Simulation of baseband BTFs using a particle-in-cell code

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Overview

- Introduction and motivation
- The BTF Model
- The beam-beam model
- Conclusion

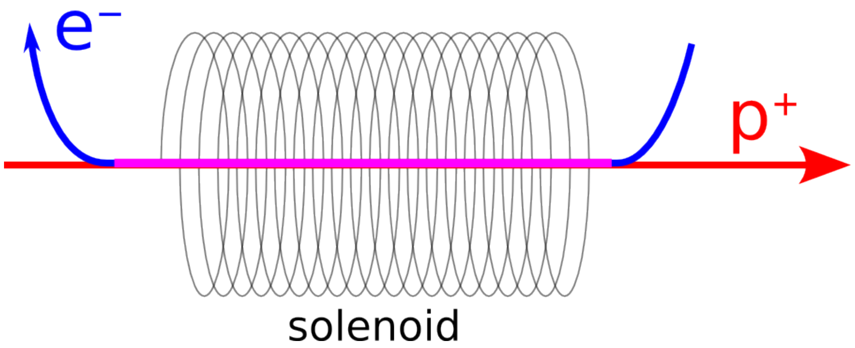
Motivation: Why Particle in Cell?

- We would like to have a working model of BTF and beam-beam to start working on the tune distribution reconstruction
- PIC simulation is the tool of choice
  - Tune distributions can be reconstructed from particle trajectories
  - BTF can be simulated as will be shown
  - Have BTF and tune distributions for same simulation beam conditions
  - Can work with code to optimize models before taking results to the machine

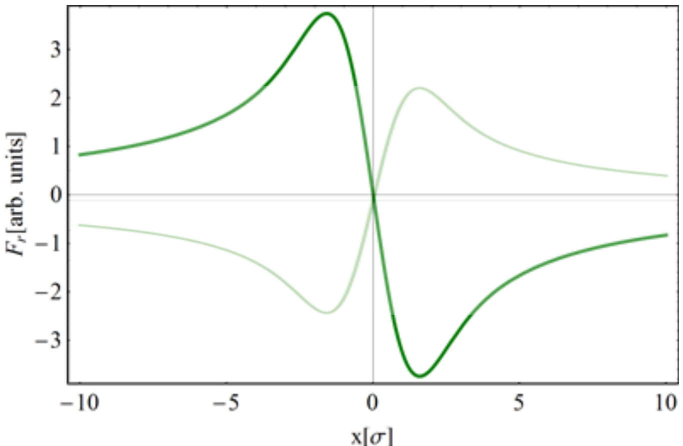
Motivation: Beam-Beam and Electron Lens

- Transverse BTF give good diagnostic opportunities, example: direct space charge tune shift of coasting and bunched beams
- Would like to recover tune distribution of beams under the beam-beam effect
  - Diagnostics for the upcoming electron lens at RHIC

Compensate beam-beam kicks by kicks of an electron beam of comparable charge density distribution at identical betatron phase (not necessarily full compensation)



