Modification of the CESR-B cavity for low Q-ext

CWRF 2010

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U.S. DEPARTMENT OF ENERGY

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Acknowledgements

- This work was performed by B. Gash, Y. V. Ravindranath, J. Rose and M. Yeddulla as well as the support of the entire NSLS-II team.

- We would also like to thank the SCRF groups at Cornell, KEK, CLS and TPS for their continuing help and encouragement, in particular H. Padamsee, S. Belomestnykh, V. Shemelin, T. Furuya, M. de Jong and C. Wang

Outline

- Introduction
- An aside about the ASME code compliance
- Coupler Requirements
- KEK cavity geometry and coupling
- CESR-B type cavity:
    - Modification of coupling aperture geometry
    - Modification of waveguide with conical post
    - $\lambda/4$ Tapering of waveguide into simple slot

- Summary

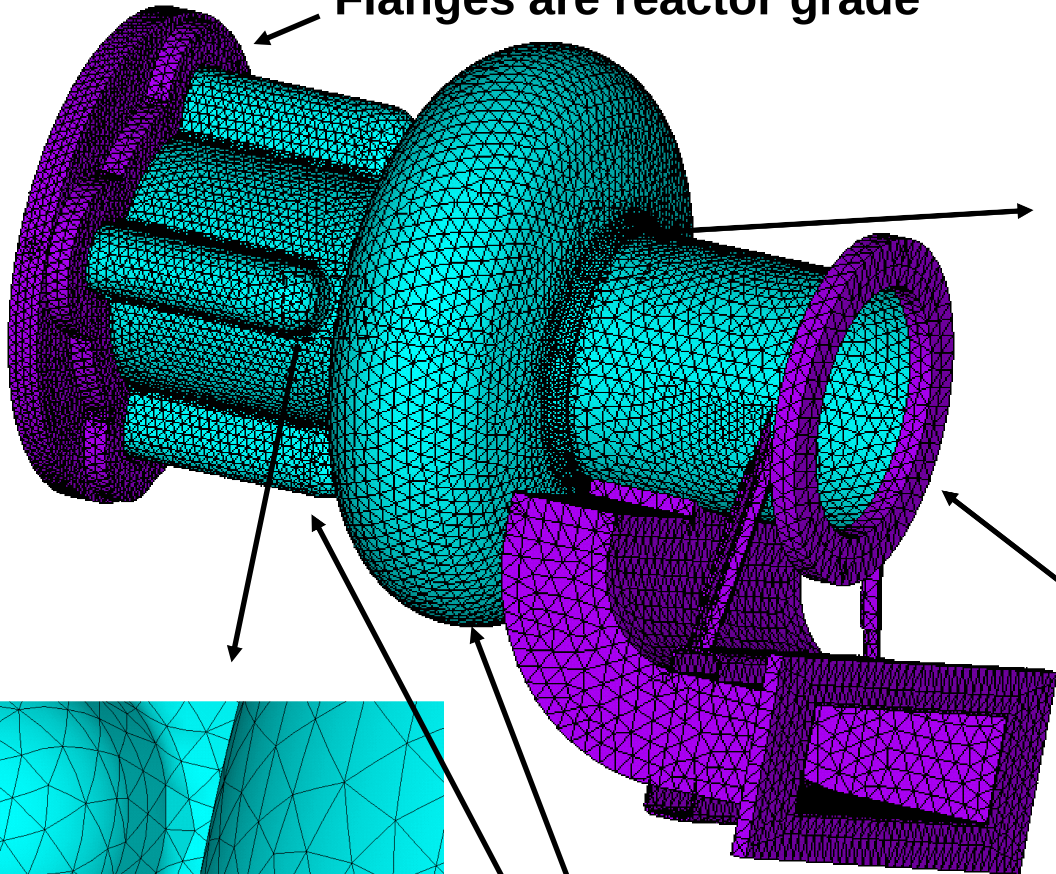
ASME Equivalence by design

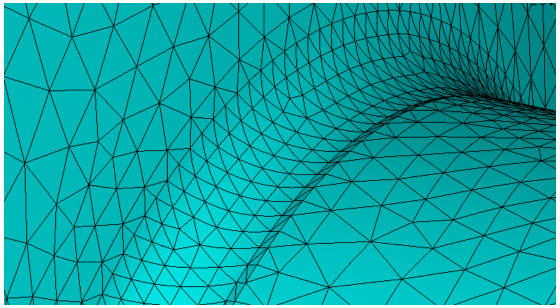
- DOE laboratories must now certify SRF cavities to Boiler code
- Equivalence By Analysis ASME2007 Section VIII, Division 2
  - Applicable Failure Modes 5.1.1.2
    - Protection Against Plastic collapse 5.2
      - Finite Element Model
        - Limit Load Analysis 5.2.3
    - Protection Against Local failure 5.3
      - Finite element model
        - Elastic-Plastic Analysis 5.3.3.1
    - Protection against collapse From Buckling 5.4
      - Bifurcation – Eigenvalue Buckling 5.4.1.2
    - Protection Against Failure From Cyclic Loading 5.5
      - Experience with comparable equipment operating under similar conditions 5.5.2
      - Ratcheting Assessment – Elastic-Plastic Stress Analysis 5.5.7

Navigating the ASME code and applying to equivalence by design was a significant part of the effort- relatively easy to apply to KEK, Harmonic cavities

