Energy spikes of signals & backgrounds, from PQCD to experiments

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CERN (tomorrow)

R. Alon, E. Duchovni, GP & P. Sinervo, for the CDF Col., CDF/PUB/JET/PUBLIC/10199; CDF/ANAL/TOP/PUBLIC/10234; 1106.5952 [hep-ex].

Almeida, Lee, GP, Sterman & Sung, PRD (10).

Almeida, Erdogan, Juknevich, Lee, GP, Sterman, in preparation.

Gur-Ari, Field, Kosower, Mannelli & GP, in preparation.

Implications of LHC results for TeV scale physics

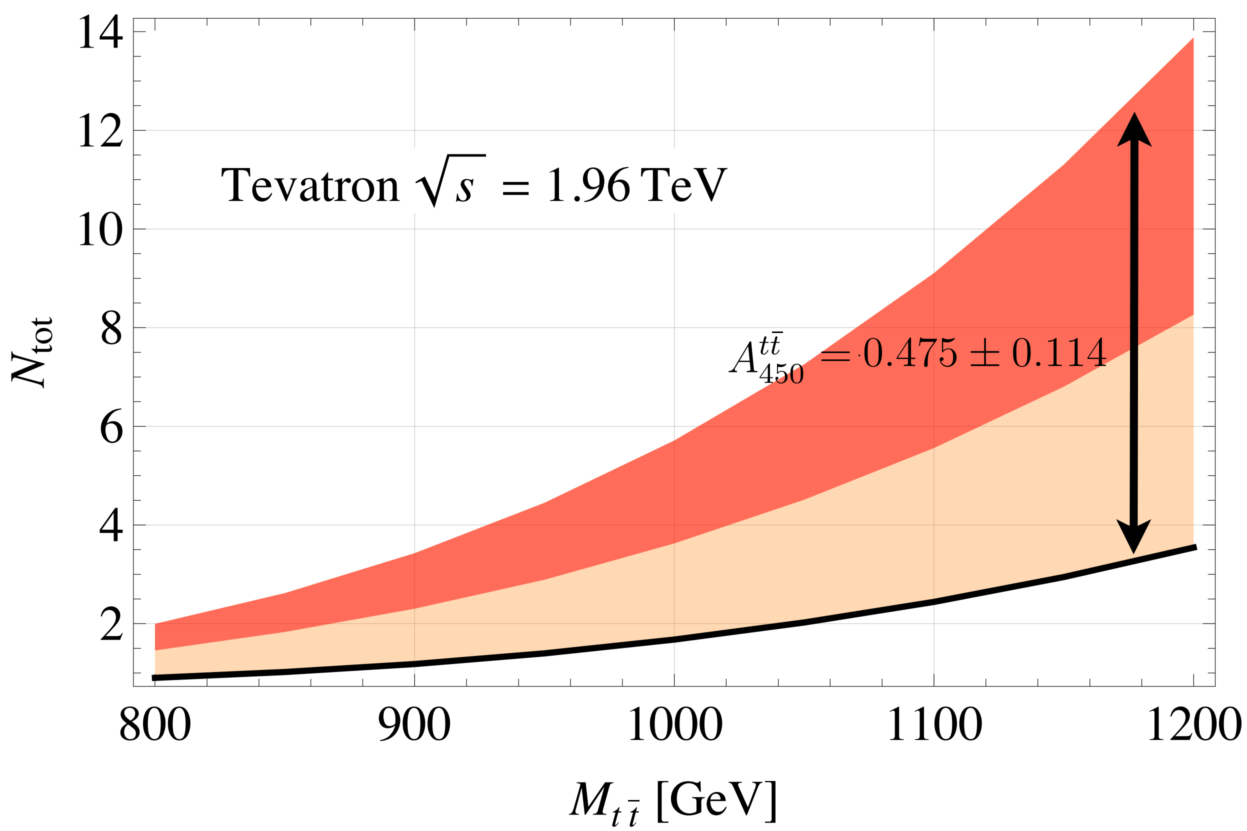
Outline

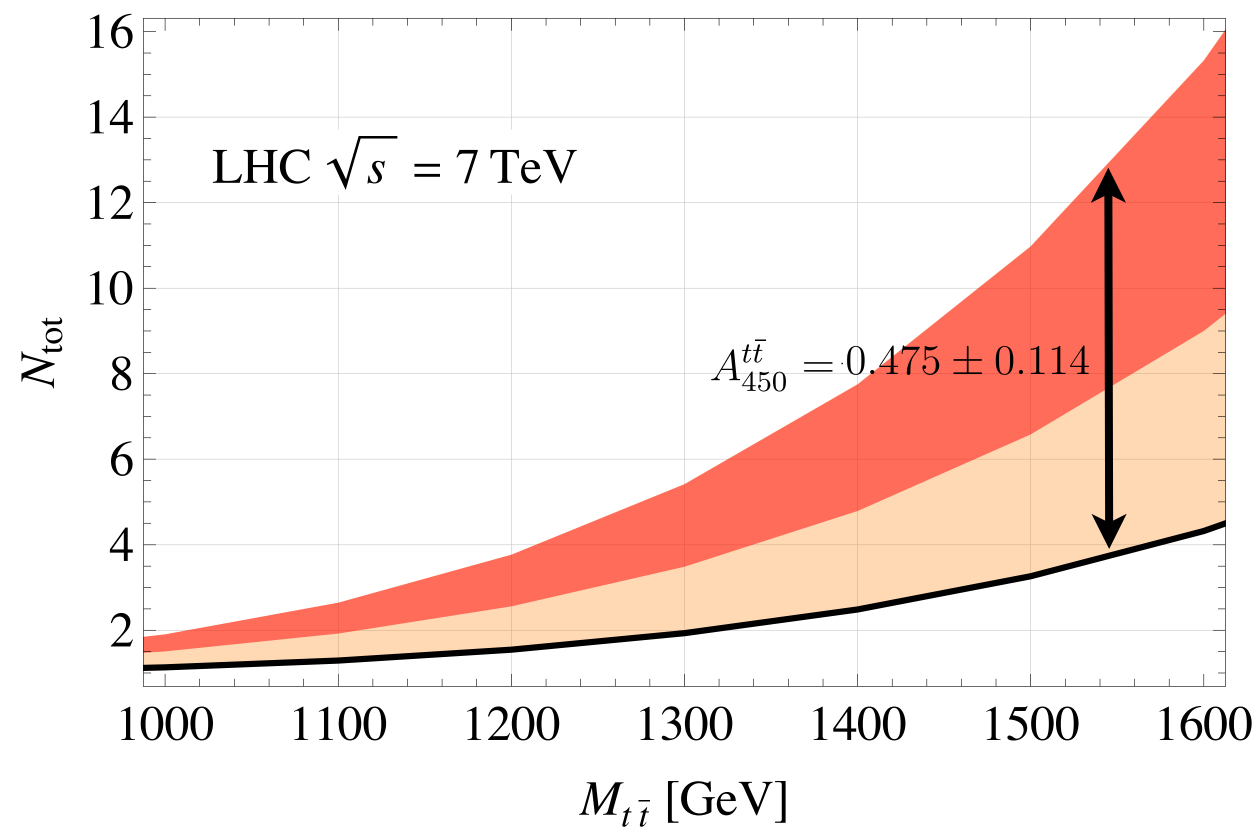
- Brief motivation.
- Jet mass+angularity, QCD vs. Higgs, theory + exp'.
- Template function, LO top+Higgs.
- New: NLO Higgs (& QCD).
- Summary.

