Stochastic Cooling and
Beam-Beam Transfer Functions
for Working Point Optimization

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27Apr10

- ***The One Slide Summary***
- Schottky and BTF
- Timeline
- The LARP Tune Feedback Task
- The Scattering Matrix
- Coupling Transfer Functions
- Beam-Beam Transfer Functions
- Summary and Conclusion

The One Slide Summary

- The success of bunched beam stochastic cooling in RHIC is the key enabling technology of this proposal
- It permits to do studies at store without irreversible emittance growth
- Without cooling one can tweak machine parameters very little before the resulting emittance growth requires a machine cycle for fresh beam
- The hope is that with cooling one can explore the parameter space with some freedom, learn how to apply BBTF to working point optimization
- There is a substantial amount of BBTF data in the RHIC archives

Thomas Roser "…if the LARP BBTF proposal is approved, **RHIC can and should be used as a test bed.**"

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Schottky and BTF

- need both for working point optimization
  - passive – Schottky (incoherent)
  - active – transfer function (coherent? doesn’t see image fields)
- Time/Frequency Domain
  - Schottky is viewed in frequency domain – in time domain it looks like noise (except in the limit of very few particles)
  - BTFs and BBTFs likewise in frequency domain
    - Bode plot – two plots, ampl and phase vs frequency
    - Nyquist plot – one plot, ampl vs phase at each frequency
    - Stability diagram – one plot, ‘inverse’ of BTF, commonly called a ‘root-locus’ plot
    - BBTF – one plot, beam 1 (H or V, ampl or phase) vs beam 2 (H or V, ampl or phase) at each frequency

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Timeline

- ISR – Borer, Jung, Koutchouk, Hofman, Vos, Sacherer, Zotter,…

  then a pretty big jump, with GSI team bridging some of it
- Serendipity in the RHIC PLL tune system
  - four VME 8ch digitizers – one per eigenmode
  - digitizers clocked by 4x the respective eigenfrequencies!!!
- Acquiring the complete transfer function matrix required only
  - a few splitters and some cables
  - cloning existing DAQ software, assigning new names
  - using existing Control System software to make correlation plots

- *OK, we've got it. Now what do we do with it?*

not obvious until

- Bunched beam **Stochastic Cooling** of ions in RHIC becomes operational
- Stochastic Cooling is the enabling technology of this proposal

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The LARP Tune/Coupling/Chromaticity Feedback Task

- A fine example of the LARP mission at its best, mutually beneficial to US and CERN
  - successful tune, coupling, and chromaticity feedback at **RHIC**
  - excellent BBQ/PLL performance during **LHC** commissioning
- At RHIC, <u>coupling feedback</u> was essential for the success of the tune feedback effort (also relevant to LHC)
  - coupling from vertical orbit offsets in sextupoles during ramping
  - when coupling exceeds dQ_{min}, the tune feedback loop breaks
- PLL tune and coupling measurements are **Beam Transfer Function** measurements at a single phase/frequency
- The standard formalism for transfer function measurements is the scattering matrix, whose elements are the ‘s-parameters’

