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Design Challenges with PIP-II Cryomodules

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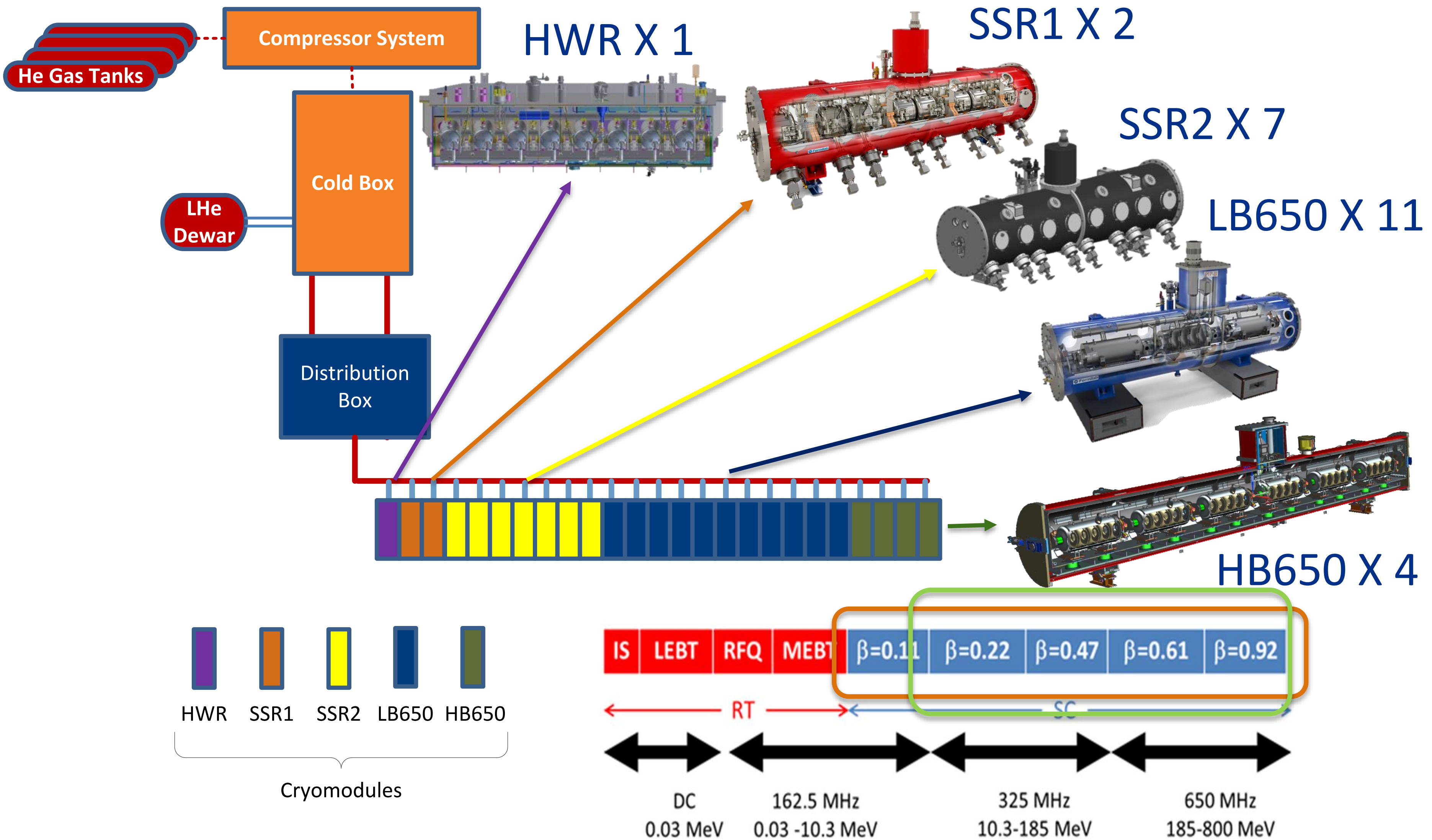
TTC-Milan, WG-4 Session 3, Pulsed Cryomodules and Components

08-February-2018

PIP-II Cryomodule Flavors and Quantities



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Cryomodule Design Challenges

- Challenge 1
  - Design CMs to operate in both pulsed and CW regimes
  - Duty factor of ~ 1% -> 100%
  - High Q0, Low FE, high average power RF couplers
- Challenge 2
  - Design SSR1, SSR2, LB650, and HB650 CMs using a single design platform
- Challenge 3
  - Incorporate lessons learned from LCLS-II, others
    - Minimize TAOs & microphonics, material procurement
- Challenge 4
    - Design and produce cryomodules and components within a multi-partner International Collaboration – a first-of-a-kind endeavor for an accelerator project under the auspices of DOE Office of HEP

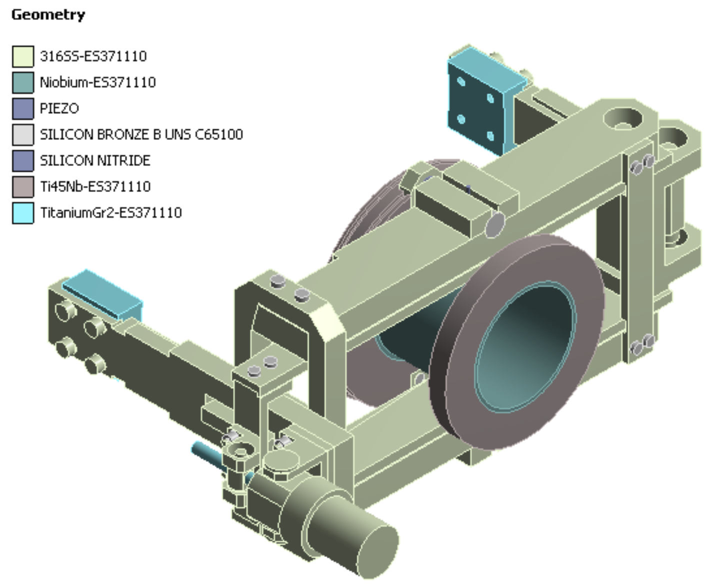
Challenge 1 – Pulsed operation + CW compatibility

