# On Tevatron Beam Transverse Emittance and Luminosity at CDF and D0
# Beams-doc-1002
# Version 1.0

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## Abstract

We present data pertaining to Tevatron Effective Beam Emittance and Luminosity for stores in 3052 to 3147 range.

## 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 a previous note [4] and covers a new store range.

## 2 Data Selection

The stores for this analysis were selected from post November 2003 startup running period namely stores 3052–3132 with the exception of the store 3053. The resulting 15 stores were: 3052, 3057, 3080, 3083, 3101, 3103, 3108, 3118, 3120, 3122, 3123, 3125, 3127, 3130, 3132. The stores correspond to the period when horizontal E11 flying wire was operational and occurred before January 19th when there was a change in D0 luminosity determination procedure.

The Tevatron Case chosen for analysis was "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 rescaled according to the "Flattop" Case T:IBEAM and SBD measurements. It was required that this rescaling 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 Antiproton Bunch Intensity had to be greater than $15 \cdot 10^{9}$.

## 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

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

$\delta t$ is the T:SBD[A,P]WS ACNET variable (longitudinal beam bunch spread in ns), $p$ is the beam momentum in GeV, $\gamma_L$ is the Lorentz gamma, $\sigma$ are bunch width as measured by each of the detectors (ACNET variables T:FW[H,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 $\beta$ lattice functions at E11 location (location of the 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 formulas from [3]:

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

| Detector | beta Function [m] | dispersion Function [m] |
|---|---|---|
| FW E11H $p$ & $\overline{p}$ | 80.161 | 2.030 |
| FW E11V $p$ & $\overline{p}$ | 80.804 | |

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

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 and rescaled 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 35.6$cm$). $H$ 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 $\sigma_l$ 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. 1 shows calculated Bunch Luminosity over the measured one versus the measured one for B0 and D0 locations. One can see that the predicted luminosity is overestimated by about 35%. From the two plots related to B0 measured luminosity one can see that either the B0 luminosity detectors seem to overestimate luminosity for higher values or that the calculated luminosity is underestimated due to an unknown effect or that something was changed during the store range under study. The above plots differ significantly from the plots from the previously studied store range [4]. 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 although the ratio of the two is closer to one than it was before (an average ratio of about 0.97).

Fig. 2 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 although there may be a sign of a discontinuity in the profile of the B0 Effective Emittance distribution. The Effective Emittance is about 35% higher than the measured Emittance.

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 note [4].

We would like to point out that during the store period luminosity was changing significantly (Fig. 11) from 20 to 50 $\cdot 10^{30} \cdot cm^{-2} \cdot sec^{-1}$ and that other beam related quantities were showing significant store to store fluctuations, e.g. ratios of vertical and horizontal Bunch Emittance (Fig 8), Effective Emittance (Fig 9) Effective Emittance ratios (Fig 10) or measured Emittance especially the one for antiprotons, possibly suggesting that the accelerator characteristics were changing significantly over the store range under study. One of the significant changes was the move of B0 interaction point which took place before store 3101.

# 5 Conclusions

More studies are needed to understand the observed effects and especially the changes of the quantities which should remain constant from store to store like the ratios of the effective and measured emittances.


## Acknowledgments

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

## References


[1] M. Church, *A Study of the Emittances of P1 during Proton Injections for Store 2070*, talk on 01/16/2003, Beams-doc-694-v1 Note
http://www-bd.fnal.gov/sdahomepage/osda/devices/p1_2070_study_pdf.pdf

