Beam-Beam Studies

S. White on behalf of A. Valishev

Thanks to S. Paret, J. Qiang and R. Miyamoto for the material

Beam-Beam Studies at LARP

- **Persons involved:**
  - Fermilab: A. Valishev
  - LBNL: S. Paret, J. Qiang
  - BNL: S. White

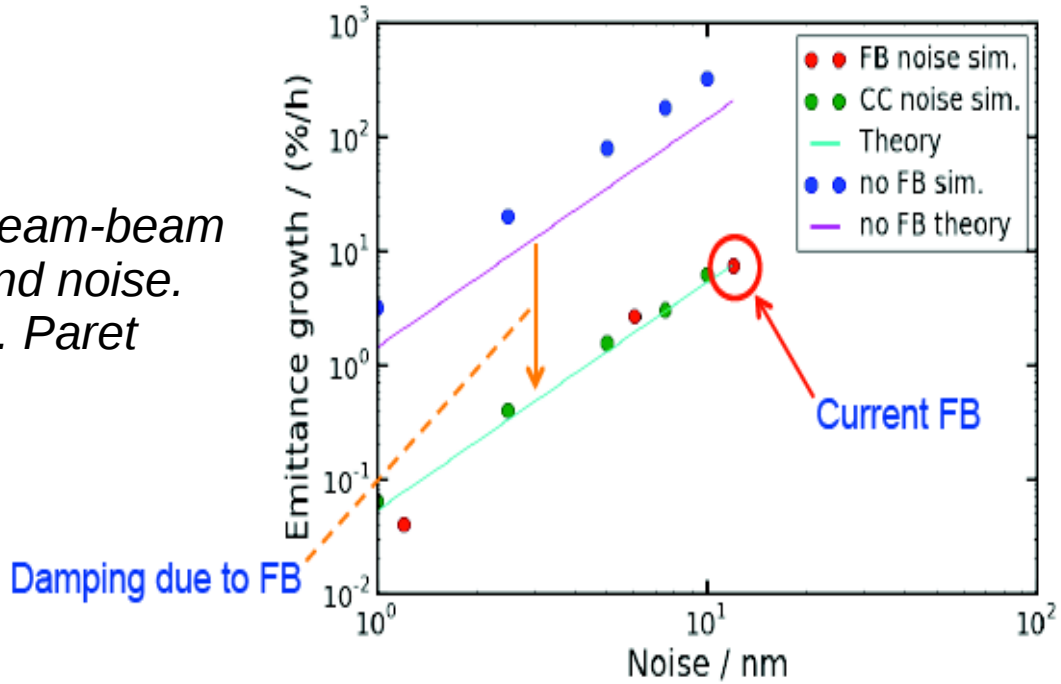
- **2011 Studies (covered here):**
  - Crab cavities and beam-beam
  - LHC operation - simulation support
  - Tevatron beam-beam studies

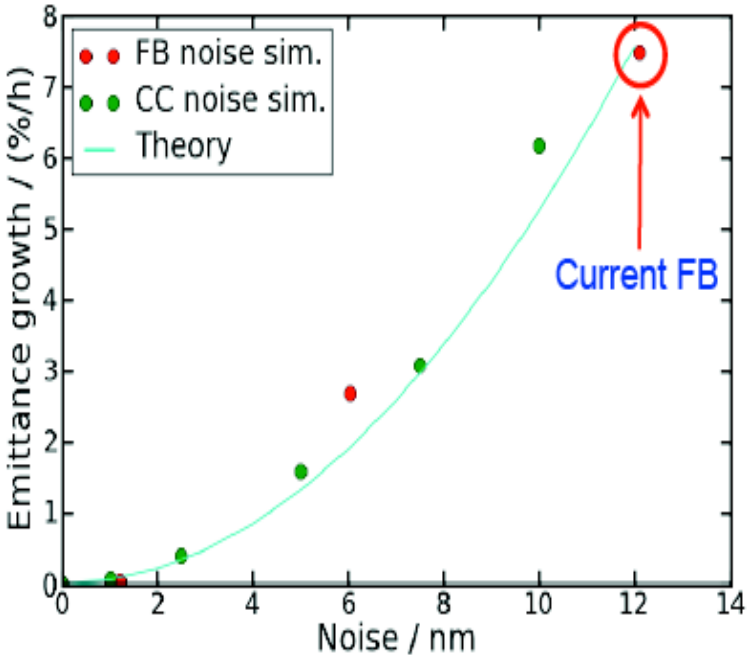
- **Motivations:** provide support in understanding limitations and defining the parameter space for future LHC upgrades

C.C. Studies – Beam-Beam and Noise

- LHC Crab Cavity workshop held at CERN on the 14th and 15th of November 2011. LARP contributions on beam-beam effects:
  - S. Paret, *"Beam-Beam Simulations with Crab Cavities"*
  - S. White, *"Synchro-Betatron Effects"*

