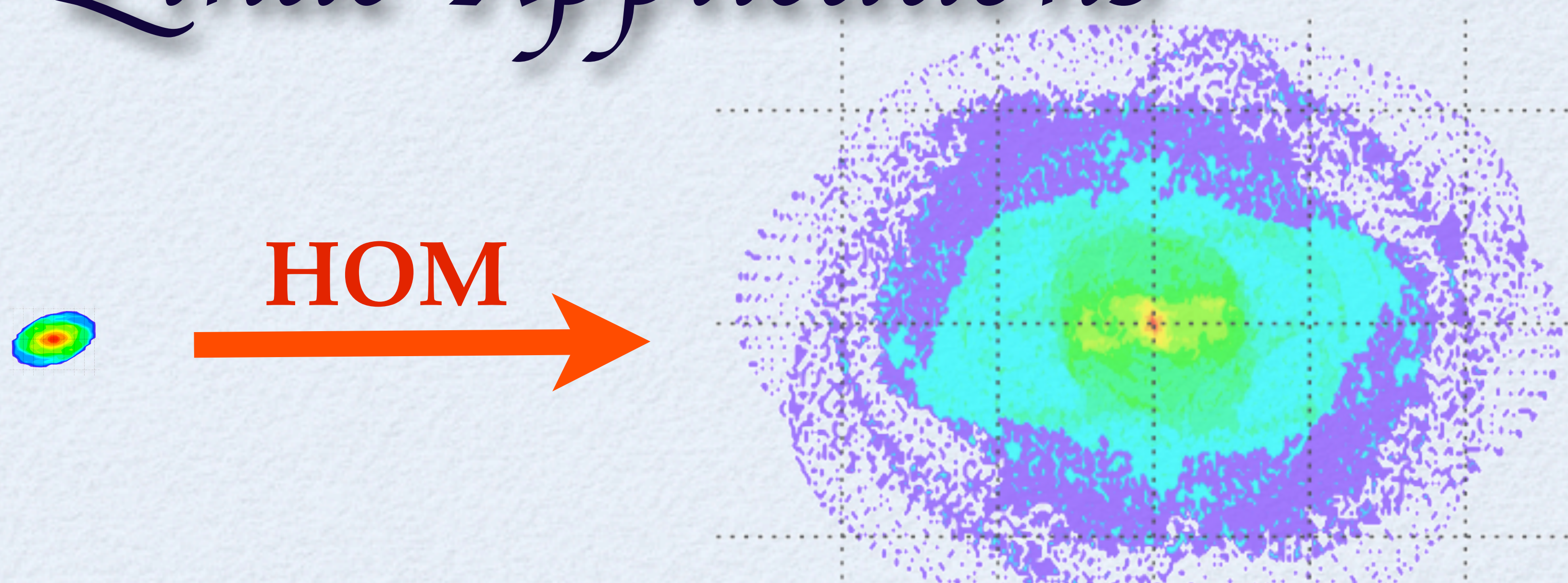
Joint QUASAR and THz Group Workshop on Accelerator Science and Technology 2010

Beam Dynamics

Simulation of Higher Order Modes in Linac Applications



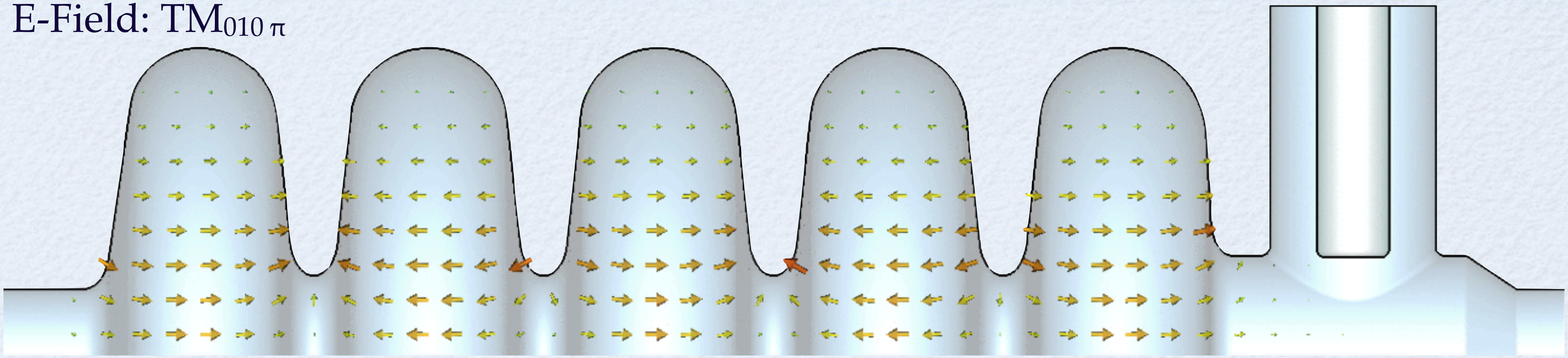
Marcel Schuh
CERN-BE-RF-LR
CH-1211 Geneva 23, Switzerland
marcel.schuh@quasar-group.org

OUTLINE

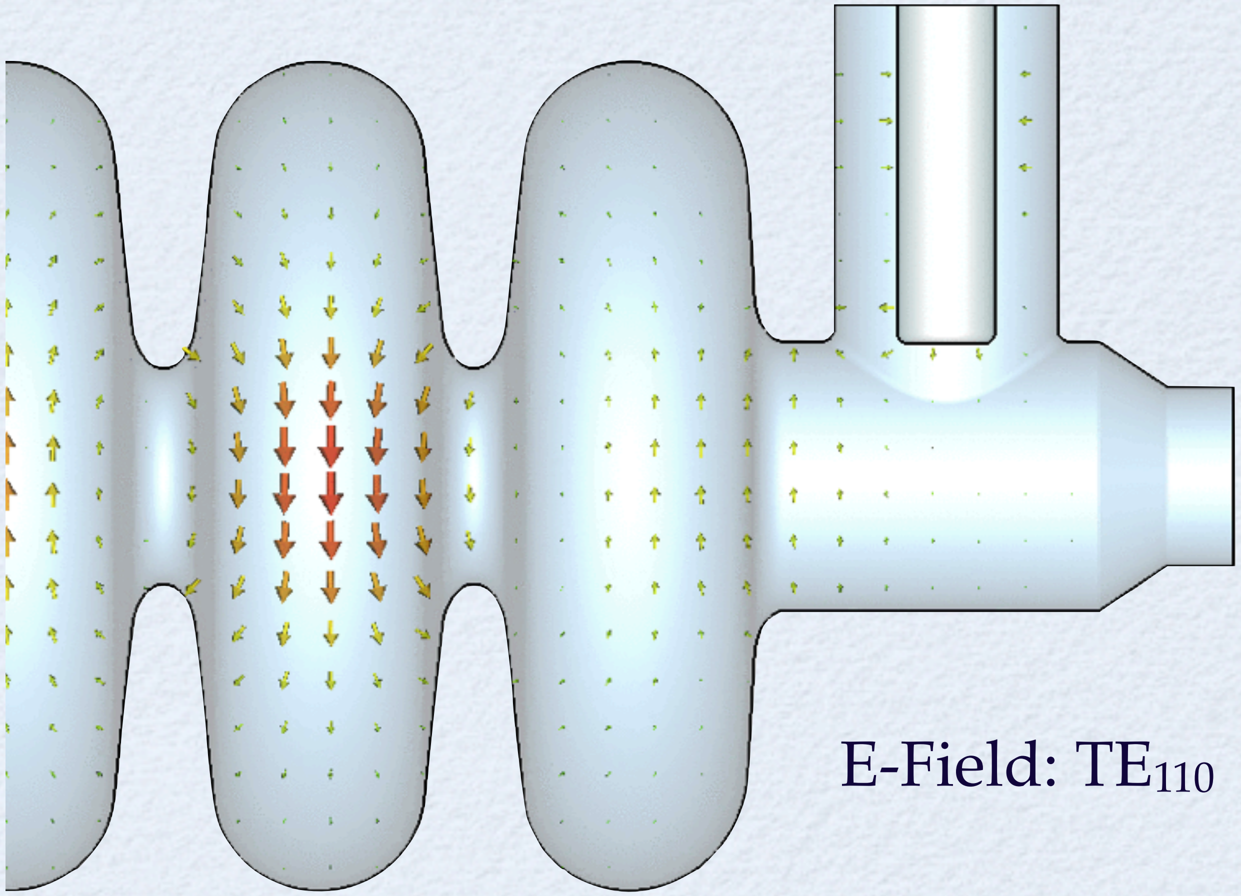
- What are Higher Order Modes?
- Simulation tools and models
- Results

