Pattern Recognition Studies for Parity Analysis

and the Introduction of kTwist

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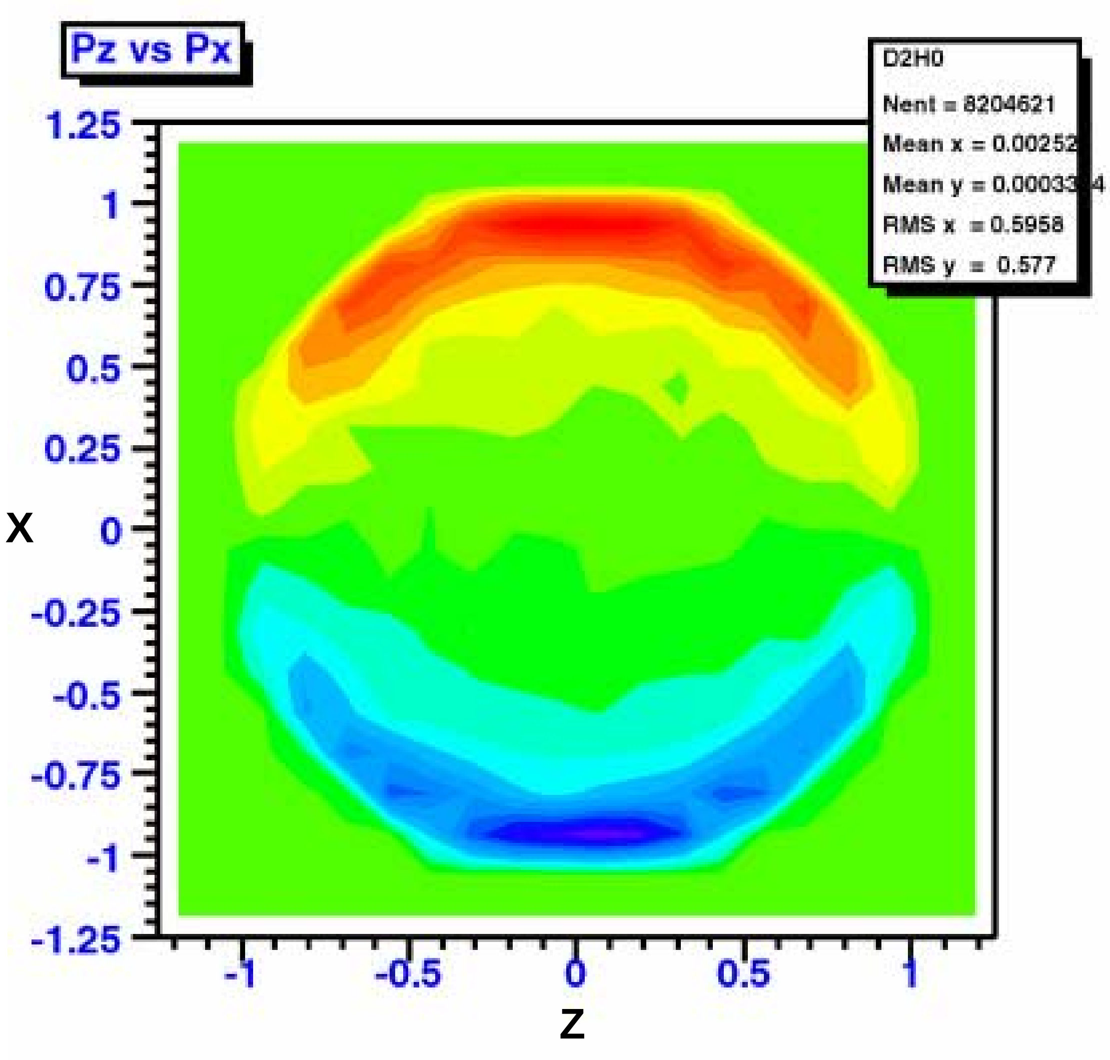
1/20/99

Visualizing Charged flow in HI collisions



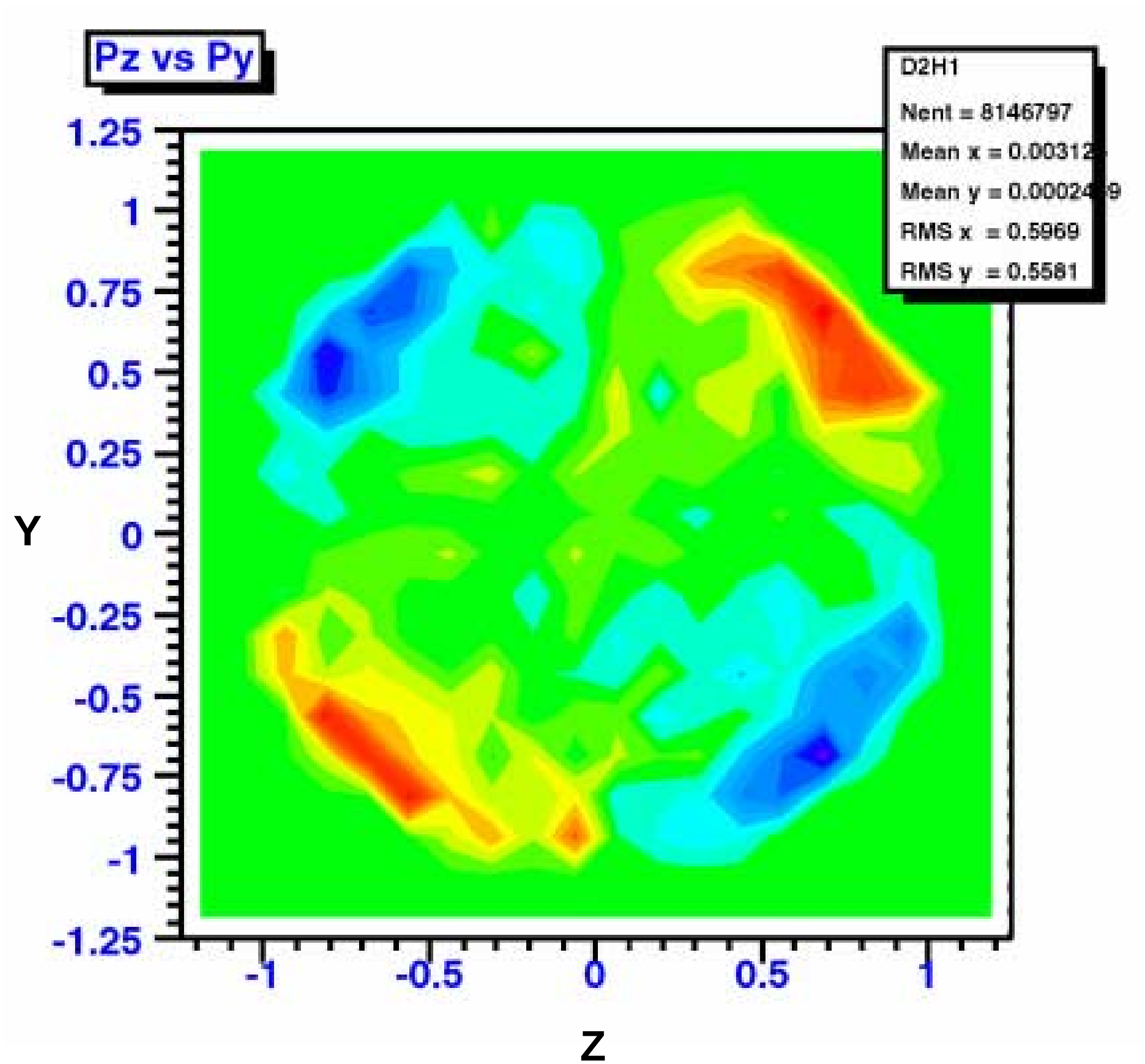
- Treat the pion momenta as unit vectors
- Find the charge flow axis,

$$k^- = \frac{1}{N^+}\sum_k \pi_k^+ - \frac{1}{N^-}\sum_l \pi_l^-$$

  and align the X axis with it
- Plot Pz vs Px for all pions in the event
- Add π^+ and subtract π^-

  π^+ in red, π^- in blue
- All events will look like this due to the random walk of pions in phase space
  - and due to the conservation of charge and momentum
- But k^- will also be biased towards alignment with other physical processes such as CP violation

