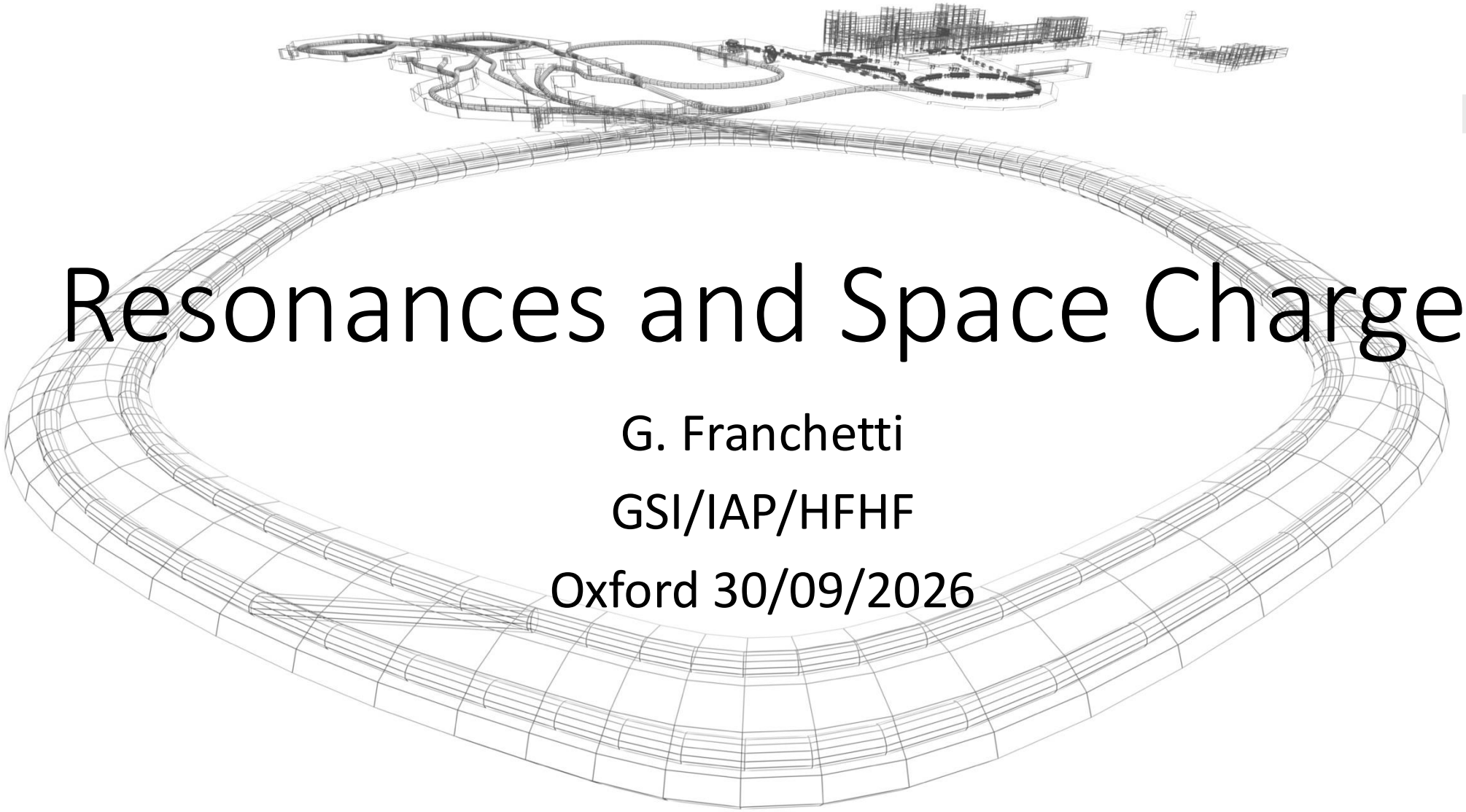


Resonances and Space Charge

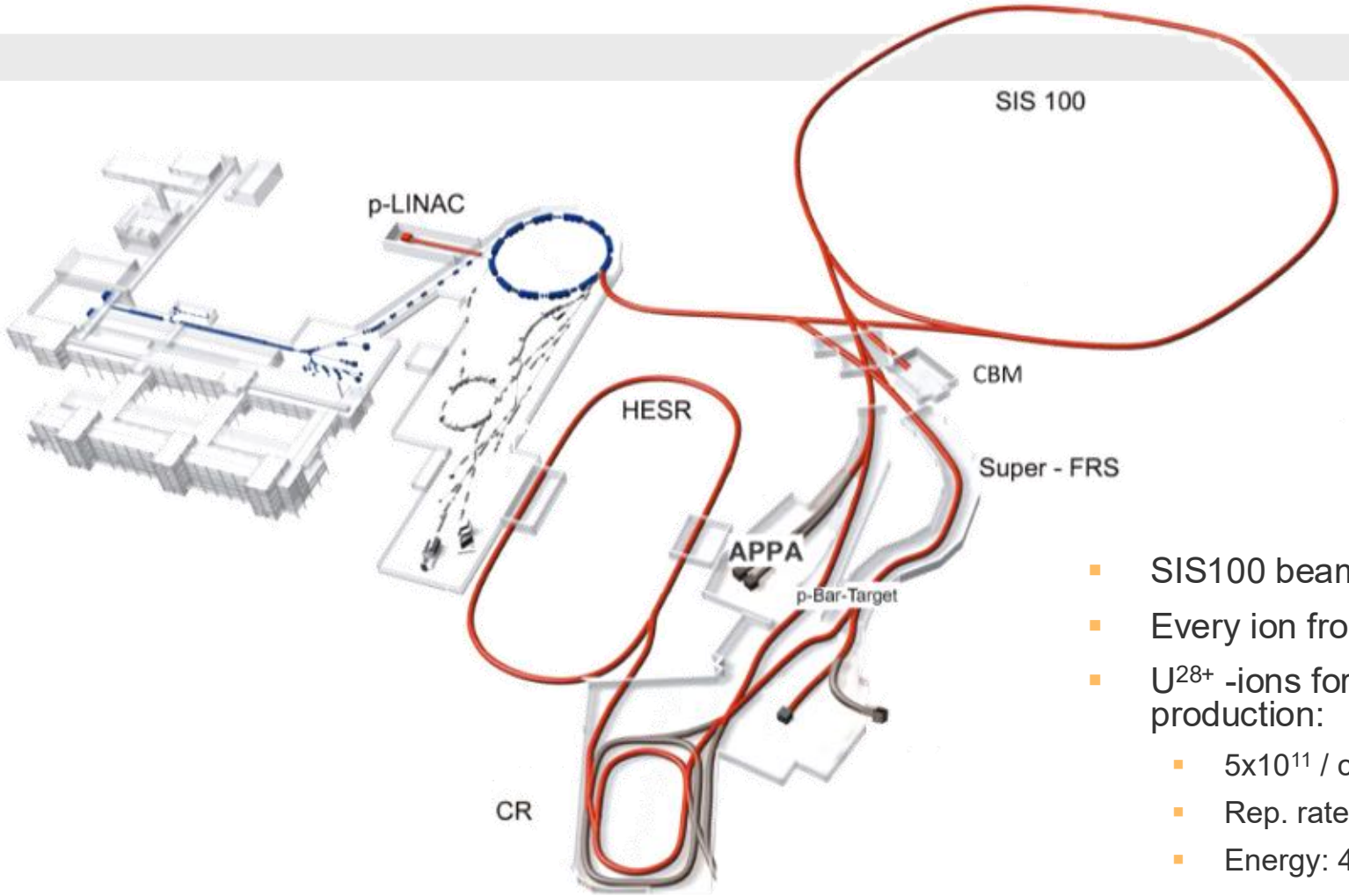
G. Franchetti

GSI/IAP/HFHF

Oxford 30/09/2026

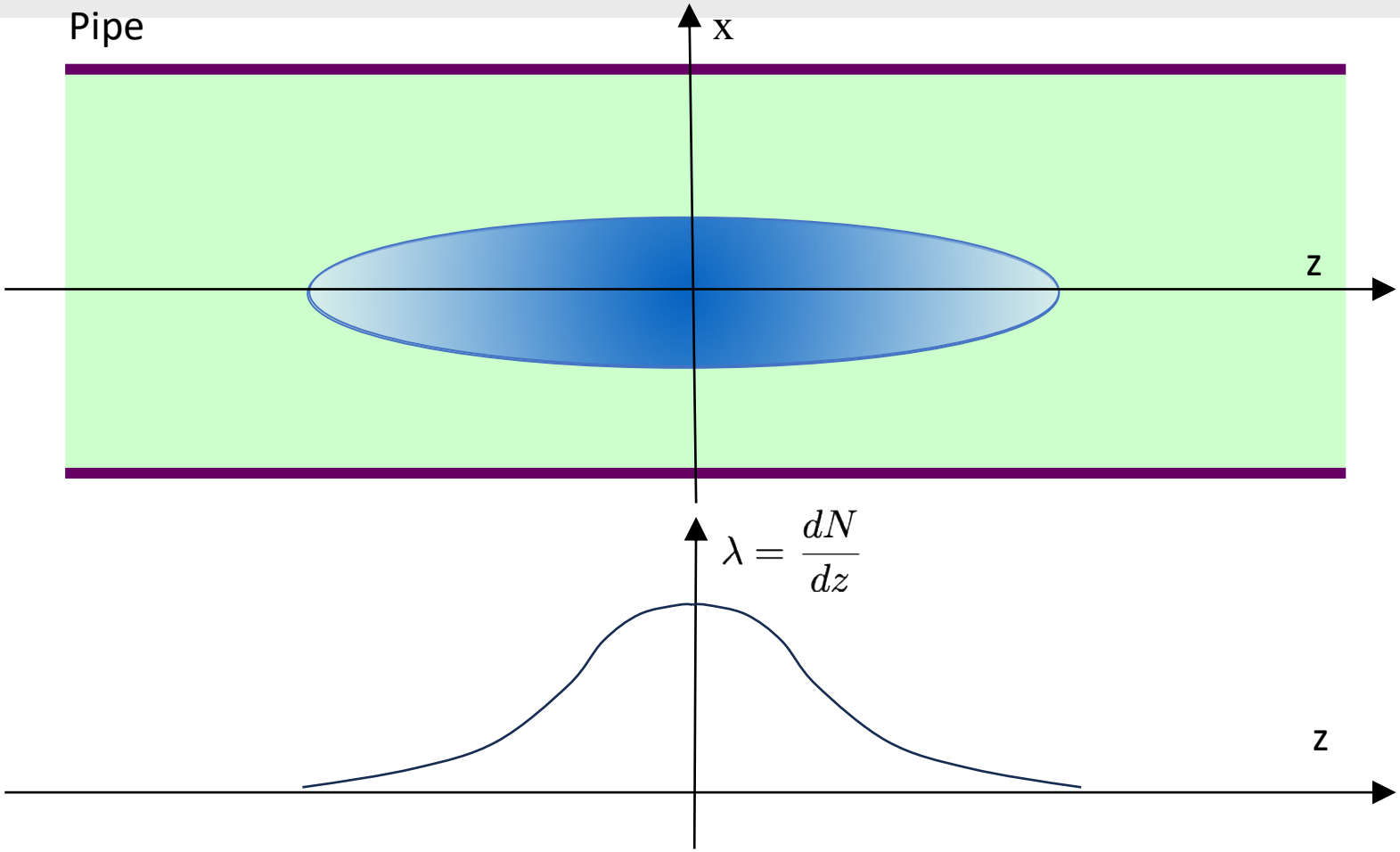
The issue

Motivation: the FAIR project → Controlling beam loss

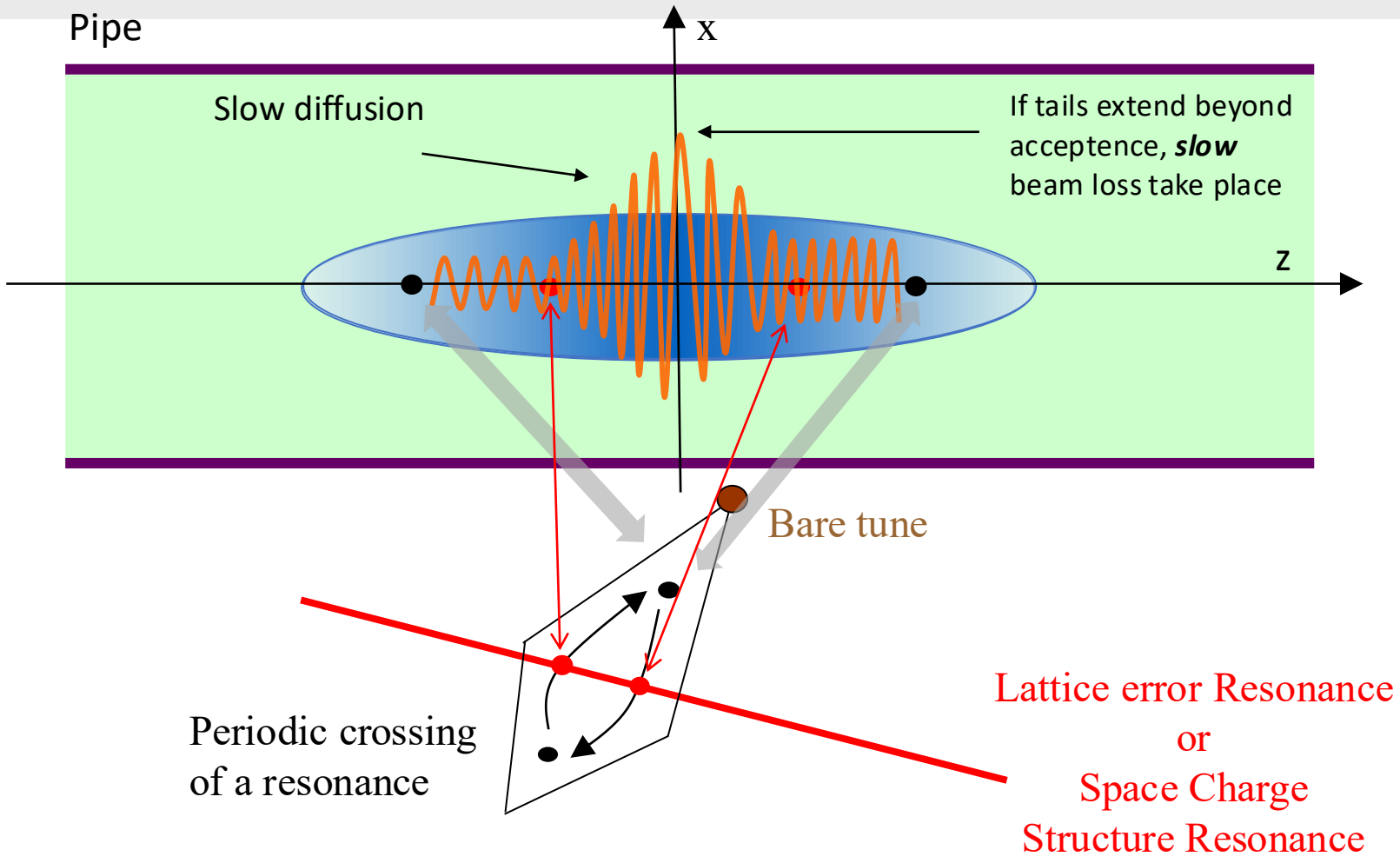


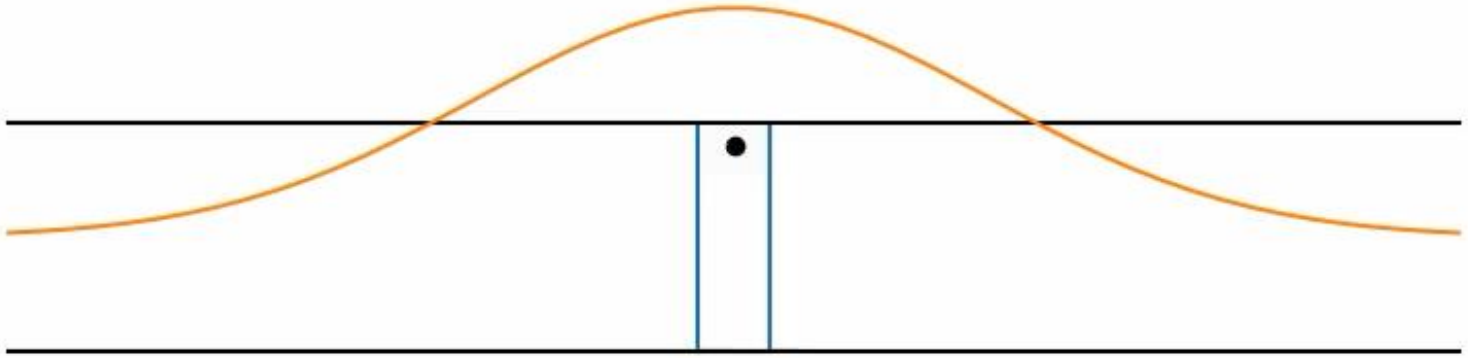
- SIS100 beam parameters:
- Every ion from p to U
- U^{28+} -ions for RIB production:
  - $5x10^{11}$ / cycle
  - Rep. rate: 0.5 Hz
  - Energy: 400–2715 MeV/u

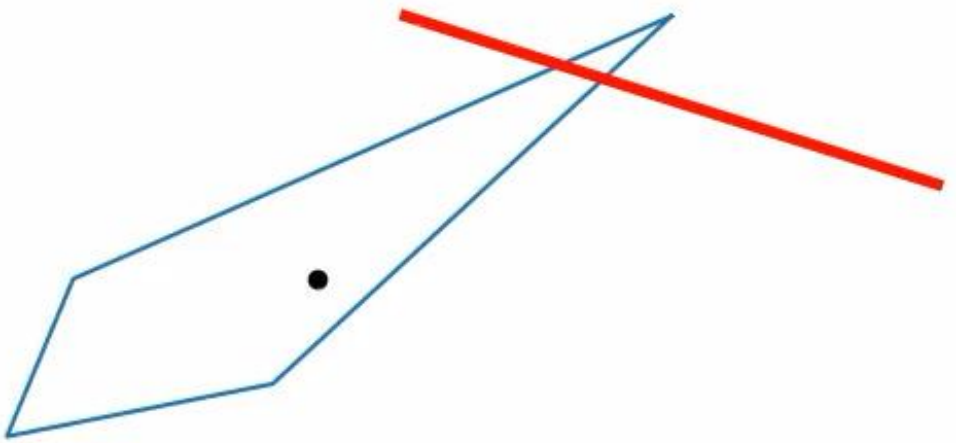
Space charge and resonances in a bunched beam

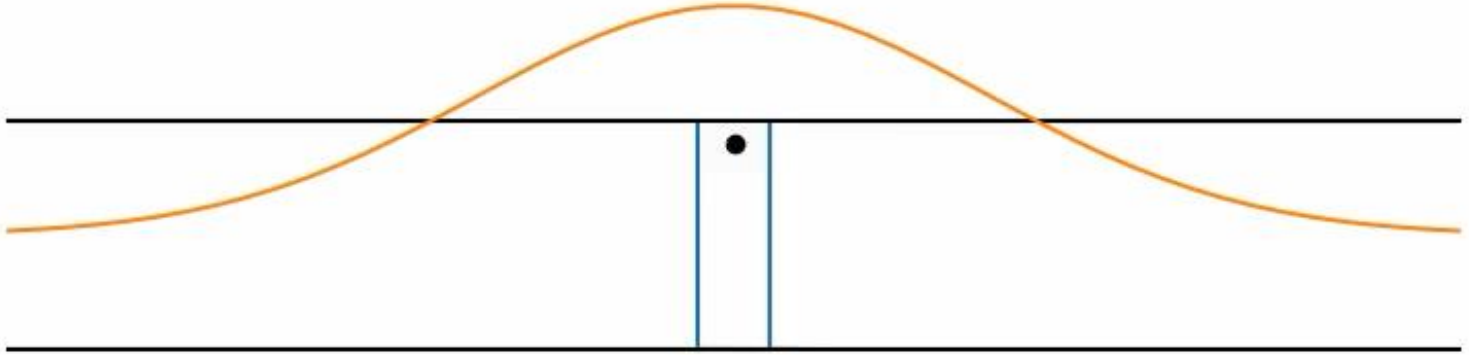


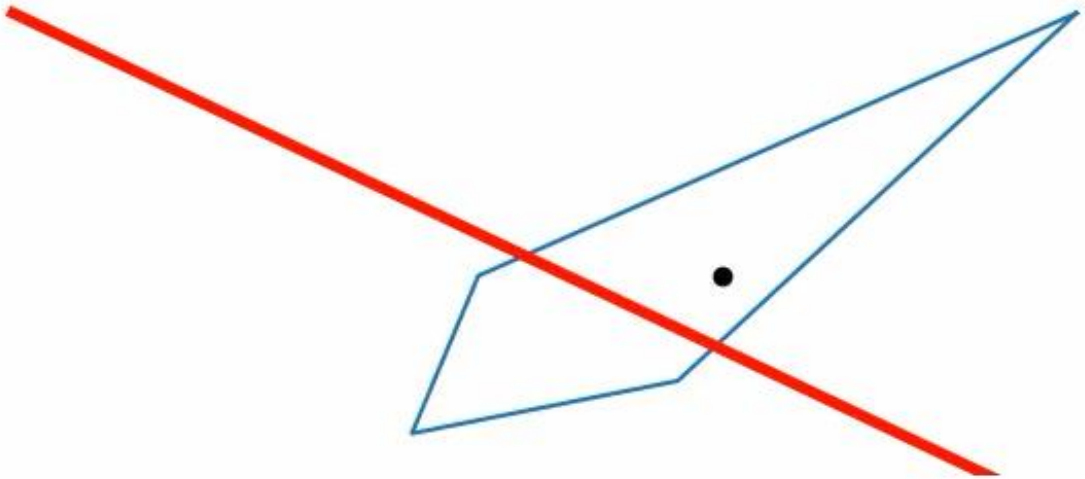
Space charge and resonances in a bunched beam