Higher Order Modes (HOMs)

E-Field: $TM_{010\,\pi}$



- **All modes beside accelerating mode**
- Present in all cavities
- Divide modes in monopole, dipole ...
- Characteristics depend on cavity shape
- Excited by the beam itself ($V \propto I \cdot R/Q$)
- Interact with cavity and beam

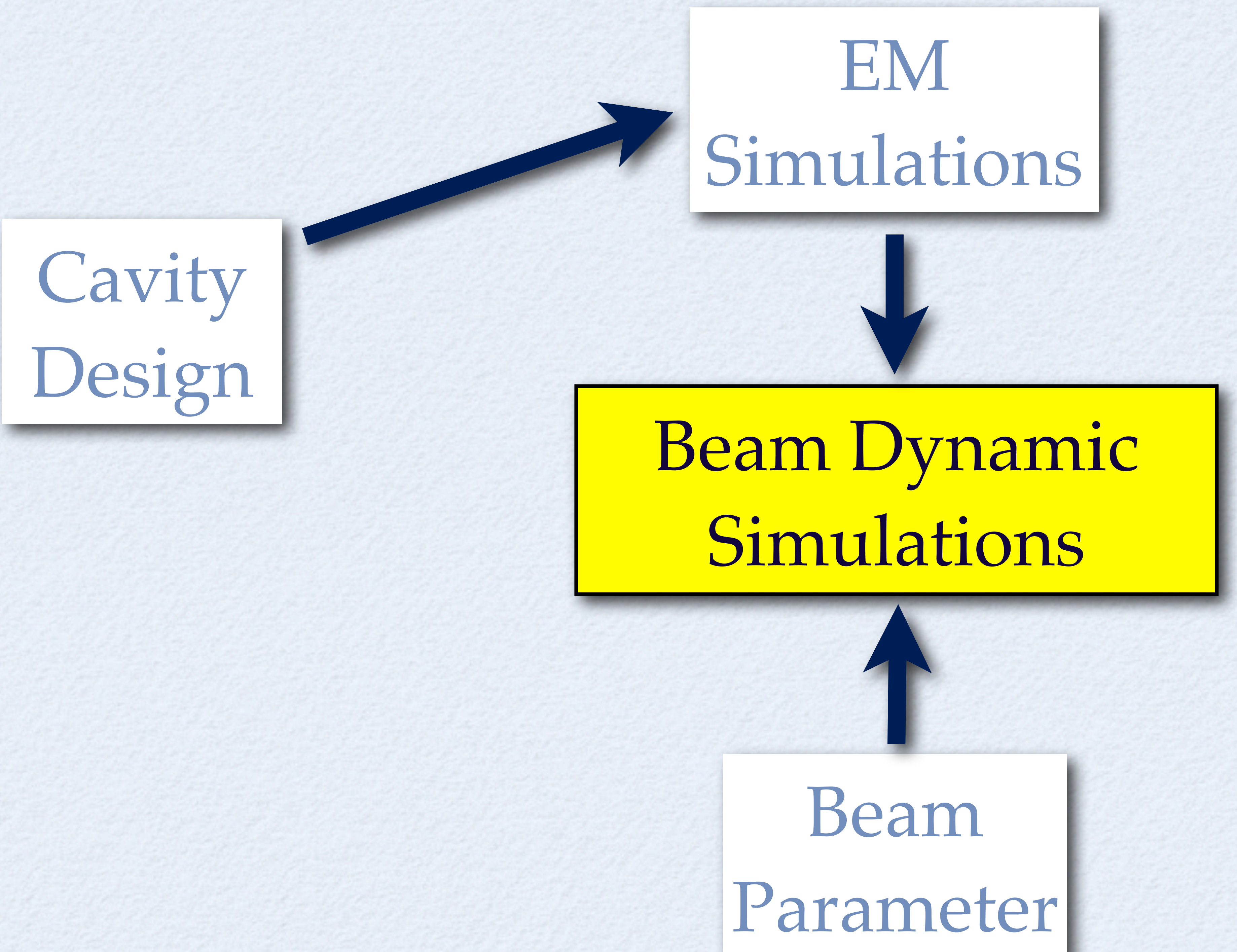


E-Field: TE_{110}

WORK FLOW

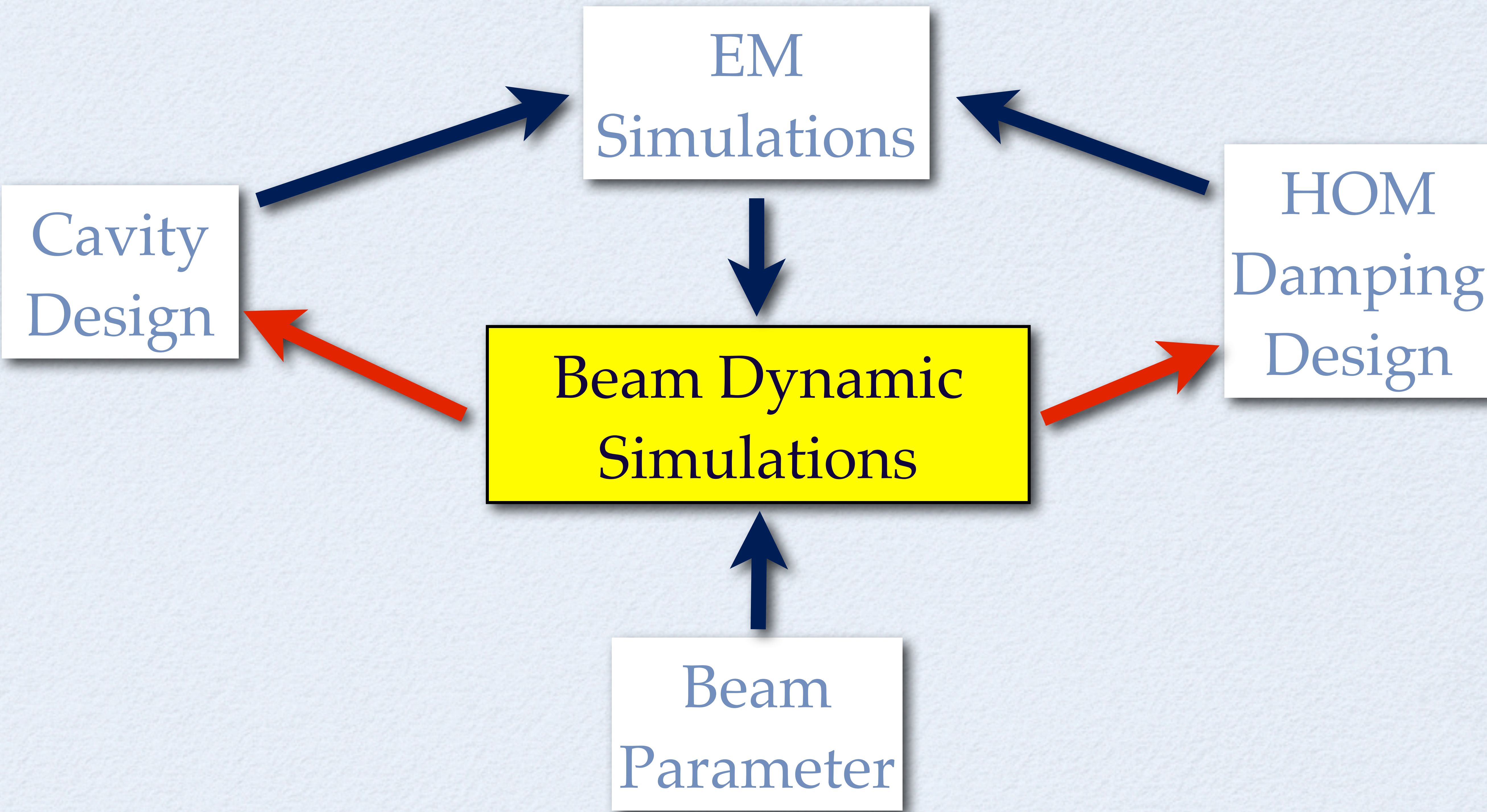
Beam Dynamic Simulations

WORK FLOW

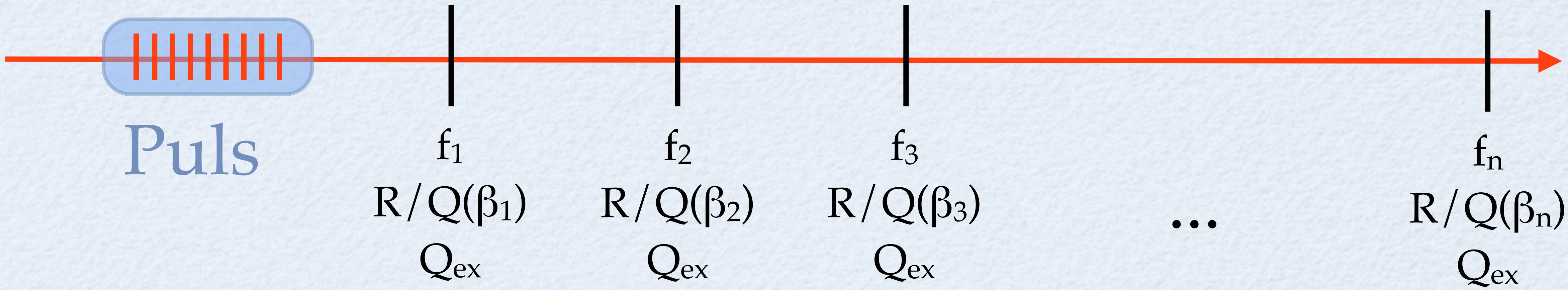


Marcel.Schuh@quasar-group.org

WORK FLOW


EM Simulations
Cavity Design
HOM Damping Design
Beam Dynamic Simulations
Beam Parameter

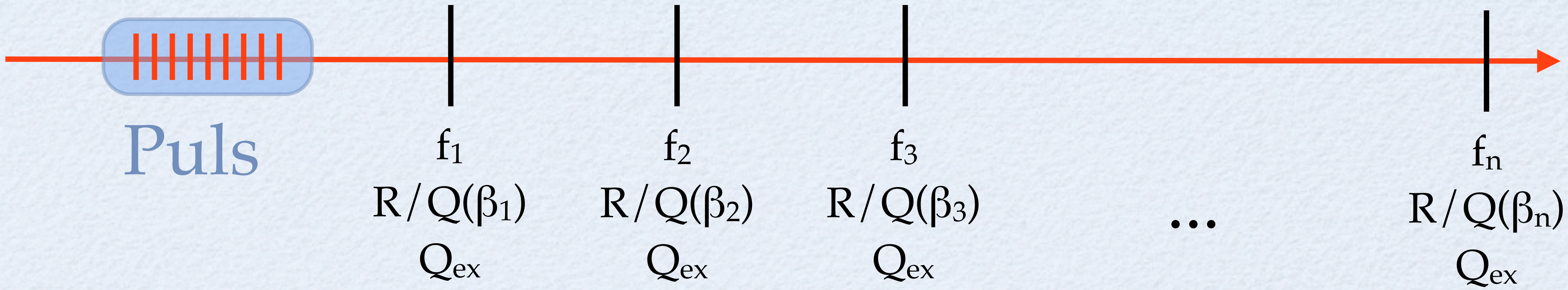
Simulation Model



