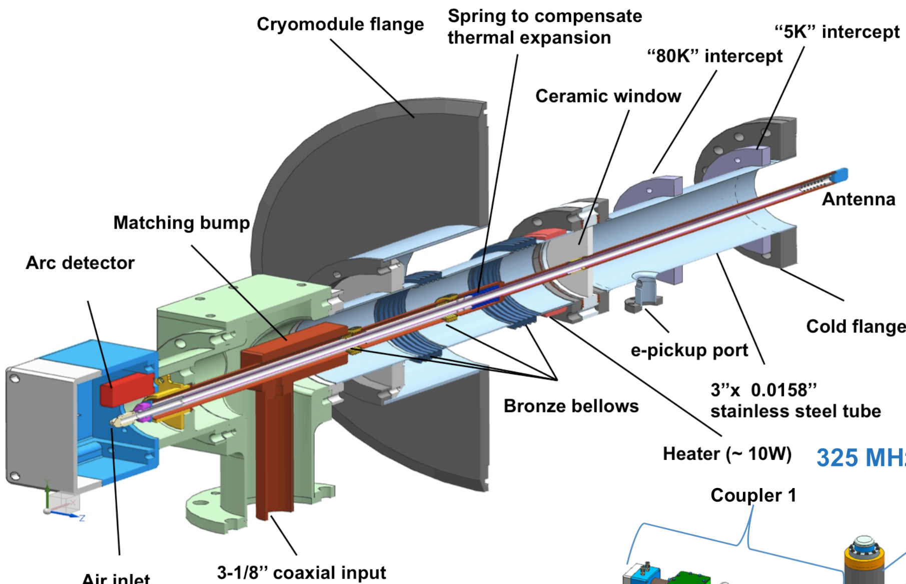


Fermilab

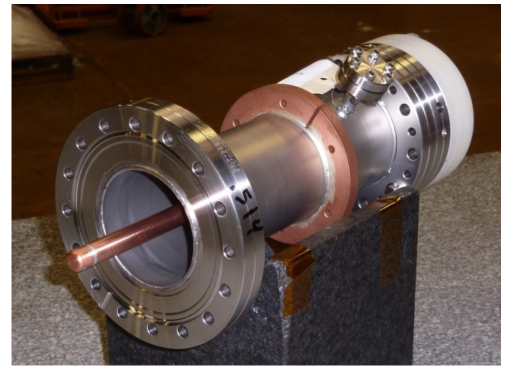
PIP-II

Status of development of critical components

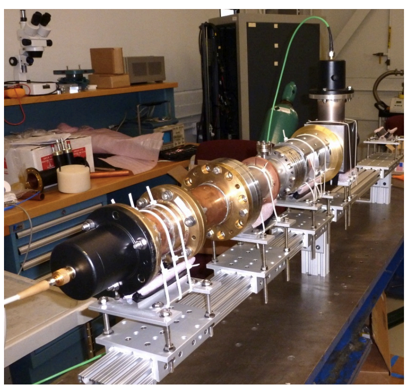
325 MHz coupler anatomy



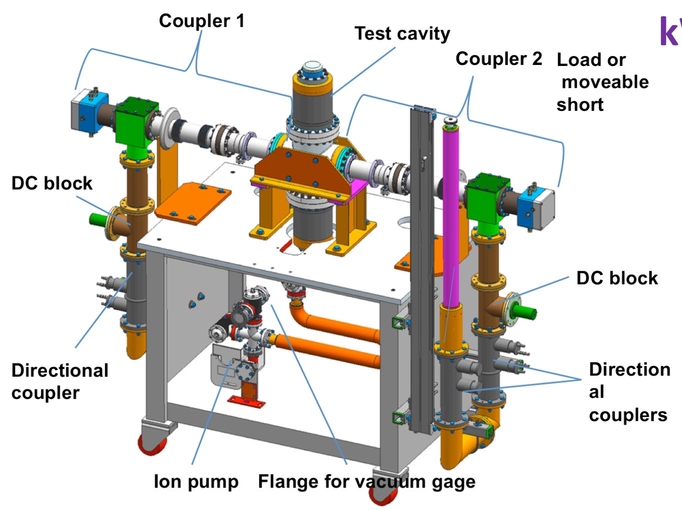
S. Kazakov – O. Pronitchev



- 325 MHz couplers work well up to 7.8 kW CW inTW mode.



