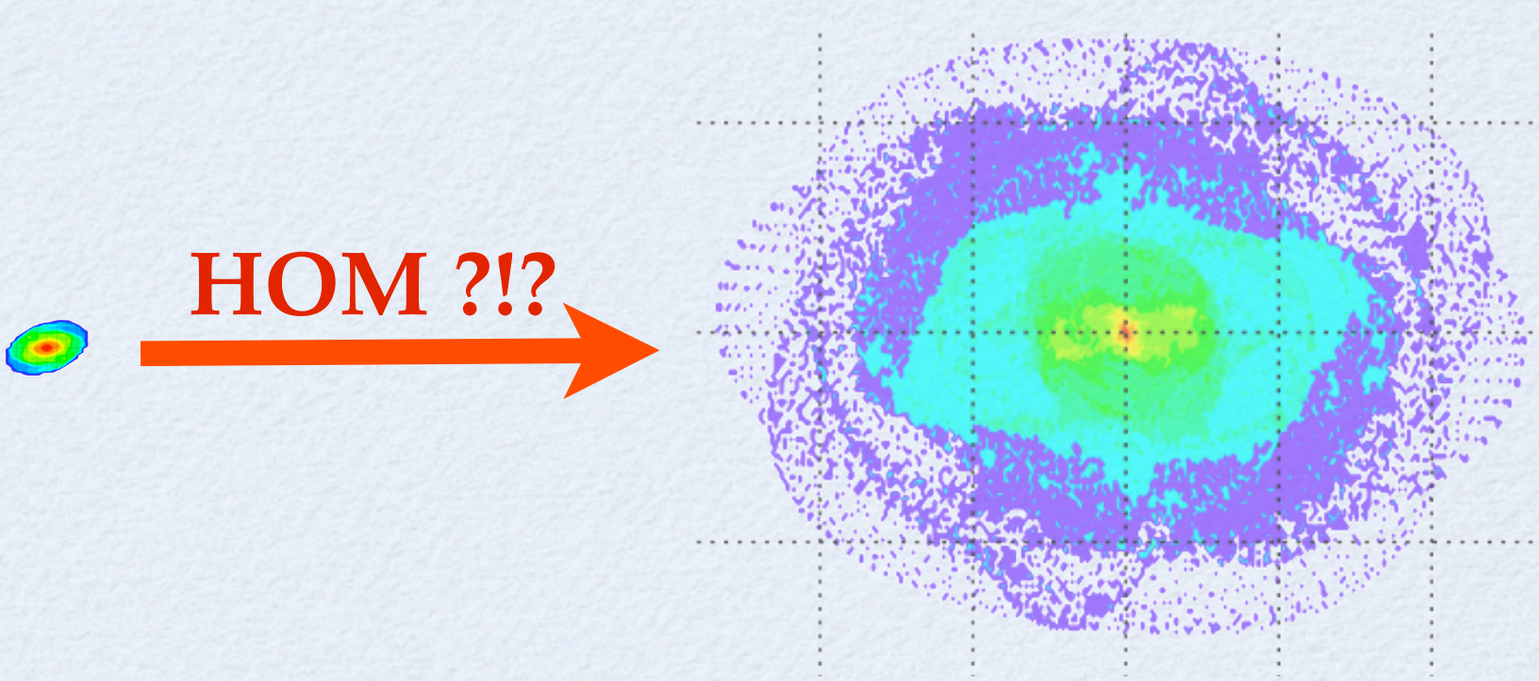
5th SPL collaboration Meeting

25-26.11.2010 at CERN

Latest results of HOM simulations



Marcel Schuh
CERN-BE-RF-LR
CH-1211 Geneva 23, Switzerland
marcel.schuh@quasar-group.org

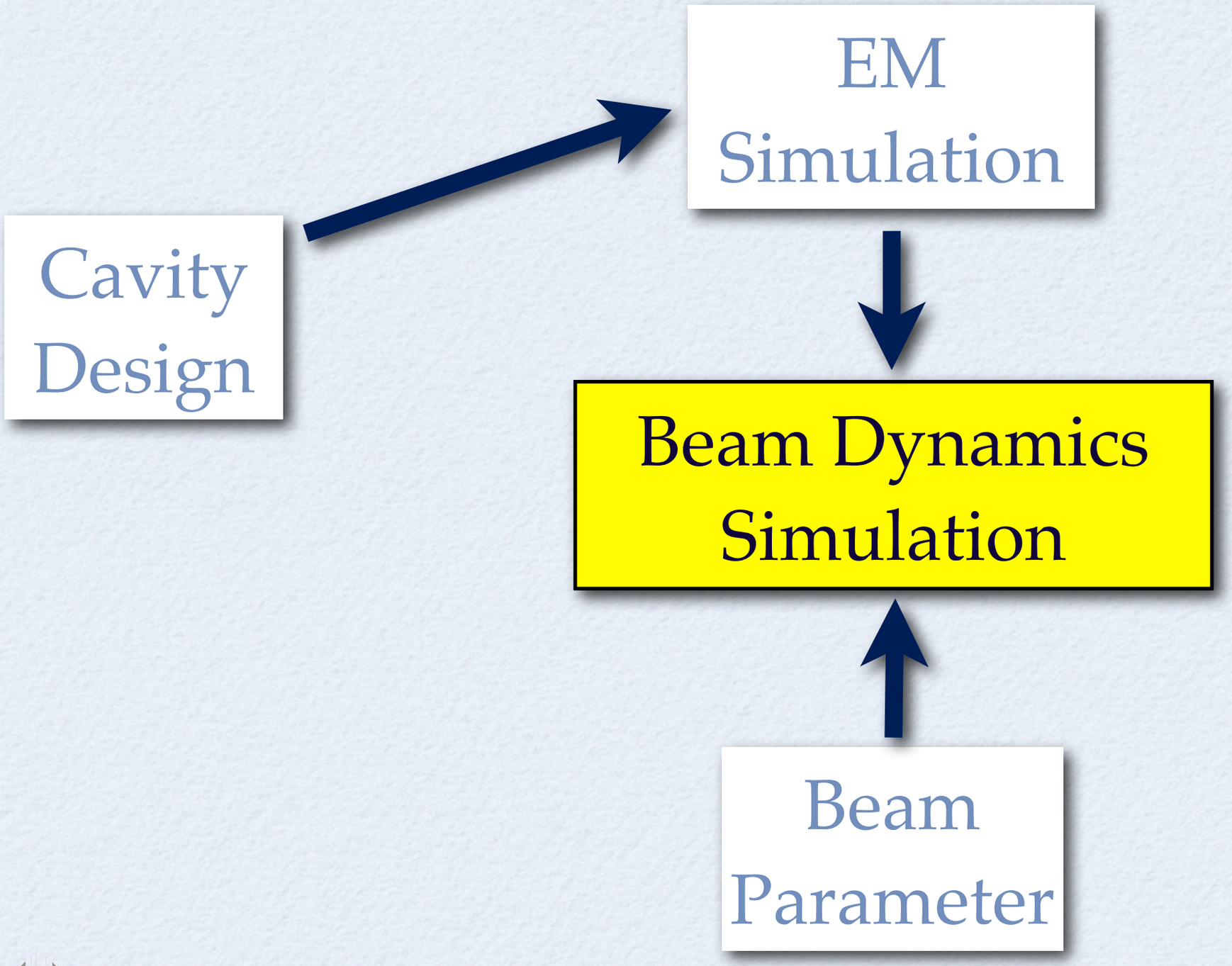
Outline

- Simulation tools and models
- General results
- SPL baseline cavities
- Conclusions

