Probing double parton scattering with same-sign W pairs at the LHC

Workshop on Multi-Parton Interactions at the LHC, DESY

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Steve Chun-Hay Kom (Cambridge)

with J. Gaunt, A. Kulesza, J. Stirling

(arXiv:1003.3953)

Outline

- Introduction
- A probe at the LHC : same sign W pair
- Signal and background studies
- Summary

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Two simultaneous hard interactions in one (p-p) collision.

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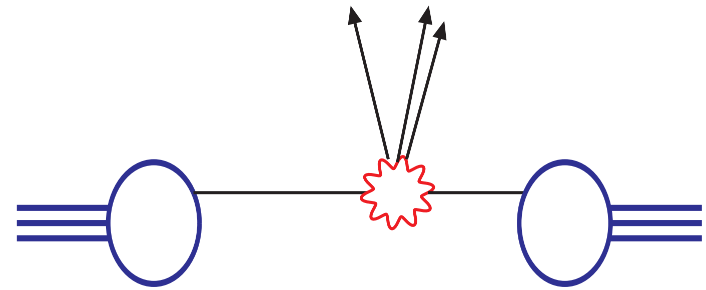

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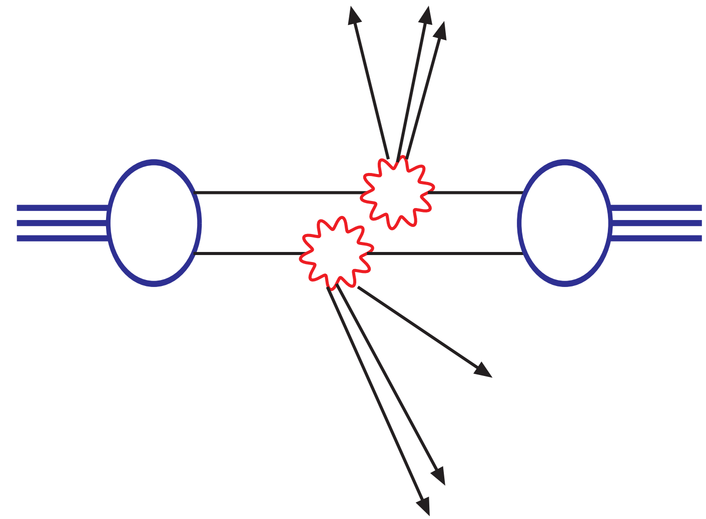

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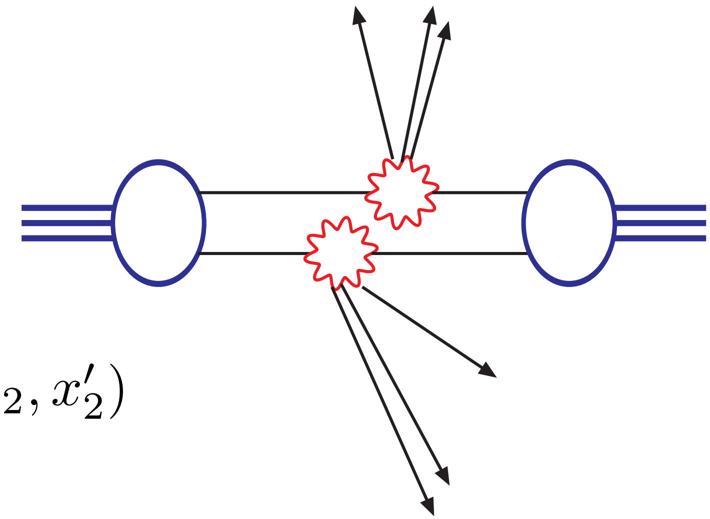

$$\sigma_{\rm DS}{}^{(W_1,W_2)} = \frac{1}{2\sigma_{\rm eff}} \int dx_1 dx_2 dx_1' dx_2'$$
$$D^{ij}(x_1,x_2,t) D^{kl}(x_1',x_2',t) \hat{\sigma}_{ik}^{W_1}(x_1,x_1') \hat{\sigma}_{jl}^{W_2}(x_2,x_2')$$

