Trip Report: RHIC Transverse Beam Transfer Function measurements

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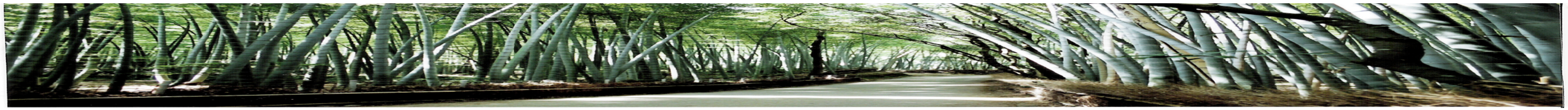
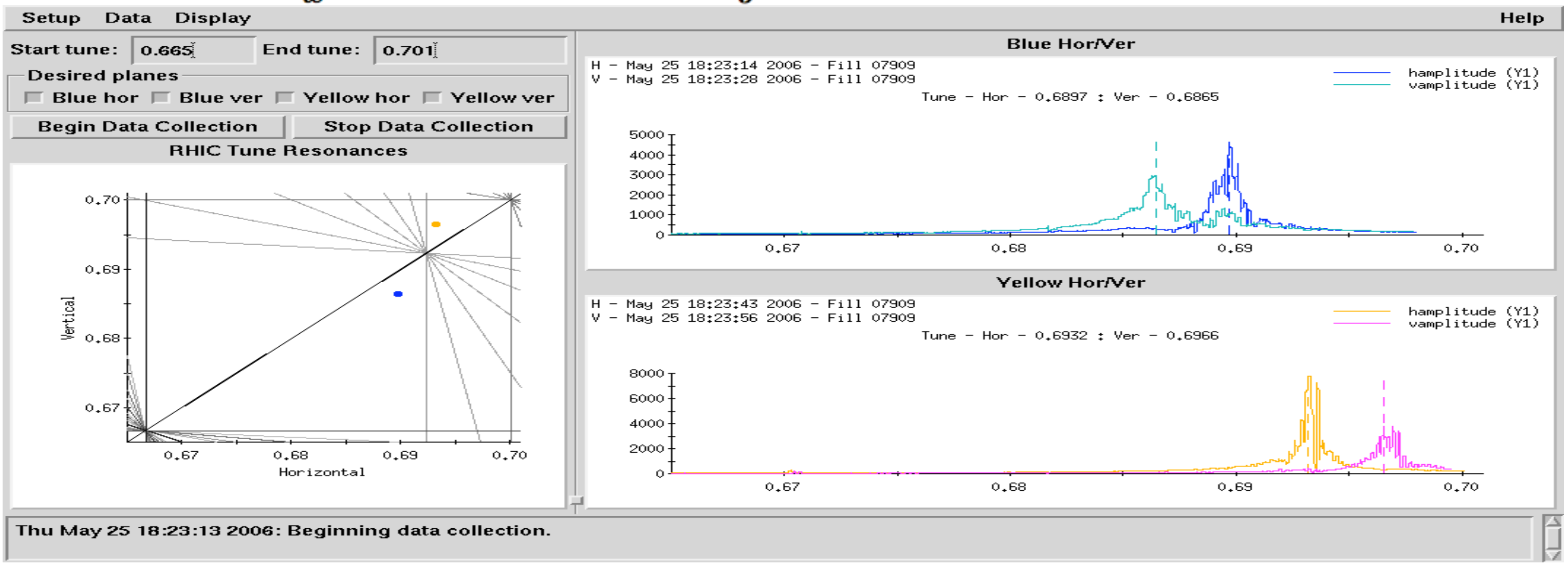


BTF measurements

BTF: tune distributions of colliding beams, amplitude response of the beams $\langle x \rangle$ as a function of exciting frequency Ω

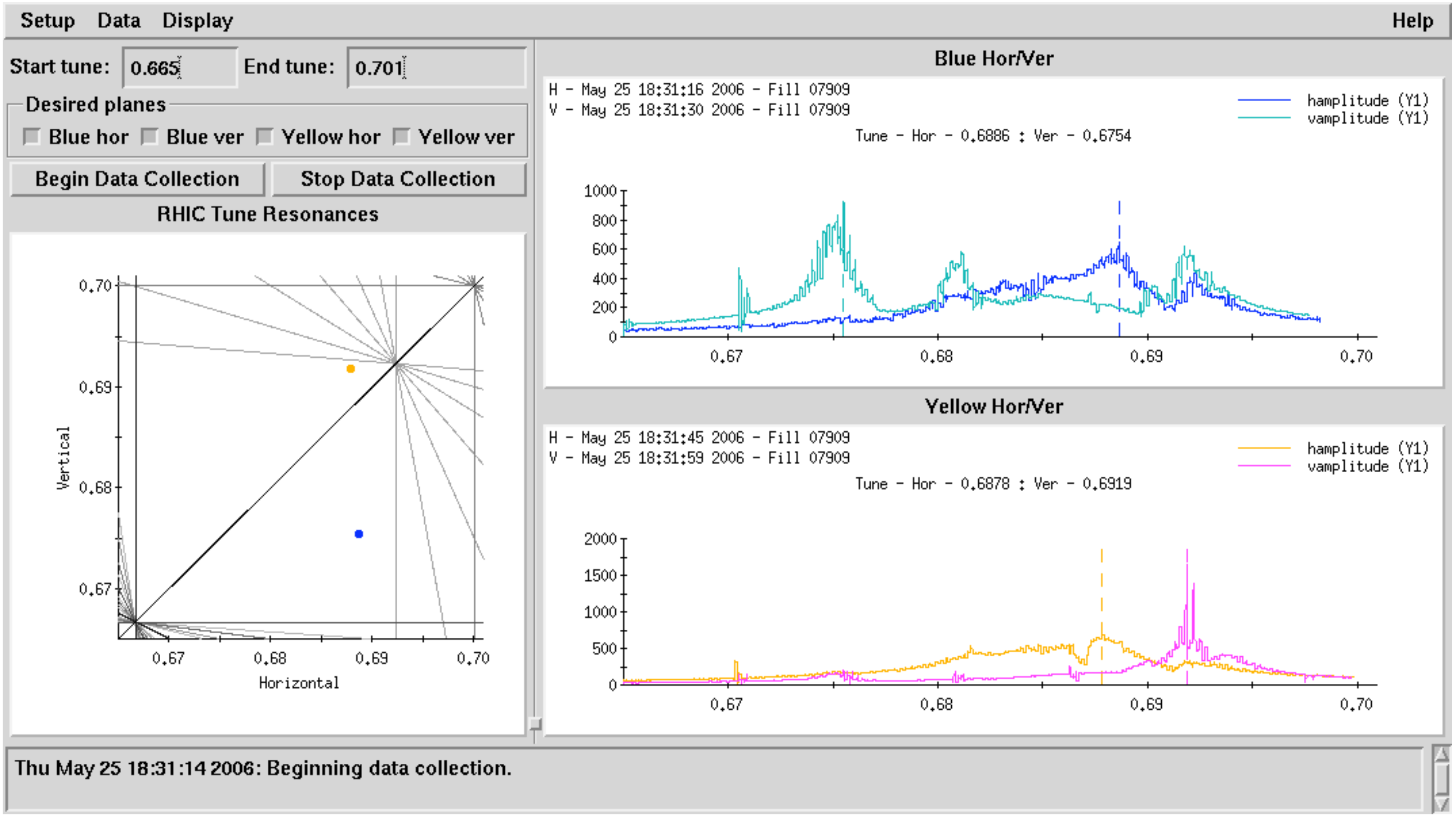
- Beam: set of oscillators with transverse tune distribution $\rho(\omega)$
- External driving force $A\cos(\Omega t + \phi)$

