

Kinetic Discriminants of DPS in Vector Boson Final States

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Sept 4, 2025

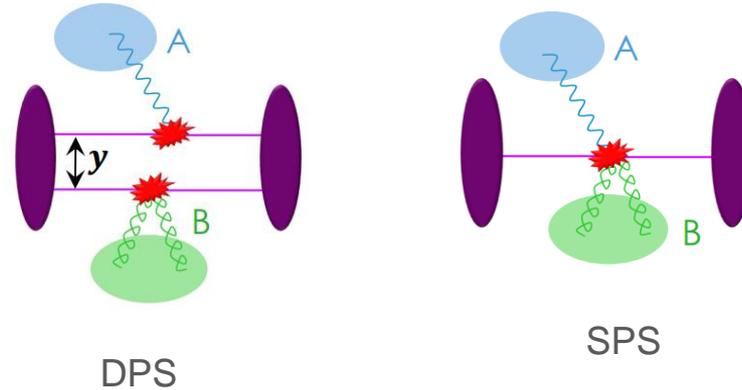
Hot QCD Matter 2025
(Series 3)



- Double Parton Scattering
- Why DPS
- Vector Bosonic Final States
- Results and Discussions
- Summary

Double Parton Scattering

- Two separate hard scattering from a single pp collision



- DPS Factorization Formula :

$$\sigma_{DPS}^{(A,B)} = \int F_{ik}(x_1, x_2, \mathbf{y}) \otimes \hat{\sigma}_{ij}^A \hat{\sigma}_{kl}^B \otimes F_{jl}(x'_1, x'_2, \mathbf{y}) d^2\mathbf{y}$$

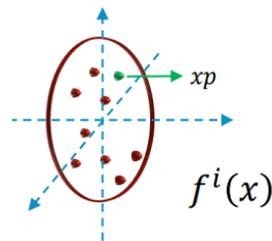
↑ Double parton density (DPD)

Phys. Rev. D32 (1985) 2371

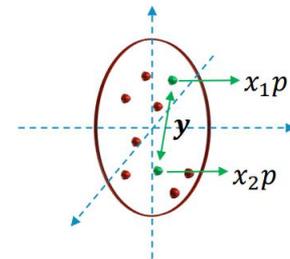
$$\sigma_D^{(A,B)} = \frac{\sigma_S^{(A)} \sigma_S^{(B)}}{\sigma_{\text{eff}}}$$

"DPS pocket formula"

- Unique window to probe correlation between partons
 - So far have lots of information on single parton distributions (PDFs, GPDs, TMDs,..) – only tells us about distribution of a single parton
- Clean experimental signature (WW, WZ, ZZ)
- Unique feature of MPI.



Parton densities (PDFs)

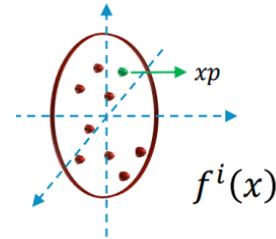


Double parton distributions (DPDs)

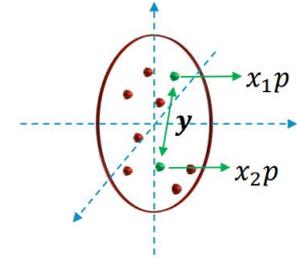
source: [Jonathan Gaunt - DPS WW](#) (LHC-EW Multiboson WG meeting, 30/06/25)

Why DPS ?

- DPS reveals new information about the structure of the proton – in particular, correlations between partons in the proton.
- DPS becomes more important relative to SPS as the collider energy grows, and we probe smaller x values where there is a larger density of partons.



Parton densities (PDFs)



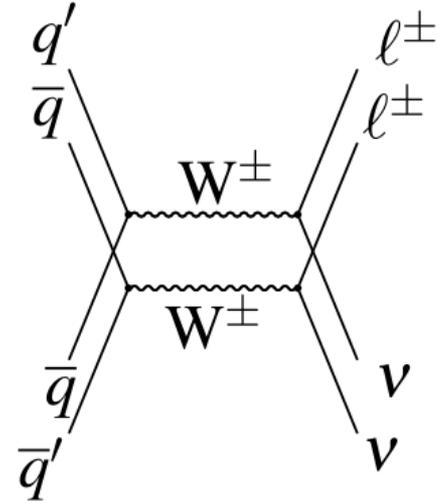
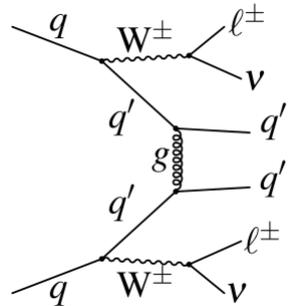
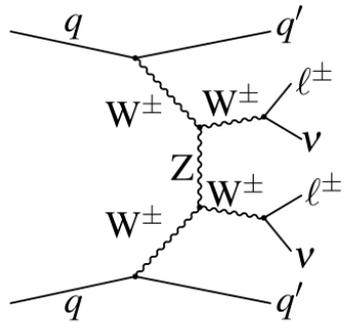
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Vector Bosonic Final States: WW

