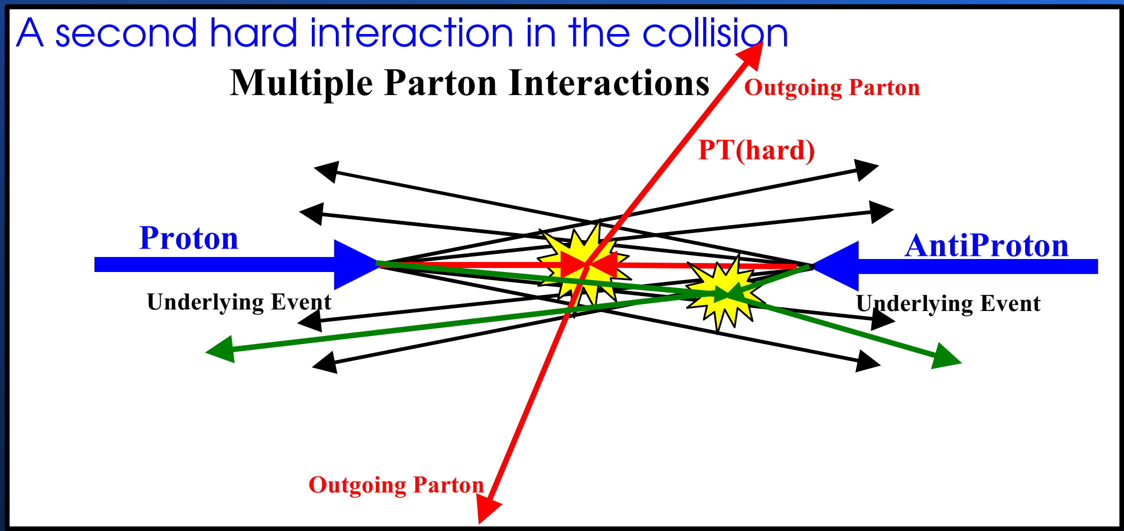
Double Parton Scattering Contributions in W bb and Z bb



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based in part on work with

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arXiv: 1107.3150, Phys Rev **D 84 (2011) 074021**

MPI@LHC 2012, CERN, December 7, 2012

Message

- We need a few definitive measurements of well defined SM DPS signals at LHC: validate the phenomenology; determine the effective cross section σ_{eff} for DPS at LHC
- Goal is to help motivate such analyses
- The focus is on finding clear evidence,so emphasis is on the choice of variables,regions of phase space, and distributions that make this task possible

Outline

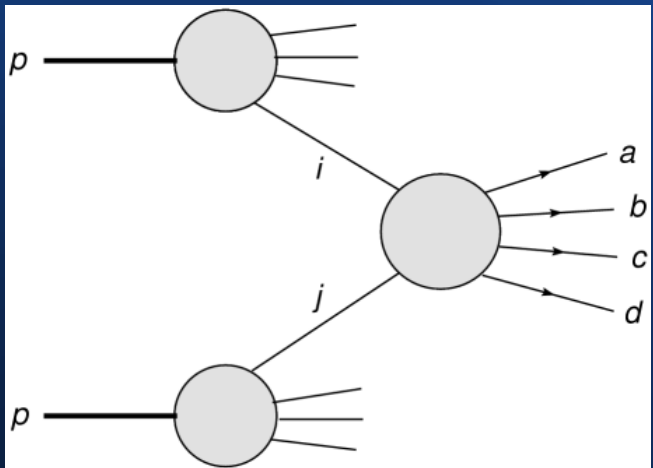
- Role of Double Parton Scattering (DPS)
- Example: $pp \to Wb\bar{b}X \to \ell\nu b\bar{b}X$ at 7 TeV
- Extraction of a DPS signal from Single Parton Scattering (SPS) and backgrounds
- Results
- Summary

Why study and measure DPS?

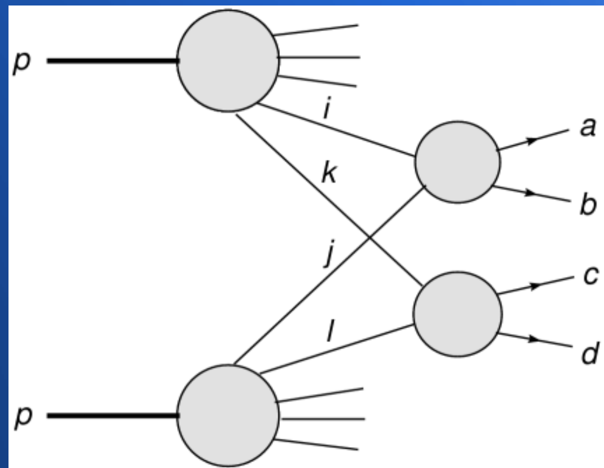
- QCD dynamics beyond SPS scattering (including parton correlations)
- Validate a hard component in underlying event modeling, with distinct dynamic properties (DPS is ``not a tuneable parameter'')
- Added SM background to interesting final states --- Measuring one DPS final state gives insight into 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 measurement possible?

