Tevatron Flying Wires
Transverse Emittance Measurements at 150GeV

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This note summarizes plots discussed on January 10th Emittance Working Meeting. The plots made had been motivated by the earlier talks given by Alberto Marchionni [1] and Mike Church [2] as well as discussions during subsequent meetings.

All plots correspond to proton beam in Tevatron stores 2114 or 2138 case 6 which is "Inject pbars" at 150GeV for all 9 pbar injection sets.

Figure 1 shows distributions related to Shot Data Analysis (SDA) variable T:WHEP00 which is Tevatron Flying Wire Normalized Horizontal Emittance (in $\pi \cdot mm \cdot mrad$). The top left scatter plot shows T:WHEP00 versus bunch number $(0-35)$ with one point for each of the nine injection sets giving nine points per bunch. The top right plot shows T:WHEP00 versus set number $(1-9)$ with one line per bunch for each set. Middle left plot shows T:WHEP00 averaged over sets versus bunch number. The square root of the variance for each bunch is shown on the middle right plot. The lines and p0 values shown correspond to the straight horizontal line fits for each of the quantities. Bottom left plot shows T:WHEP00 averaged over bunches versus set number. The square root of the variance for each set is shown on the bottom right plot. Again, horizontal lines and p0 values shown correspond to the straight horizontal line fits for each of the quantities. Figure 2 shows T:WVEP00 the Tevatron Flying Wire Normalized Vertical Emittance (in $\pi \cdot mm \cdot mrad$).

The main concern regarding the plots are the large set to set variations of the transverse esp. horizontal emittance.

In order to re-calculate and study T:WHEP00 more quantities were plotted: i.e.: T:FWHPSG_1, T:FWHPSG_2, the E11 Horizontal Proton Beam Sigma measurement from first and second pass of the flying wire. T:FWHPSG, the E11 Horizontal Proton Sigma averaged over two Flying Wire passes (in mm) see figures 3–5. The T:FWHPSG plots suggest that the average measurement fluctuates less than measurements corresponding to each individual pass. The T:FWEPSG (E17 Horizontal Proton Sigma) plots shown on figures 6 –8 also show a slight decrease of the fluctuations when the average over passes is used. Similar conclusion can be drown from plots corresponding to T:FWVPSG, the E11 Vertical Proton Sigma, figures 9–11. Figures 12–13 show relative momentum spread $\delta p/p$ in 10^{-4} as coming from Flying Wires (T:WEEP00) and Sampled Bunch Display (SBD) systems (T:SBDPPS). The SBD data shows smaller fluctuations and seems to decrease monotonically over time. Figure 14 shows variable T:SBDPSS SBD "Proton RMS sigma(?)" in ns which will be used in quantities shown in further plots.

Plots on figure 16 show various quantities related to T:WHEP00 (Normalized Horizontal Emittance). Top left scatter plot shows T:WHEP00 versus the same quantity recalculated using T:FWHPSG_1 and T:FWEPSG_1. Top right plot is a vertical profile of the previous plot i.e. mean value of "Y" and its RMS for each bin in "X", with a straight line fit. Middle left plot shows original T:WHEP00 minus recalculated T:WHEP00, middle right plot shows their ratio (original/recalculated). Bottom left plot shows T:WHEP00 versus set number with one line per bunch for each set. Bottom right plot shows T:WHEP00 versus bunch number $(0-35)$ with two lines for each of the nine injection sets. The solid line is the original T:WHEP00 whereas the dashed line is the recalculated one.

Given the good agreement (better than 2%) the plots strongly indicate that only E11/E17 Horizontal Proton Beam Sigma measurements from the first pass of the wires are used in the front end calculations which are done to derive T:WHEP00. The formula used to re-calculate T:WHEP00 was

$$\left({\sigma_{E11}}^2 - \frac{{\sigma_{E17}}^2 * \beta_{E17} - {\sigma_{E17}}^2 * \beta_{E11}}{D_{E11}^2 * \beta_{E17} - D_{E17}^2 * \beta_{E11}} * D_{E11}^2\right) * \gamma_L * \frac{6}{\beta_{E11}}$$

or "numerically"

$$\left(\mathrm{T:FWHPSG_1}^2 - \frac{\mathrm{T:FWHPSG_1}^2 * 60.364 - \mathrm{T:FWEPSG_1}^2 * 82.595}{2.754^2 * 60.364 - 4.588^2 * 82.595} * 2.754^2\right) * \frac{150.0}{0.938} * \frac{6}{82.595}$$

where horizontal dispersion (D) and β lattice functions at E11 and E17 together with proton mass and beam energy values were explicitly kept for documentation purposes.

Plots on figure 17 show T:WHEP00 compared to itself when recalculated using average sigma measurement. Such calculated emittance does show slightly smaler fluctuations as compared to the original one. Figure 18 show T:WHEP00 compared to itself when recalculated using $\delta p/p$ from T:SBDPPS. Here the fluctuations are actually larger then when using Flying Wires data. Figure 19 show T:WHEP00 compared to itself when recalculated using δp (in MeV) formula as advocated by M. Church [2]:

$$34.9680 * \text{T_SBDPSS} - 6.4322 * \text{T_SBDPSS}^2 + 1.3028 * \text{T_SBDPSS}^3 - 0.1520 * \text{T_SBDPSS}^4$$

but keeping the same values for the dispersion and beta functions as above to be able to compare fluctuations coming only form $\delta p/p$ recalculation. It can be seen that the above prescription gives emittance values with smallest fluctuations as well as absolute values which are larger than then original ones. (Using dispersion and beta functions as in [2] gives horizontal emittance values which are about 5% smaller).

Figures 20–21 show recalculated E11 Normalized Vertical Emittance. Again, using both passes decreases the fluctuations.

Figures 22–42 show data for store 2138. This store shows much larger horizontal emittance fluctuations than store 2114. The conclusions drawn for store 2114 hold for store 2138 (except for the T_SBDPPS case, figure 18 which does not change the main conclusions below).

Summary

Tevatron Flying Wires Emittance data were analyzed.

Using average Flying Wire measurement sigmas gives more stable emittance results than when using pass one measurements used in the front end calculations.

Using $\delta p/p$ from SBD (derived using T:SBDPSS using M. Church formula) to calculate Horizontal Emittance one obtains results with smaller fluctuations than when using relative momentum spread based on the Horizontal Flying Wire measurements even when average Flying Wire measurements are used.

We would like to thank All who were so kind to provide us with the information which helped us to prepare the plots presented.

References

[1] A. Marchionni *Tevatron Flying wires at 150 GeV*, talk on 11/12/2002, http://www-bd.fnal.gov/sdahomepage/osda/devices/tevatronfw_pdf.pdf

[2] M. Church *A Study of the Emittances of P1 during Proton Injections for Store 2070*, talk on 12/18/2002, http://www-bd.fnal.gov/sdahomepage/osda/devices/p1_2070_study_pdf.pdf

