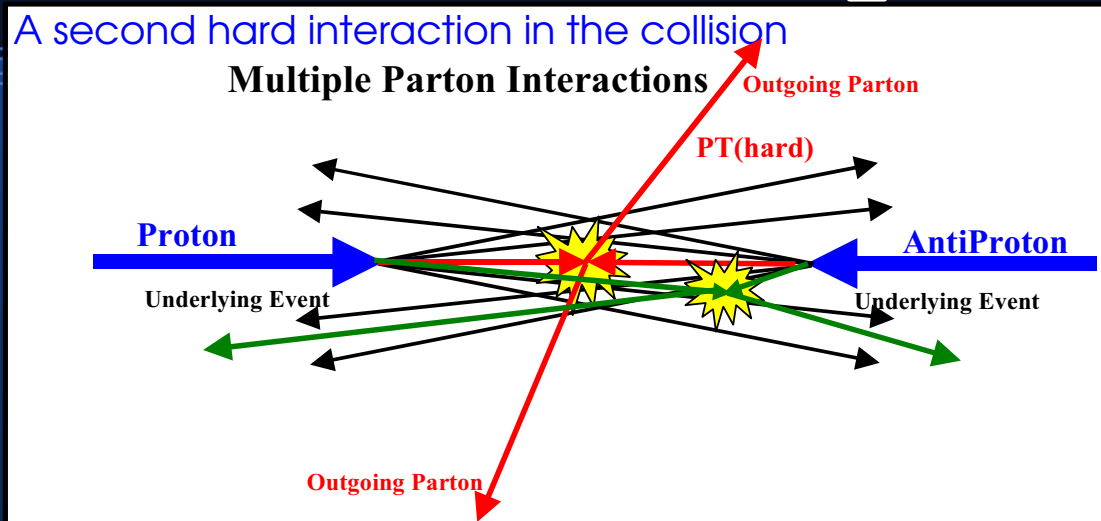


Double Parton Scattering at the LHC



Edmond Berger
Argonne National Laboratory

based in part on work with
C. Jackson, S. Quackenbush, and G. Shaughnessy
arXiv: 1107.3150, Phys Rev D **84 (2011) 074021**

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Assignment

- “What is the status of understanding of Double Parton Scattering (DPS) in final states that overlap with Higgs or New Physics signals”?
- Answer: first, we need definitive measurements of some well defined SM DPS signals at LHC: **validate the phenomenology; determine the effective cross section σ_{eff} for DPS at LHC; ...**
- Goal here is to help motivate such analyses

Outline

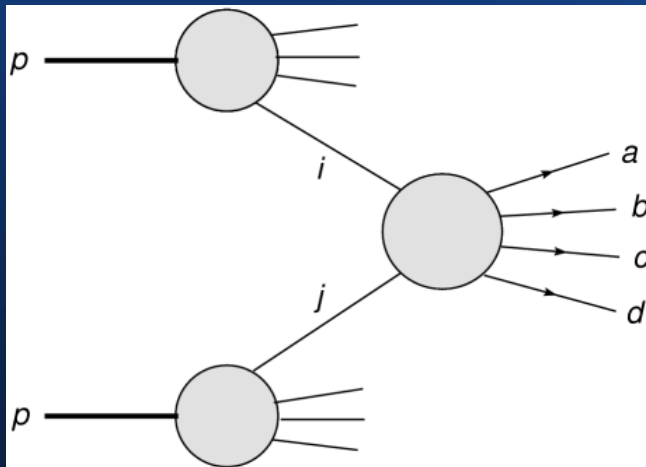
- Role of Double Parton Scattering (DPS)
- Example: $pp \rightarrow W b \bar{b} X \rightarrow \ell \nu b \bar{b} X$ at 7 TeV
- Extraction of a DPS signal from Single Parton Scattering (SPS) and backgrounds
- Results
- Summary

Why study and measure DPS?

