Double electroweak scattering processes at the LHC

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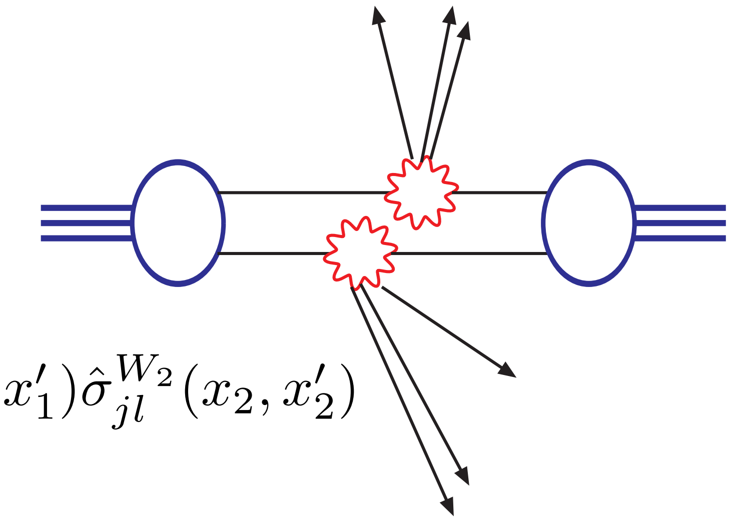
(arXiv:1003.3953 + work in progress)

Outline

- Quick recap of DPS basics
- Singal/background studies of
  - same sign W pairs
  - $Z(\gamma^*)$ pairs
- Summary

Double parton scattering (DPS)

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



$$\sigma_{\rm DS}{}^{(W_1,W_2)} = \frac{1}{2\sigma_{\rm eff}} \int dx_1 dx_2 dx'_1 dx'_2$$
$$D^{ij}(x_1,x_2,t_1,t_2) D^{kl}(x'_1,x'_2,t_1,t_2) \hat{\sigma}_{ik}^{W_1}(x_1,x'_1) \hat{\sigma}_{jl}^{W_2}(x_2,x'_2)$$

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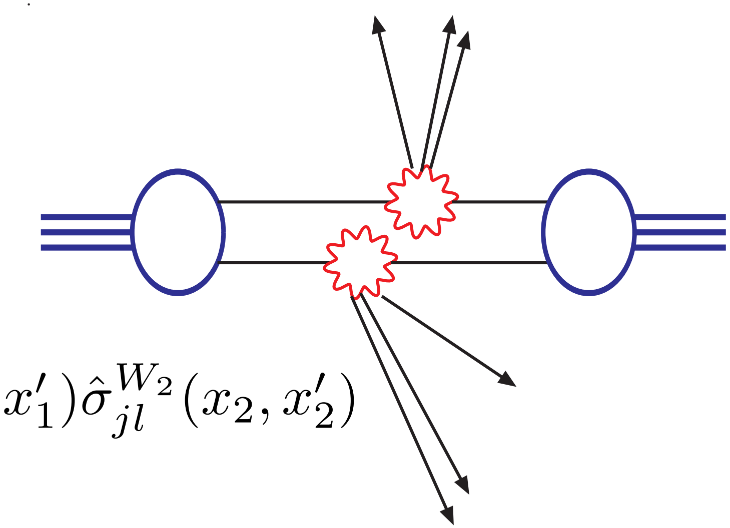

$$\sigma_{\rm DS}{}^{(W_1,W_2)} = \frac{1}{2\sigma_{\rm eff}}\int dx_1 dx_2 dx_1' dx_2' \; D^{ij}(x_1,x_2,t_1,t_2) D^{kl}(x_1',x_2',t_1,t_2) \hat\sigma_{ik}^{W_1}(x_1,x_1') \hat\sigma_{jl}^{W_2}(x_2,x_2')$$

Usual assumptions:

- Uncorrelated longitudinal and transverse distributions ($\sigma_{\rm eff}$)
- Same transverse distributions for different partons (universal $\sigma_{\rm eff}$)
- Factorised double distributions ($D^{ij}(x_1,x_2) = D^i(x_1) D^j(x_2)$)

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- momentum and number sum rule constraints ?