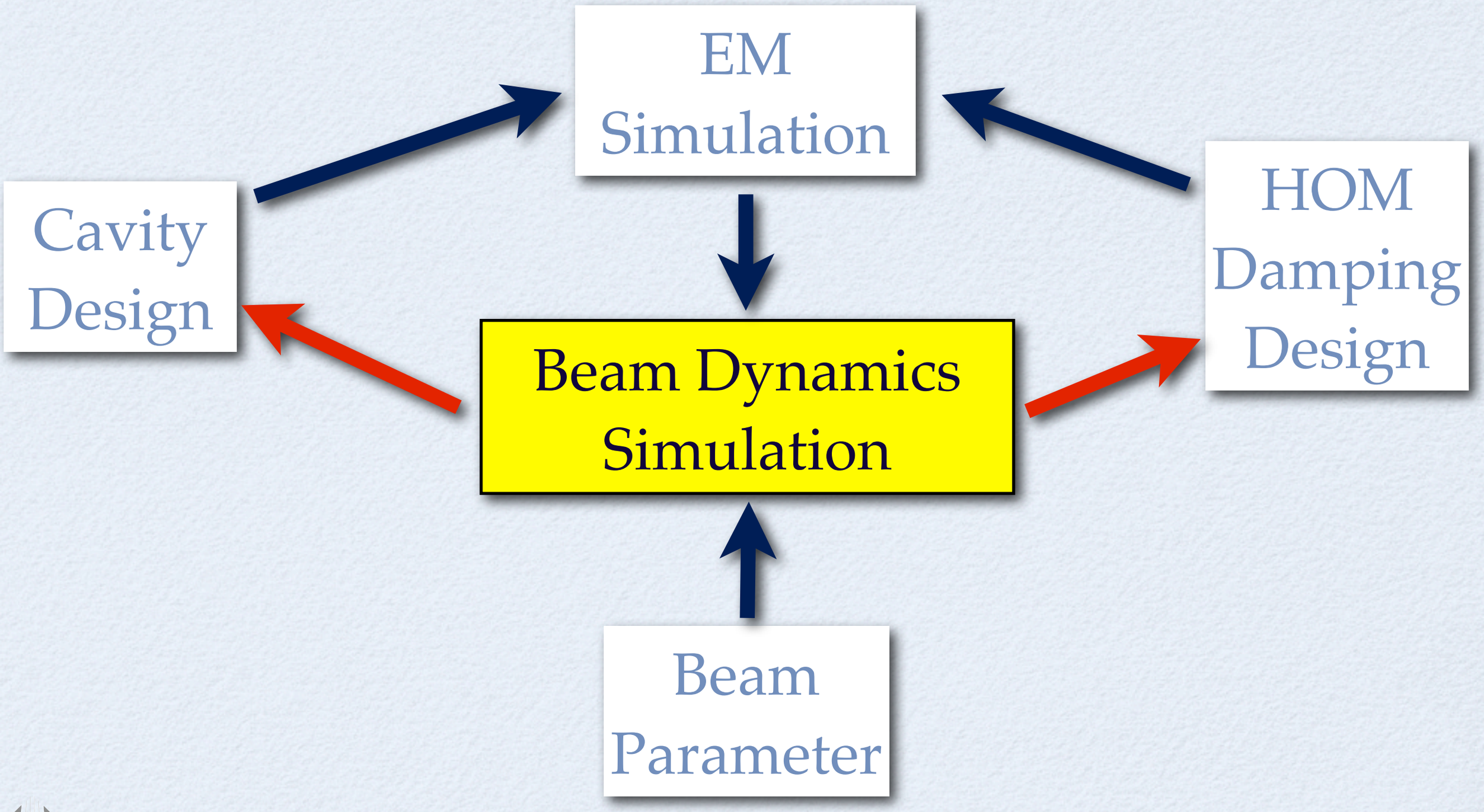
Work flow

Beam Dynamics Simulation

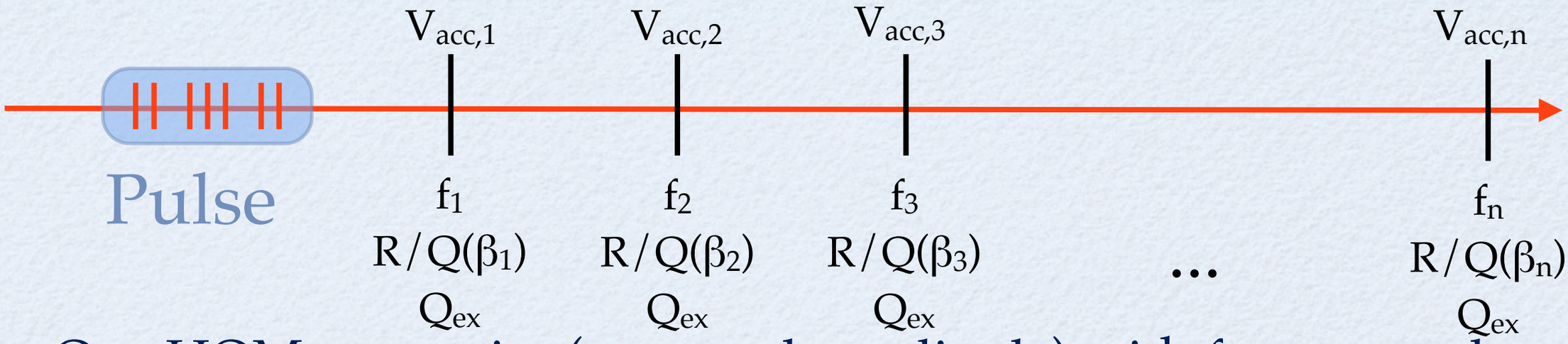
Work flow


Cavity Design
EM Simulation
Beam Dynamics Simulation
Beam Parameter

Work flow

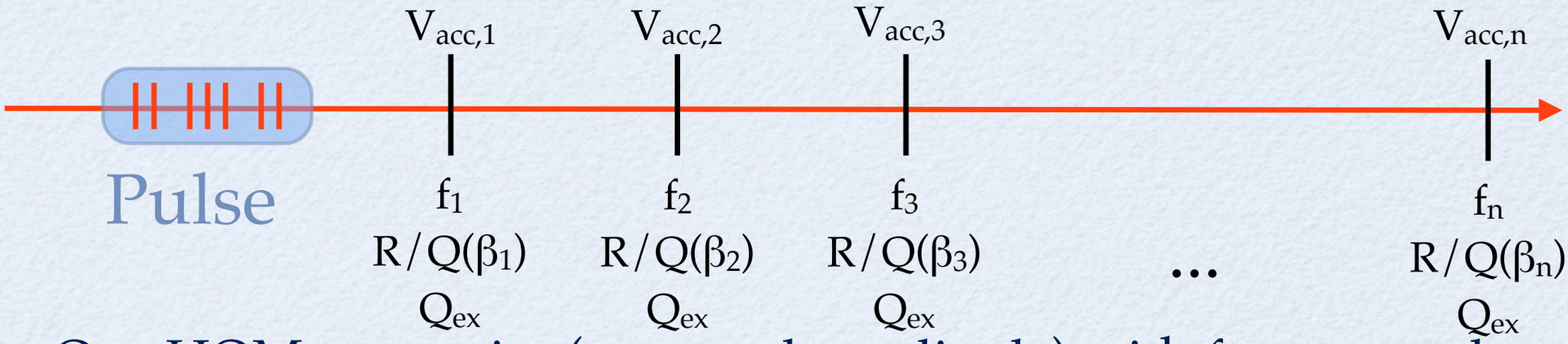

EM Simulation
Cavity Design
HOM Damping Design
Beam Dynamics Simulation
Beam Parameter

Simulate higher order Mode Dynamics (SMD)



- One HOM per cavity (monopole or dipole) with freq. spread
- $R/Q(\beta_{beam})$
- Set global Q_{ex} (Damping)
- Other effects: RF-Errors, beam noise, pulse substructure, ...

Simulate higher order Mode Dynamics (SMD)



- One HOM per cavity (monopole or dipole) with freq. spread
- $R/Q(\beta_{beam})$
- Set global Q_{ex} (Damping)
- Other effects: RF-Errors, beam noise, pulse substructure, ...

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

- **GOAL: Define upper limits for Q_{ex}**

Studied effects

Effect	Longitudinal	Transversal
HOM Frequency Spread	↘	↘
Machine Lines	↗	→
I · R/Q	↗	↗
Charge Scatter	↗	→
Chopping	↗	↗ (bunch charge)
Passband Modes	↗ (Chopping)	-
RF-Errors	→ (on HOM)	-
Alignment Errors	-	→

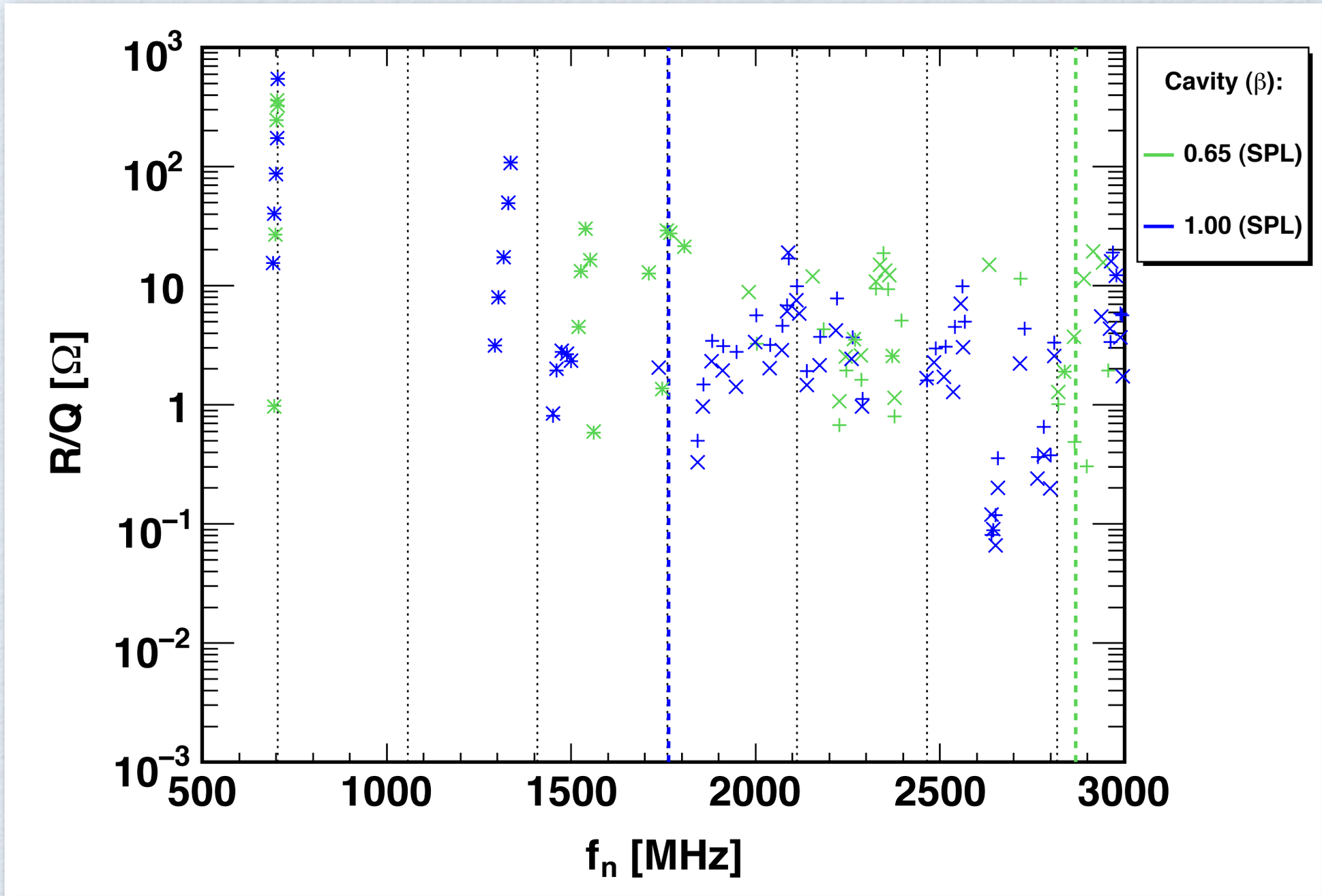
M. Schuh et al. „Influence of Higher Order Modes on the Beam Stability in a High Power Superconducting Proton Linac“, submitted to PRST-AB

General results

- HOM impact on longitudinal plane dominant due to resonances and $\beta < 1$.
- Beam blow up caused by RF-Errors can be used as upper limit for tolerable HOM caused effects.
- Maximum Q_{ex} strongly depends on operation schema (chopping).