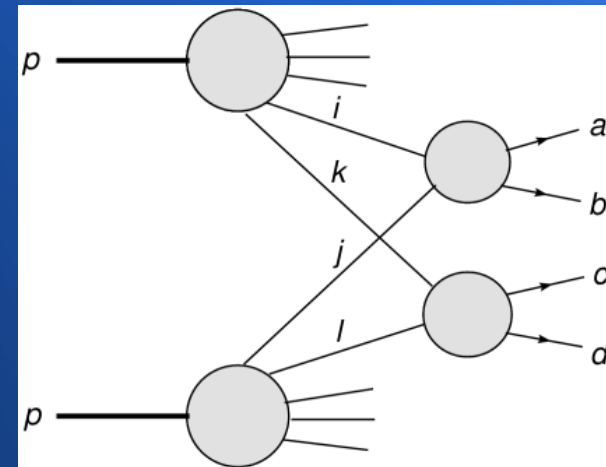
- QCD dynamics beyond SPS scattering (including parton correlations)
- Validate a hard component in underlying event modeling, with distinct dynamic properties (DPS is “not some tuneable parameter” – LeCompte)
- Added SM background to interesting final states
--- Measuring one DPS final state gives insight into the size of DPS contributions elsewhere

Single and Double Parton Scattering both Contribute

Single Parton Scattering (SPS)



Double Parton Scattering (DPS)



Measure the relative size of these two contributions

What are the distinguishing variables and regions of phase space that make this possible?

Why Wbb as an example?

- New physics often has a W (isolated lepton plus missing energy) and/or bb final states.
 - Wbb is a possible background
- bb has a large cross section (μb) \rightarrow large probability of second scattering
- $W \rightarrow$ lepton easy to identify
- NLO calculation exists for SPS Wbb

DPS calculation of $pp \rightarrow W b \bar{b} X \rightarrow \ell \nu b \bar{b} X$

Two hard subprocesses: $pp \rightarrow W X \rightarrow \ell \nu X$ $pp \rightarrow b \bar{b} X$

- * Assume weak dynamic and kinematic correlations between the two subprocesses

- * Final expression:

$$d\sigma^{DPS}(pp \rightarrow W b \bar{b} X) = \frac{d\sigma(pp \rightarrow W X) d\sigma(pp \rightarrow b \bar{b} X)}{\sigma_{\text{eff}}}$$

- * σ_{eff} dimensional factor related to overlap in impact parameter
- * Theoretical treatise: Diehl, Ostermeier, Schafer, [arXiv:1111.0910](https://arxiv.org/abs/1111.0910)

Analysis details

- Signal and backgrounds, including Wbb DPS and Wbb SPS, generated with POWHEG-BOX
 - NLO calculation in a shower Monte Carlo code; fully differential so analysis cuts can be made
- Simple detector effects (b tagging and muon efficiencies, resolution, mistagging) included
- Acceptance cuts, backgrounds, background rejection,
- See arXiv: 1107.3150, Phys Rev D **84** (2011) 074021

Separation of DPS and SPS

- Kinematic variables that exploit 2 to 2 nature of the underlying DPS subprocesses
 - (i) Back to back in transverse momentum, so vector sum is small, for each subprocess
 - (ii) Back to back in azimuthal angle
- Look at each, separately and then together

i. Transverse momentum balance

- Useful kinematic variables to exploit different character of 2 to 2 from 2 to 4 processes
- Define for $pp \rightarrow Wb\bar{b}X \rightarrow \ell\nu b\bar{b}X$

