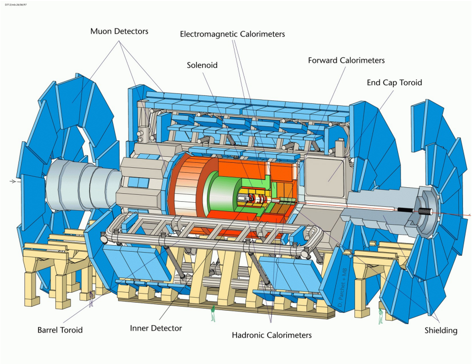
NLO templates for Higgs jets

José Juknevich
tmini workshop
May 30, 2011



Outline:

- Introduction
- Template Overlap Method
- NLO template for Higgs
- Summary

L. Almeida, O. Erdogan, JJ, S. Lee, G. Perez, & G. Sterman   Work in progress

Motivation

- A key task in the search for BSM physics is to efficiently identify “signature” particles – W/Z, Higgs, top quarks – in various kinematic regimes
  - At the LHC, these particles will be frequently produced at high-transverse momentum
  - When these boosted objects decay they form a highly collimated topology in the detector
  - Standard approaches for indentifying these particles (e.g. jet recombination) fail, because all decay products end up in a single jet

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- Energy flow methods have been proposed to address these questions

Almeida, Lee, Perez, Sterman, Sung, Virzi
Gur-Ari, Papucci, Perez;...

  - These take advantage of the different energy flow in the decay pattern of signal and background
  - IR-safe observables based on correlations of energy flow have been used to probe the jet substructure with increasing precision
    - E.g. jet cross sections, angularities, planar flow,...
    - Note that some useful original information is lost when computing correlations

Overlap formalism

L. Almeida, S. Lee, G. Perez,
G. Sterman, & I. Sung '10

- We would like to measure how well the energy flow of a physical jet matches that of a boosted partonic decay

Functional measure

$$Ov(j,f) = \langle j|f\rangle \equiv \mathcal{F}\left[\frac{dE(j)}{d\Omega}, \frac{dE(f)}{d\Omega}\right]$$

j → set of particles that conform a jet

f ⇒ $\{p_1, p_2, \ldots, p_n\}$ partonic distributions ("templates") with $\sum p_i = P$, $P^2 = M^2$

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- A natural measure being the weighted difference of energy flows integrated over a fixed region of phase space

$$Ov^{(F)}(j,f) = \max_{\tau_n^{(R)}} \exp\left[-\frac{1}{2\sigma_E^2}\left(\int d\Omega \left[\frac{dE(j)}{d\Omega} - \frac{dE(f)}{d\Omega}\right] F(\Omega,f)\right)^2\right]$$

$$\tau_n^{(R)} \equiv \int \prod_{i=1}^{n} \frac{d^3\vec{p}_i}{(2\pi)^3 2\omega_i} \delta^4\Big(P - \sum_{i=1}^{n} p_i\Big)\Theta(\{p_i\}, R)$$

F(Ω,f) ⇒ weight function , smooth enough

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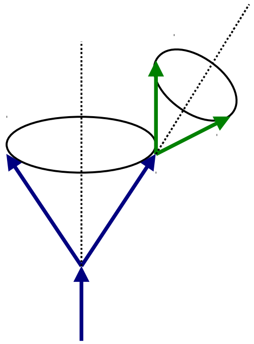
Example: Top and QCD jets

- At Lo, top decay has a simple 3 body kinematics



Top decay: $t \to W^{+} b \to q\, q'\, b$

- While we expect high mass, QCD jets typically have a two-subjet topology

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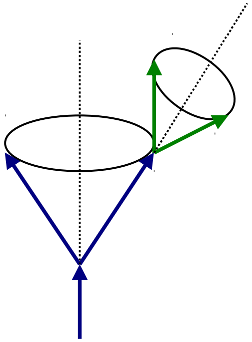

