HUMBOLDT-UNIVERSITÄT ZU BERLIN

Searches for top quark resonances in boosted topologies with the ATLAS detector

Outline:

Motivation

Recent ATLAS results

Retrospect and outlook

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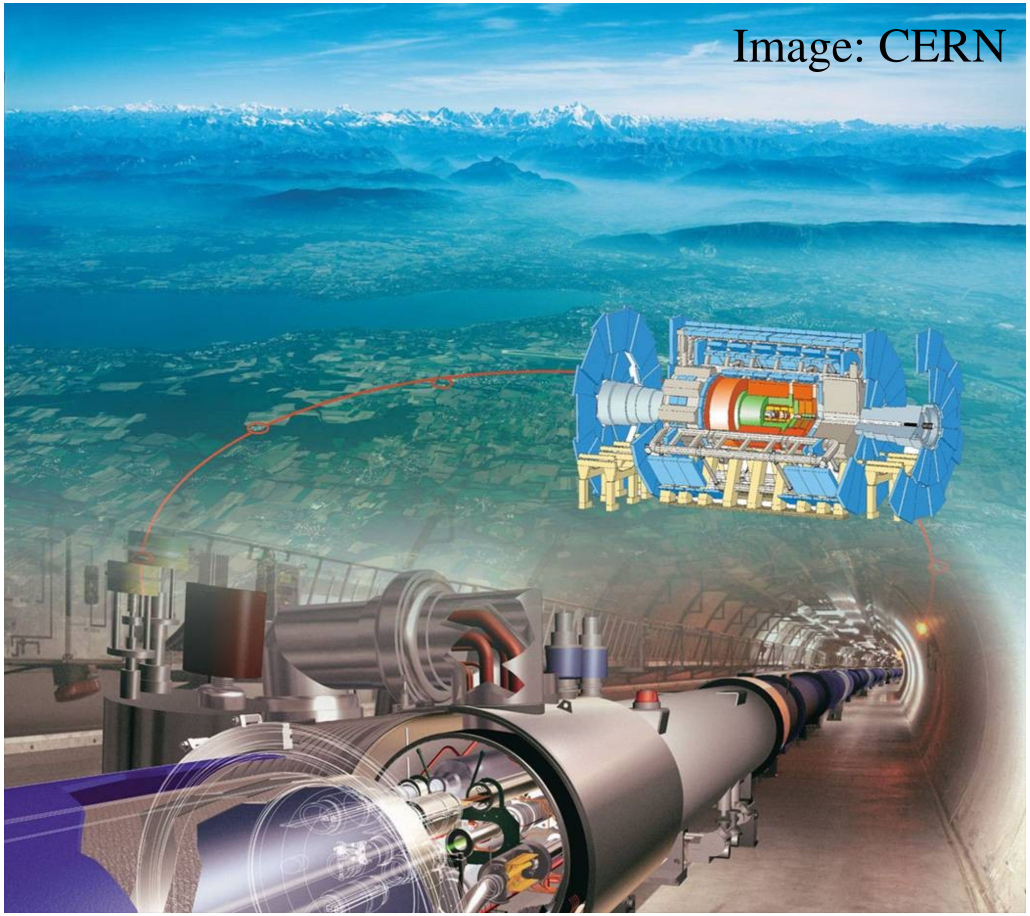
FSP 101 ATLAS

Motivation for the ATLAS experiment

Test the Standard Model:

- Find the missing particle(s) of the theory
  - The Higgs boson, ...
- Precision measurements
  - Top quark, ...



Search for new physics beyond the Standard Model

- Dark matter candidates (SUSY?)
- **top quark pair ($t\bar{t}$) resonances**
- ...

Why $t\bar{t}$ resonances?

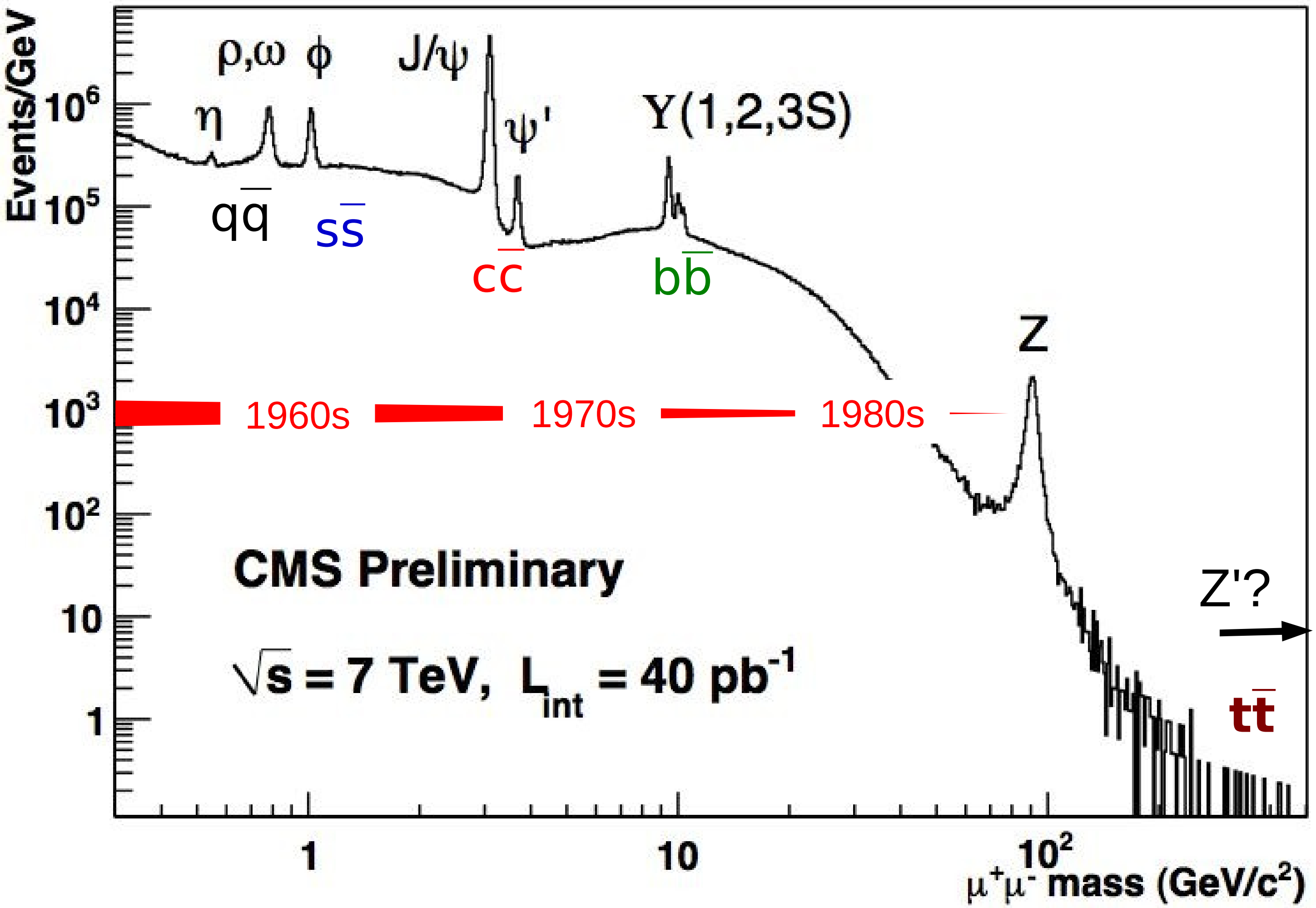
- Look for a new heavy elementary particle that decays to top quark pairs ($t\bar{t}$).
- Why? Power of analogy!