ANSYS Analysis Model

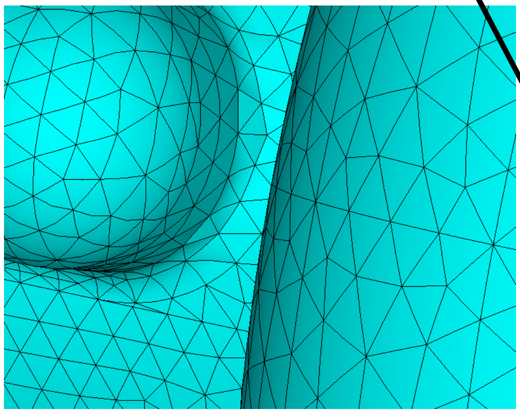
Flanges are reactor grade





Higher order element
Stiff 92 (187) – tetrahedral
with midside node

Flanges, waveguide
are reactor grade

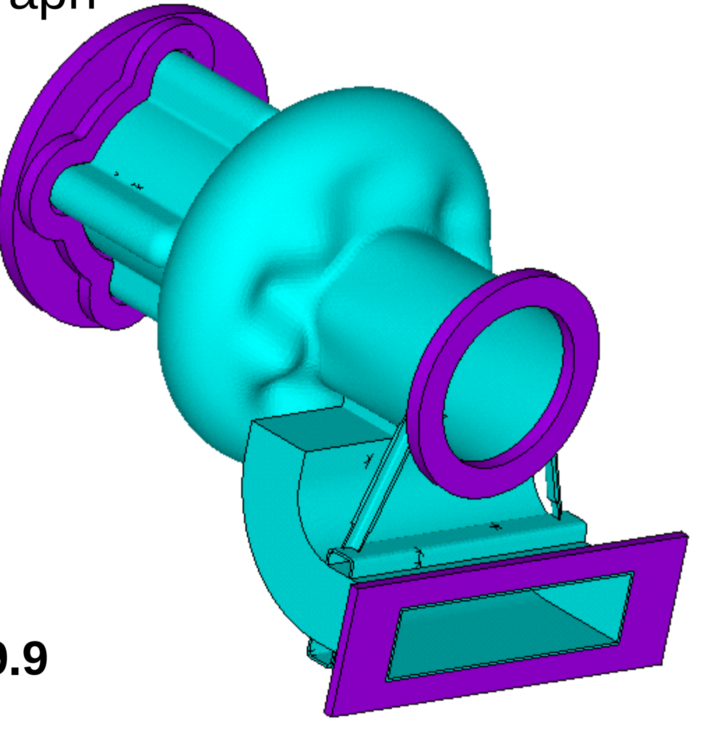


Central cell, cavity, beam
pipe, and fluted beam
pipe are RRR grade

Protection Against Collapse from Buckling

Example of compliance analysis to first paragraph

- Use Bifurcation method to check for buckling Section 5.4
  - Design Factor = 2.0/bcr
  - For Pre-Stress in the component
    - P = MAWP = 1.49 Bar
    - D = gravity load
    - Bcr = .124 for spherical or elliptical head with external pressure
  - Design Factor = 16.13



First Buckling Mode Load is 19.9

3mm Cavity Cell Thickness Passes ASME code

There is a significant effort and cost required to approve even an existing, proven design. Efforts continue with 100% material, braze and weld tests

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Optimize coupling from machine commissioning through full build-out

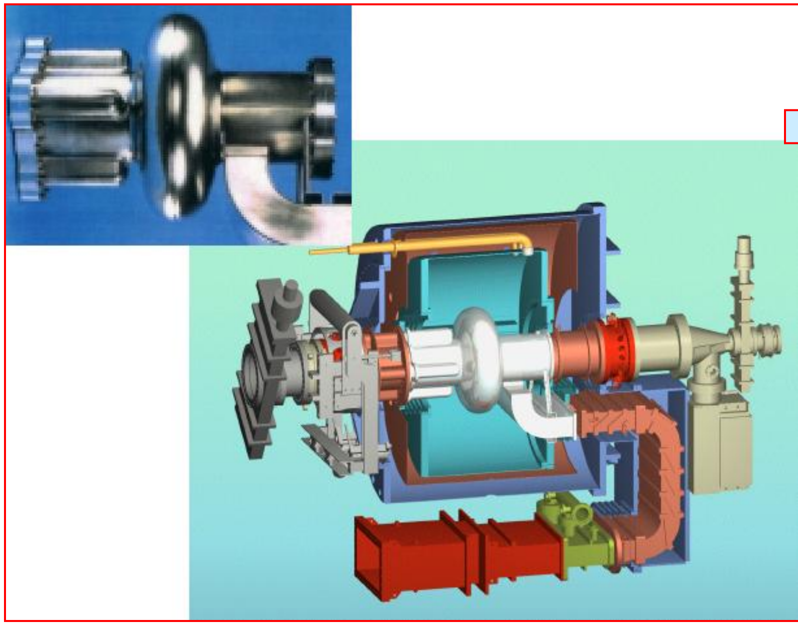
3-GeV machine RF parameters with CESR cavities and Qext = 65000						
Machine version			Baseline	2 Cavities	3 Cavities	4 Cavities
Beam current	Iav	mA	300	500	500	500
Energy loss / turn from dipoles		MeV	0.288	0.288	0.288	0.288
Energy loss / turn from IDs		MeV	0.528	0.65	1.218	1.712
Accelerating voltage		MV	2.40	3.40	4.20	4.85
Momentum acceptance		%	2.34	2.99	3.03	3.04
Number of cavities			1	2	3	4
Per cavity parameters						
Cavity voltage	V	MV	2.400	1.700	1.400	1.213
Cavity power	Pcav	W		32.1	21.8	16.3
Forward power	Pf	kW	384.8	272.0	260.3	254.6
Reverse power	Pr	kW	138.3	32.9	4.7	0.0

Q_{ext} ~ 65000 is optimal for full build-out, meets baseline, interim conditions