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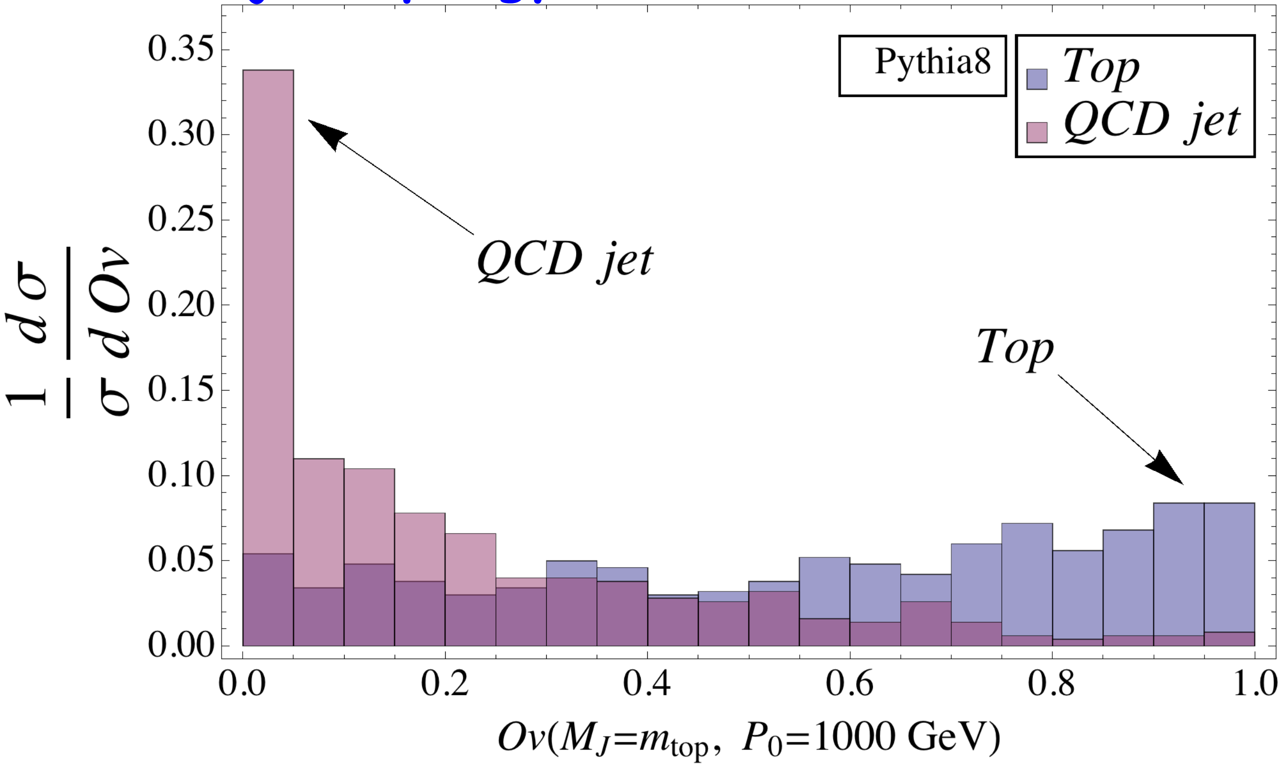


Selection cuts:

160 GeV < m_J < 190 GeV,

950 GeV < E_J < 1050 GeV

Jets found with anti-kt algorithms D=0.5

Calorimeter discretized with

$\Delta\theta = 0.06$ and $\Delta\varphi = 0.1$

Showering smears the top distributions, but top decays tend to give larger overlaps.

