Situation and outlook for (hadronic) diboson resonances in ATLAS

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GGI
29th Sept 2015

- Run 1 summary
- Run 2 prospects
- A word on Higgs!

Disclaimer

- I am no expert on jet substructure techniques
  - Core though they are to this subject
  - I am a simple user/observer
- All mistakes in this talk are my personal fault.

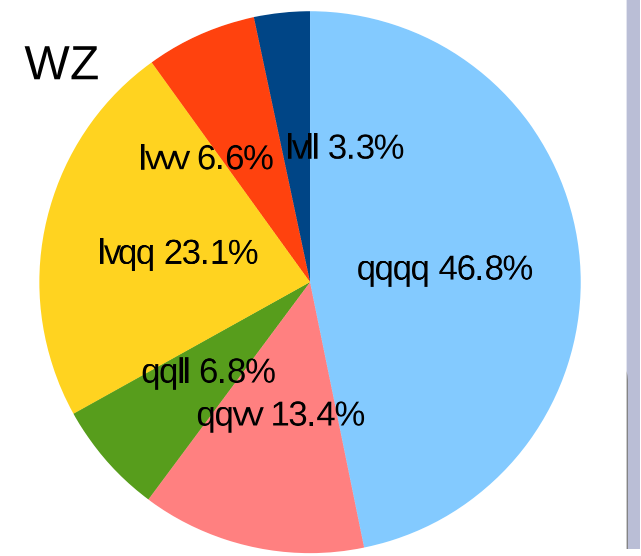
ATLAS diboson 2012 results

- Probabaly I missed some, but here is what I can find:

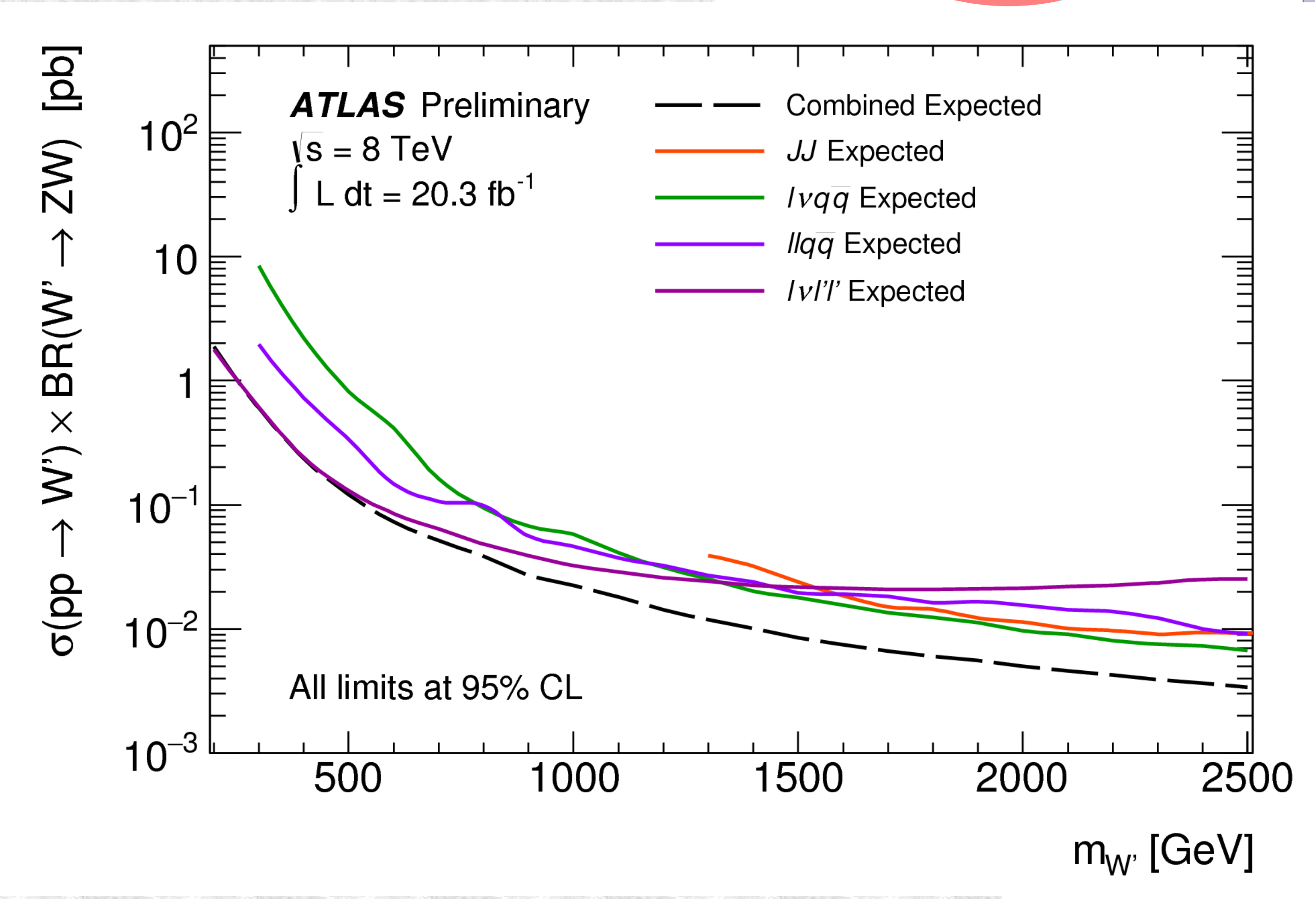
	WW	WZ	ZZ	WH	ZH	HH
Hadronic	Exot res.	Exot res.	Exot res.			hh comb
Mixed	H→WW lvjj reso	lvjj reso lljj reso	H->ZZ lljj reso	Vh, Vh→bb Resonant	Vh, A→ Zh Resonant	hh comb
Leptons, neutrinos	SM, H→WW, offshell H, h→WW	SM lvll reso	SM 4l, H->ZZ, offshell H, h→ ZZ	Vh	Vh, A→ Zh Zh→llχχ	

- There are many measurements and searches based on these states
  - I shall be focussed on the top row here,
    - And mostly the non-H

Why *hadronic* diboson Resonances?

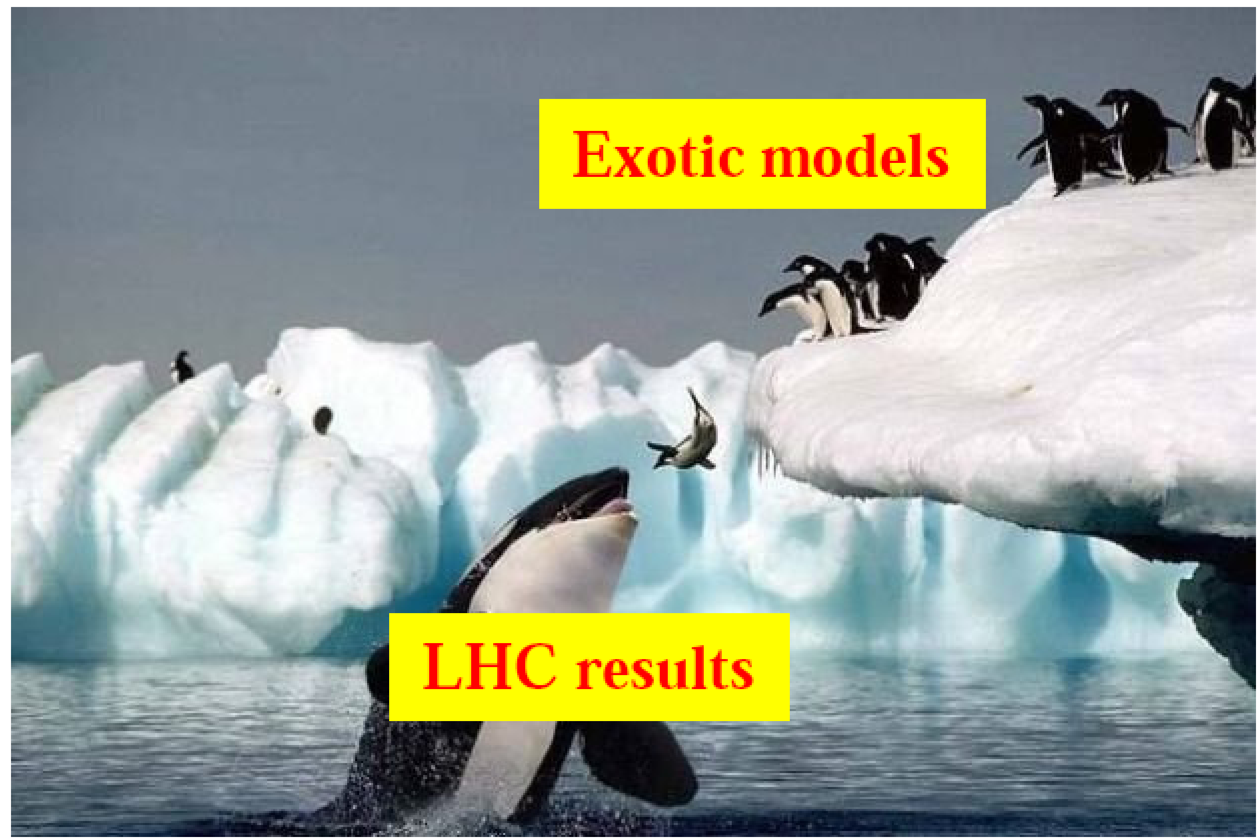


- A high-mass object coupling noticeably to bosons is plausible: W', HVT…
- The BRs favour hadrons
- Leptons needed for purity & trigger
- As p_T rises these get easier
- Should do all modes of course



LHC run 1

- Henri Bachacou summarised Run 1 like this:
- But for W' you had a more detailed summary from Andrea Thamm last week.
  - I show a couple of his slides as a reminder.
  - He fits ATLAS diboson with HVT



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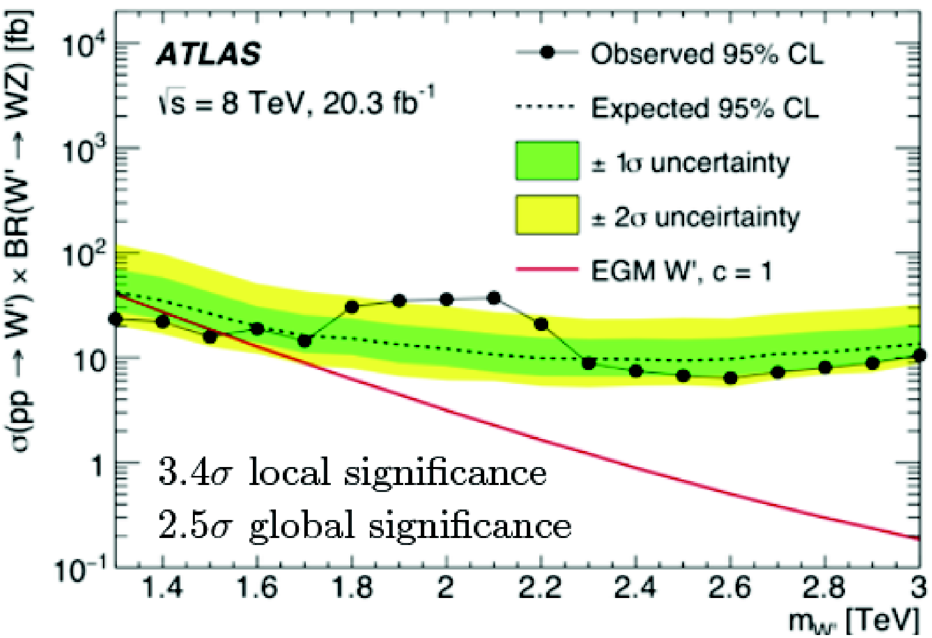
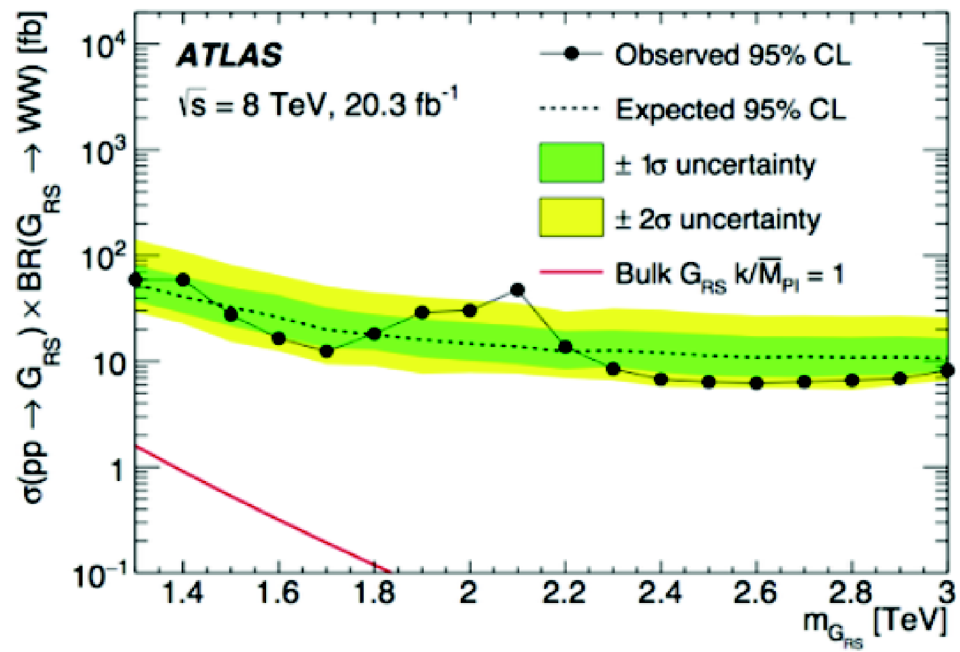
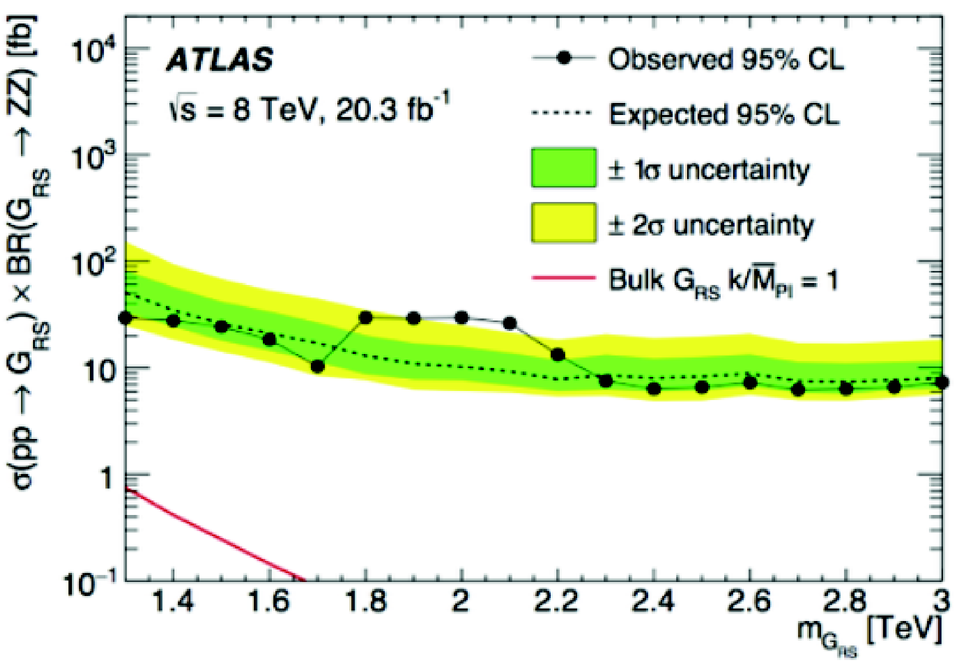
Di-boson excess?