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

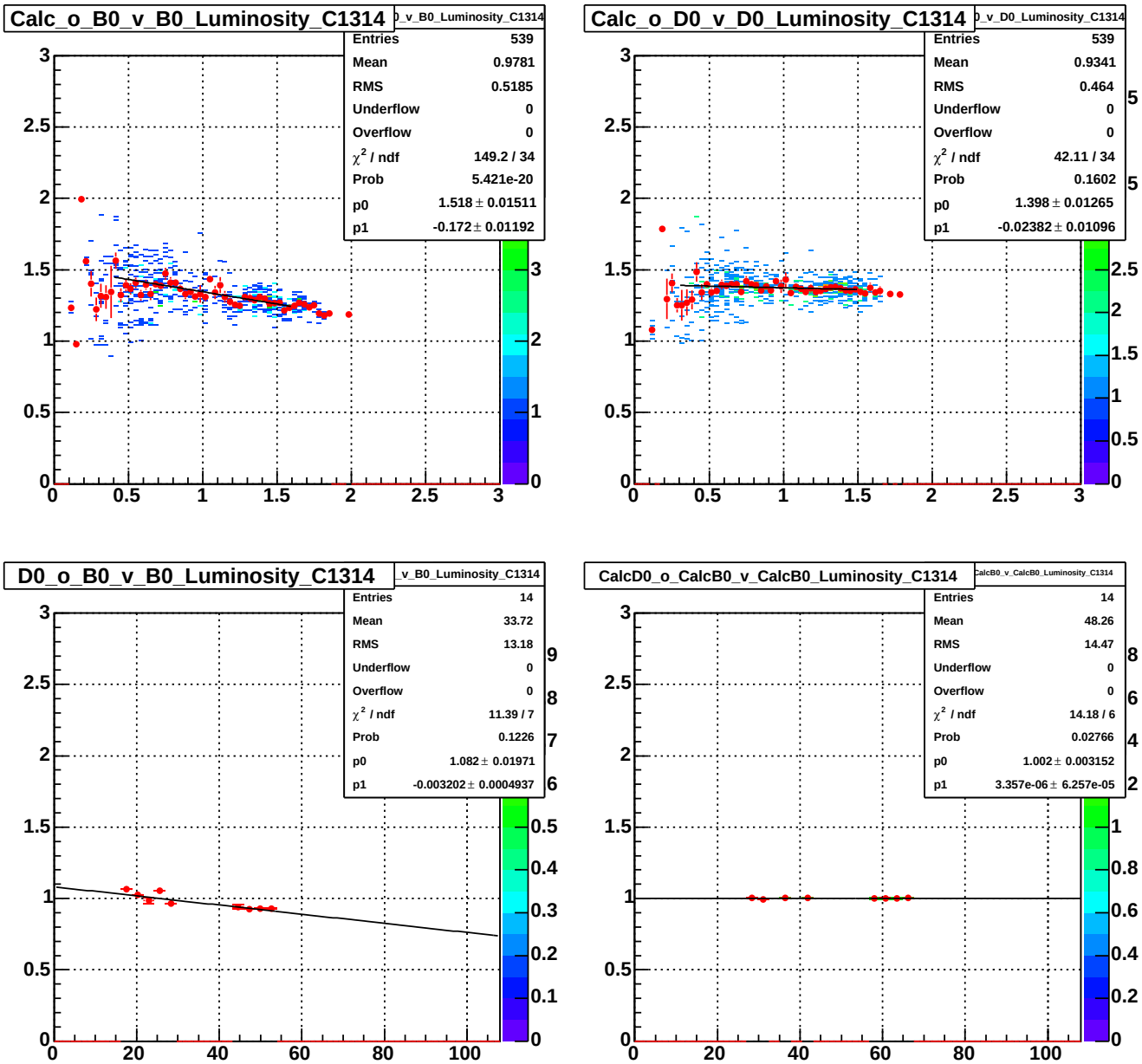


Figure 1: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. 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 HEP Case Set. Stores 3052–3132.

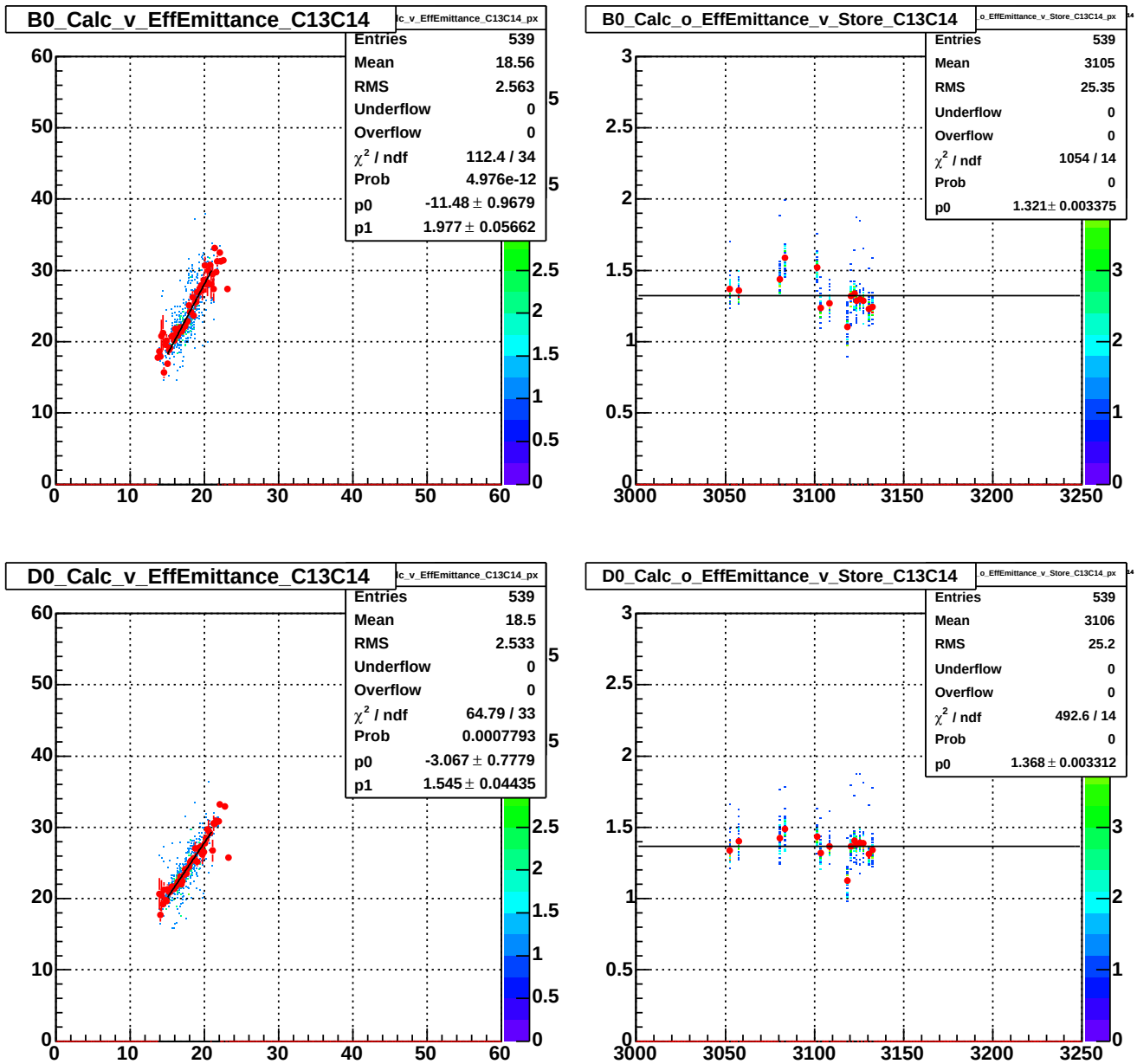


Figure 2: B0 and D0 calculated (Effective) versus measured Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores 3052–3132.

