Update on CW SRF at Jlab

Bob Rimmer, JLab

ICFA FLS workshop

3/4/10

Outline

- Challenges in CW SRF for light sources
- State of the art (?)
- Cost drivers and technical risks
- Choices/optimization
- Structure examples
- Conclusions

Challenges in CW SRF for FLS

- CW SRF requires a lot of cryogenic capacity
- Without energy recovery high average currents require a lot of RF power
  - E.g. 100 mA x 5 GeV = 500 MW!
- High RF power requires robust couplers (e.g. injector)
  - E.g. 20 MV/cavity @100 mA = 2MW!

  (SNS couplers good for ~200 kW, 1 MW windows OK?)
- Modest average gradient requires longer tunnel
- High average current requires strong BBU control
- FLS user operations will require stability, low trip rate
- All these things could cost a lot of money

(Recirculation might help if beam quality can be preserved)

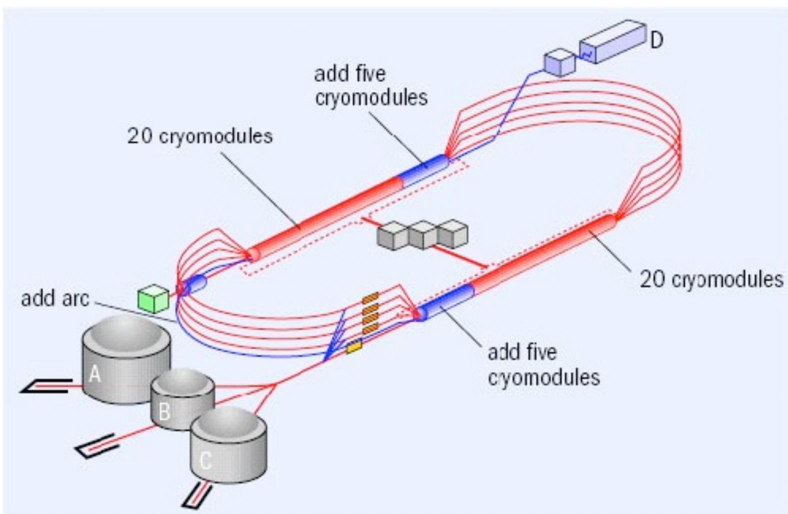
State of the art

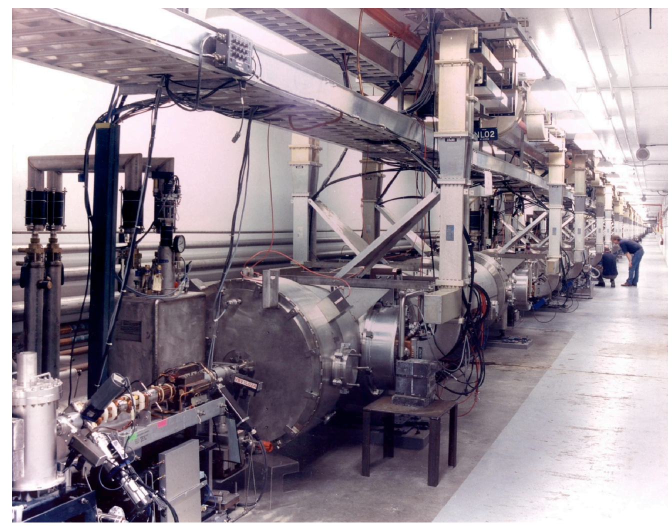
The good news:

- Large CW SRF facilities work (CEBAF, LEP, Dalinac, etc...)
- Many "ERL optimized" cavities are in development
  - ANL BNL, Cornell, JLab, KEK, …
- Cavity performance continues to improve (E_{acc} and Q_o)
- BBU limits and mitigations are well understood/tested
- Large 2K cryogenic plants are getting more efficient
- New CW RF sources continue to be developed
  - IOTs, multi-beam tubes, magnetrons(!)
- Science case for new machines is very strong

CEBAF

- CEBAF is a 5-pass 6 GeV* CW recirculated linac based on SRF.
- Three experimental halls for nuclear physics research
- Nuclear structure, Gluonic excitation etc…
- $42^{1}/_{4}$ original cryomodules assembled in-house.
- (Then) world's largest 2K Cryo plant.
- Worlds Largest operating installed base of SRF.

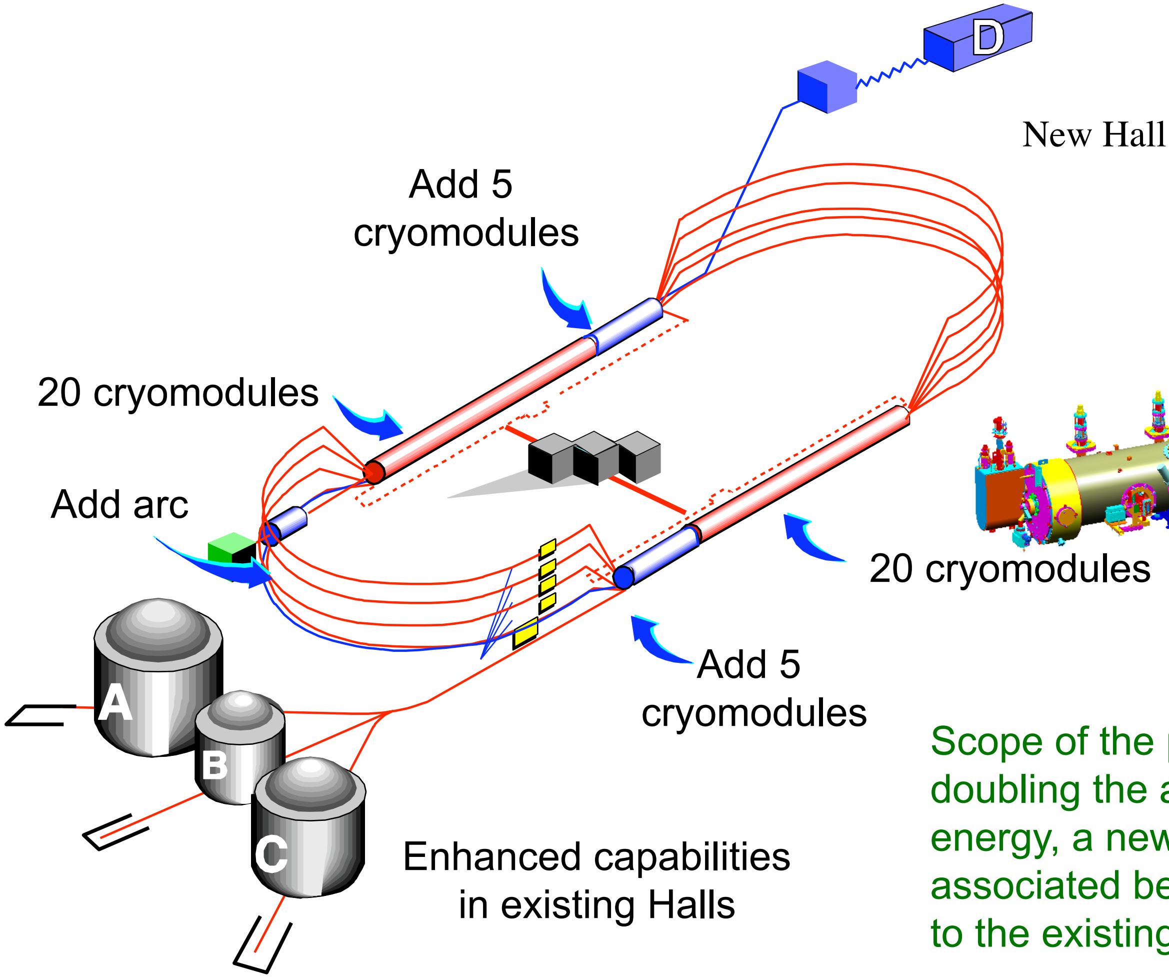


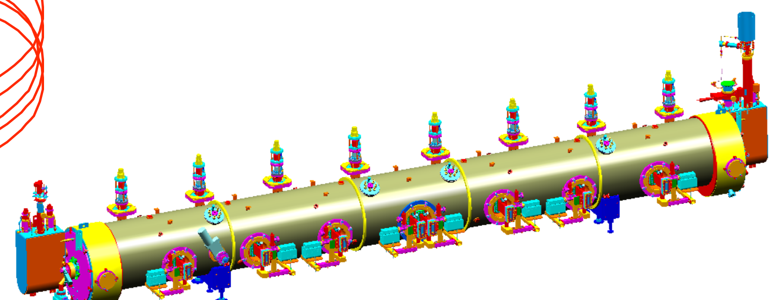


* originally 4 GeV design specification, soon to be upgraded to 12 GeV

SCOPE OF 12 GeV UPGRADE

Upgrade is designed to build on existing facility:
vast majority of accelerator and experimental equipment have continued use



