Multiple Jets at the LHC with HEJ

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HEPTools Final Meeting
Granada

Jets at the LHC with High Energy Jets (HEJ)

Outline

- Jets at the LHC
- Overview of HEJ framework
- Jet Results
- W + jets

in collaboration with Jeppe Andersen arXiv:0908.2786, 0910.5113

www.cern.ch/HEJ

Why do we need something new?

- The Large Hadron Collider will probe new energy regime
  – the "same" physics will behave differently!

- At LHC, impact of hard QCD corrections greater than previous colliders
  – pdf suppression of extra radiation is not as large.
  – extra power of coupling, but *huge* phase space.

- Multi-jet signals are common signals of new physics
  $\Longrightarrow$ Standard Model contribution key backgrounds.

Why do we need something new?

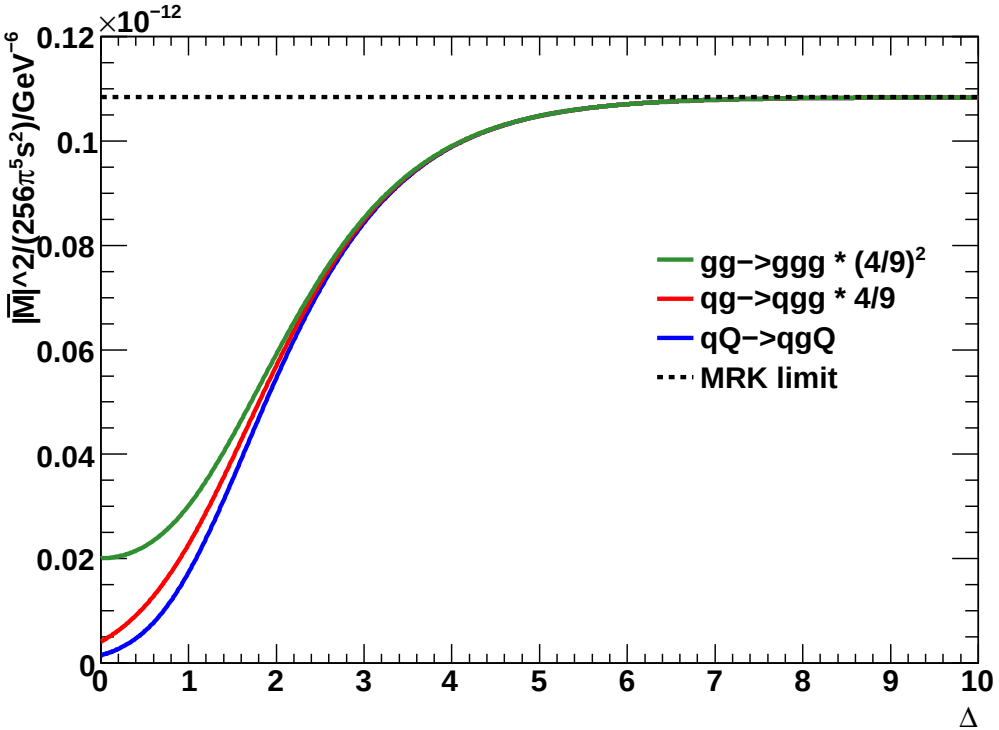
- Usual approach = Monte Carlo + parton shower:
  Herwig, Pythia, AlpGen, MadEvent, Sherpa, WHIZARD
  MC@NLO, POWHEG,...
- Parton shower sums the large contribution at small s_{ij} between quarks/gluons
  - good at jet structure, *but* underestimates rate and hardness.
- HEJ concentrates on the description of emission at large s_{ij}
  – captures hard jet production.
  – has been applied to jets, W+jets, Z+jets, Higgs + jets.

High Energy Behaviour

Universal behaviour in all channels

before exact limit reached.

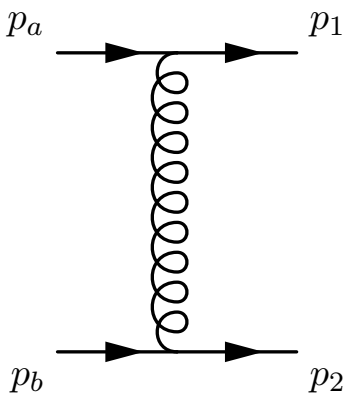
We extract the parts of the amplitude which dominate at large s_{ij}



Increasing rapidity spans $(y_f - y_b)$

Example 1: $qQ \to qQ$

The simplest case is $qQ \to qQ$.