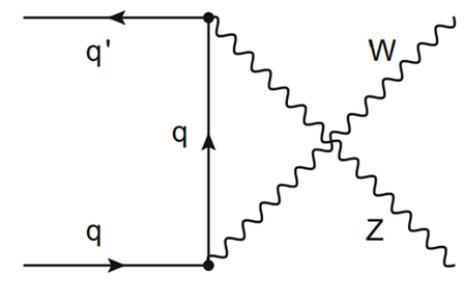
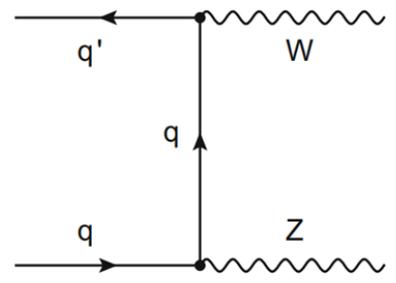
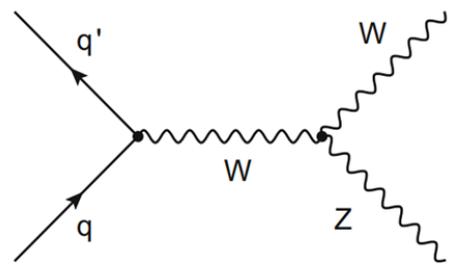


