LARP/HL-LHC Beam-Beam Simulations

A.Valishev (FNAL)

Contributors
D. Shatilov (BINP/FNAL), S. Fartoukh, F. Schmidt (CERN), M. Zobov (INFN/Frascati), S. White (BNL), J. Qiang, S. Paret (LBNL)

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LARP CM18

Study Topics

- Investigate the options for HL-LHC
  - Choice of basic options – β^*, crossing scheme
  - Luminosity levelling techniques
  - Imperfections
- Develop self-consistent simulations of the beam-beam phenomena with other dynamical effects
  - Crab cavity
  - Interplay with machine impedance
- Help understand the experimental data from LHC as it becomes available
  - Also use RHIC for beam-beam experiments (S.White's talk)
- Support new ideas

Collaboration

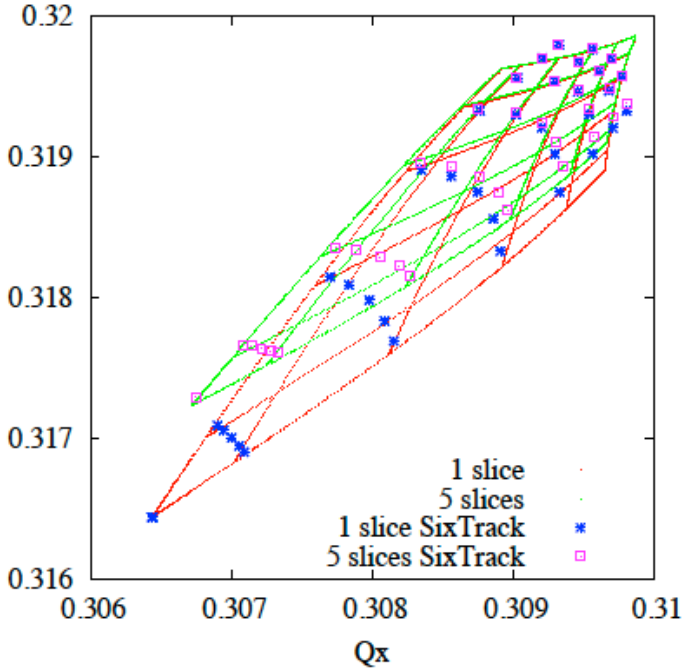
- LARP
  - S. White, BNL
  - J. Qiang, S. Paret, LBNL
  - T. Sen, A. Valishev, FNAL
- HL-LHC
  - CERN Beam-Beam Group: W. Herr, T. Pieloni
  - D. Shatilov, BINP
  - M. Zobov, INFN/Frascati

Methods, HL-LHC Integration

- Begin with madx lattice (WP2 Task 2.1) and performance parameters (Task 2.6)
  - Present performance data (CERN BB group)
  - Impedance models (Task 2.4)
- Tools / Characteristics for evaluation
  - Tune footprint (weak-strong, very fast)
  - Dynamic Aperture (weak-strong, fast)
  - Full-scale multiparticle simulation of intensity and emittance life time (weak-strong, slow)
  - Self-consistent multi-effect simulation (strong-strong, short reach as far as the number of turns, slowest)

Tools

- Weak-strong
  - SixTrack (F. Schmidt). Well-tested code, the backbone of tracking studies for LHC design.
  - Lifetrac (D. Shatilov). Many years of use for electron machines and Tevatron. Very good support of 6D beam-beam with crossing angle.
  - The two codes were benchmarked against each other as part of LARP collaboration. Good agreement for the case of LHC simulations was established. (CERN-ATS-Note-2012-040)

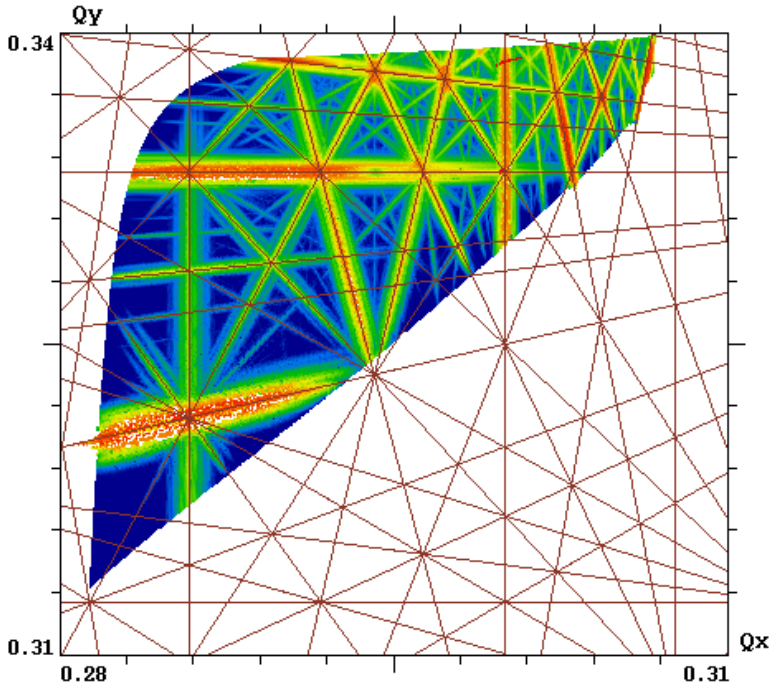


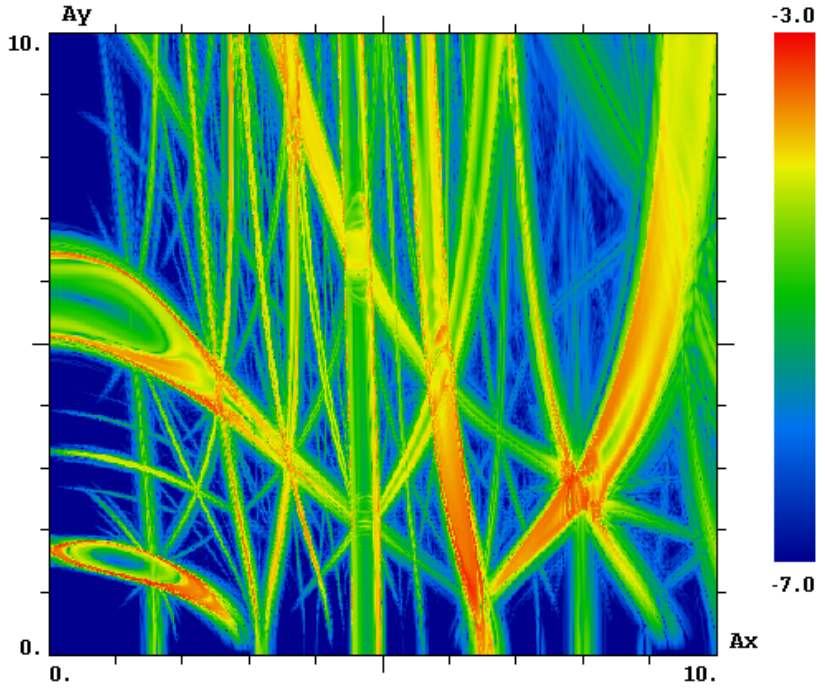
- Strong-Strong
  - BeamBeam3D (J. Qiang).

