On Tevatron Beam Transverse Emittance and Luminosity at CDF and D0 Version 1.0

Krzysztof Genser
September 10th 2003

Computing Division, Fermilab

Abstract

We present data pertaining to Tevatron Effective Beam Emittance and Luminosity for stores in 2500 to 3000 range.

1 Introduction

We study Tevatron Transverse Effective 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 and D0 (and recorded in C:B0ILUM and C:D0ILUM ACNET variables) using formulas described below.

2 Data Selection

The stores for this analysis were selected from May-September 2003 running period namely stores 2500–3000 with the exception of stores: 2560–2646, 2746, 2805, 2973, 2988 since they were considered atypical.

The Tevatron Case chosen for analysis was "Remove Halo" (with the beam energy of 980GeV) and 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. Other requirements imposed on the data were: For Luminosity and Effective Emittance plots: B0 and D0 measured effective bunch emittance had to be smaller than 25 $\pi \cdot mm \cdot mrad$ 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 formulas described in [4]:

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

where

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

δt is the T:SBD[A,P]SS 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[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).

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]:

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

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), $\beta_r\gamma_r$ 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 caclulated 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).

4 Results

Fig. 1 shows B0 and D0 Effective Emittance calculated based on measured Luminosity compared to the Effective Emittance as measured using Flying Wires. One can see that the calculated (predicted) Effective Emittance depends quite linearly on the measured one and that the calculated Emittance predicted based on the Luminosity measurements is about 25–40% higher than the measured Effective Emittance.

Fig. 2 shows calculated Bunch Luminosity over measured one versus measured one for B0 and D0 locations. It 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. From the two plots related to D0 measured luminosity one can conclude that the D0 luminosity detectors seem to saturate at higher luminosities.

The remaing figures (3–18) are included for completeness (with the two already shown figures included once again in the different context to make comparisons easier) and to show the effect of inserting light attenuators in the antiproton Flying Wires detector systems. First set of figures 3–10 shows data for the entire 2500 to 3000 store range before and after attenuators insertion, whereas figures 11–18 show stores after light attenuators insertion only (Stores 2668-3000).

From plots on Figure 4 and 9 (compared to Fig. 12 and 17) one can see that the insertion of attenuators had a significant effect on the Transverse Emittance measurements (esp. given the fact that the bunch intensities remained basically unchanged over the entire period (Figures 6 and 14). Figures 6 and 14 also show that Bunch Emittance is smaller for higher bunch numbers for protons and that bunch Emittance and Intensity is smaller for antiprotons. Bunch Emittance for antiprotons had decreased after attenuators had been inserted (Fig 7).

The more correct emittance measurements lead to different dependencies of the ratio of calculated and measured B0 and D0 Luminosities versus Luminosity (Figures 5 and 13).

Comparisons of vertical and horizontal Bunch Emittance show that the horizontal emittance is about 0.7 of the vertical one (Figure 16).

5 Conclusions

1. Inserting attenuators in the Antiproton Flying Wire scintillator system had a very significant effect on the Transverse Emittance measurements and therefore on the predicted luminosity values.

2. Effective Emittance is about 20-30% lower than the calculated emittance predicted based on the luminosity measurements (Fig. 1).

3. D0 Luminosity Detectors seem to saturate at higher luminosities (Fig. 2).

It is worth to note that the calculated total luminosity for CDF is equal to that one for D0 and their ratio remains constant over the observed luminosity range.

Acknowledgments

We would like to thank Paul Lebrun, 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, 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, *A Snapshot of Tevatron Flying Wire and Synchrotron Light Detector Transverse Emittance Measurements at 980GeV*, Note dated 06/03/2003

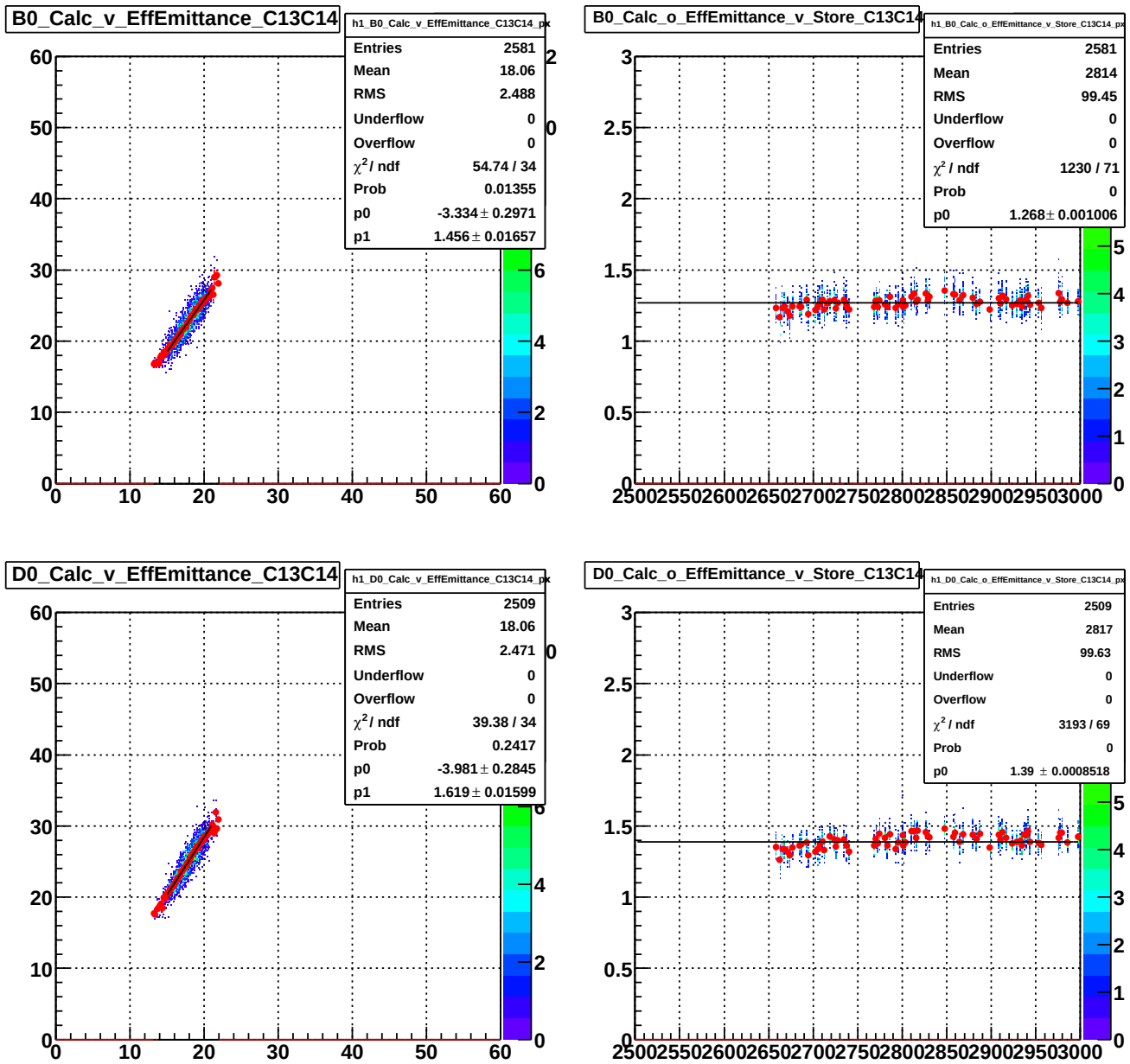

Figure 1: B0 and D0 calculated versus measured Effective Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Effective Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Calculated Effective Emittance based on Bunch Intensities measured with SBD and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

