Prospects for top anti-top resonance searches using early ATLAS data.

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Outline

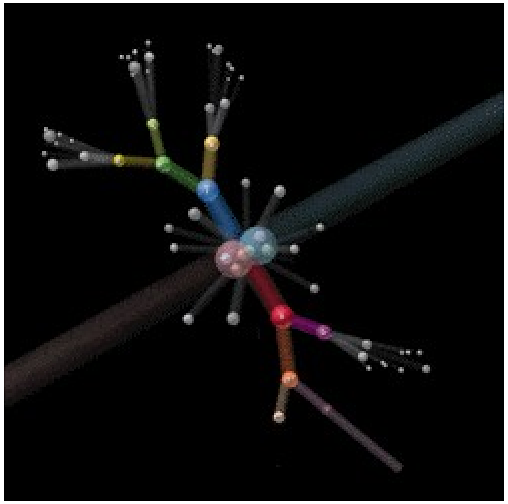
- Why top quark resonances?
- Top-tagging
- Expected cross section limits for $\mathscr{L}$ =200 pb^{-1}, $\sqrt{s}$ = 10 TeV

The results in this talk are publicly available in **ATL-PHYS-PUB-2010-008**.
All plots shown are taken from this note, unless otherwise stated.
All results are based on $\sqrt{s}$ = 10 TeV simulations only.

Why top pair resonances?

- The top quark is the heaviest known elementary particle (M ~173 GeV), and not yet well-studied.
- What if there are particles that decay into top pairs, top pair resonances?
  Like $Z^0 \rightarrow q\,\bar{q}$
- Many interesting extensions to the SM contain top pair resonances:
  - Extra dimensions: **Kaluza-Klein excitations** (especially **gluons**, also gravitons).
  - General heavy gluon-like particles.
  - New SM-like bosons (Z') from a little Higgs scenario or an additional strong coupling, technicolour.

Image: Fermilab



(Standard) semileptonic top decay and reconstruction

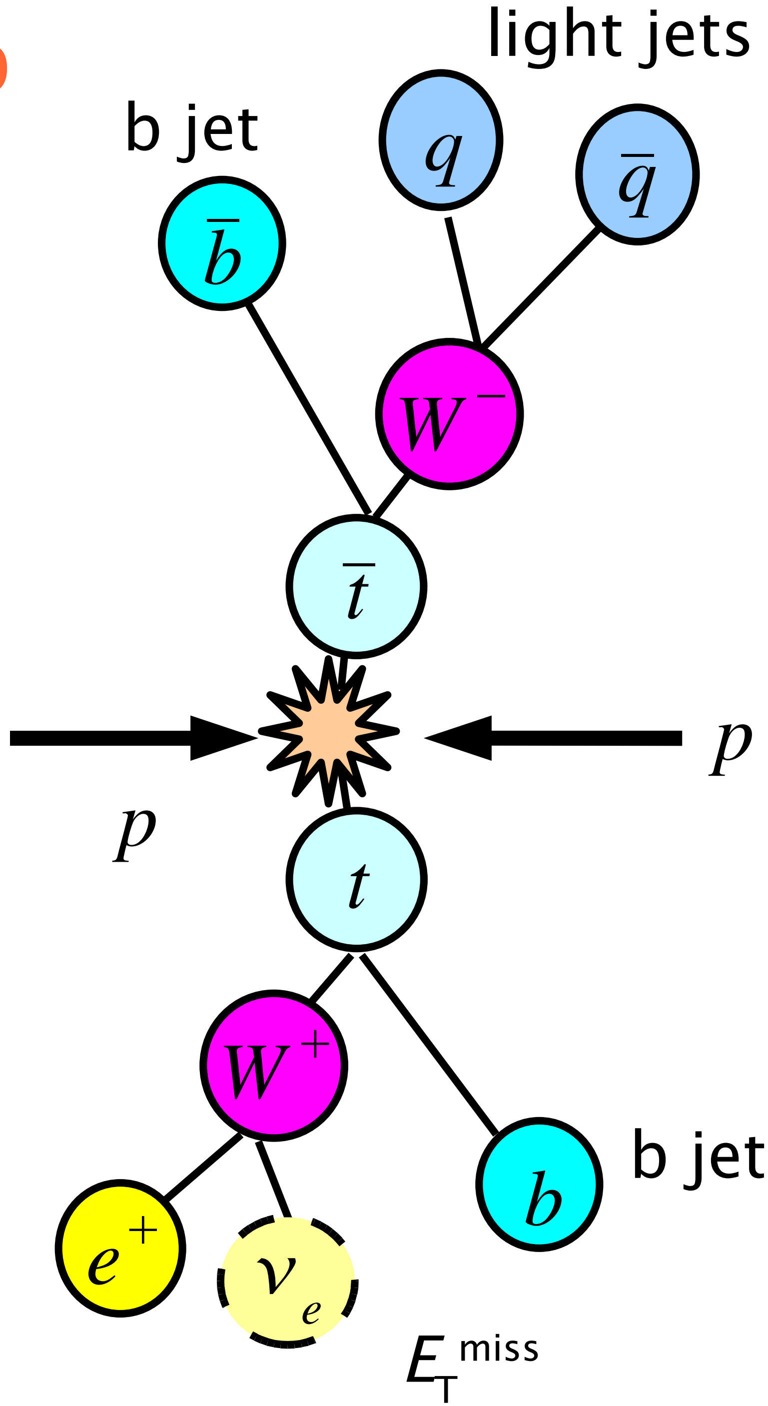
Require:

- 1 lepton (μ or e) and trigger
- E_T^{miss} (from ν)
- 3 jets, $p_T > 40$ GeV +1 jet, $p_T > 20$ GeV.

Use the leptonic side to "tag" the event.

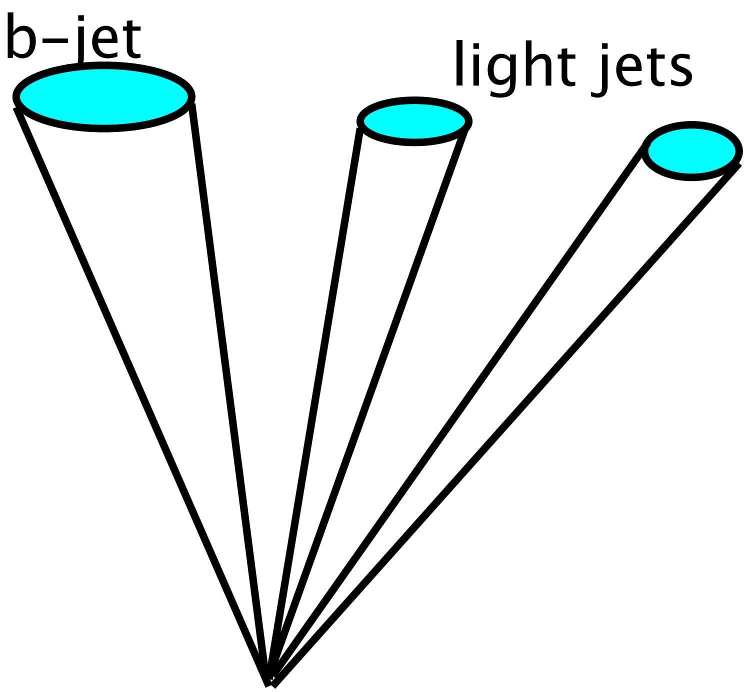
Additional requirements:

- W and top mass constraints from the hadronic side.



Complications...

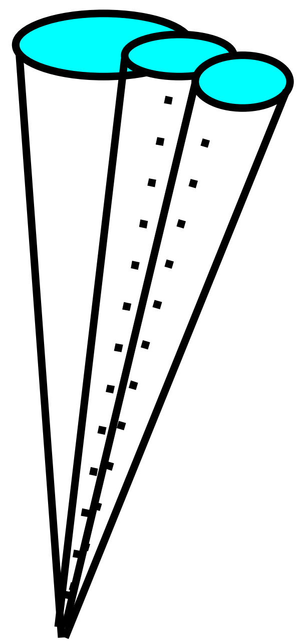
Normal (hadronic) top decay.



$t \rightarrow b + W$

$\hookrightarrow q\,q$

If lots of energy is available in the system, the top decay can be **boosted** and the jets from the decay products overlap.



The jet algorithms see only one jet.
=> Normal top reconstruction impossible.

Is this a problem?

