Beam-beam Experiments at RHIC

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LARP Collaboration Meeting CM18

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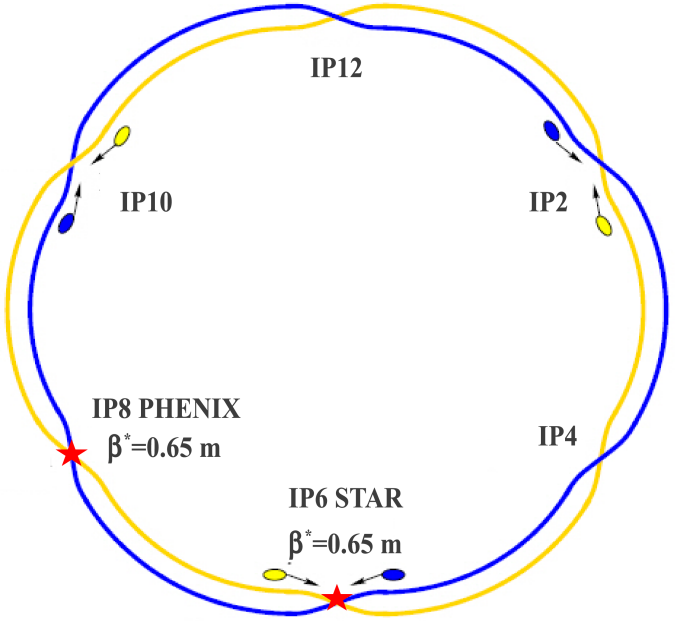
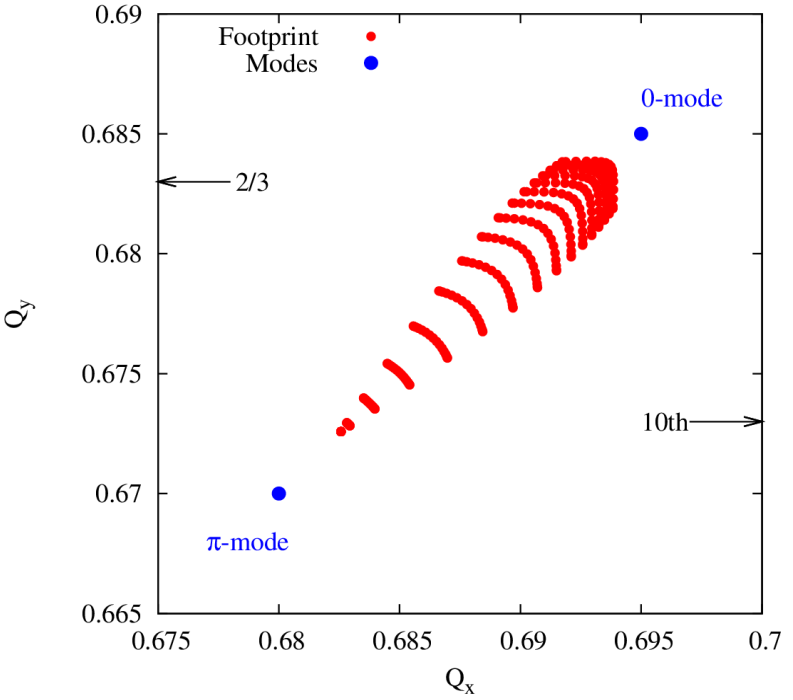
Acknowledgments: W. Fischer, Y. Luo, X. Buffat, R. Giachino, T. Pieloni, W. Herr, RHIC operation

The RHIC Ring(s)



- Bunches collide in two interaction points
- No long-range interactions or crossing angle
- This year additional interaction at IP2 towards end of fills

- RHIC is currently operated between the 2/3 and 7/10 resonances with ξ~0.016
- 2/3 strong resonance: hard limit
- 7/10 depolarization resonance
- Mirror of LHC tunes



Beam parameters

	Design LHC	HL-LHC	RHIC 2011
N [p/bunch]	1.15e11	2.2e11	1.7e11
ε_N [μm]	3.75	2.5	2.5-3.3
Q_x / Q_y / Q_s	0.31 / 0.32 / 0.002	0.31 / 0.32 / 0.002	0.695 / 0.685 / 4.0e-4
β* [m]	0.55	0.15	0.65
σ_s [m]	0.075	0.075	0.7
dp/p	1.129e-4	1.129e-4	1.5e-4
θ [μrad]	285	590	0.0
N_{LR} / IP side	15	18-24	0.0
ξ/IP	**~3.1e-3**	**~3.2e-3**	**8.0e-3-6.0e-3**
L_{peak} [$cm^{-2}.s^{-1}$]	1.0e34	7.2e34 (w/o C.C.)	~1.5e32 (250 GeV)

→ This summer electron lenses for head-on compensation will be installed – hope to get an increase of at least a factor 2 in luminosity

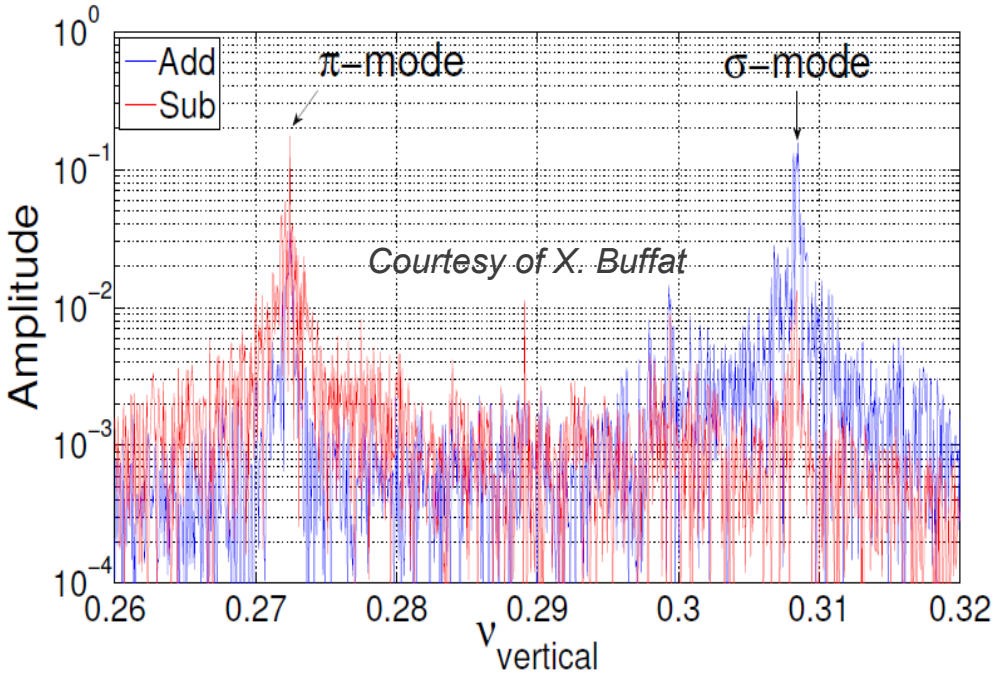
→ Common interest at RHIC and LHC to better understand beam-beam effects

→ **No long range interactions at RHIC: only head-on studies are possible**

Beam Experiments at RHIC

- Several beam-beam studies performed this year at RHIC:
  - **Coherent beam-beam effects:** modes suppression, tune scans
  - **Beam beam and noise:** white noise, orbit modulations, π-mode excitation
  - **Large Piwinski angle** was proposed. Due to a lack of time it was not conducted. Synchrotron tune much smaller at RHIC
- The beam-beam and noise experiments were organized in collaboration with CERN. **Hosted two visitors at BNL, X. Buffat and R. Giachino, for two weeks.**

Coherent Beam-Beam at the LHC



- Coherent modes observed at the LHC in 2011 - observed without external excitation and only HO interactions for single bunch
  → **not naturally damped**

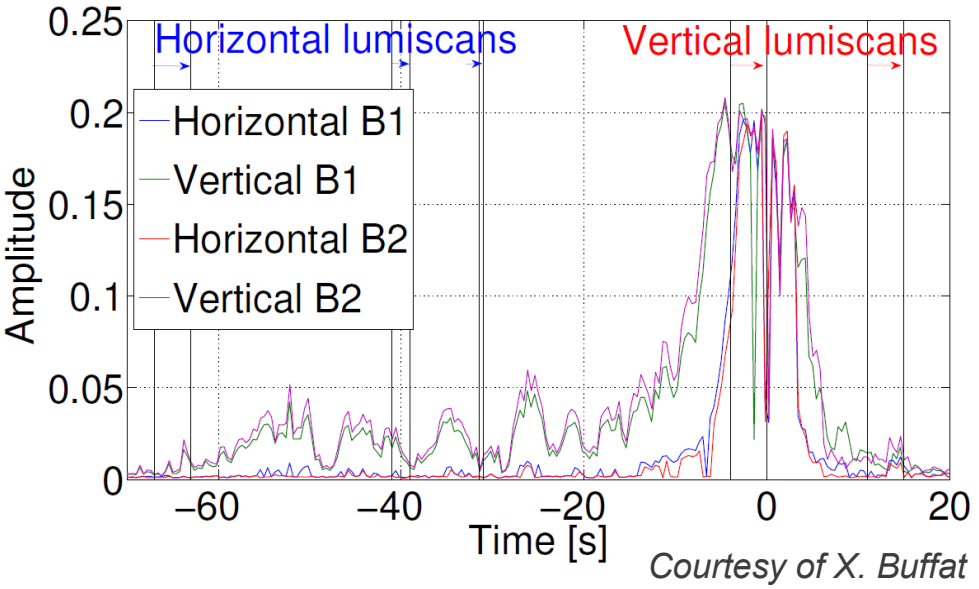
- Recent observations with many bunches are being analyzed