A Simulation of Dima’s CP Violation Effect

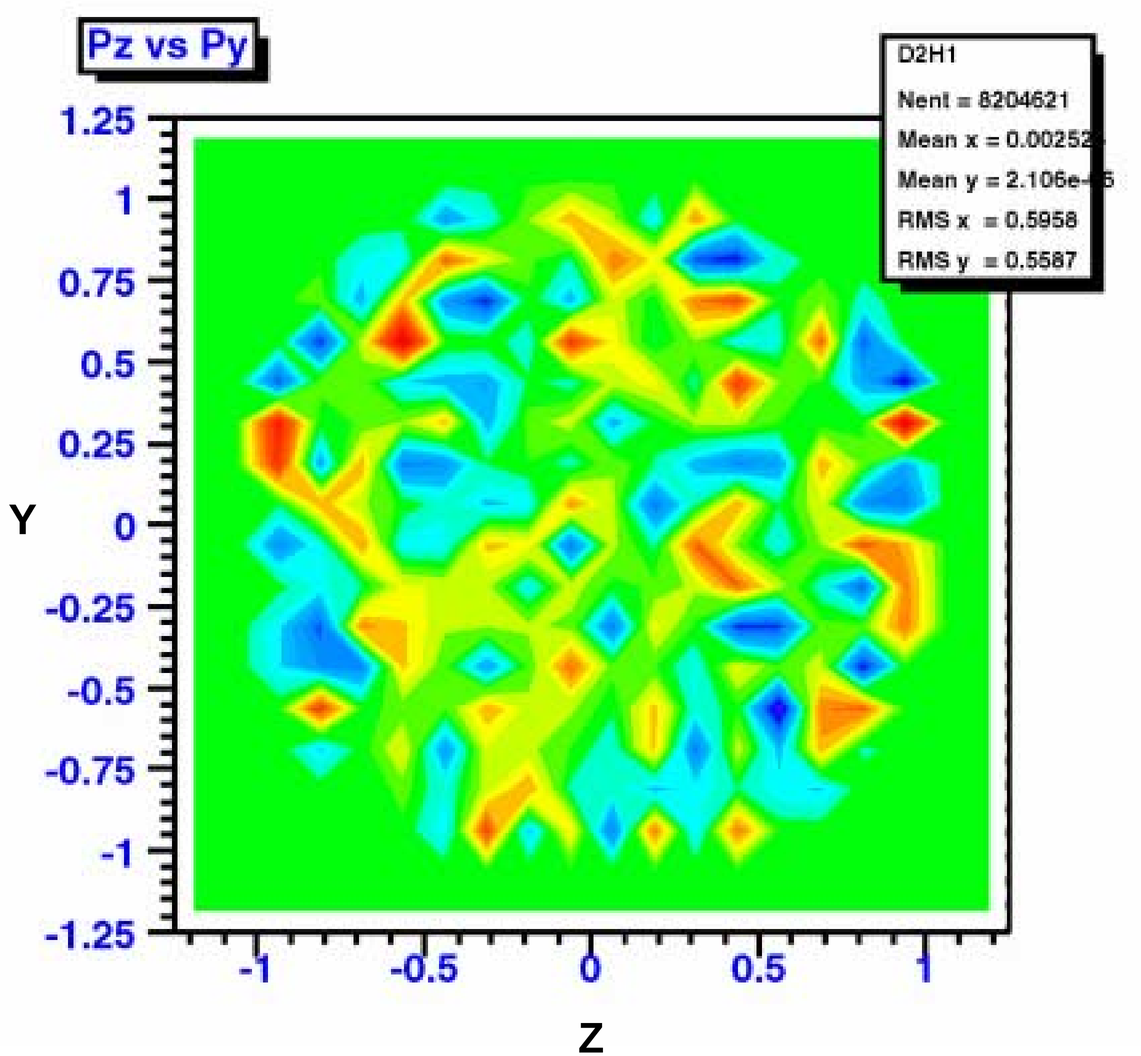


- Same rules as before
- Look in the YZ plane
  - Model = Broken
  - N = 400
  - Kick = 90 MeV

- π^+ in red, π^- in blue

- Note the diagonal motion of the pion groups
- This is the unique signature of aligned E and B fields in a heavy ion collision

The Null Case (CP violating fields turned off)



- **Same rules as before**
- **Look in the YZ plane**
  - **Model = Broken**
  - **N = 400**
  - **Kick = 0 MeV**
- π^+ **in red,** π^- **in blue**
- **Note the lack of a diagonal pattern and random contours**

Diagonal motion is unique to E•B effects

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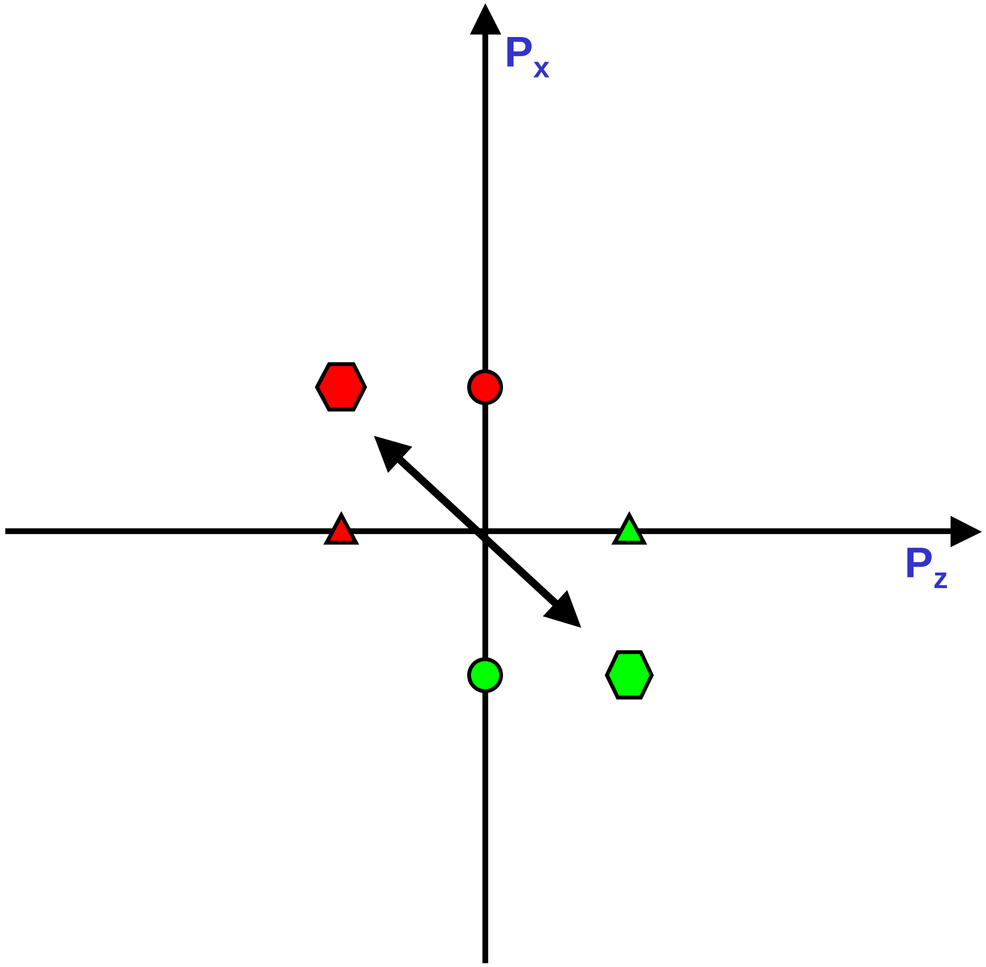
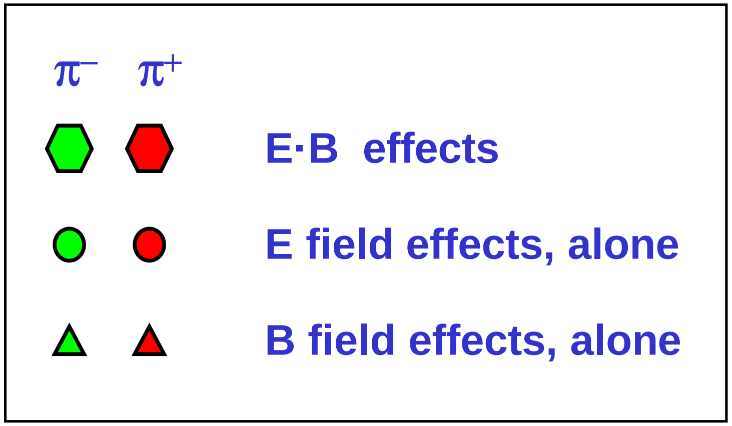
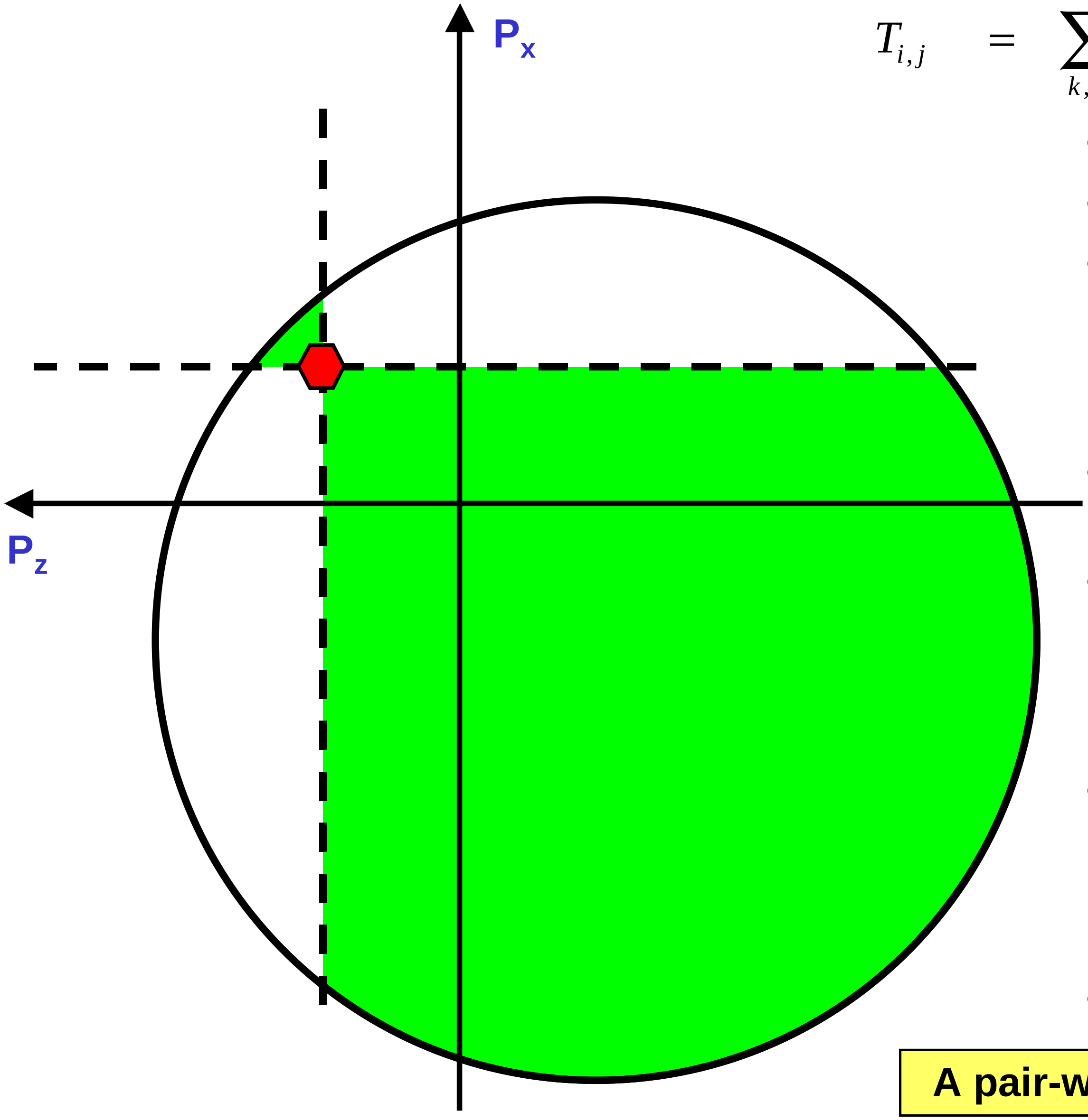




