CP Properties of Higgs-Boson Couplings from Hjj through Gluon Fusion

Stabilising the Extraction against Higher Order Corrections

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in collaboration with
K. Arnold and D. Zeppenfeld
arXiv:1001.3822

Moriond
March 17, 2010

Why Hjj, The Problem, The Solution

Why study Higgs Boson production in Association with Dijets?

The distribution in the **azimuthal angle** between the **two** jets in *Hjj* allows for a **clean extraction** of CP properties

The Problem

. . . in a region of phase space where the **perturbative corrections are large**.
How do we deal with events with **three or more** jets?

The Solution

By constructing an azimuthal observable, which takes into account the **information from all the jets** of the event!

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Which Scalar?

Once/if a scalar is discovered, it is important to determine whether this is the **Higgs Boson** of the **Standard Model** (or something else).

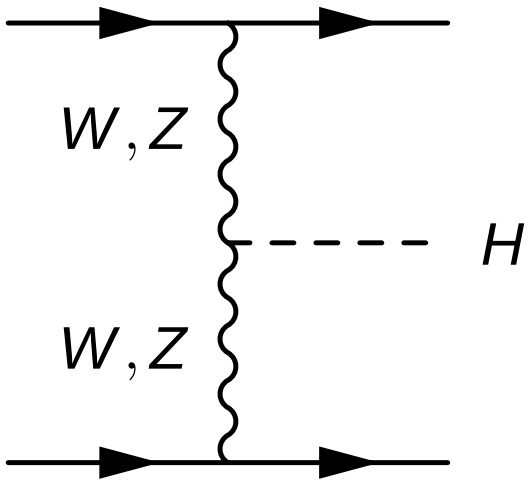
Measure the **strength** and **Lorentz structure** of the Higgs boson couplings:

1. **production mechanism** (independent of the Higgs decay channel)

or

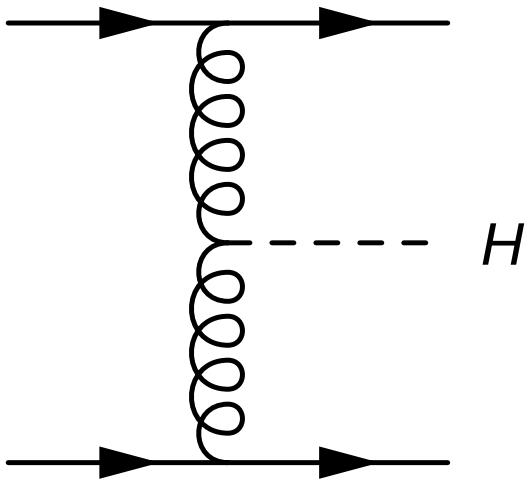
2. detailed study of the Higgs boson **decay products** (independent on the production mechanism)

Higgs Couplings through Azimuthal Correllations



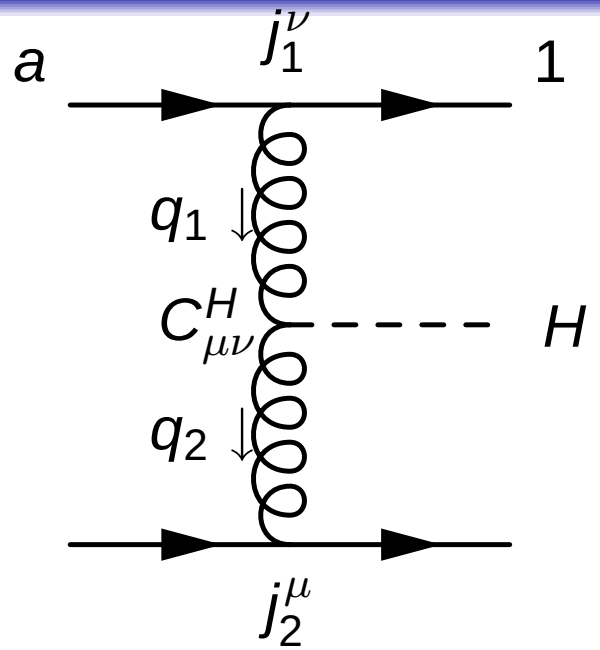
Considerations for Weak Boson Fusion

Higgs Couplings through Azimuthal Correllations



. . . and gluon fusion (Higgs coupling to gluons through top loop)

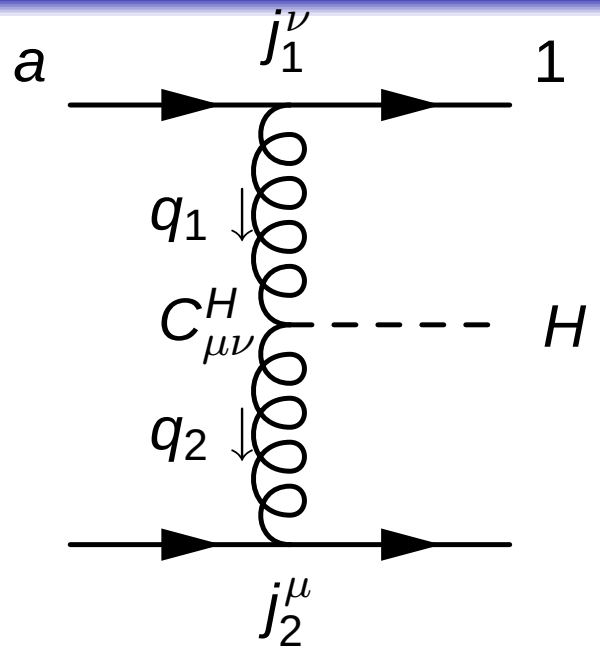
Higgs Couplings through Azimuthal Correllations



$$\mathcal{M} \propto \frac{j_1^\mu \, C^H_{\mu\nu} \, j_2^\nu}{t_1 \, t_2}, \qquad j_1^\mu = \overline{\psi}_1 \gamma^\mu \psi_a$$

$$C_H^{\mu\nu} = a_2 \, (q_1 q_2 g^{\mu\nu} - q_1^\nu q_2^\mu) + a_3 \, \varepsilon^{\mu\nu\rho\sigma} \, q_{1\rho} \, q_{2\sigma}.$$

