# STUDIES FOR THE SPL AT CERN

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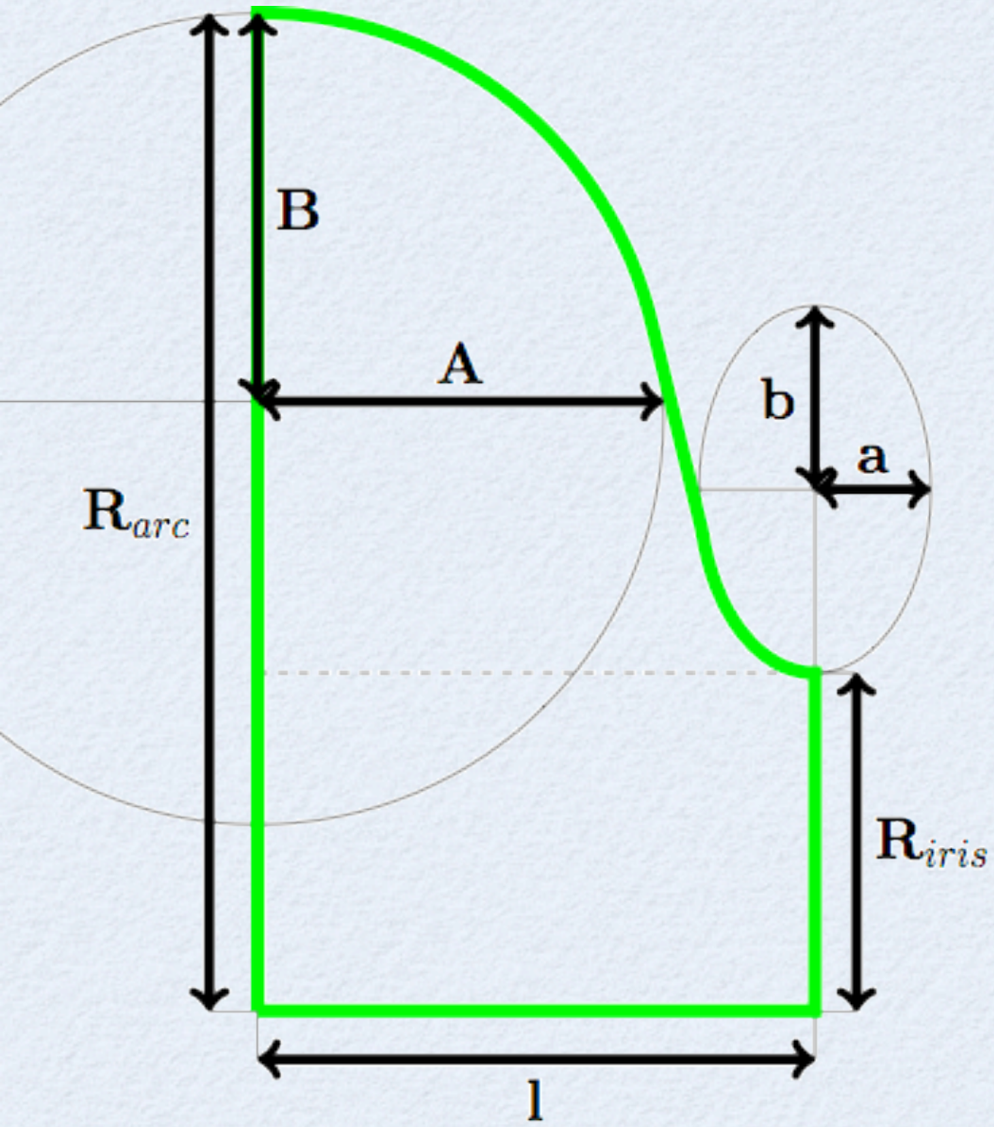
# OUTLINE

- Cavity models,  found HOMs
- Simulation setup
- Monopole modes
- Dipole modes
- Conclusions & Outlook

# CAVITY GEOMETRY

Cavitiy shapes at 704.4MHz (symmetrical):




| | Medium β | | High β | |
|---|---|---|---|---|
| 5 Cells | mid | end | mid | end |
| β | 0.658 | | 1.0 | |
| $R_{arc}$ [mm] | 186.4 | | 190.8 | |
| $R_{iris}$ [mm] | 45 | 45 | 64.6 | 70 |
| $l_{cell}$ [mm] | 70 | 70 | 106.47 | 103.07 |
| A [mm] | 45.1 | 45.06 | 77.5 | 76.89 |
| B [mm] | 45.1 | 49.56 | 77.5 | 74.45 |
| a [mm] | 12.14 | 12.11 | 22.1 | 18.5 |
| b [mm] | 15.79 | 15.74 | 35.1 | 24.9 |

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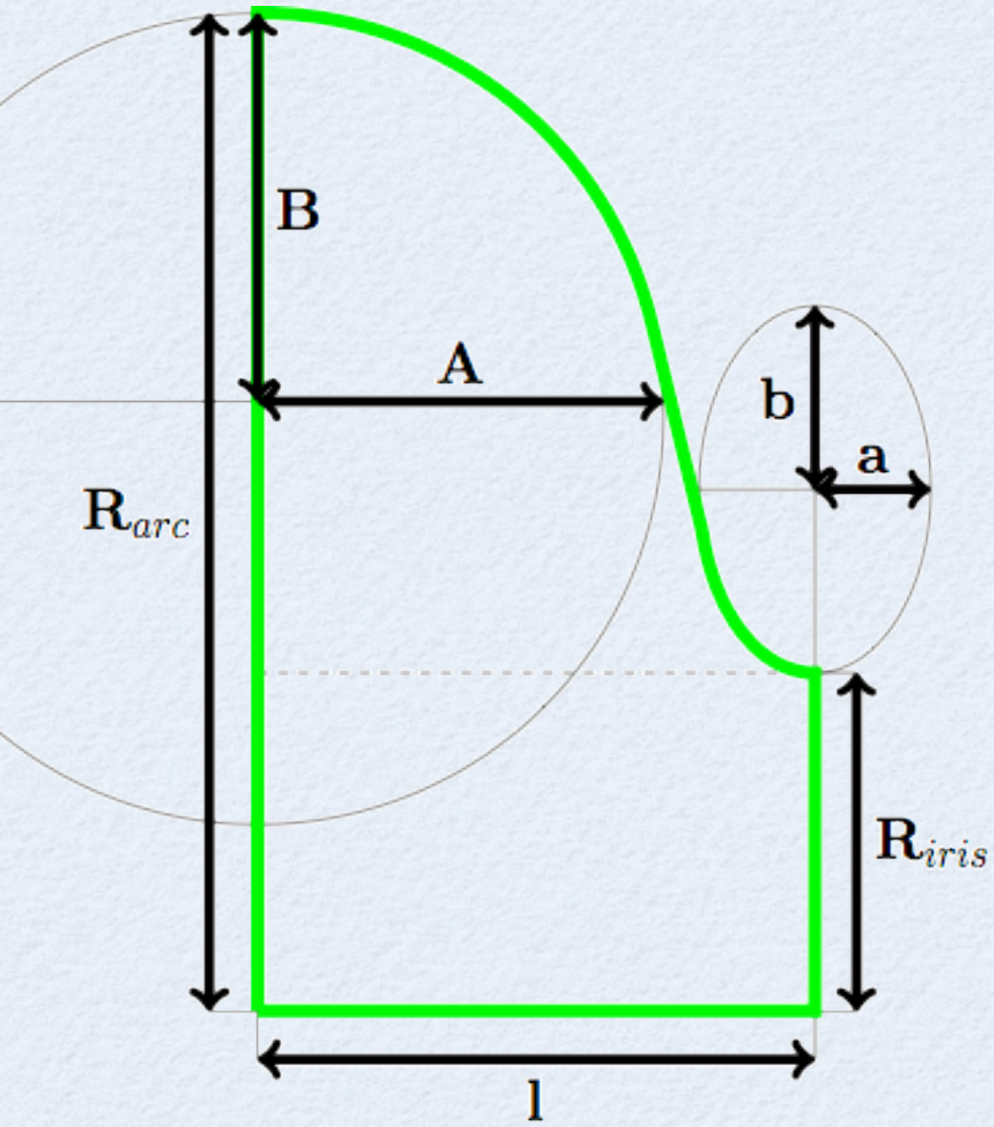