325 MHz Test Stand



The couplers have been designed, prototyped, tested, and ordered.

Status of development of critical components

Status of SSR1 cavities (L. Ristori)

- ED0002558						IB4	IB4	IB4	IB4	ANL	ANL	MP9	IB4	ANL	ANL	MP9	VTS (IB1)	ROARK	IB4	MEYER TOOL	IB4	IB4	IB4	IB4	IB4	ICB	ICB	ANL	ANL	MP9	STC (MDB)
OPERATION -->	Deep drawing	Sub-assy EBW	Freq. trimming	Final EBW	Delivery to FNAL	Visual QC	Dimensional QC	RF QC	Leak QC	Bulk BCP	HPR	600 C Bake	RF Tune	Light BCP	HPR + Prep for VTS	120 C Bake	VTS Tests	Ring EBW	RF Tune	Jacketing	Visual QC	Dimensional QC	RF QC	Leak QC	RF Tune	Flange Polishing	Thread Maintenance	Light BCP	HPR + prep for STC	120 C Bake	STC Tests
TRAVELER # -->	-	-	-	-	-	333990	333884	464013	464012	333862		464022			464116	464121														464121	
LINKS TO VECTOR (ONSITE ACCESS ONLY)	Leonardo	Leonardo	Leonardo	Leonardo	Leonardo	Donato	Donato	Paolo Mohamed		Brent		Margherita	Paolo Mohamed	Brent	Brent	Margherita	Anna Sukhanov Sergatskov	Leonardo	Paolo Mohamed	Donato	Donato	Donato	Paolo Mohamed		Paolo Mohamed	Damon	Damon	Brent	Brian	Margherita	Andy, Joe
S103 travelers																															
S104 travelers																															
S105 travelers					no estimate															type B											
S106 travelers					8-Jan-14												20 MV/M			type A											
S107 travelers					4-Nov-11												22 MV/m			type A						skipped	skipped				in proc
S108 travelers					4-Nov-11												21 MV/m			type A	in proc										
S109 travelers					19-Dec-11												20 MV/m			type A	in proc										
S110 travelers					19-Dec-11												17 MV/m			type A											
S111 travelers				equator repaired	31-Dec-12												19 MV/m			type B											
S112 travelers					10-Dec-12												17 MV/m			type B											
S113 travelers		spoke repaired			10-Dec-12												19 MV/m			type B											
S114 travelers		spoke repaired			31-Dec-12												21 MV/m			type B											
S1H-RK-115	in proc				no estimate																										

9 of 10
Delivery
(Bare Cavity)

9 of 10
Cold Test
(Bare Cavity)