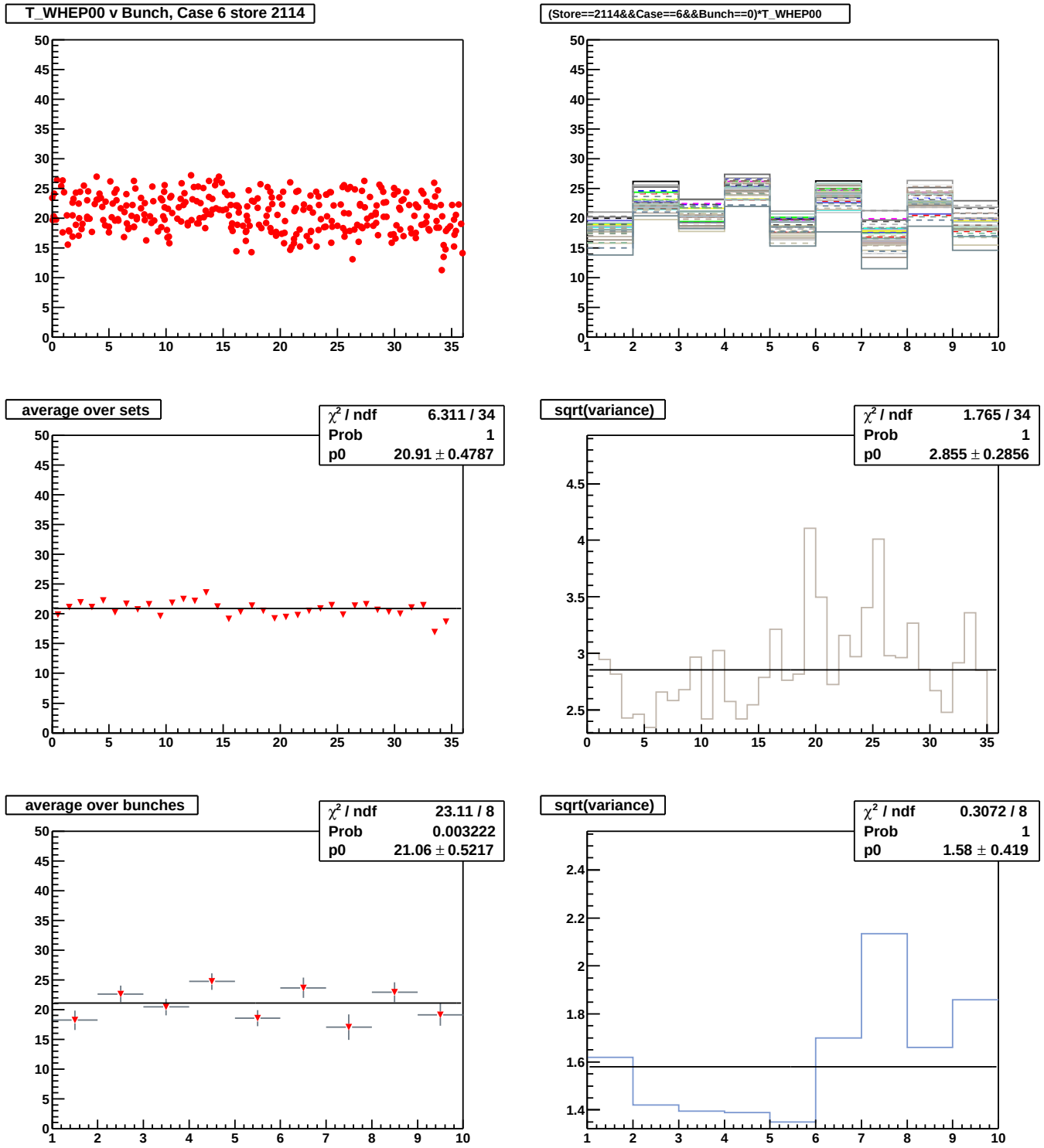

Figure 1: T:WHEP00, store 2114, case 6

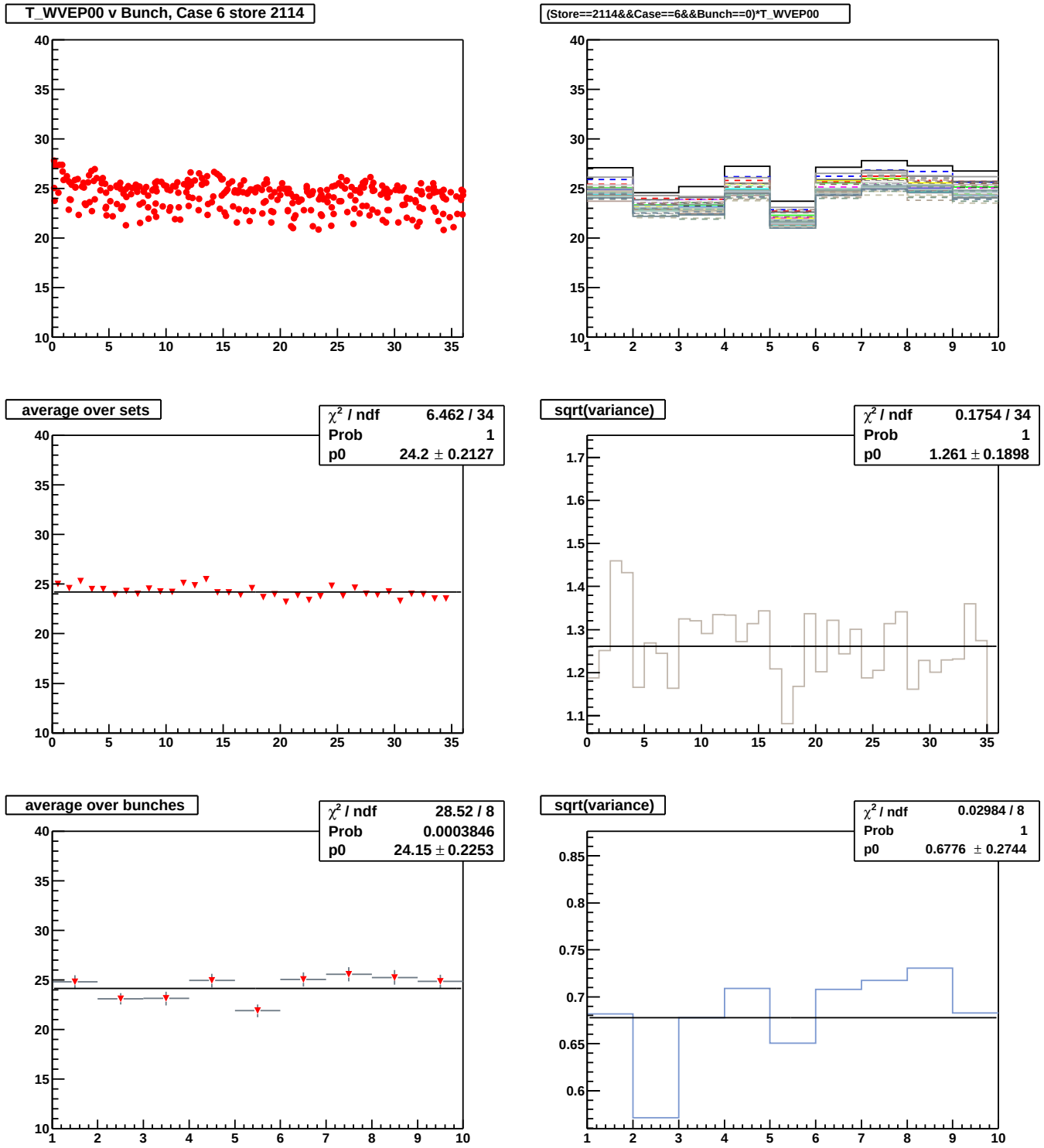

Figure 2: T:WVEP00, store 2114, case 6

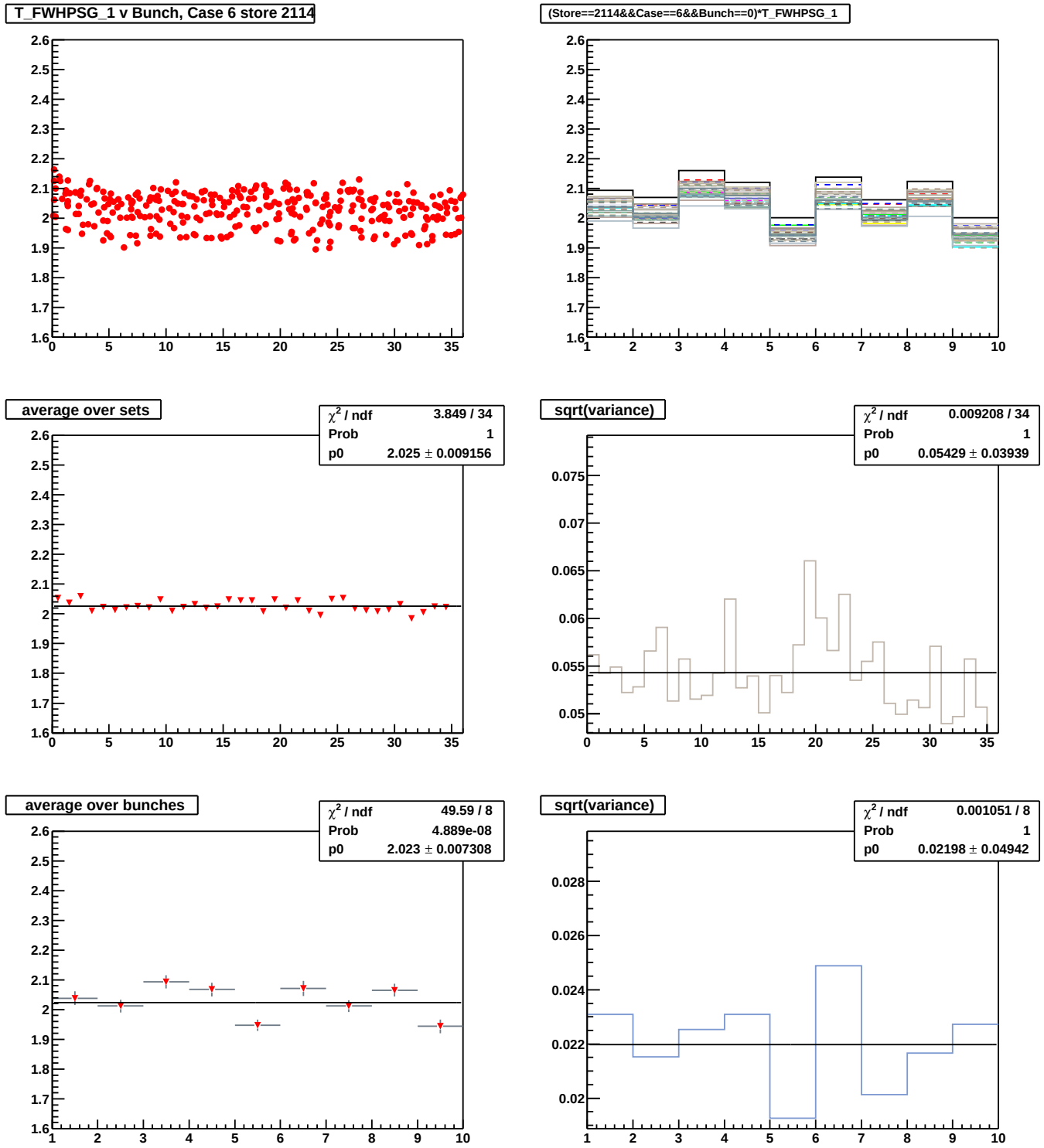

Figure 3: T:FWHPSG pass 1, store 2114, case 6

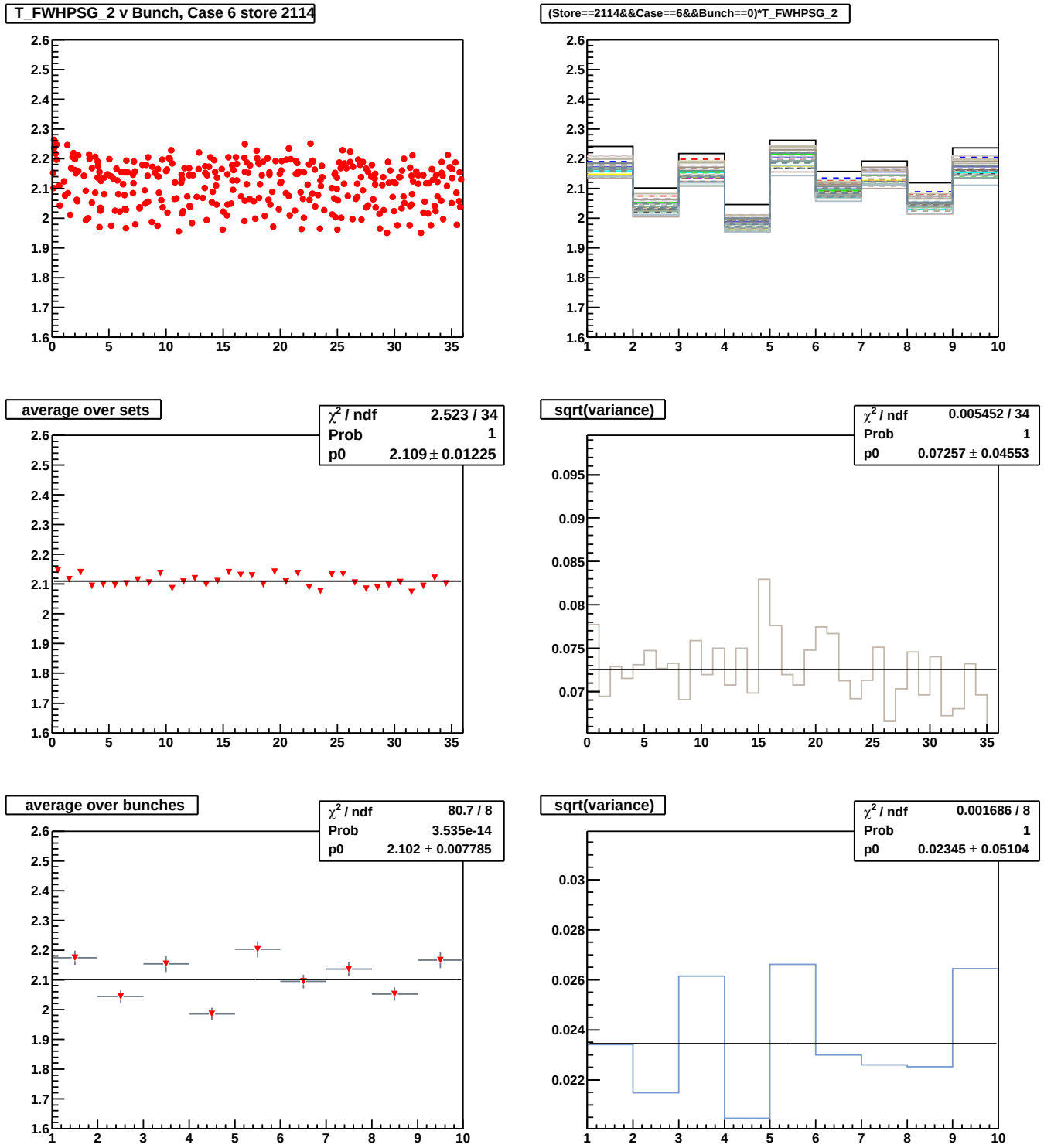

Figure 4: T:FWHPSG pass 2, store 2114, case 6

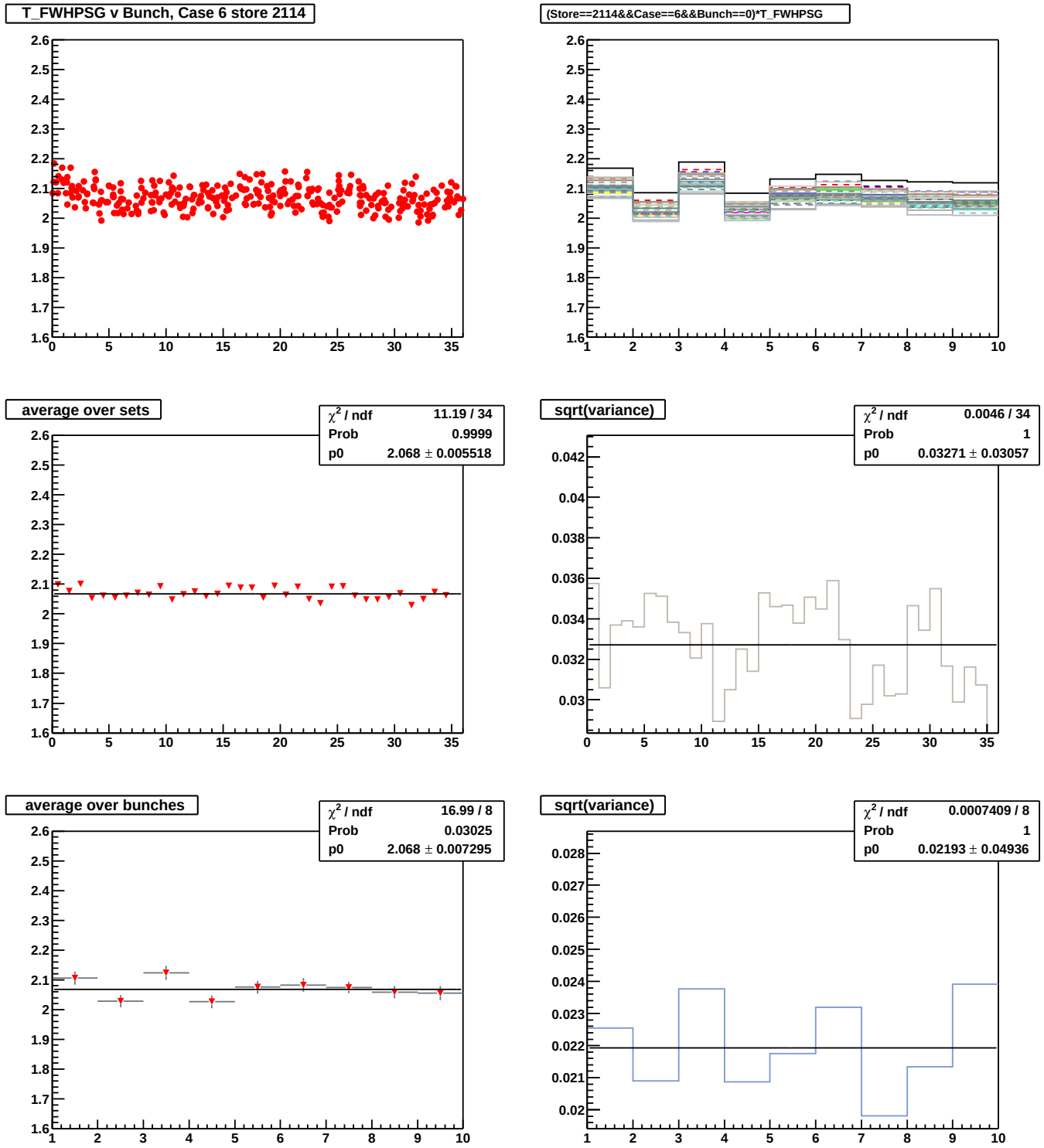

Figure 5: T:FWHPSG, store 2114, case 6

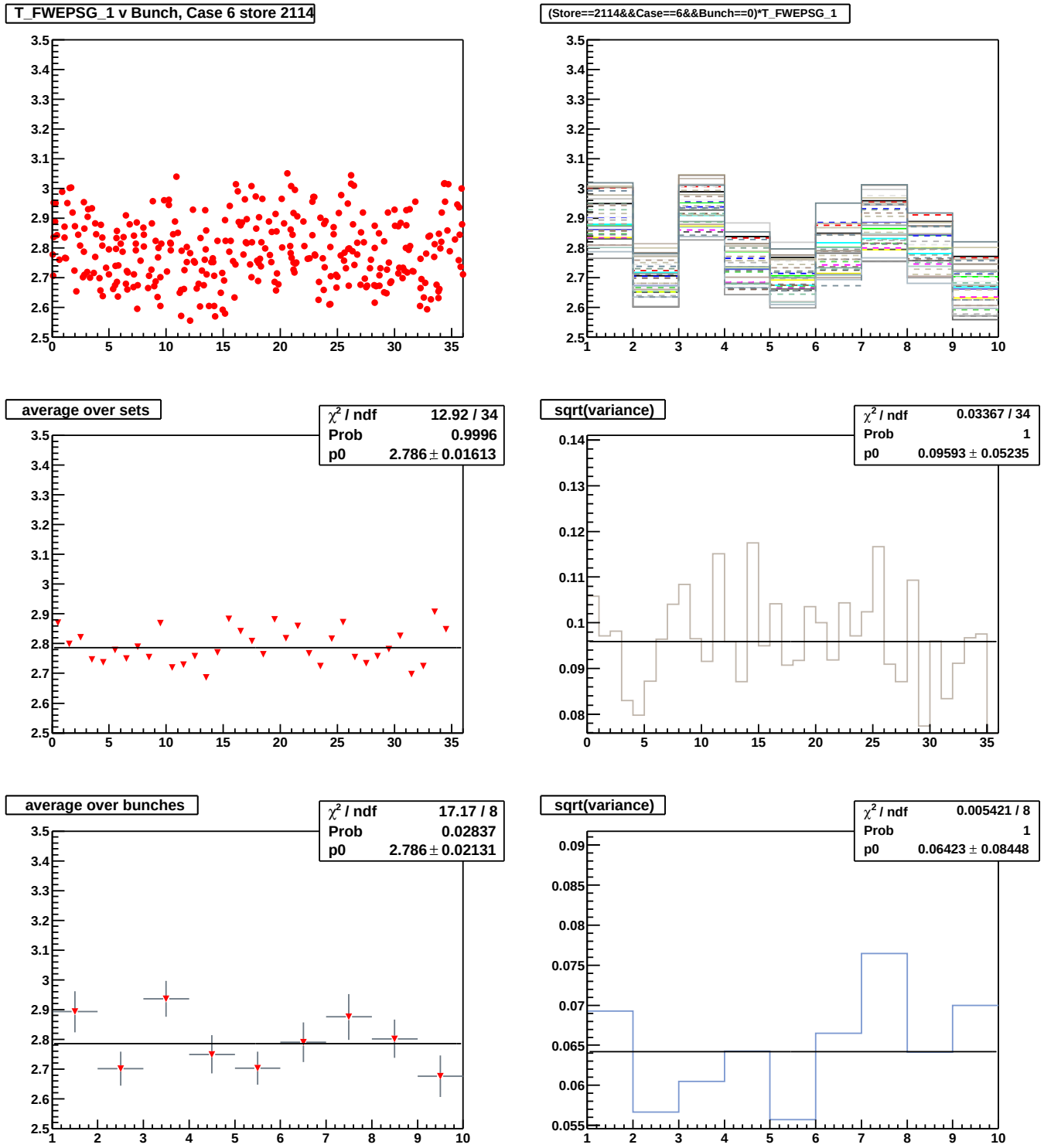

Figure 6: T:FWEPSG pass 1, store 2114, case 6

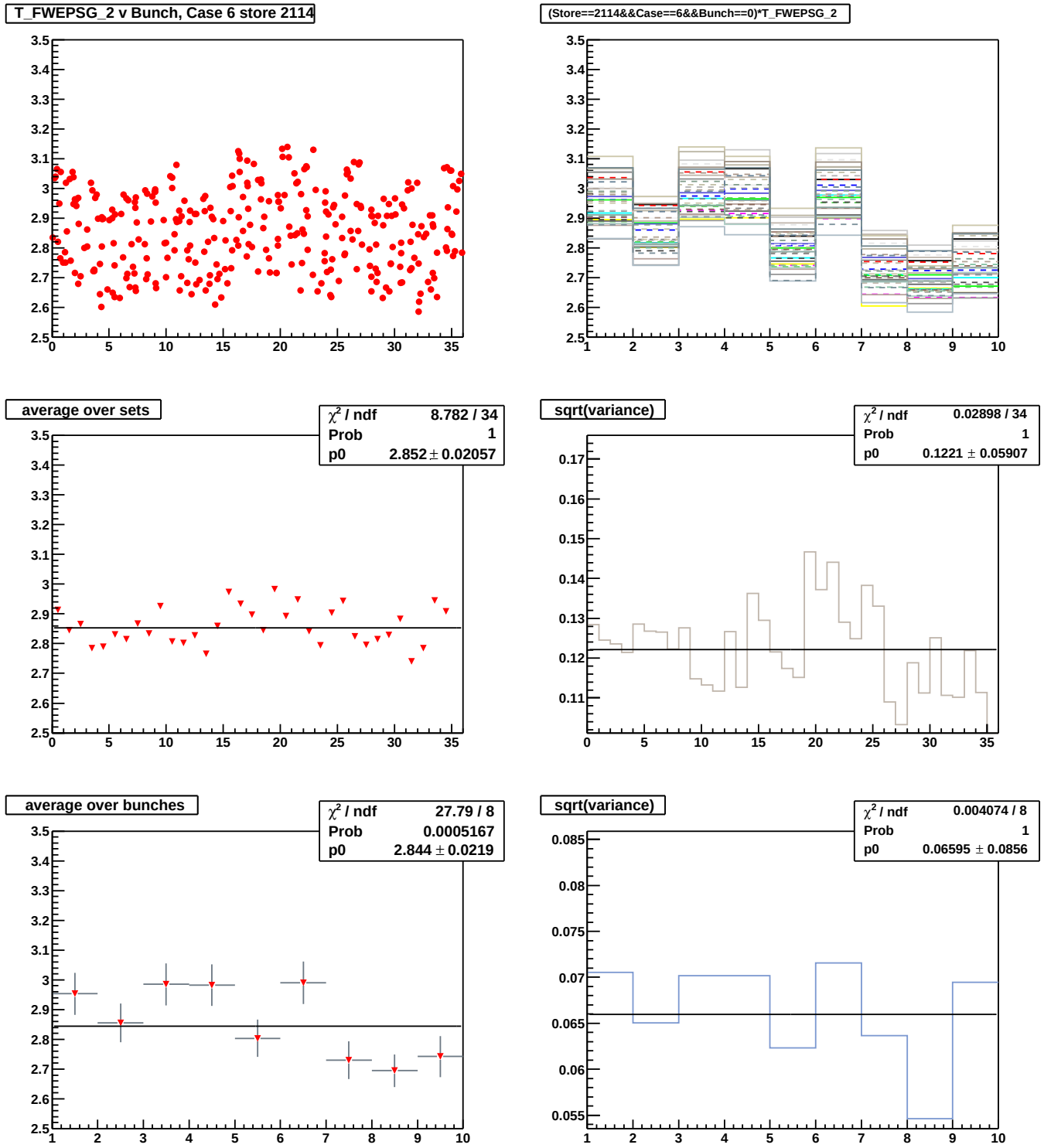

Figure 7: T:FWEPSG pass 2, store 2114, case 6

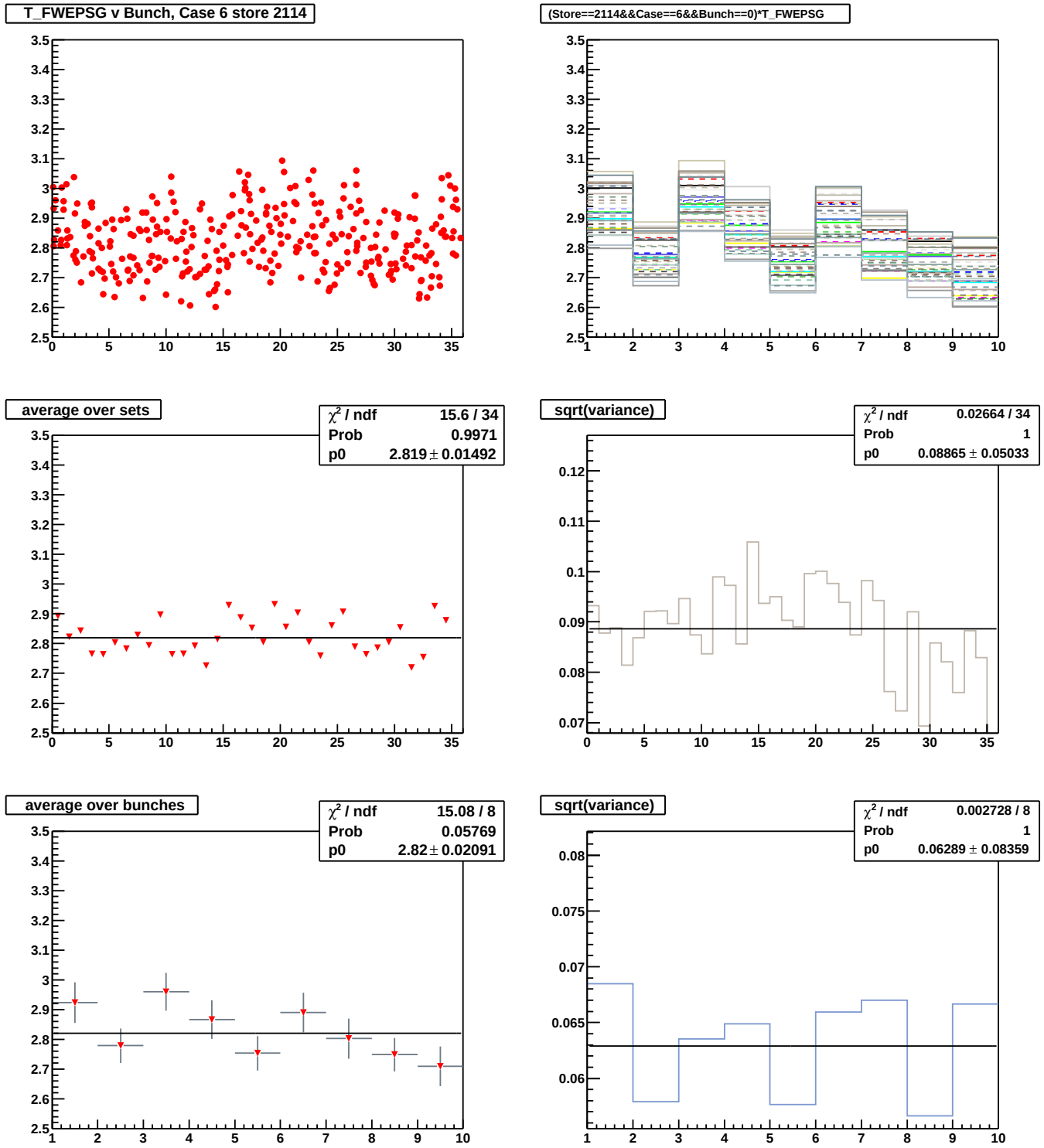

Figure 8: T:FWEPSG, store 2114, case 6

