New techniques to study rapidity gaps and radiation between jets

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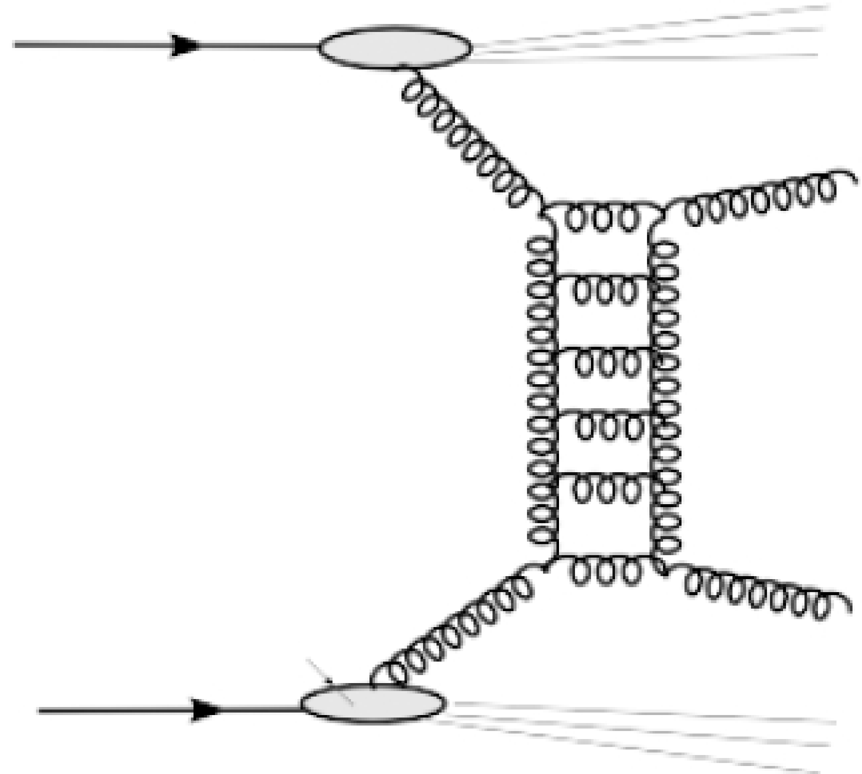
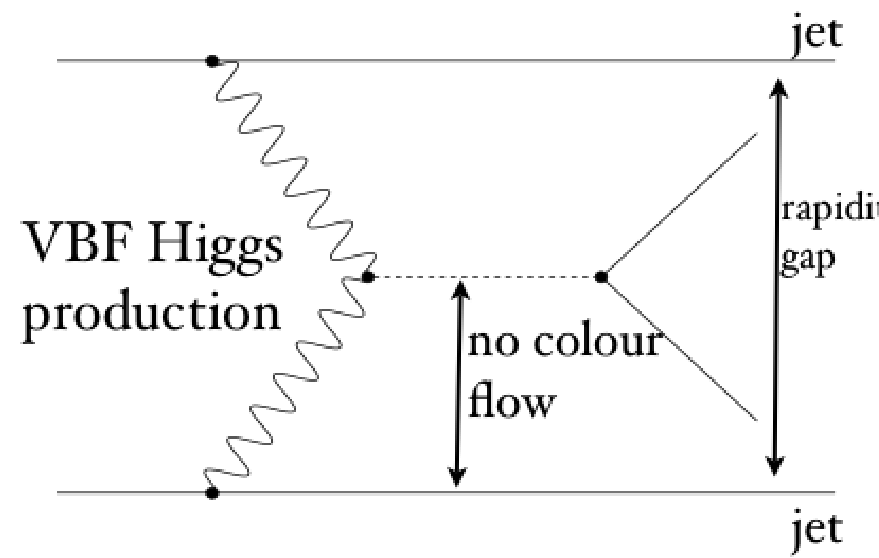
- ·First measurements at the LHC
- ·A more refined approach
- ·Effect of pileup and possible corrections
- ·The Fourier transformation

Introduction

Events with jets and rapidity gaps are interesting from the theoretical and experimental point of view.
We are producing them now in fully hadronic final states through colour-gluon ladders, we will have them me by electroweak processes for instance in VBF.



Atlas and CMS have a comprehensive program to study these events, but we would like to discuss here some points of theoretical and experimental relevance



Some theoretical points of discussion

"Diffractive" final states are referred to as:

interaction mediated by a colour singlet

interaction with a large rapidity gap at hadron level

The two definitions are not equivalent! (you can have evan large gaps from fluctuations)

Should we stick to the physics-driven (but model-dependent) definition 1), or the operational one 2) ?

However also the second definition is not free from ambiguity

Defining a rapidity gap as an eta region with no radiation at all (or based on multiplicity above a given threshold) is not infrared safe

Solution proposed by G.Oderda and G.Sterman (Phys. Rev. Lett. 81, 3591 (1998)) is to use the Et sum of kt jets in gap. This is the solution used in Hera from 2002

It is unlikely we are going to use kt at the LHC, so a possibility would be to use Anti-Kt instead

This way rapidity gap definition would equate a 'third jet veto' approach

which would be a safe value to cut on?

energy deposits close to a jet has a completely different physical meaning than one in the middle of the gap. Treat them equally?

How well do we trust description of soft radiation?

Which measurements of radiation in the gap could

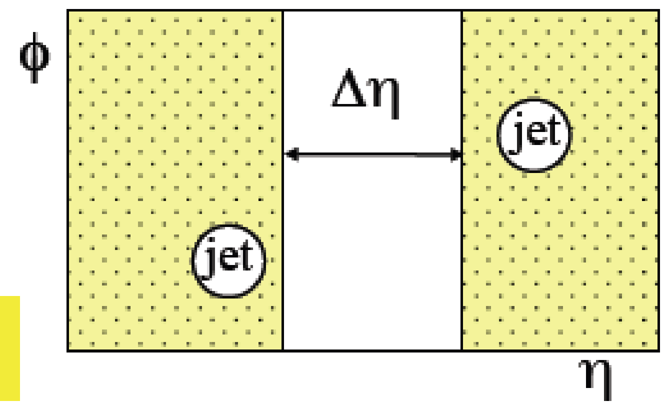
help modeling of this radiation?

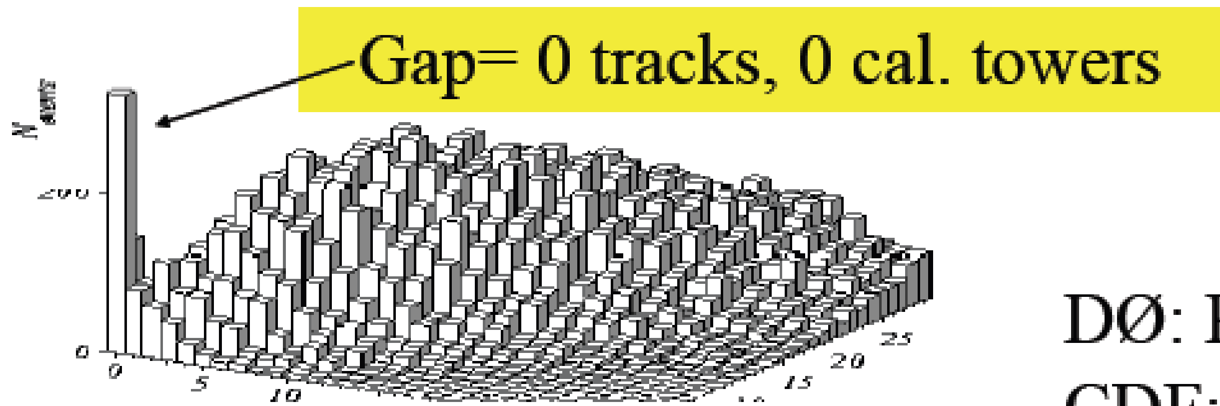
(examples from M.C. et al. Les Houches'09 tools p.114)

How to relate QCD measurements to VBF?

