W with multiple jets at the LHC

A Comparative Study of the Description of the Jet Activity

Jeppe R. Andersen

DESY LHC Physics, Dec 5 2011

Outline

Idea/Motivation

Investigate the radiation pattern in W+Jets for two reasons:

1. A good understanding may give additional handle to suppress W+Jets when viewed as a background
2. W+Jets may act as a test bed for studies of h+Jets

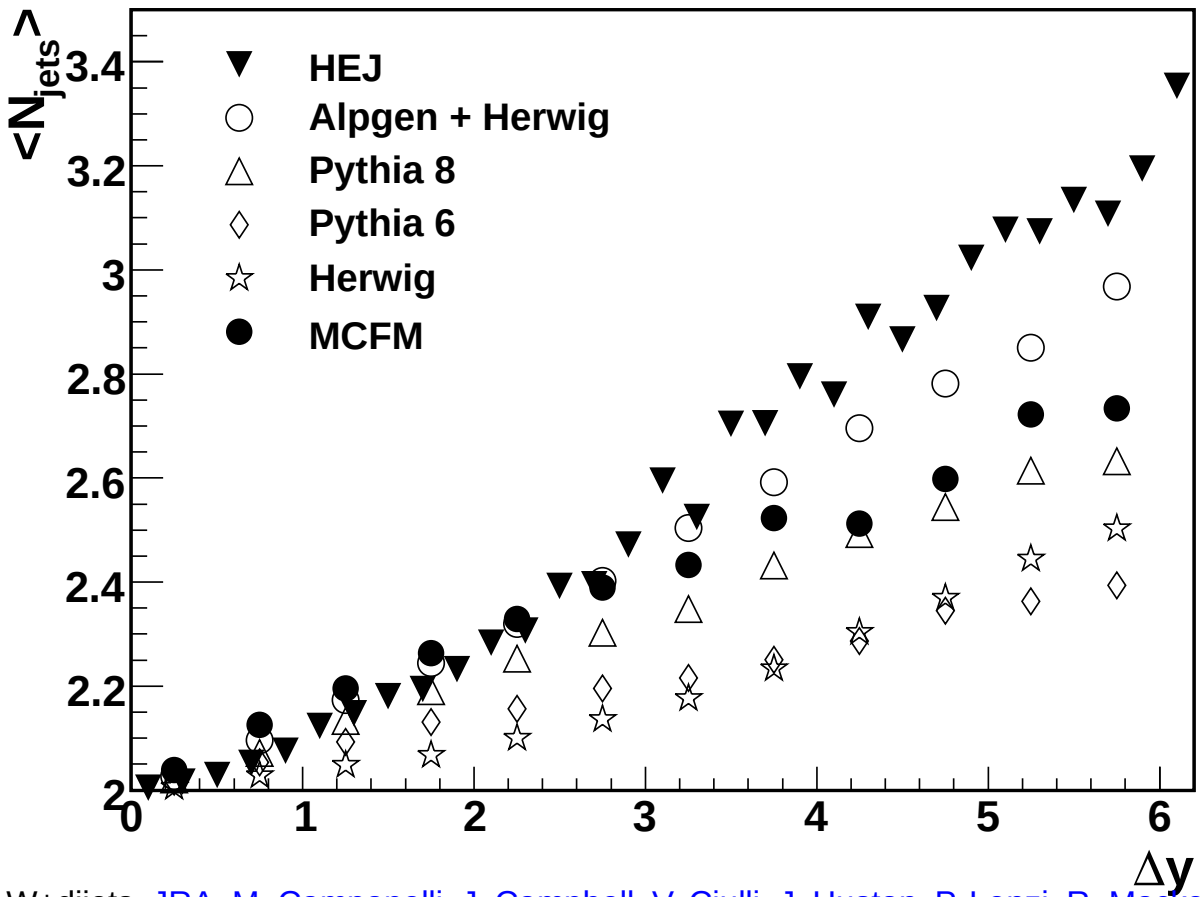
Which regions of phase space receive large corrections from hard perturbative corrections (= additional jet activity)

Compare the description of hard jet activity from NLO, “stacked NLO”, NLO+shower, High Energy Jets.
Dijets, W+Dijets, H+Dijets; Similarities in Jet Activity

Drivers of Emission

1. Collinear (jet profile)
2. Soft (p_t-hierarchies)
3. Opening of phase space (semi-hard emissions - not related to a divergence of $|M|^2$).
   Think (e.g.) multiple jets of fixed p_t, with increasing rapidity span (span=max difference in rapidity of two hard jets=Δy).
   All calculations will agree that number of additional jets increases - but the amount of radiation will differ (wildly) - e.g. due to limitations on the number (NLO) or hardness (shower) of allowed additional radiation.