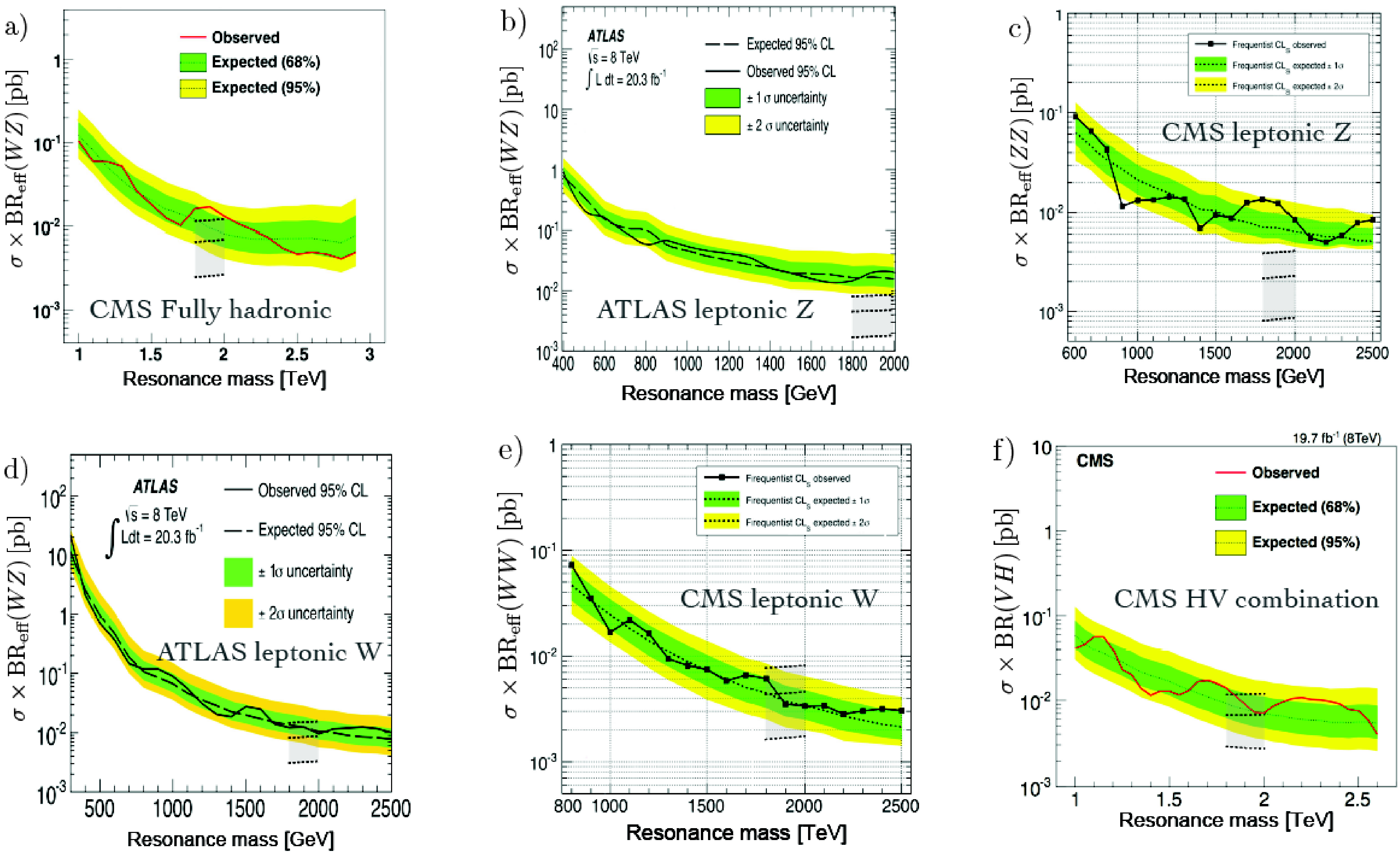






[ATLAS, arXiv:1506.00962]

Compatibility with other searches

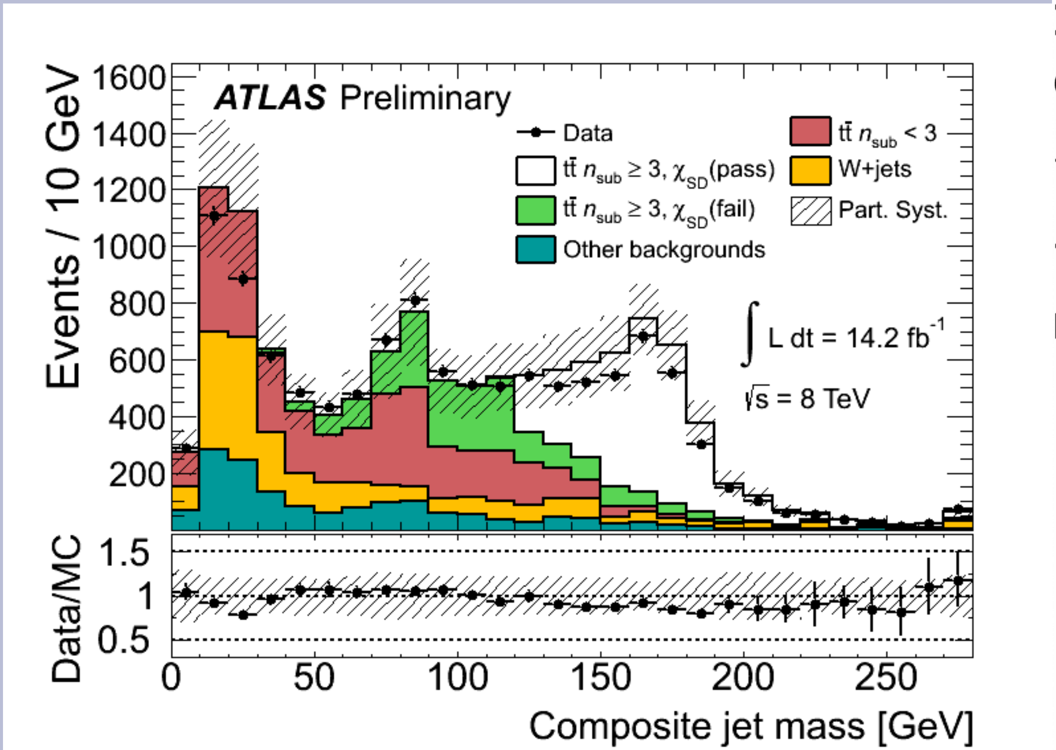


Thamm, Torre, Wulzer, arXiv:1506.08688

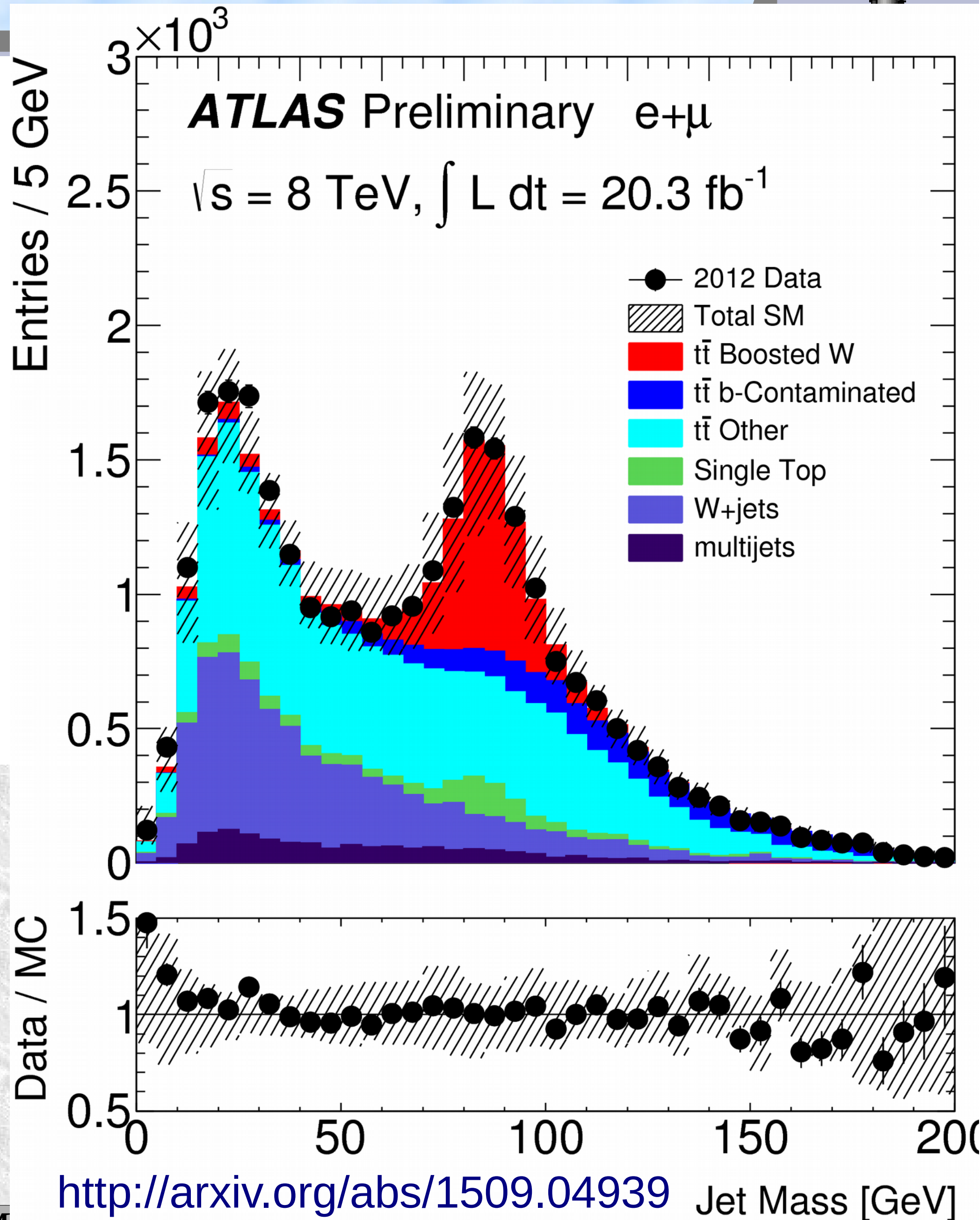
A little more experimental detail

- Trigger
  - Always ask first what the trigger is
  - Large-radius jet trigger
  - 99% efficient for C/A R=1.2 jets for raw p_T>540 GeV
- Cleaning
  - Events with isolated leptons > 20 GeV or E_T^{miss}>350 GeV
    - ensures independence from other searches
- Jets
  - Two C/A 1.2 Jets, $|\eta|<2$, p_T>20GeV
  - $|y_1 - y_2|<1.2$ enhances sensitivity to s-channel processes
  - $(p_{T1}-p_{T2})/(p_{T1}+p_{T2})<0.15$ removes tails
- Boson tagging
  - See next

Boson tagging improves



- Evolution of tt→W peak from 2014 (SD) to 2015 ('new method')