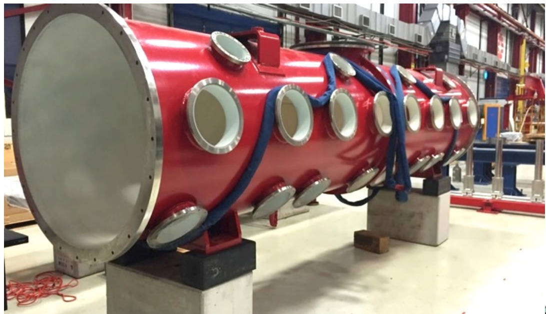
3 of 10
Jacketing

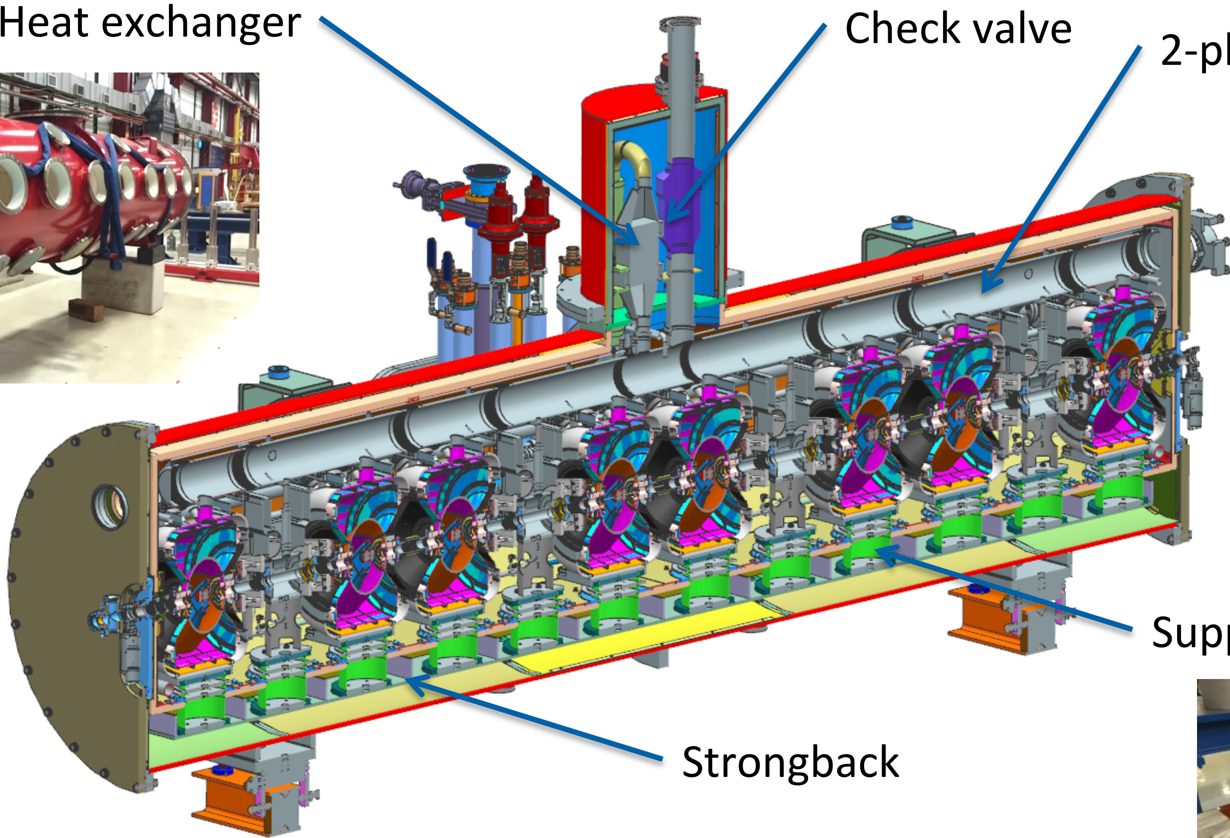
1 of 10
Cold Tes
(Jacketed
Cavity)

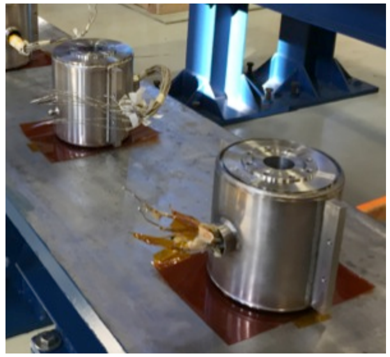
- Two bare SSR1 received from IIFC for VTS tests;
- The fully-equipped (the coupler and tuners) S107 is in STC under the high power tests;
- LFD compensation tests are underway.

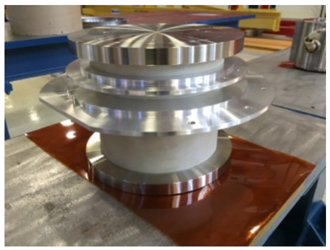
Status of development of critical components

SSR1 Cryomodule (T. Nicol)





