Vector Boson Scattering status report

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Overview

- A light-hearted introduction
  - ie. lots of words and no colorful plots
- The dirty bits
  - Distinguishing features, jet structure, corrections…
- Results
- Where next?

What I will not talk about?

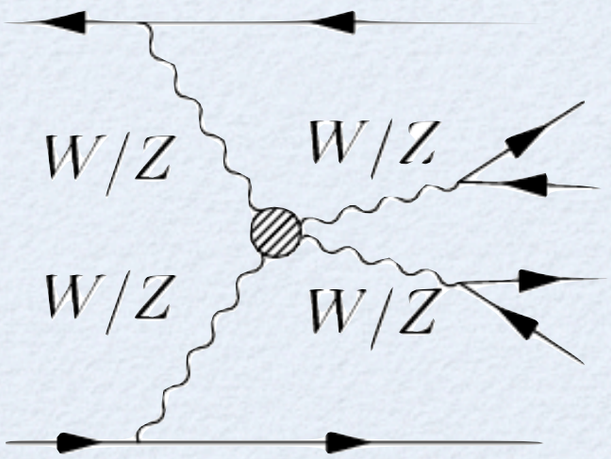
Artemis deliverable on the measurement of underlying event with data.
But some work that is relevant to this topic has recently appeared on *arXiv: 0806.2949*
M. Bahr, J. Butterworth, M. Seymour

Why Build the LHC?

- Vector bosons we observe: Ws, Z and photon
  - EW sym. broken: heavy W/Z, but massless photon
- How do we explain this?
  - Higgs mechanism in the SM
    - Many alternatives: technicolor, string interactions, interactions in extra dimensions, bulk-brane interplay…
- But the SM is well-tested and appears complete…
  - No, we have not found the Higgs yet!
  - No fundamental reason why physics responsible for EWSB is weakly interacting.

Life Without Higgs

- What happens to SM (and its extensions like SUSY) if no (light) Higgs exists?
  - Nature is more interesting than what we have thought.
  - Aleph's finding turns out to be a real stat. fluctuation.
  - Enhancement to <favorite_channel_for_exotic_particle> changes by a factor of <X>.
    - VV (V=W/Z) scattering x-section blows up.
    - Why? When Vs are on-shell, quasi-elastic scattering amplitude will diverge at the lowest order.
      ==> There must be something else then.



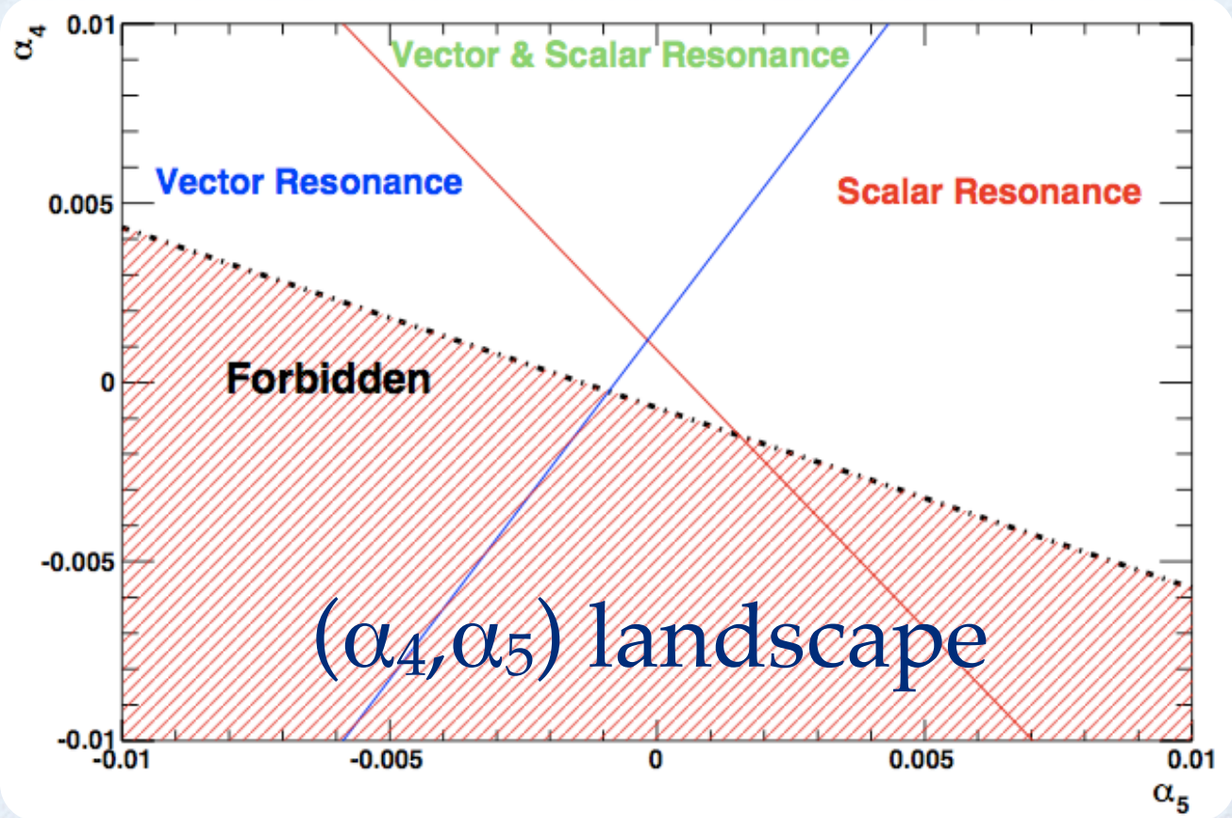
Experimental Goal

- In short: Measure differential scattering cross-section as a function of VV center-of-mass energy.
  - Identify WW, WZ or ZZ at high momenta.
  - Try to make sure they interacted with each other. (Don't want two Ws from two tops, for instance.)
  - Make a histogram of their invariant mass.
    - If you see a resonance or a total cross-section higher than SM prediction => New Physics!
    - If not, stringent constraints on SM extensions.
- Do all this as model-independent as possible!