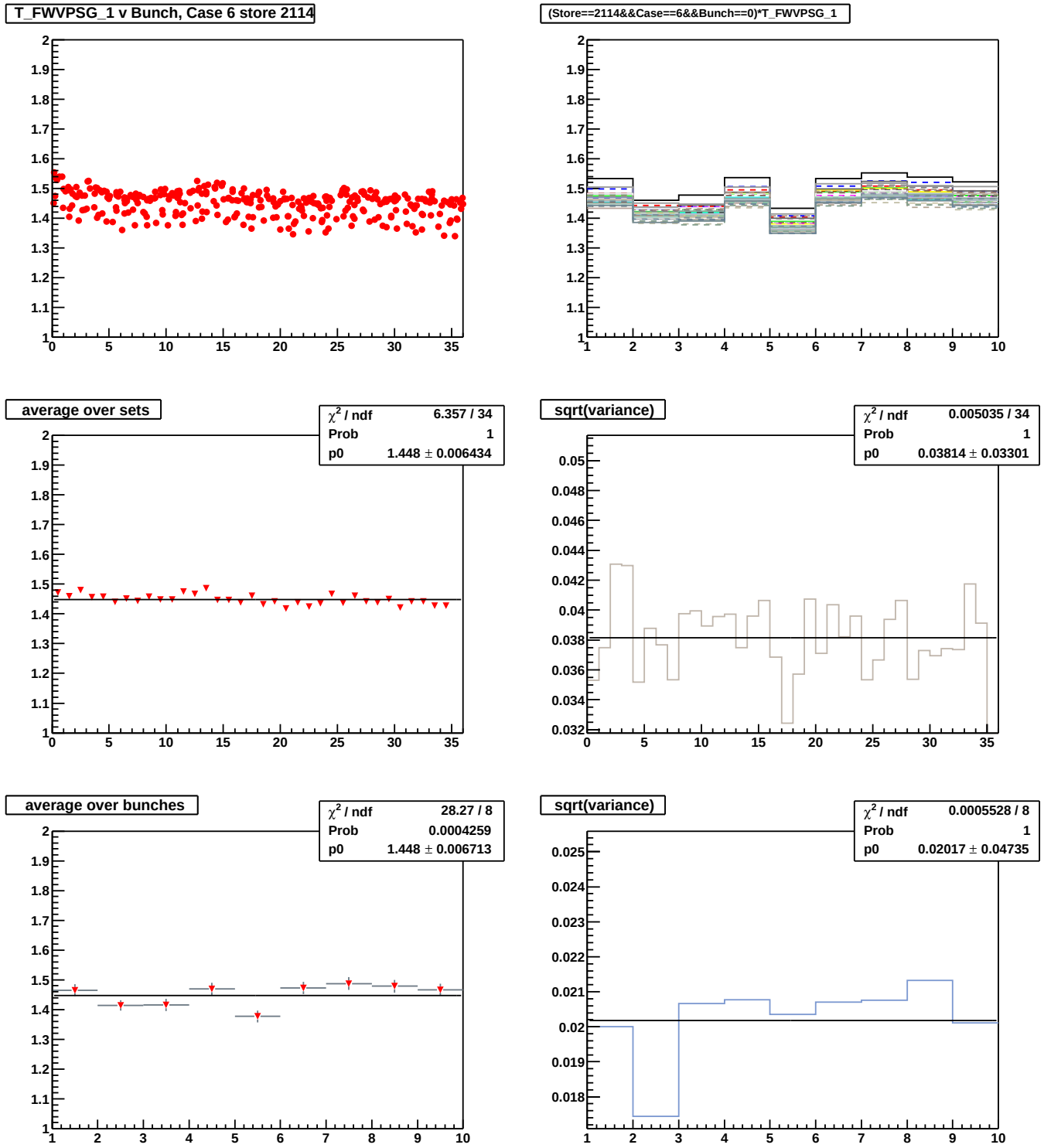

Figure 9: T:FWVPSG pass 1, store 2114, case 6

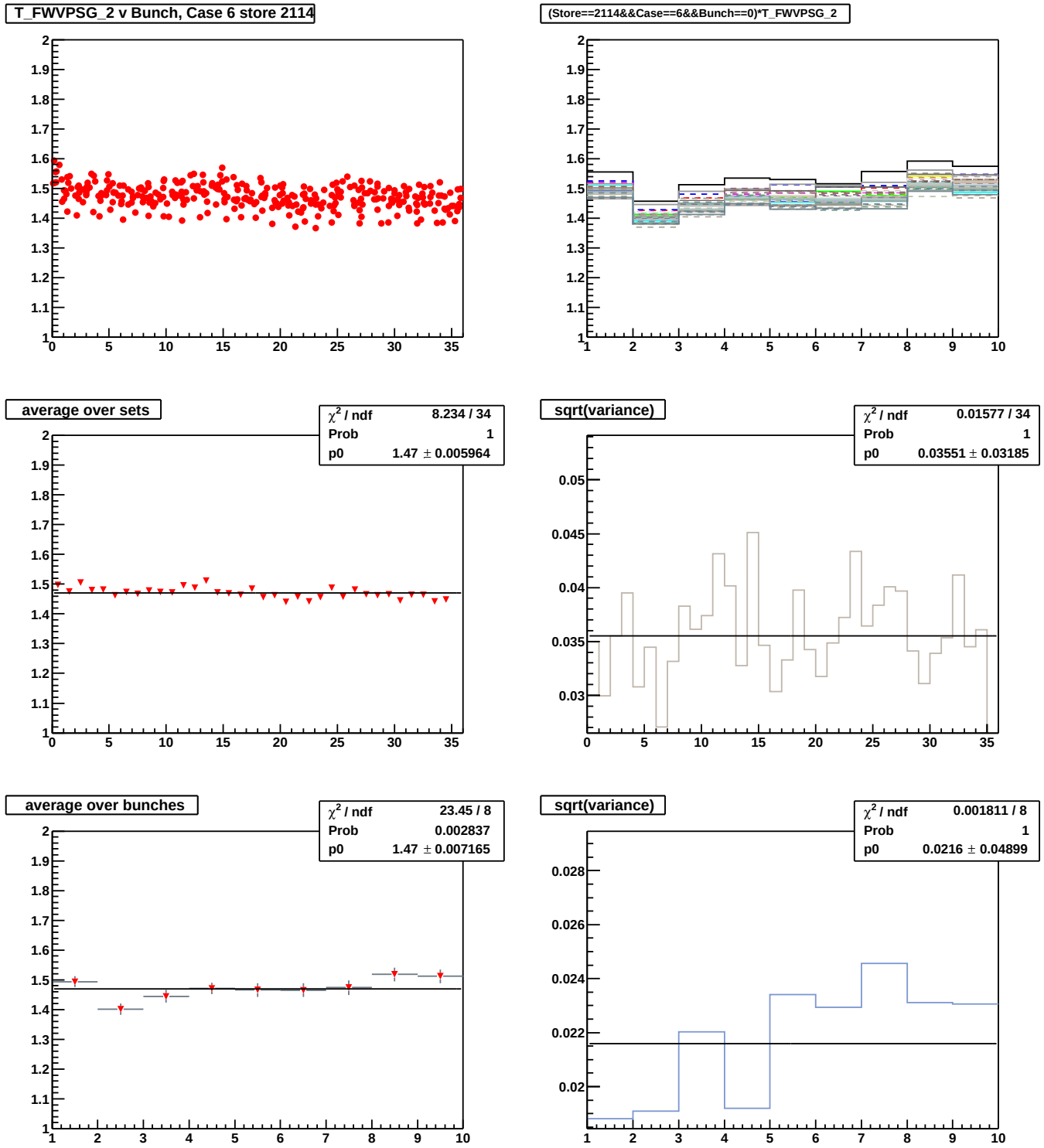

Figure 10: T:FWVPSG pass 2, store 2114, case 6

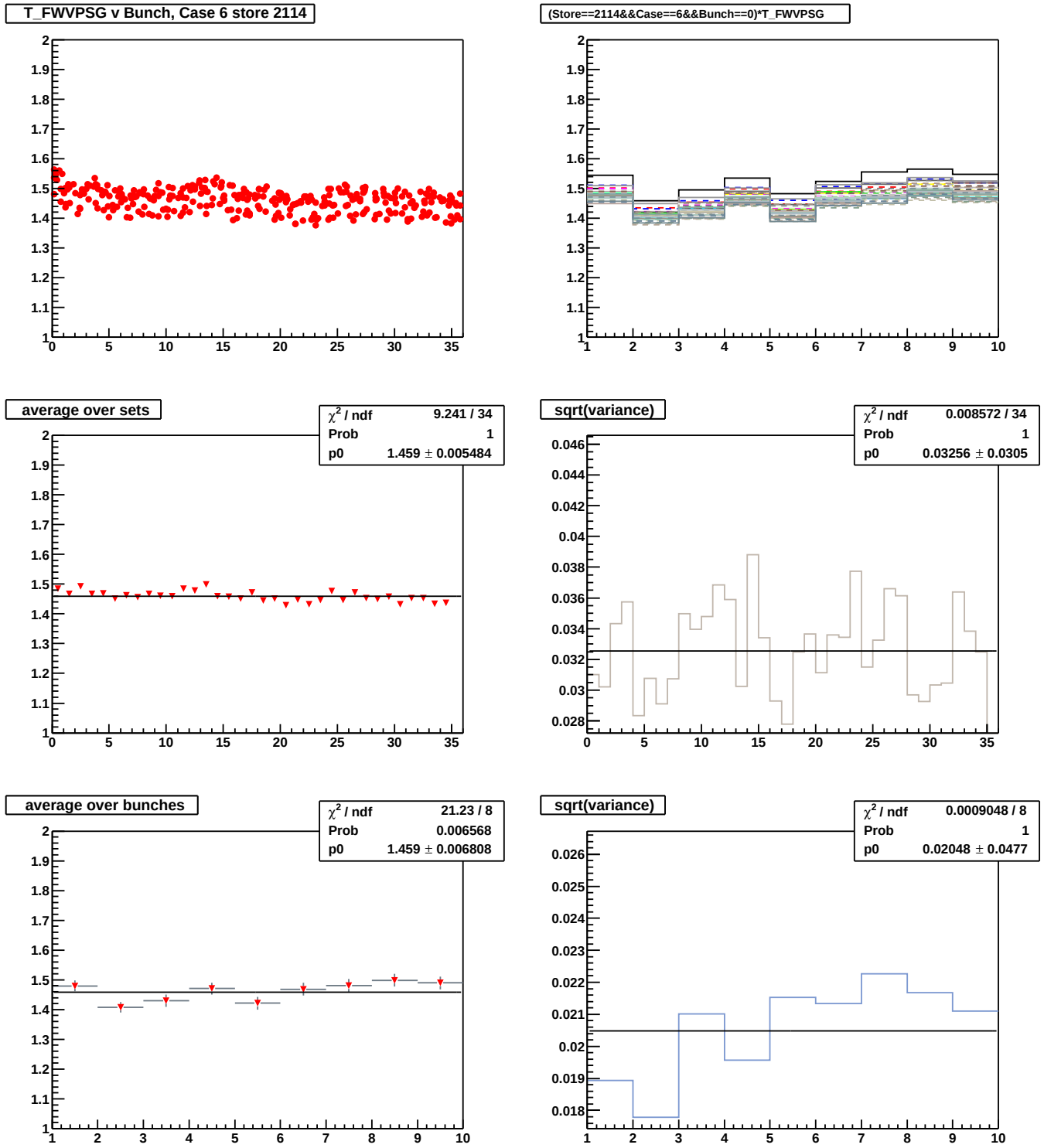

Figure 11: T:FWVPSG, store 2114, case 6

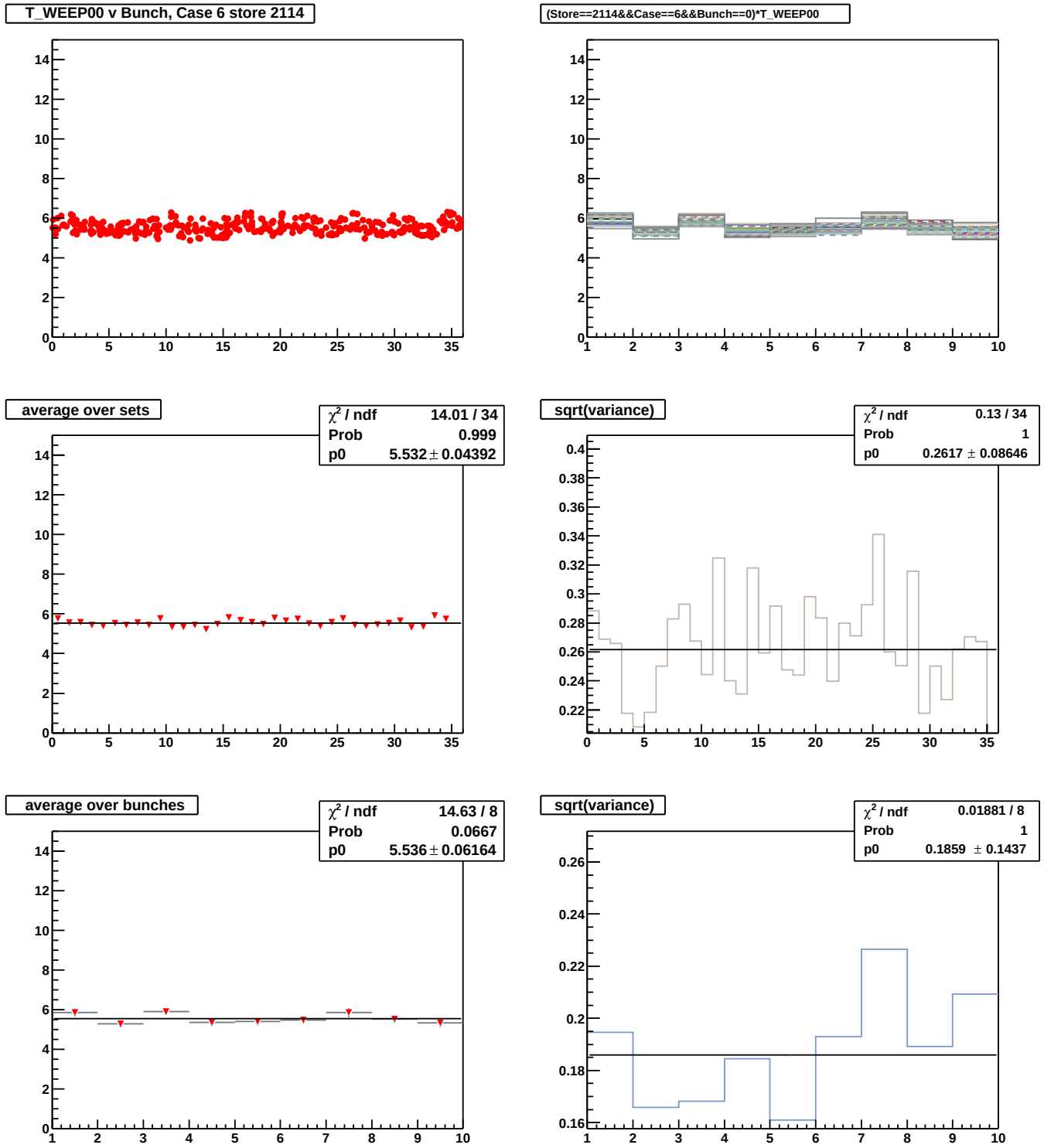

Figure 12: T:WEEP00, store 2114, case 6

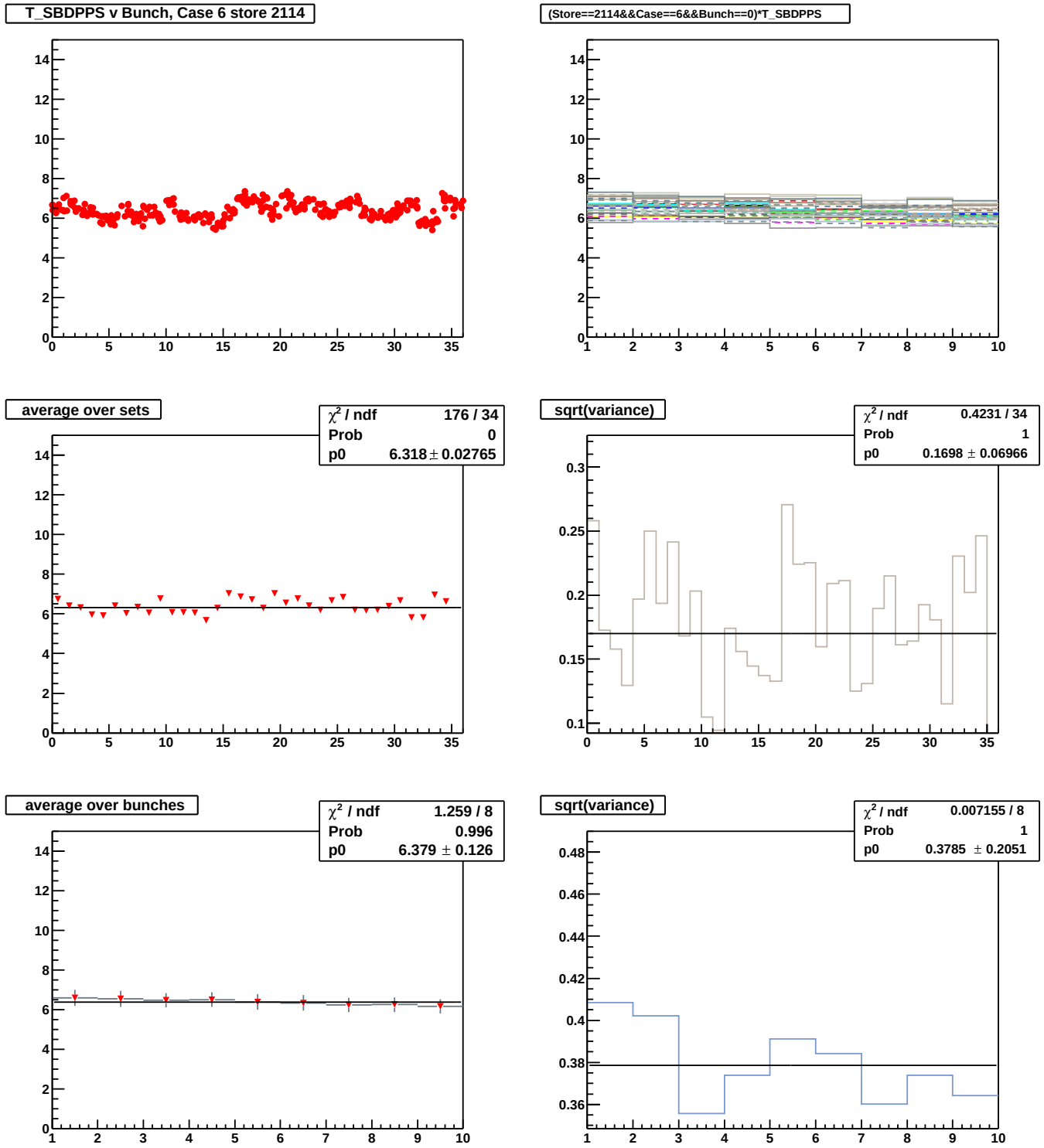

Figure 13: T:SBDPPS, store 2114, case 6

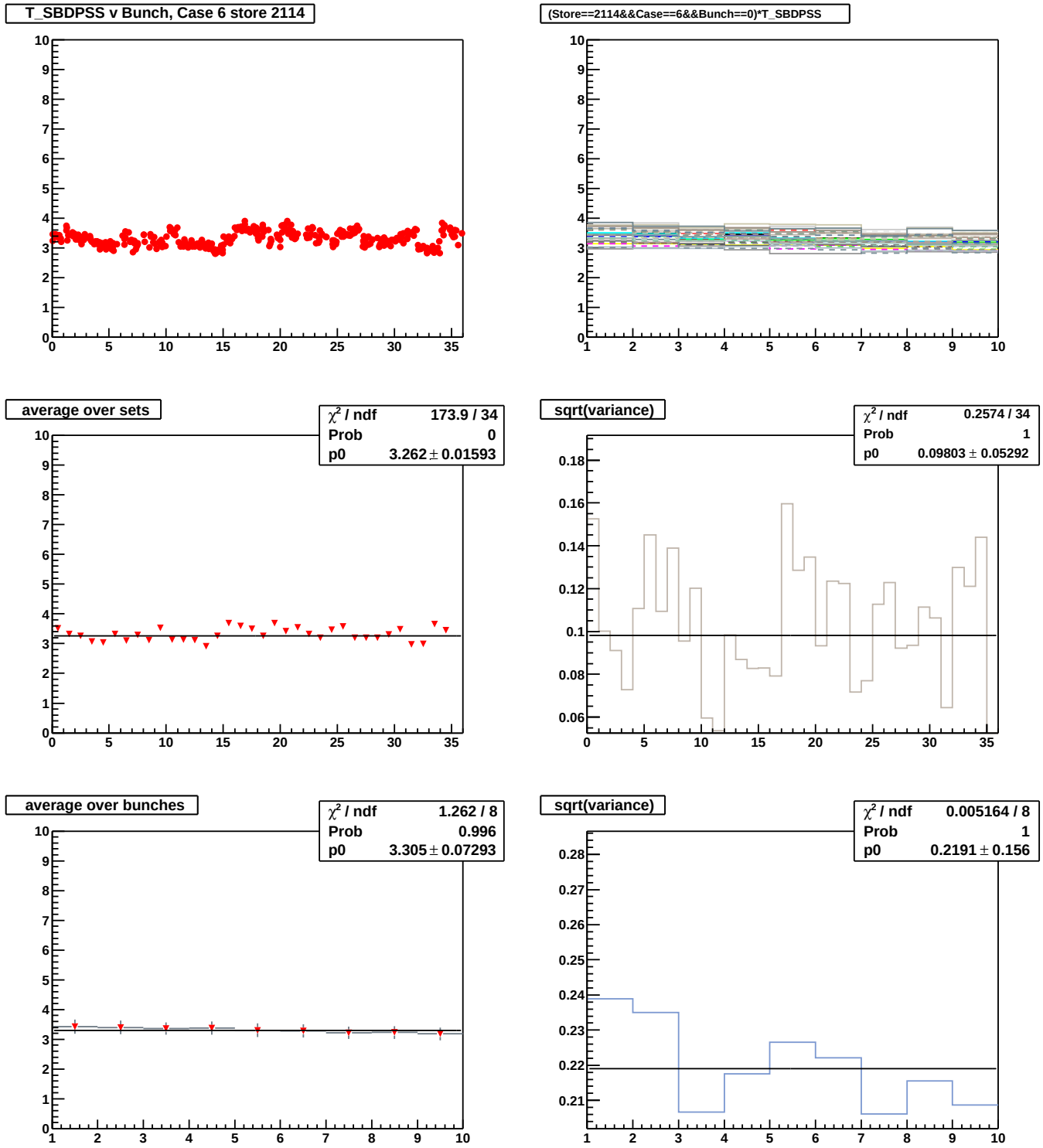

Figure 14: T:SBDPSS, store 2114, case 6

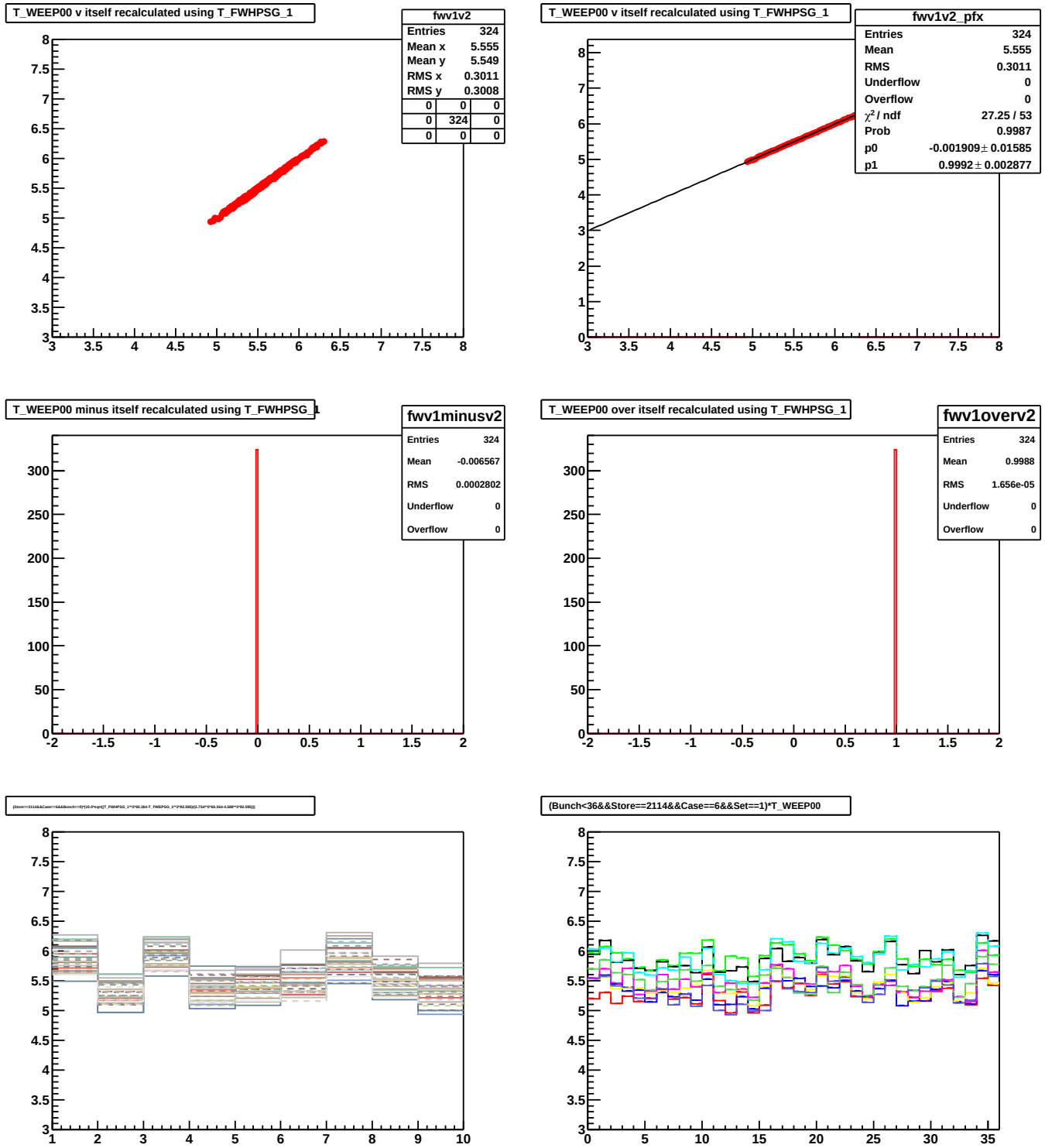

Figure 15: T:WEEP00 versus itself, recalculated using dp/p from T:FWHPSG pass 1, store 2114, case 6