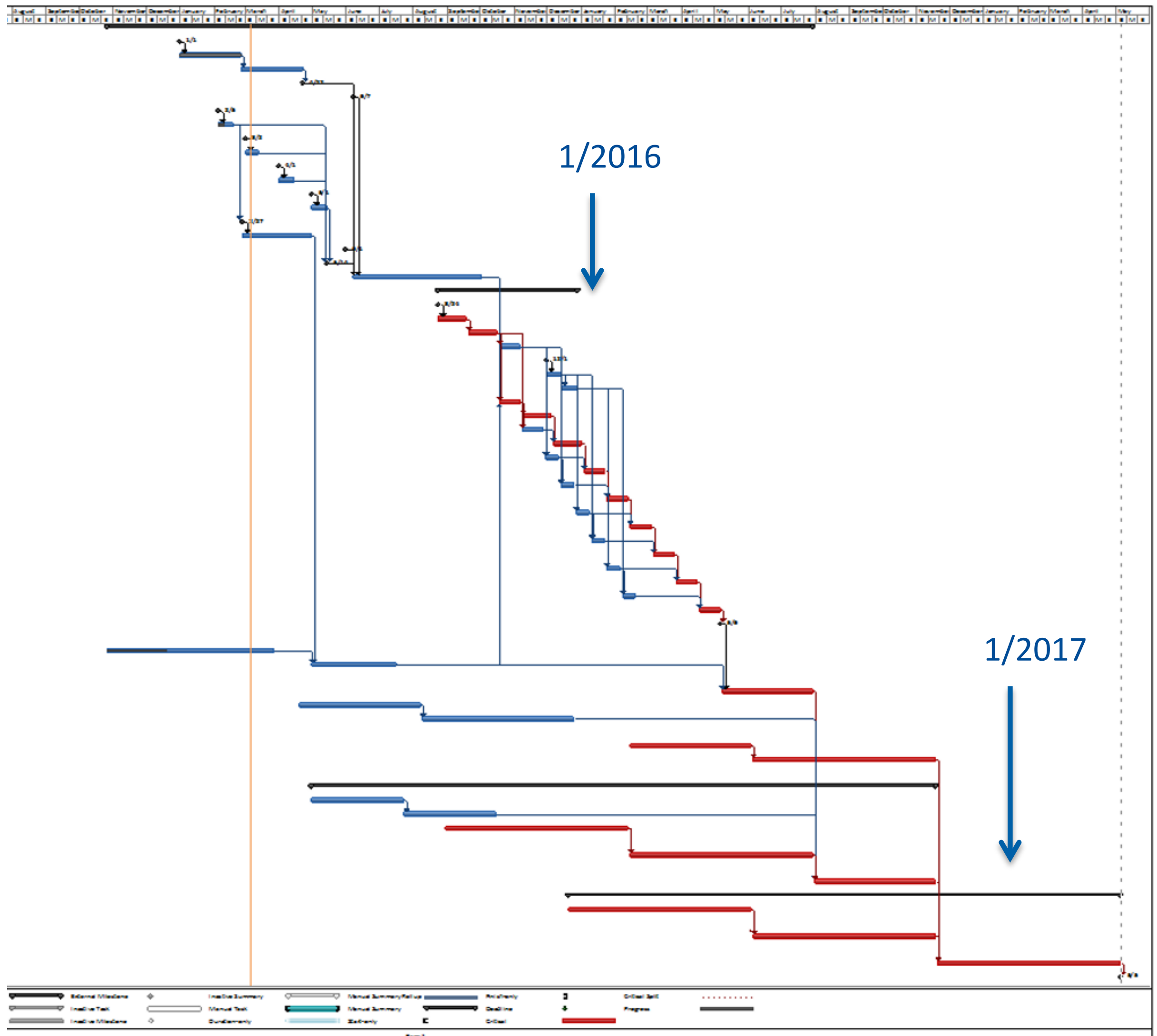




Status of development of critical components

PXIE SSR1 Cryomodule Schedule

- String assembly rehearsal
  - July - Aug 2015
- Cav. qualifications
  - Nov 2015 - Apr 2016
- String assembly
  - May - July 2016
- Cold mass assembly
  - Aug - Nov 2016
- Cryomodule assembly
  - Oct 2016 - May 2017



Status of development of critical components

650 MHz section:

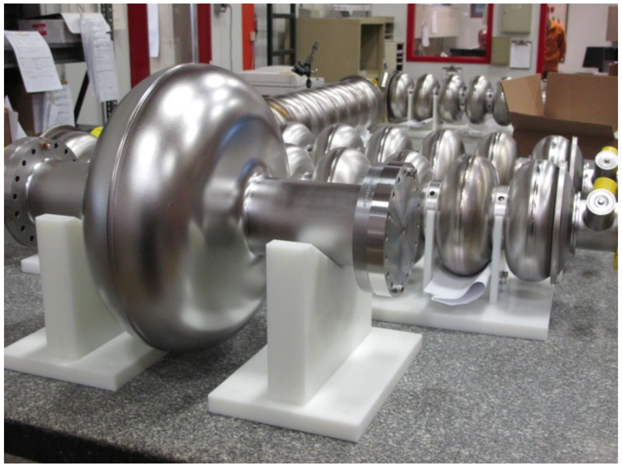
EM design of LB 650 and HB 650.v2* are ready.