Planar Flow

Thaler & Wang, 08
Almeida, Lee, Perez, Sterman, Sung & Virzi, 09

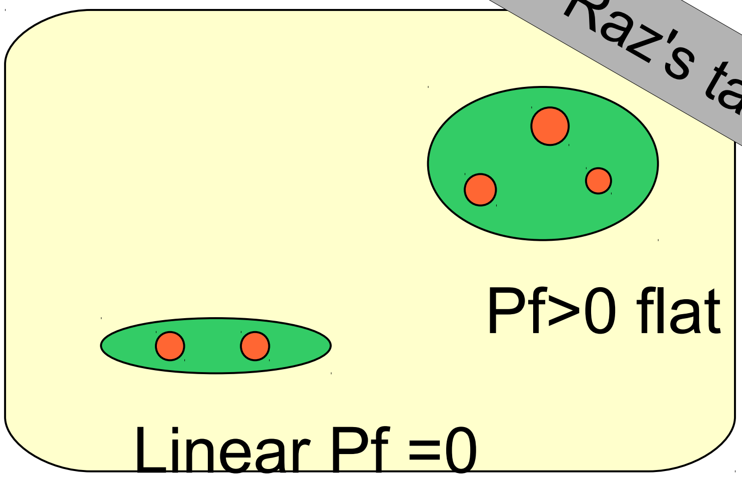
See Raz's talk

Top decays often feature a triangular structure, transverse to the boost axis

Planar flow: measures the planarity of the energy flow within a jet

$$I_{\omega}^{kl} = \frac{1}{m_J} \sum_i \omega_i \frac{p_{i,k}}{\omega_i} \frac{p_{i,l}}{\omega_i}$$

$$\mathrm{Pf} = \frac{4 \det I_{\omega}}{(\mathrm{tr} I_{\omega})^2}$$



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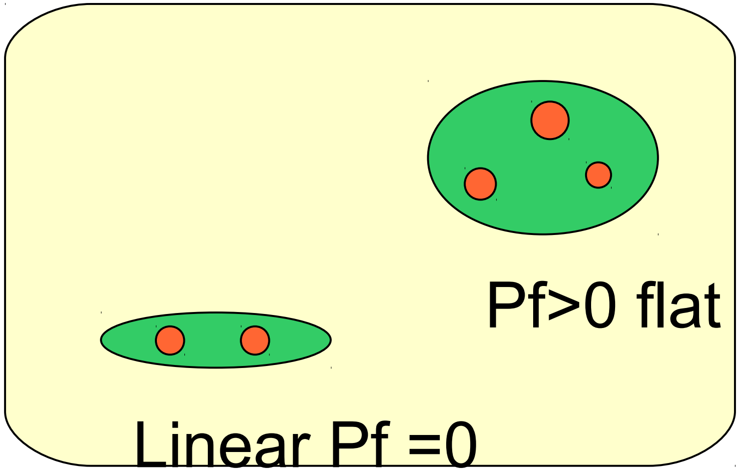

