Jet structures in Higgs and New Physics searches

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LPTHE, UPMC Paris 6 & CNRS

High-Energy Theory Seminar
Physics Department, Princeton University, NJ, USA
28 September 2009

Part based on work with
Jon Butterworth, Adam Davison (UCL) & Mathieu Rubin (LPTHE)

This seminar is about two things:

- A new Higgs search channel at LHC

  Work with Butterworth, Davison & Rubin

- Which overlaps with the question of how to get the best out of jets at LHC

  A broader body of work
  centred on the FastJet program with Cacciari & Soyez
  and work also with: Dasgupta, Ellis, Magnea, Raklev, Rojo

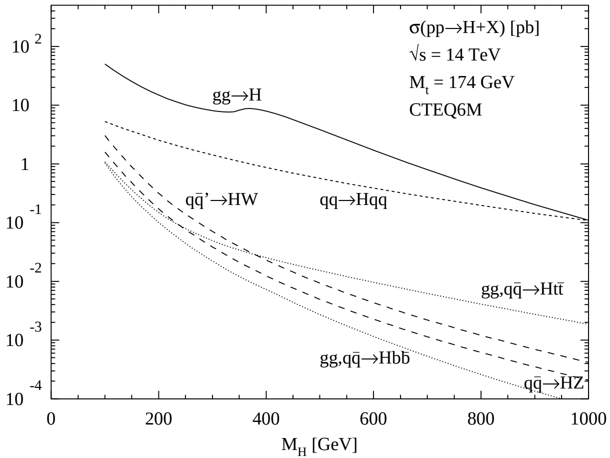
The Higgs search will provide the backbone of the talk.

This talk will take two things for granted:

Finding the Higgs boson is crucial for completing our verification of the standard model.

Finding the Higgs boson is one of the main goals motivating the LHC programme.

Higgs production at LHC



Dominant Higgs production channels:

- Gluon fusion

  via top loop

- Vector-boson fusion

  with two forward jets

- Associated production

  H radiated off top-quark or W or Z boson

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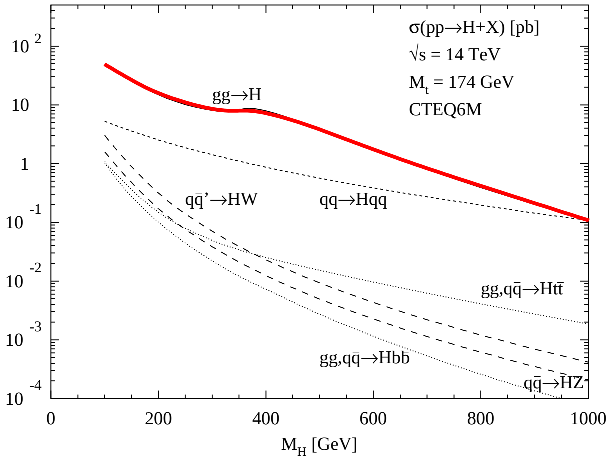

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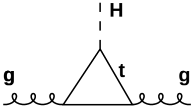

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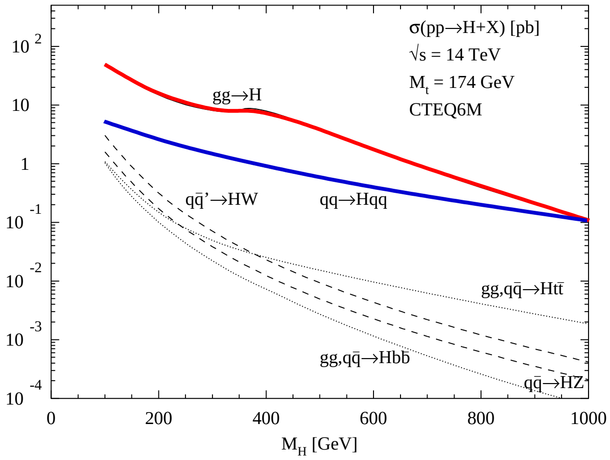

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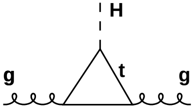

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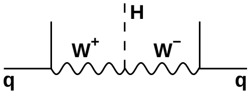

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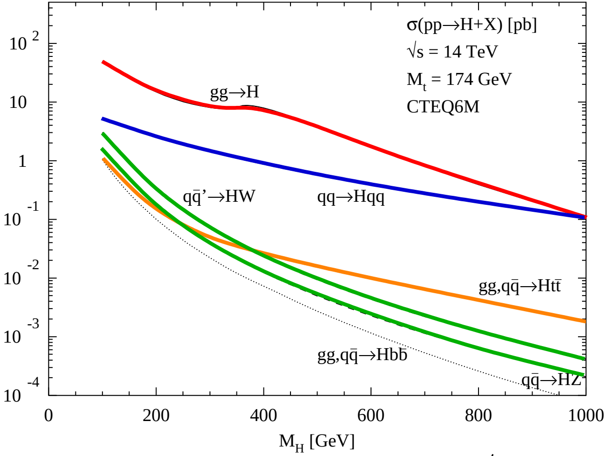

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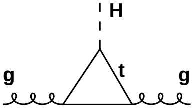

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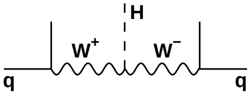

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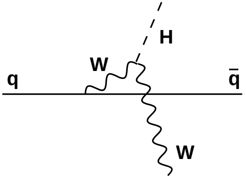
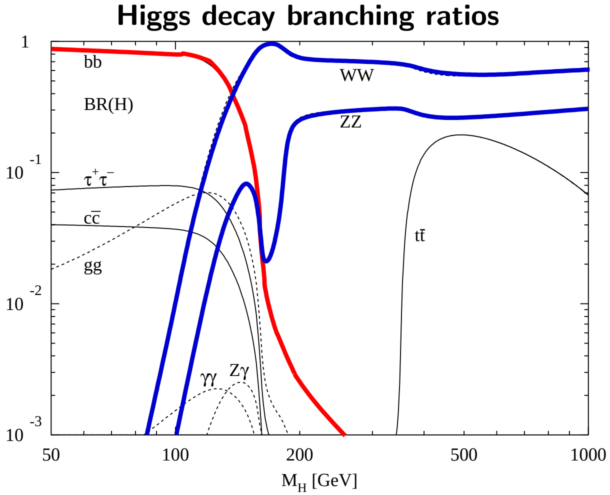


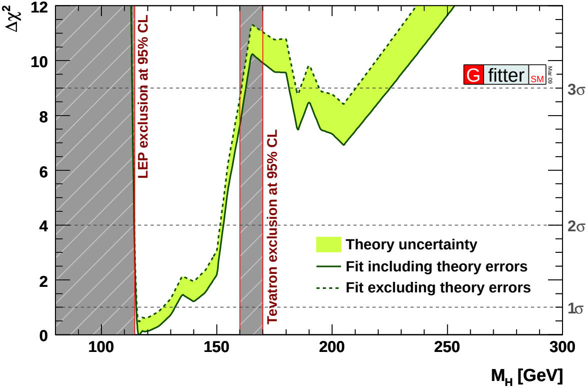
Higgs decay



Dominant Higgs decay mode depends on mass.

- Low mass: $H \to b\bar{b}$
- High mass: $H \to WW/ZZ$

Higgs mass constraints

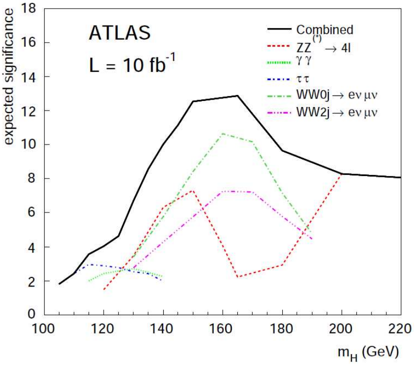


Mass constraints come from

- LEP exclusion
- Tevatron exclusion
- EW precision fits

Strong preference for low-mass Higgs, one that decays mainly to $b\bar{b}$

LHC search propspects



Low-mass Higgs search (**$115 \lesssim m_h \lesssim 130$ GeV**) complex because dominant decay channel, $H \to bb$, often swamped by backgrounds.

Various production & decay processes

- $gg \to H \to \gamma\gamma$ — feasible
- $WW \to H \to \tau\tau$ — feasible
- $gg \to H \to ZZ^* \to 4\ell$ — feasible
- $gg \to t\bar{t}H, H \to b\bar{b}$ — v. hard
- $q\bar{q} \to WH, ZH, H \to b\bar{b}$ — v. hard

What does a “very hard” search channel look like?

WH/ZH search channel @ LHC

- Signal is $W \to \ell\nu$, $H \to b\bar{b}$.

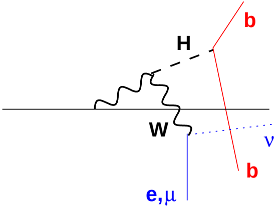
Studied e.g. in ATLAS TDR

- Backgrounds include $Wb\bar{b}$, $t\bar{t} \to \ell\nu b\bar{b}jj$, ...

Difficulties, e.g.

- Poor acceptance ($\sim 12\%$)

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



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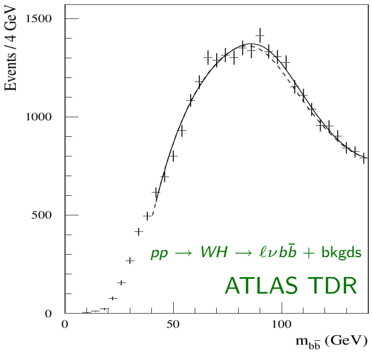

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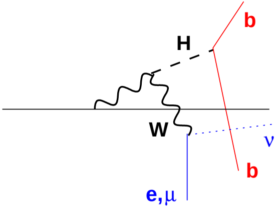

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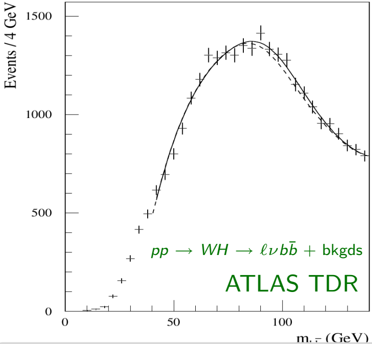

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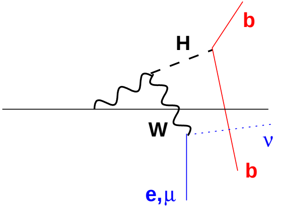
Conclusion (ATLAS TDR):

"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 [...]"



LHC will (should...) span two orders of magnitude in p_t:

$$\frac{m_{EW}}{2} \longleftrightarrow 50 m_{EW}$$

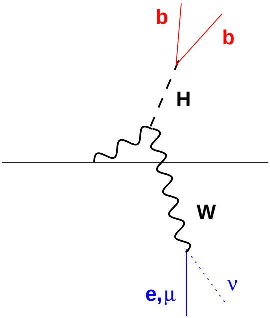
That's why it's being built

In much of that range, EW-scale particles are **light**
[a little like b-quarks at the Tevatron]

Can large phase-space be used to our advantage?
[At Tevatron, $p_t = 0$ is not easiest place to look for B-hadrons...]