Simple Observation

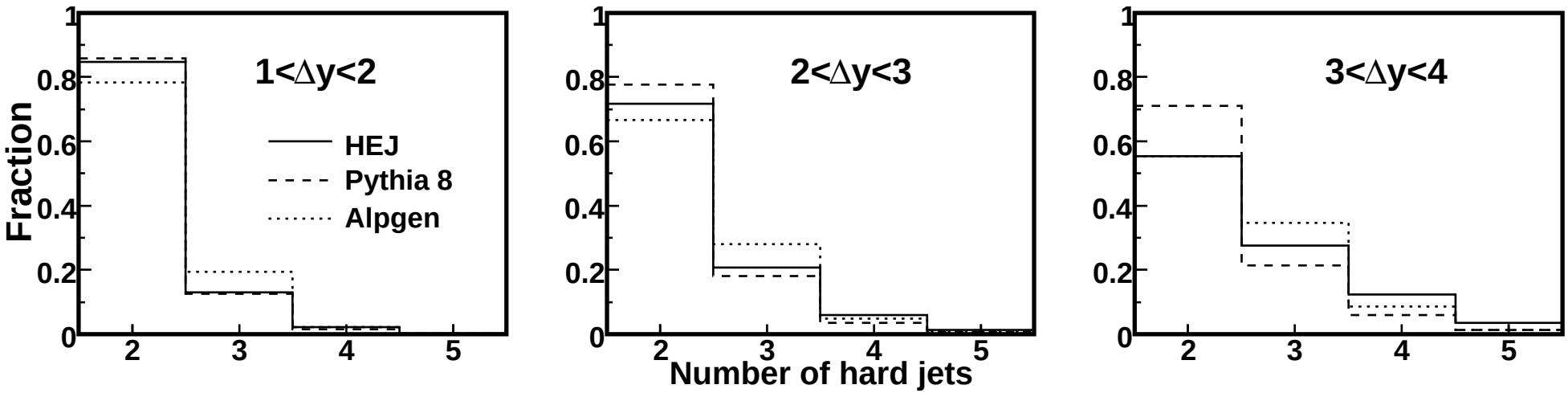


W+dijets, JRA, M. Campanelli, J. Campbell, V. Ciulli, J. Huston, P. Lenzi, R. Mackeprang, arXiv:1003.1241

$5fb^{-1}$@7TeV should be enough to tell the predictions apart!

Obviously, similar results for pure dijets with much less data

Simple Observation



Many handles to distinguish the predictions from various perturbative approaches using early data

W+dijets, JRA, M. Campanelli, J. Campbell, V. Ciulli, J. Huston, P. Lenzi, R. Mackeprang, arXiv:1003.1241

$5fb^{-1}$@7TeV should be enough to tell the predictions apart!

Obviously, similar results for pure dijets with much less data

Average Number of Jets at NLO

The observable we are interested in is the expectation value for the number of jets

$$\langle n \rangle = \frac{2n_2 + 3n_3 + 4n_4 + \ldots}{n_2 + n_3 + n_4 + \ldots} = \frac{\sum_{i \geq 2} i n_i}{\sum_{i \geq 2} n_i} \tag{1}$$

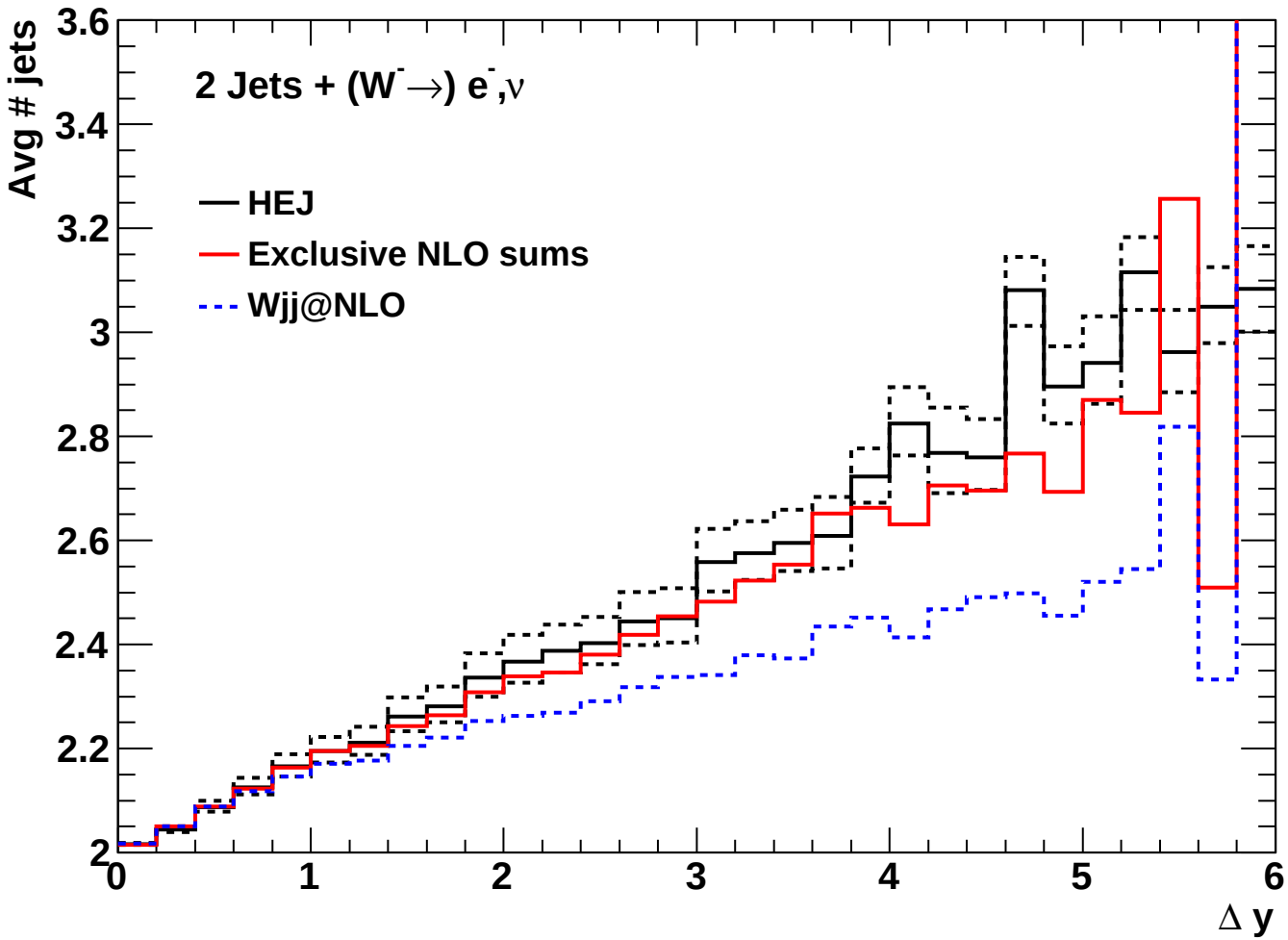
One NLO approach: Choose e.g. W+dijets@NLO. 2jet,3jet sample
An alternative approach is to approximate each n_i in formula (1) with the best available fixed order prediciton, NLO in our case.

