LHC searches: what role for QCD?

Gavin Salam

LPTHE, CNRS and UPMC (Univ. Paris 6)

Big Bang and Beyond: Forefronts of LHC Physics
Princeton Center for Theoretical Science
Princeton University, New Jersey, USA
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An often-repeated argument

LHC collides quarks and gluons

Quarks and gluons interact strongly → huge QCD backgrounds

Therefore we will need to rely on our understanding of QCD in order to make discoveries at LHC.

True, false, or only half the story?

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Contrasting views (1)

It must be true, otherwise why would there be such a large effort devoted to QCD calculations?

- Parton shower Monte Carlo Generators — Pythia, Herwig, Sherpa
- LO tree-level calculations — Alpgen, Madgraph, Sherpa, ...
- NLO calculations — $\sim 50 - 100$ people, cf. talk by Zvi Bern
- NNLO calculations — Higgs, W/Z, next step jets
- All-orders calculations — resummations, SCET
- Parton Distribution Functions (PDFs) — CTEQ, MSTW, NNPDF, . . .

Contrasting views (2)

Healthy scepticism

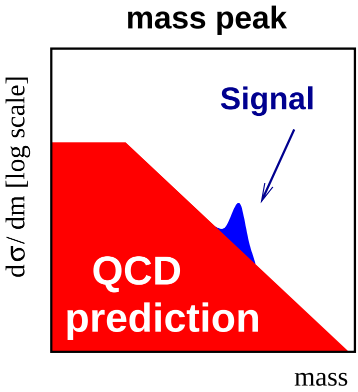
> *[...] unless each of the background components can be separately tested and validated, it will not be possible to draw conclusions from the mere comparison of data against the theory predictions.*
>
> *I am not saying this because I do not believe in the goodness of our predictions. But because claiming that supersymmetry exists is far too important a conclusion to make it follow from the straight comparison against a Monte Carlo.*

Mangano, 0809.1567

This talk

Try to examine the question of how much QCD matters, how much it can help with searches.

What kinds of searches?



New resonance (e.g. Z') where you see all decay products and reconstruct an invariant mass

QCD may:

- swamp signal
- smear signal

leptonic case easy; hadronic case harder

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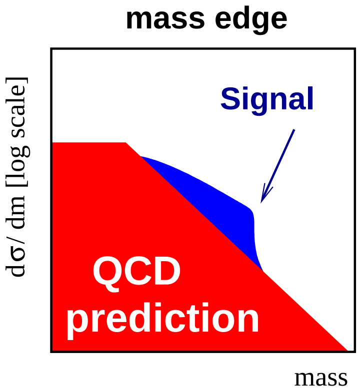

New resonance (e.g. R-parity conserving SUSY), where undetected new stable particle escapes detection.

Reconstruct only *part* of an invariant mass → kinematic edge.

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- swamp signal
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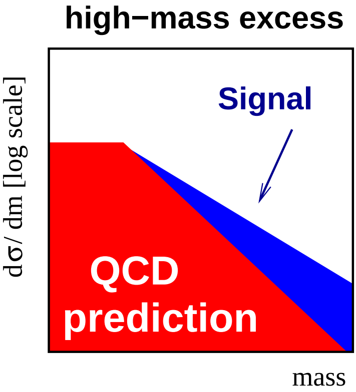
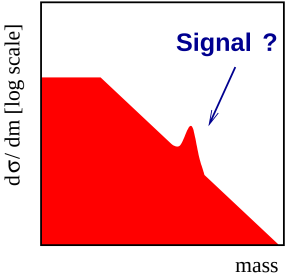


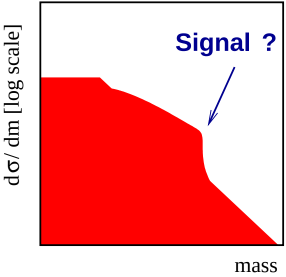
Unreconstructed SUSY cascade. Study *effective* mass (sum of all transverse momenta).

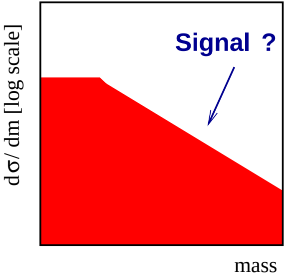
Broad excess at high mass scales.

Knowledge of backgrounds is crucial is declaring discovery.

QCD is *one way* of getting handle on background.







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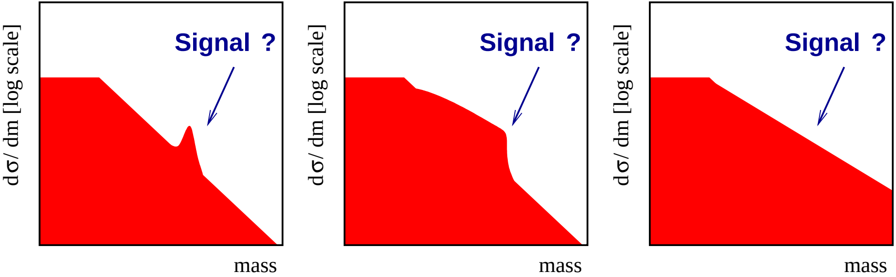

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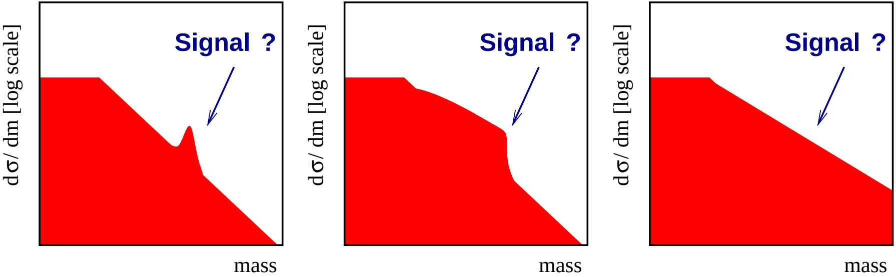

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START HERE

Before Starting

The most pervasive role of QCD at LHC

Every single paper that comes out from the ATLAS and CMS pp physics programmes will involve the use of one or more QCD-based parton-shower Monte Carlo event generators: Pythia, Herwig or Sherpa.

For simulating physics signals.

For simulating background signals.

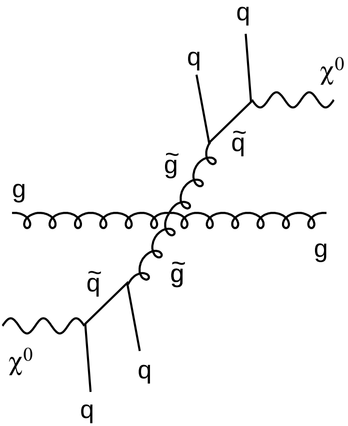
For simulating pileup.

As input to simulating detector respone.

Predicting QCD

SUSY example: gluino pair production

Signal



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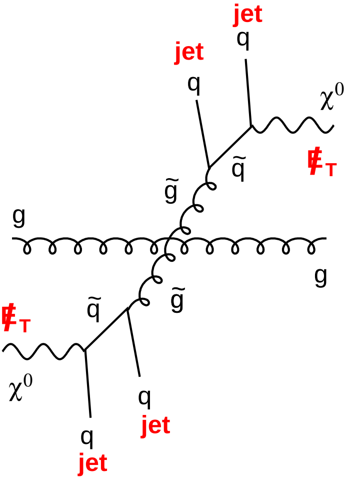

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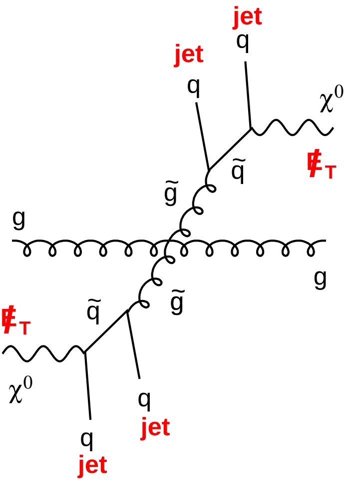
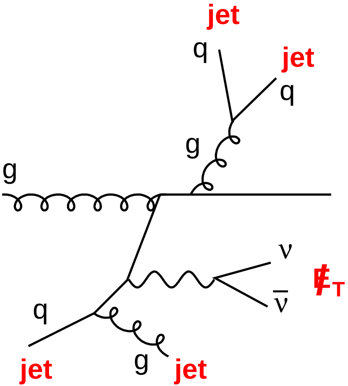


Background



SUSY searches: what excesses?

Atlas selection [all hadronic]

- no lepton
- MET > 100 GeV
- 1^{st},2^{nd} jet > 100 GeV
- 3^{rd},4^{th} jet > 50 GeV
- MET / m_{eff} > 20%

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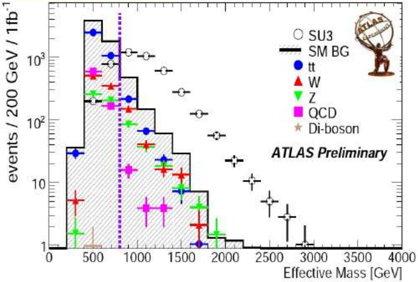
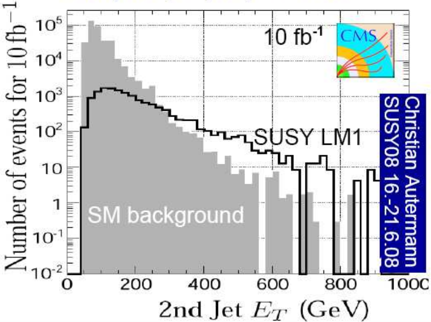
SUSY08 16.-21.6.08
4



CMS selection [leptonic incl.]

(optimized for 10fb^{-1}, using genetic algorithm)

- 1 muon pT > 30 GeV
- MET > 130 GeV
- 1^{st}, 2^{nd} jet > 440 GeV
- 3^{rd} jet > 50 GeV
- −0.95 < cos(MET,1^{st}jet)<0.3
- cos(MET,2^{nd}jet) < 0.85



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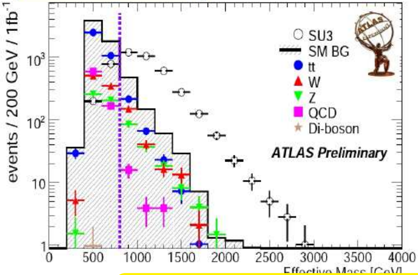

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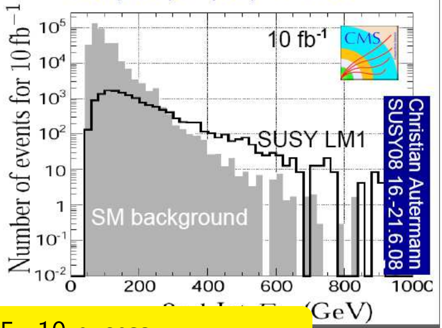


SUSY $\simeq$ factor 5−10 excess

How accurate is QCD?

$$\alpha_s \simeq 0.1$$

That implies LO QCD should be accurate to within 10%

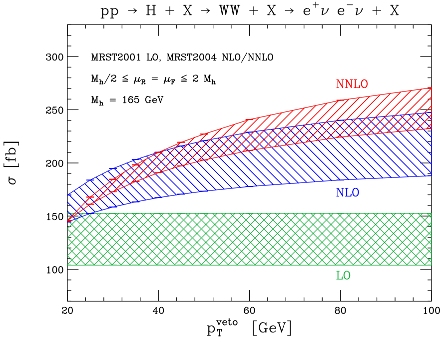
It isn't

Rules of thumb:

LO good to within factor of 2

NLO good to within scale uncertainty

How accurate is QCD?