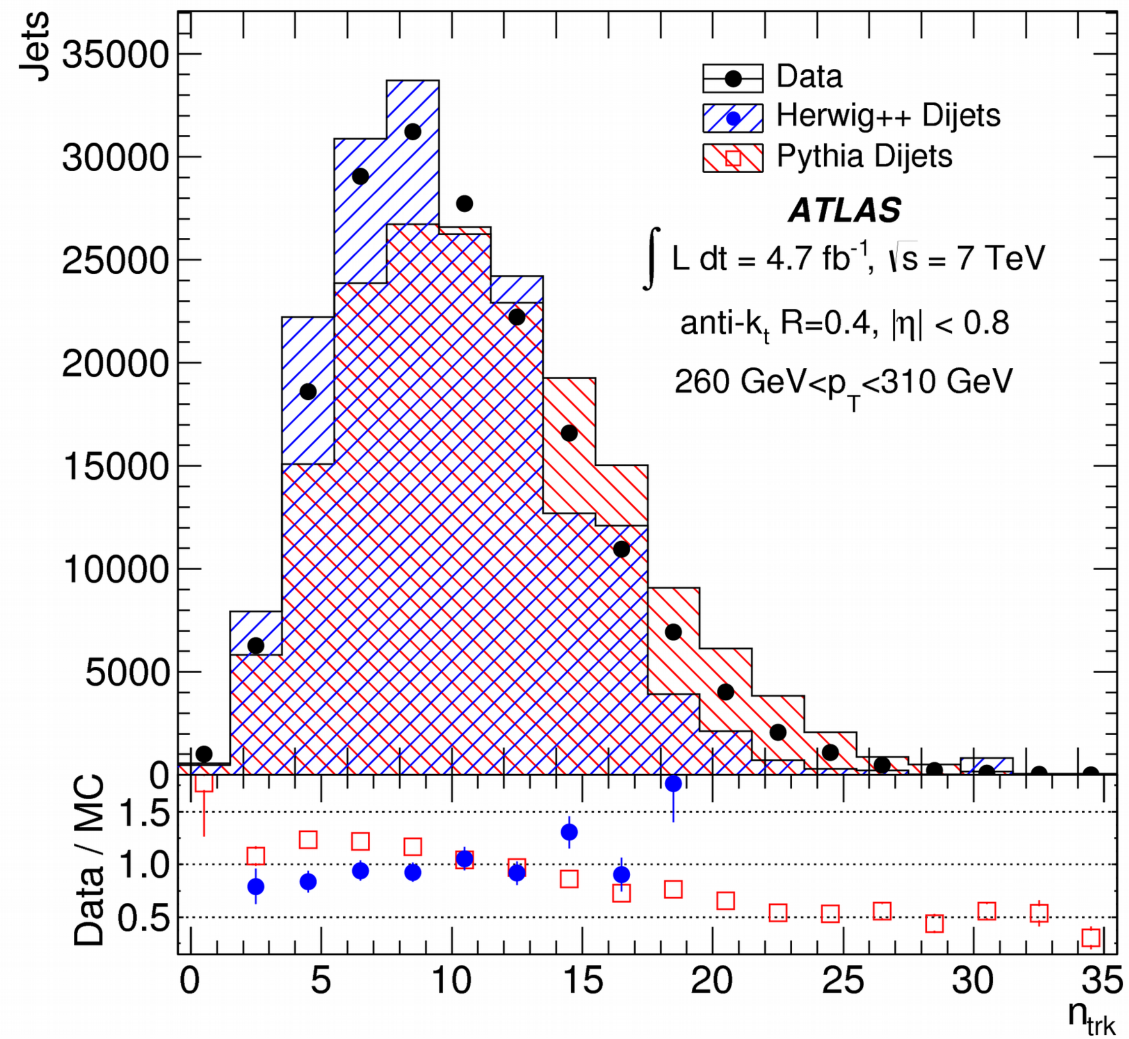
http://arxiv.org/abs/1509.04939

Tagging Cuts used for WZ:

- The jets are groomed with mass-drop filtering
  - But the mass drop criterion is removed
  - A subjet momentum balance, $\sqrt{y_f}$, is retained
  - Then filtered to keep only the 3 hardest sub-jets.
- Three basic cuts:
  - $\sqrt{y}>0.45$
    - Will likely change for Run 2
  - $|m_J-m_V|<13$GeV
    - Select the mass range around the boson desired
    - W/Z ranges overlap
      - Searches are not independent.
  - $n_{trk}<30$
    - Contentious, but seems powerful

Track multiplicity

- Track multiplicity is not an infra-red safe variable
- Quite well modelled for Z (from LEP)
- Not well controlled in gluon jets
- This has been a contentious issue
  - But with background from data it seems OK



http://link.springer.com/article/10.1140/epjc/s10052-014-3023-z

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Track multiplicity

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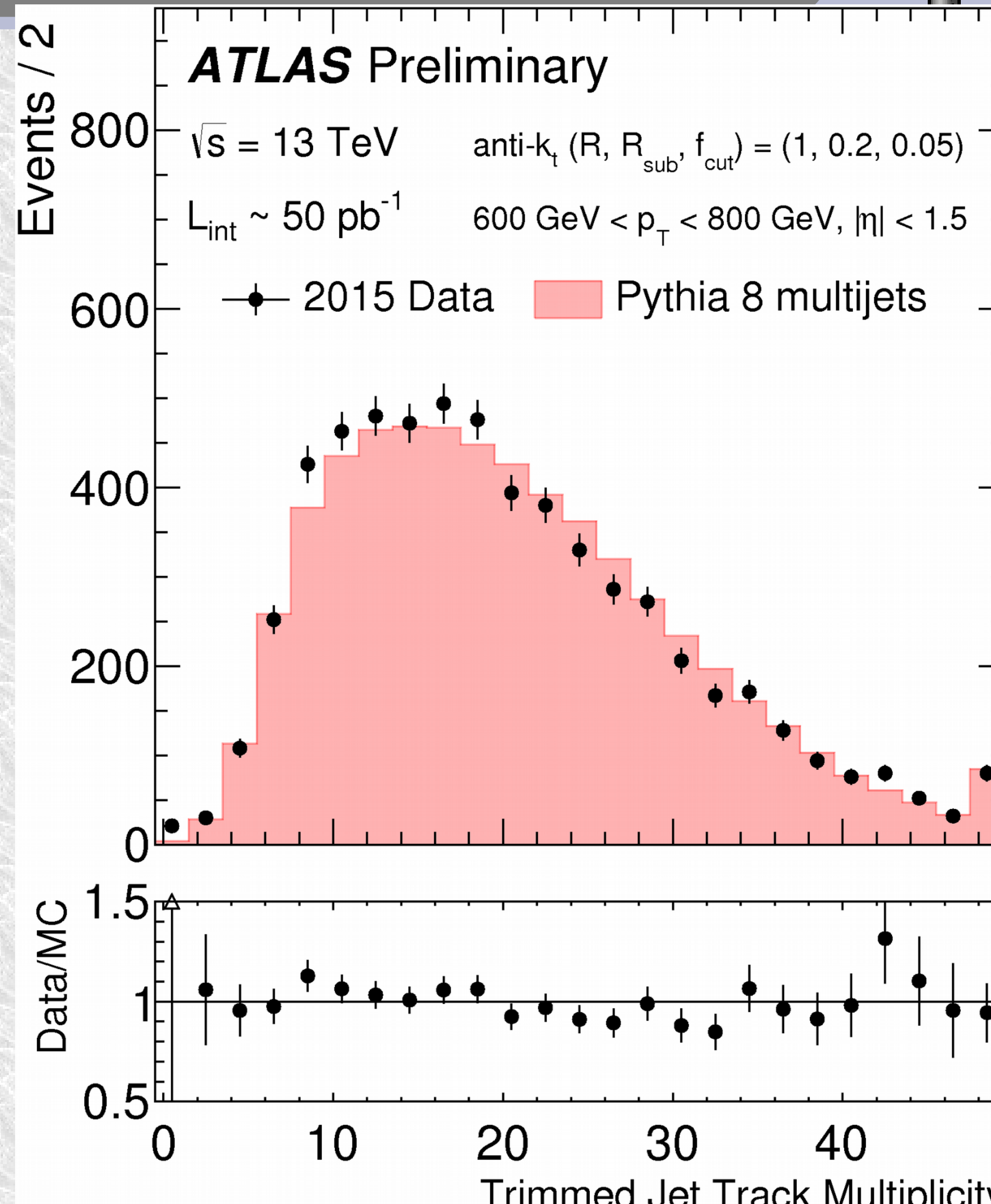
- Quite well modelled for Z (from LEP)
- Not well controlled in gluon jets
- This has been a contentious issue
  - But with background from data it seems OK
- And it looks better in 2015 / Pythia 8



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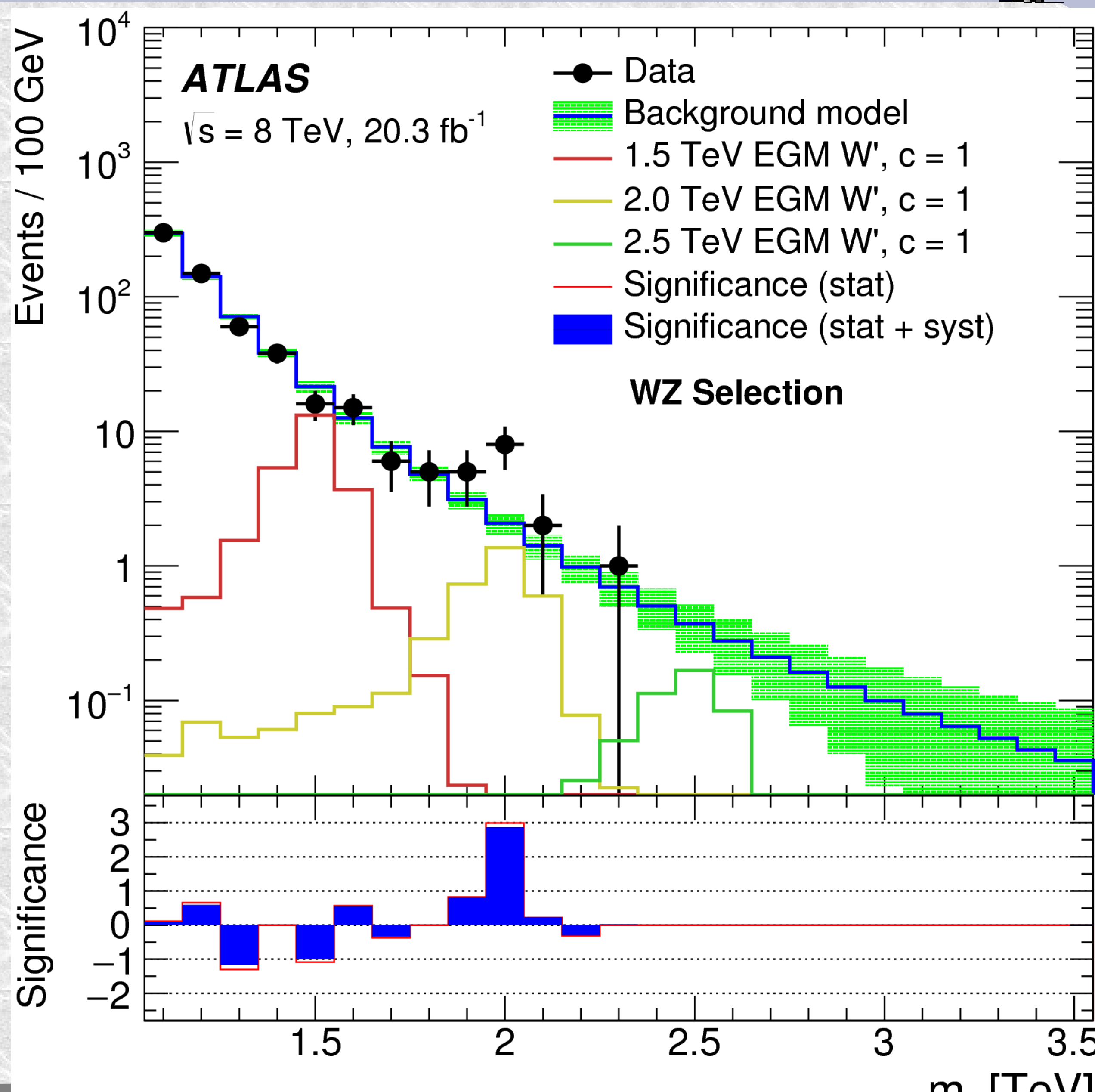
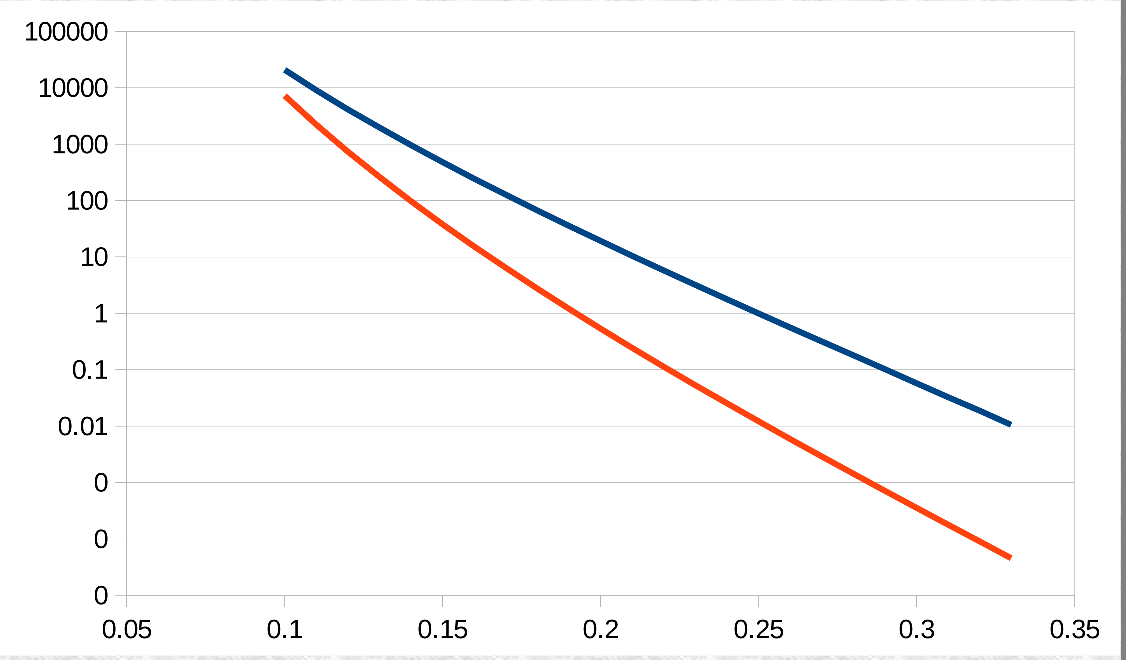
The data (WZ channel)