  → **coherent effects well present at LHC**
  → **should be carefully studied**

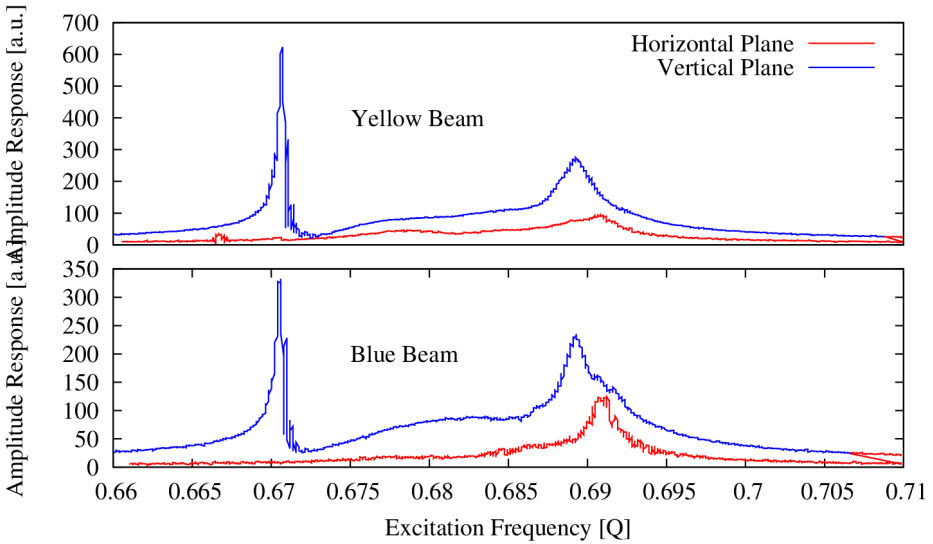
- **Instabilities were observed at the LHC in collision**

- In this example, happened during luminosity scans – tune, orbit changes

- **The source of these instabilities is not yet understood – may not be directly related to beam-beam: impedance model under construction in BB3D**

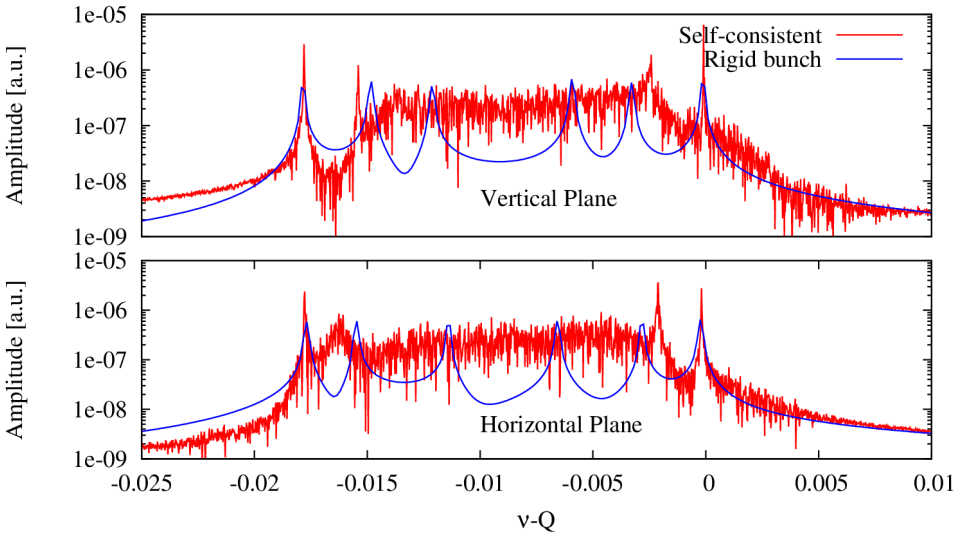


Coherent Effects at RHIC

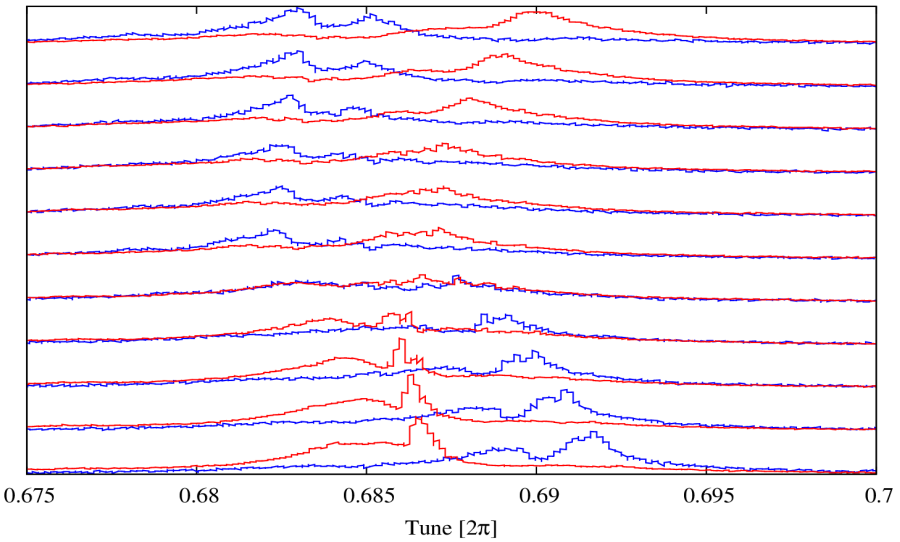


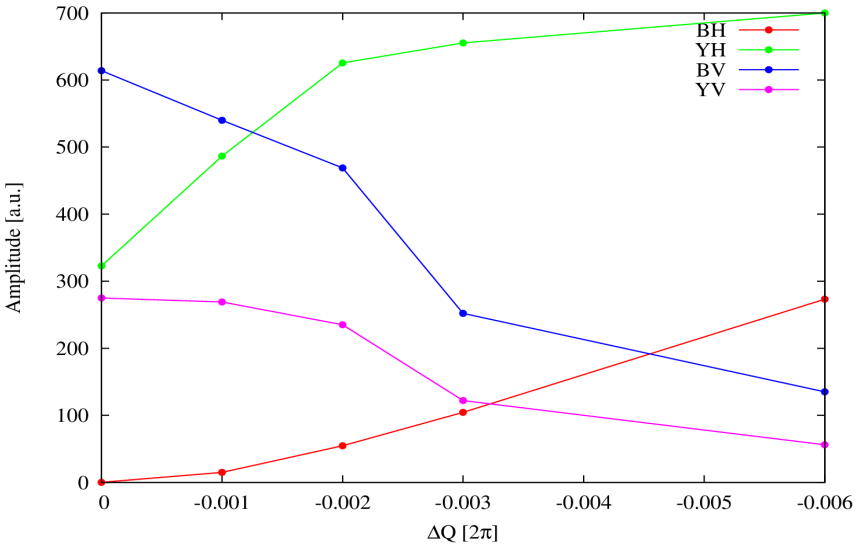
- Coherent beam-beam modes routinely observed at RHIC with BTF
- **Observed only when excited – no detrimental effects as of now**
- Absence of π-mode in the horizontal plane
- This example: ξ ~ 0.016 – 2 IPs colliding

- Three fold symmetry – if no Landau damping expect 6 distinct coherent modes
- In reality only the two outer modes are observed – other modes damped

