JLAB waveguide couplers

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for

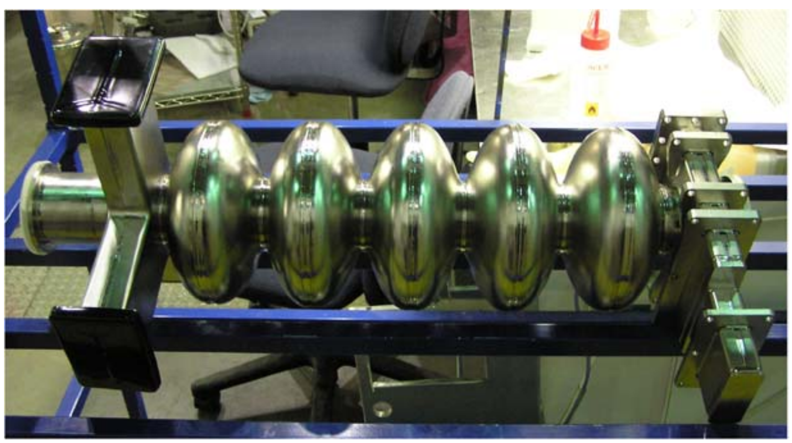
JLab SRF Institute

Outline

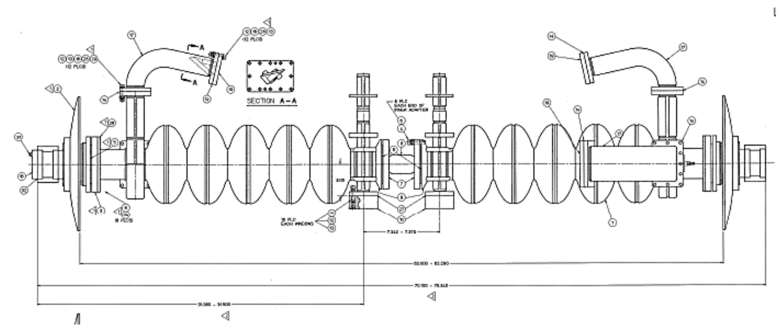
- Background
- Original CEBAF cavity pairs
- Reworked “C50” configuration
- FEL injector cryounit
- 12 GeV upgrade “C100” cavities
- High-current ERL/FEL concept
- Other applications (APS SPX, new CEBAF quarter)
- Conclusions

Background

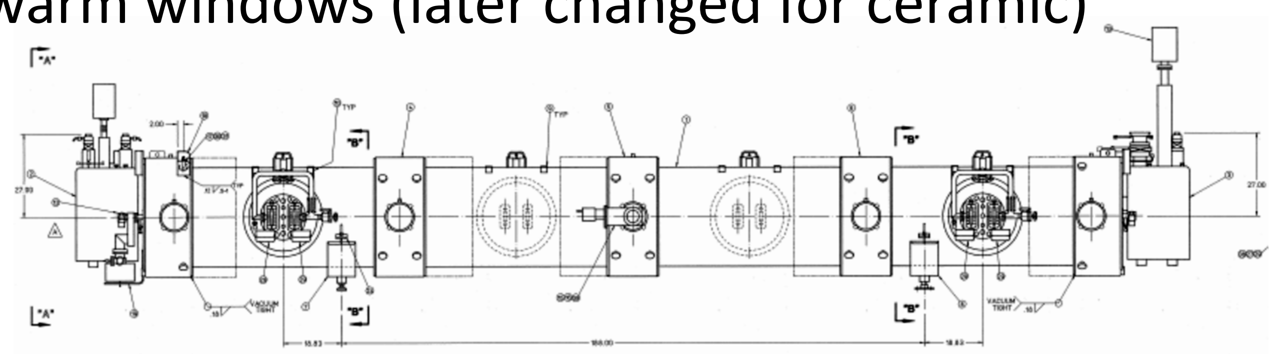
- JLab original 5-cell cavity was initially developed for the CESR storage ring at Cornell
- Waveguides chosen for power handling capability (FPC), broad-band damping (HOMs, ~70W per load)
- "Stub on stub" design (to manage other passband modes) has some residual coupler dipole kick, mitigated in CEBAF by alternating left & right.



Original CEBAF pairs



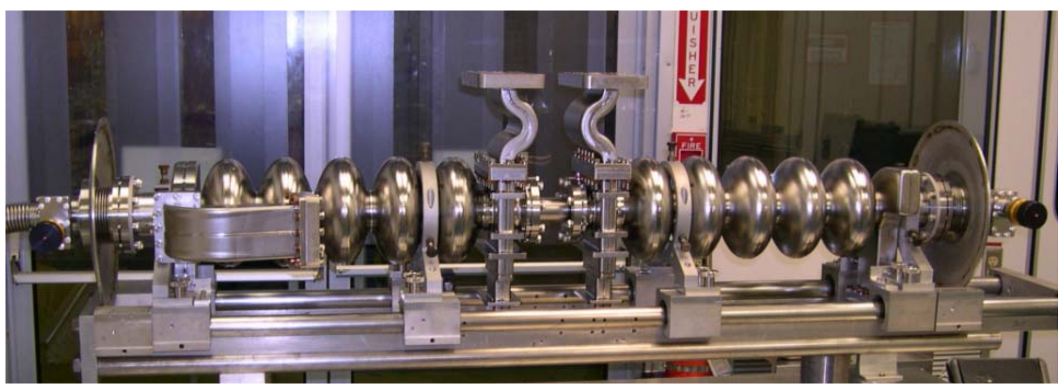
- Two 5-cell cavities back to back
- Waveguide FPC's with "stub on stub"
- 6 kW CW at full power (later 8 kW)
- Ceramic cold windows close to beam line, inside helium vessel
  - Cold window charging by field emission and arcing was a major cause of downtime
  - Managed by developing trip rate models for each cavity based on Fowler Nordheim field emission
- Waveguide HOM dampers cooled by helium (except for FEL)
- Polyethylene warm windows (later changed for ceramic)