Why Wbb as an example?

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

DPS calculation of $pp \to Wb\bar{b}X \to \ell\nu b\bar{b}X$

Two hard subprocesses: $pp \to WX \to \ell\nu X$ $pp \to b\bar{b}X$

- Assume weak dynamic and kinematic correlations between the two subprocesses (e.g. no color connections)

$$d\sigma^{DPS}(pp \to Wb\bar{b}X) = \frac{d\sigma(pp \to WX)\, d\sigma(pp \to b\bar{b}X)}{\sigma_{\text{eff}}}$$

- σ_{eff} dimensional factor related to overlap in impact parameter
- Theoretical treatise: Diehl, Ostermeier, Schafer, arXiv:1111.0910

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 included (b tagging and muon efficicencies, resolution, mistagging)
- Acceptance cuts, backgrounds, background rejection, ….
- See arXiv: 1107.3150, Phys Rev **D 84 (2011) 074021**

Basic acceptance cuts

- $p_{Tb} > 20$ GeV, $|\eta_b| < 2.5$
- 20 GeV $< p_{T\mu} < 50$ GeV, $|\eta_\mu| < 2.1$;
  - Upper cut on $p_{T\mu}$ to reject boosted W's (e.g., from top decays)
- $E_t^{miss} > 20$ GeV
- $\Delta R_{bb} > 0.4$, $\Delta R_{b\mu} > 0.4$
- Focus on W decays to muons
- Computations done for 7 TeV c.o.m energy

Backgrounds

- Other processes contribute to and/or fake the $Wb\bar{b} \to b\bar{b}\ell\nu$ final state.