Anastasiou, Melnikov & Petriello '04
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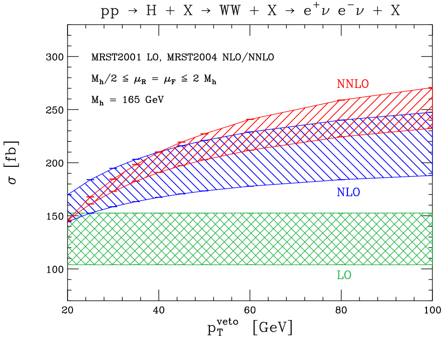

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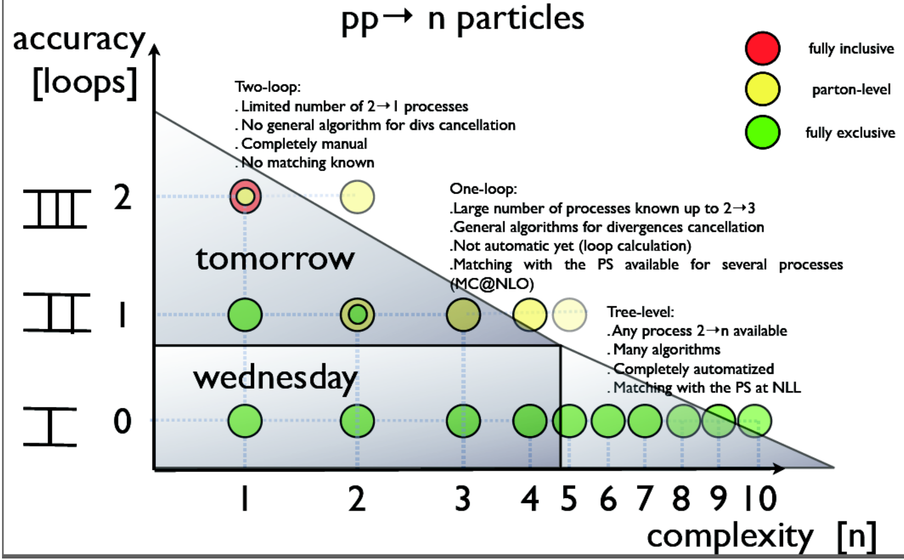
Theory status

from lectures
by F. Maltoni '07



pp→ n particles

Two-loop:
. Limited number of 2→1 processes
. No general algorithm for divs cancellation
. Completely manual
. No matching known

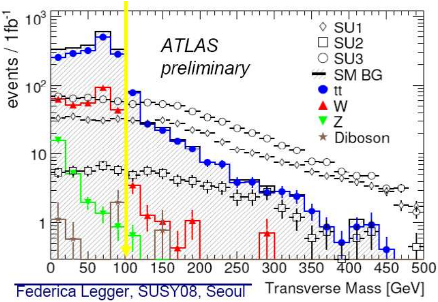
One-loop:
.Large number of processes known up to 2→3
.General algorithms for divergences cancellation
.Not automatic yet (loop calculation)
.Matching with the PS available for several processes (MC@NLO)

Tree-level:
.Any process 2→n available
. Many algorithms
. Completely automatized
. Matching with the PS at NLL

Control samples

We don't have NLO for the background (e.g. 4 jets + Z, a 2 → 5 process).

Only LO (matched with parton showers). How does one verify it?



Common procedure (roughly):

- Get control sample at low p_t
- SUSY should be small(er) contamination there
- Once validated, trust LO prediction at high-p_t

Is this safe?

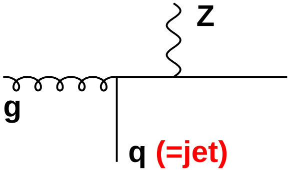
A conservative QCD theory point of view:

It's hard to be sure: since we can't calculate Z+4 jets beyond LO.

But we would tend to think it is safe, as long as control data are within usual factor of two of LO prediction

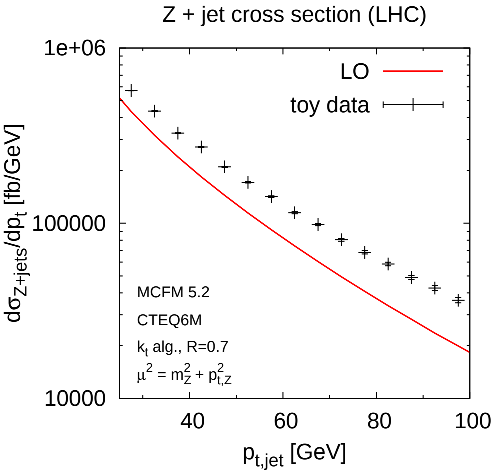
Illustrate issues with toy example: Z+jet production

- It's known to NLO and a candidate for "first" $2 \to 2$ NNLO $\sim e^+e^- \to 3$ jets, NNLO: Gehrman et al '08, Weinzierl '08
- But let's pretend we only know it to LO, and look at the p_t distribution of the hardest jet (no other cuts — keep it simple)



example based on background work for Butterworth, Davison, Rubin & GPS '08

Toy data, control sample



stage 1: get control sample

Check LO v. data at low p_t

- normalisation off by factor 1.5 (consistent with expectations)

  So renormalise LO by K-fact

- shape OKish

  Don't be too fussy: SUSY could bias higher p_t

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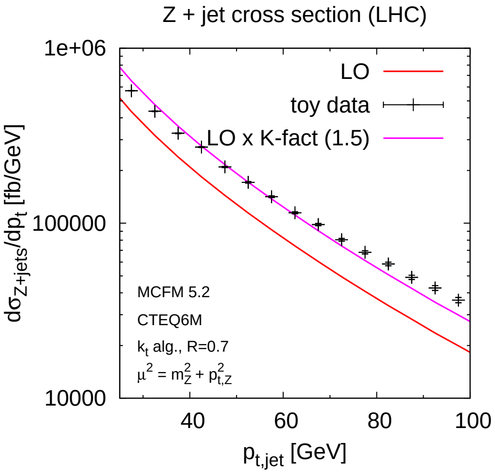

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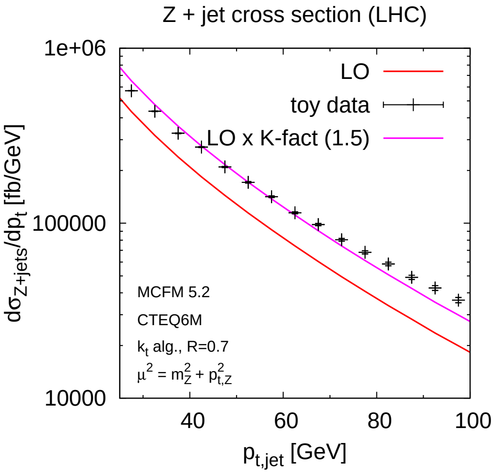

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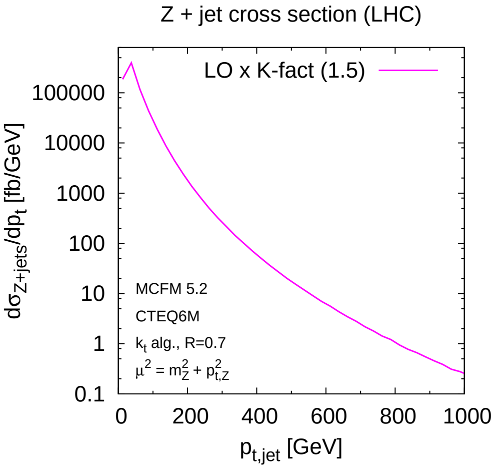
Toy data, high p_t

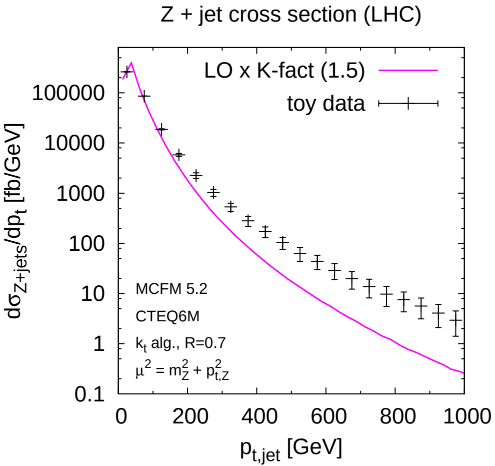


stage 2: look at high p_t

- good agreement at low p_t, by construction
- excess of factor ~ 10 at high p_t
- check scale dependence of LO

[NB: seldom done except
e.g. Alwall et al. 0706.2569]
still big excess

Toy data, high p_t



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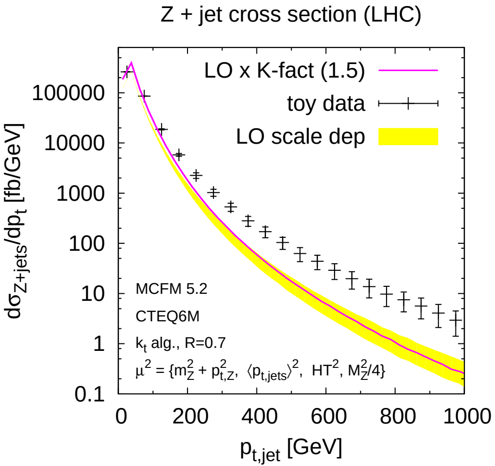

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What's in the toy data?

Is it:

- QCD + extra signal?
- just QCD? But then where does a K-factor of 10 come from?

Here it's just a toy illustration. In a year or two it may be for real:

- Do Nature / Science / PRL accept the paper?

  Discovery of New Physics at the TeV scale
  We report a 5.7σ excess in MET + jets production that is consistent with a signal of new physics . . .

- Do we proceed immediately with a linear collider?

  It'll take 10–15 years to build; the sooner we start the better

- At what energy? It would be a shame to be locked in to the wrong energy. . .

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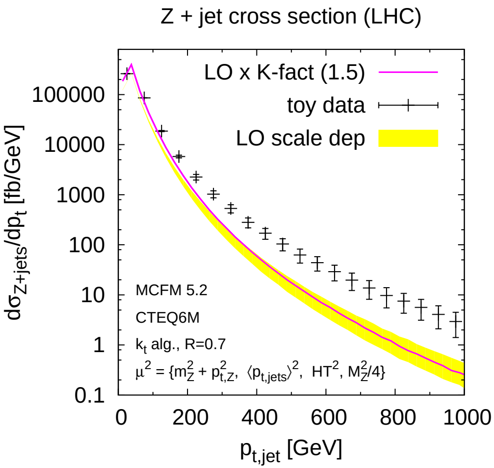

Unlike for SUSY multi-jet searches, in the Z+jet case we do have NLO.

Once NLO is included the excess disappears

The "toy data" were just the upper edge of the NLO band

Hold on a second: how does QCD give a K-factor $\mathcal{O}(5-10)$*?*

NB: DYRAD, MCFM consistent

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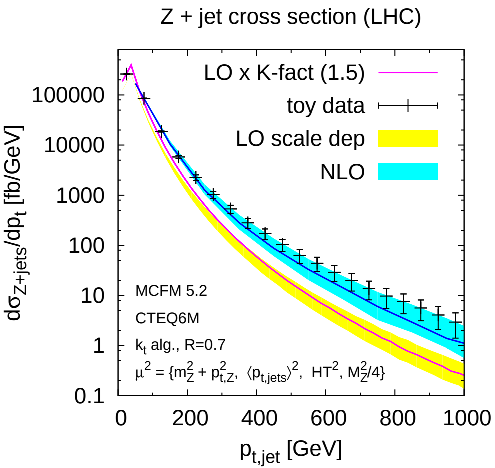

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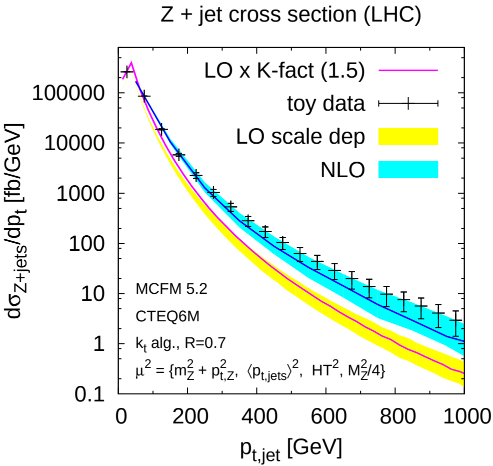

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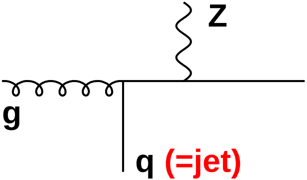
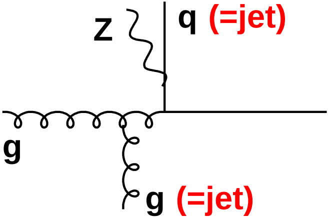
Why the large *K*-factor?

