Investigating jet superstructure in Higgs and vector boson production at the LHC

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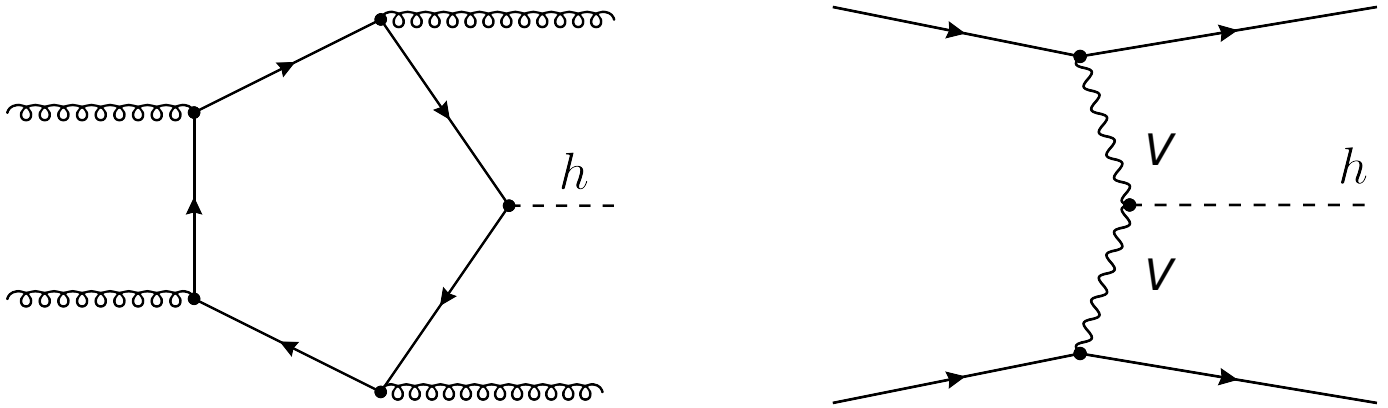


[in collaboration with Andreas Papaefstathiou (KSU) and Kostantinos Theofilatos (U. Athens)]

SESAPS @ KSU, November 12 – 14, 2026

Introduction

- W and Z bosons → properties known very precisely.
- Higgs boson → 2012 discovery @ LHC, properties relatively well known.
- **Two main production modes** of Higgs/W/Z bosons: **gluon fusion** and **vector boson fusion**.