EW Chiral Lagrangian

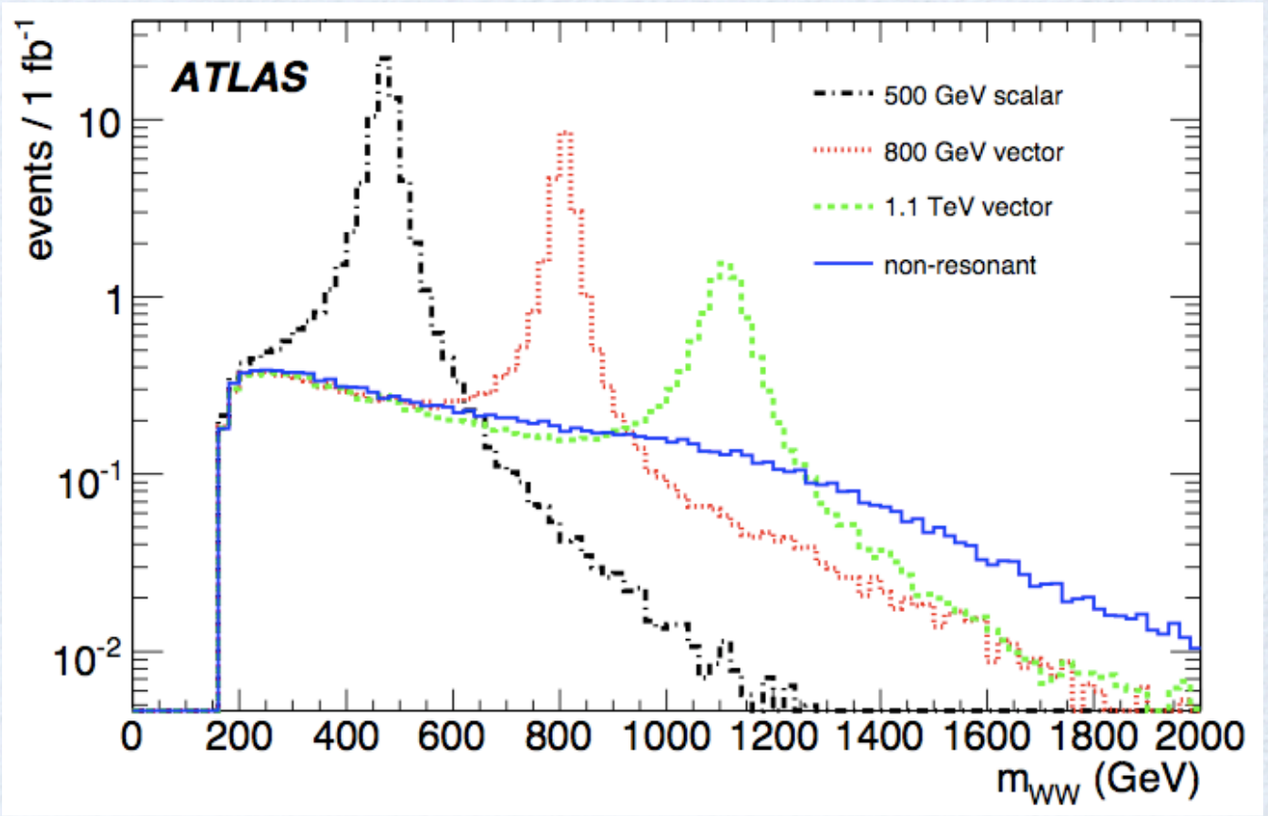
- The SM is well-tested (and not yet fully complete).
  - So take what is "known" (SM Lagrangian without the Higgs) and make it as complete as imaginable…
  - Introduce 3 Goldstone-boson fields to give mass to VBs.
  - Starting from lowest-dimension and expanding, write all possible operators for these fields. (Keeping in mind the EW precision observables).
  - A nice low-energy effective theory that can yield model-independent predictions.
    - Caveat: Needs to be unitarized for TeV scale.
    - After unitarization, can generate MC signal events.