$$\langle x(t) \rangle = \frac{A}{2\omega_x}[\cos(\Omega t + \phi)\mathrm{P.V.}\int d\omega \frac{\rho(\omega)}{\omega - \Omega} + \pi\rho(\Omega)\sin(\Omega t + \phi)]$$

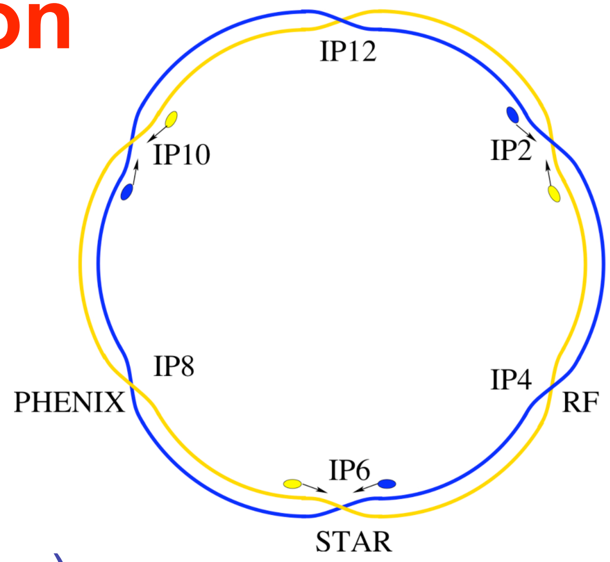


BTF during store: Beam-Beam

BTF MEASUREMENT Fill 7909 pp Run06



RHIC configuration



Proton-Proton run 06

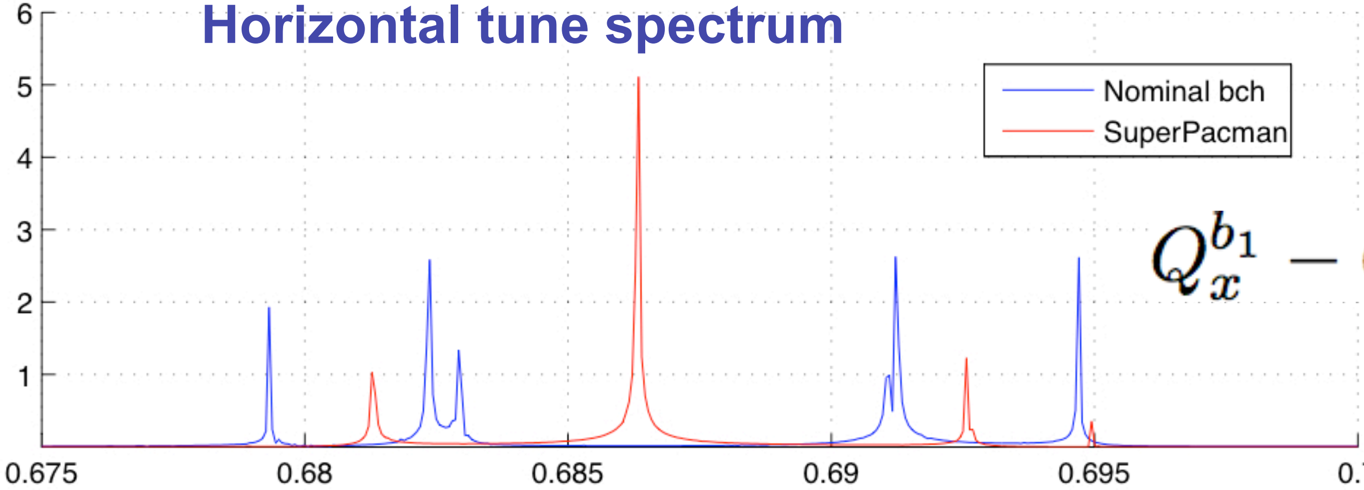
- 2 IPs (6 and 8)
- 111 bunches over 120 buckets
    - 9 SuperPacman bunches (1HO collision)
    - 108 Nominal bunches (2 HO collisions)
- Different working points for the two beams

Simulation tools: COMBI

I. Analytical Linear Model (ALM)
II. Rigid Bunch Model (RBM)
III. Parallel Multi Particle Simulation (MPS) **+ BTF routine**