$$\langle n \rangle = \frac{2n_2 + 3n_3 + 4n_4 + \ldots}{n_2 + n_3 + n_4 + \ldots} = \frac{2\sigma_2^{NLO,ex} + 3\sigma_3^{NLO,ex} + 4\sigma_4^{NLO,ex} + \ldots}{\sigma_2^{NLO,ex} + \sigma_3^{NLO,ex} + \sigma_4^{NLO,ex} + \ldots} \tag{2}$$

This will be labelled “Exclusive Sums”.
25GeV jets

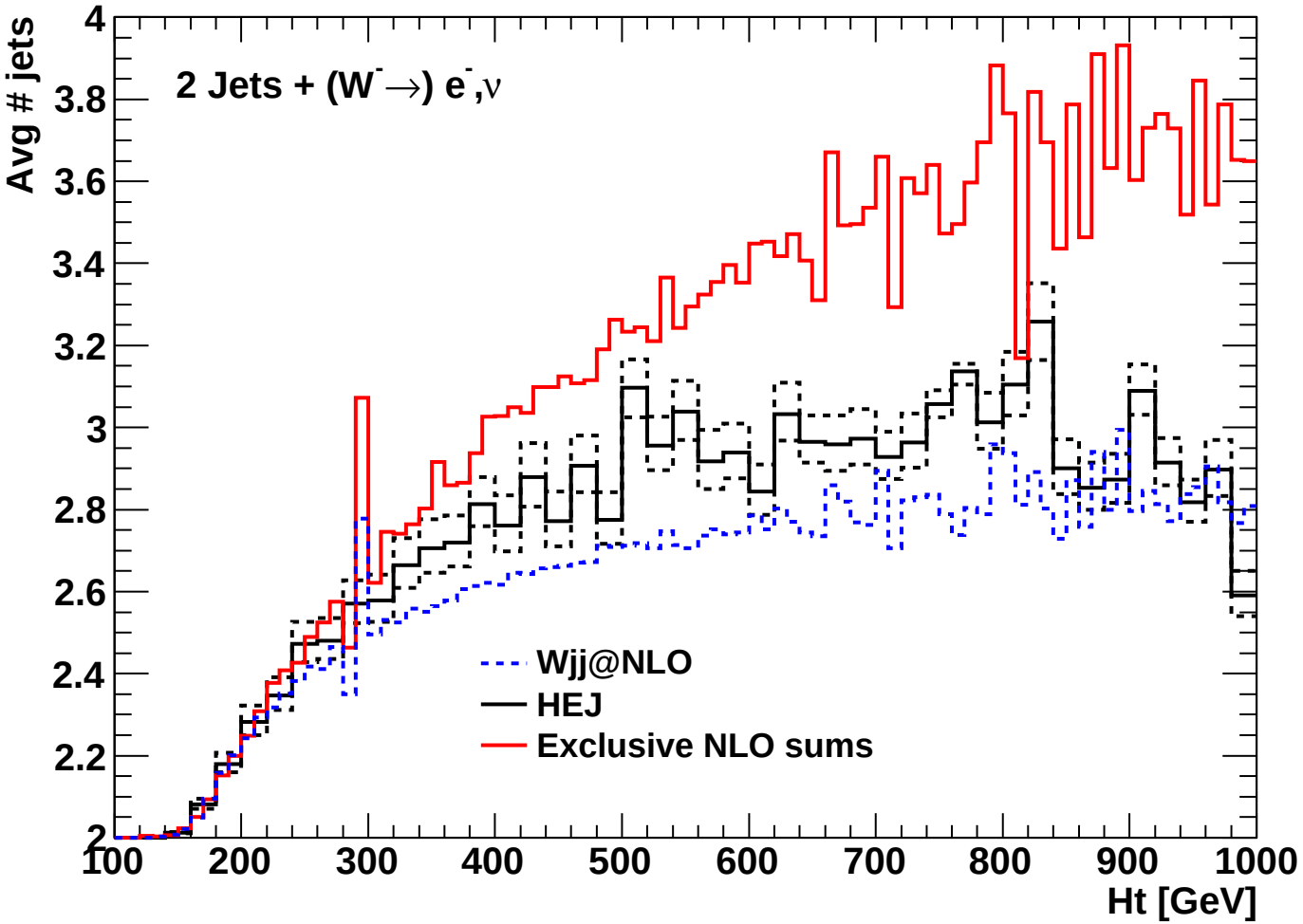
with the BlackHat Collaboration

Avg Jets vs Δy



with the BlackHat Collaboration