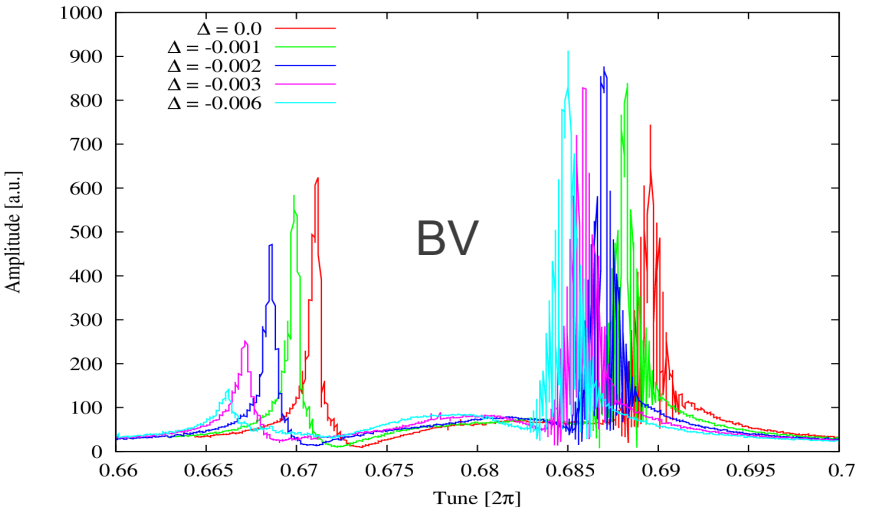


Absence of Horizontal π-mode

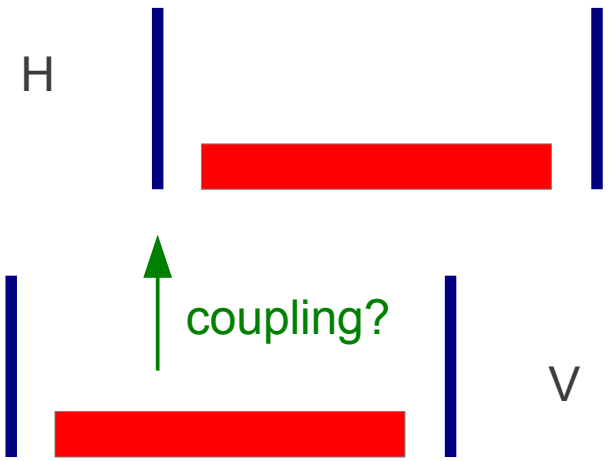




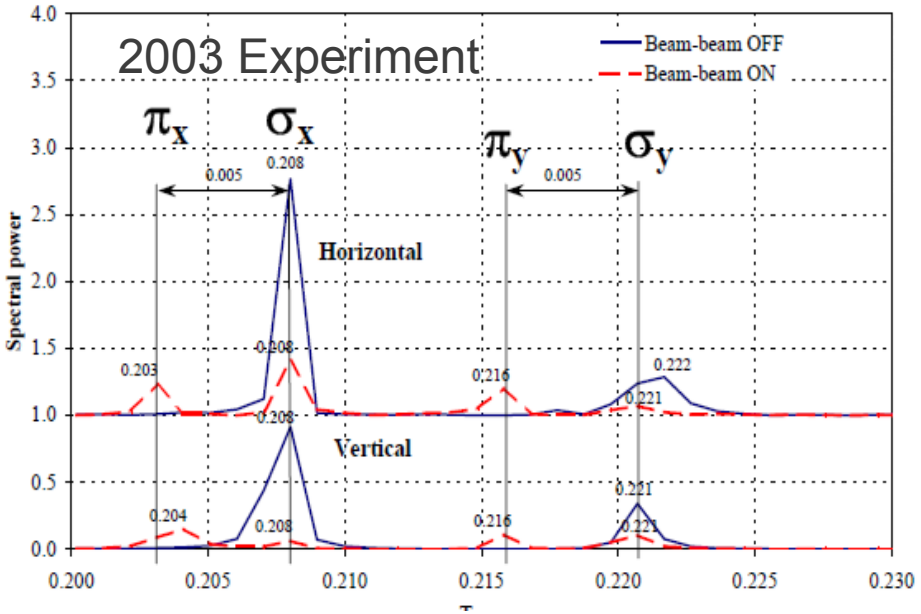
- Tune scans crossing the coupling resonance:
- Full ξ → as we cross the resonance the modes in **one plane are damped while the other plane is increased**. Could not scan further because of 2/3 resonance
- Small ξ → not ideal conditions (strong mismatch in vertical emittances). **Clear effect on coherent motion observed**

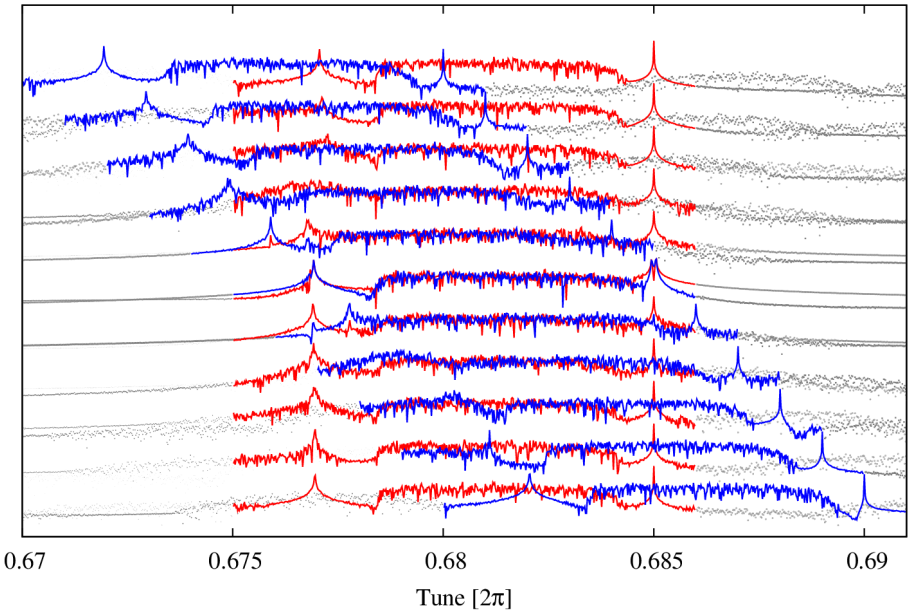


Tentative Explanation



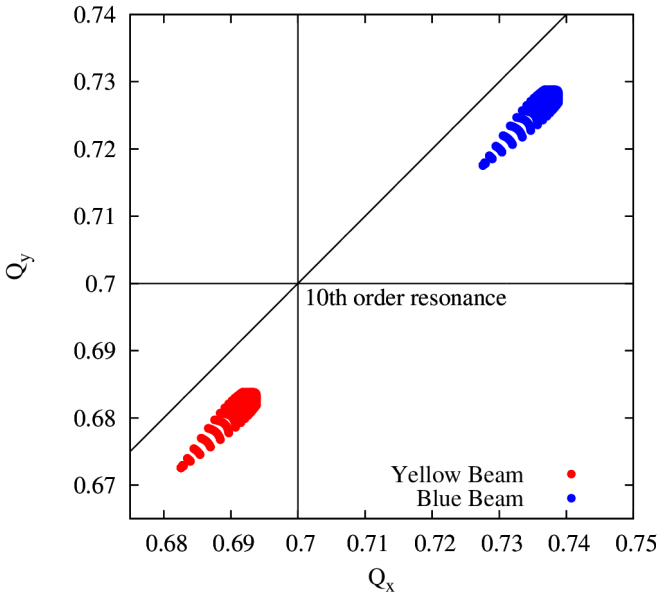
- RHIC generally operates with $Q_x > Q_y \rightarrow$ the horizontal π-mode lies the vertical tune spread
- Transfer of Landau damping through coupling mechanism?
- Four modes observed when tunes well separated
- Observed to some extend in simulations – no effect on σ-mode

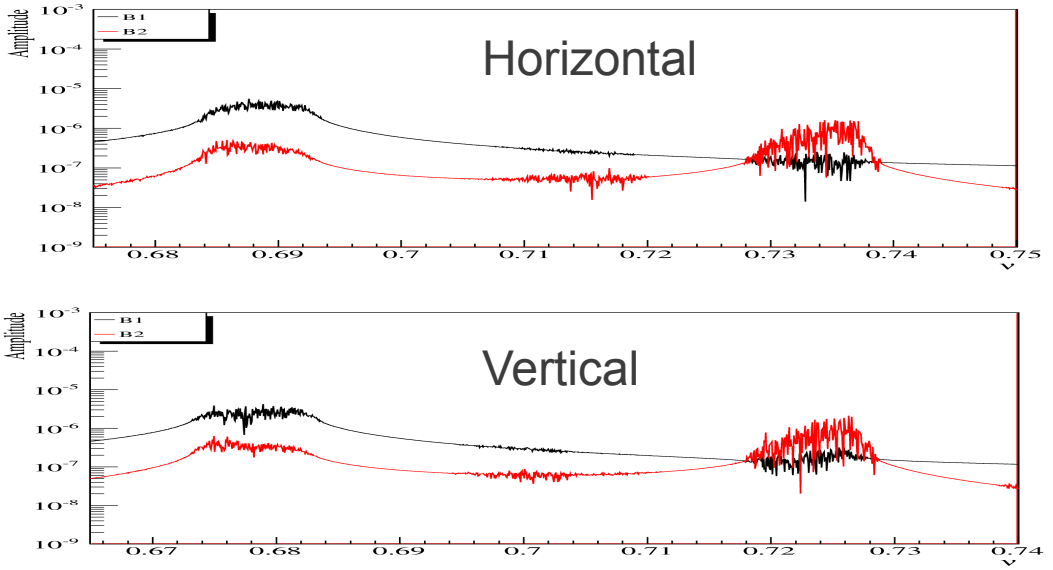




Modes Suppression

- Coherent modes can be suppresses by splitting the tunes by an amount $\Delta Q > \xi$