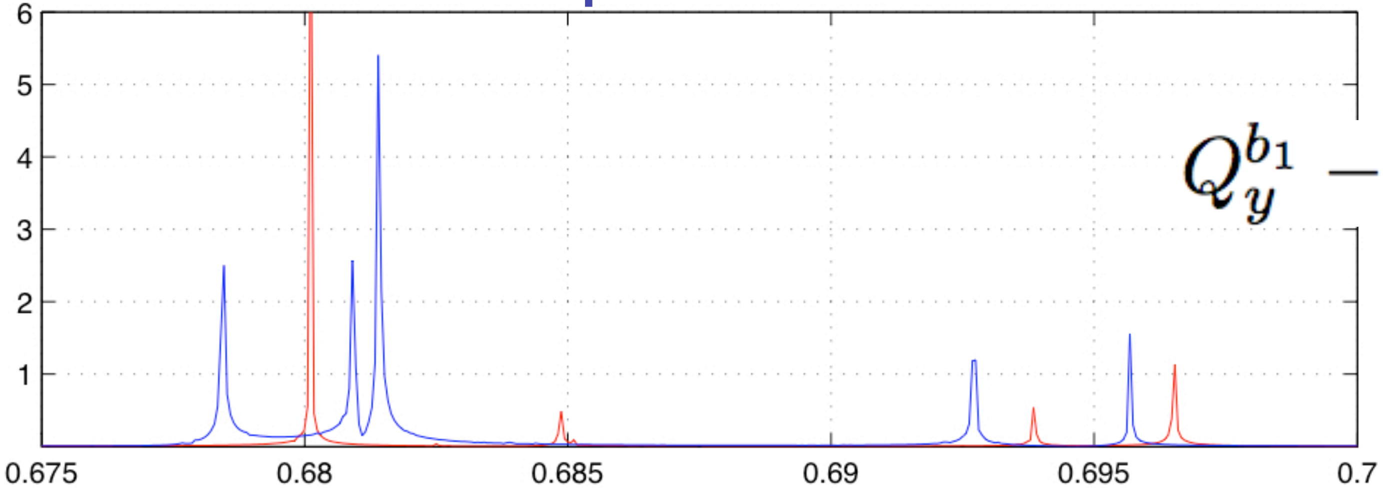
Tune spectra from RBM Fill 7915:

Horizontal tune spectrum



$$Q_x^{b_1} - Q_x^{b_2} = 0.0035$$

Vertical tune spectrum

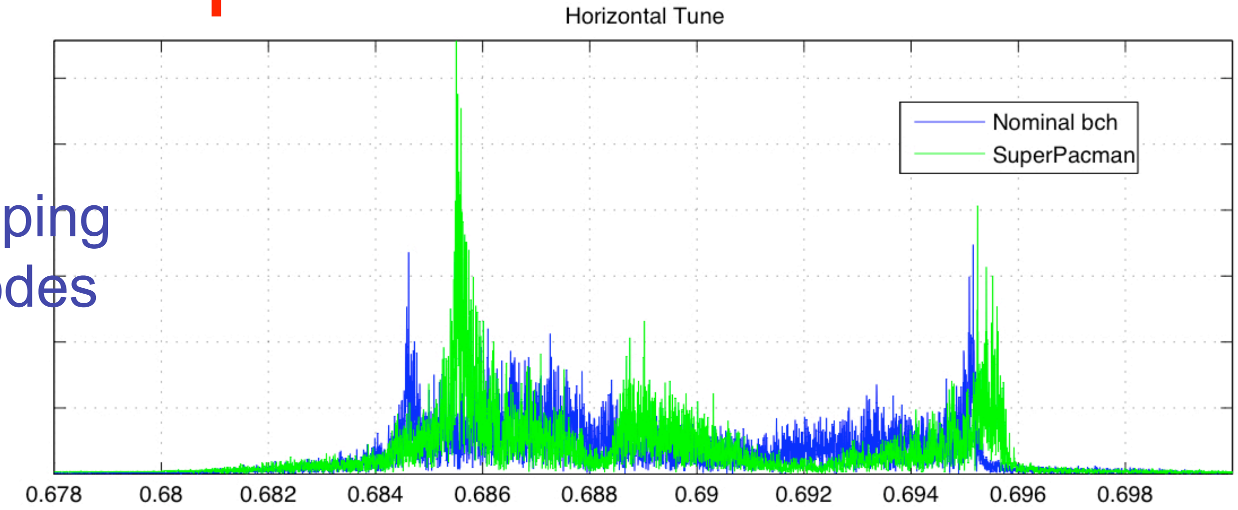


$$Q_y^{b_1} - Q_y^{b_2} = 0.01$$

Tune spectra from MPS:

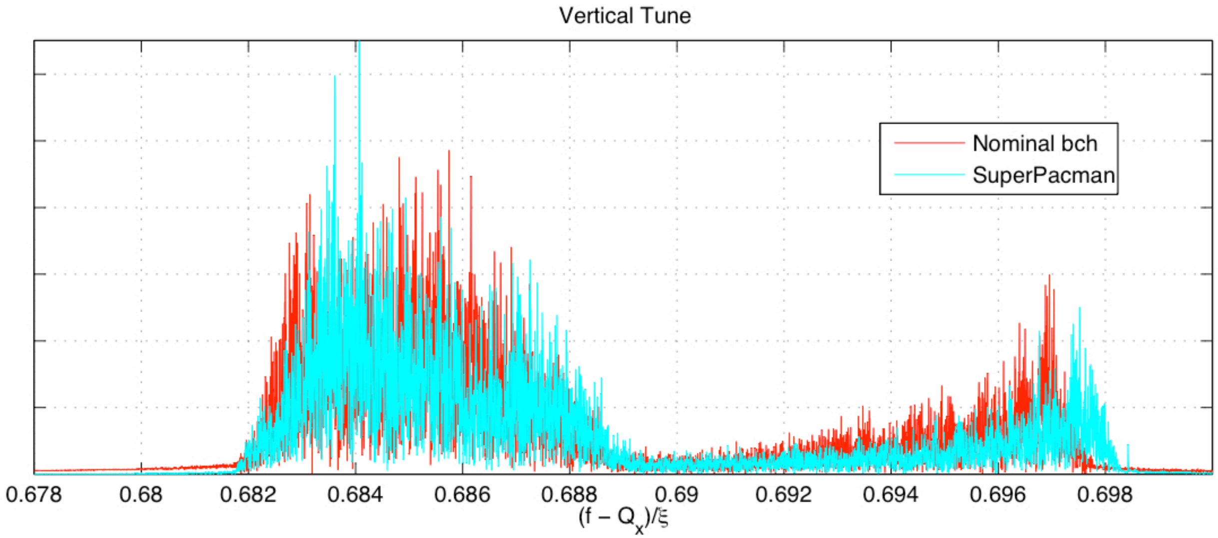
$$\Delta Q_x \leq \xi$$

- Landau damping of coherent modes

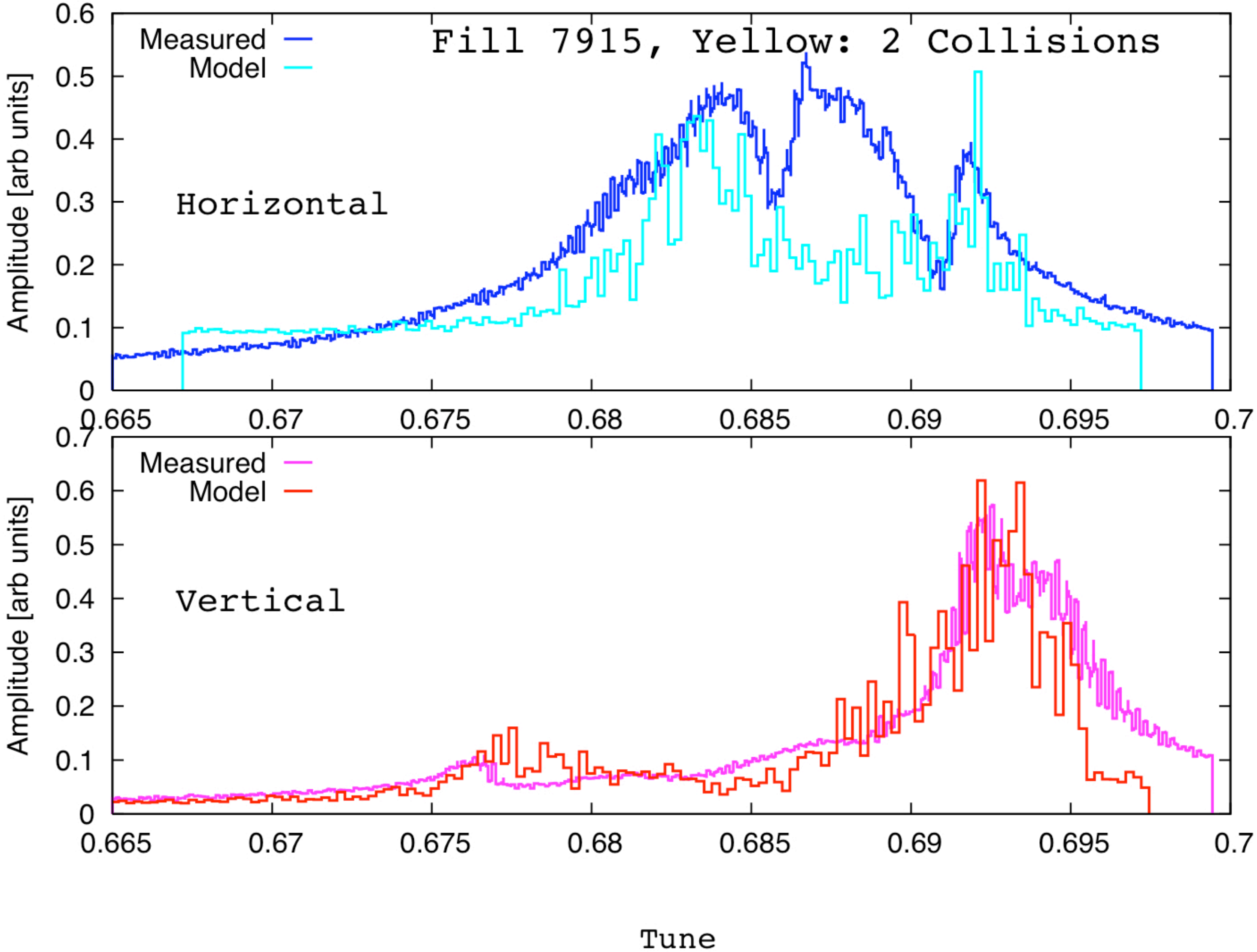


$$\Delta Q_y \geq \xi$$

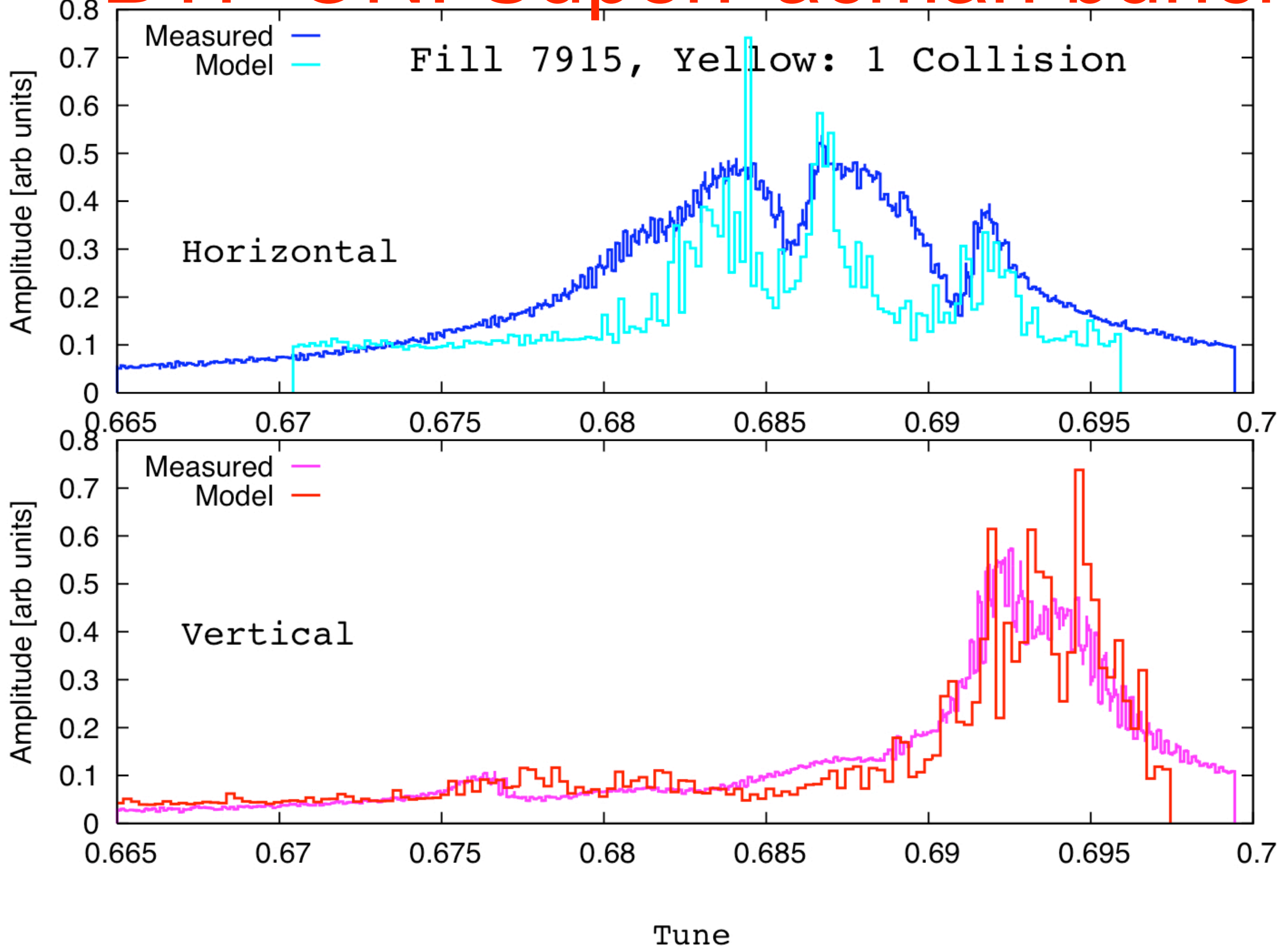
- Two beams decoupled



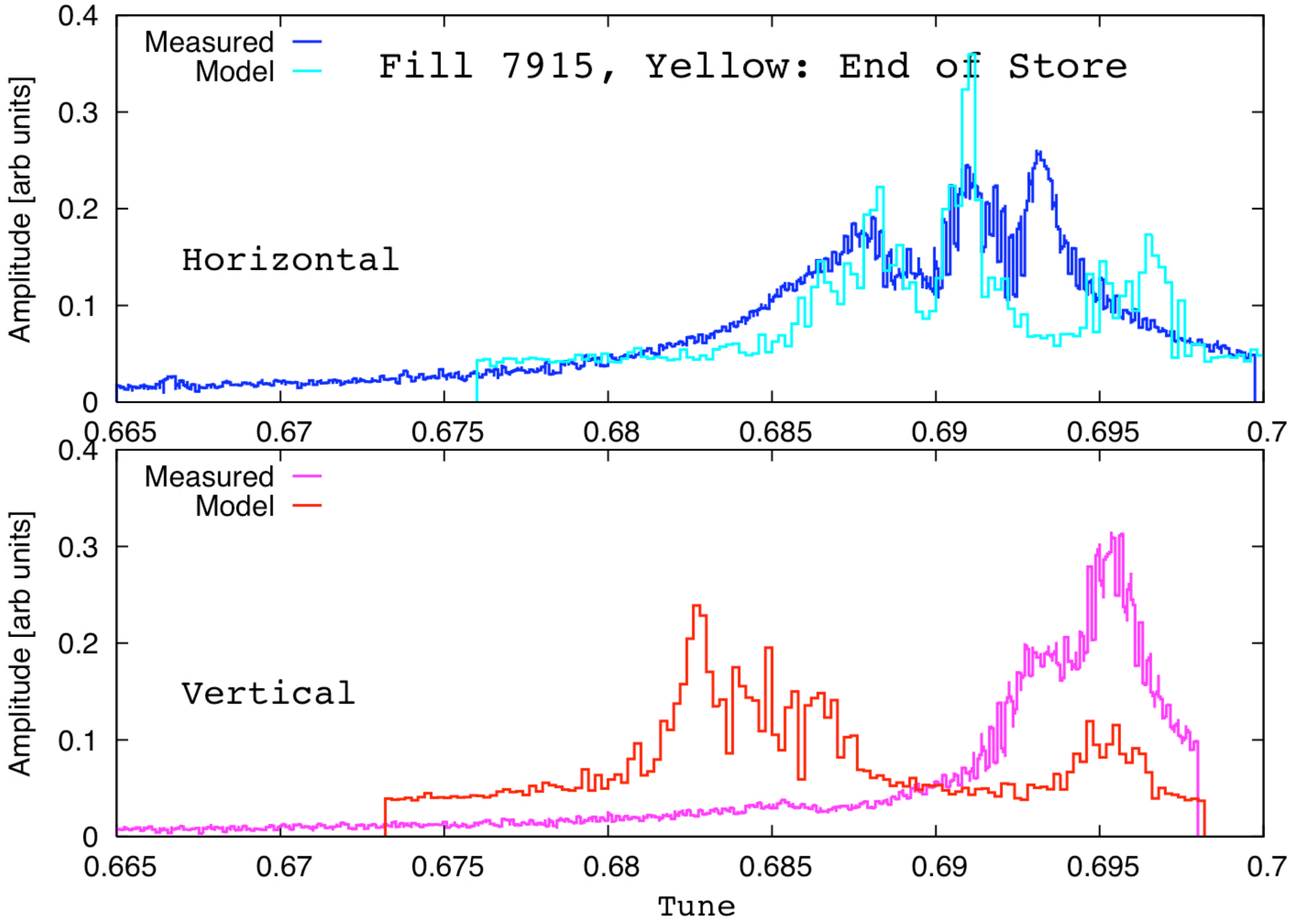
BTF ON: Nominal Bunch



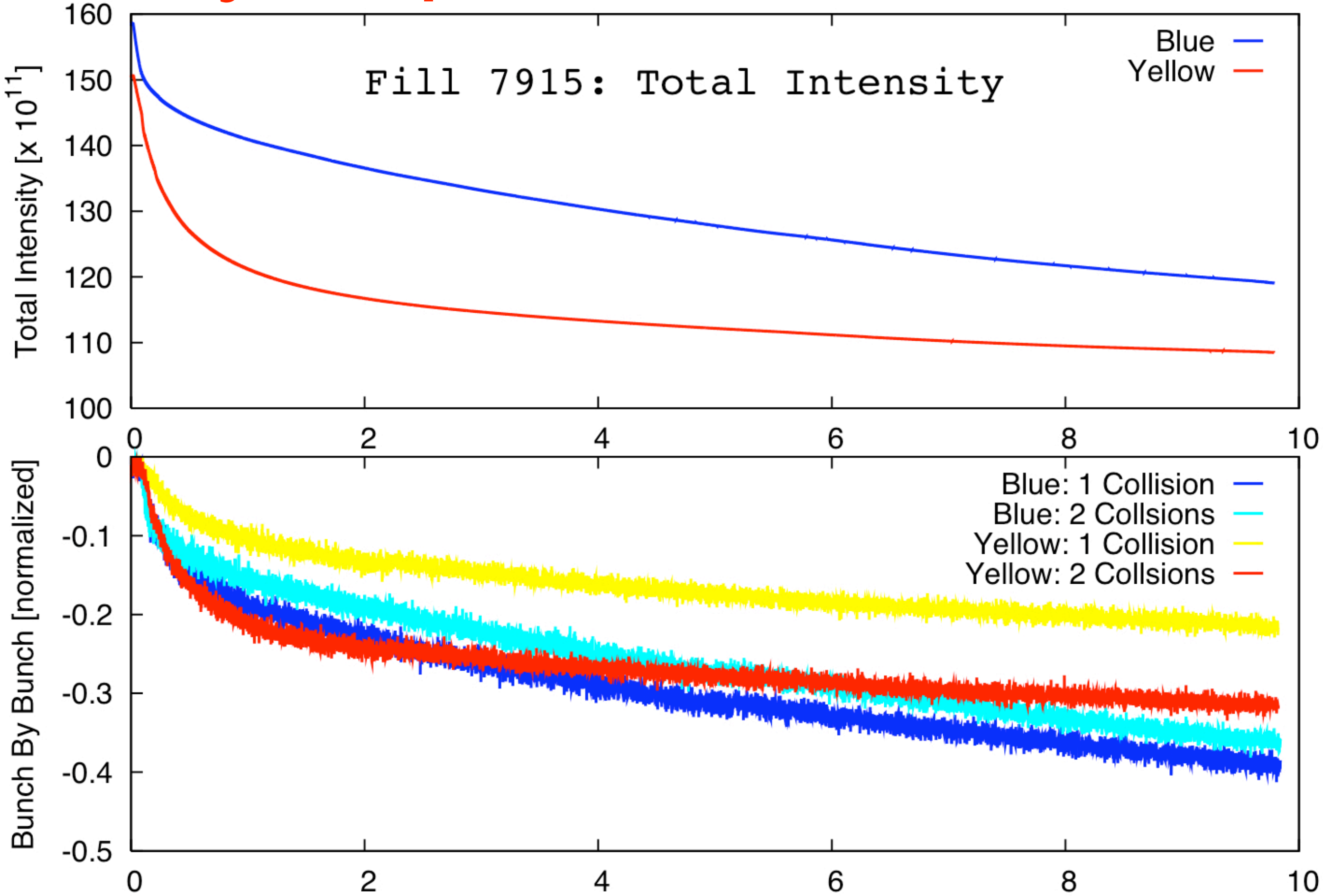
BTF ON: SuperPacman bunch



BTF ON: SuperPacman bunch



Why SuperPacman bunches?



- Bunch amplitude response measure with stripline pickup: single bunch measurement, takes signal from bunch with highest intensity
- SuperPacman bunches loose less, therefore are the most intense

Conclusions:

- COMBI code benchmarked with experimental data give good agreement in simplified case as RHIC

