HOMs in Spokes
Are They a Problem?

Spoke Workshop
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- **Beam loading of HOMs**
- **HOMs in spokes and elliptical cavities**
- **Longitudinal & transverse stability analysis**
- **HOM damping requirements**
- **HOM damping techniques**

Beam Loading

- **Treat bunch as a point charge, q**
- **Single point charge induces a voltage**

$$V_q = \mp \frac{\omega_n R}{2Q} |q| \exp(i\omega_n t) \exp(-\frac{t}{T_d})$$

$$\frac{R}{Q} = \frac{\left| \int E_z(r,z) \exp(i\omega z / v) dz \right|^2}{\omega U}$$

- **Voltages induced in all higher order modes at their respective frequency**
- **Later bunches add via superposition, and thus see different voltages until equilibrium is reached (ie. cw beam)**
- **Worst case, on resonance with $T_b << T_d$**

$$V_b = V_q \frac{T_d}{T_b}$$

$$= \frac{R}{Q} Q_L I_o$$

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HOMs

- **Elliptical Cavities**
  - Axisymmetric, single/hollow conductor
  - Cylindrical waveguide modes
    - TE and TM modes
  - $TM_{010,\pi}$ for acceleration

- **Spoke Cavities**
  - Two conductor structure
    - Coaxial TEM modes
    - Coaxial TE and TM modes
    - Cylindrical waveguide modes
  - $\lambda/2$ (1^{st} TEM mode) for acceleration

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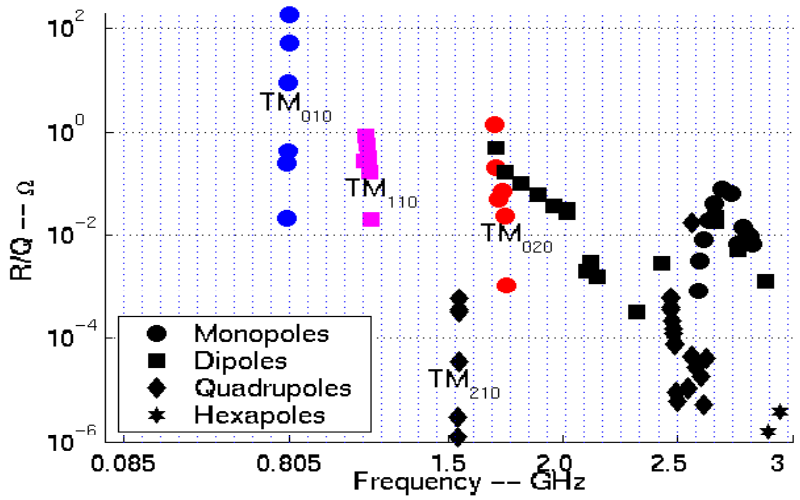
Shunt Impedance

- **Elliptical cavities**
  - Sacrifice R/Q for large aperture and tapered walls
  - All HOMs couple to the beam tubes

RIA 805 MHz β_g=0.47 six-cell (7.7 cm aperture)



- **Spoke cavities**
  - Higher shunt impedance for accelerating mode and HOMs
  - Smaller aperture
  - More difficult processing