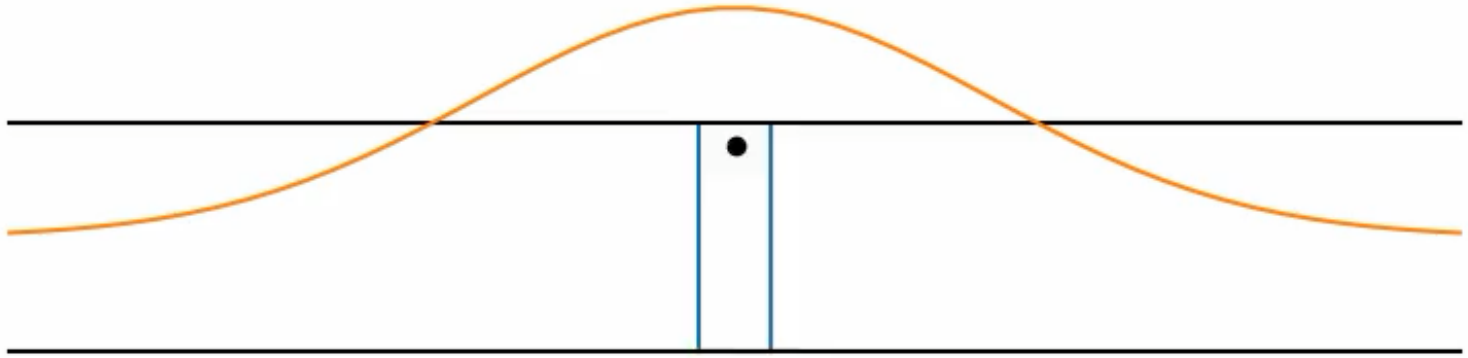


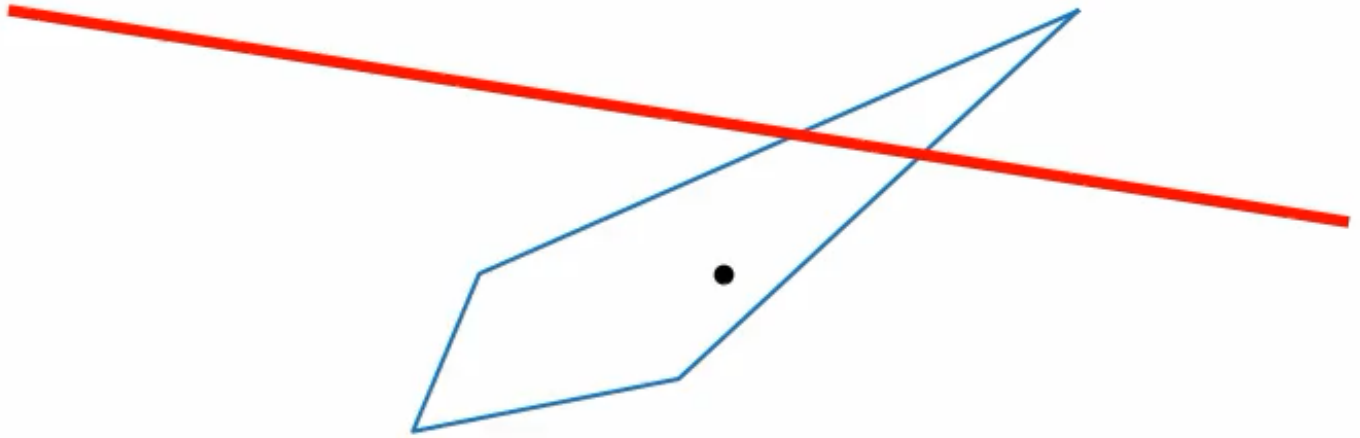


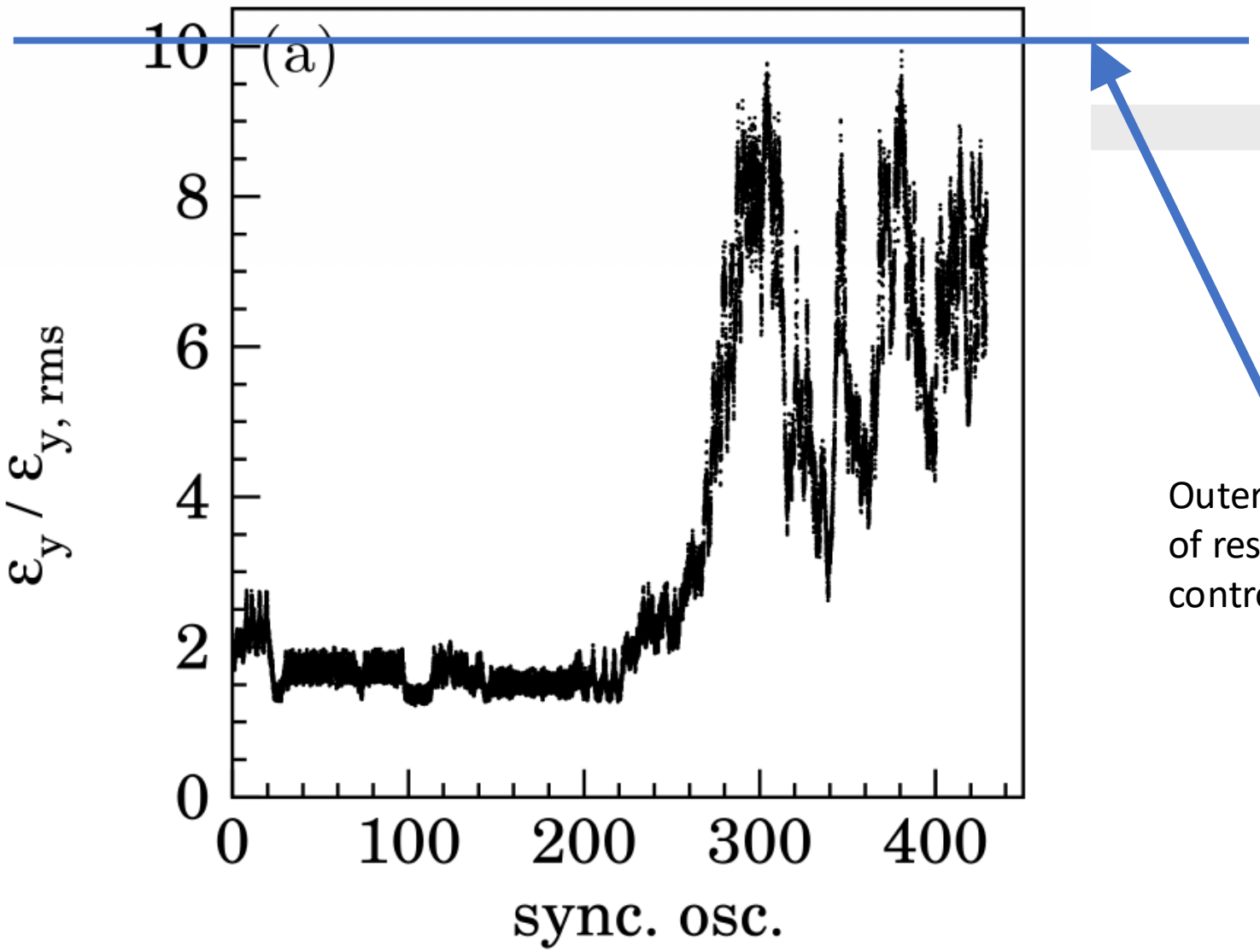






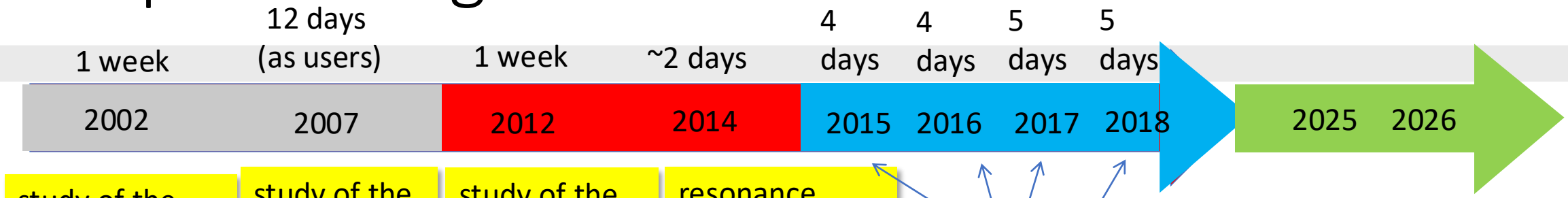






Outer position
of resonant orbit
controlled by space charge

The incoherent effects of space charge



study of the space charge on **1D** 4th order resonance

study of the space charge on **1D** 3th order resonance: proof of principle

study of the space charge on **2D** 3th order resonance

resonance compensation with space charge

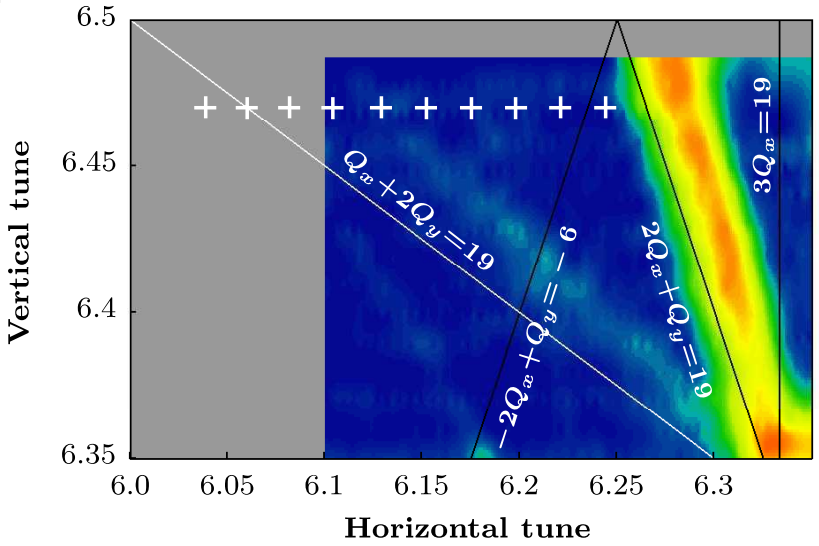
Quest for the fixed lines

Half integer

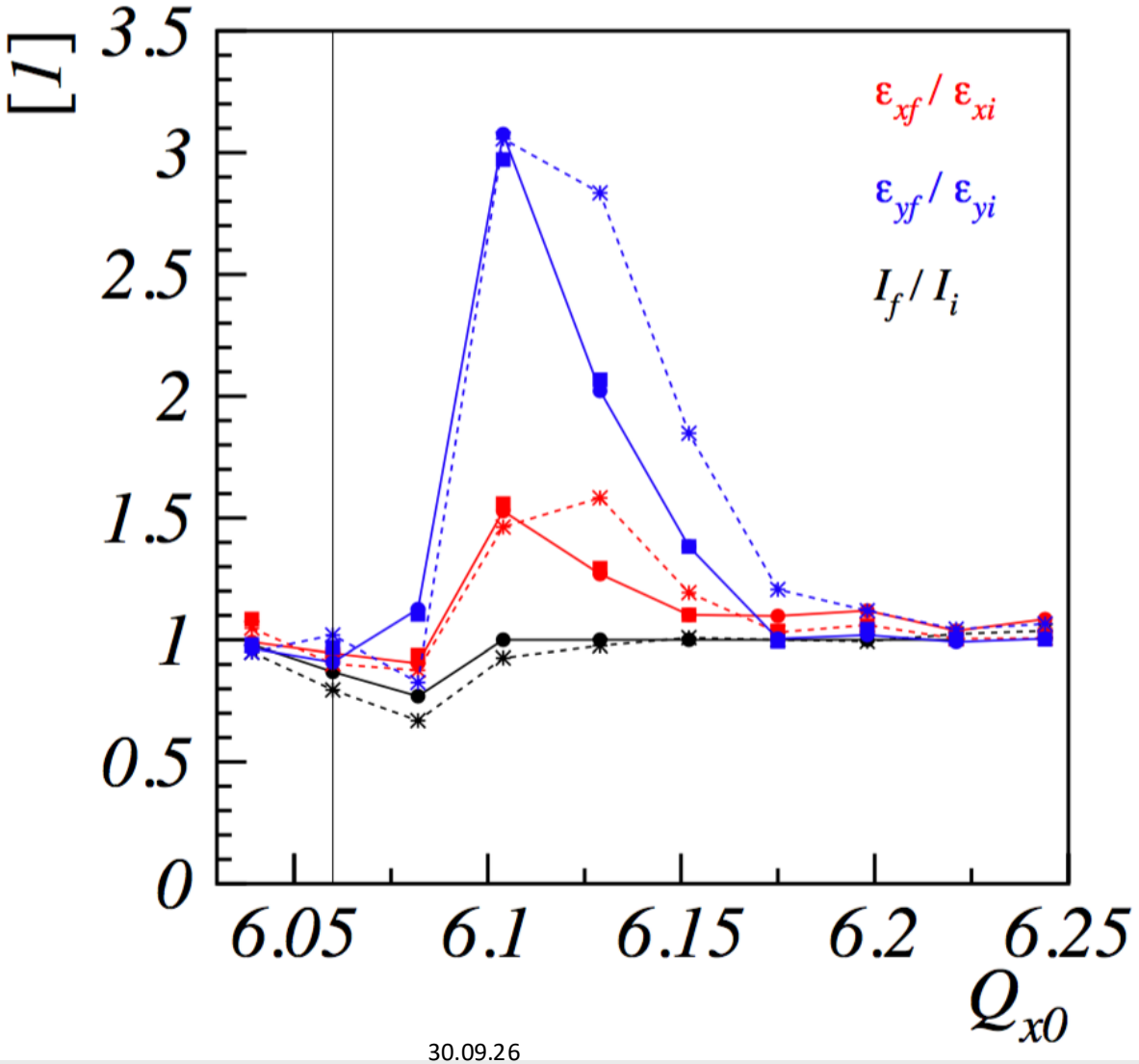
Mitigation studies Longitudinal bunch shaping