Higgs Couplings through Azimuthal Correllations



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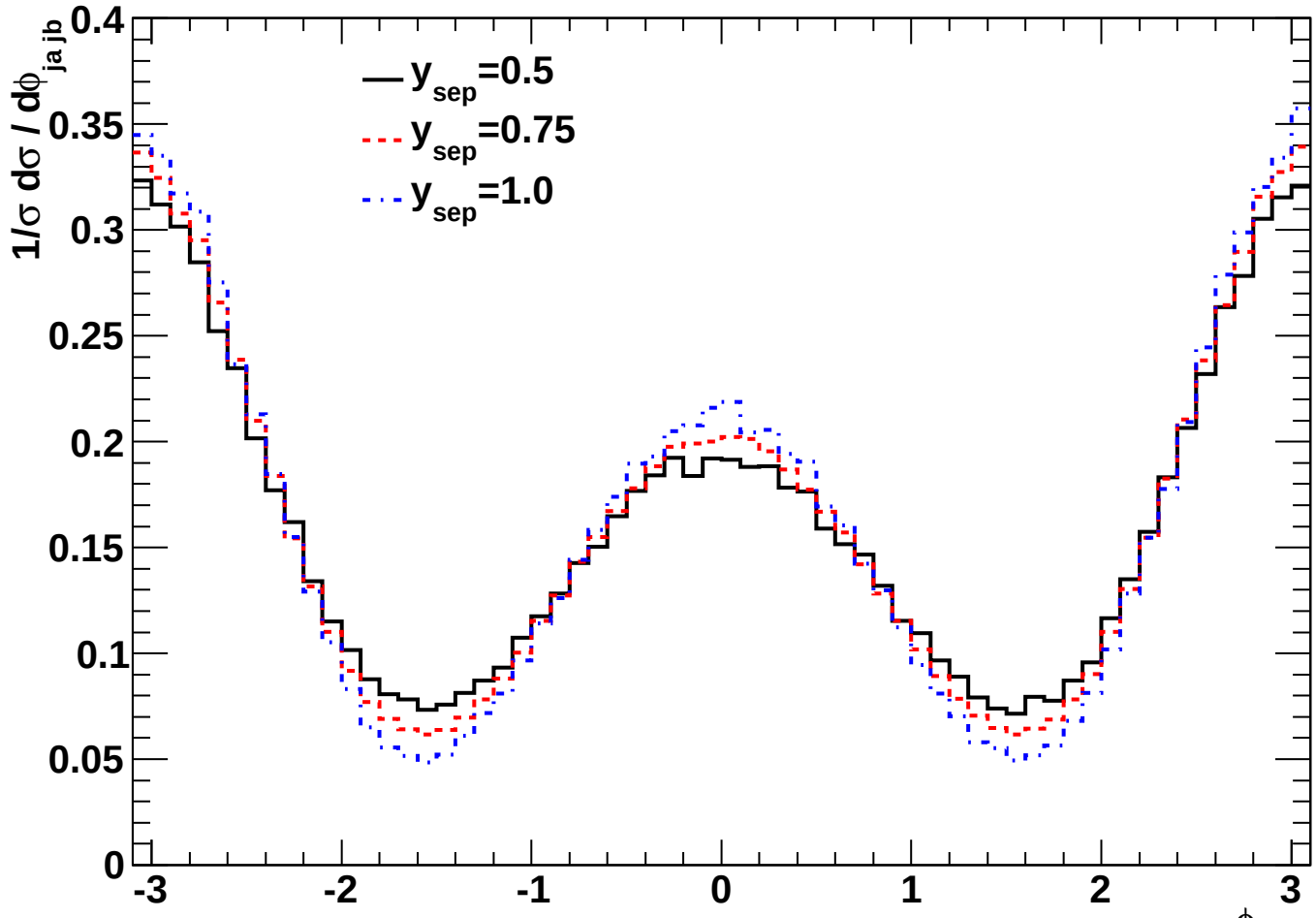
Take e.g. the term $\varepsilon^{\mu\nu\rho\sigma} \, q_{1\rho} \, q_{2\sigma}$: for $|p_{1,z}| \gg |p_{1,x,y}|$ and for small energy loss (i.e. $p_{a,e} \sim p_{1,e}$):

$$\left[j_1^0 \, j_2^3 - j_1^3 \, j_2^0 \right] (\mathbf{q}_{1\perp} \times \mathbf{q}_{2\perp}) \, .$$

In this limit, the azimuthal dependence of the propagators is also suppressed: $|\mathcal{M}|^2$:$\sin^2(\phi)$ **(CP-odd)**, $\cos^2(\phi)$ **(CP-even)**.

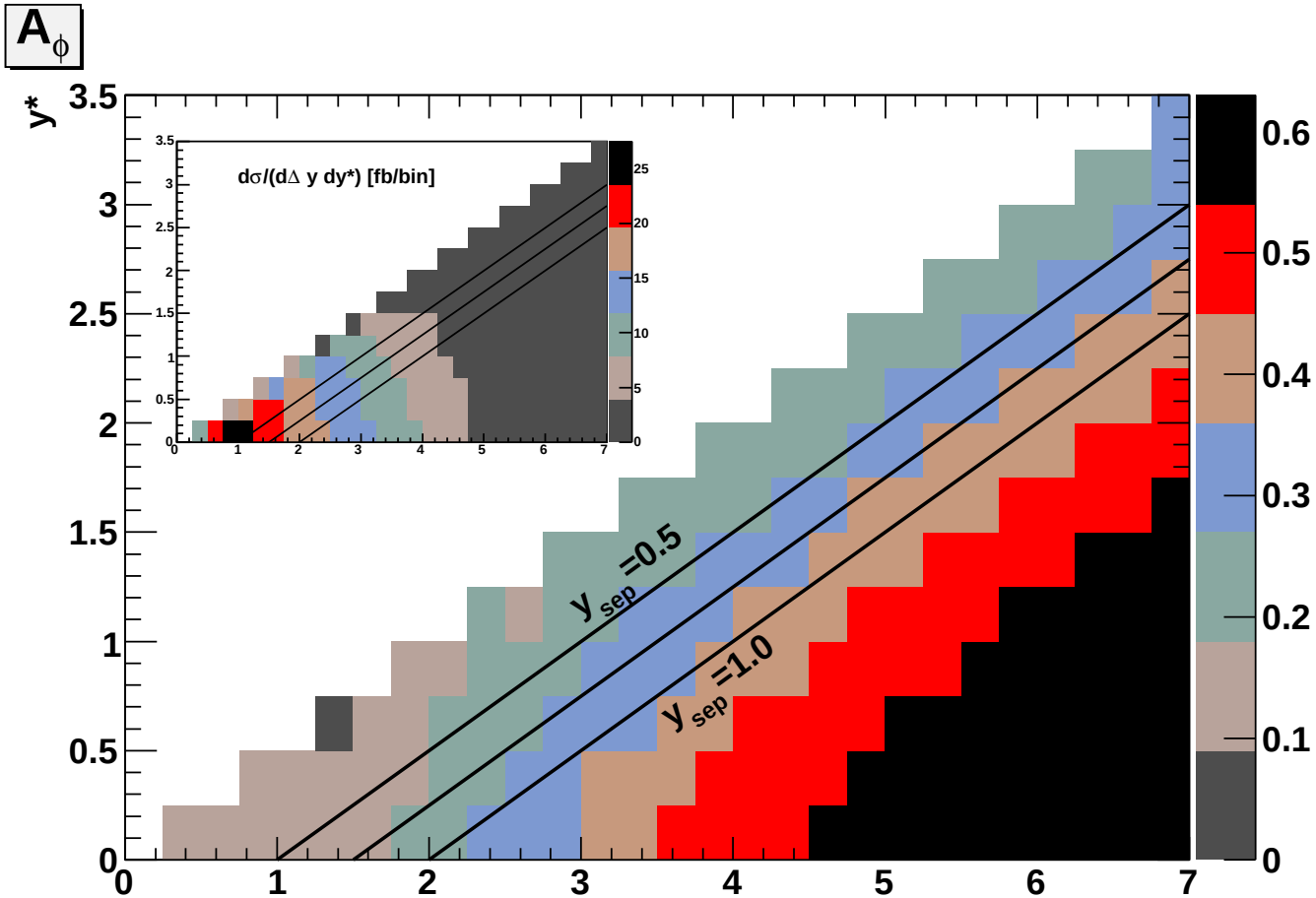
Azimuthal distribution



CP-even, $p_{j\perp} > 40$ GeV, $y_{ja} < y_h < y_{jb}$,

$|y_{ja,jb}| < 4.5, \min\left(|y_h - y_{ja}|, |y_h - y_{jb}|\right) > y_{\text{sep}}$.