SPS

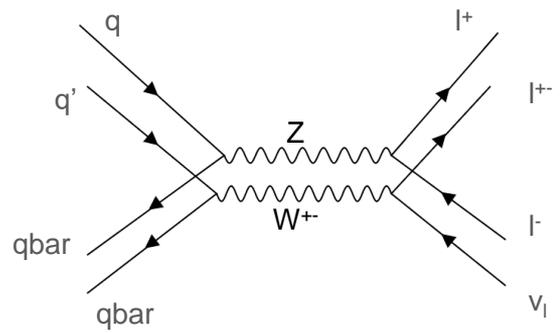


DPS

Vector Bosonic Final States: WZ

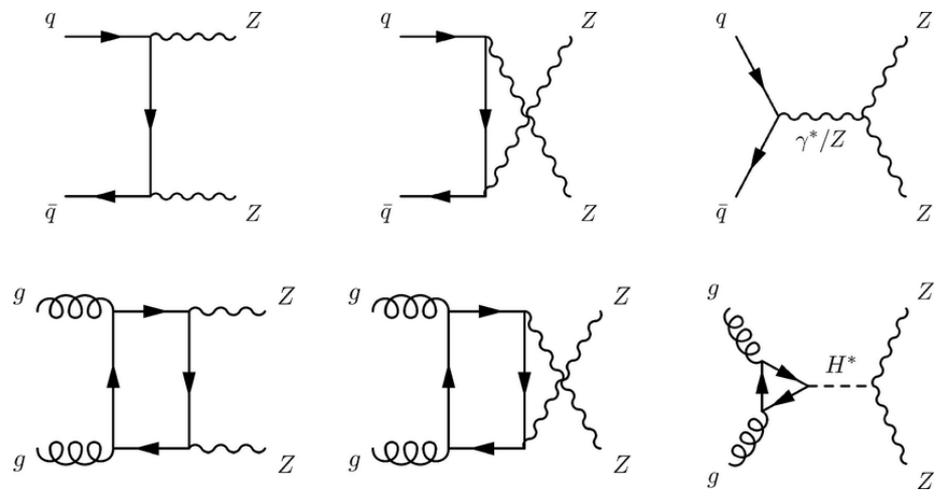


SPS

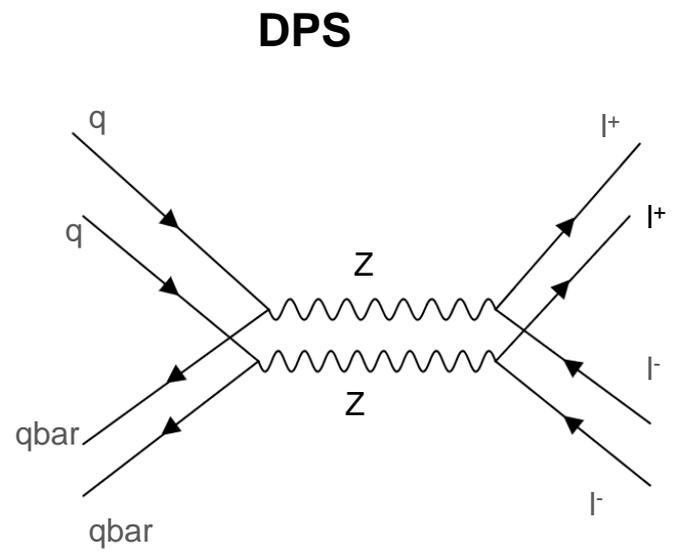


DPS

Vector Bosonic Final States: ZZ



SPS



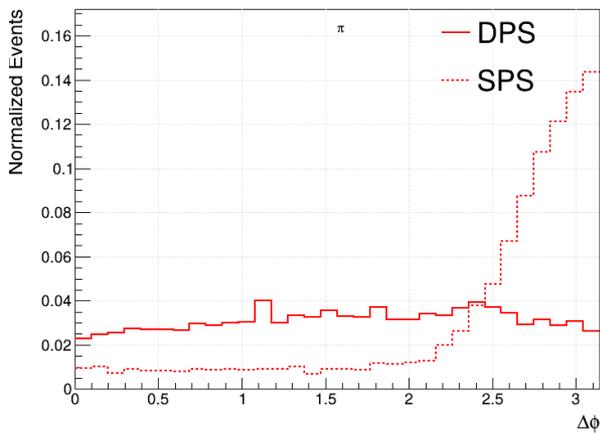
Results and Discussion

- PYTHIA8 MC generator has been used to simulate both processes SPS as well as DPS for dibosonic (WW, WZ, ZZ) final states at $\sqrt{s} = 13$ TeV.

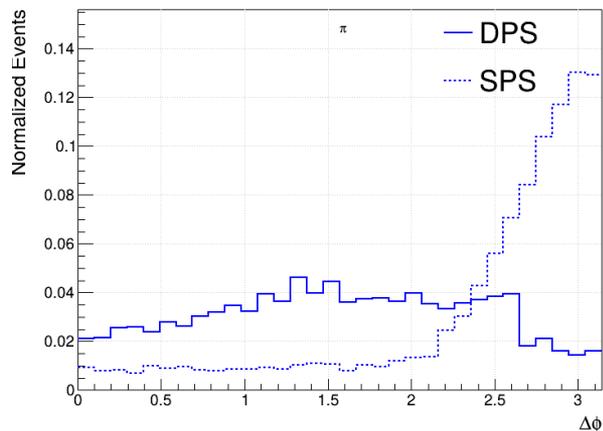
Azimuthal Separation $\Delta\phi(V_1, V_2)$

- Ideally as both the bosons come from different hard scattering, we expect $\Delta\phi$ to be flat for DPS.
- For sps as they are correlated so should peak at π , meaning back to back.