- Falling mass spectrum
  - 8 events at 2 TeV where 2 were expected
  - Thats all the excitement…
- ZZ, WZ show smaller (overlapping) excess



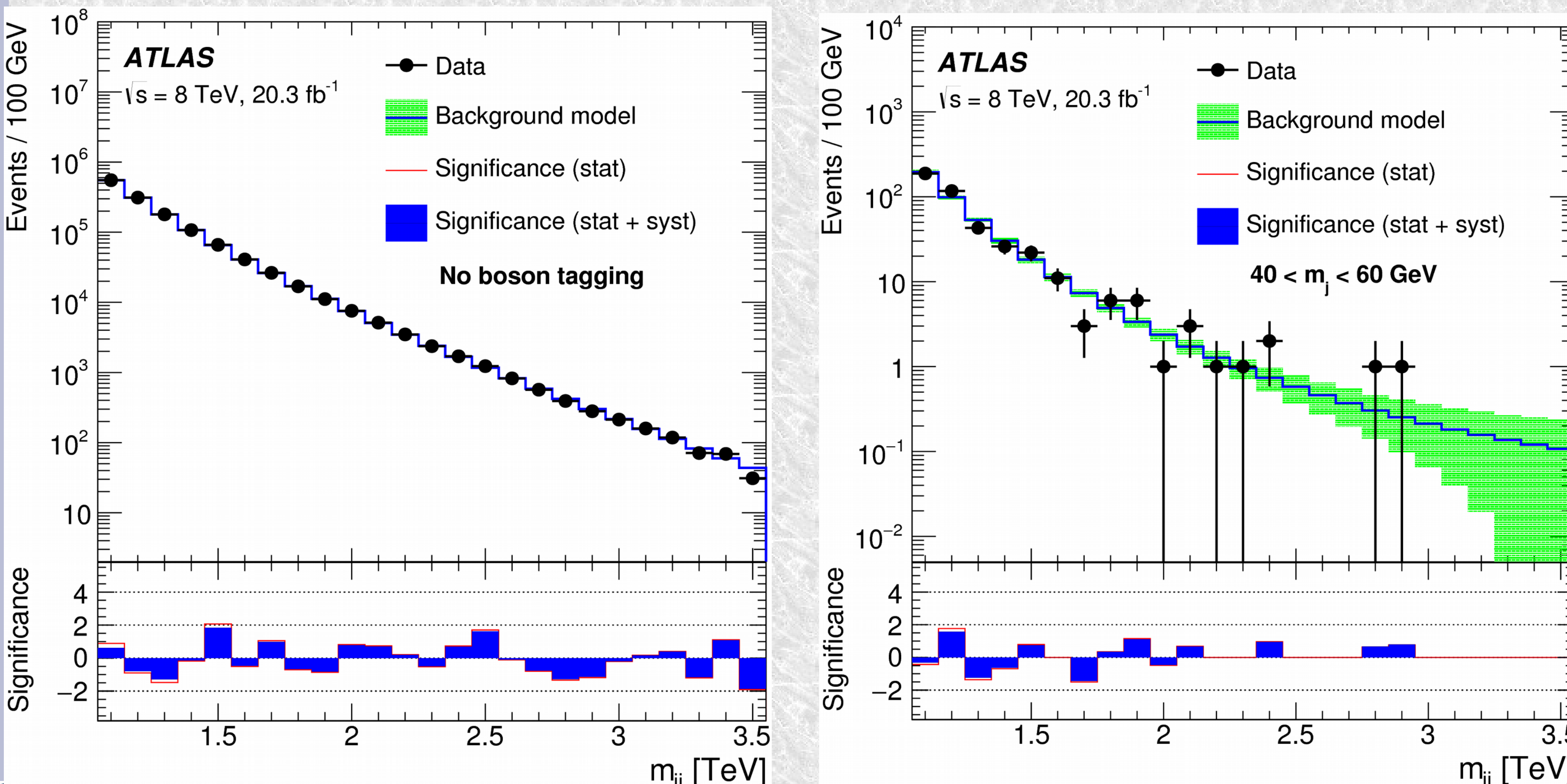
Background extraction

- This analysis was done using a model for the background shape: $$\frac{dn}{dx} = p_1 (1-x)^{p_2 - \xi p_3} x^{p_3}$$
- Here x is m/√s and ξ is a chosen parameter reducing p2/p3 correlation
- The plot shows this function as fitted to the inclusive dijets and WZ tagged
  - You can see the multijet tag rate drop with m_{JJ}
  - Not a bad thing – but needs to be understood



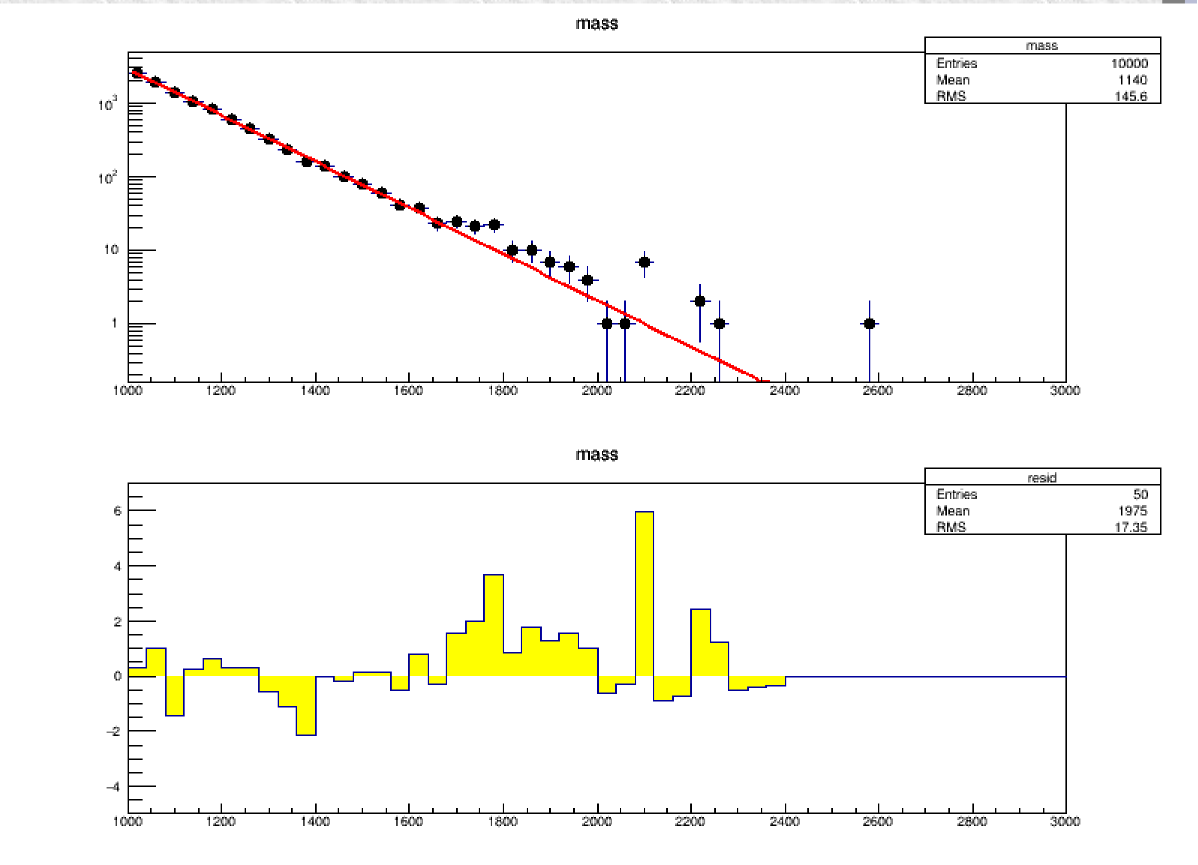
Background extraction

- Validate fit using 0 tag, 1 tag, 2 tag (m_{WZ} sidebands)



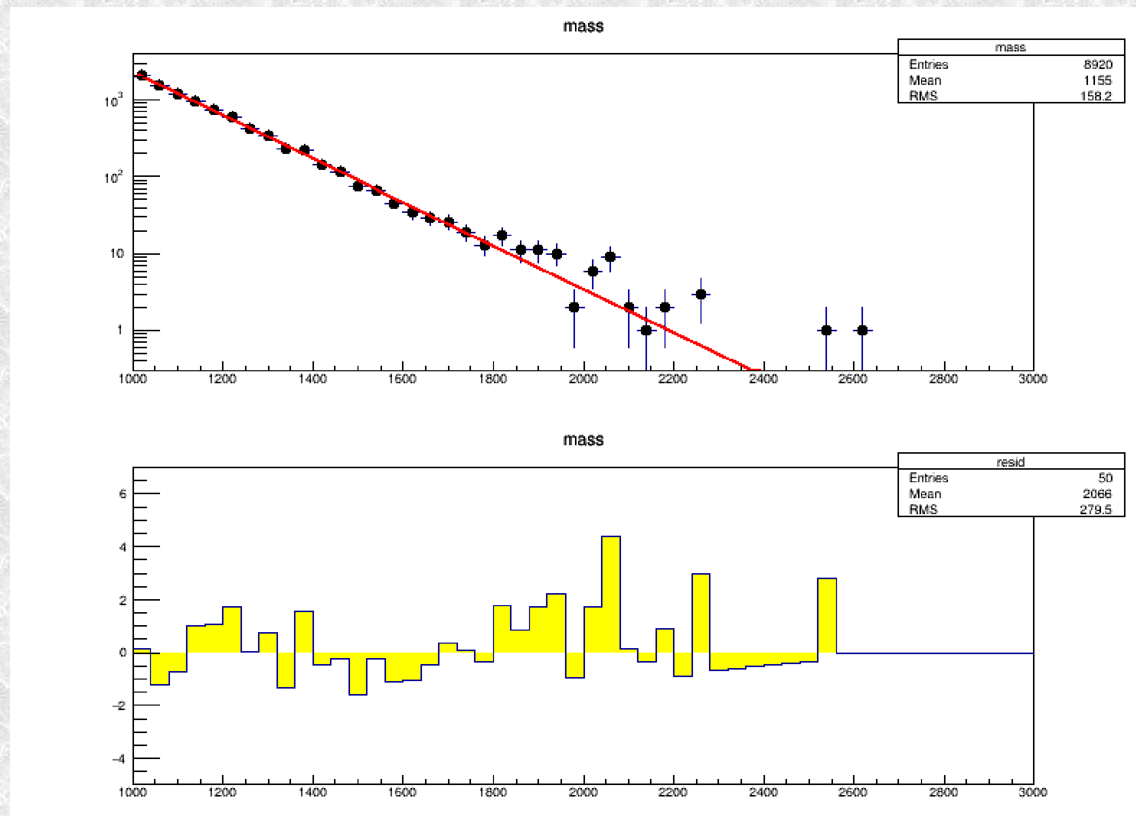
Maybe background is special?

- What if there is a component of background in signal region which is not typical?
  - e.g. Boson production in the parton shower
- The result will be two different distributions overlayed
  - Which always leads to a long tail
- The fit model might not cope
- Here I have 2 exponentials, fitted with one



Is efficiency mass dependent?

- Another possibility is the background events have a mass-dependent rejection probability
- Here I assume efficiency is 60% at 1.6TeV of what it is at ends of spectrum
- Again, fit describes the high-stats side
  - But the low end is less well described than you thought
  - Could go either way.
- I have over-simplified here to make the point.