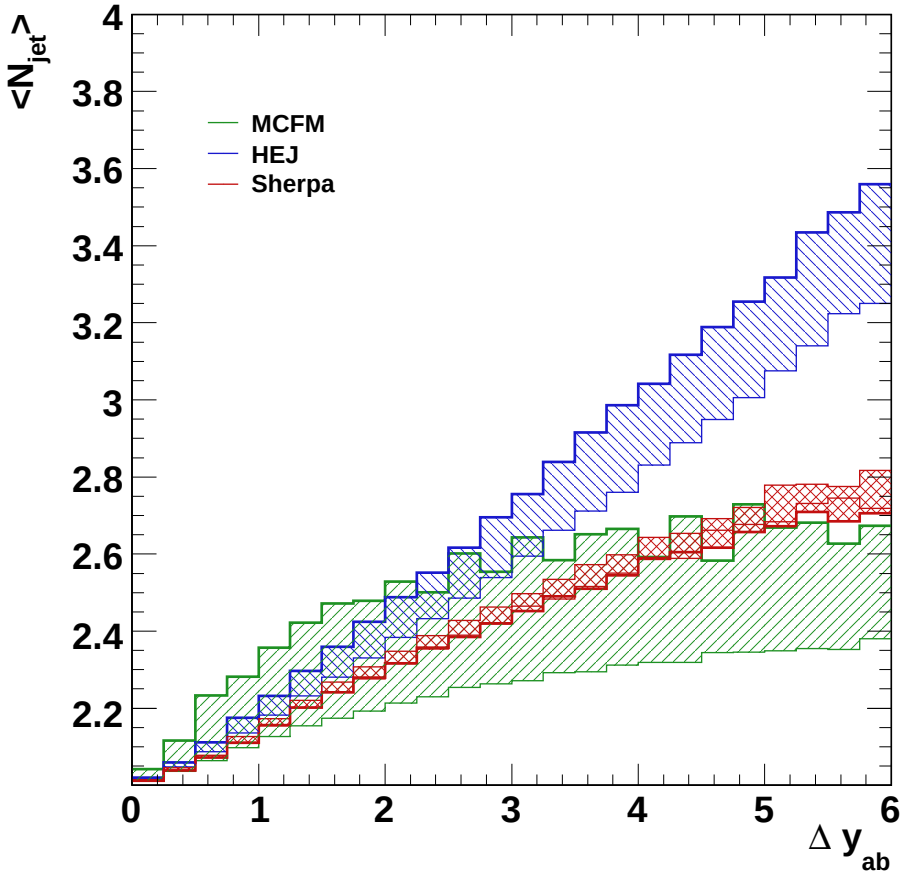
Signature and Cross Section



$$\Delta y = |y_{j_a} - y_{j_b}|, \quad y^* = y_h - \frac{y_{j_a} + y_{j_b}}{2}.$$

Rapidity separation between the jets and the Higgs Boson **enhance the azimuthal correlation**.

Increasing Rapidity Span → Increasing Number of Jets



All models show a clear increase in the number of hard jets as the rapidity span increases.

How to extract the *CP*-structure of the Higgs boson coupling from events with **three or more** jets?

2 hardest jets?

J.R. Andersen, J. Campbell, S. Höche, arXiv:1003.

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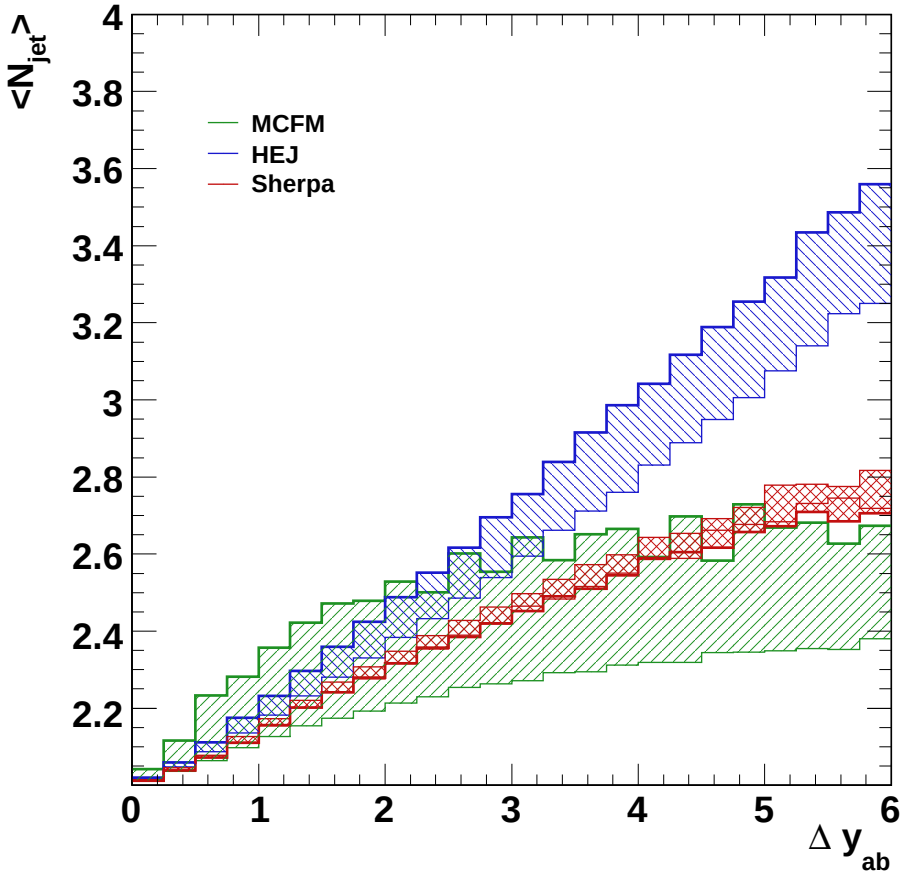

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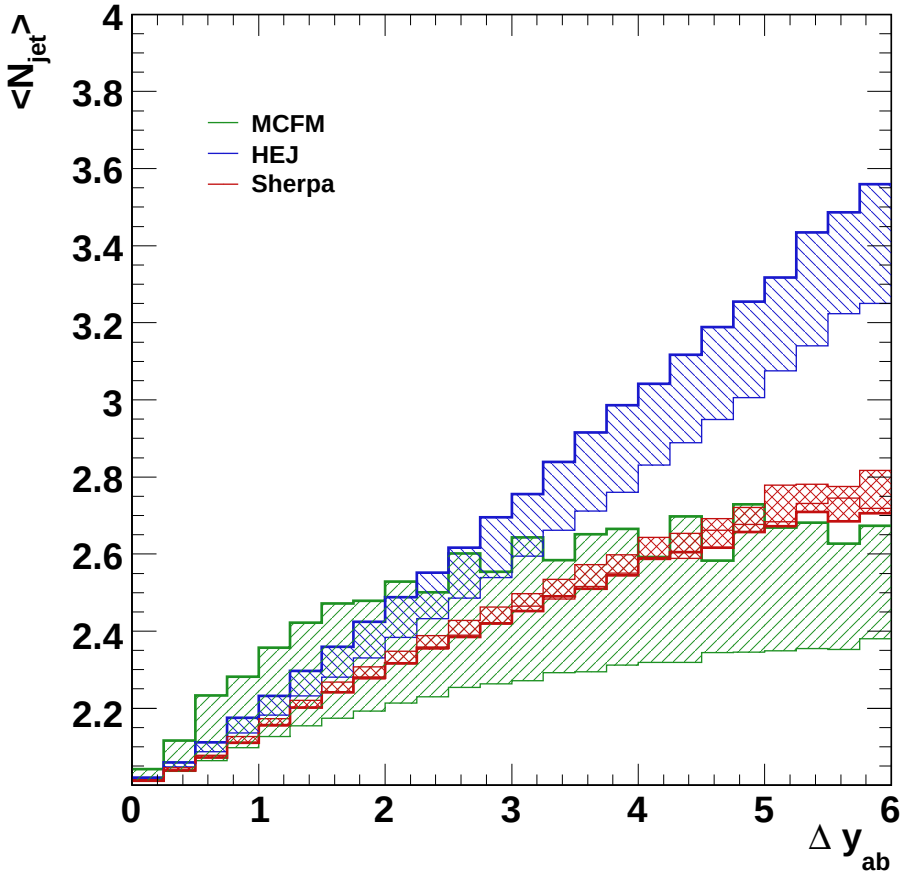
2 hard jets furthest apart in rapidity?