Options and work-in-progress

- KEK type cavity
- Design studies to modify CESR –B coupler for Q-ext = 65000
- New antennae coupled cavity design
  - Phase 2 SBIR has been awarded to design and produce 500kW antennae coupler- two will be produced for testing
  - Phase 2 award for design of antennae coupled ASME compliant second generation HOM damped SRF cavity- niobium cavity may be built under the phase 2-in negotiation
  - These are with the same company and may influence upgrade plans

CESR-B and KEK-B Cavity Input Couplers

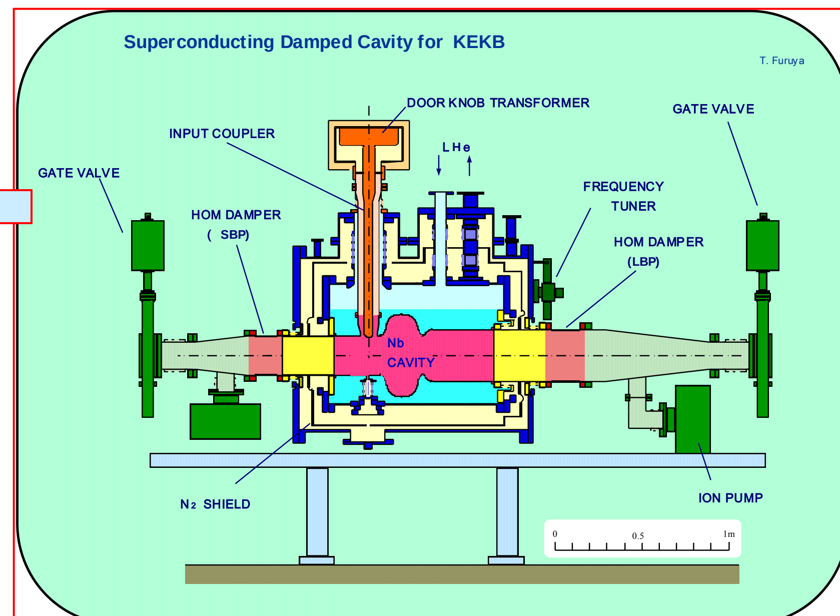


CESR (f_{RF} = 500 MHz):

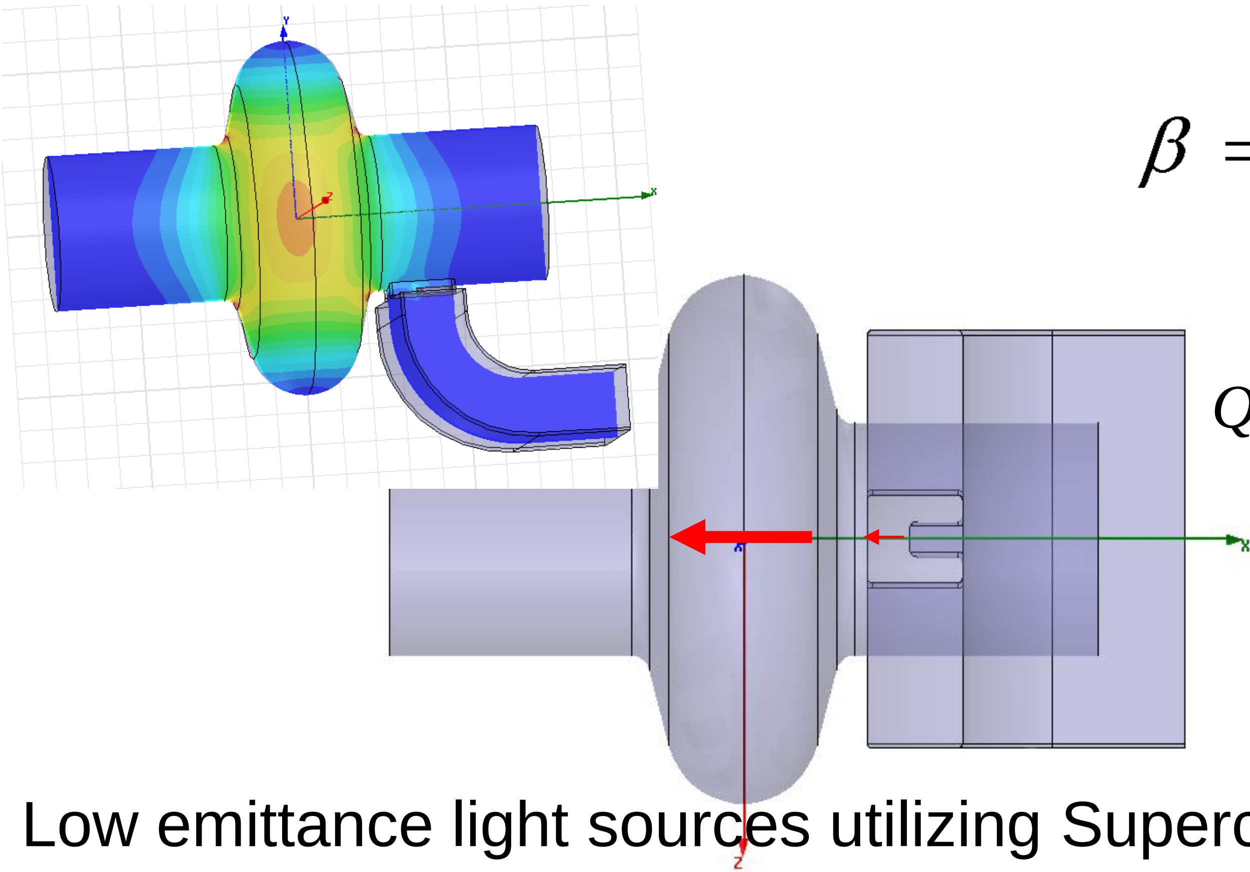
- Aperture waveguide coupled
- Qext ~ 200,000-150,000
- Operate typically up to 300 kW
- Operated up to 360 kW (through)

KEK-B (f_{RF} = 508 MHz):