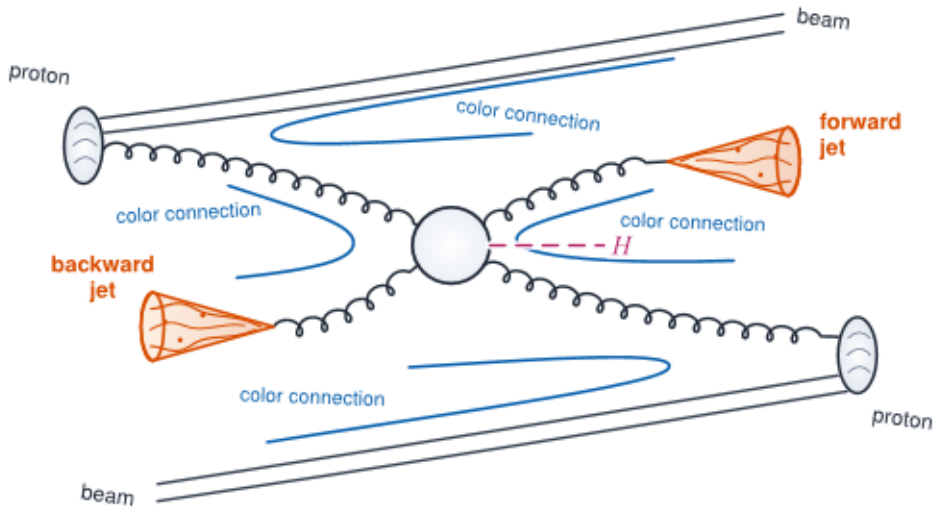


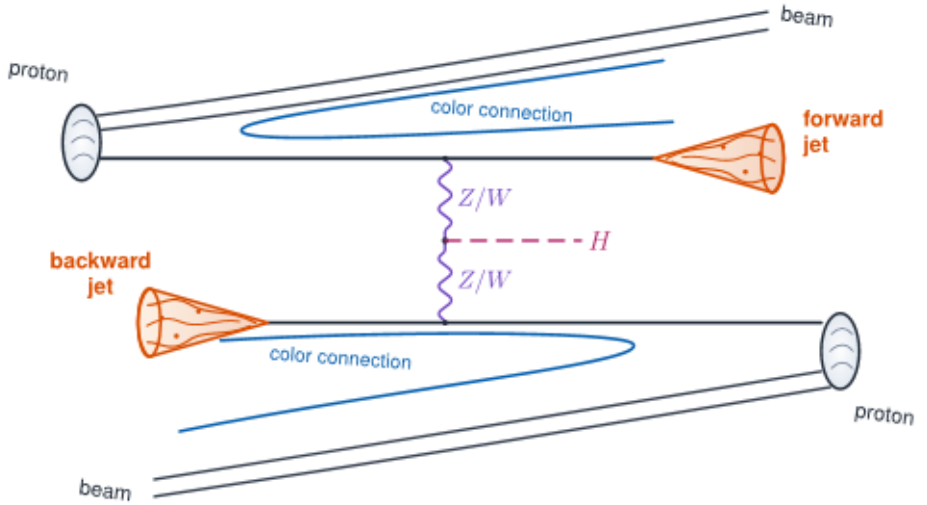
- **Goal**: distinguish between methods of production, using observables that exploit QCD color structure.

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Color flow differences

- Vector Boson Fusion (**VBF**): Color more connected to the beam
- Gluon-Gluon Fusion (**GGF**): Less connected to the beam





- Measuring color flow in events can lead to a new way for differentiation.

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Defining the jet pull

- How can we probe the color flow?
- **Jet pull**: an observable used to probe color flow of events. [Gallicchio, Schwartz, arXiv:1001.5027]
- Jet pull vector (modified):

$$\vec{s} = \sum_{i \in \text{jet}} \frac{p_{T,i}}{p_T^{\text{jet}}} \sqrt{(\Delta y_i)^2 + (\Delta \phi_i)^2} \begin{pmatrix} \text{sgn}\left(y_{\text{jet}}\right) \cdot \Delta y_i \\ \Delta \phi_i \end{pmatrix}$$

- Jet pull angle:

$$\vec{s} = \left(\left|\vec{s}\right| \cos\theta_s, \left|\vec{s}\right| \sin\theta_s \right)$$

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Analysis of H, Z, and W boson production

- **Herwig and Pythia** Monte Carlos for Higgs, Z, and W boson production.
- **FastJet** framework for jets, R=0.4, anti-kT algorithm, E-Scheme recombination
- Applied reasonable cuts to enhance VBF events:

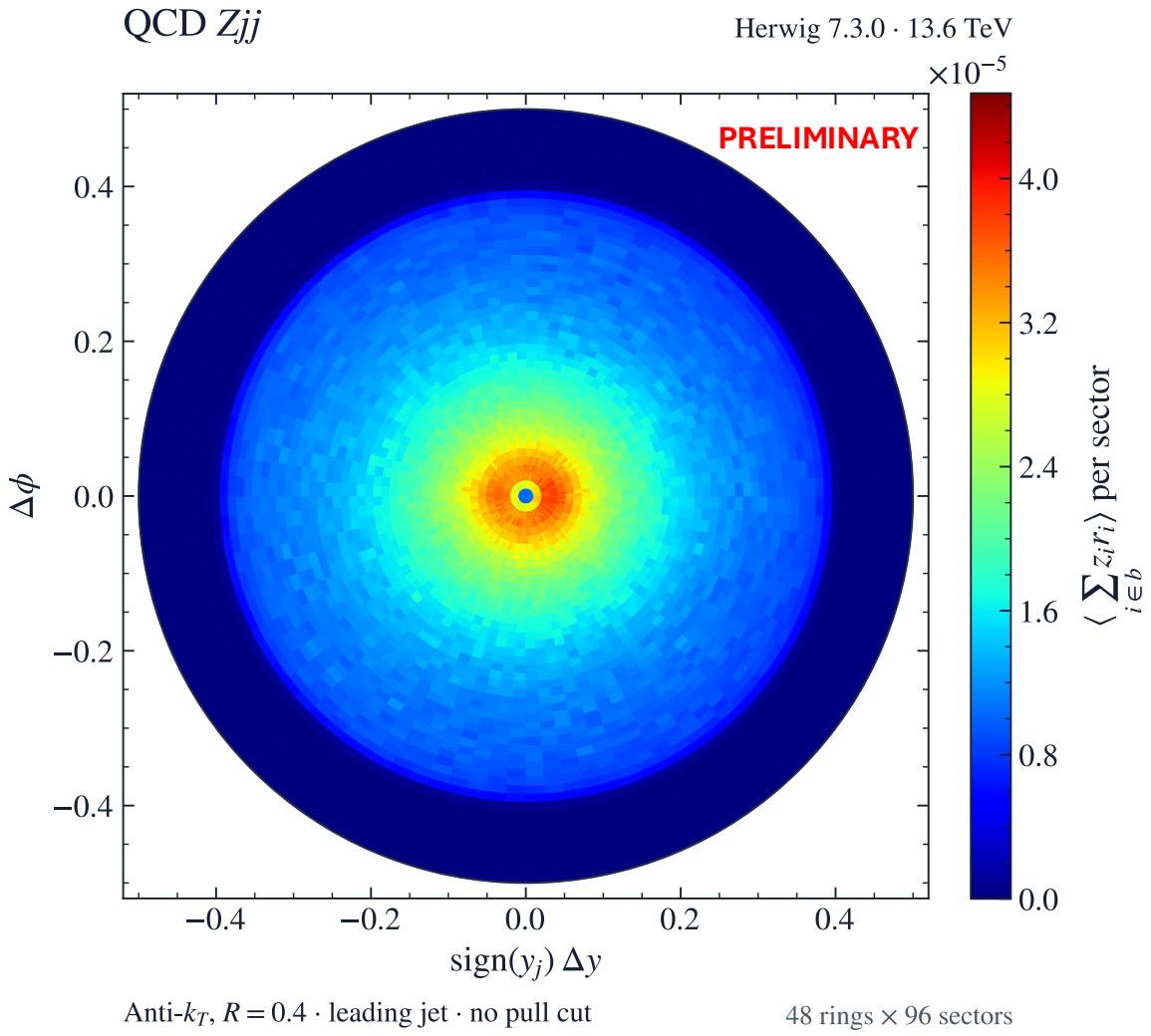
$$m_{JJ} > 400\ \mathrm{GeV}$$

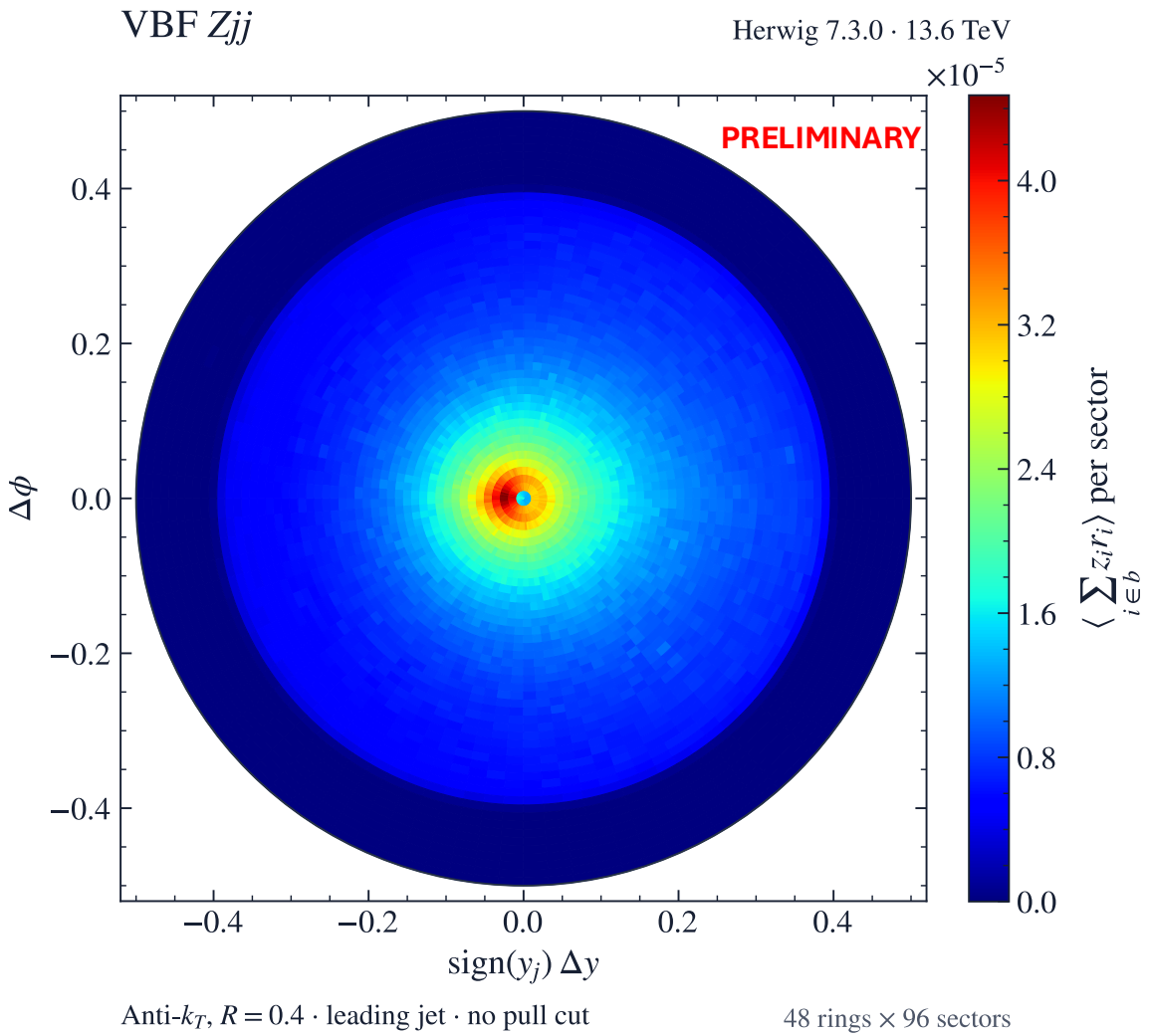
$$|y_J| < 3$$