PS **SIS18** **PS** **SIS18** **SPS** **PSB**

Measurements and simulations

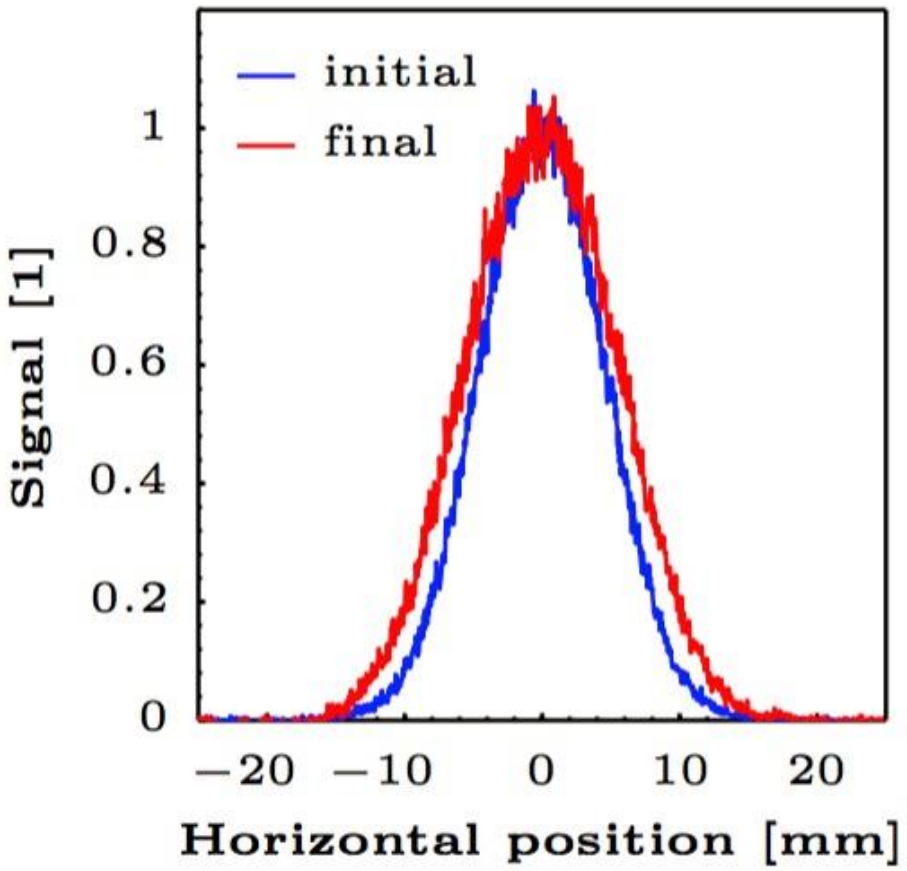


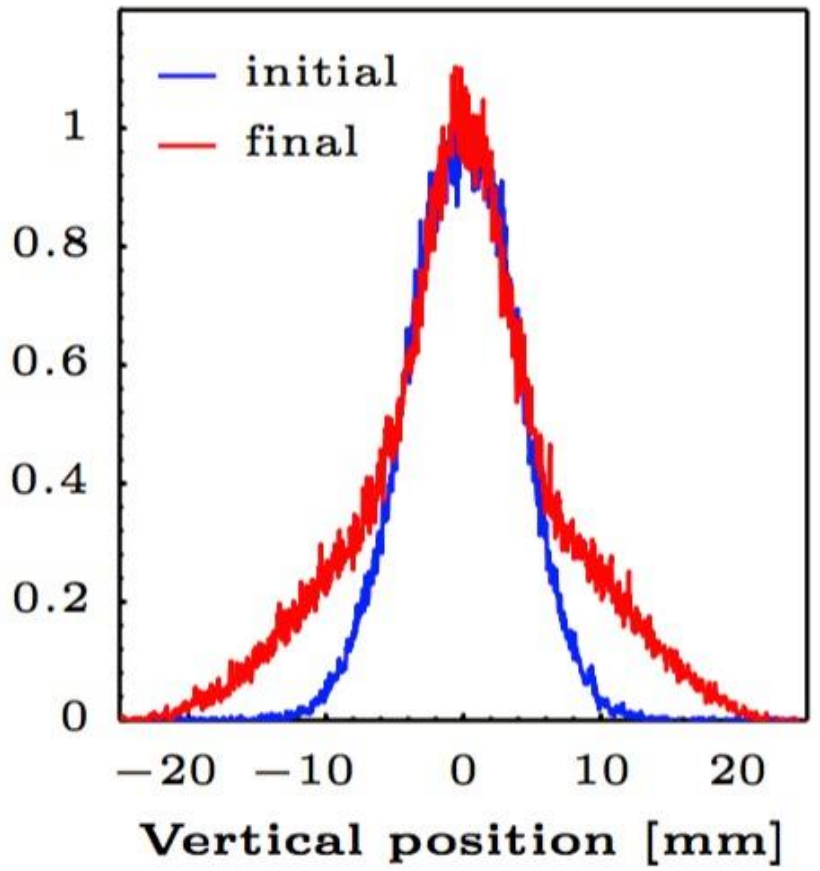
CERN-PS 2012-2017



Beam Profiles for $Q_{x0} = 6.104$

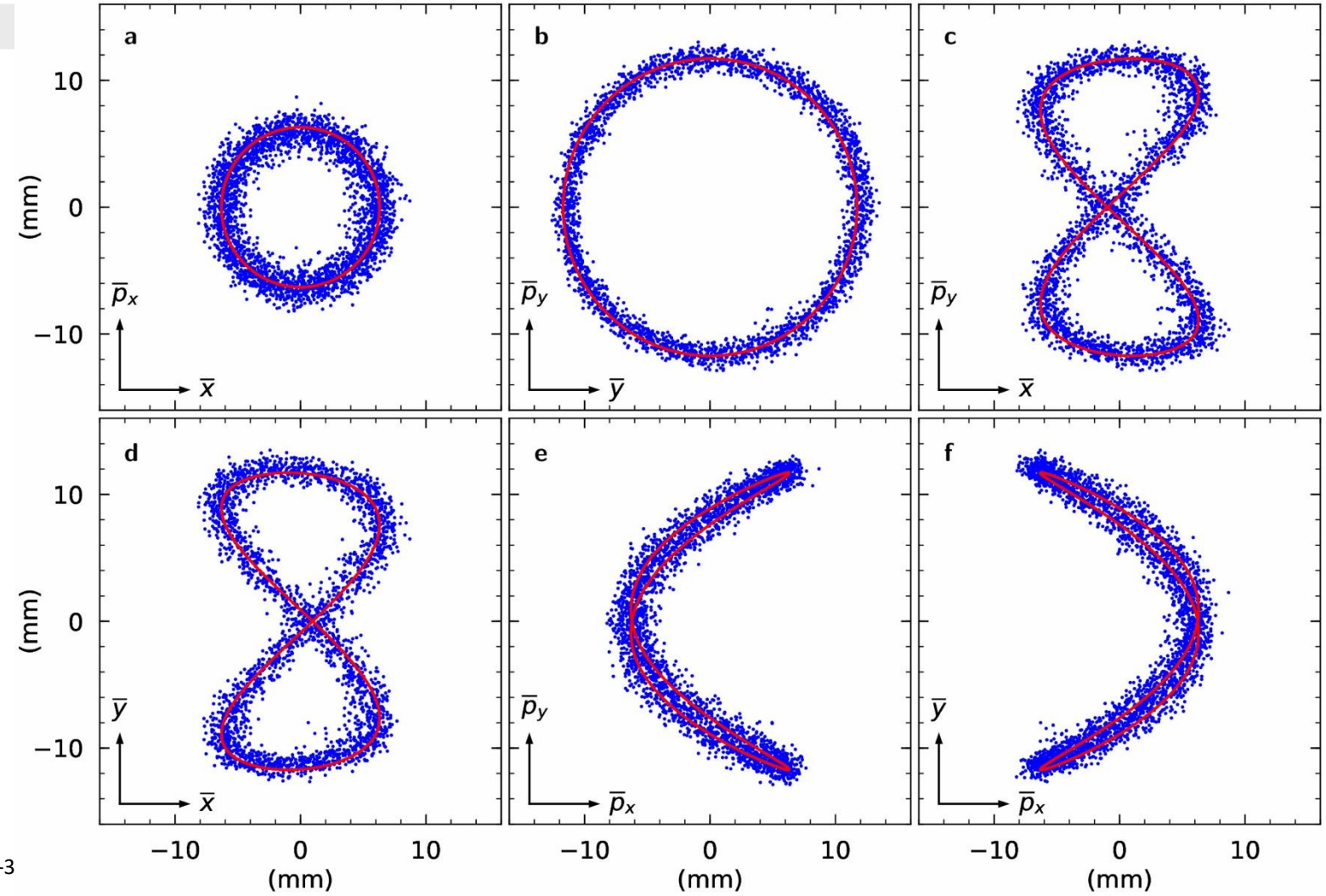
CERN-PS 2012-2017





Phys.Rev.Accel.Beams,vol.20,no.8,p.081006,
Aug. 2017. doi:10.1103/PhysRevAccelBeams.20.081006

The topology of resonant orbits is relevant as their location is controlled by space charge



Nature Physics, vol. 20, no. 6, pp. 928–933, 2024. doi:10.1038/s41567-023-02338-3

Mitigation of periodic resonance crossing induced by space charge

1) Compensating nonlinear resonances → is difficult

2) Compensating space charge → is also difficult
never been implemented

Alternative approach?

New ideas for mitigation strategy

Multi harmonics → towards barrer-bucket

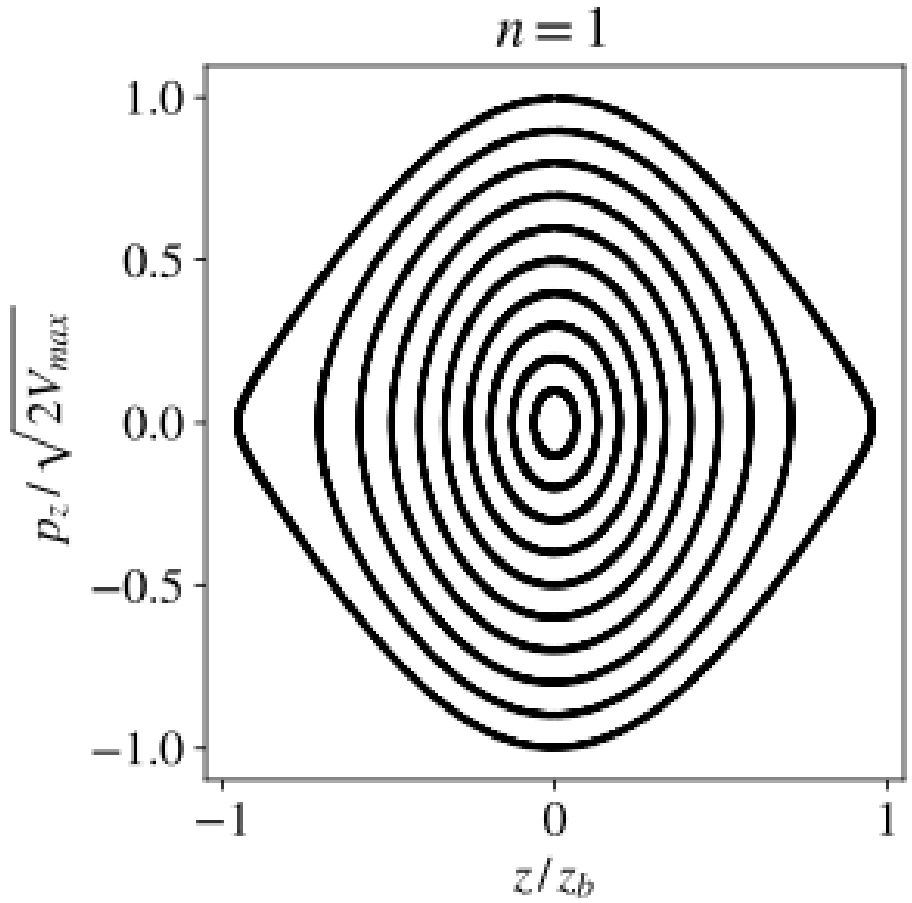
Potential model

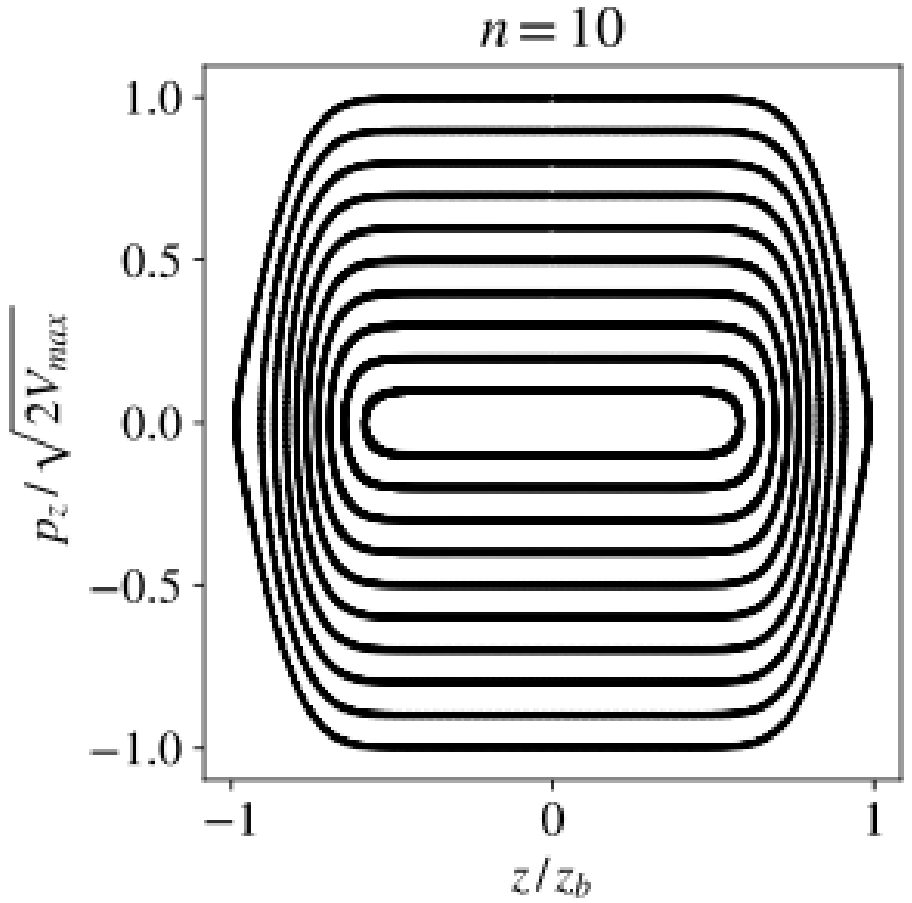
$$V(z) = V_{max} \sin^{2n}\left(\frac{\pi}{2}\frac{z}{z_b}\right)$$