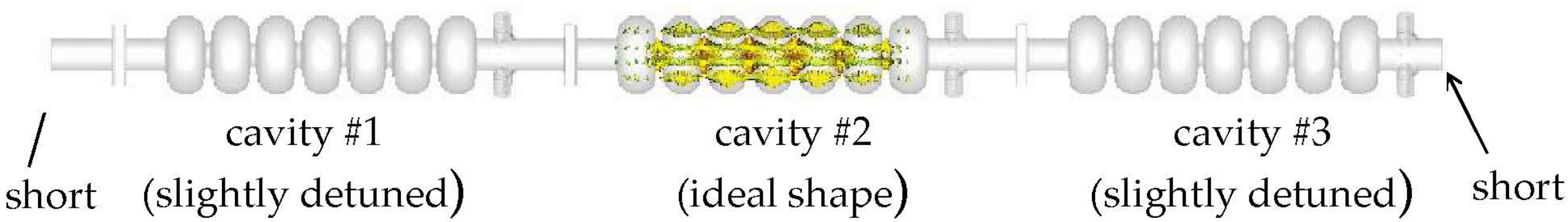


Scope of the proposed project includes doubling the accelerator beam energy, a new experimental Hall and associated beamline, and upgrades to the existing three experimental Halls.

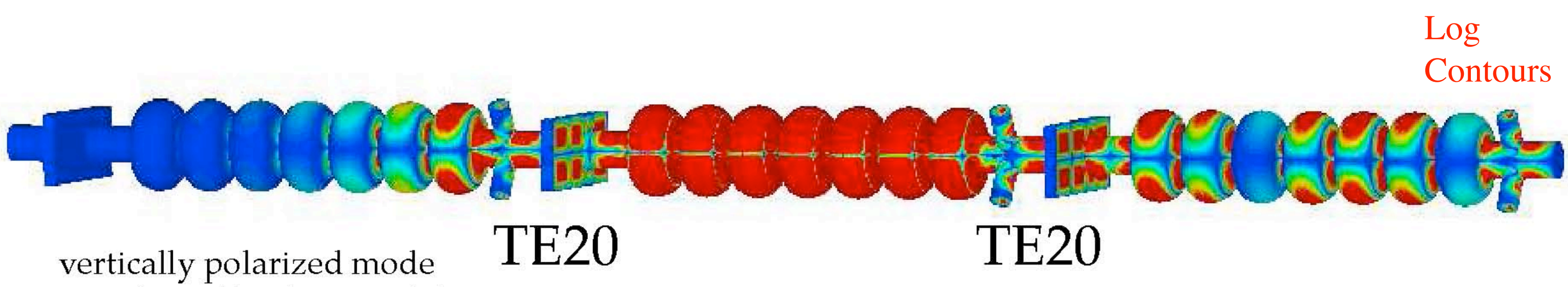
Simulation of real module conditions

CST Microwave Studio Eigenmode Solver Simulations (MWS)
- Trying to resemble real World -

- Simulation of cavity string



- how far and strong the field propagates in neighboring cavities may depend on detuning
- cavities share 2 HOM couplers and 2 FPCs (except for cavity at end of cryomodule)



vertically polarized mode
up to $|E_{max}|/10$ (Log. scale)

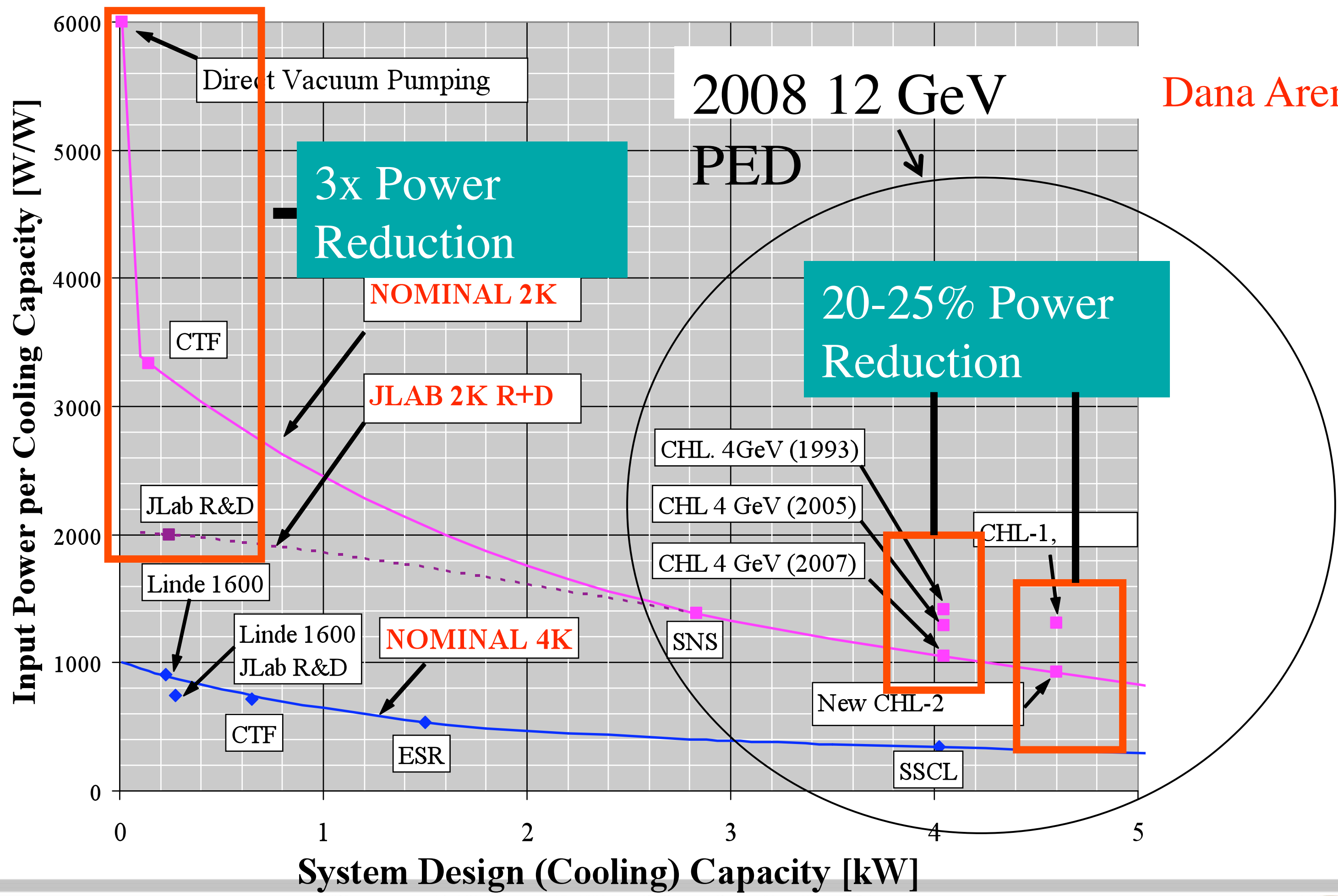
Some typical CW parameters (JLab upgrade)

- Frequency 1.5 GHz (could be lower?)
- 15-20 MV/m CW (~10 MV/m real estate gradient)
- $Q_o \sim 10^{10}$ at 20 MV/m (has been demonstrated)
- CM Cost ~$2.6M*/100 MeV (Jlab upgrade module)
- RF ~$1.7M/cryomodule (8x13kW RF stations) @~1mA
- 2K cryogenic plant ~$30M/GeV (4.5 kW CHL2) excluding distribution
- ~7.3 cents/volt or $73M/GeV (excluding tunnel costs)
- ~$73/watt electron beam power (1ma @ 1GeV =1MW)

