Mumbai, 14 December 2017

Search for heavy resonances decaying to top quarks

Christoph Anders
Physikalisches Institut — Universität Heidelberg
On behalf of the ATLAS collaboration

UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386

FSP 103 ATLAS

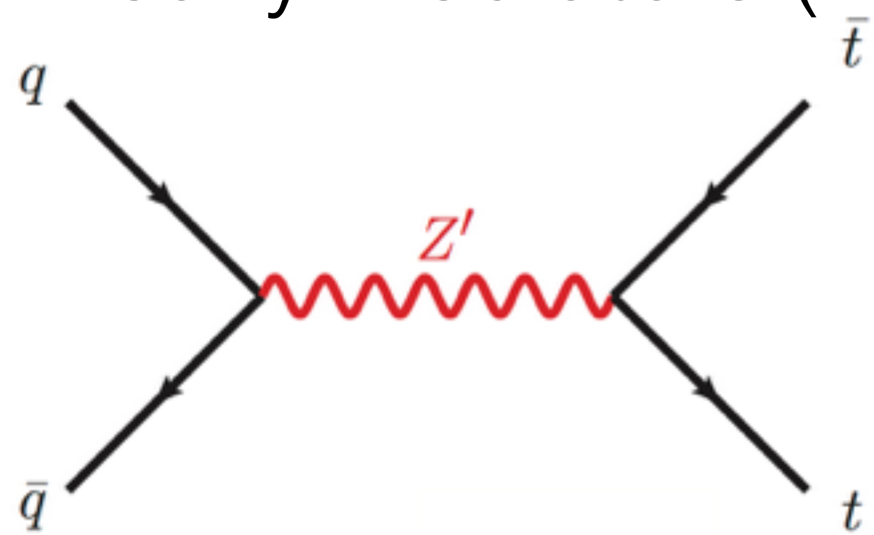
GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

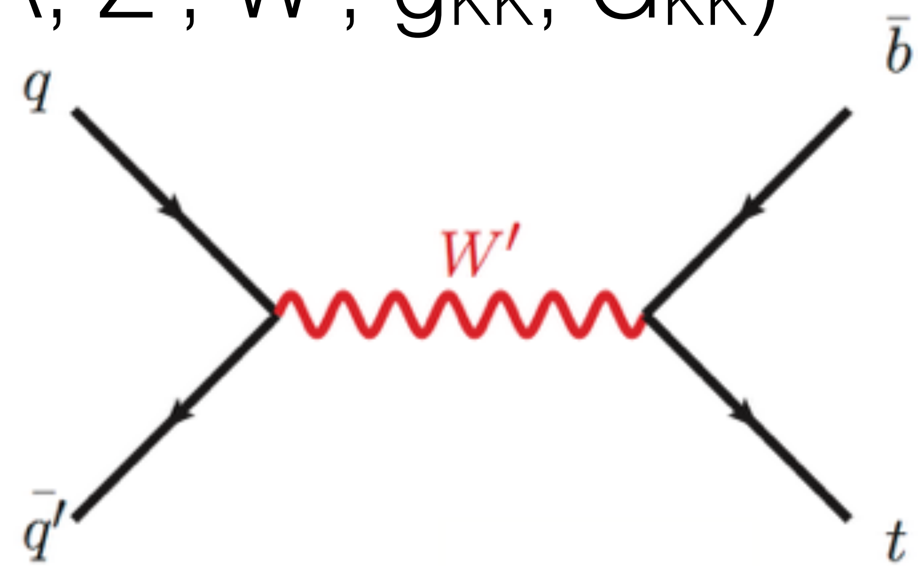
Why top quarks?

- Top quarks are heavy —> Very large Yukawa coupling

- Many scenarios for beyond the Standard Model physics predict enhanced couplings to third generation quarks, non-SUSY examples:

  - heavy mediators (H, A, Z', W', g_{KK}, G_{KK})

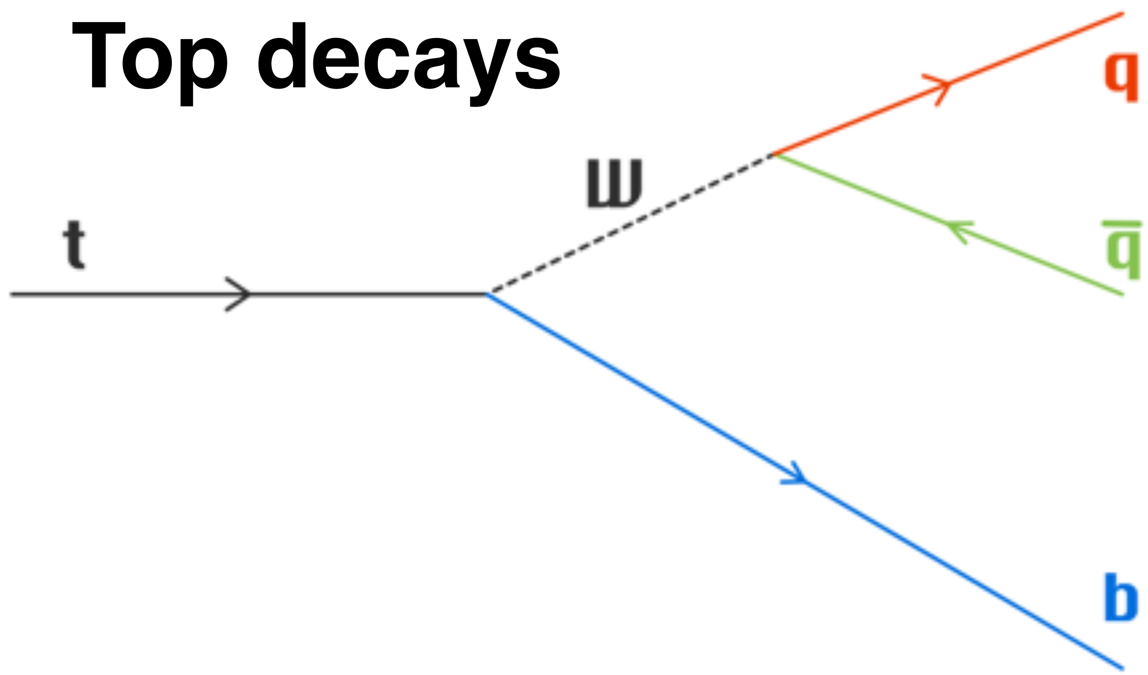




  - top partners (Vector-like quarks, see Romain Kukla's talk)

Intermission:

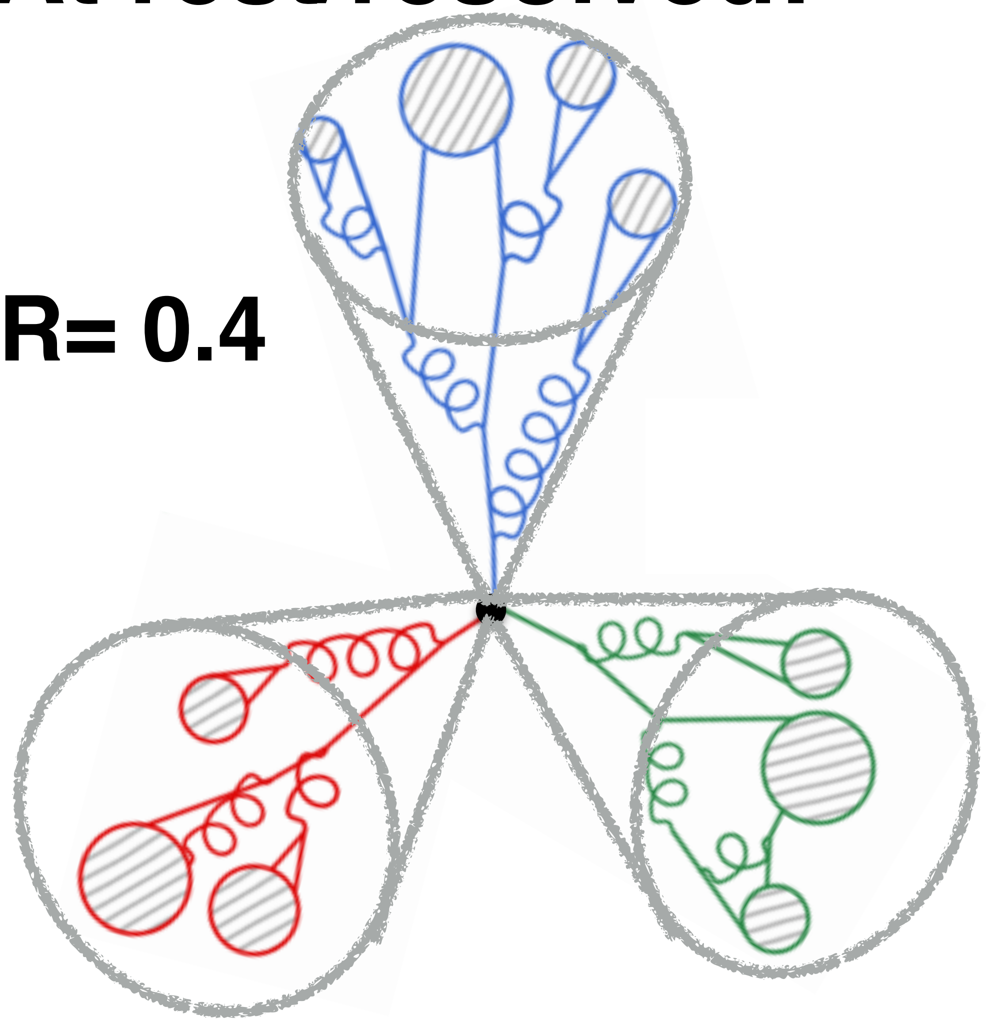
Top decays



"Jet substructure as a new Higgs search channel at the LHC"
Phys.Rev.Lett. 100 (2008) 242001

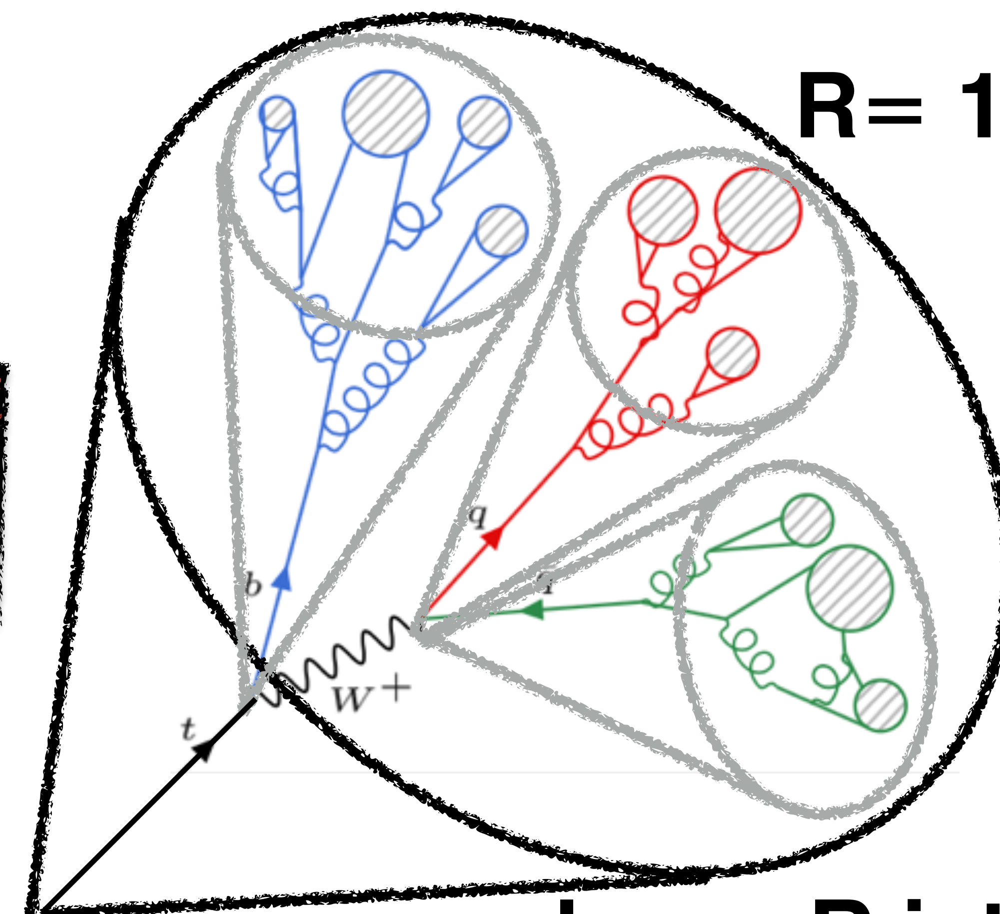
At rest/resolved:

R= 0.4



"Boost"

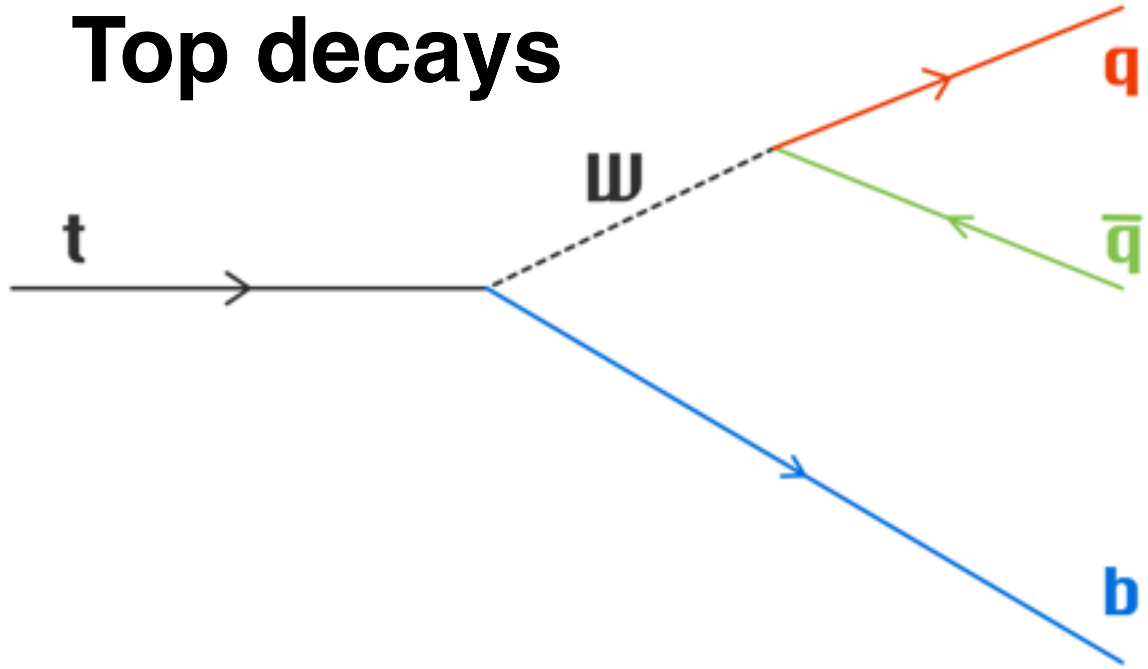
R= 1.0

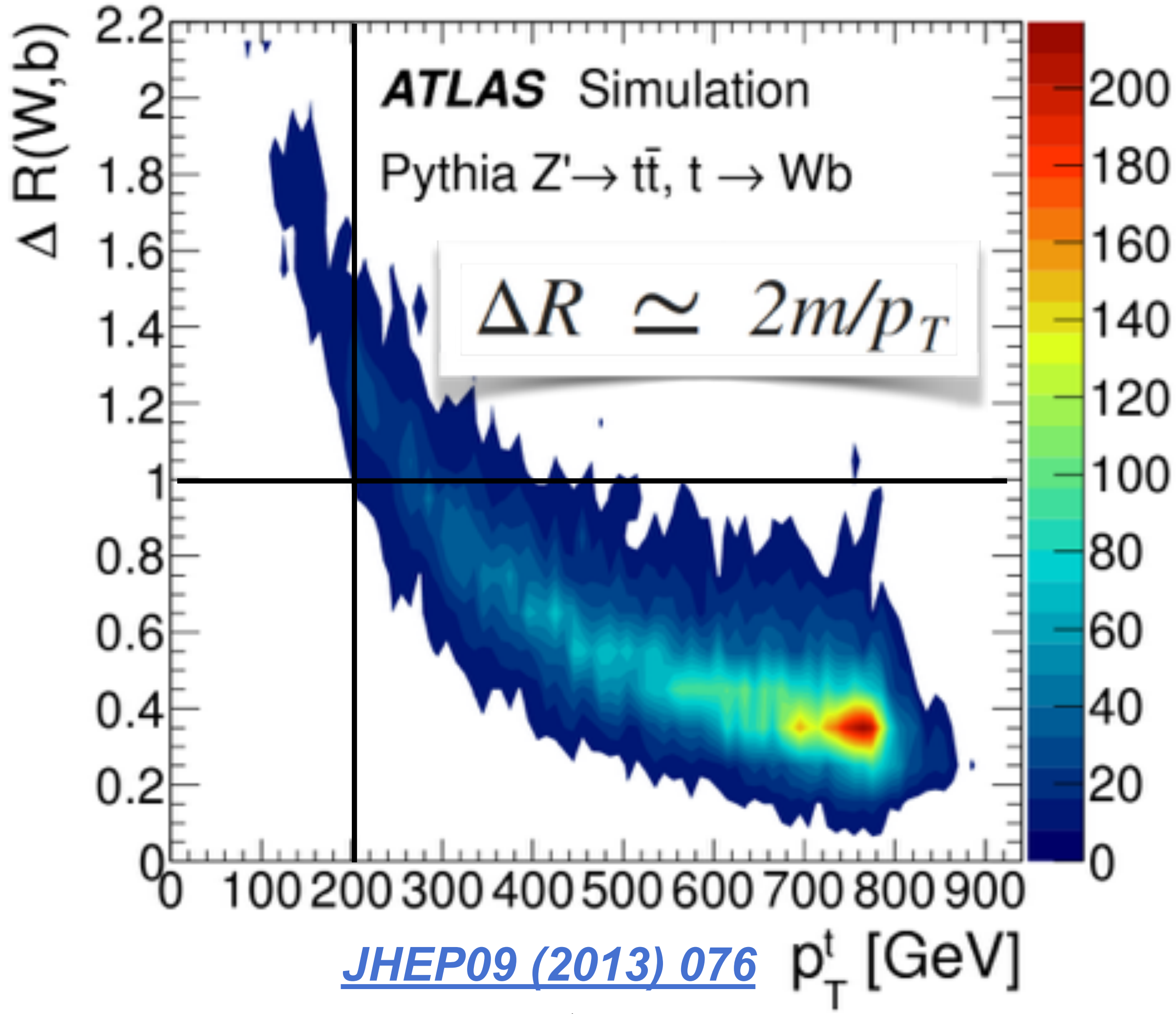


large-R jet

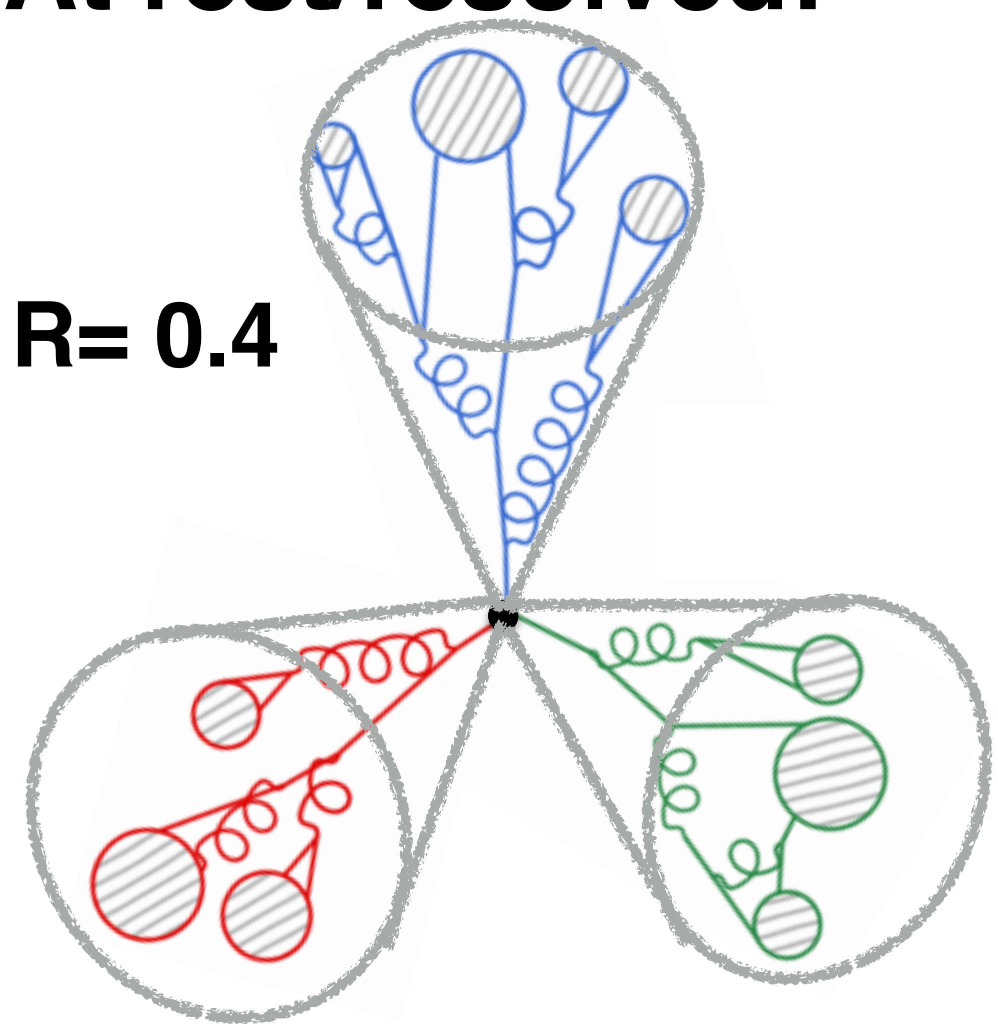
Intermission:

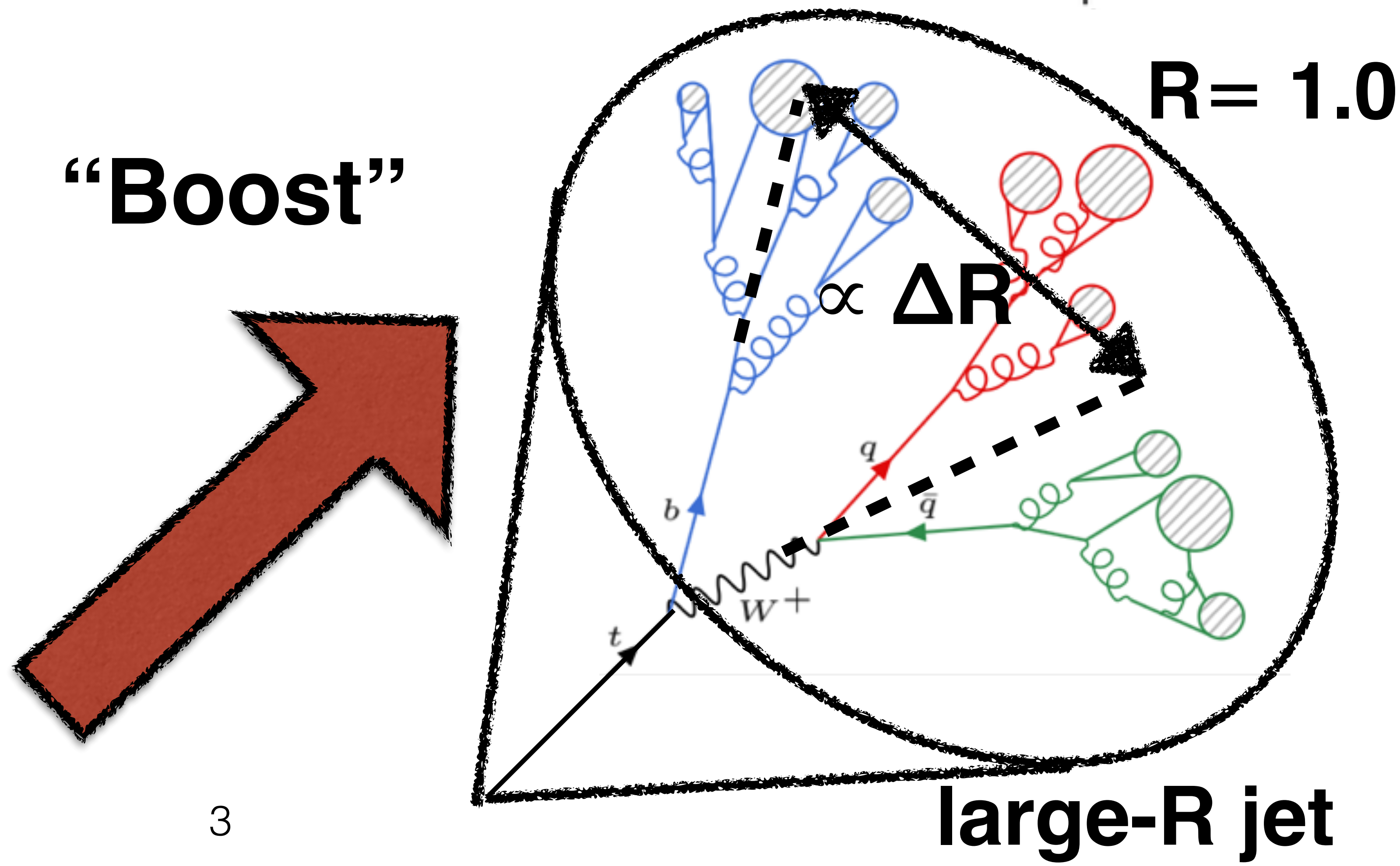
Top decays





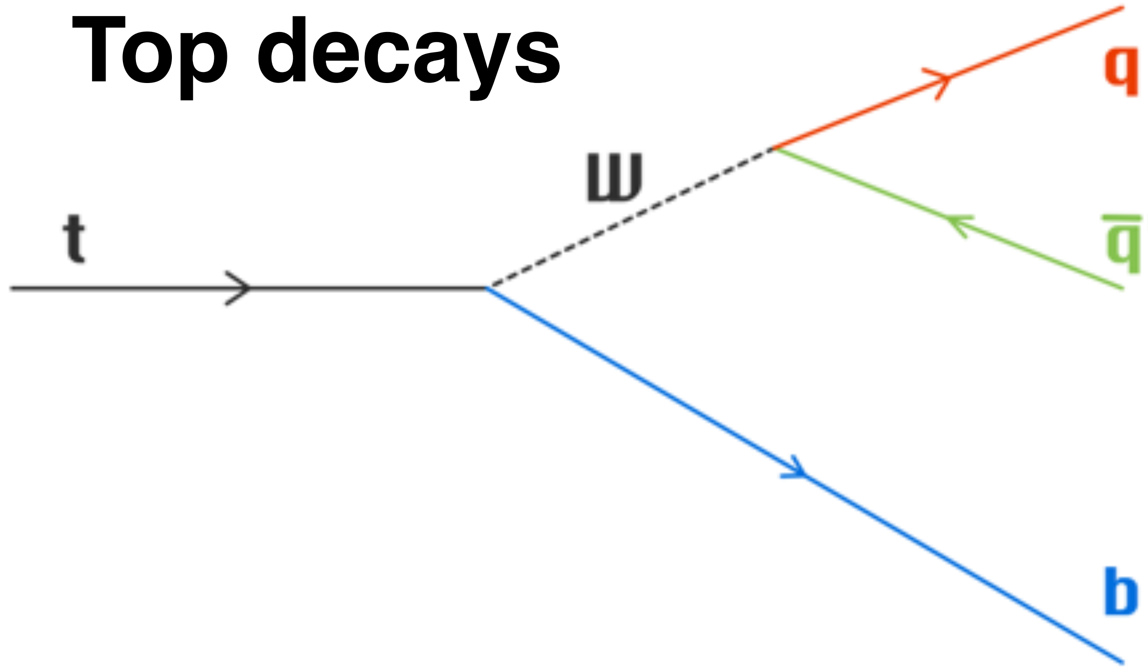
At rest/resolved:

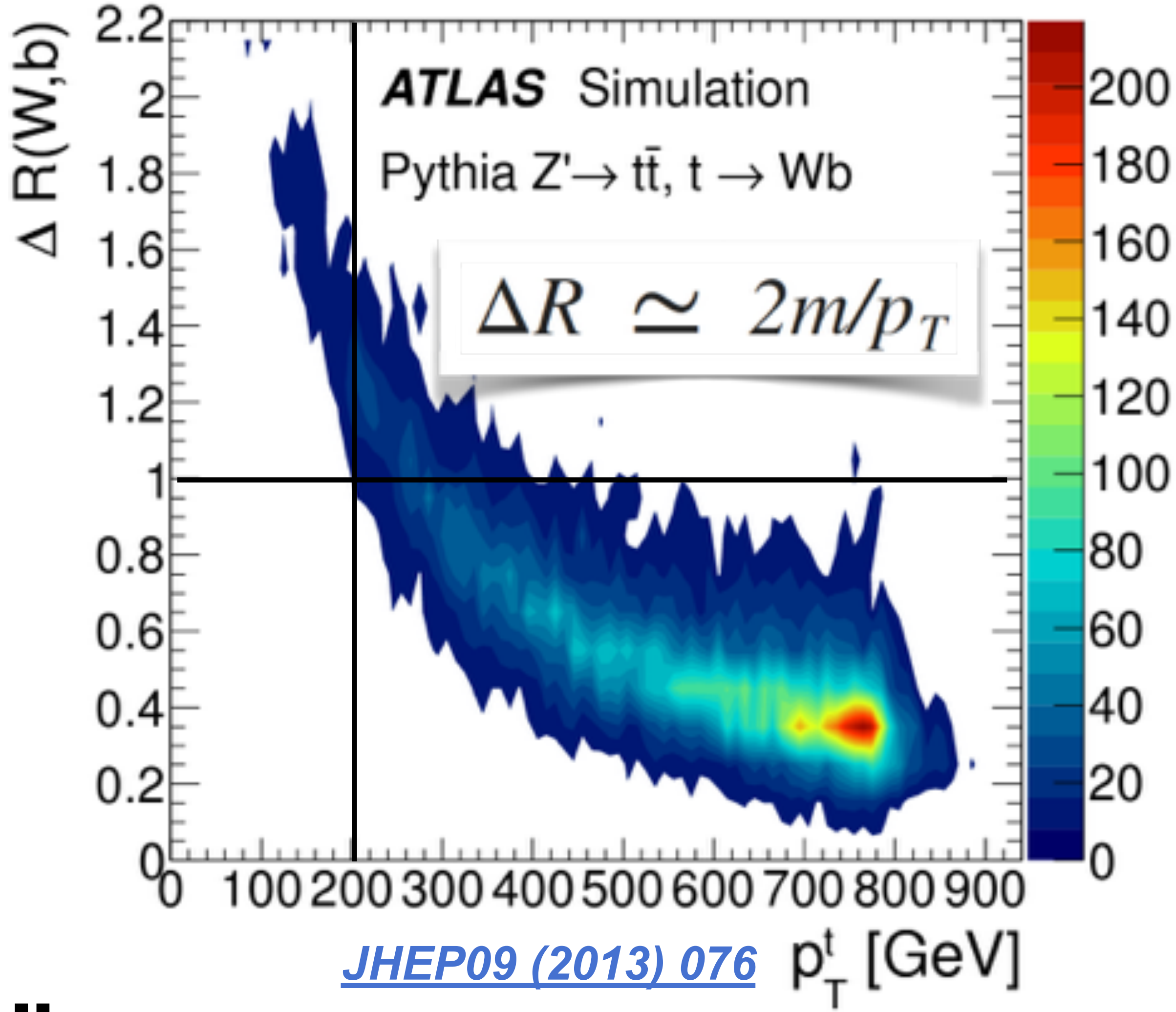




Intermission:

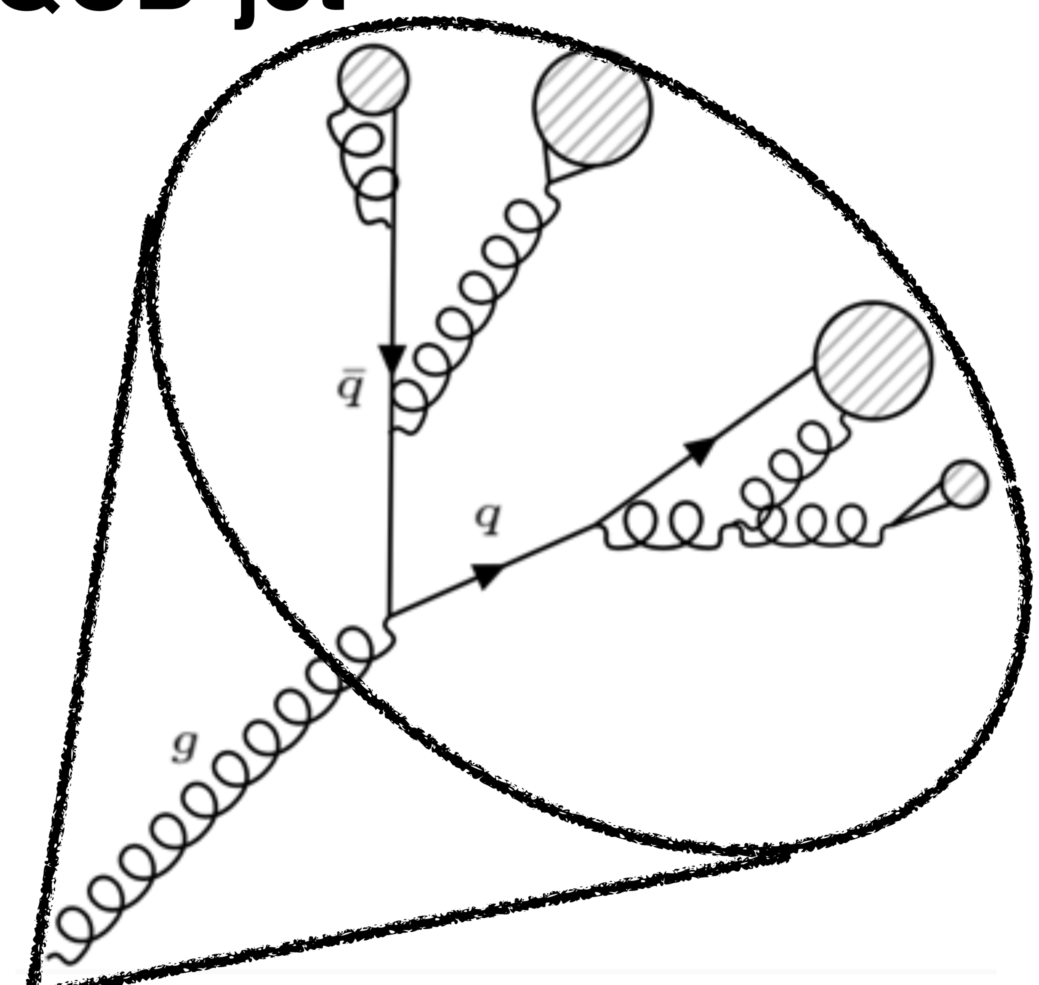
Top decays



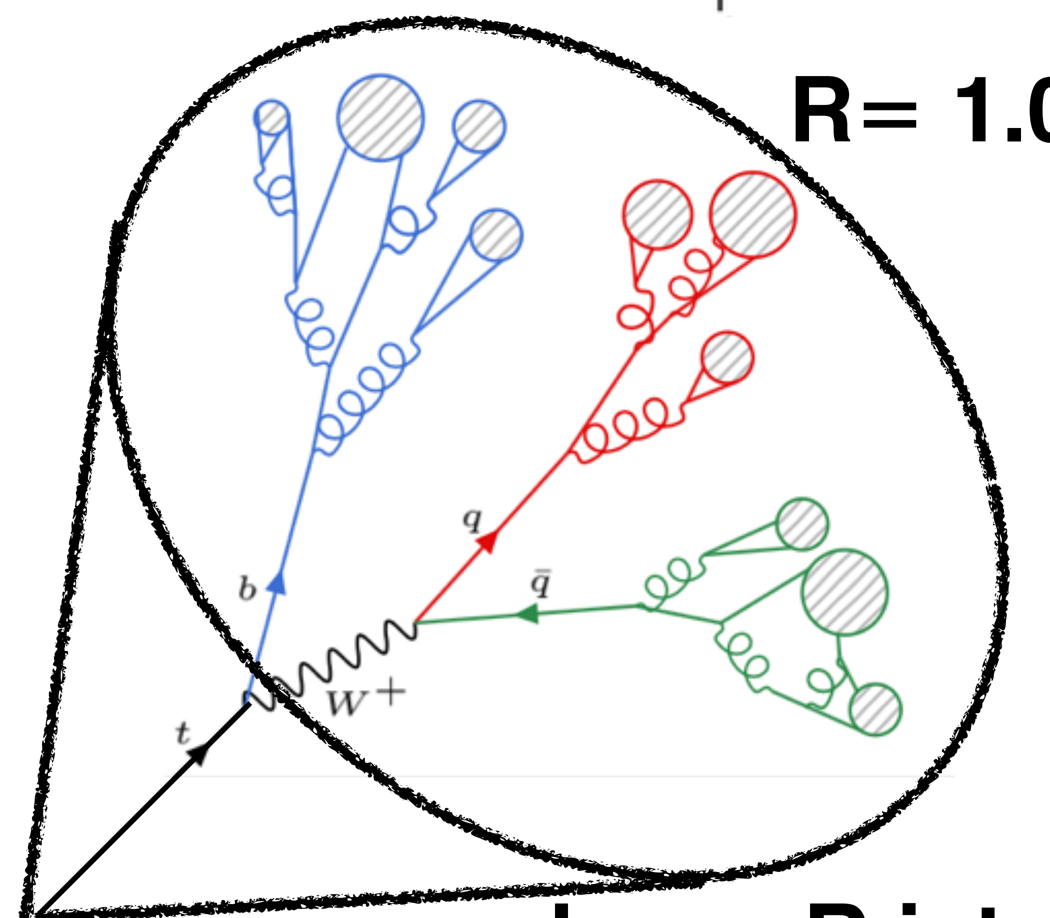


JHEP09 (2013) 076

“QCD-jet”



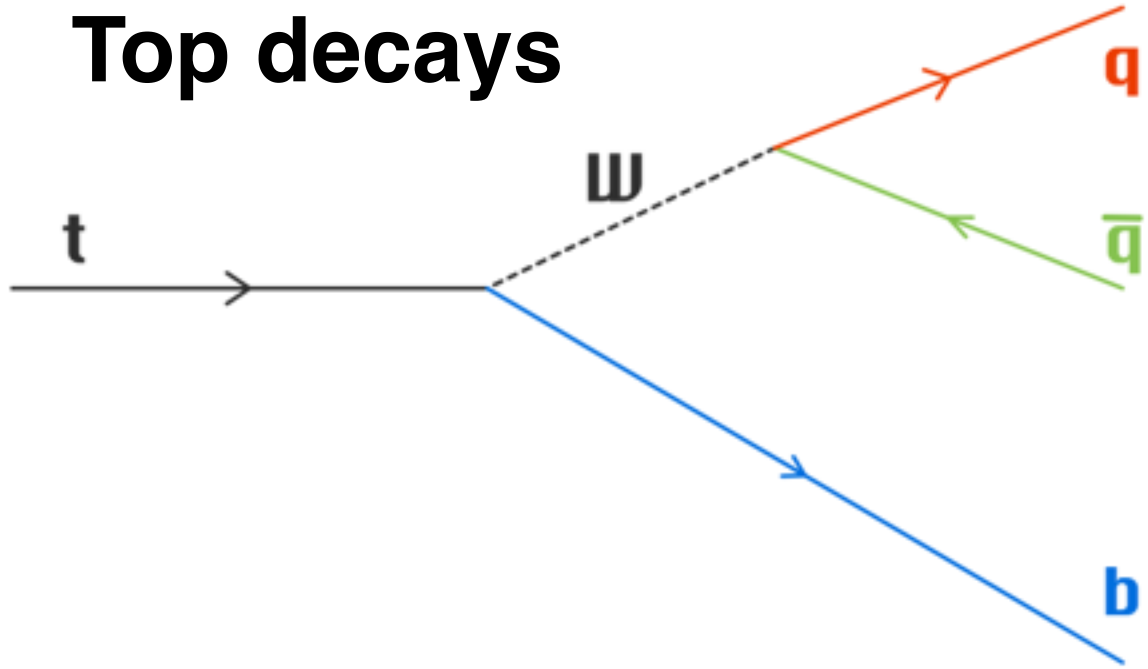
“top-jet”



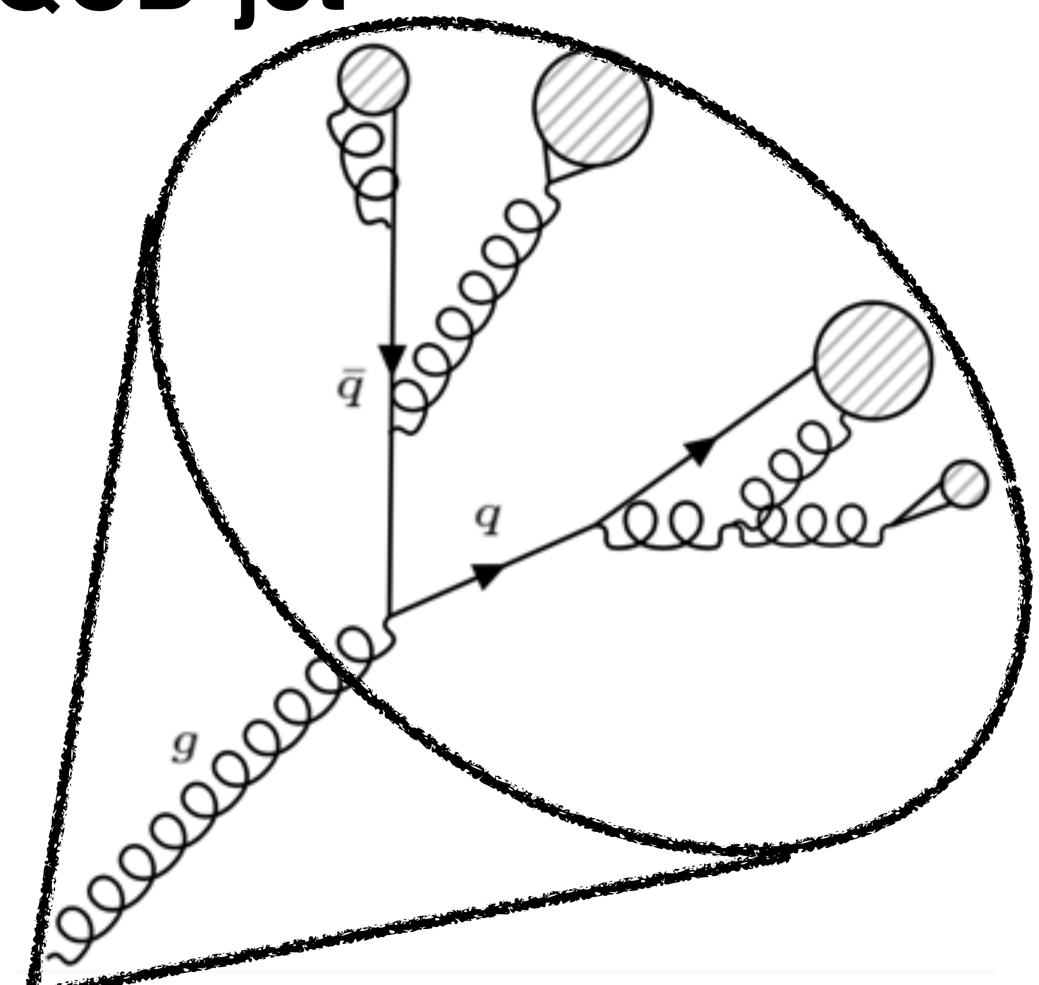
large-R jet

Intermission:

Top decays

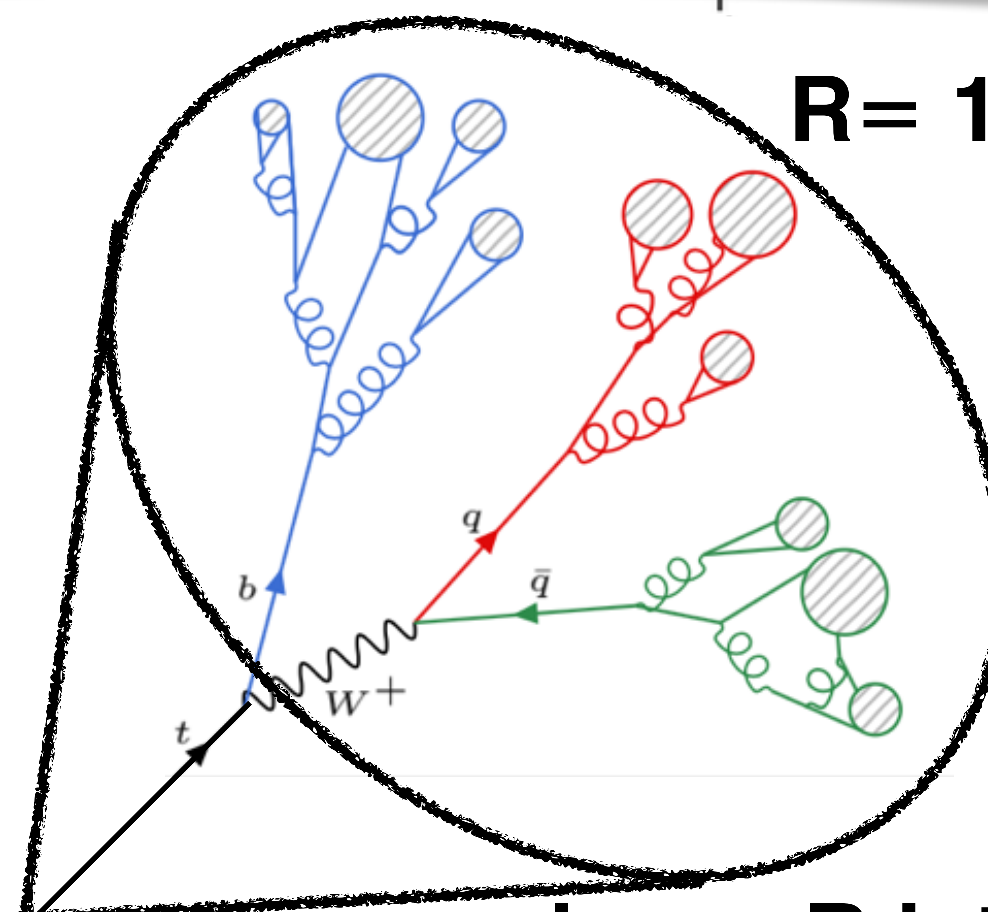


“QCD-jet”



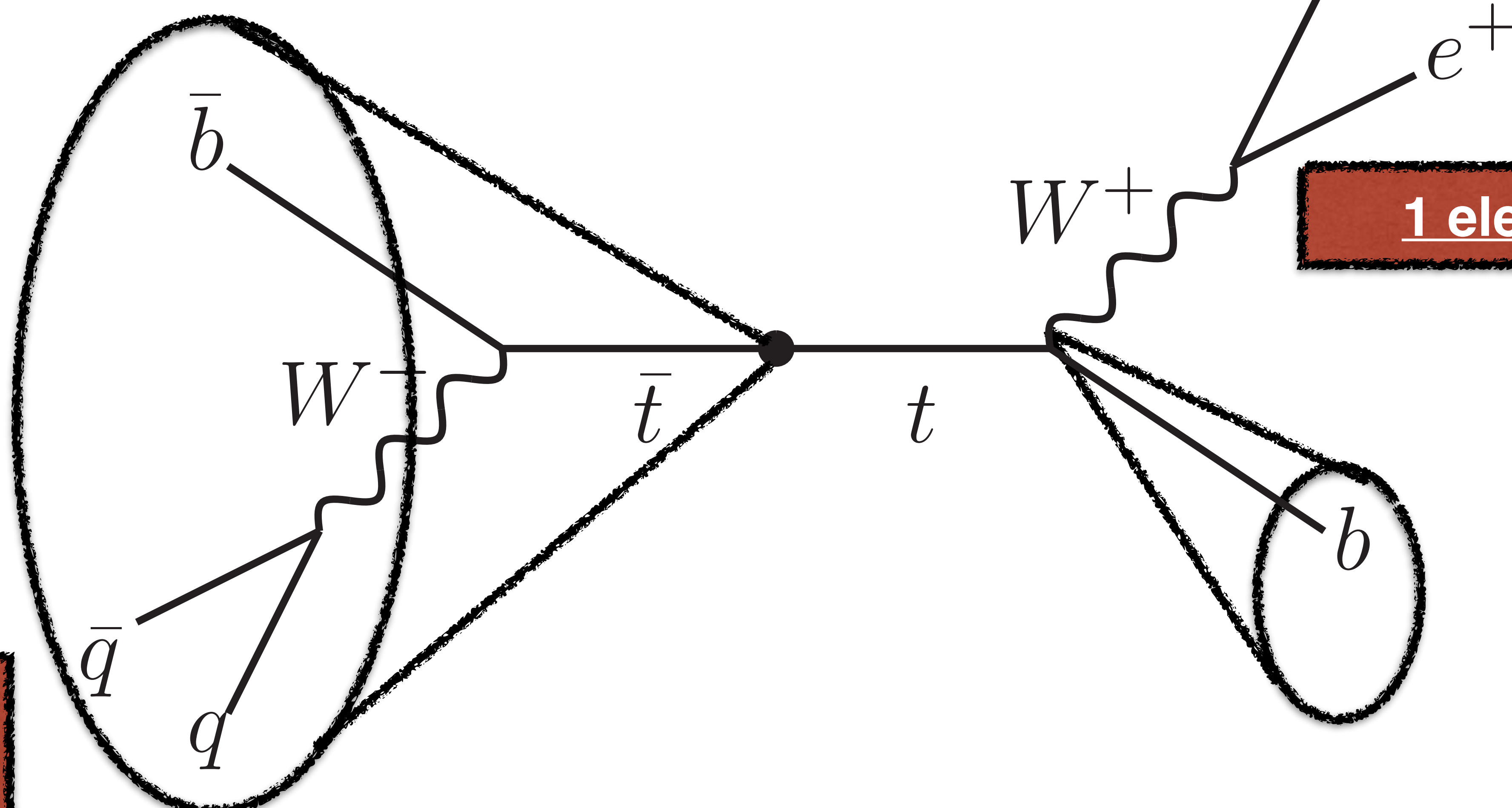
“top-jet”

R= 1.0



large-R jet

Search for $t\bar{t}$ resonances in the lepton + jets channel @ 13 TeV



1 large-R jet (trimmed anti-k_t, R=1.0, p_T>300 GeV), **top-tagged**

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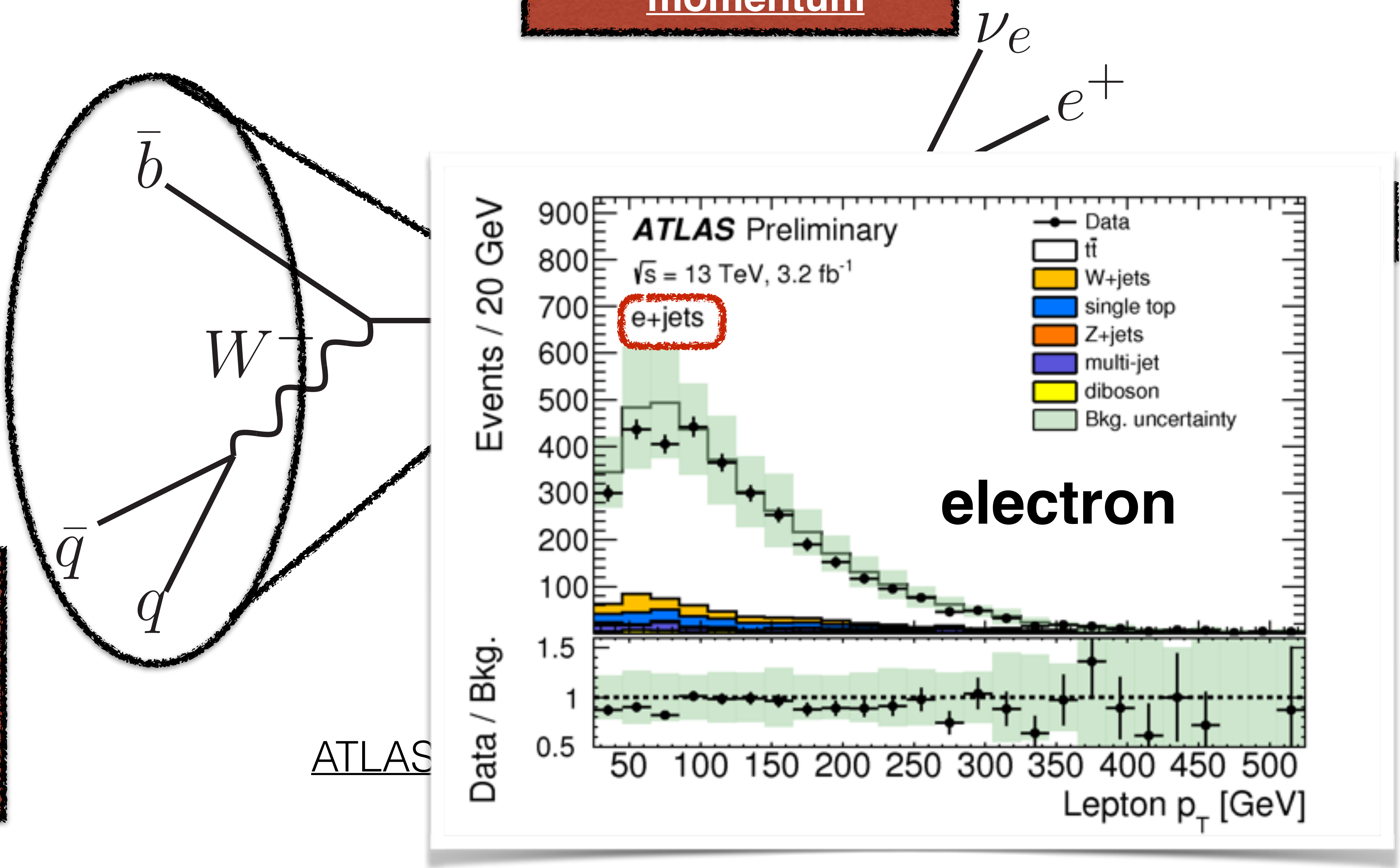
1 b-tagged Jet (anti-k_t track Jet, R=0.2)

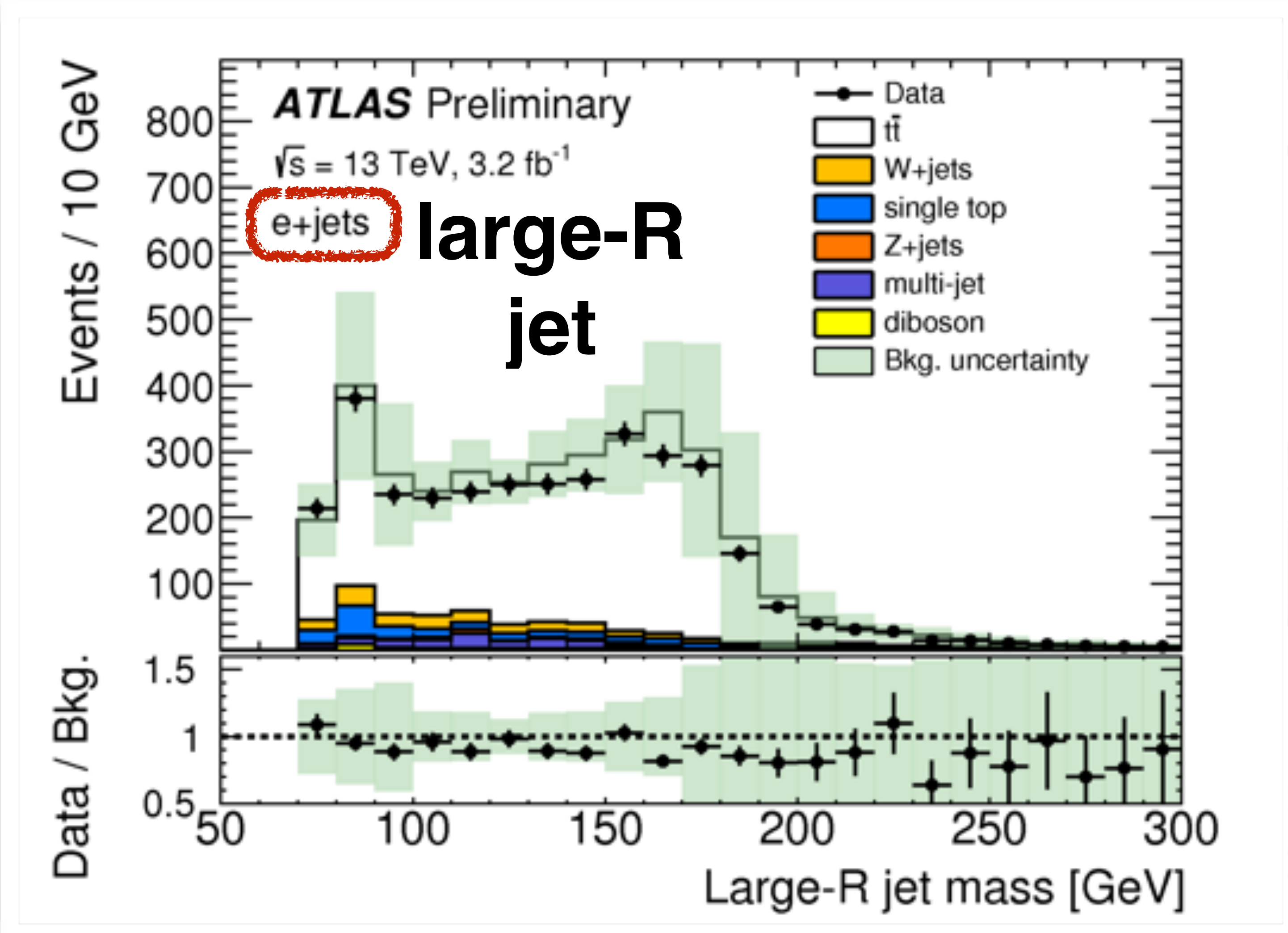
Search for $t\bar{t}$ resonances in the lepton + jets channel @ 13 TeV

missing transverse momentum

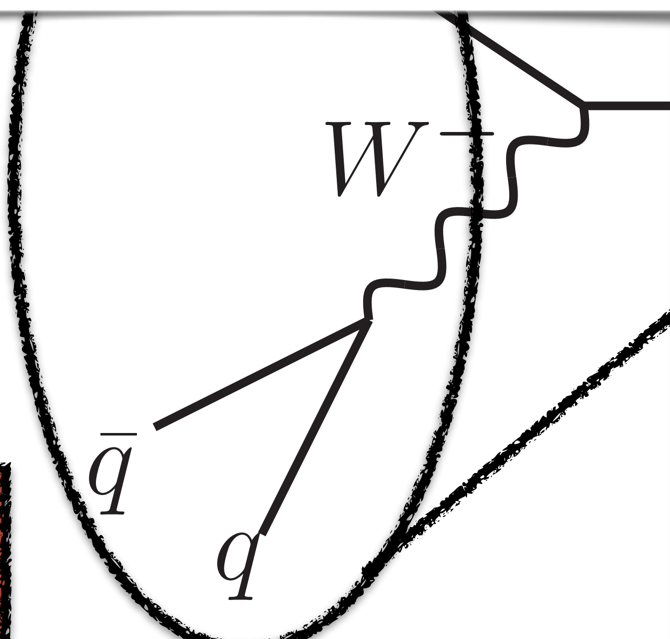


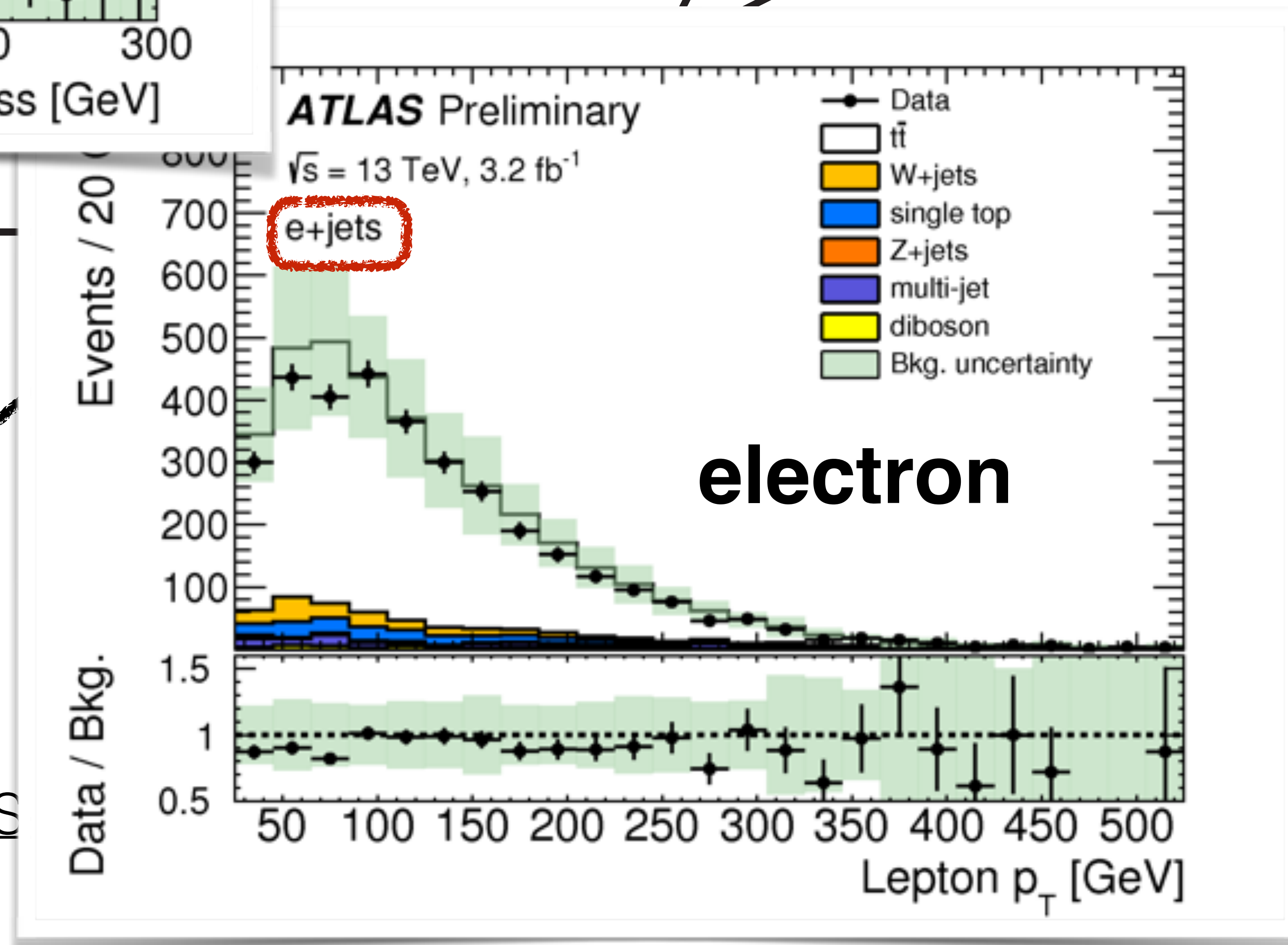
1 large-R jet (trimmed anti-k_t, R=1.0, p_T>300 GeV), **top-tagged**