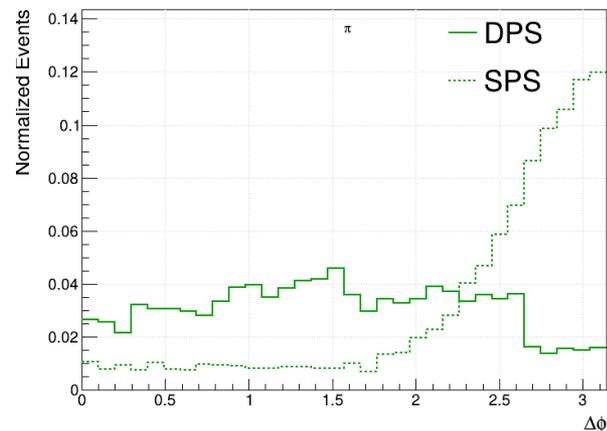
WW



WZ



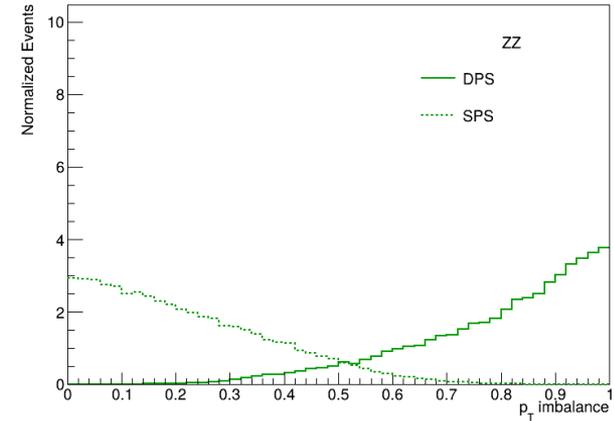
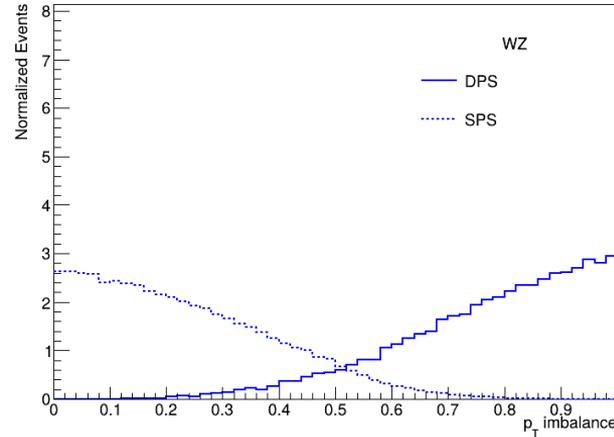
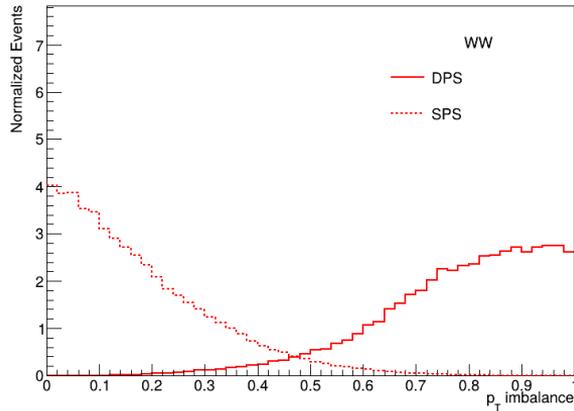
ZZ



Relative p_T imbalance

$$\Delta^{\text{rel}} p_T = (|p_T^{V1}| - |p_T^{V2}|) / (|p_T^{V1}| + |p_T^{V2}|)$$

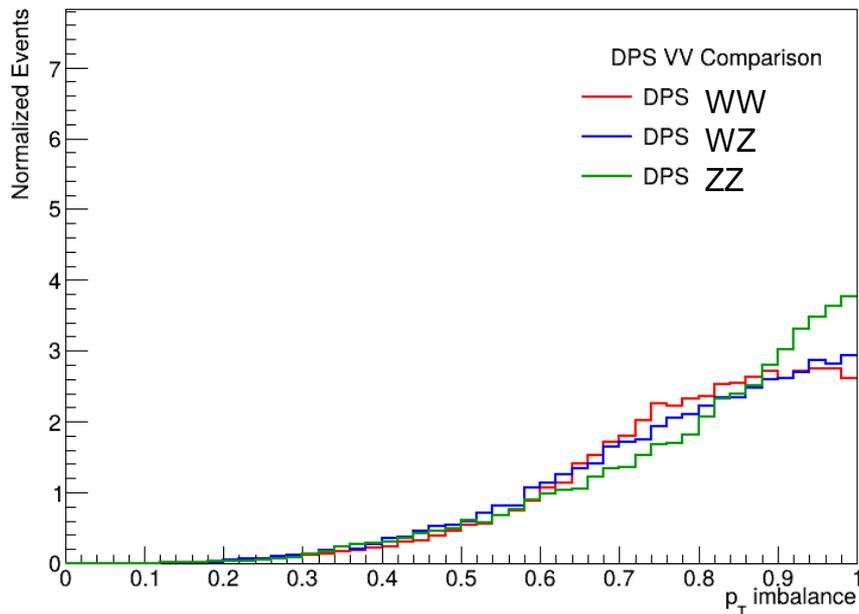
- If imbalance $\rightarrow 0$ maximally correlated (back to back)
- Else if imbalance $\rightarrow 1$ not correlated.



