Searches for new physics using top quarks in ATLAS

With a very strong emphasis on tt resonance searches

Marcel Vos (IFIC Valencia)

Coimbra, november 2009

Looking for exotic phsyics with top quarks
tt resonance searches - an “early” analysis
ATLAS prospects for tt resonances – results of the traditional approach
ATLAS prospects for tt resonances – some new tools
ATLAS prospects for tt resonances – a paper (finally)
Further exotic physics with tops

Top as a signature for new physics?

Wishful thinking?: Will the top and bottom quarks be the messenger by which Beyond The Standard Model physics reveals itself?

the top is too heavy, it's less constrained by (LEP) data

An experimentalist's view: of 12 known fermions, 7 potential signatures:

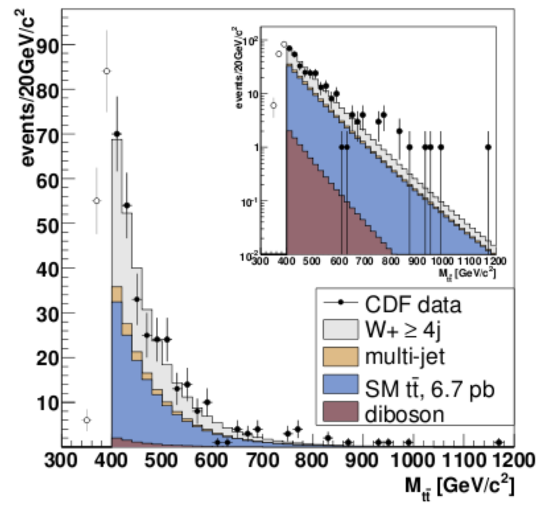
$\mu^{\pm}$, $e^{\pm}$, $\tau^{\pm}$, E_t^{miss}, uds(g), b/c and top

Quark signatures benefit from strong coupling (large production cross-section), but suffer from large Standard Model background

Bottom and top quarks can be identified efficiently. Top is the only quark that produces isolated leptons and where quarks can be easily distinguished from anti-quarks.

Tt resonance searches - early?

CDF arXiv:0709.0705



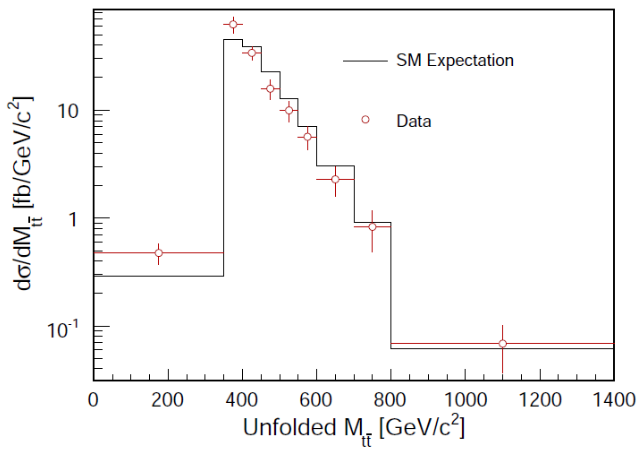
Tevatron

- Limited statistics
  → *8 fb⁻¹ ppbar @ 1.96 TeV = 64.000 $t\bar{t}$ pairs*
- Tops produced at rest
  → *limited mass reach, heaviest observed pair ~ 1 Te*

~20 papers on tt resonance searches, limits σ x BR ~ 300 fb for 0.7 < M < 1 TeV

LHC early days:

- A top factory
  → *200 pb⁻¹ pp @ 10 TeV = 80.000 $t\bar{t}$ pairs*
- Well above threshold
  → 1 in 5 tops has p_T > 200 GeV
- But, will we understand the detector well enough
  → Definitely not to measure **$d\sigma/dM_{tt}$**



→ **no counting experiments,** but reconstruction of mass spectrum does not depend crucially on understanding of luminosity, jet energy scale, alignment

(CDF, PRD 77, 051102, 2008!)

Tt resonance searches - early?

Resonances are present in many models (sequential Z', little Higgs, extra dimensions, ...)
Cross-sections and Branching Ratio can BOTH be sizeable (in some cases downright spectactular)

resonance X	Γ/M	B.R. ($X \to tt$)	σ (1 TeV)	σ x BR (1 TeV)
sequential Z'	3.0%	11%	12.7 pb	1.39 pb
Little Higgs Z_H (cot θ = 1)	3.4%	13%	16.8 pb	2.10 pb
LR Twin Higgs Z_H	2.7%	8%	13.3 pb	1.0 pb
KK g* (universal couplings)	20%	17%	1109 pb	190 pb
Basic RS g*	15%	92%	30 pb	28 pb
Black holes ($2 \to 2$ a la Randall/Meade	X	3% (tt)	30 nb	1 nb

LHC (14 TeV) cross-sections for different extensions of the Standard Model

PRELIMINARY

ATLAS benchmark amples for electroweak (narrow) and colored resonances (broad!) have been defined. **Colored resonances can be early physics.**

Production cross-section decreases rapidly with decreasing center-of-mass energy (forget about 7 TeV)

LHC cross-sections for the KK gluon in the basic RS setup for different center-of-mass energies

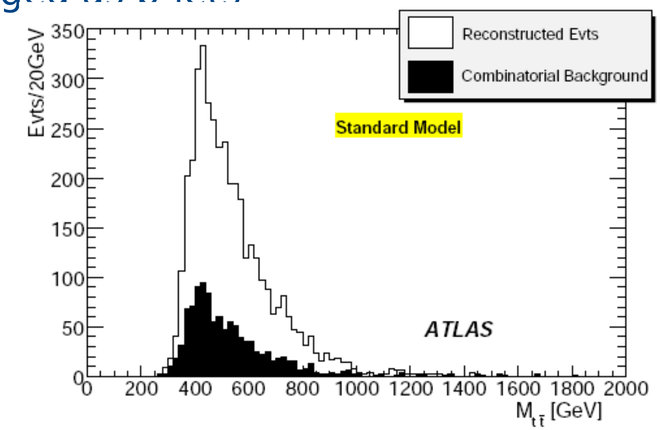
	10 TeV	7 TeV
1 TeV	4.0	1.6
2 TeV	0.142	0.038

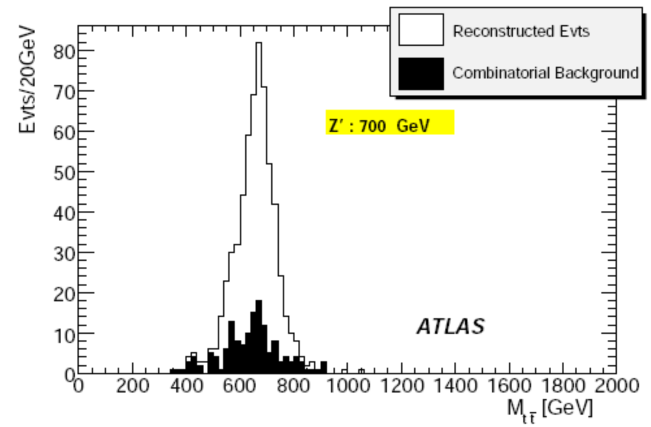
The standard, resolved approach:

Thorougly exercised on full simulation (ATL-PHYS-PUB-2006-033, ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020).