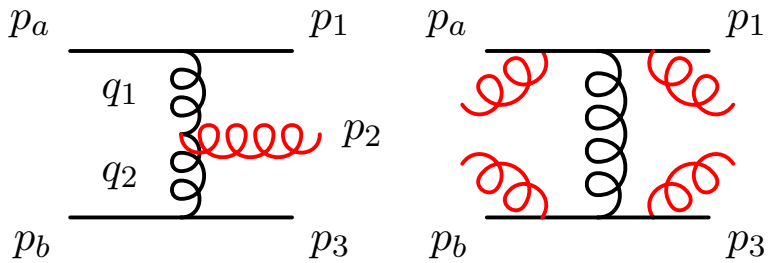
$$\frac{8g_s^4}{9}\frac{|j^\mu(p_a,p_1)\cdot j_\mu(p_b,p_2)|^2}{\hat{t}^2}$$

$$= \frac{4g_s^4}{9}\frac{\hat{s}^2+\hat{u}^2}{\hat{t}^2}$$

- "Factorised" form – p_a and p_1 can be split from p_b and p_2.
- In High Energy limit, $\to \propto \hat{s}^2/\hat{t}^2$ as in plot.
- We will model all processes as current-current scattering.

Example 2: $qQ \to qgQ$

Add these together to get effective vertex:



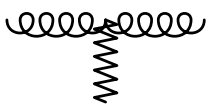
$$\mathcal{A}_{qQ\to qgQ} = g_s^3\, C_g\, \varepsilon_\rho^*\, \frac{j^\mu(p_a,p_1)\cdot j_\mu(p_b,p_2)}{q_1^2 q_2^2}\, V^\rho(q_1,q_2)$$

$$\begin{aligned} V^\rho(q_1,q_2) = & -(q_1+q_2)^\rho \\ & + \frac{p_a^\rho}{2}\left(\frac{q_1^2}{p_2\cdot p_a} + \frac{p_2\cdot p_b}{p_a\cdot p_b} + \frac{p_2\cdot p_3}{p_a\cdot p_3}\right) + p_a \leftrightarrow p_1 \\ & - \frac{p_b^\rho}{2}\left(\frac{q_2^2}{p_2\cdot p_b} + \frac{p_2\cdot p_a}{p_b\cdot p_a} + \frac{p_2\cdot p_1}{p_b\cdot p_1}\right) - p_b \leftrightarrow p_3. \end{aligned}$$

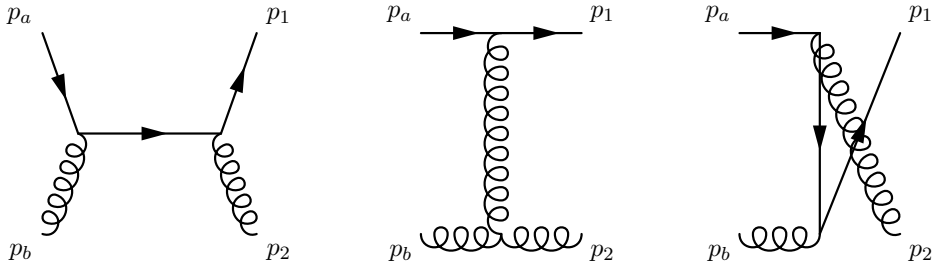
Gauge invariant and in HE limit, agrees with the Lipatov vertex.
Andersen&JS [arXiv:0908.2786]

More Pieces

- Gluons:



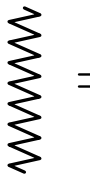
from



only t-pole remains with $j^\mu j_\mu$ structure in hel. cons. configs

Andersen & JS arXiv:0910.5113

- Regulate the divergences from soft emissions with HE limit of virtual corrections – given by the Lipatov ansatz:

