From Jet Scaling to Jet Vetos

Tilman Plehn

Heidelberg

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Jet counting

Why count jets

– complete event reconstruction crucial at LHC [Higgs plus 0,1,2 jets; jets plus $\not{p}_T$]

– utilize tagging and recoil jets in Higgs searches

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

– identify decay jets in BSM searches

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

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Why not [intro: arXiv:0910.4182, Springer Lecture Notes]

- remember $qg \to qZ$
- collinear divergence from $g \to q\bar{q}$ splitting [overlapping with soft divergence]

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

universal form following factorization

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

- universally divergent, fixed order poorly defined

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

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DGLAP equation and jet-inclusive rates

- 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'
- factorization scale as inclusive momentum cutoff [vanishing at all orders]

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

$\Rightarrow$ collinear jets automatically included [veto on hard jets ok only if $p_{T,j}^{\text{max}} >$ hard scale]

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$\Rightarrow$ but still...

Poisson scaling

Theory: soft gluon radiation [Peskin & Schroeder Ch 6]

– 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 $\bar{n}$ expected]

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

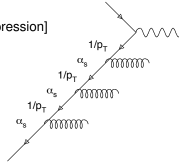
Basis of Poisson distribution

1– radiation matrix element $\bar{n}^n$:
abelian fine, non-abelian a little tricky [ISR-FSR, see Ioffe, Fadin, Lipatov]

2– phase space factor $1/n!$:
only combinatorics, matrix element ordered [angular ordering, color suppression]

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

– just like parton shower in collinear regime



Staircase scaling

Experiment: from UA1 to ATLAS/CMS [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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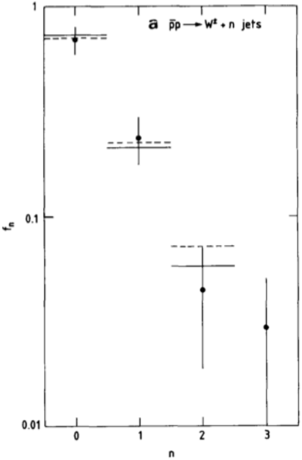
- W/Z+jets production
- many equivalent descriptions

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



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- same for inclusive and exclusive rates [Blackhat-Sherpa]

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

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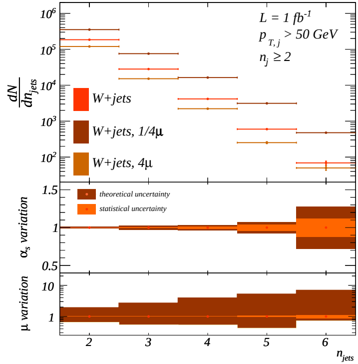
Theoretical studies [Englert, TP, Schichtel, Schumann]

– CKKW/MLM merging [we used Sherpa]

– phase space effects? $\to$ moderate

– α_s uncertainties? $\to$ small

– scale uncertainties? $\to$ tuning parameter?



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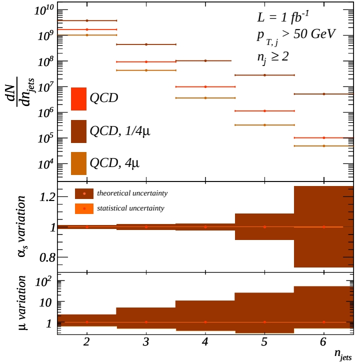
– same for QCD jets

– correctly described by ME-PS merging!?



Interpolating scaling patterns

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

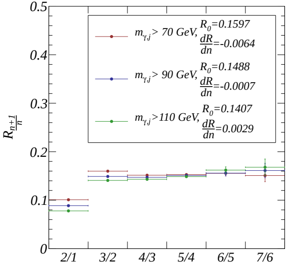
– naively, no scaling at all [CMS, private complaint]

– after appropriate cuts, great playground

1– staircase

democratic γ and jet acceptance
large γ-jet separation [m or ΔR, no large logs]
no reason for ordered emission [$1/n!$ in Poisson form]

dominant: non-abelian splitting of ISR gluon
helping: pdf effect shifting to high-n_{jets}



