NLO Predictions for Wbb Production via Double Parton Scattering at the LHC

Edmond Berger
Argonne National Laboratory

with C. Jackson, S. Quackenbush, and G. Shaughnessy

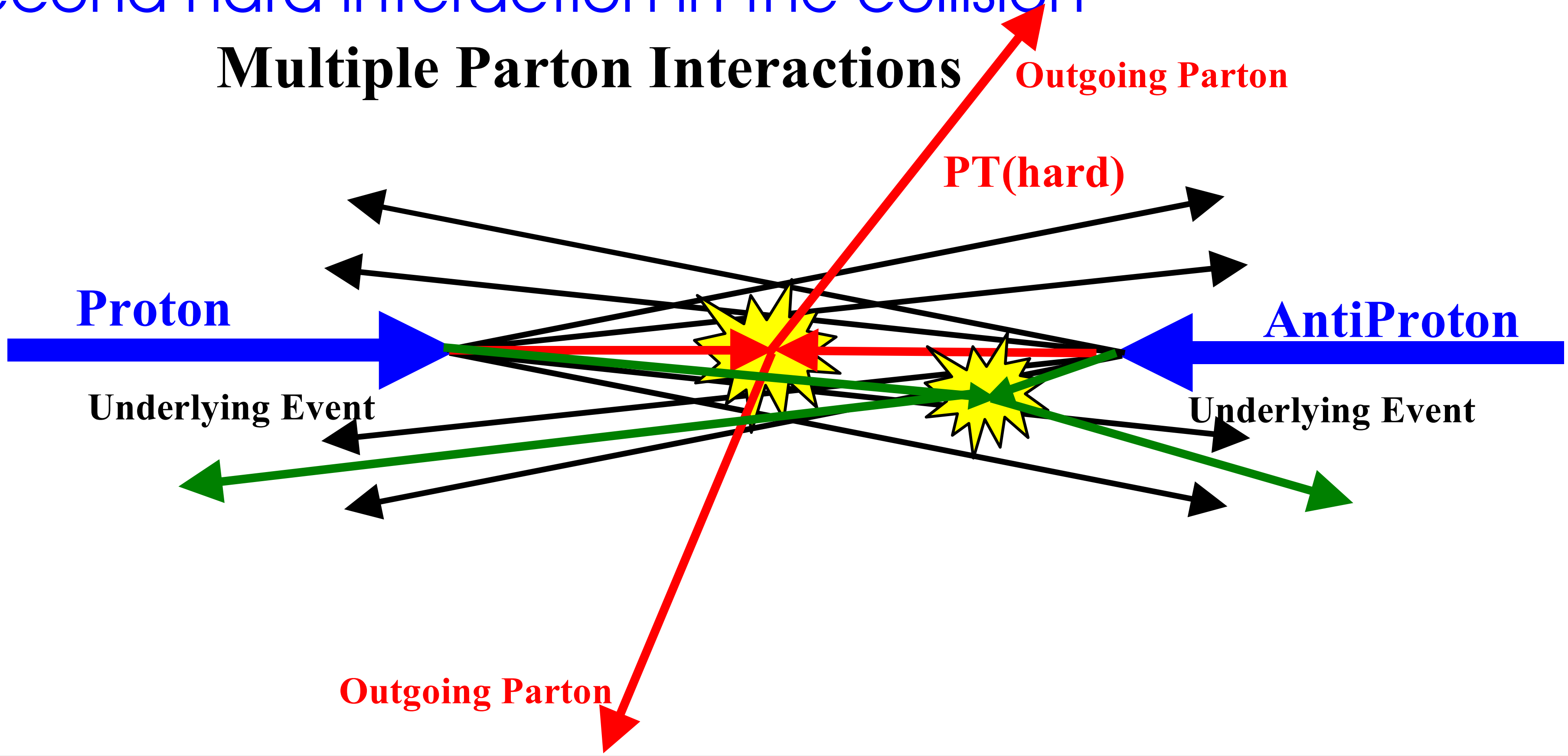
arXiv: 1107.3150, Phys Rev **D 84 (2011) 074021**

Outline

- Role of Double Parton Scattering (DPS)
- Motivation
- Calculation, analysis details, and backgrounds
- Extraction of a DPS signal from Single Parton Scattering (SPS) and backgrounds
- Results
- Summary