- Six single-cell cavities HB 650.v1* are manufactured by AES, one is manufactured by RRCAT.
- Two HB 650.v1* cavities are processed and tested.
- Four 5-cell HB 650 cavities are manufactured by AES and ready for processing and tests.
- Five additional single cell and five five-cells HB 650.v1 cavities ordered from industry (PAVAC).
- Concept design of He vessel for HB 650.v2 with low df/dP and reduced LFD is completed
- Concept design of the tuners (slow and fast) is completed.

*v1 is an initial version having an aperture of 120 mm versus 118 mm for v2.

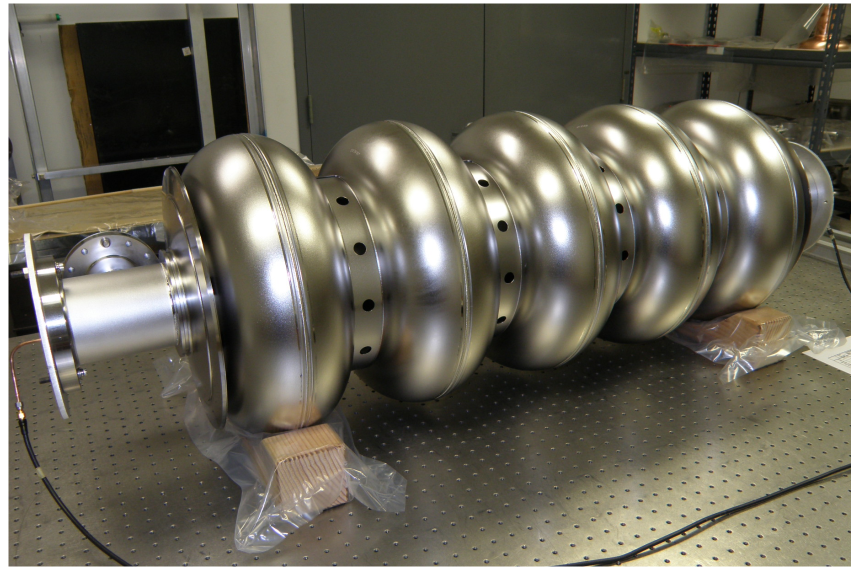
Status of development of critical components

650 MHz section:



Currently Available Cavities:

1-Cell 650 MHz	5-Cell 650 MHz
1. B9AS-AES-001*	1. B9A-AES-007
2. B9AS-AES-002*	2. B9A-AES-008
3. B9AS-AES-003	3. B9A-AES-009
4. B9AS-AES-004	4. B9A-AES-010
5. B9AS-AES-005	*VTS Tested
6. B9AS-AES-006	



Expected Cavities:

1-Cell 650 MHz	5-Cell 650 MHz
Pavac, Inc.	Pavac, Inc.
Six to be delivered	Five to be delivered
late spring 2014.	winter 2015.