  Many users – LBNL, FNAL, BNL
  - BBSIM (T. Sen). Module for crab-cavity

Lifetrac (D. Shatilov)

- Weak-strong beam-beam tracking code
  - Frequency Map Analysis (J. Lascar, "The Chaotic Motion of the Solar System: A Numerical Estimate of the Size of the Chaotic Zones", Icarus 88, 266, 1990)
  - Multi-particle, multi-turn tracking
  - Machine model with full set of features imported from madx – lattice, crossing schemes, nonlinearities

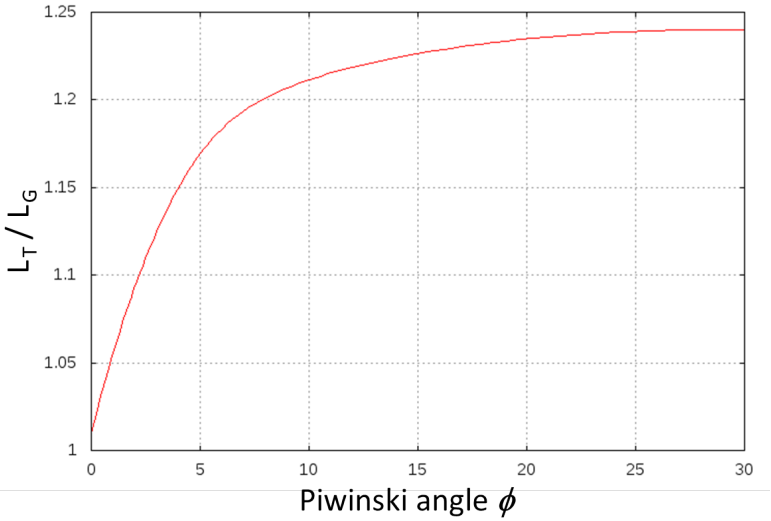


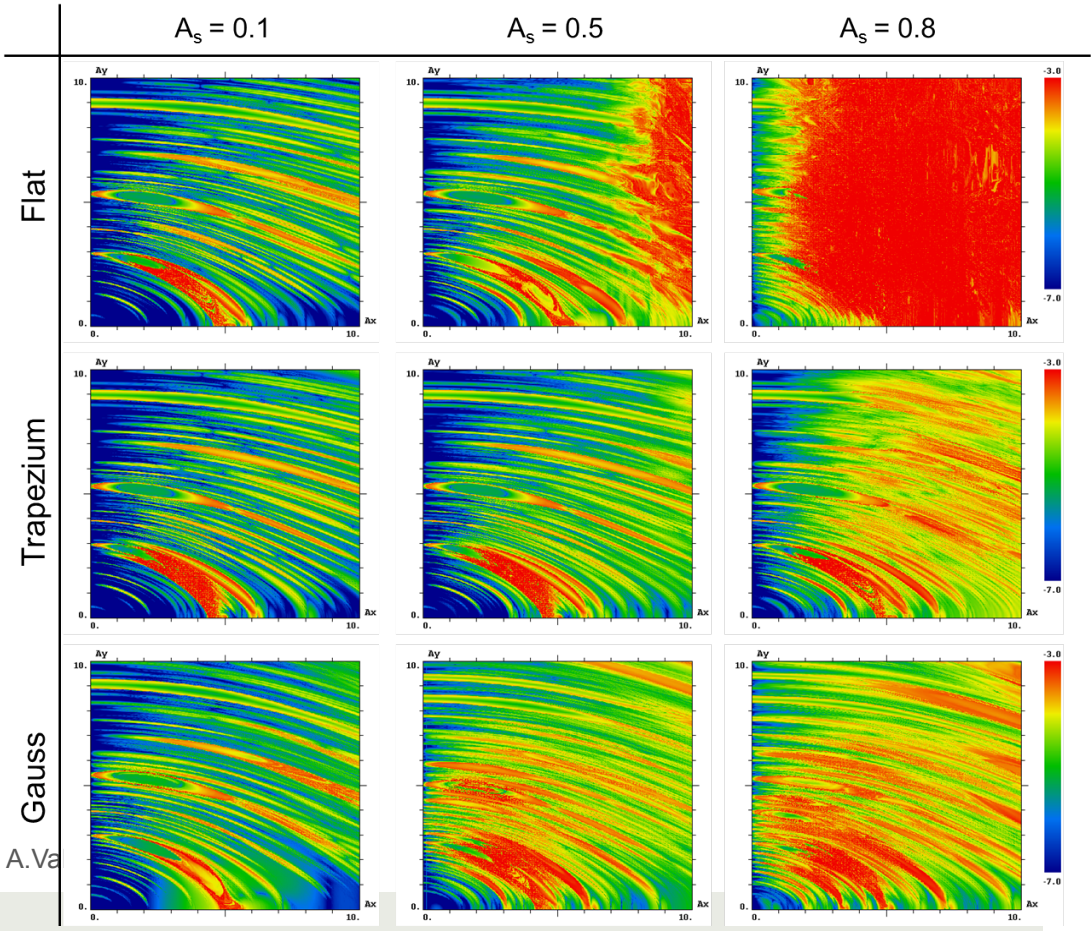


Study of Flat-Bunch Collisions (D. Shatilov, M. Zobov)

- Found that luminosity gain is highly dependent on the actual longitudinal profile and Piwinski angle. For realistic case the gain much less than √

- Studied limitations due to synchro-betatron dynamics

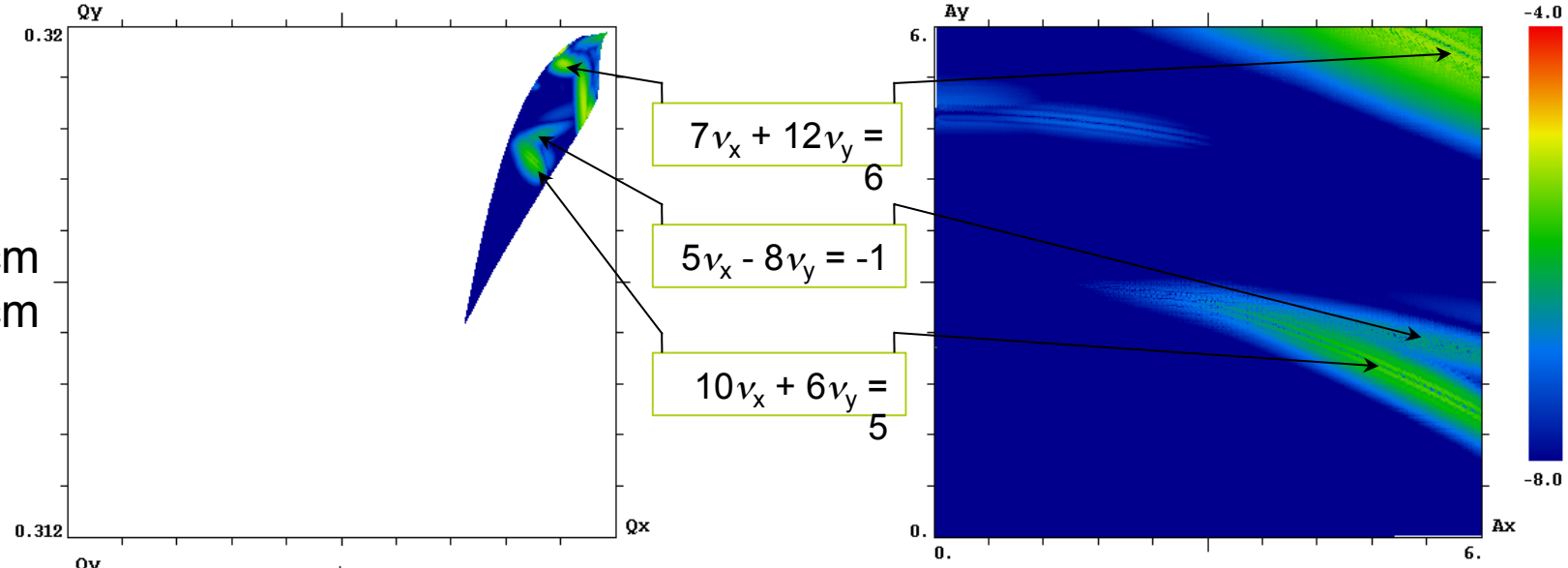




Effect of Large Piwinski Angle and β^* (D. Shatilov)

