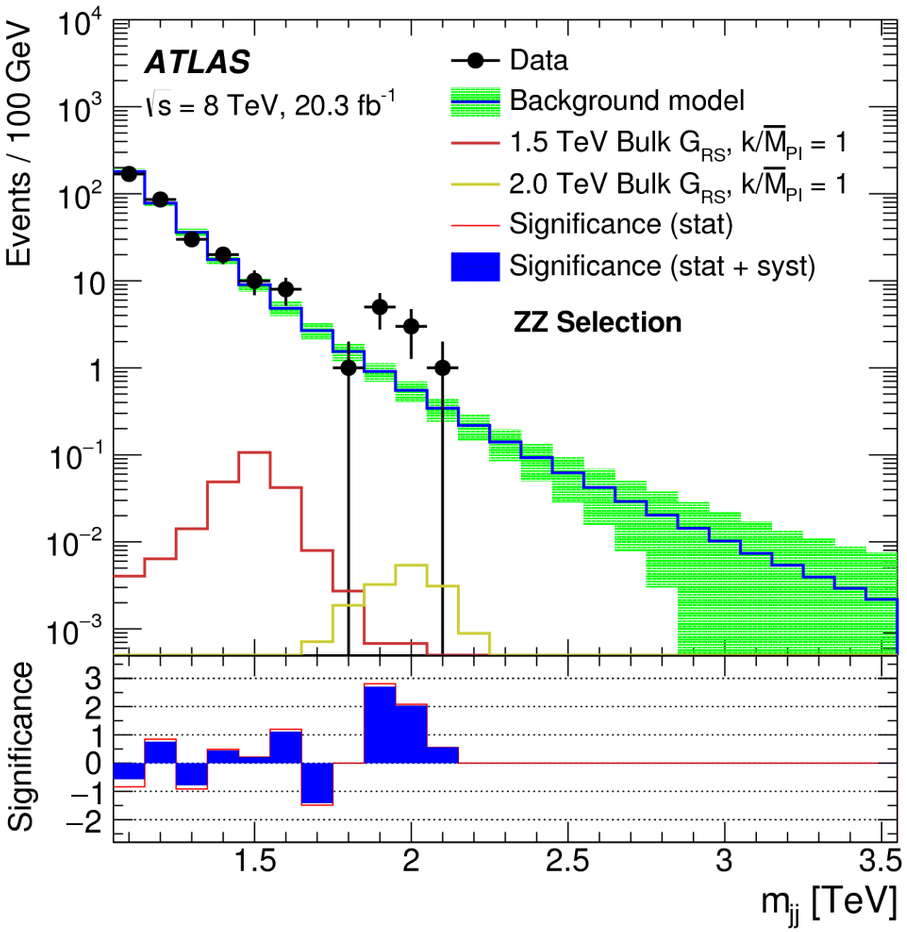
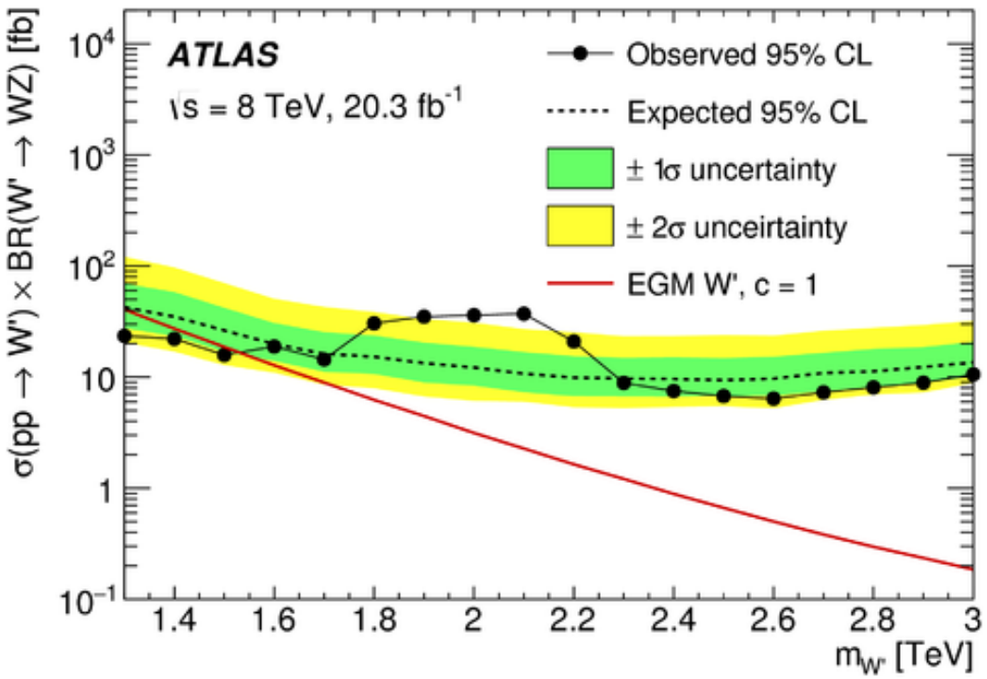
Diboson excesses at 2 TeV: signals and models

Adam Martin (amarti41@nd.edu)
University of Notre Dame

KITP, 8/7/15

what all the excitement is about





VV search in all hadronic mode.
Looks for 2 W/Z-‘tagged’ jets, form m_{JJ}

why this excess? there are plenty of anomalies out there

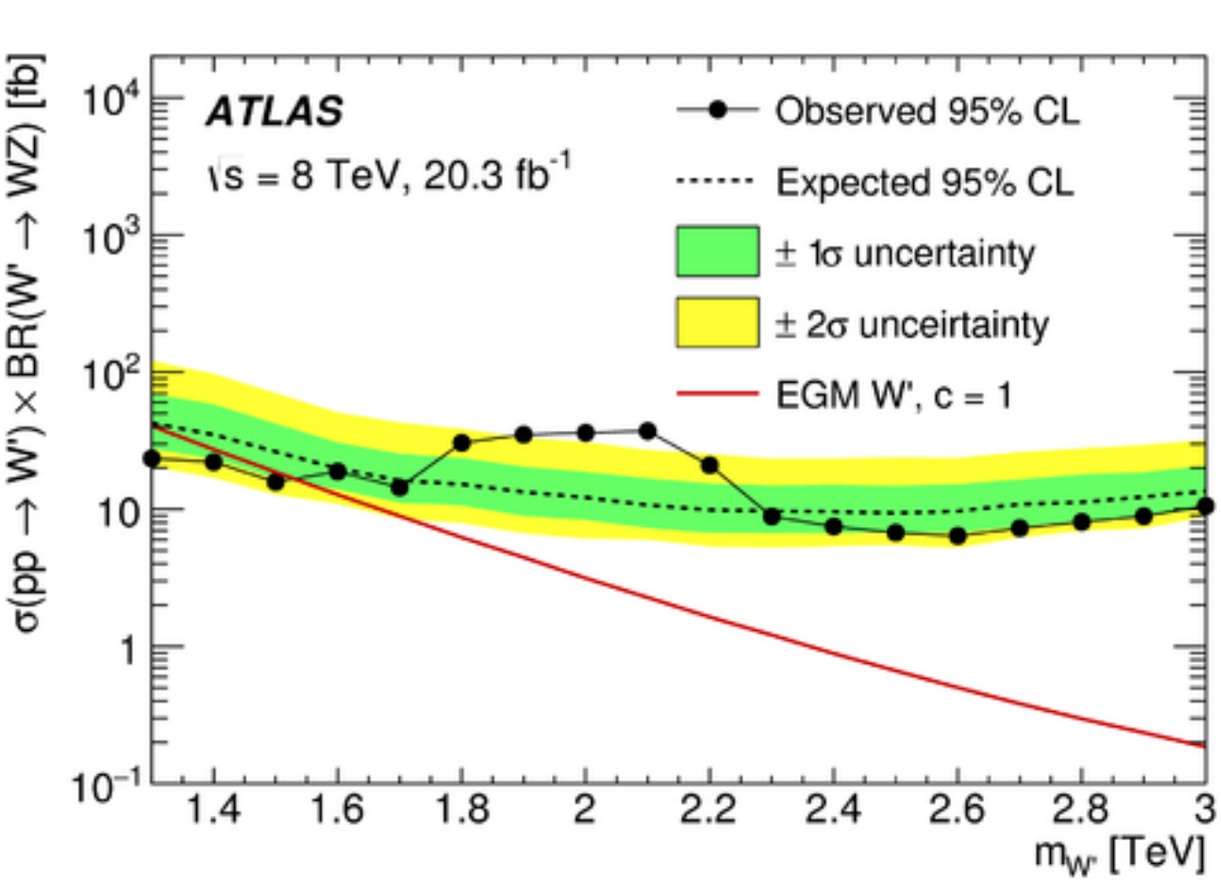
(even just focusing on the high-p_T results)

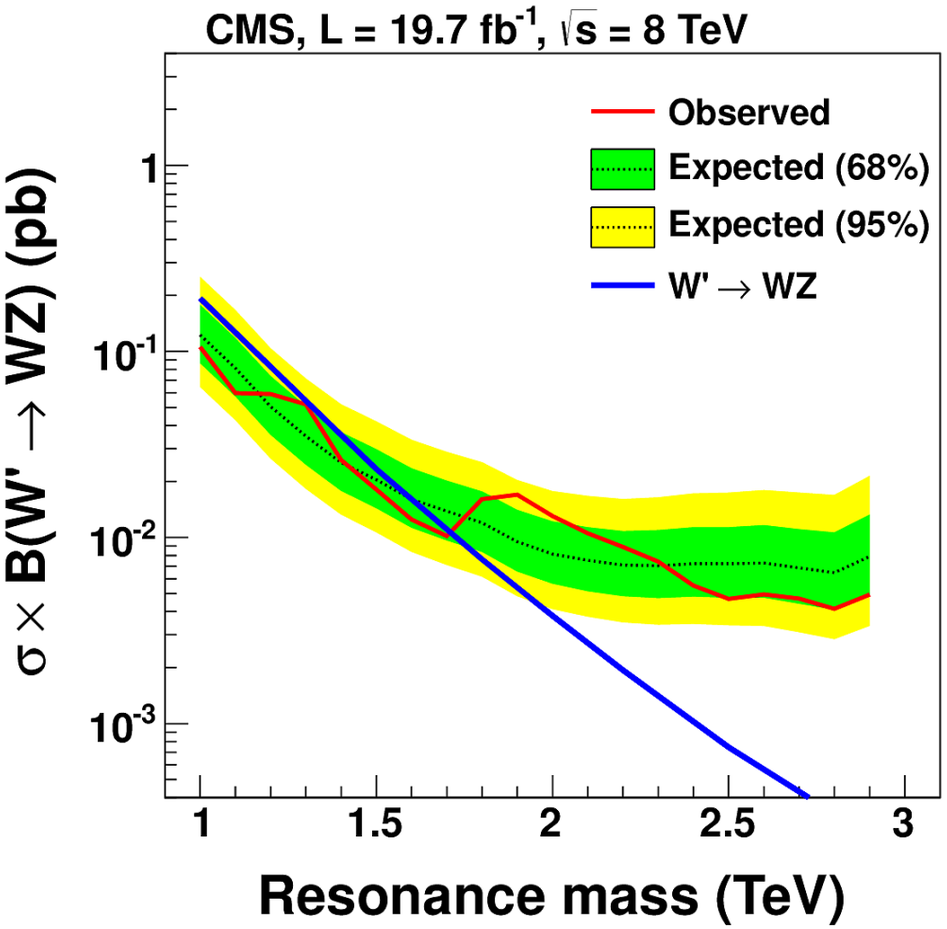
- CMS eejj, evjj "leptoquark excess", 2.4/2.6σ, CMS PAS EXO-12-041
- CMS eejj "W' excess", 2.8σ, 1407.3683
- CMS OS dilepton "edge", 2.4σ, 1502.06031
- CMS LFV Higgs decay (μτ), 2.4σ 1502.07400
- ATLAS dileptons + jets + MET, 3.0σ, 1503.03290
- ATLAS SS dileptons + b-jets + MET, 2.5σ, 1504.04605

...

+ others in Ayana's talk

similar search in CMS shows same effect!





CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO12024

ATLAS: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-08/

(plots & references taken from talk by C. Pollard at LesHouches ’15)

whenever a new excess comes out

[AM, MC4BSM ’15]

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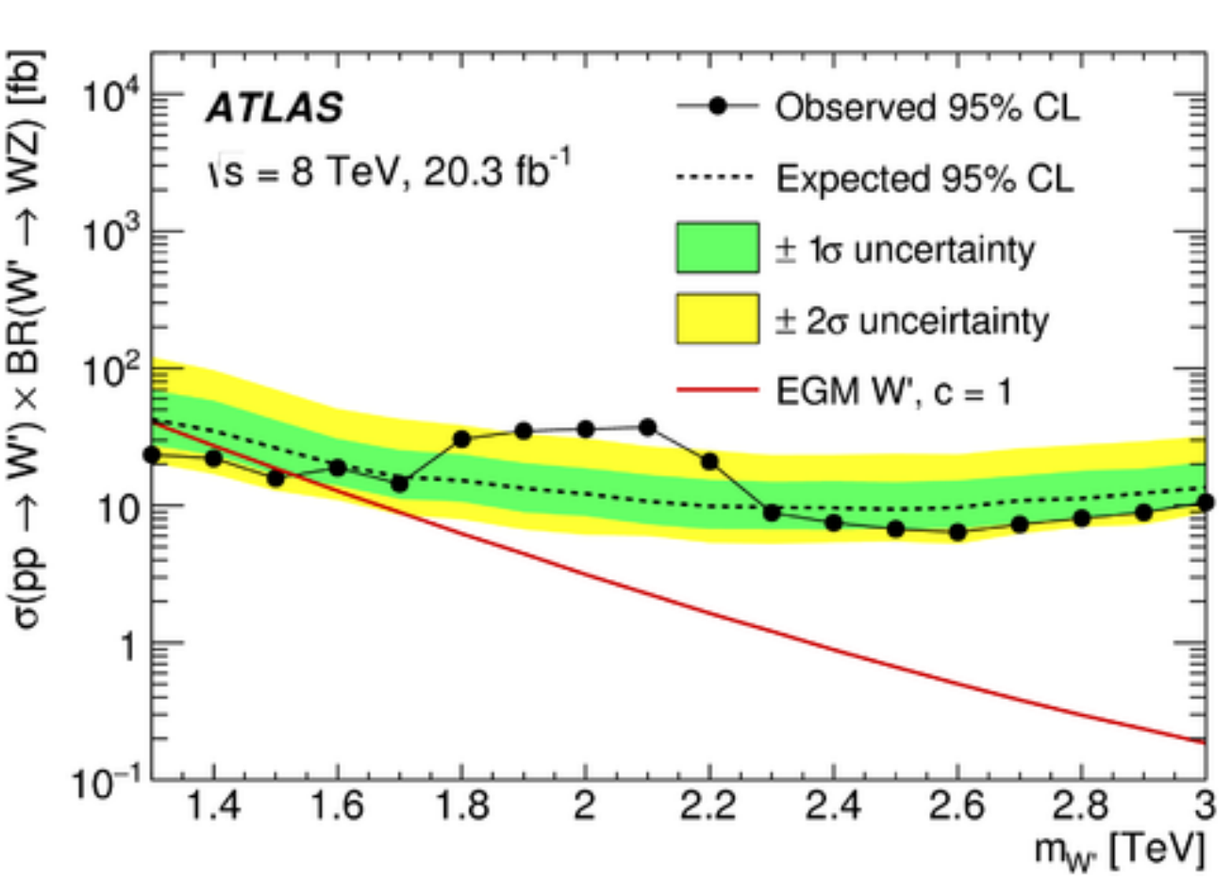
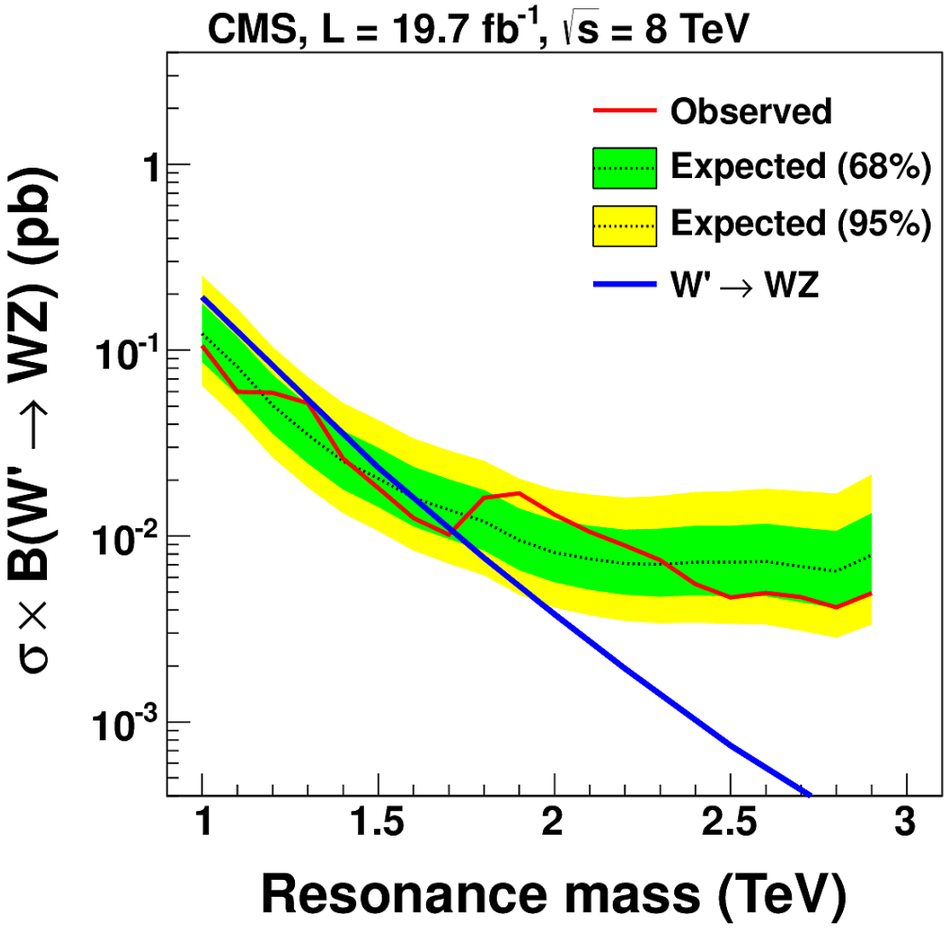
maybe its the beginning of new physics!! we **are** in this business to look for new phenomena, after all!
who cares if its a 'motivated' model?

similar search in CMS shows same effect!