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

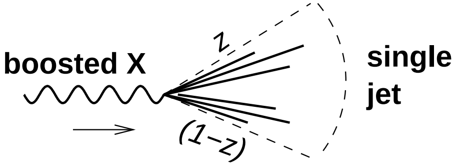
By a factor of 20 for $p_{tH} > 200$ GeV

Will the benefits outweigh this?

And how do we ID high-p_t hadronic Higgs decays?

Boosted massive particles, e.g.: EW bosons

Hadronically decaying EW boson at high $p_t \neq$ two jets



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

Rules of thumb: $m = 100$ GeV, $p_t = 500$ GeV

- $R < \dfrac{2m}{p_t}$: always resolve **two** jets — $R < 0.4$
- $R \gtrsim \dfrac{3m}{p_t}$: resolve **one** jet in 75% of cases ($\frac{1}{8} < z < \frac{7}{8}$) — $R \gtrsim 0.6$

Finding a boosted Higgs?

How do we find a boosted Higgs inside a single jet?

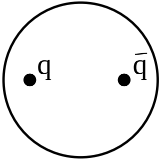
Special case of general (unanswered) question: how do we best do jet-finding?

Various people have looked at boosted objects over the years

- Seymour '93 [heavy Higgs $\to WW \to \nu\ell$jets]
- Butterworth, Cox & Forshaw '02 [$WW \to WW \to \nu\ell$jets]
- Agashe et al. '06 [KK excitation of gluon $\to t\bar{t}$]
- Butterworth, Ellis & Raklev '07 [SUSY decay chains $\to W, H$]
- Skiba & Tucker-Smith '07 [vector quarks]
- Lillie, Randall & Wang '07 [KK excitation of gluon $\to t\bar{t}$]
- ...

ETC.

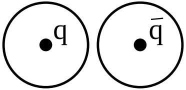
Boosted ID strategies



Select on the jet mass with one large (cone) jet

Can be subject to large bkgds

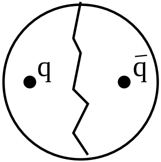
[high-p_t jets have significant masses]



Choose a small jet size (R) so as to resolve two jets

Easier to reject background if you actually see substructure

[NB: must manually put in “right” radius]



Take a large jet and split it in two

Let jet algorithm establish correct division

To understand what it means to split a jet, let's take a detour, and look at how jets are built up

Sequential recombination

k_t algorithm:

Find smallest of

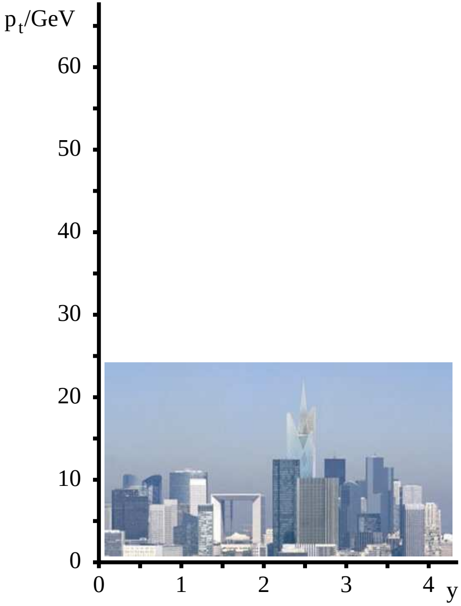
$$d_{ij} = \min(k_{ti}^2, k_{tj}^2)\Delta R_{ij}^2/R^2, \quad d_{iB} = k_{ti}^2$$

If d_{ij} recombine; if d_{iB}, i is a jet

Example clustering with k_t algorithm, $R = 0.7$

ϕ assumed 0 for all towers

Sequential recombination



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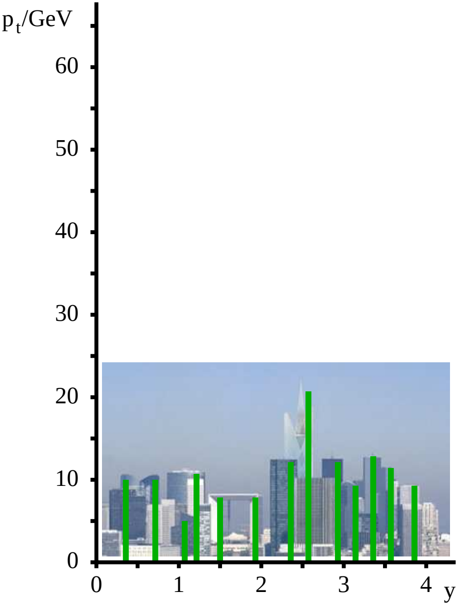

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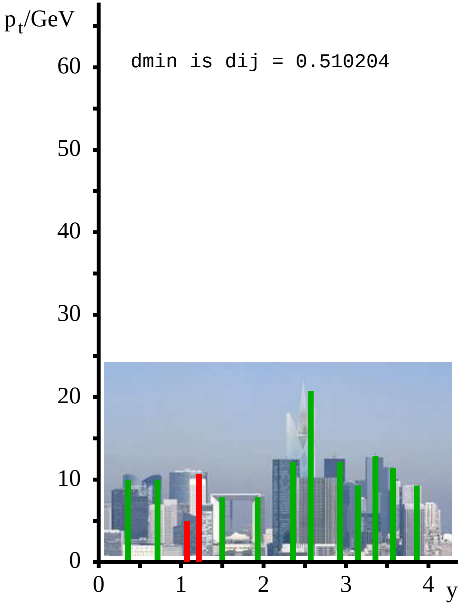

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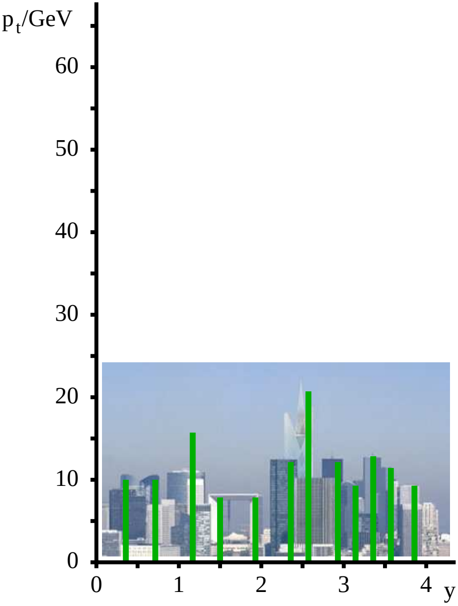

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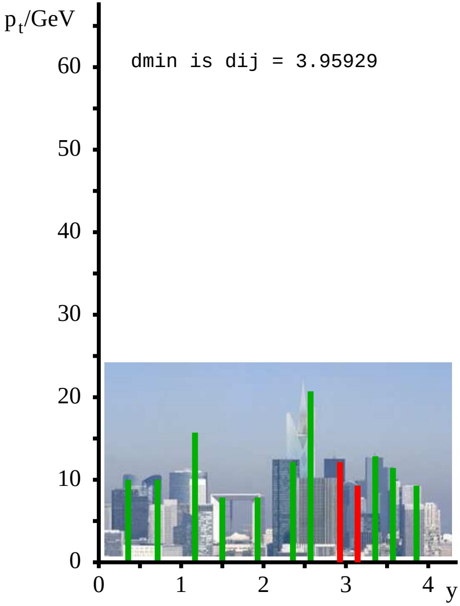

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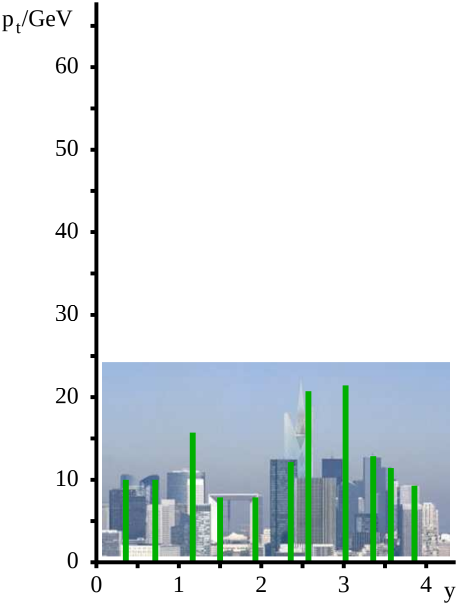

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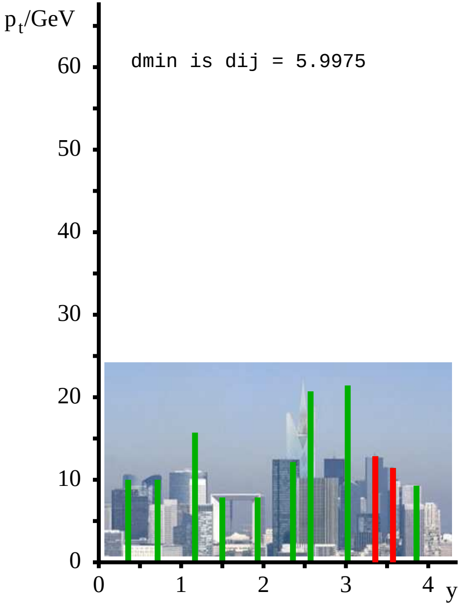

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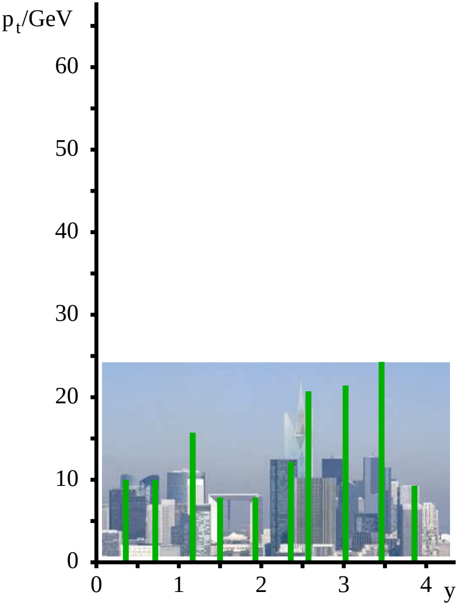

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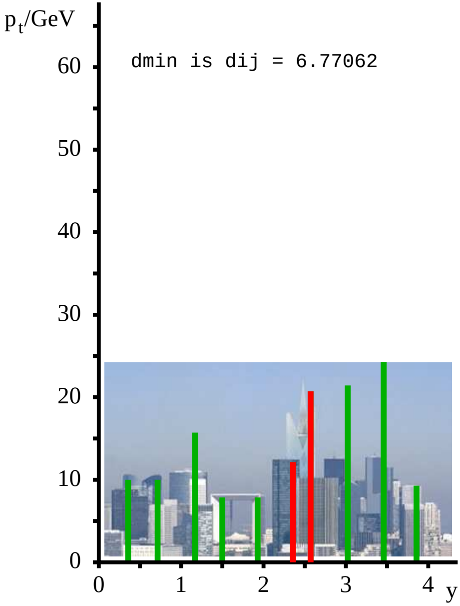

