Many Jets at Hadron Colliders

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Heidelberg

Shanghai, 6/2011

Counting jets

Understanding multi-jet events: W+jets, QCD, etc [Englert, TP, Schumann, Schichtel]

- DGLAP and parton densities: jet-inclusive
  SUSY & Higgs: jet-exclusive [get to this later]
  jet merging key to precision predictions [Sherpa, Alpgen, MadEvent]
- exclusive n_{jet} distribution:
  expected for soft/collinear jets: Poisson scaling [Peskin & Schroeder]
  observed since UA2: 'staircase scaling' with constant R [Ellis, Kleiss, Stirling]

$$\hat{R} \equiv \frac{\hat{\sigma}_{n+1}}{\hat{\sigma}_n} = \frac{\sigma_{n+1} \sum_{j=0}^{\infty} R^j}{\sigma_n + \sigma_{n+1} \sum_{j=0}^{\infty} R^j} = \frac{R\sigma_n}{(1-R)\sigma_n + R\sigma_n} = \frac{\sigma_{n+1}}{\sigma_n} \equiv R$$

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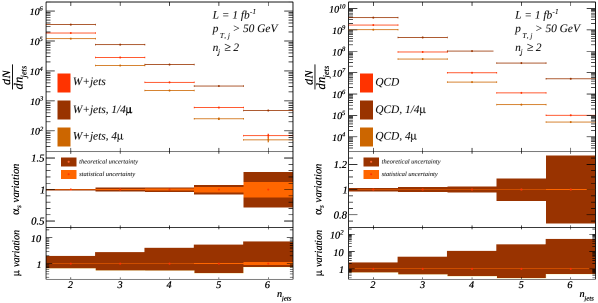
– testable including errors: scales and $\alpha_s(m_Z)$



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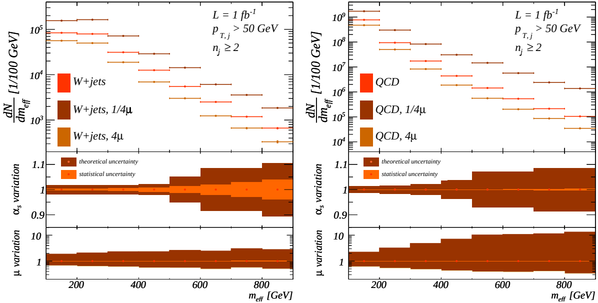

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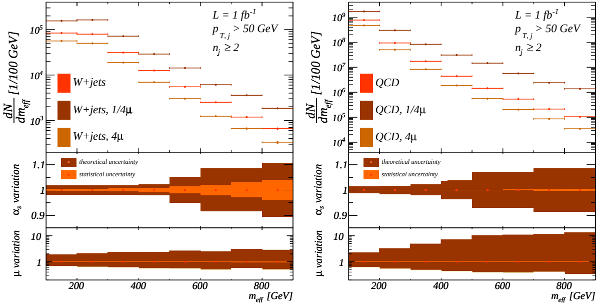

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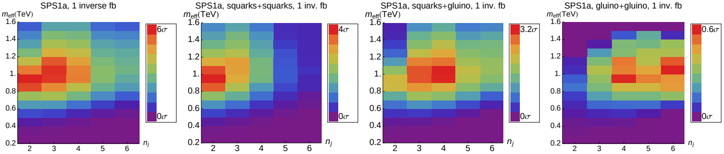
Autofocus into m_{eff} vs n_{jet}

– keep n_{jet} free in inclusive analyses [early LHC analyses]

– mass of heavy states from m_{eff} [like ATLAS analyses]
color charge from n_{jet} [no gluon decay]

– exclusive two-dimensional likelihood



Fewer fatter jets

Fat jets from boosted massive particles decaying hadronically [Seymour, 1994]

– Starting frenzy: VH, $H \to b\bar{b}$ [Butterworth, Davison, Rubin, Salam]