With ”n” harmonics

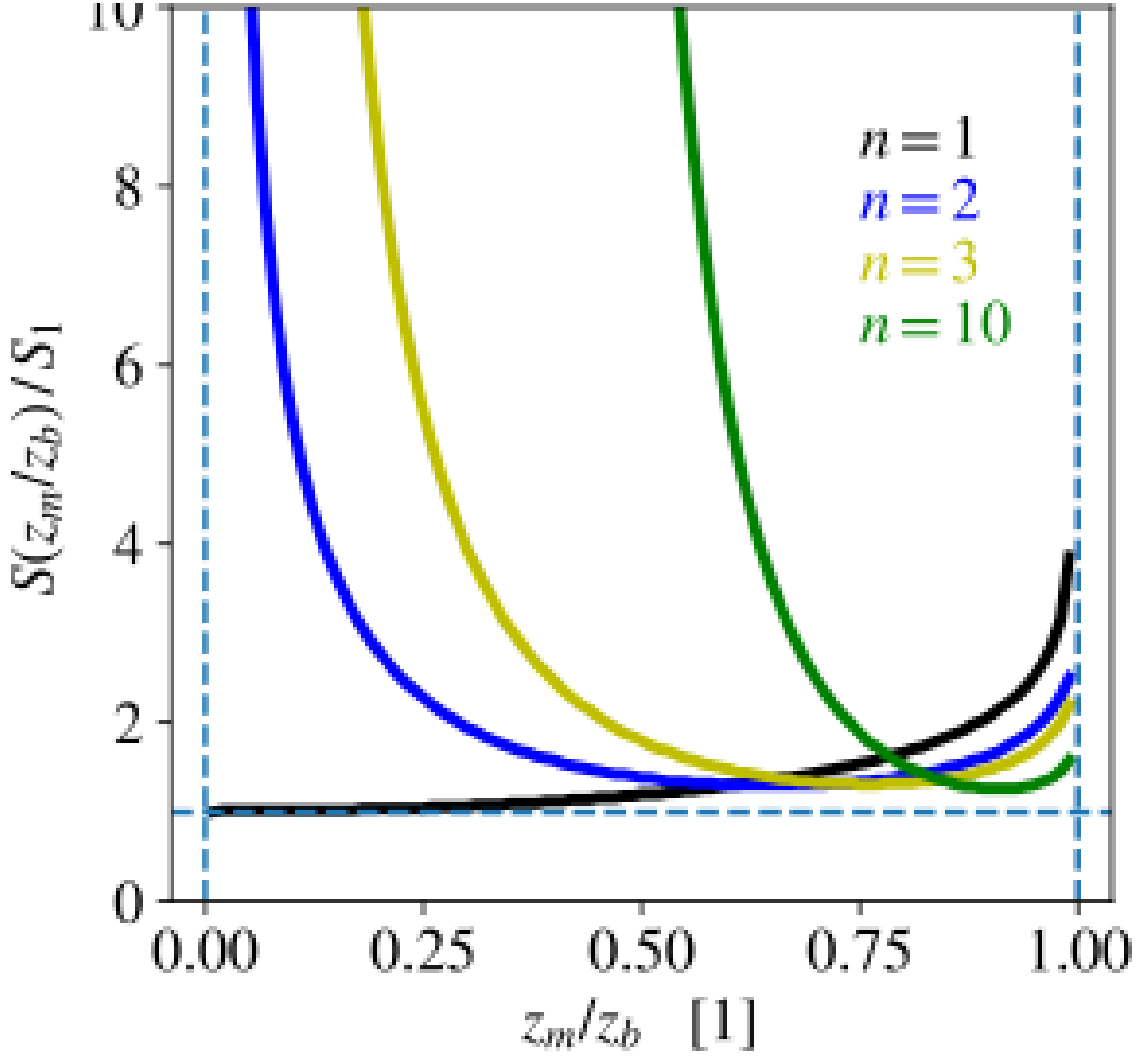
$$\begin{cases} F &= \sum_{q=1}^{n} V_q \sin\left(q\frac{\pi}{z_b}z + q\pi\right) \\ V_q &= V_{max}\frac{1}{2^{2n-1}}\binom{2n}{n+q} q\frac{\pi}{z_b} \end{cases}$$

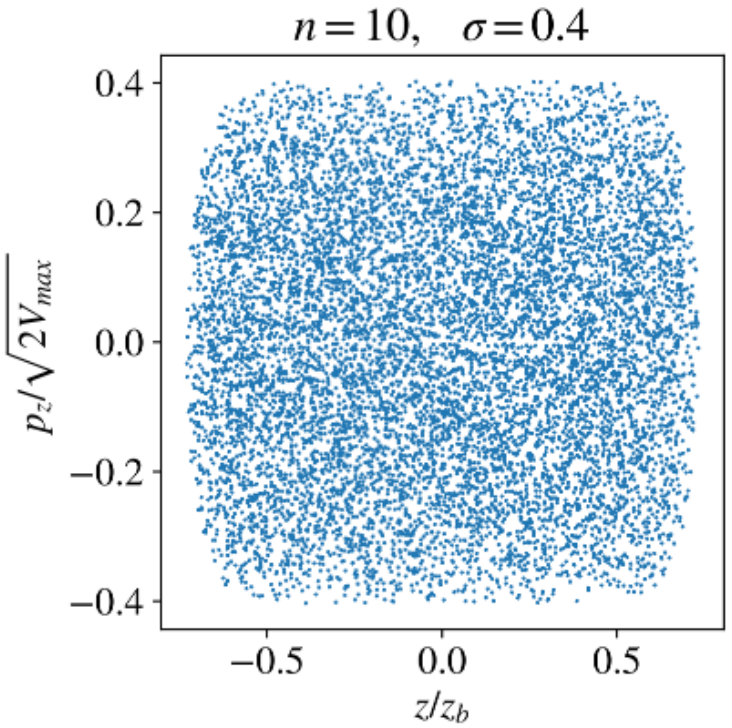
Phase space orbits

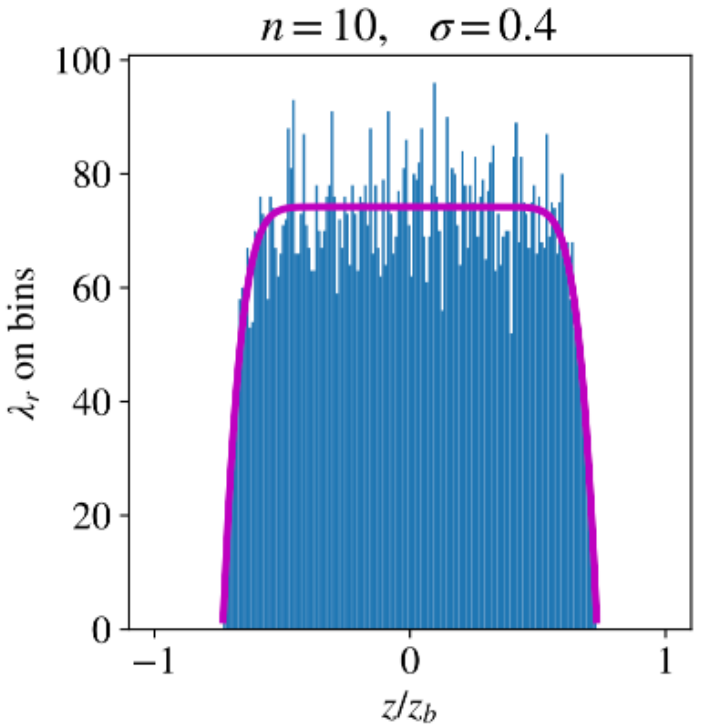




Nonlinear synchrotron oscillation period

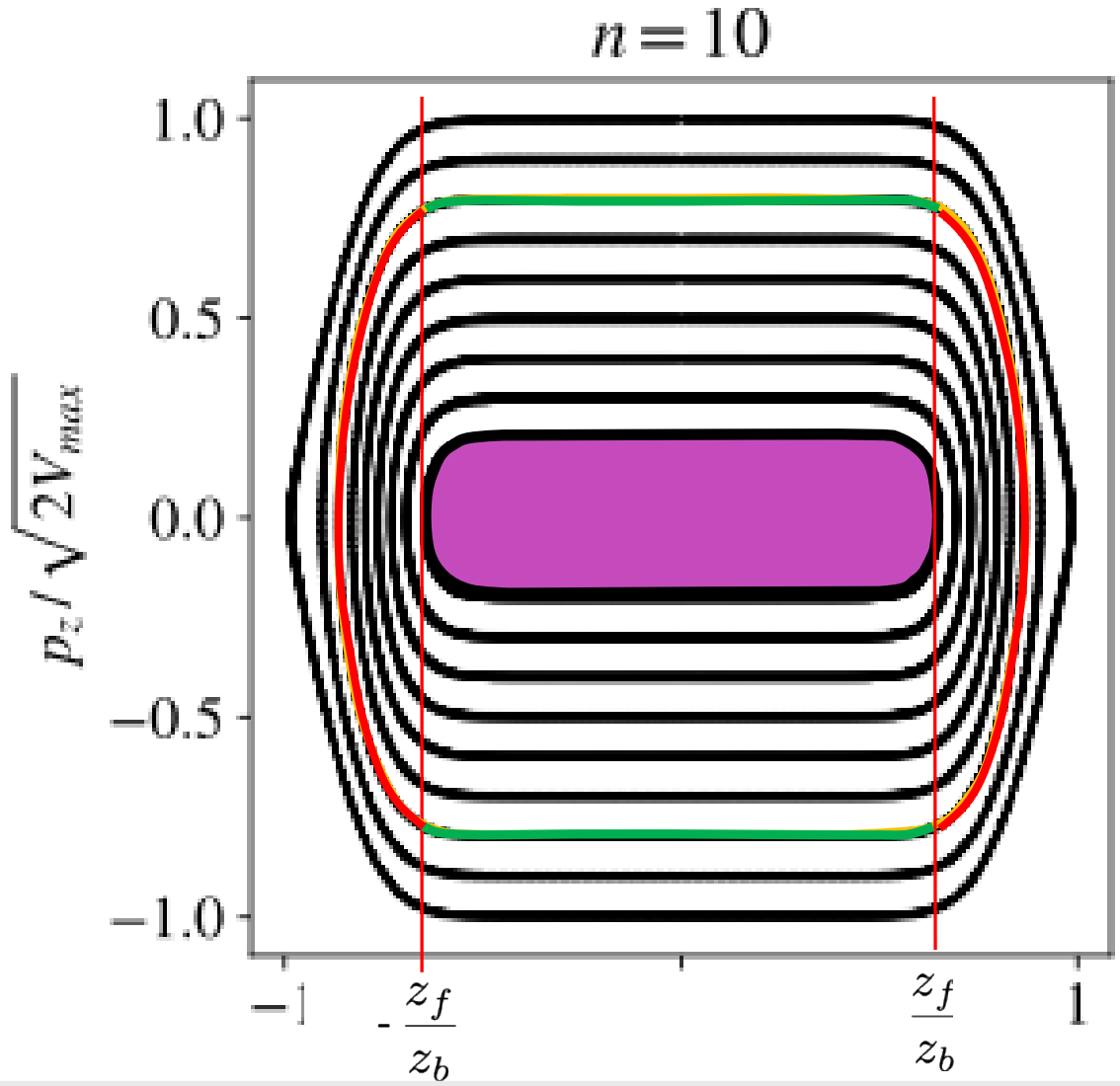






$$\lambda(\tilde{z}) = \frac{N_0}{z_b \Lambda_n(\sigma)} \left[1 - \frac{1}{\sigma^2} \sin^{2n}\left(\frac{\pi}{2} \tilde{z} \right) \right]^{\frac{m+1}{2}}$$

