Chris Jackson (postdoc)

- In the past year:
  - "Higgs Triplets, Decoupling and Precision Measurements," w/ M.-C. Chen and Sally Dawson, PRD78, 093001(2008).
  - "One-loop Corrections to the S Parameter in the Four-site Model," w/ Sally Dawson, PRD79, 013006 (2009).
  - "The WIMP Forest: Indirect Detection of a Chiral Square," w/ G. Bertone, G. Shaughnessy, T. Tait and A. Vallinotto, PRD80, 023512 (2009).
- In the coming months:
  - "Higgs in Space!", w/ G. Shaughnessy, G. Servant, T. Tait and M. Taoso
  - "Sommerfeld Enhancements in Models of Universal Extra Dimensions," w/ P. Fox, T. Tait and K. Zurek
  - "LHC Coordinate Analysis: Searching for the SM Higgs Boson," w/ E. Berger, Q.-H. Cao, T. Liu and G. Shaughnessy
  - "New Physics and Loop-induced Decay of a Scalar into Two Z Bosons," w/ Q.-H. Cao, W.-Y. Keung, I. Low and J. Shu
  - and...

Double Parton Scattering at the LHC

Chris Jackson
with Ed Berger and Gabe Shaughnessy

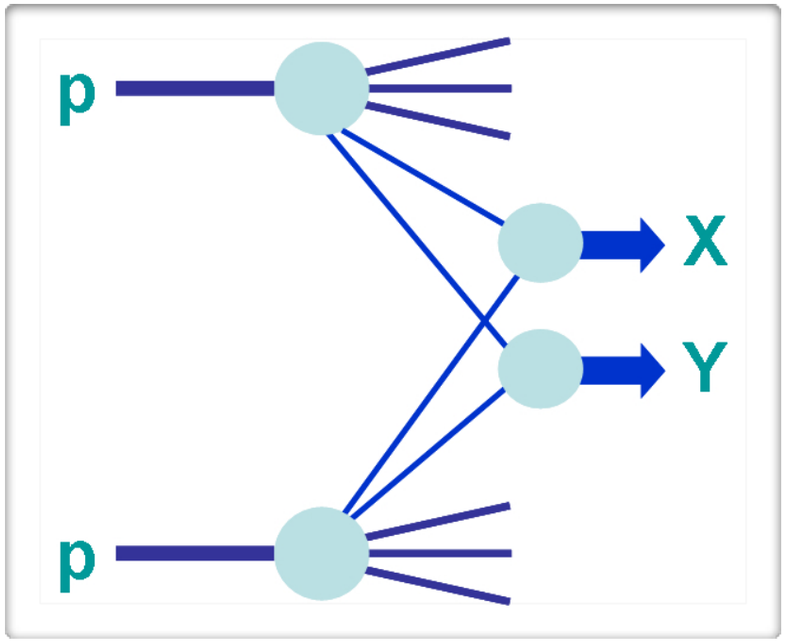
(Draft in Preparation)

Outline

- What is Double Parton Scattering (DPS) and why do we care?
- Past studies of DPS
- Make the case for bbjj at the LHC
- Results/Conclusions

The Idea of DPS

- TWO independent scatterings in ONE proton-proton collision:



$$\sigma_{DPS} = \frac{\sigma_a \sigma_b}{\sigma_{eff}},$$

- <u>Motivation</u>?
  - QCD: Modeling of "underlying event", parton distributions, etc.
  - Searches for complex signatures typically rely on fact that new, heavy particles decay "spherically" while QCD backgrounds are correlated.
  - This breaks down, however, when part of signature comes from a SECOND SCATTERING!
  - Probability is low... but needed background reduction can be high!