...onances in the ...nnel @ 13 TeV



...ssing transverse momentum





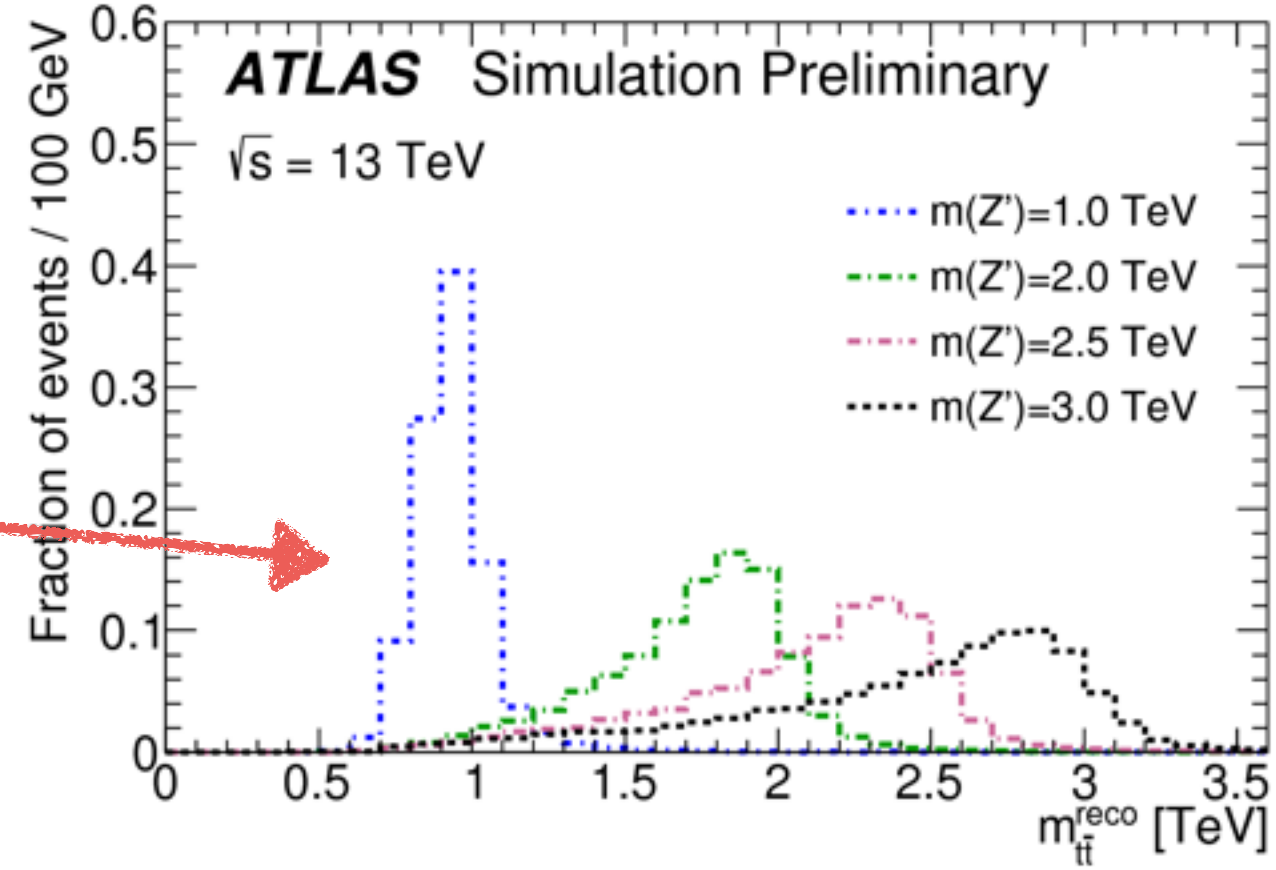
1 large-R jet (trimmed anti-k_t, R=1.0, p_T>300 GeV), **top-tagged**

ATLAS

Top pair mass

Signal (simulation)

Z'—> $t\bar{t}$



data+background MC

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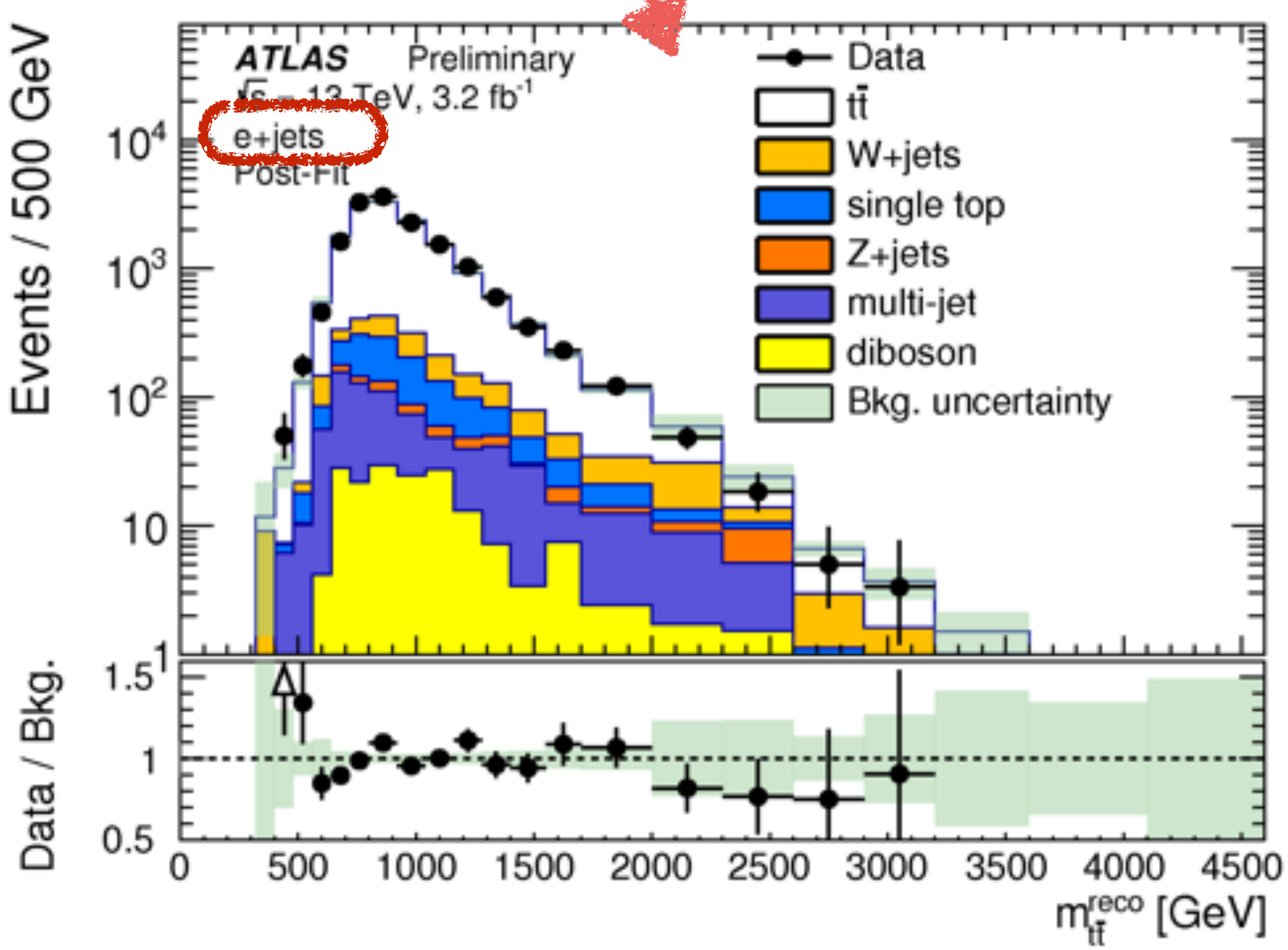
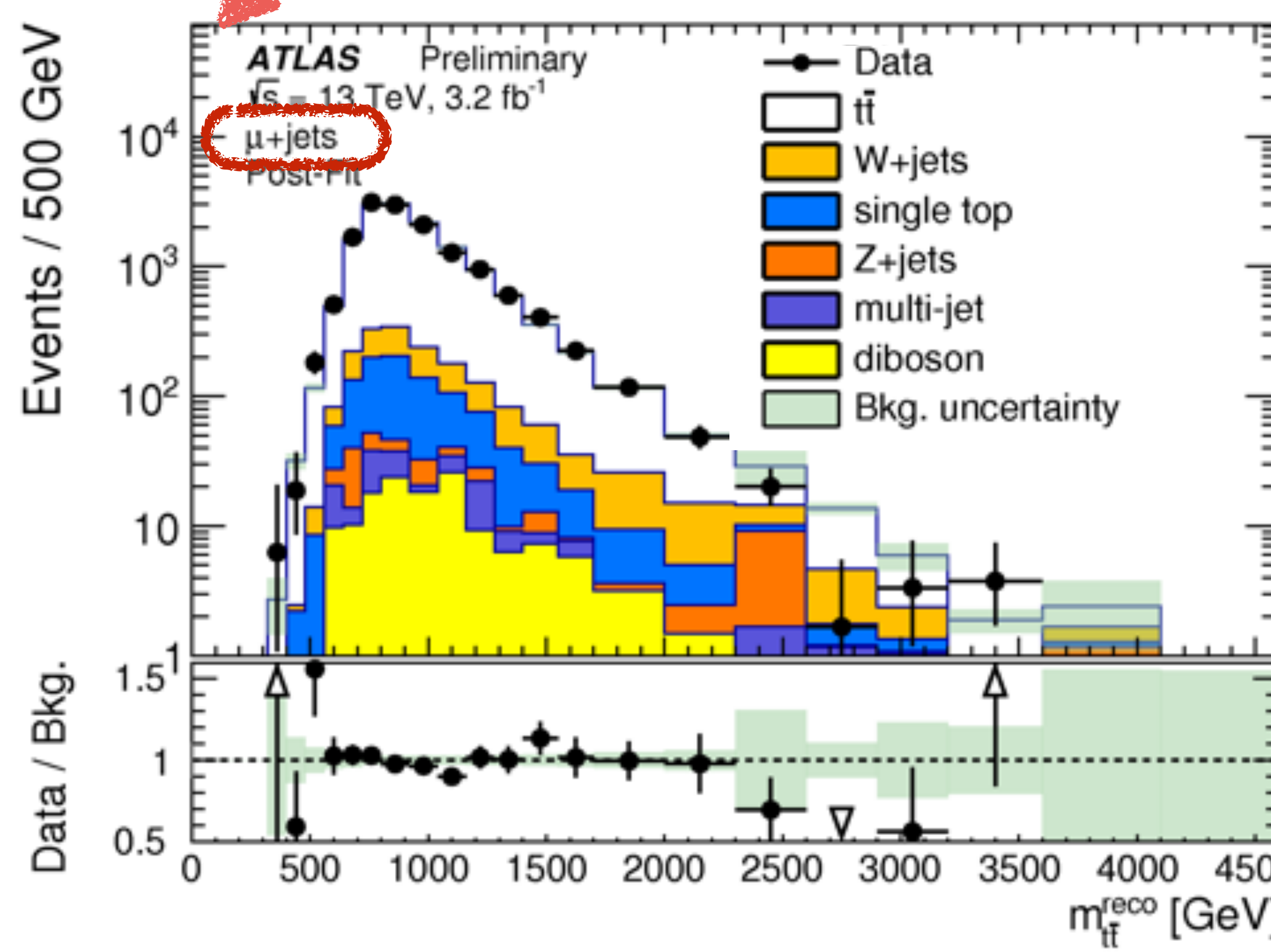
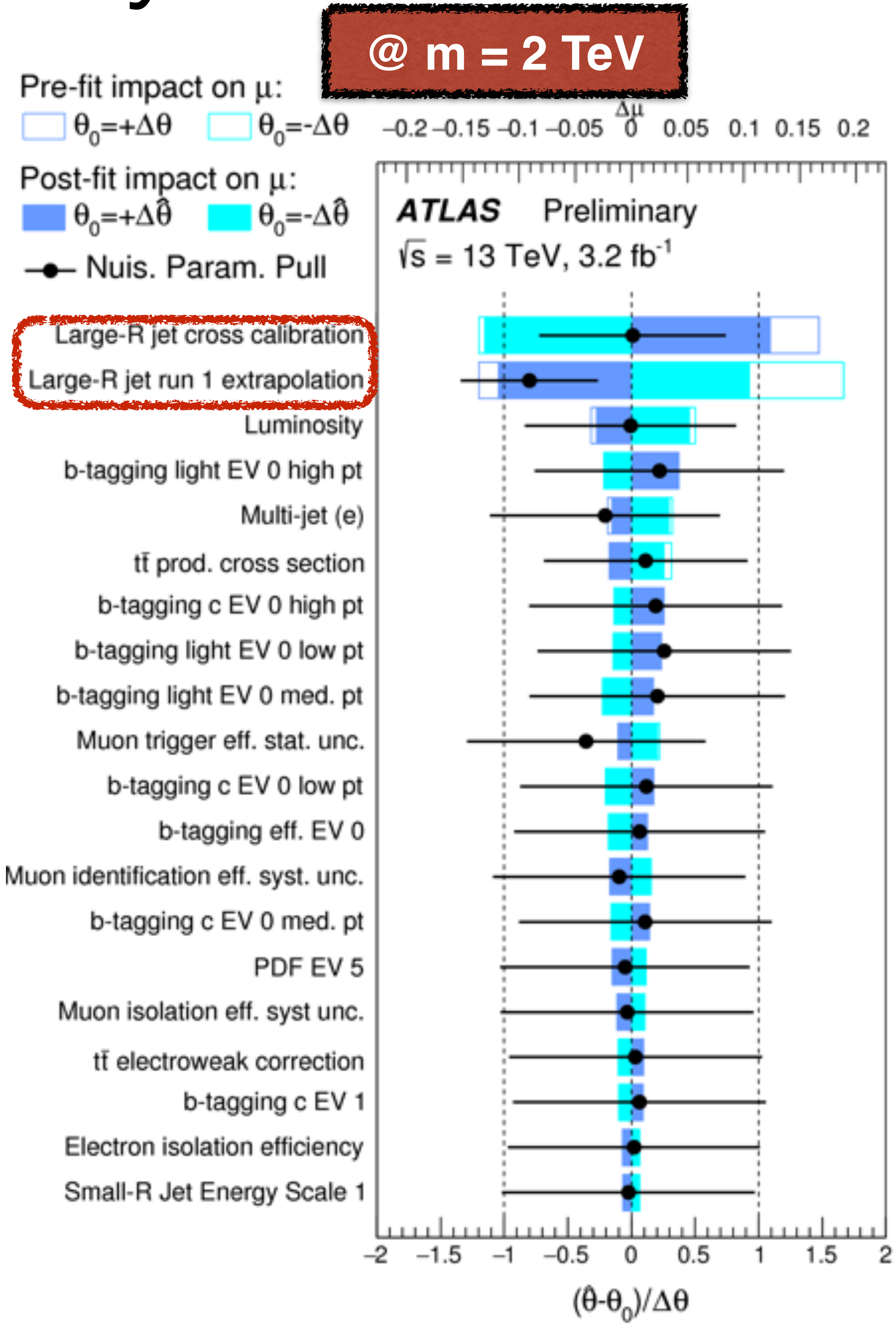
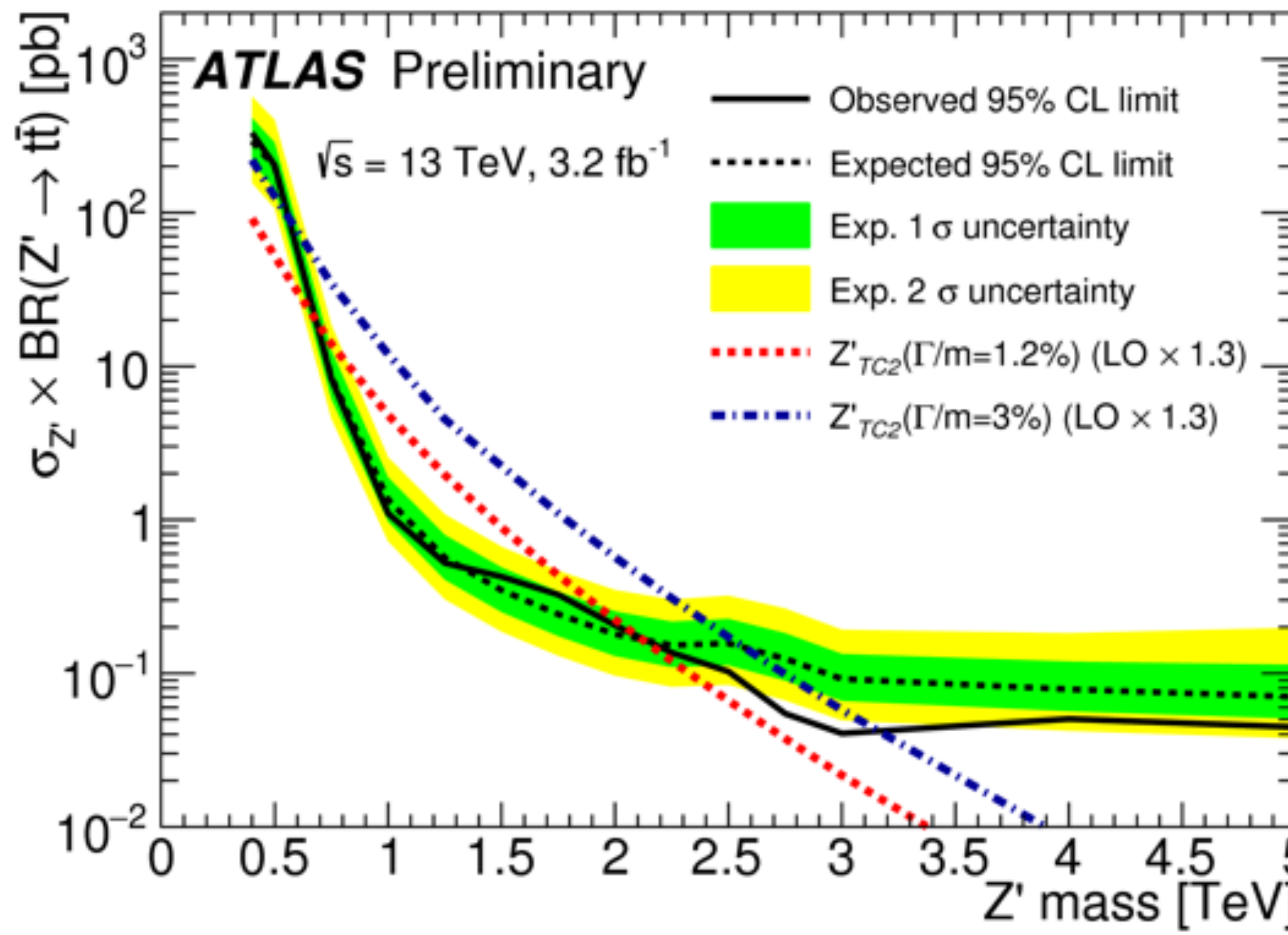




Systematics and limits for Z'—>tt̄





- biggest uncertainties due to large R jet scale uncertainties
- $0.7 < m_{Z'} < 2.0$ TeV excluded at 95% C.L.

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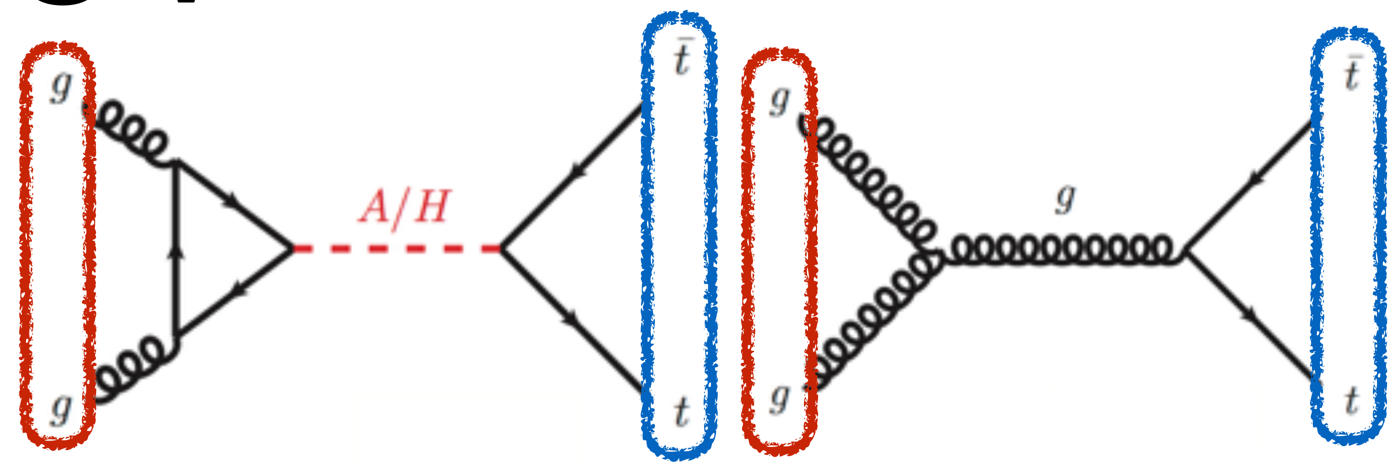
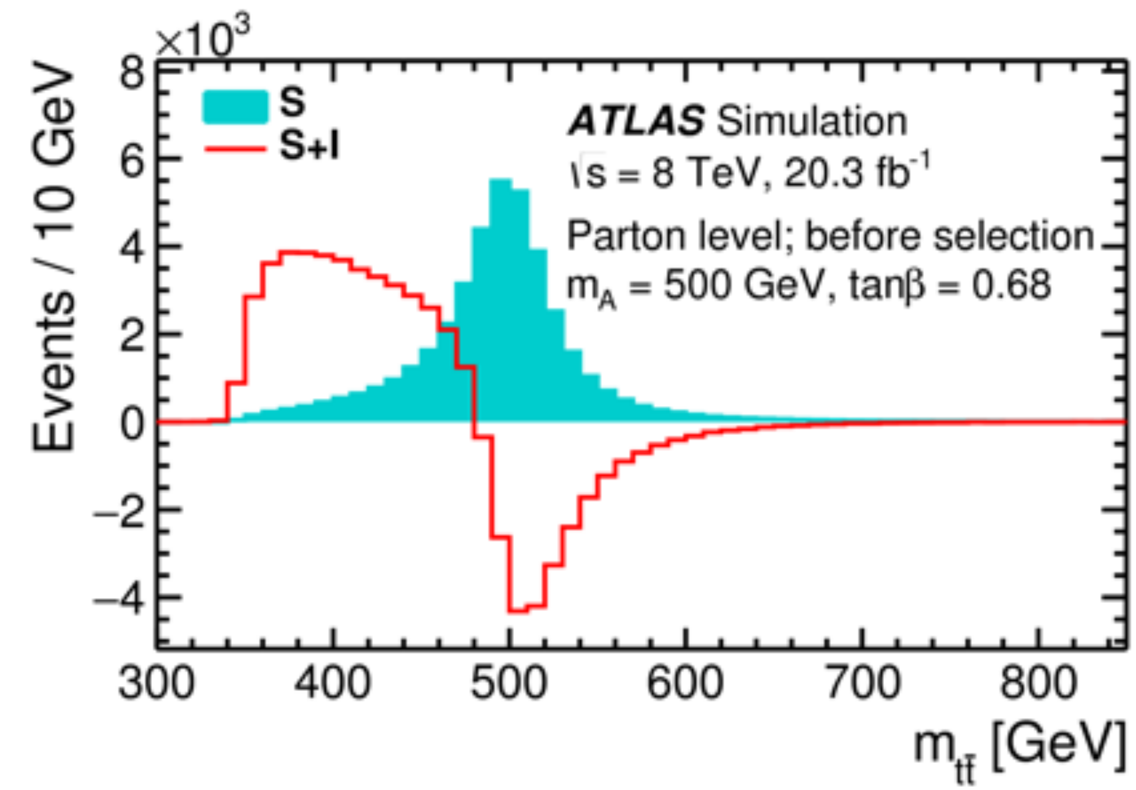
H/A—>$t\bar{t}$ @8 TeV

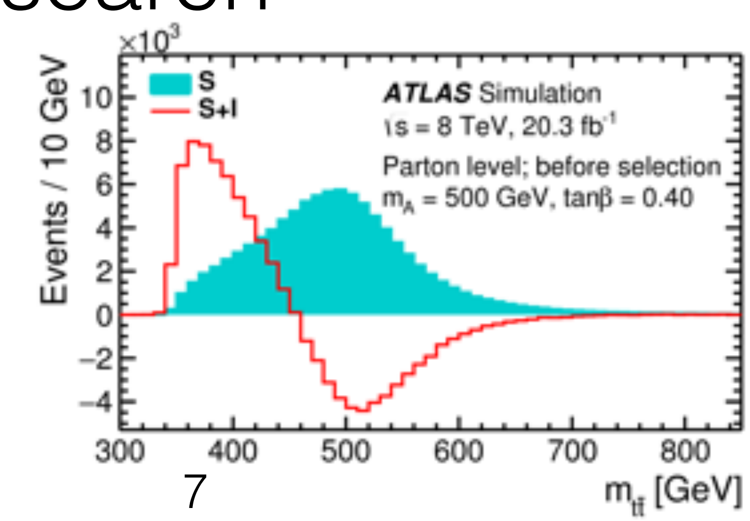
[Phys. Rev. Lett. 119 (2017) 191803](https://doi.org/10.1103/PhysRevLett.119.191803)

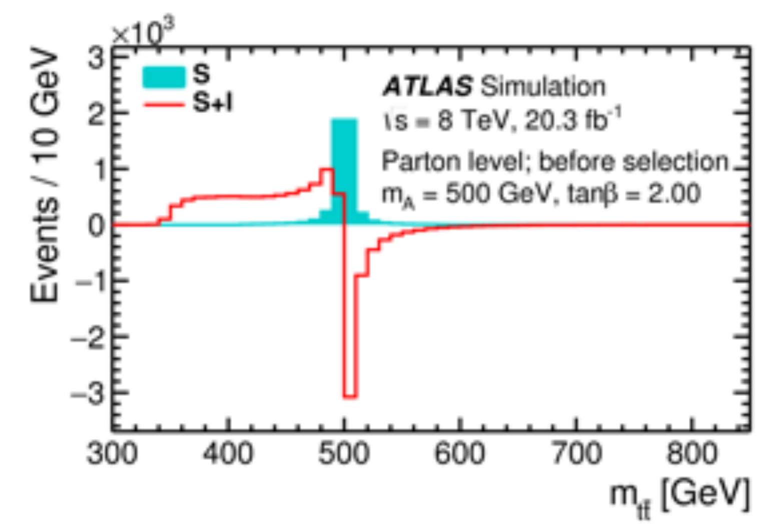


- 2HDM Type II: heavy pseudo/scalar A/H —> $t\bar{t}$
- Interferes with SM $t\bar{t}$ production (same initial and final states)