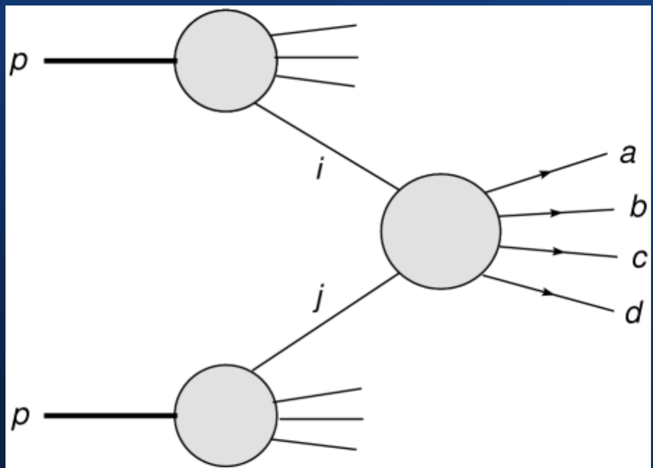
Double Parton Scattering

A second hard interaction in the collision

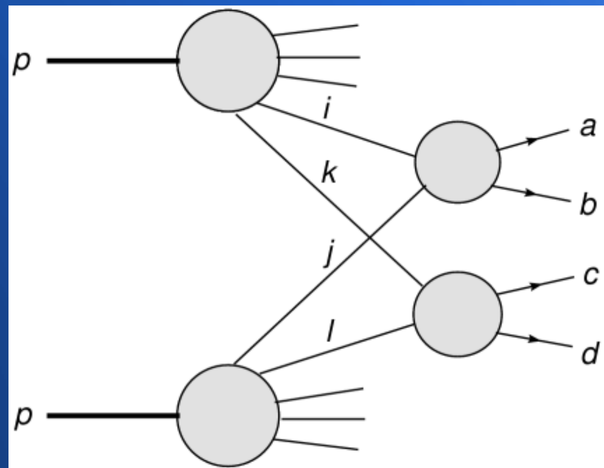


Single and Double Parton Scattering both Contribute

Single Parton Scattering (SPS)



Double Parton Scattering (DPS)



Goal: Measure the relative size of these two contributions

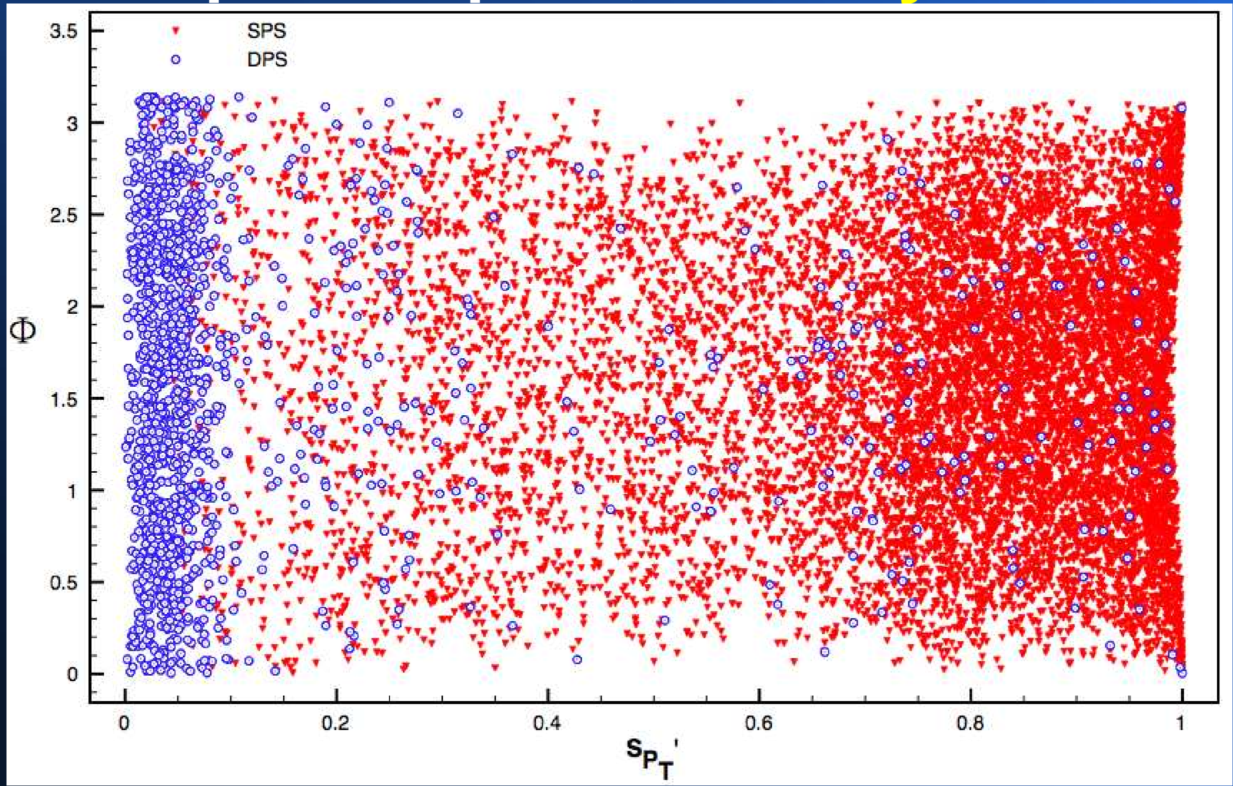
What are the distinguishing variables and regions of phase space that make this possible?