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- connections between sea and valence distributions ?

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Need experimental handles from processes sensitive to different **scales** and **initial state partons.**

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- LHC studies:
  $b\bar{b}b\bar{b}, b\bar{b}jj, jjjj$ Del Fabbro, Treleani 02, Cattaruzza et. al. 05, Berger et. al. 09, Blok et. al. 10
  W/Z + $4j$ Maina 09
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- Background:
  Associated W/Z+H production Del Fabbro, Treleani 00, Hussein 06

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$Z(\gamma^*)Z(\gamma^*) \to 4l$:

- characteristic DPS kinematics
- low scales compared to jet based observables possible

Double electroweak processes 2

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$W^{\pm}W^{\pm} \to l^{\pm}l^{\pm} + \not{E}_T$:

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Note:

The rate for these processes are low (signal $\sim$ bkgd $\mathcal{O}(1)$ fb after BRs at 14TeV).

We are talking about longer term LHC possibilities here.

$W^{\pm}W^{\pm}$: DPS correlations

- 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)	σ_{GS09}	σ_{MSTW_0}	σ_{MSTW_1}	σ_{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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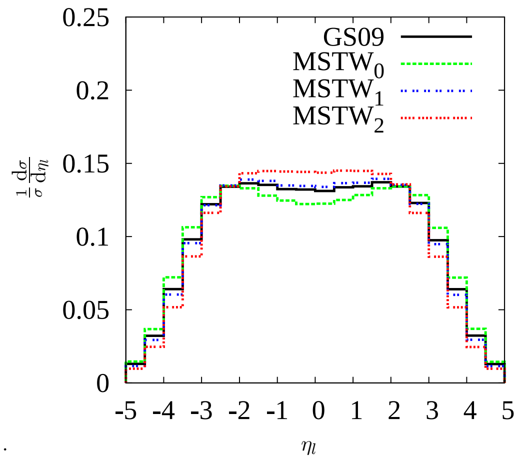
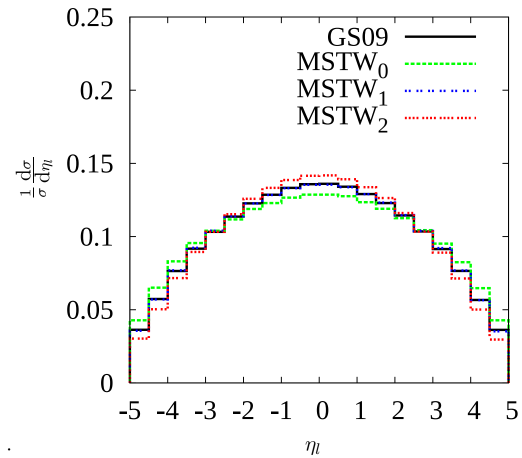
- Factorised approximation becomes better when $\sqrt{s}$ increases.

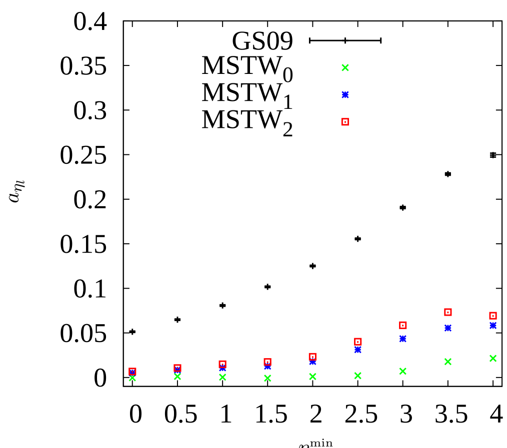
$W^{\pm}W^{\pm}$: DPS correlations (2)