- Assume that the E and B fields are parallel and aligned with the X axis

Pion Lasers and how they interact with the E and B fields

The Twist Tensor example using pion lasers



$$T_{i,j} = \sum_{k,l} \left(\pi_k^+ \times \pi_l^-\right) \cdot \mu_i \;\; \mu_j \cdot \left(\pi_k^+ - \pi_l^-\right)$$

- Expand the π^- beam
- Consider i = j = z
- The 1st term measures the up-down angle in a cylindrical coordinate system
- The 2nd term measures left-right distance
- The vector relations yield unusual but benign weights of unknown origin
- Bottom line: Count the π^- in the green areas and subtract those in the clear areas.
- Repeat for each π^+

A pair-wise counting exercise

But … Re-arrange the sum over pairs

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The Twist tensor is defined as

$$T_{i,j} \equiv \sum_{k,l} \left(\pi_k^+ \times \pi_l^-\right) \cdot \mu_i \quad \left(\pi_k^+ - \pi_l^-\right) \cdot \mu_j$$

$$\Rightarrow \sum_l \left(\left(\pi_l^- \cdot \mu_j\right) \left(\sum_k \left(\pi_k^+\right) \times \mu_i \right) \cdot \pi_l^- \right) + \sum_k \left(\left(\pi_k^+ \cdot \mu_j\right) \left(\sum_l \left(\pi_l^-\right) \times \mu_i \right) \cdot \pi_k^+ \right)$$

Define k$^+$ and k$^-$ so that

$$\frac{\sum_k \left(\pi_k^+\right)}{N^+} = \frac{1}{2}\left(k^+ + k^-\right), \qquad \frac{\sum_l \left(\pi_l^-\right)}{N^-} = \frac{1}{2}\left(k^+ - k^-\right)$$

and substitute

$$T_{i,j} \Rightarrow \left[\frac{N^+}{2} \sum_l \left(\left(\pi_l^- \cdot \mu_j\right) \left(k^- \times \mu_i\right) \cdot \pi_l^- \right) - \frac{N^-}{2} \sum_k \left(\left(\pi_k^+ \cdot \mu_j\right) \left(k^- \times \mu_i\right) \cdot \pi_k^+ \right) \right] +$$
$$\left[\frac{N^+}{2} \sum_l \left(\left(\pi_l^- \cdot \mu_j\right) \left(k^+ \times \mu_i\right) \cdot \pi_l^- \right) + \frac{N^-}{2} \sum_k \left(\left(\pi_k^+ \cdot \mu_j\right) \left(k^+ \times \mu_i\right) \cdot \pi_k^+ \right) \right]$$

k$^-$ rotates due to interactions with the fields. k$^+$ does not. Note that the second term goes to zero because k$^+$ does not contain information about the E and B fields on a pair by pair basis. k$^+$ is random with respect to the detector acceptance cuts.

‘Pairs analysis’ reduces to ‘singles’ analysis

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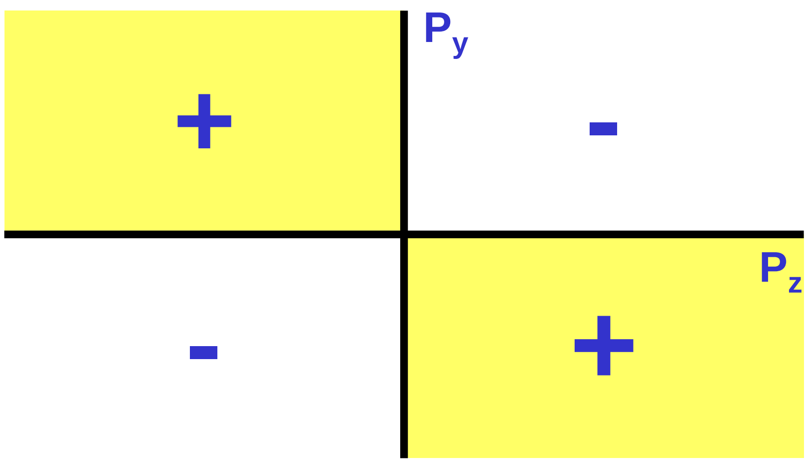
The conclusion, then, is that

$$\frac{-2\cdot T_{3,3}}{N^{+}N^{-}} \Rightarrow \quad kTwist \;=\; \left[\; \frac{1}{N^{+}}\sum\left(\; \pi_y^{+}\pi_z^{+} \;\right) \;-\; \frac{1}{N^{-}}\sum\left(\; \pi_y^{-}\pi_z^{-} \;\right) \;\right]$$

Z axis = z and Y axis = k^{-} x z

We can use this expression directly, or, simply count the number of pions in each quadrant of this new reference frame.



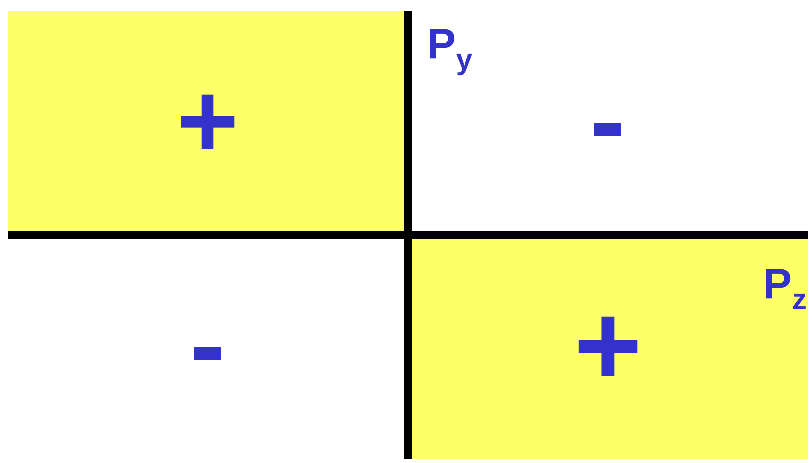
Systematic Error Check

A valuable check on our systematic errors is to monitor

$$kTwist^{+} = \left[\frac{1}{N^{+}} \sum \left(\pi_y^{+} \pi_z^{+} \right) + \frac{1}{N^{-}} \sum \left(\pi_y^{-} \pi_z^{-} \right) \right]$$

Z axis = z and Y axis = k^{+} x z

As usual, we can use this expression directly, or better yet, count the number of pions in each quadrant of this new reference frame where we use k^{+} as the reference direction. kTwist^{+} will be zero in the absence of systematic errors.



kTwist

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- **We define a new 'counting' observable called kTwist**

  (with humble apologies to Dima Kharzeev[1], Miklos Gyullassy[2], and the authors of C++)

  and normalize it on a 'per event' basis:

$$kTwist = \left[\frac{1}{N^+} \sum sign\left(\pi_y^+ \pi_z^+\right) - \frac{1}{N^-} \sum sign\left(\pi_y^- \pi_z^-\right) \right]$$

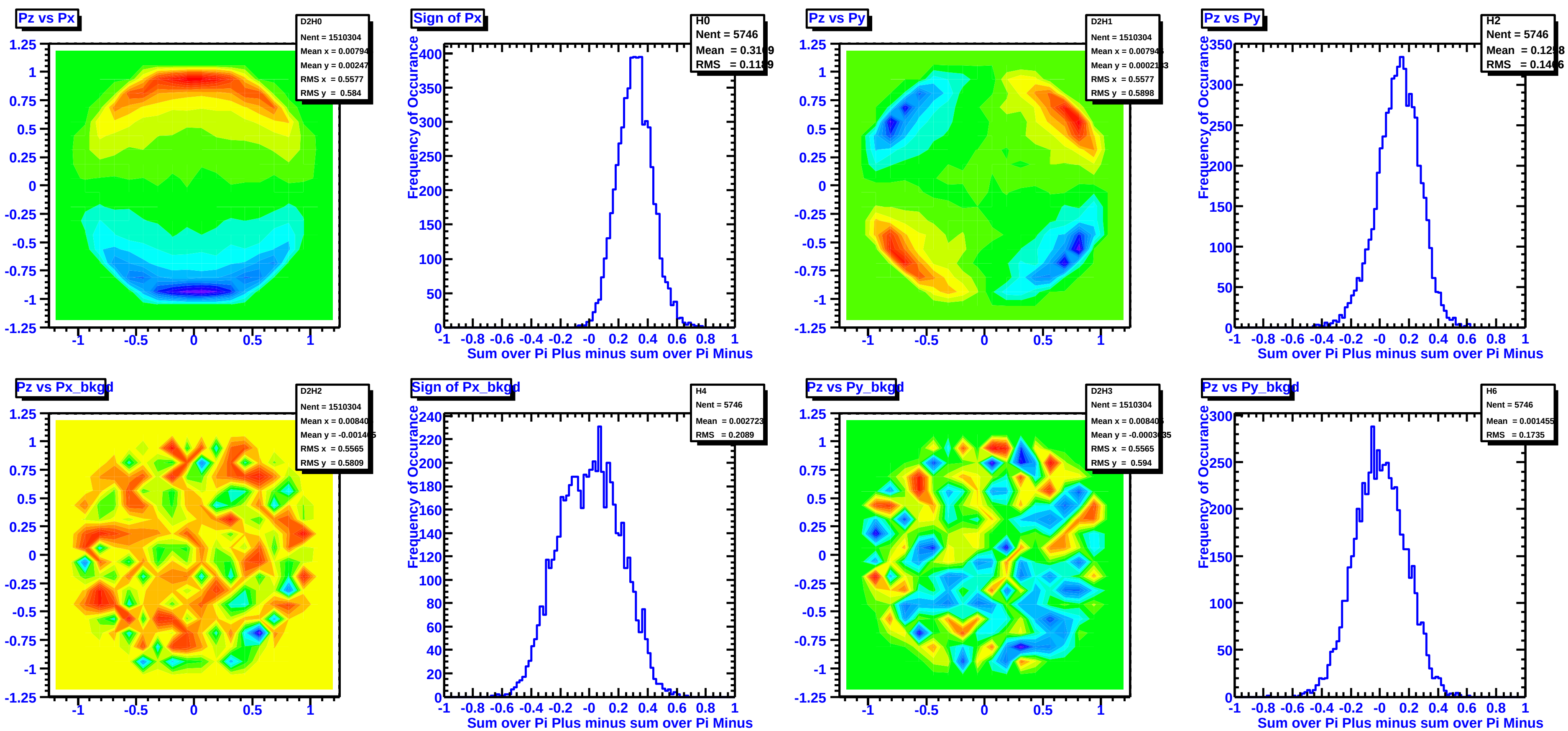
where $\pi = p_\pi / |p_\pi|$, $\pi_z = \pi \bullet z_{lab}$, $\pi_y = \pi \bullet (k^-_{lab} \times z_{lab})$, and $k^- = \frac{1}{N^+}\sum_k \pi_k^+ - \frac{1}{N^-}\sum_l \pi_l^-$