Why study and measure DPS?

- QCD dynamics beyond SPS scattering
- Parton correlations
- Validate a (second) hard component in underlying event modeling
- Additional background to interesting final states
  - Measuring one DPS final state gives insight into the size of DPS contributions elsewhere

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

Why Wbb?

- 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 easy to identify
- NLO calculation exists for SPS Wbb

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 (DPS) calculation

Final expression:

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

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
  - NLO improves reliability of distributions used to distinguish DPS from SPS and backgrounds
- Simple detector effects (b tagging and muon efficicencies, resolution, mistagging) included

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., 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 $Wb\bar{b} \rightarrow b\bar{b}\ell\nu$ final state.

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

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

Wjj, Wbj

Wbb Signal and Backgrounds

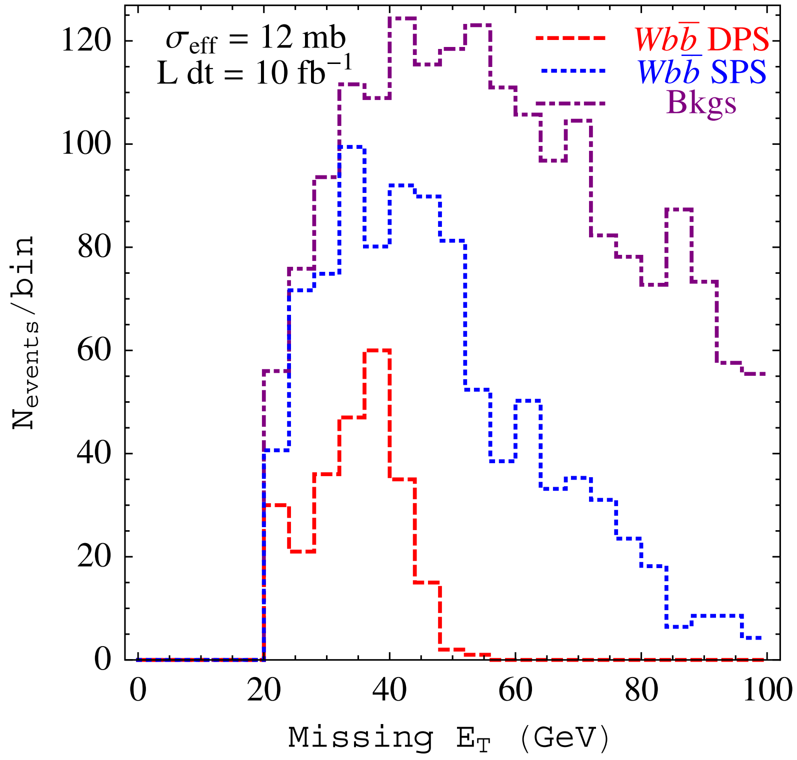
- Event rates for $10\ \mathrm{fb}^{-1}$ of integrated luminosity