AFB from hard phys.: anomalies in spectrum

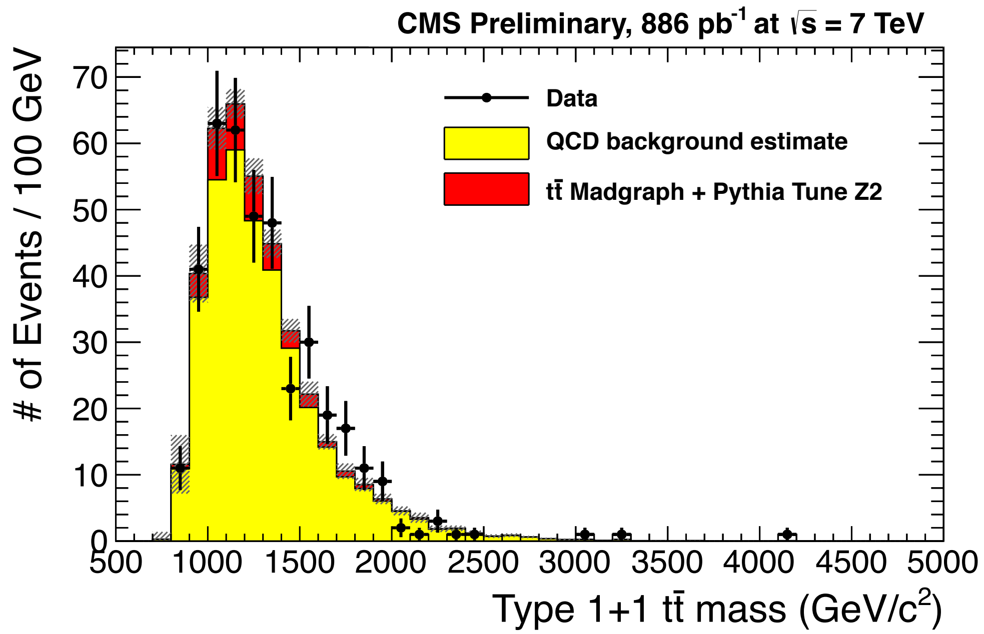
Chivukula, et al. (10); Cao, et al. (10);
Delaunay, et al.; Aguilar-Saavedra, et al. (11).

$$N_{\rm tot} \equiv \frac{d\sigma^{\rm SM+NP}/dM_{t\bar{t}}}{d\sigma^{\rm SM}/dM_{t\bar{t}}} \,,$$



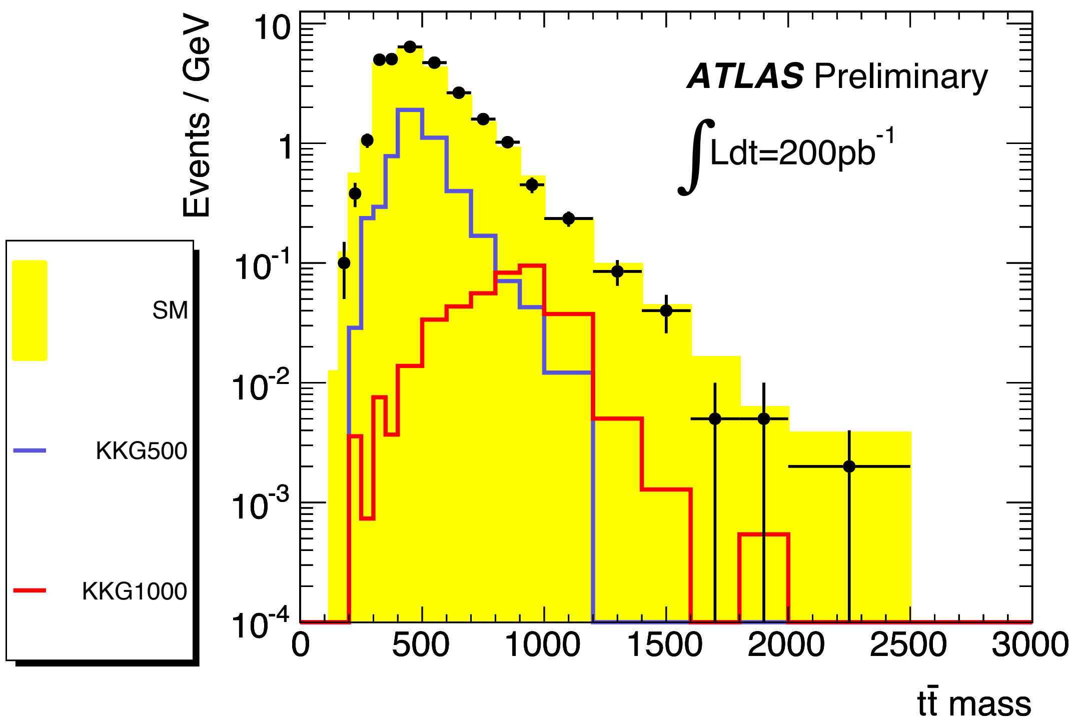


Experimental Frontier



CMS PAS EXO-11-006

(nothing interesting found by CMS in the 2+1 case)



ATLAS-CONF-2011-087

And ... possible hint at the CDF massive boosted jets study.

`CDF/ANAL/TOP/PUBLIC/10234;` Eshel, Gedalia, GP & Soreq, PRD Rapid Com. (11)

Finally, desire to study/improve boosted Higgs+W rejection factor.

Background rejection, basic approaches

- **Filtering.** (simple to implement, very successful)

  Seymour (93); Butterworth, Cox, Forshaw (02);
  Butterworth, Davison, Rubin & Salam (08);
  Krohn, Thaler & Wang (10); Ellis, Vermilion & Walsh (09).

- **Moments.** (easy to get LO PQCD, weak jet finder dep')