Standard event selection for semi-leptonic events:

- exactly one isolated electron (muon),
- $|\eta| < 2.5$ and $p_T > 25$ GeV ($p_T > 20$ GeV)
- at least four jets with $|\eta| < 2.5$ and $p_T > 30$ GeV
- at least 2 jets tagged as b-jets
- $E_t^{miss} > 20$ GeV

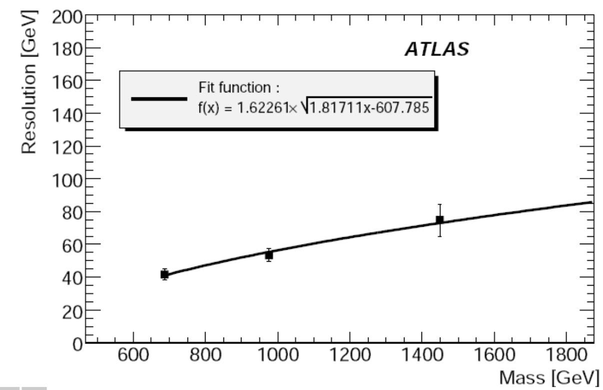


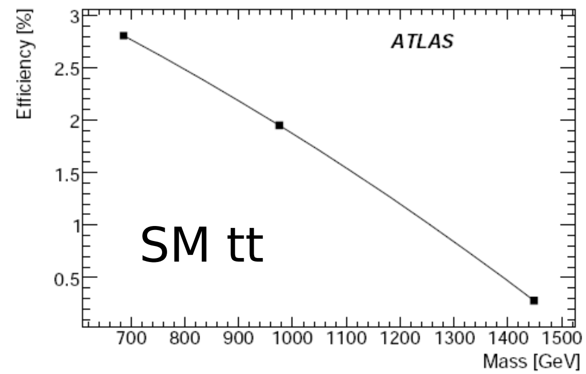


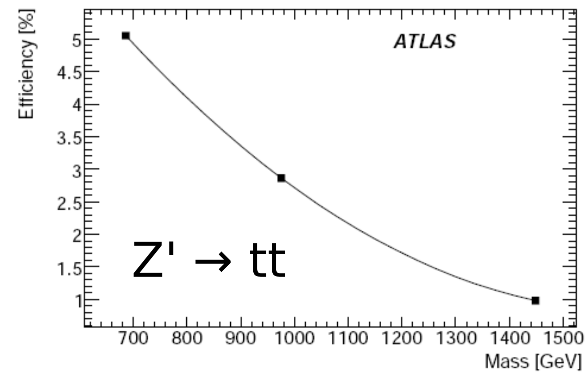
Reconstruction: combine jets, lepton and Etmiss to form top candidates

- **Hadronic W** ⇒ the jet combination with the smallest ΔR separation
- **Hadronic top** ⇒ add the nearest b-jet
- **Leptonic W** ⇒ solve for p_z^ν. (two solutions) using W-mass
- **Leptonic top** ⇒ Combine with remaining b-jet. Choose the neutrino solution that gives the leptonic top mass closest to the average mass of the hadronic top.

ATLAS tt resonance searches



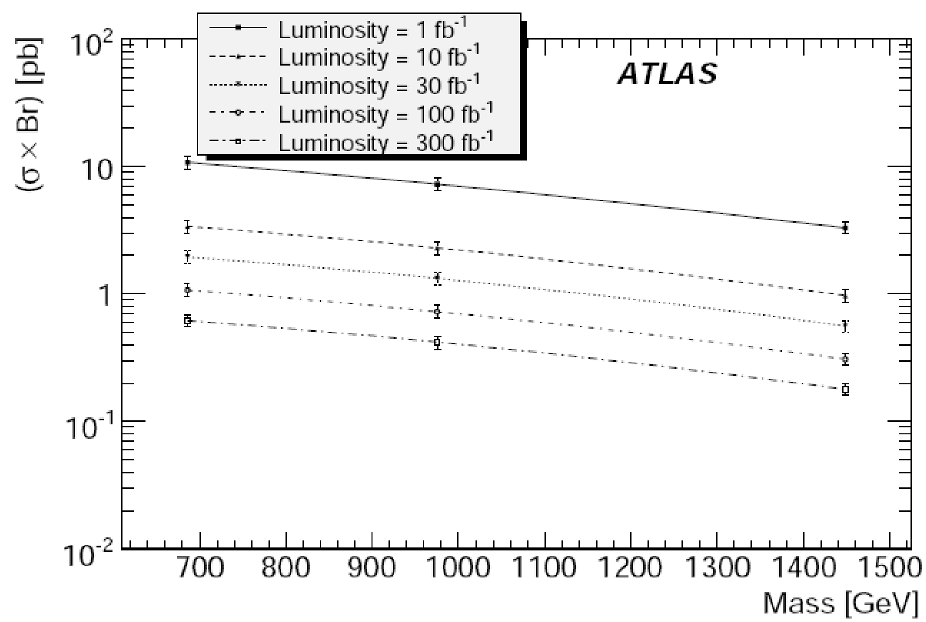




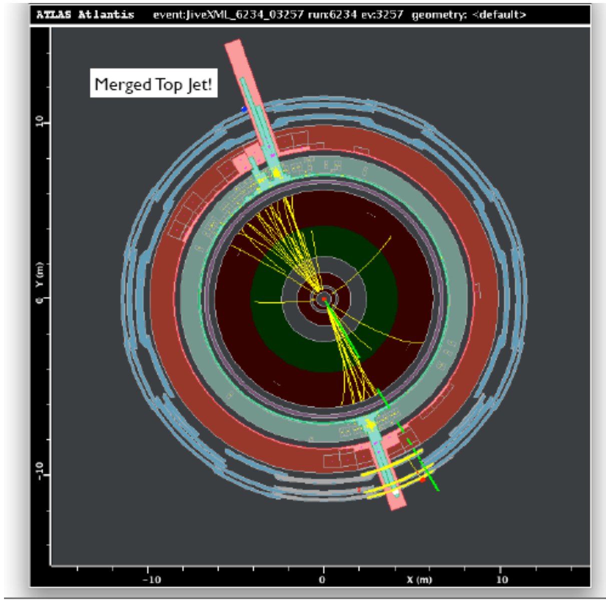
- Resonance mass resolution ~5 % in mass range from 700 to 1500 GeV.
- A sharp efficiency drop towards larger resonance mass

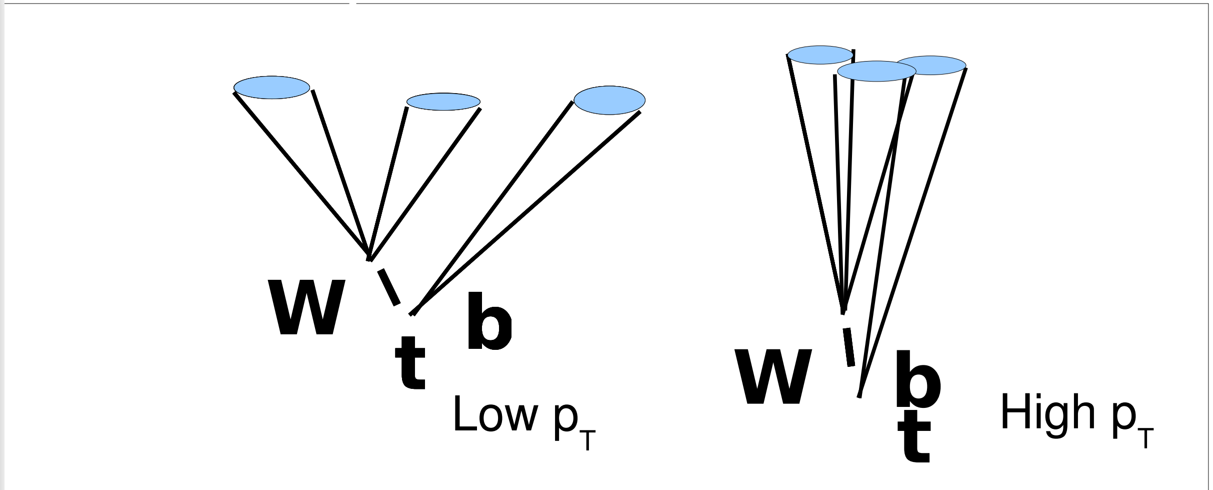
5 %	@ 700 GeV
< 1 %	@ 1500 GeV

The sensitivity of the standard approach for tt resonances versus mass and integrated luminosity