- Biased coaxial coupler
- Qext = 65,000
- Operate typically up to 350 kW
- For Super-KEKB hope to reach 500 kW
- Tested up to 800 kW (through)



Waveguide Coupling in the CESR-B cavity: Nomenclature

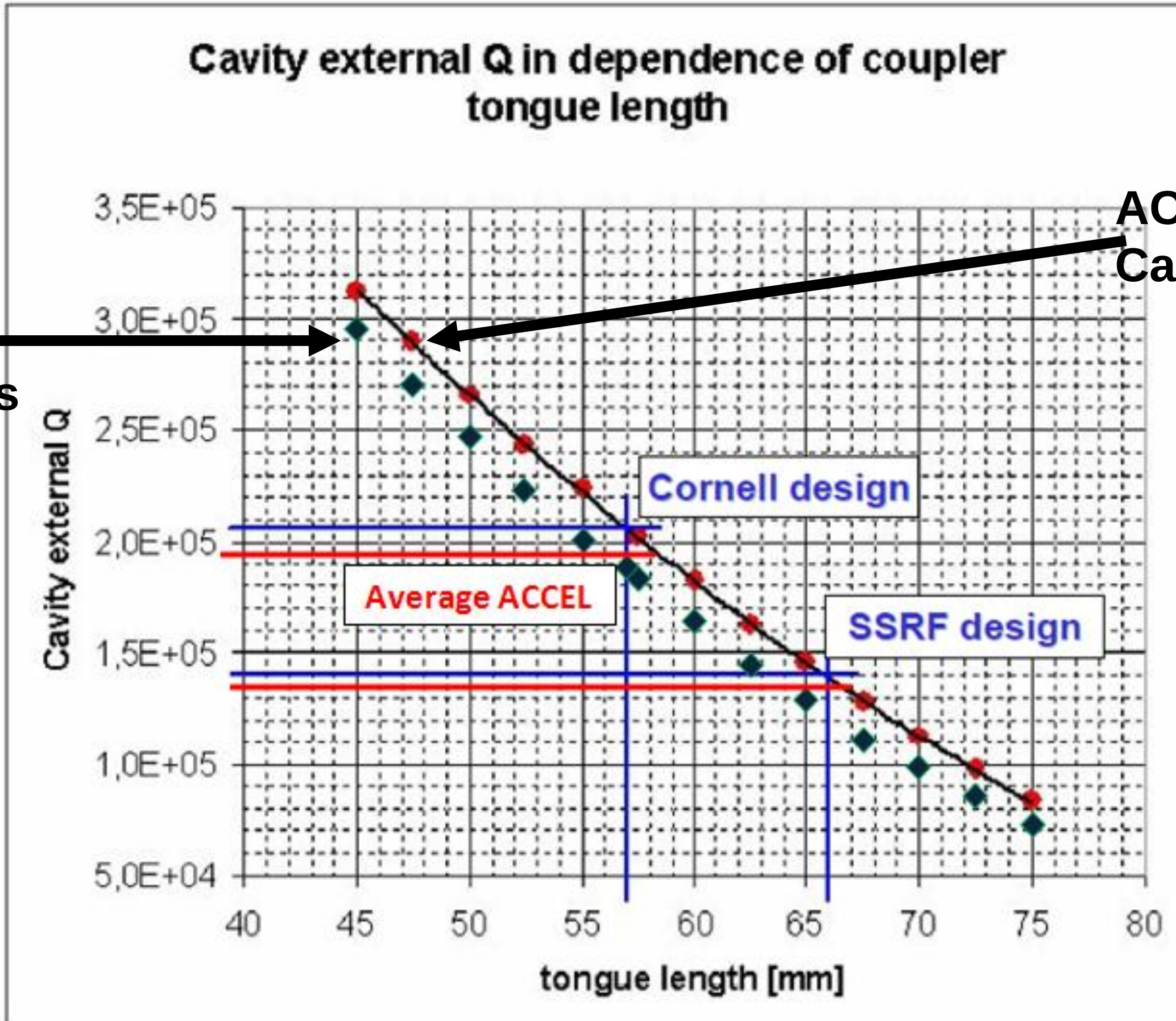


$$\beta = 1 + \frac{P_{beam}}{P_{cav}}$$

$$Q_{ext} = \frac{Q_0}{1 + P_{beam}/P_{cav}}$$

Low emittance light sources utilizing Superconducting cavities (NSLS-II, TPS, SOLEIL, SSRF, PLS) are characterized by very large ratios of P_{beam}/P_{cav} that result in large coupling β and corresponding low Q_{ext}

Benchmarking the HFSS Code on CESR-B cavity

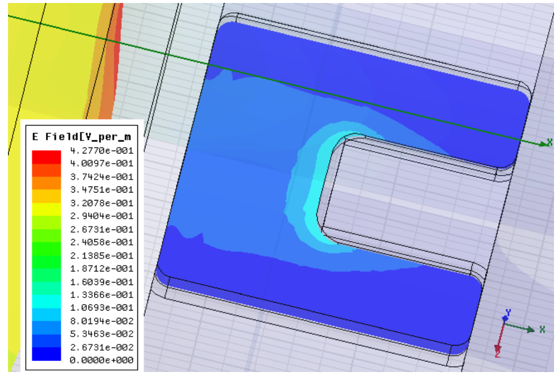


NSLS-II calculations

ACCEL Calculations

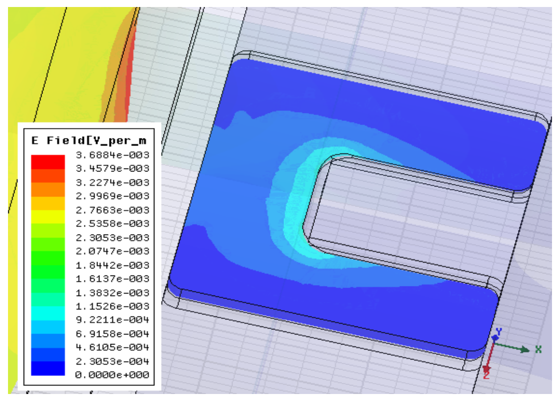
Comparison of Cornell, SSRF, proposed NSLS-II Couplers