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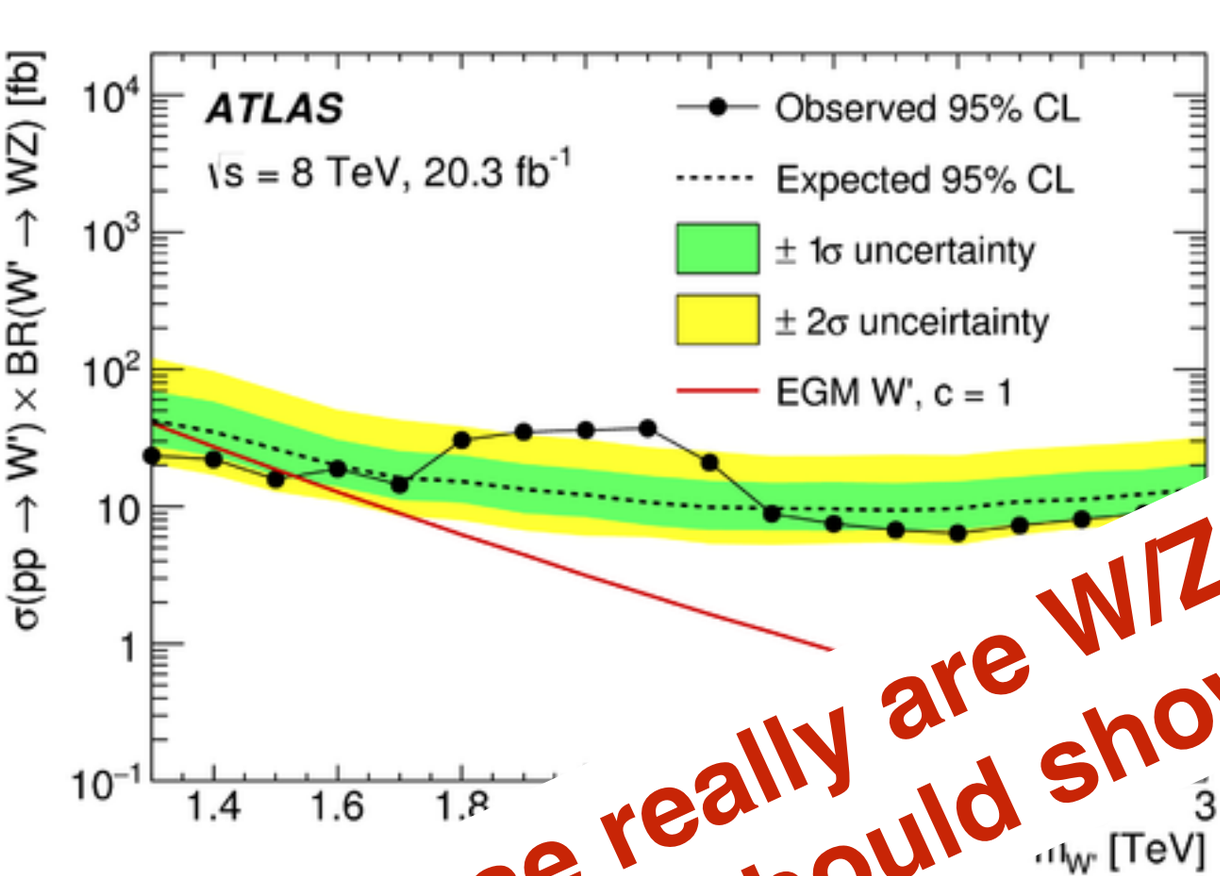

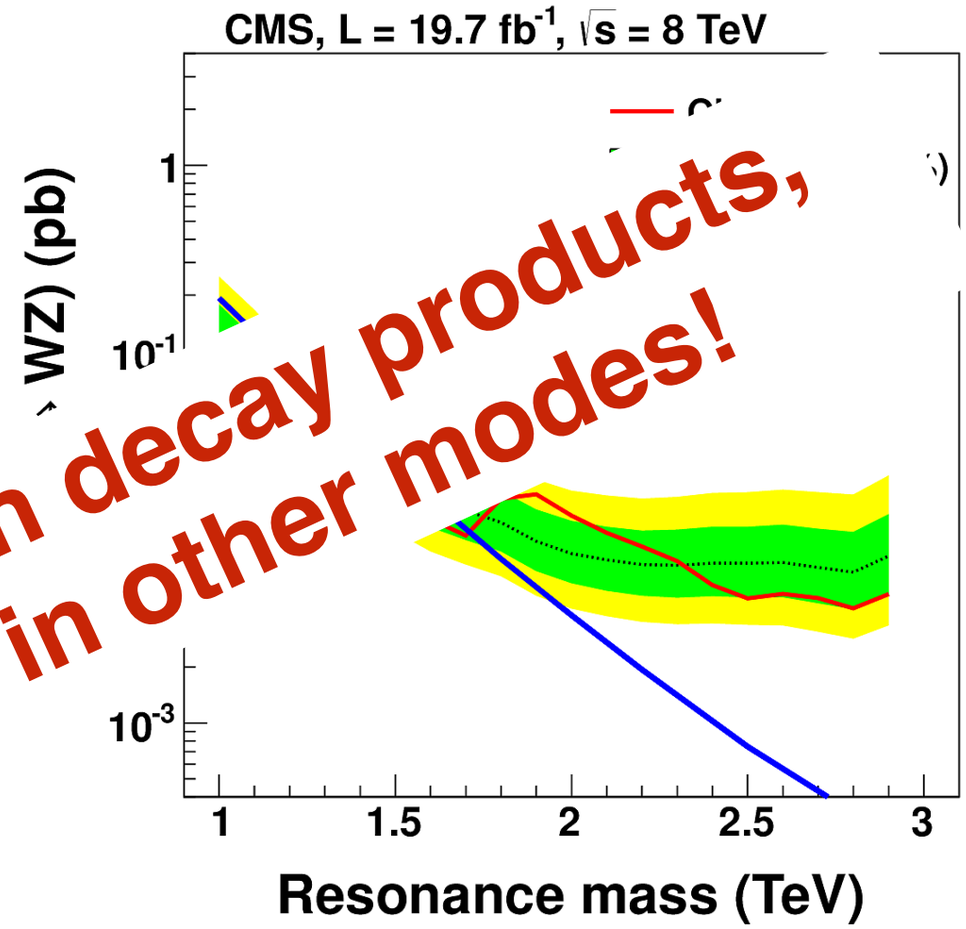

if these really are W/Z in decay products, effect should show in other modes!

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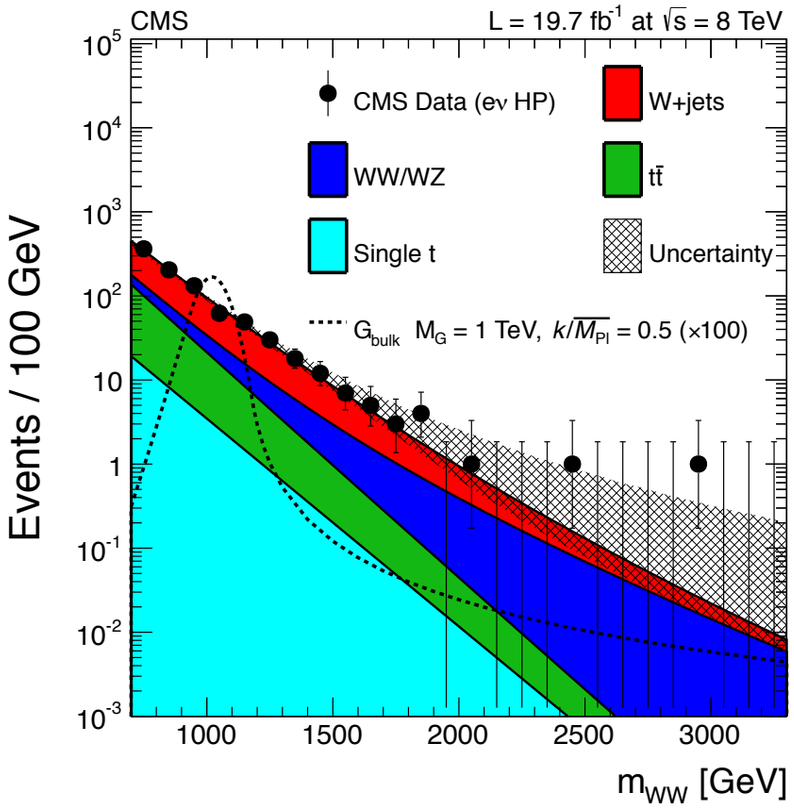
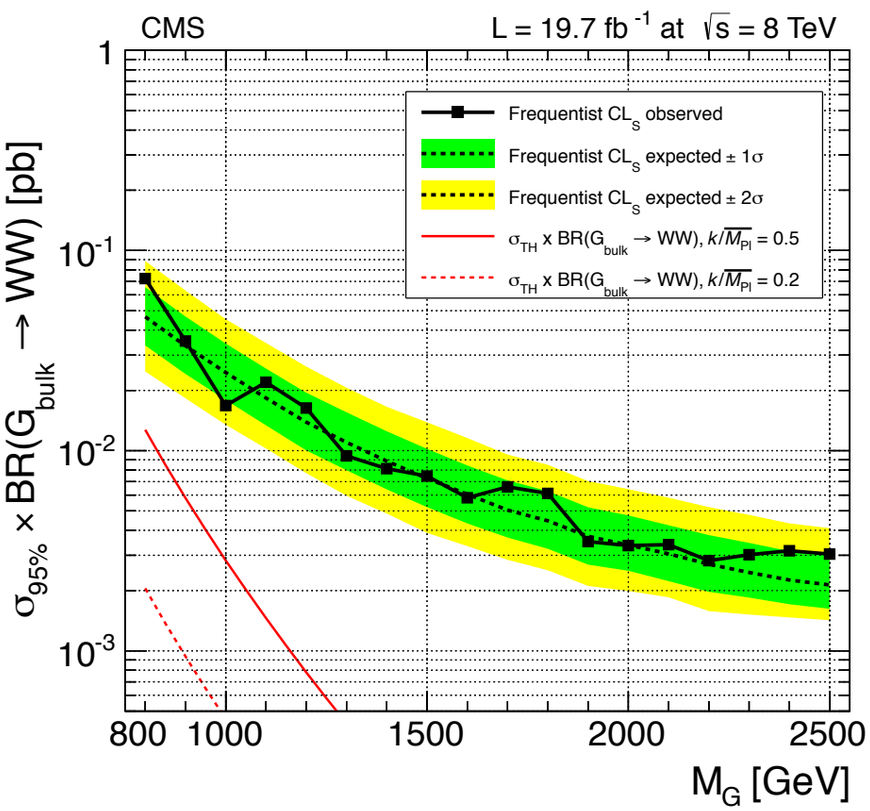
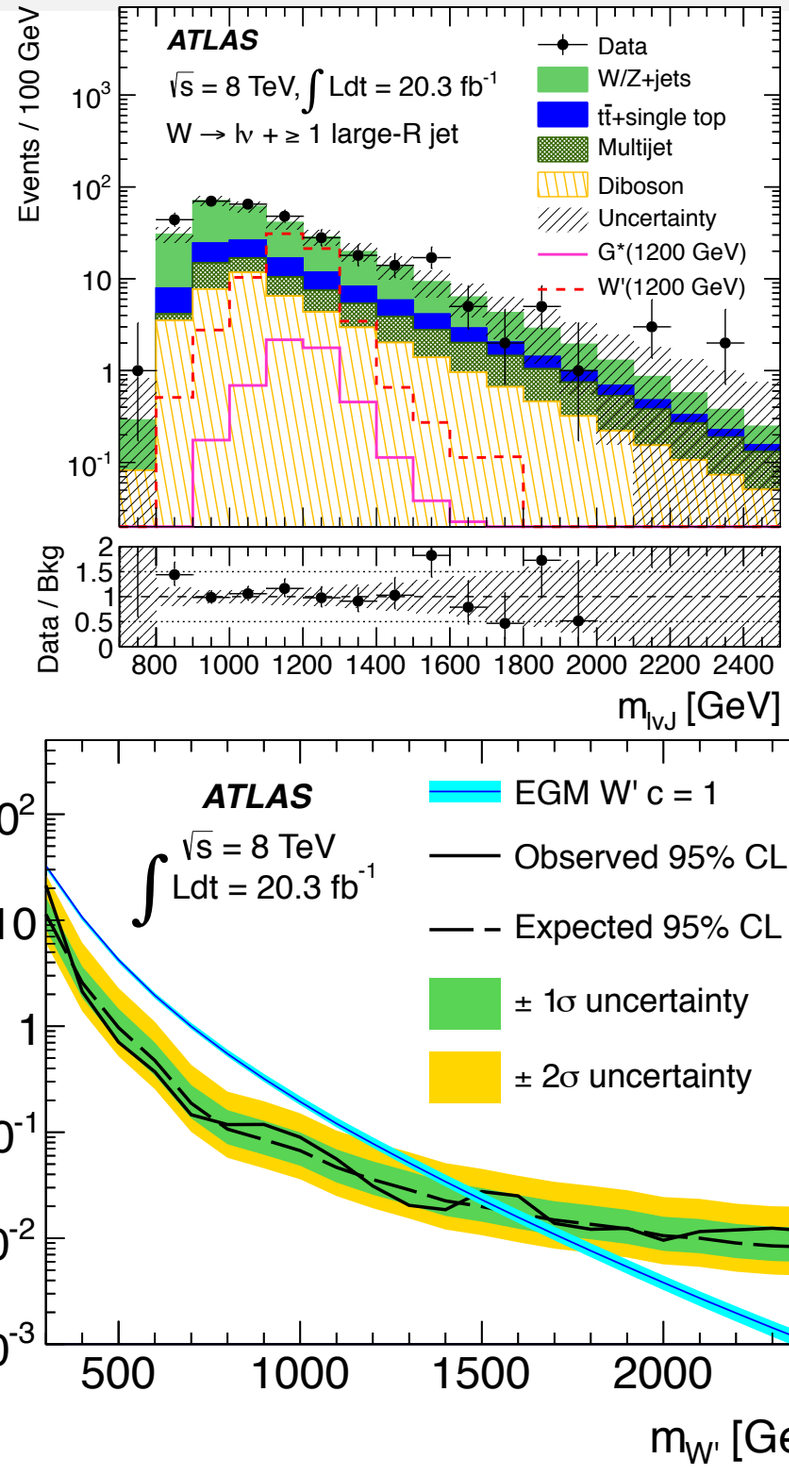
semileptonic mode: V(ℓν) V(jj)







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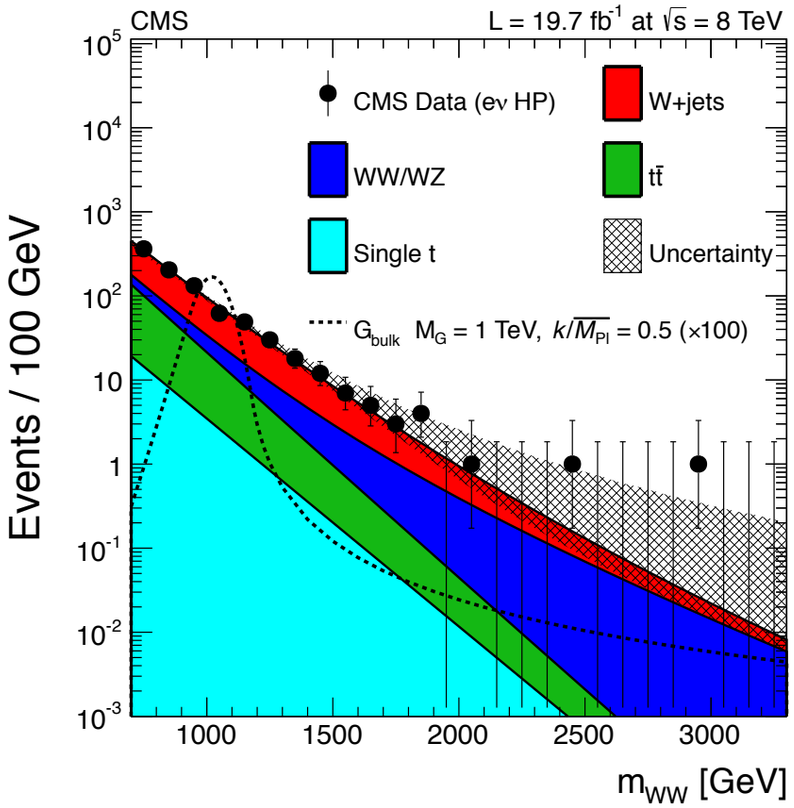
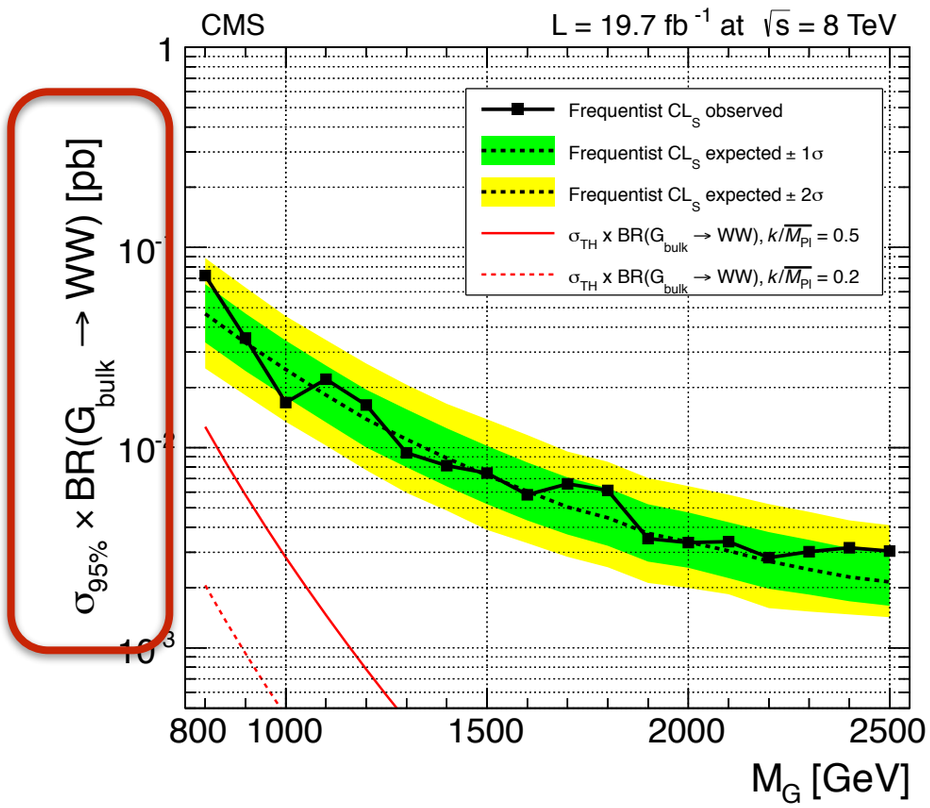
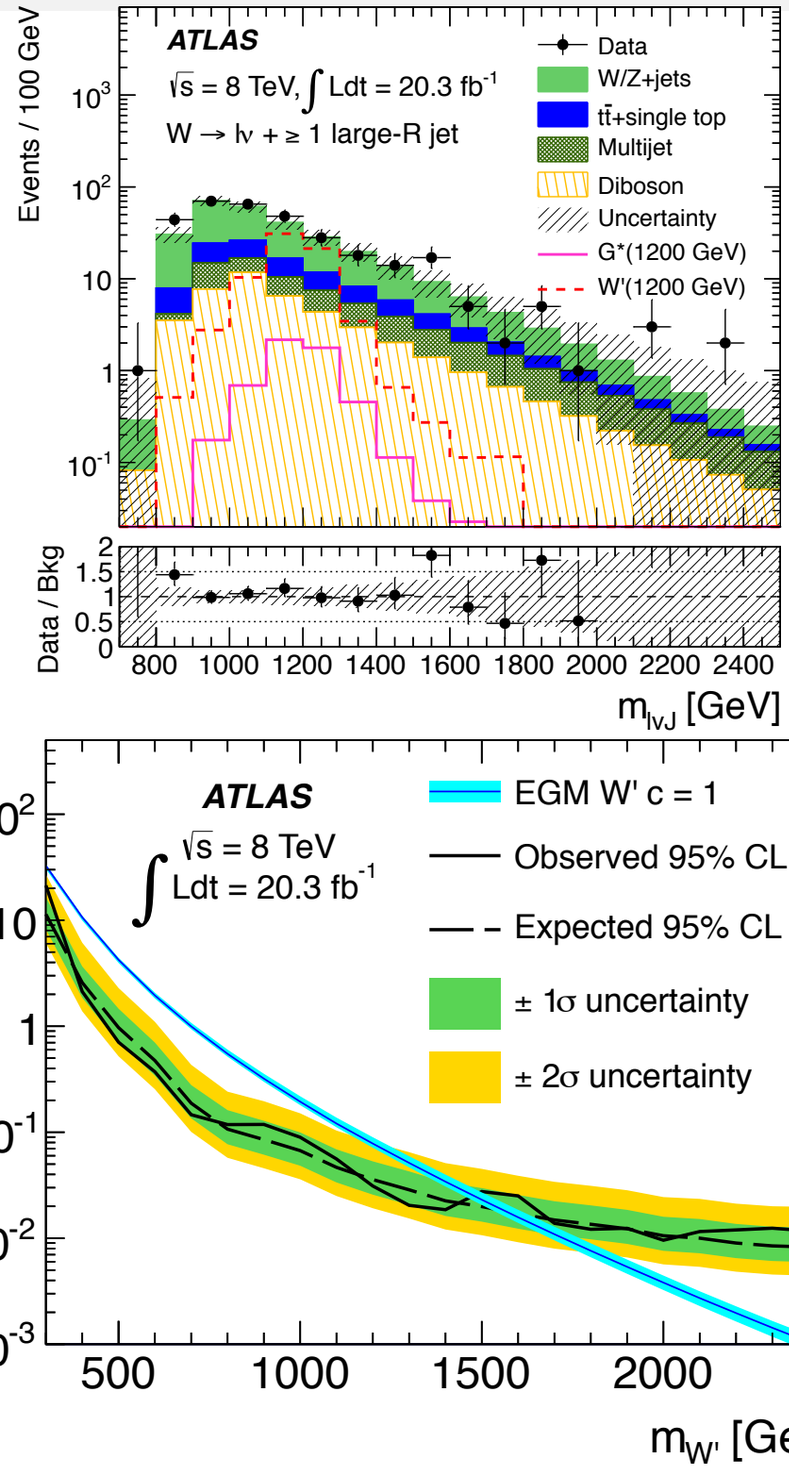
ATLAS: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-01/

semileptonic mode: V(ℓν) V(jj)