- Generate Signal+Interference events using MadGraph5_aMC@NLO
- Reinterpretation of Run 1 search (JHEP 08 (2015) 148)

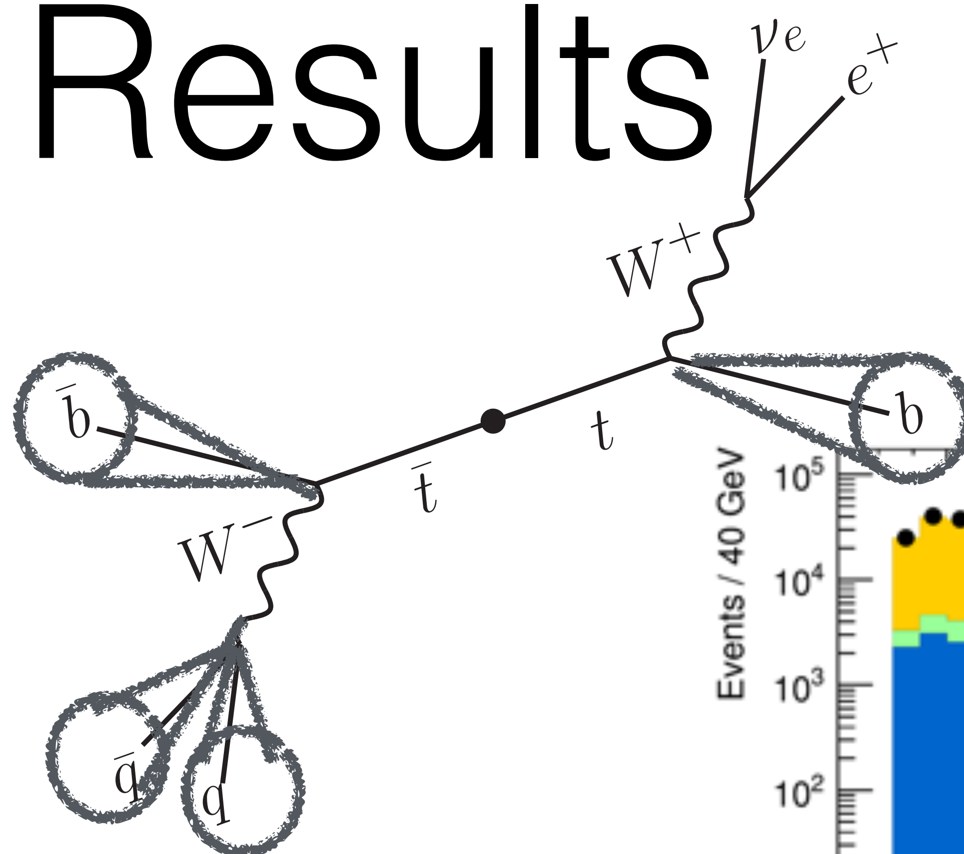


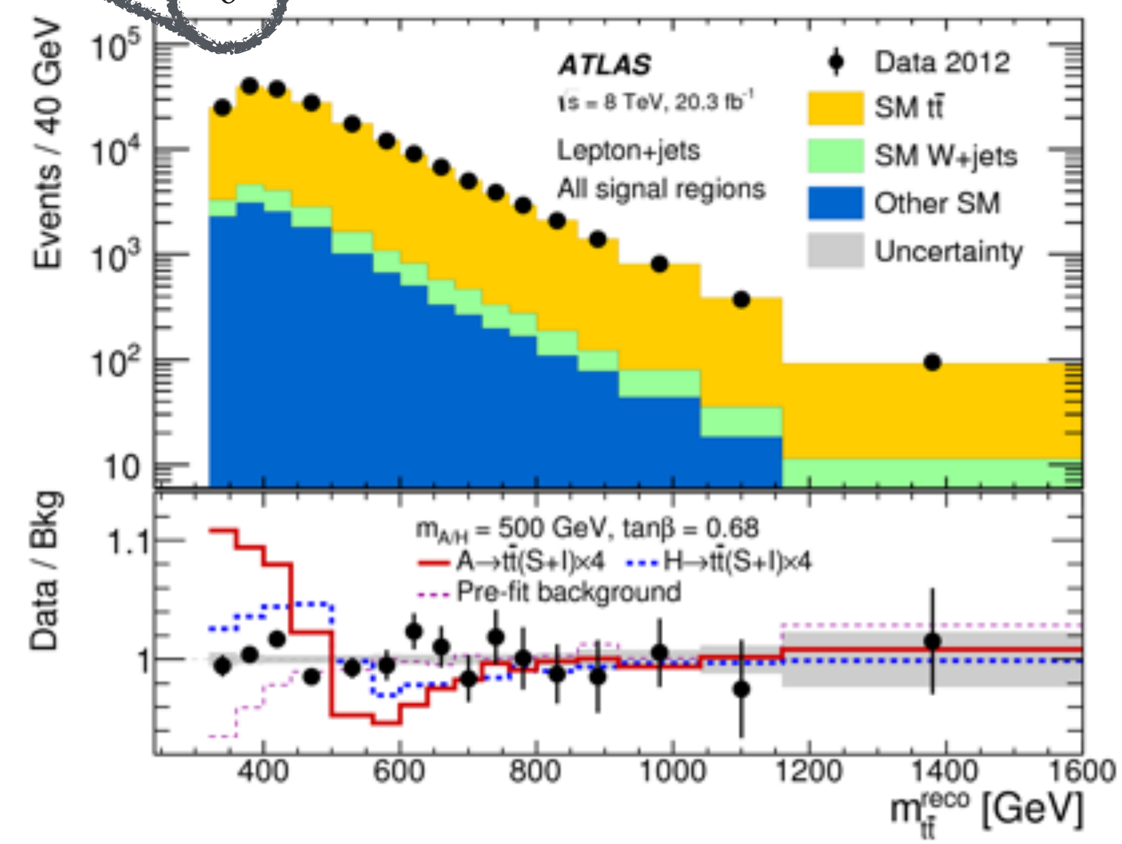


H/A—>tt̄ Results

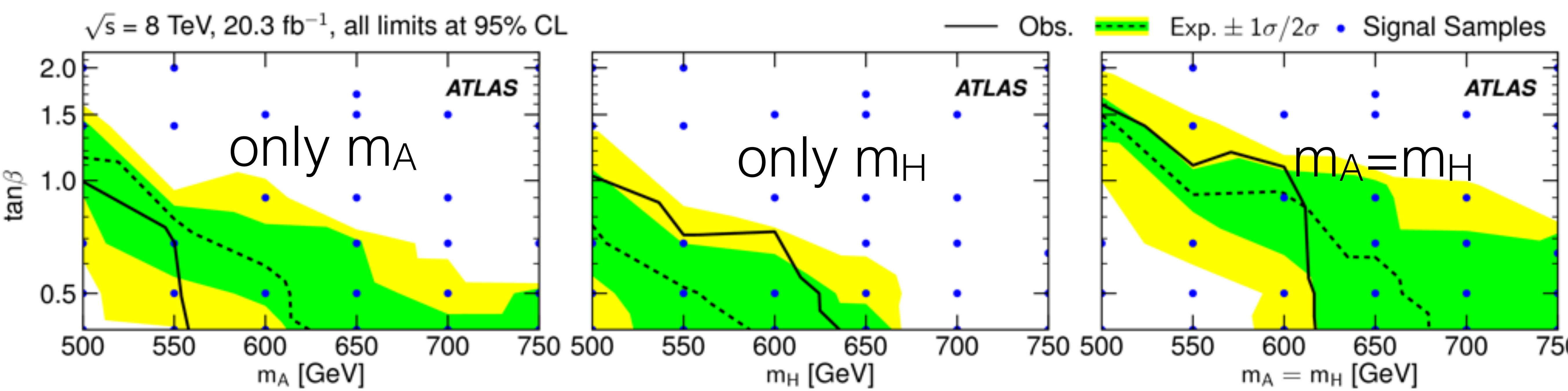
[Phys. Rev. Lett. 119 (2017) 191803]

- Resolved selection:
  - 1 electron/muon
  - at least 4 jets
  - at least 1 b-jet
  - χ^2 to reconstruct top candidates



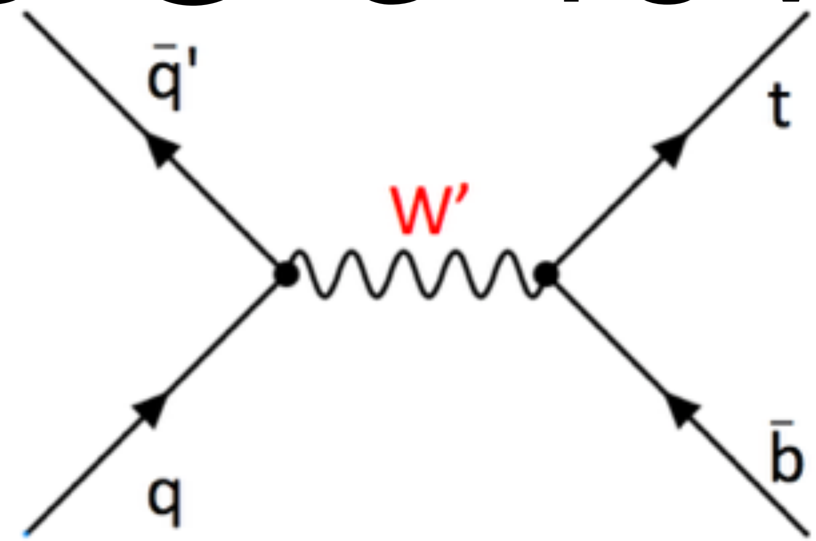


No sign of scalar/pseudo scalar
—> set limits in 3 scenarios:

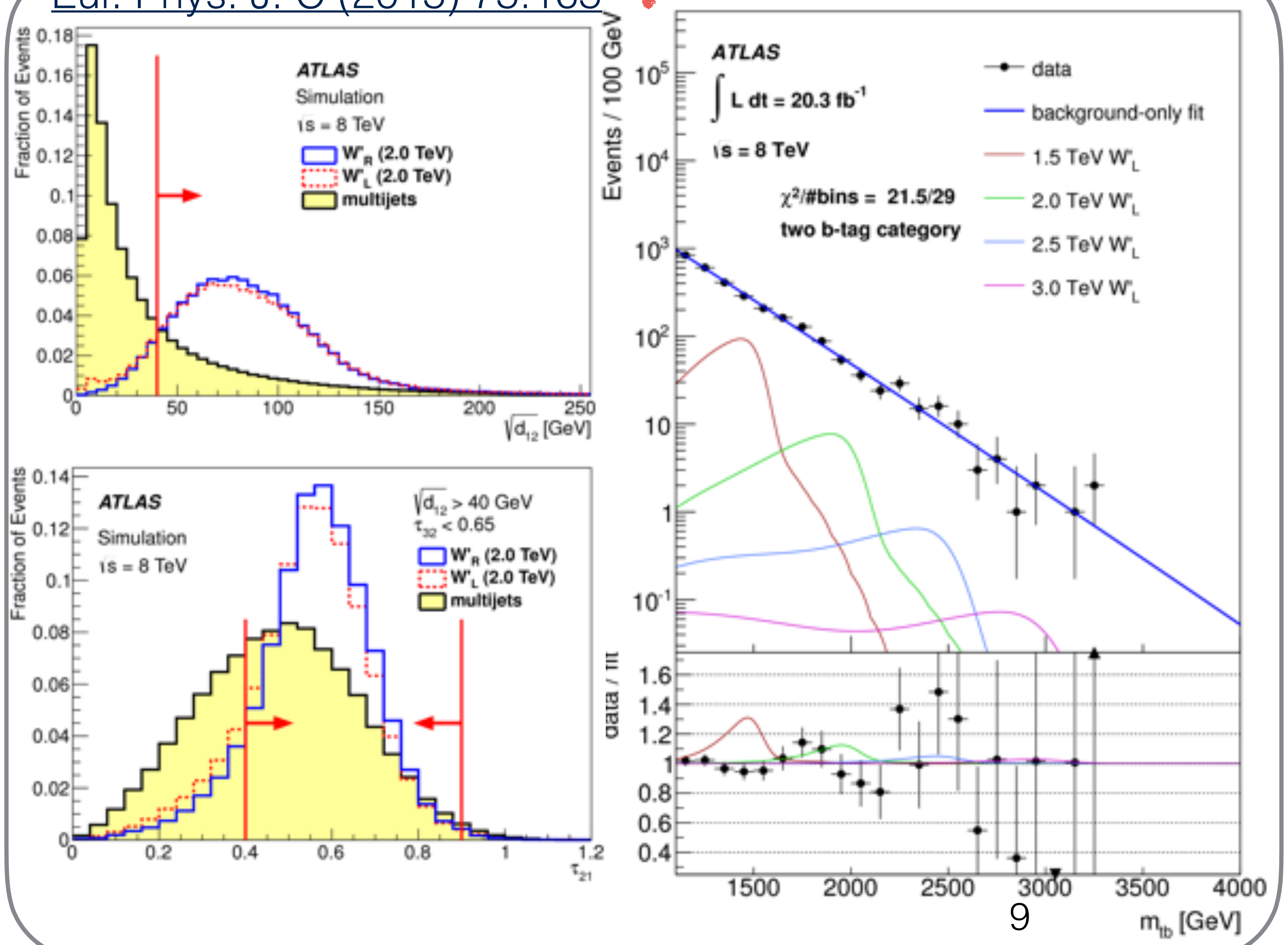


W’ to t$\bar{\text{b}}$ resonances @ 8 TeV

- Leptophobic W’ to t$\bar{\text{b}}$
- Boosted all hadronic with substructure based top tagging
- l+jets



Eur. Phys. J. C (2015) 75:165



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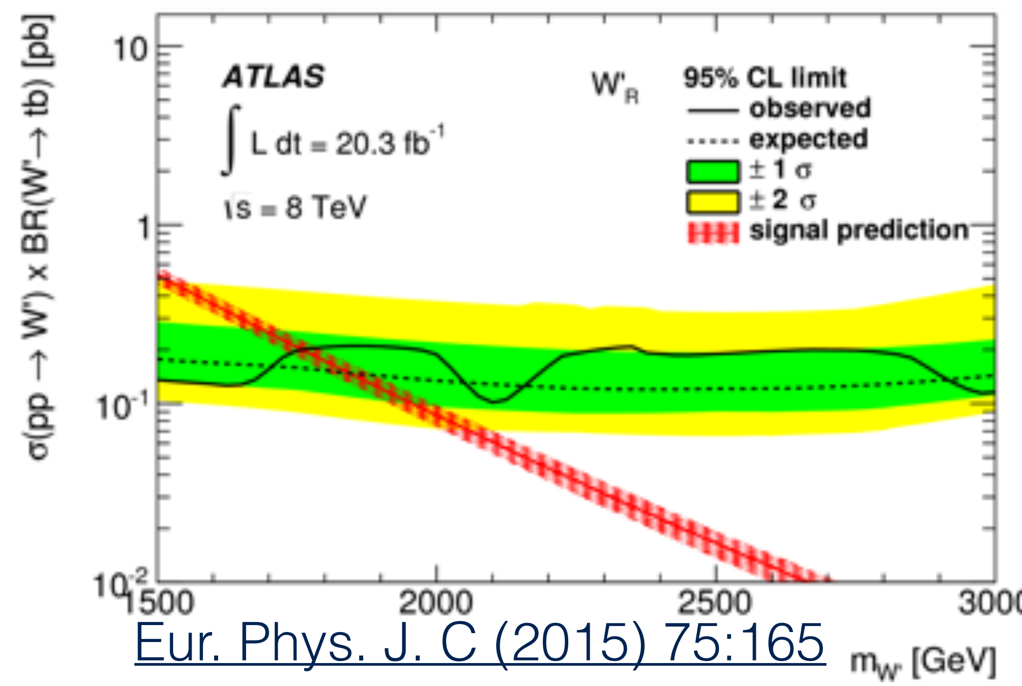


Eur. Phys. J. C (2015) 75:165

Exclusion:

$m_{W'L} < 1.68$ TeV

$m_{W'R} < 1.76$ TeV

all hadronic

$m_{W'L} < 1.7$ TeV

$m_{W'R} < 1.92$ TeV

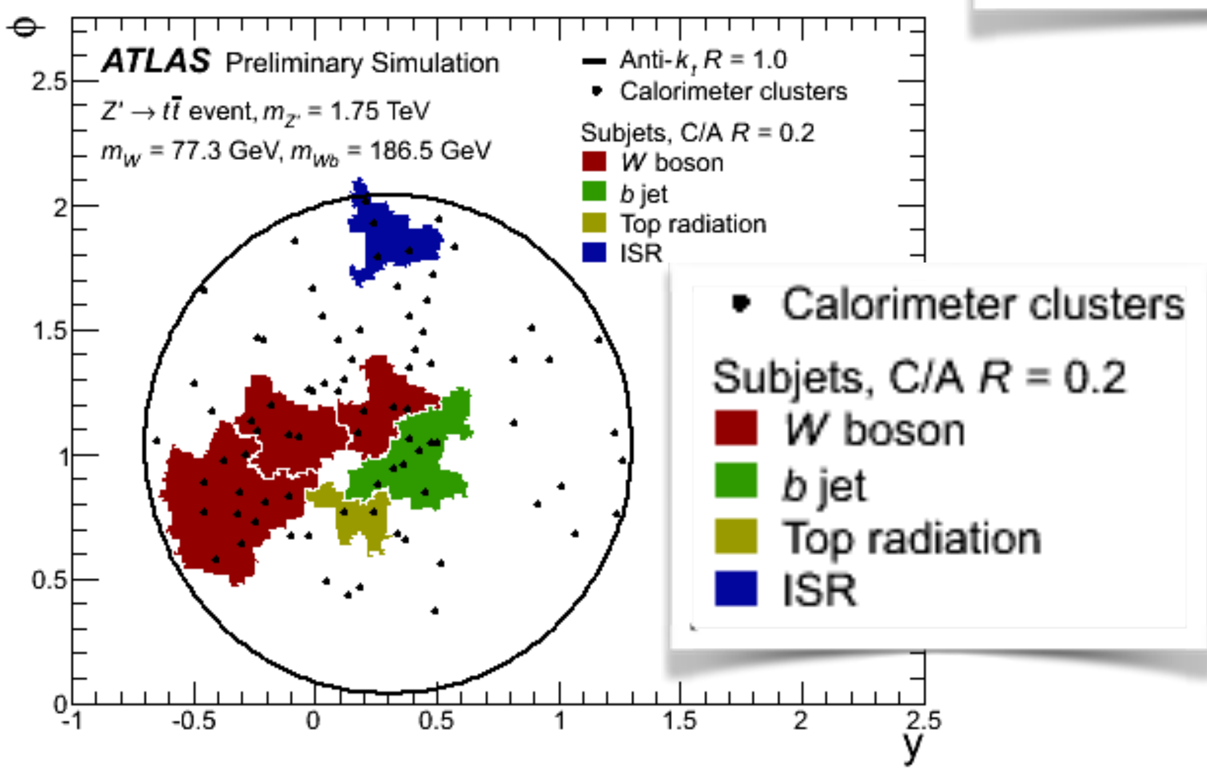
1 lepton

Intermission: Shower deconstruction

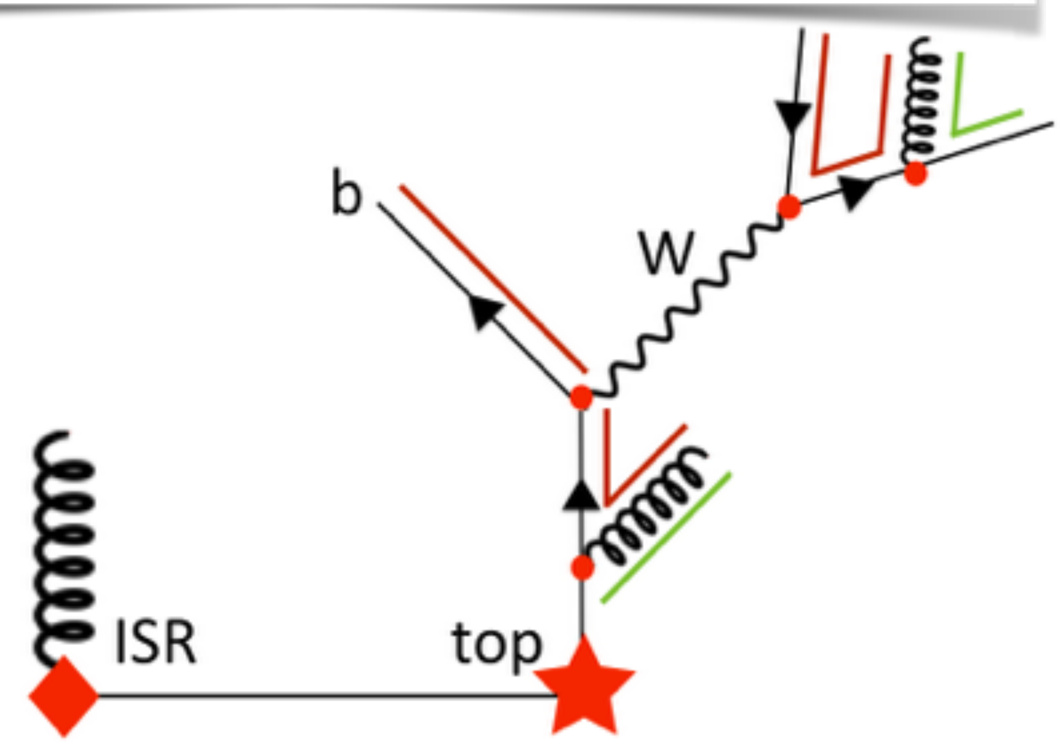
Phys. Rev. D 84 (2011) 074002, Phys. Rev. D 87 (2013) 054012

- Make subjets from large R jets
- Assume each subjet comes from a certain particle
- Calculate probability of particle-subjet association using QCD principles
- Repeat for all possibilities and with signal* and background hypothesis
- Single analytic function:

$$\chi_{\mathrm{SD}}(\{p_i^k\}) = \frac{\sum_{\mathrm{perm}} P(\{p_i^k\}|\text{top-quark jet})}{\sum_{\mathrm{perm}} P(\{p_i^k\}|\text{gluon/light-quark jet})}$$



ATLAS-CONF-2014-003



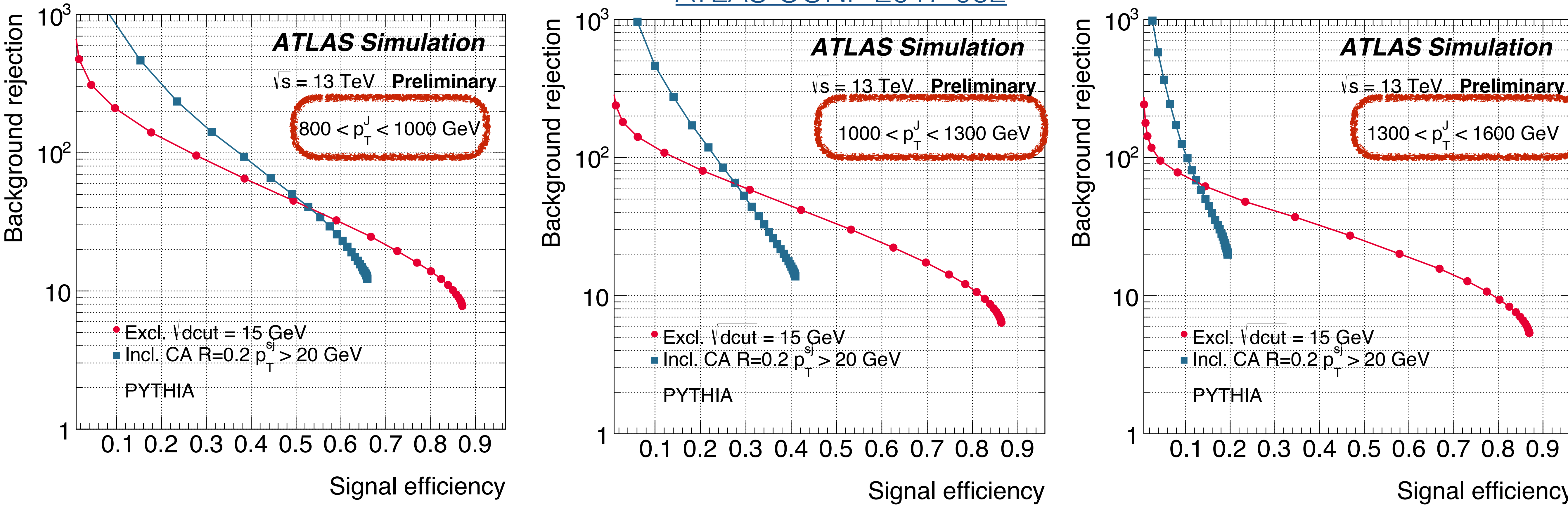
* Signal can be any hadronic decay (top, W, H,…)

SD Update for high p_T

NEW!

- So far used SD with C/A R=0.2 subjets, good proxies for partons with $\Delta R>0.2$
- SD needs $n_{subjet} \geq 3$ to work (i.e. for three top decay partons)

ATLAS-CONF-2017-082



- New: At large p_T use exclusively k_T* clustered jets
- Provides more $n_{subjet} \geq 3$ large input jets to SD
  —> Larger efficiency at high p_T.

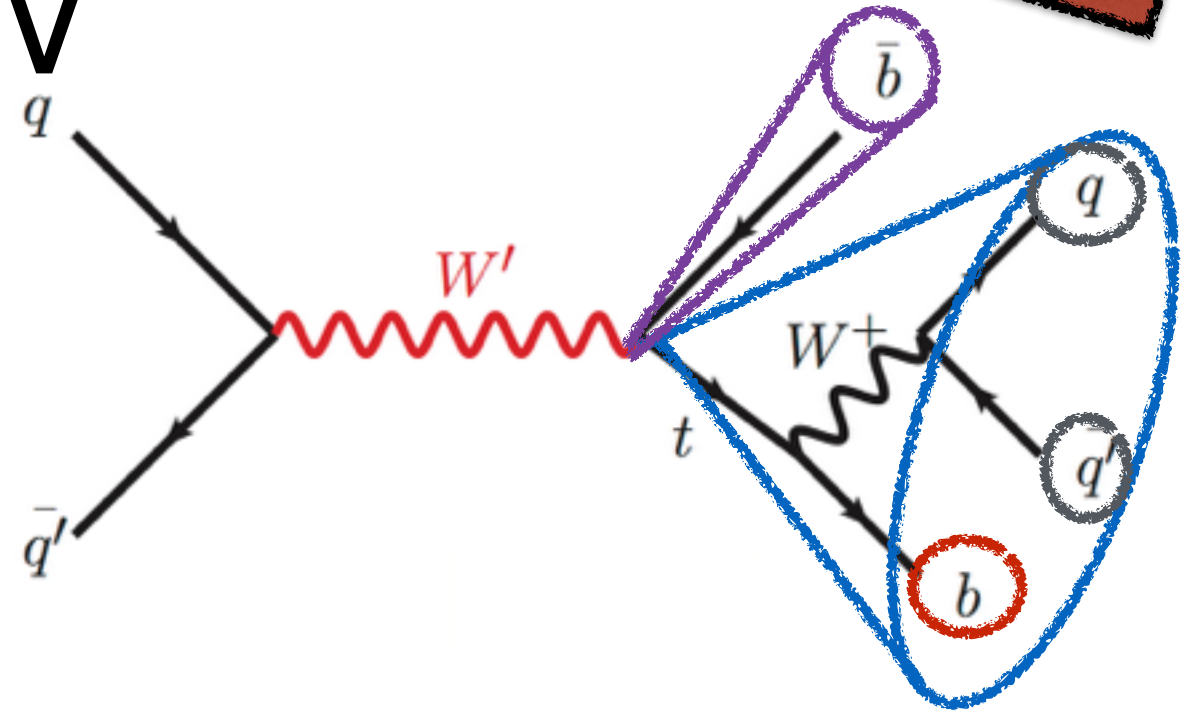
*Eur. Phys. J. C 72 (2012) 1896

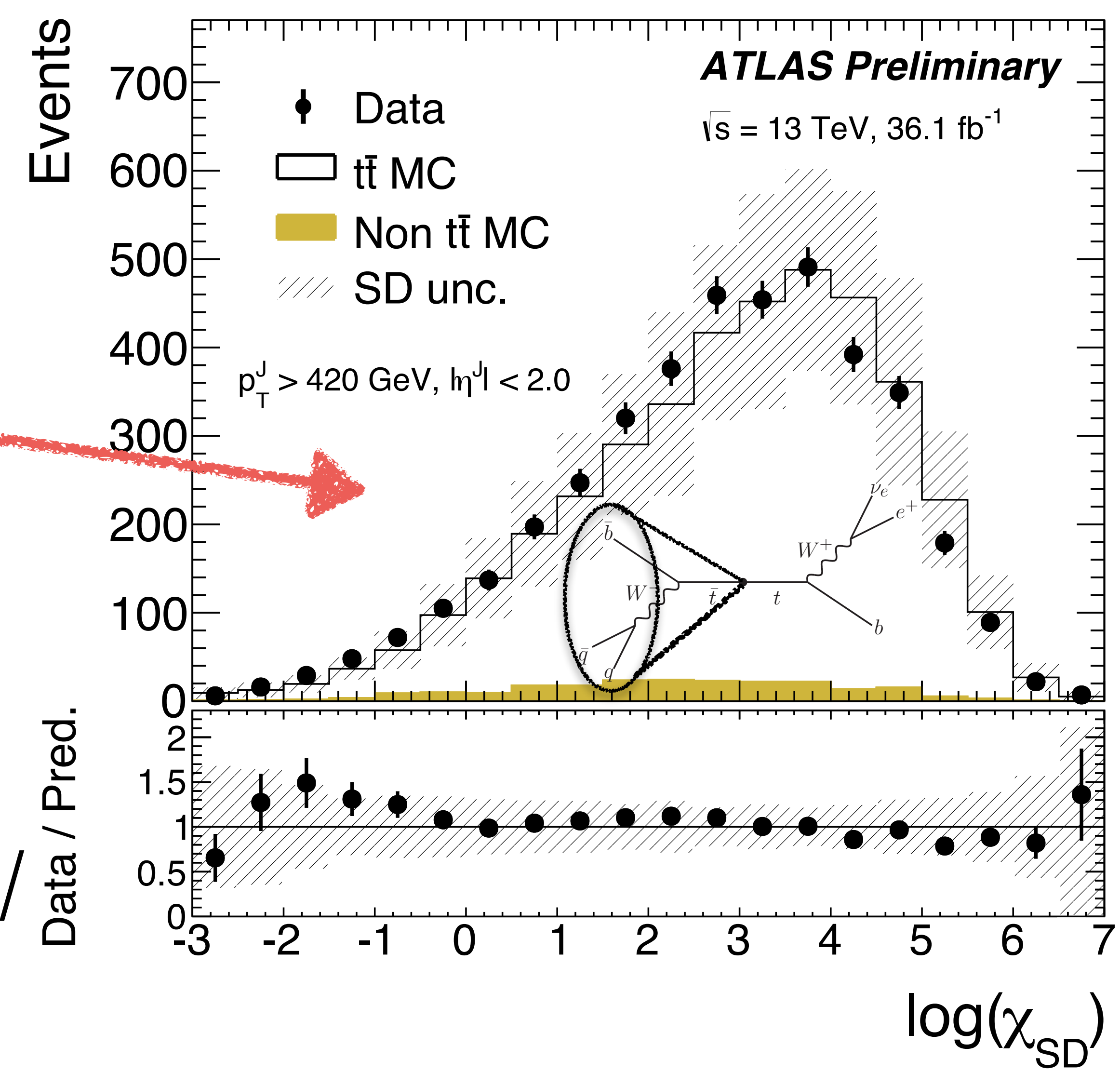
W' to $t\bar{b}$ @13 TeV

ATLAS-CONF-2017-082

NEW!