Cornell Design



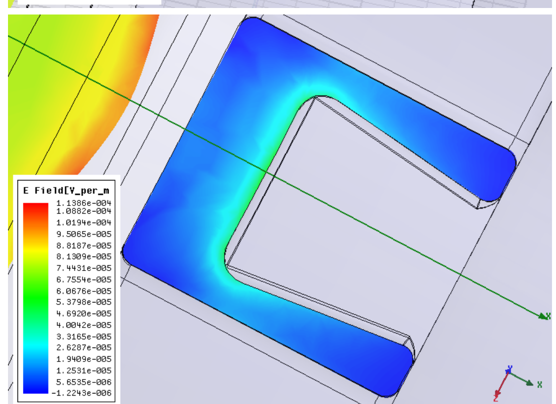
$Q_{ext} = 250000$

SSRF



$Q_{ext} = 150000$

NSLS-II
(Initial geometry)



$Q_{ext} = 65000$

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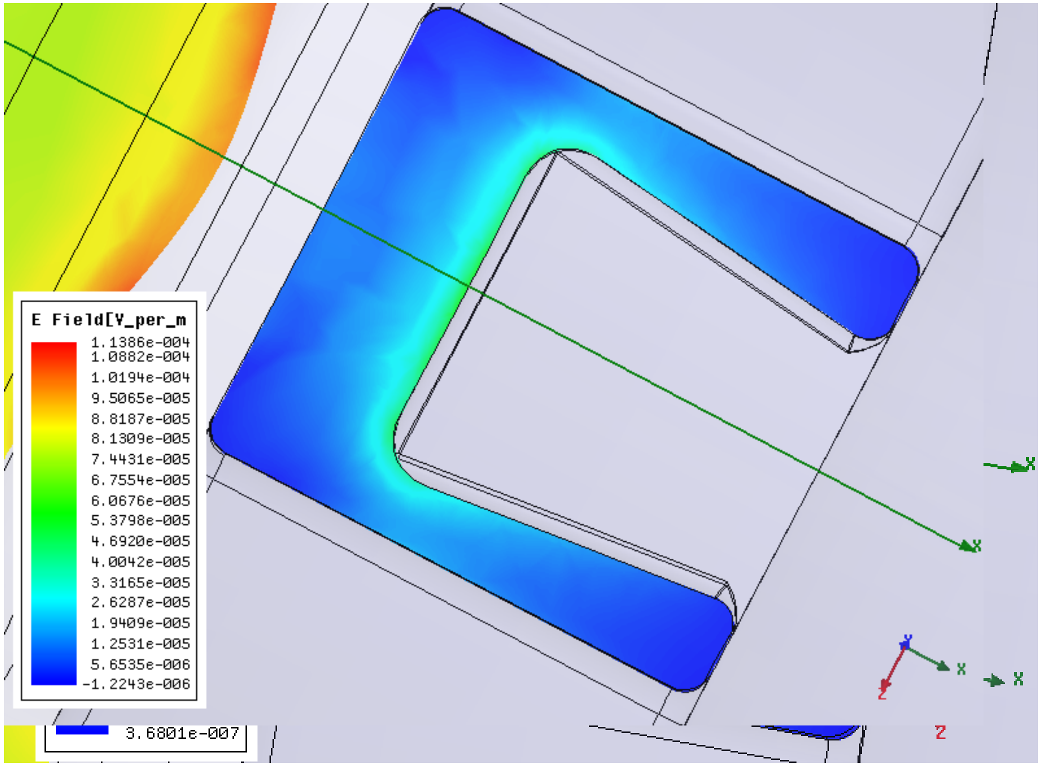
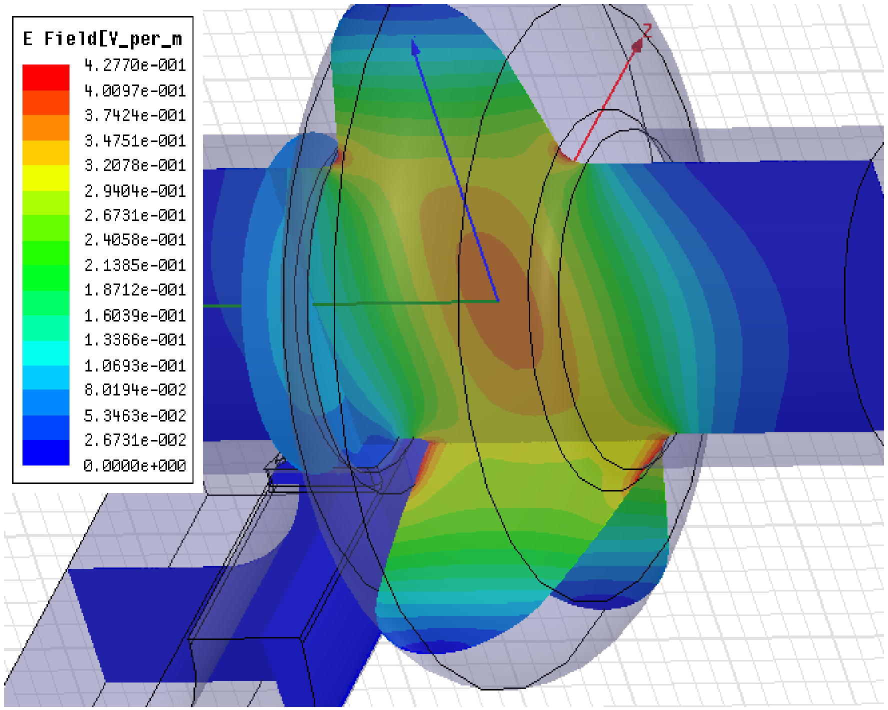
Modified Coupling Aperture