- **It is 'singles' analysis and it is 'projective' in the (y,z) plane**
- **It is the algebraic manifestation of the graphical analysis technique we introduced last year and it is similar to the quantity discovered independently by Voloshin[3], but without the unusual weights.**
- **There are many possible systematic checks on our event analysis using kTwist$^+$ or the kTwisted version of the other components of the Twist tensor.**

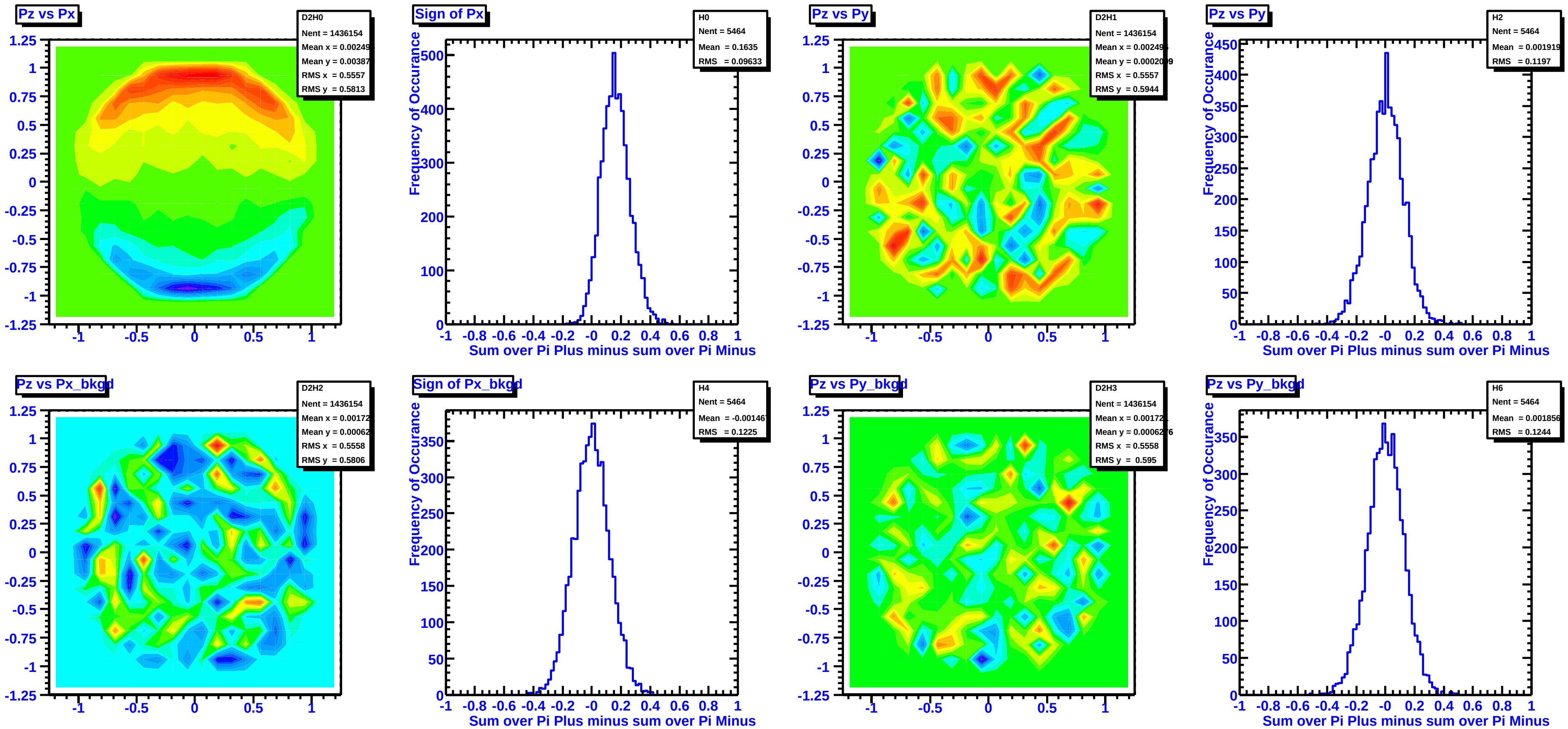
$$\frac{1}{N^-}\sum_l \left(\left(\pi_l^- \cdot \mu_j\right) \left(k^- \times \mu_i\right) \cdot \pi_l^- \right) - \frac{1}{N^+}\sum_k \left(\left(\pi_k^+ \cdot \mu_j\right) \left(k^- \times \mu_i\right) \cdot \pi_k^+ \right)$$

[1]Kharzeev and Pisarski hep/ph 9906401, [2]Gyullassy RBRC Memo, [3]Voloshin, private communication

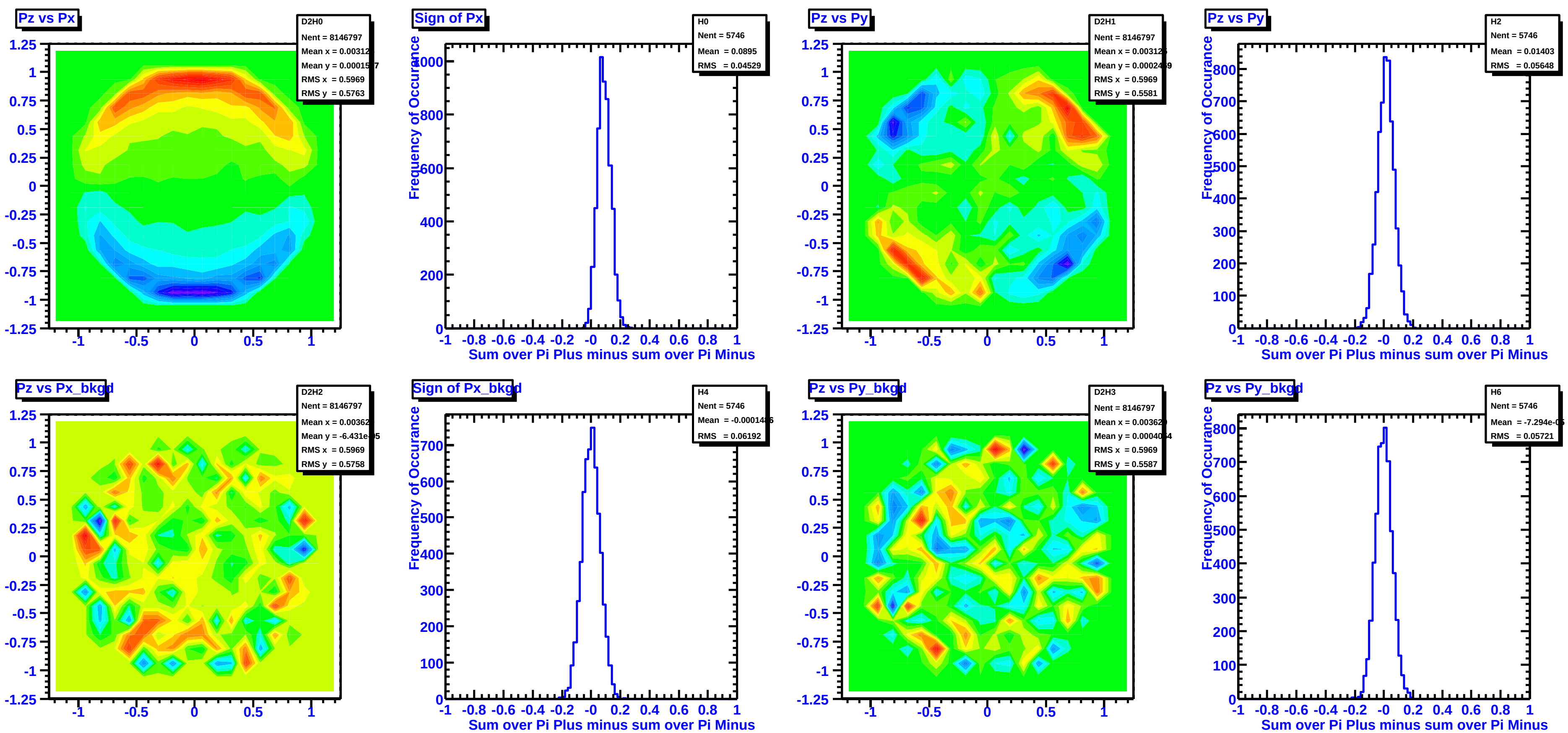
Model = Broken N = 400 Kick = 90 (Bubble only)



Model = Broken N = 400 Kick = 0 (Bubble only)



Model = Broken N = 400 Kick = 90 (Full events)