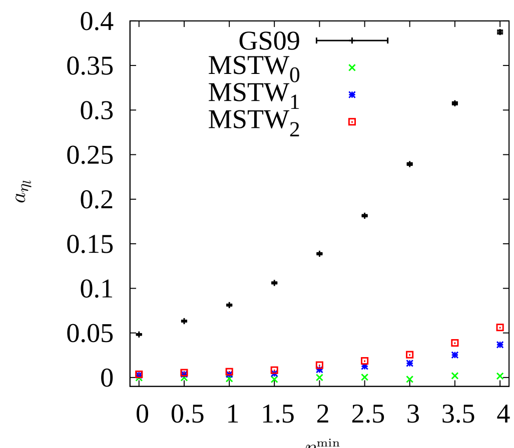




η_l well modelled by MSTW_1

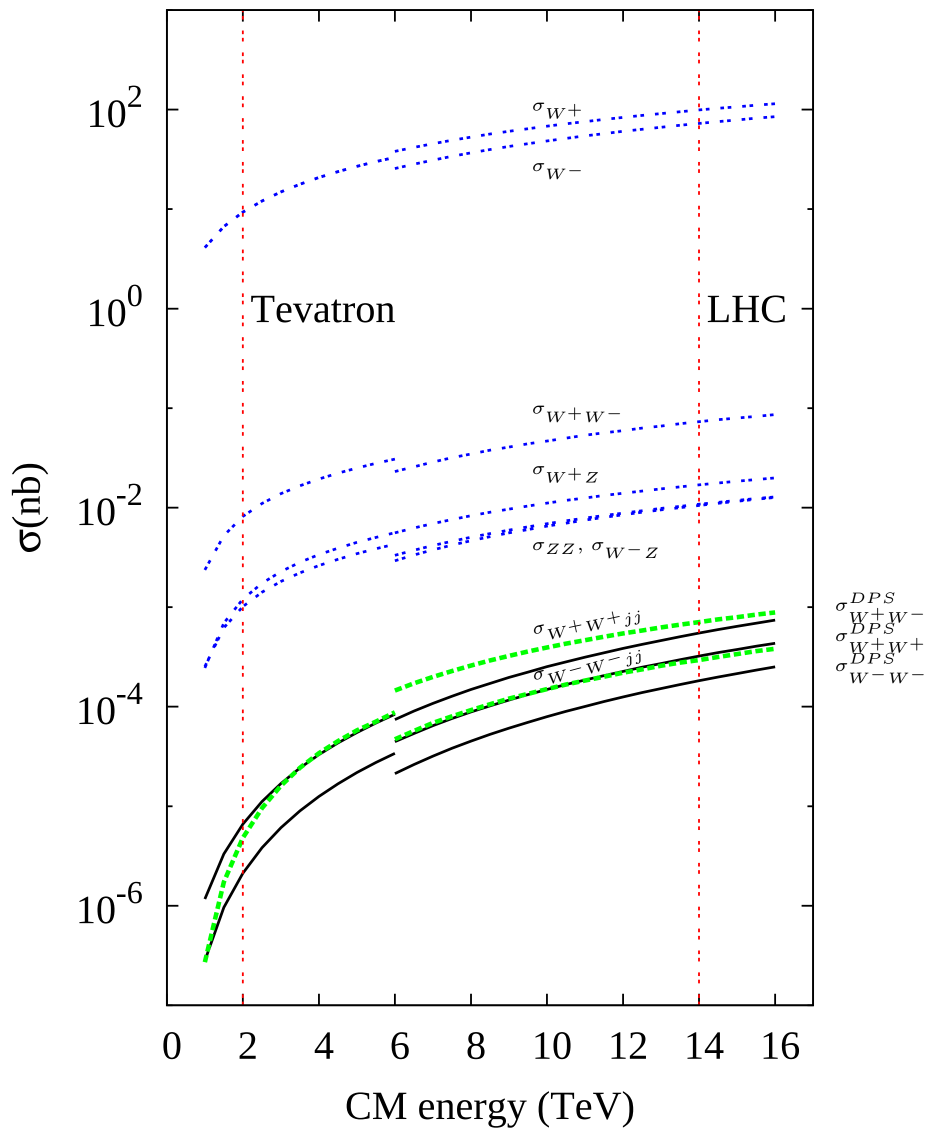
$$a_{\eta_l} = \frac{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) - \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) + \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}$$





Large η_l asymmetry

$W^{\pm}W^{\pm}$: signal vs (SPS) bkgd



Assume @ LHC

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

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

Bkgd considered:

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

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

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

$W^{\pm}W^{\pm}$: SPS bkgd

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

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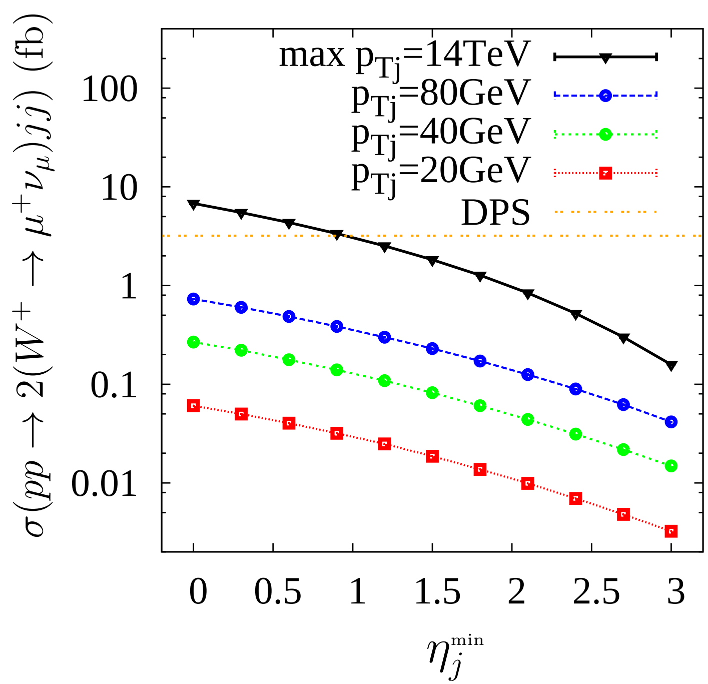
- $W^{\pm}W^{\pm}jj$: total cross section $\sim \sigma_{\rm DS}(W^{\pm}W^{\pm})$
- Central jet veto ($\eta_{\rm j}^{\rm min}$, $p_{\rm Tj}^{\rm max}$) effective:



$W^{\pm}W^{\pm}$: SPS 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 $\sigma_{\rm DS}(W^{\pm}W^{\pm})$
  - 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

$W^{\pm}W^{\pm}$: SPS 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

$W^\pm W^\pm$: SPS bkgd (3)

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  - cut: central jet veto, max lepton p_T, tight lepton isolation
- $b\bar{b}$: $gg \to b\bar{b} \to B\bar{B} + ...$

  $B \to l^+ \nu X$

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

$W^{\pm}W^{\pm}$: 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. $\sigma_{b\bar{b}}(p_T^b > 20\text{GeV}) \sim 5\,\mu\text{b}$.
- 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.