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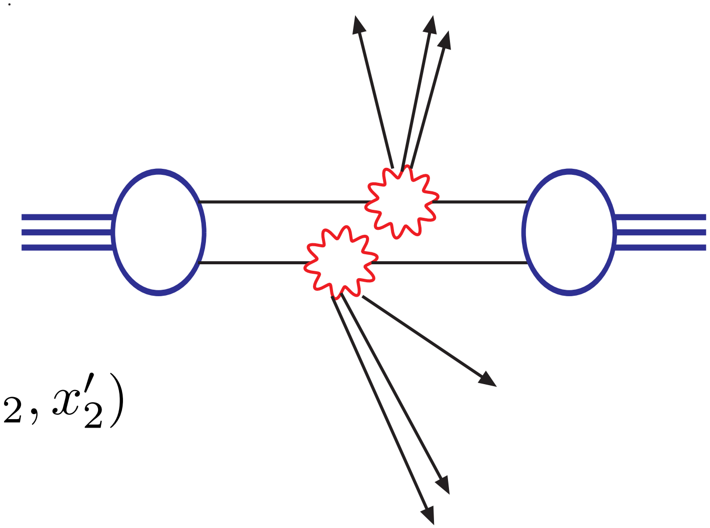

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Assumptions:

- Uncorrelated longitudinal and transverse distributions
- Same factorisation scale t
- Same transverse distributions for different partons

Correlations in DPS

Longitudinal:

- breakdown of simple factorised PDFs by dDGLAP Snigirev 03, Korotkikh, Snigirev 04, Cattaruzza et. al. 05
- momentum and number sum rules Gaunt, Stirling 09

Improved (longitudinal) dPDFs now available (GS09 Gaunt, Stirling 09).

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Transverse:

- sea distribution correlated with valence (charged form factor) Calucci, Treleani 99
- different σ_{eff} for different terms in dDGLAP Cattaruzza, Treleani et. al. 05
- transverse proton wave fucntions grow in $\ln\frac{1}{x}$ Domdey et. al. 09

DPS phenomenology

- Experimental studies:
  AFS, (UA2,) & CDF on $4j$, more recently CDF & D0 on $\gamma + 3j$
  also Drees, Han 96 and Bill Murray's talk

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- Possible (LHC) DPS signal:
  $b\bar{b}b\bar{b}, b\bar{b}jj, jjjj$ Del Fabbro, Treleani 02, Cattaruzza et. al. 05, Berger et. al. 09
  W/Z + $4j$ Maina 09
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  Associated W/Z+H production Del Fabbro, Treleani 00, Hussein 06

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Often assume uncorrelated PDFs in phenomenology analysis
We investigate effects from improved longitudinal dPDF description
& study ($W^{\pm}W^{\pm}$) background in more detail

$W^{\pm}W^{\pm}$ pair production

- No ‘irreducible’ single scattering at the same order !
  - Lowest order at : $W^{\pm}W^{\pm}jj$ ($\mathcal{O}(\alpha_S^2\alpha^2, \alpha^4)$)

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- Same scale for the 2 collisions
- Good understanding of single $W^{\pm}$ properties, and will be measured accurately at the LHC.

Correlations in DS $W^{\pm}W^{\pm}$

- dPDFs correlations break factorisations :
  $R \equiv 4\frac{\sigma_{W^+W^+}\,\sigma_{W^-W^-}}{\sigma^2_{W^+W^-}}$ $(= 1$ in the factorised limit)

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  For comparison we have MSTW$_n$ ($n = 0, 1, 2$) sets :
  $$D_h^{ab}(x_1, x_2, t) = D_h^a(x_1, t) D_h^b(x_2, t)\theta(1 - x_1 - x_2) \times (1 - x_1 - x_2)^n$$