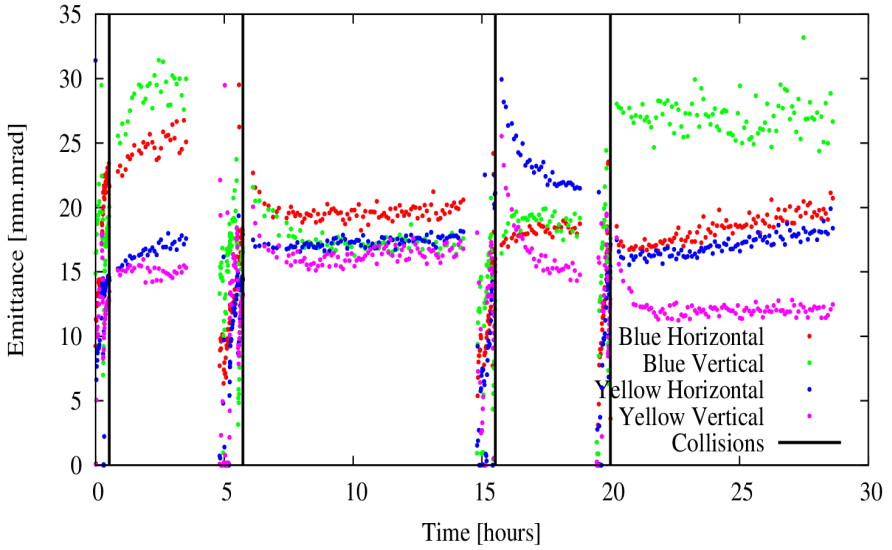


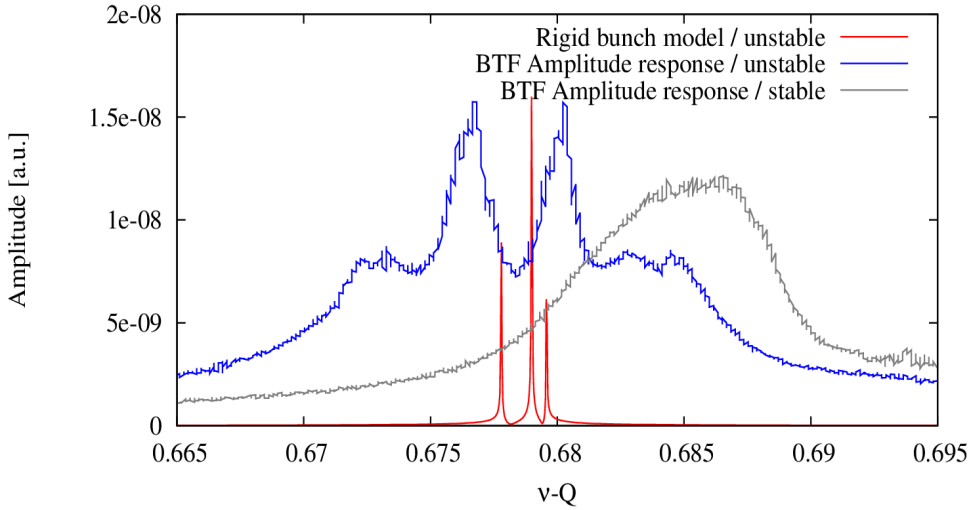


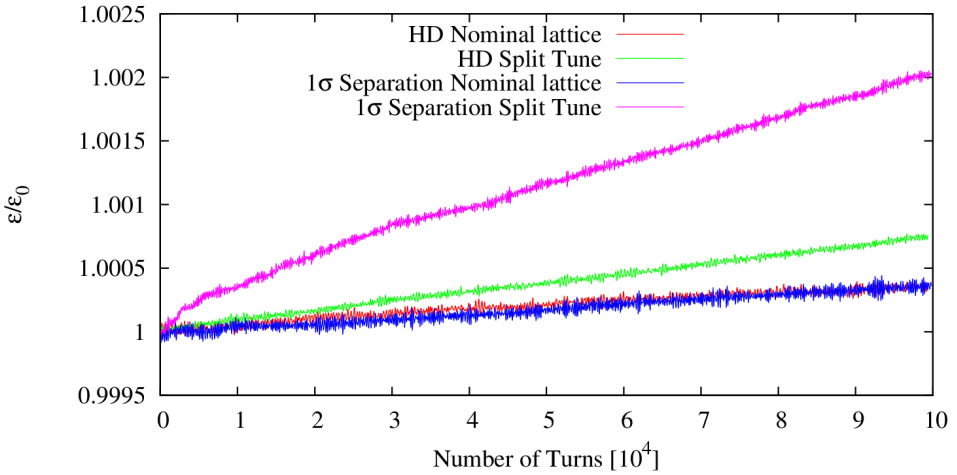
- Past studies (*Y. Alexahin et al. LHC Project-Note 226*) predicted excitation of coherent beam-beam resonances leading to emittance blow-up
- Interesting to verify experimentally. At RHIC it is possible to move one beam above 7/10 resonance to split the tunes by sufficient amount
- In this configuration simulations show a clear suppression of the modes

Experiment

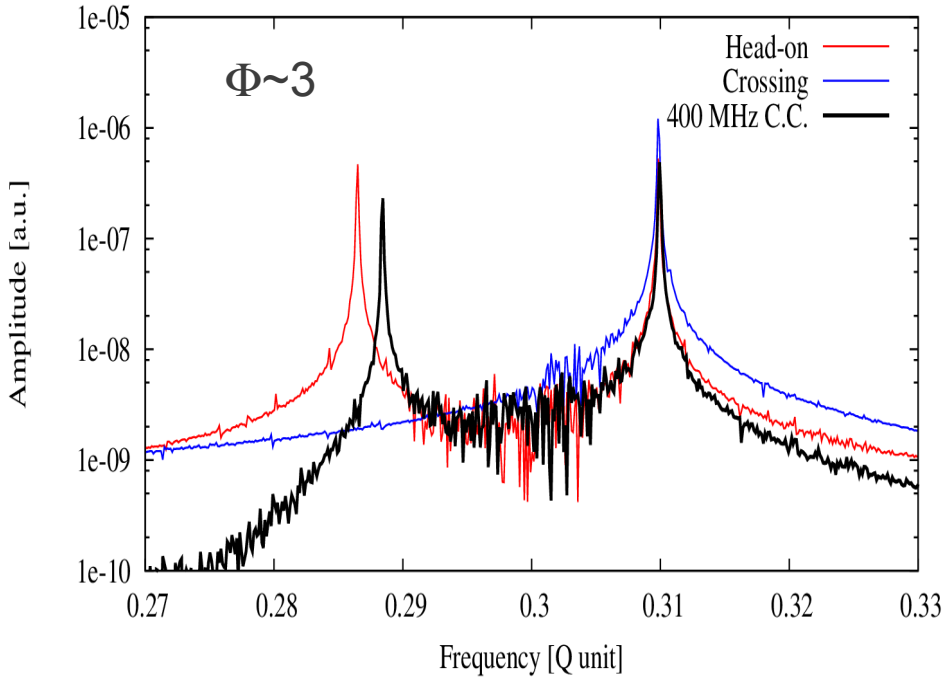
- 4 fills done with split tunes:
- **Strong emittance blow-up observed when going into collision in 3 of them**
- Excitation of odd order resonance (offset collision) – tune dependent effect
- Also observed in simulations – requires more detailed analysis