- Baseline requirements of PIP-II are 1.2 MW beam power to LBNF/DUNE which can be achieved with pulsed beam.
- Future customers require CW, so PIP-II establishes a platform to serve LBNF/DUNE beam power upgrade >2MW, 100 kW Mu2e CW operations, and eventually other simultaneous high beam power users.
- PIP-II FRS identifies CW Compatible SRF/Cryogenics elements as follows:
  - Superconducting cavities, cryomodules, RF sources, instrumentation, and integrated components will be capable of operating in CW mode.
  - Installed cryogenics plant and distribution system will be sized to support CW operations of the 800 MeV SC LINAC.
- Approach avoids costly upgrade path in the future

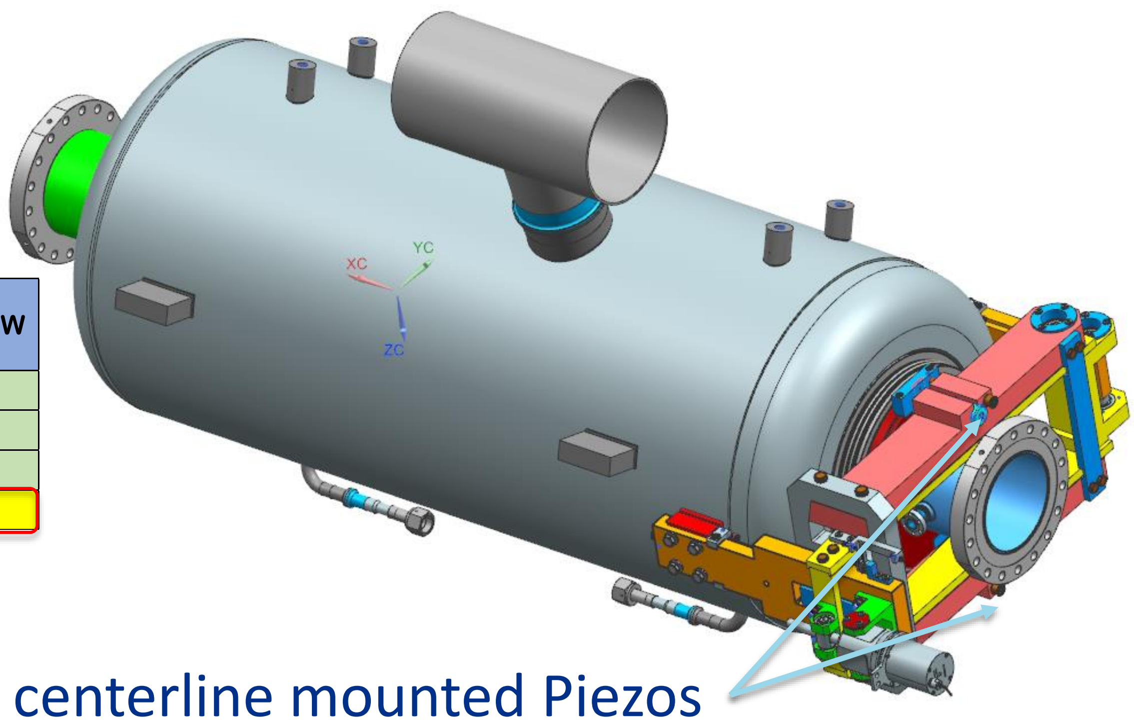
Pulsed and CW Design Implications

- Pulsed Operation
  - Narrow cavity operating bandwidth (30 Hz HBW), dominated by LFD. Active compensation required.
  - Optimized cavity and tuner system design to minimize LFD and provide reliable active compensation.
    - Stiff tuners (40 kN/mm for 650 MHz)
    - Piezo lifetime requires ~10^{11} cycles, must be replaceable in-situ
- CW Operation
  - Optimize cavity/CM designs to minimize df/dp, microphonics
  - Minimize cryosystem induced microphonics
  - Minimize dynamic heat loads (high Q0, thermal loss management)
  - Minimize Field Emission (reduce integrated tunnel radiation)
  - High average RF coupler power (up to 50 kW for 2mA, up to 120 kW for 5 mA)

Examples of design approach:
~40 kN/mm Tuner + optimized LB650 MHz cavity



- Original prototype ~ 30kN/mm
- New design ~ 42kN/mm
- Stiff tuner minimizes LFD sensitivity
- LB650 LFD of 1.4 Hz/(MV/m)^2 still difficult to achieve