$W^{\pm}W^{\pm}$: cuts

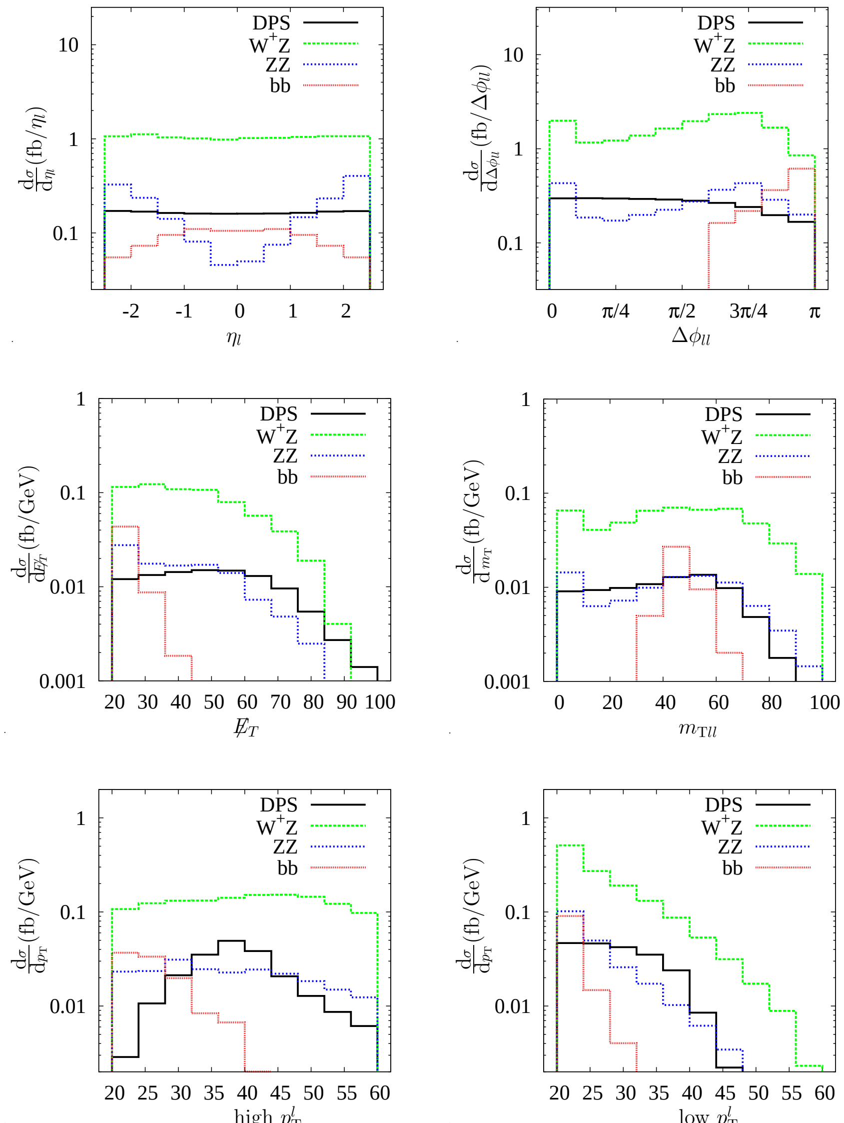
- Isolated SSL pair $|\eta| < 2.5$, $20 \leq p_T^l \leq 60$ GeV.
- OSSF lepton veto when a 3rd lepton is identified (100% eff. assumed when $p_T^l \geq 10$ GeV and $|\eta| < 2.5$.
- $\not{E}_T \geq 20$ GeV.
- Reject an event if a charged (lepton) track with $p_T^{\text{id}} \geq p_T \geq 1$ GeV forms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

$W^{\pm}W^{\pm}$: results

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

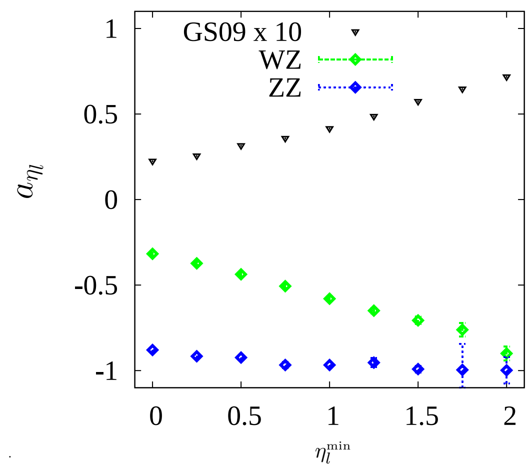
After cuts	$\sigma_{\mu^+\mu^+}$ (fb)	$\sigma_{\mu^-\mu^-}$ (fb)
$W^{\pm}W^{\pm}$(DPS)	0.82	0.46
$W^{\pm}Z(\gamma^*)$	5.1	3.6
$Z(\gamma^*)Z(\gamma^*)$	0.84	0.67
$b\bar{b}$ ($p_T^b \geq 20$ GeV)	0.43	0.43

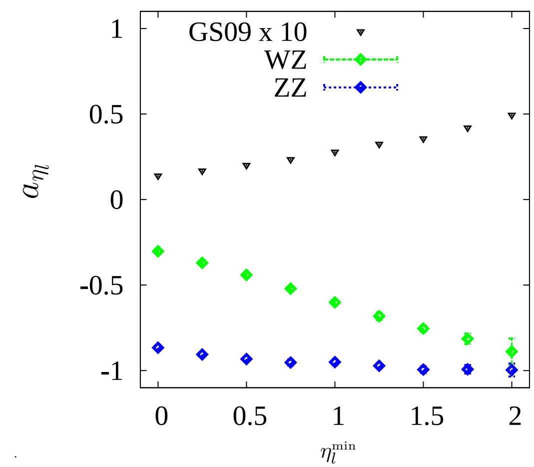
Bkgd dominated by $W^{\pm}Z(\gamma^*)$, basic kinematic distributions similar to DPS signal.