Padé Unitarization

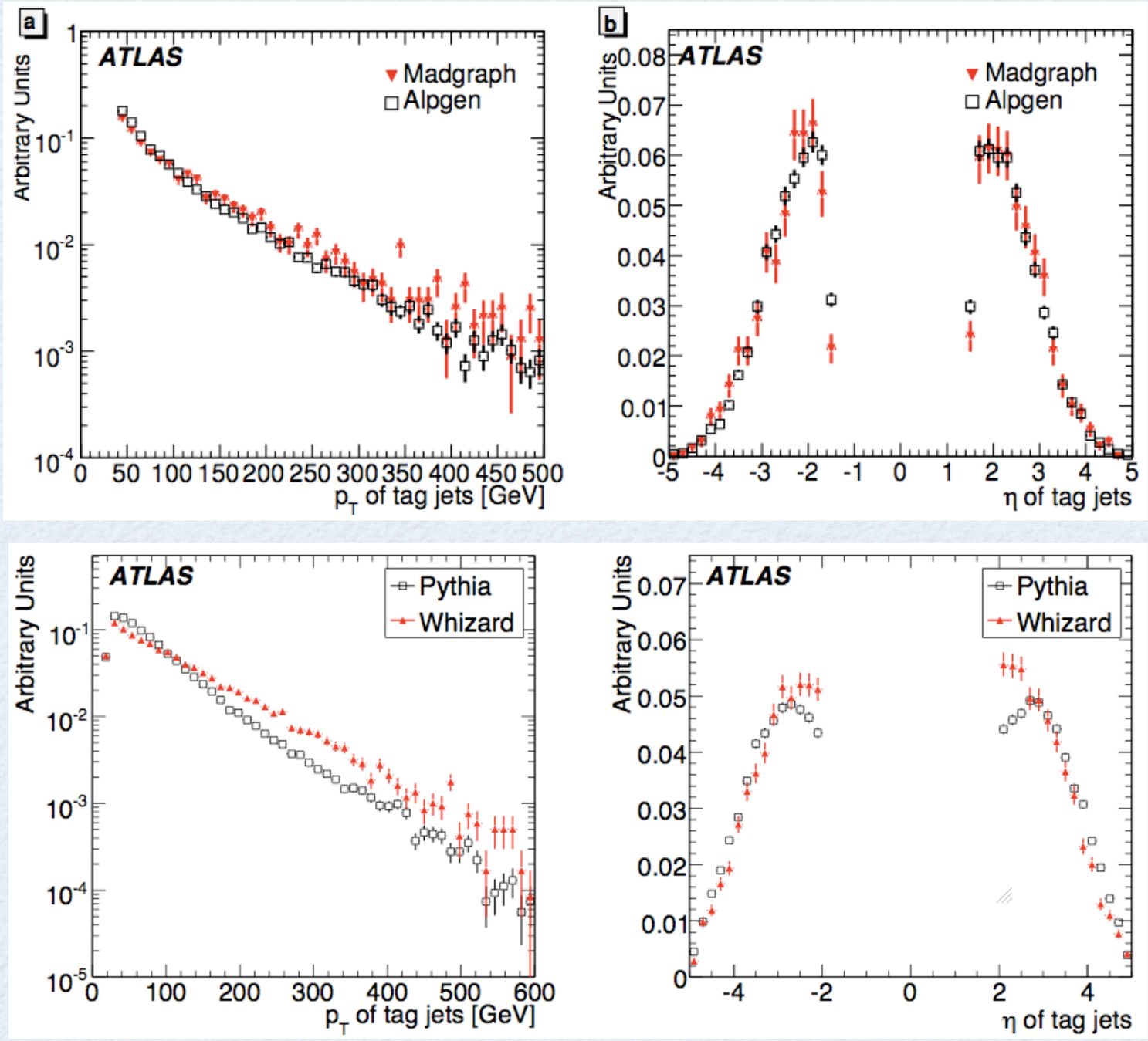


- Measure spectrum
  - Look for resonance
- For signal MC: unitarization scheme with resonances.

- Padé unitarization gives excellent description for π-scattering in QCD.
- (α_4,α_5) determine mass, spin & presence of resonances.



Monte Carlo

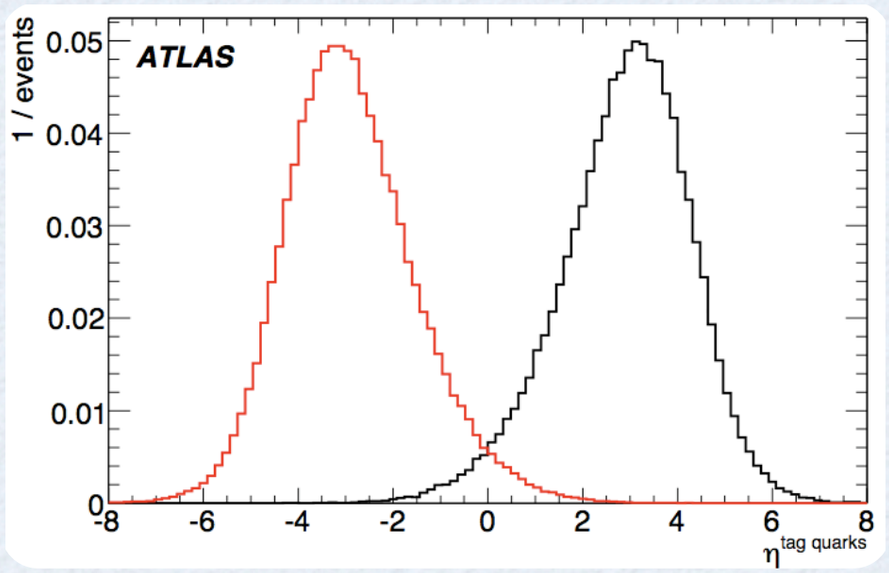


$t\bar{t}$: *MC@NLO, Herwig, Jimmy*

W/Z+3/4 jets: *Madgraph* (crosschecked against *Alpgen*)

Signal: Modified *Pythia* (crosschecked against *Whizard*)

