From Jet Counting to Jet Vetoes

work with: E. Gerwick, C. Englert, T. Plehn and S. Schumann
[PRD 83,2011][JHEP02 030,2012][PRL 108,2012]

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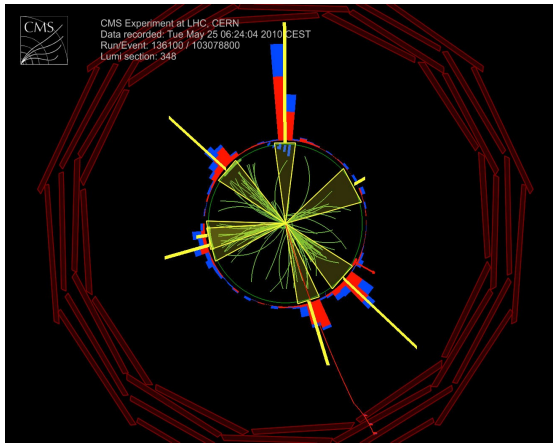
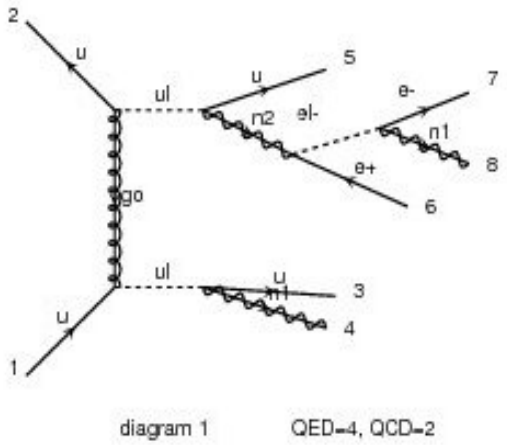
Jets

- W/Z plus jets & QCD jets
  - theoretical predictions/MC
  - background to NP searches
- Higgs searches
  - CJV, color structure (central jet veto)
  - $H \to WW$ exclusive $0, 1, 2$ bins
- SUSY
  - decay & radiation jets
  - $m_{\text{eff}} = \not{p}_T + \sum_{n_{\text{jets}}} p_{T,\text{jet}}$
- also: fat jets (Michi's talk), ...





LHC is a jet machine

Jet Counting

- observable n_{jets}
- issue exclusive vs. inclusive observables
  - higher order predictions inclusive
  - exclusive statistically independent
- correlation to other multi-jet observables
- study exclusive quantities
- jet cross-section ratios

two patterns observed: **Poisson & Staircase**

Poisson Scaling

- eikonal approximation
  [Peskin & Schroeder][E. Laenen]

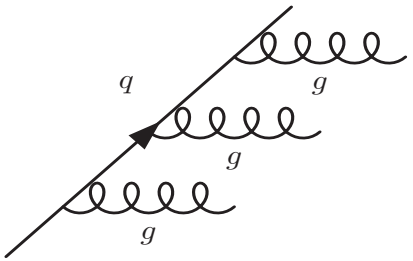
$$\mathcal{M}_{n+1} = g_s T^3 \epsilon^*_\mu \bar{u}(q) \frac{q^\mu + \mathcal{O}(\not{k})}{q\,k + \mathcal{O}(k^2)} \mathcal{M}_n$$

- resummation yields ($1/n!$ bosonic phase space factor):

$$\sigma_n \propto \frac{\bar{n}^n}{n!} e^{-\bar{n}} \qquad \text{with} \qquad \bar{n} \propto \frac{\alpha}{\pi} \log \frac{E_{\text{hard}}}{E_{\text{soft}}}$$

$$R_{\frac{n+1}{n}} \equiv \frac{\sigma_{n+1}}{\sigma_n} = \frac{\bar{n}}{n+1}$$

- all QED processes show Poisson
  (in soft limit)
- QCD: non-splitting secondaries
  [Konishi '79]
  - double logarithmic approximation
    (DLA)
  - $C_A \to 0$