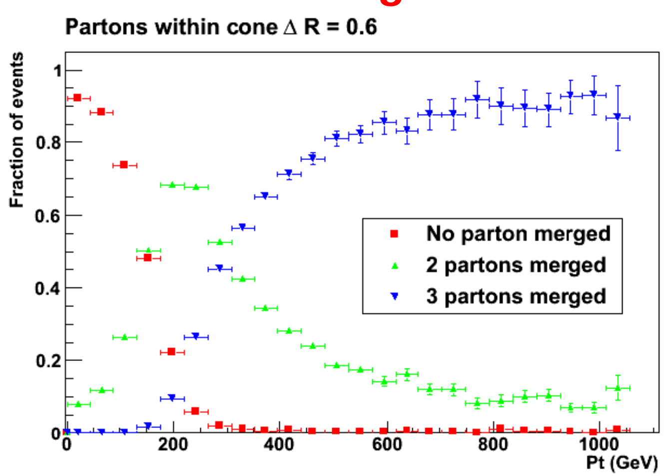
Reconstruction of high p_T tops





Problems for standard "resolved" top reconstruction at high p_T

- **Partons from top decay are not resolved by jet reconstruction algorithms**
- isolation of leptons (trigger)
- E_T^{miss} resolution in events with TeV jets
- tracking performance in jets (b-tagging)
- control samples (jet calibration, b-tag)



Top-tagging

See also, among others:
K. Agashe et al., hep-ph/0612015
Randall, Lillie and Wang, JHEP 0709:074 (2007)
Kaplan et al., arXiv:0806.0848

The mono-jet alternative in a nut shell:

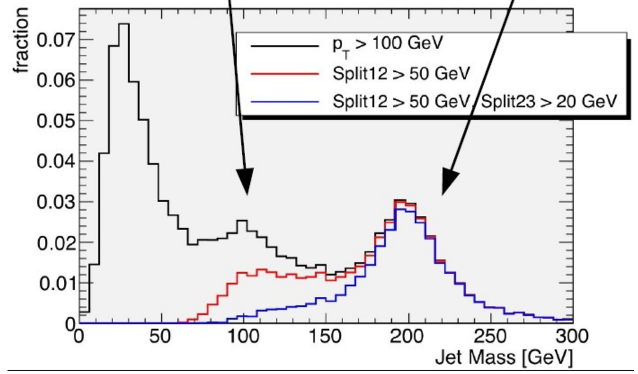
Reconstruct the hadronic top decay as a single jet
Tag it (to reduce non-top backgrounds)
High p_T Hadronic Top Quark Identification

Part 1 : **Jet Mass and Ysplitter** *ATL-PHYS-CONF-2008-008*

Part 2 : **the life-time signature** *ATL-PHYS-CONF-2008-016*

W-mass - partial merge

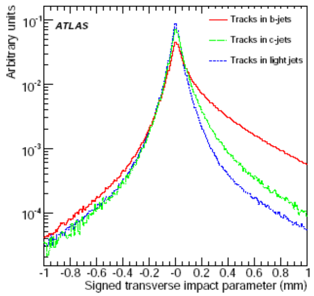
Top mass – fully merged

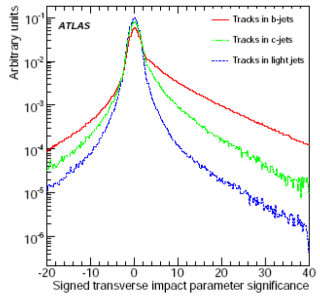


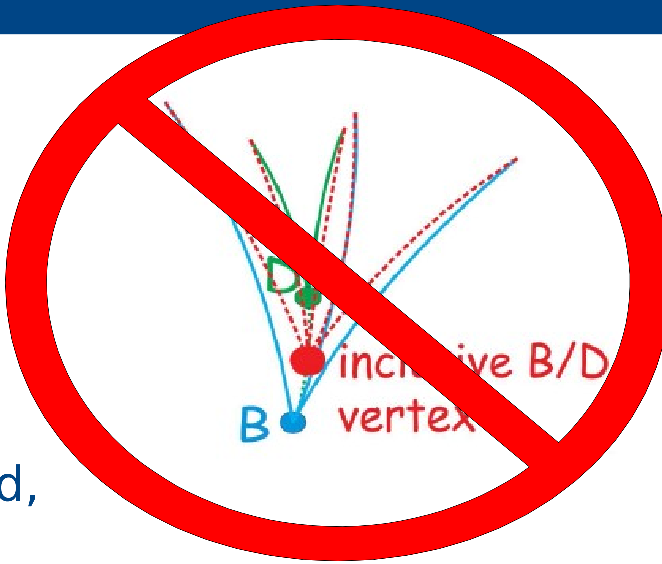
Many caveats apply:

- Resolved approach needed for $d\sigma/dM_{tt}$
- Early physics is in transition region