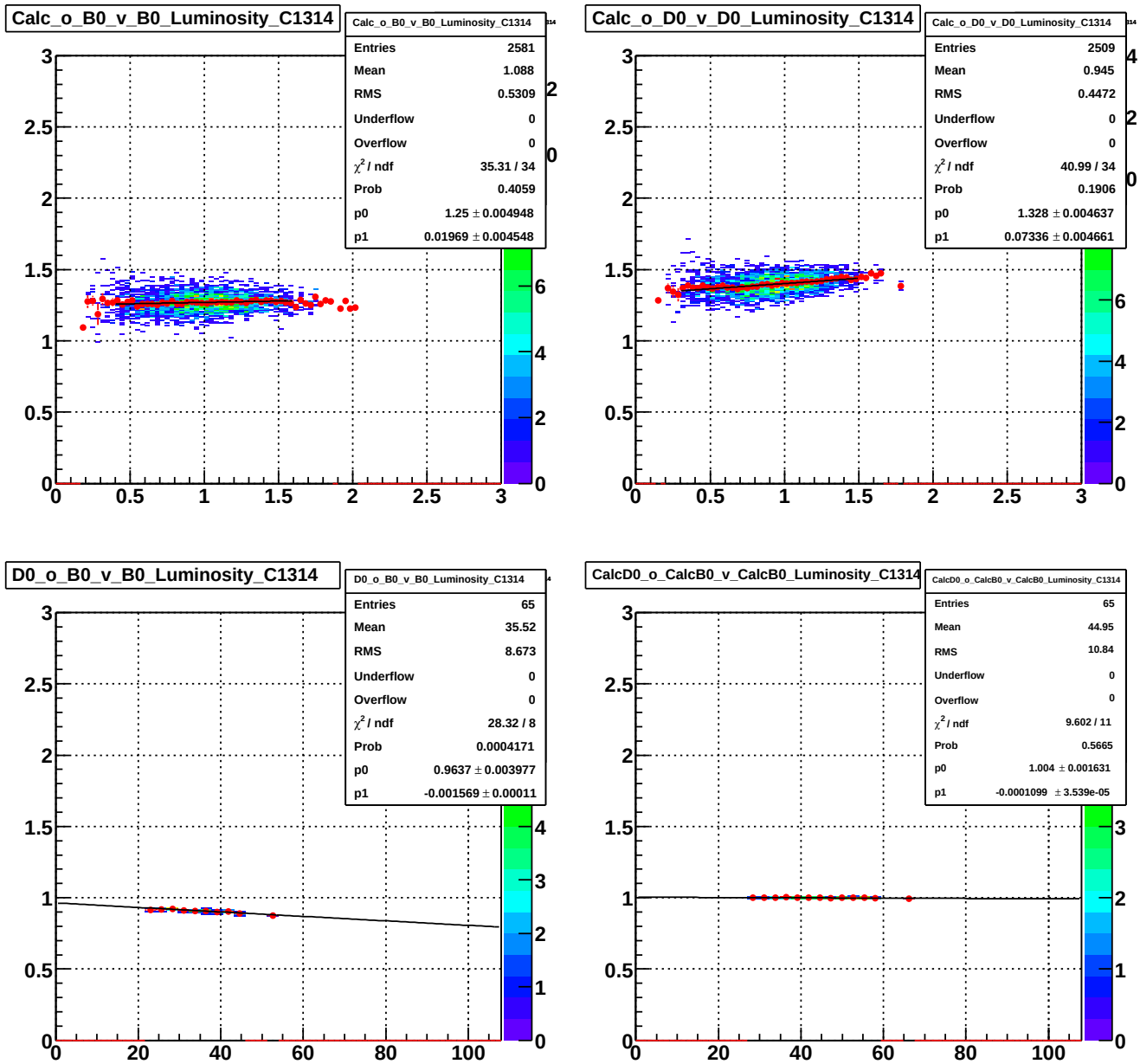

Figure 2: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. 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. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

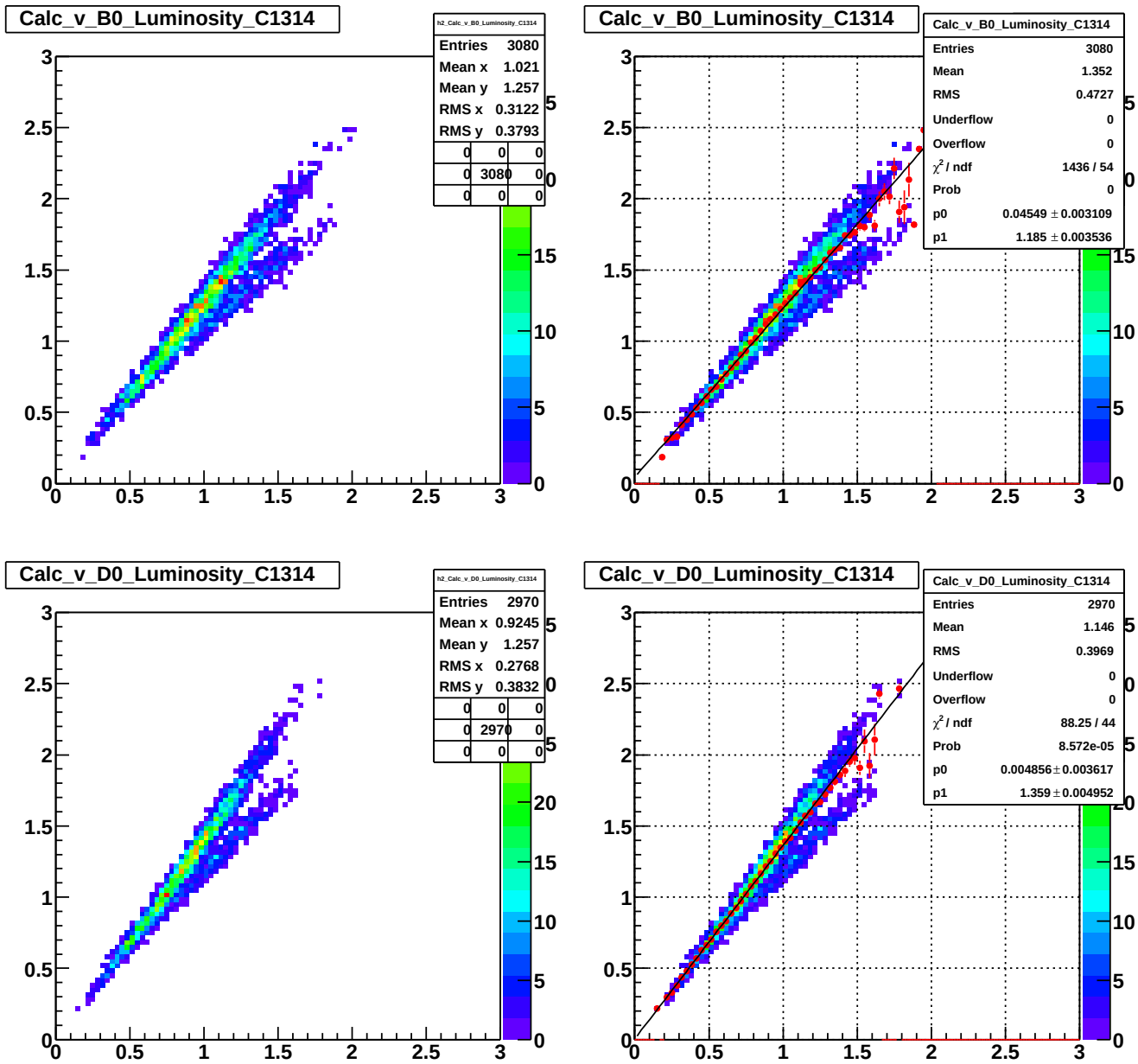

Figure 3: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus measured one for B0 and D0 locations (shown with and without a straight line fit). Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores before and after Flying Wires light attenuators insertion (2500-3000).

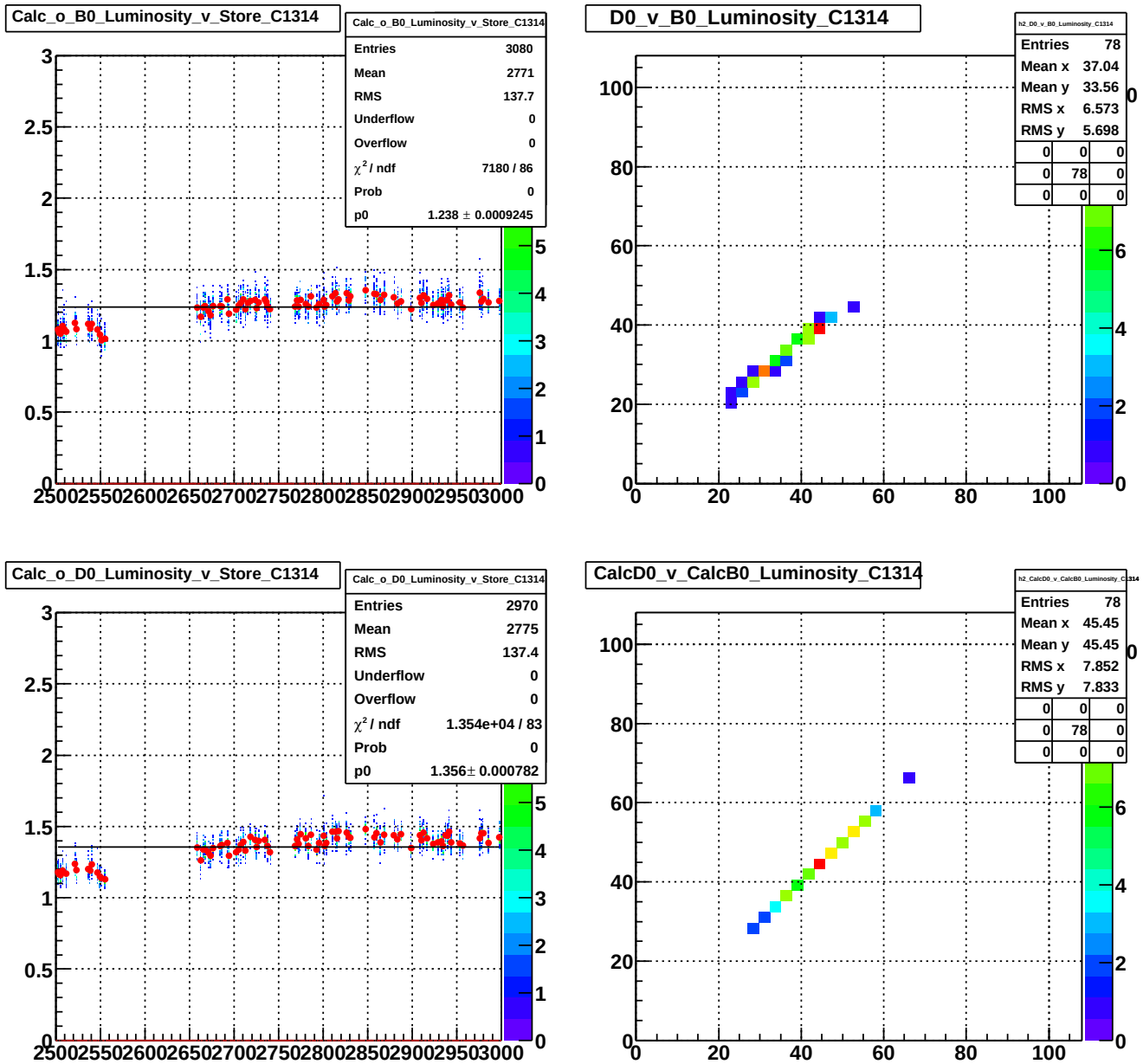

Figure 4: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus Store Number for B0 and D0 locations together with total measured D0 v B0 Luminosity and total calculated D0 v B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores before and after Flying Wires light attenuators insertion (2500-3000).

