Tevatron Transverse Beam Emittance and Luminosity at CDF and D0 for stores 3179–3293
Beams–doc–1075
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Abstract

We present data pertaining to Tevatron Effective Beam Emittance and Luminosity measurements for stores between 3179 and 3293.

1 Introduction

We study Tevatron Transverse Beam Emittance measurements done using Flying Wires (FW) (See ref [2]) and Sampled Bunch Display (SBD). We compare those measurements to Luminosity observed by CDF(B0) and D0 (and recorded in C:B0ILUM and C:D0ILUM ACNET variables) using formulas described below. This note complements previous notes [5, 6] and covers a new store range. The main differences compared to the previous notes are the use of the new D0 luminosity determination procedure [4] and usage of horizontal E17 flying wire for the horizontal emittance calculations (due to the failure of the horizontal E11 wire) as well as a correction to the 33 pbar bunch length as we had found it was overestimated between stores 3030 and 3240.

2 Data Selection

The stores for this analysis were selected from post January 19th running period when there was a change in D0 luminosity determination procedure [4]. The Tevatron Cases chosen were "Remove Halo" (with the beam energy of 980GeV) and the first Set of "HEP" Case as this is a set of cases where Transverse Emittance Flying Wire measurement and B0 and D0 luminosity measurements are done only within a few minutes apart. The SBD bunch intensity measurements were re-scaled according to the "Flattop" Case T:IBEAM and SBD measurements. It was required that this re-scaling be no greater than 2.5%. Other requirements imposed on the data were: For Luminosity and Effective Emittance plots: B0 and D0 measured bunch emittance (F_{emitt} see below) had to be smaller than 30 $\pi \cdot mm \cdot mrad$ and B0 and D0 measured and calculated bunch luminosity had to be greater than 0.01 $10^{30} \cdot cm^{-2} \cdot sec^{-1}$; For Emittance plots: The Bunch Intensity had to be greater than $15 \cdot 10^9$. We had also corrected the length of the 33rd pbar bunch when used in the horizontal emittance calculations and set it to be the average length of the all pbar bunches in a given set (as it has been mis-measured prior to store 3240).

3 Emittance and Luminosity Calculations

We calculate Normalized 95% Transverse Emittance $\varepsilon_{h,v}$ (in $\pi \cdot mm \cdot mrad$)) using the following formulas:

$$\varepsilon_h = 6\left(\sigma^2 - (\frac{\delta p}{p})^2 D^2\right)\frac{\gamma_L}{\beta} \qquad \varepsilon_v = 6\sigma^2\frac{\gamma_L}{\beta}$$

where

$$\delta p = \delta t(83.293 + \delta t(-10.562 + \delta t 0.8023)) \text{ (See ref [1])}$$

δt is the T:SBD[A,P]WS ACNET variable (longitudinal beam bunch spread in ns), p is the beam momentum in GeV, γ_L is the Lorentz gamma, σ are bunch width as measured by each of the detectors (ACNET variables T:FW[E,V][A,P]SG). In the FW case the width is the arithmetic average of the two measurements (for both of the wire passes trough the beam). The dispersion (D) and β lattice functions at E17 and E11 locations (location of the used Flying Wire Detectors) are shown in Table 1. Luminosity L (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) and Effective Emittance F_{emitt} in $\varepsilon_{h,v}$ (in $\pi \cdot mm \cdot mrad$)) are calculated using

Detector	beta Function [m]	dispersion Function [m]
FW E17H p & $\overline{p}$	68.157	5.278
FW E11V p & $\overline{p}$	80.804	

Table 1: Tevatron beta and dispersion functions for corresponding measurement locations

formulas from [3]:

$$L = \frac{6 \cdot 10^{-5} f N_B N_p N_a \beta_r \gamma_r}{4\pi\beta^\star F_{emitt}} \cdot H(\sigma_l/\beta^\star)$$

where

$$F_{emitt} = 0.5 \cdot \sqrt{(\varepsilon_p + \varepsilon_a)_h (\varepsilon_p + \varepsilon_a)_v}$$

f is the revolution frequency (47.7 KHz), N_B is the number of bunches (36), N_p, N_a are the numbers of protons and antiprotons per bunch (in 10^9) measured with SBD (ACNET variables T:SBD[A,P]IS re-scaled using "Flattop" Case T:IBEAM and SBD measurements), $\beta_r\gamma_r$ is the relativistic factor (1045), $\beta^\star$ is is the beta function at the interaction point (assumed equal in both horizontal and vertical directions as well as at B0 and D0 and to be 35.6cm). H is the Hourglass Factor calculated as

$$H(\sigma_l/\beta^\star) = 1.0831 + (\frac{\sigma_l * 29.98}{\beta^\star})(-0.3916 + (\frac{\sigma_l * 29.98}{\beta^\star})(0.06758 + (\frac{\sigma_l * 29.98}{\beta^\star}) - 0.0030907))$$

and σ_l is longitudinal beam bunch spread in ns (T:SBD[A,P]WS ACNET variable). In the text that follows we use the term Effective or Calculated Emittance to mean the F_{emitt} derived from Luminosity (and other beam parameters) and the term Measured Emittance or Emittance to mean Emittance measured using the Flying Wire Detectors. We use the term Calculated Luminosity to mean Luminosity calculated from Emittance (and other beam parameters) whereas we use the term Measured Luminosity to mean the Luminosity as measured by the corresponding luminosity detectors.

4 Results

Fig. 2 shows calculated Bunch Luminosity over the measured one versus the measured Bunch Luminosity for B0 and D0 locations. One can see that the predicted luminosity is overestimated by about 10-22% (the fact that the horizontal emittance is calculated baded on the e17 wire measurement and not e11 one decreased the ratio by about 11% if one extrapolates from the store range 3052-3147 where both wires were operational, mainly due to the proton horizontal emittance measurement discrepancy between the e11 and e17 wires). From the two plots related to B0 and D0 measured luminosity one can see that either the B0 and D0 luminosity detectors seem to underestimate luminosity for higher values or that the calculated luminosity is overestimated. The trends in above plots differ significantly from the trends from the previously studied store range (3052-3147) [6], but are more consistent with trends from the older store range(2668-2997) [5]. The figure also shows total measured D0 Luminosity over B0 Luminosity versus measured B0 Luminosity as well as total calculated D0 Luminosity over B0 Luminosity versus calculated B0 Luminosity. The comparison of D0 and CDF measured luminosity shows similar trend to the one observed in the past for the 2668-2997 store range namely that the luminosity ratio as reported is a function of luminosity and decreases for higher luminosities (and an average ratio of about 0.90, for a higher than previously studied range of luminosities though).

Fig. 1 shows B0 and D0 Effective Emittance compared to the Emittance as measured using Flying Wires. One can see that the Effective Emittance depends quite linearly on the measured one, which is the reflection of the trends seen in the luminosity plots.

The remaining figures (3–11) are included for completeness, with the two already shown figures included once again in the different context to allow for easier comparisons with the results presented in the previous notes [5, 6].

A new Fig.12 shows calculated Bunch Luminosity over the measured one versus proton bunch length for B0 and D0 locations. One can see that the ratios decrease as the bunch length increases. To understand the impact of various observables onto the ratio plots shown on Fig.16 were made. The plots show the dependence of the Hourglass Factor, Emittance, and Hourglass Factor divided by the Emittance and beta star as a function of bunch length. They also show the relative change in Hourglass Factor divided by the Emittance and beta star versus relative change of beta star and horizontal dispersion. The plots are made assuming average values of all other observables except for the ones varying explicitly. Based on them, within the validity range of the formulas used, the most likely cause of the discrepancy between the predicted and measured luminosity is

the uncertainty on the lattice beta functions including the beta star (+80% to -20% uncertainty causes +12% to -32% uncertainty on the luminosity) . The source of the the proton bunch length dependence of the ratio is most likely the uncertainty on the measurement of lattice dispersion functions ($\pm$10% uncertainty causes +25% to -15% uncertainty on the luminosity).

5 Summary and Conclusions

A comparison of luminosity measurements done by CDF, D0 and accelerator detectors was done. There is a discrepancy between the accelerator and detector measurements. The ratios of predicted and measured luminosity show dependence on the luminosity. The ratio of CDF and D0 luminosity depends on the luminosity as well. The ratios of predicted and measured luminosity also depend on the bunch lengths. Some of the discrepancies can be explained by the uncertainties in the lattice function measurements, but there is still the ratio of CDF and D0 luminosity dependence on the luminosity which is most likely some sort of a saturation effect. More studies are needed to understand the effects.

Acknowledgments

We would like to thank Stephen Pordes and Jean Slaughter for their suggestions and comments.