ATLAS flavour tagging

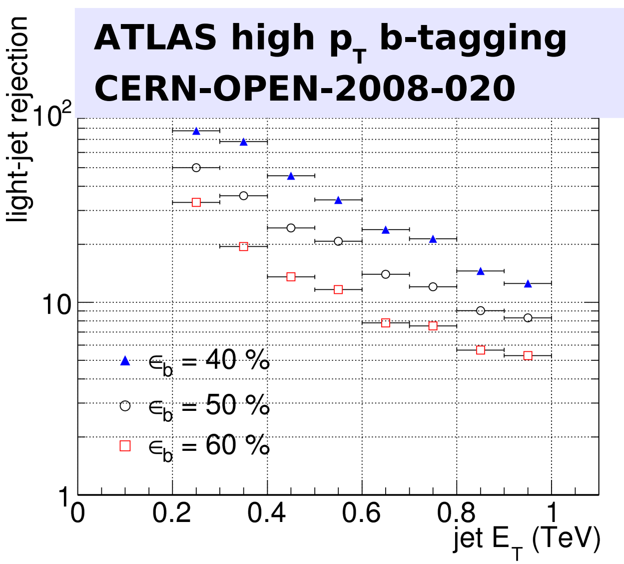


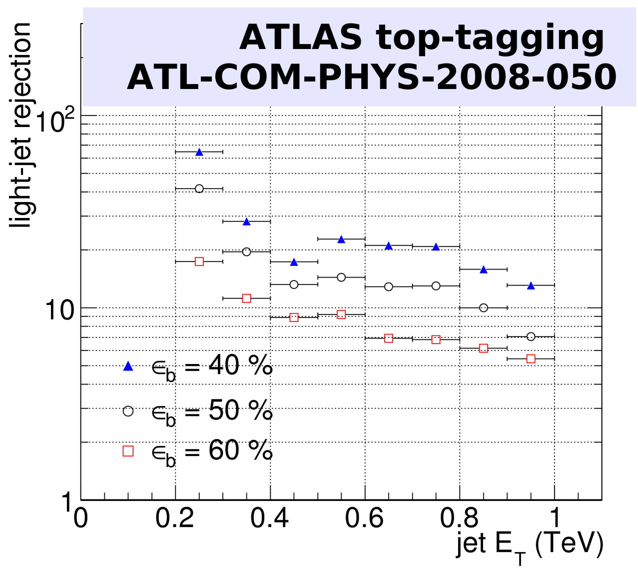


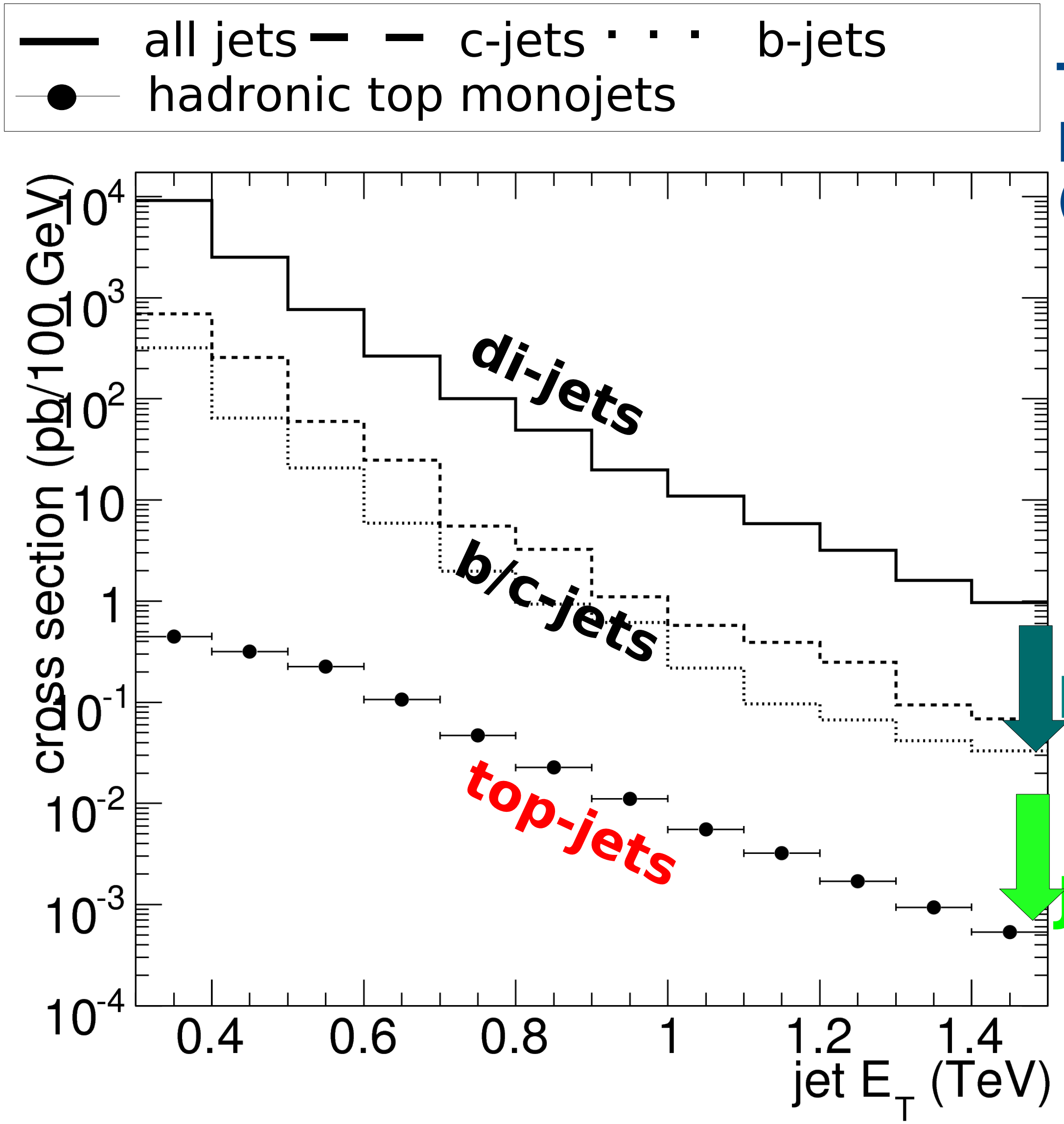


Early days: use simple, impact parameter based, self-calibrating b-tagging algorithms

$R_u < 100$ for $\varepsilon_b = 50$ %



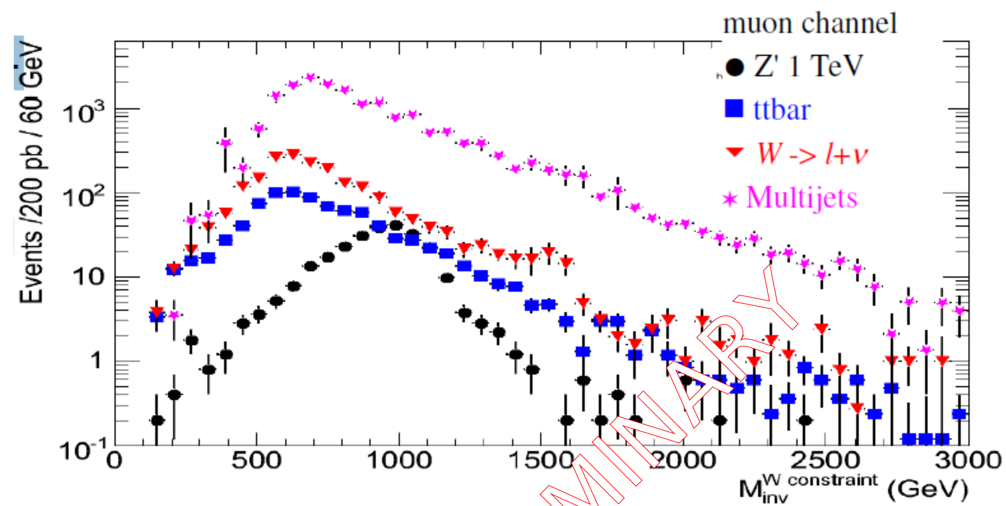




The abundance of heavy flavour ...
(according to Pythia)

Results

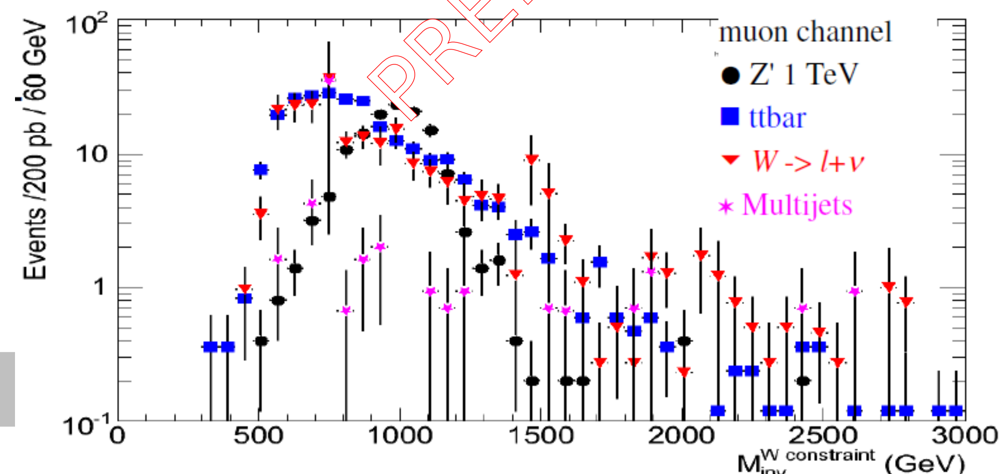
Before selection



Existing selection is able to reduce QCD and W+jets backgrounds to the level of irreducible SM tt background at an acceptable efficiency

Detailed comparison of ATLAS potential among analyses and earlier publications is starting

After



Elin Bergeaas Kuutman

Tt resonance paper

Feasibility studies (2006-2008)

Joint Top properties/Exotics-Jet+X

tt-resonance MC paper (2009)

- early (100s of pb-1) ATLAS sensitivity
- concentrate on tt (forget about tt+X for now)
- semi-leptonic tt only (we'll get to the fully leptonic channel in due time)
- mass reach 350 GeV to 1-2 TeV
  → Exercises all reconstruction strategies
- merge "similar" analysis where possible

Initial deadline already passed → let's start finalizing things!
Edited by Dominique Pallin, M.V.

The real thing (2010)

A bit further...

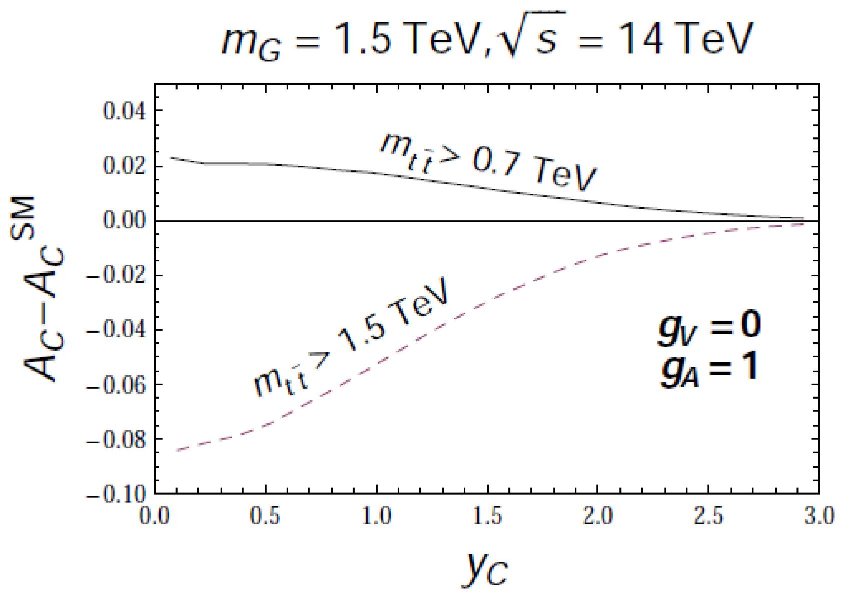
Smarter analysis may increase sensitivity