J.R. Andersen, J. Campbell, S. Höche, arXiv:1003.

Increasing Rapidity Span → Increasing Number of Jets



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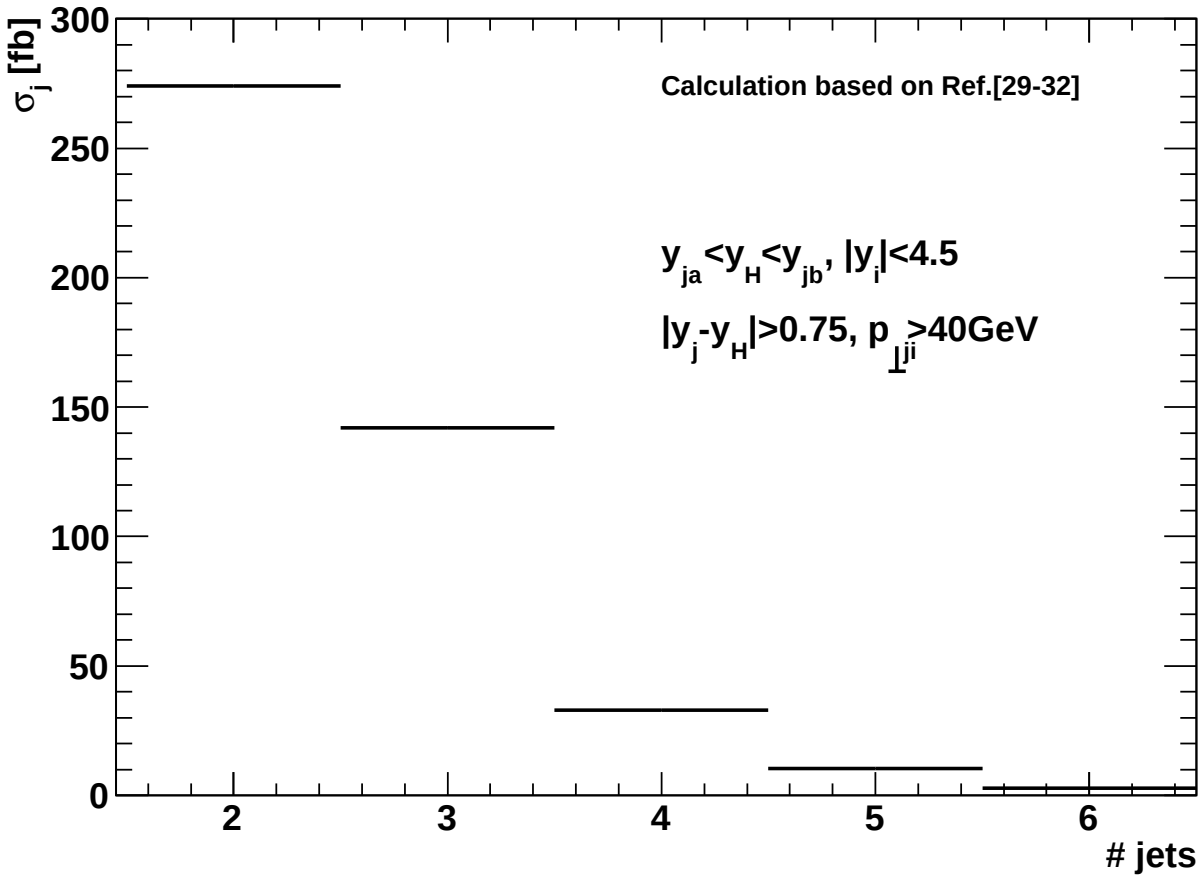
Significant washing out of the azimuthal correlation observed at tree-level *hjj*

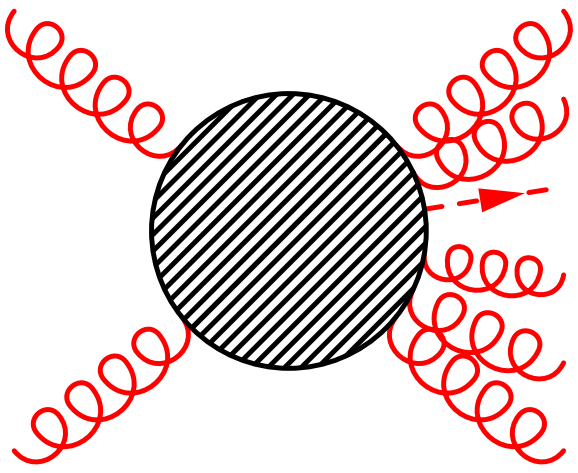
Many Jets!



Calculation based on all-order approximant to the *n*-particle matrix element, which reproduces the exact result in the limit of large invariant mass between all particles.

JRA&C.D. White, JRA&J.M. Smillie

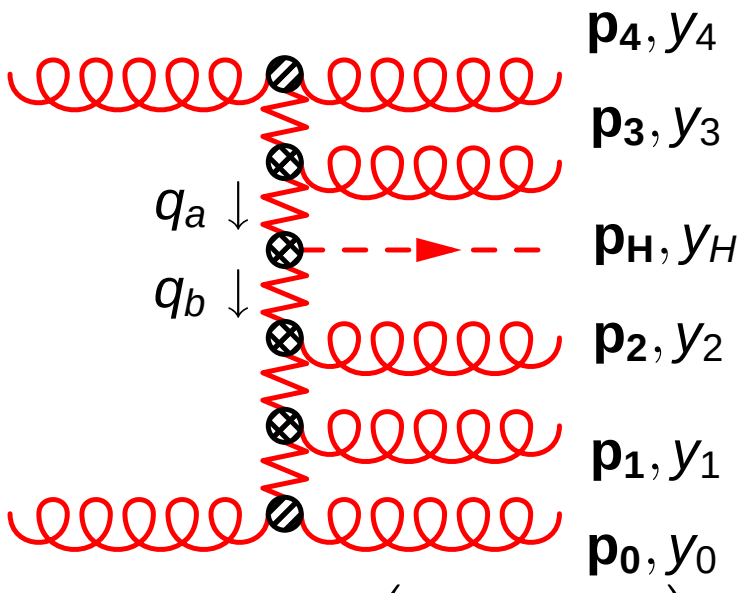
Develop Insight Into the Perturbative Corrections