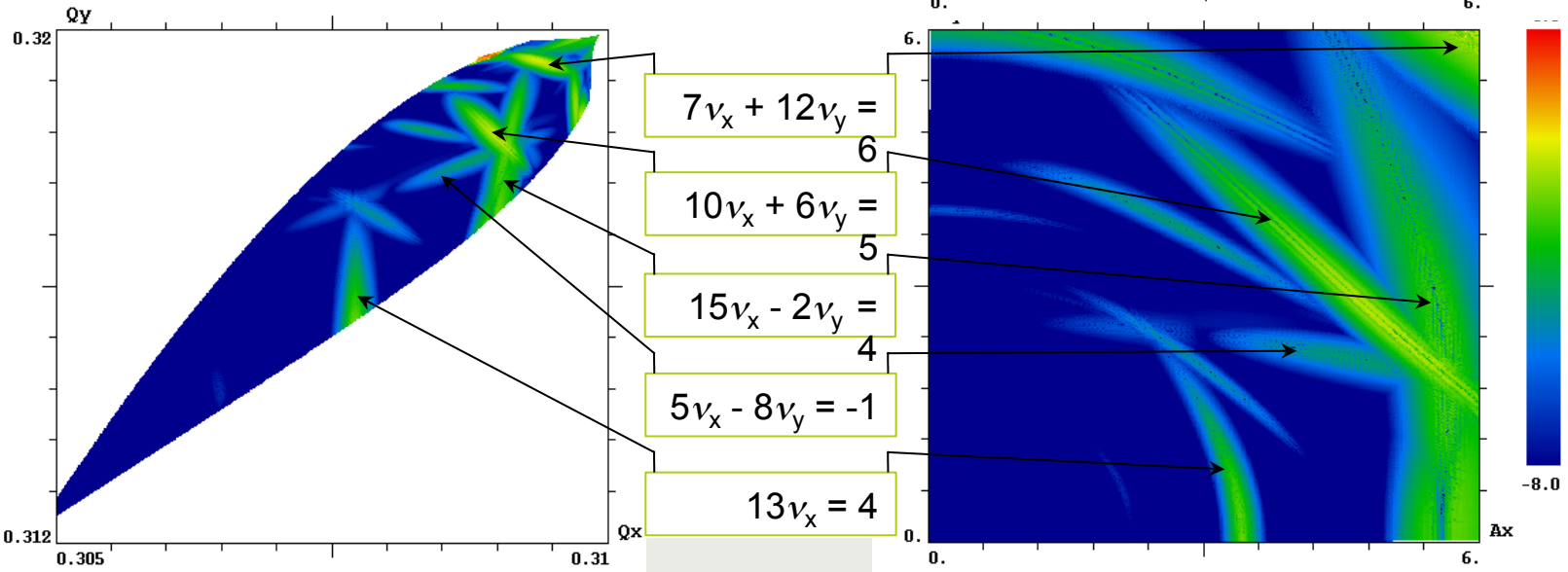
- Very simplified model: 1IP with horizontal crossing at 590 μrad

σ_z = 7.5 cm
β^* = 15 cm



As=0

σ_z = 4.0 cm
β^* = 33 cm



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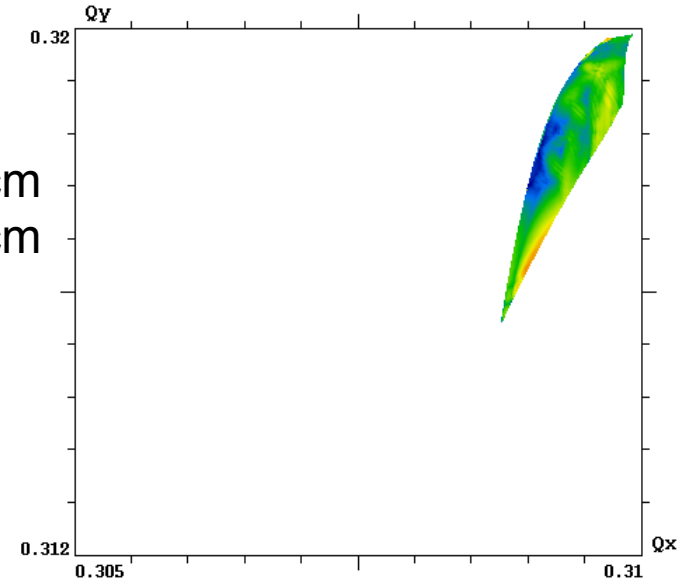

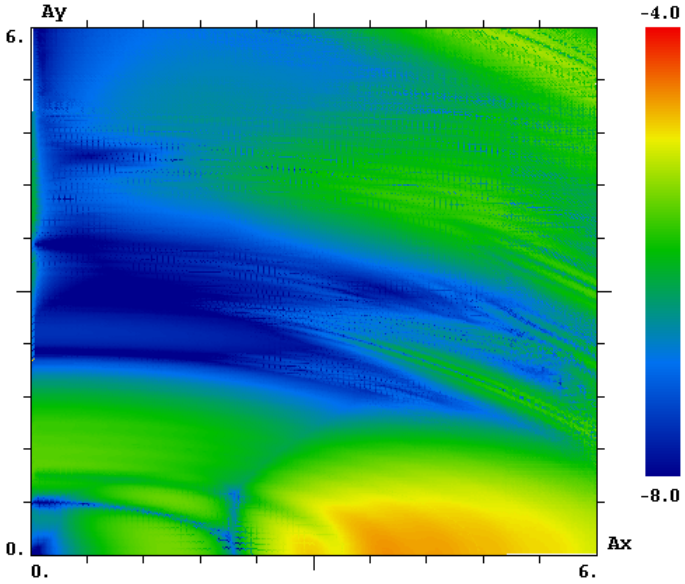

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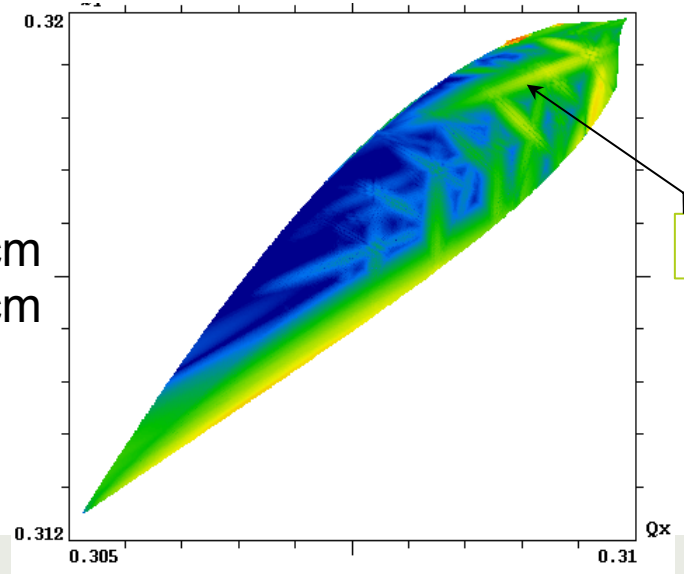
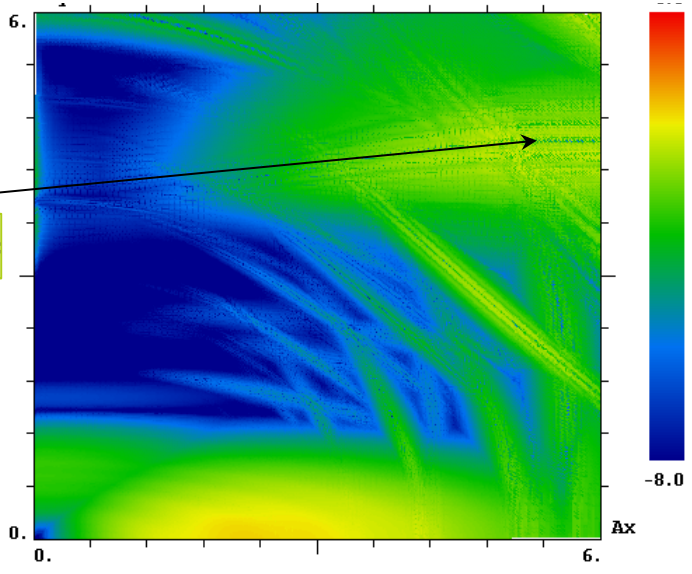


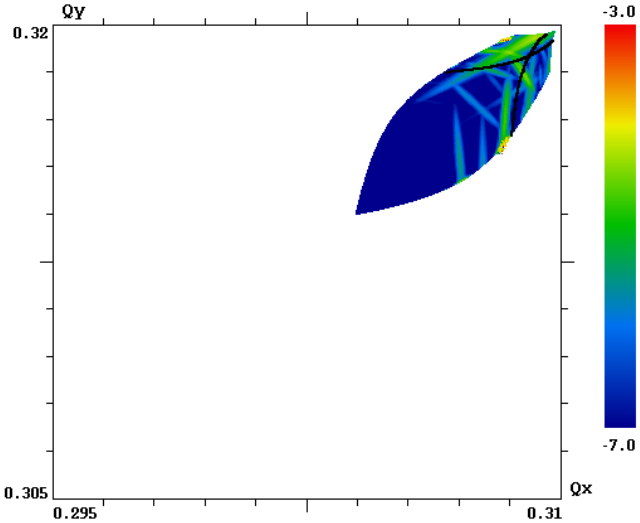
$5\nu_x - 8\nu_y + \nu_s = -1$

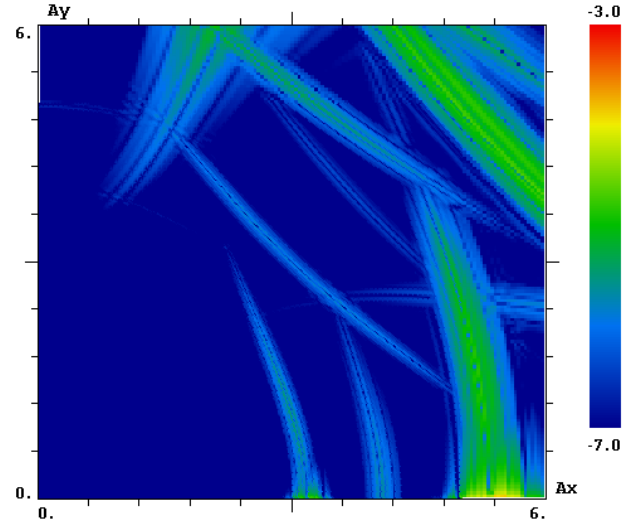


Effect of Large Piwinski Angle and β^* (D. Shatilov)