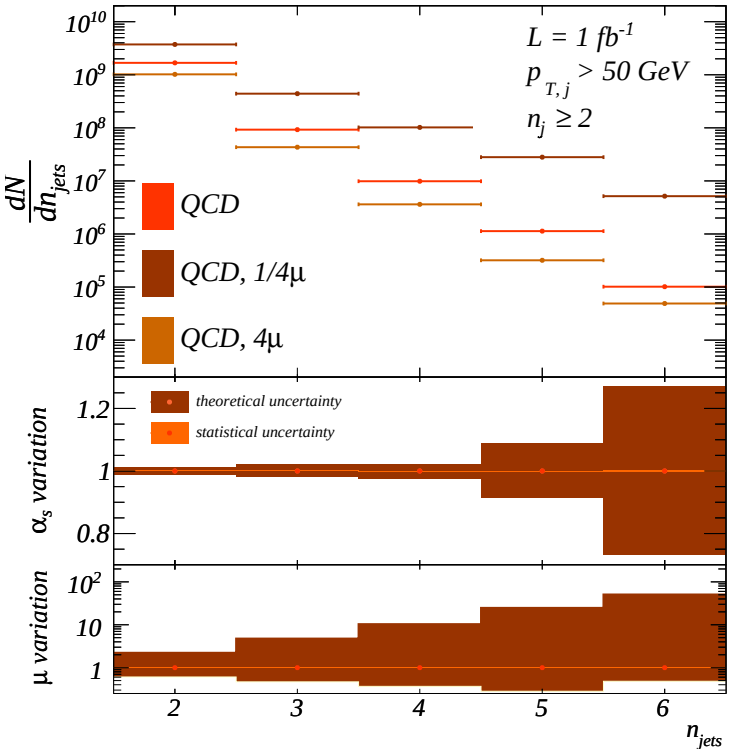
Staircase Scaling

in contrast:
constant ratios for QCD & W/Z + jets

$$R_{\frac{n+1}{n}} \equiv \frac{\sigma_{n+1}}{\sigma_n} = R$$

[PRD 83,2011]

- known from UA1
  [Ellis, Kleiss, Stirling '85]
- also at LHC
  [ATLAS Phys. Let. B 698]
  [CMS PAS EWK-10-012]
- simulated up to $n_{\text{jets}} = 8$
  [Sherpa]
- theoretical uncertainties
  - small α_s variation
  - existence independent of μ
  - μ tuning parameter
    (Sherpa close to unity)



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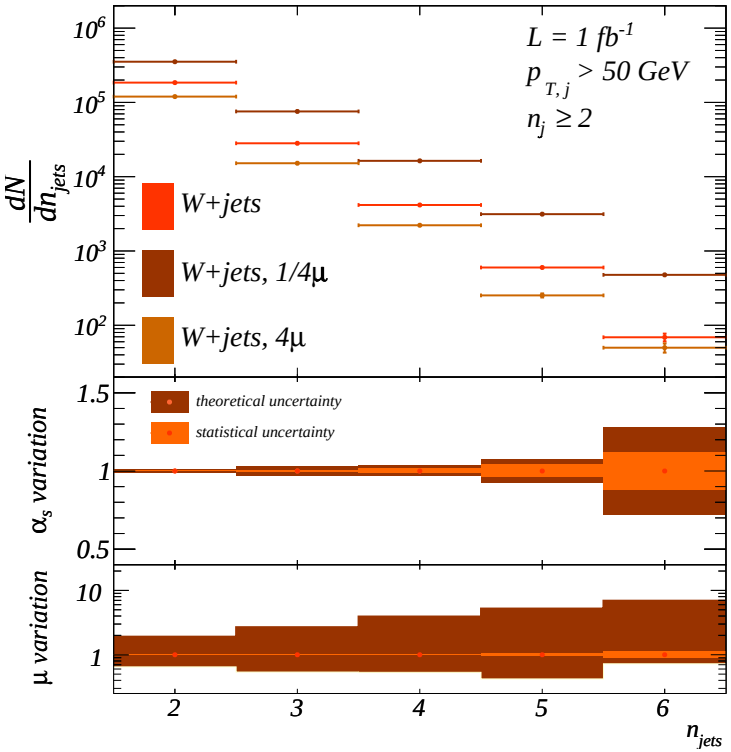