Beam-beam and noise. S. Paret

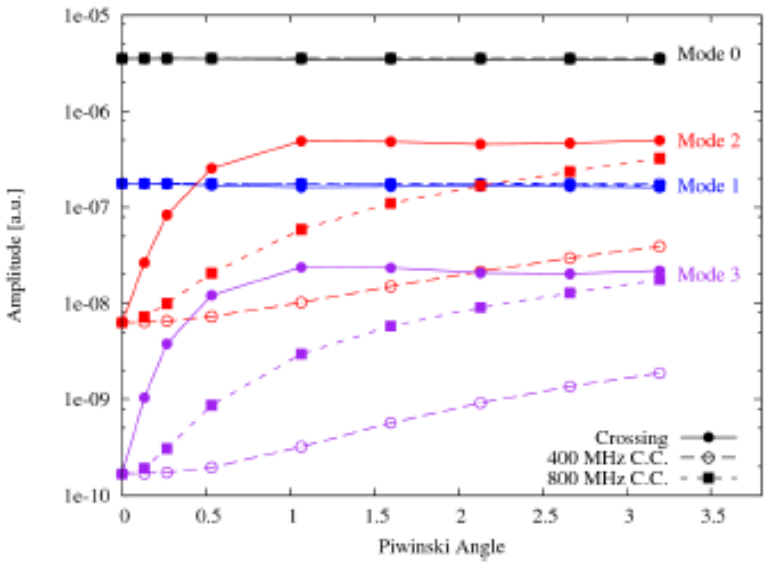


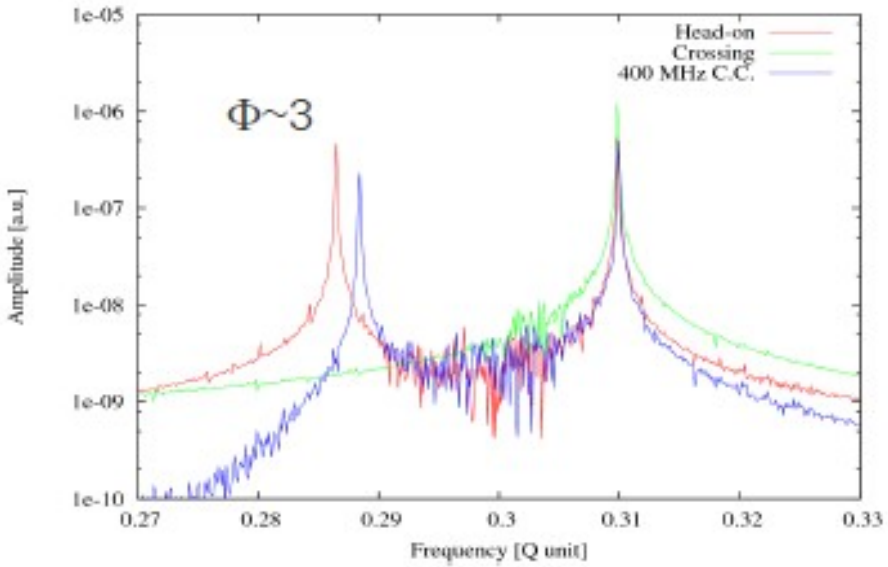


=> Crab cavity / FB noise can be the source of (large) emittance growth
=> Feedback system would help recovering from C.C. noise

C.C. Studies – Synchro-Betatron Effects

Synchro-Betatron Effect. S. White

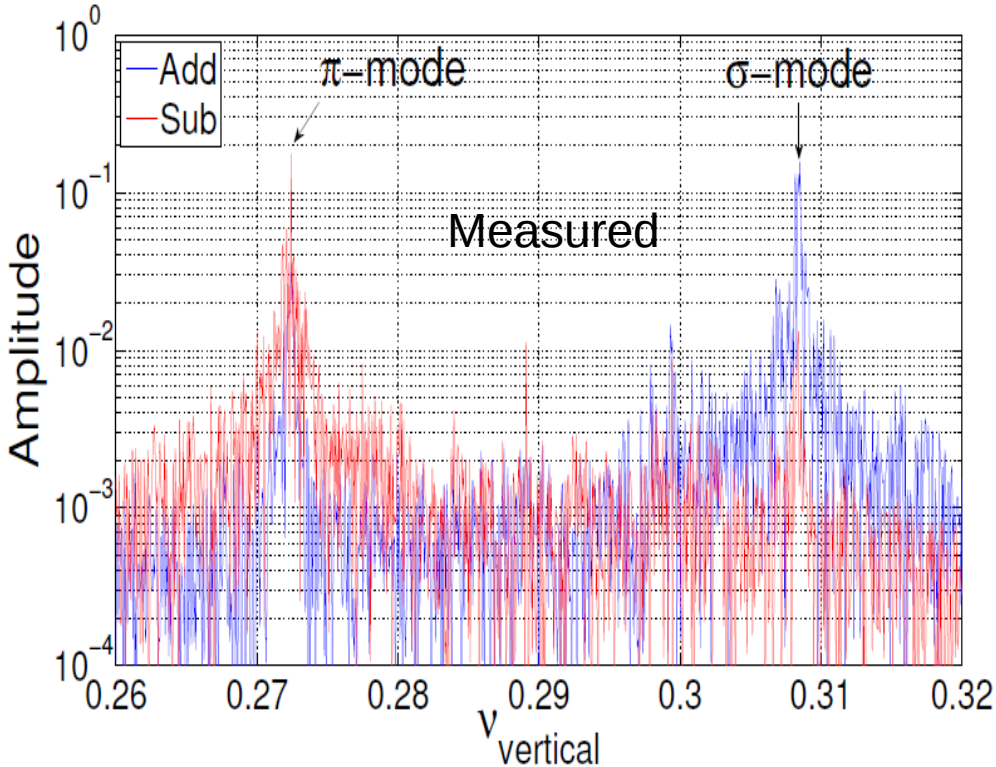


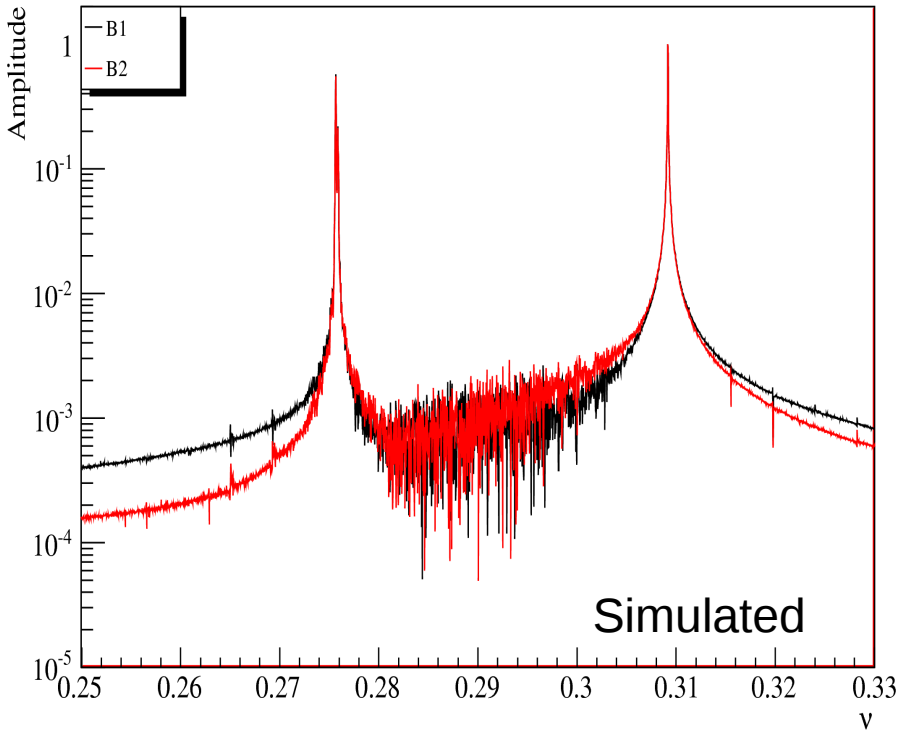


=> Large Piwinski angle excites synchrotron sides bands – C.C. compensate for for the crossing angle and damps the side-bands
=> Large Piwinski angle and $\xi \sim Q_s$ could damp the π–mode – C.C. restore it.