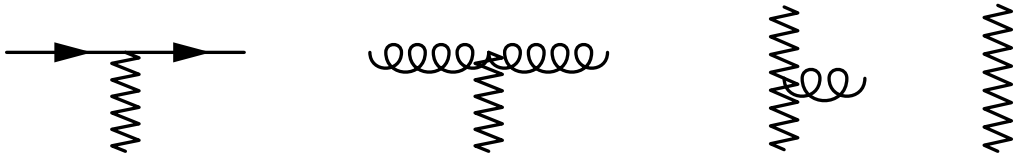


$$= \frac{1}{t_i} \exp[\hat{\alpha}(q_i)(y_{i-1} - y_i)]$$

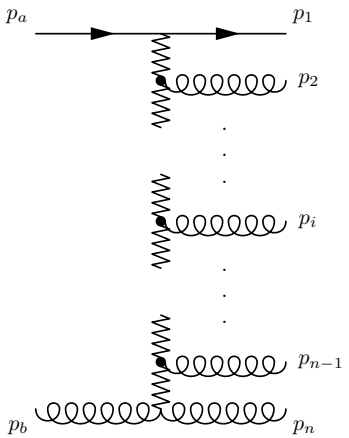
Add to real corrections to leave finite sum.

Resummation

We have:



- Assembled like this:



- The number of emissions is a variable in our integration.
- These give us the leading log terms ($\alpha_s^i \log^i s/t$) for *all* i.

Assembly

- These pieces are implemented in a fully flexible Monte Carlo.

  $\longrightarrow$ Allows arbitrary cuts and analyses.

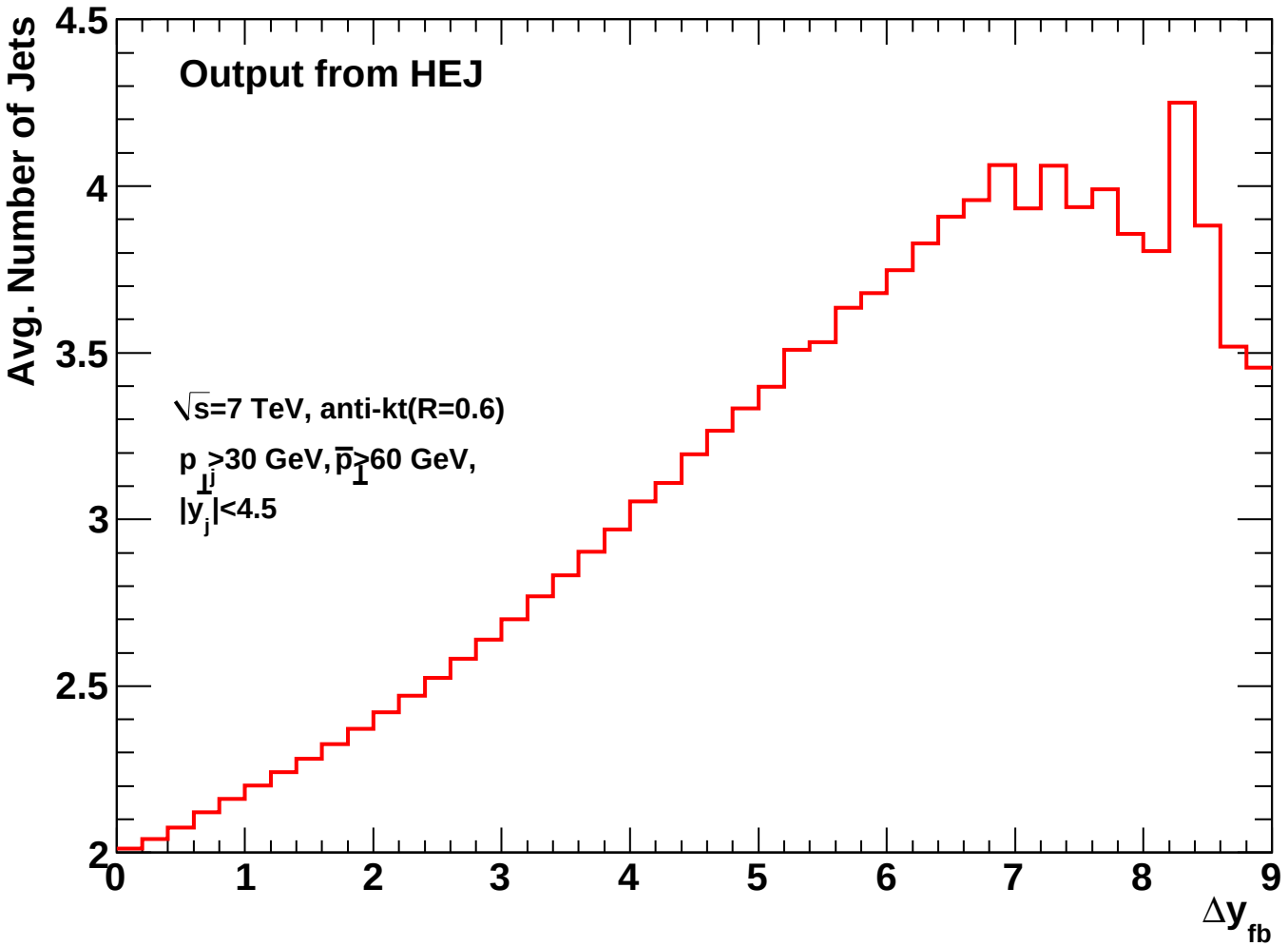
- Matching included for jets and W+jets, up to 4 jets.