Leading Order



$\alpha_s\alpha_{EW}$

Next-to-Leading Order



$\alpha_s^2\alpha_{EW}\,\ln^2\frac{p_t}{M_Z}$

LHC will probe scales well above EW scale, $\sqrt{s} \gg M_Z$.
QCD and EW effects **mix**, EW bosons are **light**.
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Why the large *K*-factor?

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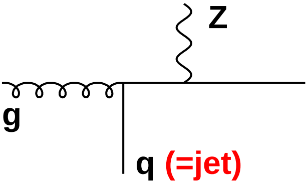

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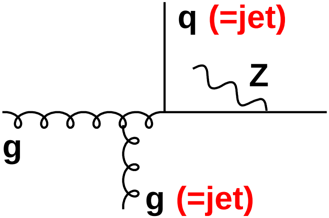

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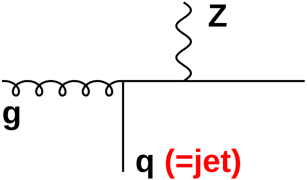

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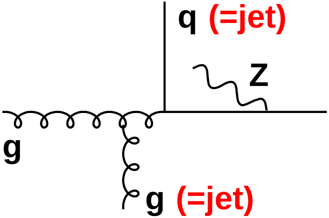

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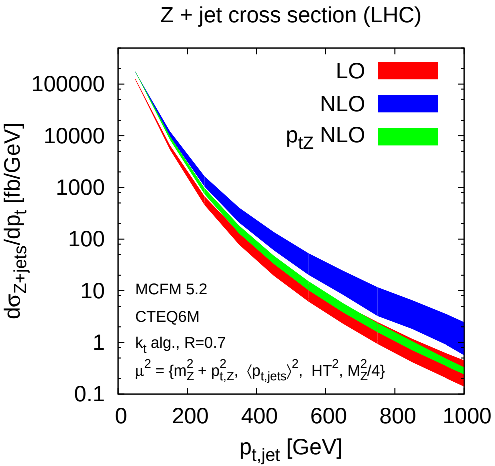
Cross-check



Plot distribution for p_{tZ}.

This selects events in which the Z is the hardest object.

Kills diags with EW double-logs.

NLO is well-behaved.

Where does this leave us?

- Excess $\equiv$ New Physics, **iff** you are really, really sure you understand backgrounds;
- Control samples may not be good enough cross-check
- Plain LO QCD can be misleading, understanding the physics is crucial

  This can be non-trivial even in simplest of cases

  But can help you choose good observables
- NLO provides a powerful cross check — and progress is being made in multi-jet case

  BlackHat: Berger et al. '08

  Rocket: Ellis, Kunszt, Giele, Melnikov & Zanderighi '08
- What about MLM, CKKW matching for combining different tree-level contributions?

  Designed to avoid deficiences of Parton Showers

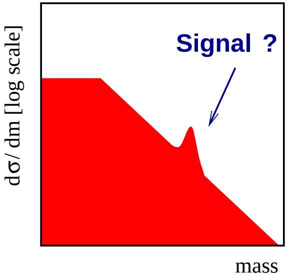
  But does more — a sort of "LO++". Still, not NLO

  Couldn't tell from literature how it would do in this case

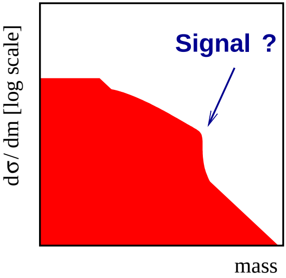
  One should double-check it!

Viewing QCD

Consider case of *mass peaks* — but bear in mind that other kinematic structures are fundamentally related.

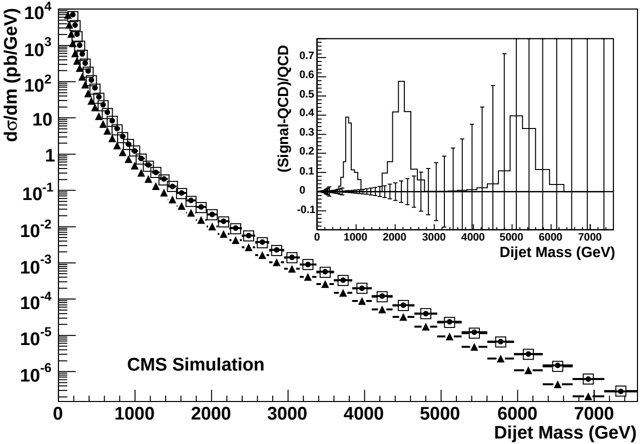


$$\sim \frac{d}{dm}$$



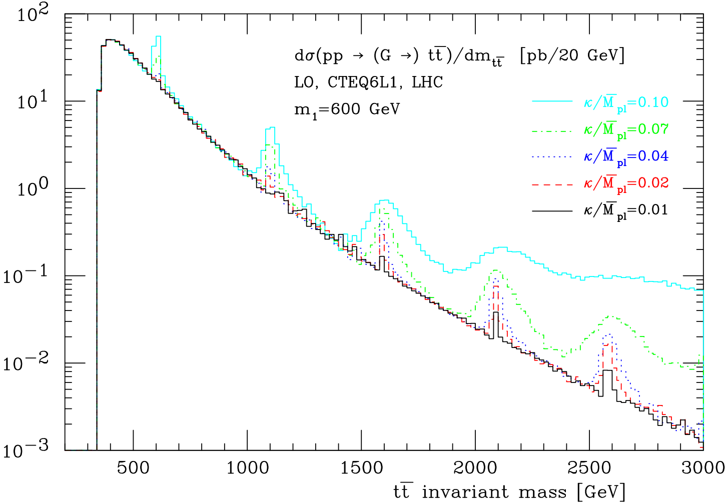
Some peaks are easy — QCD not needed

e.g. resonance $\to \ell^+\ell^-$, or big broad resonance to jets



Bhatti et al (for CMS), study of dijet mass resonances (q^*), 0807.4961

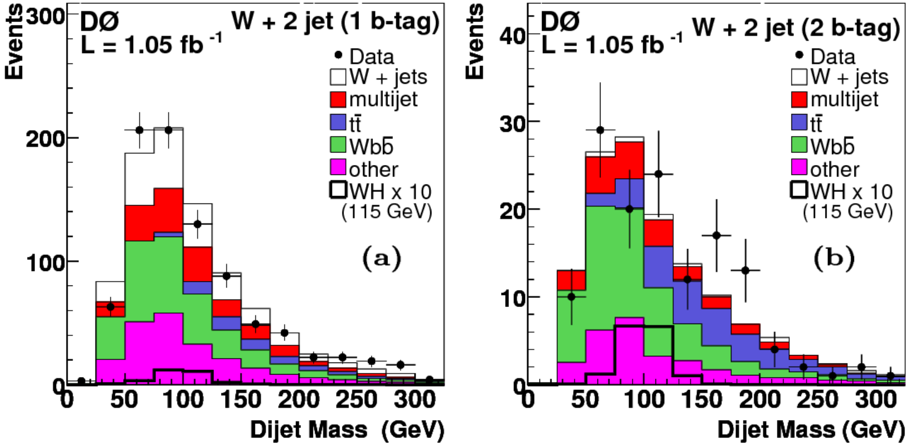
Observability may depend on parameters



RS KK resonances, from Frederix & Maltoni, 0712.2355

Cases where QCD has the most to contribute are those that are borderline

Signal peak may sit on background peak

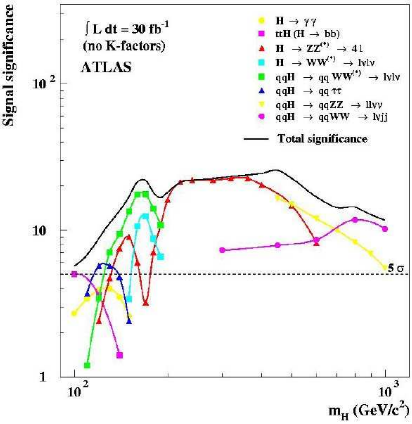


DO low-mass Higgs-boson search, 0808.1970

As example, a Higgs-boson search illustrates two things:

- Using LHC scale hierarchy $\sqrt{s} \gg M_{EW}$ to our advantage
- Using QCD to help us extract cleaner signals

taken from Butterworth, Davison, Rubin & GPS '08



Low-mass Higgs search @ LHC: complex because dominant decay channel, $H \to bb$, often swamped by backgrounds.

Various production processes

- $gg \to H\ (\to \gamma\gamma)$ feasible
- $WW \to H \to \ldots$ feasible
- $gg \to t\bar{t}H$ v. hard
- $q\bar{q} \to WH, ZH$

small; but gives access to
WH and ZH couplings
Currently considered impossible

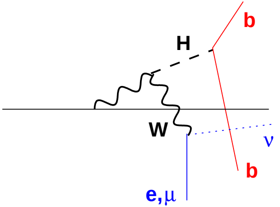
WH/ZH search channel @ LHC

- Signal is $W \rightarrow \ell\nu$, $H \rightarrow b\bar{b}$.
- Backgrounds include $Wb\bar{b}$, $t\bar{t} \rightarrow \ell\nu b\bar{b}jj$, …

Studied e.g. in ATLAS TDR

Difficulties, e.g.

- Poor acceptance ($\sim 12\%$)
  Easily lose 1 of 4 decay products
- p_t cuts introduce intrinsic bkgd mass scale;
- $gg \rightarrow t\bar{t} \rightarrow \ell\nu b\bar{b}[jj]$ has similar scale
- small S/B
- Need exquisite control of bkgd shape



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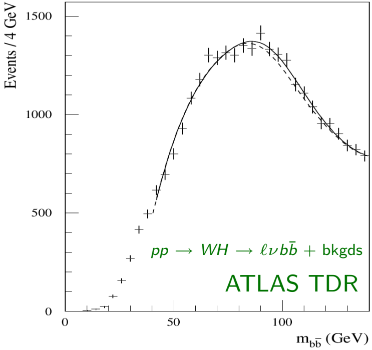

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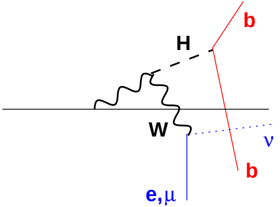

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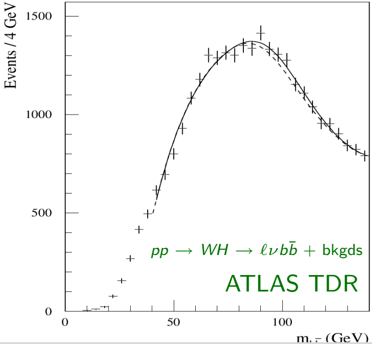

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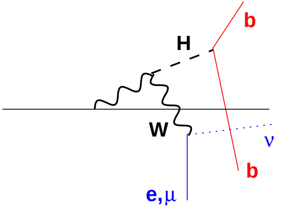
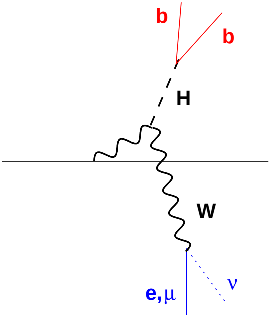
Conclusion (ATLAS TDR):

"The extraction of a signal from $H \to b\bar{b}$ decays in the WH channel will be very difficult at the LHC, even under the most optimistic assumptions [...]"