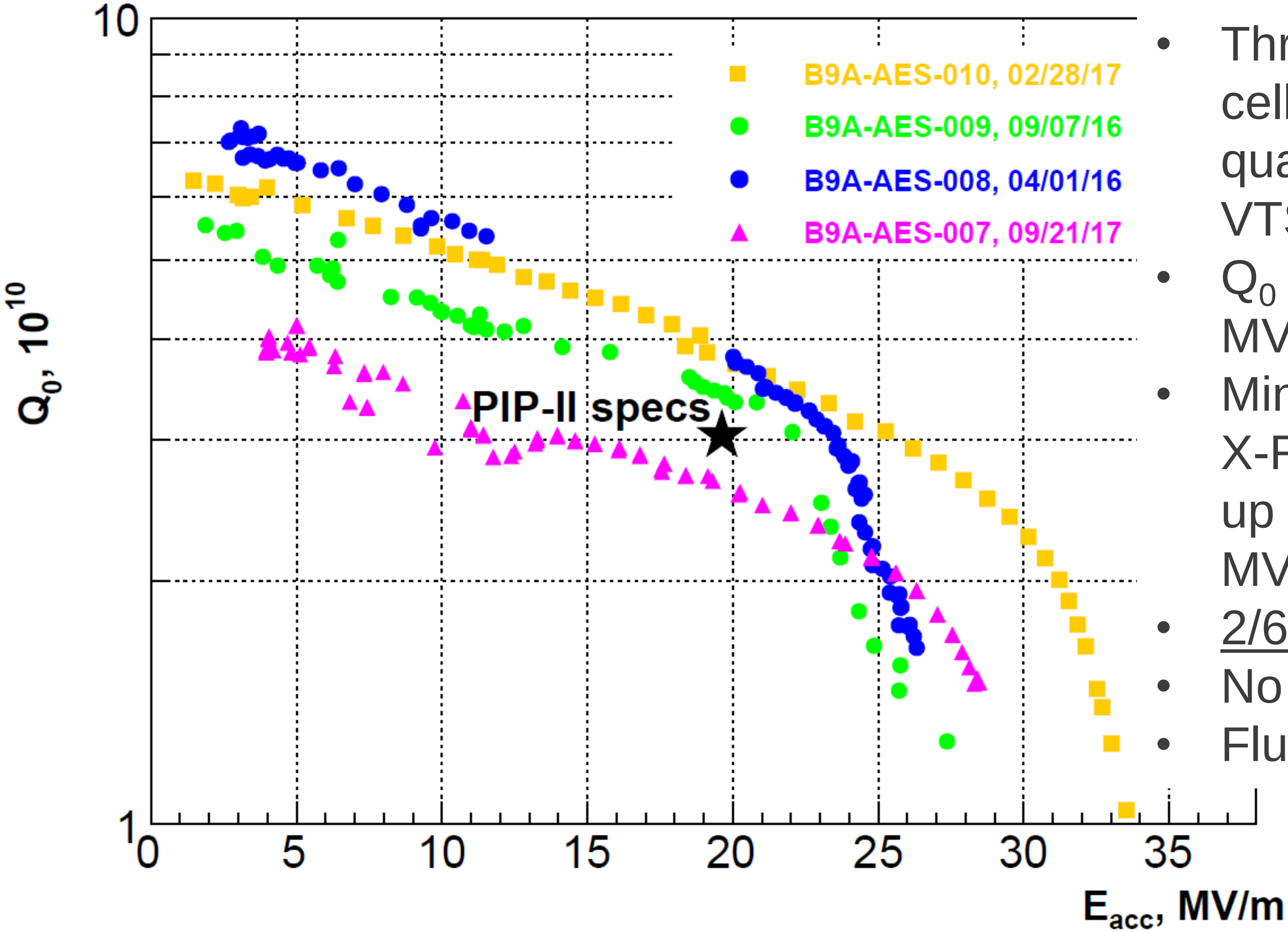


Pulsed SRF accelerators, existing and projects	Cavities Half-bandwidth, Hz	LFD, Hz	LFD/HBW
SNS	**550**	**300**	**0.6**
ESS	**500**	**400**	**0.8**
EuXFEL	**140**	**550**	**4**
PIP II	**30**	**510**	**17**

See Y. Pischalnikov Talk

Cavity centerline mounted Piezos

LCLS-II processing regime implemented: β.9 650 MHz Multi-cells. – High Q0, Low FE, good gradient



- Three of four multi-cell B.90 cavities qualified through VTS.
- Q_0 > 3.5 E10 @ 20 MV/m demonstrated
- Minimal FE induced X-Rays during tests up to E_{acc} < 25 MV/m.
- 2/6 N2 + 5um EP
- No anti Q-slope?
- Flux sensitivity?

*No data on dressed cavity in Horiz. Test config.

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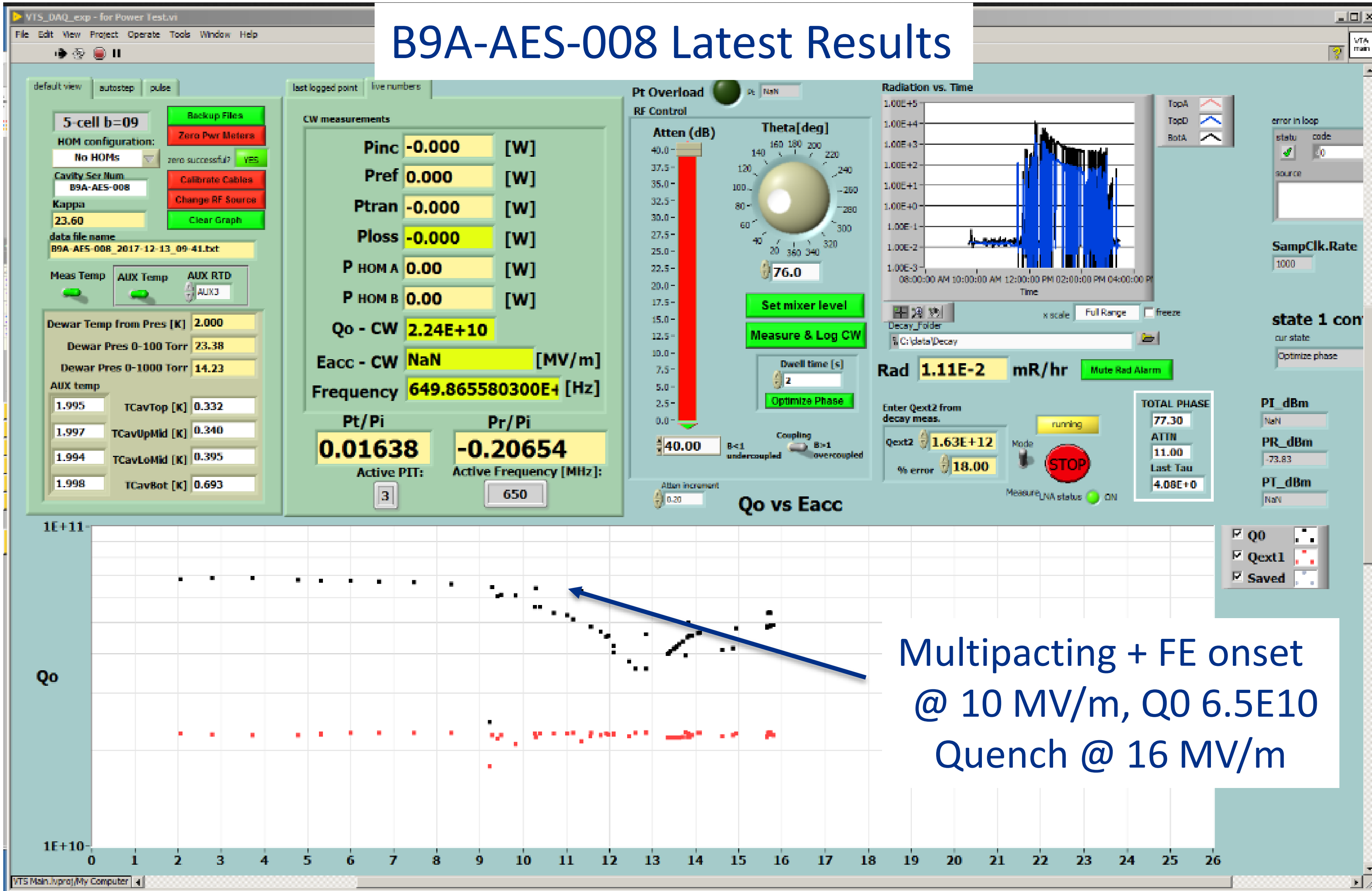
…but, 650MHz Performance/prep not optimized