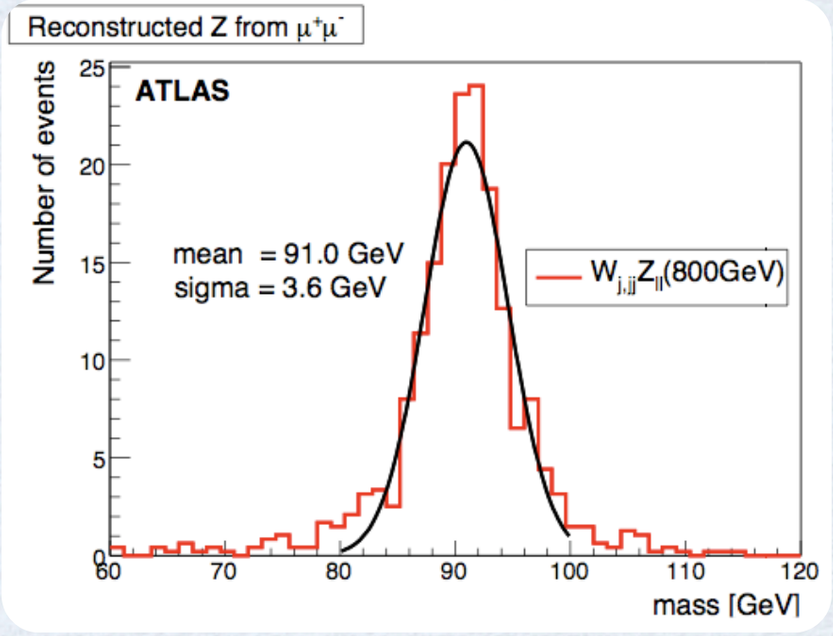
Signal at a Glance



Tag jet at high rapidity

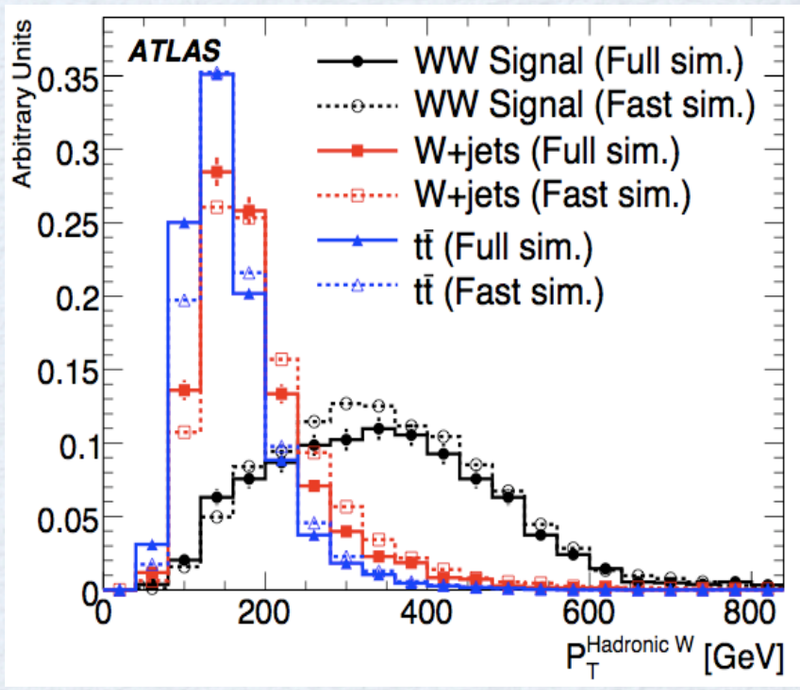
Tag jet at high rapidity and on opposite side

Leptonically decaying VB at high momentum



no color exchange so suppression of QCD activity (no central jets)

Hadronically decaying VB at high momentum

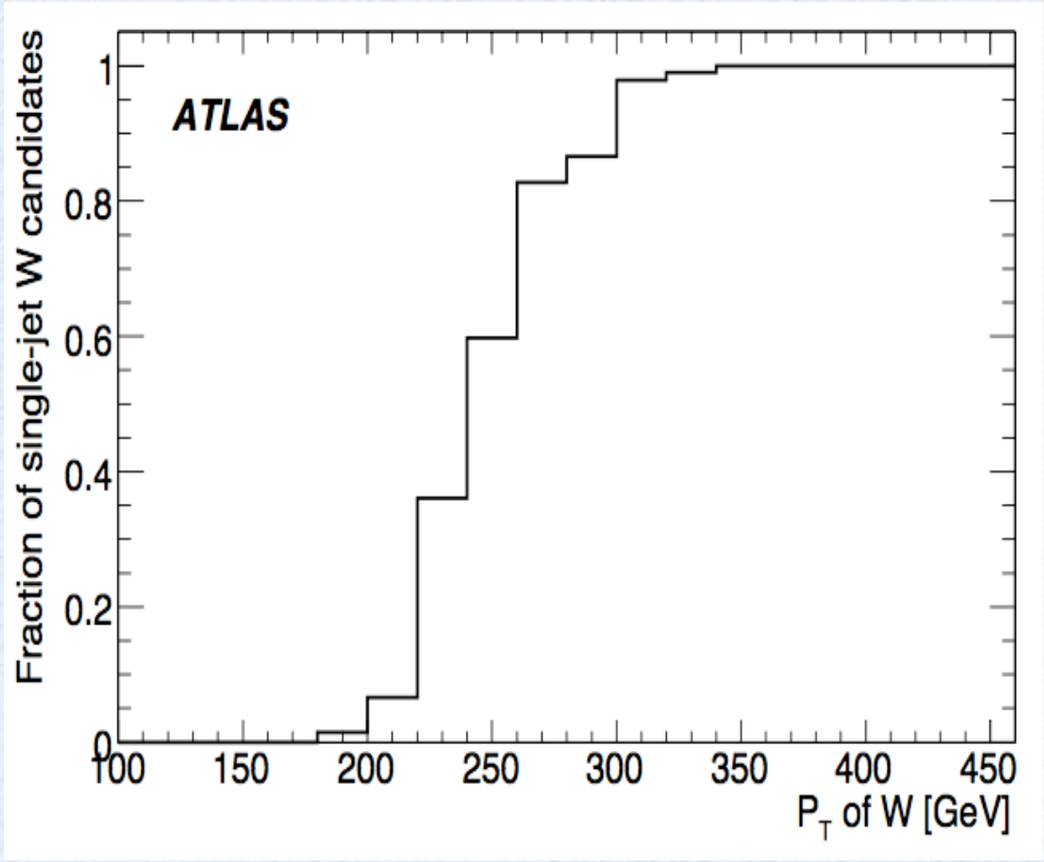


Hadronic VBs: 1 or 2 jets

- At high enough P_T, hadronic VB starts to create a single jet.
- In each event: Take highest P_T jet. Mass close to W/Z ?