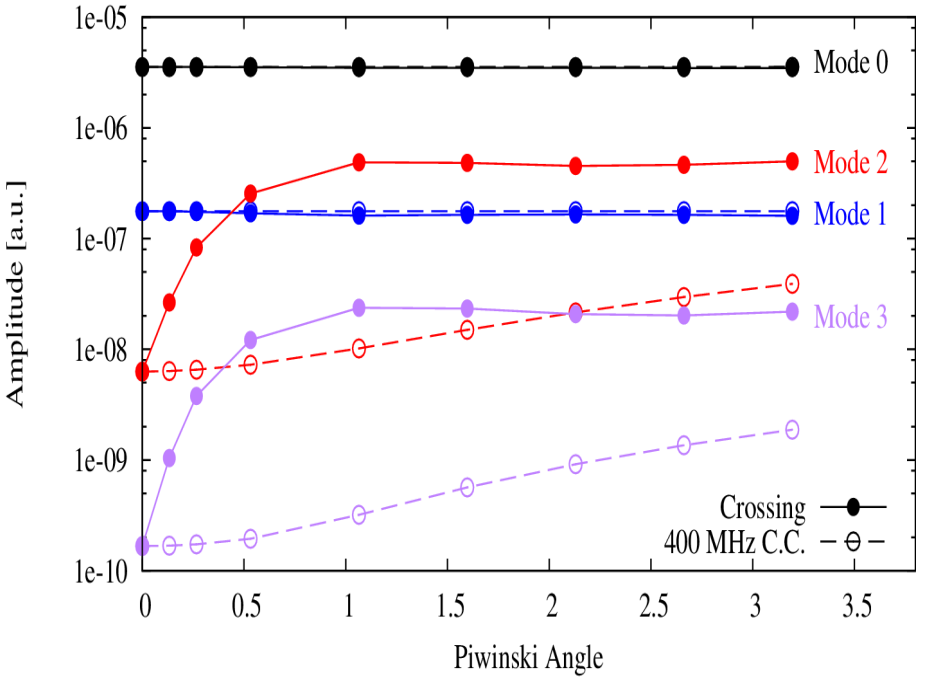






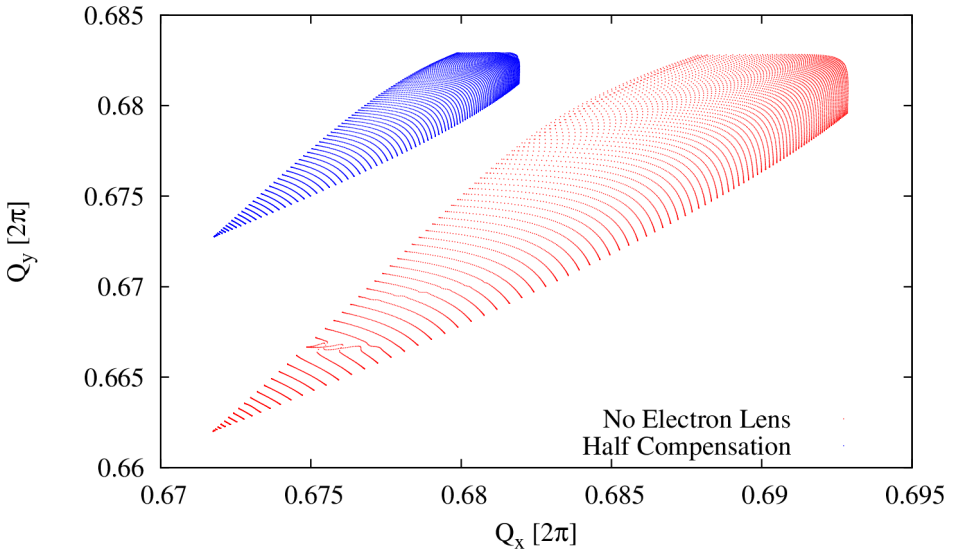
At the HL-LHC

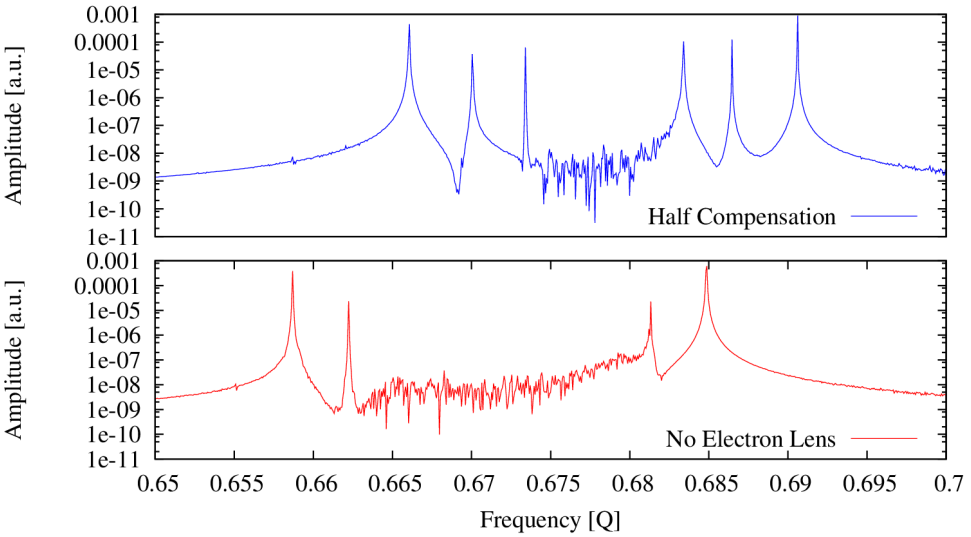




- The HL-LHC will be operated with large Piwinski angle Φ (2-3) **leading to strong synchro-betatron coupling**
- **The continuum of synchrotron side-bands could overlap the π-mode and damp it**
- Predicted by Y. Alexahin (*NIM A 480, 253–288*) and seen in simulations. Crab compensation restores the head-on collision and cancels this effect – **experimental verification would be interesting**

Few Words on the Electron Lens





- Electron lenses for head-on compensation are under construction for installation in RHIC next year – performance test of the main solenoid ongoing
- The goal is to gain at least a factor of 2 in luminosity
- The incoherent tune spread is reduce by the non-linear lens. The electron beam does not couple back to the proton beam → coherent modes not affected

→ **This makes it a perfect tool to study coherent modes stability**

Beam-Beam and Noise

- The beam-beam and noise experiment was fully driven by CERN interests as relevant for operation with crab cavities and transverse damper

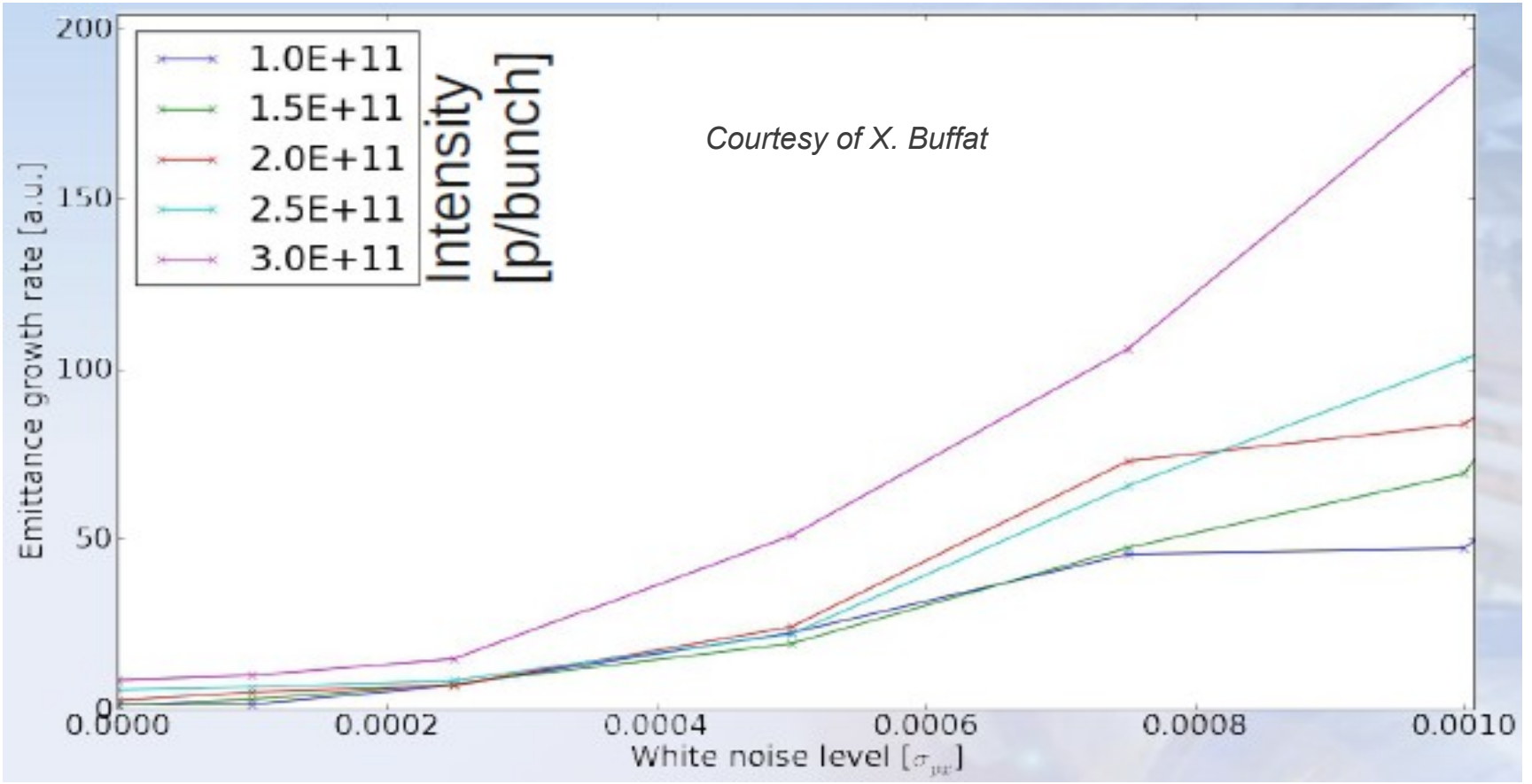
- Two visitors from CERN, X. Buffat (ABP) and R. Giachino (OP) were hosted at BNL to participate in these experiments

- **Goal:** understand the impact of noise on beam-beam interactions

- **Experimental setup:**
  - Fill RHIC with bunches of different ξ
  - Inject white noise into the beam and measure emittance blow-up as a function of ξ

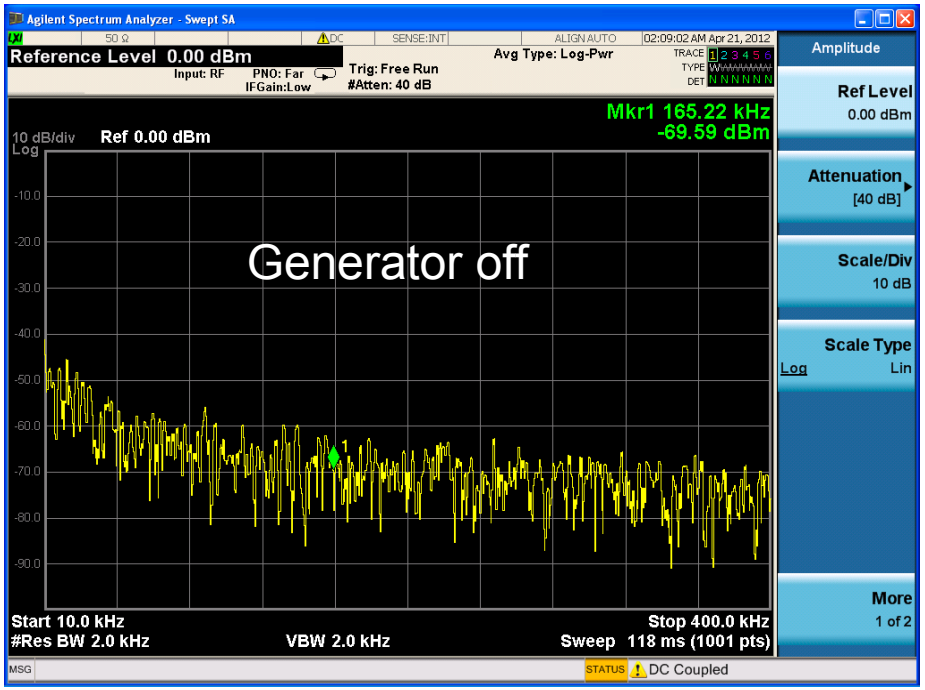
→ **Heavily relies on bunch-by-bunch emittance measurements**