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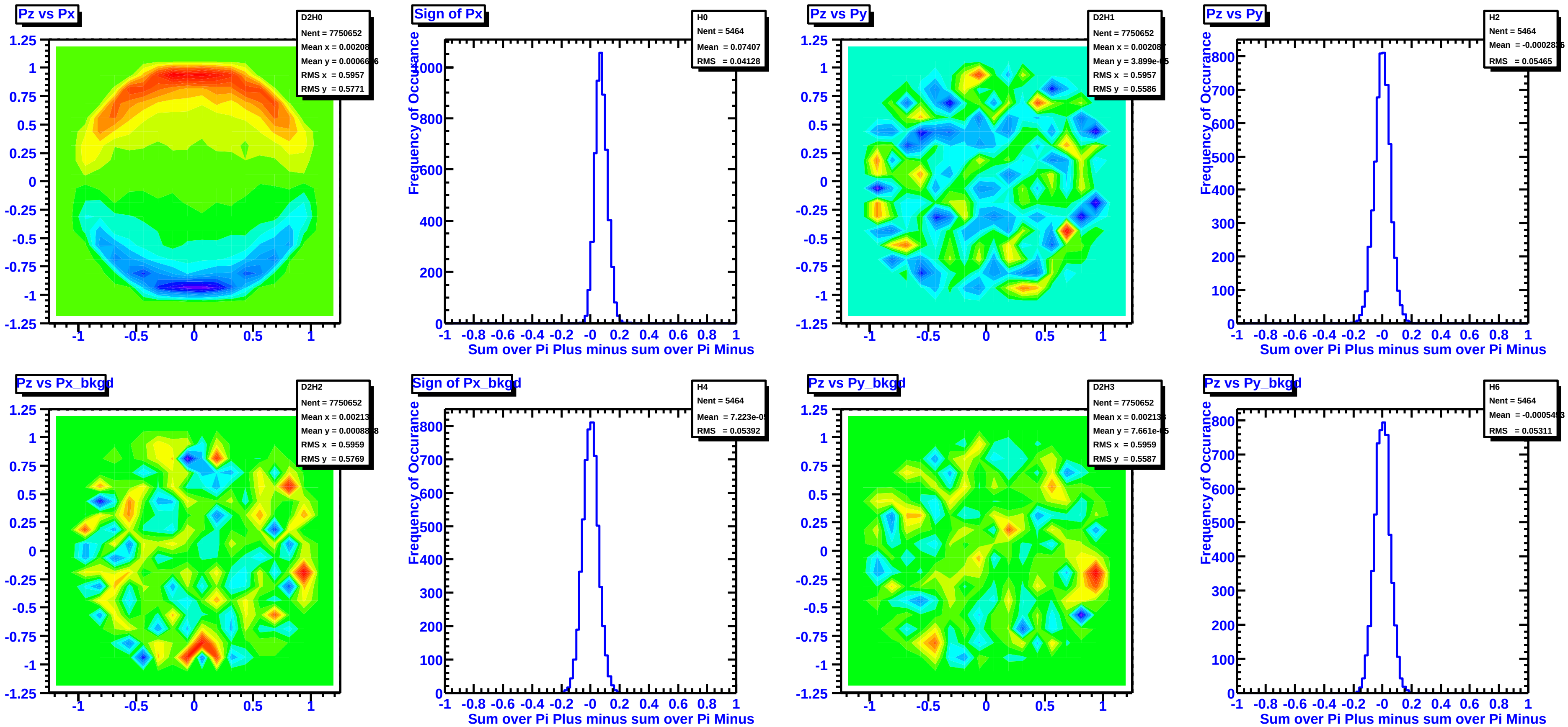
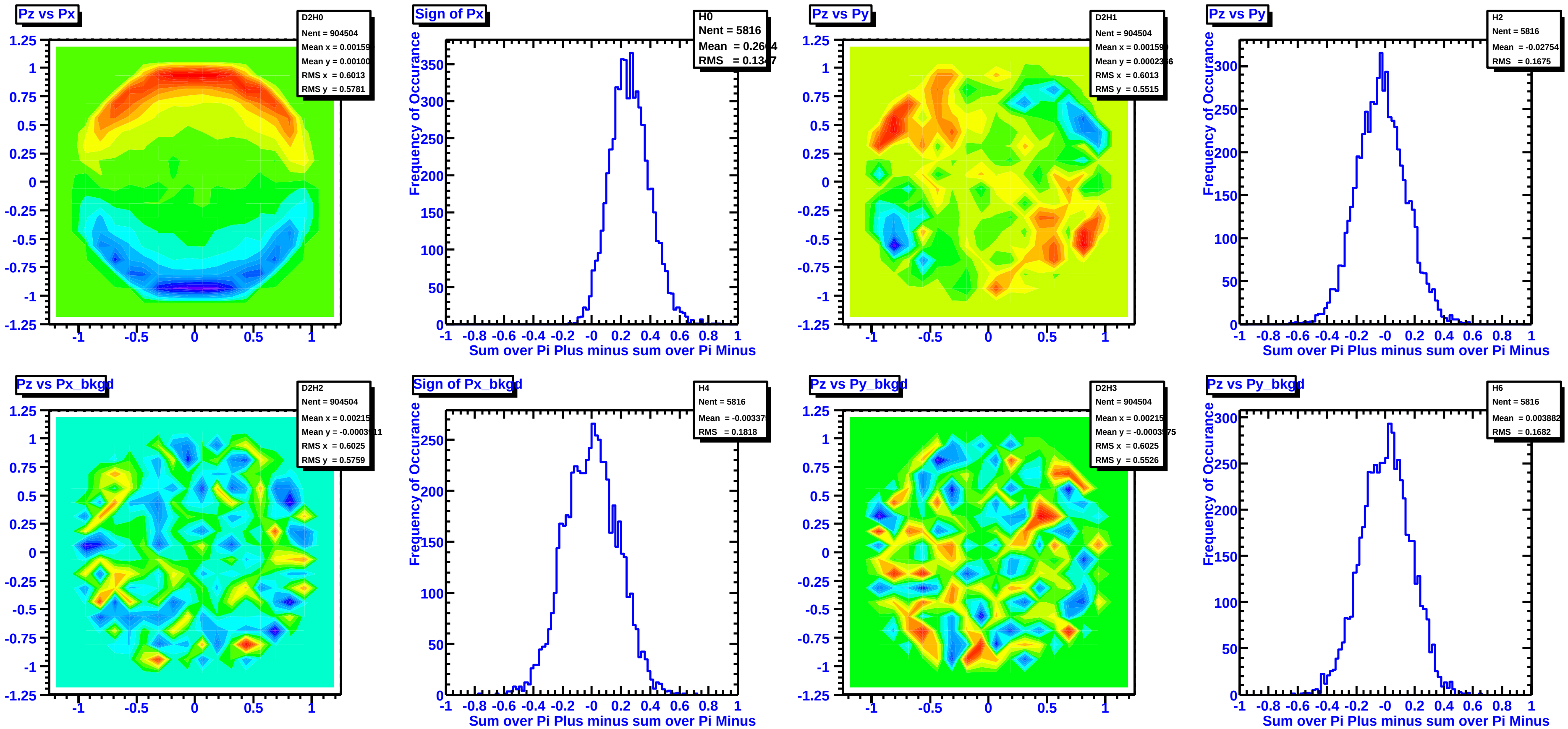
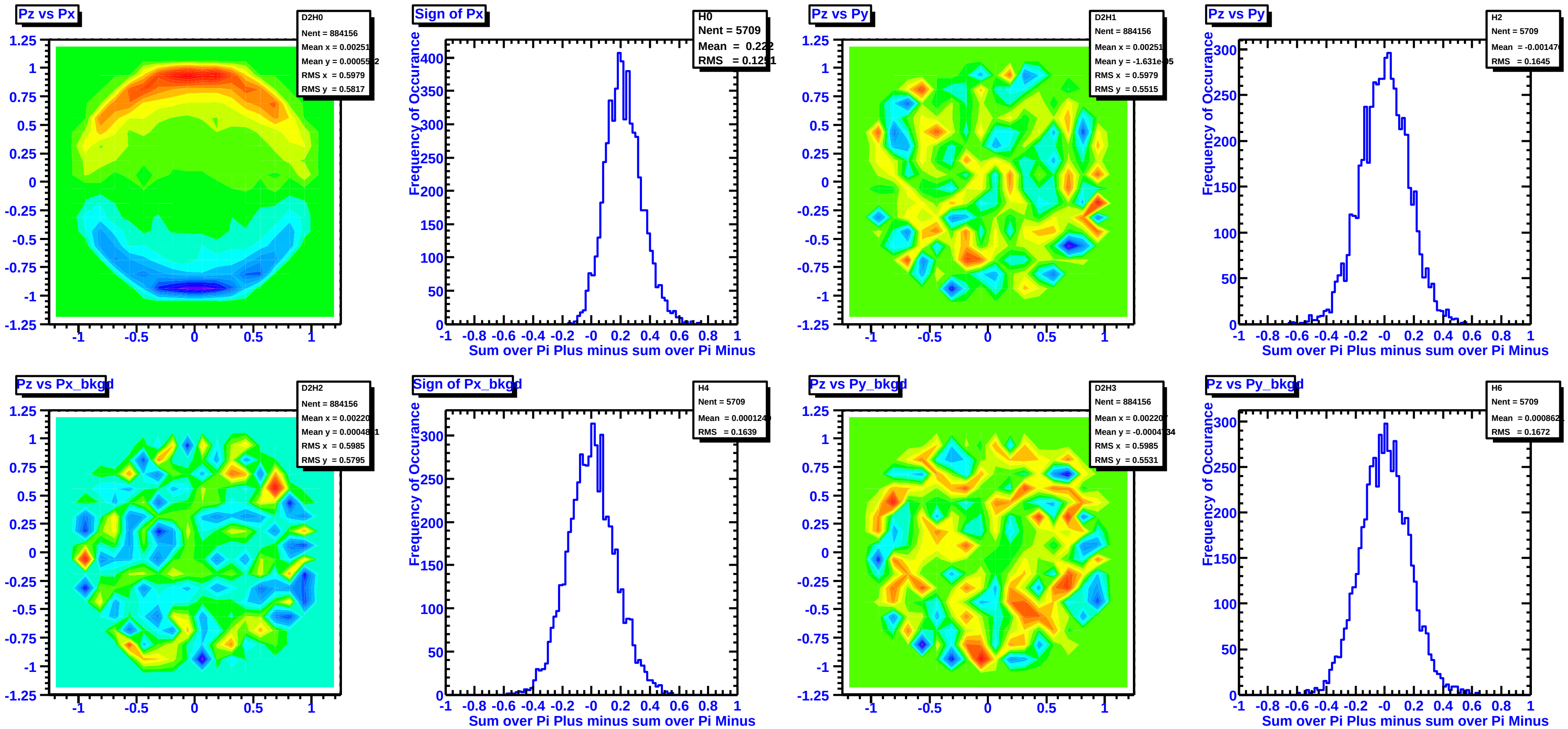