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Scattering Matrix

$$\begin{bmatrix} S11 & --- \\ --- & S22 \end{bmatrix}$$

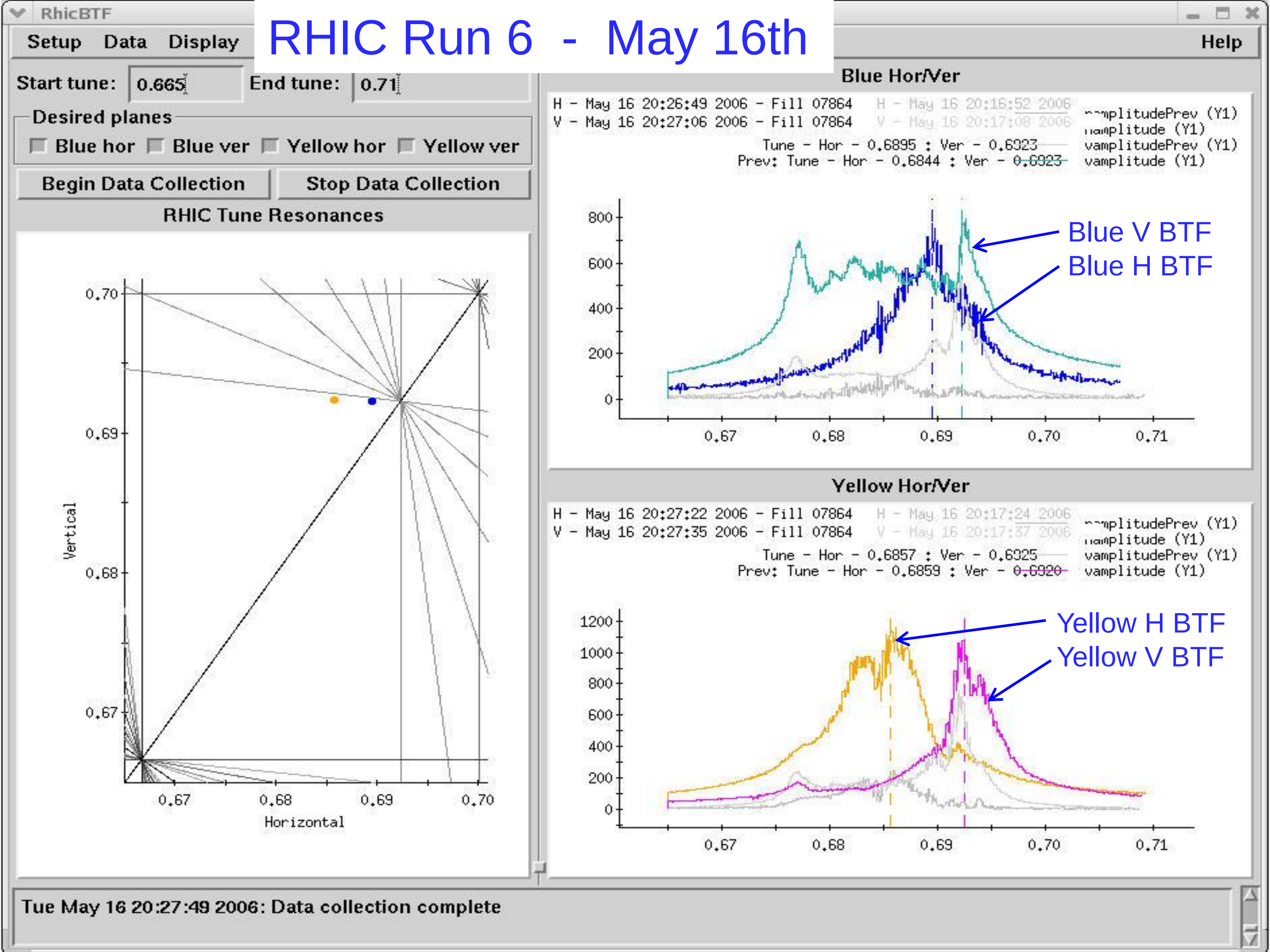
S11 – excite horizontal, measure horizontal

S22 – excite vertical, measure vertical

- The s-parameters are complex numbers. The real part is the amplitude of the response, and the imaginary the phase relative to the excitation
- Betatron motion (the thing we excite) has two eigenmodes/observables
    - S11 is the projection of eigenmode 1 into the horizontal measurement plane
    - S22 is the projection of eigenmode 2 into the vertical measurement plane
- *In the case of PLL tune measurement*
    - the eigenmode 1 and 2 phase loops are locked to the zero phase point, at the center of the resonance
    - S11 and S22 are single complex numbers
    - the betatron tunes are the frequencies of these zero phase points
- *In the case of Beam Transfer Function measurements*, S11 and S22 are arrays of complex numbers, one for each frequency point

- **What about S12 (the horizontal projection of eigenmode 2) and S21 (the vertical projection of eigenmode 1)?**

RHIC Run 6 - May 16th



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Coupling Transfer Functions

$$\begin{bmatrix} S11 & S12 \\ S21 & S22 \end{bmatrix}$$

S11 – excite horizontal, measure horizontal
S12 – excite vertical, measure horizontal
S21 – excite horizontal, measure vertical
S22 – excite vertical, measure vertical