Crossing the varying density



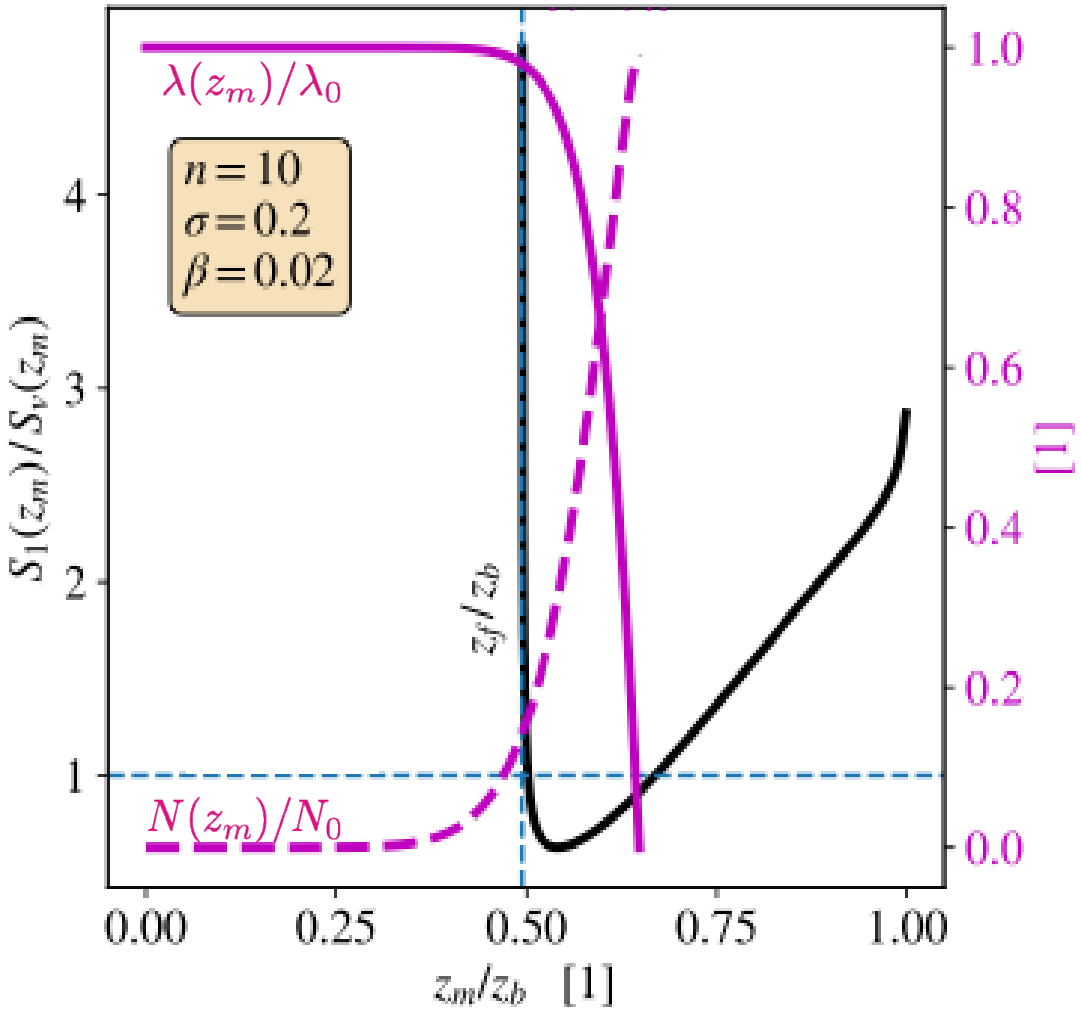
$S(w)$ "Time" for one synchrotron oscillation