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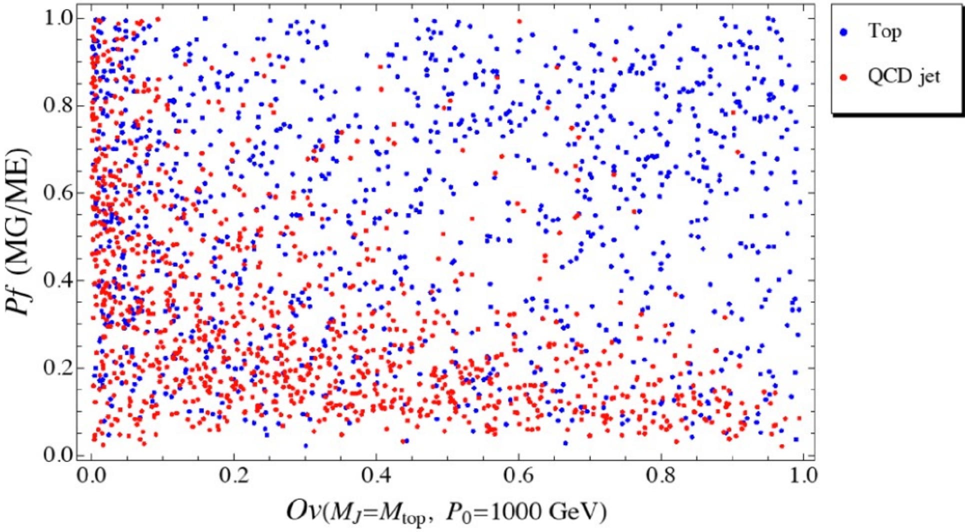
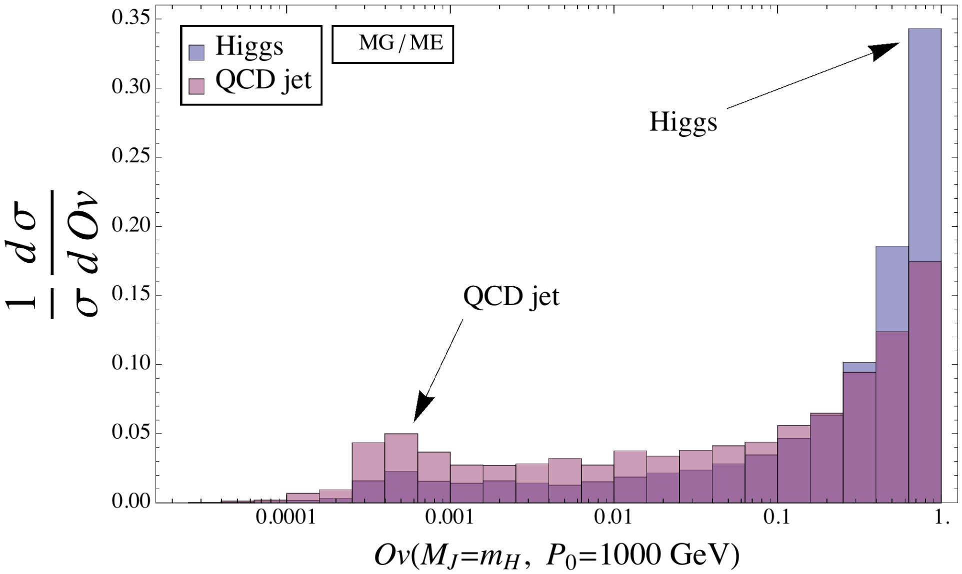
Planar-flow jet shapes can be used to distinguish between many 3-jet events with large template overlap



Templates and Pf for Higgs

Almeida, Lee, Perez, Sterman, & Sung '10



For the Higgs, both signal and background have two-parton states at LO.
Hence, their templates are only slightly different.

Templates and Pf for Higgs

Almeida, Lee, Perez,
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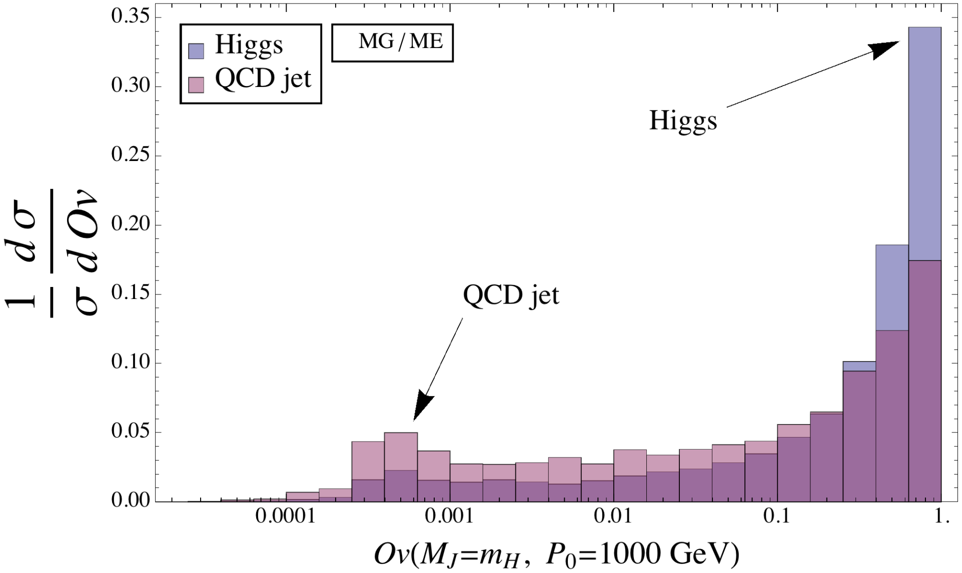