Model = Landau N = 400 Kick = 90 (Bubble only)



Model = Landau N = 400 Kick = 0 (Bubble only)



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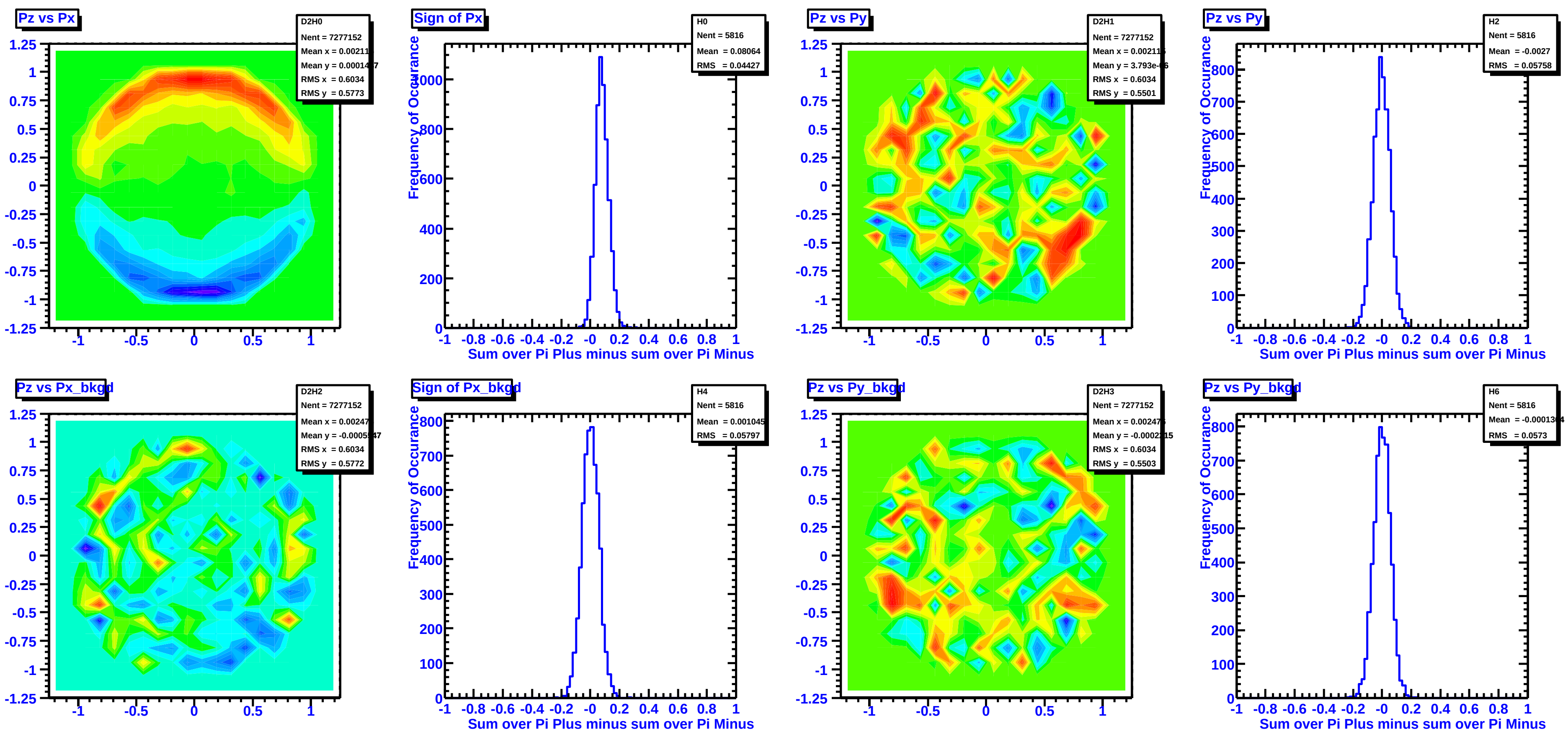

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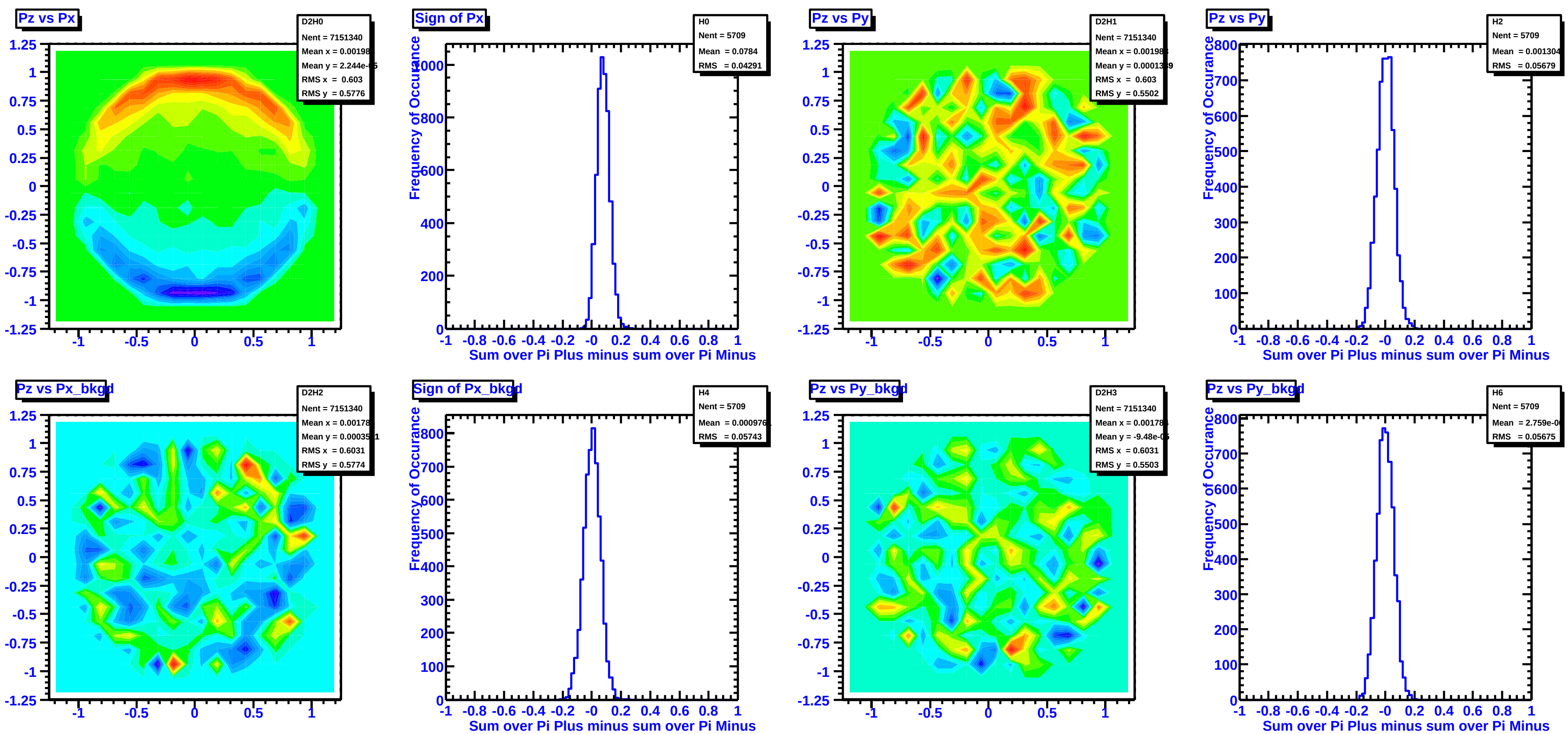
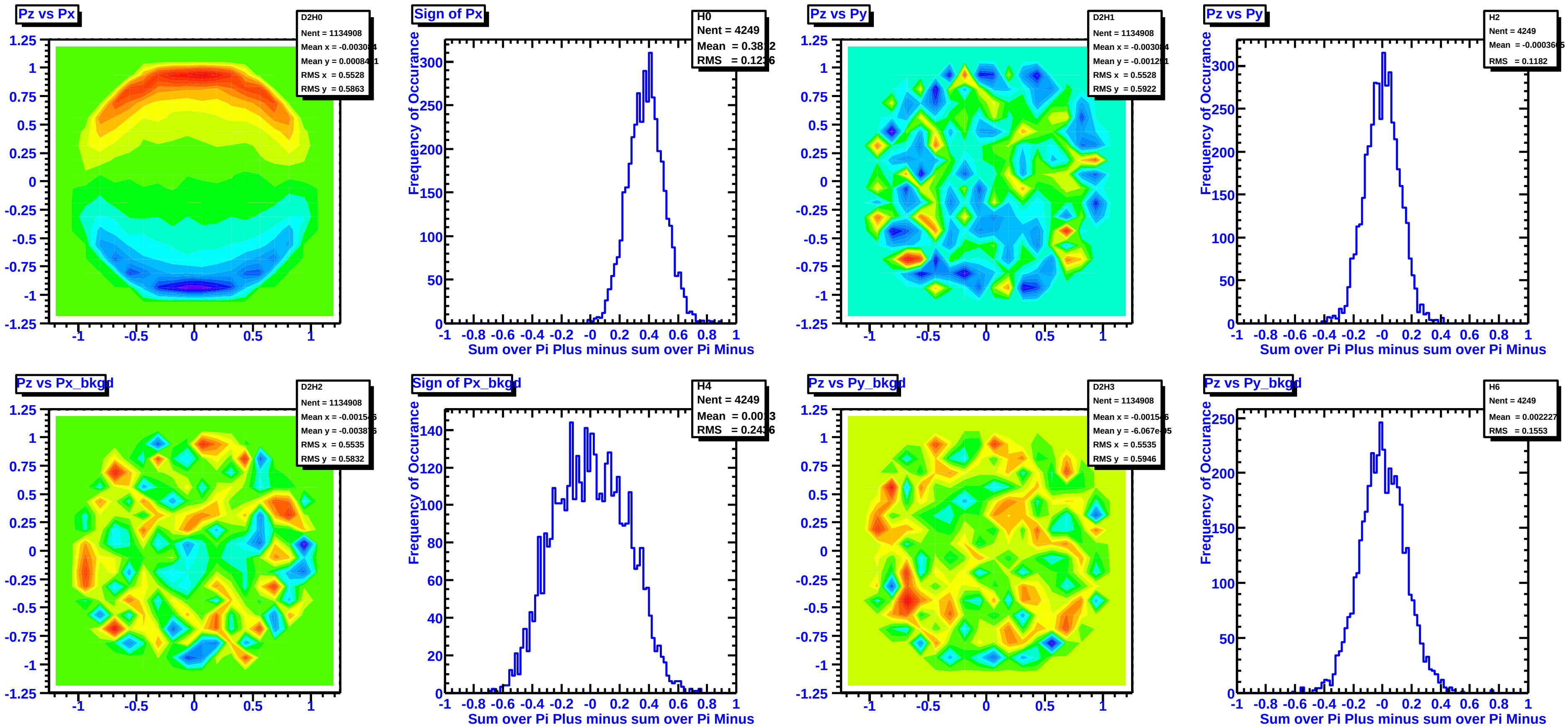