B9A-AES-008 Latest Results



Multipacting + FE onset @ 10 MV/m, Q0 6.5E10

Quench @ 16 MV/m

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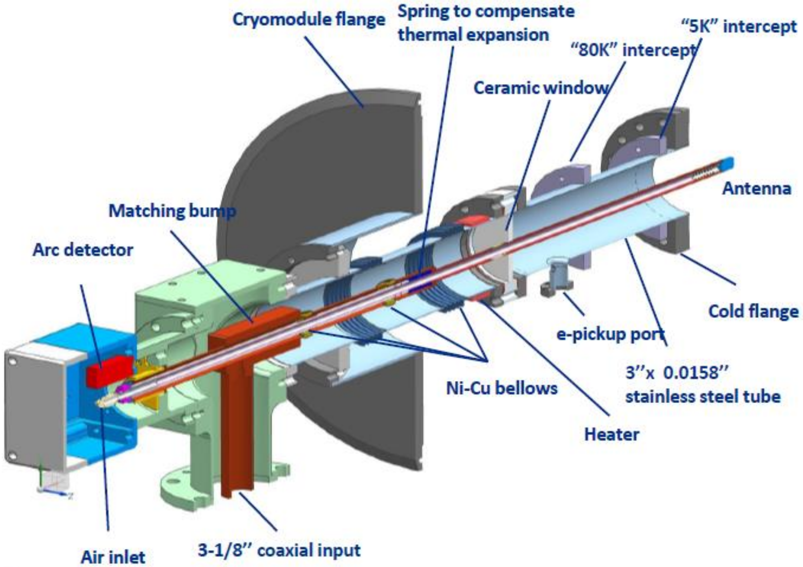
Developed High Avg. Power RF couplers, Sources

325 MHz Production Coupler



30 kW, CW, full reflection

RF Sources:

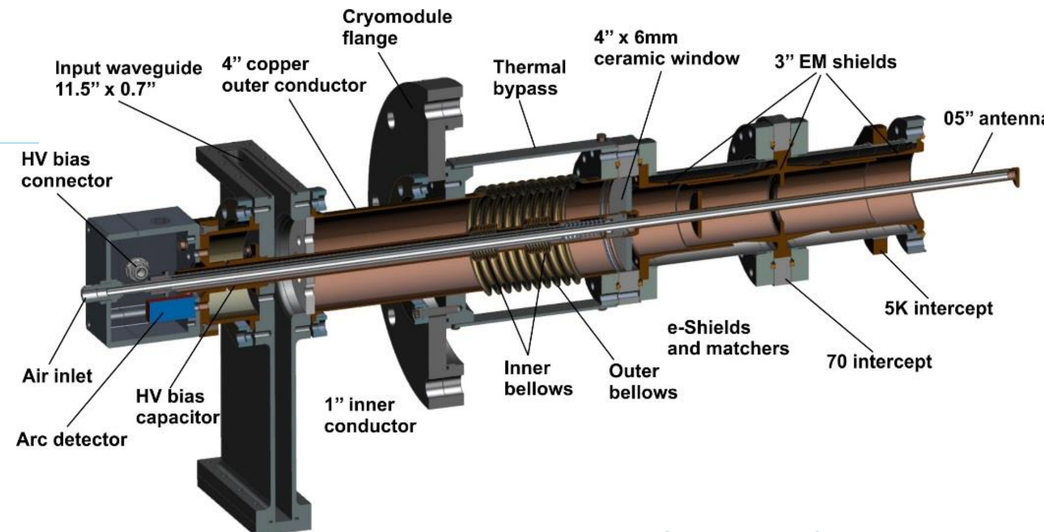
3 kW – 70 kW

CW, one/cavity

See S. Kazakov talk

- Minimize heat load to cryo
- Quality control essential to minimize manufacturer errors and development time
- Lost prototypes due to poor ceramics and vendor control