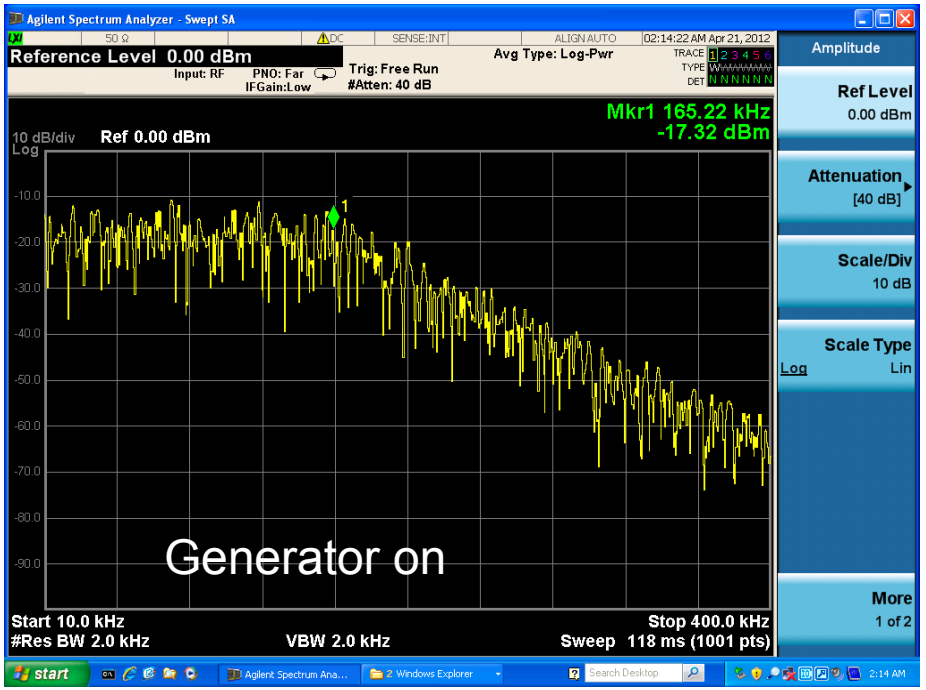
Simulations



- Simulations show a non-linear dependency on the emittance growth rate and ξ
- **Preliminary results done with COMBI code – detailed studies ongoing**
- **Benchmarking and cross-check of emittance simulations with BB3D foreseen**
- The goal was to try to confirm these observations experimentally

Noise Generator



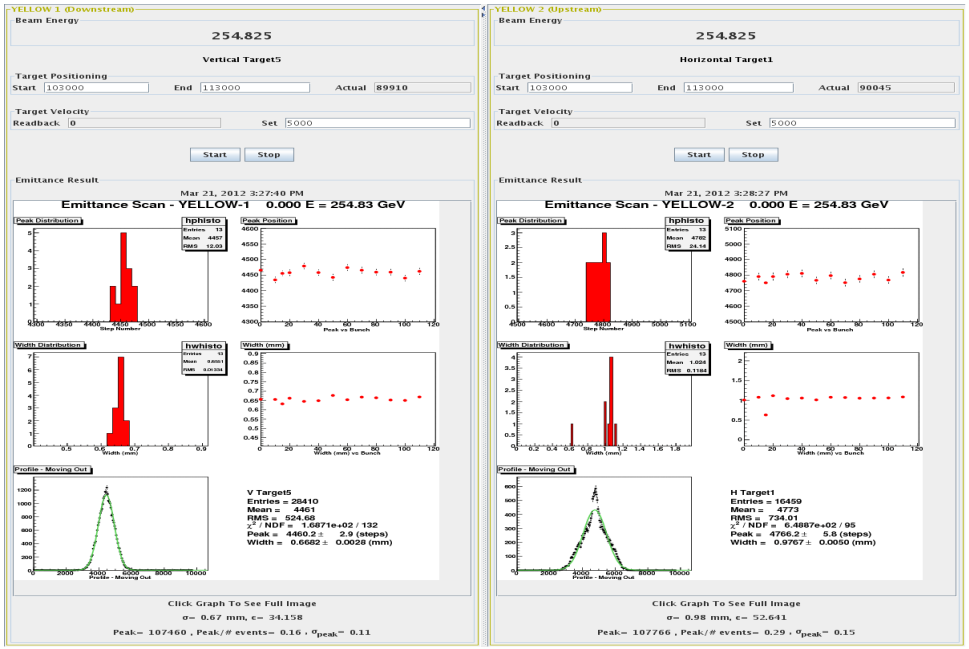


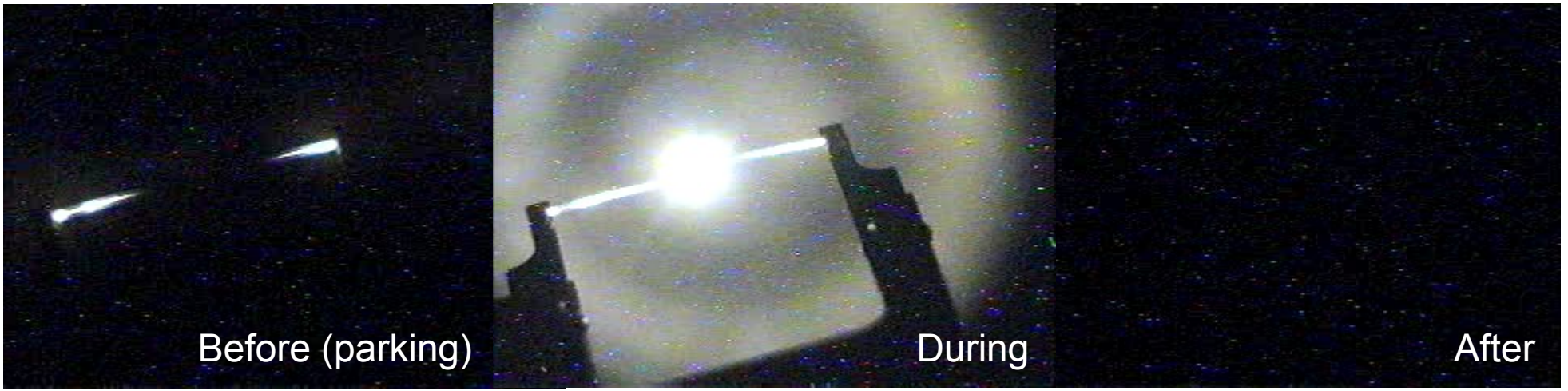
- We used a white noise generator with a cut-off frequency around 100 kHz
- The RHIC revolution frequency is approximately 79 kHz
- The generator was plugged in the blue BBQ kicker to inject the noise onto the beam

Emittance measurements

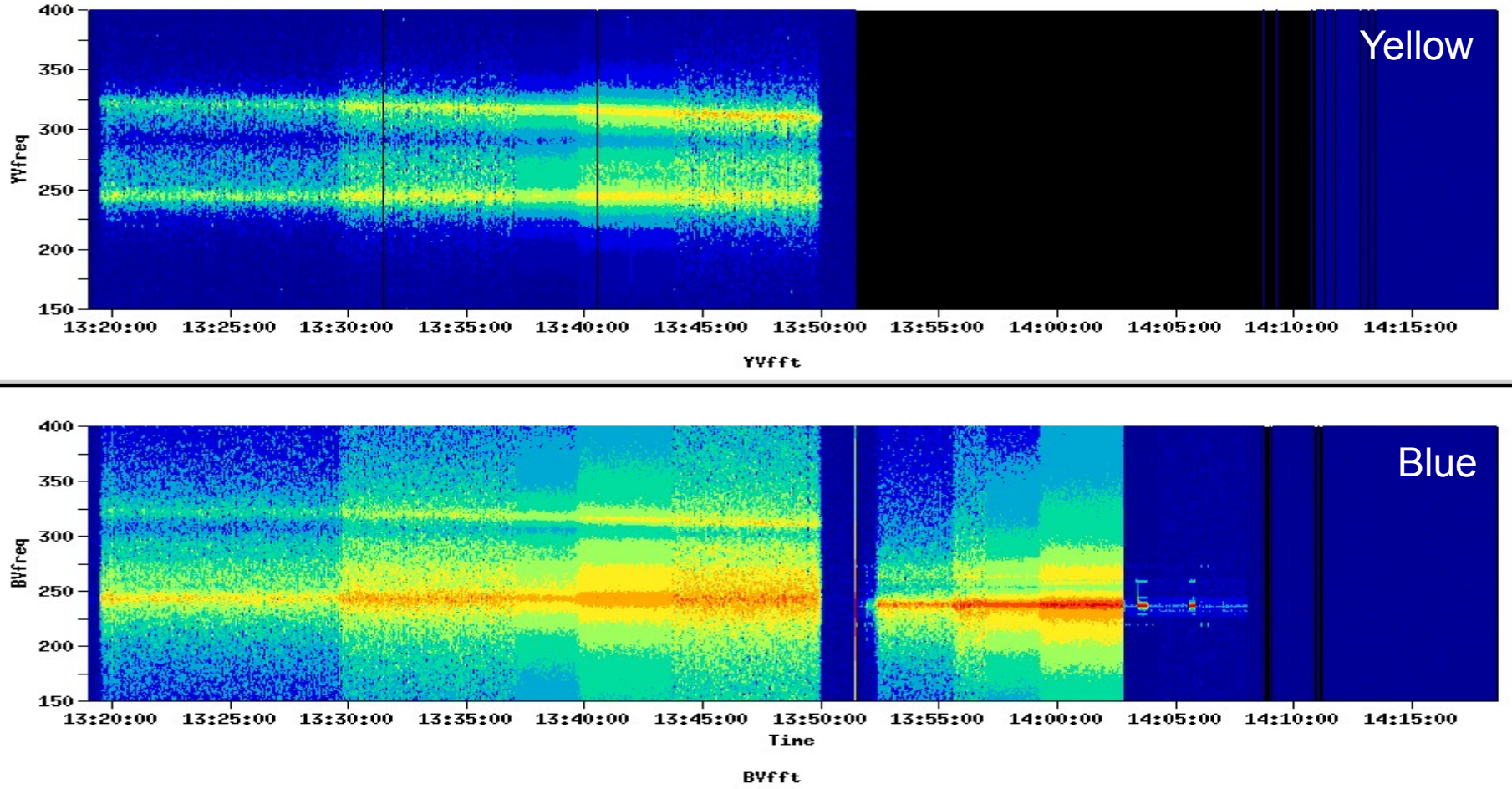
- PC polarimeters can provide accurate bunch-by-bunch emittance measurements
- Wire scanner type of measurement
- Unfortunately, major issues this year made them unavailable for the experiment