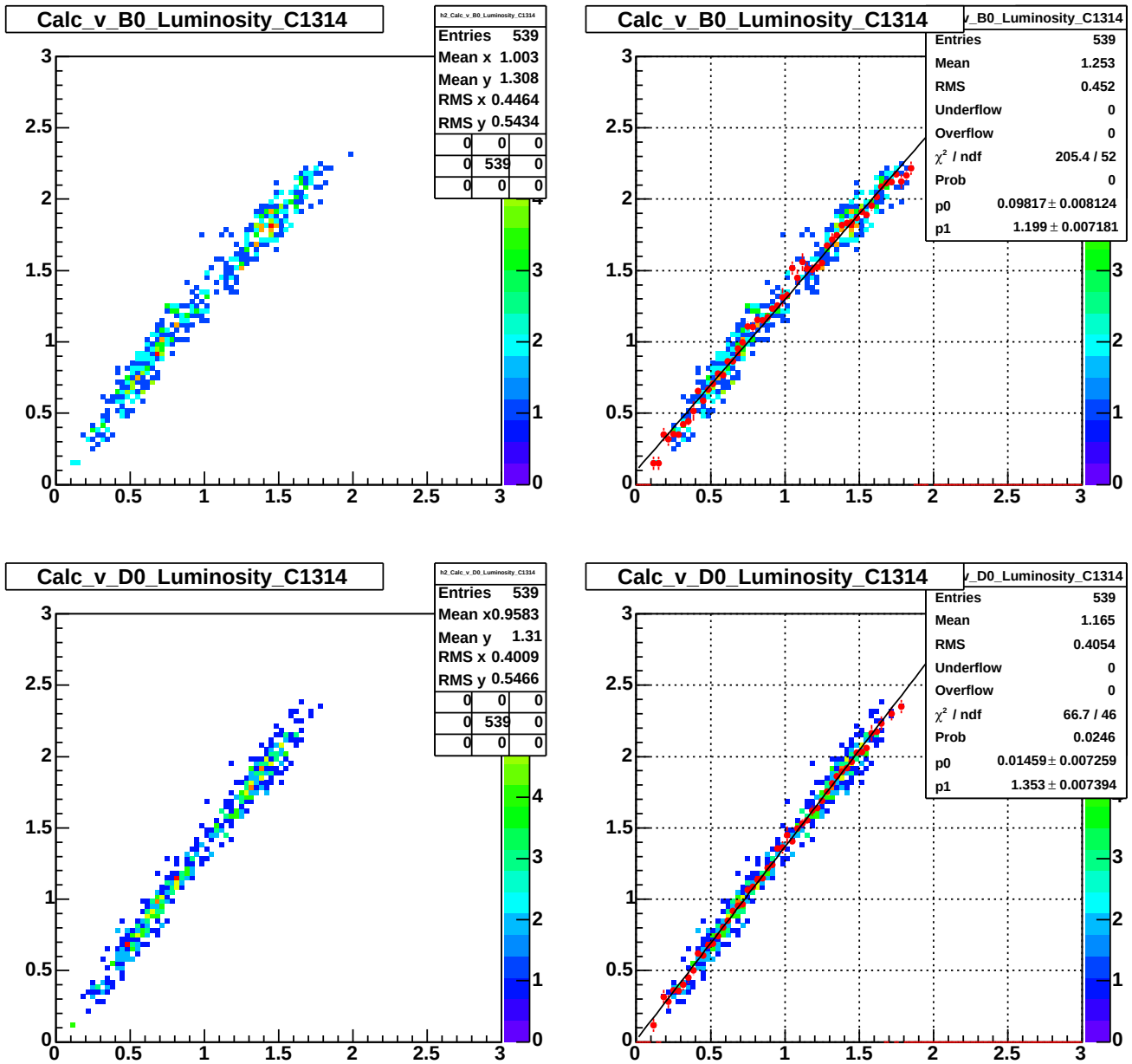


Figure 3: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus measured one for B0 and D0 locations (shown with and without a straight line fit to the profile of the histograms). Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires 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 HEP Case Set. Stores 3052–3132.