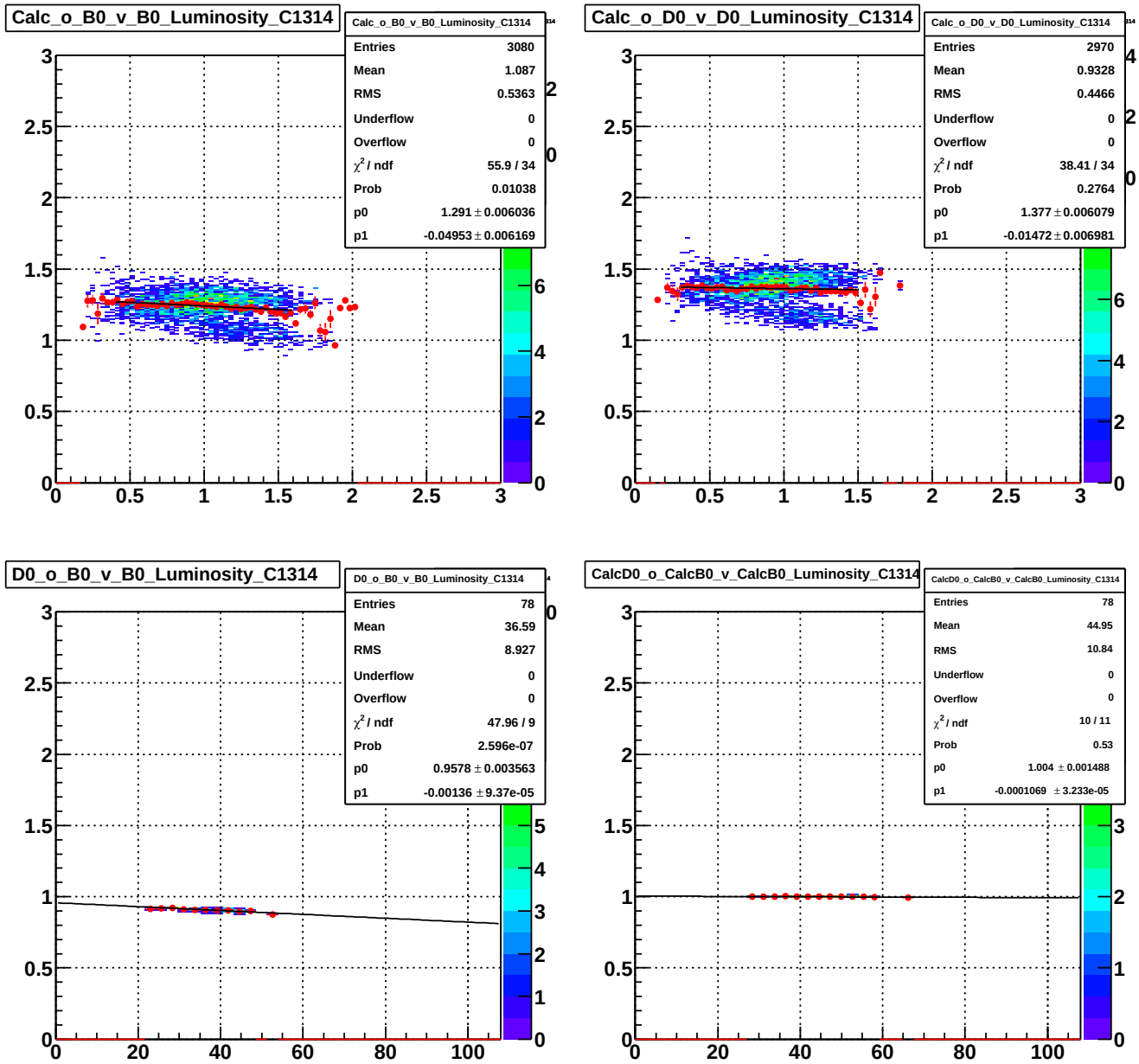

Figure 5: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. 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. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores before and after Flying Wires light attenuators insertion (2500-3000).

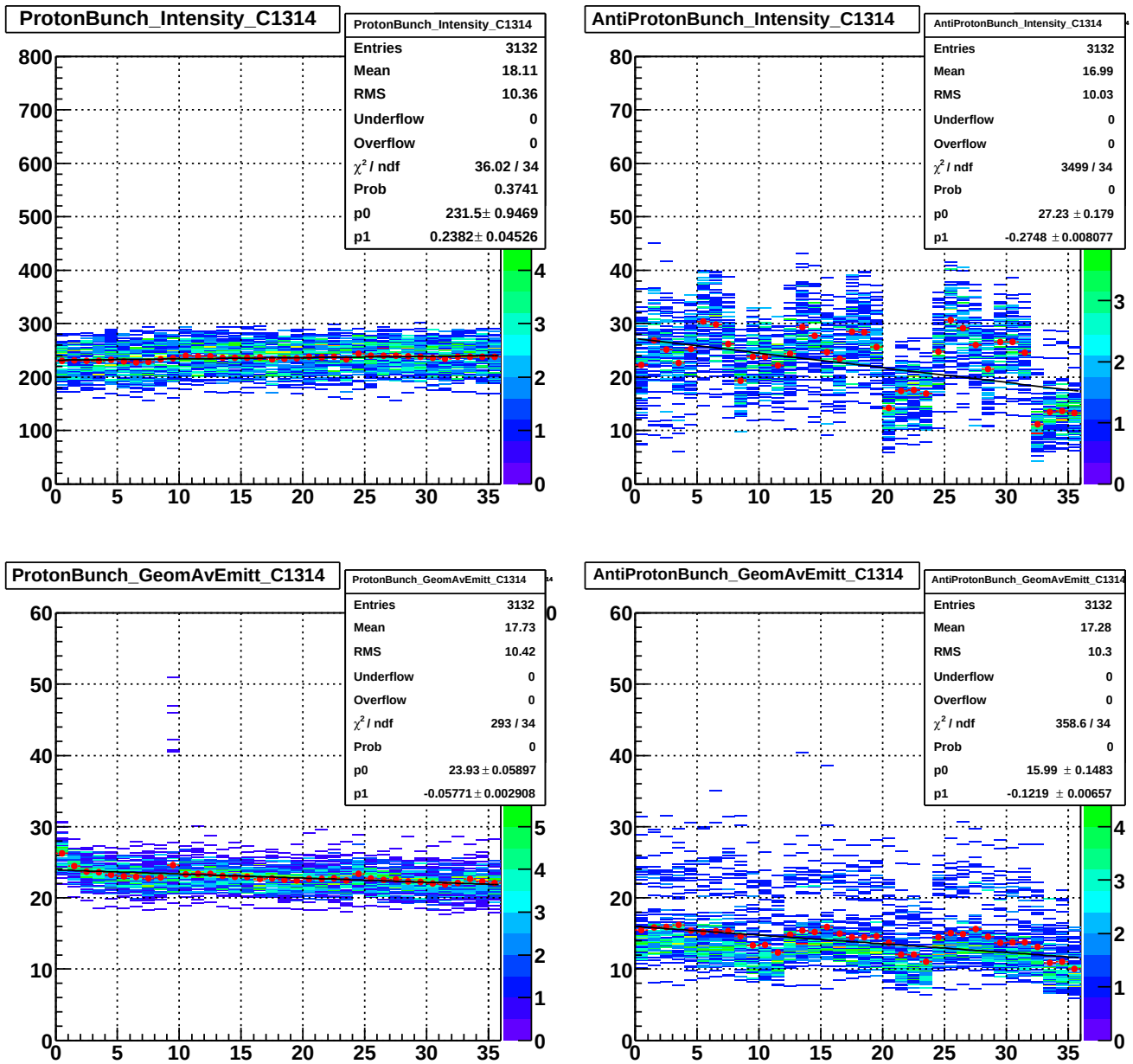

Figure 6: Bunch Intensity (in 10^9) and (Geometrical) Average Transverse Emittance (in $\pi \cdot mm \cdot mrad$)) for Proton and Antiproton Bunches. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores before and after Flying Wires light attenuators insertion (2500-3000).