Status of development of critical components

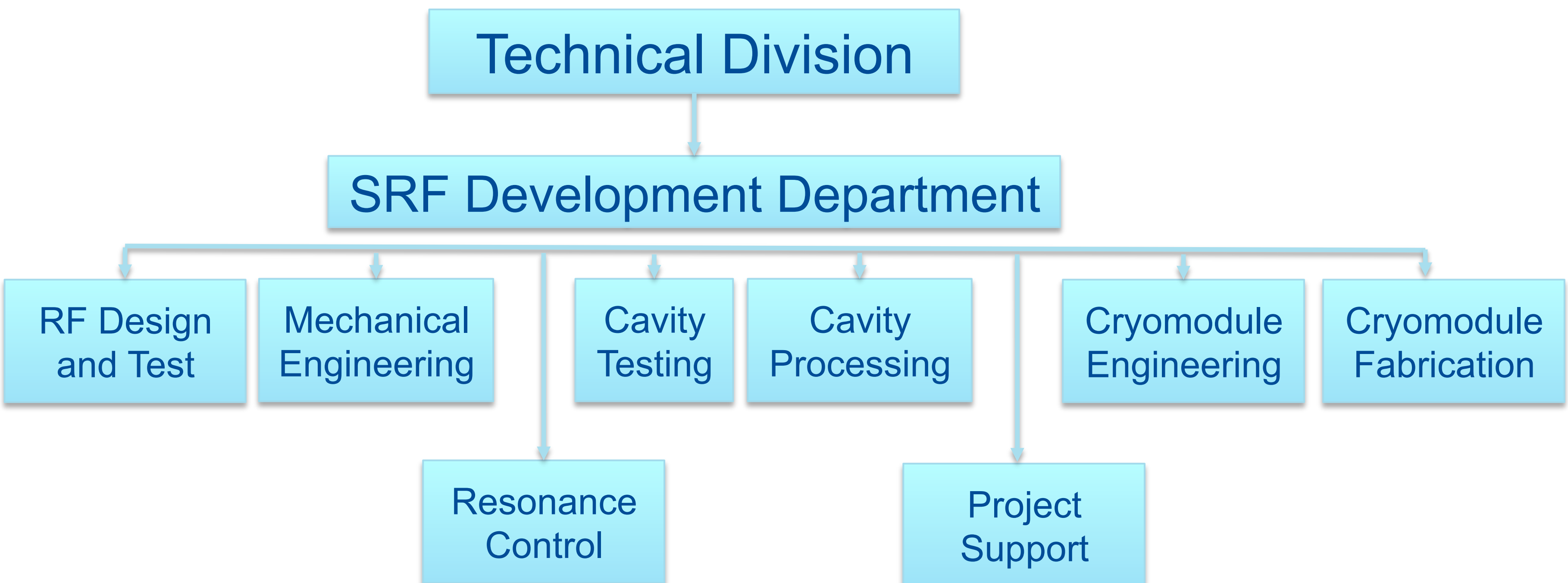
- SRF Development Status

Cavity	Frequency	Cavity Type	Beta	Collaboration?	Cavity EM Design Complete	Cavity Mech Design Complete	Single Cell / Prototype Ordered	Full Cavity Prototype Received	Prototype Tested	Cavities for CM Ordered	Cavities for CM Received	Cavities for CM Tested	Cavities for CM Dressed	CM Cold Mass Design	CM Parts Ordered	# of CM Assembled	Est % complete
Half Wave Resonator (HWR)	162.5 MHz	1-HWR CW	0.11	ANL	yes	yes	yes	yes	yes	9	9	2	2	yes	yes	15%	70
Single Spoke Resonator 1 (SSR1)	325 MHz	1-spoke CW	0.22	India	yes	yes	2	2	2	10	10 +2	10	6	80%	70%	not started	75
Single Spoke Resonator 2 (SSR2)	325 MHz	1-spoke CW	0.47	India	yes	yes	not started	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
Low Energy 650 (LE 650)	650 MHz	5-cell CW	0.6	India, JLAB	yes	yes	5	not started	not started	not started	not started	not started	not started	not started	not started	not started	10
High Energy 650 (HE 650)	650 MHz	5-cell CW	0.9	India	yes	yes	5 of 10	4	not started	9	4	not started	not started	5%	not started	not started	20

- Green: complete
- Yellow: in progress
- Red: not started

TD organization, staffing and facilities

SRF Development Department, Technical Division



TD organization, staffing and facilities

Infrastructure:

- MDB for HTS/STF/CTS, HTS-2 (IIFC)
- MP9 (clean rooms)
- ICB (CM assembly floor)
- IB4 CPL area
- IB4 RF Lab
- ANL SCSPF (cavity processing)
- IB1 VTA (cavity tests)
- LAB2 (new clean room for SSR1 CM assembly)

LCLS II issues

- LCLS II project R&D and design is very well aligned to the PIP II.
- PIP-II construction will be starting up as LCLS-II construction rolls off
- Technical staff will move from LCLS-II onto PIP-II
- PIP-II will benefit from the extensive cryomodule production experience of LCLS-II
- R&D challenges are very similar between the two projects (High Q0, Resonance Control)

Summary

- The linac reference design is ready;
- The main challenges and technical risks are identified;
- Relevant R&D are organized and are in progress;
- The concept design of most critical parts is done;
- The low energy part of the linac is in process of fabrication;
- We work intensively in the frame of IIFC collaboration on the 650 MHz CM design;
- TD organization and staffing are ready for the project;
- LCLS II activity is well-aligned to PIP II