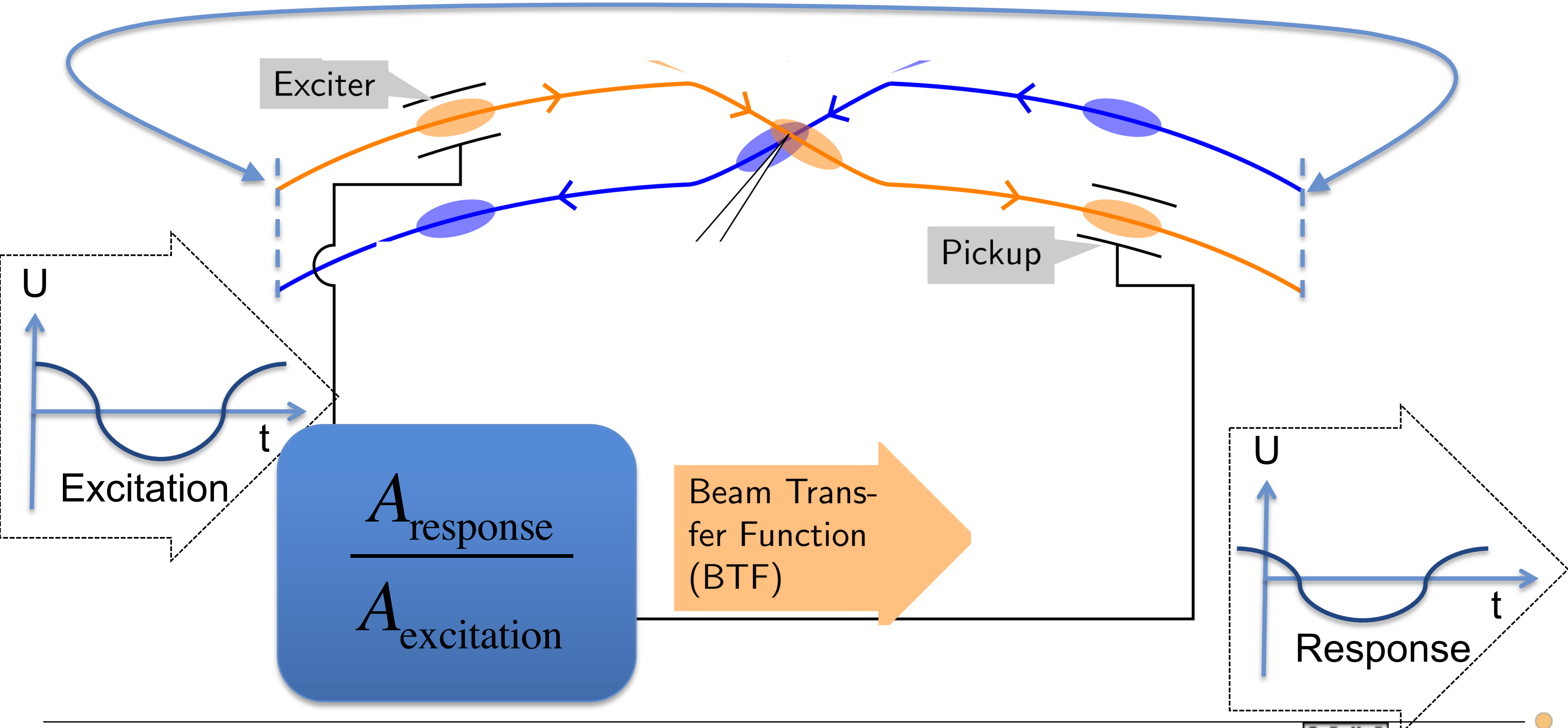
Elens cartoon modified from "RHIC electron lenses" slides by W. Fischer et al.



Elens force (negative beam-beam force)

BTF (in case with beam-beam)

Synchrotron, beam continuously passes same exciter and pickup



Baseband Q (BBQ) measurement system

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Step through excitation frequencies, excite at each for 33 ms, step to next frequency

→

Pick up beam offset for every bunch every turn (through analogue filters)

→

Record beam response at excitation frequency in phase and amplitude, division by exciting signal gives BTF

Normal parameters (polarized protons)	
Time per frequency	33 ms
Number of frequencies scanned	A few thousand
Turns per sample	~2500
Synchrotron period	125ms*

* M. Bai et al. *RHIC Spin Flipper Status and Simulation Studies. Proceeding*s of PAC 2011, 447-449.