The above should not happen

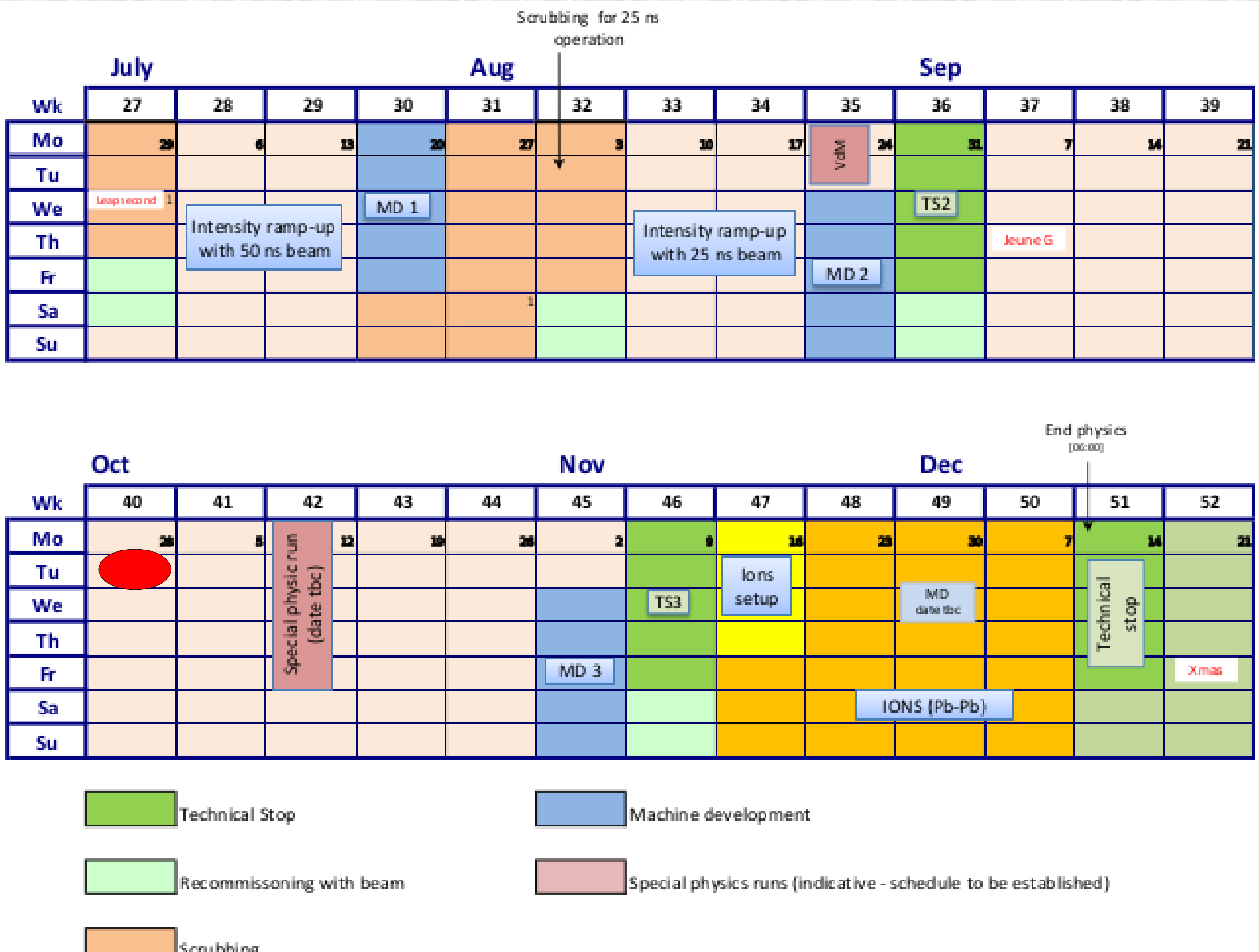
- The experiments do a lot of tests of their results
  - The double-tagged sidebands should catch these issues
- I am not saying these effects caused the various 2 TeV bumps we have seen
  - I am just pointing out some of the pitfalls to watch out for.

Combination: good or bad?

- Combination assumes a model
  - You need the relative signal rates in different modes
- This is no problem if your model is WZ
- But starts to be if you study $Z'\rightarrow ZZ$ & $Z'\rightarrow WW$
  - Now you need to impose the relative Brs
- Suppose your model grows to include $W'\rightarrow WH$
  - With $H\rightarrow bb$ there is some cross-talk to $Z\rightarrow bb$
  - Small, but needs to be considered
- In the all hadronic channel W, Z and H all overlap.
  - The space of your model has more than two dimensions and cannot be plotted..
  - So fall back to simplified BR=100% models, or specific benchmarks.
- All trivial: but needs to be fixed before data if you want meaningful p-values

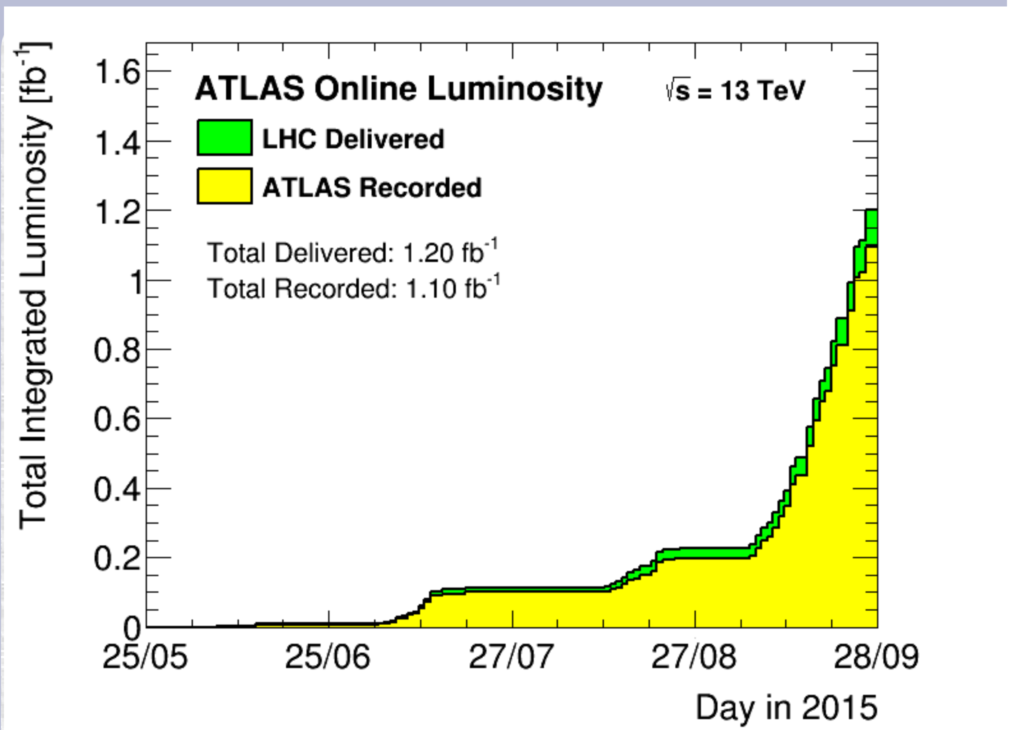
2015

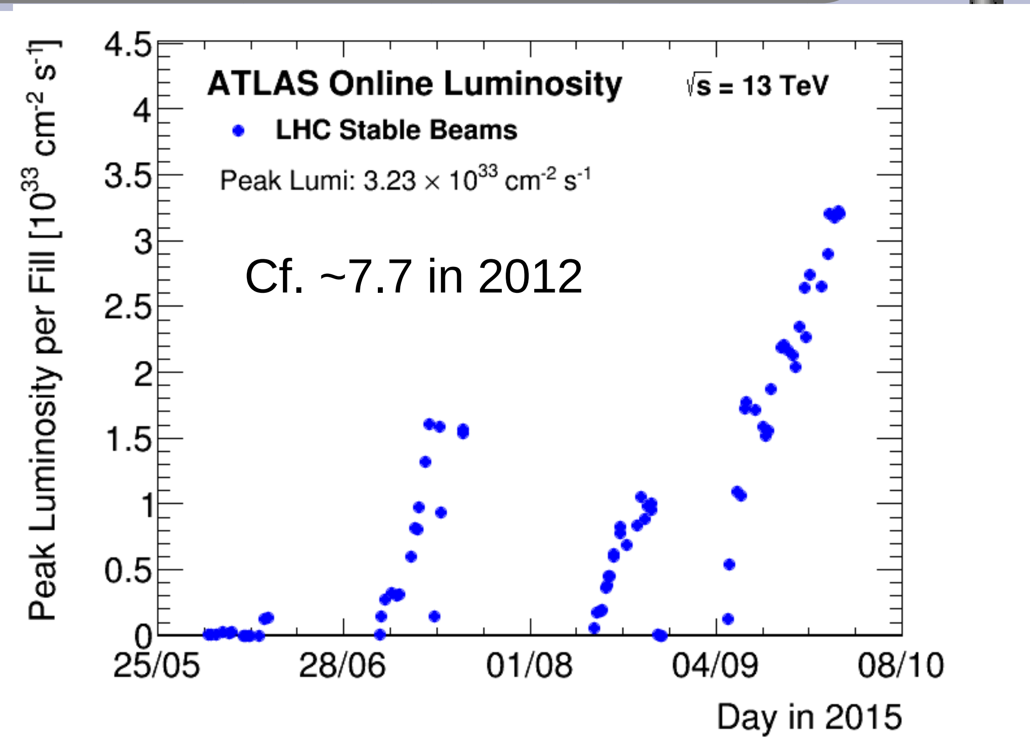
LHC schedule 2015



30 days of pp physics to go!

2015 data





- Data delivery was going slowly, but is moving now
  - Total >3fb^{-1} if we keep current weekly average
  - Shift from 80 cm to 40cm β* should double rate :)
- Pileup is moderate
  - 50ns was like 2012
  - Shift from 80 cm to 40cm β* should double rate :(

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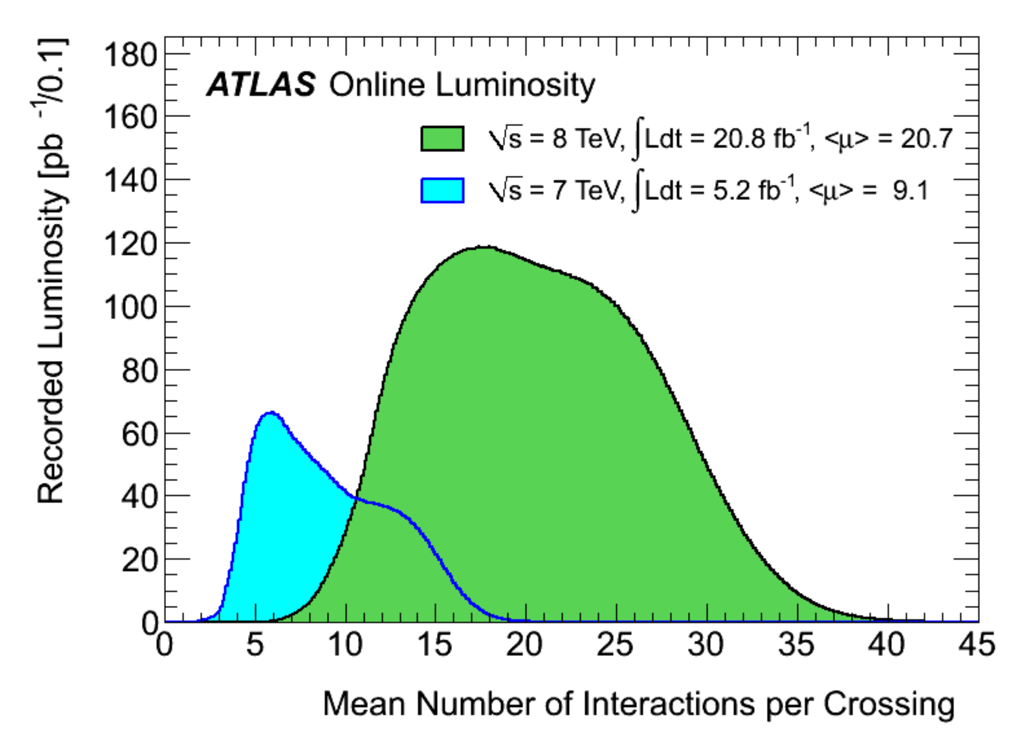
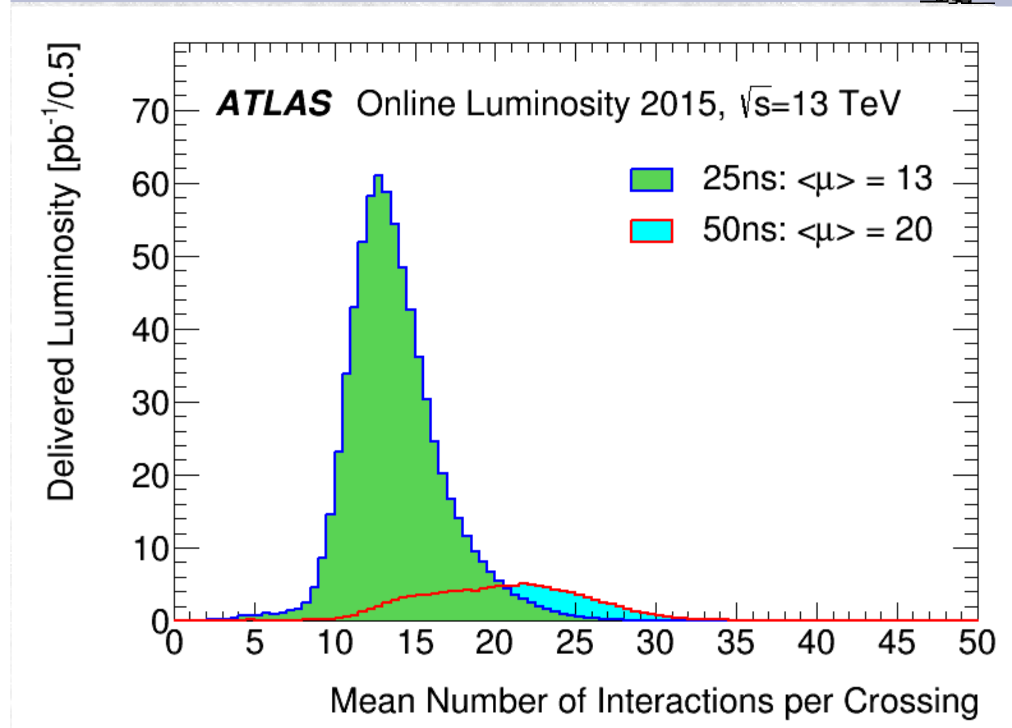
2011/2012/2015 pileup