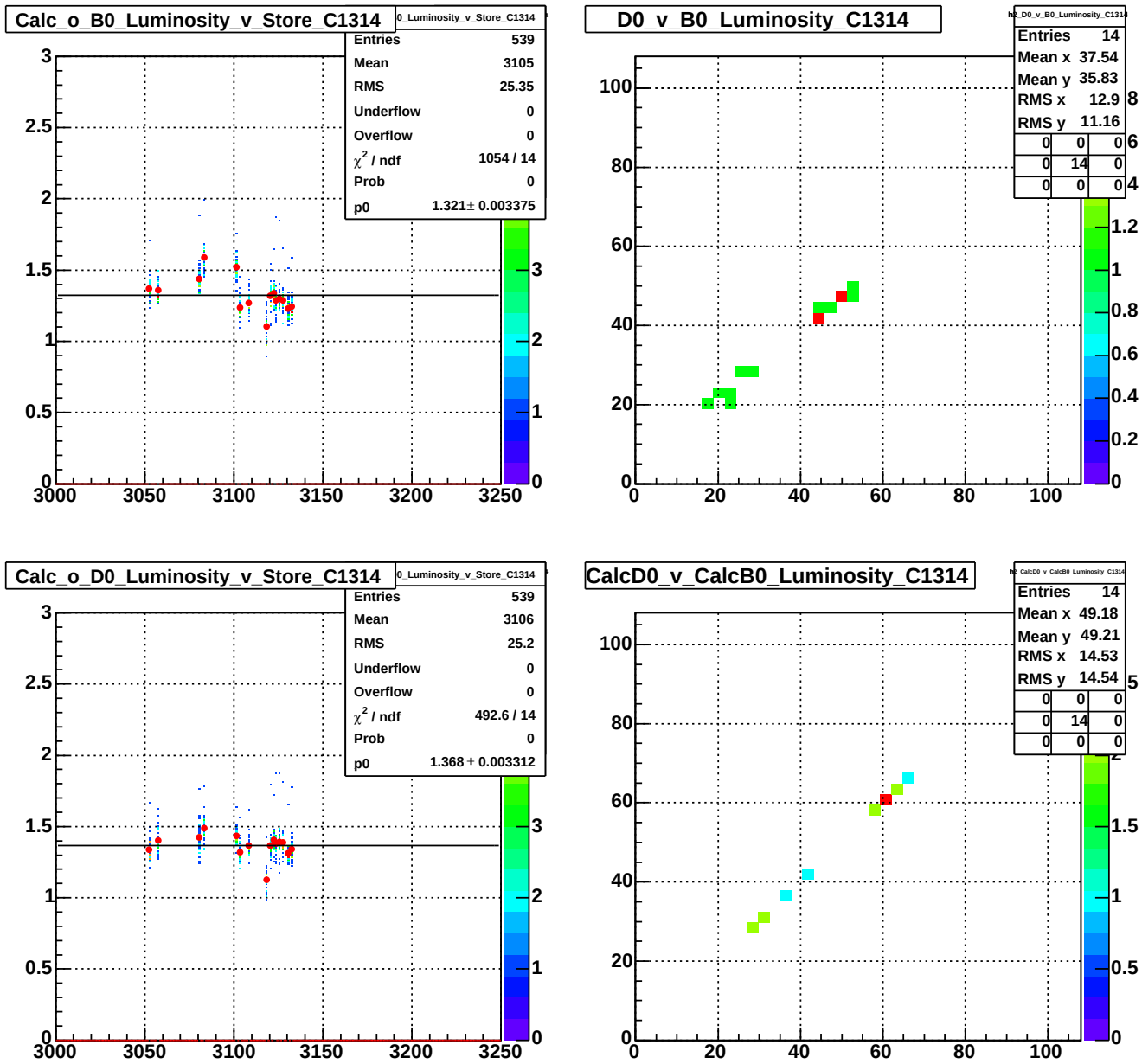


Figure 4: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus Store Number for B0 and D0 locations together with total measured D0 v B0 Luminosity and total calculated D0 v B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case 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 HEP Case Set. Stores 3052–3132.

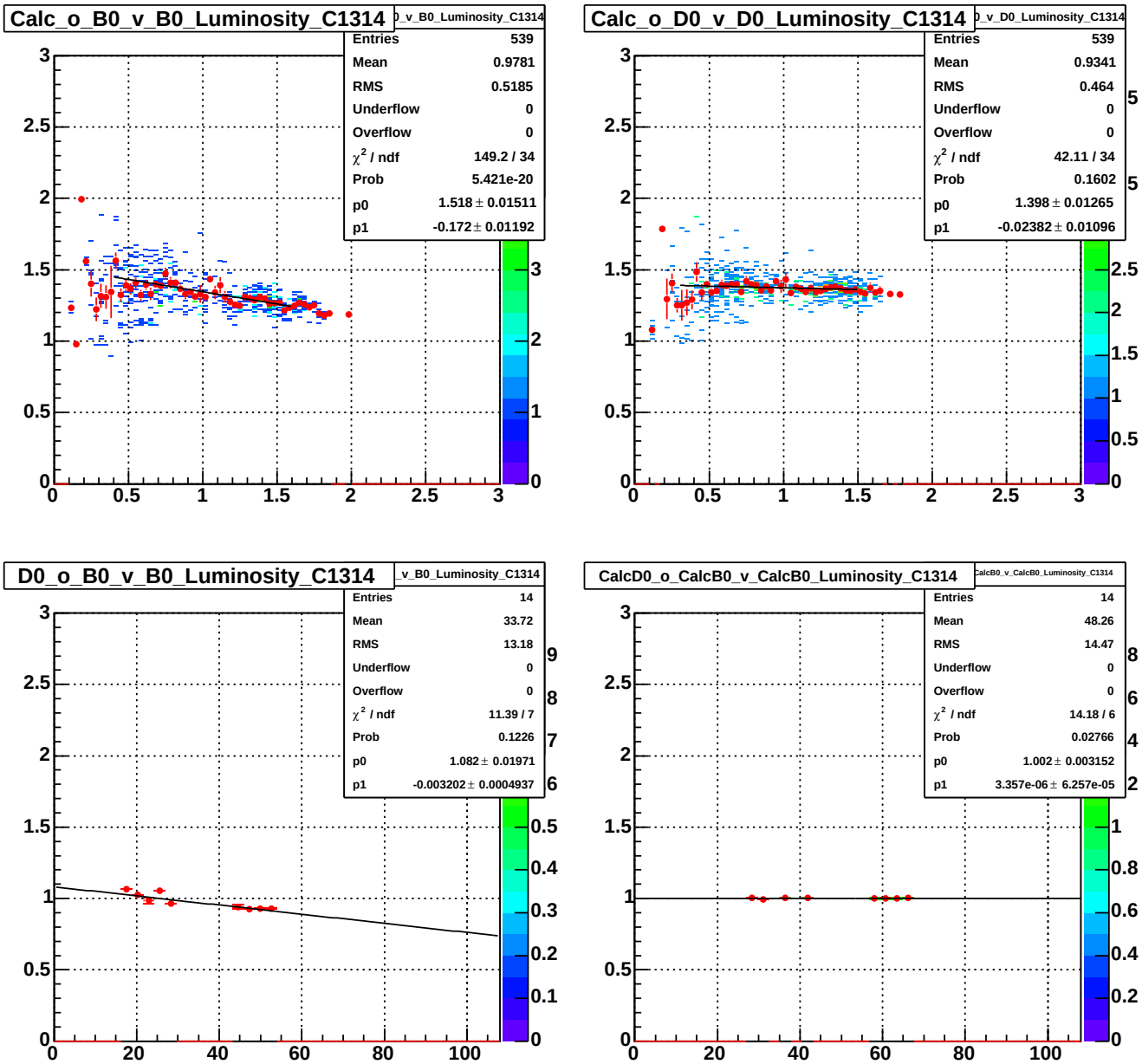


Figure 5: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. 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 HEP Case Set. Stores 3052–3132.