$W^{\pm}W^{\pm}$: further handles

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





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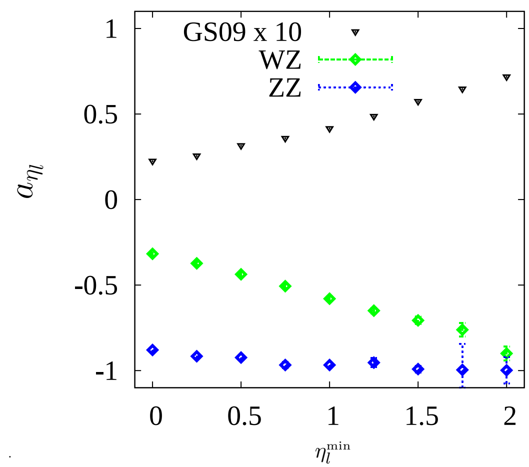
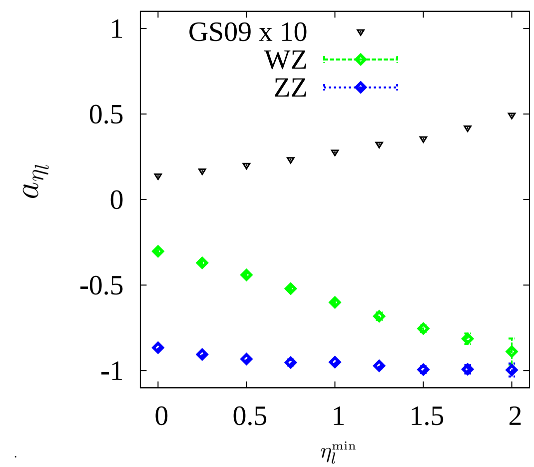
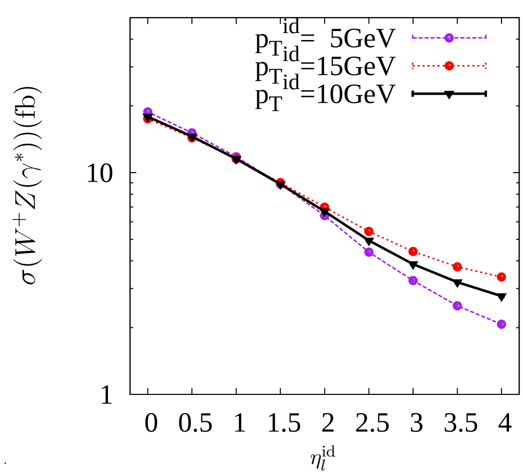
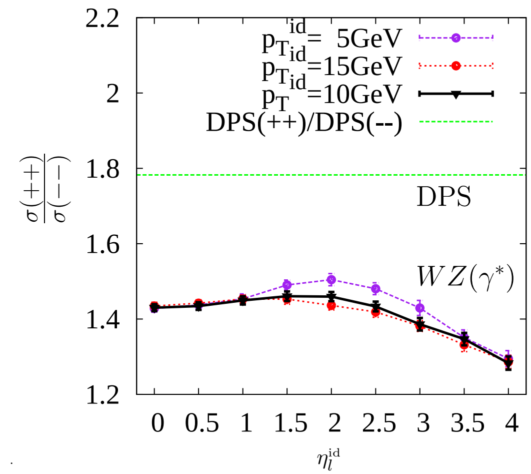








Charge asymmetry ratio $\frac{\sigma(++)}{\sigma(--)}$ also different

$Z(\gamma^*)Z(\gamma^*)$

Look for 4 muons, $2\mu^+2\mu^-$

- 4 isolated leptons: very clean signal
- double $Z \to l^+l^-$ rate low
- want to go to low scales, where DPS rate increases
- need to trigger on (low p_T) leptons

