From Jet Scaling to Jet Vetos

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LHC Higgs analyses

Two problems for LHC Higgs analyses [talks Rauch, Englert]

1– observe $H \to b\bar{b}$ decays [fat Higgs jets, Marcel's talk]

2– understand jet vetos [this talk]

Understanding Jet Scaling and Jet Vetos in Higgs Searches
E Gerwick, TP, S Schumann
PRL 108 (2012)

Establishing Jet Scaling Patterns with a Photon
C Englert, TP, P Schichtel, S Schumann
arXiv:1108.5473

Jets plus Missing Energy with an Autofocus
C Englert, TP, P Schichtel, S Schumann
PRD83 (2011)

Exclusive jet counting

Why count numbers of jets?

– hard event reconstruction crucial for LHC measurements [Higgs plus 0,1,2 jets]

– utilize tagging and recoil jets in Higgs searches

– identify decay jets in BSM searches

– reduce $t\bar{t}$ and $\tilde{g}\tilde{g}$ backgrounds

$\Rightarrow$ $d\sigma/dn_{\text{jets}}$ just another distribution to cut on?

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Why avoid jet counting? [intro: arXiv:0910.4182, Springer Lecture Notes]

- 'soft' gluon radiation infinitely likely [like soft photons]
- 'collinear' parton splitting divergent [try $qg \to Zq$]
- parton densities defined including collinear jets [DGLAP]

$$\sigma_{\text{tot}}(s) = \int_0^1 dx_1 \int_0^1 dx_2 \sum_{\text{partons } ij} f_i(x_1)\, f_j(x_2)\, \hat{\sigma}_{ij}(x_1 x_2 s)$$

- fiducial volume vs 'soft' or 'collinear' critical
- 'A jet or not a jet' ill defined in perturbative QCD

⇒ study features of n_{jets} distributions

Poisson scaling

Soft gluon radiation [Peskin & Schroeder]

– example: photons off hard electron [abelian diagrams, successive radiation]

– factorization of 'hard process' and soft radiation
eikonal approximation [cf E Laenen, next-to-eikonal]

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

– Poisson distribution [normalized pdf for n if $\bar{n}$ expected]

$$\sigma_n = \frac{\bar{n}^n e^{-\bar{n}}}{n!} \qquad \Longleftrightarrow \qquad R_{(n+1)/n} \equiv \frac{\sigma_{n+1}}{\sigma_n} = \frac{\bar{n}}{n+1}$$

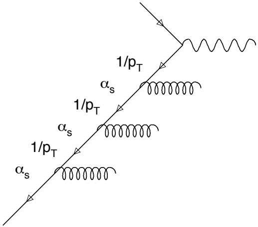
Ingredients of Poisson distribution

1– radiation matrix element $\bar{n}^n$:
abelian fine, non-abelian for leading log and color

2– phase space factor $1/n!$:
only combinatorics effect, matrix element ordered

3– normalization factor $e^{-\bar{n}}$:

– same expected for ISR at LHC?



Staircase scaling

From UA2 to ATLAS [Steve Ellis, Kleiss, Stirling; Berends scaling???]

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.

Staircase scaling

From UA2 to ATLAS [Steve Ellis, Kleiss, Stirling; Berends scaling???]

– many equivalent descriptions

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

– same for inclusive and exclusive rates

$$R^{\text{incl}}_{(n+1)/n} = \frac{\sum_{j=n+1}^{\infty} \sigma_j^{(\text{excl})}}{\sigma_n^{(\text{excl})} + \sum_{j=n+1}^{\infty} \sigma_j^{(\text{excl})}} = R^{\text{excl}}_{(n+1)/n}$$

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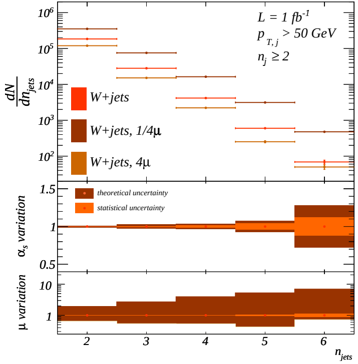
Theory [Englert, TP, Schichtel, Schumann]

– appropriate: CKKW/MLM merging [Sherpa]

– α_s uncertainties? → small

– scale uncertainties? → tuning parameter



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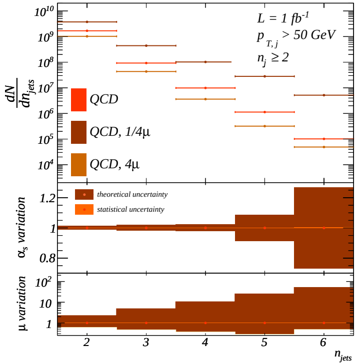
– same thing for pure QCD jets

– correctly described by QCD simulations



Induced scalings

Scaling for photon plus jets [Englert, TP, Schichtel, Schumann]

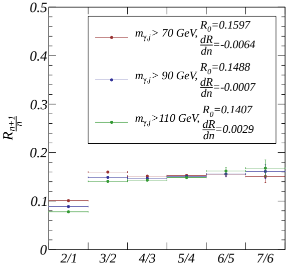
– naively, no scaling at all [CMS, private complaint]