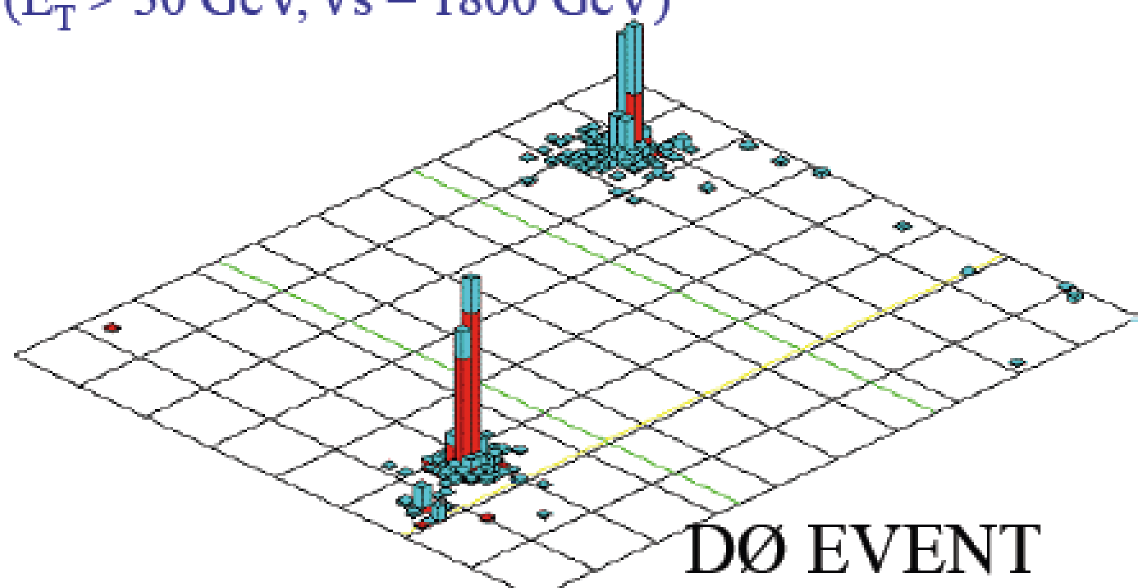
Previous Hard Color-Singlet Mesurements

QCD color-singlet signal observed in ~ 1 % opposite-side events (ppbar)





(E_T > 30 GeV, √s = 1800 GeV)



DØ EVENT

Publications

DØ: PRL 72, 2332(1994)
CDF: PRL 74, 885 (1995)
DØ: PRL 76, 734 (1996)
Zeus: PLB369, 55 (1996)
CDF: PRL 80, 1156 (1998)
DØ: PLB 440, 189 (1998)
CDF: PRL 81, 5278 (1998)
H1: Eur.Phys.J. C24 517 (2002)

Experimental considerations

Additional effects to study on data:

calorimeter noise

can appear anywhere, inside or outside the gap, and can destroy 'innocent' gaps

perhaps an algorithm could look at the jet shape before killing a gap based on noise?

pileup

can hit us already this summer. Some techniques can associate clusters to non-primary vertexes, but efficiency far from 100%.

just raise the threshold for this 'third jet veto'?

raise noise thresholds for clusters?

or try to estimate average activity on the event looking at large correlations or jet density?

how do we treat forward gaps where pileup will be higher?

Third jet veto

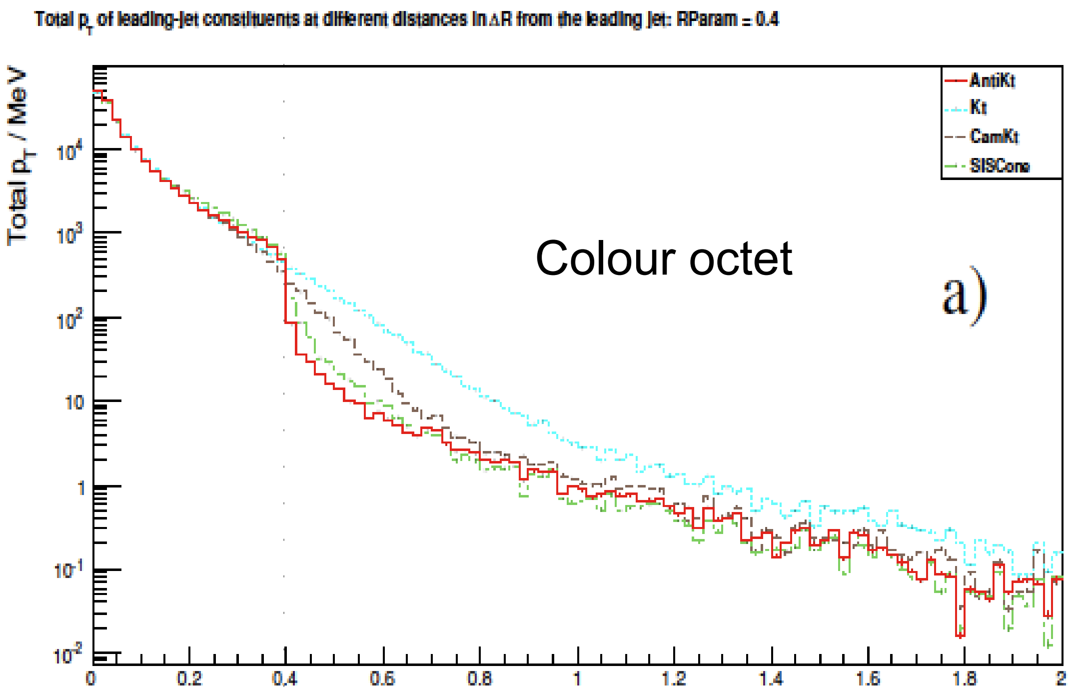
The issues outlined in the previous slides won't be addressed immediately.
Despite a lot of work and remarkable success in data/MC comparisons, the LHC detectors are still not 100% understood and calibrated.
It is likely that measurements presented to this summer's conferences will rather be based on jets.
Likely, the first measurement of interest for rapidity gap physics will be the third-jet veto, i.e.

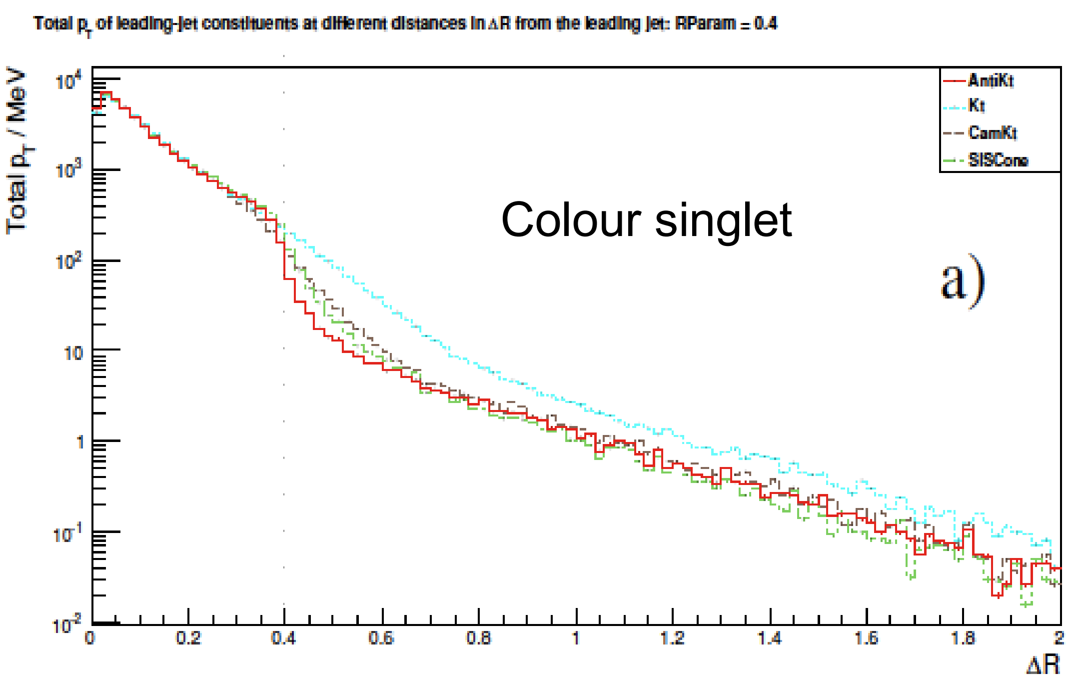
$$\text{Ratio (third jet)} = \frac{\text{Events without a third jet between the main two}}{\text{All events with forward and backward jets above a threshold}}$$

This is the default cut used in Higgs VBF studies; ever it was shown that up to 40% discrepancy exist on the efficiency of this approach for Higgs searches among various MC models.
Measuring this ratio from data will reduce these uncertainties, but a more systematic program to study of radiation between jets should be carried on with first data.