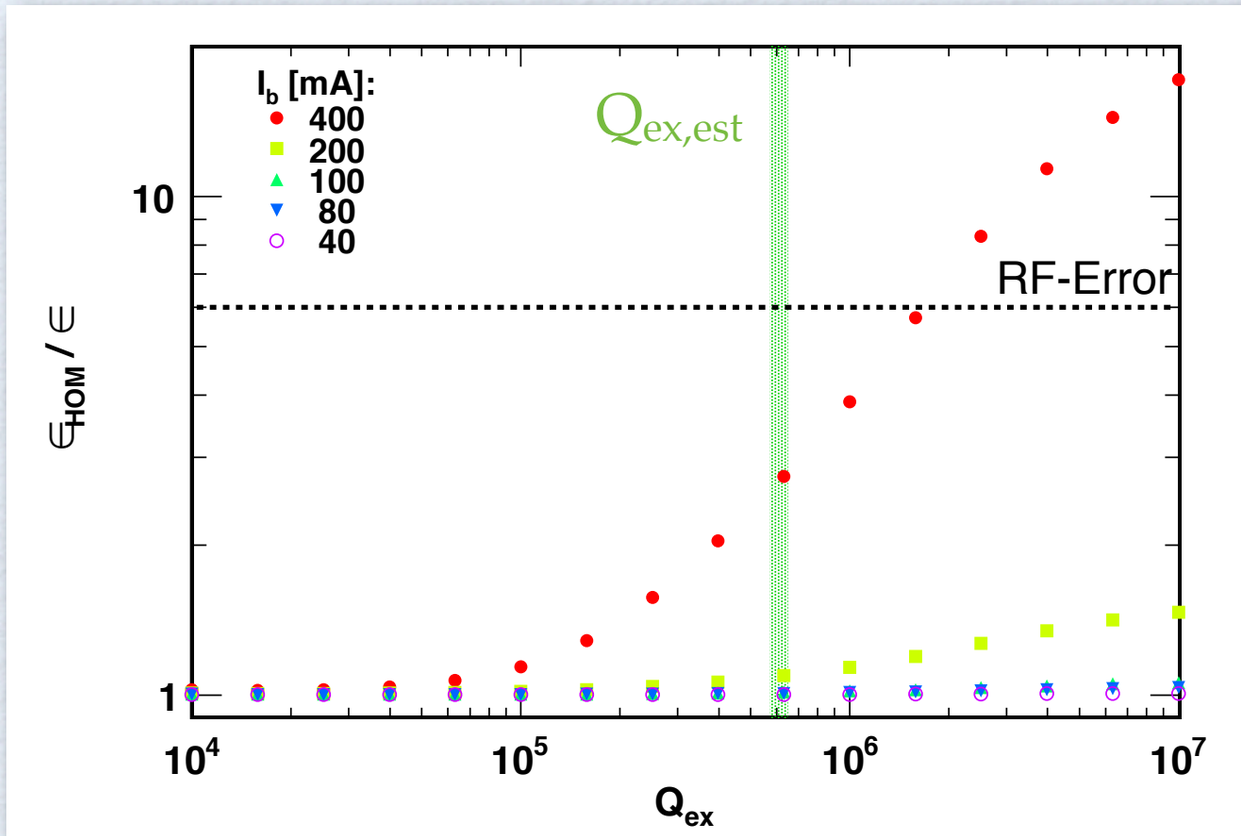
Monopole modes in SPL baseline cavities

$R/Q(\beta)_{max}$ for different boundaries in SUPERFISH model

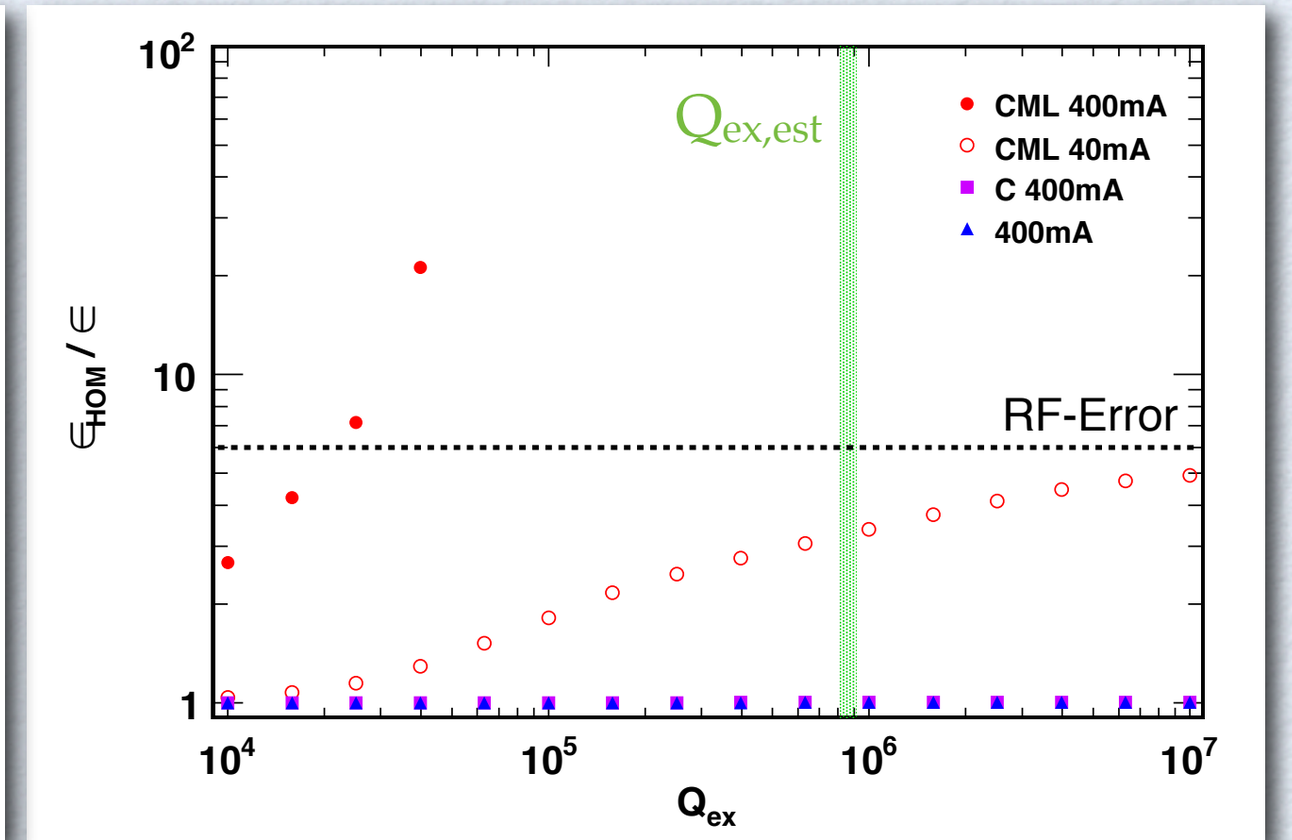


TM_{010} modes

TM_{010},4/5π



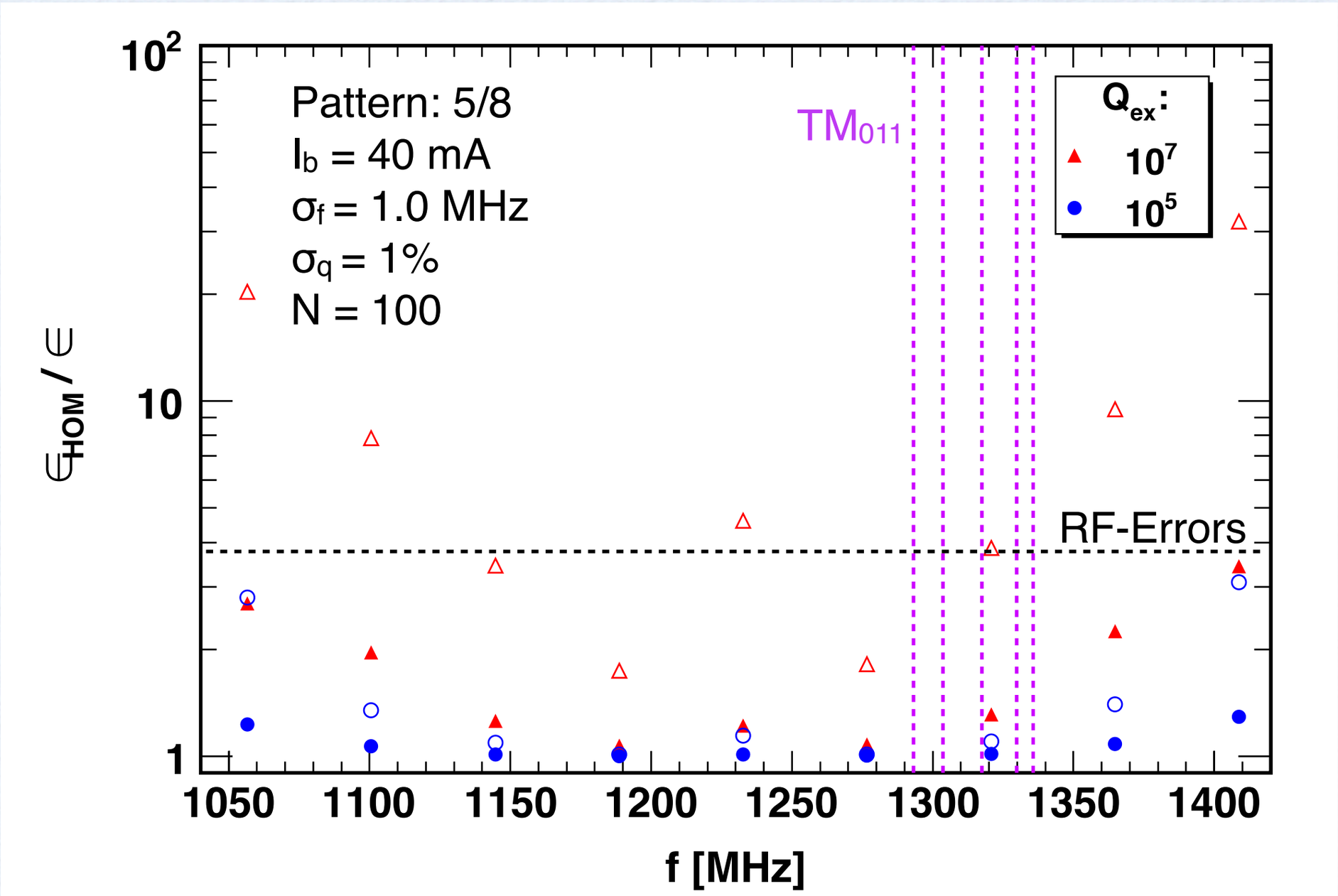
TM_{010},3/5π



703.5 / 703.1	f_n [MHz]	701.0 / 699.8
268 / 167	$R/Q(\beta)_{max}$	52 / 25
-	CML	699.998

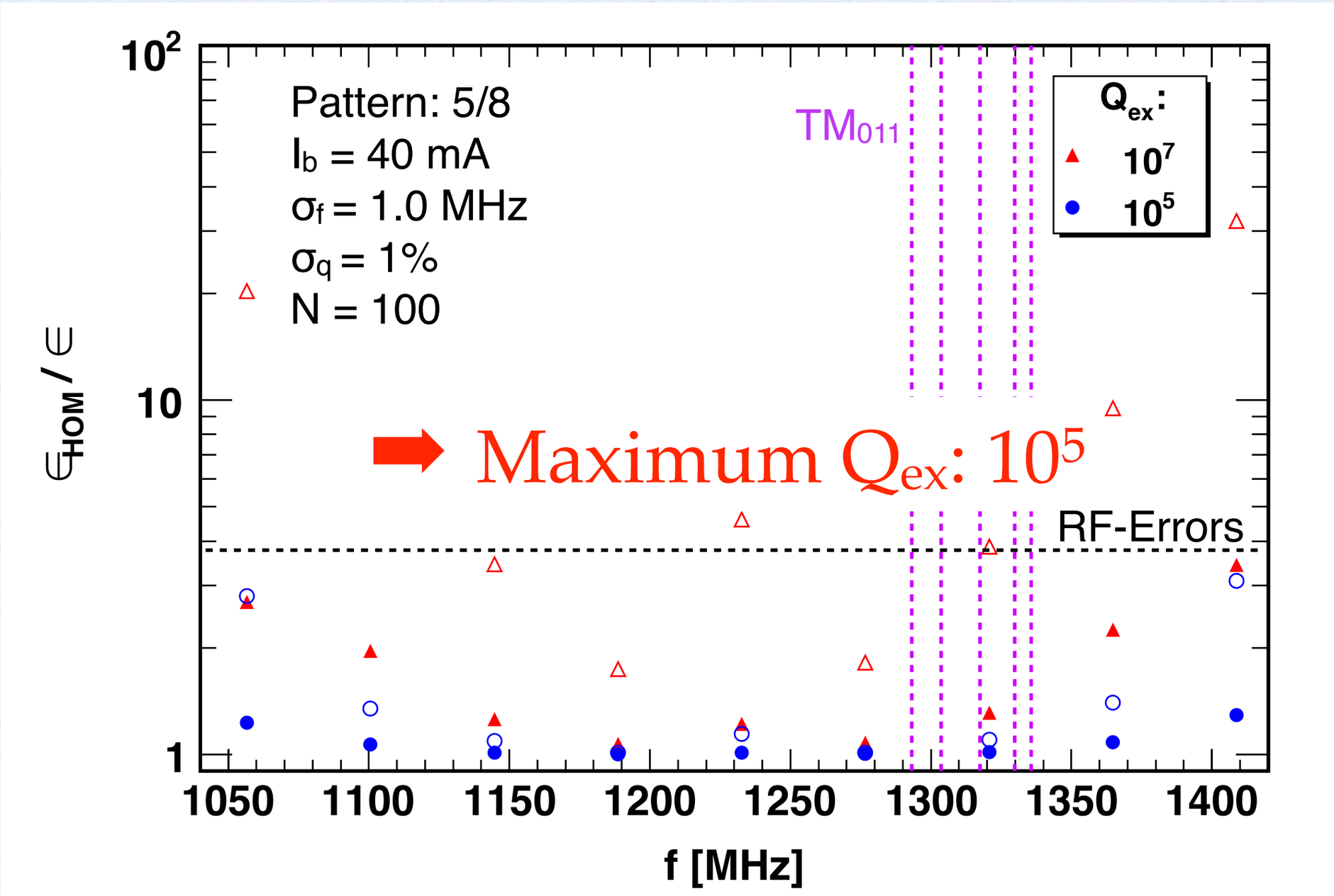
Chopping

New machine lines, created by the pulse substructure, can resonantly excite HOMs!

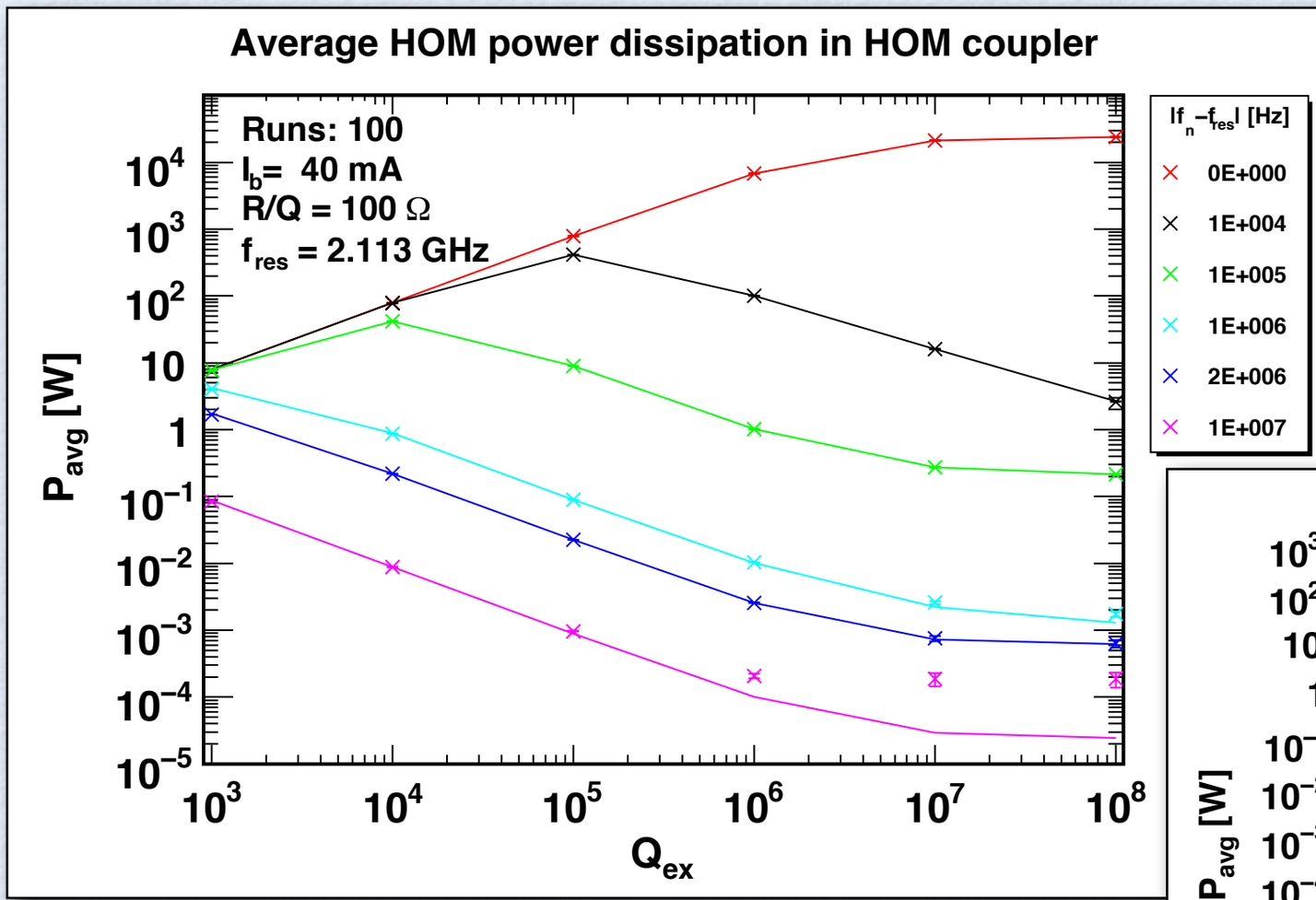


Chopping

New machine lines, created by the pulse substructure, can resonantly excite HOMs!