*FY08 loaded dollars, actual 12 GeV project costs will be known soon

2K and 4K JLab Technology Development Areas

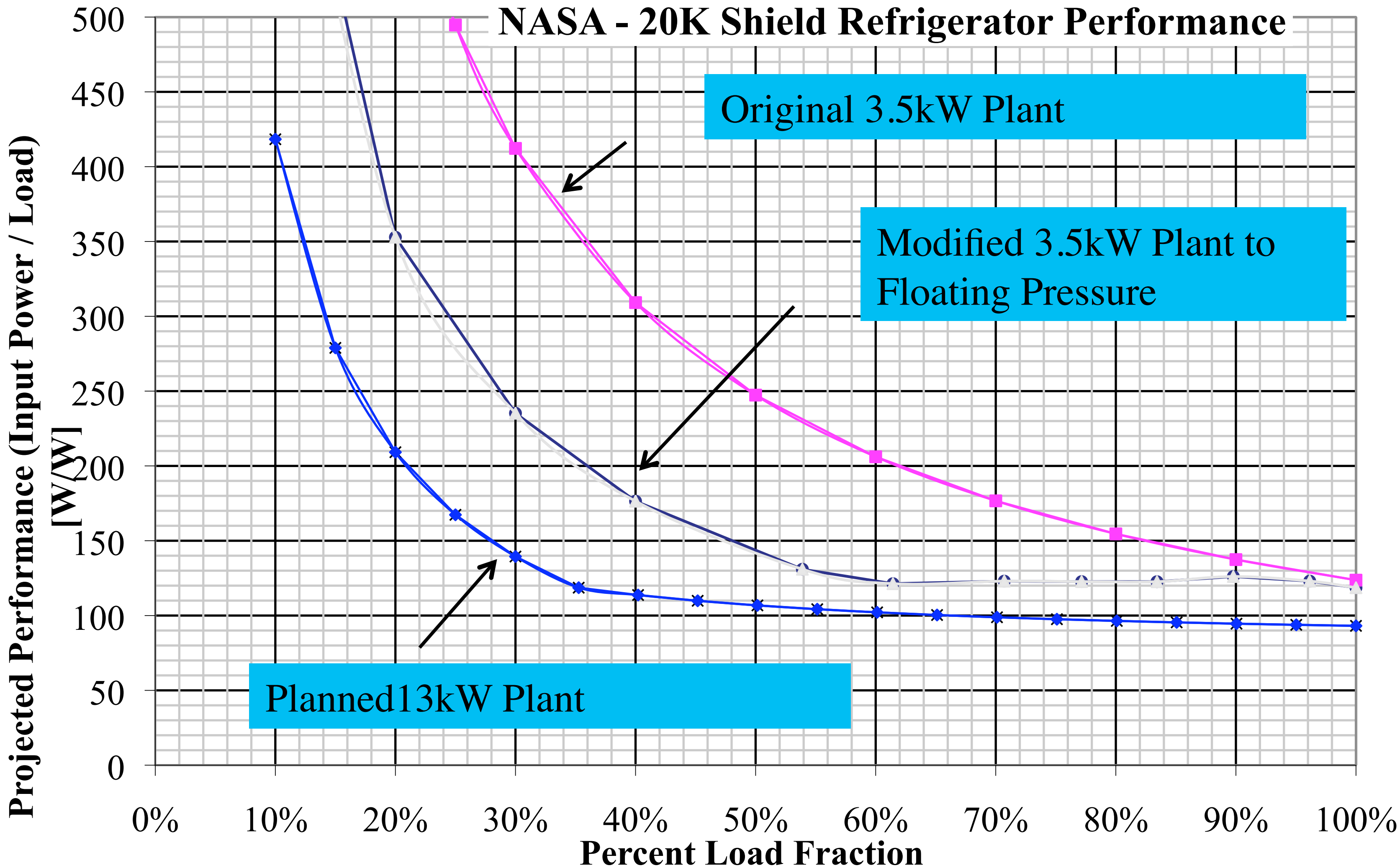
- Large machines are getting more efficient
- Difference between 2K and 4K does not make up for BCS losses