LHCb might find easier in studying this process

Signal: $(q\bar{q} \to Z(\gamma^*) \to \mu^+\mu^-)^2$

Bkgd: $q\bar{q} \to Z(\gamma^*) \to 4\mu$, $q\bar{q} \to 2(Z(\gamma^*) \to \mu^+\mu^-)$

Again consider only physics bkgd

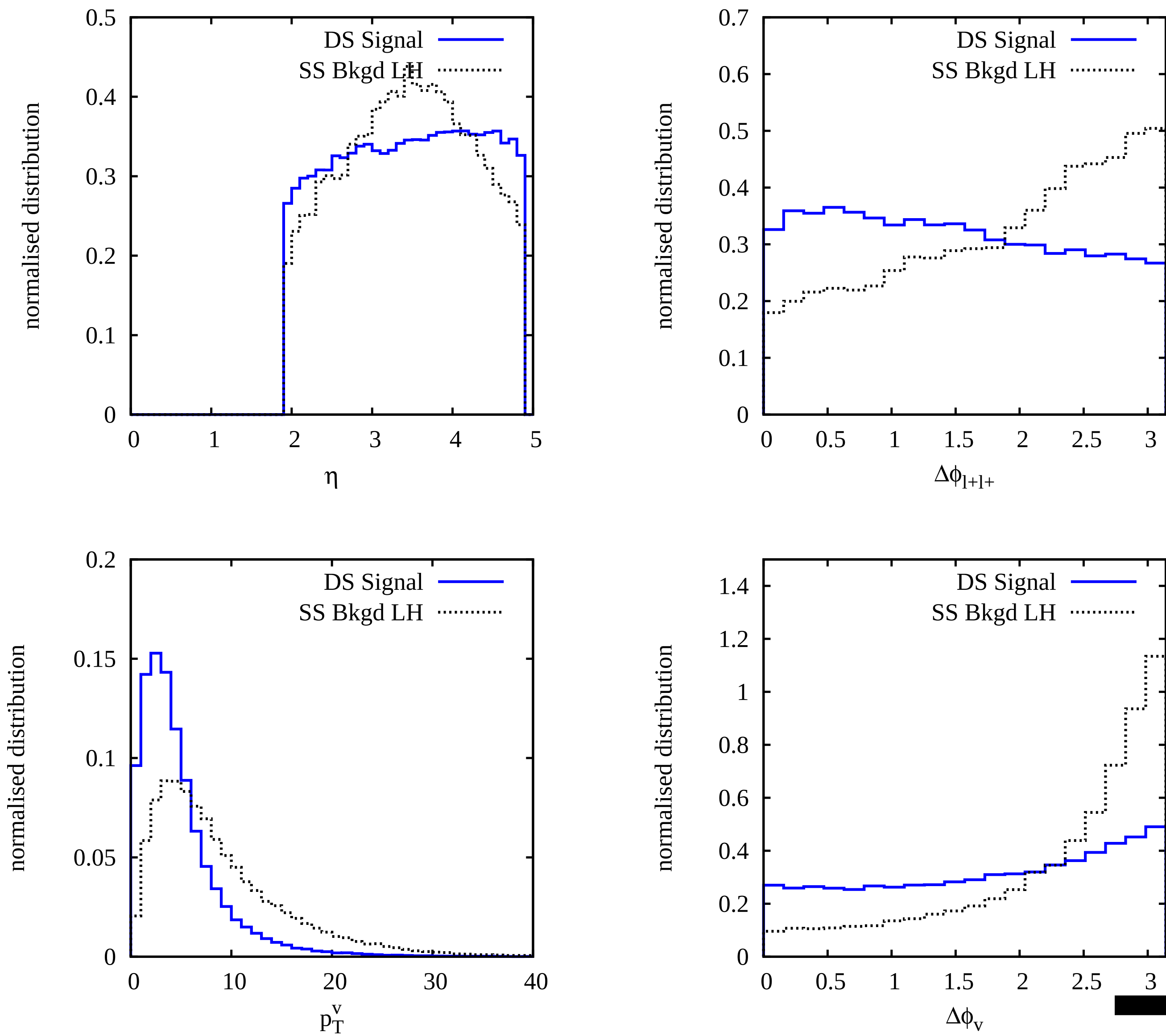
$Z(\gamma^*)Z(\gamma^*)$: simulation

- Signal: HERWIG++ , assuming simple factorised model
- Bkgd: MADEVENT + HERWIG++