$$p_{T_J} > 30\ \mathrm{GeV}$$

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Constructing jet pull

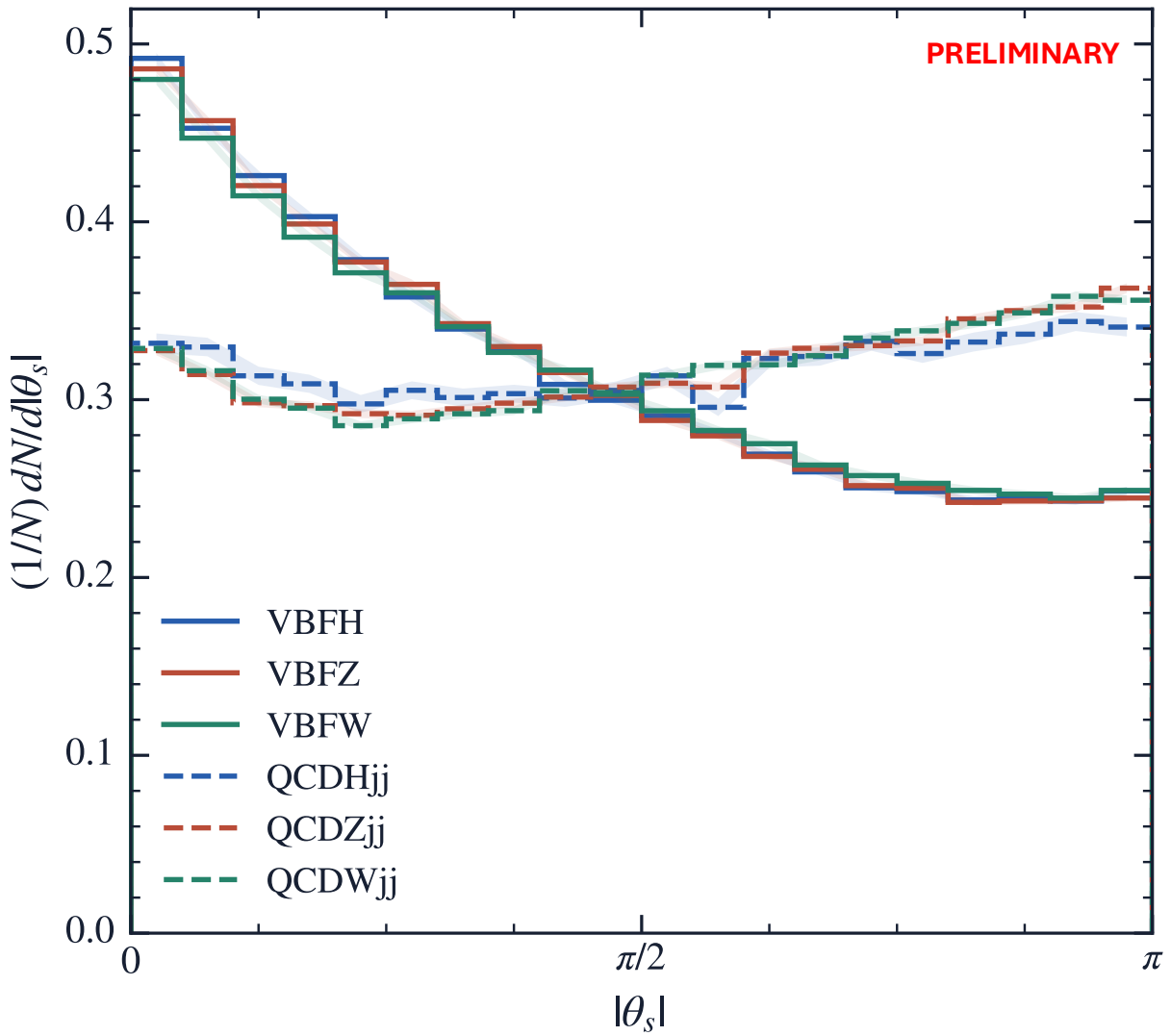




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Jet pull: Process independence