Study subset of WH/ZH with high p_t

Take advantage of the fact that $\sqrt{s} \gg M_H, m_t, \ldots$



Go to high p_t:

- ✓ Higgs and W/Z more likely to be central
- ✓ high-p_t $Z \to \nu\bar{\nu}$ becomes visible
- ✓ Fairly collimated decays: high-p_t $\ell^\pm, \nu, b$

Good detector acceptance

- ✓ Backgrounds lose cut-induced scale
- ✓ $t\bar{t}$ kinematics cannot simulate bkgd

Gain clarity and S/B

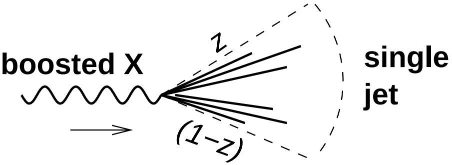
- ✗ Cross section will drop dramatically

By a factor of 20 for $p_{tH} > 200$ GeV

Will the benefits outweigh this?

Boosted EW bosons

Hadronically decaying Higgs boson at high $\mathbf{p_t}$ = single massive jet?



$$R \gtrsim \frac{m}{p_t}\frac{1}{\sqrt{z(1-z)}}$$

discussion of this & related problems: Seymour '93; Butterworth, Cox & Forshaw '02; Butterworth, Ellis & Raklev '07; Skiba & Tucker-Smith '07; Holdom '07; Baur '07; Agashe et al. '07; Lillie, Randall & Wang '07; Contino & Servant '08; Brooijmans '08; Thaler & Wang '08; Kaplan et al '08; Almeida et al '08; [. . .]

What does QCD tell us about how to deal with this?

Boosted EW bosons

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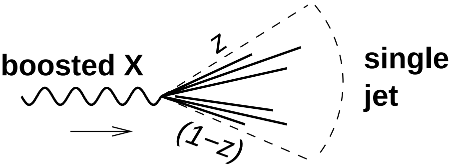

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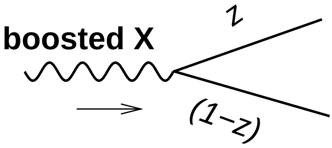
What does QCD tell us about how to deal with this?

QCD principle: soft divergence

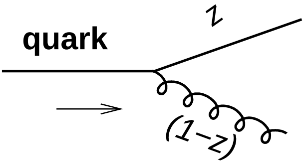
Signal



Splitting probability for Higgs:

$$P(z) \propto 1$$

Background



Splitting probability for quark:

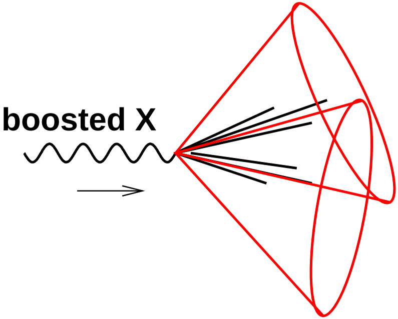
$$P(z) \propto \frac{1+z^2}{1-z}$$

$1/(1-z)$ divergence enhances background

Remove divergence in bkdg with cut on z
Can choose cut analytically so as to maximise $S/\sqrt{B}$

Originally: ad-hoc cut on (related) k_t-distance
Seymour '93; Butterworth, Cox & Forshaw '02

QCD principle: angular ordering



Given a color-singlet $q\bar{q}$ pair of opening angle R_{bb}:

Nearly all the radiation from the pair is contained in two cones of opening angle R_{bb}, one centred on each quark.

Standard result also in QED

Use this to capture just the radiation from the $q\bar{q} \Rightarrow$ good mass resol^n

#1: Our tool

The Cambridge/Aachen jet alg.

Dokshitzer et al '97
Wengler & Wobisch '98

Work out $\Delta R_{ij}^2 = \Delta y_{ij}^2 + \Delta\phi_{ij}^2$ *between all pairs of objects* i, j*;*
Recombine the closest pair;
Repeat until all objects separated by $\Delta R_{ij} > R$*.*

Provides a "hierarchical" view of the event;
work through it backwards to analyse a jet

Implemented in FastJet
Cacciari, GPS & Soyez, '05-08, `http://fastjet.fr/`

All MC done with Herwig 6.510 and Jimmy 4.31

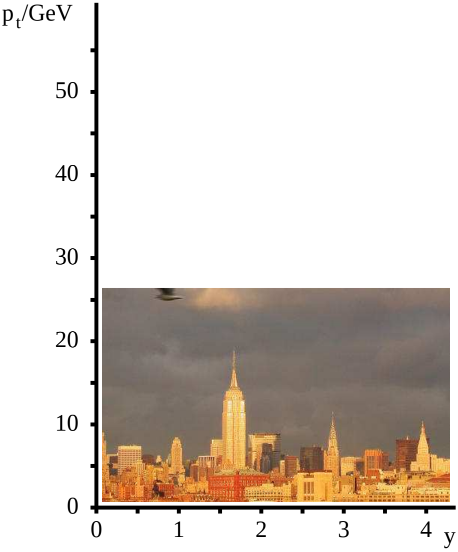
Cambridge/Aachen at work

Example clustering with C/A algorithm, $R = 0.7$

Repeatedly recombine closest pair of objects, until all separated by $\Delta R_{ij} > R$.

ϕ assumed 0 for all towers

Cambridge/Aachen at work



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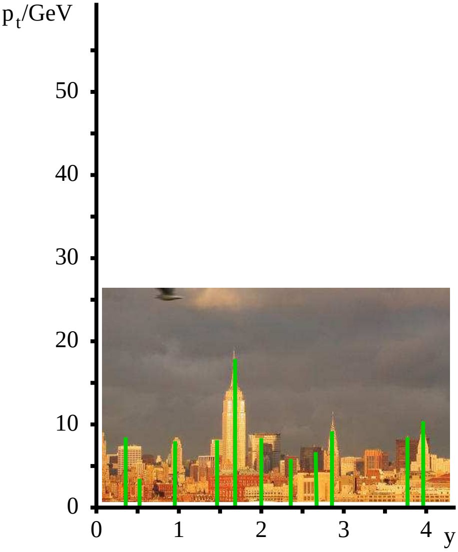

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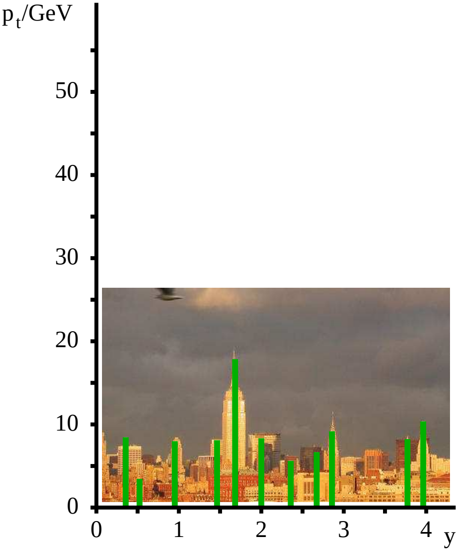

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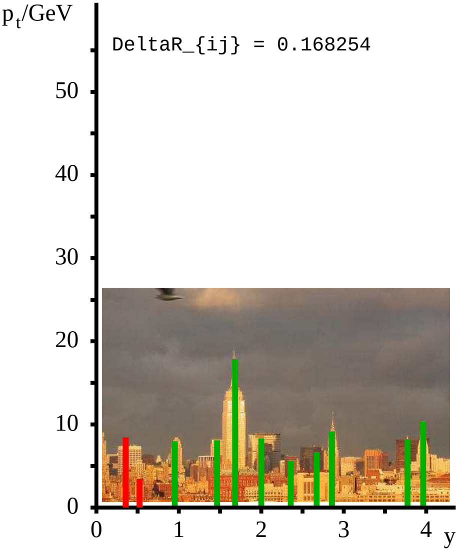

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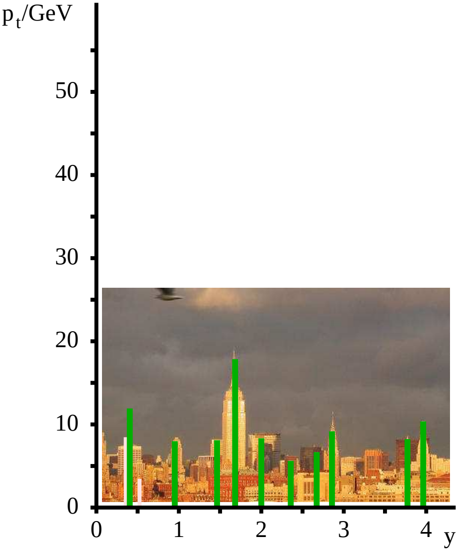

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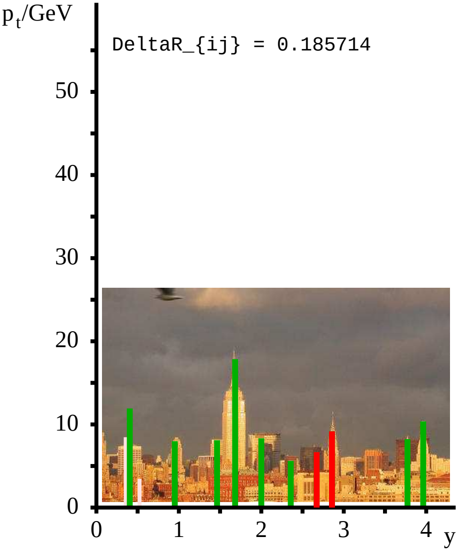

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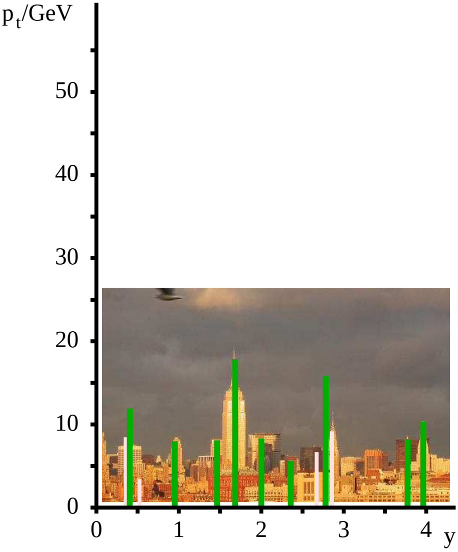

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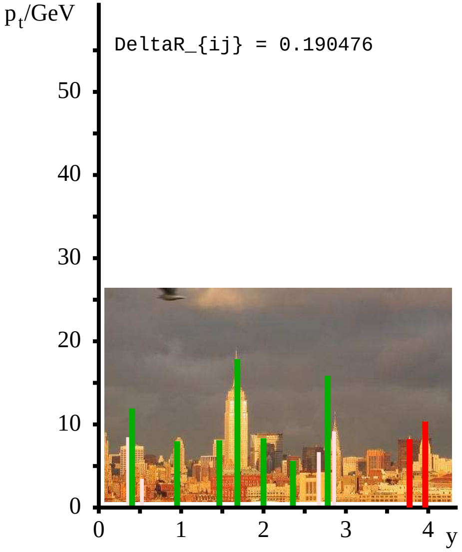

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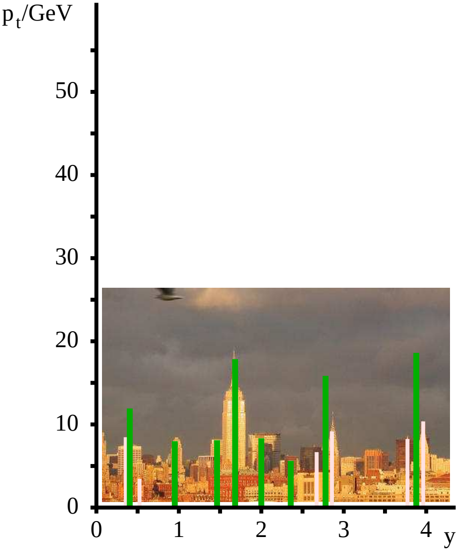