Di-muon resonances,
$Z \rightarrow \mu^+\mu^-$

and quark resonances
$Z \rightarrow q\bar{q}$

Why not top?
$Z' \rightarrow t\bar{t}$

Does the story continue?

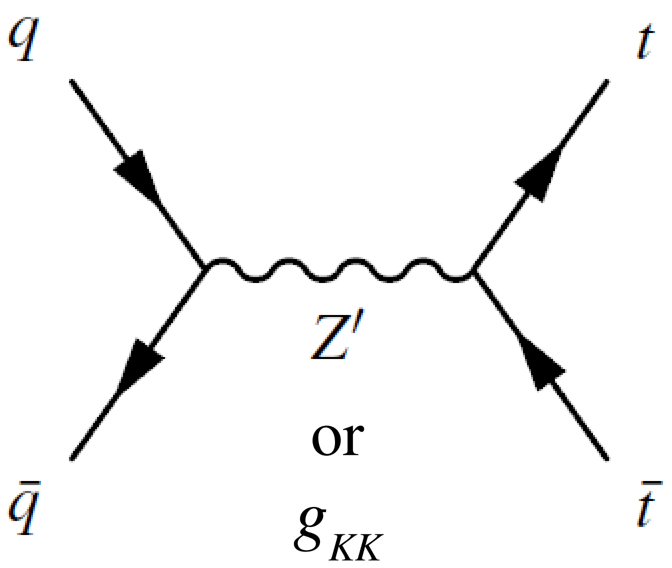


$t\bar{t}$ resonances – models

Two benchmark theories with X → $t\bar{t}$:

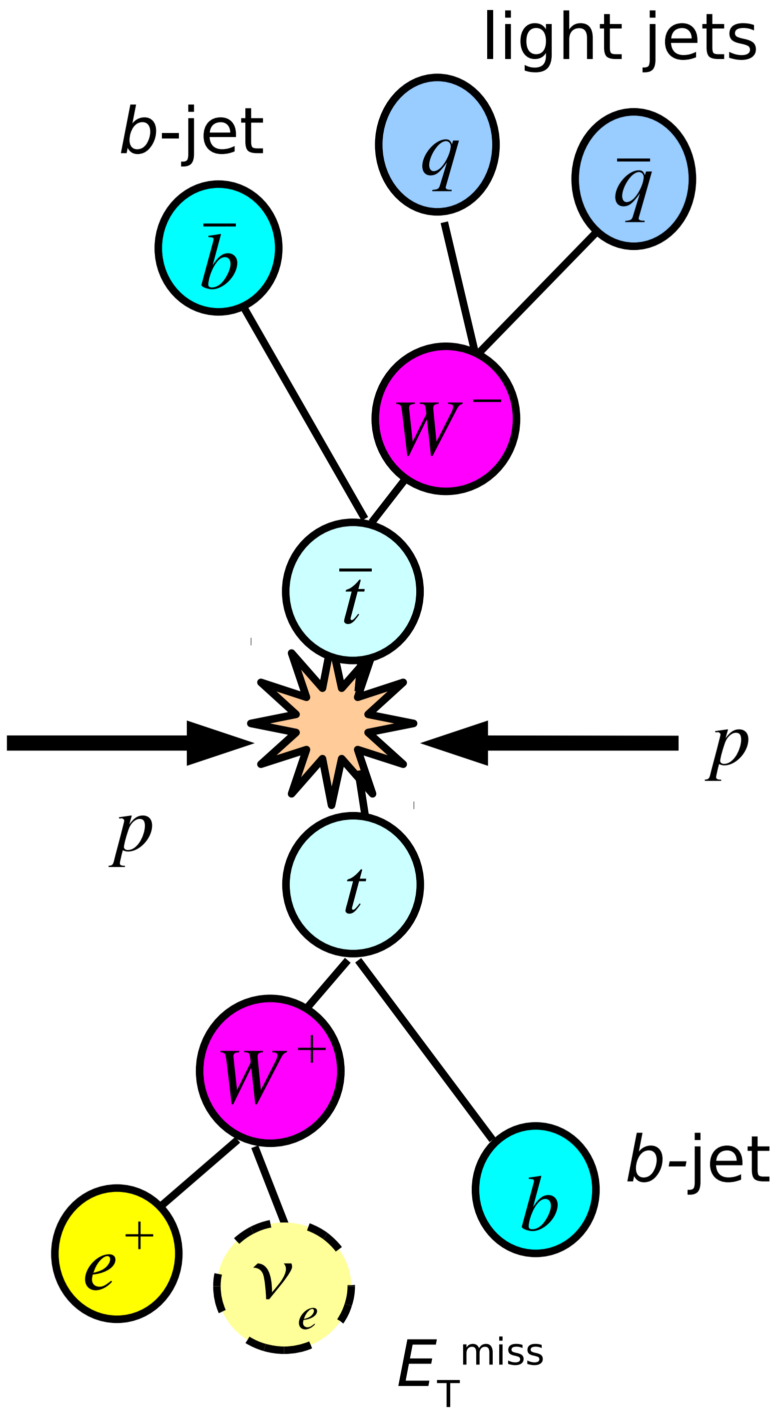
- Leptophobic topcolor **Z'**
  Topcolor: new strong dynamics.
  A **new Z-like boson, Z_t'**, couples strongly to top quarks.
  $Z_t' \rightarrow t\bar{t}$
  Narrow ($\Gamma_{Z'} / m_{Z'} = 1.2\%$),
  colour singlet

- Kaluza-Klein gluons (**g_{KK}**).
  Randall-Sundrum scenario I:
  extra spatial dimension.
  excitation –
  Kaluza-Klein gluon.
  $g_{KK} \rightarrow t\bar{t}$ (~90% BR)
  Broad ($\Gamma / m = 15\%$), colour octet