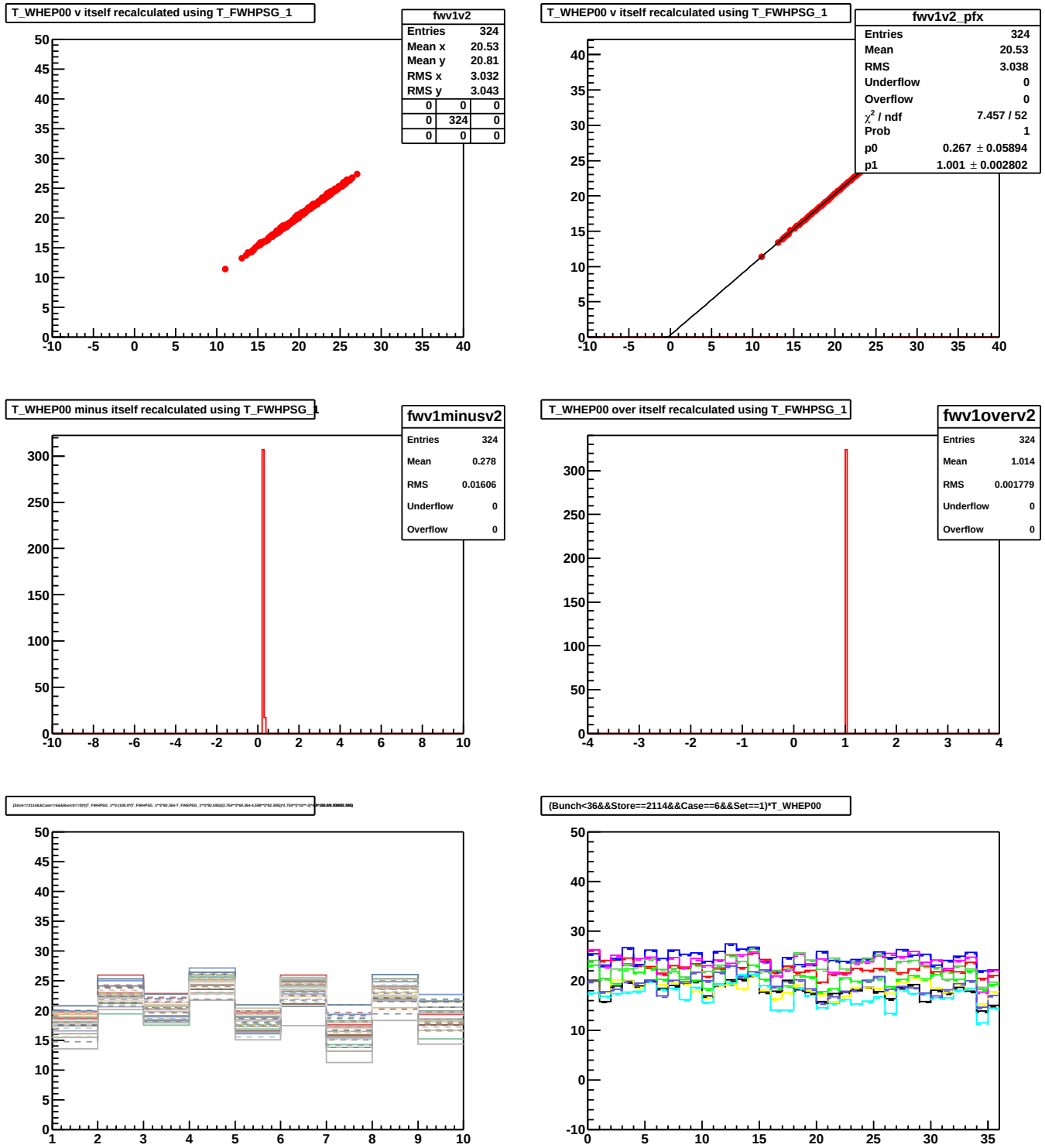

Figure 16: T:WHEP00 versus itself, recalculated using dp/p from T:FWHPSG pass 1, store 2114, case 6

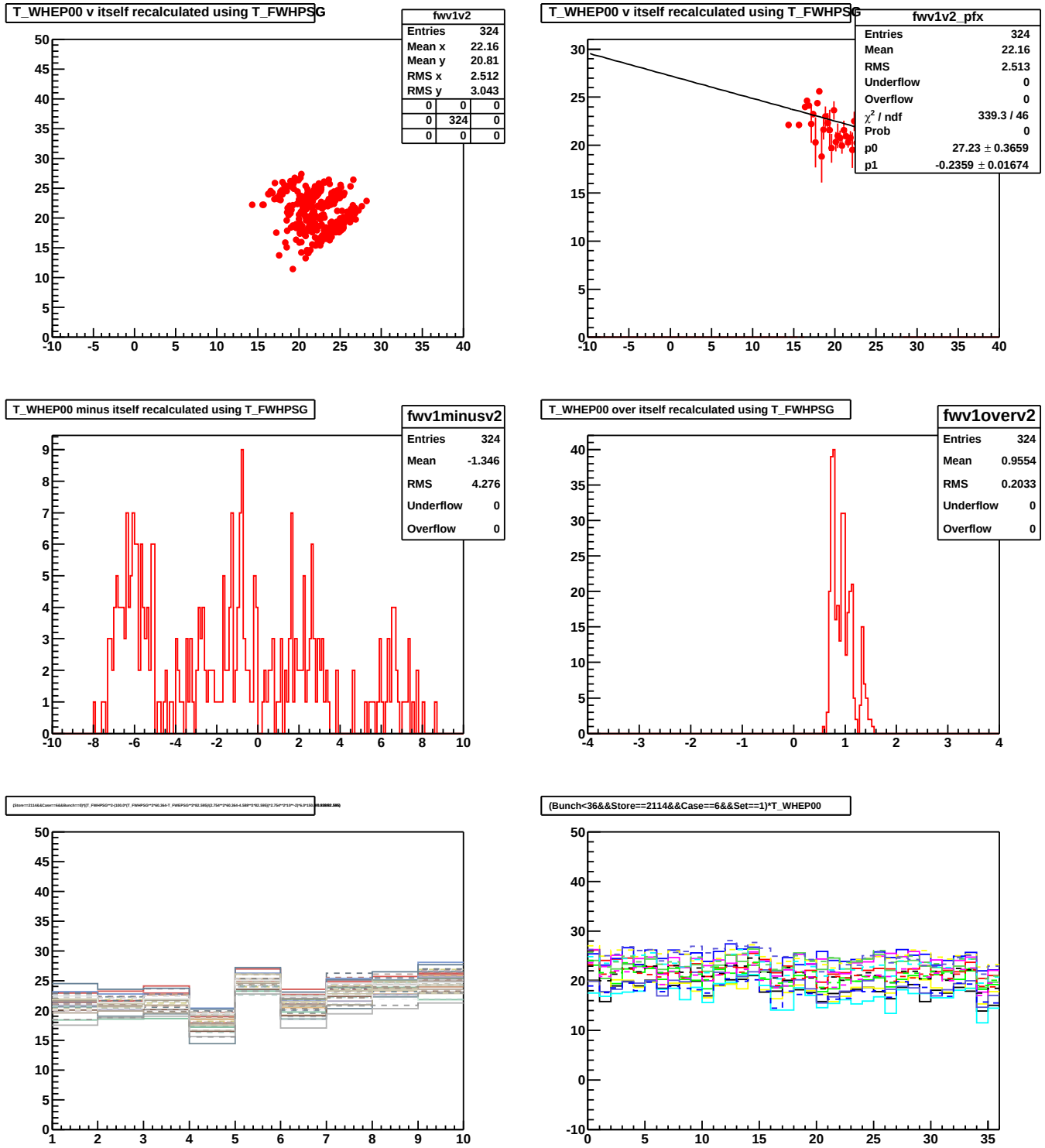

Figure 17: T:WHEP00 versus itself, recalculated using dp/p from T:FWHPSG, store 2114, case 6

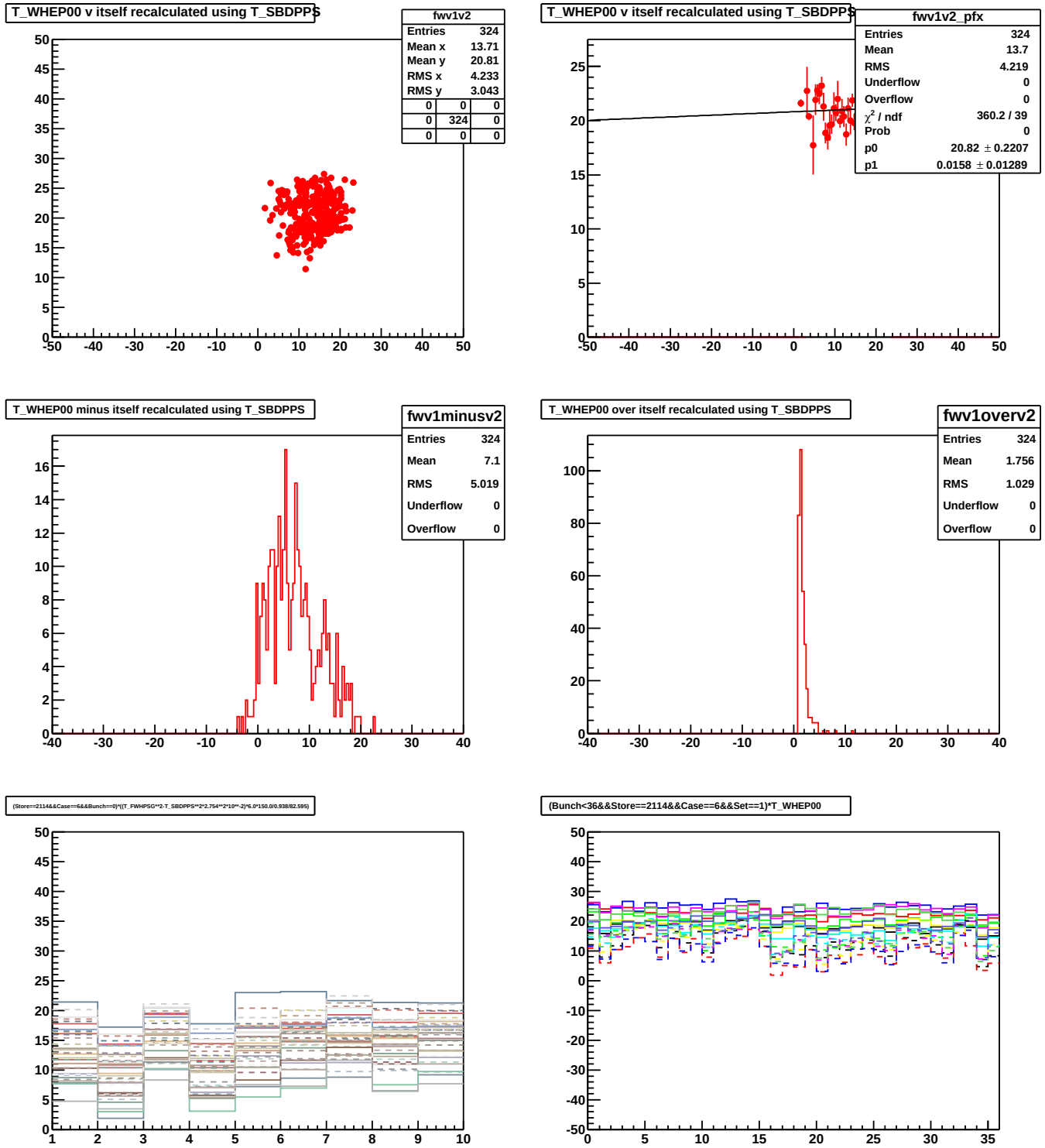

Figure 18: T:WHEP00 versus itself, recalculated using dp/p from T:SBDPPS, store 2114, case 6

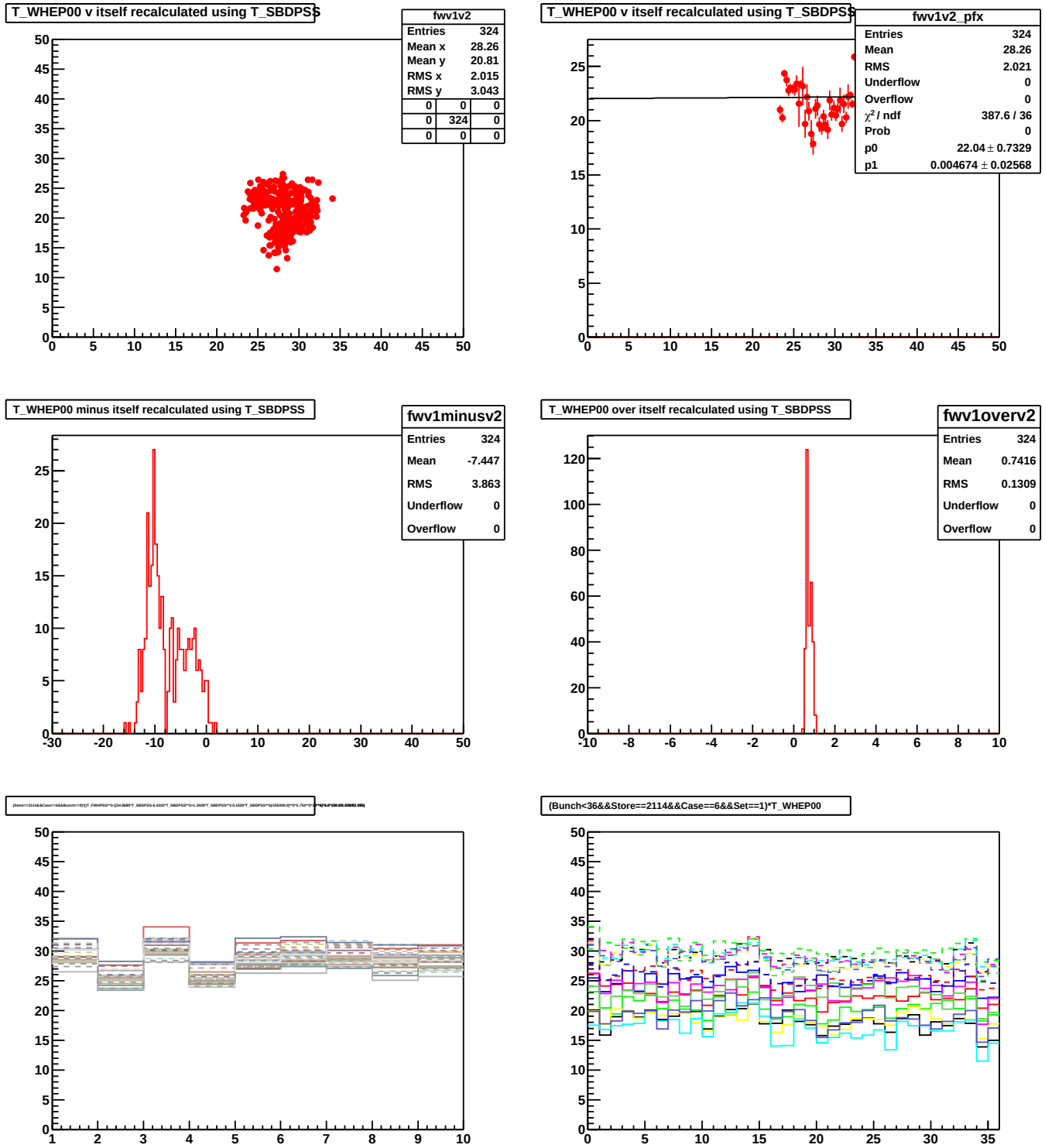

Figure 19: T:WHEP00 versus itself, recalculated using dp/p from T:SBDPSS, store 2114, case 6

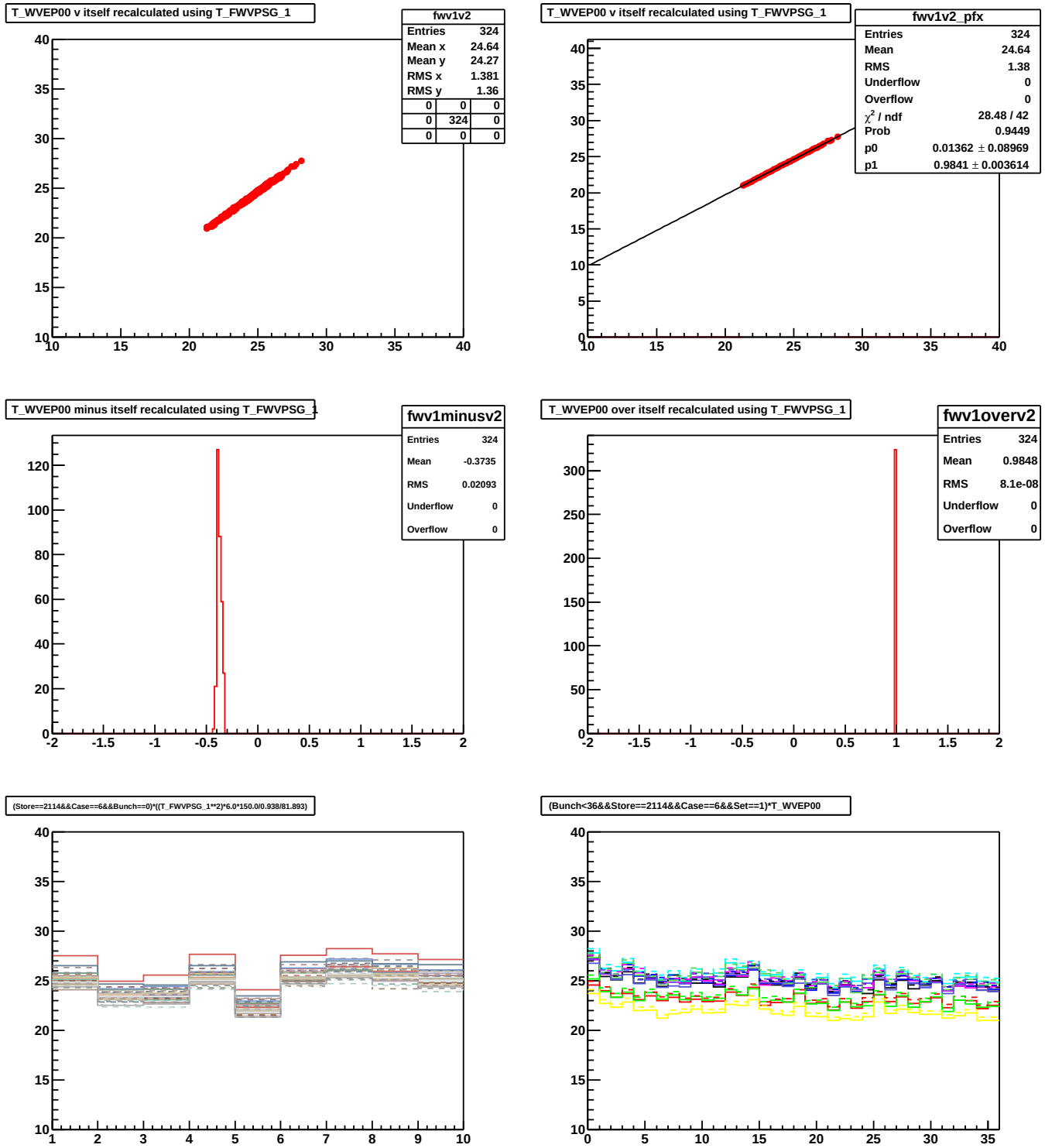

Figure 20: T:WVEP00 versus itself, recalculated using dp/p from T:FWVPSG pass 1, store 2114, case 6