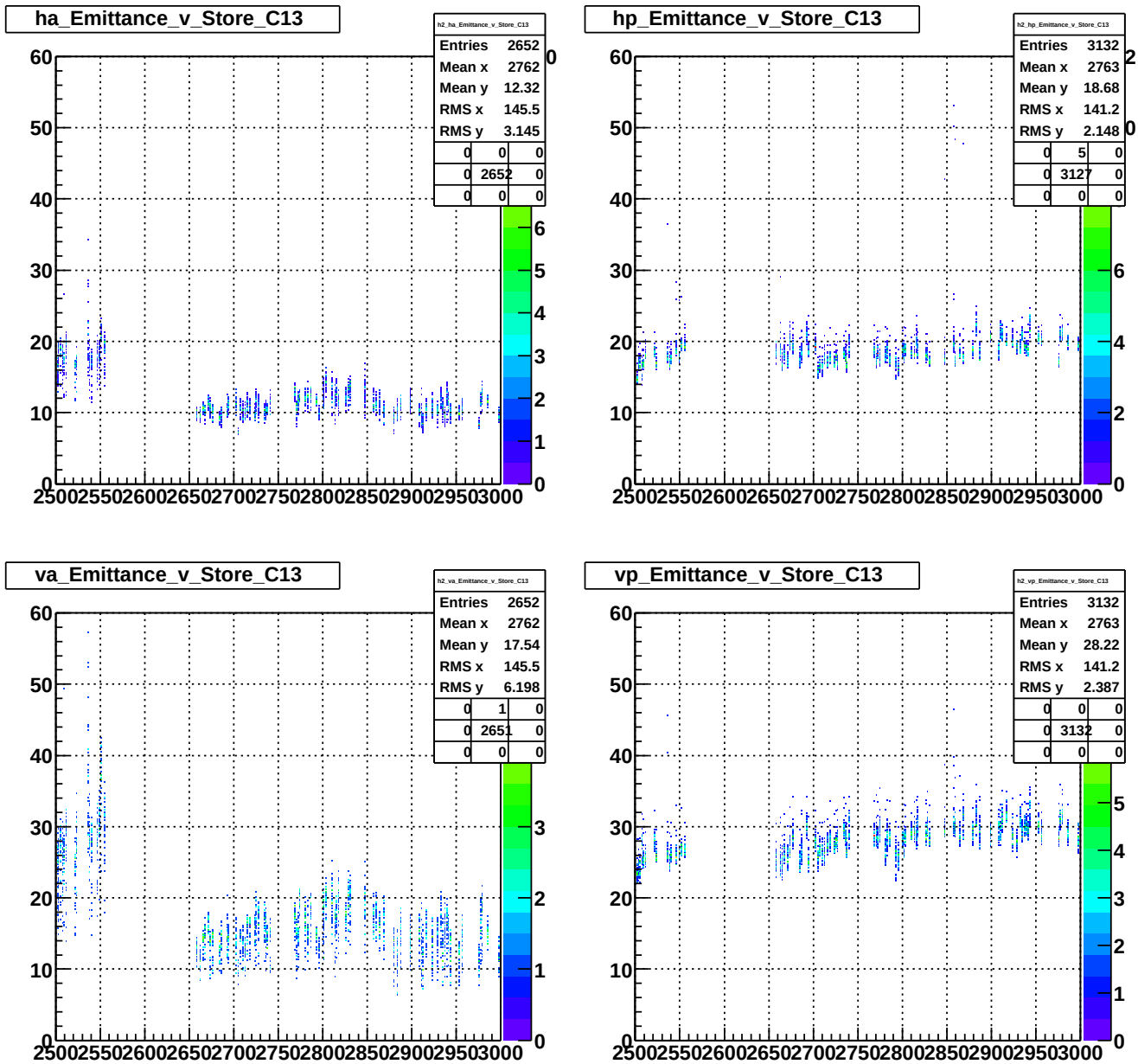

Figure 7: Horizontal Antiproton and Proton Emittance (in $\pi \cdot mm \cdot mrad$)) together with Vertical Antiproton and Proton Emittance versus Store Number. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores before and after Flying Wires light attenuators insertion (2500-3000).

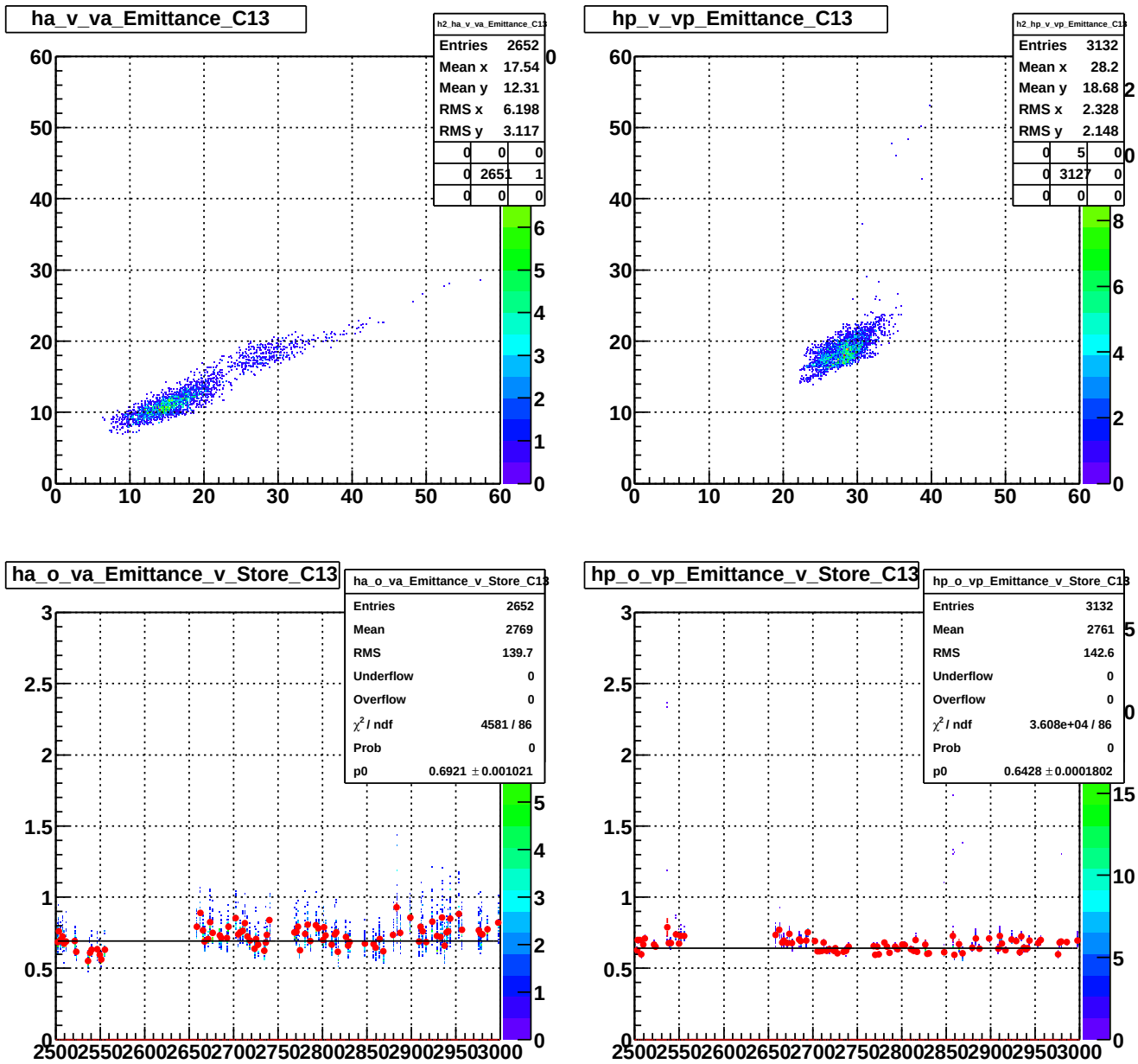

Figure 8: Horizontal Antiproton Emittance (in $\pi \cdot mm \cdot mrad$)) versus Vertical Antiproton Emittance (same for Protons) together with Horizontal Antiproton Emittance over Vertical Antiproton Emittance versus Store (same for Protons). Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores before and after Flying Wires light attenuators insertion (2500-3000).

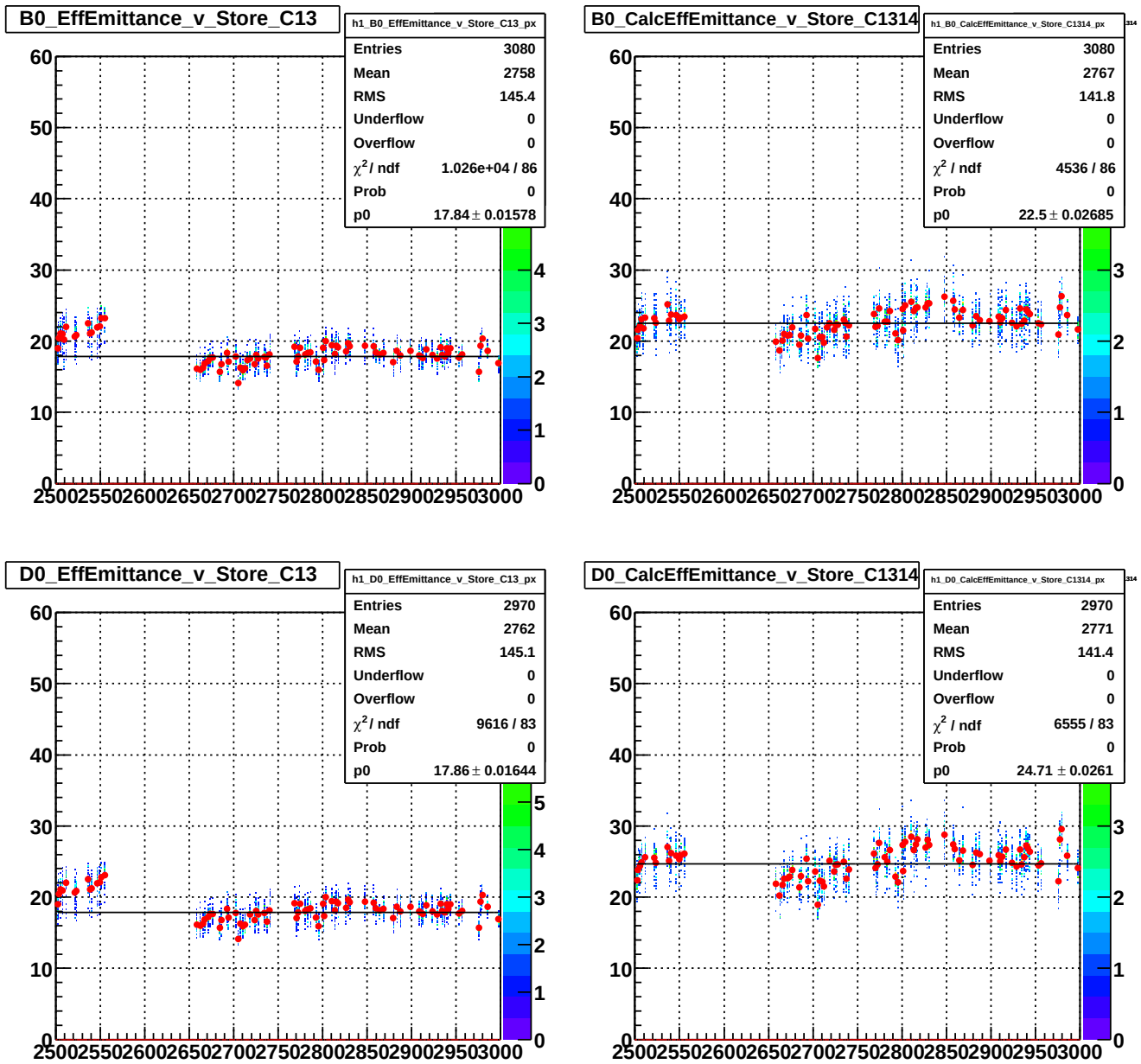

Figure 9: B0 and D0 measured and calculated Effective Emittance (in $\pi \cdot mm \cdot mrad$)) versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Calculated Effective Emittance based on Bunch Intensities measured with SBD and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores before and after Flying Wires light attenuators insertion (2500-3000).