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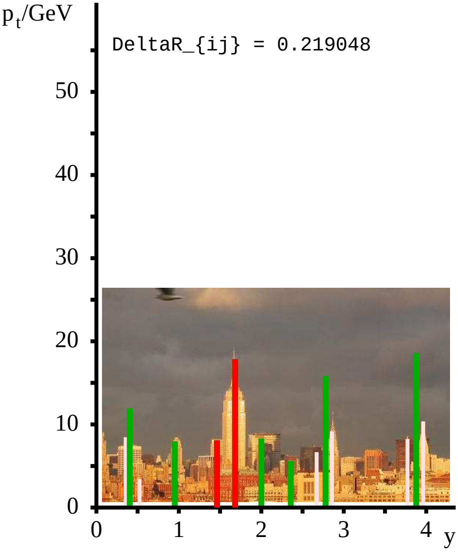

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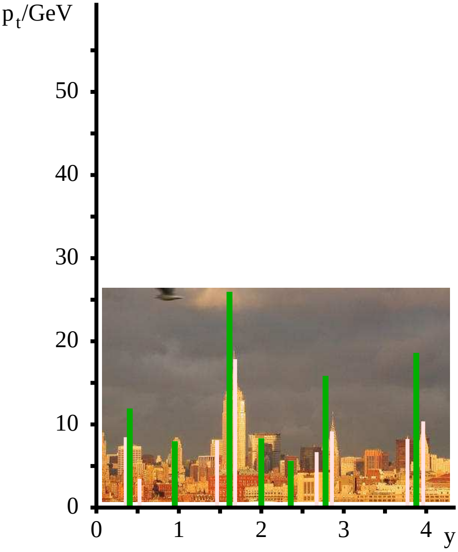

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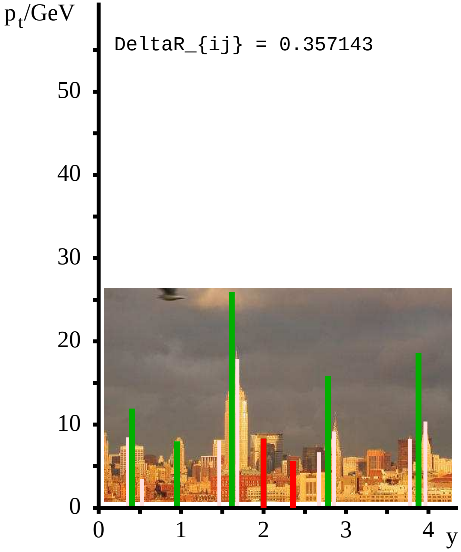

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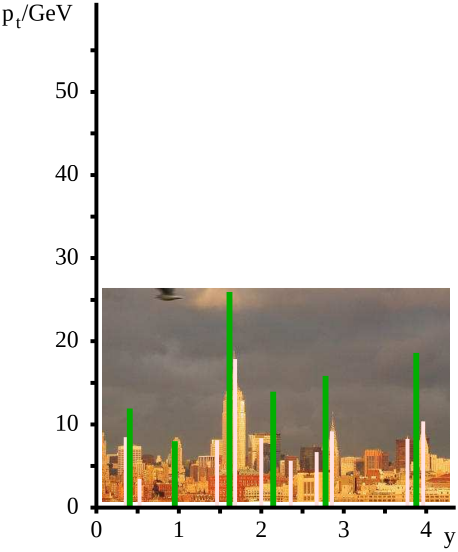

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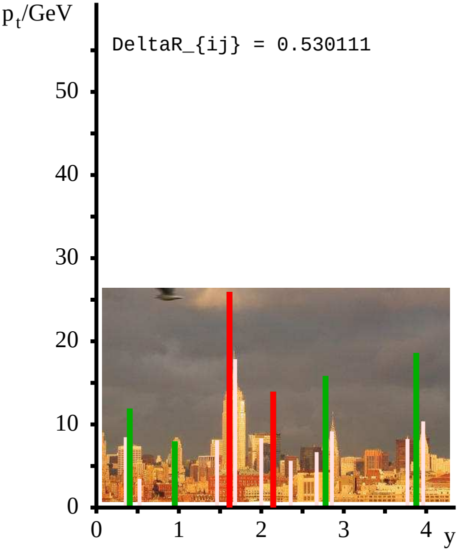

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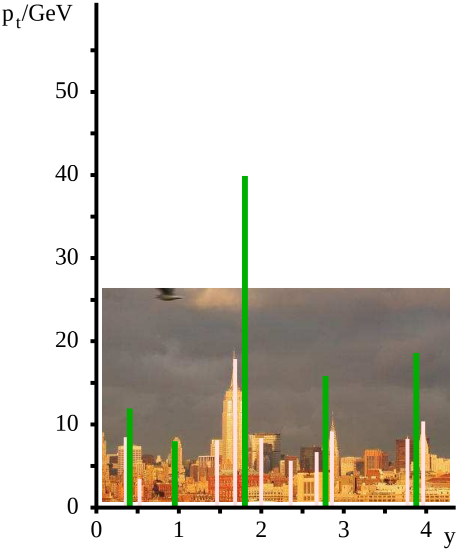

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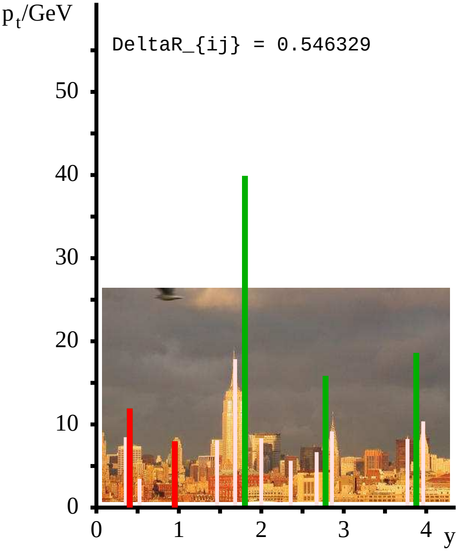

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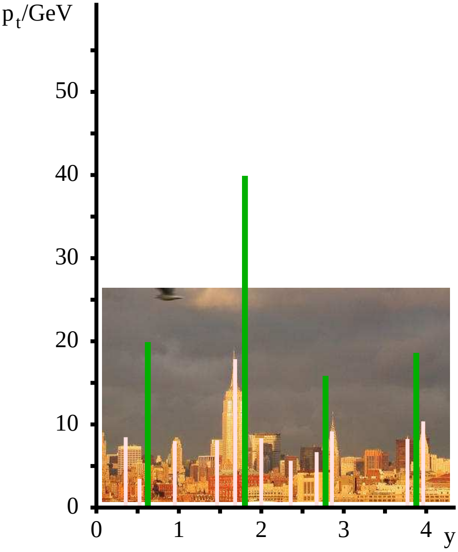

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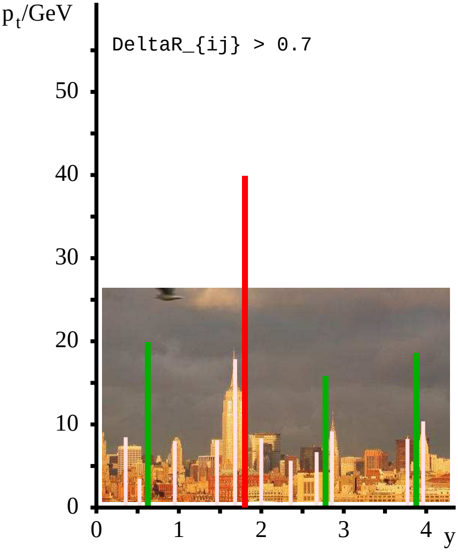

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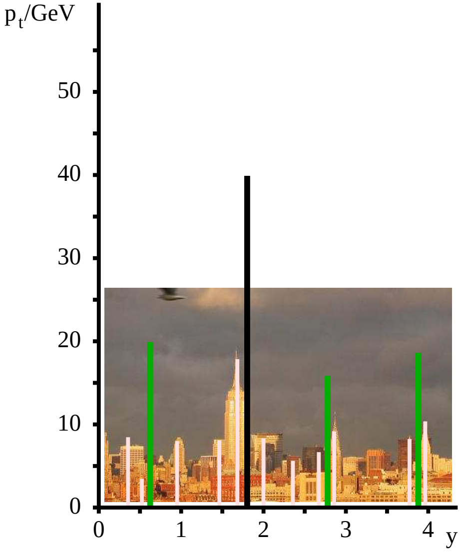

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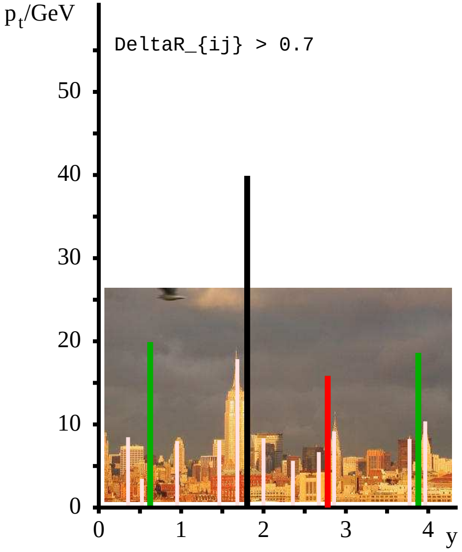

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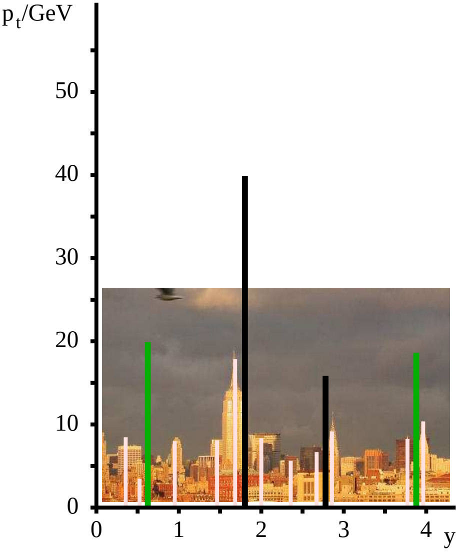

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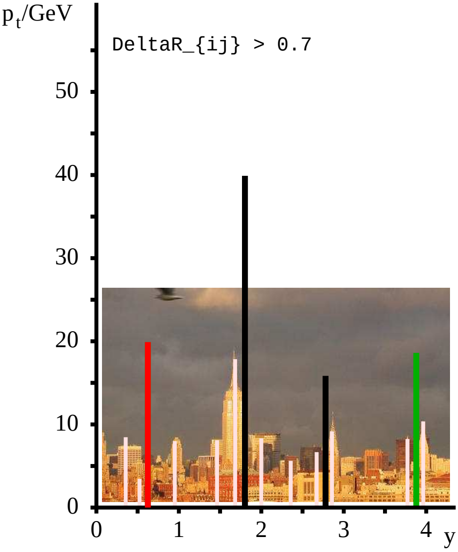

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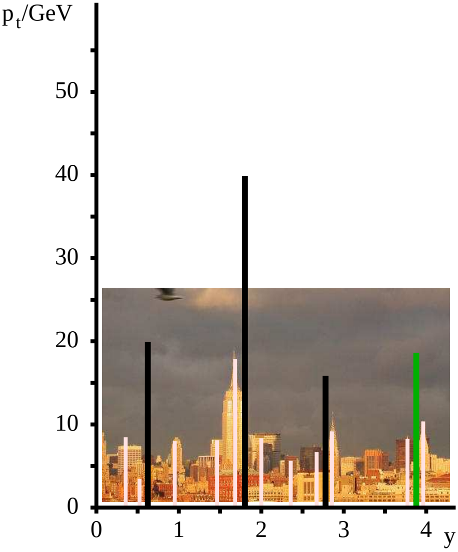