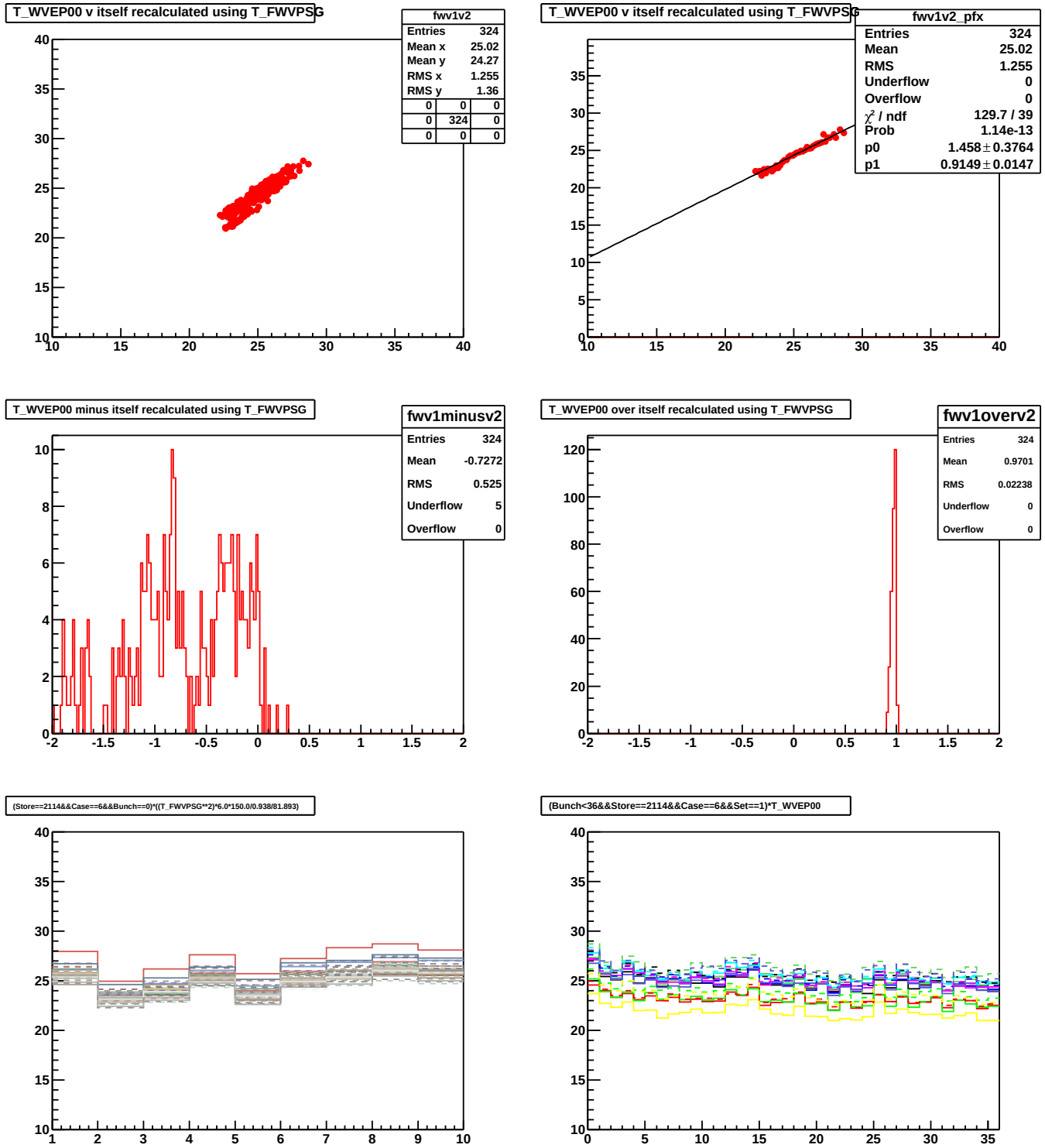

Figure 21: T:WVEP00 versus itself, recalculated using dp/p from T:FWVPSG, store 2114, case 6