Cuts:

- $1.9 < \eta_l < 4.9$
- $1 < p_T^l < 50$ GeV
- $\Delta R_{\mu\mu} > 0.2$ for all muon ($++$,$--$,$+-$) pairs
- $4 < m_{\mu^+\mu^-} < 50$ GeV for both $\mu^+\mu^-$ pairs
- $m_{4l} < 50$ GeV (to suppress the Z single resonance bkgd)

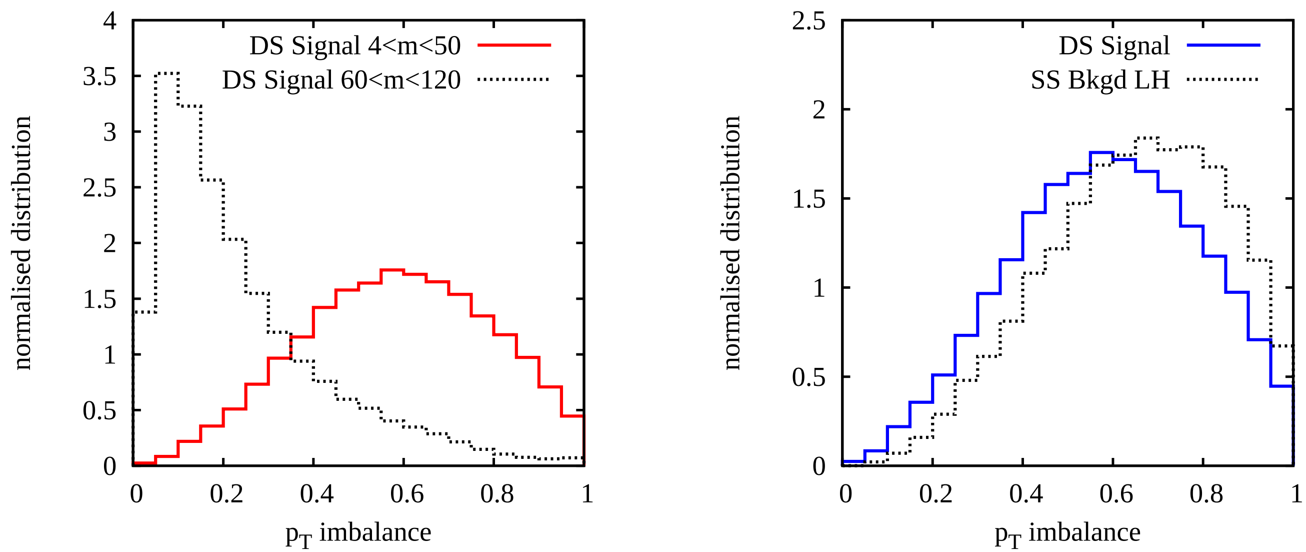
$Z(\gamma^*)Z(\gamma^*)$: preliminary results



$Z(\gamma^*)Z(\gamma^*)$: pair-wise balance

Define p_T imbalance S as

$$S = \frac{1}{2}\left(\frac{|\boldsymbol{p_T^{l_1}} + \boldsymbol{p_T^{l_2}}|}{p_T^{l_1} + p_T^{l_2}} + \frac{|\boldsymbol{p_T^{l_3}} + \boldsymbol{p_T^{l_4}}|}{p_T^{l_3} + p_T^{l_4}}\right)$$



- different from D0 variables. Comparisons needed.
- effectiveness depends on mass scales involved

Summary and next steps

- 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, but background can be problematic. However strategies are available to help suppress bkgd beyond basic cuts.
- DPS $Z(\gamma^*)Z(\gamma^*)$ very clean signal. Simple distributions different from bkgd, but can be hard to cut on.
- Looking at correlations between different dilepton/vector boson observables

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 $\sim \mathcal{O}(0.1)$%.