(pb)	$\sigma_{\rm GS09}$	$\sigma_{\rm MSTW_0}$	$\sigma_{\rm MSTW_1}$	$\sigma_{\rm MSTW_2}$
	$\sqrt{s} = 14$ TeV			
W^+W^-	0.546	0.496	0.409	0.348
W^+W^+	0.321	0.338	0.269	0.223
W^-W^-	0.182	0.182	0.156	0.136
	R			
	0.784	1.00	1.00	1.00

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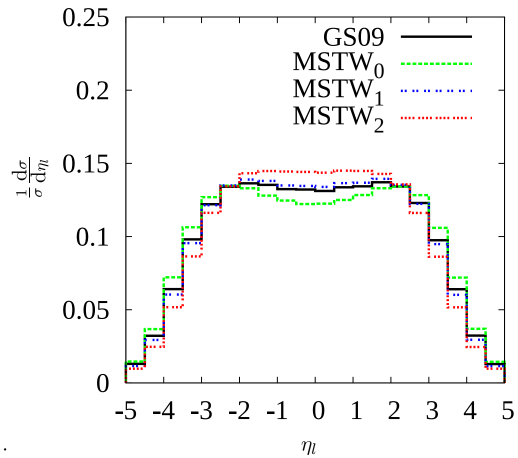
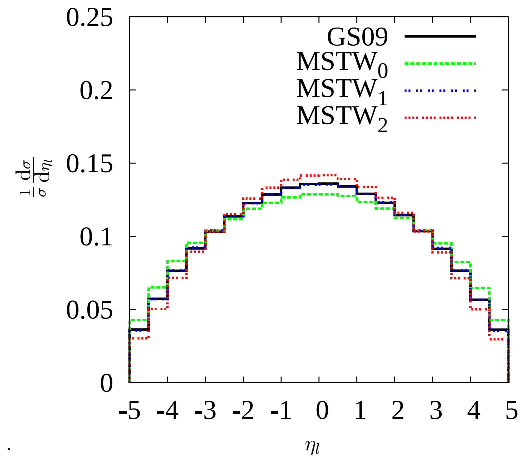
- Factorised approximation becomes better when $\sqrt{s}$ increases.

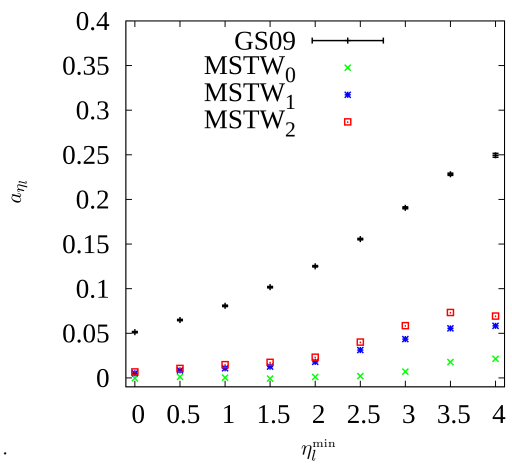
Correlations in DS $W^{\pm}W^{\pm}$ (2)