YES:
Merged decay products in the hadronic top decay

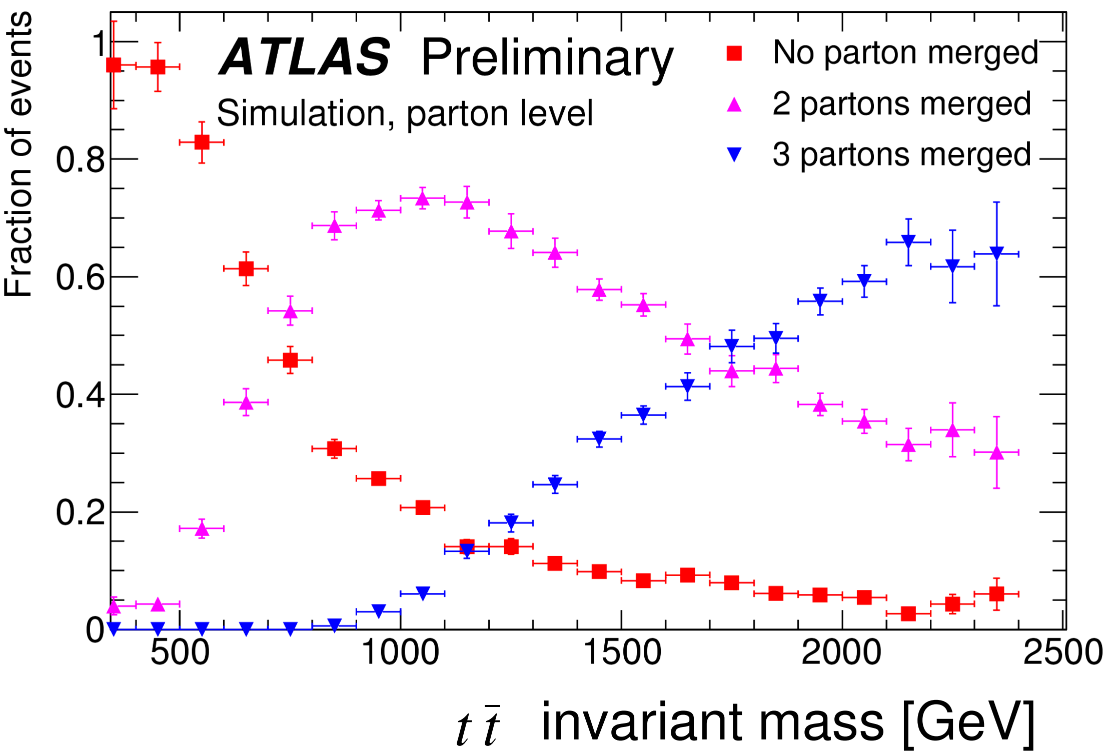
- Probability that the 3 partons from the top decay are found within a $\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 0.8$ radius
  (corresponds to a cone jet with opening angle $\Delta R = 0.4$).
  This is a *small* jet size!

- Above $M \approx 800$ GeV:
  partially merged.

- Above $M \approx 1800$ GeV:
  fully merged.

==> Massive resonances cannot be reconstructed with standard methods!

Will discuss the *monojet* (fully merged) case. Partially merged is also covered in note.



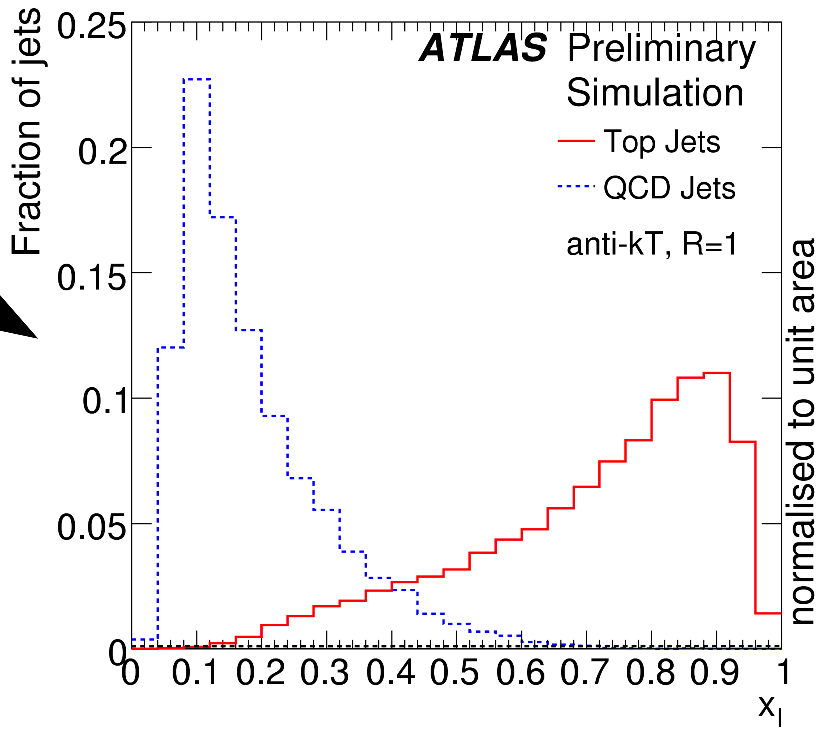
Find the (boosted) top quarks

- Search in the *semileptonic* top quark decay channel.
  - High branching ratio, good reconstruction possibilities due to the charged lepton.
- Search for heavy top pair resonances (M =1–2 TeV) => assume boosted top decays => expect merged top products => **top-tag**!
  - Label jets that originate from top quarks:
    - leptonic (1 charged lepton, e or μ, in the jet),
    - hadronic (the jet has 3 sub-jets).
  - "Taggable" jets: anti-k_T algorithm on locally calibrated clusters, opening angle $R = (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 1.0$ (**fat** jet).
  - The muons (and electrons) are included in the jet clusters.
  - The top-tagging is performed using variable cuts.