650 MHz EM Shielded Prototype



>100 kW, CW, full reflection

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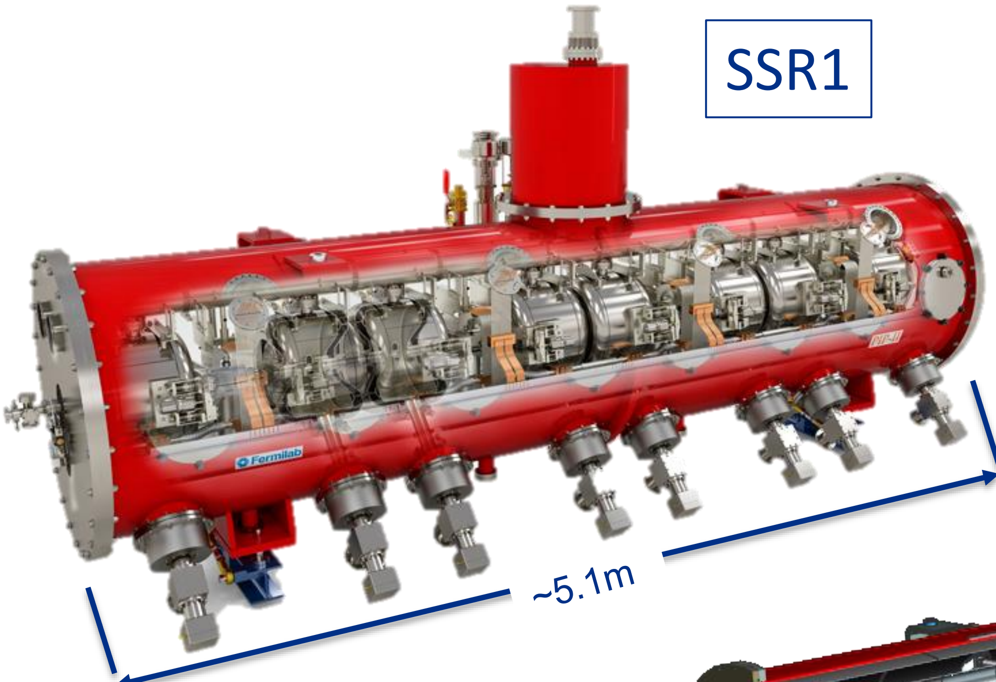
Challenge 2: Single PIP-II CM Design Platform

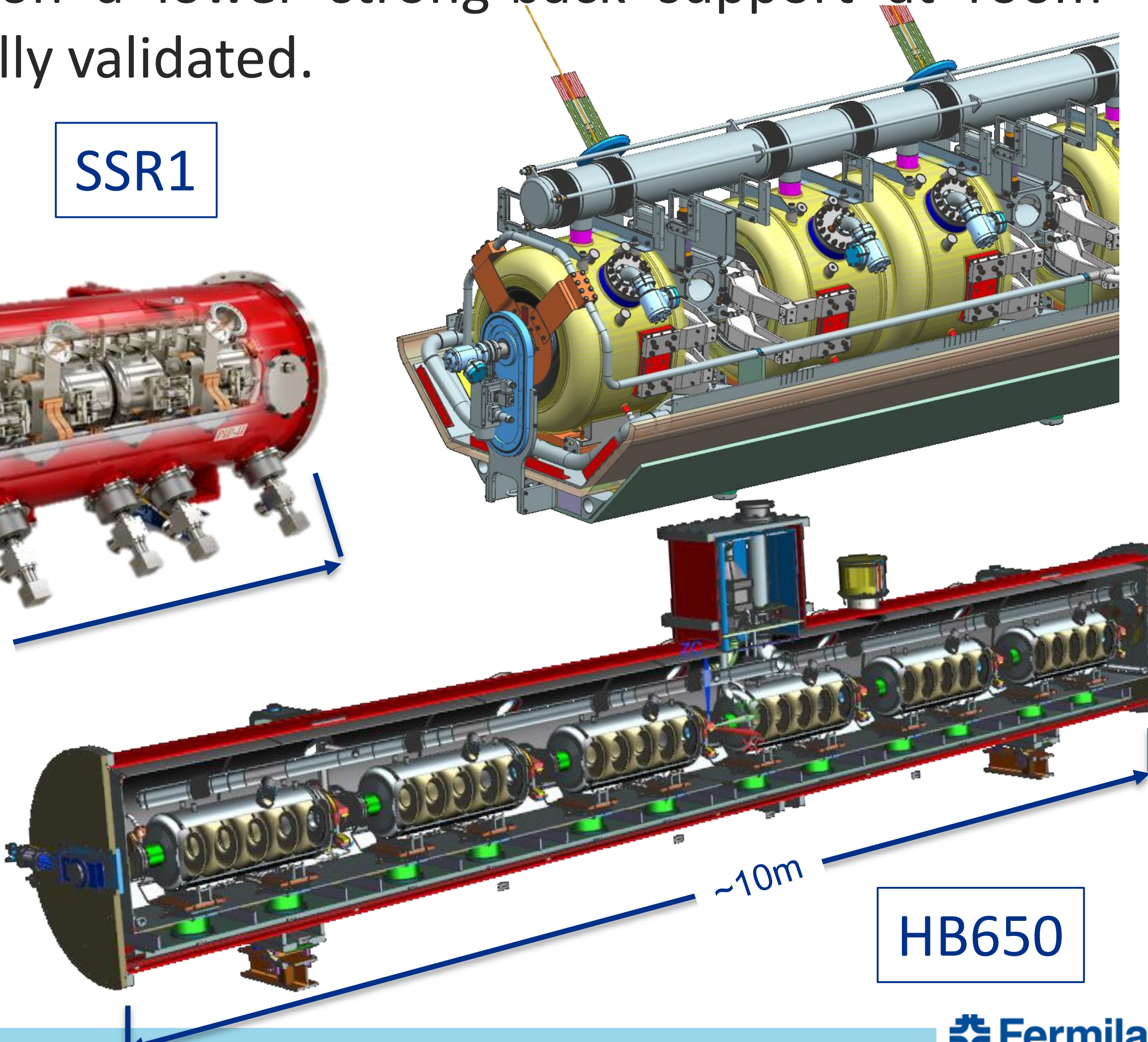
SSR1 Cryomodule design platform for SSR1, SSR2, LB650, and HB650 CM types