- S12 and S21 are the Coupling Transfer Functions.
- The success of the LARP Tune Feedback Task required that
  - the CTFs be measured,
  - and that the data be used to close feedback loops on coupling
  - only then was tune control possible
- The lesson here
  - **Don’t ignore the off-diagonal elements**

This matrix is symmetric

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consider both beams simultaneously

$$\begin{matrix} \begin{bmatrix} S11 & S12 \\ S21 & S22 \end{bmatrix} & \begin{matrix} --- & --- \\ --- & --- \end{matrix} \\ \begin{matrix} --- & --- \\ --- & --- \end{matrix} & \begin{bmatrix} S33 & S34 \\ S43 & S44 \end{bmatrix} \end{matrix}$$

beam 1
- S11 – excite H, measure H
- S12 – excite H, measure V
- S21 – excite V, measure H
- S22 – excite V, measure V

beam 2
- S33 – excite H, measure H
- S34 – excite H, measure V
- S43 – excite V, measure H
- S44 – excite V, measure V

green indicates coupling to the orthogonal measurement plane

nulling beam-beam induced coupling should be straightforward?

$$\begin{bmatrix} S11 & S12 & S13 & S14 \\ S21 & S22 & S23 & S24 \\ S31 & S32 & S33 & S34 \\ S41 & S42 & S43 & S44 \end{bmatrix}$$

excite beam 1 measure beam 2
- S13 – excite 1H, measure 2H
- S14 – excite 1H, measure 2V
- S23 – excite 1V, measure 2H
- S24 – excite 1V, measure 2V

excite beam 2 measure beam 1
- S31 – excite 2H, measure 1H
- S32 – excite 2H, measure 1V
- S41 – excite 2V, measure 1H
- S42 – excite 2V, measure 1V

this matrix is symmetric as well, helps for setting excitations, gains, normalizing,…

We want to diagonalize this matrix (with the beams in collision)

RHIC digitizer channel assignment

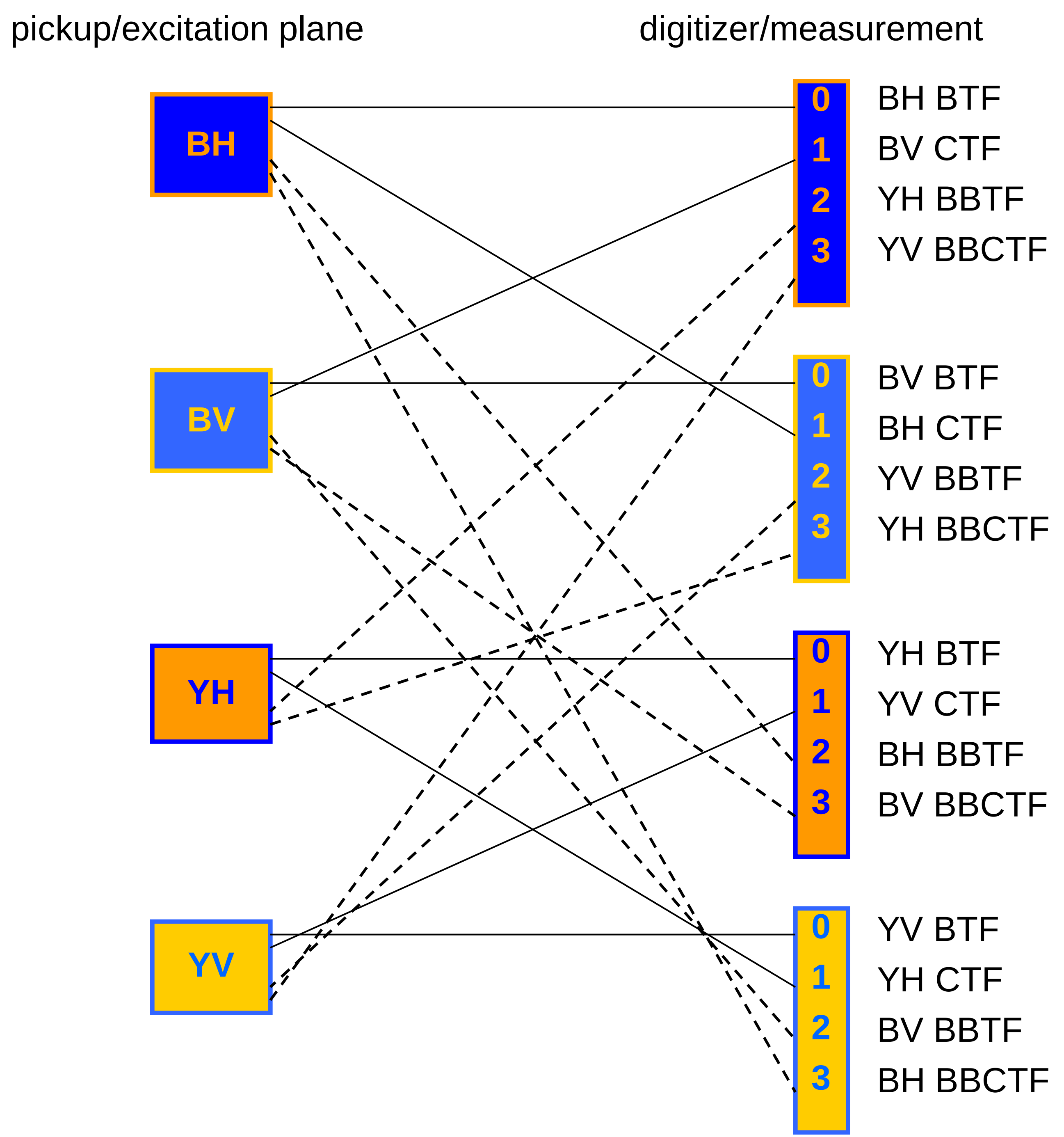
pickup	excitation plane/digitizer			
	BH	BV	YH	YV
BH	0	1	2	3
BV	1	0	3	2
YH	2	3	0	1
YV	3	2	1	0