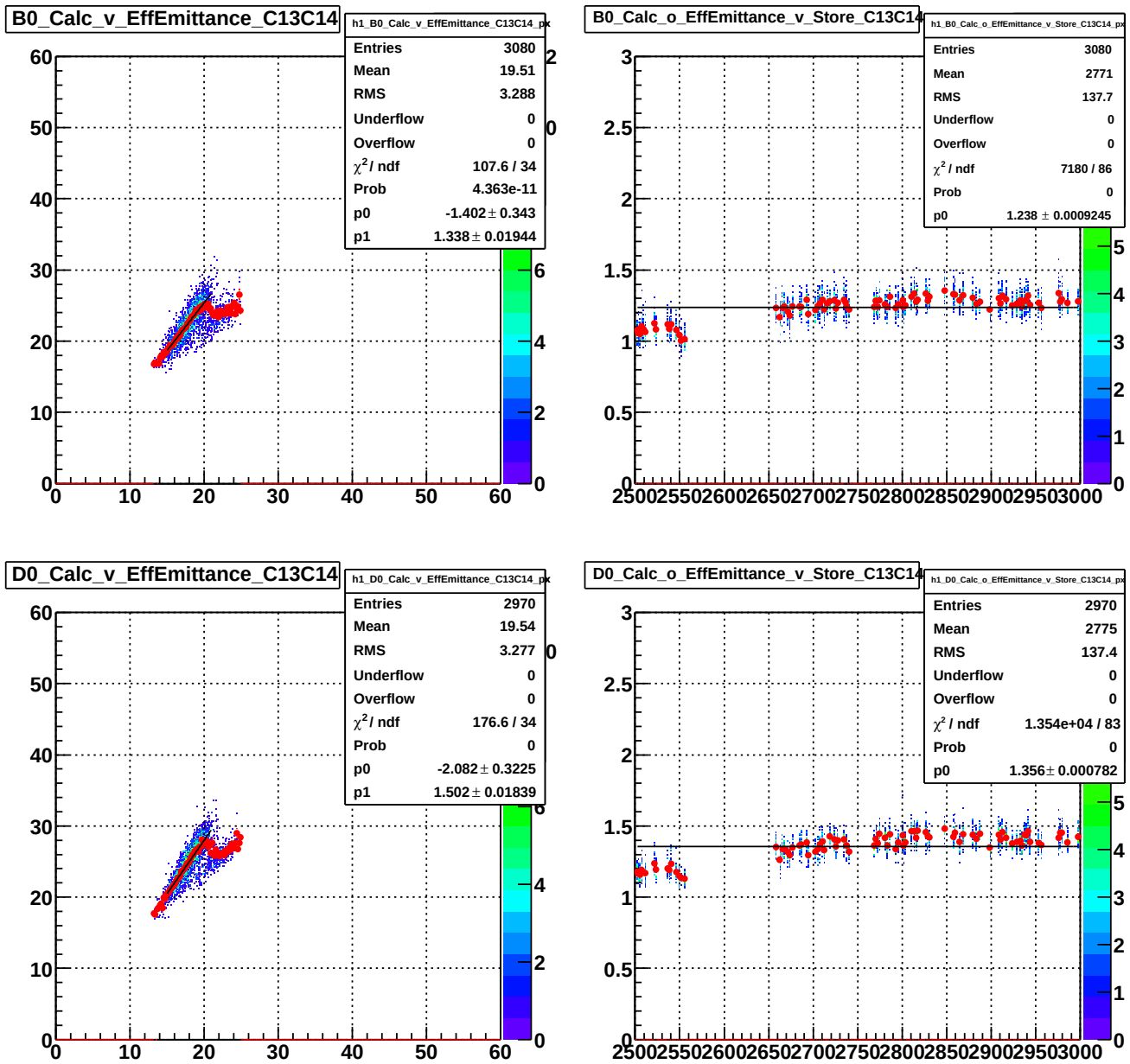

Figure 10: B0 and D0 calculated versus measured Effective Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Effective Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Calculated Effective Emittance based on Bunch Intensities measured with SBD and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores before and after Flying Wires light attenuators insertion (2500-3000).

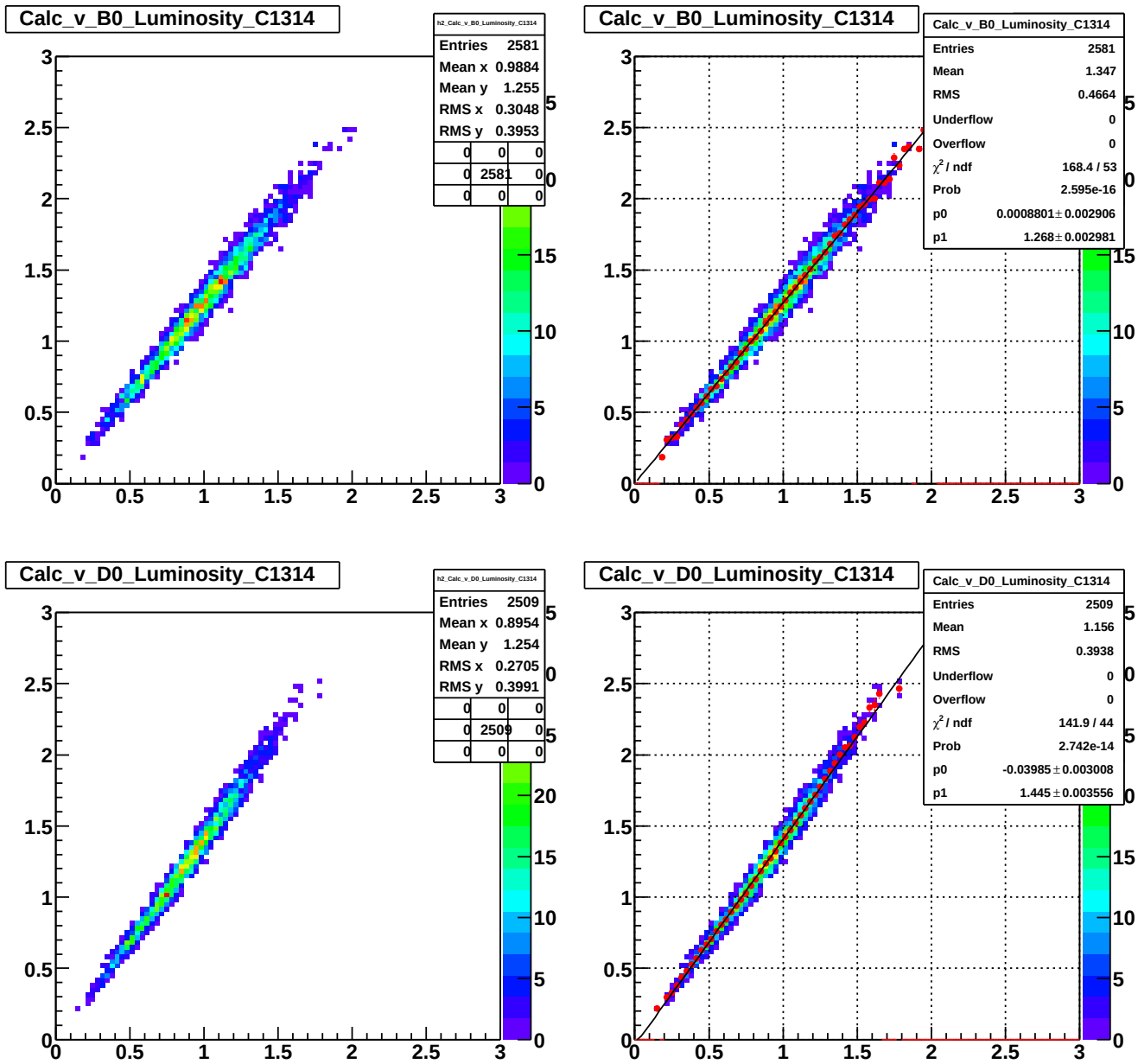

Figure 11: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) versus measured one for B0 and D0 locations (shown with and without a straight line fit). Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