Radiation distribution for jet constituents

(M.C., J.Robinson, proceedings Les Houches'09, p. 114)





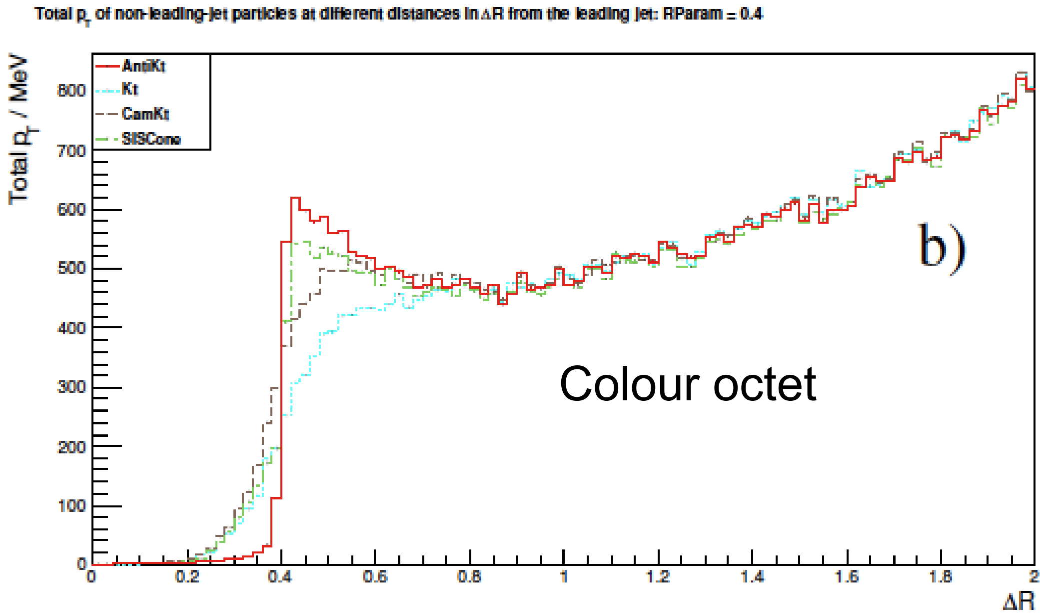
Jet shape can give us interesting information about underlying physics.

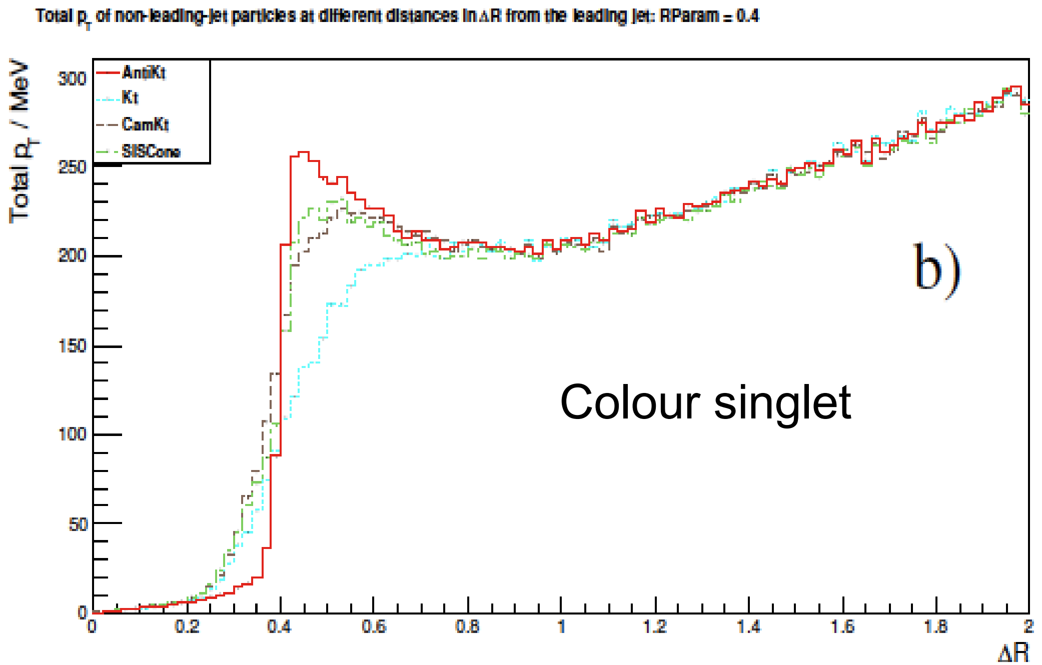
While no dependance on jet algorithm is seen inside the jet boundaries, differences are quite marked just outside the nominal radius of 0.4

Both the energy distribution close to the jet core and just outside the boundaries show clear differences between production mechanism (also due to gluon jets present in octet sample), both in overall density and shape

Radiation distribution for particles outside jets

(M.C., J.Robinson, proceedings Les Houches'09, p. 114)





Less dramatic differences observed for particles ending up outside the jet.

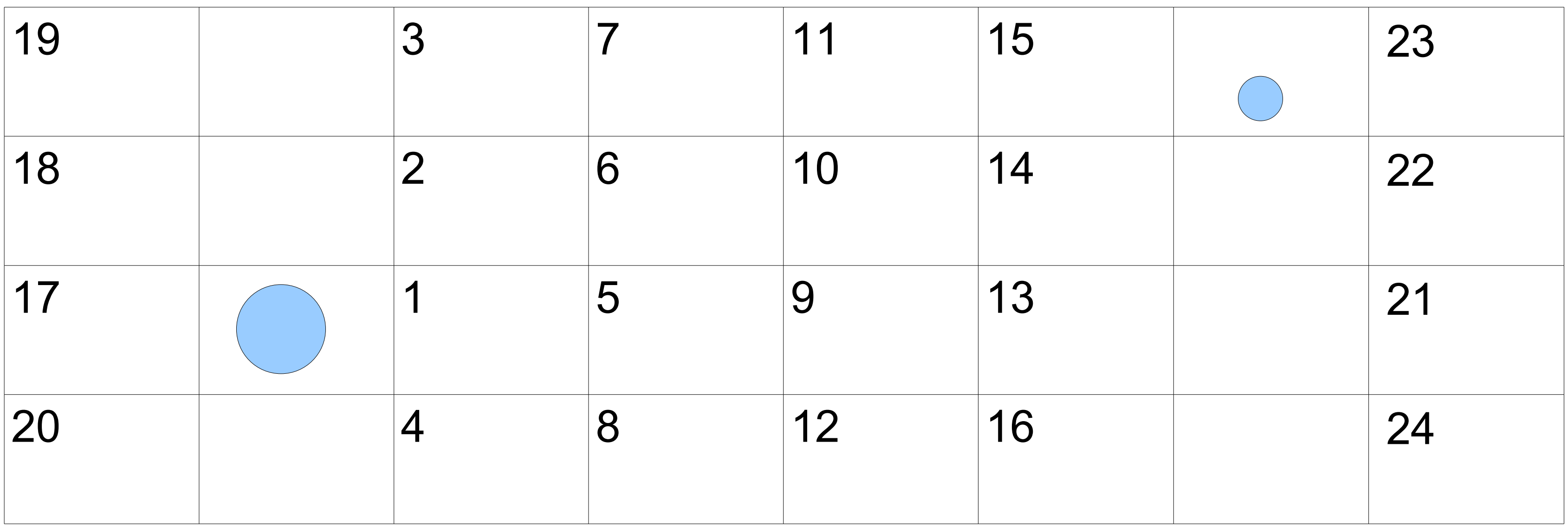
Radiation density is quite different, but shape (more sensitive to different models) is much more similar