- **Crab cavity and beam-beam effort ongoing:**
  - First results encouraging – more systematic studies required
  - Refine the model
  - Beam experiments – code benchmarking

LHC Operation Support – LHC MDs

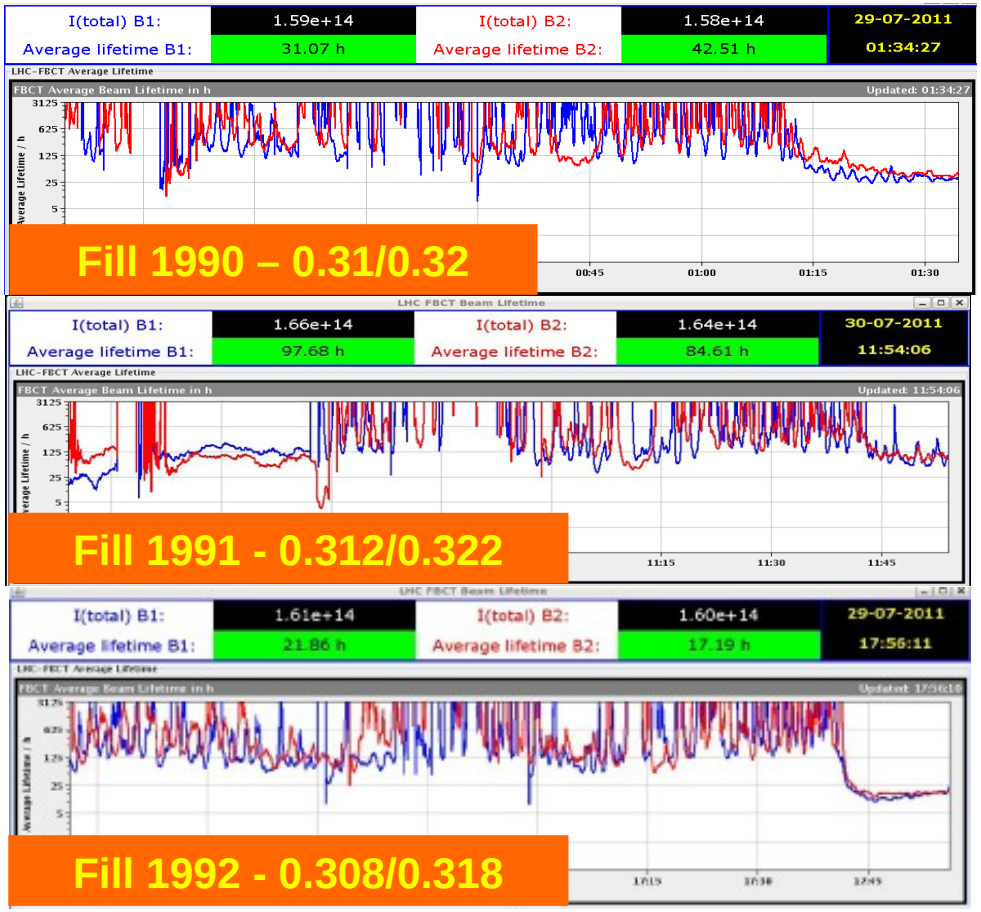


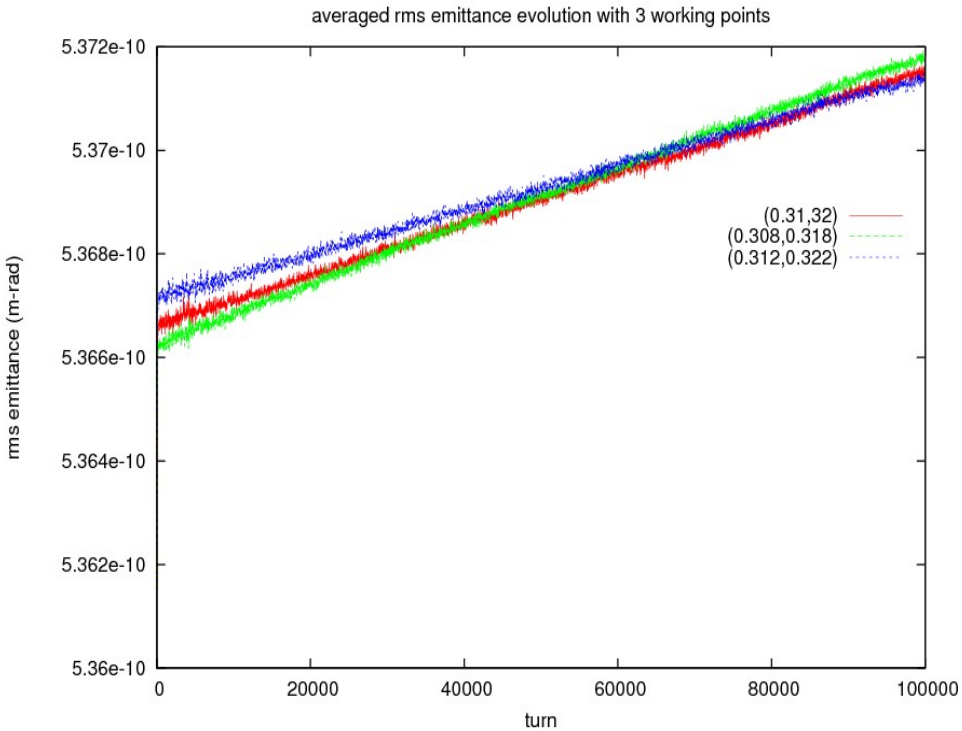


X. Buffat et al., "Observation of Coherent Beam-Beam Effects in the LHC", IPAC11

=> Simulated (using measured beam parameters) and measured coherent beam-beam modes
=> Results agree within the error on the emittance measurement (+/-10%)

LHC Operation Support – W.P. Optimization





Emittance growth vs W.P. J. Qiang

=> Emittance growth simulated with BB3D as a function of the W.P. Consistent with lifetime measurements

=> Effects of the 10th order resonance could be qualitatively reproduced

Tevatron Beam Studies

1. AC Dipole with colliding beams
   - AC dipole is a device that adiabatically excites transverse oscillations of the beam. Turn-by-turn detection of oscillations at the excitation frequency allows to restore the beam optics.
2. Coherent Beam-Beam Modes
   - Colliding beams represent a system of coupled oscillators with their eigenfrequencies determined by beam and machine properties. Coherent instabilities may happen under certain conditions
3. Beam-Beam Resonances vs Separation
   - Study the importance of transverse beam-beam misalignment
4. Betatron Phase Averaging
   - Theory predicts that the magnitude of beam-beam effects is strongly affected by the ratio of transverse beta-function to the bunch length.
5. Diffusion Driven by Beam-Beam Resonances
   - Beam-beam effects interplay with other diffusion and noise sources

Organization & Scheduling

- **Participants:**
  - Fermilab: A. Valishev, Y. Alexahin, G. Annala, B. Hanna, V. Lebedev, R. S. Moore, V. Shiltsev, D. Still
  - LBNL: J. Qiang
  - BNL: X. Gu, R. Miyamoto, S. White
  - CERN: F. Schmidt

- **Scheduling:**
  - We have requested 40 hours of beam time over the two weeks period
  - RunCo team calculated that 43 hours were used
    - **Actual time with beam ~35 hours (2 quenches)**
  - First week strongly affected by ecool troubles
  - Nevertheless some good results!