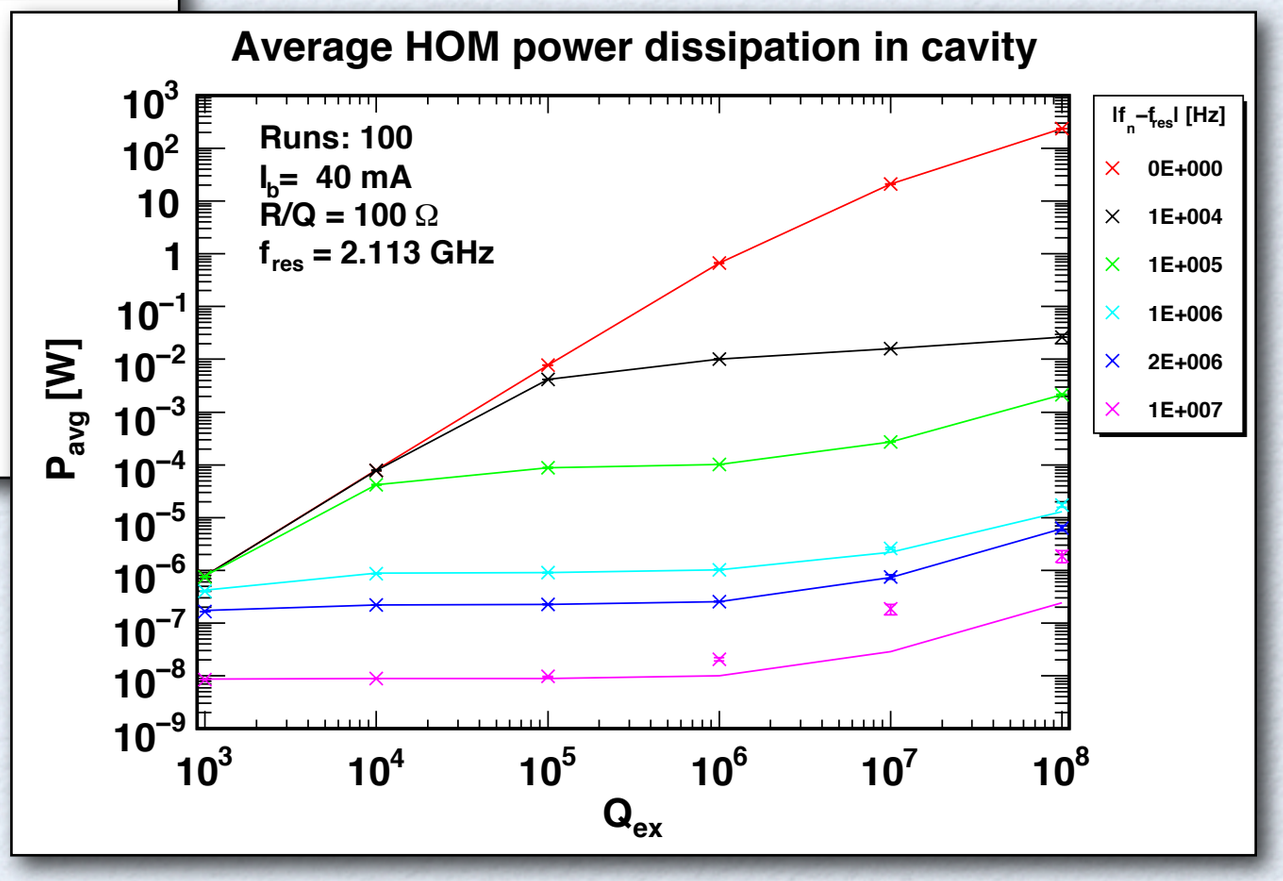


HOM Power Simulation



Beam noise:

- $\sigma_q = 1\%$
- $\sigma_\phi \approx 0.4$ ps (not const. during pulse)

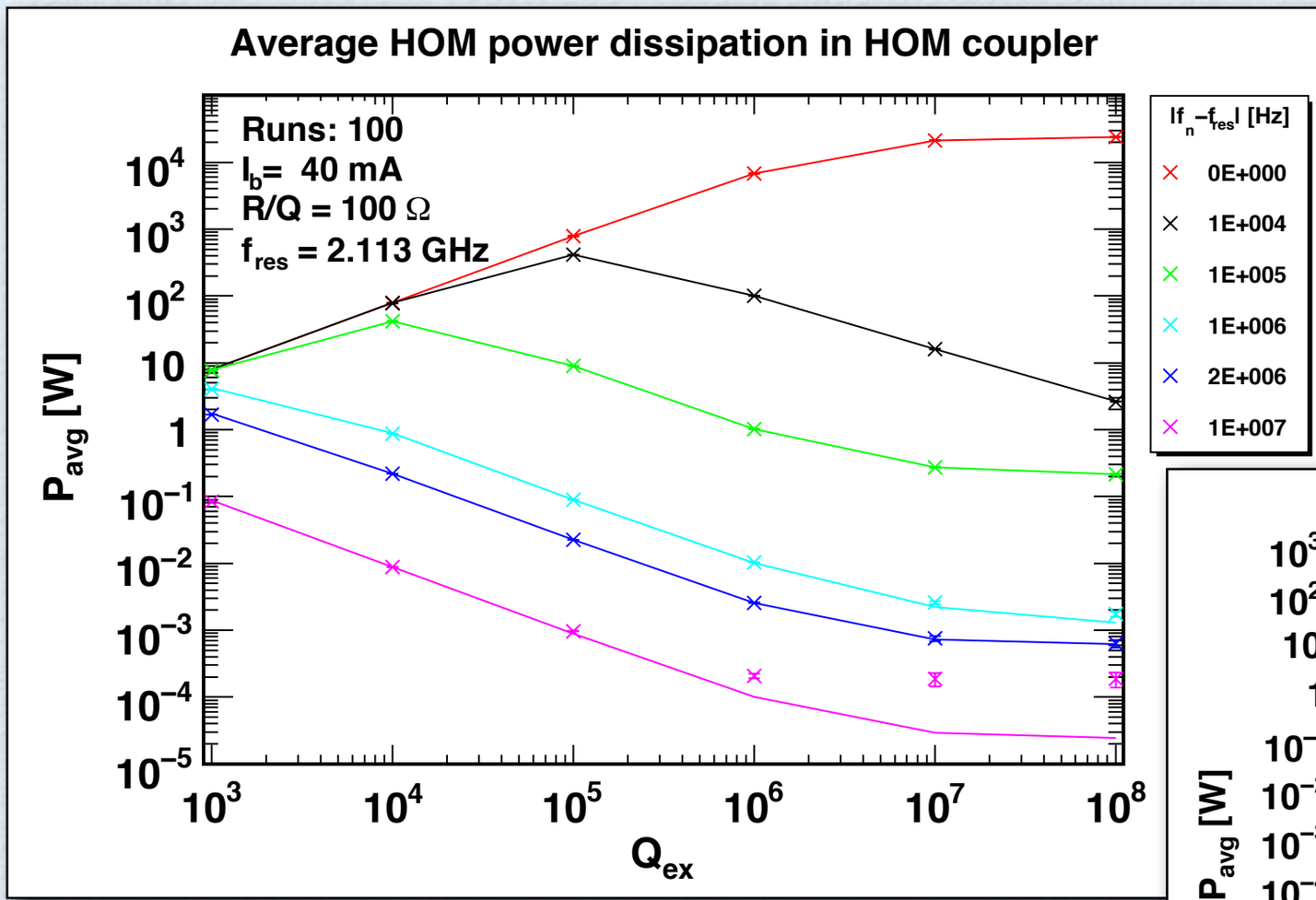


Solid lines are analytic values without noise.

Deviation only off resonance!

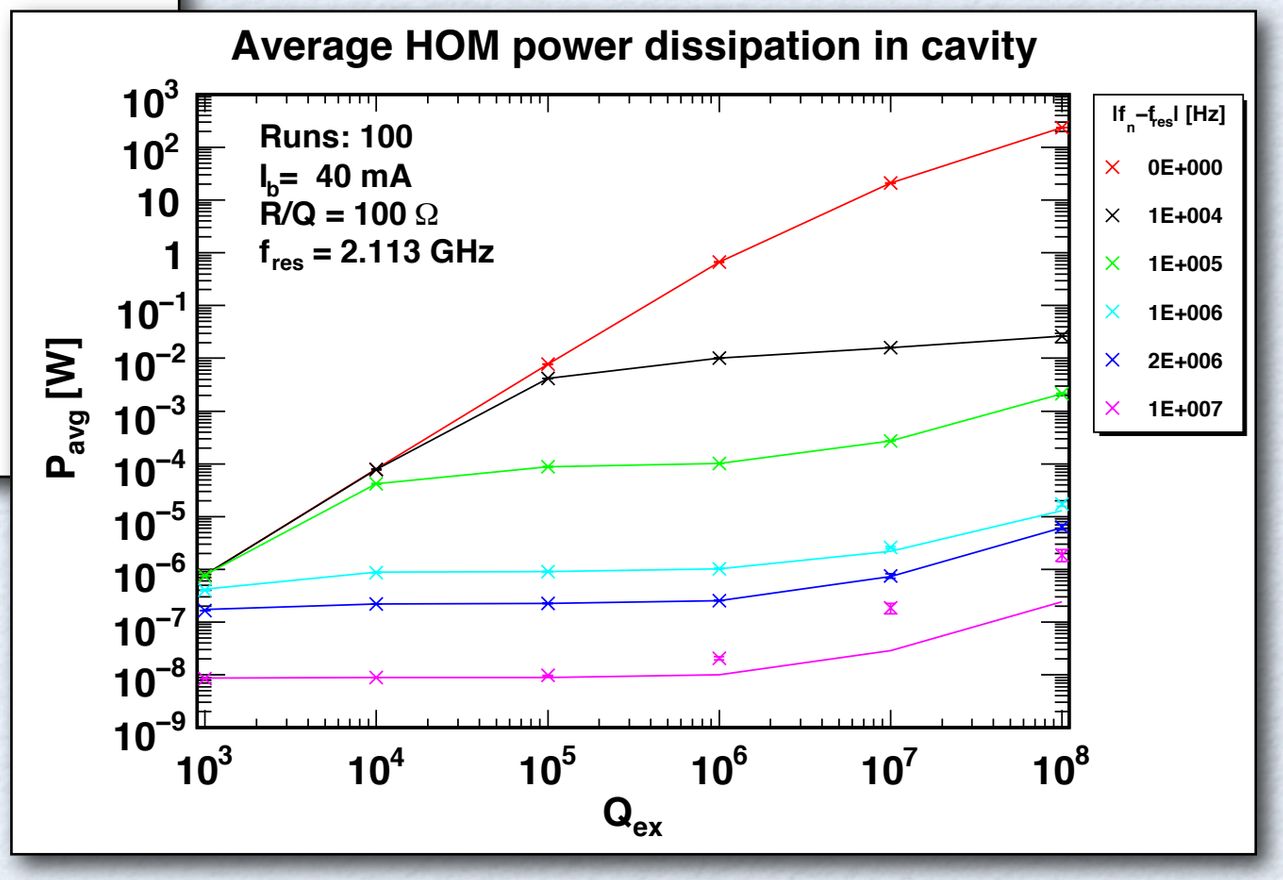
M. Schuh et al. „Power dissipation by Higher Order Modes“, sLHC Project note

HOM Power Simulation



Beam noise:

- $\sigma_q = 1\%$
- $\sigma_\phi \approx 0.4$ ps (not const. during pulse)



Solid lines are analytic values without noise.

Deviation only off resonance!