- Trigger: 1 small-R jet, p_T>420 GeV
- Large-R jets: trimmed anti-k_t R=1.0 jet, p_T>420 GeV
- Pick **large-R jet** with highest $m_{\text{leading small-R; }\Delta R<1.0} + 0.15\, m_{\text{large-R}}$
- Top tag via *Shower Deconstruction*
  - eff = 50% —> rejection = 80
  - eff = 80% —> rejection = 25
  - Test SD in lep+jet tt events
- b-tagging: 77% eff., MVA-based
- **b-jet candidate** = highest p_T small-R jet, ΔR>2.0 from large-R
- Split in **1 and 0 "b-tag-in"**, i.e. within/not within ΔR=1.0 of top jet





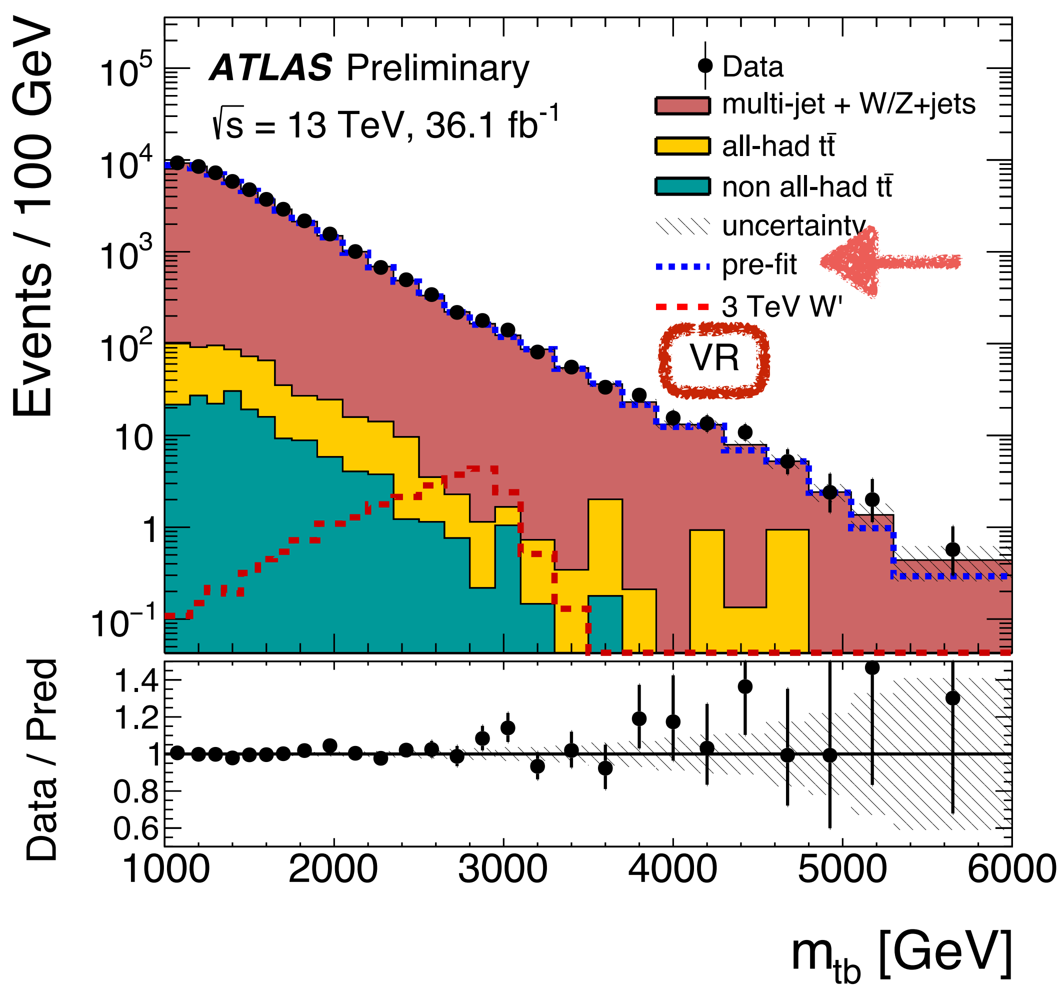
QCD Estimate

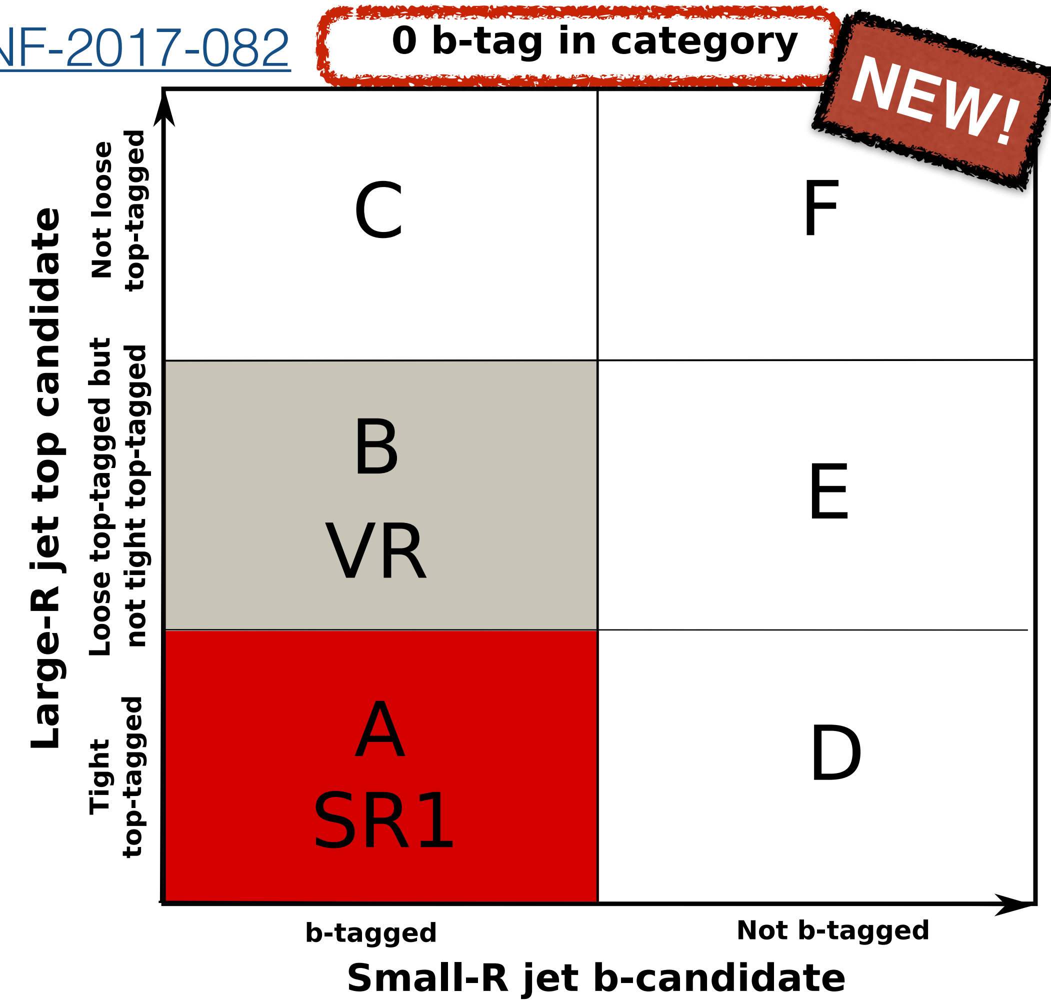
ATLAS-CONF-2017-082

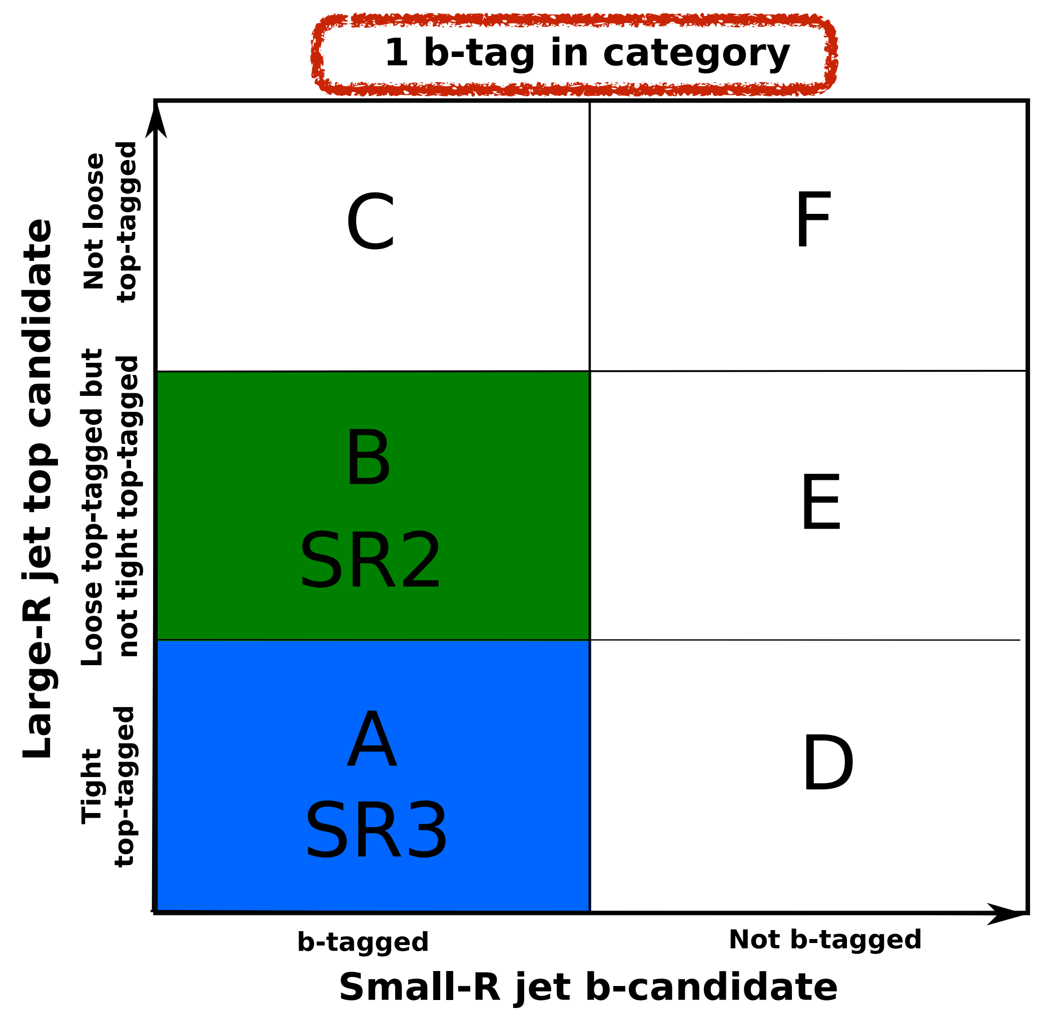
- Estimate QCD multijet (and a few V+jet) events from $t\bar{t}$ subtracted data in control regions:

$$N_A^{\text{bkg}} = R_A^{\text{corr}} \cdot \frac{(N_C^{\text{data}} - N_C^{t\bar{t}}) \cdot (N_D^{\text{data}} - N_D^{t\bar{t}})}{N_F^{\text{data}} - N_F^{t\bar{t}}}$$

- Correlation of top- and b-tagging from PYTHIA, uncertainties from 4 alternative multijet samples







Uncertainties and fit to data

NEW!

- Profile LLH fit to data
- Systematic uncertainties are constraint
- Main uncertainties: QCD-estimate and b-tagging, statistically dominated for m_{tb}> 2 TeV

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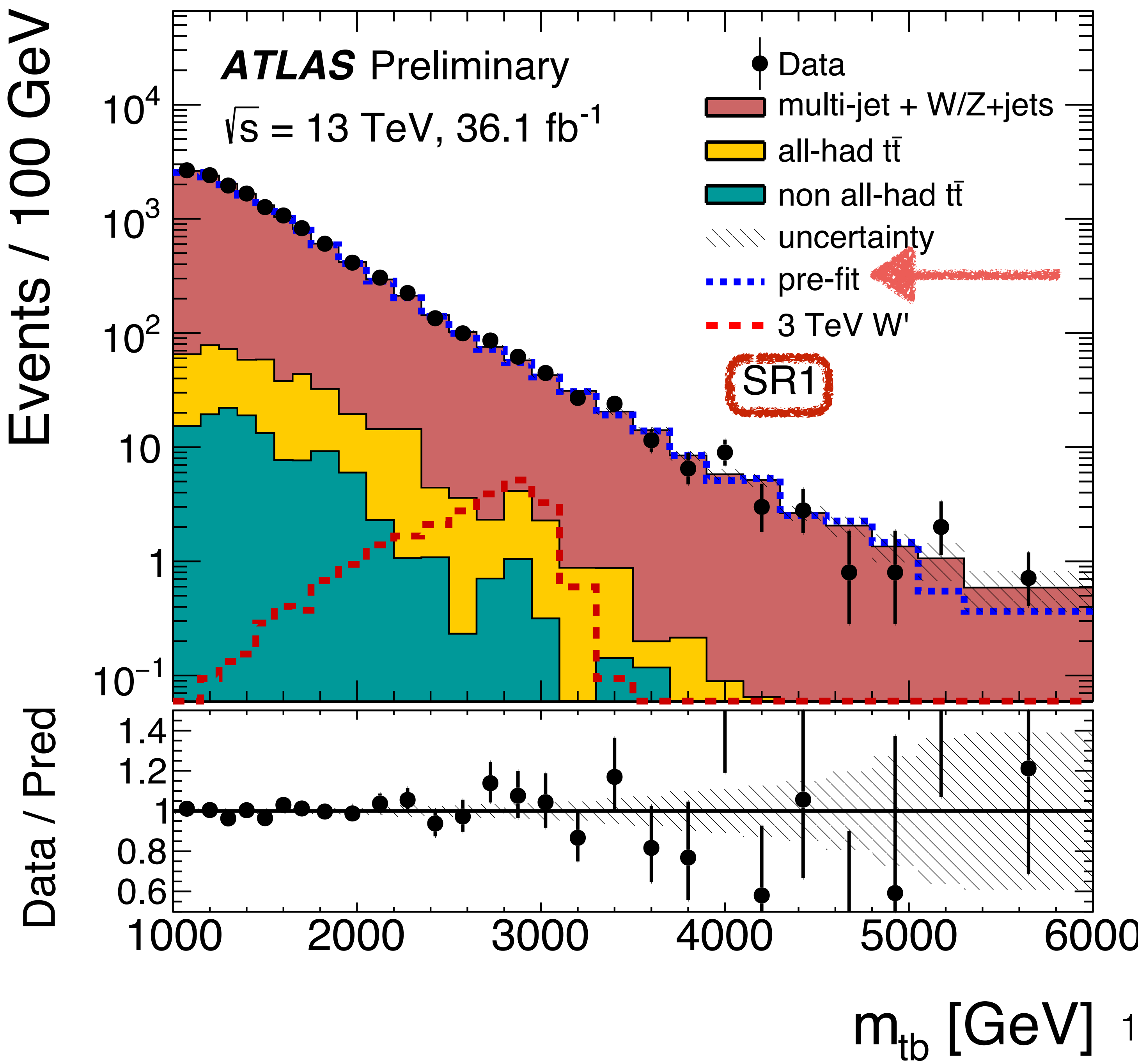

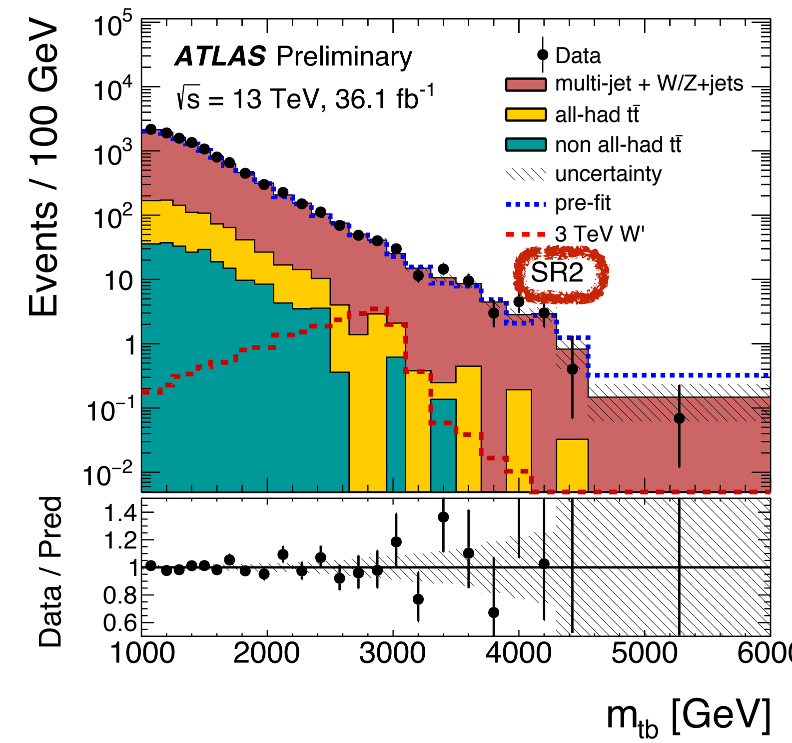

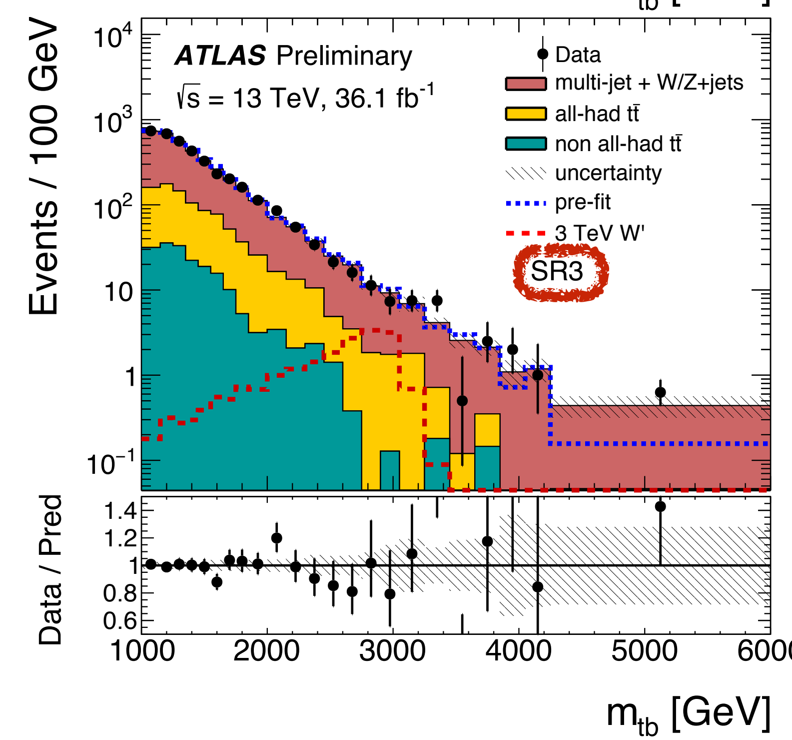

Limits on W'—>tb̄

NEW!

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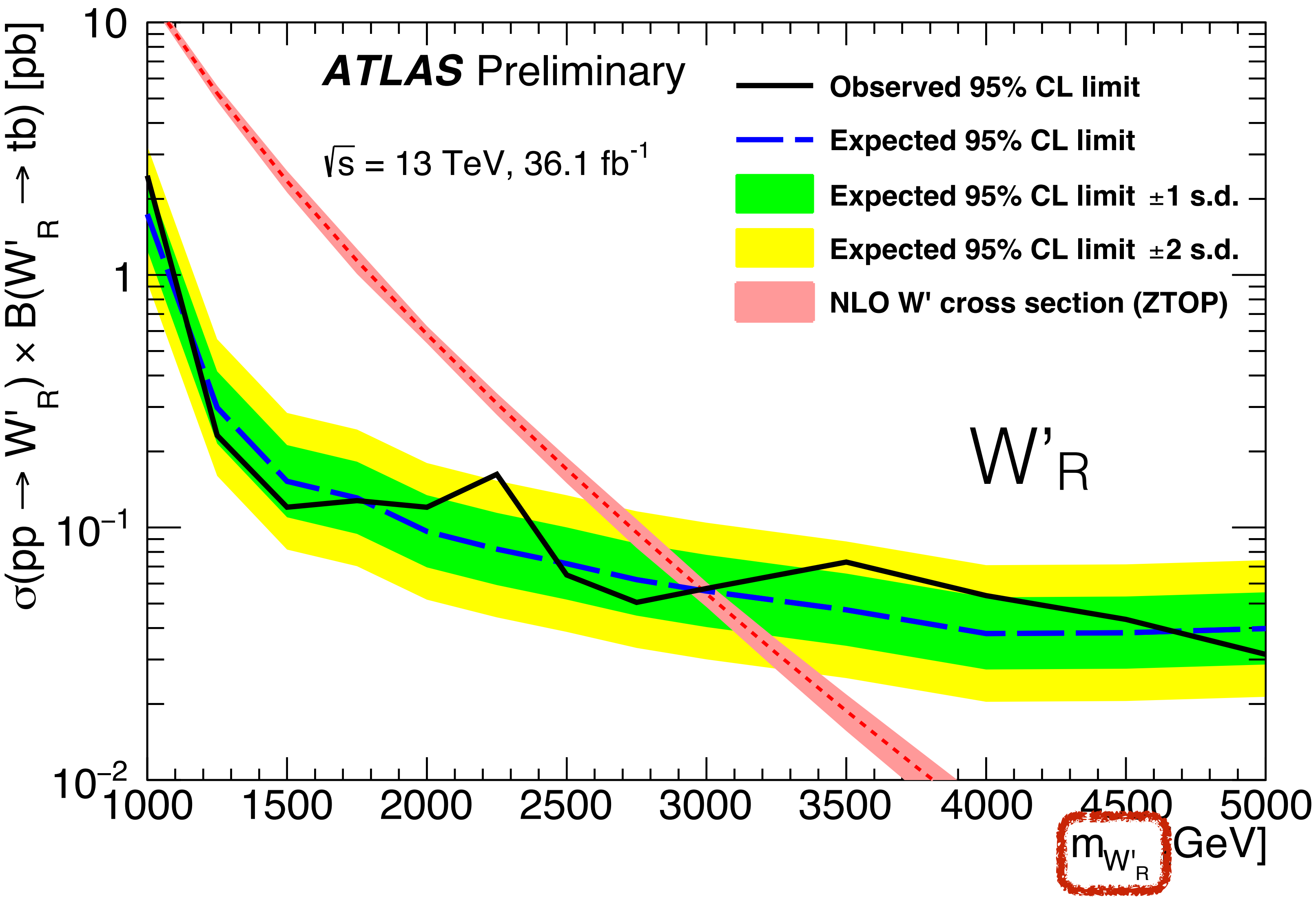
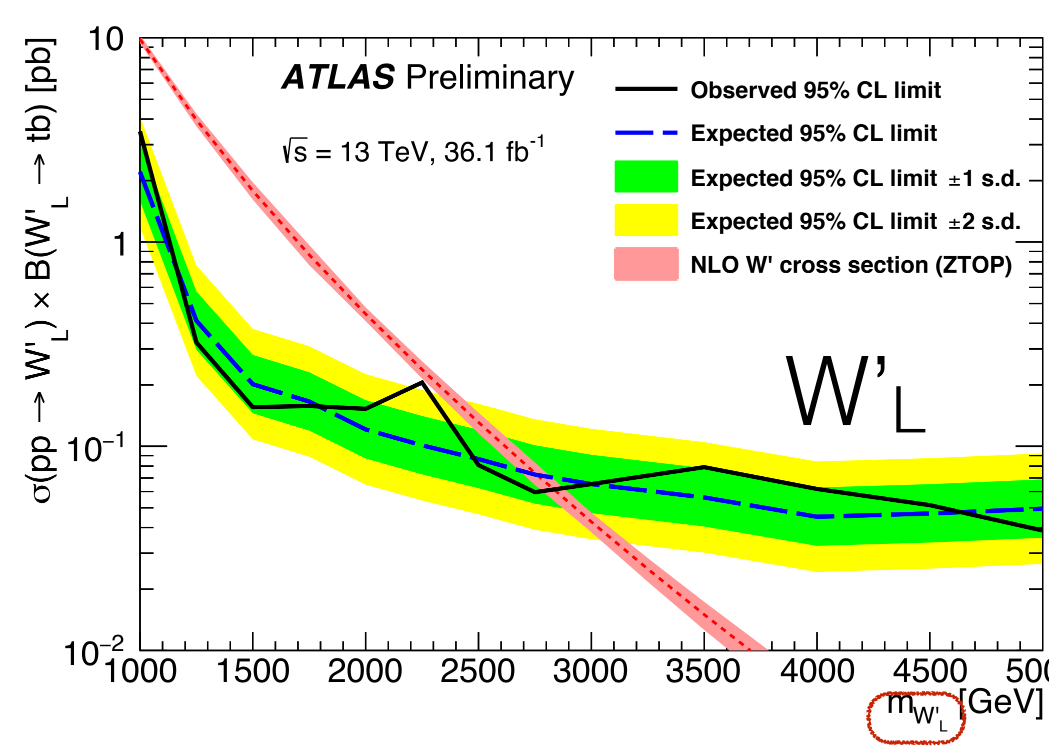


- Observed 95% CL limits, exclude:
  - $m_{W'L} < 2.95$ TeV,
  - $m_{W'R} < 2.98$ TeV

Reminders:

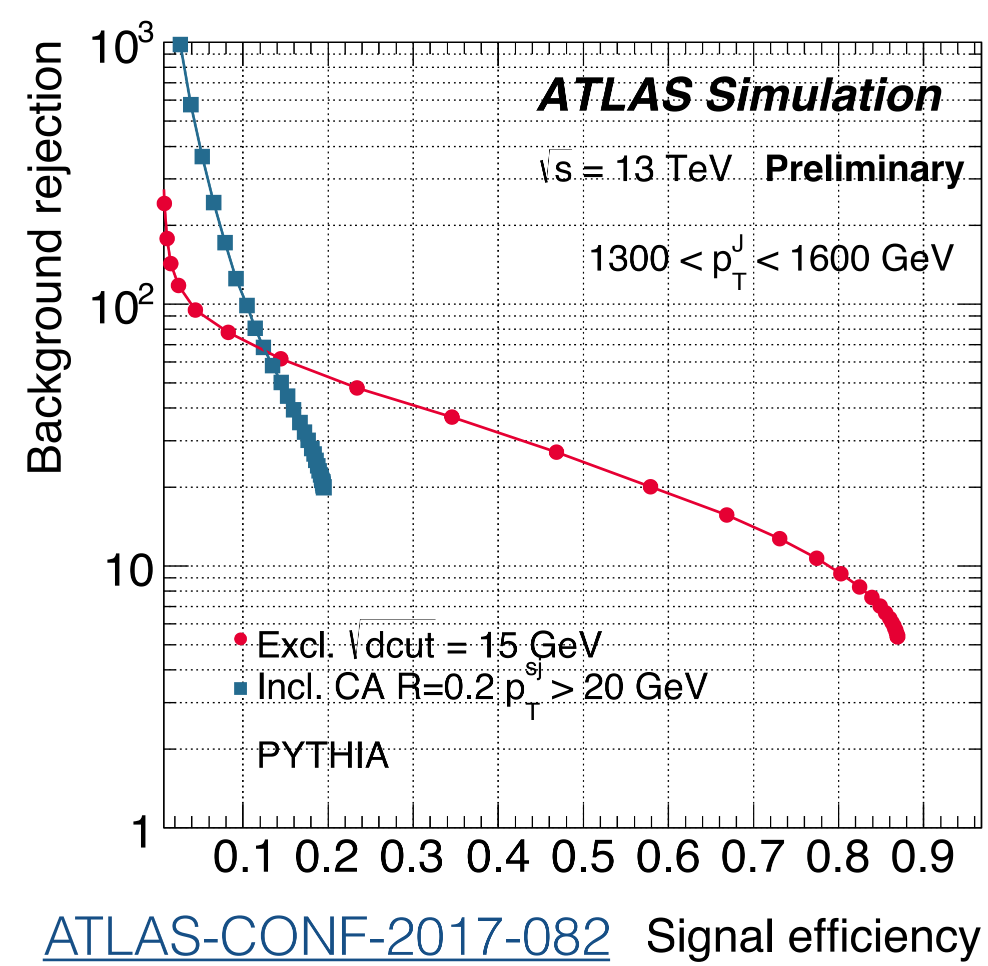
- Best Run 1 W'—>tb limit was just below 2 TeV!
- W'—>**e/μν** @ 5 TeV, but not sensitive to W'_R

arXiv:1706.04786 [hep-ex]



Conclusions

- No sign of new heavy resonances decaying to top quarks
- Leptophobic Z’ excluded up to 2 TeV with a subset of the Run2 data
- Inclusion of interference effects in search for scalar
- Significant improvement of limit on W’ mass compared to Run 1
- More data and improved analysis strategies will push the limits further and will hopefully reveal signs of new physics!