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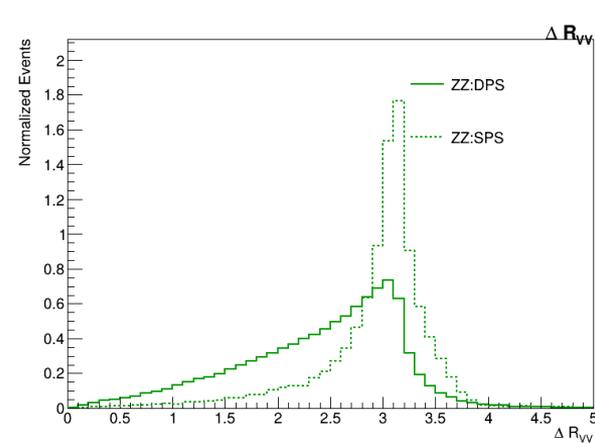
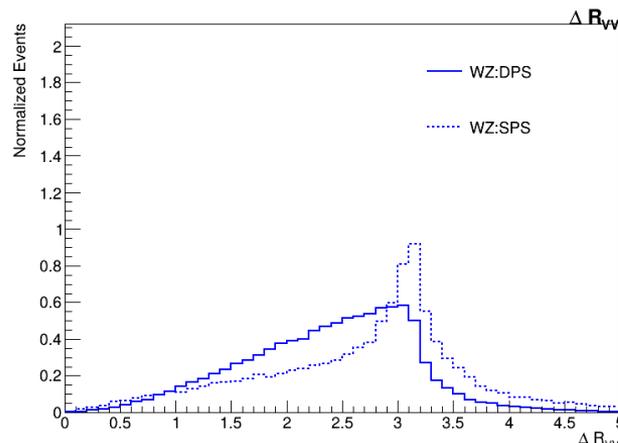
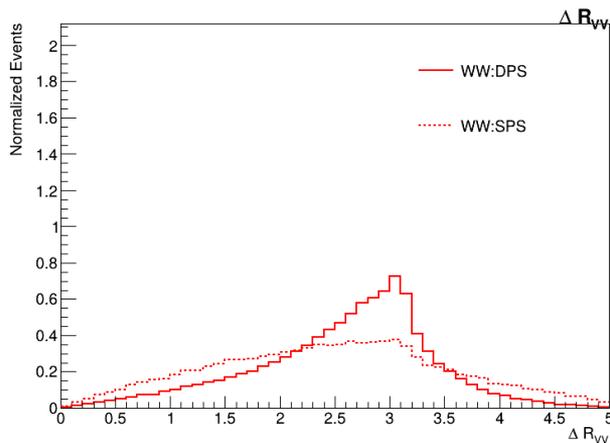
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Angular Separation $\Delta R(V_1, V_2)$

$$\Delta R_{VV} = \sqrt{(\Delta\eta_{VV})^2 + (\Delta\phi_{VV})^2}$$

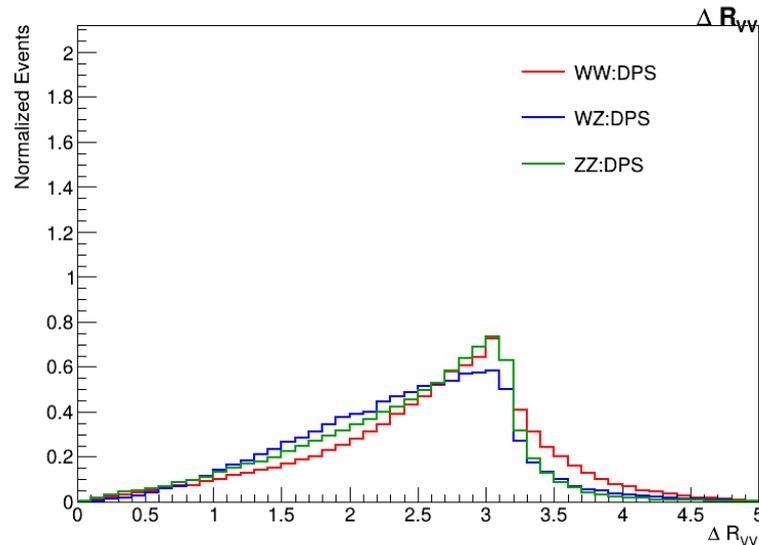
- Measures the **angular separation** of the two bosons in the detector.
- **Small ΔR** : bosons are produced close together (like in SPS).
- **Large ΔR** : bosons are widely separated, more likely in DPS where the scatterings are uncorrelated in direction.