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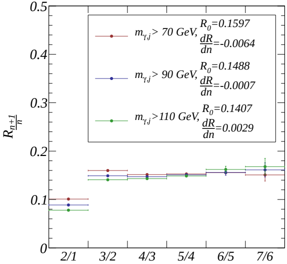
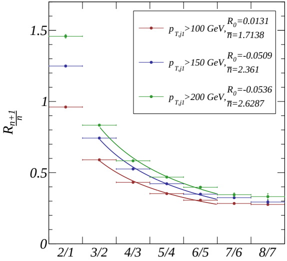
2– Poisson

generate 'hard process' [m, p_T, ΔR, ...]
lower general p_T^{min} for soft-collinear logarithm
rely on lot-enhanced radiation

dominant: successive ordered ISR
remaining: high-n staircase tail

$\Rightarrow$ staircase–Poisson transition tunable!





Jet veto in Higgs searches

Jet veto in Higgs analyses [Barger, Phillips, Zeppenfeld; Rainwater]

– particularly useful for WBF signals [remove $t\bar{t}$ and Z+jets backgrounds]

– veto central (semi-hard) jets
estimate P_{veto}
apply as 'efficiency factor'

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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Using jet counting [Gerwick, TP, Schumann]

– avoid P_veto as single number

– study exclusive n_jets distribution:

1– understand basic features:
   staircase for inclusive samples
   Poisson for radiation processes
2– predict from theory [including error]
3– validate simulation
4– estimate alowed parameter range
5– extrapolate to Higgs

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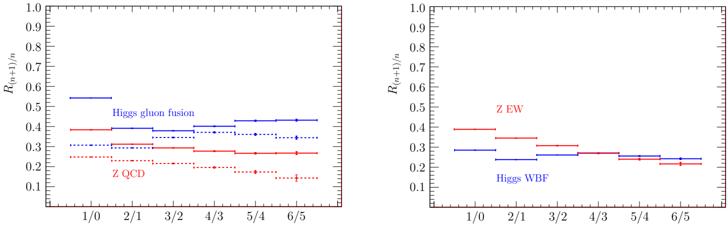
	staircase scaling	Poisson scaling
σ_n	$\sigma_0 \; e^{-bn}$	$\sigma_\text{tot} \; \dfrac{e^{-\bar{n}} \bar{n}^n}{n!}$
$R^\text{excl}_{(n+1)/n}$	e^{-b}	$\dfrac{\bar{n}}{n+1}$
$R^\text{incl}_{(n+1)/n}$	e^{-b}	$\left(\dfrac{(n+1) \, e^{-\bar{n}} \, \bar{n}^{-(n+1)}}{\Gamma(n+1) - n\Gamma(n,\bar{n})} + 1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

Jet veto in Higgs searches

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

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



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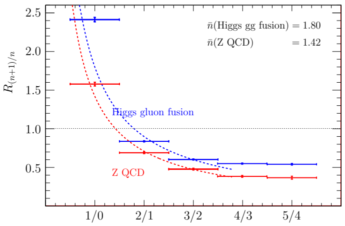
Forward tagging jets

- count add'l veto 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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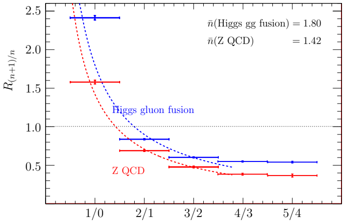
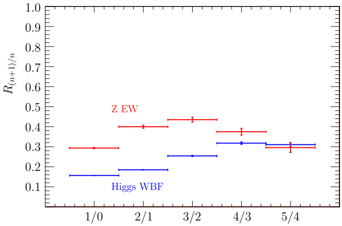
- Poisson for QCD processes ['radiation' pattern]
- staircase-like for e-w processes [generic]
- features of n_{jets} distributions understood

⇒ cut on n_{jets} fine, your job now





Higgs couplings

Veto probabilities crucial for coupling extraction [SFitter: Lafaye, TP, Rauch, Zerwas (2009ff)]

