Report from the LANL Spoke Cavity Workshop in October 2002

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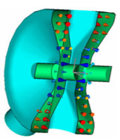
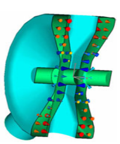
Presented at the
11th Workshop on RF Superconductivity
Travemünde, Germany
September 8-12, 2003



LA-UR-03-5985

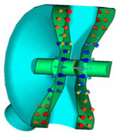
Introduction

- Spoke resonators considered as low-β structures in recent proposals (AFCI, RIA, ESS, Eurisol, XADS)
- Based on Delayen's and Shepard's work (1980s) new spoke resonators have recently been built and demonstrated in low power tests
- Workshop at LANL to report and compare approaches and to discuss paths to demonstrate their usefulness in real accelerators
- This is a summary of the meeting from last October, where basically the whole community active in the field was present
- Recent progress will be pointed out also



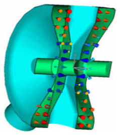
Some Statistics

- Dates: October 7-8, 2002
- Participants: 37
- Organizations: 11 laboratories and universities from the USA, Germany, France and Italy
- Industry: 3 companies participated
- Proceedings: 642 pages
- Website: http://laacg1.lanl.gov/spokewk/
- Pre-workshop cavity test: 12 participants



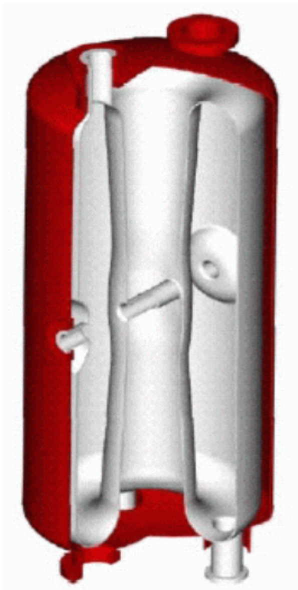
History

- Range of cavity shapes needed to cover particles' β-range
- Acceleration of low-β particles requires low frequency resonators (active length proportional to λ)
- First structures used: variations of $\lambda/4$ resonators, provide smallest transverse dimensions for longest gap
- Quarter wave resonators susceptible to mechanical vibrations, not easily stackable for improved real estate gradient (multi-gap resonators)
- Coaxial $\lambda/2$ resonators address mechanical vibrations only
- Jean Delayen and Ken Shepard first investigated the spoke resonator as a variant of a $\lambda/2$ resonator in the mid 1980s.



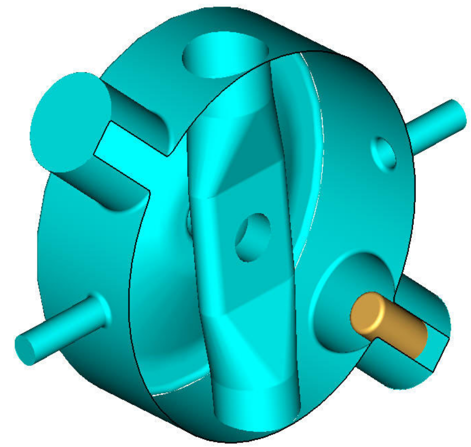
Types of $\lambda/2$ Resonators

Coaxial, β=0.252



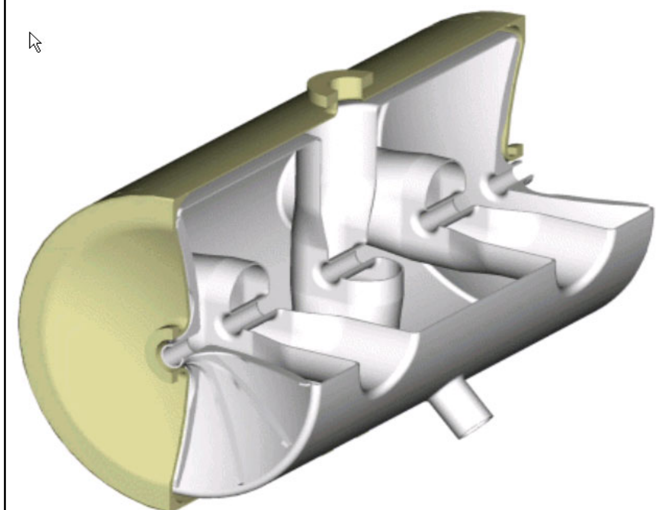
ANL
f_0=172 MHz

2-gap Spoke, β=0.175



LANL
f_0=350 MHz

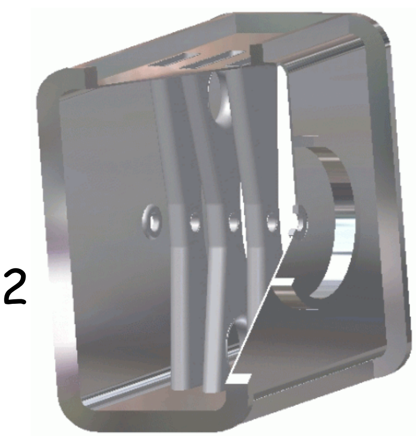
Multi-gap Spoke
''Cross-bar'' Type

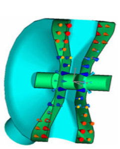


ANL
f_0=345 MHz, β=0.62

Multi-gap Spoke
''Ladder'' Type

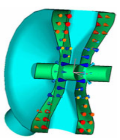
Legnaro
f_0=352 MHz, β=0.12





Advantages of Spoke Resonators

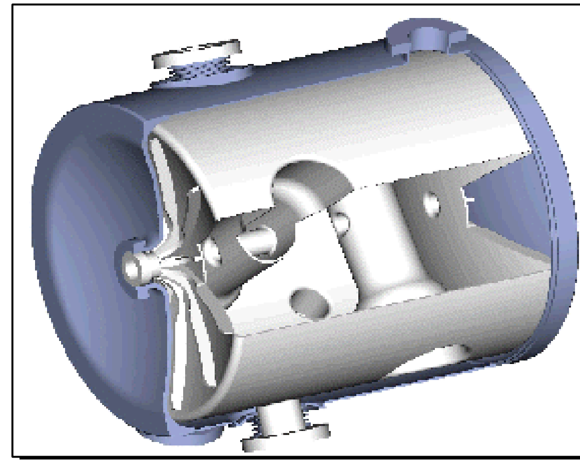
- Suitable for bridging the gap between very low βs (<0.1) and βs, where elliptical resonators become useful ($\approx$ 0.5)
- Stable field profile due to high cell-to-cell coupling
- Mechanically more stable than $\lambda/4$ (and λ) resonators
- Large number of degrees of freedom for RF-design
- Can support high field levels even at low β (low peak field ratios)
- No clear-cut transition energy from spokes to elliptical resonators:
  - At given f_0 more compact than elliptical resonators
  - For given size extends operability at 4K
- Stackable, can be operated as multi-gap device



RF Design Specifics

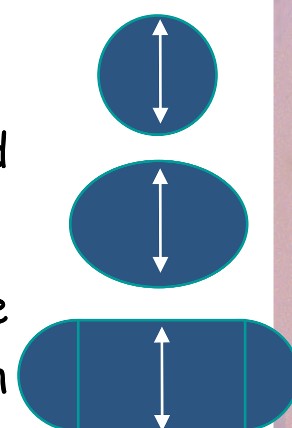
ANL: 2 spoke resonator (β=0.4), 4 gap resonators (β=0.50, 0.62)

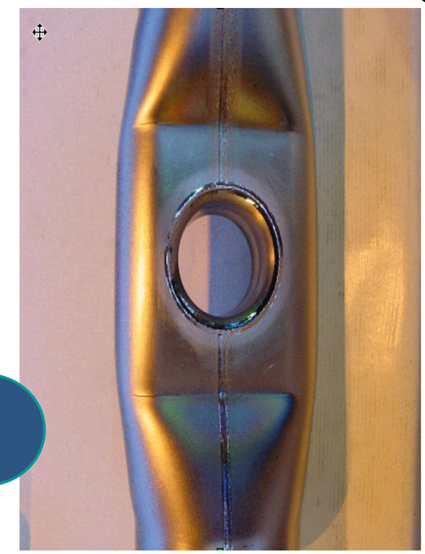
- Emphasis on 4 gap resonator advantages over 6 gap elliptical resonators (SNS) at same βs
- Presented results on mode splitting advantage of the cross-spoke compared to the ladder structure