Analytic Jet Rates

- normalized jet rates, generating function (GF)

$$P(n) = \frac{1}{n!}\frac{d^n}{du^n}\Phi(u)\Big|_{u=0}$$

- coherent branching & k_T algorithm $\rightarrow$ evolution equation
- resum all splittings to logarithmic accuracy (DLA,MLLA)
  [Konishi][Catani,Dokshitzer,Webber][Ellis]
- solution DLA single quark & gluon jets
  [Konishi '79]
  - gluon jet: staircase
  - quark jet: staircase for large n
- extension to i gluons in Yang-Mills in MLLA

$$\Phi_g^i(t, t_0, u) = \left(\frac{u}{u + (1-u)/\Delta_g(t, t_0)}\right)^i$$

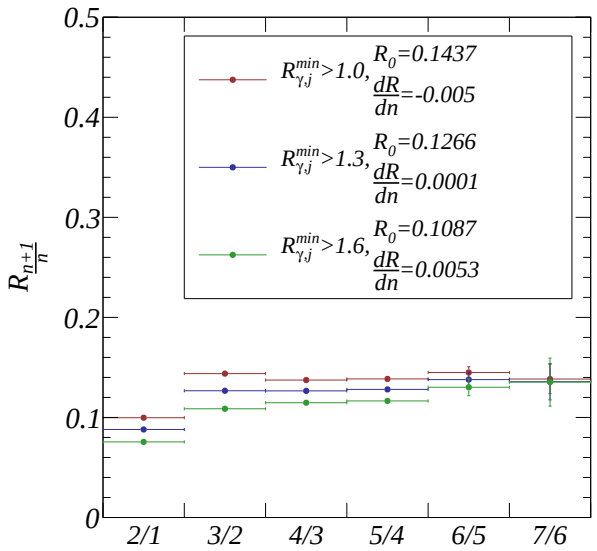
$$\Rightarrow P_g(n; i) = \frac{(n-1)!}{(n-i)!}\frac{\Delta_g^i}{(i-1)!}(1-\Delta_g)^{n-i}$$

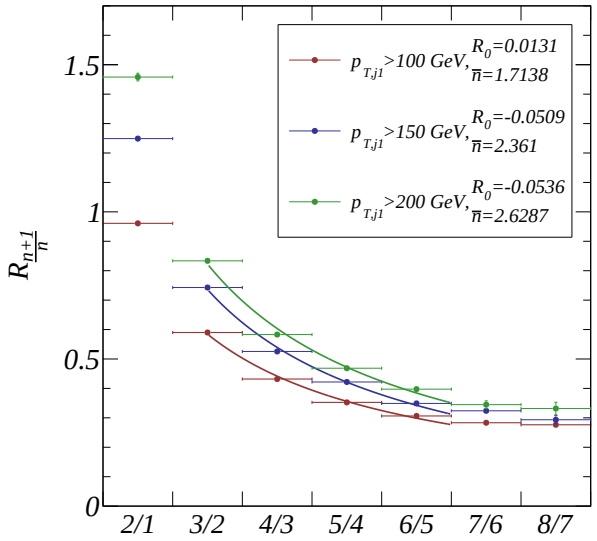
- pdf effects expected to suppress low multiplicity ratios

