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IP3

Probing colour flow with jet vetoes

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in collaboration with Jeff Forshaw and Mike Seymour (*et al.*)

JHEP 1108 (2011) 157, JHEP 0907 (2009) 023

Introduction

- The basic picture:
  - hard partons are produced in high energy collisions
  - they hadronise into colour-neutral particles
  - these hadrons are highly collimated into jets

- Colour correlations between jets can help us in many studies
- For instance in reducing overwhelming QCD backgrounds
- A better understanding of QCD is interesting on its own

- Colour connections measured in the past (DESY, LEP, Tevatron)

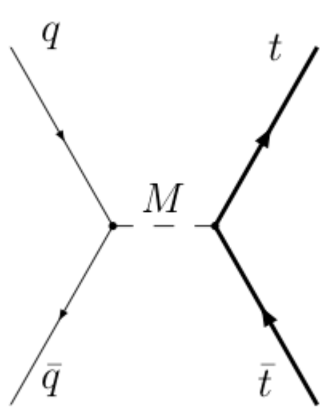
Jet vetoes

- Jet vetoes appear very often in particle physics analyses
- For instance, as tool to keep the jet multiplicity fixed
- Or, to enhance certain contributions (Higgs production in VBF)
- Jet vetoes can be used to probe the colour structure of a hard process
- Fairly simple ideas but theoretical issues (e.g. non-global logarithms)

Dasgupta and Salam
hep-ph/0104277

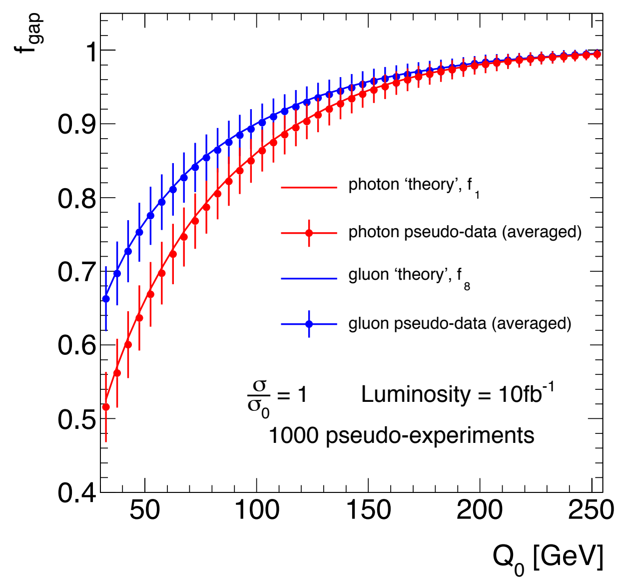
Identifying a 2 TeV resonance

- If a new resonance is identified it would be important to measure its properties (mass, spin and colour)
- The associated radiation depends on the new resonance's colour charge
- Difficulties because this is influenced by the UE
- We can study the response of this radiation to the presence of a jet veto
- If we keep the veto scale Q_0 large enough we can minimize contaminations from the UE



$$pp \to K \to t\bar{t}$$

$$\sqrt{s} = 14\,\mathrm{TeV}$$



with a jet veto in the central rapidity interval

Experimental uncertainties largely cancel when considering gap fractions

Sung
arXiv:0908.3688

Ask, Collins, Forshaw, Joshi and Pilkington
arXiv:1108.2396

Jet vetoes in Hjj

- Jet vetoes are used in VBF analysis to reduce the GF contribution
- Study the cross section as a function of the veto scale Q_0

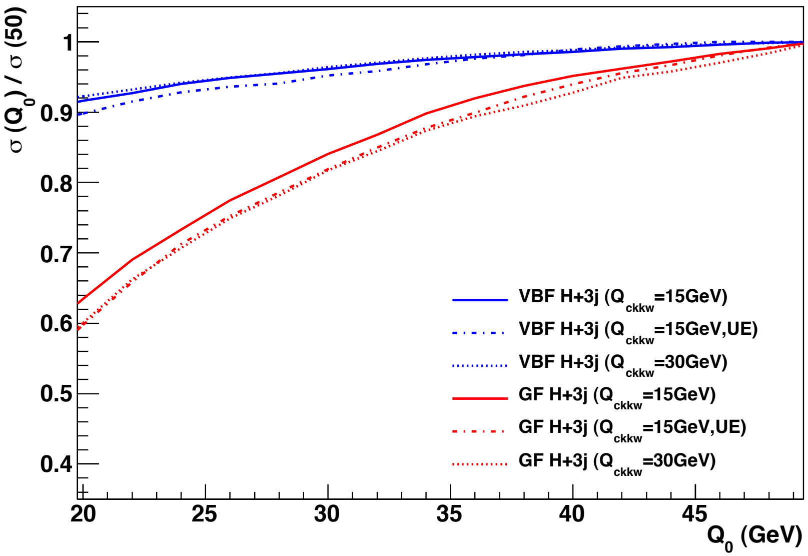
$$\sigma(Q_0) = \Lambda_g \sigma_g^{\rm SM}(Q_0) + \Lambda_V \sigma_V^{\rm SM}(Q_0)$$

- Fit to the data to simultaneously extract both couplings

- It makes sense only if we control the SM cross sections

$$\sigma(Q_0) = \sigma_{jj}(1 - P(Q_0))$$

- Theoretical uncertainties:
  VBF: ± 2 % (partial NNLO), ± 1%
  GF: ± 20 % (NLO), ± 20% (???)
  + PDFs and UE (both less than 5 %)
  Exp. Syst. (JES) ±20(30) % for VBF(GF)



The main theoretical issue is the Q_0 dependence in GF

Cox, Forshaw, Pilkington
arXiv:1006.0986

How well do we understand jet vetoes ?