- Very simplified model: 2IPs with h-v crossing at 590 μrad
- β^* = 15 cm, σz = 7.5 cm, νs = 0.002

As = 0





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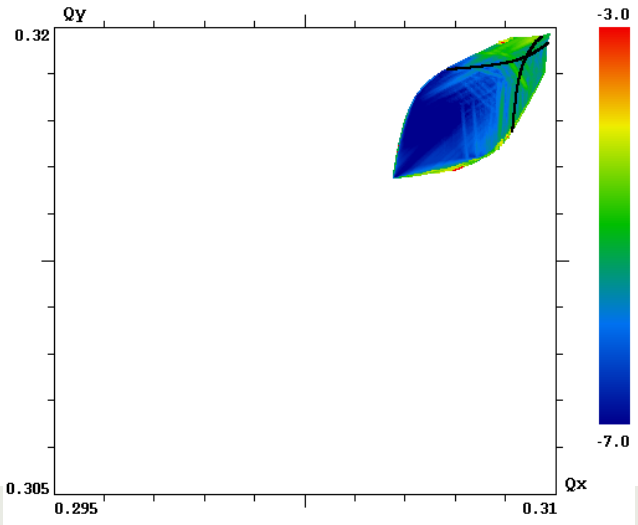
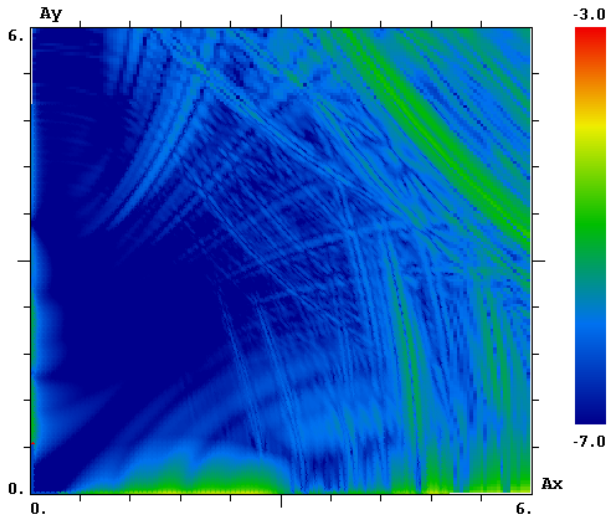
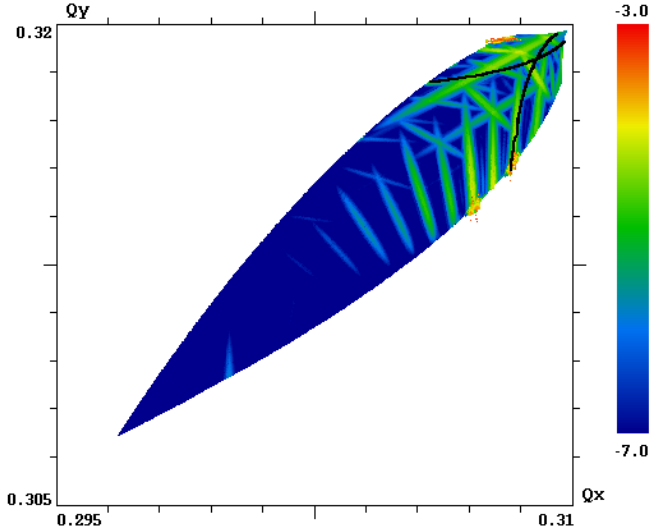
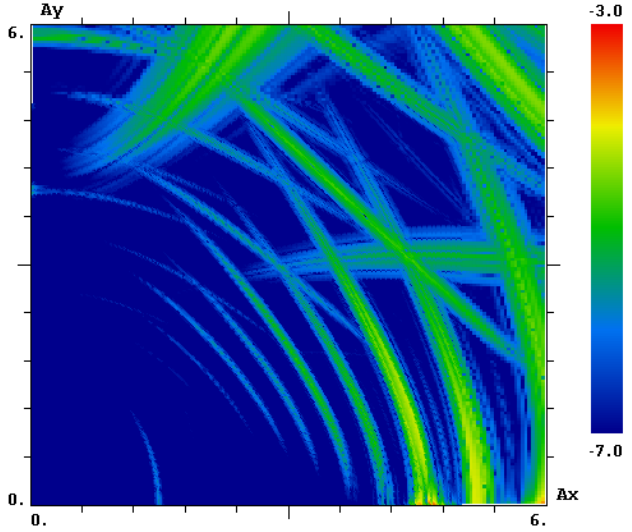


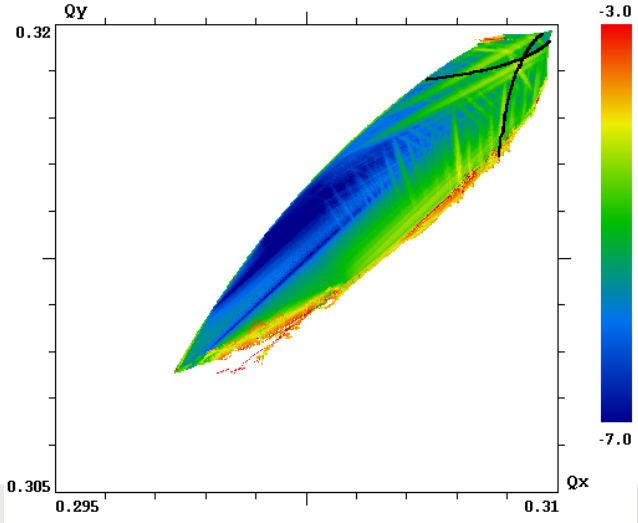


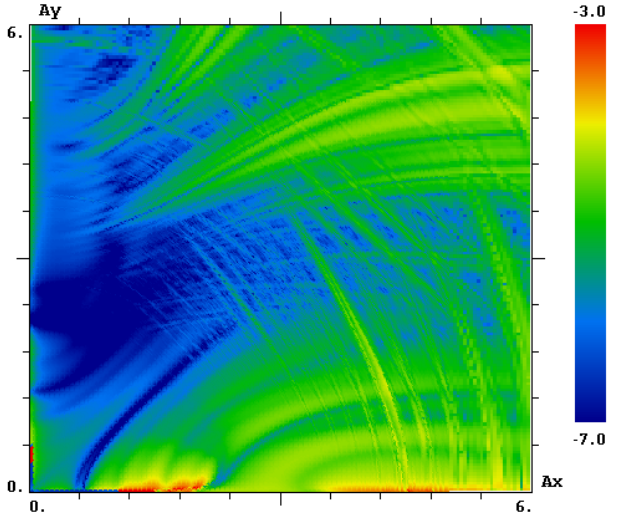
Effect of Large Piwinski Angle and β^* (D. Shatilov)

- Very simplified model: 2IPs with h-v crossing at 590 μrad
- β^* = 33 cm, σz = 4.0 cm, νs = 0.004