Reworked "C50" pairs

- Reprocessed 10 weakest modules
  - Reworked original cavities (BCP + HPR)
  - Gradients improved from ~5 MV/m to ~12MV/m
- 8 kW CW maximum power
- Added dogleg to shield cold window
  - Eliminated cold window arcing
- Rework of tuners to reduce backlash
- Next module will be the same except EP and remove some magnetized components from the tuner

Dogleg waveguide

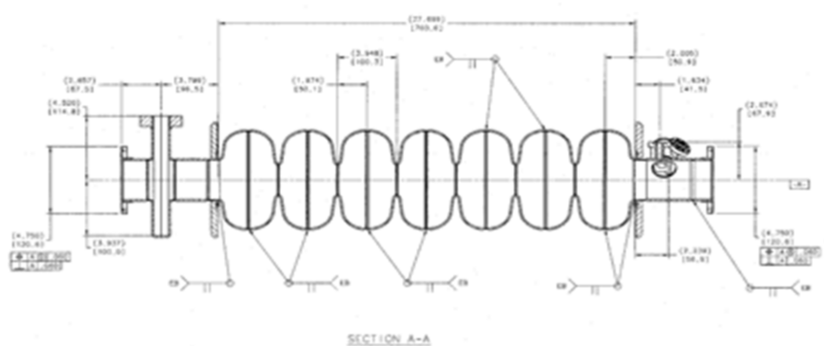


FEL Injector Cryounit

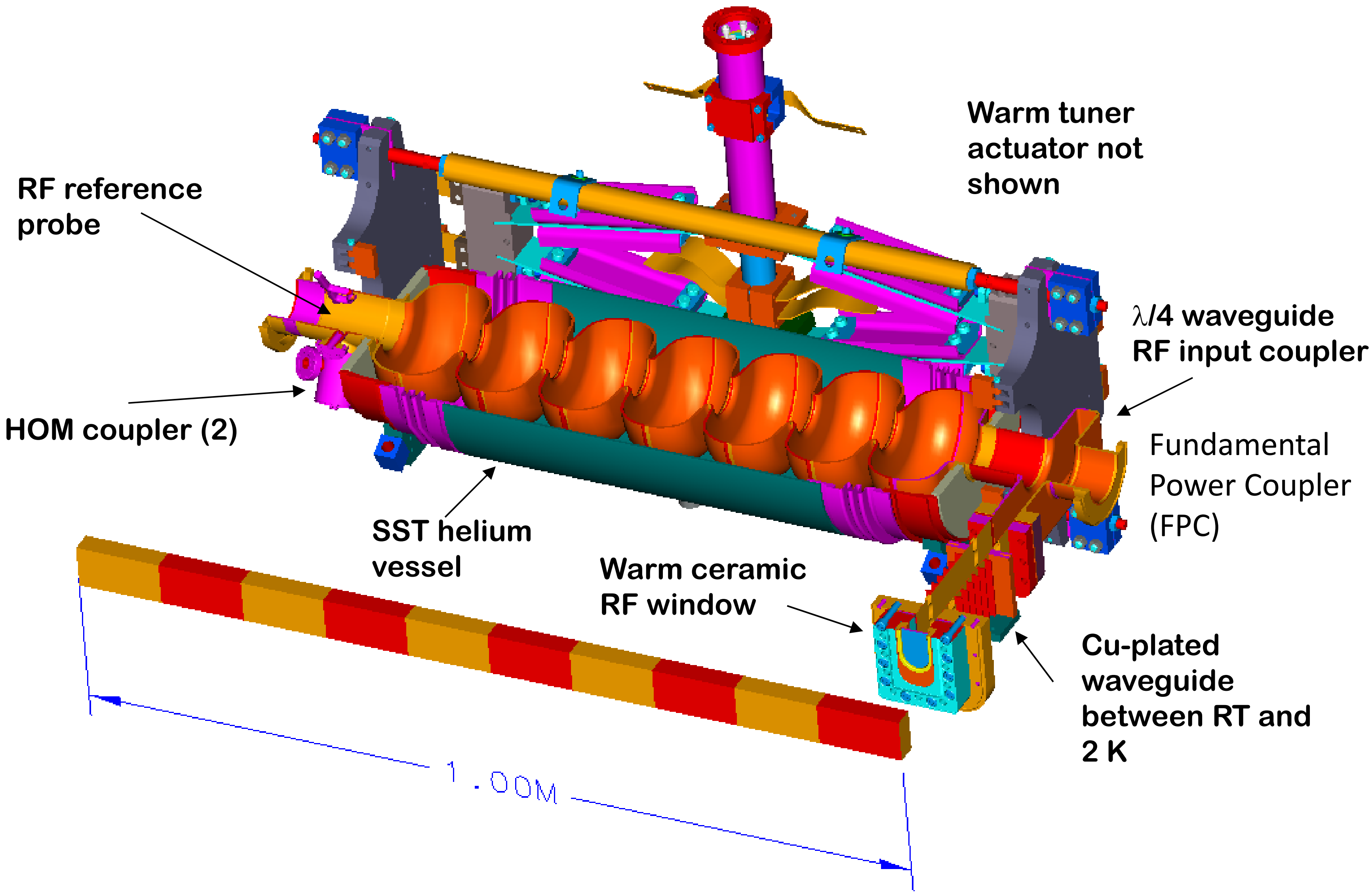
- 2 each 5-cell CEBAF cavities
- 100 kW Klystrons
- Designed for 10 mA beam current.
- Water cooled CEBAF style ceramic warm window.
- Standard CEBAF cold window.
- Day to day operation at 25 kW (low to moderate current) in excess of 10 years.
- Occasional operation above 50 kW for days at a time.
- 1 warm window failure (slow leak) due to defect in eyelet braze.