Dana Arenius

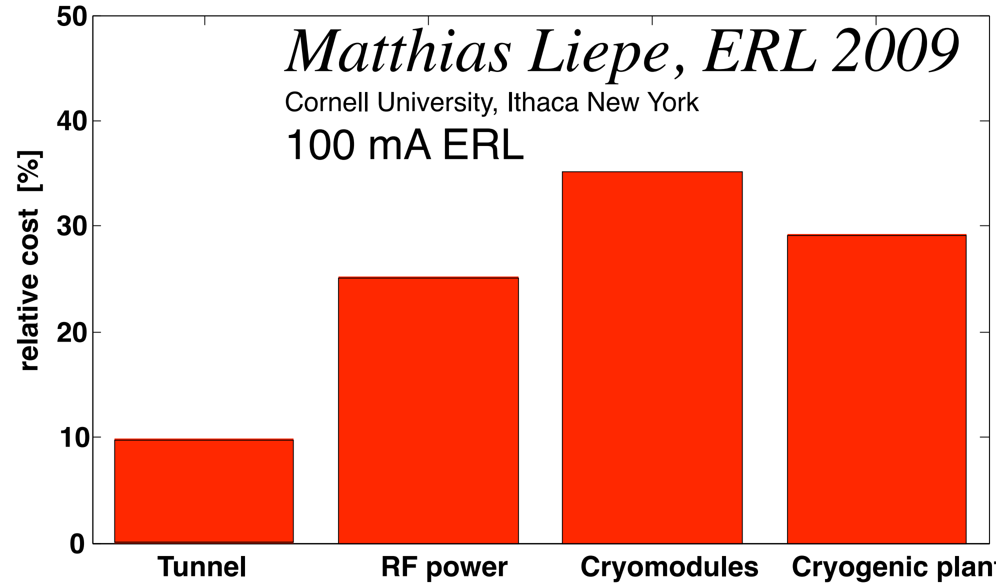
NASA-JSC 2008 Plant Test Results

Ganni cycle allows good efficiency at high turn-down ratio



Cost drivers & technical risk

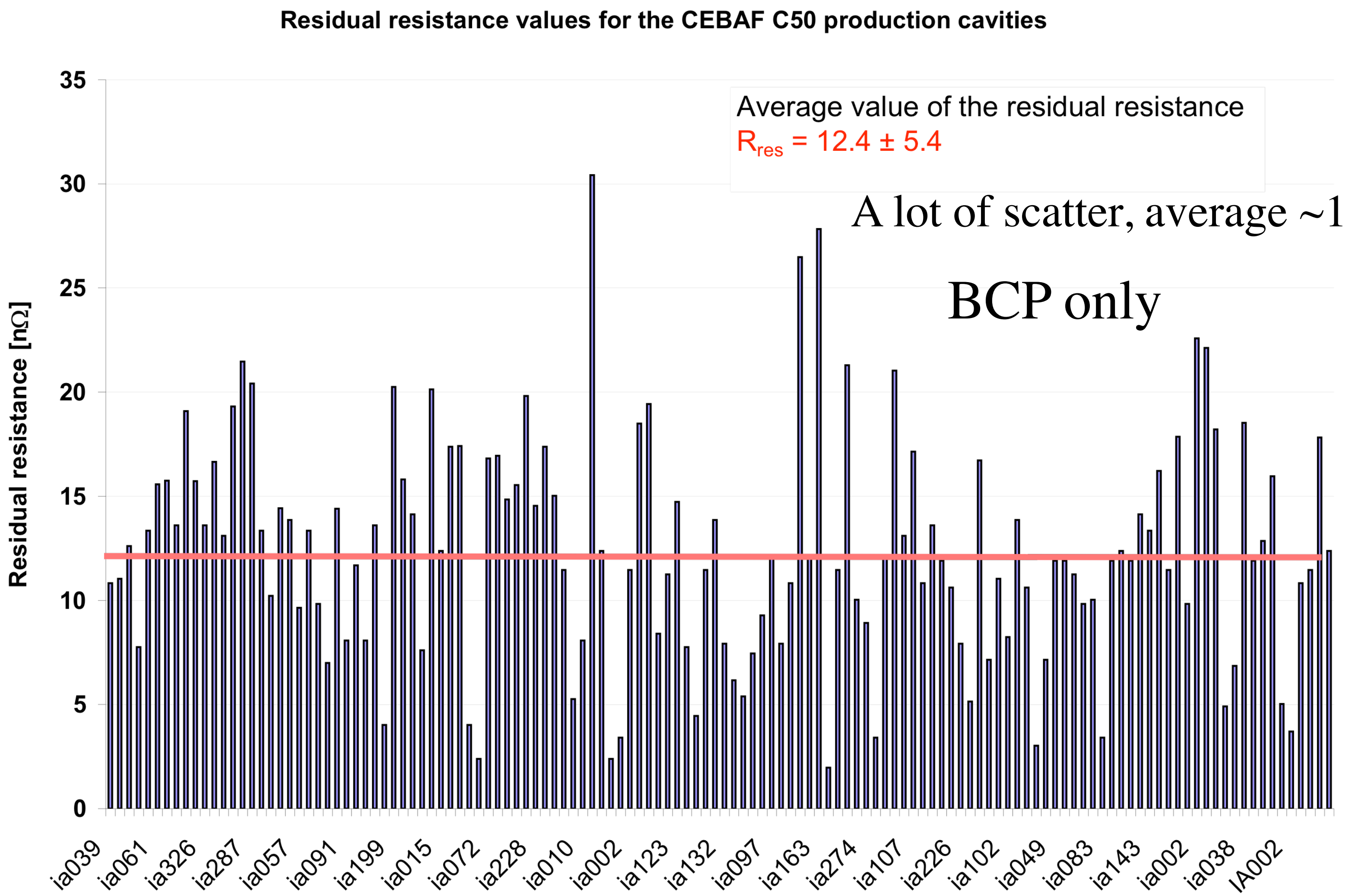
- Linac cost drivers:
  - Cryomodules
  - RF
  - Cryogenics
  - tunnel
- Technical risks
  - Field emission
  - BBU
  - ???



Choices (optimization)

- Current ≤ 100mA?
- Optimum Frequency (depends on R_s & beam physics)
- Operating temperature, depends on R_s
- Gradient depends on Q_o (R_s)
- Number of cells per cavity (5-9?)
- Complex optimization, sensitive to assumptions
  - E.g. M. Liepe ERL 2009, Cornell ERL
  - NLS project outline design report 7/09) (P. Macintosh)

Jlab data: CEBAF 5-cells 1.5 GHz *G. Ciovati*



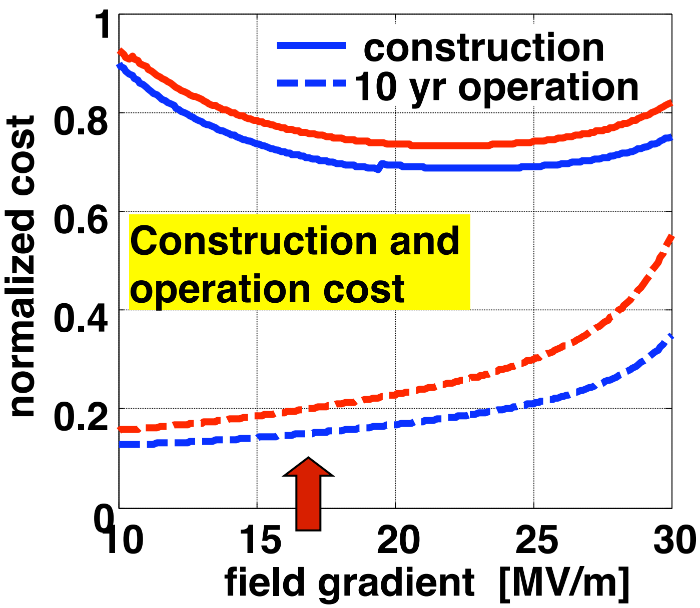
A lot of scatter, average ~12 nΩ

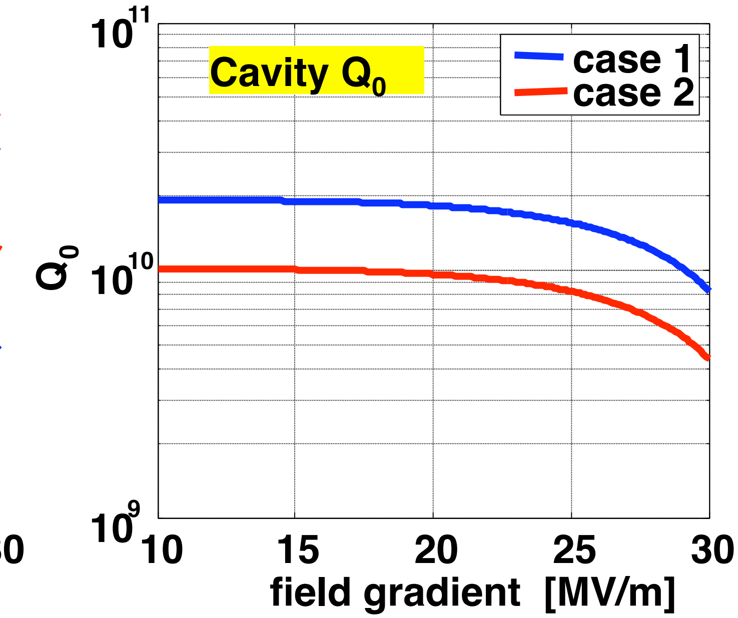
BCP only

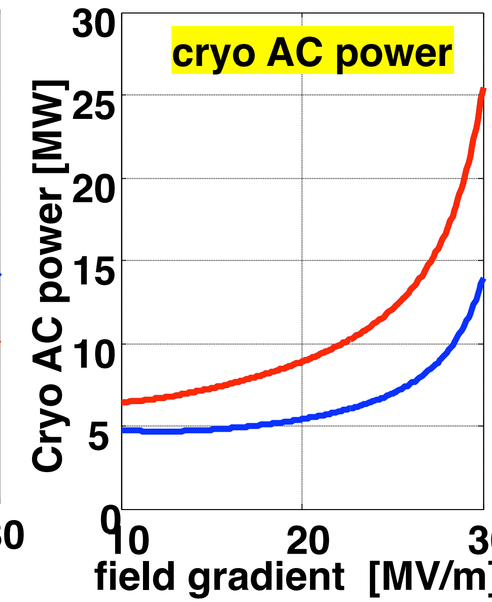
Residual resistance not constant with frequency?