Top-tagging variables*

Leptonic jet: A charged lepton belongs to this jet, $E_T^{jet} > 40$ GeV

- Q_{vis} = mass of the leptonic top jet cand
- ΔR (*lepton,jet*)
- $x_l = [p_{lepton} (p_{jet} - p_{lepton})] / (p_{jet}^2)$
- $z_l = E_{lepton} / E_{jet}$
- *iso* – relative energy in a 0.2 cone around the lepton.



Hadronic jet: with substructure, $E_T^{jet} > 100$ GeV

- Q_{jet} – the mass of the hadronic top jet.
- $z_{12} = d_{12}/(d_{12}+M(p_1 + p_2)^2)$ where d_{12} is the k_T splitting level into the subjets 1 and 2.
- Q_W – the invariant mass of the subjet pair with lowest mass, assuming the jet has been split into 3 subjets.

* Inspired by Thaler & Wang, JHEP 0807:092, 2008

Invariant mass spectrum
of backgrounds after tagging selection

After selection, we have:

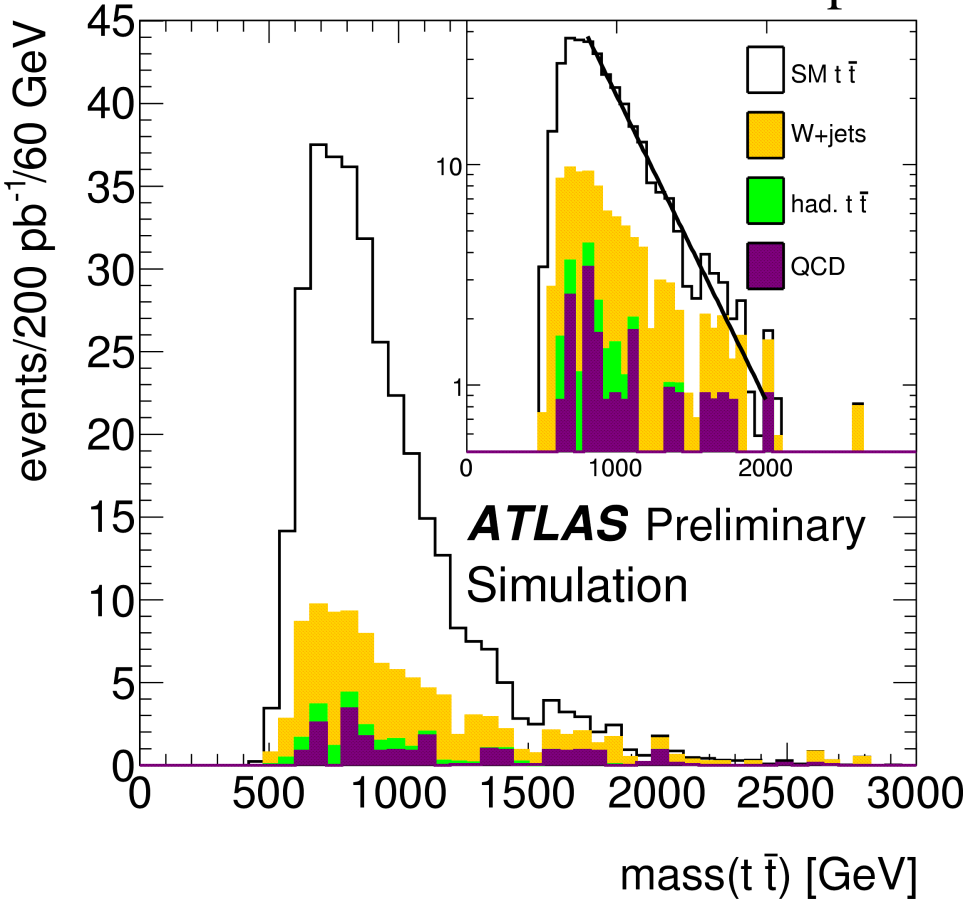
- 1 jet containing a charged lepton (leptonic top)
- 1 jet with 3 subjets (hadronic top)
- A neutrino candidate (E_T^{miss})

Invariant mass from the leptonic top jet + hadronic top jet + E_T^{miss}.

W mass constraint on $l + \nu$ system.

Sum of all backgrounds compatible with exponential for $800 < M_{inv} < 2500$ GeV.

$\sqrt{s}$ = 10 TeV and $\mathscr{L}$ = 200 pb^{-1}.