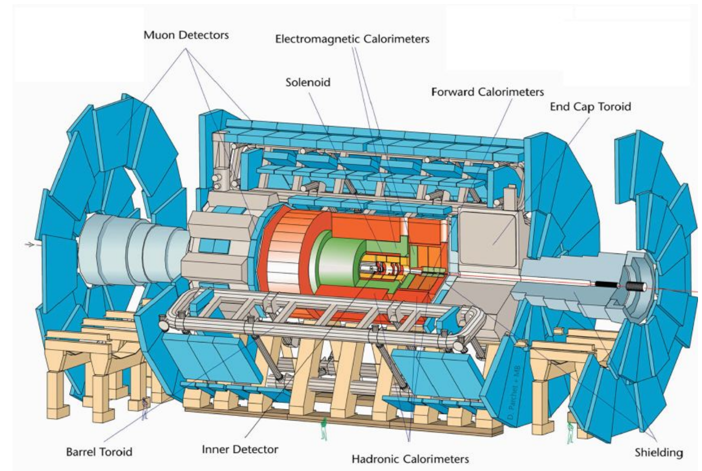
- If we want study jet vetoes to extract information on the colour flow we need theoretical control of the Q_0 dependence
- Large logarithms of Q_0/Q may appear
- MC parton showers can give a first idea but they neglect sub-leading N_c terms
- We need to do a better job in resumming those logarithms

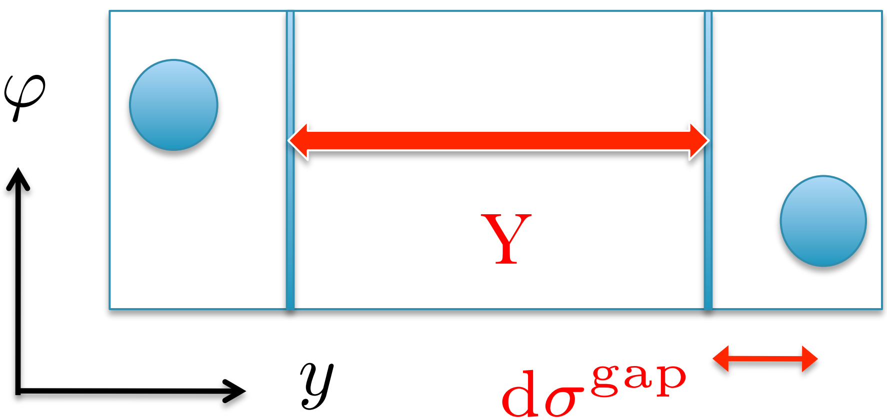
- We start by considering the simplest process, i.e. dijets events
- We want to compare theoretical predictions to LHC data to validate our tools

The observable

Production of two jets with

- transverse momentum Q
- rapidity separation Y
- Emission with $k_T > Q_0$ forbidden in the inter-jet region





$$Y = |y_3 - y_4| - 2D$$

$D \geq R$ azimuthally symmetric gap

$D = 0$ ATLAS choice

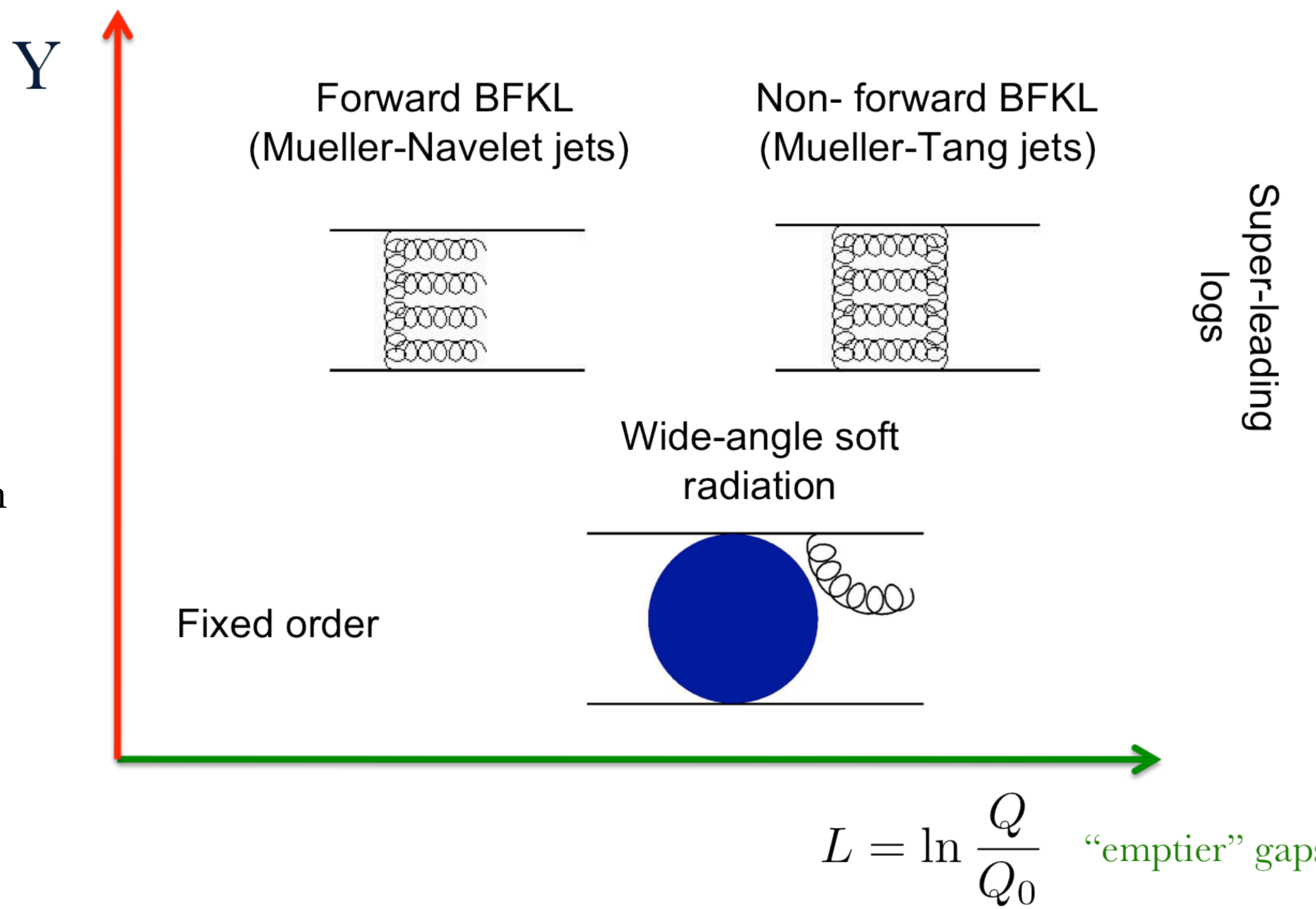
$$f^{\text{gap}} = \frac{\frac{d\sigma^{\text{gap}}}{dQ\,dY}}{\frac{d\sigma^{\text{incl}}}{dQ\,dY}}$$