Tevatron Beam Parameters

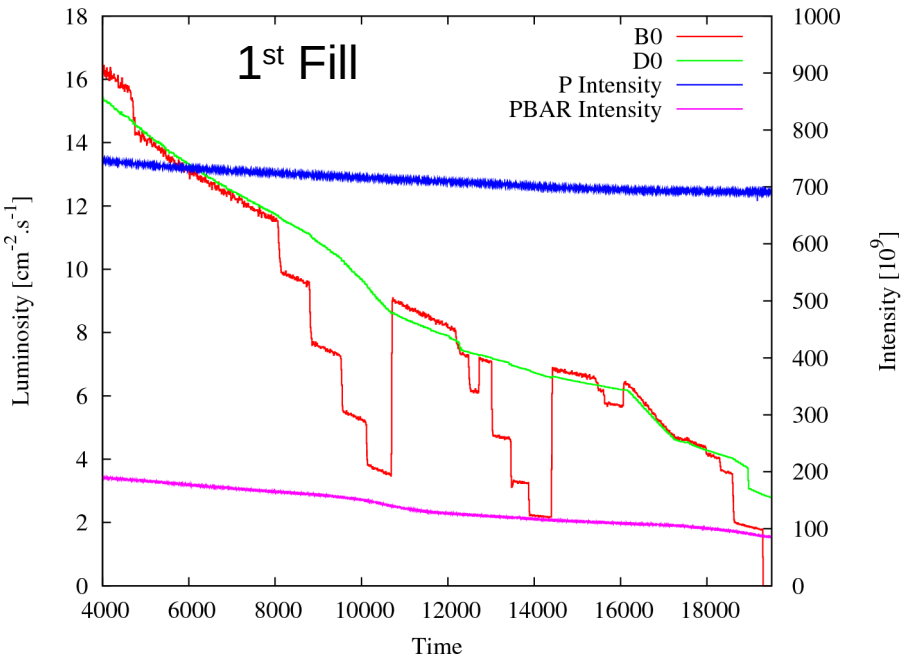
- All experiments were performed at 980 GeV in squeezed optics (0.3 m)
- Machine was loaded with 3 proton and 3 antiproton bunches: P1, P13, P25 and A1, A13, A25
- Beams were on the helix – head-on collisions at B0 and D0, separated at A0, C0, E0 and F0 by 8-10σ

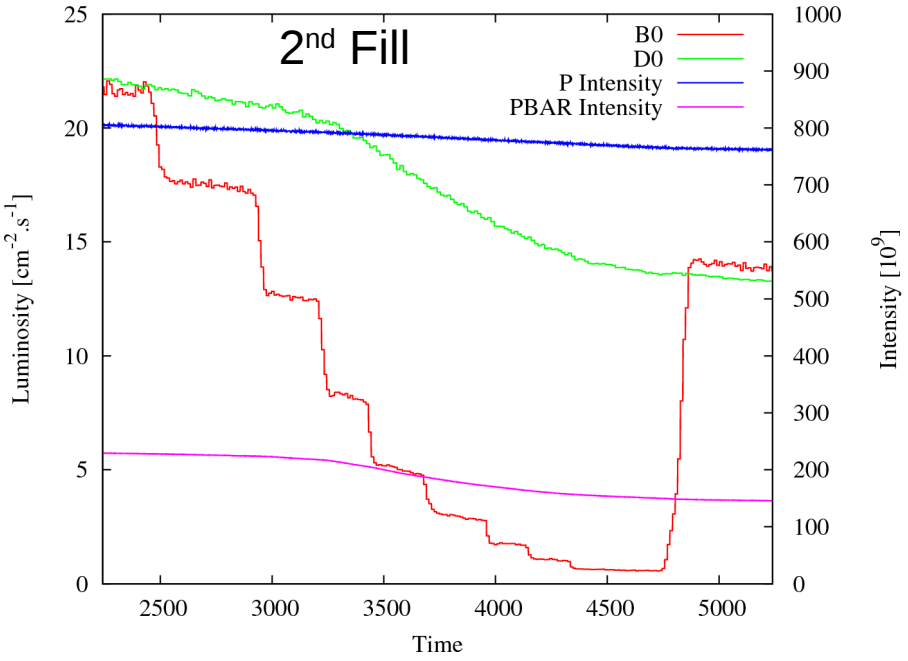
- Typical beam parameters (* ecool off):

Parameter	Value
Protons / bunch	2.8×10^{11}
Antiprotons / bunch	0.8×10^{11} (0.4x1011 *)
Transverse Emittance (P, A)	22, 8 μm (22, 14 *)
Bunch Length (P, A)	0.51, 0.45 m
Momentum Spread (P,A)	1.4, 1.2 $\times10^{-4}$
Hourglass Factor	0.61
Beam-Beam Tune Shift (P, A)	0.013, 0.02

Separation Scans

- Motivation: simulations indicate that offset collisions could have detrimental effects on lifetime and/or emittance growth
- Not observed at the LHC: leveling with separation → try to confirm these observations with different conditions