for excitation in a given plane:

digitizer channel	measurement	
0	BTF	beam transfer function
1	CTF	coupling transfer function
2	BBTF	beam-beam transfer function
3	BBCTF	beam-beam coupling transfer function

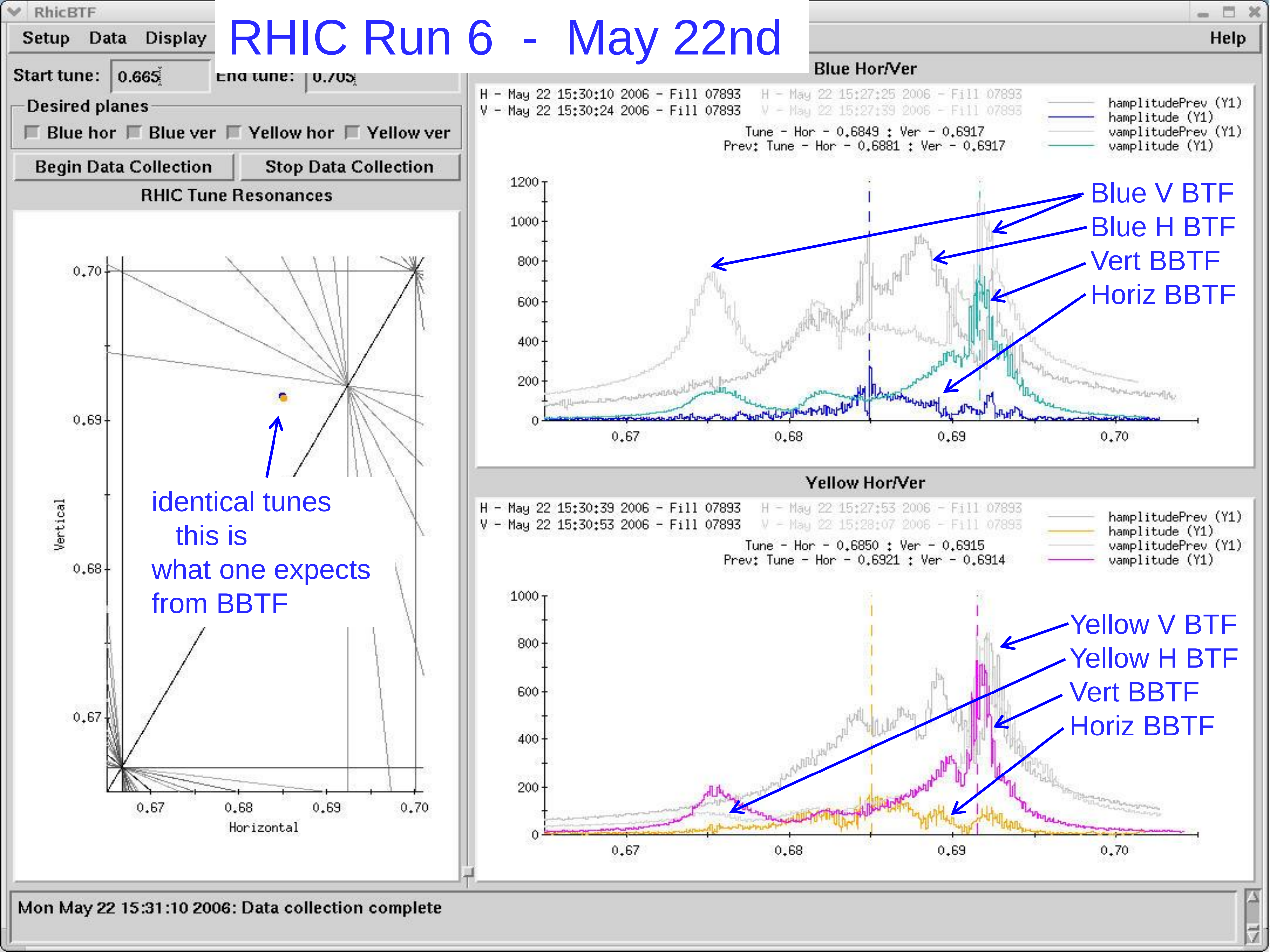
pickup	excitation plane/digitizer			
	BH	BV	YH	YV
BH	BH BTF	BV CTF	YH BBTF	YV BBCTF
BV	BH CTF	BV BTF	YH BBCTF	YV BBTF
YH	BH BBTF	BV BBCTF	YH BTF	YV CTF
YV	BH BBCTF	BV BBTF	YH CTF	YV BTF