- One HOM per cavity (monopole or dipole)
- Gaussian HOM frequency distribution
- $R/Q(\beta_{beam})$
- Set global Qex (Damping)

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

Simulation Model



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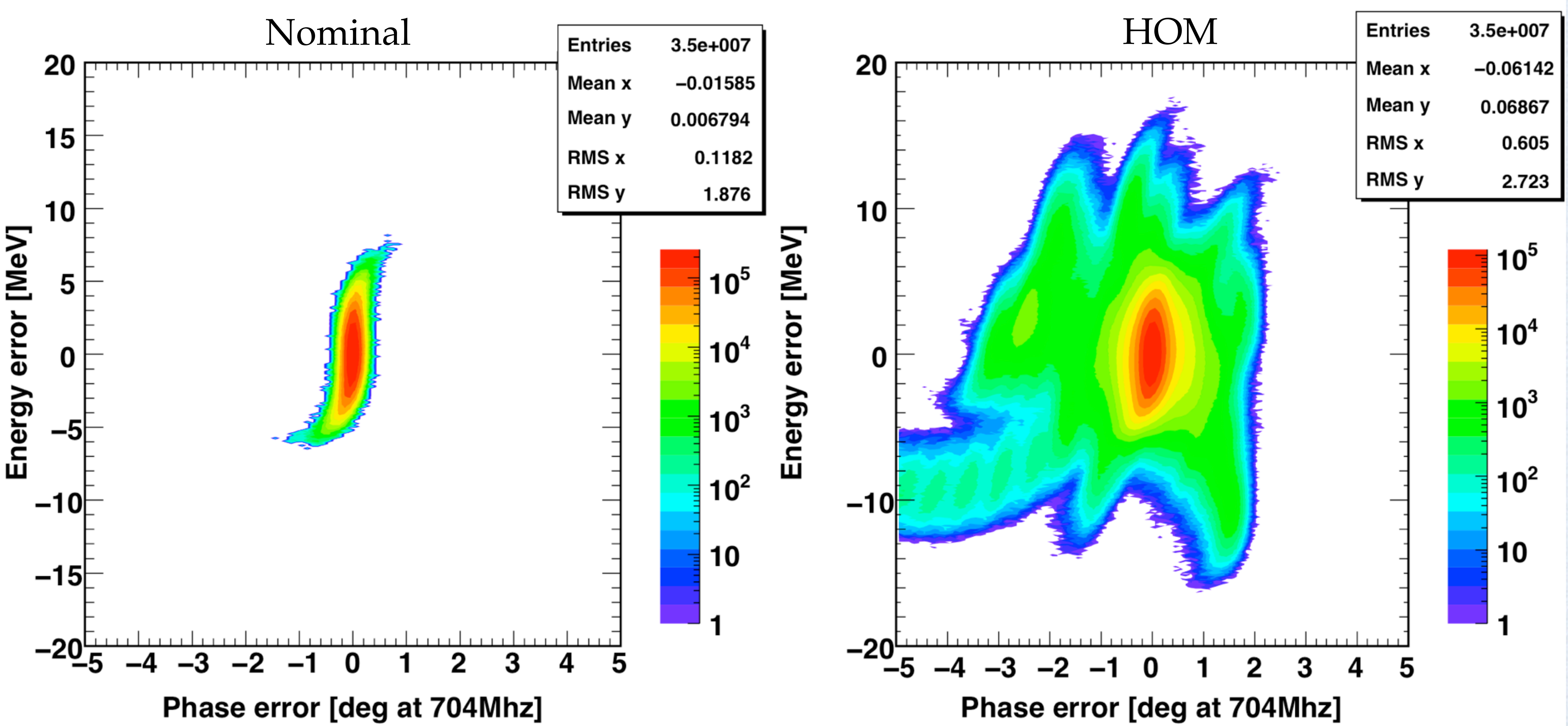
➡**Load HOM via bunch tracking simulation (Bunch ⇔ HOM interaction)**

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

Beam Blow Up

Phase space at the exit of the linac



Results

Effect	Longitudinal	Transversal
HOM Frequency Spread	↘	↘
Machine Lines	↗	→
I · R/Q	↗	↗
Charge Scatter	↗	→
Chopping	↗	↗
Input Phase Space	→	→
RF-Errors	→	
Alignment Errors		→

