From Jet Scaling to Jet Vetos

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Heidelberg

Madgraph Meeting, Rome, 9/2011

Exclusive jet counting

Remember $qg \to qZ$ [intro: arXiv:0910.4182, Springer Lecture Notes]

– collinear divergence from $g \to q\bar{q}$ splitting

$$\int_{p_T^{\min}}^{p_T^{\max}} dp_T^2 \frac{C}{p_T^2} = 2 \int_{p_T^{\min}}^{p_T^{\max}} dp_T \; p_T \frac{C}{p_T^2} \simeq 2C \int_{p_T^{\min}}^{p_T^{\max}} dp_T \frac{1}{p_T} = 2C \; \log \frac{p_T^{\max}}{p_T^{\min}}$$

universal form following factorization

$$\sigma_{n+1} = \int \sigma_n \frac{dp_a^2}{p_a^2} dz \frac{\alpha_s}{2\pi} \hat{P}(z)$$

– but still divergent, fixed order prediction poorly defined

– find object to 'renormalize' [i.e. absorbe universal divergence]

DGLAP equation and logarithms

– re-organize perturbation series [sum collinear logs]

$$\sigma_{n+1}(x,\mu) \sim \frac{1}{n!} \left(\frac{1}{2\pi b_0} \log \frac{\alpha_s(\mu_0^2)}{\alpha_s(\mu^2)} \right)^n \int_{x_0}^1 \frac{dx_n}{x_n} \hat{P}\left(\frac{x}{x_n}\right) \cdots \int_{x_0}^1 \frac{dx_1}{x_1} \hat{P}\left(\frac{x_2}{x_1}\right) \sigma_1(x_1,\mu_0)$$

– DGLAP equivalent to infrared RGE

– collinear jets included, only jet-inclusive observables

Successive radiation

Soft gluon radiation [Peskin & Schroeder]

– example: photons off hard electron
  only abelian diagrams, successive radiation
– eikonal approximation

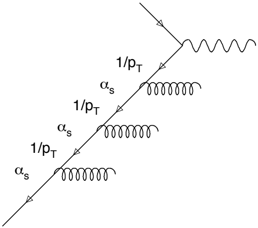
$$\mathcal{M}_{n+1} = g_s T^a \; \epsilon^*_\mu(k) \; \bar{u}(q) \frac{q^\mu + \mathcal{O}(\not{k})}{(qk) + \mathcal{O}(k^2)} \; \mathcal{M}_n$$

– factorization of 'hard process' and soft radiation factors
– Poisson distribution [normalized pdf for n if n_0 expected]

$$f(n; n_0) = \frac{n_0^n e^{-n_0}}{n!} \qquad \Longleftrightarrow \qquad \frac{f(n+1; n_0)}{f(n, n_0)} = \frac{n_0}{n+1}$$

Ingredients of Poisson distribution

1– radiation matrix element n_0^n:
  abelian fine, non-abelian fine for leading log
2– phase space factor $1/n!$:
  only combinatorics effect, matrix element ordered
3– normalization factor e^{-n_0}:
  nothing to worry about...
– anyone reminded of ISR parton shower?



Staircase scaling: W+jets

From UA2 to ATLAS [Steve Ellis, Kleiss, Stirling]

Volume 154B, number 5,6 PHYSICS LETTERS 9 May 1985

W's, Z's AND JETS

S.D. ELLIS [1,2], R. KLEISS and W.J. STIRLING

CERN, CH 1211 Geneva 23, Switzerland

Received 24 January 1985

The process $p+\bar{p} \to W^{\pm}, Z^0$ plus 2 jets is discussed in the context of perturbative QCD. The magnitude of the expected rate for this process and the correlations anticipated between the jets are presented.