BBQ BTF simulation

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Equilibration without excitation for a few 1000 Turns

Store equilibrium particle distribution

Set BTF excitation frequency

BTF kick: 1x per turn: change transverse momentum coordinate x' according to:

$$x' = x' + A\sin(\omega_{\mathrm{BTF}} t)$$

Translate particles on lattice

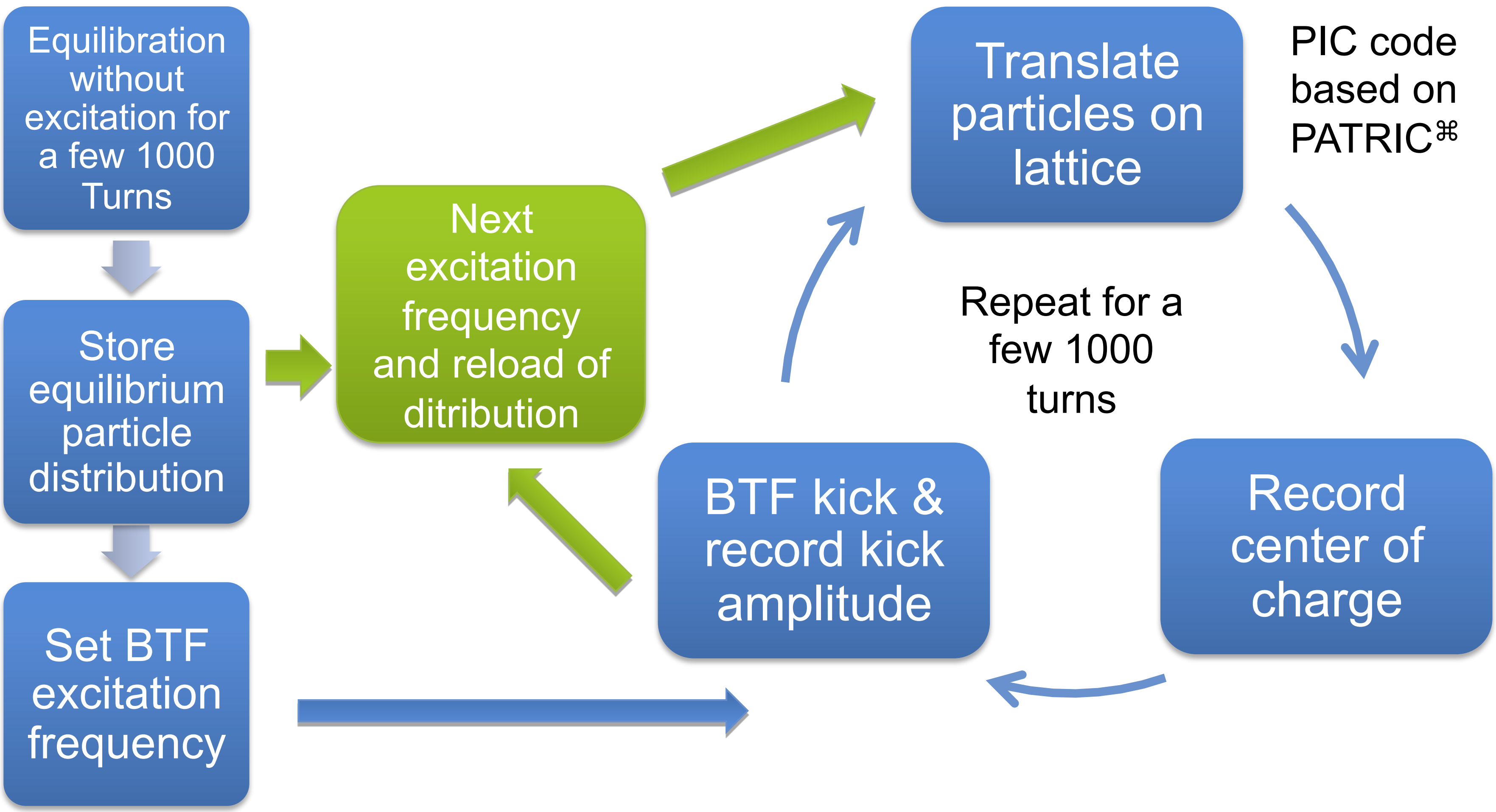
PIC code based on PATRIC⌘

Record center of charge

BTF kick & record kick amplitude

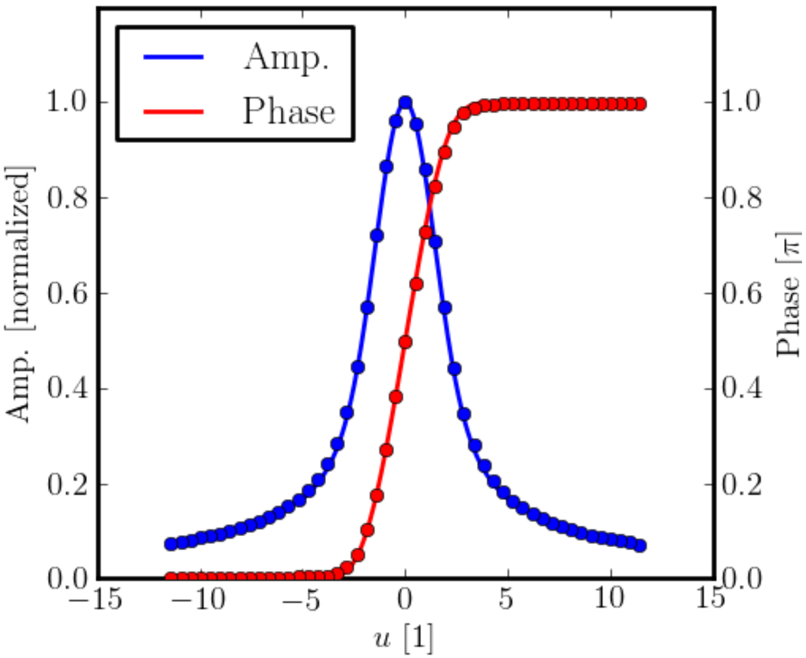
⌘ O. Boine-Frankenheim, V. Kornilov, Proc. of ICAP, 2006, pp 267ff

BBQ BTF simulation



⌘ O. Boine-Frankenheim, V. Kornilov, Proc. of ICAP, 2006, pp 267ff

Verification of the numerical BTF model



Analytic expectation (—,—)