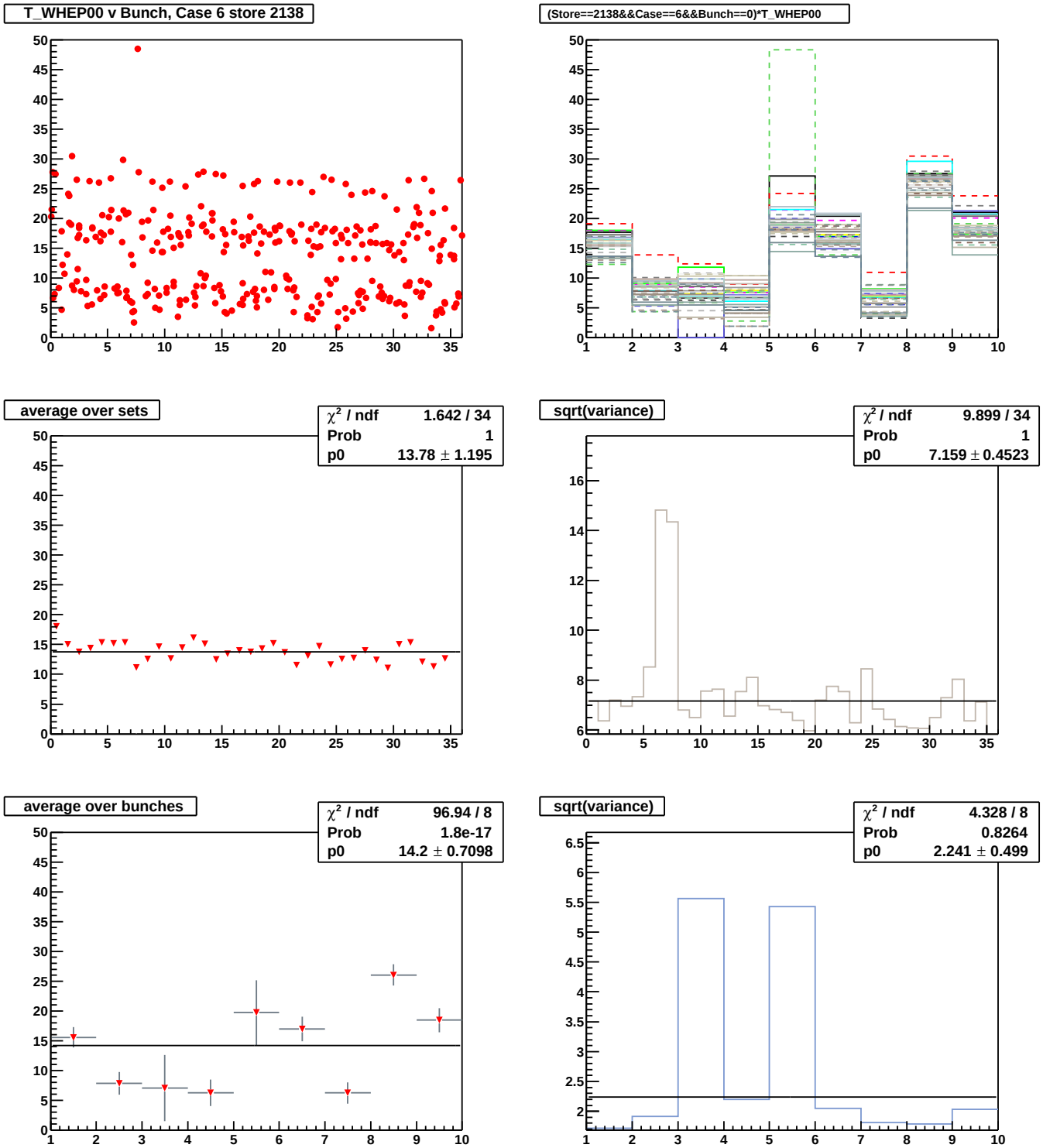

Figure 22: T:WHEP00, store 2138, case 6

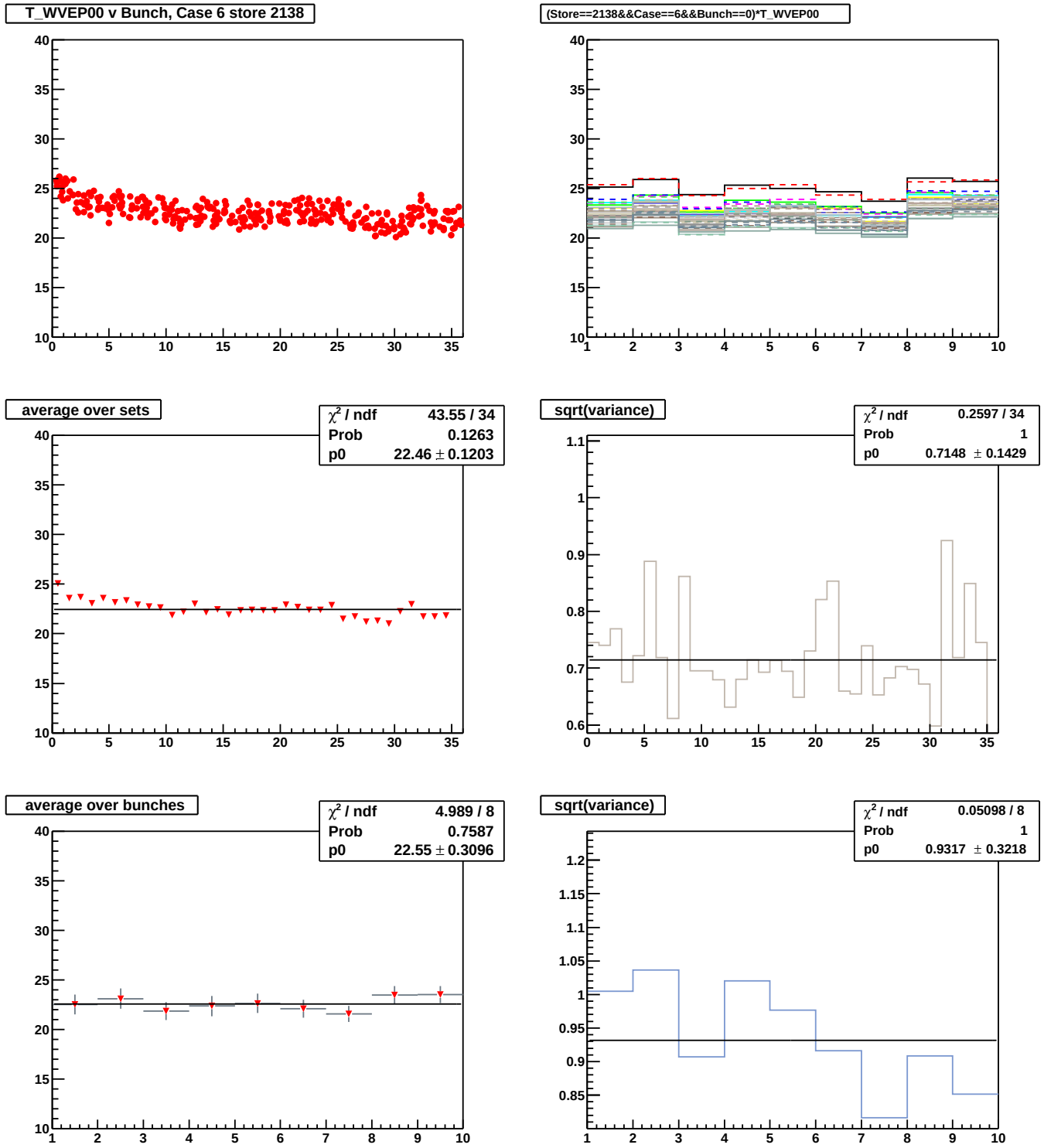

Figure 23: T:WVEP00, store 2138, case 6

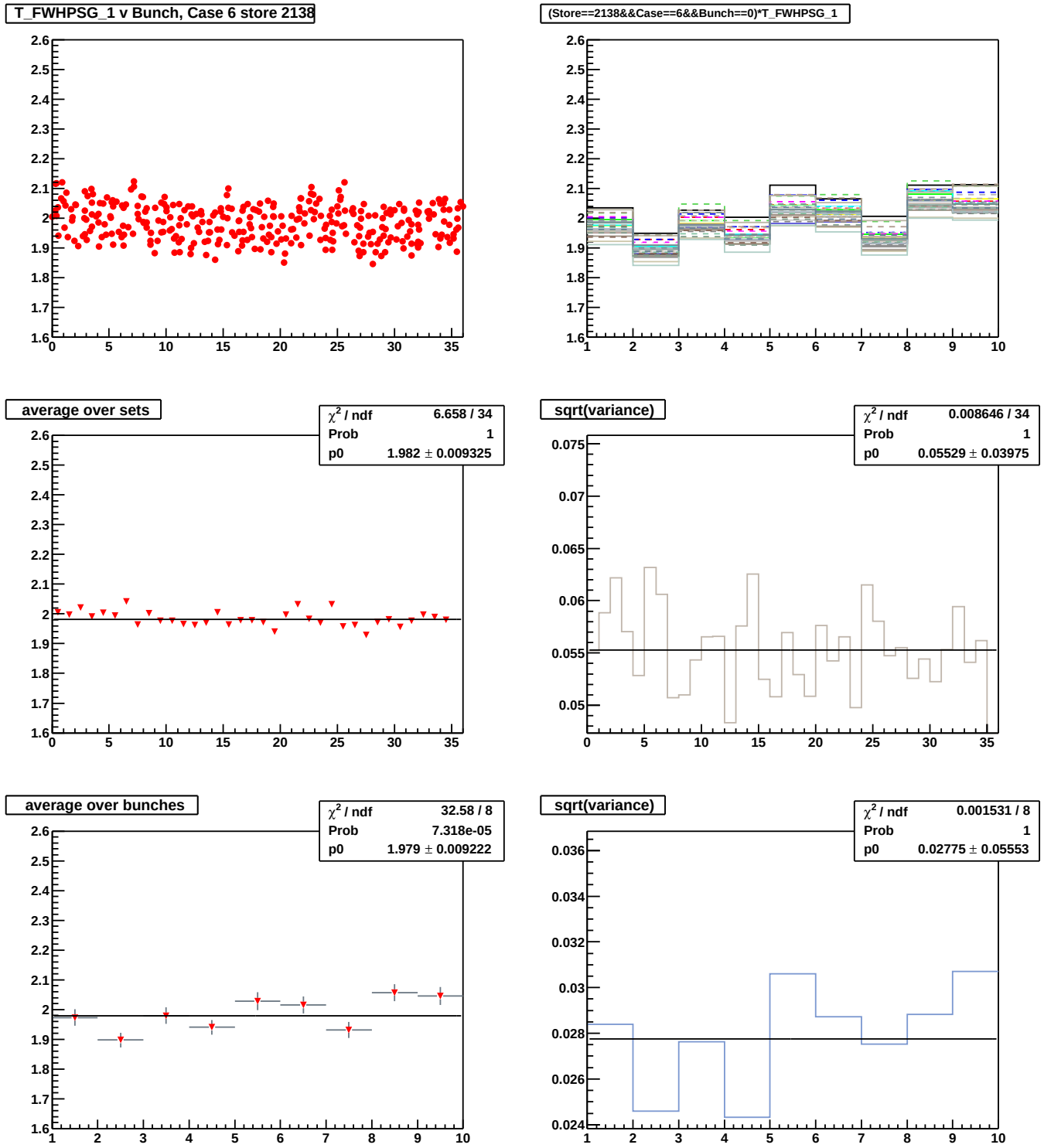

Figure 24: T:FWHPSG pass 1, store 2138, case 6

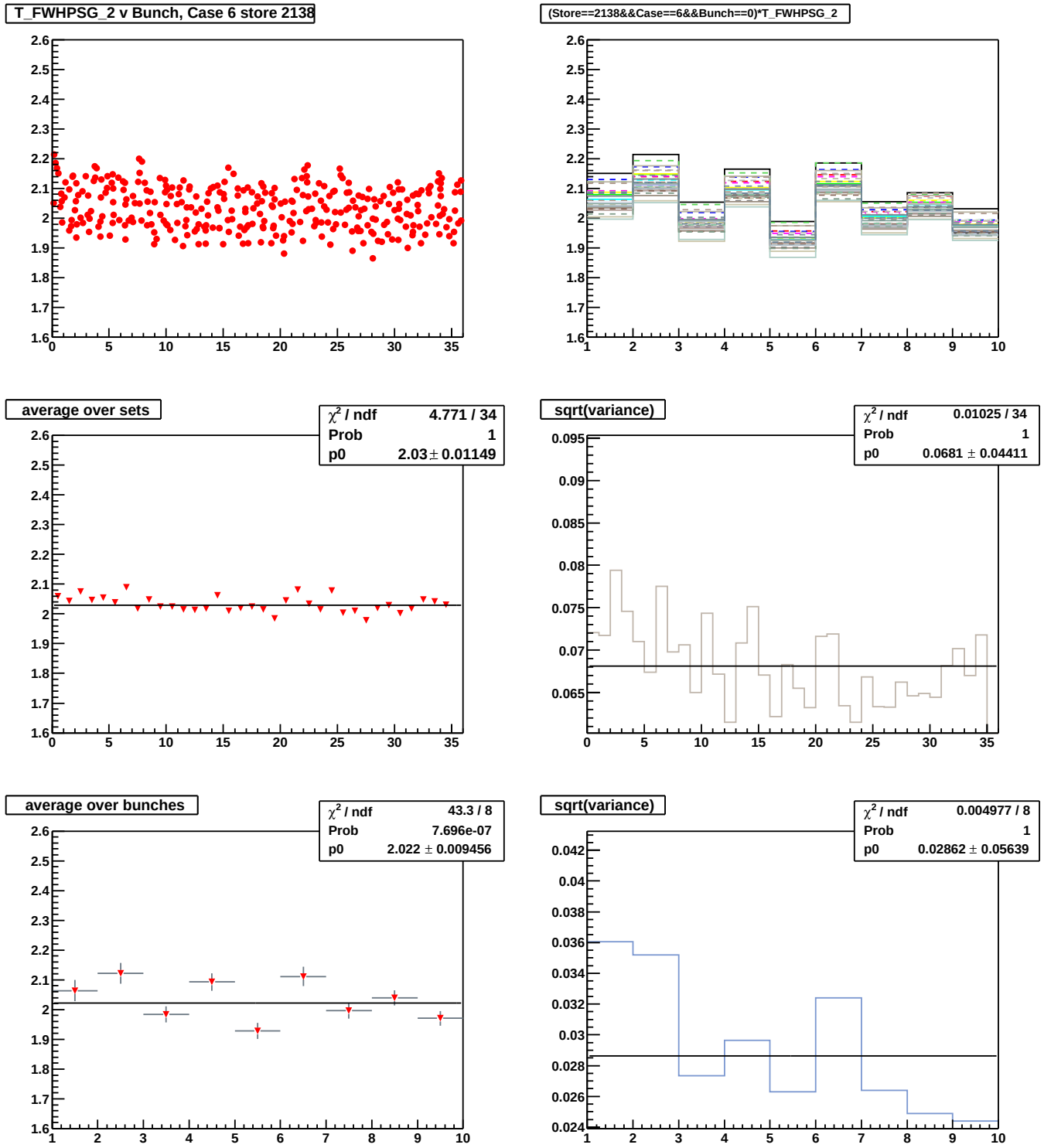

Figure 25: T:FWHPSG pass 2, store 2138, case 6

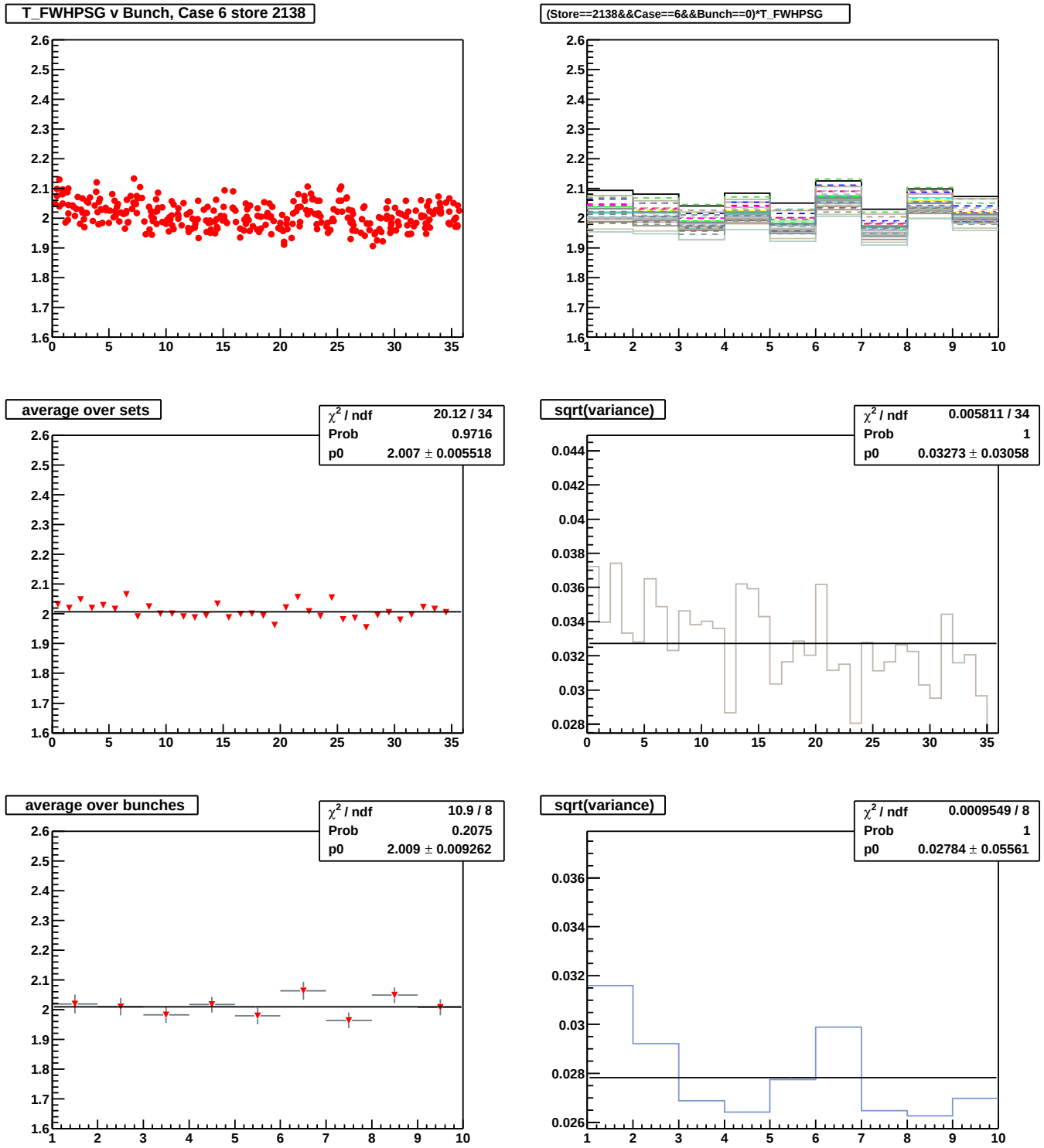

Figure 26: T:FWHPSG, store 2138, case 6

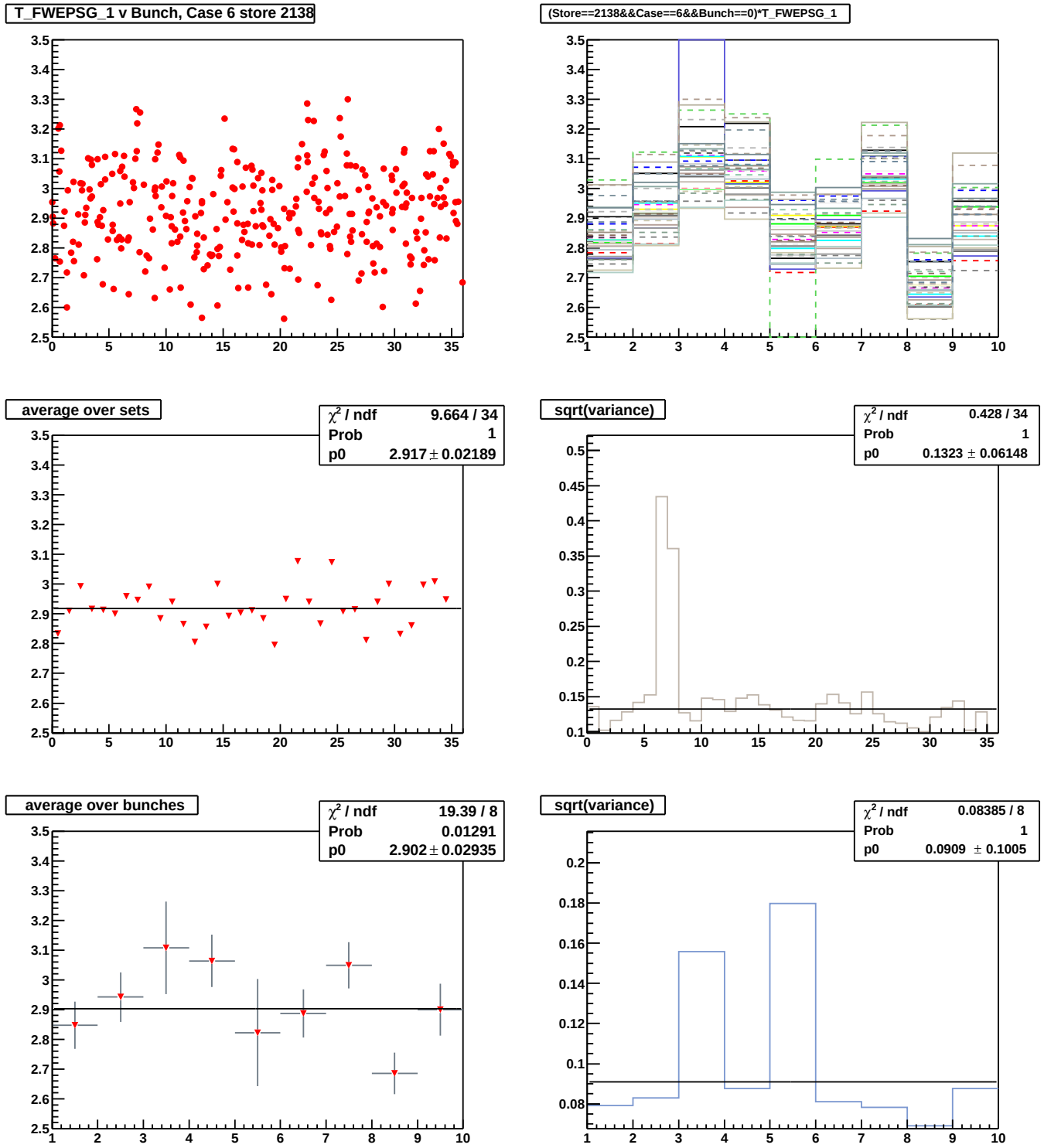

Figure 27: T:FWEPSG pass 1, store 2138, case 6

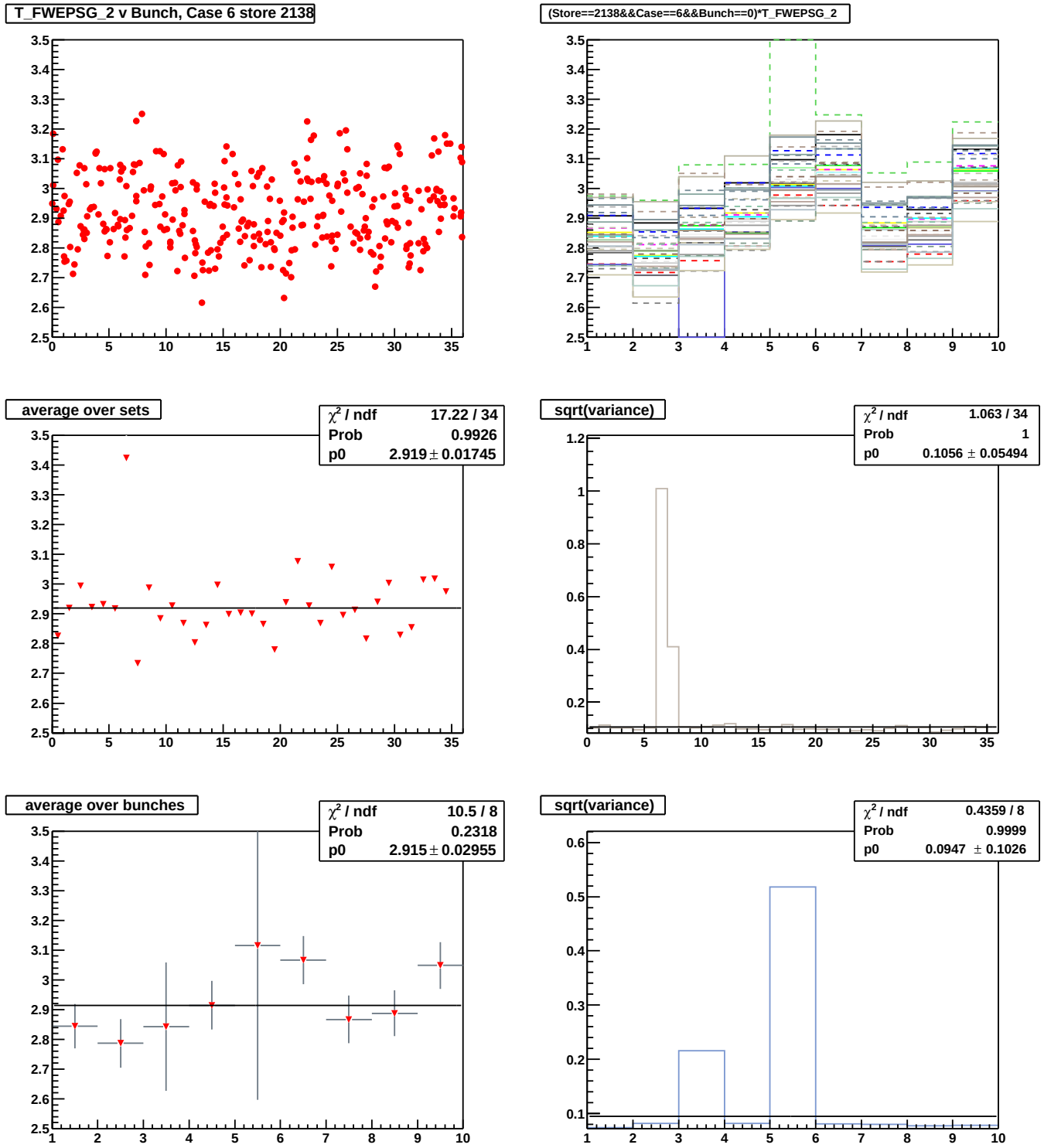

Figure 28: T:FWEPSG pass 2, store 2138, case 6

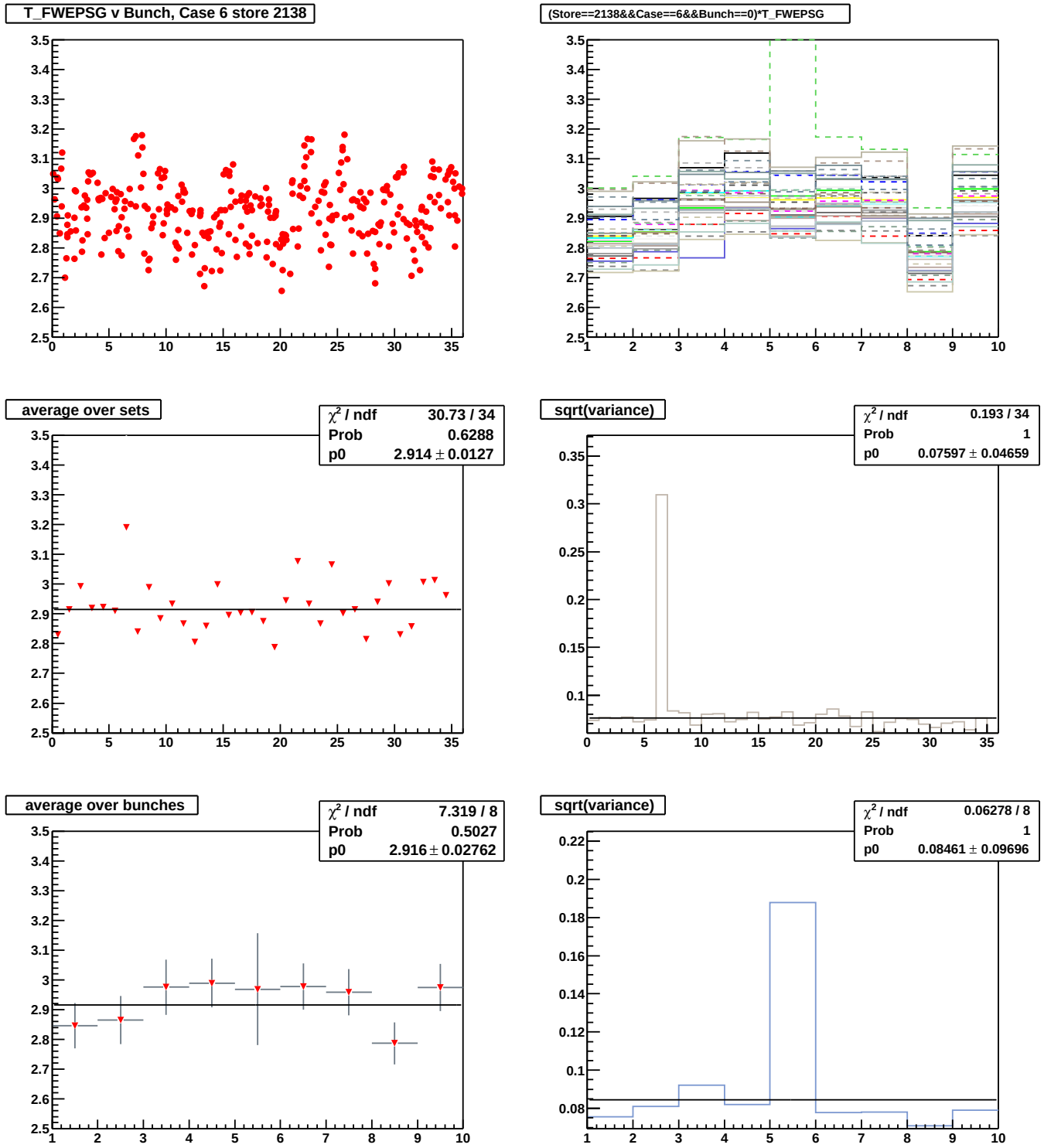

Figure 29: T:FWEPSG, store 2138, case 6

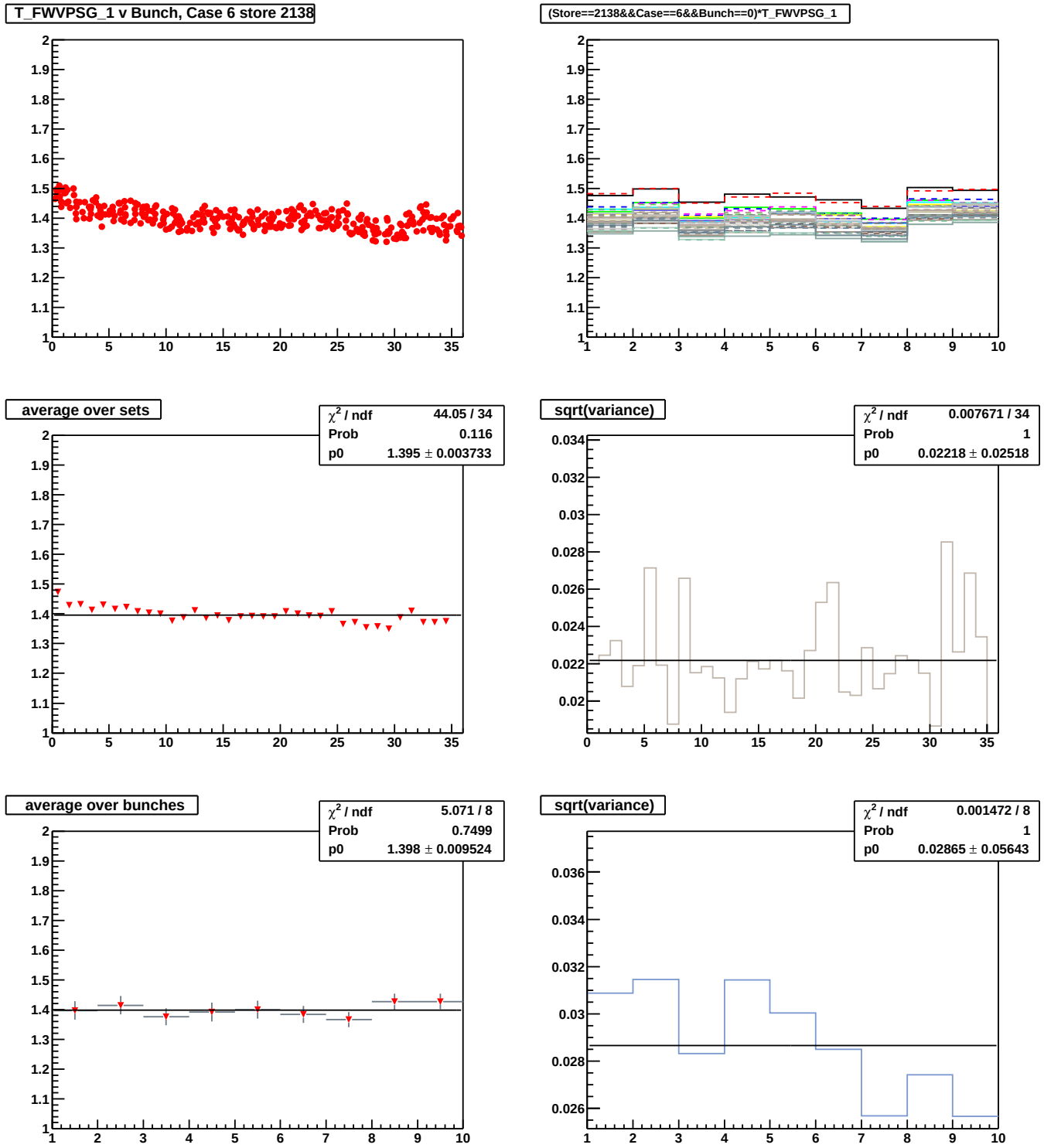