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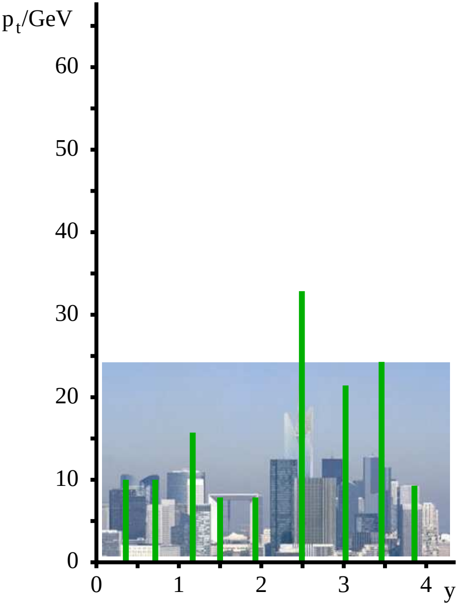

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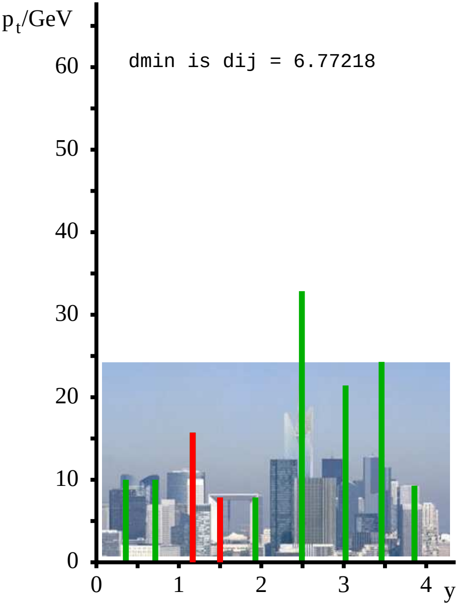

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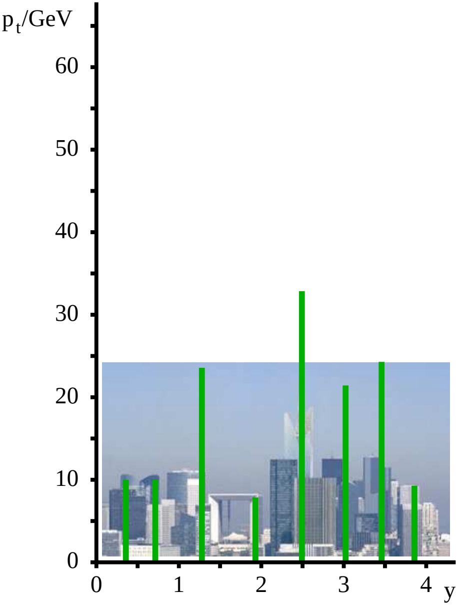

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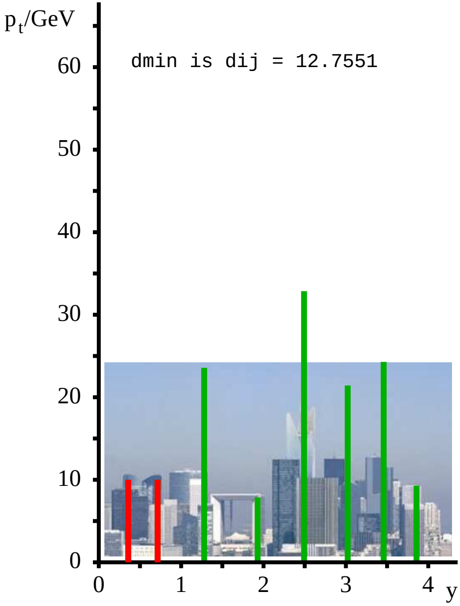

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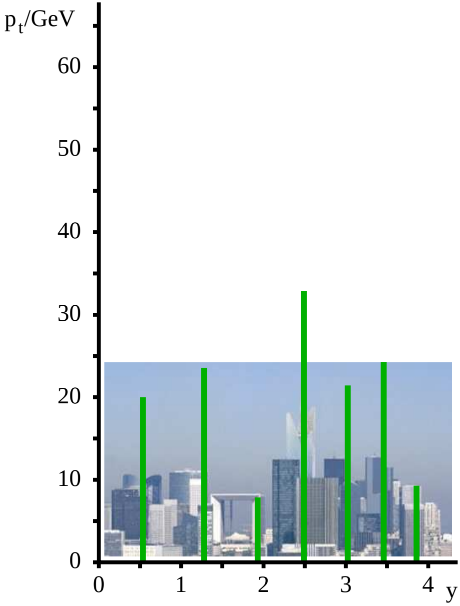

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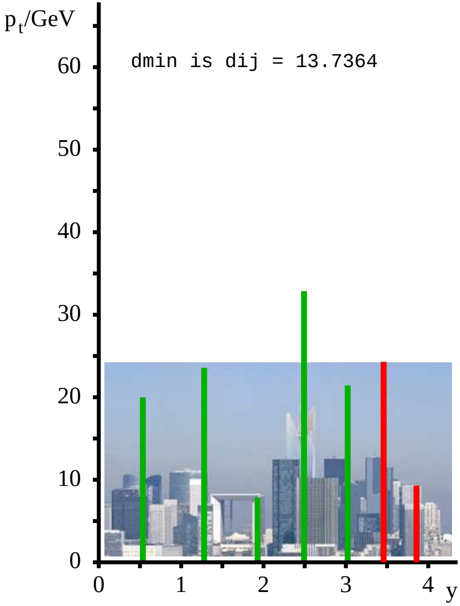

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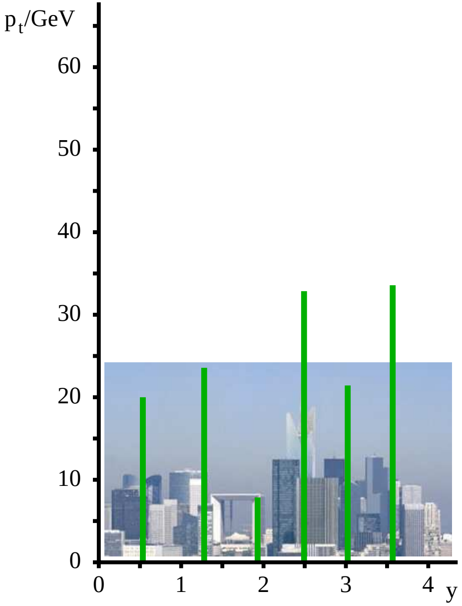

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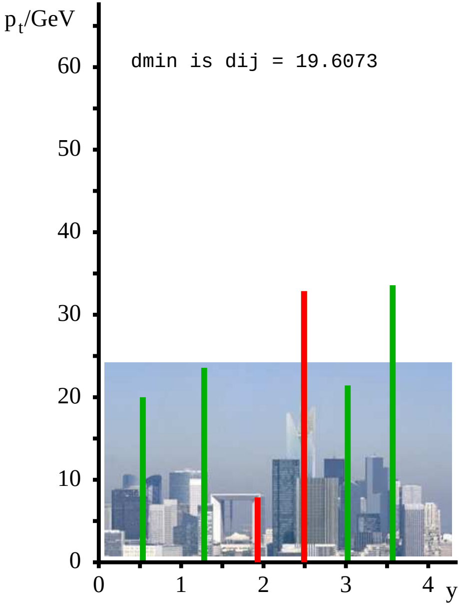

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Find smallest of

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Example clustering with k_t algorithm, $R = 0.7$

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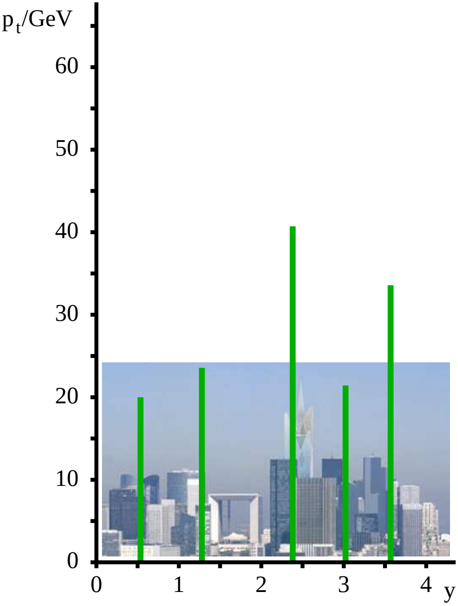

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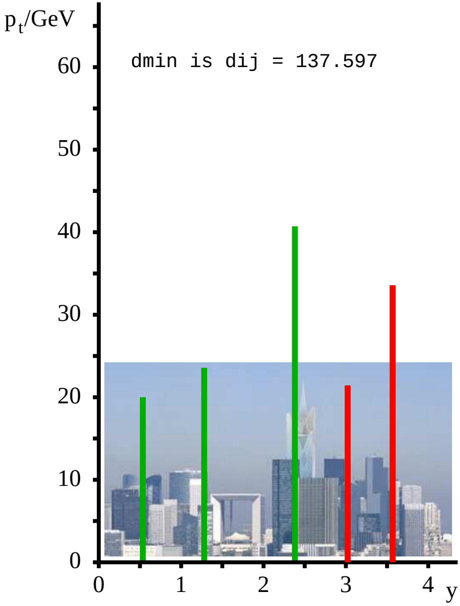

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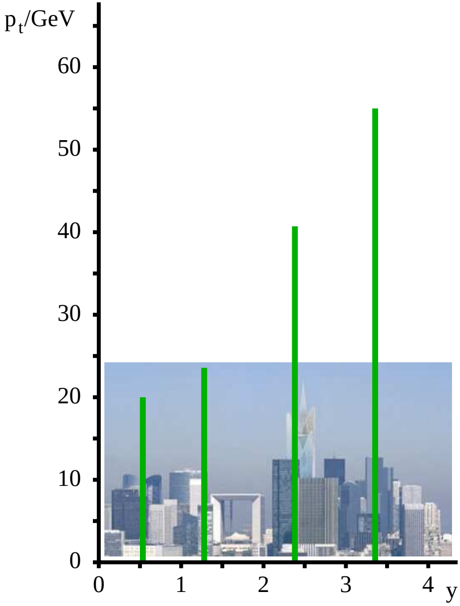

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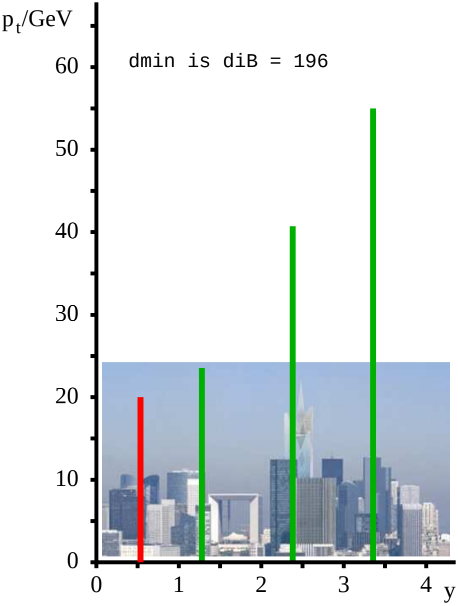