Shape similarities mainly due to the Underlying Event

The gap-grid technique

(M.C., C. Taylor, Les Houches'09 proceedings p. 115)

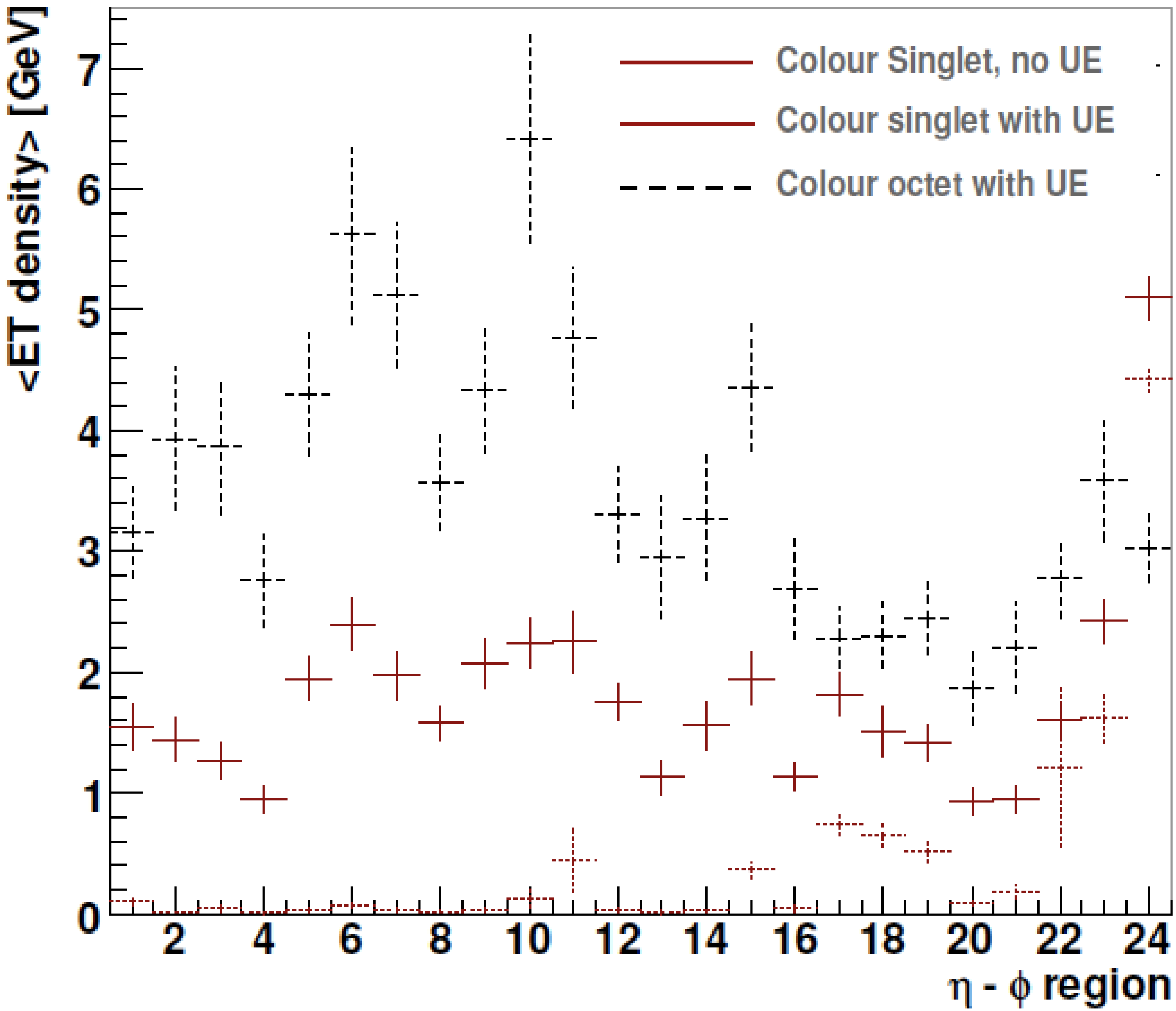
Treating all radiation as equal is not optimal, since colour flow is supposed to follow well-defined patterns. In a dijet events we can divide the detector in various η-φ zones, as follows:



Area between the two main jets is divided in 16 equal regions of size [(η1-η2)/4, π/2],η numbered 4*η + φ + 1 (both η and φ region numbers running from 0 to 3 from leading to direction of second jet).

Regions between jets and beam pipe are numbered from 17 to 24, following same φ convention.

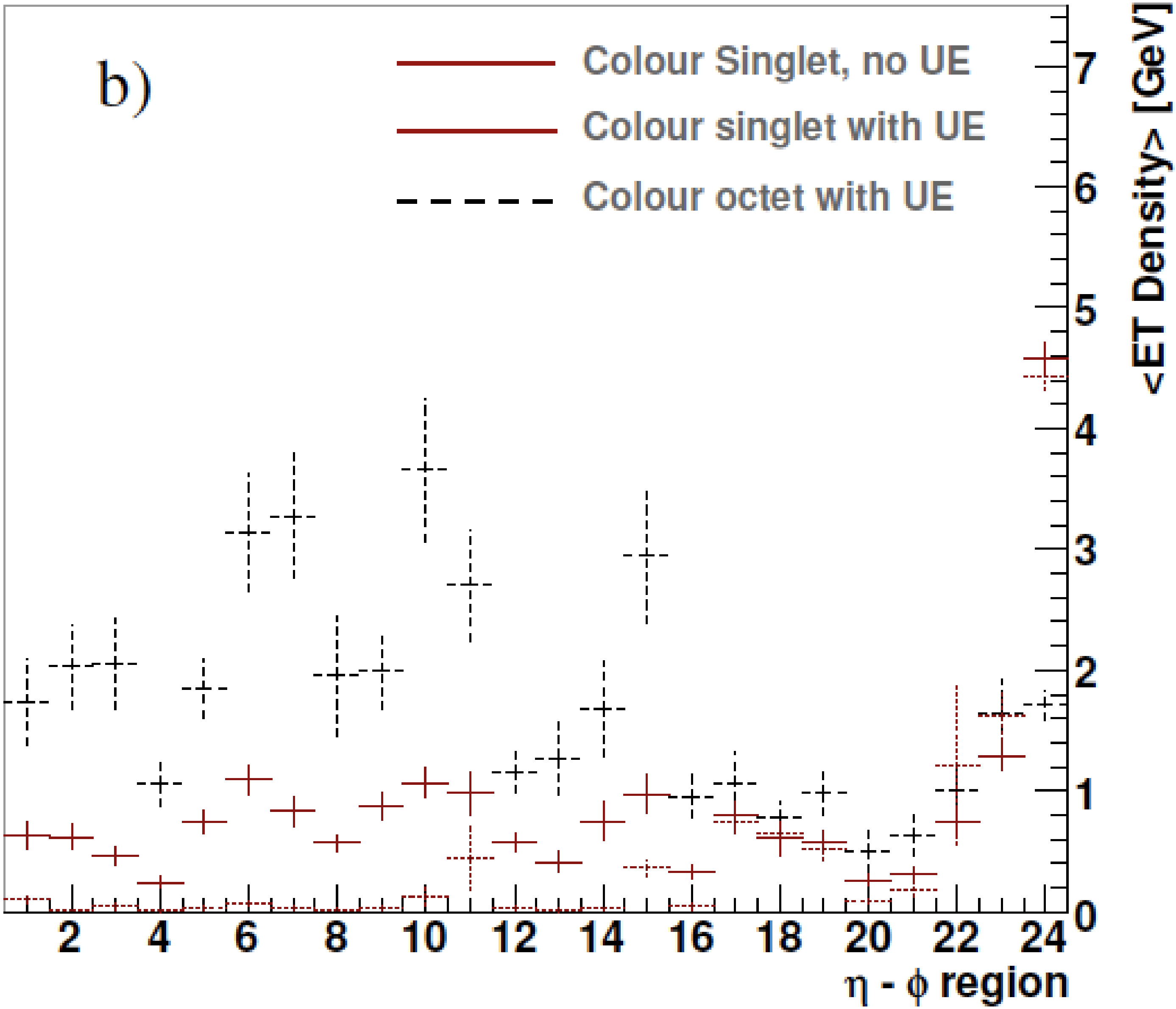
Average radiation density in various regions



A periodicity of 4 is present in the central region, with largest radiation density in regions between the jets

UE amounts to a similar radiation as the difference between colour singlet and octet.