– S: large m_{bb}, boost-dependent R_{bb}
B: large m_{bb} only for large R_{bb}
S/B: go for large m_{bb} and small R_{bb}, so boost Higgs

– implement in jet algorithm for one large Higgs jet

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...so tag hadronic top jets instead [bring down number of jets by factor 1/3]

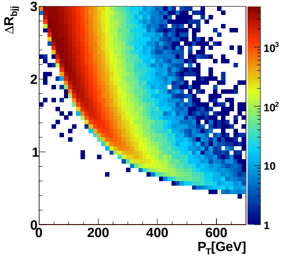
Hadronic top tagging

HEPTopTagger sales pitch

– many taggers available for medium-high p_T [Thaler & Wang, etc]

– but:
there is no heavy Z'
there is no RS graviton
there are top pairs

– $p_T \gtrsim 250$ GeV is possible



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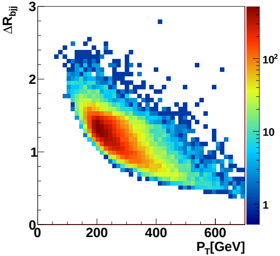

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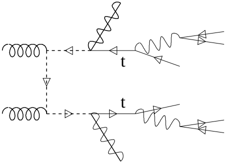

Stop pairs vs multi-jet QCD [TP, Spannowsky, Takeuchi, Zerwas; + Salam]

- know there are top partners [Meade & Reece]
  know there is dark matter [with WIMP miracle]
  search for $\tilde{t} \to t \not{p}_T$
- multi-jet nightmare: $\tilde{t}\tilde{t}^* \to t\tilde{\chi}_1^0\ \bar{t}\tilde{\chi}_1^0$
- stop mass from m_{T2} endpoint [like sleptons or sbottoms]
- six jets as easy as $b\bar{b} + \not{E}_T$

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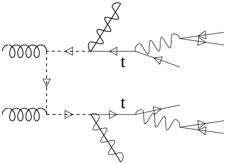

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events in 1 fb^{-1}	$\tilde{t}_1\tilde{t}_1^*$						$t\bar{t}$	QCD	W+jets	Z+jets	S/B	$S/\sqrt{B}_{10\,\text{fb}^{-1}}$
$m_{\tilde{t}}$[GeV]	340	390	440	490	540	640					340	
$p_{T,j} > 200$ GeV, ℓ veto	728	447	292	187	124	46	87850	$2.4 \cdot 10^7$	$1.6 \cdot 10^5$	n/a	$3.0 \cdot 10^{-5}$	
$\not{E}_T > 150$ GeV	283	234	184	133	93	35	2245	$2.4 \cdot 10^5$	1710	2240	$1.2 \cdot 10^{-3}$	
first top tag	100	91	75	57	42	15	743	7590	90	114	$1.2 \cdot 10^{-2}$	
second top tag	15	12.4	11	8.4	6.3	2.3	32	129	5.7	1.4	$8.3 \cdot 10^{-2}$	
b tag	8.7	7.4	6.3	5.0	3.8	1.4	19	2.6	$\lesssim 0.2$	$\lesssim 0.05$	0.40	5.9
$m_{T2} > 250$ GeV	4.3	5.0	4.9	4.2	3.2	1.2	4.2	$\lesssim 0.6$	$\lesssim 0.1$	$\lesssim 0.03$	0.88	6.1

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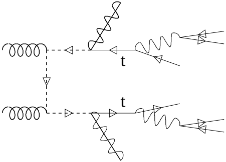

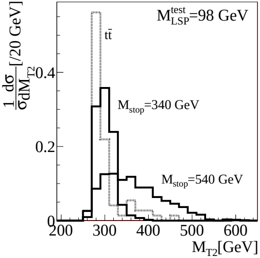

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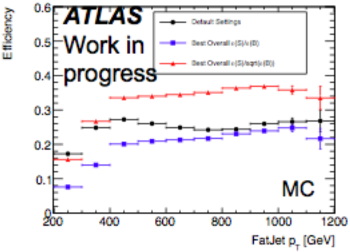
Improving top taggers