Q_0 = 20 GeV:
the gap is a region of limited hadronic activity

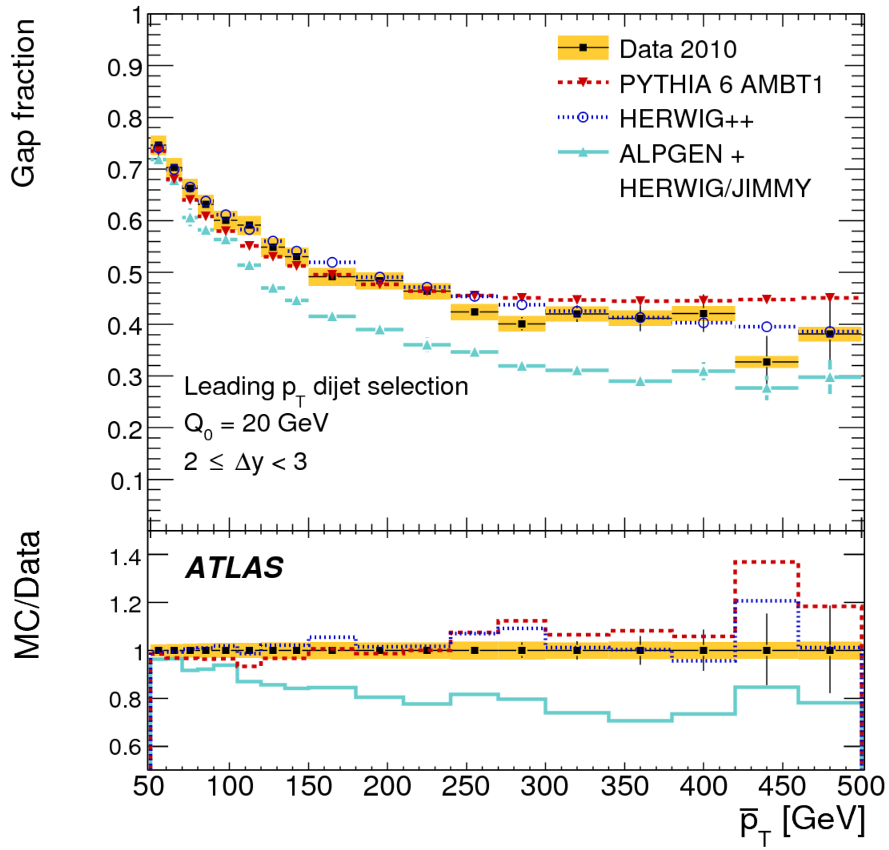
Exploring QCD in different regions

e.g.
High
Energy
Jets

by
Andersen
and
Smillie



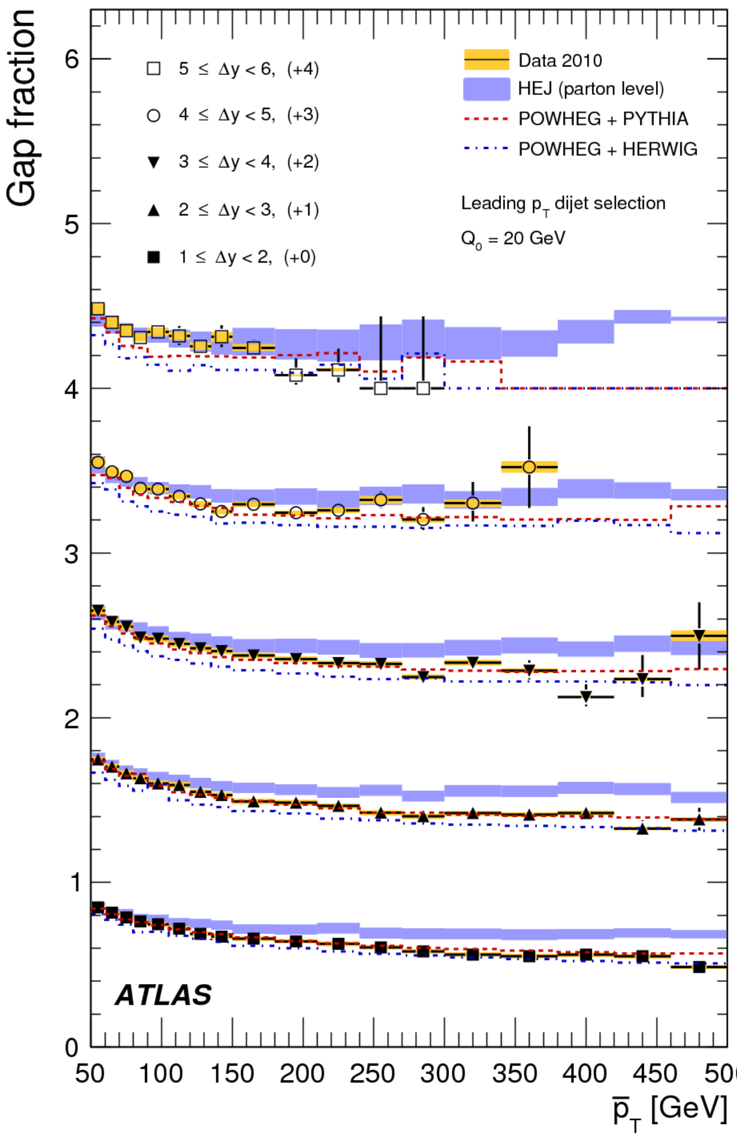
ATLAS data VS standard MC tools