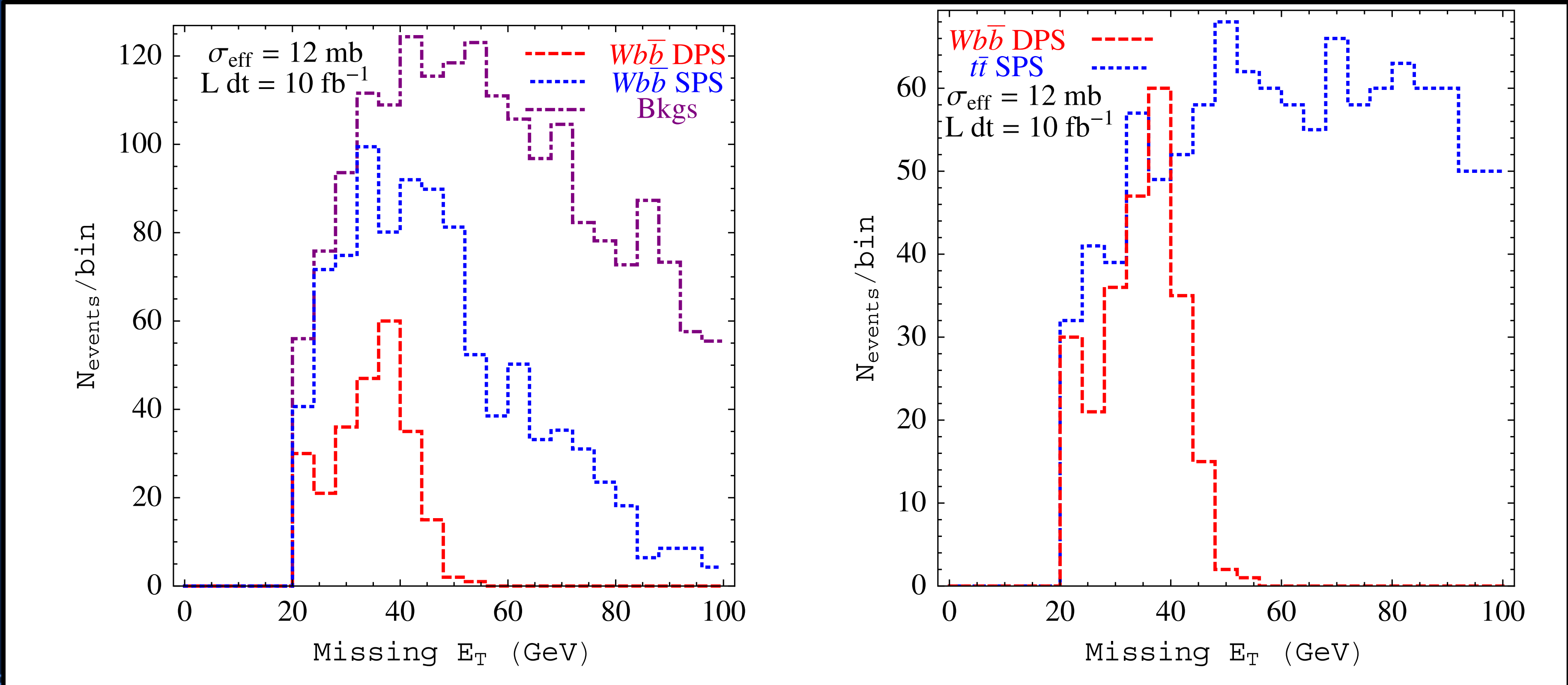
Top quark pair production $t\bar{t}$

Single top quark production (tb, $\bar{t}b$, tj, and $\bar{t}j$

Wjj, Wbj

$t\bar{t}$ BACKGROUND REJECTION

- Upper cut on missing energy (45 GeV) is very effective for reducing t tbar



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 both, separately and then together

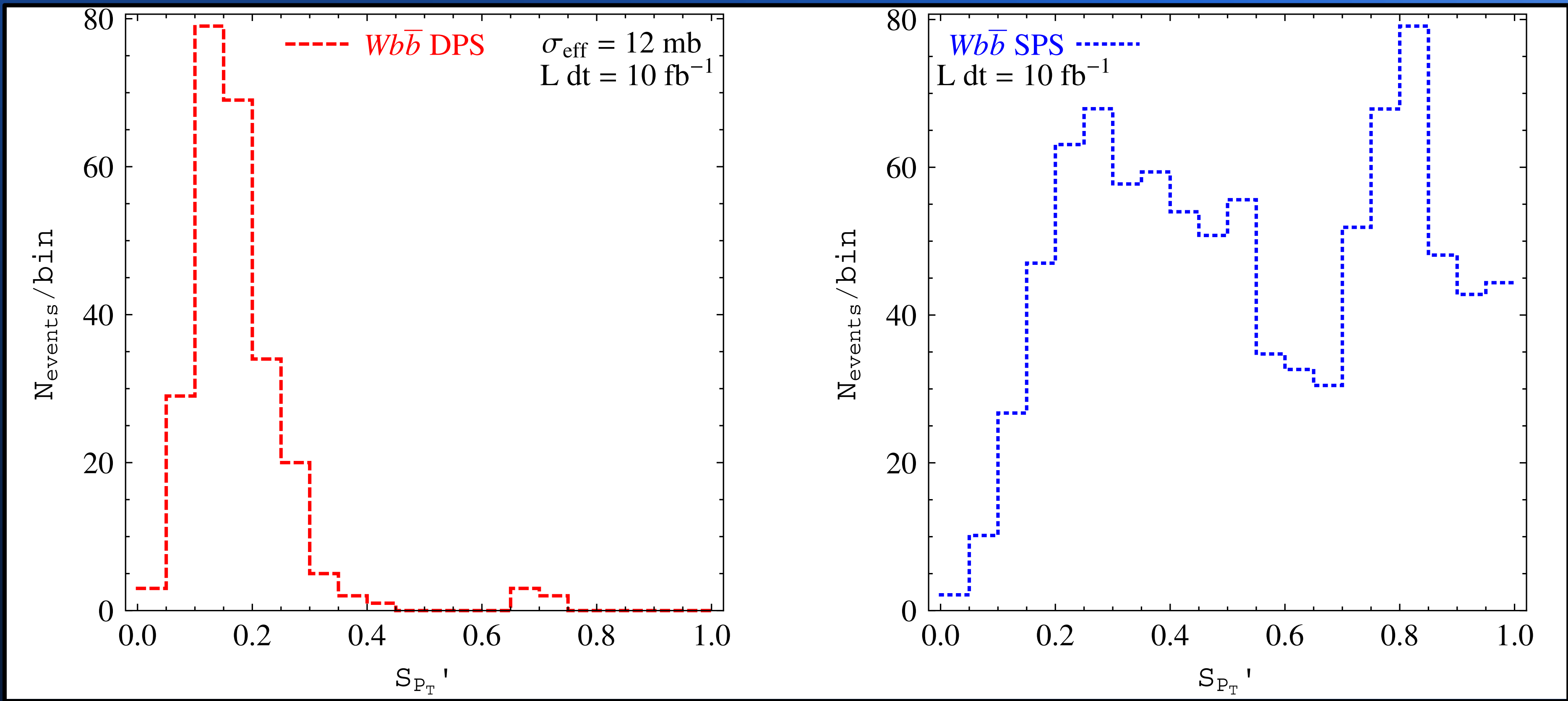
i. Transverse momentum balance

- Useful kinematic variables to exploit different character of 2 to 2 from 2 to 4 processes
- Define

$$S'_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(b_1, b_2)|}{|p_T(b_1)| + |p_T(b_2)|}\right)^2 + \left(\frac{|p_T(\ell, \not{E}_T)|}{|p_T(\ell)| + |\not{E}_T|}\right)^2}.$$