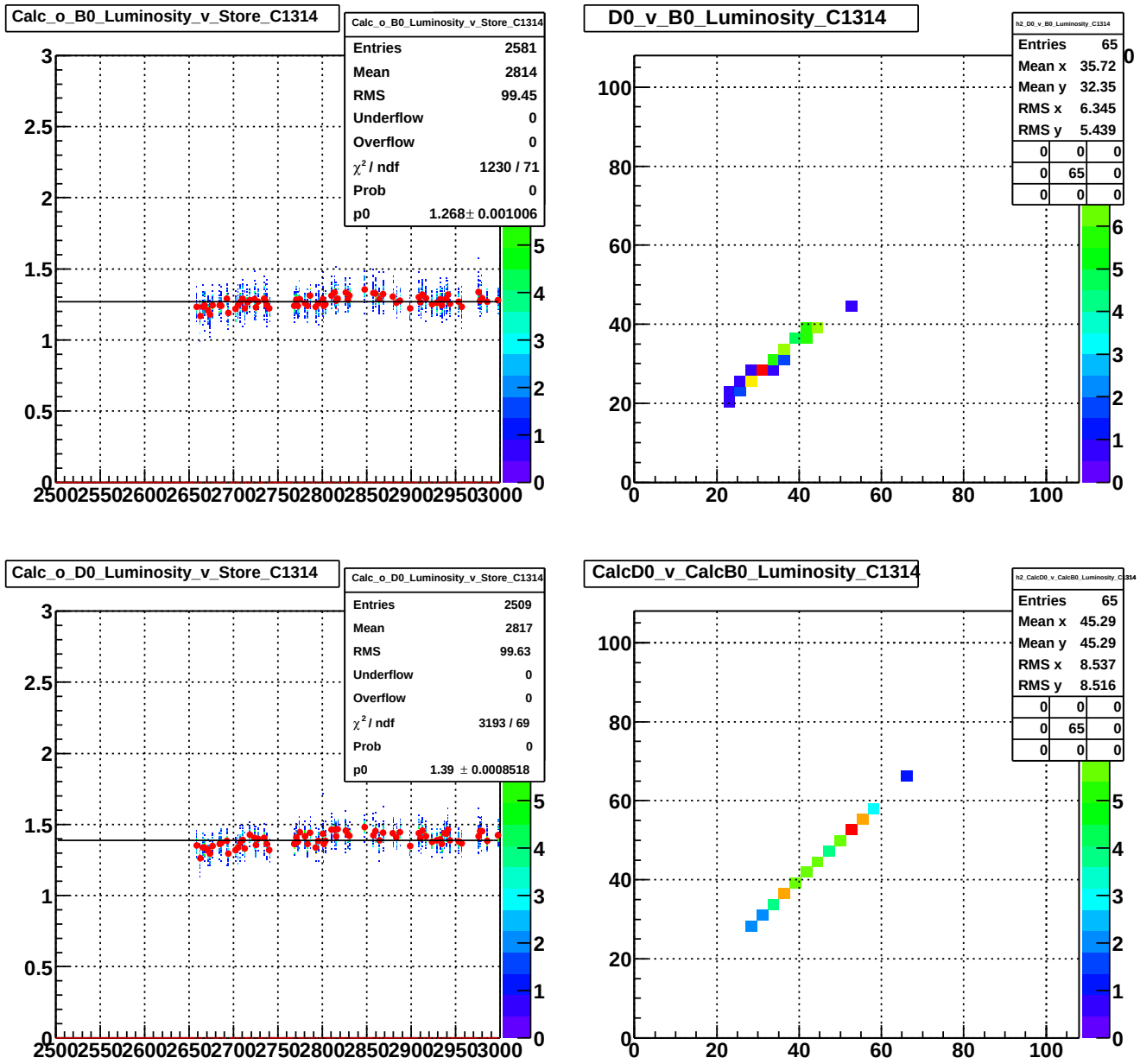

Figure 12: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus Store Number for B0 and D0 locations together with total measured D0 v B0 Luminosity and total calculated D0 v B0 Luminosity. Luminosity calculated based on transverse Emittance at Remove Halo Case measured with Flying Wires and SBD and Bunch Intensities at first HEP Case Set measured with SBD. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

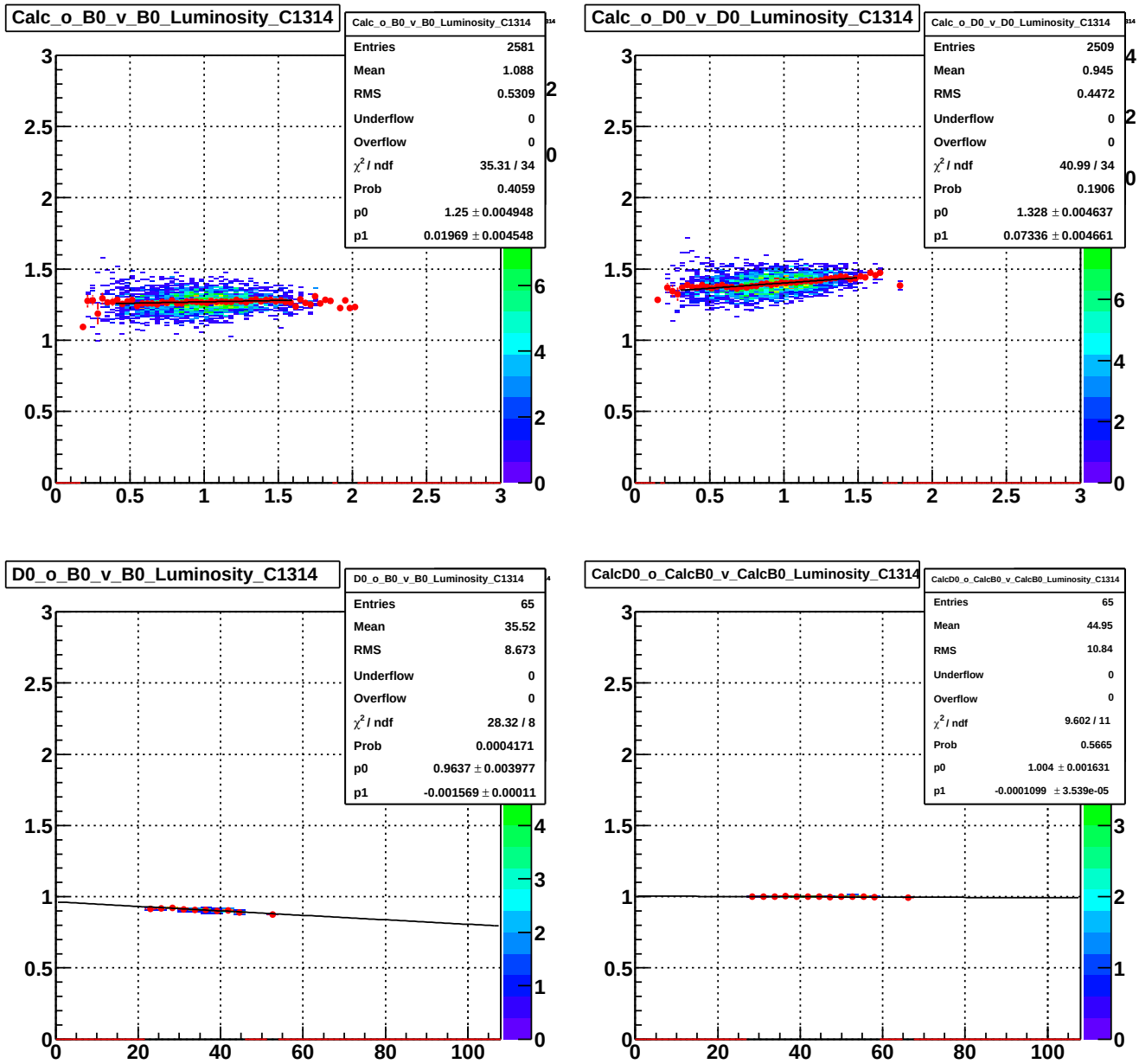

Figure 13: Calculated Bunch Luminosity (in $10^{30} \cdot cm^{-2} \cdot sec^{-1}$) over measured one versus measured one for B0 and D0 locations together with total measured D0 over B0 Luminosity versus measured B0 Luminosity and total calculated D0 over B0 Luminosity versus calculated B0 Luminosity. 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. Measured Luminosity based on B0 and D0 measurements at the first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