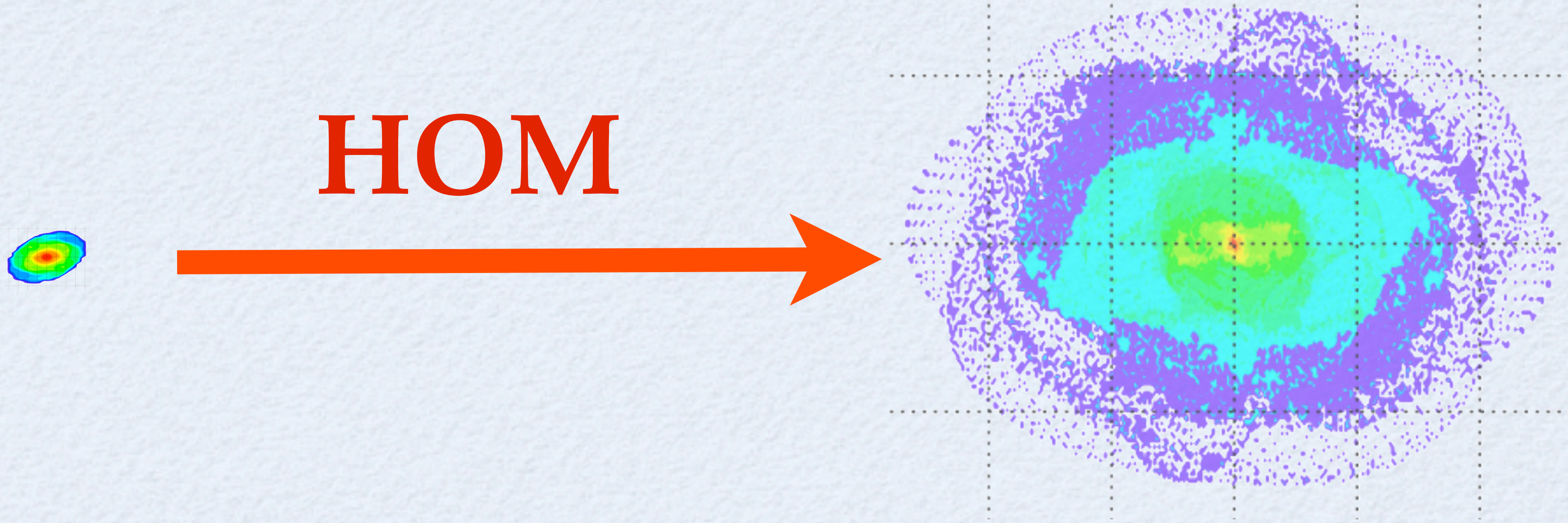
CONCLUSION

- Complex and powerful tools developed to simulate influence of HOMs
- Influence of various effects have been studied
- Damping requirements can be defined by taking into account all these effects and the machine specific beam parameters

Marcel.Schuh@quasar-group.org

THANK YOU!

Questions?



Marcel.Schuh@quasar-group.org

THE SPL PROJECT

www.cern.ch/project-spl

Superconducting Proton Linac

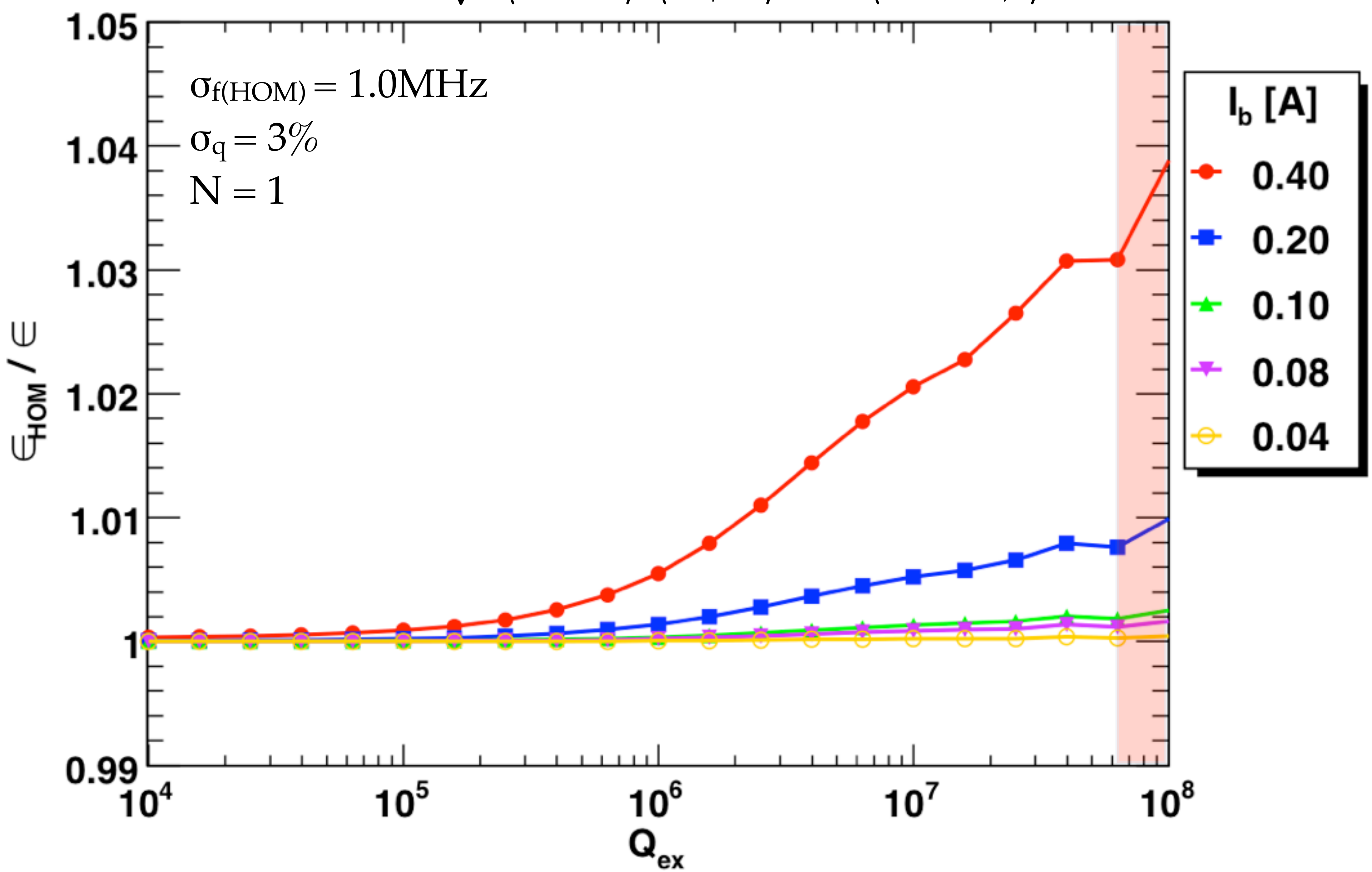
160 MeV → $\beta = 0.65$ | $\beta = 1.0$ → 4/5 GeV

SPL Parameter	
Beam power [*MW*]	4 - 8
Beam current [mA]	20 - 40
Pulse length [ms]	0.4 - 1.2
Rep. frequency [Hz]	50
Physical length [m]	~500

Cavity parameter	$\beta_g = 0.65$	$\beta_g = 1.0$
Operation Frequency [MHz]	704.4	704.4
Cells per cavity	5	5
Design gradient [MV/m]	19	25
$R/Q(\beta_g)$ [linac Ω]	320	560
Cavities installed (5GeV)	~54	~192