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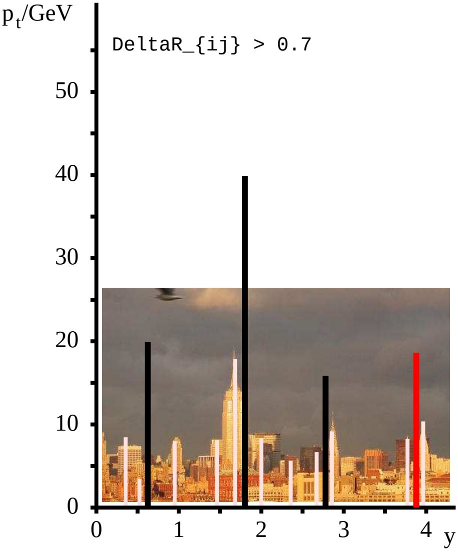

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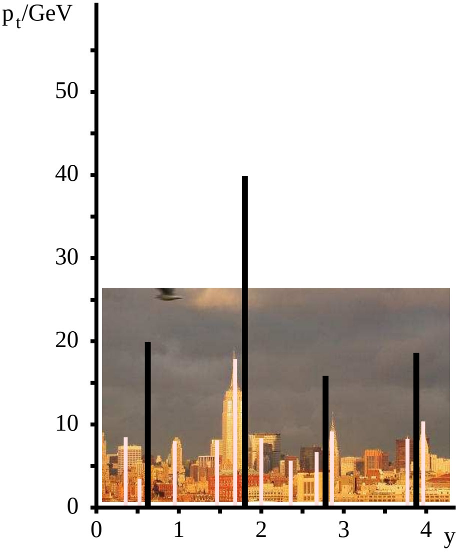

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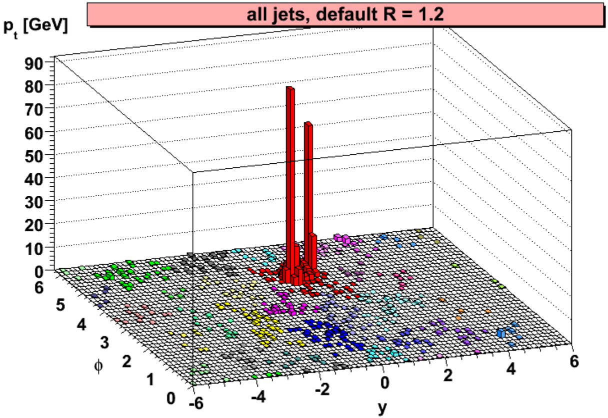
$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



Zbb BACKGROUND

Cluster event, C/A, R=1.2

arbitrary norm.

$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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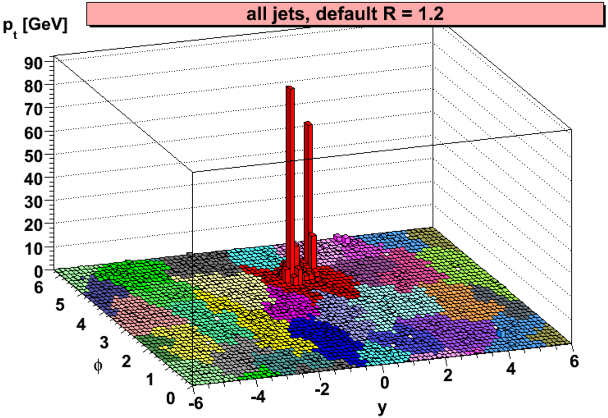

Zbb BACKGROUND

Fill it in, → show jets more clearly

arbitrary norm.

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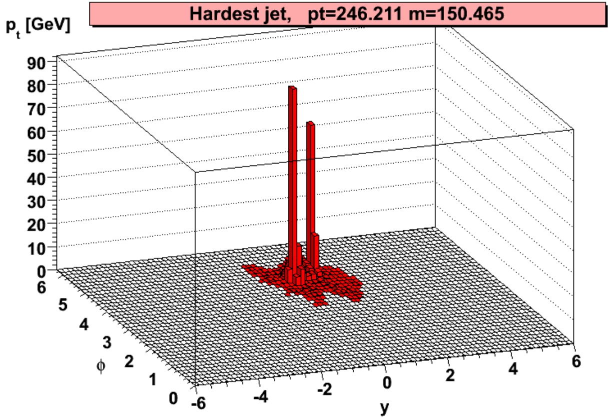
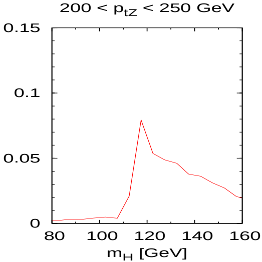
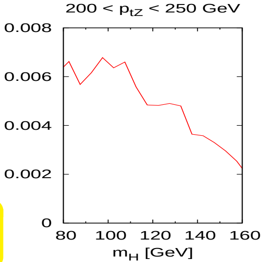


SIGNAL



Zbb BACKGROUND

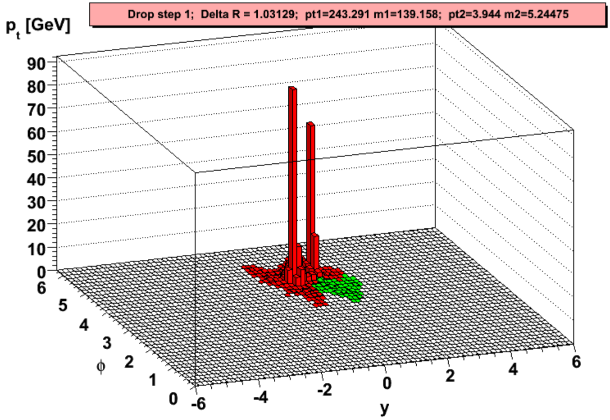


arbitrary norm.

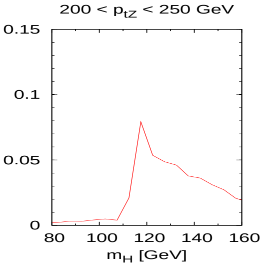
Consider hardest jet, $m = 150$ GeV

$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

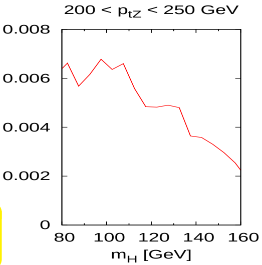
Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



Zbb BACKGROUND

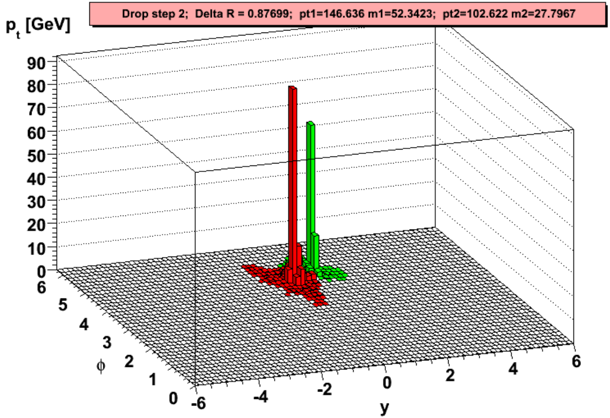


split: $m = 150$ GeV, $\frac{\max(m_1, m2)}{m} = 0.92 \longrightarrow$ repeat

arbitrary norm.

$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



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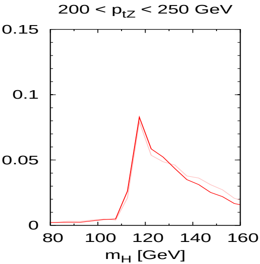
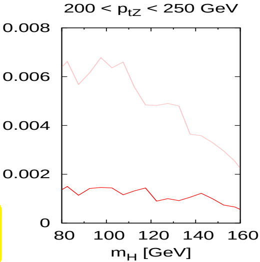


Zbb BACKGROUND

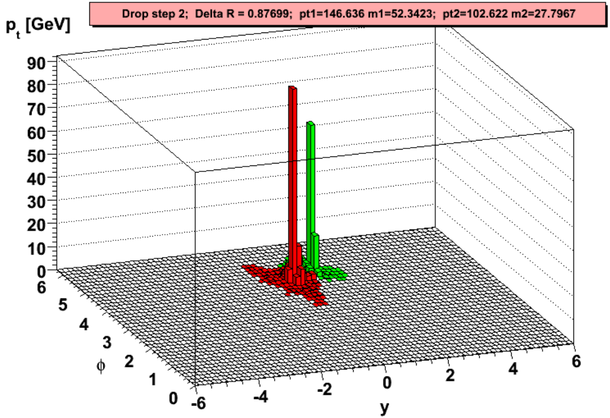


split: $m = 139$ GeV, $\frac{\max(m_1, m2)}{m} = 0.37 \longrightarrow$ mass drop

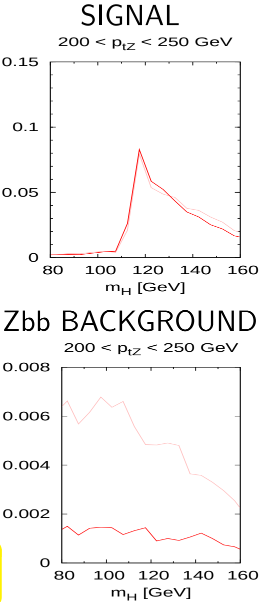
arbitrary norm.

$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



check: $y_{12} \simeq \frac{p_{t2}}{p_{t1}} \simeq 0.7 \rightarrow$ OK + 2 b-tags (anti-QCD)



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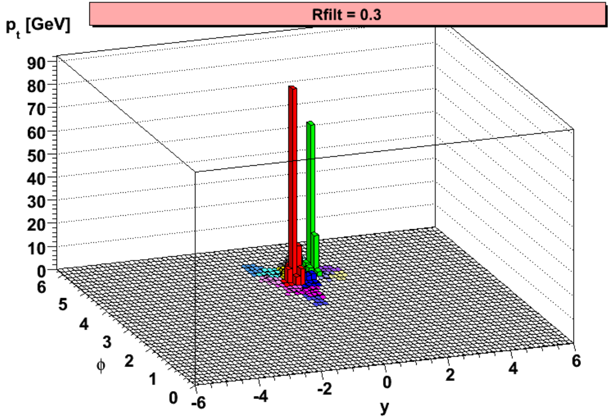

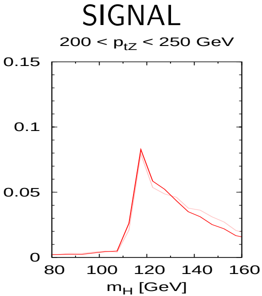

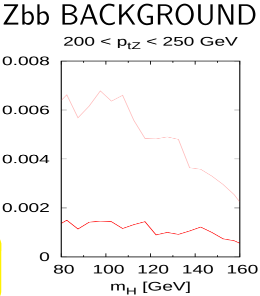

$R_{filt} = 0.3$

arbitrary norm.