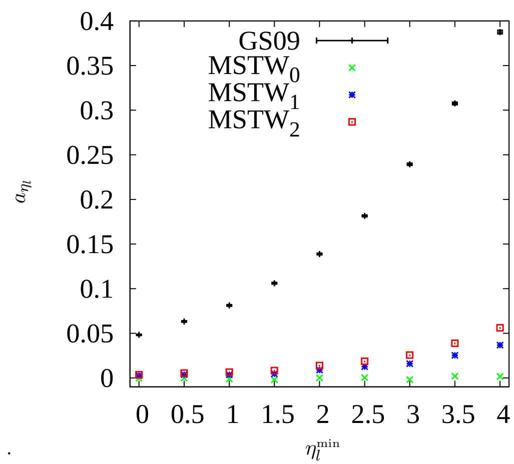




η_l well modelled by MSTW_1

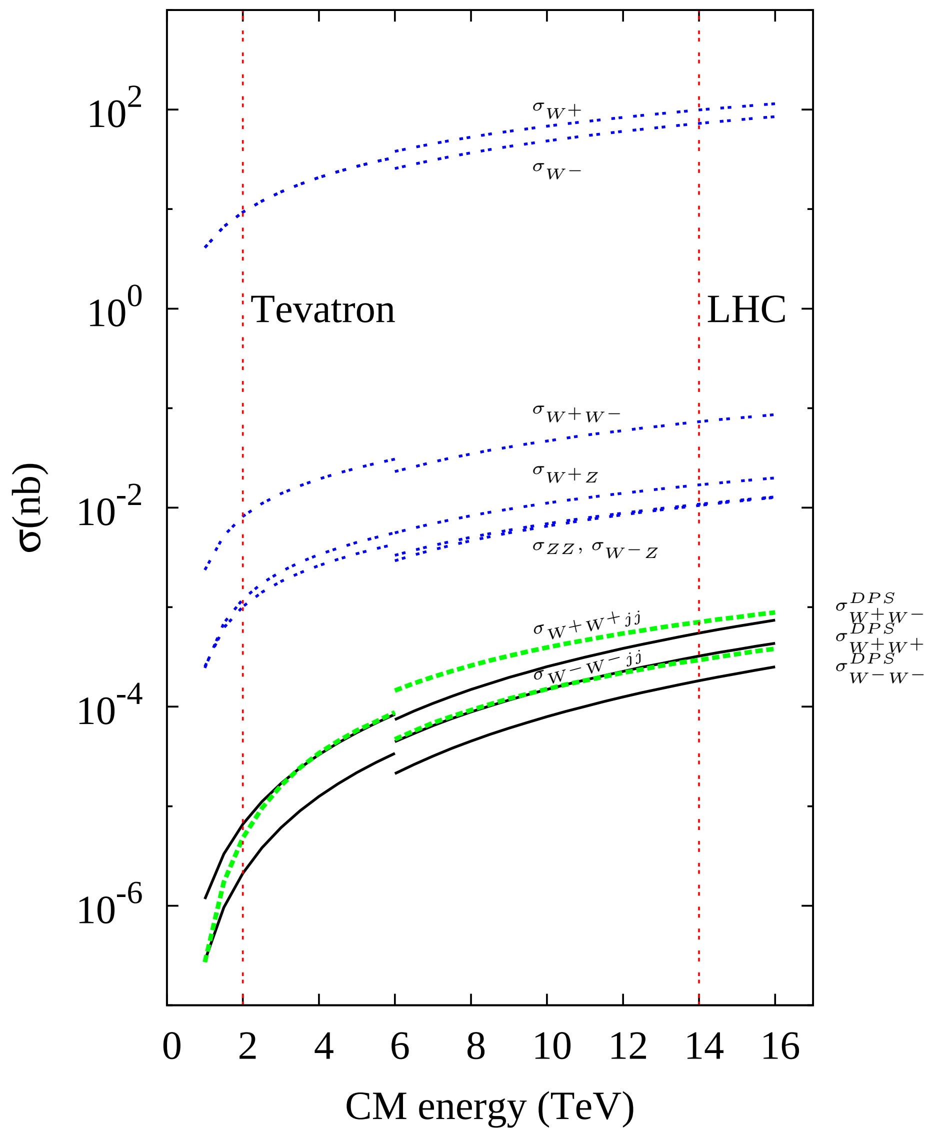
$$a_{\eta_l} = \frac{\sigma(\eta_{l_1}\times\eta_{l_2}<0)-\sigma(\eta_{l_1}\times\eta_{l_2}>0)}{\sigma(\eta_{l_1}\times\eta_{l_2}<0)+\sigma(\eta_{l_1}\times\eta_{l_2}>0)}$$





Large η_l asymmetry

DPS signal vs SPS bkgd



Assume @ LHC

$\sigma_{\rm eff} = 14.5\,{\rm mb}$

$\sigma_{\rm DS}(2W^\pm) \sim \mathcal{O}(500)\,{\rm fb}$

Bkgd considered:

1) single scattering $W^\pm W^\pm jj$

2) diboson ($W^\pm Z(\gamma^*)$)

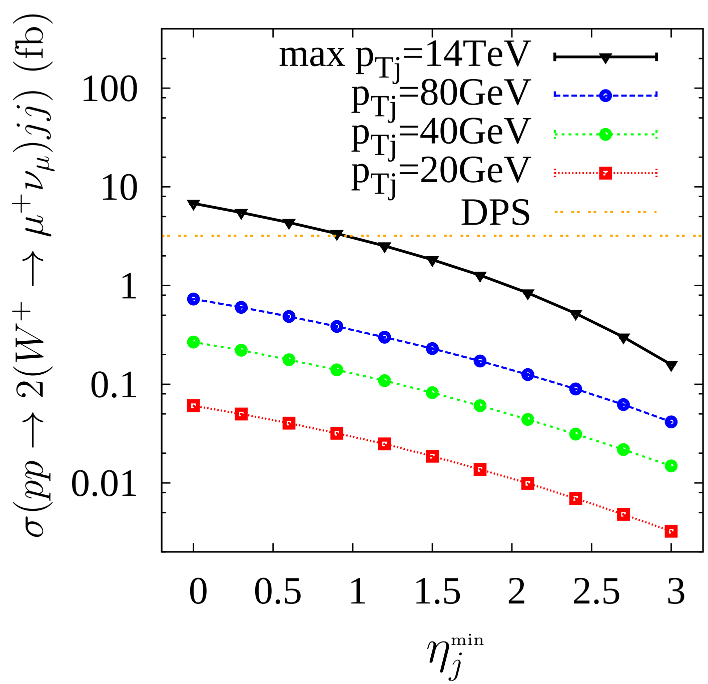
3) heavy flavours ($Q\bar{Q}$)

Single scattering bkgd

- $W^{\pm}W^{\pm}jj$: total cross section $\sim \sigma_{\rm DS}(W^{\pm}W^{\pm})$

Single scattering bkgd

- $W^\pm W^\pm jj$: total cross section $\sim \sigma_{\rm DS}(W^\pm W^\pm)$
- Central jet veto ($\eta_{\rm j}^{\rm min}$, $p_{\rm Tj}^{\rm max}$) effective:



Single scattering bkgd (2)

- Diboson production, and when some leptons not identified :
  $q\bar{q}' \to W^{\pm}Z(\gamma^*) \to l^{\pm}\nu l^{\pm}(l^{\mp})$
  $q\bar{q} \ \to Z(\gamma^*)Z(\gamma^*) \to l^{\pm}(l^{\mp})l^{\pm}(l^{\mp})$
  - Z contributions $\sim$ 2 orders larger than $\sigma_{\mathrm{DS}}(W^{\pm}W^{\pm})$
  - γ^* even larger (asymmetric decay into 1 hard + 1 soft l's)
  - cuts : central OSSF lepton veto, max lepton p_T,
    isolated charged tracks Chanowitz,Kilgore 95

Single scattering bkgd (3)

- Heavy flavour production: $pp \to Q\bar{Q} + X$, $Q = t, b$
- $t\bar{t}$: e.g. $t \to W^+ b \to l^+ \nu b$
  $\bar{t} \to W^- \bar{b} \to q\bar{q}' l^+ \nu \bar{c}$
  - nominally final state is $l^\pm l^\pm + \not{E}_T + 4j$
  - cut: central jet veto, max lepton p_T, tight lepton isolation

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- $b\bar{b}$: $gg \to b\bar{b} \to B\bar{B} + ...$
  $B \to l^+ \nu X$
  $\bar{B}^0 \to B^0 \to l^+ \nu \tilde{X}$
  - huge cross section, b p_T falls steeply, ν soft
  - cut: tight lepton isolation, min lepton p_T & $\not{E}_T$