$|p_T(b_1, b_2)|$ and $|p_T(\ell, \not{E}_T)|$ go to zero for 2-2 in LO limit

S_{pT}'



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

ii. Angle observables

- An interplane angle, used in our b b jet jet study

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

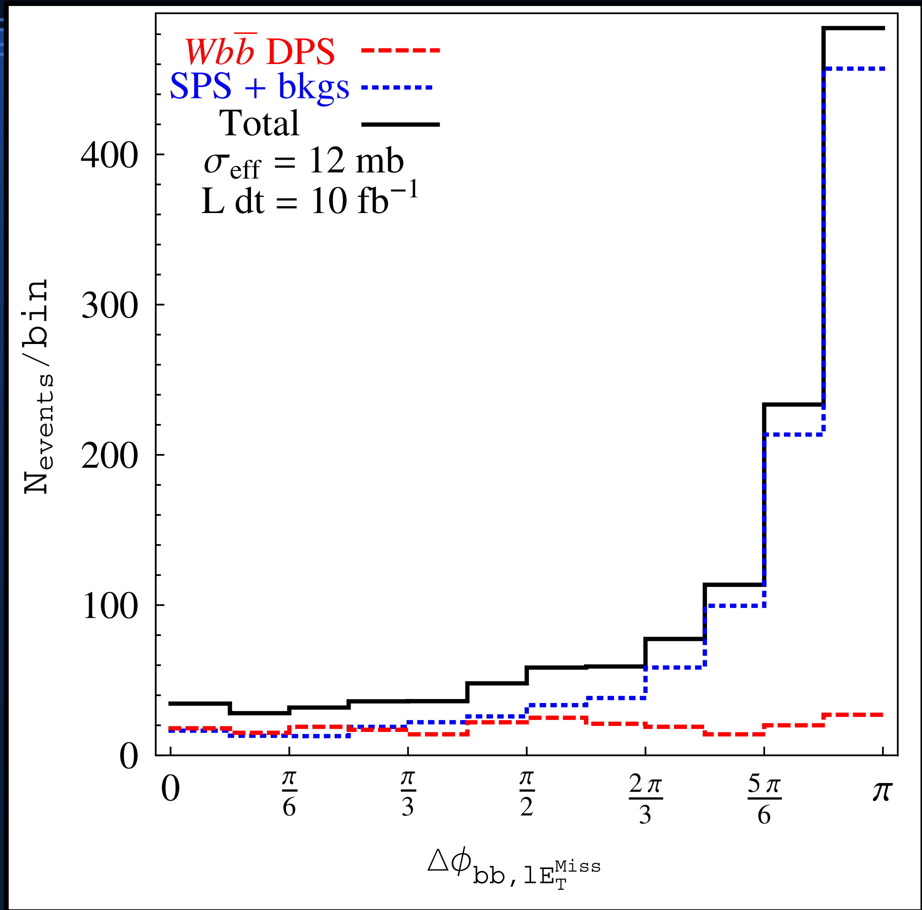
angle between the normals to the planes defined by the two subsystems

  - Requires reconstruction of neutrino longitudinal momentum in the W bb case

- Azimuthal angle between bb and lv systems is more useful in the W bb 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 (2 to 4) 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 $\ell \not{E}_T$