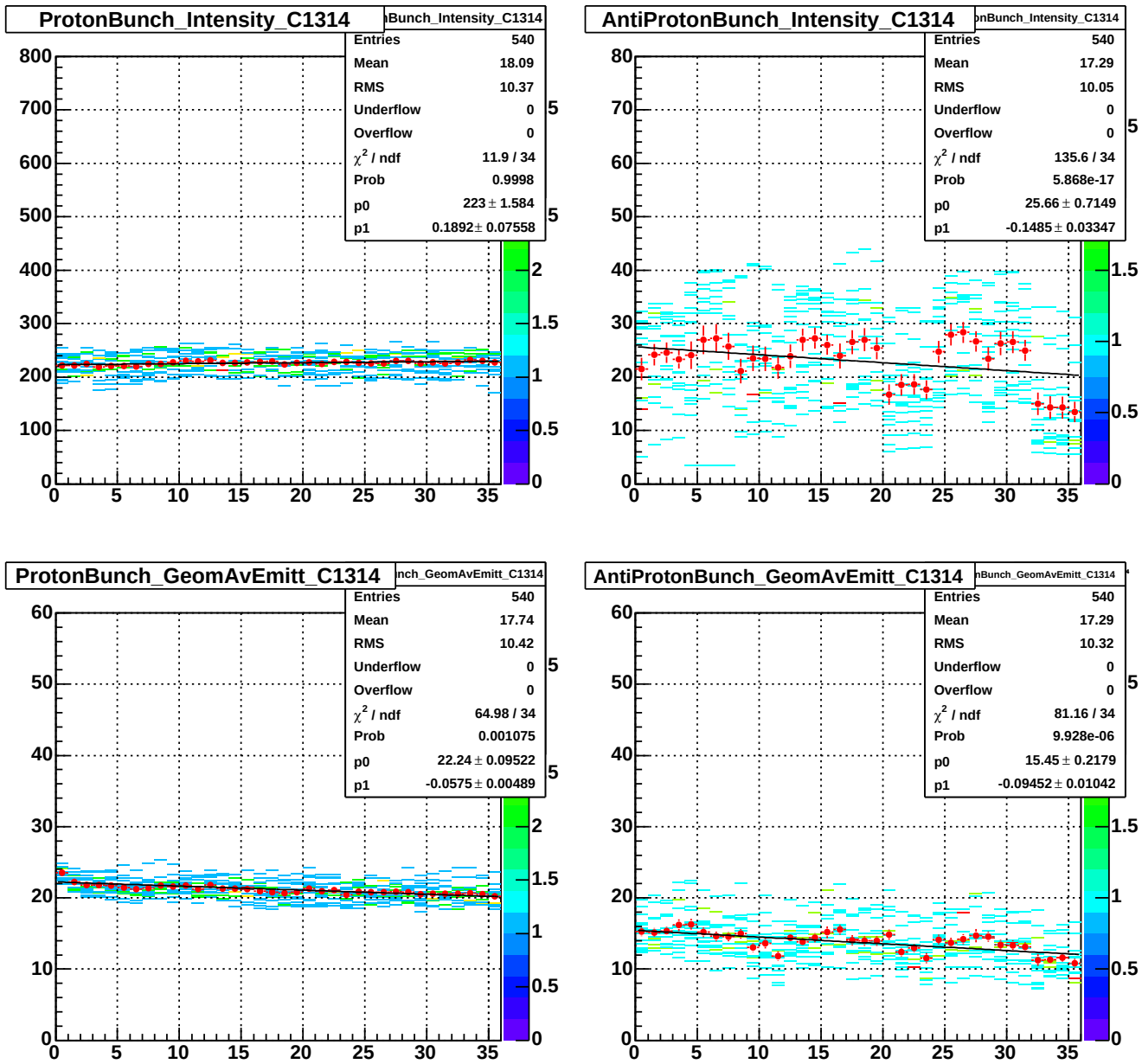


Figure 6: Bunch Intensity (in $10^9$) and (Geometrical) Average Transverse Emittance (in $\pi \cdot mm \cdot mrad$)) for Proton and Antiproton Bunches. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Stores 3052–3132.