  MEs taken from Standalone `MadGraph`.

- Also:
  - Matching to a parton shower almost complete. Andersen, Lönnblad & JS
  - Interface to LHAPDF

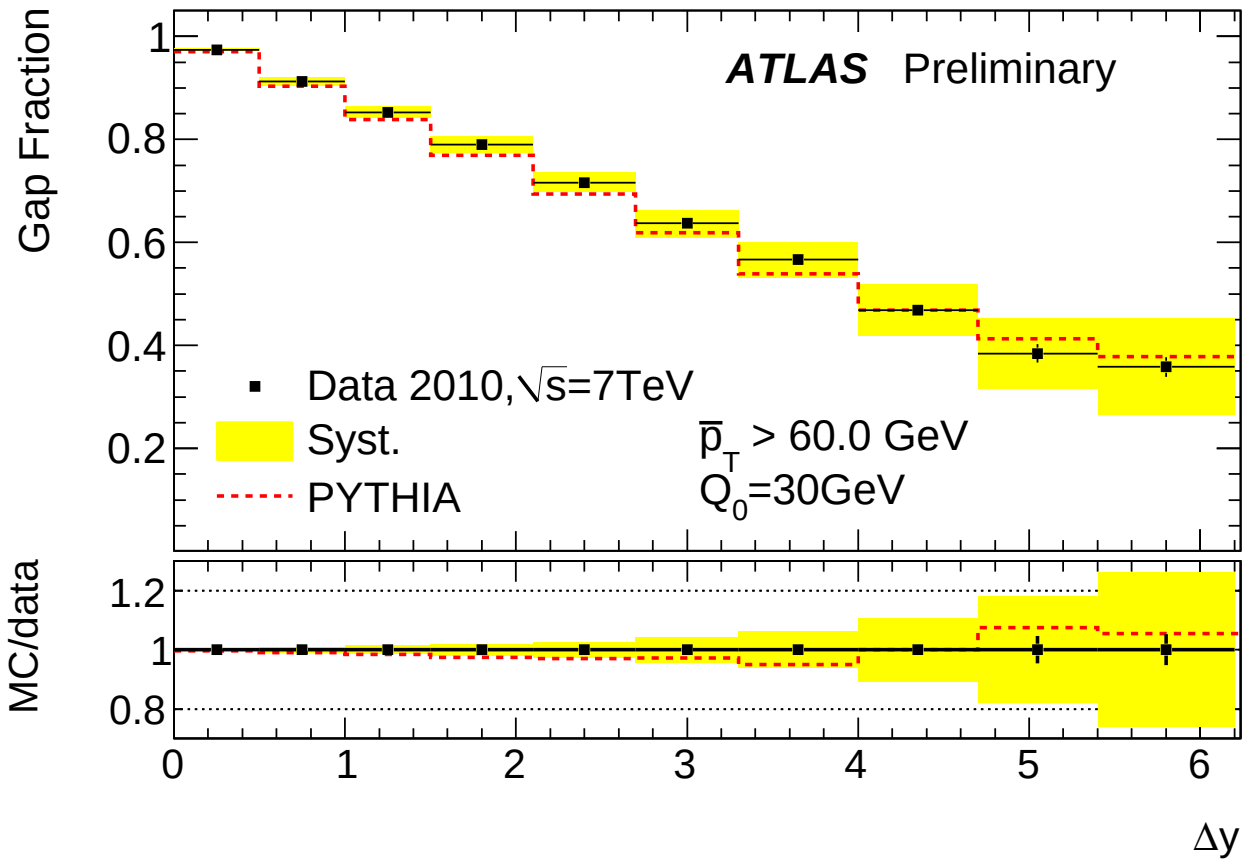
Jet code available at `www.cern.ch/HEJ` and in GENSER library.