Simulation

- DS signal: MADGRAPH with GS09 and resummed $W\ p_T$ distribution.
- $b\bar{b}$: HERWIG6.510 with parton level cuts, forced semi-leptonic B decay and one B_d^0-$\bar{B}_d^0$ mixing. $\sigma_{b\bar{b}}(p_T^b > 20\mathrm{GeV}) \sim 5\,\mu\mathrm{b}$.
- Diboson: MADGRAPH + VEGAS at LO.
- $W^\pm W^\pm jj$ & $t\bar{t}$: neglected as discussed before.
- Other backgrounds: multi-particle interactions estimated. Found negligible.
- Detector effects: not simulated.

Cuts

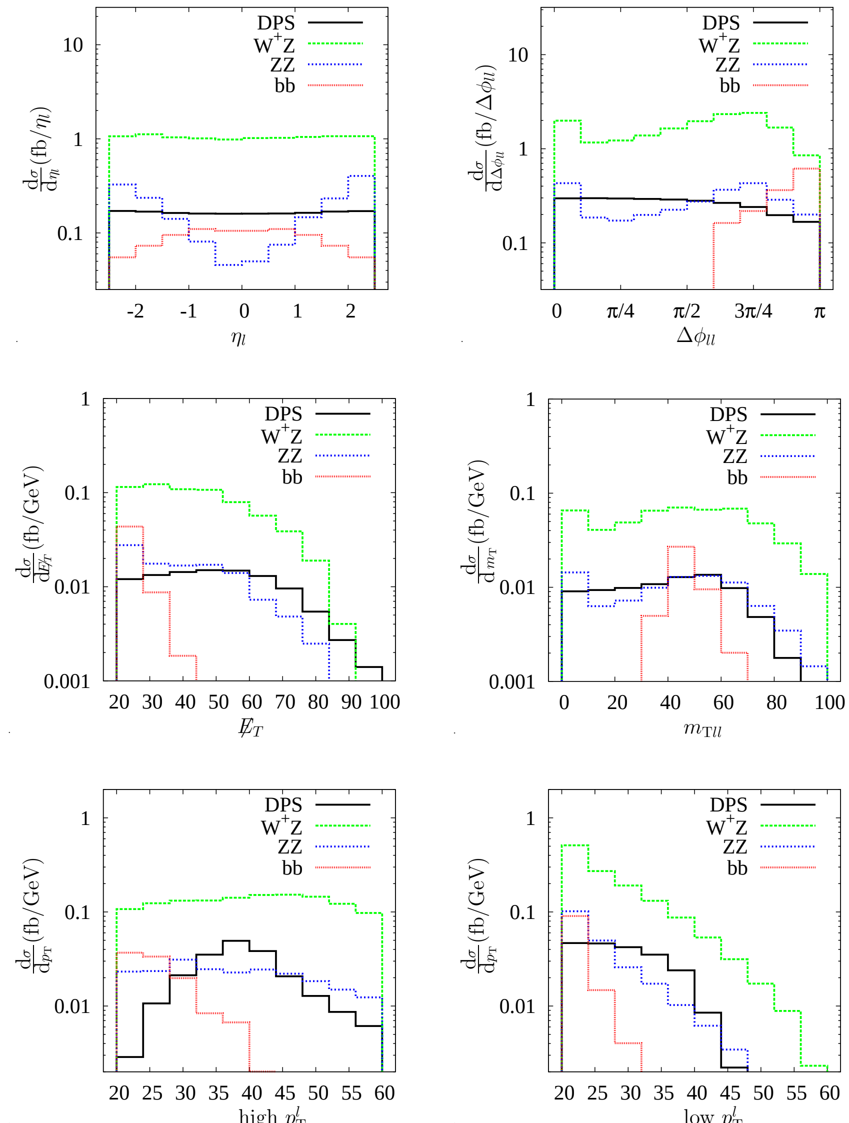
- Isolated SSL pair $|\eta| < 2.5$, $20 \leq p_T^l \leq 60$ GeV.
- OSSF lepton veto when a 3rd lepton is identified (100% eff. assumed when $p_T^l \geq 10$ GeV and $|\eta| < 2.5$.
- $\not{E}_T \geq 20$ GeV.
- Reject an event if a charged (lepton) track with $p_T^{\text{id}} \geq p_T \geq 1$ GeV forms an invariant mass < 1 GeV with one of the same-sign leptons.
- Jet veto to reject $W^\pm W^\pm jj$.