Model = Chiral N = 400 Kick = 90 (Bubble only)



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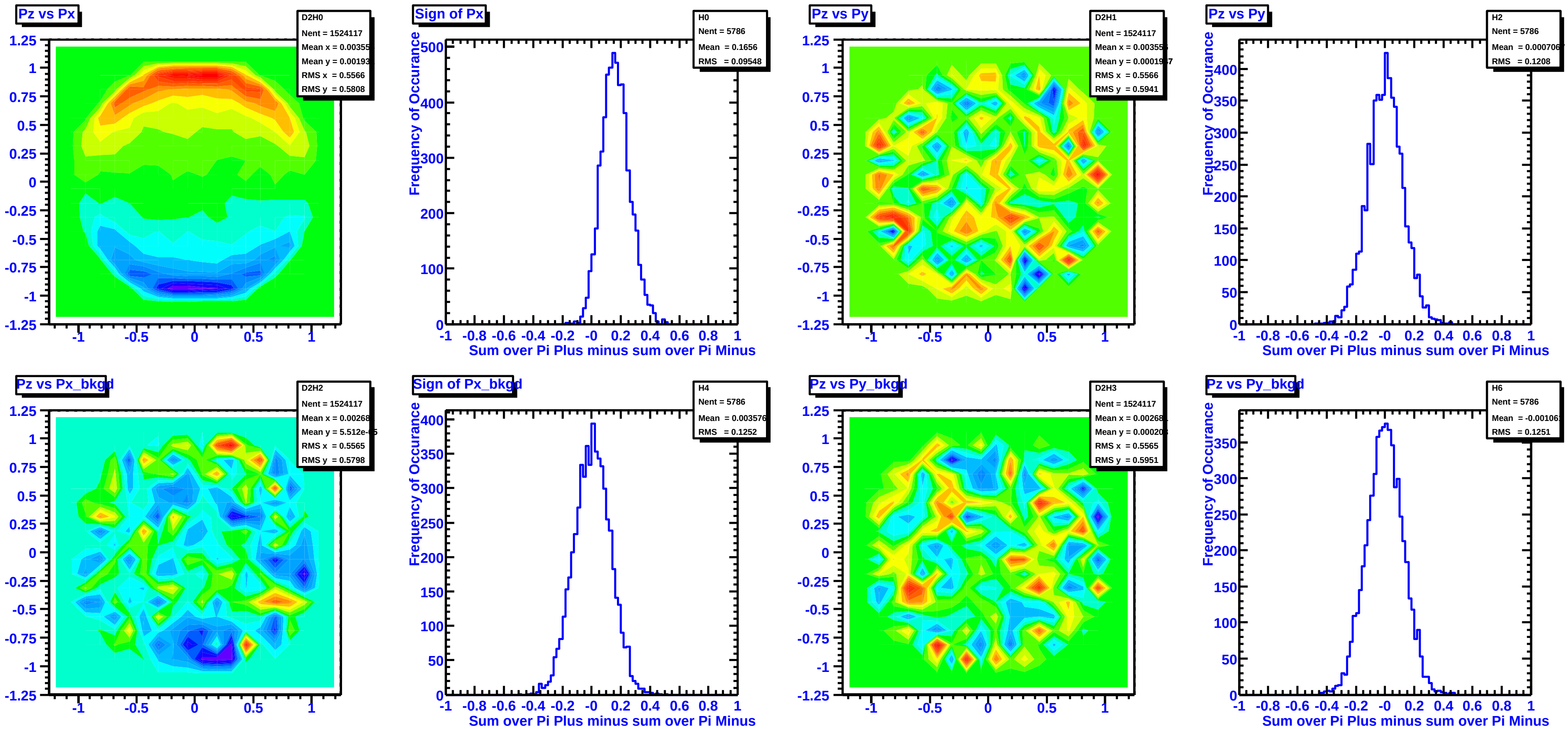

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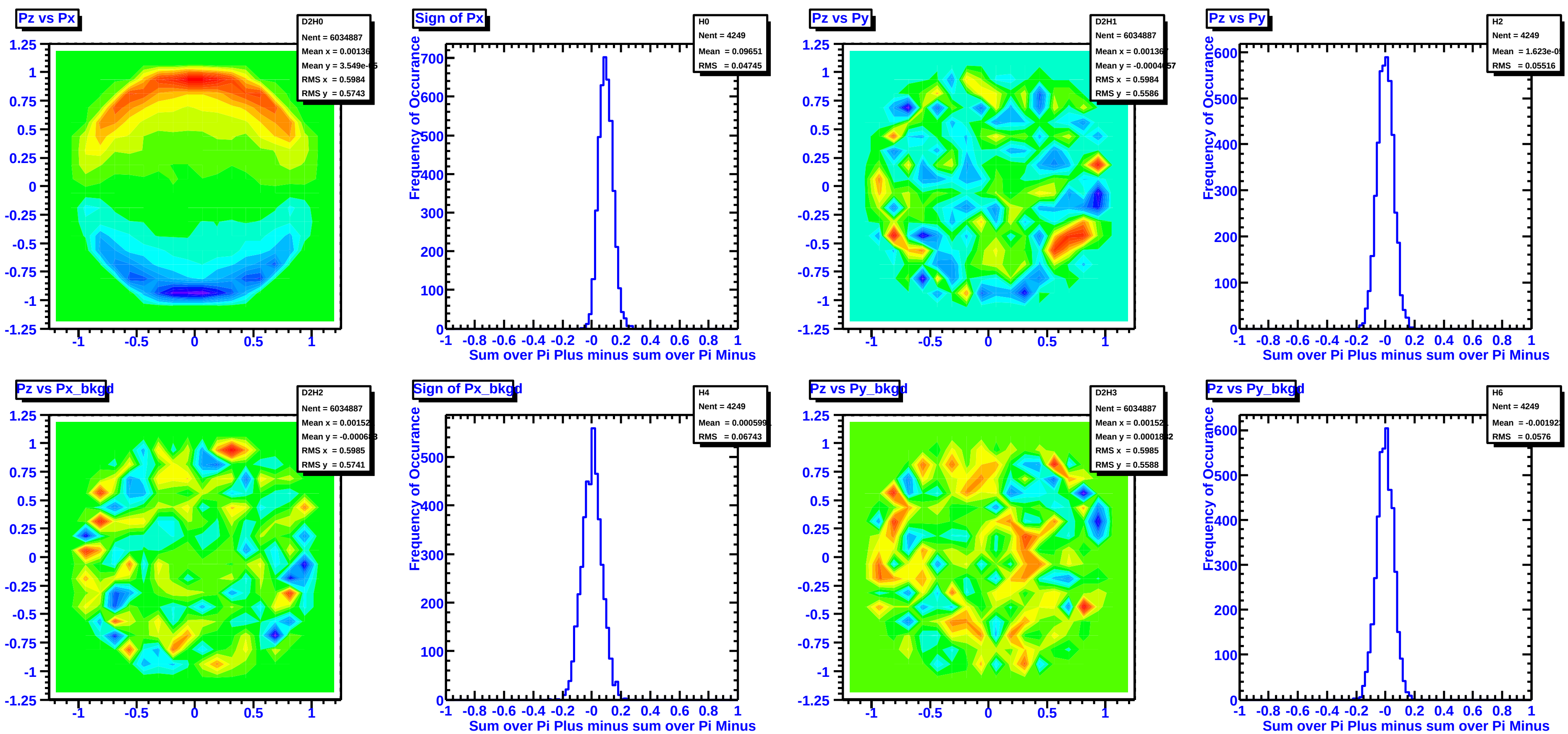