Average Number of Jets



Jet Gap Fractions

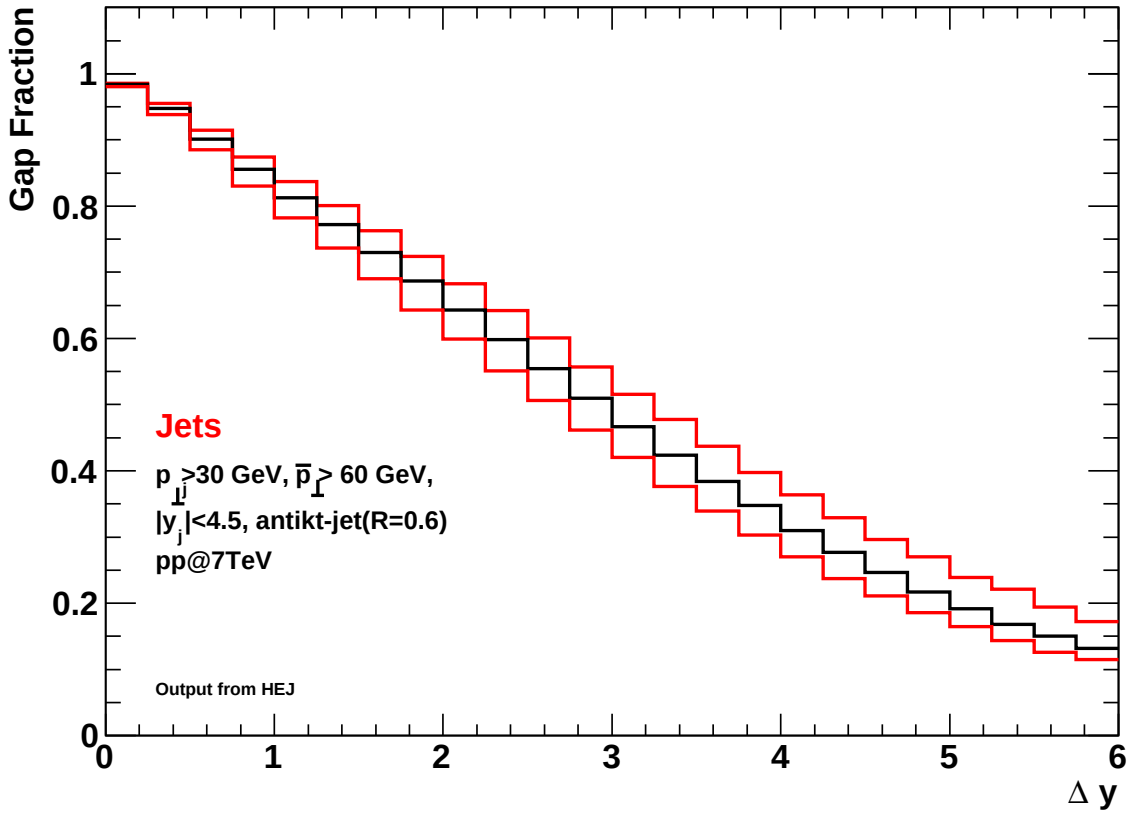
Atlas now has data for fraction of events with rapidity gap:



ATLAS-CONF-2010-085

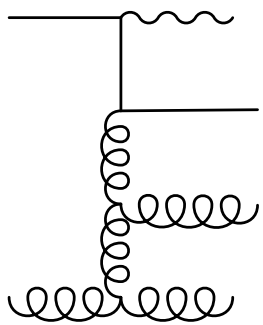
Jet Gap Fractions

HEJ does too . . .



Red lines show scale uncertainty.