1– staircase

democratic γ and jet acceptance

large separation [m or ΔR, no large logs]

dominant: non-abelian gluon splitting of ISR jet



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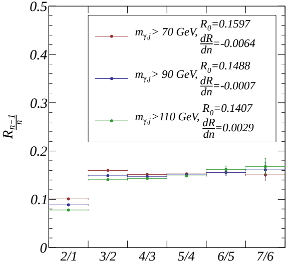
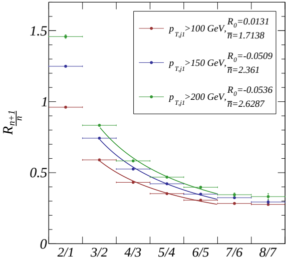
2– Poisson
generate 'hard process' [$m, p_T, \Delta R, \ldots$]
lower standard p_T for logarithm
dominant: successive ordered ISR
remaining: high-n staircase tail

$\Rightarrow$ either staircase or Poisson and tunable!





Jet veto

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

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1– avoid survival probability as one number [uncertainty?]

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  1– avoid survival probability as one number [uncertainty?]
  2– study exclusive n_{jets} distributions
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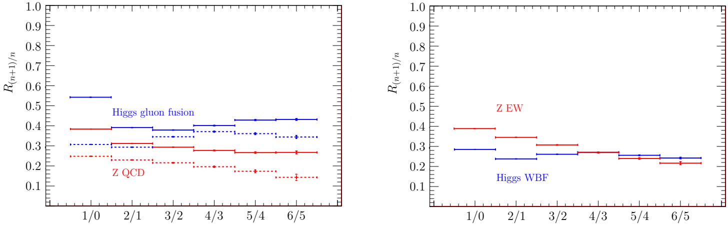
  4– extrapolate to interesting regimes/processes
- basic features
  1– staircase scaling for inclusive samples
  2– Poisson scaling for radiation processes

	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}	$1 - e^{-b}$	$e^{-\bar{n}}$

WBF Higgs production

Example: WBF $H \to \tau\tau$ [Gerwick, TP, Schumann]

- staircase scaling before WBF cuts [QCD and e-w processes]
- e-w *Zjj* production with too many structures



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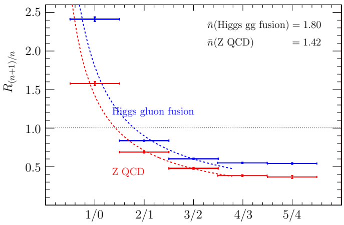
WBF cuts: two forward tagging jets

– count add'l jets to reduce backgrounds

$$p_T^{\text{veto}} > 20 \text{ GeV} \qquad \min y_{1,2} < y^{\text{veto}} < \max y_{1,2}$$

– Poisson for QCD processes ['radiation' pattern]



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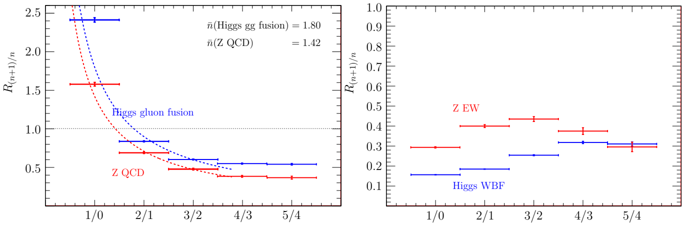
– Poisson for QCD processes ['radiation' pattern]

– (fairly) staircase for e-w processes [generic]

– n_{jets} distributions understood

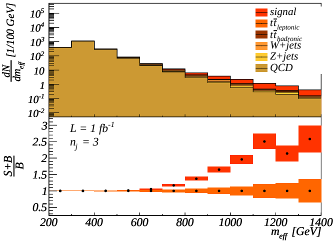
$\Rightarrow$ cut on n_{jets} fine



New physics

Effective mass [Englert, TP, Schichtel, Schumann]

- signal: measure for heavy masses
- backgrounds: $m_{\text{eff}} \sim \langle p_T \rangle \times n_{\text{jets}}$



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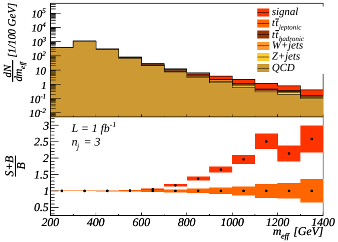
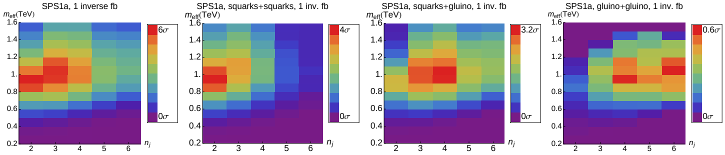


Mass vs color charge

1– effective mass for BSM masses

2– jet counting for BSM color charge [no octet decay to gluon]

⇒ analysis in exclusive 2D likelihood



Exclusive jet counting

Challenge for LHC-Higgs analyses

- described by appropriate QCD
- staircase scaling (non-abelian) vs Poisson scaling (ordered)
- waiting for dedicated ATLAS/CMS studies
- key to jet vetos