Cross section estimation

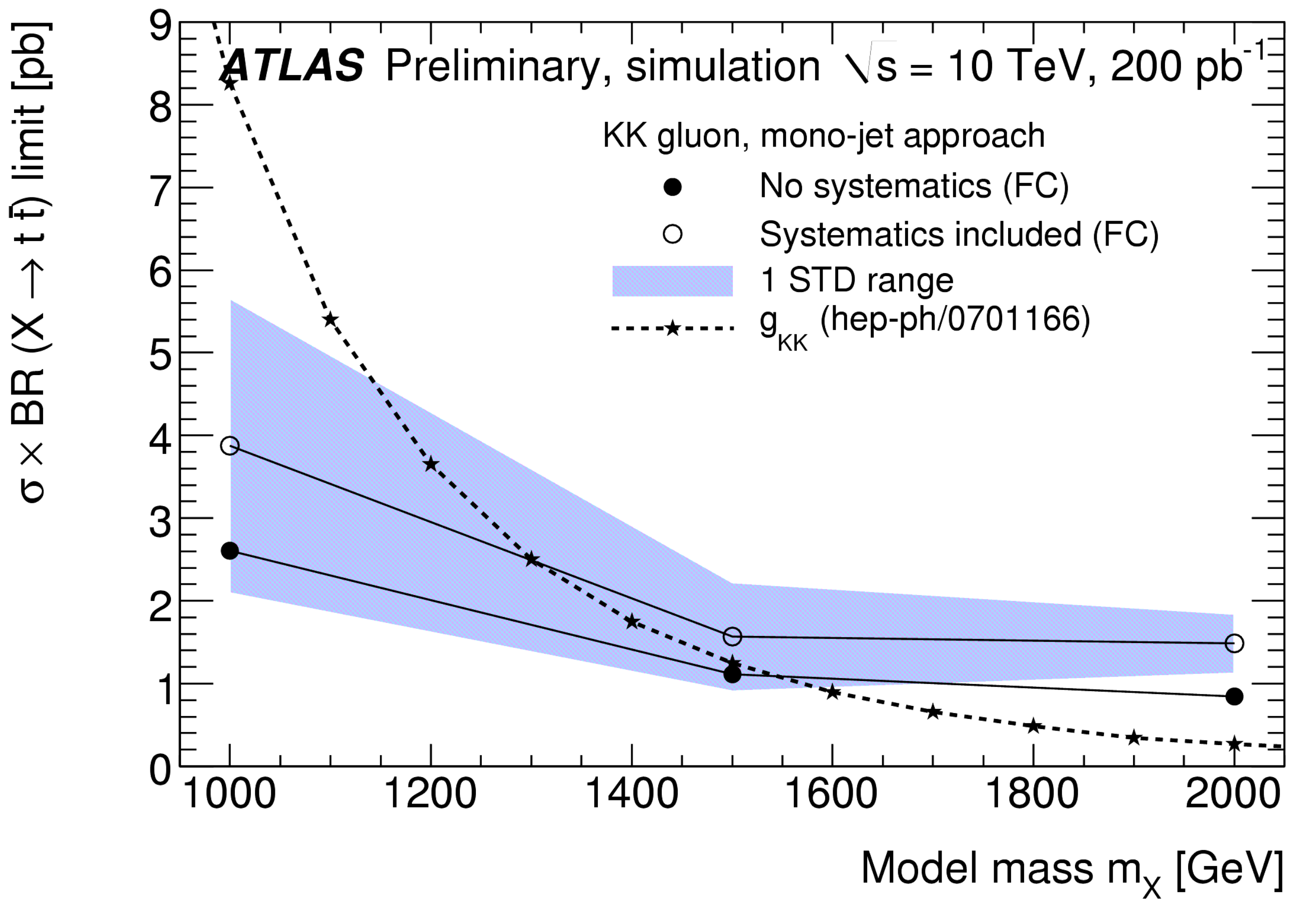
- Create a “data mix” from SM background and one signal sample.
  - SM background: ttbar, multijets, $W \to l+\nu$, single top.
    Use exponential consistently fitted to MC, with Poisson fluctuations.
  - Signal: given mass point M_0 (1–2TeV) and any given cross section σ_{theory}.
- Fit the normalised data mix with sig + bkg hypothesis, using the muon and electron channels simultaneously with an extended binned maximum likelihood fit.
  - Signal: the shape of the signal, Z' or g_{KK} (fixed mass point* M_0).
  - Background: exponential, $C_l \exp(-\lambda_l M_{\text{inv}})$.
  - Parameters of the fit: σ, C_e, λ_e, C_μ, λ_μ.
  - Extended ML (total number of events is Poisson) since we want to measure the cross section.
- Repeat many times in pseudo-experiments (changing Poisson fluctuations, start guesses etc.).

* The parameters don't fix the tested hypothesis if there is no signal present, unless the mass is fixed.