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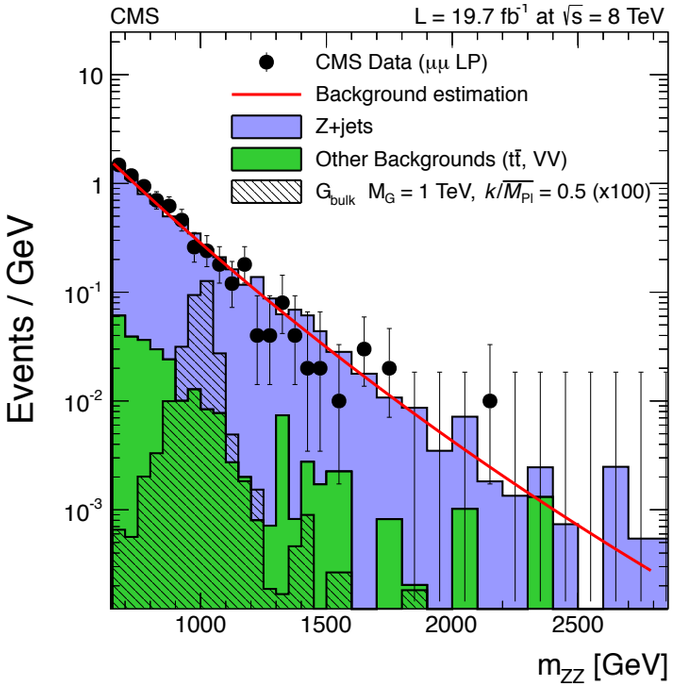

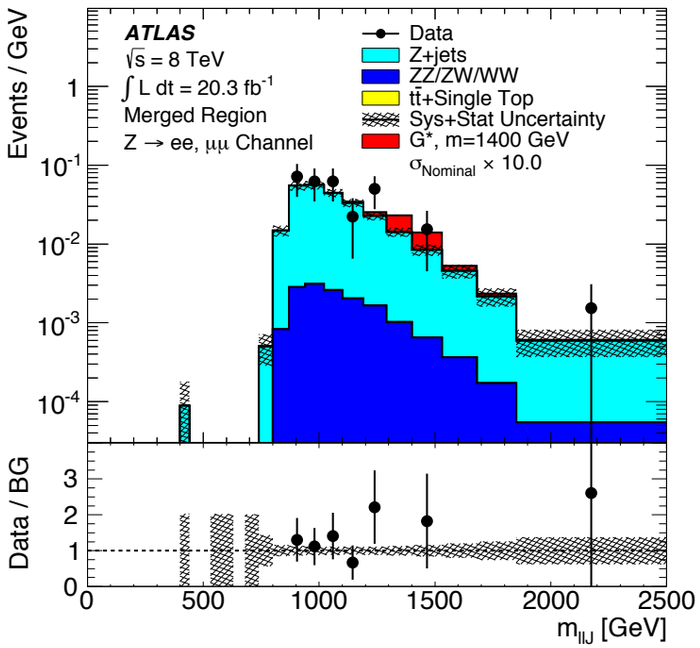

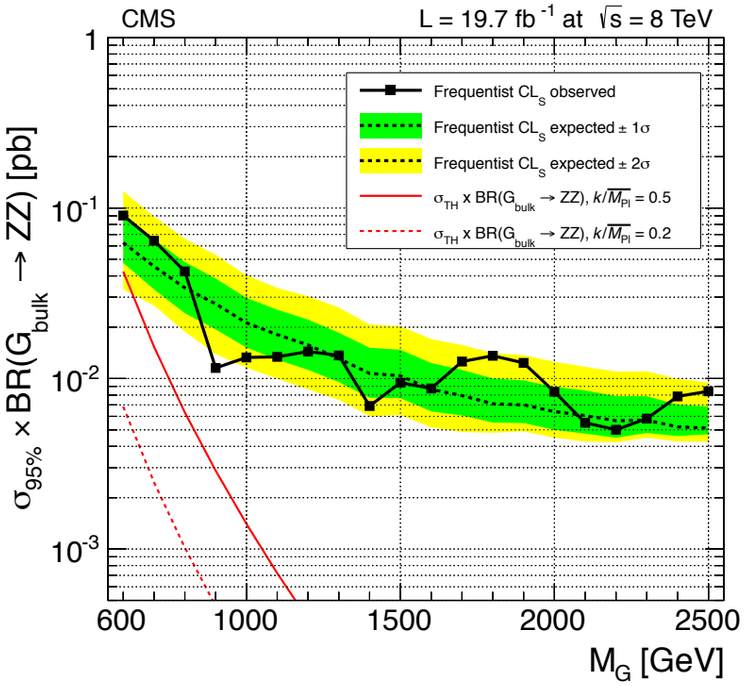

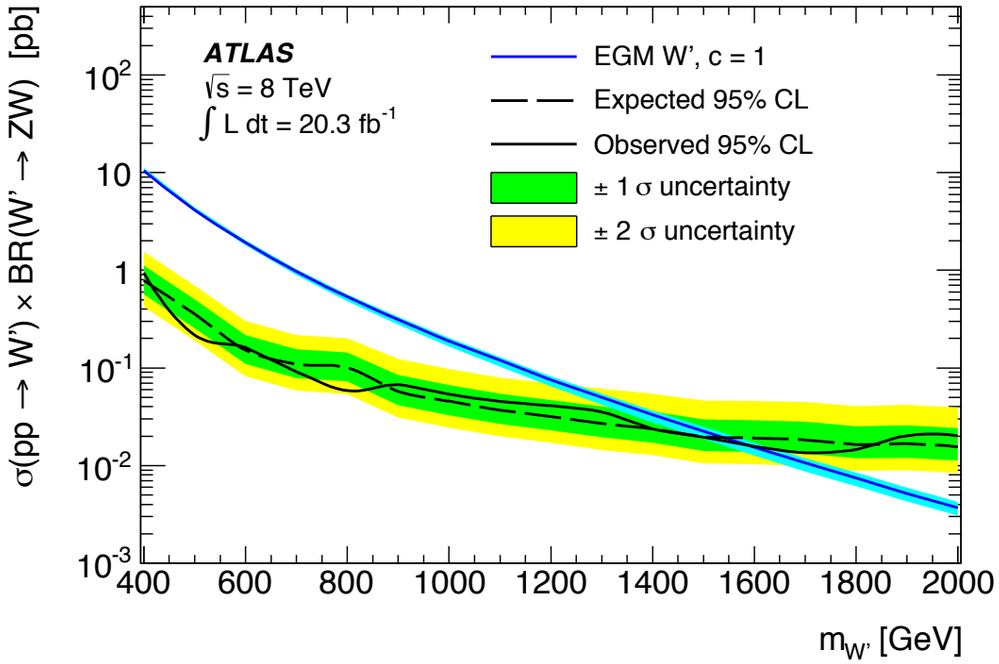

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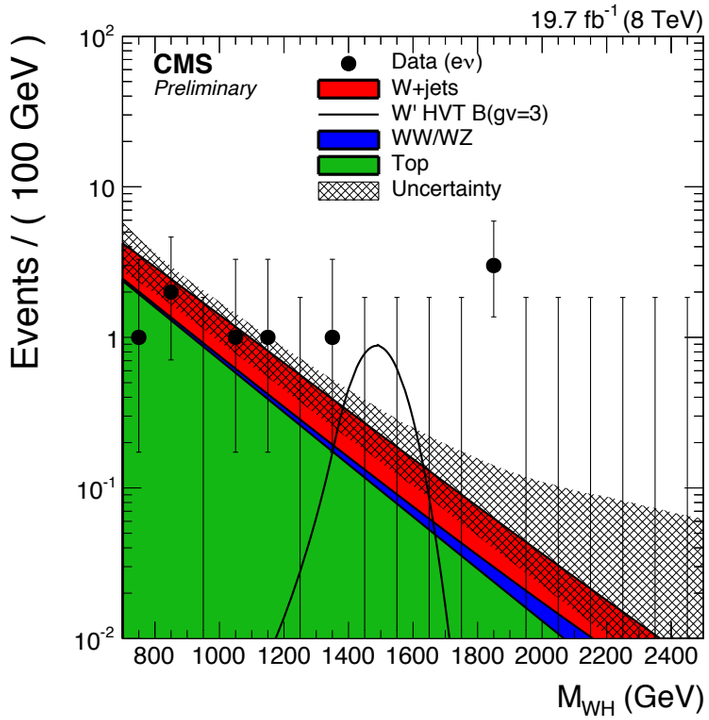
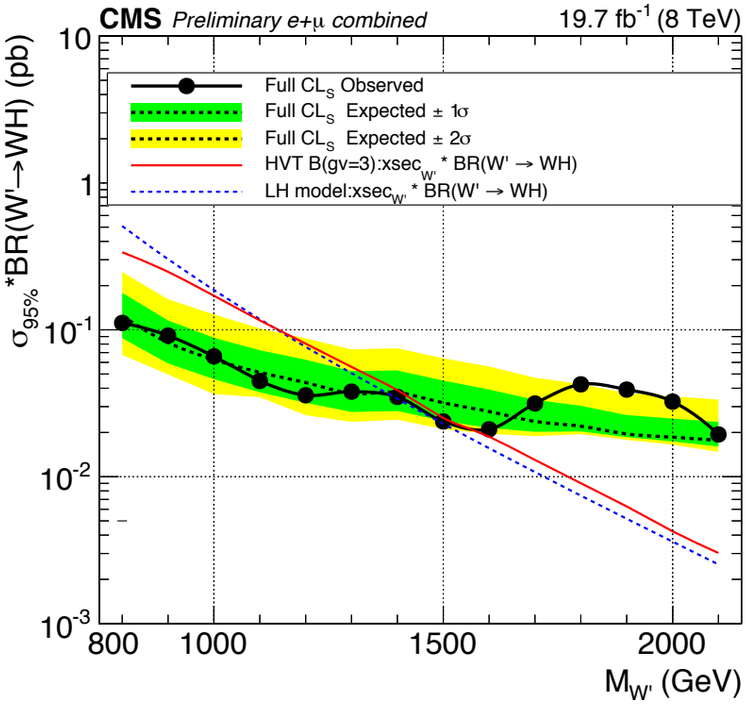
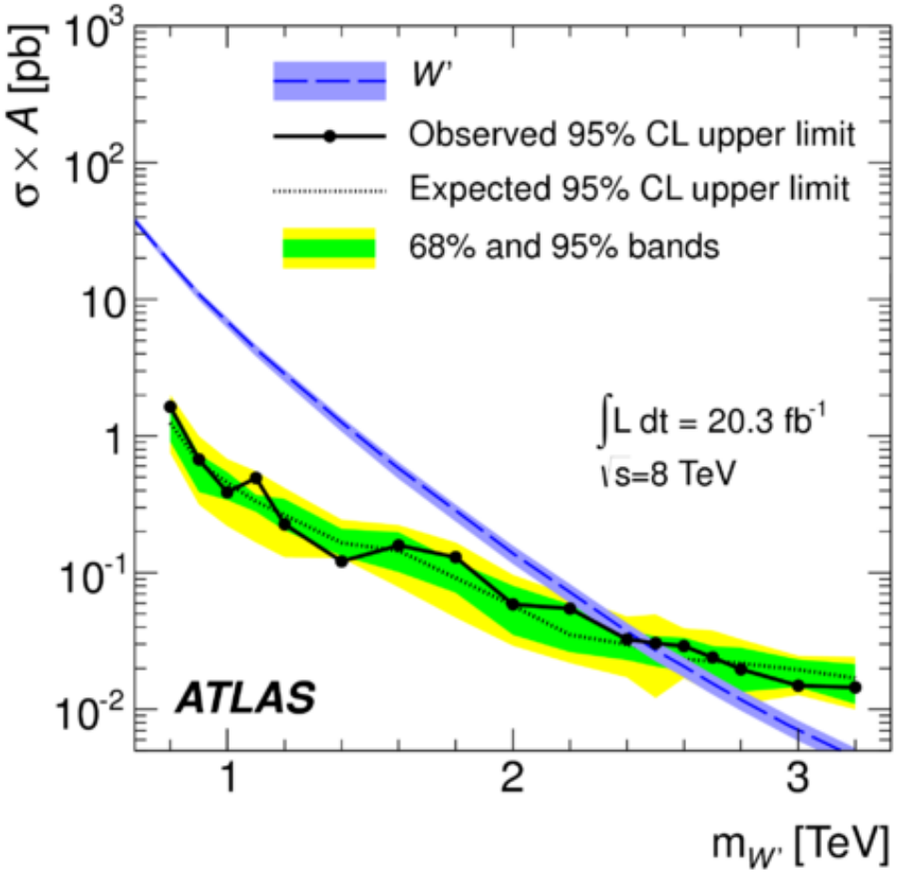
ATLAS: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-06/

CMS V(ℓν) H(b$\bar{b}$)





ATLAS dijets



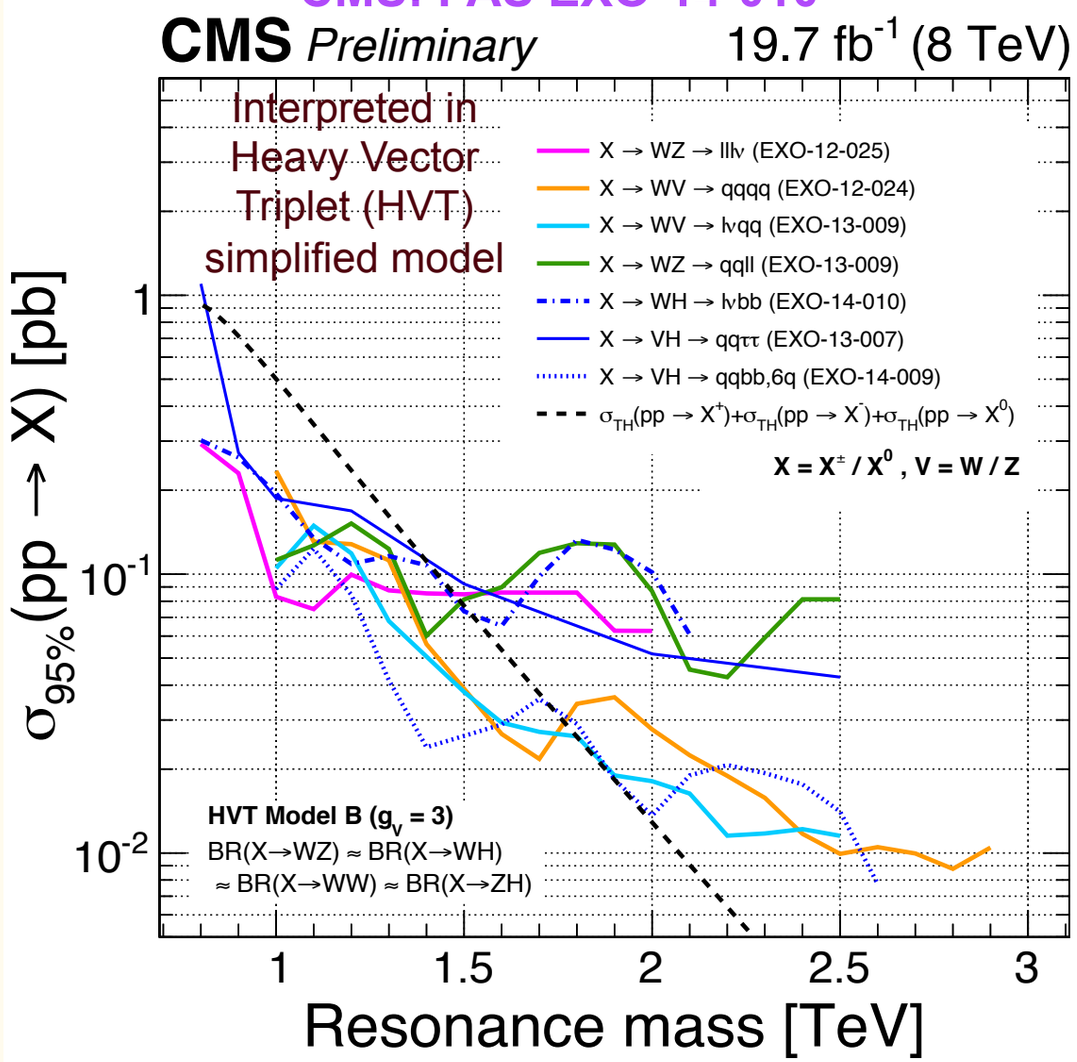
http://arxiv.org/abs/1407.1376

CMS: https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO14010

ATLAS: https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/EXOT-2013-23/

(V(ℓℓ) + H(b$\bar{b}$) shows no excess)

CMS: PAS EXO-14-010



excesses ~ consistent with:

~5-10 fb in hadronic VV

~0-3 fb in V(ℓν)V

~5-10 fb in V(ℓℓ)V

~100 fb signal in dijets

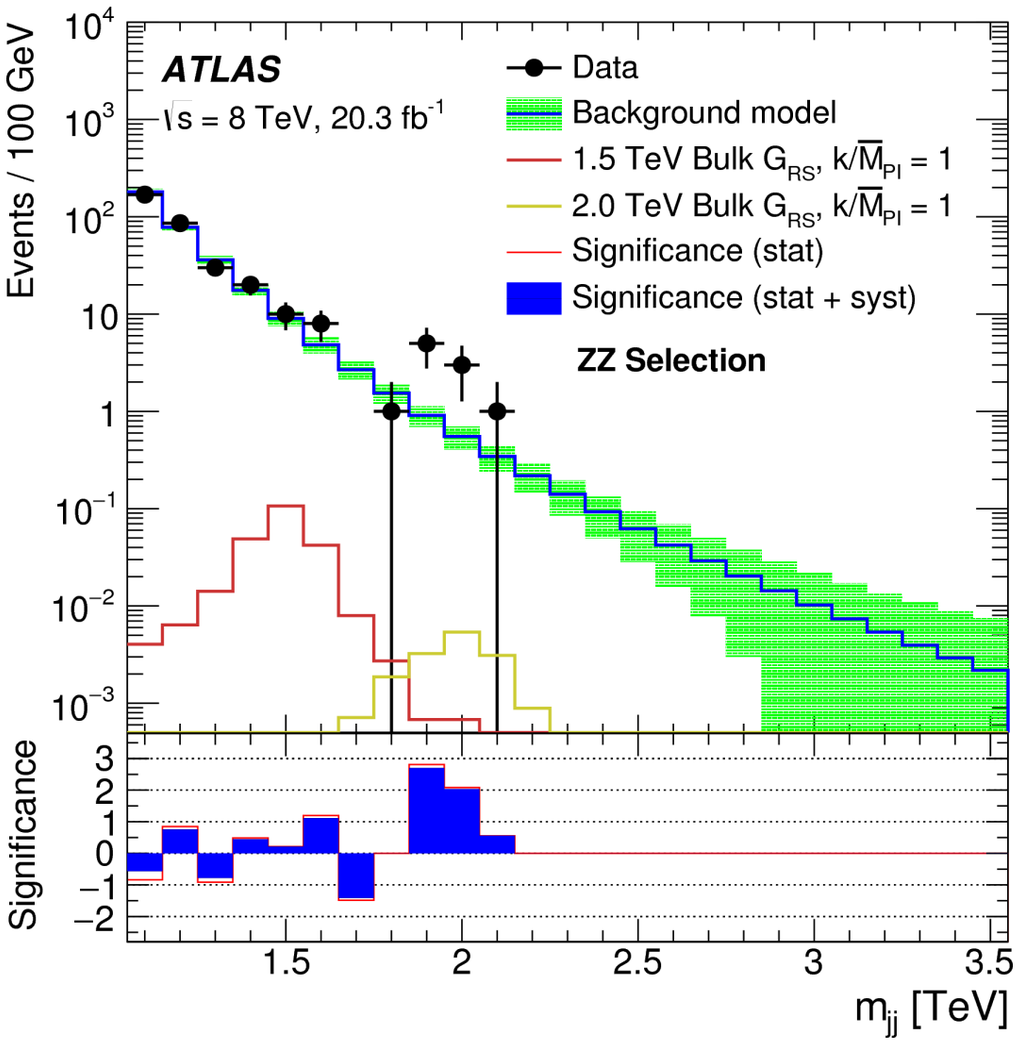
WZ/ZZ favored over WW

(roughly taken from 1507.00013)

more accurate recap in LesHouches 2015 pre-proceedings, coming soon!

not a lot of events…

diboson excess
(ATLAS, 2015)



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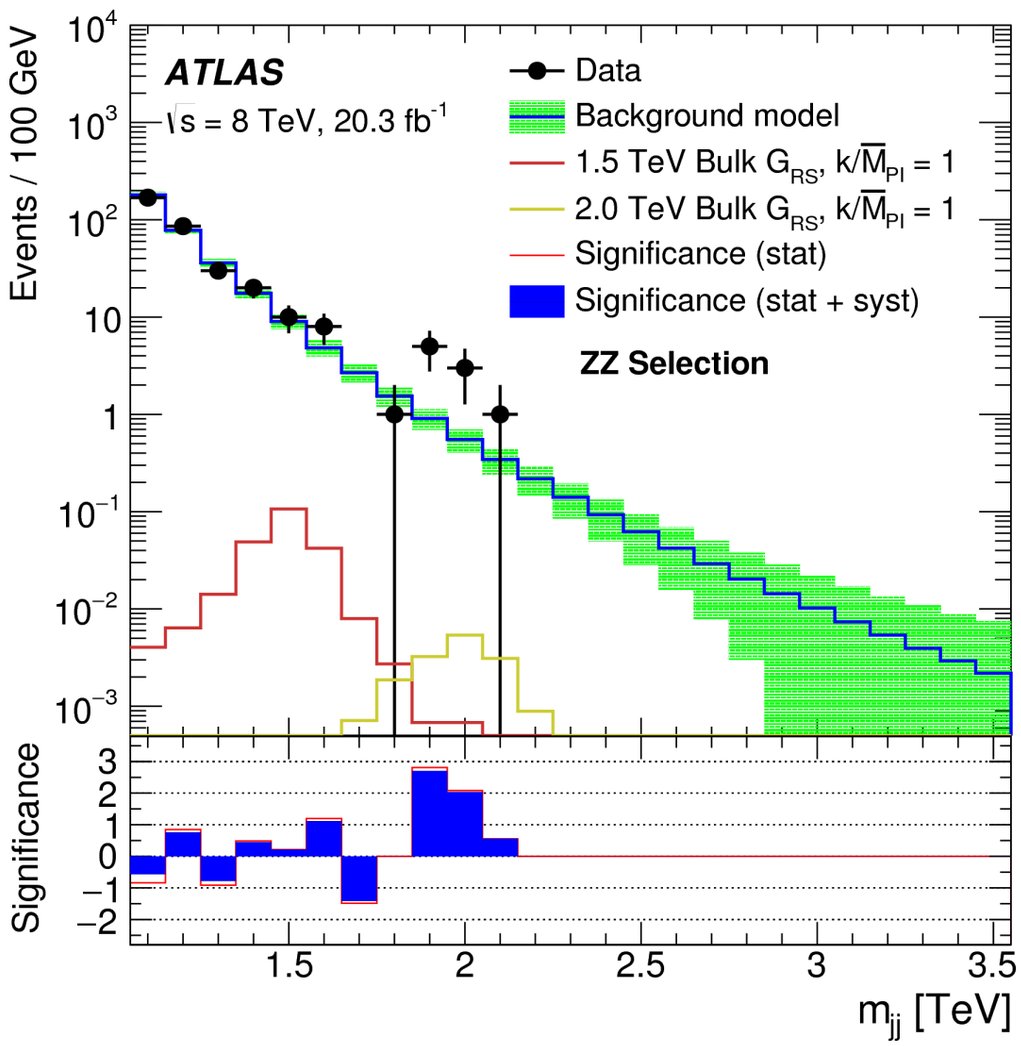
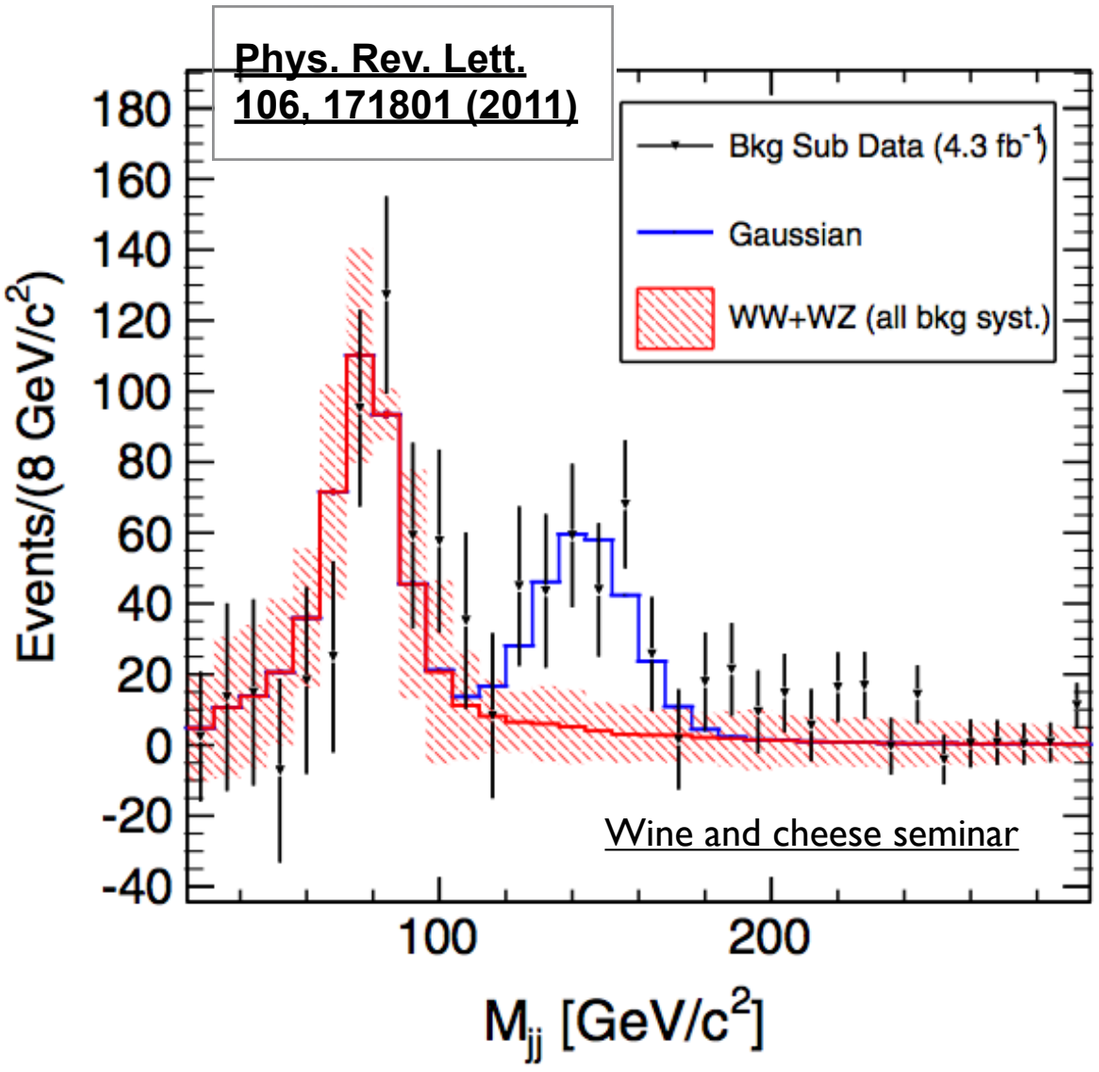


golden oldie: W+jj (CDF, 2011)



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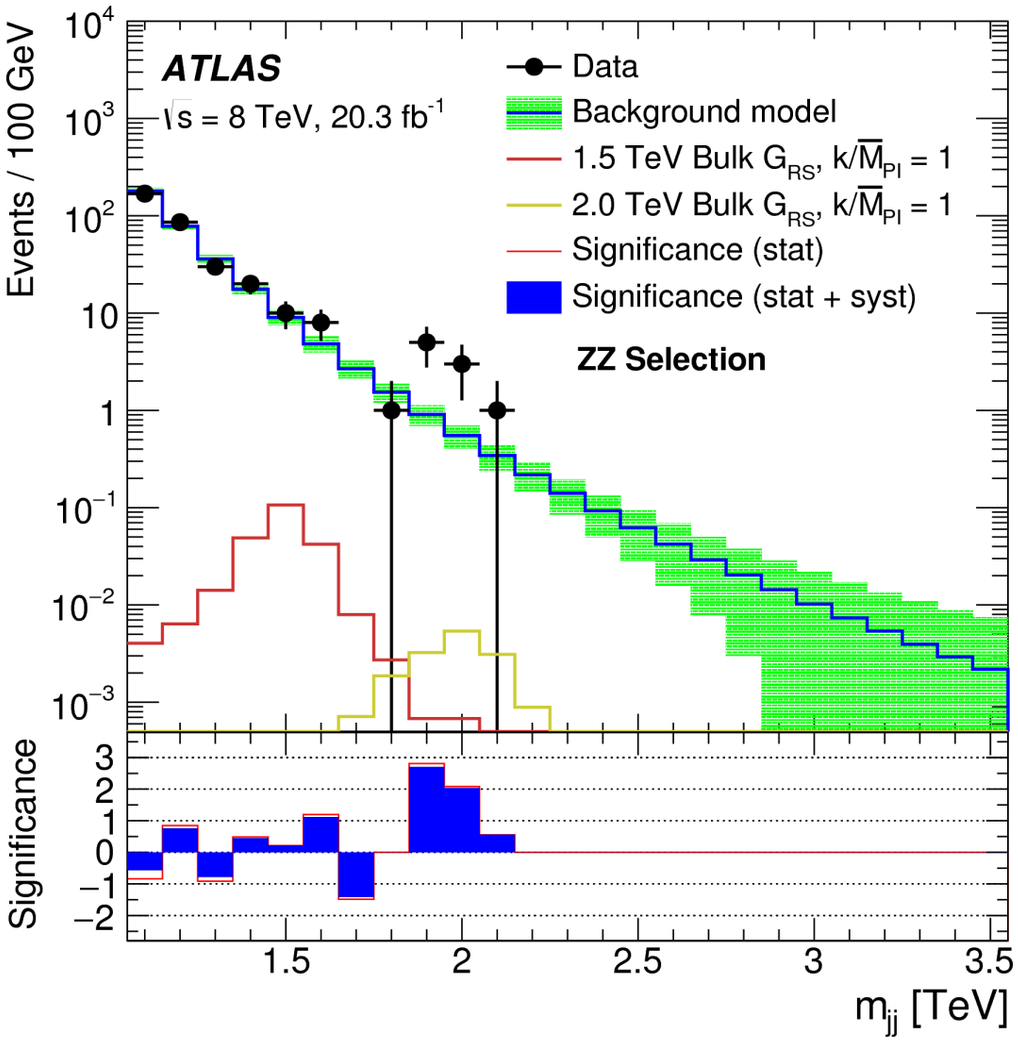

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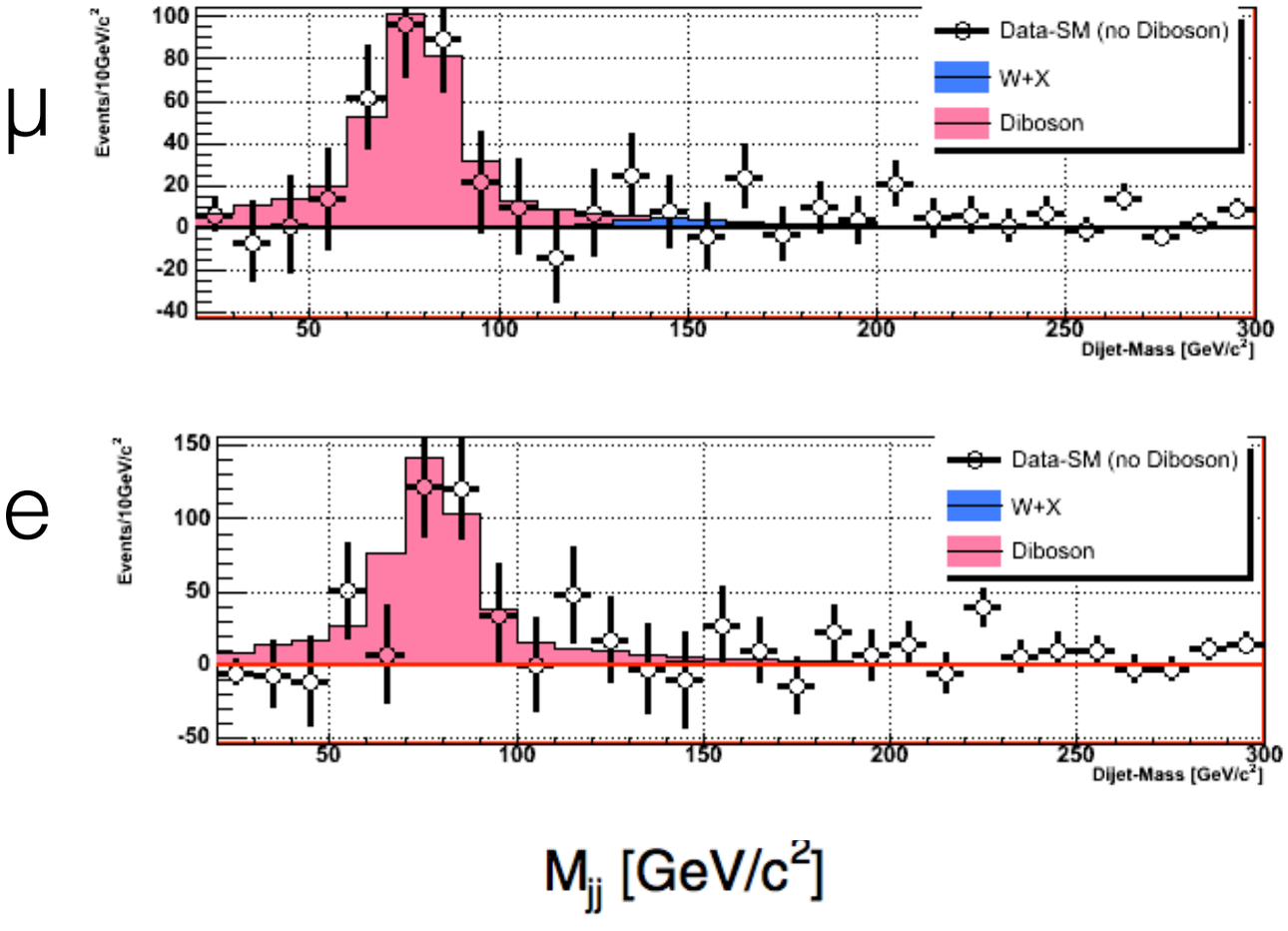