Past Studies of DPS

- Need process with a large rate... and relatively clean signal
  (e.g. multi-jet + prompt photon)

- Most (if not all) experimental studies to date have focussed on γ + 3 jets:

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Measurement of Double Parton Scattering in $\bar{p}p$ Collisions at $\sqrt{s} = 1.8$ TeV

(CDF Collaboration)

Double parton interactions in γ + 3 jet events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV in DØ

The DØ Collaboration
URL: *http://www-d0.fnal.gov*
(Dated: April 24, 2009)

- Measurements of "effective cross section":

$$\sigma_{eff} = \begin{array}{l} 14.5 \pm 1.7 \text{ mb [CDF]} \\ 15.1 \pm 1.9 \text{ mb [D0]} \end{array}$$

DPS at the LHC

- Can't compute σ_{eff} from first principles. Does it scale with Bjorken *x*? If so, need an independent measurement at the LHC.

- Our goal(s):

  - map out phenomenology of DPS at the LHC and tell experimentalists what to look for

  - (Hopefully) have them measure σ_{eff} from a "clean" process

  - Use measurement of σ_{eff} to make absolute predictions for other processes (e.g., WW fusion where "forward" jets could originate from a second scattering)

- Case study: Bottom Quark Pair Production with Two Jets

  - Large rates over a large kinematic range

  - b-tagging provides a relatively clean signal

  - Relatively unambiguous which jets go with which other jets (one scattering produces bb, while other produces jj system)

Study of bbjj at the LHC

- Basic strategy:
  - Produce events for 2 → 4 (partonic) process (SPS) w/ Alpgen
  - Produce events for 4 → 4 (partonic) process (DPS) w/ Madgraph/MadEvent
  - Look for distributions where the two are discernible
- Basic acceptance cuts:

$$p_{T,j} \geq 25 \text{ GeV}, \quad |\eta_j| \leq 2.5$$
$$p_{T,b} \geq 25 \text{ GeV}, \quad |\eta_b| \leq 2.5$$
$$\Delta R_{jj} \geq 0.4, \quad \Delta R_{bb} \geq 0.4$$

- Detector resolution effects/tagging efficiencies (w/ "PEAT"), e.g.:
  - $dE/E = a/\sqrt{E} \oplus b$ (where a = 50% and b = 3% for jets)
  - Bottom quark tagging efficiency of 60% (for $p_T > 20$ GeV and $|\eta| < 2.0$)

The bbjj Subprocesses

- Double Parton Scattering:

$$b\bar{b} \otimes jj$$

⊗ denotes the combination of one event for each of the two final states it connects

$$bb(j) \otimes jj \ , \quad bbj \otimes (j)j \ , \quad bbj \otimes j(j)$$
$$bb \otimes (j)jj \ , \quad bb \otimes j(j)j \ , \quad bb \otimes jj(j) \, ,$$

We also account for additional jets which are undetected (either soft or outside of accepted rapidity range)

- Single Parton Scattering:

$$b\bar{b}jj \, ,$$

$$b\bar{b}(j)jj \ , \quad b\bar{b}j(j)j \ , \quad b\bar{b}jj(j) \, .$$

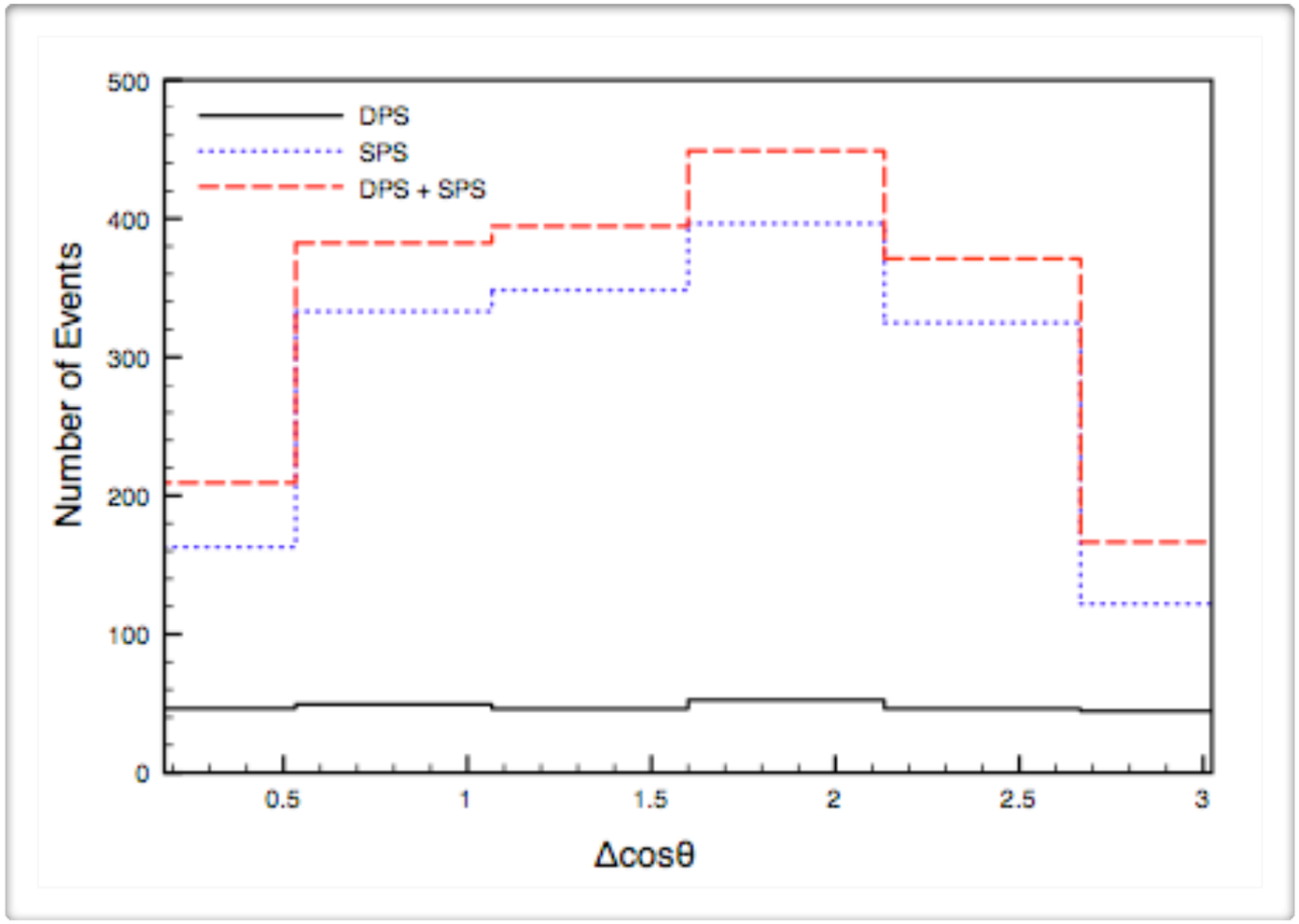
We also considered 4j and 5j final states where 2 j's fake b's

- Use CTEQ6L1 PDFs and a "dynamic" renormalization/factorization scale:

$$\mu^2 = \sum_i p_{T,i}^2 + m_i^2$$

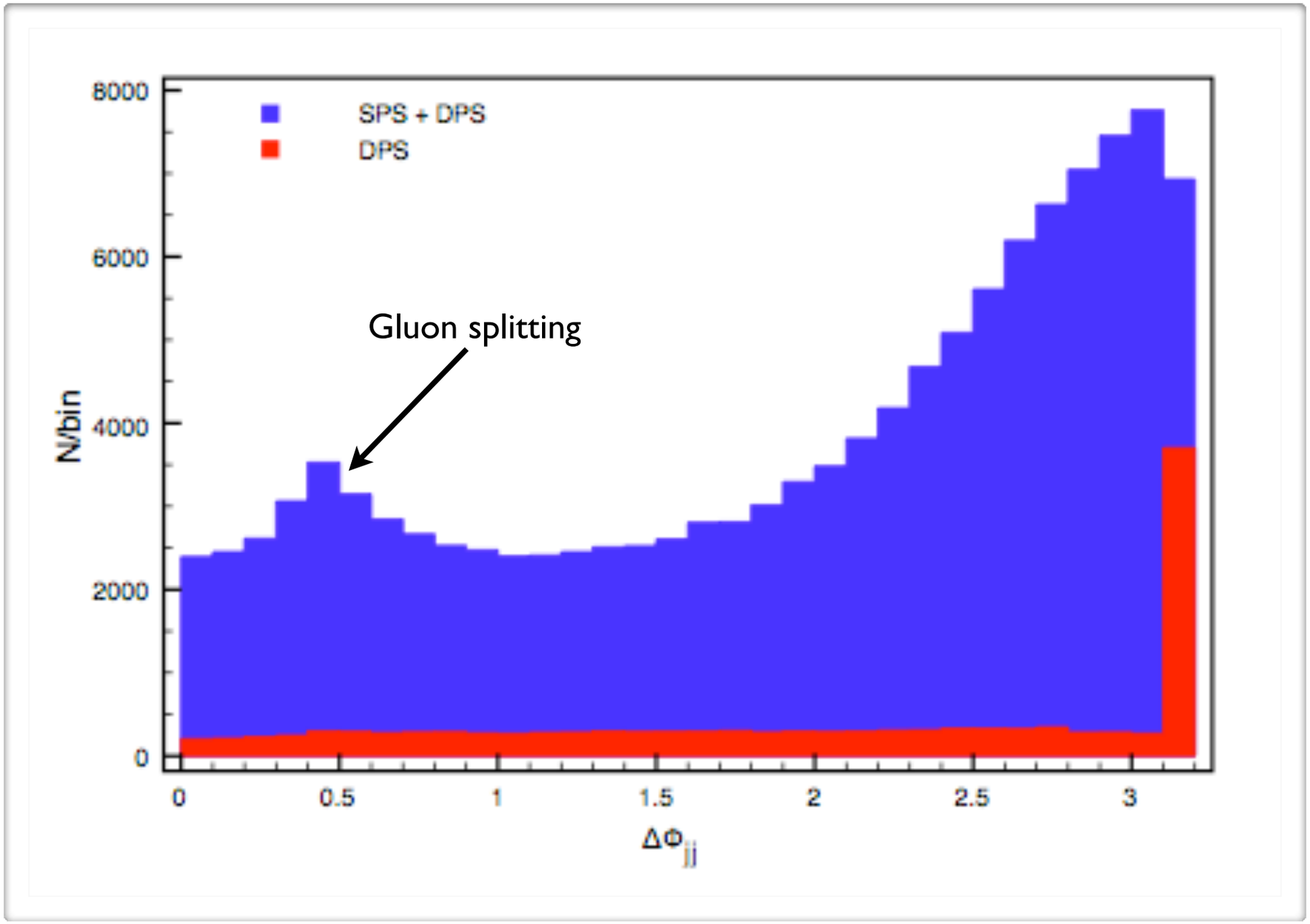
A Check on Our DPS Results

- Must check that we are generating DPS in an uncorrelated manner
- Study angle between plane defined by bb system and plane defined by jj system
- For truly uncorrelated scatterings, the DPS angle should be flat
- However, there are many diagrams which contribute to SPS s.t. some correlation between the two planes is expected