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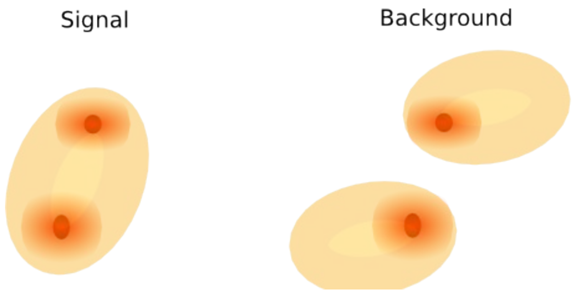
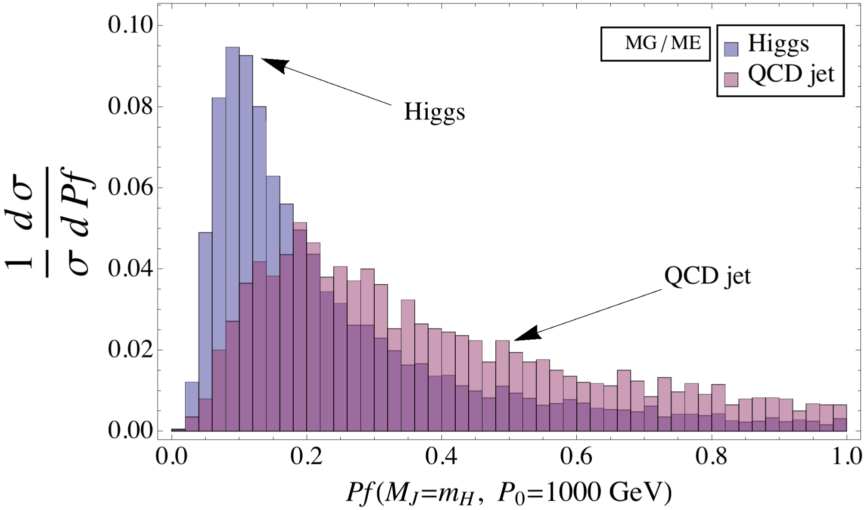
Templates can be improved by making use of color flow, partly captured by planar flow





NLO templates

L. Almeida, O. Erdogan, JJ, S. Lee,
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For the Higgs, both signal and background have a two-subjet topology at LO

IDEA: Enhance templates by including the effects of gluon emissions

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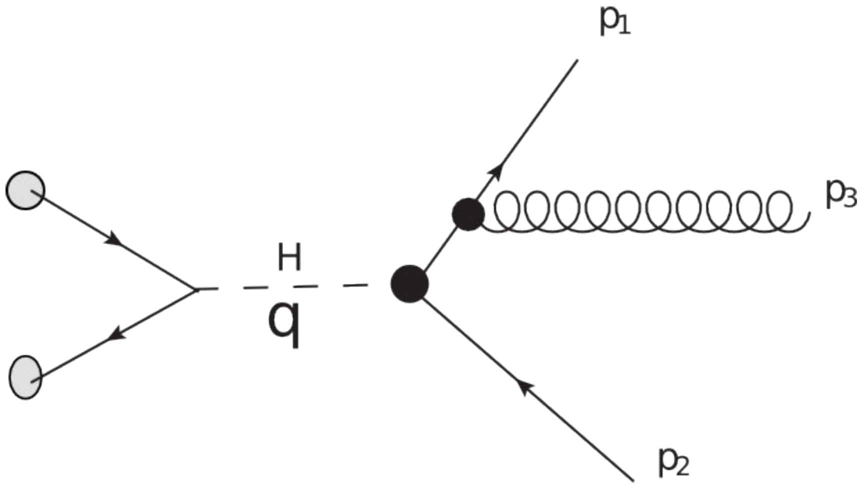
NLO template:



$$x_i = \frac{2p_i \cdot q}{s}$$

$$0 < x_i < 1$$

Templates

Three Euler angles
Ψ,θ,φ

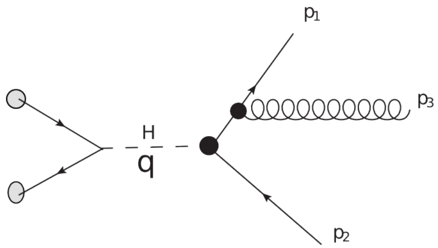
Two energy fractions
x_1, x_2

$$p_a^\mu(x_1, x_2, \psi, \theta, \phi) = L_z(\gamma) R_z(\psi) R_x(\theta) R_z(\phi)\, p_a^\mu|_{P_j^z=0}(x_1, x_2)$$