Simulation result (•, •)

BTF analytic solution for case⌘:

- Frozen longitudinal motion
- Gaussian tune spread from chrom.

BTF *R* as a function of norm. freq. dev. *u*:

$$R = f(u) + i \cdot g(u)$$

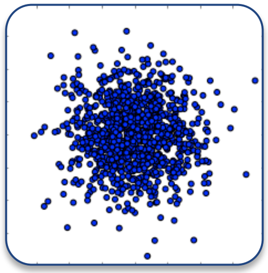
$$f(u) = \sqrt{\frac{2}{\pi}} e^{\frac{u^2}{2}} \int_0^\infty \frac{dy}{y} e^{-\frac{y^2}{2}} \sinh uy$$

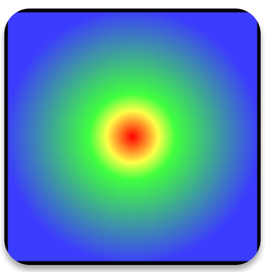
$$g(u) = \sqrt{\frac{\pi}{2}} e^{-\frac{u^2}{2}}$$

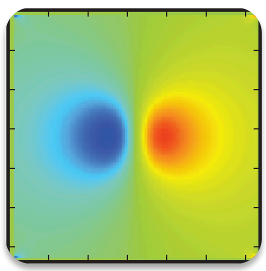
⌘K. Y. Ng, *Intensity Dependent Beam Instabilities*, World Scientific, 2006

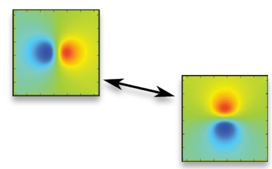
Strong-strong Beam-Beam interaction model

Parallelization on bunch level:
1 Bunch =
1 PIC process









Two field models:

- Soft Gaussian
- 2D Poisson solver

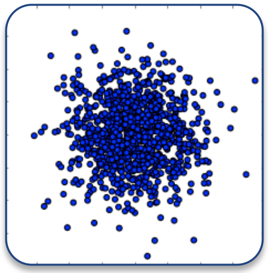
Bunches compute their charge density **projected onto the h/v-plane**

Bunches compute 2D fields

Field exchange with collision partner

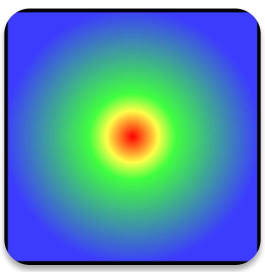
Strong-strong Beam-Beam interaction model

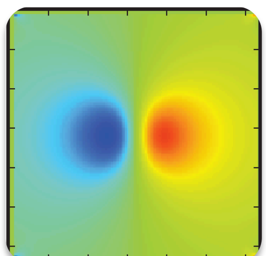
Parallelization on bunch level:
1 Bunch =
1 PIC process

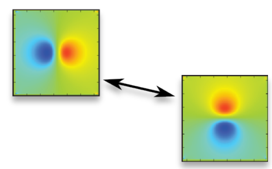


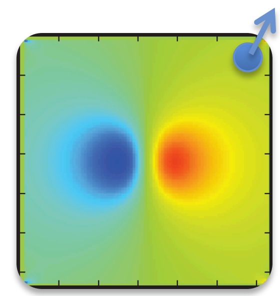
$$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{pmatrix}$$

Translation on lattice using linear 1 turn map









Bunches compute their charge density **projected onto the h/v-plane**

Bunches compute 2D fields

Field exchange with collision partner

Particle *x'* change according to received field

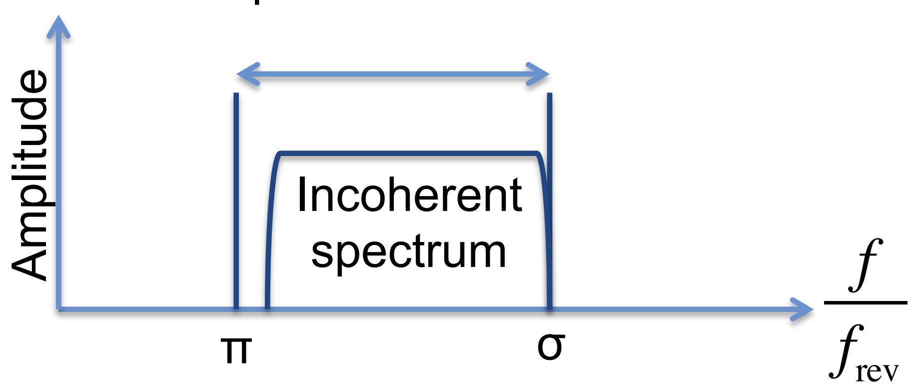
Coherent Beam-Beam Modes

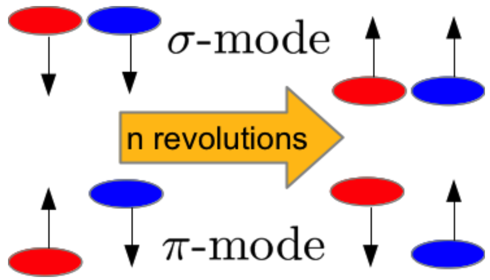
In general colliding bunches can coherently oscillate against each other

π mode: out of phase

σ mode: in phase (nominal tune)

Spectrum cartoon:





Spectrum cartoon and modes illustration taken from W.Herr CAS on Beam-Beam

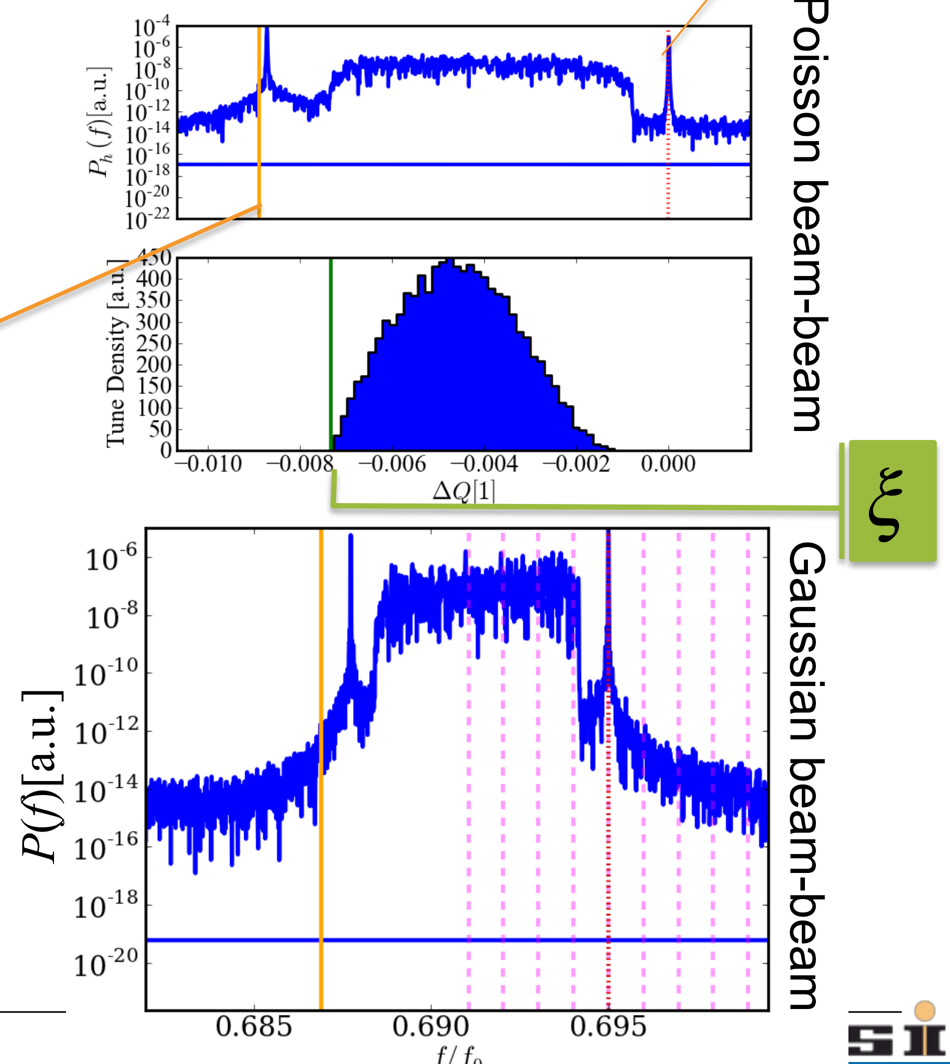
Testing of the numerical strong-strong beam-beam model

- Analytic expectation for the position of the coherent beam-beam modes:

Position of the Pi-Mode as computed by[⌘]:

$$q_\pi = Q - \xi \cdot \Lambda_{\text{yokoya}}$$

- Compare with simulation of Schottky type beam-beam spectra
- Tune shift of pi mode is expected to be reduced for Gaussian approximation