➡ Maximum Q_{ex} : 10^4

M. Schuh et al. „Power dissipation by Higher Order Modes“, sLHC Project note

SPL vs SNS

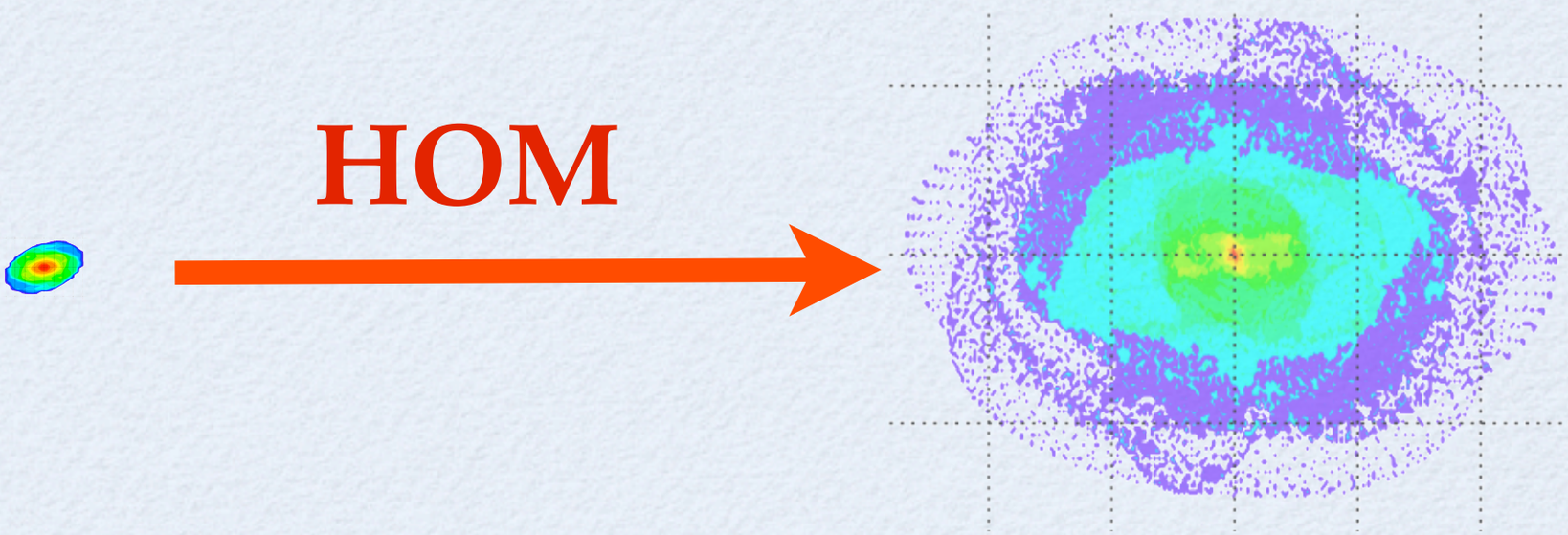
	SPL	SNS
Cavities	~250	81
Max $\left(\frac{R/Q(\beta)_{\mathrm{HOM}}}{R/Q(\beta)_{\mathrm{acc}}}\right)$	6% and 20%	2% and 7%
Max $\left(\frac{R/Q(\beta)_{\mathrm{PB}}}{R/Q(\beta)_{\mathrm{acc}}}\right)$	83% and 31%	46% and 27%
Chopping	high frequent	low frequent
HOM frequency statistics	not available	available (no HOM at machine line)

Conclusions

- Damping requirements strongly depend on the operation scenario (chopping).
- Operation conditions at SNS are different.
- To allow any operation scenario, a HOM damping of $Q_{ex}<10^5$ is recommended.

Thank You!

Questions?

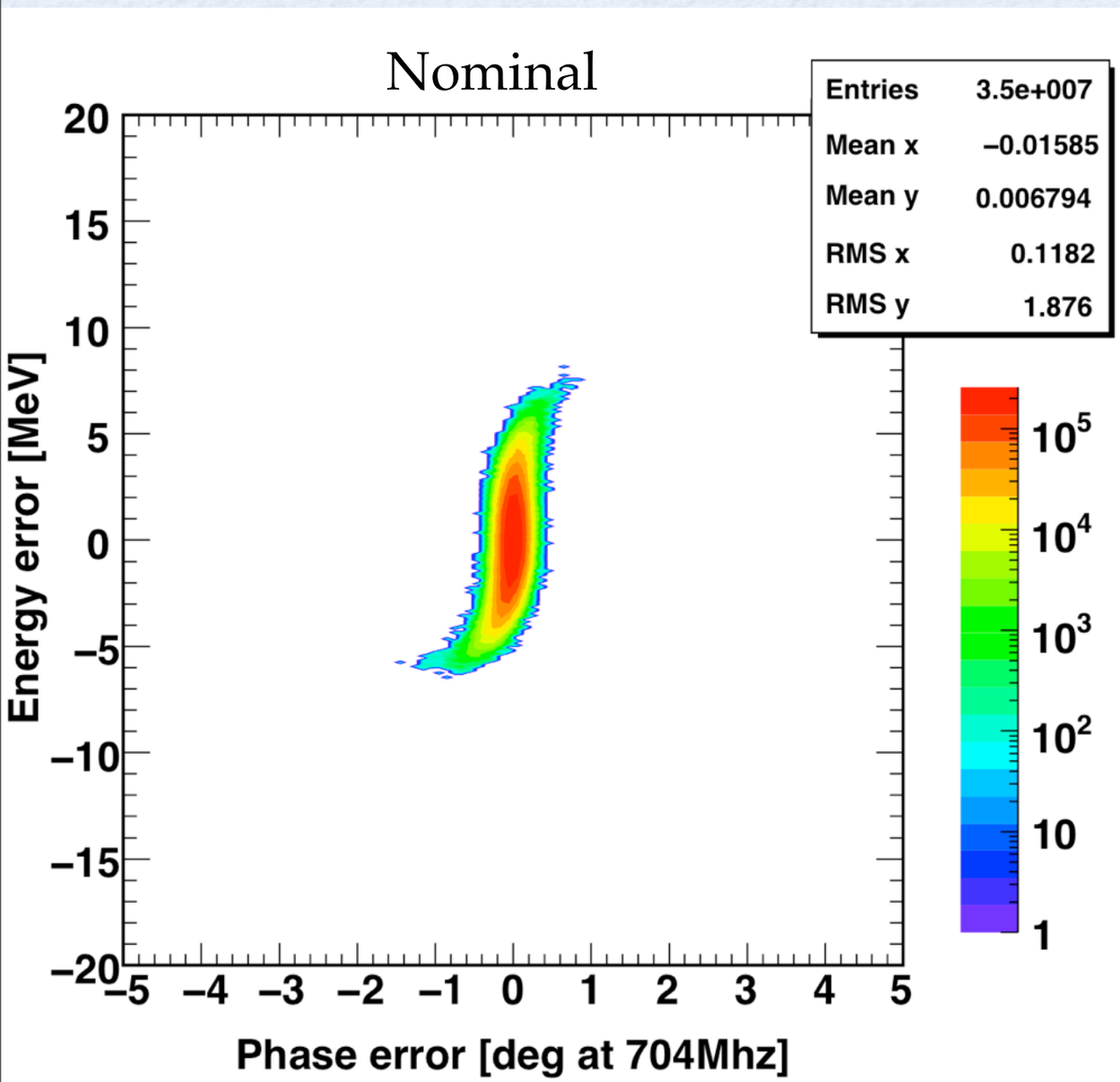


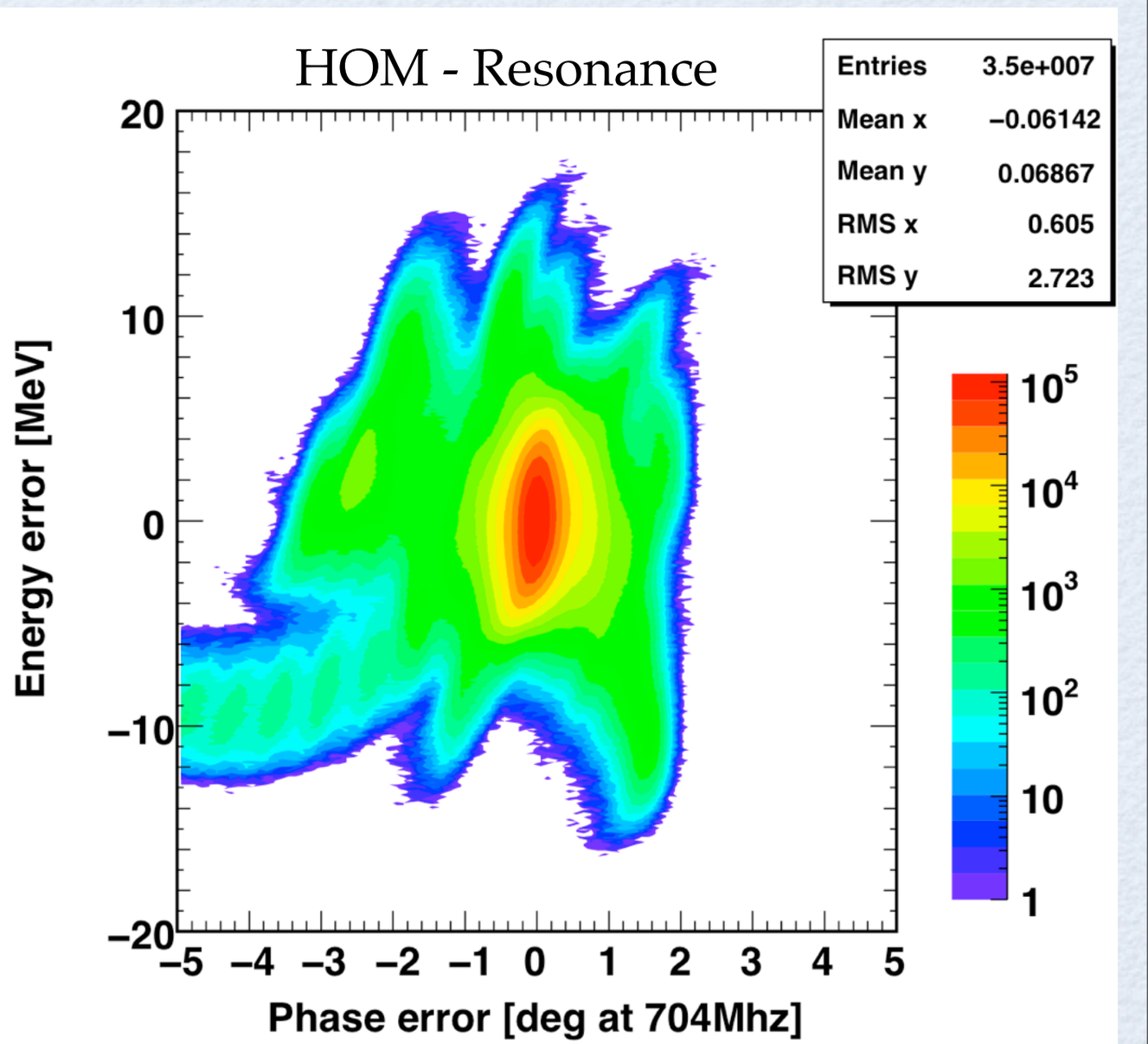
References:

- M. Schuh et al., Influence of Higher Order Modes on the Beam Stability in a High Power Superconducting Proton Linac, submitted to PRST-AB
- M. Schuh et al., Power dissipation by Higher Order Modes, CERN-sLHC-Project-Note
- M. Schuh et al., Higher Order Mode Beam Breakup Limits in the Superconducting Cavities of the SPL, IPAC'10, Kyoto, Japan
- M. Schuh et al., Higher Order Mode Beam Breakup Limits in the Superconducting Cavities of the SPL, SRF 2009, Berlin, Germany
- M. Schuh et al., Code Benchmarking of Higher Order Modes Simulation Codes CERN-sLHC-Project-Note-0010, 2010
- https://twiki.cern.ch/twiki/bin/view/SPL/SplHom