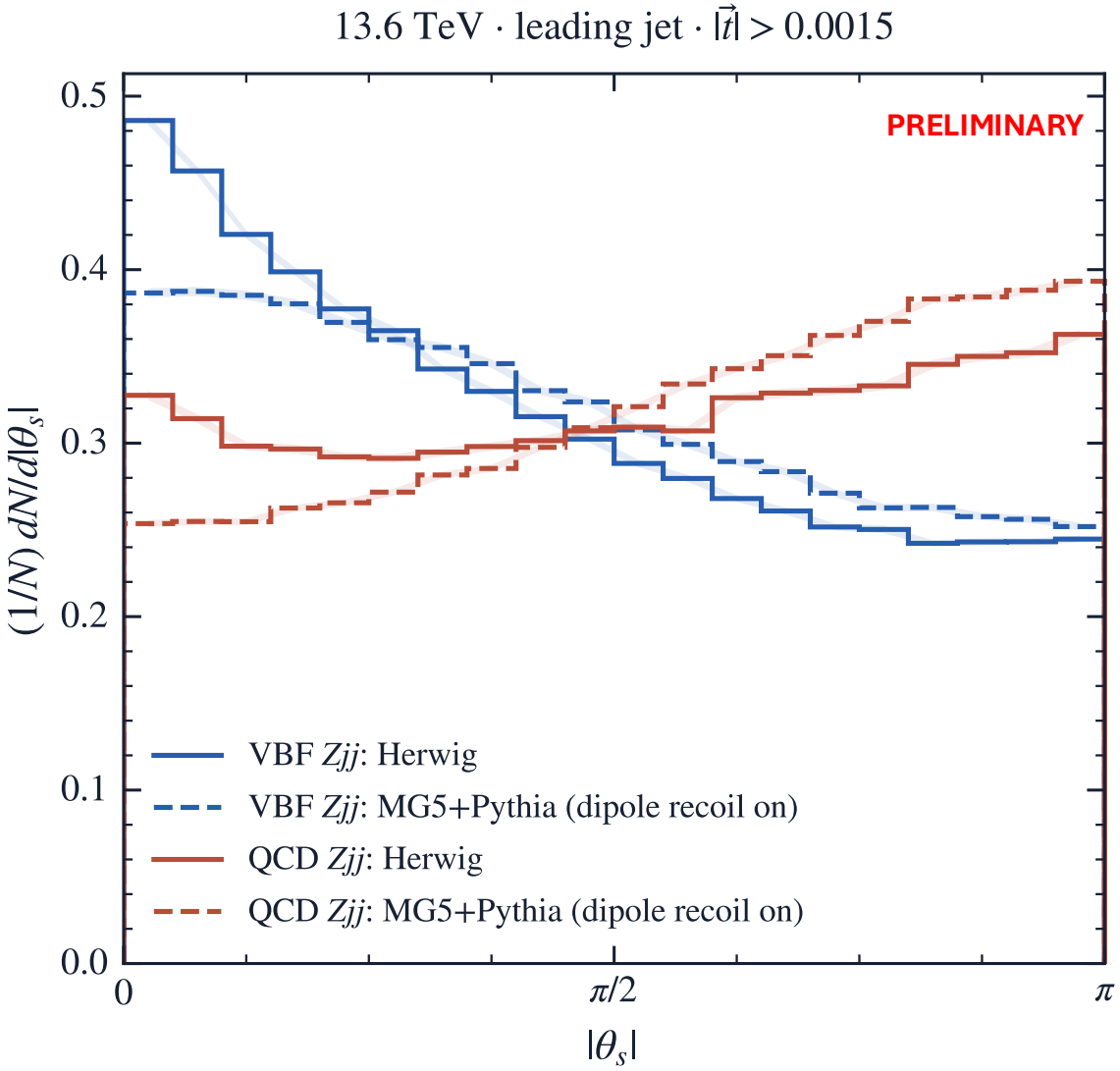
- Jet pull angle distribution results for Z and W and Higgs boson samples in **Herwig**
- VBF points towards $|\theta_s| \sim 0 \rightarrow$ jets are connected to the beam, more flat for QCD



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Jet pull: Monte Carlo dependence

- Jet pull distribution results for Z boson samples. (Herwig: solid, Pythia: dashed)
- VBF points towards $|\theta_s| \sim 0 \rightarrow$ jets are connected to the beam.
- There exists *significant* Monte Carlo event generator variation!



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Color reconnection

- Color flow can be distorted by **non-perturbative** effects, e.g.:
  - Multiple parton interactions & soft radiation
  - **color reconnection**

  → pull distributions can change.
- Example in a semi-realistic Z boson analysis at LHC using **Herwig**:

	CR		MPI		Soft
ID	p_{Reco}	p_{RecoB}	$p_{\perp,0}^{\text{min}}$ [GeV]	μ^2 [GeV^2]	`ladderMult`
B0	0.95	0.70	2.8700	1.1000	0.6000
B1	0.70	0.70	2.9417	1.0087	0.5844
B2	0.60	0.70	3.1035	0.9969	0.6261
B3	0.70	0.50	2.9365	1.0105	0.5839
B4	0.95	0.70	2.8700	1.1000	0.5000

Variations of **Herwig parameters for** color reconnection (**CR**), multiparton interactions (**MPI**) and **soft** physics.

These are compatible with other data!