Paola Ferrario, German Rodrigo, Charge asymmetries of top quarks: A Window to new physics at hadron colliders, J.Phys.Conf.Ser.171 (2009) 012091

$$A_C(y_C) = \frac{N_t(|y| \leq y_C) - N_{\bar{t}}(|y| \leq y_C)}{N_t(|y| \leq y_C) + N_{\bar{t}}(|y| \leq y_C)}$$

Good to get a grip on the background for very broad resonances

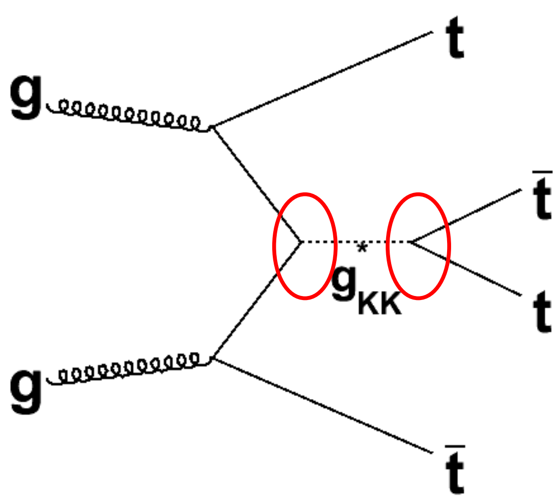
Requires efficiency versus η to be understood to some level



Outlook: tt+X

As soon as SM tt spectrum is understood, tt+X studies start

Even looking for four tops!



What if only the top quark couples to new sector (significantly)?

top compositeness, Lillie, Shu, Tait; Kumar, Tait, Vega-Morales; Pomarol, Serra

Relatively easy to isolate (same-sign lepton), but will we ever be able to reconstruct such events?

ad-hoc working group with A-I Etienvre, G. Servant (Saclay) and E. Bussato (Cl. Ferrand)

Spanish involvement

My, hopefully incomplete, list of Spanish institutes involved in (ATLAS) exotic physics with tops

Granada

J.A. Aguilar Saavedra/N. Castro → anomalous couplings

IFAE theory

J. Serra → top compositeness

IFIC: experiment

E. Ros → convenor ATLAS exotics 2007-2009

M. Vos → convenor ATLAS exotics / Jet + X 2009-2010

→ coordinator tt resonance searches

M. Villaplana, E. Oliver, directed S. Gonzalez de la Hoz and J. Salt → Ph.D. Thesis on first data

IFIC: theory

G. Rodrigo, P. Ferrario → asymetries

IFIC

Summary

Top quarks may be abundantly produced through resonant new physics channel → searches for (strongly interacting) tt resonance are "early physics"

high $p_T \neq$ low p_T
ATLAS has developed top reconstruction/tagging algorithms based on jet substructure and lifetime

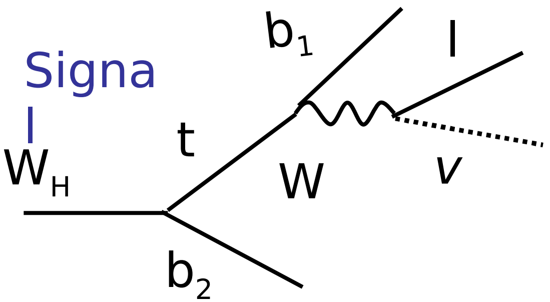
MC paper on ATLAS prospects for tt resonances to be finalized by the end of the year.
Hopefully, competitive limits (or discovery) will follow soon after.

tt resonances pave the way for a large number of tt+X searches

CSIC
IFIC

$W_H \rightarrow tb$, the topology that has it all

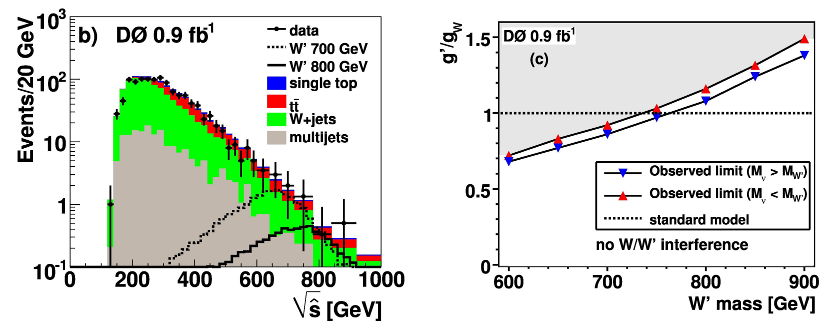
Signal



Dominant backgrounds:
tt, W+jets, single top

D0 collaboration, Search for W-prime Boson Resonances Decaying to a Top Quark and a Bottom Quark.

m(W') > 700 GeV

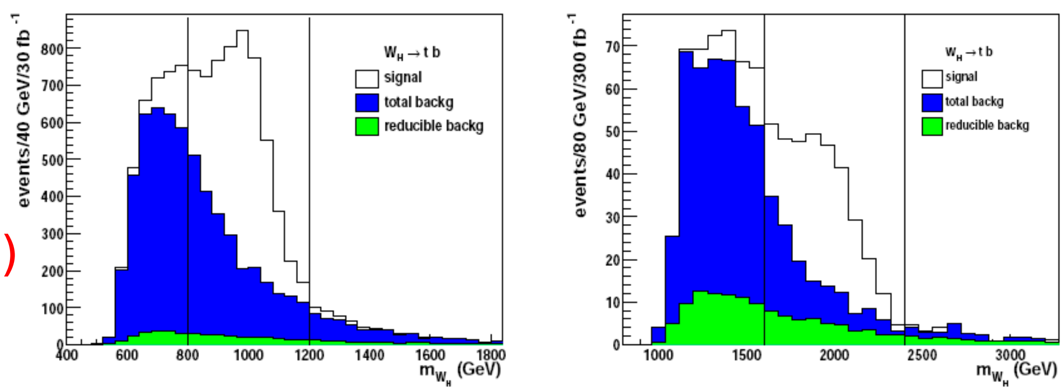


ATLAS fast simulation
Littlest Higgs $W_H \rightarrow tb$

discovery up to 2.5 TeV

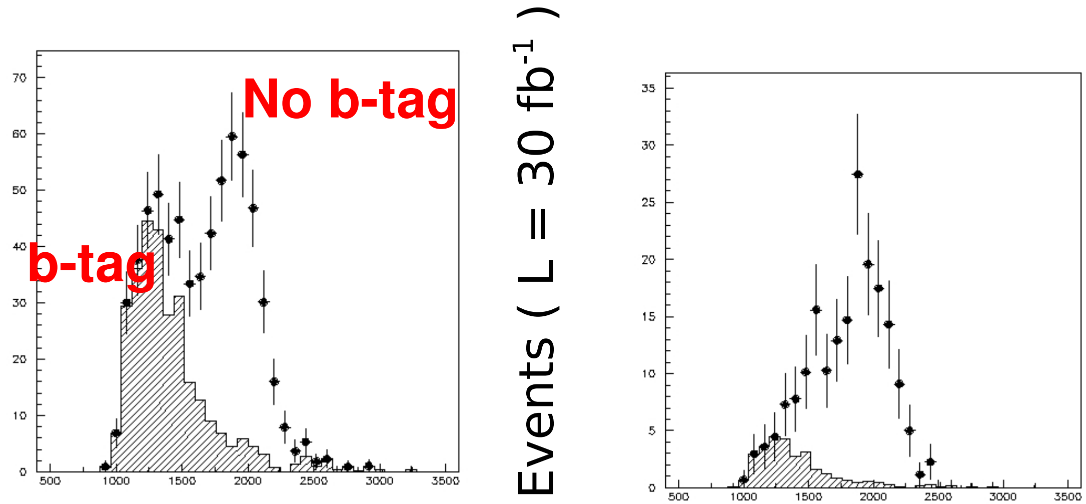
($\cot\theta = 1$, PHYS-PUB-2006-003)