Results

$\sqrt{s} = 14\text{TeV}$

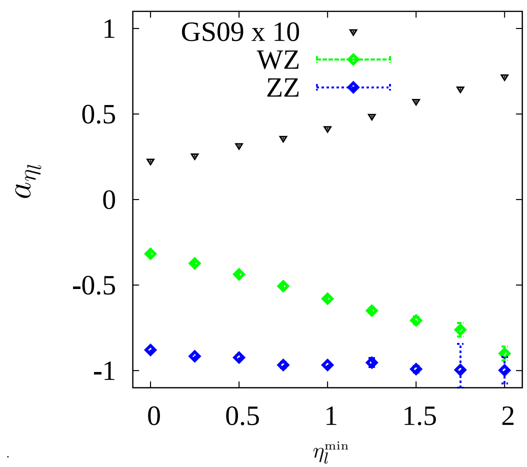
After cuts	$\sigma_{\mu^+\mu^+}$ (fb)	$\sigma_{\mu^-\mu^-}$ (fb)
$W^\pm W^\pm$(DPS)	0.82	0.46
$W^\pm Z(\gamma^*)$	5.1	3.6
$Z(\gamma^*)Z(\gamma^*)$	0.84	0.67
$b\bar{b}$ ($p_T^b \geq 20$ GeV)	0.43	0.43

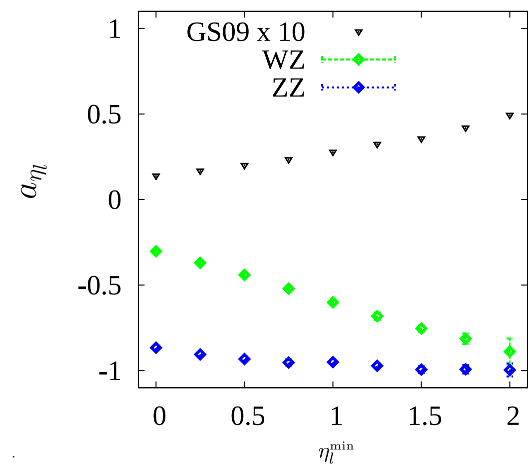
Bkgd dominated by $W^\pm Z(\gamma^*)$, basic kinematic distributions similar to DPS signal.



Further handles

η asymmetry: SPS final states prefer small $\Delta\eta$, less so for signal :





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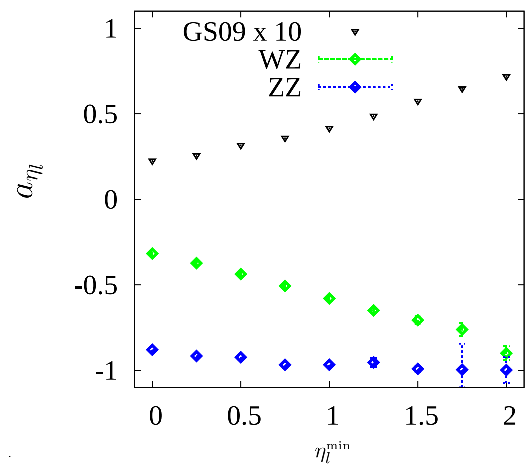