$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

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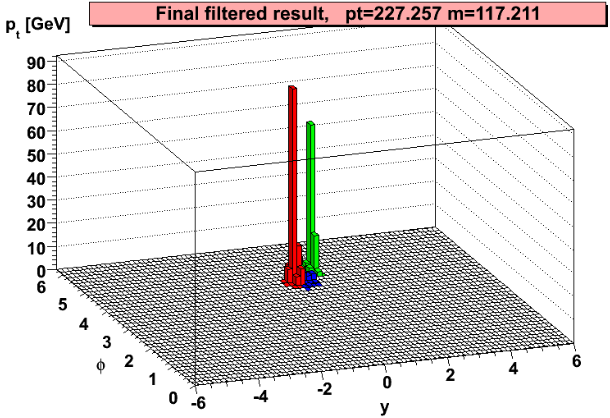
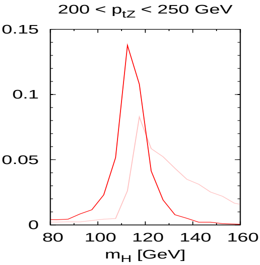
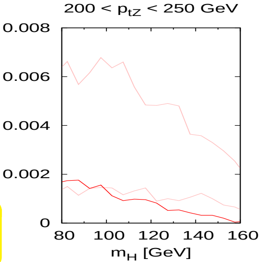


$R_{filt} = 0.3$: take 3 hardest, **m = 117 GeV**

SIGNAL

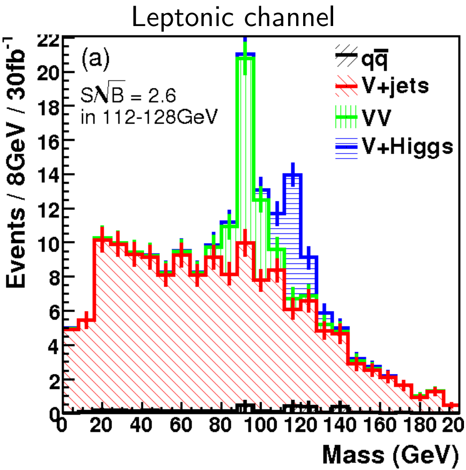


Zbb BACKGROUND



arbitrary norm.

combine HZ and HW, $p_t > 200$ GeV



Leptonic channel

Common cuts

- $p_{tV}, p_{tH} > 200$ GeV
- $|\eta_H| < 2.5$
- $[p_{t,\ell} > 30 \text{ GeV}, |\eta_\ell| < 2.5]$
- No extra ℓ, b's with $|\eta| < 2.5$
- Real/fake b-tag rates: 0.7/0.01
- $S/\sqrt{B}$ from 16 GeV window

Leptonic channel

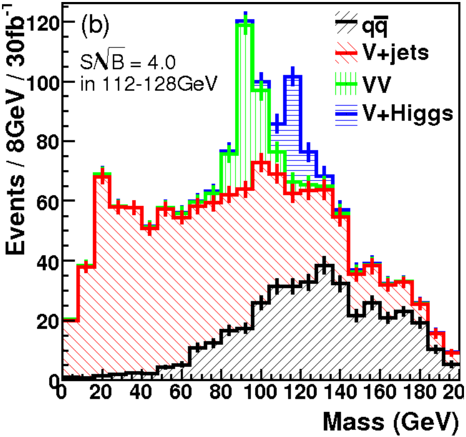
$Z \to \mu^+\mu^-, e^+e^-$

- $80 < m_{\ell^+\ell^-} < 100$ GeV

At 5.9σ for 30 fb^{-1} this looks like a possible new channel for light Higgs discovery. **Deserves serious exp. study!**

combine HZ and HW, $p_t > 200$ GeV

Missing E_T channel



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- Real/fake b-tag rates: 0.7/0.01
- $S/\sqrt{B}$ from 16 GeV window

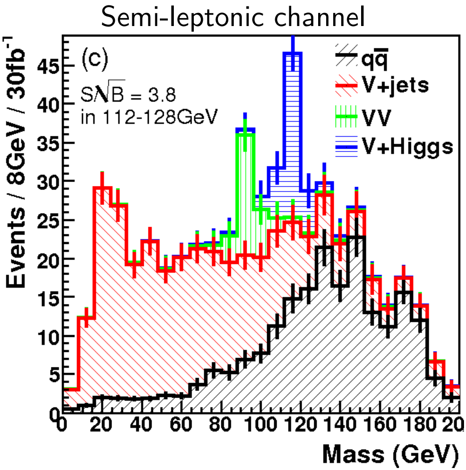
Missing-E_t channel

$Z \to \nu\bar{\nu}$, $W \to \nu[\ell]$

- $\not{E}_T > 200$ GeV

At 5.9σ for 30 fb^{-1} this looks like a possible new channel for light Higgs discovery. **Deserves serious exp. study!**

combine HZ and HW, $p_t > 200$ GeV



Semi-leptonic channel

Common cuts

- $p_{tV}, p_{tH} > 200$ GeV
- $|\eta_H| < 2.5$
- $[p_{t,\ell} > 30$ GeV, $|\eta_\ell| < 2.5]$
- No extra ℓ, b's with $|\eta| < 2.5$
- Real/fake b-tag rates: 0.7/0.01
- $S/\sqrt{B}$ from 16 GeV window

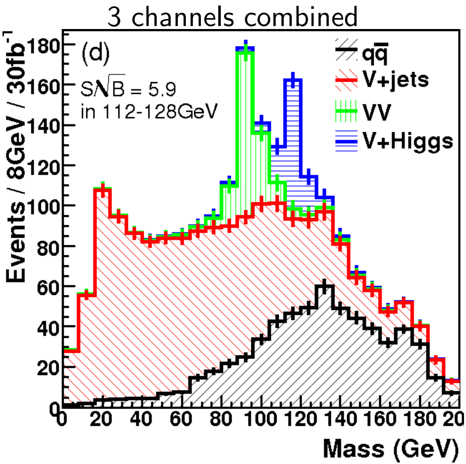
Semi-leptonic channel

$W \to \nu\ell$

- $\not{E}_T > 30$ GeV (& consistent W.)
- no extra jets $|\eta| < 3, p_t > 30$

At 5.9σ for 30 fb^{-1} this looks like a possible new channel for light Higgs discovery. **Deserves serious exp. study!**

combine HZ and HW, $p_t > 200$ GeV



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- Real/fake b-tag rates: 0.7/0.01
- $S/\sqrt{B}$ from 16 GeV window

3 channels combined

Note excellent VZ, $Z \to b\bar{b}$ peak for calibration

NB: $q\bar{q}$ is mostly $t\bar{t}$

At 5.9σ for 30 fb^{-1} this looks like a possible new channel for light Higgs discovery. **Deserves serious exp. study!**

Not just about Higgs discovery

Higgs physics means establishing whether it has the expected SM couplings.

Crucial part of that is seeing WH and ZH cleanly and separately from each other.

This channel seems to be the only good way of doing that for a light Higgs.

Alternative WW fusion: but mixes with ZZ fusion, gg fusion

Tagging boosted top-quarks

High-p_t top production often envisaged in New Physics processes.
$\sim$ high-p_t EW boson, but: top has 3-body decay and is coloured.

4 papers on top tagging in ’08 (at least). All use the jet mass + something extra.

Questions

- What efficiency for tagging top?
- What rate of fake tags for normal jets?

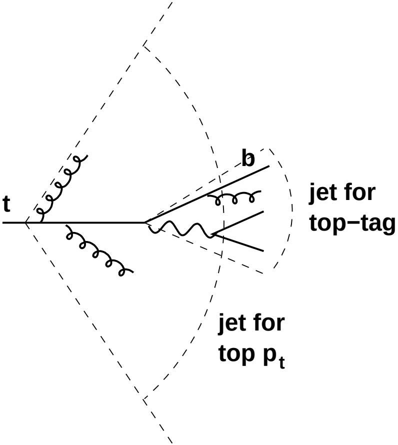
Rough results for top quark with $\mathbf{p_t \sim 1}$ TeV

	“Extra”	eff.	fake
[from T&W]	just jet mass	50%	10%
Broojimans	3,4 k_t subjets, d_{cut}	45%	5%
Thaler & Wang	2,3 k_t subjets, z_{cut} + various	40%	5%
Kaplan et al.	3,4 C/A subjets, $z_{cut} + \theta_h$	40%	1%
Almeida et al.	predict mass dist^n, use jet-shape	?	?

Using (coloured!) boosted top-quarks

If you want to use the tagged top (e.g. for $t\bar{t}$ invariant mass) QCD tells you:

the jet you use to tag a top quark $\neq$ the jet you use to get its p_t



Within inner cone $\sim \frac{2m_t}{p_t}$ (dead cone) you have the top-quark decay products, but no radiation from top

ideal for reconstructing top mass

Outside dead cone, you have radiation from top quark

essential for top p_t

Cacciari, Rojo, GPS & Soyez '08

Impact of using small cone angle

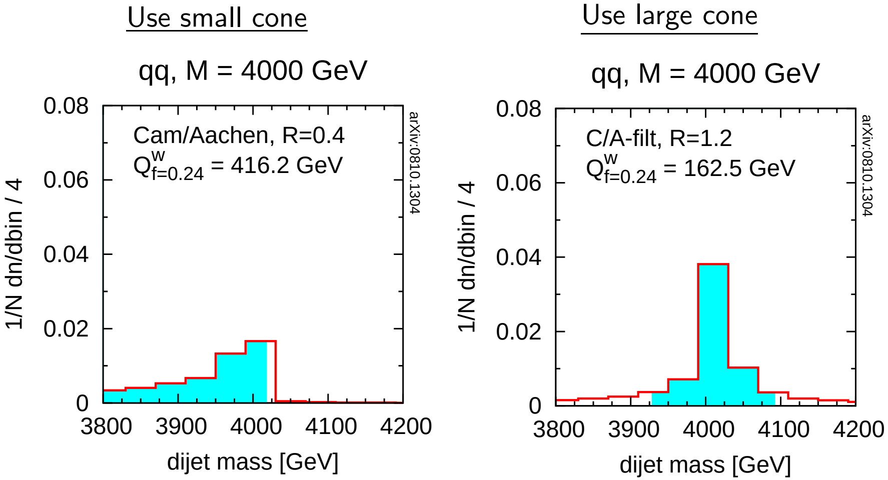


Figure actually from 0810.1304, for light $q\bar{q}$ resonance — but $t\bar{t}$ will be similar

How you look at your event matters: `http://quality.fastjet.fr/`

Conclusions

Conclusions

We've seen examples where doing the QCD "right" makes a big difference.

From first part: it's clear that relative $\mathcal{O}(\alpha_s)$ ("the details") in QCD predictions (NLO) may be more than just a luxury refinement.

Part of the motivation for the large calculational effort in the field

Crucial in building confidence in our understanding of any LHC "excess"

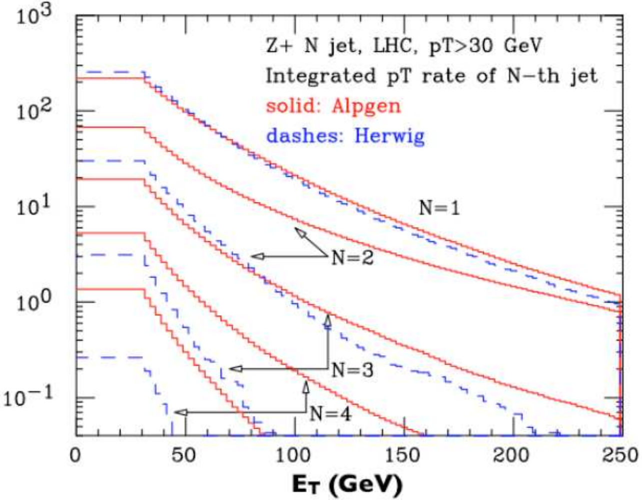
From second part: there's much freedom in how we view events at LHC. QCD can guide us in making good choices, with large gains at hand.

A much smaller field — but several groups making good progress

Crucial in order to maximise LHC's senstivity to new physics

Common theme: LHC, for the first time, will take us well above the EW scale. That can take getting used to.

EXTRAS



Mangano, 0809.1567

Leading jet seems not to be enhanced?

Other “matched” plots do suggest some enhancement.

0-lepton search

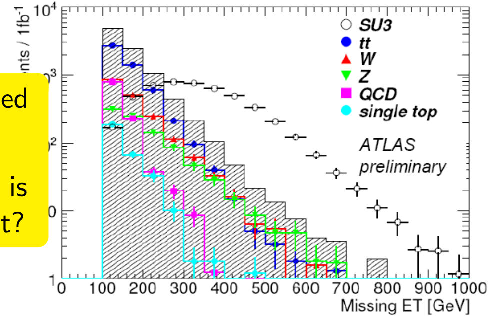
Is there a larger excess when plotted v. MET ($\sim p_{tZ}$)?