ZH -> tt and ZH -> bb more difficult

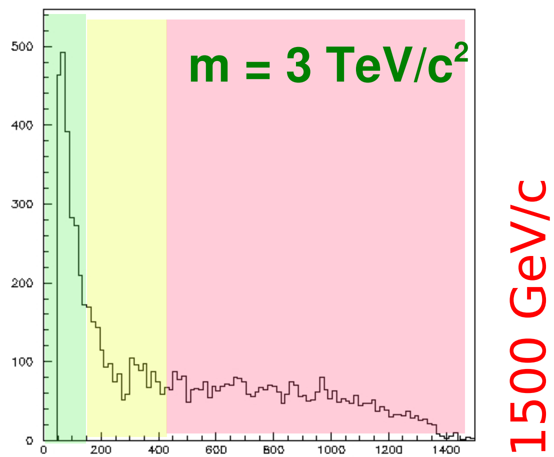


Full simulation study within more challenging LR Twin Higgs model (PHYS-PUB-2008-004)

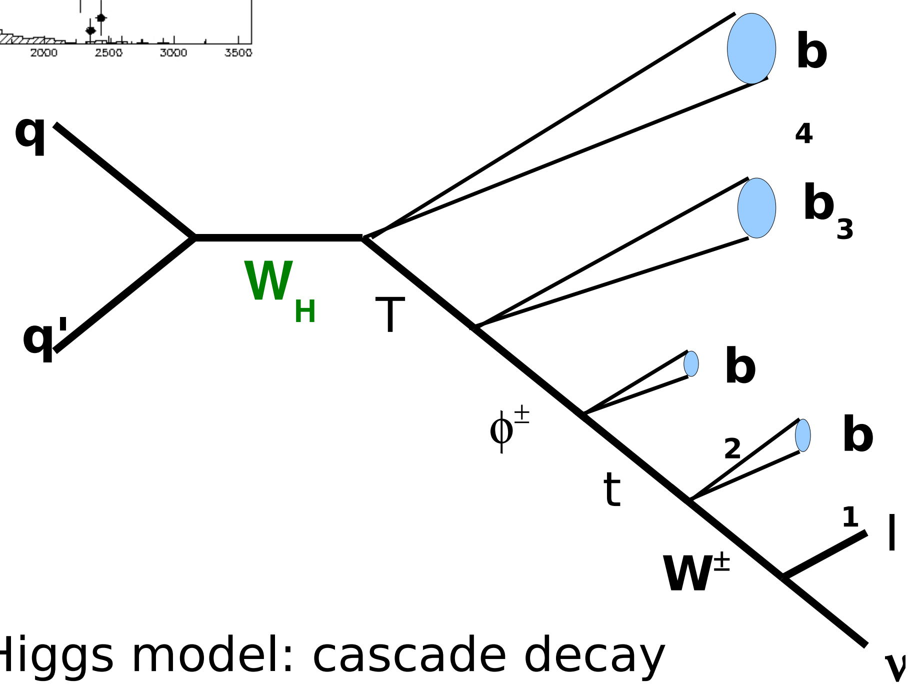
Now, for something a bit more complex: tbbb



2 TeV	no b-tag	b-tag
N_{sig}	301	120
N_{tt}	48	4.8
N_{wj}	1.9	-
$N/\sqrt{B}$	43	55



P_T spectrum of b-jets



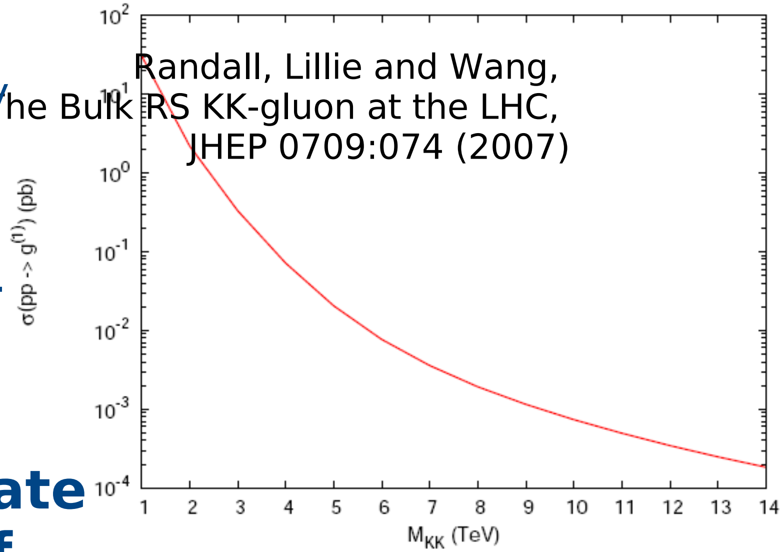
LR Twin Higgs model: cascade decay

$W_H \rightarrow Tb \rightarrow \phi^{\pm}bb \rightarrow t+3b \rightarrow bb + l + E_t^{miss}$

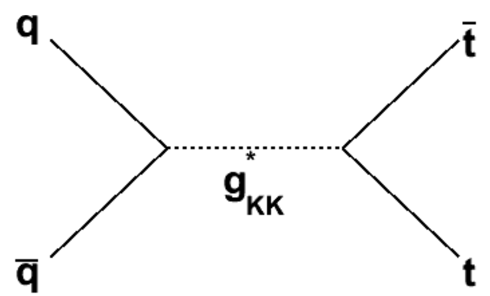
And more spectacular

RS warped extra dimensions

L. Randall, R. Sundrum, A Large Mass Hierarchy from a Small Extra Dimension. Physical Review Letters 83 (1999): 3370–3373
L. Randall, Warped Passages: Unraveling the Mysteries of the Universe's Hidden Dimensions. New York: HarperCollins (2005).
"possibly the most attractive ....")



When SM gauge bosons penetrate the bulk, Kaluza Klein towers of excited states appear. The KK gluon has some quite attractive features for experimentalists



couples strongly to quarks:

large cross-section: 15 pb for m(g^*_{KK}) = 1 TeV @ 10 TeV

but, by the same token:

not a narrow resonance! Basic RS model: Γ = 0.17 M

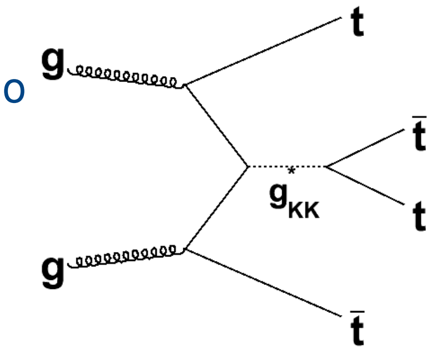
Large branching fraction into tt

Basic RS scenario: 92.6 %

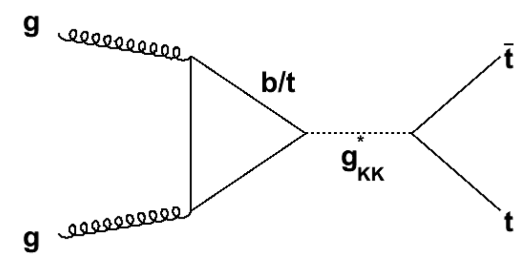
Fast simulation study into ATLAS potential of heavy gluon searches, March, Ros, Salvachua, PHYS-PUB-2006-002

tt+X

Tt + missing ET, tt + jets, tt + additional leptons
Or even four tops!
(see also: top compositeness, Lillie, Shu, Tait; Kumar, Tait, Vega-Mo



Scenario	g^q	$g_L^b = g_L^t$	g_R^b	g_R^t	$\Sigma(g^*_{KK} \to qq)$	$\Sigma(g^*_{KK} \to bb)$	$\Sigma(g^*_{KK} \to tt)$	$\Gamma g^*/Mg^*$
Basic RS	-0.2	1	-0.2	4	1.7%	5.7%	92.6%	0.153
$kr_{IR} = 5$	-0.4	-0.2	-0.4	0.6	68.1%	10.6%	21.3%	0.016
$Kr_{IR} = 20$	-0.8	-0.6	-0.8	-0.2	78.5%	15.3%	6.1%	0.054
SO(5), N=0	-0.2	2.76	-0.2	0.07	2.0%	49.1%	48.9%	0.130
SO(5), N=1	-0.2	2.76	-0.2	0.07	0.7%	16.0%	15.9%	0.400
E_1	-0.2	1.34	0.55	4.9	1.1%	7.4%	91.4%	0.235
E_2	-0.2	1.34	3.04	4.9	0.9%	29.7%	69.4%	0.310
E_3	-0.2	1.34	0.55	3.25	2.2%	14.2%	83.6%	0.123
E_4	-0.2	1.34	3.04	3.25	1.3%	46.6%	52.1%	0.198