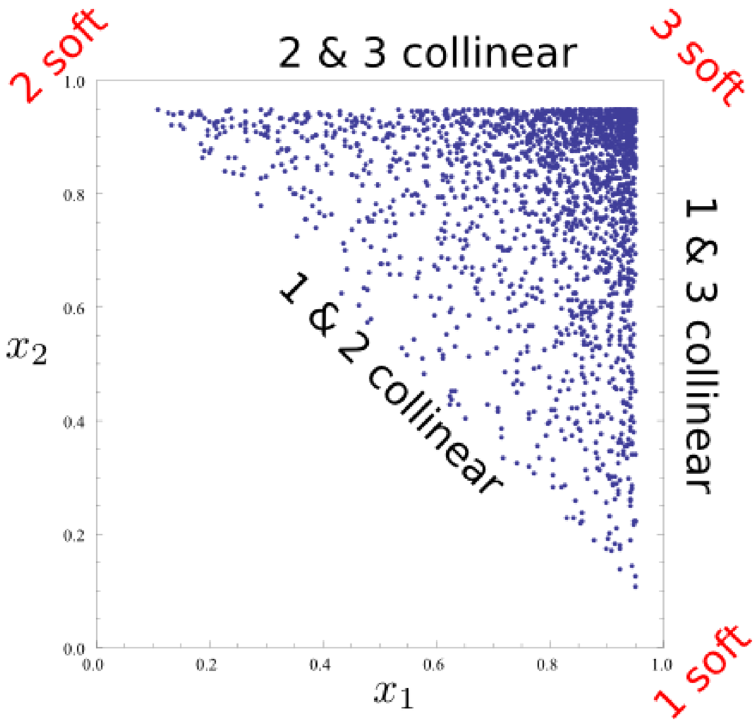
NLO templates and Higgs decay

Differential branching ratio

Since the Higgs is a color singlet, we can provide a precise NLO computation



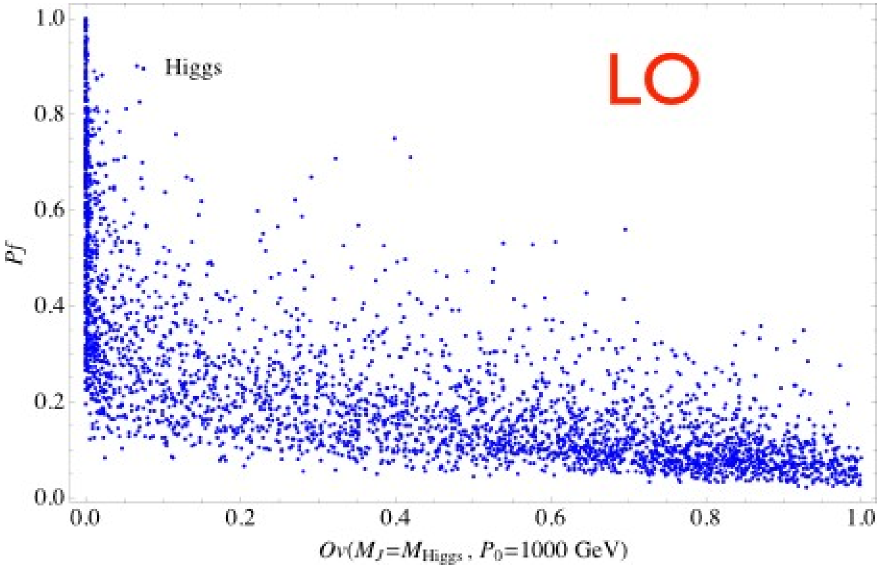
$$\frac{d\Gamma(H\to q\bar{q}g)}{\Gamma_0} = \frac{1}{8\pi^2} C_F \alpha_s \frac{(1-x_1-x_2)^2+1}{(1-x_1)(1-x_2)}\, dx_1 dx_2\, d(\cos\theta) d\phi.$$