- tested by ATLAS [Kasieczka & Schätzel]
  include QCD parameters
  include pileup rejection/filtering
- different optimization for S/B or $S/\sqrt{B}$



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– small dipolarity from W [Baryakthar, Hook, Janowiak, Wacker]

$$\sum_{\text{cells}} p_{T,i} R_i^2$$

– code public under `www.thphys.uni-heidelberg.de/~plehn/`

Wjj at CDF

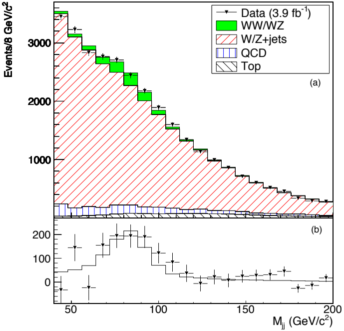
Of course, I would love it to be new physics!

- SUSY only with R parity violation, sigh
- Z' too UV-inconclusive for my taste
- Wjj standard technicolor search channel
- but: new physics is what is left after all SM attempts
  and there are issues with the analysis...

Wjj at CDF

Inclusive Wjj analysis

- test for anomalous gauge couplings in WV production [$m_{jj} = 65 - 95$ GeV, 0911.4449]
- anomaly around $m_{jj} = 160$ GeV known
- obvious issue with WV shape
  $\sigma_{WV}^{\text{electrons}} = 13.5 \pm 4.4$ pb and $\sigma_{WV}^{\text{muons}} = 23.5 \pm 4.9$ pb consistent?
  interesting binning effect at upper edge of peak
- systematics to-do list



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Second peak

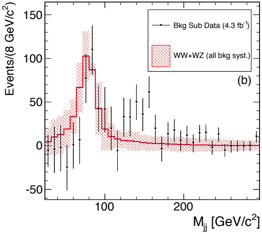
– CDF strategy:
ignore issues with first analysis
focus on secondary peak instead [$m_{jj} = 120 - 120$ GeV, 1104.0699]

1– subtract poorly understood continuum [m_{jj} side bands?]

2– add'l problem with top background [in a minute]

3– add'l problem with jet veto [don't get me started]

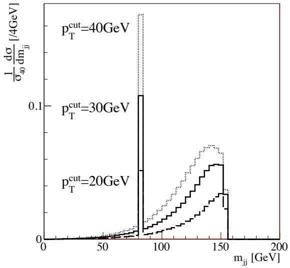
4– quote statistics-dominated evidence



Tops plus jets

Top backgrounds [TP, Takeuchi]

– endpoint $m_{bj} < 154.6$ GeV giving second peak [confirmed: Campbell, Martin, Williams]



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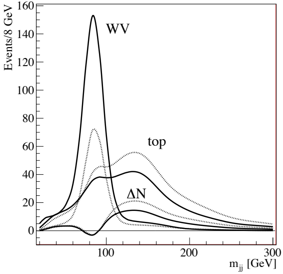
– first top peak (i.e. WV) not understood
continuum Wjj merged from multiple samples [tilt]
hear systematics alarm bells ringing? [peak-on-peak]

– increase top sample, compensate with WV

$$\Delta N_{[64,96]} = 475 \, \frac{\Delta\sigma_{WV}}{\sigma_{WV}} + 137 \, \frac{\Delta\sigma_{\text{top}}}{\sigma_{\text{top}}}$$

$$\Delta N_{[120,170]} = 45 \, \frac{\Delta\sigma_{WV}}{\sigma_{WV}} + 244 \, \frac{\Delta\sigma_{\text{top}}}{\sigma_{\text{top}}} .$$

– shift top normalization after jet veto by 40% [10% for inclusive analysis]