12 GeV upgrade "C100" cavity

- Waveguide FPC but tesla-type HOMs
- 13 kW CW maximum power
- Quarter wave stub to minimize coupler kicks
- Double warm window (single on early prototypes)
- Double bellows in cold-warm waveguide
  - Allows for longitudinal and transverse motion
- HOMs needed modification for CW
  - Reoriented HOM hooks, sapphire feedthroughs



Upgrade cavity – Optimized Configuration



C100 SRF cavities

C100: string of **8 7-cell cavities**, **1497 MHz**, produced by **RI** (Research Instruments)

80 cavities + 8 pre-production tested and assembled at JLAB

18-step qualification process

EP derived from **ILC R&D**

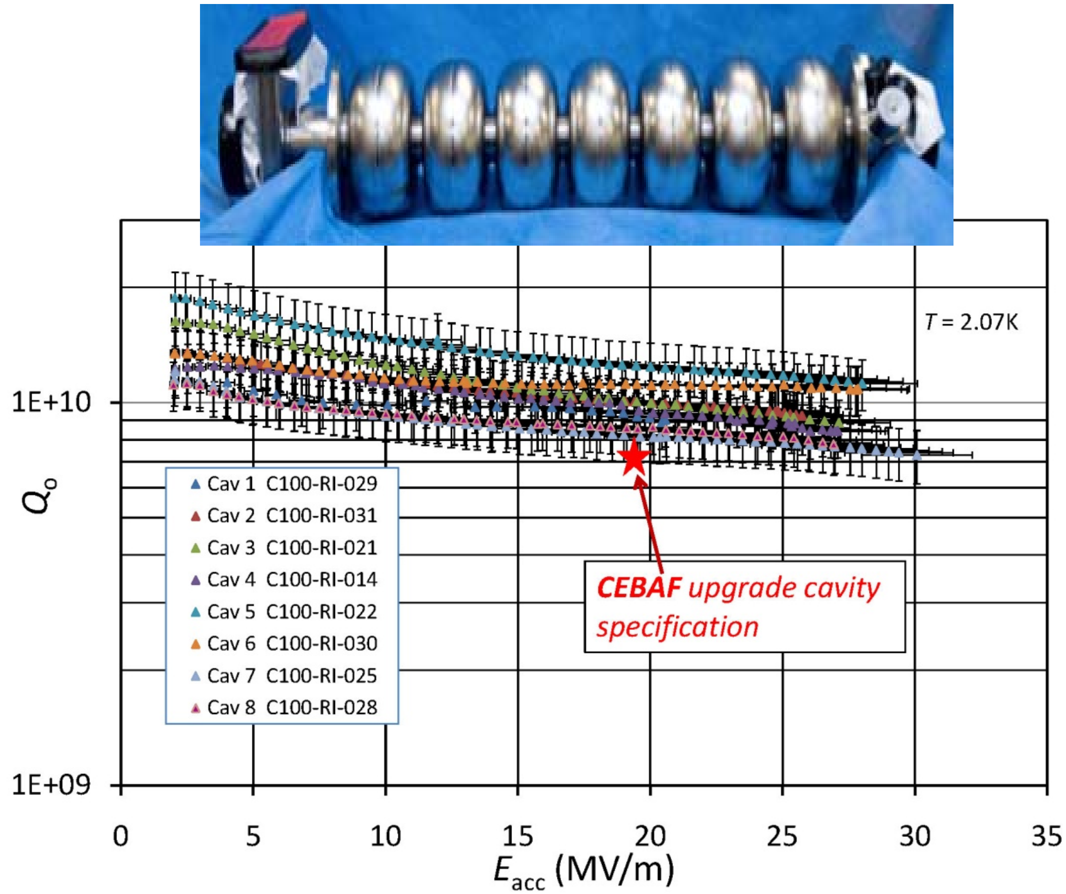
The cavity tests are performed at the Vertical Test Area (VTA)

Design gradient: **19.2 MV/m** average

Average heat/cavity: **29 W**

Operational limit: **25 MV/m**

(limited by the klystron RF power and possibly field emission)