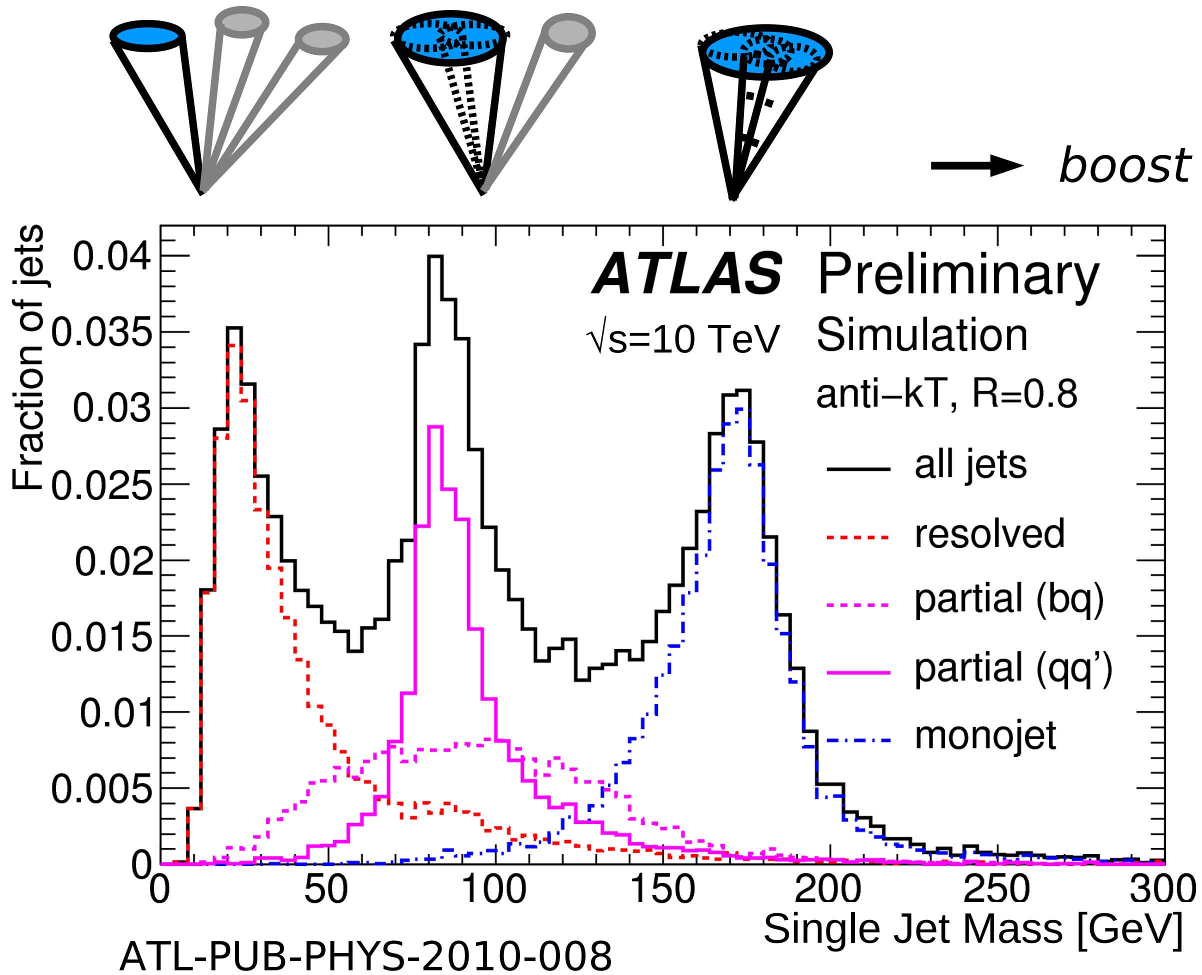
$t\bar{t}$ identification

- Top quark decay: three-pronged =>
  - Decay at rest:
    three reconstructed objects
    1 *b*-jet, 2 light jets
    or
    1 *b*-jet, 1 charged lepton, E_T^{miss}
    (resolved)
  - Decay at large p_T: the decay products **merge**
    – Hadronically: one broad jet
    – Leptonically: lepton and b-jet close
    (boosted)
- Z' and g_{KK} excluded at low masses.
  High-mass resonances
  => boosted top decay



Visibility of boosted tops

- Simulation of $g_{KK} \to t\bar{t}$, (various masses) leading jet.
- If m_{jet} >~ 60 GeV: jet from something heavier than a light quark or a gluon.
  $W \to q\bar{q}$?
  $t \to bq\bar{q}$?



- Identifying boosted top quarks: **top-tagging**.

Analysis strategy

- Identify the top quark decay products:
  - lepton, E_T^{miss}, one narrow jet, one broad jet (boosted)
  - lepton, E_T^{miss}, 3 or 4 narrow jets (resolved)

- Search for local data excesses in $m_{t\bar{t}}$ (bumps signifying $X \rightarrow t\bar{t}$)

- Data/bgr agreement: set upper cross section limits on benchmark models.

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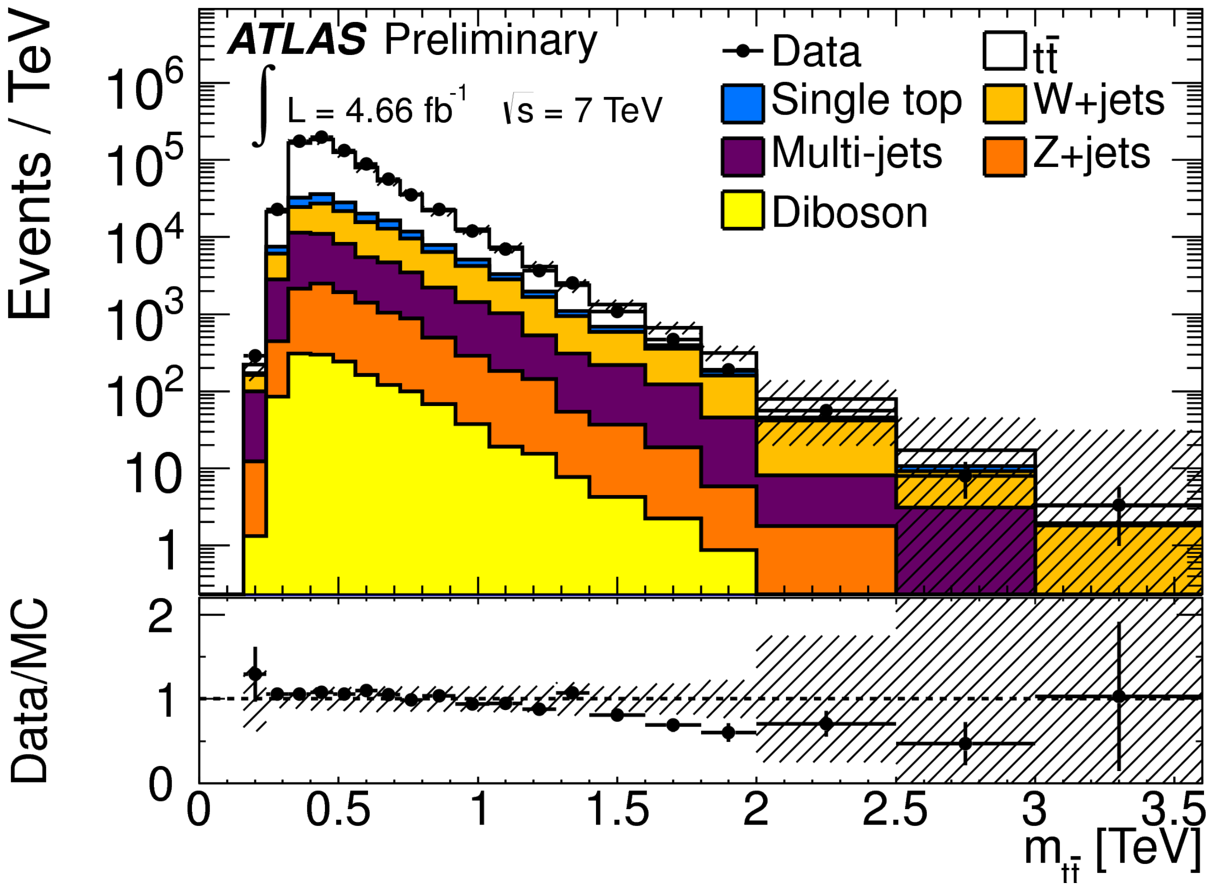