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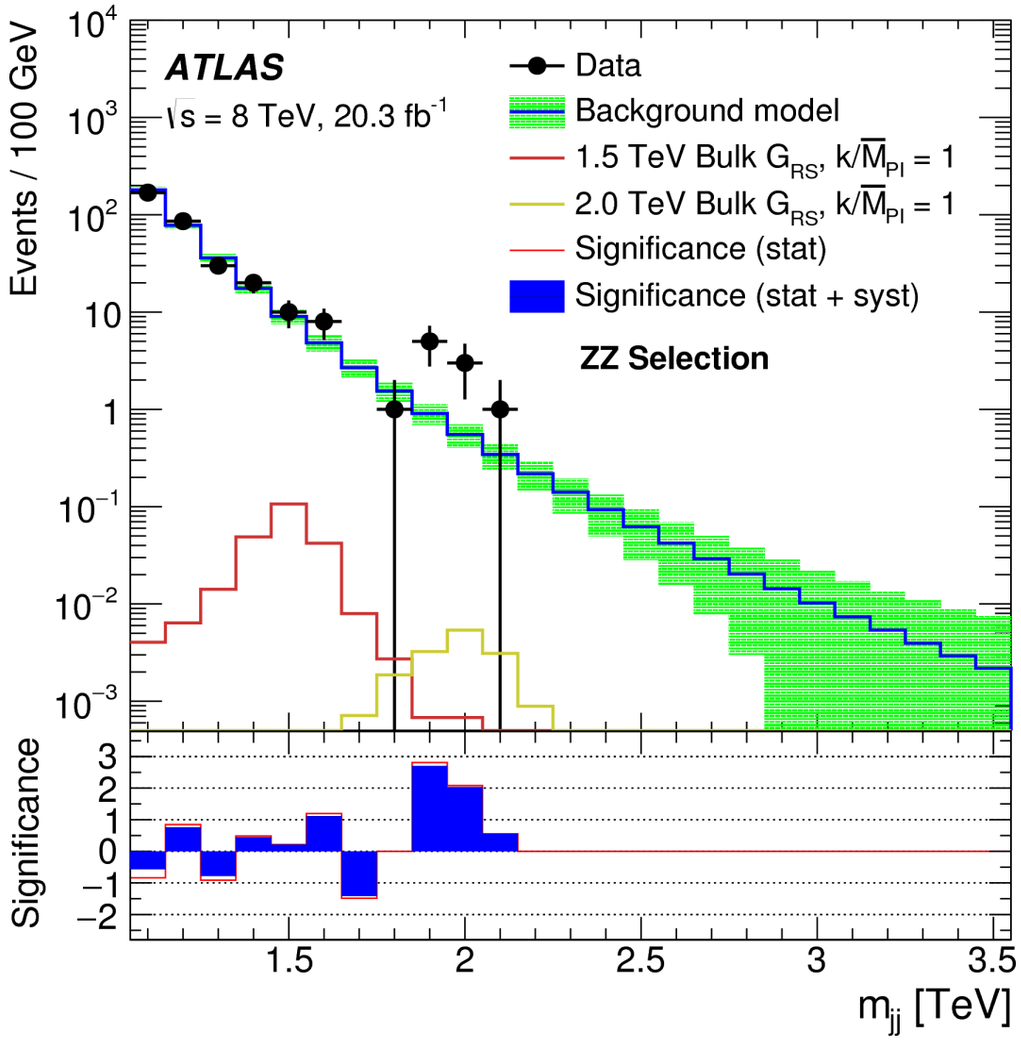

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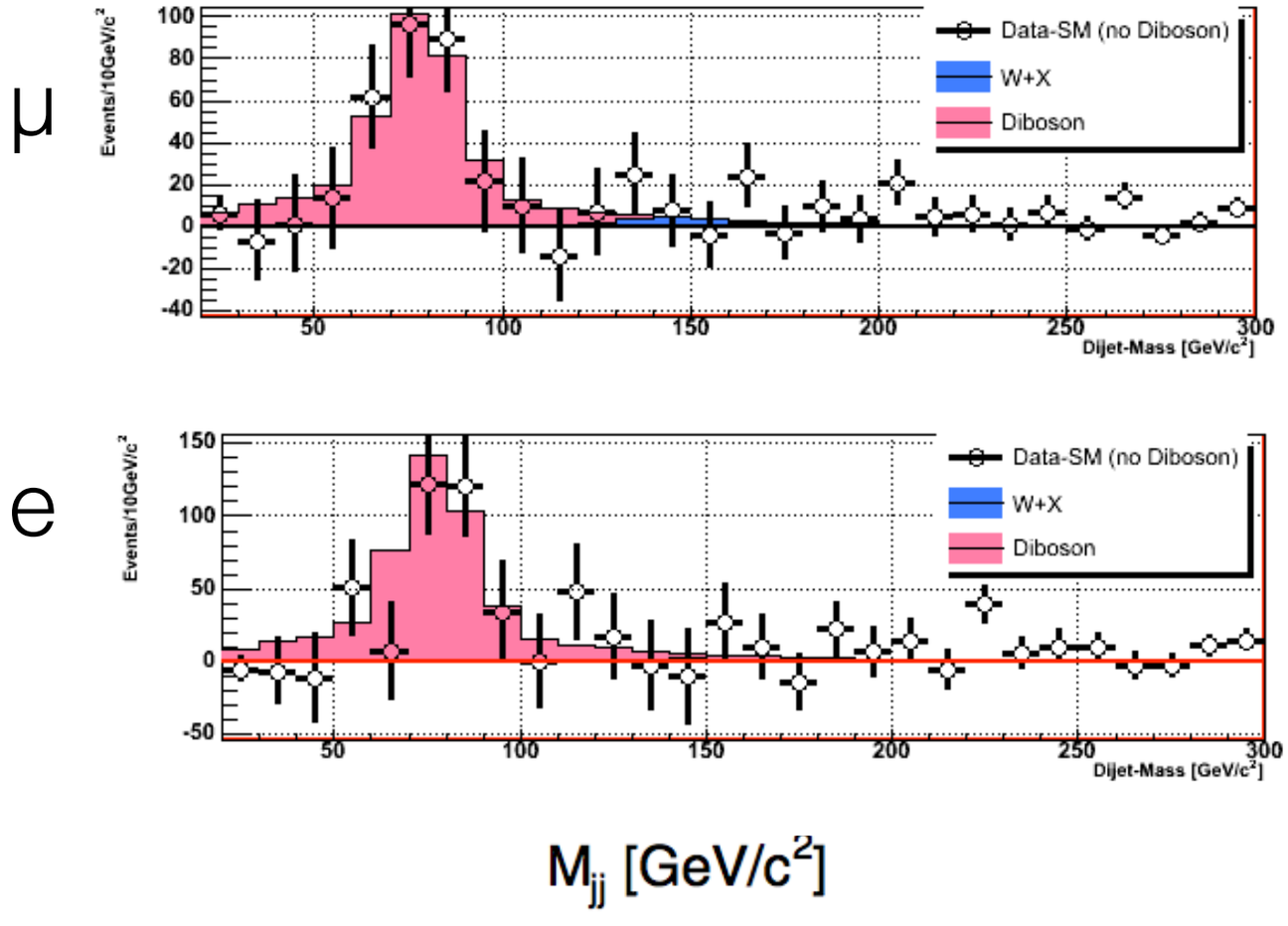
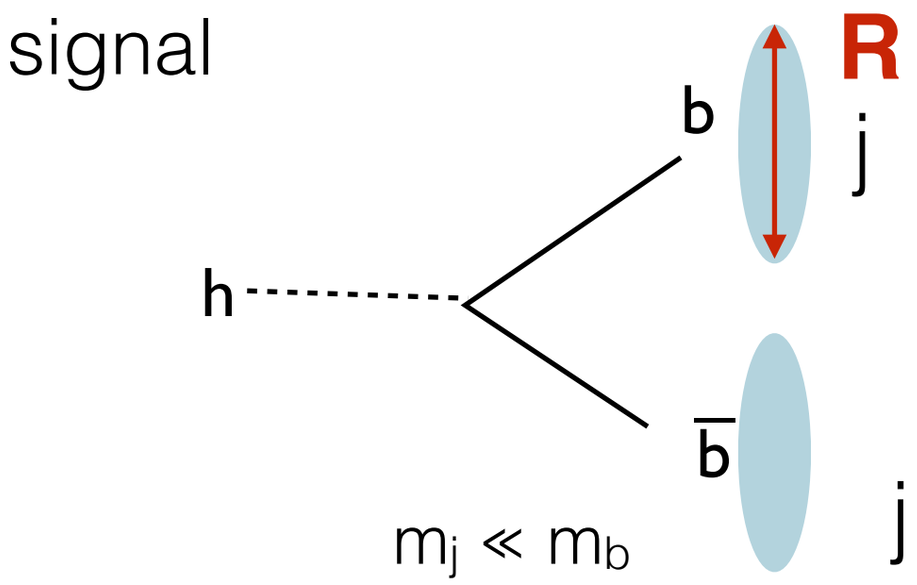


we'll know a LOT more with more data

several searches rely on jet substructure



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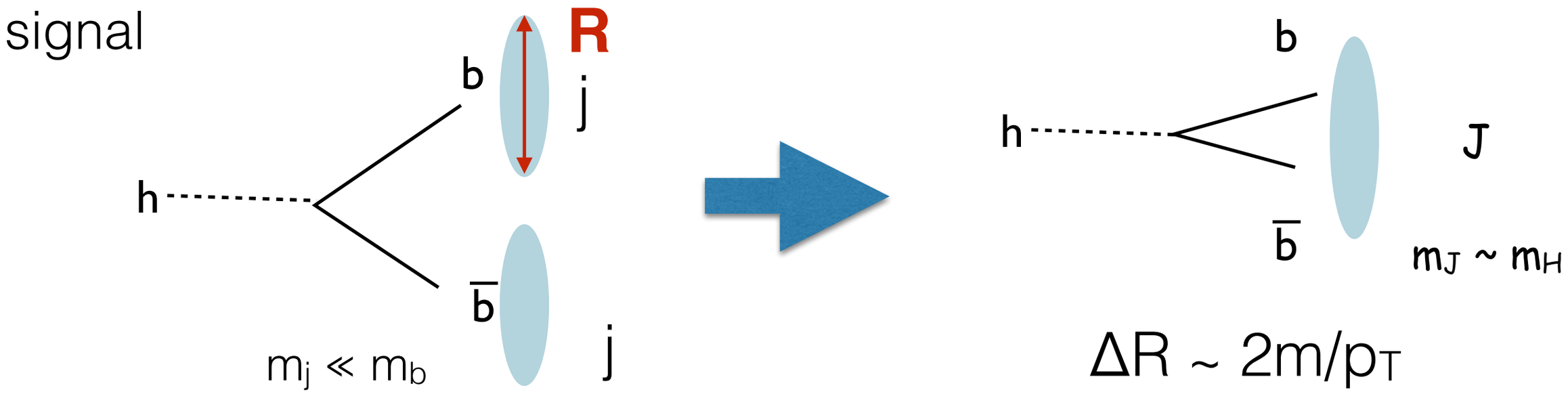

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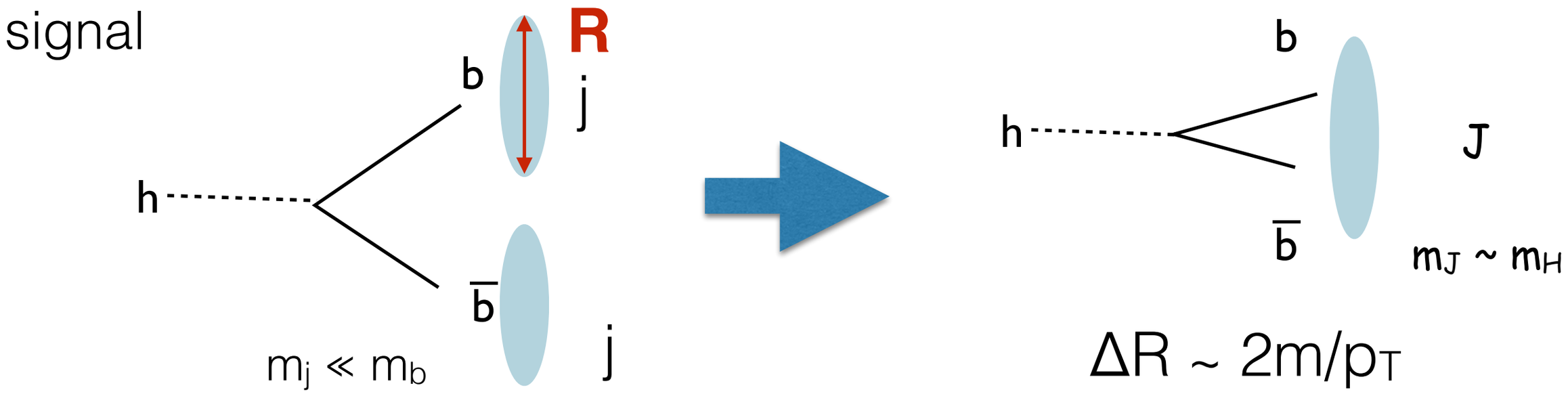
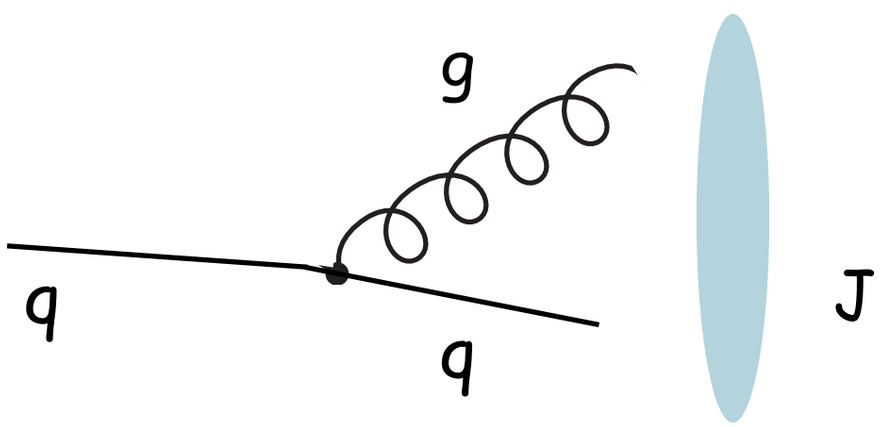


individual q/g massless, QCD jets build up mass from radiation



$m_{ij} \sim p_{Ti} p_{Tj} \Delta R$

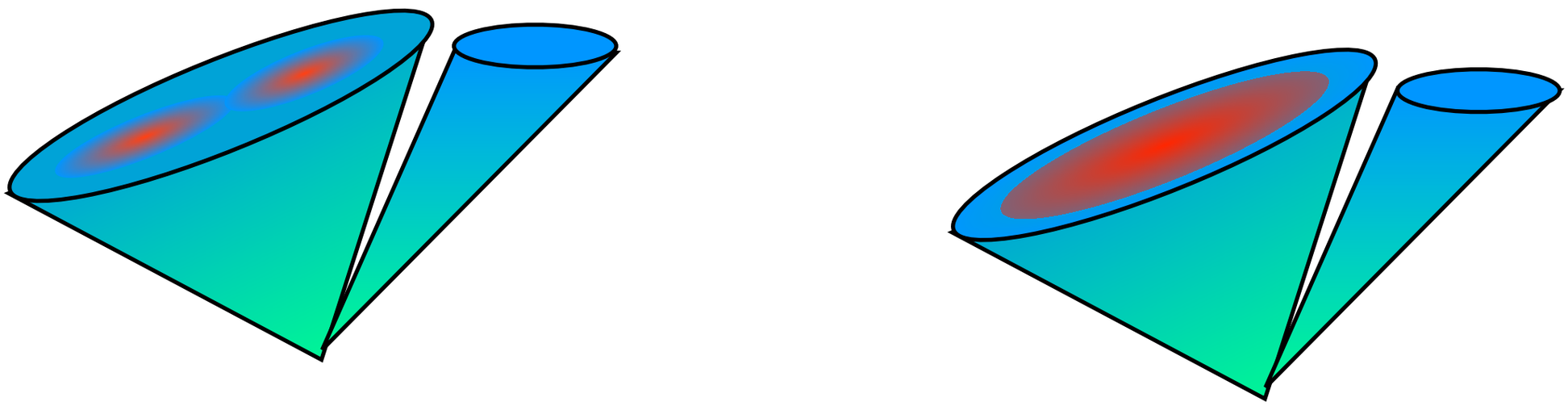
soft/collinear radiation enhanced

substructure idea: uncluster, seeing how jet changes at each stage/smaller scales

at some point, signal jet will fall apart into **~2 subjets with similar properties**. QCD background is dominated by **asymmetric splitting**,

so it will rarely look like the signal..

substructure idea: uncluster, seeing how jet changes at each stage/smaller scales



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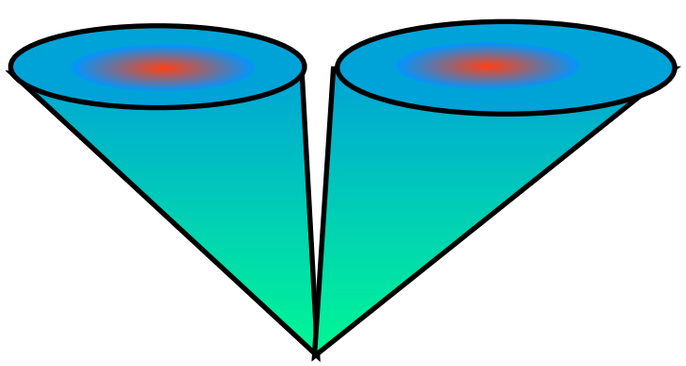

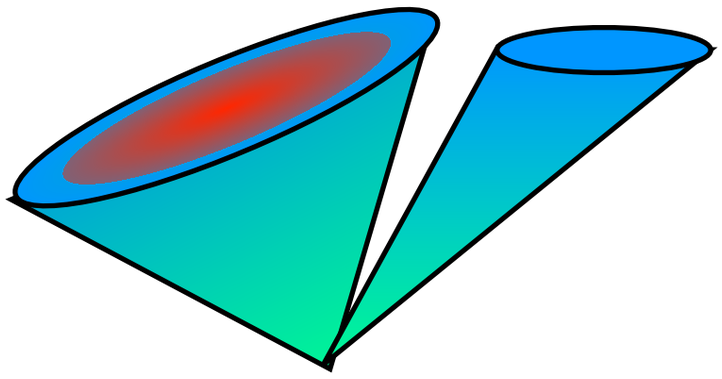

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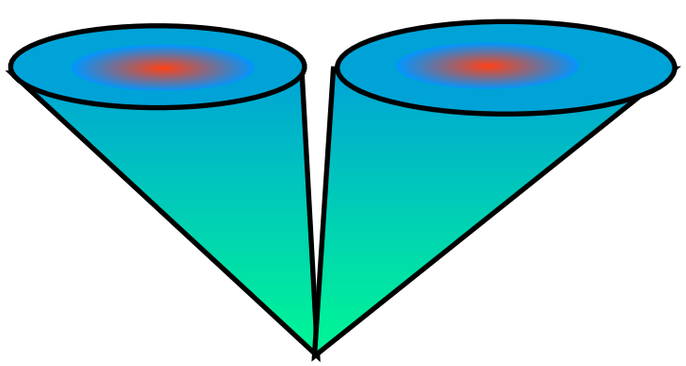

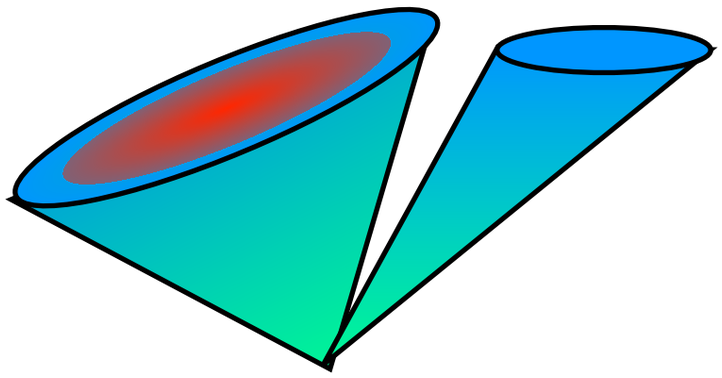

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conditions:

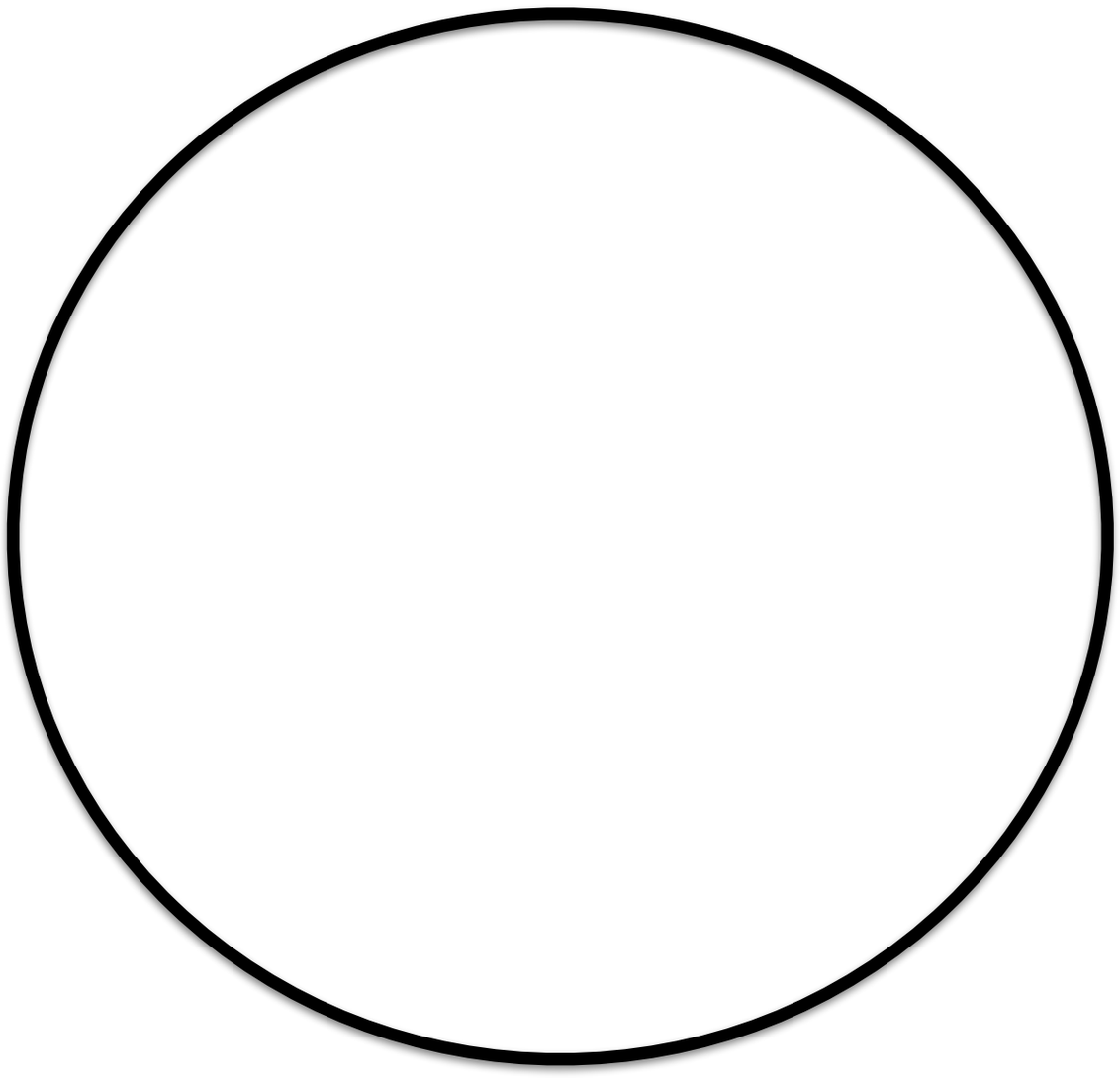
“mass drop” : $m_{J-1}/m_J < \#$

asymmetry: $\min(p_{T,i}, p_{T,J-i})/m_J > \#$

substructure for ATLAS signal

start with jet R = 1.2, start unclustering

no mass drop condition,
just asymmetry



once satisfied,
recluster R = 0.3

form mass from **3** hardest subjets

if less than three, take mass of entire groomed jet

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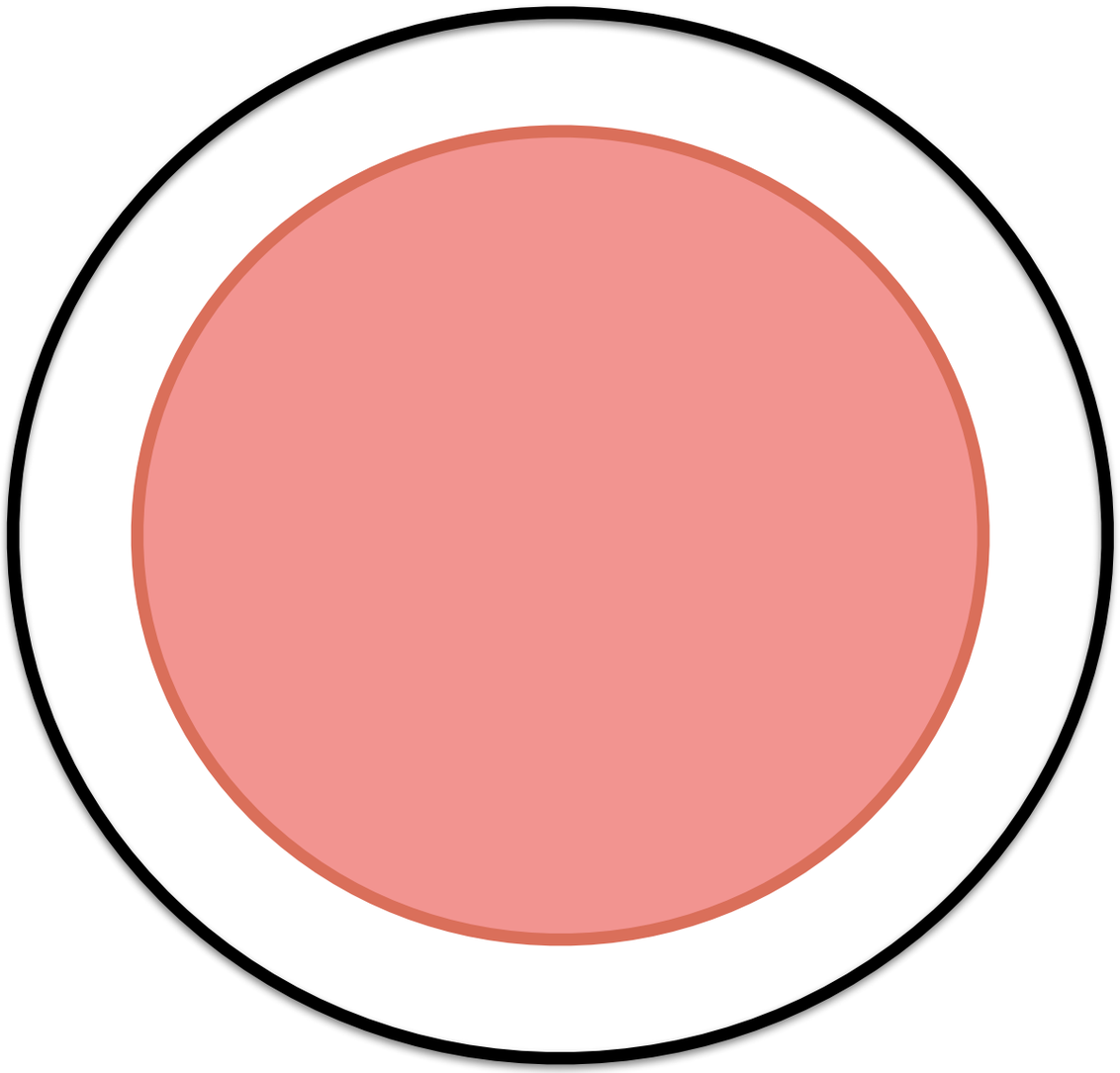

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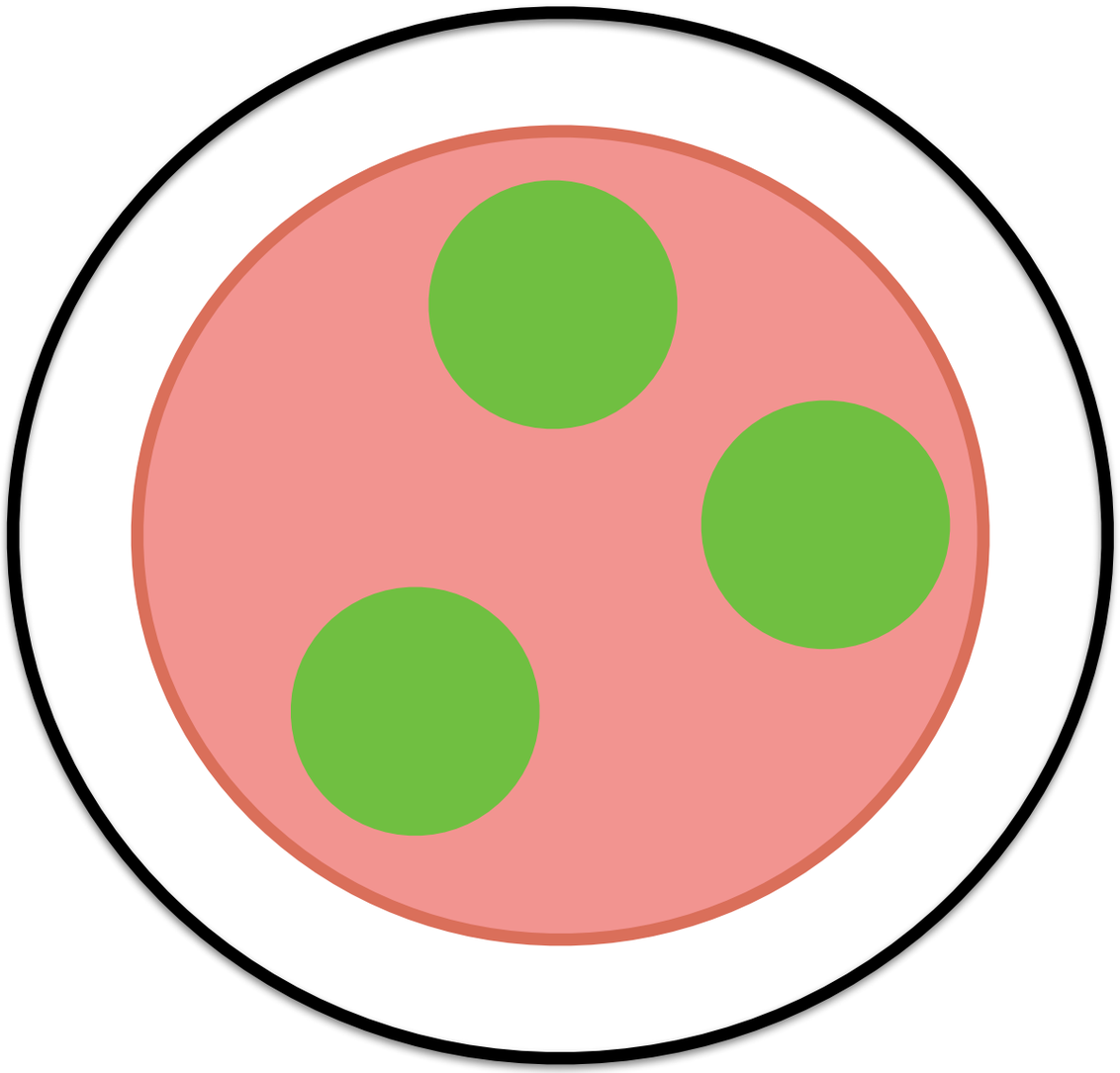

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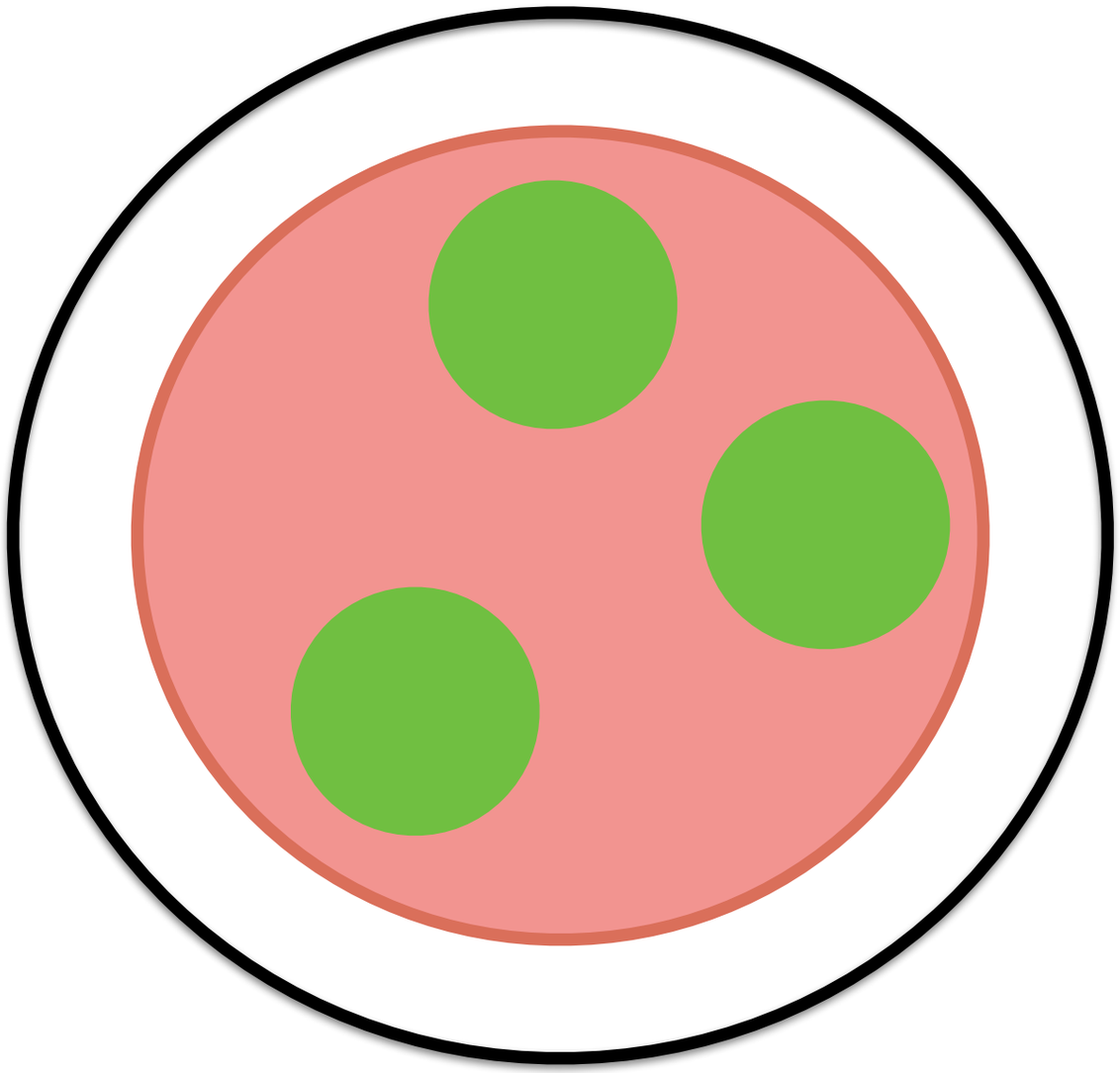

once satisfied,
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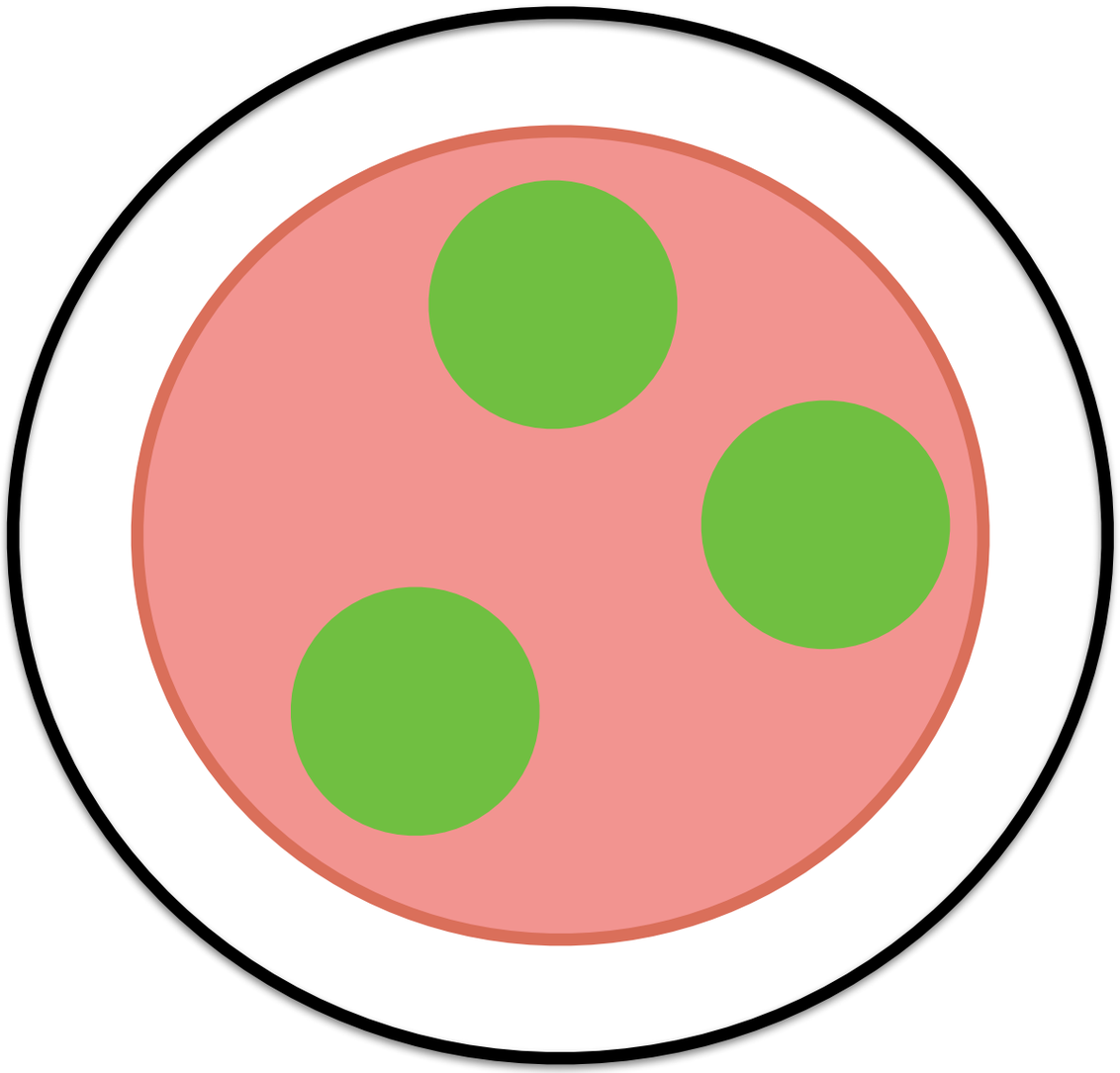
(CMS does this slightly differently, shouldn't matter)