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

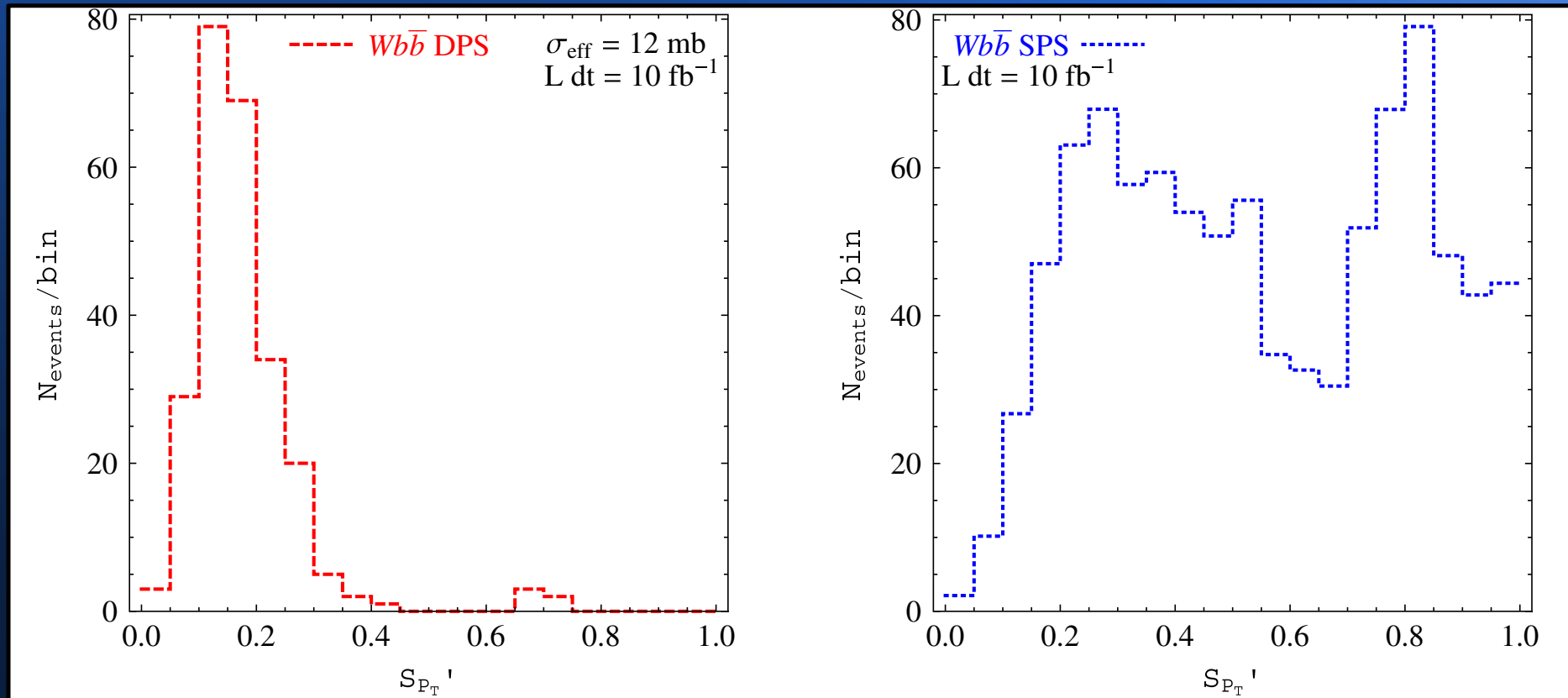
$|p_T(b_1, b_2)|$

and

$|p_T(\ell, \cancel{E}_T)|$

go to zero for 2-2 in LO limit

$$S_{pT}'$$



- DPS is peaked at low values, even after NLO; contrast with broad distribution for SPS (2 to 4) ¹¹