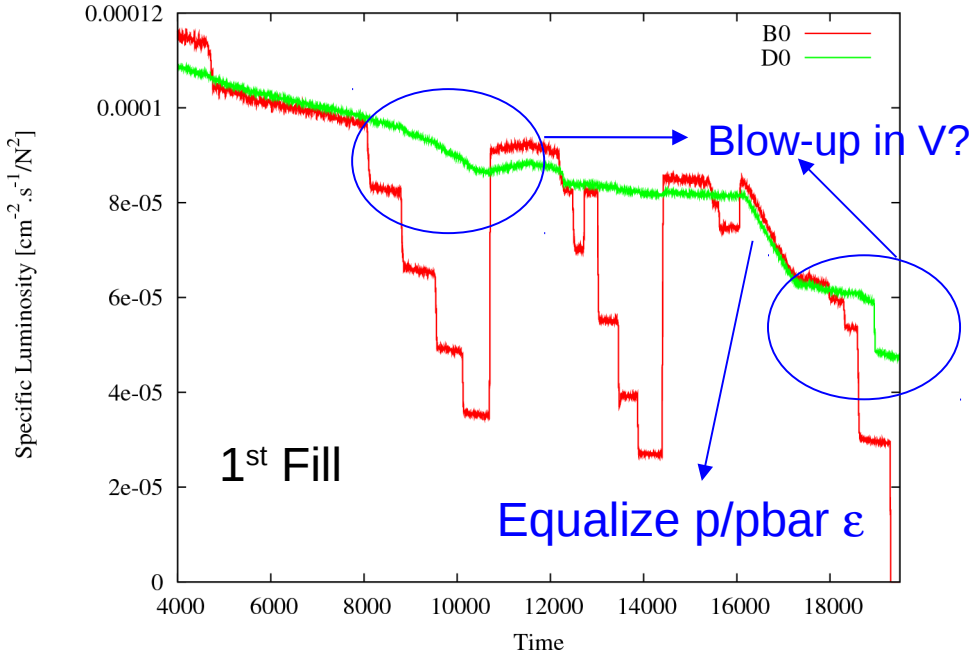


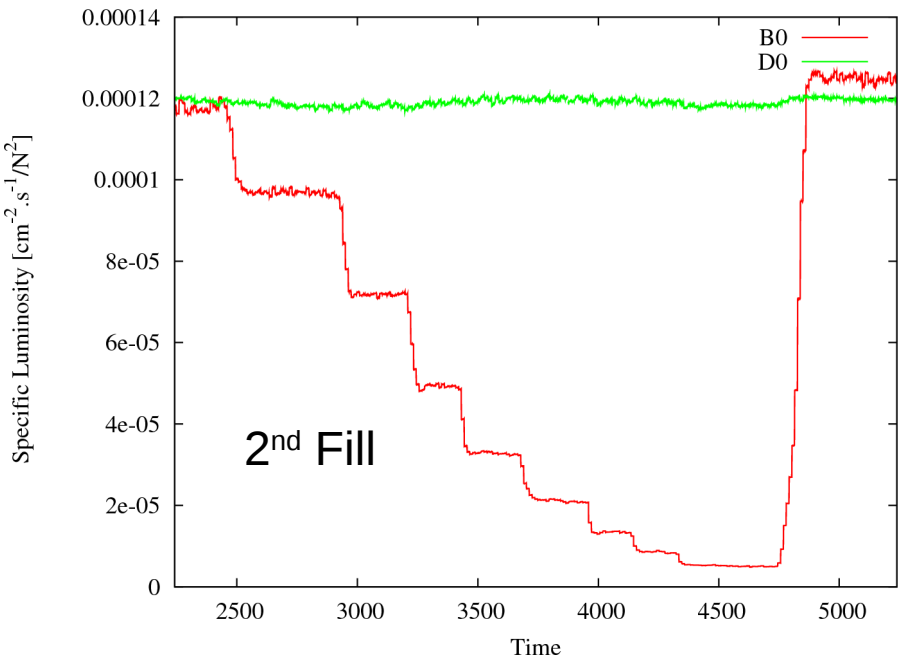


=> 1st Fill: 3 scans performed (V-H-V) over a limited range (0-1.2 proton σ)
=> 2nd Fill: 1 scan performed in the horizontal plane over a larger range (0-2.2 proton σ)
In both case losses are mostly observed in the pbar beam

Specific Luminosity

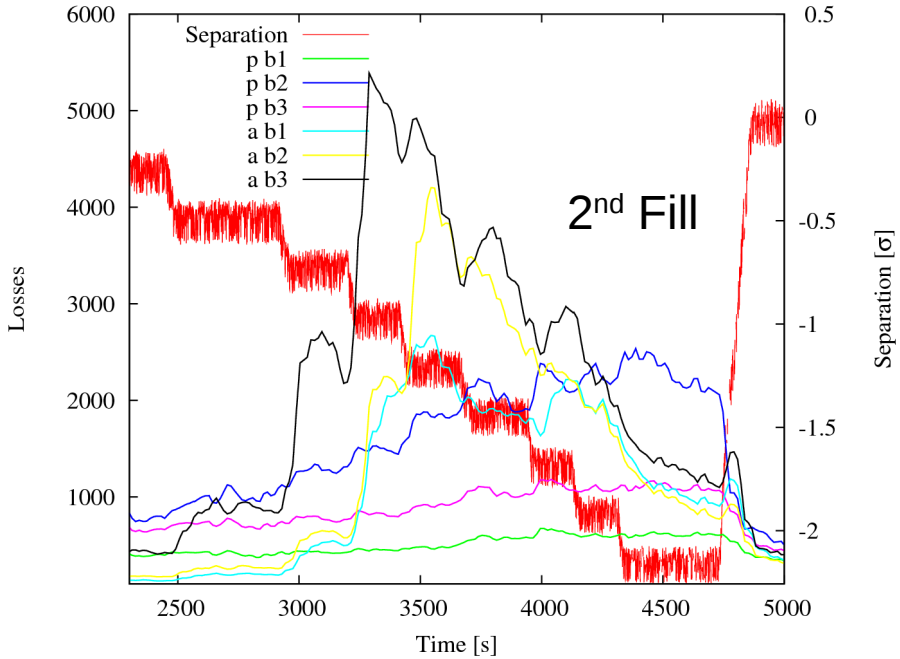
- Emittance at the Tevatron measured with synchrotron light monitors → more accurate measurement given by the specific luminosity