UE correction



•Determine average radiation density in the event, as the truncated mean of the ratio

jet Et/area (suppressing hard jets)

•Subtract this density from the Et of each jet, multiplying it by its area

(original idea in M. Cacciari, G. Salam, and G. Soyez, JHEP 0804 (2008) 005, [arXiv:0802.1188 [hep-ph]].)

Discrimination between production mechanisms improves, even if the no-UE case is still not reached

Fourier transformation of the Δϕ distribution

(M. Campanelli and J. W. Monk, arXiv:0910.5108 [hep-ph]., submitted to JHEP)

A Fourier decomposition of the radiation density can offer insides into the various structures and scales present in the event. In 1 dim, if we bin the Δϕ distribution of clusters in the event (taking as ϕ=0 the direction of the leading jet) is 16 bins, the coefficients will be

$$
\begin{aligned}
C_n &= \frac{1}{\sqrt{N}} \sum_{l=0}^{N} E_T(\phi_l)\, e^{in\phi_l} \\
C_{N-n} &= \frac{1}{\sqrt{N}} \sum_{l=0}^{N} E_T(\phi_l)\, e^{-in\phi_l} e^{iN\frac{2\pi l}{N}} \\
C_{N-n} &= C_n^{\star}
\end{aligned}
$$

(so, symmetry implies only 8 complex coefficients are independent, e.g. the 16 independent numbers do not lose information wrt the original distribution)

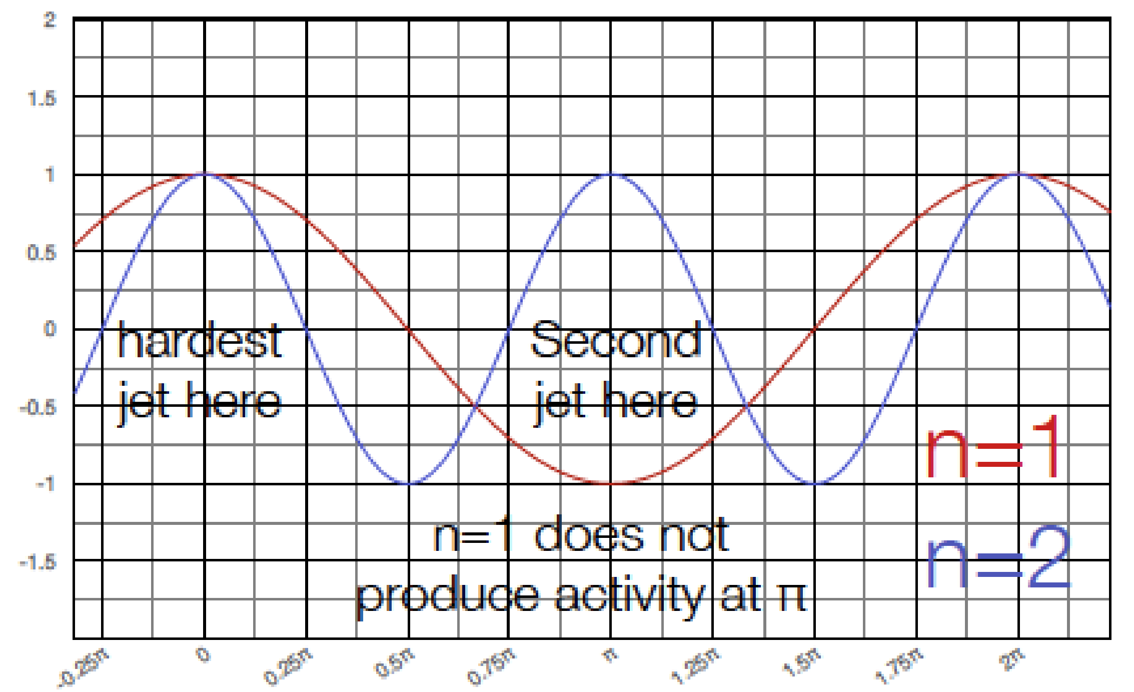
We see that coefficient n corresponds to structures of size

2π/n

And coefficient 0 is an overall normalisation factor

Di-jet structure

- The nth Fourier coefficient corresponds to features of size ~π/n
- The odd coefficients can never have a peak at both 0 and π



So underlying event should be in the small coefficients. Di-jets should be in the even coefficients and inter-jet radiation should be in the odd coefficients.

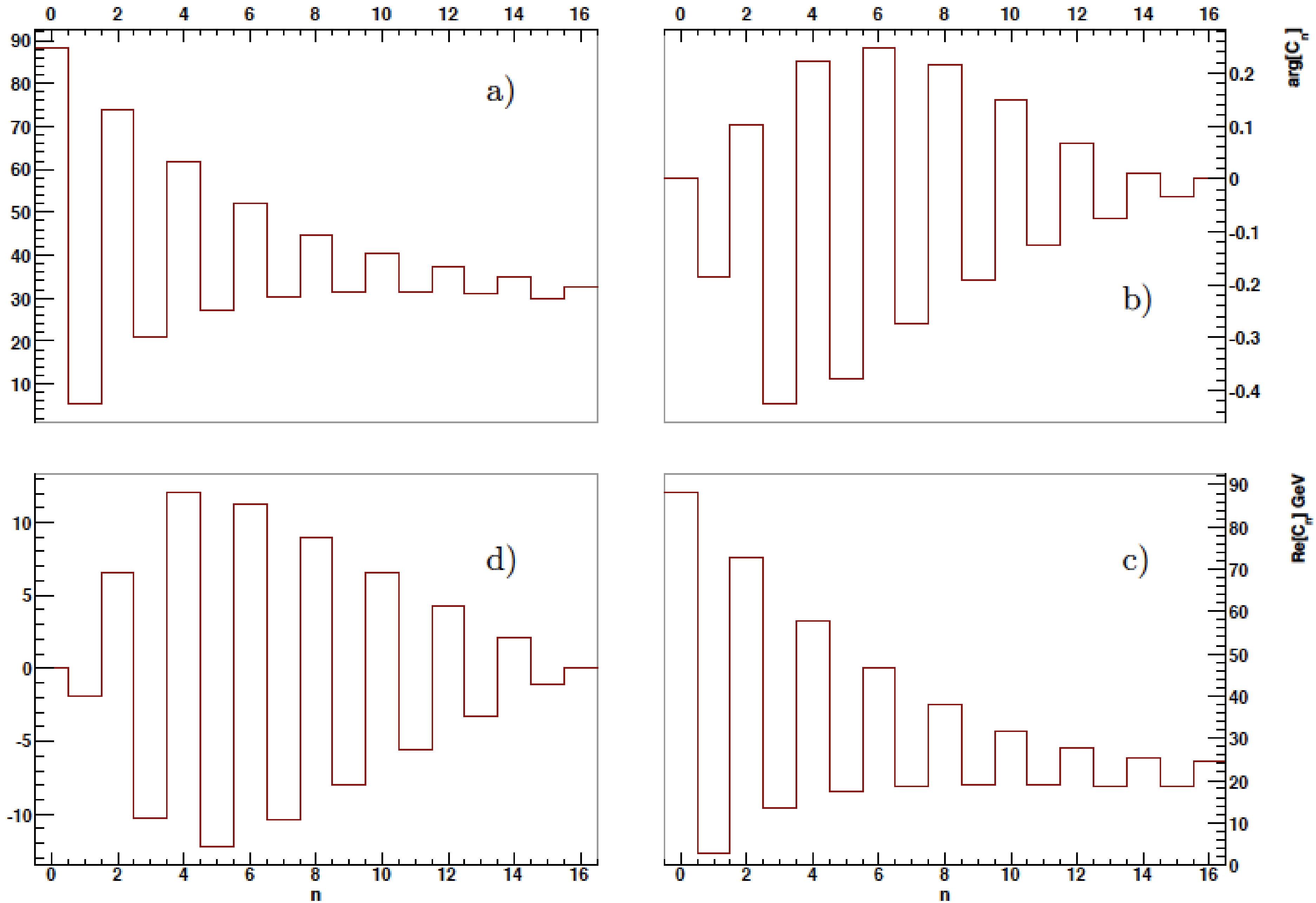


Figure 4: Clockwise from top left: the mean a) magnitude, b) phase, c) real part and d) imaginary part of the first sixteen coefficients for colour singlet exchange events without underlying event.

