SMTF
cw possibilities

FNAL Accelerator Advisory Committee

November 18, 2004

Applications for ß=1 cw scrf

- Stable rf fields
- Inherently small perturbative effects on the beam
- Reduced rf power requirements (cf. warm)

- Storage rings
- Energy recovery linacs (ERL's)
- Recirculating linacs
    - bunch manipulation in storage ring light sources
    - high flux/brightness synchrotron light sources (linac and storage ring)
    - free-electron lasers
    - electron-hadron colliders
    - electron cooling
    - nuclear physics facilities
    - Compton scattering
    - THz CSR sources

cw scrf structures

- Accelerating cavities
- Beam conditioning structures
  - harmonic cavities
    - manipulation of longitudinal phase space
    - transverse deflecting cavities
- RF photoinjectors
- Single-cell & multi-cell

cw scrf projects & proposals (US)

- Applications in future and existing facilities
- BNL ERL for e^- cooling
- CEBAF 12 GeV upgrade
- TJNAF ERL FEL
- Stanford HEPL
- MIT x-ray FEL
- LBNL recirculating linac light source
- Cornell / TJNAF ERL light source
- ALS (LBNL) and APS (ANL) deflecting cavities

cw scrf interests

- High gradients ~ 20 MV/m
- High Q values. One goal, with most relevance to multi-GeV linac applications, is $Q_o > 3\times10^{10}$
- High external Q values at operating gradients of ~20 MV/m
  - Goal of $Q_{ext} > 2.5\times10^{7}$ for low beam loading applications
- High stability and control of microphonics, with a goal of phase error < 0.1° and amplitude error $<10^{-4}$
- Wakefield suppression
  - HOM's and LOM's
- Stable operations with realistic beam parameters

Q and filling time for scrf systems

- $Q_0 \sim 10^{10}$
  - $\tau \approx$ 2.4 s for unloaded 1.3 GHz structures
- Overcoupling reduces filling time
  - requires additional rf power
- Beam loading may provide conditions closer to a match
- Many applications do not have heavy beam loading
  - Q_{ext}, coupling, and filling time are limited primarily by the ability to provide feedback of the system against field fluctuations induced by microphonics
  - 50 Hz cavity/feed system bandwidth
    - Encompass the cavity mechanical vibration modes
  - Q_{ext} of 2.6×10^7 for the TESLA cavities
  - $\tau \approx$ milliseconds

Time constants, dynamic heat load

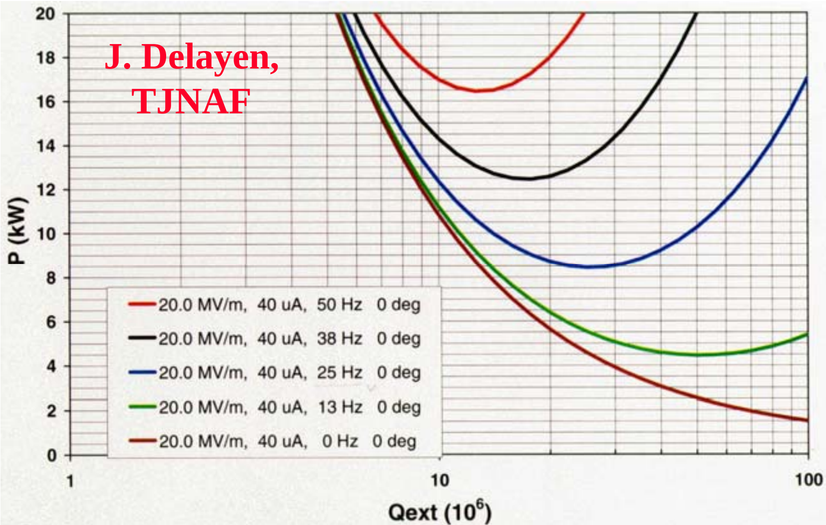
- Applications of interest discussed here require bunch rates >> 1-10 ms time constant
  - operate in continuous wave (cw) mode
- Power dissipation from rf currents on the cavity inner surfaces ("dynamic load")
  - TESLA cavity operating at 20 MV/m cw dissipates approximately 40 W at liquid helium temperature
    - cf.~ 1 W for the nominal pulsed operating mode
- Operating in cw mode at a gradient of up to 20 MV/m requires development and testing of systems to accommodate the thermal load