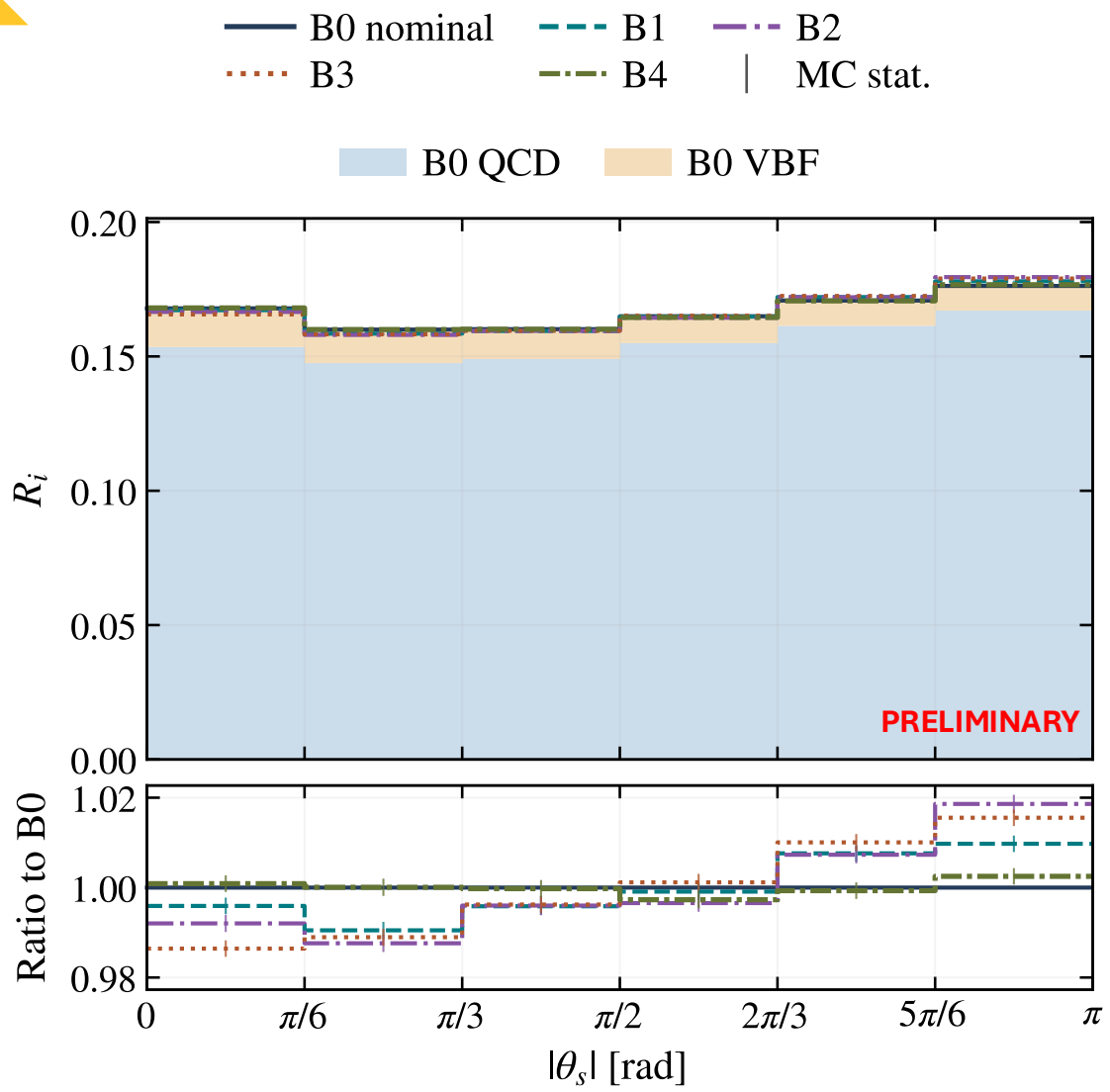
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Color reconnection

Using **Herwig**:

In a **semi-realistic** Z boson analysis at the LHC: *clear* variation between B0-B1-B2-B3 models.

[B4 not so different, soft physics doesn't to seem to matter.]



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Conclusions

- **Jet pull** probes color flow in Higgs and W/Z production.
- Can be used to **distinguish production modes**.
- There exists modeling/event generator dependence,
  - **Jet pull distributions may contain independent information versus other experimental data!**
- We can exploit this at the LHC to constrain models of multiparton interactions and color reconnection, e.g. through a Z+jets analysis.
- Future work will include using **jet pull asymmetries** to make it more theoretically sound .[Larkoski, Marzani, Wu, arXiv:1911.05090v2]

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THANK YOU! QUESTIONS?

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