$S_f(w)$ "Time" to cross the flat region

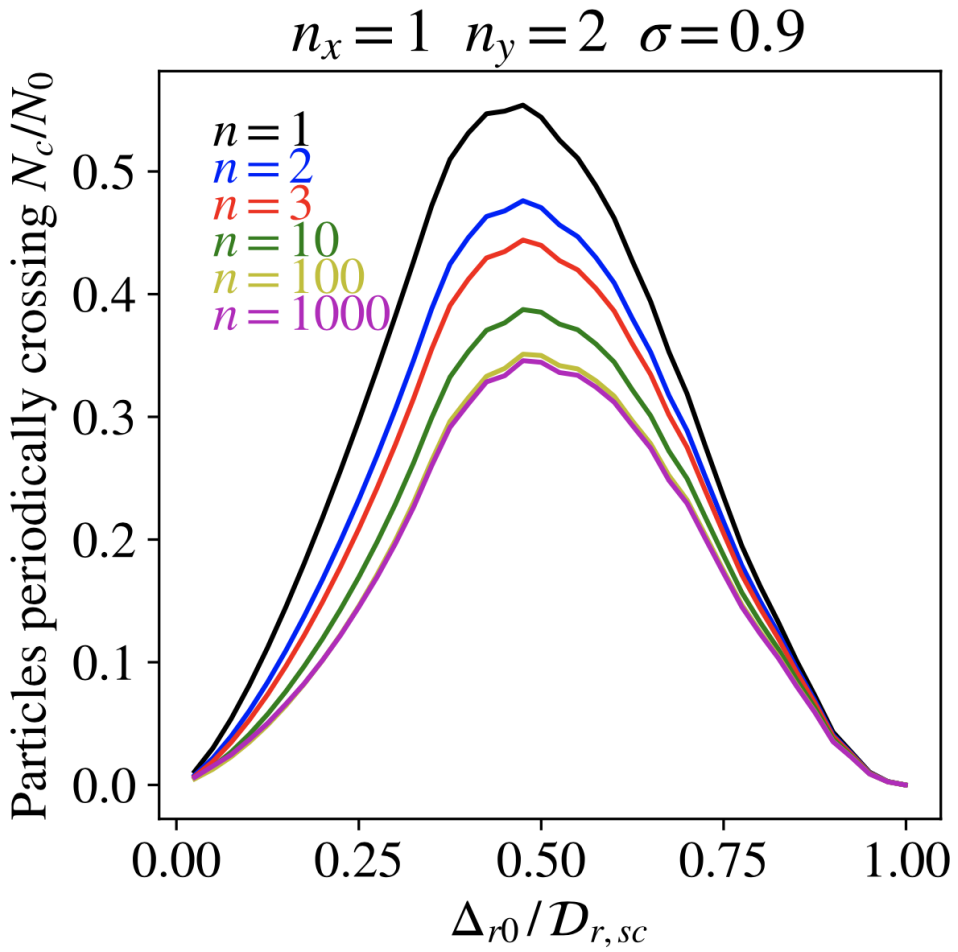
"Time" to cross the varying region

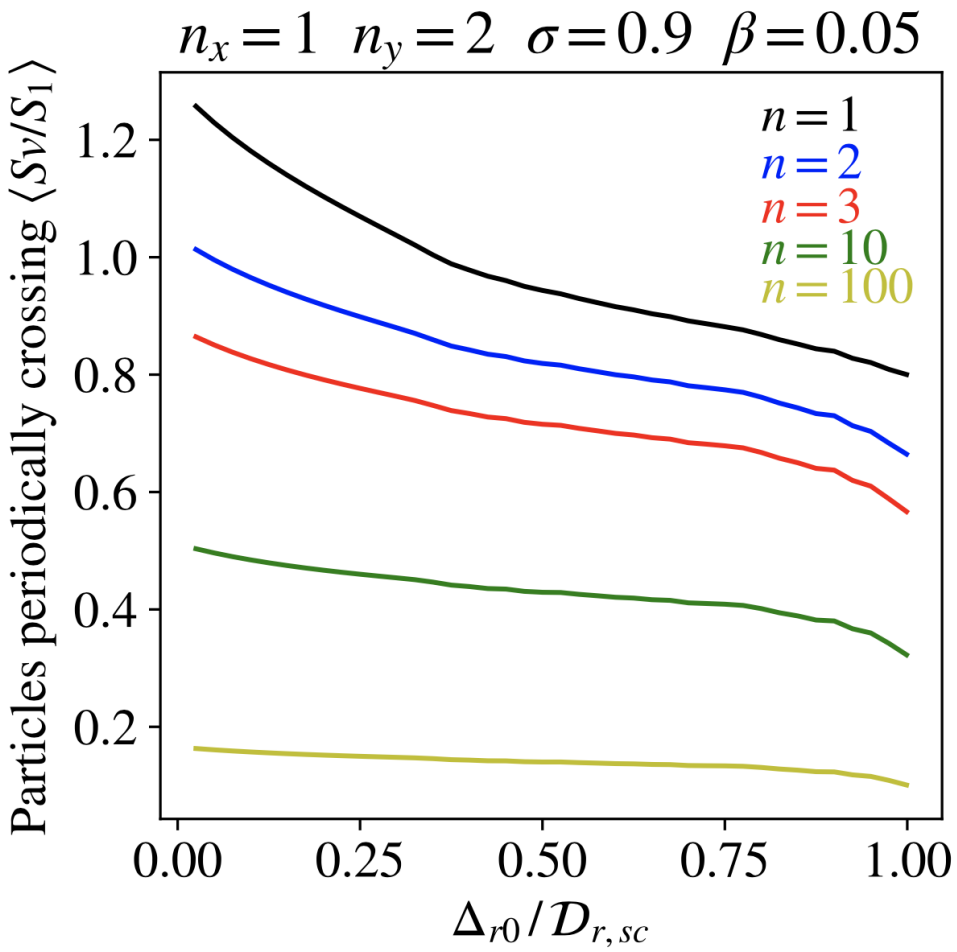
$$S_v(w) = S(w) - S_f(w)$$

The longitudinal motion is complex

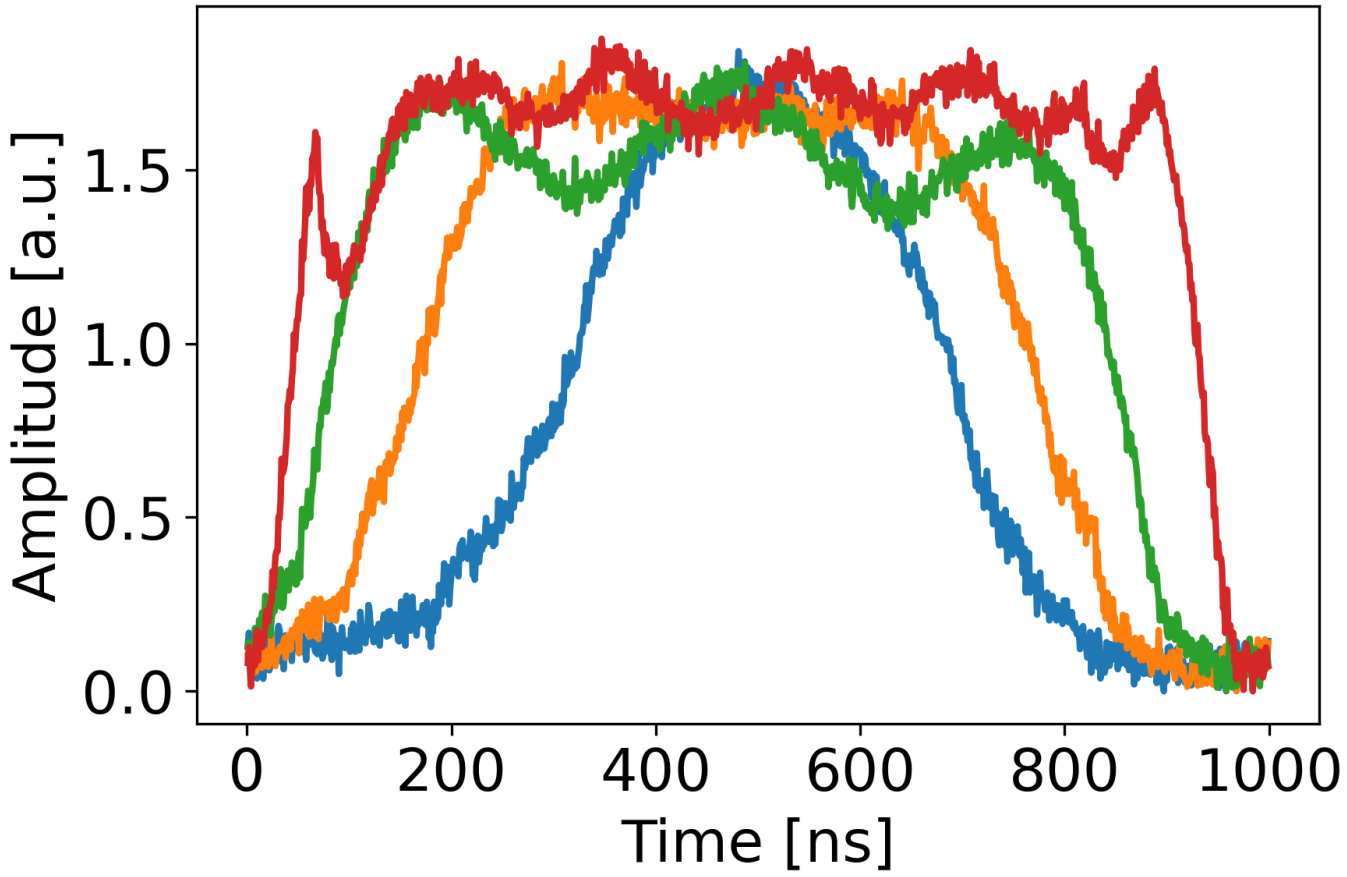


Particles crossing, and average crossing speed





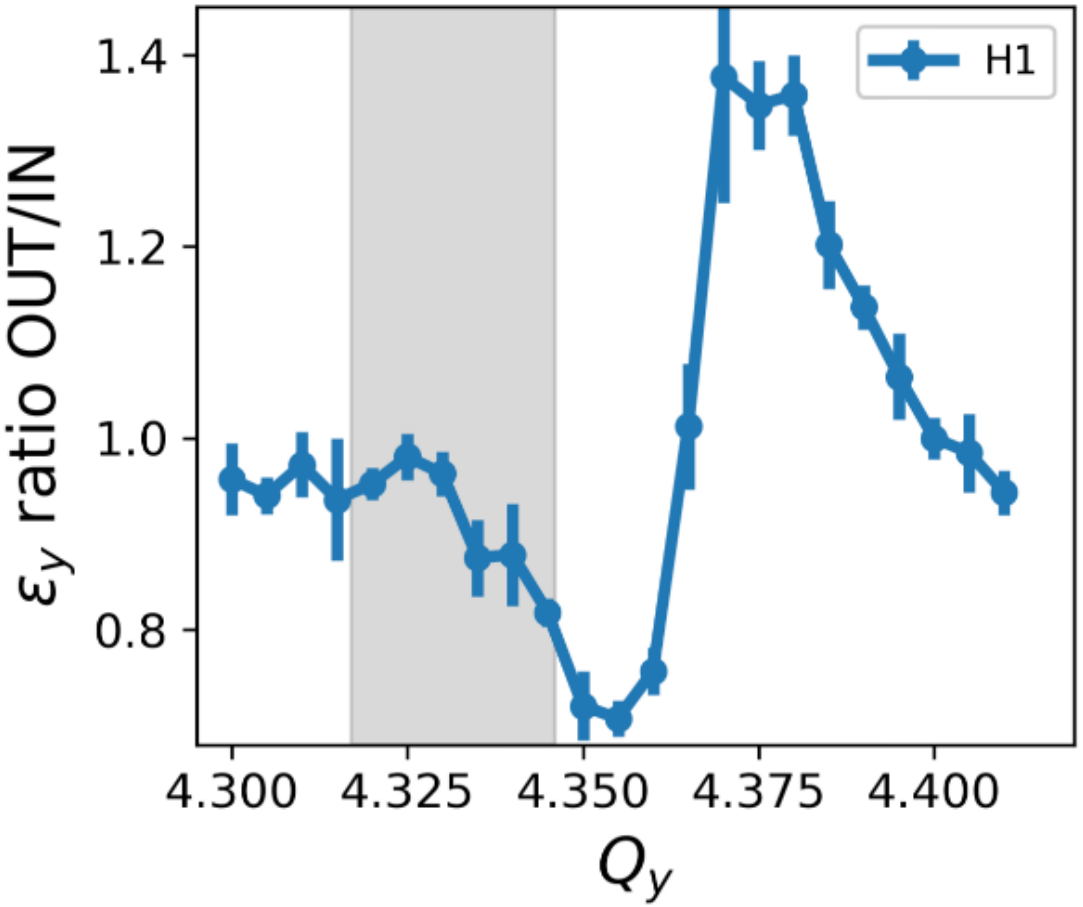
Experimental campaign of July/August 2025

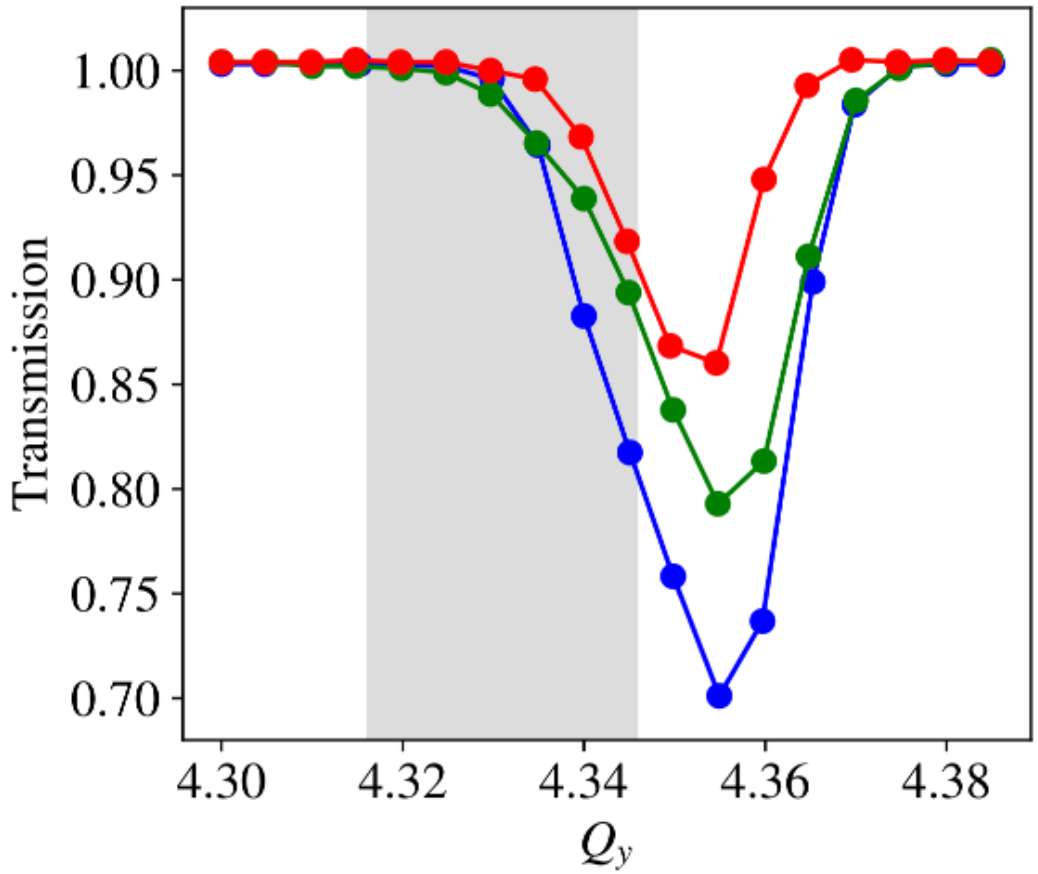


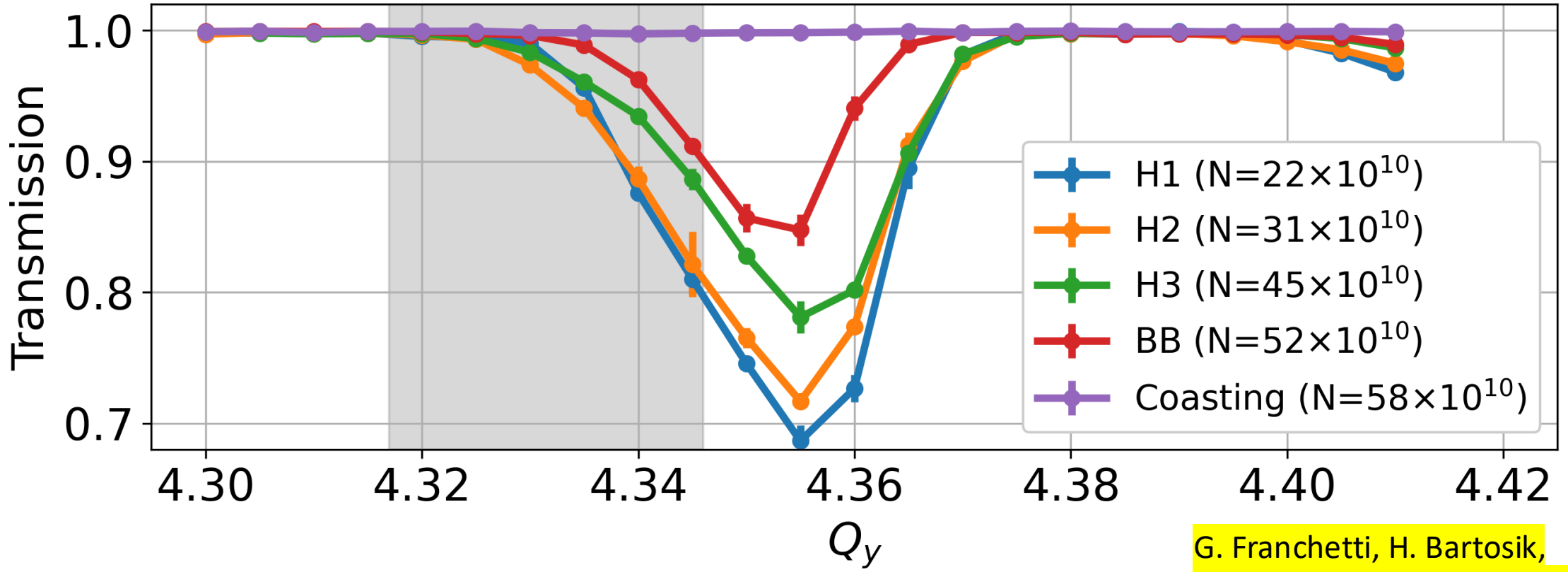
RF-harmonics

1, 2, 3, 11

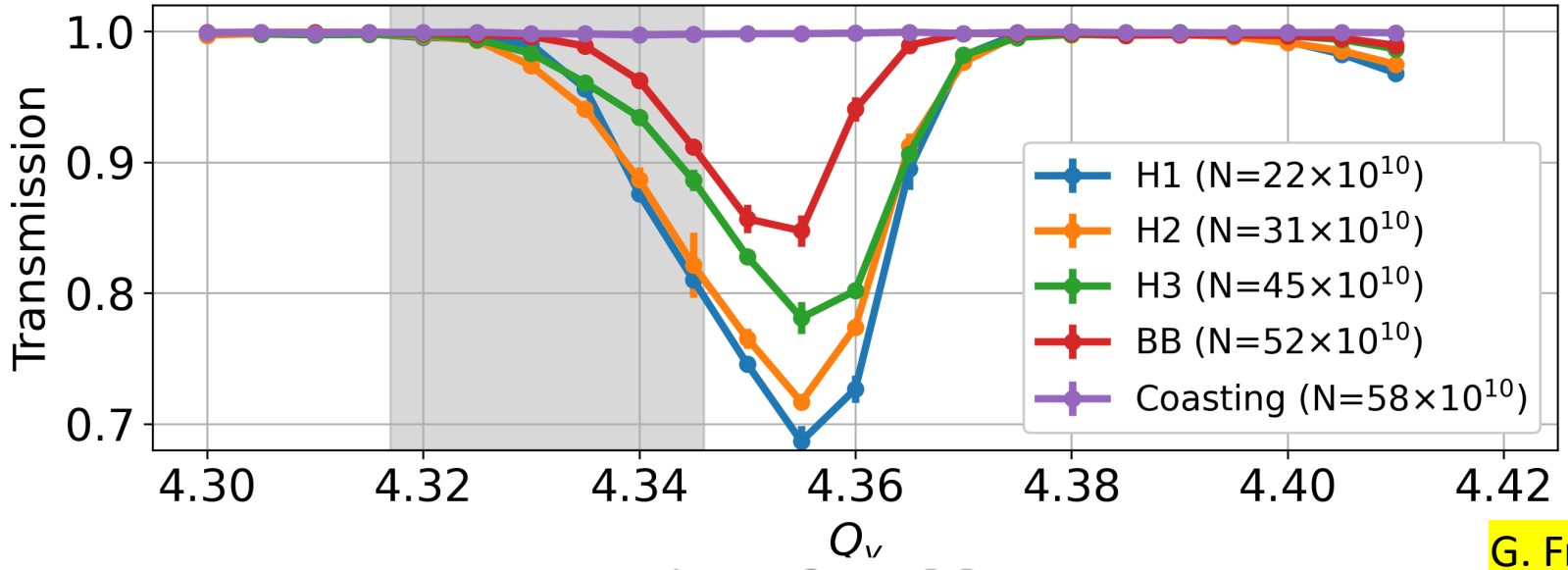
G. Franchetti, H. Bartosik,
F. Asvesta, T. Prebibaj, S. Albright