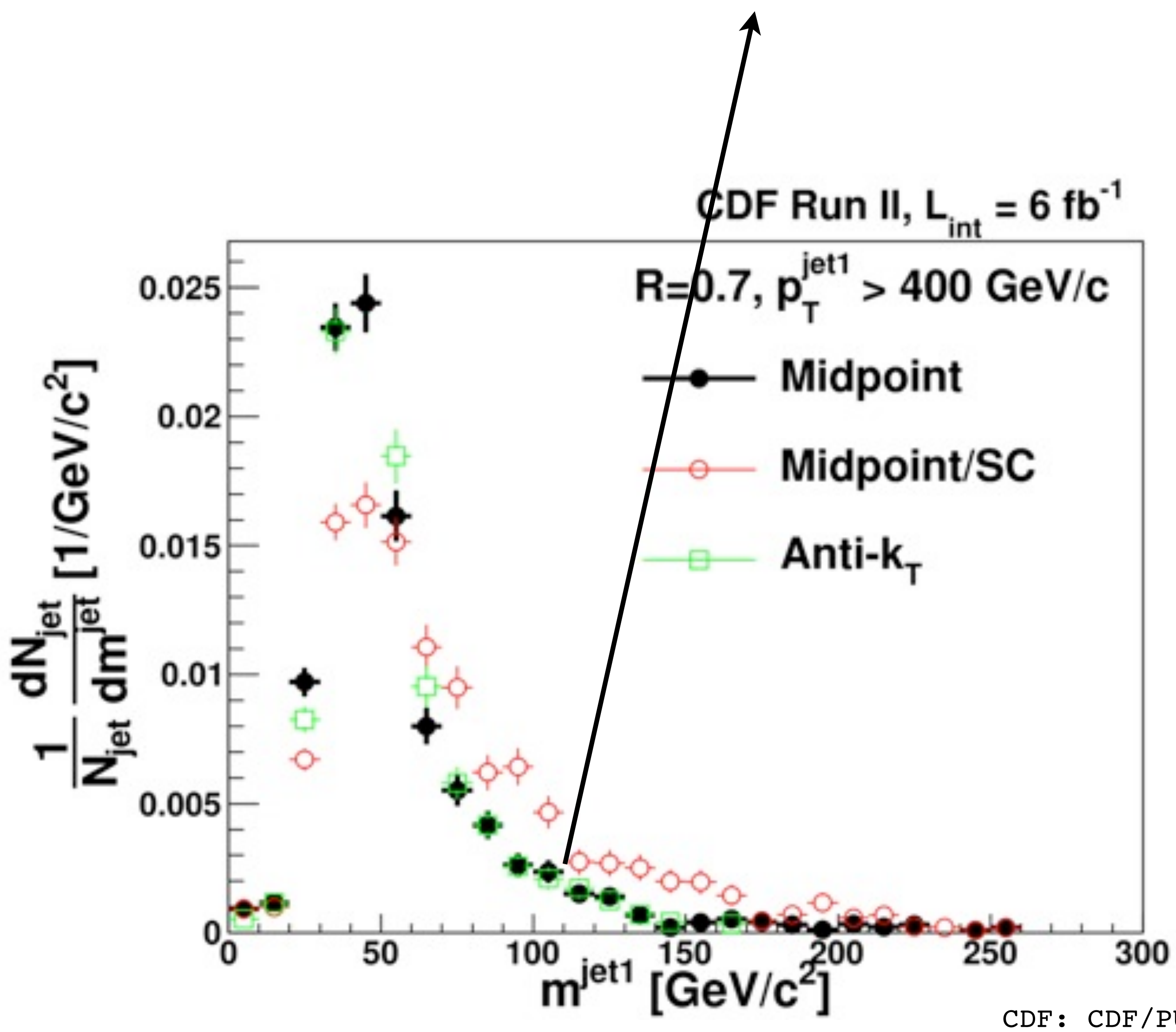
  Recently: Almeida, Lee, GP, Sterman, Sung & Virzi (08).

- **Template function.** (easy to get LO PQCD, weak jet finder dep' & beyond)

  Almeida, Lee, GP, Sterman & Sung (10).

The big picture: Energy flow of massive narrow jets, QCD first

- Interesting in studying narrow, massive high Pt jets: $m_{\mathrm{peak}} \ll m_J \ll P_T R\,, \quad R \ll 1$



(ignore non-IR safe red dots)

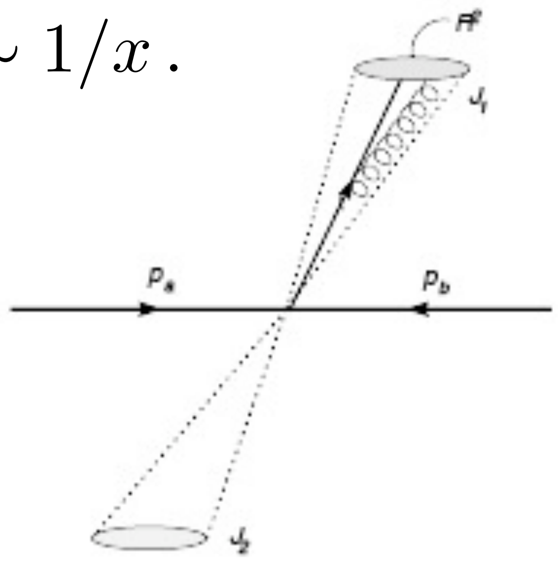
CDF: CDF/PUB/JET/PUBLIC/10199; 1106.5952 [hep-ex].

Energy dist' massive jets, splitting function

In QCD the probability for a parton j to emit a parton i with energy fraction x at angle θ is

$$d\sigma \propto \alpha_s P_{ij}(x) dx \frac{d\theta}{\theta}$$

$P_{ij}(x)$ is the Altarelli-Parisi matrix $P_{ij} \sim 1/x$.



Given $m_J^2 \approx x E_J^2 \theta^2 \Rightarrow \frac{d\sigma}{dm_J^2} \propto \alpha_s \frac{C_F}{m_J^2} \int_{\frac{m_J}{E_J}}^{R} \frac{d\theta}{\theta} \propto \alpha_s \frac{C_F}{m_J^2} \log\left(\frac{E^2 R^2}{m_J^2}\right)$

$C_F = 4/3$ for quarks, $C_A = 3$ for gluons.

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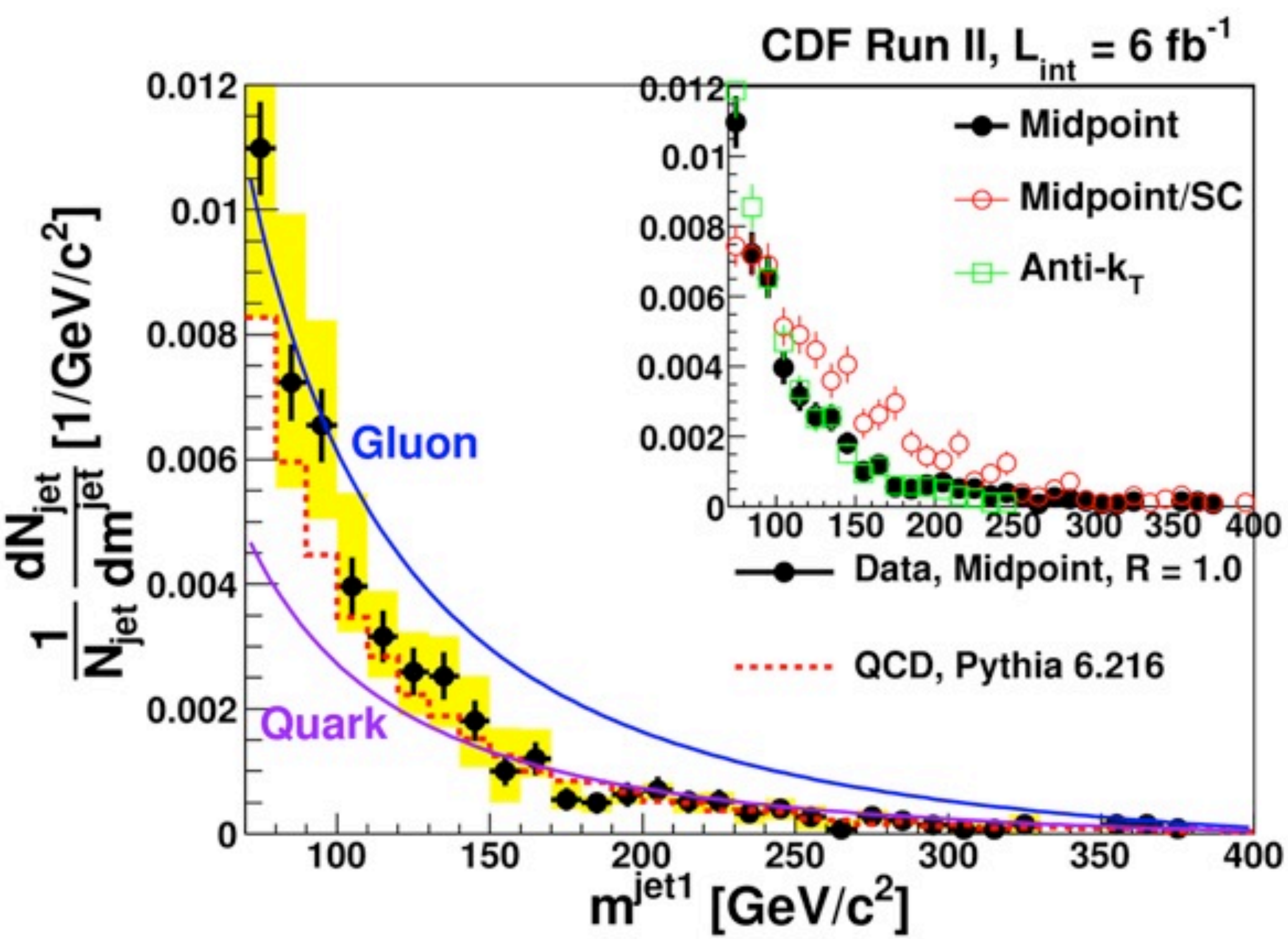