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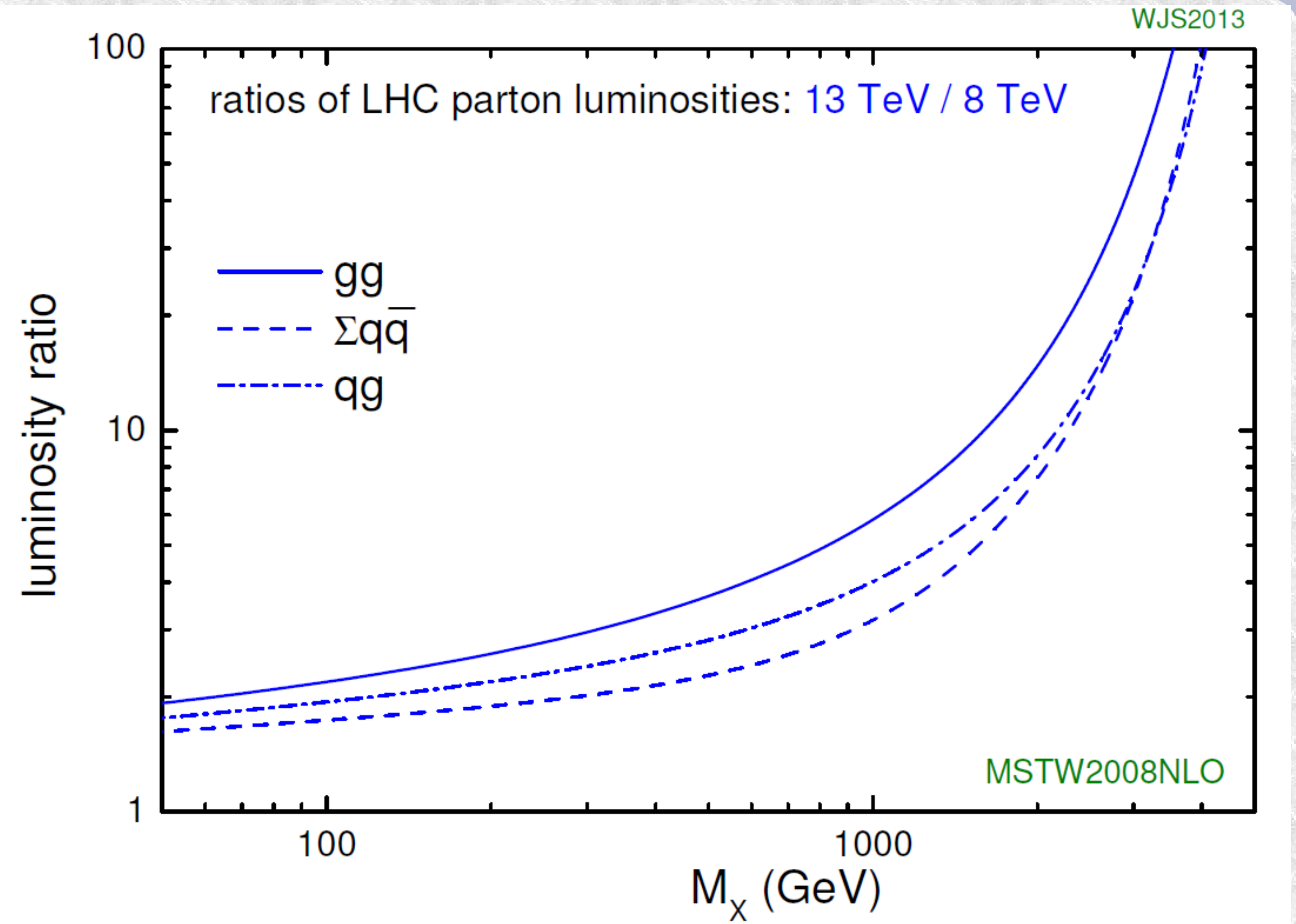
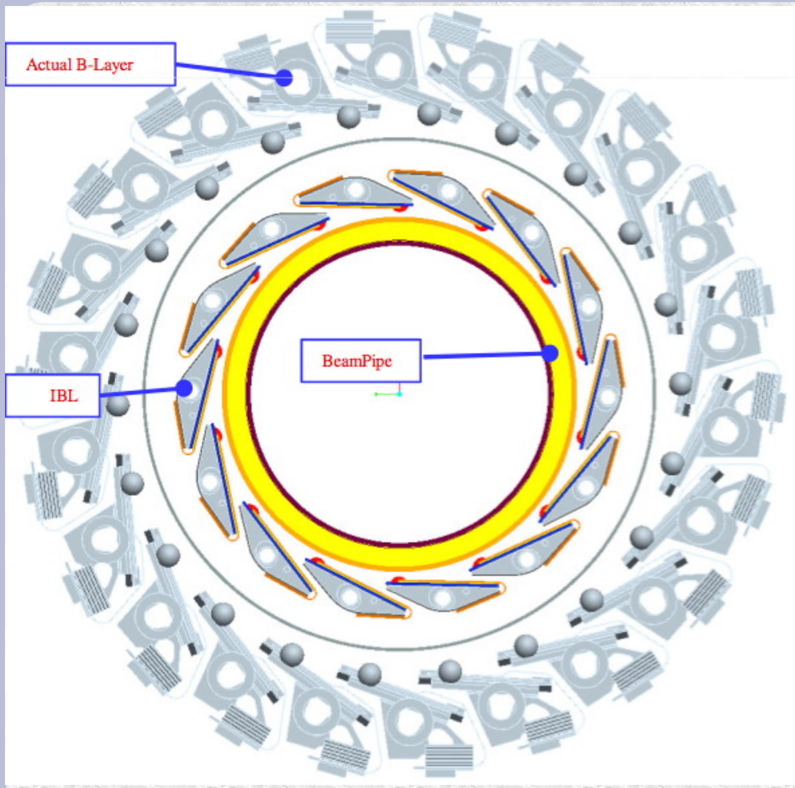
2015 luminosity ratio

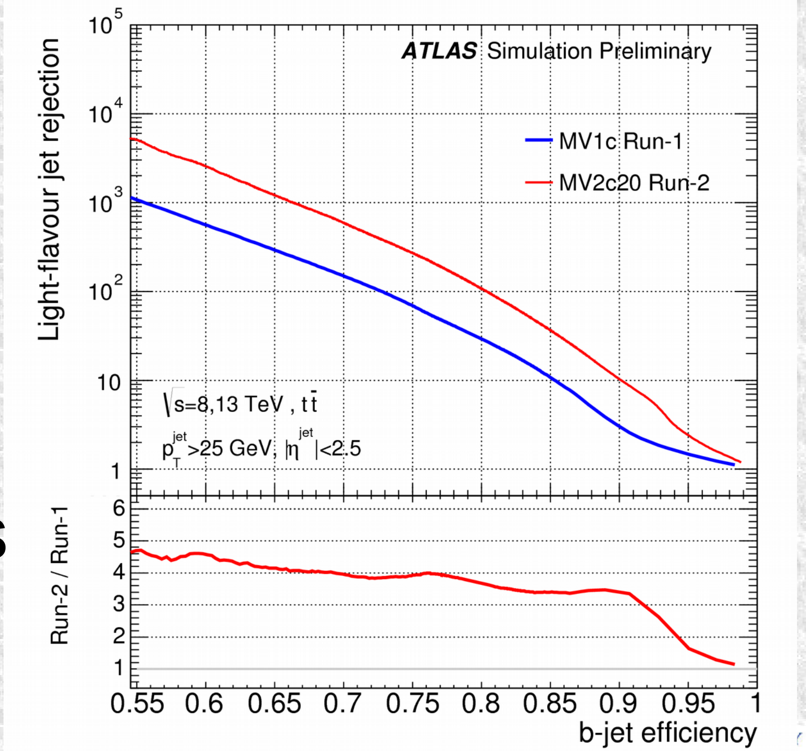
- We have Stirling's famous luminosity plots
  - At 2 TeV ratio is 7($q\bar{q}$) or 14(gg)
  - (Factor 20 at 2.9TeV btw)
- So we are now equalling 2012 for 3 TeV resonances
- And will do so at 2TeV by years end



ATLAS Insertable B Layer



- Installed and working well
- Beampipe shrunk allowed new layer
- Radius ~ 3.3cm

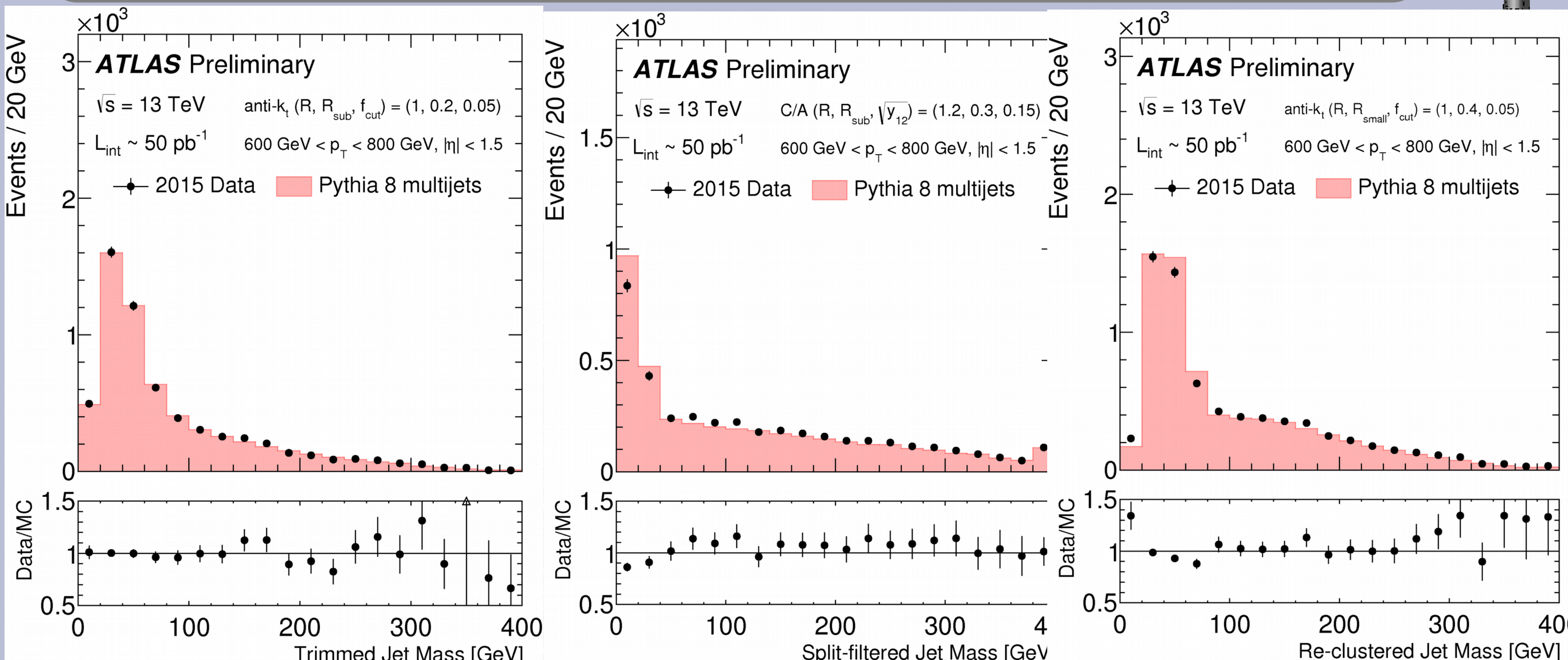


- Improves b-tag
  - Factor 3-4 rejection improvement
- Note: at p_T 1 TeV half B hadrons hit it!