References

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[2] S. Pordes et al, *Measurements of Proton and Antiproton beam intensities in the Tevatron*, Particle Accelerator Conference, Portland, Oregon, USA, May 12-16, 2003

[3] J. Slaughter et al, *Tevatron Run II Luminosity, Emittance and Collision Point Size*, Particle Accelerator Conference, Portland, Oregon, USA, May 12-16, 2003

[4] T. Edwards et al, *The Updated DO Luminosity Determination - Short summary*, D0 Note 4328 dated January 21st, 2004

[5] K. Genser, *On Tevatron Beam Transverse Emittance and Luminosity at CDF and D0*, Beams-doc-831 Note dated September 10th, 2003

[6] K. Genser et al, *On Tevatron Beam Transverse Emittance and Luminosity at CDF and D0*, Beams-doc-1002 Note dated February 5th, 2004

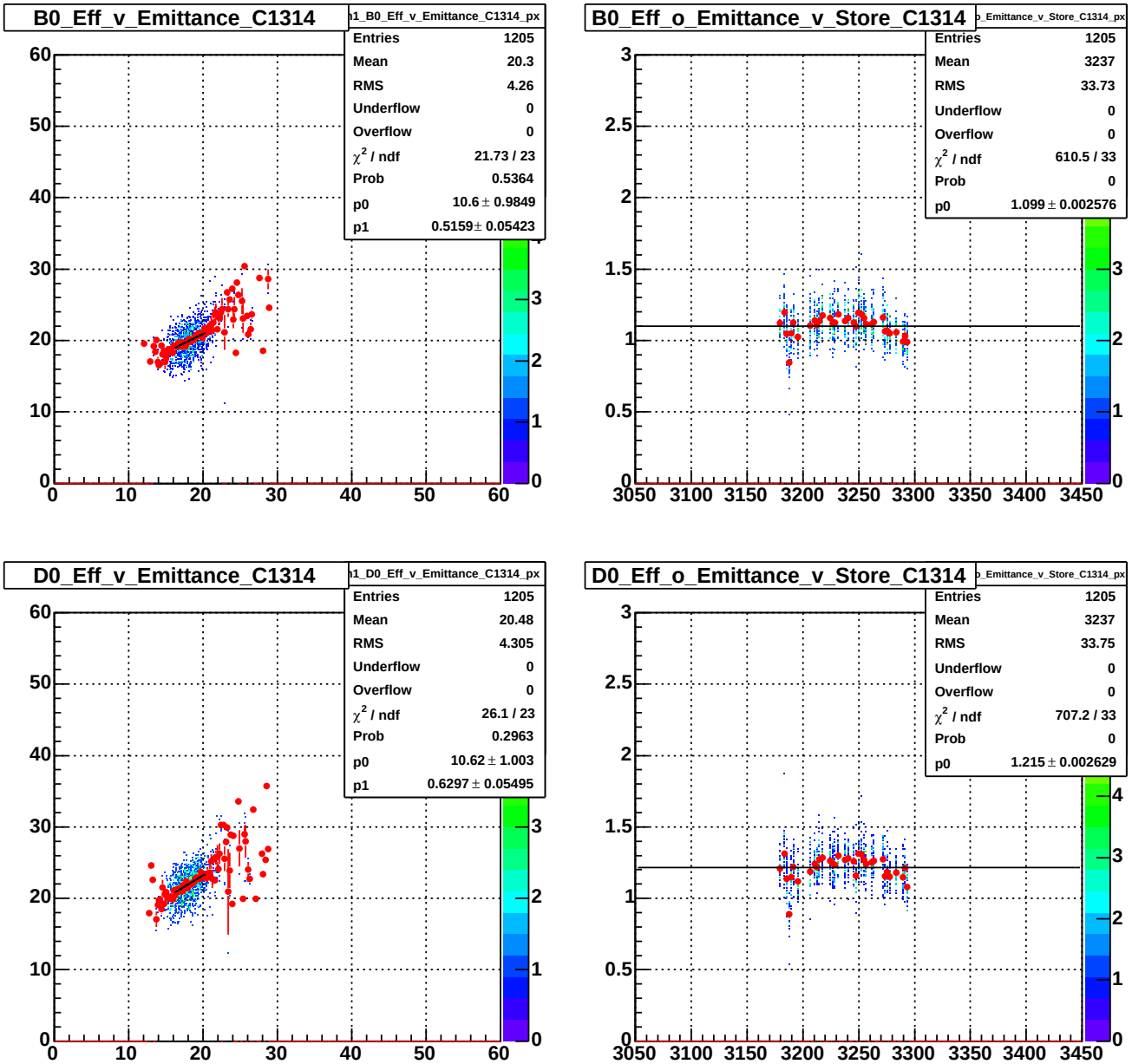

Figure 1: B0 and D0 calculated (Effective) versus measured Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first Set of HEP Case. Stores 3179–3293.

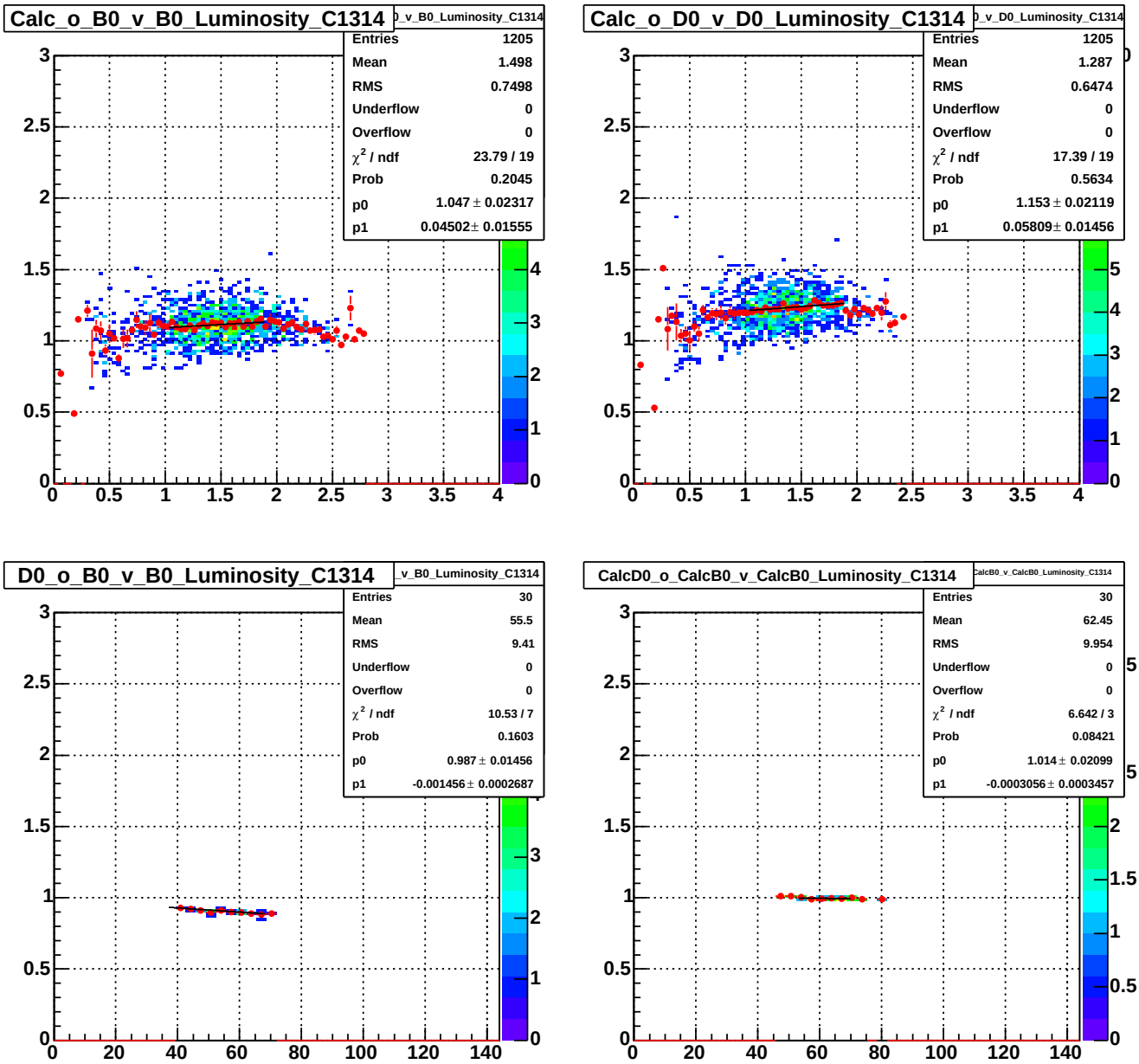

Figure 2: Calculated Bunch Luminosity over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