Results #1: $\Delta\varphi_{jj}$

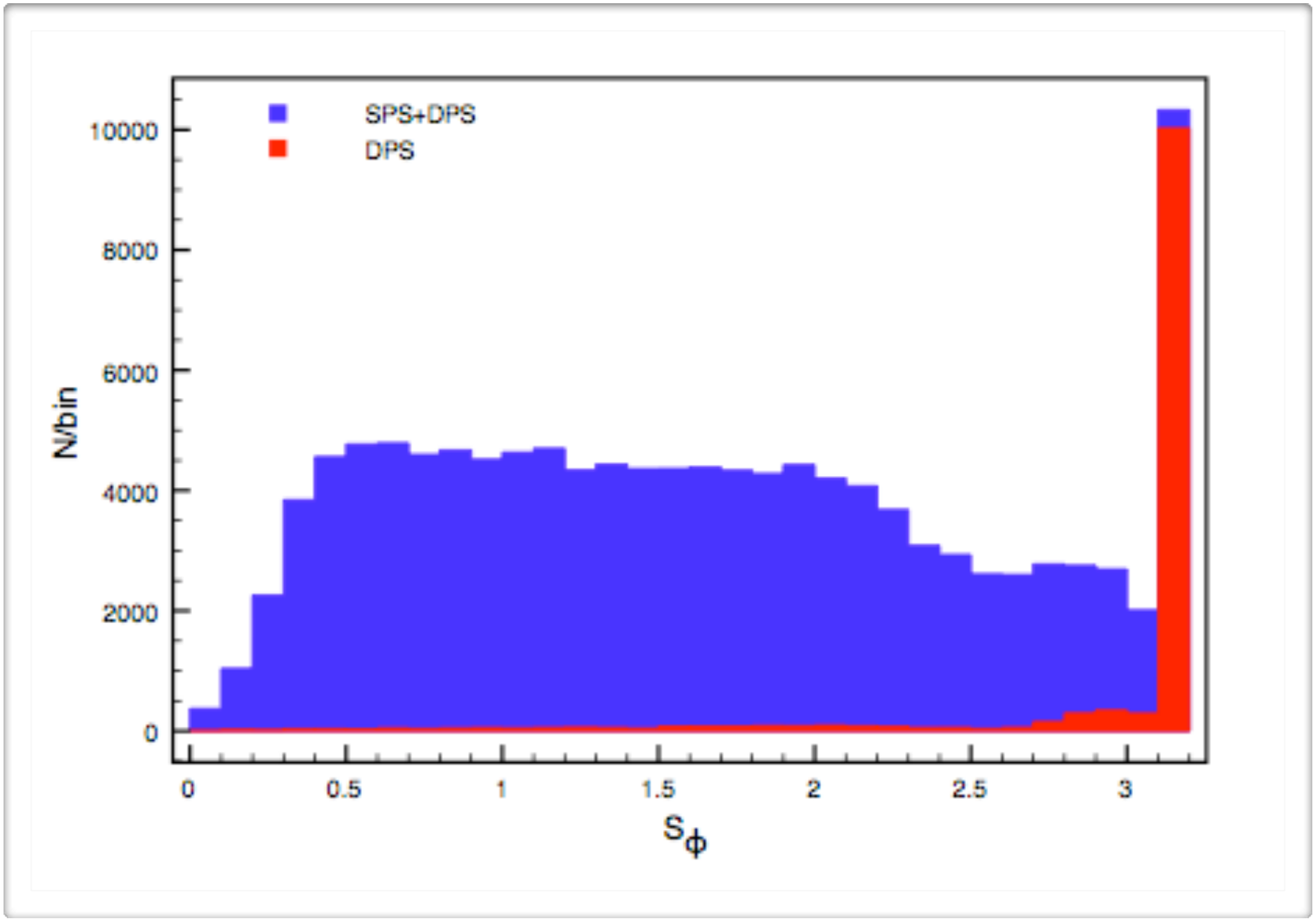
- One possible good discriminant is the angle of separation between two jets (or two bottom quarks) in the φ direction
- DPS: jets are back-to-back so $\Delta\varphi = \pi$(?)



Results #2: S_φ

- Separation between DPS/SPS events becomes more pronounced when we use information about angle separation from BOTH jj AND bb systems:

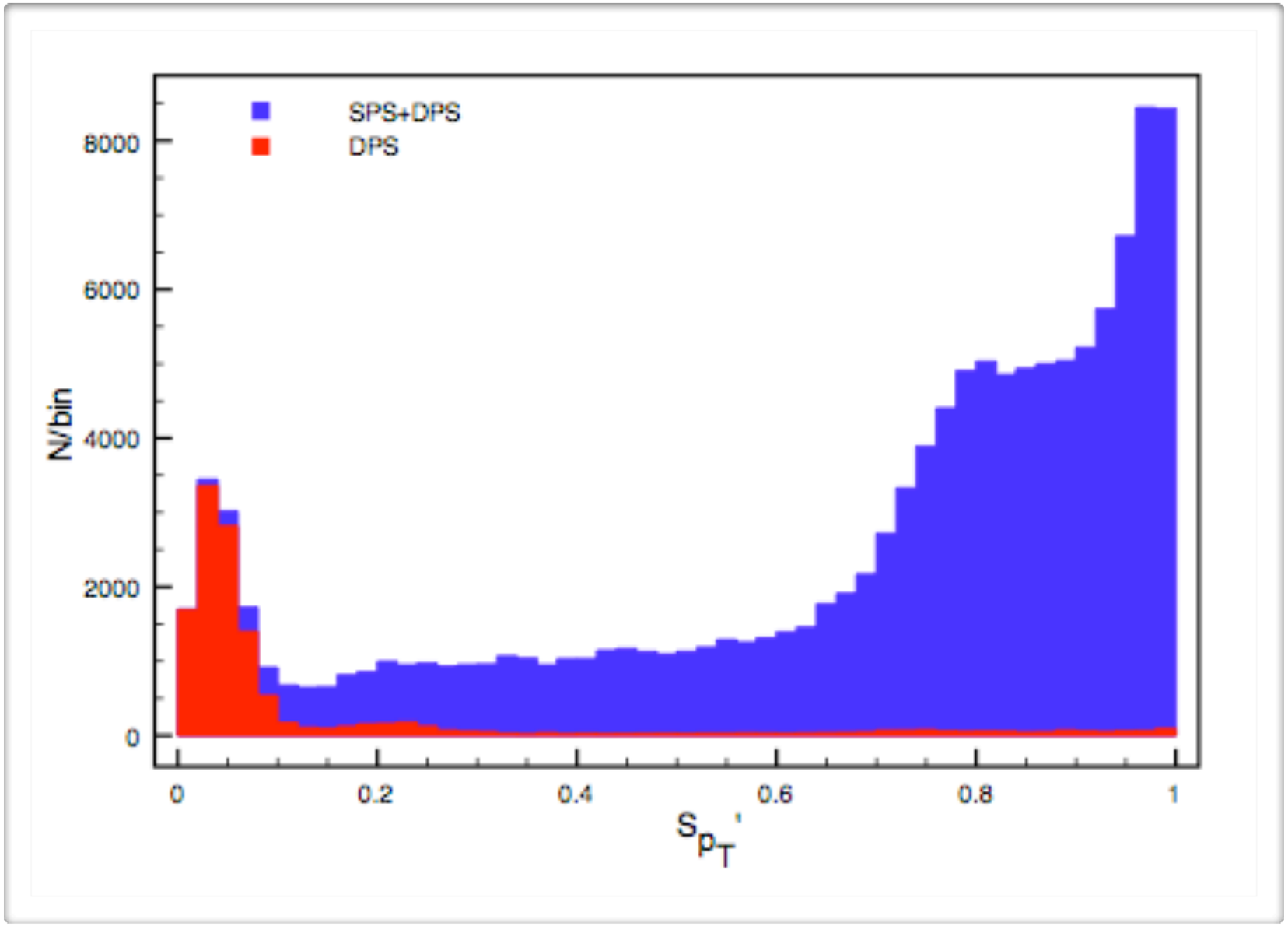
$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\Delta\phi(b_1,b_2)^2 + \Delta\phi(j_1,j_2)^2}.$$