ii. Angle observables

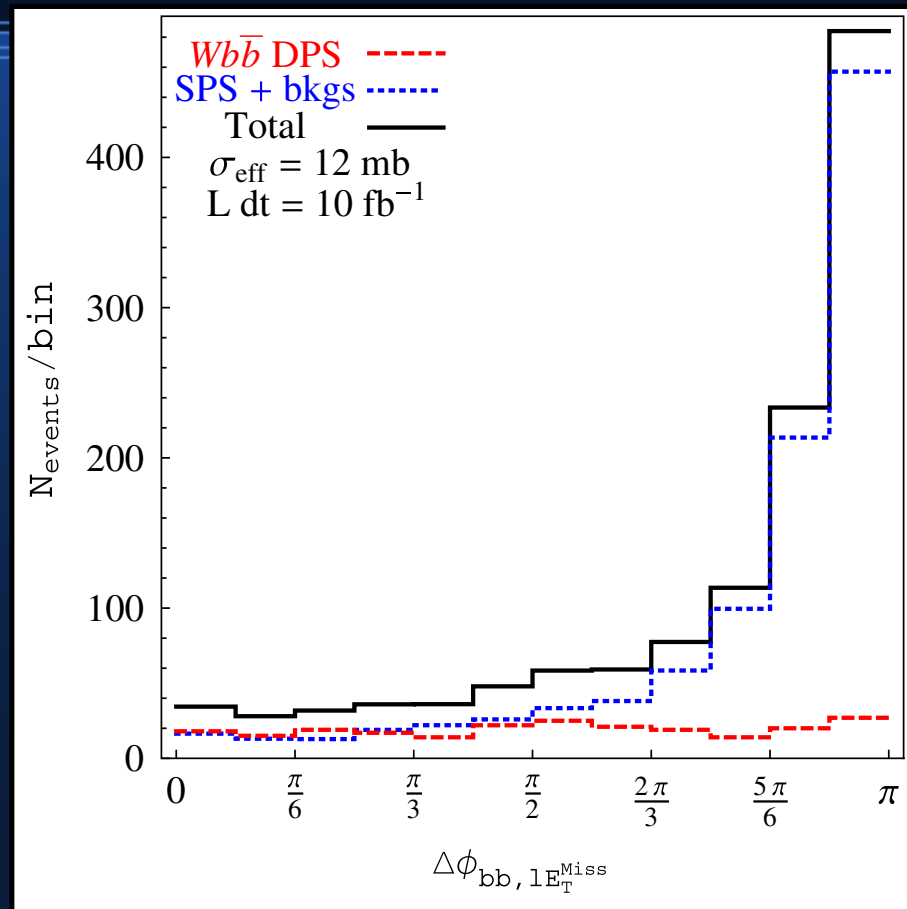
- Interplane angle used in $b\bar{b}$ jet jet study

$$\cos\Delta\Theta_{b\bar{b},\ell\nu} = \hat{n}_3(b_1, b_2) \cdot \hat{n}_3(\ell, \nu)$$

angle between the normals to the planes defined by the two subsystems

- Requires reconstruction of neutrino longitudinal momentum in the $W b\bar{b}$ case
- Azimuthal angle between $b\bar{b}$ and $\ell\nu$ systems is more useful in the $W b\bar{b}$ case
 - Systems tend to be back-to-back in SPS (momentum conservation), but not in DPS

Azimuthal angle observable



DPS relatively flat
(uncorrelated)
but SPS
peaked
strongly near
180 degrees

Sharp distinction in azimuthal angle, even with NLO included,
between the transverse momentum vectors of the $b\bar{b}$ and ℓE_T^{Miss}