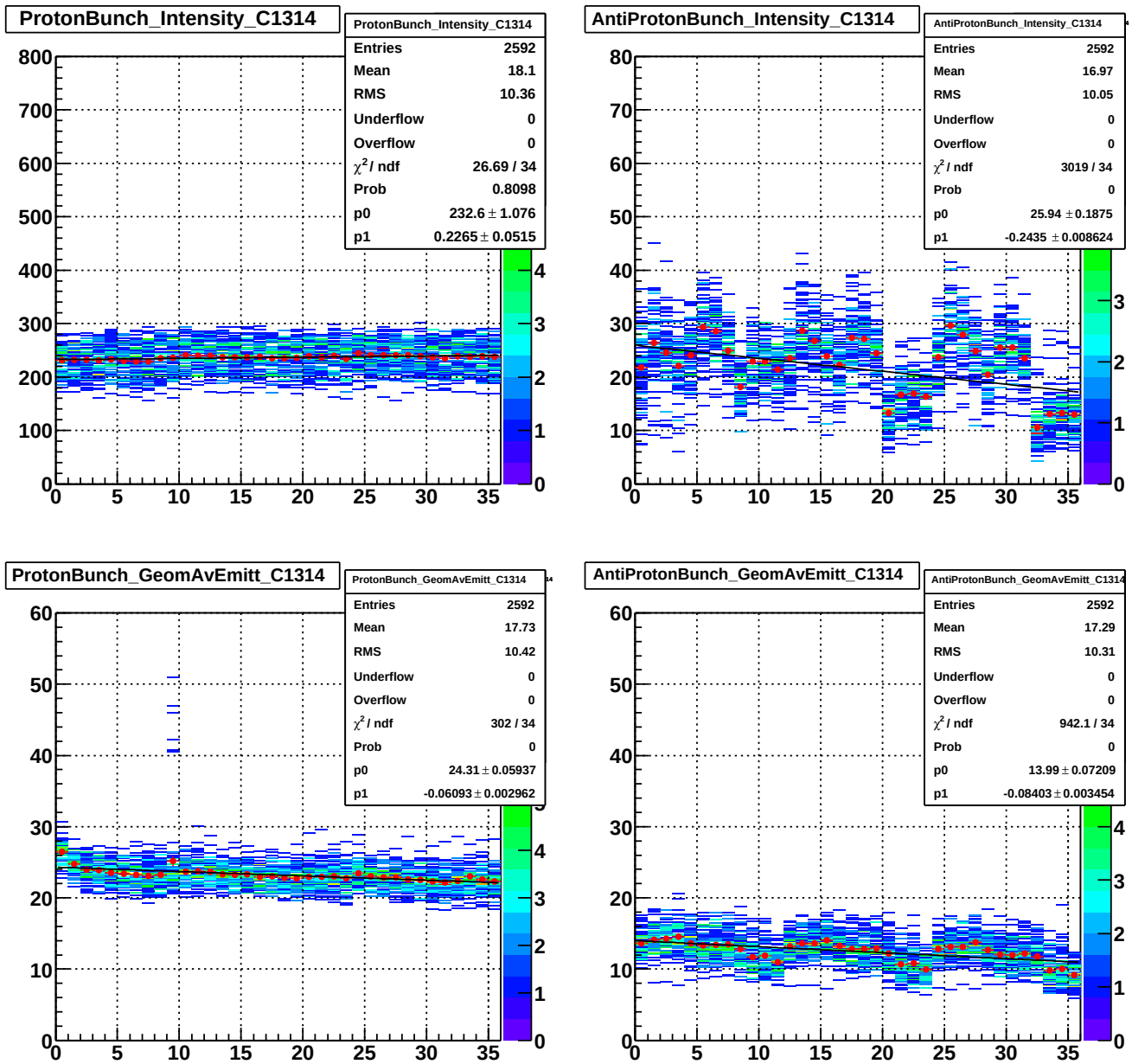

Figure 14: Bunch Intensity (in 10^9) and (Geometrical) Average Transverse Emittance (in $\pi \cdot mm \cdot mrad$)) for Proton and Antiproton Bunches. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores after Flying Wires light attenuators insertion only (2668-3000).

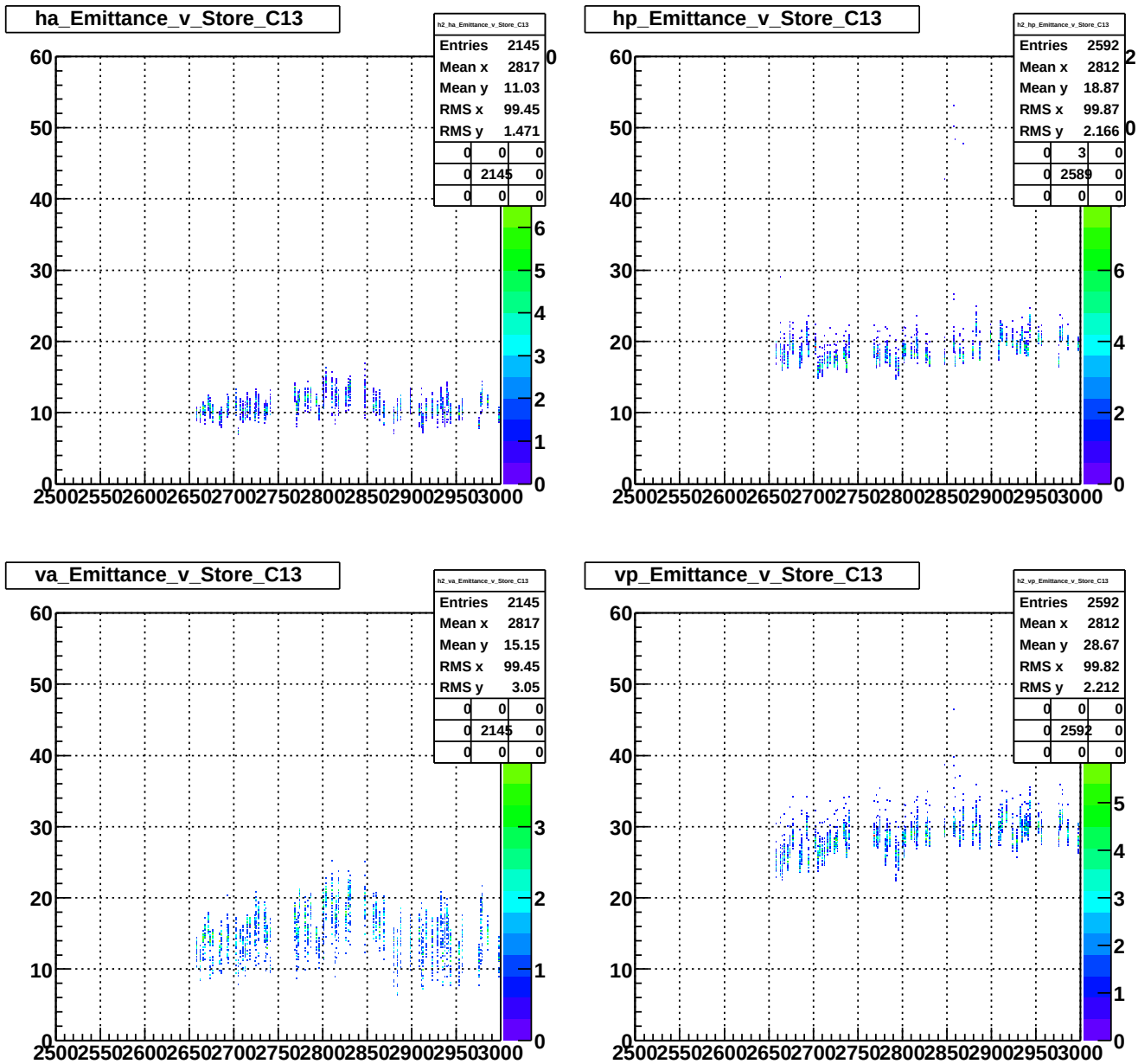

Figure 15: Horizontal Antiproton and Proton Emittance (in $\pi \cdot mm \cdot mrad$)) together with Vertical Antiproton and Proton Emittance versus Store Number. Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores after Flying Wires light attenuators insertion only (2668-3000).

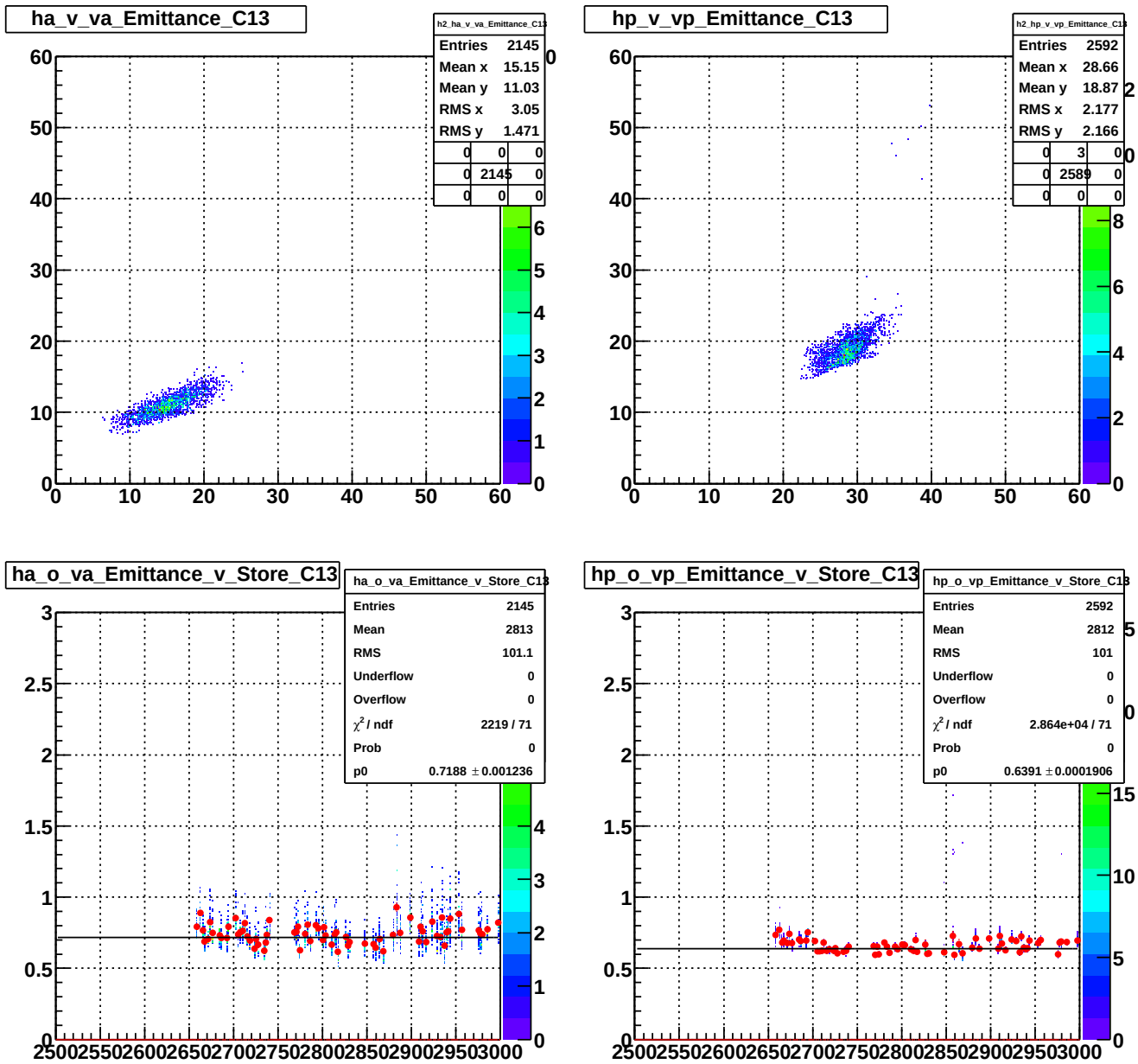

Figure 16: Horizontal Antiproton Emittance (in $\pi \cdot mm \cdot mrad$)) versus Vertical Antiproton Emittance (same for Protons) together with Horizontal Antiproton Emittance over Vertical Antiproton Emittance versus Store (same for Protons). Transverse Emittance measured with Flying Wires and SBD at Remove Halo Case. Bunch Intensities at first HEP Case Set measured with SBD. Stores after Flying Wires light attenuators insertion only (2668-3000).