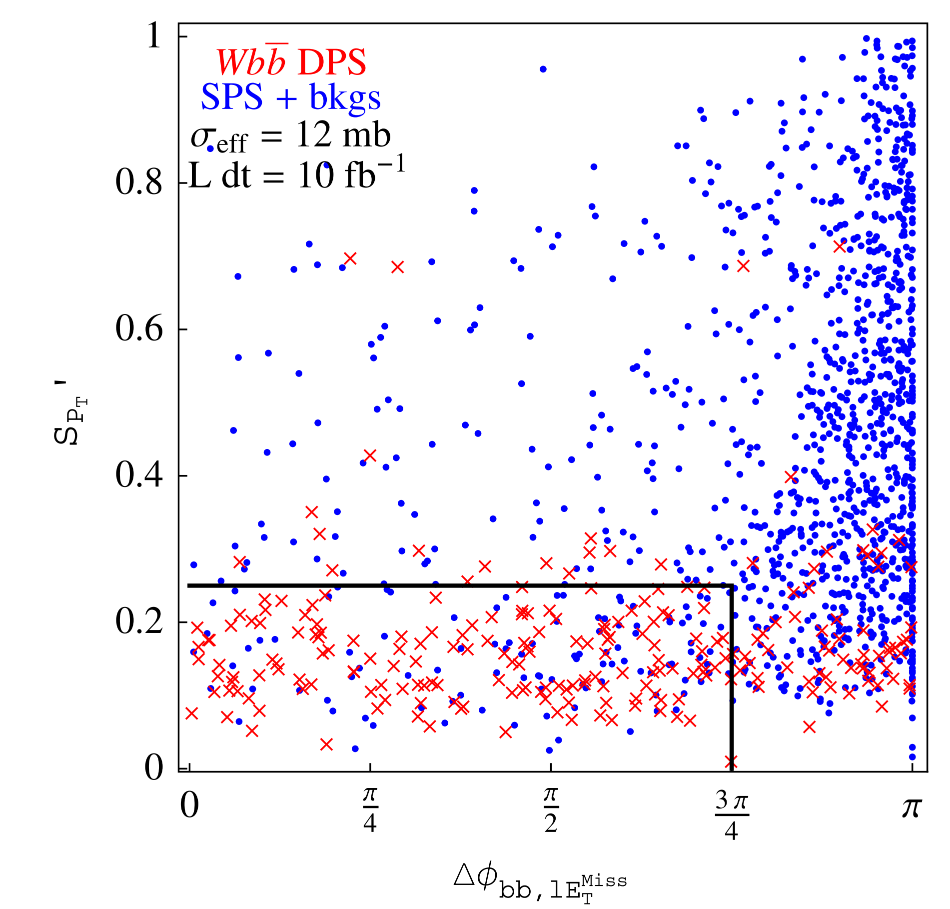
2D distribution

S'_{p_T} and $\Delta\phi_{bb,\ell\not{E}_T}$.