Avg Jets vs H_T

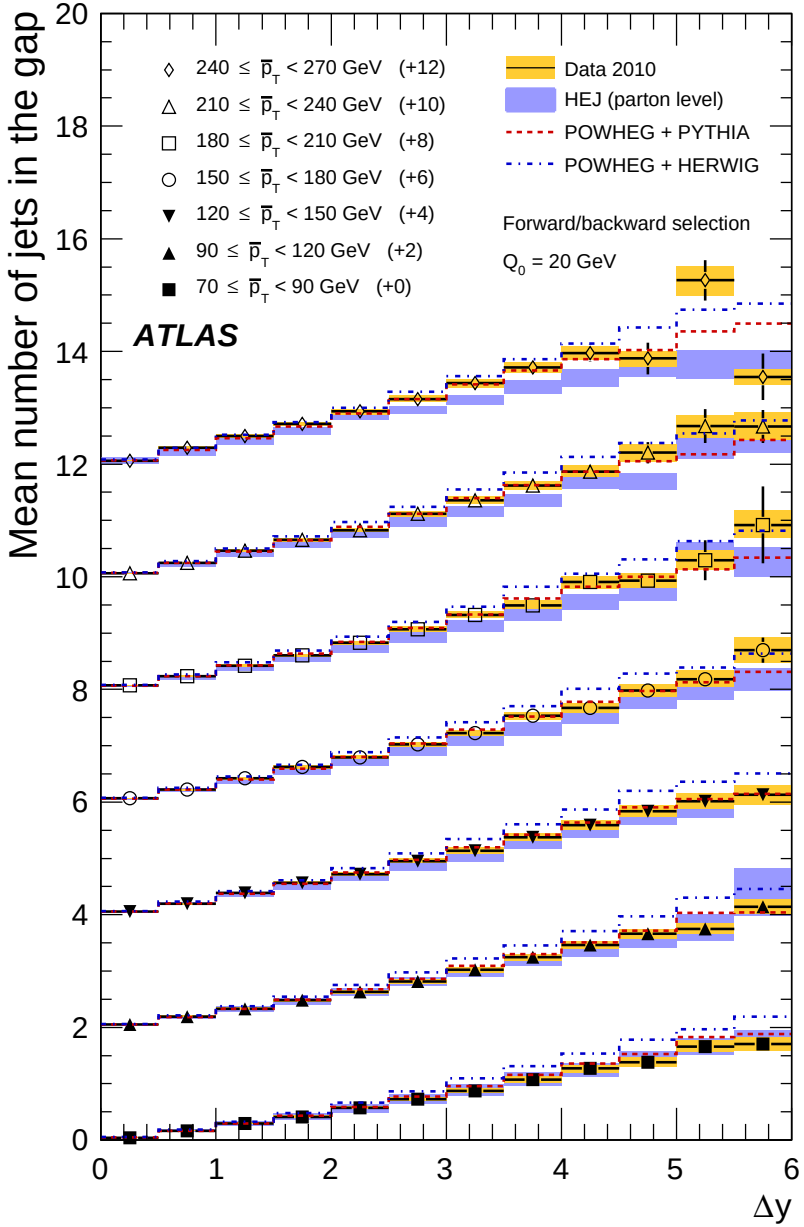


with the BlackHat Collaboration

What Has Already Been Studied?

Similar patterns in dijets for increasing Δy.
Dijet studies by both ATLAS and CMS

Atlas Study of Further Jet Activity in Dijet Events

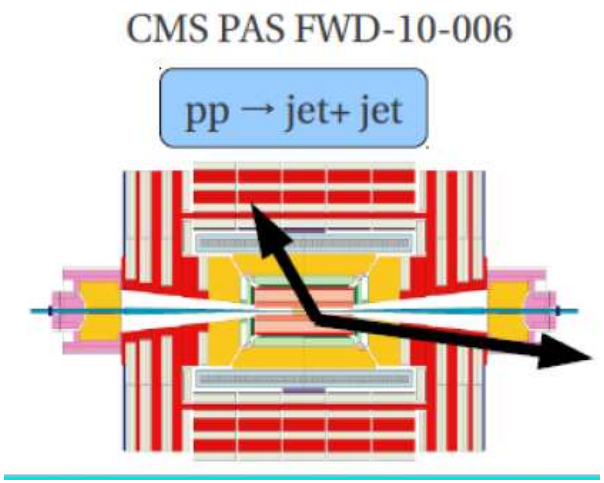


The Atlas event selection does not cleanly separate the “drivers” of jet production (soft vs. Δy).