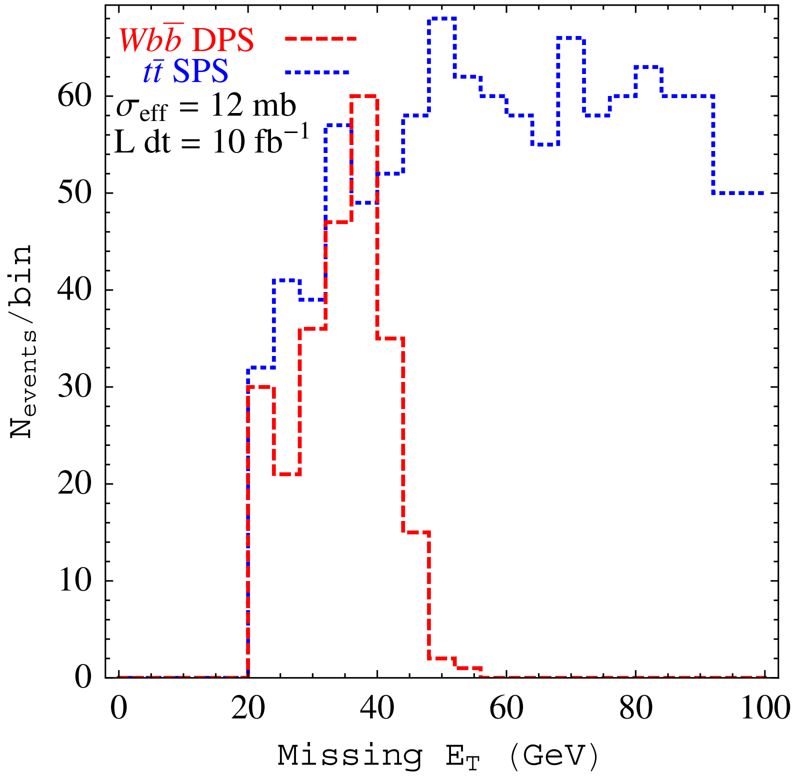
Process	Generator-level cuts	Acceptance cuts	$\not{E}_T \leq 45$ GeV	$S'_{p_T} \leq 0.2$
$W^{\pm}b\bar{b}$ (DPS)	10 000	247	231	173
$W^{\pm}b\bar{b}$ (SPS)	44 000	1142	569	114
$t\bar{t}$	225 000	1428	290	13
$W^{\pm}jj$ (DPS)	476 000	43.5	37.7	27.3
$W^{\pm}jj$ (SPS)	20 300 000	101	55.7	19.6
Single top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

After acceptance cuts, t tbar background is tough!