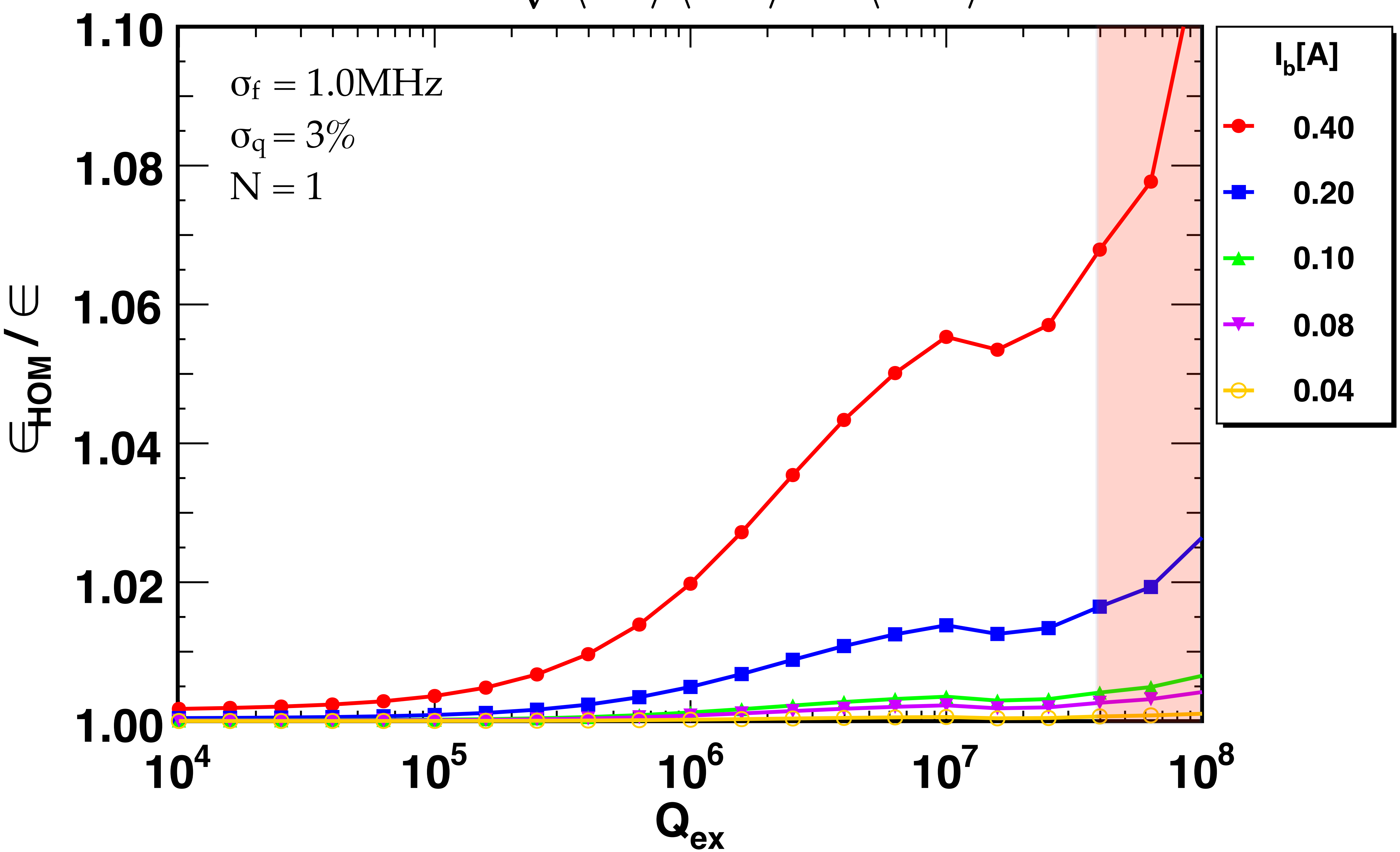
LONGITUDINAL

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



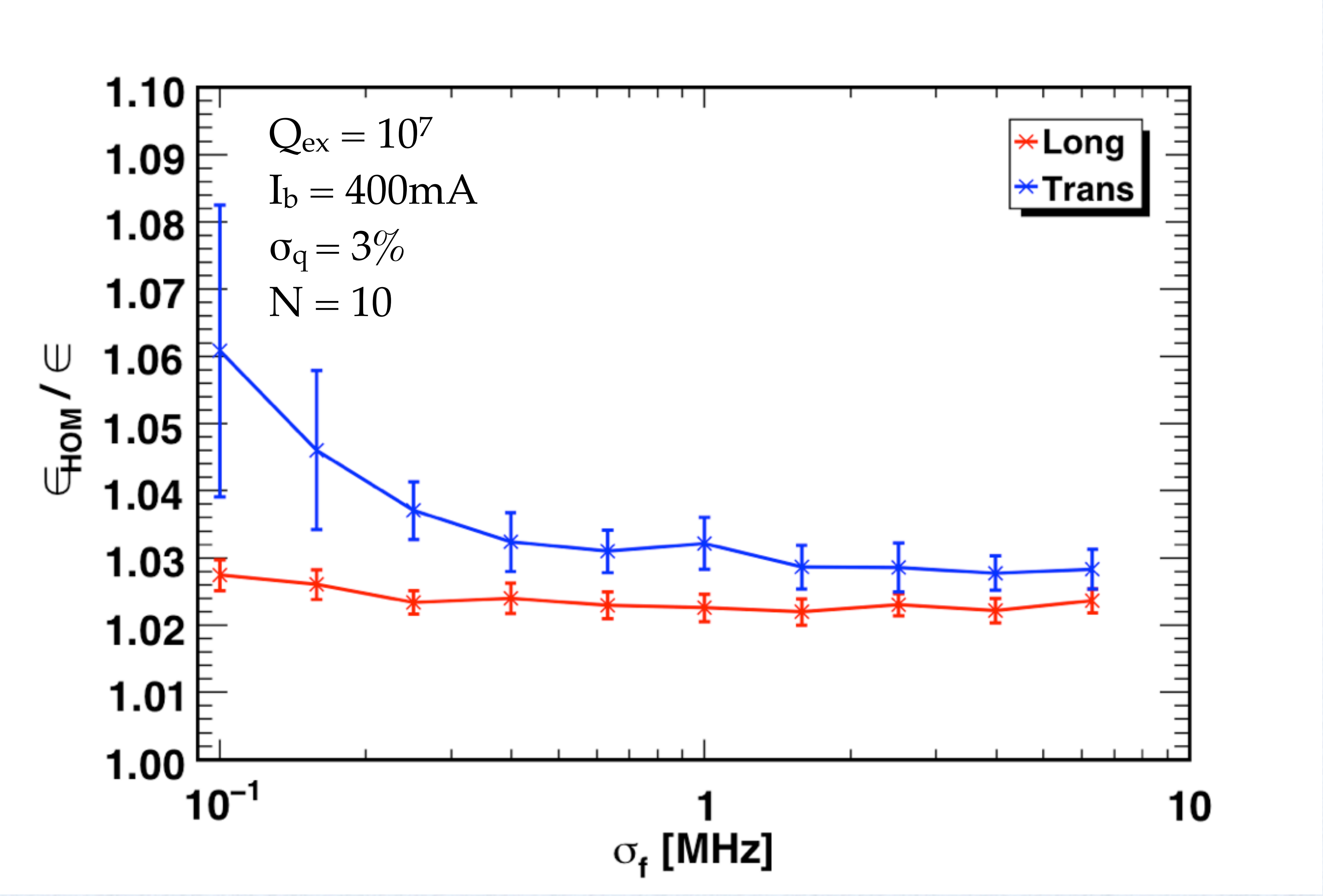
Transversal

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



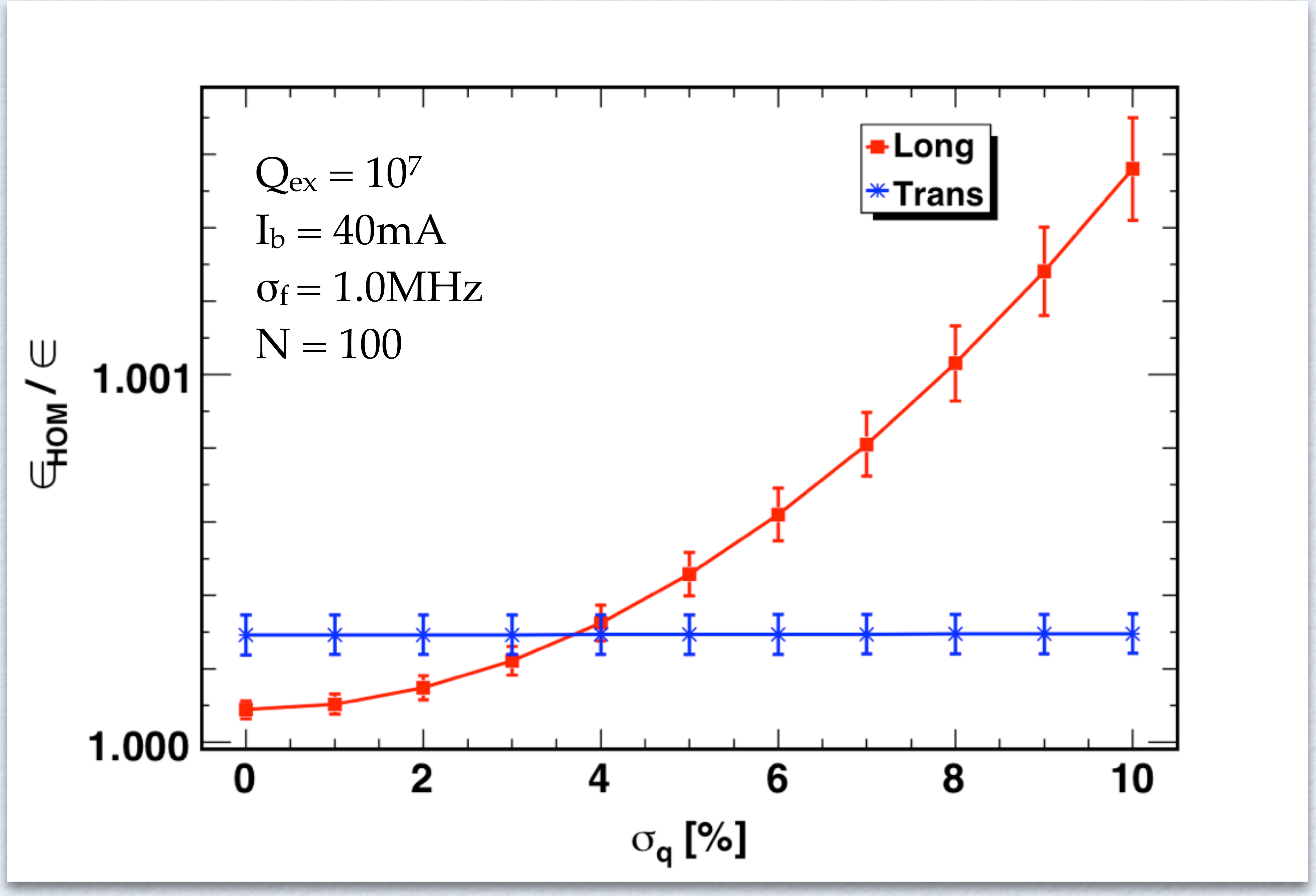