JADE, δ=0.05

NLO template and Higgs decay

- Template overlap from LO to NLO



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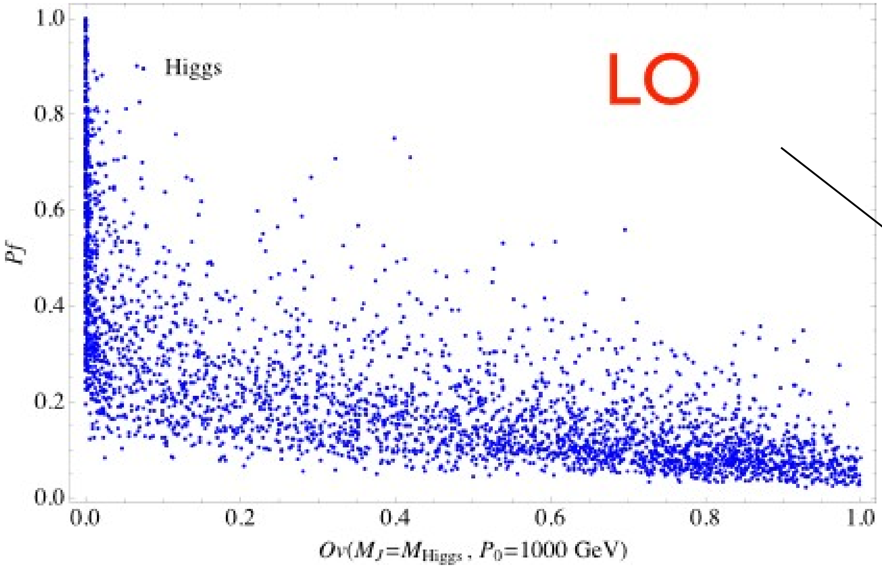

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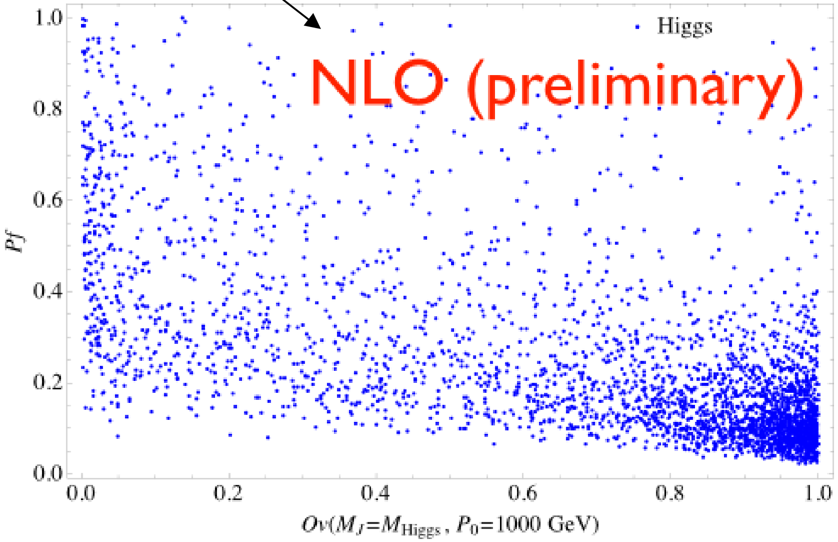