$t\bar{t}$ BACKGROUND REJECTION

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





Wbb Signal and Backgrounds

- Event rates

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

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

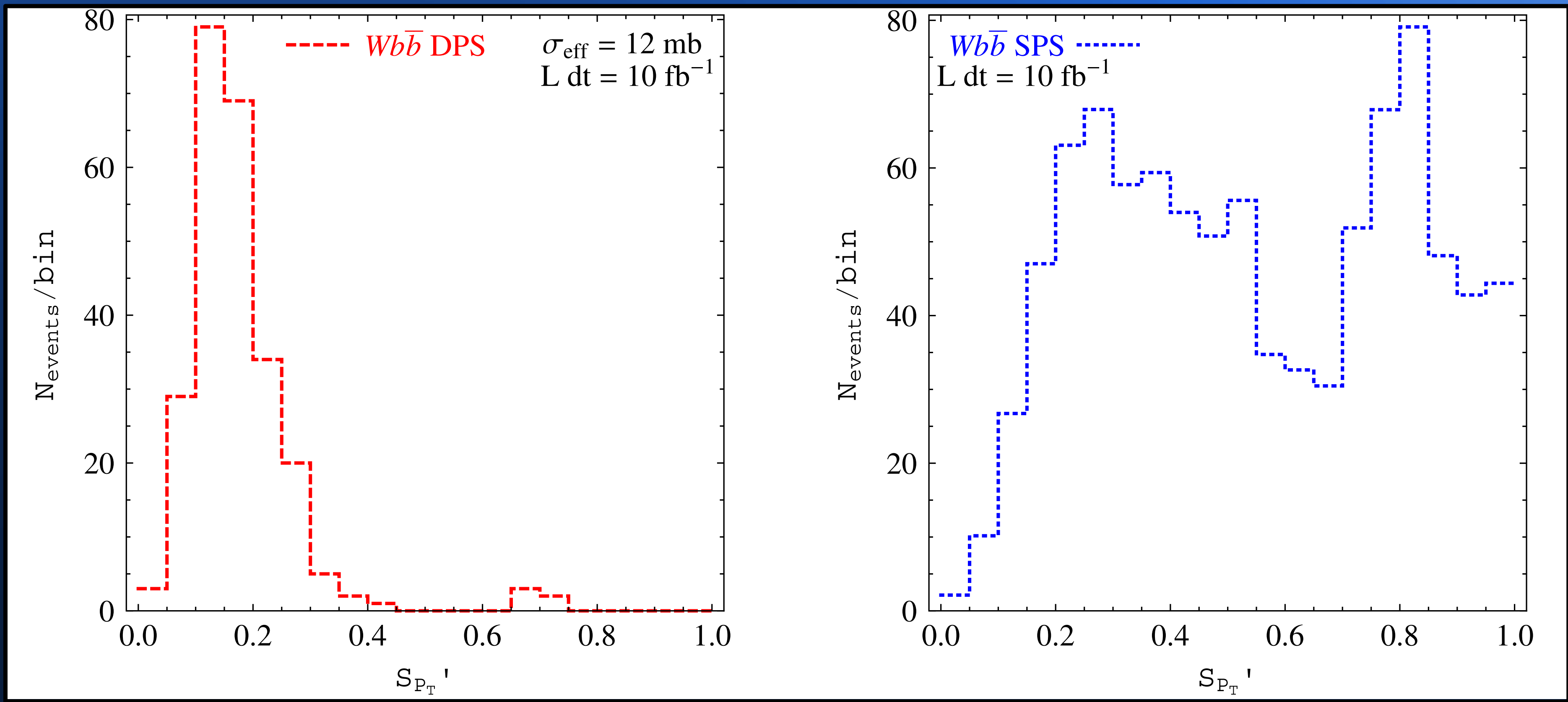
i. Transverse momentum balance

- 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 after NLO; contrast with broad distribution for SPS (2 to 4)

ii. Angle observables

- Interplane angle was used in b b jet jet study

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

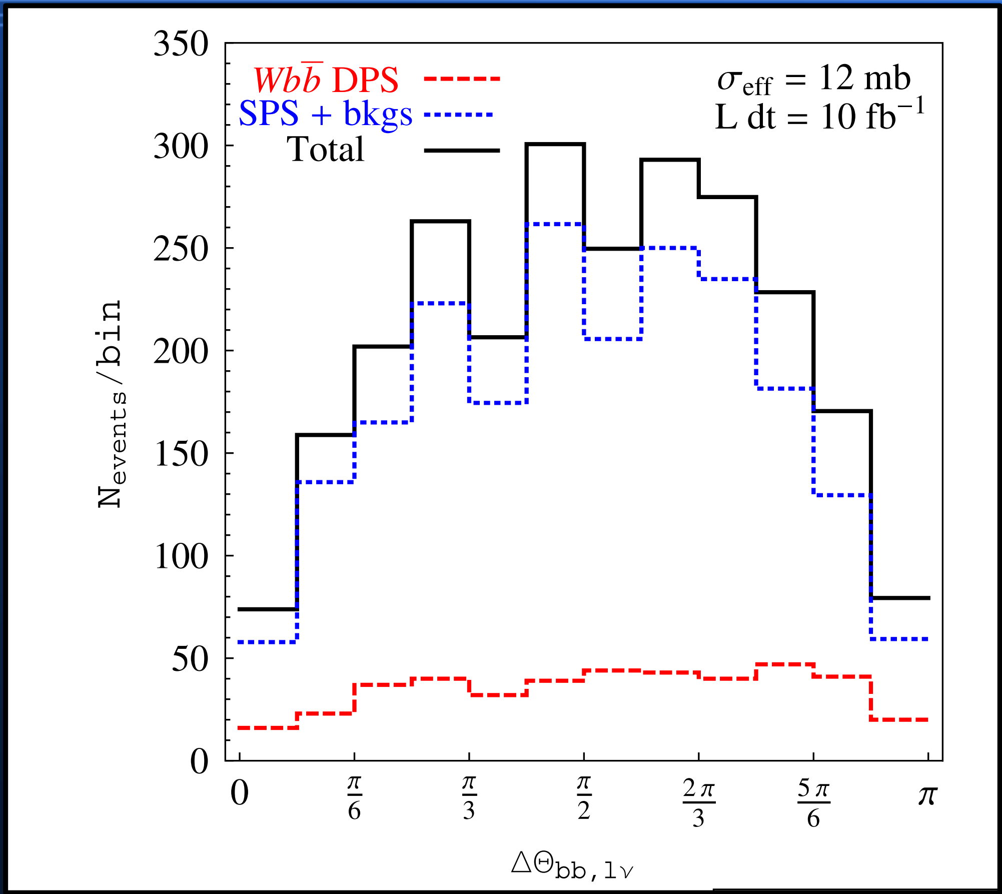
angle between the normals to the planes defined by the two subsystems