Boosted semi-leptonically decaying top: mini-isolation

Standard isolation: $p_T^{cone} - p_T^{\ell} < 2$ - 4 GeV
fixed cone size (typically ΔR=0.2-0.3)

Mini-isolation definition:

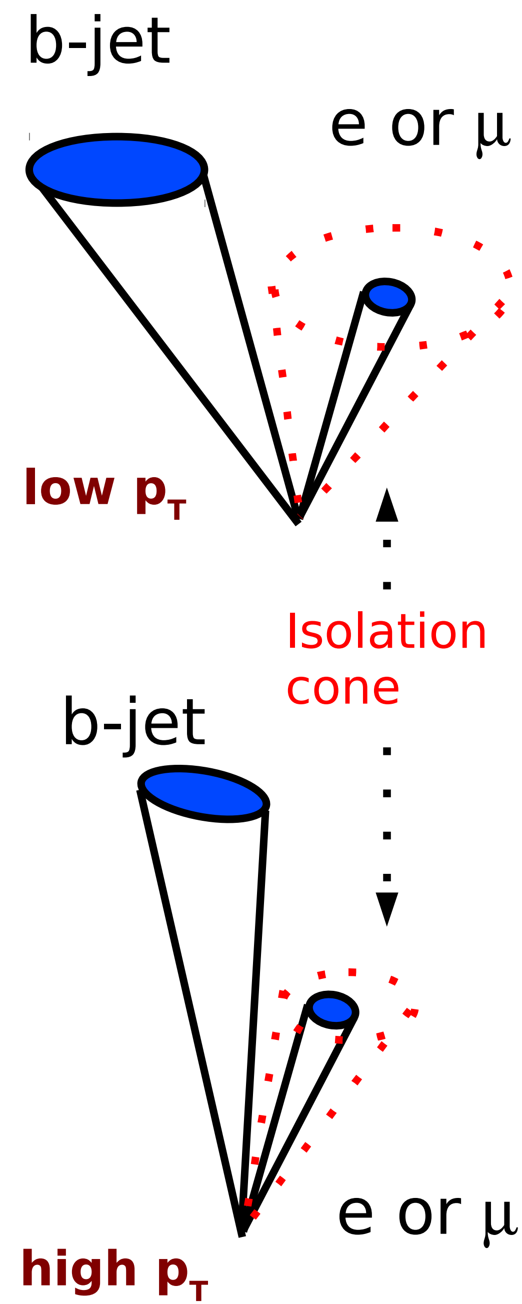
$$I^{\ell}_{\mathrm{mini}} = \sum_{\mathrm{tracks}} p_{\mathrm{T}}^{\mathrm{track}} \,, \quad \Delta R(\ell, \mathrm{track}) < K_{\mathrm{T}}/p_{\mathrm{T}}^{\ell}$$

sum runs over all tracks (except lepton)
K_T =10 GeV empirical scale parameter

Cut on **$I^{\ell}_{mini}/p_T^{\ell} < 0.05$**

Performs much better for boosted $t \rightarrow \ell \nu b$.
Equivalent to standard iso in low-p_T limit.

K. Rehermann and B. Tweedie,
JHEP 1103 (2011) 059, arXiv:1007.2221 [hep-ph]

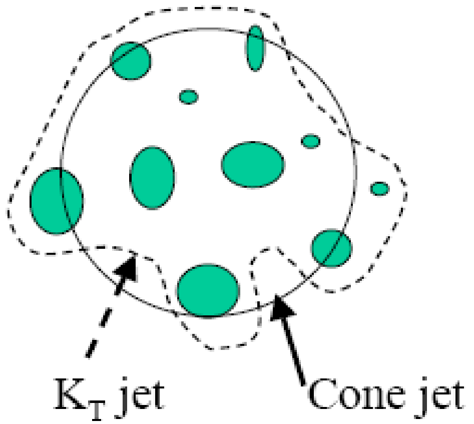


(… Parenthesis for boosted hadronically-decaying top

Sequential clustering jet algorithms

Make a jet:

Start with a list of protojets i
(e.g. calorimeter energy deposits)



1) For each component, define $d_i = p_{T,i}^{\;2}$

For each pair (i, j) define

$d_{ij} = \min(p_{T,i}^{\;2n},\; p_{T,j}^{\;2n})\, \Delta R_{ij}^{\;2} / R^2$

Radius parameter R (O(1))

2) Find d_{min} = minimum of all d_i, d_{ij}

3) If d_{min} is a d_{ij}, merge protojets to a new protojet d_n

If d_{min} is a d_i, the object is a **jet**.

Remove protojet from list.

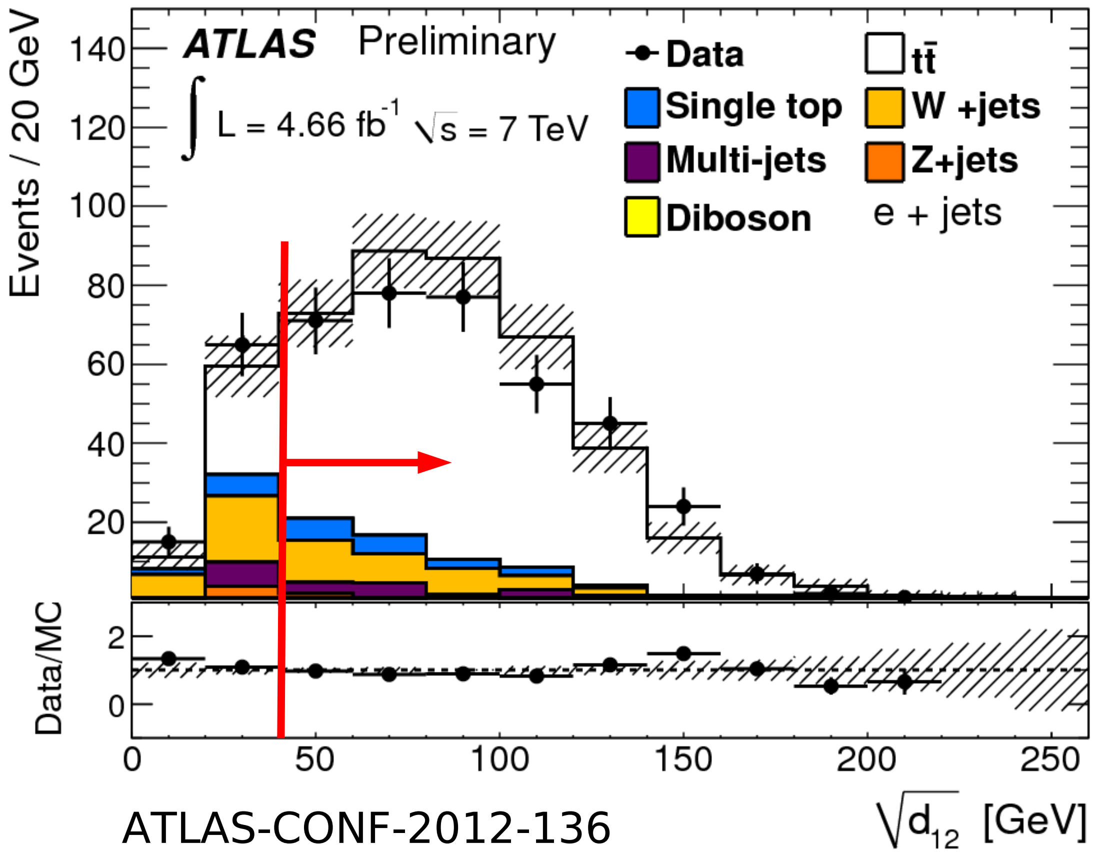
Repeat 1-3 until all protojets are in jets.