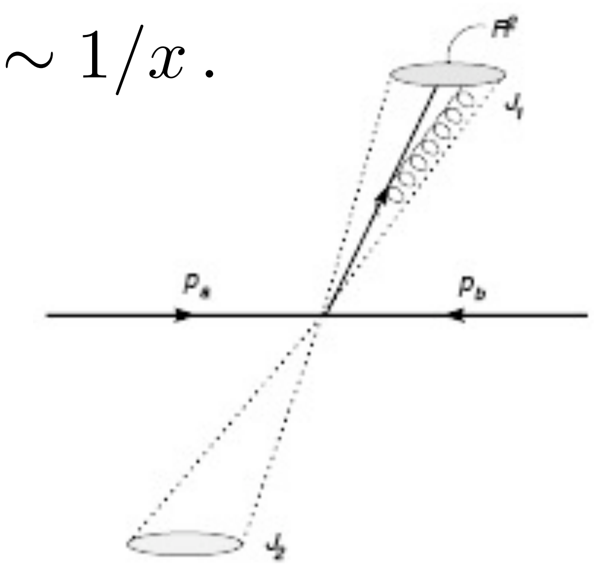

Given m ... $\frac{C_F}{m_J^2} \log\left(\frac{E^2R^2}{m_J^2}\right)$

... $C_A = 3$ for gluons.

See also: ATLAS-CONF-2011-073 & CMS PAS EXO-11-006.

Going beyond mass, angle dist', angularity,

To LO there's only a single variable E-ratio or angle -

QCD: $$\frac{d^2\sigma}{dm_J^2 d\theta} \propto \alpha_s \frac{C_F}{m_J^2}\frac{1}{\theta}\,\Big|_{R>\theta>\frac{m_J}{E_J}}$$

Higgs: $$\frac{d^2\sigma}{dm_J^2 d\theta} \propto \delta(m_J - m_H)\frac{1}{\theta^3}\,\Big|_{R>\theta>\frac{m_J}{E_J}}$$

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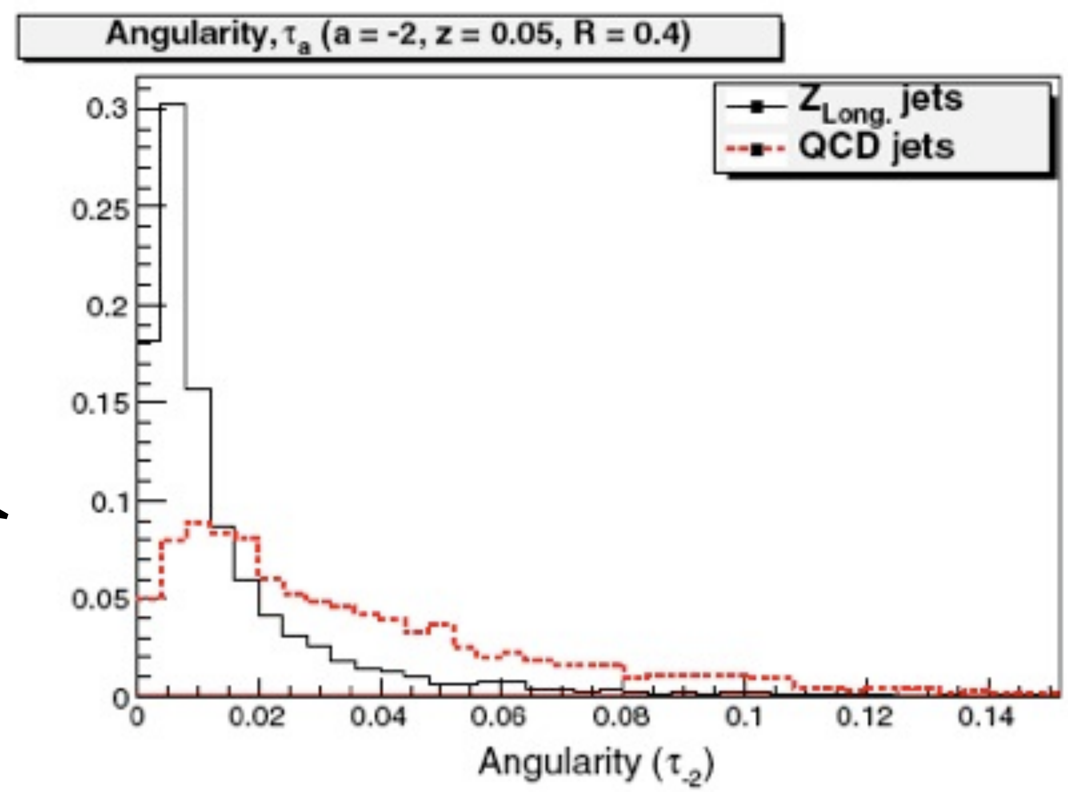
Signal & backgroun dist' are similar in shape !



The angularity distribution for QCD (red-dashed curve) and longitudinal Z (black-solid curve) jets obtained from MADGRAPH. Both distributions are normalized to the same area.

Almeida, Lee, GP,

Sterman & Sung, PRD (08).

How to make progress ?

Need NLO!

But before NLOing let's take a step backwards:

Template method (useful both for top & Higgs case).

Template Overlap Method, E-Spikes

Almeida, Lee, GP, Sterman & Sung, PRD (10).