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Preliminar

# MONOPOLE MODES

| β | Mode | f [MHz] | HFSS (R/Q)† [Ω] | Superfish (R/Q)† [Ω] |
|---|---|---|---|---|
| 0.65 | $TM_{010}$ 4/5π | 703.7 | 1 | 1 |
| **0.65** | **$TM_{010}$ π** | **704.4** | **318** | **330** |
| **0.65** | **$TM_{011}$ 3/5π** | **1765** | **3** | **4** |
| 0.65 | $TM_{010}$ 4/5π | 1774 | 4 | 3 |
| 0.65 | $TM_{01}$ cuttoff | 2550 | | |
| **1** | **$TM_{010}$ π** | **704.4** | **525** | **562** |
| 1 | $TM_{011}$ 4/5π | 1328 | 37 | 36 |
| **1** | **$TM_{011}$ π** | **1332** | **137** | **135** |
| 1 | $TM_{021}$ | 2090 | 25 | 21 |
| 1 | $TM_{01}$ cuttoff | 1639 | | |

†linac definition

# DIPOLE MODES

| β | Mode | f [MHz] | HFSS (R/Q)† [Ω] |
|---|---|---|---|
| 0.65 | $TM_{110}$ 2/5π | 1020 | 19 |
| **0.65** | **$TM_{110}$ 3/5π** | **1027** | **28** |
| 0.65 | $TM_{110}$ 4/5π | 1033 | 6 |
| 0.65 | $TE_{111}$ 1/5π | 1270 | 13 |
| 0.65 | $TE_{11}$ cuttoff | 1952 | |
| 1 | $TE_{111}$ 3/5π | 915.1 | 18 |
| **1** | **$TE_{111}$ 4/5π** | **939.8** | **33** |
| 1 | $TE_{111}$ π | 966.4 | 13 |
| 1 | $TM_{110}$ 3/5π | 1014 | 19 |
| 1 | $TE_{11}$ cuttoff | 1255 | |

†linac definition

# BASIC LINAC MODEL

- Drift kick model with **exact** cavity spacing
- $E_0T(\beta)$ via field integration (**only sync. particle**)
- Phase and field controlled individually for each cavity
- Transfer matrix between cavities (transverse) using phase advance per period (**no. magnets modeled**)
- Longitudinal and transverse plane are independent

➡ Bunch (point charge)/particle tracking without space charge effects

# BASIC HOM MODEL

- One HOM per cavity (Monopole or Dipole)
- Gaussian or uniform HOM frequency distribution with no change over time
- **const. R/Q** in all cavities (section) - no β changes
- Global $Q_{ex}$

➡ **Load HOM via bunch tracking**
**(Bunch ⇔ HOM interaction)**

# BEAM INPUT PARAMETERS

## Basic beam settings used in all simulations:

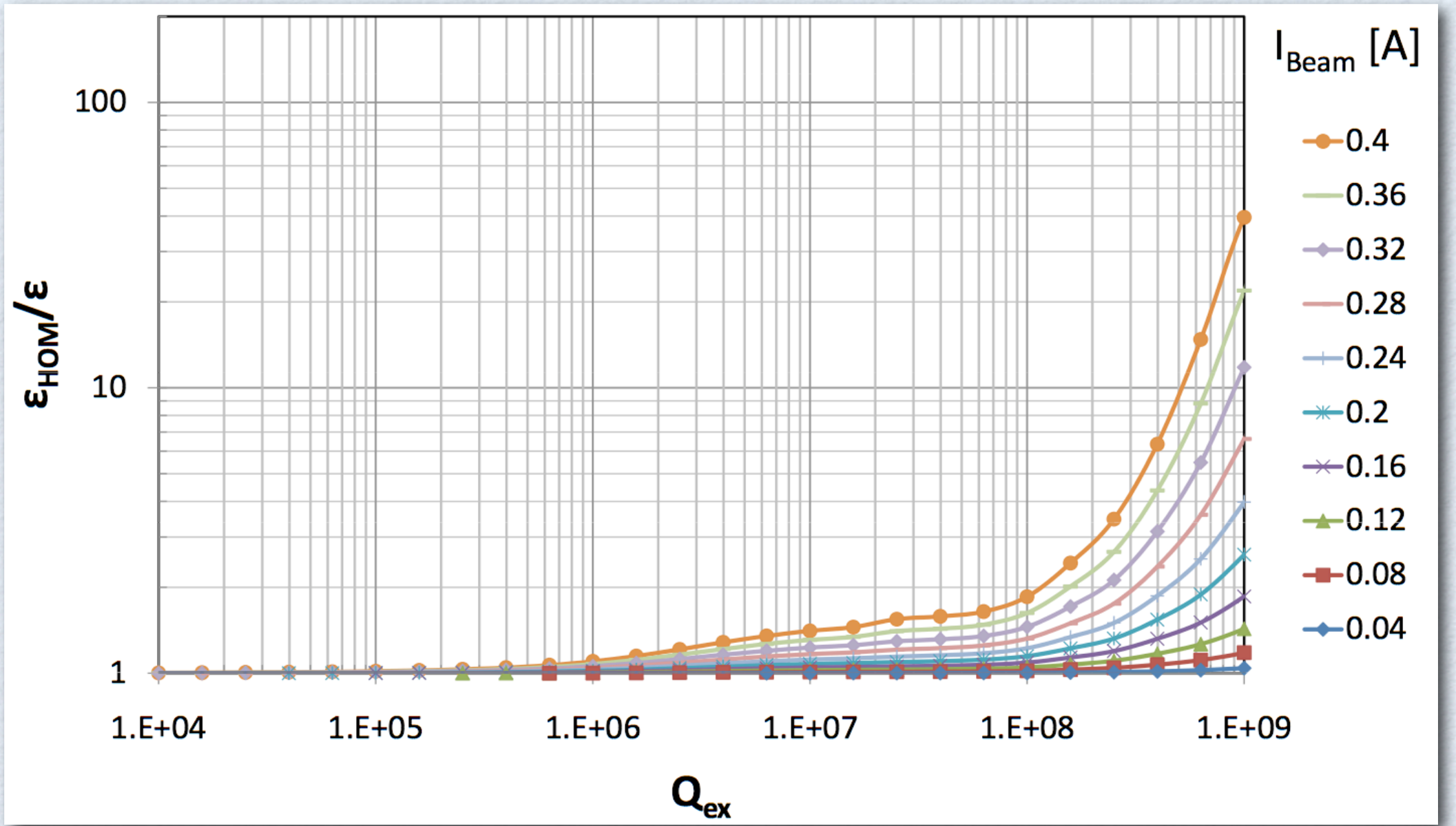
| Parameter | Mean | Variance | Simulation |
|---|---|---|---|
| **Bunch period [ns]** | $1/f_b \approx 3$ | 0.00315 | long |
| **Pulse length [ms]** | 1.0 | 0 | both |
| **Period length [ms]** | 20 | 0 | both |
| **Beam current [mA]** | 40...400 | 10% | both |
| **$W_{Input}$ [MeV]** | 160 | 0.078 | long |
| **Tr. position [mm]** | 0 | 0.3 | trans |
| **Tr. momentum [mrad]** | 0 | 0.3 | trans |

**https://twiki.cern.ch/twiki/bin/view/SPL/SplHom**

# PARAMETER SWEEP

- Perform parameter sweeps:
  - Beam current: 40 - 400 mA
  - $Q_{ex}$: $10^4$ - $10^9$
- Compare phase space (ε) of one pulse (35000 bunches) with (loaded HOM) and without HOM interaction at the exit of the linac.