Q is BCS-limited

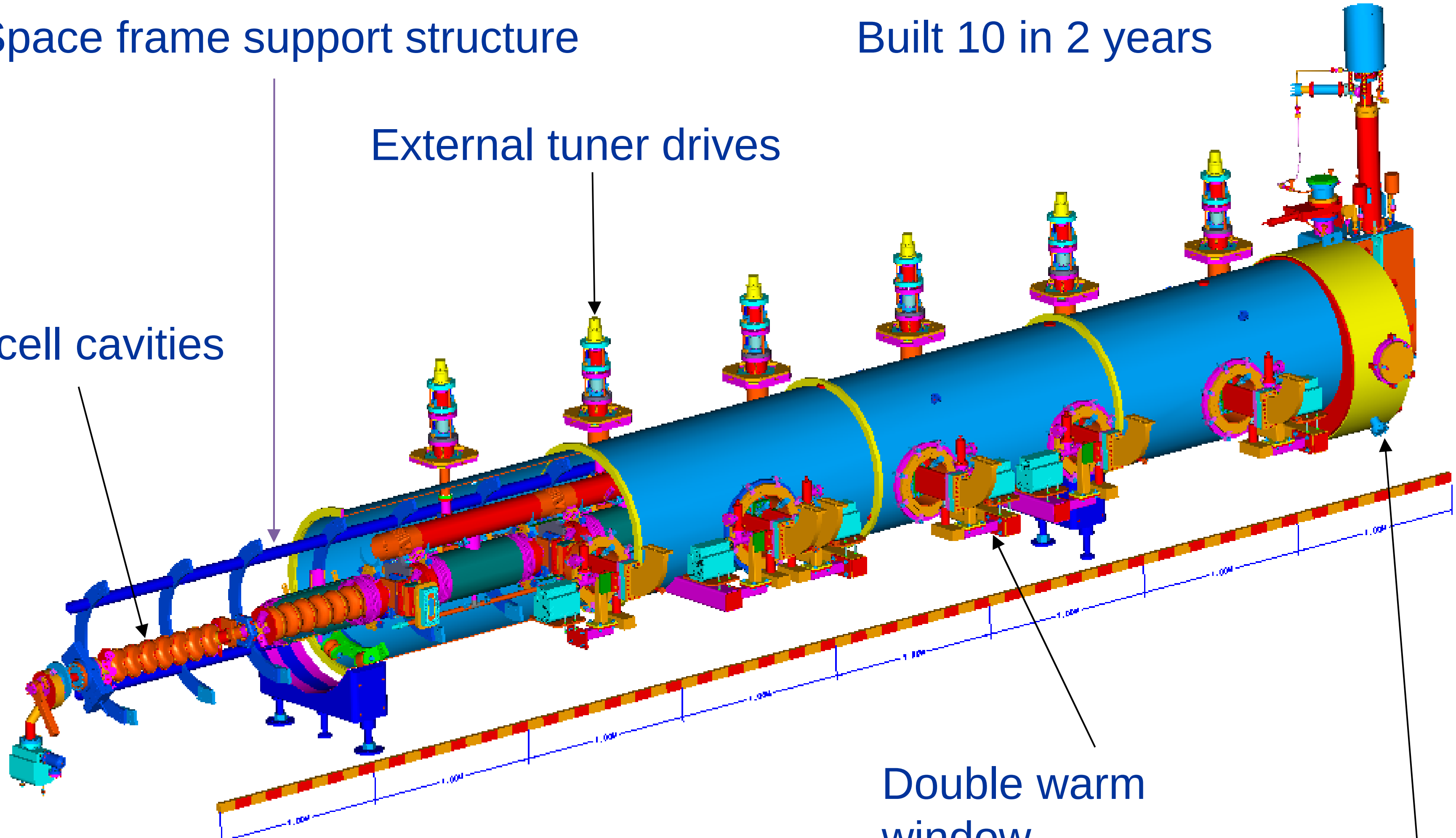
12 GeV upgrade cryomodule (C100)