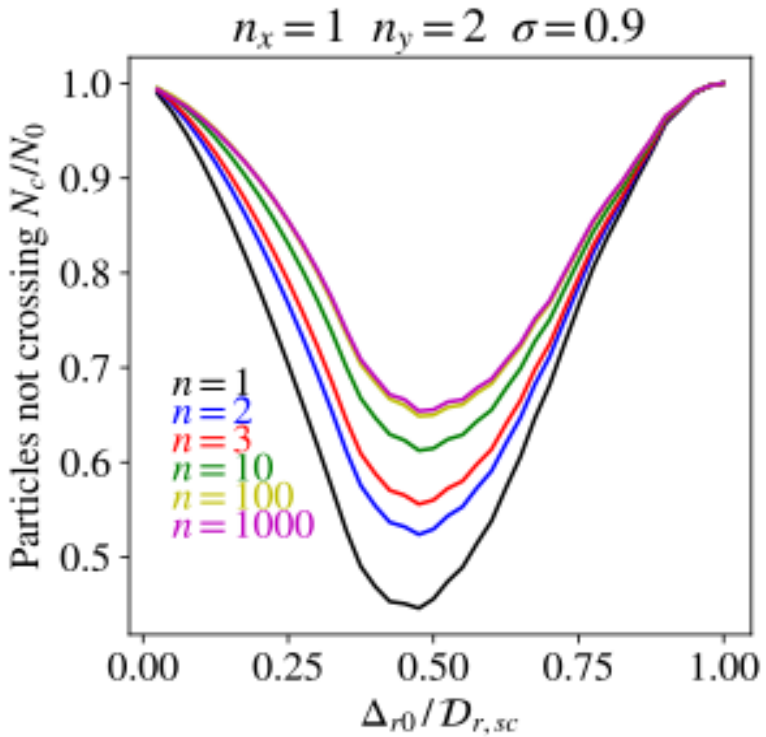

H1
1.4
1.2
1.0
0.8
ε_y ratio OUT/IN
4.300
4.325
4.350
4.375
4.400
Q_y


1.00
0.95
0.90
0.85
0.80
0.75
0.70
Transmission
4.30
4.32
4.34
4.36
4.38
Q_y



G. Franchetti, H. Bartosik,
F. Asvesta, T. Prebibaj, S. Albright





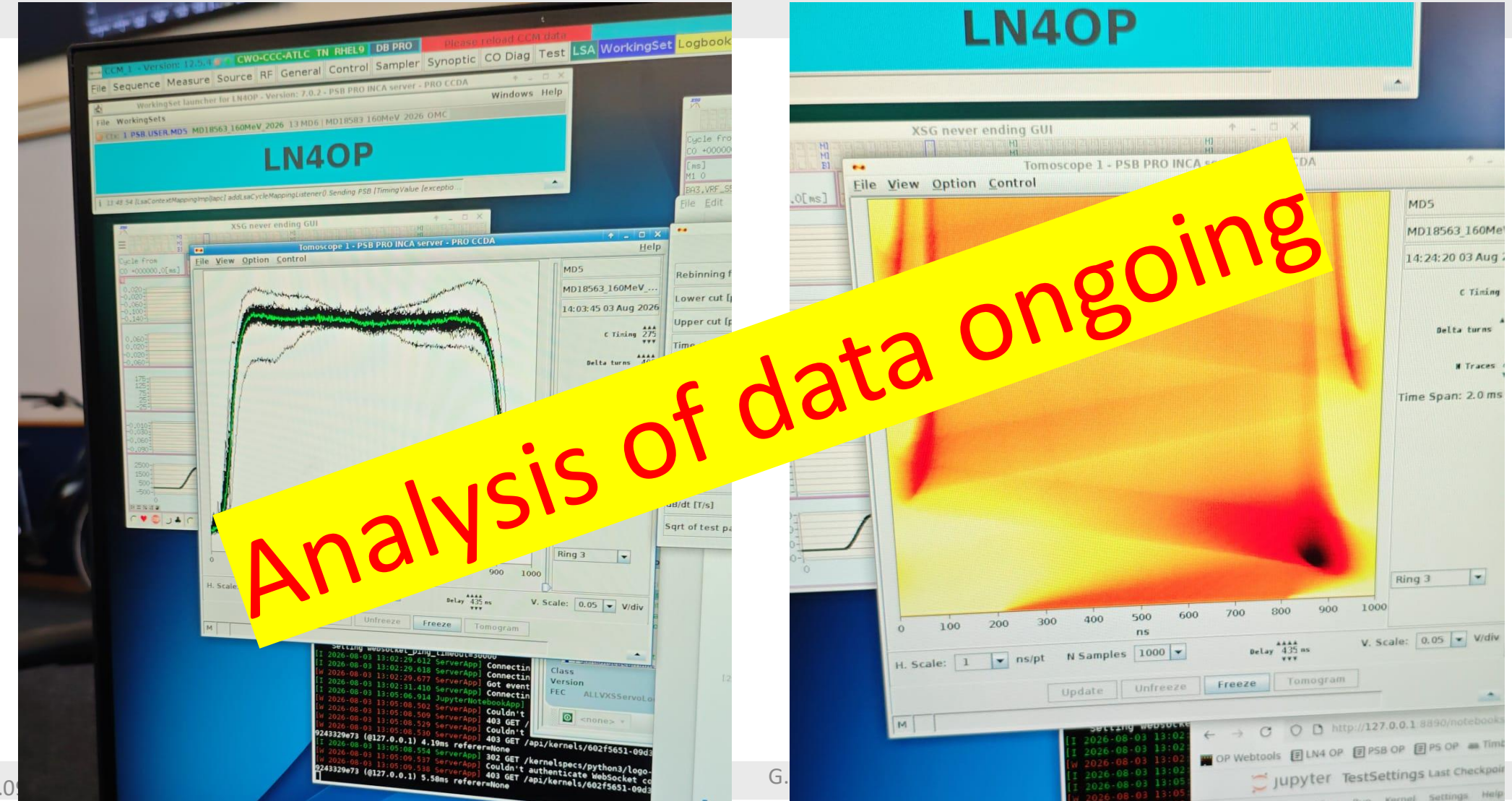
G. Franchetti, H. Bartosik,
F. Asvesta, T. Prebibaj, S. Albright

The asymmetry is due to a dynamical effect

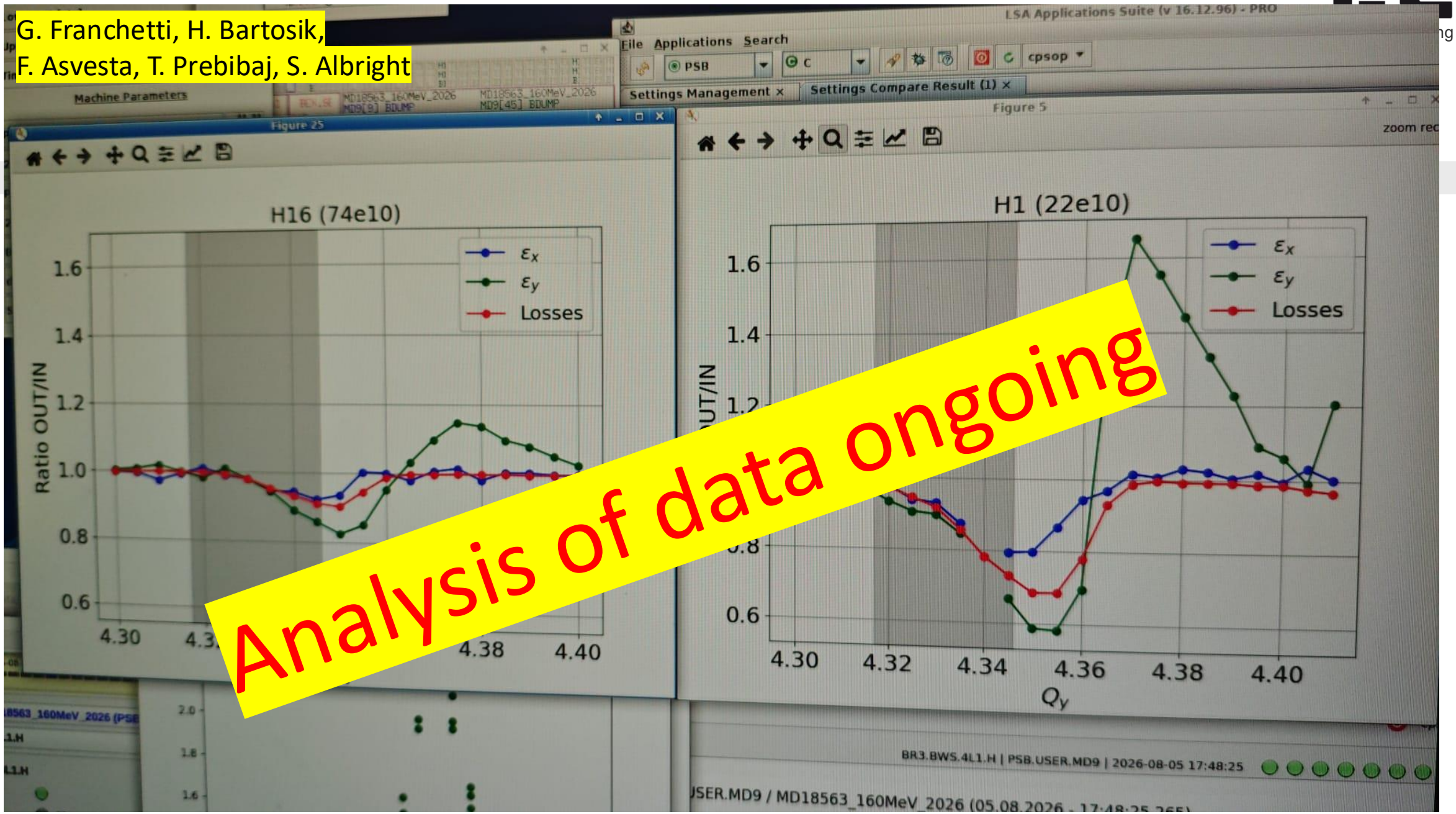
$$\frac{\Delta_{r0}}{\mathcal{D}_{r,sc}}$$ shifts right with the beam loss

Campaign in 2026

G. Franchetti, H. Bartosik,
F. Asvesta, T. Prebibaj, S. Albright



G. Franchetti, H. Bartosik,
F. Asvesta, T. Prebibaj, S. Albright



Summary

Resonances and space charge yield damaging long-term effects

Multi-harmonics may be an interesting option to mitigate the periodic resonance crossing

Experiments at the PSB show very convincing results

There are intriguing details to disentangle

If confirmed, the advantages are very seductive:
No need to compensate for any resonance or to go through the E-Lenses, reduction of relative beam loss, increase of amount of stored beam

This session

Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		12:30 - 13:30
Lead talk: Resonances and Space Charge	*Giuliano Franchetti*	
Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		13:30 - 13:50
Resonance Studies in the SPS for High-Brightness Beams.	*Ingrid Mases Sole*	
Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		13:50 - 14:05
Study of beam redistribution on approach to the half integer resonance with space charge and the implications for ISIS		
Chris Warsop		
Space charge simulation for the third order resonance corrections at J-PARC MR	*Susumu Igarashi*	
Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		14:20 - 14:35
Space Charge Effects in a Ring-Based Electron Cooler	*Sergey Seletskiy*	
Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		14:35 - 14:50
Discussion Session C-1	*Giuliano Franchetti*	
Denys Wilkinson Building, Dennis Sciama Lecture Theatre, Oxford University, Physics Department		14:50 - 15:15
Afternoon Coffee Break		