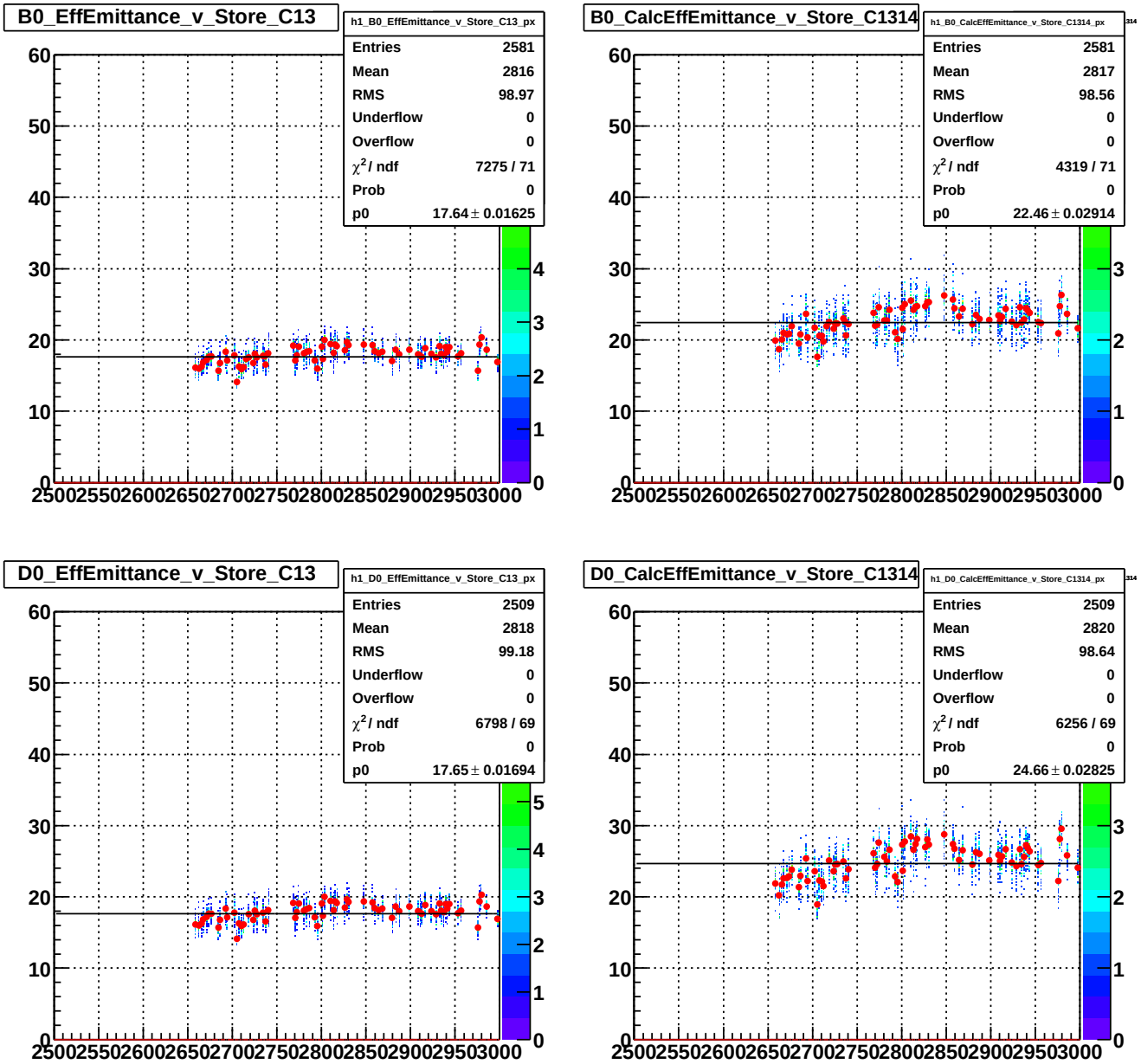

Figure 17: B0 and D0 measured and calculated Effective Emittance (in $\pi \cdot mm \cdot mrad$)) versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Calculated Effective Emittance based on Bunch Intensities measured with SBD and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).

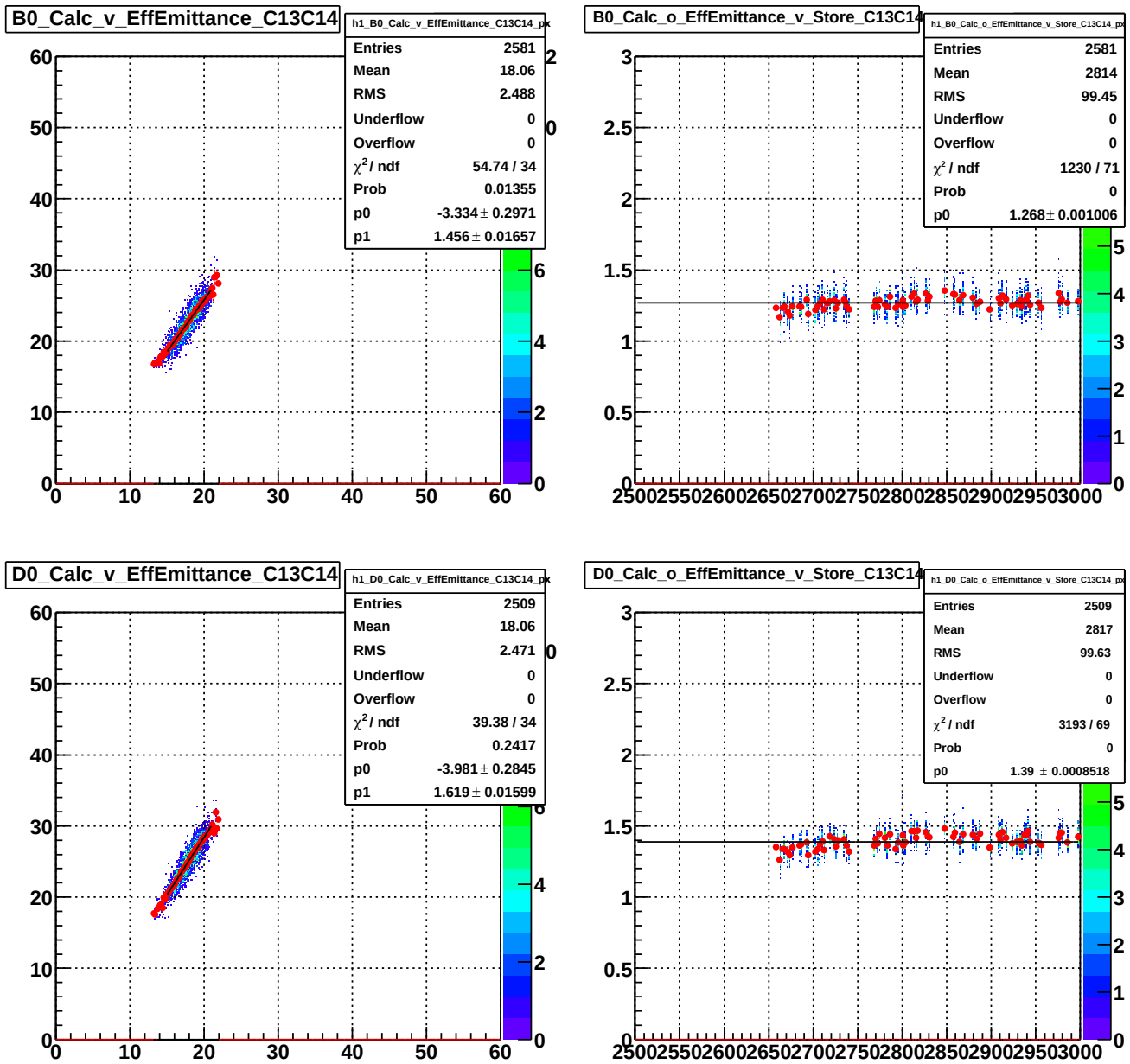

Figure 18: B0 and D0 calculated versus measured Effective Emittance (in $\pi \cdot mm \cdot mrad$)) together with calculated over measured Effective Emittance versus Store Number. Transverse Emittance at Remove Halo Case measured with Flying Wires and SBD. Calculated Effective Emittance based on Bunch Intensities measured with SBD and on B0 and D0 Luminosity measurements at first HEP Case Set. Stores after Flying Wires light attenuators insertion only (2668-3000).