Space frame support structure

Built 10 in 2 years

External tuner drives

7-cell cavities



Double warm window

Individual cryogenic connections per module

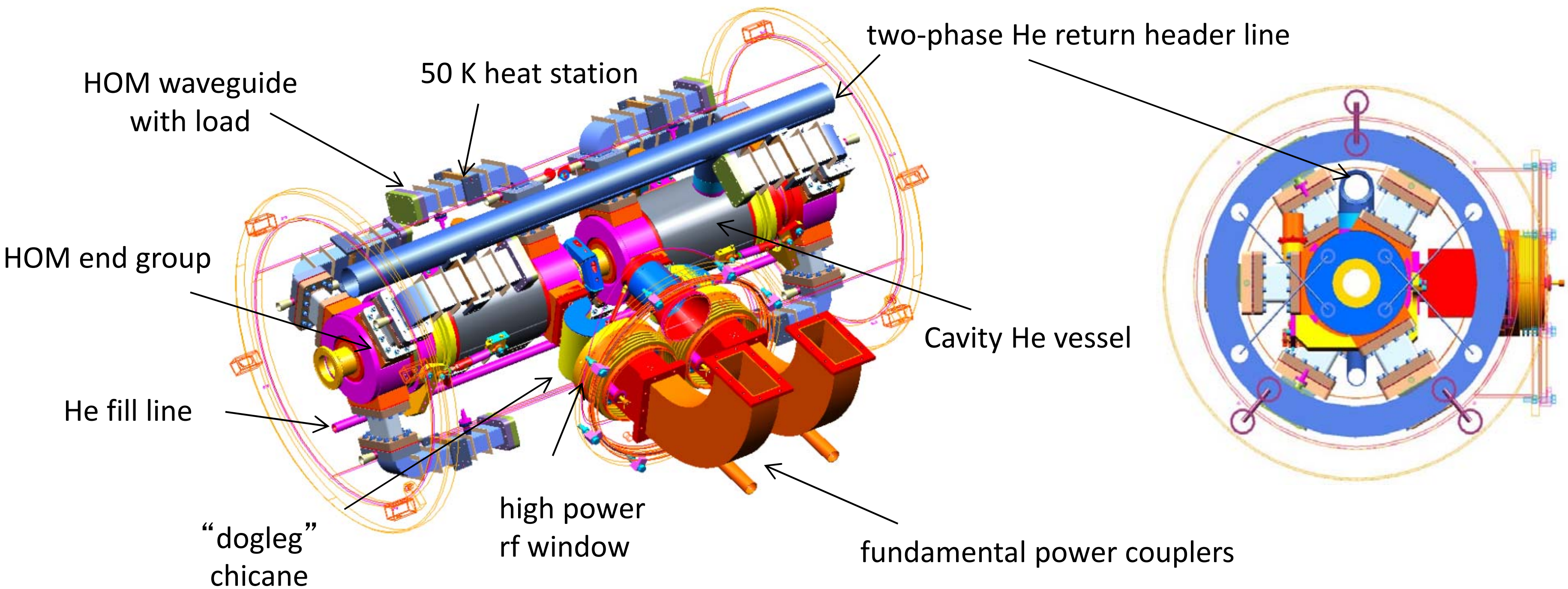
John Hogan

JLab "high-current" cryomodule

- Was an R&D project for next generation ERL/FEL
- Goal of >100 mA at 1.5 GHz (>1A at 750 MHz)
  - Very strong HOM damping required
  - Potentially high HOM power to be extracted
- Waveguide FPC and HOM dampers
  - "Y" end group performs both functions
- ~100 kW CW max (injector) ~10 kW (ERL)
- Cavities and windows prototyped
- Module concept developed
- Funding withdrawn ☹
- Some parts may be used in new FEL booster module

JLAB HC Cryomodule Development

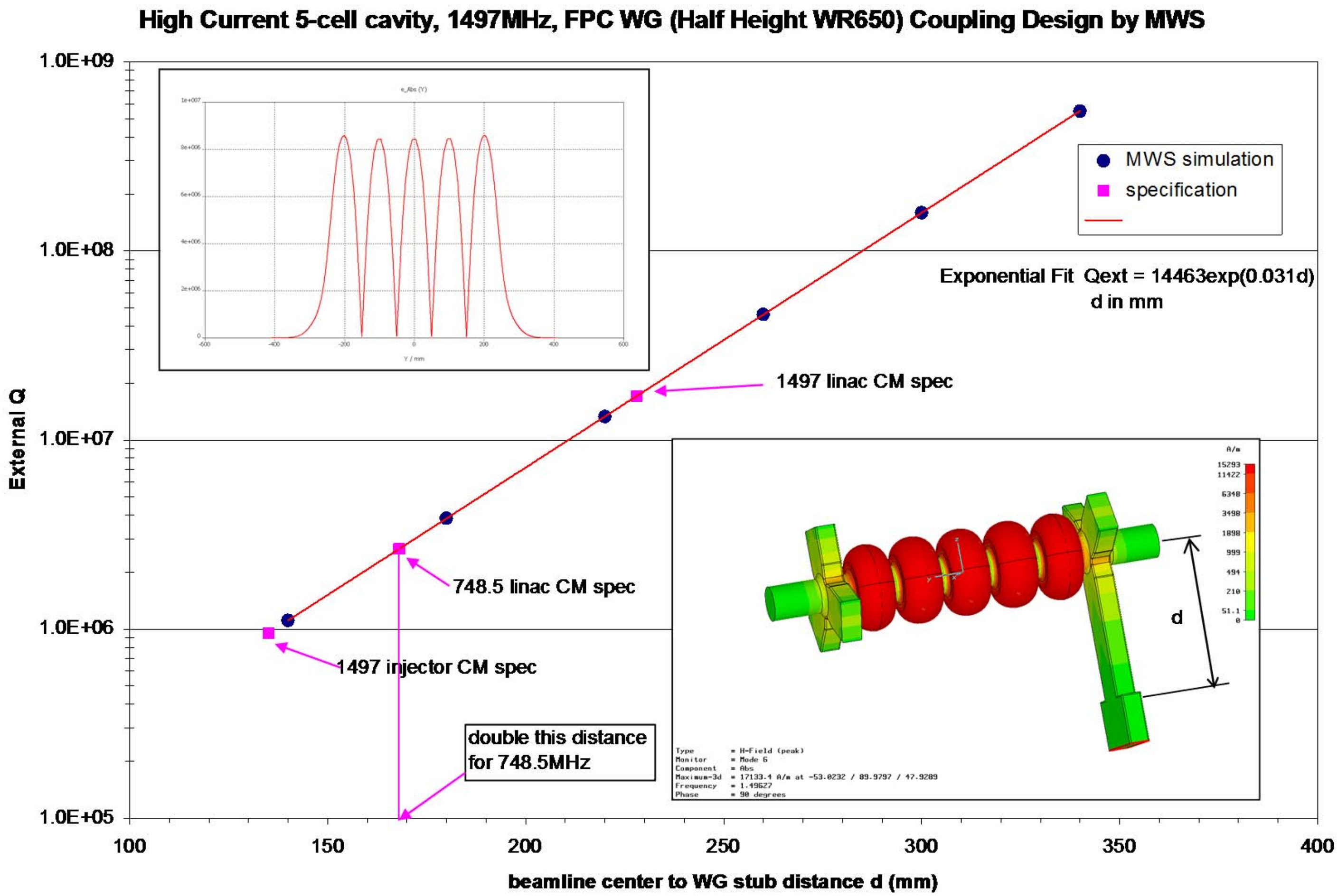
High-current cavity developed for high-power ERL/FELs
HC optimized cell shape, 5-7 cells, WG FPC, WG HOMs



Conceptual design of a cavity-pair injector cryomodule (L=2.6m)

F. Marhauser ERL09

Cavity waveguide fundamental power coupling calculation using half scale and MWS eigen mode simulation



- Qext calculation has cross-checked with MAFIA, HFSS, Omega-3P.
- MWS uses E&M BCs (Balleyguier’s method) at waveguide port.
- Qext is accurate but not the E/M field in coupler section.
- Only using impedance BC on the waveguide port can properly simulate the SW and TW in the coupler region like frequency domain solver (MWS and HFSS).