ATLAS-CONF-2017-082


End of presentation
Thank You

Sequential jet clustering algorithms

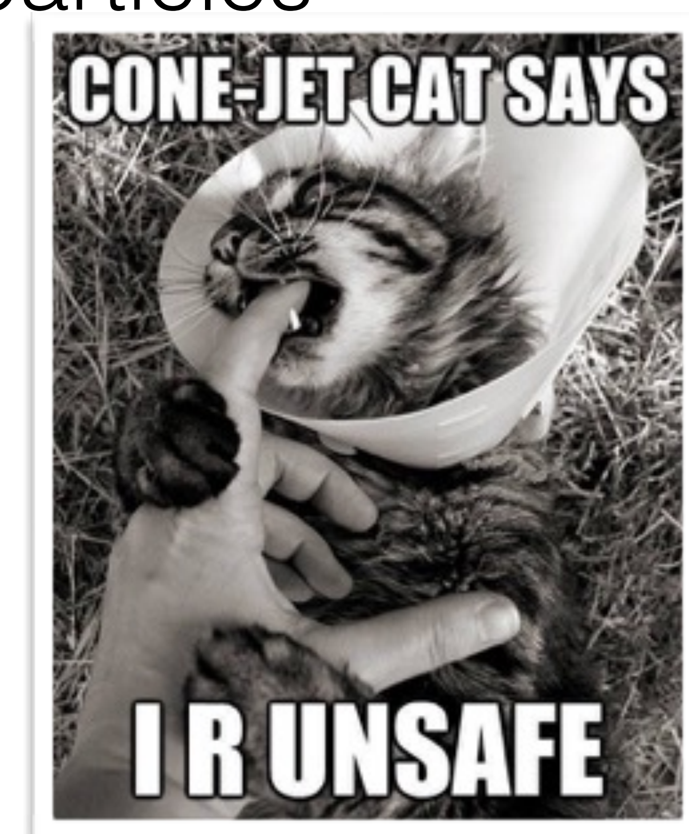
- Use clusters of calorimeter energy as input "particles" (also tracks or truth particles can be used)
- Distance:

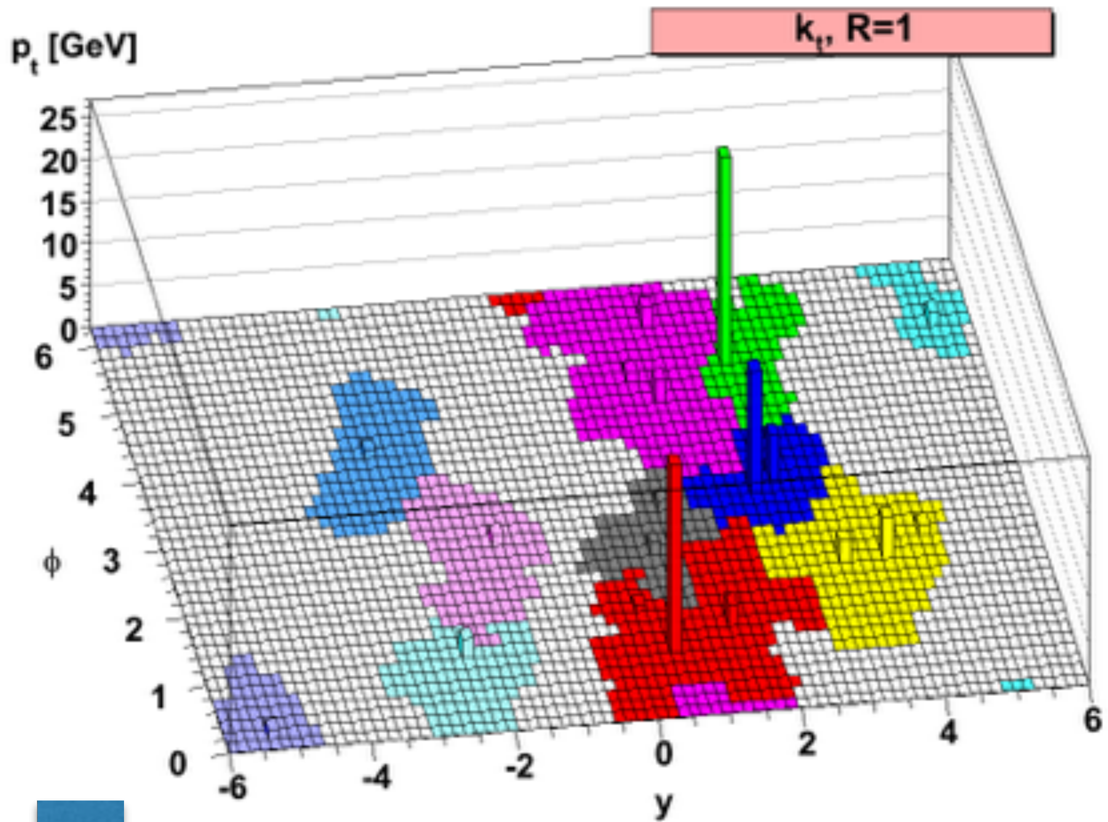
$$d_{ij}=\min(p_{Ti}^{2p},p_{Tj}^{2p})\ \Delta R_{ij}^2/R^2$$

- algo:

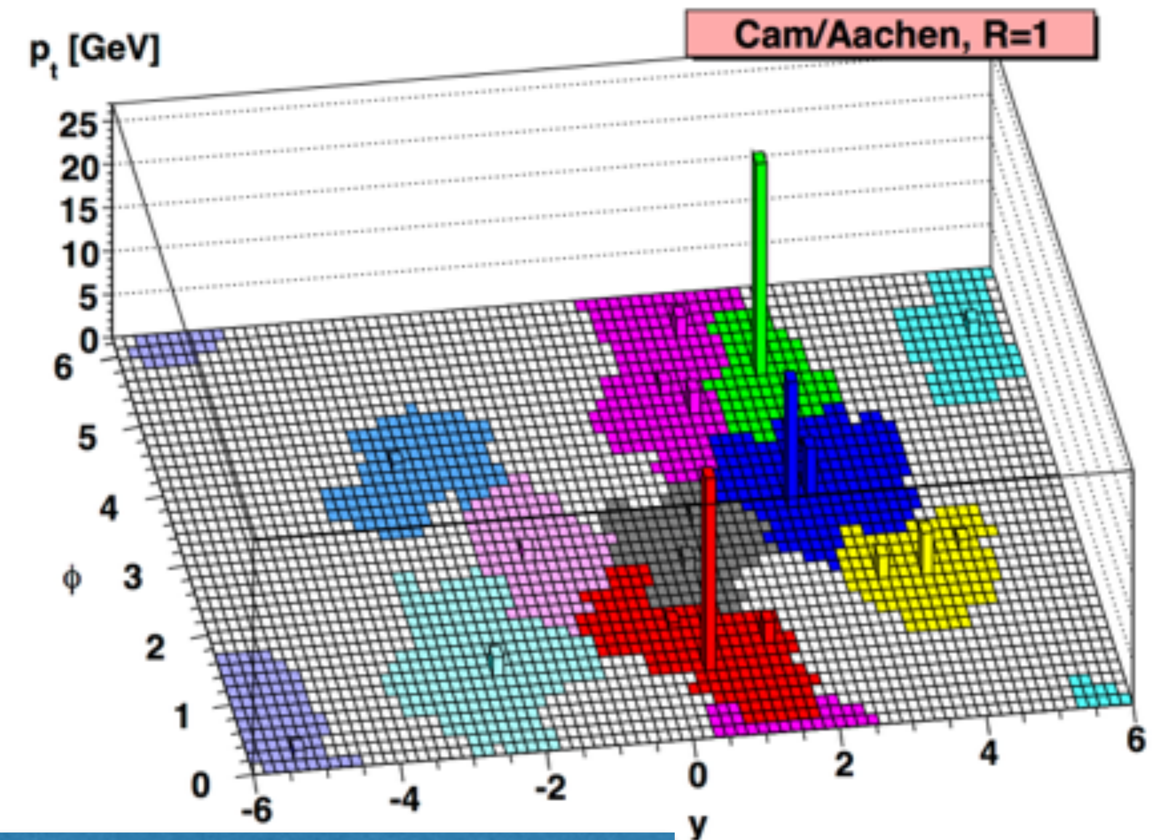
  find pair with smallest d_{ij}
  `if` $d_{ij} > d_{iB} = p_{Ti}^{2p}$ —> `i` is already a jet, remove it
  `else` —> merge `i,j`
  `repeat` until all particles are clustered into a jet

- parameters:
  - R: geometrical separation, "radius parameter", not a radius!
  - p: energy vs geometry, 2=k_t ; 0=C/A ; -2=anti-k_t

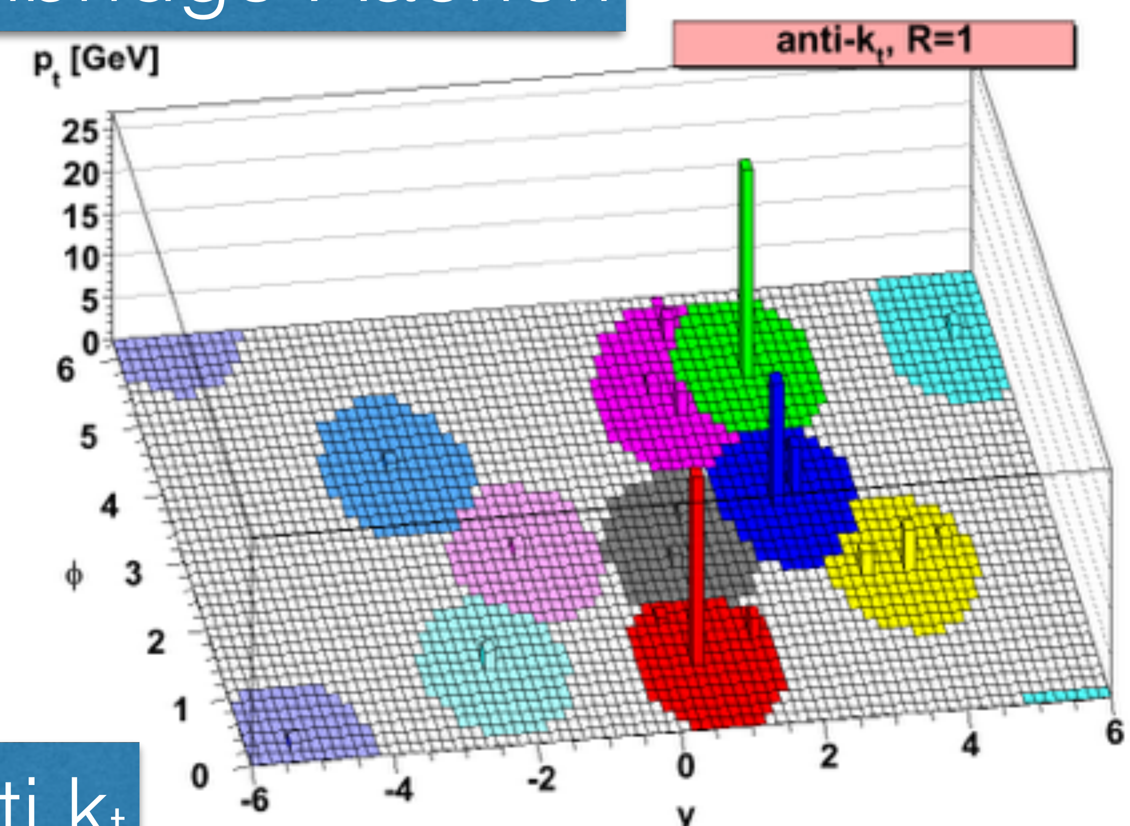




k_t



Cambridge-Aachen



anti k_t

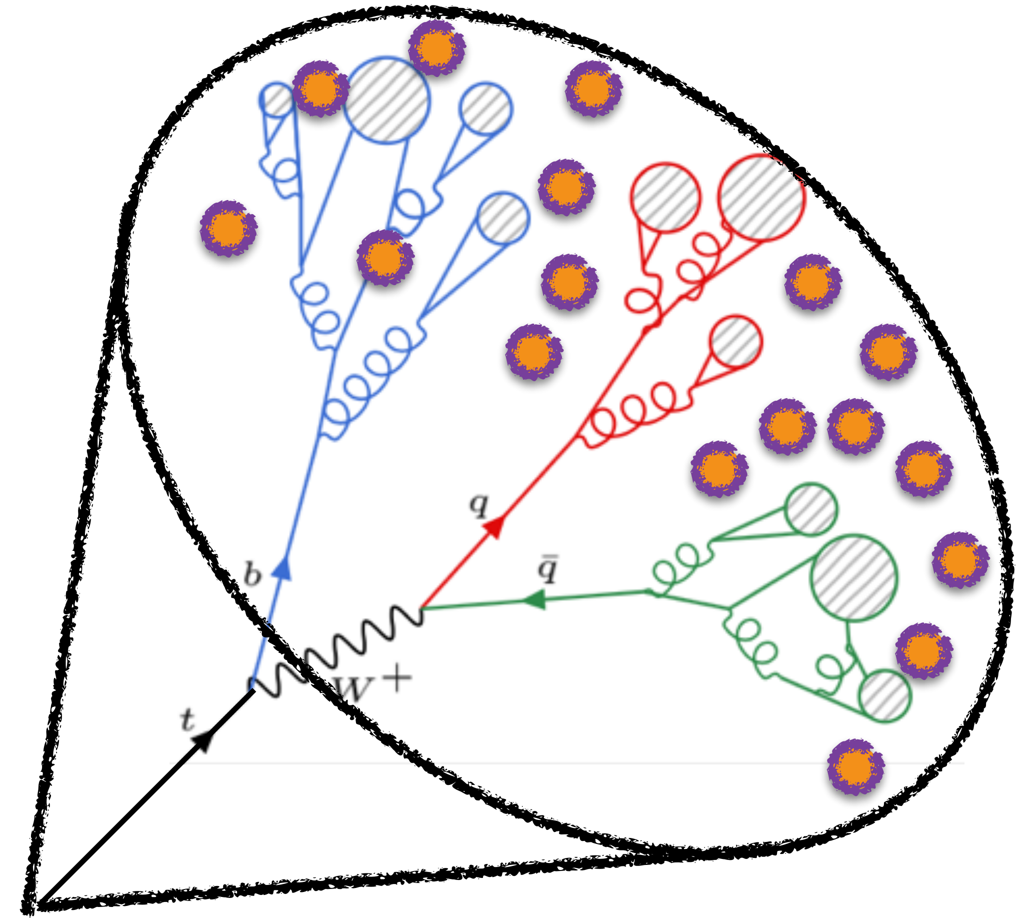
Take home message:

k_t	= *soft first*
C/A	= *closest first*
anti k_t	= *hard first*

Towards Jetography, G. Salam, Eur.Phys.J. C67 (2010)

Trimming

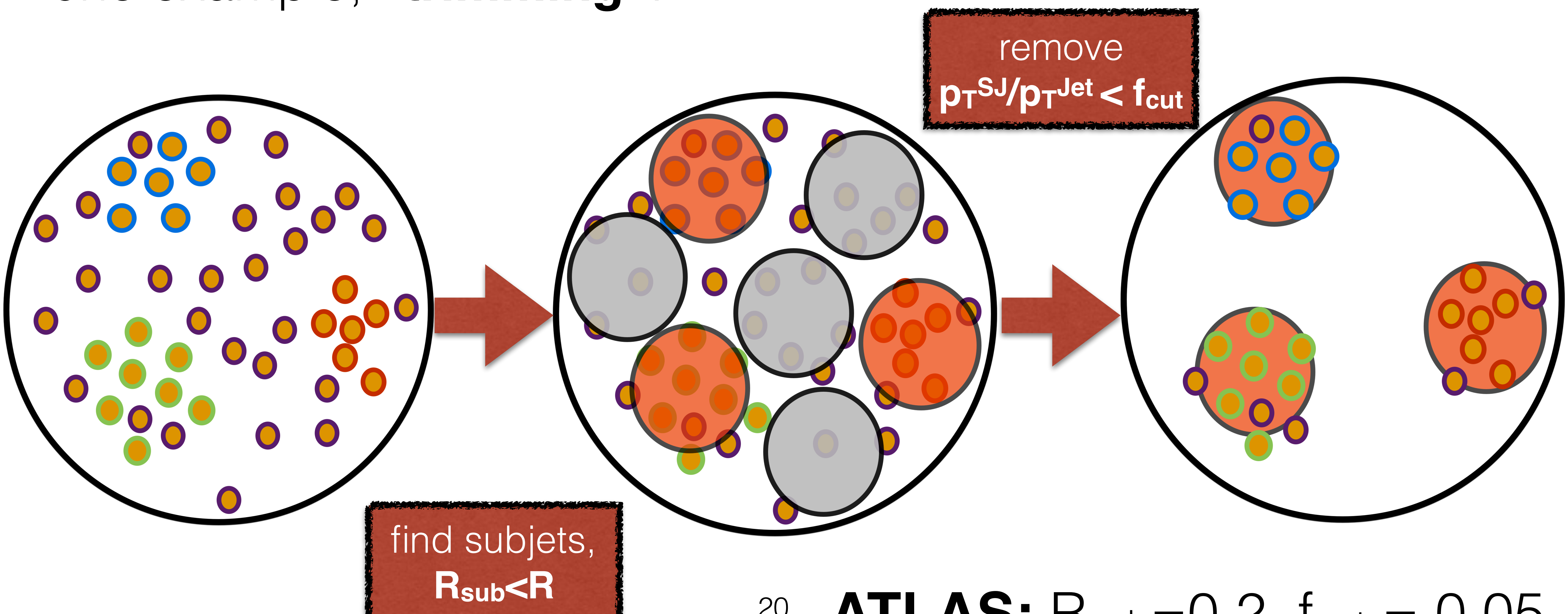
JHEP 02 (2010) 084



- **pile up**
  —> large R jets pick up more “junk”

- **“grooming” algorithms**
  —> clean the large R jet

- one example, **“trimming”**:

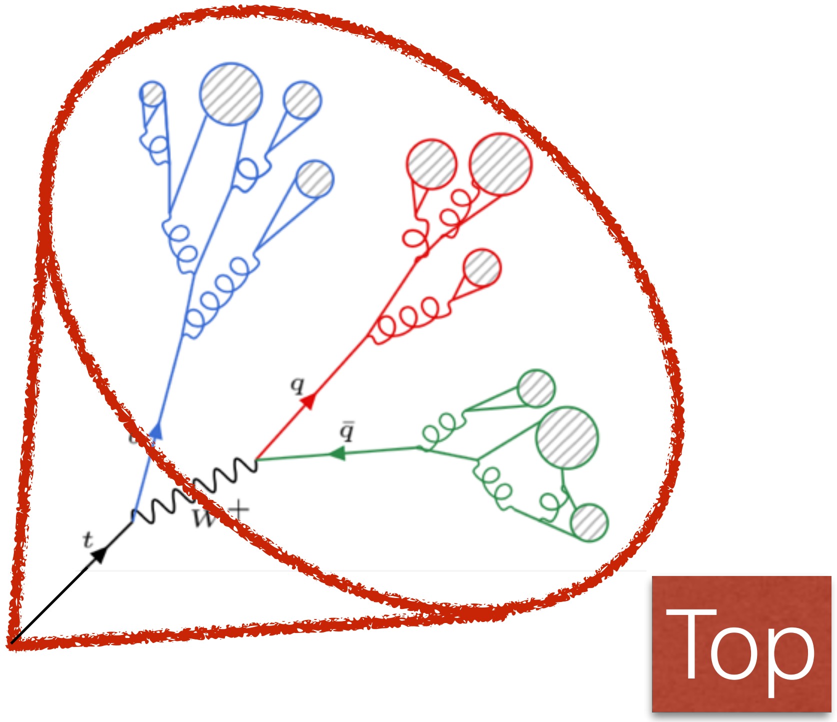


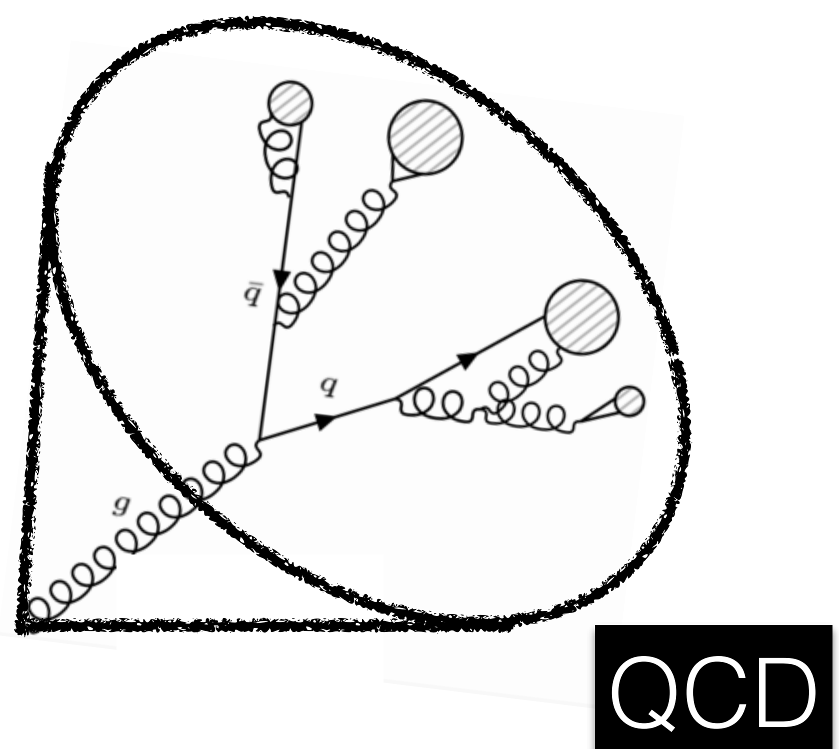
ATLAS: $R_{sub}=0.2$, $f_{cut} = 0.05$

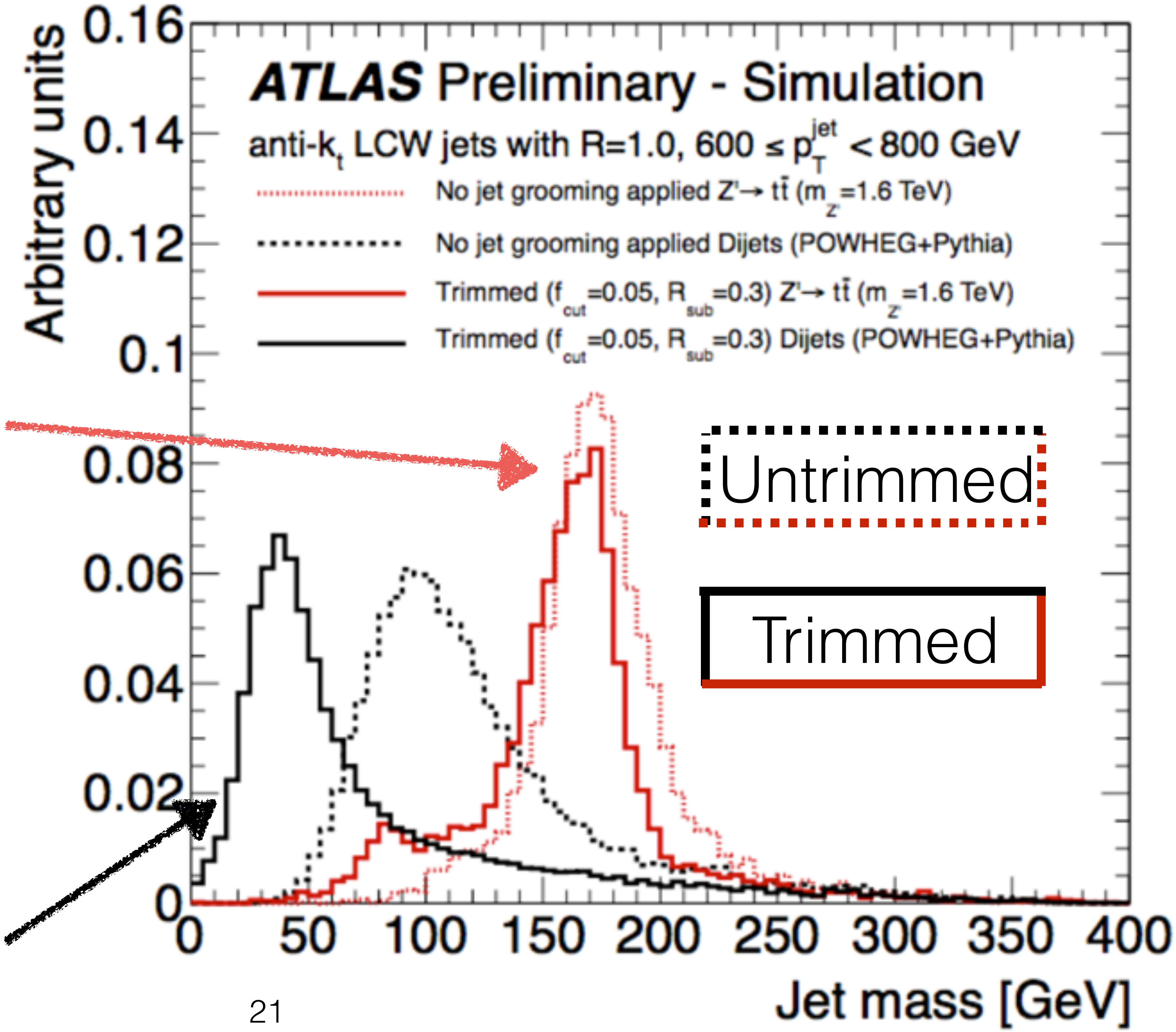
Jet mass

$$m_{jet}^2 = \left(\sum_i E_i\right)^2 - \left(\sum_i p_i\right)^2$$

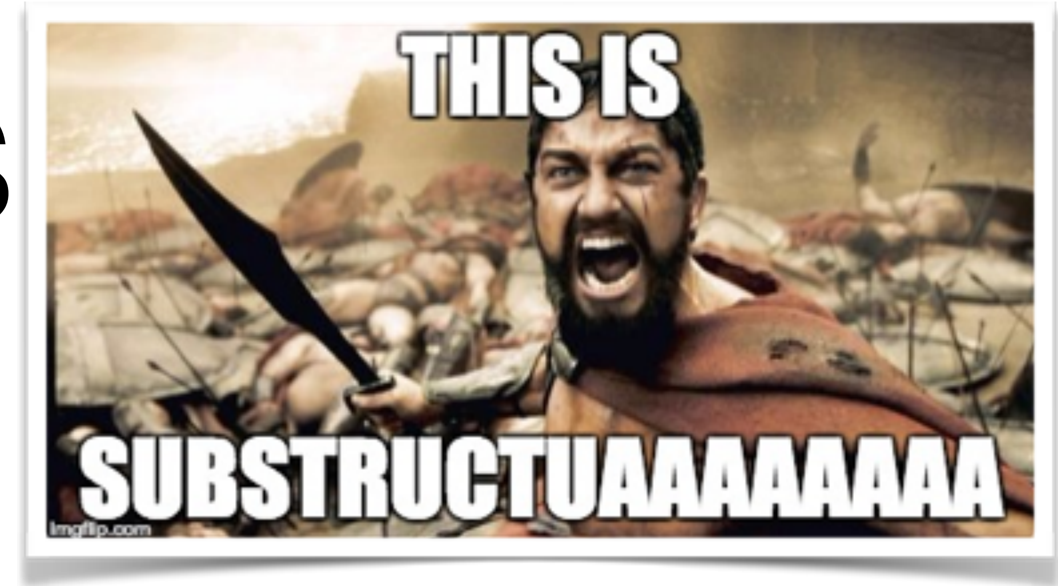
i = all cluster



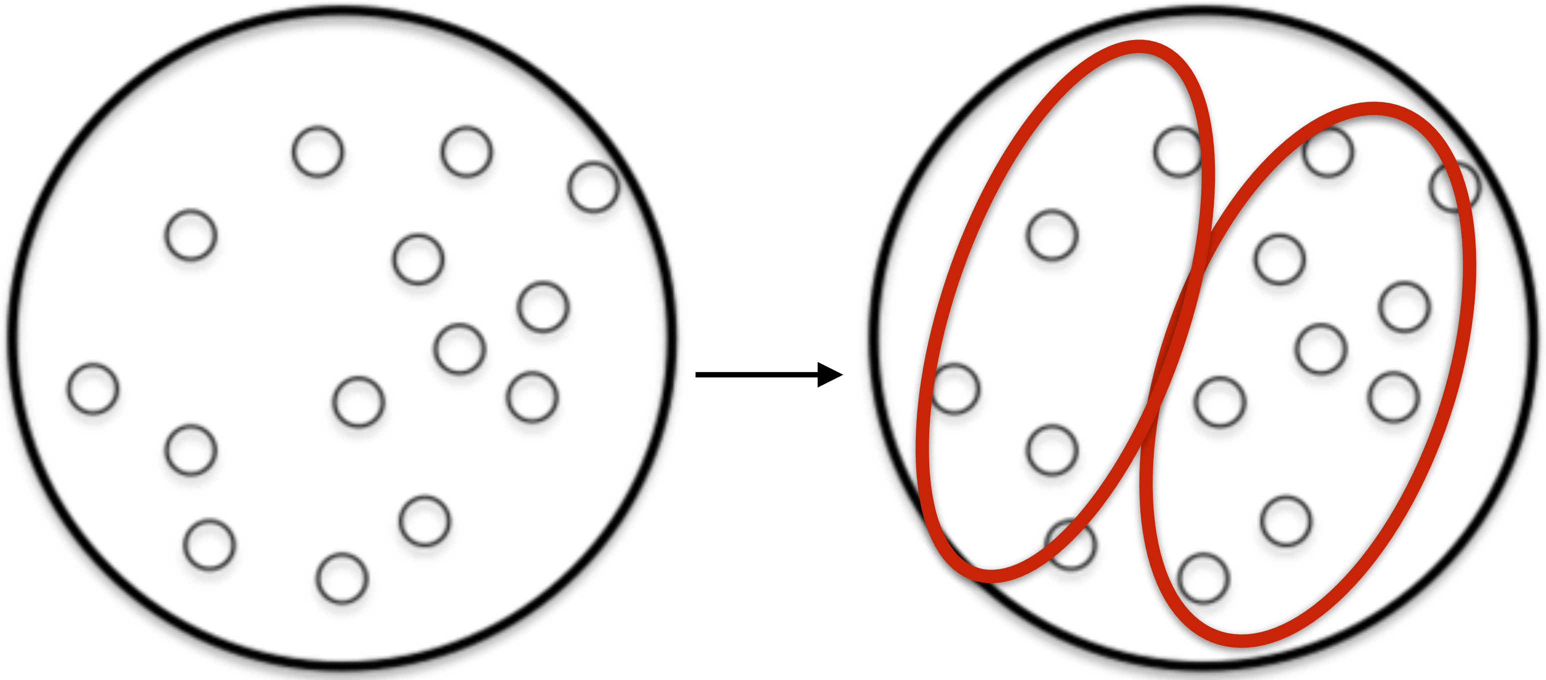


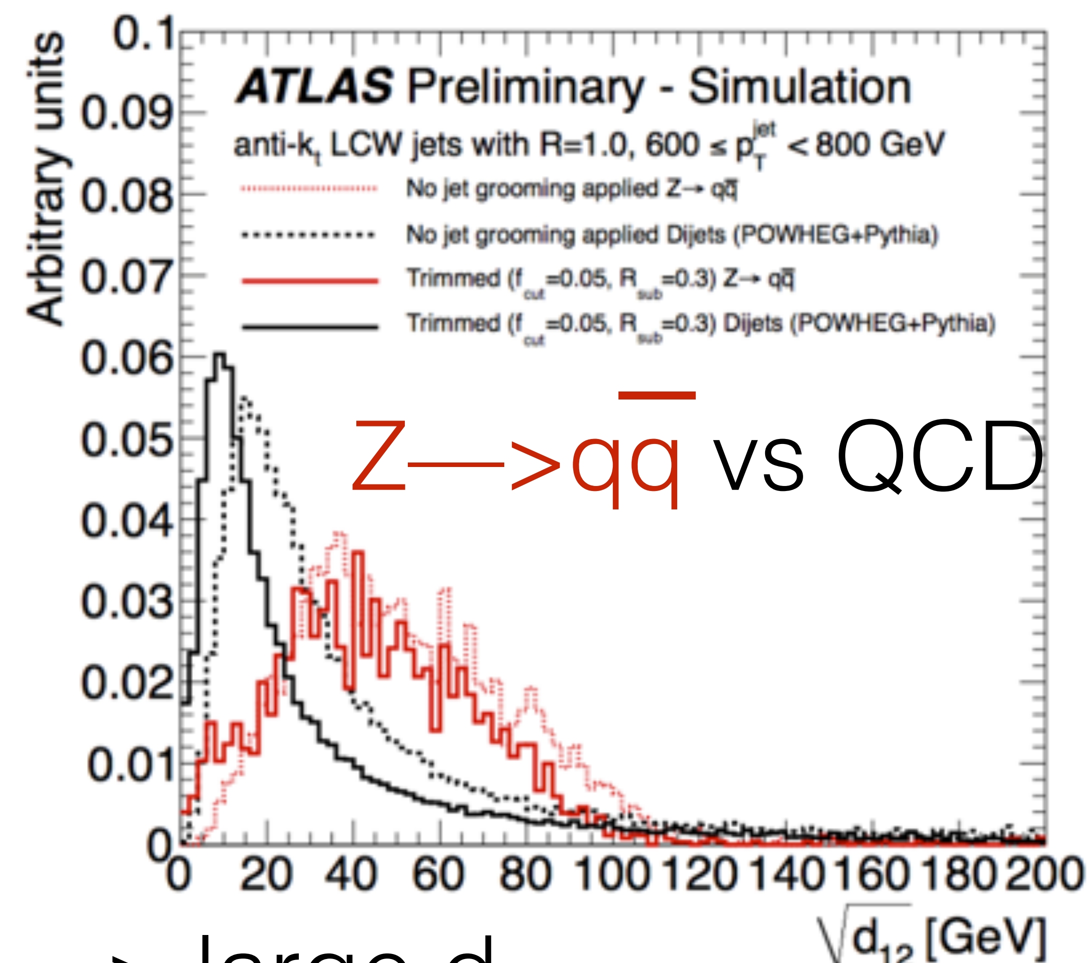


k_T splitting scales



go back one step in the k_T clustering





$$d_{12} = min(p_{T,1},\ p_{T,2})\Delta R_{12}$$

Example: $Z \rightarrow q\bar{q}$:

- symmetric two-body decay:
  both subjets apart and of similar p_T —> large d_{12}
- For top decay: go back one more step: d_{23}

n-subjettiness

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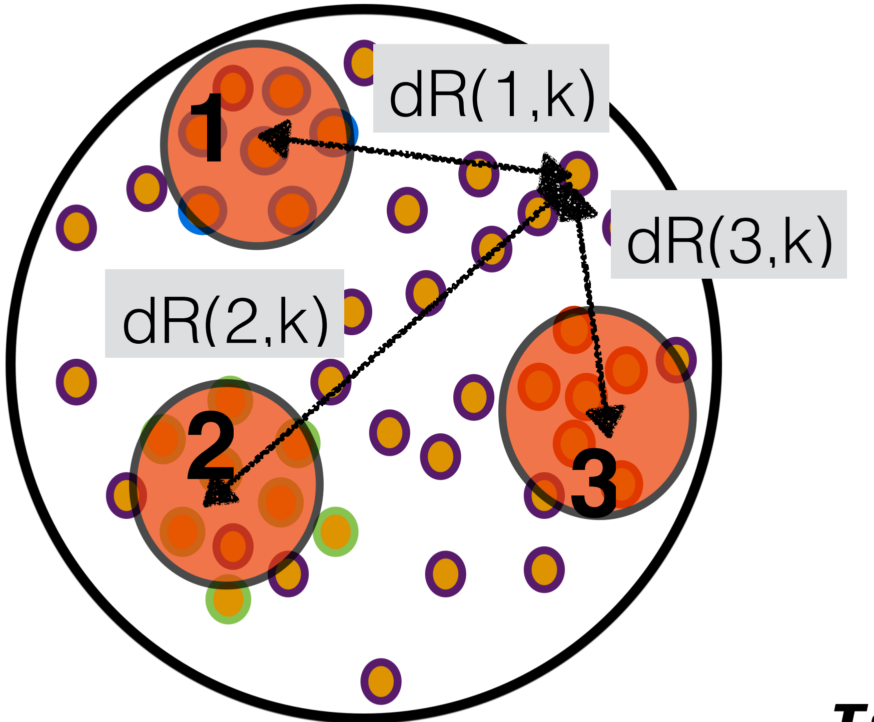
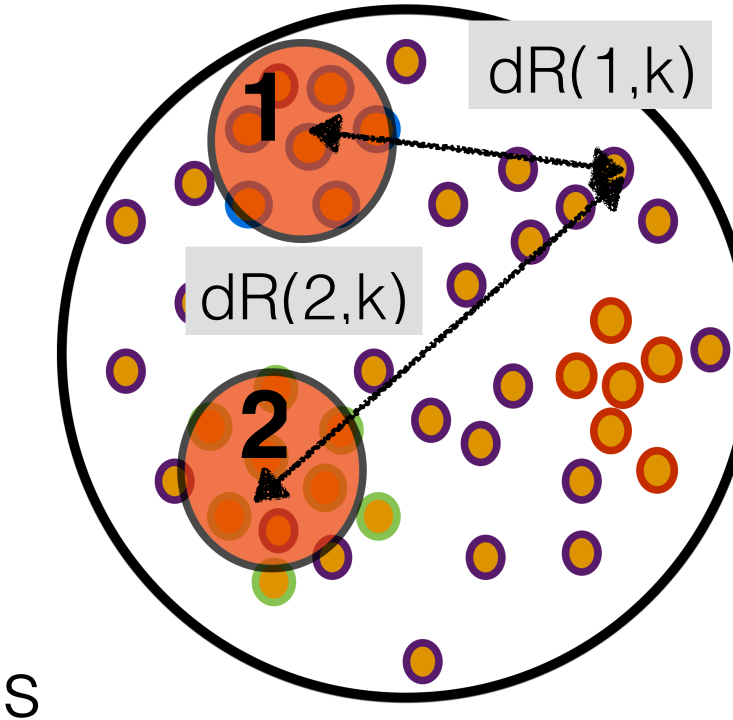


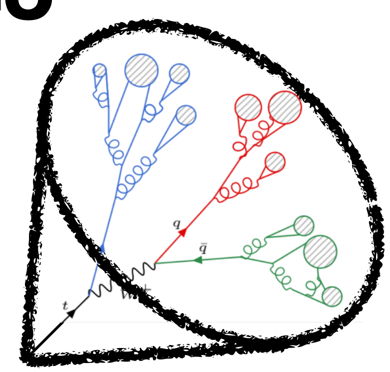
d(k)=
$p_T(k)$ x <u>min</u>(dR(1,k),
…,dR(n,k))

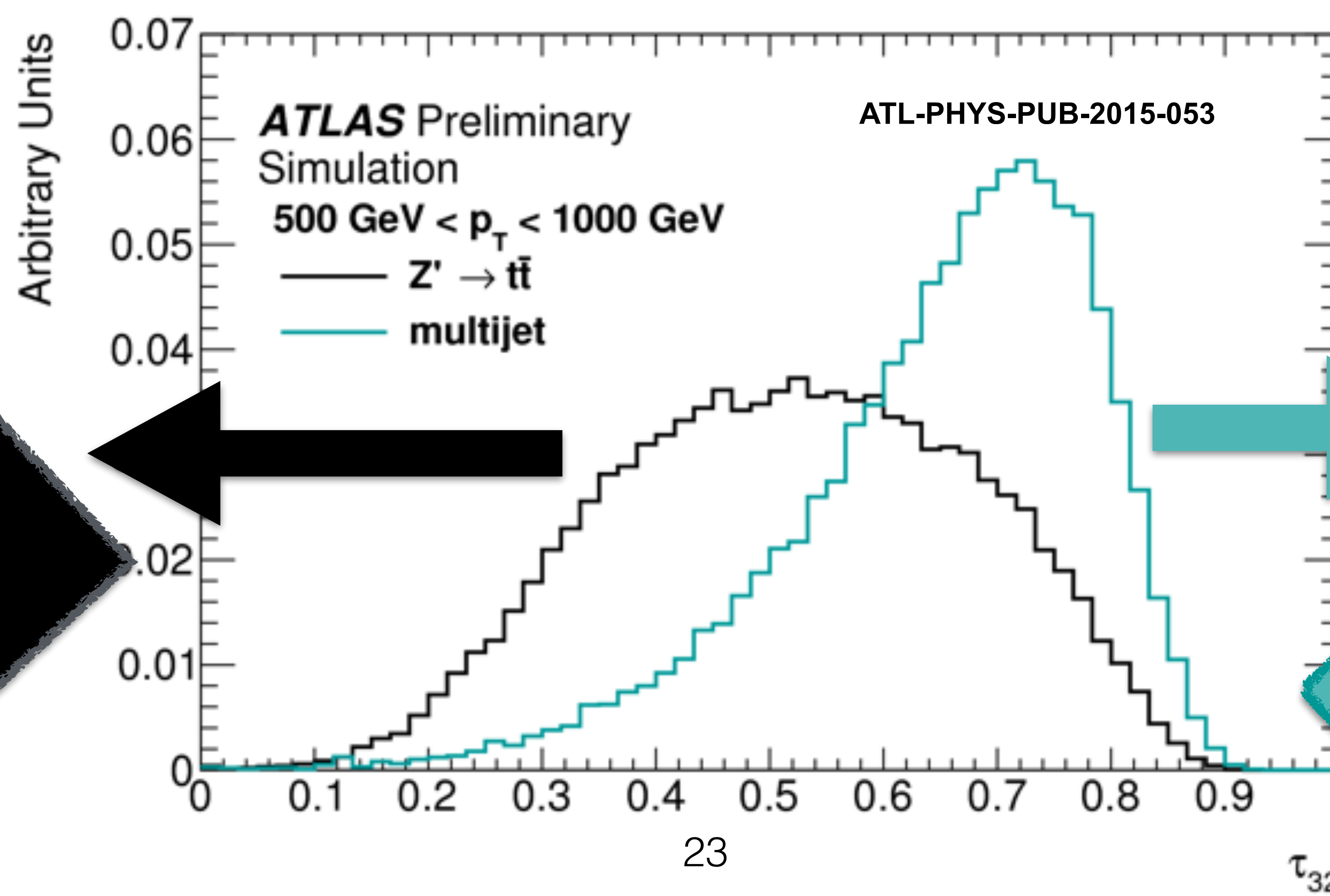
$\boldsymbol{\tau_n \propto \sum d(k)}$



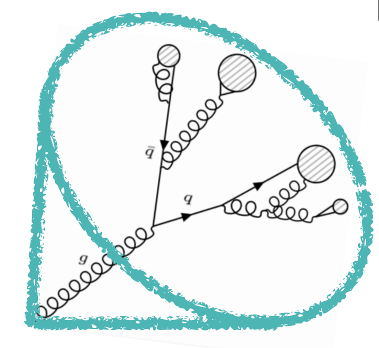
τ_3/τ_2 separates 3 and 2 subjets

n=3





n=2



3 subjet-like

2 subnet-like

2 variable ATLAS top tagger

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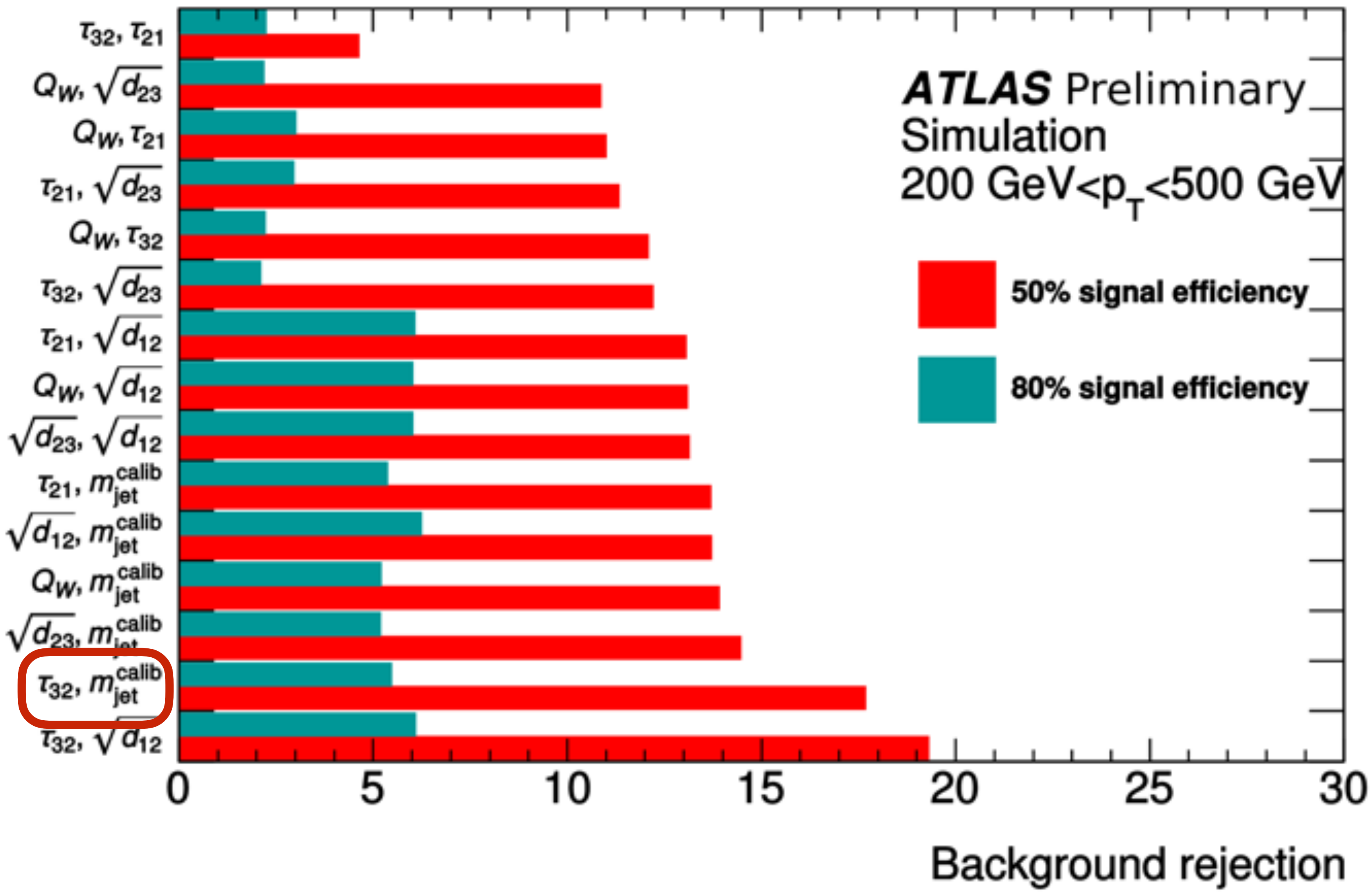
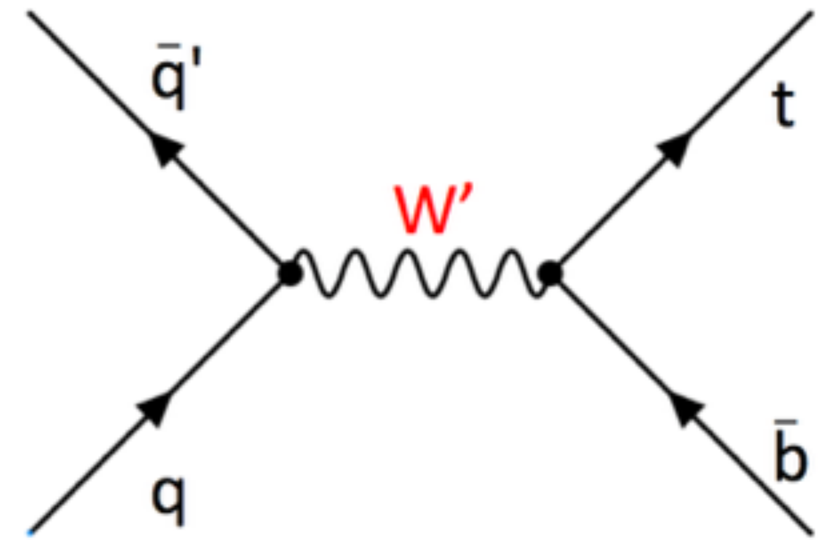
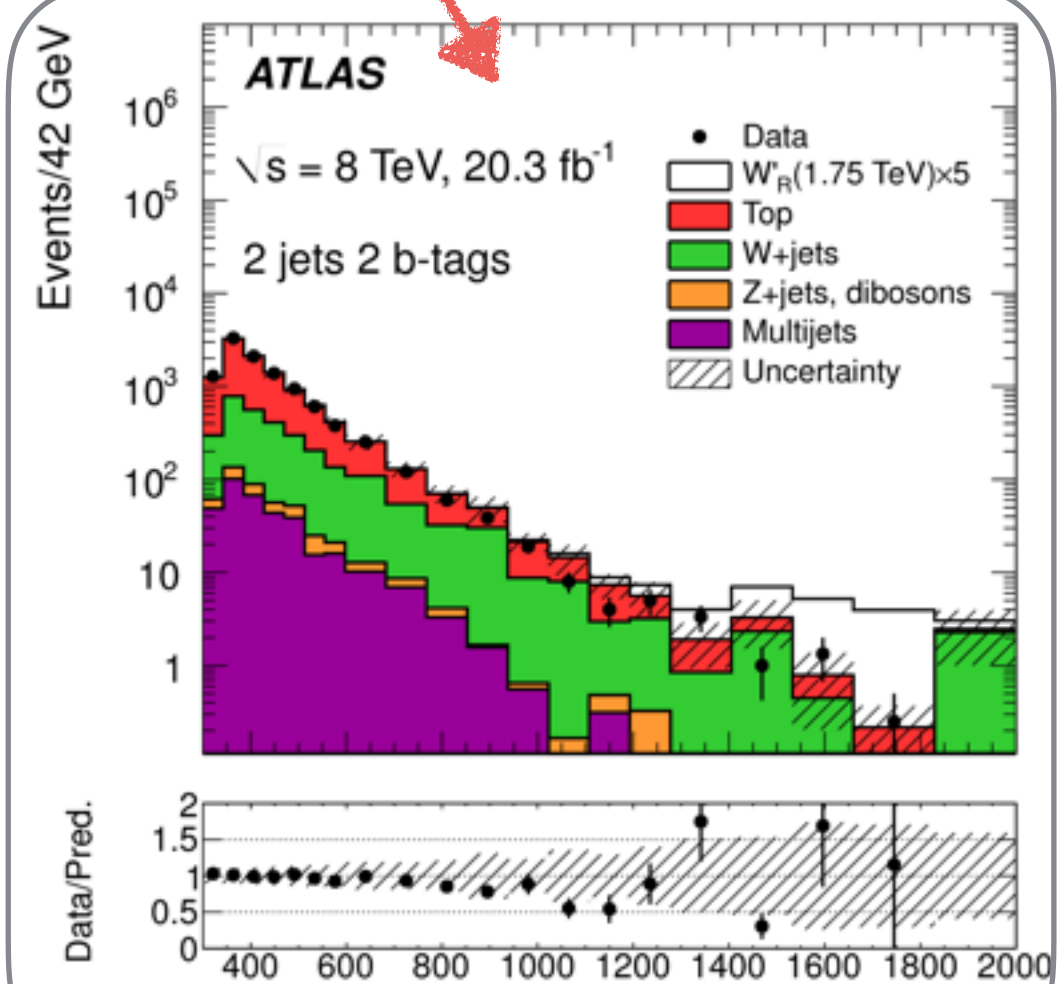


- Check combinations of 2 variables
- Compare background rejection at 50% 80% signal efficiency
- Pick best combination: m_{jet} & τ_{32}

W' to tb resonances @ 8 TeV

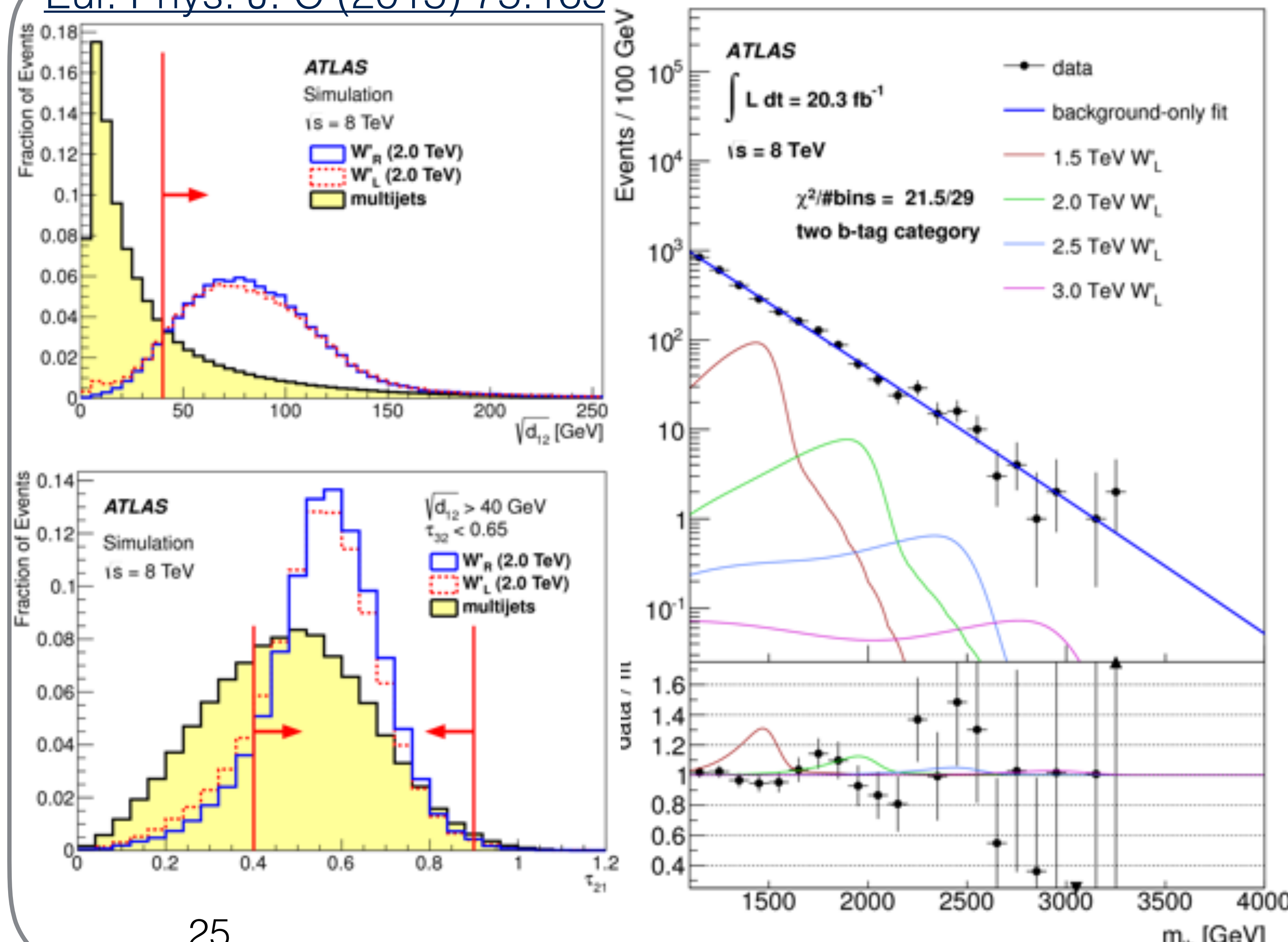
- Leptophobic W' to tb
- Boosted all hadronic w/ substructure based top tagging
- l+jets





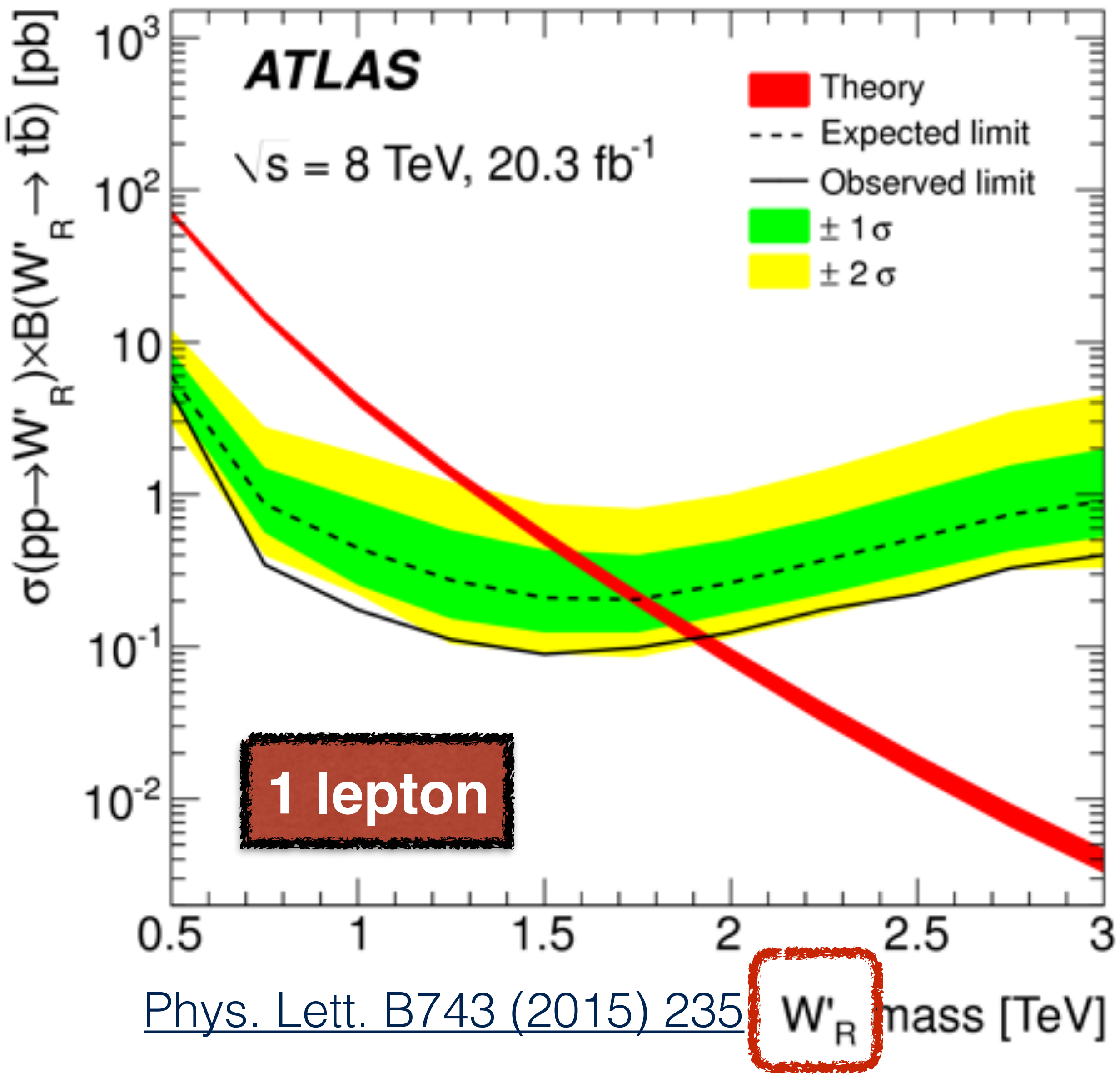
[Phys. Lett. B743 (2015) 235]

[Eur. Phys. J. C (2015) 75:165]

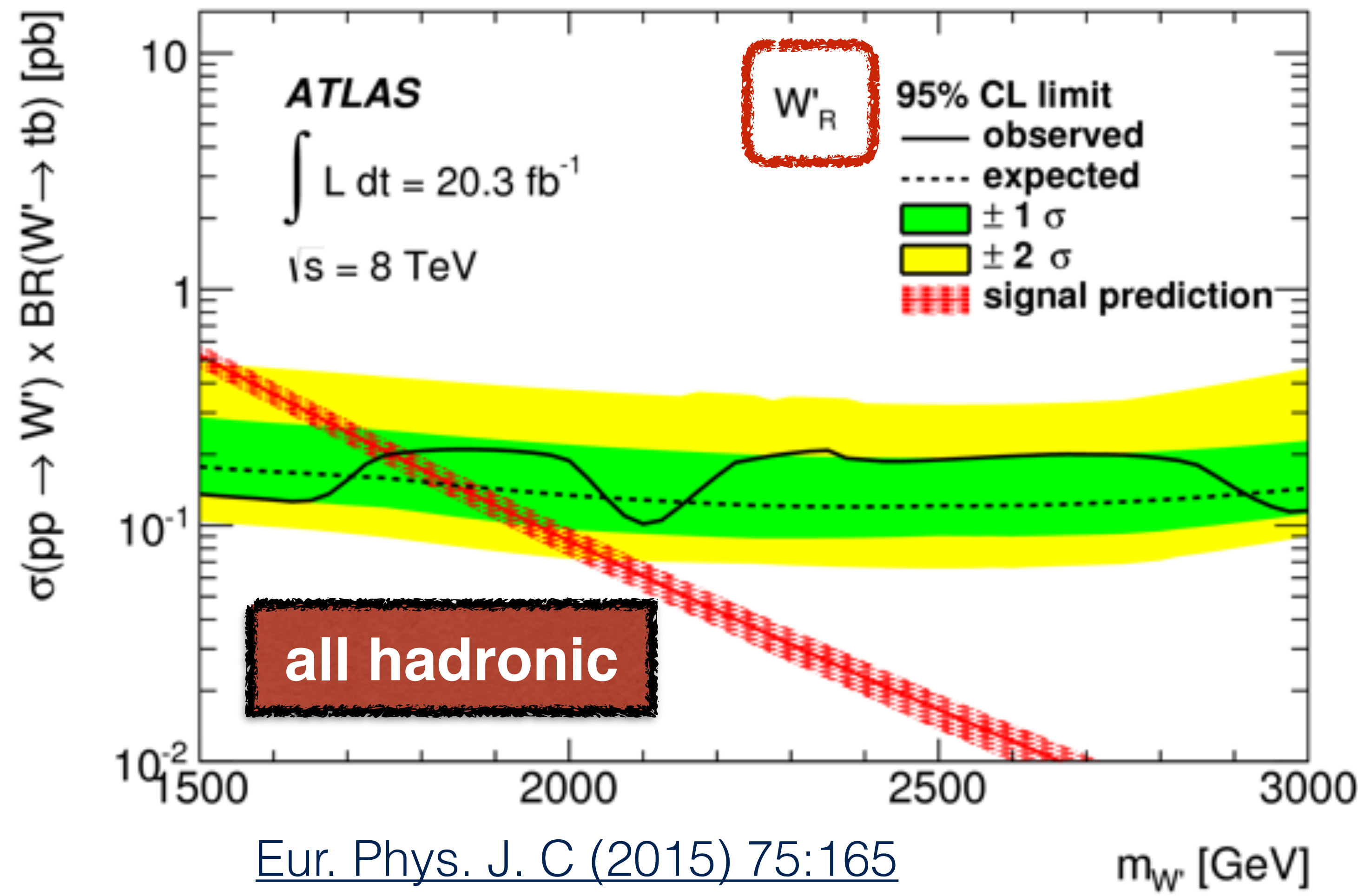


W’ to tb limits @8 TeV

Tested right- and left-handed coupling hypotheses, results very similar.