- Template overlap: functional measure of how well jet-energy-flow matches flow of a certain template calculated from 1st principle (fixed order partonic)

Ex. top:

$$|t> \;=\; \text{top distribution}$$
$$|g> \;=\; \text{massless QCD distribution}$$

We need a probe distribution, $|f>$, such that

$$R = \left(\frac{<f|t>}{<f|g>}\right) \text{ is maximized.}$$

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

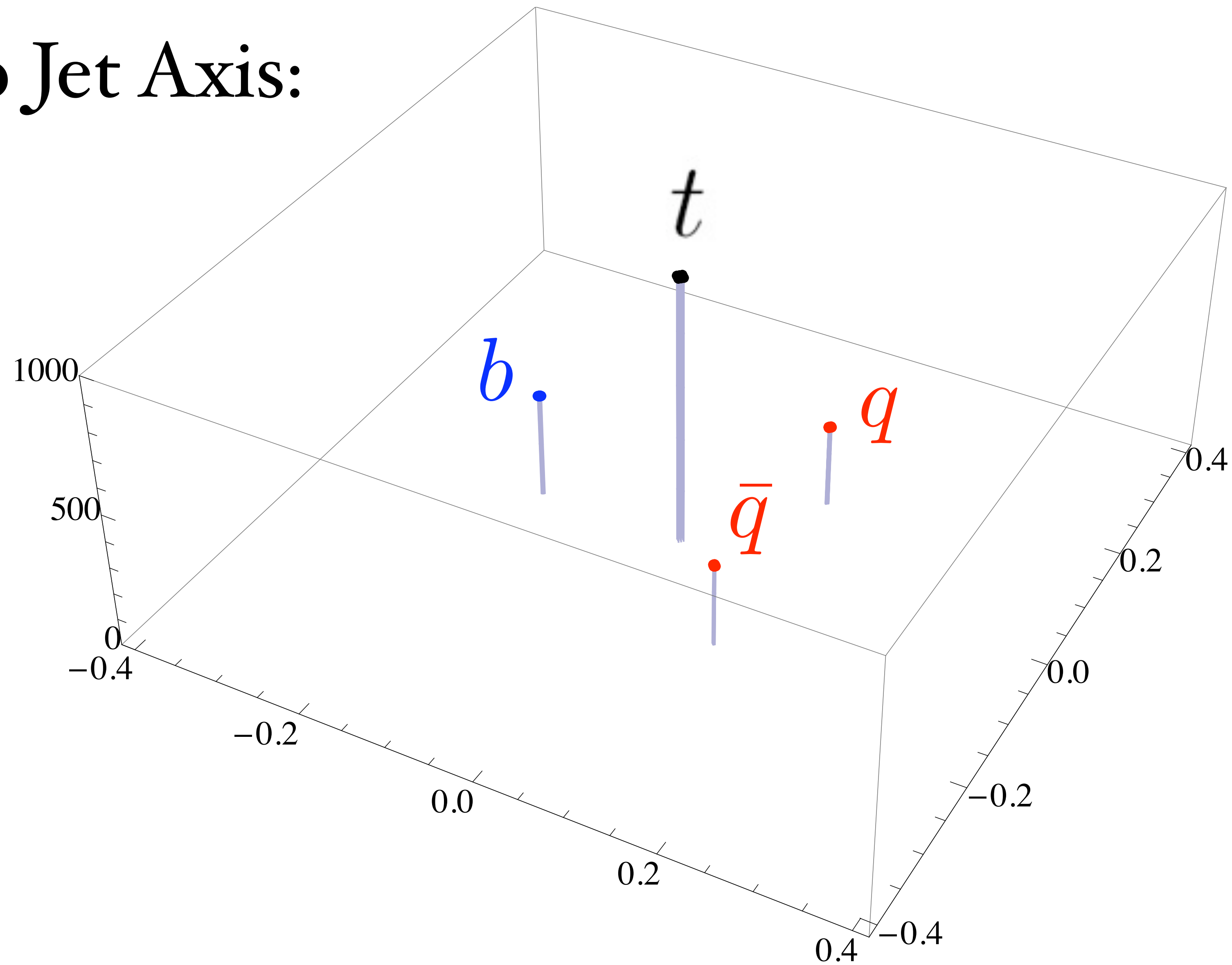
Example, top jet: "Golden Triangle"

In principle for 3-body there are 5 variables, for top there are ~ 3.

Gur-Ari, Papucci & GP (11)

$$E(\hat{p}_x, \hat{p}_y)$$

Plane $\perp$ to Jet Axis:



Three-particle Templates and Top Decay

- jet mass window 160 GeV < m_J <190 GeV,

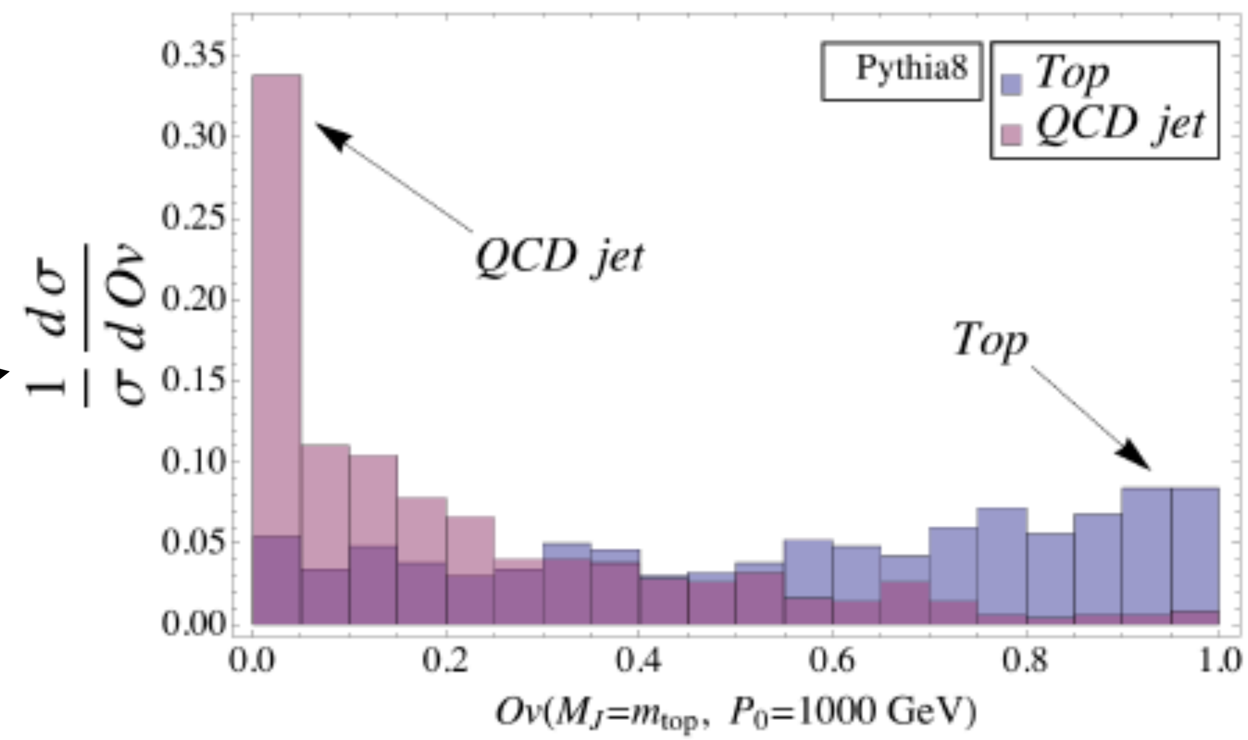
cone size R = 0.5 (D = 0.5 for anti-kT jet),
jet energy 950 GeV < E_J < 1050 GeV.