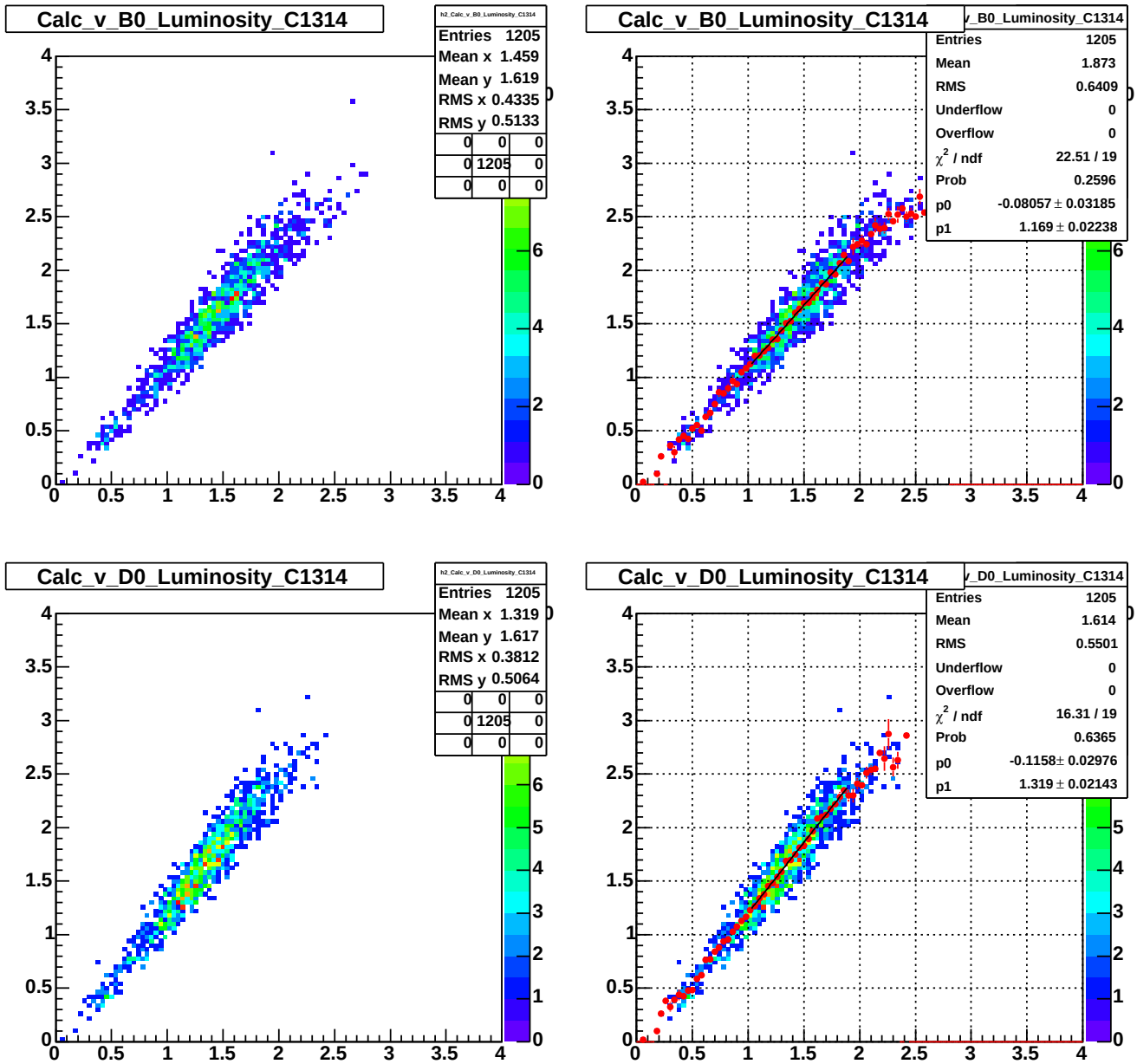

Figure 3: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus measured one for B0 and D0 locations (shown with and without a straight line fit to the profile of the histograms). Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

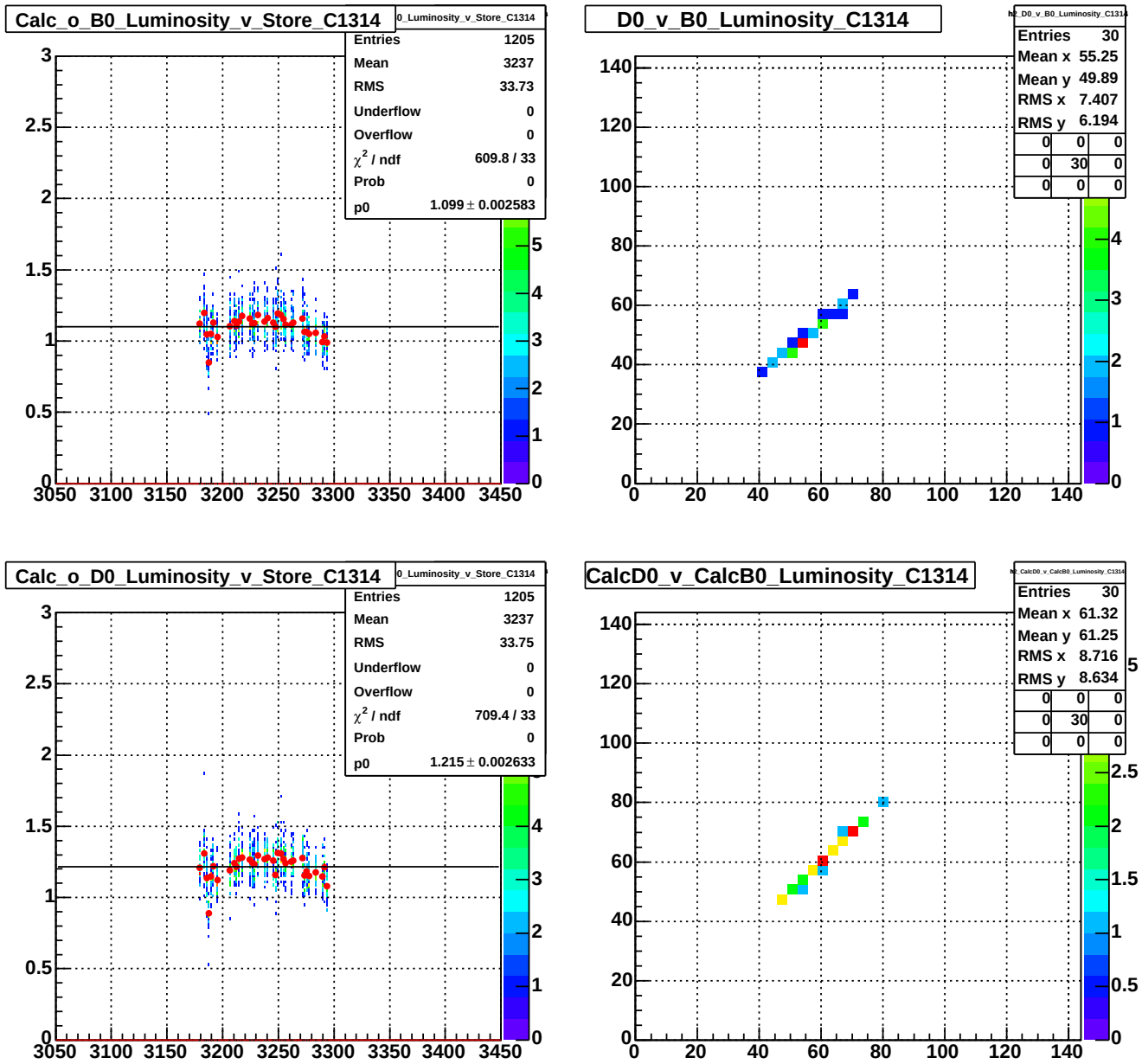

Figure 4: Calculated Bunch Luminosity over measured one versus Store Number for B0 and D0 locations together with total measured D0 v B0 Luminosity and total calculated D0 v B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