CNRS: β=0.35 2-gap resonator,

- design uses spokes in the range of β=0.1 – 0.5,
- presented their optimization strategy and results of a parameter study,
- showed effect of the variation of the spoke cross-section in high electric vs. high magnetic field regions

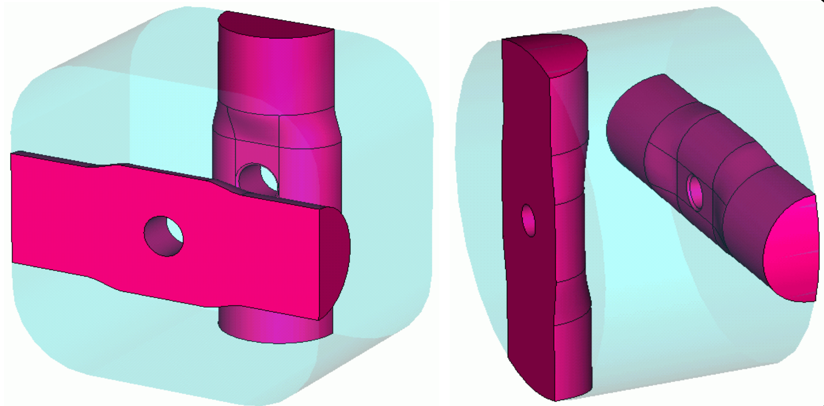




RF Design Specifics

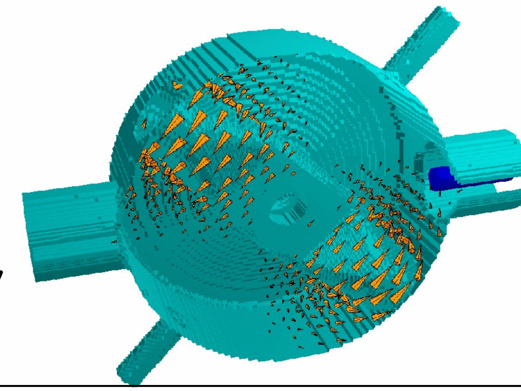
Jülich:

- Wide range of geometries,
- Rectangular cavity cross section
- End spokes different from mid spokes
- Relation between end-shape and tuning



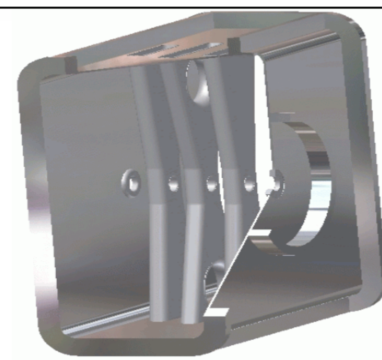
LANL: β=0.175 2-gap resonator

- Integration issues
  - Mechanical/em design
  - Ports for high power operation (100 mA beam),
  - Coupler influence,



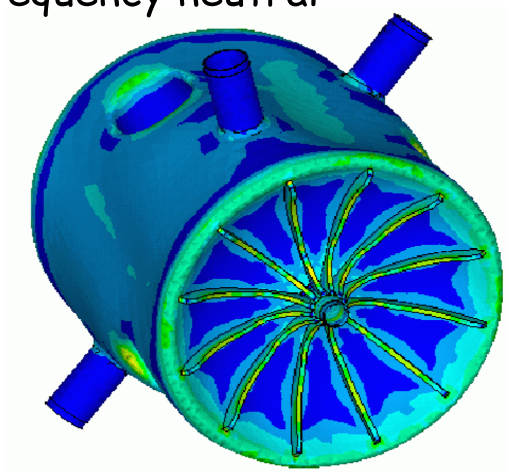
Legnaro: β=0.12, 4 gap, ladder spoke structure,

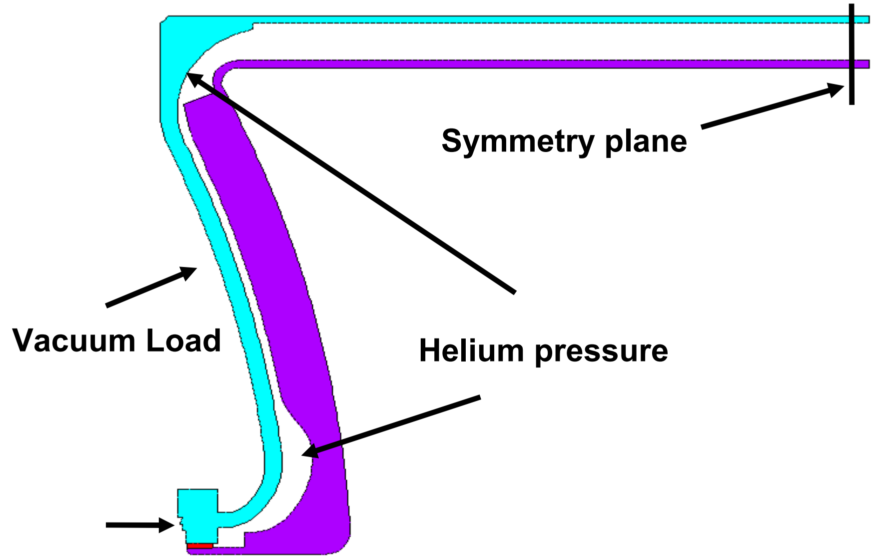
- Compactness
- Cleaning issues



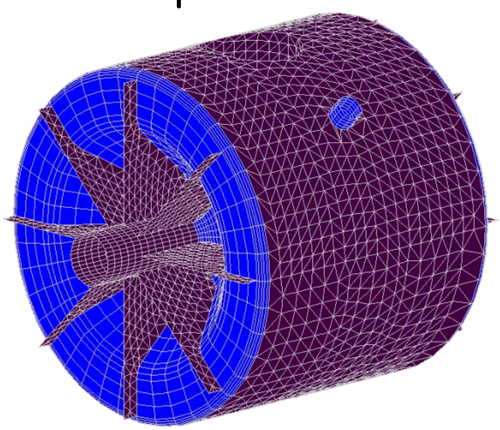
Mechanical Design

ANL: integrated cavity and helium vessel design: net effect of cool-down is frequency neutral

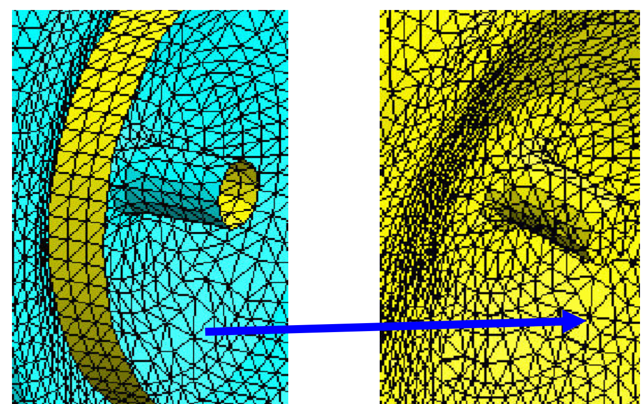




CNRS: Presented stiffener design for testing, needs improvement for operation



LANL: Presented integrated em and mechanical design approach, ring stiffener

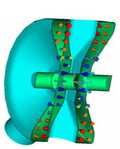


Shell Mesh ⟷ Volume Mesh

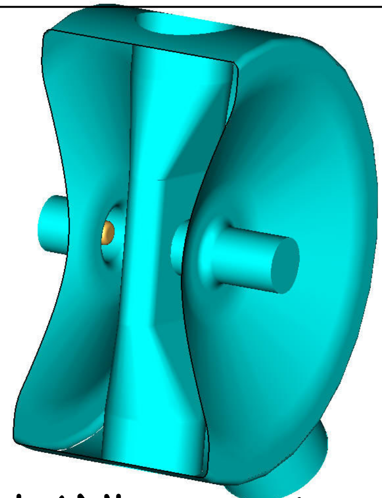
Spectrum of Spoke Geometries

- Large number of degrees of freedom for RF and mechanical design
- Smaller experience base of what is working best
- Different emphasis on importance of criteria, based on application
- Tradeoff between optimization and keeping things simple