Photon plus Jets

- interpolate between two patterns
  [JHEP02 030,2012]
- high cross section
- Staircase
  - large $R_{\gamma j} > 1$
  - large $m_{\gamma j} \approx 90\,GeV$
  - $p_{T,\text{jets}} \geq 50\ GeV$
- Poisson
  - enhance logarithm
  - high p_T-jet $> 100\,GeV$
  - $p_{T,\text{jets}} \geq 20\ GeV$
  - consistent staircase tail

laboratory to study jet scaling

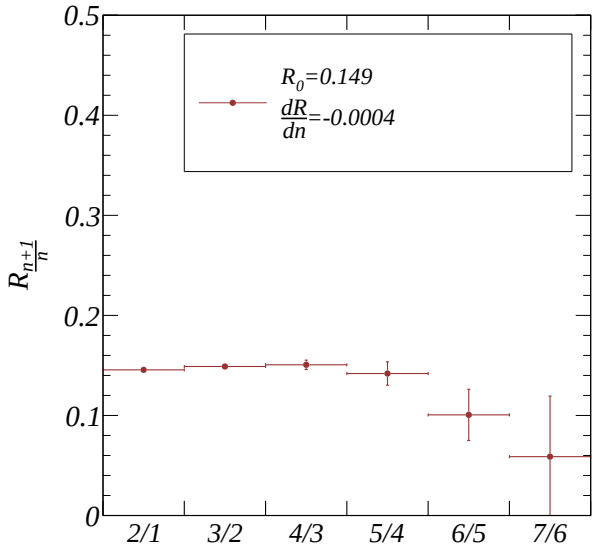


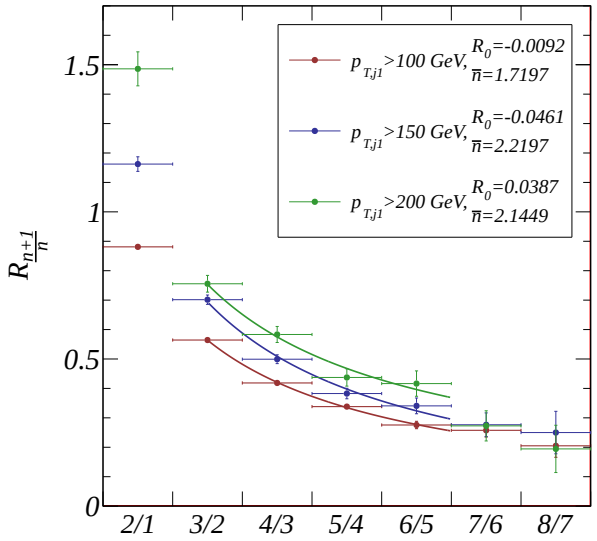


Z plus jets background

- Z plus jets important background
  - Higgs studies
  - missing energy searches
- observe staircase & Poisson
- propagate photon numbers
  [JHEP02 030,2012]

experimental control





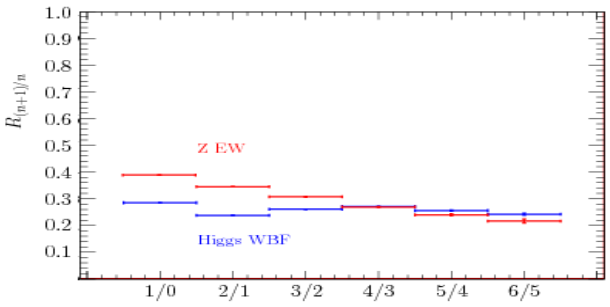
Higgs searches

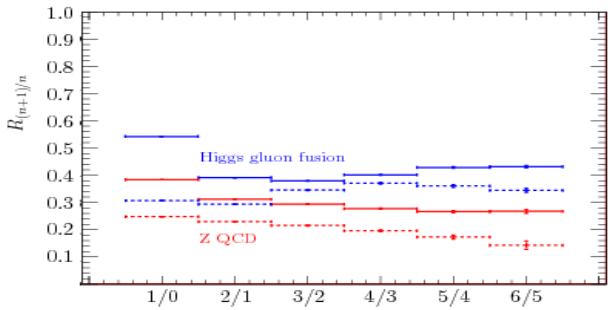
- WBF: cuts and jet veto; veto probability?