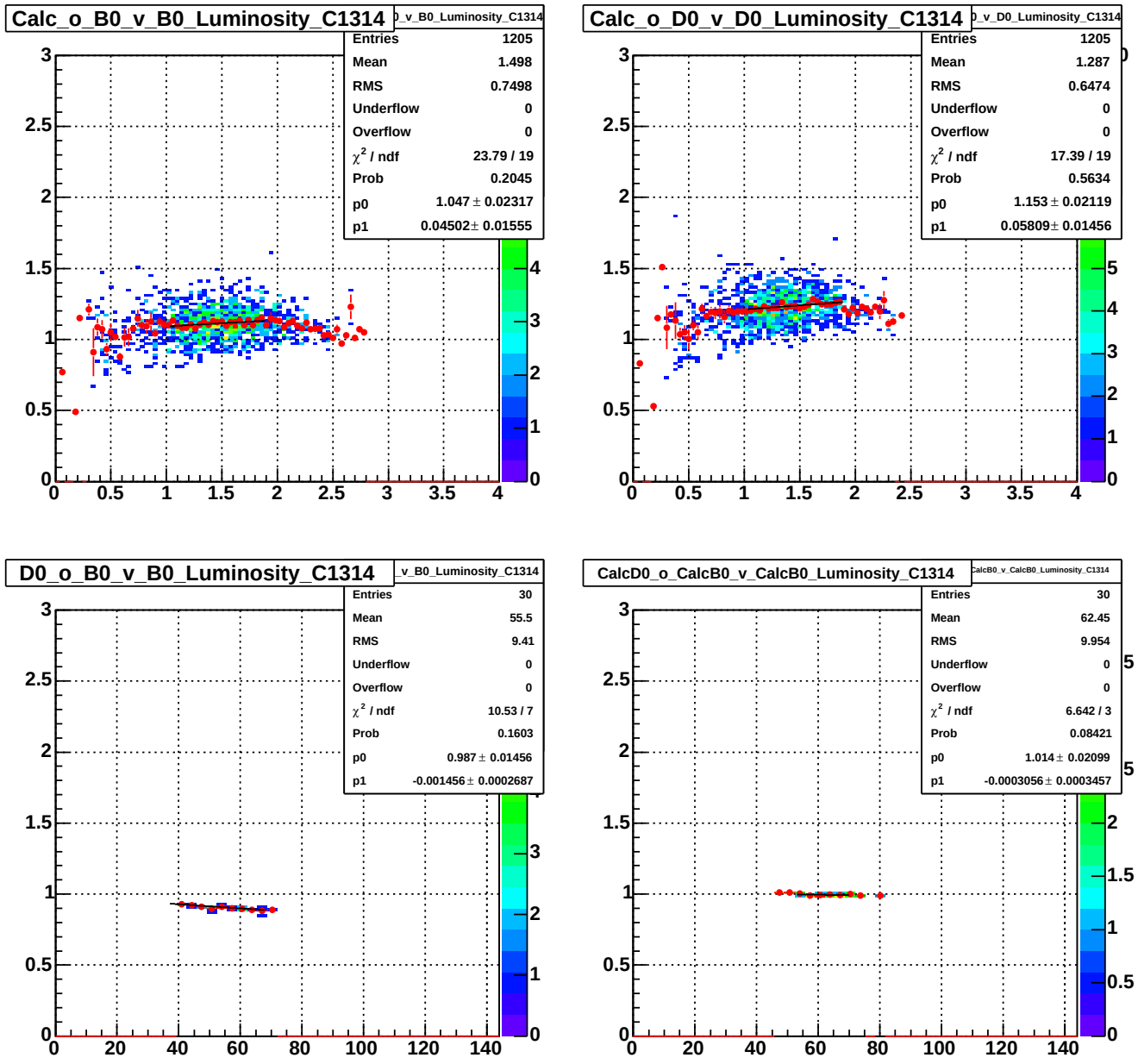

Figure 5: Calculated Bunch Luminosity over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

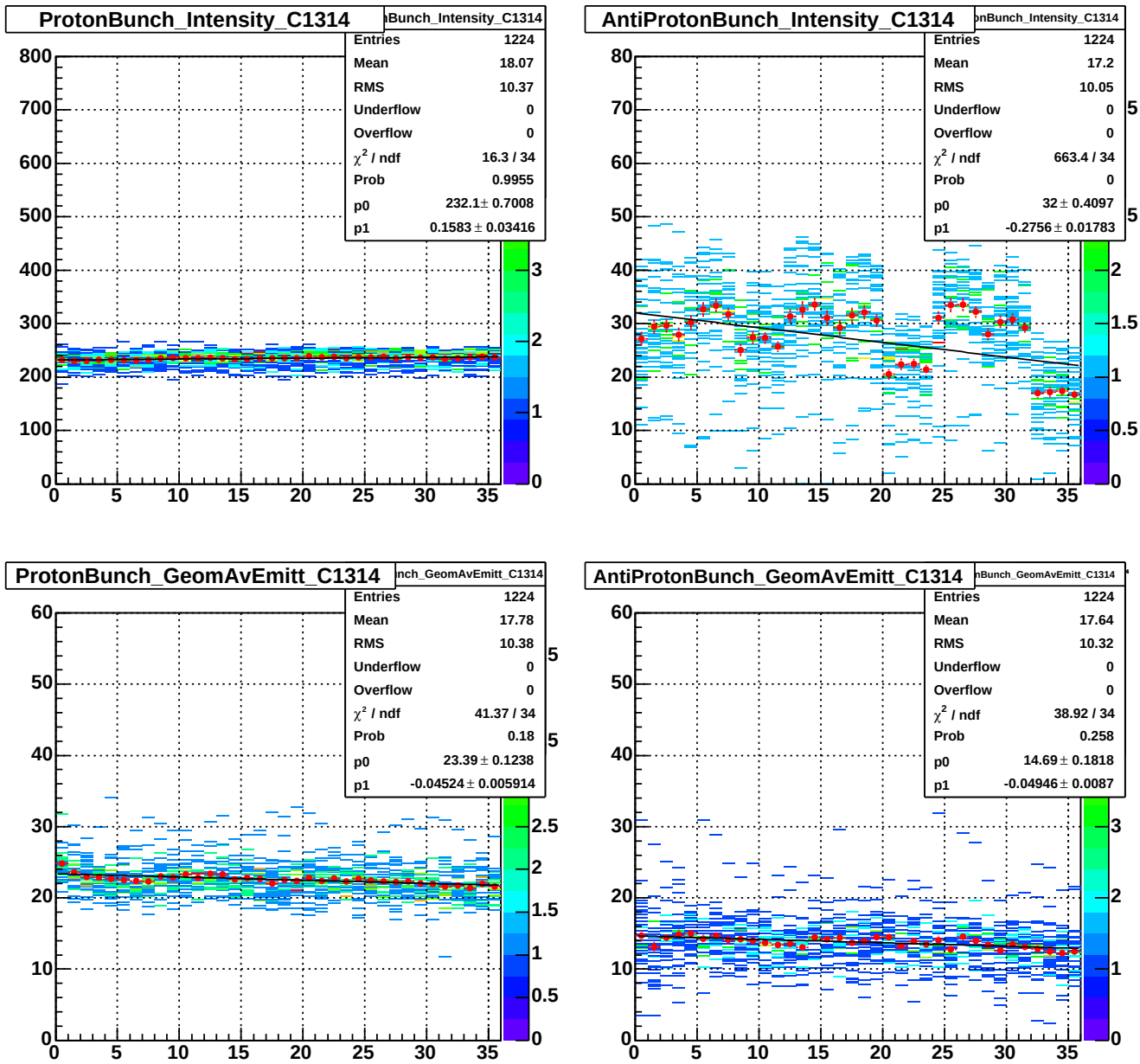

Figure 6: Bunch Intensity (in 10^9) and (Geometrical) Average Transverse Emittance (in $\pi \cdot mm \cdot mrad$)) for Proton and Antiproton Bunches. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Stores 3179–3293.

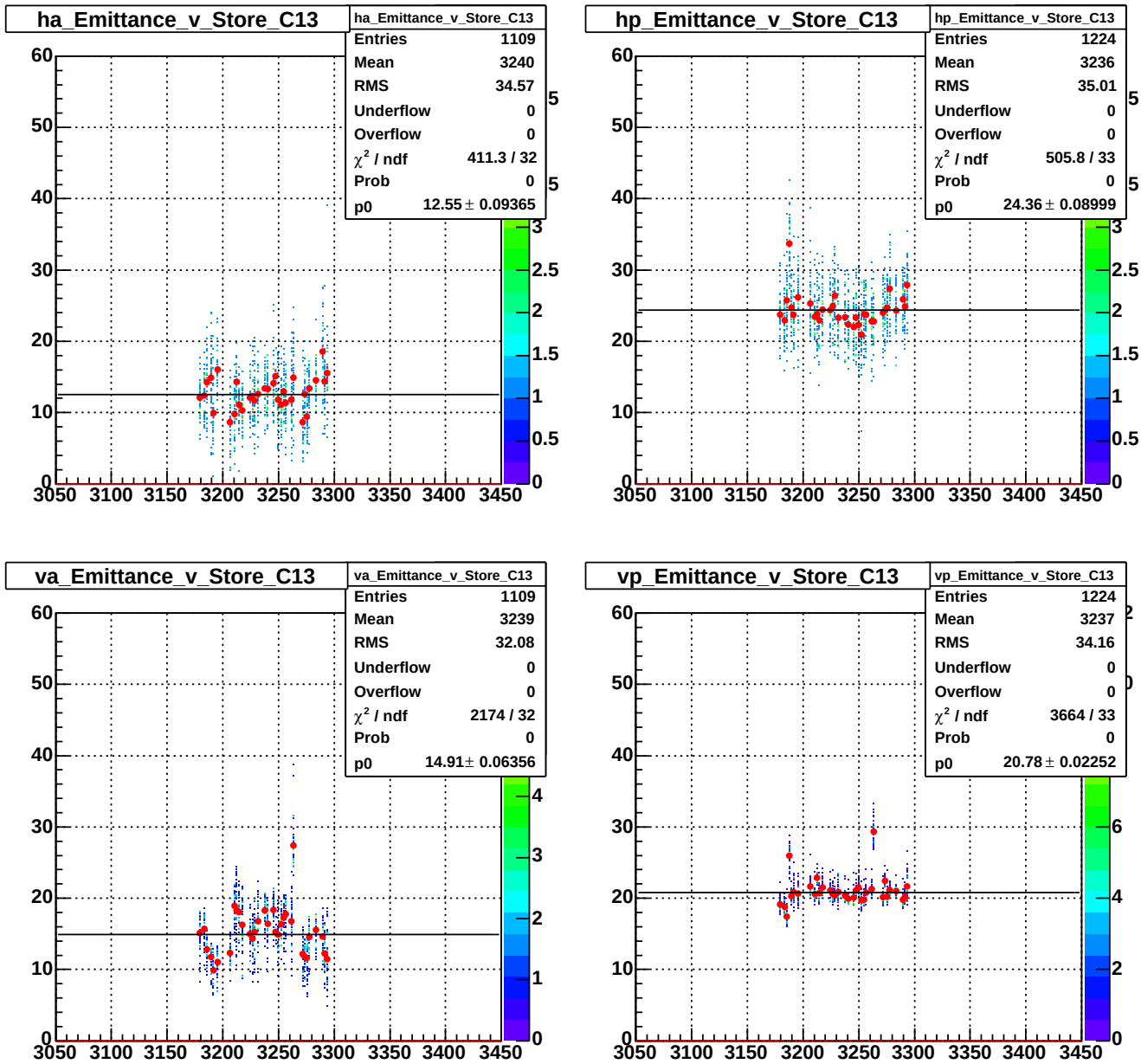

Figure 7: Horizontal Antiproton and Proton Emittance (in $\pi \cdot mm \cdot mrad$)) together with Vertical Antiproton and Proton Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Stores 3179–3293.