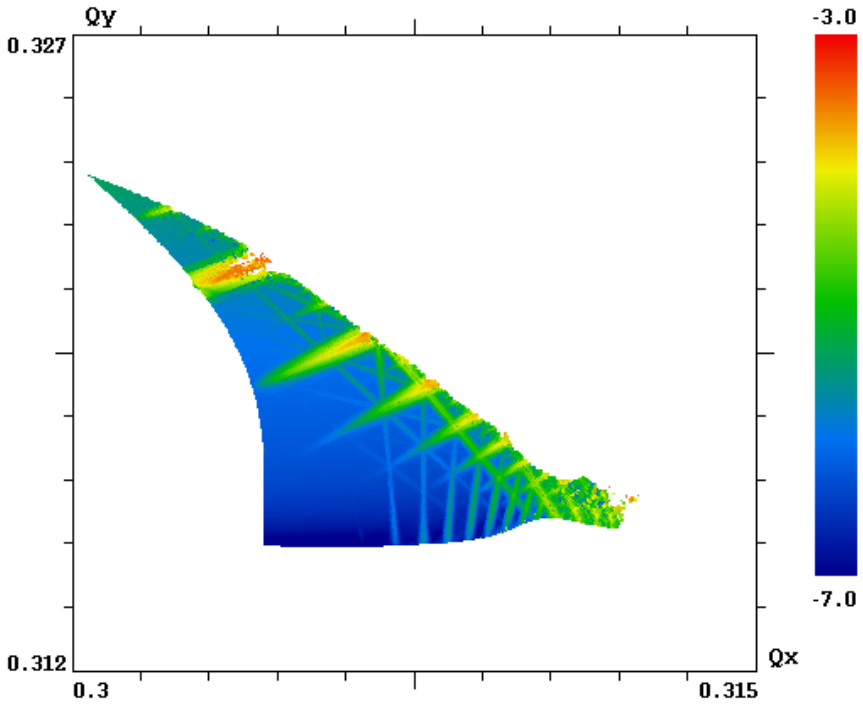


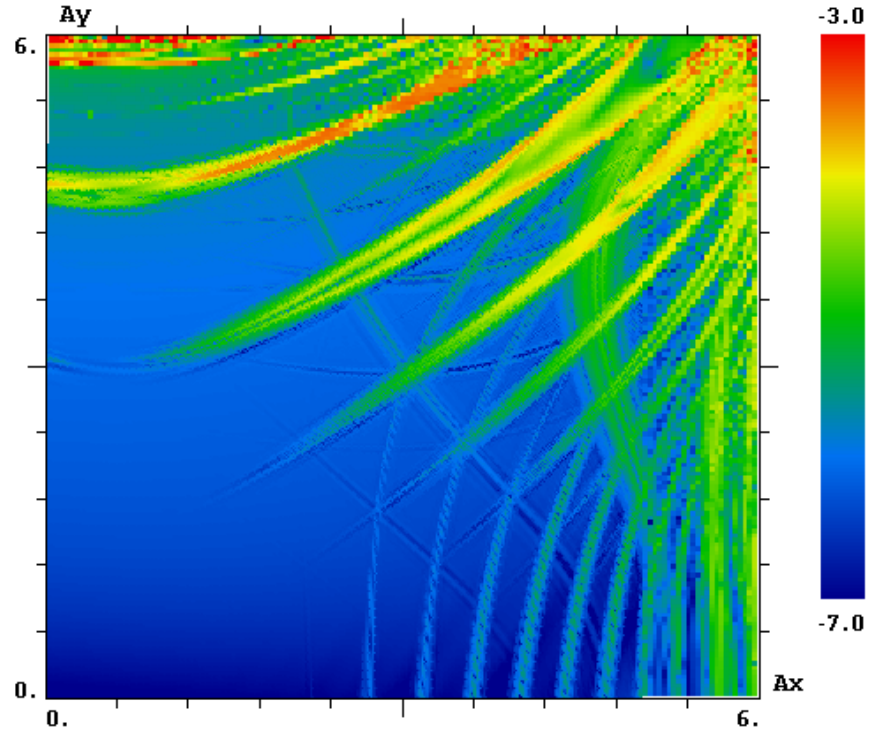


Effect of Large Piwinski Angle and β^* (D. Shatilov)

- Model: 2IPs with h-v crossing at 590 μrad + long-range
- β^* = 15 cm, σz = 7.5 cm, νs = 0.002

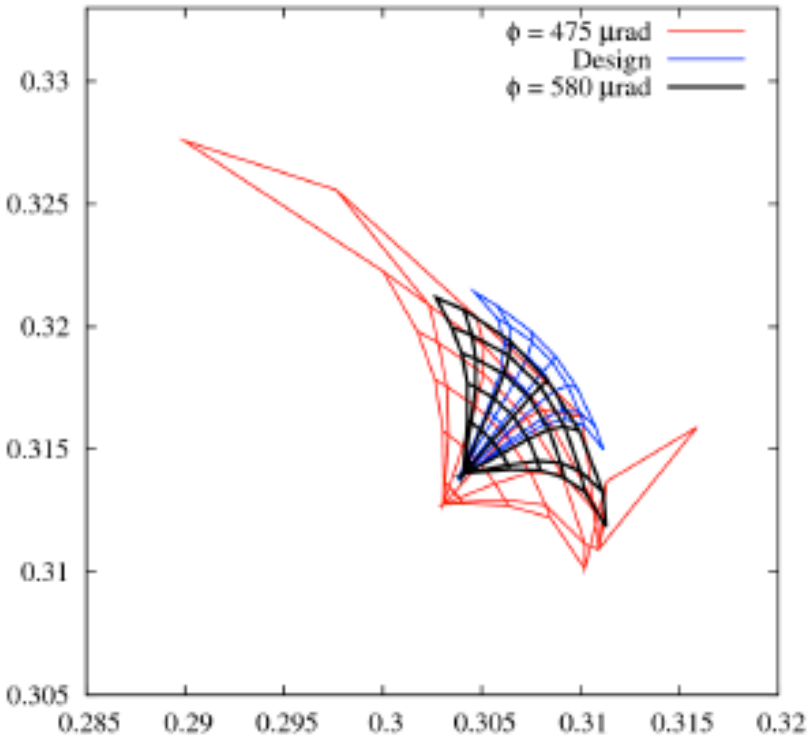
As = 0

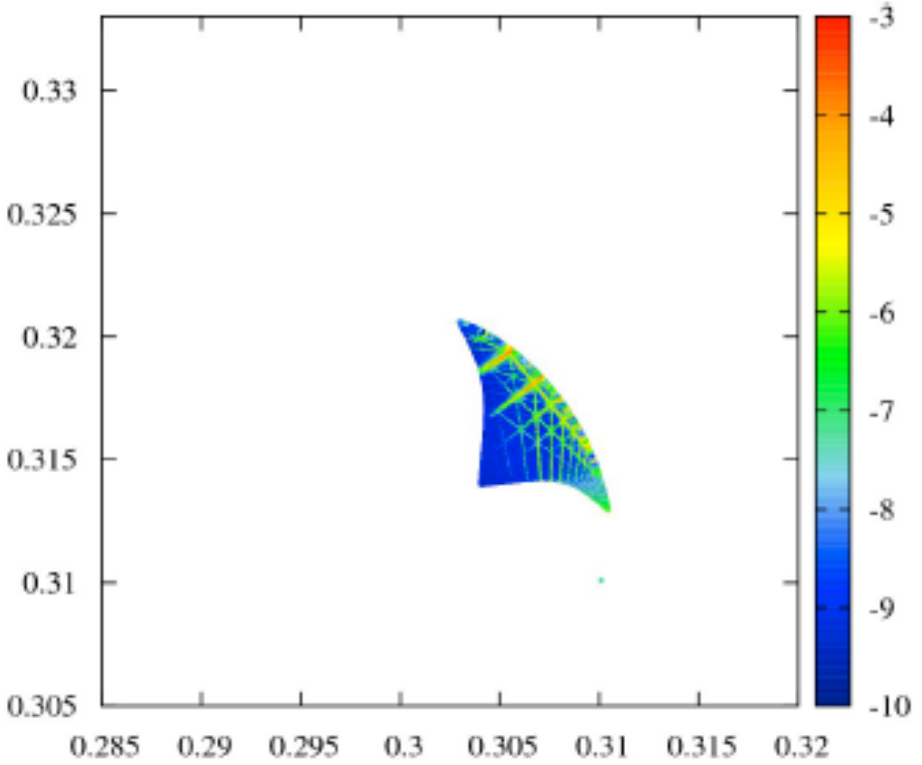




Effect of Large Piwinski Angle and β^* (S. White, R. Calaga, R. Miyamoto)

- Model: 2IPs with h-v crossing at 580 μrad + lumped long-range
- β^* = 15 cm, σz = 7.5 cm, νs = 0.002