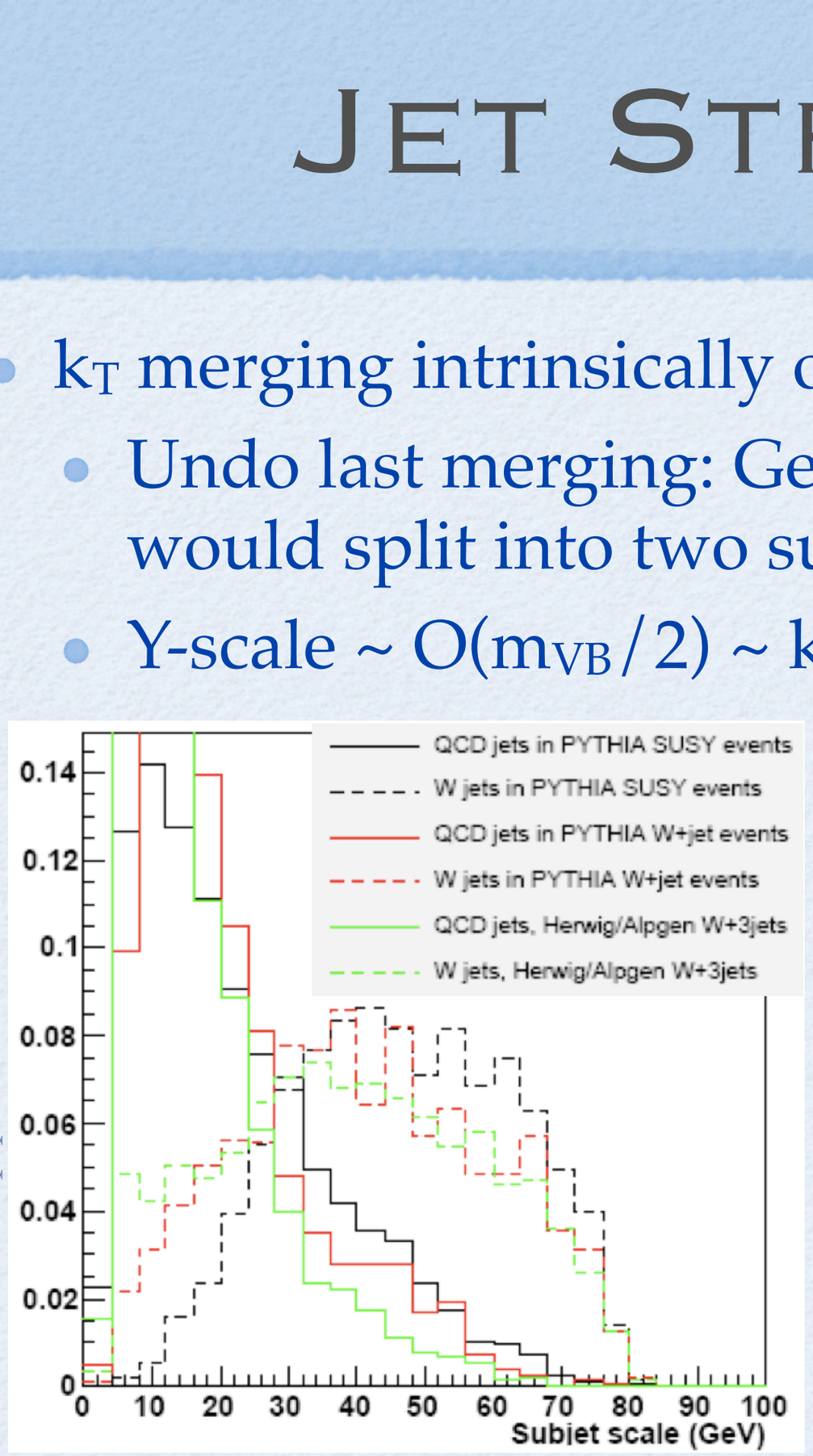
  Yes: This jet is the VB candidate. Apply cut on jet substructure.

  No: Loop over all pairs of jets. Find the pair whose combination gives the highest P_T. The combination is the VB candidate. Apply mass and relative-momentum cuts.