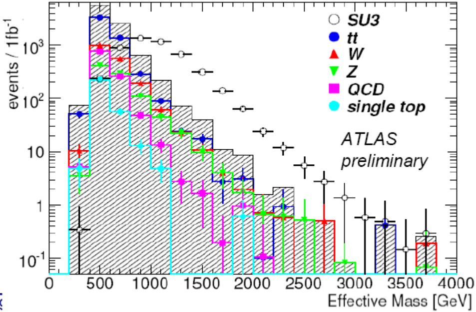
Is this because Eff.Mass ($\sim p_{t,jet}$) is enhanced in bkgd, but MET is not?

  - at least 1 jet with PT>100GeV
  - 0 lepton (e, μ) with PT > 20 GeV
  - MET > 100 GeV
  - MET > 0.2 effective mass
  - Transverse Sphericity ST > 0.2
  - Δφ(ET – jet *i*) > 0.2 (*i* = 1, 2, 3)

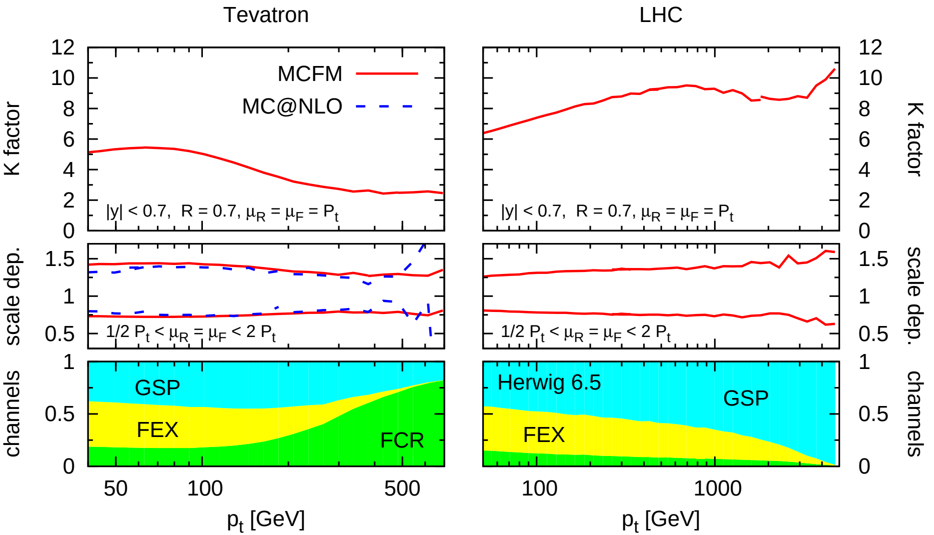
- Main backgrounds:
  - tt
  - W+jets
  - Z+jets
  - QCD

SM	0-l
tt	62%
W	17%
Z	10%
QCD	10%





Another example: *b*-jet production



Banfi, GPS & Zanderighi, '07

#2: The jet analysis

Start with high-p_t jet

1. Undo last stage of clustering ($\equiv$ reduce R): $J \to J_1, J_2$
2. If $\max(m_1, m_2) \lesssim 0.67m$, call this a **mass drop** [else goto 1]

   Automatically detects correct $R \sim R_{bb}$ to catch angular-ordered radn.
3. Require $y_{12} = \frac{\min(p_{t1}^2, p_{t2}^2)}{m_{12}^2} \Delta R_{12}^2 \simeq \frac{\min(z_1, z_2)}{\max(z_1, z_2)} > 0.09$ [else goto 1]

   dimensionless rejection of asymmetric QCD branching
4. Require each subjet to have b-tag [else reject event]

   Correlate flavour & momentum structure

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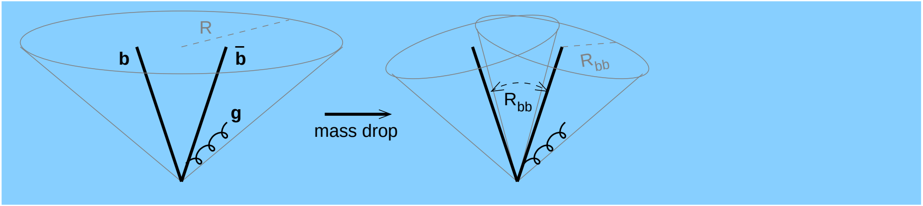

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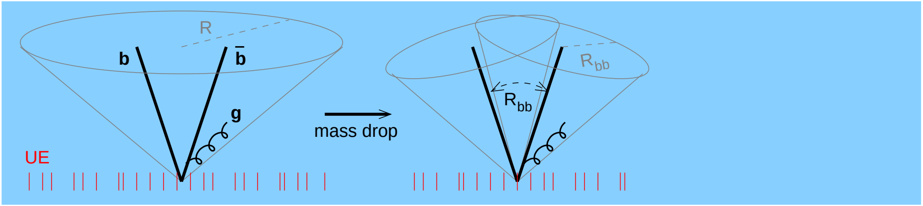
#3: jet filtering



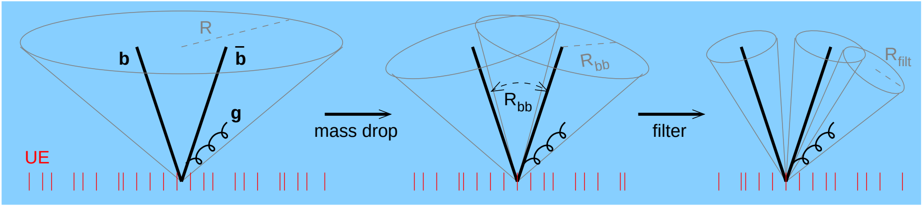
At moderate p_t, R_{bb} is quite large; *UE & pileup degrade mass resolution*

$\delta M \sim R^4 \Lambda_{UE} \frac{p_t}{M}$ [Dasgupta, Magnea & GPS '07]

Filter the jet

- Reconsider region of interest at smaller $R_{filt} = \min(0.3, R_{b\bar{b}}/2)$
- Take **3** hardest subjets b, $\bar{b}$ and leading order gluon radiation

#3: jet filtering



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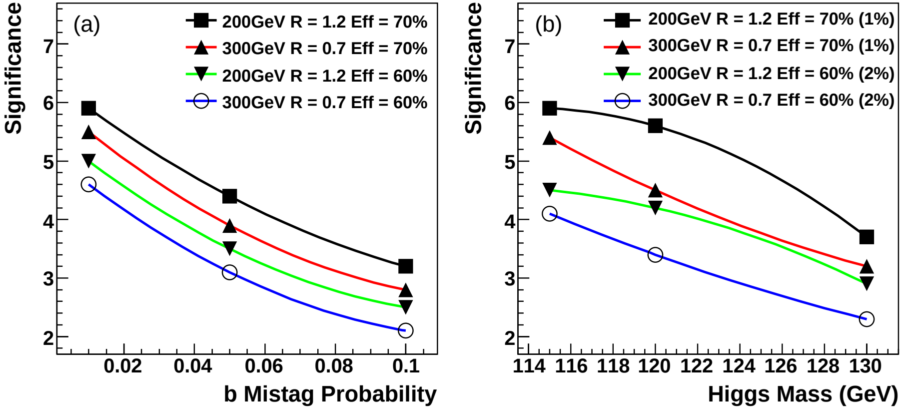
Impact of *b*-tagging, Higgs mass

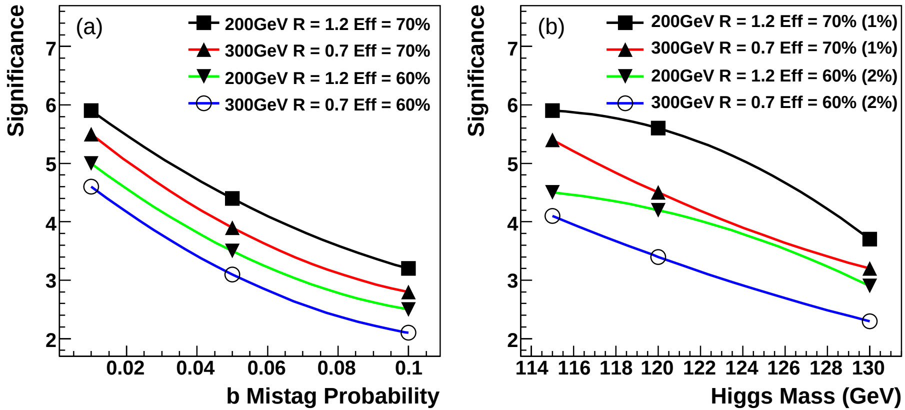


Most scenarios above 3σ

For it to be a significant discovery channel requires decent *b*-tagging, lowish mass Higgs [and good experimental resolution]

In nearly all cases, looks feasible for extracting *WH*, *ZH* couplings

Impact of *b*-tagging, Higgs mass



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Rough impact of going to high-p_t

How can we be doing so well despite losing factor 20 in X-sct?

	Signal	Background	
Eliminate $t\bar{t}$, etc.	–	$\times 1/3$	[very approx.]
$p_t > 200$ GeV	$\times 1/20$	$\times 1/60$	[bkgds: $Wb\bar{b}, Zb\bar{b}$]
improved acceptance	$\times 4$	$\times 4$	
twice better resolution	–	$\times 1/2$	
add $Z \to \nu\bar{\nu}$	$\times 1.5$	$\times 1.5$	
total	$\times 0.3$	$\times 0.017$	

much better S/B; better $S/\sqrt{B}$

[exact numbers depend on analysis details]

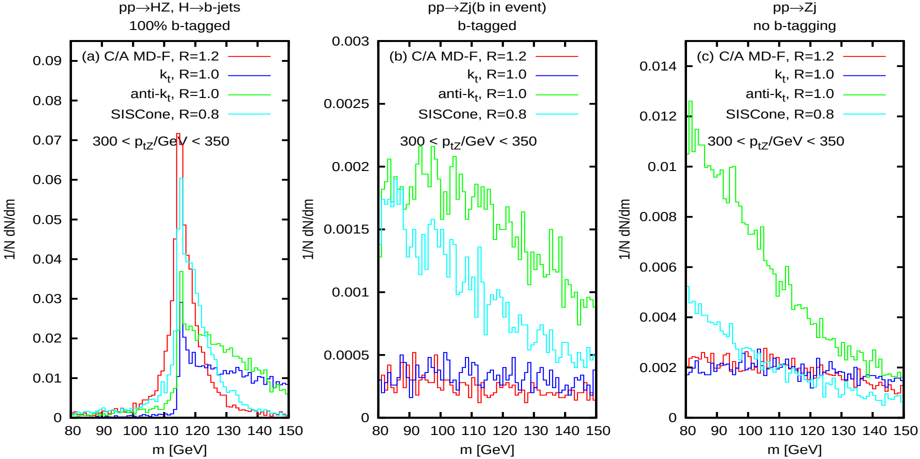
Jet-alg comparison

Cross section for signal and the Z+jets background in the leptonic Z channel for $200 < p_{TZ}/\,\text{GeV} < 600$ and $110 < m_J/\,\text{GeV} < 125$, with perfect b-tagging; shown for our jet definition (C/A MD-F), and other standard ones close to their optimal R values.

Jet definition	σ_S/fb	σ_B/fb	$S/\sqrt{B \cdot \mathrm{fb}}$
C/A, $R = 1.2$, MD-F	0.57	0.51	0.80
k_t, $R = 1.0$, y_{cut}	0.19	0.74	0.22
SISCone, $R = 0.8$	0.49	1.33	0.42
anti-k_t, $R = 0.8$	0.22	1.06	0.21

Compare with “standard” algorithms

Check mass spectra in HZ channel, $H \to b\bar{b}$, $Z \to \ell^+\ell^-$



Cambridge/Aachen (C/A) with mass-drop and filtering (MD/F) works best