Feedback control of tuning variations

- Lorentz force not an issue in cw applications
- Random tuning variations
    - Slow perturbations e.g. from variations in He pressure
        - Slow (narrow-band) mechanical tuners
    - Faster perturbations from microphonics at acoustic frequencies - structural resonances
        - Fast feedback of rf drive

$$P_g = \frac{P_c}{4\,\beta}\left\{(1+\beta+b)^2 + \left[2\,Q\,\frac{\Delta f}{f} - b\,tan(\Psi_B)\right]^2\right\}$$

$$\beta_c = \frac{Q_0}{Q_{ext}}; \quad b = \frac{P_{beam}}{P_C}$$



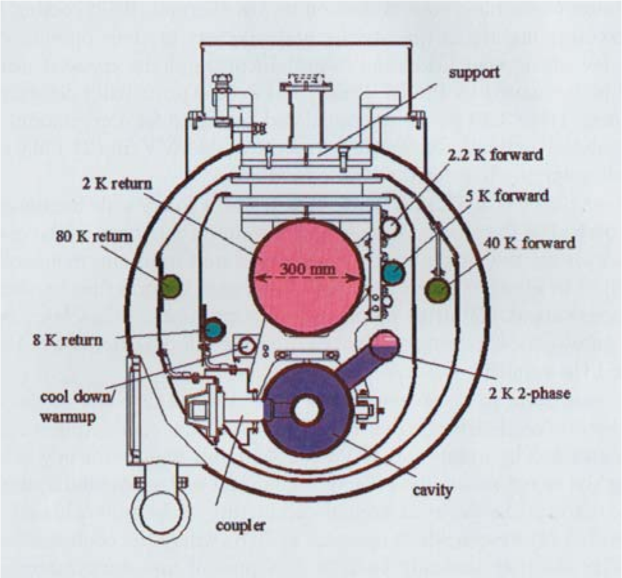
Thermal management

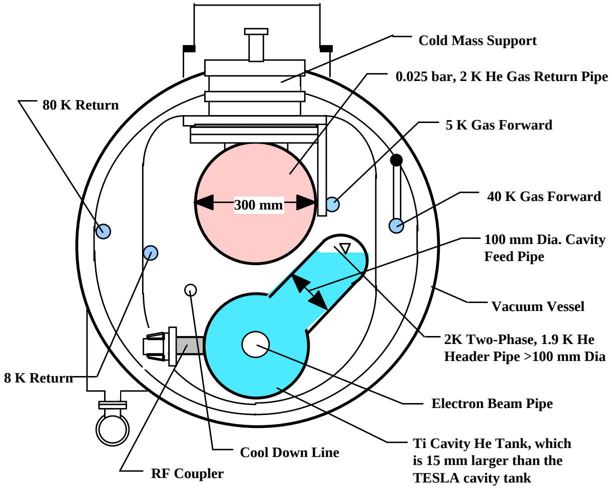
- Example: modifications of TESLA design for cw operations
  - Increase number of feed pipes between the rf cavity helium tank and the two-phase helium stand pipe
  - Position the helium feeds near ends of the helium tank
  - Increase the inside diameter of the helium tank
  - Increase the liquid helium feed pipe diameter
  - Increase the two-phase helium header pipe diameter

- Increase Q_o
  - Improved materials processing
  - Lower frequency
  - Reduced temperature
    - Pressure control, magnetic shielding,cryo system, costs, …

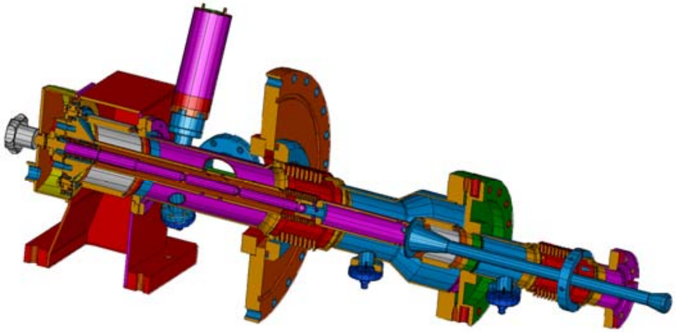
Thermal management

- Heat transport from cavity





- Input coupler
  - 10 – 20 kW
  - Variable coupling
    - Multipacting, thermal load