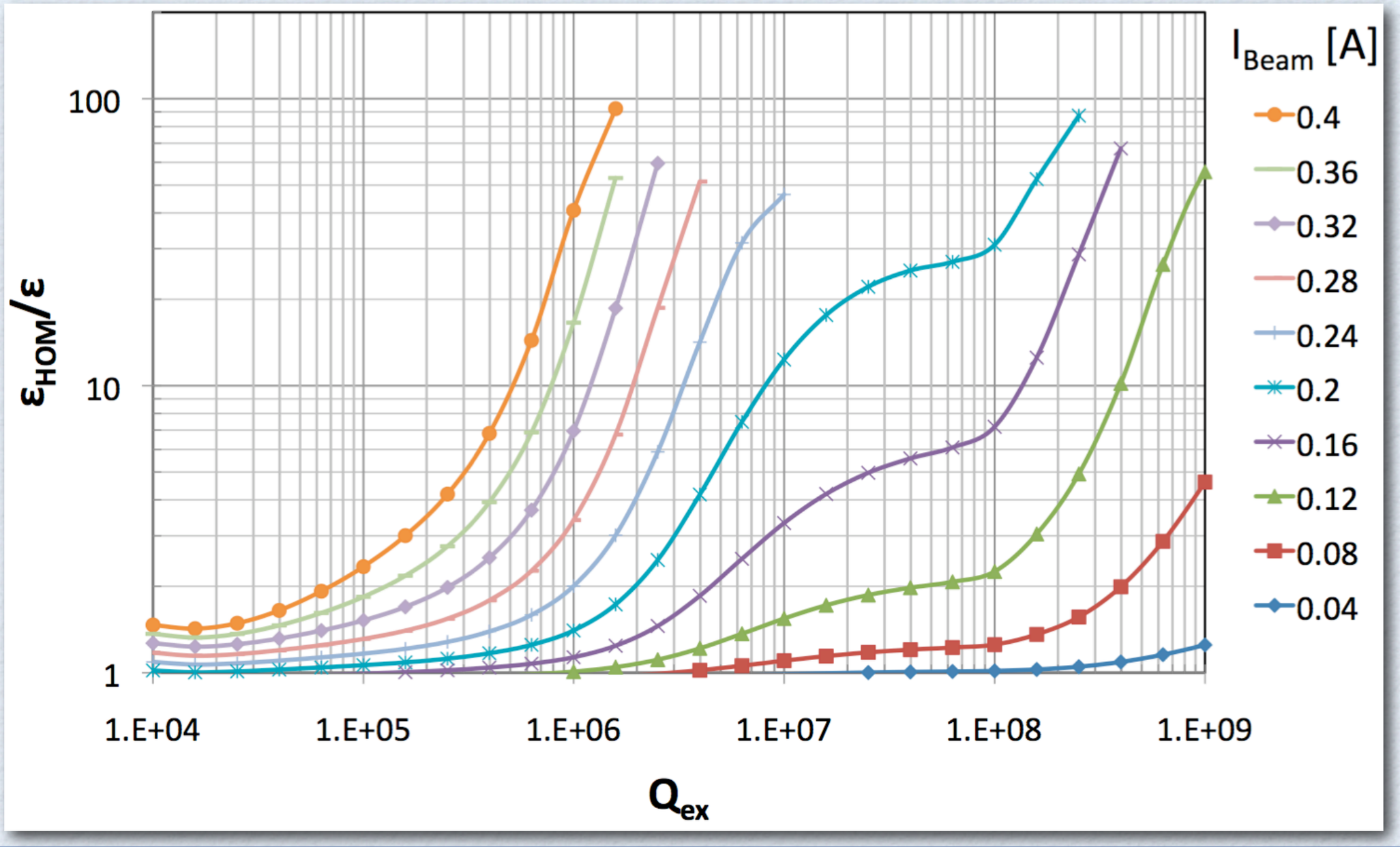
# LONGITUDINAL: CHARGE SCATTER




| $f_m$ [MHz] | $\sigma_f$ [MHz] | $R/Q_m$ [Ω*] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $R/Q_h$ [Ω*] |
|---|---|---|---|---|---|
| 1773 | 0.1 | 10 | 1331 | 0.1 | 150 |

* linac def.

# LONGITUDINAL: NEXT TO ML

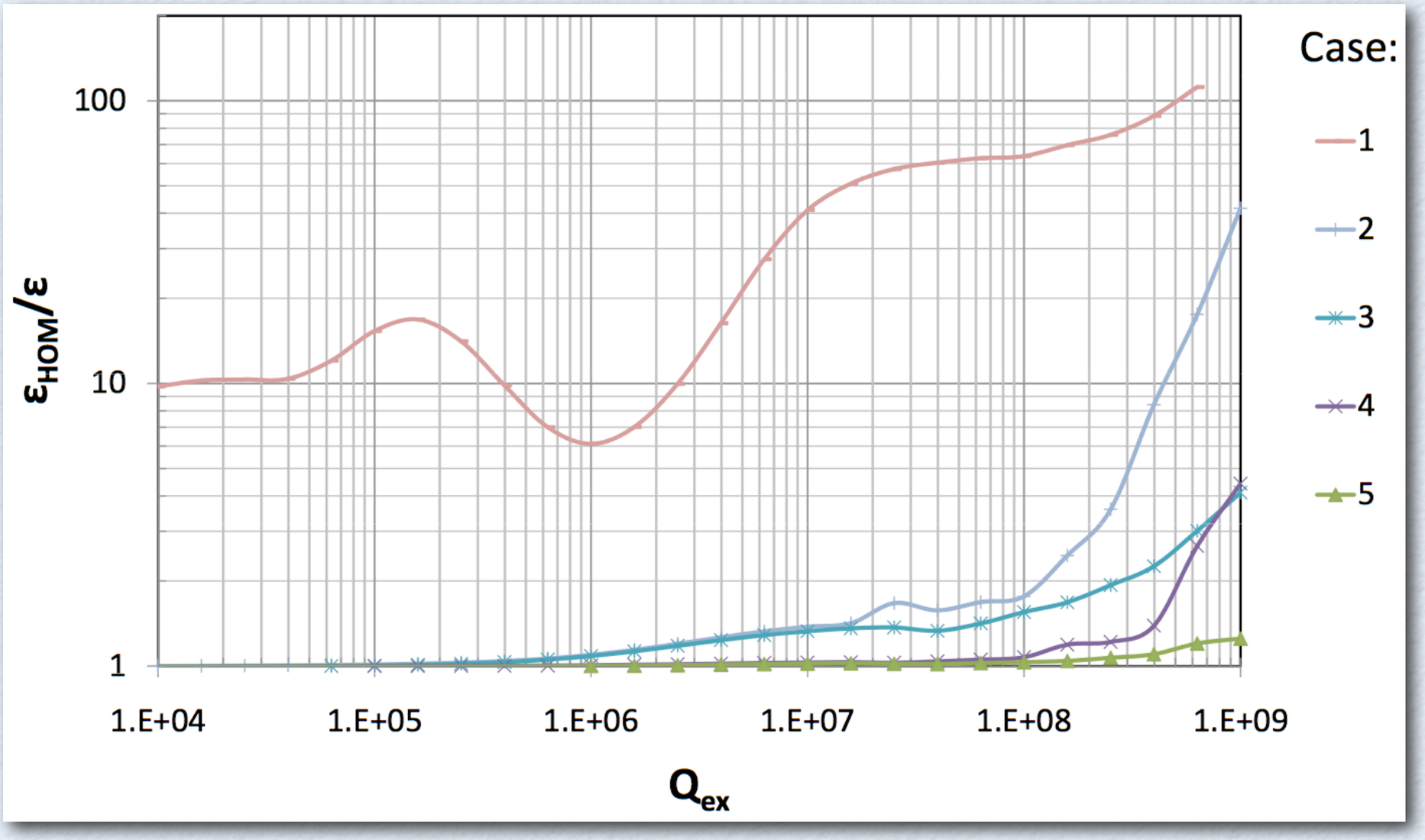



| $f_m$ [MHz] | $\sigma_f$ [MHz] | $R/Q_m$ [Ω*] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $R/Q_h$ [Ω*] |
|---|---|---|---|---|---|
| 2114 | 0.1 | 10 | 1760 | 0.1 | 150 |

* linac def.