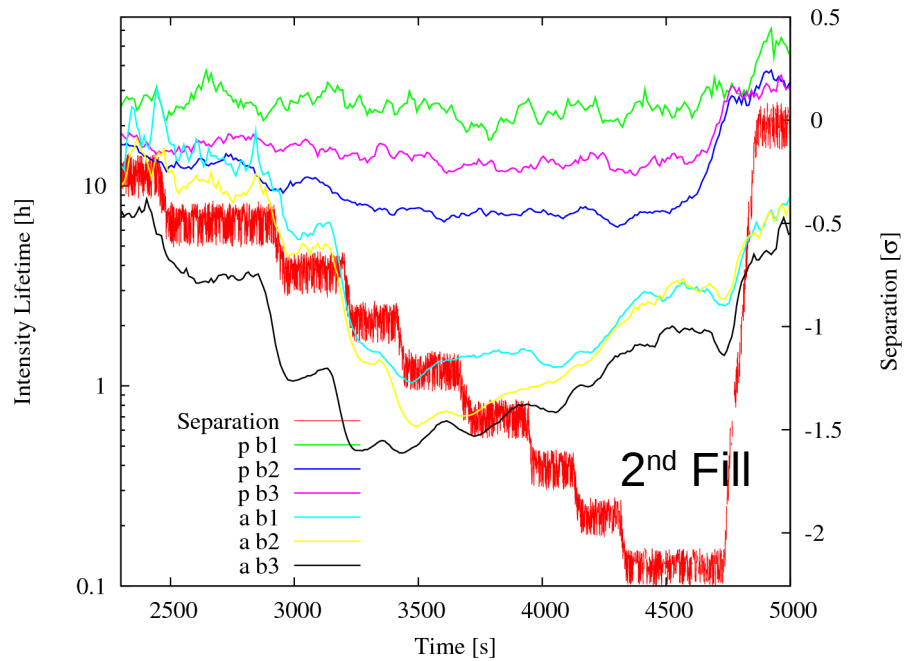


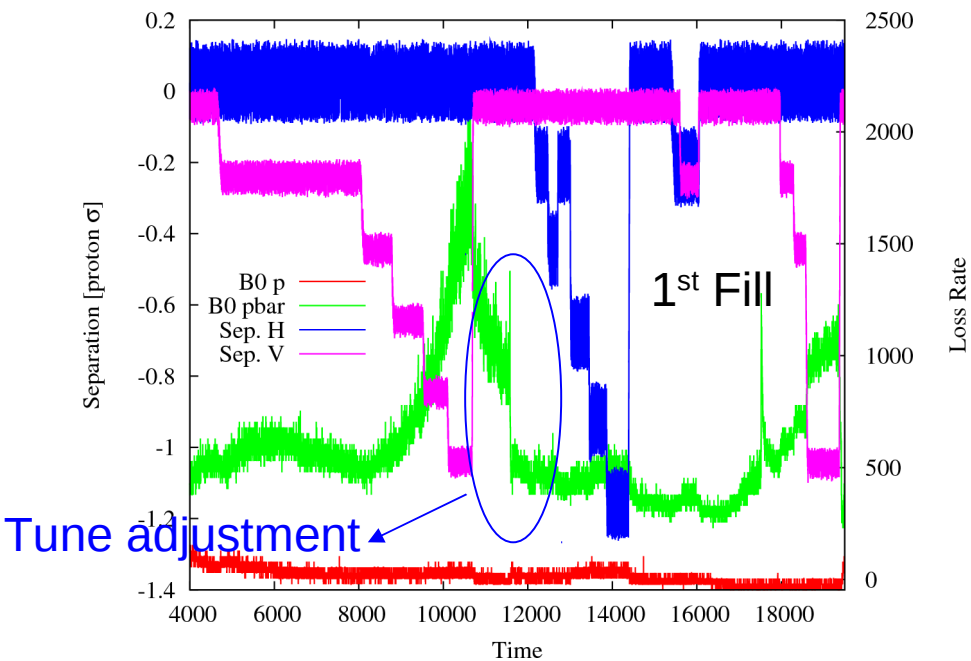


=> Horizontal plane: no emittance blow-up was observed in either fill
=> Vertical plane: performed only during the first fill. Emittance growth observed
=> During the first the AC dipole was not fully turned off and exciting the beams in the vertical plane close to the tunes → **could be the source of the observed blow-up - tunes dependency - separating the beams was bringing the low amplitude particles towards excitation line)**
=> To be noted that the natural blow-up was also larger during the first fill

Losses and Lifetime

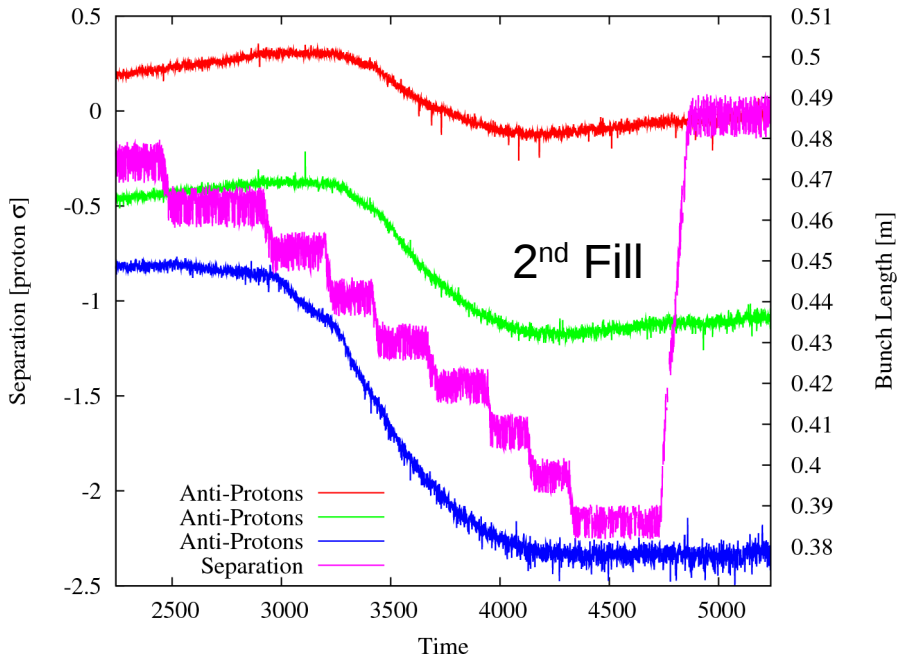


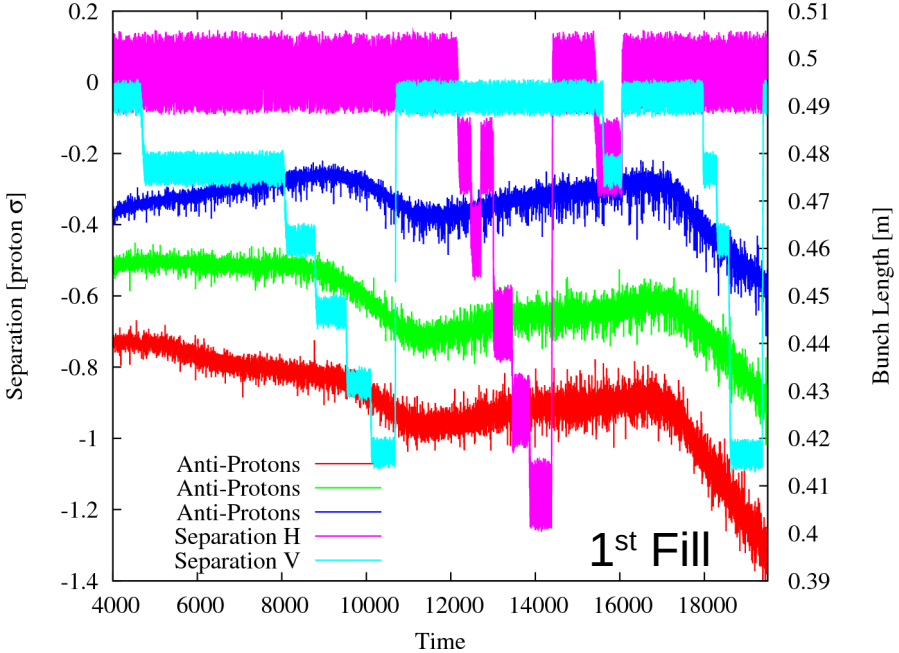




- Losses clearly associated with the scans
- Mostly observed in the pbar beam
- Steps were not long enough to fully recover the lifetime
- **Losses seem however to be peaked around 1.0-1.5 σ**
- **1st Fill: tune adjustments helped recovering lifetime → point towards tune dependent effect (ACD - blow-up)**