TESLA TDR, DESY

Cavity HOM and wakefields

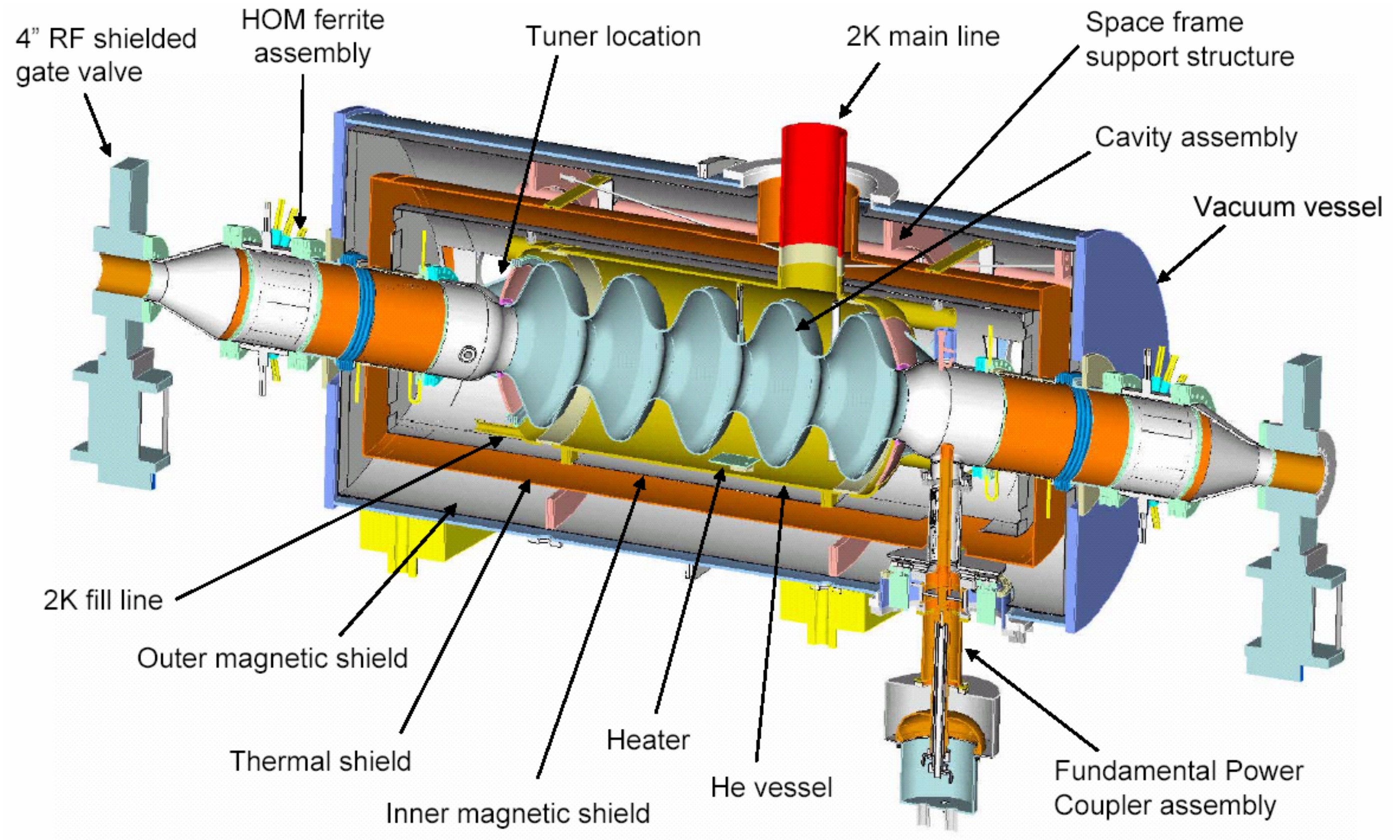
- Wakefields may persist for long periods
- Many modes in multi-cell structures
  - Higher-order and *lower-order* modes
- May present problems with collective effects
  - High-current applications, multi-bunch effects, BBU
  - Single-bunch emittance growth
  - Energy spread
- Control of cavity fields under beam loading
  - Transient behavior
- Beam tests important

BNL 703.75 MHz cw scrf cryomodule

I. Ben-Zvi

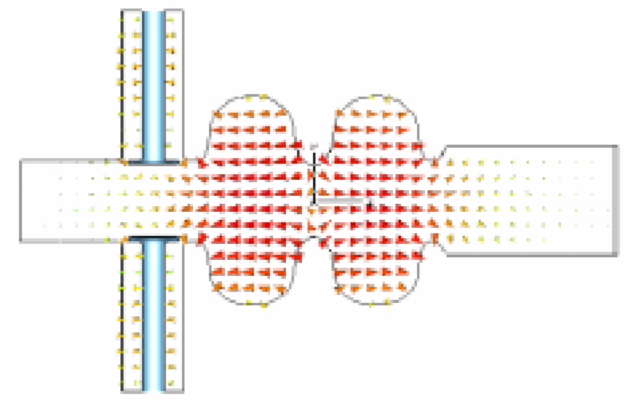
BNL, TJNAF, AES

Cryomodule design passed Final Design Review



Cornell - multi-GeV ERL

- R&D program for injector cavities
  - 2-cell cavities
  - 4.3 MV/m
  - 100 mA
  - 50 kW beam power
  - Q_{ext} of $4.6x10^4$
- Main linac - TESLA-like cavities
  - 20 MV/m
  - Amplitude stability ~10^{-3}
  - Phase stability 0.1° @ 1300 MHZ