Cross section limits

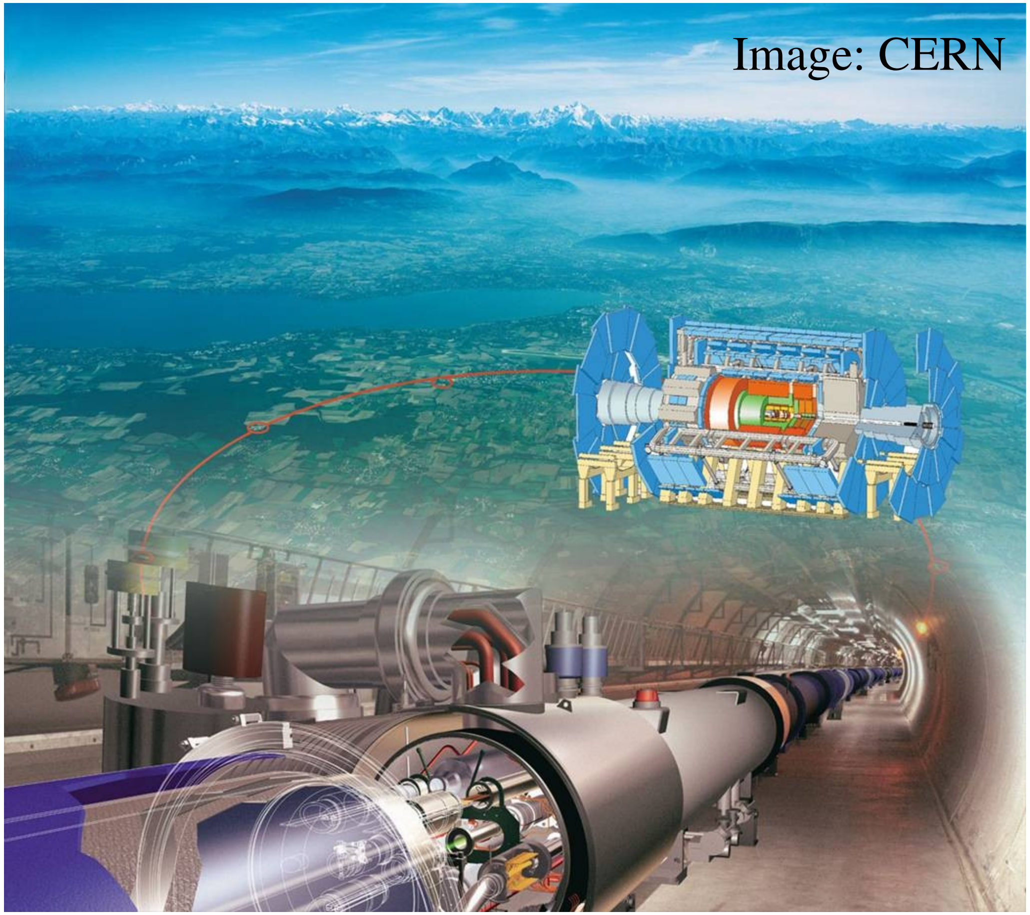
- Cross section limits derived with the Feldman–Cousins method (FC).
- Systematic uncertainties included. The jet energy scale uncertainty dominates (not shown explicitly).
- 95% CL (*exclusion*).
- Current limit: $M > 800$ GeV (CDF, note 9164).

Theory curve: broad ($\Gamma = 0.15M$) Kaluza–Klein gluon, colour octet.
(Lillie et al. hep-ph/0701166)



Outlook

- Results shown for $\mathscr{L}$ =200 pb^{-1}, $\sqrt{s}$ =10 TeV. Corresponds roughly to the expectation for $\mathscr{L}$ =1 fb^{-1}, $\sqrt{s}$ =7 TeV.
  The cross section of the ttbar background (mainly *gg*–induced) is reduced more than the signal cross section (*qq*–induced) when the CMS energy is lowered.
- Now: apply to data!
  With the 2010 data sample + the data expected for 2011, we may be able to extend the current limit into the TeV region.
  Or maybe see the first hint of new physics.



Summary & Acknowledgements

- An interesting physics prospect for the LHC is to look for top quark pair resonances.
- For heavy resonances ($M > 1$ TeV) the top quark decay products can be boosted and merged.
- If no signal is found, broad coloured resonances (KK gluons) could be excluded at 95% CL for cross sections larger than
  ~4 pb ($M = 1$ TeV) and
  ~2 pb ($M = 2$ TeV)
  with $\mathscr{L} = 200\ \mathrm{pb}^{-1}$ and $\sqrt{s} = 10$ TeV.
  Approximately, similar limits can be expected for
  $\mathscr{L} = 1\ \mathrm{fb}^{-1}$, $\sqrt{s} = 7$ TeV.