- BTF measurements are now reproduced and understand number and location of peaks:
  - BTF measurements excite coherent modes which are Landau damped
  - RHIC BTF measurements clear signature of SuperPacman bunches therefore it's very important to know which bunch is measured

- Chromaticity and non linear field errors effects understudy

Collider description:

Run parameters:

collision: coll_LHC.in
filling: fill_ref_1.in fill_ref_2.in
number of turns: 124000
number of ips: 8 8
bunches to kick: 1015
bunches to measure: 1001 2017
QX0: 63.3200
QY0: 58.3100
beam-beam parameter: 0.0025

Collision pattern:

```
#Collision scheme LHC (for filling scheme LHC)
   1  -2   -15  +15
 447   3    8.046   6.940   8.032   6.920
 892  -2   -0   +0
2229   3   23.015  21.821  23.125  21.821
3565   2   -15  +15
4902   3   23.533  20.689  23.533  20.689
6235   2   -0   +0
6684   3    7.716   7.870   7.736   7.820
```

Beam filling scheme:

```
#Bunch filling example LHC
#Number of groups
8
72 0 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 72 1 39 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 72 1 39 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 72 1 39 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 30 0  0 0
72 1 8 0 72 1 8 0 72 1 8 0 72 1 39 0
```

Other action codes:
- 4 only long range interactions
- 5 excitation (white noise, defined kicks)
- 8 BPMs
- 9 AC excitation (for BTFs)