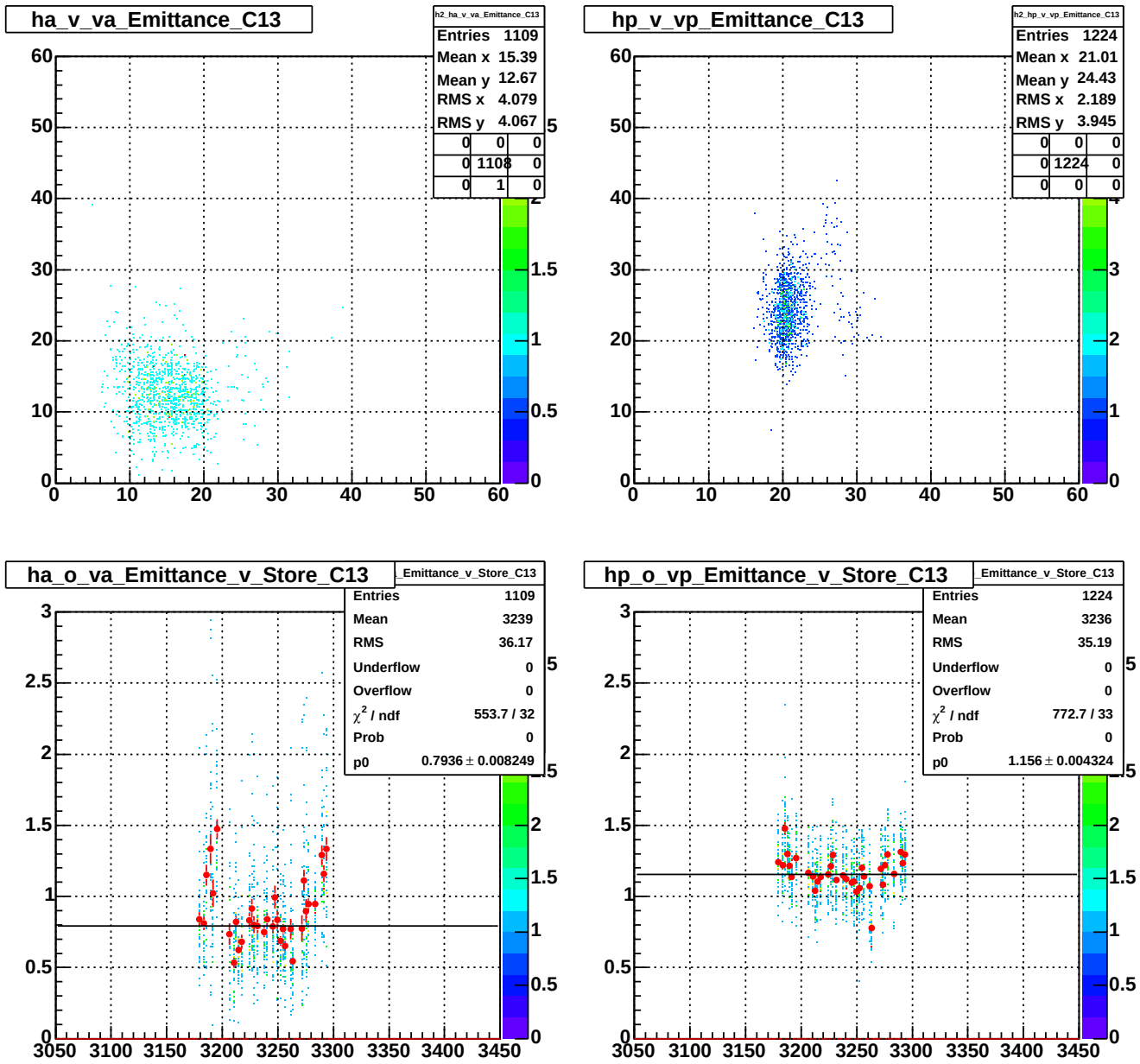

Figure 8: Horizontal Antiproton Emittance (in $\pi \cdot mm \cdot mrad$)) versus Vertical Antiproton Emittance (same for Protons) together with Horizontal Antiproton Emittance over Vertical Antiproton Emittance versus Store Number (same for Protons). Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Stores 3179–3293.

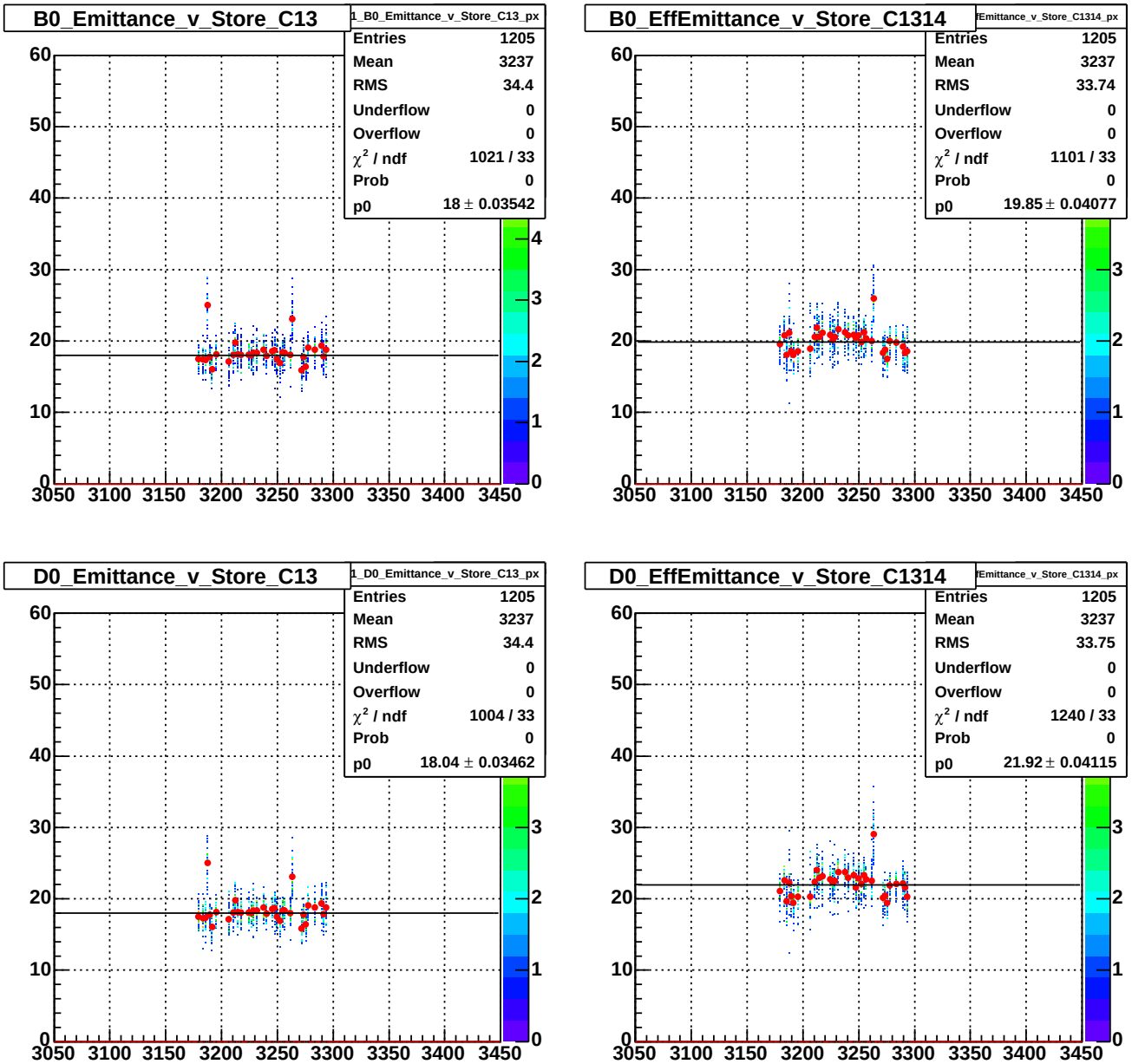

Figure 9: B0 and D0 measured and Effective (calculated) Emittance (in $\pi \cdot mm \cdot mrad$)) versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first Set of HEP Case. Stores 3179–3293.