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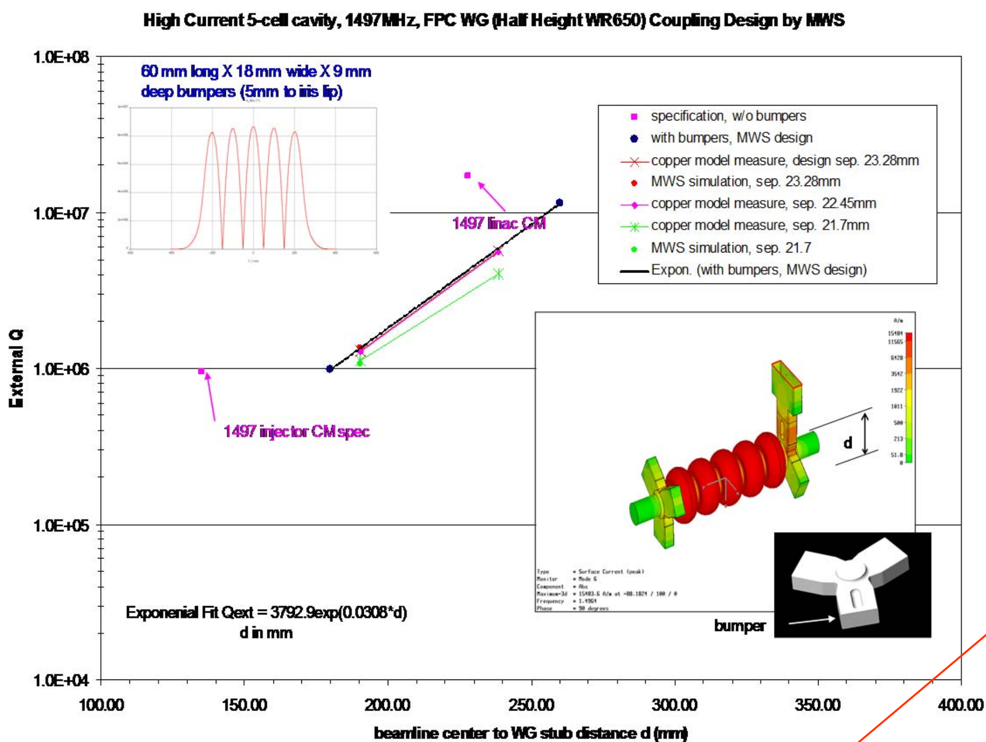
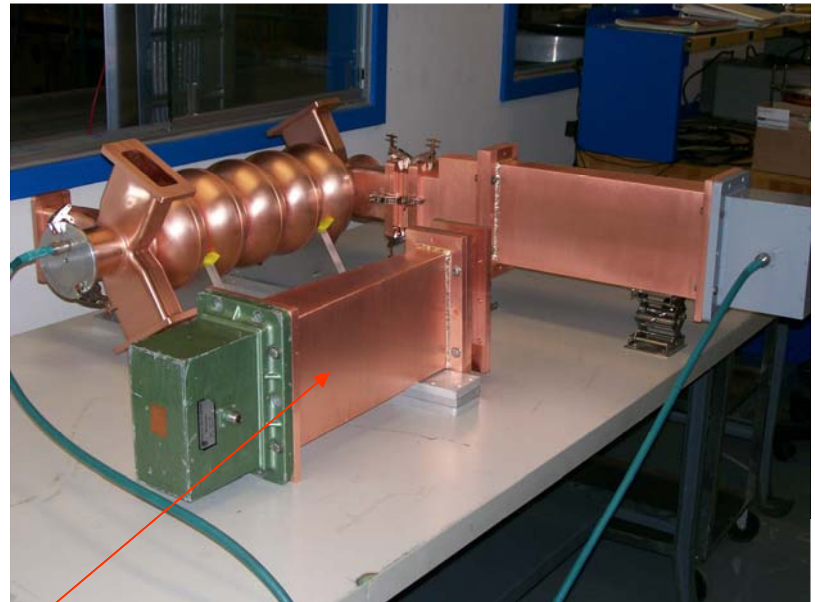
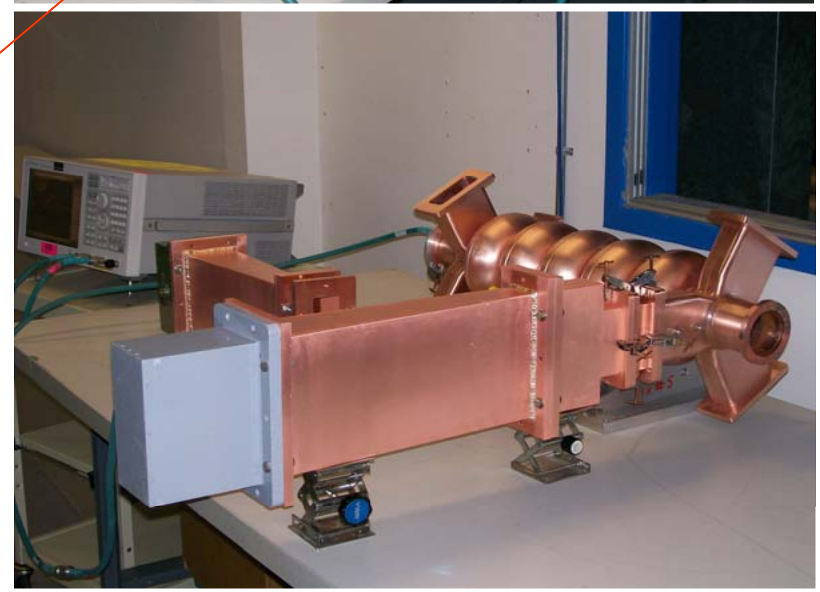
d=336.2 mm