  - 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

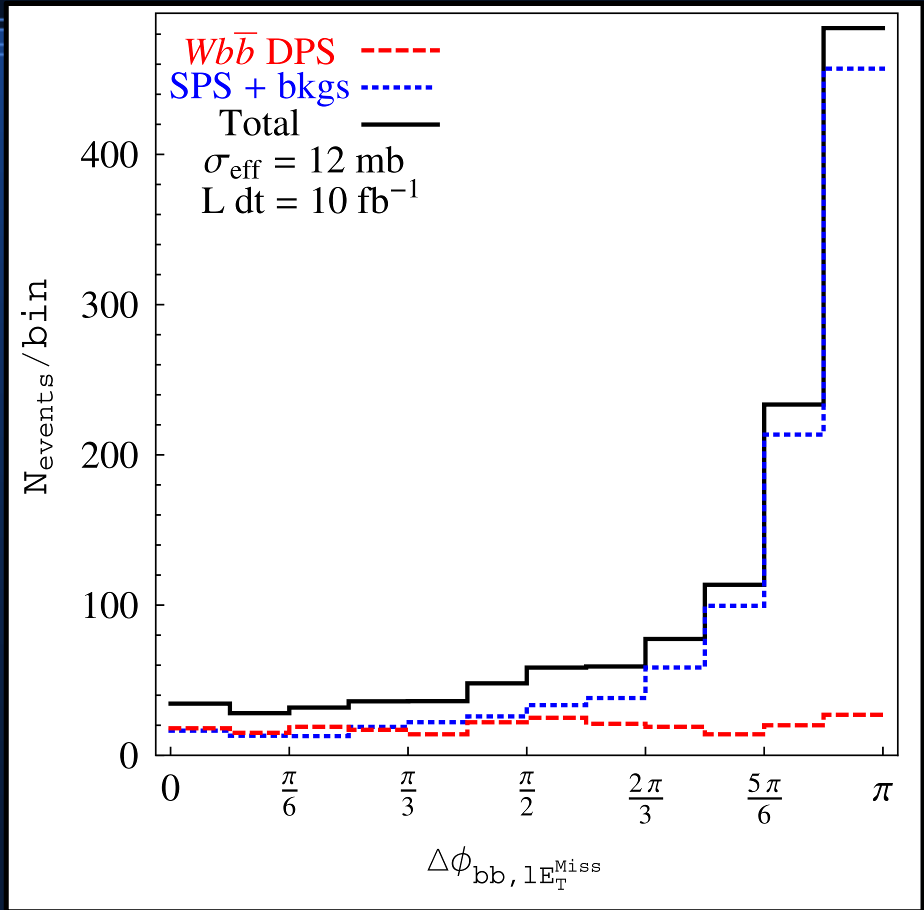
Interplane angle observable



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

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 $\ell \not{E}_T$

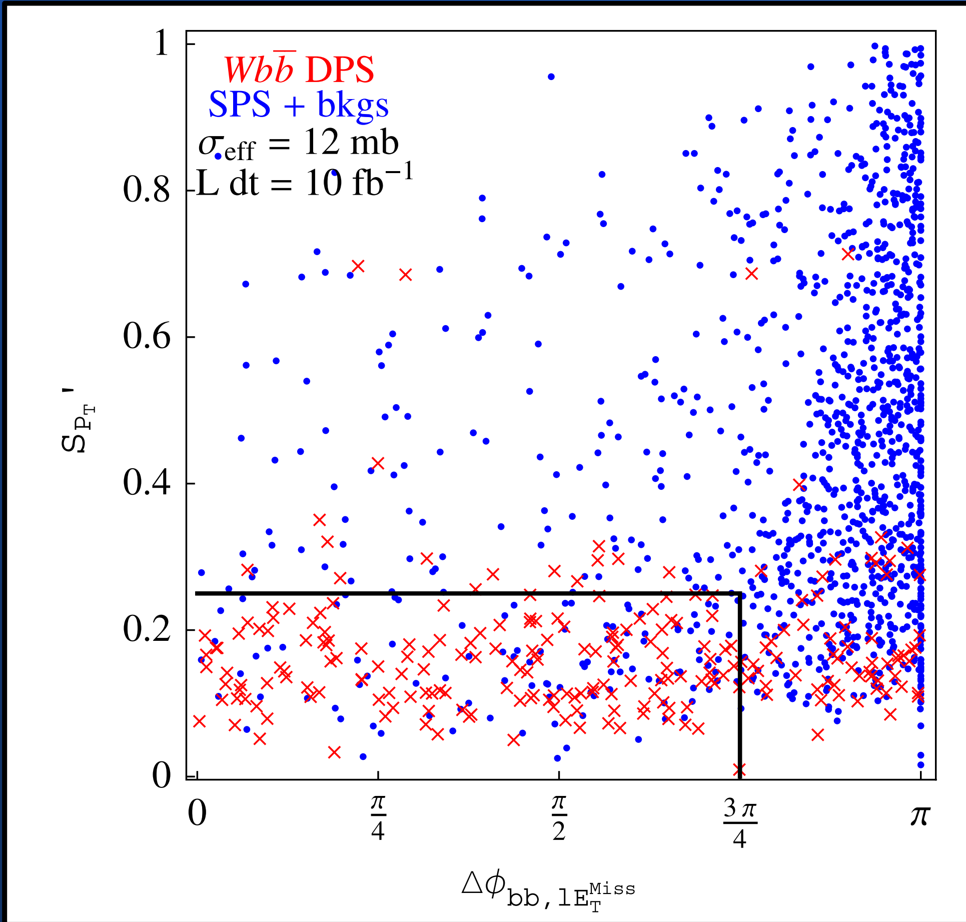
2D distribution