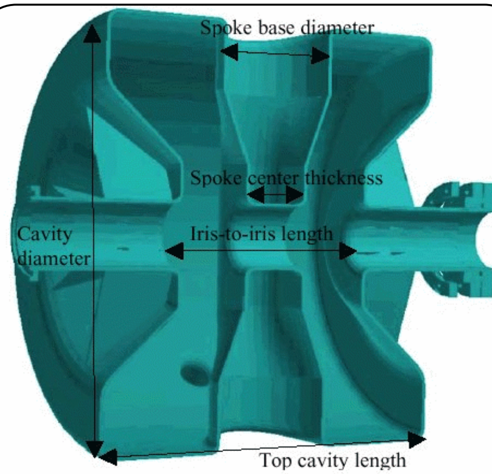
➢ Wide range of ''Results''



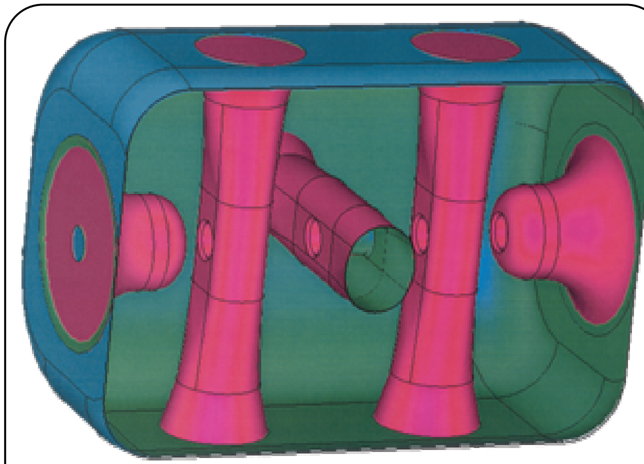
''Spoke Gallery''