I. Analytical Linear Model

Solve eigenvalue problem of 1 turn map

Beam-Beam Matrix:

$$B = \begin{pmatrix} 1 & 0 & 0 & 0 & \dots & 0 & 0 & 0 & 0 & \dots \\ -b_x & 1 & k & 0 & \dots & b_x & 0 & 0 & 0 & \dots \\ 0 & 0 & 1 & 0 & \dots & 0 & 0 & 0 & 0 & \dots \\ k & 0 & -b_y & 1 & \dots & 0 & 0 & b_y & 0 & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \dots & 1 & 0 & 0 & 0 & \dots \\ b_x & 0 & 0 & 0 & \dots & -b_x & 1 & k & 0 & \dots \\ 0 & 0 & 0 & 0 & \dots & 0 & 0 & 1 & 0 & \dots \\ k & 0 & b_y & 0 & \dots & 0 & 0 & -b_y & 1 & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \end{pmatrix}$$

BEAM 1 / BEAM 2

$$\begin{pmatrix} x_{1^{b_1}} \\ x'_{1^{b_1}} \\ y_{1^{b_1}} \\ y'_{1^{b_1}} \\ \dots \\ x_{1^{b_2}} \\ x'_{1^{b_2}} \\ y_{1^{b_2}} \\ y'_{1^{b_2}} \\ \dots \end{pmatrix}_{s_0+C} = M_C \begin{pmatrix} x_{1^{b_1}} \\ x'_{1^{b_1}} \\ y_{1^{b_1}} \\ y'_{1^{b_1}} \\ \dots \\ x_{1^{b_2}} \\ x'_{1^{b_2}} \\ y_{1^{b_2}} \\ y'_{1^{b_2}} \\ \dots \end{pmatrix}_{s_0}$$

bunch1 beam1 … **bch2, …**

bunch1 beam2 … **bch2, …**

Bunches: Rigid Gaussian distributions

Transfer Matrix:

$$T = \begin{pmatrix} \cos(\Delta\mu_x^{b_1}) & \sin(\Delta\mu_x^{b_1}) & 0 & 0 & \dots & 0 & 0 & 0 & 0 & \dots \\ -\sin(\Delta\mu_x^{b_1}) & \cos(\Delta\mu_x^{b_1}) & 0 & 0 & \dots & 0 & 0 & 0 & 0 & \dots \\ 0 & 0 & \cos(\Delta\mu_y^{b_1}) & \sin(\Delta\mu_y^{b_1}) & \dots & 0 & 0 & 0 & 0 & \dots \\ 0 & 0 & -\sin(\Delta\mu_x^{b_1}) & \cos(\Delta\mu_y^{b_1}) & \dots & 0 & 0 & 0 & 0 & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & 0 & 0 & \dots & \cos(\Delta\mu_x^{b_2}) & \sin(\Delta\mu_x^{b_2}) & 0 & 0 & \dots \\ 0 & 0 & 0 & 0 & \dots & -\sin(\Delta\mu_x^{b_2}) & \cos(\Delta\mu_x^{b_2}) & 0 & 0 & \dots \\ 0 & 0 & 0 & 0 & \dots & 0 & 0 & \cos(\Delta\mu_y^{b_2}) & \sin(\Delta\mu_y^{b_2}) & \dots \\ 0 & 0 & 0 & 0 & \dots & 0 & 0 & -\sin(\Delta\mu_y^{b_2}) & \cos(\Delta\mu_y^{b_2}) & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots & \dots \end{pmatrix}$$

- $\Delta\mu_x^{b_1}$ • Phase advance
- b_x • Linearized HO or LR B-B kick
- k • Coupling factor

One Turn Matrix ➡ $$M_C = T_1 * B_1 * T_2 * B_2 * \dots$$

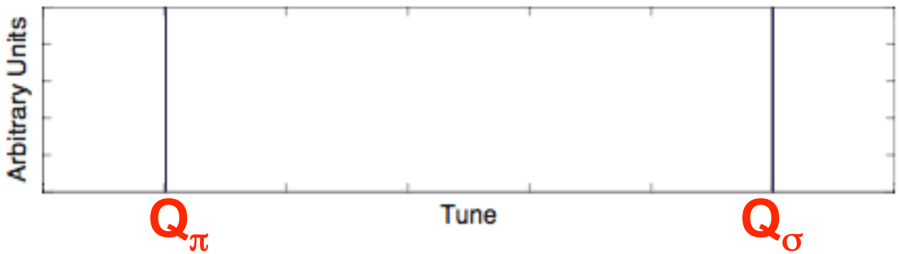
I. Analytical linear model

Solving the eigenvalue problem, like for a system of coupled oscillators:

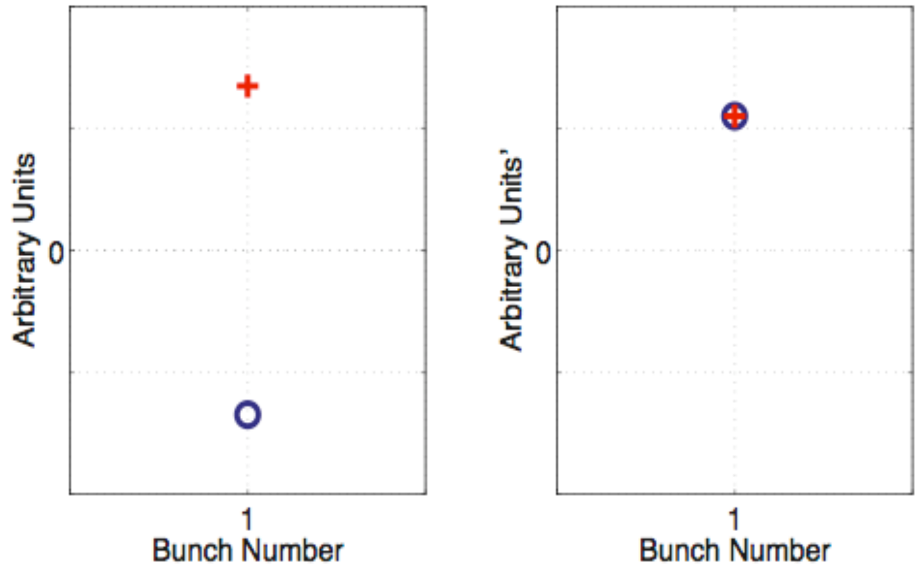
- **Eigenvalues:** give the system dipolar mode eigen-frequencies (**tune**):