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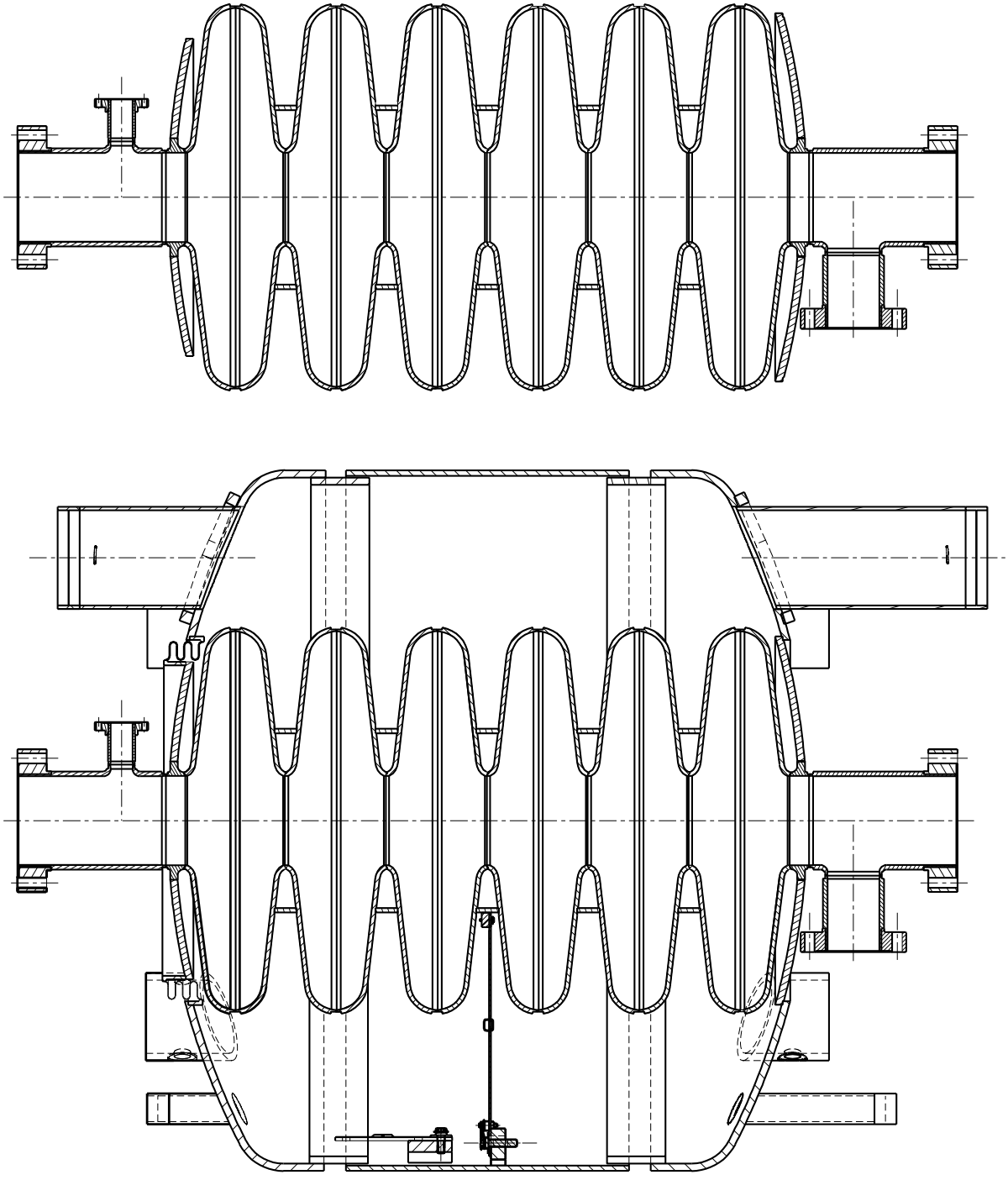
β=0.47 Final 6-Cell Prototype



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Instability Analysis

- **Multi-bunch, single pass**
  - **$\beta<1$ can have longitudinal or transverse instability**
- **Simulation with point charges**
  - **HOM frequency spread due to fabrication**
    - **SNS 0.02 % (standard deviation)**
  - **Focussing lattice**
  - **Cavity and magnet misalignment**
- **For a given Q_L track**
  - **Longitudinal voltage for each bunch**
  - **Transverse kick generated for each bunch**
  - **Track through lattice**
- **Determine acceptable Q_L**
  - **Emittance growth (long. and trans.)**
  - **Halo formation**
  - **Excessive cavity voltage**
  - **Excessive cryogenic power**

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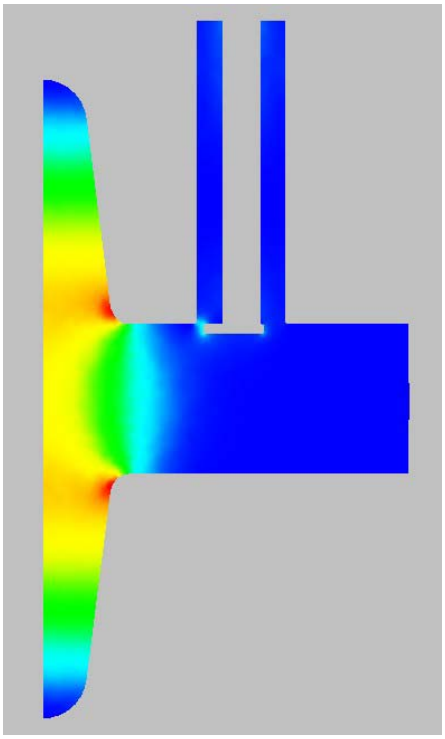
Instability Analysis - Examples

- **SNS (Sundelin et al, PAC01)**
  52 mA, 6% duty cycle

  β=0.61 & 0.81 six-cell 805 MHz
  HOM dampers must limit $Q_L<10^8$
  Cavity to cavity frequency variation
  Passband modes Q_L are as predicted

- **RIA (Grimm et al, EPAC02)**
  0.38 mA, cw

  β=0.47 six-cell 805 MHz
  Power coupler and pickup adequately damp HOMs without need for additional HOM couplers



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Damping Techniques

- **Increase damping of HOM (lower $Q_L=\omega U/Ptot$)**
  - Ptot=Po+Pcoupler+Ploss
  - Couple power out of cryogenics
    - Coaxial antenna with high pass filter
    - Rectangular waveguide
    - Ferrite load on beam pipe wall
- **Elliptical cavities**
  - HOMs field in beam pipe
    - Easy access, outside He vessel
  - Above cutoff propagate in pipe (low Q_L)
    - 7.7 cm aperture, high pass filter
    - TE11- 2.28 GHz, TM01- 2.97 GHz
- **Spoke cavities**
  - Power and transmission coupler
  - Additional couplers with filters
    - Lower Q_L
    - Trapped modes
  - Beam pipe has very high cutoff frequency