- Template Overlap with data discretization

$$Ov(j,f) = \max_{\tau_n^{(R)}} \exp\left[-\sum_{a=1}^{3} \frac{1}{2\sigma_a^2} \left(\sum_{k=i_a-1}^{i_a+1} \sum_{l=j_a-1}^{j_a+1} E(k,l) - E(i_a,j_a)^{(f)} \right)^2 \right]$$

$$\sigma_a = E(i_a, j_a)^{(f)}/2 \,.$$

after mass cut



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- jet mass window 160 GeV < m_J <190 GeV,

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- Templ … on

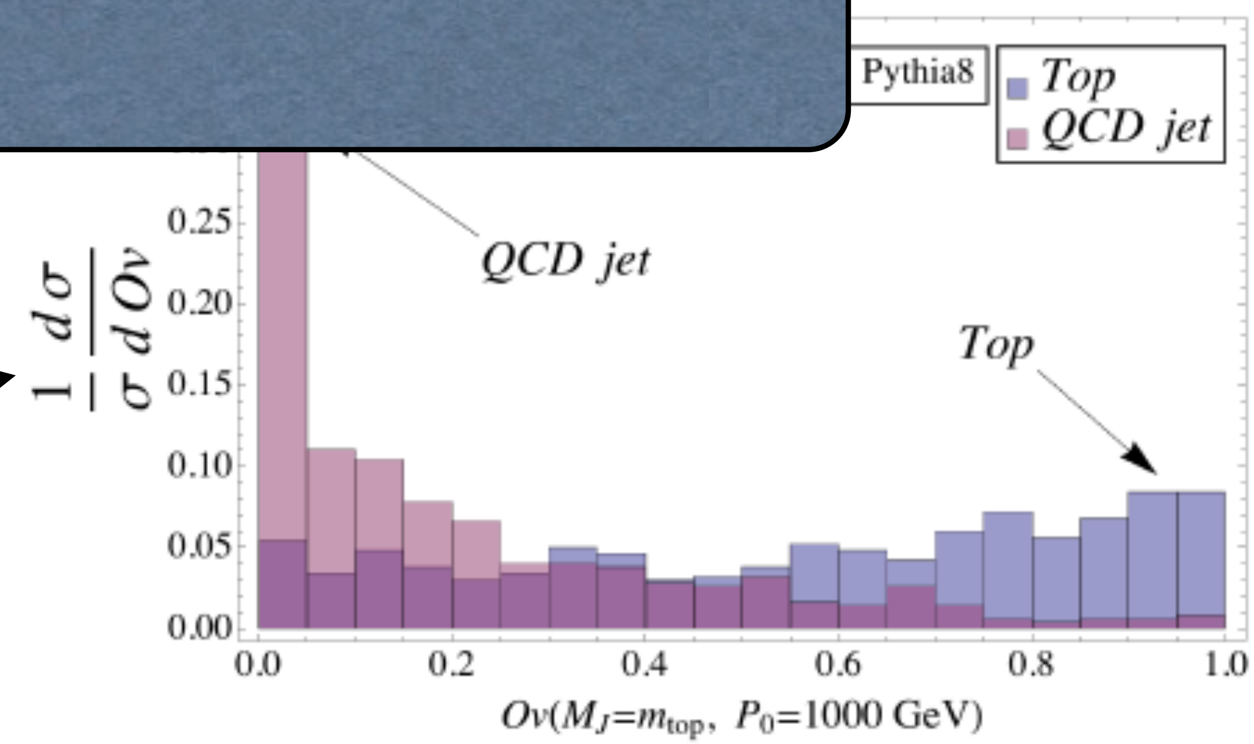
Final rejection power (eff'/fake rate) -

Pythia8: 1 in 1000
MadGraph: 1 in 600

$Ov(j, f) = \ldots$ $\ldots, j_a)^{(f)} \Big) \Big]^2$

$\sigma_a = E(\ldots$

after mass cut



Back to Higgs case, all below is preliminary

Almeida, Erdogan, Juknevich, Lee, GP, Sterman, in preparation.

- The 2-body template function is easy to construct.
- However, similarity of S & B dist' => milder success.

Back to Higgs case, all below is preliminary

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- The 2-body template function is easy to construct.
- However, similarity of S & B dist' => milder success.
- For Higgs (W/Z) simple to compute NLO templates:

(i) Go to the rest frame (Higgs=color neutral).

(ii) Calculate the NLO Xsection:

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

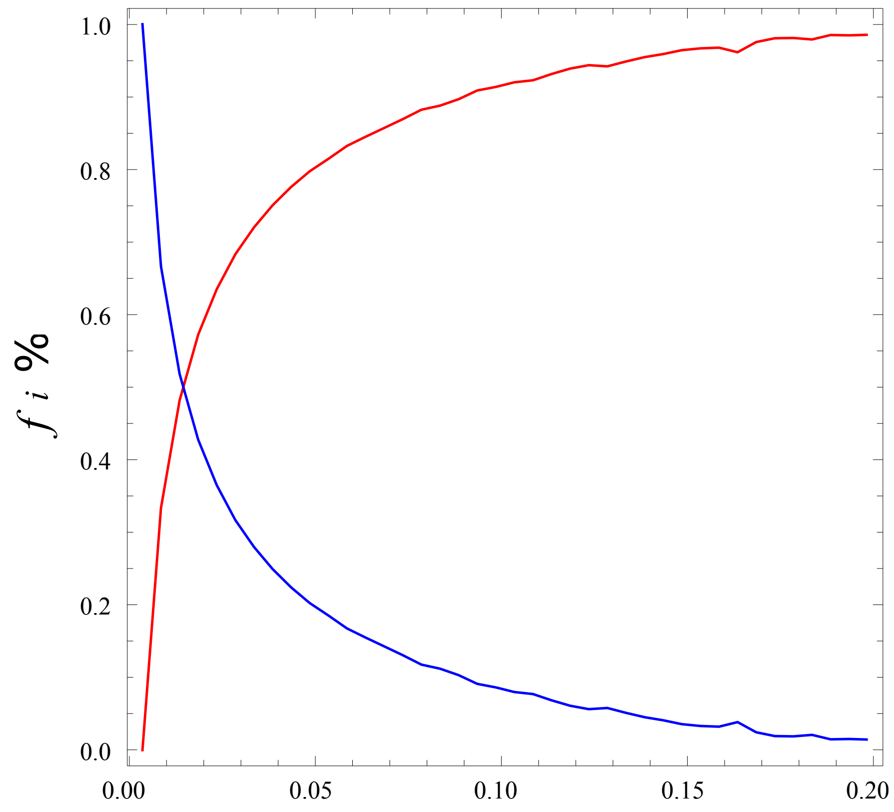
Drees & Hikasa, PLB (90)

(iii) Jade separate 2 vs 3-jet case: $y_{\rm cut} = \frac{m_{ij}^2}{m_H^2} = 0.05$.