High Energy Limit

$$\longrightarrow$$

$$|p_{\perp,i}| \text{ fixed}, \ \hat{s}_{ij} \to \infty$$

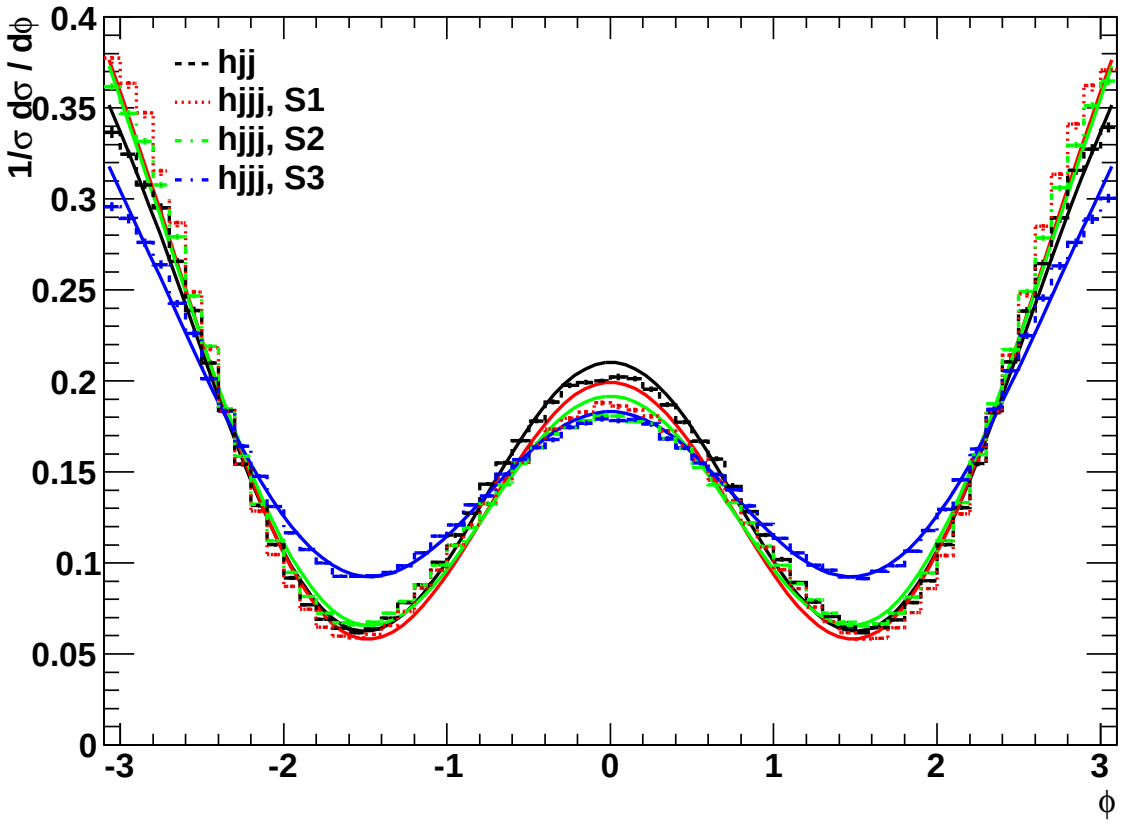


$$\left|\mathcal{M}_{gg\to g\cdots ghg\cdots g}\right|^2 \to \frac{4\hat{s}^2}{N_C^2-1}\left(\prod_{i=1}^{j}\frac{C_A\, g_s^2}{\mathbf{p}_{i\perp}^2}\right)\frac{|C^H(\mathbf{q}_{a\perp},\mathbf{q}_{b\perp})|^2}{\mathbf{q}_{a\perp}^2\,\mathbf{q}_{b\perp}^2}\left(\prod_{i=j+1}^{n}\frac{C_A\, g_s^2}{\mathbf{p}_{i\perp}^2}\right)$$

$$C^H(\mathbf{q}_{a\perp},\mathbf{q}_{b\perp}) \;=\; -i\,\frac{\alpha_s}{3\pi v}\,\mathbf{q}_{a\perp}\cdot\mathbf{q}_{b\perp}, \quad y_0 < \cdots < y_j < y_H < y_{j+1} < y_n$$

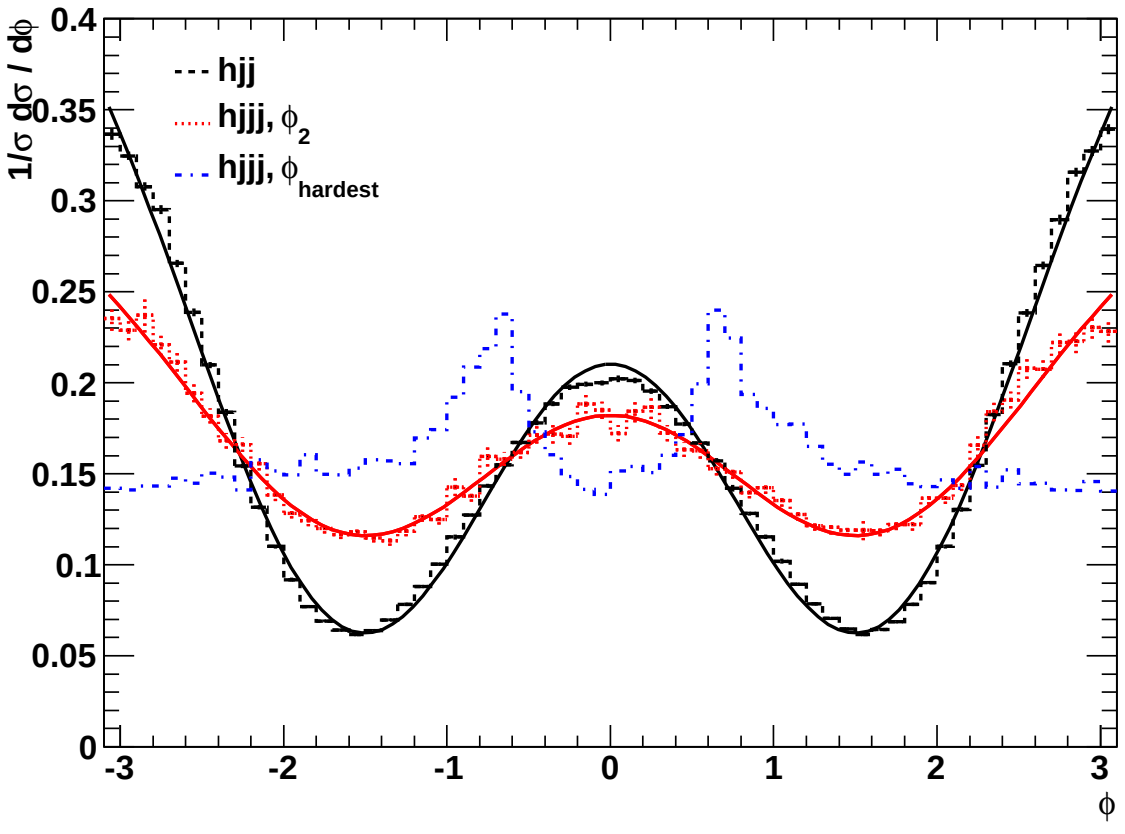
The **High Energy Limit** tells us to investigate the **azimuthal angle** between the **sum of the jet vectors** either side in rapidity of the Higgs Boson!

And It Even Works!



Three subsamples of tree-level three-jet events: two jets on same side of the Higgs boson parallel (S1), perpendicular (S2) or anti-parallel (S3). Azimuthal correlation almost unchanged from hjj.