NLO Planar Flow for Higgs decay

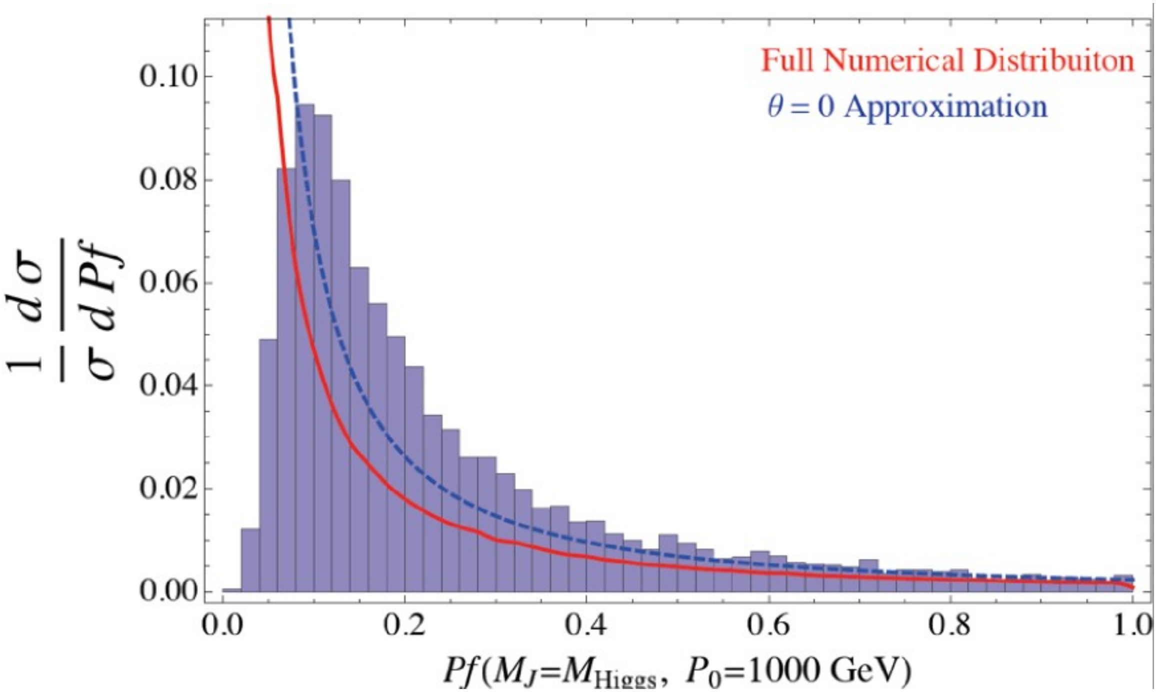
NLO planar flow for Higgs:

$$\frac{d\sigma^{\mathrm{NLO}}}{d\mathrm{Pf}} = \int dx_1 dx_2 d(\cos\theta) d\phi \, \frac{d\sigma}{dx_1 dx_2} \delta\left(\mathrm{Pf} - \frac{E_J^3}{E_1 E_2 E_3} S \cos^2\theta\right)$$

$S=(1-x_1)(1-x_2)(x_1+x_2-1)$

θ=0 approximation:

$$\frac{1}{\sigma_0}\frac{d\sigma^{(3)}}{d\mathrm{Pf}} = \frac{\alpha_s}{2\pi} \mathrm{C_F} \int_{x_2^-}^{x_2^+} dx \, \frac{8x\left[\mathrm{Pf}((x-3)x^2+4x)+8x((x-1)x+1)-8\right]}{\mathrm{Pf}(\mathrm{Pf}+8)^2\left(\frac{8}{\mathrm{Pf}+8}-x\right)\sqrt{\left(\frac{8}{\mathrm{Pf}+8}-x\right)(x_2^+-x)(x_2^- -x)x}}$$



Resummation needed. But, tail (Pf»0) region already well described by simple NLO

Summary

- Template overlaps:
  - New class of finite jet observables, based on functional comparison of the energy flow in data with the flow in selected templates of partonic states → help identify boosted jets from tops/Higgs
  - Do not require computationally intensive algorithms
  - Allow for systematic improvement
    - By incorporating higher order QCD matrix element corrections
  - Can be combined with jet shapes to improve rejection power.
  - Can use our knowledge of the signal to design a custom analysis for each resonance

Recent progress on understanding how to generate NLO templates for Higgs...
…but more ideas on the way…