- Primary Design Features
  - Room temperature lower Strongback support
  - Fully segmented – individual cryogenic feed/return
  - Integrated thermal shield in cavity support base
  - Side-mounted cryogenics feed and control box
  - Tuner access ports
  - Individual RF sources/RF Coupler/SRF cavity
  - Common Instrumentation strategy
- Design uniformity kept to the extent practical
  - Facilitates CM assembly and repairs
  - Shared components by frequency: couplers, tuners, interfaces

PIP-II Cryomodule Layout

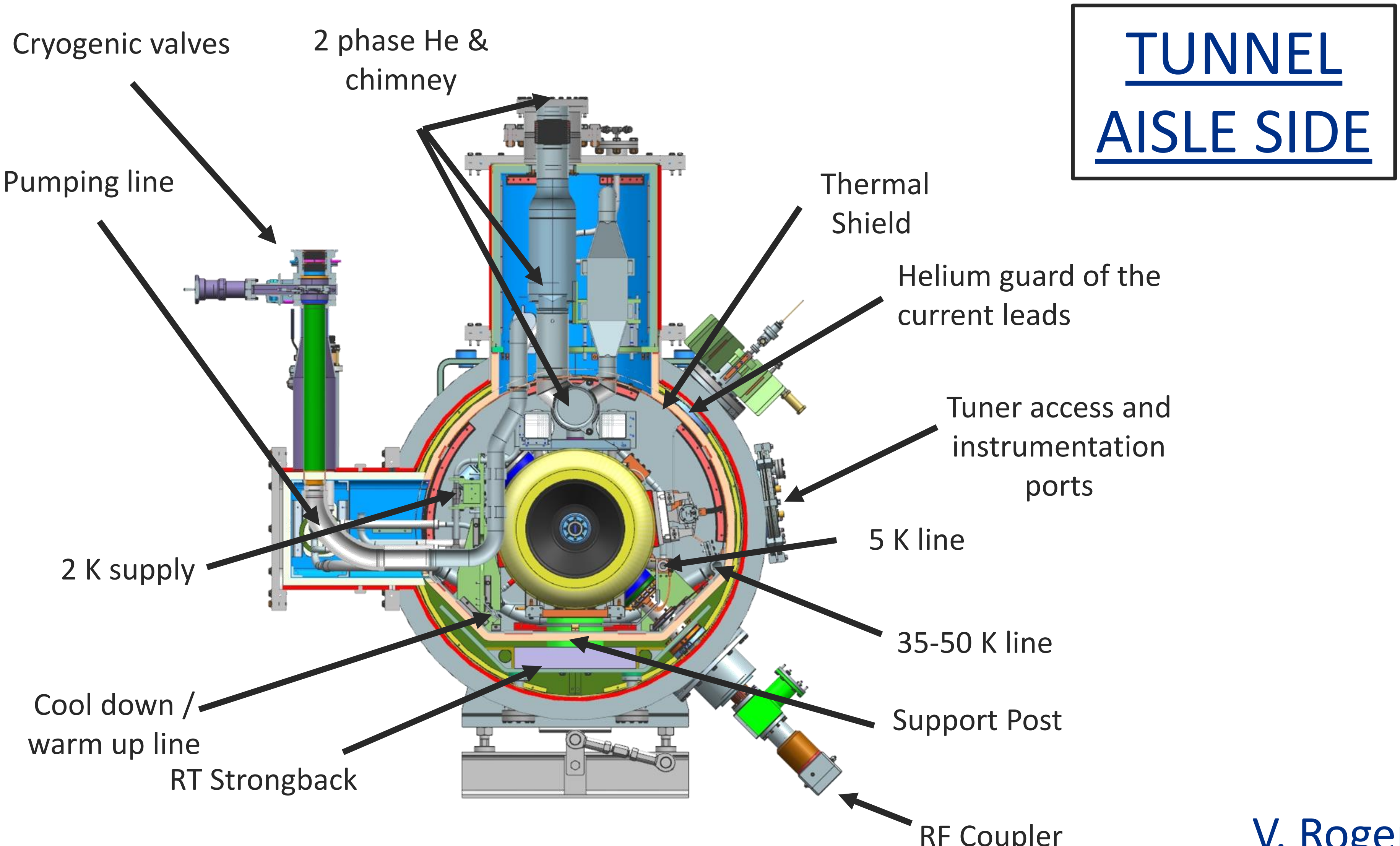
PIP-II CMs are based on a lower strong-back support at room temperature. Analytically validated.





V. Roger

PIP-II Cyomodule Layout (SSR1 shown)