Beam Blow Up

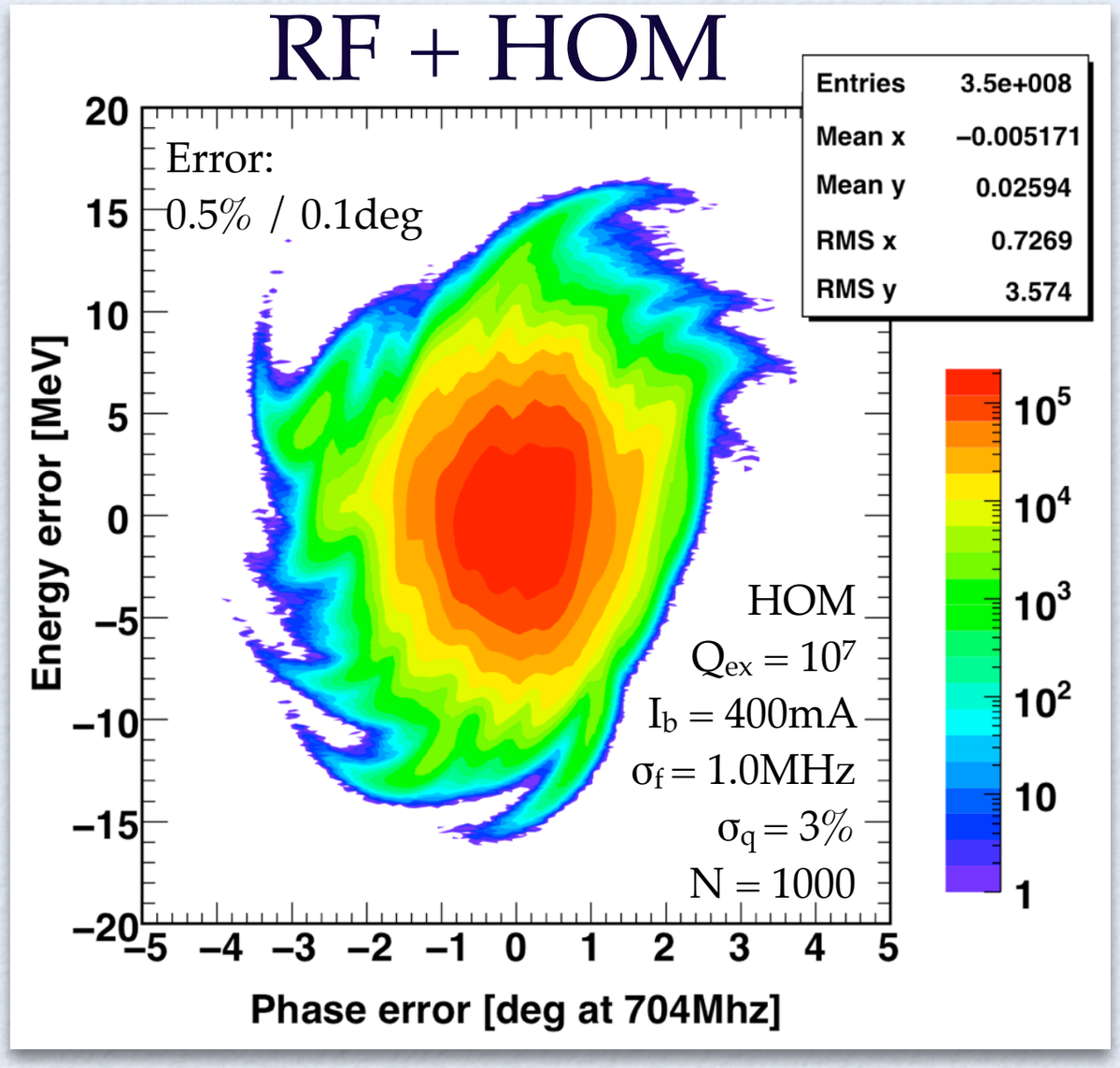
Phase space at the exit of the SPL

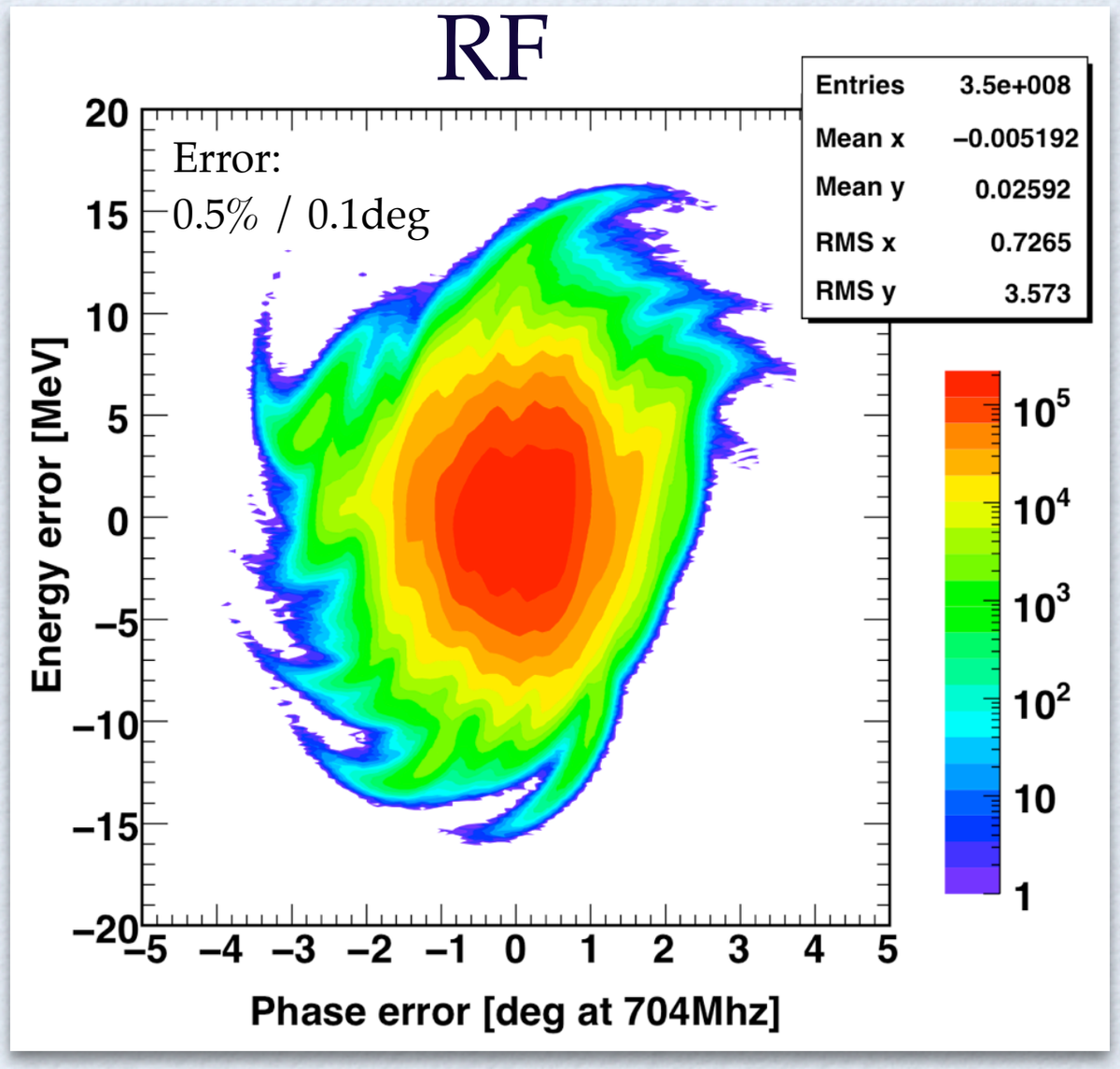




RF-Errors

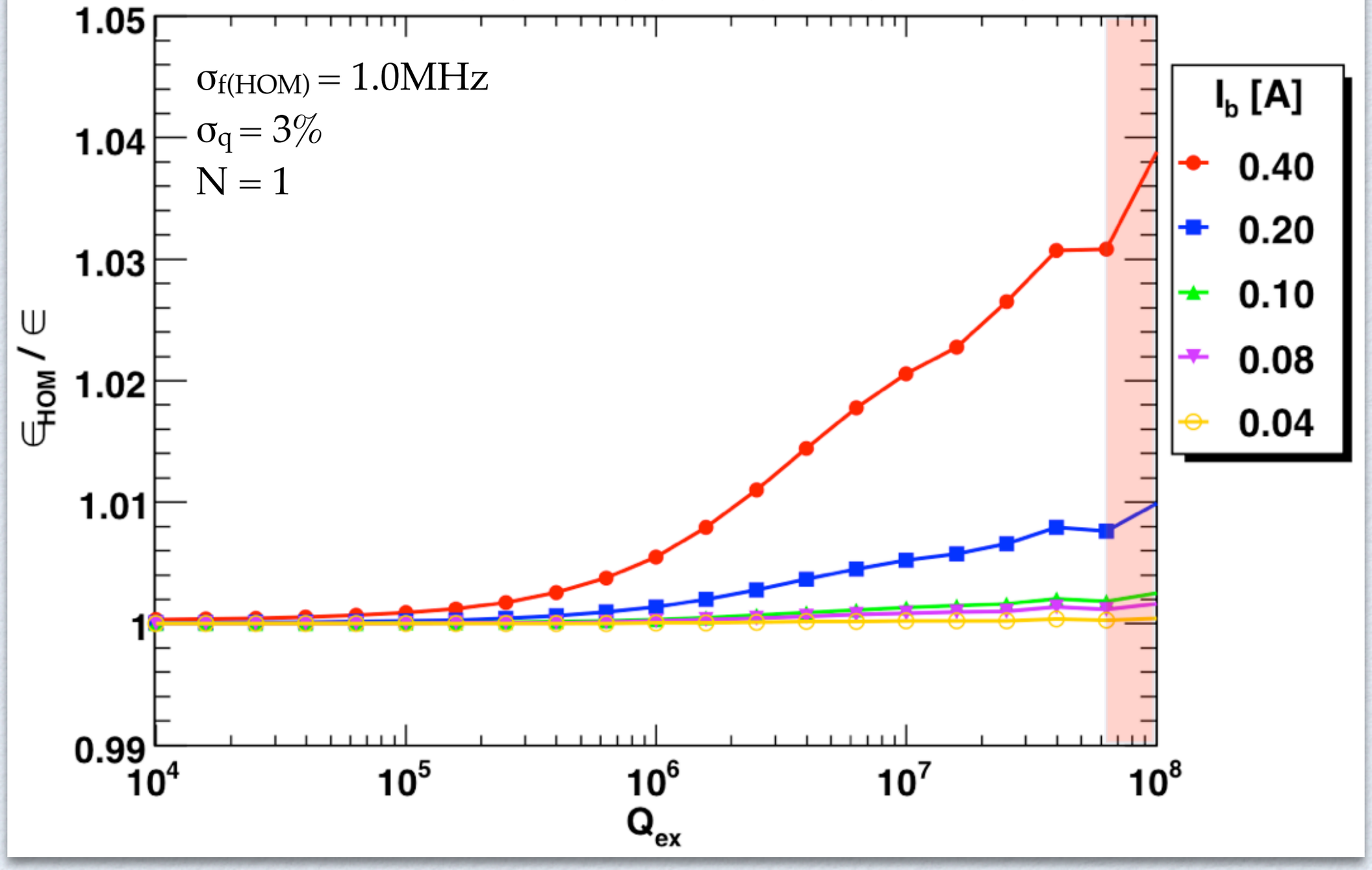
- RF-Errors dominate compared to HOM influence





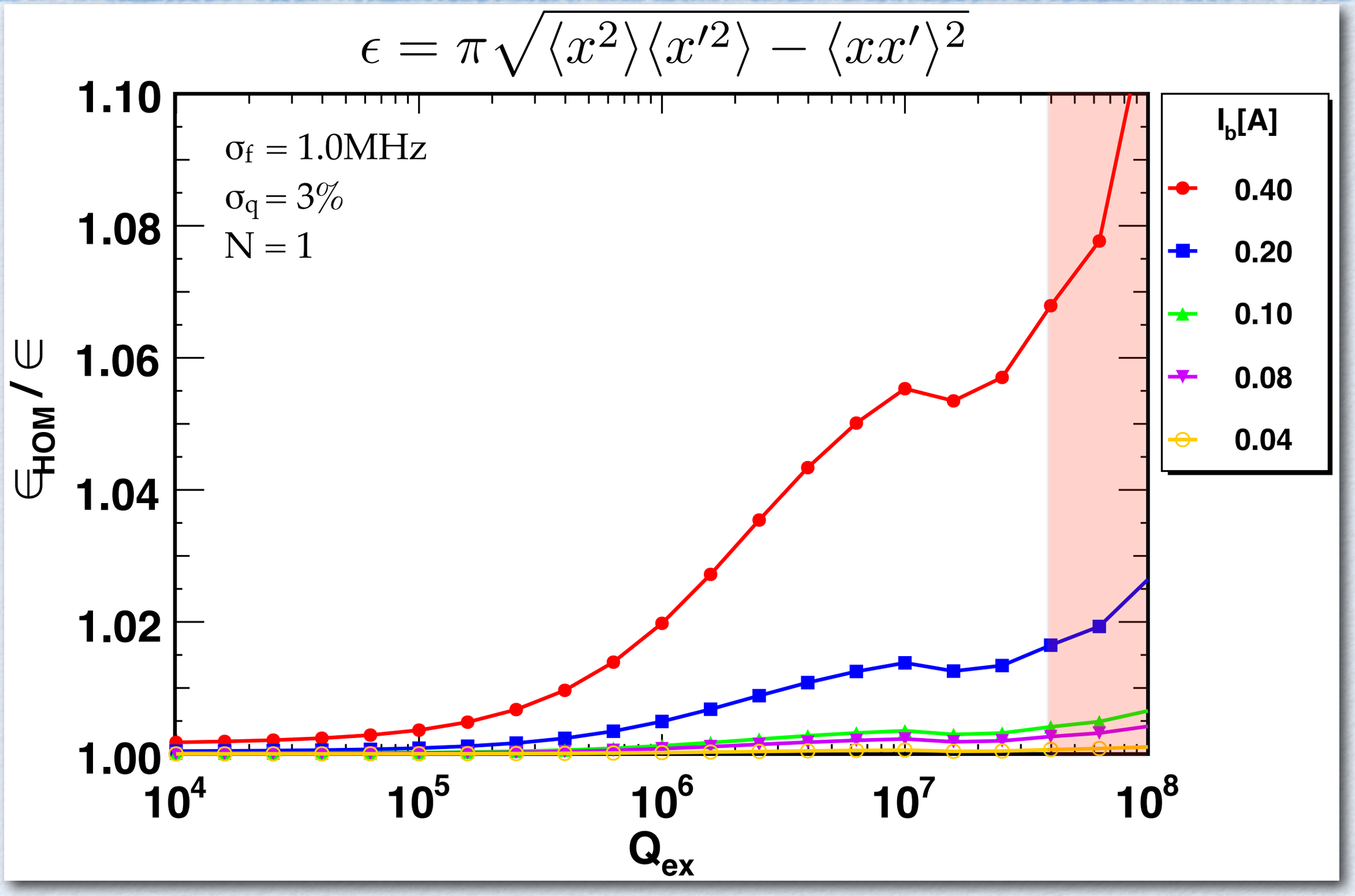
Longitudinal

$$\epsilon = \pi\sqrt{\langle dE^2\rangle\langle d\phi^2\rangle - \langle dEd\phi\rangle^2}$$