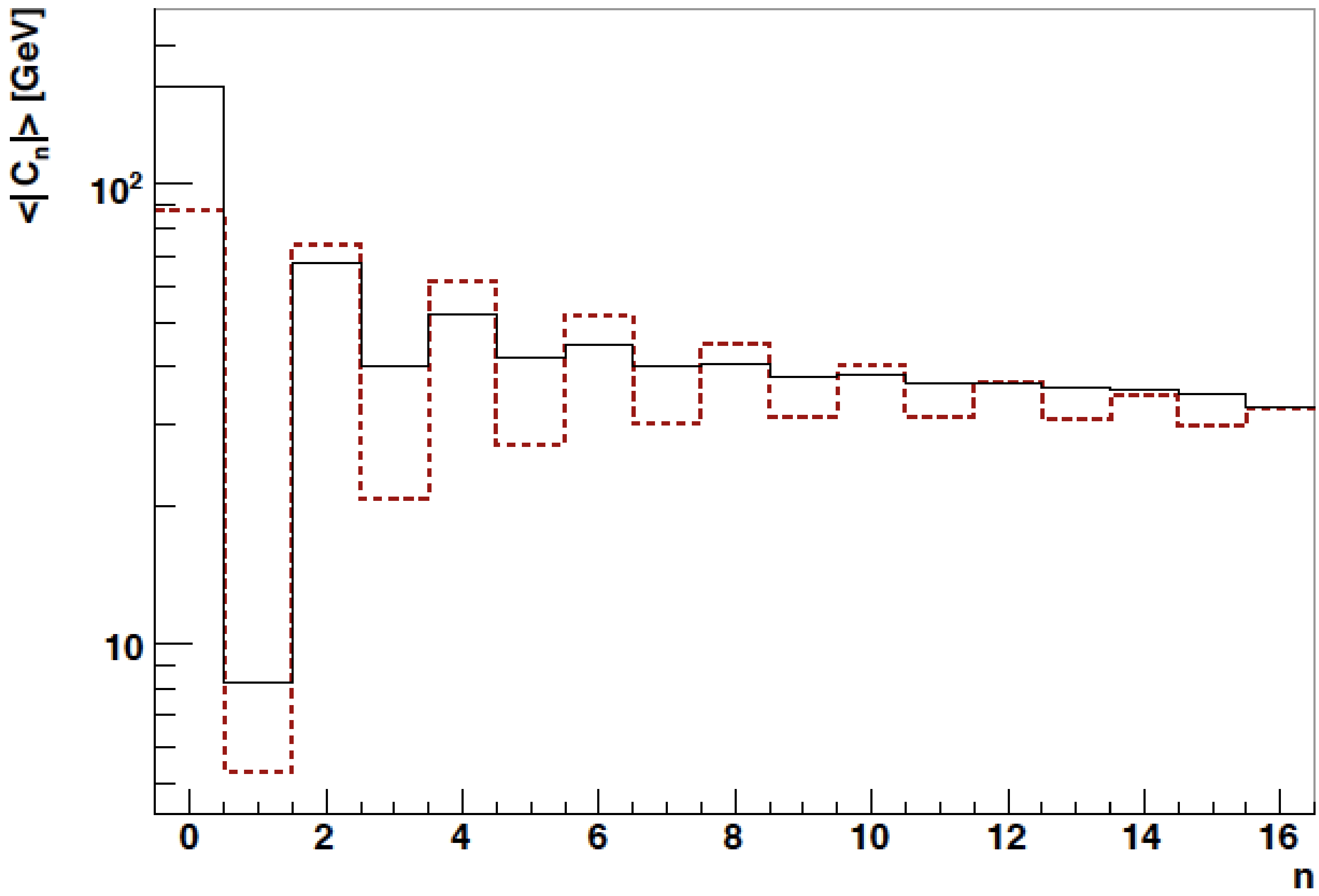
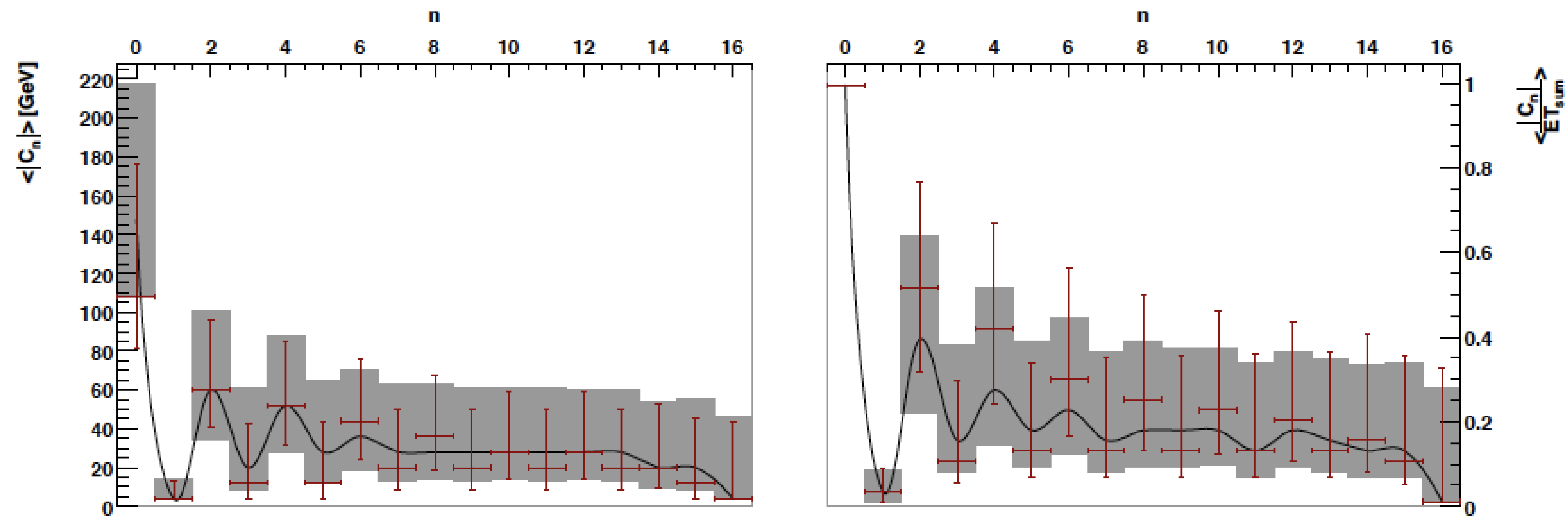


Figure 5: The average magnitude of the first 16 Fourier coefficients for QCD di-jets with underlying event (black solid line). Compared to the colour singlet jets without underlying event (red dashed line) the events with colour flow show less suppression of the small n odd coefficients.