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

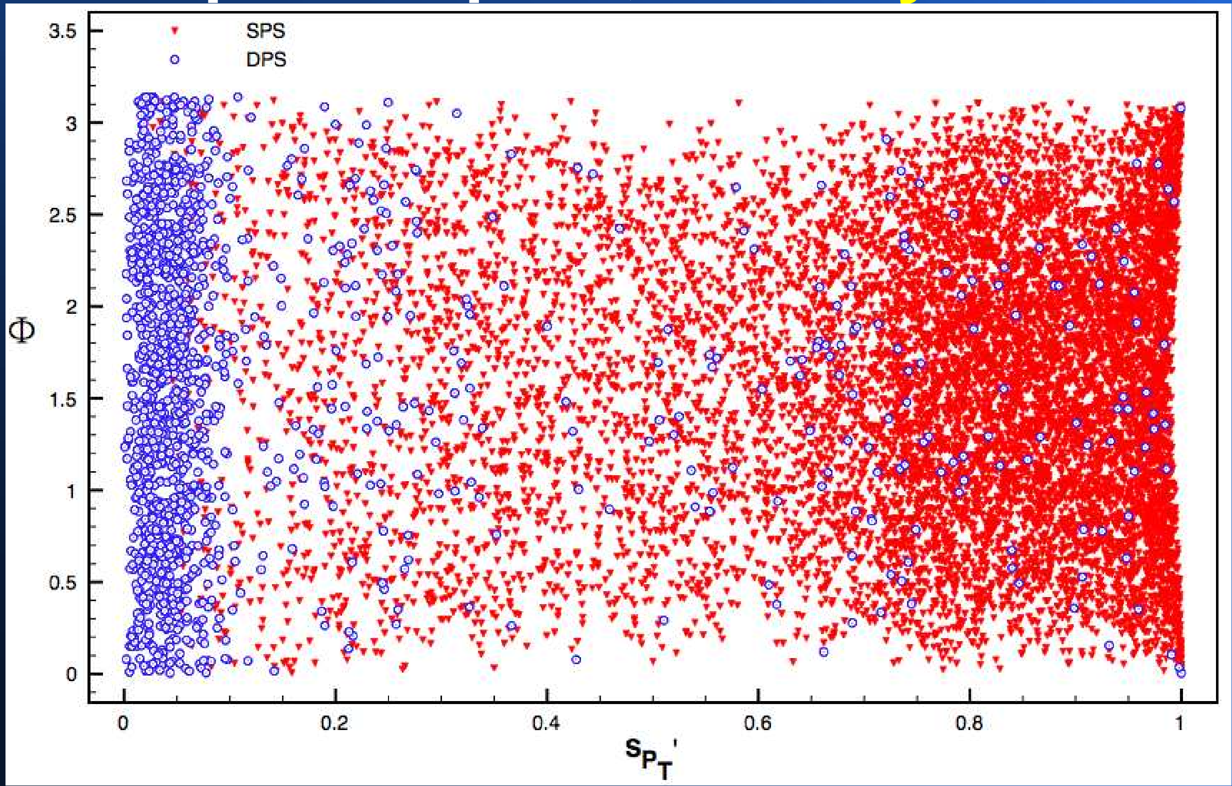
$S/\sqrt{B} = 15.2$

inside the box area



Previous study done of b bbar jet jet

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



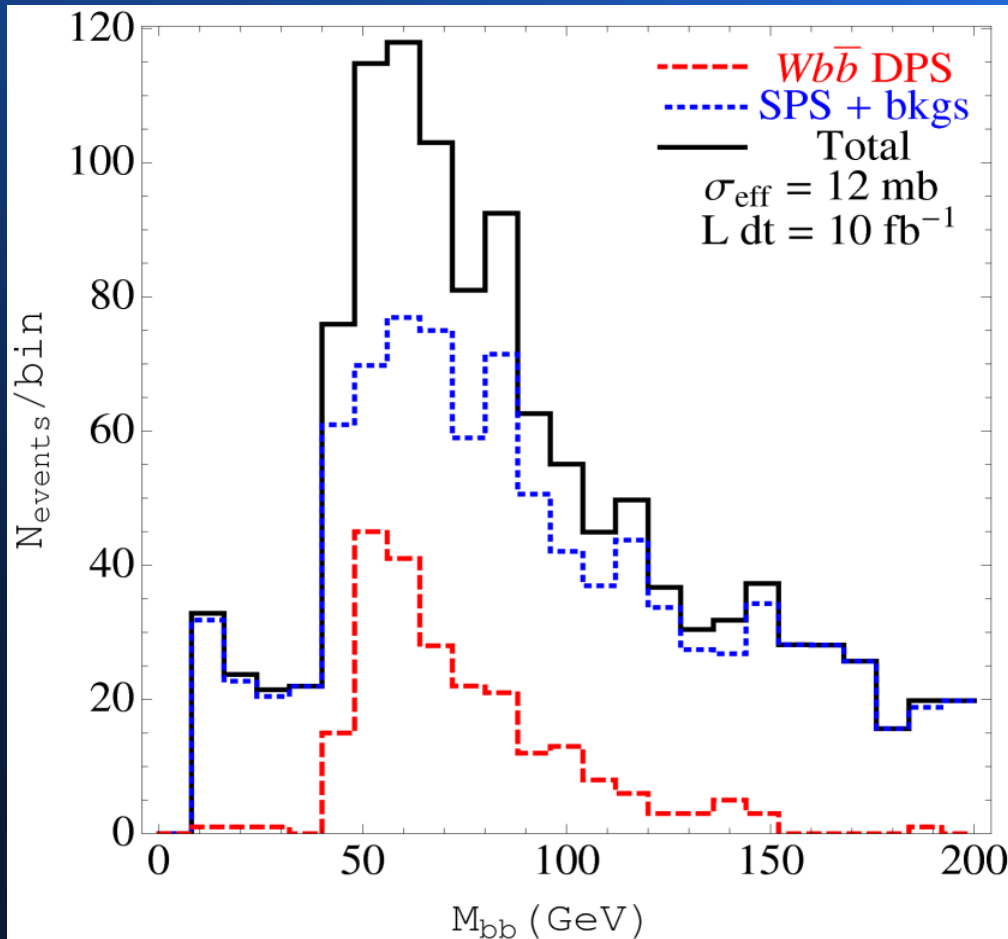
Phys. Rev. D 81 (2010) 014014 arXiv:0911.5348

Summary

- Double parton production can be important relative to the single parton rate in specific parts of phase space
- Example of W b bbar computed at NLO. Z b bbar is still in progress; phenomenologically simpler.
- 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 $\sigma_{eff,}$ and verify expected dynamic characteristics of DPS: (e.g., leading p_T spectra are harder in SPS), ``factorization'', dependence on initial partons
- Data (and analyses) are needed!

Backup figures

New physics searches?



Wbb Signal and Backgrounds

- Event rates for $10\ \text{fb}^{-1}$ of integrated luminosity

Process	Generator-level cuts	Acceptance cuts	$\not{E}_T \leq 45$ GeV	$S'_{p_T} \leq 0.2$
$W^{\pm}b\bar{b}$ (DPS)	10 000	247	231	173
$W^{\pm}b\bar{b}$ (SPS)	44 000	1142	569	114
$t\bar{t}$	225 000	1428	290	13
$W^{\pm}jj$ (DPS)	476 000	43.5	37.7	27.3
$W^{\pm}jj$ (SPS)	20 300 000	101	55.7	19.6
Single top	20 000	492	168	15
$W^{\pm}bj$	153 000	152	53.1	8.2

After acceptance cuts, t tbar background is tough!