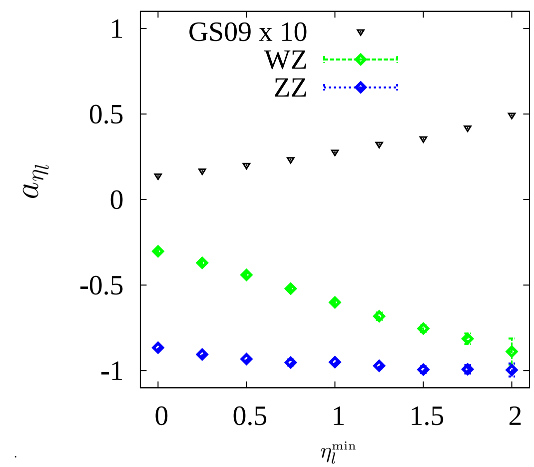

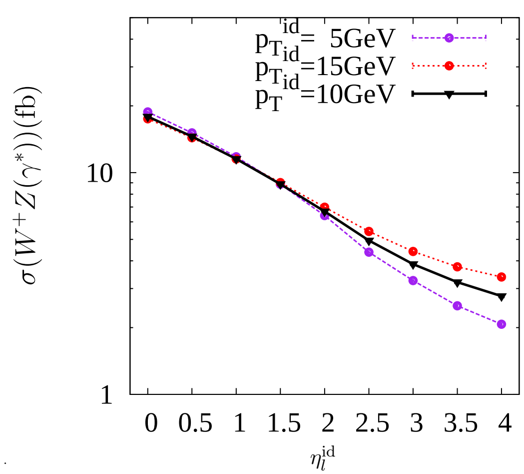

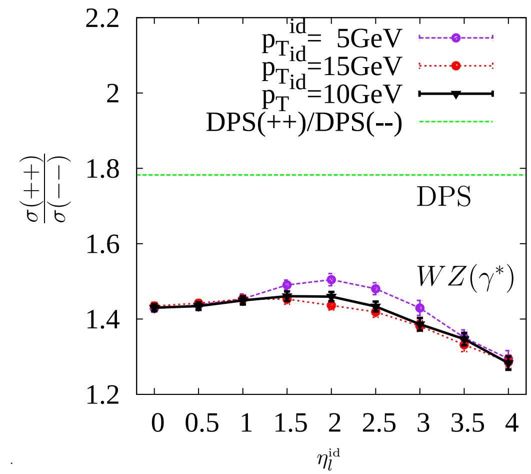

Charge asymmetry ratio $\frac{\sigma(++)}{\sigma(--)}$ also different

Next step and summary

- dPDFs including correlation effects (GS09) leads to qualitative changes in signal properties (rapidity asymmetry, cross section ratios).
- DPS $W^{\pm}W^{\pm}$ has many appealing properties, and SSDL+$\not{E}_T$ is a clean signature in principle.
- Background can be problematic, but strategies are available to help further suppress backgrounds beyond basic cuts.
- More detailed background study beneficial.
- Other EW DPS processes : double Drell Yan at LHCb ? Work in progress (Cambridge + Anna)

Backup slides

Multiple particle interactions

- Given luminosity ($L = 10^{34}$ cm$^{-2}s^{-1}$), single scattering cross section (σ), rate of bunch crossing ($B = 4 \cdot 10^7 s^{-1}$):
  Average number of events per bunch crossing, $\langle n \rangle = \frac{L\sigma}{B}$
- Multiple particle interaction cross section, σ_N:
  $$\sigma_N = e^{-\langle n \rangle} \frac{\langle n \rangle^N}{N!} \frac{B}{L} \simeq \frac{\sigma^N}{N!} \left(\frac{L}{B}\right)^{N-1}$$
  $$= \frac{\sigma^N}{N!(\sigma_{N,\text{eff}})^{N-1}}$$
  $$\sigma_{N,\text{eff}} \equiv \left(\frac{B}{L}\right) = 4\,\text{mb}$$
- RMS bunch length : 7.5 cm, z-resolution : 115 μm (Pixel), 580 μm (SCT) at ATLAS
  the probability that 2 independent scatterings overlap $\sim \mathcal{O}(0.1)$%.