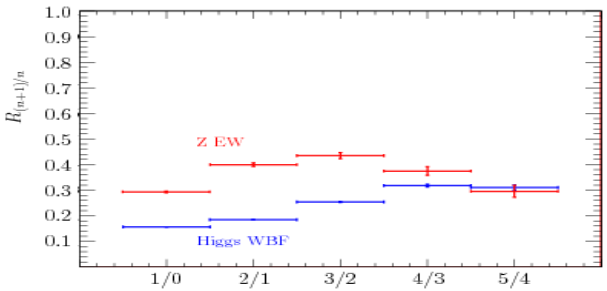
$$y_1\, y_2 < 0 \qquad |y_1 - y_2| > 4.4 \qquad m_{jj} > 600\,GeV$$
$$p_T^{\text{veto}} > 20\,GeV \qquad \min y_{1,2} < y^{\text{veto}} < \max y_{1,2}$$

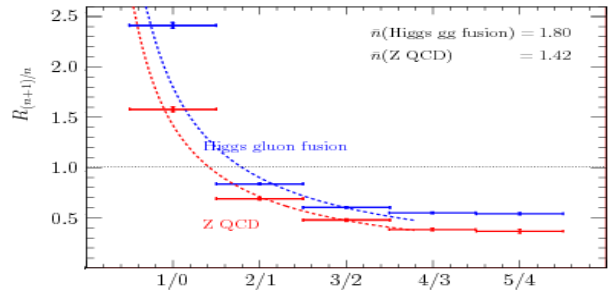
[Rainwater, Zeppenfeld, Plehn]

- drive background in Poisson regime, but signal in staircase
- fit $n_{\text{jets}} \to$ jet veto survival probability
- WBF cuts kill large log
  [PRL 108,2012] (y-axis in plots)