Longitudinal Effects

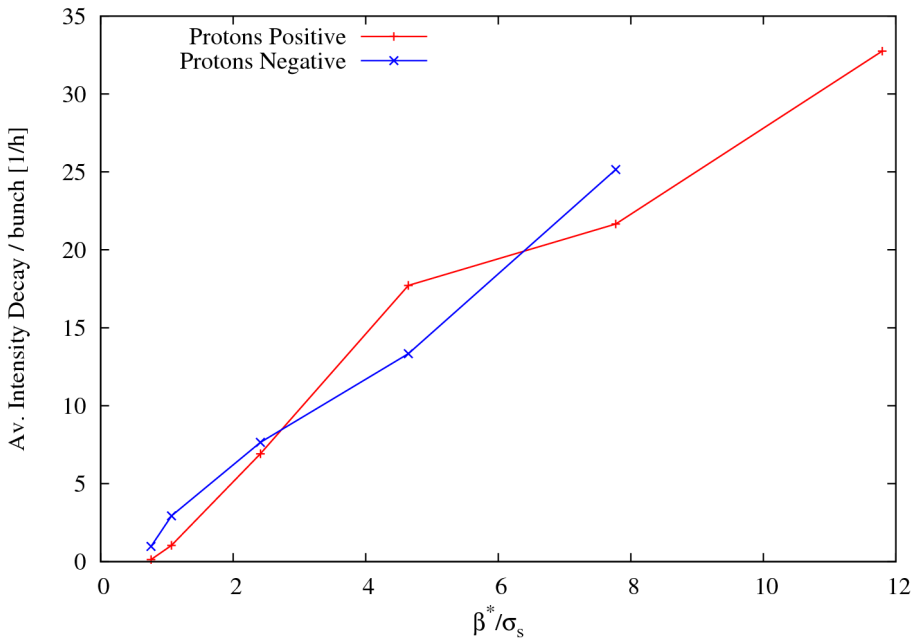


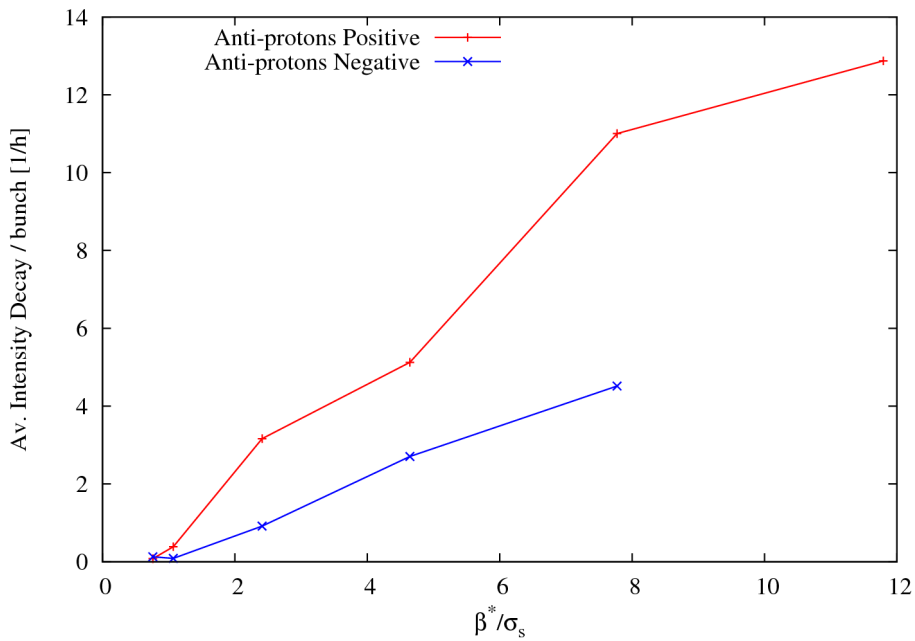


=> Bunch shortening associated to the losses, mostly observed for pbar
=> Very little or no effect on the proton beam (smaller tune shift)
=> Possibly longitudinal tails shaving (off-momentum particles)
=> Not observed during the H scan / 1st Fill: not enough time to repopulate the tails?
=> **One possible explanation is the dynamic effect due to beam-beam close to the half integer**

Phase Averaging

- An improvement of the lifetime was predicted for small ratio of β^*/σ_s
- For simplicity this was achieved by cogging (longitudinal displacement) one of the two beams





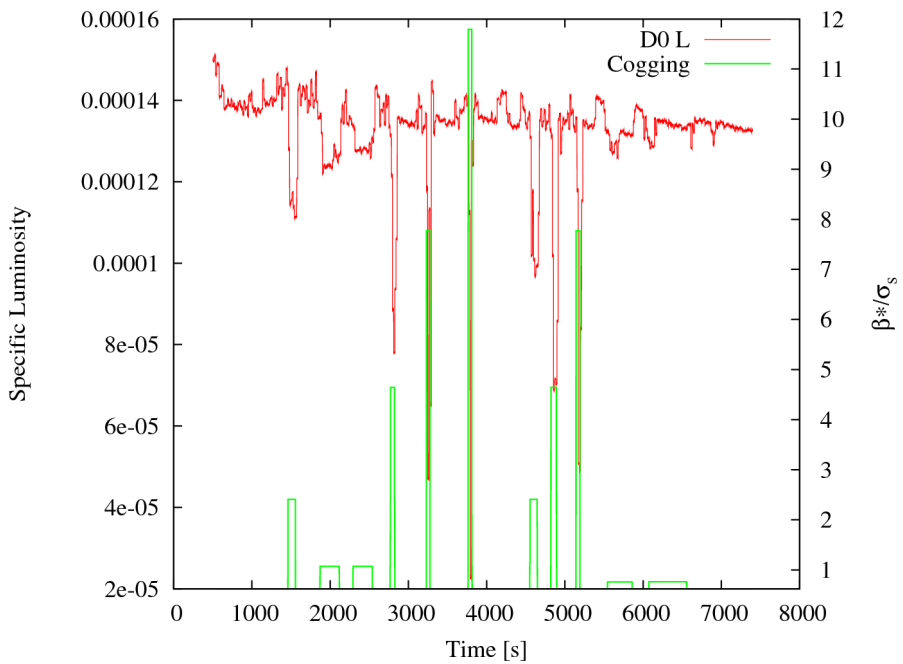
=> Qualitative agreement with expectation → lifetime degradation with larger ratio β^*/σ_s

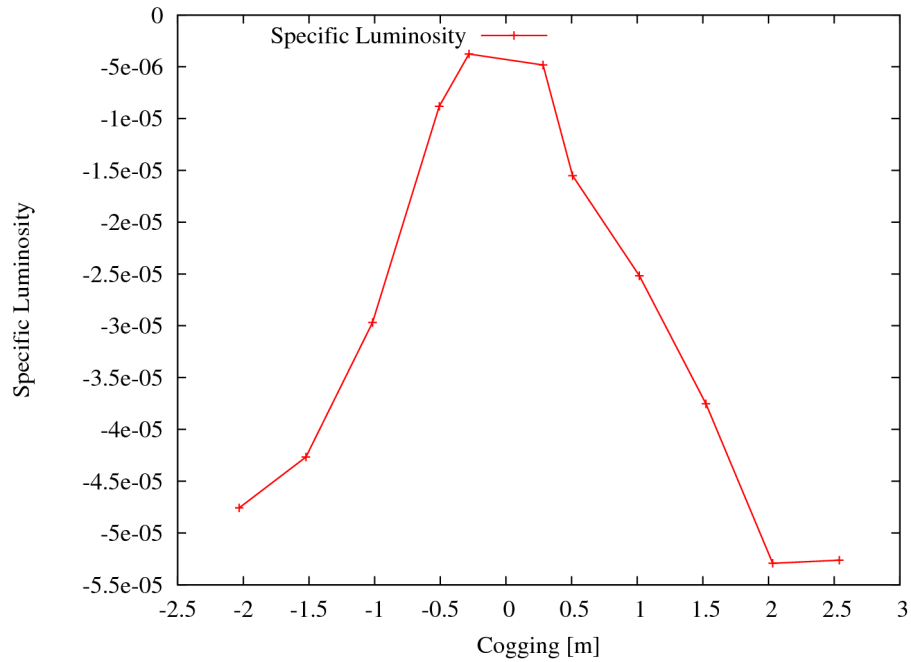
=> Some unexplained features: asymmetry / lifetime keeps degrading