n =	1:	k_T algorithm
n =	–1:	anti-k_T algorithm
n =	0:	Cambridge-Aachen algorithm

…)

Boosted hadronically-decaying top:
Jet substructure

- With the k_T algorithm, the last protojets added to the final jets are the hardest.
- Last merging step holds information about the jet substructure
  $d_{12} = \min(p_{T,1}^2,\ p_{T,2}^2)\ \Delta R_{12}^2 / R^2$
- If jet contains **top decay** (t → Wb → qqb)
  $d_{12} \approx (m_{top} / 2)^2$
  (heavily smeared)
  Light jets: $d_{12} \approx 0$
- Take any jet (anti-k_T, Cambridge-Aachen...) and recluster with k_T. Undo the last clustering to obtain the split/merge scales.



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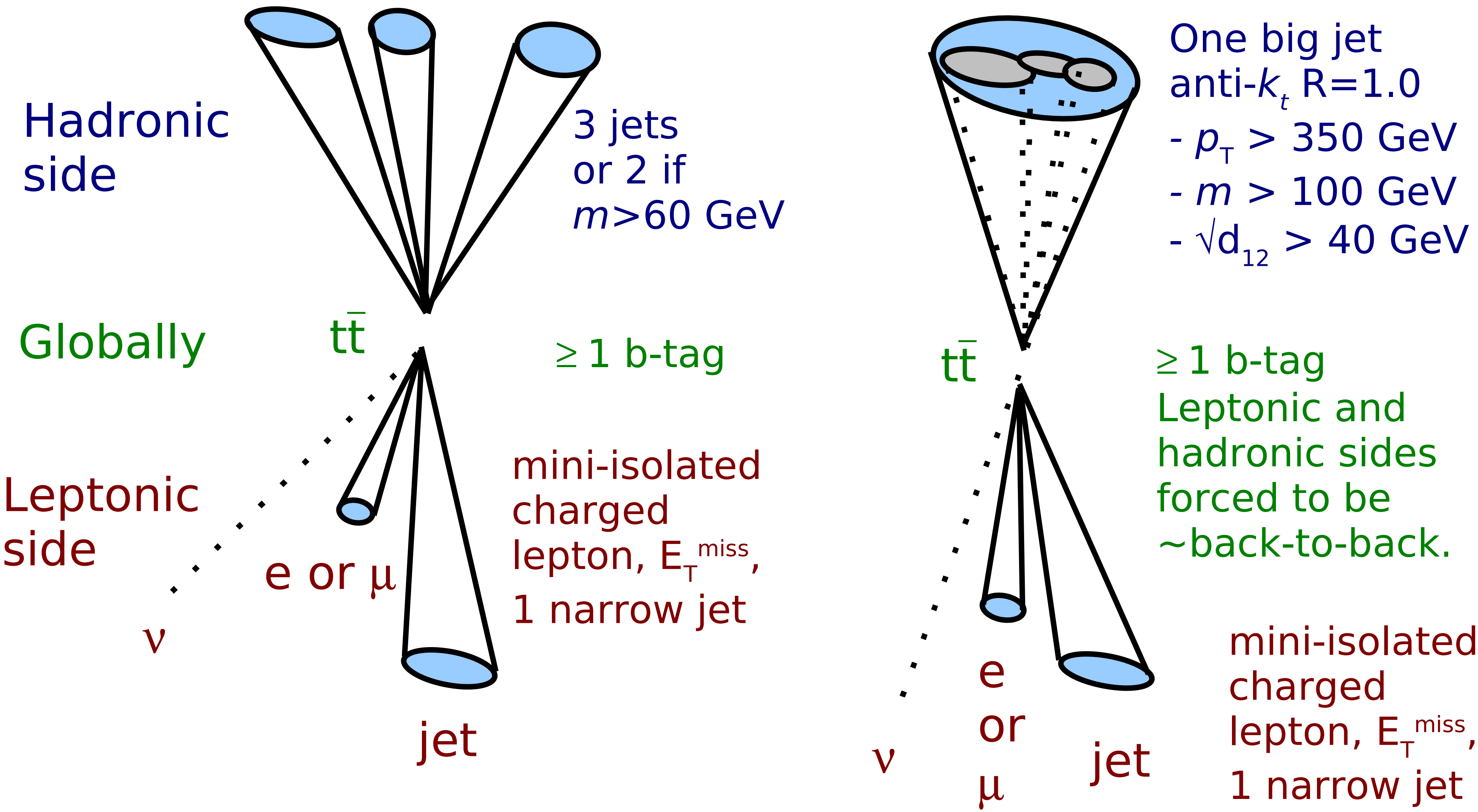
$t\bar{t} \to l$ +jets reconstruction overview