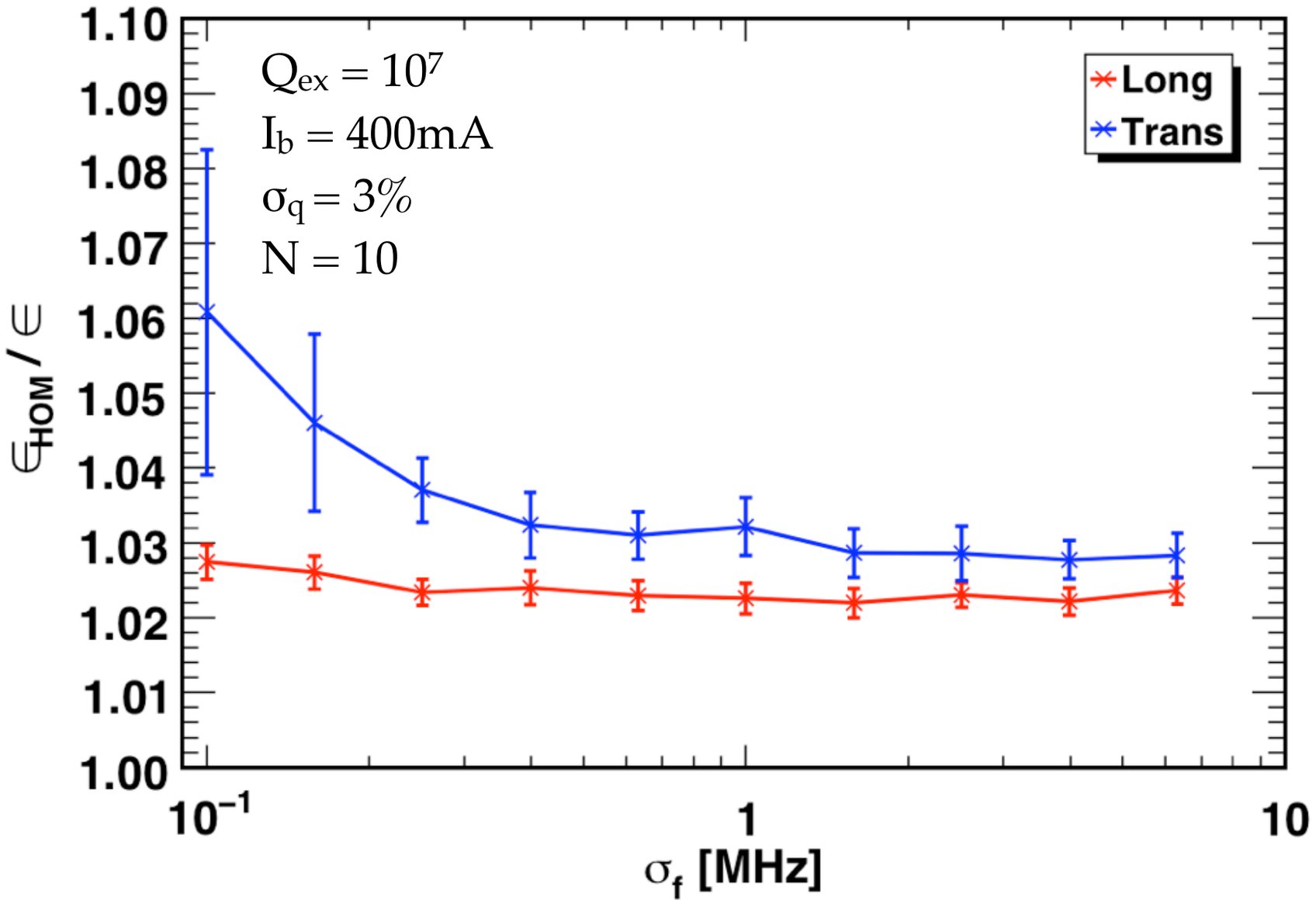
Transversal

$$\epsilon = \pi\sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$



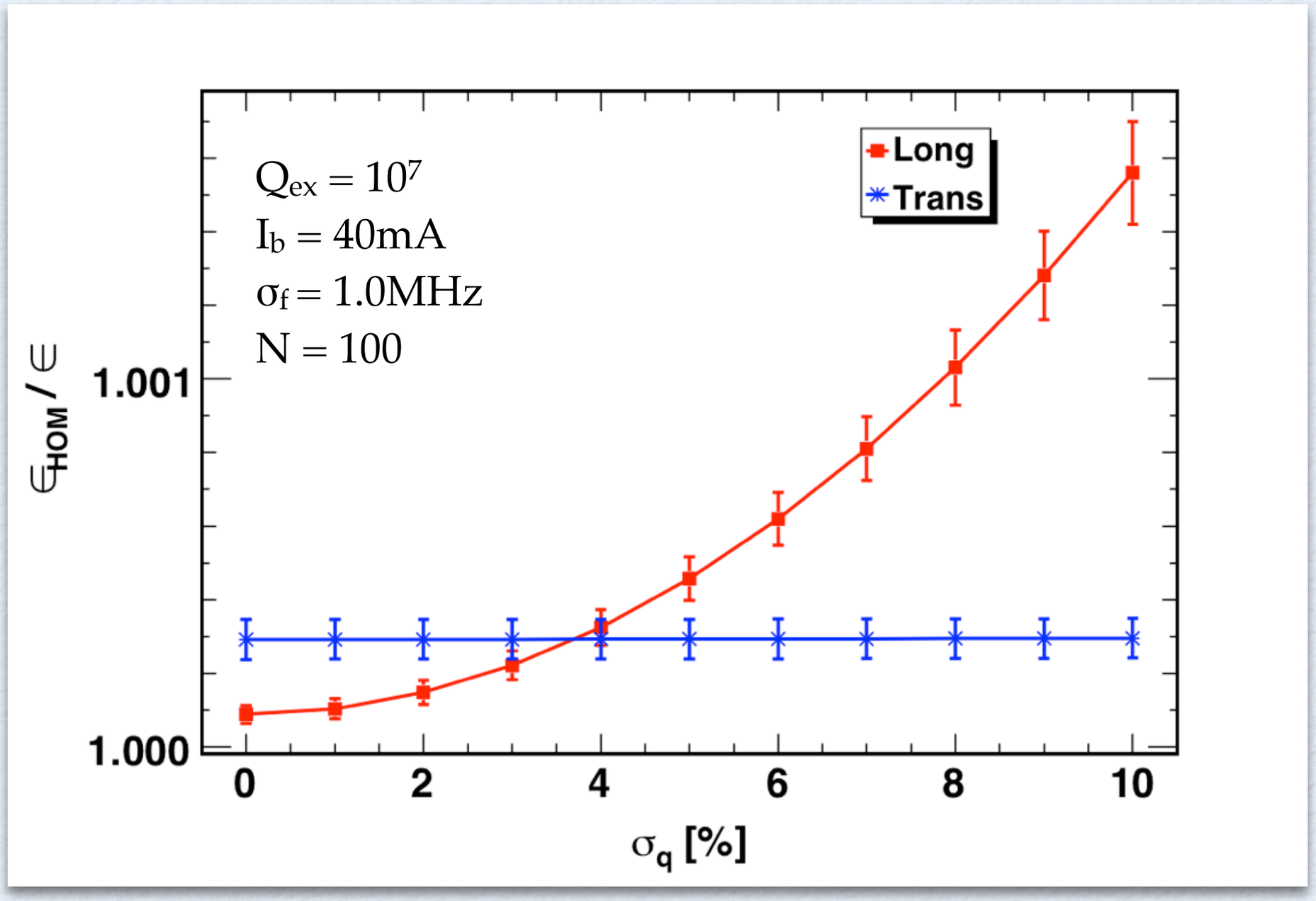
HOM frequency spread

- Higher HOM frequency spread decreases growth



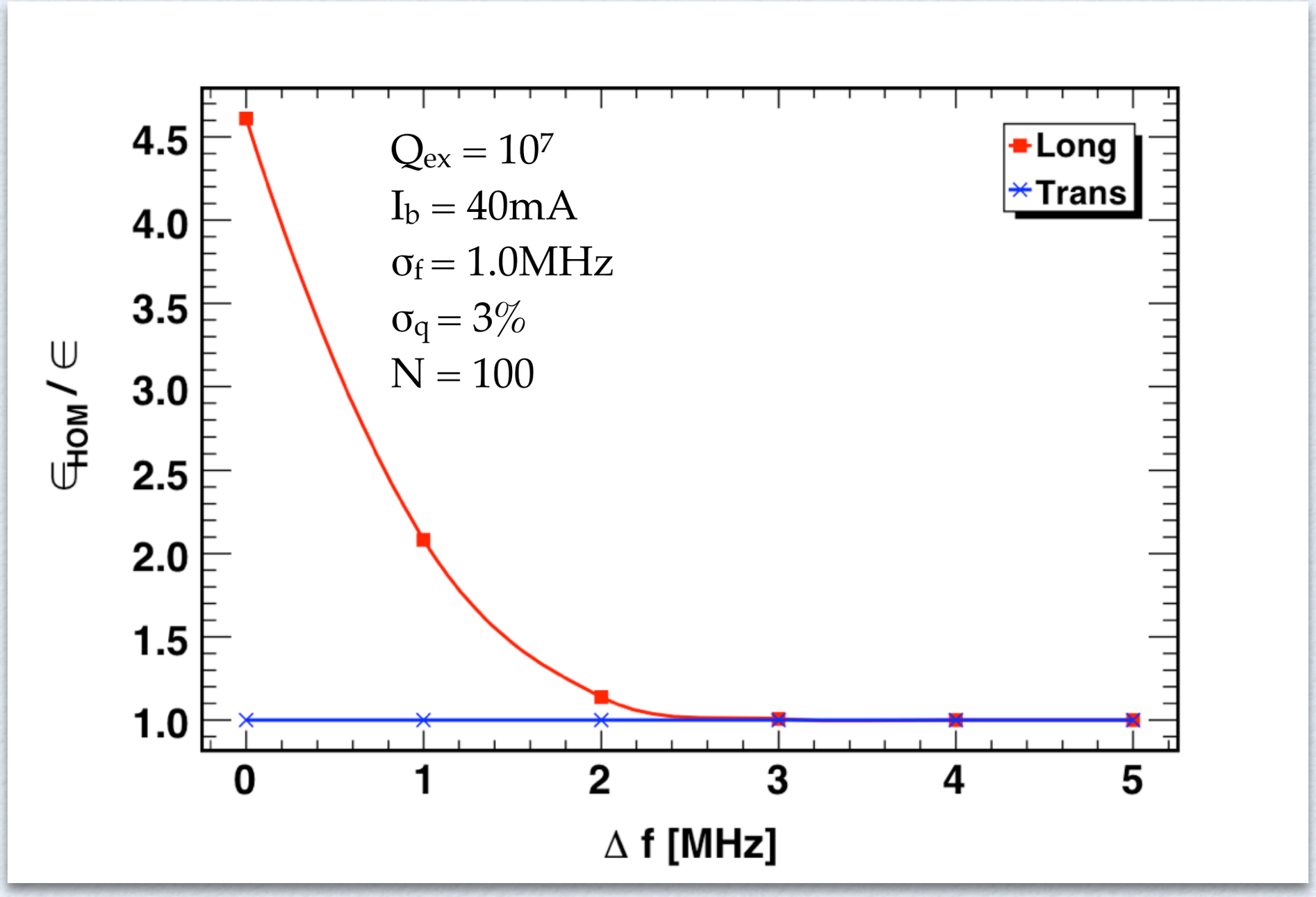
Bunch Charge Scatter

- Bunch charge scatter drives HOM in longitudinal plane



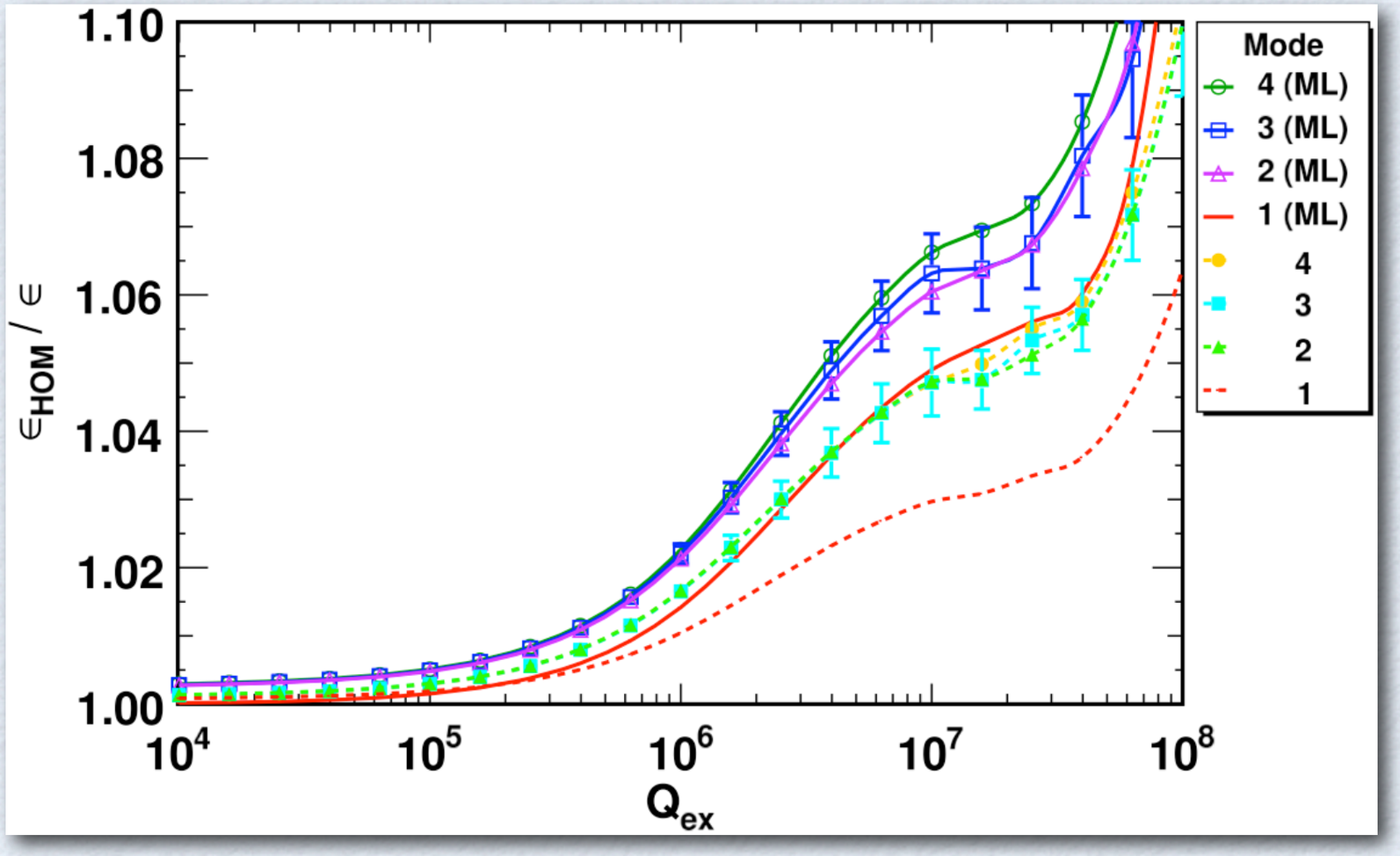
Machine Lines (ML)

- ML are only a major concern for monopole modes



Chopping

Transversal emittance growth



- Increase due to higher bunch current

Beam Input Parameters

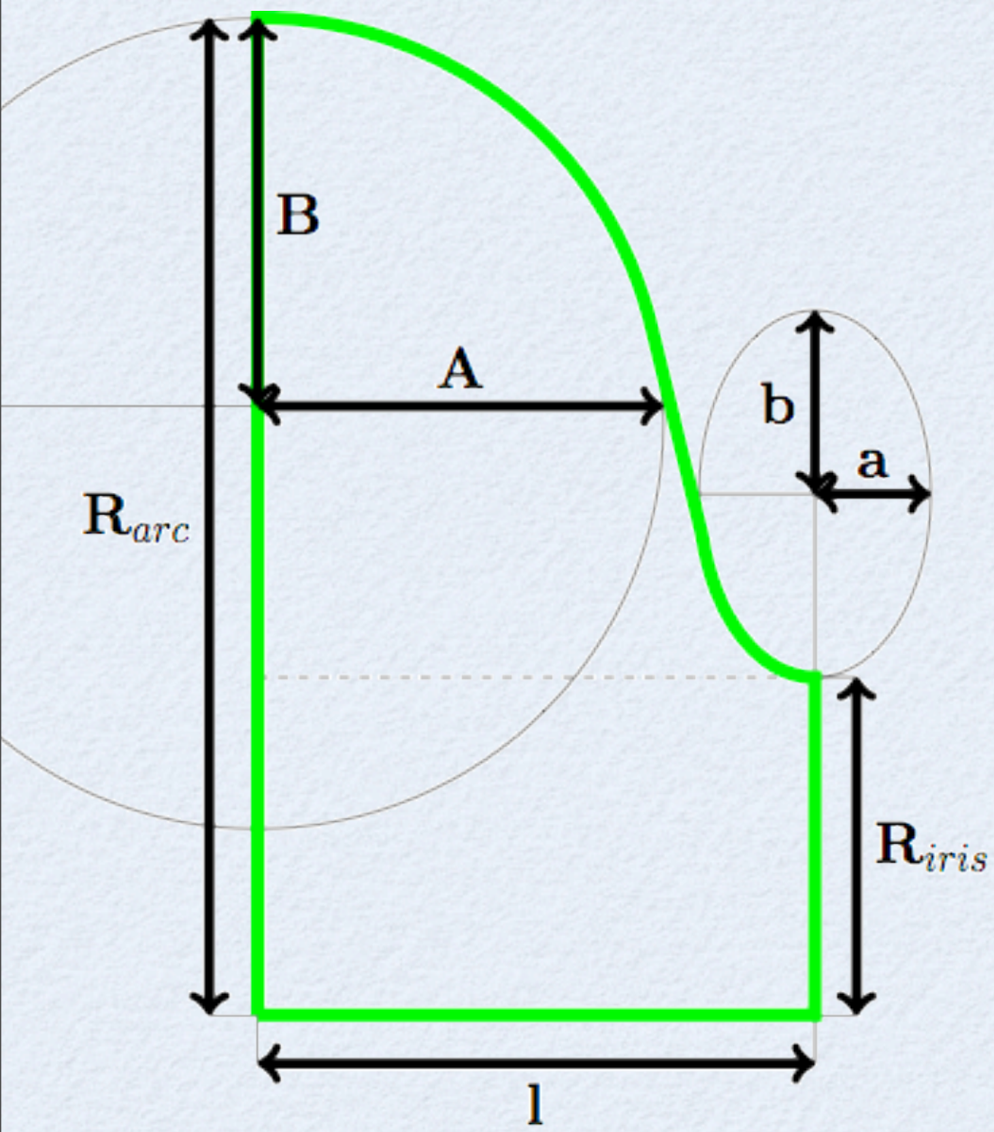
Basic beam settings used in all simulations:

Parameter	Mean	Variance