ATLAS collaboration
arXiv:1107.1641

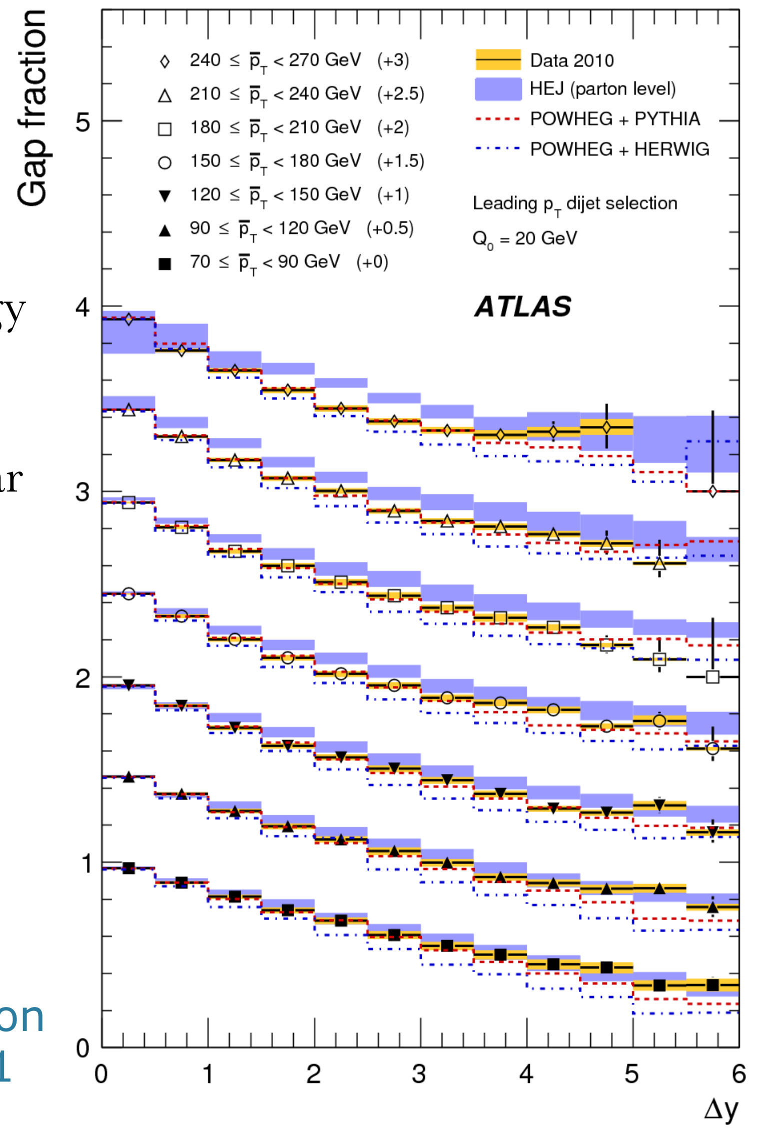
- Large spread in the theoretical predictions
- ALPGEN produces extra jets via matrix elements: harder radiation (gap fraction lower)
- But away from the data …