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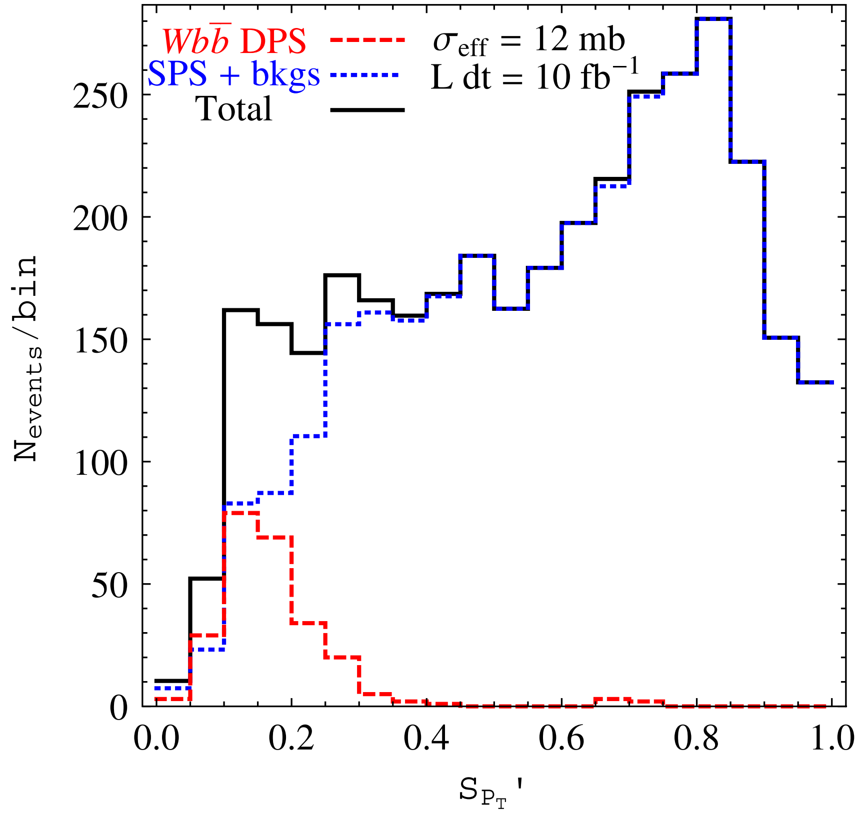
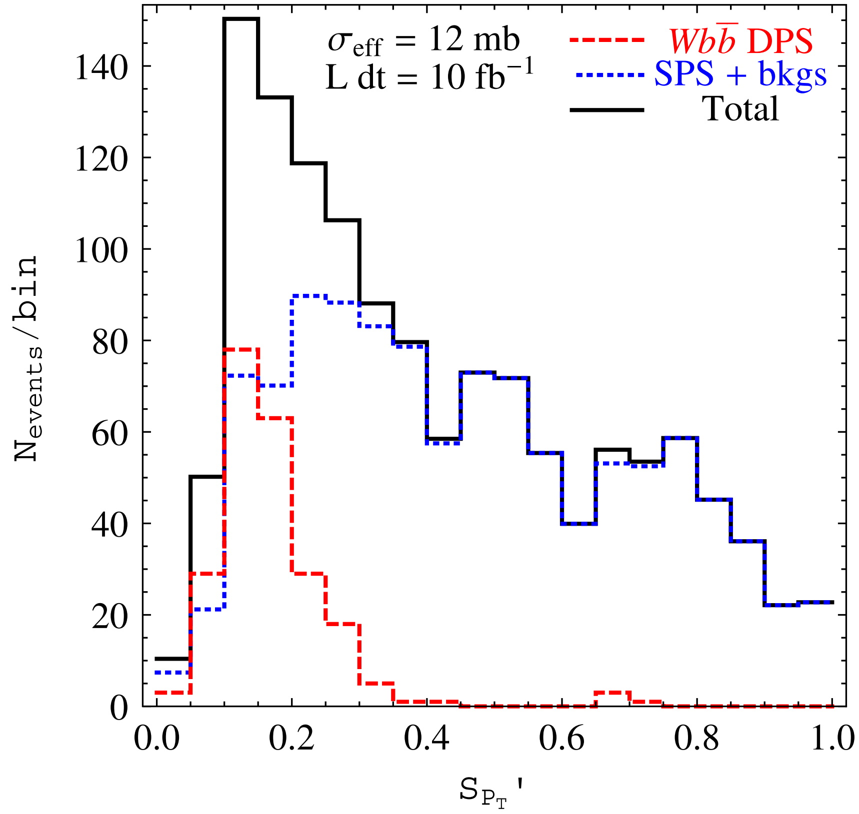
Single top	20 000	492	168	15
$W^\pm bj$	153 000	152	53.1	8.2