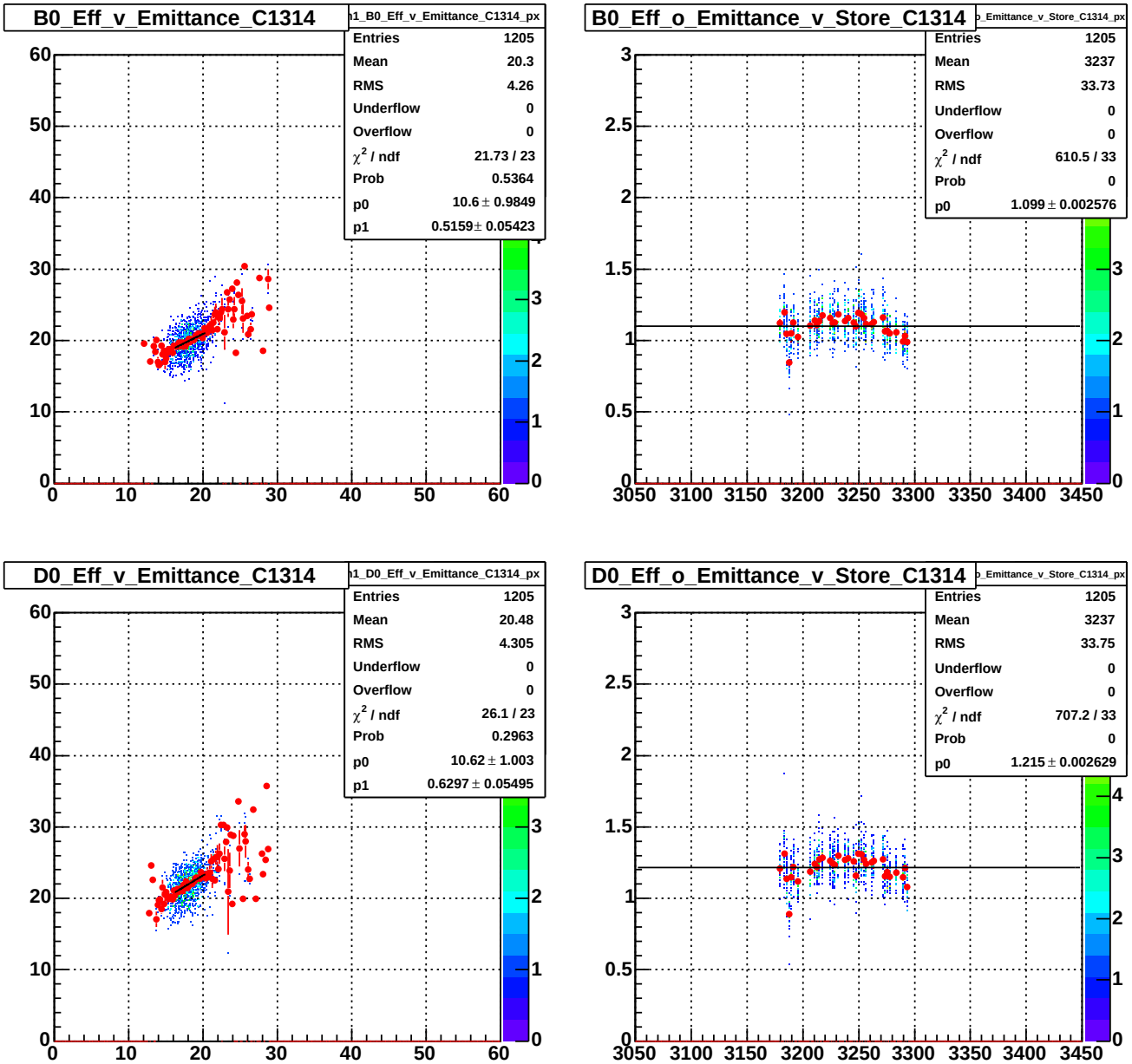

Figure 10: B0 and D0 calculated (Effective) versus measured Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first Set of HEP Case. Stores 3179–3293.

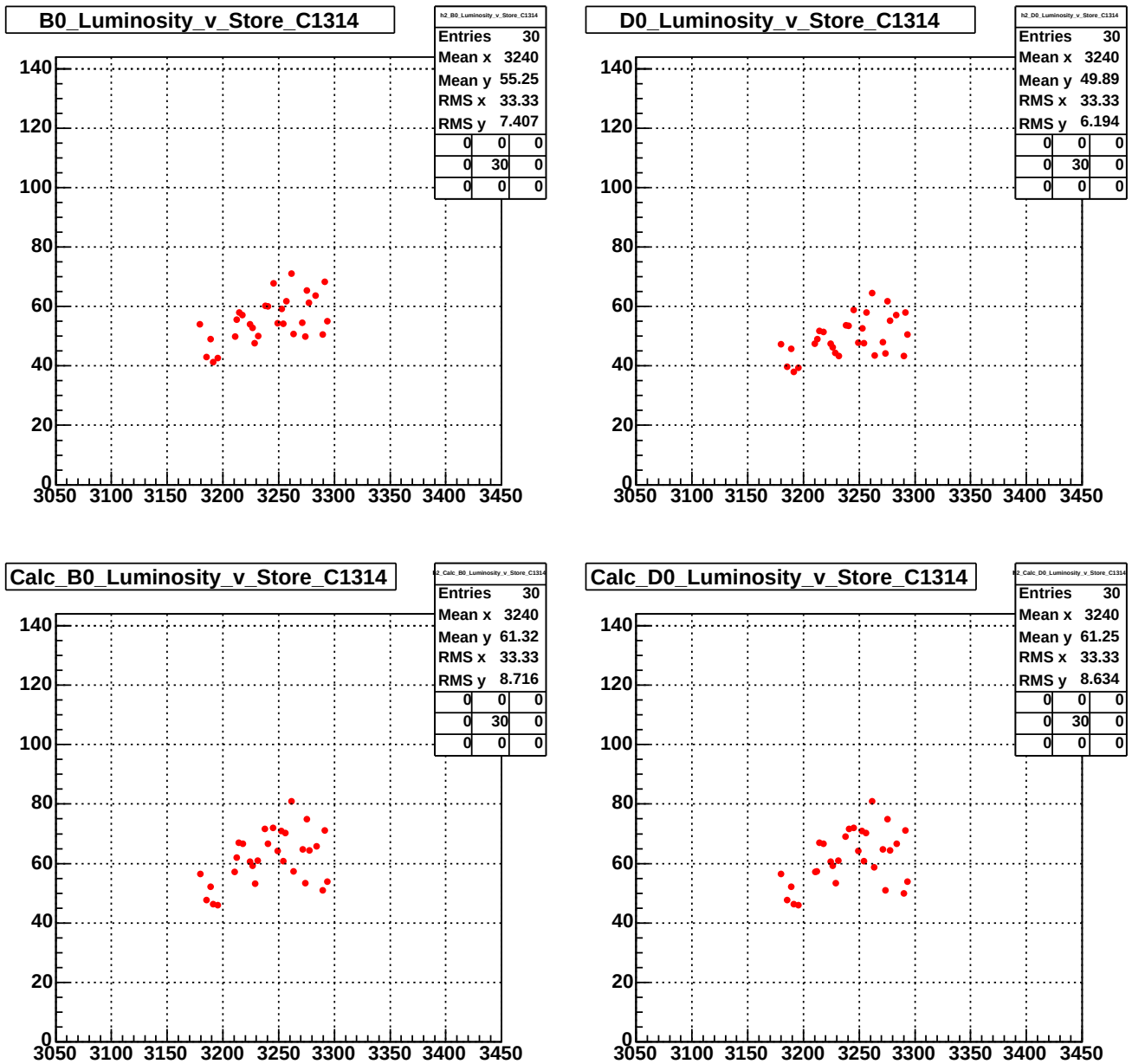

Figure 11: B0 and D0 measured and calculated Luminosities (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus Store Number. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