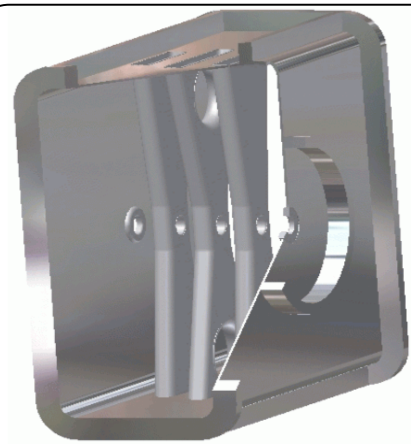
LANL: re-entrant, large coupler port



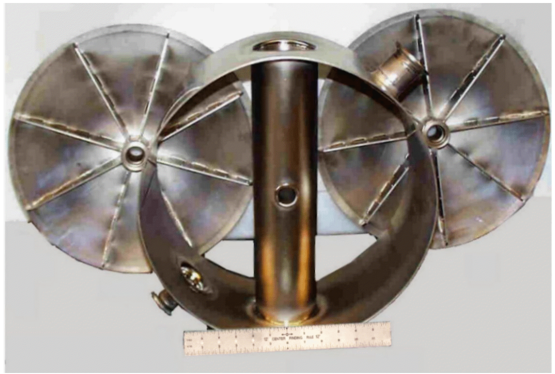
CNRS: re-entrant, small ports



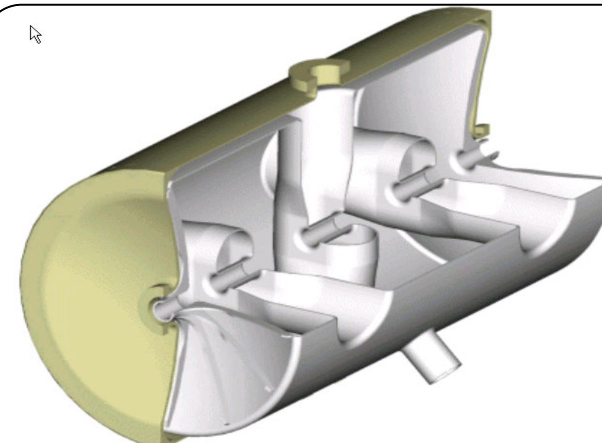
FZJ: flat w/ nose, rectangular body



LNL: ladder spoke, wall flanges



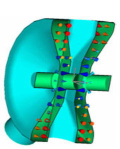
ANL: simple spoke dish-shaped endwalls



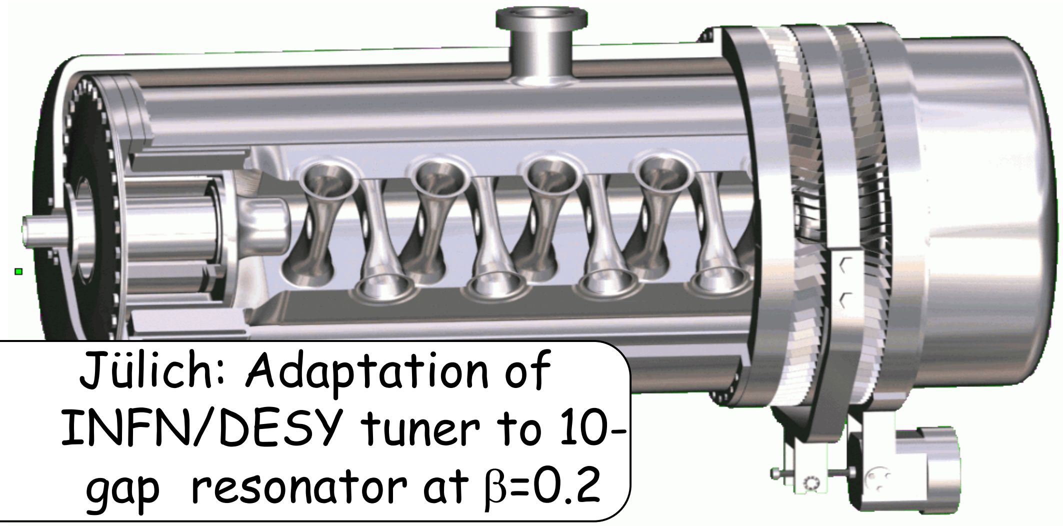
ANL: cross spoke dish-shaped endwalls

Design Parameter Summary

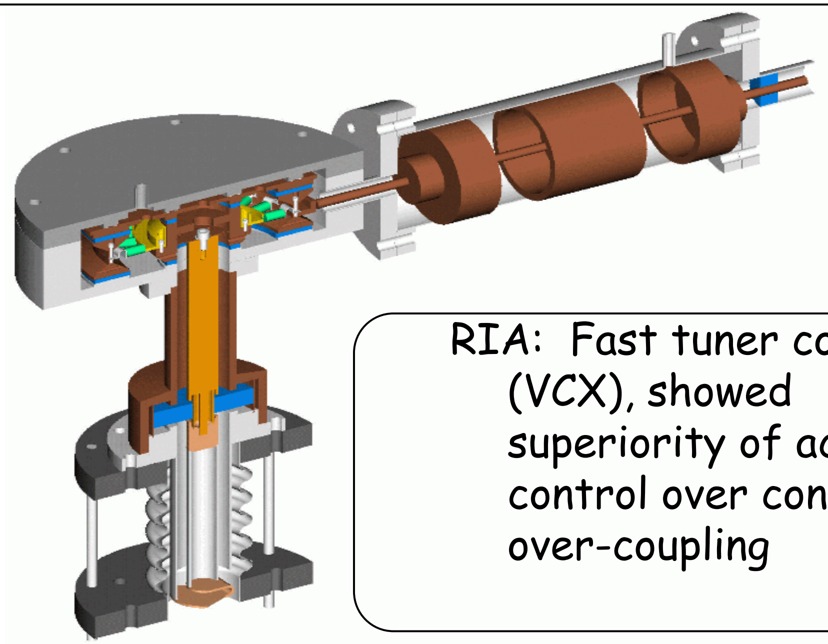
Institute	When	f_0	β	Gaps	Radius	Length	Aperture	Ep/Ea	Bp/Ea	G	U @ 1MV/m	df/dz
		MHz			cm	cm	cm		mT/MV/m	Ω	mJ	kHz/mm
ANL	1998	340	0.300	2	22.0	17.7	1.3	4.20	9.100	71	51	368
	1998	340	0.400	2	22.0	22.2	1.3	4.00	10.700	75	85	-
	2002	345	0.393	3	24.0	38.1	3.0	3.47	6.900	71	151	-
	2003	345	0.500	4	21.7	67.0	4.0	2.88	8.650	92	397	-
	2003	345	0.620	4	22.9	85.0	4.0	2.97	8.860	103	580	-
CNRS	2002	359	0.350	2	20.4	15.0	3.0	3.06	8.280	101	-	500
	-	352	0.150	2	-	-	-	-	-	-	-	-
FZJ	2003	775	0.200	4	7.2		1.5	4.93	16.600	-	-	-
	-	700	0.200	10	7.2	-	-	-	-	-	-	-
LANL	2002	350	0.175	2	19.6	10.0	2.5	2.82	7.380	85	39	1010
	-	350	0.200	3	-	-	3.0	-	-	-	-	-
	-	350	0.340	3	-	-	3.0	-	-	-	-	-
LNL	2002	352	0.170	4	22.5	29.0	1.3	3.13	8.700	69	89	-
	2002	352	0.124	4	22.5	20.0	1.3	3.45	11.200	45	59	1080



uners

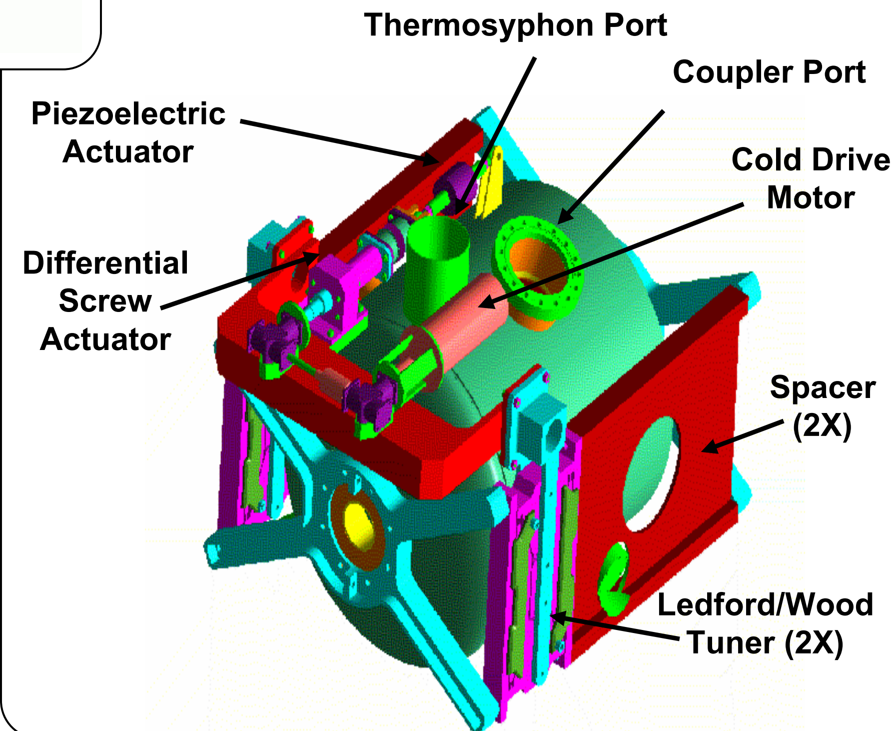


Jülich: Adaptation of INFN/DESY tuner to 10-gap resonator at β=0.2



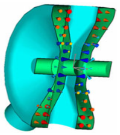
RIA: Fast tuner concept (VCX), showed superiority of active control over control by over-coupling

LANL: Slow tuner plus PZT concept



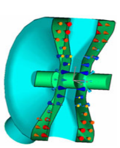
Other Related Topics

- Fabrication:
  - Main fabrication steps: ANL,CNRS and LANL
  - Fabrication: in industry or w/ industry involvement
- Cryomodules:
  - ANL: ATLAS based concept, separated beam vacuum from cryo module vacuum
  - CNRS: relation of cryomodule design to reliability requirement for XADS
  - LANL: ADTF based, thermosyphon, power coupler as cavity support, assembly by axial insertion
- Microphonics:
  - Overview talk by Delayen
  - ANL: Measurement setup, relation to mechanical modes, influence of refrigerator noise.



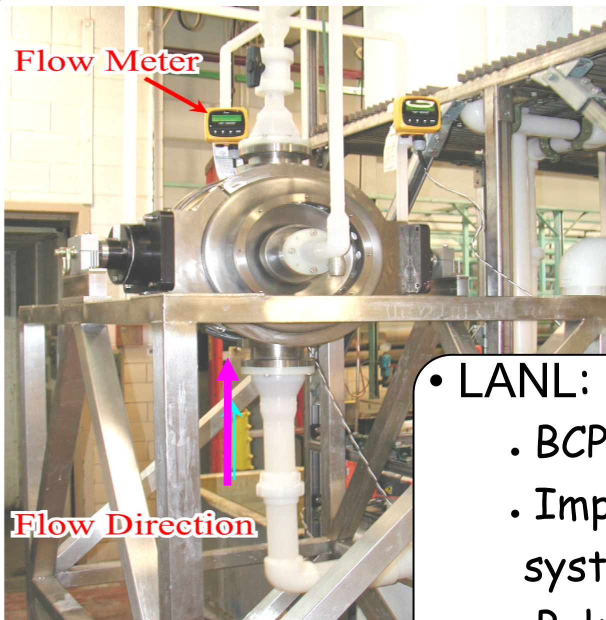
Other Related Topics

- Powercoupler:
  - ANL: RIA coaxial loop coupler for spokes, combination with VCX investigated (500 W-20 kW)
  - LANL: Coaxial antenna coupler, incorporated benefical concepts from APT coupler (up to 212 kW)
- Multipacting:
  - Using the MULTP (Moscow University) code, requirements for full 3D simulations shown. No sufficiently benchmarked tools available, yet
- HOMs:
  - No experience yet, HOM removal by couplers more important due to smaller beam pipes