# LONGITUDINAL

## Different cases with a 400 mA beam:

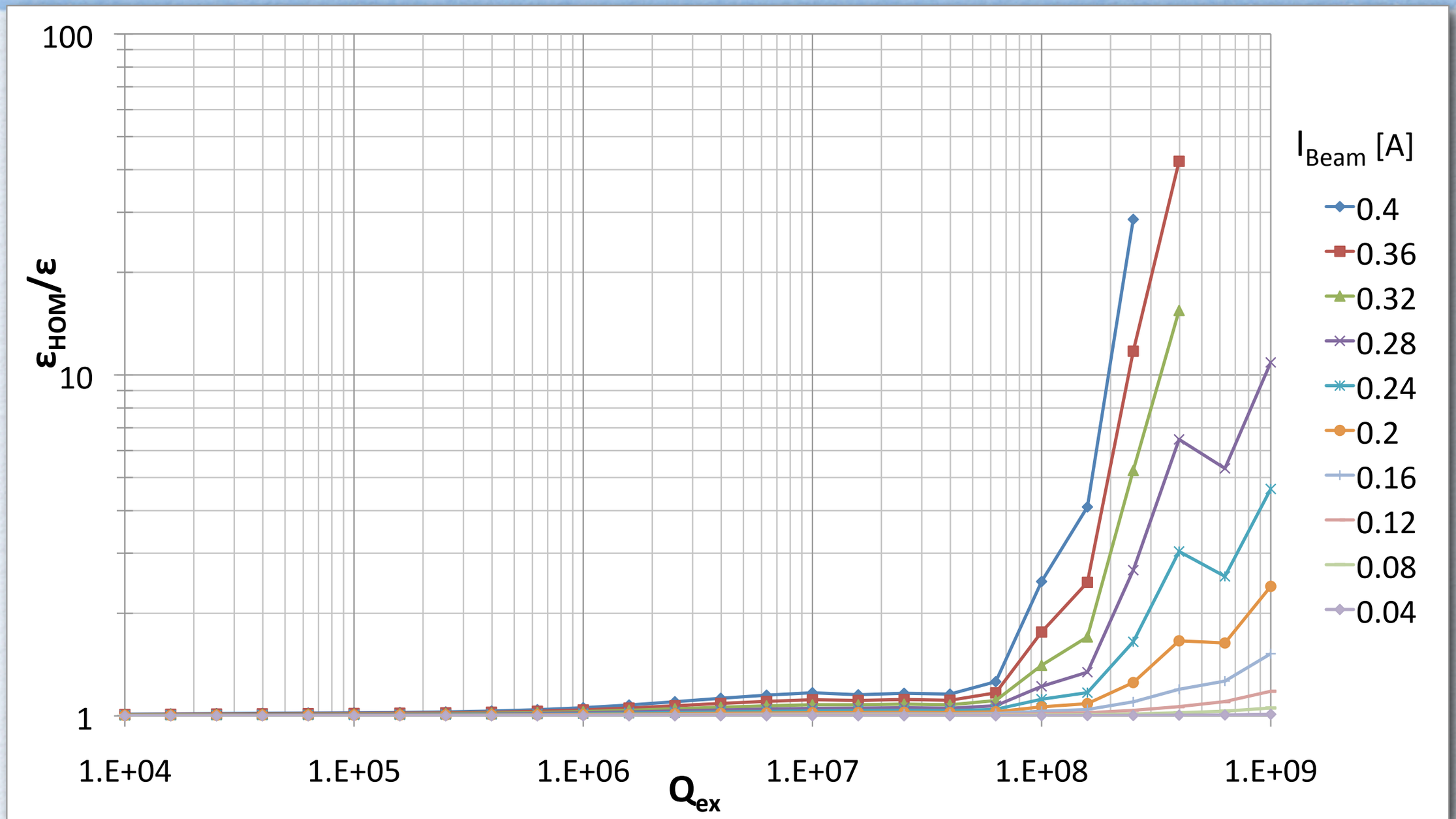



| $f_m$ [MHz] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $\sigma_l$ [A] |
|---|---|---|---|
| 2465.4 | 2817.6 | 3.0 | 0.04 |
| 1774 | 1332 | 0.1 | 0.04 |
| 1774 | 1332 | 3.0 | 0.04 |
| 1774 | 1332 | 0.1 | 0.0 |
| 1774 | 1332 | 3.0 | 0.0 |

| $R/Q_m$ [Ω*] | $R/Q_h$ [Ω*] |
|---|---|
| 10 | 150 |

* linac def.

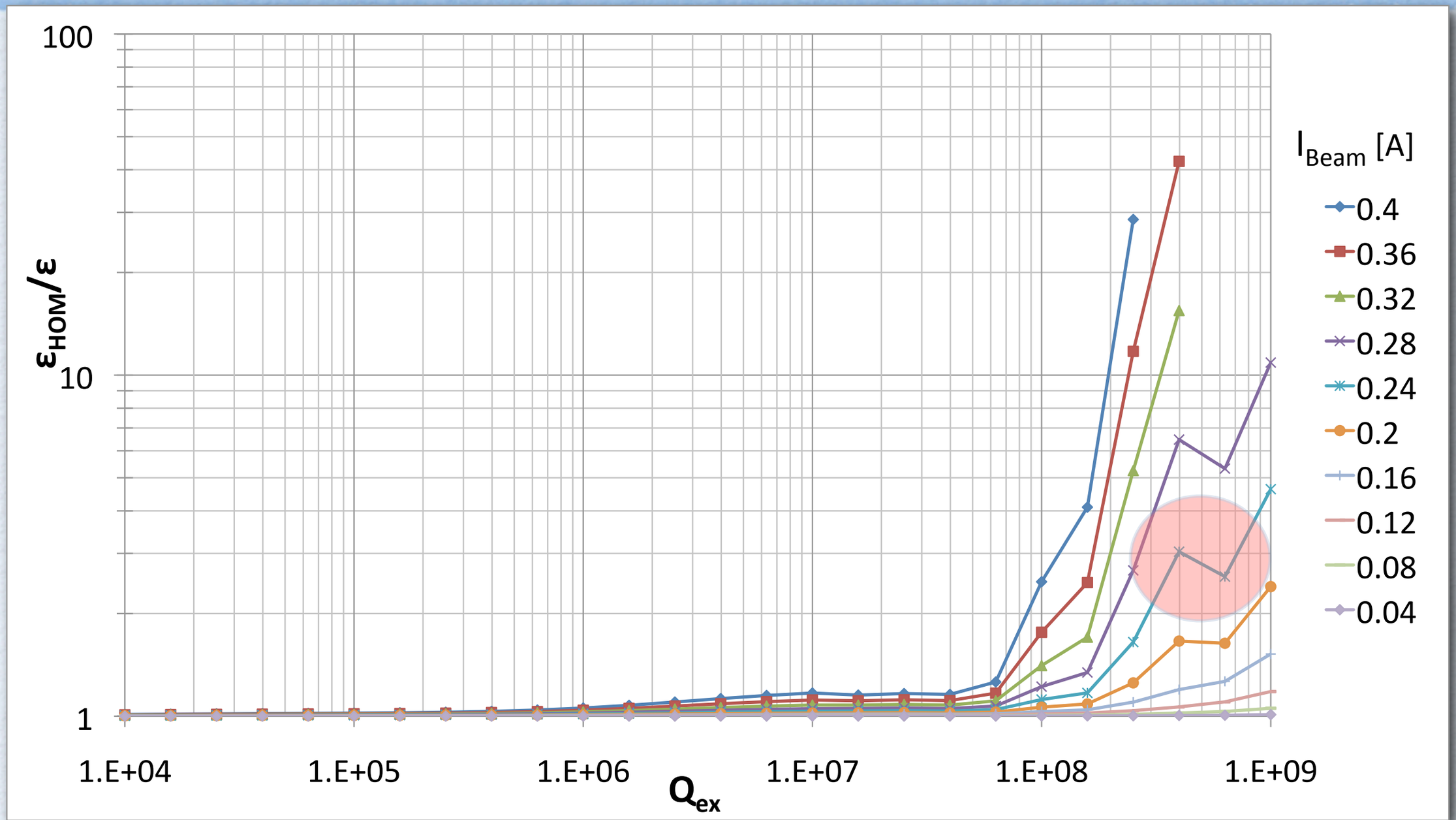
# TRANSVERSAL




| $f_m$ [MHz] | $\sigma_f$ [MHz] | $R/Q_m$ [Ω*] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $R/Q_h$ [Ω*] |
|---|---|---|---|---|---|
| 1026.7 | 0.1 | 60 | 939.8 | 0.1 | 70 |

* linac def.