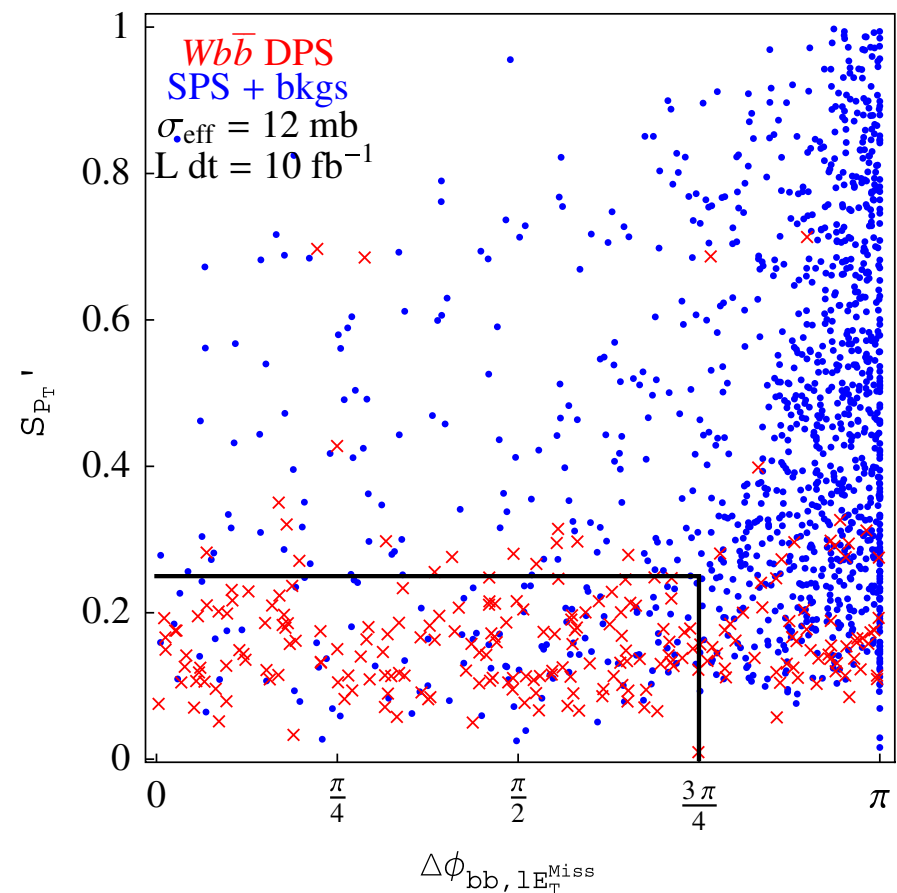
2D distribution

S'_{p_T} and $\Delta\phi_{bb, \ell \cancel{E}_T}$.

DPS (red X) is well separated from SPS and backgrounds (blue dots) in this 2 D plot