After missing E cut, t tbar background is reduced, as is Wbb SPS

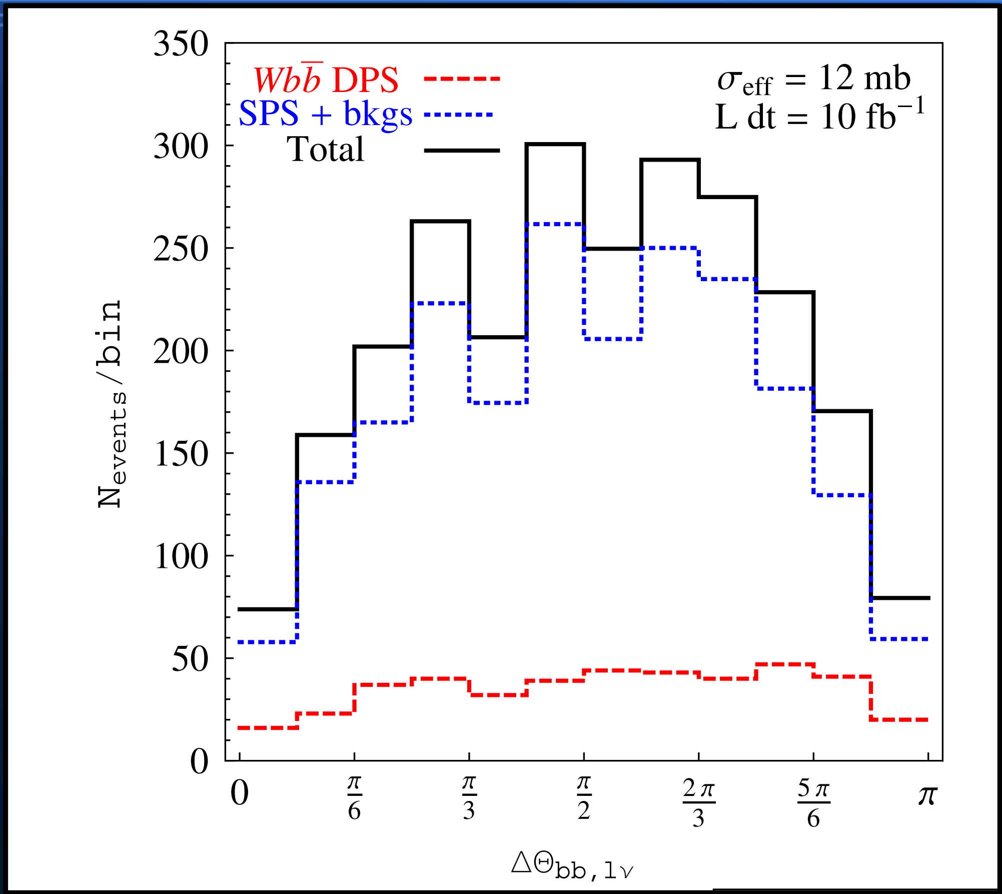
S_{pT}' (with all backgrounds)





- Missing transverse energy cut (on the right) reduces backgrounds; leaves signal at low S_{pT}'

Interplane angle observable



DPS is relatively flat (except for cut suppressions near 0 and 180 degrees) but SPS is peaked near 90 degrees

Liability in this case is that neutrino longitudinal momentum must be reconstructed

Double parton (DPS) calculation

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

$$d\sigma_{pp}^{\mathrm{DPS}} = \frac{m}{2\sigma_{\mathrm{eff}}} \sum_{i,j,k,l} \int H_p^{ik}(x_1, x_2, \mu_A, \mu_B) H_p^{jl}(x_1', x_2', \mu_A, \mu_B) \times d\hat{\sigma}_{ij}(x_1, x_1', \mu_A) d\hat{\sigma}_{kl}(x_2, x_2', \mu_B) dx_1 dx_2 dx_1' dx_2',$$

- Joint probabilities approximated as the product of single PDFs.

$$H_p^{i,k}(x_1, x_2, \mu_A, \mu_B) = f_p^i(x_1, \mu_A) f_p^k(x_2, \mu_B).$$

Double Parton Scattering

A second hard interaction in the collision