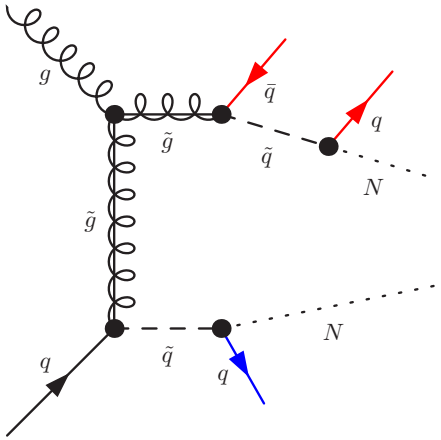


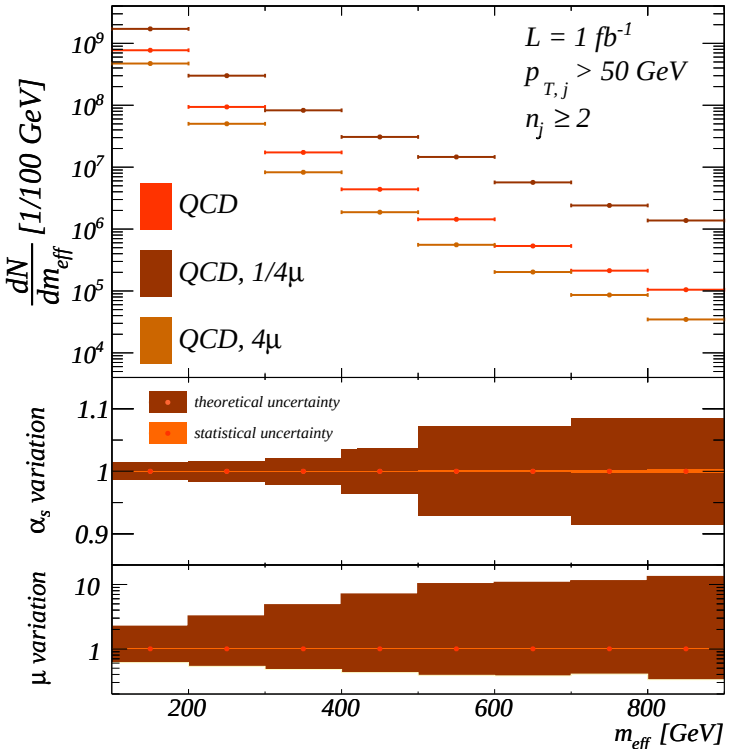
New Physics Searches

- heavy colored states
  (decay jets, mass scale)
- dark matter
- jets plus missing energy
  - count jets
  - electron veto
  - missing energy
- not spectrum dependent
  (inclusive cuts)
- $m_{\text{eff}} \propto n_{\text{jets}} \times p_T^{\text{min}}$
- uncertainties under control
- staircase: $R_{\text{exclusive}} \equiv R_{\text{inclusive}}$
- NLO W plus jets
  [Blackhat]

understand n_{jets} to use m_{eff}

[PRD 83,2011]





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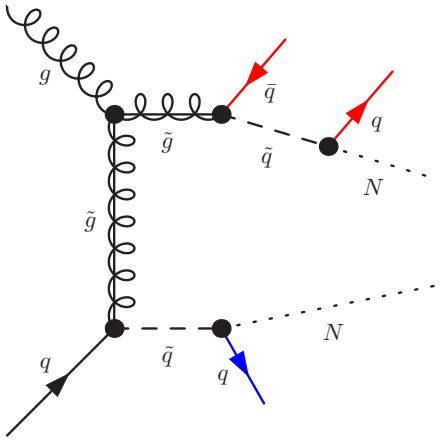
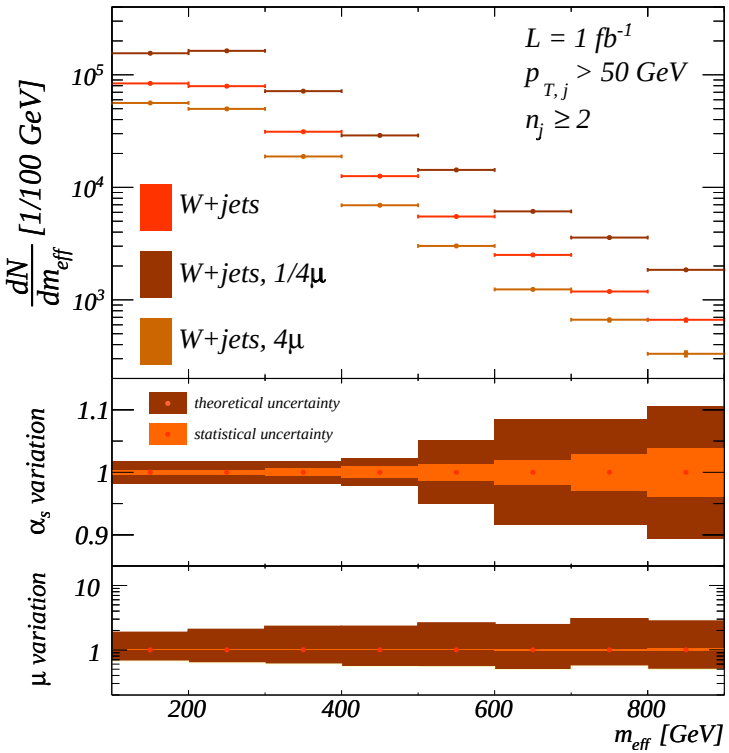
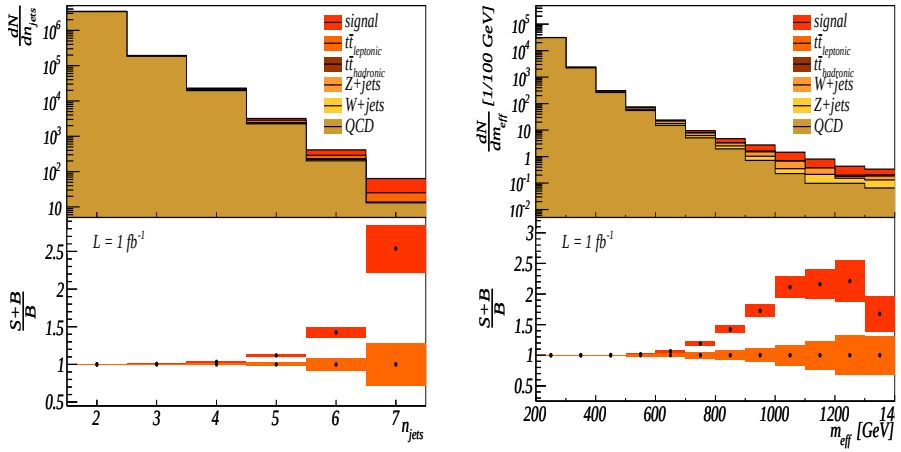