Cavity Processing

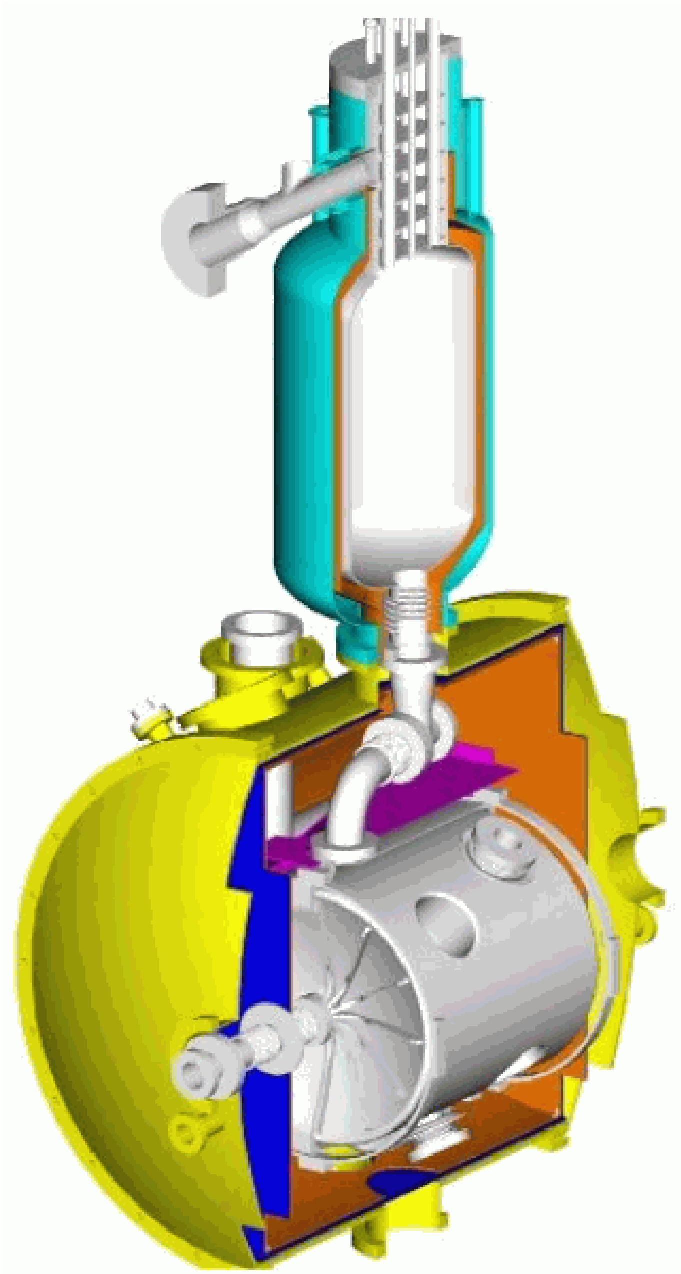
- ANL:
  - Parts are electropolished before final welding
  - Light BCP plus HPR after completion
  - RF processing

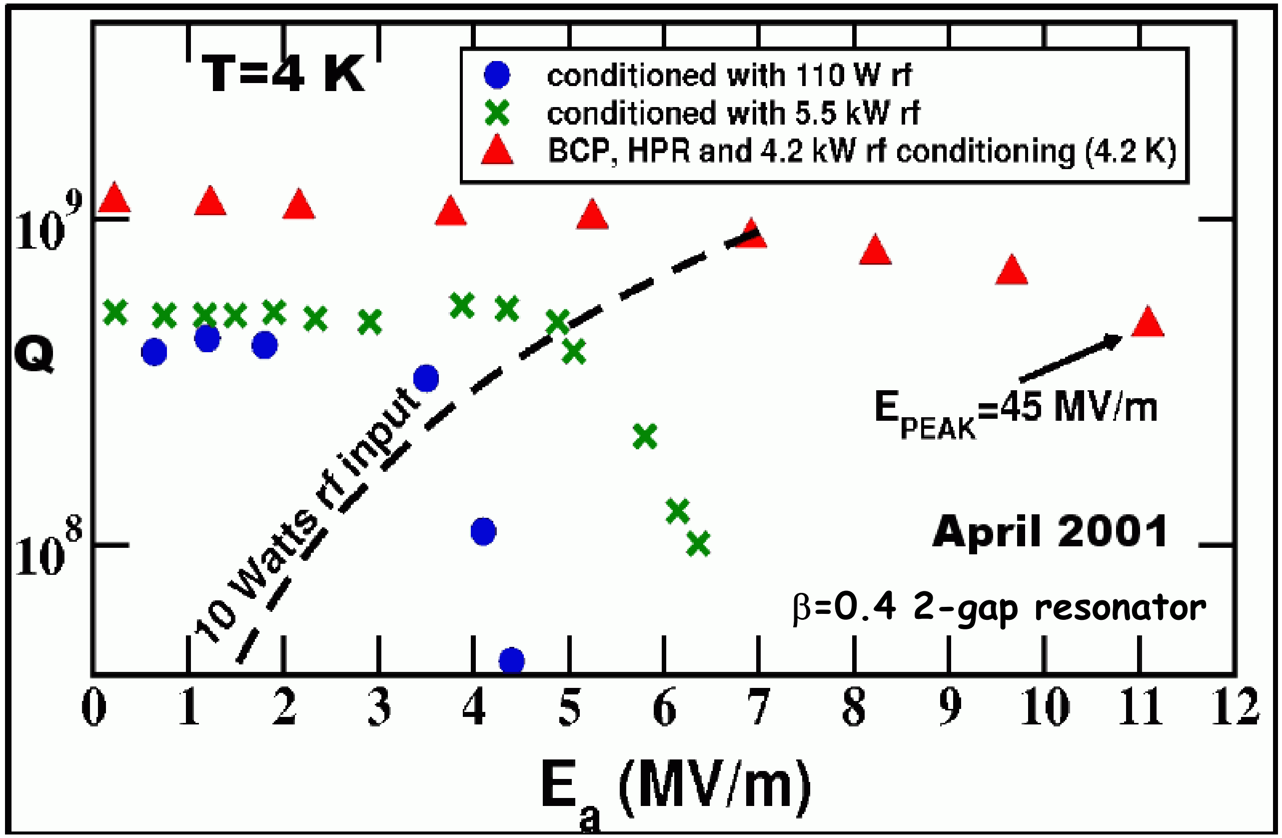


- CNRS:
  - BCP plus HPR treatment planned
  - Do not have in-house capability yet, done at Saclay

- LANL:
  - BCP plus HPR treatment
  - Implemented multiport BCP system for better flow
  - Baking at 110 ° C

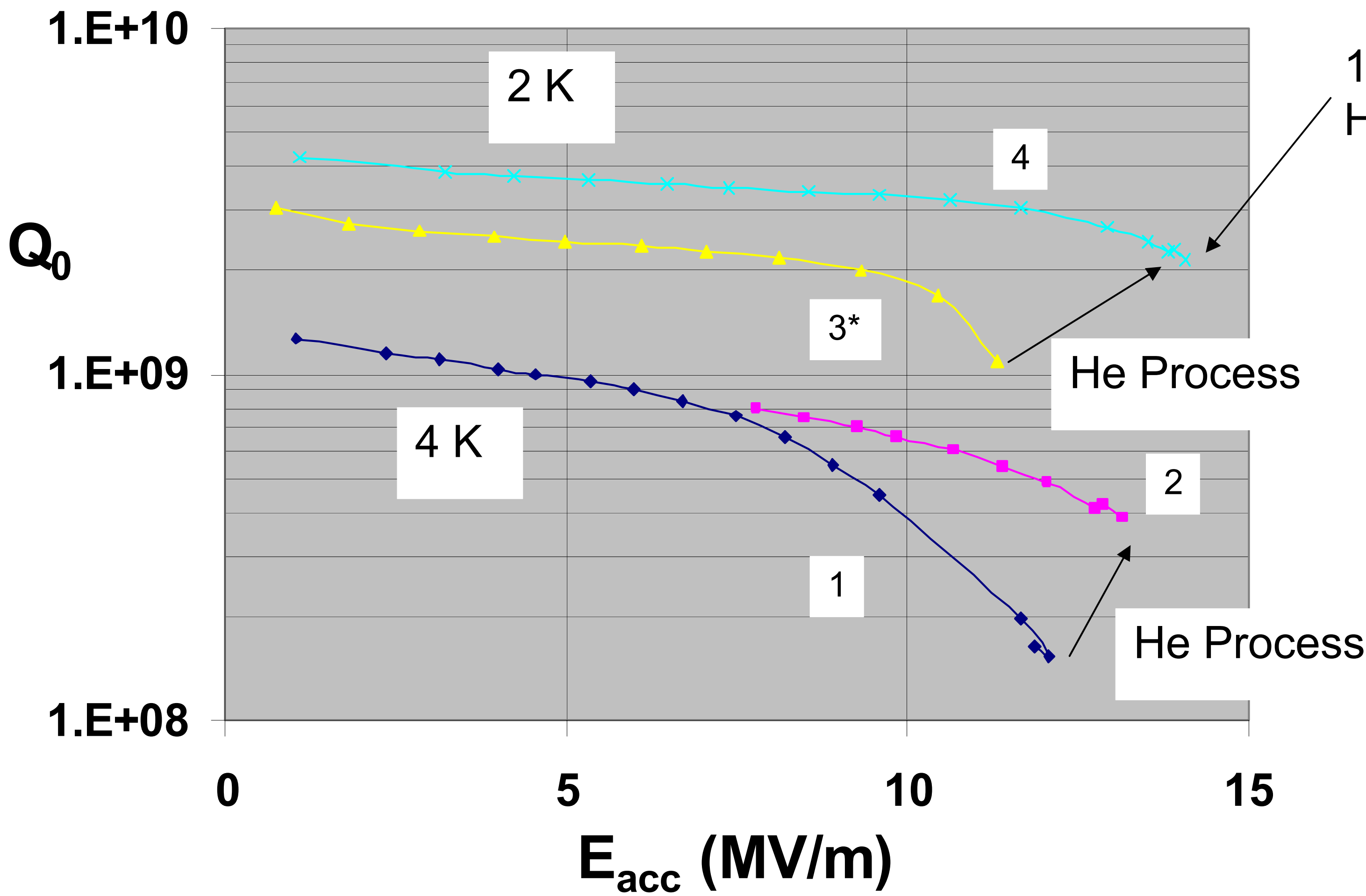
Testing (ANL)