HEJ slightly undershoots the jet activity when large ratios of transverse scales are imposed (fully understood).

Very good agreement in the most important regions of phase space

Simultaneous production of central and forward jet

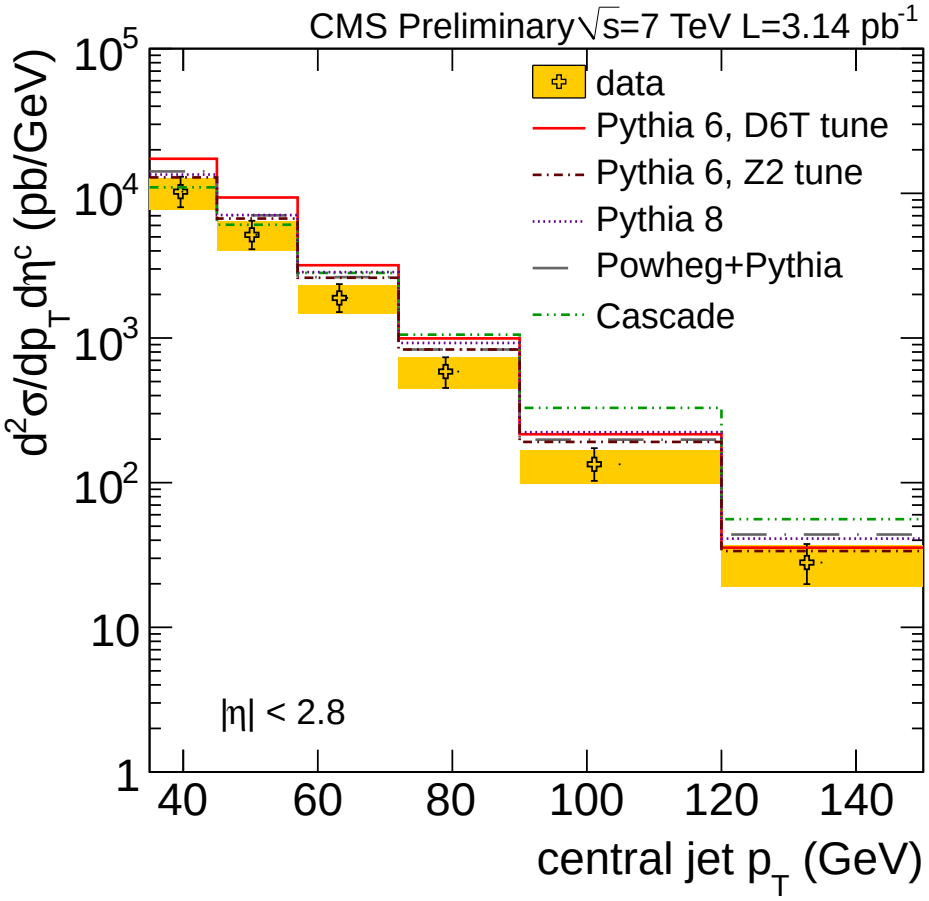


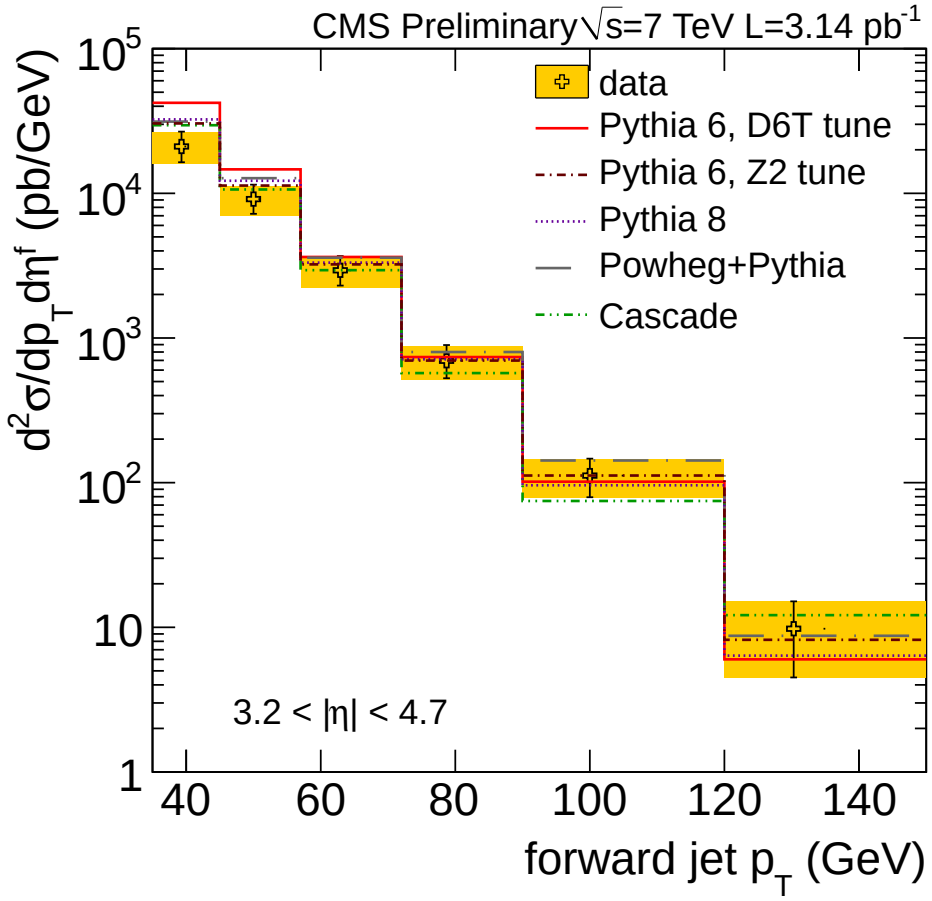