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HOM Measurements

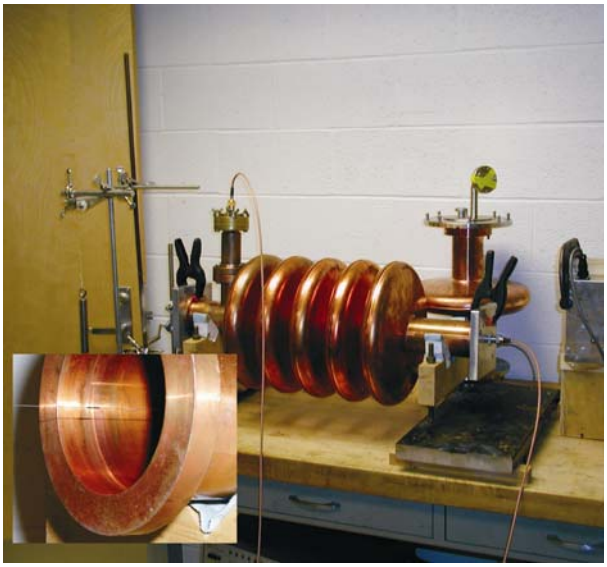


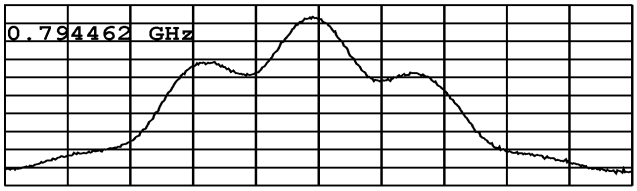
Table 1: Input power coupler Qext for single cell HOMs with penetration into beam tube of 5mm.

f	Qext	Type	*f*	Qext	Type
0.805[a]	$2.17\text{x}10^{6}$	TM010	**2.041**	$1.11\text{x}10^{4}$	TM120
1.154[b]	$9.58\text{x}10^{5}$	TM110	**2.270**	$6.40\text{x}10^{11}$	TM410
1.547	$1.58\text{x}10^{8}$	TM210	**2.476**	$3.10\text{x}10^{5}$	TM220
1.725[c]	$3.41\text{x}10^{5}$	TM020	**2.591**	$2.43\text{x}10^{4}$	TE211
1.897	$6.30\text{x}10^{3}$	TE111	**2.627**	$5.61\text{x}10^{3}$	TM030
1.939	$1.93\text{x}10^{4}$	TM310	**2.720**	$3.90\text{x}10^{2}$	TM121

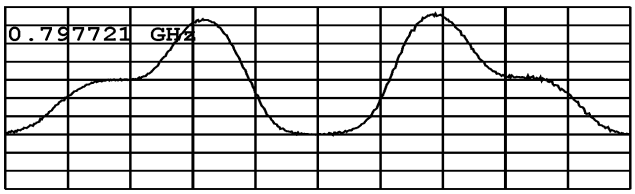
Qext results confirmed experimentally:
(a) $2.82\text{x}10^{6}$ *(b)* $1.53\text{x}10^{6}$ *(c)* $4.42\text{x}10^{5}$

$|E_Z(r,z)|^2$ TM_{010} 5 CELL measurements

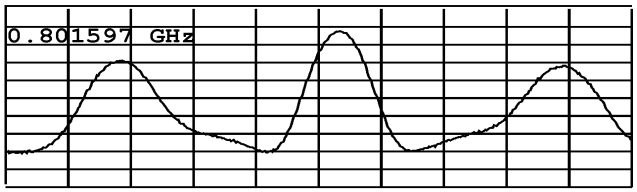
$\pi/5$ - mode (1)



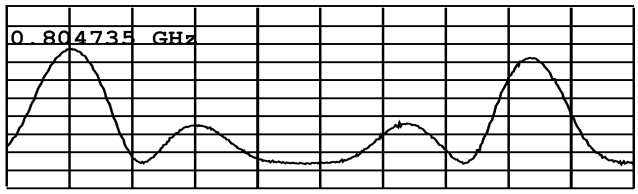
$2\pi/5$ - mode(2)



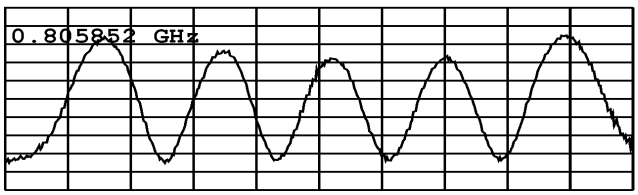
$3\pi/5$ - mode(3)



$4\pi/5$ - mode(4)



$5\pi/5$ - mode(5)



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Conclusion -- HOMs

- **HOM damping is required for many accelerators**

- **Elliptical cavities**
  - **Demonstrated solutions**
  - **Power & HOM couplers on beam pipe outside Helium vessel**

- **Spoke cavities (single and multi-spoke)**
  - **Implement same techniques as elliptical**
  - **Location of couplers may be problematic**
  - **Large HOM frequency range to damp due to small beam pipe**