  → **Two measurements:** one in dedicated APEX and one at the end of a physics store to profit from experiment bunch-by-bunch luminosity data



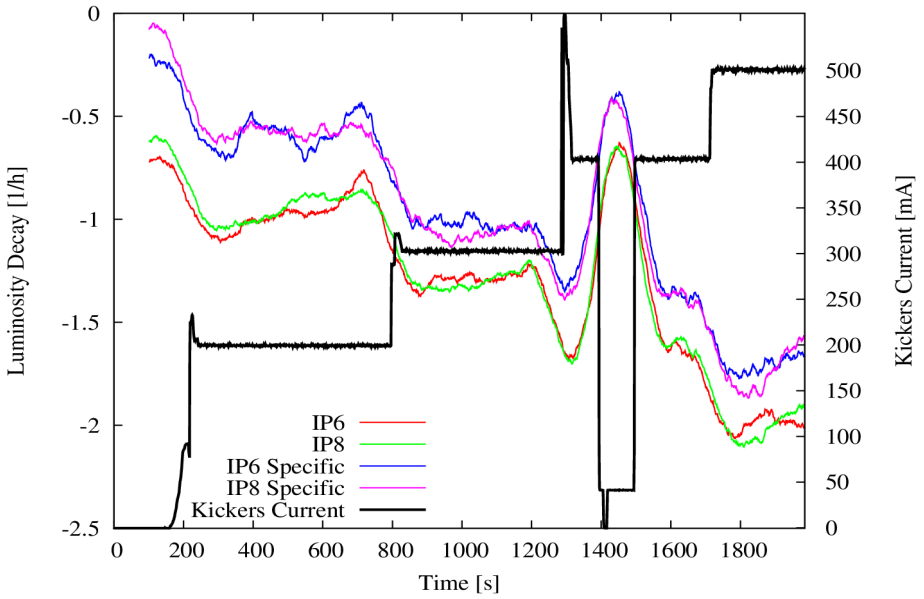


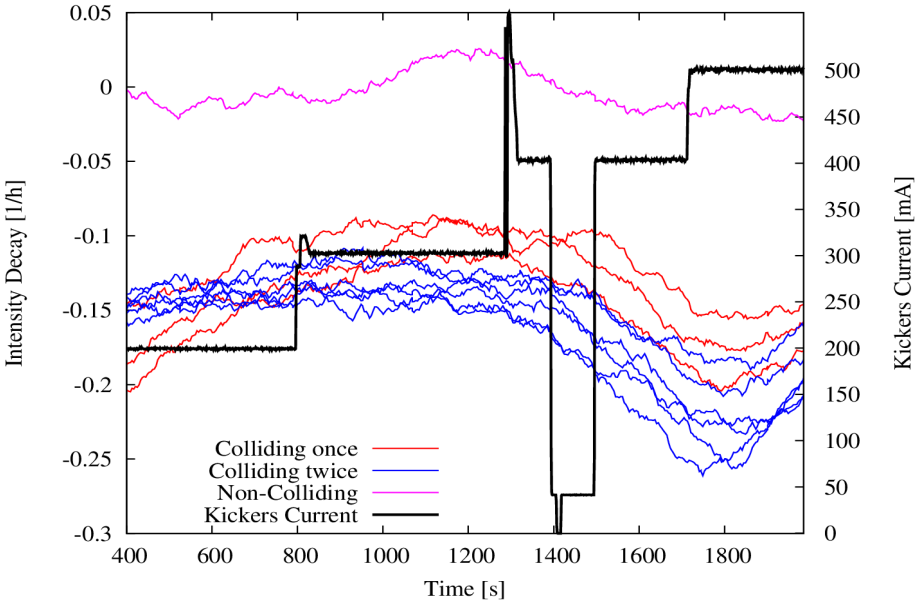
BBQ Spectrum

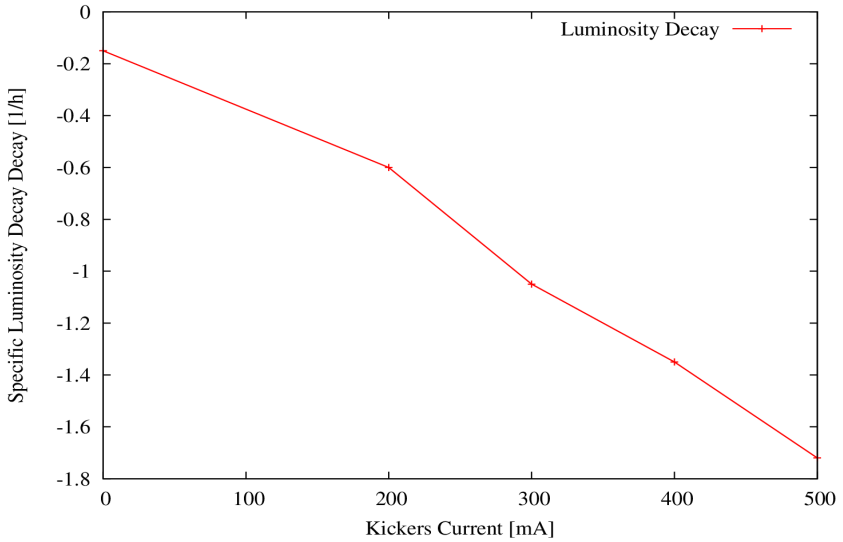


- Yellow and blue beams vertical BBQ spectrum
- The excitation is applied only on the blue beam and then transferred to the yellow beam through the beam-beam force → π-mode observed