# TRANSVERSAL

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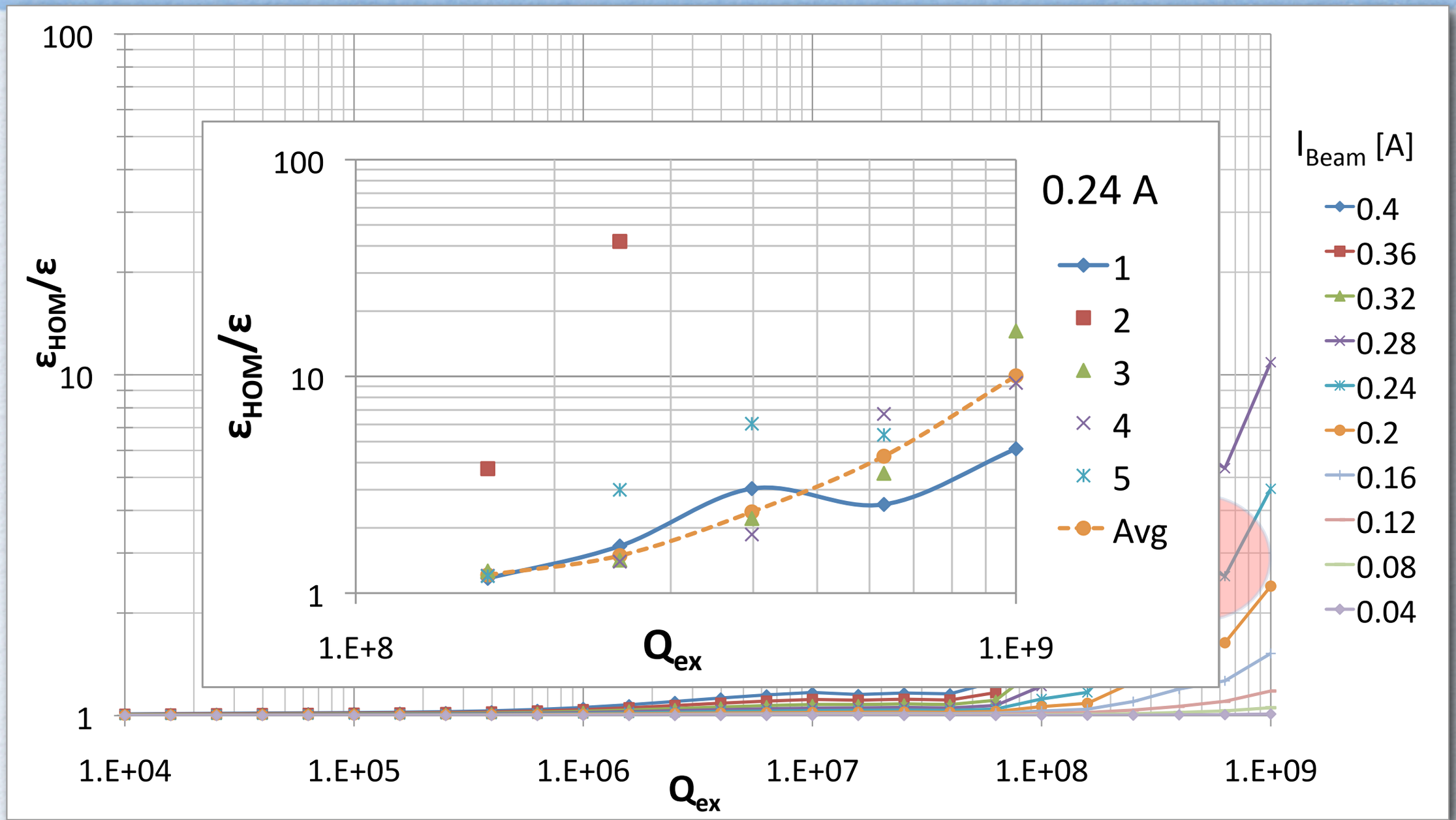
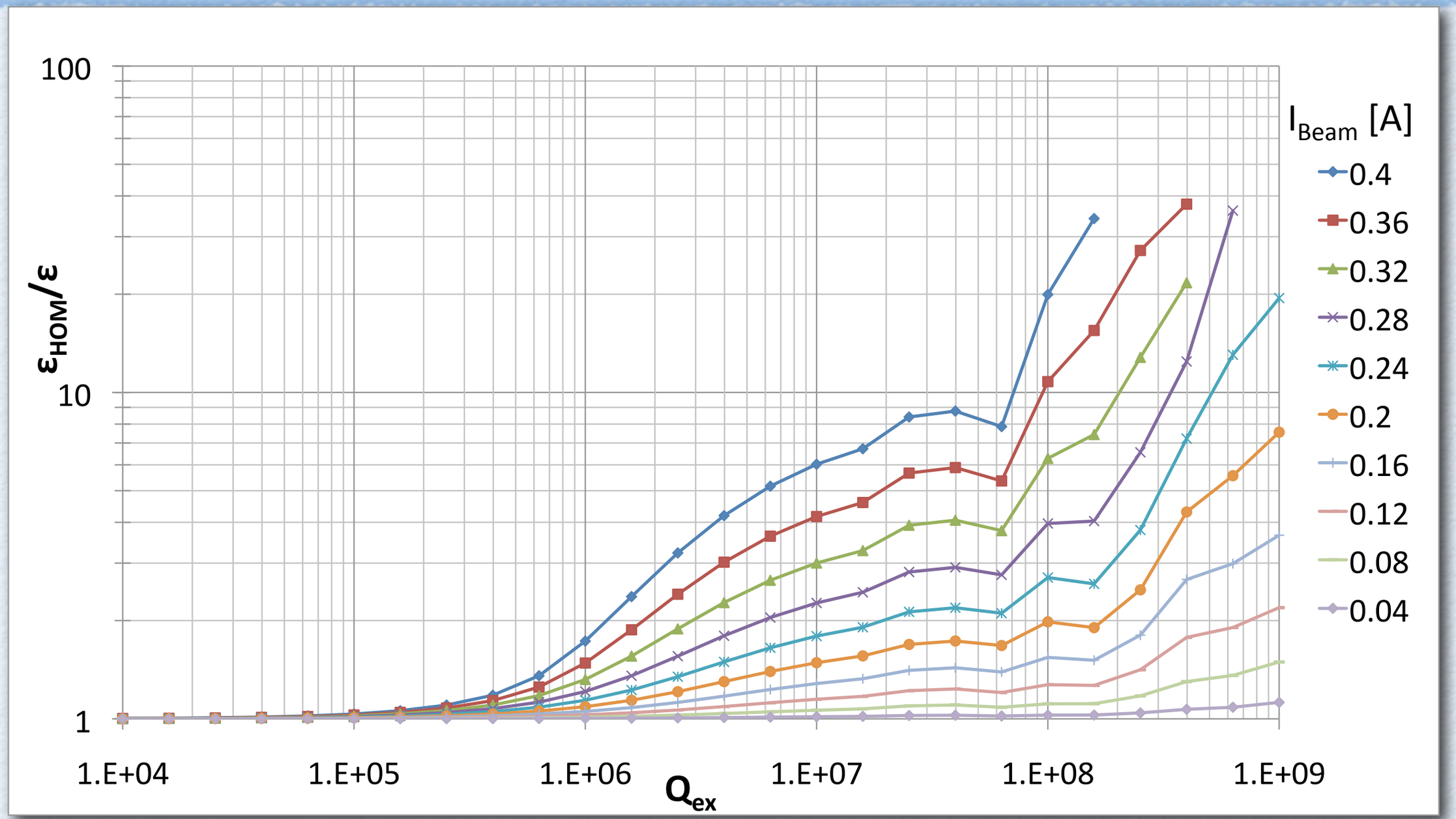



| $f_m$ [MHz] | $\sigma_f$ [MHz] | $R/Q_m$ [Ω*] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $R/Q_h$ [Ω*] |
|---|---|---|---|---|---|
| 1026.7 | 0.1 | 60 | 939.8 | 0.1 | 70 |

* linac def.

# TRANSVERSAL: ML




| $f_m$ [MHz] | $\sigma_f$ [MHz] | $R/Q_m$ [Ω*] | $f_h$ [MHz] | $\sigma_f$ [MHz] | $R/Q_h$ [Ω*] |
|---|---|---|---|---|---|
| 1761 | 3.0 | 60 | 2465.4 | 3.0 | 70 |

* linac def.

# RESULTS

## Effect of different parameters:

| Parameter | LONG | TRANS |
|---|---|---|
| frequency spread | ↘ | ↘ |
| machine lines | ↗ | ↗ |
| I · R/Q | ↗ | ↗ |
| charge scatter | ↗ | → |
| input phases pace | → | → |

# CONCLUSIONS

- Simulations show HOM damping seeming to be necessary in order to provide a high brilliance beam!
- **The limit of $Q_{ex}$ depend strongly on the input parameters and varies between $10^5$ and $10^8$ !**
- The input parameters have to be chosen carefully and should be discussed at this workshop!