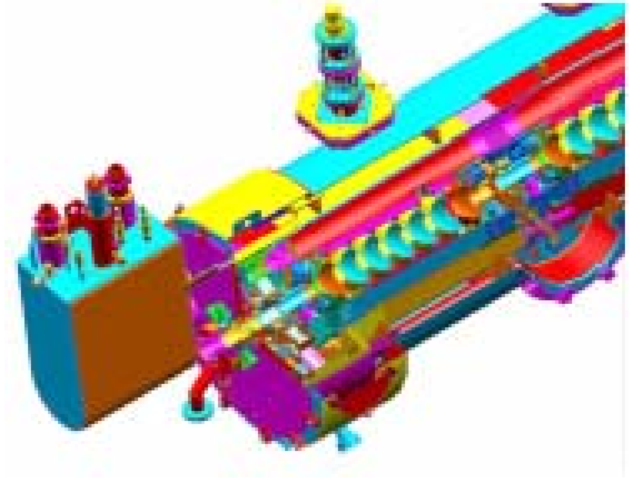


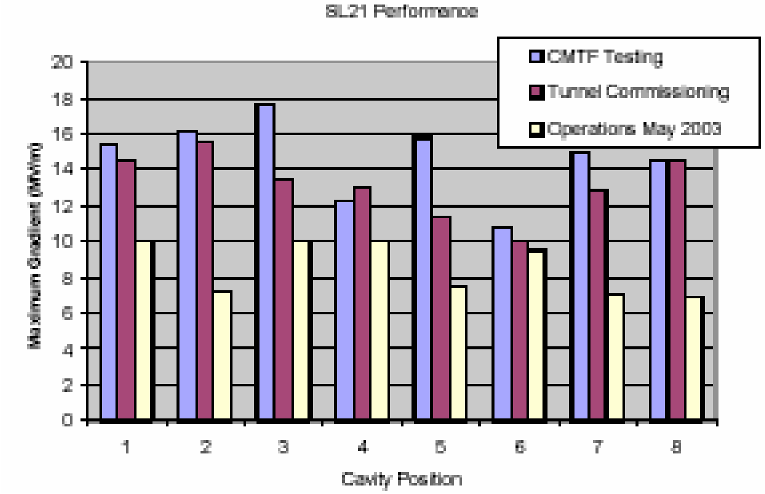
	buncher cavity	2-cell injector	9-cell main linac
Frequency	1300 MHz	1300 MHz	1300 MHz
Num. of cells	1	2	9
R/Q	210.5 Ω	218 Ω	1036 Ω
Q_0	20,000	$> 5 \cdot 10^9$	$> 1 \cdot 10^{10}$
Q_{ext}	9,900	$4.6 \cdot 10^4$ $(4.1 \cdot 10^5)$	$2.6 \cdot 10^7$
Acc. voltage	120 kV	1MV (3MV)	$\approx 21 MV$

	gun timing jitter	buncher cavity	s.c. cavities
Ampl. stab. (rms)	-	$8 \cdot 10^{-3}$	$9.5 \cdot 10^{-4}$
Phase stab. (rms)	2ps	0.1°	0.1°
Contrib. of ampl. fluct. to energy spread	-	-	4.7 keV
Contrib. of phase fluct. to energy spread	0.87 keV	2.35 keV	2.35 keV

TJNAF 12 GeV upgrade and FEL

- 460 μA CEBAF @ 12 GeV
- > 10 mA FEL





Parameter	70 MV CM [1,2]	12 GeV CM
Average cavity gradient (MV/m)	12.5	19.2
Q_{cavity}	6 E+09	8 E+09
$Q_{external}$	2 E+07	2 E+07
Klystron power, cw (kW)	8	13
2K RF heat load (W)	140	240
50K RF heat load (W)	120	104

Goals for an SMTF cw scrf component

- High-Q_o
  - $Q_o > 3\times10^{10}$
    - Efficient operations, particularly for large high-gradient linacs
- Tight phase and amplitude control
  - $\Delta\phi < 0.01°$, $\Delta V < 10^{-4}$
    - Existing light sources - bunch manipulation & x-ray compression
    - FEL's - synchronization, seeding
- The above performance in the presence of beam
  - Modest average current but high peak current
  - ~ nC, ~ 10 kHz
    - 1 nC, repetition rate ~ 10 kHz (~100 MHz in storage rings)
- These parameters are not addressed in existing cw scrf programs
- Extends the reach of the existing US program in cw scrf