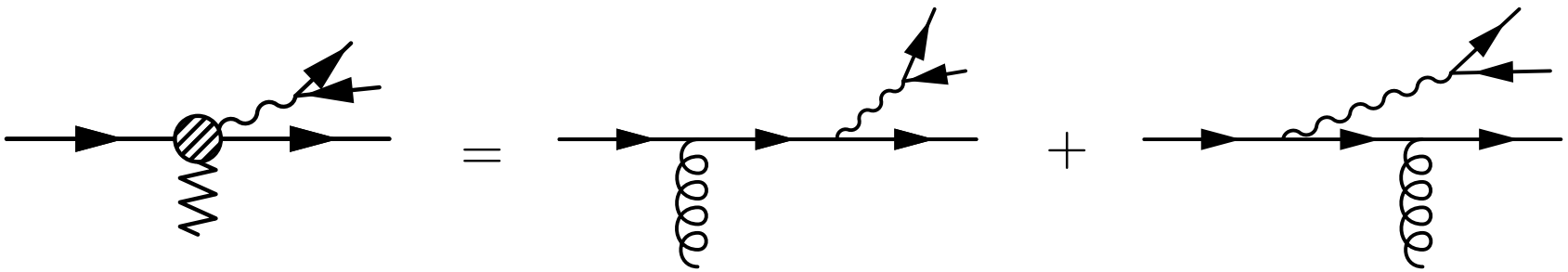
Remaining Parts – Weak Bosons



- W+jets at the LHC:

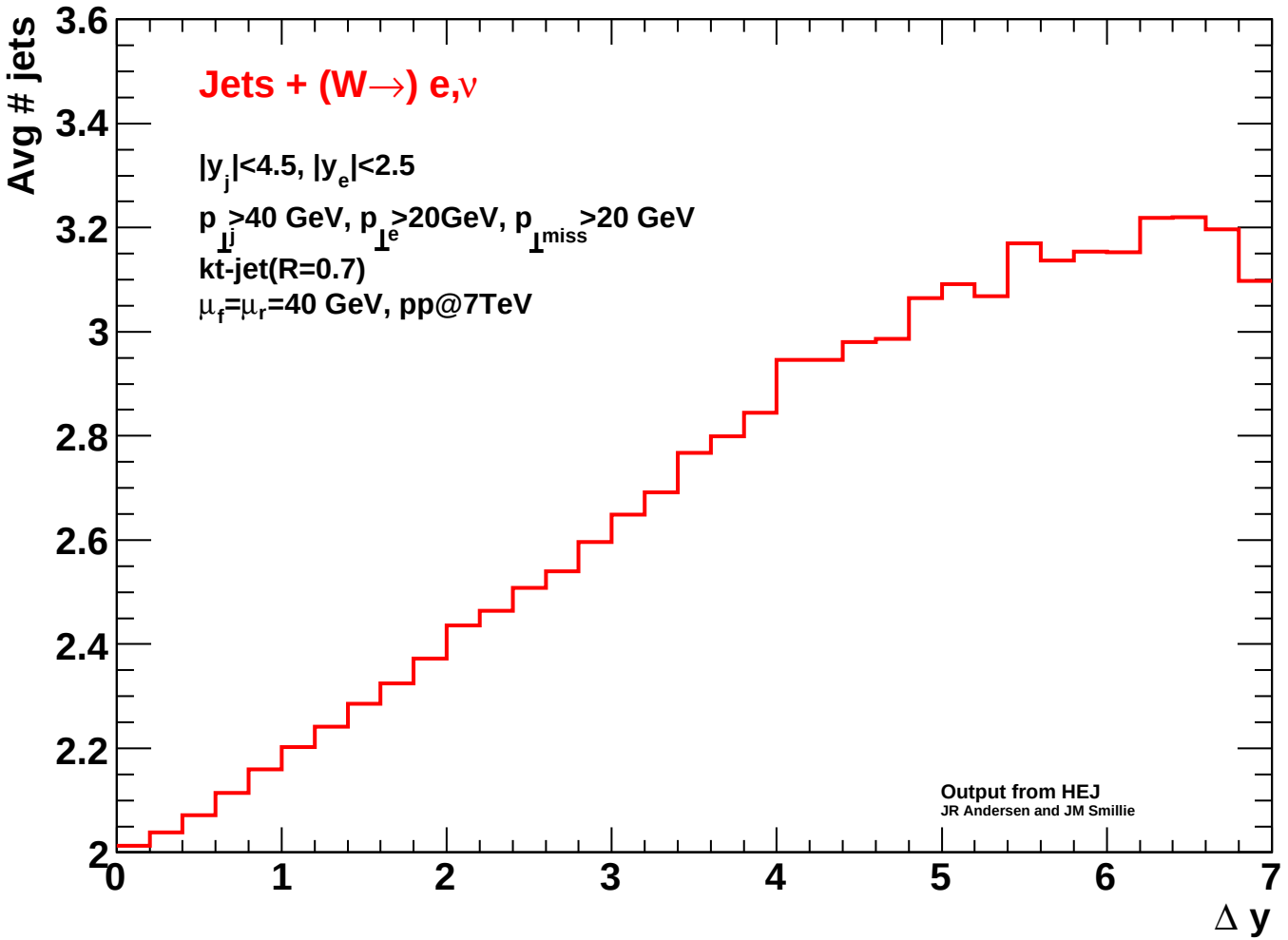
- Treated in full HE limit before, with constraint on decay products. Andersen, Del Duca, Maltoni, Stirling: hep-ph/0105146