substructure for ATLAS signal

for a heavy resonance (W/Z/H), the angle between decay products

$$R \sim \frac{2\,m}{p_T}$$



for 2 TeV resonance, 1 TeV jets

R ~ 0.16

substructure for ATLAS signal

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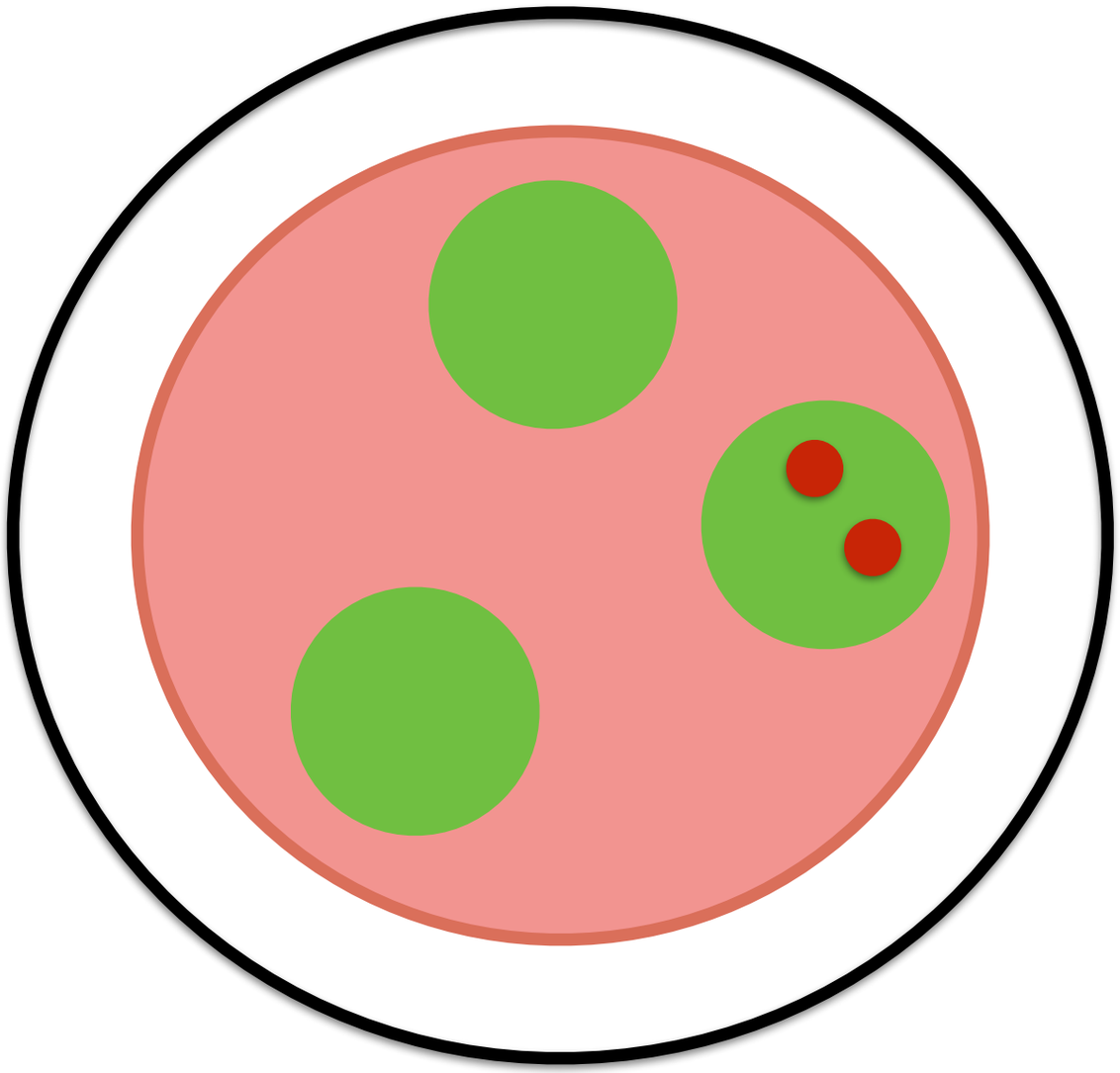

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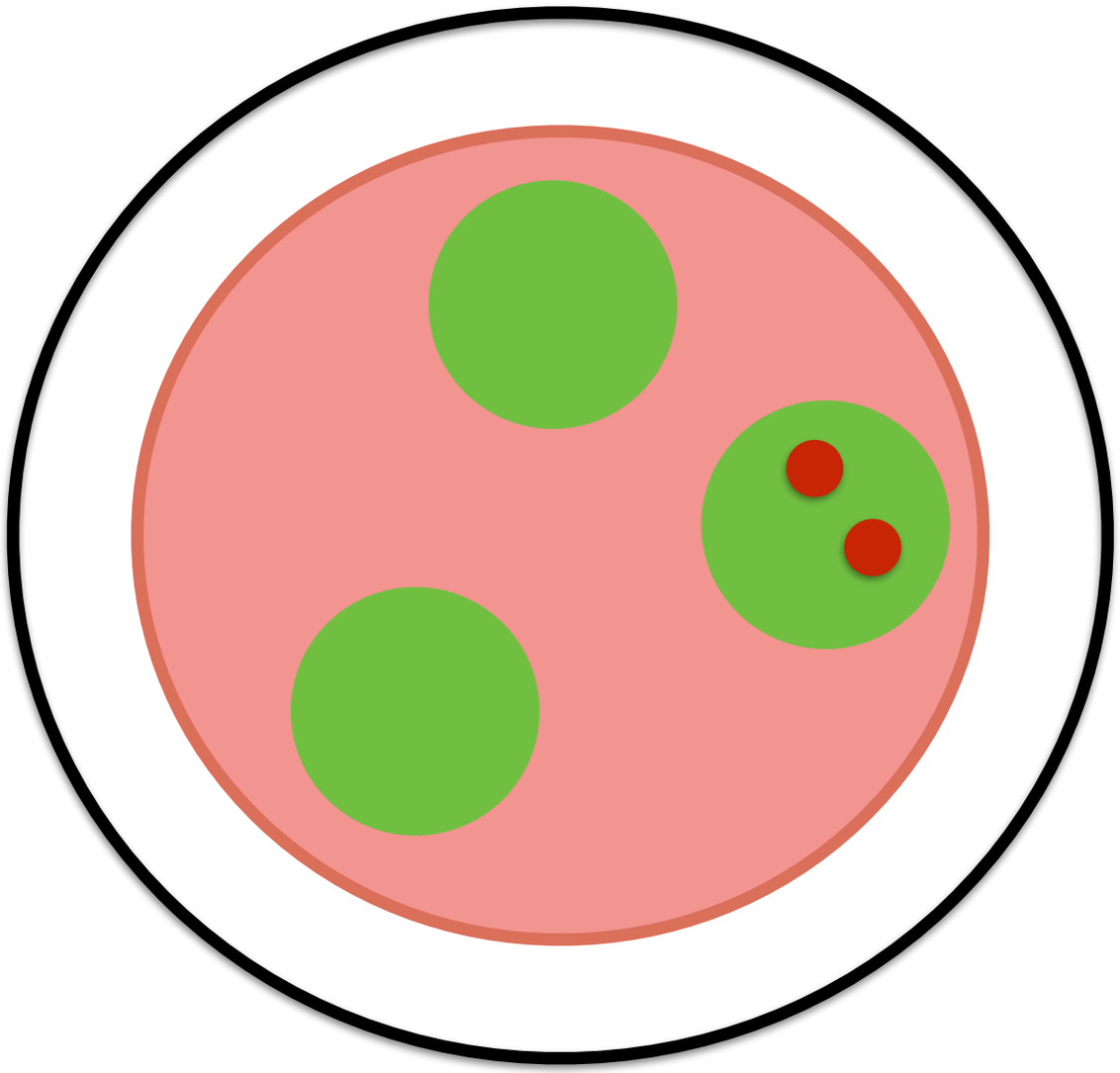

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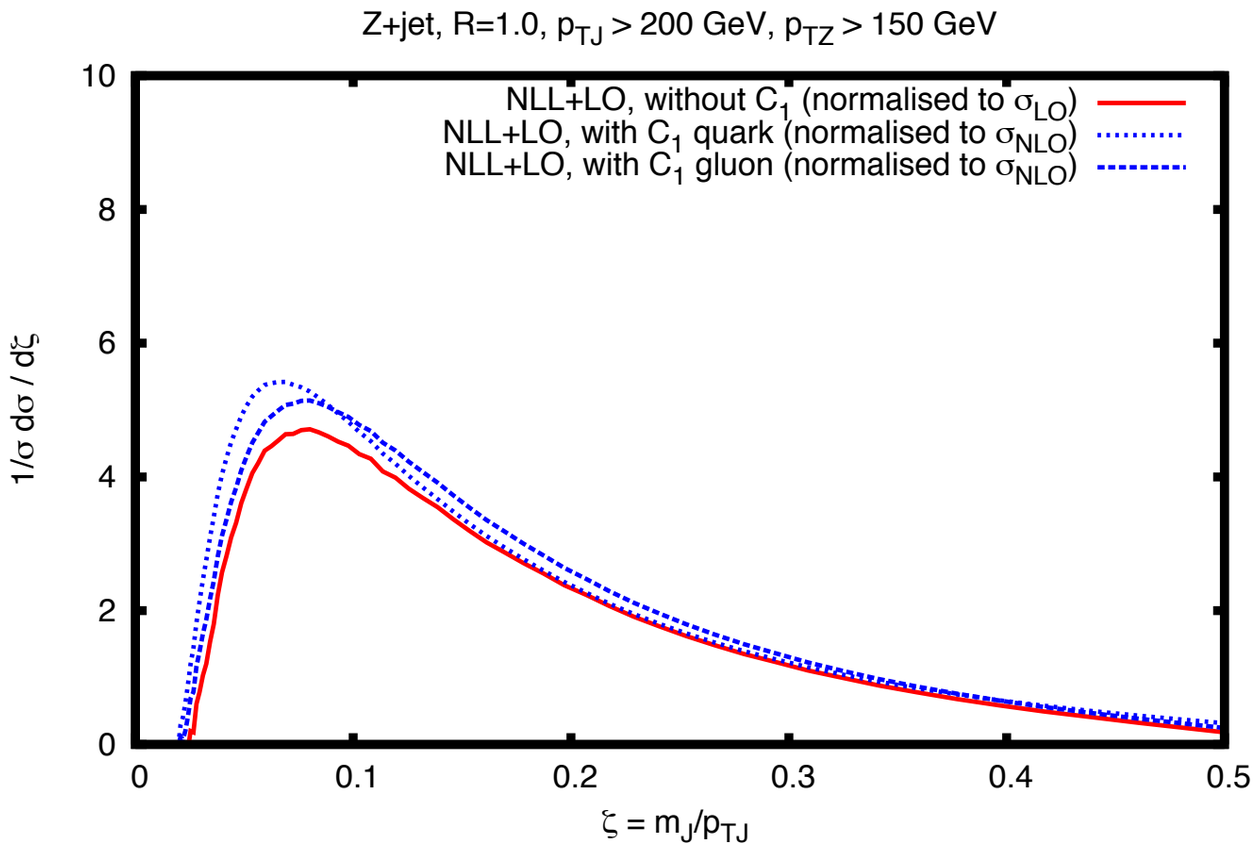
R ~ 0.16

naively, W should appear within a **single** subject

so I'm confused why should there be a feature in m_{jjj}

jet mass is a tricky thing



Dasgupta et al 1207.1640

for this size jet,
$m_J \sim 0.1\ p_T \sim 100$ GeV..

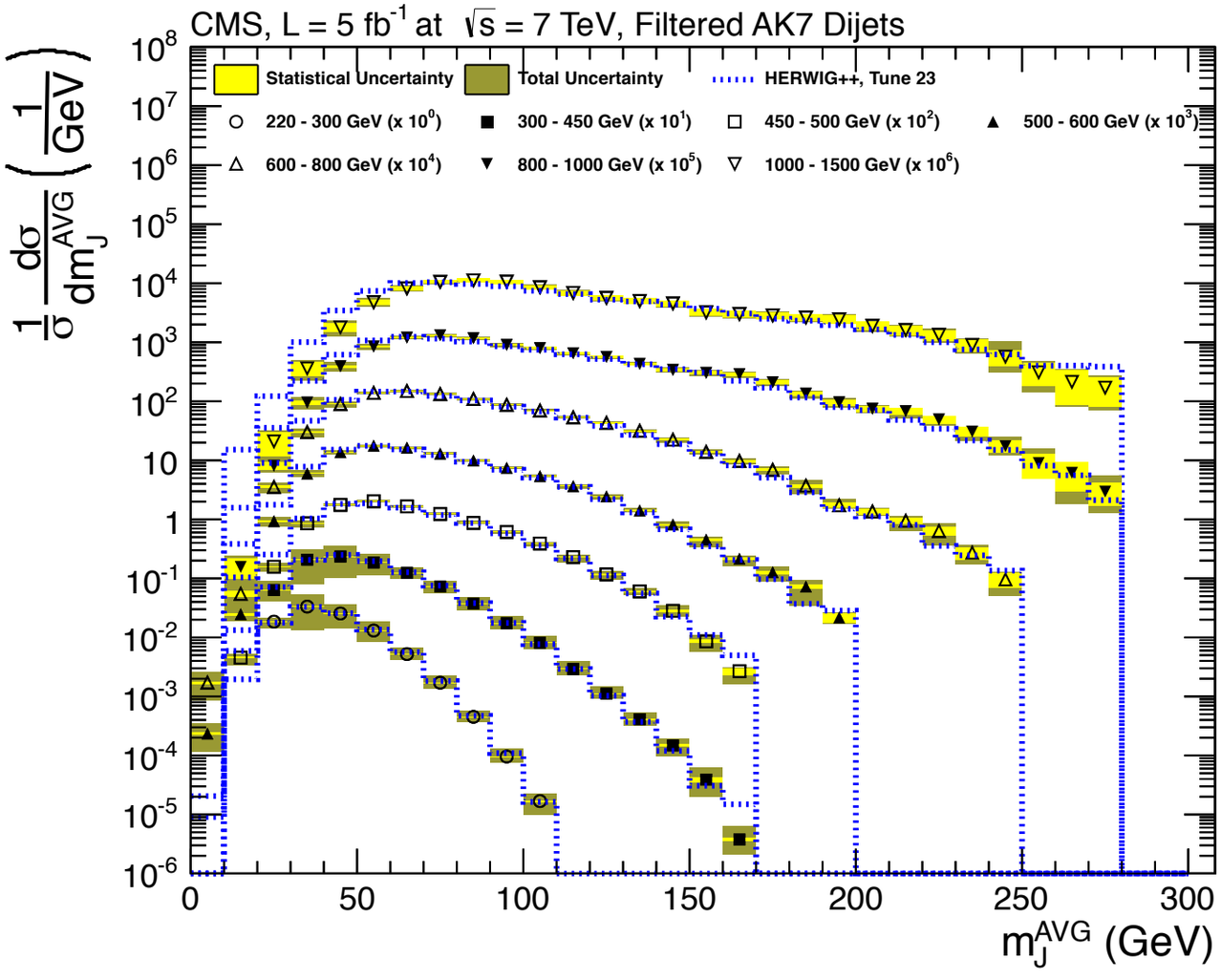
right in the W/Z mass window

worry that forcing W/Z mass selects out 1 TeV jets, causing a feature in m_{JJ}..

(2012, CMS found significance varies strongly with substructure method)

nothing wrong, jets are just complicated

jet mass is a tricky thing



CMS 1303.3811

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FOX

so you want to fit the excess?

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"composite" or "elementary" spin-1 W'

models where Higgs is pNGB, 'conformal TC' style models

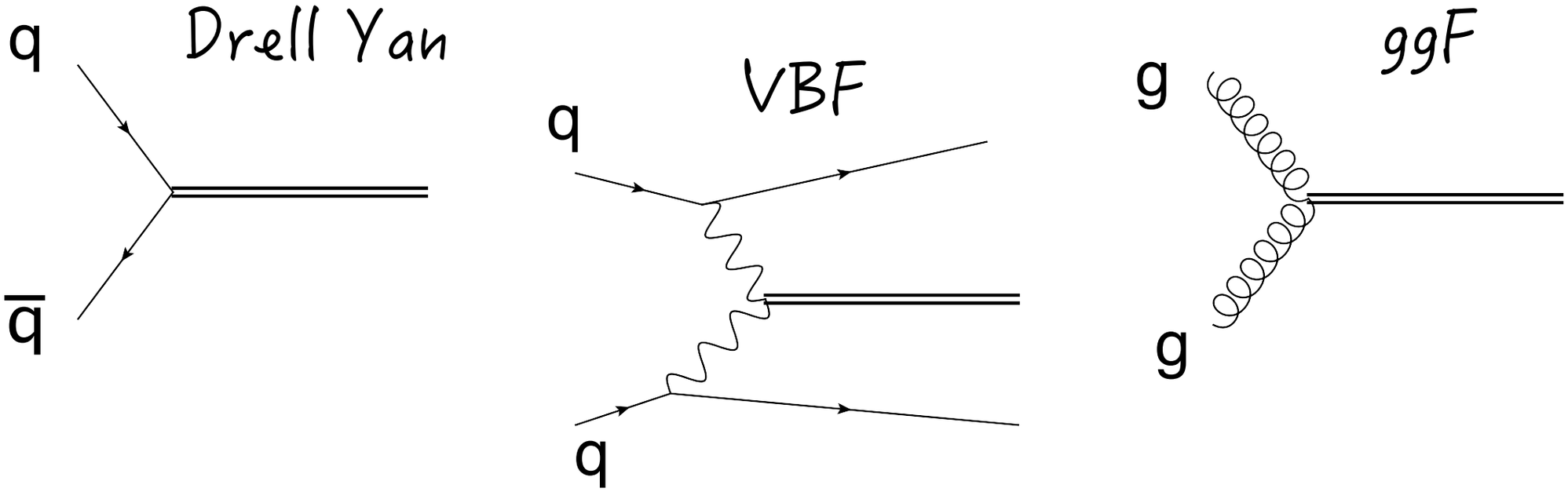
left-right models galore

"leptophobic", "LR + DM", "string inspired",...

so you want to fit the excess?

must be produced, must decay: key quantities

$$\sigma(pp \to V) BR(V \to X) = \sum_{i,j \in p} \frac{dL_{ij}}{d\hat{s}}\Big|_{\hat{s}=M_V^2} \times \frac{16\pi^2(2J+1)}{(2S_i+1)(2S_j+1))} \frac{C}{C_i\, C_j} \times \frac{\Gamma(V \to ij)\Gamma(V \to X)}{M_V\, \Gamma_V}$$



W' models to fit the excess

"composite" vs. "elementary"

differ in how W' couples to fermions and how it couples to WZ

$$g_{W'WZ} = g\,\xi \qquad g_{W'ff} = g\,\kappa$$

$$\Gamma(W' \to WZ) \sim \frac{g^2\,\xi^2\,M_{W'}^5}{192\pi\,m_W^4} \qquad \Gamma(W' \to ff) \sim \frac{N_C\,g^2\,\kappa^2\,M'_W}{12\pi}$$