Goals for a cw scrf test facility (2)

- Tests at SMTF can also address the following issues
  - Thermal management for a range of projected Q values
  - HOM damping validation
    - And LOM's for dipole mode cavities
  - Cavity tuning control
  - Power coupler designs
  - Multipacting
  - Dark current
  - …

Prototype cw scrf cryomodule

- Multi-cell ILC cavity
- L-band 1.3 GHz
  - Suitable for modest beam loading
    - ~ 10 μA
- 2 cavities per cryomodule initially

- Complementary to other cw scrf programs
- Intellectual and technical interactions between CW and ILC enthusiasts

- Other structures with application in existing light sources
  - Deflecting cavities, harmonic cavities

Infrastructure for cw scrf test facility

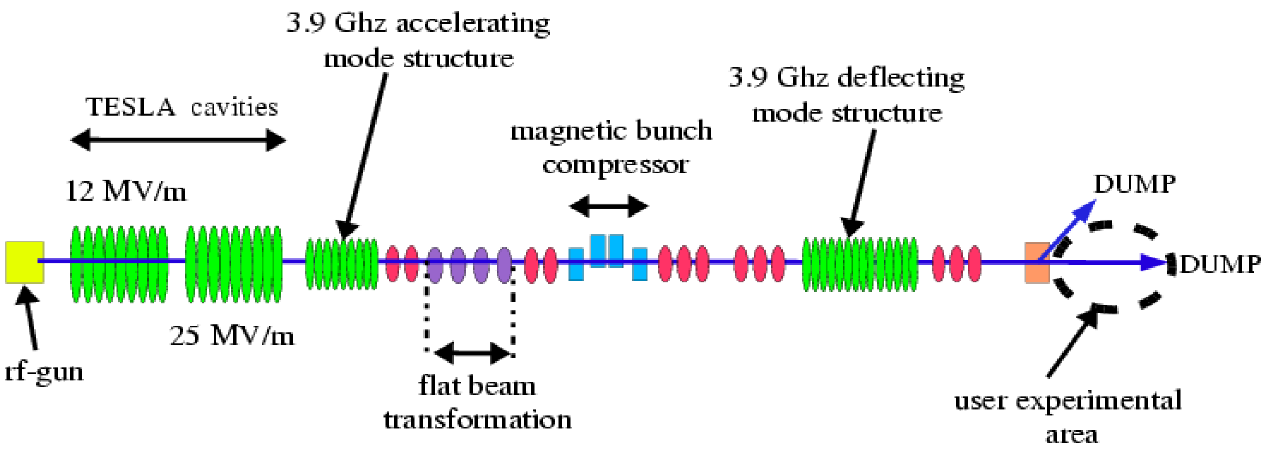
- RF power
  - L-band 1.3 GHz (ILC)
  - ~ 15 kW per m @ 20 MVm^{-1}
    - 50 Hz bandwidth
  - IOT or klystron (2 required initially, one for each cavity)
  - dc power supply
  - drive amplifier
- Space for other rf hardware at different frequencies
  - To test harmonic cavities for 3rd generation light sources
- Cryogenic fluids & transport
  - 120 W @ 2 K (40 W @ 1.8 K) (includes safety factor 1.5)
  - 10 W @ 4.5 K
  - Pumps to reach He vapor pressure corresponding to 1.8K

Beam tests for cw scrf test facility

- 10 kHz bunch rate highly desirable
  - Study transient effects with 1 nC bunches
- Bunch lengths of 1 – 10 ps
- Transverse emittance ~ mm-mrad (normalized)
  - Requires gun and injector development
    - Laser, rf cavity, modulator
    - Could be superconducting gun

- High average current measurements may be made at other facilities (e.g. TJNAF, BNL)

Injector development for cw tests



- Require development of rf photocathode & injector for 10 kHz cw operations
  - laser
  - rf cavities
  - modulators & klystrons

Summary - cw possibilities at SMTF

- SMTF cw component would provide capabilities to research parameters not addressed by existing programs
- Major applications in existing and future light sources
- "ILC"-like accelerating cavities for linac-based facilities
  - 20 MVm^{-1} cw
    - $Q_o > 3x10^{10}$
    - $Q_{ext} > 2.5x10^7$
  - 2 x 15 kW RF power @ 20 MVm^{-1}
  - 120 W heat load @ 2 K, 20 MVm^{-1}
- Harmonic & deflecting cavities for existing light sources
- Beam tests provide additional performance validation