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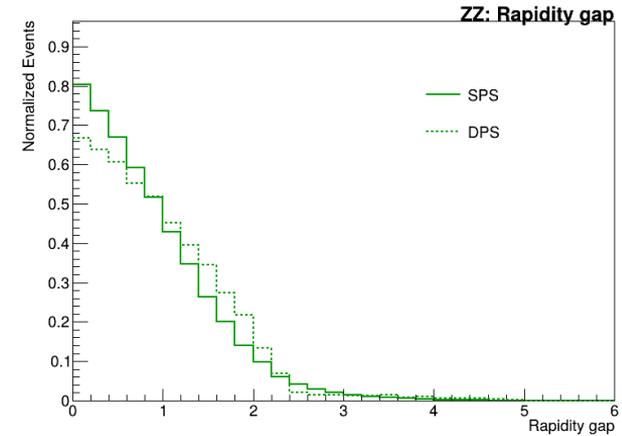
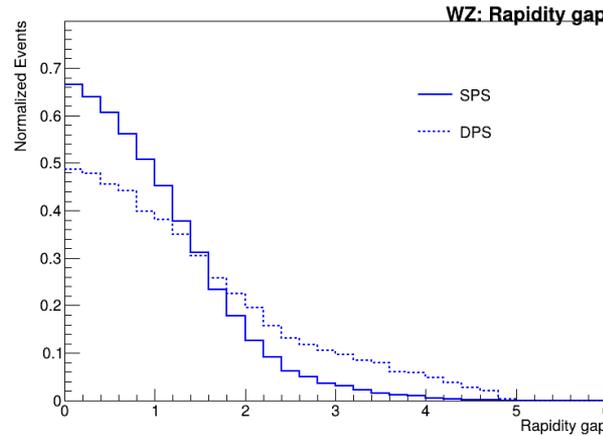
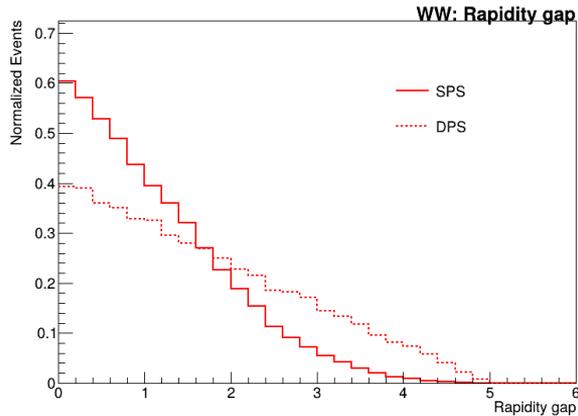
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Rapidity Gap

$$\Delta y_{VV} = |y_{V1} - y_{V2}|$$

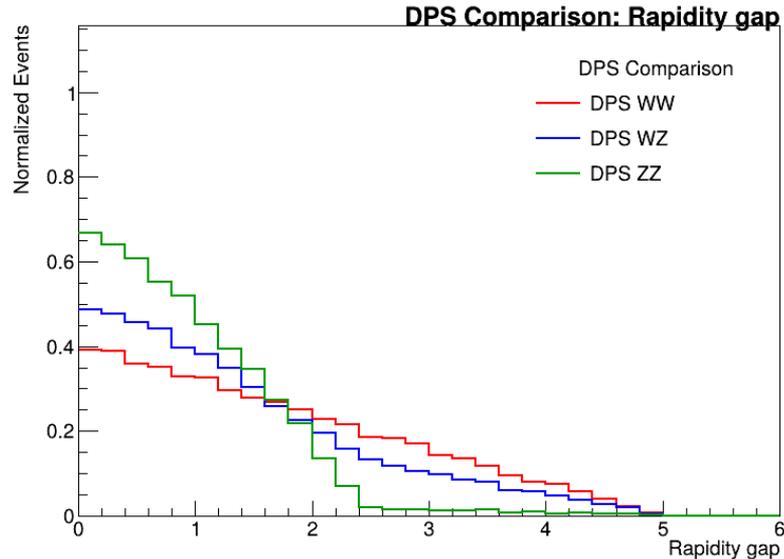
- Probes how far apart the two bosons are
- **Small Δy** : bosons produced centrally and close in rapidity, usually in SPS.
- **Large Δy** : bosons are widely separated in rapidity, a typical feature of DPS because each boson originates independently and can go in very different rapidity regions.