HOM frequency spread

- Higher HOM frequency spread decreases growth



Bunch charge scatter

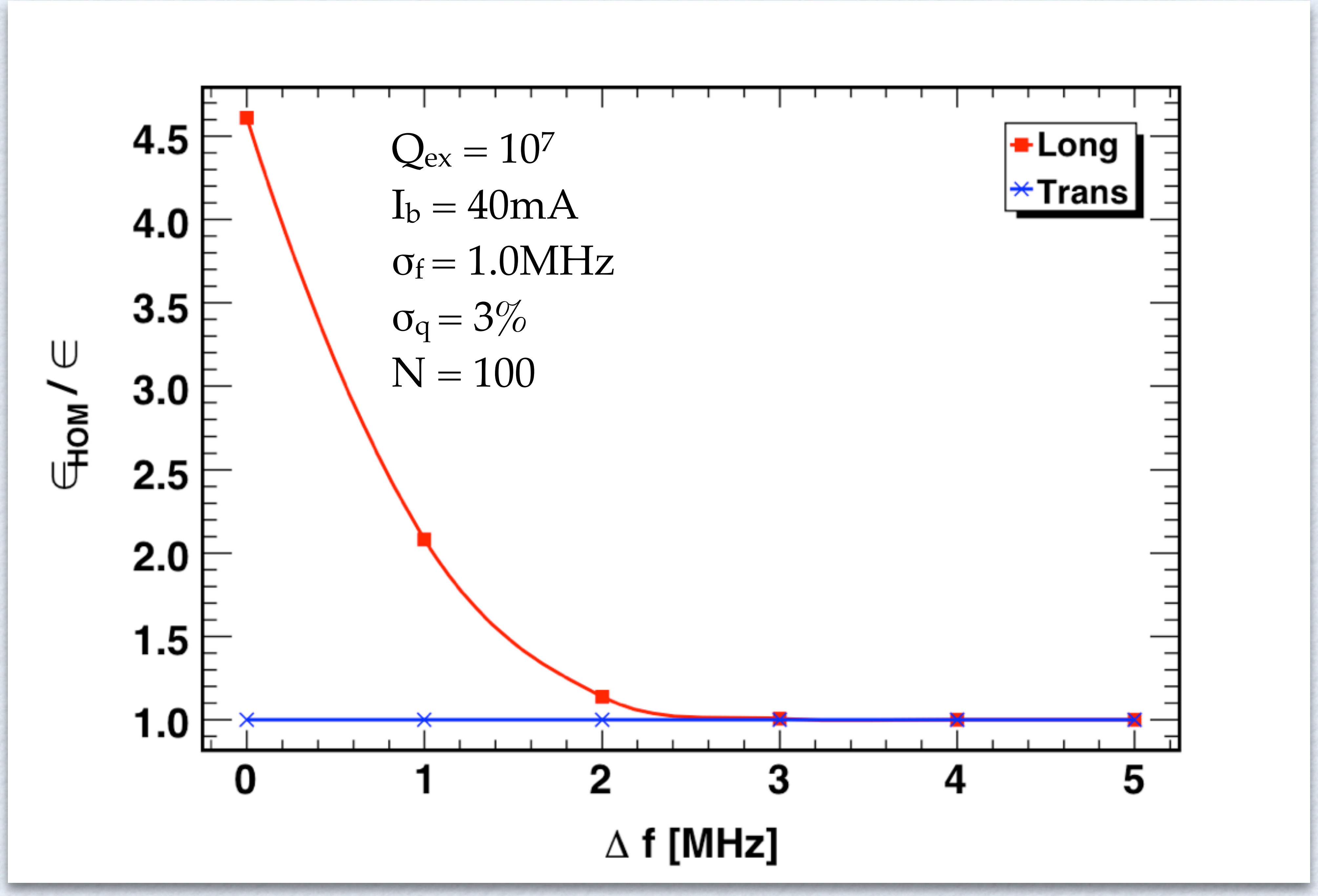
- Bunch charge scatter drives HOM in longitudinal plane



Marcel.Schuh@quasar-group.org

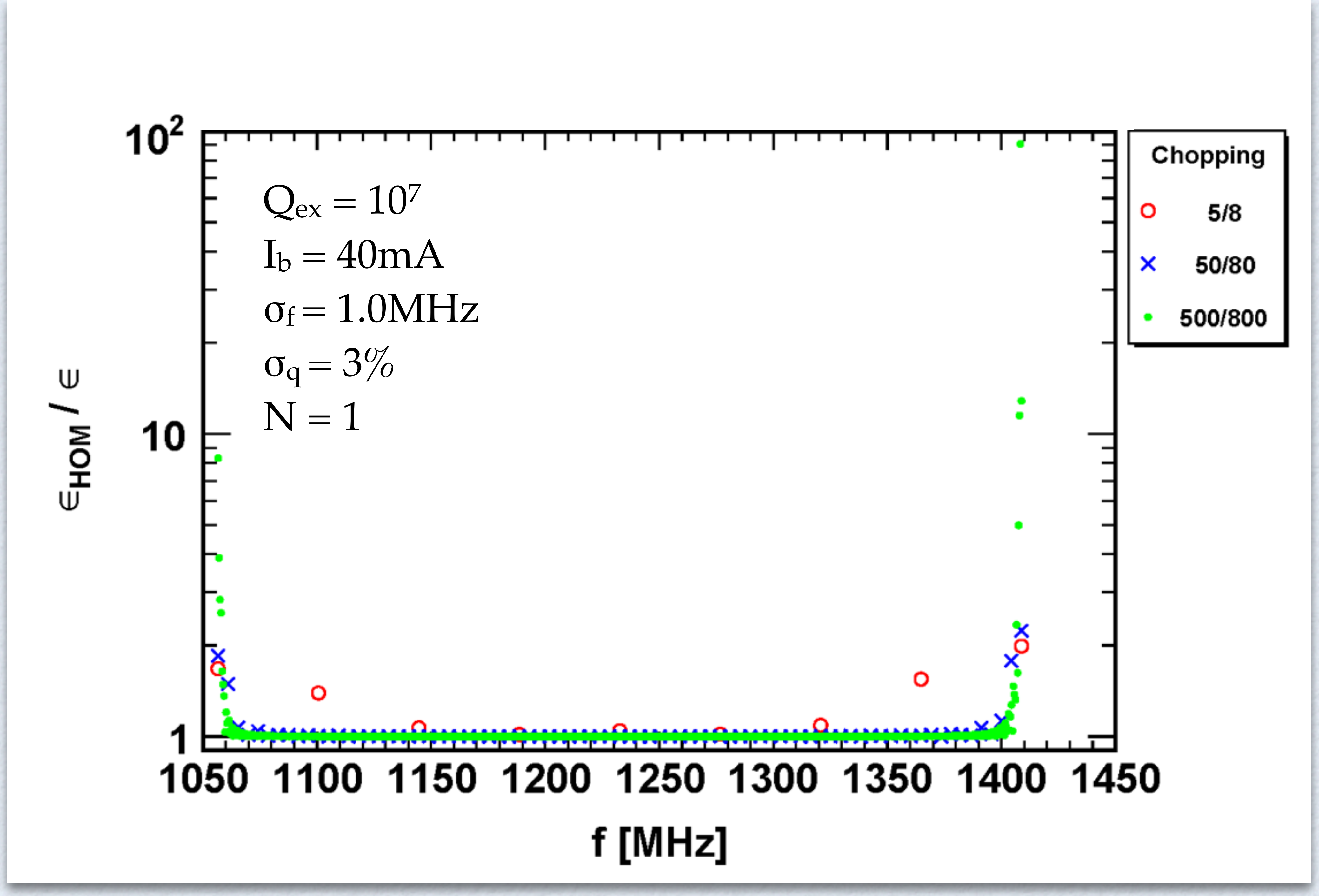
MACHINE LINES (ML)