Cavity coupling external Q bench measurement







- Using TRL calibration and S21 measurement technique
- To avoid "ghost" waveguide mode, "adapter removal" procedure has been specially developed for the waveguide coupler measurement using Agilent 8753ES ENA.
- Waveguide measurement data agrees with MWS simulation prediction.

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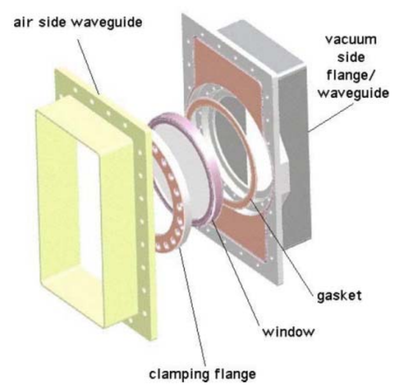
JLAB HC Cryomodule RF High Power Window

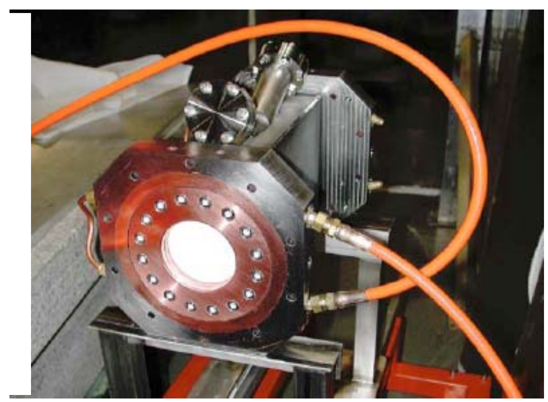
High power capability required.

- A waveguide RF window was preferred to a co-axial design
- Design is based on water cooled scaled PEP-II type window design, (tested near 1 MW CW at 700 MHz for LEDA)
- 1497 MHz prototypes have been built, window ceramic thickness optimized in test fixture
- High power tested to 60 kW CW at JLab FEL (limited by klystron)

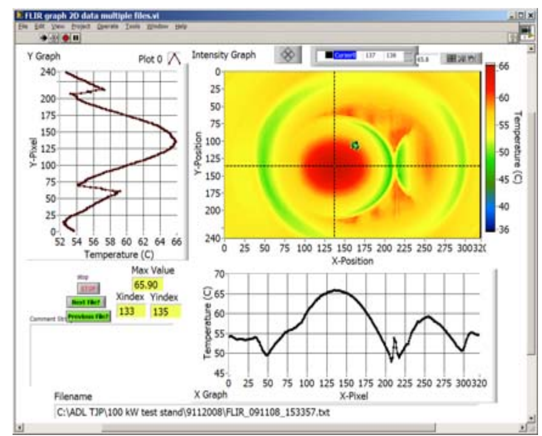
PEP-II 476 MHz waveguide window assembly



LEDA 700 MHz waveguide window assembly



JLab 1497 MHz window on test box



High power IR image

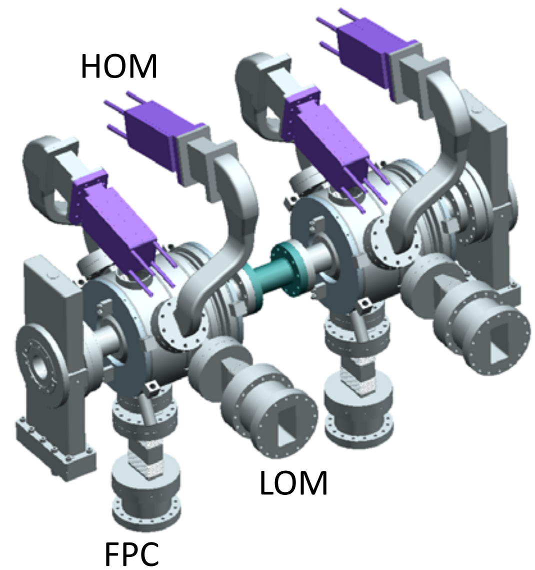
Rimmer, Elliott, Marhauser, Powers, Stirbet