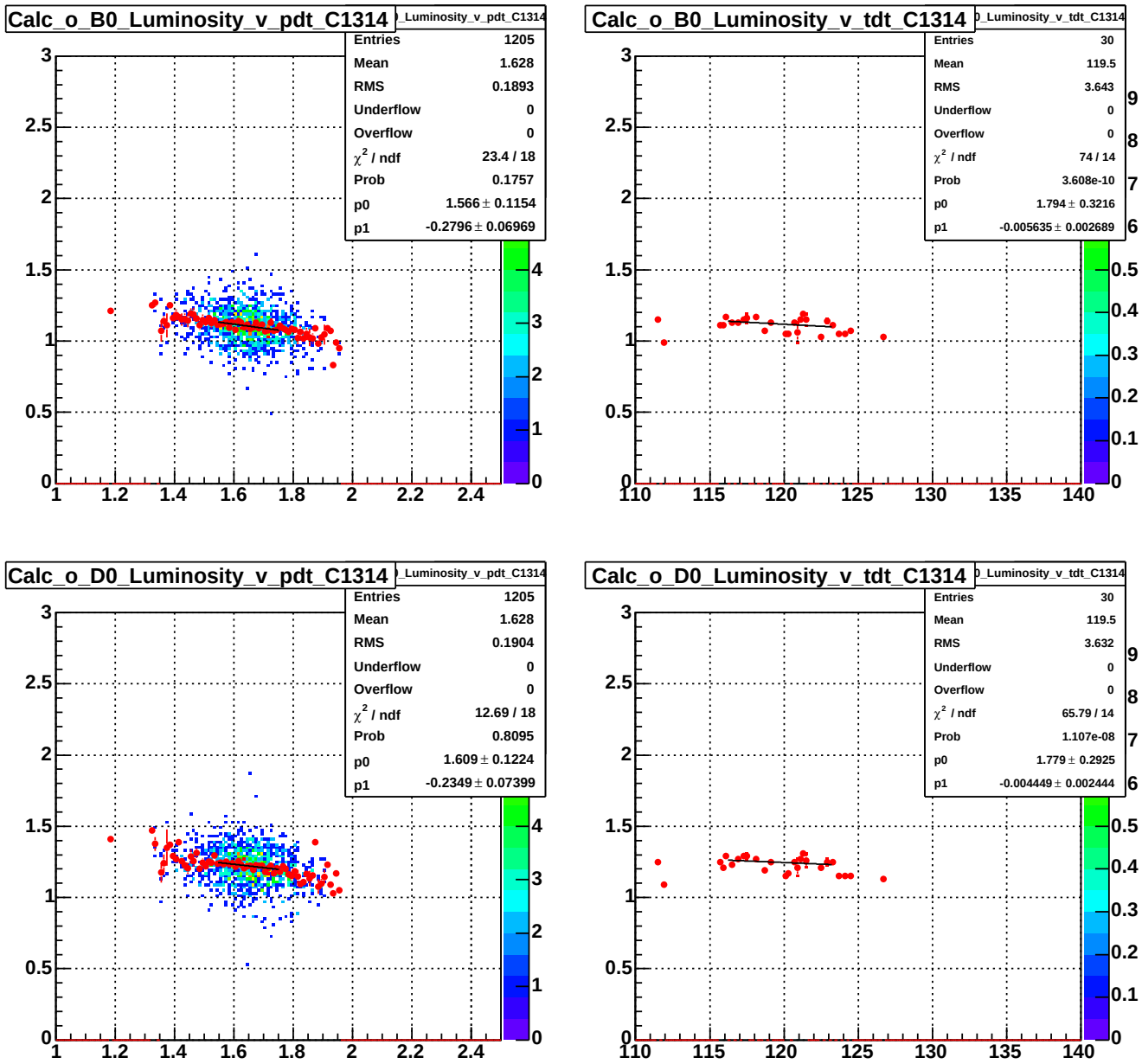

Figure 12: Calculated Bunch Luminosity over measured one versus Proton Bunch Length for B0 and D0 locations together with Calculated Total Luminosity over measured one versus Total Sum of All Bunch Lengths. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

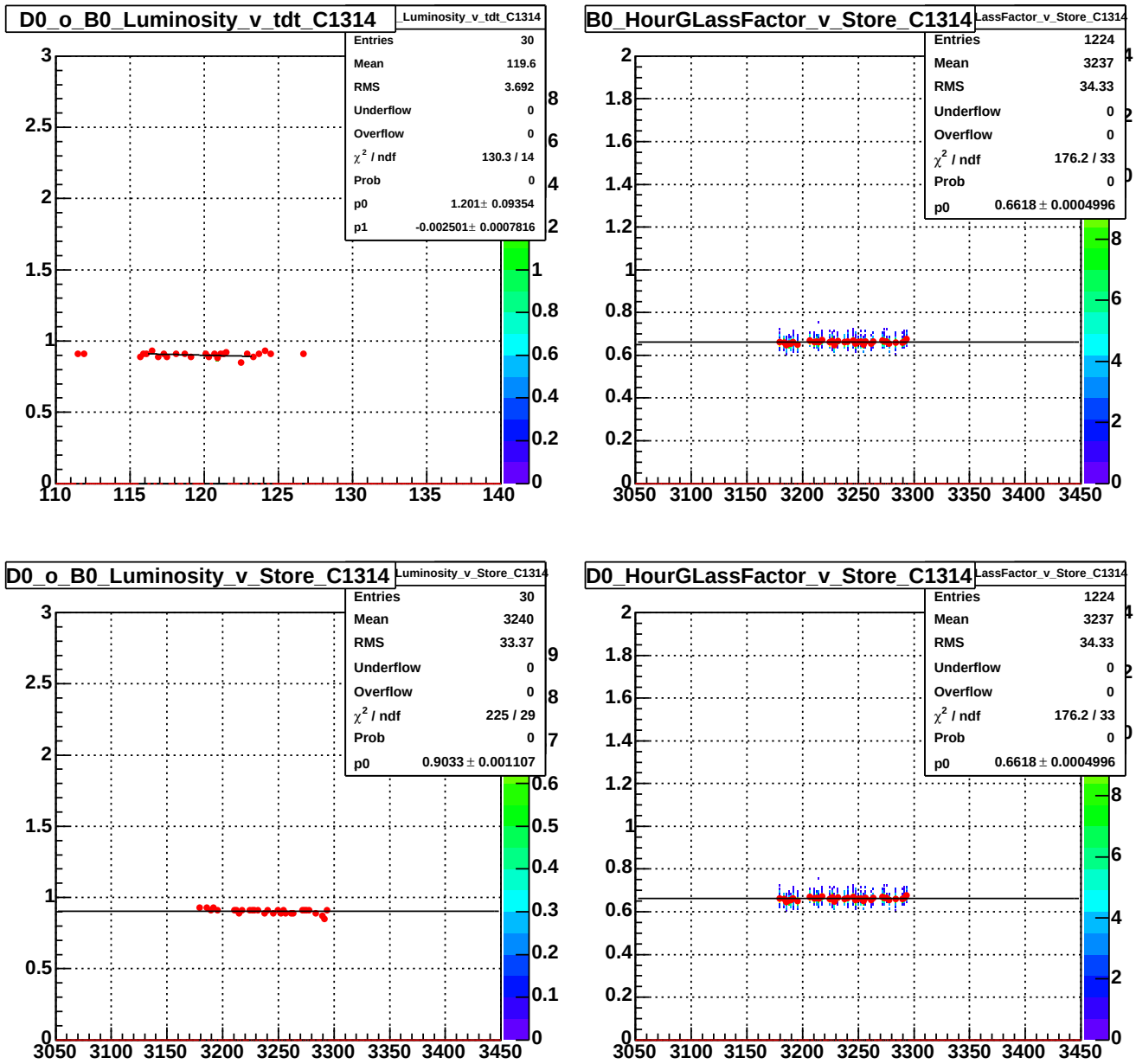

Figure 13: Total D0 over B0 Luminosity Luminosity versus Total Sum of All Bunch Lengths; B0 and D0 Hour Glass Factor versus Store Number together with Total D0 over B0 Luminosity Luminosity versus Store Number. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first Set of HEP Case. Stores 3179–3293.