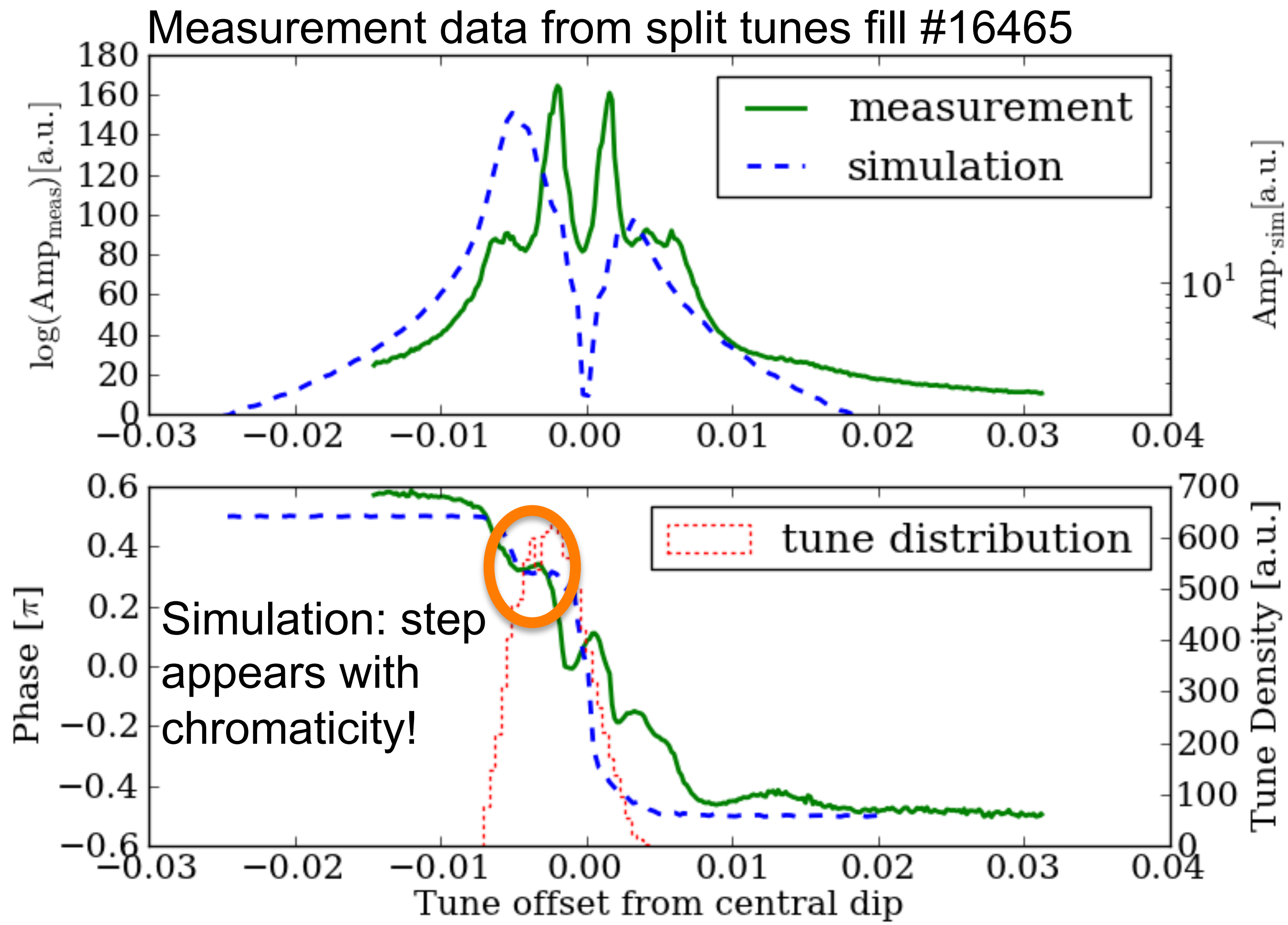
⌘ *Tune shifts of coherent beam-beam oscillations*, Yokoya and Haruyo, Part. Accel. 1990

Physics comparison: Split tunes BTF

Qh	28.691
Qv	29.689
Qh	28.735

N	1.8e11
εx	20mm mrad
εy	20mm mrad
E	100GeV

normalized 95% emittances



Conclusion and Outlook

- We have an implementation of BTF that agrees with analytic expectation
- We have a simplified implementation of the beam-beam effect that reproduces expected coherent mode positions
- We can analyze tune distributions

- Now we can move on and use our simulation as a source of data against which to test models for tune footprint reconstruction from BTF

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THANK YOU FOR YOUR ATTENTION