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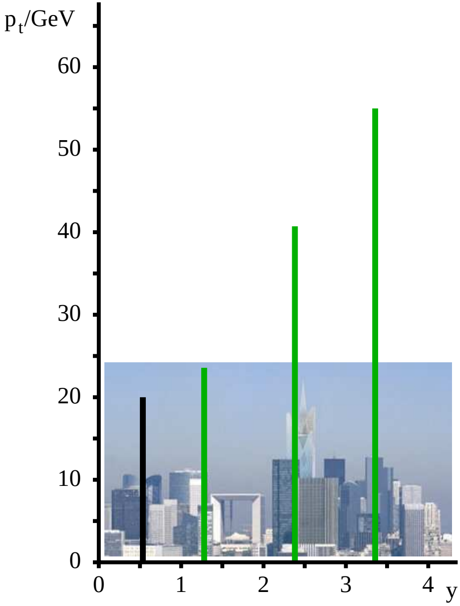

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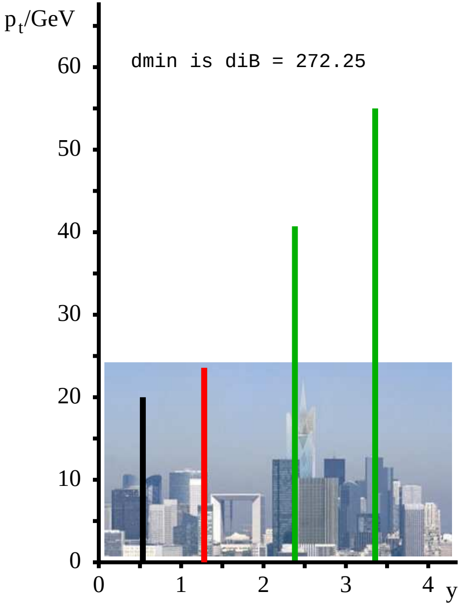

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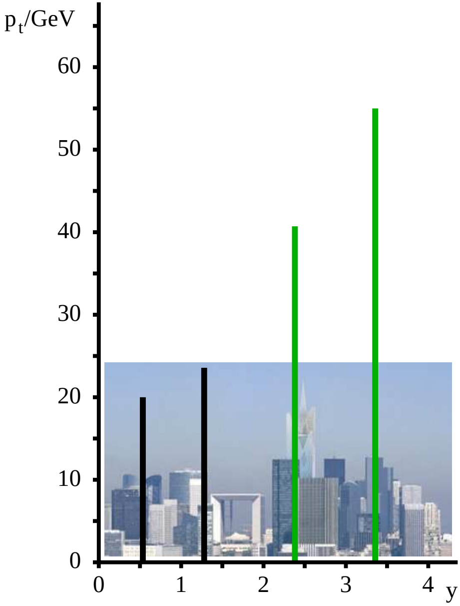

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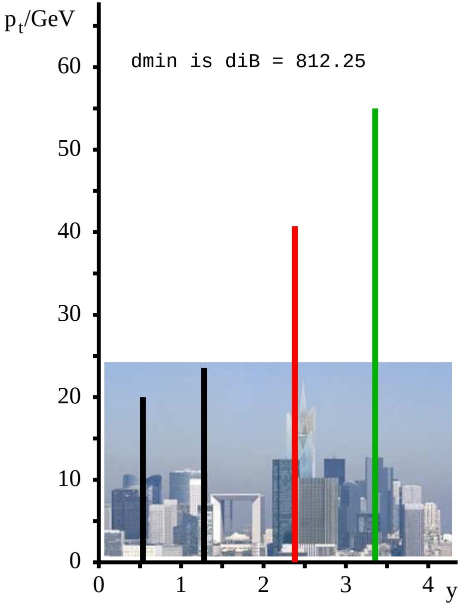

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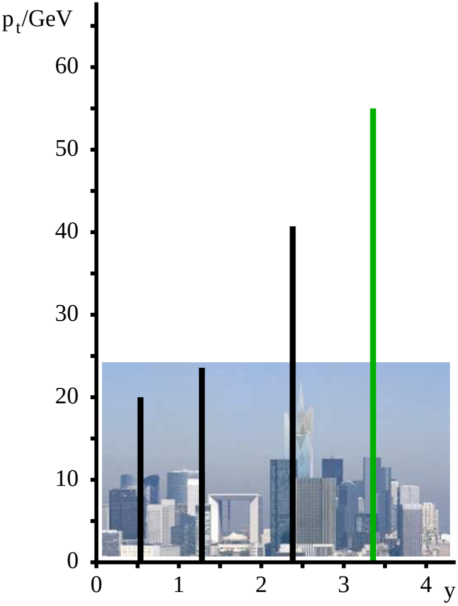

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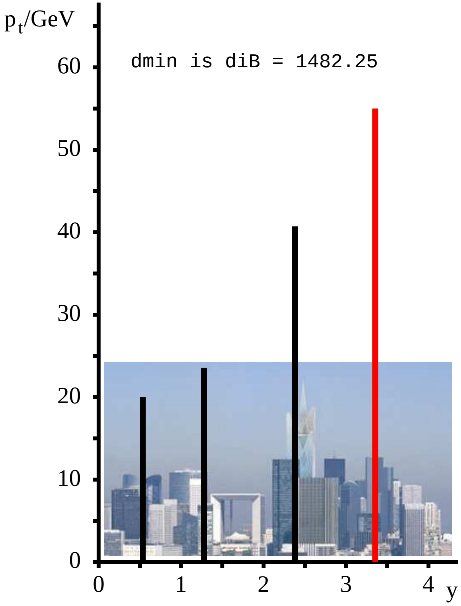

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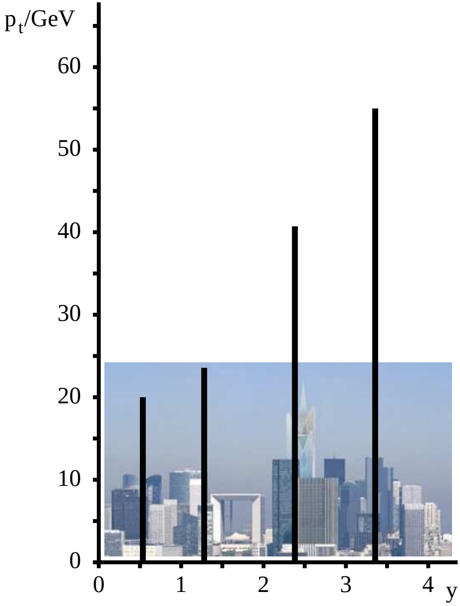

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Past methods

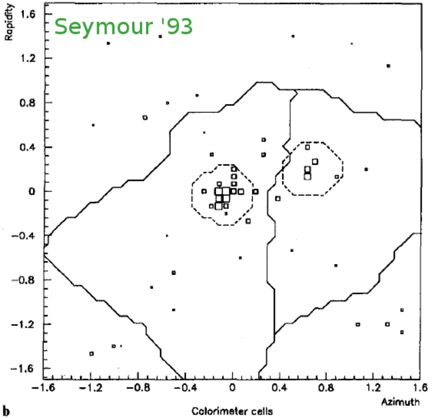
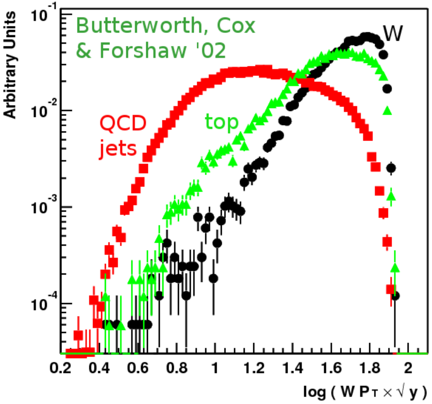


Fig. 2. A hadronic W decay, as seen at calorimeter level, **a** without, and **b** with, particles from the underlying event. Box sizes are logarithmic in the cell energy, lines show the borders of the sub-jets for infinitely soft emission according to the cluster (solid) and cone (dashed) algorithms

Use k_t jet-algorithm's hierarchy to split the jets



Use k_t alg.'s distance measure (rel. trans. mom.) to cut out QCD bkgd:

$$d_{ij}^{k_t} = \min(p_{ti}^2, p_{tj}^2)\Delta R_{ij}^2$$

Y-splitter

only partially correlated with mass

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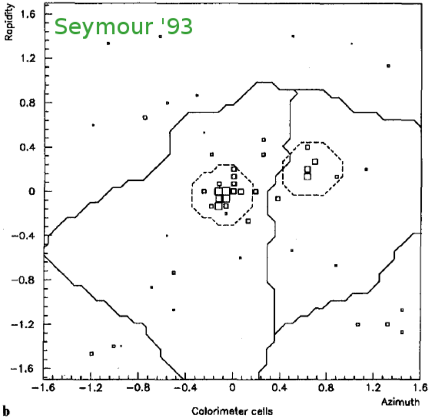

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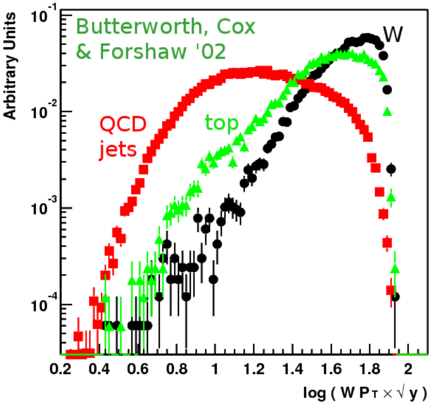

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3 QCD principles help guide our analysis

- QCD radiation from a boosted Higgs decay is limited by angular ordering
- Higgs decay shares energy symmetrically, QCD background events with same mass share energy asymmetrically
- QCD radiation from Higgs decay products is point-like, noise (UE, pileup) is diffuse

#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 $\Delta R_{ij} > R$. [in FastJet]

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

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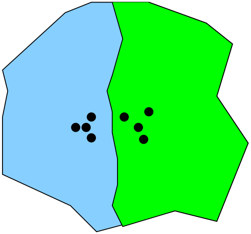
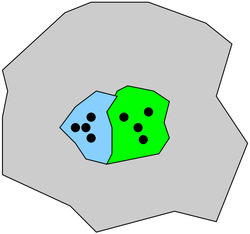
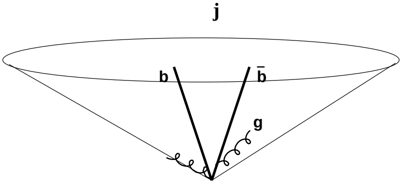


Cam/Aachen algorithm



Allows you to "dial" the correct R to keep perturbative radiation, but throw out UE

#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.