$$t\bar{t} \to W^{+}b + W^{-}\bar{b} \to l\nu b + q\bar{q}b$$

Resolved selection | **Boosted** selection

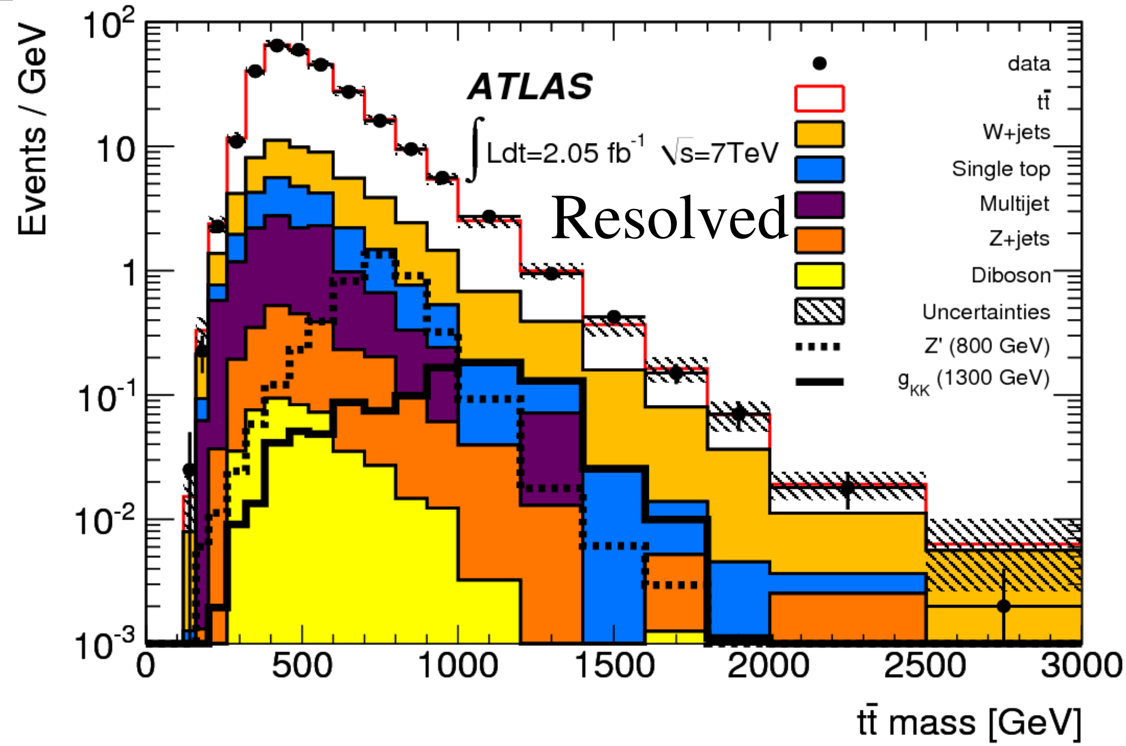


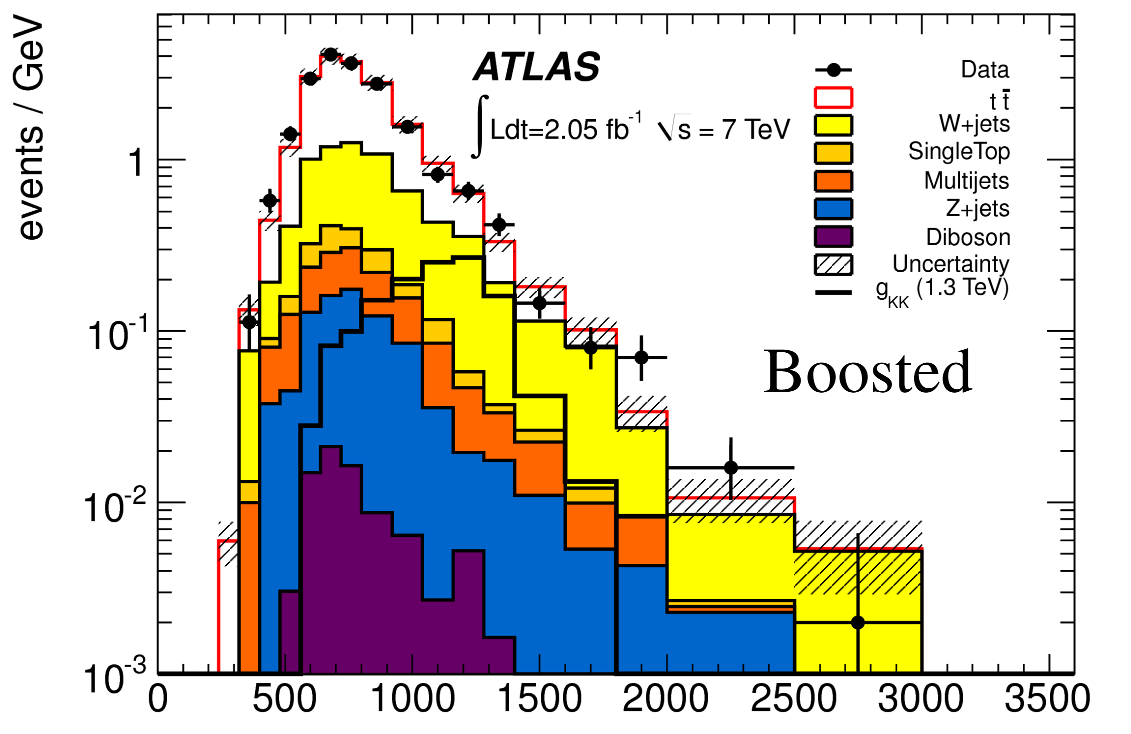
$m_{t\bar{t}}$ resolved and boosted

The $m_{t\bar{t}}$ spectra, **resolved** and **boosted** selection.

Better S/B for boosted at high masses despite worse statistics!

(Figures from the 2 fb^{-1} analyses)





EPJC 72 (2012) 2083, JHEP 1209 042

$m_{t\bar{t}}$ spectrum, 4.66 fb^{-1}

- Good agreement between data and expectation ==> set upper cross section limits

Type	Resolved selection
$t\bar{t}$	44 000 ± 4 700
Single top	3 250 ± 250
Multi-jets e+jets	2 500 ± 1 500
Multi-jets μ+jet	1 010 ± 610
W+jets	6 940 ± 730
Z+jets	840 ± 410
Di-bosons	124 ± 43
Total	58 700 ± 5 300
Data	61 954

Type	Boosted selection
$t\bar{t}$	950 ± 100
Single top	49 ± 4
Multi-jets e+jets	12 ± 7
Multi-jets μ+jet	20 ± 12
W+jets	82 ± 15
Z+jets	11 ± 5
Di-bosons	0.88 ± 0.30
Total	1 120 ± 100
Data	1079

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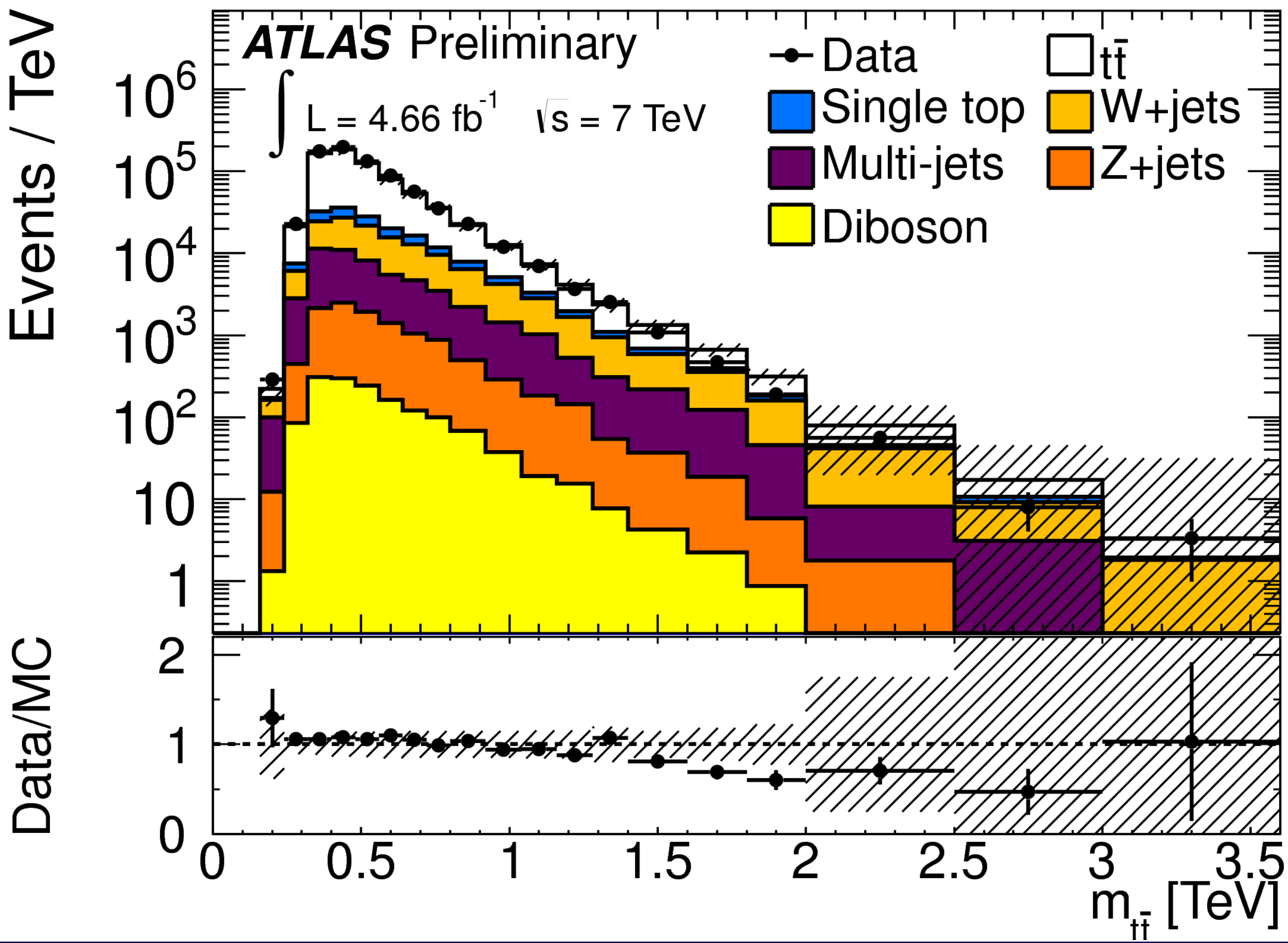