- In HEJ:



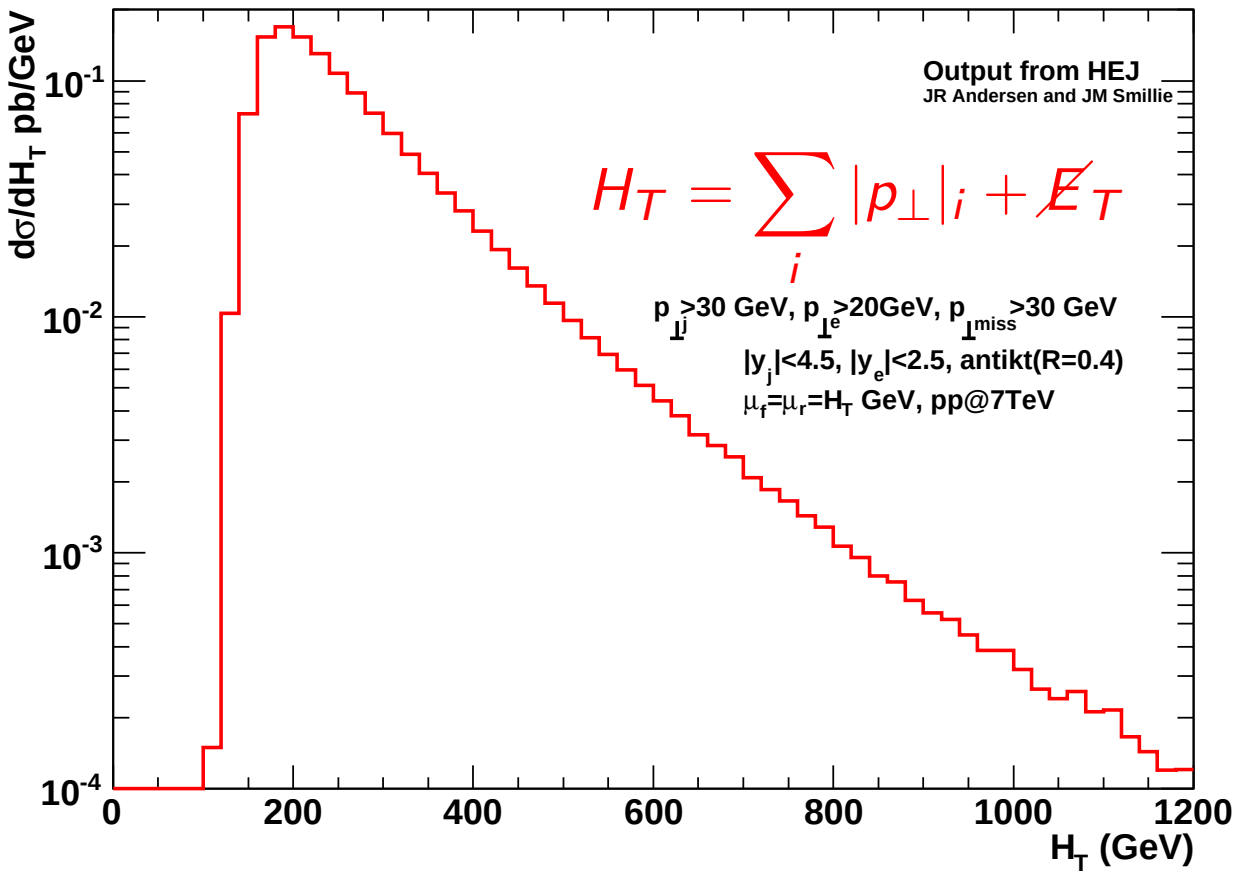
No constraints on the decay products of the W/Z.