ATLAS data VS resummed calculations



- HEJ: high-energy resummation
- PS: soft/collinear resummation

ATLAS collaboration arXiv:1107.1641



Soft gluon resummation

- Real and virtual contributions cancel everywhere except within the gap region for

$$k_T > Q_0$$

  - One only needs to consider virtual corrections with

$$Q_0 < k_T < Q$$

- Leading logs (LL) are resummed by iterating the one-loop result:

$$\mathcal{M} = e^{-\alpha_s L \Gamma} \mathcal{M}_0$$

soft anomalous dimension

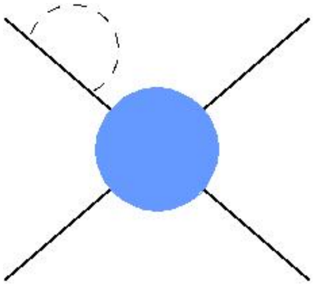
Born

Oderda and Sterman
hep-ph/9806530

Colour evolution

The anomalous dimension can be written as

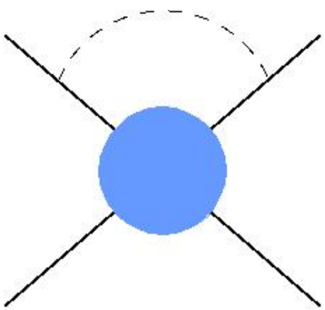
$$\Gamma = \frac{1}{2} Y T_t^2 + i\pi T_1 \cdot T_2 + \frac{1}{4}\rho(T_3^2 + T_4^2)$$



$$T_t^2 = (T_1^2 + T_3^2 + 2T_1 \cdot T_3)$$

is the colour exchange in the *t*-channel

- The $i\pi$ term is due to Coulomb (Glauber) gluon exchange

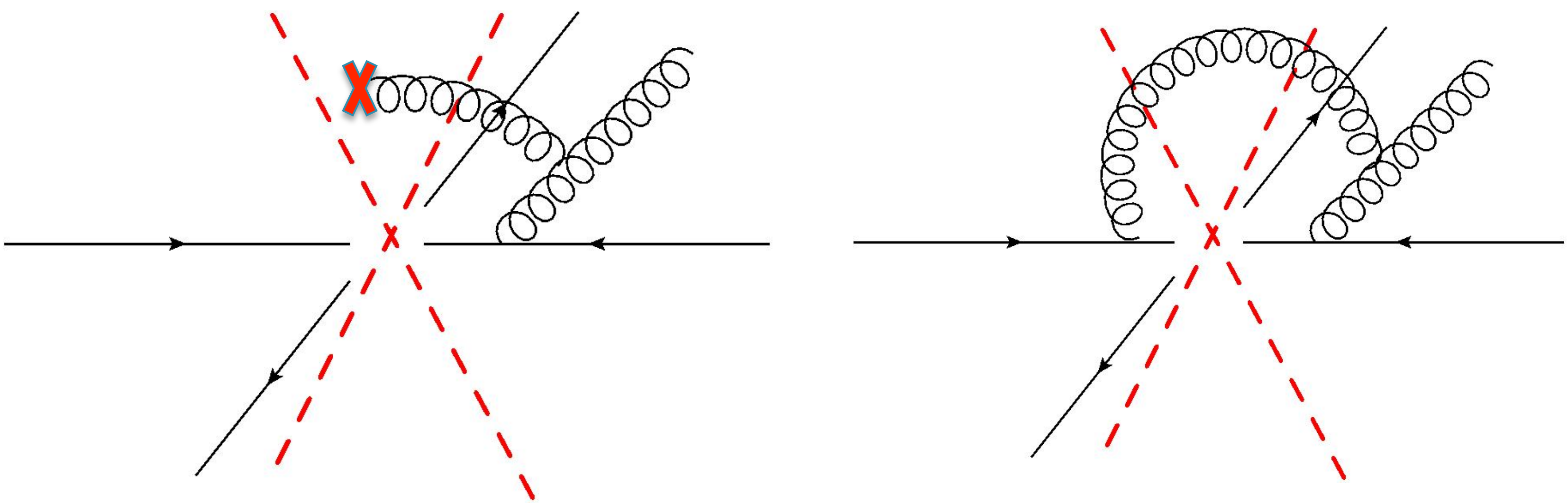


- Coulomb gluon contributions are *not* implemented in parton showers

Non-global effects

Dasgupta and Salam
hep-ph/0104277

- However this approach completely ignores a whole tower of LL
- Virtual contributions are not the whole story because real emissions out of the gap are forbidden to remit back into the gap



Resummation of non-global logs

- The full LL result is obtained by dressing the 2 to *n* (i.e. *n-2* out of gap gluons) scattering with virtual gluons (and not just 2 to 2)
- The colour structure soon becomes intractable
- Resummation can be done (so far) only in the large N_c limit

Dasgupta and Salam
hep-ph/0104277

Banfi, Marchesini and Smye
hep-ph/0206076

- As a first step we compute the tower of logs coming from only one out-of-gap gluon but keeping finite N_c:

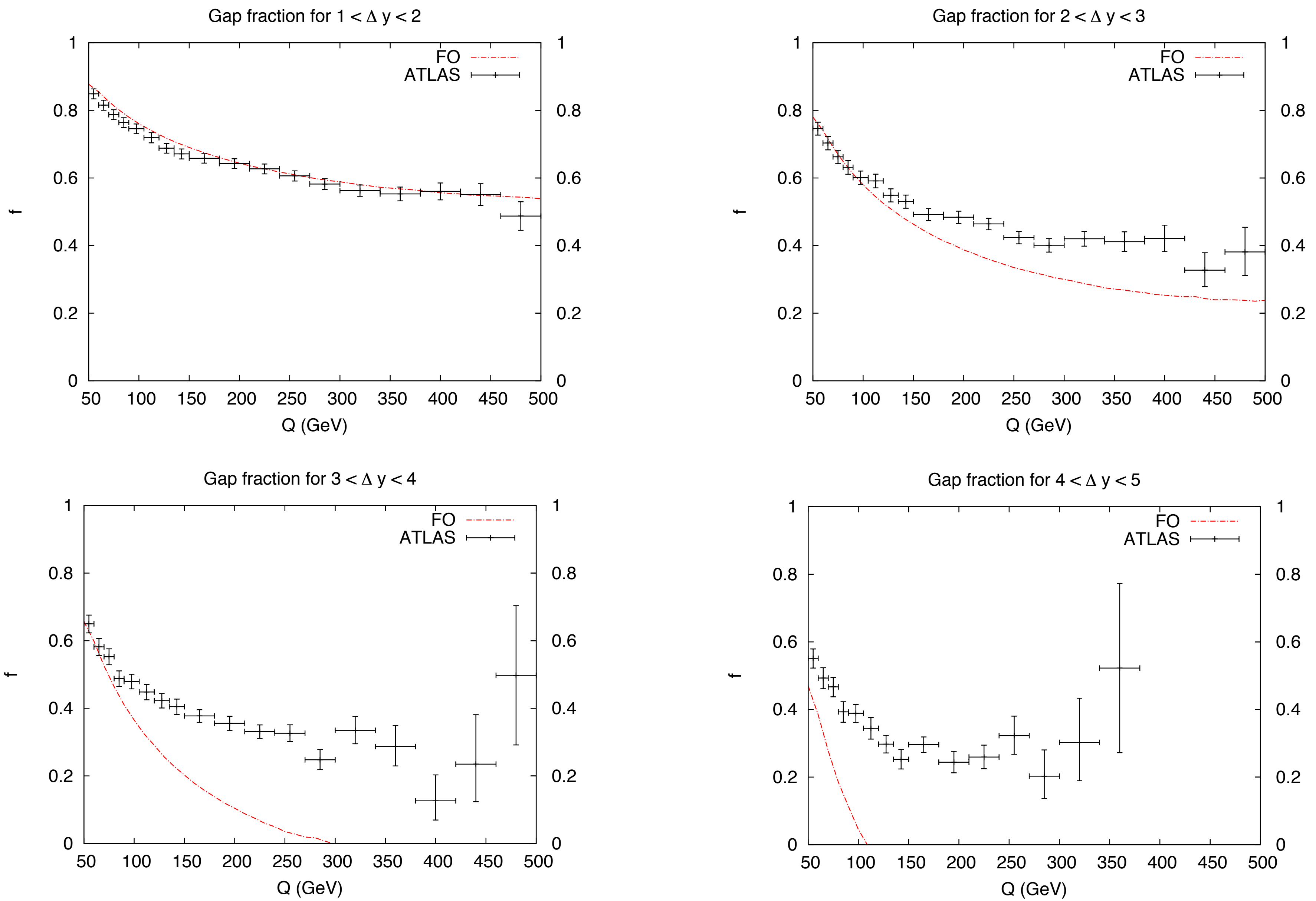
$$\sigma^{(1)} = -\frac{2\alpha_s}{\pi} \int_{Q_0}^{Q} \frac{dk_T}{k_T} \int_{\text{out}} (\Omega_R + \Omega_V)$$

- Related issue: super-leading logs at $O(\alpha_s^4)$, violation of collinear factorisation (?)

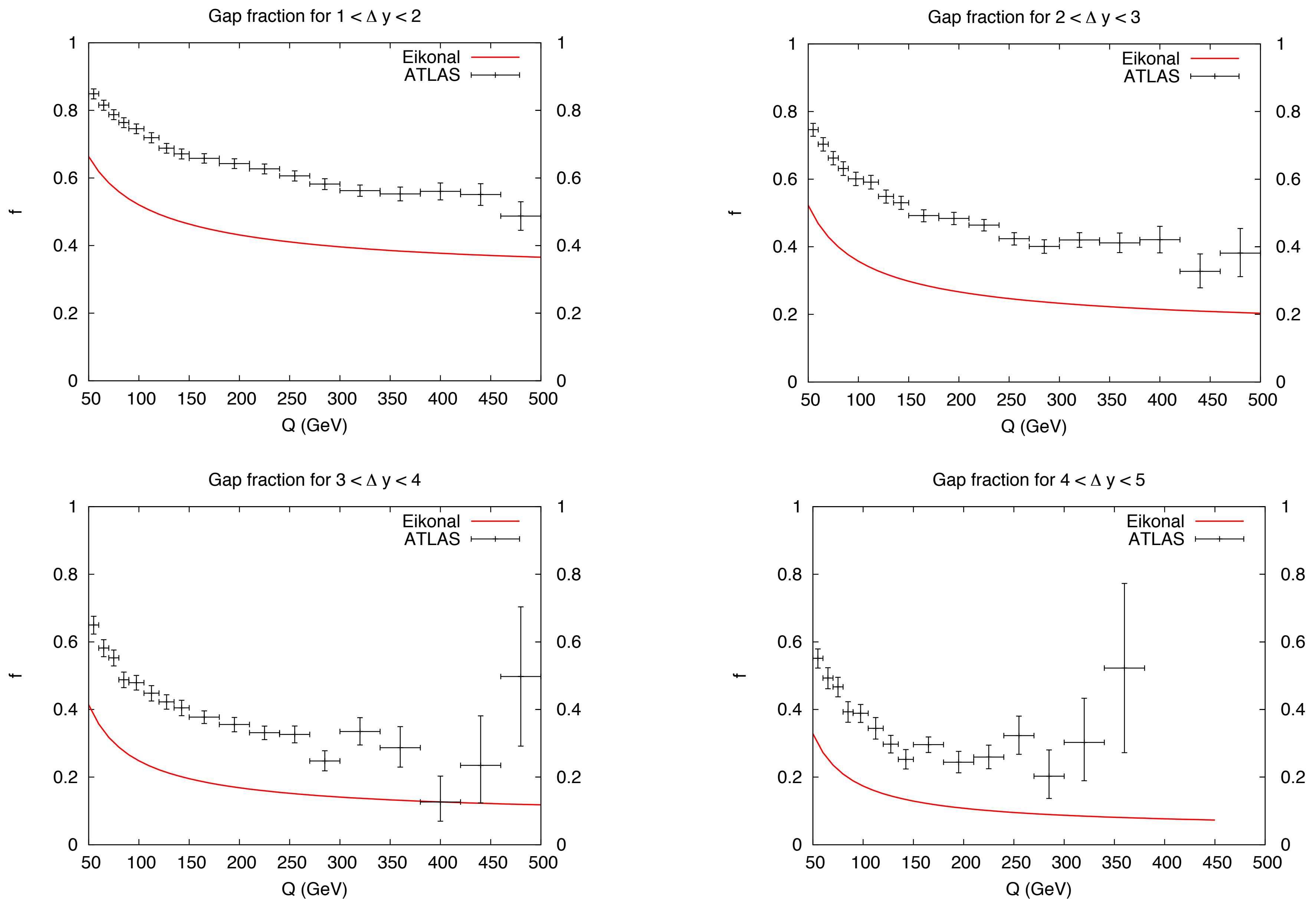
Forshaw, Kyrieleis, Seymour
hep-ph/0604094