Jets: anti-kt, R=.5, $p_t > 35$GeV

$$\text{central} : |\eta| < 2.8$$
$$\text{forward} : 3.2 < |\eta| < 4.7$$

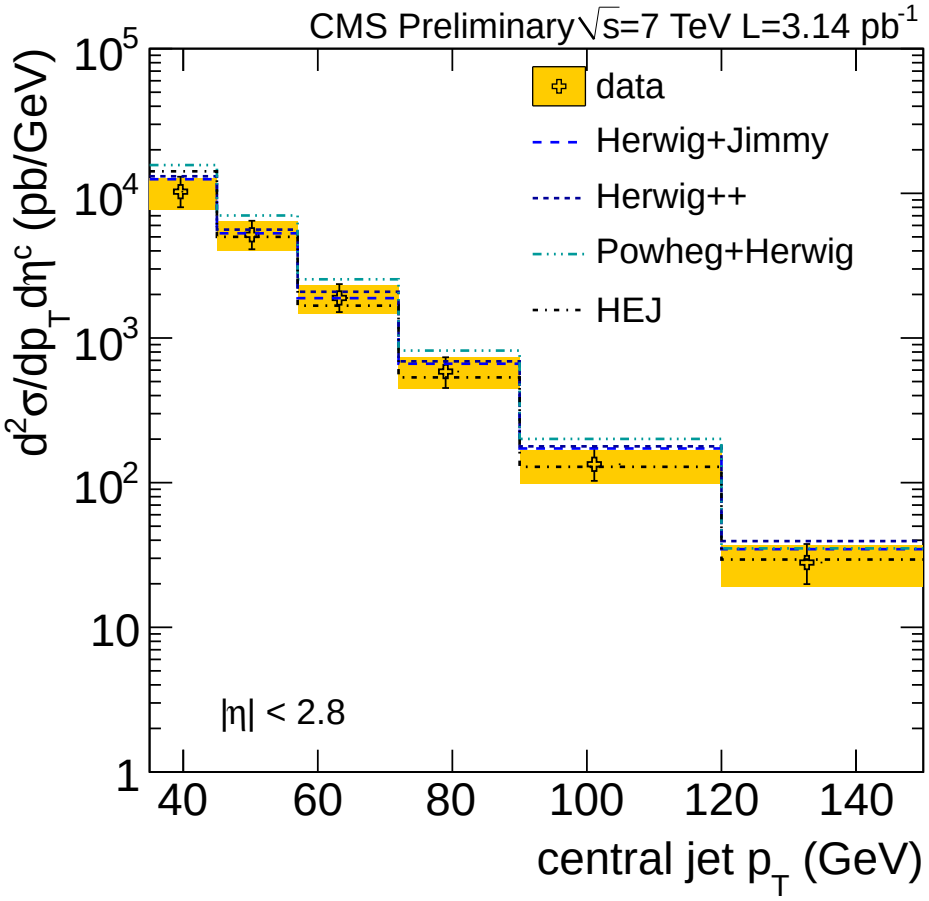
(not particularly large rapidity spans, typically 1 unit).
Measure the p_t-spectrum of the central and the forward jet. Any difference is obviously due to additional radiation.