Optimal Field Gradient

Matthias Liepe, ERL 2009
Cornell University, Ithaca New York





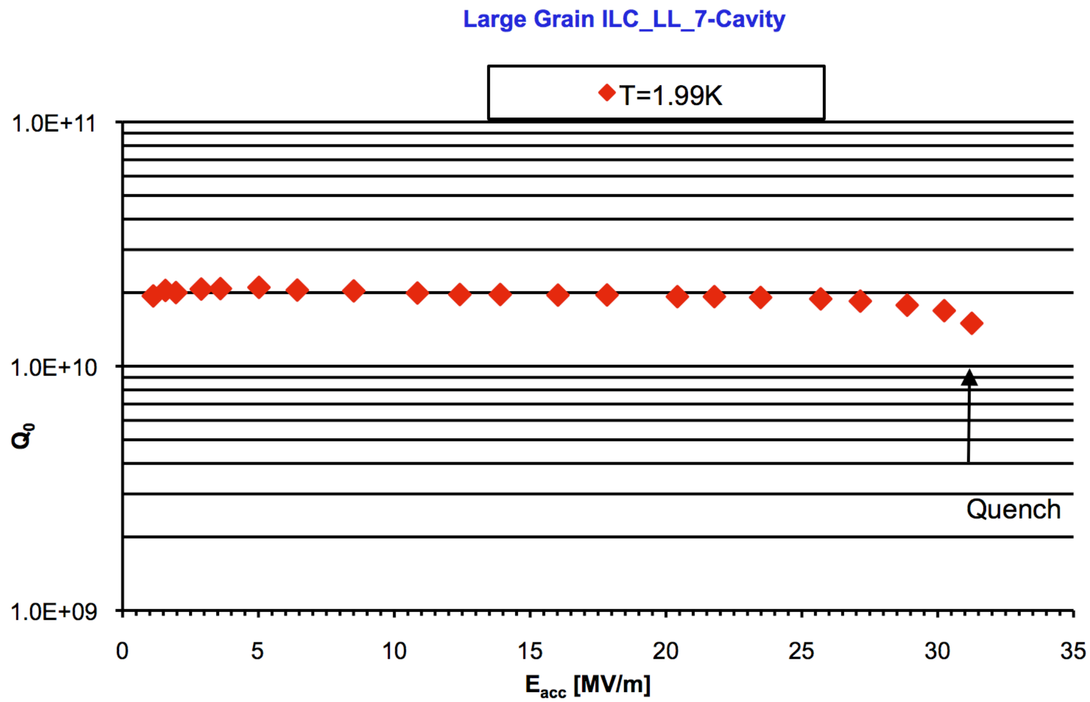


- Q_0-value has significant impact on cost (high impact and risk parameter)
- Construction cost changes only moderately for gradients between ~16 and ~27 MV/m
- Operating cost / AC power increases with gradient
- Select gradient at lower end: *16.2 MV/m*

⇒ Less risk for same cost!

Encouraging results

- Further evaluation of 1.3 GHz R&D 7-cell cavity performance
  - JLab large grain low-loss cavity with just BCP and 120°C bake

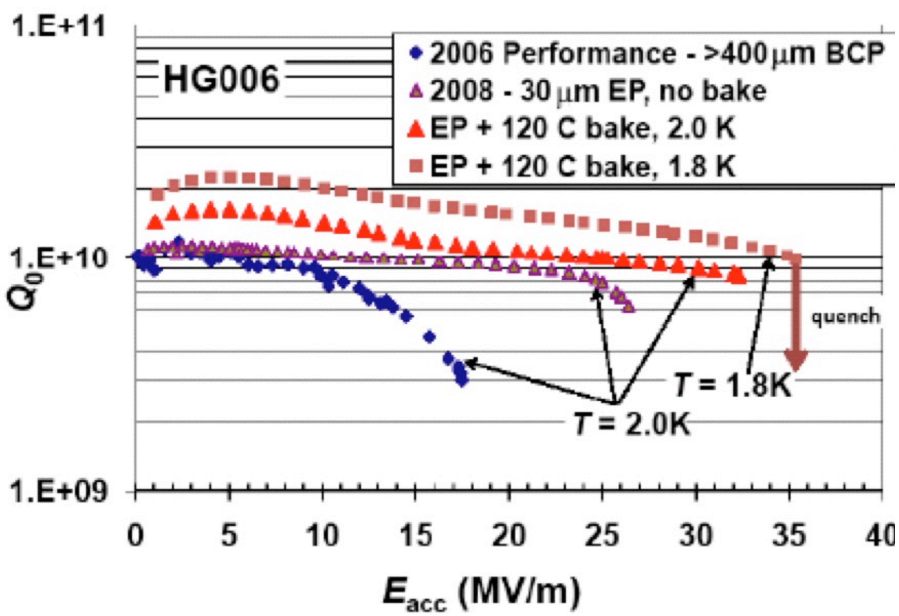


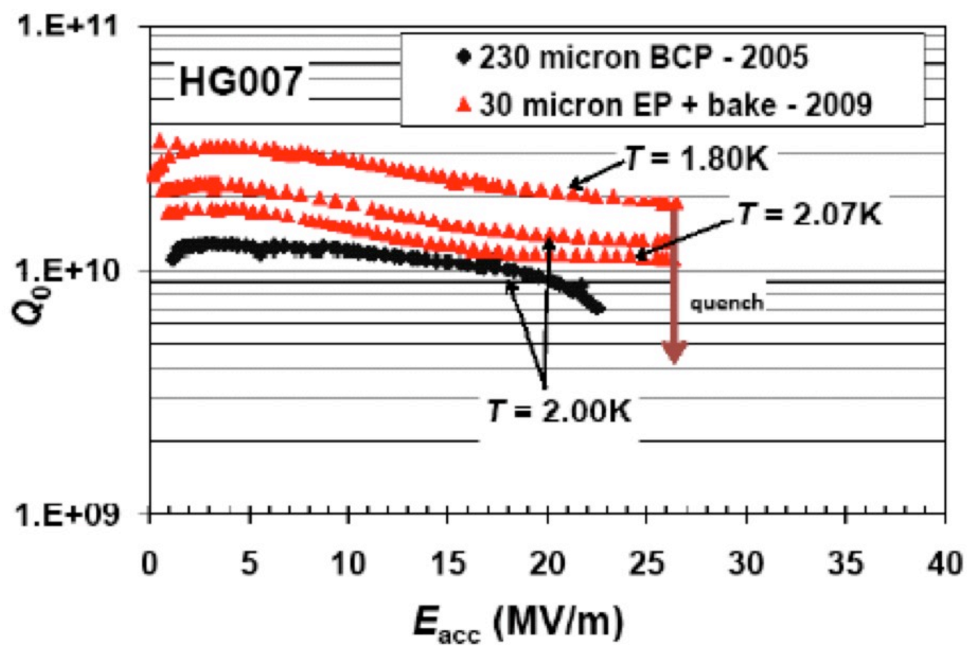
P. Kneisel

EP after BCP on 1.5 GHz cavities

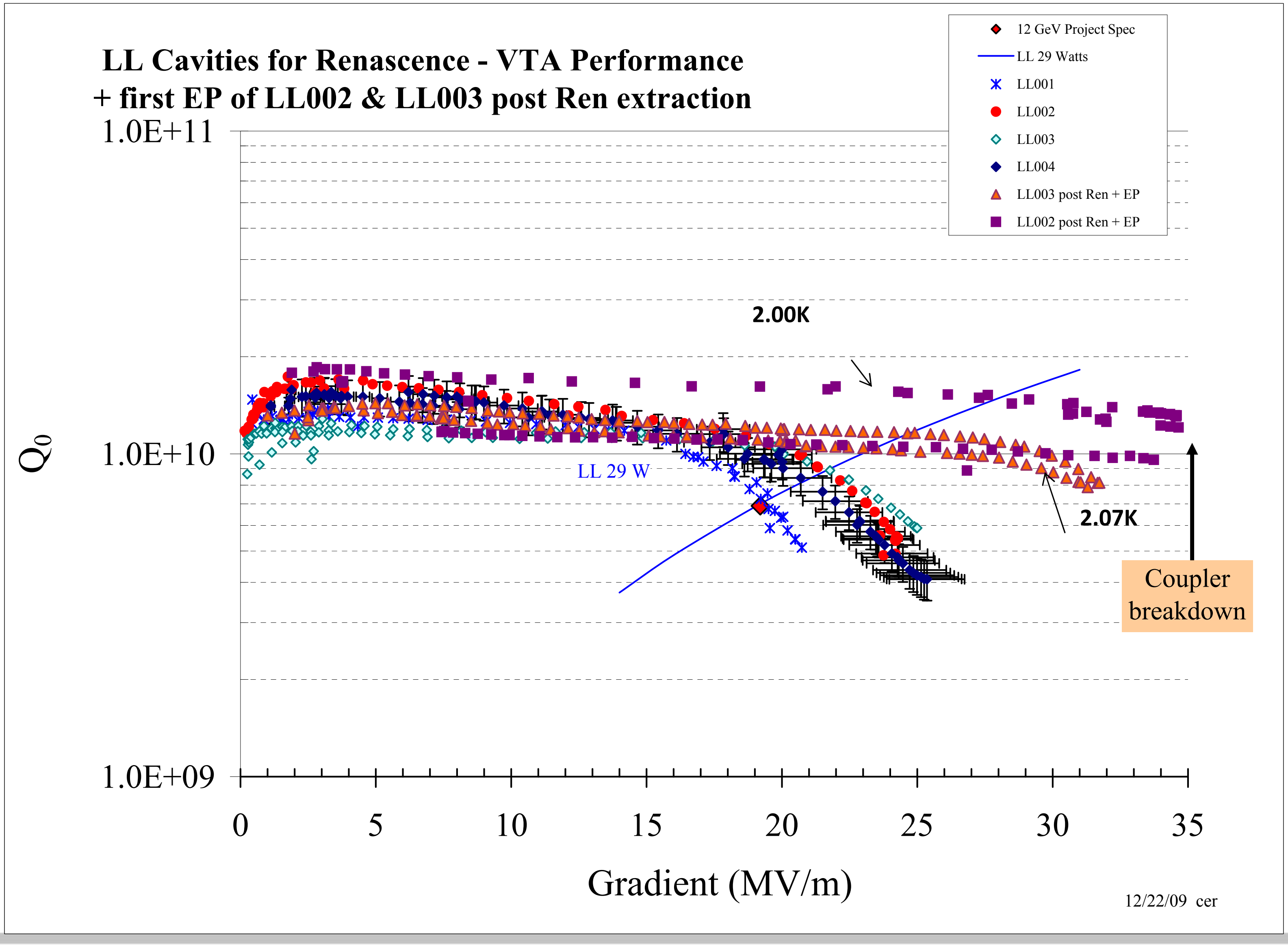
- EP tests on existing 7-cell cavities with prior BCP
- Dramatic improvement with final light EP
  - High field Q slope removed (after 120°C baking)
  - Lower residual resistance