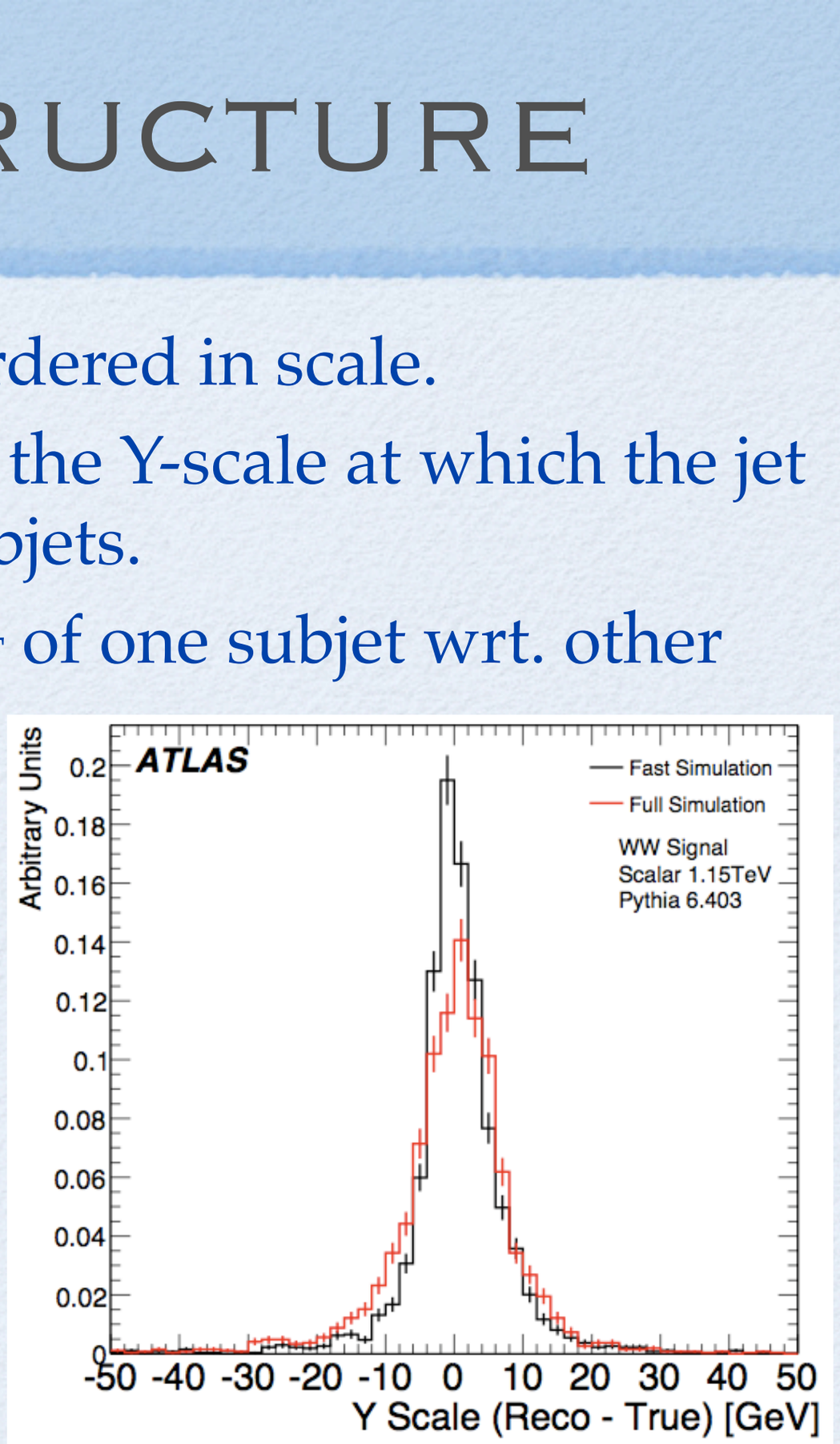


Jet Structure

- k_T merging intrinsically ordered in scale.
  - Undo last merging: Get the Y-scale at which the jet would split into two subjets.
  - Y-scale ~ $O(m_{VB}/2)$ ~ k_T of one subjet wrt. other



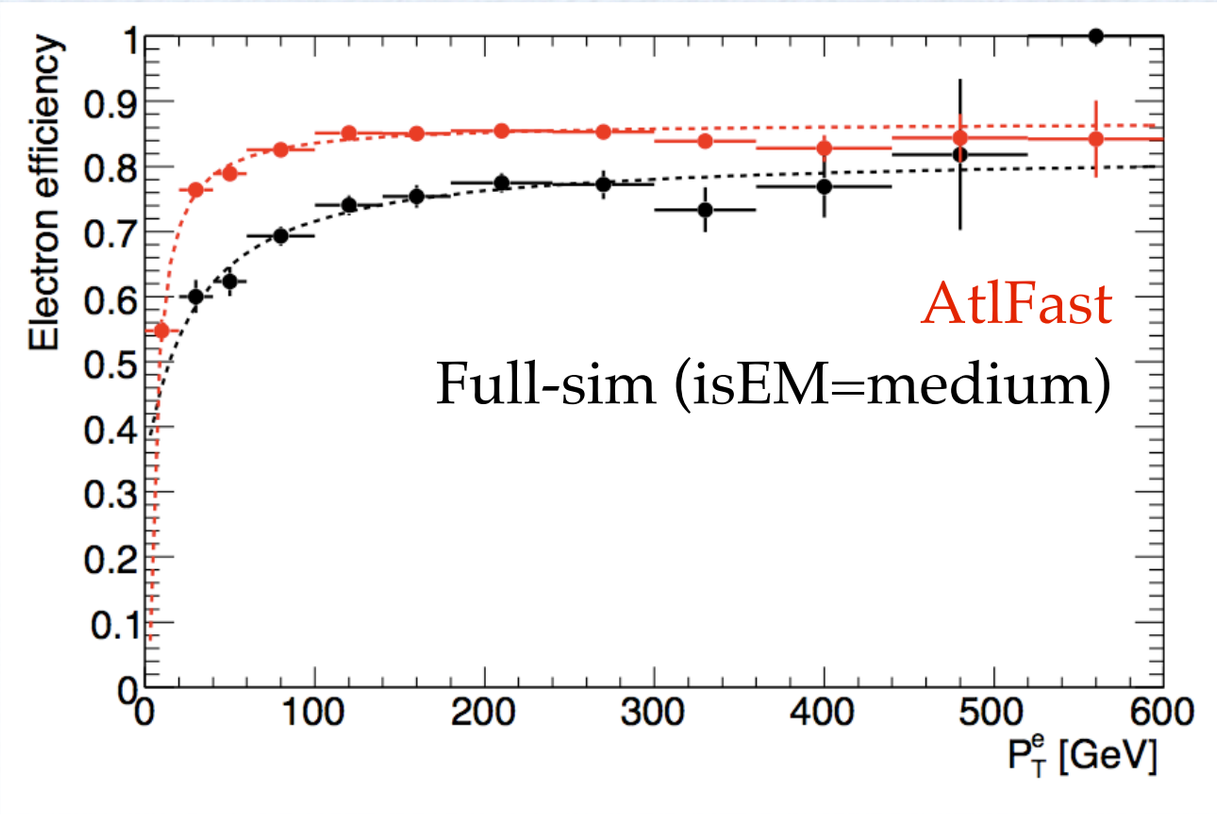
Butterworth, Ellis, Raklev
hep-ph/0702150



Other Bits Under the Hood

- "Realistic" study: Not enough full-sim MC
  - AtlFast is quite good overall, but had(has?) no lepton inefficiency implemented.
  - Manually added P_T-dependent correction.