# OUTLOOK

- Simulate influence of:
  - Several HOMs in one Cavity
  - Klystron and field errors
  - Chopped beam, different pulses
- Statistical simulations (>1000 linacs) with a set of realistic parameter

# QUESTIONS?

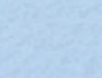
I do have some:

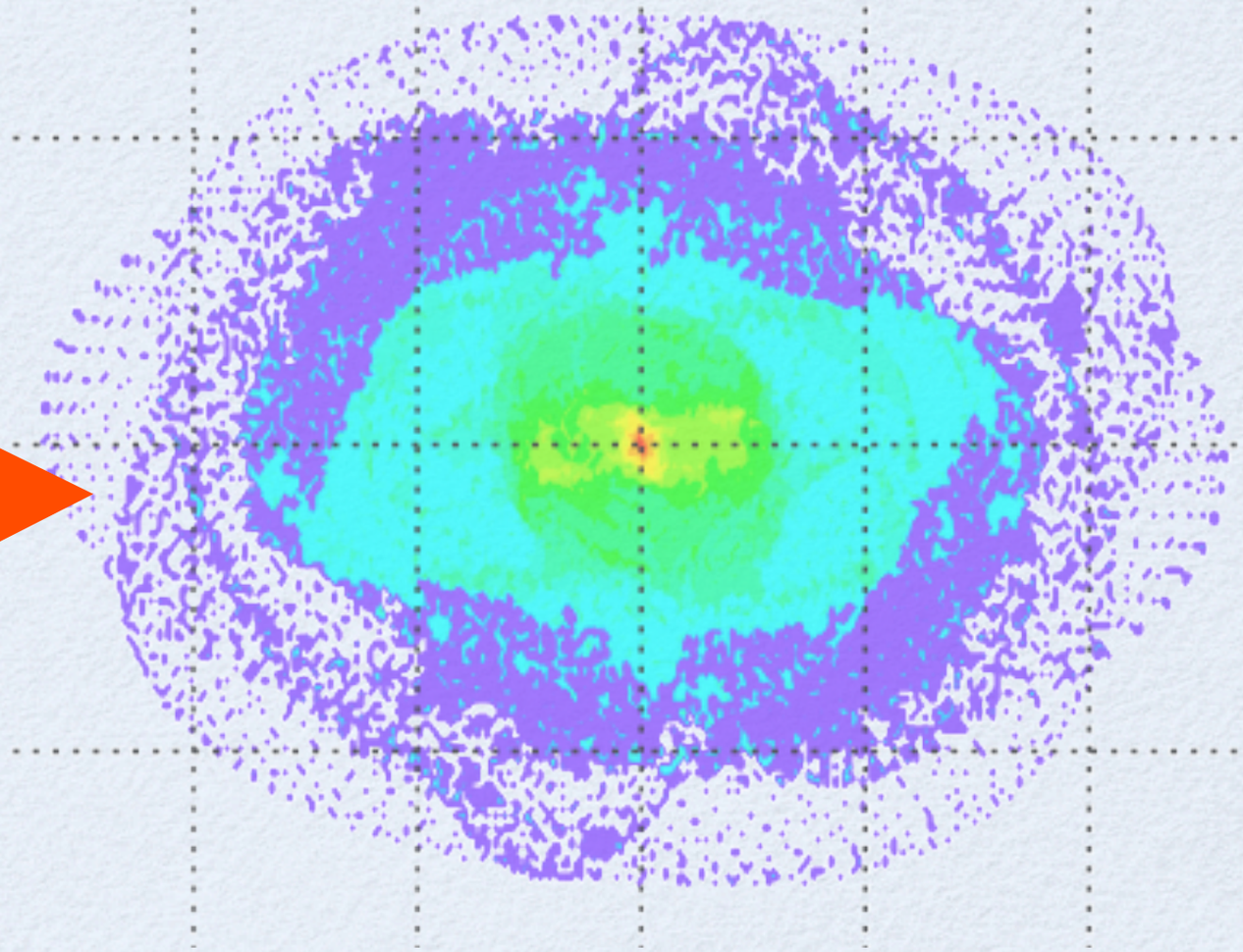
- Are the chosen input parameters realistic?
- Should the model improved in certain details?
- Are there any other aspects which should be investigated?

# TANK YOU!

Trying to prevent this:

**HOM**





# BEAM HOM INTERACTION

## Monopole modes:

- Each bunch sees half of its self-induced voltage $V_b$:
- Energy error caused by HOM:

$$dU_H = e\left(\Re(V_H)\cos(\omega_H dt) - \Im(V_H)\sin(\omega_H dt)\right) - \frac{1}{2}V_b$$

- Iteration over linac:

$$dE^{(n+1)} = dE^{(n)} + dU_{RF} + dU_H$$

$$dt^{(n+1)} = dt^{(n)} + (dt/dE)_E \cdot dE$$

# LONGITUDINAL BEAM DYNAMIC

- Particle velocity: $\beta < 1$
- Energy error causes arrival time / phase error:

$$dt = -\frac{L}{c \cdot m_0 c^2 \cdot (\gamma^2 - 1)^{3/2}} dE$$

- Phase error causes a different energy gain in next cavity:

$$dU_{RF} = eV^*_{RF} \cdot \cos(\phi_s + \omega_{RF} dt) - \Delta U$$

# TRANSVERSE BEAM DYNAMIC

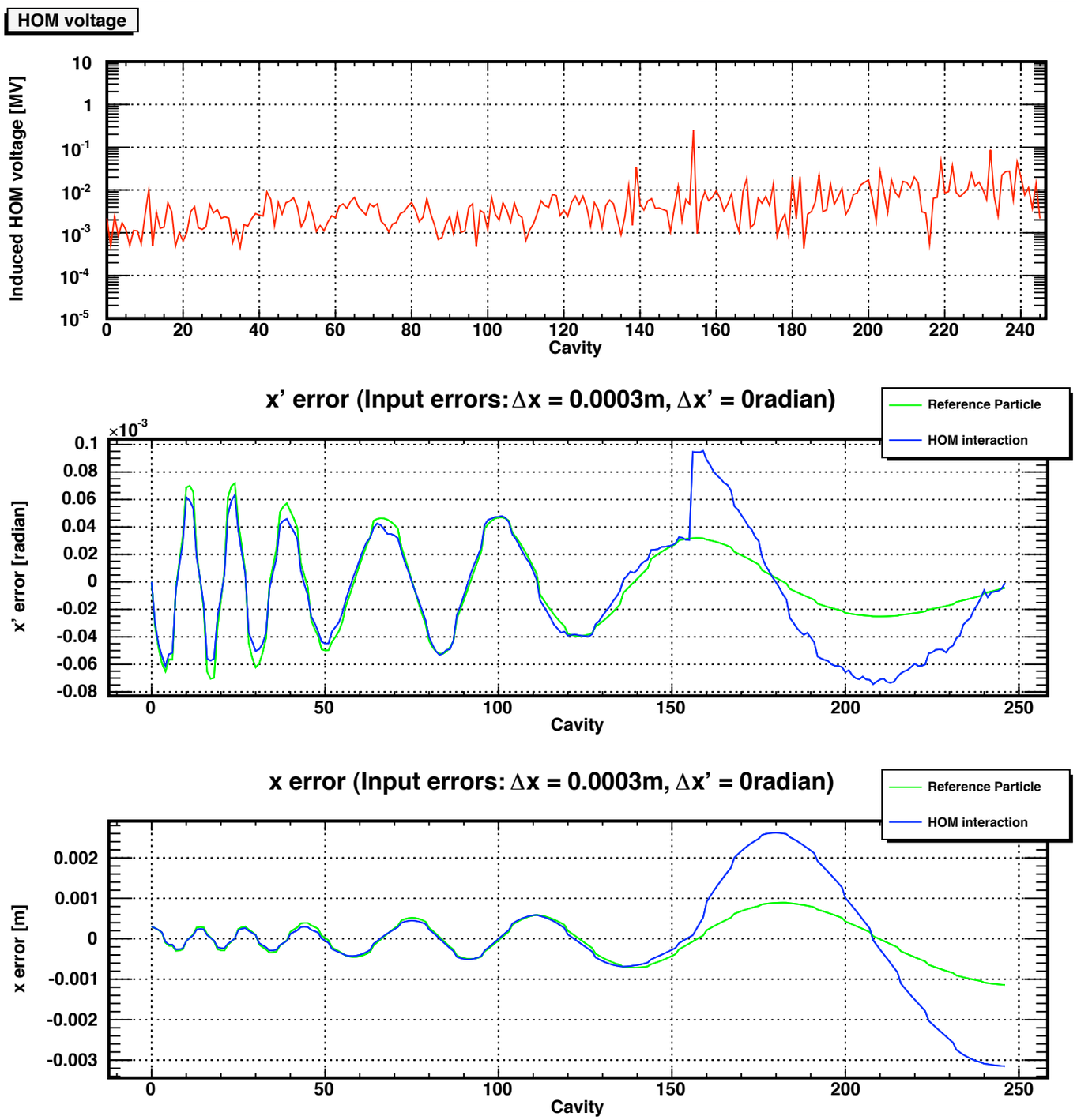
- Transfer Matrix between cavities
- Bunch induce a imaginary voltage:

$$\Delta V_\perp = ixq\frac{\omega^2}{c}(R/Q)_\perp$$

- HOM kicks bunch / particle - momentum change:

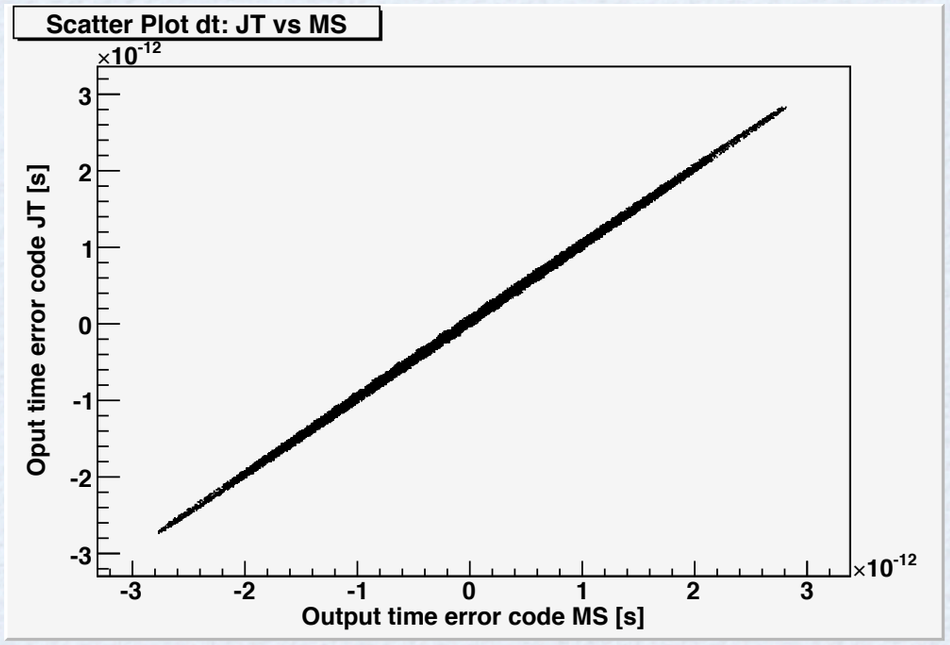
$$\Delta x' = \frac{e\Re(V_\perp)}{c \cdot p_\parallel}$$