(suggests BCP Q-slope is due to small scale surface roughness)



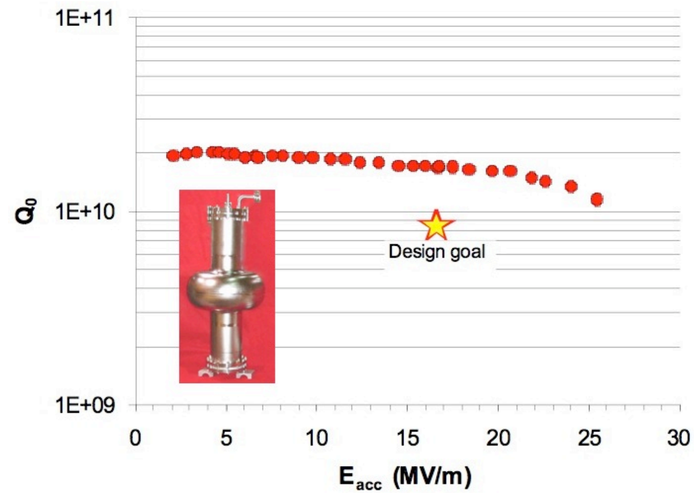


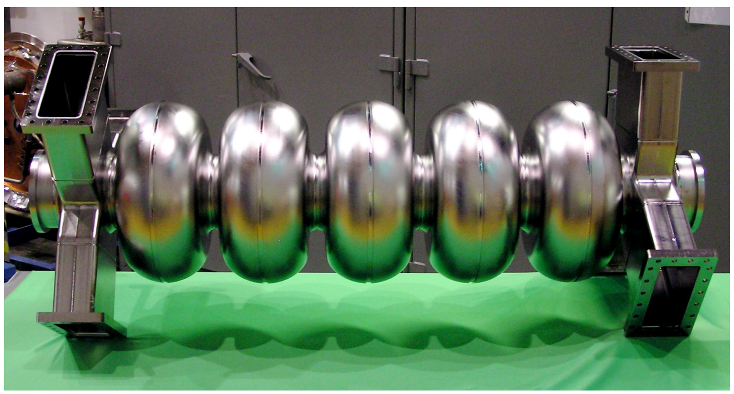
EP after BCP on Jlab LL 7-cells

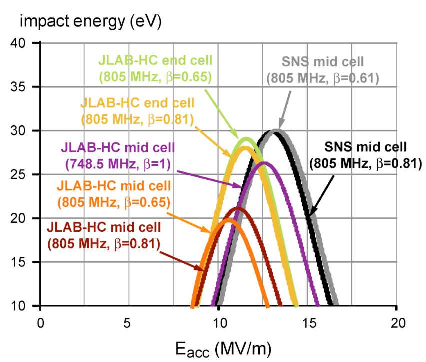


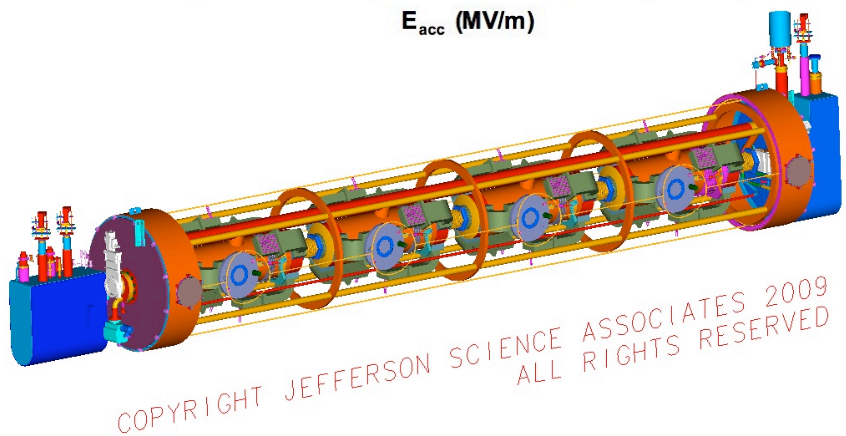
E.g. JLab high-current cavity

- Development of electron cavity for ≥100 mA.
- Very large apertures (halo!) Very high BBU threshold.
- Use TV band RF sources.
- Lost funding in 2006.