- Results for β=0.3 and β=0.4 2-gap resonators
- Testcryostat for β=0.4 3-gap resonator
- Long term (1 month) test at 7 MV/m

Testing (LANL)

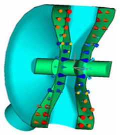


3*. There was a vacuum failure on the previous night and the cavity vacuum was ~E-4 Torr, although it recovered before this test.

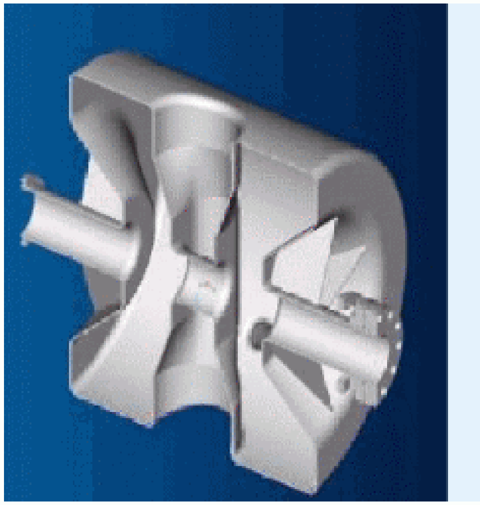
- Cavities need more MP processing than ANL cavities
- Flange on power coupler port needs to be moved further out
- Q disease occurs when held around 100 K for more than 60 hours

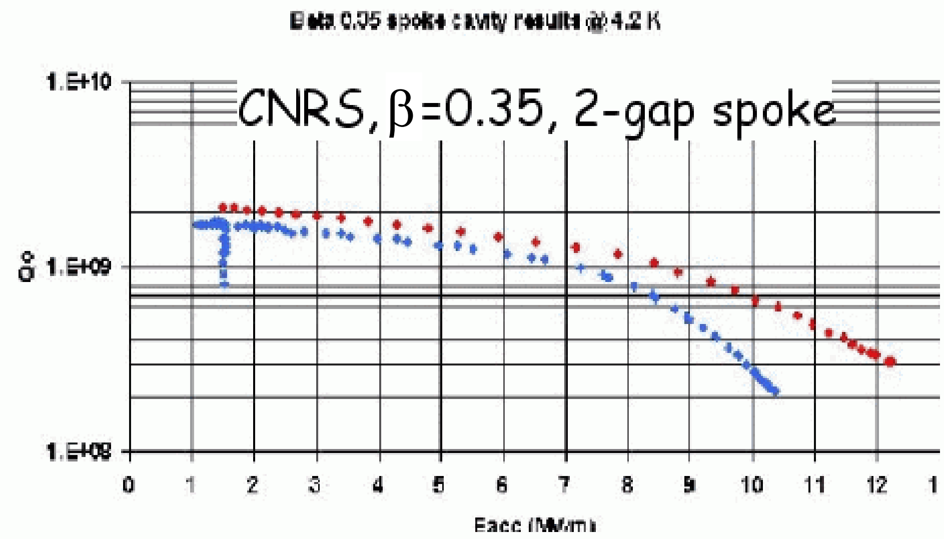
Performance Summary

Institute	f_0 MHz	β	Gaps	Q_0 (4K) Low Field	Q_0 (2K) Low Field	E_{amax} MV/m	E_{pmax} MV/m	B_{pmax} mT	Limit
ANL	340	0.300	2	2.00E+09	8.50E+09	12.5	52.5	113.75	Quench
	350	0.400	2	1.00E+09	1.30E+09	11.5	46.0	123.05	Quench
	345	0.400	3	1.30E+09	-	11.5	39.9	79.35	Quench
CNRS	359	0.350	2	1.10E+09	-	12.2	37.3	101.02	Power
LANL	350	0.175	2	1.74E+09	7.00E+09	13.5	38.1	99.63	Quench

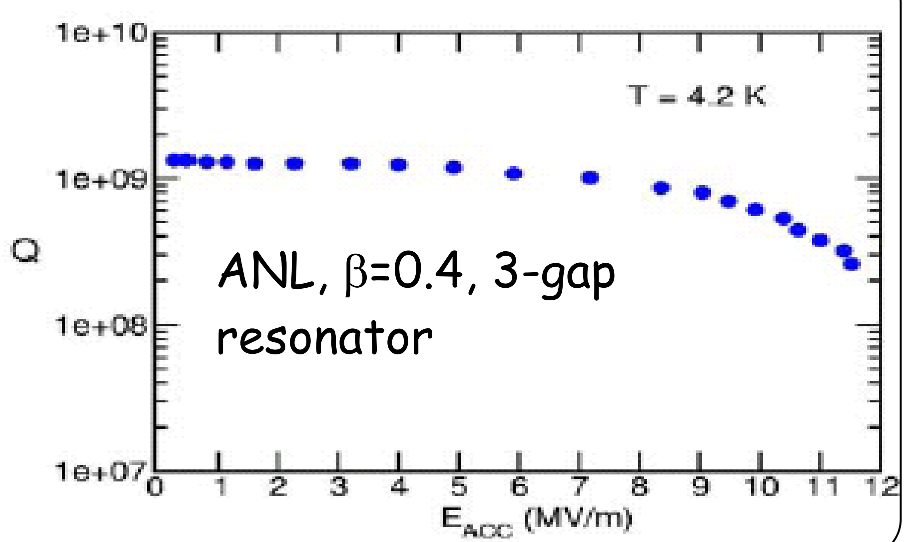


Recent Results





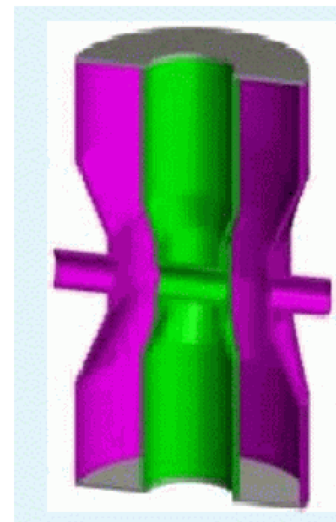
CNRS, β=0.35, 2-gap spoke



ANL, β=0.4, 3-gap resonator

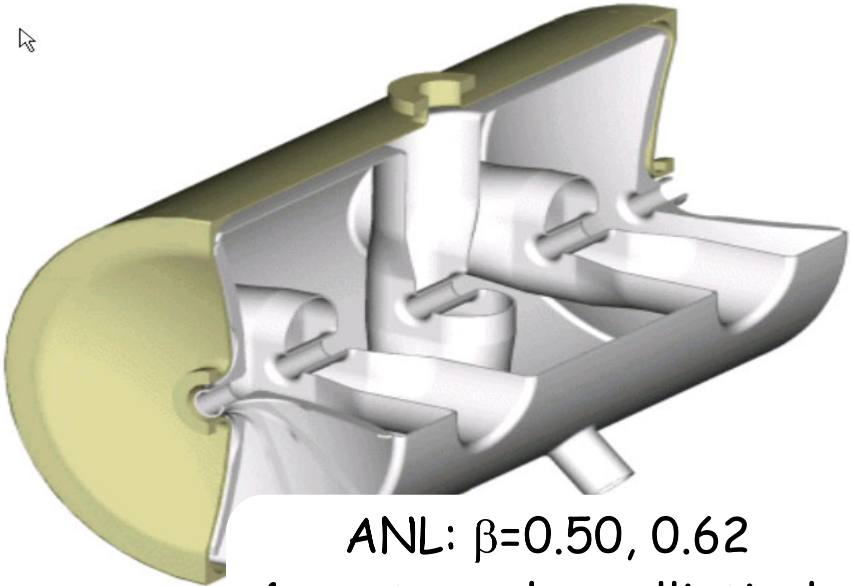
LANL:
Q-disease study
- 24 hrs at 100K ok
- effect accumulative