Results #3: S'_{pt}

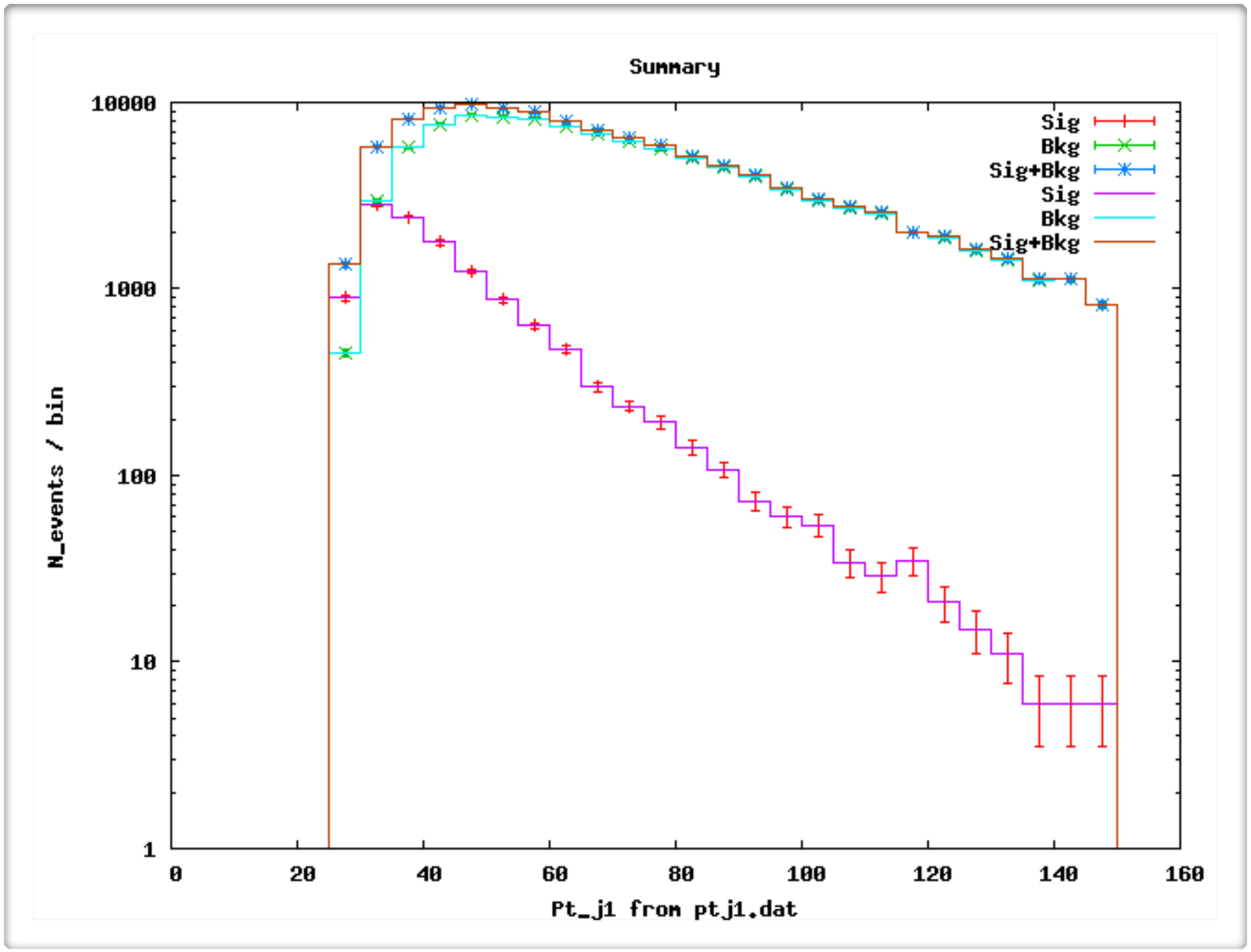
- Likewise, using info from the transverse momentum vector sums of the bb and jj systems can also provide a strong discriminant:

$$S'_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(b_1,b_2)|}{|p_T(b_1)|+|p_T(b_2)|}\right)^2+\left(\frac{|p_T(j_1,j_2)|}{|p_T(j_1)|+|p_T(j_2)|}\right)^2}.$$



Sidenote on p_T Variables

- DPS events tend to be at much softer values of p_T than SPS events



- By studying p_T variables, experimentalists should see the DPS "turning off"
- For new physics with a hard enough scale... DPS might not be a factor

Conclusions

- Double Parton Scattering can play an important role in QCD studies (underlying event, PDFs, etc.) as well as the discovery of new physics
- It's real! DPS has been observed at the Tevatron and effective cross section has be measured (both by CDF and D0)
- However, if σ_{eff} scales with Bjorken x values, we need a new measurement at the LHC
- In this work, we have investigated the feasibility of using bb+jj production in order to extract σ_{eff}
- The "usual" distributions (transverse momentum, invariant masses, etc.) don't show clean separations between DPS and SPS
- However, by using information from BOTH the bb AND jj systems, a clean separation can be made between DPS and SPS
- Finally, with a measurement of σ_{eff} at the LHC, we can make absolute predictions for other processes