...Much Better Than Any Alternative



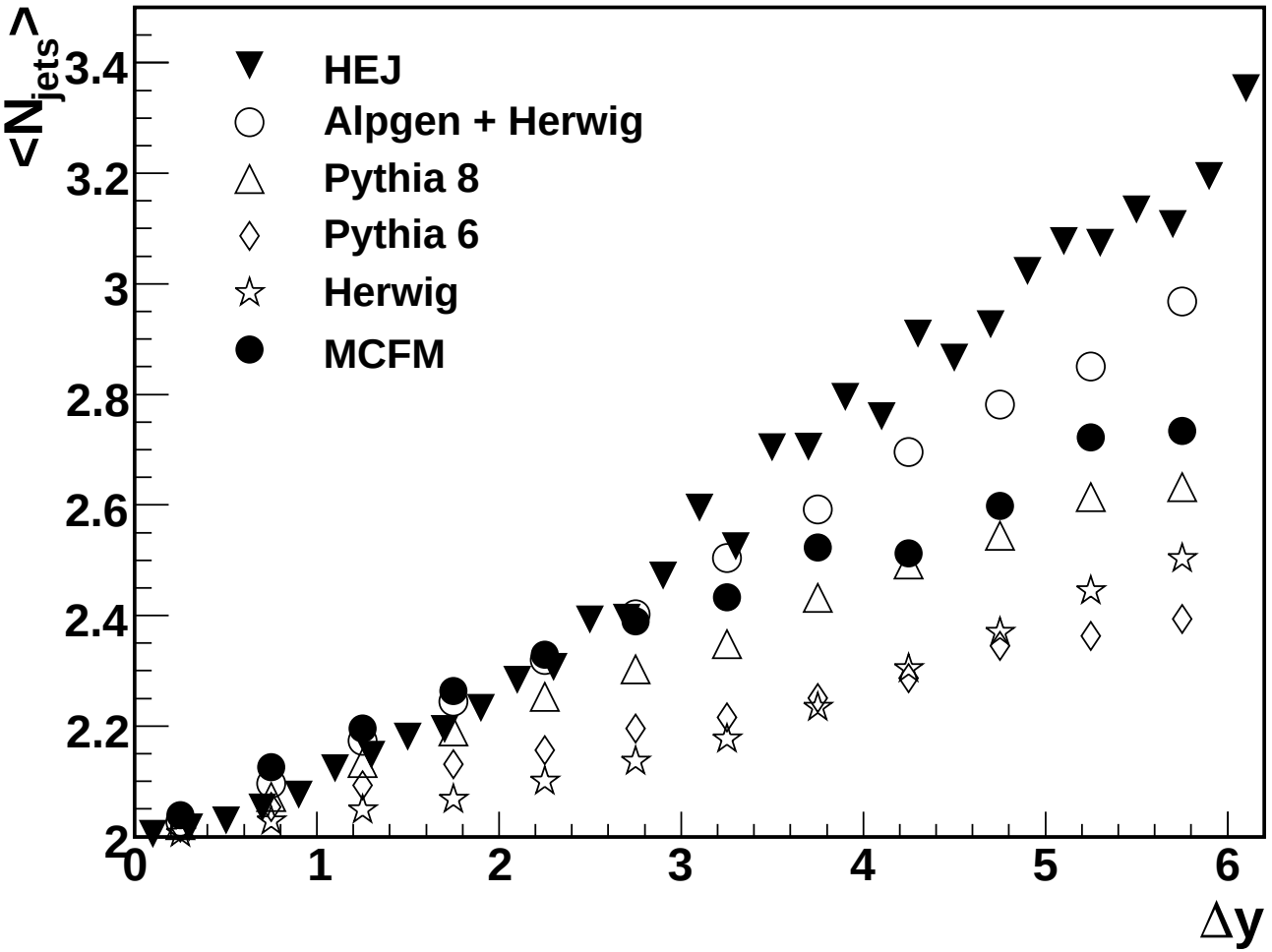
Two hardest jets on one side, and the softest on the other (all above 40GeV - 1/3 of inclusive 3-jet cross section). Using **just the two hardest** jets gives **unsatisfactory** result.

Summary of Study

1. Full hjjj tree-level confirms expectations from High Energy Limit
2. Observable stable when shower+hadronisation effects are added (LO+HERWIG++)
   1. However, the parton shower delivers a very poor description of the multi-jet configurations, when compared to e.g. hjjj tree-level
3. Observable stable when additional hard perturbative corrections are summed to all orders (HEJ)

See arXiv:1001.3822 for all the details

Relevance of Early Data on W+dijets

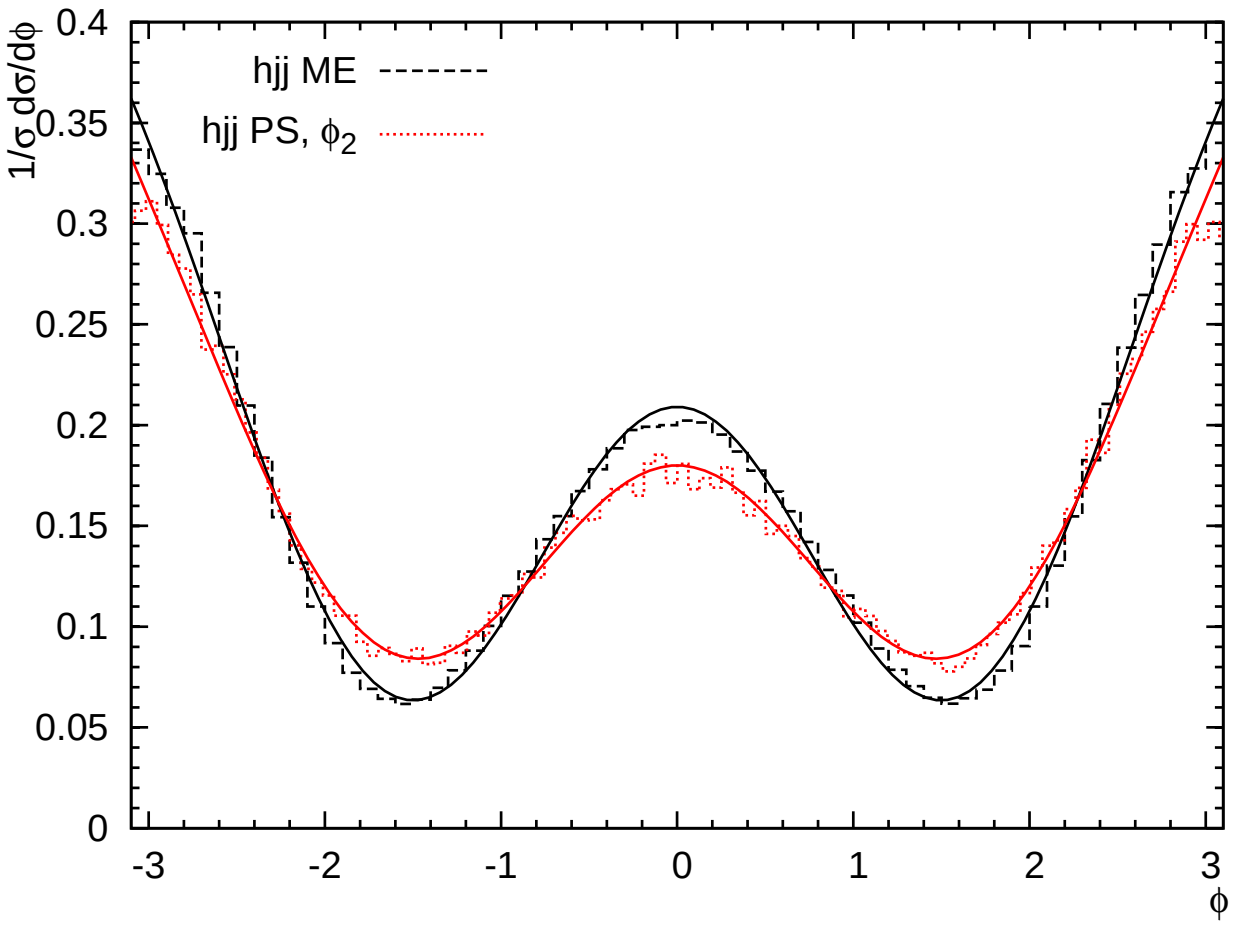


Radiation pattern for hard jets is similar in W+jets!
Clear differences between different theoretical descriptions.
Early data will drive theory developments!