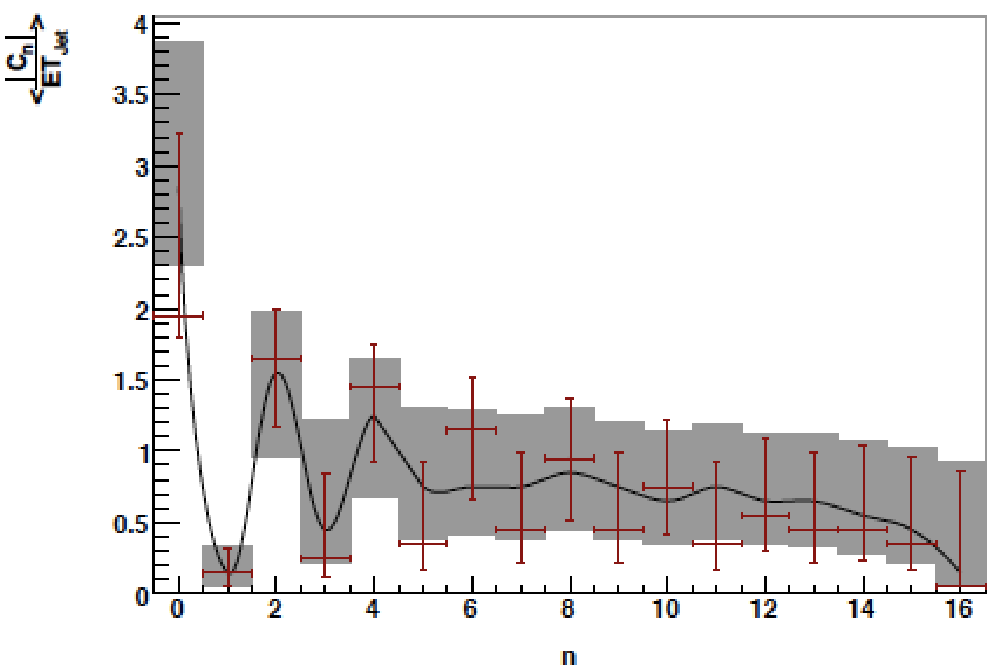


Figure 8: The spread of the coefficients of the Fourier transform. The black curve shows the modal value for the coefficients from the QCD sample, the grey shaded region showing the spread about the mode. The red crosses show the colour singlet exchange. a) Shows the spread unnormalised, b) shows the spread when the coefficients for each event have been normalised by the E_T sum in the event and c) shows the effect of normalising each event by the E_T of the leading jet.

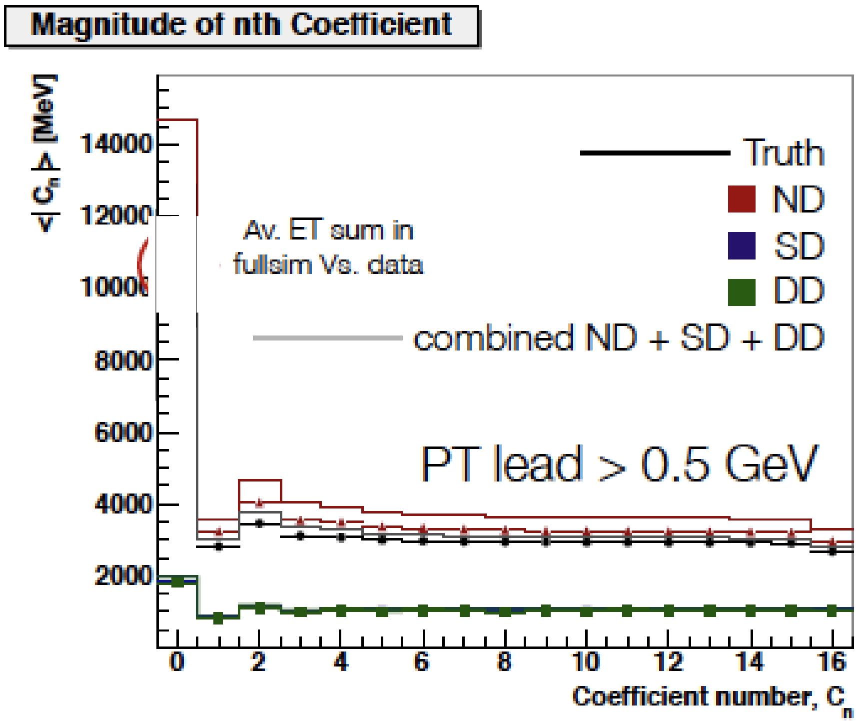
Fourier transformation to study MinBias events

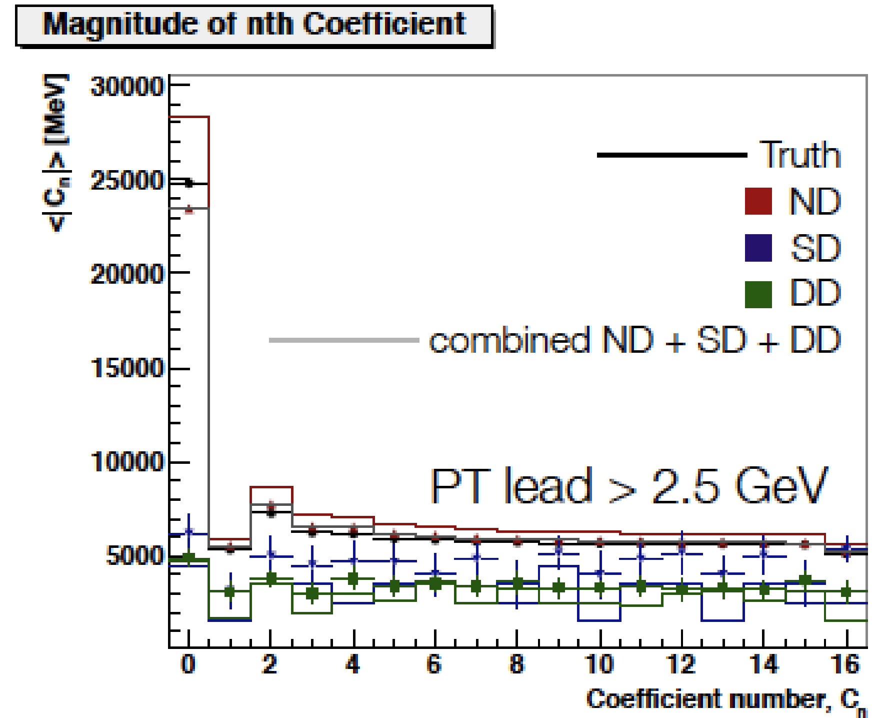
The Fourier Transformation technique can be applied to any fully-hadronic final state, since it does not distinguish the different final state particles but only cares about shapes

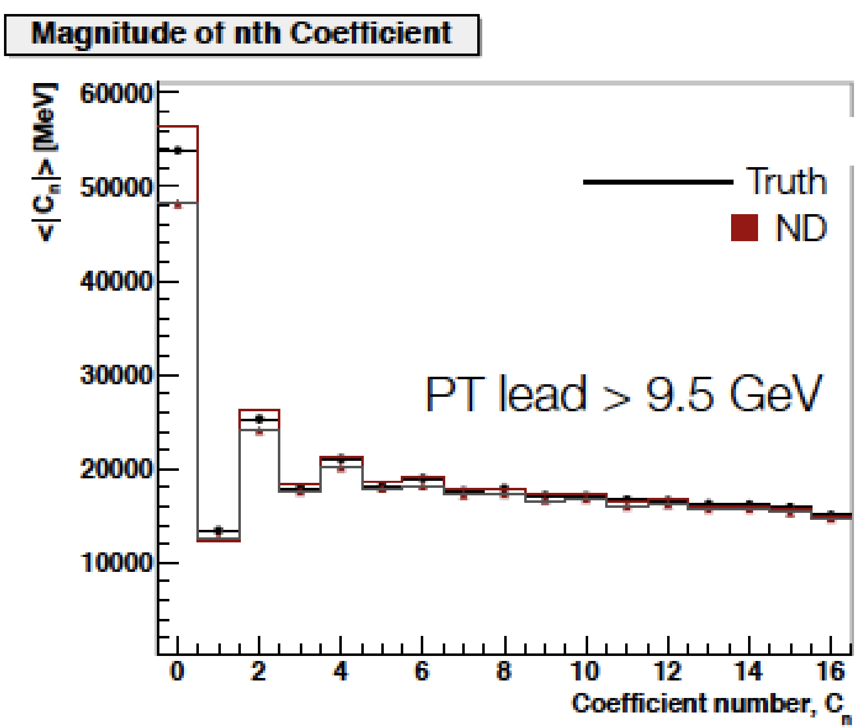
One of the interesting things to see with first LHC data is the emergence of structures with increasing hardness of the event