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- composition of top sample [cf Menon, Sullivan]

	tbW	tb	tj	single t	$t\bar{t}$	top combined	WV
	loose cuts						
$N_{[28,200]}$	246	79.3	135	460 (19%)	2013 (81%)	2473 (100%)	1384
$N_{[65,95]}$	54.8	18.1	29.8	103 (19%)	439 (81%)	542 (100%)	926
$N_{[120,170]}$	90.2	23.1	42.8	156 (17%)	759 (83%)	915 (100%)	88
	hard cuts						
	tbW	tb	tj	single t	$t\bar{t}$	top combined	WV
$N_{[28,200]}$	57.5	38.5	67.9	164 (26%)	476 (74%)	640 (100%)	704
$N_{[65,95]}$	12.9	7.7	12.9	33.5 (24%)	103 (76%)	137 (100%)	475
$N_{[120,170]}$	21.3	13.3	25.3	59.8 (25%)	184 (75%)	244 (100%)	45

CDF response

'But, the answer is NO — this cannot possibly be top' [Punzi in Blois]

0– 'implies huge error in previous top cross section measurement'

10% for the inclusive rates state of the art for theory [Ahrens et al, yesterday]
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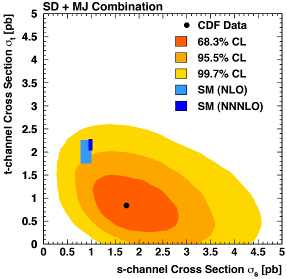
third, does CDF understand central *b* vs forward light-flavor? [single top]



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‘the top background does not peak at the right place’

good news: inclusive peak is moving down
serious issue: how does the detector shift a peak by 20 GeV?
are we looking at the same ‘simulation’?
possibly the key to the puzzle [cf Campbell, Martin, Williams]

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Lessons I take home

– why do new physics guys have to play advocatus diaboli???
– forget about jet vetos until we really understand them
– systematics hurts more than statistics

Understanding jets for the LHC

Jet counting in V+jets, QCD jets

- do not call it Berends scaling [Ellis, Kleiss, Stirling]
- described by modern Monte Carlos
- key to QCD and other SUSY backgrounds
- key to jet vetos?

Top tagging

- mature field by now
- testable by the end of the year
- applications: heavy resonances or top partners

W+jets at CDF

- still got doubts
- forget about jet vetos for now
- D0 should comment, but CDF needs to clean up
- please prove me wrong and find new physics [but do it right]

New physics at the LHC

	missing energy (p.89)	cascade decays (p.91)	mono-jets/photon (p.15)	lepton resnce (p.109)	di-jet resnce (p.109)	top resnce (p.120)	WW/ZZ resnce (p.15)	W' resnce (p.93)	top partner (p.116)	charged tracks (p.123)	displ. vertex (p.123)	multi-photons (p.29)	spherical events (p.47,76)
SUSY (heavy grav.) (p.17,26)	✓✓	✓✓							✓				
SUSY (light grav.) (p.17,27)	✓	✓	✓						✓	✓	✓		
large extra dim (p.39)	✓✓		✓✓										✓
universal extra dim (p.47)	✓✓	✓✓		✓	✓	✓	✓	✓	✓				
technicolor (vanilla) (p.51)				✓	✓	✓	✓	✓✓					
topcolor/top seesaw (p.53,54)					✓	✓✓	✓						
little Higgs (w/o T) (p.55,58)				✓	✓	✓	✓	✓					
little Higgs (w T) (p.55,58)	✓✓	✓✓	✓	✓	✓	✓	✓	✓	✓				
warped extra dim (IR SM) (p.61,63)				✓	✓	✓	✓						
warped extra dim (bulk SM) (p.61,64)				✓	✓	✓✓	✓	✓					
Higgsless/comp. Higgs (p.69,73)				✓	✓	✓✓	✓✓						
hidden valleys (p.75)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

[arXiv:0912.3259, Morrissey, TP, Tait]