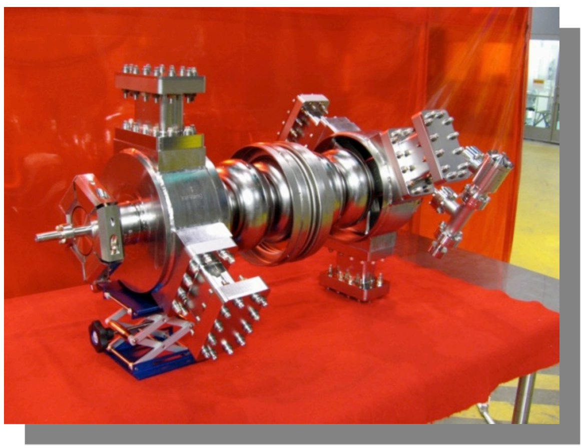


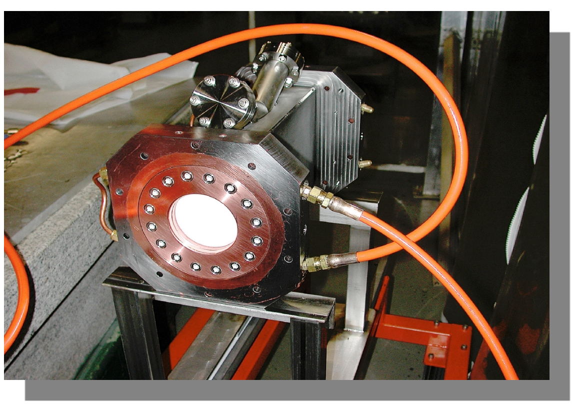


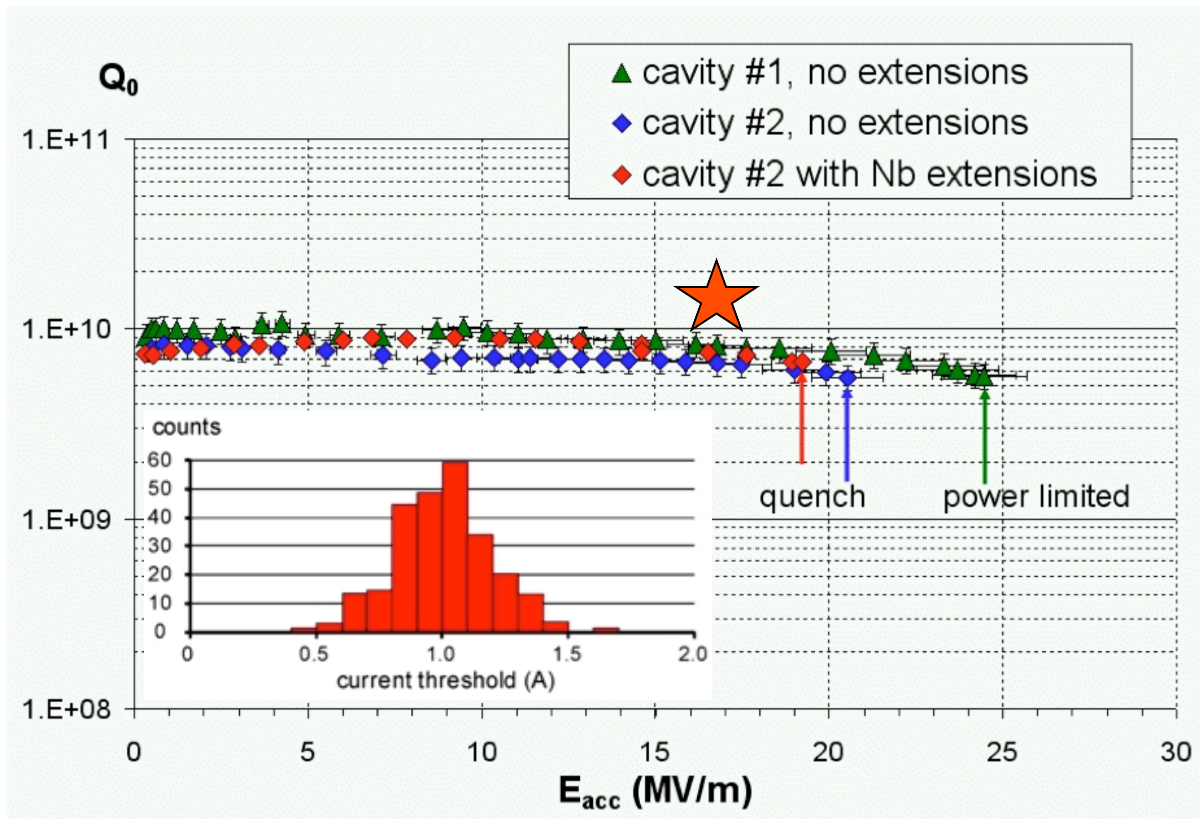


JLab high-current cryomodules

- Two full 1.5 GHz prototypes of FEL high current cavity built and tested
  - Results exceed requirements for 4th gen. light source
  - Aiming to build demo cryounit for beam test in FEL.



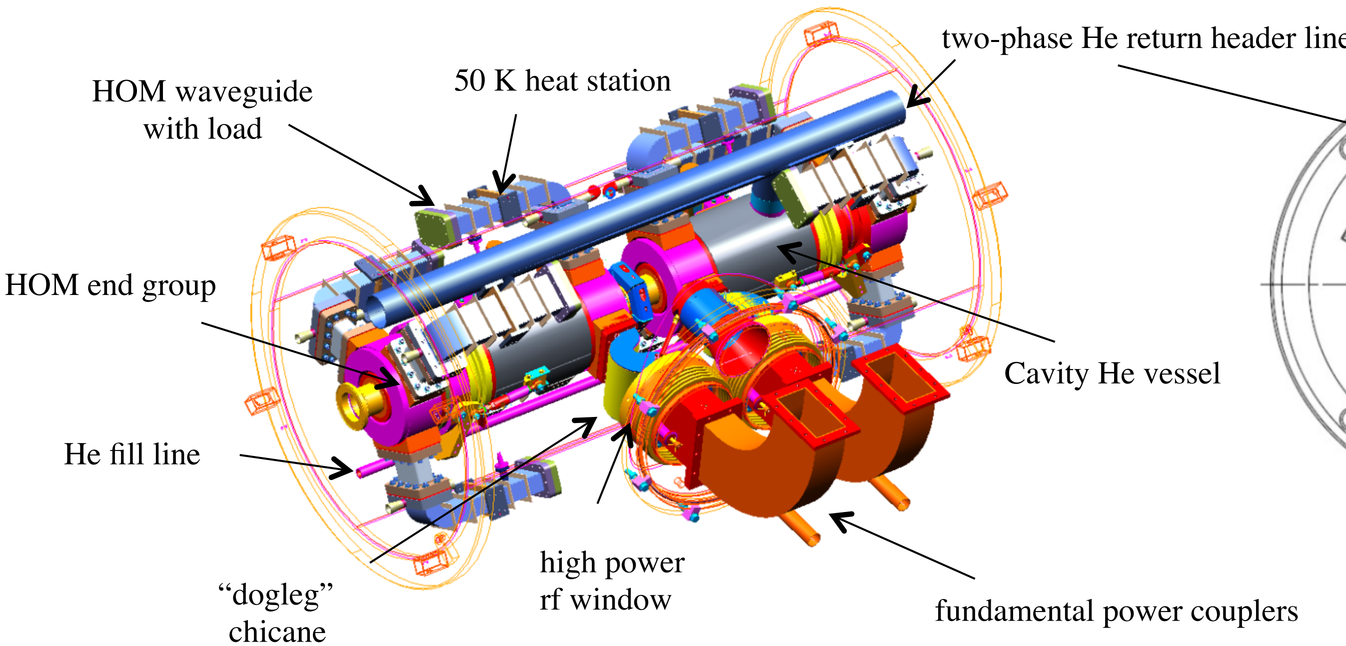


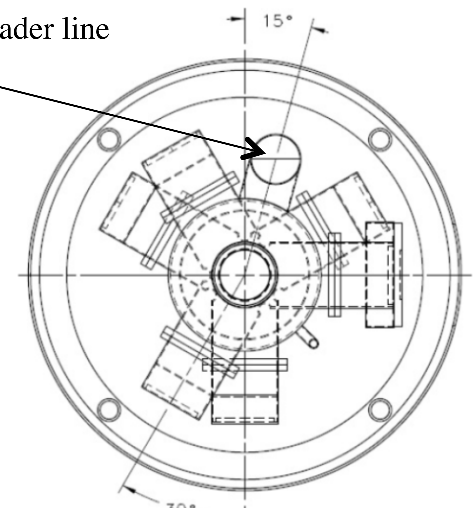


Example: JLAB HC Cryomodule Development

HC optimized cell shape, 5 cells, WG FPC, WG HOMs

Aiming for beam test in JLab FEL in 2010



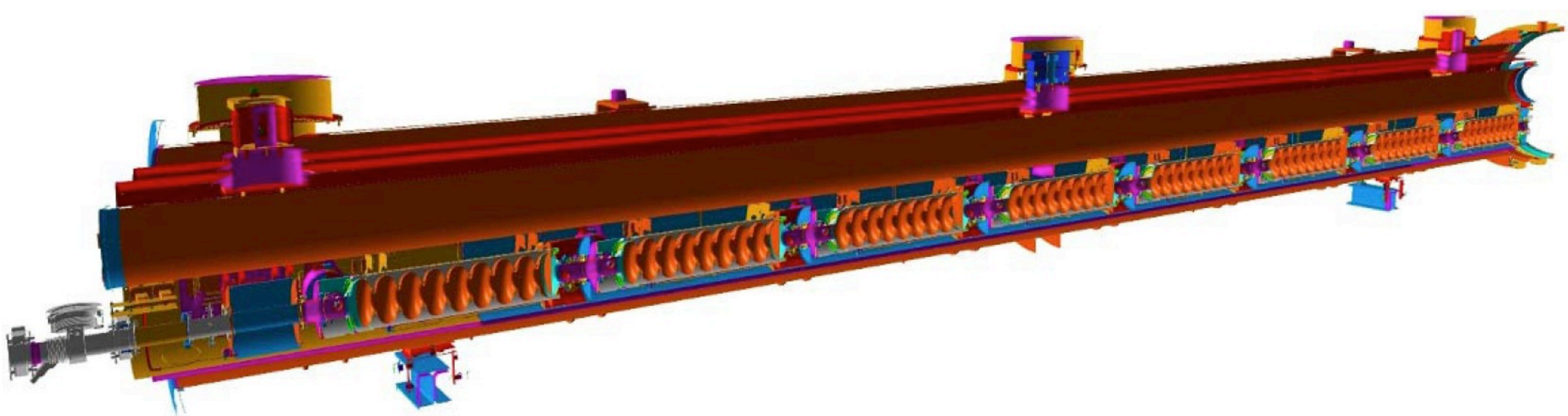


Conceptual design of a cavity-pair injector cryomodule (L=2.6m)