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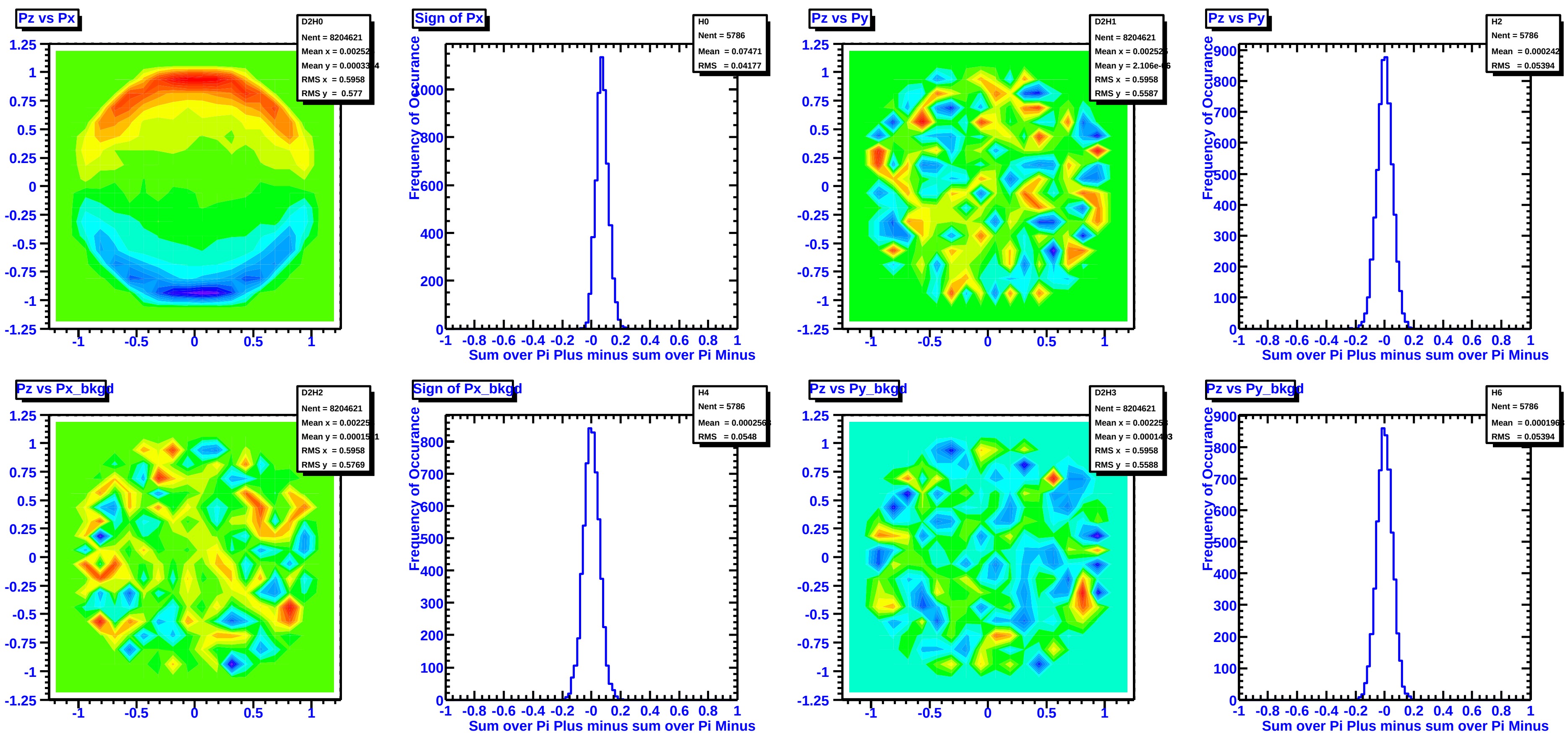
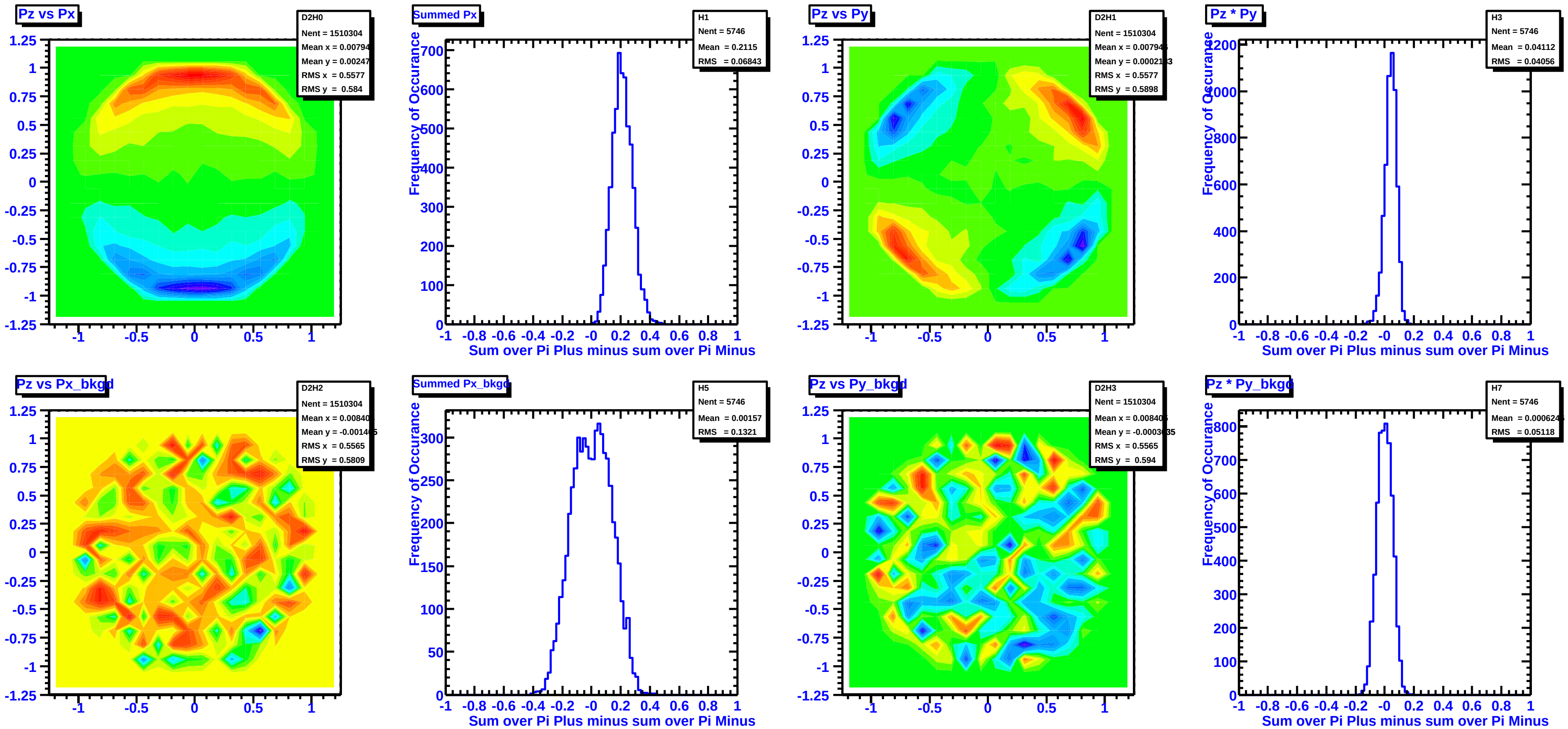
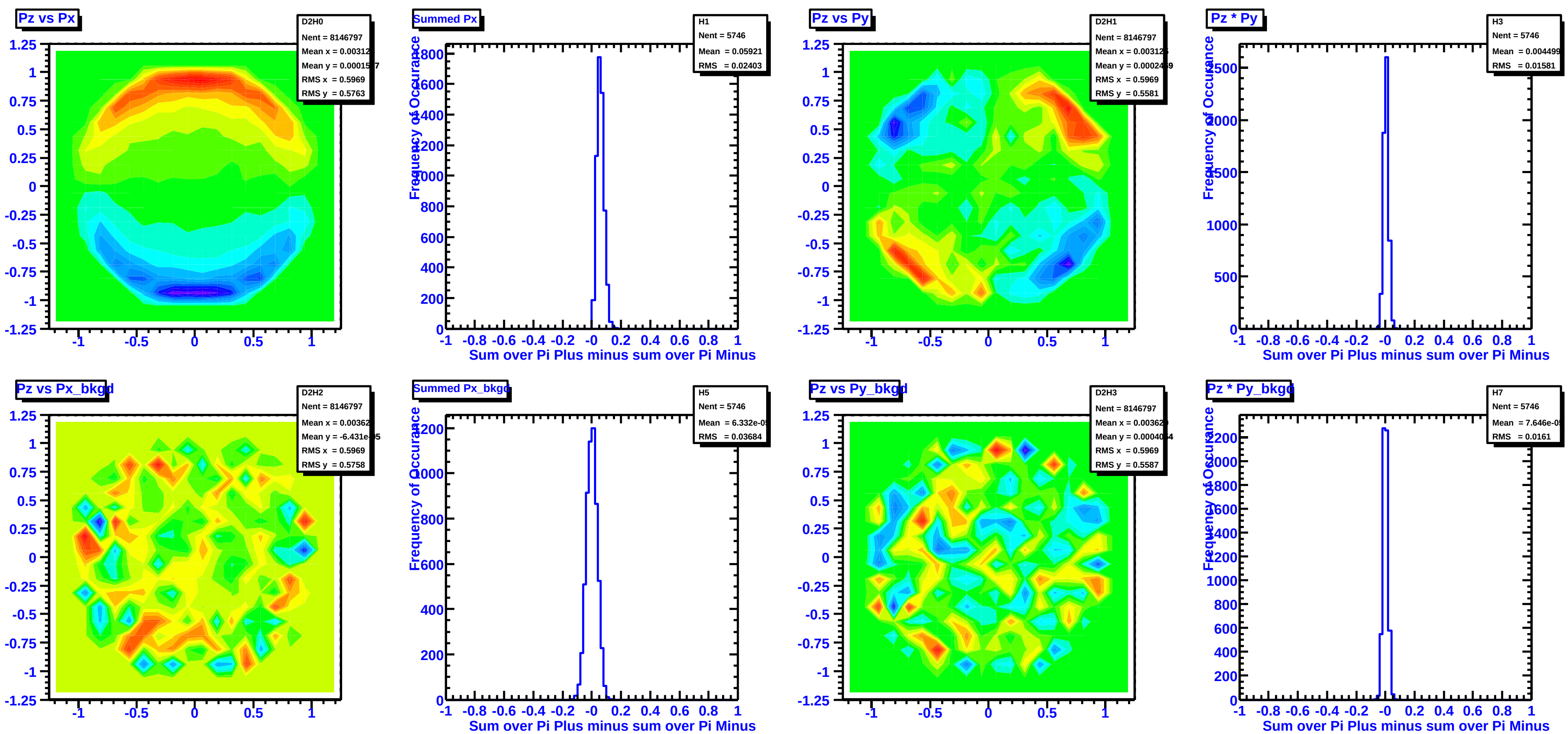


Model = Broken N = 400 Kick = 90 (Bubble only)



Weighted Sum (py * pz)

Model = Broken N = 400 Kick = 90 (Full events)



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