MSU:
●/2 resonator

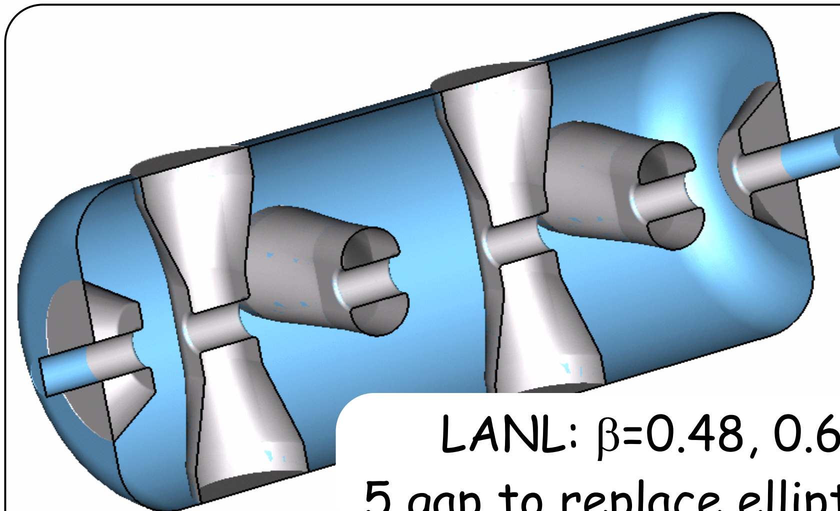


E_p/E_a=2.7,
B_p/E_a=7.4mT/MV/m
E_{peak} > 35 MV/m (2K)

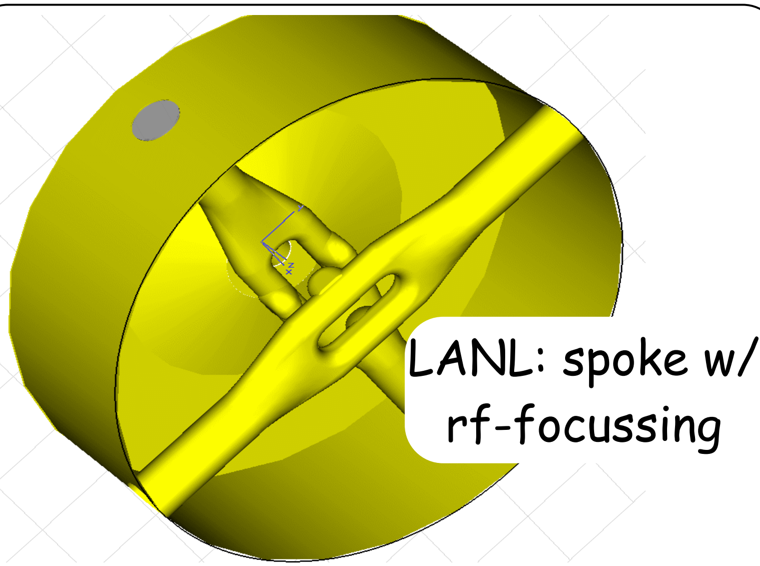
Next Generation Examples



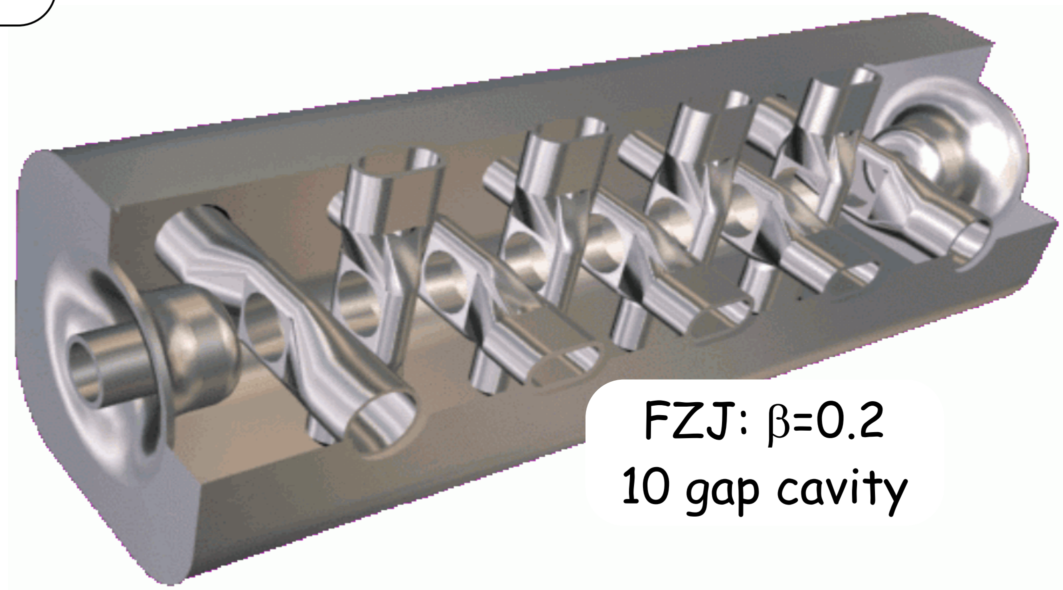
ANL: β=0.50, 0.62
4 gap to replace ellipticals