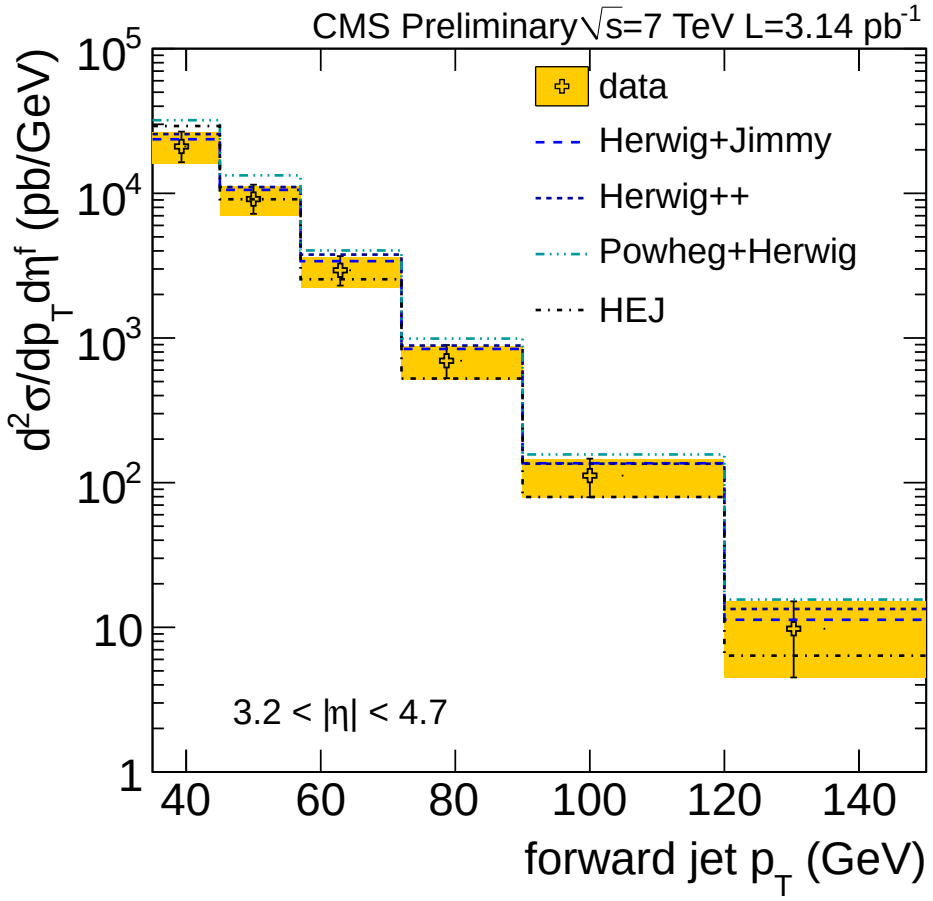
Comparison to Theory, I





Comparison to Theory, II

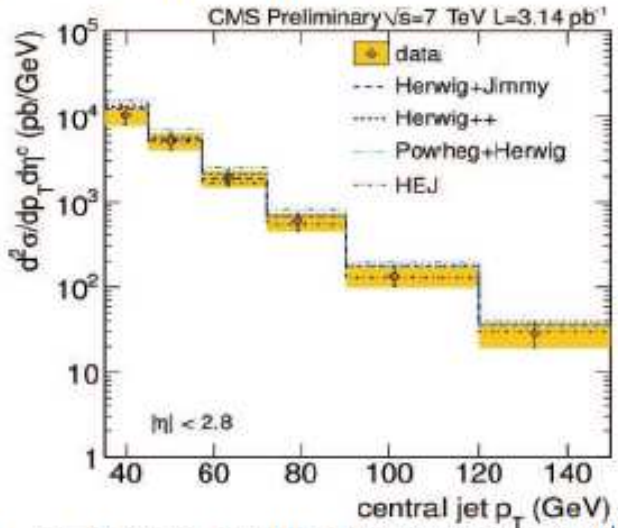


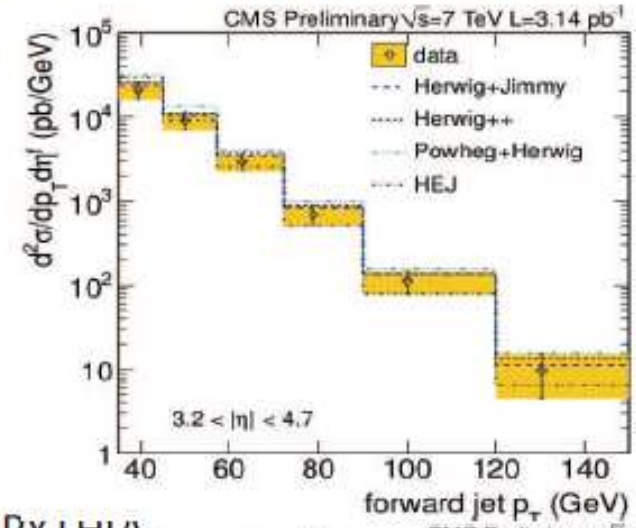


Comparison to Theory, Conclusion

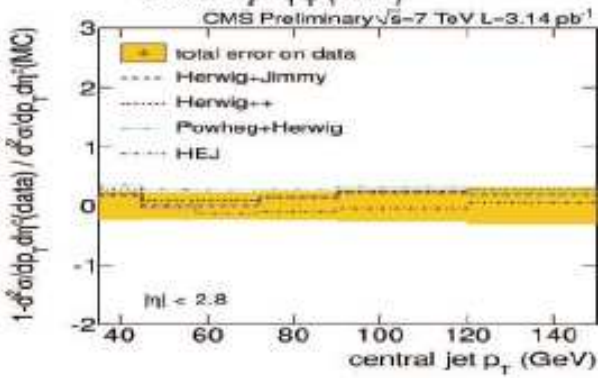
Forward-central jets (pp, LHC)

- Constrains multi-jets production & DGLAP vs BFKL dynamics





- HERWIG somehow better than PYTHIA.
- POWHEG (NLO) does not help.
- HEJ (BFKL-multijets) best agreement.



CMS (A. Massironi)

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!

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!

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!

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).