Upper cross-section limits

Z' and g_{KK} limits.

Results:

ATLAS, **4.7 fb^{-1}**,

$m_{Z'}$ > 1.7 TeV/c^2

m_{gKK}> 1.9 TeV/c^2

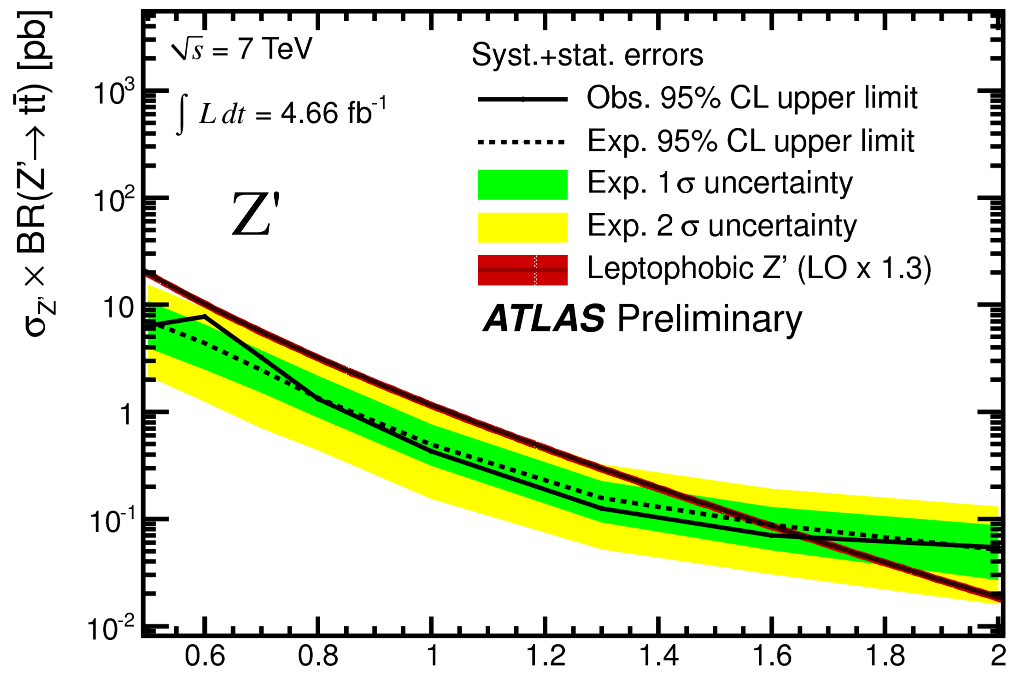
CMS, **5 fb^{-1}**

JHEP 1212 (2012) 015

$m_{Z'}$ > 1.49 TeV/c^2

m_{gKK}>1.82 TeV/c^2

All limits at 95% CL



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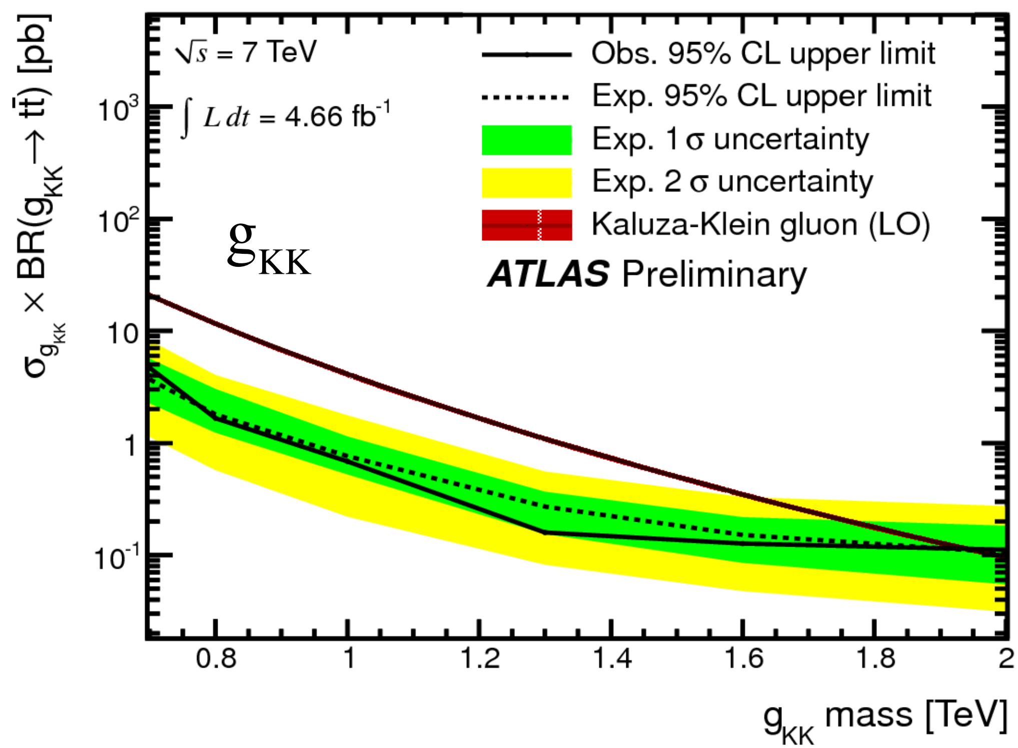