W+jets


Avg # jets
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
0
1
2
3
4
5
6
7
Δ y
Jets + (W→) e,ν
|y_j|<4.5, |y_e|<2.5
p_⊥^j >40 GeV, p_⊥^e >20GeV, p_⊥^miss >20 GeV
kt-jet(R=0.7)
μ_f=μ_r=40 GeV, pp@7TeV
Output from HEJ
JR Andersen and JM Smillie

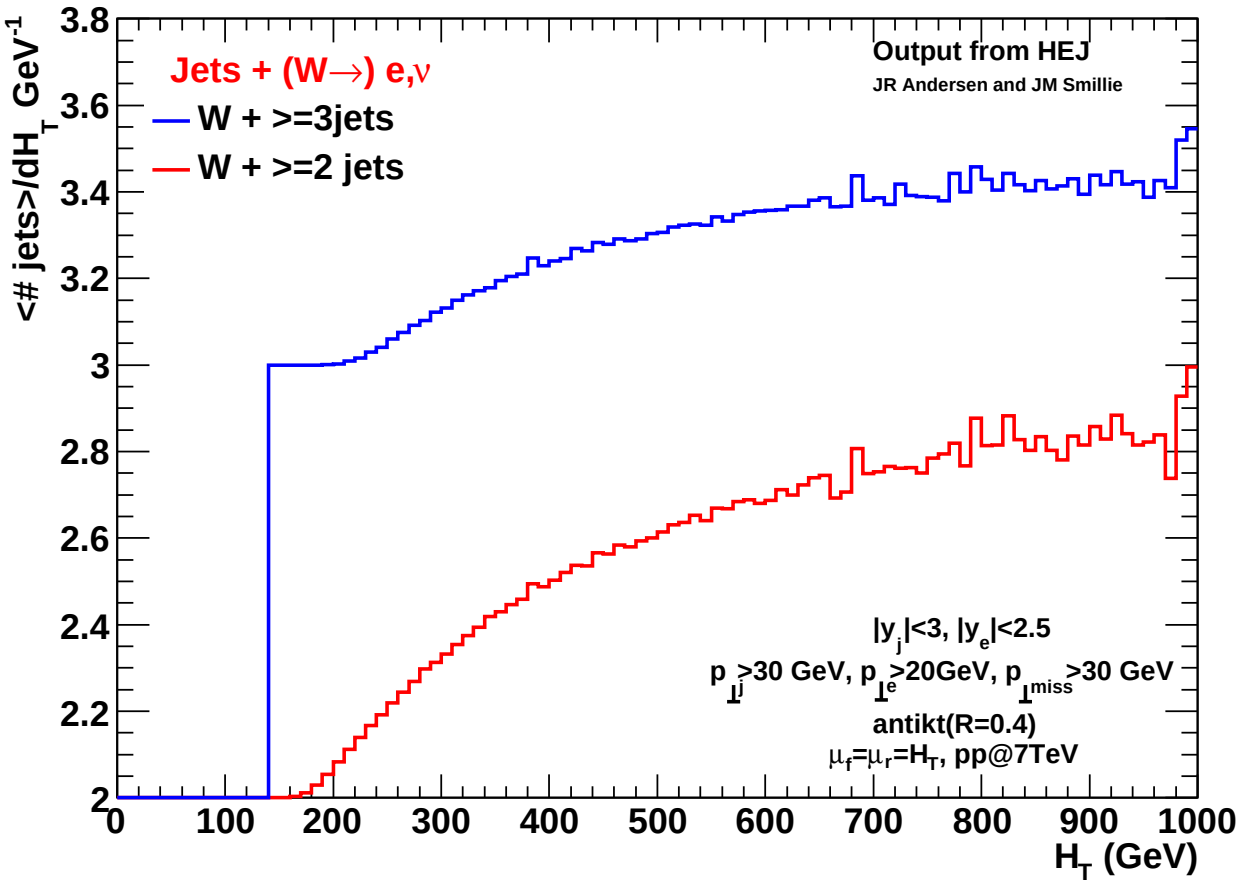
H_T Distribution

The H_T distribution is used to gauge the scale of new physics.



H_T Distribution

In $\geq 2j$ and $\geq 3j$ samples, averages show effect of extra emissions.



Conclusions and Outlook

- The HEJ framework approximates production of multiple hard jets.
- Applied to jets, W+jets, Z+jets, H+jets in a flexible way.
- Available at `www.cern.ch/HEJ` and through the GENSER library.
- An important tool to make the most of LHC data.

Coming soon . . .

- Jet analysis paper
- W+jets code publicly available