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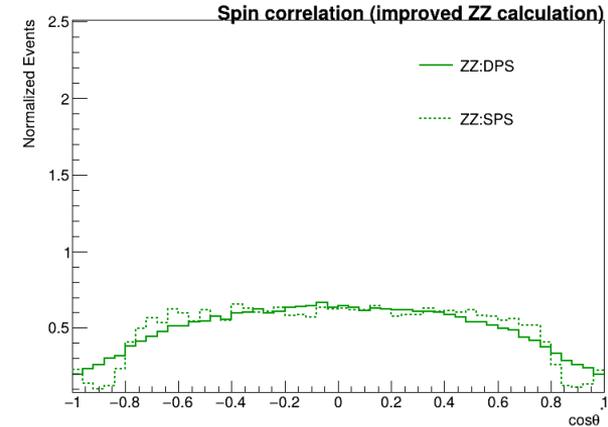
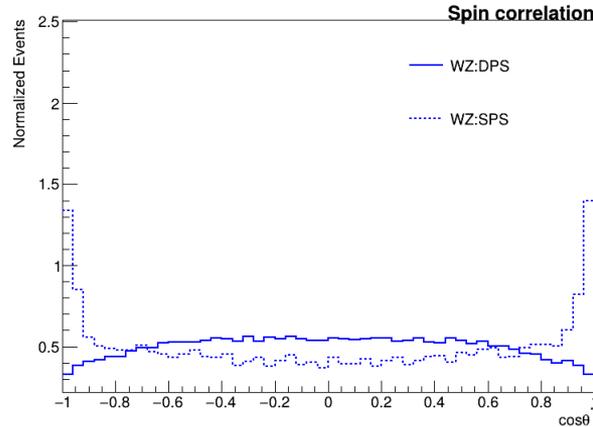
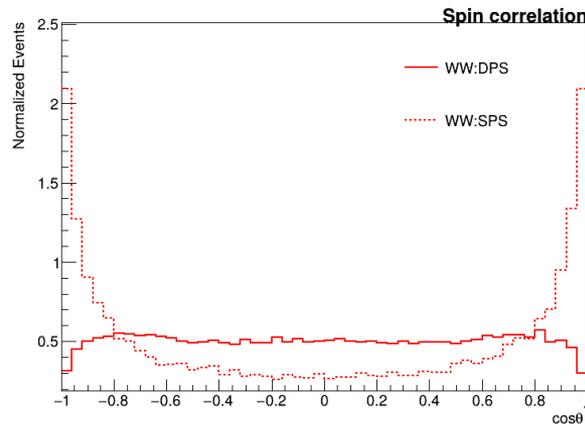
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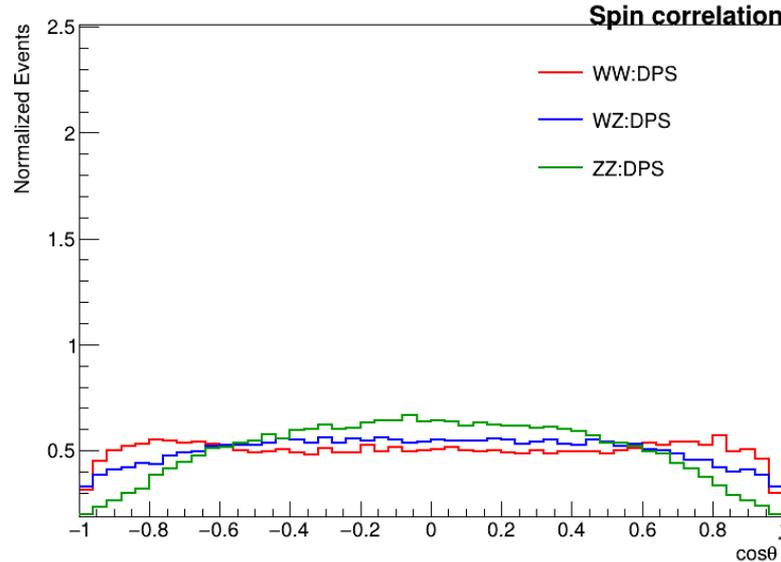
Spin correlation

- **DPS** Distributions are more **flat and smooth** this reflects that in double parton scattering, the bosons originate from the **separate hard scatter**, so correlation is **weaker** after averaging over all kinematics.
- **SPS**: **peaked at $\cos\theta^* \approx \pm 1$** indicates strong alignment or anti-alignment of the final-state particles.