Catani, de Florian, Rodrigo
arXiv:1112.4405

Data and FO (2 to 3 ME)



Data and Resummation



Resummation and kinematics

- When compared to the data our resummation performs poorly
- Why is that?

  - it has the full colour structure

  - it has approximate non-global logs

  - it does not conserve energy and momentum (eikonal approximation)

- Because of the fairly large value of Q_0 the region considered is not asymptotic and fixed-order effects are not negligible

- Thus we need matching to fixed order

Improving the resummation

- It turns out that energy-momentum effects are so extreme that naïve matching procedures fail

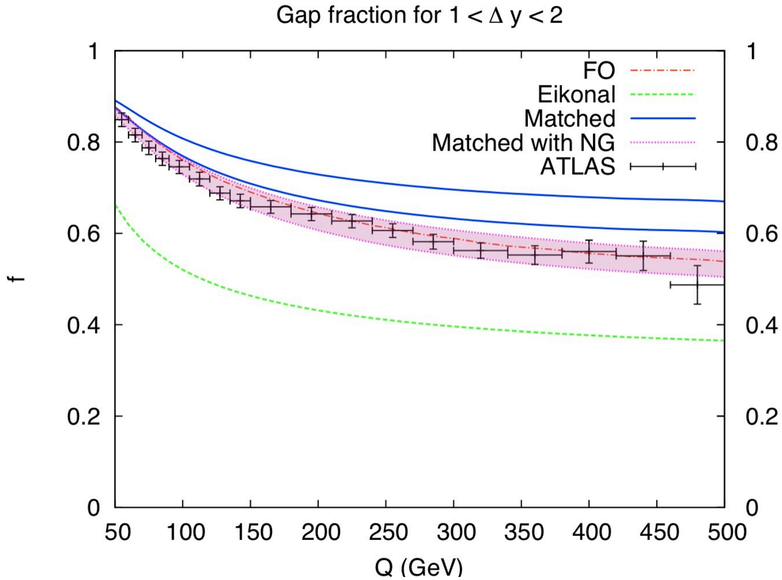
- We would like to modify our resummation so that energy and momentum are conserved at least for the first (hardest) emission

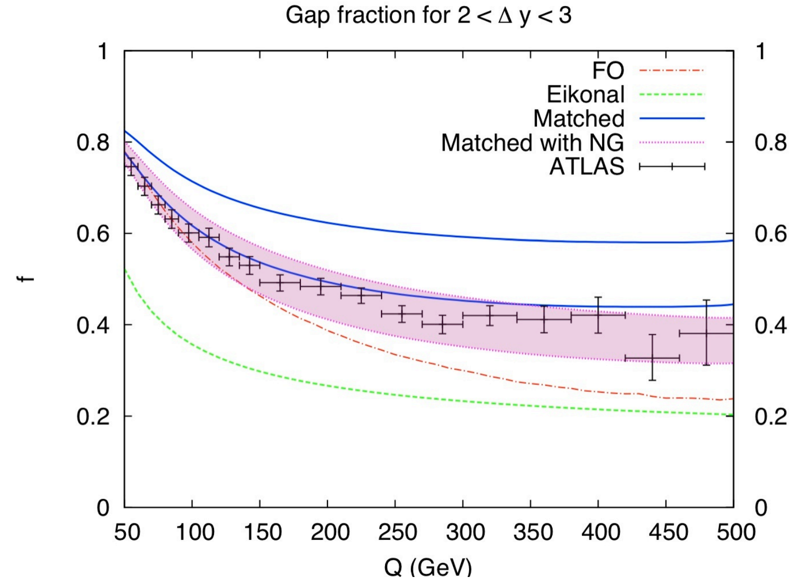
- The biggest effect comes from a shift in the PDFs x

- We construct a modified resummation that approximately takes into account this shift in x values