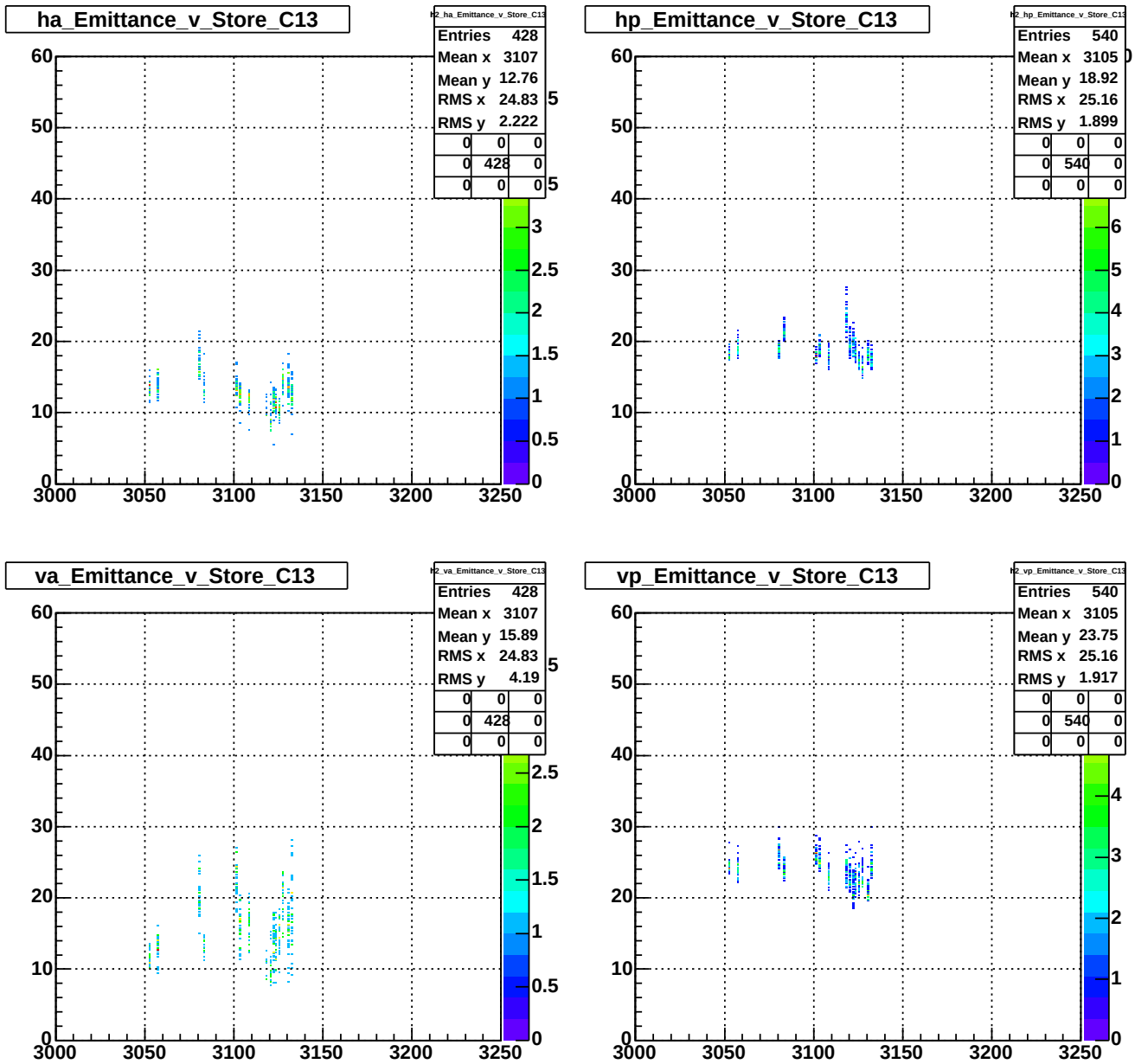


Figure 7: Horizontal Antiproton and Proton Emittance (in $\pi \cdot mm \cdot mrad$)) together with Vertical Antiproton and Proton Emittance versus Store Number. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Stores 3052–3132.

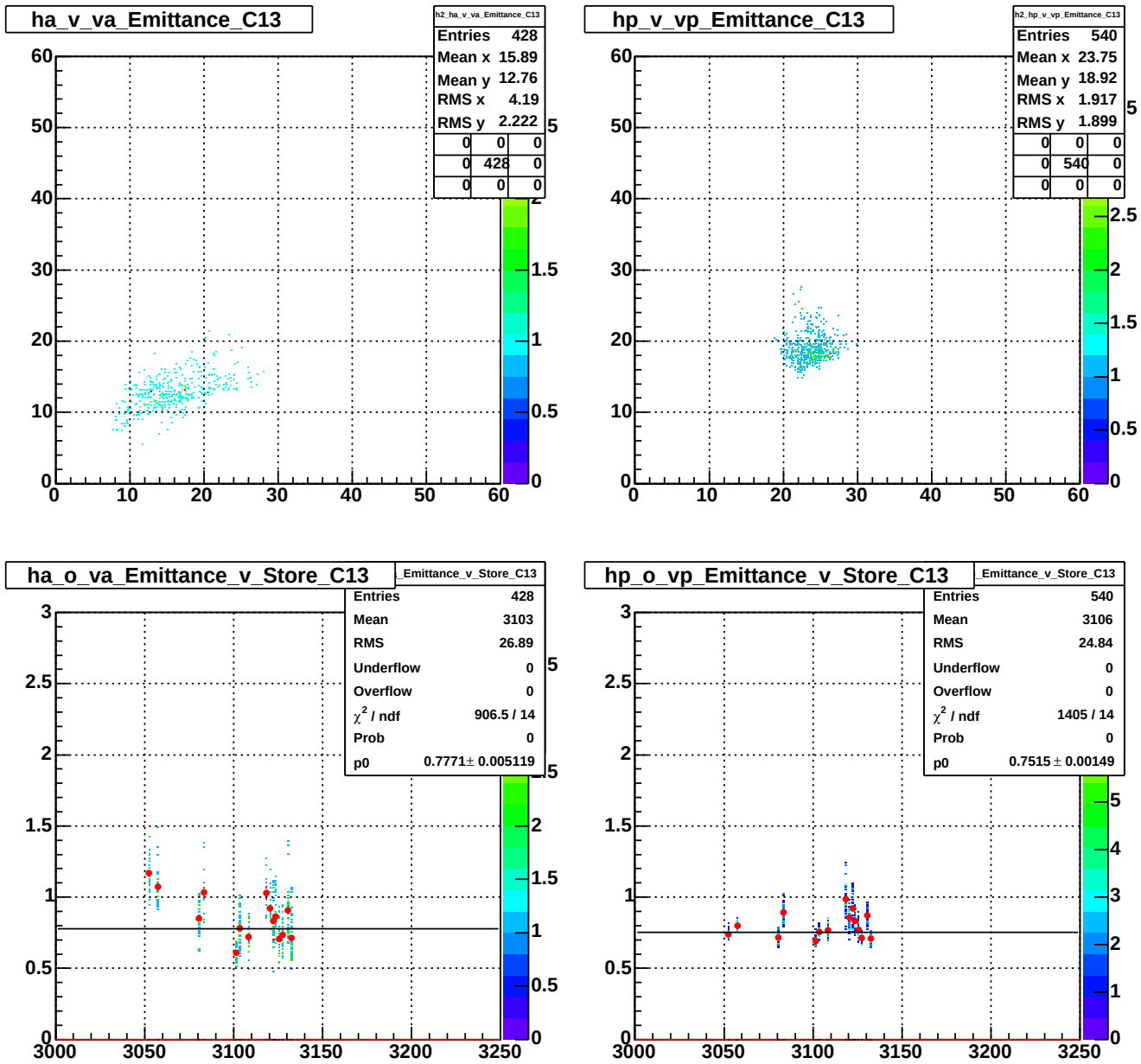


Figure 8: Horizontal Antiproton Emittance (in $\pi \cdot mm \cdot mrad$)) versus Vertical Antiproton Emittance (same for Protons) together with Horizontal Antiproton Emittance over Vertical Antiproton Emittance versus Store (same for Protons). Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Stores 3052–3132.