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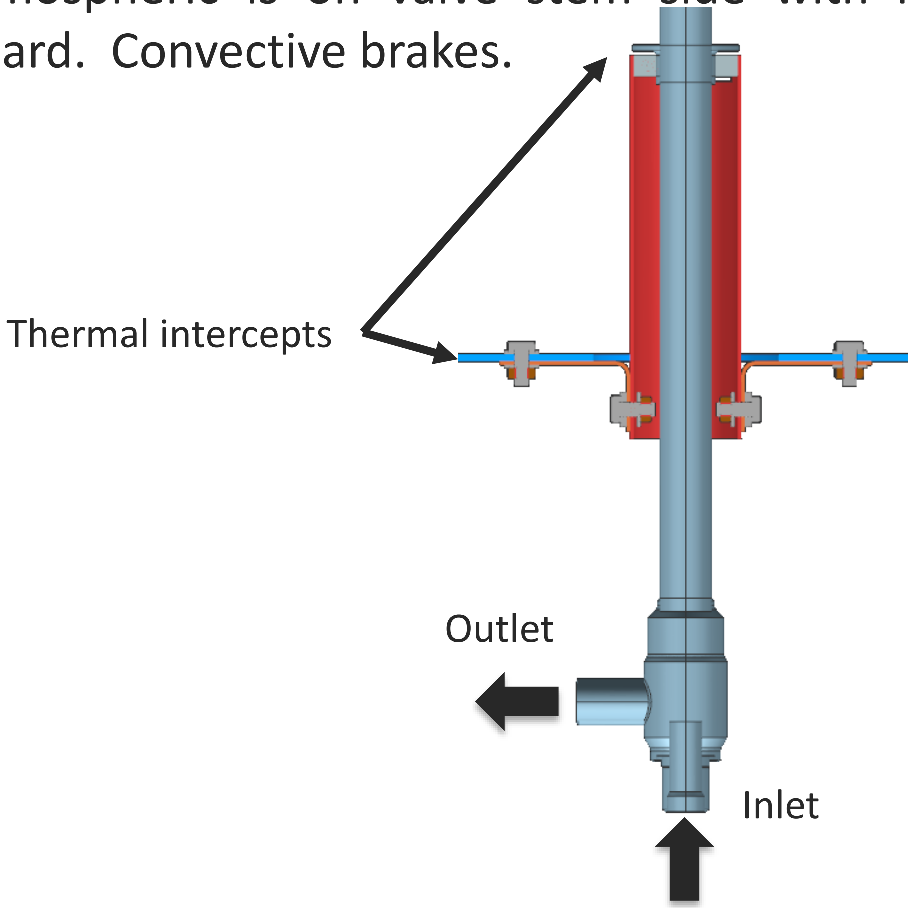
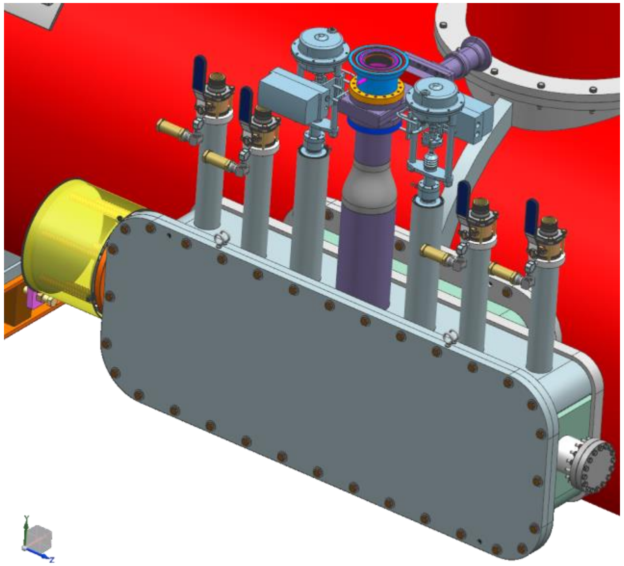
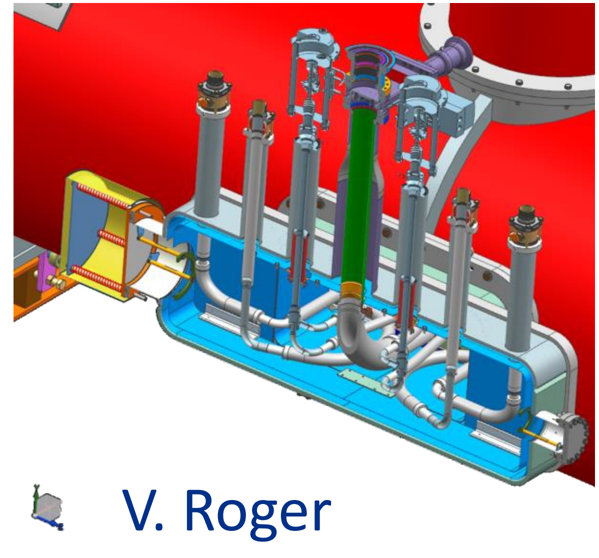
Challenge 3 – Incorporate Lessons Learned

TAO Experience from LCLS II

The cryogenic valves are set up in the same way as LCLS II cryomodules. Reverse helium flow so sub-atmospheric is on valve stem side with helium guard. Convective brakes.