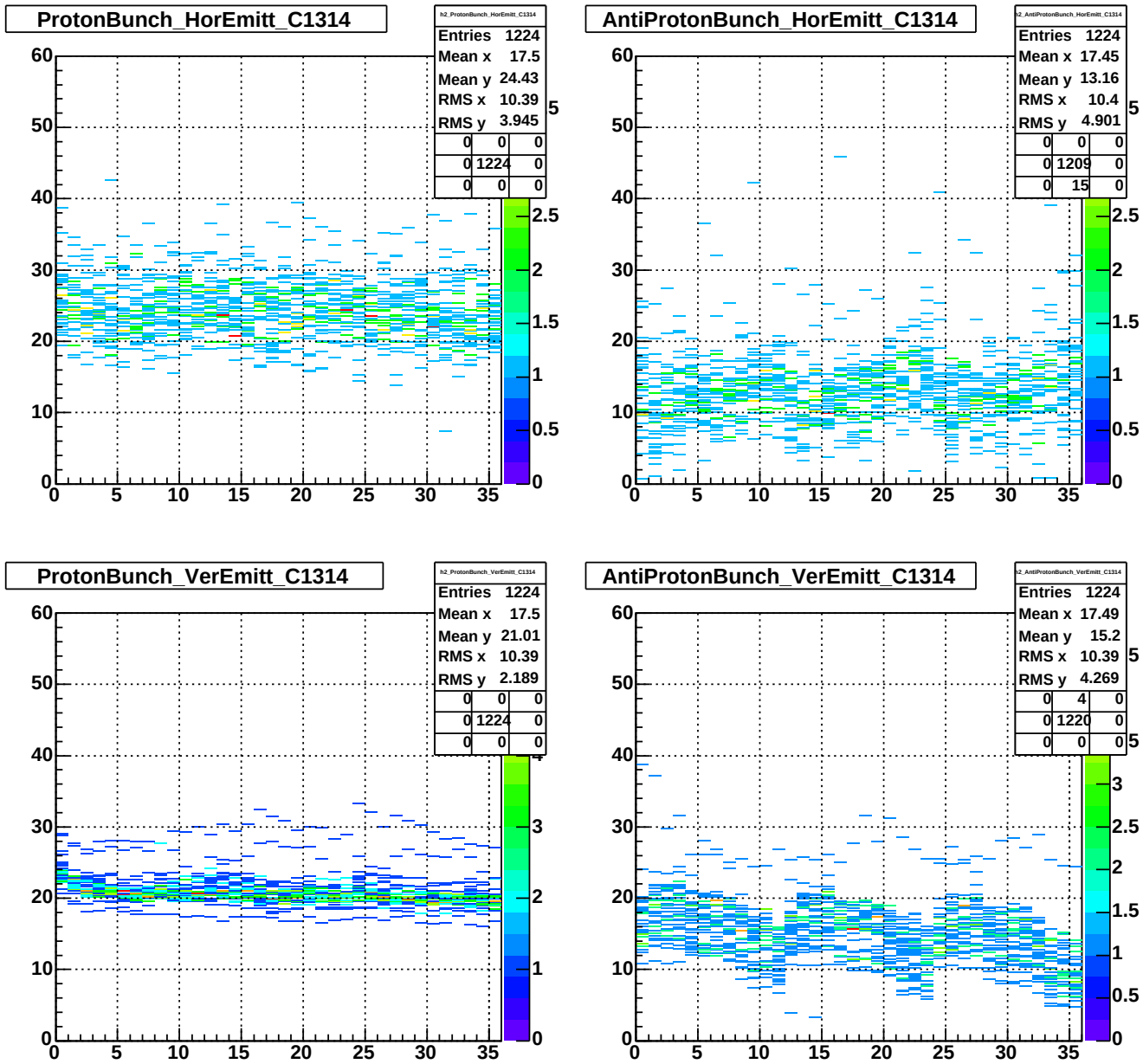

Figure 14: Horizontal Proton and Antiproton Emittance (in $\pi \cdot mm \cdot mrad$)) together with Vertical Proton and Antiproton Emittance versus Bunch Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Stores 3179–3293.

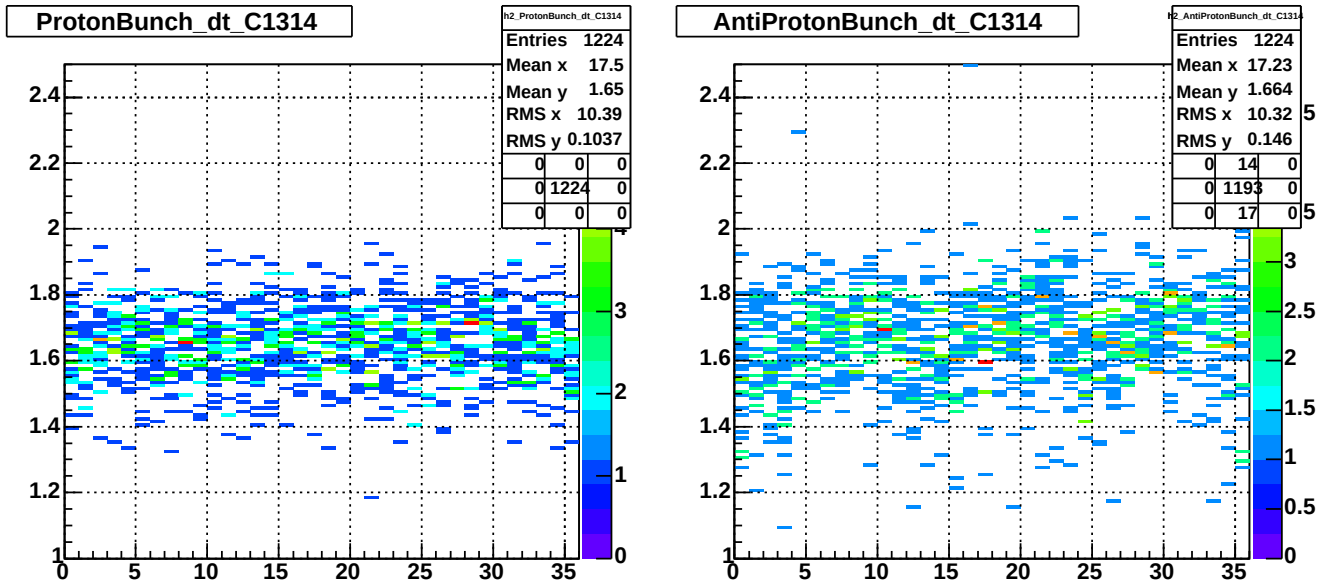

Figure 15: Proton and Antiproton Bunch Length (in *ns*) versus Bunch Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Stores 3179–3293.

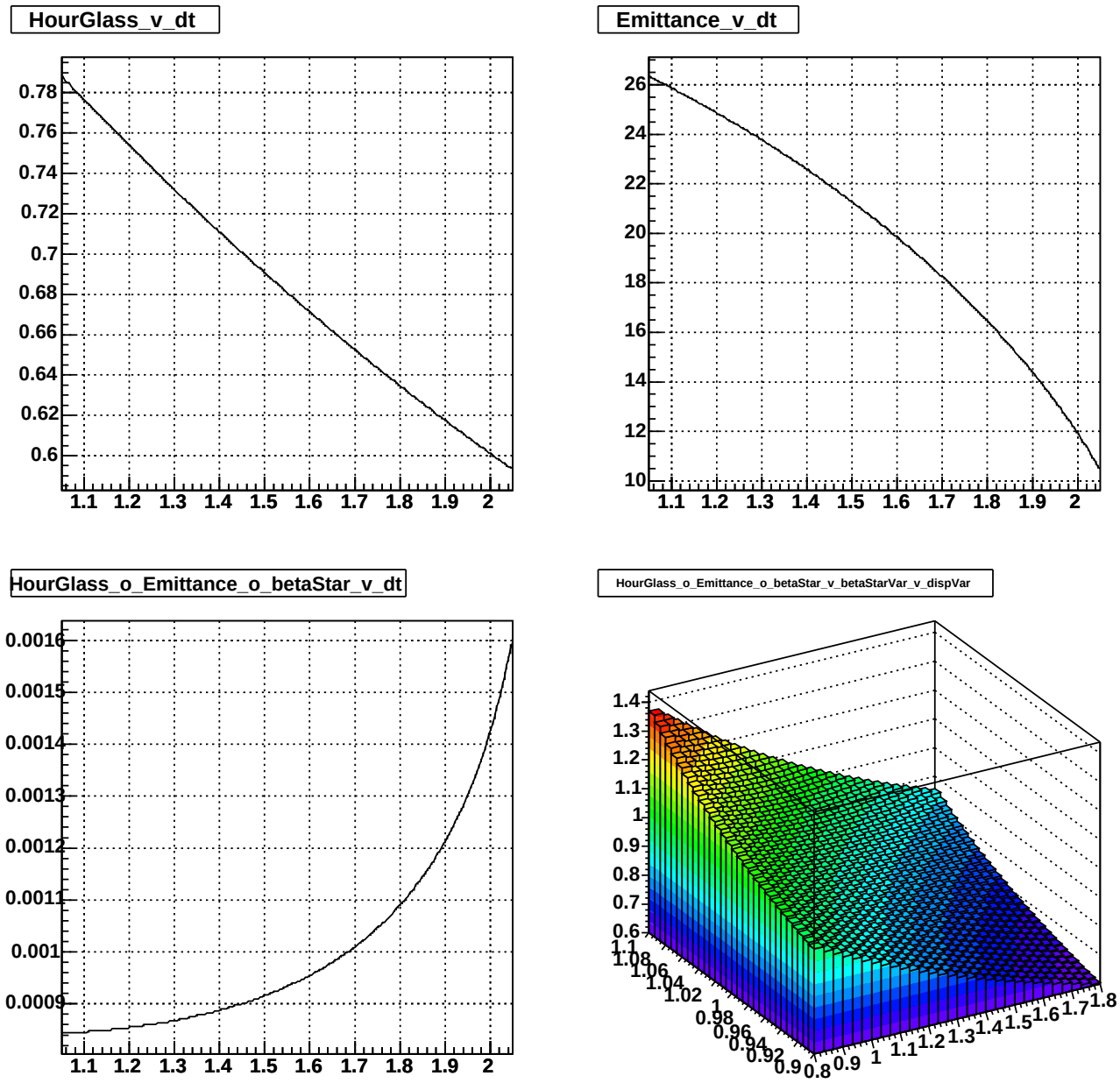

Figure 16: Predicted Hourglass Factor versus Bunch Length (in *ns*) ; Predicted Emittance (in $\pi \cdot mm \cdot mrad$)) versus Bunch Length, and Hourglass Factor divided by the Emittance and beta star (in $10 \cdot \pi^{-1} \cdot mrad^{-1}$) as a function of bunch length; Relative change in Hourglass Factor divided by the Emittance and beta star versus relative change of beta star and horizontal dispersion Stores 3179–3293.