Figure 30: T:FWVPSG pass 1, store 2138, case 6

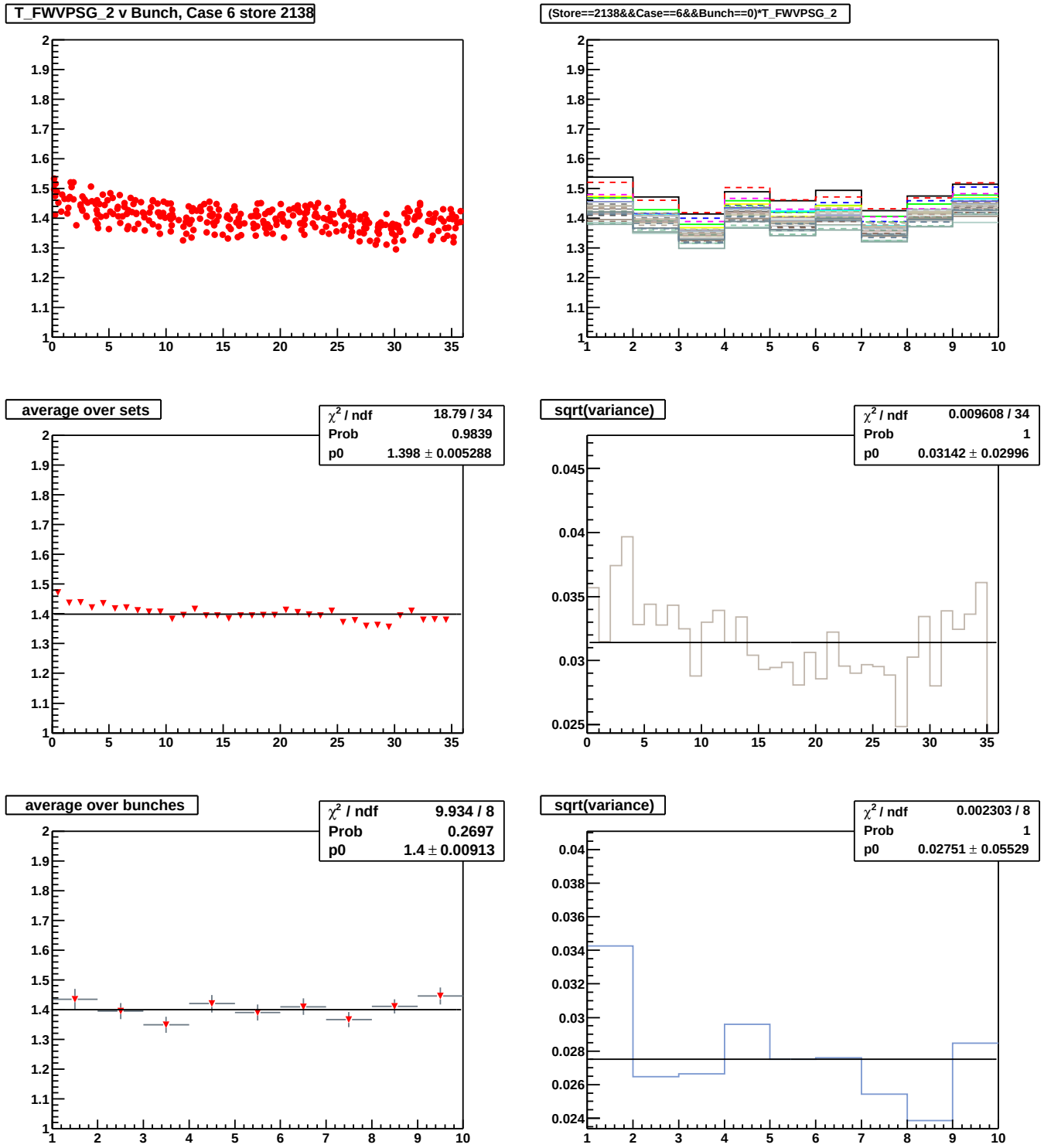

Figure 31: T:FWVPSG pass 2, store 2138, case 6

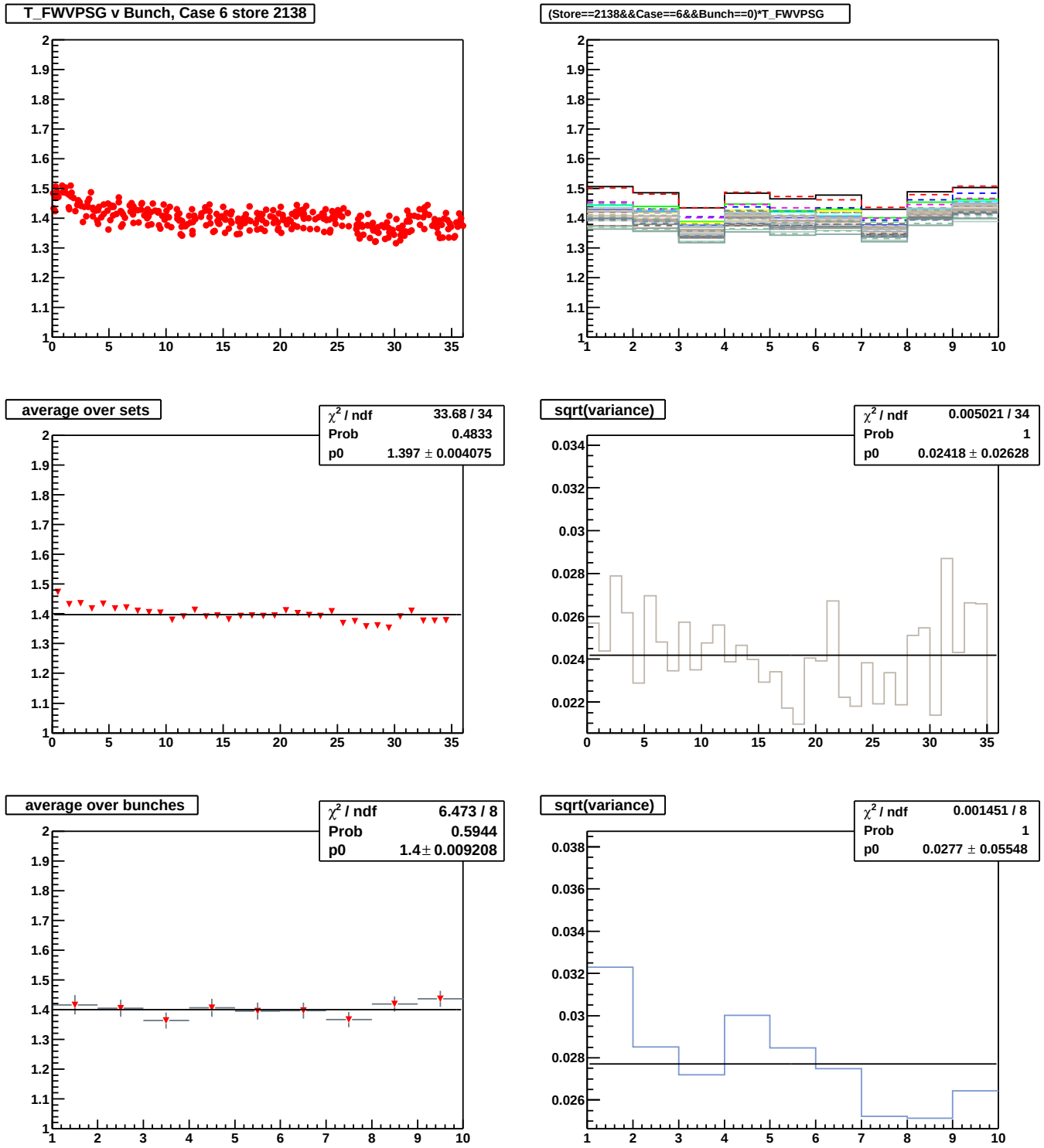

Figure 32: T:FWVPSG, store 2138, case 6

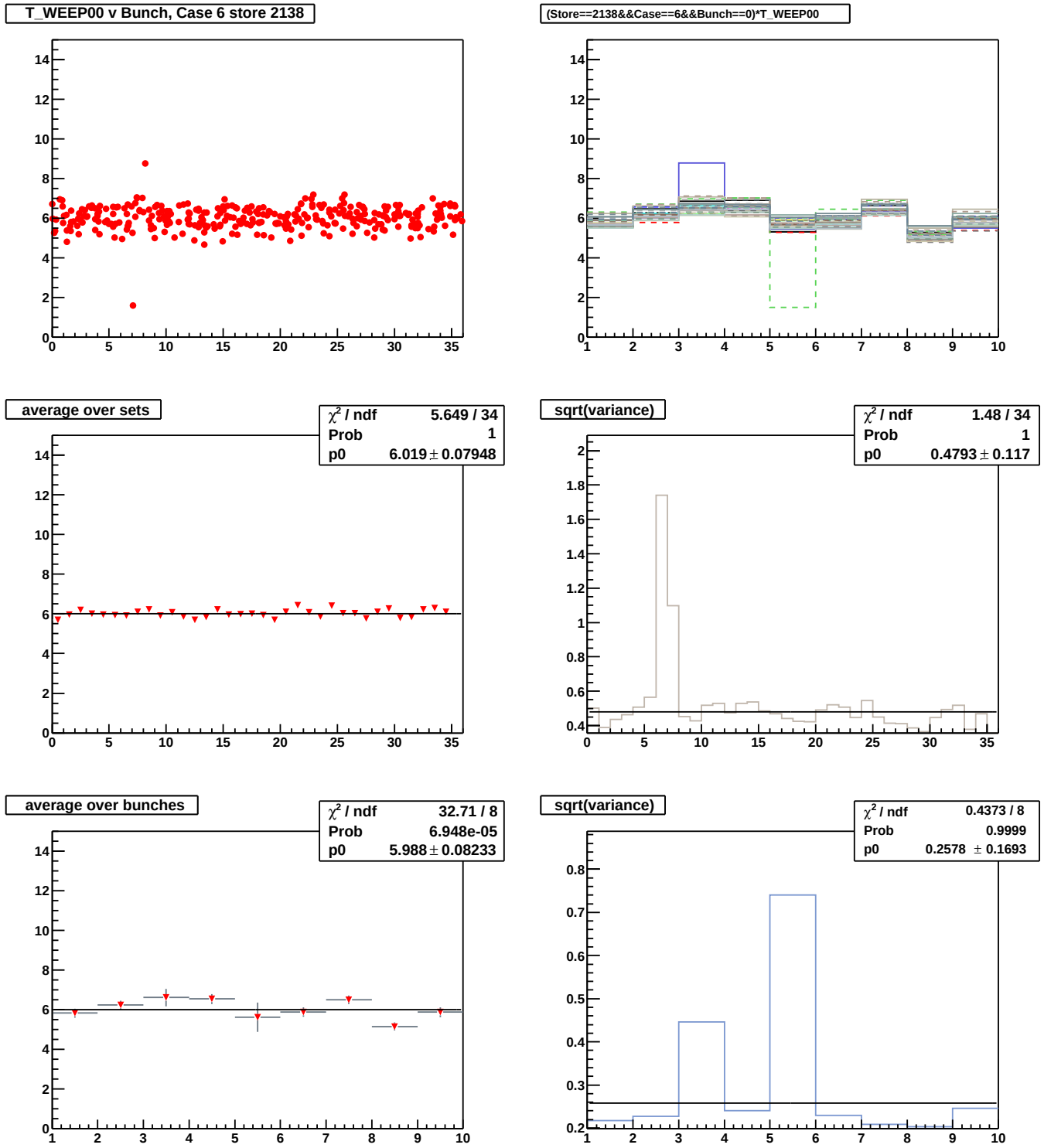

Figure 33: T:WEEP00, store 2138, case 6

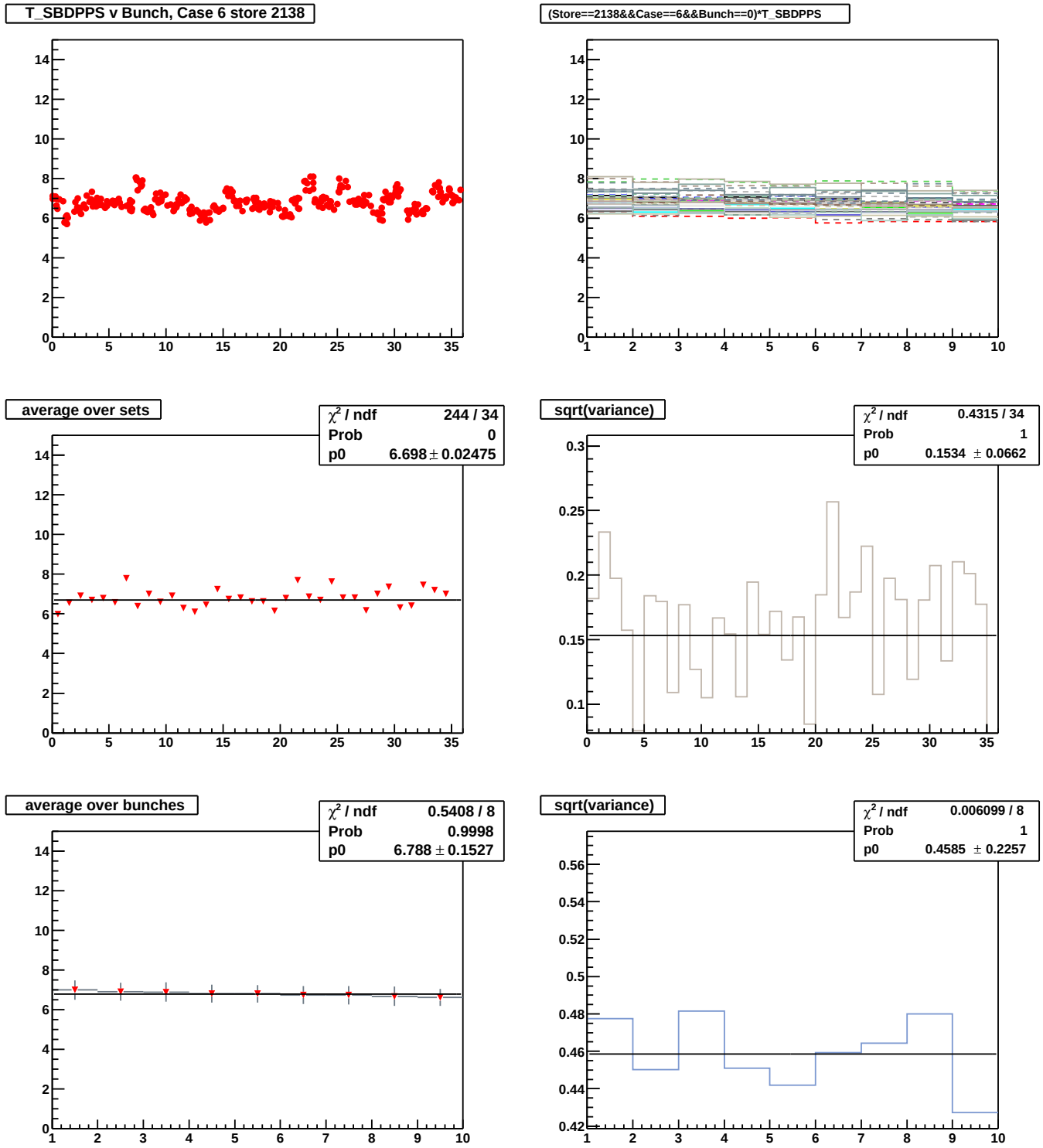

Figure 34: T:SBDPPS, store 2138, case 6

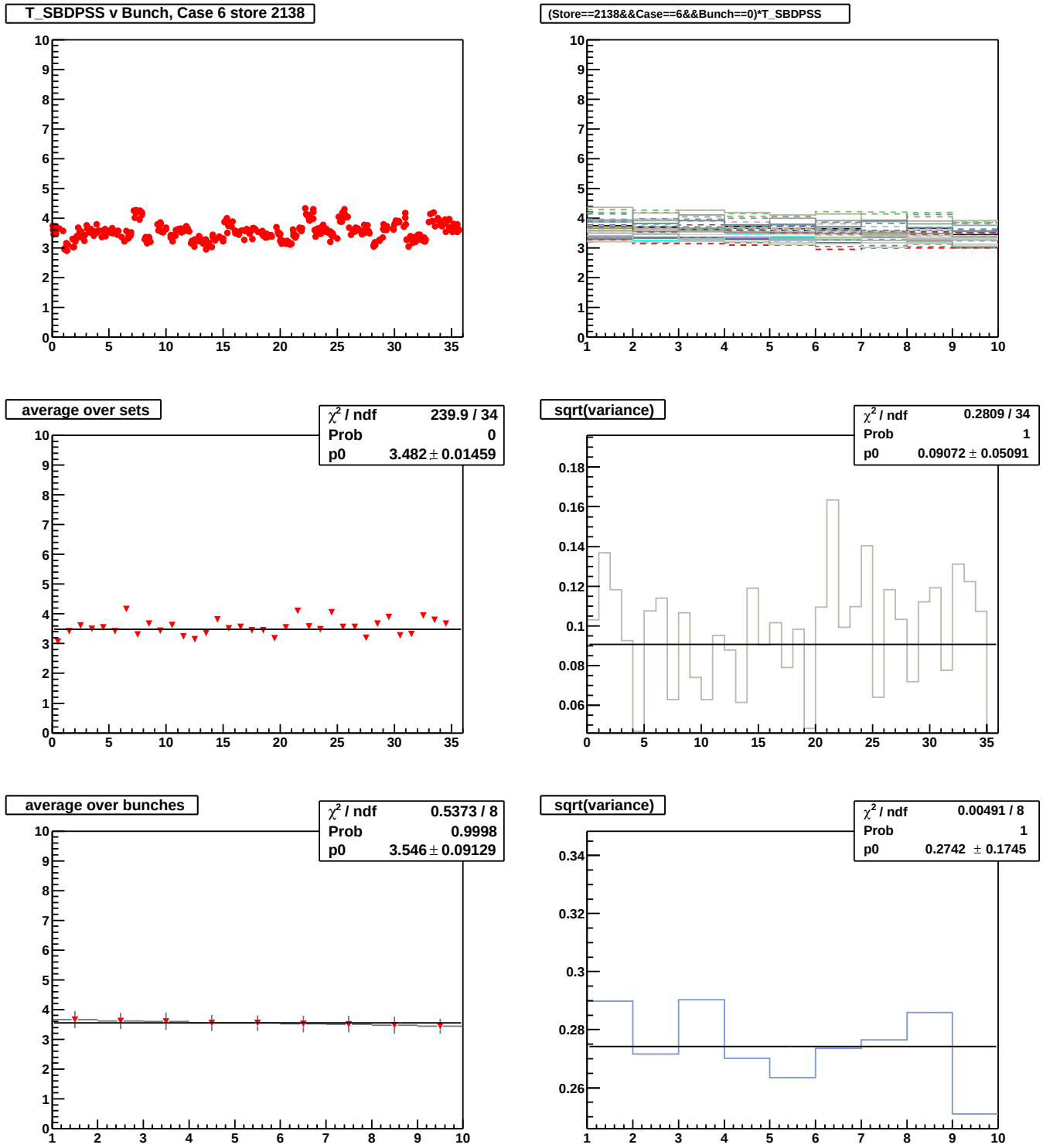

Figure 35: T:SBDPSS, store 2138, case 6

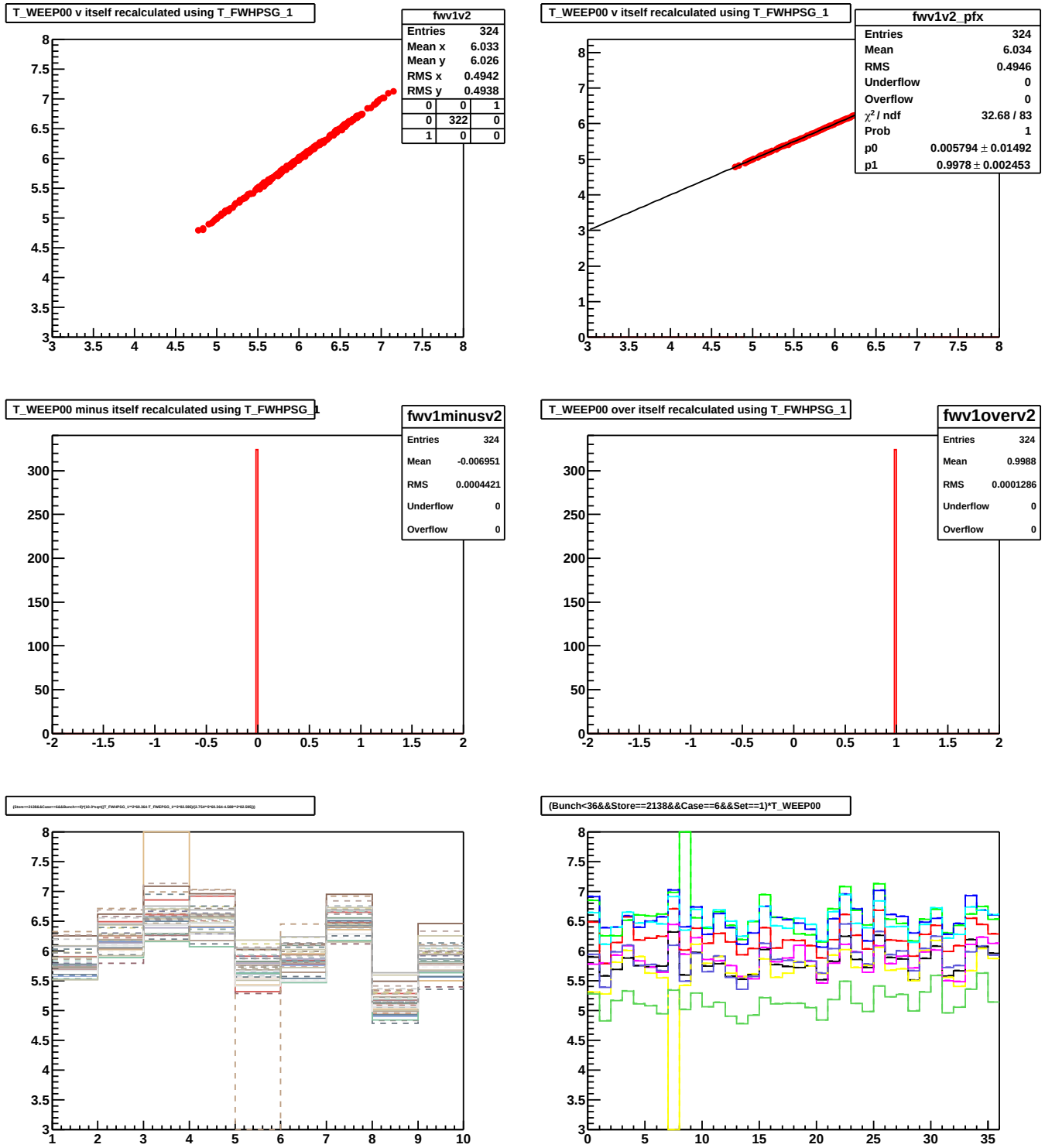

Figure 36: T:WEEP00 versus itself, recalculated using dp/p from T:FWHPSG pass 1, store 2138, case 6

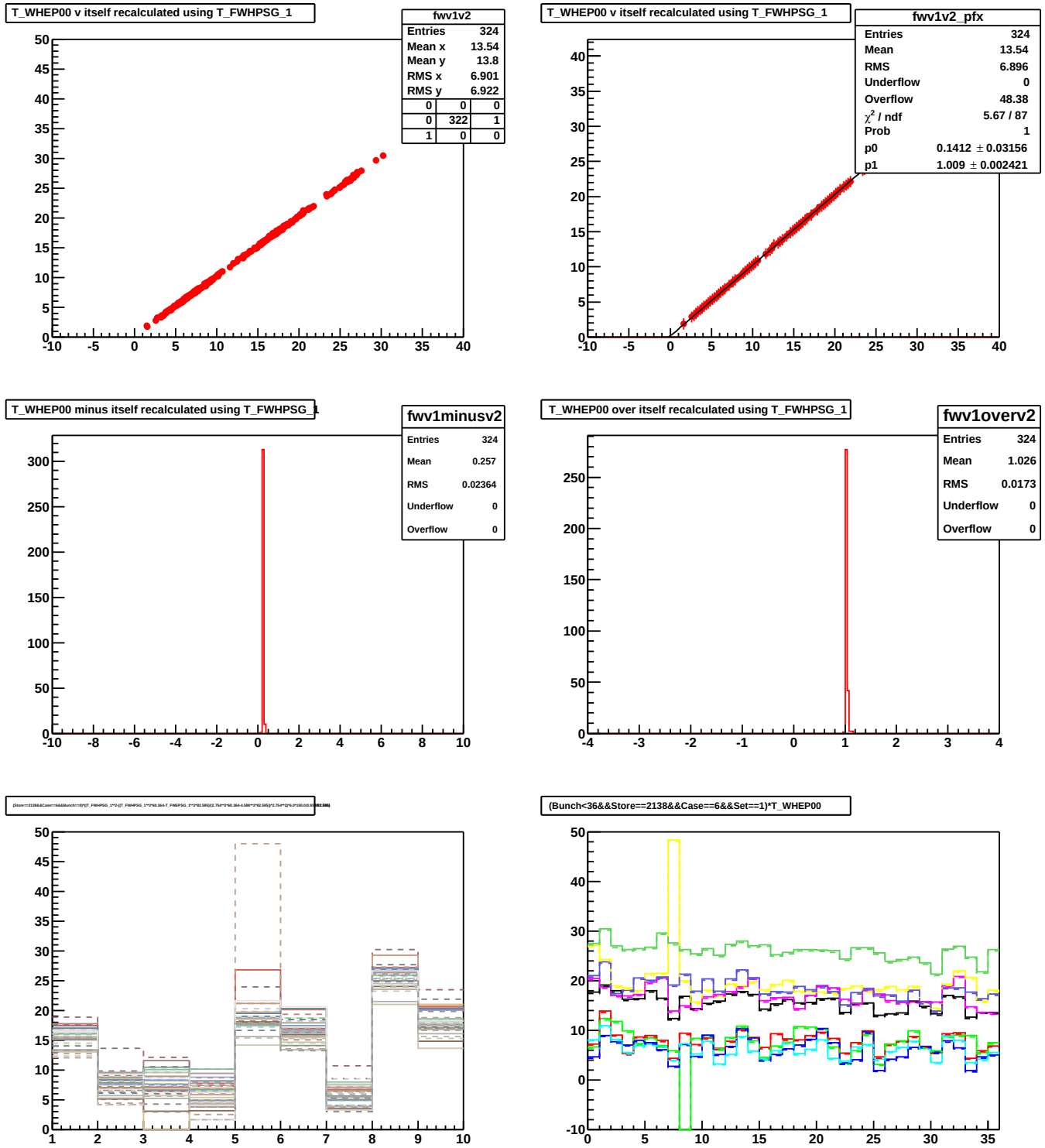

Figure 37: T:WHEP00 versus itself, recalculated using dp/p from T:FWHPSG pass 1, store 2138, case 6