- ML are only a major concern for monopole modes



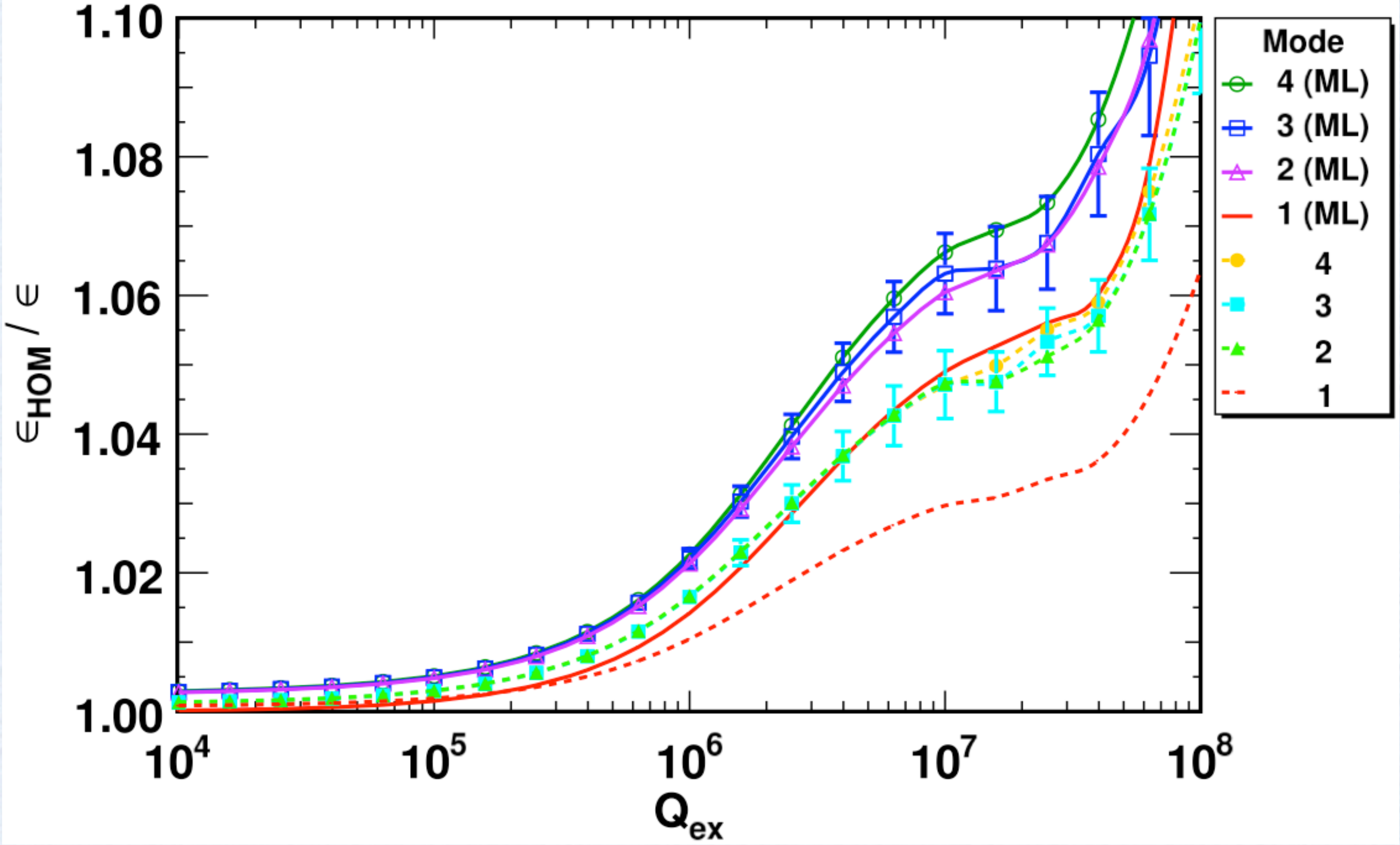
CHOPPING

- New machine lines excite HOMs if they match



CHOPPING

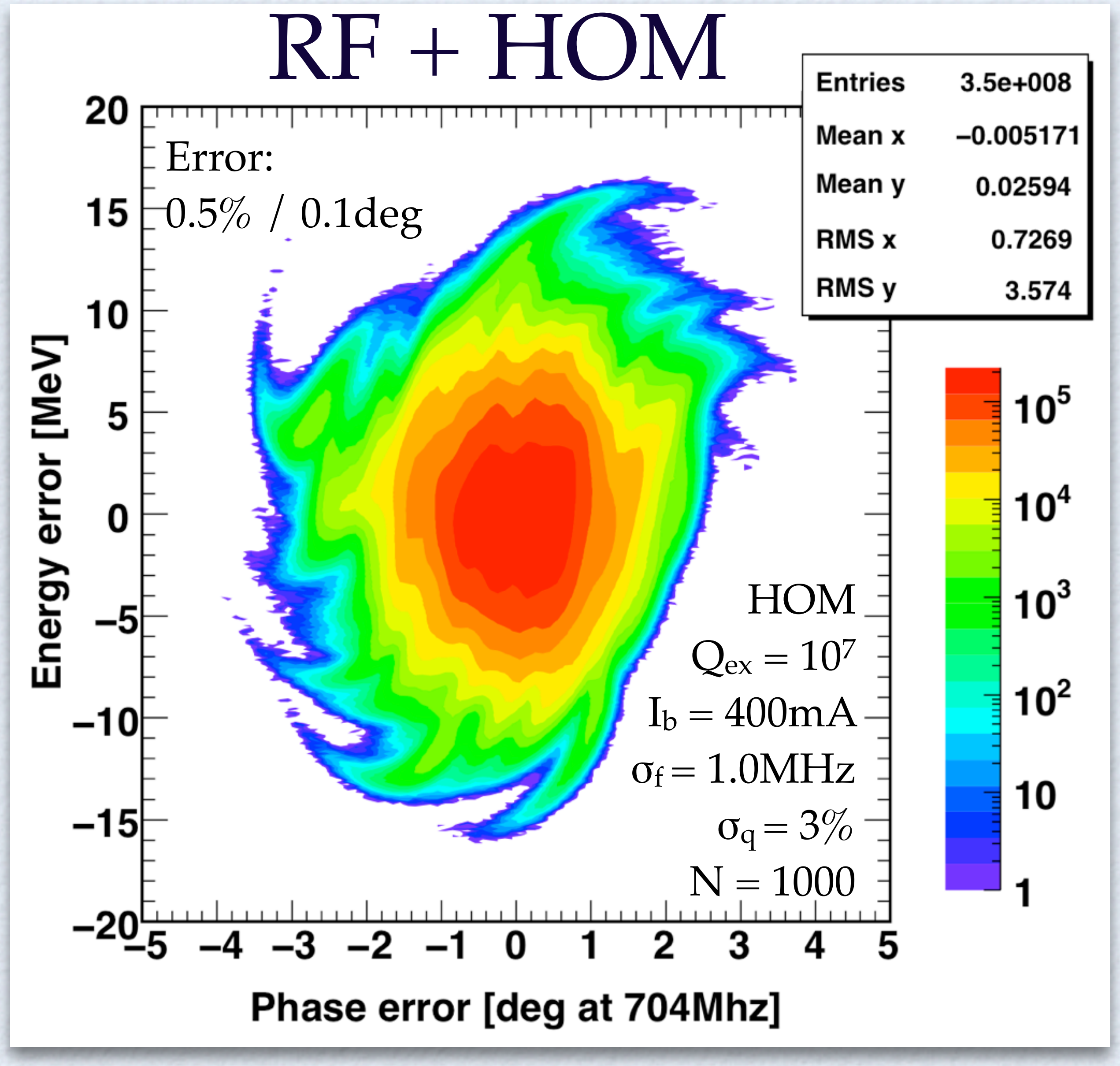
Transversal emittance growth

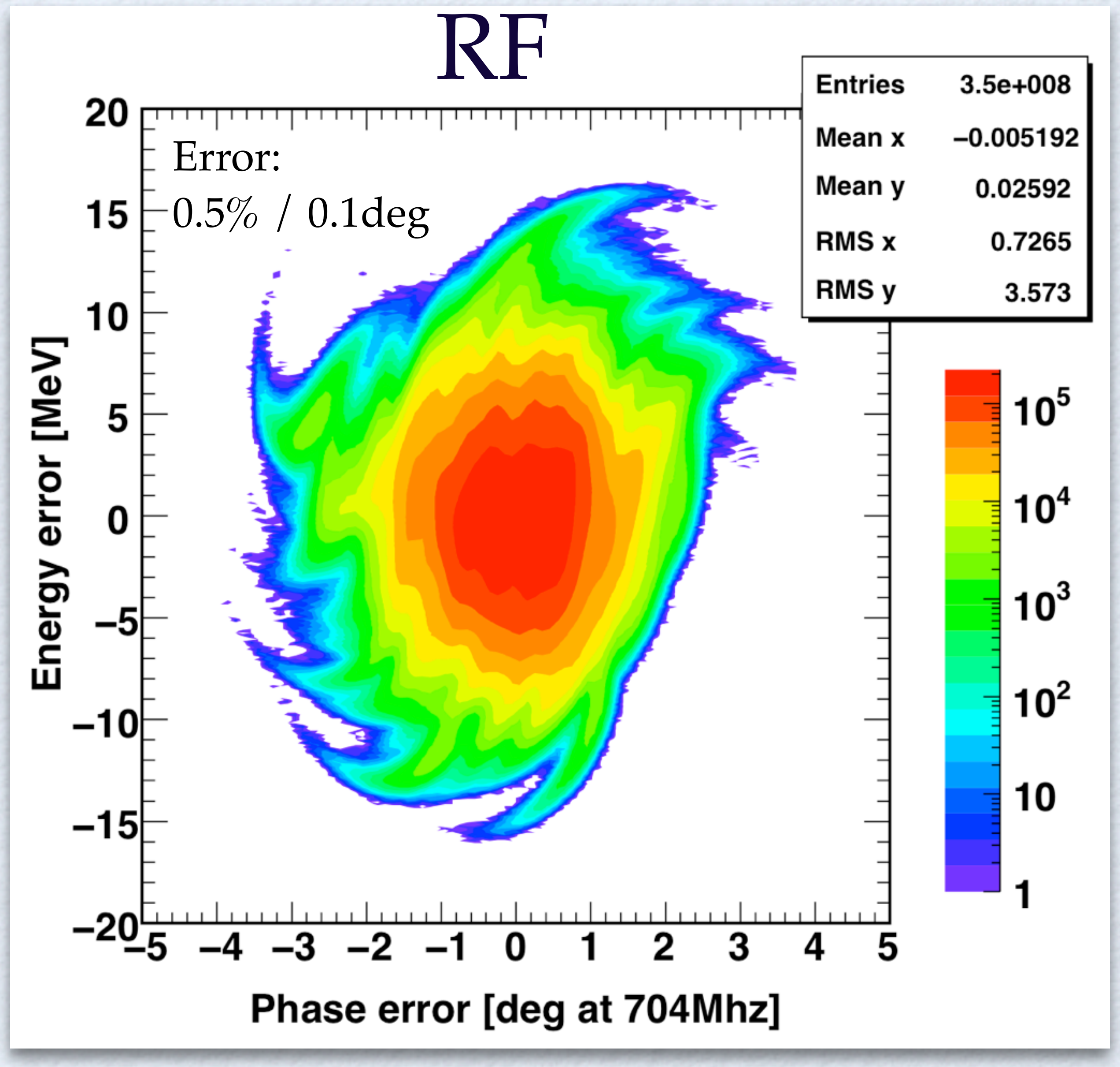


- Increase due to higher bunch current

RF-Errors

- RF-Errors dominate compared to HOM influence





References:

- M. Schuh et al., Influence of Higher Order Modes on the Beam Stability in a High Power Superconducting Proton Linac, to be submitted to Phys. Rev. ST. AB