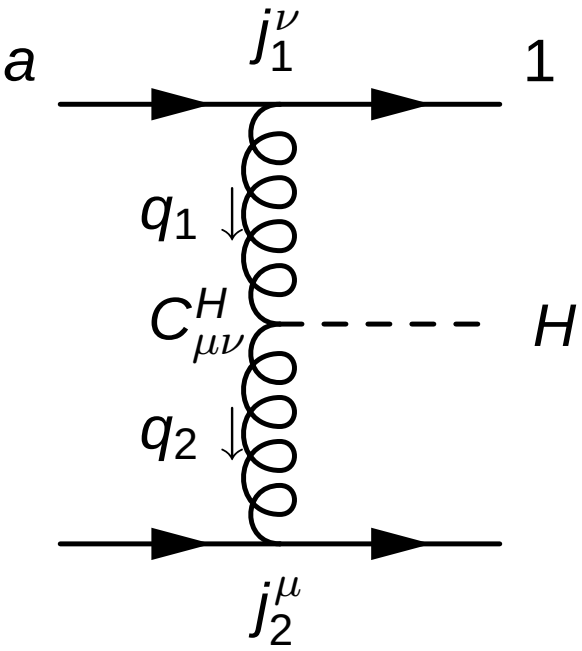
Measure the **strength** and **Lorentz structure** of the Higgs boson couplings:

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



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

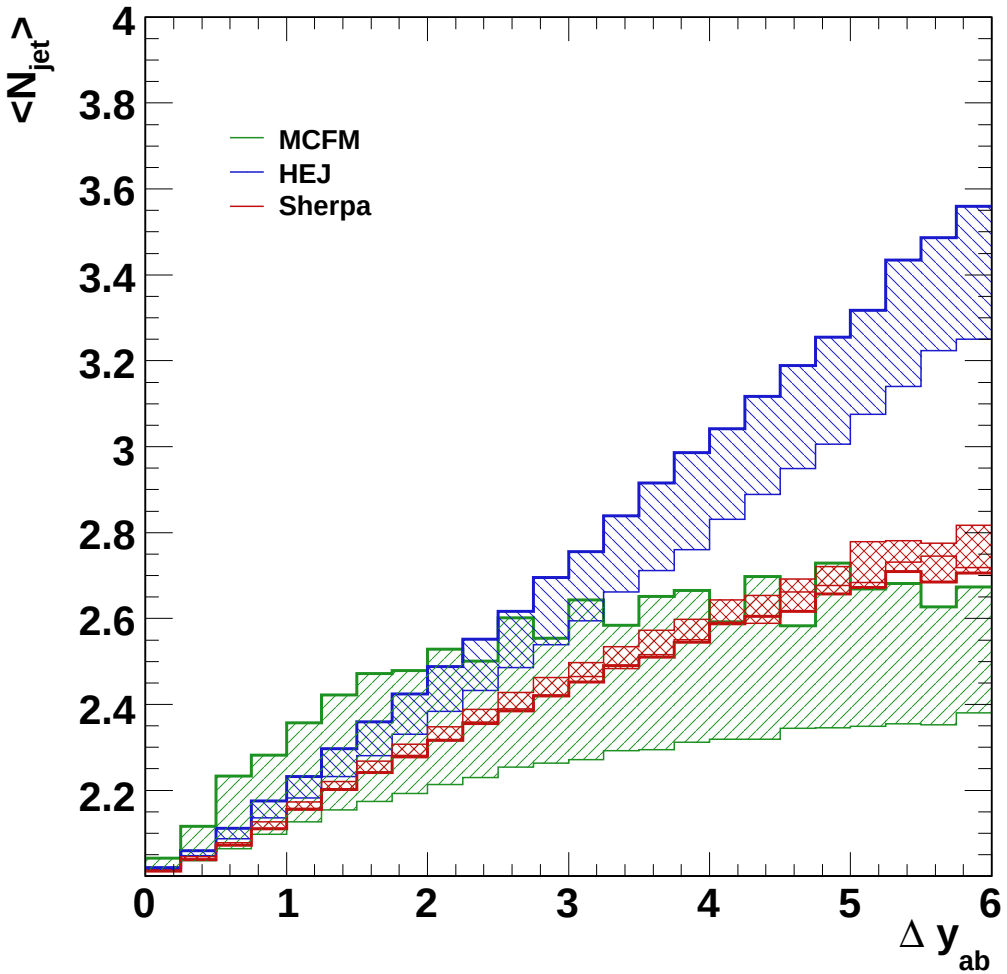
$$C_H^{\mu\nu} = a_2 \, (q_1 q_2 g^{\mu\nu} - q_1^\nu q_2^\mu) + a_3 \, \varepsilon^{\mu\nu\rho\sigma} \, q_{1\rho} \, q_{2\sigma}.$$

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)**.

Increasing Rapidity Span $\longrightarrow$ 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?

J.R. Andersen, J. Campbell, S. Höche, arXiv:1003.1241

Please recall the results of the ATLAS study of $\langle N_{\text{jets}} \rangle$ vs. Δy.

Conclusions

- Study highlights **large differences** in current **perturbative descriptions of high-energy collisions**
- Already, **LHC data confirms the importance** of taking into account these hard, radiative corrections.
- (W+)Dijets serve as a test bed for studies of h+jets