   Require $y_{12} = \frac{\min(p_{t1}^2, p_{t2}^2)}{m_{12}^2} \Delta R_{12}^2 \simeq \frac{\min(p_{t1}, p_{t2})}{\max(p_{t1}, p_{t2})} > 0.09$ [else goto 1]

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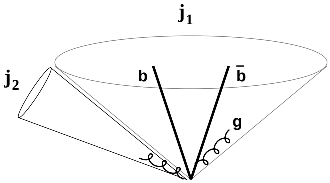

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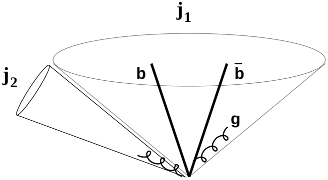

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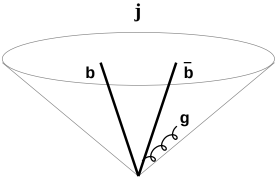

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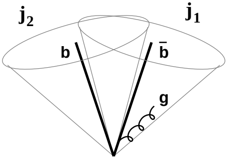

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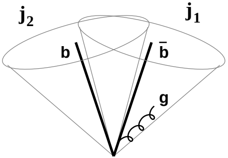

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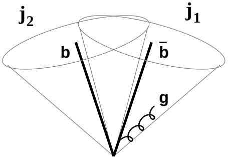

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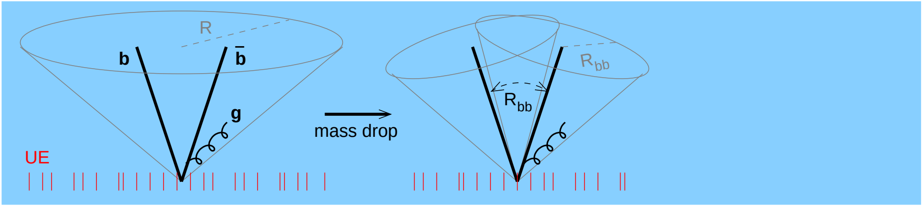

At moderate p_t, R_{bb} is quite large; *UE & pileup degrade mass resolution*

$\delta M \sim R^4 \Lambda_{UE} \frac{p_t}{M}$ [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

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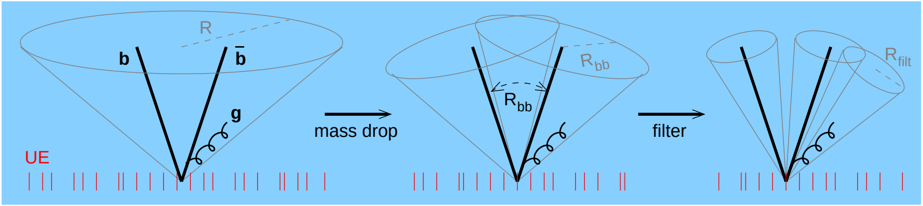

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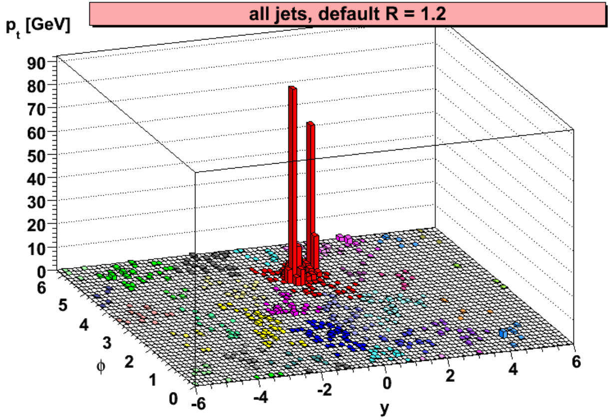
$pp \longrightarrow ZH \longrightarrow \nu\bar{\nu}b\bar{b}$, @14 TeV, $m_H = 115$ GeV

SIGNAL

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



Zbb BACKGROUND

Cluster event, C/A, R=1.2

arbitrary norm.

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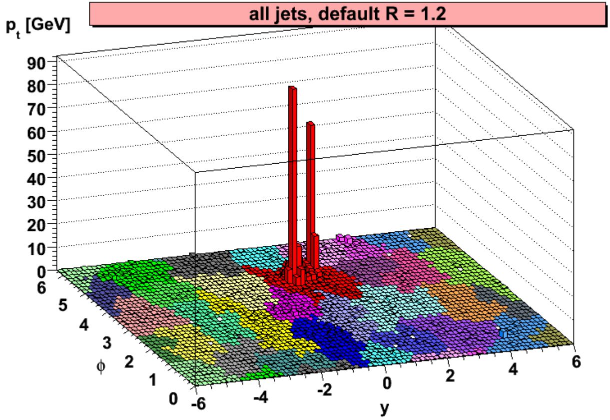

Zbb BACKGROUND

Fill it in, → show jets more clearly

arbitrary norm.

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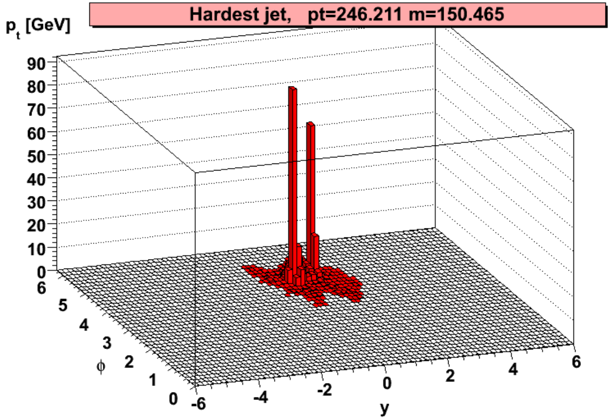
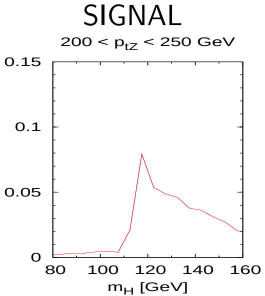
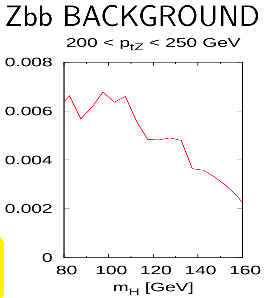


Consider hardest jet, $m = 150$ GeV





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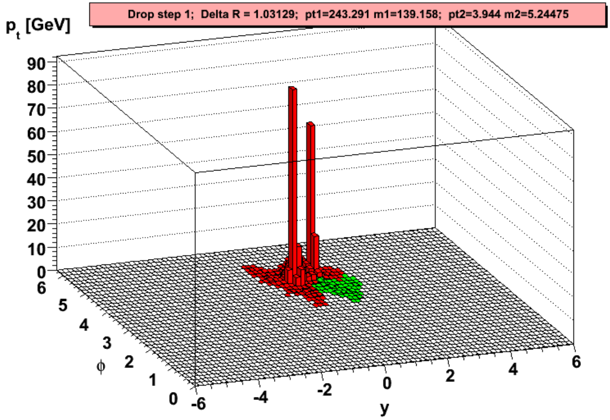

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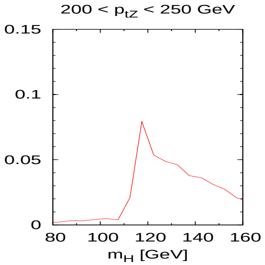

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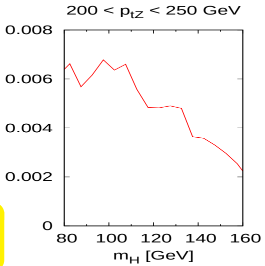

split: $m = 150$ GeV, $\frac{\max(m_1, m2)}{m} = 0.92 \to$ repeat

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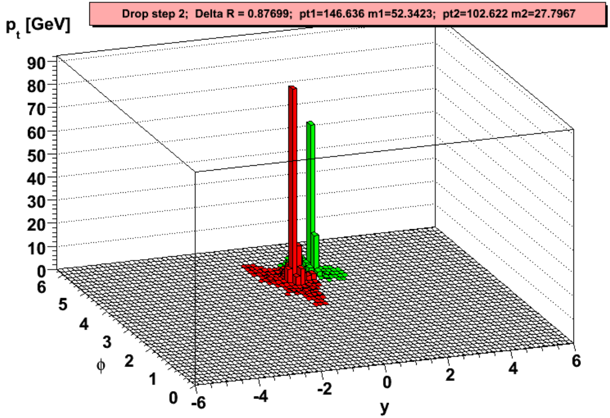

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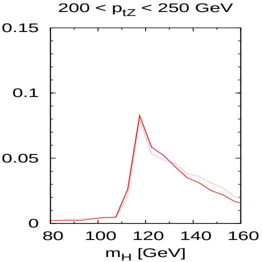
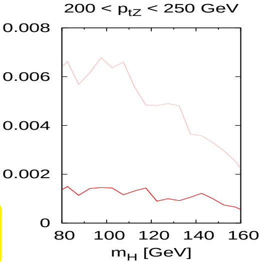


Zbb BACKGROUND

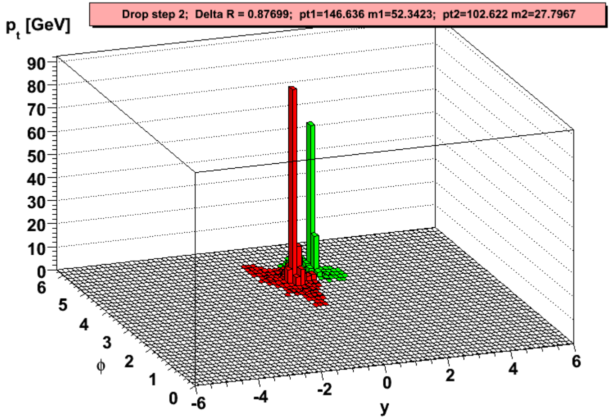


split: $m = 139$ GeV, $\frac{\max(m_1, m2)}{m} = 0.37 \longrightarrow$ mass drop

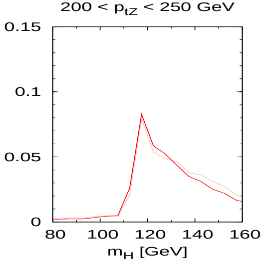
arbitrary norm.

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

Herwig 6.510 + Jimmy 4.31 + FastJet 2.3



SIGNAL



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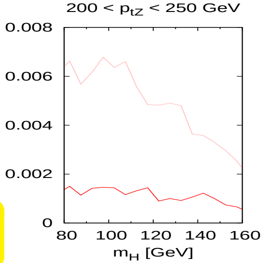

check: $y_{12} \simeq \frac{p_{t2}}{p_{t1}} \simeq 0.7 \to$ OK + 2 b-tags (anti-QCD)

arbitrary norm.

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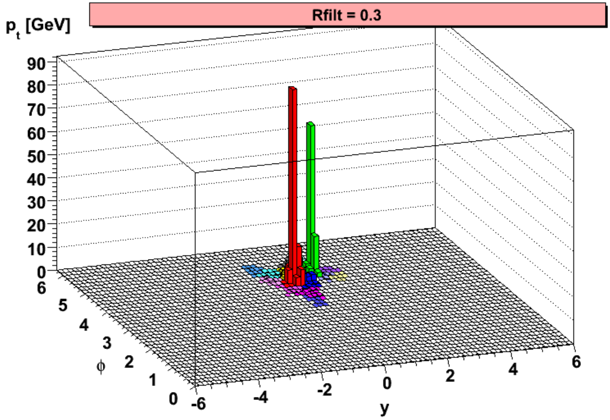
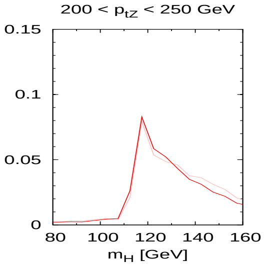
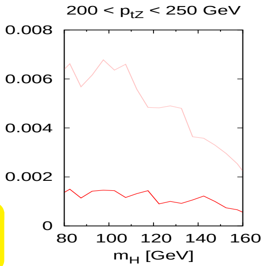


$R_{filt} = 0.3$

SIGNAL



Zbb BACKGROUND



arbitrary norm.