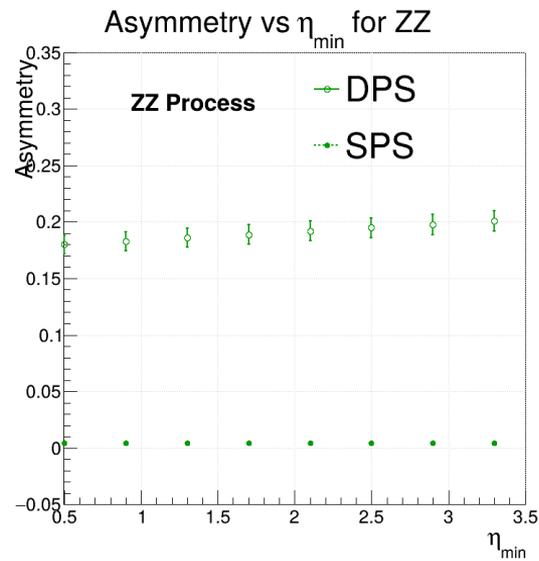
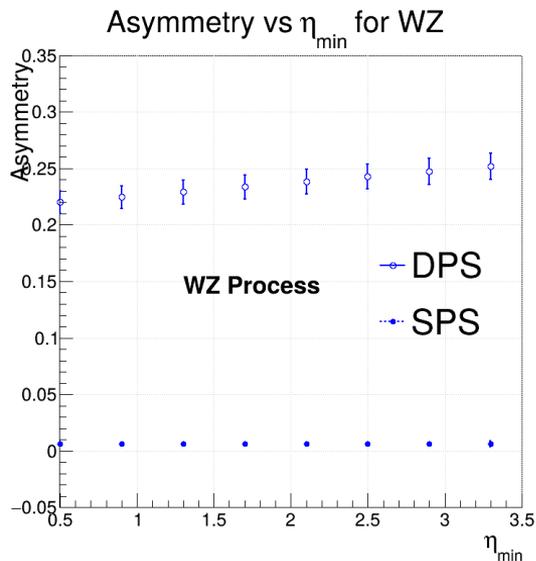
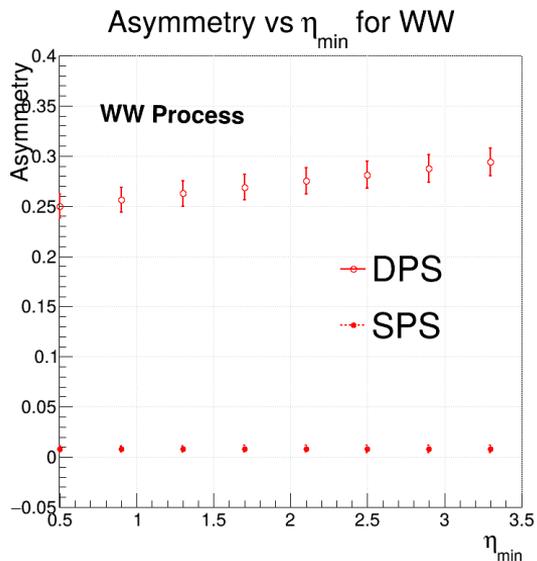
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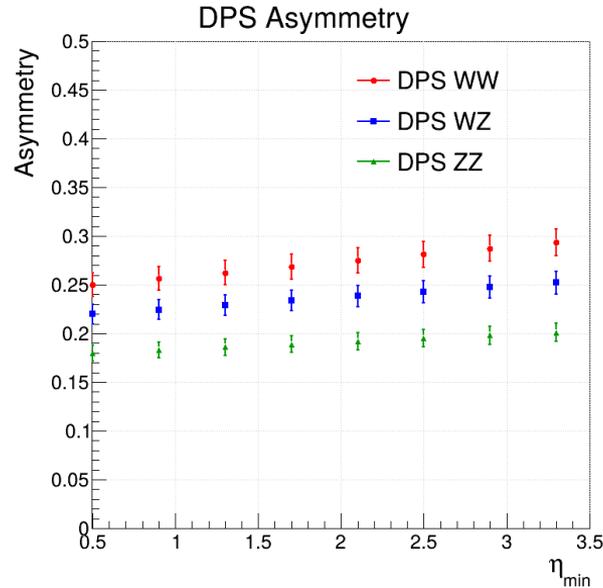
$$A(\eta) = (N^+(\eta) - N^-(\eta)) / (N^+(\eta) + N^-(\eta))$$

- SPS stays closer to zero, since a single hard scatter with balanced kinematics is more symmetric.
- DPS deviates more due to **independent scatterings**, bosons can emerge in more forward/backward regions, leading to asymmetry.



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Summary



- DPS provides **new insights into parton correlations** beyond PDFs.
- Vector boson final states (WW, WZ, ZZ) are **clean channels** for studying DPS.
- Angular and kinematic variables ($\Delta\phi$, ΔR , Δy , imbalance) show **clear separation** between SPS and DPS.
- Spin correlation is a particularly **powerful discriminator**: DPS shows stronger alignment.
- Combining multiple observables strengthens the case for identifying DPS in experiments.

Summary



- DPS provides **new insights into parton correlations** beyond PDFs.

Thankyou !!

- Combining multiple observables strengthens the case for identifying DPS in experiments.