– theory:
  Higgs portal? [$\phi^\dagger \phi$ gauge singlet]
  $\gamma\gamma H$ and ggH couplings w/o naive decoupling
  SUSY or strongly interacting Higgs simple coupling measurements
– experiment:
  Higgs decays to fermions crucial
  associated Higgs-jet channels/WBF crucial
– current observables: $\sigma \times$ BR
  more relevant: g_{jjH}

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Dedicated parameter analysis in progress [SFitter+Dührssen, Klute]

- general fit of all couplings [Moriond 2012]

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- prelim: SM central values, proper errors
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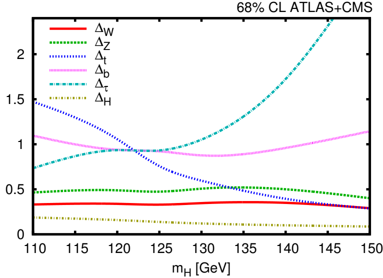

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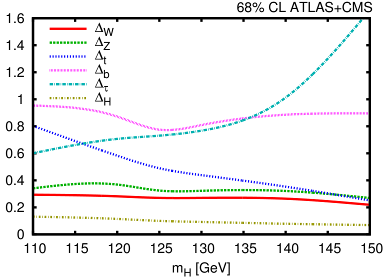

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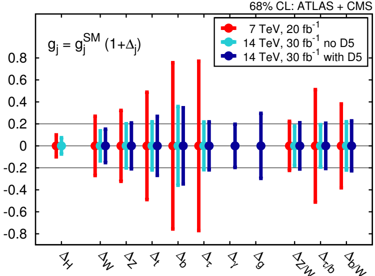

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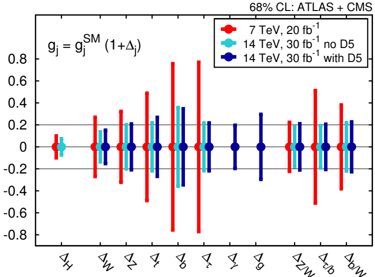
⇒ LHC task for coming years



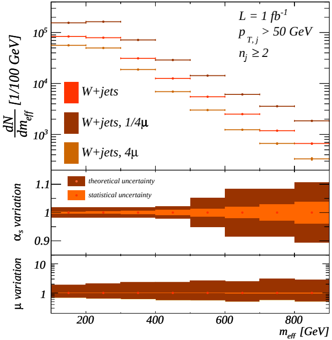
New physics

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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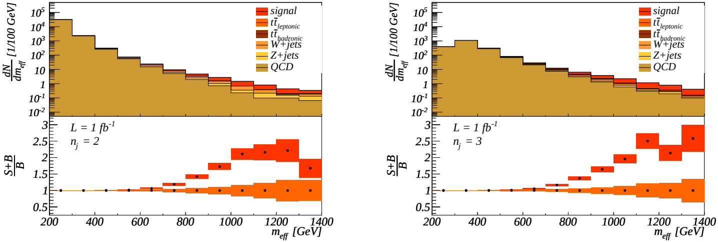

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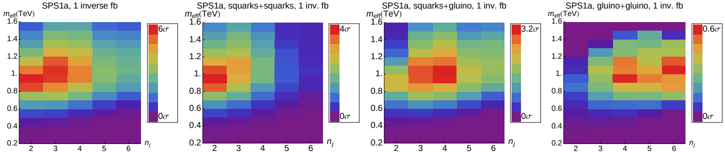
Mass vs color charge

- now, significance as function of n_{jets}
- representing new physics color charge [gluino does not decay via gluon]
- exclusive 2D likelihood including all information



Exclusive jet counting

staircase (non-abelian) vs Poisson (ordered)

- start by measuring $d\sigma/dn_{\text{jets}}$
- test both regimes in photon+jets
- test ME-PS merging [CKKW/MLM, unchanged by NLO]
- key to jet vetos
- key to coupling measurements [SFitter+friends]

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, JHEP in print

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

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