$$Q_i = \frac{\arccos(\lambda_i)}{2\pi}$$

  - Mode frequencies calculations for bunches
  - Stability studies



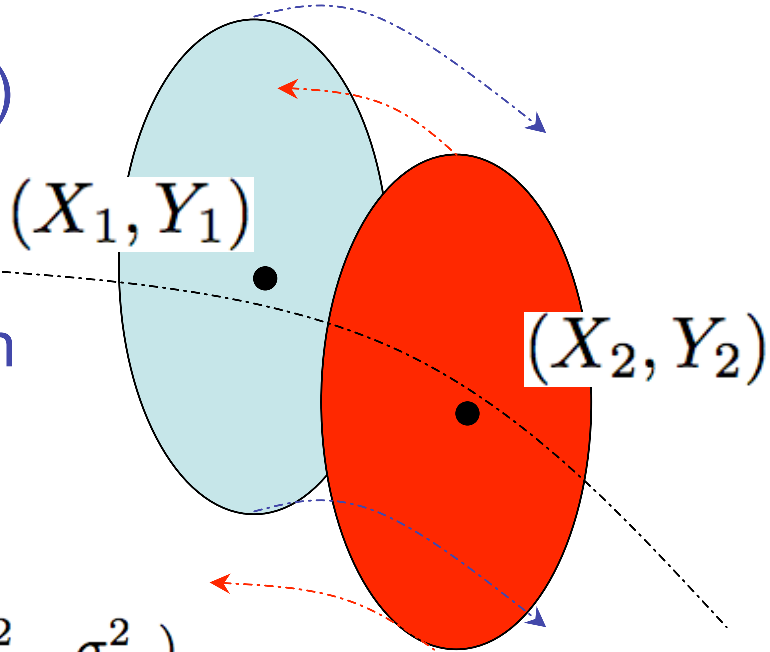
- **Eigenvectors** give the system oscillating patterns:
  - To understand bunches oscillation patterns
  - With other simulations to understand bunch to bunch differences



II. Rigid Bunch Model

- **Bunches:** rigid objects assumed Gaussian with varying barycentres (X,Y) and fixed (σ_x,σ_y)

- **At BBI** bunch at (X_1,Y_1) receives a transverse **kick** from the opposite bunch at (X_2,Y_2) and transverse sizes (σ_x,σ_y) and vice versa



$$\Delta(X_1)' = \frac{2r_pN_p}{\gamma}\frac{\beta_x}{\sigma^2_{X_2}}F_{X_2}(X_1 - X_2, Y_1 - Y_2, \sigma^2_{X_2}, \sigma^2_{Y_2})$$

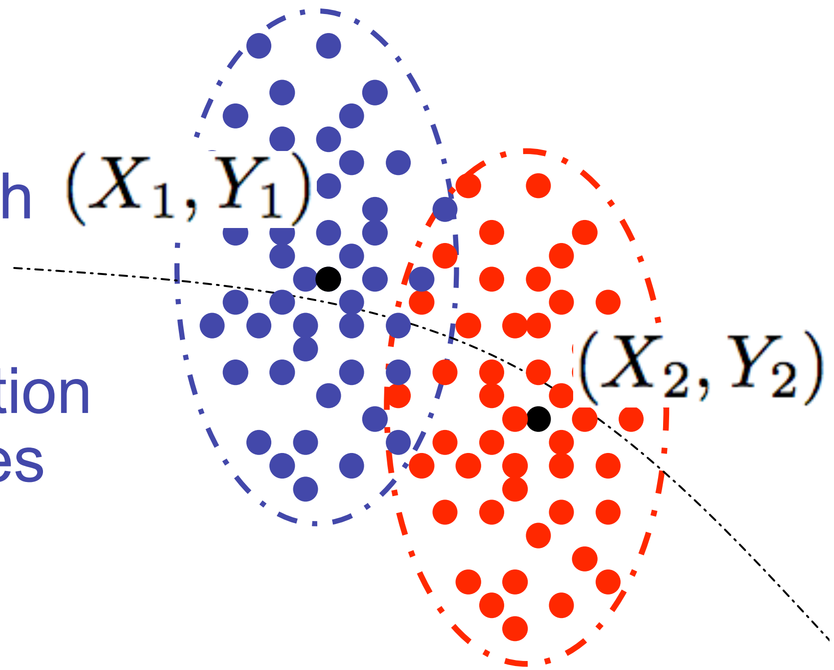
- **Between BBI:** linear transfer (rotation in phase space) and anything else (transverse kick from collimators, kickers…)

- **Fourier analysis** of the bunch barycentres turn by turn gives the tune spectra of the dipole modes

Multi Particle Simulations

- **Bunches: N_{tot} (10^4-10^6)** macro particles

- **BBI:** each particle of bunch **(X_1,Y_1)** receives a transverse **kick** from bunch **(X_2,Y_2)** and vice versa.



- **BB kick:** solving the Poisson equation for any distribution of charged particles (FMM) or Gaussian approximation:

$$\Delta(x_1)' = \frac{2r_p N_p}{\gamma} \frac{\beta_x}{\sigma^2_{X_2}} F_{X_2}(x_1 - X_2, y_1 - Y_2, \sigma^2_{X_2}, \sigma^2_{Y_2})$$

- **Between the BBIs:** linear transfer (rotation in phase space) and anything else (kickers, collimators, BTF device, etc)

COMBI MPS to Parallel mode

- MPI-protocol
- Master/Slave Architecture
- Clusters: EPFL MIZAR (448 CPUs) and EPFL BlueGene (8000 CPUs)

❑ MASTER:

- ❑ Controls propagation of the bunches
- ❑ Controls the calculation for the interactions of bunches

❑ Slaves:

❑ **Store the macro-particle parameters** and **perform calculation** when an action is required from the MASTER :

- ❑ **Single bunch action**: do not need information from opposite bunch
- ❑ **Double bunch action**: need information barycentre and field from opposite bunch.