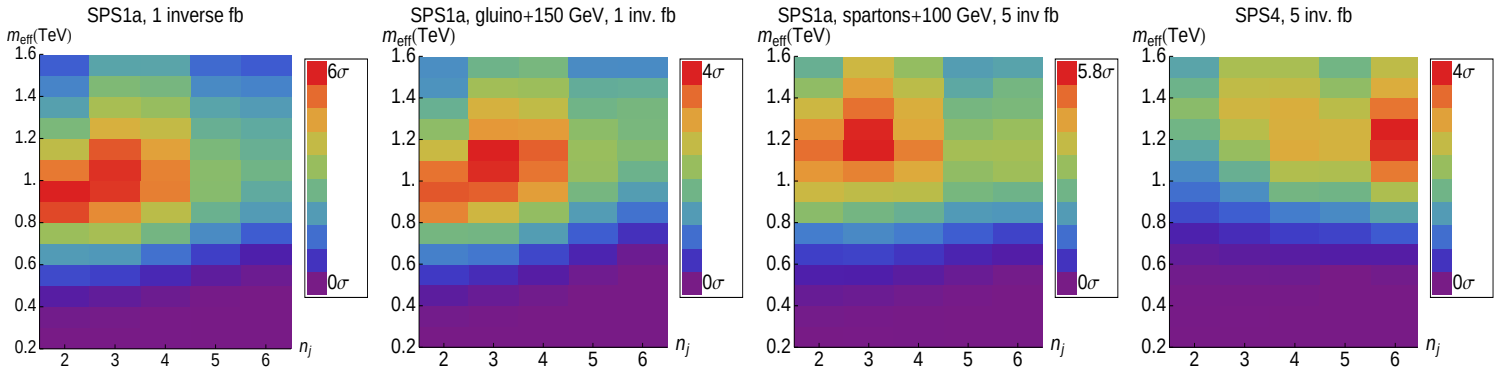
Autofocus

- e.g. SPS1a
  (ruled out by now)
- n_{jets} & m_{eff}
  complementary
- log-likelihood maps



- color code shows significance
- maximum yields information
  - m_{eff}: mass scale
  - n_{jets}: decay jets $\rightarrow$ color structure

[PRD 83,2011]



Conclusion and Outlook

Counting jets is a powerful tool at hadron colliders to understand QCD as well as Higgs and new physics searches.

- staircase
  - experimental fact
  - well reproduced in simulations
  - linked to gluon self interaction
- more on the origin of staircase scaling soon
- useful in physics analysis
  - study SM backgrounds
  - Higgs searches
  - new heavy colored states
- looking forward to CMS & ATLAS analysis in photon plus jets