$$S/\sqrt{B} = 15.2$$

inside the box area

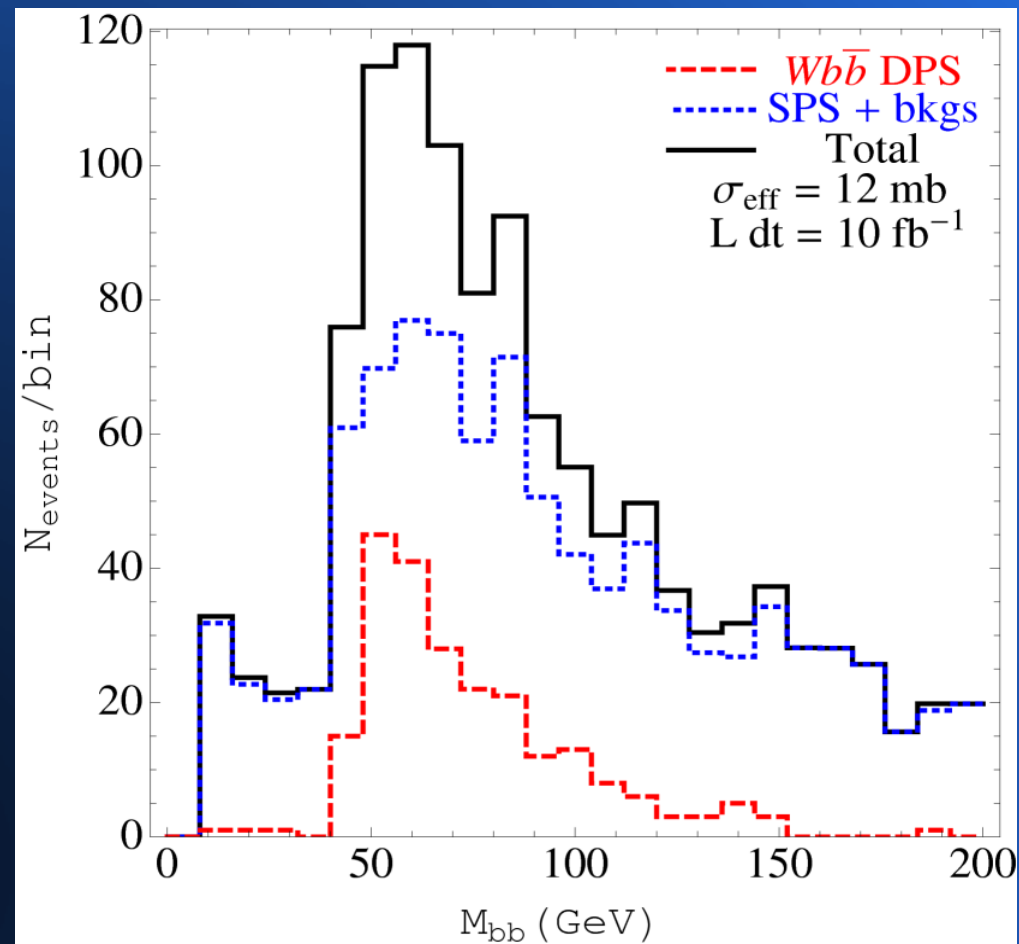


Summary

- Double parton production can be important relative to the single parton rate in specific parts of phase space
- Example of $W b \bar{b}$ computed at NLO
- Variables designed to exploit nature of 2 to 2 subprocesses can be used to differentiate DPS from SPS at excellent significance (12-15 σ)
- Once DPS is isolated, can determine σ_{eff} and verify expected dynamic characteristics of DPS (e.g., p_T spectra), “factorization”, dependence on initial partons
- **Data (and analyses) are needed!**

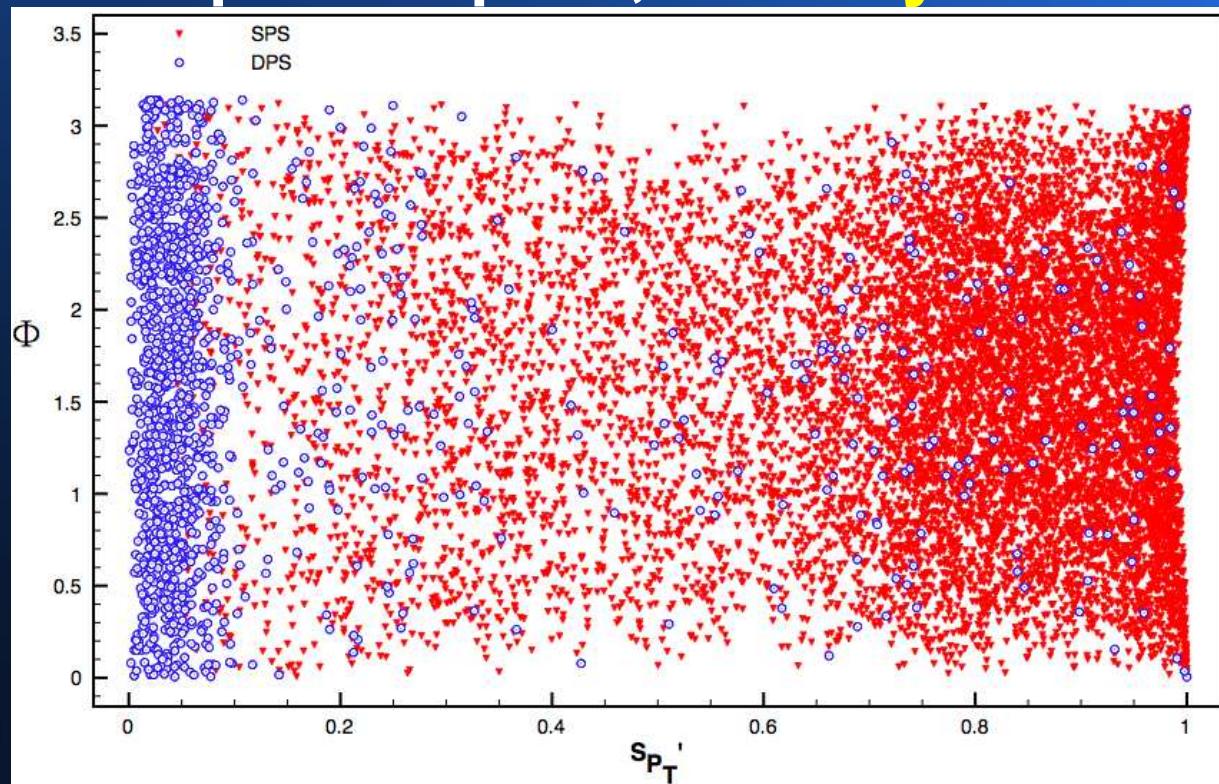
Backup figures

New physics searches?



Previous study done of $b \bar{b}$ jet jet

- Identified signature kinematic variables and regions of phase space, **but only a LO calculation**



Phys. Rev. D 81 (2010) 014014 arXiv:0911.5348