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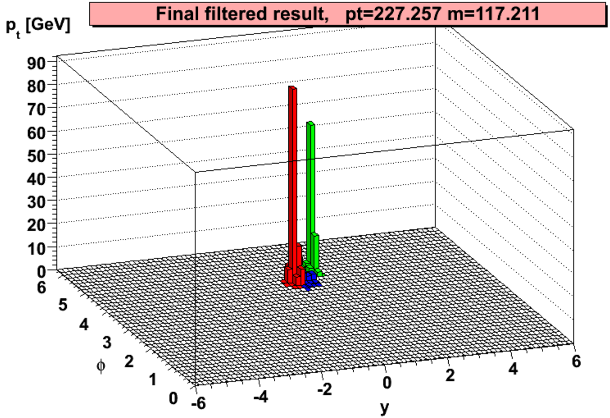
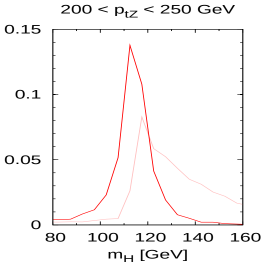


$R_{filt} = 0.3$: take 3 hardest, **m = 117 GeV**

SIGNAL



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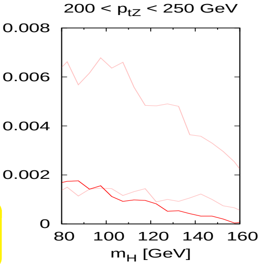
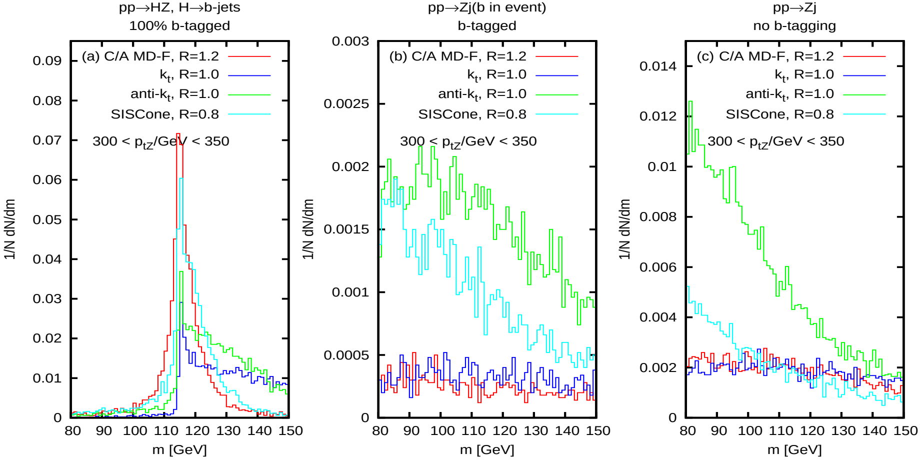


arbitrary norm.

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

The full analysis (scaled to 30 fb^{-1})

Consider HW and HZ signals: $H \to b\bar{b}$, $W \to \ell\nu$, $Z \to \ell^+\ell^-$ and $Z \to \nu\bar{\nu}$,

3 channels: $\ell^\pm + \not{E}_T$; $\ell^+\ell^-$; $\not{E}_T$

Common cuts

- $p_{tV}, p_{tH} > 200$ GeV
- $|\eta_{Higgs-jet}| < 2.5$
- $\ell = e, \mu$, $p_{t,\ell} > 30$ GeV, $|\eta_\ell| < 2.5$
- No extra ℓ, b's with $|\eta| < 2.5$

Channel-specific cuts:

See next slides

Assumptions

- Real/fake b-tag rates: 0.6/0.02 — should be fairly safe
- $S/\sqrt{B}$ from 16 GeV window — ATLAS jet-mass resln $\sim$ half this?

Tools: Herwig 6.510, Jimmy 4.31 (tuned), *hadron-level* $\to$ FastJet 2.3
Backgrounds: VV, Vj, jj, $t\bar{t}$, single-top, with > 30 fb^{-1} (except jj)

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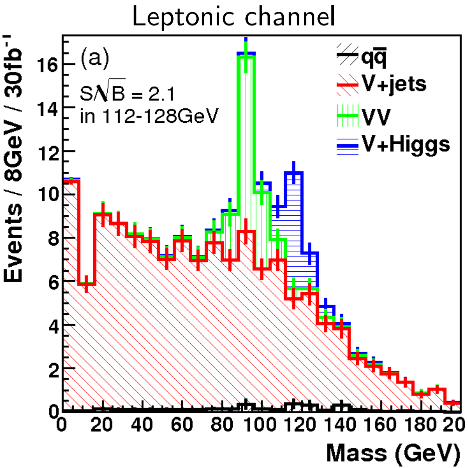
combine HZ and HW, $p_t > 200$ GeV



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- No extra ℓ, b's with $|\eta| < 2.5$
- Real/fake b-tag rates: 0.6/0.02
- $S/\sqrt{B}$ from 16 GeV window

Leptonic channel

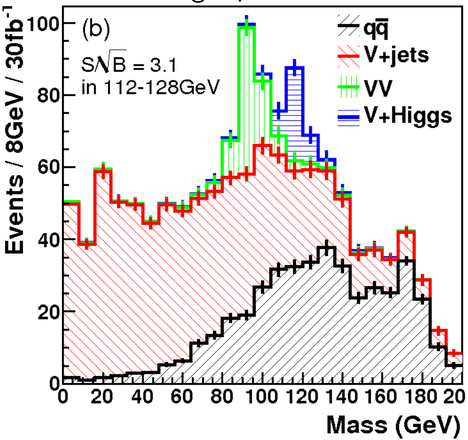
$Z \to \mu^+\mu^-, e^+e^-$

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

At 4.5σ 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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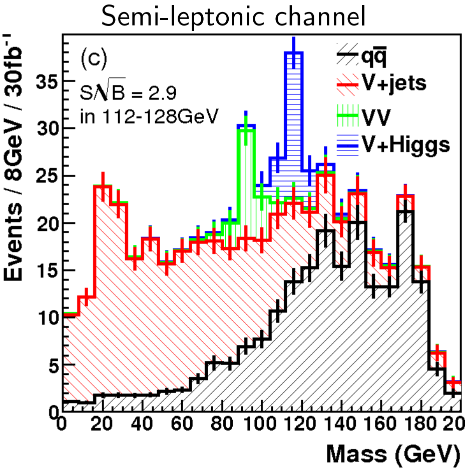
Missing-E_t channel

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

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

At 4.5σ 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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- $S/\sqrt{B}$ from 16 GeV window

Semi-leptonic channel

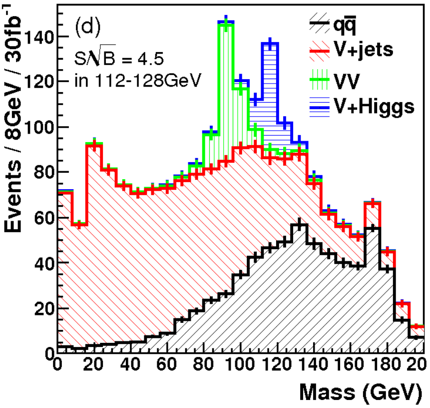
$W \to \nu\ell$

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

At 4.5σ 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

3 channels combined



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- Real/fake b-tag rates: 0.6/0.02
- $S/\sqrt{B}$ 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 4.5σ for 30 fb^{-1} this looks like a possible new channel for light Higgs discovery. **Deserves serious exp. study!**

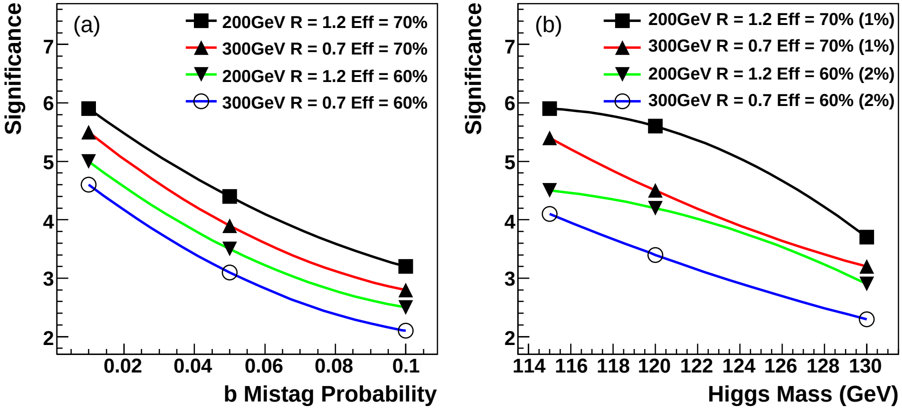
Rough impact of going to high-p_t

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]

Impact of *b*-tagging, Higgs mass

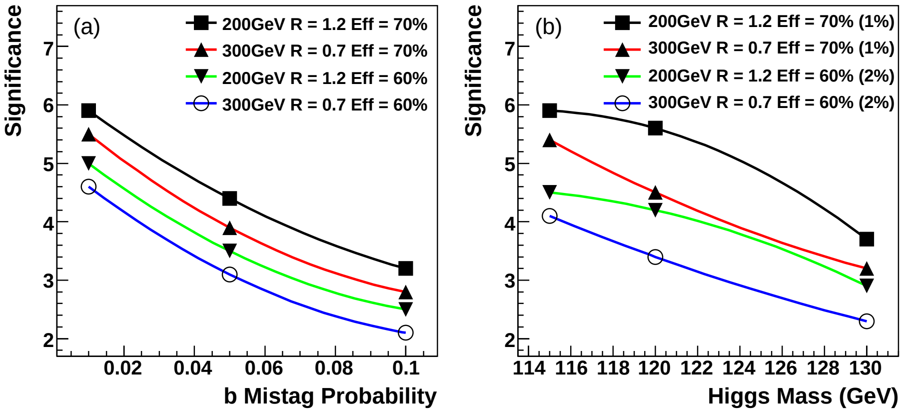


Most scenarios above 3σ

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

In nearly all cases, suitable for extracting $b\bar{b}$H, WWH, ZZH couplings

Impact of *b*-tagging, Higgs mass



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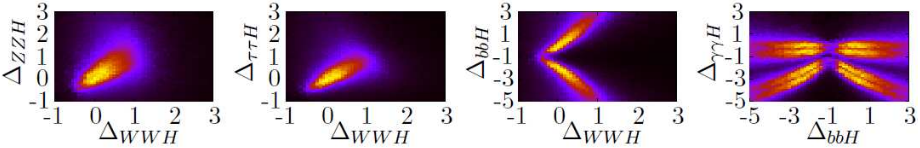
Higgs coupling measurements

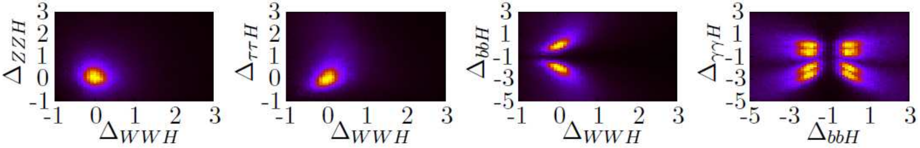
You only know it's the SM Higgs if couplings agree with SM expectations.