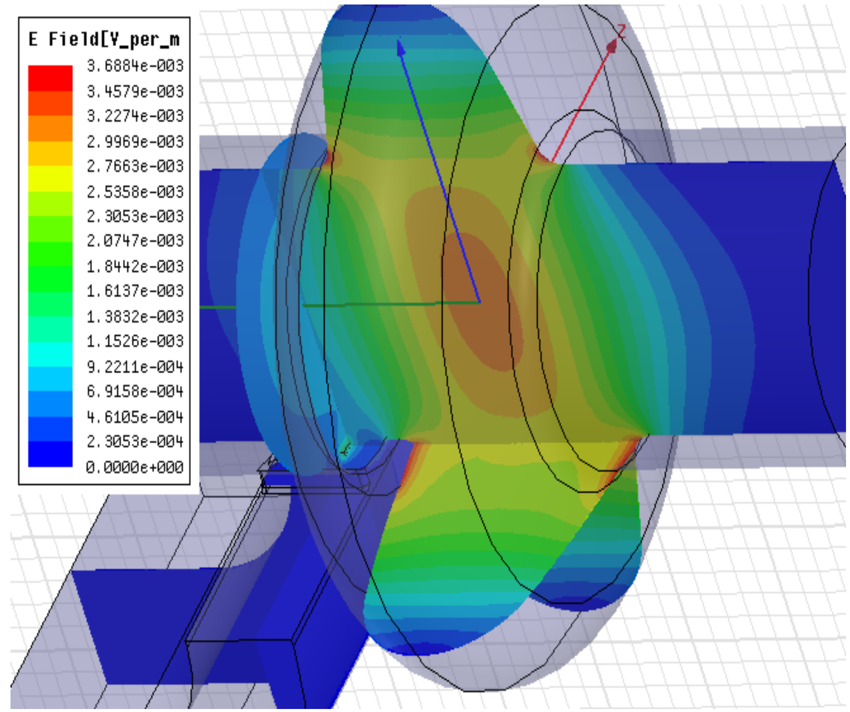


- Minimal change to overall cavity, unlikely to multipactor in complex fields
- Easy to manufacture: little additional cost
- RI (ACCEL) approved as far as manufacturing
- TLS studying our design
- Other options still to be considered: tapered waveguide.

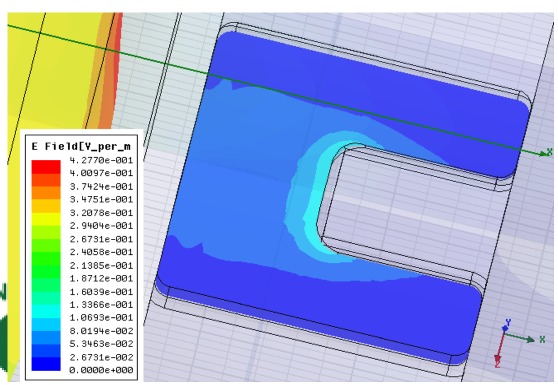
The change in coupling will not change the field levels in the waveguide for fixed input power. Therefore multipactor in the waveguide won't be changed, only at the coupler itself. This will be analyzed using a 3-D multipactor code.

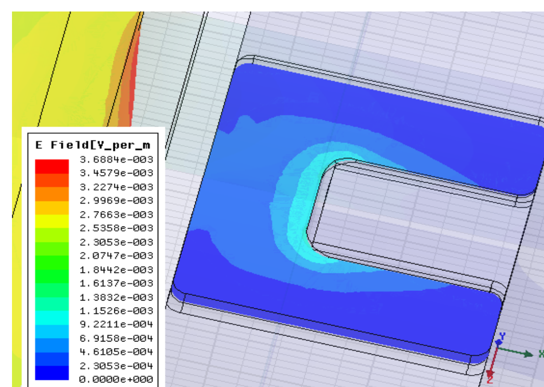
E-field distribution for Cornell and SSRF designs