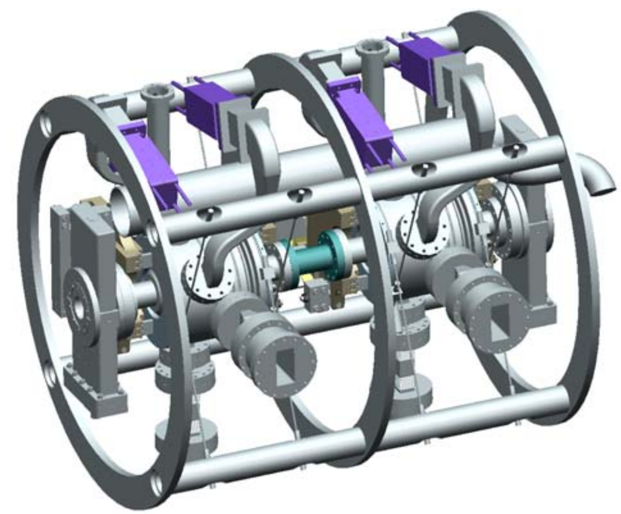
Other applications

- ANL upgrade short pulse X-ray (SPX)
  - Crab cavities to produce short bunches
  - Waveguide HOM dampers, LOM and FPC
  - Potentially high HOM and LOM power from APS stored beam
  - Waveguide FPC and LOM have double warm windows
- New CEBAF quarter cryomodule
  - Low beta 2-cell in first position
  - Eliminate coupler dipole kicks

ANL SPX crab cavity development

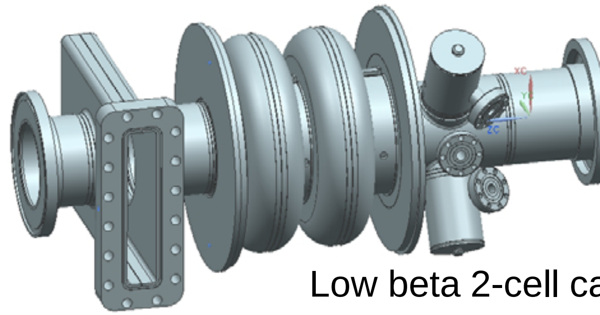
- SPX upgrade project to produce short X-ray pulses at the APS
  - Crab the beam through an insertion device (and un-crab afterwards)
  - Select fraction of radiation with a slit
- JLab developing compact deflecting system
  - SRF crab cavities with HOM/LOM damping
  - Fully integrated cryomodule package
- Waveguide FPC, LOM and HOM's



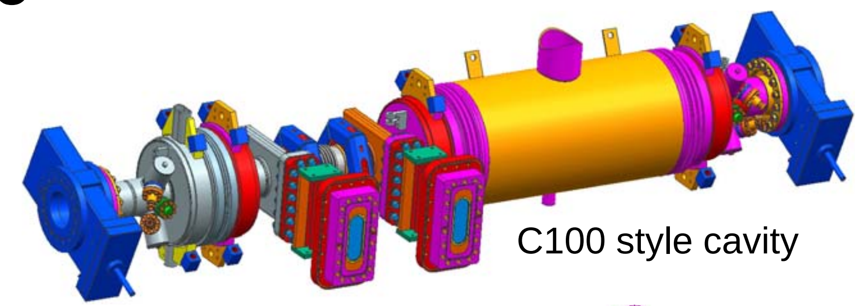


New CEBAF booster cryomodule

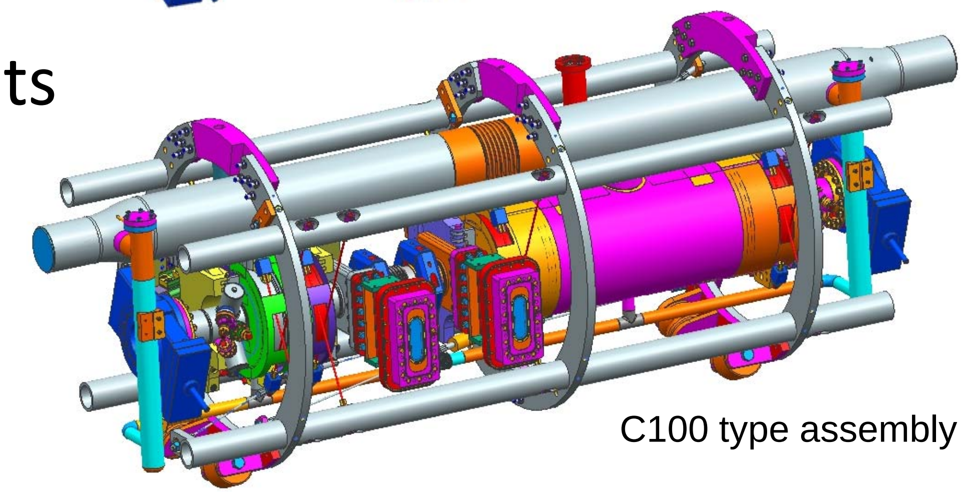
- Improved “quarter” cryomodule with accelerating capability of up to 10 MeV
- Short, Low beta first cavity to eliminate velocity mismatch
- Symmetric FPC to minimize x/y coupling
- Based on C100 components
- Fits in existing footprint



Low beta 2-cell cavity



C100 style cavity



C100 type assembly

Conclusions

- Waveguide FPC's and windows can handle very high power
  - ~0.5 MW for CESR-B, PEP-II, LEDA
- Simple mechanical construction
  - No center conductor to worry about
  - Can accommodate x,y and z motion via bellows
- Manageable static heat load
  - Intercepts and option of trace cooling for higher power
  - Small compared to CW cavity losses
- No electrical DC bias (can use magnetic bias on warm section or second frequency to disrupt multipactor?)
- Care must be taken with windows (double warm?)
- Long history of reliable operation in CEBAF