ATLAS jet measurements

- ATLAS jet measurements start from the calorimeter
  - The 3D structure of the energy measurements is used to create 'topoclusters'
    - Achieve significant noise suppression by tuning this
  - Optionally locally calibrated as had/em
  - Final calibration includes tracking information
    - Add muons if trying get bb mass
- Tracking is then used to identify which jets originate from the primary vertex
  - JVT
- Studies of large-R jets in first 50pb^{-1} have been released

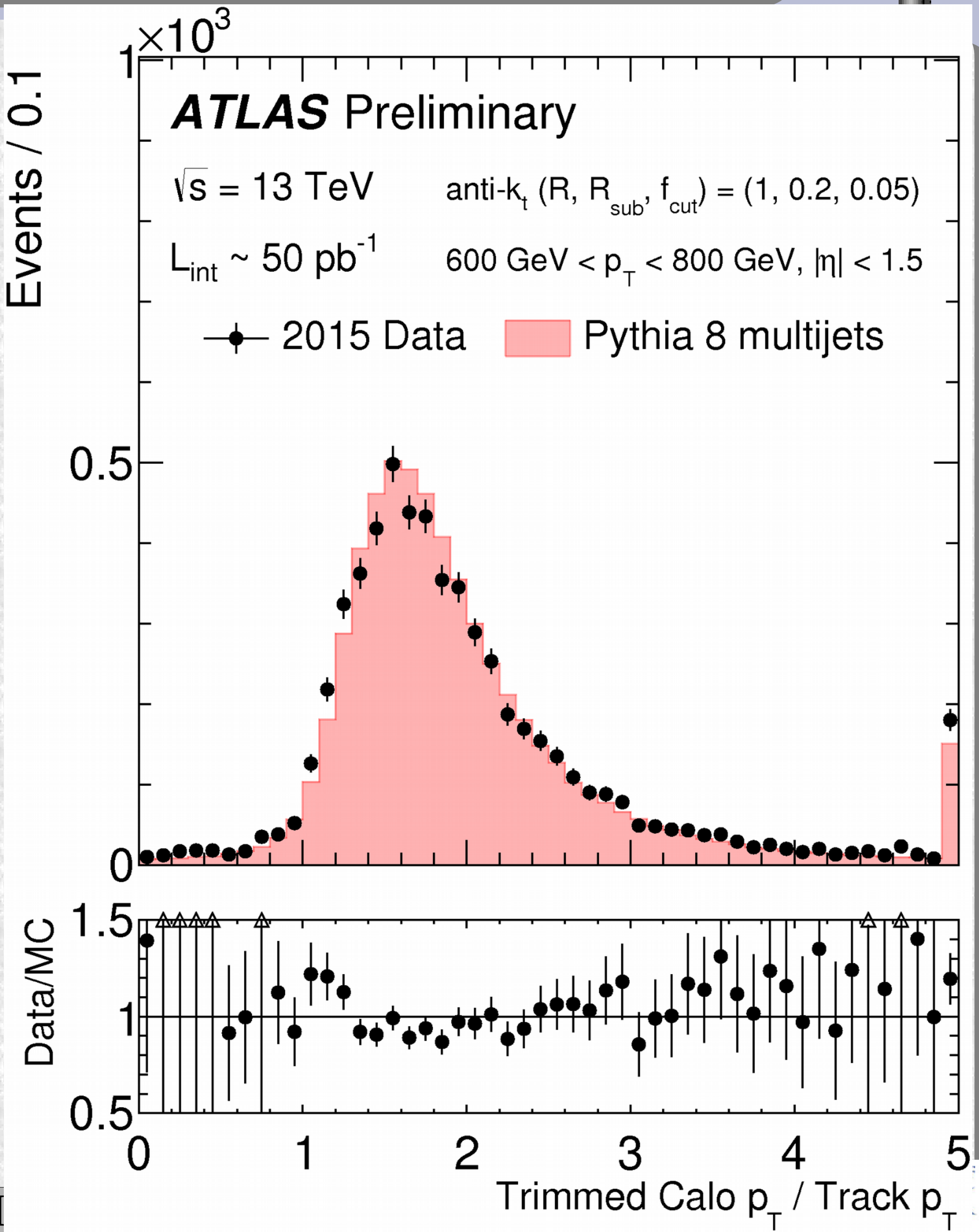
Jet mass after grooming



- Compare trimmed, split-filtered and re-clustered jet mass
  - Agreement good to <10% below 200 GeV
  - Possibly different trends visible

Track/calo calibration

- Tracking and calorimetry have very different systematic effects in jet reconstruction
- Calo jets:
  - More pileup effects
  - EM/Had calibration sensitive
- Track jets
  - Miss neutral fraction
  - Sensitive to track efficiency
  - Possible tail from fake tracks
- Use ratio of p_T to calibrate
  - One of many methods



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  - Sensitive to track efficiency
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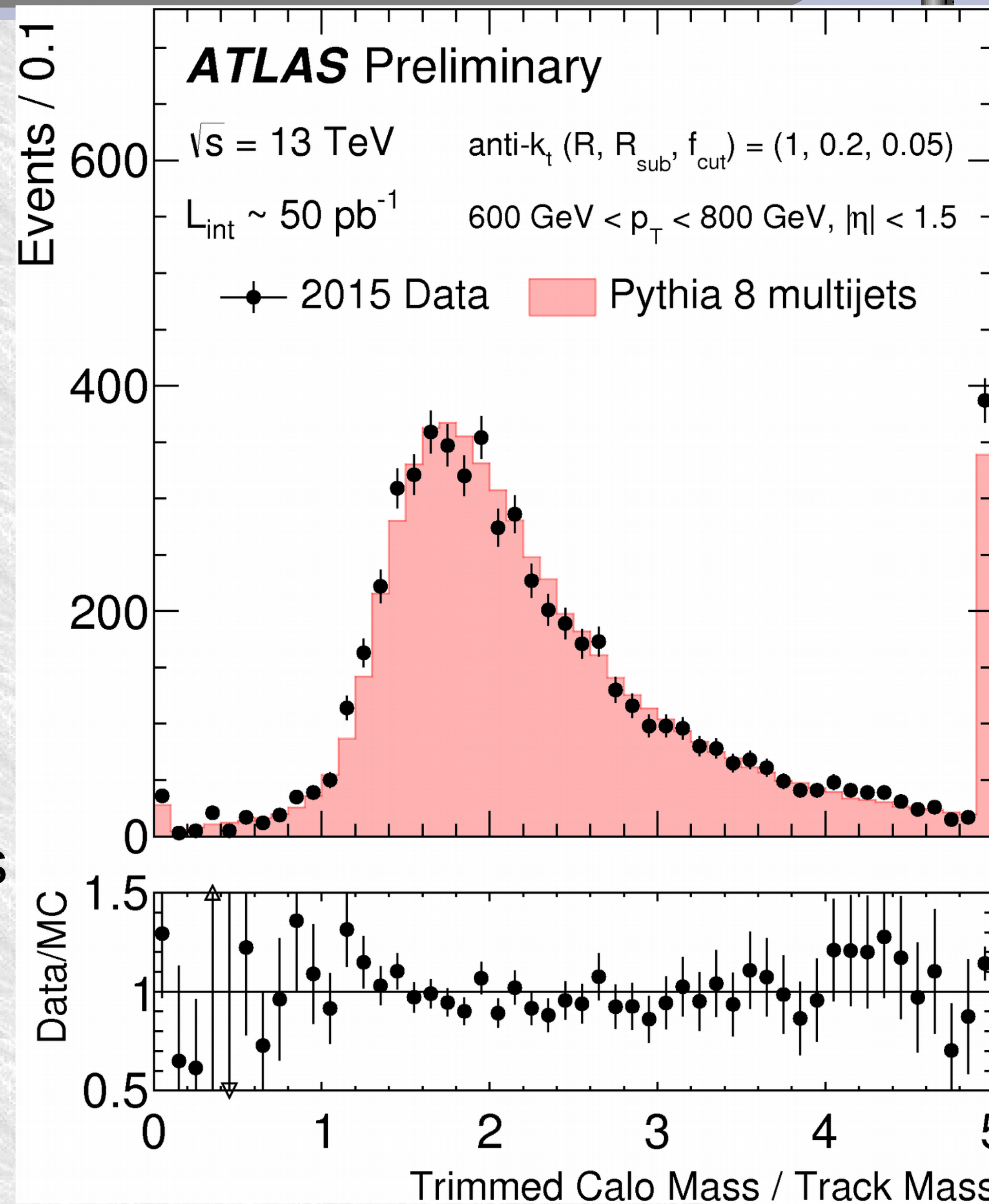
- Use ratio of masses to calibrate
  - Far less controls on this

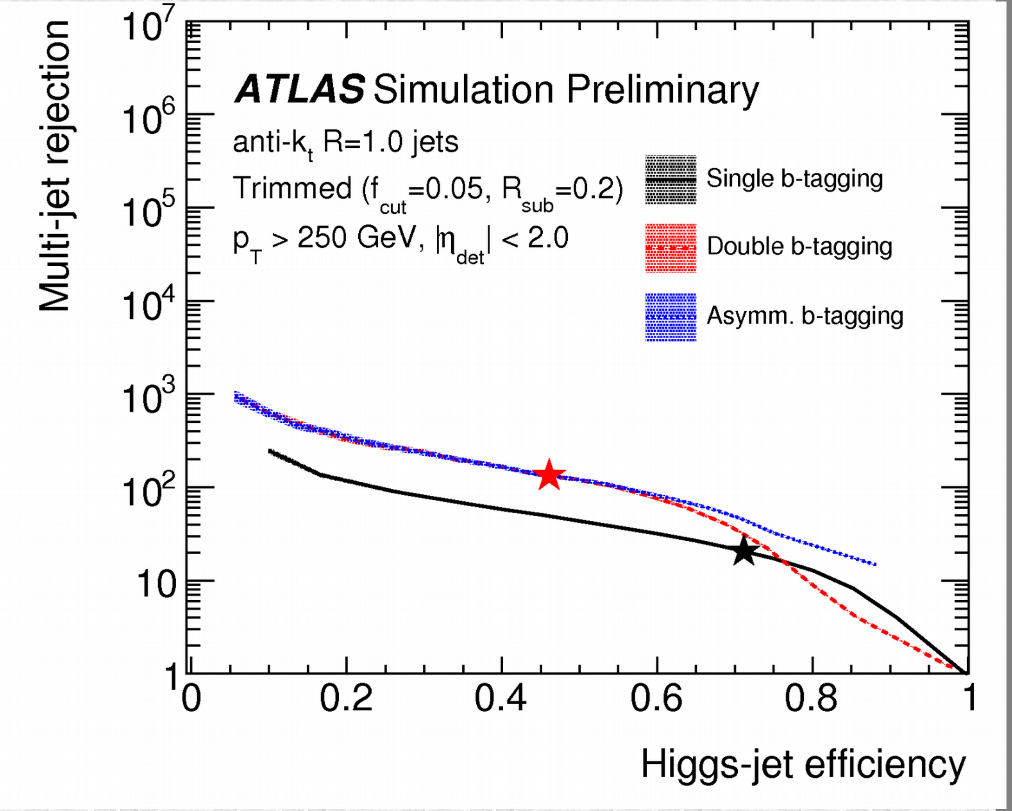


Jet recoginition

- ATLAS calorimetry is depth segmented:
  - 3 EM compartments
    - Gives the famous 'pointing' for photons
    - Most energy in 2nd
  - 3 Hadronic compartments
- The EM calorimeter has 0.025x0.025 ηφ granularity in main layer
- But the hadronic is 0.1x0.1
  - This sets a lower scale on jet size
- Track jets do not have this restriction
  - But at high p_T suffer from cluster merging which confuses the pattern recognition
    - Can lose a track or increase the p_T

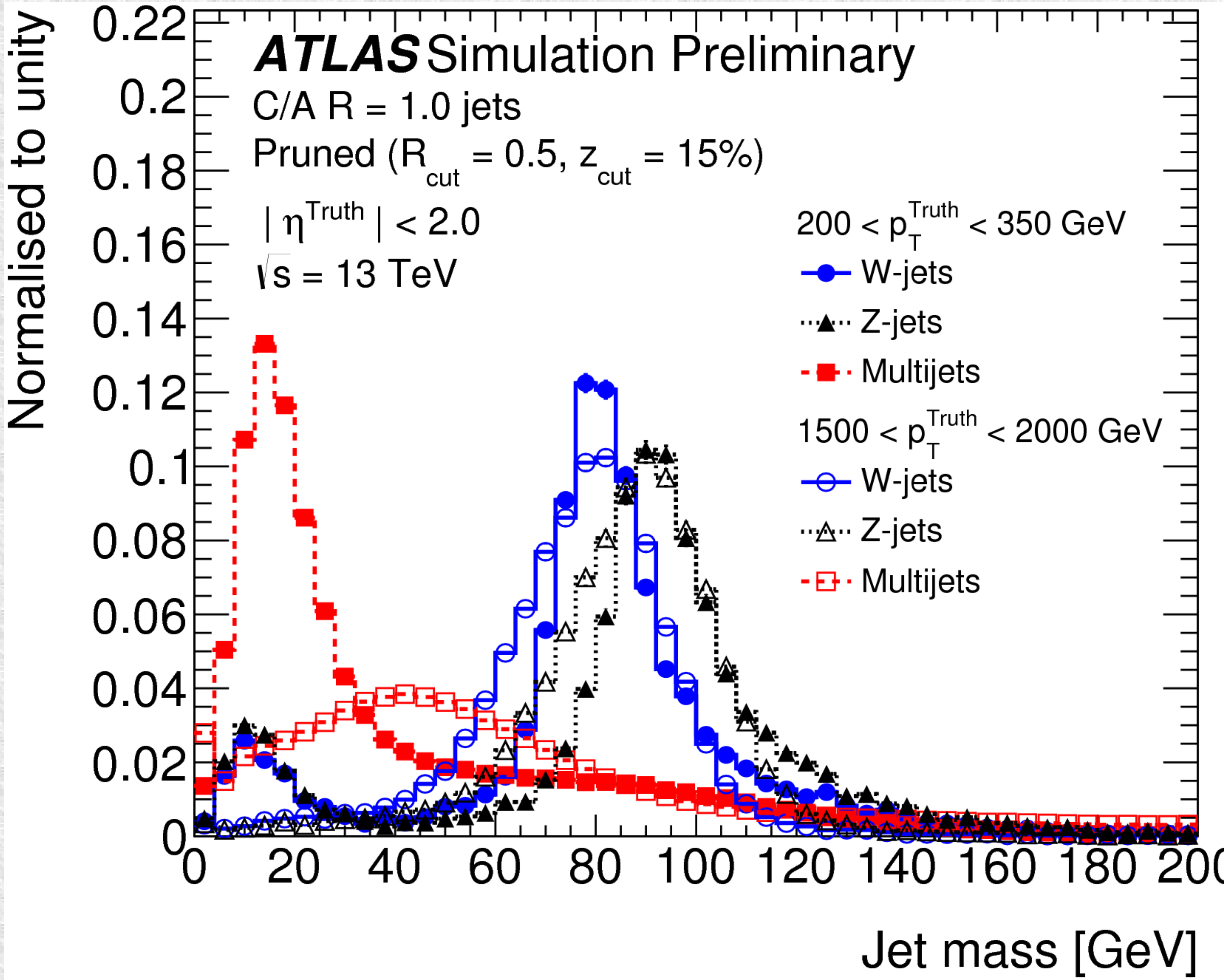
Typical approach

- Find a high-p_T large-R calorimeter jet
  - Establish the mass through your favourite grooming
- Use small-R track jets
  - Ghost-associated to calo jet
  - B tag these and choose your working point