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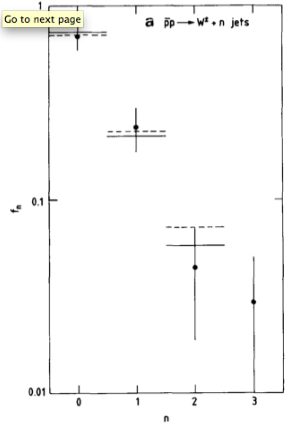
- exclusive staircase scaling [Berends scaling???]
- many equivalent descriptions

$$R_{(n+1)/n} = \frac{\sigma_{n+1}}{\sigma_n} = \text{const}$$



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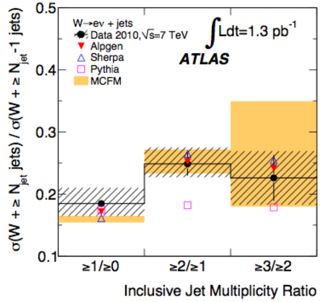
– confirmed by ATLAS and CMS



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Simulations with uncertainties [Englert, TP, Schichtel, Schu

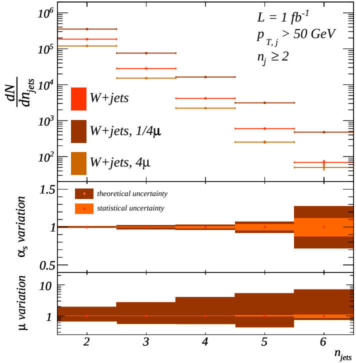
– appropriate tool: CKKW/MLM [Sherpa]

– phase space effects? → moderate

– α_s uncertainties? → small

– scale uncertainties? → tuning parameter?

– correctly described by ME-PS merging



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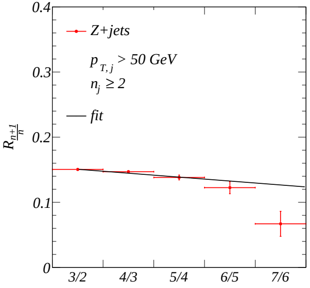

Staircase scaling: QCD jets

Democratic cuts

- absence of 'hard process' important?
- ATLAS/CMS studies available
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- phase space effects? $\to$ none
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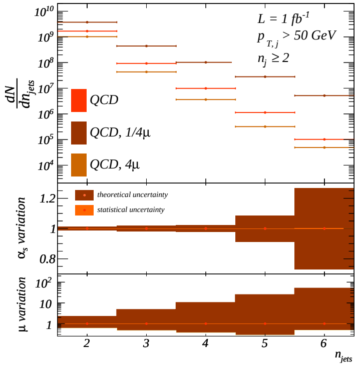

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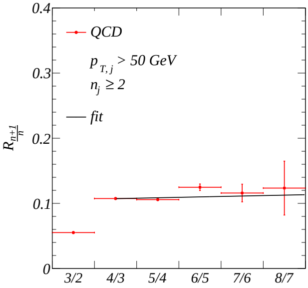


Staircase scaling: Photon plus jets

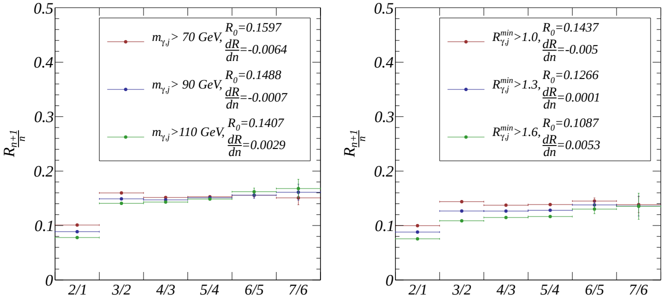
Ensure scaling properties [Englert, TP, Schichtel, Schumann]

– naively, no scaling observed [CMS, private complaint]

– remove any logarithmic enhancement
high separation requirement [compare m and ΔR]
democratic γ and jet acceptance

– no phase space effects

– dominant diagram: FSR gluon splitting of single ISR jet



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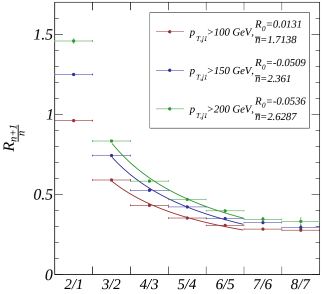
What about Poisson scaling?

- generate a 'hard process'
  many options: $m, p_T, \Delta R, \ldots$
- turns out $p_{T,j_1} > 100$ GeV works best
  lower standard p_T enhances logarithm
- high-n tail always staircase
- dominant diagram: successive ordered ISR
- scaling either staircase or Poisson and tunable!