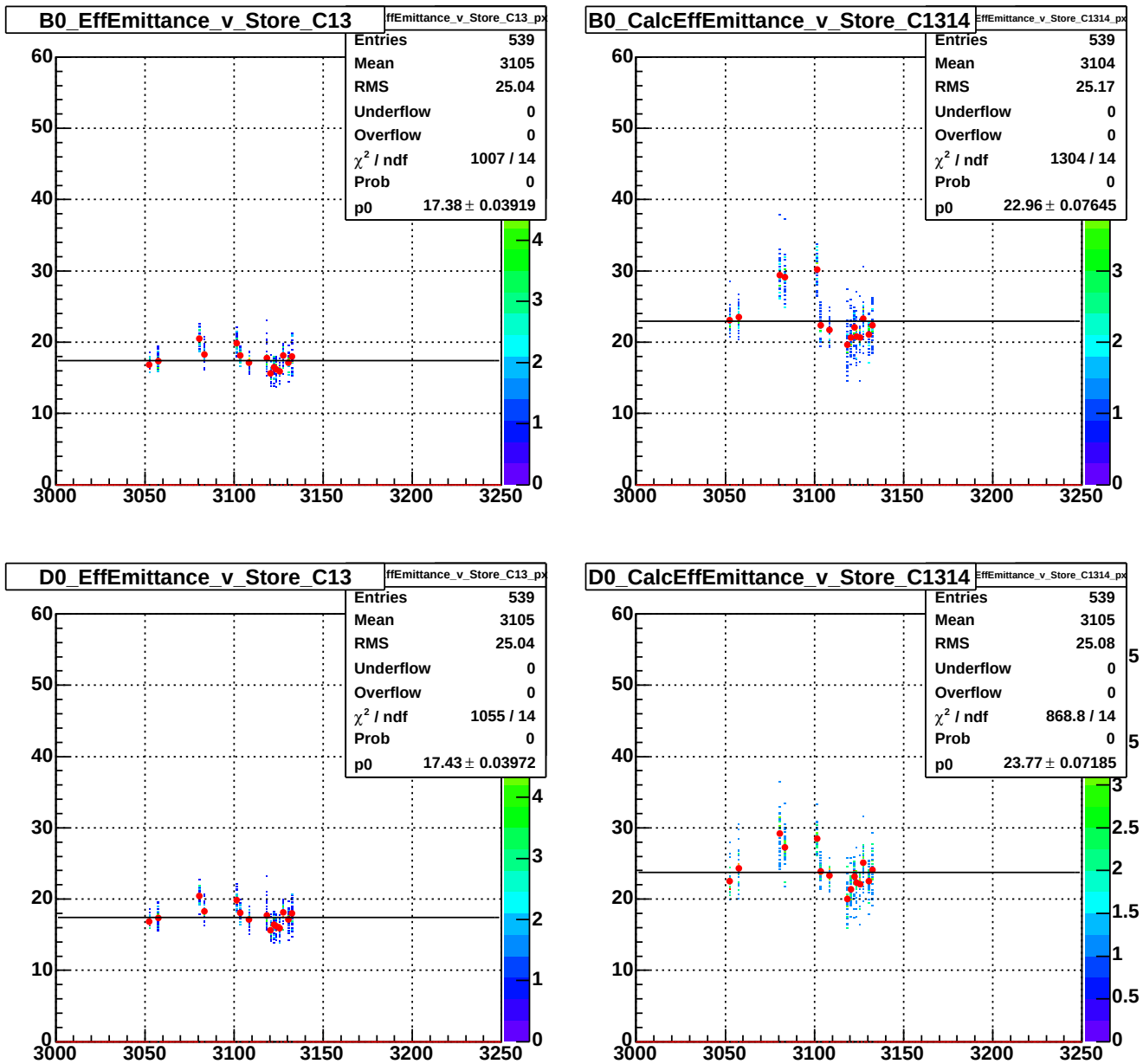


Figure 9: B0 and D0 measured and Effective (calculated) Emittance (in $\pi \cdot mm \cdot mrad$)) versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores 3052–3132.