Higgs NLO template, cont'

$$\sigma^{NLO} = \sigma(2\,\text{jet}) + \sigma(3\,\text{jet}) \qquad \sigma(n\,\text{jet}) = f_n\,\sigma$$

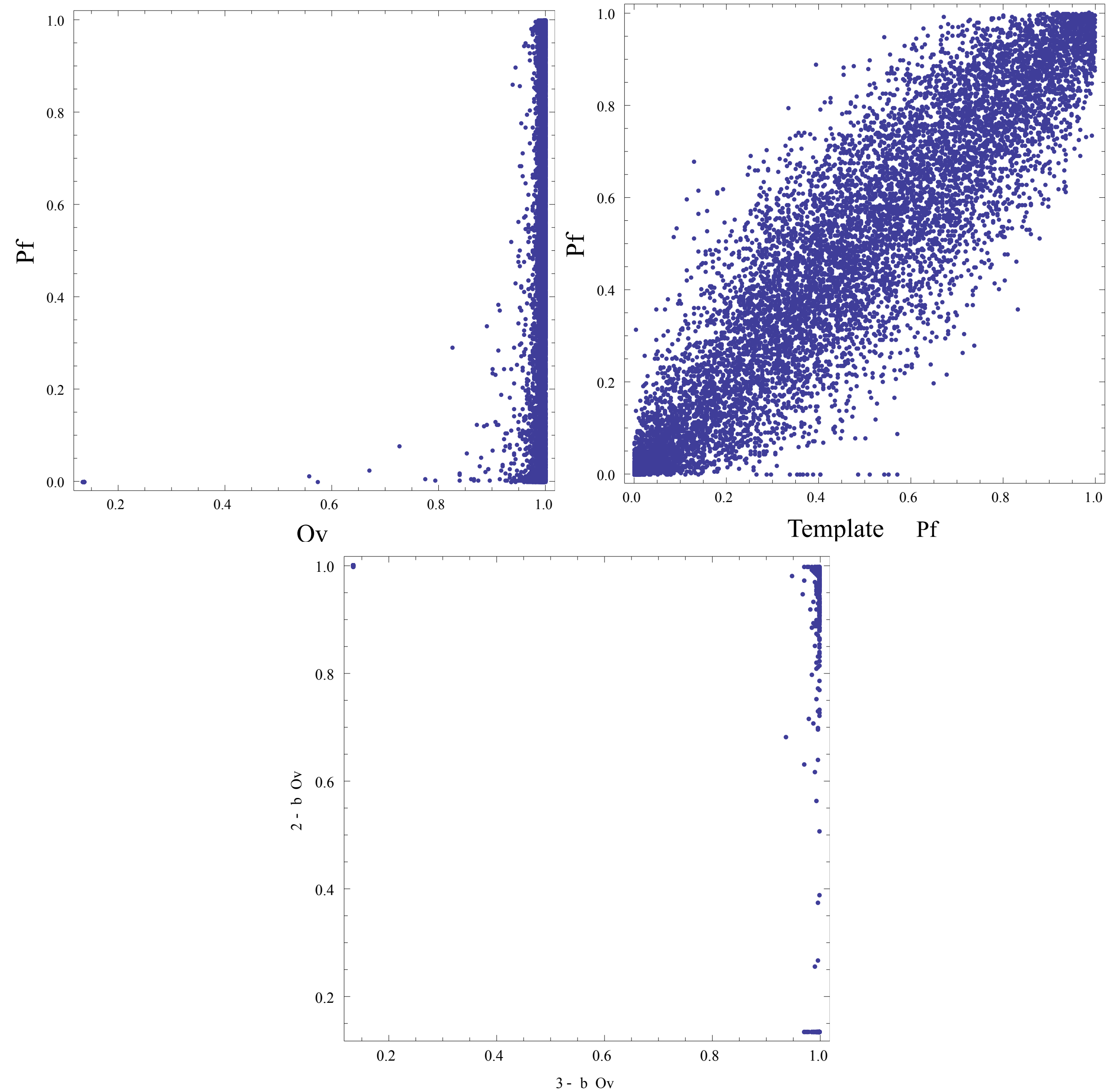
$$f_2 = 1 - f_3.$$



(iv) Boost it to the lab frame (now depends on all 5 variables).

Results

Few sanity partonic checks:

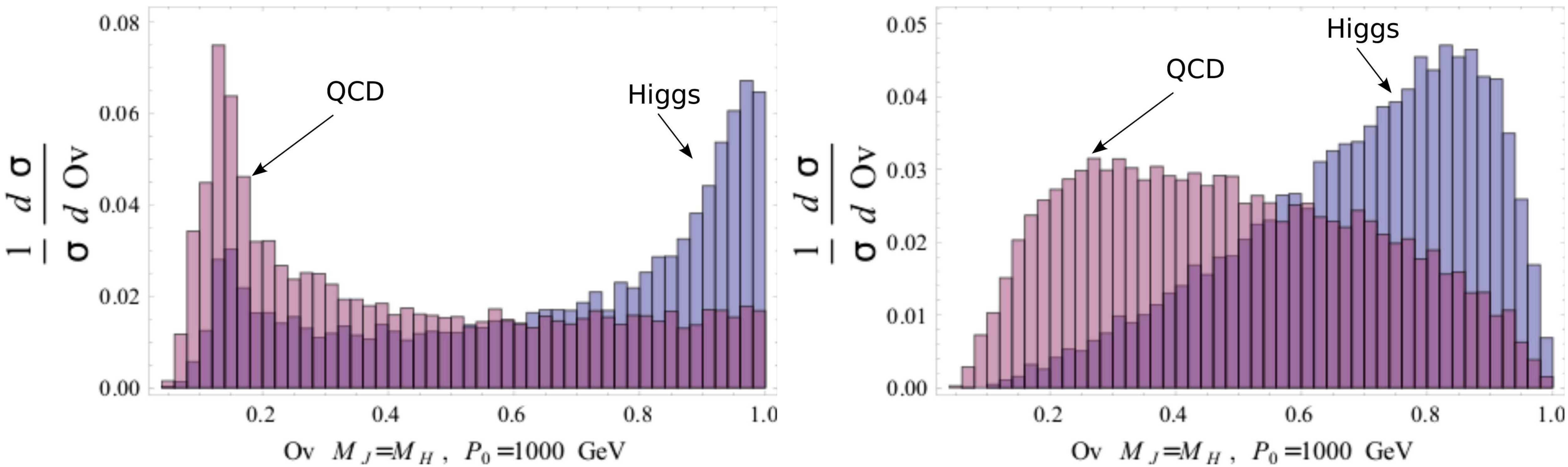


A scatter plot of template overlap and Pf for LO parton-level MC output for higgs decay, with $P_0 = 1$ TeV, $m_{higgs} = 120$ GeV.

- Can now calculate semi-analytically various shapes:

Pf, x_1-x_2 etc...; focus on rejection.