Retrospect

This plot was made with support from

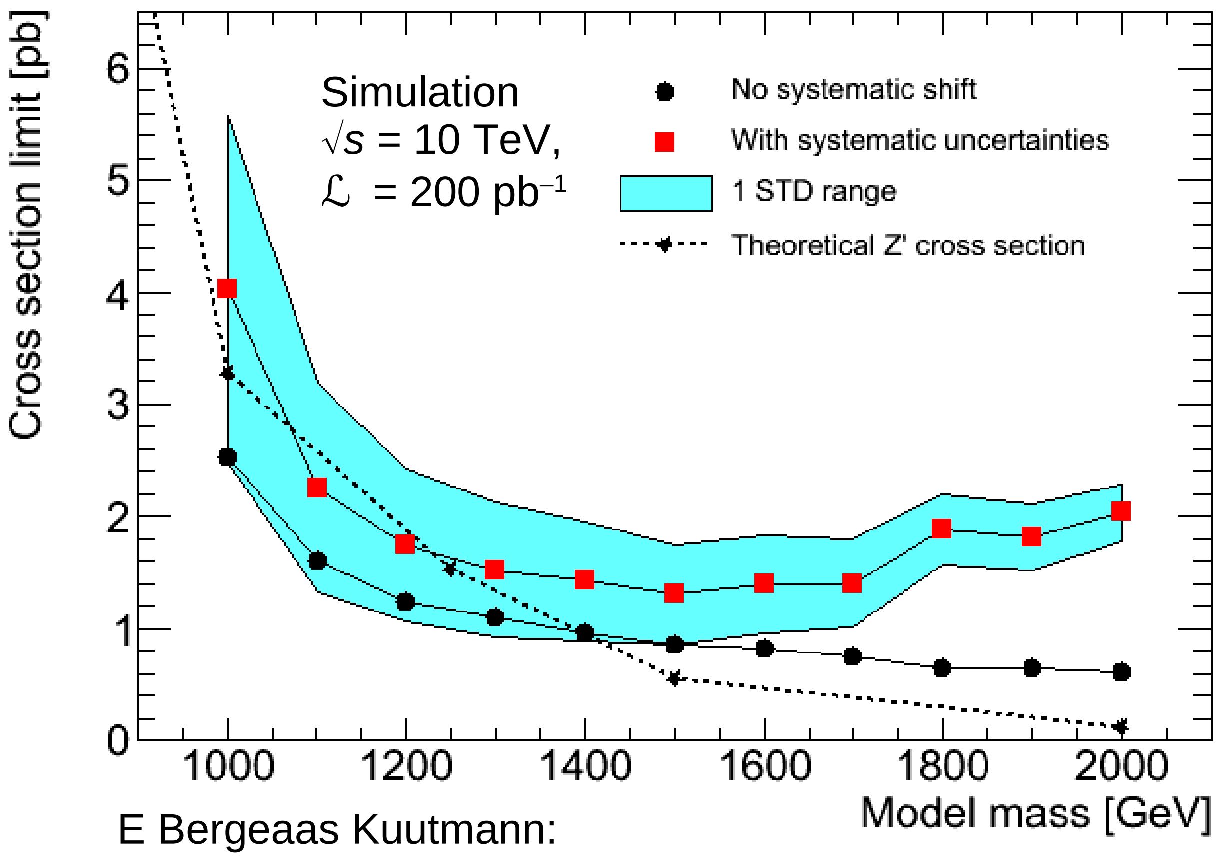
Stockholm University

Vetenskapsrådet

WALLENBERGSTIFTELSERNA
stödjer svensk forskning

THE ROYAL SOCIETY

- From DPG 2010 (Bonn)
- MC predictions (no LHC data at that time)
- Now, three years later:
  Z' excluded up to $m=1.7$ TeV/c^2!
- 5 fb^{-1} of 7 TeV data and
  20 fb^{-1} of 8 TeV data on tape.
- 13 TeV coming up



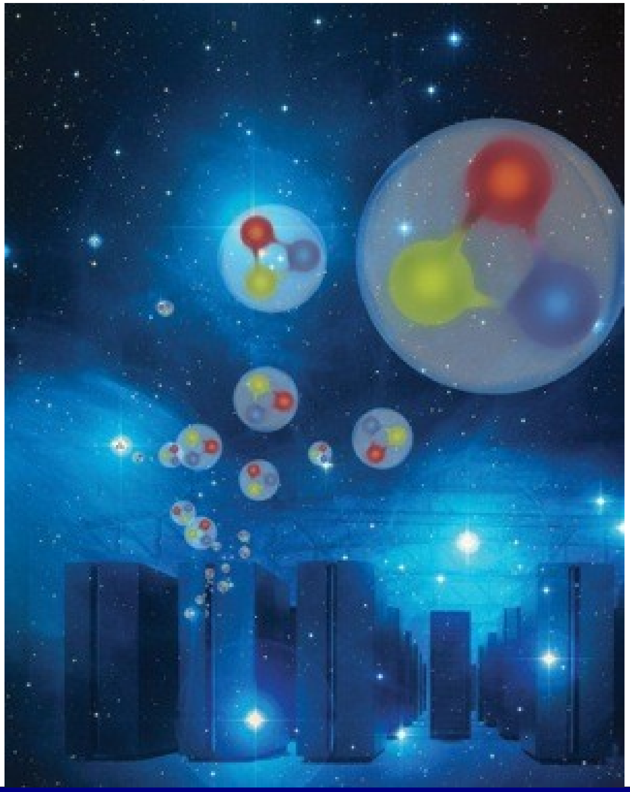
E Bergeaas Kuutmann:
CERN-THESIS-2010-026

Summary and outlook

- To reconstruct the highest-p_T top quarks, we must account for merging in the detector.
- The last three years have seen the first boosted top studies
- Techniques for reconstructing hadronically- and semi-leptonically-decaying top quarks exist.
- $t\bar{t}$ resonances as pilot studies – time to boost other top analyses too!
  - Stop searches
  - $t\bar{t}$ cross section
  - Single top
  - $b^* \rightarrow Wt$
  - ....

13 TeV data in 2015.

Image: scientificamerican.com



Extra material

Systematic uncertainties

Impact on Systematic effect	*Resolved selection* yield [%] total bgr.	*Resolved selection* yield [%] Z'	*Boosted selection* yield [%] total bgr.	*Boosted selection* yield [%] Z'
ISR/FSR	0.3	–	5.9	–
PDF	3.5	–	7.9	–
$t\bar{t}$ normalization	8.0	–	9.0	–
EW Sudakov	1.9	–	4.2	–
$t\bar{t}$ higher order QCD corr.	1.2	–	9.0	–
W + heavy flavor	1.3	–	1.2	–
Multi-jets norm, e+jets	2.6	–	0.6	–
Multi-jets norm, μ+jets	1.0	–	1.1	–
Parton shower	0.2	–	7.3	–
JES, anti-k_t R = 0.4 jets	7.8	2.9	0.5	0.5
JES, anti-k_t R = 1.0 jets	0.2	4.8	17.0	2.8
b-tag efficiency	3.8	7.7	6.0	3.5
c-tag efficiency	1.2	0.6	0.1	2.5
Mistag rate	1.0	0.3	0.7	0.1

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