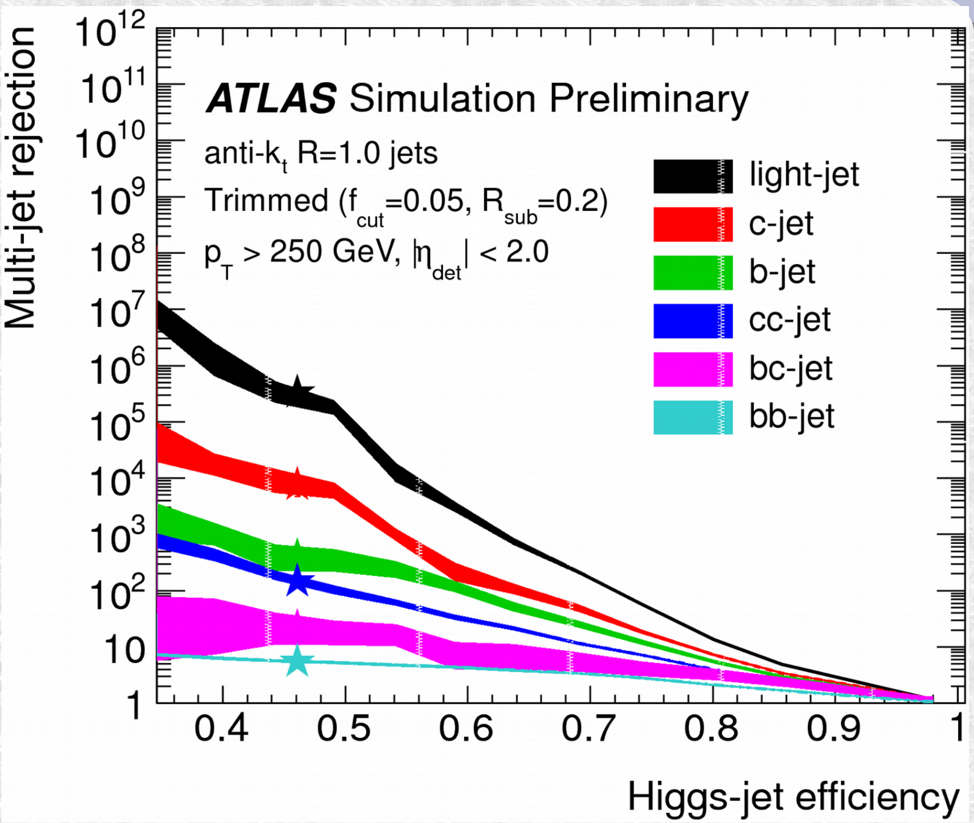
Jet mass reconstruction

- Uncalibrated jet masses
- Already well centred, after pruning
- But note separation deteriorating at high p_T



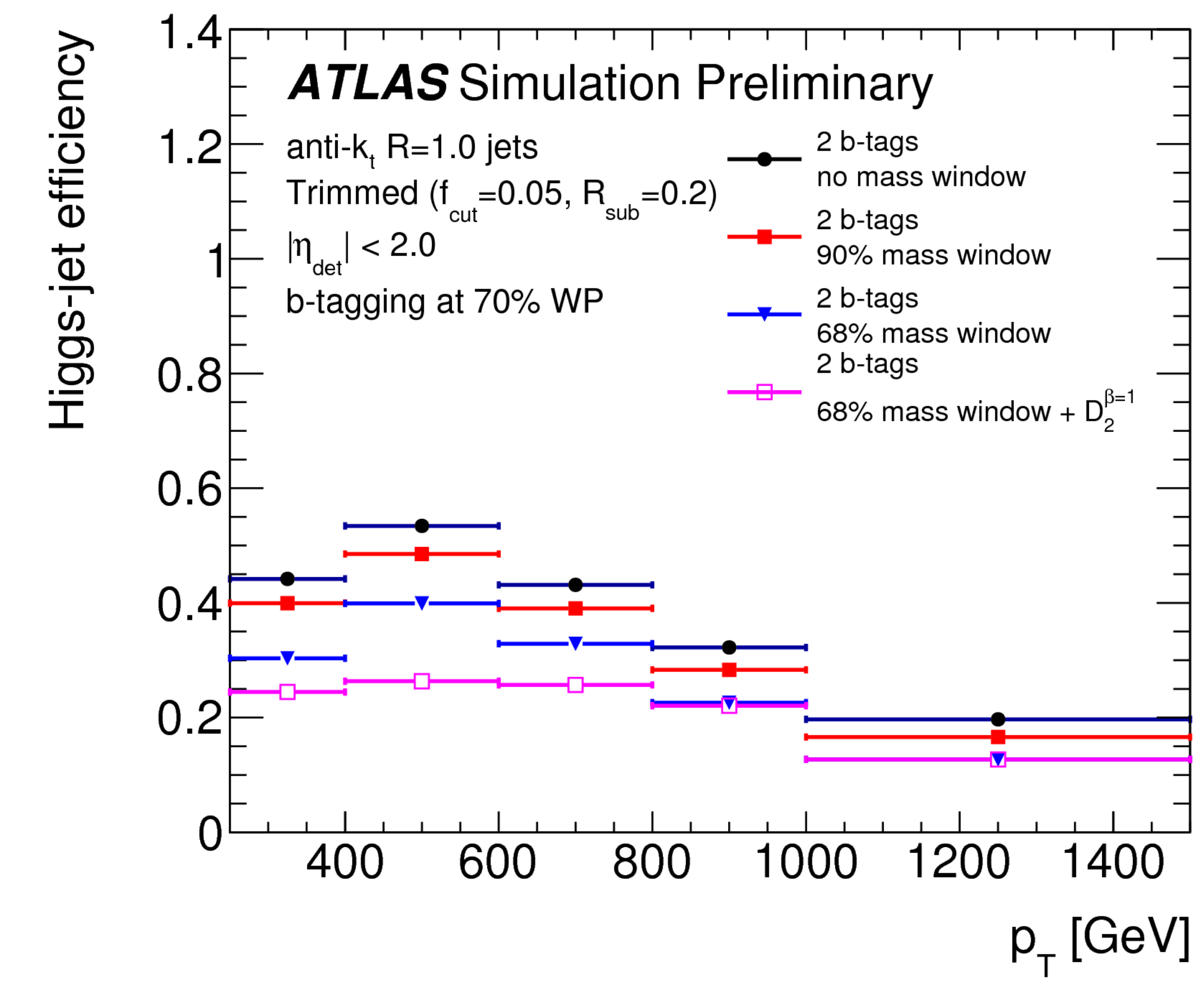
Correlation of b-tag & structure

- The plot right shows the power of a double-btag versus the eff. for H→ bb
  - The * represents the only point currently calibrated, but others will come
- $>10^5$ rejection of light jets is very useful
- Note rejection of bb jets: factor 5, when H eff. 46%
  - The kinematics is working for us
- B-tagging is doing some of the substructure work!



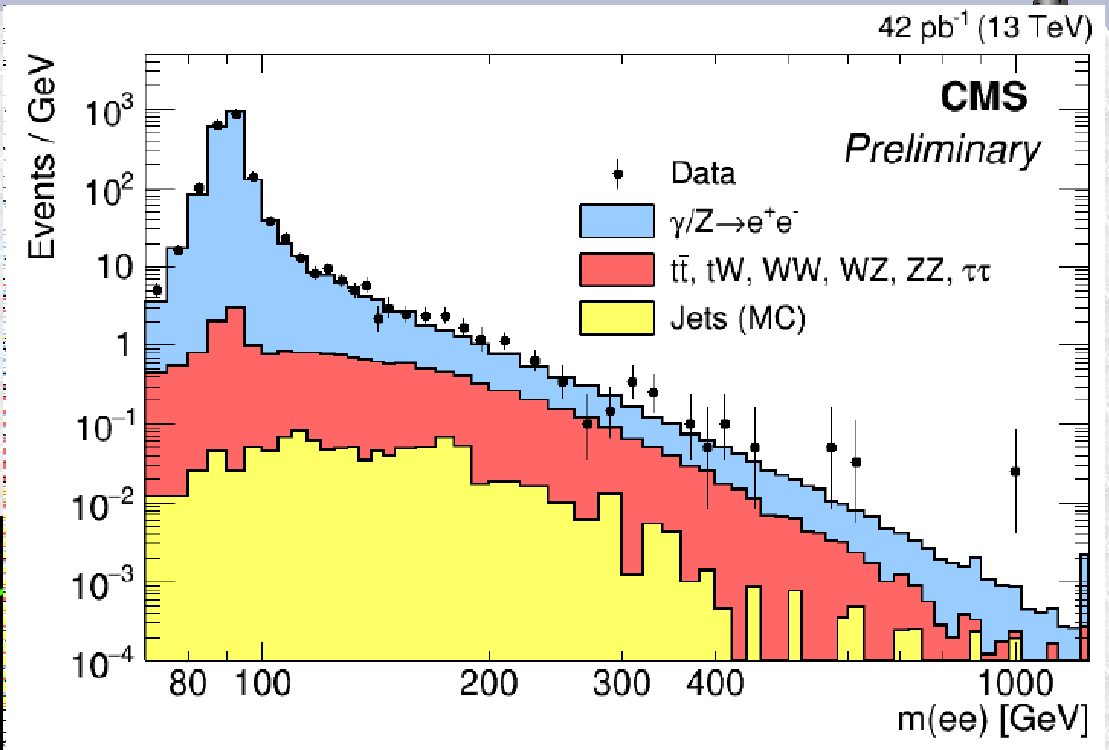
Efficiency trends

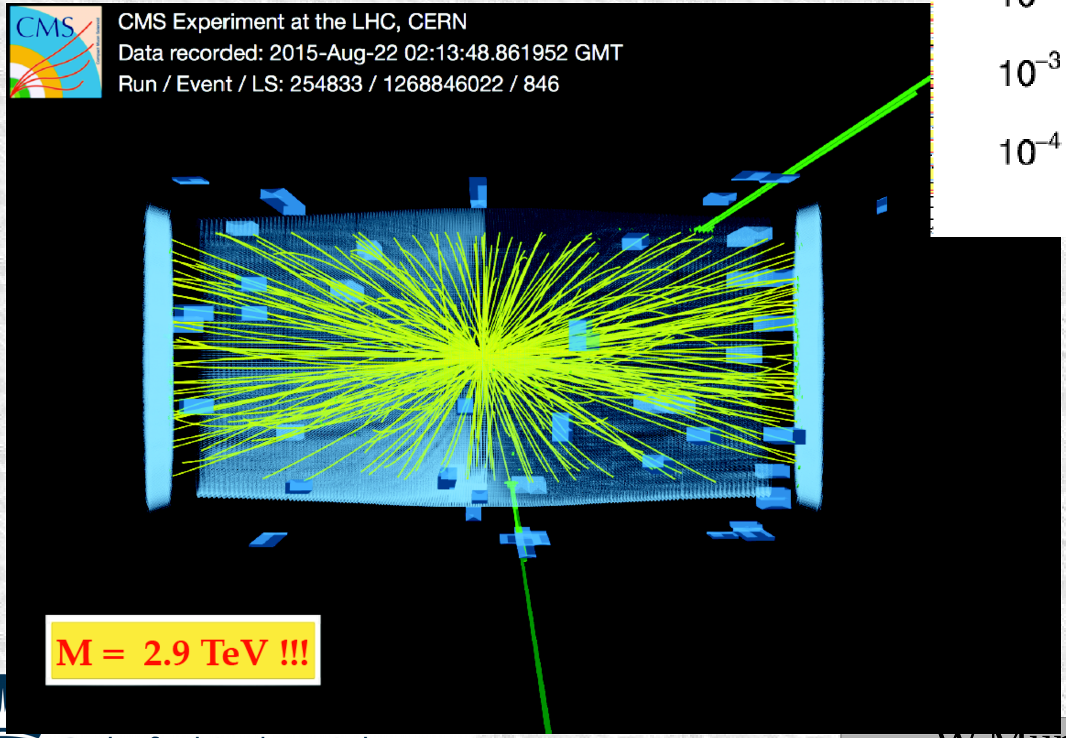
- Hard to maintain efficiency beyond a TeV



One nice surprise: Drell-Yan

- CMS di-electron
- $42pb^{-1}$ plot is on right
- Note $2x10^{-3}$ events expected in overflow





- Next $20pb^{-1}$ or so includes the event left
- "One swallow does not a summer make"

Aristotle

Outlook

- Run 2 is moving nicely now
  - >1fb^{-1} recorded and lumi passed 3 10^{33}
- There should be >3fb^{-1} be end of run
  - enough data to at least equal Run 1 for m(X)≥2TeV
- The pileup is lower than 2012
  - This could change → implies more luminosity
- The detectors are in better shape than 2012
- The jet grooming is better understood than in 2012
  - But (personal opinion) I think we can do better at highest p_T
- The MC modelling is better than in 2012
- We have and end-of-year event mid December
  - Presumably the experiments will want to tell what they know?