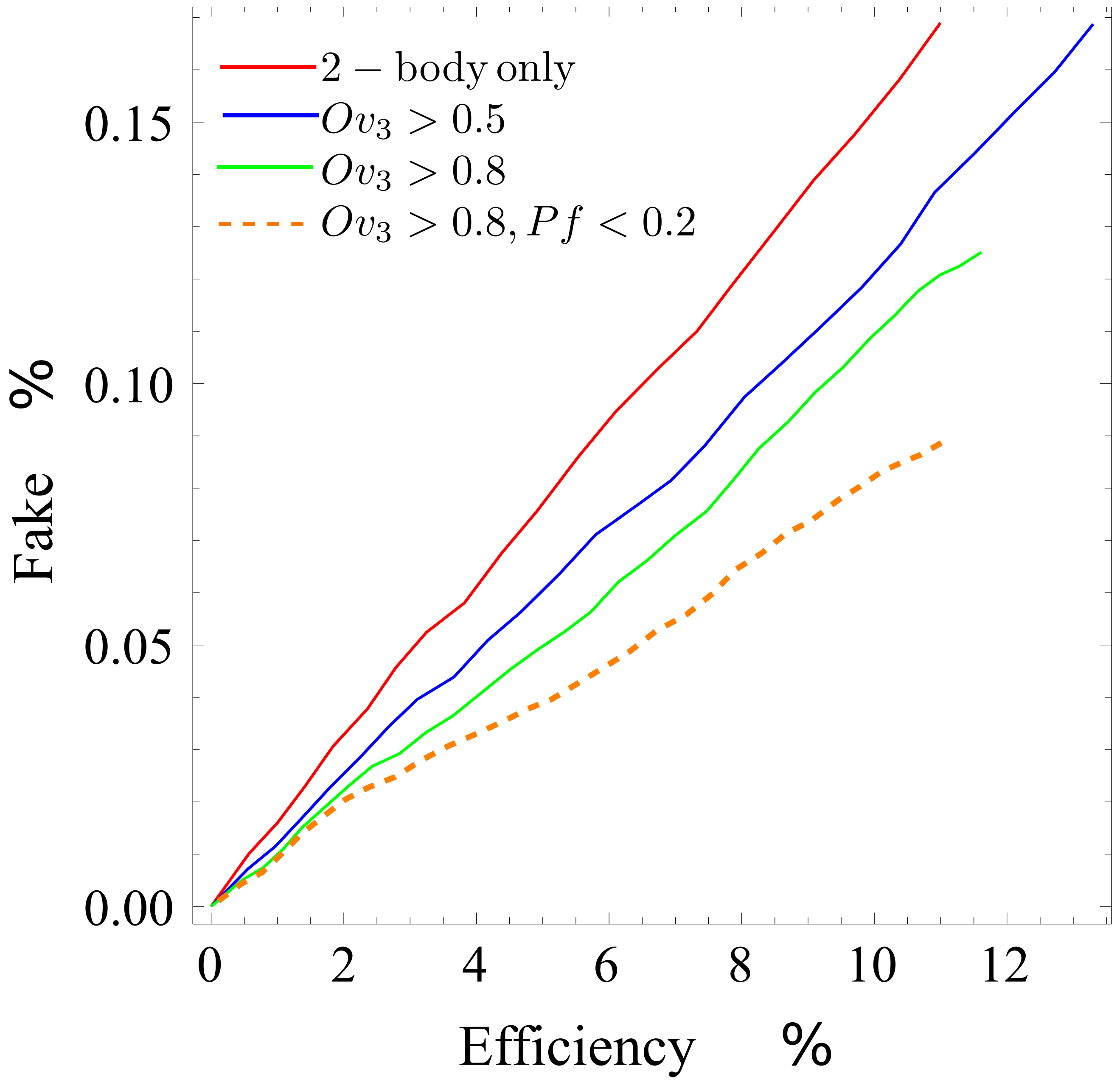
2body & 3body S vs. B max(Ov) dist'



Histograms of template overlap Ov with Higgs jets and QCD jets from Pythia 8, for $R = 0.5$, 950 GeV$\leq P_0 \leq$1050 GeV, 110 GeV$\leq m_J \leq$130 GeV and $m_{higgs} = 120$ GeV using 2-body templates (Left) and 3-body templates (Right).

Fake vs. efficiency 2-body vs. 3-body

Varying 2-body max(Ov) value (including mass cut)



Fake vs. efficiency 2-body vs. 3-body

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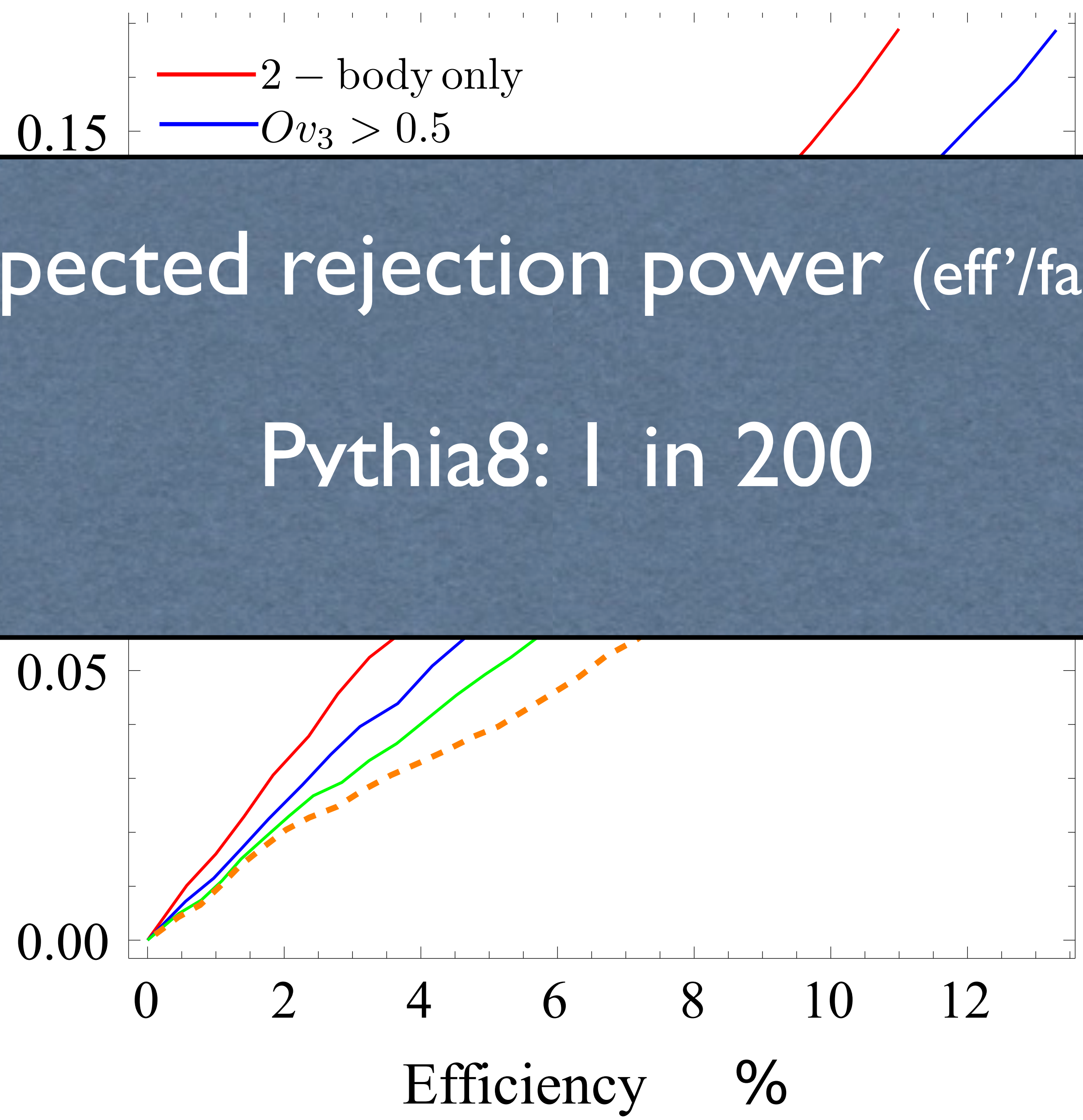

Expected rejection power (eff'/fake rate) -

Pythia8: 1 in 200

Summary

- Fixed order LO prediction => adequate for boosted massive narrow jets.
- LHC+CDF: Qualitative agreement with data.
- Can calculate jet shapes => smooth moments.
- Other extreme: describe jet energy flow as spikes => template function.
- Higgs: calculated NLO energy flow + template function => expected to yield very strong rejection power.

Backups

Higgs vs. QCD Pf