- M. Schuh et al., Higher Order Mode Beam Breakup Limits in the Superconducting Cavities of the SPL, IPAC'10, Kyoto, Japan
- J. Tückmantel, Phys. Rev. ST Accel. Beams 13, 011001, 2010
- 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 Input Parameters

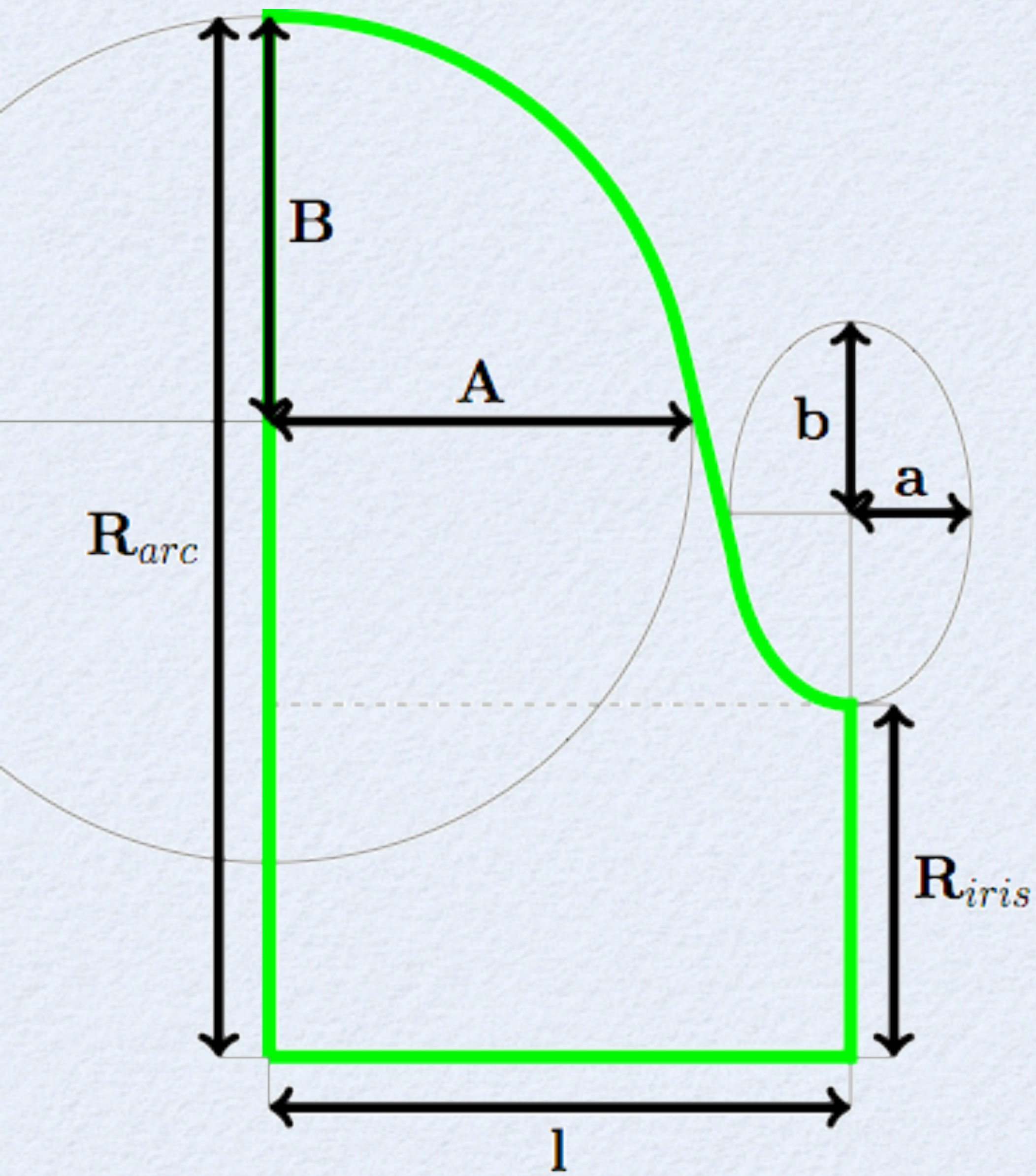
Basic beam settings used in all simulations:

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

Old data

HOM INPUT DATA