Detailed study of all observable LHC Higgs production/decay channels carried out by Lafaye, Plehn, Rauch, Zerwas, Duhrssen '09

Without VH, $H \to b\bar{b}$



With VH, $H \to b\bar{b}$



Without direct $H \to b\bar{b}$ measurement, errors on couplings increase by $\sim 100\%$

Does any of this hold with a real detector?

ATLAS had *WW* scattering studies with the k_t algorithm that suggested that general techniques were realistic.

But kinematic region was different ($p_t > 500$ GeV).
And Higgs also has *b*-tagging of subjets, ...

ATLAS analysis

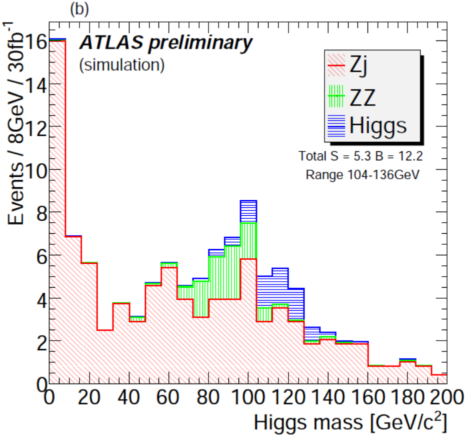
As of August 2009: ATLAS have preliminary public analysis of this channel
ATL-PHYS-PUB-2009-088

What changes?

- Inclusion of detector simulation — mixture of full and validated ATLFAST-II
- Study of triggers — All OK
- New issue: *importance of fake b tags from charm quarks*
- *New background: Wt production* with $t \to bW$, $W \to cs$, giving bc as a Higgs candidate.
- Larger mass windows, $24 - 32$ GeV rather than 16 GeV for signal, reflecting full detector resolution
- Various changes in details of cuts
- ATLAS numbers shown for $m_H = 120$ GeV (previous plots: $m_H = 115$ GeV)

ATLAS results

Leptonic channel



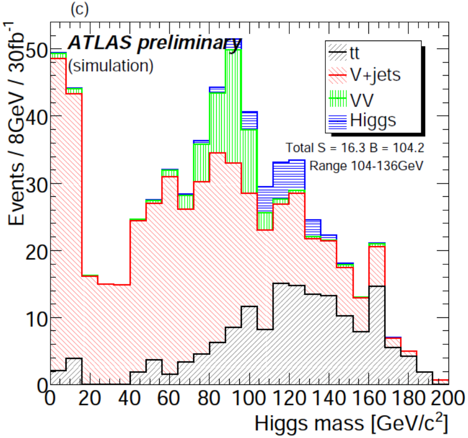
What changes compared to particle-level analysis?

$\sim 1.5\sigma$ as compared to 2.1σ

Expected given larger mass window

ATLAS results

Missing E_T channel



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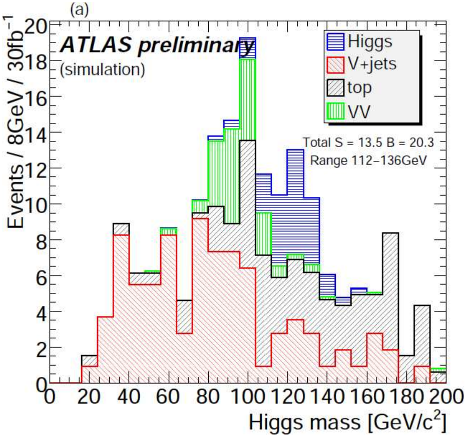
Suffers: some events redistributed to semi-leptonic channel

ATLAS results

Semi-leptonic channel



What changes compared to particle-level analysis?

$\sim 3\sigma$ as compared to 3σ

Benefits: some events redistributed from missing E_T channel

ATLAS combined results

Likelihood-based analysis of all three channels together gives signal significance of

3.7σ for 30 fb^{-1}

To be compared with 4.2σ in hadron-level analysis for $m_H = 120$ GeV

With 5% (20%) background uncertainty, ATLAS result becomes 3.5σ (2.8σ)

Comparison to other channels at ATLAS ($m_H = 120$, 30 fb^{-1}):

$gg \to H \to \gamma\gamma$	$WW \to H \to \tau\tau$	$gg \to H \to ZZ^*$
4.2σ	4.9σ	2.6σ

Extracted from 0901.0512

Prospects?

ATLAS: "Future improvements can be expected in this analysis:"

- b-tagging might be calibrated [for this] kinematic region
- jet calibration [...] hopefully improving the mass resolution
- background can be extracted directly from the data
- multivariate techniques

CMS is looking at this channel

- Biggest difference wrt ATLAS could be jet mass resolution

But CMS have plenty of good ideas that might compensate for worse hadronic calorimeter

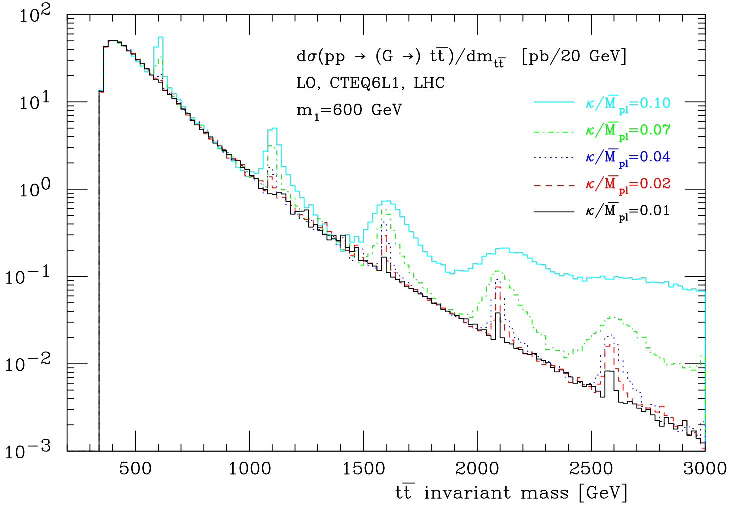
Combination of different kinematic regions

- E.g. in original analysis, $p_t > 300$ GeV (only 1% of VH, but very clear signal) was almost as good as $p_t > 300$ GeV (5% of VH).
- Treating different p_t ranges independently may have benefits.

What about other boosted objects?

e.g. Boosted top
[hadronic decays]

$X \to t\bar{t}$ resonances of varying difficulty



RS KK resonances $\to t\bar{t}$, from Frederix & Maltoni, 0712.2355

NB: QCD dijet spectrum is $\sim$ 500 times $t\bar{t}$

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.

6 papers on top tagging in '08-'09 (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%
Brooijmans '08	3,4 k_t subjets, d_{cut}	45%	5%
Thaler & Wang '08	2,3 k_t subjets, z_{cut} + various	40%	5%
Kaplan et al. '08	3,4 C/A subjets, $z_{cut} + \theta_h$	40%	1%
Almeida et al. '08	predict mass dist^n, use jet-shape	–	–
Ellis et al '09	C/A pruning	10%	0.05%
ATLAS '09	3,4 k_t subjets, d_{cut} MC likelihood	90%	15%

Boosted new-physics objects?

R-parity violating SUSY

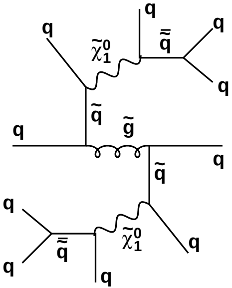
As a final example, a search for neutralinos in R-parity violating supersymmetry.

Normal SPS1A type SUSY scenario, *except* that neutralino is not LSP, but instead decays, $\tilde{\chi}_1^0 \to qqq$.

Jet combinatorics makes this a tough channel for discovery

- Produce pairs of squarks, $m_{\tilde{q}} \sim 500$ GeV.
- Each squark decays to quark + neutralino, $m_{\tilde{\chi}_1^0} \sim 100$ GeV
- Neutralino is somewhat boosted → jet with substructure

Butterworth, Ellis, Raklev & GPS '09



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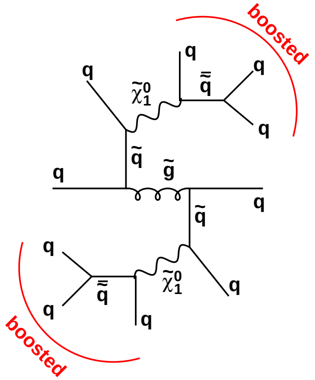
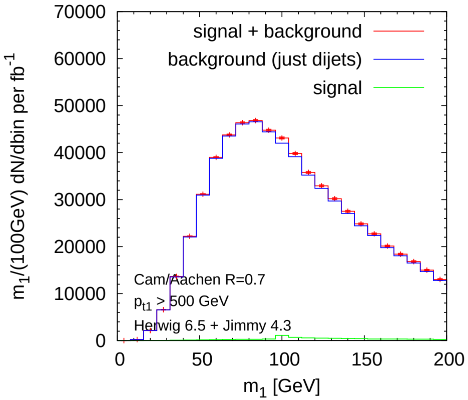


RPV SUSY, SPS1a, 1 fb^{-1}



Keep it simple:

Look at mass of leading jet

- Plot $\frac{m}{100\text{ GeV}}\frac{dN}{dm}$ for hardest jet ($p_t > 500$ GeV)
- Require 3-pronged substructure
- And third jet
- And fourth central jet

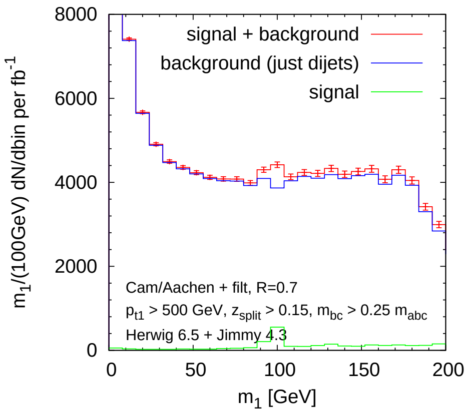
99% background rejection
scale-invariant procedure
so remaining bkgd is flat

Once you've found neutralino:

- Look at m_{14} using events with m_1 in neutralino peak and in sidebands

Out comes the squark!