Jet veto in Higgs searches

Jet veto as Higgs analysis tool [Barger, Phillips, Zeppenfeld; Rainwater]

– particularly useful for WBF signals
– remove $t\bar{t}$ and Z+jets backgrounds
– count central (semi-hard) jets
apply survival probability

Table C.1: Summary of veto survival probabilities for $p_T^{veto} = 20$ GeV used in Chapters 3-5.

search	Hjj	$t\bar{t}$	$t\bar{t}j$, $t\bar{t}jj$	QCD $V(V)jj$	EW $V(V)jj$	QCD $Wjjj$	QCD $b\bar{b}jj$	DPS $\gamma\gamma jj$
$\gamma\gamma jj$	0.89	-	-	0.30	0.75	-	-	0.30
$W^{(*)}W^{(*)}jj$	0.89	0.46	0.29	0.29	0.75	-	-	-
$\tau\tau jj$	0.87	-	-	0.28	0.80	0.28	0.28	-

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In terms of jet counting [Gerwick, TP, Schumann]

– avoid survival probability as one number

– study exclusive n_{jets} distribution:

1– predict from theory including error
2– validate by experiments
3– extrapolate to interesting regimes

– understand basic features:

staircase scaling for inclusive samples
Poisson scaling for hard processes

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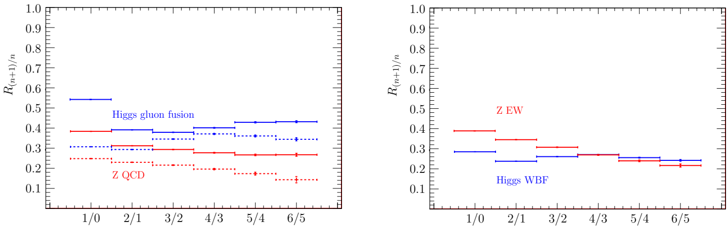
	staircase scaling	Poisson scaling
σ_n	$\sigma_0\, e^{-bn}$	$\sigma_{\text{tot}} \dfrac{e^{-\bar{n}}\bar{n}^n}{n!}$
$R^{\text{excl}}_{(n+1)/n}$	e^{-b}	$\dfrac{\bar{n}}{n+1}$
$R^{\text{incl}}_{(n+1)/n}$	e^{-b}	$\left(\dfrac{(n+1)\, e^{-\bar{n}}\, \bar{n}^{-(n+1)}}{\Gamma(n+1) - n\Gamma(n,\bar{n})} + 1\right)^{-1}$
$\langle n_{\text{jets}} \rangle$	$\dfrac{1}{2}\, \dfrac{1}{\cosh b - 1}$	$\bar{n}$
P_{veto}	$1 - e^{-b}$	$e^{-\bar{n}}$

Jet veto in Higgs searches

Staircase scaling [Gerwick, TP, Schumann]

- example: WBF $H \longrightarrow \tau\tau$ [plus GF *Hjj* and *Zjj*]
- jet scaling before WBF cuts
  staircase, as expected [QCD and e-w processes]
- first emission sensitive to cuts
- e-w *Zjj* production with too many structures



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Poisson scaling

- apply WBF jet cuts [tagging jets]

$$p_{T,j} > 20 \text{ GeV} \qquad |y_j| < 4.5$$
$$y_1 y_2 < 0 \qquad |y_1 - y_2| > 4.4 \qquad m_{jj} > 600 \text{ GeV}$$

- count add'l jets with: $p_T^{\text{veto}} > 20$ GeV, $\min y_{1,2} < y^{\text{veto}} < \max y_{1,2}$
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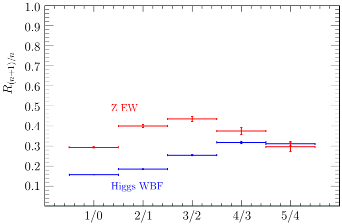

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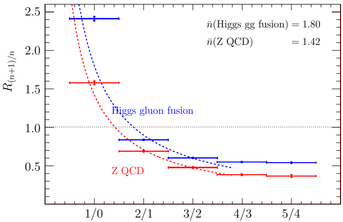

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– Poisson for QCD processes

– veto on first jet very efficient against QCD

– inclusive n_{jets} distribution key to predictions

– try it and tell us if we are wrong...