From: Baur and Orr, arXiv:0803.1160

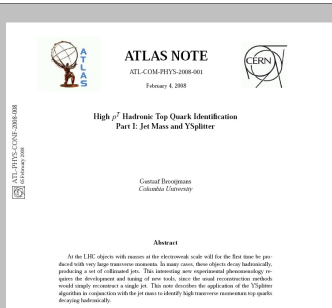
Basic RS: Randall, Lillie and Wang, JHEP 0709:074 (2007)

Large brane kinetic terms:H. Davoudias, J.L. Hewett, T.G. Rizzo,Phys. Rev. D 68, 045002 (2003), M. S. Carena, E. Ponton, T. M. P. Tait and C. E. M. Wagner, Phys. RevD 67 (2003), Phys. Rev. D 71 (2005)

Custodial symmetry (SO(5) x U(1)$_x$:M. S. Carena, E. Ponton, J. Santiago and C. E. M. Wagner, Phys. Rev. D 76, 035006 (2007)

A^b_{FB} inspired: A. Djouadi, G. Moreau, and R.K. Singh, Nucl. Phys. B 797 (2008)

The high p_T alternative

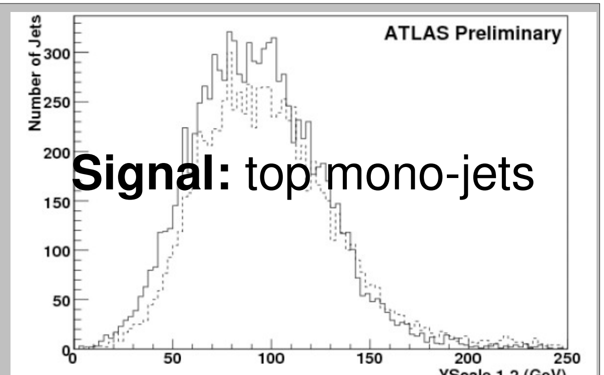


ATLAS NOTE
ATL-COM-PHYS-2008-001
February 4, 2008

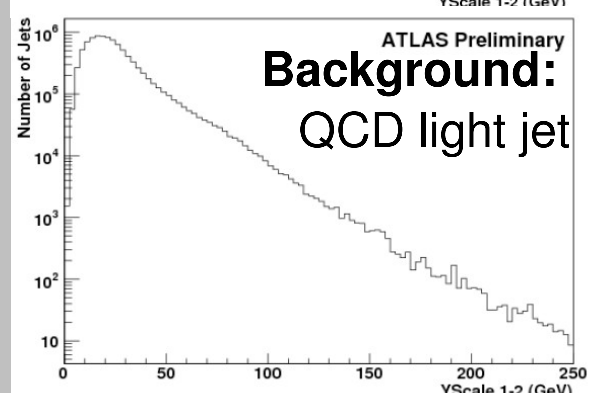
High p^T Hadronic Top Quark Identification
Part I: Jet Mass and YSplitter

Gustaaf Brooijmans
Columbia University

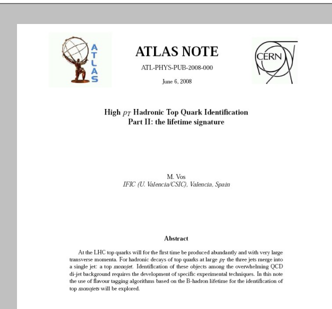
Abstract



Signal: top mono-jets



Background: QCD light jet

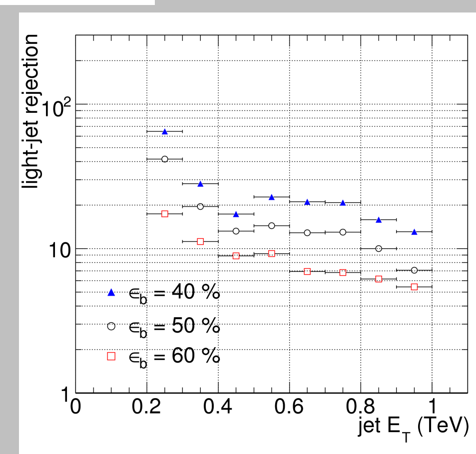


ATLAS NOTE
ATL-PHYS-PUB-2008-000
June 6, 2008

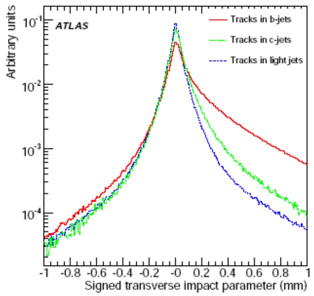
High p_T Hadronic Top Quark Identification
Part II: the lifetime signature

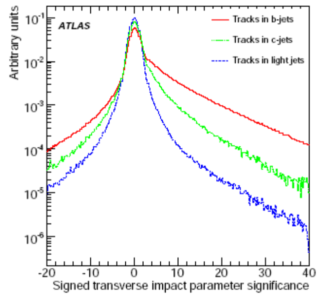
M. Vos
IFIC (U. Valencia/CSIC), Valencia, Spain

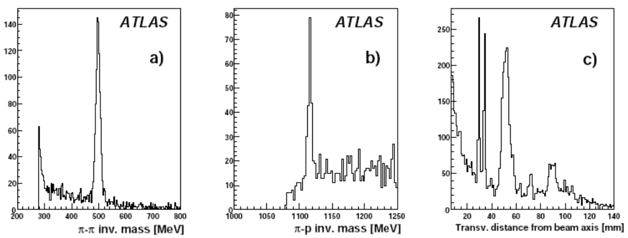
Abstract

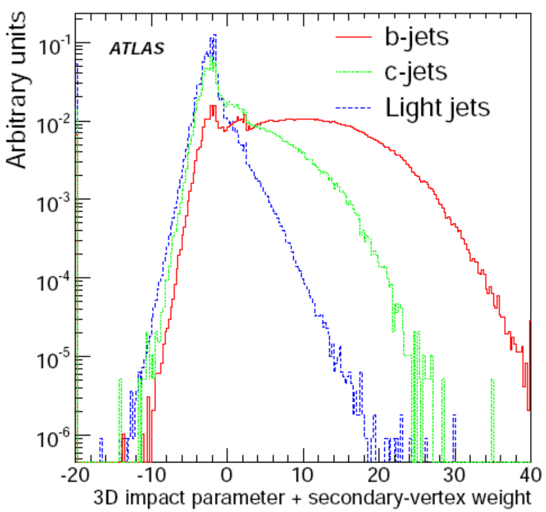


ATLAS flavour tagging









Selection:

good (low fake rate) tracks

reliable (precise IP) tracks

Assign category: shared hits

Clean track collection: remove V0s (neutral two track vertices, mostly conversions)

Calculate impact parameter significance

significance = d_0/σ

Determine likelihood

PDF -> MC significance distribution for b-, c- and light jets

Construct jet likelihood

Sum 3D impact parameter log(likelihood) of all (good) tracks in the jet

Examples of ATLAS exotic physics studies

ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008, to appear

Z' and W' searches:

SM tt is an important background.