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References

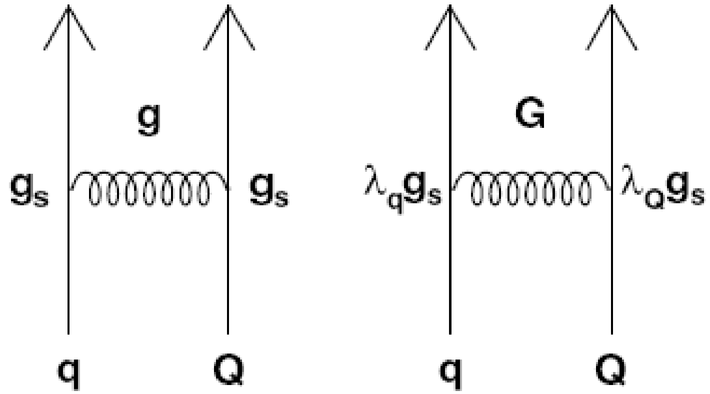
- ATLAS collaboration: *Prospects for top anti-top resonance searches using early ATLAS data*. Refereed public note, CERN 2010, ATL-PHYS-PUB-2010-008
- J. Thaler, L.-T. Wang: *Strategies to Identify Boosted Tops*. JHEP 0807:092, 2008. (hep-ph/0806.0023)
- B. Lillie et al: *The Bulk RS KK-gluon at the LHC*, JHEP 0709:074,2007 (hep-ph/0701166)
- G. Feldman and R. Cousins: *A Unified Approach to the Classical Statistical Analysis of Small Signals*. Phys. Rev. D57 (1998) 3873-3889 (physics/9711021)
- CDF Collaboration: *A search for massive gluon decaying to top pair in lepton +jet channel*, CDF note 9164 (2008).
- CMS collaboration: *Study of the top-pair invariant mass distribution in the semileptonic muon channel at* $\sqrt{s} = 10$ *TeV*. CMS PAS TOP-09-009, 2009.
- CMS collaboration: *Search for heavy narrow* $t\bar{t}$ *resonances in muon-plus-jets final states with the CMS detector*. CMS PAS EXO-09-008, 2009.
- ATLAS collaboration: *Expected performance of the ATLAS experiment: detector, trigger and physics,* CERN-OPEN-2008-020. Top quark properties, section 6.

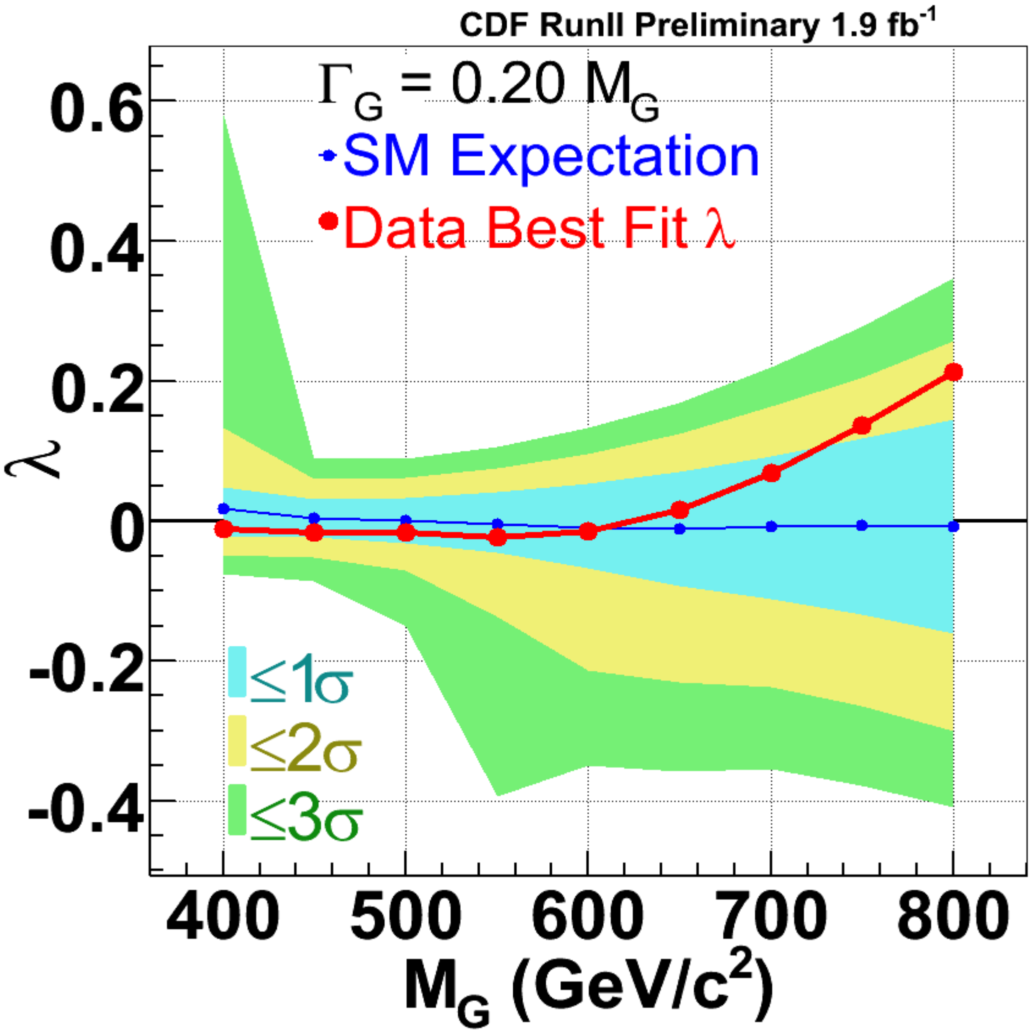
Back-up

Previous searches in CDF

Search for a coloured massive particle decaying to top pairs.