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

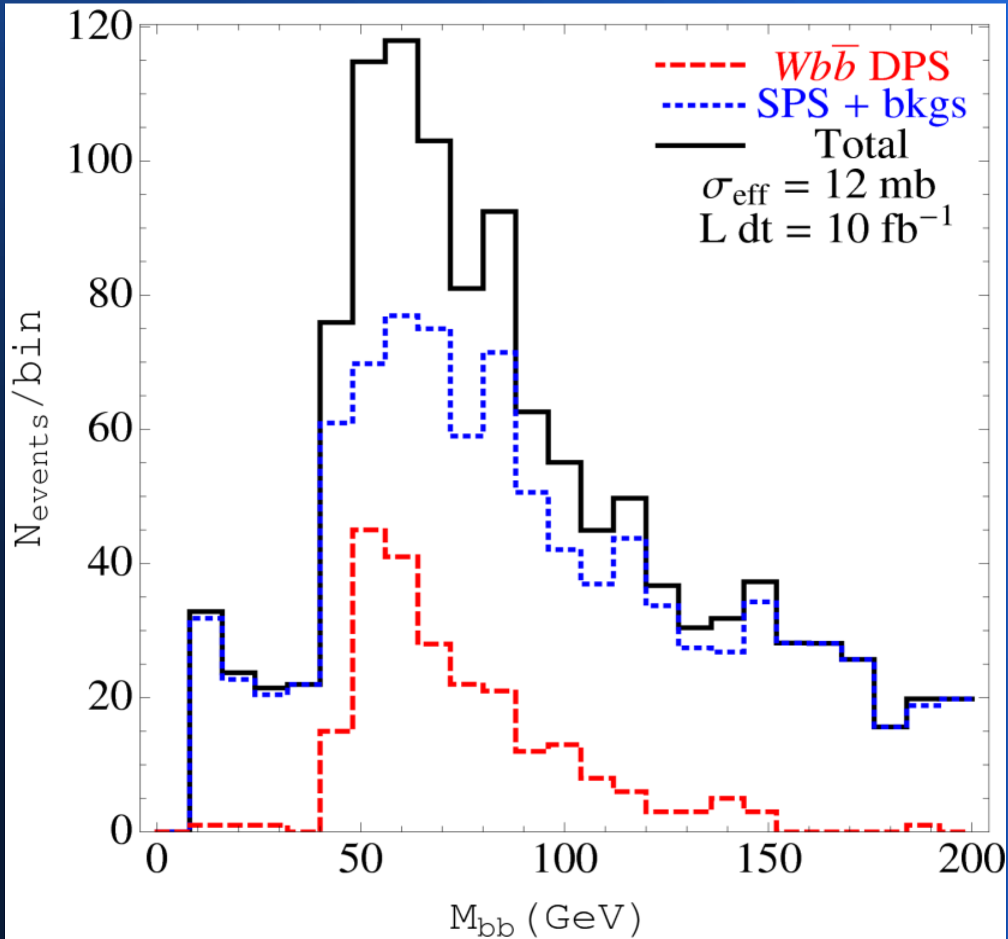


Summary

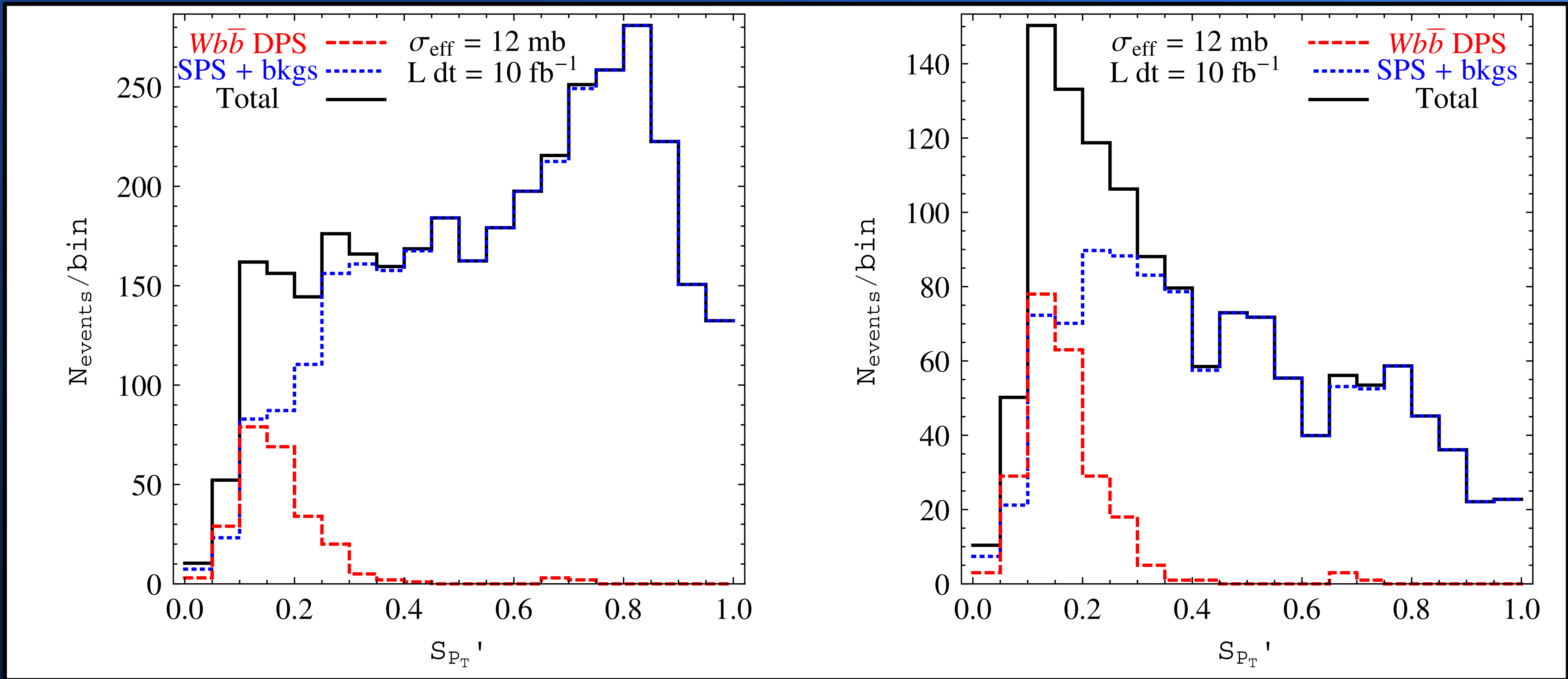
- Double parton production can be important relative to the single parton rate in specific parts of phase space
- Calculation of W b bbar done here at NLO
- Variables designed to exploit nature of 2 to 2 subprocesses can be used to differentiate DPS from SPS at excellent significance (12-15 σ)
- Once DPS is isolated, can determine σ_{eff}
- Data (and analyses) are needed!

Backup figures

New physics searches?



S_{pT}' (with all backgrounds)



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