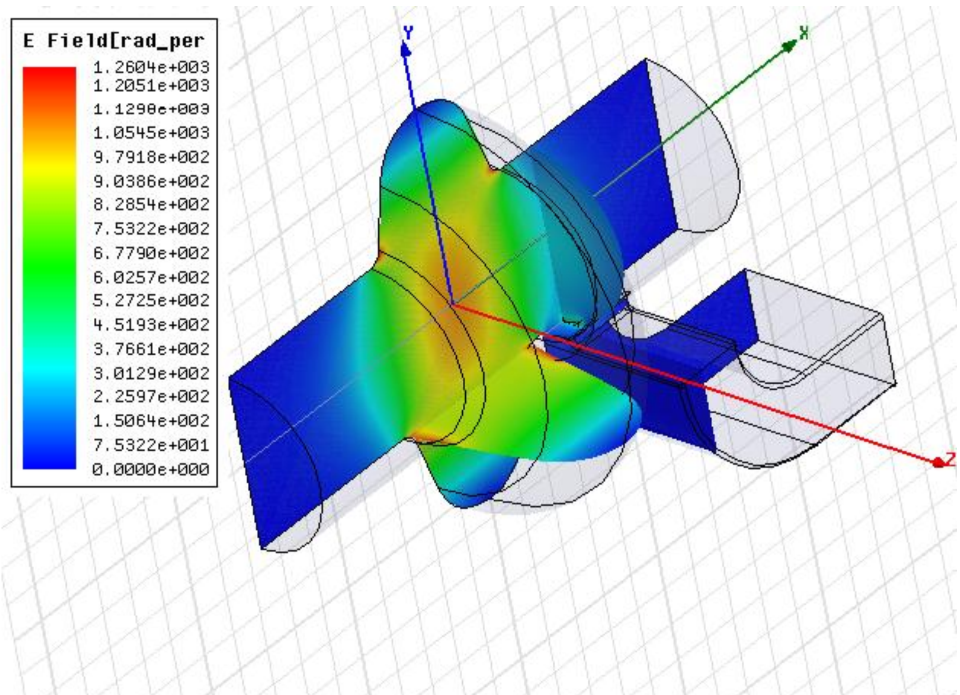
Original Cornell design

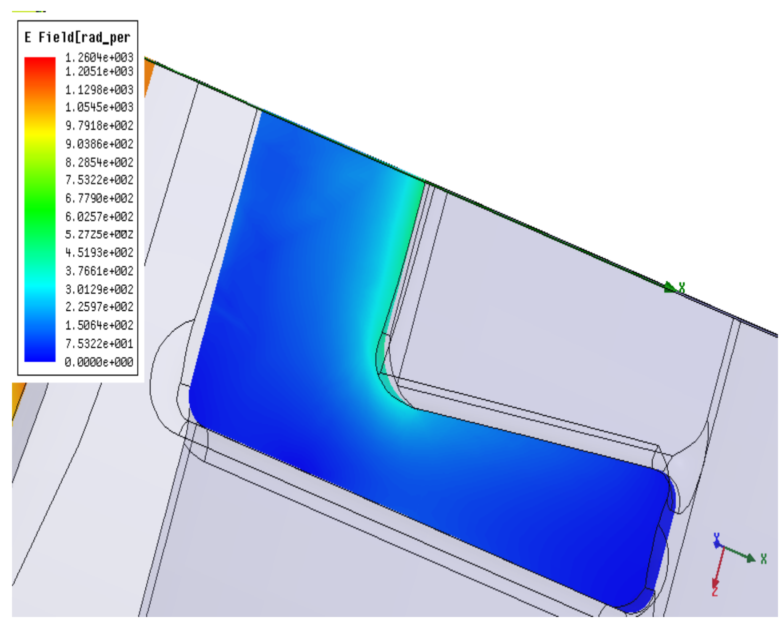




SSRF design

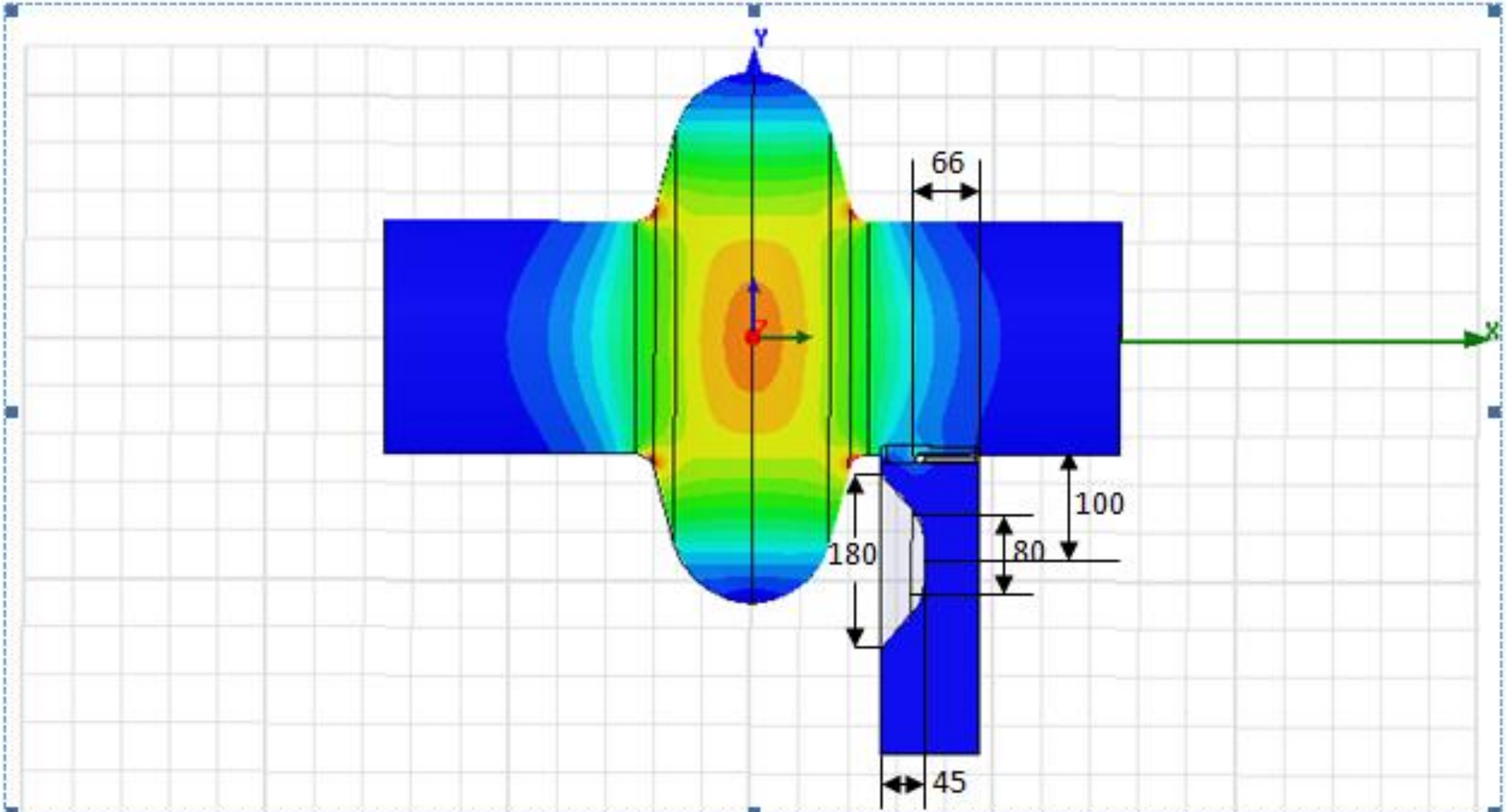
E-Field plots for wedge shaped tongue



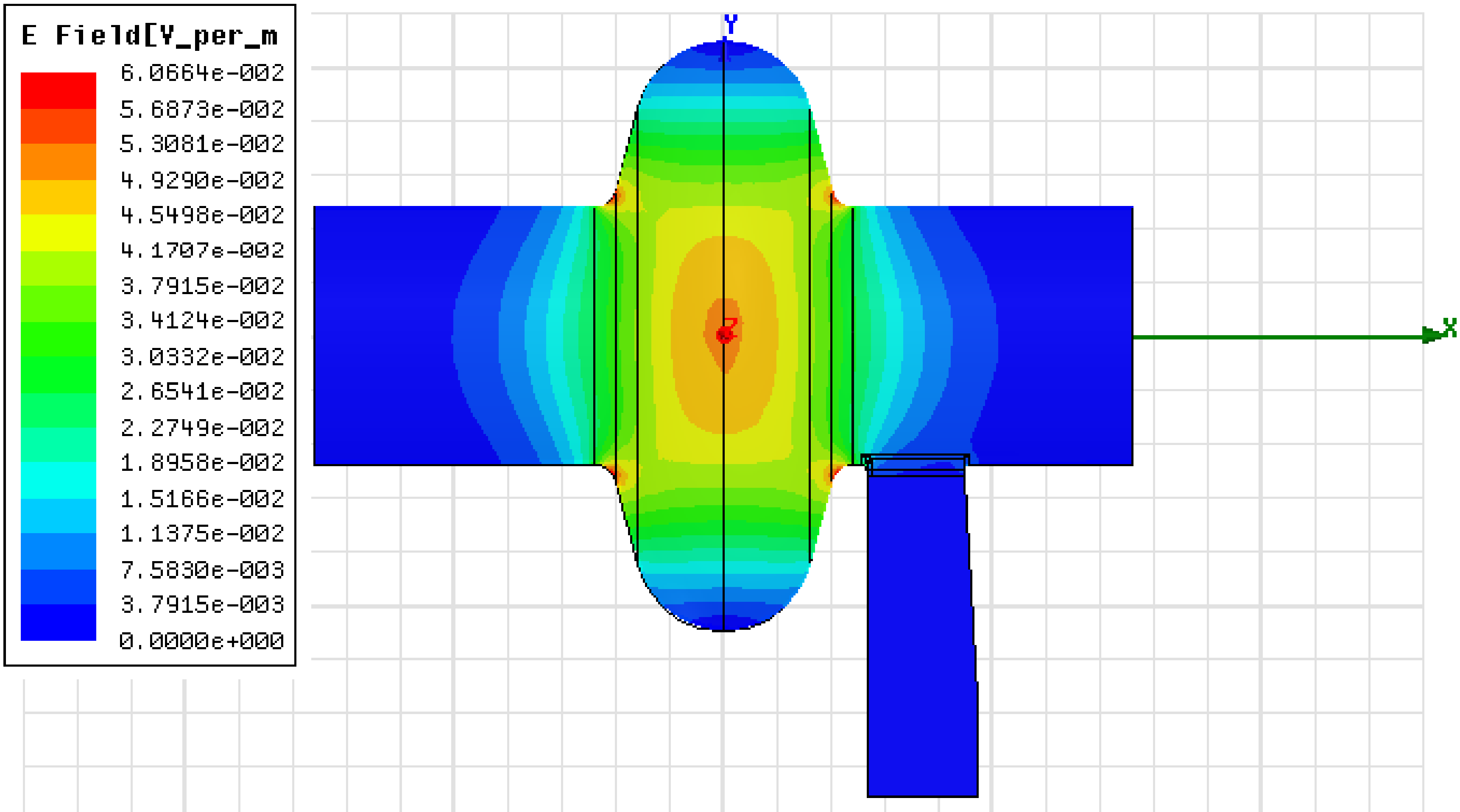


Increased dimension of window frame to reduce peak fields

Electric field across the cross section of the cavity-coupler waveguide-post



Electric field across cavity-coupler- waveguide with no "tongue" in the coupler



Summary of coupling approaches and figure of merit

	Tongue Length L (mm)	Back Width W_b ,mm	Front Width W_f , mm	Tongue thicknes s t, mm	Aperture box width b, mm	Q_{ext} HFSS (10^3)	PD tongue gap (kV)	∫H.H* ds Coupler wall 10^6	∫H.H* ds Tongue wall 10^6
Cornell original	57	37	37	12	91	225	48.95	0.28	0.074
SSRF	66	37	37	12	91	153	59.13	0.37	0.145
NSLS-II	66	53	70	11.9	100	65.74	73.374	0.77	0.35
SSRF, WG buckle	66	37	37	12	91	60.87	55.35	0.377	0.141
No tongue	0	0	0	0	91	532.96			

Figure of merit is tongue gap voltage power density

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Summary

- We have two tentative solutions to increase the coupling of the CESR-B type cavity to achieve Q-external of 65,000.
- Our preference to date is for the wedge tongue design- mostly from subjective feeling that it is a smaller less risky perturbation to a sensitive area of the cavity.
- Analysis of these plus other options will continue for another month at most: we will go out for competitive bid for cavities in ~July time frame for industry built KEK-like or CESR-like superconducting cavities