Effect of Crab Cavities (S. White, R. Calaga, R. Miyamoto)

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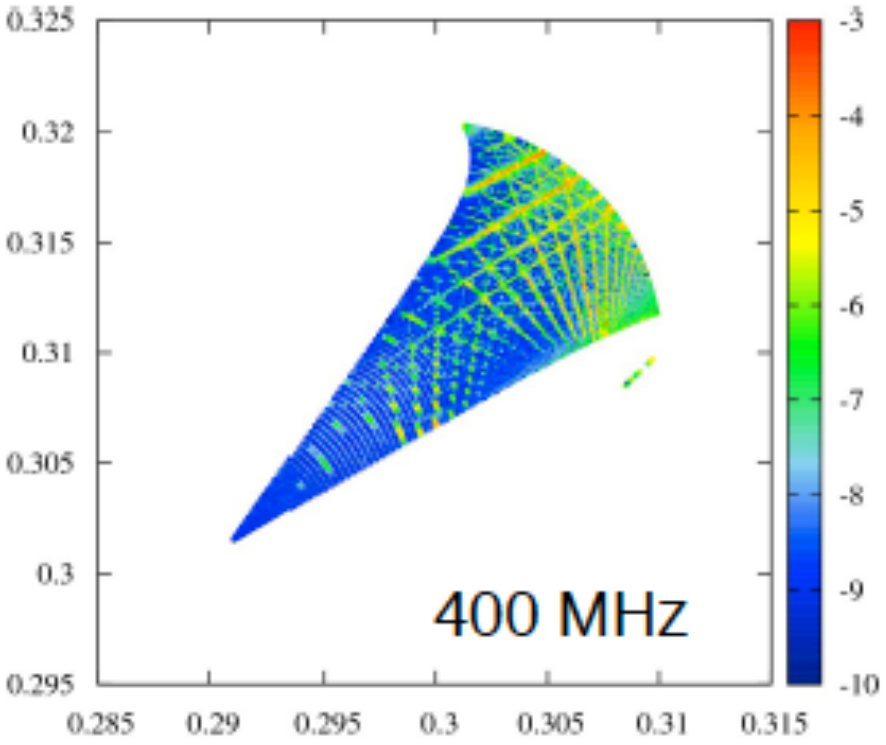

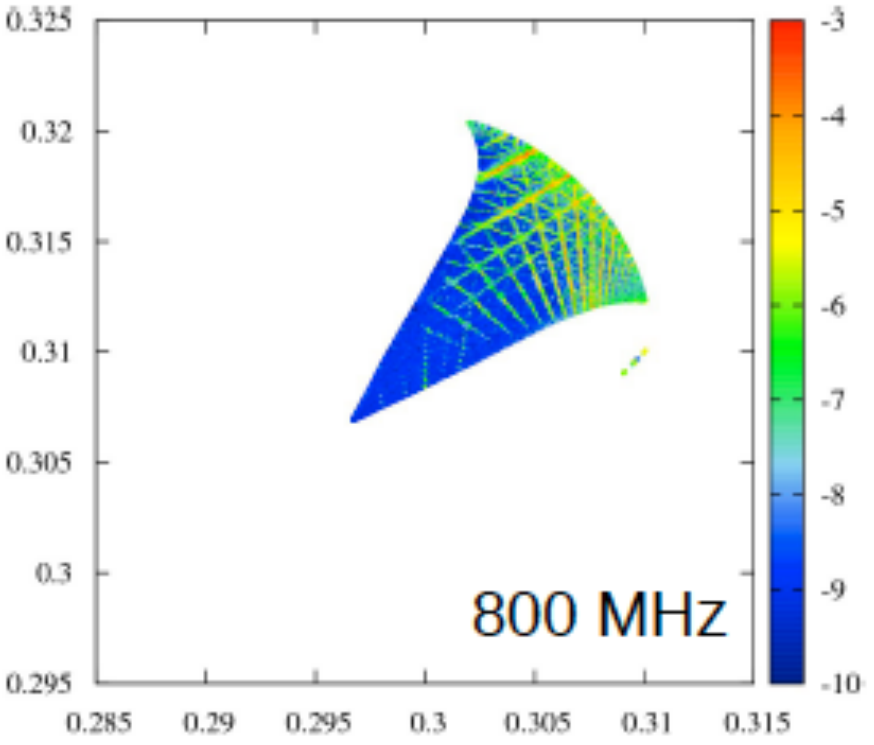

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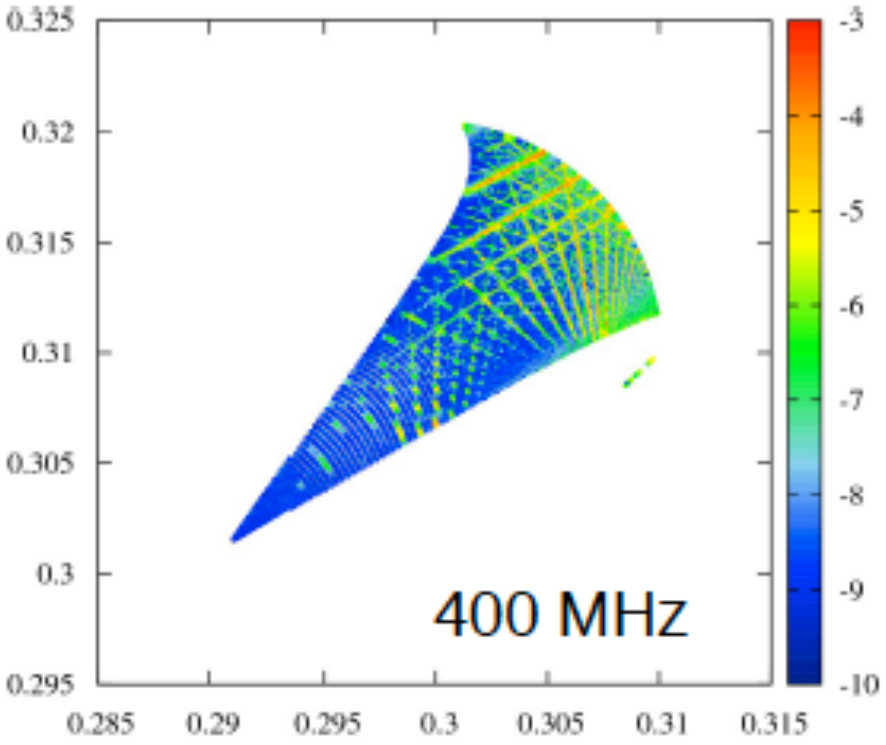
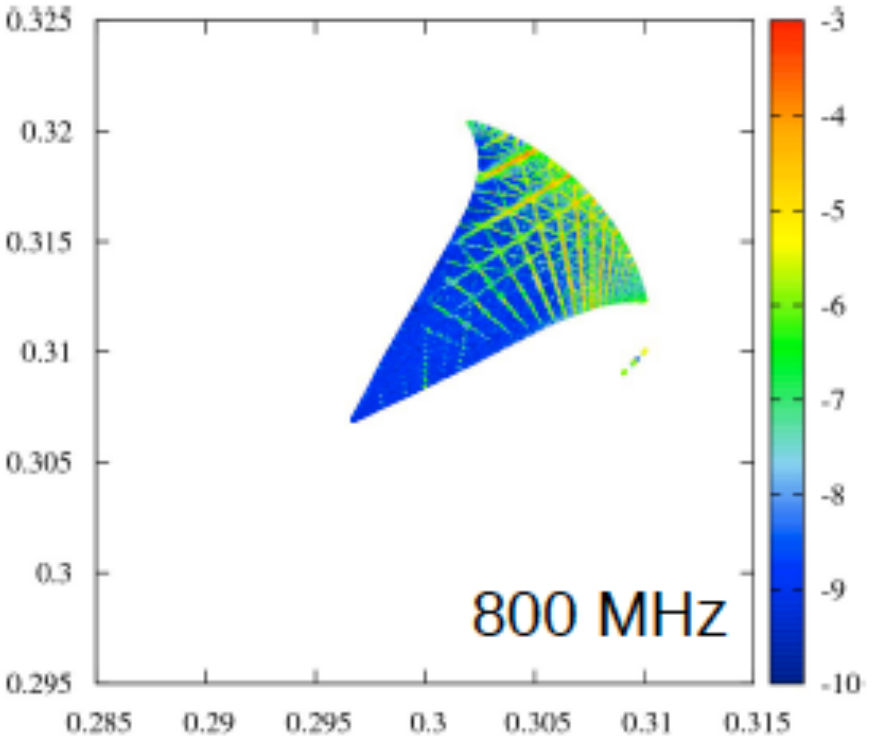
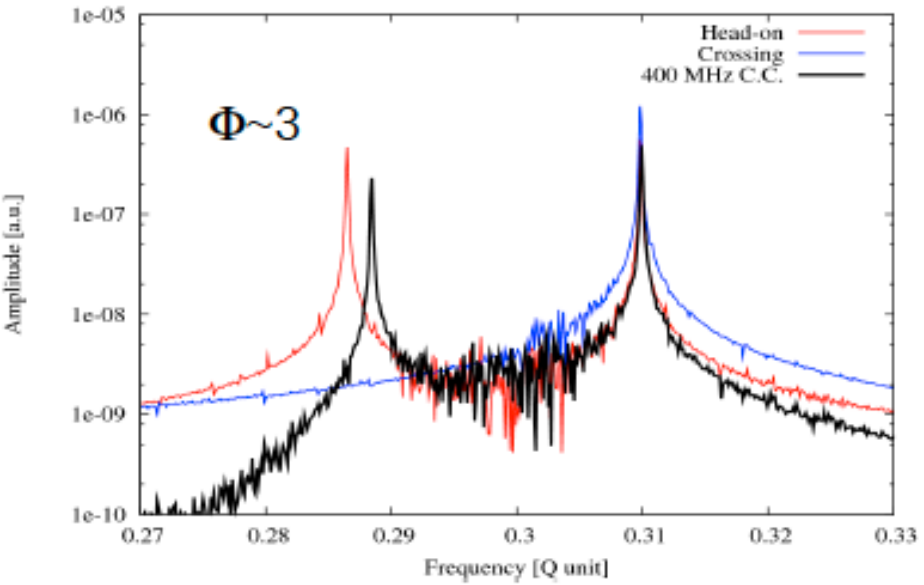
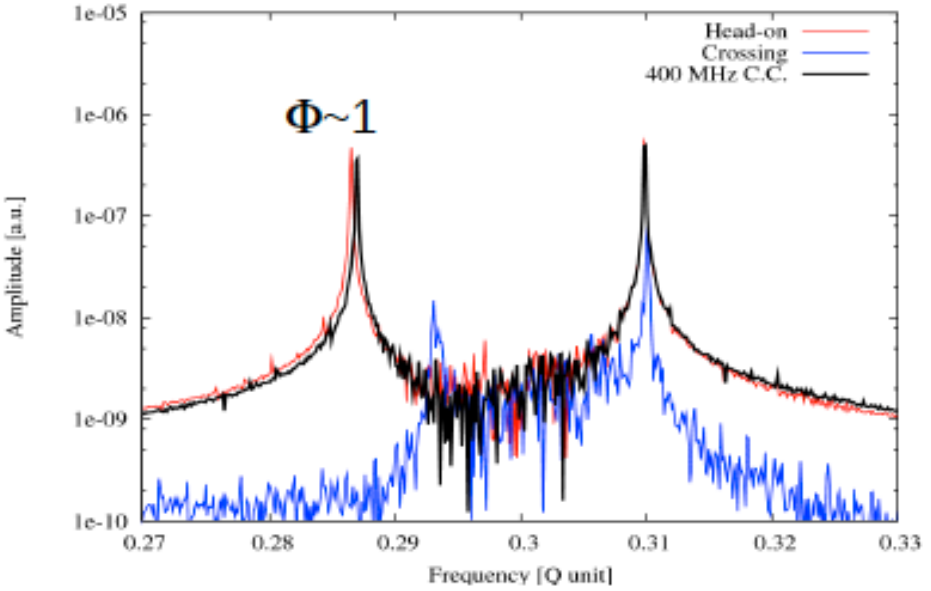