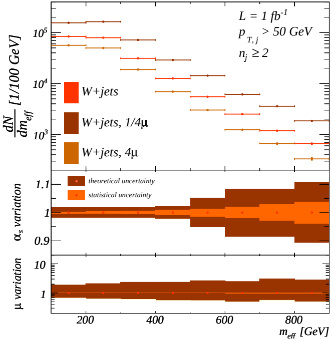
New physics

Effective mass [Englert, TP, Schichtel, Schumann]

– obviously sensitive to new physics masses
but awful variable, after theory uncertainty

– correlation $m_{\text{eff}} \sim \langle p_T \rangle \times n_{\text{jets}}$

– use merged sample for m_{eff}
estimate scale and α_s uncertainties



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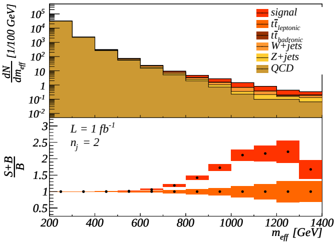

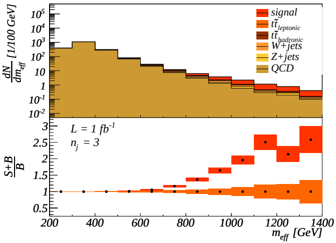

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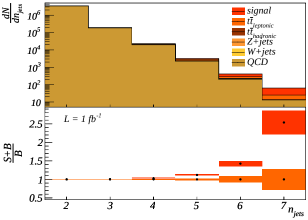
Mass vs color charge

– now, significance as function of n_{jets}



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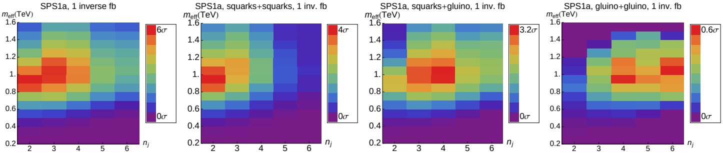
– representing new physics color charge
  gluino does not decay via gluon

– compute exclusive 2D likelihood



Understanding many jets

Exclusive jet counting

– either staircase (non-abelian) or Poisson (ordered)
– do not call it Berends scaling [Ellis, Kleiss, Stirling]

– described by ME-PS merging [Sherpa]
– nothing changing with NLO [Blackhat]

– both regimes fully testable at LHC
– photon+jets best laboratory
– key to jet vetos
– key to SUSY signal and backgrounds

New physics at the LHC

	missing energy (p.89)	cascade decays (p.91)	mono-jets/photon (p.15)	lepton resnce (p.109)	di-jet resnce (p.109)	top resnce (p.120)	WW/ZZ resnce (p.15)	W' resnce (p.93)	top partner (p.116)	charged tracks (p.123)	displ. vertex (p.123)	multi-photons (p.29)	spherical events (p.47,76)
SUSY (heavy grav.) (p.17,26)	✓✓	✓✓							✓				
SUSY (light grav.) (p.17,27)	✓	✓	✓						✓	✓	✓		
large extra dim (p.39)	✓✓		✓✓										✓
universal extra dim (p.47)	✓✓	✓✓		✓	✓	✓	✓	✓	✓				
technicolor (vanilla) (p.51)				✓	✓	✓	✓	✓✓					
topcolor/top seesaw (p.53,54)					✓	✓✓	✓						
little Higgs (w/o T) (p.55,58)				✓	✓	✓	✓	✓					
little Higgs (w T) (p.55,58)	✓✓	✓✓	✓	✓	✓	✓	✓	✓	✓				
warped extra dim (IR SM) (p.61,63)				✓	✓	✓	✓						
warped extra dim (bulk SM) (p.61,64)				✓	✓	✓✓	✓	✓					
Higgsless/comp. Higgs (p.69,73)				✓	✓	✓✓	✓✓						
hidden valleys (p.75)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[arXiv:0912.3259, Morrissey, TP, Tait]