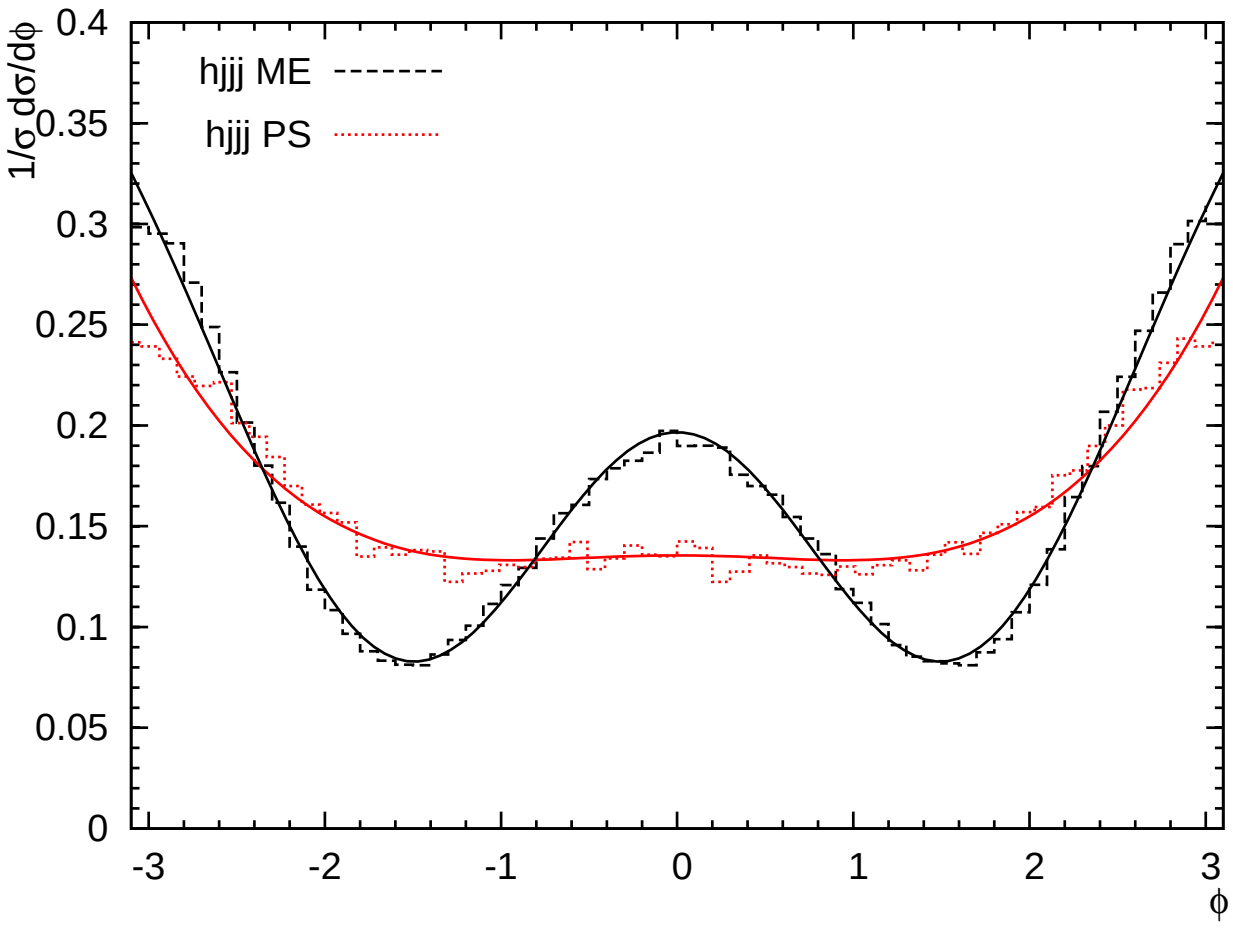
Conclusions

- The insight gained from studying the **High Energy Limit** useful for constructing a **very robust** extraction of the **CP properties of the Higgs boson couplings**
- . . . and for constructing an **all-order approximation** to the perturbative corrections to **all hard processes with at least two jets** (current-current scattering)
- Study highlights **differences** in current **theoretical descriptions of high-energy collisions**
- **early data** will investigate the importance of taking into account all-order hard corrections

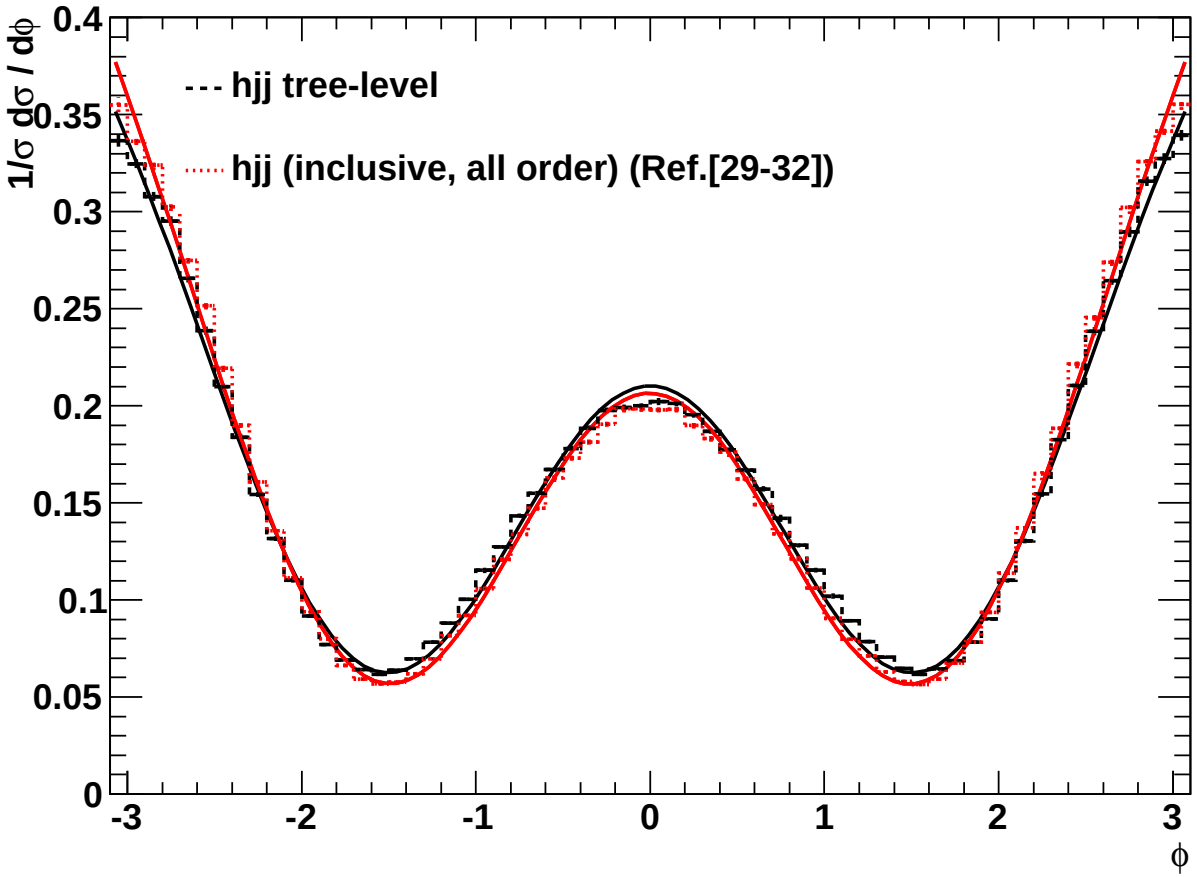
Stability Against Corrections Implemented in a Parton Shower