- "Smart" overlap removal:
  - First find hadronic VB candidates.
  - Then apply electron overlap rejection to other jet candidates.



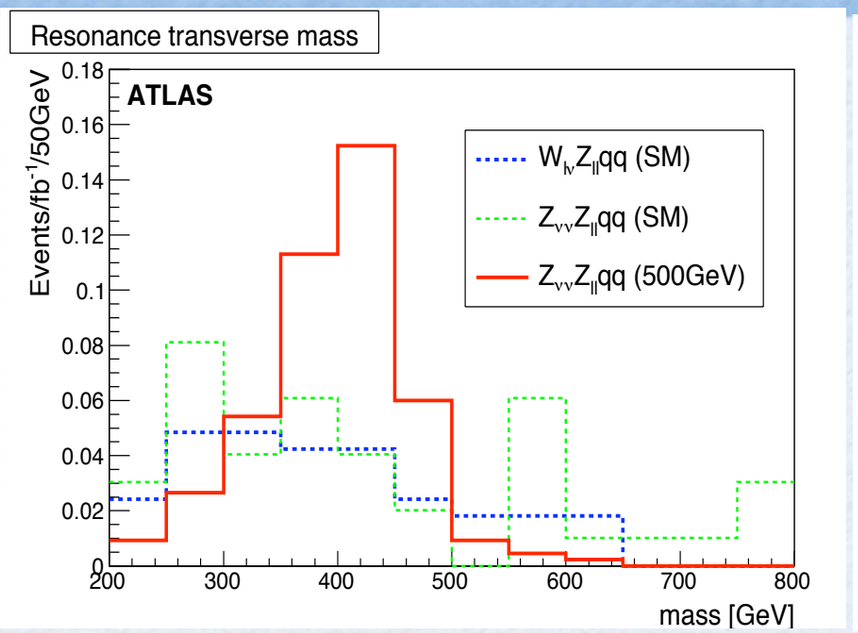
Putting it Together

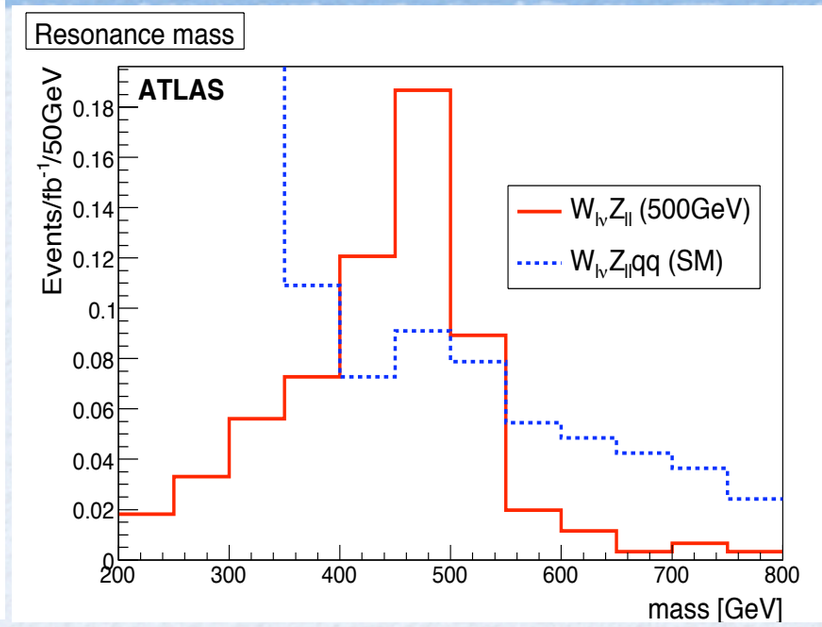
Cut	Non-resonant Signal		tt Background		W+jets Backgrounds	
	Efficiency (%)	σ (fb)	Efficiency (%)	σ (fb)	Efficiency (%)	σ (fb)
Starting sample	–	10	–	450000	–	21365
$\equiv$ 1 Hadronic W	38.0 ± 0.7 (41)	3.8 (4.1)	18.9 ± 0.1 (19)	85000 (84000)	8.3 ± 0.1 (9)	1760 (1820)
$\equiv$ 1 Leptonic W	48.2 ± 1.1 (55)	1.8 (2.3)	22.1 ± 0.2 (29)	19000 (25000)	23.3 ± 0.7 (31)	410 (570)
p_T (Had. W) > 200 GeV	82.1 ± 1.3 (86)	1.5 (1.9)	16.8 ± 0.4 (20)	3200 (5000)	34.4 ± 1.7 (43)	140 (240)
$\lvert\eta\rvert$ (Had. W) < 2	94.4 ± 0.8 (94)	1.4 (1.8)	90.3 ± 0.7 (90)	2900 (4500)	80.1 ± 2.4 (77)	110 (190)
p_T (Lep. W) > 200 GeV	90.4 ± 1.1 (87)	1.3 (1.6)	34.5 ± 1.3 (29)	990 (1300)	48.5 ± 3.3 (40)	55 (75)
$\lvert\eta\rvert$ (Lep. W) < 2	96.0 ± 0.8 (96)	1.2 (1.5)	94.6 ± 1.0 (90)	930 (1200)	80.4 ± 3.9 (79)	44 (59)
$\equiv$ 2 tag jets	45.1 ± 2.0 (54)	0.6 (0.8)	8.1 ± 1.3 (10)	76 (120)	13.9 ± 3.5 (22)	6 (13)
$\equiv$ 0 top candidates	56.5 ± 3.0 (47)	0.3 (0.4)	7.9 ± 4.4 (2)	5 (2)	60.5 ± 13.1 (23)	4 (3)
Central jet veto	91.1 ± 2.3 (94)	0.3 (0.4)	< 50 (< 25)	< 5 (< 1)	84.9 ± 13.7 (91)	3 (3)
Trigger efficiency	98 ± 1	0.3 (0.4)	~ 100	< 5 (< 1)	82 ± 16	3 (3)