Effect of Crossing Angle and CC on Coherent Effects (S. White)

- Φ~3: strong synchro-betatron coupling + low ξ, π-mode fully damped
- Φ~1: weaker synchro-betatron coupling + higher ξ, π-mode not fully damped
- Crab Cavities restore the π-mode



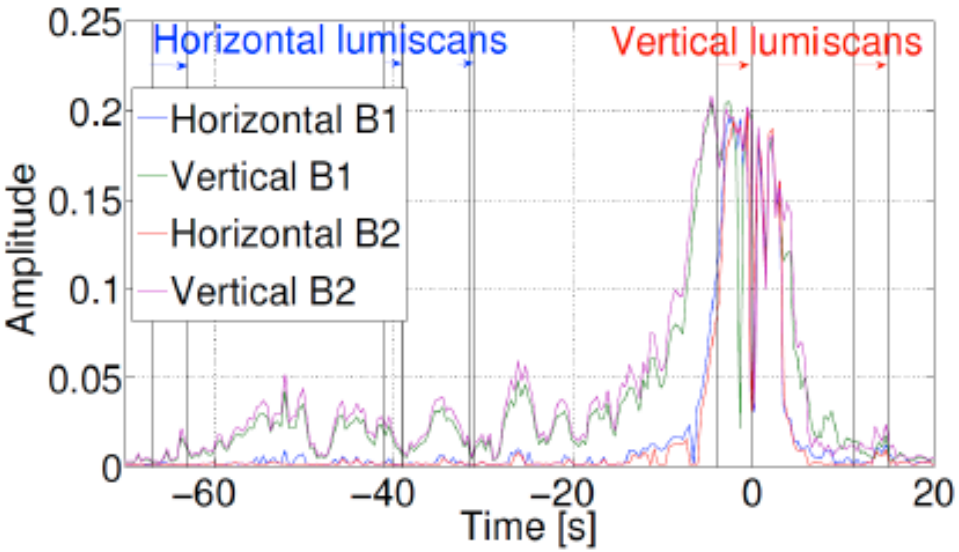


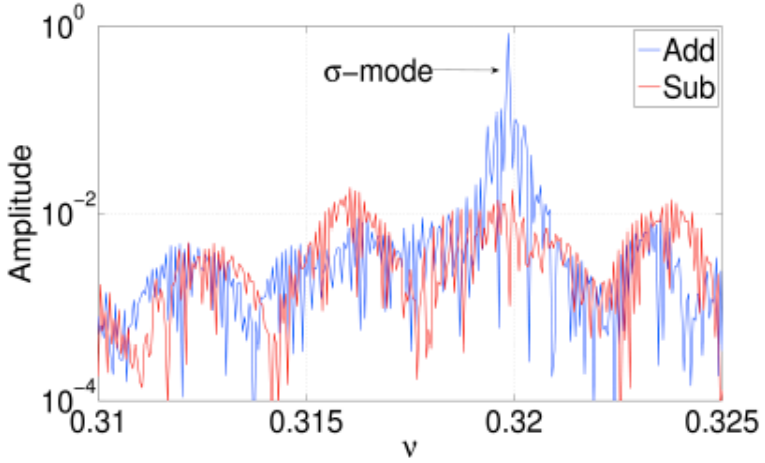
Interplay of Impedance and Beam-Beam (S. White)

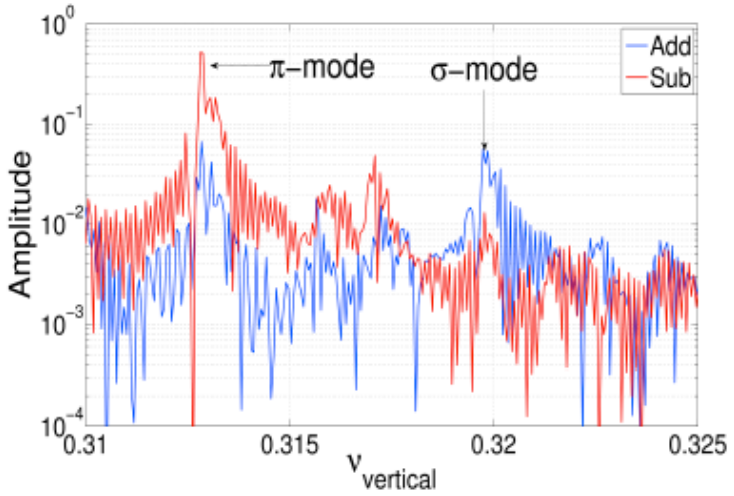
- Instabilities were observed in collision at the LHC
  - The actual cure is to run with the transverse damper on in collision: emittance blow up
  - HL-LHC will run with significantly higher bunch intensity – issues?
- We have a well benchmarked strong-strong beam-beam code (BB3D, J. Qiang)
  - Add impedance model → resistive wall and broadband resonator implemented for multi-bunch
  - Benchmark against hea-dtail ongoing using SPS lattice which was already extensively studied – plan also to cross-check model against VEPP data
  - The challenge would be to simulate a full LHC train with head-on and long-range interactions → the code needs significant development in terms of computing efficiency to achieve this goal (multi-bunch parallelization?)damped