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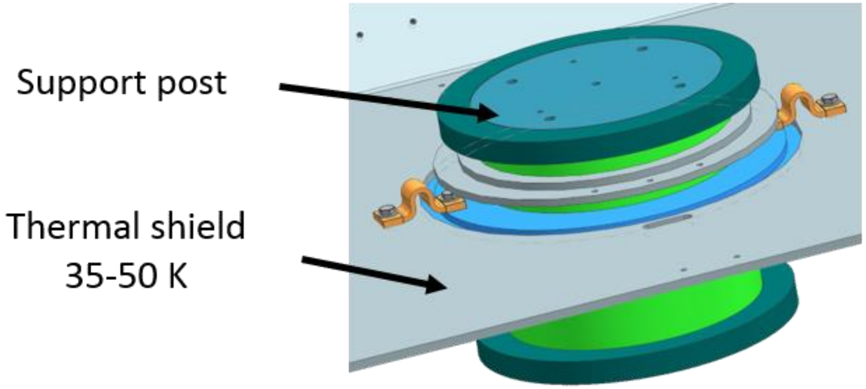
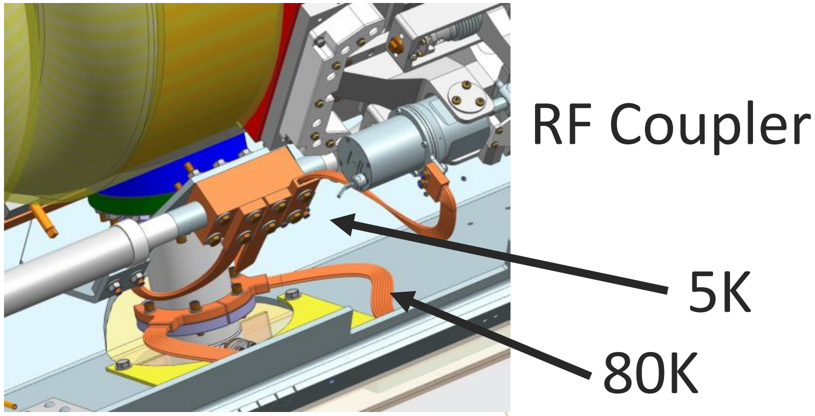
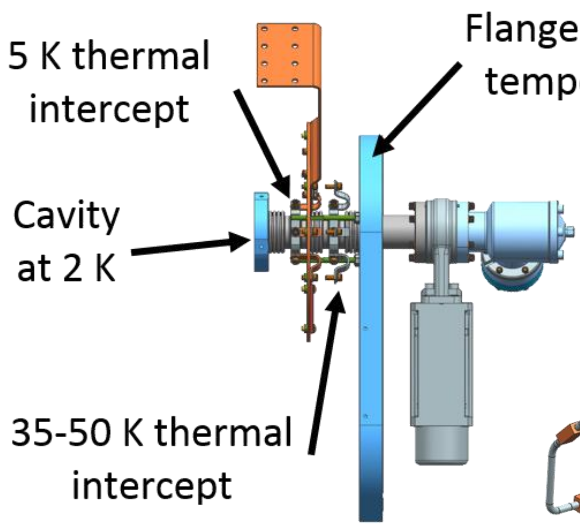
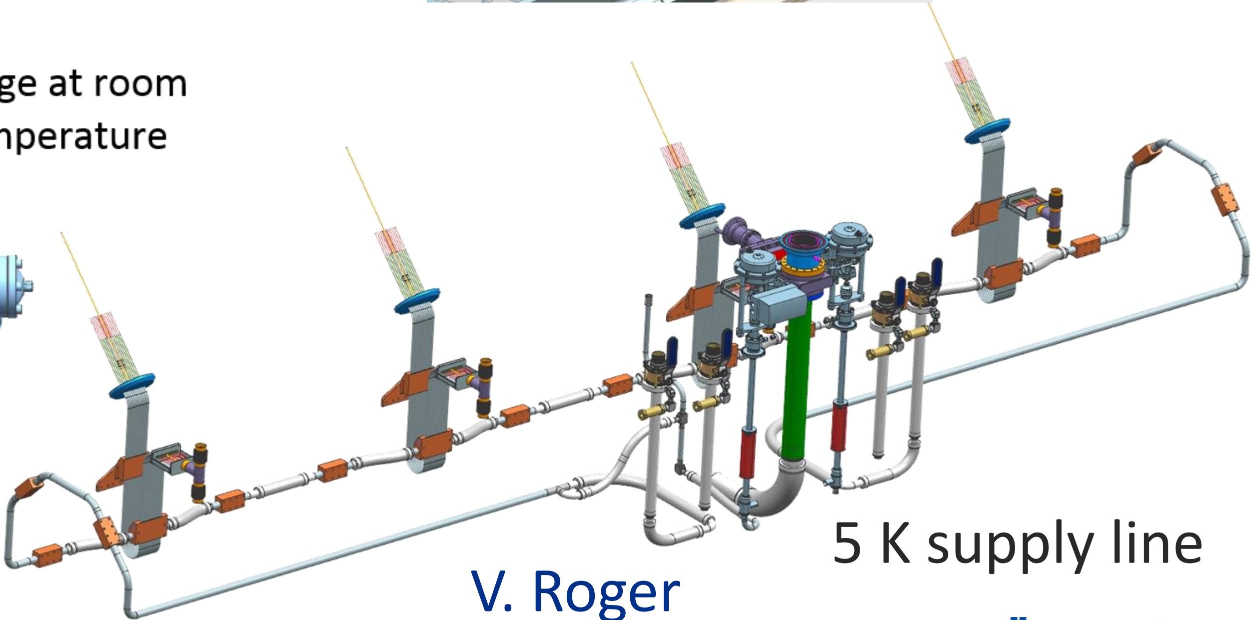
Careful Heat Load Management (SSR1 shown)

- 134 thermal straps in the SSR1 cryomodule.









Other lessons, optimizations implemented

- Minimize cryogenics noise, pressure fluctuation. TAOs not the only possible issue.
  - Unknown cryo system performance if SC LINAC operated in pulsed regime – only 600 W of 2 kW cooling capacity @ 2k req’d.
  - RMS pressure fluctuations should be <0.1 mbar
- Cavities separated from gate valves by bellows
- 2-phase line support brackets designed to reduce vibration
- Nb material specification
  - Can the material spec be improved to prevent flux trapping problems?
  - HT >800C baking not possible with PIP-II cavity designs.
- Incorporate magnetic material hygiene strategies
- Analyze magnetic shielding strategy prior to final design approval
- FE reduction/assembly strategies, esp. for SSR CMs (M. Parise talk)
- Vendor selection and procurement controls, esp. for component with high technical risk.

Challenge 4 -- CM Design and Production through Collaborations and Partnerships

- Establishing Collaboration Agreements
- Interface Control
  - Technical
  - Institutional
- ESH&Q Requirements
  - Delivered, tested, and installed devices must work and abide by FNAL ESH&Q design and testing standards or agreed upon equivalent standards
- Development and Production schedule management
  - Partners' activities and contributions to be incorporated into the Project Schedule, including first-of-a-kind device development and qualification (cavities, RF sources, etc.)
- Contributed device acceptance criteria

Collaborations / Partnerships

India Institutes Fermilab Collaboration

European Collaborations – being formed now

In-kind Contributions

- RF sources
- LLRF controls
- Dressed cavities (325 + 650 MHz)
- RF couplers
- Integrated CMs
- Cryogenics plant
- Instrumentation

HWR CM

Acknowledgements

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  - D. Passarelli
  - Y. Pischalnikov
  - V. Roger
  - V. Yakovlev
  - …many others
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