Search for scalar lepto-quarks and right-handed W-bosons in di-lepton+jets final states:

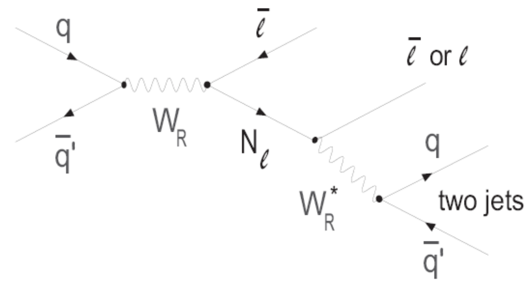
SM tt is the dominant background for LRSM
important also for lepto-quarks

Vector-boson scattering:

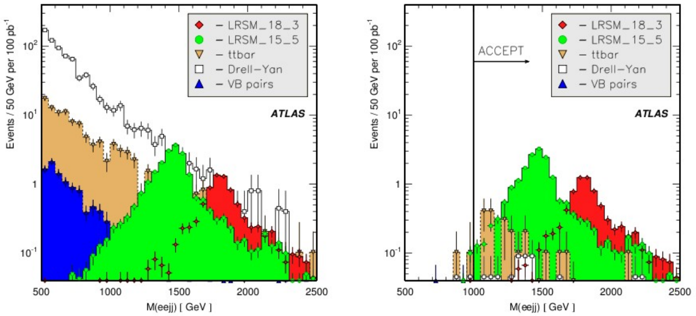
SM tt and tW events are an important background

Black holes:

SM tt among important backgrounds

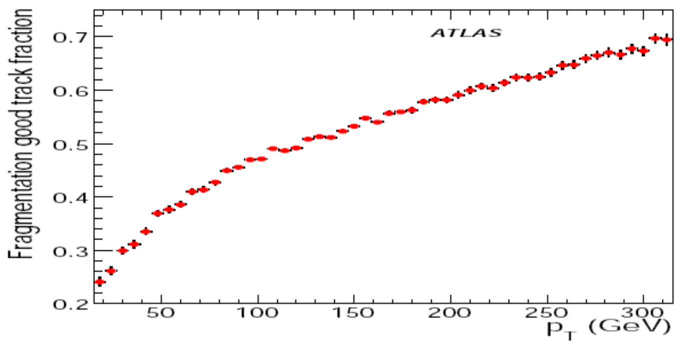


Exotics/di-lepton+jets studies (Stroehmer, Savinov)



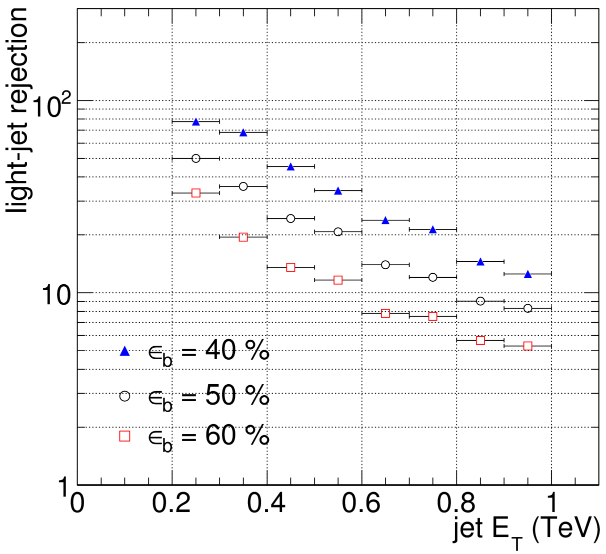
Event selection reduces SM tt sample to a tiny fraction with extraordinary properties (Etmiss, #jets, p_T of final state objects)

High p_T b-tagging



More and more fragmentation tracks “dilute” the signal from ~5 B/D decay tracks

B-hadrons fly too far (impact parameter approximately constant)



	R_B > 2.9 (%)	R_B > 5.1 (%)
E_T > 100 GeV	12.2	3.9
E_T > 200 GeV	21.1	7.9

Tracking efficiency for tracks from displaced vertex in dense jet core strongly degraded

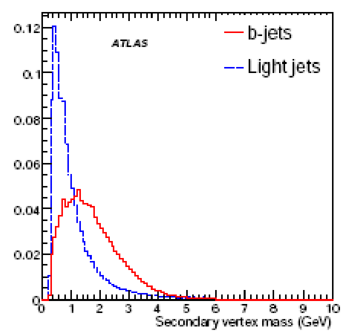
Flavour tagging performance suffers

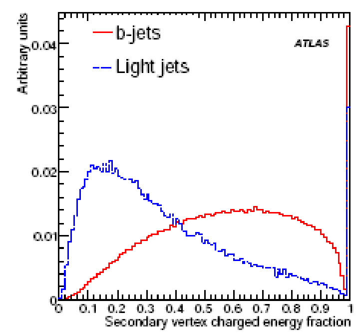
ATLAS flavour tagging: SV

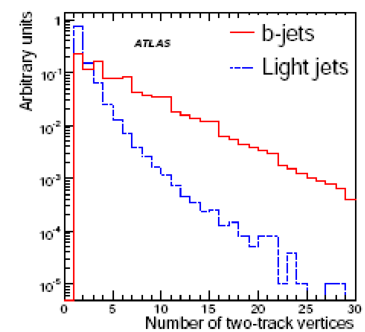
JetFitter

SV1

Add secondary vertex information (lifetime, but also mass and topology)







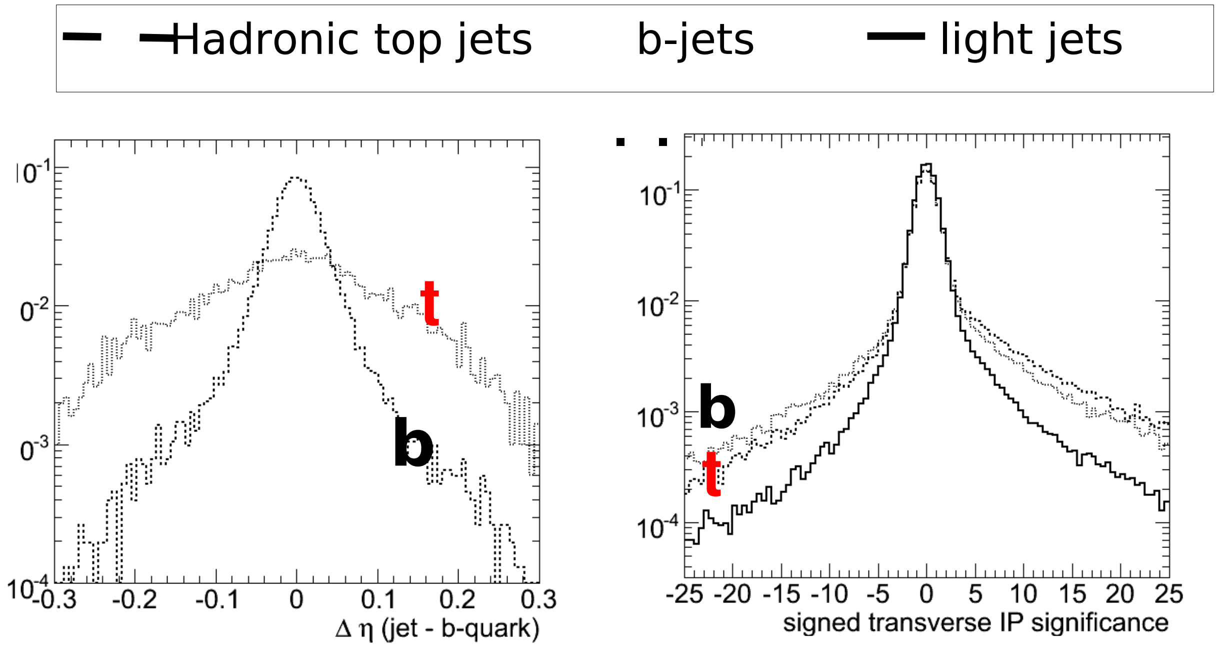
LY <---...---> sophisticated

JetProb	IP2D	IP3D	IP3D+SV1	IP3D + JetFitter
83 ± 1	116 ± 2	190 ± 3	458 ± 13	555 ± 17
30 ± 0	42 ± 0	59 ± 1	117 ± 2	134 ± 2

Light jet rejection ($R_u = 1/\varepsilon_u$) for two values of the b-tag efficiency

The lifetime signature

Very high p_T jets challenge the tracking pattern recognition.
High p_T B-decay products challenge the pixel detector two-track resolution



What about top-jets. Does the "noise" from close-by W-decay affect the tagging performance?

- jet direction no longer as readily identified with B-hadron flight path
- impact parameter sign more often incorrect
- additional tracks without life-time information dilutes the likelihood