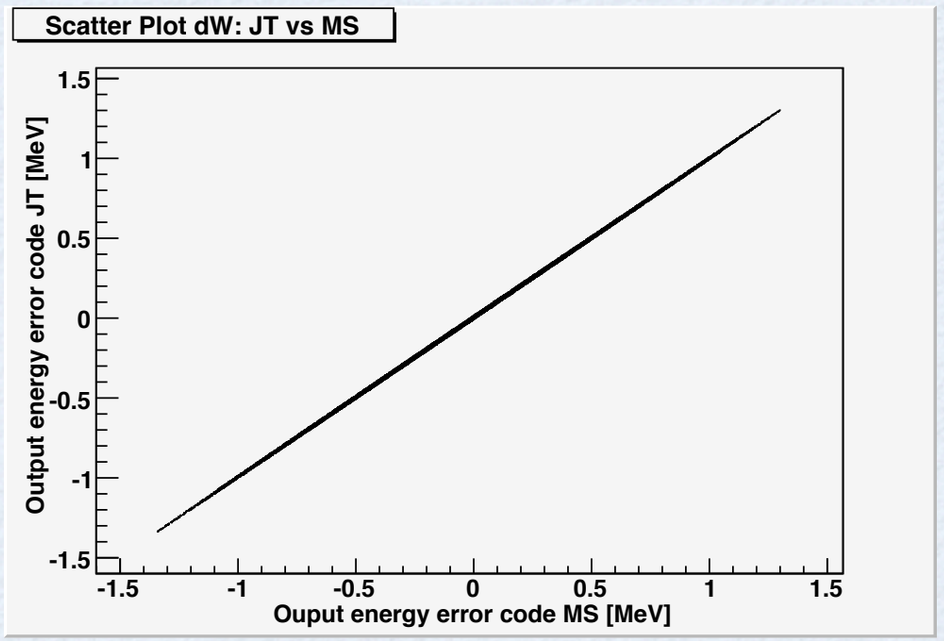
# OBSERVED DIPOLE KICK



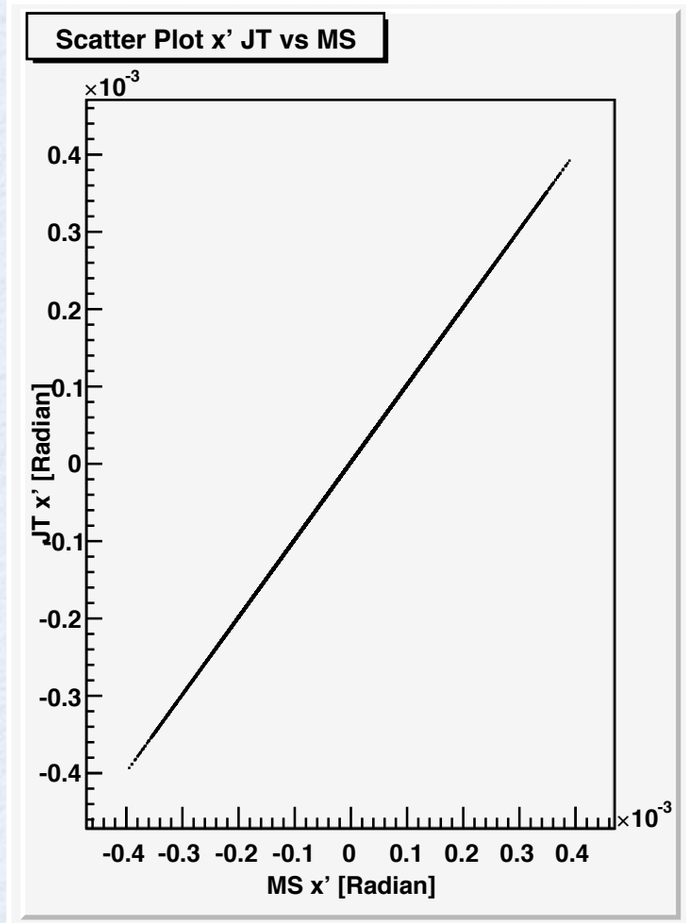
# CODE BENCHMARK

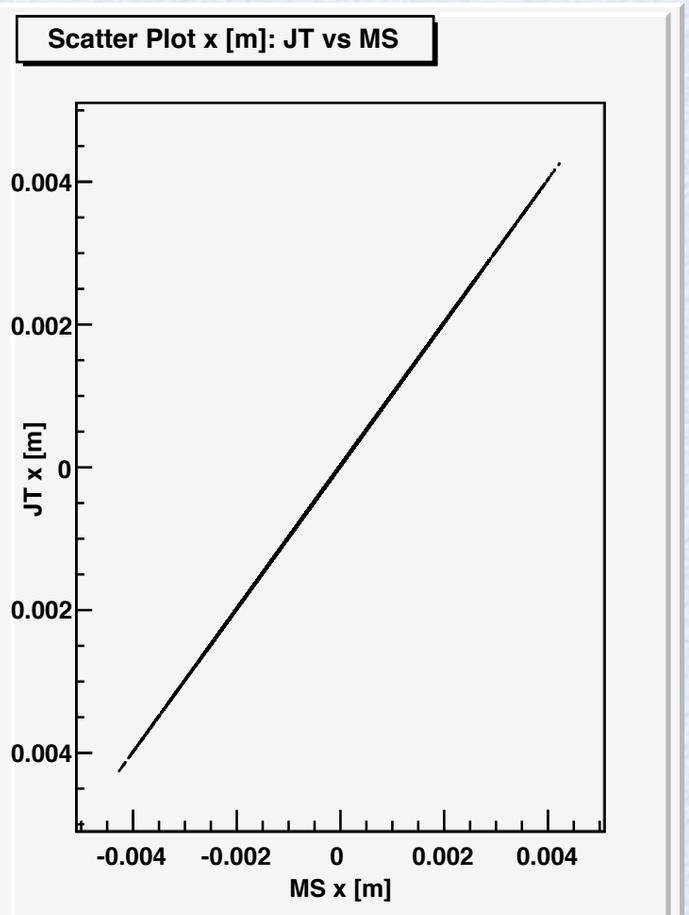
## Longitudinal:



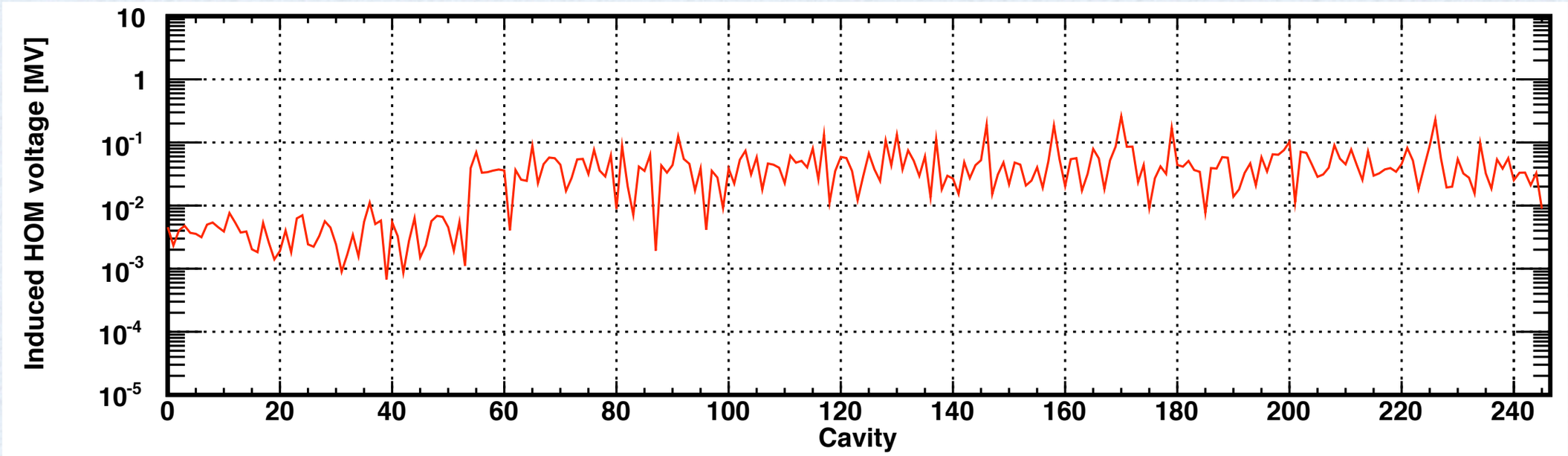

## Transverse:



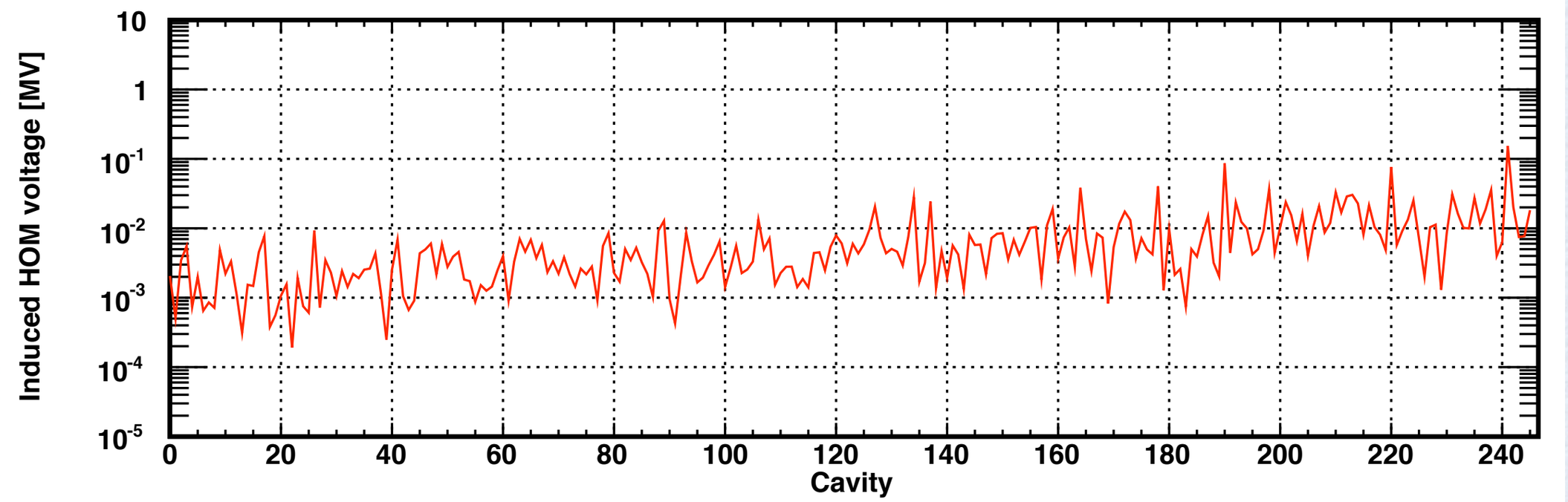



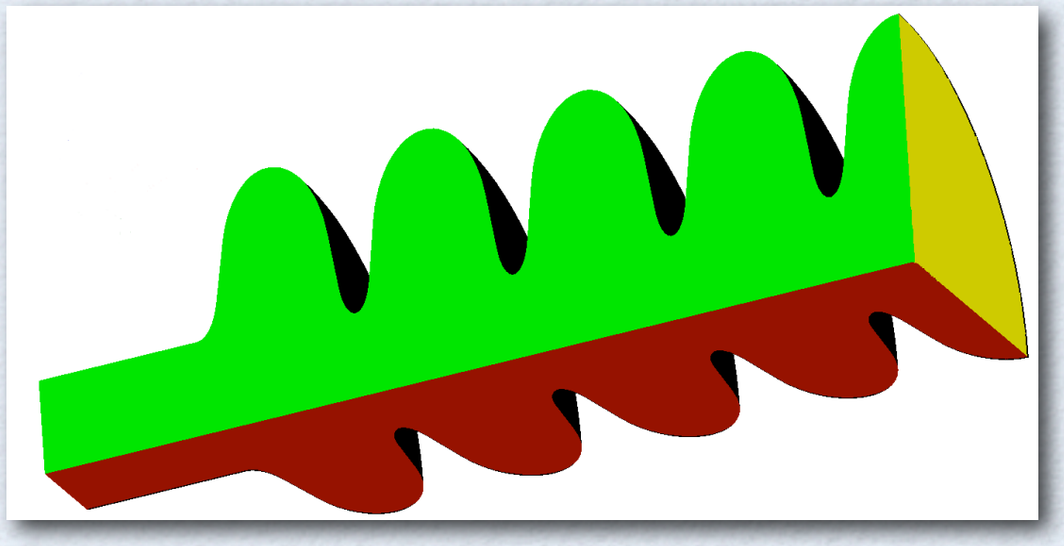
# HOM VOLTAGE DISTRIBUTION

**Mono-pole:**




**Dipole:**



# CAVITY MODELING

- 2d Superfish model
- 3d HFSS model
  - half cavity length
  - quarter rotation
  - boundary conditions