Interplay of Impedance and Beam-Beam (S. White)

- Instability observed in collision at the LHC during luminosity scans with damper off
  - σ-mode excited first. Excitation then transferred to the π-mode leading to strong losses and fast emittance blow-up

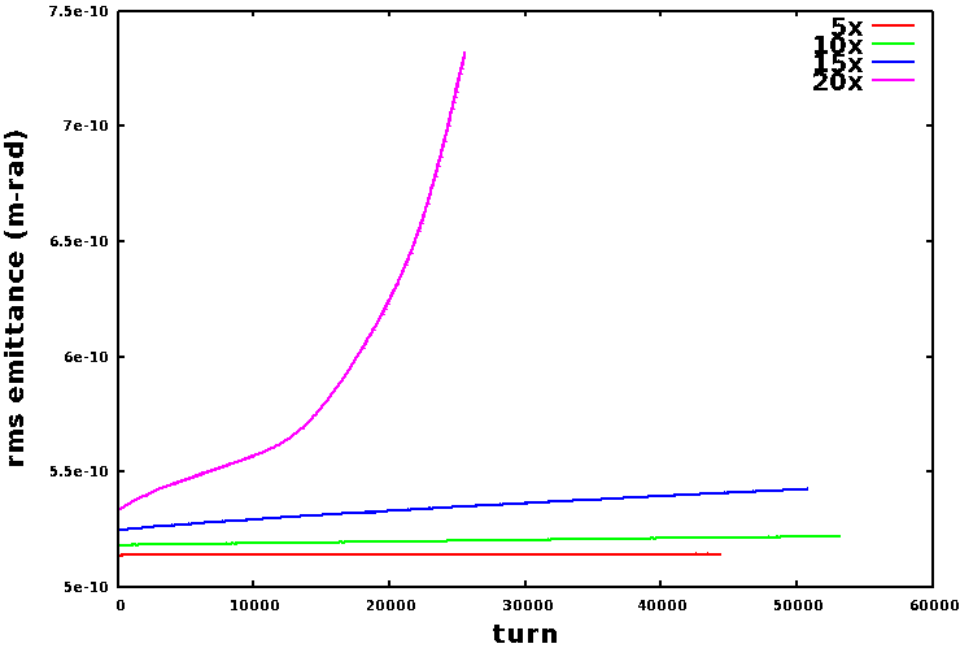


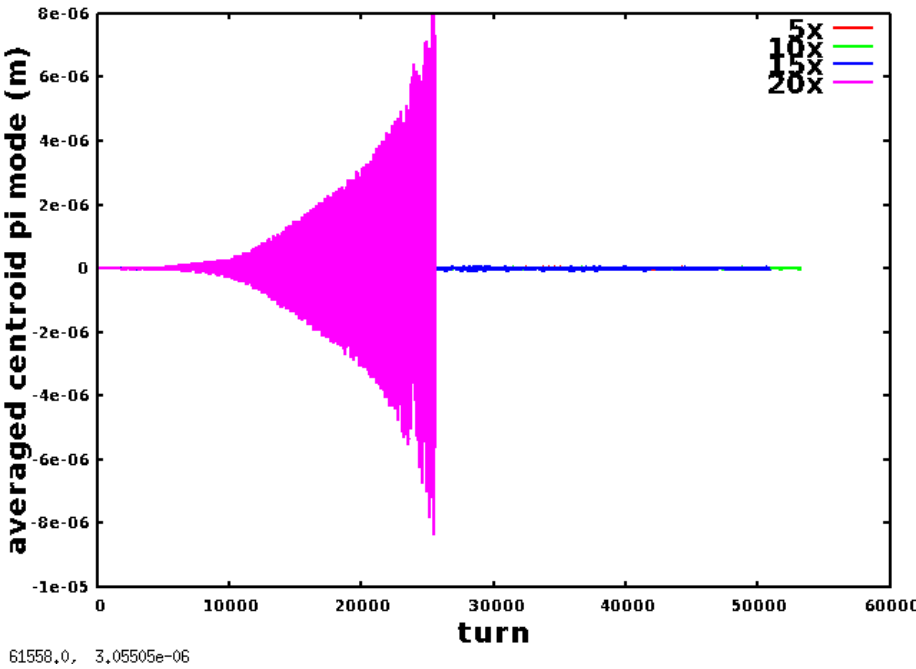




Studies of Coherent Beam-Beam Limit (J. Qiang)

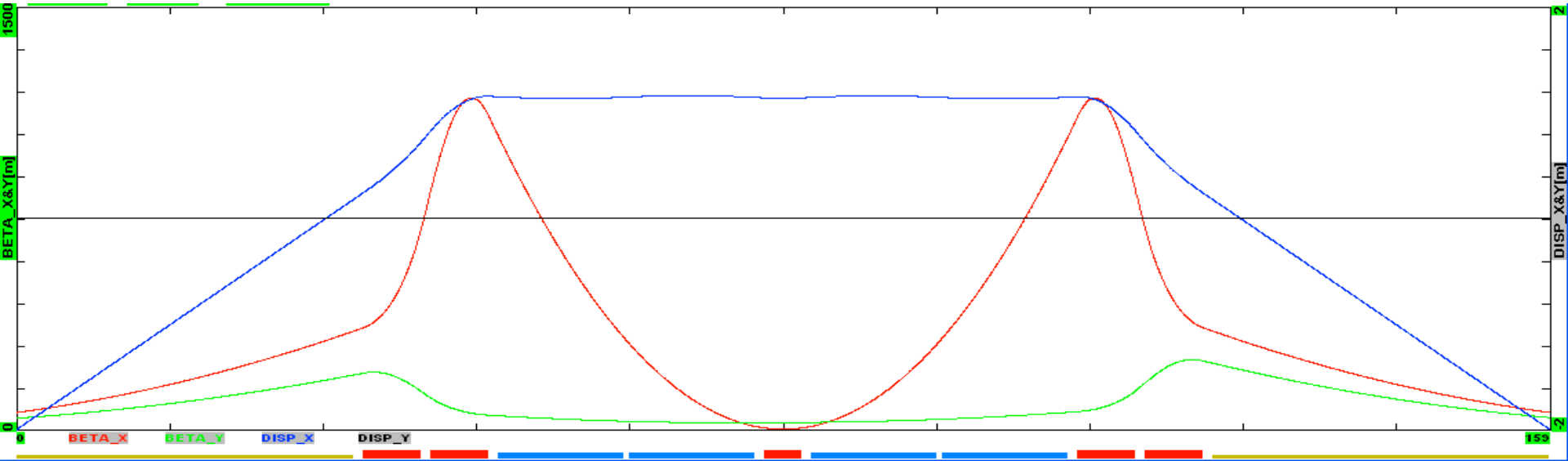
- Nominal Parameters:
  - 1.05 x 1011
  - beam-beam parameter: 0.0034
- One collision point
- No long-range 5x, 10x, 15, 20x nominal b-b parameters





New Idea: Optical Stochastic Cooling for Luminosity Leveling (V. Lebedev, FNAL)

- Fermilab pursues this topic within the Advanced Accelerator R&D at ASTA
  - Integrable Optics Test Accelerator is under construction with operation scheduled to begin in 2014
  - OSC proof-of-principle experiment is one of the studies planned at the machine
- Outlook for application of the method – luminosity leveling at HL-LHC
  - Preliminary estimates predict 2-4 hour cooling time above 5 TeV without active amplifier! Transverse cooling acceptance of 6 σ can be achieved.
  - Would require ~150m chicane insertion with 11T magnets



Outlook

- We have a well-established collaboration on beam-beam effects within LARP as well as internationally
  - Pursue better integration with HL-LHC design study team
  - Participate in beam experiments at the LHC
  - Put together a work plan
- Near-term plans
  - Finish evaluation of HL-LHC options with all effects included
  - Study the luminosity leveling scenarios
  - Investigate coherent effects