Phys. Lett. B743 (2015) 235



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<u>Excluded:</u>

$m_{W'L}$ < 1.7 TeV and

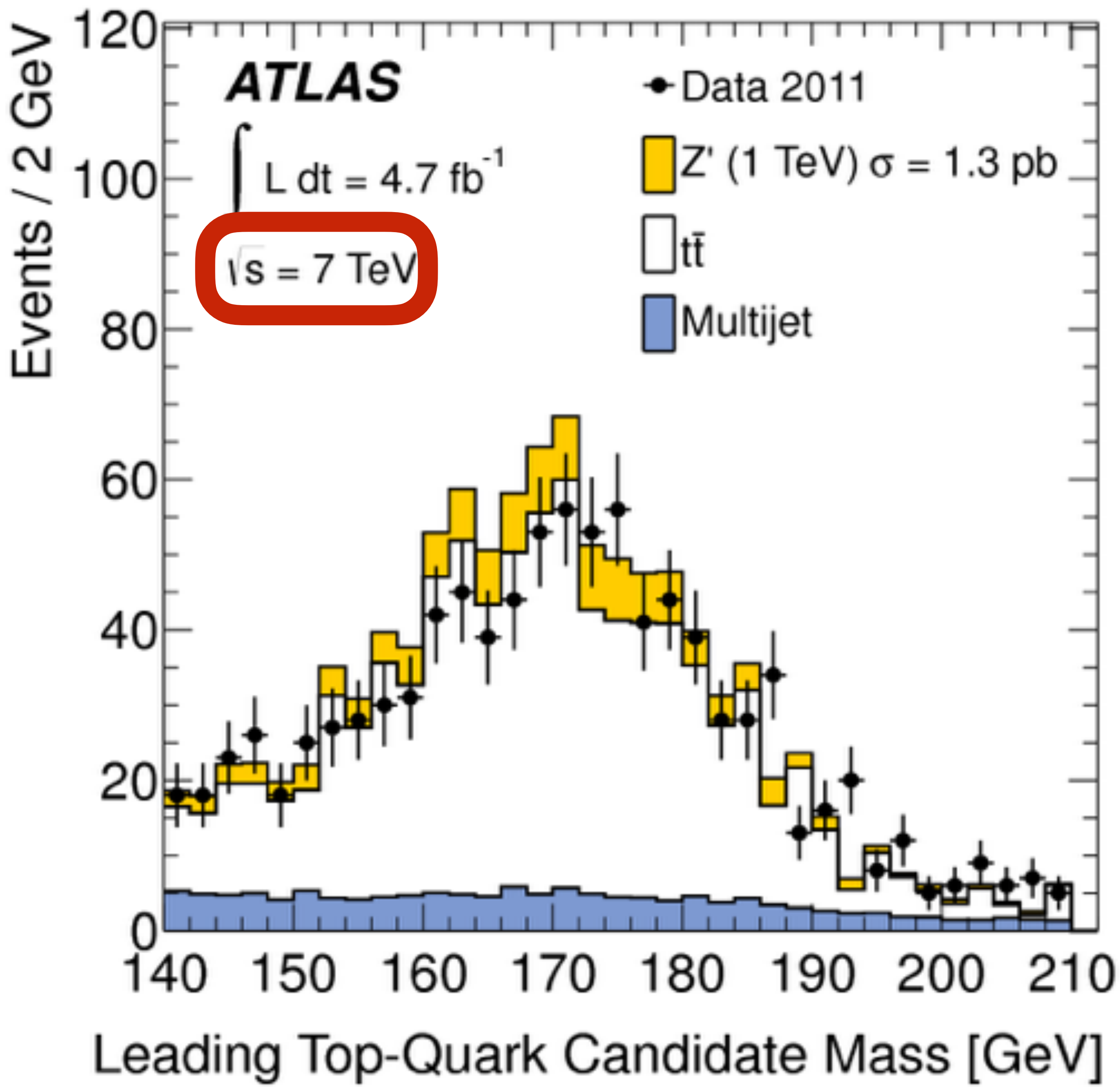
$m_{W'R}$ < 1.92 TeV; 1 lep

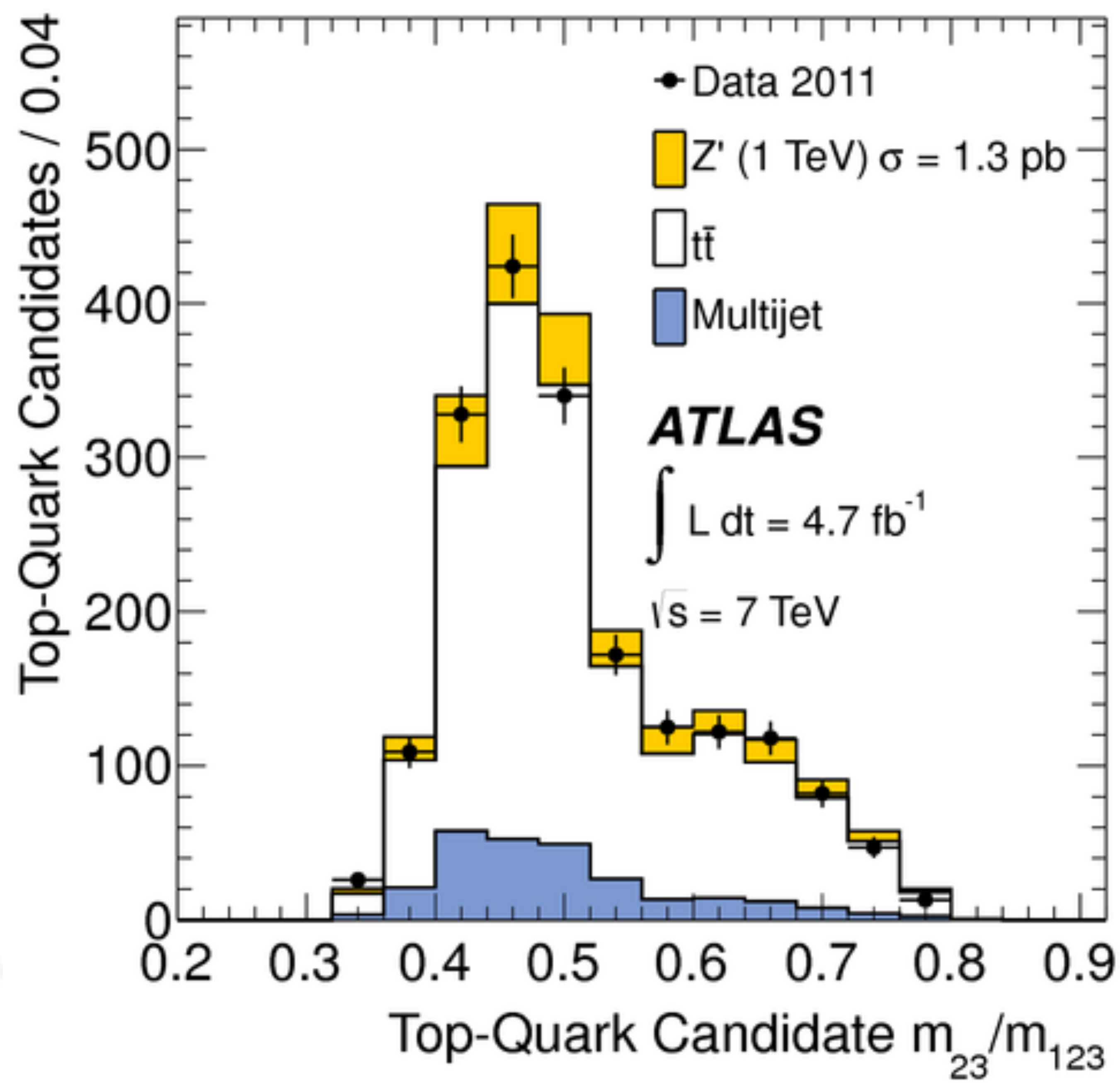
$m_{W'L}$ < 1.68 TeV and

$m_{W'R}$ < 1.76 TeV; all had

Fully hadronic $t\bar{t}$ resonance search

Lots of non top background (QCD)





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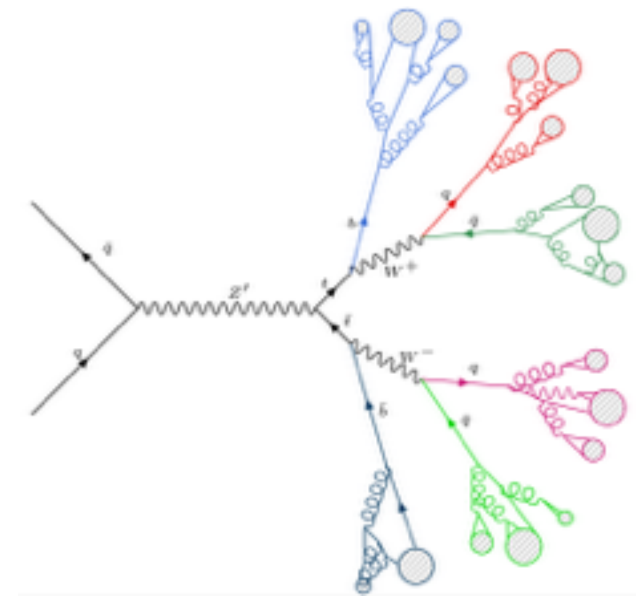
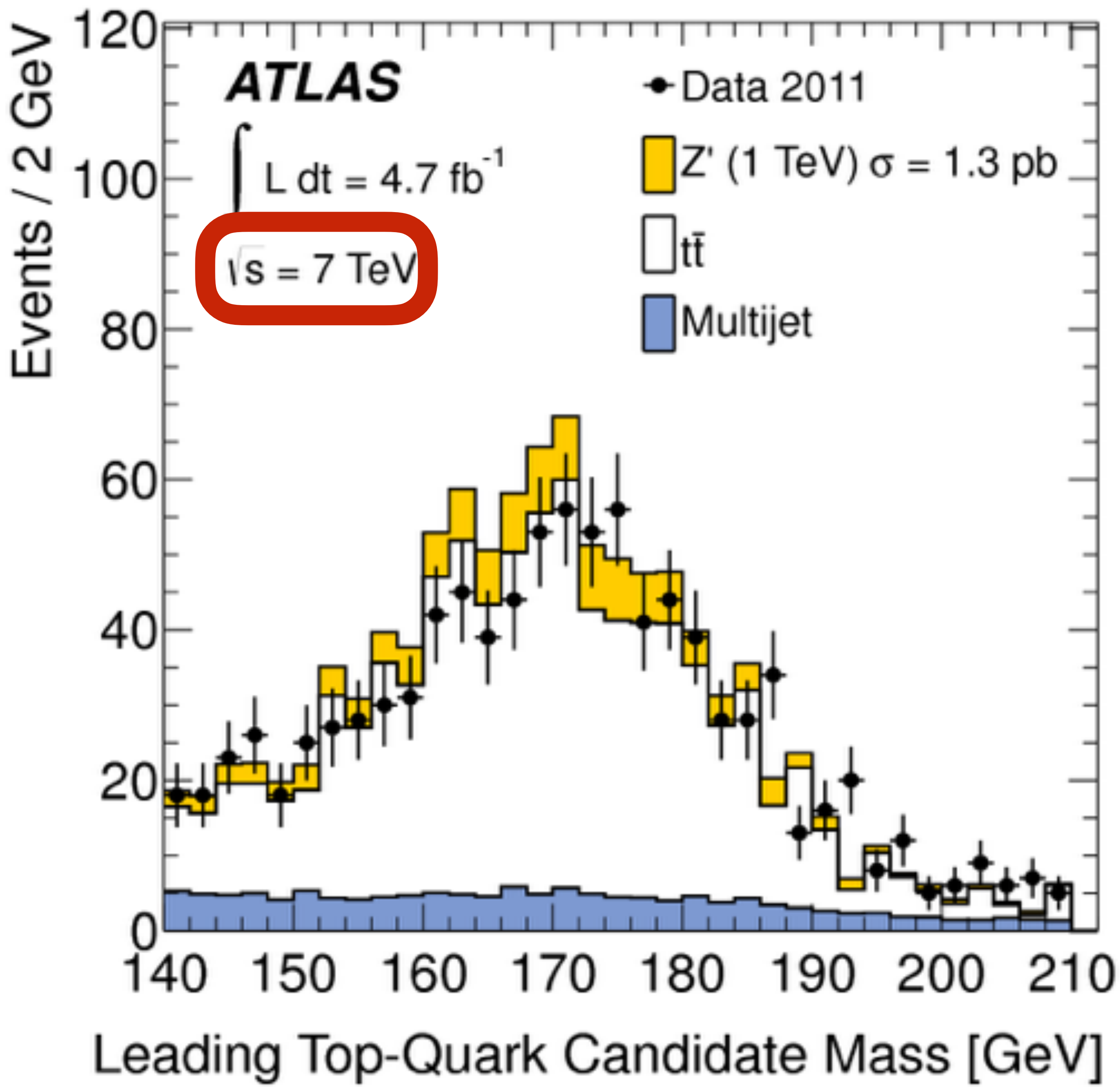
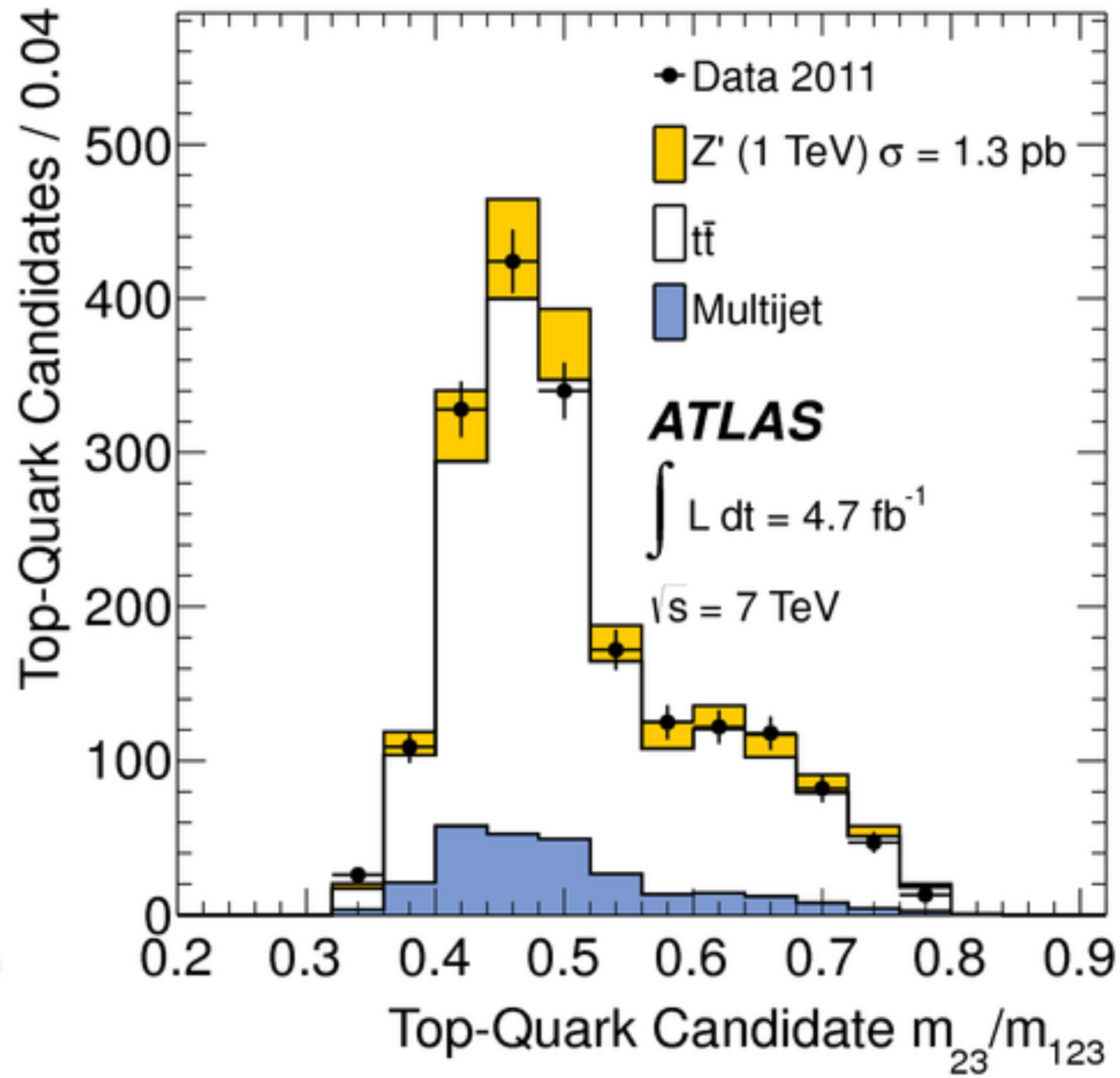
Fully hadronic $t\bar{t}$ resonance search



Lots of non top background (QCD)





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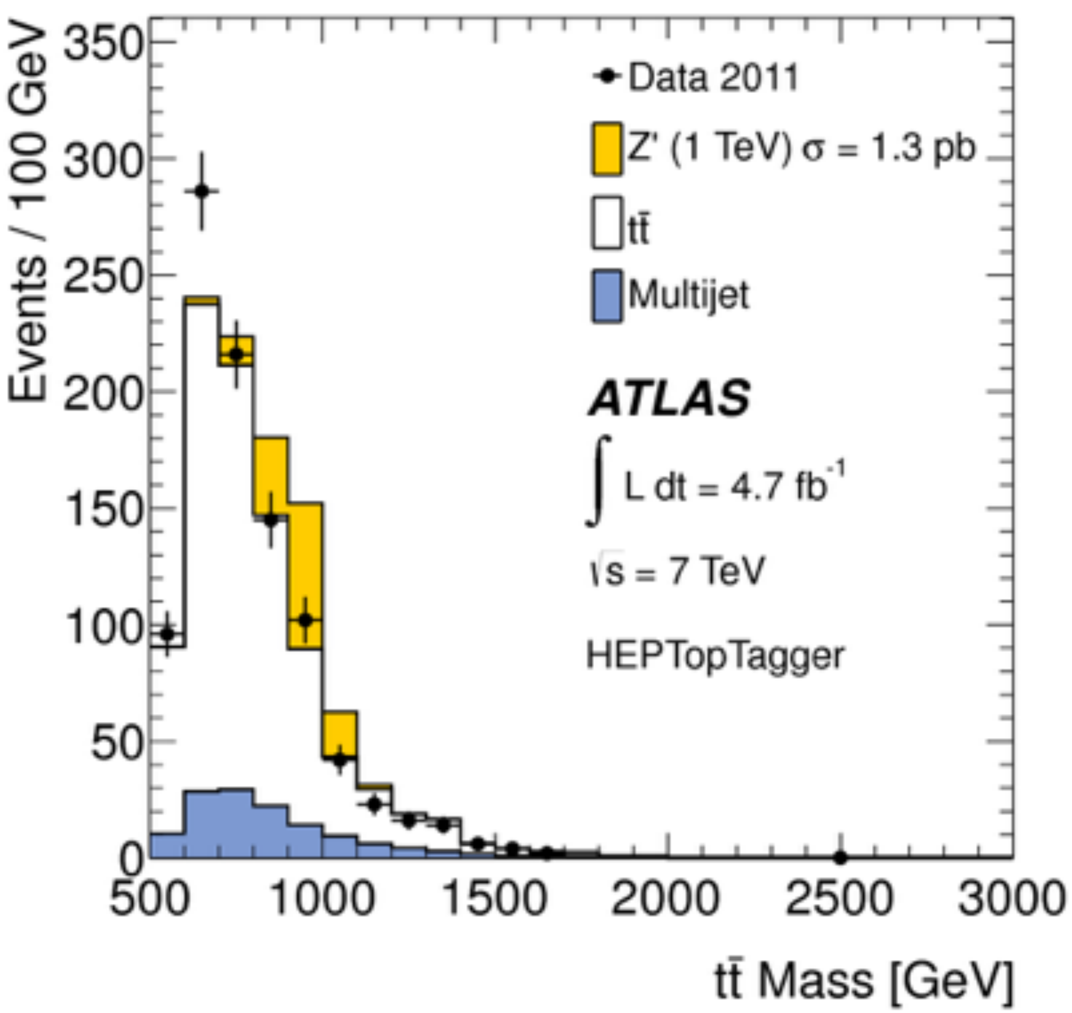
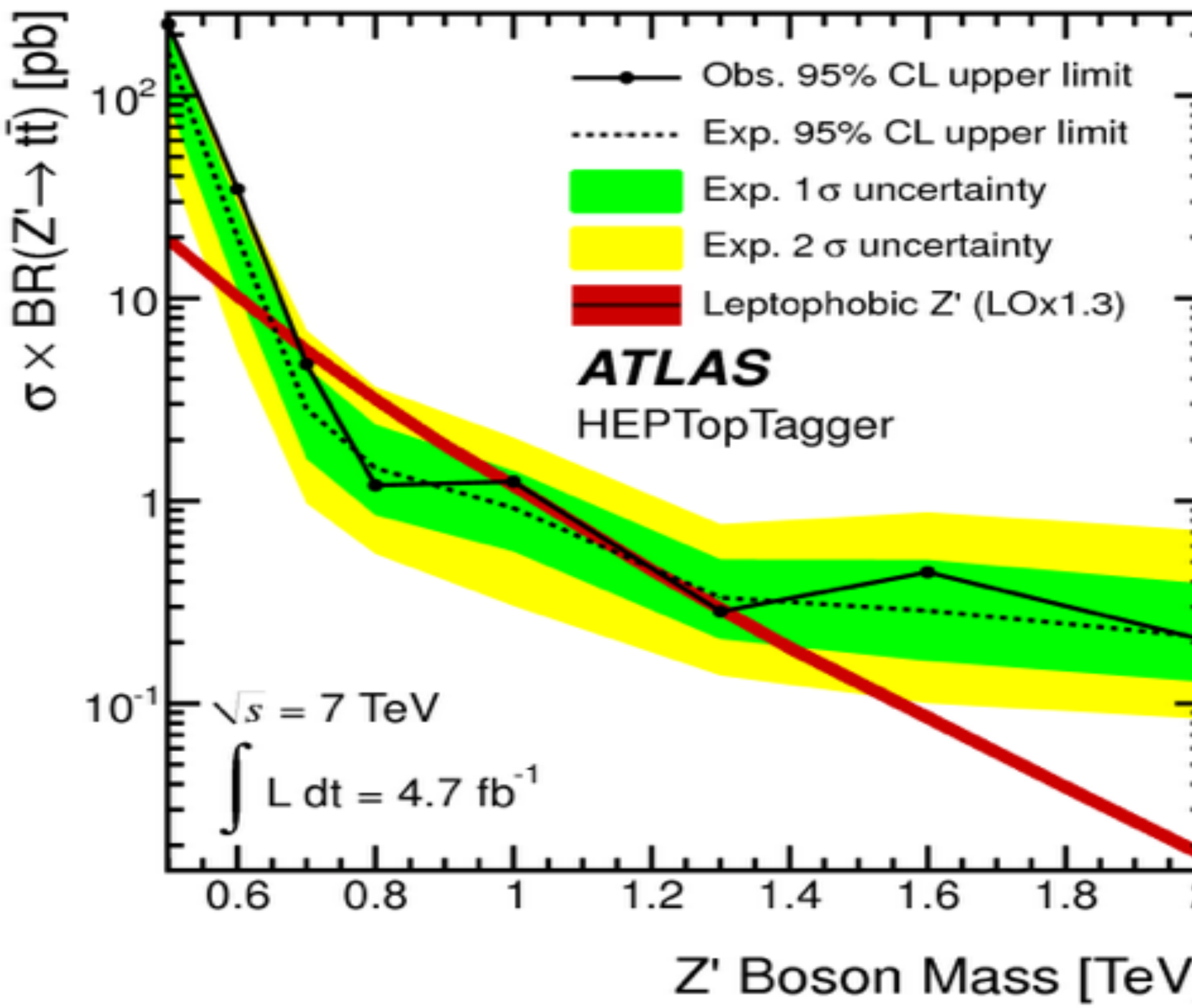
Fully hadronic $t\bar{t}$ resonance search (Run 1)





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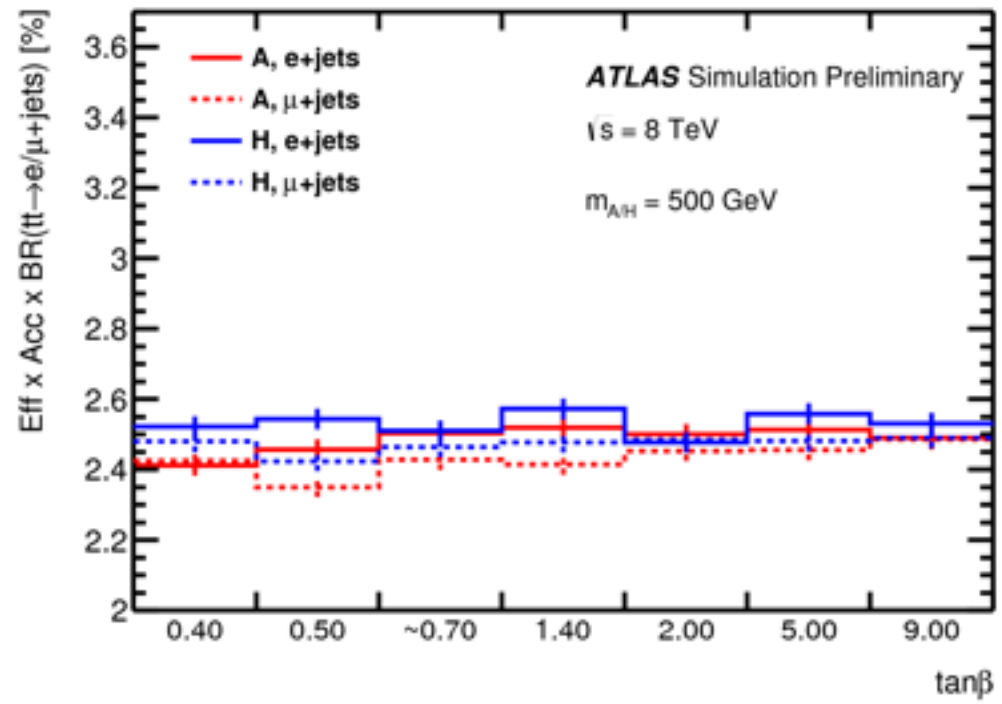
Scalar interpretation

- Selection eff ~flat vs tanβ
- gg production dominates over qq
- large cross section at low mass, sharply falling off
—> sensitivity up to ~1TeV



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- X—> tt best suited for low tanβ as, i.e. where couplings to up-type quarks are larger
- limits are set on sqrt(mu)

$$\mu S + \sqrt{\mu} I + B = (\mu - \sqrt{\mu}) S + \sqrt{\mu}(S + I) + B$$