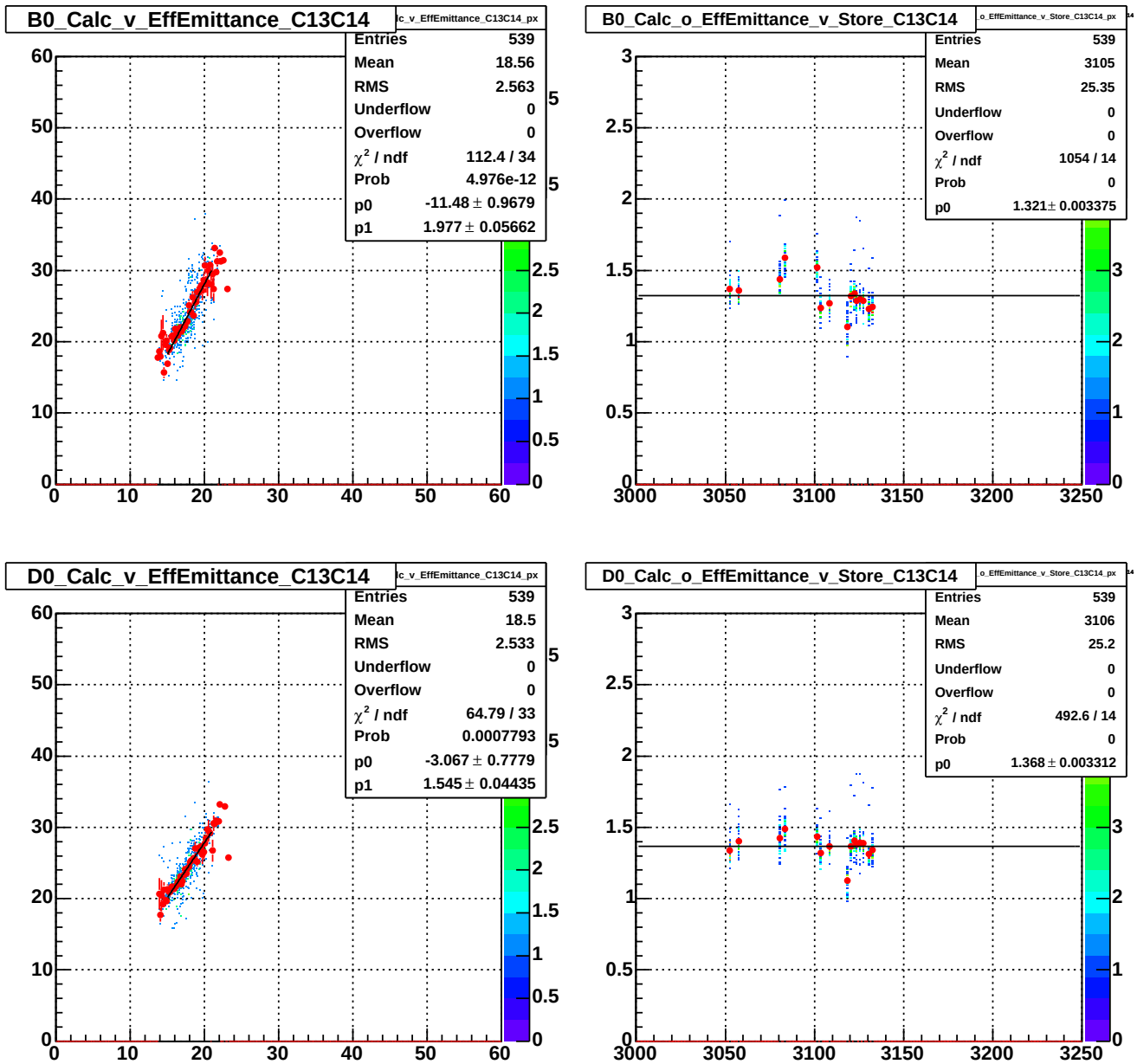


Figure 10: B0 and D0 calculated (Effective) versus measured Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Effective Emittance based on Bunch Intensities measured with SBD (rescaled according to the T:IBEAM measurement) and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores 3052–3132.

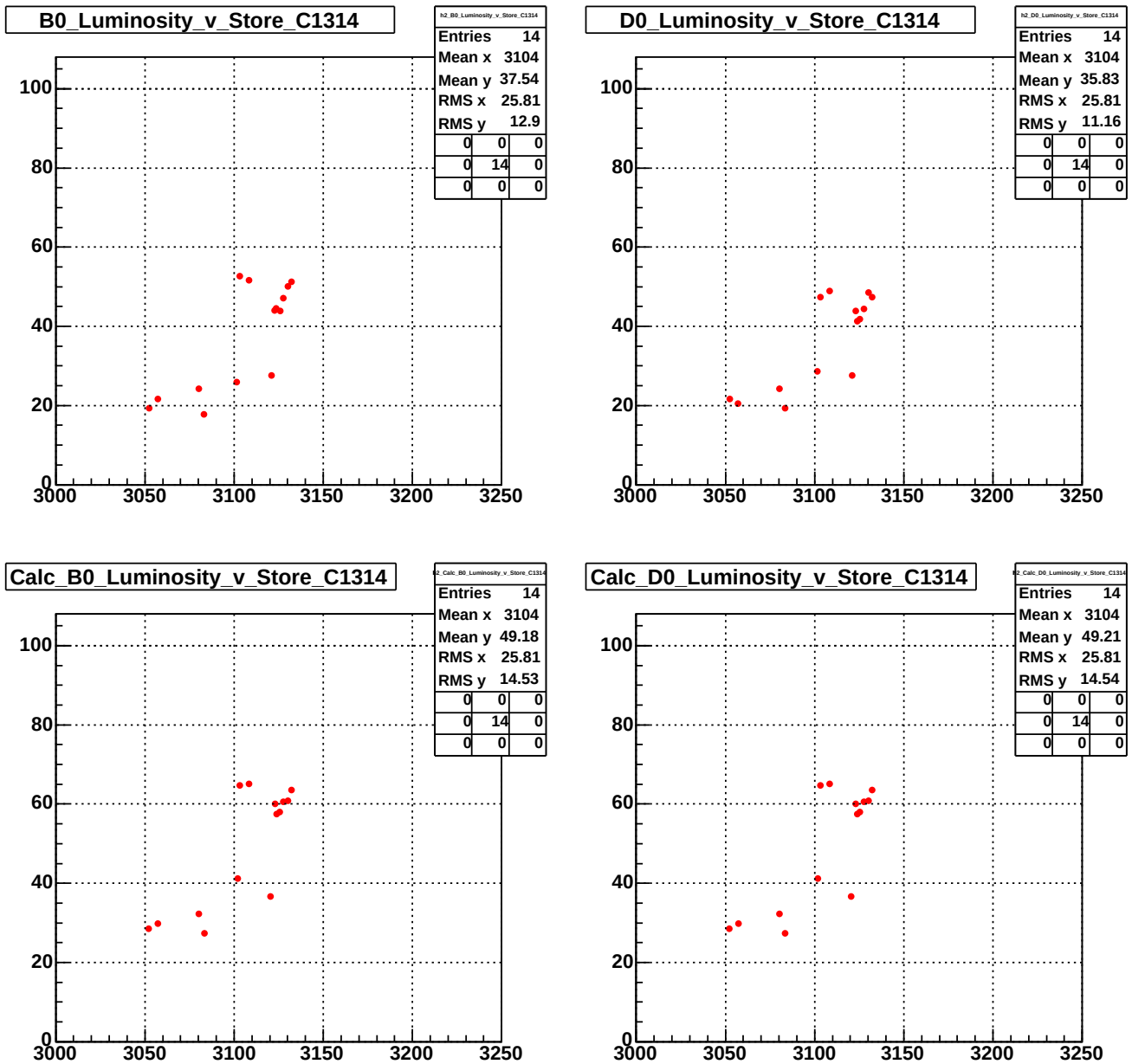


Figure 11: B0 and D0 measured and calculated Luminosities (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus Store Number. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD (rescaled according to the T:IBEAM measurement). Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores 3052–3132.