Bunch period [ns]	$1/f_b = 2.84$	0.00315
Pulse length [ms]	1	0
Period length [ms]	20	0
Beam current [mA]	40...400	3 %
W_{Input} [MeV]	160	0.078
Tr. position [mm]	0	0.3
Tr. momentum [mrad]	0	0.3

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

Cavity geometry

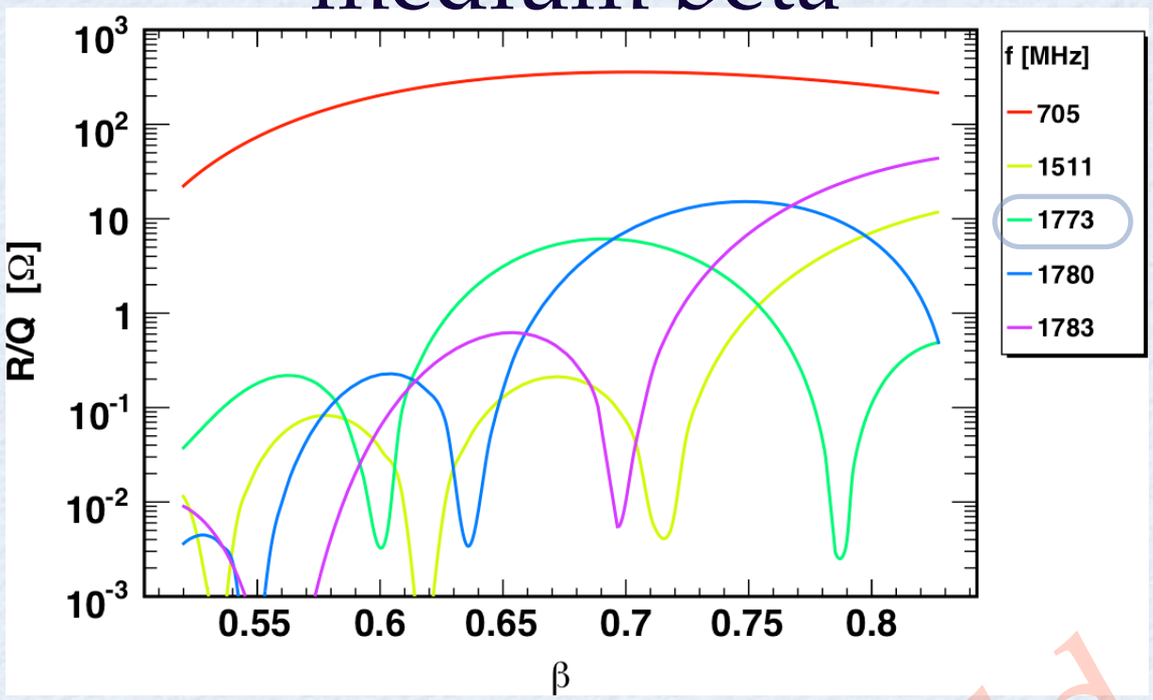
Cavity shapes at 704.4MHz (symmetrical):



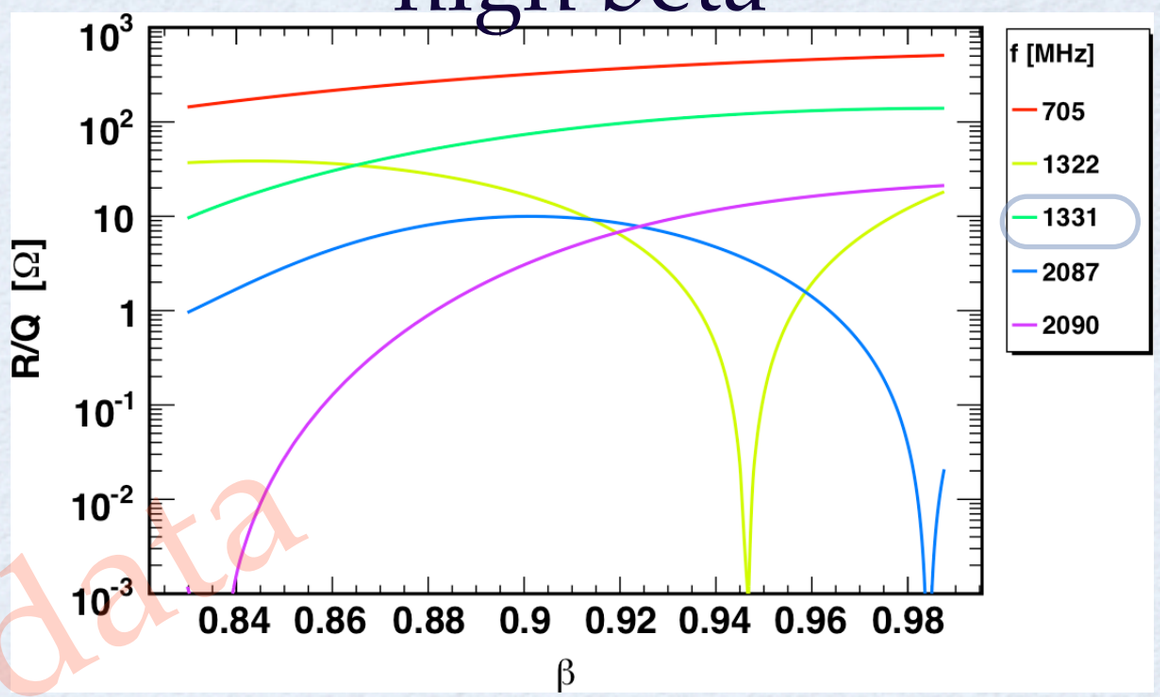
	Medium β		High β	
5 Cells	mid	end	mid	end
β	0.658		1.0	
R_{arc} [mm]	186.4		190.8	
R_{iris} [mm]	45	45	64.6	70
l_{cell} [mm]	70	70	106.47	103.07
A [mm]	45.1	45.06	77.5	76.89
B [mm]	45.1	49.56	77.5	74.45
a [mm]	12.14	12.11	22.1	18.5
b [mm]	15.79	15.74	35.1	24.9

HOM Input Data

medium beta



high beta



Monopole

Dipole