F. Marhauser ERL09

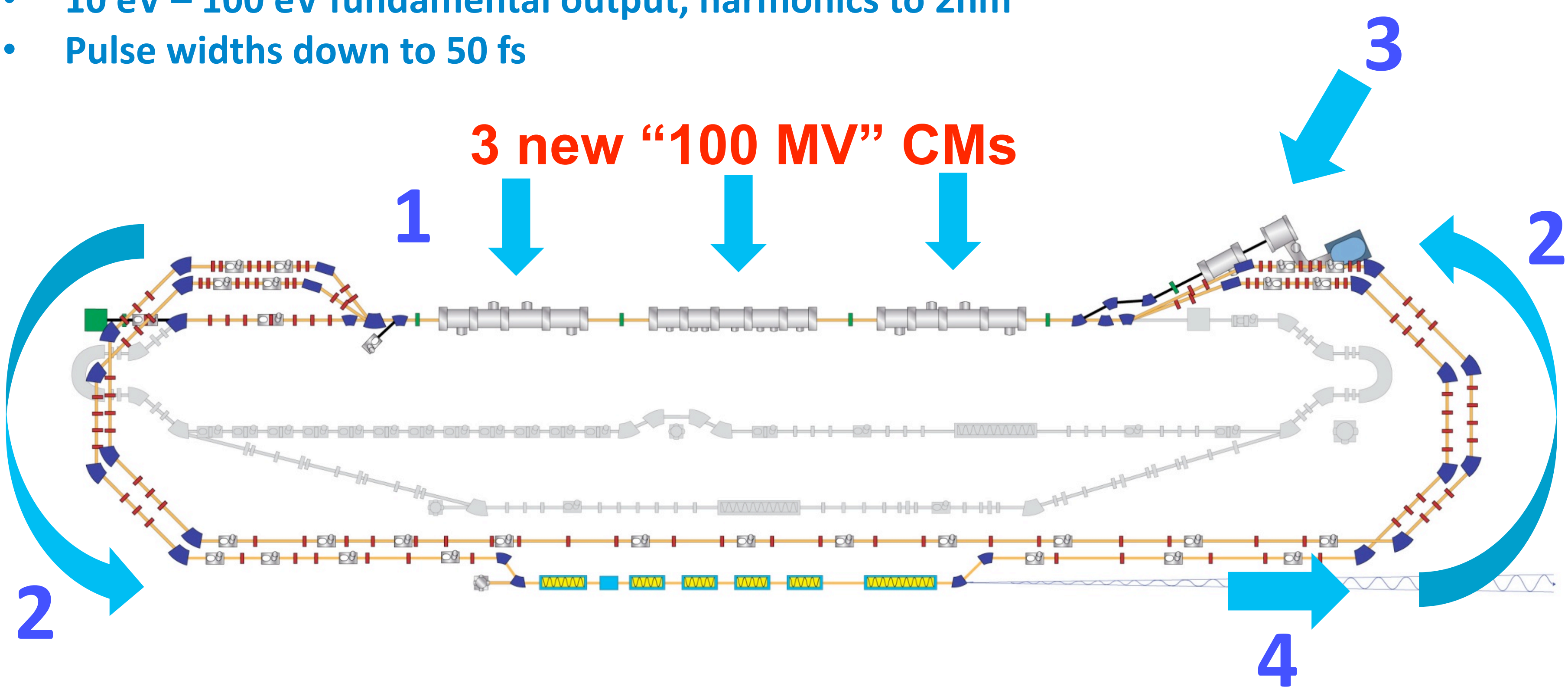
Example: XFEL module converted to CW

- Larger cryogenic piping (chimney, 2-phase line)
  - Gas return pipe OK (sized for ILC!)
- Higher-power FPC (e.g. Cornell, Daresbury)
- Modified HOM probes (temp. stabilized)
- Different cavities needed for high current/ERL



JLab Conversion to JLAMP

- 4 steps
- 600 MeV, 2 pass acceleration
- 200 pC, 1 mm mrad injector
- Up to 4.68 MHz CW repetition rate
- Recirculation and energy recovery
- 10 eV – 100 eV fundamental output, harmonics to 2nm
- Pulse widths down to 50 fs



SRF GUN collaborations

DESY/Jlab/BNL

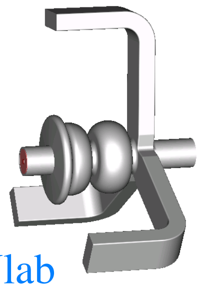
- Two types of approaches: Lead directly deposited on Nb, Cavity with lead plated “plug”.

CRADA with FZD

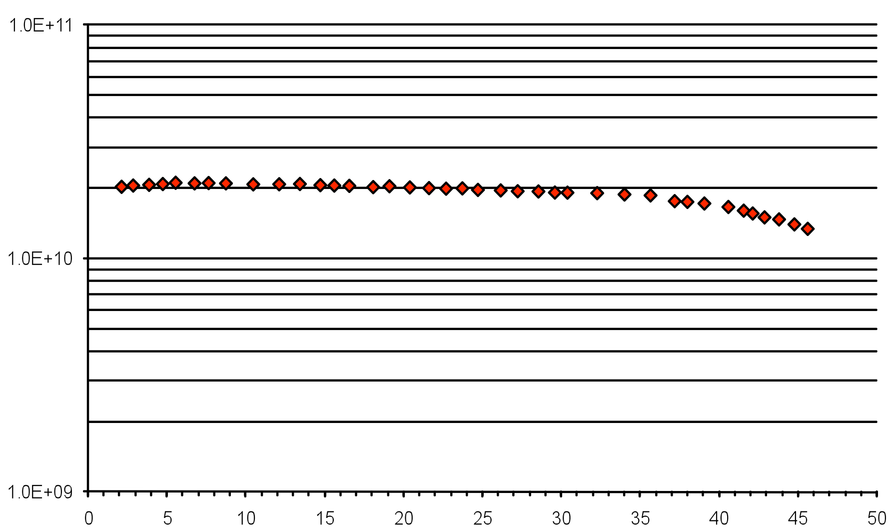
- Fabricate and test two 3.5 cell photo injector cavities to FZD design (large grain and fine grain). Fabrication has started ~ March 1, 2009.

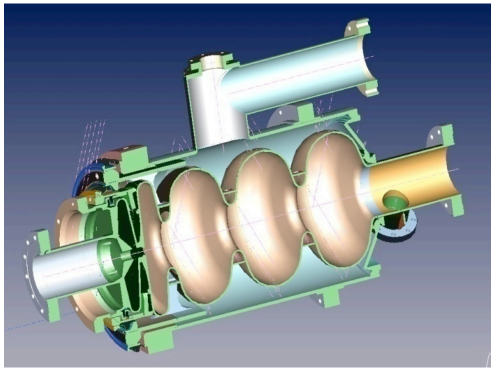
Other labs

Tested gun cavity for PKU, 1.5 cell for BESSY, others for future light source.

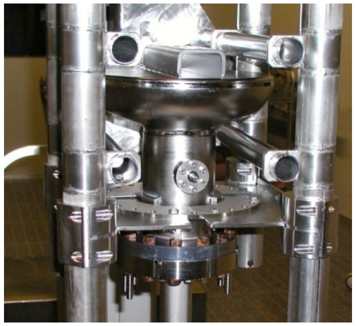


Jlab





FZD



DESY

Result from 1.6 cell cavity

Improved charge and QE measurements planned for the future

Conclusions

- CW SRF established technology for user facilities
- Jlab 12 GeV upgrade ramping up (10 CM's in 2 years)
- Cavity performance encouraging with EP or large grain
  - Q_o critical cost driver for CW
- BBU control critical but well understood
- Jlab high current cavity development has regained a pulse
- Aiming for beam test of prototype1.5 GHz cavities in FEL
- Jlamp ERL/FEL will test many physics and technology issues
- SRF guns look promising, need test beds for cathode development