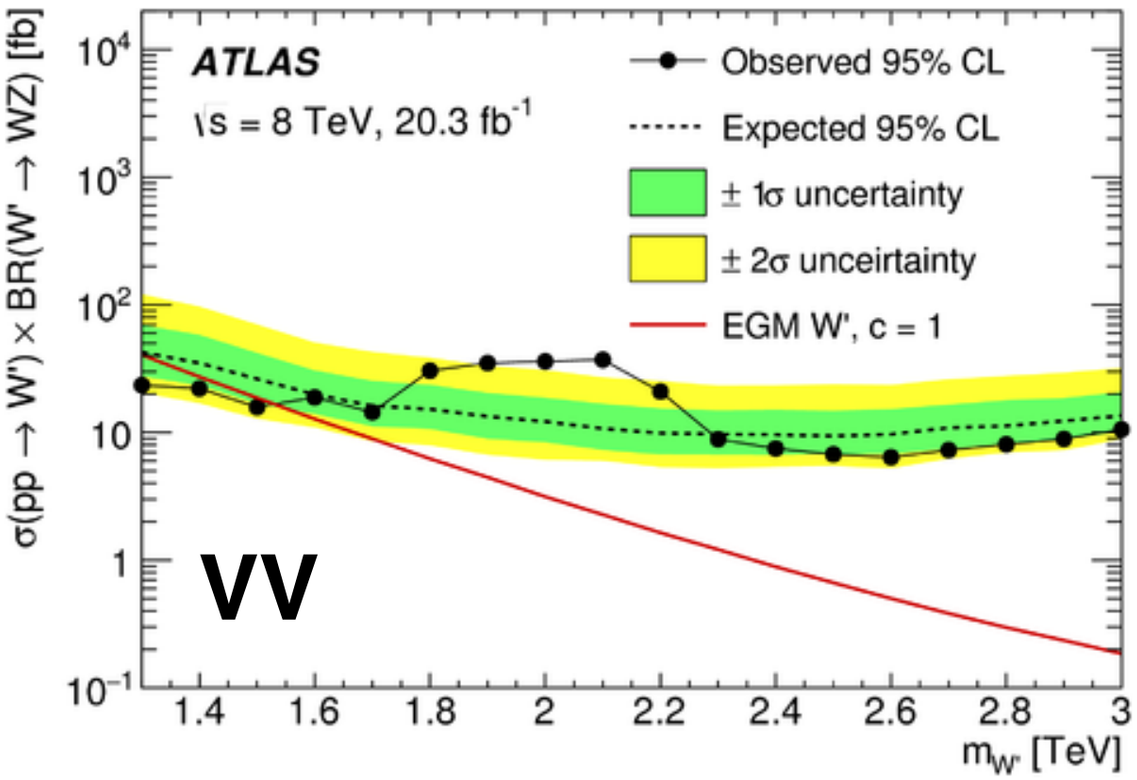
comes from decays to longitudinal gauge bosons

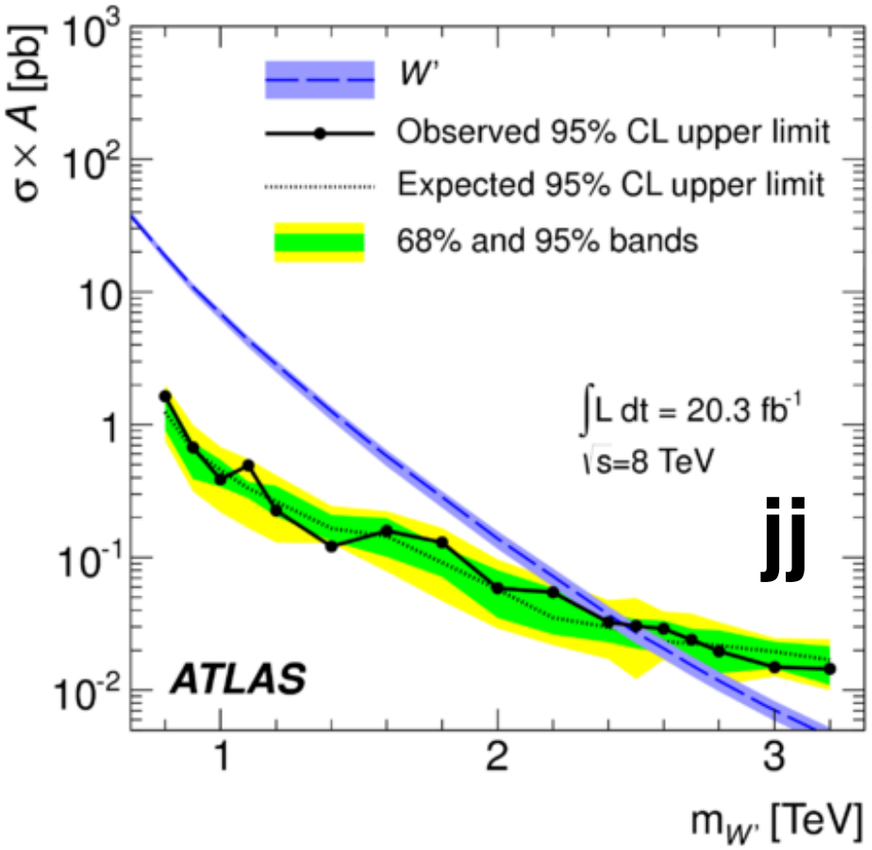
elementary models:

$$\xi \sim m_W^2/M_{W'}^2, \qquad \kappa \sim O(1)$$

both widths grow linearly with $M_{W'}$, width to fermions is bigger due to multiplicity

W' produced via Drell-Yan, most decay to $q\bar{q}$, but below the dijet limit. few % decay to WZ, form excess





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example:

$SU(2)_L \otimes SU(2)_R \otimes U(1)_X \rightarrow SU(2)_L \otimes U(1)_Y$ via $SU(2)_R$ triplet

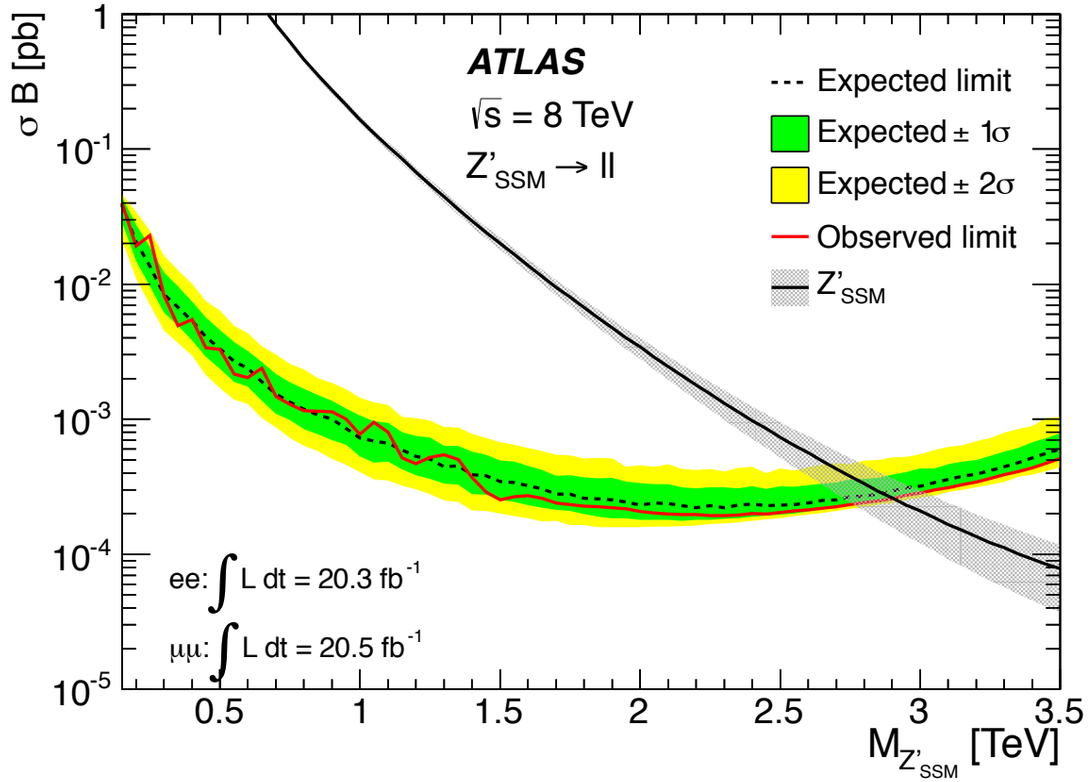
$g_R \sim 0.8\ g_L$

[Dobrescu, Liu 1506.08688, Brehmer et al1507.00013, …]

if it's an elementary W' model:

these models always have a neutral partner Z'

Z' → ℓℓ has a significant BR, and Z' bounds are O(100) stronger than W'→ WZ



way out is to make g_X coupling large such that Z' is heavier and evades existing limits

higher Z' limits → larger g_X …

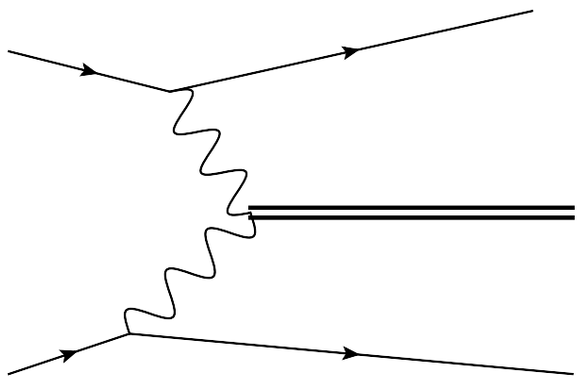
composite models

$$\xi \sim \kappa \sim m_W / M_{W'} \sim g/g_\rho$$

width to WZ grows as $\Gamma \sim M^3_{W'}$, **completely dominates**

smaller production cross section than elementary models, but 100% decay to W/Z

unlike elementary models, VBF production can play a role



small pdfs, but compensated by W_L W_L W' amplitude

[Fukano et al 1506.03751, Franzosi et al1506.04392, Thamm et al1506.08688, Lane 1507.07102, …]

if it's a composite model

very tricky to get the rate high enough while keeping the resonance narrow (max few fb in hadronic channel)…

no dijet resonance. neutral Z' → WW, so no dilepton worry

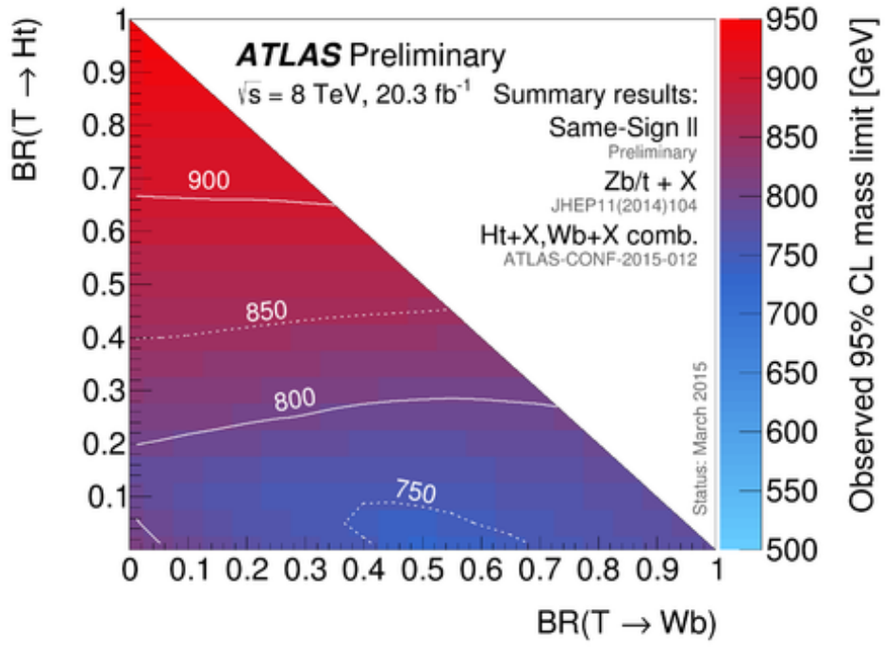
'light' resonance with $m_W/M_{W'}$ size couplings wreaks havoc with PEW and perturbative unitarity (though not sure I care in a strongly coupled model)

other resonances could help? [Lane 1507.07102]

if it’s a composite model

in composite models there are usually ‘top partners’

the W’ couple strongly to these particles, opens new decay modes, further increases the width…



W’ → WH mode (if observed) could provide some info about strong dynamics

side by side

elementary W’	composite W’
narrow	wide
larger rate	smaller rate
dominant decay to jj	dominant decay to VV
VH must be present	VH ?
must be dijet, dilepton signals nearby	other resonances/ signs of strong dynamics

Conclusions

with all the searches done by ATLAS/CMS, there will be excesses.
Exciting in that both have slight excesses in similar place

tantalizing, but: low statistics, analyses involve complex objects..

‘explanations’ focused on W’ models, either elementary or composite.

predict different signals that must also arise

we WILL know the answer soon, ~5 fb^{-1} at LHC 13

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regardless of diboson outcome: lattice studies of near-conformal theories are interesting & important

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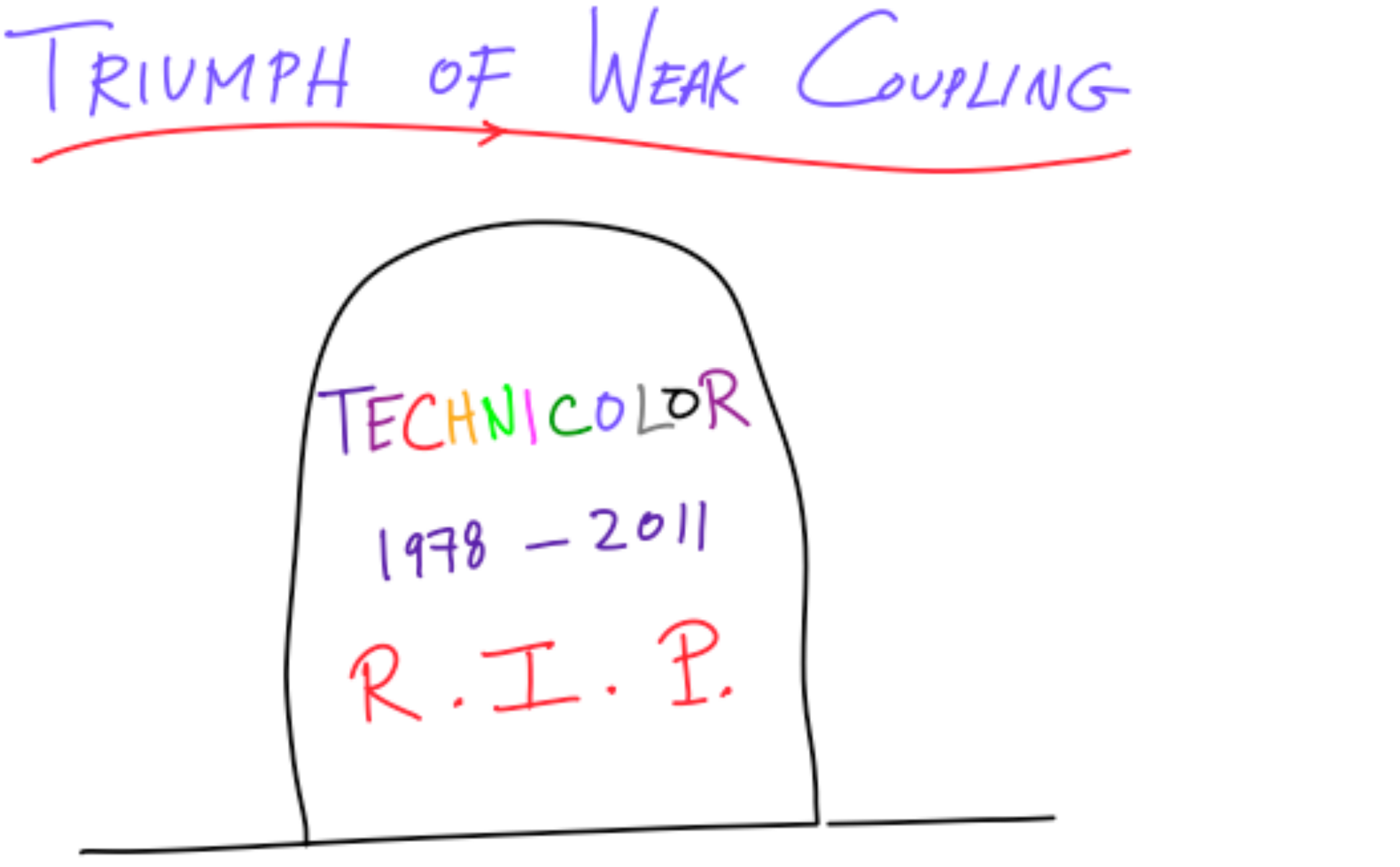
maybe, just maybe…

wait… Technicolor?!?!



[AM, USQCD 2012]

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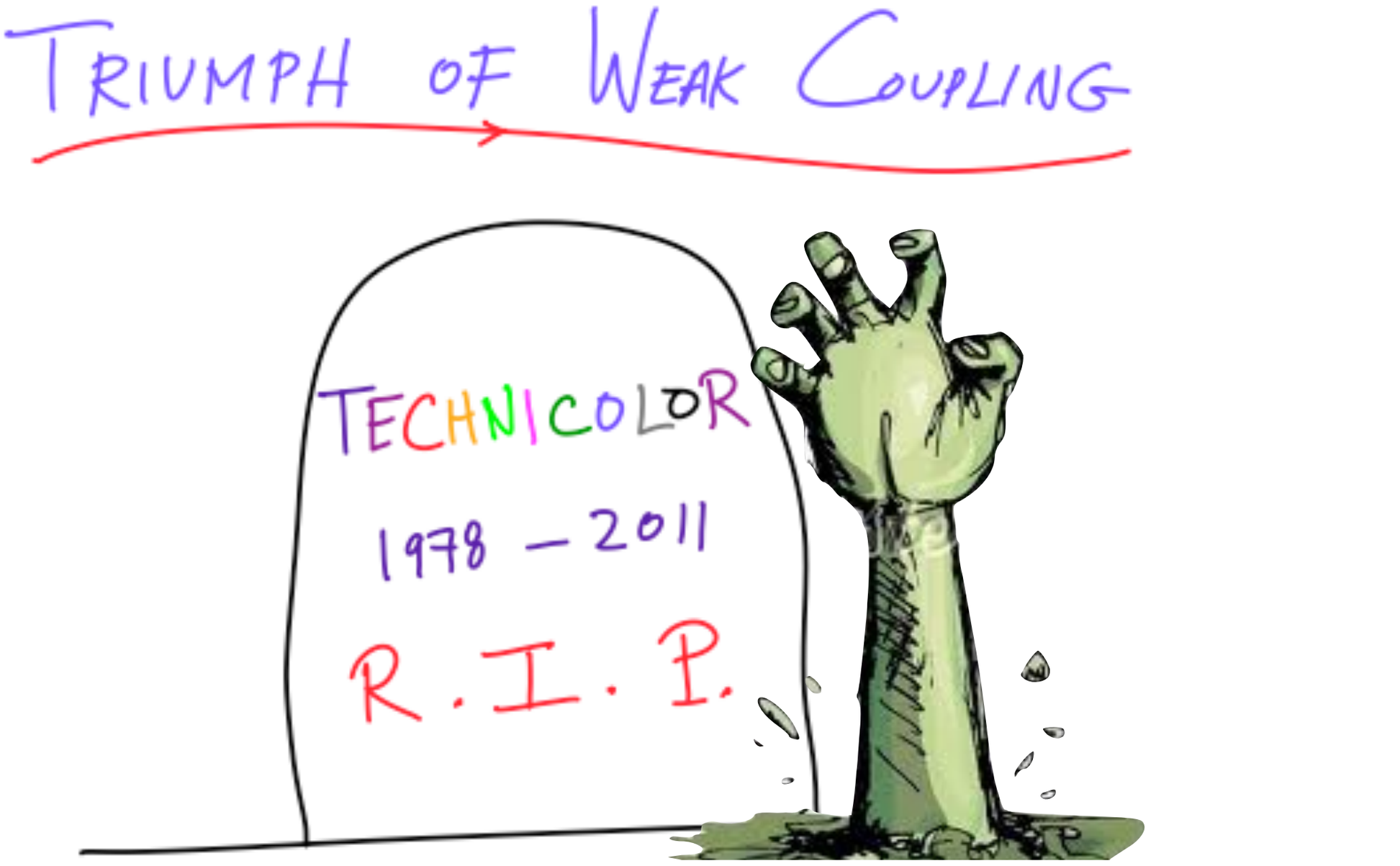

[AM, USQCD 2012]