=> More in details analysis required - ongoing

Luminosity

- Look at the specific luminosity for emittance blow-up and displacement of the waist



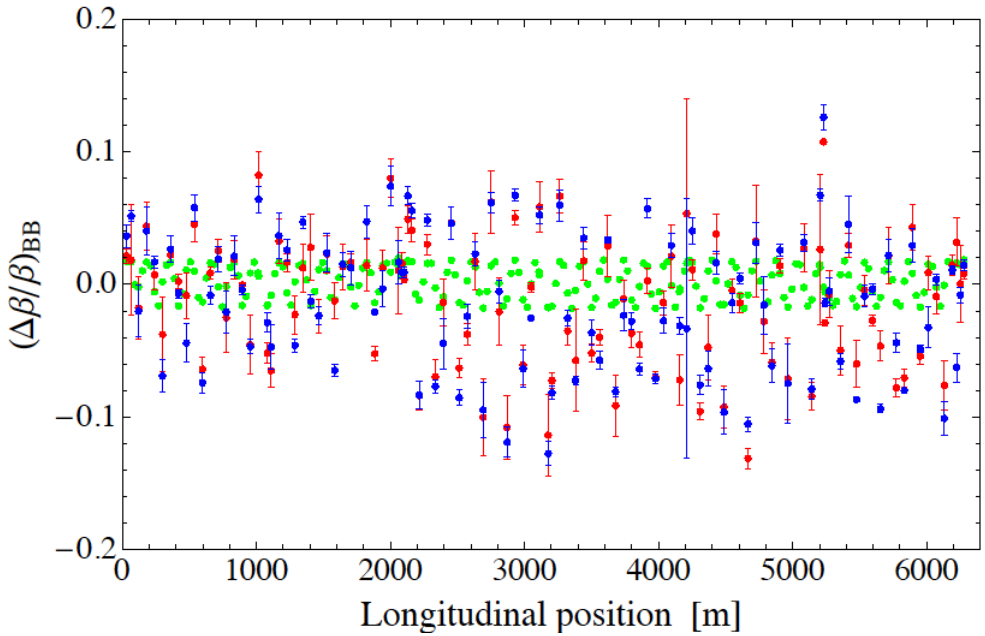


=> No emittance blow-up due to the scan observed
=> The position of the waist seems rather well centered on the IP and **does not explain the asymmetry in the pbar scan**

AC Dipole Study

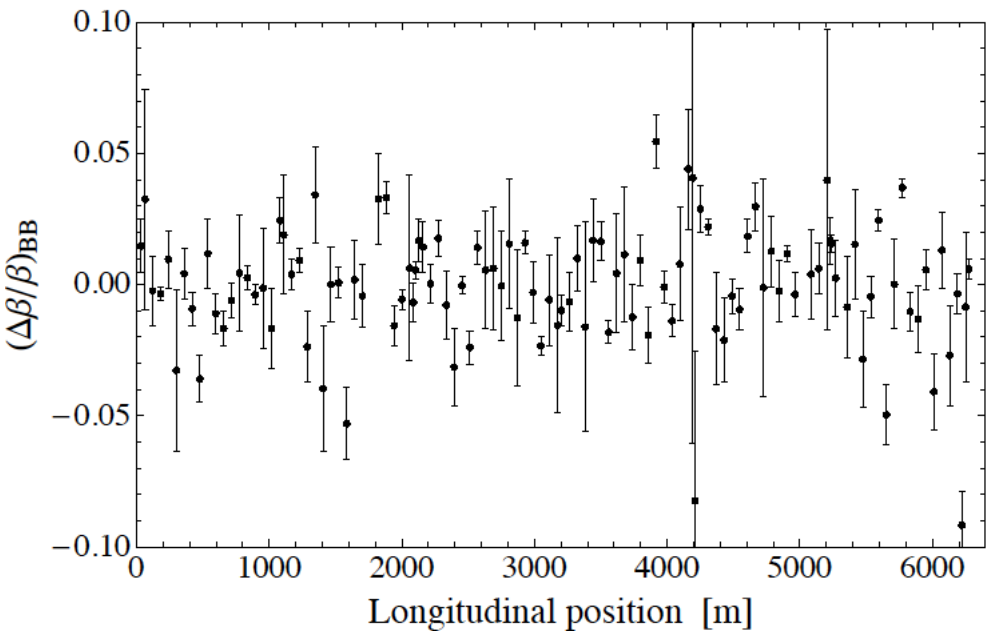
- **Experiment procedure**
  -Make the proton beam “weaker”.
  -Excite the proton beam in collisions with an AC dipole (V only in Tevatron).
- **Objectives: direct measurements of WS beam-beam effects**
  -Incoherent tune shift (via the amplitude response)
  -Dynamic beta-beating
  -Nonlinear effects (amplitude response, spectrum)
- **Difficulties**
  -Anti-proton beam is also excited.
  -Coupling was strong.
  -Weak proton beam => BPM noise worse than usual.
  -AC dipole degraded? (After not used for ~3 years, the signals had sidebands and the excitations seemed smaller…)
- **Brief conclusions**
  -Saw something but not as expected. (Theory too simple ??)
  -Data quality not great (due to make the proton beam weak) but first 2 points of the “Difficulties” should/will be further investigated.

Dynamic Beta-beating



Blue and red show the beating w.r.t. to the data with no BB for kicks with different amplitudes (1-2σ). Much larger beating compared to the expectation (green) ??

Relative difference between the red and blue. The emittance growth should make ~0.5% difference. The data seems to indicate a larger difference but very noisy.



Proposals for Beam Experiments at RHIC

- Easiest way for BNL/RHIC to contribute to HL-LHC studies is through beam experiments
- The APEX (equivalent of the LHC MDs) workshop will take place next December to approve the proposals
- Unfortunately RHIC cannot do long-range interactions
- Possible topics already identified:
  - Large Piwinski angle
  - Beam beam with noise
  - Coherent beam beam effects
  - Beam beam effects close to the integer W.P.

- Priority seems to be beam-beam and noise studies
- Ideas and proposals welcome – discussion ongoing with CERN collaborators

Summary

- **Simulation support for present and future LHC studies:**
  - Excellent collaboration - already nice results obtained on various topics
  - Simulations seem to be consistent with observations – more confidence regarding predictive capabilities for LHC upgrades

- **Tevatron beam studies:**
  - Availability and beam conditions were not optimal – but some good quality data were acquired
  - Data analysis is well advance. Simulations and modeling ongoing – some observations are not understood yet

- **Outlook:**
  - Very positive returns regarding the ongoing simulation efforts – code benchmarking and refined model would be desirable
  - HL-LHC related beam experiments at RHIC – discussions ongoing