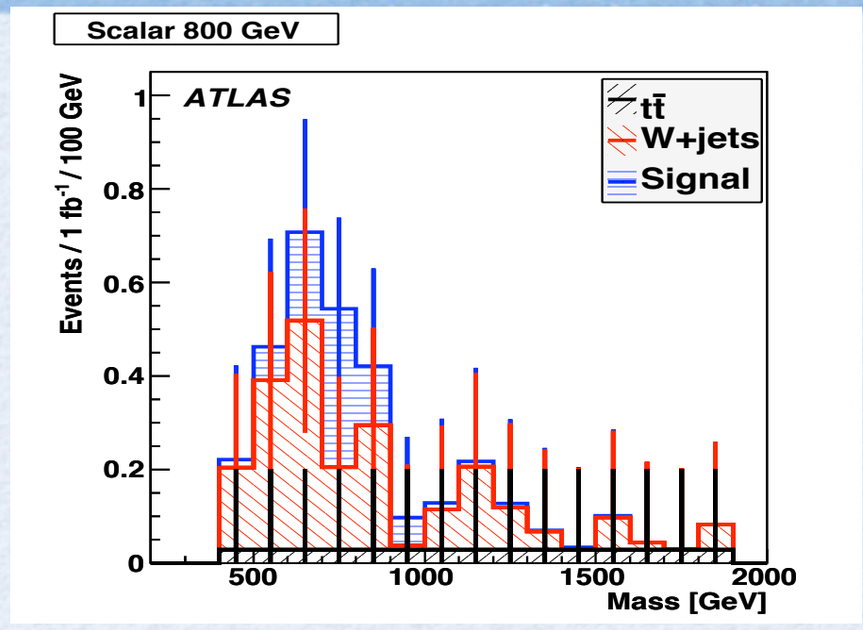
- Two VB candidates: $P_T > 200$ GeV and $|\eta| < 2$.
- Two tag jets: $|\eta| > 2$, $P_T > 20$ GeV, $E > 300$ GeV, $\Delta\eta > 4.4$
- No W + other jet close to top mass.
- No central jets with $P_T > 30$ GeV.

Triggering no problem...

Some Results







ZZ (llνν) WZ (lνll) WW (lνqq)

Process	Cross-section (fb)		Luminosity (fb^{-1})		Significance
	signal	background	for 3σ	for 5σ	for 100 fb^{-1}
$WW/WZ \to \ell\nu\ jj$, 500 GeV	0.31 ± 0.05	0.79 ± 0.26	85	235	3.3 ± 0.7
$WW/WZ \to \ell\nu\ jj$, 800 GeV	0.65 ± 0.04	0.87 ± 0.28	20	60	6.3 ± 0.9
$WW/WZ \to \ell\nu\ jj$, 1.1 TeV	0.24 ± 0.03	0.46 ± 0.25	80	230	3.3 ± 0.8
$W_{jj}Z_{\ell\ell}$, 500 GeV	0.28 ± 0.04	0.20 ± 0.18	30	90	5.3 ± 1.9
$W_{\ell\nu}Z_{\ell\ell}$, 500 GeV	0.40 ± 0.03	0.25 ± 0.03	20	55	6.6 ± 0.5
$W_{jj}Z_{\ell\ell}$, 800 GeV	0.24 ± 0.02	0.30 ± 0.22	60	160	3.9 ± 1.2
$W_jZ_{\ell\ell}$, 800 GeV	0.20 ± 0.02	0.09 ± 0.06	30	90	5.3 ± 1.3
$W_jZ_{\ell\ell}$, 1.1 TeV	0.11 ± 0.01	0.10 ± 0.06	90	250	3.1 ± 0.8
$W_{\ell\nu}Z_{\ell\ell}$, 1.1 TeV	0.070 ± 0.004	0.020 ± 0.009	70	200	3.6 ± 0.5
$Z_{\nu\nu}Z_{\ell\ell}$, 500 GeV	0.32 ± 0.02	0.15 ± 0.03	20	60	6.6 ± 0.6

CSC Conclusion and What Have We Learned?

- Discovery of possible resonances will need few tens of fb^{-1}.
  - Larger than earlier estimates. Why?
    - First full simulation study. Stuff we worried about, ex. jet substructure, turns out to be modeled ok, stuff we weren't worried about, ex. lepton eff., is quite bad.
      - More realistic backgrounds.
        - Earlier estimates of W/Z+ jets with *Pythia* and/or QCD diagrams not considered.
        - W/Z+jets turns out to be much more significant. (Now worse than tt for lνqq analyses.)
- Successful conclusion to this "commissioning" exercise. Developed techniques (and tools) applicable to real data…
    - ysplitter tool (part of Jetrec for some time)

What Next?

- Many things to tune with improved MC statistics…
  - Lepton ID at medium-to-high momenta.
- Promising ideas not yet exploited…
  - b-tagging : in WW/WZ (lvqq) analyses, tt suppression with top veto => combinatoric loss on signal.
    - P_T balance of VB+VB+tag+tag system.
  - Expertise in highly-boosted vector bosons.
    - Would like to be involved in understanding jets in early data.
      - Jet substructure, calibrating jet mass…
      - Distinguishing hadronic W and Z jets
    - Even fully-hadronic channels might be viable for exploitation.

expertise with jet structure already put to use for VH (Adam's talk)

What Next?

- VBS = A flagship channel to keep on looking year-after-year.
  - Even if we see nothing, that means a lot in model building.
  - Need a robust framework which shields the conceptual analysis from "fashion" trends of the day.
    - Developing a toolkit to support an analysis that:
      - can be run both as part of Athena or independently.
      - easily archive-able and repeatable.
- We (as Atlas) should have a systematic program to look for model-dependent signatures of strong EW breaking…