APEX

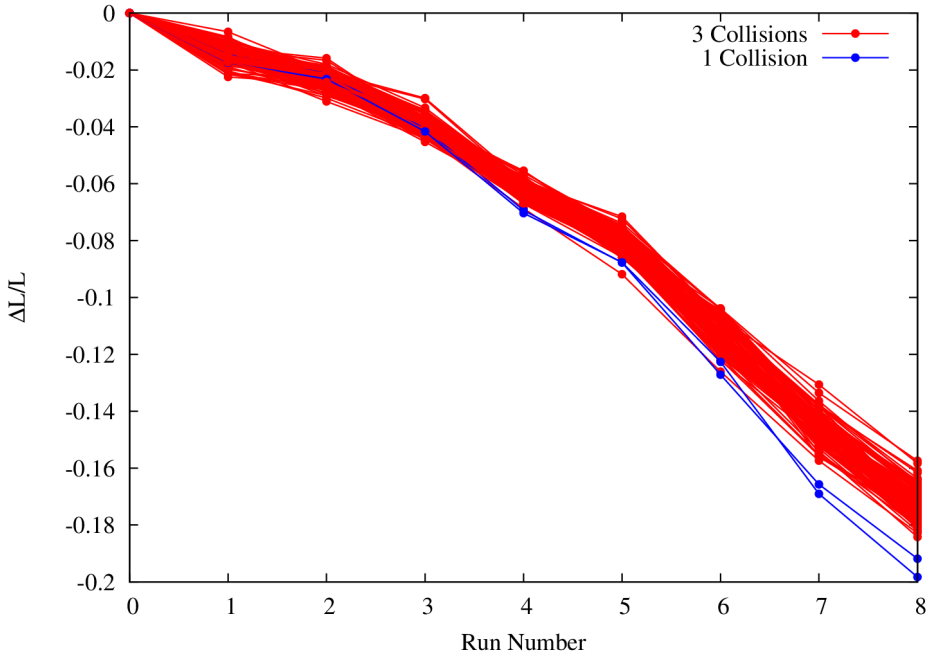


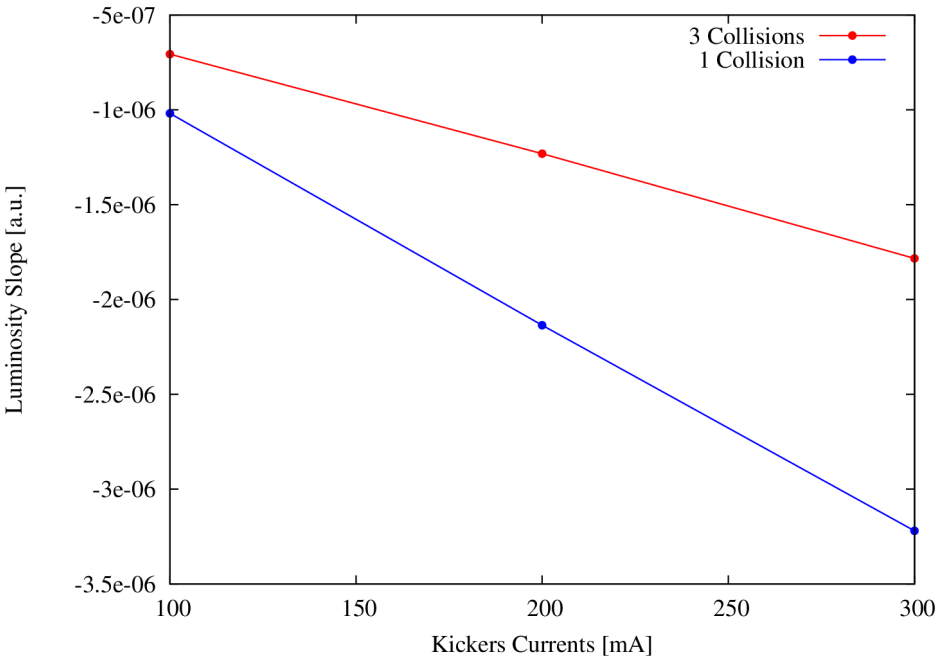




- Some bunches collide twice and others only once
- No difference observed in average luminosity lifetime at the two experiments
- Specific luminosity decay clearly correlated to the noise amplitude: emittance growth
- The luminosity decay appears to be linear with noise amplitude → **to be checked in simulations**

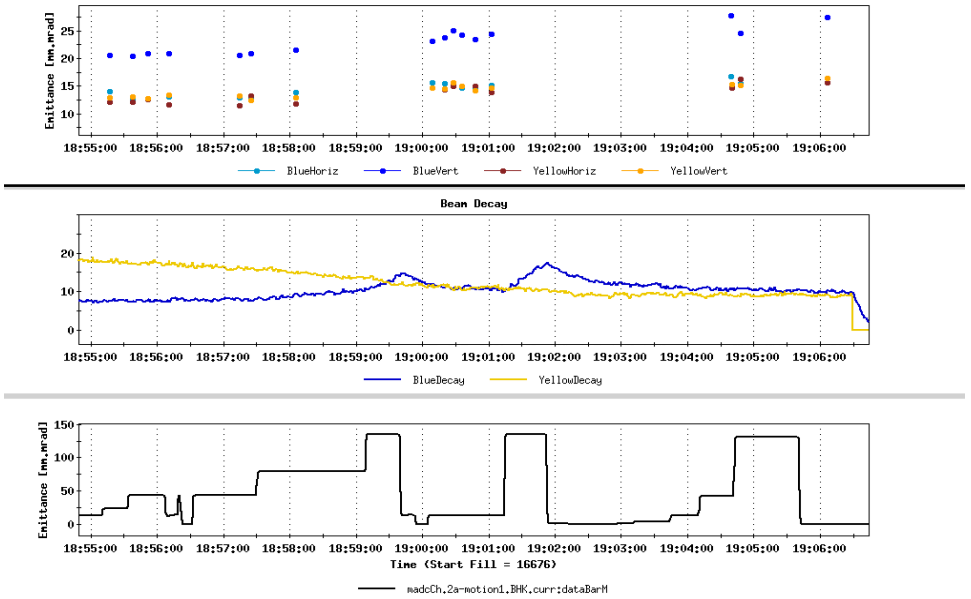
End of Fill Study

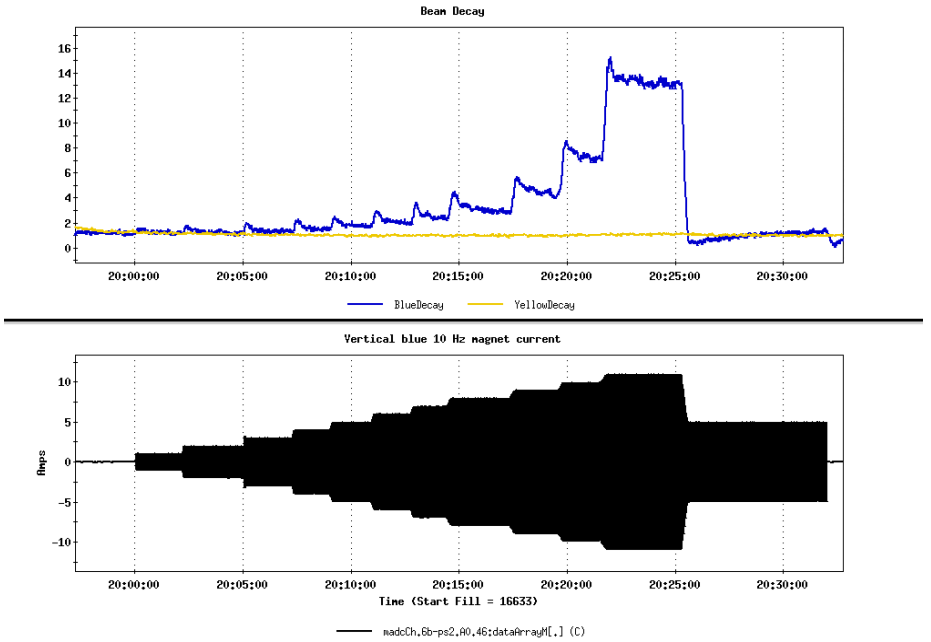




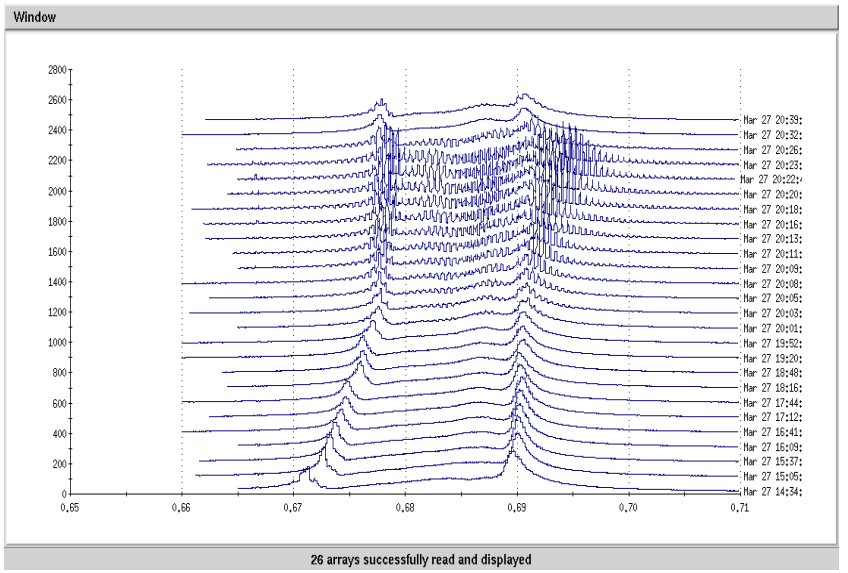
- Profit from the fact that two bunches are colliding only in STAR were the others are colliding in the 3 IPs:
- **It appears that the bunches colliding only in one IP have a larger decay → not yet understood – requires more detailed simulations**
- The linear behavior of the decay as a function of the noise amplitude seems to be confirmed

Other Excitations





- **π-mode excitation:** had to drive the kicker to its maximum gain to see losses and emittance blow-up
- **10Hz orbit modulation:** up to several mm in the triplets. Observed only losses, probably by cleaning up the tails on the collimators. No emittance blow-up from BTF
- **For both cases no sign of coherent instability**



Summary

- Several studies conducted during this year's proton run focusing on coherent beam-beam and noise
- **Coherent beam-beam:**
  - Suppression of modes with **tune split** → **emittance blow-up** – tune dependent effect, most likely not applicable in operation
  - **Transfer of Landau damping through coupling** observed
- **Beam-beam and noise:**
  - **White noise** → emittance blow-up, losses at high amplitudes – **requires more detailed analysis and modeling**
  - **Orbit modulation and π-mode excitation → no instability observed**, losses and emittance blow-up at (very) large amplitude. True for RHIC, may not be the case at LHC
- **All results presented are preliminary, more detailed modeling is required to fully understand the data**
- Collaboration with CERN foreseen to benchmark the different codes (COMBI/BB3D)
- I**nstabilities in collision observed at LHC – not yet understood.** Some interest in looking into the **interplay of beam-beam and impedance** – code development and benchmarking ongoing (BB3D) – (see A. Valishev's talk)