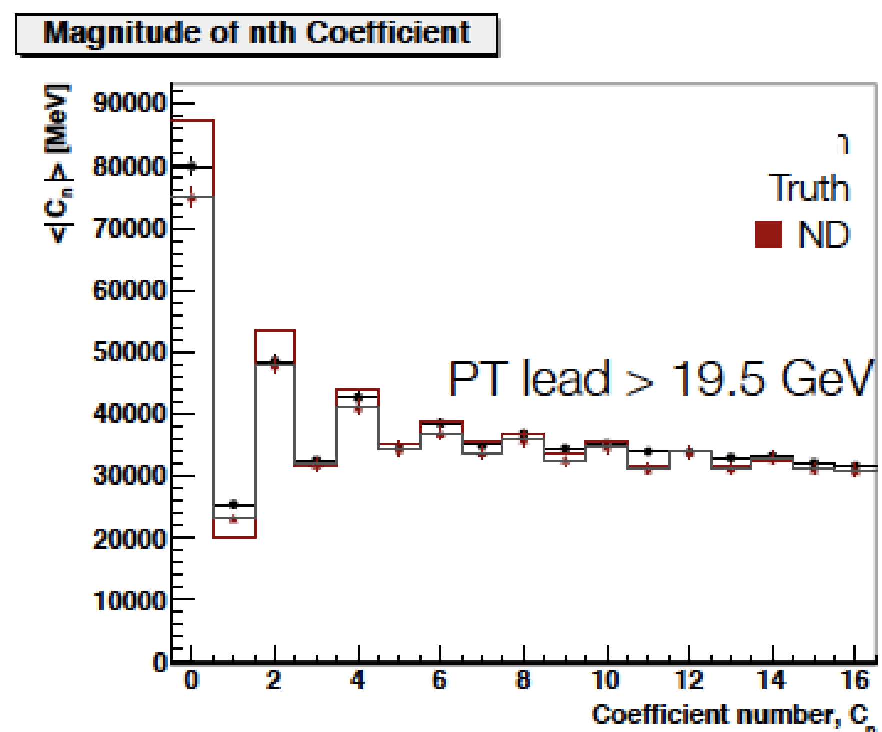
Very soft events do not have a preferential direction, and final state particles have a roughly uniform distribution;
that corresponds to a peak at zero (FT of a uniform distribution) plus a uniform tail for the larger coefficients (FT of a delta, due to single-track events)

As soon as events get harder, we start seeing the familiar odd-even coefficient alternance, an indication of the formation of jet structures


Magnitude of nth Coefficient
<|C_n|> [MeV]
Coefficient number, C_n
Truth
ND
SD
DD
combined ND + SD + DD
Av. ET sum in
fullsim Vs. data
PT lead > 0.5 GeV

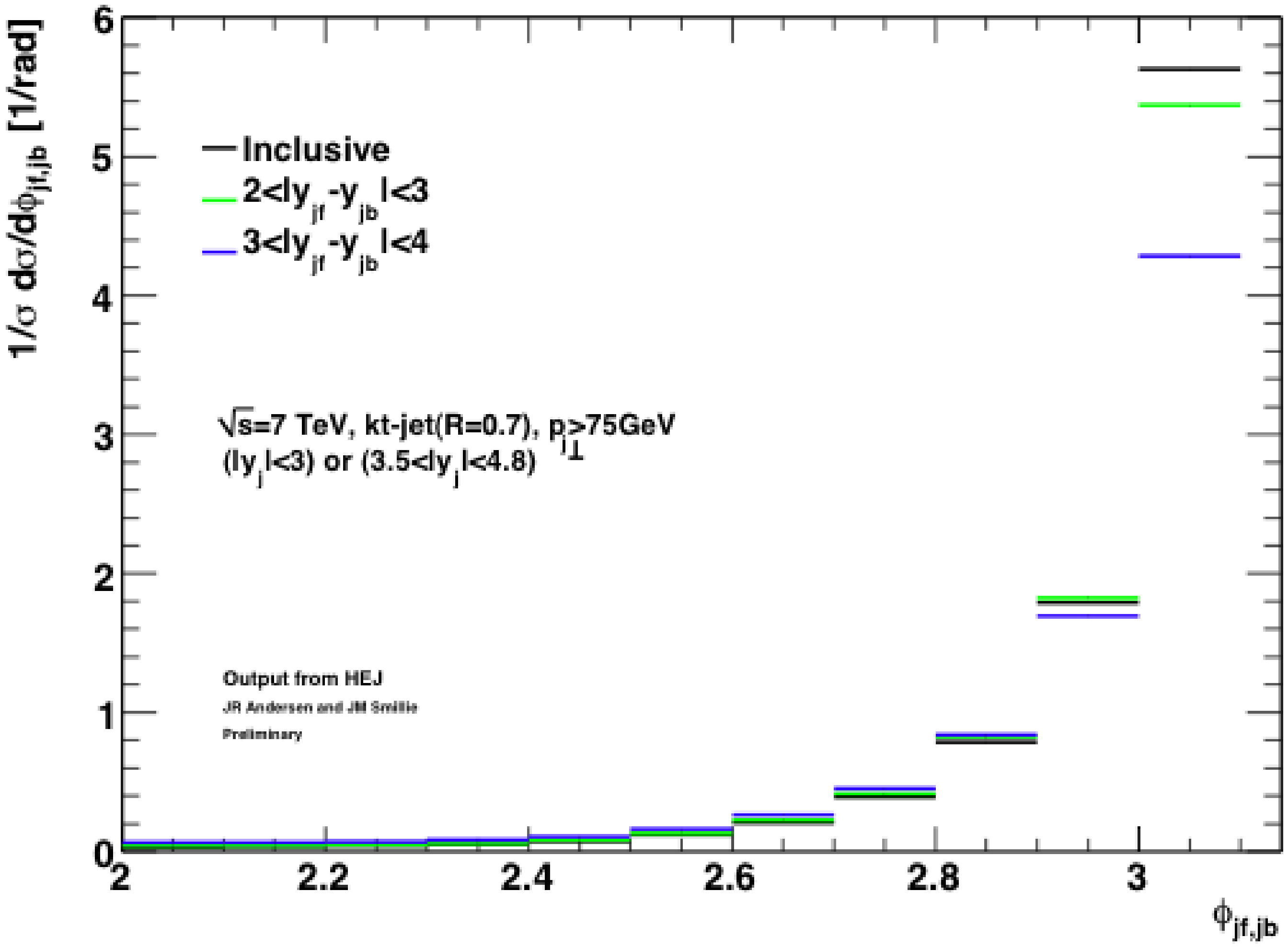

Magnitude of nth Coefficient
<|C_n|> [MeV]
Coefficient number, C_n
Truth
ND
SD
DD
combined ND + SD + DD
PT lead > 2.5 GeV


Magnitude of nth Coefficient
<|C_n|> [MeV]
Coefficient number, C_n
Truth
ND
PT lead > 9.5 GeV


Magnitude of nth Coefficient
<|C_n|> [MeV]
Coefficient number, C_n
Truth
ND
PT lead > 19.5 GeV

Mueller-Navelet jets

Not much to add to the talk from Christoph... apart that there is a new tool on the market:
High-Energy Jet code from J.Andersen and J.Smiley, based on the
resummation procedure presented in arXiv:0908.2786, arXiv:0910.5113
So far no matching, only parton level final states available
Effects already visible for modest rapidity differences.



Conclusions

It's not so easy to say 'a gap', especially when we want to use them as a tool for discovery
Experimentally, the two extreme approaches have been:

- third jet veto (accept anything in the gap as soon as it does not form a had jet
- Clean gap, with survival probability O(%)

We want to study radiation between jets, and identify gaps resulting from colour singlet exchange, even if some radiation is present

Interesting results are found dividing the gap in various parts, and applying some UE correction improves separation

Interesting results from the use of the Fourier transformation on 1 dimension

Presently applying it to the study of MinBias, but very powerful tool to separate various scales of the event and select very clean dijet events.