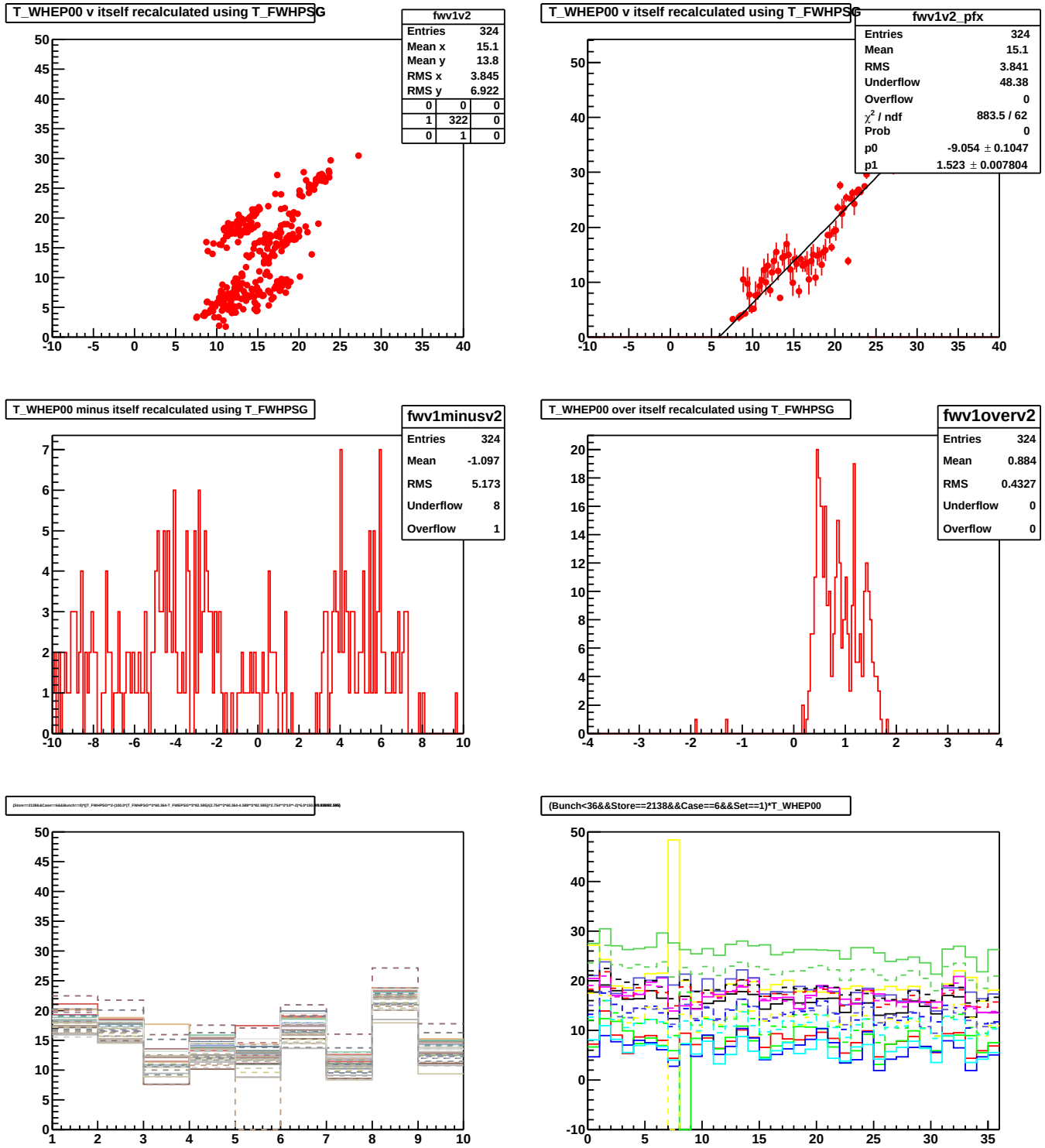

Figure 38: T:WHEP00 versus itself, recalculated using dp/p from T:FWHPSG, store 2138, case 6

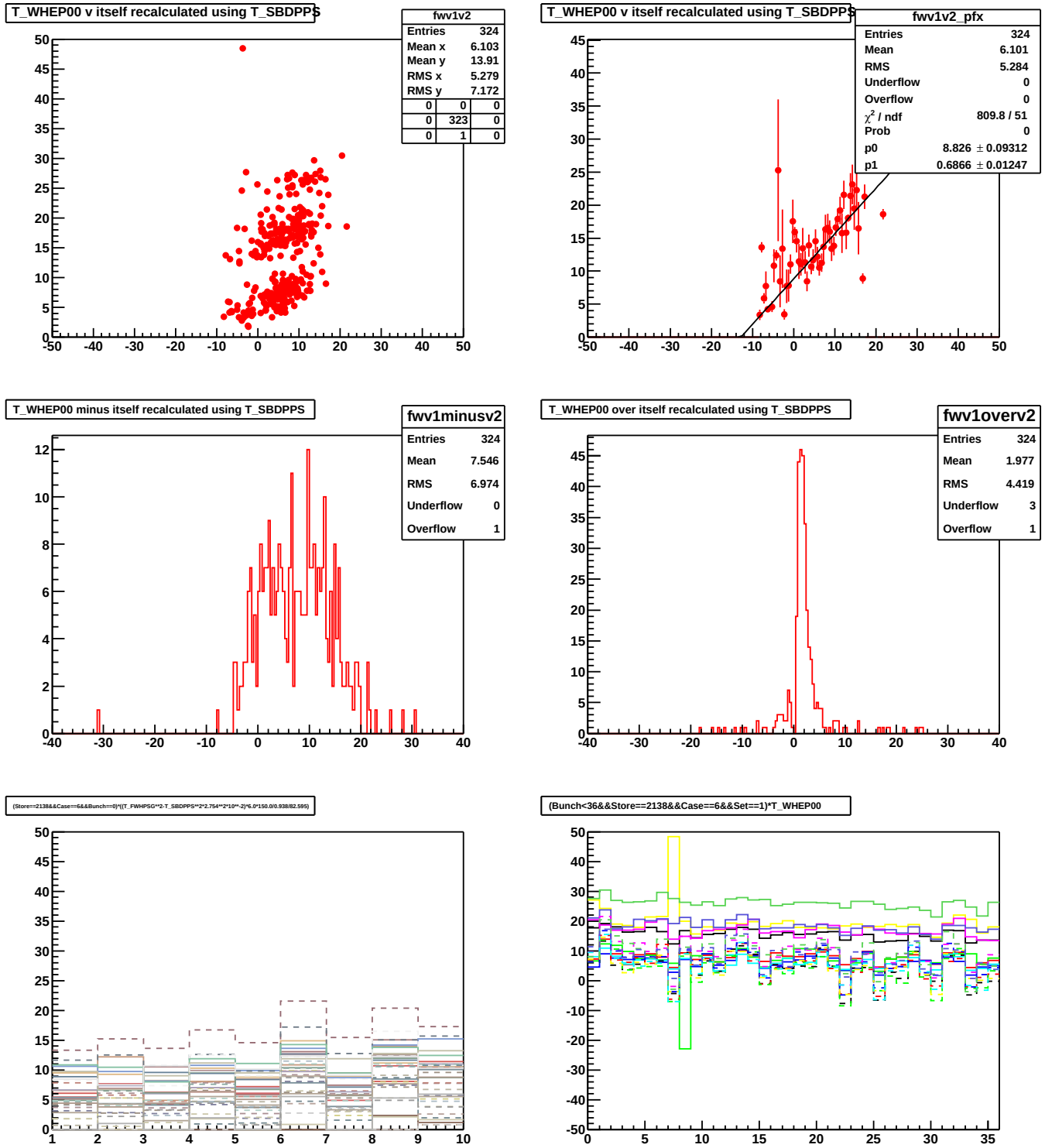

Figure 39: T:WHEP00 versus itself, recalculated using dp/p from T:SBDPPS, store 2138, case 6

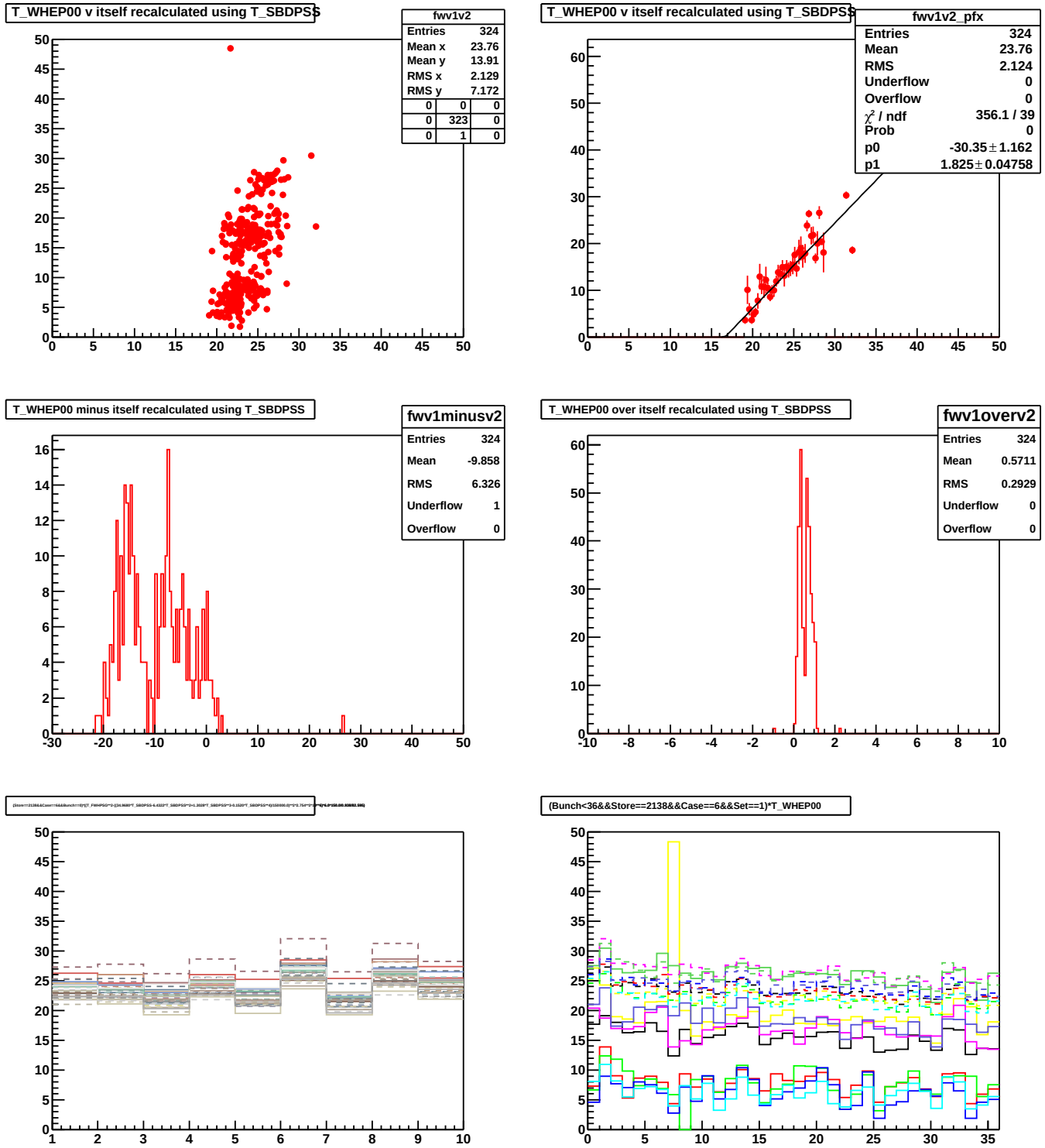

Figure 40: T:WHEP00 versus itself, recalculated using dp/p from T:SBDPSS, store 2138, case 6

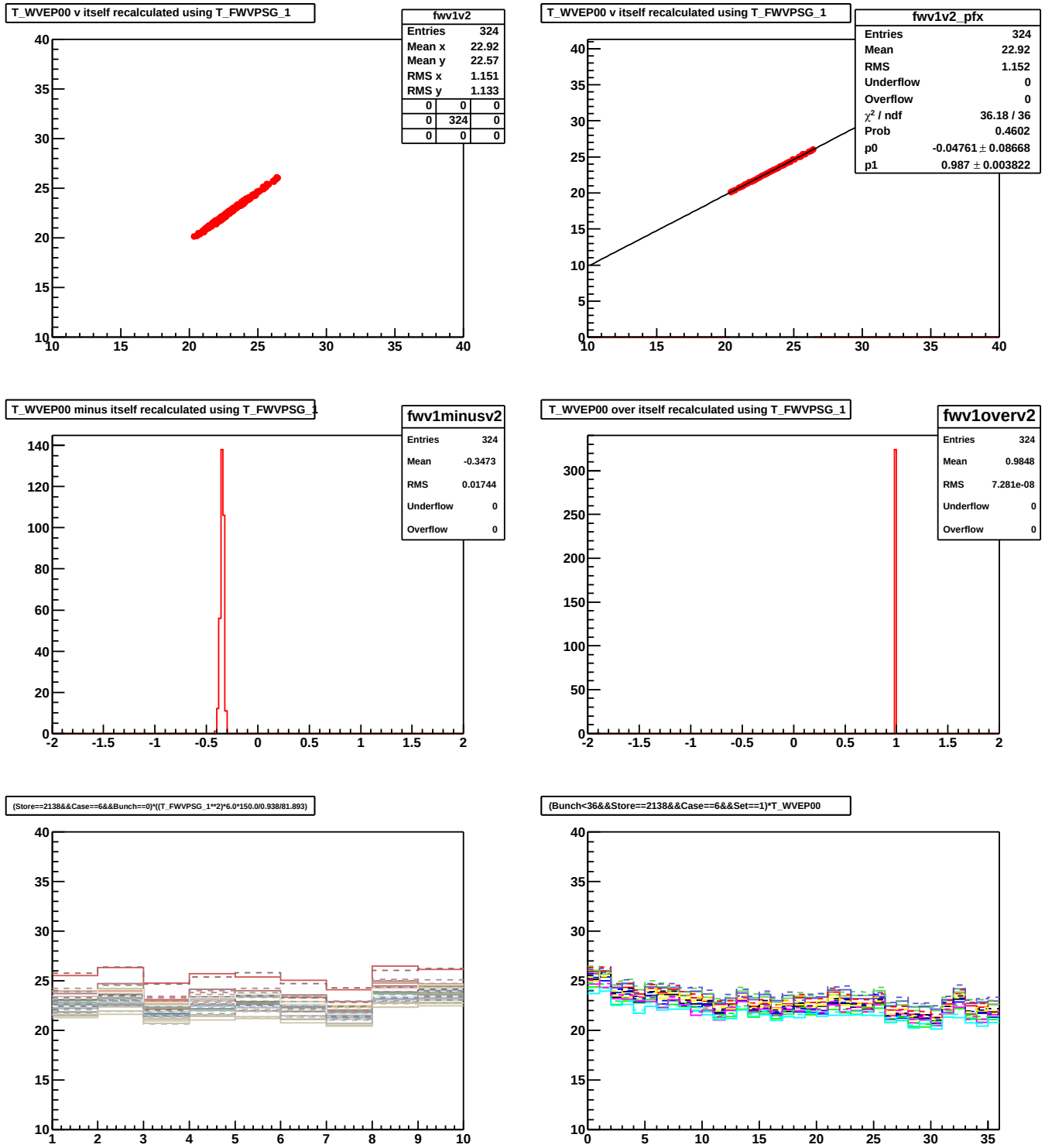

Figure 41: T:WVEP00 versus itself, recalculated using dp/p from T:FWVPSG pass 1, store 2138, case 6

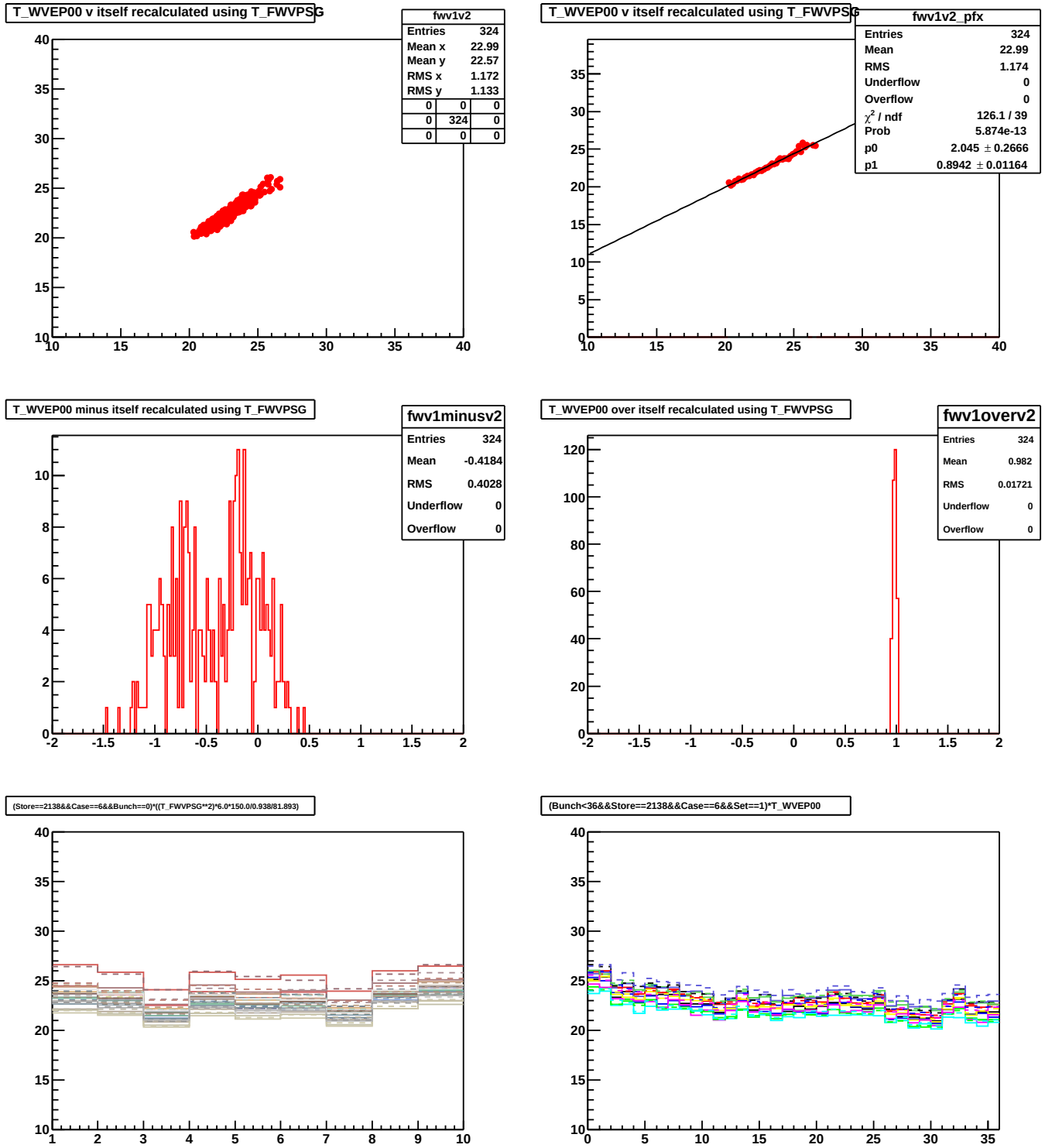

Figure 42: T:WVEP00 versus itself, recalculated using dp/p from T:FWVPSG, store 2138, case 6