RPV SUSY, SPS1a, 1 fb^{-1}



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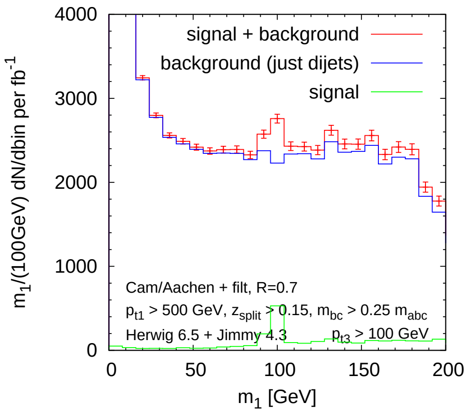

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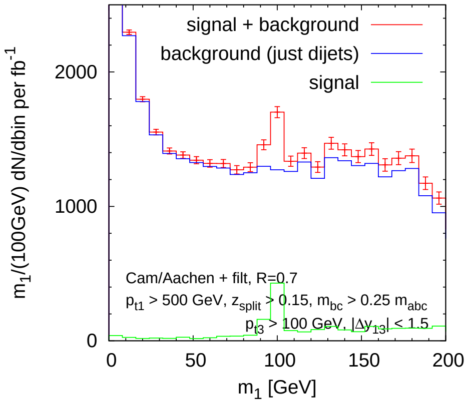

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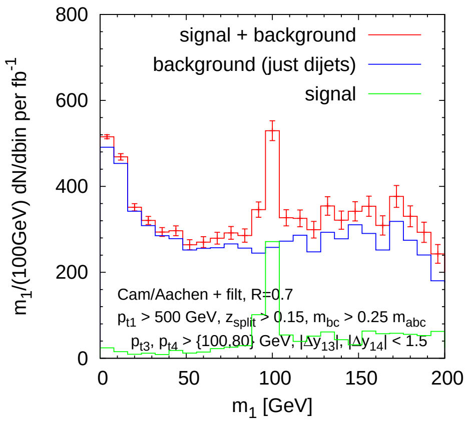

Keep it simple:

Look at mass of leading jet

- Plot $\frac{m}{100\text{ GeV}}\frac{dN}{dm}$ for hardest jet ($p_t > 500$ GeV)
- Require 3-pronged substructure
- And third central jet
- And fourth central jet

99% background rejection
scale-invariant procedure
so remaining bkgd is flat

Once you've found neutralino:

- Look at m_{14} using events with m_1 in neutralino peak and in sidebands

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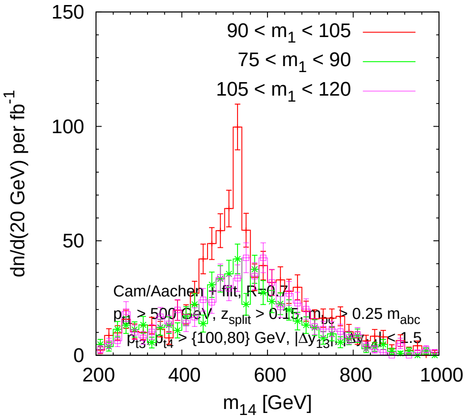

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Conclusions

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Higgs discovery

- high-p_t limit recovers WH and ZH ($H \to b\bar{b}$) channel at LHC
- Only viable channel that can see $H \to b\bar{b}$ decay
- First in-depth experimental study from ATLAS has promising results

Work continues in ATLAS. Also being looked at in CMS

New Physics searches

- Can be used for ID of high-p_t top from decaying multi-TeV resonances

  40%/1% efficiency / fake rate is similar to moderate-p_t b-tag performance!
- Can be used for ID of EW-scale new particles, e.g. neutralino

General

- Boosted EW-scale particles can be found in jets
- Cambridge/Aachen alg. is very powerful (flexible, etc.) tool for this

Being used in many different ways

EXTRAS

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

K-factors

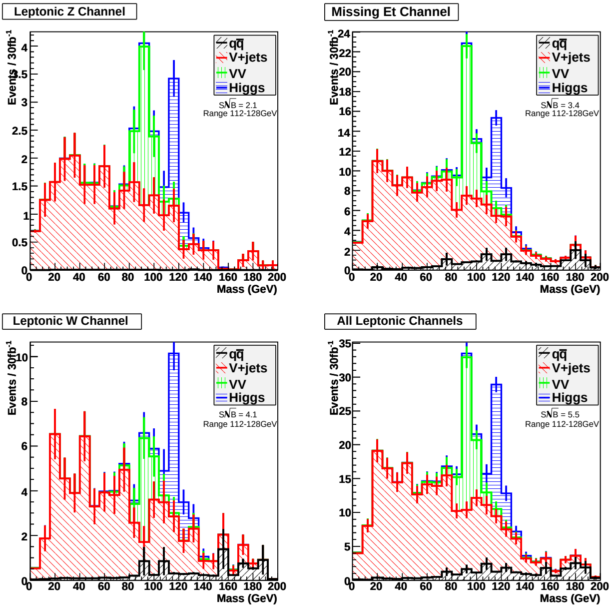
Analysis shown without K factors. What impact do they have?

Determined with MCFM, MC@NLO

- Signal: $K \sim 1.6$
- Vbb backgrounds: $K \sim 2 - 2.5$
- $t\bar{t}$ backgrounds: $K \sim 2$ — for total; not checked for high-p_t part

Conclusion: $S/\sqrt{B}$ should not be severely affected by NLO contributions

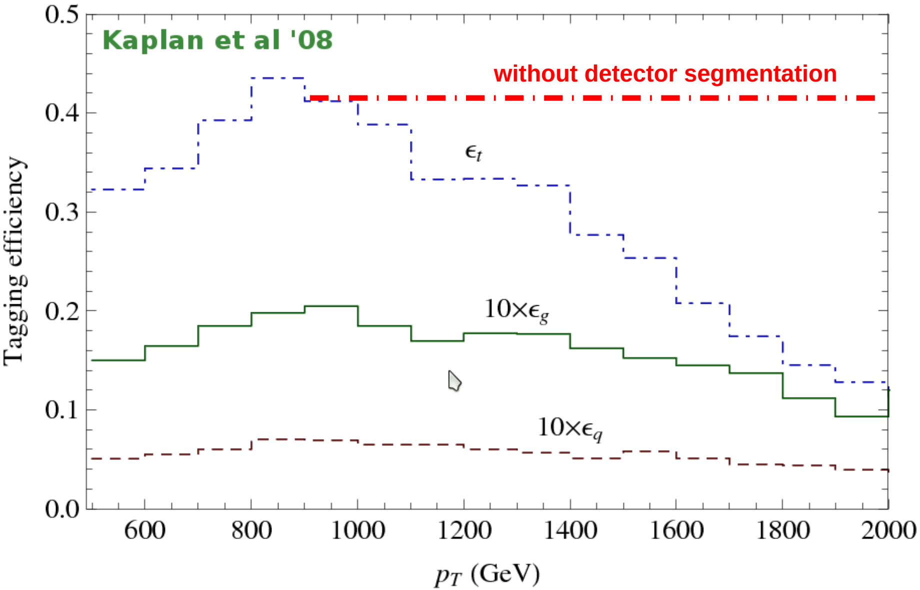
Raise p_t cut to 300 GeV (70%/1% b-tagging



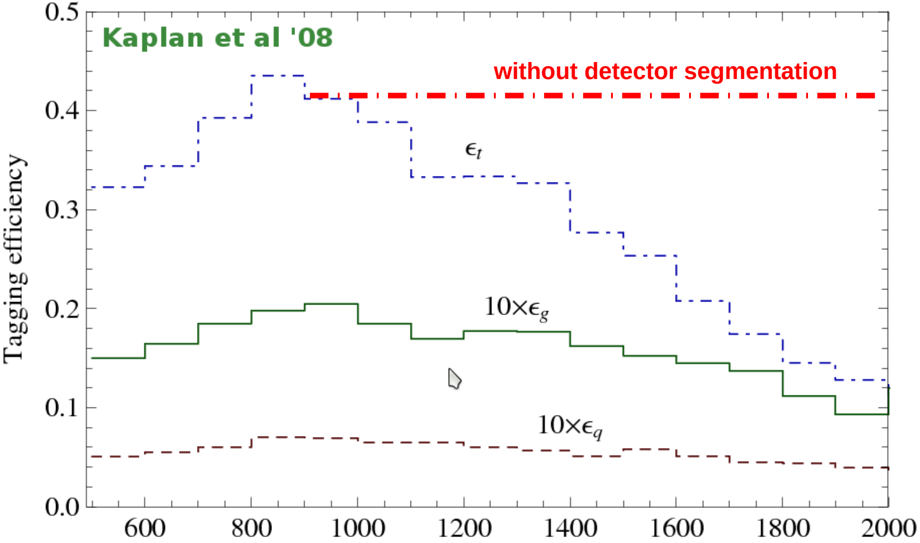
NB: kills $t\bar{t}$ background

Boosted top extras

Efficiency v. p_t (ideal detector)



Efficiency v. p_t (ideal detector)

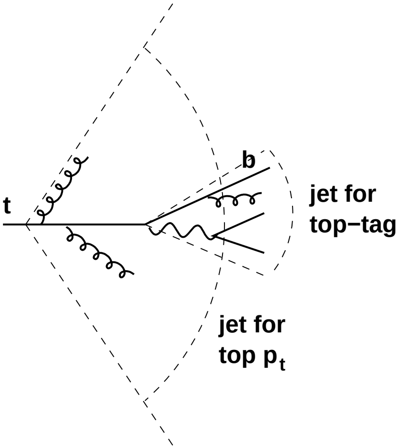


1-TeV Top tagging looks almost as good as 50 GeV b-tagging!

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

Use small cone | Use large cone

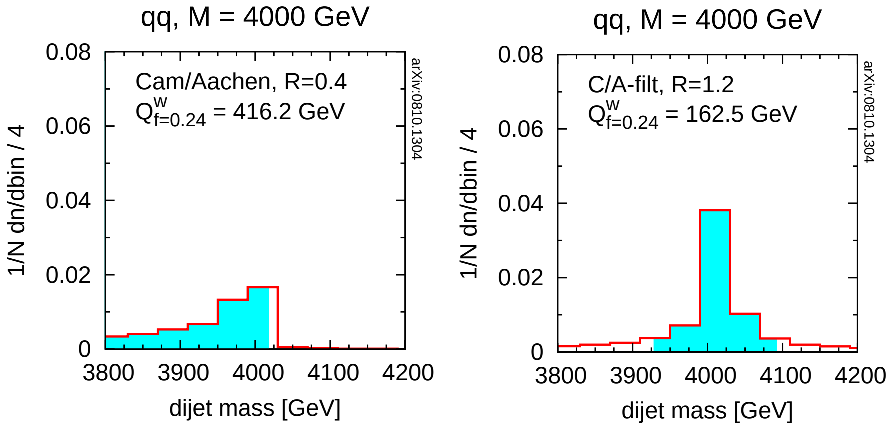
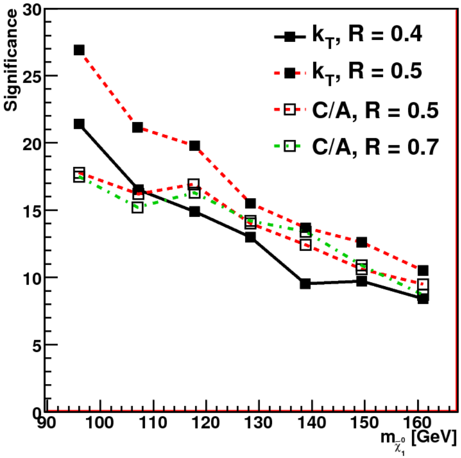


Figure actually from 0810.1304 (Cacciari, Rojo, GPS & Soyez)
for light $q\bar{q}$ resonance — but $t\bar{t}$ will be similar

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

Neutralino extras

RPV SUSY: significance v. mass scale



- All points use 1 fb^{-1}
- as m_χ increases, $m_{\tilde{q}}$ goes from 530 GeV to 815 GeV
- Same cuts as for main SPS1A analysis

no particular optimisation