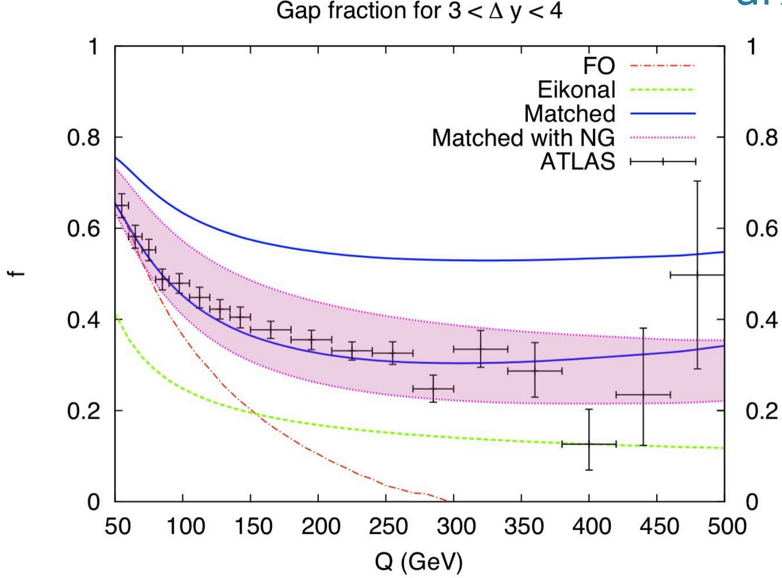
- This does not change the accuracy of our calculation (leading log)

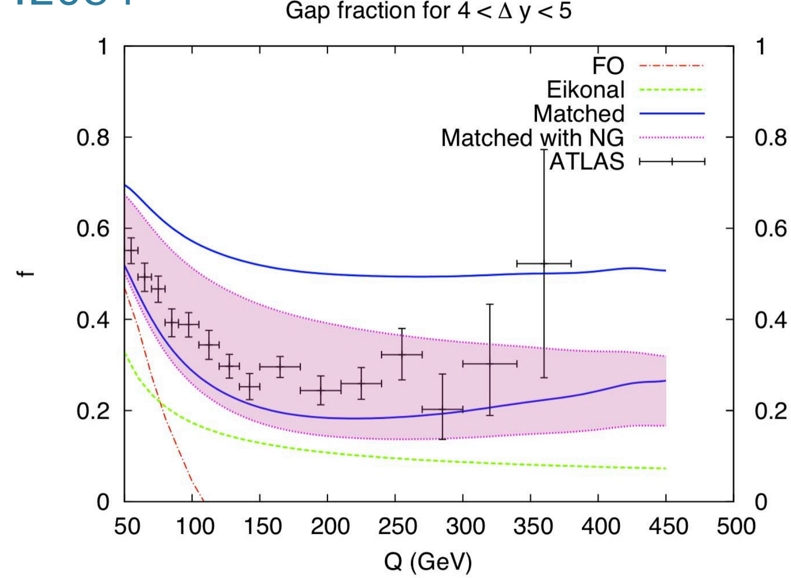
FO+Resummation





Duran, Forshaw, SM, Seymour
arXiv:1107.2084





More complicated final states

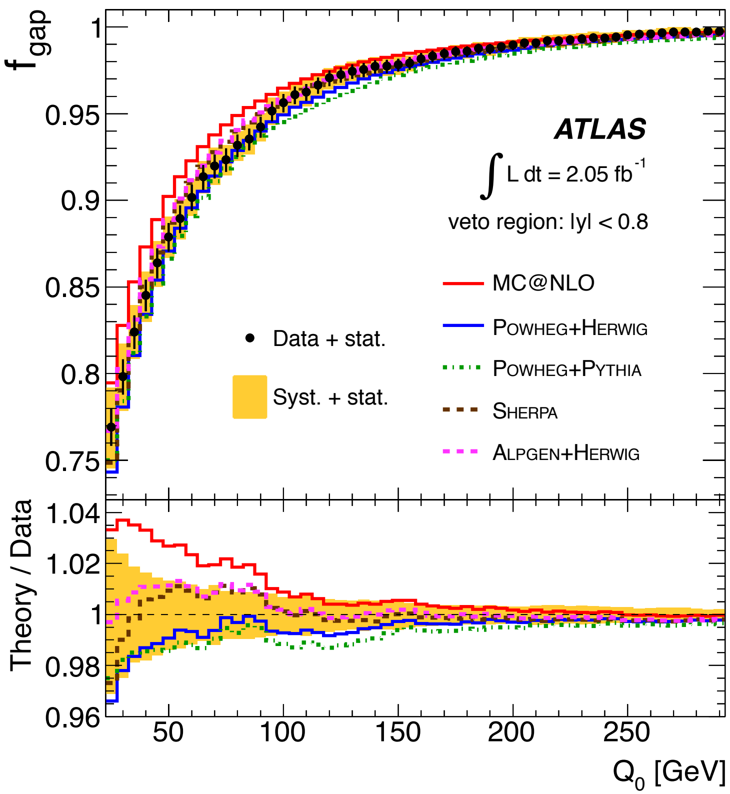
- ATLAS performed a measurement of gap events in top pair production

- Significant spread of standard MC

- We are working on prediction for Z+ 2 jets + veto

- The structure of the resummation remains the same

- Matching to NLO is possible



ATLAS collaboration
arXiv:1203.5015

Conclusions

- I have discussed jet vetoes as a probe colour flow in hard scatterings
- Perturbative choices for Q_0 reduce the influence of the UE
- The gap fraction is very good observable from the experimental viewpoint
- Theoretical issues:
    - resummation of large logs
    - non-global observable
- At the moment large theoretical uncertainties
- Improvement is expected with NLO matching