LANL: β=0.48, 0.64
5 gap to replace ellipticals



LANL: spoke w/
rf-focussing



FZJ: β=0.2
10 gap cavity

Los Alamos
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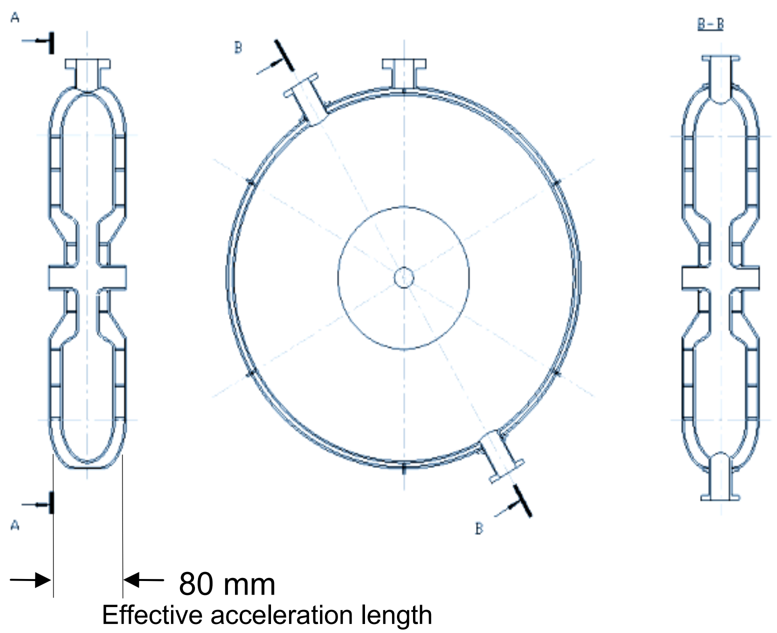
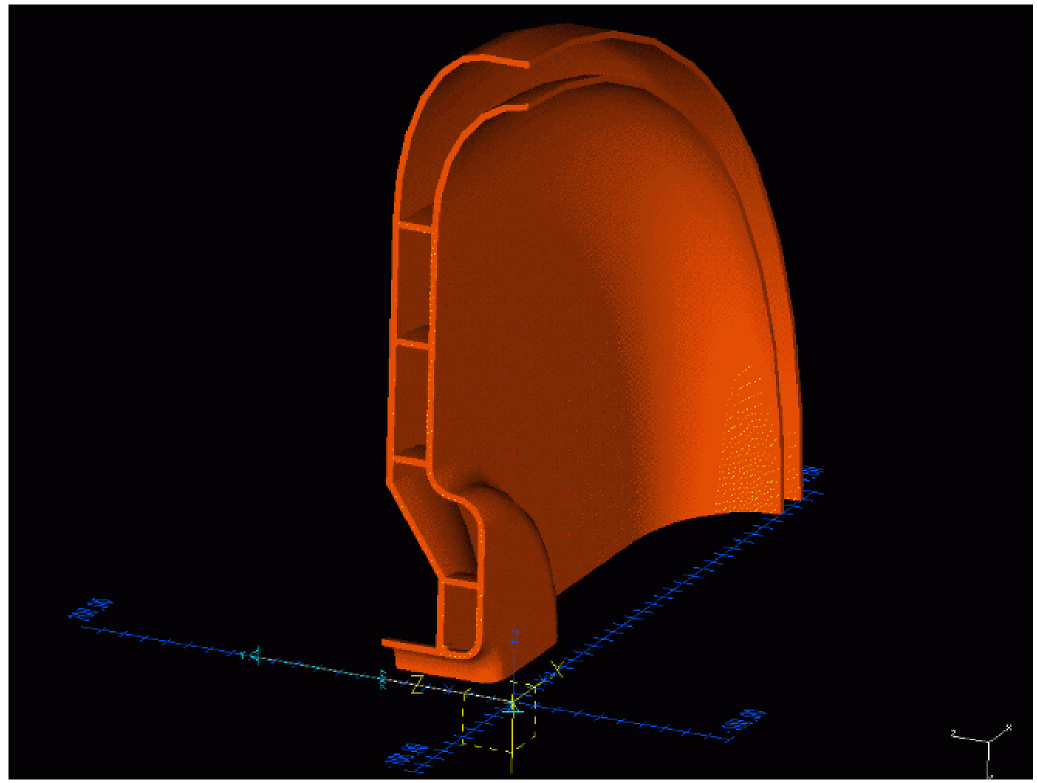
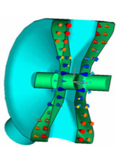
Alternate Designs

LNL: Re-entrant Resonator: β=0.1, 352 MHz, tested: E_a=8.5 MV/m, no multipacting



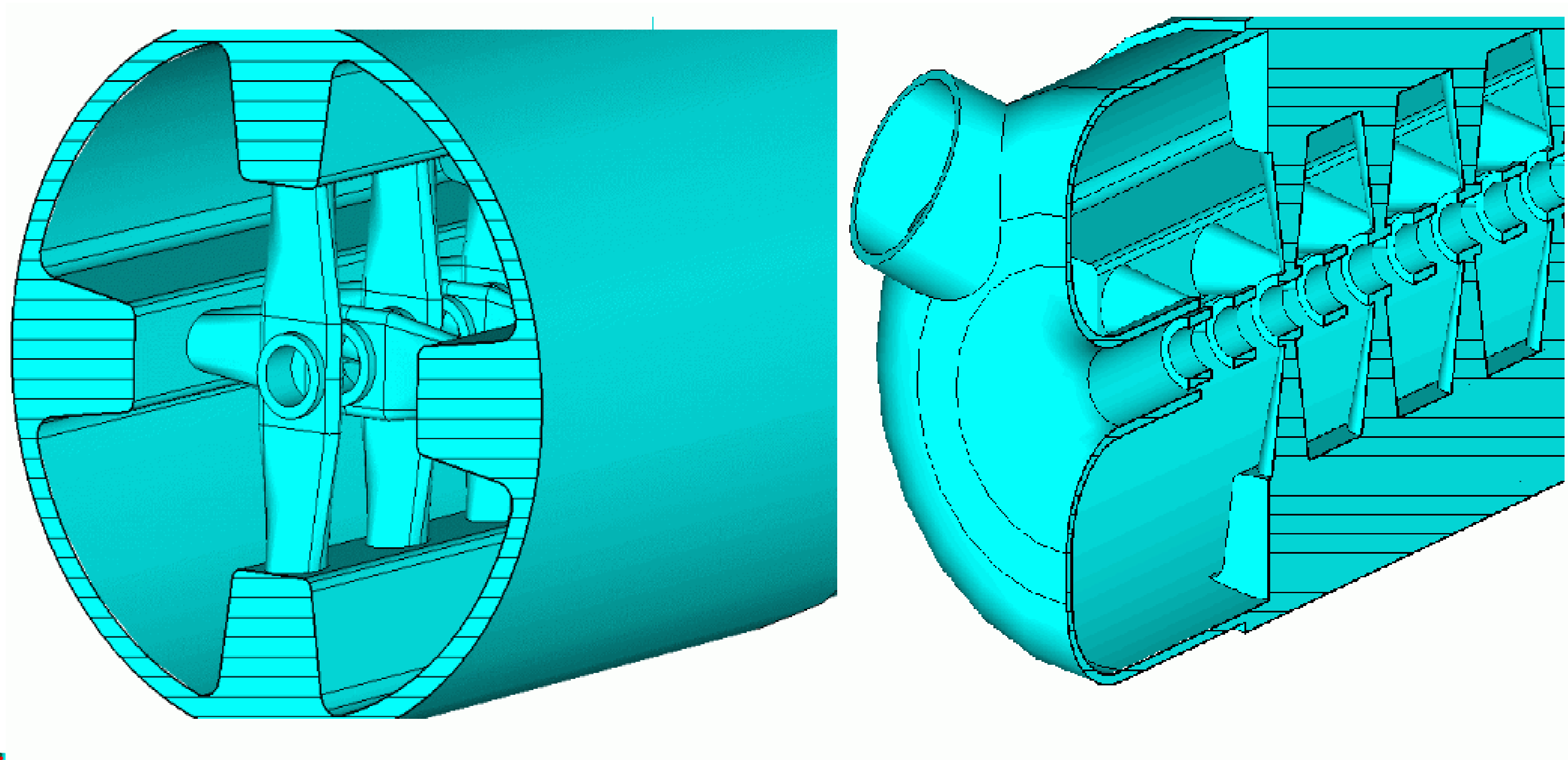




Alternate Designs

University of Frankfurt: CH structure

β=0.1, 175/350 MHz, H_{210} mode



Summary

- All groups active in the field presented their work and shared their approaches on the details of the spoke resonator design process and related issues
- Open technical discussion provided a good understanding of details
- A lot of ''dos and dont's'' that normally are not published, were shared
- Recent successes by all groups were clearly related to the introduction of high cleaning standards to these structures (BCP, EP and HPR)
- Importance of multi-gap spokes acknowledged (better E_{real}), may be of limited benefit, if failure tolerance is an issue

Outlook

- Proof-of-principle has been done for a variety of different resonators
- What is still missing is
  - a high power demonstration
  - demonstration of a spoke resonator operation with beam
- Further issues that have not been sufficiently addressed:
  - High power coupling,
  - HOMs,
  - 3D-Multipacting simulations,
  - Applicable β-range

Acknowledgments

- Jean Delayen and Ken Shepard for the constant support in advancing the understanding of low-β structures
- All presenters and participants in the discussions that openly shared their knowledge to benefit the community
- Ken Shepard, Jean Delayen, Brian Rusnak, Dale Schrage and Tsuyoshi Tajima for helping in structuring the workshop to cover all that is important