Needed for interpreting the archived data

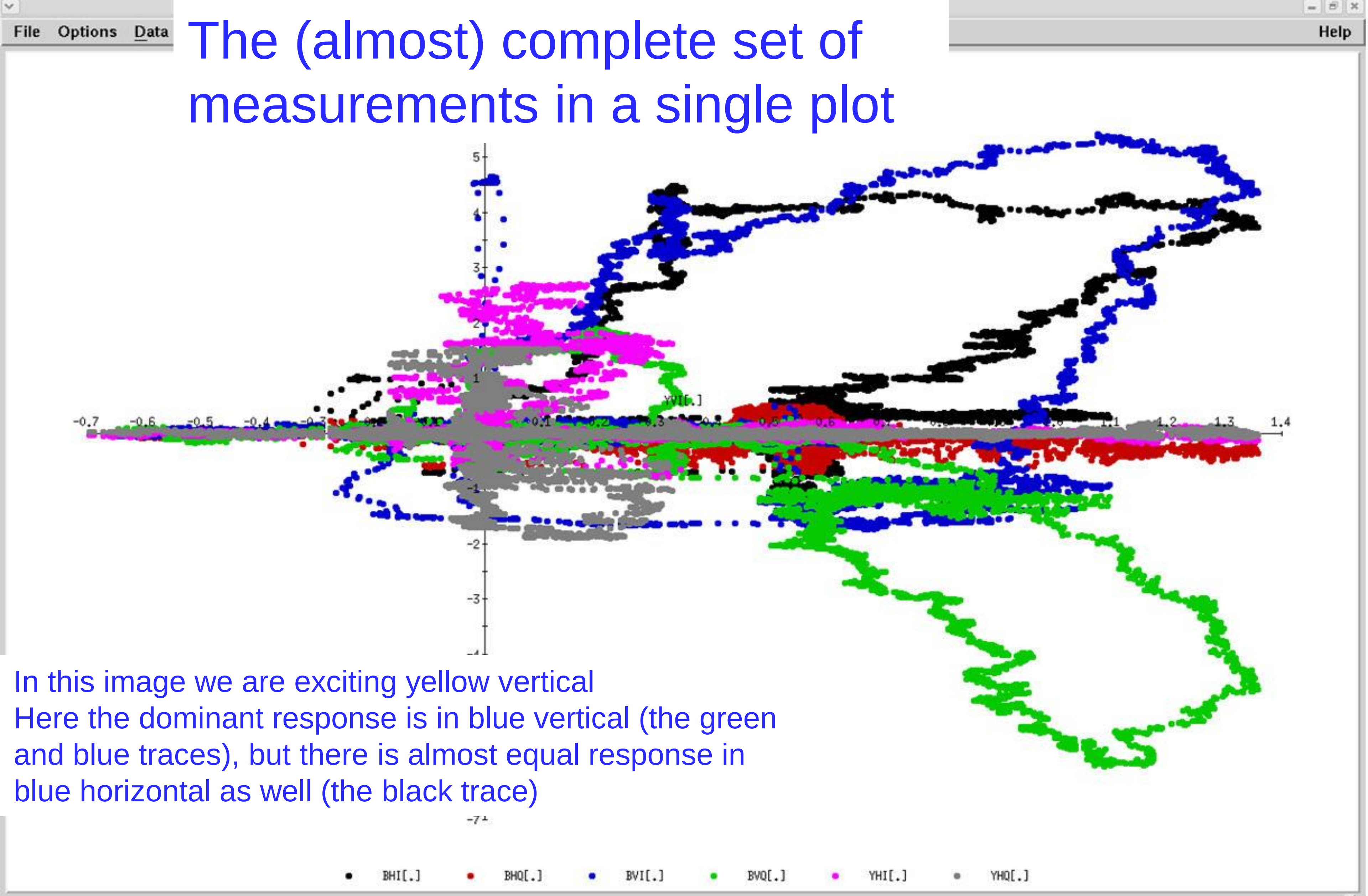


pickup/excitation plane
digitizer/measurement
BH
BV
YH
YV
0
1
2
3
BH BTF
BV CTF
YH BBTF
YV BBCTF
BV BTF
BH CTF
YV BBTF
YH BBCTF
YH BTF
YV CTF
BH BBTF
BV BBCTF
YV BTF
YH CTF
BV BBTF
BH BBCTF

RHIC Run 6 - May 22nd



The (almost) complete set of measurements in a single plot



In this image we are exciting yellow vertical
Here the dominant response is in blue vertical (the green and blue traces), but there is almost equal response in blue horizontal as well (the black trace)

Index	YVI[.]	BHI[.]	BHQ[.]	BVI[.]	BVQ[.]	YHI[.]	YHQ[.]	YVQ[.]
0	0.118959	0.0270585	−0.0129989	−0.0552635	0.0827087	−0.0282511	0.0355544	0.0827087
1	0.10659	0.0210239	−0.0221337	−0.0496155	0.0669594	−0.0188481	0.0296806	0.0669594
2	0.0999871	0.0234376	−0.0300905	−0.0482912	0.0908686	−0.0181281	0.0229719	0.0908686

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Summary and Conclusion

- Four step process
  - Study archived data, settle on rigorous formalism,…
  - Studies in RHIC with ions/stochastic cooling
  - Studies in RHIC with protons/no cooling
  - Studies in LHC
- Bunch-by-bunch gating must be included in the studies
- The possibility is open to have a diagnostic that goes beyond beam lifetime/emittance growth
- Many learning scenarios are possible
  - all involve tweaking some machine parameter (tune, coupling, chromaticity, beam position, phase between IPs, …) and observing resultant effect on BBTF
  - comparison with simulations will be helpful
  - goal is to be able to look at LHC BBTFs at store and know what to do to improve lifetime.