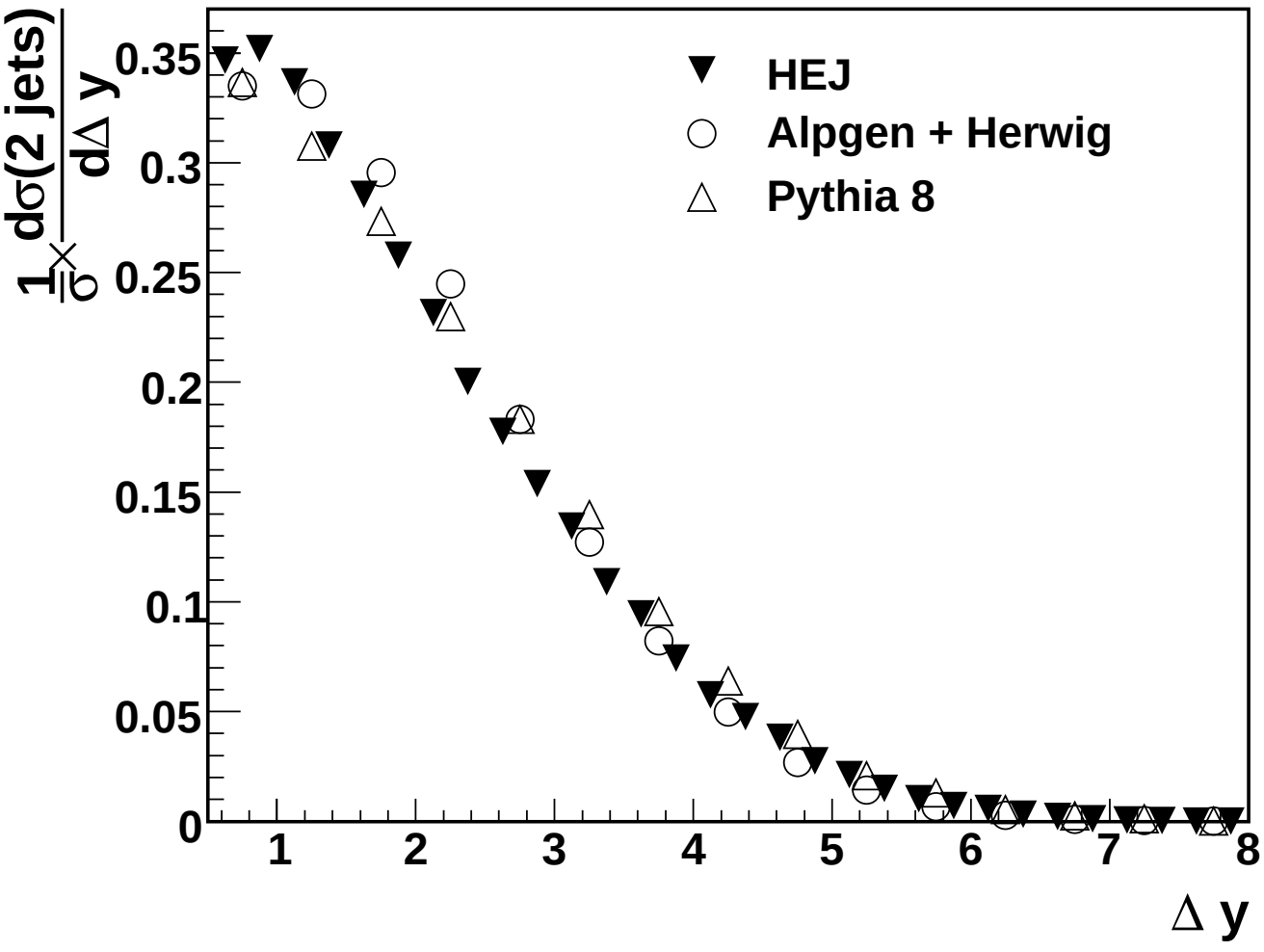
. . . however, shower does not describe three-jet sample accurately



Stability Against Hard, Higher Order Corrections



Exclusive 2-Jet Rates



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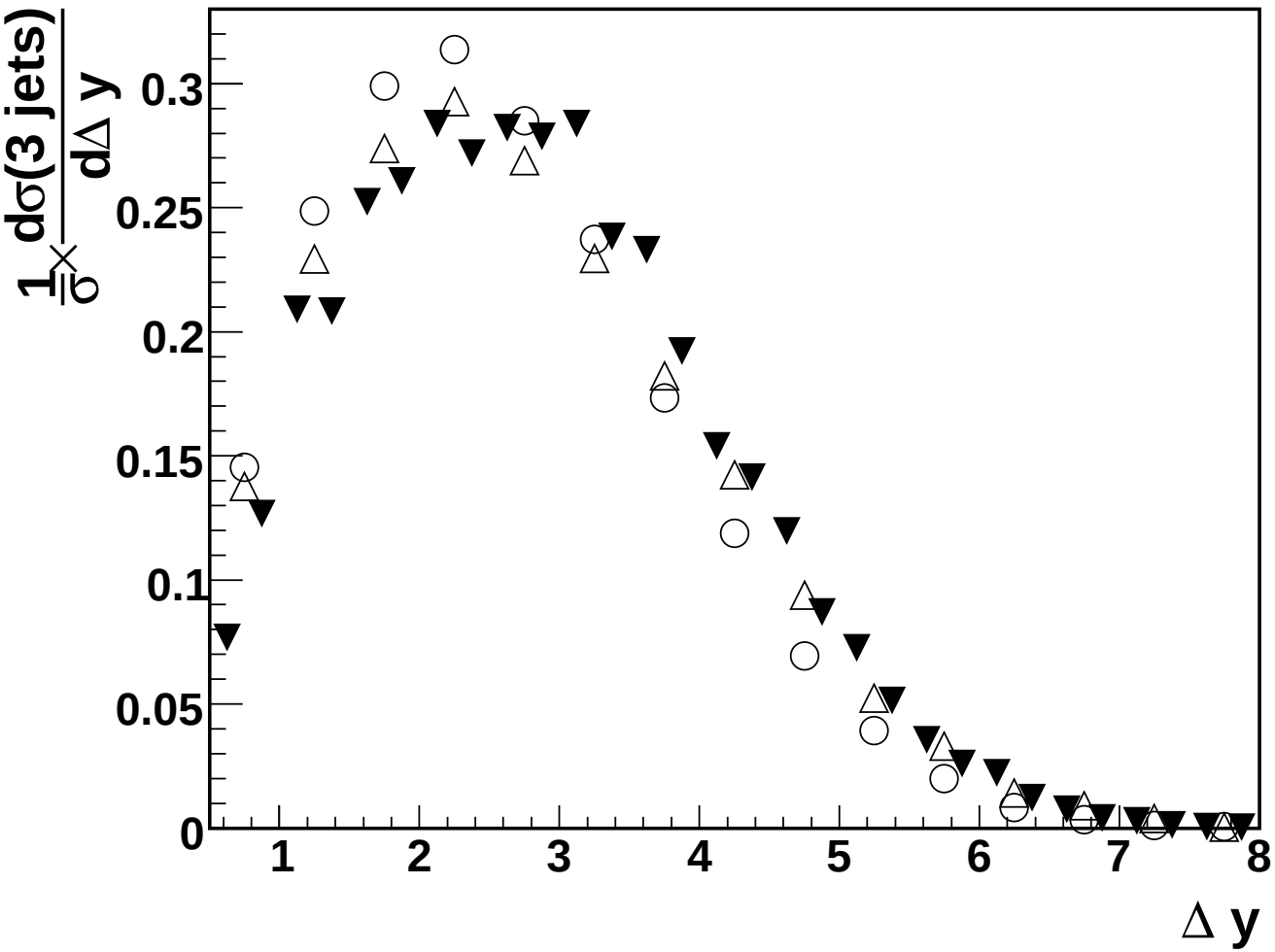

Exclusive 4-Jet Rates