- $\lambda = \lambda_q \lambda_Q$ is the relative strength of coupling to light and heavy quarks
- Γ_G is the resonance width
- M_G: resonance mass
- Experiment compatible with SM



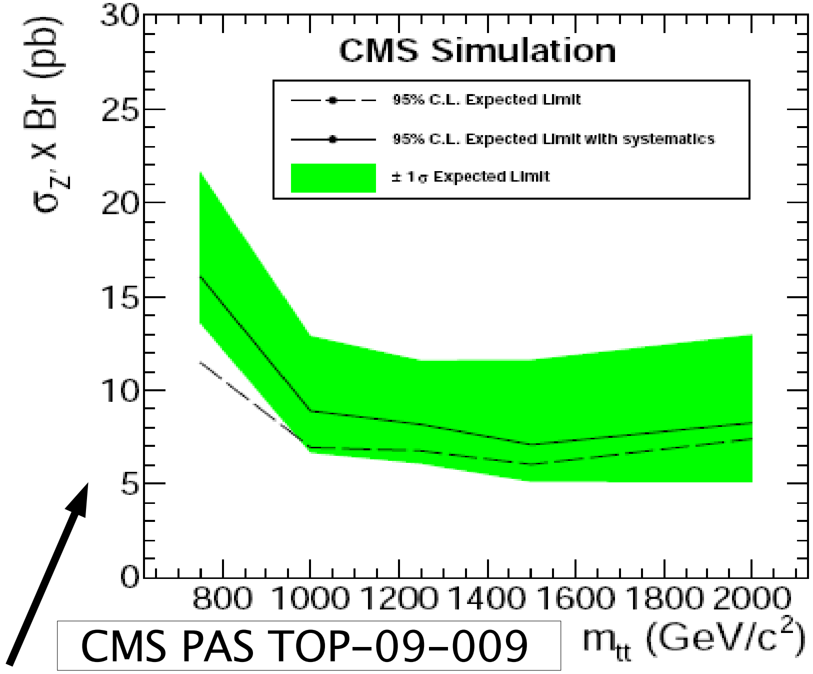


From CDF note 9164

Comparison with CMS and ATLAS results from 2008

Narrow, uncoloured resonances (Z'). Comparison without systematics.
Monojet analysis: limit between 3.3 pb (1 TeV) and 1.1 pb (2 TeV) for 200 pb^{-1}

CMS expectations, $\sqrt{s}$=10 TeV:



CMS PAS TOP-09-009

(1) μ channel, resolved, 95% CL, 100 pb^{-1}

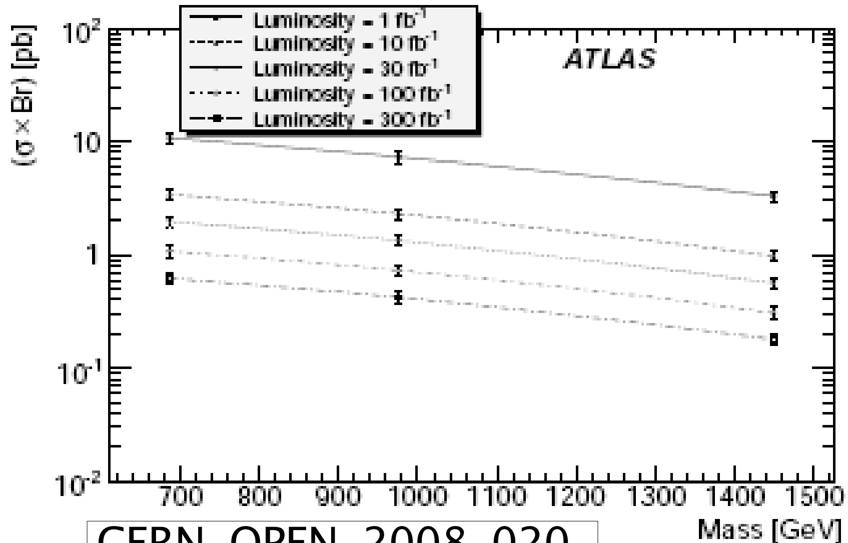
1 TeV: 6.9 pb, 2 TeV: 7.4 pb

(2) μ channel, monojet, 95% CL, 200 pb^{-1}

1 TeV: 6.6 pb, 2 TeV: 0.25 pb

ATLAS expectation,

5σ discovery, $\sqrt{s}$ = 14 TeV



CERN-OPEN-2008-020

Figure 16: 5σ discovery potential of a generic narrow $t\bar{t}$ resonance as a function of the integrated luminosity.